Air Pollution Training Institute

Air Pollution Meteorology

September, 1975

Air Pollution Meteorology

AIR POLLUTION TRAINING INSTITUTE COURSE 411

Conducted by

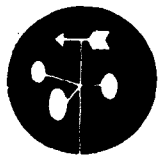
Air Pollution Training Institute MD 17
Research Triangle Park, North Carolina 27711

Office of Air and Waste Management
Office of Air Quality Planning and Standards
Control Programs Development Division
Air Pollution Training Institute

September, 1975

US EPA
This is not an official policy and standards document.
The opinions, findings, and conclusions are those of the authors
and not necessarily those of the Environmental Protection Agency.
Every attempt has been made to represent the present state of the art
as well as subject areas still under evaluation.
Any mention of products or organizations does not constitute endorsement
by the United States Environmental Protection Agency.

Air Pollution Meteorology



This course is designed for engineers and professional personnel responsible for measuring air pollution levels or for measuring and evaluating meteorological parameters which affect the diffusion and concentration of pollutants in the atmosphere. Instruction provides the trainee with a knowledge of the effects of meteorology on air pollution. He learns the role of meteorology in the transport and diffusion of air pollution, calculates estimates of pollutant concentrations for continuous releases, and studies meteorological instrumentation and correct instrument exposure. The instruction also enables him to discuss the important factors related to site selection, control programs, and the planning and interpreting of surveys. Discussions concern sources of meteorological information and the availability of additional professional assistance. This training manual has been specially prepared for the trainees attending this course and should not be included in reading lists or periodicals as generally available.

AIR POLLUTION TRAINING INSTITUTE
MANPOWER AND TECHNICAL INFORMATION BRANCH
CONTROL PROGRAMS DEVELOPMENT DIVISION
OFFICE OF AIR QUALITY PLANNING AND STANDARDS

The Air Pollution Training Institute (1) conducts training for personnel working on the development and improvement of state, and local governmental, and EPA air pollution control programs, as well as for personnel in industry and academic institutions; (2) provides consultation and other training assistance to governmental agencies, educational institutions, industrial organizations, and others engaged in air pollution training activities; and (3) promotes the development and improvement of air pollution training programs in educational institutions and state, regional, and local governmental air pollution control agencies. Much of the program is now conducted by an on-site contractor, Northrop Services, Inc.

One of the principal mechanisms utilized to meet the Institute's goals is the intensive short term technical training course. A full-time professional staff is responsible for the design, development, and presentation of these courses. In addition the services of scientists, engineers, and specialists from other EPA programs, governmental agencies, industries, and universities are used to augment and reinforce the Institute staff in the development and presentation of technical material.

Individual course objectives and desired learning outcomes are delineated to meet specific program needs through training. Subject matter areas covered include air pollution source studies, atmospheric dispersion, and air quality management. These courses are presented in the Institute's resident classrooms and laboratories and at various field locations.

Robert G. Wilder
Program Manager
Northrop Services, Inc.

Jean J. Schueneman
Chief, Manpower & Technical
Information Branch

CONTENTS

SECTION ONE

METEOROLOGICAL FUNDAMENTALS

Meteorological Fundamentals
Adiabatic Diagram

SECTION TWO

AIR POLLUTION METEOROLOGY

Effects of Meteorological Parameters on Transport and Diffusion
Pollutant Concentration Variation
Influence of Topography on Transport and Diffusion
Equation of State and Conversion of Concentrations
Meteorological Roses

SECTION THREE

ATMOSPHERIC DIFFUSION

Principles of Turbulence and Diffusion
Introduction to Turbulence and Diffusion Theory
The Generalized Gaussian Diffusion Equation
Atmospheric Diffusion Computations
Effective Stack Height

SECTION FOUR

AIR POLLUTION CLIMATOLOGY

SECTION FIVE

INTERRELATIONSHIPS - METEOROLOGY AND AIR POLLUTION

Urban Effect Upon Meteorologic Parameters
Atmospheric Turbidity
Atmospheric Chemistry of Air Pollution
Natural Removal Processes in the Atmosphere
Analysis of Air Quality Cycles

SECTION SIX

METEOROLOGICAL INSTRUMENTS

General Instrumentation Requirements
Meteorological Instruments
Exposure of Instruments

SECTION SEVEN

FURTHER APPLICATIONS OF METEOROLOGY TO AIR POLLUTION

Air Pollution Weather Forecasts
Air Pollution Surveys
Site Selection for a Pollutant Source
Atmospheric Tracers and Urban Diffusion Experiments
Meteorological Models for Urban Areas
Sources of Meteorological Data

SECTION EIGHT

ASSISTANCE IN AIR POLLUTION METEOROLOGY

Assistance in Meteorologic Problems
Sources of Air Pollution Literature

APPENDIX

Glossary
Elementary Statistical Description of Data
Index
Units of Measure for Dimensional Systems
Values and Logarithms of Exponential Functions
Logarithms to Base 10
Conversion Factors
  Temperature, Pressure
  Length, Area
  Volume, Flow
  Weight, Concentration
  Velocity, Emission Rates
  International Atomic Weights

Course Objectives.....

At the conclusion of this course the trainee should:

1 Know the primary effects of meteorology on air pollution and the effects of air pollution on meteorology, emphasizing the former.

2 Know the role of meteorology in the transport and diffusion of air pollutants.

3 Know the Pasquill-Gifford method for estimating pollutant concentrations from continuous releases and the limitations of the method.

4 Know what the primary meteorological instruments used in air pollution work are, their operating characteristics, and correct exposure of them.

5 Know the important meteorological factors that should be considered in site selection, control programs, and in planning and interpreting surveys.

6 Be familiar with the current research activities in air pollution meteorology.

7 Know the important sources of meteorological information and how assistance on meteorological problems in air pollution may be obtained.

SECTION ONE

METEOROLOGICAL FUNDAMENTALS

Meteorological Fundamentals
Adiabatic Diagram

METEOROLOGIC FUNDAMENTALS

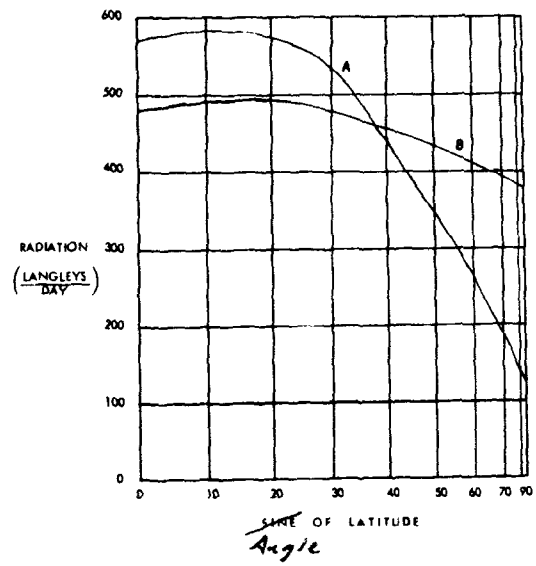
D. B. Turner*

RADIATION

The energy expended in the atmospheric processes originally was derived from the sun. This transfer of energy from the sun to the earth and its atmosphere is by radiation of heat by electromagnetic waves. The radiation from the sun has its peak of energy transmission in the visible range (0.4 to 0.7 microns) of the electromagnetic spectrum but releases considerable energy in the ultraviolet and infrared regions as well. The greatest part of the sun's energy is emitted at wave lengths between 0.1 and 30 microns. Some of this radiation is reflected from the tops of clouds and from the land and water surfaces of the earth. The general reflectivity is the albedo and for the earth and atmosphere as a whole is 36 per cent, for mean conditions of cloudiness over the earth. This reflectivity is greatest in the visible range of wavelengths. When light (or radiation) passes through a volume containing particles whose diameter is smaller than the wavelength of the light, scattering of a portion of this light takes place. Shorter wavelengths scatter most easily which is the reason the scattered light from the sky appears blue. Sunlight, near sunrise and sunset, when passing through a greater path-length of the atmosphere appears more red due to the increased scattering of shorter wave lengths. Absorption of solar radiation by some of the gases in the atmosphere (notably water vapor) also takes place. Water vapor, although comprising only 3 per cent of the atmosphere, on the average absorbs about six times as much solar radiation as all other gases combined. The amount of radiation received at the earth's surface is considerably less than that received outside the atmosphere.

The earth reradiates energy in proportion to its temperature according to Planck's law. Because of the earth's temperature, the maximum emission is about 10 microns, which is in the infrared region of the spectrum. The gases of the atmosphere absorb some wave length regions of this radiation. Water vapor absorbs strongly between 5.5 and 7 microns and at greater than 27 microns but is essentially transparent from 8 to 13 microns. Carbon dioxide absorbs strongly between 13 and 17.5 microns. Because of the absorption of much more of the terrestrial radiation by the atmosphere than of the solar radiation, some of the heat energy of the earth is conserved. This is the "greenhouse" effect.

Figure 1 shows as a function of latitude the amount of solar radiation absorbed by the earth and atmosphere compared to the long wave radiation leaving the atmosphere. The sine of the latitude is used as abscissa to represent area. It can be seen that if there were no transfer of heat poleward, the equitorial regions would continue to heat up and the polar regions continue to cool. Since the temperatures remain nearly the same for various areas of the earth, such a transfer does take place. The required transfer of heat across various latitudes is given in Table 1.



A SOLAR RADIATION ABSORBED BY EARTH AND ATMOSPHERE

B LONG WAVE RADIATION LEAVING THE ATMOSPHERE

FIGURE 1

*Supervisory Research Meteorologist, NOAA
Meteorology & Assessment Division, EPA
Research Triangle Park, NC 27711

PA.ME.el.5a.12.62

Table 1. Required Flux of Heat Toward the Poles Across Latitudes (10^{19} calories per day) From Houghton

Latitude	Flux
0	0
10	4.05
20	7.68
30	10.46
40	11.12
50	9.61
60	6.68
70	3.41
80	0.94
90	0

THE GENERAL CIRCULATION

The previous section has indicated the necessity of transfer of heat from the warm equatorial regions to the cold polar regions in order to maintain the heat balance of the atmosphere. This thermal driving force is the main cause of atmospheric motion on the earth. The rotation of the earth modifies this motion but does not cause it since the atmosphere essentially rotates with the earth. The portion of the earth near the equator acts as a heat source and the polar regions as a heat sink. The atmosphere functions as a heat engine transforming the potential energy of heat difference between tropics and poles to kinetic energy of motion which transports heat poleward from source to sink.

If the earth did not rotate, rising air above the equator would move poleward aloft where in giving up some of its heat would sink and return toward the equator as a surface current. Since the earth does rotate, the Coriolis force (to be discussed in the section on wind) deflects winds in the northern hemisphere to the right. Therefore flow from the tropics toward the poles become more westerly and flow from the poles toward the equator tends to become easterly. The result is that most of the motion is around the earth (zonal) with less than one-tenth of the motion between poles and equator. The meridional (along meridions i.e. between poles and equator) circulation is broken into three cells shown in Figure 2 according to Palmen's model. Of considerable importance is the fact that the jet stream does not remain long in one position but meanders and is constantly changing position. This causes changes in the location of the polar front and perturbations along the front. The migrating cyclones and anticyclones resulting, play an important part in the heat exchange, transferring heat northward both as a sensible heat and also latent heat. Also a small amount of heat is transferred poleward by the ocean currents.

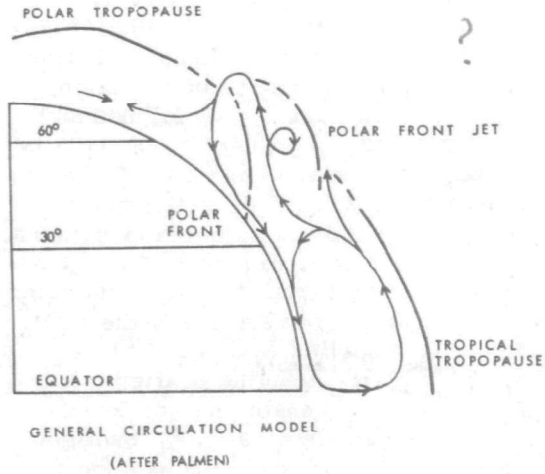


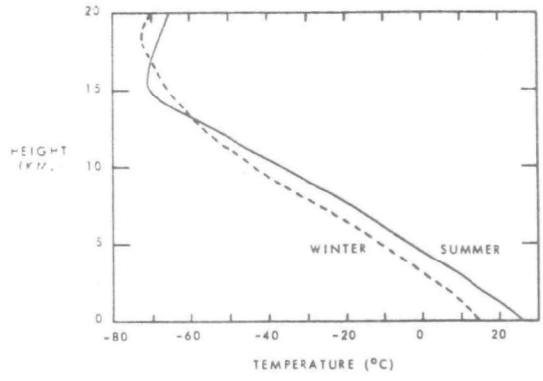
FIGURE 2

TEMPERATURE

Variation with Height

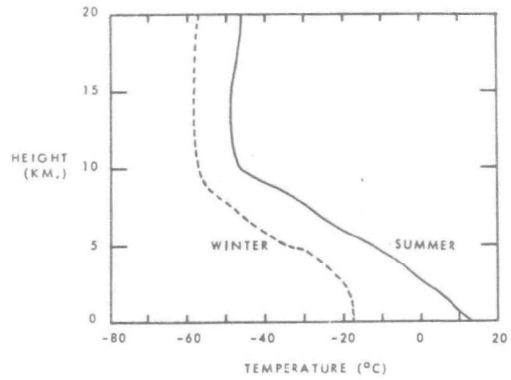
In the lower region of the atmosphere extending from the surface to about 2 km., the temperature distribution varies considerably depending upon the character of the underlying surface and upon the radiation at the surface. The temperature may decrease with height or it may actually increase with height (inversion). This region is the lower troposphere and is the region of most interest in air pollution meteorology. The remainder of the troposphere has a decrease of temperature with height on the

order of 4 to 8°C per km. The stratosphere is a region with isothermal or slight inversion lapse rates. The layer of transition between the troposphere and stratosphere is called the tropopause. The tropopause varies in height from about 8 to 20 km. and is highest near the equator, lowest near the poles. Figures 3 and 4 indicate typical temperature variations with height for two latitudes for summer and winter in the troposphere and lower stratosphere.



VARIATION OF TEMPERATURE WITH HEIGHT AT 30° NORTH LATITUDE

FIGURE 3



VARIATION OF TEMPERATURE WITH HEIGHT AT 60° NORTH LATITUDE

FIGURE 4

Above the stratosphere, the high atmosphere has several layers of differing characteristics. A rough indication of the variation of temperature with height including the high atmosphere is shown in Figure 5.

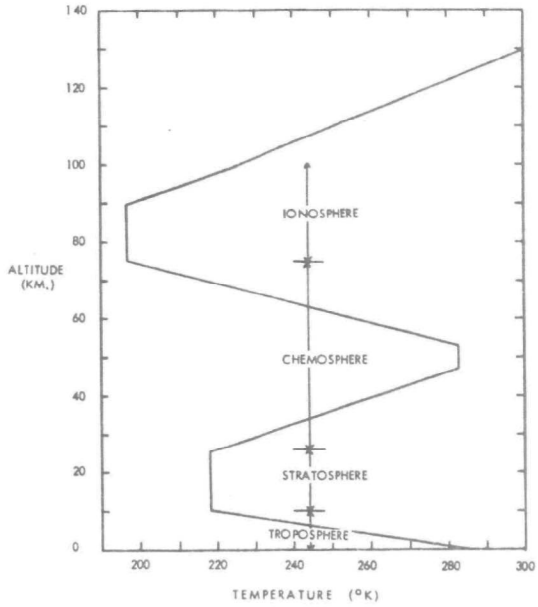


FIGURE 5

Horizontal Variation

Temperature also varies horizontally particularly with latitude, being colder near the poles and warmer near the equator. However the influence of continents and oceans have considerable effects on modifying temperatures. The continents have more extreme temperatures becoming warmer in summer and colder in winter, whereas the oceans maintain a more moderate temperature year-round.

STABILITY AND INSTABILITY

Whether the atmosphere has a tendency to enhance vertical motions or to damp out vertical motions is important to atmospheric processes which produce weather as well as to the effects upon air pollutants. The stability of the atmosphere is highly dependent upon the vertical distribution of temperature with height.

Adiabatic Lapse Rate

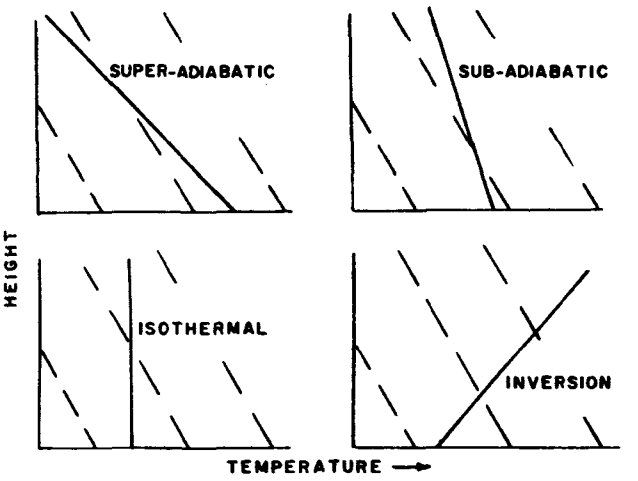
Due to the decrease of pressure with height, a parcel of air lifted to a higher altitude will encounter decreased pressure and will expand and in undergoing this expansion will cool. If this expansion takes place without loss or gain of heat to the parcel, the change is adiabatic. Similarly a parcel of air forced downward in the atmosphere will encounter higher pressures, will contract and will become warmer. This rate of cooling with lifting or heating with descent is the dry adiabatic process lapse rate and is 5.4°F per 1000 feet or approximately 1° C per 100 meters. This process lapse rate is the rate of heating or cooling of any descending or rising parcel of air in the atmosphere and should not be confused with the existing temperature variation with height at any one time, the environmental lapse rate.

Environmental or Prevailing Lapse Rate

The manner in which temperature changes with height at any one time is the prevailing lapse rate. This is principally a function of the temperature of the air and of the surface over which it is moving and the rate of exchange of heat between the two. For example, during clear days in midsummer the ground will be rapidly heated by solar radiation resulting in rapid heating of the layers of the atmosphere nearest the surface, but further aloft the atmosphere will remain relatively unchanged. At night radiation from the earth's surface cools the ground and the air adjacent to it, resulting in only slight decrease of temperature with height or if surface cooling is great enough, temperature will increase with height.

If the temperature decreases more rapidly with height than the dry adiabatic lapse rate, the air has a super-adiabatic or strong lapse rate and the air is unstable. If a parcel of air is forced upwards it will cool at the adiabatic lapse rate, but will still be warmer than the environmental air. Thus it will continue to rise. Similarly, a parcel which is forced downward will heat dry adiabatically but will remain cooler than the environment and will continue to sink.

For environmental lapse rates that decrease with height at a rate less than the dry adiabatic lapse rate (sub-adiabatic or weak lapse) a lifted parcel will be cooler than the environment and will sink; a descending parcel will be warmer than the environment and will rise. Figure 6 shows the relative relation between the environmental lapse rates of super-adiabatic (strong lapse), sub-adiabatic (weak lapse), isothermal, and inversion with the dry adiabatic process lapse rate as dashed lines.



Types of Temperature Structure with Height Related to the Dry Adiabatic Process Lapse Rate

FIGURE 6

Lifting motions which will cause cooling at dry adiabatic lapse rates may be due to upslope motion over mountains or rising over a colder air mass. Descending motion (subsidence) may occur to compensate for the lateral spreading of air in high pressure areas.

WATER IN THE ATMOSPHERE

In the section on radiation the importance of water vapor on the balance of incoming and

outgoing radiation was shown. The temperature of the atmosphere is below the boiling point of water, yet water is volatile enough to evaporate (change from liquid to gas) or sublimate (change from solid to gas) at atmospheric temperatures and pressures. Condensation or crystallization of water vapor in the atmosphere as clouds and on the ground as dew or frost is commonplace. Certainly, water in the form of clouds, fog, and precipitation are familiar elements of weather and the latter one necessary for agriculture and supplies of ground water.

One measure of the amount of moisture in the air is the dew point, which is the temperature at which saturation is reached if the air is cooled at a constant pressure without addition or loss of moisture. In the atmosphere, saturation frequently occurs due to the adiabatic cooling of lifted air parcels until the dew point for the lower pressure is reached. Further cooling will condense water vapor, releasing the heat of condensation, and because of this release of heat, cooling of ascending saturated air does not occur at the dry adiabatic lapse rate but at the pseudo-adiabatic lapse rate which is a smaller temperature decrease with height.

WINDS

Wind is nothing more than air in motion and although it is a motion in three dimensions, usually only the horizontal component is considered in terms of direction and speed. In the free atmosphere (above the effects of the earth's friction) two forces are important, the first, the Coriolis force, is due to the tendency for the air to move in a straight path while the earth rotates underneath. The Coriolis force is at right angles to the wind velocity, to the right in the northern hemisphere and to the left in the southern hemisphere, is proportional to the wind velocity, and decreases with latitude. The other force is the pressure gradient force, with direction from high to low pressure. Above the friction layer, in regions where the lines of constant pressure (isobars) are straight and the latitude is greater than 20°, the two forces are in balance (See Figure 7) and the wind blows parallel to the isobars with low pressure to the left. For curved isobars the forces are not in balance, their resultant producing a centripetal acceleration. In the lowest portion of the atmosphere frictional drag (not due to molecular friction but to eddy viscosity) slows down the wind speed, and since the Coriolis force is proportional to the wind speed, reduces the Coriolis force. The balance of forces under Frictional flow is shown in Figure 8. It will be noted that under frictional flow the wind has a component across the isobars toward lower pressure.

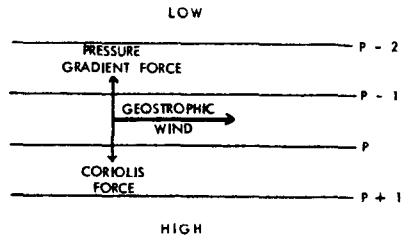


FIGURE 7

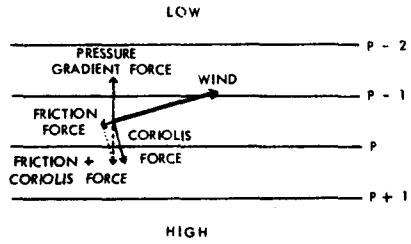
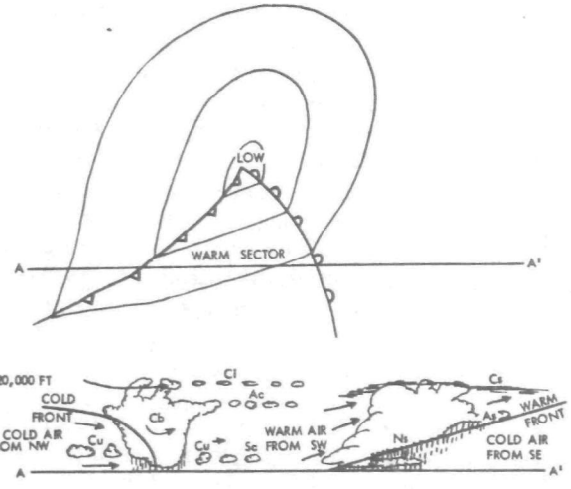


FIGURE 8

ANTICYCLONES AND CYCLONES

Migrating areas of high pressure (anticyclones) and low pressure (cyclones) and the fronts associated with the latter are responsible for the day to day changes in weather that occur over most of the mid-latitude regions of the earth. The low pressure systems in the atmospheric circulation are related to perturbations along the jet stream (the region of strongest horizontal temperature gradient in the upper troposphere and con-

sequently the region of strongest winds) and form along frontal surfaces separating masses of air having different temperature and moisture characteristics. The formation of a low pressure system is accompanied by the formation of a wave on the front consisting of a warm front and a cold front both moving around the low in a counterclockwise sense. The life cycle of a typical cyclone is shown in Figure 9. The cold front is a transition zone between warm and cold air where the cold air is moving in over the area previously occupied by warm air. Cold fronts generally have slopes from 1/50 to 1/150. Warm fronts separate advancing warm air from retreating cold air and have slopes on the order of 1/100 to 1/300 due to the effects of friction on the trailing edge of the front. Figure 10 illustrates a vertical cross section though both a warm and a cold front.



CROSS SECTION THROUGH A COLD FRONT AND A WARM FRONT

FIGURE 10

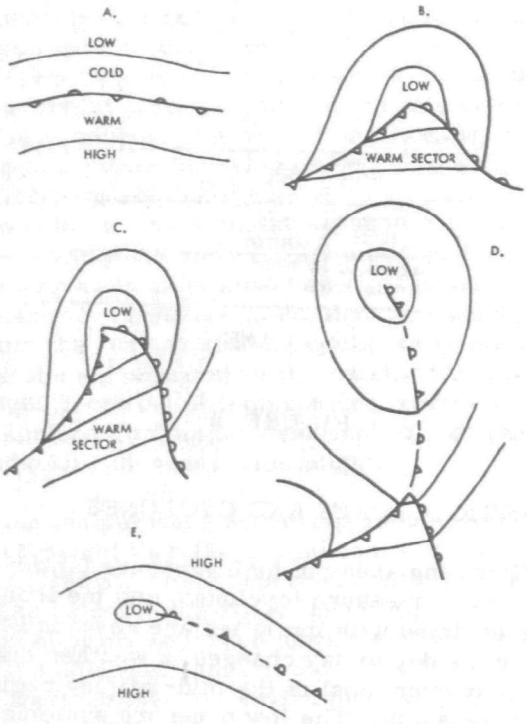


FIGURE 9

AIR MASSES

Air masses are frequently divided by frontal systems and are usually classified according to the source region of their recent history. Air masses are classified as maritime or continental according to origin over the ocean or land, and arctic, polar, or tropical depending principally on the latitude of origin. Air masses are modified by vertical motions and by the effects of radiation upon the surfaces over which they move.

CONDENSATION, CLOUDS, AND PRECIPITATION

Condensation of water vapor upon suitable condensation nuclei in the atmosphere causes clouds. Large hygroscopic nuclei will condense water vapor upon them even before saturation is reached. Table 2 indicates the relative sizes of different particles. At below freezing temperatures supercooled water frequently exists for few nuclei act as crystallization nuclei. Of course, only a small proportion of all clouds produce rain. It is necessary that the droplets increase in

size both so that they will have appreciable fall velocity and also so that complete evaporation of the drop will not occur before it reaches the ground. Table 3 indicates the distance of fall for different size drops before evaporation occurs. Growth of condensation drops into drops large enough to fall is thought to originate with the large condensation nuclei which grow larger as they drop through the cloud. The presence of an electric field in clouds generally helps the growth into raindrops.

TABLE 2

Sizes of Particles

Particles	Size (microns)
Small ions	less than 10^{-3}
Medium ions	10^{-3} to 5×10^{-2}
Large ions	5×10^{-2} to 2×10^{-1}
Aitken nuclei	5×10^{-2} to 2×10^{-1}
Smoke, haze, dust	10^{-1} to 2
Large condensation nuclei	2×10^{-1} to 10
Giant condensation nuclei	10 to 30
Cloud or fog droplets	1 to 100
Drizzle drops	100 to 500
Raindrops	500 to 4000

TABLE 3

Distance of Fall Before Evaporation (from Findeisen)

Radius (microns)	Distance of Fall
1	$3.3 \quad 10^{-4}$ cm.
10	3.3 cm.
100	150 m.
1000	42 km.
2500	280 km.

REFERENCES

1 Blair, T.A. and Fite, R.C. Weather Elements, Prentice-Hall, Englewood Cliffs, N.J. 5th ed., 1965.

2 Byers, H.R. General Meteorology, McGraw-Hill, New York, 3rd ed., 1959.

3 Findeisen, W., Meteorol. Z., 56, 453, 1939.

4 Hewson, E.W.; and Longley, R.W. Meteorology, Theoretical and Applied, Wiley, New York, 1944.

5 Houghton, H.G. "On the Annual Heat Balance of the Northern Hemisphere," J. Meteorol., 11, 1, 1-9. Feb. 1954.

6 Palmén, E., Quart. J. Roy. Meteorol. Soc., 77, 337. 1951.

7 Petterssen, S. Introduction to Meteorology, McGraw-Hill, New York, 2nd ed., 1958.

8 Shulman, M.D. Climates of the United States. Seminar on Human Biometeorology, Public Health Service Pub. No. 999-AP-25. 1967.

ADIABATIC DIAGRAM

D. B. Turner*

The adiabatic diagram can be used to plot the distribution of temperature, and moisture with height in the atmosphere. This is of considerable use to the meteorologist in determining freezing levels, condensation levels of moisture in lifted air parcels, forecasting cloud bases and tops, determining stability for cloud formation and thunderstorm forecasting. To the air pollution meteorologist a sounding plotted on an adiabatic chart is principally useful to determine the large scale stability of the atmosphere over a given location. The principal source of atmospheric measurements that may be plotted on the adiabatic chart are the radiosonde measurements taken twice daily: 0000 GCT (1900 EST) and 1200 GCT (0700 EST) at about 66 stations in the contiguous United States. The method of obtaining these soundings is to release into the atmosphere a balloon borne instrument package having sensors for temperature, pressure, and humidity and a radio transmitter for relaying this information to the ground station. This information on the upper air is collected primarily to serve the purpose of forecasting and aviation briefing. Consequently, the information is not as detailed in the lowest 5000 feet as an air pollution meteorologist desires. Also, in air pollution meteorology, it is desirable to have information more frequently than 12 hours apart. In spite of these deficiencies for air pollution purposes, the soundings from the radiosonde network will give indications of the stability of the atmosphere.

The adiabatic chart used by the Weather Service (WEA D-11) is shown at the end of this section. Temperature on a linear scale is plotted against pressure on a logarithmic scale. The different lines are explained in the legend in the upper right. The important lines for air pollution purposes in addition to the pressure and temperature lines are the dry adiabats, the solid green lines running diagonally from lower right to upper left.

A temperature sounding may be plotted by locating each significant level reported by the temperature and pressure given for that level. The plotted points may then be connected by straight lines. This gives the temperature sounding. The dew point curve may also be plotted giving a measure of humidity.

The stability of a portion of the sounding may be compared with the dry adiabatic lapse rate and with the isotherms. If the temperature decreases more rapidly than the dry adiabats through a layer, this layer is super adiabatic and quite unstable. If the temperature decreases, but at a rate less than the dry adiabatic lapse rate, the layer is sub-adiabatic and is more stable than super adiabatic. A sub-adiabatic layer may be relatively unstable or stable depending upon the humidity structure in the layer. If the temperature increases with height, the layer is an inversion. Inversions are stable layers.

Inversions that form based at ground level are generally radiation inversions caused by the cooling of the earth's surface and the adjacent air. However, there may also be advection inversions formed by the air's passage over a relatively cold surface. These two types of surface based inversion generally cannot be distinguished by inspection of the sounding plotted on an adiabatic diagram. A surface based inversion on an afternoon sounding is more apt to be an advection inversion.

There are two general classifications of inversions with bases above the ground: frontal inversions and subsidence inversions. Both of these can be ground based inversions as well as found aloft.

Frontal inversions are discontinuities in the temperature profile due to the transition between the cold air below and the warm air aloft. Frontal inversions usually are accompanied by increase in moisture through

*Supervisory Research Meteorologist, NOAA
Meteorology & Assessment Division, EPA
Research Triangle Park, N. C. 27711

the inversion. Subsidence inversions are caused by the sinking motion above high pressure areas and generally have rapidly decreasing humidities above the base of the inversion.

Surveys of the meteorological aspects of air pollution are often concerned with the extent of horizontal and vertical mixing. A quantity referred to as the mixing depth is quite useful when considering dilution of pollutants in the vertical. The usual method of estimating mixing depths is to consider the stability as portrayed on a temperature sounding remembering that unstable lapse rates favor vertical mixing and stable lapse rates restrict vertical motion. The mixing depth is generally the height above the ground to which a super or dry adiabatic lapse rate is maintained. Thus, the maximum mixing depth is frequently determined where the dry adiabat drawn through the maximum temperature for the day intersects the sounding on an adiabatic diagram.

In the figures are some soundings representative of different types of conditions in the atmosphere. Figure 1 is the temperature sounding for 12 GCT (0700 EST) for Dayton, Ohio on a clear day in summer. There is a radiation inversion based at the surface. The sounding 12 hours later (Figure 2) shows that the surface inversion has been eliminated and that nearly dry adiabatic conditions exist from the surface to 800 mb (2068 meters).

Figure 3 (5 days later than Figure 1) is representative of a cloudy summer period. Sub-adiabatic conditions occur on the morning sounding and dry adiabatic (through 187 meters) conditions occur on the evening sounding (Figure 4).

Figures 5 and 6 are for Los Angeles for a day with no smog. On the morning sounding (12 GCT, 0400 PST) sub-adiabatic conditions occur from the surface to about 1000 meters with the marine inversion layer about 200 meters thick above this. On the afternoon sounding (Figure 6) strong lapse (super adiabatic) conditions occur through a shallow surface layer with sub-adiabatic conditions extending to almost 1500 meters. The winds beneath the inversion range from 5 to 15 knots.

Figures 7 and 8 for Los Angeles are for a smog day just 4 days before Figures 5 and 6. The morning sounding (0400 PST) indicates sub-adiabatic conditions through less than 300 meters with a strong inversion above. The afternoon sounding (Figure 8) shows super adiabatic conditions from the surface to the inversion base about 300 meters above the surface. Winds beneath the inversion are less than 5 knots during the morning and are about 15 knots during the afternoon.

Figures 9 and 10 are for Dayton, Ohio during an air pollution potential alert for the Northeast U. S. and Ohio Valley. On the morning sounding (0700 EST) Figure 9 an inversion extends from the surface to 940 millibars (about 400 meters). In spite of clear skies causing temperatures to reach about 60°F, this was insufficient to break the inversion. The surface based radiation inversion is reforming by 1900 EST (Figure 10).

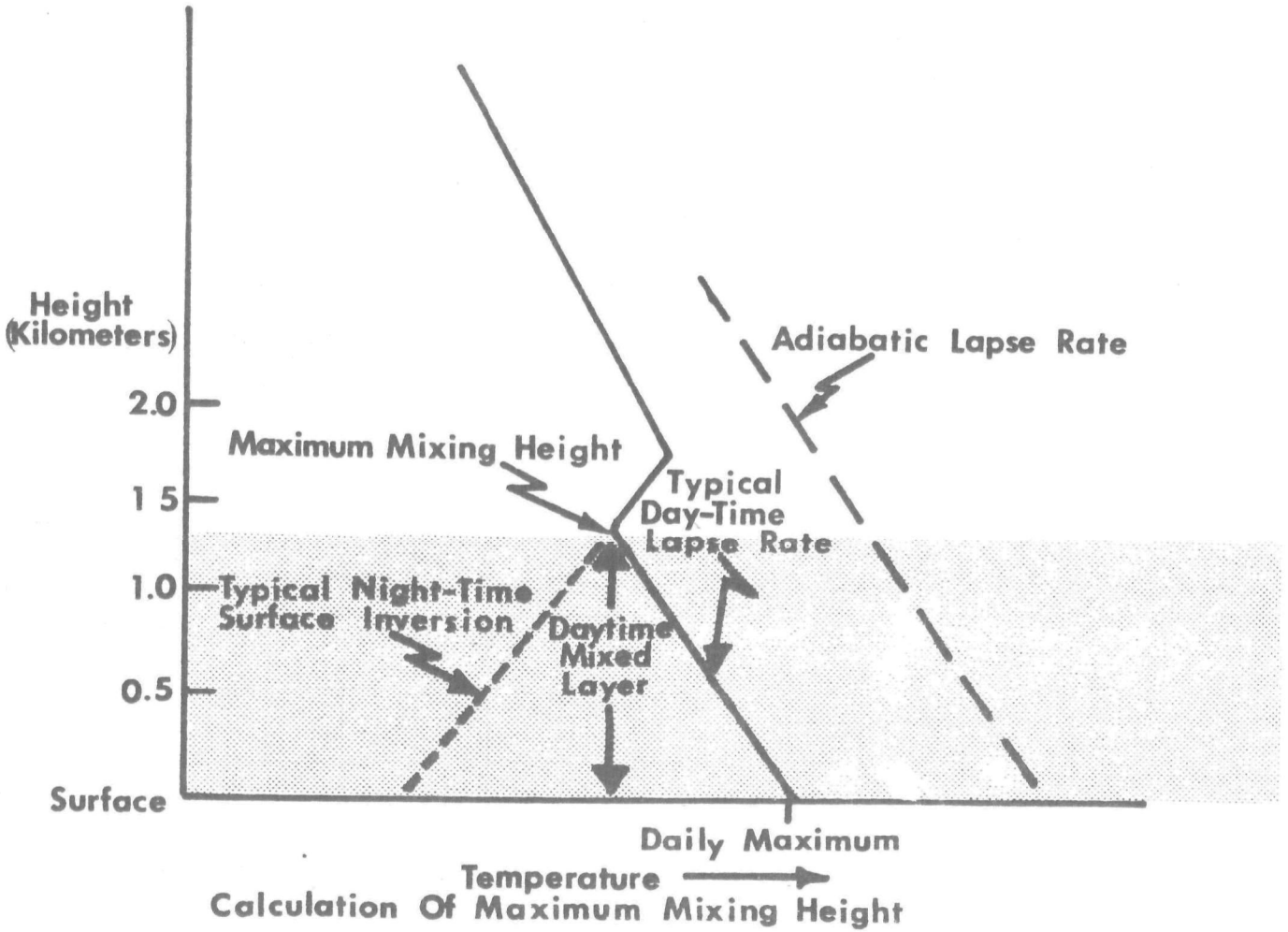
It is estimated that the maximum mixing height achieved during this day was about 350-400 meters, (the height where the dry adiabat through 15.5°C (60°F) intersects the 00 GCT sounding).

Note that the terms "mixing height" and "mixing depth" are synonymous and are used interchangeably in practice. Further information is contained in Section Four, Air Pollution Climatolog and Section Seven, Air Pollution Weather Forecasts. For further discussions on meteorologica charts and diagrams, consult most meteorological texts.

REFERENCES

1. Saucier, W. J. Principles of Meteorological Analysis. The University of Chicago Press, 1955.

2. Hess, S. L. Introduction to Theoretical Mete ology. Holt, Rinehart and Winston, Inc. New York 1959.



Calculation Of Maximum Mixing Height

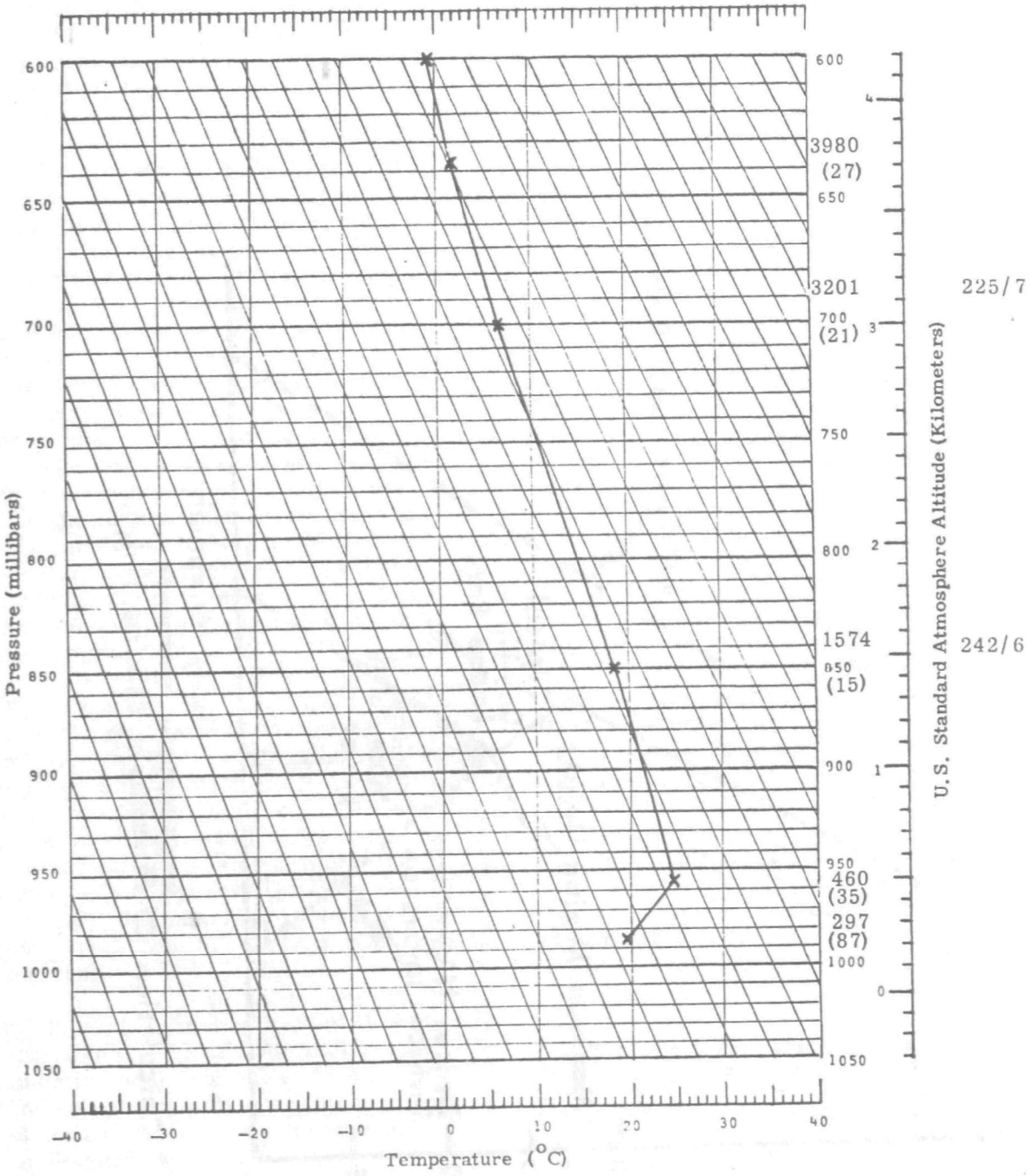


Figure 1 - Temperature Sounding For a Relatively Clear Day, Dayton, Ohio 1 July 1961, 1200 GCT (0700 EST).

Heights in meters are given for each level at the right hand margin. Figures in parenthesis are relative humidities in percent. Winds in degrees and meters per second are given at the extreme right.

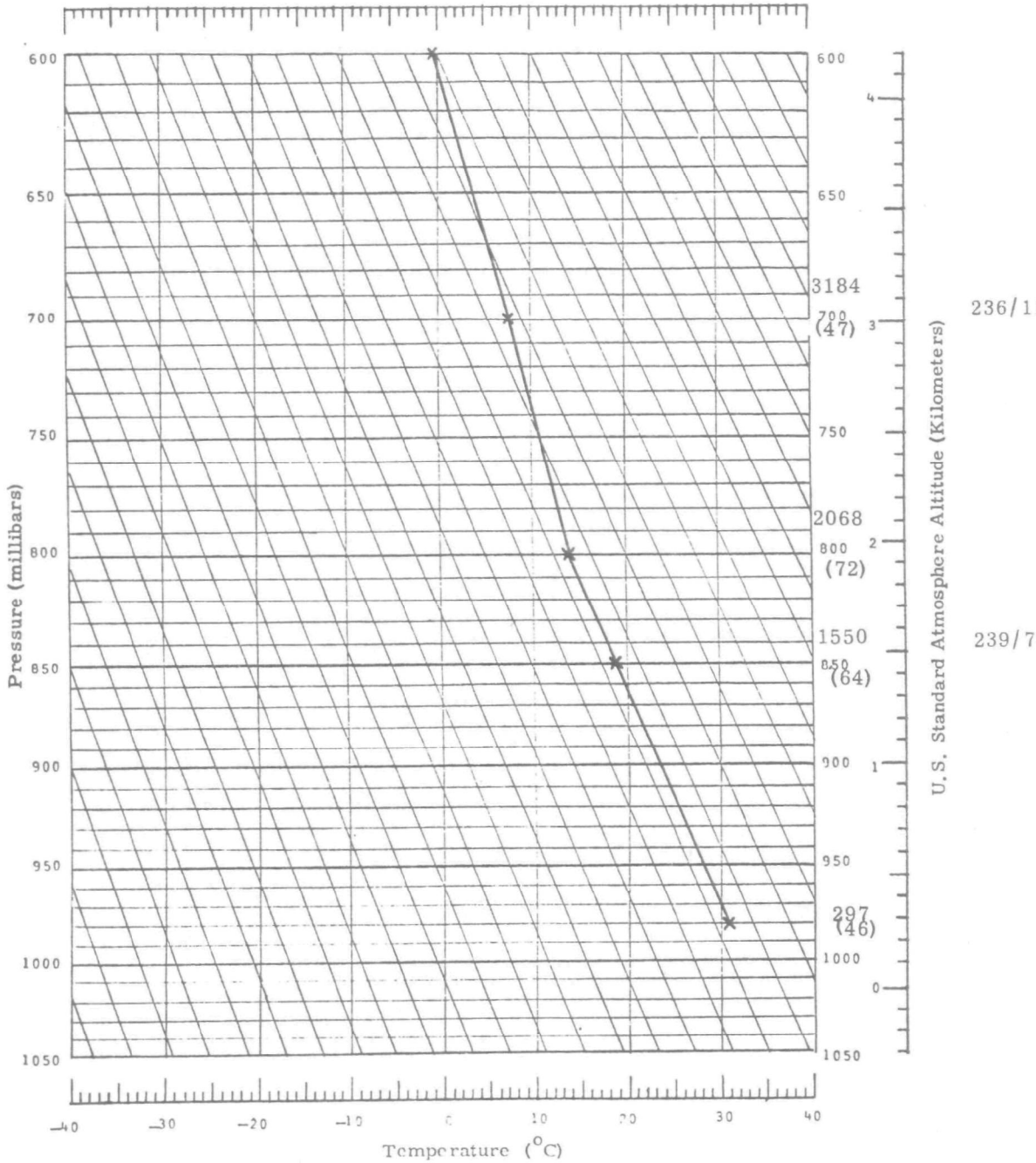


Figure 2- Temperature Sounding For a Relatively Clear Day Dayton, Ohio, 2 July 1961, 0000 GCT, (1900 EST 1 July).

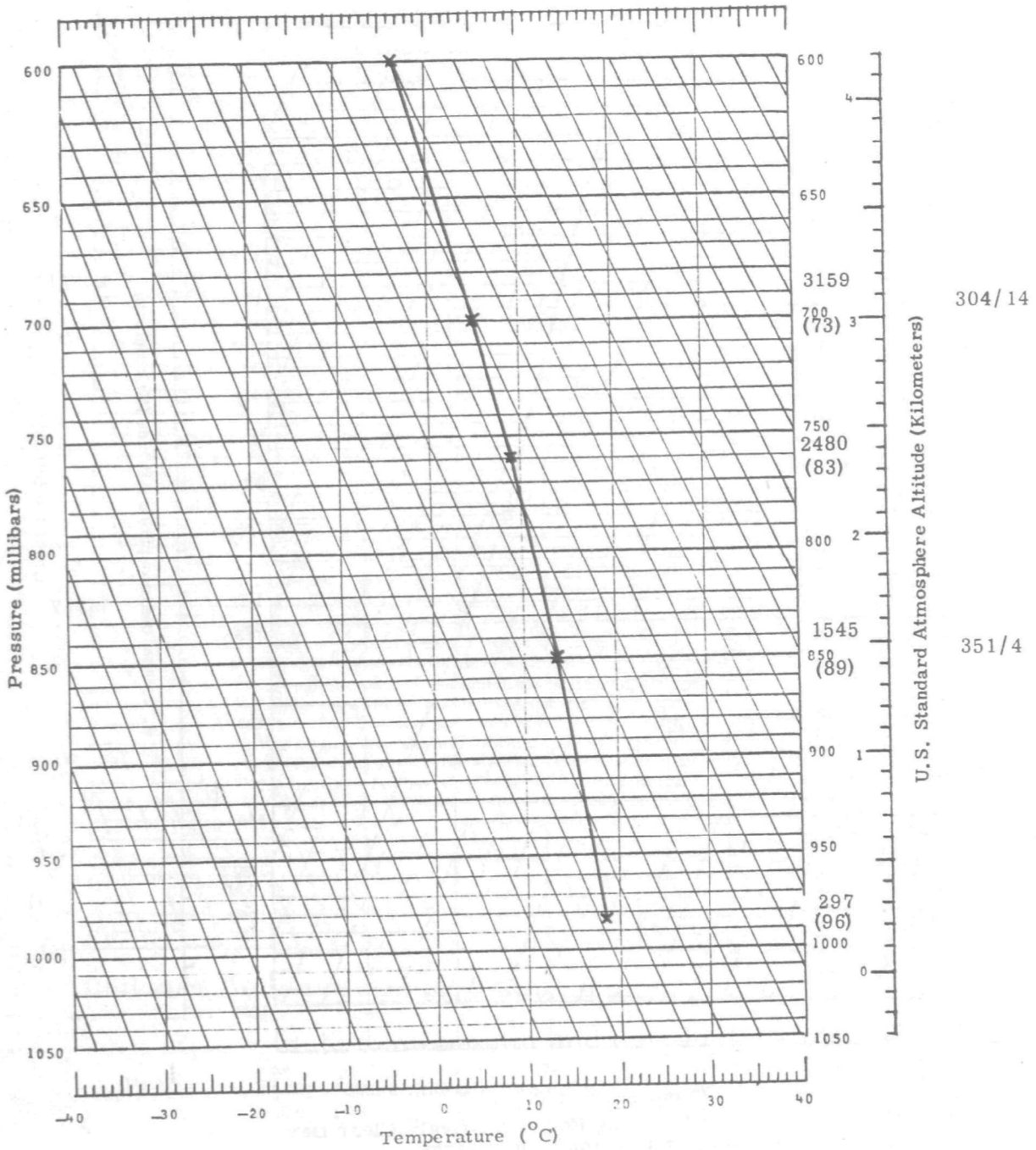
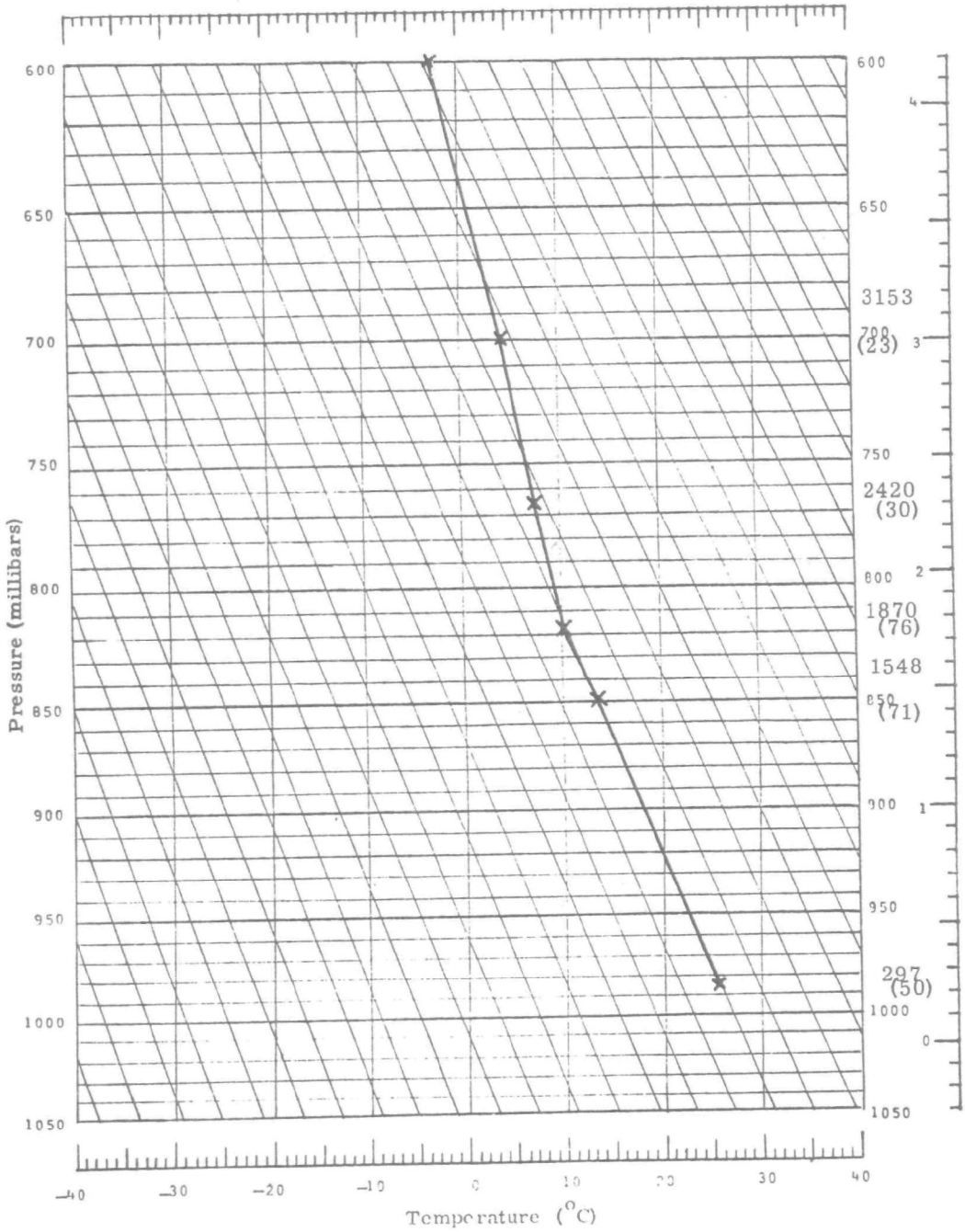


Figure 3 - Temperature Sounding For a Cloudy Day, Dayton, Ohio, 6 July 1961, 1200 GCT (0700 EST).



305/8

056/2

Figure 4 - Temperature Sounding For a Cloudy Day, Dayton, Ohio, 7 July 1961, 0000 GCT, (1900 EST 6 July).

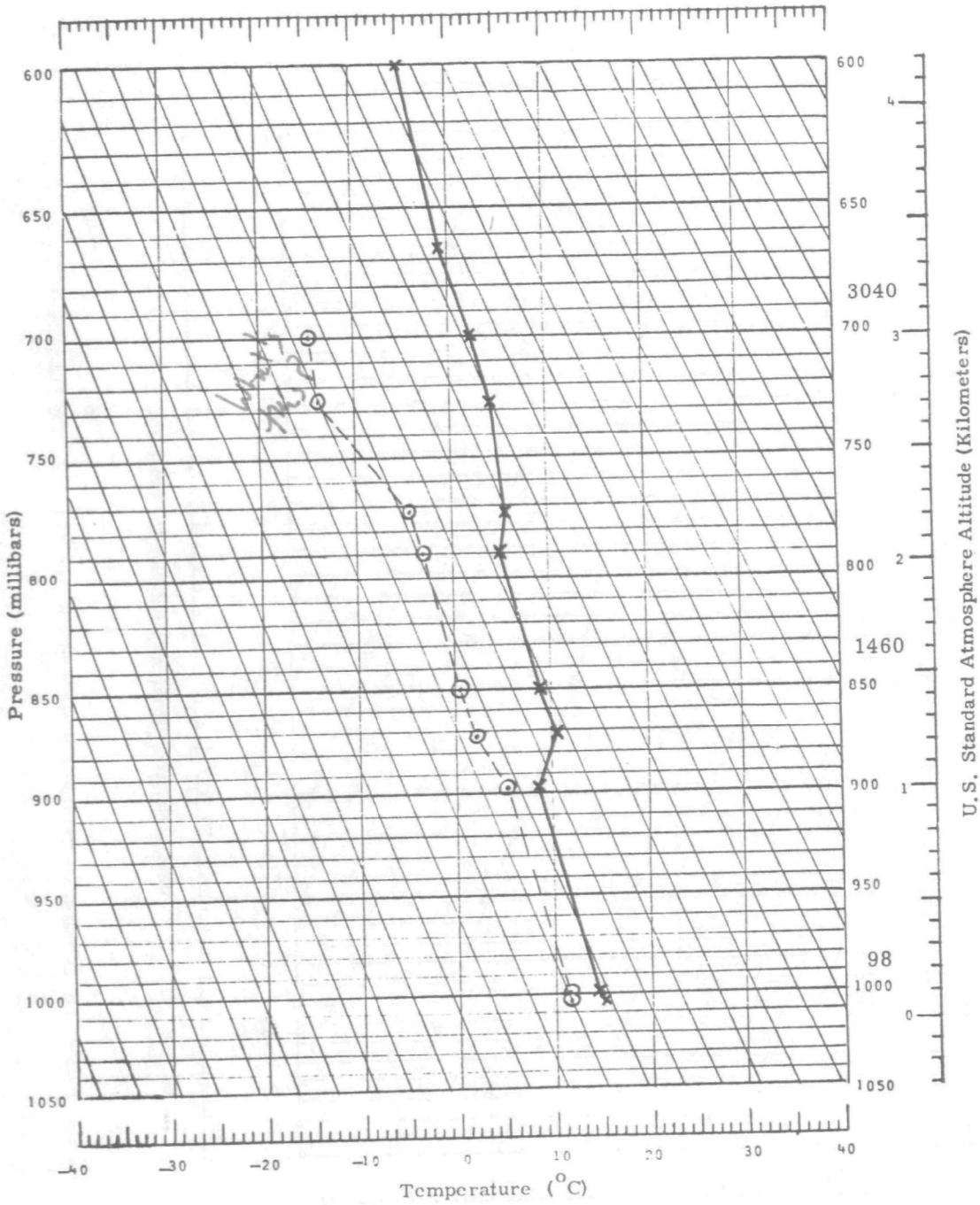


Figure 5- Temperature Sounding For a Day Free of Smog, Los Angeles, 5 October 1962, 1200 GCT. (0400 PST).

010/3

330/2

110/7

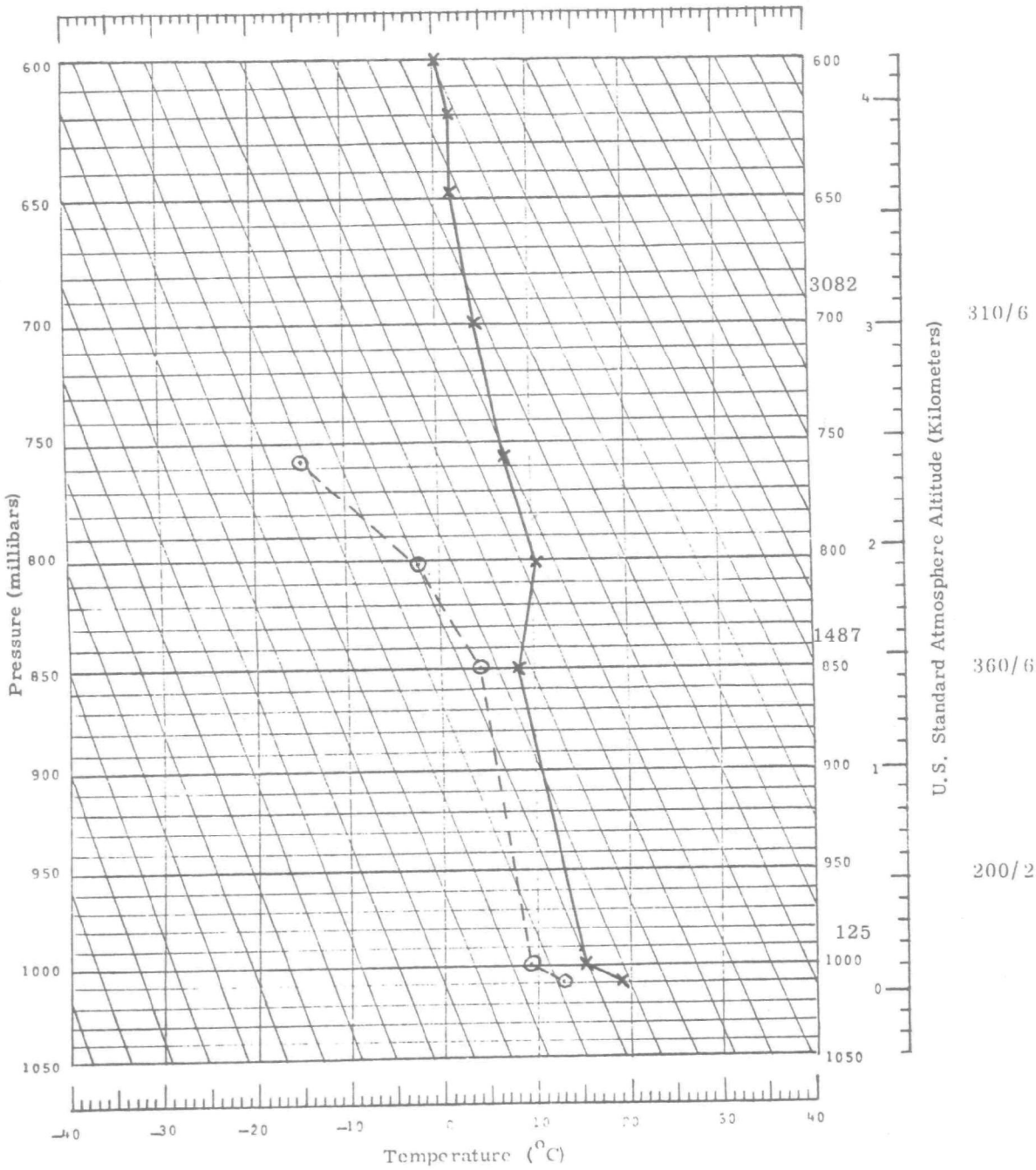


Figure 6- Temperature Sounding For a Day Free of Smog, Los Angeles, 6 October 1962, 0000 GCT (1600 PST, 5 October).

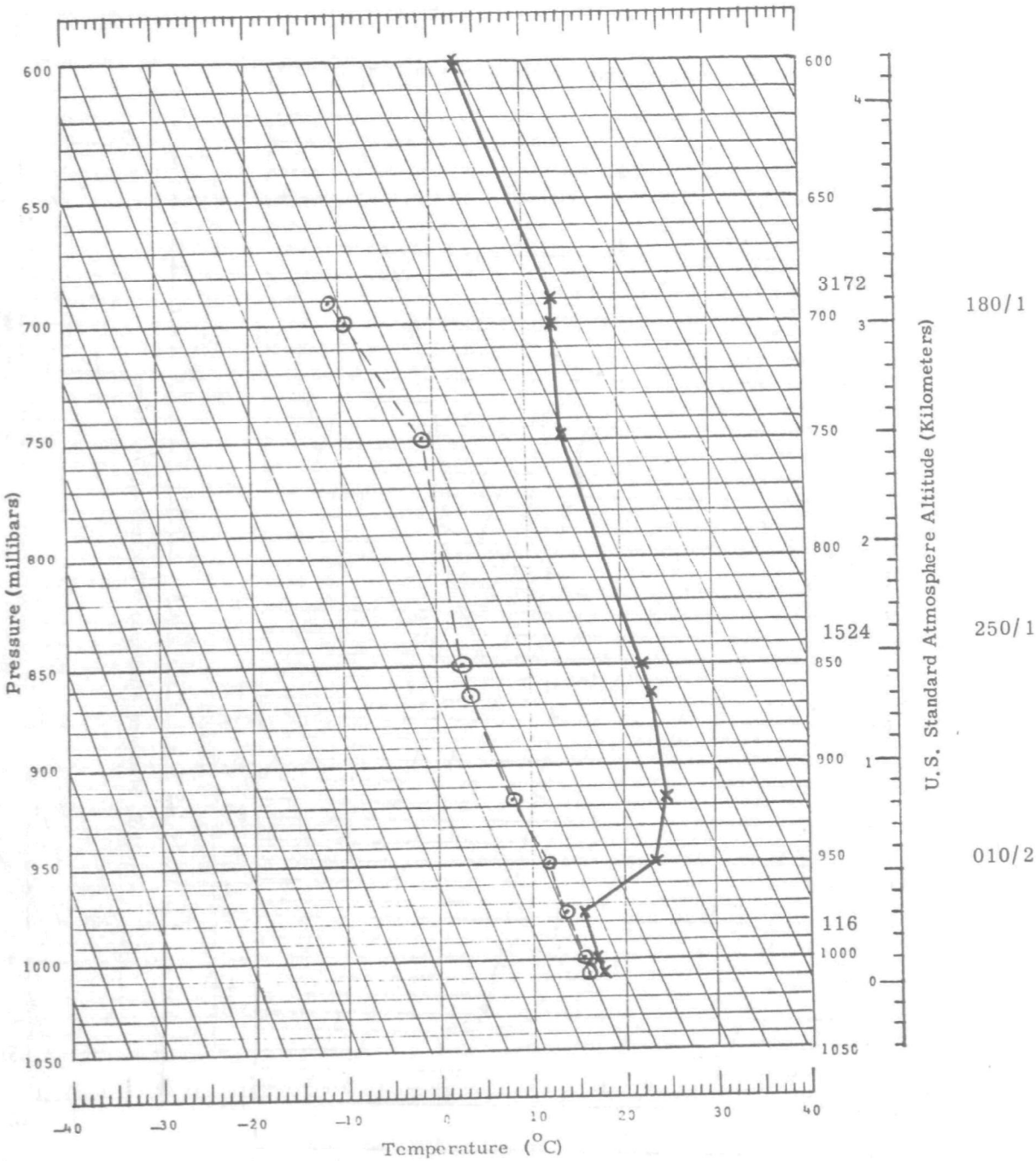


Figure 7- Temperature Sounding For a Day With Smog, Los Angeles, 1 October 1962, 1200 GCT, (0400 PST).

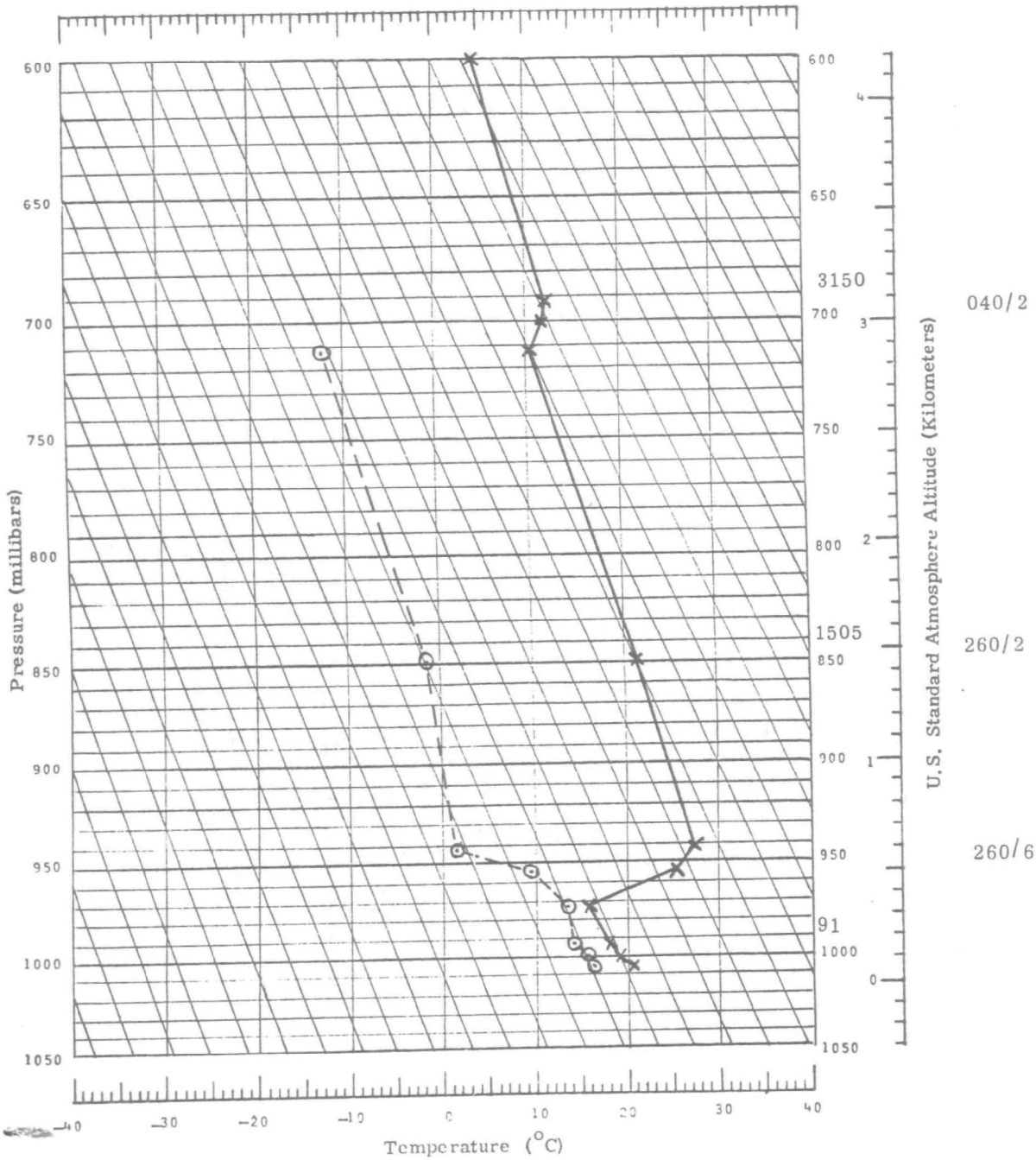


Figure 8- Temperature Sounding For a Day With Smog, Los Angeles, 2 October 1962, 0000 GCT (1600 PST, 1 October).

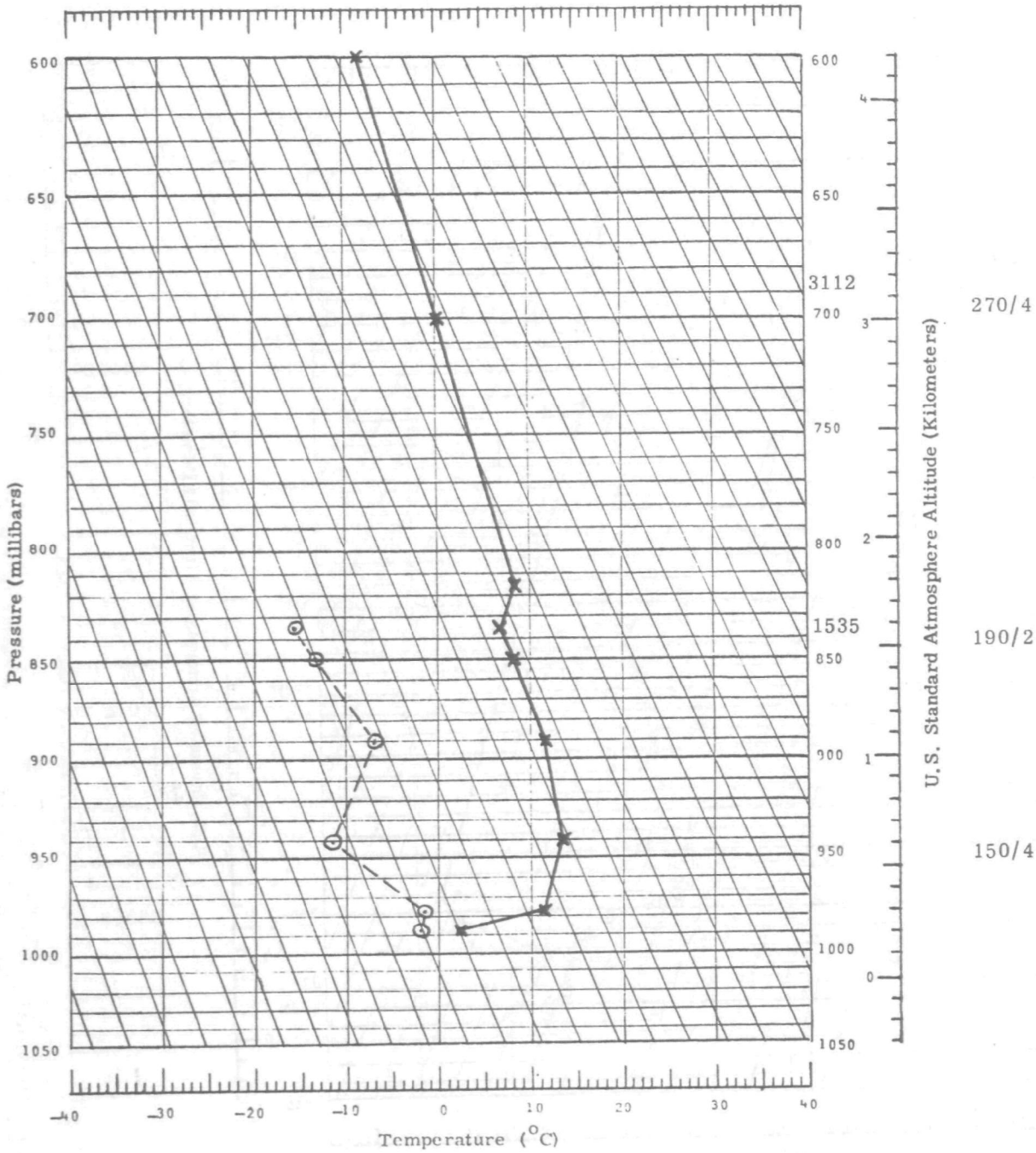


Figure 9- Temperature Sounding During an Air Pollution Potential Alert, Dayton, Ohio, 3 December 1962, 1200 GCT, (0700 EST).

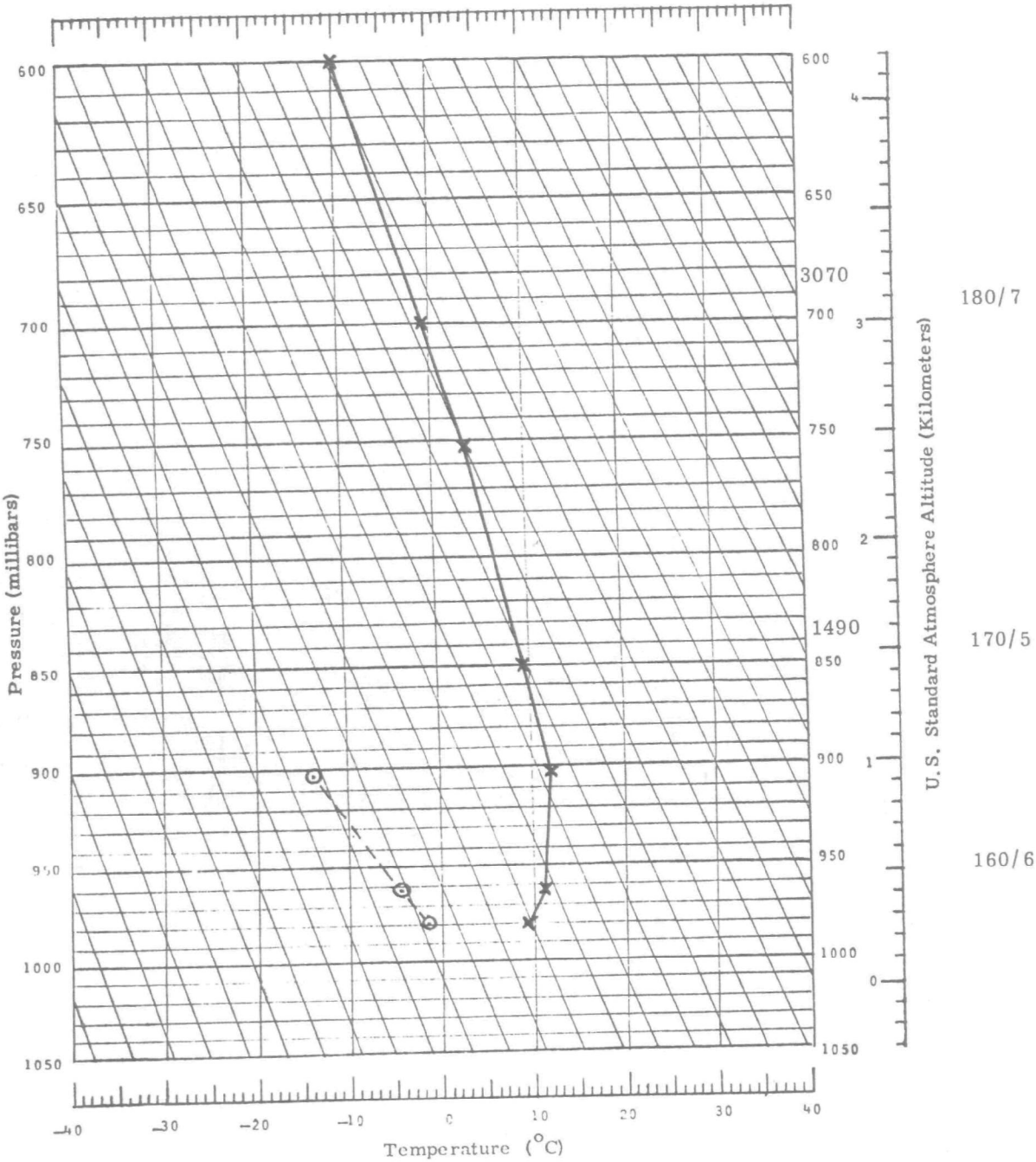
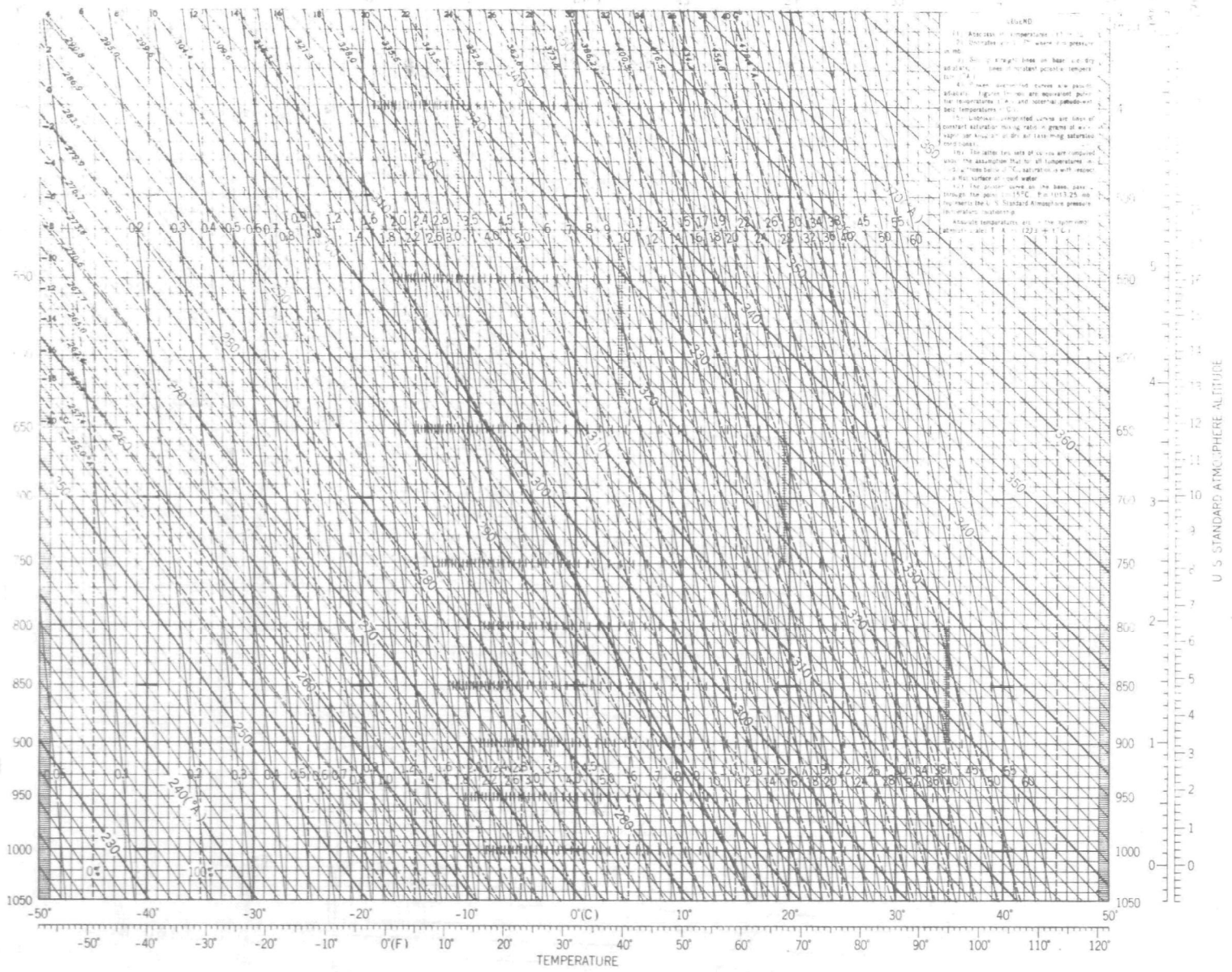


Figure 10 - Temperature Sounding During An Air Pollution Potential Alert, Dayton, Ohio, 4 December 1962, 0000 GCT, (1900 EST, 3 December).

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE

PSEUDO-ADIABATIC CHART

LOWER LEVELS



Station _____

Date (G.C.T.) _____

SECTION TWO

AIR POLLUTION METEOROLOGY

Effects of Meteorological Parameters on Transport and Diffusion
Pollutant Concentration Variation
Influence of Topography on Transport and Diffusion
Equation of State and Conversion of Concentrations
Meteorological Roses

EFFECTS OF METEOROLOGIC PARAMETERS ON TRANSPORT AND DIFFUSION

D. B. Turner*

The air pollution cycle can be considered to consist of three phases: the release of air pollutants at the source, the transport and diffusion in the atmosphere, and the reception of air pollutants in reduced concentrations by people, plants, animals, or inanimate objects. The influence of meteorology is to the greatest extent during the diffusion and transport phase. The motions of the atmosphere which may be highly variable in four dimensions are responsible for the transport and diffusion of air pollutants.

Although the distribution with time of a cloud of pollutant material will depend on the summation of all motions of all sizes and periods acting upon the cloud, it is convenient to first consider some mean atmospheric motions over periods on the order of an hour.

WIND DIRECTION

What effect will the mean wind direction have on an air pollutant? If the wind direction is representative of the height at which the pollutant is released, the mean direction will be indicative of the direction of travel of the pollutants. In meteorology it is conventional to consider the wind direction as the direction from which the wind blows, therefore a north-west wind will move pollutants to the south-east of the source.

WIND SPEED

The effect of wind speed is two-fold. The wind speed will determine the travel time from a source to a given receptor, e. g. if a receptor is located 1000 meters downwind from a source and the windspeed is 5 meters /second, it will take 260 seconds for the pollutants to travel from the source to the receptor. The other effect of wind speed is a dilution in the downwind direction. If a continuous source is emitting a certain pollutant at the rate of 10 grams/second and the wind speed is 1 meter/second then in a downwind length of the plume of 1 meter will be contained 10 grams of pollutant since 1 meter of air moves past the source each second. Next, consider that the conditions of emission are the same but the wind speed is 5 meters/second. In this case since 5 meters of air moves past the source each second, each meter of plume length contains 2 grams of pollutant. Therefore it can be seen that the dilution of air pollutants released from a source is proportional to the wind speed. This may be restated in another form: The concentration of air pollutants is inversely proportional to wind speed.

VARIABILITY OF THE WIND

In the preceding paragraphs consideration of only the mean speed and direction of wind has been made. Of course, there are deviations from this mean velocity. There are velocity components in all directions so that there are vertical motions as well as horizontal ones. These random motions of widely different scales and periods are essentially responsible for the movement and diffusion of pollutants about the mean downwind path. These motions can be considered atmospheric turbulence. If the scale of a turbulent motion i. e. the size of an eddy, is larger than the size of the pollutant plume in its vicinity, the eddy will move that portion of the plume. If an eddy is smaller than the plume its effect will be to diffuse or spread out the plume. This diffusion caused by the eddy motion is widely variable in the atmosphere but even when this diffusion is least, it is on the order of three orders of magnitude greater than the diffusion by molecular action alone.

MECHANICAL TURBULENCE

Mechanical turbulence is the induced eddy structure of the atmosphere due to the roughness of the surface over which the air is passing. Therefore the existance of trees, shrubs, buildings, and terrain features will

*Supervisory Research Meteorologist, NOAA Meteorology & Assessment Division, EPA Research Triangle Park, NC 27711

PA.ME.mm.14.6.67

cause mechanical turbulence. The height and spacing of the elements causing the roughness will affect the turbulence. In general, the higher the roughness elements the greater the mechanical turbulence. In addition the mechanical turbulence increases as wind speed increases.

THERMAL TURBULENCE

Thermal turbulence is that induced by the stability of the atmosphere. When the earth's surface is heated by the sun's radiation, the lower layer of the atmosphere becomes unstable and thermal turbulence becomes greater, expecially under conditions of light wind. On clear nights with light winds, heat is radiated from the earth's surface resulting in cooling of the ground and air adjacent to it. This results in extreme stability of the atmosphere near the earth's surface. Under these conditions turbulence is at a minimum.

RELATION OF TURBULENCE TO WIND RECORDS

Attempts to relate different measures of turbulence of the wind to atmospheric diffusion have been made for quite some time. Lowry (1951) related the distance of the maximum concentration to the standard deviation of wind direction over 10 to 15 minute periods. Smith (1951) has used a classification of wind trace types using wind vane records as an indication of atmospheric stability. Hay and Pasquill (1957, 1959), Cramer (1958), and Islitzer (1961) have all compared diffusion experiment results with statistics of wind direction fluctuations in both the horizontal and vertical. Direct methods of relating wind statistics to estimates of dispersion (Pasquill, 1961, 1962) show promise and attempts at developing suitable instrumentation to yield the necessary wind statistics directly have been made (Jones and Pasquill, 1959).

RELATION OF TURBULENCE TO ATMOSPHERIC STABILITY

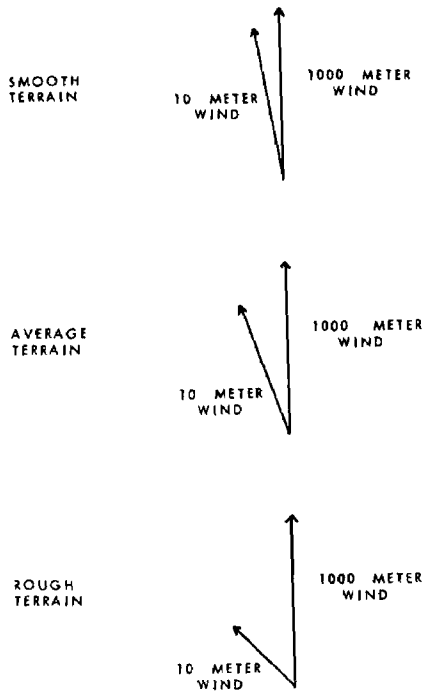
Relations of a more qualitative type have been noted between atmospheric diffusion and the stability of the atmosphere. Measurement of atmospheric stability by temperature difference measurements on a tower are frequently utilized as an indirect measure of turbulence, particularly where climatological estimates of turbulence are desired. Under strong lapse or super-adiabatic conditions of temperature change with height, strong vertical and horizontal mixing takes place in the atmosphere contrasted to inversion conditions with slight horizontal mixing but extremely limited vertical mixing. (See the section on The Influence of Vertical Temperature Structure Upon Stack Effluents)

VARIATIONS OF WIND SPEED AND DIRECTION WITH HEIGHT

Wind speed is generally found to increase with height above the ground and wind direction to veer (turn clockwise) with height (in the northern hemisphere at extratropical latitudes) due to the effects of friction with the earth's surface. The amount of these increases in speed and veering in direction are widely variable and to a great degree related to the roughness of the surface and the stability of the atmosphere.

EFFECT OF SURFACE ROUGHNESS

Consider the surface wind as measured at 10 meters compared to the wind above the influence of the earth's friction, for example about 1000 meters. Over smooth terrain such as the great plains or over the ocean the speed at the surface is on the order of 0.9 the upper wind and the degree of veering with height on the order of 10^{o}. (See Figure 1). Over average terrain with small changes in elevation and with some trees and shrubs, the surface speed is more like 4/5 of the upper wind and the amount of veering with height about 15^{o} to 20^{o}. Over rough terrain, quite hilly or mountaneous or with numerous buildings and vegetation, the surface speed may be only half the speed of the upper wind and the amount of veering with height as much as 40^{o} to 45^{o}.



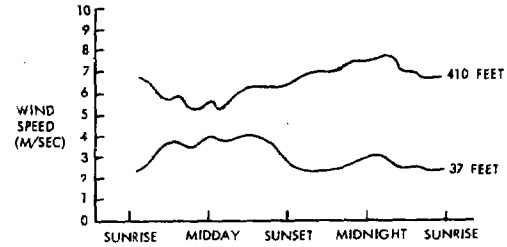
EFFECT OF ROUGHNESS ON VARIATION OF WIND WITH HEIGHT

FIGURE 1

DIURNAL VARIATION

During the daytime, solar heating causes turbulence to be at a maximum and vertical motions to be strongest. This causes the maximum amount of momentum exchange between various levels in the atmosphere. Because of this, the variation of wind speed with height is least during the daytime. Also the amount of veering with height is least (on the order of 15° to 20° over average terrain). The thickness of the friction layer will also be greatest during the day due to the vertical exchange.

At night the vertical motions are least and the effect of friction is not felt through as deep as a layer as during the day. The surface speed over average terrain is much less than the free atmosphere wind (on the order of 1/4 to 1/3 that of the 1000 meter wind) and the amount of veering with height may be on the order of 40° to 45°. Figure 2 shows the diurnal variation of wind speed at two different levels on a meteorological tower (Singer and Raynor, 1957).



DIURNAL VARIATION OF WIND SPEED

Data from Meteorological Tower
Brookhaven National Laboratory
April 1950–March 1952

FIGURE 2

FRONTAL TRAPPING

Since frontal systems are accompanied by inversions, trapping of air pollution beneath these inversions can occur. These may allow relatively high concentrations. Frontal trapping may occur with either warm fronts or cold fronts. Since warm fronts are usually slower moving and also the frontal surface slopes more gradually than that of a cold front, trapping will generally be more important with warm fronts. In addition the low level and surface wind speeds ahead of a warm front - within the trapped sector - will usually be lower than the wind speeds behind a cold front. Because of the orientation of frontal systems with respect to low pressure systems in the Northern hemisphere, most surface winds associated with cold fronts are from the quadrant west through north and winds associated with warm fronts are from the east through south quadrant. Therefore most warm frontal trapping will occur to the west through north from a given source and cold frontal trapping to the east through south of the source.

REFERENCES

Cramer, H. E.; Record, F. A.; and Vaughan, H. C. "The Study of the Diffusion of Gases or Aerosols in the Lower Atmosphere", Final Report, Contract No. AF 19(604)-1058, 15 May 58, Mass. Inst. of Tech., Dept. of Meteorol.

Hay, J. S.; and Pasquill, F. "Diffusion from a Fixed Source at a Height of a Few Hundred Feet in the Atmosphere", J. of Fluid Mech., 2, 3, 299-310, May, 1957.

Hay, J. S.; and Pasquill, F. "Diffusion from a Continuous Source in Relation to the Spectrum and Scale of Turbulence", in Atmospheric Diffusion and Air Pollution, Frenkiel, F. N.; and Sheppard, P. A., editors, Academic Press, London, 1959.

Islitzer, Norman F. "Short-Range Atmospheric Dispersion Measurements from an Elevated Source", J. Meteorol., 18, 4, 443-450, August 1961.

Jones, J. I. P.; and Pasquill, F. "An Experimental System for Directly Recording Statistics of the Intensity of Atmospheric Turbulence", Quar. J. of the Roy. Meteorol. Soc., 85, 225-236, 1959.

Lowry, P. H. "Microclimate Factors in Smoke Pollution From Tall Stacks", in: On Atmospheric Pollution, Meteorol. Mono. 1, 4, 24-29, Nov. 1951.

Pasquill, F. "The Estimation of the Dispersion of Windborne Material," The Meteorol. Mag., 90, 1063, 33-49, Feb. 1961.

Pasquill, F. Atmospheric Diffusion, Van Nostrand, London, 1962.

Singer, I. A.; and Raynor, G. S. "Analysis of Meteorological Tower Data, April 1950 - March 1952, Brookhaven National Laboratory", AFCRC TR-57-220, Brookhaven National Laboratory, June 1957.

Smith, M. E. "The Forecasting of Micrometeorological Variables", in: On Atmospheric Pollution, Meteorol. Mono., 1, 4, 50-55, Nov. 1951.

POLLUTANT CONCENTRATION VARIATION

D. B. Turner*

THE INFLUENCE OF VERTICAL TEMPERATURE STRUCTURE UPON STACK EFFLUENTS

The manner in which stack effluents diffuse is primarily a function of the stability of the atmosphere. Church (1949) has typed the behavior of smoke plumes into five classes. Hewson (1960) has added a sixth class taking into account inversions aloft.

LOOPING

Looping occurs with a superadiabatic lapse rate. Large thermal eddies are developed in the unstable air and high concentrations may be brought to the ground for short time intervals. Diffusion is good however when considering longer time periods. The superadiabatic conditions causing looping occurs only with light winds and strong solar heating. Cloudiness or high winds will prevent such unstable conditions from forming.

CONING

With vertical temperature gradient between dry adiabatic and isothermal, slight instability occurs with both horizontal and vertical mixing but not as intense as in the looping situation. The plume tends to be cone shaped hence the name. The plume reaches the ground at greater distances than with looping. Coning is prevalent on cloudy or windy days or nights. Diffusion equations are more successful in calculating concentrations for this type of plume than for any other.

FANNING

If the temperature increases upward the air is stable and vertical turbulence is suppressed. Horizontal mixing is not as great as in coning but still occurs. The plume will therefore spread horizontally but little if any vertically. Since the winds are usually light the plume will also meander in the horizontal. Plume concentrations are high but little effluent from elevated sources reaches the ground with this situation except when the inversion is broken due to surface heating, or terrain at the elevation of the plume is encountered. Clear skies with light winds during the night are favorable conditions for fanning.

LOFTING

Lofting occurs when there is a superadiabatic layer above a surface inversion. Under this condition diffusion is rapid upward but downward diffusion does not penetrate the inversion and so is damped out. With these conditions gases will not reach the surface but particles with appreciable settling velocities will drop through the inversion. Near sunset on a clear evening in open country is most favorable for lofting. Lofting is generally a transition situation and as the inversion deepens is replaced by fanning.

FUMIGATION

As solar heating increases the lower layers are heated and a super-adiabatic lapse rate occurs through a deeper and deeper layer. When the layer is deep enough to reach the fanning plume, thermal turbulence will bring high concentrations to the ground along the full length of the plume. This is favored by clear skies and light winds and is apt to occur more frequently in summer due to increased heating.

Another type of fumigation may occur in the early evening over cities. Heat sources and mechanical turbulence due to surface roughness causes a lapse condition in the lower layers of the stable air moving into the city from non-urban areas where radiation inversions are already forming. This causes a fumigation until the city loses enough heat so that the lapse condition can no longer be maintained.

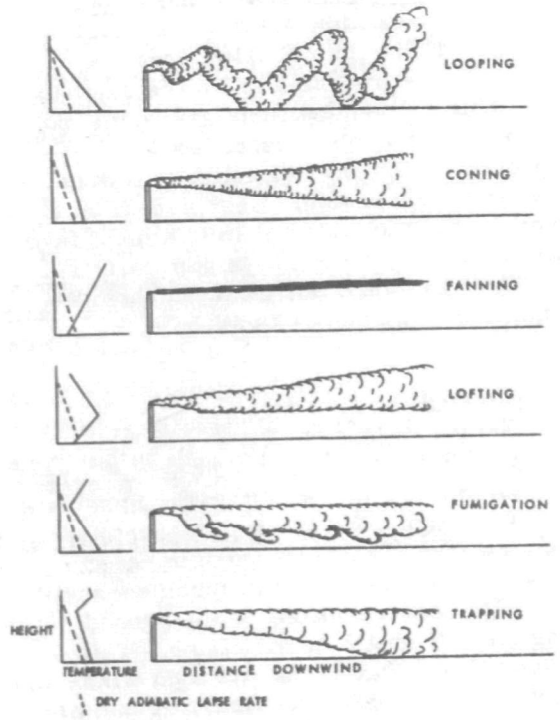
TRAPPING

When an inversion occurs aloft such as a frontal or subsidence inversion a plume released beneath the inversion will be trapped beneath it. Even if the diffusion is good beneath the inversion such as a coning plume,

* Supervisory Research Meteorologist, NOAA
Meteorology & Assessment Division, EPA
Research Triangle Park, NC 27711

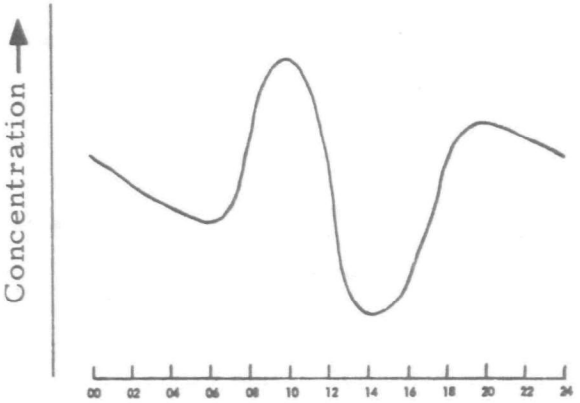
the limit to upward diffusion will increase concentration in the plume and at ground level.

The six plume classes are diagrammed in the accompanying figure.



VARIATION OF POLLUTANT CONCENTRATIONS DUE TO METEOROLOGIC VARIATIONS

An example of the diurnal variation of pollutant concentrations is given in this figure. These are the concentrations some distance down-wind from a continuous elevated urban source on a day when stability reaches extremes, i.e., on a clear day with light winds. This shows only the variations on the order of an hour's duration rather that the rapid variations which may occur a few minutes duration.



Diurnal Variations of Ground-Level Concentrations from Elevated Urban Sources

The primary maximum around 10 AM is due to fumigation. The rapid decrease in concentration following this is due to the heating of a progressively deeper layer and mixing of pollutants through this layer.

The increase of concentrations during the late afternoon are due to the slight increase in stability after the period of maximum heating. During this period the lapse rate is generally changing from strong lapse to weak lapse.

The secondary maximum that occurs in the evening is a phenomena observed only in the urban area. During the late afternoon and early evening a radiation inversion begins to form at the earth's surface in the non-urban areas, i.e., the surrounding countryside. The air over the city, however, does not have a radiation inversion in the lower layers due to release of heat from the buildings and pavings of the city. However, later in the evening, an inversion above the weak lapse layer forms above the city and a mixing of the pollutants in this layer produces the higher concentrations. This has been described by Munn and Katz

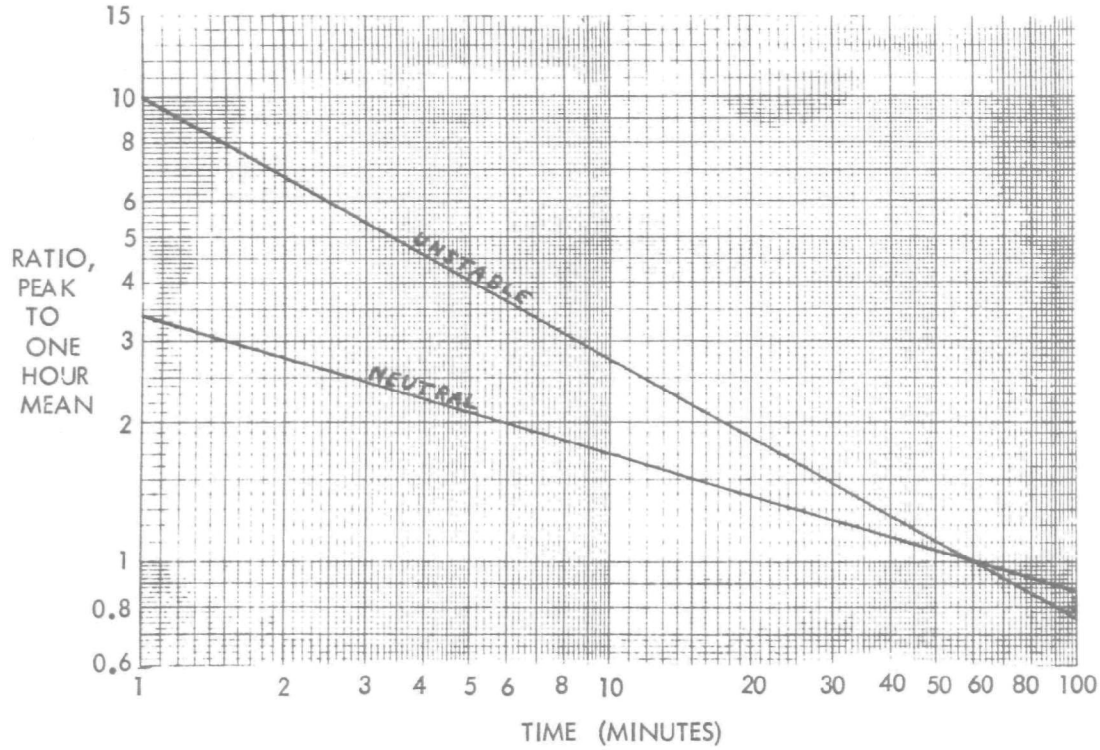
(1959). Hewson (1960) refers to this as a "Type II Fumigation".

When the base of this inversion aloft lowers enough so that the elevated emissions are into the inversion layer the concentrations decrease and continue to decrease until after sunrise. Then surface heating is sufficient to produce mixing beneath the inversion and pollution previously in the inversion layer is mixed through the layer of super-adiabatic lapse rate beneath the remaining upper portion of the inversion resulting in high ground level concentrations.

VARIATION IN CONCENTRATION AS AFFECTED BY SAMPLING TIME

Since the motions of the atmosphere are not constant with time the concentrations of pollutants are also variable with time. Mean concentrations of pollutants measured over different time periods are not directly comparable. This is due principally to the fluctuation of the horizontal wind direction. If sampling is conducted downwind from a source a short sample of 3 to 5 minutes duration will yield a certain concentration but as the sampling interval is increased to say an hour, the mean concentration will decrease due to short periods of time when the wind is not blowing directly from the source to the receptor even though the mean wind throughout the sampling interval is from source to receptor.

Relations have been experimentally determined (Stewart, Gale and Crooks, 1958; Cramer, 1959; and Singer, 1961) relating the peak short term concentration over larger sampling intervals. The accompanyin graph shows some of these findings. This shows that under neutral conditions the peak 3 minute concentration over an hour is about 2 1 /2 times the hourly mean. Under unstable conditions when the vertical direction of the wind is also rapidly changing the peak 3 minute concentration can be expected to be about 5 1/2 times the hourly concentration. It should be remembered that this graph is applicable to peak centerline concentration. Off axis concentration would be higher as the averaging time interval is lengthened.



RELATION OF PEAK SHORT TERM CENTERLINE CONCENTRATIONS TO ONE HOUR MEAN CONCENTRATIONS

Where there are multiple sources of the measured pollutant the variation of the wind does not have as large an effect on the changes of concentration with sampling time. A study (McCormick and Xintaras) on carbon monoxide concentrations in Nashville, Tennessee has shown, as an example, 3 minute peak concentration on the order of 1.5 times hourly concentrations.

An empirical mathematical relationship has been proposed for relating peak to one-hour mean concentrations

$$\frac{X_{\text{peak}}}{X_{1 \text{ hour mean}}} = \left(\frac{3600}{t}\right)^{r}$$

where:

t time in seconds
r 0.65 very unstable (class A)
0.52 unstable (class B, C)
0.35 neutral (class D)

Additional studies have analyzed the concentration of specific pollutants by averaging time and frequency of occurrence a selected concentration is exceeded, (Zimmer and Larsen, 1965; Larsen et al, 1967). However, meteorological variations, especially stability conditions, were not explicitly considered.

The question also arises about inferring what the concentration average will most likely be over periods longer than one hour up to 24 hours given a one-hourly average. While there is no substitute for actual data, the following table, extracted from Ref. 10, may be used as a first approximation:

Averaging Time	Correction
1 hour	1.0
3 hours	0.94
8 hours	0.8
24 hours	0.37

The type of source, emission rate variability, topography, and specific meteorological situation will usually result in a matrix for which a set of unique corrections will likely be required to fit observed data.

REFERENCES

1. Church, P. E.; "Dilution of Waste Stack Gases in the Atmosphere", Ind. Eng. Chem. 41, 12, 2753-2756, Dec. 1949

2. Cramer, Harrison E.; "Engineering Estimates of Atmospheric Dispersal Capacity", Amer. Ind. Hyg. Assoc. J., 20, 3, 183-189, June 1959.

3. Hewson, E. W.; "Meteorological Measuring Techniques and Methods for Air Pollution Studies" in Industrial Hygiene an Toxicology, Vol. 3. L. Silverman (Ed.) New York, Interscience

4. McCormick, R. A. and Xintaras, C.; "Variation of Carbon Monoxide Concentrations as Related to Sampling Interval, Traffic, and Meteorological Factors". J. Appl. Meteorol. 1, 2, 237-243, June 1962

5. Munn, R. E. and Katz, M. "Daily and Seasonal Pollution Cycles in the Detroit Windsor Area". Int. J. Air Poll., 2.1. 51-76, July 1959.

6. Singer, Irving A. "The Relationship Between Peak and Mean Concentrations" J. of APCA, 11, 7, 336 - 341, July 1961.

7. Stewart, N. G.; Gale, H. J.; and Crooks, R. N. "The Atmospheric Diffusion of Gases Discharged from the Chimney of the Harwell Reactor BEPO" Int. J. Air Pollution, 1, 1/2, 87 - 102, October 1958.

8. Zimmer, C. E. and Larsen, R. I. "Calculating Air Quality and its Control." JAPCA, 15, 12, 565-572. December 1965.

9. Larsen, R. I., Zimmer, C. E., Lynn, D. A., Blemel, K. G. "Analyzing Air Pollutant Concentration and Dosage Data." JAPCA, 17, 2, 85-93, February 1967.

10. EPA Guidance for Air Quality Monitoring Network Design and Instrument Siting. Guideline Series OAQPS No. 1.2-012 (Rev.) Supplement B July 1975.

INFLUENCE OF TOPOGRAPHY ON TRANSPORT AND DIFFUSION

D. B. Turner*
J. L. Dicke*

In many cases the transport and diffusion of air pollutants is complicated by terrain features. Most large urban areas are located either in river valleys or on the shores of lakes or oceans. Both of these features alter meteorologic conditions.

VALLEY EFFECTS

Channeling

Although the more extreme effects of a valley location occurs when the general flow is light, valleys tend to channel the general flow along the valley axis resulting in a bi-directional wind frequency distribution.

Slope and Valley Winds

When the general wind flow is light and skies are clear, the differences in rates of heating and cooling of various portions of the valley floor and sides cause slight density and pressure differences resulting in small circulations. During the evening hours radiation of heat from the earth's surface and consequent cooling of the ground and air adjacent to the ground causes density changes. The air at point A (Figure 1) is more dense than at point B since point A is nearer the radiating surface. Therefore the more dense air at point A tends to flow in the general direction of B and similarly at other points along the slope. This is the slope wind.

FIGURE 1

If the slope in Figure 1 is a side of a valley as in Figure 2, the cold air moving down the slopes will tend to drain into the valley floor and deepen with time, intensifying the radiation inversion that would form even without the addition of cold air. Any pollutants that are emitted into this air, because of the inversion structure, will have very limited vertical motion.

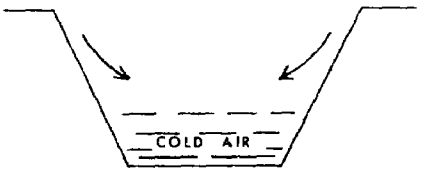


FIGURE 2

If, in addition, the valley floor has some slope, the cold air will have a tendency to move downhill along the valley axis. This is usually referred to as the valley wind (See Figure 3). Because of the necessity of some accumulation of cold air from slope winds, the onset of the valley wind usually lags several hours behind the onset of the slope wind.

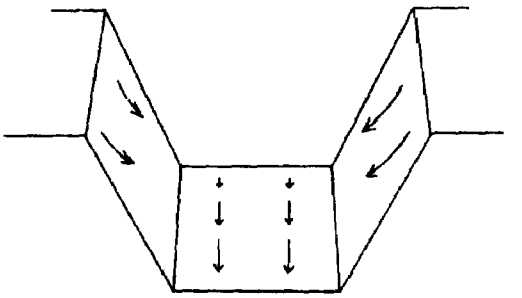


FIGURE 3

The steeper the slopes of the valley, the stronger the slope winds can become. Vegetation will tend to reduce the flow both due to impeding the flow and also restricting the amount of radiation that can take place.

*Supervisory Meteorologists, NOAA
Meteorology & Assessment Division, EPA

On a clear day with light winds, the heating of the valley may cause upslope and up-valley winds. However the occurance of upslope and up valley winds is not as frequent nor as strong as the down-slope and down-valley winds, principally due to the fact that down-slope and down-valley winds, due to their density, hug the surfaces over which they travel. Flow in complex valley systems where several valleys merge at angles or slopes vary, usually require special observations to determine flow under various meteorologic conditions.

Inversions Aloft

The trapping of air pollutants beneath inversions aloft is also a problem encountered in valleys. Two types of inversions, warm frontal and subsidence inversions, are of particular concern since they are usually slow moving. High concentrations may occur particularly if the layer of air beneath the inversion becomes unstable enough to mix pollutants from elevated sources to ground level (Hewson et al, 1961).

SHORELINE WINDS

The differences in heating and cooling of land and water surfaces and the air above them result in the setting up of circulations if the general flow is light, and in the modification of thermal characteristics and consequently the diffusive abilities of the lower layers of the atmosphere when a general flow occurs.

Sea or Lake Breeze

On summer days with clear skies and light winds the heating of the land surface adjacent to a large lake or the ocean is much more rapid than the heating of the body of water. This results in a temperature difference and consequently a density and pressure difference between the air just above the land surface and the air over the water. Because of the pressure gradient forces, a local circulation is set up with wind from the water toward the land. There is usually some upward motion over the land and subsidence over the water accompanying the sea breeze (Estoque, 1961). There may result a weak transport from land to water aloft completing a cellular structure to the sea breeze. (See Figure 4).

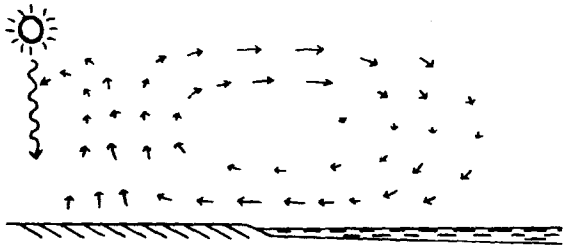


FIGURE 4

In cases where a strong lake breeze occurs, air from quite some distance out over the water may be brought toward the land and due to Coriolus forces acting over the long trajectory the resulting flow will become nearly parallel to the shoreline (Sutton, 1953). This occurs just after the sea breeze is the strongest and results in decreasing the flow normal to the coastline and subsequent breaking down of the sea breeze.

Land Breeze

At night the rapid radiational cooling of the land causes lower temperatures above the land surface than over the water. Thus a reverse flow, the land breeze, may result. The land breeze does not usually achieve as high a velocity as the lake breeze, and is usually shallower than the sea or lake breeze.

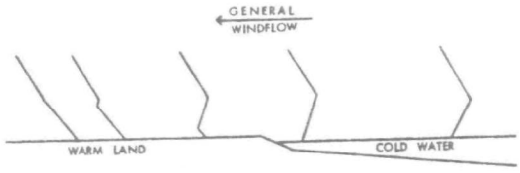
Of course, any wind flow due to the large scale pressure pattern will alter the local circulation and the flow will be the resultant of the two effects. Usually a light general flow is enough to overshadow the effects of land and sea breezes.

MODIFICATION OF THERMAL STRUCTURE BY BODIES OF WATER

At different seasons of the year and also different times of day the temperature of bodies of water and adjacent land surfaces may be quite different. For example,

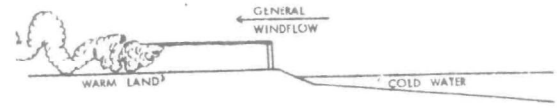
during the late spring, large bodies of water are still cold relative to adjacent land surfaces and during mid-afternoon this difference is greatest due to the more rapid heating of the land surface. If the general flow in the area is such that the wind has a lengthly trajectory over the water and is blowing toward the shore, an interesting modification of the temperature structure takes place. Because of the passage over the cold water surface, the air will have an inversion in the lower layer as it reaches the shoreline. Any air pollutants released into this inversion will essentially have the characteristics of a fanning plume. As the air passes over the warm land, a strong lapse replaces the inversion near the surface. The depth of this lapse layer becomes deeper as the air moves over more heated land surface. At the point where the lapse layer is deep enough to reach the fanning effluent from an elevated source, fumigation will occur. Fumigation of this type may last considerably longer than the usual diurnal breakup of nocturnal inversions as this fumigation will occur as long as the temperature difference between land and water is maintained and flow from water to land occurs. At greater distances from the shoreline the inversion will be eliminated and looping type of plume behavior will occur. On the other hand, if the source is high enough to be above the lake induced inversion, lofting of the plume would occur until enough distance and consequently enough heating takes place to eliminate the inversion.

Figure 5a indicates the difference in vertical temperature structure that occurs in the above example and Figure 5b indicates the effect this has on the plume characteristics of an elevated shoreline source.



MODIFICATION OF VERTICAL TEMPERATURE STRUCTURE DUE TO FLOW OVER DIFFERENTLY HEATED SURFACES (LATE SPRING, AFTERNOON)

FIGURE 5a



EFFECT UPON PLUME CHARACTERISTICS OF FLOW OVER DIFFERENTLY HEATED SURFACES (LATE SPRING, AFTERNOON)

FIGURE 5b

At other times when the water is warmer than the land surface (late fall), offshore flow will result in fumigation over the water.

INFLUENCE OF HILLS

The influence of hills upon the transport and diffusion depends upon a number of factors. Whether the source is on the windward or lee side of the hill or ridge is important. A smooth hill will alter the flow least; one with sharp ridges will cause more turbulent eddies to form. The stability of the atmosphere will affect the influence of hills. During stable conditions, the flow will tend to flow around obstructions. Under unstable conditions the tendency is for air to move over obstructions.

When a source is located upwind of a hill or ridge, the pollutants may come in contact with the facing slope, particularly under stable conditions. If the ridge is quite rough, Induced turbulence may cause mixing down to the slope even when the general flow is over the ridge. Wind tunnel studies or field trials with constant level balloons may be desirable to determine the flow under given circumstances.

For a source downwind from a hill or ridge, lee eddies will generally cause considerable downwash of the effluent near the source. If turbulent flow is induced by the hillside, diffusion will be increased but high concentrations very near the stack will result periodically due to the downwash.

Several dispersion studies such as those reported by Panofsky and Prasad (1967) in a Pennsylvania Valley and later by Start, and Dickson and Wendell (1975) through mountainous terrain of Utah illustrate the wide range of physical

effects and mechanisms which must be considered when estimating concentrations under these conditions as opposed to estimates for relatively level terrain sites. In general much greater dilution takes place, primarily due to enhanced mechanical turbulence even when plume impingement occurs. Increased mechanical turbulence is produced in at least three ways. First, the mountain top is an obstacle to the prevailing wind flow aloft and thus produces turbulence, some of which penetrates into the surrounding canyons. Second, side or feeder canyons produce downslope flows which cause turbulent interchanges with the main downvalley flow. Third, a form of wake turbulence is produced due to the flow around and over projecting cliffs, side walls and other terrain features present along the main valley or canyon. Plume impaction on terrain features has been documented but observed concentrations have generally been much lower than prior estimates. This is most likely due to the dilution already accomplished by the mechanisms previously listed. For the rough mountainous terrain of Huntington Canyon, Utah the rates of dilution under unstable lapse rates were found to be rather similar to open terrain estimates using the Pasquill stability categories (see p.3-23). Under neutral stability the canyon dilation rate was about five times greater, while under strong inversion situations the rate was about 15 times greater than for level terrain. Therefore no generalized dispersion parameters for these situations have been published and extrapolating results to locations where no field measurements have been made should be done very cautiously.

PERSISTENCE OF FOG

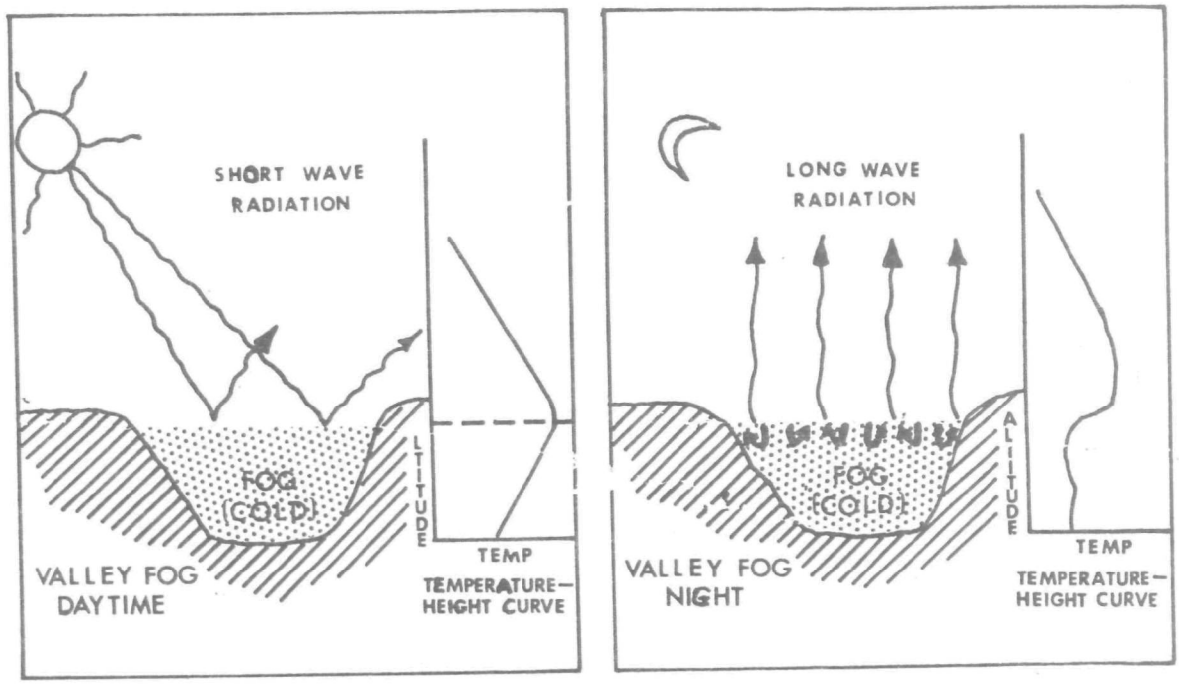
The occurrence of fog, together with very stable atmospheric conditions above the earth's surface, has been noted in several air pollution episodes, particularly in Donora, Pennsylvania, in 1948. Under clear skies at night the ground loses much heat because of outgoing radiation and the air in contact with the ground will cool. If, in such cases the air is sufficiently humid, the cooling will bring the air to the saturation point and a fog will form. This is the mechanism which produces radiation fog and is quite common in valley locations. The top of a layer of fog will radiate essentially as a blackbody and cool further, thus forming an inversion layer directly above the fog. As the earth continues to radiate in the infrared, the fog droplets absorb nearly all this heat since the droplet size distribution is similar to the wavelengths of the radiation. Theory and observation have shown that when the top of a fog layer radiates during the night the interior of the layer will become more unstable with time. Increased vertical mixing will occur from below but will be capped by the inversion. Since the air is saturated, an unstable rate will exist if the temperature decreases with height is greater than the moist or pseudo-adiabatic rate of about - 3°F. per 1000 ft., rather than the dry adiabatic lapse rate of - 5.4°F. per 1000 ft.

Thus pollutants that are emitted aloft into an originally stable layer at night and would not normally reach the ground until morning may be contained within a fog layer as the night progresses and be brought to the ground in relatively high concentrations.

After daybreak fogs will often persist for several hours or even the entire day under full sunlight due to the high reflectivity of the top layer. The reflectivity or albedo of thick fogs averages 50% and can be as high as 85%. This delays and lessens the heating of the ground and subsequent evaporation of the fog droplets. An unstable lapse rate may occur above the fog layer but due to lack of surface heating an inversion will often occur within the layer. If high concentrations of particulate pollutants are present, it may be difficult to determine just when the fog has dissipated since particulates scatter and absorb visible light very well and the visibility may remain quite restricted.

Figure 6 illustrates how fog can persist in valley situations and maintain a lid to vertical dispersion.

An excellent and detailed study of the life cycle of valley fog has been reported by Pilié et al. (1975). They describe several fog formation processes including the role of dew and radiative cooling; the former in persistence of fog after sunrise and the latter in propogation of fog downward due to instability and mixing with saturated air below. Changes in visibility during the cycle are discussed in the context of fog drop size distributions with time and height and cloud condensation nuclei concentrations. Drop size averages are near 6μm at the begining of the initial visibility decrease, increase rapidly to near 10μm and then gradually decrease to near 8μm through the mature fog stage and often to dissipation.



Persistence of Fog and Corresponding Temperature Profiles During the Day and Night

FIGURE 6

REFERENCES

Estoque, M.A. "The Sea Breeze as a Function of the Prevailing Synoptic Situation." Meteorology Division, Univ. of Hawaii, Scientific Report No. 1, Contract No. AF 19(604)-7484, October, 1961.

Hewson, E.W.; Bierly, E.W.; and Gill, G.C. "Topographic Influences on the Behavior of Stack Effluents." Proceedings of the American Power Conference, 23, 358-370, 1961.

Sutton, O.G. Micrometeorology, New York, McGraw-Hill p 267, 1953.

Fleagle, R.G., Parrot, W.H., and Barad, M.L. Theory and Effects of Vertical Temperature Distribution in Turbid Air. J. Meteorology 9:53-60, Feb. 1952.

Magono, C., Kikuchi, K., Nakamura, T. An Experiment on Fog Dispersion by the Use of Downward Air Current by the Fall of Water Drops. J. App. Meteorology 2: 484-493. Aug. 1963.

Hewson, E.W., Olsson, L.E. "Lake Effects on Air Pollution Dispersion." JAPCA, 17, 11:757-761, November 1967.

Panofsky, H.A., Prasad, B. "The Effect of Meteorological Factors on Air Pollution in a Narrow Valley." J. App. Meteorology 6:4930499, June 1967.

Pilié, R. J., Mack, E. J., Kocmond, W. C. Rogers, C. W., and Eadie, W. J. The Life Cycle of Valley Fog. Part I: Micrometeorological Characteristics. Part II: Fog Microphysics J. Appl. Meteor. 14:347-374. April 1975.

Start, G.E., Dickson, C.R. and Wendell, L.L. "Diffusion in a Canyon Within Rough Mountainous Terrain." J.Appl. Meteor. 14: 333-346, April 1975.

Schrenk, H.H., Heimann, H., Clayton, G.D., Gafafer, W.M., and Wexler, H. Air Pollution in Donora, Pa. Public Health Bulletin No. 306, 1949, 173 pp.

Buettner, K.J.K.; and Thayer, N. "On Valley and Mountain Winds," Dept. of Meteorology and Climatology, Univ. of Wash., Contract No. AF 19 (604) - 2289, Sept. 1959.

Davidson, B. "Valley Wind Phenomena and Air Pollution Problems," J. of APCA, 11, 8, 364 - 368, 383, Aug. 1961.

Geiger, R. (Translated by Scripta Technica, Inc.) The Climate Near the Ground. Rev. Ed. Harvard University Press, Cambridge, Mass. 1965.

Munn, R.E. Descriptive Micrometeorology, Academic Press, New York, 1966.

Reiter, E. R. and Rasmussen, J. L. Proceedings of the Symposium on Mountain Meteorology, June 1967. Atm. Science Paper #122, Colorado State University, Ft. Collins, Colo.

Lyons, W. A. and Olsson, L. E. "Mesoscale Air Pollution Transport in the Chicago Lake Breeze." JAPCA, 22, 11, 876-886, Nov. 1972.

THE EQUATION OF STATE AND CONVERSION OF CONCENTRATIONS

J. L. Dicke*

The atmosphere may be thought of as a huge thermodynamic engine and meteorologic changes occur through the interaction of temperature, pressure, and density. The relationship between pressure, temperature and volume (thereby density) in gases was determined by early experiments in classical physics. Boyle's law states that when the temperature is held constant the volume of a given mass of perfect gas varies inversely as the absolute pressure. From the law of Gay-Lussac it is known that at constant pressure the volume of a given mass of perfect gas varies directly as the absolute temperature. The equation of state can thus be written in familiar terms;

$$PV = \frac{m}{M} RT$$

where:

P = absolute pressure - dynes/cm^2

V = volume of a gas - cm^3

m = mass of a gas - gm

M = gram-molecular weight/gm-mole

T = absolute temperature - ^oK

R = universal gas constant -

$8.31 \times 10^7 \frac{\text{dyne cm}}{\text{gm-mole } ^oK}$

In most meteorological studies the most useful form of the equation of state or gas law is to express the pressure in millibars and the volume in m^3.

Thus: $1 \text{ mb} = 10^3 \text{ dynes cm}^{-2}$

$1 \text{ m}^3 = 10^6 \text{ cm}^3$

$R = 8.31 \times 10^{-2} \frac{\text{mb m}^3}{\text{gm-mole } ^oK}$

Example I

A certain power plant emits 0.2 % SO_2 by volume from its stack at a temperature of 260° F. The flow rate of gases emitted is 5×10^5 cu. ft./min. What is the emission rate in units of mass/time (sec.)?

$\frac{m}{t} = \frac{V}{t} \frac{PM}{RT}$ let P = 980 mb

M = 64

T = 400°K

$\frac{V}{t} = 2.36 \times 10^2 \text{ m}^3/\text{sec}$

Q = Emission Rate - gm/sec.

$$\frac{m}{t} = \frac{980 \times 2.36 \times 10^2 \times 2 \times 10^{-3} \times 64}{8.31 \times 10^{-2} \times 400} = 890 \text{ gm/sec.}$$

$Q = \frac{m}{t} = 890 \text{ gm/sec.}$

Example II

It is known that the air being sampled for SO_2 through a bubbler reaches a temperature of 77°F (T_S) before passing the critical orifice regulating the flow.

What correction must be applied to give the true outside concentration if the temperature is 10°F (T_A), assuming the pressure drop is negligible?

$T_S = 77^oF = 298^oK$

$T_A = 10^oF = 261^oK$

The measured concentration will be given by

$$\frac{m}{V_S} = \frac{PM}{RT_S}$$

*Supervisory Meteorologist, NOAA
Air Pollution Training Institute, EPA

and the true concentration will be

$$\frac{m}{V_A} = \frac{PM}{RT_A}$$

Thus:

$$\left(\frac{m}{V}\right)_A \times T_A = \left(\frac{m}{V}\right)_S \times T_S$$

and:

$$\left(\frac{m}{V}\right)_A = \left(\frac{m}{V}\right)_S \times \frac{298}{261} = \left(\frac{m}{V}\right)_S \times 1.14$$

A 14 % correction must be added to the sample concentration to give the concentration outside.

Example III

The measured SO_2 concentration after correction for temperature differences is reported as 44 $\mu gm/m^3$. The air temperature is 44°F and the pressure is 987 mb. What is the volume concentration in parts per hundred million under these conditions?

$T = 44^oF = 280^oK$

$$V = \frac{mRT}{MP} = \frac{44 \times 10^{-6} \times 8.31 \times 10^{-2} \times 280}{64 \times 987} =$$

$$0.016 \times 10^{-6}\ m^3\ SO_2$$

In one m^3 of air, therefore:

$$\frac{V_{SO_2}}{V_{air}} = \frac{0.016 \times 10^{-6}\ m^3\ SO_2}{1.0\ m^3\ air} = 1.6\ pphm$$

REFERENCES

1 Byers, H.R. General Meteorology. New York. McGraw-Hill. 3rd ed. 1952

2 Huschke, R.E. (Editor). Glossary of Meteorology. Boston, American Meteorological Society. 1959

3 Smithsonian Meteorological Tables. 6th Ed. Washington, D.C. 1951

METEOROLOGICAL ROSES

D. B. Turner*
L. E. Truppi*

A wind rose is defined in the Glossary of Meteorology as, "Any one of a class of diagrams designed to show the distribution of wind direction experienced at a given location over a considerable period; it thus shows the prevailing wind direction. The most common form consists of a circle from which eight or sixteen lines emanate, one for each compass point. The length of each line is proportional to the frequency of wind from that direction; and the frequency of calm conditions is entered in the center. Many variations exist. Some indicate the range of wind speeds from each direction; some relate wind direction with other weather occurrences." Wind roses may be constructed for data from a given time period such as a particular month or may be for a particular time of day or season from a number of years data. In constructing or interpreting wind roses it is necessary to keep in mind the meteorological convention that wind direction refers to the direction from which the wind is blowing. A line or bar extending to the north on a wind rose indicates the frequency of winds blowing from the north, not the frequency of winds blowing toward the north. Some of the specialized wind roses that may be constructed are precipitation wind roses, stability wind roses, and pollution wind roses. The latter two require additional data than are generally available at standard National Weather Service Offices. An informative article on the history and variants of wind roses has been published by Court.[1]

WIND ROSES - DATA AND PRESENTATION

Prior to January 1964 the surface wind direction was reported by U. S. Weather Bureau stations as one of the 16 directional points corresponding to the mariner's compass card or compass rose, on which each direction is equivalent to a 22 1/2 sector of a 360° circle. Table 1 illustrates a 16-point wind rose summary in the form of a frequency table of wind direction versus wind speed groups. It is an example of wind roses prepared as summaries of hourly observations published monthly until January 1964 in the Local Climatological Data (LCD) Supplement. Frequencies are totaled by direction and wind speed group; a quick look at this wind rose indicates the highest directional frequency is from the ENE and the highest speed frequency is the 8 to 12 mph column. Average speeds have been computed for each direction.

When wind roses are employed to summarize climatological data involving long periods of record, percentage frequencies are favored over numerical totals for tabular presentation since the number of observations in any one cell can become too large. Moreover, wind rose diagrams can be drafted directly from tabular data if percentages are available. Table 2 presents 10 years of hourly wind data observed at New Orleans Moisant International Airport during January for the years 1951 through 1960, as published in the "Decennial Census of United States Climate".[5] This 10-year summary of meteorological data is compiled for most U.S. Weather Bureau first order stations. See Section VII - Sources of Meteorological Data.

On January 1, 1964 the U.S. Weather Bureau changed the wind direction reporting procedure from 16 points to 36 - 10° intervals. Table 3 is the result; a 36-point wind rose. Since 36 cannot be divided by 16, there is no way of grouping 36 points into 16 points and there is no easy way of combining wind data if wind rose summaries are required that include both 16-point and 36-point wind direction observations.

Besides this feature of incompatibility, other problems have developed with the 36-point wind system; first, a 36-point system tends to spread tabulated frequencies and obscure directional significance; second, a list of

*Supervisory Research Meteorologist, NOAA
*Meteorologist, NOAA
Meteorology & Assessment Division, EPA

PA.ME.mm.17a.6.67

WIND DIRECTION
AND SPEED OCCURRENCES

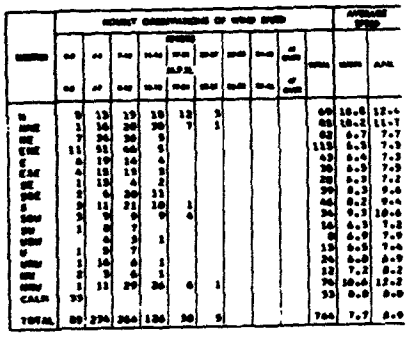


Table 1 New Orleans, Louisiana, Moisant International Airport, January 1963.

JANUARY
7440 obs.

PERCENTAGE FREQUENCIES
OF WIND DIRECTION AND SPEED:

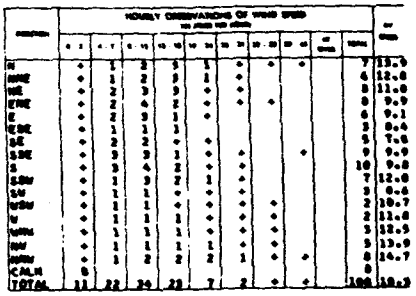
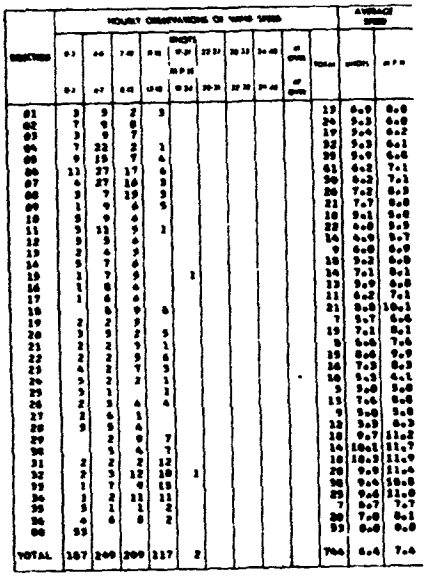


Table 2. New Orleans, Louisiana, Moisant International Airport, 10-Year Summary January 1951-1960. + indicates more than 0% but less than 0.5%.

Table 3 36-point Wind Rose Tabulation
New Orleans, Louisiana, Moisant International Airport, Central Standard Time, January 1964.

WIND DIRECTION
AND SPEED OCCURRENCES



36 directions is often too lengthy for convenience; lastly, it is almost impossible to construct the standard radial bar-type wind rose with 36 bars. The bars crowd together at the center, and variations of radial length, proportional to directional percentage frequency between given wind directions are minimized.

The 36-point wind reporting procedure has been in effect since 1964 and it has been found that the disadvantages may be offset by using a 12-point or 30° sector wind rose. Table 4 was constructed from Table 3 by grouping frequencies into 30° intervals. Directional discrimination is not as fine as in a 16- or 36-point breakdown, but the tabulation is concise and a bar diagram can be easily constructed. Additional discussion together with conversion and correction techniques are presented by Lea and Helvey (11).

POLLUTION WIND ROSES

The increasing emphasis on identifying and abating air pollution problems has resulted in the establishment of air sampling networks which determine concentrations of pollutants on a time scale as short as 5 minutes. Since transport of pollutants depends in great part on wind flow, an appropriate wind rose diagram would be very helpful in relating air pollutant and wind data. Figures 1 and 2 illustrate a type of pollution wind rose devised for the air pollution abatement study conducted in the Parkersburg, West Virginia - Marietta, Ohio region. (3)

Figure 1 shows three wind recording and SO_2 gas sampling sites that were installed at Parkersburg, Vienna, West Virginia and Marietta, Ohio from October 1965 through February 1966. The bar-type wind roses for

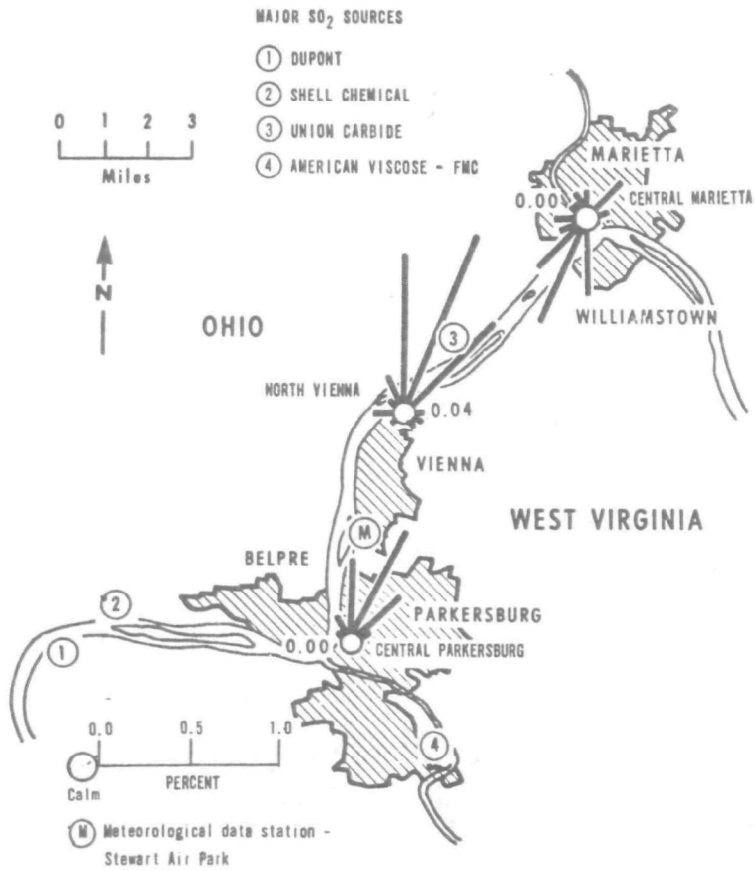
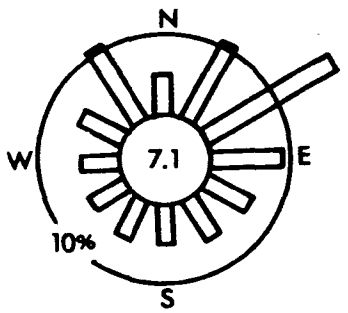


Figure 1. SO_2 Pollution Roses for Concentrations >0.10 ppm, October 1965 through February 1966.

Table 4

New Orleans, Louisiana
Moisant International Airport
January 1964
12-Point Wind Rose

DIRECTION	0-3	4-7	8-12	13-18	18-24	25-31	32-38	74-40	Tot.	AVSPD (mph)
N 35-36-01	10	12	11	7					40	7.9
NNE 02-03-04	17	40	17	1					75	6.1
ENE 05-06-07	24	69	40	13					146	7.0
E 08-09-10	9	25	23	8					65	7.6
ESE 11-12-13	12	20	12	1					45	6.0
SSE 14-15-16	7	22	15		1				45	7.0
S 17-18-19	3	14	16	6					39	7.9
SSW 20-21-22	7	9	10	12					38	8.5
WSW 23-24-25	12	5	9	5					31	6.7
W 26-27-28	7	14	9	4					34	7.0
WNW 29-30-31	2	7	15	26					50	11.6
NWW 32-33-34	4	12	32	34	1				83	11.1
CALM	53								53	
Tot.	167	249	208	117	2				744	7.4



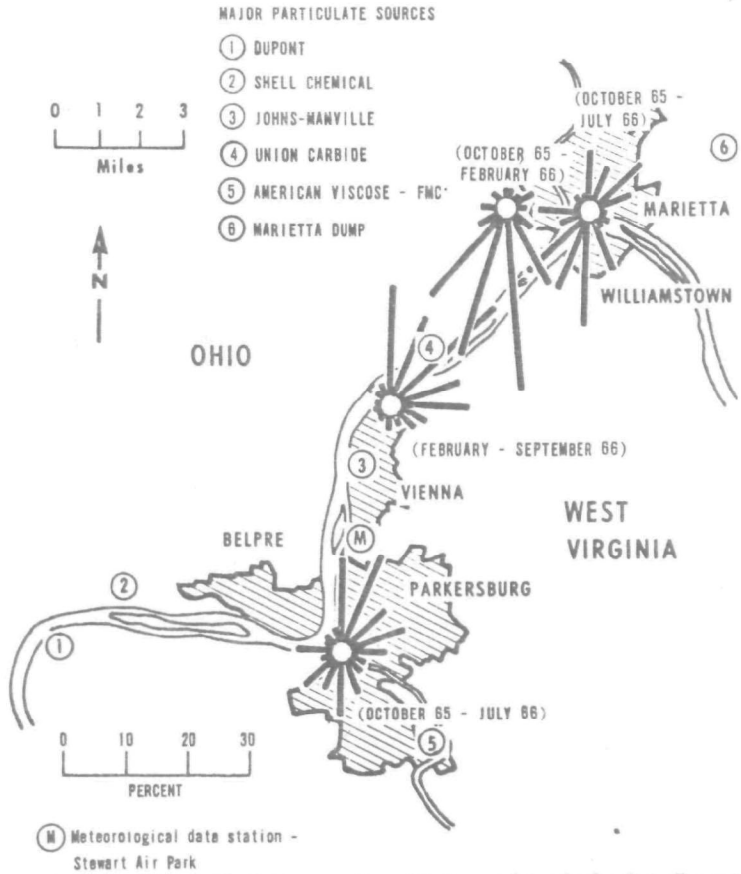
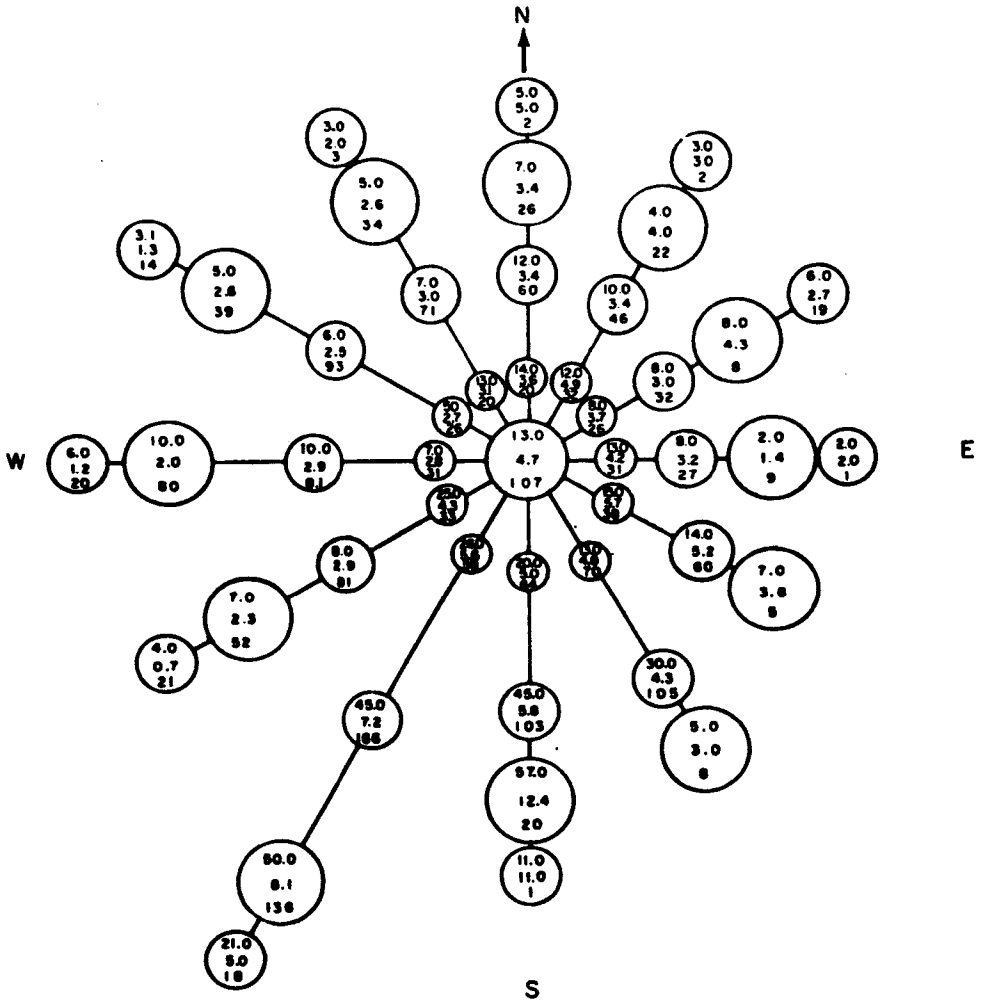


Figure 2. Hourly Wind Roses for 24-hour Periods for Suspended Particulate Concentrations >200 $\mu g/m^3$ and average Wind Speed >3 mph.

each site location represent only winds coincident with SO_2 concentrations greater than 0.10 ppm. Winds observed when the SO_2 concentration was equal to or less than 0.10 ppm were ignored in computing percentage frequencies. Figure 1 graphically identifies the major source of high SO_2 emissions as source 3; the Union Carbide Company plant.

Figure 2 is similiar to Figure 3 except the pollutant sampled was suspended particulate matter on a 24-hour basis. Another Hi-vol Sampler was in operation west of Marietta, Ohio. Since pollutant sampling was on a 24-hour basis, 24-hourly winds were tabulated, but only for periods when particulate concentrations were greater than 200 $\mu g/m^3$ and when the average wind speed over the 24 hours was greater than 3 mph. Again the pollutant rose points to the Union Carbide Company plant, source 4, as the major contributor.

Special wind instruments were installed for this abatement study, and the investigators chose to reduce the autographic wind data on direction to a 16-point tabulation. Because of this decision, 36-point wind data recorded at site M, Stewart Air Park, were used only to determine average wind conditions. It was also decided to omit the usual wind speed grouping in the pollution wind roses.



COINCIDENT WIND ROSE—CINCINNATI, OHIO, DEC-JAN-FEB, 1964

Figure 3

A more detailed pollution wind rose is displayed in Figure 3. Coincident wind data and SO_2 concentrations (pphm) for the winter month of 1964 are summarized; hourly wind data were recorded by the U.S. Weather Bureau at Greater Cincinnati Airport and pollutant data by the U.S. Public Health Service at a downtown Cincinnati location.[4] Speed groups are denoted by different sized circles, instead of the usual bar-thickness, and percentage frequency of each speed group is indicated by radial distance between circle rims. Inside each circle are listed pollutant statistics coicident with the particular direction and speed group. These are: maximum SO_2 concentration recorded, the average concentration, and the number of concentration values observed. The value of this type of pollution wind rose is demonstrated in Figure 3 where the highest maximum and average SO_2 concentrations are readily identified with S or SSW winds of 11 to 15 knots.

REMOVING BIAS IN 16-POINT WIND ROSES

Wind direction, such as for hourly airport observations where no recorder is used, is determined by an observer watching the wind direction indicator dial for one minute and recording direction to 16 points. It has been found that one of the eight principal directions (N, NE, E, etc.) is more frequently recorded than are the secondary directions (NNE, ENE, ESE, etc.). Depending upon the purpose of constructing a wind rose, it may be desirable to remove this bias. Removal of the bias may be by total frequencies of each direction or by wind speed classes. In order to determine if there is bias, the sums should be determined separately for the principal direction frequencies (N_e) and the secondary direction frequencies (N_o). Bias usually occurs if one exceeds the other on the order of 10 to 20%. Assuming that the sum of the principal frequencies (N_e) exceeds the sum of the secondary frequencies (N_o) the frequencies have the bias removed by subtracting

$$n_e\left(\frac{N_e - N_o}{2\ N_e}\right)$$

from the frequency of each primary direction where n_e is the frequency for that direction and adding

$$n_o\left(\frac{N_e - N_o}{2\ N_o}\right)$$

to the frequency of each secondary direction where n_o is the frequency for the secondary direction.

DISTRIBUTION OF CALMS

In some cases, it is also desirable to distribute the calms in the lowest wind speed class among the 16 directions. It is usually better to use the frequencies of the lowest two speed classes (0-7 mph) to distribute the calms in order to have a more respresentative sample of light winds. If N_c is the total number of calms, N_w is the total frequency of winds in the 0-7 mph range, and n_w is the frequency of winds in the 0-7 mph range for one direction, the number of calms assigned to this direction is:

$$\frac{n_w\ N_c}{N_w}$$

Example: Removing Bias in a Wind Rose.

Below is given the wind direction and speed frequencies for October, 1962, for St. Louis Mo.

Table 5. WIND DIRECTION AND SPEED OCCURRENCES

Direction	Hourly observations of wind speed (mph) 0-3	4-7	8-12	13-18	19-24	Total
N	1	5	11	3		20
NNE	5	10	4	1		20
NE	7	9	3	1		20
ENE	5	6	8	3		22
E	2	4	5	1		12
ESE	3	4	3	1		11
SE	13	8	17	6		44
SSE	5	19	21	5		50
S	15	23	26	6		70
SSW	6	29	19	2		56
SW	5	44	33	8		90
WSW	4	17	17	8		46
W	8	25	13	8		54
WNW	4	15	15	14		48
NW	4	3	17	30	6	60
NNW	0	6	18	8		32
CALM	89					89
Total	176	227	230	105	6	744

Problem: To remove the bias by two separate speed classes: 0-7 mph, and ≥ 8 mph.

First remove the bias in the 0-7 mph class. Determine N_e and N_o by adding the primary and secondary direction frequencies separately.

Table 6. 0-7 mph FREQUENCIES

N	6	NNE	15
NE	16	ENE	11
E	6	ESE	7
SE	21	SSE	24
S	38	SSW	35
SW	49	WSW	21
W	33	WNW	19
NW	7	NNW	6
N_e =	176	N_o =	138

$$\frac{N_e - N_o}{2N_e} = \frac{176 - 138}{2(176)} = 0.108$$

$$\frac{N_e - N_o}{2N_o} = \frac{176 - 138}{2(138)} = \frac{38}{276} = 0.138$$

Table 7. REMOVING BIAS FOR 0-7 mph CLASS

$n_e - n_e(0.108)$		$n_o + n_o(0.138)$	
N	6 - 1 = 5	NNE	15 + 2 = 17
NE	16 - 2 = 14	ENE	11 + 2 = 13
E	6 - 1 = 5	ESE	7 + 1 = 8
SE	21 - 2 = 19	SSE	24 + 3 = 27
S	38 - 4 = 34	SSW	35 + 5 = 40
SW	49 - 5 = 44	WSW	21 + 3 = 24
W	33 - 4 = 29	WNW	19 + 3 = 22
NW	7 - 1 = 6	NNW	6 + 1 = 7
	156		158

Next, remove the bias for the ≥ 8 mph class.

Table 8. ≥ 8 mph FREQUENCIES

N	14	NNE	5
NE	4	ENE	11
E	6	ESE	4
SE	23	SSE	26
S	32	SSW	21
SW	41	WSW	25
W	21	WNW	29
NW	53	NNW	26
N_e =	194	N_o =	147

$$\frac{N_e - N_o}{2N_e} = \frac{194 - 147}{2(194)} = 0.121$$

$$\frac{N_e - N_o}{2N_o} = \frac{194 - 147}{2(147)} = 0.160$$

Table 9. REMOVING BIAS FOR ≥ 8 mph CLASS

$n_e - n_e(0.121)$		$n_o + n_o(0.160)$	
N	14 - 2 = 12	NNE	5 + 1 = 6
NE	4 - 0 = 4	ENE	11 + 2 = 13
E	6 - 1 = 5	ESE	4 + 1 = 5
SE	23 - 3 = 20	SSE	26 + 4 = 30
S	32 - 4 = 28	SSW	21 + 3 = 24
SW	41 - 5 = 36	WSW	25 + 4 = 29
W	21 - 3 = 18	WNW	29 + 5 = 34
NW	53 - 6 = 47	NNW	26 + 4 = 30
	170		171

The debiased wind frequencies are now completed for the two wind speed classes. It will depend upon the purpose of the wind rose as to whether it is necessary to distribute the 0-7 frequencies between the 0-3 mph and 4-7 mph classes.

Problem: Distribute the calms (decalm) for the above wind frequencies.

$$\frac{N_c}{N_w} = \frac{89}{314} = 0.283$$

Table 10. DISTRIBUTION OF CALMS

Direction	n_w (debiased)		(0.283)
N	5	=	1
NNE	17	=	5
NE	14	=	4
ENE	13	=	4
E	5	=	1
ESE	8	=	2
SE	19	=	5
SSE	27	=	8
S	34	=	10
SSW	40	=	11
SW	44	=	13
WSW	24	=	7
W	29	=	8
WNW	22	=	6
NW	6	=	2
NNW	7	=	2
			89

The resulting debiased and decalmed wind frequencies in the usual classes are as follows with distributed calms shown in parenthesis.

Table 11. WIND DIRECTION AND SPEED OCCURRENCES, ST. LOUIS, MO. OCTOBER, 1962

BIAS REMOVED AND CALMS DISTRIBUTED
(Distributed Calms in Parenthesis)

Direction	Wind speed class (mph) 0-3	4-7	8-12	13-18	19-24	Total
N	1 (1)	4	9	3		18
NNE	6 (5)	11	5	1		28
NE	6 (4)	8	3	1		22
ENE	6 (4)	7	9	4		30
E	2 (1)	3	4	1		11
ESE	3 (2)	5	4	1		15
SE	12 (5)	7	15	5		44
SSE	6 (8)	21	24	6		65
S	13 (10)	21	23	5		72
SSW	7 (11)	33	22	2		75
SW	4 (13)	40	29	7		93
WSW	5 (7)	19	20	9		60
W	7 (8)	22	11	7		55
WNW	5 (6)	17	18	16		62
NW	3 (2)	3	15	27	5	55
NNW	1 (2)	6	20	9	1	39
Total	176	227	231	104	6	744

Figure 4 is a wind rose drawn from these frequencies.

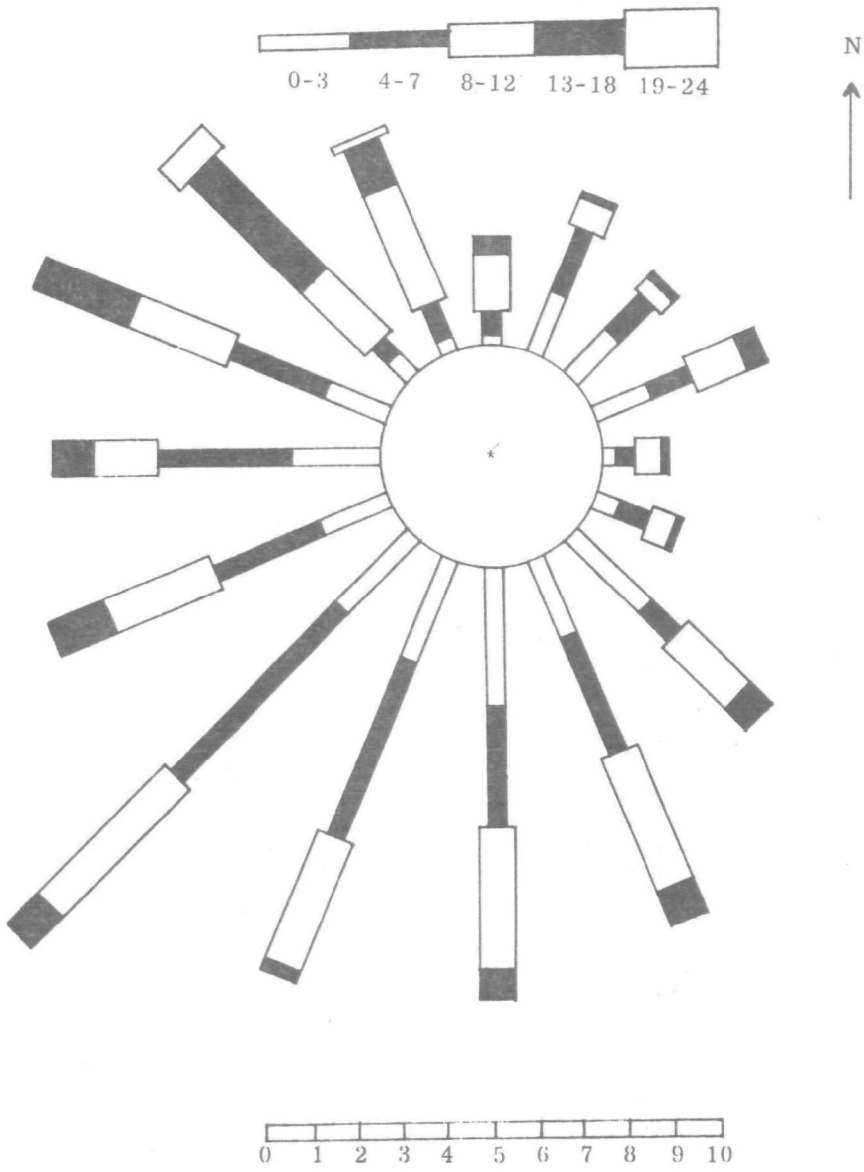
Figure 4

Wind Rose

St. Louis October 1962

Bias Removed and Calms Distributed*

Speed Classes (mph)



*Note: If the calm observations are not distributed, remember to put the % Calm Figure in the center circle of the rose.

REFERENCES

1. Court, A. Wind Roses. Weather, 18: 106-110. April 1963.

2. Crutcher, H.L. On the Standard Vector - Deviation Wind Rose. J. Meteor. 14: 28-33. 1957.

3. Technical Report: Parkersburg, W. Va. - Marietta, Ohio Air Pollution Abatement Activity. NCAPC, March 1967. 87 pp.

4. Truppi, L.E. Evolution of a Coincident Wind Rose. (ESSA manuscript) NCAPC, 1967.

5. U.S. Weather Bureau. Decennial Census of U.S. Climate - Summary of Hourly Observations, New Orleans, La. 1951-1960.

6. U.S. Weather Bureau. Local Climatological Data - Supplement. New Orleans, La., and St. Louis, Mo. 1963.

7. Ratner, B. A Method for Eliminating Directional Bias in Wind Roses. Monthly Weather Review, 78, 10:185-188, October 1950.

8. U.S. Atomic Energy Commission. A Meteorological Survey of the Oak Ridge Area. Final Report 1948-52, pp. 68-73 and 158, November 1953.

9. Marsh, K. J., Foster, M. D. An Experimental Study of the Dispersion of the Emissions from Chimneys in Reading I. The Study of Long-Term Average Concentrations of Sulfur Dioxide. Atmos. Envir. 1, 4:527-550, September 1967.

10. Truppi, L. E. Bias Introduced by Anemometer Starting Speeds in Climatological Wind Rose Summaries. Monthly Weather Review, 96, 5:325-327, May 1968.

11. Lea, D. and Helvey, R.A. A Directional Bias in Wind Roses Due to Mixed Compass Formats. J. Appl. Meteor. 10, 5: 1037-1039, October 1971.

12. Technical Report: Ironton, Ohio-Ashland, Kentucky-Huntington, W. Virginia Air Pollution Abatement Activity, Pre-Conference Investigations. NCAPC (EPA), 1968. 85 pp.

SECTION THREE

ATMOSPHERIC DIFFUSION

Principles of Turbulence and Diffusion
Introduction to Turbulence and Diffusion Theory
The Generalized Gaussian Diffusion Equation
Atmospheric Diffusion Computations
Effective Stack Height

PRINCIPLES OF TURBULENCE AND DIFFUSION

D. H. Pack* and J. L. Dicke**

When a small concentrated puff of gaseous pollutant is released into the atmosphere, it tends to expand in size due to the dynamic action of the atmosphere. In doing so, the concentration of the gaseous pollutant is decreased because the same amount of pollutant is now contained within a larger volume. This natural process of high concentration spreading out to lower concentrations is the process of diffusion.

Atmospheric diffusion is ultimately accomplished by the wind movement of pollutants, but the character of the source of pollution requires that this action of the wind be taken into account in different ways.

These sources can be conveniently grouped into three classes: point sources, line sources, and area sources. In practice, the first two classes must be further divided into instantaneous and continuous sources.

The instantaneous point source is essentially a "puff" of material created or ejected in a relatively short time, as by a nuclear explosion, the sudden rupture of a chlorine tank, or the bursting of a tear-gas shell. The wind of immediate importance is, of course, that occurring at the place and time at which the pollutant is created. Since the wind is highly variable, the initial direction of movement of the puff is also variable and difficult of prediction; a soap-bubble pipe and five minutes' close observation of the initial travel of successive bubbles will convincingly demonstrate the difficulty of predicting the exact trajectory of the next bubble. In addition, dilution of a puff source is a very strong function of time after its release. At first, the small-scale fluctuations of the wind cause it to grow rather slowly and the larger-scale wind variations simply carry it along on erratic paths. But as the puff grows, larger-scale motions can get a "hold" on it to tear it apart and dilute it more rapidly. Thus, the unique feature of the instantaneous point source is its increasing dispersion rate with time, whence the necessity to consider successively larger scales of meteorological phenomena in calculating its spread.

Continuous point sources (the smoke plume from a factory chimney, the pall from a burning dump) are the most familiar, the most conspicuous, and the most studied of pollution sources. The meteorology of the continuous source must take into account the time changes of the wind at the point of emission. The behavior of a plume from a factory chimney is very much like that of water from a hose being played back and forth across a lawn. It is evident that if the hose is steady, the same area will be continually exposed to the water. But if the hose (wind) moves back and forth in an arc, the water (pollution) will be distributed over a wider area, hence the concentration will be less. For a truly continuous source there are other changes of great importance - primarily the diurnal and seasonal cycles.

The isolated line source is less common and therefore of less general interest, with two important exceptions - heavily traveled highways, and the swath of chemicals emitted by cropdusting apparatus. In both these examples, if the line of pollutant is uniform and is long enough, the dispersion of the pollution must be attained in only two dimensions, along the wind and in the vertical. If the line source is a continuous one, as might be the case of a freeway in rush hours, spreading in the downwind direction becomes ineffective (at a particular downwind location), so that only the vertical dimension is left to provide dilution. This behavior of the continuous line source has been exploited by meteorologists in field experiments with controlled tracers to permit the detailed study of vertical diffusion, uncomplicated by effects in the other two coordinates.

*Certified Consulting Meteorologist, McLain, Va.
**Supervisory Meteorologist, NOAA
Air Pollution Training Institute, EPA

PA. ME. sd. 36. 1. 67

The area source can vary enormously in size. It may be distributed over several square kilometers, as in an industrial park, over tens or hundreds of square kilometers, as in a city, or over thousands of square kilometers, exemplified by the almost continuous strip city (the "megalopolis" or "megapolitan area") along the eastern seaboard of the United States. These area sources usually include combinations of all the single-source configurations. A large city will include many thousands of home chimneys, thousands of factories and shops, hundreds of kilometers of streets, open dumps, burning leaves, evaporating fumes from gasoline storage or from cleaning plants and paint factories, and everywhere the automobile. The weather problem of the city area source becomes, in the aggregate, quite different from that of a single source. Here we are concerned not with the increasing rate of wind dispersion with increasing scale, or with the behavior of wind with time at a single point, but rather with the replenishment rate of the air over the city. We must consider the total movement of a large volume of air as it "ventilates" the city. Anything that reduces this ventilation rate, whether it be the confining effect of surrounding mountains or the reduced velocities of a slow-moving anticyclone, is of concern.

In the construction of cities man has modified the weather. The volume of effluent injected into the air has reduced the solar radiation. The absorption characteristics of cement and asphalt instead of grass and trees create urban "heat islands." These effects must be considered in the meteorology of urban air pollution.

The atmosphere disperses pollutants because it is in constant motion, and this motion is always turbulent to some degree. There is as yet no fully accepted definition of turbulence, but empirically it can be described as random (three-dimensional) flow. There is as yet no complete explanation for the complexities even of controlled wind-tunnel turbulence, hence it is not surprising that the understanding of turbulent diffusion in the atmosphere has progressed largely through empirical treatments of controlled tracer experiments. The current tendency is to deal with turbulence through statistical concepts derived from aerodynamics and fluid dynamics. This treatment, with its emphasis on the detailed properties of the turbulence, is in contrast to earlier theories which centered around a virtual-diffusivity concept based on analogy with molecular diffusion. In the practical application of computing pollution concentrations, it is more usual to employ the statistical method for distances to perhaps 150 kilometers from the source, and equations based on virtual-diffusivity ("K") theory for longer distances, particularly for calculations on a hemispheric or global scale.

Vertical Turbulent Diffusion

To all intents and purposes rapid atmospheric diffusion in the vertical is always bounded: on the bottom by the surface of the earth and at the top by the tropopause. The tropopause - the demarcation between the troposphere, where temperature decreases with altitude, and the stratosphere, where the temperature is relatively constant or increases with altitude - is lowest over the poles, at about 8 kilometers, and highest in the tropics, about 20 kilometers. The detection of radon products throughout the troposphere is conclusive evidence of the eventual availability of the full depth of the troposphere for vertical dispersion, since the radon source is exclusively at the earth's surface. Utilization of this total vertical dimension can take place at very different rates, depending on the thermally driven vertical wind. These rates are intimately related to the vertical temperature profile. On the average (and if we neglect the effects of the phase change of water in the air), enhanced turbulence is associated with a drop in temperature with height of 10°C per kilometer or greater. (This is the dry adiabatic rate.) If the temperature change with height is at a lesser rate, turbulence tends to be decreased, and if the temperature increases with height (an "inversion"), turbulence is very much reduced.

The temperature profiles particularly over land, show a large diurnal variation as seen in Figure 1. Shortly after sunrise the heating of the land surface by the sun results in rapid warming of the air near the surface; the reduced density of this air causes it to rise rapidly. Cooler air from aloft replaces the rising air "bubble," to be warmed and rise in turn. This vigorous vertical interchange creates a "superadiabatic" lapse rate - a temperature decrease of more than 10°C per vertical kilometer - and vertical displacements are accelerated. The depth of this well-mixed layer depends on the intensity of solar radiation and the radiation characteristics of the underlying surface. Over the deserts this vigorous mixing may extend well above 3 kilometers, while over forested lake country the layer may be only one or two hundred meters thick. Obviously, this effect is highly dependent on season; in winter the lesser insolation and unfavorable radiation characteristics of snow cover greatly inhibit vertical turbulence.

In contrast, with clear or partly cloudy skies the temperature profile at night is drastically changed by the rapid radiational cooling of the ground and the subsequent cooling of the layers of air near the surface. This creates an "inversion" of the daytime temperature profile, since there is now an increase in temperature with height. In such a situation the density differences rapidly damp out vertical motions, tend to reduce vertical turbulence, and stabilize the atmosphere.

Two other temperature configurations, on very different scales, have important effects on vertical turbulence and the dilution of air pollution. At the smaller end of the scale, the heat capacity of urban areas and, to a lesser extent, the heat generated by fuel consumption act to modify the temperature profile. The effect is most marked at night, when the heat stored by day in the buildings and streets warms the air and prevents the formation of the surface-based temperature inversion typical of rural areas. Over cities it is rare to find inversions in the lowest 100 meters, and the city influence is still evident 200 to 300 meters above the surface. The effect is a function of city size and building density, but not enough observations are yet available to provide any precise quantitative relations. Although the effect even for the largest cities is probably insignificant above a kilometer, this locally produced vertical mixing is quite important. Pollution, instead of being confined to a narrow layer near the height of emission, perhaps only 100 meters in thickness, can be freely diluted in more than double the volume of air, the concentrations being reduced by a similar factor.

On a much larger scale the temperature profile can be changed over thousands of square kilometers by the action of large-scale weather systems. In traveling storm systems (cyclones) the increased pressure gradients and resulting high winds, together with the inflow of air into the storm, create relatively good vertical mixing conditions. On the other hand, the flat pressure patterns, slower movement, and slow outflow of surface air in high-pressure cells (anticyclones) result in much less favorable vertical mixing. This is primarily due to the gradual subsidence of the air aloft as it descends to replace (mass-continuity requirement) the outflow at the surface. During this descent the air warms adiabatically, and eventually there is created a temperature inversion aloft inhibiting the upward mixing of pollution above the inversion level. As the anticyclone matures and persists, this subsidence inversion may lower to very near the ground and persist for the duration of the particular weather pattern.

Horizontal Turbulent Diffusion

The most important difference between the vertical and horizontal dimensions of diffusion is that of scale. In the vertical, rapid diffusion is limited to about 10 kilometers. But in the horizontal, the entire surface of the globe is eventually available. Even when the total depth of the troposphere is considered, the horizontal scale is larger by at least three orders of magnitude, and

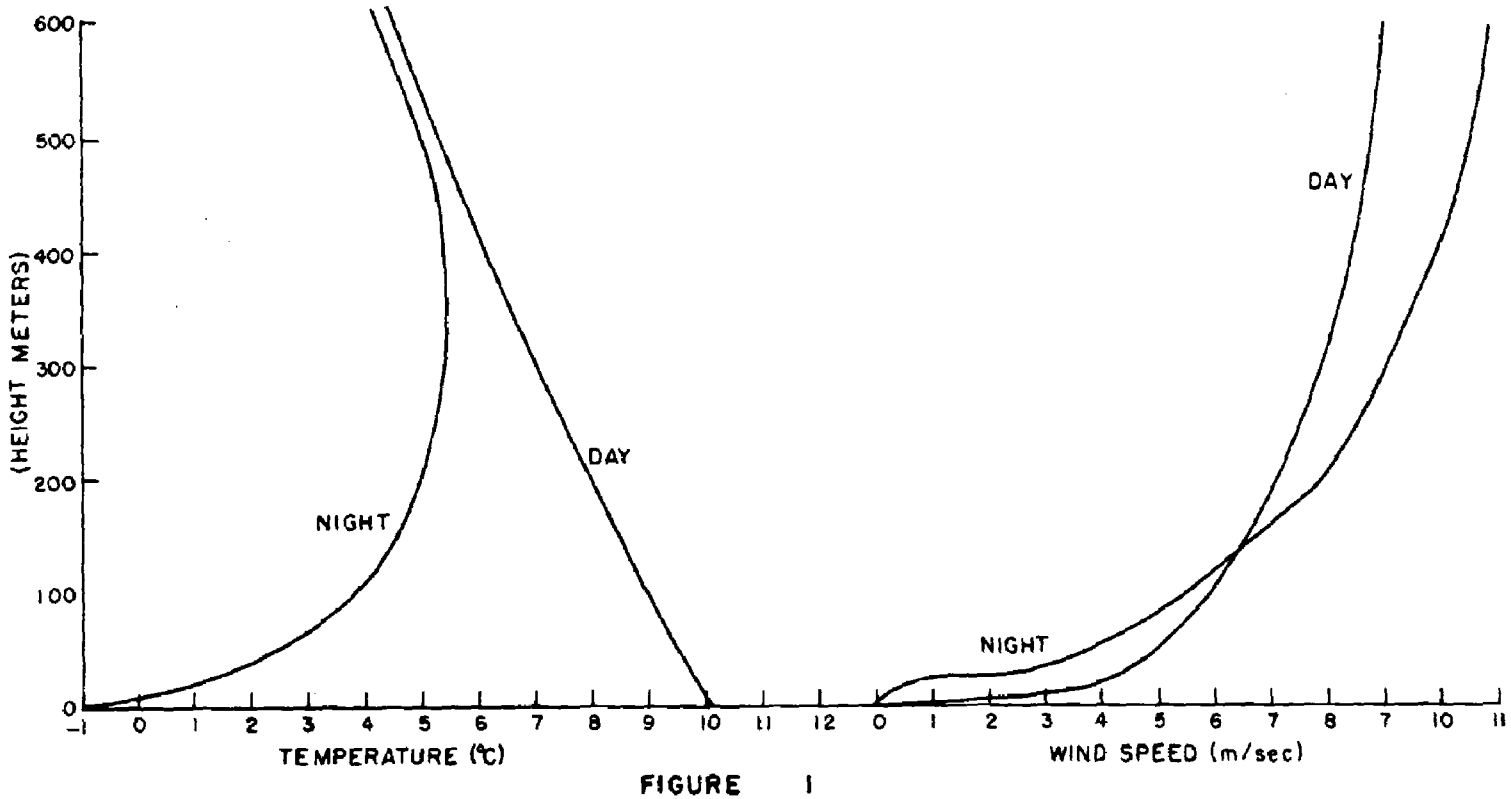


FIGURE 1

Diurnal Variation of Temperature and Wind Speed

the difference, say during a nocturnal inversion which might restrict the vertical diffusion to a few tens of meters, is even greater since the lateral turbulence is reduced less than the vertical component. Mechanically produced horizontal turbulence is, on a percentage basis, much less important than the thermal effects; its effects are of about the same order of magnitude as the vertical mechanical effects.

The thermally produced horizontal turbulence is not so neatly related to horizontal temperature gradients as vertical turbulence is to the vertical temperature profile. The horizontal temperature differences create horizontal pressure fields, which in turn drive the horizontal winds. These are acted upon by the earth's rotation (the Coriolis effect) and by surface friction, so that there is no such thing as a truly steady-state wind near the surface of the earth. Wind speeds may vary from nearly zero near the surface at night in an anticyclone to 100 meters per second under the driving force of the intense pressure gradient of a hurricane. The importance of this variation, even though in air pollution we are concerned with much more modest ranges, is that for continuous sources the concentration is inversely proportional to the wind speed.

The variation of turbulence in the lateral direction is perhaps the most important factor of all and certainly one of the most interesting. In practice this can best be represented by the changes in horizontal wind direction illustrated in Figure 2. Within a few minutes, the wind may fluctuate rapidly through 90 degrees or more. Over a few hours it may shift, still with much short-period variability, through 180 degrees, and in the course of a month it will have changed through 360 degrees numerous times. Over the seasons, preferred directional patterns will be established depending upon latitude and large-scale pressure patterns. These patterns may be very stable over many years, and thus establish the wind climatology of a particular location.

The emitted pollution travels with this ever-varying wind. The high-frequency fluctuations spread out the pollutant, and the relatively steady "average" direction carries it off - for example, toward a suburb or a business district. A gradual turning of direction transports material toward new targets and gives a respite to the previous ones. Every few days the cycle is repeated, and over the years the prevailing winds can create semipermanent patterns of pollution downwind from factories or cities.

Description of Gustiness Classifications

The original separation of wind gustiness into typical categories led to the establishment of four classes - A, B, C, and D - in order of decreasing amplitude of the azimuthal fluctuation of the wind. Further analysis indicated the need for a fifth category, and the B class was subdivided into B_1 and B_2. The classifications as developed at Brookhaven and as applied to wind data in this analysis are defined below. The types are further explained by samples of the 500-ft wind records shown in Figure 2.

Type A: Fluctuations of the wind direction exceeding 90 degrees.

Type B_2: Fluctuations ranging from 45 to 90 degrees.

Type B_1: Similar to A and B_2, with fluctuations confined to 15 and 45 degree limits.

Type C: Distinguished by the unbroken solid core of the trace, through which a straight line can be drawn for the entire hour, without touching "open space." The fluctuations must reach 15 degrees, but no upper limit is imposed.

Type D: The trace approximates a line. Short-term fluctuations do not exceed 15 degrees.

Types A and B_2 are mainly convective in nature and are associated with great instability. A combination of convective and mechanical turbulence is represented in the B_1 gustiness type, which occurs under conditions of moderate instability. Gustiness class C is primarily mechanical in origin and is associated with neutral stability. Type D, which is found with stable lapse rates, reflects little or no turbulence.

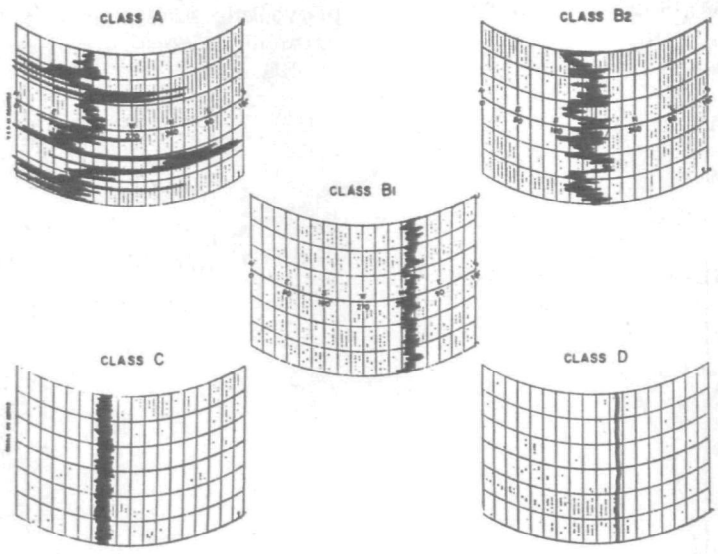


Figure 2. GUSTINESS CLASSIFICATION

REFERENCES

1 Batchelor, G.K. The Theory of Homogeneous Turbulence. Cambridge University Press, Cambridge, England, 1956.

2 Hinze, J.O. Turbulence. McGraw-Hill Book Co., New York. 1959.

3 Magill, P.L. Ed. Air Pollution Handbook. McGraw-Hill Book Co., New York 1956.

4 Pack, D.H. Meteorology of Air Pollution. Science, Vol. 146, No. 3648, pp 1119-1128, November 27, 1964.

5 Pasquill, F. Atmospheric Diffusion. (2nd Edition); John Wiley & Sons, Inc. 1974.

6 Stern, A.C. Ed. Air Pollution; (2nd Edition); Academic Press, New York, 1968.

7 Sutton, O.G. Micrometeorology, McGraw-Hill Book Co., New York, 1953.

8 Meteorology and Atomic Energy 1968 D.H. Slade, Ed., U.S. Atomic Energy Commission, Division of Technical Information. TID-24190, July 1968

9 U.S. Public Health Service, SEC Technical Report A62.5, Symposium Air Over Cities, R.A. Taft Sanitary Engineering Center, Cincinnati, Ohio 1962.

10. IUGG-IAMAP-AMS Conference on Planetary Boundary Layers. Conference Summary. Bull. AMS, Vol. 51, No. 6, June 1970 pp. 518-527.

Portions of this outline Copyright 1964 American Association for Advancement of Science (4).

INTRODUCTION TO TURBULENCE AND DIFFUSION THEORY

D. B. Turner*

I TURBULENCE

Turbulence is defined in the Glossary of Meteorology as, "a state of fluid flow in which the instantaneous velocities exhibit irregular and apparently random fluctuations so that in practice only statistical properties can be recognized and subjected to analysis." Assuming that a mean velocity may be defined for a given time period, the turbulent velocity may be considered to be a random fluctuating motion superimposed upon the mean motion. Considering a three dimensional coordinate system with the x and y axis in the horizontal and z in the vertical the components of the instantaneous velocity are:

$u = \bar{u} + u'$ in the x direction

$v = \bar{v} + v'$ in the y direction and

$w = \bar{w} + w'$ in the z direction

where $\bar{u}$, $\bar{v}$, and $\bar{w}$ are the mean velocities and u', v' and w' are the deviations from the mean, the turbulent components or eddy velocities. Usually, the mean flow is horizontal ($\bar{w} = 0$) and the x axis is taken to be in the direction of the mean flow ($\bar{v} = 0$). In this case, the instantaneous velocity is $\bar{u} + u' + v' + w'$. This is shown except for w' in Figure 1.

Clever!

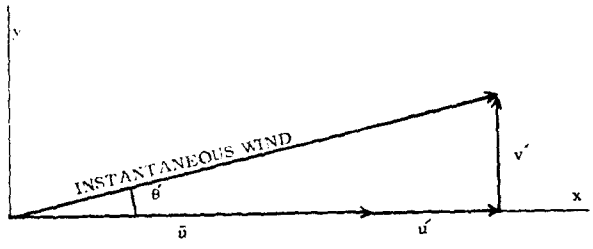


Figure 1. Instantaneous Wind Velocity Components (In Two Dimensions)

The ratio of the eddy velocities to the mean velocity, $u'/\bar{u}$, $v'/\bar{u}$, and $w'/\bar{u}$, are the components of gustiness. The squares of the eddy velocities u'^2, v'^2 and w'^2 are the eddy energies. The mean of these eddy energies indicate the kinetic energy of the motion.

Since the same mean eddy energy, $\overline{u'^2}$, may result from many different combinations of eddy velocities, the mean eddy energy does not specify the turbulence. The ratio of the square root of the mean eddy energy to the mean wind speed $\sqrt{\overline{u'^2}}/\bar{u}$ is referred to as the intensity of turbulence of the u component; $\sqrt{\overline{v'^2}}/\bar{u}$ and $\sqrt{\overline{w'^2}}/\bar{u}$ are the intensities of turbulence for the other two components.

There are two different systems of hydrodynamics used to specify turbulent motions. In the Eulerian system, the velocities at all positions in the flow are specified at a given instant. In the Lagrangian system, the velocities of a given particle or parcel are considered at different times as the particle moves in the flow.

A Theories of Turbulence

1 Prandtl's Mixing Length Theory

According to this theory, the mean path of an eddy, over which the eddy is maintained, is the mixing length. The mixing length is thus analogous to the mean free path of molecules. This theory implies a discontinuous motion of the atmosphere, but provided a way in which momentum, heat, and matter could be considered transferred according to the respective gradients of these quantities. (See Sutton, 1953;

*Supervisory Research Meteorologist. NOAA Meteorology & Assessment Division, EPA Research Triangle Park, NC 27711

Pai, 1957; Pasquill, 1962). Variations of the mixing length theory were set fourth by Taylor 1915 and von Kármán.

2. Statistical Theory of Turbulence

The first representation of the atmosphere's motion as varying continuously is due to G.I. Taylor (1921), who considered the movement of a given particle with time (Lagrangian system). This was followed by a series of papers (Taylor, 1935) describing turbulence in an Eulerian frame of reference. Something about the size of eddies could be determined by consideration of the variation in velocity at a given time between two given points. The velocities at the two points would be more nearly the same for large eddies, than for small ones (Figure 2).

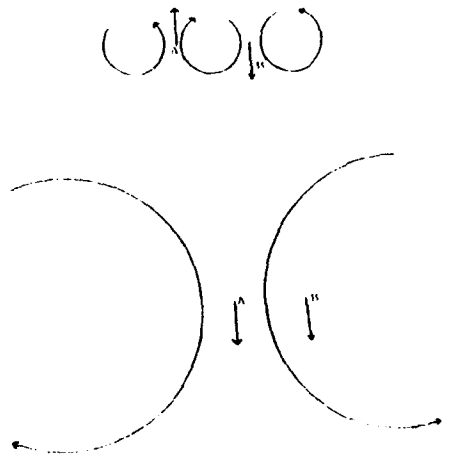


Figure 2. Comparison of Velocities at Two Points for Two Different Sizes of Eddies

a Space correlation coefficient

A statistical expression of the relation of the velocities at these two points can be obtained by using the space correlation coefficient. This measures the closeness of the relationship numerically. The correlation coefficient may vary between + 1 and - 1 being + 1 if there is a perfect relation, -1 if there is a perfect inverse relation, (i.e., as one velocity increases, the other decreases) and 0 if there is no relation. See Sutton (1961). Consider the points 1 and 2 that are a distance x apart. The correlation coefficient R(x) may be defined as

$$R(x) = \frac{\overline{\acute{u}_1 \acute{u}_2}}{\overline{\acute{u}^2}}$$

This is not a function! cont.

where $\acute{u}_1$ is the eddy velocity at point 1, $\acute{u}_2$ is the eddy velocity at point 2, and $\acute{u}^2$ is the mean eddy energy. It is assumed that R (x) and $\acute{u}^2$ are independent of position, i.e., the turbulence is homogeneous. As the distance, x, between the points increases, the correlation is expected to decrease. A graph of R(x) against x (correlogram) can be made if the correlations are known for x varying continuously. The rate of decrease of R(x) is related to the eddy sizes. A length, l, the scale of turbulence, may be defined by

$$l = \int_0^\infty R(x)\, dx$$

if this integral converges. Taylor considered l as the average size of eddies. Similarly, scales of turbulence in the y and z directions may be defined.

b Autocorrelation coefficient

A time correlation, coefficient, R(t), (an autocorrelation coefficient) may be defined by correlating eddy velocities measured at a point at different times. If the variations in wind speed at a point are caused by an unchanging pattern of turbulence passing, then

$$R(t) = R(x)$$

where $x = ut$

c Spectrum

In 1938, Taylor introduced the relation between the autocorrelation coefficient and the spectrum of turbulence. Where n is frequency (cycles per second), the portion of the total variance of frequencies between n and n + dn is $\acute{u}^2 F(n)\, dn$ where

$$\int_0^\infty F(n)\, dn = 1.$$

The curve formed by plotting F(n) or n F(n) against n is the energy spectrum or power spectrum. The quantity

$\overline{\acute{u}^2}\ F(n)$ is the spectral density. Taylor showed that R(t), the autocorrelation coefficient, and F(n) are related by :

$$R(t) = \int_0^\infty F(n) \cos 2\pi nt\, dn \text{ and } F(n) = 4 \int_0^\infty R(t) \cos 2\pi nt\, dt$$

This provides a way of calculating the spectral density and of identifying the sizes (frequencies) of eddies that most greatly affect the kinetic energy.

B Isotropy

In the theoretical considerations of turbulence, it has been frequently assumed that the turbulence is isotropic. The turbulence is isotropic if the statistical properties are unaltered by rotation or reflection of the reference axes. Thus, the mean eddy energies $\overline{\acute{u}^2}$, $\overline{\acute{v}^2}$, and $\overline{\acute{w}^2}$ are equal. It was shown by von Kármán (1937) that if the turbulence is isotropic, the spatial correlations R_x and R_y are different, but are related by $R_y = R_x + 1/2\ r \frac{dR_x}{dr}$

where r is the separation distance for both the x and y measurements. The correlation coefficient, R_x, along the wind direction is the longitudinal correlation coefficient, and R_y across wind is a transverse correlation coefficient. With isotropic turbulence, R_z is also a transverse correlation coefficient and is equal to R_y. There are also differences in the autocorrelations as well as the spatial correlations; the autocorrelation of the $\acute{u}$ component is a longitudinal one whereas the autocorrelations of the $\acute{v}$ and $\acute{w}$ components are transverse. These differences must be considered in interpreting correlation coefficients, correlograms, or spectral functions.

Isotropy does not generally exist in the atmosphere, at least, not in the vicinity of the earth's surface which is the region of particular concern in air pollution. Kolmogoroff, in 1941, set forth the idea of local isotropy, i.e., if one considers the motion on a small enough scale, this motion is isotropic. His theory known as the similarity theory or theory of universal equilibrium indicates that most of the energy is contained in a particular group of eddies and that energy is continually passed to higher frequency eddies by inertial forces. There is also dissipation of energy by viscous forces mainly at the high frequencies. During the transfer process, the eddies lose their directional preference and a scale is reached where the turbulence is isotropic. See Pasquill (1962) and Batchelor (1950) for details of Kolmogoroff's theory.

C Sampling and Averaging Times

The atmospheric spectrum extends to large scales produced by the distrubances of the general circulation. Because of this, the statistical properties are highly dependent upon sampling time. If a sample is taken for a finite length of time, τ, the effects of the slow variations (low frequencies) will not be included. In most cases, the variances and autocorrelations do not reach constant or zero limiting values. As τ increases, so does the total variance. In addition, some of the fine structure (high frequencies) will be smoothed out

since any observation must represent an average over some small time period, s. The inertia of the wind sensor will limit how small s can be. Thus, the sampling duration, τ, and the averaging time, s, have an important bearing on the values of the statistical properties. The fraction of the spectral density corresponding to each frequency is shown in Figure 3 for a sampling duration, τ, and for consecutive interval averaging times, s. Thus, only the portion of the spectrum that appears through this spectral window is known. Thus, for a sampling duration of τ = 1 hour (3600 seconds) and averaging time s = 1 second, the fraction of the spectral density is 1.0 between 5.56 x 10^{-4} cycles per second ($2/\tau$) and 5 x 10^{-2} cycles per second (0.05/s). Thus, the fraction of the spectral density is 1.0 for the motions having a cycle of less than 30 minutes and more than 20 seconds.

D Statistical Properties of Turbulence

Turbulence is neither homogeneous (spatial variation) nor stationary (time variation) due to terrain and diurnal changes. Therefore, turbulence depends upon the particular place and time. Neuberger, et al., (1956) summarized the following 6 statistical properties of turbulence.

1. Turbulent energy is greatest in unstable air, least in stable air.
2. Vertical turbulent energy is somewhat smaller than horizontal turbulent energy.
3. When the atmosphere is stable, the turbulent variations are of high frequency with fluctuations on the order of a few seconds or fractions of seconds. During unstable conditions, longer period fluctuations on the order of minutes become important due to convection.
4. The scale of turbulence increases with height due to less damping by the ground. Fluctuations of longer periods become more important higher in the atmosphere.
5. Turbulent energy increases with increasing wind speed.
6. Turbulent energy is greater over rough ground than over smooth ground.

II DIFFUSION

In the Glossary of Meteorology, diffusion is defined as, "the exchange of fluid parcels (and hence, the transport of conservative properties) between regions in space, in the apparently random motions of a scale too small to be treated by the equations of motion".

A Transfer Theory

Transfer theory is the name given to one group of early mathematical expressions describing atmospheric diffusion. One such formulation still may be applied very near the ground, within one meter, and

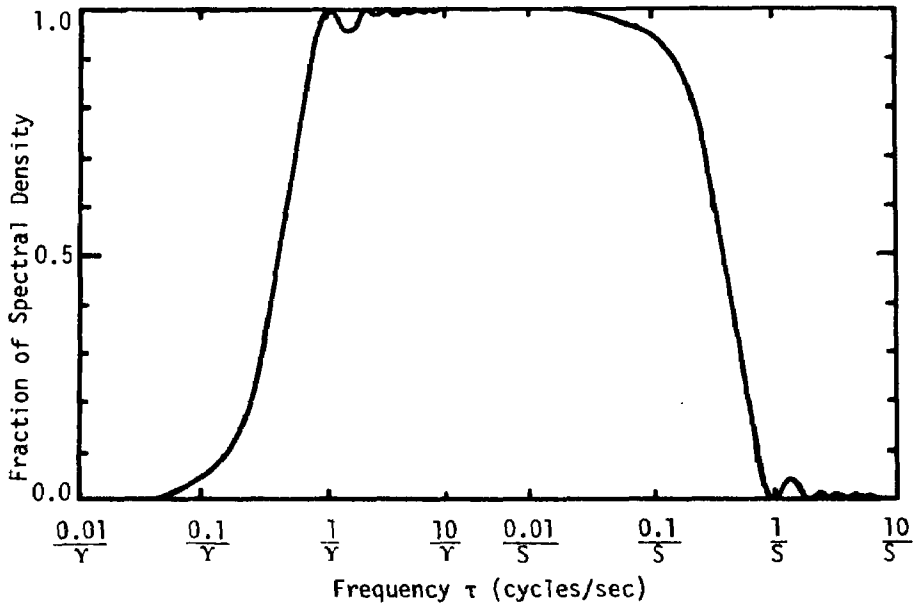


Figure 3.
The Spectral Window Dependent on Sampling Time, τ, and Averaging Time, s

another maybe used in regard to stratospheric-tropospheric exchange processes. These theories express a linear relation between the flux of a quantity and the gradient in the direction of the flux. For example:

$$F = -A \frac{\delta \bar{s}}{\delta n} \quad \text{and}$$

$$F = -\rho K \frac{\delta \bar{s}}{\delta n}$$

where F is the flux, s is the quantity per unit mass of the diffusing quantity, A is an exchange or austausch coefficient, and K is eddy diffusivity. These are equations for transfer theories. See Priestley et al., (1958).

The general diffusion equation resulting from transfer theory is:

$$\frac{d\chi}{dt} = \frac{\delta}{\delta x}\left(K_x \frac{\delta \chi}{\delta x}\right) + \frac{\delta}{\delta y}\left(K_y \frac{\delta \chi}{\delta y}\right) + \frac{\delta}{\delta z}\left(K_z \frac{\delta \chi}{\delta z}\right)$$

If $K_x = K_y = K_z$ = constant in the above equation, the resulting diffusion is termed "Fickian" after Albert Fick, a German physiologist of the mid 1800's. Frequently, this equation has been used with the K's, especially K_z, varying. One form of the equation for the continuous cross-wind line source is:

$$\bar{u} \frac{\delta \chi}{\delta x} = \frac{\delta}{\delta z}\left(K_z \frac{\delta \chi}{\delta z}\right)$$

Solutions for this equation have been worked out by O. F. T. Roberts and also by F. B. Smith, (1957).

B Statistical Theory

G. I. Taylor, in 1921, indicated that the cross-wind position of a small parcel of air or a particle of negligible size and mass that is being transported by the atmosphere at the time, t, after release is given by:

$$y = \int_o^t v'(t)\, dt$$

Tough

where v' are the instantaneous eddy velocities of the particle in the y direction. Therefore, these are Lagrangian eddy velocities. The position of one particle is of no particular interest, but rather some statistical property of the entire ensemble of particles.

If the turbulence is homogeneous and stationary, i.e., if the average properties are uniform in space and steady in time, then:

$$\sigma_y^2 = 2\overline{v'^2} \int_o^T \int_o^t R(\xi)\, d\xi\, dt$$

where σ_y is the standard deviation of the particle in time T, $\overline{v'^2}$ is the mean square eddy velocity of the particle, and $R(\xi)$ is the Lagrangian correlation coefficient between the velocity of the particle at t and at $t + \xi$. For small time, T, the Lagrangian autocorrelation $R(\xi)$ is approximately 1.0 so that

$$\sigma_y^2 = \overline{v'^2}\, T^2 \quad \text{(for small T)}$$

The spread is linear. For large T, $R(\xi)$ is approximately zero so that

$$\sigma_y^2 = 2\left[\int_o^t R(\xi)\, d\xi\right] \overline{v'^2}\, T$$

(for large T)

The spread is parabolic and the term in the brackets is a constant time scale of turbulence. It is uncertain as to just what may be considered small T and large T. The indication is that one must know the form of the Lagrangian correlogram or spectrum in order to determine the diffusion.

Measuring Lagrangian properties of the atmosphere is extremely difficult.

Sutton in 1934, suggested a form for the Lagrangian autocorrelation:

$$R(\xi) = \left(\frac{\nu}{\nu + \overline{w^2}\,\xi} \right)^n$$

where ν is the kinematic viscosity of air.

This results in:

$$\sigma_y^2 = \tfrac{1}{2} C_y^2 (\bar{u} T)^{2-n}$$

where

$$C_y^2 = \frac{4 \nu^n}{(1-n)(2-n)\bar{u}^n} \left(\frac{\overline{v^2}}{\overline{v}^2} \right)^{1-n}$$

Sutton assumed a Gaussian distribution of concentrations in the diffusing cloud and that the wind is constant with height. See Sutton (1953).

C Relation of Lagrangian to Eulerian Statistics

Another approach to obtaining estimates of Lagrangian statistics may be by relating the Lagrangian correlogram or spectrum to the Eulerian properties as measured at a fixed point. Since accurate measurement of wind velocities may be made at a fixed point, this approach may be most feasible. Michelsen (1955) in wind tunnel experiments found a relation between the Eulerian and Lagrangian correlograms:

$$R(x) = \frac{1}{B^2} R(\xi)$$

when

$$\xi = \frac{x}{B (\overline{v^2})^{1/2}}$$

This showed that the Lagrangian correlogram falls off more slowly than the corresponding Eulerian value. This certainly seems reasonable since the Lagrangian measurement is the velocity of particles moving in eddies which are being transported according to the flow, whereas the Eulerian measurements are the velocities measured at a fixed point of eddies moving past that point according to the mean flow. Hay and Pasquill (1957) came to the conclusion that also in the atmosphere the Lagrangian correlation decreased more slowly than the autocorrelation at a fixed point. They (Hay and Pasquill, 1959) assumed the relation:

$$R_L(\xi) = R_E(t) \text{ when } \xi = \beta t$$

the L referring to Lagrangian and E to Eulerian. The resulting relation between spectral densities is:

$$n F_L(n) = \beta n F_E(\beta n)$$

The assumed relations between the Eulerian and Lagrangian correlograms and spectra are shown in Figure 4.

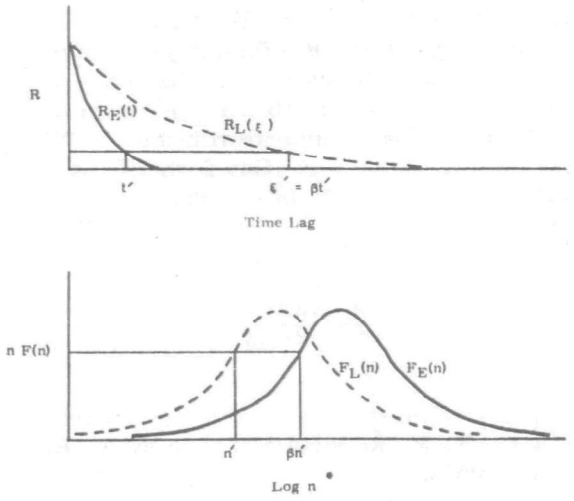


Figure 4. Hypothetical Scale Relation Between Lagrangian and Eulerian (fixed point) Correlograms (above) and Spectra (below) (From Pasquill, 1962)

The principal result of this is that the dispersion of particles in the atmosphere may be approximated by averaging the eddy velocity over time intervals of T/β over the period of release, τ, where T is the time of travel. Numerous field experiments to test this possibility are being made. See Pasquill (1961, 1962).

REFERENCES

1 Batchelor, G.K. The Application of the Similarity Theory of Turbulence to Atmospheric Diffusion. Quart. J. Roy. Meteorol. Soc. 76: 133. 1950.

2 Hay, J.S., and Pasquill, F. Diffusion from a Fixed Source at a Height of a Few Hundred Feet in the Atmosphere. J. Fluid Mech. 2: 299. 1957.

3 Hay, J.S., Pasquill, F. Diffusion from a Continuous Source in Relation to the Spectrum and Scale of Turbulence. Advances in Geophysics. 6: 345-356. Academic Press. New York. 1959.

4 Huschke, R.E., (Editor). Glossary of Meteorology. Boston, Amer. Meteorol. Soc. 638 pp. 1959.

5 Kolmogoroff, A.N. Dissipation of Energy in Locally Isotropic Turbulence. C.R. Acad. Sci. U.R.S.S. 31: 538. 32:16. 1941.

6 Mickelsen, W.R. An Experimental Comparison of the Lagrangian and Eulerian Correlation Coefficients in Homogeneous Isotropic Turbulence. N.A.C.A. Washington, Tech. Note No. 3570. 1955.

7 Neuberger, H., Panofsky, H., and Sekera, Z. Physics of the Atmosphere. Air Pollution Handbook. New York. McGraw-Hill. 61 pp. 1956.

8 Pai, Shih-I. Viscous Flow Theory. Turbulent Flow. 2: Princeton, N.J. D. Van Nostrand. 277 pp. 1957.

9 Pasquill, F. The Estimation of the Dispersion of Wind-Borne Material. Meteorol. Mag. 90:33-49. 1961.

10 Pasquill, F. Atmospheric Diffusion. D. Van Nostrand. London. 297 pp. 1962.

11 Priestley, C.H.B. McCormick, R.A., and Pasquill, F. Turbulent Diffusion in the Atmosphere. WMO Technical Note 24, Geneva, WMO No. 77, TP. 31, 68 pp. 1958.

12 Smith, F.B. The Diffusion of Smoke from a Continuous Elevated Point-Source Into a Turbulent Atmosphere. J. Fluid Mech. 2: 49. 1957.

13 Sutton, O.G. Wind Structure and Evaporation in a Turbulent Atmosphere. Proc. Roy. Soc. A. 146:701. 1934.

14 Sutton, O.G. Micrometeorology. New York. McGraw-Hill. 333 pp. 1953.

15 Sutton, O.G. The Challenge of the Atmosphere. Harper and Brothers. New York. 227 pp. 1961.

16 Taylor, G.I. Eddy Motion in the Atmosphere. Phil. Trans. Roy. Soc., A. 215:1-26. 1915. Reprinted in the Scientific Papers of Sir Geoffrey Ingram Taylor. 2: Editor: G.K. Batchelor. Cambridge University Press. pp 1-23. 1960.

17 Taylor, G.I. Diffusion by Continuous Movements. Proc. London Math. Soc. Ser. 2, 20, 196. 1921. Reprinted in the Scientific Papers of Sir Geoffrey Ingram Taylor. 2: Editor: G.K. Batchelor. Cambridge University Press. pp. 172-184. 1960.

18 Taylor, G.I. Statistical Theory of Turbulence. Pts 1-4. Proc. Roy. Soc., A. 151:421. 1935. Reprinted in the Scientific Papers of Sir Geoffrey Ingram Taylor. 2: Editor: G.K. Batchelor. Cambridge University Press. pp. 288-335. 1960.

19 Taylor, G.I. The Spectrum of Turbulence. Proc. Roy. Soc. (London) A. 164: 476-490. 1938. Reprinted in the Scientific Papers of Sir Geoffrey Ingram Taylor. 2: Editor: G.K. Batchelor. Cambridge University Press. pp. 453-465. 1960.

20 von Karman, Th. The Fundamentals of the Statistical Theory of Turbulence. J. Aero. Sci. 4: 134-138. 1937.

21. Panofsky, H. A., Prasad, B. Similarity Theories and Diffusion. Int. J. Air Wat. Poll. 9:419-430, 1965.

22. Kofoed-Hansen, O., Wandel, C. F. On the Relation between Eulerian and Lagrangian Averages in the Statistical Theory of Turbulence, Danish Atomic Energy Commission Research Establishment Risö. Risö Report No. 50, June 1967.

23. Meteorology and Atomic Energy 1968. D. H. Slade, Ed. U.S. Atomic Energy Commission, Tech. Information Div., TID-24190, July 1968.

THE GENERALIZED GAUSSIAN DIFFUSION EQUATION

The normal or Gaussian frequency curve is given by:

$$C(x) = \frac{1}{(2\pi)^{1/2}\,\sigma} \exp - \frac{(x - \bar{x})^2}{2\sigma^2} \qquad (1)$$

Where C is the probability density function, $\bar{x}$ is the mean and σ is the standard deviation. $(2\pi)^{1/2}$ makes the area under the curve from $x = -\infty$ to $= +\infty$ equal to 1. See Figure 1.

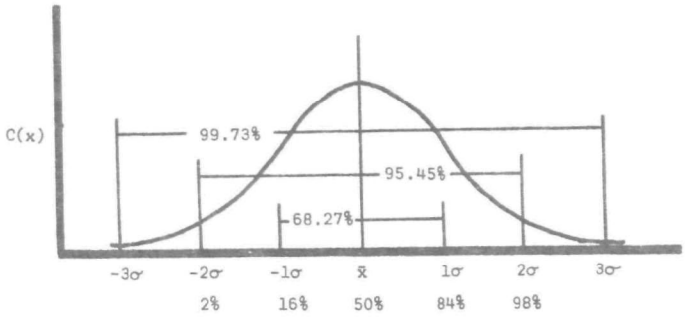


Figure 1. Normal Frequency Curve

Note: $\exp(-a/b) = e^{-\frac{a}{b}}$ where e is the mathematical constant approximately equal to 2.7183.

When a distribution is binormal in the two dimensions x and y the probability density function is:

$$C(x,y) = \frac{1}{2\pi\,\sigma_x\,\sigma_y}$$

$$\exp - \frac{1}{2}\left[\frac{(x - \bar{x})^2}{\sigma_x^2} + \frac{(y - \bar{y})^2}{\sigma_y^2}\right] \qquad (2)$$

If there is a continuous emission, Q, of gas or aerosols from a point, H, above the ground, define a 3 dimensional coordinate system so that the origin is on the ground beneath the point of emission, x is in the direction of the mean wind, $\bar{u}$, y is crosswind and z is vertical.

Assume that the diffusion in the crosswind and vertical dimensions will occur in a Gaussian manner, that the pollution will move downwind with the mean speed of the wind, and that the diffusion in the downwind direction is negligible compared with the transport.

The concentration, C, at any point (x, y, z) can be written as:

$$\frac{C(x,y,z)\,\bar{u}}{Q} = \frac{1}{2\pi\,\sigma_y\,\sigma_z}$$

$$\exp - \frac{1}{2}\left[\frac{y^2}{\sigma_y^2} + \frac{(z - H)^2}{\sigma_z^2}\right] \qquad (3)$$

Here $\bar{y}$ is assumed 0, and $\bar{z}$ assumed to be H. In this equation C has units of mass per volume; $\bar{u}$, velocity or length per time; Q, mass per time; σ_y and σ_z length; and y, z, and H, length.

Because diffusion in the z direction is bounded by the earth's surface, equation 3 cannot be strictly used. If it can be assumed that the ground acts as a perfect reflector, this has the effect of assuming a source at z = H and a virtual "image" source at z = - H then

$$\frac{C(x,y,z)\,\bar{u}}{Q} = \frac{1}{2\pi\,\sigma_y\,\sigma_z}\left[\exp \frac{-y^2}{2\sigma_y^2}\right]$$

$$\left[\exp - \frac{(z - H)^2}{2\sigma_z^2} + \exp - \frac{(z + H)^2}{2\sigma_z^2}\right] \qquad (4)$$

This is the generalized diffusion equation. We cannot expect to obtain instantaneous concentrations from this equation, but concentrations averaged over at least a few minutes time. There are several reasons why one may expect this equation to be valid for the atmosphere. This obeys the equation of continuity, i.e., the conservation of mass. The mass Q/1 second is found between any two planes perpendicular to the x axis at a distance $\bar{u}$/1 second part. Secondly, diffusion is a random process and the distribution of material from such motion may be expected to be in some statistical form; in this case, according to the Gaussian curve. There is one theoretical reason why one would not expect this equation to apply. Diffusion can only occur at a finite speed, i.e., the concentration of released material should drop at zero at some distance from the x axis because it has not diffused to this point. Assuming a Guassian distribution assumes the material to be spread from $-\infty$ to $+\infty$ crosswind. This is not of practical importance, however, as the Gaussian distribution drops off extremely rapidly within a few σ crosswind. One practical limitation is that the Gaussian distribution does not allow for any wind shear in the surface layer.

Interest is generally focused upon ground level concentrations, i.e., C(x, y, 0). Substituting z = 0 in (4) yields:

$$\frac{C(x,y,0)\,\bar{u}}{Q} = \frac{1}{\pi \sigma_y \sigma_z} \exp\left[-\frac{y^2}{2\sigma_y^2} - \frac{H^2}{2\sigma_z^2}\right] \quad (5)$$

It will be noted that the 2 in the denominator in (4) is eliminated in (5) because of the 2 resulting from $2 \exp -\frac{H^2}{2\sigma_z^2}$ occurring in the numerator.

If the source is at ground level, H = O, there is further simplification. Similarly, if one is interested only in centerline concentrations (directly downwind) then y = 0, and equation (5) may again be simplified.

This, (5), is the basic equation for calculating the ground level concentration from a continuous point source. The usual units for the variables are:

C (x, y, 0)	gms/m^3
$\bar{u}$	m/sec
Q	gms/sec
σ_y, σ_z, y, H,	meters

REFERENCES

1 Cramer, H.E., Record, F.A., and Vaughan, H.C. The Study of the Diffusion of Gases or Aerosols in the Lower Atmosphere. Final Report. Contract No. AF 19(604) - 1058. Mass. Inst. of Tech. Dept. of Meteorol. 69 pp. 1958.

2 Gifford, F.A., Jr. Use of Routine Meteorological Observations for Estimating Atmospheric Dispersion. Nuclear Safety. 2: 47-51. 1961.

3 Munn, R.E. Some Basic Concepts of Air Pollution Meteorology. Cir. 3306. TEC 316. Met. Branch. Dept. of Transport. Canada. 1960.

4 Pasquill, F. The Estimation of the Dispersion of Windborne Material. Meteorol. Mag. 90: 33-49. 1961.

ATMOSPHERIC DIFFUSION COMPUTATIONS

D. B. Turner*
J. L. Dicke*

With the increase in concern for air pollution both from conventional and radioactive sources, the need for determining the transport and diffusion of these pollutants in the atmosphere has become more pressing.

Pasquill (1961, 1962) of the British Meteorological Office devised a method of computing dispersion from an elevated or ground-level source in terms of the height and width of the plume of airborne material based on diffusion measurements made during Project Prairie Grass (Cramer et al., 1958) and other diffusion studies. This method was also published by Meade (1960). Gifford (1961) has transformed values of Pasquill's parameters of height and width to the standard deviations of plume concentration distribution in the vertical, σ_z, and horizontal, σ_y.

DIFFUSION EQUATION

Assuming that the plume has a Gaussian distribution in both the horizontal and vertical dimensions with standard deviations of plume concentration distribution in the vertical and horizontal of σ_z and σ_y respectively, the mean wind speed affecting the plume is $\bar{u}$, the height of emission is H, the crosswind distance from the plume centerline is y, the source strength is Q, and total reflection of the plume takes place at the earth's surface, the concentration at ground-level is given by:

$$C = \frac{Q}{\pi \bar{u} \sigma_y \sigma_z} \exp - \frac{H^2}{2\sigma_z^2} \exp - \frac{y^2}{2\sigma_y^2} \quad (1)$$

Any consistent set of units may be used. The most common is:

C	grams or curies/m^3
Q	grams or curies/sec
$\bar{u}$	meters/sec
σ_y	meters
σ_z	meters
H	meters
y	meters

The values of σ_y and σ_z must be in terms of a downwind distance, x. The computation of concentration, C, is therefore made for specific downwind distances. C is also the total dosage in gm-sec/m^3 or curies-sec/m^3 for the same distance for the passage of the entire plume if the total release is Q.

This equation is valid if diffusion in the downwind direction may be neglected. If the duration of release is equal to or greater than the travel time from the source to the location of interest, downwind diffusion may be assumed absent.

STABILITY

The values of both σ_y and σ_z will depend upon the turbulent structure of the atmosphere. If measures of horizontal and vertical motions of the air are made as with a bivane, the resulting records may be used to estimate σ_y and σ_z. (See Pasquill, 1961) If wind fluctuation measurements are not available, estimates of σ_y and σ_z may be made by first estimating the stability of the atmosphere from wind measurements at the standard height of 10 meters, and estimates of net radiation (Pasquill, 1961). Stability categories (in six classes) are given in Table 1 in terms of insolation during daytime (radiation received from the sun) and amount of cloud cover at night. Strong insolation corresponds to a solar altitude (above the horizon) greater than 60° with clear skies, and slight insolation corresponds to a solar altitude from 15° to 35° with clear skies. Table 170, Solar Altitude and Azimuth in the Smithsonian Meteorological Tables (List, 1951) is of considerable aid in determining insolation. Cloudiness will generally decrease insolation and should be considered along with solar altitude in determining insolation. Insolation

*Supervisory Meteorologists, NOAA
Meteorology & Assessment Division, EPA

PA.ME.sd.36.6.67

that would be strong with clear skies might be expected to be reduced to moderate with broken middle clouds and to slight with broken low clouds. Night refers to the period from one hour before sunset to one hour after sunrise. The neutral category, D, should be assumed for overcast conditions during day or night.

ESTIMATION OF VERTICAL AND HORIZONTAL DISPERSION

Having determined the stability class from Table 1, the measures of diffusion in the vertical, σ_z, and in the horizontal, σ_y, may be estimated as a function of downwind distance from the source, x, using Figures 1 and 2. These values of σ_y and σ_z are valid for concentrations, C, averaged over a few minutes time and apply to open level country with no allowance made for turbulence due to buildings or topography. With very light winds on a clear night, the vertical spread may be less than the values for class F. Because of lack of quantitative knowledge and because a plume from a surface source is unlikely to have any definable travel, and elevated plumes will generally not reach the ground, no estimates are attempted for this case.

When conditions are such that the vertical structure of temperature indicates a definite limit to the vertical convection, particularly under unstable conditions, the σ_z should be allowed to increase only to $0.47\ h_1$ where h_1 is the limit of convection. At the distance x_1 where $\sigma_z = 0.47\ h_1$, the plume is still assumed to have a Gaussian vertical distribution. It can be assumed that by the time the plume travels twice this far, $2\ x_1$, the plume has become uniformly distributed between the earth's surface and the limit of convection. A value of σ_z equal to $0.8 h_1$ may be used and the exponential term dropped at distances equal to or greater than $2\ x_1$ and will give the concentration value computed by the equation equal to that from a plume uniformly distributed in the vertical.

ESTIMATION OF WIND SPEED

For mean wind speed, $\bar{u}$, the value measured at 10 meters height (surface wind) should be used for x up to about 1 km for surface sources or short stacks. For greater distances or elevated sources a mean speed through the vertical extent of the plume (about $2\ \sigma_z$) should be used. A speed midway between the surface and geostrophic speeds should be reasonable.

CALCULATION OF CENTERLINE CONCENTRATION FROM A GROUND LEVEL SOURCE

For most practical purposes it will be sufficient to calculate the centerline concentration for the distances 100 m, 1 km, 10 km, and 100 km and plot these against downwind distance x, on log/log graph paper for interpolation of concentrations for other distances. (For unstable or stable cases it is desirable to include several other distances). This may be done using the equation:

$$C_0 = \frac{Q}{\pi\, u\, \sigma_y\, \sigma_z} = \frac{3.18 \times 10^{-1}\, Q}{u\, \sigma_y\, \sigma_z} \qquad (2)$$

The zero subscript of C, concentration, indicates emission from a ground-level source. If there is a limit to convection, h, concentrations should also be calculated for distances x_1 and $2\ x_1$ using $\sigma_z = 0.47\ h_1$ and $\sigma_z = 0.8\ h_1$ respectively. Line segments connecting the calculated concentrations for the various distances will give a plot of concentration with distance.

CALCULATION OF GROUND-LEVEL CENTERLINE CONCENTRATION FROM AN ELEVATED SOURCE

Concentrations from an elevated source may be calculated from:

$$C = \frac{Q}{\pi\, u\, \sigma_y\, \sigma_z} \exp - \frac{H^2}{2\, \sigma_z^2} \qquad (3)$$

where H is the effective height of the elevated source.

Values of exp - $H^2/2\sigma^2_z$ are found in Table 3. A is the ratio of H/σ_z and B, the expressions in the body of the table, is the computed value of the exponential. The E represents x 10 to the power indicated by the following two digits. For example, if A = 3.55, the value of the exponential is 0.183×10^{-2}.

It is possible under light wind situations at night that the plume from an elevated source will remain aloft with no significant vertical diffusion, in which case the ground-level concentrations would be zero. Vertical spread can then be started at a downwind position corresponding to the wind speed and the estimated time for breakdown of the stable situation.

GRAPHS FOR ESTIMATION OF DIFFUSION

Hilsmeier and Gifford (1962) have presented graphs of relative concentration times wind speed (Cu/Q) below the plume centerline versus downwind distance for various stability classes. Figure 3 give Cu/Q as a function of x for a ground-level source whereas Figures 4-6 are for the indicated elevated sources.

CALCULATION OF OFF-AXIS CONCENTRATIONS

Off-axis concentrations may be calculated from equation 1, or by correcting ground-level centerline concentrations by the factor; exp - $(y^2/2\sigma_y^2)$. This may be obtained from Table 3 for values of y/σ_y.

PLOTTING GROUND-LEVEL CONCENTRATION ISOPLETHS

It may be of interest in a given application to plot the position of the centerline of the plume and to determine areas covered by concentrations greater than a given magnitude. First the axial position of the plume must be known. The mean wind direction will determine the position. The surface wind may be used up to 1 km. Between 1 km and 100 km the average of the surface direction and the geostrophic direction backed by 10° will give a close approximation. The wind direction should be a mean through the vertical extent of the plume (about $2\sigma_z$).

In order to draw lines of equal concentration, it is easiest to locate on a log/log plot of centerline concentration against distance, the centerline concentration that is exp $(y^2/2\sigma_y^2)$ times the concentration desired. The value of y, the off-axis distance, can then be found by knowing the y/σ_y value corresponding to the appropriate exp $(y^2/2\ \sigma_y^2)$ (see Table 2) and the value of σ_y for this particular distance (from Figure 2). The position corresponding to the downwind distance and the off-axis distance can then be plotted. After a number of these points have been plotted, the concentration isopleth may be drawn and the area determined by using a planimeter. This assumes that the plume has a Gaussian distribution across wind. If there is a systematic veering or backing of the wind direction over a range that is large compared to the width of the trace, the plume may be assumed to be uniform in distribution across the width (4.3 σ_y) of the plume and the concentration will be 0.58 of the calculated centerline concentration.

AREAS WITHIN CONCENTRATION ISOPLETHS

Figure 8 gives areas within ground-level concentration isopleths in terms of Cu/Q for a ground-level source for various stability categories (Hilsmeier and Gifford, 1962).

RAPID DETERMINATION OF MAXIMUM CONCENTRATION

The maximum concentration of pollutant will occur along the centerline of the plume, where y is zero, as indicated in equation 3

above. The distance downwind of the source at which the maximum concentration occurs at ground level is a function of effective source height and stability. Figure 7 is a nomogram from which the relative value of the maximum concentration can be determined given the stability and effective source height. If the relative value of that concentration is multiplied by Q/u, the maximum concentration for a specific set of conditions is obtained. The nomogram is designed for source strength expressed in grams/sec and wind speed in meters/sec.

ACCURACY OF COMPUTATIONS

The method will in general give only approximate estimates of concentrations, especially if wind fluctuation measurements are not available and estimates of dispersion are obtained from Figures 1 and 2. In the unstable and stable cases, errors of σ_z of several fold may occur for longer travel distances. There are cases where σ_z may be expected to be within a factor of 2. These are: 1) all stabilites for distances of travel of a few hundred meters in open country; 2) neutral to moderately unstable conditions for distances of a few kilometers; and 3) unstable conditions in the first 1000 meters above ground with a marked inversion thereafter for distances of 10 km or more. Uncertainties in the estimates of σ_y are in general less than those of σ_z except when the wind field is indefinite. In this case, the estimate of concentrations from the plume would be the same except that a wind range should be allowed for the direction of the plume, up to 360°. For extremes of stable and unstable conditions at distances between 50 and 100 km calculated concentrations may differ from true concentrations by an order of magnitude. For these distances under neutral conditions calculated concentrations should be within a factor of 5 of true concentrations.

EXERCISES WITH DIFFUSION PARAMETERS

1. What stability category would be most likely to occur when the wind is 6 - 8 m/sec?
2. If the sky is overcast - synonymous with cloudy - what would the stability category most likely be?
3. What would the stability category most likely be on a sunny April afternoon when the wind is 3 m/sec?
4. If the surface wind at night is 3 m/sec and there is 5/8 of low clouds, what is the most likely stability category?
5. What are σ_y and σ_z at 150 m from a source under B stability?
6. How much difference is there in σ_z at 5 km under D and F stability?
7. What is the value of σ_y at 20 km under C stability?
8. At 300 m how many times larger is σ_y under B stability than under D stability?
9. Under E stability how much greater is the horizontal dispersion factor than the vertical dispersion factor at 300m?
10. If the value of H/σ_z is 1.8 what is the value of $\exp - {}^{z}1/2(H/\sigma_z)^2$?
11. The value of $\exp - 1/2(H/\sigma_z)^2$ is 2.2×10^{-3}. What is H/σ_z?
12. Under D stability and a wind speed of 5 m/sec, a plume is emitted at 100 m above the ground. What is the value of C/Q at 4 km?
13. What is the area enclosed by an isopleth whose C^u/Q value is 4×10^{-4} m^{-2} when the stability category is B?

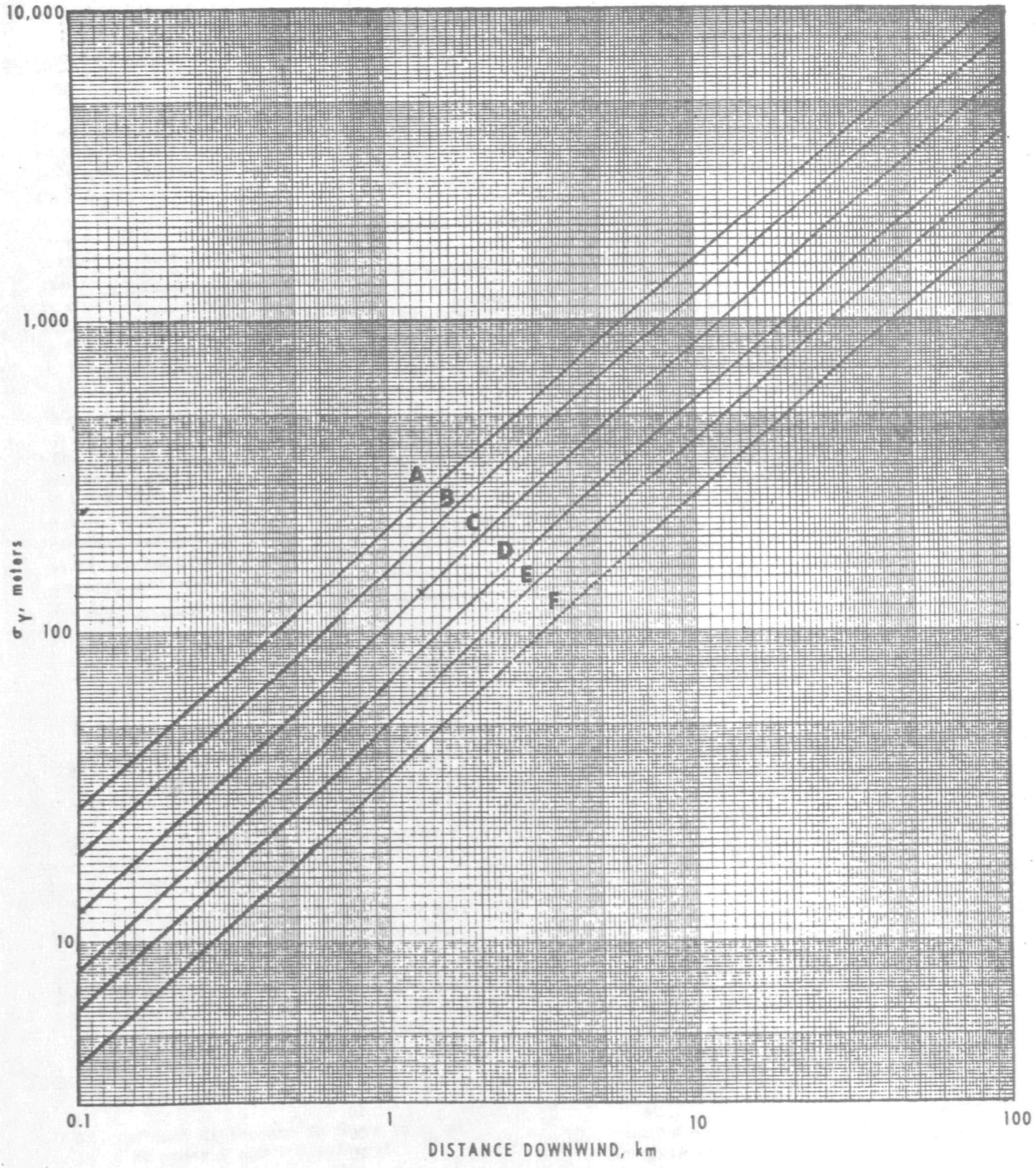
TABLE 1. KEY TO STABILITY CATEGORIES

Surface Wind Speed (at 10 m) m/sec	Insolation			Night	
	Strong	Moderate	Slight	Thinly Overcast or ≥4/8 Low Cloud	≤3/8 Cloud
< 2	A	A-B	B	-	-
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
> 6	C	D	D	D	D

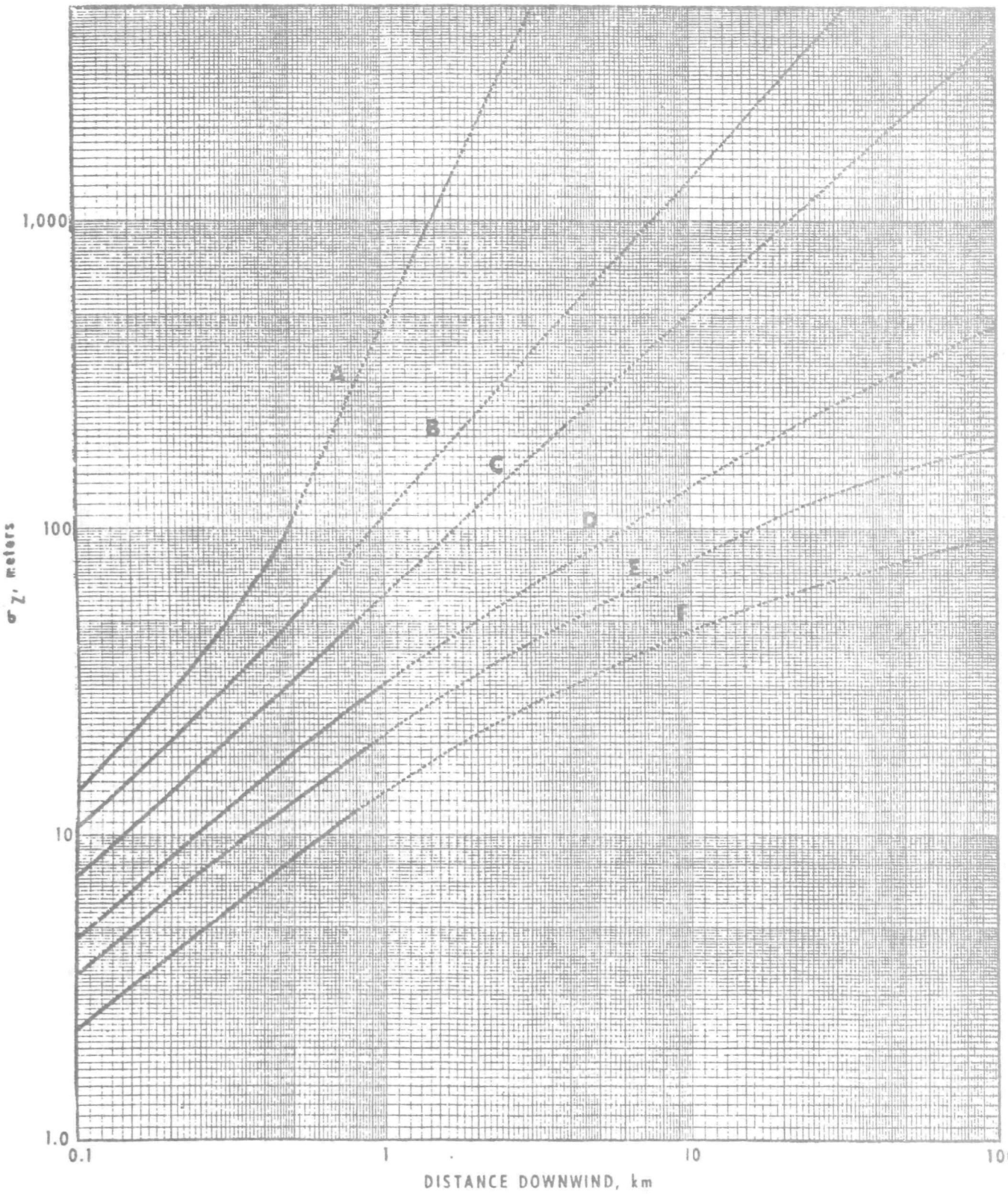
The neutral category, D, should be assumed for overcast conditions during day or night

TABLE 2

y/σ_y	$\exp(y^2/2\sigma_y^2)$
0	1.00
0.1	1.01
0.2	1.02
0.3	1.05
0.4	1.08
0.5	1.13
0.6	1.20
0.7	1.28
0.8	1.38
0.9	1.50
1.0	1.65
1.2	2.05
1.4	2.66
1.5	3.08
1.6	3.60
1.8	5.05
2.0	7.39
2.15	10
3.04	10^2
3.72	10^3
4.29	10^4
4.80	10^5



Horizontal dispersion coefficient as a function of downwind distance from the source.



Vertical dispersion coefficient as a function of downwind distance from the source.

TABLE 3

$B = \exp -\frac{1}{2}(A)^2$

A	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.00	0.100E 01	0.100E 01	0.100E 01	0.100E 01	0.999E 00	0.999E 00	0.998E 00	0.998E 00	0.997E 00	0.996E 00
0.10	0.995E 00	0.994E 00	0.993E 00	0.992E 00	0.990E 00	0.989E 00	0.987E 00	0.986E 00	0.984E 00	0.982E 00
0.20	0.980E 00	0.978E 00	0.976E 00	0.974E 00	0.972E 00	0.969E 00	0.967E 00	0.964E 00	0.962E 00	0.959E 00
0.30	0.956E 00	0.953E 00	0.950E 00	0.947E 00	0.944E 00	0.941E 00	0.937E 00	0.934E 00	0.930E 00	0.927E 00
0.40	0.923E 00	0.919E 00	0.916E 00	0.912E 00	0.908E 00	0.904E 00	0.900E 00	0.895E 00	0.891E 00	0.887E 00
0.50	0.882E 00	0.878E 00	0.874E 00	0.869E 00	0.864E 00	0.860E 00	0.855E 00	0.850E 00	0.845E 00	0.840E 00
0.60	0.835E 00	0.830E 00	0.825E 00	0.820E 00	0.815E 00	0.810E 00	0.804E 00	0.799E 00	0.794E 00	0.788E 00
0.70	0.783E 00	0.777E 00	0.772E 00	0.766E 00	0.760E 00	0.755E 00	0.749E 00	0.743E 00	0.738E 00	0.732E 00
0.80	0.726E 00	0.720E 00	0.714E 00	0.708E 00	0.703E 00	0.697E 00	0.691E 00	0.685E 00	0.679E 00	0.673E 00
0.90	0.667E 00	0.661E 00	0.655E 00	0.649E 00	0.643E 00	0.637E 00	0.631E 00	0.625E 00	0.619E 00	0.613E 00
1.00	0.607E 00	0.600E 00	0.594E 00	0.588E 00	0.582E 00	0.576E 00	0.570E 00	0.564E 00	0.558E 00	0.552E 00
1.10	0.546E 00	0.540E 00	0.534E 00	0.528E 00	0.522E 00	0.516E 00	0.510E 00	0.504E 00	0.498E 00	0.493E 00
1.20	0.487E 00	0.481E 00	0.475E 00	0.469E 00	0.464E 00	0.458E 00	0.452E 00	0.446E 00	0.441E 00	0.435E 00
1.30	0.430E 00	0.424E 00	0.418E 00	0.413E 00	0.407E 00	0.402E 00	0.397E 00	0.391E 00	0.386E 00	0.381E 00
1.40	0.375E 00	0.370E 00	0.365E 00	0.360E 00	0.355E 00	0.350E 00	0.344E 00	0.339E 00	0.334E 00	0.330E 00
1.50	0.325E 00	0.320E 00	0.315E 00	0.310E 00	0.306E 00	0.301E 00	0.296E 00	0.292E 00	0.287E 00	0.283E 00
1.60	0.278E 00	0.274E 00	0.269E 00	0.265E 00	0.261E 00	0.256E 00	0.252E 00	0.248E 00	0.244E 00	0.240E 00
1.70	0.236E 00	0.232E 00	0.228E 00	0.224E 00	0.220E 00	0.216E 00	0.213E 00	0.209E 00	0.205E 00	0.201E 00
1.80	0.198E 00	0.194E 00	0.191E 00	0.187E 00	0.184E 00	0.181E 00	0.177E 00	0.174E 00	0.171E 00	0.168E 00
1.90	0.164E 00	0.161E 00	0.158E 00	0.155E 00	0.152E 00	0.149E 00	0.146E 00	0.144E 00	0.141E 00	0.138E 00
2.00	0.135E 00	0.133E 00	0.130E 00	0.127E 00	0.125E 00	0.122E 00	0.120E 00	0.117E 00	0.115E 00	0.113E 00
2.10	0.110E 00	0.108E 00	0.106E 00	0.103E 00	0.101E 00	0.991E-01	0.970E-01	0.949E-01	0.929E-01	0.909E-01
2.20	0.889E-01	0.870E-01	0.851E-01	0.832E-01	0.814E-01	0.796E-01	0.778E-01	0.760E-01	0.743E-01	0.727E-01
2.30	0.710E-01	0.694E-01	0.678E-01	0.662E-01	0.647E-01	0.632E-01	0.617E-01	0.603E-01	0.589E-01	0.575E-01
2.40	0.561E-01	0.548E-01	0.535E-01	0.522E-01	0.510E-01	0.497E-01	0.485E-01	0.473E-01	0.462E-01	0.450E-01
2.50	0.439E-01	0.428E-01	0.418E-01	0.407E-01	0.397E-01	0.387E-01	0.377E-01	0.368E-01	0.359E-01	0.349E-01
2.60	0.340E-01	0.332E-01	0.323E-01	0.315E-01	0.307E-01	0.299E-01	0.291E-01	0.283E-01	0.276E-01	0.268E-01
2.70	0.261E-01	0.254E-01	0.247E-01	0.241E-01	0.234E-01	0.228E-01	0.222E-01	0.216E-01	0.210E-01	0.204E-01
2.80	0.198E-01	0.193E-01	0.188E-01	0.182E-01	0.177E-01	0.172E-01	0.167E-01	0.163E-01	0.158E-01	0.154E-01
2.90	0.149E-01	0.145E-01	0.141E-01	0.137E-01	0.133E-01	0.129E-01	0.125E-01	0.121E-01	0.118E-01	0.114E-01
3.00	0.111E-01	0.108E-01	0.105E-01	0.101E-01	0.984E-02	0.955E-02	0.926E-02	0.898E-02	0.871E-02	0.845E-02
3.10	0.819E-02	0.794E-02	0.769E-02	0.746E-02	0.723E-02	0.700E-02	0.679E-02	0.658E-02	0.637E-02	0.617E-02
3.20	0.598E-02	0.579E-02	0.560E-02	0.543E-02	0.525E-02	0.509E-02	0.492E-02	0.477E-02	0.461E-02	0.446E-02
3.30	0.432E-02	0.418E-02	0.404E-02	0.391E-02	0.378E-02	0.366E-02	0.354E-02	0.342E-02	0.331E-02	0.320E-02
3.40	0.309E-02	0.299E-02	0.289E-02	0.279E-02	0.269E-02	0.260E-02	0.251E-02	0.243E-02	0.235E-02	0.227E-02
3.50	0.219E-02	0.211E-02	0.204E-02	0.197E-02	0.190E-02	0.183E-02	0.177E-02	0.171E-02	0.165E-02	0.159E-02
3.60	0.153E-02	0.148E-02	0.143E-02	0.138E-02	0.133E-02	0.128E-02	0.123E-02	0.119E-02	0.115E-02	0.110E-02
3.70	0.106E-02	0.103E-02	0.989E-03	0.952E-03	0.918E-03	0.884E-03	0.851E-03	0.820E-03	0.789E-03	0.760E-03
3.80	0.732E-03	0.704E-03	0.678E-03	0.653E-03	0.628E-03	0.604E-03	0.582E-03	0.560E-03	0.538E-03	0.518E-03
3.90	0.498E-03	0.479E-03	0.460E-03	0.443E-03	0.426E-03	0.409E-03	0.393E-03	0.378E-03	0.363E-03	0.349E-03
4.00	0.335E-03	0.322E-03	0.310E-03	0.297E-03	0.286E-03	0.274E-03	0.263E-03	0.253E-03	0.243E-03	0.233E-03
4.10	0.224E-03	0.215E-03	0.206E-03	0.198E-03	0.190E-03	0.182E-03	0.175E-03	0.168E-03	0.161E-03	0.154E-03
4.20	0.148E-03	0.142E-03	0.136E-03	0.130E-03	0.125E-03	0.120E-03	0.115E-03	0.110E-03	0.105E-03	0.101E-03
4.30	0.966E-04	0.925E-04	0.886E-04	0.849E-04	0.813E-04	0.778E-04	0.745E-04	0.713E-04	0.683E-04	0.653E-04
4.40	0.625E-04	0.598E-04	0.572E-04	0.548E-04	0.524E-04	0.501E-04	0.479E-04	0.458E-04	0.438E-04	0.419E-04
4.50	0.401E-04	0.383E-04	0.366E-04	0.350E-04	0.334E-04	0.320E-04	0.305E-04	0.292E-04	0.279E-04	0.266E-04
4.60	0.254E-04	0.243E-04	0.232E-04	0.221E-04	0.211E-04	0.202E-04	0.193E-04	0.184E-04	0.175E-04	0.167E-04
4.70	0.160E-04	0.152E-04	0.145E-04	0.139E-04	0.132E-04	0.126E-04	0.120E-04	0.115E-04	0.109E-04	0.104E-04
4.80	0.993E-05	0.946E-05	0.902E-05	0.859E-05	0.819E-05	0.780E-05	0.743E-05	0.708E-05	0.674E-05	0.642E-05
4.90	0.611E-05	0.582E-05	0.554E-05	0.528E-05	0.502E-05	0.478E-05	0.455E-05	0.433E-05	0.412E-05	0.392E-05

TABLE 3 Con't.

$$B = \exp -\tfrac{1}{2}(A)^2$$

A	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
5.00	0.373E-05	0.354E-05	0.337E-05	0.321E-05	0.305E-05	0.290E-05	0.276E-05	0.262E-05	0.249E-05	0.237E-05
5.10	0.225E-05	0.214E-05	0.203E-05	0.193E-05	0.183E-05	0.174E-05	0.165E-05	0.157E-05	0.149E-05	0.142E-05
5.20	0.134E-05	0.128E-05	0.121E-05	0.115E-05	0.109E-05	0.103E-05	0.982E-06	0.932E-06	0.884E-06	0.838E-06
5.30	0.795E-06	0.754E-06	0.715E-06	0.678E-06	0.643E-06	0.609E-06	0.577E-06	0.547E-06	0.519E-06	0.491E-06
5.40	0.466E-06	0.441E-06	0.418E-06	0.396E-06	0.375E-06	0.355E-06	0.336E-06	0.318E-06	0.301E-06	0.285E-06
5.50	0.270E-06	0.255E-06	0.242E-06	0.229E-06	0.216E-06	0.205E-06	0.194E-06	0.183E-06	0.173E-06	0.164E-06
5.60	0.155E-06	0.147E-06	0.139E-06	0.131E-06	0.124E-06	0.117E-06	0.111E-06	0.104E-06	0.987E-07	0.932E-07
5.70	0.881E-07	0.832E-07	0.786E-07	0.742E-07	0.701E-07	0.662E-07	0.625E-07	0.590E-07	0.556E-07	0.525E-07
5.80	0.496E-07	0.468E-07	0.441E-07	0.416E-07	0.393E-07	0.370E-07	0.349E-07	0.329E-07	0.311E-07	0.293E-07
5.90	0.276E-07	0.260E-07	0.245E-07	0.231E-07	0.218E-07	0.205E-07	0.193E-07	0.182E-07	0.172E-07	0.162E-07
6.00	0.152E-07	0.143E-07	0.135E-07	0.127E-07	0.120E-07	0.113E-07	0.106E-07	0.998E-08	0.939E-08	0.884E-08
6.10	0.832E-08	0.782E-08	0.736E-08	0.692E-08	0.651E-08	0.612E-08	0.576E-08	0.541E-08	0.509E-08	0.478E-08
6.20	0.450E-08	0.423E-08	0.397E-08	0.373E-08	0.351E-08	0.329E-08	0.309E-08	0.291E-08	0.273E-08	0.256E-08
6.30	0.241E-08	0.226E-08	0.212E-08	0.199E-08	0.187E-08	0.175E-08	0.165E-08	0.154E-08	0.145E-08	0.136E-08
6.40	0.128E-08	0.120E-08	0.112E-08	0.105E-08	0.987E-09	0.925E-09	0.867E-09	0.813E-09	0.762E-09	0.714E-09
6.50	0.669E-09	0.627E-09	0.587E-09	0.550E-09	0.516E-09	0.483E-09	0.452E-09	0.424E-09	0.397E-09	0.371E-09
6.60	0.348E-09	0.325E-09	0.305E-09	0.285E-09	0.267E-09	0.250E-09	0.234E-09	0.218E-09	0.204E-09	0.191E-09
6.70	0.179E-09	0.167E-09	0.156E-09	0.146E-09	0.137E-09	0.128E-09	0.119E-09	0.112E-09	0.104E-09	0.974E-10
6.80	0.910E-10	0.850E-10	0.794E-10	0.742E-10	0.693E-10	0.647E-10	0.604E-10	0.564E-10	0.527E-10	0.492E-10
6.90	0.459E-10	0.428E-10	0.400E-10	0.373E-10	0.348E-10	0.325E-10	0.303E-10	0.282E-10	0.263E-10	0.246E-10
7.00	0.229E-10	0.213E-10	0.199E-10	0.186E-10	0.173E-10	0.161E-10	0.150E-10	0.140E-10	0.130E-10	0.121E-10
7.10	0.113E-10	0.105E-10	0.981E-11	0.914E-11	0.851E-11	0.792E-11	0.738E-11	0.687E-11	0.639E-11	0.595E-11
7.20	0.553E-11	0.515E-11	0.479E-11	0.446E-11	0.415E-11	0.386E-11	0.359E-11	0.334E-11	0.310E-11	0.288E-11
7.30	0.268E-11	0.249E-11	0.232E-11	0.215E-11	0.200E-11	0.186E-11	0.173E-11	0.160E-11	0.149E-11	0.138E-11
7.40	0.129E-11	0.119E-11	0.111E-11	0.103E-11	0.955E-12	0.887E-12	0.823E-12	0.764E-12	0.709E-12	0.658E-12
7.50	0.610E-12	0.566E-12	0.525E-12	0.487E-12	0.452E-12	0.419E-12	0.388E-12	0.360E-12	0.334E-12	0.309E-12
7.60	0.287E-12	0.266E-12	0.246E-12	0.228E-12	0.211E-12	0.196E-12	0.181E-12	0.168E-12	0.156E-12	0.144E-12
7.70	0.133E-12	0.124E-12	0.114E-12	0.106E-12	0.980E-13	0.907E-13	0.839E-13	0.777E-13	0.718E-13	0.665E-13
7.80	0.615E-13	0.569E-13	0.526E-13	0.486E-13	0.450E-13	0.416E-13	0.384E-13	0.355E-13	0.328E-13	0.303E-13
7.90	0.280E-13	0.259E-13	0.239E-13	0.221E-13	0.204E-13	0.189E-13	0.174E-13	0.161E-13	0.149E-13	0.137E-13
8.00	0.127E-13	0.117E-13	0.108E-13	0.996E-14	0.919E-14	0.848E-14	0.782E-14	0.722E-14	0.666E-14	0.614E-14
8.10	0.566E-14	0.522E-14	0.481E-14	0.444E-14	0.409E-14	0.377E-14	0.348E-14	0.320E-14	0.295E-14	0.272E-14
8.20	0.251E-14	0.231E-14	0.213E-14	0.196E-14	0.180E-14	0.166E-14	0.153E-14	0.141E-14	0.130E-14	0.119E-14
8.30	0.110E-14	0.101E-14	0.930E-15	0.856E-15	0.787E-15	0.724E-15	0.666E-15	0.613E-15	0.564E-15	0.518E-15
8.40	0.477E-15	0.438E-15	0.403E-15	0.370E-15	0.340E-15	0.313E-15	0.287E-15	0.264E-15	0.243E-15	0.223E-15
8.50	0.205E-15	0.188E-15	0.173E-15	0.159E-15	0.146E-15	0.134E-15	0.123E-15	0.113E-15	0.103E-15	0.949E-16
8.60	0.871E-16	0.799E-16	0.733E-16	0.672E-16	0.617E-16	0.566E-16	0.519E-16	0.476E-16	0.436E-16	0.400E-16
8.70	0.367E-16	0.336E-16	0.308E-16	0.282E-16	0.259E-16	0.237E-16	0.217E-16	0.199E-16	0.182E-16	0.167E-16
8.80	0.153E-16	0.140E-16	0.128E-16	0.117E-16	0.107E-16	0.983E-17	0.900E-17	0.823E-17	0.753E-17	0.689E-17
8.90	0.631E-17	0.577E-17	0.528E-17	0.483E-17	0.441E-17	0.404E-17	0.369E-17	0.337E-17	0.308E-17	0.282E-17
9.00	0.258E-17	0.235E-17	0.215E-17	0.197E-17	0.180E-17	0.164E-17	0.150E-17	0.137E-17	0.125E-17	0.114E-17
9.10	0.104E-17	0.952E-18	0.869E-18	0.793E-18	0.724E-18	0.661E-18	0.603E-18	0.550E-18	0.502E-18	0.458E-18
9.20	0.418E-18	0.381E-18	0.347E-18	0.317E-18	0.289E-18	0.263E-18	0.240E-18	0.219E-18	0.199E-18	0.182E-18
9.30	0.166E-18	0.151E-18	0.137E-18	0.125E-1	0.114E-18	0.104E-18	0.946E-19	0.861E-19	0.784E-19	0.714E-19
9.40	0.650E-19	0.592E-19	0.538E-19	0.490E-19	0.446E-19	0.406E-19	0.369E-19	0.336E-19	0.305E-19	0.278E-19
9.50	0.253E-19	0.230E-19	0.209E-19	0.190E-19	0.173E-19	0.157E-19	0.143E-19	0.130E-19	0.118E-19	0.107E-19
9.60	0.972E-20	0.883E-20	0.802E-20	0.729E-20	0.662E-20	0.601E-20	0.545E-20	0.495E-20	0.450E-20	0.408E-20
9.70	0.370E-20	0.336E-20	0.305E-20	0.277E-20	0.251E-20	0.228E-20	0.207E-20	0.187E-20	0.170E-20	0.154E-20
9.80	0.140E-20	0.127E-20	0.115E-20	0.104E-20	0.943E-21	0.855E-21	0.775E-21	0.702E-21	0.636E-21	0.576E-21
9.90	0.522E-21	0.472E-21	0.428E-21	0.387E-21	0.351E-21	0.318E-21	0.288E-21	0.260E-21	0.236E-21	0.213E-21

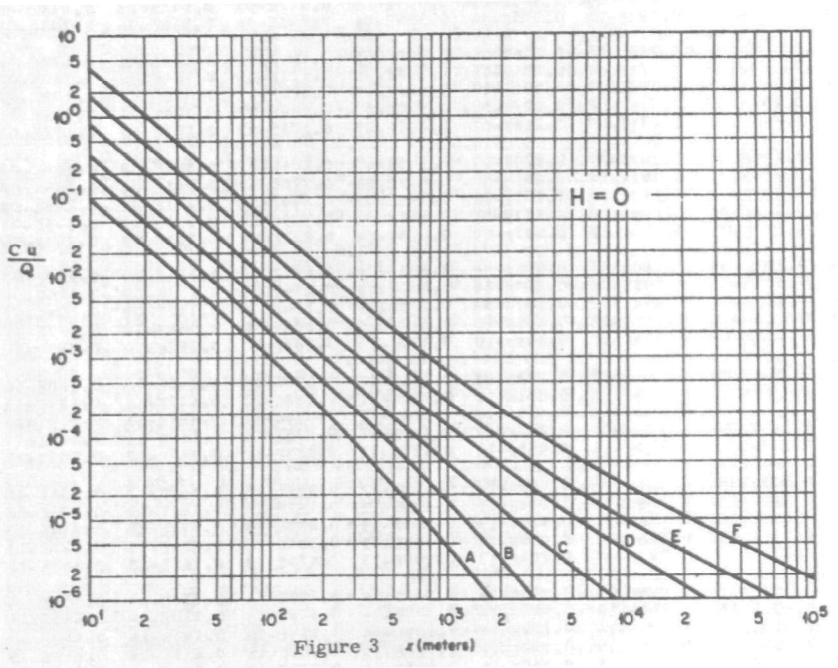

H = 0
A
B
C
D
E
F
$\frac{C\,u}{Q}$
10^{1}
5
2
10^{0}
5
2
10^{-1}
5
2
10^{-2}
5
2
10^{-3}
5
2
10^{-4}
5
2
10^{-5}
5
2
10^{-6}
10^{1} 2 5 10^{2} 2 5 10^{3} 2 5 10^{4} 2 5 10^{5}
x (meters)

Figure 3

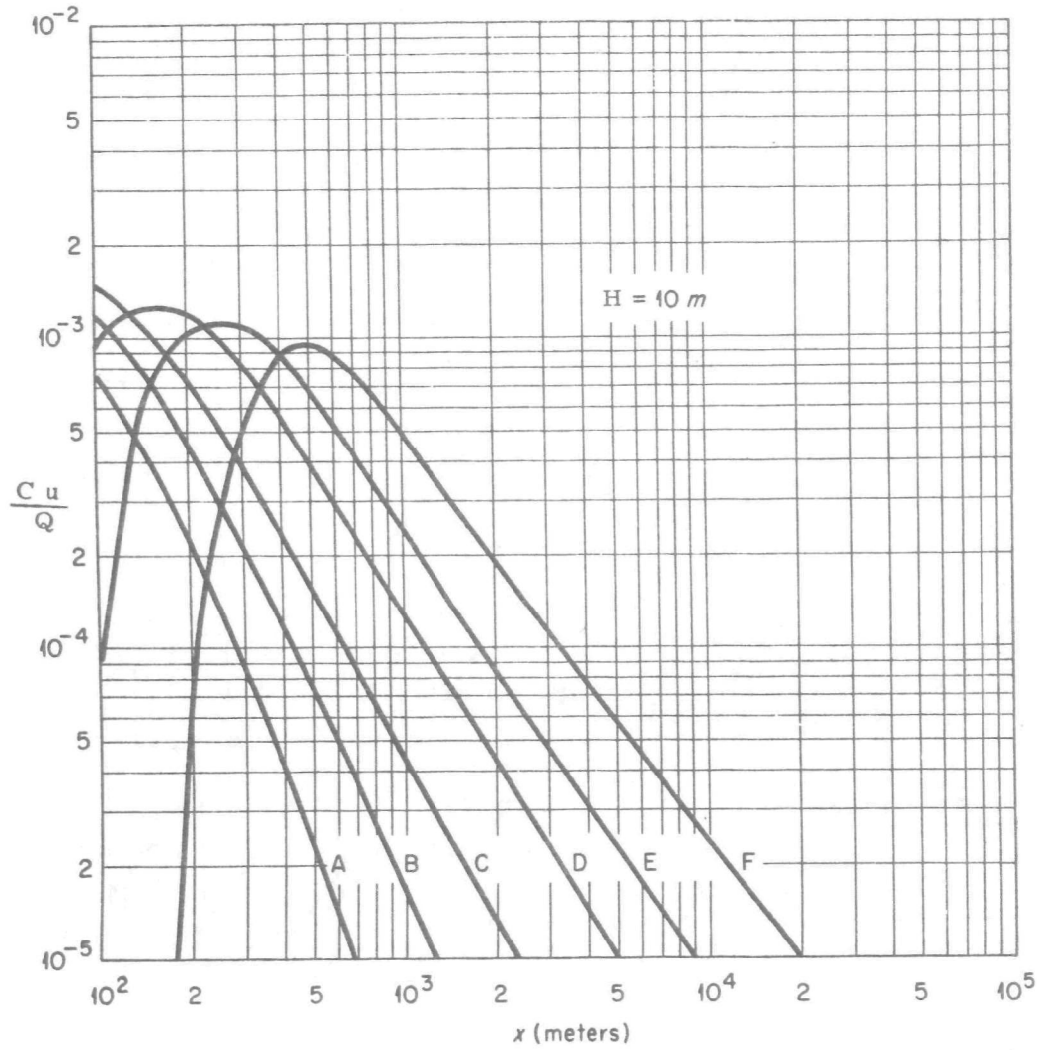

10^{-2}
5
2
10^{-3}
5
2
10^{-4}
5
2
10^{-5}
$\frac{C\,u}{Q}$
H = 10 m
A
B
C
D
E
F
10^2
2
5
10^3
2
5
10^4
2
5
10^5
x (meters)

Figure 4

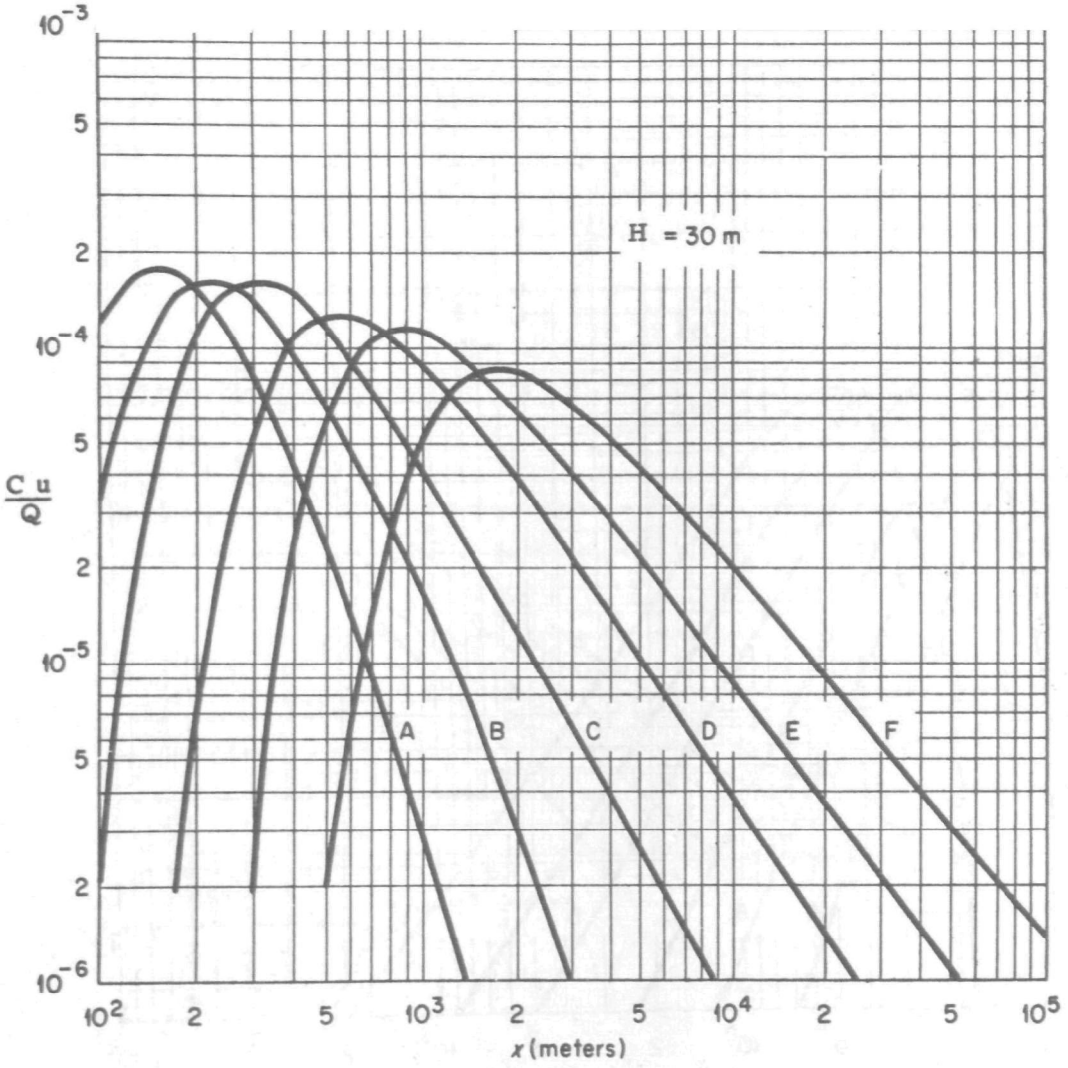

H = 30 m
A
B
C
D
E
F
$\frac{C}{Q}u$
10^{-3}
5
2
10^{-4}
5
2
10^{-5}
5
2
10^{-6}
10^2
2
5
10^3
2
5
10^4
2
5
10^5
x (meters)

Figure 5

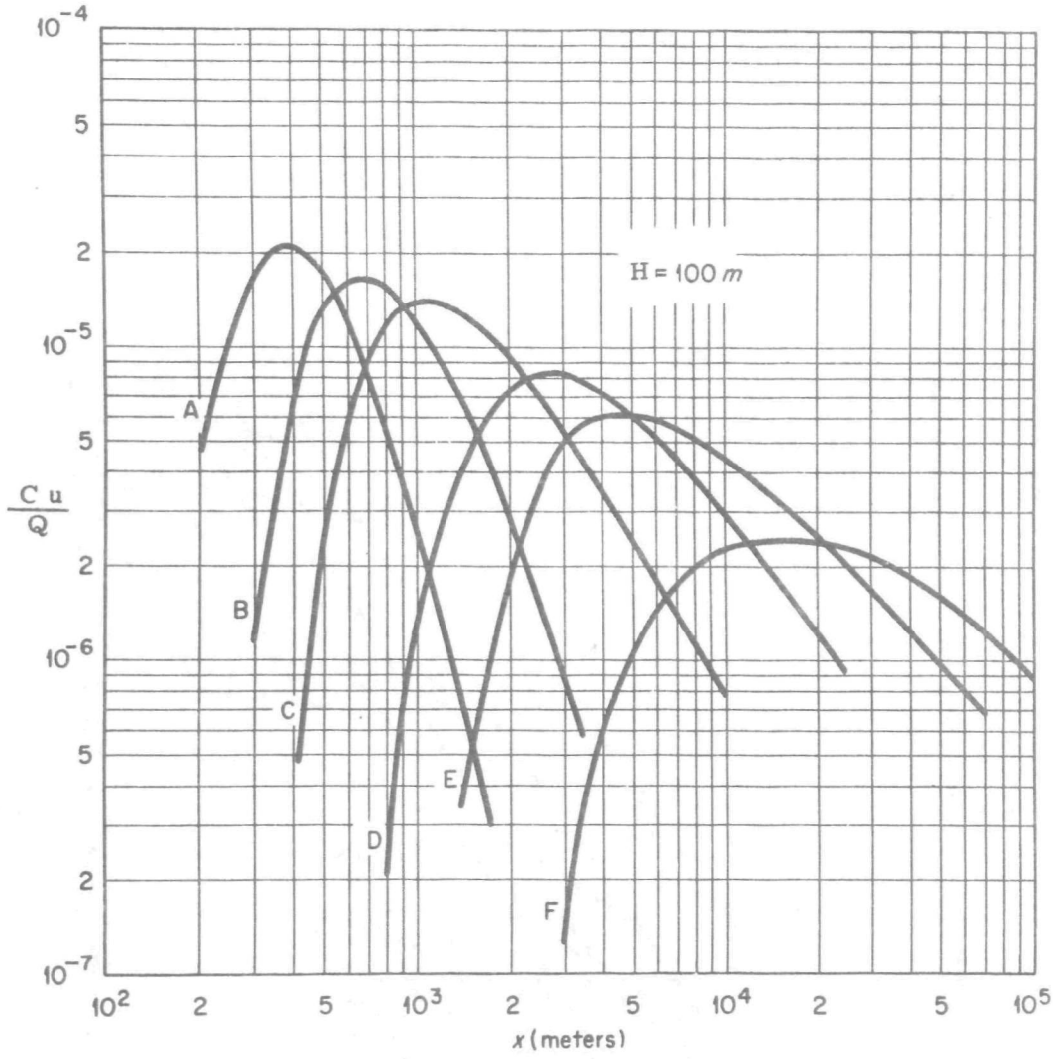

10^{-4}
5
2
10^{-5}
5
2
10^{-6}
5
2
10^{-7}
$\frac{C\,u}{Q}$
H = 100 m
A
B
C
D
E
F
10^2
2
5
10^3
2
5
10^4
2
5
10^5
x (meters)

Figure 6

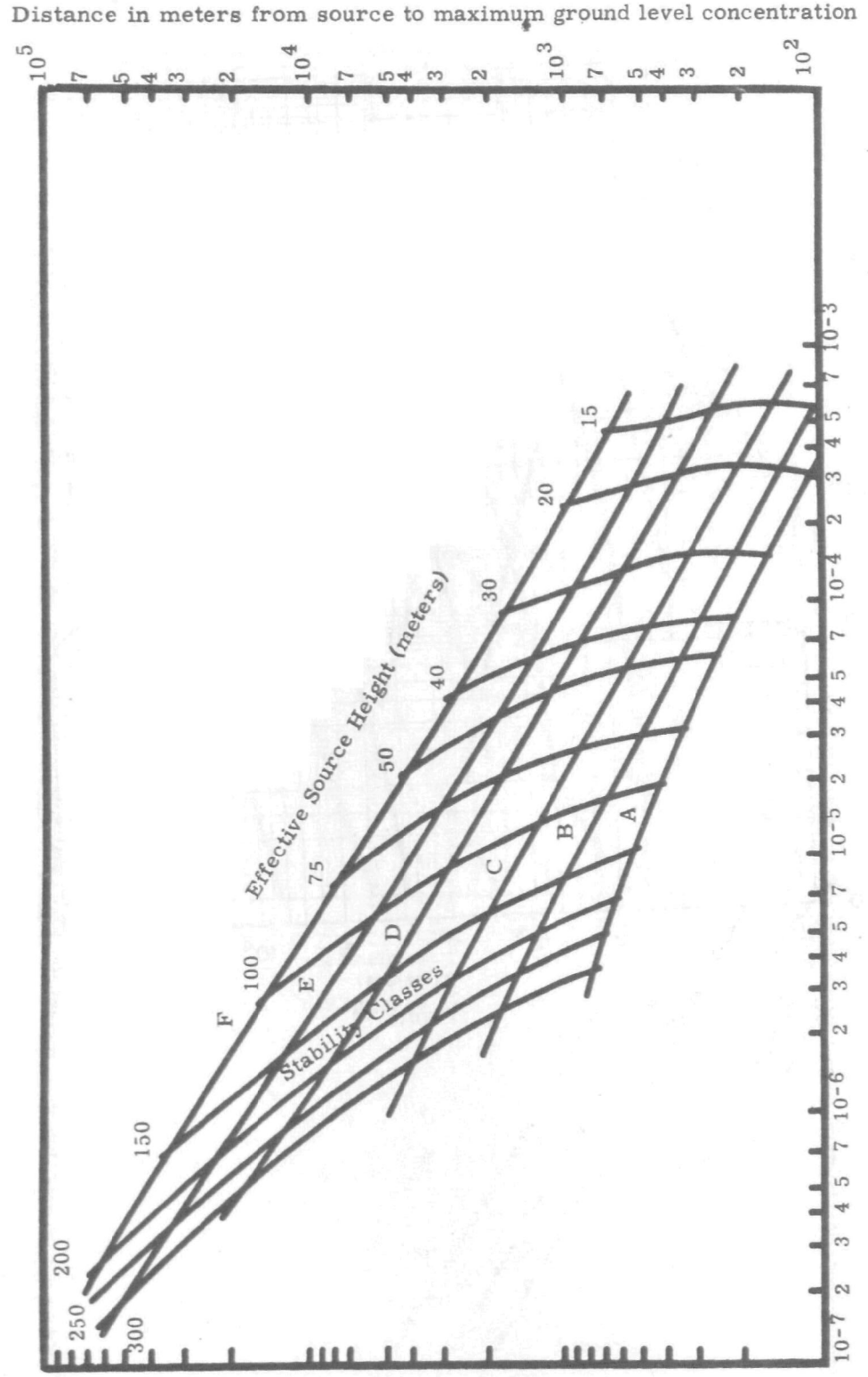


Figure 7. DISTANCE FROM SOURCE AND RELATIVE VALUE OF MAXIMUM CONCENTRATIONS FOR VARIOUS SOURCE HEIGHTS AND STABILITY CLASSES

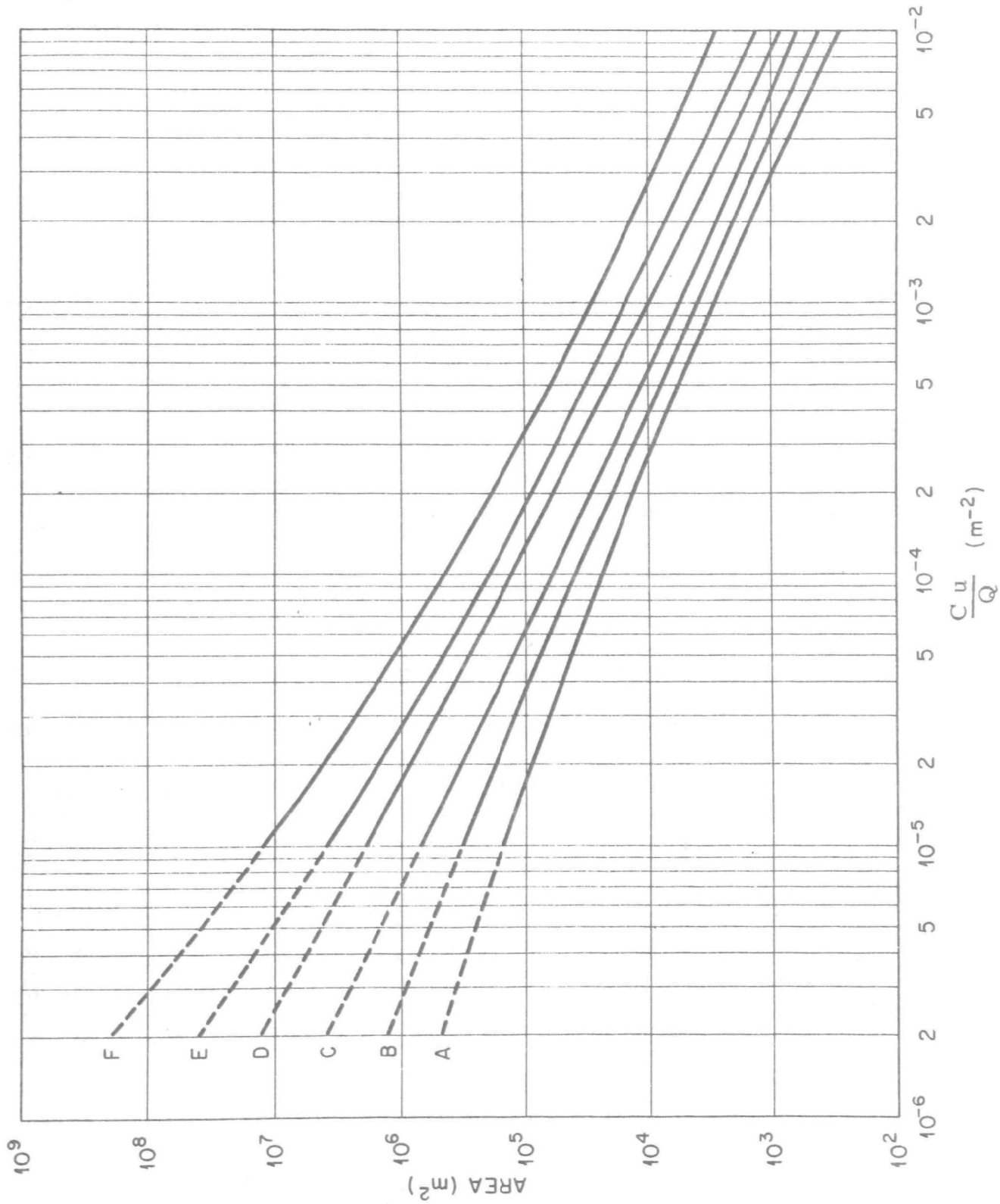

F
E
D
C
B
A
AREA (m^2)
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
5
2
$\frac{C u}{Q}$ (m^{-2})

Figure 8

EXAMPLE DIFFUSION COMPUTATIONS

I A power plant burns 10 tons per hour of 3% sulfur coal releasing the effluent from a single stack. On a sunny summer afternoon the wind speed at 10 meters is 4 m/sec from the northeast. The morning radiosonde run in the vicinity has indicated that a frontal inversion aloft will limit the convection to 1500 meters. The 1200 meter wind is from 30° at 5 m/sec. The effective height of emission is 150 meters. What is the maximum concentration and where does it occur?

Solution: On a sunny summer afternoon the isolation should be strong. From Table 1, strong isolation and 4 m/sec winds yield B class stability. The amount of sulfur burned is:

$$\text{Sulfur} \quad \frac{10 \text{ tons}}{\text{hour}} \times \frac{2000 \text{ lbs.}}{\text{ton}} \times$$

$$0.03 \text{ sulfur} = 600 \text{ lbs/hr.}$$

Sulfur has a molecular weight of 32 and combines with O_2 with a molecular weight of 32; therefore, for every pound of sulfur burned, there results two pounds of SO_2.

$$Q \quad \frac{2\ SO_2}{S} \times \frac{600 \text{ lbs. S}}{\text{hr.}} \times \frac{453.6 \text{ gms/lb.}}{3600 \text{ sec/hr}}$$

$$151 \text{ gms. } SO_2/\text{sec.}$$

The maximum concentration may be found by using Figure 7. Given stability class B and effective source height of 150 m., enter the nomogram and read the C_U/Q value of 8×10^{-6} from the abscissa. Solve for the maximum concentration, $C_{(max)}$, using the wind speed, u, of 4 m/sec and the source strength, Q, of 151 gms. SO_2/sec.

$$C_{(max)} \quad 8 \times 10^{-6} \times \frac{151 \text{ gms/sec}}{4 \text{ m/sec}} = 3 \times 10^{-4} \text{ gm/m}^3$$

The distance from the power plant at which the maximum concentration occurs under these meteorological condition can be read from the ordinate in Figure 7. The distance is 1000m.

II Using the conditions in the above problem, draw a graph of centerline sulfur dioxide concentrations beneath the plume with distance from 100 meters to 100 km.

Solution: Since the frontal inversion limits the convection to $h_1 = 1500$ meters, the distance where $\sigma_z = 0.47\ h_1 = 700$ meters is $x_1 = 5.5$ km. At distances equal to or greater than $2\ x_1 = 11.0$ km, $\sigma_z = 0.8\ h_1 = 1200$ meters. Equation 3 is used to find concentration as a function of distance:

$$C = \frac{151}{\pi\ u\ \sigma_y\ \sigma_z} \exp -\frac{1}{2} \left(\frac{H}{\sigma_z} \right)^2$$

In this case H = 150 meters. Solutions for this equation are given in Table 4. The values of concentration in Table 4 are plotted against distance in Figure 9.

III Draw a graph of concentration versus cross-wind distance at a downwind distance of 800 meters for the conditions of problem 1 and 2.

Solution: From problem 2, the centerline concentration at 800 meters is 2.9×10^{-4} gms / m^3. To determine the concentrations at distances y from the x axis the centerline concentration must be multiplied by the factor $\exp -\frac{1}{2}(y/\sigma_y)^2$. σ_y 120 meters at x = 800 meters. Values for this computation are given in Table 5.

3-34

TABLE 4

Col. a	Col. b	Col. c	Col. d	Col. e	Col. f	Col. g
x (km)	u (m/sec)	σ_y m	σ_z m	H/σ_z	$\exp -\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2$	C gms/m^3
0.3	4	52	30	5.0	3×10^{-6}	2.3×10^{-8}
0.5	4	77	53	2.83	1.7×10^{-2}	5.0×10^{-5}
0.8	4	120	93	1.61	0.27	2.9×10^{-4}
1	4	150	125	1.20	0.48	3.1×10^{-4}
2.8	4.5	375	330	0.45	0.90	7.8×10^{-5}
5.5	4.5	720	700	0.214	0.98	2.1×10^{-5}
11	4.5	1300	1200	0.125	0.99	7.3×10^{-6}
100	4.5	8400	1200	0.125	0.99	1.04×10^{-6}

Col. c from Figure 2.

Col. d from Figure 1.

Col.e 150 m over value in Col. d.

Col f Value in Table 3 corresponding to H/σ_z in Col. e.

Col g Solutions to equation 3.

TABLE 5

y (m)	y/σ_y	$\exp -\frac{1}{2}(y/\sigma_y)^2$	C(y) gms/m^3
$\pm$ 100	0.834	0.7	2.03×10^{-4}
$\pm$ 200	1.67	0.25	7.25×10^{-5}
$\pm$ 300	2.5	4.2×10^{-2}	1.22×10^{-5}
$\pm$ 400	3.33	3.7×10^{-3}	1.07×10^{-6}

This is graphed in Figure 10

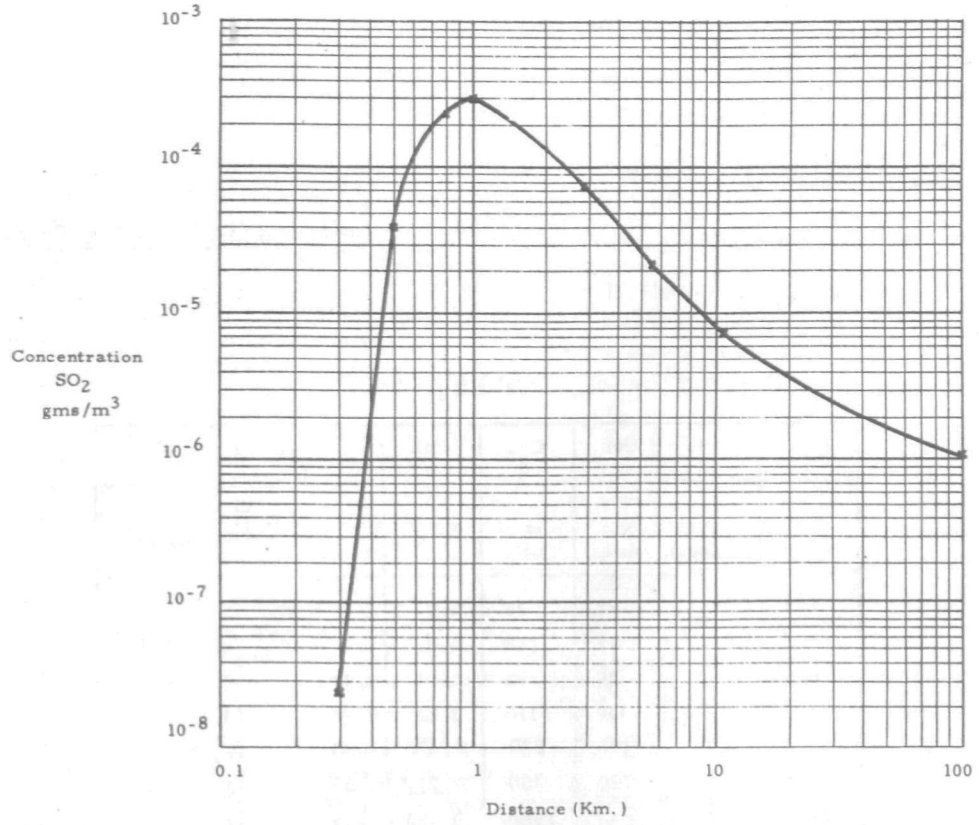


Figure 9 - Concentration of SO_2(gms/m^3) as a Function of Distance (km). (Problem 2)

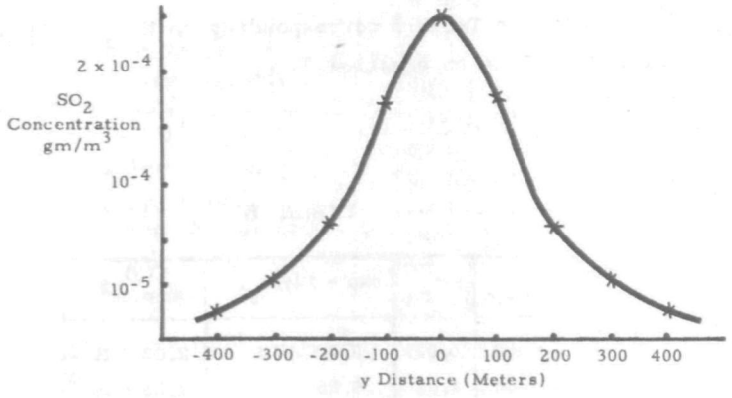


Figure 10 - Concentration of SO_2 (gms. m^3) Across Wind at a Distance of 800 Meters. (Problem 3)

REFERENCES

1. Cramer, H. E., Record, F. A. and Vaughan, H. C. The Study of the Diffusion of Gases or Aerosols in the Lower Atmosphere. Final Report, Contract No. AF 19 (604) - 1058. Mass. Inst. of Tech. Department of Meteorol. 1958.

2. Gifford, F. A., Jr. Uses of Routine Meteorological Observations for Estimating Atmospheric Dispersion. Nuclear Safety. 2:4. 1961.

3. Hilsmeier, W. F., and Gifford, F. A., Jr. Graphs for Estimating Atmospheric Diffusion, ORO-545 Atomic Energy Commission. Oak Ridge, Tennessee. 1962. 10 pp.

4. List, R. J. Smithsonian Meteorological Tables. Sixth Revised Edition. 497-505. Smithsonian Institution, Washington, D. C. 1951.

5. Martin, D. O. An Evaluation of the Meteorological Potential for Air Pollution at Muskegon, Michigan. Unpub. Report to Muskegon County Health Dept. from Tech. Assist. Branch, DAP, SEC, 1966.

6. Mead, P. J. Meteorological Aspects of the Peaceful Uses of Atomic Energy, Part 1. Tech. Note No. 33. World Meteorological Organization. Geneva, 33 pp. 1960.

7. Pasquill, F. Atmospheric Diffusion. (2nd Edition) John Wiley & Sons, Inc. London, 1974

8. Pasquill, F. The Estimation of the Dispersion of Windborne Material. The Meteorological Magazine. 90: 1063. 33-49. 1961.

9. Turner, D. B. - Workbook of Atmospheric Dispersion Estimates. U.S. Public Health Service Pub. No. 999-AP-26, 1967.

10. Meteorology and Atomic Energy 1968. D. H. Slade, Ed. U. S. Atomic Energy Commission, Tech. Information Div., TID-24190, July 1968.

11. Recommended Guide for the Prediction of the Dispersion of Airborne Effluents. M. E. Smith, Ed. The Am. Soc. Mech. Engrs. United Engineering Center. 345 E. 47th Street, New York, N.Y. 10017, May 1968.

12. Slade, D. H. Estimates of Dispersion from Pollutant Releases of a Few Seconds to 8 Hours in Duration. ESSA Air Resources Laboratory Tech. Note 39-ARL-3. April 1966.

13. Pasquill, F. Atmospheric Dispersion of Pollution, QJRMS, 97; 414, 369-395, October 1971.

Answers to Exercise (Page 3-22)

1.	D	8.	2
2.	D	9.	8.5
3.	B-C	10.	0.198
4.	D-E	11.	3.5
5.	28,15	12.	1.4×10^{-6} sec/m^3
6.	55m	13.	$10^4 m^2$
7.	1450		

EFFECTIVE STACK HEIGHT

J.L. Dicke

In any consideration of concentrations downwind from a source, it is desirable to estimate the effective stack height, the height at which the plume becomes level. Rarely will this height correspond to the physical height of the stack.

A high velocity of emission of the effluents and a temperature higher than that of the atmosphere at the top of the stack will act to increase the effective stack height above the height of the actual stack. The effect of aerodynamic downwash, eddies caused by the flow around buildings or the stack, and also the evaporative cooling of moisture droplets in the effluent may cause lowering of the plume to the extent that it may be lower than the physical stack height.

EFFECT OF EXIT VELOCITY AND STACK GAS TEMPERATURE

A number of investigators have proposed formulas for the estimation of effective stack height under given conditions: Davidson (1949), Sutton (1950), Bosanquet et al. (1950), Holland (1953), Priestley (1956).

A recent comparison of actual plume heights and calculations using six of the available formulas was made by Moses and Strom (1961). The formulas used were Davidson-Bryant, Holland, Scorer, Sutton, Bosanquet-Carey-Halton, and Bosanquet (1957). They found that "There is no one formula which is outstanding in all respects." The formulas Davidson-Bryant, Holland, Bosanquet-Carey-Halton, and Bosanquet (1957) appear to give satisfactory results for many purposes. It must be pointed out that the experimental tests made by Moses and Strom used stack gas exit velocities less than 15 m/sec and that temperatures of the effluent were not more than 35°C higher than that of the ambient air. Moses and Strom expect to make field tests using higher temperatures and higher stack velocities.

Supervisory Meteorologist, NOAA
Meteorology & Assessment Division, EPA

Stewart, Gale, and Crooks (1958) compared effective stack heights for the Harwell reactor emitting radioactive Argon with computations using the formula of Bosanquet et al. (1950). The temperature of the gases was 50°C above that of the ambient air and stack gas velocity was 10 m/sec. At low wind speeds, agreement between formula and plume height were quite good. At wind speeds greater than 6 m/sec and distances greater than 600 meters from the stack the formula underestimates effective stack height.

Two of the formulas for estimation of effective stack height are given below. Both the Davidson-Bryant formula and Holland's formula frequently underestimate the effective stack height. Therefore, a slight safety factor is frequently made by using these formulas.

The Davidson-Bryant formula is:

$$\Delta H = d\left(\frac{v_s}{u}\right)^{1.4}\left(1 + \frac{\Delta T}{T_s}\right) \qquad (1)$$

Where:

- ΔH = the rise of the plume above the stack
- d = the inside stack diameter
- v_s = stack gas velocity
- u = wind speed
- ΔT = the stack gas temperature minus the ambient air temperature (°K)
- T_s = the stack gas temperature (°K)

PA.ME.sd.31e.9.71

Any consistent system of units for ΔH, d, v_s, and u may be used. It is recommended that v_s and u be in meters/sec and d in meters which will give ΔH in meters.

The Holland stack rise equation is:

$$\Delta H = \frac{v_s d}{u}\left(1.5 + 2.68 \times 10^{-3} \, p \, \frac{\Delta T}{T_s} \, d\right) \quad (2)$$

Where:

ΔH = the rise of the plume above the stack (meters)

v_s = stack gas velocity (m/sec)

d = the inside stack diameter (meters)

u = wind speed (m/sec)

p = atmospheric pressure (mb)

T_s = stack gas temperature (^oK)

ΔT = as in equation (1) and

2.68×10^{-3} is a constant having units of $(m^{-1} \, mb^{-1})$.

It is recommended that the result from the above equation be used for neutral conditions. For unstable conditions a value between 1.1 and 1.2 times that from the equation should be used for ΔH. For stable conditions a value between 0.8 and 0.9 times that from the equation should be used for ΔH.

Since the plume rise from a stack occurs through some finite distance downwind, these formulas should not be applied when considering effects near the stack. Note that these formulas do not consider the stability of the atmospheric but only the ambient air temperature. Actually, stability should have some effect upon the plume rise.

Lucas et al., 1963, have tested Priestley's theory on stack rise at two power stations. These investigators write the formula for stack rise as:

$$z_{max} = \alpha \frac{Q^{\frac{1}{4}}}{u} \quad (3)$$

Where:

z_{max} = effective rise above the top of the stack (feet)

α = a variable affected by lapse rate and topography ($ft^2 \, MW^{-1/4} \, sec^{-1}$)

Q = the rate of heat emission from the stack in megawatts (MW)

u = the wind speed (ft/sec)

They determined α to be 4900 and 6200 for the 2 power stations under neutral conditions. Clarke (1968) states that if the exit velocity at the stack gases exceeds 2000 fpm (23mph), no rain will enter the stack. As an example, he found from a ten year summary of U.S. Weather Bureau wind data for Chicago that 98% of the days had a maximum wind velocity $\leq$ 20 mph.

EFFECT OF EVAPORATIVE COOLING

In the washing of effluent gases to absorb certain gases before release to the atmosphere, the gases are cooled and become saturated with water vapor. Upon release from the absorption tower further cooling is likely due to contact with cold surfaces of ductwork or stack. This causes condensation of water droplets in the gas stream. Upon release from the stack, the water droplets evaporate withdrawing the latent heat of vaporization from the air and consequently cooling the plume, causing it to have negative buoyancy, thereby reducing the stack height. (Scorer 1959).

The practice of washing power plant flue gases to remove sulfur dioxide is practiced at Battersea and Bankside power stations in London, where frequent lowering of the plumes to ground level is observed.

EFFECT OF AERODYNAMIC DOWNWASH

The influence of the mechanical turbulence around a building or stack may significantly alter the effective stack height. This is especially true under high wind conditions when the beneficial effect of high stack gas velocity is at a minimum and the plume is emitted nearly horizontally. The region

of disturbed flow surrounds a building generally to twice its height and 5 to 10 times its height downwind. Most of the knowledge about the turbulent wakes around stacks and buildings have been gained through wind tunnel studies. Sherlock and Stalker (1940), (1941), Rouse (1951), Sherlock (1951), Sherlock and Lesher (1954), (1955), Strom (1955-1956), Strom et al. (1957), and Halitsky (1961), (1962),(1963) . By using models of building shapes and stacks the wind speeds required to cause downwash for various wind directions may be determined.

In the use of a wind tunnel the meteorological variables that may most easily be taken into account are the wind speed and the wind direction (by rotation of the model within the tunnel). The plant factors that may be taken into consideration are the size and shape of the plant building, the shape, height, and diameter of the stack, the amount of emission, the stack gas velocity, and perhaps the density of the emitted effluent. The study of the released plume from the model stack has been done by photography (Sherlock and Lesher, 1954), decrease in light beam intensity (Strom, 1955), and measurement of concentrations of a tracer gas (Strom et al., 1957, Halitsky, 1963).

By determining the critical wind speeds that will cause downwash from various directions for a given set of plant factors, the average number of hours of downwash annually can then be calculated by determining the frequency of wind speeds greater than the critical speeds for each direction (Sherlock and Lesher, 1954). It is assumed that climatological data, representative of the site considered, are available.

It is of interest to note that the maximum downwash about a rectangular structure occurs when the direction of the wind is at an angle of 45 degrees from the major axis of the structure and that minimum downwash occurs with wind flow parallel to the major axis of the structure (Sherlock and Lesher, 1954).

It has been shown by Halitsky (1961), (1963) that the effluent from flush openings on flat roofs frequently flows in a direction opposite to that of the free atmosphere wind due to counter-flow along the roof in the turbulent wake above the building. In addition to the effect of aerodynamic downwash upon the release of air pollutants from stacks and buildings, it is also necessary to consider aerodynamic downwash when exposing meteorological instruments near or upon buildings so that representative measurements are assured.

In cases where the pollution is emitted from a vent or opening on a building and is immediately influenced by the turbulent wake of the building, the pollution is quite rapidly distributed within this turbulent wake. An initial distribution may be assumed at the source with horizontal and vertical variances of δy^2 and δ^2 in the form of a binormal distribution of concentrations. These variances are related to the building width and height.

The resulting equation for concentrations from this source has $(\sigma_y^2 + \delta_y^2)^{1/2}$ in place of σ_y and $(\sigma_z^2 + \delta_z^2)^{1/2}$ in place of σ_z in the point source equations.

EFFECT OF VERY LARGE POWER PLANTS

A power generating plant in the range of 1000-5000 megawatt capacity emits heat to such an extent that its own circulation pattern will be set up in the air surrounding the plant. It is doubtful that extrapolation of dispersion estimates from existing smaller sources can be applied to these large plants. Fortunately, the effluent plume will rise far above the ground and surface concentrations of pollutants downwind will increase by only a rather small amount most of the time. Such large plants will usually be engineered to minimize the effects of the two preceding topics. The "2 1/2" rule will tend to eliminate downwash and the "4/3's" rule for stack gas velocity will tend to eliminate entrainment of the effluent into the wake of the stack. (Pooler, 1965)

Three weather conditions, however, can still bring ground level fumigations: high winds, inversion breakup, and a limited mixing layer with light winds. The climatology of these conditions will determine the magnitude and frequency of the pollution problem. Pooler (1965) has presented nomograms for estimating ground-level SO_2 concentrations for these three

situations together with effective stack height formulas. Briggs (1965) has also presented a plume rise model which has been compared with data from various TVA power plants. Pooler (1967) introduced a slight modification to one of Briggs's equations and suggests this latter equation be substituted for the Pooler (1965) inversion breakup fumigation equation. Thus the basic equation for this important weather condition is:

$$\Delta H = \left[2.31 \frac{v_s r^2 T_A}{u} \left(\frac{\Delta T}{T_s} \right) \Big/ \frac{d\theta}{dz} \right]^{1/3} \quad (4)$$

Where: u = wind speed (m/sec)

r = inside stack radium (m)

T_A = ambient air temperature (°K)

$\frac{d\theta}{dz}$ = potential temperature lapse rate

Other symbols are defined as in equation (2) above.

A correction term for the additive effect of multiple-stack sources is also presented in Pooler (1967). Briggs (1975) has also proposed a calculation technique, however his experience indicates the additive effect is usually 5-15% and rarely exceeds 30%.

Other industries are also utilizing tall stacks for pollutant dispersion and anticipate results similar to the low measured ground level concentrations found near tall British power plant stacks. A case in point is the 1250 foot stack constructed in 1971 at a cost of $5.5 million to serve the Inco Copper Cliff smelter in the Sudbury district of Ontario, Canada. This gigantic stack is 116 feet in diameter at the base, tapering to just under 52 feet in diameter at the top. The interior diameter is 45 feet. A recent article in Environmental Science & Technology (1975) discusses interesting construction aspects of tall stacks.

STATE OF THE ART

Considerable research is being conducted to further quantify the dilution effects of tall stacks and to develop better models for predicting the dispersion of power plant effluent in complex terrain and meteorological regimes. An extensive series of field experiments is being conducted, called the Large Power Plant Effluent Study (LAPPES), near Indiana, Pennsylvania and reports have been published by Schiermeier and Niemeyer (1968) (1967 and 1969) (1970). Field measurements include determining plume geometry by laser-radar, in-plume and ground level SO_2 concentrations, vegetation damage and meteorological conditions during the experiments.

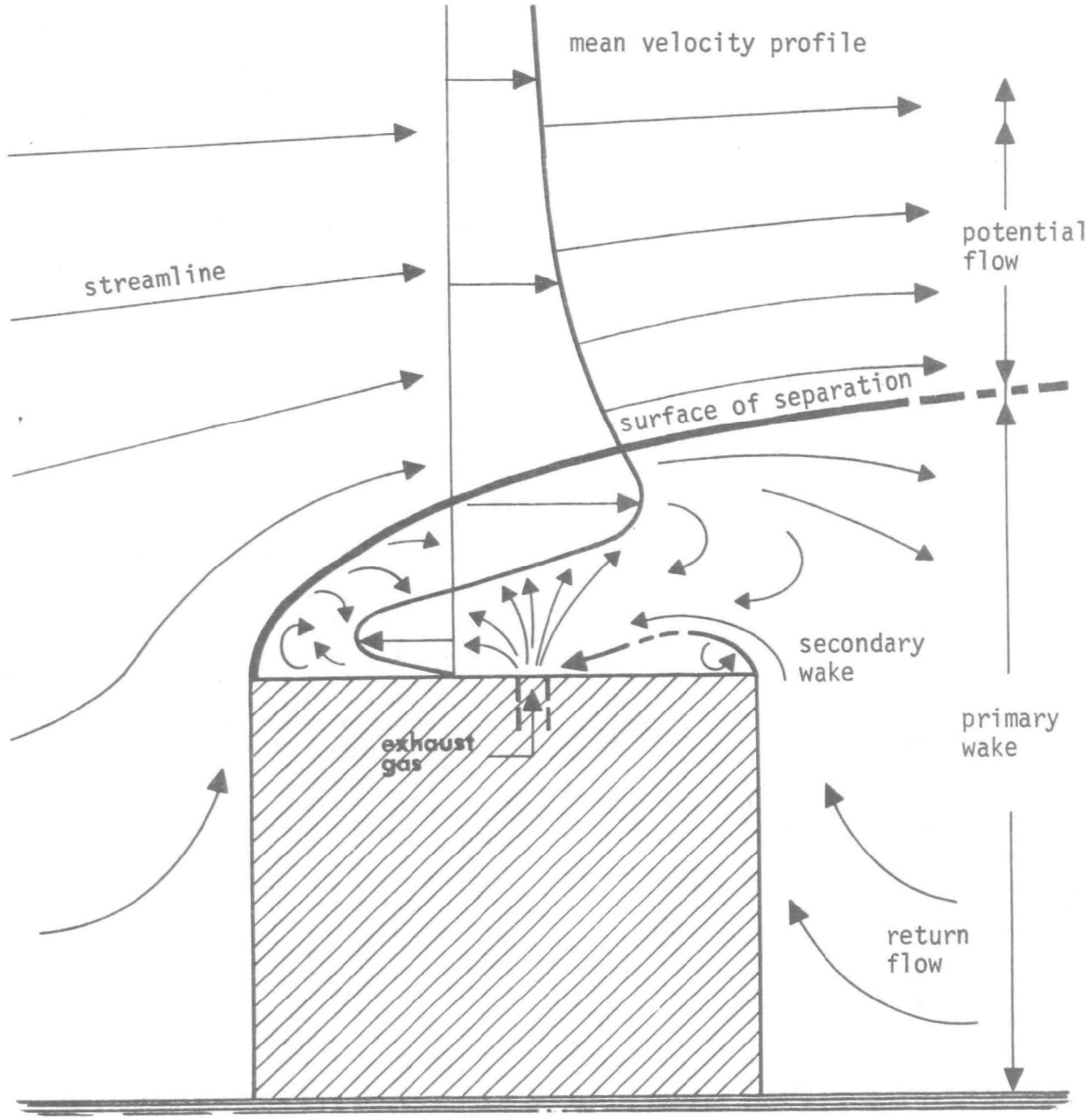
A summary of recent European studies dealing with plume rise and stack effluent dispersion is contained in the July 1967 issue of the journal Atmospheric Environment.

In addition another recent publication which contains a specific chapter on calculating effective stack height is the ASME Recommended Guide for the Prediction of the Dispersion of Airborne Effluents (1968), and revised (1973).

A comprehensive literature survey in this field was conducted by NAPCA and incorporated into an annotated bibliography of over 200 references. The publication, "Tall Stacks, Various Atmospheric Phenomena and Related Aspects" (1969), includes articles published through mid-1968.

A recent series of EPA publications deal with air pollution aspects of emission sources. Of particular interest is OAP Pub. No. AP-96, "Electric Power Production - A Bibliography with Abstracts". Section D on air quality measurements and Section E on atmospheric interactions contain many specific references to plume rise determination, plume behavior, and pollutant concentrations associated with this class of sources.

Briggs in his recent publication, Plume Rise (1969), has presented both a critical review of the subject and a series of equations applicable to a wide range of atmospheric and emission conditions. These equations are being employed by an increasing number of meteorologists and are used almost exclusively within EPA. An important result of this study is that the rise of buoyant plumes from fossil-fuel plants with a heat emission of 20 megawatts (MW) - 4.7×10^6 cal/sec - or



Typical flow pattern around a cube with one face normal to the wind.

Figure 1.

more can be calculated from the following equations under neutral and unstable conditions.

$$\Delta H = 1.6\ F^{1/3}\ u^{-1}\ x^{2/3} \qquad (5)$$

$$\Delta H = 1.6\ F^{1/3}\ u^{-1}\ (10\ h_s)^{2/3} \qquad (6)$$

where:

- ΔH = plume rise
- F = buoyancy flux
- u = average wind at stack level
- x = horizonal distance downwind of the stack
- h_s = physical stack height

Equation (5) should be applied out to a distance of 10 h_s from the stack; equation (6) at further distances.

The buoyancy flux term, F, may be calculated from:

$$F = \frac{g\ Q_H}{\pi\ c_p\ \rho T} \simeq 3.7 \times 10^{-5}\ \frac{m^4/sec^3}{cal/sec}\ Q_H \qquad (7)$$

where:

- g = gravitational acceleration
- Q_H = heat emission from the stack, cal/sec
- c_p = specific heat of air at constant pressure
- ρ = average density of ambient air
- T = average temperature of ambient air

Alternatively, if the stack gases have nearly the same specific heat and molecular weight as air, the buoyancy flux may be determined from:

$$F = \frac{\Delta T}{T_s}\ g\ v_s\ r^2 \qquad (8)$$

where the notation has been previously defined.

In stable stratification with wind equation (5) holds approximately to a distance $x = 2.4\ u\ s^{-1/2}$ where:

$$s = \frac{g}{T}\ \frac{\partial \theta}{\partial z}\ , \text{ a stability parameter} \qquad (9)$$

$\frac{\partial \theta}{\partial z}$ = lapse rate of potential temperature

Beyond this point the plume levels off at about

$$\Delta H = 2.4 \left(\frac{F}{u\ s}\right)^{1/3} \qquad (10)$$

However, if the wind is so light that the plume rises vertically, the final rise can be calculated from:

$$H = 5.0\ F^{1/4}\ s^{-3/8} \qquad (11)$$

For other buoyant sources, emitting less than 20 MW of heat, a conservative estimate will be given by equation (5) up to a distance of:

$$x = 3x^* \qquad (12)$$

where:

$$x^* = 0.52 \left[\frac{sec^{6/5}}{ft.^{6/5}}\right]\ F^{2/5}\ h_s^{3/5} \qquad (13)$$

is the distance at which atmospheric turbulence begins to dominate entrainment.

Anyone who is responsible for making plume rise estimates should familiarize himself thoroughly with Briggs' work. The Air Pollution Training Institute has prepared a packaged, correspondence course, SI-406 Effective Stack Height/Plume Rise, requiring 8-10 hours to complete which may be purchased for $30. from the National Audiovisual Center, Washington, D. C. 20409.

Singer and Frankenberger (1975) have studied the changes in ambient SO_2 concentrations at 4 monitoring sites before and after twin 250 m (800 ft) stacks were built for a power plant on the Muskingum River. Over an 18 month period with 90% valid data collection, the NAAQS have not been exceeded at the 4 sites despite using 5% S coal with no stack gas removal equipment. A one hour concentration of 0.1 ppm occur more than once a month only between the hours of 11 a.m. and 7 p.m., illustrating the effect of unstable lapse rates and "looping" plume conditions.

COOLING TOWERS

Over the past few years concern has been voiced over the possible environmental effects of cooling towers utilized by more power plants to mimimize cooling water requirements and to avoid significant thermal discharges to water supplies. Two major symposia have been held,

one in England in March 1973 as reported in the journal Atmospheric Environment, the other at the University of Maryland in March 1974 as published by the U. S. Nuclear Regulatory Commission in 1975. Fourteen papers were published at the British meeting and thirty at the College Park, MD, meeting. The general consensus of the latter symposium is that modeling efforts have been carried as far as possible in the light of field experiments and that detailed verification/validation data are sorely needed.

1. Bosanquet, C. H., Carey, W. F. and Halton, E. M. Dust Deposition from Chimney Stacks. Proc. Inst. Mech. Eng. 162:355-367. 1950.

2. Bosanquet, C. H. The Rise of a Hot Waste Gas Plume. J. Inst. Fuel. 30:197. 322-328. 1957.

3. Davidson, W. F. The Dispersion and Spreading of Gases and Dust from Chimneys. Trans. Conf. on Ind. Wastes. 14 Annual Meeting, Industrial Hygiene Found. Amer. 38-55. November 18, 1949.

4. Gifford, F. A., Jr. Atmospheric Dispersion Calculations Using the Generalized Gaussian Plume Model. Nuclear Safety. 2:56-59. December, 1960.

5. Halitsky, James. Diffusion of Vented Gas Around Buildings. J. of APCA. 12:2. 74-80. February, 1962.

6. Halitsky, James. Wind Tunnel Model Test of Exhaust Gas Recirculation at the NIH Clinical Center. New York Univ. Tech. Report No. 785.1. 1961.

7. Halitsky, James. Some Aspects of Atmospheric Diffusion in Urban Areas. Air Over Cities. Robert A. Taft Sanitary Engineering Center Technical Report A 62-5. 1962.

8. Halitsky, James, Gordon, Jack, Halpern, Paul, and Wu, Paul. Wind Tunnel Tests of Gas Diffusion From a Leak in the Shell of a Nuclear Power Reactor and From a Nearby Stack. New York Univ. Geophysical Sciences Laboratory Report No. 63-2. 1963.

9. Halitsky, James. Gas Diffusion Near Buildings, Theoretical Concepts and Wind Tunnel Model Experiments with Prismatic Building Shapes. New York Univ. Geophysical Sciences Laboratory Report No. 63-3. 1963.

10. Holland, J. Z. A Meteorological Survey of the Oak Ridge Area. AEC, Washington, Report ORO-99. 554-559, 1953.

11. Lucas, D. H., Moore, O. J., and Spurr, G. The Rise of Hot Plumes from Chimneys. Int. J. Air Wat. Poll. 7:473-500. 1963.

12. Moses, Harry, and Strom, Gordon H. A Comparison of Observed Plume Rises with Values Obtained from Well-Known Formulas. J. APCA. 11:10. 455-466. October, 1961.

13. Priestley, C. H. B. A Working Theory of the Bent Over Plume of Hot Gas. Quart. J. Roy. Met. Soc. 82:352. 165-176. 1956.

14. Rouse, Hunter. Air-Tunnel Studies of Diffusion in Urban Areas. On Atmospheric Pollution. Meteorol. Monogr. 1:4. 39-41. November, 1951.

15. Scorer, R. S. Natural Aerodynamics. Pergamon. London. 186-217. 1958.

16. Scorer, R. S. The Behavior of Chimney Plumes. Int. J. of Air Poll. 1:3. 198-220. January, 1959.

17. Sherlock, R. H., and Stalker, E. A. The Control of Gases in the Wake of Smokestacks. Mech. Eng. 62:455. 1940.

18. Sherlock, R. H., and Stalker, E. A. A Study of Flow Phenomena in the Wake of Smokestacks. Univ. of Mich. Eng. Res. Bulletin. 29: 1941. 49 pp.

19. Sherlock, R. H. Analyzing Winds for Frequency and Duration. On Atmospheric Pollution. Meteorol. Monogr. 1:4. 42. 1951.

20. Sherlock, R. H., and Lesher, E. J. Role of Chimney Design in Dispersion of Waste Gases. Air Repair. 4:2. 1-10. August 1954.

21. Sherlock, R. H., and Lesher, E. J. Design of Chimneys to Control Downwash of Gases. Trans. Amer. Soc. Mech. Engrs. 77:1. 1955.

22. Stewart, N. G., Gale, H. J., and Crooks, R. N. The Atmospheric Diffusion of Gases Discharged from the Chimney of the Harwell Reactor BEPO. Int. J. Air Poll. 1: 1/2. 87-102. 1958.

23. Strom, G. H. Wind Tunnel Scale Model Studies of Air Pollution from Industrial Plants. Ind. Wastes. September - October 1955, November-December 1955, January - February 1956.

24. Strom, G. H., Hackman, M., and Kaplin, E. J. Atmospheric Dispersal of Industrial Stack Gases Determined by Concentration Measurements in Scale Model Wind Tunnel Experiments. J. APCA. 7:3 November, 1957.

25. Sutton, O. G. The Dispersion of Hot Gases in the Atmosphere. J. Meteorol. 7:307-312. 1950.

26. Briggs, G. A. A Plume Rise Model Compared with Observations. J. APCA 15:9. 433-438. 1965.

27. Pooler, F., Jr. Potential Dispersion of Plumes from Large Power Plants, PHS Publication No. 99-AP-16. 1965.

28. Pooler, F., Jr. Derivation of Inversion Breakup Ground Level Concentration Frequencies from Large Elevated Sources. Air Resources Field Research Office, ESSA, NCAPC, Cincinnati, Ohio, 1967. (Unpublished Manuscript)

29. Symposium on Plume Behavior. Air and Water Pollut. Int. J. Vol. 10 Nos. 6/7, 393-409. 1966.

30. Moore, D. J. Physical Aspects of Plume Models. Air and Water Pollut. Int. J. Vol. 10 Nos. 6/7, 411-417. 1966.

31. Nonhebel, G. British Charts for Heights of Industrial Chimneys Air and Water Pollut. Int. J. Vol. 10 No. 3, 183-189.

32. Gartrell, F. E., Thomas, F. W., and Carpenter, S. B. Full-Scale Study of Dispersion of Stack Gases - A Summary Report. Chattanooga, Tennessee, 1964. (Reprinted by the U.S. Dept. HEW, Public Health Service.)

33. Carson, J. E. and Moses, Harry. Calculation of Effective Stack Height. Presented at 47th Annual Meeting, Amer. Meteor. Soc. New York, January 23, 1967.

34. Culkowski, W. M. Estimating the Effect of Buildings on Plumes from Short Stacks. Nuclear Safety. 8: 257-259. Spring 1967.

35. Symposium on Chimney Plume Rise and Dispersion. Atmos. Environ. 1:351-440. July 1967.

36. Recommended Guide for the Prediction of the Dispersion of Airborne Effluents. Ch. 3, M.E. Smith, Ed. ASME, 345 E. 47th St. New York, N.Y. 10017, May 1968, and revised 1973.

37. Clarke, John H. Effective Stack Design in Air Pollution Control, Heating, Piping and Air Condition. 125-133, March 1968.

38. Tall Stacks, Various Atmospheric Phenomena and Related Aspects. National Air Pollution Control Administration, Pub. No. APTD 69-12, May 1969.

39. Briggs, G. A. Plume Rise AEC Critical Review Series. 1969. Avail. as TID-25075 from CFSTI, NBS, U.S. Department Commerce, Springfield, Virginia 22151. $6.00

40. Fay, J. A., Escudier, M., Hoult, D. P. A Correlation of Field Observations of Plume Rise, JAPCA Vol. 20, No. 5, pp. 391-397, June 1970.

41. TVA. Report on Full-Scale Study of Inversion Breakup at Large Power Plants. Div. of Env. R&D Muscle Shoales, Alabama. March 1970.

42. Schiermeier, F. A., Niemeyer, L. E. Large Power Plant Effluent Study (LAPPES) Vol. 1 (1968). NAPCA Pub. No. APTD 70-2, June 1970; Vol.2 (1967 and 1969) APTD 0589, November 1970; Vol. 3 (1970) APTD- 0735, January 1972.

43. Air Pollution Aspects of Emission Sources: Electric Power Production A Bibliography with Abstracts. EPA, Office of Air Programs, Pub. No. AP-96, May 1971.

44. Moses, Harry and Kraimer, M. R. Plume Rise Determination - A New Technique Without Equations. JAPCA Vol.22, No. 8, pp. 621-630, August 1972.

45. Bowman, W. A. and Biggs, W. G. Meteorological Aspects of Large Cooling Towers. Paper 72-128 pres. APCA, June 1972.

46. Briggs, G. A. Some Recent Analyses of Plume Rise Observations. pp. 1029-1032 in Proceedings of the Second International Clean Air Congress. Ed. by H. M. Englund and W. T. Berry. Academic Press, New York. 1971

47. Briggs, G. A. Discussion on Chimney Plumes in Neutral and Stable Surroundings. Atmos. Environ. 6:507-510, July 1972.

48. Weil, J. G. The Rise of Moist Buoyant Plumes. J. App. Meteor. Vol. 13 No.4: 435-443. June 1974

49. Briggs, G. A. Plume Rise from Multiple Sources. Proceedings "Cooling Towers Environment 1974." U. S. Nuclear Regulations Commission CONF 740302. NTIS, Springfield, VA. 1975.

50. Miller, S. Special Report: The Building of Tall (and not so tall) Stacks. Env. Science & Tech. Vol. 10, No. 6: 522-527, June 1975.

51. Smith, M. E. and Frankenberg, T. T. Improvement of Ambient Sulfur Dioxide Concentrations by Conversion from Low to Tall Stacks. JAPCA. Vol. 25, No. 6: 595-601, June 1975.

52. Environmental Effects of Cooling Towers Proceedings of a Symposium held at Central Electricity Research Laboratories Leatherhead Survey 27-28 March 1973. Atmospheric Environment. Vol. 8 No. 4: 305-440, April 1974.

53. U. S. Nuclear Regulary Commission and University of Maryland. Cooling Towers Environment - 1974. Proceedings of a Sumposium at College Park, M. D. 4-6 March 1974. Available as CONF 740302 NTIS, Springfield, VA 22151

54. U.S. EPA, The World's Air Quality Management Standards. Vol. 1 pp 219-241 lists effective stack height requirements/ regulations for 15 nations. EPA-650/ a-75-001 , October 1974.

SECTION FOUR

AIR POLLUTION CLIMATOLOGY

AIR POLLUTION CLIMATOLOGY

J. L. Dicke*

INTRODUCTION

It is obvious that meteorology is very important in the transport and dispersion stages of the air pollution cycle. Meteorological factors are also related to the emission and reception stages. Since no region of the country is immune to air pollution problems, especially considering the increasing population and industrial areas, meteorologists have turned to broad scale or synoptic climatology to discover similarities and differences which may mean two locations hundreds or thousands of miles apart may have pollution problems arising from the same climatological influences.

In past years considerable research and climatological study were done on low pressure or cyclonic circulations. The severe weather changes, storms, aviation problems were associated with low atmospheric pressure systems and high pressure or anticyclones were greeted as breathers between storms, good flying weather, or at worst a hot spell. The harmful effects of stagnating air masses, very low wind speeds, clear skies and subsidence have been brought to the fore in recent years, unfortunately due to the sickness, death, property damage caused by high air pollution episodes.

Two factors which tend to increase air pollution concentrations are: light winds and stability of the atmosphere. Light winds cause only slight dilution of pollutants due to wind speed. Stability of the atmosphere limits the vertical dispersion of pollutants. High pressure systems or anticyclones are characterized by both of the above features: light winds and atmospheric stability.

SUBTROPICAL ANTICYCLONES

There are several areas of high pressure over the oceans that are quite permanent features of the general circulation. The Pacific anticyclone centered in the region between Hawaii and the west coast of North America, and the Azores anticyclone centered over the Azores in the Atlantic, both affect areas in the U. S. In the western portions of these highs, convergence and ascending motions are more prevalent than in the eastern portions where subsidence produces strong inversions. Although the Azores anticyclone extends westward occasionally enough to affect the Southeastern portion of the U. S., the influence of the Pacific anticyclone on the west coast is more important since the eastern portion of the anticyclone is affecting the region and the center of the high is nearer the affected area. This combined with the topography of the Los Angeles basin contribute greatly to the extent of the air pollution problem in that area.

TRACKS OF CYCLONIC AND ANTICYCLONIC SYSTEMS

Storm tracks have been compiled for many years, particularly hurricanes and tropical storms. The first general climatology of both cyclones and anticyclones was published by Klein in 1957 for the northern hemisphere. Visher in 1954 compiled the tracks of cyclones and anticyclones shown in Figures 1 and 2 where the width of the track indicates approximate frequency of occurrence.

Migrating anticyclones are generally of two types: those that originate in middle latitudes and move mainly eastward or those that originate at high latitudes and move southward.

The continuity of path and long life of these relatively stable systems are of particular importance because the pollutants emitted within a source region or along the track

*Supervisory Meteorologist, NOAA
Meteorology & Assessment Division, EPA

PA.ME.e1.7c.9.75

may easily have a trajectory similar to the track of the system and may finally be deposited great distances from their sources.

Cyclones are generated in a much more diverse manner, particularly in different seasons. Low pressure areas tend to develop and track further north in summer, further south in winter. Source regions for cyclonic systems are quite numerous which means a high pressure area may be displaced from any one of the several directions indicated by the cyclonic tracks.

STAGNATING ANTICYCLONES

Climatological study has shown that the major air pollution episodes are usually related to the incidence of stagnating anticyclones, especially those lingering 4 days or more. During such periods surface wind speeds may be very low, subsidence inversions may severely limit vertical mixing in spite of warm daytime temperatures and the clear skies at night which often occur also restrict dispersion of pollutants through a small volume.

Korshover in 1957 studied the climatology of stagnating anticyclones east of the Rocky Mountains. By determining the number of stagnation cases (4 or more days) he prepared charts which delineate areas where stagnation occurred most frequently and found October in the southern Appalachians to have the highest frequency of occurrence with a secondary maximum in June. This is undoubtedly due in part to the extension of the Azores anticyclone into this region. Figure 3 illustrates the total number of stagnation days east of the Rockies during 1936-1956.

An experimental forecast program to recognize and forecast conditions of high air pollution potential was instituted in 1957. Results for certain periods have been reported (Niemeyer, 1960; Boettger, 1961; Miller and Niemeyer, 1963)

A comparable study by months is not available for the western United States; however, Holzworth in 1962 studied frequencies of the location of high pressure centers in the west. Figure 4 depicts the frequency of anticyclonic centers which occurred with a warm ridge aloft from 1949-1956. The majority of centers were in the Great Basin, bounded by 40-45N latitude and 110-120W longitude. The heavy lines on the figure are normal sea level isobars for November, December and January in millibars. The highest frequency of occurrence of quasi-stationary anticyclones coincides exactly. Holzworth also found that 90% of the days with quasi-stationary anticyclones occurred during October through February. This is in sharp contrast to the eastern United States where Korshover found only about 20% of the cases 4 or more days stagnation occurred from November through March.

INVERSION FREQUENCY

Atmospheric dilution of pollutants is a function of temperature gradient both in the vertical and horizontal as well as with time. Pollutants are dispersed very slowly when a stable stratified layer of air exists near the earth's surface. Hosler in 1961 presented a climatological study of the frequency of low-level stability which can be used to evaluate pollution potential for a given region. The tabulations he presented are for percent frequency of inversion and isothermal conditions at or below 500 feet above station elevation computed during a two-year period.

Two general areas of maximum inversion frequency predominate: one in the great basin areas of the western states, and one in the area of Eastern Tennessee, Northern Georgia, and the Carolinas.

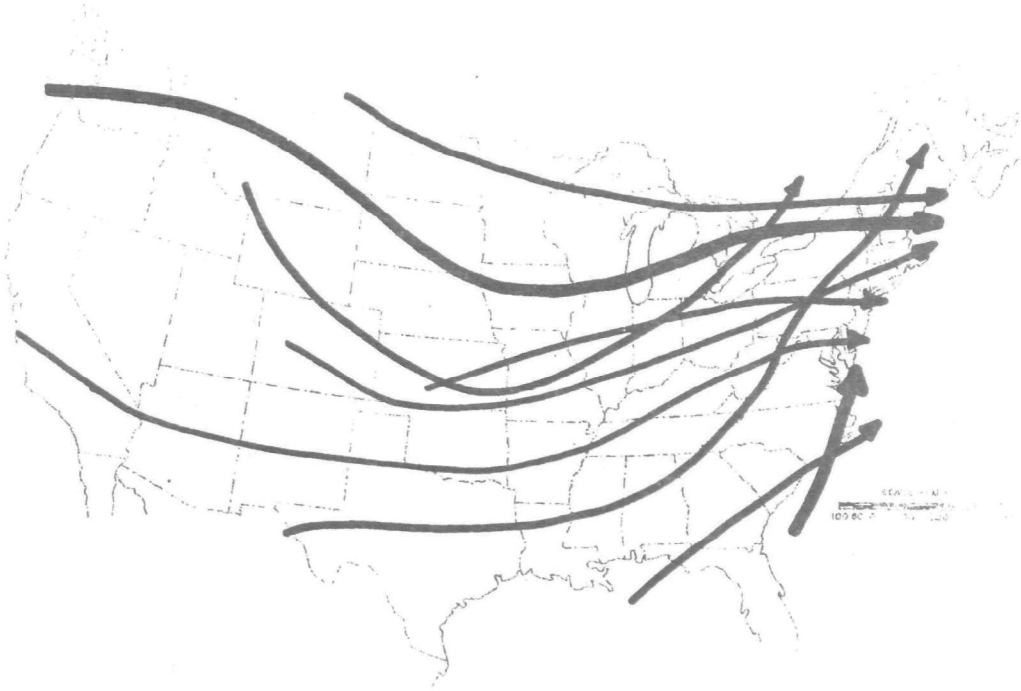


Figure 1. AVERAGE TRACKS OF CYCLONES

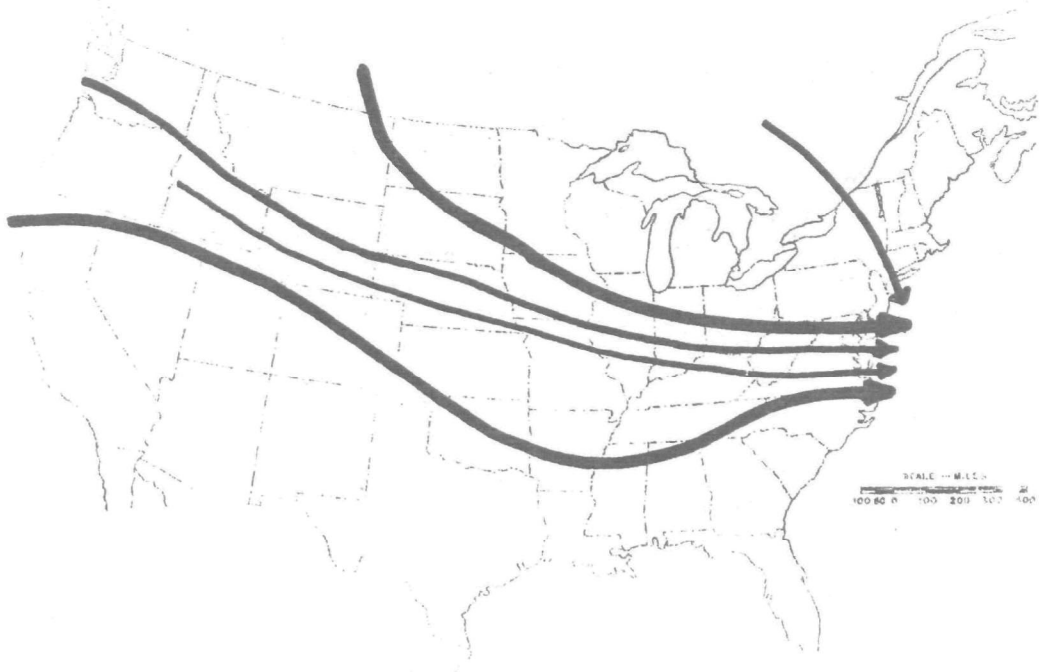


Figure 2. AVERAGE TRACKS OF ANTICYCLONES

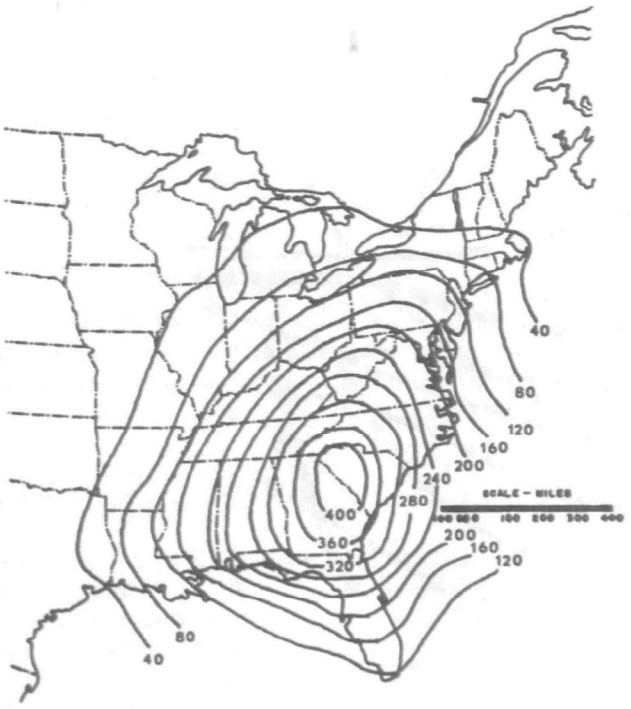


Figure 3. TOTAL STAGNATION DAYS (1936-1956)

Figure 4. FREQUENCIES OF ANTICYCLONE CENTERS (1949-56)

Inversion frequency data must be tempered by regional and local considerations based on geography. Coastal stations reflect marine influences primarily resulting from advection whereas inland stations have inversions caused by radiation processes. Ocean temperature and land-sea temperature differentials are reflected in frequencies from most coastal locations. Inland stations are most often in valleys in the Rocky Mountain and Appalachian regions and consequently higher inversion frequencies would be expected. Urban-rural influences must also be considered when interpreting the data for a large city since most Weather Bureau radiosonde stations are located in semi-rural, suburban locations. With these climatic-geographic distinctions in mind, Hosler evaluated 8 general areas of the country and on an annual basis found the inversion frequencies listed in Table 1.

Also included in Table 1 is the annual average wind speed as compiled by Visher in 1954. For a more specific discussion of inversion frequencies by season for various areas refer to the original paper by Hosler.

MAXIMUM MIXING DEPTH

The concept and calculation of mixing depths was presented in Meteorologic Fundamentals. Continuing the discussion on temperature structure in the vertical, Holzworth in 1964 has prepared estimates of the mean maximum mixing depths for each month based on Weather Bureau radiosonde observations. Since Hosler has shown that marked stability at low levels is generally the rule at night outside of large urban complexes, it is important to know what mixing in the vertical can be expected in the daytime to alleviate possible air pollution episodes.

The major assumption of the mixing depth method is that vertical mixing is a function only of the vertical temperature structure at the time of the sounding and surface maximum temperature. Thus, it is evident that MMD's are not overall indices of potential pollution but must be used in conjunction with several other tools.

TABLE 1

Region	Annual average* wind speed (miles per hour)	Annual low-level** inversion frequency (percent of total hours)
Atlantic Coast	10-15	10-35
Appalachian Mountains	7-11	30-45
Great Lakes	9-15	20-30
Gulf Coast	9-12	10-35
Central Plains	8-15	25-40
Rocky Mountains	5-11	35-50
Northwest Pacific Coast	6- 9	25-30
West Coast	5- 9	35-40

*From Visher, (1954)

**From Hosler, (1961)

Since the highest temperature observed between noon and 4 p.m. is often used instead of the daily maximum temperature, the term "afternoon mixing depth" may be used synonymous with MMD although this is not strictly true.

Mean MMD's are less than 1500 meters over the entire country during October through February except for southern Florida. Generally they are less than half this height in December and January. Along the middle Atlantic and New England coasts MMD's are quite shallow during the entire year. Relatively moderate wind speeds and frequent storms offset the effect of lower mixing depths.

During March through September, Holzworth found that MMD's were practically unlimited over the Rockies and Florida. Otherwise, most areas, MMD's are less than 1500 meters and, in late summer along the Pacific Coast, MMD's are less than 500 meters. Coastal regions in general, including the Great Lakes, show only small variations throughout the year.

WIND SPEED

Wind speed and mixing depth are the parameters commonly used in studying pollution potential as they determine the volume through which pollutants are mixed and diluted. Wind speed varies markedly throughout the country, throughout the day and throughout the area over a given location. Referring back to Table 1, the gross features are seen across the country by geographic regions. The West Coast generally has the lowest average annual wind speeds due to stratification of the air aloft from the semi-permanent anticyclone in the Pacific while increased storm passage and offshore wind flow have the opposite effect on the Atlantic Coast.

An extensive compilation of average daily wind speeds for the western United States was made by Holzworth in 1962. Using a definition of 5 mph or less daily average wind speed and no precipitation as being a light wind day he typed 48 western cities according to the frequency of occurrence of these days. Most cities could be classified as: a) practically zero in all seasons (5); b) high in winter, low in summer (27); and c) high in fall, low in summer (10) while only 6 had double classifications. The Pacific Northwest has the lowest frequency of light wind days in winter because storms most often enter the United States along the Washington-Oregon coast. Light wind days generally occur most often in winter and fall and least often in summer.

WIND DIRECTION PERSISTENCE

Calculations of short-term concentrations from a point source may be developed into an average dispersion climatology by expanding the evaluation in time through summation of successive periods. This will take into account the variability of wind direction, wind speed and dispersion conditions. In atmospheric diffusion modeling for time periods at least as long as a season, the equations are often integrated over an appropriate crosswind sector and summed. The persistence of the wind direction within various sectors gives guidance for appropriate time and space integration intervals.

Techniques for calculating the steadiness of the wind for various time periods have been presented by Singer (1967). The results of such a climatology, together with a probability statement, can be used to determine which areas will be highly affected and what the expected dosage will be for various time periods during which an air pollutant is released. In addition those meteorological conditions associated with a high steadiness value can be compiled and used in air pollution episode planning.

Van der Hoven (1969) has also investigated wind persistence probability using wind direction alone. The study was based on 5 years of data for 61 U.S. Weather Bureau stations throughout the United States. He found a correlation of about 0.9 between wind direction frequency and wind direction persistence. Wind roses that favor a particular sector also tend to persist in that sector. As a general rule the higher the wind speed the more persistent the wind direction will remain. Finally, the probability that the wind will remain within a 22 1/2 degree sector for 24 hours or more was less than 1% for all stations in this study.

FRONTAL TRAPPING

Since frontal systems are accompanied by inversions, trapping of air pollution beneath these inversions can occur. These may allow relatively high concentrations. Frontal trapping may occur with either warm fronts or cold fronts. Since warm fronts are usually slower moving and also the frontal surface slopes more gradually than that of a cold front, trapping will generally be more important with warm fronts. The surface winds ahead of an advancing warm front, i.e., in the region of the retreating cold air mass, will usually be much lighter than the surface wind behind an advancing cold front, at least in the sectors affected by trapping. Because of the orientation of frontal systems with respect to low pressure systems in the Northern hemisphere most surface winds associated with cold fronts are from the quadrant west through north and winds associated with warm fronts are from the east through south. Thus warm frontal trapping would occur to the west and north from a given source and cold frontal trapping to the east through south of the source.

ATMOSPHERIC AREAS

The Federal Register (1968) contains the codified definition of atmospheric areas based on conditions which affect the interchange and diffusion of air pollutants. Figure 5 shows the boundaries of these areas for the contiguous U.S., which are naturally broad since average annual conditions were considered. Table 2 lists the primary characteristics of each area's air pollution climatology based on topographic features as well as low level inversion frequency, maximum mixing depth and frequency of low wind speeds as presented earlier in this Section.

ATMOSPHERIC STAGNATION CLIMATOLOGY

Miller (8) has published a method of forecasting afternoon mixing depths and transport wind speeds through the mixing depth based on data from 67 rawinsonde stations in the contiguous U.S. This mehtod is utilized primarily in the National Air Pollution Weather Forecast Program.

Holzworth (3) has presented results of an air pollution climatology study which combine estimates of morning and afternoon mixing depths with average wind speeds through the mixing layer into an urban diffusion model for forecasting relative pollutant concentrations. The estimates of mixing depths and wind speeds were made for seven locations typical of several climatic regions in the United States. Diffusion model calculations were presented for four cities - New York, St. Louis, Salt Lake City, and Los Angeles - in the form of annual cumulative frequency curves which are a function of the size of the city. Highest relative concentration in the morning occurred at Los Angeles, followed by Salt Lake City, St. Louis, and New York. Afternoon relative concentrations followed the same order. However, calculations based on the assumption that all four cities were

FIGURE 5

ATMOSPHERIC AREAS OF THE UNITED STATES

(Section 107 (a) (1), Clean Air Act, as amended)

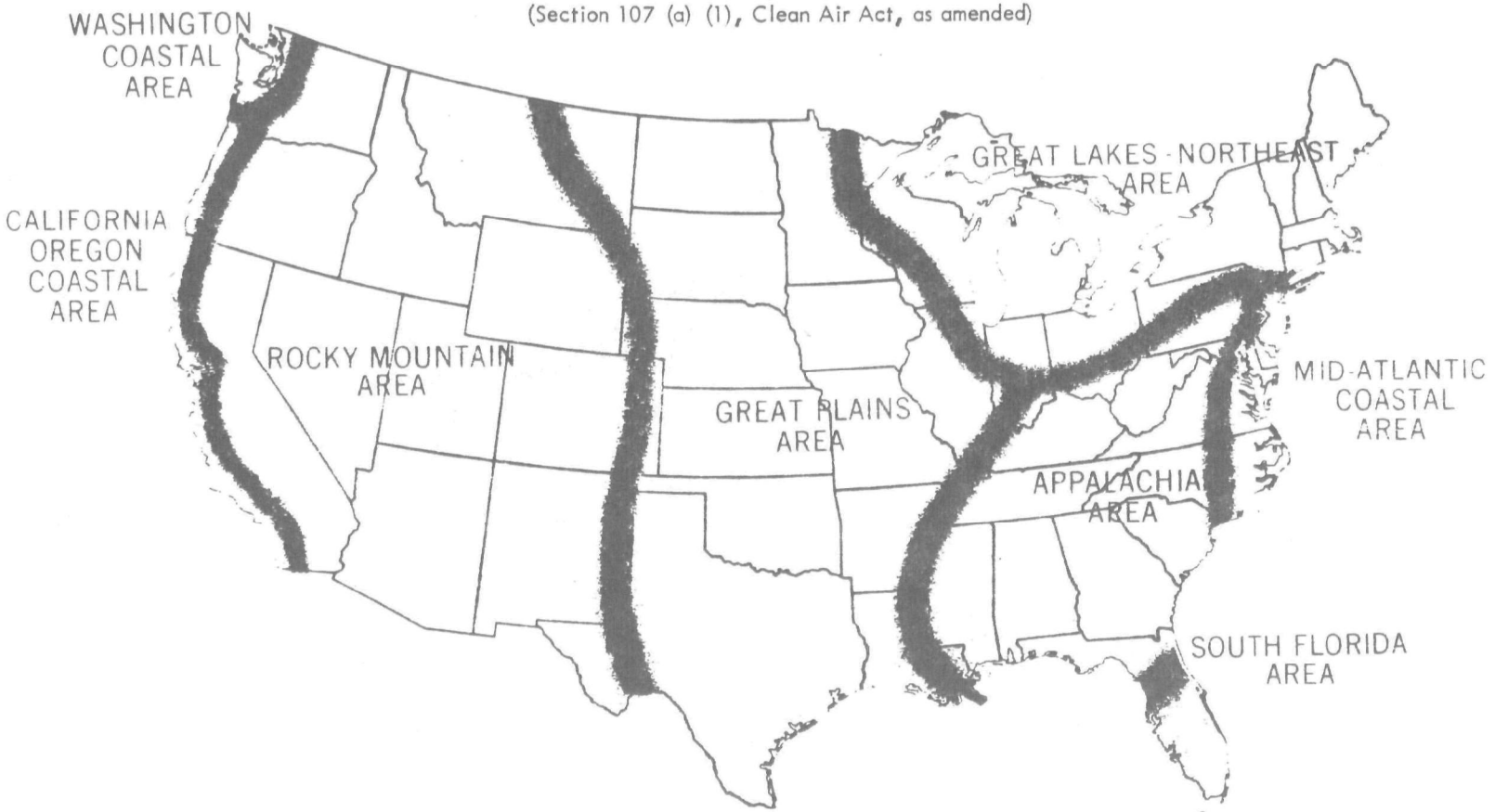


TABLE 2

DESCRIPTION OF ATMOSPHERIC AREAS AND THEIR CHARACTERISTICS, AIR QUALITY ACT OF 1967

Atmospheric Area	Characteristic Air Pollution Climatology
California-Oregon coastal area.	Maritime air penetration, prevailing shallow vertical mixing depths; topographic restraints on ventilation in coastal valleys and basins.
Washington coastal area	Precipitation, cloudiness, and relatively high winds are dominant features of the climate which distinguishes this area from the adjacent areas. Storm activity is frequent, particularly during winter and spring seasons; the frequent storm passages result in a low occurrence of persistent stagnation.
Rocky Mountain area	Topographic restriction, channeling of winds, particularly frequent surfacebased inversions at night, and relatively deep mixing depth during the afternoon are prevalent features of the dilution climate of the area.
Great Plains area	Relatively flat terrain, which streches from the Canadian border to the Gulf of Mexico, characterizes the topography. The dilution climate is characterized by negligible persistent atmospheric stagnation and the frequent occurrence of relatively high winds with rapidly changing meteorological conditions.
Great Lakes-Northeast area	The meteorology is characterized by frequent storm passages with attendant high winds and generally good dilution conditions. During the spring and early summer months, winds blowing from over the cold waters of the Great Lakes and Atlantic Ocean enhance low-level stability in regions adjacent to these bodies of water.
Appalachian area	Dominant features of the dilution climate include light wind speeds and the most frequent stagnation conditions of any region east of the Rocky Mountains.
Mid-Atlantic area	Shallow mixing depths, less frequent low-level stability and higher wind speeds are features of the dilution climate that distinguish this coastal area from those adjacent.
Southern Florida-Caribbean area	The climate of this area is predominanity tropical-marine in nature. Atmospheric stagnation is practically nonexistent; there is a small frequency of low level stability; and relatively good vertical mixing prevails.

TABLE 3

Frequency of occurrence of the month in which most of the period of a slowest dilution episode occurred for stations East (E) and West (W) of the 95th meridian, and all (A) 62 stations together.

	Duration														
	1-Day			2-Day			3-Day			4-Day			5-Day		
	E	W	A	E	W	A	E	W	A	E	W	A	E	W	A
JAN	4	12	16	9	11	20	6	9	15	5	9	14	8	11	19
FEB	3	5	8	4	3	7	1	2	3	3	3	6	0	1	1
MAR	2	1	3	1	2	3	0	2	2	0	1	1	1	0	1
APR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MAY	0	1	1	0	0	0	0	0	0	0	0	0	2	0	2
JUN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUL	2	0	2	0	0	0	0	0	0	0	0	0	0	2	2
AUG	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
SEP	0	0	0	1	0	1	0	1	1	0	0	0	1	1	2
OCT	4	0	4	1	0	1	2	0	2	4	1	5	5	0	5
NOV	8	1	9	5	2	7	10	2	12	9	6	15	5	3	8
DEC	8	11	19	10	13	23	12	15	27	10	11	21	9	12	21

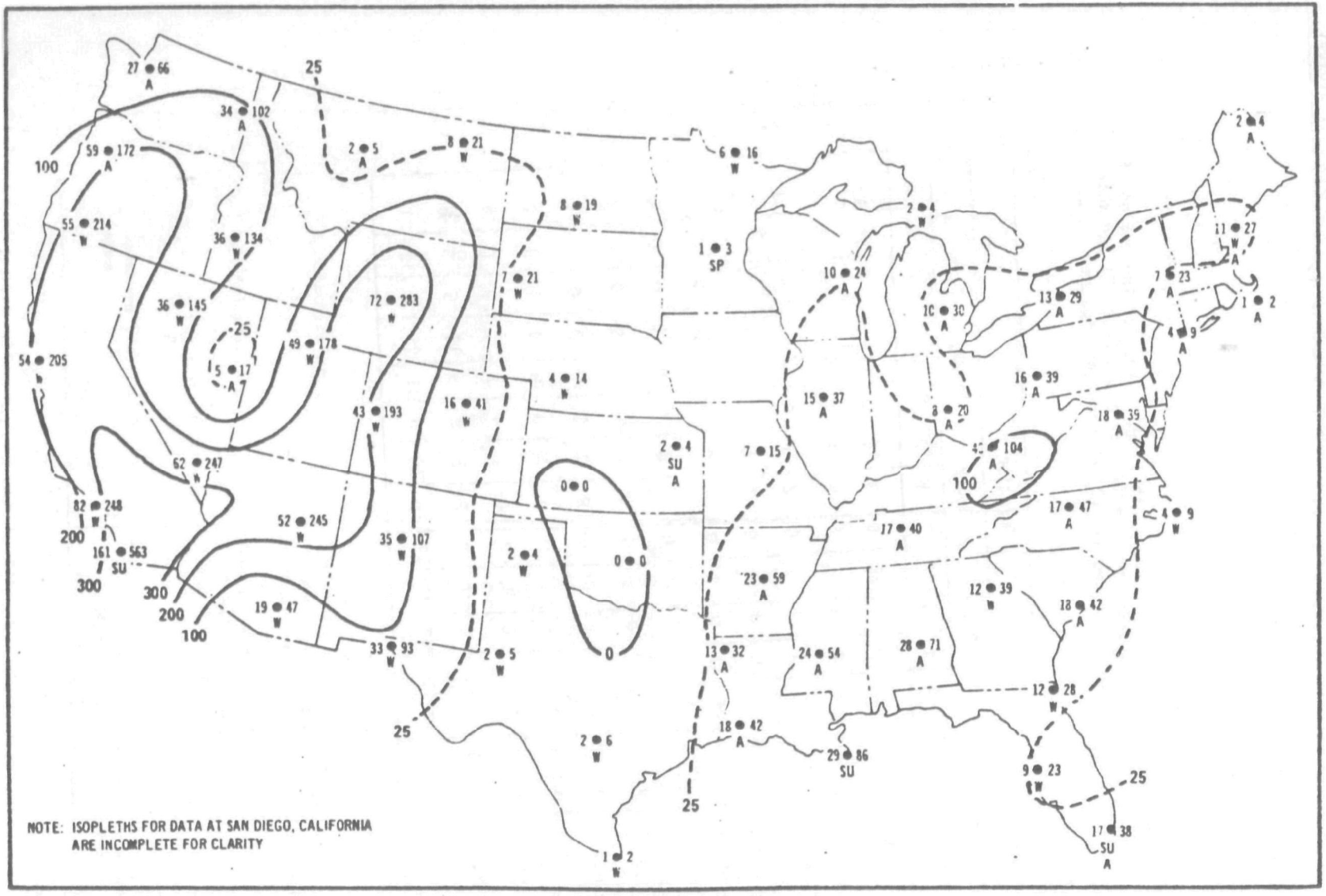


Figure 6 Isopleths of total number of episode-days in 5 years with mixing heights $\leq$1500 m, wind speeds $\leq$ 4.0 m sec^{-1}, and no significant precipitation (see text) - - for episodes lasting at least 2 days. Numerals on left and right give total number of episodes and episode-days, respectively. Season with greatest number of episode-days indicated as W (winter), SP (spring), SU (summer), or A (autumn).

the same size as Los Angeles show that the highest relative concentration at the 50 percentile frequency in the morning would occur at Salt Lake City, followed by Los Angeles, St. Louis and New York. In the afternoon the order is Los Angeles, Salt Lake City, St.Louis and New York with only slight differences between cities.

This study has now been expanded to other cities to provide an air pollution climatology for the contiguous United States, (Holzworth, 1971). Mixing height and wind speed data from 62 stations were calculated and tabulated by the National Climatic Center (NCC) based primarily on the five year period 1960 through 1964. Using a simple mathematical model of urban diffusion, normalized pollutant concentrations averaged over a city as a function of mixing height, wind speed and city size were calculated. Frequencies of normalized pollutant concentration for different city sizes were also prepared. Finally, episode-day maps of high meteorological potential are presented based on specified combinations of mixing height and wind speed. The criteria of mixing $H \leq 1500$ m and wind speed $U \leq 4$ m sec^{-1} are particularly important since they have been incorporated in the National Air Pollution Weather Forecasting program. Figure 6 illustrates that the meteorological potential for episodes is much greater in the West than in the East with barely 100 episode days at one eastern station and over 100 episode days at most western stations.

Following this, Holzworth (1974) used these data to determine episodes of slowest dilution lasting 1,2,3,4, and 5 days based on the product of HxU. An episode is defined as a continuous period during which:

1. All values of H_1 and U_1, respectively, were less than or equal to H_1=250,500,750,1000,1500,2000, or 3000 m U_1=2.0,4.0,6.0 or 8m/sec. and $H_1 x U_1$ was a minimum

2. The episode average of individual morning and afternoon values of HxU (i.e., $\overline{HxU}$) was smallest

3. No significant precipitation

The dates and meteorological data are given for each episode, the 62 stations are ranked by their values of $\overline{HxU}$ and maps are presented showing isopleths of slowest dilution values. Table 3 presents frequency of occurrence of the month during which slowest dilution episodes occurred during the period of record, 1960-1964. Note that with only one exception December is the month during which most slow dilution episodes occurred. Stations having the lowest HxU values for 1-5 day episodes include Lander WY, Medford, OR, Rapid City, SD, and Winnemucca, NV. Stations having the highest HxU values include Oklahoma City, OR, Brownsville, TX, Jacksonville, FL, San Antonio, TX and Miami, FL.

Finally, Holzworth (1974) has developed an objective system for analyzing temperature inversions and lapse conditions in the lowest 3km from the twice-daily NWS rawinsonde ascents. Ten classes of $\Delta T/\Delta Z$ are used to classify those loose rates which may occur on a given temperature profile. Percent frequency tables have been prepared relating inversion thickness to inversion base height for each of the four seasons and both mornings and afternoons. Solar elevation is also given so the influence of surface heating or cooling may be inferred. These data are to be included in a climatological summary of rawinsonde measurements now being prepared.

REFERENCES

1. Holzworth, G. C. A Study of Air Pollution Potential for the Western United States. J. Applied Meteorology. 1:366-382. September 1972.

2. Holzworth, G. C. Estimates of Mean Maximum Mixing Depths in the Contiguous United States. Monthly Weather Review. 92:235-242. May 1964.

3. Holzworth, G. C. Mixing Depths, Wind Speeds and Air Pollution Potential for Selected Locations in the United States. J. Applied Meteorology 6:1039-1044, December, 1967.

4. Hosler, Charles R. Low-Level Inversion Frequency in the Contiguous United States. Monthly Weather Review. 89:319-339.

5. Klein, William H. Principal Tracks and Mean Frequencies of Cyclones and Anticyclones in the Northern Hemisphere. U.S. Weather Bureau Research Paper No. 40. 1957.

6. Korshover, J. Synoptic Climatology of Stagnating Anticyclones East of the Rocky Mountains in the United States for the Period 1936-1956. Tech. Rep. A60-7 SEC. 1960. 15 pp.

7. Korshover, J. Climatology of Stagnating Anticyclones East of the Rocky Mountains 1936-1965. Public Health Service Pub. No. 999-AP-34. 1967.

8. Miller, M. E. Forecasting Afternoon Mixing Depths and Transport Wind Speeds. Monthly Weather Review. 95: 35-45. January 1967.

9. Visher, Stephan S. Climatic Atlas of the United States. Harvard University Press. Cambridge, Massachusetts. 1958. $8.10.

10. Singer, I. A. Steadiness of the Wind. J. Applied Meteorology 6:1033-1038, Dec. 1967.

11. Needfall, R. O. and Linsky, B. A. Meso-climatological Classification System for Air Pollution Engineers, JAPCA 19, 511-513, July 1969.

12. Orton, Robert. The Meteorological Potential for Air Pollution in Texas. Texas Business Review. 42; 1-6, October 1968.

13. Van der Hoven I. Wind Persistence Probability. ESSA Research Laboratories Tech. Memo. ERLTM-ARLTD, February 1969.

14. Holzworth, G. C. Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States. OAP, Publication No. AP-101, January 1972.

15. U.S. Dept. HEW. Definition of Atmospheric Areas. Federal Register, Vol. 33, No. 19, Tuesday, January 16, 1968 and also No. 221, Wednesday, November 13, 1968.

16. McCormick, R.A. Air Pollution Climatology. Vol. I, Ch. 9 in Air Pollution, 2nd Edition, A. C. Stern (Ed.) Academic Press, 1968.

17. Holzworth, G. C. Meteorological Episodes of Slowest Dilution in Contiguous U.S. EPA-650/4-74-002, February 1974.

18. U.S. EPA Guidance for Air Quality Monitoring Network Design and Instrument Siting (Revised.) OAQPS No. 1.2-012, July 1975.

19. Holzworth, G. C. Climatological Data on Atmospheric Stability in the U. S. Paper presented Amer. Meteorological Society Symposium on Atmospheric Diffusion and Air Pollution, Santa Barbara, CA, September 1974.

SECTION FIVE

INTERRELATIONSHIPS-METEOROLOGY AND AIR POLLUTION

Urban Effect Upon Meteorologic Parameters
Atmospheric Turbidity
Atmospheric Chemistry of Air Pollution
Natural Removal Processes in the Atmosphere
Analysis of Air Quality Cycles

URBAN EFFECT UPON METEOROLOGIC PARAMETERS

There is hardly any meteorologic element that can be named that is not influenced to some extent by cities. It is, however, difficult to separate urban effects from microclimatologic effects since very few measurements have been made with the specific aim of comparing urban and non-urban measurements. There are several causes for the differences between urban and open country climates. One of these is the alteration of the surface, the change from meadow, forest or swamp to buildings and streets of concrete, brick, steel, and asphalt. Not only does this cause changes in reception and reflection of solar radiation, and evaporation but changes the roughness of the surface over which the wind moves. Another is the production of a sizable quantity of heat due to combustion processes carried on in the city. Another cause is the addition of material to the atmosphere in the form of dusts, gases, and vapors such as to change the atmosphere's composition in the vicinity of cities.

TEMPERATURE

The comparison of temperatures within cities with those outside reveal that city temperatures, especially at time of minimum, are higher (Mitchell, 1961). Also during the period right after sunset the city temperature does not cool as rapidly as does the country air due to heat content of buildings and radiation toward each other rather than toward the sky. Between sunrise and noon urban and non-urban temperatures are nearly the same. (Landsberg, 1956). The influence of the city extends in the vertical on the order of three times the height of the buildings (Duckworth and Sandberg, 1954). The average heat island effect over New York City extends to 300 meters and has been observed as high as 500 meters (Bernstein, 1968) Also, the change of temperature with height is quite different over the city especially at night. In the open country radiation inversions form frequently whereas in the city weak lapse conditions frequently exist through the night with a radiation inversion layer above the lapse conditions, (DeMarrais, 1961).

Urban-rural daily minimum temperature differences for 31 U. S. Cities have been summarized, (DeMarrais. 1975) The heat island intensities 1) showed large day-to-day changes, 2) varied over a large range, and 3) frequently showed seasonal variations.

Variations between city and country temperatures are extremely noticeable at northern latitudes when the countryside is covered with snow but has melted in the city.

HUMIDITY

There are lower relative humidities in cities partly due to higher temperatures but there is also lower absolute humidity. Although little is available in the way of measurements, it is felt that lower absolute humidities are due to the rapid runoff of precipitation in the cities. Also the existance of little vegetation in the city reduces moisture received from evapotranspiration processes. (Landsberg, 1956).

PRECIPITATION

Precipitation is one of the most widely variable meteorological elements and because of this it is difficult to establish significant differences between urban and non-urban areas. However, numerous studies have been made which show either greater precipitation amounts and/or greater frequency of precipitation within cities. Schmauss, in 1927 showed 11 per cent increase of days with small amounts of precipitation occurring in Munich compared to stations outside the city. Bolgolepow, in 1928, reported an increase of 10 per cent in total amount in Moscow compared to a country station for 17 years of record. Ashworth noted in 1929 the increase of average annual precipitation over 3 decades amounting to 13 per cent. He also noted less increase for Sundays than for weekdays. Wiegel, in 1938, using a 35 year record, noted a 5 per cent increase in precipitation, as well as a 12 to 18 per cent increase in the number of days with precipitation for the Ruhr area of Germany. These are all reported in Landsberg (1956). Landsberg also reports a study for Tulsa where topographical effects are at a minimum and the urban area is confined to a rather definite area. In addition to an increase within the city over a 70 year period, there was an increase of 7 per cent in the city compared to surroundings for a 14 year period.

An eight city study for the period 1955-70 (Huff and Chagnon, 1973) showed warm season rainfall increases of 9-17% in six areas:St. Louis, Chicago, Cleveland, Washington-Baltimore, Houston and New Orleans. Results for Indianapolis were indeterminate and Tulsa showed no urban influence.

The principal suspected causes of the increase of precipitation over cities is the increase of condensation nuclei over cities due to air pollutants and the increased turbulence over the city due to both increased roughness of the surface and release of heat from the city. Although water vapor is added to the air from combustion sources this is not expected to add significant precipitable water to have a major effect.

SNOW

Precipitation in the form of snow indicates to some extent the influence of temperature in the urban area. Kossner in 1917 and Maurain in 1947 indicated greater frequencies of snowfall outside as compared to within Berlin and Paris respectively. On the other hand, Kratzer in Munich in 1937 reported occurrances of snow within the city when none occurred in the surroundings, and Kienle in Mannheim, a heavy industry location, reported that snow fell from a fog and stratus layer on two successive days in January 1949 while none fell outside the urban area. It is probable that this was due to air pollutants furnishing condensation nuclei for supercooled water vapor. Landsberg (1968) estimates a 5% average decrease in snowfall for urban areas.

CLOUDINESS

From climatological records there seems to have been a slight increase in cloudiness over the years but this has been so slight (less than 1/10 of mean sky cover) that for so subjective a measure as sky cover this may not be significant. Any increase may be primarily due to city fogs, as increases in early morning cloud cover seems to be greatest. Nearly all large cities show a decrease in the number of clear days over that observed in adjacent rural areas. The primary effects may be expected to be due to addition of condensation nuclei by air pollution and the release of additional water vapor. Kratzer in Munich indicated in 1937 an 8 per cent increase in summer cloudiness compared to a 3 per cent increase in winter cloudiness over the city (Landsberg, 1956). This may indicate that surface roughness increasing turbulence may play a part in the formation of cumulus type summer clouds. Cloud formations due to urban pollutant sources are often seen on satellite photos, (Detwiler, 1974).

WIND

Because of the increases generally of the size of the roughness elements in the city over that in the rural areas, wind speeds are decreased within the city. Also the frequency of calms is increased on the order of 5 to 20 per cent (Landsberg, 1956). Recently Pooler (1961) has shown that under conditions of light stable flow that an inflow of air toward the center of the city of Louisville occurs (heat island effect). In addition to the decrease of wind speed in cities, there is of course channeling of the wind in the canyons formed by alternating streets and groups of buildings.

RADIATION

The decrease of solar radiation within cities as compared to rural areas is on the order of 15 to 20 per cent. This is due to the absorption, reflection, and scattering of particles in the atmosphere, and the absorption of gases. These particles and gases are primarily the result of air pollution. The radiation most affected is that of the ultraviolet with the infra-red least affected. This is of importance due to the bactericidal effect of ultraviolet radiation.

Many groups, McCormick (1960), are now measuring the attenuation of the solar beam at 0.5 micron wave length in order to have an objective measure of the entire pollution layer. In terms of duration of sunshine, Landsberg (1968), presents a range of 5-15% as the decrease of this parameter in urban areas. Randerson (1970) attributed an average 23% loss in intensity of light to pollution in Houston, TX and Rouse (1973) found a 12% loss in Hamilton, Ontario industrial atmosphere.

VISUAL RANGE

The decrease of visibility in urban areas is probably the most noticeable of meteorological differences between urban and rural areas. The increase of fogs in cities has already been mentioned under cloudiness. Comparisons between hourly observations of visibility at city locations and at rural locations (Landsberg, 1956) have shown higher frequencies of fog, smoke, and low visibilities than in neighboring rural areas.

Holzworth and Maga (1960) analyzed visibility measurements from California locations to determine if trends were noticeable which might be caused by increases in air pollution. Results indicated that several cities showed trends toward lowering visibilities. Another showed lowering visibilities until efforts at controlling certain pollutants were made after which no trend was discernible.

URBAN EFFECT EXPERIMENTS

Meteorological and air quality data for most large urban areas as well as medium and small localities have been gathered and studied to determine relationships, correlations, synergistic effects and secular trends. Biometeorology, epidemiology, ecology, regional planning and other interdisciplinary fields require basic data on the city and its environment to make interpretations, verify cause/effect relationships and develop projections for the future. From these studies models of varying degrees of sophistication have been developed, although generalization with good validation is still lacking. (Munn, 1973)(Summers, 1965) The "urban plume" (Clarke, 1969) has been well documented, (Haagenson and Morris, 1974) and (Stampfer and Anderson, 1975). Urban heat island dynamics are becoming better understood through studies such as for Montreal and Vancouver in Canada (Oke and Maxwell, 1975) and the continuing results derived from Project METROMEX, begun in 1971 in the greater St. Louis region of Illinois-Missouri and scheduled to terminate in 1976. Since METROMEX (Metropolitan Meteorological Experiment) is becoming a "household" scientific word, there are three major areas of potential applications. The first is physical meteorology, i.e. cloud physics and process modification, aerosols and radiant heat exchange the role of these in climate modifications. The second area is air pollution meteorology; remote monitoring of the boundary layer and the role of convection in injecting pollutants into large scale circulations. The third area is regional planning and urban design; the atmospheric role in energy exchange and climate modification within urban boundaries. An excellent review of projects, early results and discussions by METROMEX scientists is contained in a 46-page article appearing in the February, 1974 issue of the Bulletin of the American Meteorological Society.

A second major experiment also in the St. Louis regional area, the Regional Air Pollution Study (RAPS), is being conducted by the U.S. EPA. The basic objective of RAPS is to develop and validate improved air quality simulation models. One of the key parts is the collection of data to test and validate such models. (ES&T, 1973) The instrumentation network consists of 25 stations, each measuring CO, HC, NO_x, SO_2 and fine particulates as well as wind, temperature and moisture. Six sites will measure solar radiation, five will measure turbulence when necessary and twelve will measure lapse rate between 5 and 30 meters, (Pooler, 1974). In addition ten monitoring stations are operated by local agencies, field experiments have begun, and routine data are being archived at the Environmental Research Laboratory, Research Triangle Park, North Carolina.

REFERENCES

1 Changnon, Stanley A. Jr., "Precipitation Contrasts Between the Chicago Urban Area and An Offshore Station in Southern Lake Michigan", Bull. of the American Meteorol. Soc., 42, 1, 1 - 10, Jan. 1961.

2 Changnon, Stanley A.,Jr., "A Climatological Evaluation of Precipitation Patterns Over an Urban Area." Symposium on the Air Over Cities, Tech. Rep. A62-5 1962.

3 DeMarrais, Gerard A. "Vertical Temperature Difference Observed Over an Urban Area", Bull. of the Amer. Meteorol. Soc., 42, 8, 548 - 554, Aug. 1961.

4 Duckworth, F.) [illegible] and Sandberg, J. S. "The Effect of Cities Upon Horizontal and Vertical Temperature Gradients", Bull. of the Amer. Meteorol. Soc, 35, 5, 198-207, May 1954.

5 Holzworth, G. C. and Maga, J. A., "A Method for Analyzing the Trend in Visibility", J. Air Poll. Control Assoc., 10, 6, 430-435, Dec. 1960.

6 Landsberg, H. E. "The Climate of Towns" in Man's Role in Changing the Face of the Earth, Thoms, W. L. Jr., ed. Univ. of Chicago Press, 1956.

7 McCormick, R. A. and Tabor, E. C. "U. S. Weather Bureau-Public Health Service Precipitation Chemistry and Aerometric Studies" presented at the 12th General Assembly, Int. Union of Geodesy and Geophysics, Helsinki, Finland, July 26 - Aug. 6, 1960.

8 Mitchell, J. Murray, Jr. "The Temperature of Cities", Weatherwise, 14,6, 224-229, December 1961.

9 Pooler, Francis, Jr. "Stable Airflow Patterns at Louisville, Ky.", Presented at joint meeting of Amer. Geophy. Union Amer. Meteorol. Soc., Wash., D. C., April 18-21, 1961.

10 Ludwig, F. L., Urban Climatological Studies Standford Research Institute Interim Report No. 1, February, 1966.

11 Bernstein, R. D., Observations of the Urban Heat Island Effect in New York City. J. Appl. Meteor. 7, 4:575-582, Aug., 1968.

12 Landsberg, H. E. Climate and Urban Planning Pres. WMO Symposium of Urban Climates and Building Climatology. Brussels, October 1 9, 1968.

13 Fluor Products Co., Inc.Evaluated Weather Data for Cooling Equipment, Design Addendum No. 1. Winter and Summer Data. 1964. $22.50.

14 Peterson, J. T. The Climate of Cities: A Survey of Recent Literature. National Air Pollution Control Administration Publication No. AP-53, October 1969.

15 Kopec, R.J., Further Observations of the Urban Heat Island in a Small City. Bull. AMS, 51, 7:602-606, July 1970.

16 Preston-Whyte, R. A., A Spatial Model of an Urban Heat Island. J. Appl. Meteoro., 9, 4:571-573, Aug.,1970.

17 Randerson, D., A Comparison of Spectral Distribution of Solar Radiation in a Polluted and a Clear Air Mass. JAPCA, 20,8:546-548, Aug., 1970.

18 Mitchell, J. M., Jr. The Effect of Atmospheric Aerosols on Climate with Special Reference to Temperature near the Earth's Surface. J. Appl. Meteor. 10:4, pp.703-714, August 1971.

19 DeMarrais, G. A. Nocturnal Heat Island Intensities and Relavance to Forecasts of Mixing Heights. Monthly Weather Review, 103, 3; 235-245, March, 1975.

20 Huff, F. A. and Chagnon, S. A., Jr. Precipitation Modification by Major Urban Areas. Bull. AMS. 54, 10:1220-1232, December, 1973.

21 Detwiler, A. Urban Influence on Cumulus Formation. Bull. AMS. 55, 10:1240-1241 October, 1974.

22 Rouse, W. R., Noad, D. and McCutcheon, J. Radiation, Temperature and Atmospheric Emissivities in a Polluted Urban Atmosphere at Hamilton Ontario, J. Appl. Meteor. 12, 5: 798-807. August 1973.

23 Munn, R. E. Urban Meteorology: Some Selected Topics. Bull. AMS. 54, 2:90-93, February 1973.

24 Summers, P. W. An Urban Heat Island Model Its Role in Air Pollution Problems with Applications to Montreal. Paper pres. First Canadian Conference on Micrometeorology, Toronto, April, 1965.

25 Clarke, J. F. Nocturnal Urban Boundary Layer over Cincinnati, Ohio. Monthly Weather Review, 97, 8:582-589, August, 1969.

26 Haagenson, P. L. and Morris, A. L. Forecasting the Behavior of the St. Louis, Missouri, Pollutant Plume. J. Appl. Meteor. 13, 8:901-909.

27 Stampfer, J. F. Jr. and Anderson, J. A. Locating the St. Louis Urban Plume at 80 and 120 km. and Some of its Characteristics. Atmos. Env. 9,3:301-313, March 1975.

28 Oke, T. R. and Maxwell, G. B. Urban Heat Island Dynamics in Montreal and Vancouver. Atmos. Env. 9, 2:191-200, February 1975.

29 Project METROMEX: A Review of Results. Bull. AMS. 55, 2:86-121, February 1974.

30 RAPS: Unwrapping the Largest Air Monitoring Program Ever, in St. Louis, Env. Science & Techn. 7, 7:598-599. July 1973.

31 Pooler, F. Jr. Network Requirements for the St. Louis Regional Air Pollution Study.JAPCA, 24, 3: 228-231, March 1974.

ATMOSPHERIC TURBIDITY

J.L. Dicke

INTRODUCTION:

Fine particulates, dust, and various aerosols produce haze, reduce visibility. The reduced visibility may be used, in a qualitative sense, to judge the degree of particulate air pollution present over a given location. Often, this is the only way by which the average person recognizes and is aware of the presence of air pollution. Particulates have specific optical properties which can be used to determine their spatial and temporal variation, particularly over urban areas. The presence of particulates characterized almost exclusively a property of the atmosphere termed "turbidity", especially at the wavelength of 0.5 micron. Turbidity generally means the degree of transparency of a cloud-free atmosphere to visible radiation. The vertical distribution of aerosol materials up to 2000 ft. is the basis for considerable research effort and preliminary results in this country have been published by McCormick and Baulch (1962).

THEORY:

The transmission of solar radiation through the atmosphere depends primarily on Rayleigh scattering (molecules), scattering and absorption by dusts and aerosols, and selective absorption by gases. At a given wavelength, λ, the transmission through the atmosphere can be written, following McCormick and Baulch above:

$$I(\lambda) = I_o(\lambda)\, e^{-\sigma M}$$

where

$I(\lambda)$ = intensity of incident radiation
(λ) = extraterrestrial radiation value
M = optical path length of air mass
σ = attenuation coefficient

$\frac{I(\lambda)}{I_o(\lambda)}$ = transmissivity

At 0.5 micron the attenuation is due almost entirely to Rayleigh scattering and the scattering and absorption by dusts and aerosols. Volz's work (1959) led McCormick and Baulch to develop a working equation.

$$I = \frac{I_o}{F}\, 10^{-(aK\frac{P}{Po} + B)M}$$

where

F = reduction factor for mean solar distance

a = atmospheric extinction coefficient of pure air including ozone

K = factor to allow for differences between optical path length of the atmosphere for air, haze and ozone.

P,Po = ambient and sea level pressure

B = extinction coefficient for dust, haze, etc. The turbidity.

M = relative optical path length or air mass

Thus, by observing I, B values can be determined from a nomogram since all the terms can be obtained independently or approximated.

B is directly related to the amount of the atmospheric particulate and can serve at least as an index of pollution, even if it is not exactly quantitative. Values of B are obtained under clear skies, or at least with no clouds between the observer and the sun, in a relatively easy manner. The data can be used to evaluate aerosol and dust loadings over the observation point.

*Supervisory Meteorologist, NOAA
Air Pollution Training Institute, EPA

PA.ME.28c.3.70

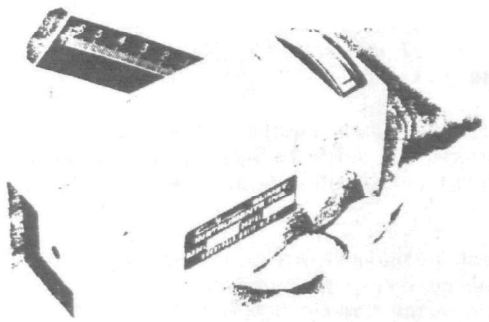


Figure 1. SUN PHOTOMETER

MEASUREMENT:

The instrument used, Figure 1, is called a sun photometer and is modeled fairly closely to that first developed by Volz. The small wooden box contains a filter, photoelectric cell, microammeter and level. The movable diopter mounted on a pivot is used to determine optical path length (relative air mass M). The Kodak Wratten 65 filter-photocell combination results in an instrument sensitive to essentially monochromatic light at $\lambda = 0.5$ micron. The observations must be made where there are no obstructions between the instrument and the sun although very thin cirrus clouds are allowable. The optical air mass M must be determined for every incident radiation observation. Then, using a nomogram, B can be read directly. Values of B generally range from 0.02 in very clean air to more than 0.60 in dirty air.

RESULTS:

In Cincinnati, Ohio, a large number of vertical observations of turbidity have been made, both from a helicopter and from roofs of tall buildings. At the same time vertical temperature soundings were made and the transmissivity compared to the lapse rate. The effects of temperature stratification can easily be demonstrated. McCormick and Baulch have shown that very often more than one-half of the solar radiation incident at 2000 ft. (height of helicopter sounding) is attenuated by the 1000 ft. closest to the ground during times of high air pollution. From surface observations of B, i.e., B_o, an idea of the particulate loading may be approximated by the relation:

$$m \approx 10^3 B_o$$

where

m = mass loading in micrograms per cubic meter

B_o = turbidity at ground level

It must be kept in mind, however, that the photometer "sees" only the aerosols in the 0.1 - 1.0 micron radius size range. Under high relative humidity conditions, the $10^3 B_o$ factor will result in calculated mass loadings that are too high when compared to actual Hi-vol samples. Erroneous estimates of mass loading at ground level will also occur if there is a significant haze layer aloft.

An early summary of the atmospheric turbidity program in the San Francisco Bay Area has been presented by Bell (1963). Results of research experiments on the vertical diffusion of aerosols over a city have been published by McCormick and Kurfis (1966). Two recent papers which deal with the effects on climate of observed increasing turbidity values with time have been written by McCormick (1967) and McCormick and Ludwig (1967).

NETWORK:

Turbidity observations are being made at about 50 locations around the United States and at about 75 locations throughout the world, as part of a continuing program (see Figure 2). Each month observational forms from each station are mailed to the National Climatic Center in Ashville. The main objective of this program is to obtain a climatology of background readings of the principal air masses and synoptic situations affecting each location. An example is shown in Figure 3 for continental polar air mass in the fall. Each quarter a summary listing of all observations is prepared and a copy sent to each contributor. After sufficient information is assembled and "normal" monthly frequency distributions are established, a relatively quick appraisal of the air pollution envelope over a given area may be possible.

Analyses of 5 years of turbidity measurements made with Volz sunphotometers at a network of stations in the United States by Flowers, et al, (1969), have produced the following conclusions:

Figure 2 Turbidity Network (January 1970)

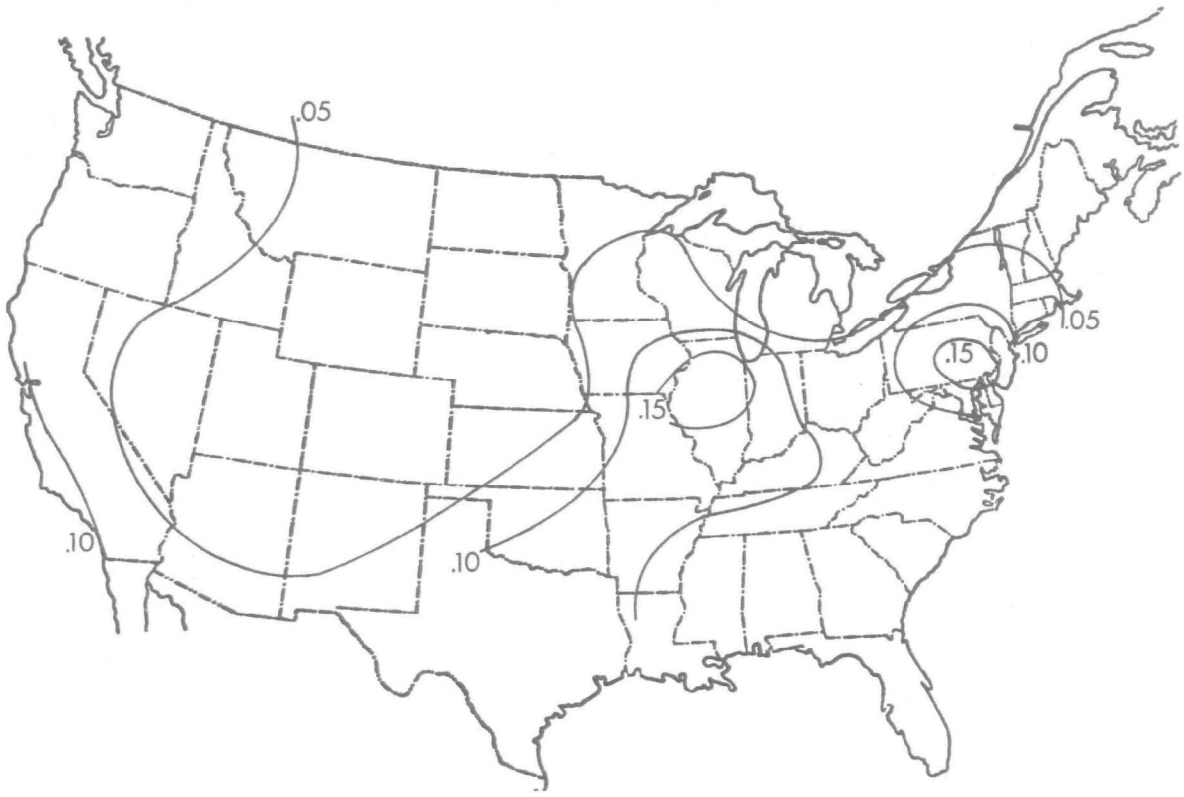


Figure 3 Turbidity, Continental Polar – Winter

1) On an annual basis, lowest turbidity is observed over the Rocky Mountain area, and highest in the eastern United States.

2) Mean monthly turbidity values for all stations indicate higher turbidity in summer than in winter.

3) The minimum turbidity observed at sea level is near 0.020.

4) On the average, lowest turbidities are observed in polar continental air masses in winter and highest in maritime tropical air masses in summer.

5) Turbidity values are usually lower immediately after the passage of a cold front.

6) Precipitation in itself does not appear to have a noticeable effect in lowering turbidity.

CURRENT STATUS:

The network of stations is now administered by Mr. E. C. Flowers, Air Resources Laboratory RB-3, Boulder, Colorado 80302 and instruments are also recalibrated and distributed by his office. The National Climatic Center receives observed data, generally monthly, from each station, performs quality control, archives and then publishes the data on an annual basis (Ref.12).

Instruments are available from two sources. The Eppley Laboratory, Inc. Newport, Rhode Island manufactures a dual wavelength sunphotometer which consists of a photovoltaic cell and two narrow bandpass interference filters with peak transmission centers at 380 and 500nm. Thus a measure of ultraviolet extinction can be obtained in addition to a more precise value of B than with the original 1959 Volz sunphotometer mentioned above.

A three-wavelength sunphotometer is manufactured by F. Volz, 24 Tyler Road, Lexington, Massachusetts which measures incoming solar radiation at 500nm and 940nm. The 940nm wavelength was selected because of water vapor absorption while at 880nm, there is essentially none. By subtraction, then, the amount of water vapor present can be calculated. Turbidity is, of course still calculated from observations at 500nm.

REFERENCES

1 Angstrom, Anders. Techniques of Determining the Turbidity of the Atmosphere. Tellus, 13:3, p.214. 1961.

2 Bell, G.B. Applications of the Volz Solar Photometer. Presented at the Fifth Conference of Air Pollution Methods, Los Angeles, California, January 18,1963.

3 McCormick, R.A. and Baulch, D.M. The Variation with Height of the Dust Loading Over a City as Determined from the Atmospheric Turbidity. J. Air Pollution Control Association, Vol.12,No.10.October 1962.

4 McCormick, R.A. and Kurfis, K.R. Vertical Diffusion of Aerosols Over a City. Quar. J. Royal Meteorol. Soc. 92:393 pp 392-396. July 1966.

5 McCormick, R.A. Atmospheric Turbidity. Pres. at 60th Annual Meeting, APCA. June, 1967.

6 McCormick, R.A. and Ludwig, J. H. Climate Modification by Atmospheric Aerosols. Science, 1967. 156:3789 pp 1358-1359, June 1967.

7 Sun Photometer for the Determination of Haze Extinction at = 0.5 Micron, Instructions for Measurement and Evaluation. (Mimeographed Booklet. 1963).

8 Gates, D.M., Spectral Distribution of Solar Radiation at the Earth's Surface. Science, 151:3710 pp 523-529. February 1966.

9 Flowers, E.C., McCormick, R.A., and Kurfis, K.R. Atmospheric Turbidity over the United States, 1961-1966.J. Appl.Meteor.8:955-962,December, 1969.

10 Bach, W. Variation of Solar Attenuation with Height over an Urbanized Area. JAPCA 21:10, pp 621-628, October 1971.

11 Atmospheric Turbidity and Precipitation Chemistry Data for the World-1972.Prepared by NOAA Environmental Data Service National Climatic Center, Federal Bldg. Asheville, N.C. 28801, January 1974 $2.75
Part I-Atmospheric Turbidity
Part II-Precipitation Chemistry
Part III-Delayed Data

12 World Meteorological Organization: WMO Operations Manual for Sampling and Analysis Techniques for Chemical Constituents in Air and Precipitation: WMO-No.299,1971.

13 Volz,F. Economical Multi-Spectral Sunphotometer for Measurements of Aerosol Extinction from 440nm to 1600 nm and Precipitable Water, J.Applied Optics, 13:8 p.1732, August 1974.

ATMOSPHERIC CHEMISTRY OF AIR POLLUTION

J. L. Dicke*

The solution of many air pollution problems involves utilizing knowledge of the chemistry of the atmosphere when it may be termed "clean" and when it is "dirty." Also, the nature of the air pollutants as they react as a whole must be determined. In general the two classes of polluted smogs are called either the London type - a reducing smog where contaminants form nuclei for condensation of water vapor into fogs -- or the Los Angeles type - an oxidizing smog where contaminants are photolysed to irritants.

I SOLAR RADIATION

The sun approaches a perfect blackbody radiator most closely in the region of 6000°K. Its maximum energy per wavelength occurs at 4500 Å, while its maximum photon emission occurs at 6000 Å. Photons produce many chemical and energy changes in matter at the molecular level upon absorption by upsetting vibrational, rotational and electronic balance. Vibrational and rotational changes occur mainly in the infrared region while electronic shifts need the higher energy of the ultraviolet range.

II PHOTOCHEMICAL REACTIONS

There are four main steps in a photochemical reaction which occur in time sequence: (1) Radiation, (2) Absorption, (3) Primary Reactions, and (4) Secondary reactions. We are mainly interested in substances which absorb photons in the 3000-7000 Å spectral region.

ABSORBERS	NON-ABSORBERS
O_2	N_2
O_3	H_2O
NO_2	CO
SO_2	CO_2
HNO_3 - HNO_2	NO

ABSORBERS	NON-ABSORBERS
RCHO	SO_3 - H_2SO_4
RCO	RCH
RCOO	RCOH
Particulates	RCOOH

III OXYGEN

The most important photochemical reactions involve the very reactive single oxygen atom.

$$O + O_2 \longrightarrow O_3$$

$$O + \text{Olefins} \longrightarrow \text{Several Fragments}$$

$$O + NO_2 \longrightarrow NO + O_2$$

$$O + SO_2 \longrightarrow SO_3$$

These atoms are produced by two main reactions:

$$\left.\begin{aligned} NO_2 + h\nu &\rightarrow NO + O \\ O_3 + h\nu &\rightarrow O_2 + O \end{aligned}\right\} \text{Major fragments of photochemical reaction in the atmosphere.}$$

Oxygen atoms are produced at the rate of 150 pphm hr^{-1}, but because of their reactivity, their stationary concentration in air usually is only 1-2 ppht (parts per hundred trillion).

IV OZONE

Ozone is very important as a reactant in photochemical type smog. It is produced through the photolysis of nitrogen dioxide and the reactive oxygen atom.

$$NO_2 + h\nu \rightarrow NO + O$$

*Supervisory Meteorologist, NOAA
Meteorology & Assessment Division, EPA

PA.ME.17a.S.63

$$O + O_2 \rightarrow O_3$$

Ozone is a strong oxidizer and its main atmospheric reactions are:

90% $O_3 + NO \rightarrow NO_2 + O_2$

Equal Rate
- $O_3 + NO_2 \rightarrow NO_3 + O_2$
- O_3 + Olefins → Free radicals, other organic fragments

V SULFUR DIOXIDE

Sulfur dioxide is the major sulfur containing compound formed during fuel combustion. Hydrogen sulfide is easily oxidized to sulfur dioxide in air especially in sunlight. In sunlight sulfur dioxide reacts with either atomic or molecular oxygen to form an aerosol particularly if water vapor is present. This aerosol is dilute sulfuric acid when uncontaminated with the particulates, etc., which are found in reducing type smogs. Sulfur Dioxide also reacts with organics to form various sulfonic acids which are also irritants. Relative humidity plays the most important role in photochemical reactions of sulfur dioxide by determining particulate-aerosol formation.

VI ORGANIC COMPOUND REACTIONS

The range of classes of organic compounds emitted from various processes and industries is very wide. Most of the higher molecular weight products settle rapidly, but short carbon chain molecules tend to be more reactive as ionic character outweighs the usual covalent nature of organic materials and they are very important as irritant progenitors. Absorption of photons often leads to dissociation into free radicals - short fragments with extra electrons which are extremely reactive. Olefins, aldehydes, ketones, peroxides, are classes which easily absorb photons and form free radicals and are among the usual products of combustion, especially from oil base fuels.

VII NITROGEN OXIDE REACTIONS

Oxides of nitrogen are formed in practically all combustion processes in air, but the diurnal peaks and valleys of concentration are a matter of concern in air pollution studies due to the high buildup in the morning hours within urban areas as vehicular traffic reaches a peak. The sequence of reactions

$$NO_2 + h\nu \rightarrow NO + O$$

$$O + O_2 \rightarrow O_3$$

$$NO + O_3 \rightarrow NO_2 + O_2$$

is the fastest, most important, and results in the highest concentrations of actual and potential irritant producing compounds in air pollution - atmospheric chemistry. Second in importance, photochemically, is olefin photolysis and ozone-organic molecule interaction. Other nitrogen oxide reactions of less importance are:

$$NO_2 + O_3 \rightarrow NO_3 + O_2$$

$$NO + NO_2 + H_2O \rightarrow 2\,HNO_2$$

$$N_2O_5 + H_2O \rightarrow 2\,HNO_3$$

VIII NON-PHOTOCHEMICAL REACTIONS

A secondary reaction following photochemical reaction which is very important is:

O_3 + Olefins → free radical fragments

Olefins are the most important beginning class of organic compounds for production of irritants and phytotoxicants.

Reaction with water vapor:

$$NO_x + H_2O \longrightarrow HNO_2 - HNO_3$$

$$SO_3 + H_2O \longrightarrow H_2SO_4$$

Other inorganic and organic classes of compounds are also emitted to the atmosphere such as: fluorides which quickly react with various surfaces, ammonia which forms acids, hydrogen sulfide which reacts with organics and forms sulfates, carbon monoxide which slowly oxidizes to carbon dioxide and organic amines which oxidize to acids. The above reactions are generally not of importance except in small localized areas.

IX PARTICULATE MATERIAL REACTIONS

Particulate matter is of an entirely different size category than we have examined thus far. As such, it provides reactive surfaces and can act as a third body and catalyst. Interaction with a particulate surface can cause either an energy level change or a complete chemical change.

Examples of the former are:

$O_{\lambda_1}2 + M \longrightarrow O_{\lambda_2}2 + M$ Change in absorption

$\cdot CH_3 + M \longrightarrow CH_3 + M$ Termination of free radical

Examples of the latter are:

$ZnO(M) + H_2O$ vapor $\xrightarrow{h\nu} H_2O_2 + M$

Catalyzed by photons

$SO_2 + H_2O$ drop $\longrightarrow H_2SO_3$ drop

$H_2SO_4 \cdot H_2O$ drop $+ CaCO_3 \longrightarrow CaSO_4 +$

$CO_2 + H_2O$ Change in particulate

X KINETICS IN ATMOSPHERIC CHEMISTRY

Without becoming involved in the rigors of kinetic theory, a few elementary definitions should be stated. The basis for determining the importance of any photochemical reaction, stationary concentration, rate of reaction, etc., is the Stark-Einstein Law which states that one photon must be absorbed to initiate photolysis. From this is defined the important equation:

$$k_a = \frac{I_a}{jc}$$

Where k_a is the specific absorption rate, I_a is the rate of absorption, j is a conversion factor, and c is the concentration of the absorbing substance. k_a represents the average fraction of absorbing molecules which receive photons per unit time. Primary quantum yield is very important as it tells us what percent of molecules that absorb photons will actually react to the absorbed energy via a specific process. Absorption of a photon may result either in energy level change, shown by fluorescence, or chemical change, shown by dissociation or direct reaction. The rate of formation of excited molecules A' is given by:

$$+\frac{d(A')}{dt} = I_a = k_a (A) = k_a c \quad \text{where}$$

(A) = c the concentration of the absorber.

For secondary photochemical reactions rate constant is important. For a bimolecular reaction $A + B \rightarrow C + D$ the decrease in concentration of A will be:

$$-\frac{d(A)}{dt} = k_1 (A)(B) \text{ where } k_1 \text{ is the rate}$$

constant of the reaction. In general, the larger the rate constant, the more probable and more important part the reaction plays in the atmosphere.

XI SUMMARY

Thus, a knowledge of what general reactions take place in the atmosphere under different meteorological conditions can help answer questions concerning relative importance of contaminating substances. From a meteorological point of view, relative humidity and percent possible sunshine are the most important parameters to consider. This is because nitrogen dioxide-olefin photolysis and the reactions which follow are sunshine dependent and the sulfur dioxide-particulate reactions are largely humidity dependent. Next to consider is precipitation which functions as a removal method and low wind speed which causes the atmosphere to function as a stable reaction vessel. Extremes of temperature either help catalyze photochemical reactions, as in Los Angeles, or enhance fog formation - particulate - SO_2 reactions, as in London.

The state of knowledge of atmospheric chemical reactions and interactions leaves a good bit to be desired as the subject is very complex. Experiments in all the areas discussed are increasing our knowledge and the total picture is slowly emerging.

REFERENCES

1 Altshuller, A.P. Reactivity of Organic Substances in Atmospheric Photooxidation Reactions. PHS Pub. No. 999-AP-14, July 1965.

2 Haagen-Smit, A.J. and Wayne, L.G. Atmospheric Relations and Scavenging Processes. Air Pollution 2 Ed. Vol. 1. Ed. A.C. Stern. New York Academic Press, 694 pp 1968

3 Hangebrauck, R.P., vonLehmden, D.J. and Meeker, J.E. Sources of Polynuclear Hydrocarbons in the Atmosphere. Public Health Service Publication No. 999 - AP-33, 1967.

4 Johnson, John C. Physical Meteorology, Ch. 4. Technology Press of M.I.T. 393 pages. 1954.

5 Leighton, Philip A. Photochemistry of Air Pollution. New York, Academic Press. 300 pages. 1961.

6 Magill, Paul L., Holden, F.R., Ackley, C. Air Pollution Handbook. Section 3. New York. McGraw Hill. 1956.

7 Meetham, A.R. The Behavior of Sulfur Dioxide in the Atmosphere. Atmospheric Chemistry of Chlorine and Sulfur Compounds. Geophysical Monograph No. 3. American Geophysical Union. 115-121. 1959.

8 Swearengin, R.D. Hydrocarbon Reactivity Search. General Motors Research Laboratories. Vol. 1 No. 3, May-June 1966.

9 Proceedings of the CACR Symposium.Tellus, Vol. 18, Nos. 2-3, 1966.

10 Friedlander, S.K. and Seinfeld, J. H. A Dynamic Model of Photochemical Smog. Environmental Science and Technology. Vol. 3. No. 11, 1175-1181. November 1969.

11. Altshuller, A.P., Bufalini, J.J. Photochemical Aspects of Air Pollution; A Review, Environmental Science and Technology, Vol. 5. No. 1, 39-64. January 1971.

12. Hydrocarbons and Air Pollution; An Annotated Bibliography. Parts 1 and 2. NAPCA Pub. No. AP-75, Jan. 1971.

13. Photochemical Oxidants and Air Pollution; An Annotated Bibliography. Parts 1 and 2. EPA. APCO Pub. No. AP-88, March 1971.

14 Bufalini, J.J. Oxidation of Sulfur Dioxide in Polluted Atmospheres- A Review Environmental Science & Technology. Vol. 5. No. 8, 685-700. August 1971.

15. Hecht, T.A. and Seinfeld, J.H. Development and Validation of a Generalized Mechanism for Photochemical Smog. Env. Sc.&Tech. Vol. 6, No. 1, 47-57, Jan. 1972.

16 Workshop on Mathematical Modeling of Photochemical Smog: Summary of the Proceedings. Ed. M.C. Dodge. EPA-R4-73-010 avail. from APTIC, RTP, N.C. 27711, 1973.

17 Stasiuk, W. N. Jr. and Coffey, P. E. Rural and Urban Ozone Relationships in New York State. JAPCA, Vol. 24, No. 6, 564-568, June 1974.

18 Coffey, P. E. and Stasiuk, W. N. Evidence of Atmospheric Transport of Ozone into Urban Areas, Env. Science & Technology Vol. 9, No. 1, 59-62, January 1975.

19 U.S. EPA. Investigation of Rural Oxidant Levels as Related to Urban Hydrocarbon Control Strategies. EPA-450/3-75-076, March 1975.

20 U. S. EPA. Control of Photochemical Oxidants Technical Basis and Implications of Recent Findings. EPA-450/2-75-005, July 1975.

NATURAL REMOVAL PROCESSES IN THE ATMOSPHERE

J. J. Fuquay*

I INTRODUCTION

All too often, atmospheric removal processes are considered to result in aggravating consequences such as depositions of fly ash, soiling of clothing and painted surfaces, and creating a general nuisance. However, these are the processes by which impurities are removed from the air such that the pollutant concentrations do not continually increase. Without such mechanisms, the atmosphere would ultimately become untenable. Table 3.

The removal of material from the atmosphere may occur in a number of different ways. Particles large enough and heavy enough will settle to the ground due to the action of gravity. Some gaseous material may be removed by adsorption upon particulate matter in the atmosphere or by chemical reactions changing the material into a new compound. Adsorption may also take place at the ground by the earth's surface or by vegetation. Impaction of particles onto buildings and vegetation and turbulent impaction upon the earth's surface are very significant removal processes. Precipitation also removes material from the atmosphere by interception of particulates by falling raindrops (washout) or by raindrop formation within clouds and subsequent falling as precipitation (rainout).

A Gravitational Settling

A freely falling particle within the size range found in dusts, smokes, and mists rapidly attains a constant or terminal velocity when the aerodynamic drag on the particle is equal to the weight of the particle. When the particle is of a size comparable with the mean free path of the gas molecules, bombardment by the molecules results in a random or Brownian. motion which is superimposed on its downward motion. In considering falling speed, it is desirable to take the simplest case of a rigid spherical particle falling independently of other particles and not so large as to cause inertia effects from the displaced gas to arise, then Stokes' law applies. A spherical particle of density D falling through a medium of density ρ is accelerated under the action of gravity with a force:

$$f = \frac{4}{3}\pi (D - \rho) r^3 g \qquad (1)$$

Equation (1) represents the difference between the unimpeded fall of the particle ($\frac{4}{3}\pi D r^3 g$), and the buoyant force of the air ($\frac{4}{3}\pi \rho r^3 g$). r is the radius of the particle and g the acceleration of gravity. The accelerating force is opposed by a frictional force arising from the viscosity of the air and the turbulence induced in the air by the passage of the drop. A measure of the turbulence is given by a dimensionless parameter, the Reynold's number, that enters in the theory of the flow of fluids. The Reynold's number is defined as:

$$R_e = \frac{2 \rho r v}{\mu} \qquad (2)$$

where v is the relative velocity of the particle to the air of density ρ and viscosity μ. 2 r is the principal cross-sectional dimension of the particle. The ratio:

$$\eta = \frac{\mu}{\rho}$$

is called the kinematic viscosity and has dimensions of $cm^2\ sec^{-1}$. The generalized resisting force on spheres has been found to be of the form:

$$f_r = 6\pi \mu r v \left(\frac{C_D R_e}{24}\right) \qquad (3)$$

*Batelle-Northwest, Pacific Northwest Laboratory, Richland, Washington

C_D is called the drag coefficient and is the constant of proportionality between the measured force fr and the physical quantities in the equation. For low Reynold's numbers, $R_e < 1$, $C_D R_e/24 = 1$, and equation 3 becomes:

$$f_r = 6\pi \mu r v \qquad (4)$$

Equation 4 is called Stokes' Law.

C_D is not a constant but is a function of the Reynold's number. However, since C_D varies only slowly with r and v, it is useful to use equation 2 to write equation 3.

$$f_r = \frac{\pi}{2} C_D \rho r^2 v^2 \qquad (5)$$

Thus, over a limited range of r and v, an average value of C_D may be selected.

Freely falling particles accelerated by a force given by equation 1 are opposed by a constantly resisting force given by equation 3. A point is reached where the two forces balance one another and equilibrium exists. At this point, the velocity reaches a maximum, called the terminal velocity. By equating equation 1 and 3, the terminal velocity v_T becomes:

$$v_T = \frac{2}{9} \frac{(D - \rho)}{\mu} g \left(\frac{24}{C_D R_e} \right) r^2 \qquad (6)$$

For most of our applications, $D \gg \rho$ so that $D - \rho = D$ to all practical limits. When Stokes' Law is followed (valid for unit density particles in air for $r \leq 40$ microns) equation 6 becomes:

$$v_T = \frac{2}{9} \frac{Dg}{\mu} r^2 = \frac{1}{18} \frac{Dg}{\mu} a^2 \qquad (7)$$

Calculation of v_T by equation 7 is straightforward. Once Stokes' Law has become invalid, the calculation of v_T from equation 6 becomes tedious because v_T is explicit in the definition of R_e and implicit in the definition of C_D. Table 1 gives values of a, R_e, and v_T for unit density spheres at sea level pressure.

Table 1.* A Short Table of Terminal Velocities, Reynold's Number, and Correction Terms to Stokes' Law for Unit Density Spheres

Diameter (microns)	$\frac{C_D R_e}{24}$	v_T (cm/sec)	R_e
20	1.00	1.24	0.017
50	1.00	7.72	0.268
80	1.00	20.	1.11
200	1.68	72	9.61
400	2.98	162	43.2
800	5.94	327	175
1200	9.41	464	372
2000	18.7	649	866

*Physical Meteorology - J.C. Johnson, Wiley and Sons 1954. Page 230.

Thus, particles large enough or dense enough to have appreciable terminal velocities will fall to the ground within rather short travel distances, depending on their height of release. This process constitutes a significant removal process for very large particles, of fly ash or dusts from cement plants. Because of the inertia of these particles, their reaction to the turbulence in the atmosphere is retarded. Also, because of their settling, they are in motion relative to specific eddies. Therefore, the action of settling actually changes the diffusion of these particles relative to what would occur with gases.

The concentrations in air of an effluent released from a single source can be expressed in the Gaussian form:

$$X = \frac{Q}{\pi \sigma_y \sigma_z \bar{u}} \exp \left[-\frac{1}{2} \left(\frac{y^2}{\sigma_y^2} + \frac{H^2}{\sigma_z^2} \right) \right] \qquad (8)$$

Where:

X represents the concentration in gm/m^3

Q represents the source strength in gm/sec

$\bar{u}$ represents the mean wind speed in m/sec

y represents the distance crosswind from the plume axis in meters

H represents the source height in meters

σ_y^2 σ_z^2 represents dispersion coefficients in m^2

This equation describes the distribution of concentration only when there are no processes depleting the cloud. One method used for correcting this equation for deposition amounts to permitting the diffusing plume to settle at the average terminal velocity of the particles as the material travels downwind (see p. 93, Meteorology and Atomic Energy). Thus, the height of emission is decreased with distance according to the settling velocity. The corrected emission height is then substituted into the diffusion equation. The corrected height of emission, H', is given by the following equation:

$$H' \text{ (meters)} = H \text{ (meters)} - \frac{v \text{ (m/sec)} \times x \text{ (m)}}{\bar{u} \text{ (m/sec)}} \qquad (9)$$

Where H is the effective stack height of the source, v is the settling velocity determined by Stokes' Law, x is the distance downwind, and $\bar{u}$ is the mean wind speed. Van der Hoven (1962) used a deposition model of the tilted plume type to estimate the deposition from ground tested nuclear engines. As explained by Csanady (1957), the tilted plume model should have a further correction for the source strength term for loss by deposition.

B Diffusion to the Surface and Impaction

Generally, only particles in the size range greater than 10 microns have appreciable gravitational settling velocity. However, recent studies (Simpson 1961: Islitzer and Dumbauld, 1962) indicate deposition of micron and submicron particles upon the ground and vegetation may be considerable. Accounting for deposition of these smaller particles requires extension beyond the simple gravitational settling model.

Using the concepts presented by Chamberlain (1953) along with extensions reported by Healy (1957), a reasonable model can be developed. For these small particulates, deposition from the cloud to the ground is conceived as a process limited by meteorological diffusion and processes of impaction and sticking to objects on the ground rather than the settling of particles through the influence of gravity. It is visualized that the particles are brought through the boundary layer to the ground by the turbulent diffusion process. They then deposit on vegetation or other objects by inertial impaction and diffusion and stick by electrostatic forces, chemical attraction or other means. Investigations of this process in the neutral atmospheric condition assuming that the transfer coefficients for mass and momentum are equal indicates that the velocity of deposition should vary with wind speed. There is also evidence that the velocity of deposition changes with atmospheric stability. Data on the velocity of deposition of Iodine-131 at Hanford and from experiments conducted by the English have indicate indicated a value of about 2.7 cm/sec. Calculations based on the equivalence of mass and momentum transfer coefficients during neutral conditions yield about the same value. Measurements of the velocity of deposition of fission products from arc burned uranium have indicated that the velocity of deposition of these particles is considerably lower, on the order of 0.1 cm/sec.

Gifford and Pack (1962) recently published an evaluation of most of the experimental data obtained to date on deposition velocities of interest in nuclear safety studies.

Major conclusions were that the deposition velocities for active materials such as Iodine-131, sulfur dioxide, and ruthenium on flat plates or bare soil is less than 1 cm/sec and is between 1 and 3 cm/sec for deposition on vegetation. Also, it was concluded that the average deposition velocity of inert materials such as Cesium-137 and Strontium-90 on flat plates and vegetation is less than 0.1 and 0.1-0.2 cm/sec, respectively. These results are quite consistent, indicating that for particles of diameter less than 10-15 microns, the relative effects of impaction, diffusion, and absorption are more important than the widely varying gravitational settling velocities.

It is postulated that the particles are brought to the ground by turbulent diffusion where the iodine reacts with the vegetation to absorb strongly on the surface. The small smoke particles must depend on impaction or some other process to stick. Thus, although the rate of transfer of both materials to the ground was the same, the velocity of deposition was different because of the difference in retention.

Chamberlain (1953) bypasses these effects, and simplifies the problem by defining a deposition velocity V_g, as:

$$V_g = \frac{\text{amount deposited/cm}^2 \text{ per sec}}{\text{volumetric concentration above the surface}} \qquad (10)$$

This definition may be expressed in the integral form as:

$$V_g = \frac{\text{total deposition/cm}^2}{\text{dosage/cm}^3} \qquad (11)$$

Thus, the deposition becomes:

$$w(x,y) = X\ V_g \qquad (12)$$

To account for depletion of material from the cloud, the equation must satisfy mass continuity principles such that:

$$\int_0^\infty \int_0^\infty X\ V_g\ dy\ dx = Q \qquad (13)$$

This equation is analytic in the first integration, but the resulting equation from combining (13) and (8):

$$I = \int_0^\infty \frac{V_g}{\sqrt{\pi}\,\sigma_z\,\bar{u}} \exp -\tfrac{1}{2}\left(\frac{H^2}{\sigma_z^2}\right) d_x \qquad (14)$$

can be solved analytically if σ_z can be expressed in terms of x.

To account for cloud depletion resulting from the deposition, the constant source strength, Q, is replaced by a quantity Q_x, depending on x, which is defined so that:

$$\frac{\partial Q_x}{\partial_x} = -\int_{-\infty}^{\infty} w(x,y)\ dy \qquad (15)$$

Q_x is the total depletion to a distance x. Again, it is necessary to employ explicit relationships for the dispersion in order to derive specific deposition formulae.

C Removal by Rainfall - Rainout

The cleansing of the air by rain is an everyday experience and is one of the most important scavenging mechanisms in the atmosphere. In an analysis of rain scavenging of radioactive particulate matter from the atmosphere, Greenfield (1957) found that the direct interaction of raindrops and particles does not account for the efficient removal of material whose diameter is below approximately one micron. However, he was able to explain the removal of smaller particles by allowing them to mix with the water cloud before the rain starts. The small particles that are scavenged by coagulation are then placed in a position to be more efficiently removed by the rain.

Our present knowledge is still inadequate to provide anything beyond a suggestion of the scavenging processes in the atmosphere for such finely divided material as radioactive debris. Evidence from world-wide fallout studies suggests that the very small fission products become attached to the natural aerosol particles and then have a history in the atmosphere similar to that of the host. The time required for such a coalition to near completion is not known, but one would expect it to be as rapid as the coagulation with larger water droplets because of the relative differences in mean free paths. Junge (1958) suggests that the predominant cause of the modification in size-distribution of the stratospheric aerosols on the way down through the troposphere is the repeated cycle of condensation and evaporation of clouds, a process requiring considerable time. Thus, the scavenging mechanism for small particles is envisioned as cloud-droplet-scavenging coupled with later scavenging of the cloud droplets by larger raindrops. The amount of activity that will fall out as rain will depend upon the time of mixing of the contaminant and the cloud elements and the rate at which the cloud elements are swept from the cloud by larger raindrops.

Barad, Haugen, and Fuquay (1960) made estimates of some of these scavenging parameters. The effective scavenging constants, that is, the time required for the number of particles to decrease to 1/e of the initial value, for the contaminant activity in the presence of cloud droplets characteristic of stratus and cumulus cloud conditions were computed from Greenfield's curves, assuming that the activity was proportional to the volume of the particle. The cloud characteristics used by Greenfield compared favorably with later data reported by aufm Kampe and Weickman (1957) and were not altered. The calculated times required for one-half the activity from the air to enter the cloud droplets, that is, the scavenging constant Φ, is shown in Table 2.

The amount of activity that will fall out as rain will depend upon the time of mixing of the contaminant cloud elements and the rate at which the cloud droplets are swept from the cloud by larger raindrops. This latter aspect was studied by Chamberlain using Langmuir's theory (1948) of the formation of raindrops by coalescence with smaller raindrops and Best's (1950) relationship between raindrop size and rainfall rate. Results of Chamberlain's study applicable to this type of scavenging are also summarized in Table 2. The scavenging of materials by clouds can only occur at heights at which clouds form. The heights of the various types of clouds vary within wide limits. However, scavenging by stratus clouds should be limited to 5000 feet and below, whereas scavenging by cumuliform clouds can occur at any height between 2000 feet and the tropopause.

Table 2. Parameters for Cloud-Droplet Scavenging of Particulate Cloud and Precipitation Scavenging of Cloud Droplets

Height interval	Cloud type	Rainfall rate (mm/hr)	Scavenging constant, Φ (sec^{-1})	Elimination constant, (sec^{-1})
500- 5,000 feet	Stratus	0.5	5×10^{-6}	2×10^{-4}
5,000-35,000 feet	Cumulus	3.5	6×10^{-5}	1×10^{-3}

D Removal by Rainfall - Washout

Calculations for precipitation scavenging of materials released into the lower atmosphere usually consider only the interaction between the falling raindrop and the contaminant particles. However, the computed values correspond only approximately to the actual conditions, as the size of raindrops always show a spectral distribution. Best's curves contain mean values. Large deviations from this curve are found in individual rains with the extreme range in rainfall rate for a given mean drop size about a factor of two. In addition, the Langmuir theory is applicable to coalescence of waterdrops, with certain restrictions, and particle interception could be quite different, depending on the physical and chemical nature of the particle.

In an effort to clarify the scavenging processes in the lower layers of the atmosphere, a part of the total scavenging problem, Hanford meteorologists have been dispersing zinc sulfide into the air and measuring the amounts scavenged by both natural and artificial rain. Results thus far indicate a peak scavenging efficiency for raindrops of about 0.4 mm diameter and suggest a minimum scavenging efficiency for raindrops of 0.7-1.0 mm diameter for this material. This deviation from currently used theoretical calculations which predict a rather flat peak in efficiency for drops larger than 1.0 mm suggests that rainfall intensity as now related to rainfall type may not have as great an effect on washout values as previously thought.

In order to account for washout in the dispersion equations, we can write:

$$Q_r = Q \exp\left(-\frac{\Lambda x}{\bar{u}}\right) \qquad (16)$$

where Q_r is the source strength correction for the scavenged material. Since rain removes material from the whole cloud depth, the process can be likened to radioactive decay in that the entire cloud is affected uniformly rather than preferentially near the ground, and the shape of the cloud distribution function is not altered. In this case, the concentration from a ground level source becomes:

$$x = \frac{Q}{\pi \bar{u} \sigma_y \sigma_z} \exp\left(-\frac{\Lambda x}{\bar{u}}\right) \exp\left[-\left(\frac{y^2}{2\sigma_y^2} + \frac{z^2}{2\sigma_z^2}\right)\right] \qquad (17)$$

The amount of material deposited per second by rainout, w_r, is obtained by multiplying equation (17) by Λ and integrating with respect to z.

$$W_r(x,y) = \frac{Q\Lambda e^{-\frac{\Lambda x}{\bar{u}}}}{\sqrt{2\pi}\,\bar{u}\,\sigma_y} \exp\left[-\frac{y^2}{2\sigma_y^2}\right] \qquad (18)$$

Values of Λ, the washout per second, are the subject of considerable speculation, and observational data are only now becoming available.

E Scavenging in a Pollution Episode

Meetham (1956) has discussed some interesting aspects of the London smog of 5-9 December, 1952, in which about 4000 people died above the normal death rate in Greater London.

Much can be learned by studying the physics of fogs themselves. City fogs of this episode magnitude have an estimated chance of recurrence of about 2% in any given winter. They are persistent, of limited area and volume, and relatively homogeneous; but not too well understood. You will recall that daily measurements of smoke and sulfur dioxide were being made at this time, but little if anything was known regarding concentrations of trace constituents, such as vanadium

compounds, coal distillates, or aldehydes. Other materials, no doubt, present in the smog include sulphuric acid, carbon monoxide, hydrochloric acid, fluorides, and excess carbon dioxide. Consequently, the smog was greatly different in chemical composition from a relatively clear fog.

Meetham considered an area of 450 square miles in the London Basin containing about 8 million people. The fog covered the entire area to a height of about 500 feet. The temperature was near freezing so that the mass of air in this volume was 226 million tons. Material could diffuse from this volume upward at only a very slow rate because of the capping inversion above the fog. He estimated that the light and variable winds could have produced no more than one air change in about four days. Thus, he considered the region as a closed system in which to make estimates.

The air contained about 2,000,000 tons of liquid water as fog and 750,000 tons as vapor. The film of water on the ground, vegetation, and other objects was estimated to weigh 500,000 tons. The air also contained 380 tons of free smoke and 370 tons of free sulfur dioxide, not including any that was attached to or dissolved in fog droplets, or any other sulfur dioxide attached to smoke. The other impurities were not accounted for in the estimates.

About 70,000 tons of coal were burned each day in the region; releasing 1000 tons of smoke particles, 2000 tons of carbon dioxide, 140 tons of hydrochloric acid, and about 14 tons of fluorine compounds. Imperfect combustion of coal and motor vehicle exhaust contributed 8000 tons per day of carbon monoxide. In addition, 200,000 tons of carbon dioxide were emitted per day to be added to the 90,000 tons originally present.

Now, let us look at the heat balance. Essentially all of the heat from burning 70,000 tons of coal went into the fog volume and the heat equivalent of another 1400 tons of coal was added from the earth and surrounding air, which was warmer than the fog. This incoming heat was sufficient to warm the whole volume by 10°C per day, yet the temperature over the five days remained essentially constant. Fog behaves in the opposite way to a greenhouse so that radiation permitted this heat loss from the fog. If it had warmed up, the fog would have dissipated.

Another paradox is in the water balance. As in most persistent fogs, droplets of water are continually falling to the ground, and yet there is no reduction in the number of droplets in the air. In the London fog, the droplets had to fall through saturated air an average distance of 250 feet to reach the ground, a process would take about 6 hours. Thus, an estimated 800,000 tons of water per day left the fog and someway an equal amount replaced it.

Combustion of coal added some 35,000 tons per day and humans an additional 2000 tons. The remaining 763,000 tons per day, must have been evolved from evaporation from the ground. The heat coming up from the ground was sufficient to evaporate 18 million tons of water per day, so that it appears reasonable to assume that 4.3% of this heat was used for the evapoartion of water, which utlimately replenished the fog.

Thus, we have a somewhat plausible explanation of how fogs can persist in spite of apparently losing water and gaining heat.

Now let us examine the smoke balance. Smoke particles entered the fog at the rate of 1000 tons per day, and must have left at the same rate because a fairly steady equilibrium was maintained at 2.2 mg/m^3, or 380 tons in the whole region. The average smoke particles must have remained in the air for 380/1000 of a day or about 10 hours. Smoke particles are far too small to fall of their own weight as much as 250 feet in 10 hours. Meetham calculated that any smoke particle must collide with a fog droplet every couple of minutes or so and could have stuck to the droplet after

some 4-10 hours. There was considerable dirt on the pavement which may have been smoke originally.

In the sulfur balance calculation, he assumed a rate of 2000 tons of sulfur dioxide per day entering the fog, and left at the same rate, maintaining a fairly steady equilibrium of 370 tons in the air. The average free life of a sulfur dioxide molecule would, therefore, be 370/2000 of a day or 4.5 hours. He considers that a few sulfur dioxide molecules were dissolved in the water on ground, vegetation, etc., but most of them were removed by the fog droplets, whose total surface area was about 170,000 km^2 compared with only 1160 km^2 of ground. The average sulfur dioxide molecule spent, perhaps, 0.05% of its time dissolved in fog droplets, moving freely in and out of them. Eventually, after a free life of 4.5 hours, during which about 8 seconds were spent within droplets, it became oxidized within a droplet, and remained fixed there as sulphuric acid. Six hours later, on the average, the droplet fell to the ground. If these calculations are correct, the mass of sulphuric acid in equilibrium in the fog must have been 800 tons. Its concentration was 4.5 mg/m^3 in the air, and, on the average, the fog droplets were a 0.4% solution of sulphuric acid.

Chlorine from coal entered the air in the form of hydrochloric acid at a rate of 140 tons per day. It was quickly dissolved in the fog droplets, remaining in the air an average of 6 hours. Its concentration was 0.2 mg/m^3 in the air or 0.02% in the fog droplets. Fluorine was present in about one-tenth of these amounts.

Oxides of carbon are not scavenged effectively and probably increased steadily throughout the period of fog. It was calculated that carbon dioxide reached a maximum concentration in the air of 0.4% by weight, or ten times its natural concentration. The concentration of carbon monoxide was calculated to be 180 mg/m^3 or 0.07% by weight.

REFERENCES

1 aufm Kampe, H.J. and Weickmann, H.K. Physics of Clouds. Met. Monographs. 3:182-225. No. 18. 1957.

2 Barad, M.L., Haugen, D.A., and Fuquay, J.J. A Diffusion-Deposition Model for In-Flight Release of Fission Fragments. Air Force Surveys in Geophysics. No. 123. June 1960. (TN-60-60-400)

3 Best, A.C. The Size Distribution of Raindrops. Quart. Journ. Roy. Met. Soc. 76:16-36. 1950.

4 Chamberlain, A.C. Aspects of Travel and Deposition of Aerosol and Vapor Clouds. A.E.R.E., HP/R 1261 H.M.S.O. 1953.

5 Csanady, G.T. Dispersal of Dust Particles from Elevated Sources. Aust. J. Phys. 10. 559. 1957.

6 Gifford, F.A., and Pack, D.H. Surface Deposition of Airborne Material. Nuclear Safety. 3:76-80. June 1962.

7 Greenfield, S.M. Rain Scavenging of Radioactive Particulate Matter from the Atmosphere. Journ. of Meteor. 14:115-125. No. 2. 1957.

8 Healy, J.W. Calculations on Environmental Consequences of Reactor Accidents. HW-54128. December, 1957.

9 Islitzer, N.F., and Dumbauld, R.K. Atmospheric Diffusion-Deposition Studies Over Flat Terrain. Presented at the National Meeting of the American Meteorological Society. Jan. 22-26. New York, New York. 1962.

10 Junge, C.E. Advances in Geophysics. 4: Ch. I. 1958.

11 Langmuir, I. The Production of Rain by a Chain Reaction in Cumulus Clouds at Temperatures Above Freezing. Journ. of Meteor. 5:175-192. 1948.

12 Meetham, A. R. Atmospheric Pollution. Pergamon Press. 266-272. 1956.

13 Simpson, C.L. Some Measurements of the Deposition of Matter and Its Relation to Diffusion from a Continuous Point Source in a Stable Atmosphere. HW-69292 REV. Richland, Washington. 1961. 26pp.

14 Meteorology and Atomic Energy 1968. D. H. Slade, Ed., U.S. Atomic Energy Commission, Division of Technical Information. TID-24190, July 1968.

15 Van der Hoven, I. A Diffusion-Deposition Model for Particulate Effluents from Ground-Tested Nuclear Engines. Presented at the Fourth Conference on Applied Meteorology. American Meteorological Society. Sept. 10-14. Hampton, Virginia 1962.

16 Hales, J. M., Thorp, J. M., Wolf, M. A. Theory and Field Measurements of Sulfur Dioxide Washout from an Elevated Plume. Conference on Air Pollution Meteorology, Raleigh, N. C., April 5-9, 1971.

17 Engelmann, R. J. Scavenging Prediction Using Ratios of Concentrations in Air and Precipitation, Journal of Applied Meteorology. Vol. 10. No. 3, 493-497, June, 1971.

18 Hales, J. M. Fundamentals of the Theory of Gas Scavenging by Rain. Atmos. Environment Vol. 6, No. 9, pp. 635-660. September 1972.

19 Dana, M. T., Hales, J. M., Slinn, W.G.N. and Wolf, M. A. Natural Precipitation Washout of Sulfur Compounds from Plumes. E.P.A. R-3-73-047, June 1973.

20 Dingle, A. N. and Lee, Y. An Analysis of In-Cloud Scavenging. J. Appl. Meteor. Vol. 12, No. 8; 1295-1302, December 1973.

21 Hales, J. M. Wolf, M. A. and Dana, M. T. A Linear Model for Predicting the Washout of Pollutant Gases from Industrial Plumes. AICLE Journal, Vol. 19, No. 2:292-297, March 1973.

22 Hutcheson, M. R. and Hall, F. P. Jr. Sulfate Washout from a Coal Fired Power Plant Plume. Atmos. Env. Vol. 8 No. 1:23-28, January 1974.

23 Owers, M. J. and Powell, A. W. Deposition Velocity of Sulfur Dioxide on Land and Water Surfaces Using a ^{35}S Tracer Method. Atmos. Env. Vol. 8, No.1:63-67, January 1974.

24 Shepherd, J. G. Measurements of the Direct Deposition of Sulfur Dioxide Onto Grass and Water by the Profile Method.Atmos. Env. Vol.8, No. 1:69-74, January 1974.

25 Garland, J. A., Atkins, D.H.F. Readings C. J. and Caughey, S. J. Deposition of Gaseous Sulfur Dioxide to the Ground. Atmos. Env. Vol.8, No. 1:75-79, January 1974.

26 Slinn, W. G. N. The Redistribution of a Gas Plume Caused by Reversible Washout. Atmos. Env. Vol. 8, No. 3: 233-239, March 1974.

27. U.S. EPA Sources and Natural Removal Processes for Some Atmospheric Pollutants. EPA-650/4-74-032, June 1974.

28. Högstrom U. Wet Fallout of Sulfurous Pollutants Emitted from a City During Rain or Snow. Atmos. Env. Vol. 8, No. 12:1291-1303.

29 Israel, G. W. Deposition Velocity of Gaseous Flourides on Alfalfa. Atmos. Env. Vol. 8 No. 12:1329-1330, December 1974.

30. Scriven, R. A. and Fisher, B.E.A. The Long Range Transport of Airborne Material and its Removal by Deposition and Washout - I. General Considerations II. The Effect of Turbulent Diffusion. Atmos. Env. Vol.9, No.1:49-68, January 1975.

31 Forland, E. J. And Gjessing, Y. T. Snow Contamination from Washout, Rainout and Dry Deposition. Atmos. Env. Vol. 9 No. 3:339-352, March 1975.

32 Li, T-A., and Landsberg, H. E. Rainwater pH Close to a Major Power Plant. Atmos. Env. Vol. 9, No. 1, 81-88, January 1975.

Table 3. SUMMARY OF SOURCES, ANNUAL EMISSION, BACKGROUND CONCENTRATION AND MAJOR SINKS OF ATMOSPHERIC GASEOUS POLLUTANTS

Pollutant	Major Source		Estimated Emission, Kilogram		Background Concentration ug/m^3	Major Identified Sinks
	Anthropogenic	Natural	Anthropogenic	Natural		
SO_2	Combustion of coal and oil	Volcanoes	65×10^9	2×10^9	1-4	Scavenging; Chemical reactions; soil and surface water absorption; Dry deposition
H_2S	Chemical processes; Sewage treatment	Volcanoes; Biological decay	3×10^9	100×10^9	0.3	Oxidation to SO_2
N_2O	None	Biological decay	None	590×10^9	460-490	Photodissociation in stratosphere; Surface water and soil absorption
NO	Combustion	Bacterial action in soil; Photodissociation of N_2O and NO_2	53×10^9 Combined with NO_2	768×10^9	0.25-2.5	Oxidation to NO_2
NO_2	Combustion	Bacterial action in soil; Oxidation of NO			1.9-2.6	Photochemical reactions; Oxidation to nitrate; Scavenging
NH_3	Coal burning; fertilizer; waste treatment	Biological decay	4×10^9	170×10^9	4	Reaction with SO_2; Oxidation to nitrate; Scavenging
CO	Auto exhaust and other combustion process	Oxidation of methane; Photo dissociation of CO_2; Forest fires; Oceans	360×10^9	3000×10^9 (?)	100	Soil absorption; Chemical oxidation
O_3	None	Tropospheric reactions and transport from stratosphere		(?)	20-60	Photochemical reactions; Absorption by land surfaces (soil and vegetation) and surface water
Non-Reactive hydrocarbons	Auto exhaust; Combustion of oil	Biological processes in swamps	70×10^9	300×10^9	CH_4=1000 non CH_4 <1	Biological action
Reactive hydrocarbons	Auto exhaust; Combustion of oil	Biological processes in forests	27×10^9	175×10^9	<1	Photochemical oxidation

ANALYSIS OF AIR QUALITY CYCLES

James L. Dicke*

There are several important factors to be considered in evaluating a time sequence of atmospheric pollutant concentrations. The periodic recurrence of similar pollutant levels may result in a rather smooth curve with time and be termed cyclic or the concentration levels may appear to be random. In either case it is important to have enough background data to analyze the types of cycles which may exist. This background information should consist of data on the following items:

1. Source variables
2. Meteorological variables
3. Atmospheric reactions and removal mechanisms
4. Geometry of sources and samplers

I TYPES OF CYCLES

The first two areas are most important in determining air quality cycles. In general the most important types of cycles are the daily and annual. Together these cycles represent the day to day variations and the long term, 20-30 year, averages of pollutant levels. The day to day variations are principally due to meteorological variables, if the weekday to weekend variation in industrial activity is excluded. The long term variations in pollutant concentration can be attributed to source variables since the climatology of an area will remain relatively constant.

Figure 1 represents a generalized daily cycle. The two assumptions inherent in this figure should be remembered: continuous emission and elevated source. The curve represents the effects of two stability regimes

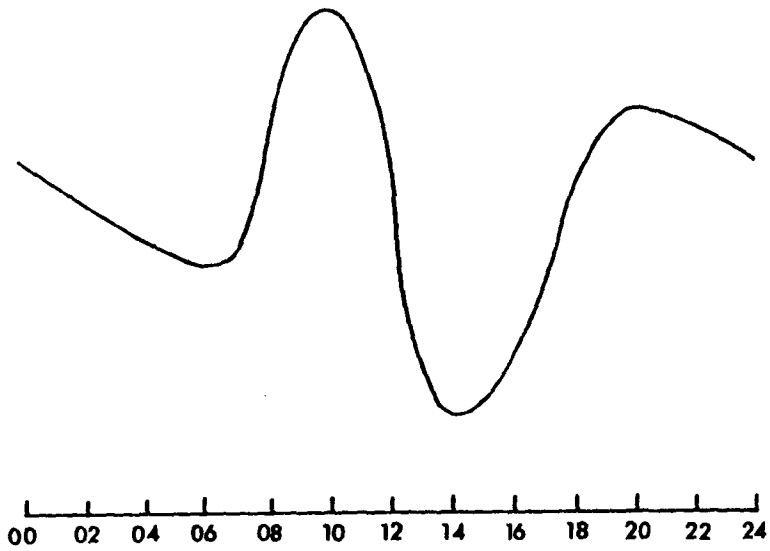


Figure 1. DAILY VARIATION OF GROUND-LEVEL CONCENTRATIONS FROM ELEVATED SOURCES

*Supervisory Meteorologist , NOAA
Meteorology & Assessment Division, EPA

P.P.A.Vol.9.75

in the lower atmosphere: stable conditions at night and unstable conditions in the afternoon. However, the cycles of many pollutants do not resemble each other as illustrated in Figure 2 for NO_2 and oxidant in California.[17]

The difference in daily curves between pollutants can best be understood by knowing the atmospheric reactions, methods of decay or half-life, and natural removal processes of the pollutants. Irregularities or peculiarities in pollutant cycles for specific locations can often be explained by being thoroughly familiar with both the meteorology and human activities of the community.

Annual or seasonal cycles of air quality also illustrate the inter-relationship of source and meteorological variables as shown in Figure 3.

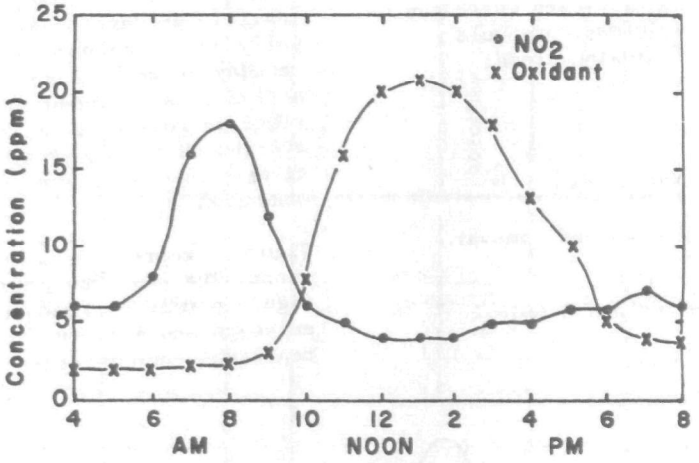


Figure 2. CONCENTRATION CYCLE OF NO_2 AND OXIDANT

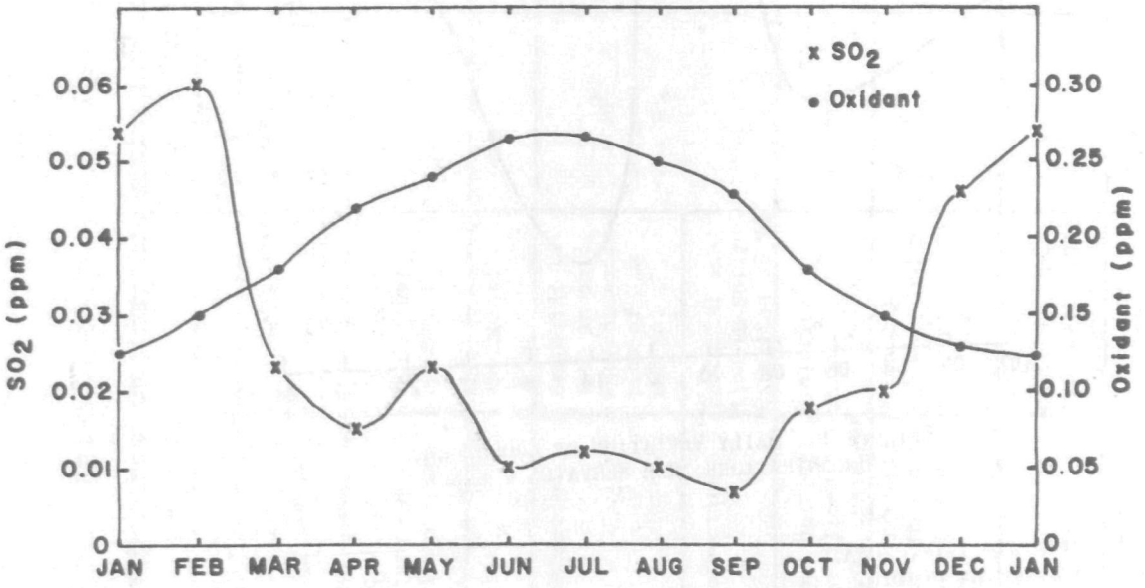


Figure 3. ANNUAL CYCLE OF SO_2 AND OXIDANT

If SO_2 emissions from industrial processes are considered fairly constant during the year, the annual curve of SO_2 concentration may be explained in terms of temperature or heating degree days.[12] Monthly averages of daily maximum oxidant concentration in California are primarily dependent on the amount and duration of sunshine and also high temperatures.[11] The annual cycle of maximum mixing depth in the atmosphere, wind speed, frequency of temperature inversions, and temperature will usually provide valuable information on interpreting the annual cycle of air quality in a community. Annual or seasonal cycles of air quality are more likely to be influenced by the geometry of the sampling network than are daily cycles. In most regions this is a function of meteorology, too, because the seasonal wind regimes may change by 180°.

II SAMPLING TIME

When planning an air pollution survey or pollutant sampling program, it is important to decide which of the two types of cycles, or both, is most important. Is the long-term effect of pollution being studied or are short-time peaks, e.g., 5 minutes, in concentration important? The answer will aid in determining both the sampling time and equipment to be used.

Short-time or spot sampling generally will not reveal pollutant cycles but may be used to determine the source of a particular pollutant or the contribution of a specific source to the general pollution level of the area.

Continuous sampling at fixed locations is best when the purpose of a study is to:

1 Determine the general level of pollution.

2 Determine improvement achieved by control measures.

3 Determine correlations between weather and different pollution levels.

4 Determine cycles of air pollutants with respect to the specific city.

III AVERAGING TIME

Another very important decision to be made concerns averaging time. This is the time duration over which either single air pollution samples are measured or a series of samples are grouped together to obtain a single measurement. Daily cycles, of course, cannot be ascertained from two, 12 hour samples, and compiling an annual curve from 20 minute samples is tedious and time consuming. Averaging time for samplers should be determined by:

1 Objectives of the study

2 Equipment limitations

3 Analytical threshold values

4 Facilities and manpower for analysis

Starting and ending time of samples becomes important when averaging times are more than two hours. Figure 4 illustrates the difference in average concentration when comparable length samples are taken beginning at different times of the day. A knowledge of pollutant variation may enable the averaging time to be lengthened from 5 to 20 minutes or 20 minutes to an hour depending on whether or not very short time peaks of concentration are important.

The effect of averaging time on measured SO_2 concentrations for several cities (one sampling station per city) is shown in Figure 5, as taken from reference 19. Relationships for other pollutants will vary, depending on source distribution and reactions in the atmosphere.

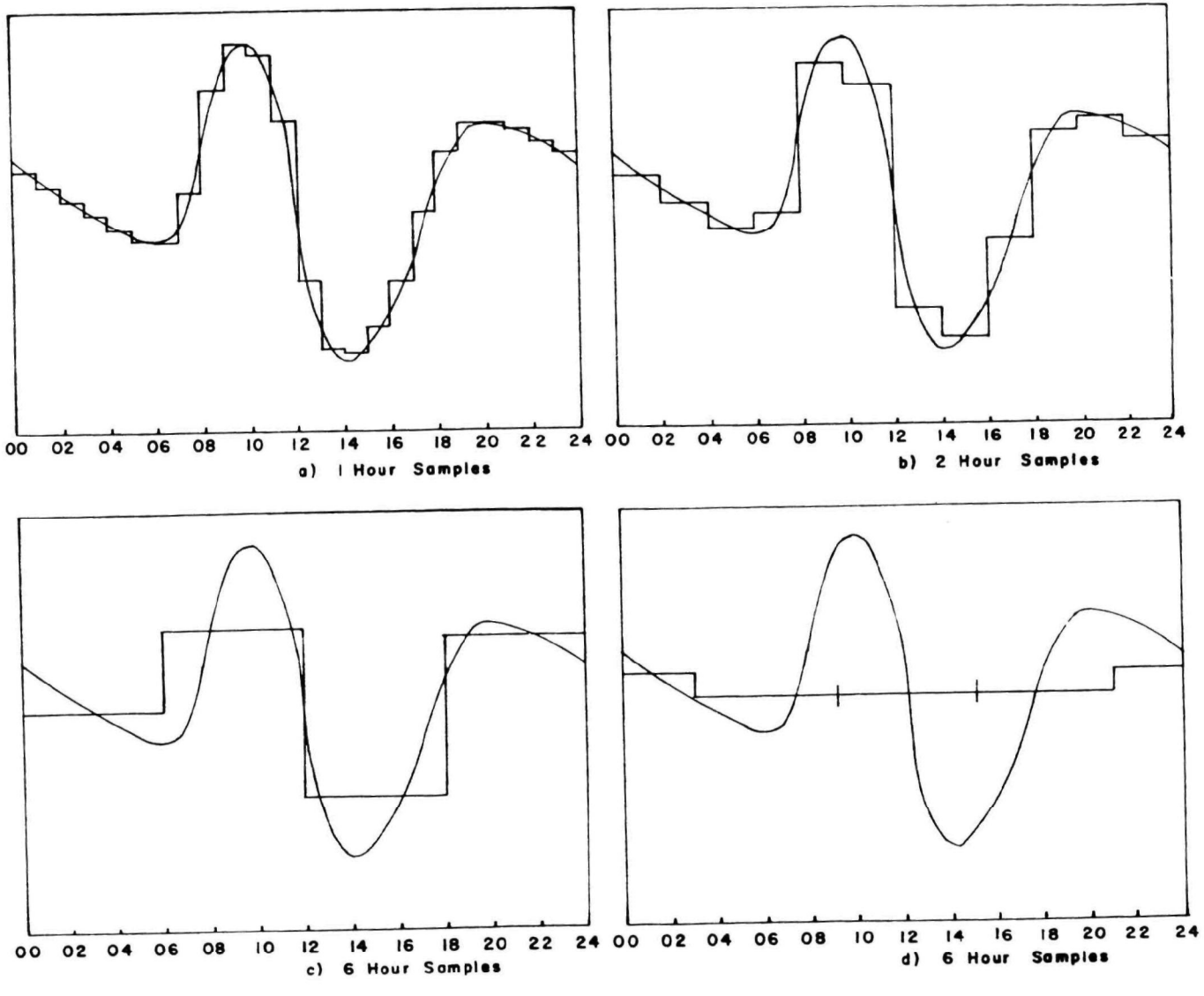
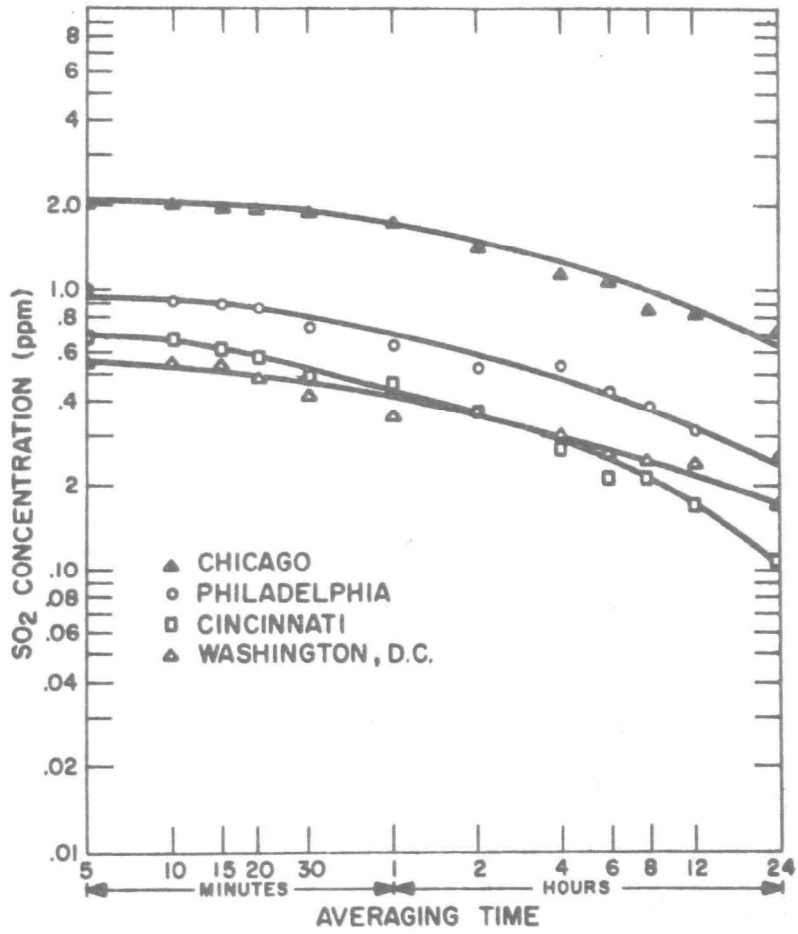


Figure 4. DAILY VARIATION OF GROUND-LEVEL CONCENTRATIONS FROM ELEVATED SOURCES – PROBABLE EFFECT OF SAMPLING DURATION AND START/END TIME.



MAXIMUM SULFUR DIOXIDE CONCENTRATION FOR SELECTED AVERAGING TIMES DECEMBER 1962 - JANUARY 1963

FIGURE 5

IV METHODS OF ANALYSIS

The methods of analysis used to evaluate and interpret data depend primarily on the aim of the pollution study. Three main considerations are:

1 Amount and type of data available.

2 Representativeness of the number of samples taken.

3 Required accuracy of the results.

Evaluation of data can be divided into two broad, and not mutually exclusive categories:

1 Comparative

2 Statistical

Examples of the first method are surveys during different periods of the year, improvement due to process changes or corrective measures, and comparisons of one locality with another to illustrate relative degrees of pollution. Sophisticated statistical methods would not be required in these cases.

Statistical methods are necessary to gain a deeper understanding of multiple influences on concentration variations. Statistical treatment of data aids in the evaluation of relative influences of a number of parameters, the significance of differences in concentration levels, and the correlation of two or more series of data.

One of the first steps in analysis should be to plot the data against time. This will emphasize any cycles present and also the length of period or times of daily maximum and minimum concentration. A few anomalies in the plot will occur, but for comparative evaluation these usually are not significant. Elementary statistical parameters which characterize the data and can easily be computed or approximated are the mean; or average value, the range or amplitude of values, the median or value which divides the data into an upper and lower half, and mode or most frequently observed value. Other plots of the data versus meteorological and source variables should be made to indicate where relationships occur which need further investigation. Plots which approximate straight lines are usually best candidates for future analysis. If short sampling time data, e.g., 5 minutes, have been averaged to give hourly values, the ratio of peak 5 minute concentration to the mean hourly value will give a qualitative idea of atmospheric stability during the sampling period. Under neutral stability conditions, 5 minute peak concentrations about twice the hourly mean can be expected. Under unstable conditions, 5 minute peak concentrations about four to five times the hourly mean will occur. If wind direction data are available, evaluation should be by frequency distribution in tabular form. The per cent frequency of a given concentration is entered with the corresponding wind direction that occurred at the time the samples were taken.

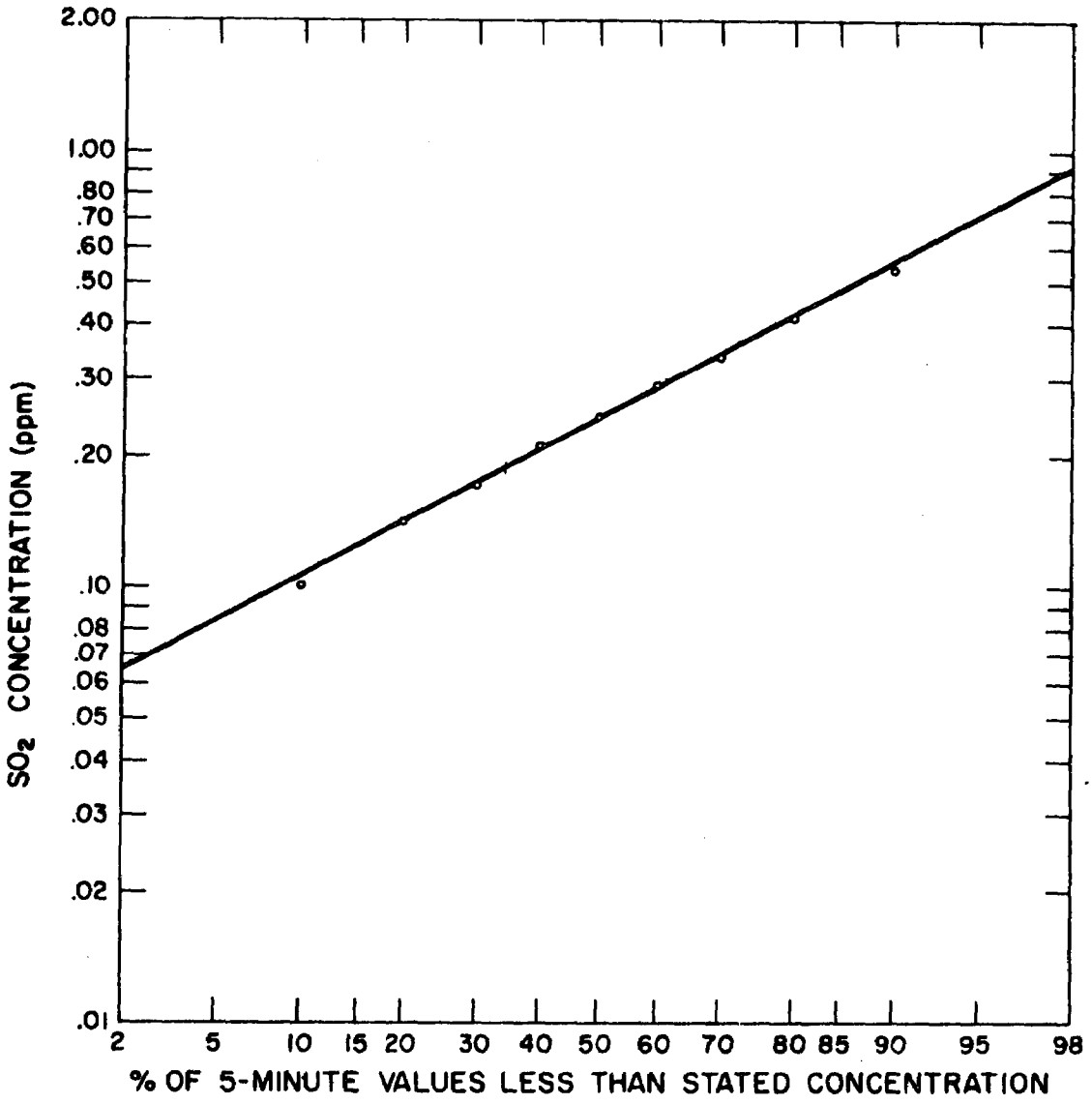
A common form of data representation used in air pollution work is the "cumulative frequency distribution" in which the logarithm of pollutant concentration is plotted as a function of frequency of occurrence. Frequency of occurrence is expressed as "percent of values equal to or less than a stated concentration". Typical data is shown in Figure 6.(19)

Cumulative frequency distribution of individual pollutants will exhibit different characteristics. This is illustrated by the data of Figure 7,(20) wherein the frequency scale has been changed to "percent of values equal to or greater than a given concentration".

In situations wherein the same pollutant is emitted from ground-level and elevated sources, the cumulative frequency distribution curve, especially for short survey periods, may take the form shown in Figure 8. (21)

A few of the parameters, in addition to those mentioned above, which are calculated for a statistical study include the standard deviation, variance, correlation and autocorrelation coefficients, and regression equation coefficients. Statistical analysis is best accomplished by computer methods.

Since measured air quality data are increasingly compared to air quality standards having several averaging times, Larsen (1971) has developed a model which is being used extensively. Figure 9 is an example of this technique. EPA has also published guidelines (1974 a.b.) which contain techniques for evaluating air quality data as well as trends in air quality. These techniques are used to portray and interpret the observed air quality of the nation and a report is issued annually (EPA, 1974 c.). Statistical aspects are discussed in a Symposium Proceedings (EPA, 1974 d) and a research report (EPA, 1975).



CUMULATIVE FREQUENCY DISTRIBUTION OF 5-MINUTE MEASUREMENTS OF SULFUR DIOXIDE CONCENTRATION CHICAGO, ILL., DECEMBER 1962 - JANUARY 1963

FIGURE 6

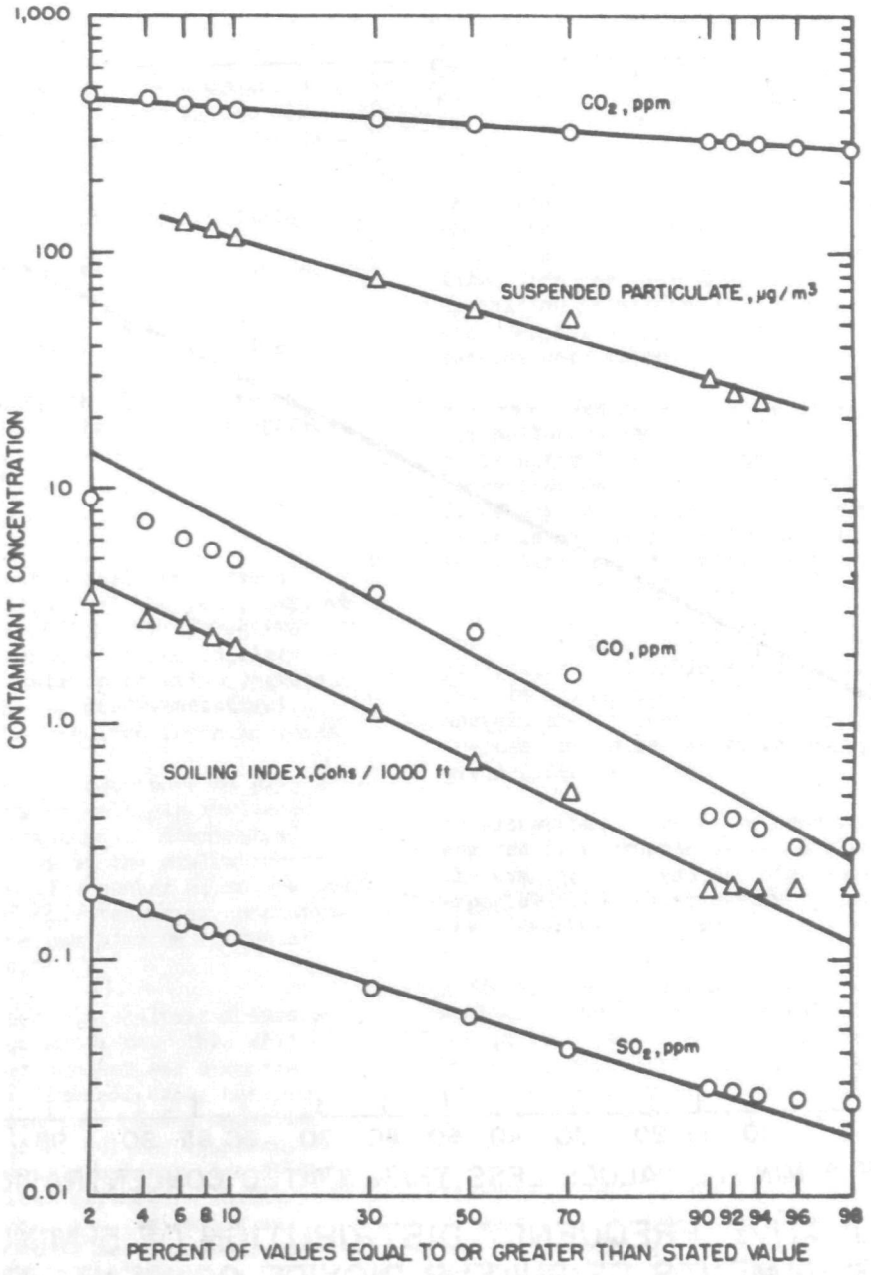


Figure 7. CUMULATIVE FREQUENCY DISTRIBUTION OF CONCENTRATIONS OF VARIOUS CONTAMINANTS

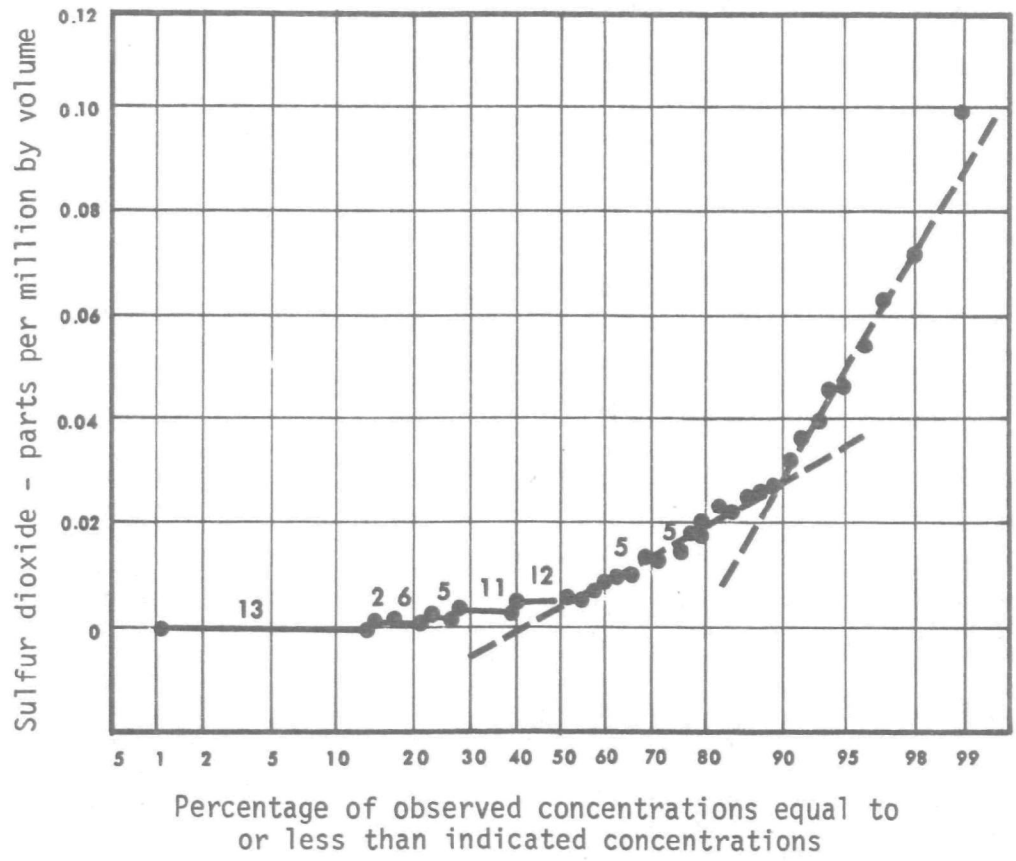


Figure 8. DISTRIBUTION OF OBSERVED SULFUR DIOXIDE CONCENTRATION - STATION A SEPTEMBER 5 - 13, 1961

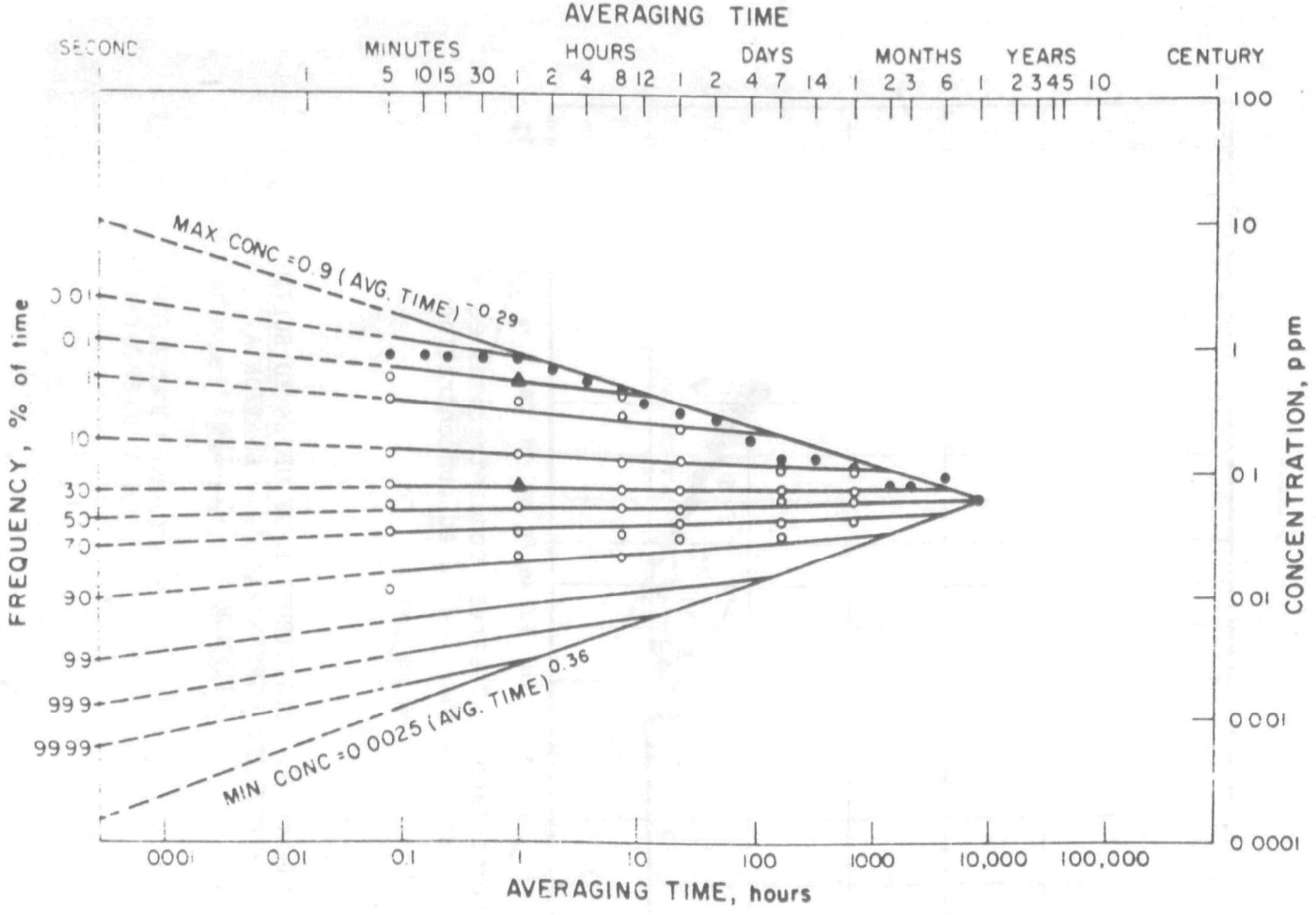


Figure 9. Frequency of various nitrogen oxides concentrations for various averaging times in Washington, D.C., 3/1/62 - 3/1/63.

REFERENCES

1 Bauleh, D. M. Relation of Gustiness to Sulfur Dioxide Concentration. J. of Air Pollution Control Assoc. 12:539-542. 1962.

2 Baynton, H. W. Multiple Correlations of Particulate Air Pollution with Weather Factors at Detroit and Winsor. Bull. Amer. Meteorol. Soc. 37:333. 1956.

3 Burt, E. W. A Study of the Relation of Visibility to Air Pollution. Amer. Ind. Hyg. Assoc. J. 22:102-108. 1961.

4 Davidson, W. F. A Study of Atmospheric Pollution. Mon. Wea. Rev. 70:10, 225-234. 1942.

5 Davis, F. K., Jr. The Air Over Philadelphia in Air Over Cities. Tech. Rep. A62-5. R. A. Taft Sanitary Engineering Center. Cincinnati, Ohio. 1962. pp 115-126.

6 Dickson, R. R. Meteorological Factors Affecting Particulate Air Pollution of a City. Bull. Amer. Meteorol. Soc. 42:556-560. 1961.

7 Hilst, G. R., and Bryan, J. G. Preliminary Meteorological Analysis of National Air Sampling Network Data Vol. I. Methods and Results. Vol. 2. Comparison and Interpretation of Results. The Travelers Research Center, Inc., Hartford, Conn. 1962.

8 Holzworth, G. C. Some Effects of Air Pollution on Visibility In and Near Cities in Air Over Cities. Tech. Rep. A62-5. R. A. Taft Santiary Engineering Center. Cincinnati, Ohio. 1962. pp 69-88.

9 Kanno, S., Fukui, S., Ikeda, H. and Ono, Y. Atmospheric SO_2 Concentration Observed in Keihin Industrial Center and Their Relation to Meteorological Elements. Int. J. Air Poll. 1:3, 234-240. 1959.

10 Larsen, R. I. Determining Basic Relationships Between Variables Presented at Symposium on Environmental Measurements. Cincinnati, Ohio. Sept. 4-6. 1963.

11 Markee, E. H., Jr. Relationship of an Air Quality Measurement to Meteorological Parameters. Amer. Ind. Hyg. Assoc. J. 20:50-55. 1959.

12 Munn, R. E., and Katz, M. B. Daily and Seasonal Pollution Cycles in the Detroit - Windsor Area. Int. J. Air Poll. 2-1, 57-76. 1959.

13 Munn, R. E., and Ross, C. R. Analysis of Smoke Observations at Ottawa, Canada. J. of Air Pollution Control Assoc. 11:9, 410-416, 443. 1961.

14 Summers, P. W. Smoke Concentrations in Montreal Related to Local Meteorological Factors in Air Over Cities. Tech. Rep. A62-5. R. A. Taft Sanitary Engineering Center. Cincinnati, Ohio. 1962. pp 89-112.

15 Magill, Paul L., Holden, F. R., and Ackley, C. Air Pollution Handbook, McGraw-Hill Book Company, Inc., New York, 1956. $15.00.

16 Stern, Arthur C. Air Pollution. Vol. I. Academic Press, Inc., New York. 1962. $18.00.

17 Leighton, P. A. Photochemistry of Air Pollution. Academic Press, III 5th Street, New York 3, New York. 1961. $9.90.

18 Los Angeles Air Pollution Control District. Monthly Reports of Meteorology, Air Pollution Effects and Contaminant Maxima - 1960.

19 Larsen, R. I., Zimmer, C. E., Lynn, D. A., and Blemel, K. G. Analyzing Air Pollutant Concentration and Dosage Data. JAPCA 17:2, 85-93, 1967.

20 Turner, D. B. The Diurnal and Day-to-day Variations of Fuel Usage for Space Heating in St. Louis, Mo. Atmos. Envir. 2, 4:339-352, July 1968.

21. Ripperton, L.A., Kornreich, L. and Worth, J.J.B. Nitrogen Dioxide and Nitric Oxide in Non-Urban Air. JAPCA 20:9, 589-592, 1970.

22. Larsen R. I. A Mathematical Model for Relating Air Quality Measurements to Air Quality Standards. OAP Pub. No. AP-89, November 1971.

23. U. S. EPA. Guidelines for the Evaluation of Air Quality Trends. OAQPS No.1.2-014 February 1974.

24. U. S. EPA. Guidelines for the Evaluation of Air Quality Data. OAQPS no. 1.2-015, February 1974.

25. U.S. EPA. Monitoring and Air Quality Trends Report, 1973. EPA-450/1-74-007, October 1974.

26. U. S. EPA. Proceedings of the Symposium on on Statistical Aspects of Air Quality Data. EPA-650/4-74-038, October 1974.

27. U. S. EPA. Studies of Pollutant Concentration Frequency Distributions. EPA 650/4-75-004, January 1975.

28. Kubin, F. S. The Influence of Annual Meteorological Variations on Regional Air Pollution Modeling; A Case Study of Allegheny County, PA. JAPCA Vol. 24, No. 4, 349-356, April 1974.

29. Knox, J. B. and Lange, R. Surface Air Pollutant Concentration Frequency Distributions: Implications for Urban Modeling. JAPCA, Vol.24,No. 1, 48-53, January 1974.

SECTION SIX

METEOROLOGICAL INSTRUMENTS

General Instrumentation Requirements
Meteorological Instruments
Exposure of Instruments
    Exposure of Surface Instruments
    Exposure of Instruments on Towers or Stacks
    Exposure of Airborne Instruments

General Instrumentation Requirements

Ronald C. Wilfiker

"Precision Instruments", "Handsome Walnut Console", "High Degree of Accuracy", "Rugged Construction", "Black Crackle Finish", "Corrosion Resistant", and "Ultra-sensitivity" are among the many descriptive phrases used in instrumentation catalogs. Some of these attributes should be considered in detail, while others may be stereotyped as "window dressing".

The purchase of an instrument requires the consideration of two classes of requirements:

1. General Instrumentation Requirements
2. Specific Objective Oriented Requirements

There are many instrumentation requirements that will obviously depend on the specific objectives of the study that the instrument is to support. There are, however, a number of instrument requirements that should be considered before the purchase of any instrument. It is the purpose of this section to describe these general requirements so that a buyer will be able to distinguish between the instrumentation attributes that are important, and those that are only "window dressing".

RELIABILITY

Reliability is possibly the most important criterion for an instrument in continuous use. Regardless of how accurately an instrument is calibrated and read, it must be reliable to give reproducible results.

ACCURACY

Accuracy is defined as the closeness of the instrument output reading to the true value of the parameter. The qualifications of an accurate instrument are as follows:

1. It is properly calibrated under known conditions
2. It has characteristics that are unchanging with time
3. The reactions of the instrument (dynamic response) to changes in the measured parameter are known to within the limits of error requirements

PRECISION

Precision is generally defined as the degree of closeness of a series of readings of an unchanging parameter. There often is confusion between the terms accuracy and precision. One way of clarifying their meanings is through the use of the "bulls eye" analogy. Figure 1 depicts this analogy.

SENSITIVITY

Sensitivity is defined as the smallest change in the measured variable that causes a detectable change in the output of the instrument.

Environmental Research and Technology, Inc.
Concord, MA 01742

PA.15.mm.20.9.71

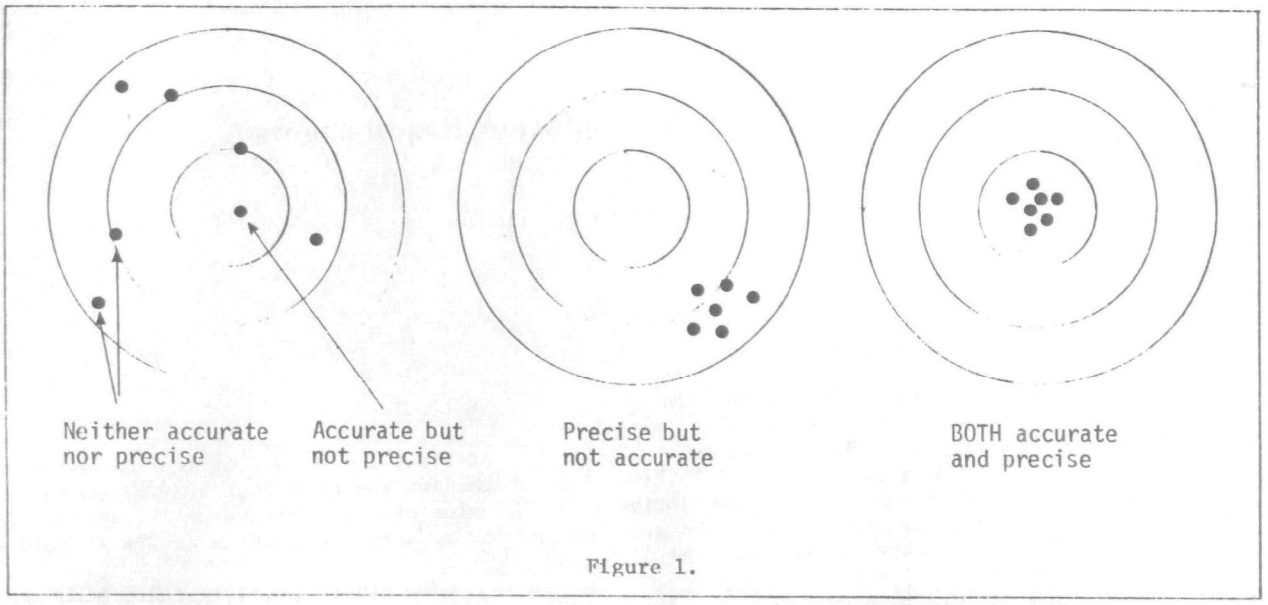


Figure 1.

SIMPLICITY

The lack of instrumentation experience among most observers makes this attribute a must for most meteorological instrumentation. The qualifications of a simple instrument are as follows:

1. Operational adjustments of the instrument should be simple
2. A simply written SOP manual should accompany the instrument
3. Adjustments that are not intended to be made by the purchaser should require a special tool

DURABILITY

Obviously, an instrument should be durable enough to survive vibrations and shock encountered in transportation, rough handling, etc. A meteorological instrument, in addition, should be able to perform reliably in all seasons of the year, and in a smoggy and corrosive atmosphere.

CONVENIENCE

Convenience of operation is definitely a must for an operational instrument. As a general rule, an instrument that is simple to operate is also convenient to operate.

Other requirements such as time constants, damping ratio, etc. are objective oriented, and will be covered in a later section.

METEOROLOGICAL INSTRUMENTS

Ronald C. Hilfiker

I INTRODUCTION

Measurement of atmospheric variables that affect the diffusion and transport of air pollutants is of necessity in nearly every air pollution investigation. Suitable measurements may be available from existing instrumentation at Weather Service city offices, airport stations, or from universities or industries with meteorological installations. Frequently, however, existing instrumentation does not give detailed enough measurements, is not representative of the area in question, or does not measure the variables desired (such as turbulence) and additional instruments must be operated.

Of primary importance in air pollution meteorology is the measurement of wind, both velocity (direction and speed) and the turbulence of the wind. The stability of the lower layers of the atmosphere in which the pollution diffuses is important and may be determined from an analysis of the turbulence characteristics of the atmosphere or the temperature lapse rate.

Of secondary importance is the measurement of humidity (which may affect atmospheric reactions), temperature, precipitation (of importance in washout of pollutants), and solar radiation (which affects photochemical reactions in the atmosphere). Particularly for research studies, it may be desirable to measure meteorological elements affected by pollutants, mainly: visibility, solar radiation, and illumination (radiation in the visible region).

II WIND MEASUREMENTS

A Surface Instrumentation

1 Wind Speed

Generally, wind speed sensors are broken down into the following categories:

a Rotational Anemometers

1) Vertical Shaft

2) Horizontal Shaft

b Pressure Anemometers

1) Flat Plate Type Anemometer

2) Tube Type Anemometer

c Bridled Cup Anemometer

d Special Types

1) Hot Wire Anemometer

2) Sonic Anemometer

3) Bivane

4) UVW Anemometer

Pressure anemometers, hot wire and sonic anemometers have enjoyed extensive use in research type operations, but they all have disadvantages which have prohibited their use in operational type situations such as air pollution surveys. The rotational type anemometers are the most common type of wind speed sensor in use today mainly because they are the only types that satisfy all of the following desirable operational features:

a Essentially linear relationship between the sensor output and the wind speed.

b Calibration is unaffected by changes in the temperature, pressure or humidity of the atmosphere.

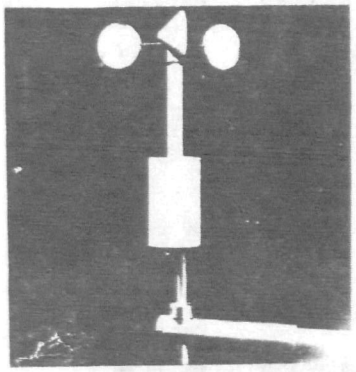
c Able to measure a wide range of wind speeds (<2 to ~ 200 mph [.9 to ~ 90 m/s]).

d Long term calibration stability. The calibration often is unchanged after 10 years continuous operation.

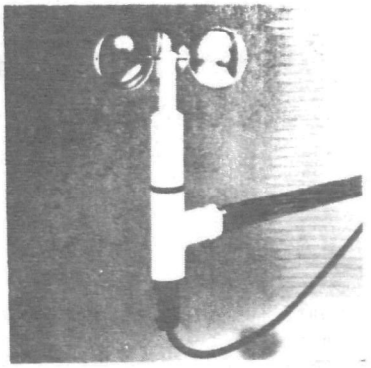
e Output of the sensor is easily adapted to remote indication.

f Recording of the wind speed data is easily adaptable to either analog or digital form.

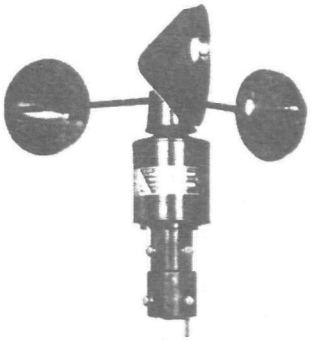
Environmental Research and Technology, Inc.
Concord, MA 01742



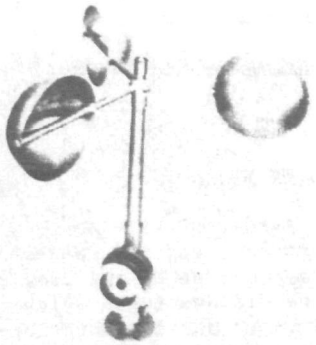
Climet Inst. Co. (a)



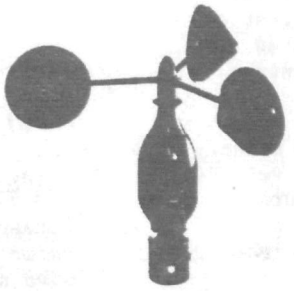
R.M. Young Co. (b)



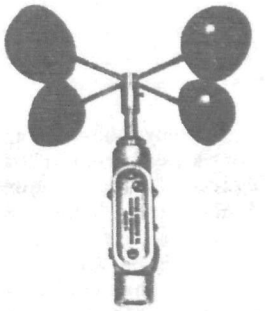
Belfort Inst. Co. (c)



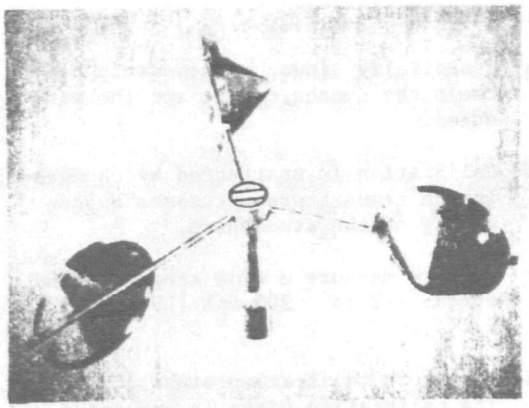
Henry J. Green Co. (d)



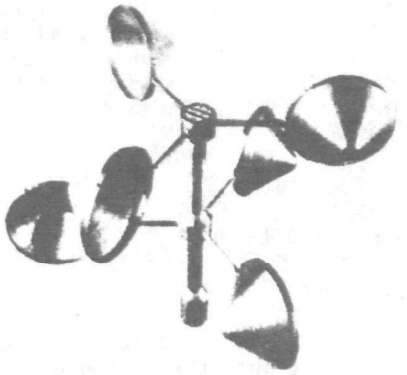
Electric Speed Indicator Co. (e)



Science Associates Inc. (f)



Teledyne-Geotech (Bkmn & Whtly) (g)



Teledyne-Geotech (Bkmn & Whtly) (h)

Figure 1 - Cup Anemometers

g Generally require extremely little maintenance.

Types

a Rotational Anemometers

1) Vertical Shaft - a cup anemometer revolving about a vertical shaft is probably the most commonly used anemometer in use today. The most common of the cup anemometers are the 3-cup types shown in Figure 1. Traditionally, anemometers have only had to yield average wind speeds for use in the support of aviation and weather forecasting operations. Sensors such as those in Figure 1c and 1e were developed with durability as the primary requirement. These cups are about 10 cm. in diameter, with a moment arm of about 42 cm.

These anemometers, due to their large mass, have a relatively high starting speed (that wind speed at which the cups first begin to rotate or reach the manufacturers accuracy specifications) of about 3 mph (1.4 m/sec). This factor of high mass combined with a long moment arm will also produce a high moment of inertia which tends to cause the cups to indicate erroneous wind speeds under gusty conditions. Not only will the instantaneous readings be in error, but because the cups accelerate faster than they decelerate, the mean speed indicated may be slightly higher than the true speed.

With the advent of environmental concern, an anemometer was needed that would measure light winds, which are of great importance in air pollution meteorology. Also, to support turbulence and diffusion studies, an anemometer was needed that would approach giving an instantaneous response to wind speed fluctuations. Lightweight anemometers such as those in Figure 1a, 1b, and 1g were developed for such purposes.

To provide accuracy at low speeds and greater sensitivity, these small 3-cup anemometers are lightweight in construction (plastic or very thin aluminum) and employ a relatively short moment arm. In addition, friction has been reduced by utilizing miniature ball bearings and special type transmitters. The cups are generally 5 cm. in diameter and have a moment arm of about 7 cm. The result of these design considerations is more accurate instantaneous and average windspeeds.

An attempt at further reducing the starting speed is shown in Figure 1h. This cup wheel design, employing six staggered cups, yields a greater surface area exposed to the wind. This factor decreases the starting threshold from .75 mph (.35 m/s) for the standard 3-cup of Figure 1g) to .4 -.5 mph (.2 - .25 m/s). This design also produces a more uniform torque around the entire shaft revolution.

2) Horizontal Shaft - The second most commonly used wind speed measuring system is one that has a propeller on the end of a horizontal shaft that is oriented into the wind by a vane on the opposite end of the shaft. A propeller anemometer is shown in Figure 2, and several pro-

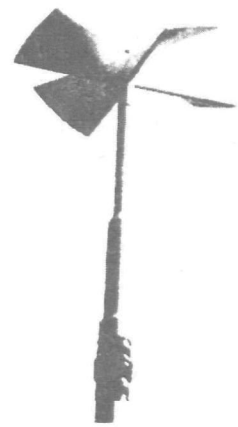


Figure 2 - Propeller Anemometer

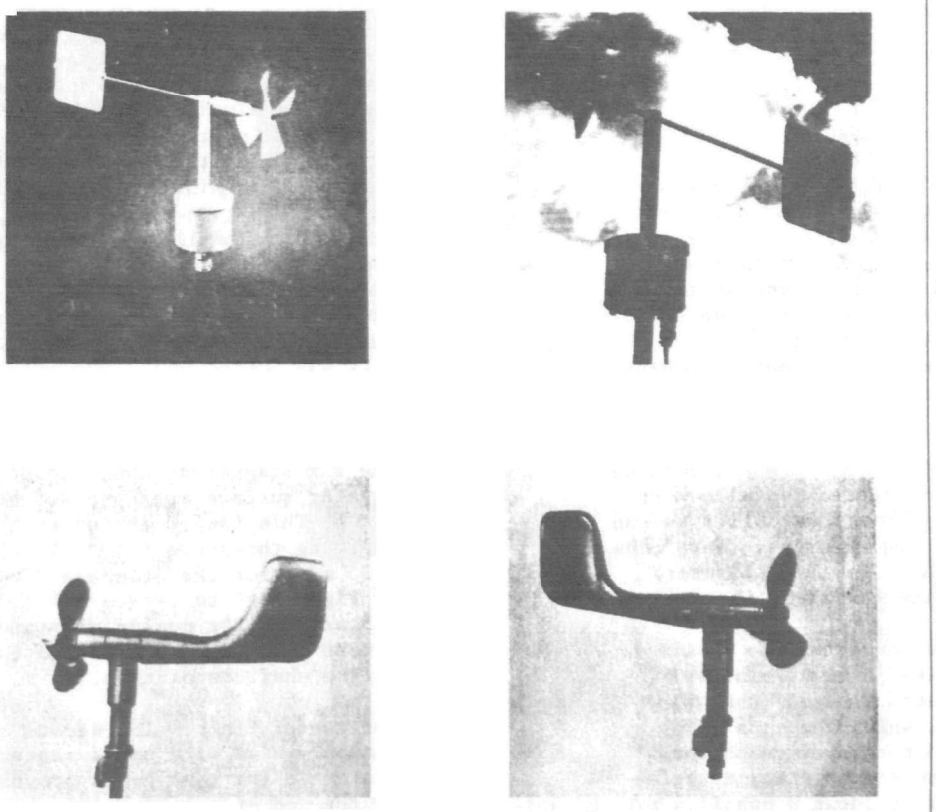


Figure 3 - Propeller-vanes

peller-vanes are shown in Figure 3. These propellers are usually helicoidal in design with the rate of rotation of the propeller being linearly proportional to the wind speed. As with the cup anemometers, the propeller anemometers generally fall into two design categories:

i. Those designed with durability as a prime consideration (Figure 3c,d)

ii. Those designed with sensitivity as a prime consideration (Figure 2, 3a,b)

The more sensitive propeller anemometers utilize lightweight aluminum or plastic as blade material, and generally employ either 2 or 4 blades. The 2-bladed propellers (Figure 3b) have starting speeds of about .4 - .7 mph (.2 - .35 m/s), while the 4-bladed propellers have a threshold of about .3 - .5 mph (.15 - .25 m/s).

The more durable propeller anemometers use heavy gauge plastic or steel in the blade construction. Because of their relatively heavy mass, the 3-blade design of Figure 3c, d have higher starting speeds of about 2.5 - 3 mph (1.2 - 1.5 m/s).

The sensitivity argument developed earlier for the cup anemometers also applies to propeller anemometers. However, because of the helicoidal design of the blades, the number of blades has no effect on the torque uniformity. The design produces a uniform torque independent of the number of propeller blades.

b Special Types

1) Propeller Bivane - These anemometers are capable of measuring the magnitude of the wind vector and will be discussed more fully in the wind direction sensor portion of this section.

2) UVW Anemometer - Another sensor configuration that yields the wind vector and its fluctuations is the UVW anemometer. Figure 4 shows one type manufactured by R. M. Young Company. In this sensor configuration, a propeller anemometer is mounted in each principal axis (thus the name UVW), and each yields the component wind vector in that axial direction. This anemometer has found limited operational use because of the sophisticated data reduction that is necessary to convert from an output of 3 wind speeds to a vector magnitude and direction.

The UVW anemometer has, however, enjoyed easy application to those situations where the 3 component vectors are the only desired output, or where data reduction is accomplished through the use of a computer.

As with all sensors of the propeller type, serious error is introduced during periods of heavy precipitation, and with this particular propeller configuration there is some mutual interference error with certain wind directions.

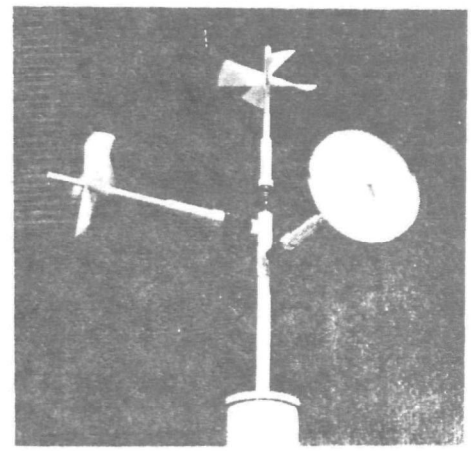


Figure 4.- UVW Anemometer

2 Wind Speed Measuring Transducers

The most common aerodynamic sensor for the measurement of wind speed is the cup or propeller. The wind speed measuring transducer must convert this cup or propeller rotation to an energy form that is easily transmittable. The energy form is usually electric and the transducer is commonly one of four types.

a D.C. Generator

Small, permanent field generators are used that have an output that is linearly proportional to the rate of turning of the cup or propeller and hence is linearly proportional to the wind speed. The main disadvantage of D.C. generators is the relatively high starting or threshold speeds. The brush and bearing friction combine to produce a lower limit to the threshold speed of about 1 mph (.5 m/s) on the most sensitive systems. The brushes on these generators usually need servicing only about once a year under continuous use. On some of the more sensitive sensors the unit is sealed and it is recommended that the unit be sent to the factory for servicing or replaced completely.

Figure 5 illustrates a typical D.C. generator (brushes not shown) from the sensor of Figure 1e. The output from this transducer can be recorded directly on any D.C. galvanometer recorder.

b A.C. Generator

In an attempt to lower the threshold speed by eliminating brush friction, some manufacturers are using A.C. generators instead of D.C. generators. A.C. generators reduce the friction considerably and eliminate brush and commutator maintenance. A.C. generators are available with either two, four, six or eight-pole permanent magnet rotors. The larger the number of poles, the more pulses are available per shaft revolution, producing a smoother record.

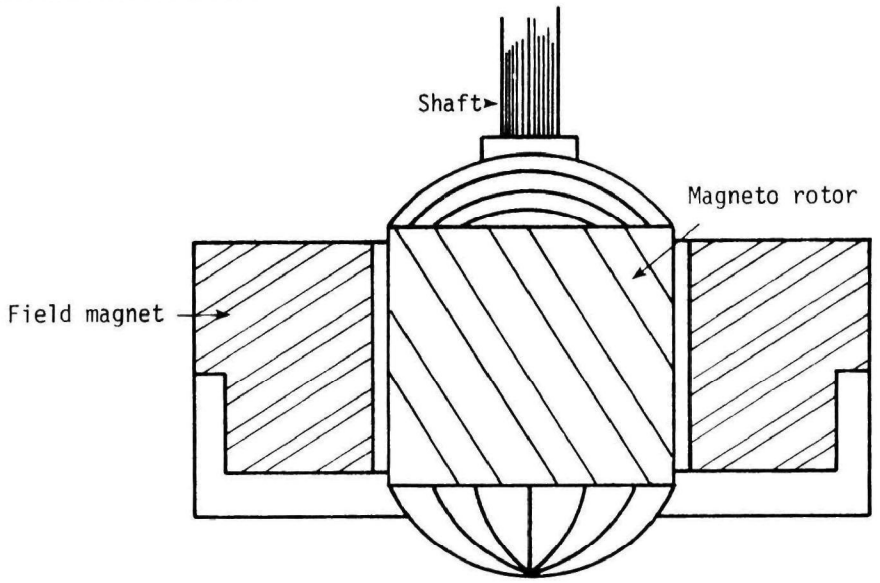


Figure 5 - D.C. Tachometer Generator

The largest disadvantage of the A.C. generator is associated with the number of pulses per shaft revolution. These pulses must be rectified by a modifying transducer (rectifier) in order to have a suitable energy form for recording. Low wind speeds generate a low frequency of A.C. pulses and normal rectifiers do not function properly with a low frequency input. Thus, spurious oscillations may be produced at low wind speeds. Therefore, to obtain wind speeds below about 2 m/sec (4 mph) some sort of electronic correction is needed.

This disadvantage defeats the purpose of reducing the friction and has therefore resulted in a minimal use of this type of transducer.

Interrupted Light Beam

Further reduction in friction with accompanying lower threshold speed and quicker response can be accomplished with the use of an interrupted light beam (light chopper) transducer. This transducer employs either a slotted shaft (Figure 6) or a slotted disc (Figure 7), a light source and a photocell or photo-diode. The cup or propeller rotates the

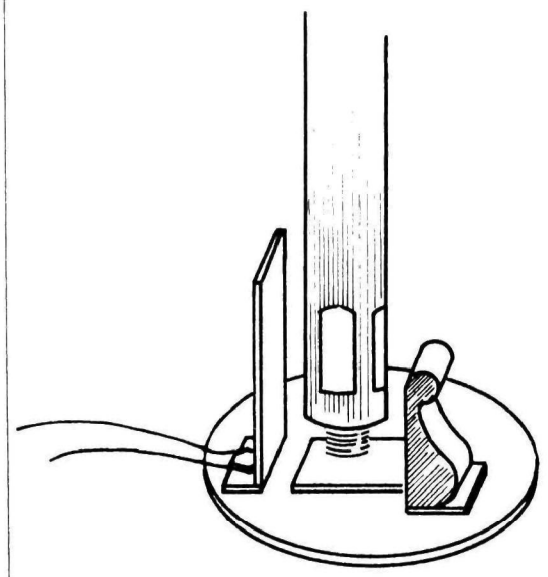


Figure 6 - Slotted Shaft Light Chopper

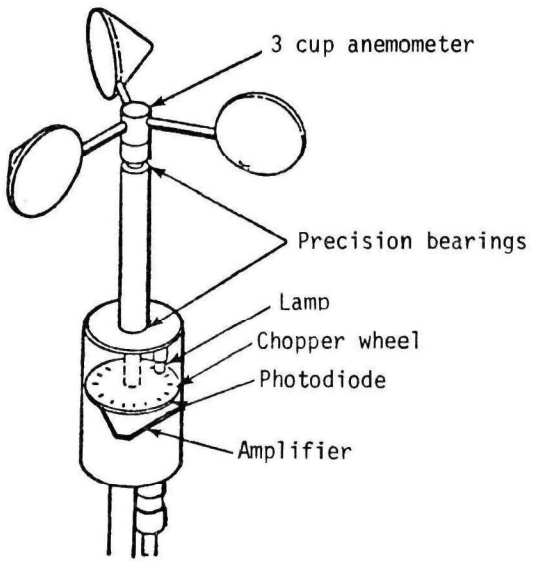


Figure 7 - Slotted Disc Light Chopper

slotted shaft or disc and a pulse is created each time a slot allows light from the source on one side of the shaft or disc to fall on the photocell on the other side of the shaft or disc. The larger the number of slots in the shaft or disc, the smoother will be the output, especially at low wind speeds. The out put from the transducer is handled in the same manner as the output from the A.C. generator. The large number of slots (about 100) prevent spurious oscillations in the output at low wind speeds. The sensors of Figure 1a, g utilize this type of transducer.

d Mechanical - contact type

All of the measuring transducers mentioned so far produce an analog signal. There are circumstances where the desired output might be total miles of wind passage instead of a time plot of wind speed. Under these circumstances, a mechanical-contact transducer is used. In this type of transducer, the anemometer shaft is connected through one or more gears to a cam or similar device that opens or closes a contact after the passage of a pre-determined amount of air. This contact closure can operate a readout device such as an event marker pen on a recorder. Recorders, such as the one shown in Figure 8 can be furnished with circuitry to provide a pen actuation for each 10, 100 or 1000 contact closures in the transducer. If the average wind speed is desired instead of length of wind passage, the number of contact closures are determined for a given time increment and, knowing the miles or meters of wind passage for each contact closure, the average wind speed over the given time increment is easily determined.

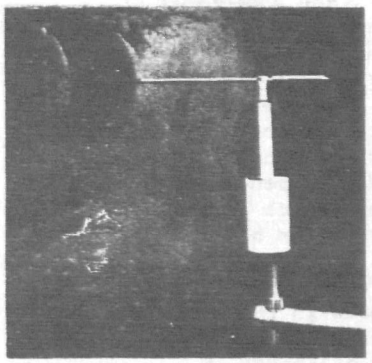
Figure 8 - Event Marker Recorder

3 Wind Direction

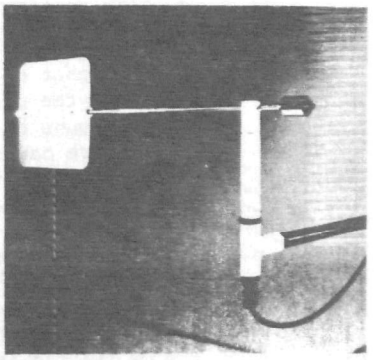
a Type

1) Flat Plate Vane

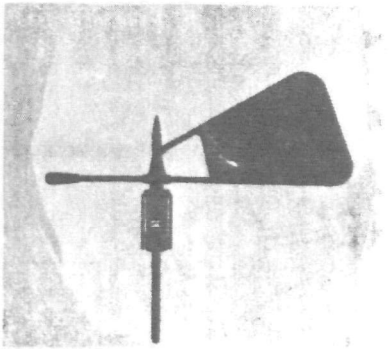
Typical flat plate vanes are shown in Figure 9a, b, c, d, g, i, k, and l. The term flat plate refers to the tail shape which is simply a flat plate. The flat plate can take on a number of different shapes and be made out of a number of different materials.



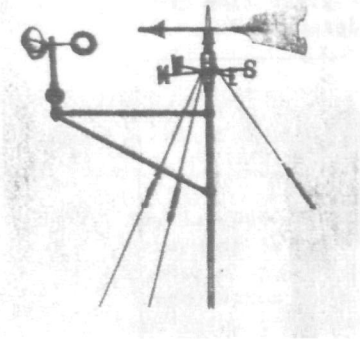
Climet Inst. Co. (a)



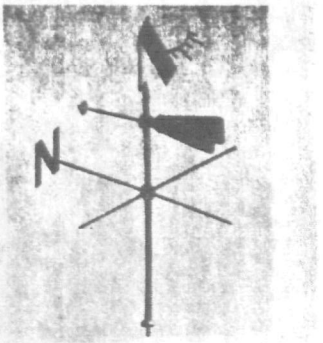
R.M. Young Co. (b)



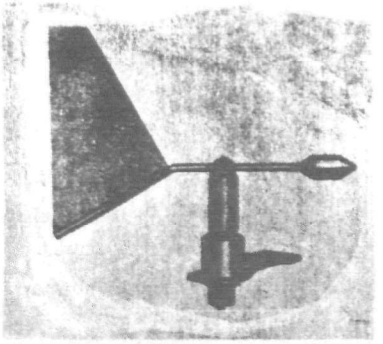
Belfort Inst. Co. (c)



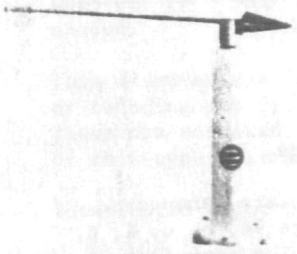
Science Associates Inc. (g)



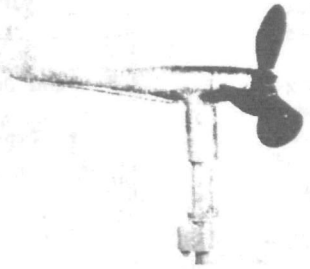
Epic Co. (h)



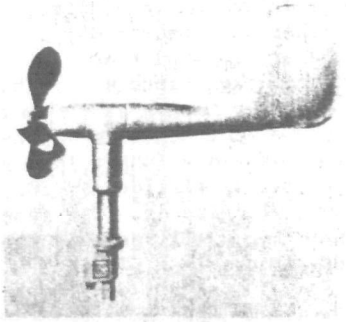
Epic Co. (i)



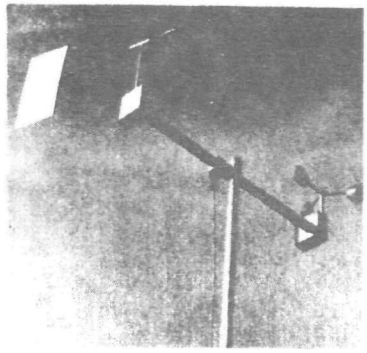
Teledyne-Geotech (l)



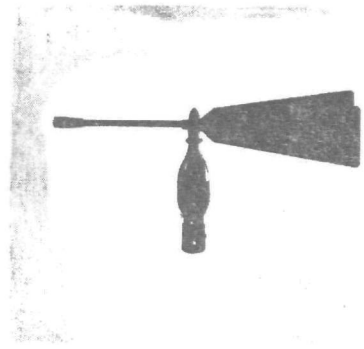
Bendix Co. (m)



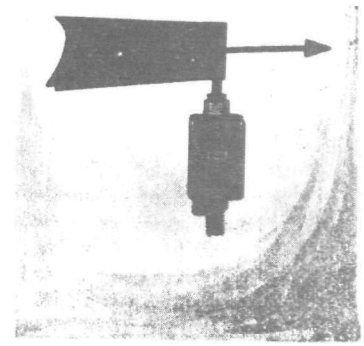
Belfort Inst. Co. (n)



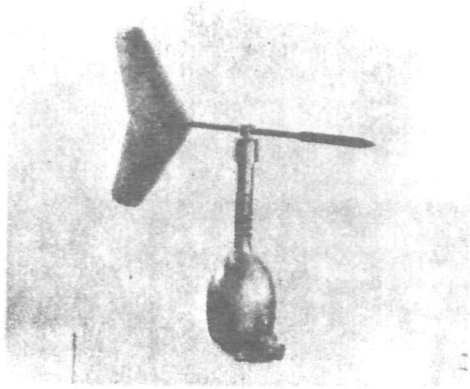
Wong Lab. (d)



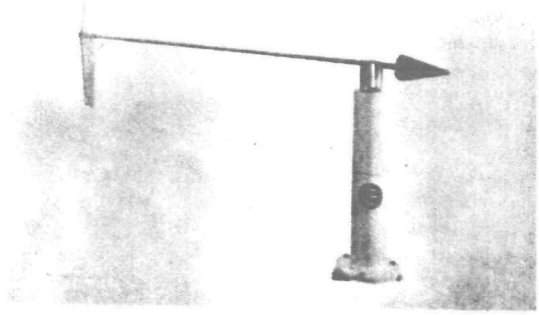
Electric Speed Indicator Co. (e)



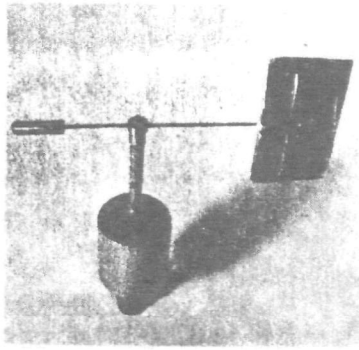
Science Associates Inc. (f)



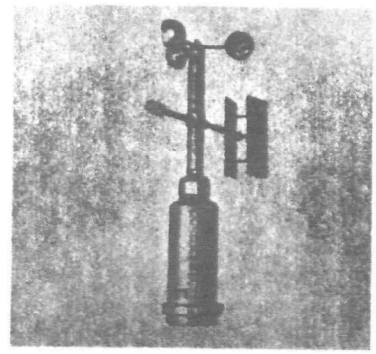
Teledyne-Geotech (j)



Teledyne-Geotech (k)



Raim Inst. Co. (o)



Epic Co. (p)

● Figure 9 - Wind Vanes

As with wind speed sensors, the material used in constructing the wind vane will generally determine the proper use of the vane. Vanes made out of heavy gauge metal or plastic such as in Figure 9 should be used only for obtaining average wind direction. The large mass creates a high moment of inertia which will give, under certain conditions, a much higher indication of wind fluctuations than actually exists.

The lightweight sensitive vanes of Figure 9a, b, d, k and l have tails made out of thin gauge aluminum or plastic or molded expanded polystyrene. The counterweights are also close to the center of rotation. This design creates a highly sensitive vane that can be suitably used for turbulence or other fine analyses of the wind trace.

2) Splayed Vane

Typical splayed vanes are shown in Figure 9e, f, h, and p. In this type of vane, two flat plates are joined at a small angle (usually about 15°) at one end of the horizontal shaft. This design came about through experimentation that showed that the splayed vane followed small changes in wind direction better than the flat plate. However, the increased mass incurred by two flat plates makes this type of vane unsuitable for anything but the measurement of average wind direction.

The splayed vane of Figure 9 has, mainly because of its durability and reliability, found widespread use in its role as the main wind direction sensor for the National Weather Service. Therefore, it should be noted that wind direction data obtained from a National Weather Service should be used only as an indication of average wind direction.

3) Aerodynamic Shaped Vane

This type of wind vane is shown in Figure 9j, m, n, and o. The aerodynamic shaped vane has an airfoil cross section. This type of vane has been shown to produce up to 15% more torque for certain ranges of attack angles than a flat plate vane of similar physical dimensions.

This type of design, as with the splayed vane, incorporates more mass than the flat plate vane and therefore produces a higher moment of inertia, yielding a poor dynamic performance. An aerodynamic wind vane that has found wide-spread use in air pollution studies is shown in Figure 9m, n. This device is commonly called an "aerovane". It should be remembered that its dynamic performance is inferior to the sensitive vanes of Figure 9a, b, d, k, l, and the use of the data gathered by the "Aerovane" should reflect this fact.

4 Wind Direction Measuring Transducers

The measurement of wind direction consists of converting the angular position of the wind vane to an energy form that can be transmitted easily. The system of Figure 9h has direct readout obtainable simply by observing the sensor. This system is, at best, very crude.

More advanced wind direction systems usually employ one of 3 types of measuring transducers.

a Potentiometer system

b Synchro-motor system

c Commutator system

Types

a Potentiometer System

The most common and inexpensive way of converting the angular position of the vane to an electrical signal is through the use of a potentiometer system such as the one shown in Figure 10.

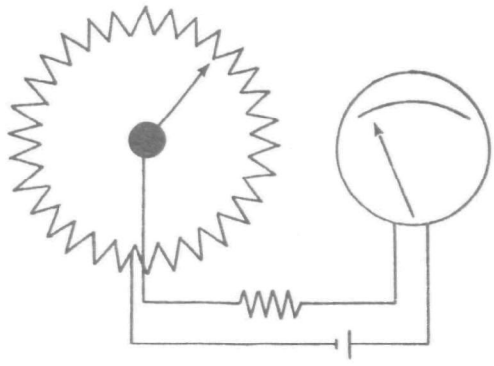


Figure 10 - Potentiometer Transducer System

In this system the shaft of the vane is attached to the wiper arm of the potentiometer. The swinging vane therefore produces a continuously varying voltage that can be recorded on a recording voltmeter or dial indicator. With proper calibration, the recorded voltage gives a direct reading of the angular position of the vane.

The biggest drawback to this system is the unavoidable discontinuity in the potentiometer. If the wind direction is oscillating about a direction corresponding to this gap (usually north), the voltage output will oscillate between the maximum and minimum value producing what is commonly called "chart painting". With the recorder pen swinging from one end of the chart to the other, the record produced is, at best, very confusing.

There are some types of recorder pen movements available that circumvent this problem. Double contact potentiometers with dual pen recorders produce a trace along each edge of the chart when the wind direction corresponds to the gap. Figure 11 illustrates a chart record of this type. In newer recorders, there is available electronic circuitry and a 540° chart that can keep the pen trace in the central portion of the chart. Figure 12 illustrates a chart record of this type.

Wire potentiometers present a problem of excessive wear produced as the contact moves along the wires. The life expectancy of wire-wound potentiometers is only about 6 months-1 year under continuous operation. Recent advances in this area have produced a conductive plastic potentiometer.

The life expectancy of these potentiometers is about 50 x 10^6 oscillations, or about 3 - 5 years, under continuous operation. The linearity

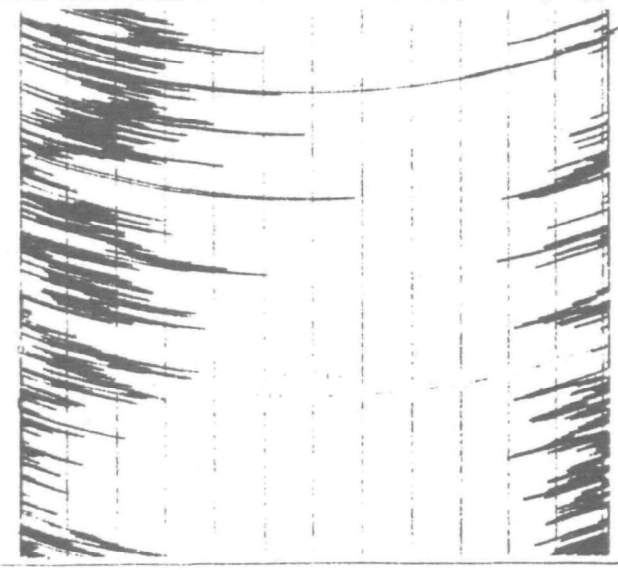


Figure 11.
Dual pen recorder chart

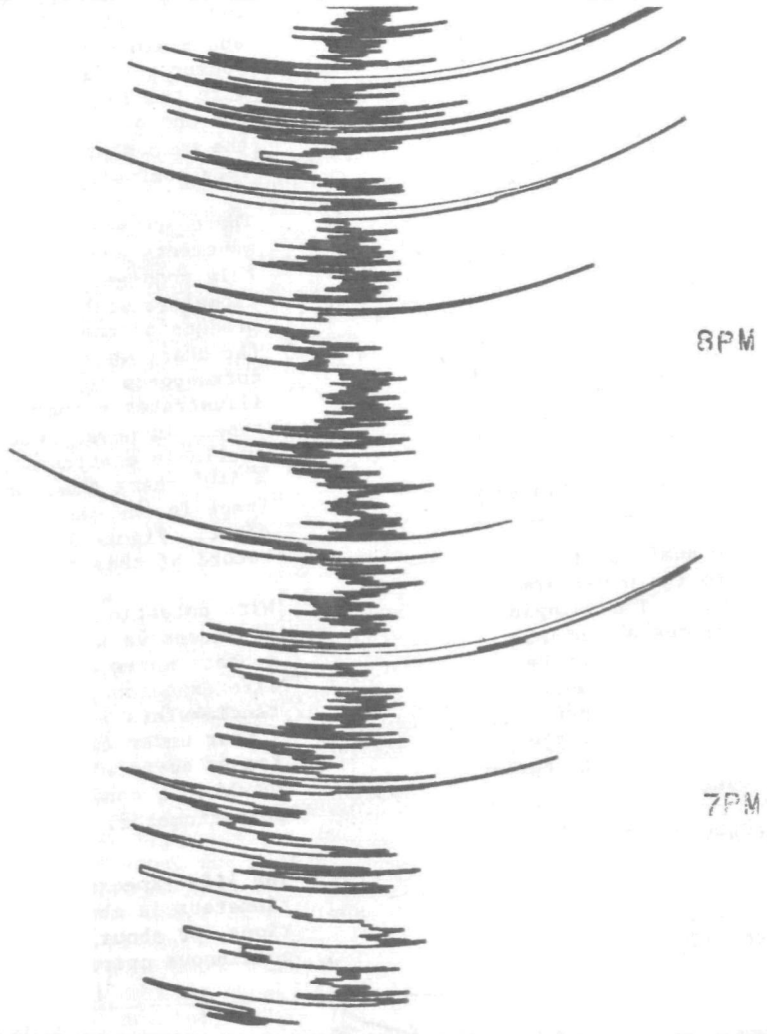


Figure 12.
540° Recorder chart

of these devices is about .5%.

The use of micro-potentiometers produces the lowest movement of inertia of any of the direction transducers available today. This fact has led to their widespread use in the sensitive wind vanes that are noted for their good dynamic performance.

b Synchro-motor System

This transducer system consists of two synchronous motors wired as shown in Figure 13.

They are commonly known as "Autosyn", "Selsyn" or "Synchrotie" systems.

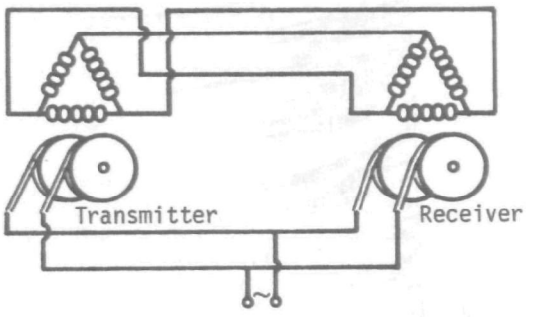


Figure 13 - Synchro-motor System

In this mode, any movement by the shaft of the transmitter will be duplicated by the shaft of the receiver motor usually to an accuracy of about 2°, provided the lead resistance is kept to a maximum of 20Ω.

The vane shaft is coupled to the shaft of the transmitter motor and the shaft of the receiver motor is coupled to a recorder pen or some other read-out indicator. Therefore, any vane movement is duplicated by a movement of the dial needle, recorder pen etc., and with proper calibration and alignment, a direct indication of wind direction is obtained. There is no discontinuity in the movement as with the potentiometer. This transducer system is usually coupled with a 540° chart recorder system or a dial indicator to produce an analog trace of wind direction. The system also lends itself readily to a dial indicator display. The only disadvantage of this transducer system is the relatively large movement of inertia of the motor assembly. This produces a poorer dynamic performance than the micro-potentiometer system and limits their use to the more rugged vane types such as the aerovane sensors of Figure 9m, n.

c Commutator System

The wind direction transducers discussed so far produce an analog signal that can be converted to an analog chart trace. The commutator transducer system shown in Figure 14 produces contact closures which can be used to activate lights, event marker pens etc.

In this system, the vane shaft is coupled to a unit that has two brush type contacts, (A and B), spaced 22 1/2 degrees apart. These brushes make contact with one or two of the 8 conducting sectors (C) that are spaced 45° apart and correspond to 45° of wind direction. When both brushes contact the same sector, the direction indicated is one of the 8 compass points, eg., N, NE, E. If the brushes are contacting two of the sectors, the indicated direction corresponds to an intermediate direction, such as NNE, ENE, ESE, etc. Therefore, direction indication to 16 points can be obtained with this system.

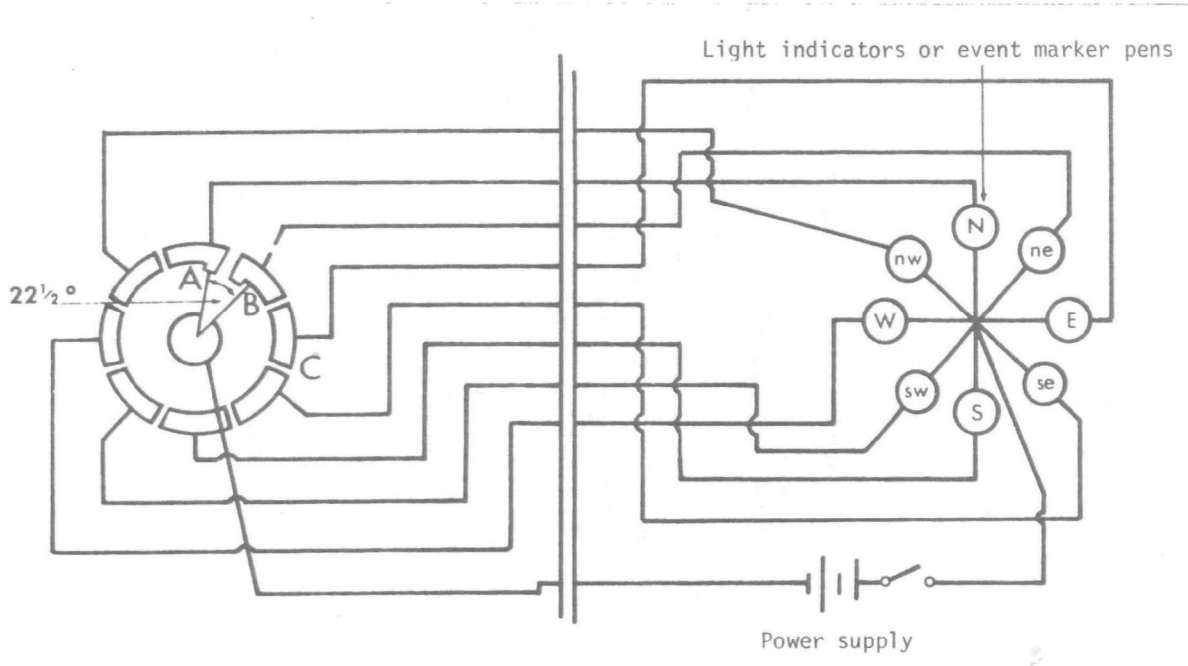


Figure 14 - Commutator Transducer System

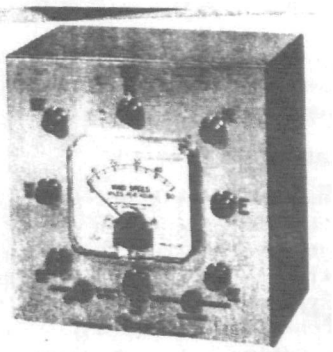


Figure 15 - Commutator System Visual Display

Figure 16 - Commutator System Chart Record

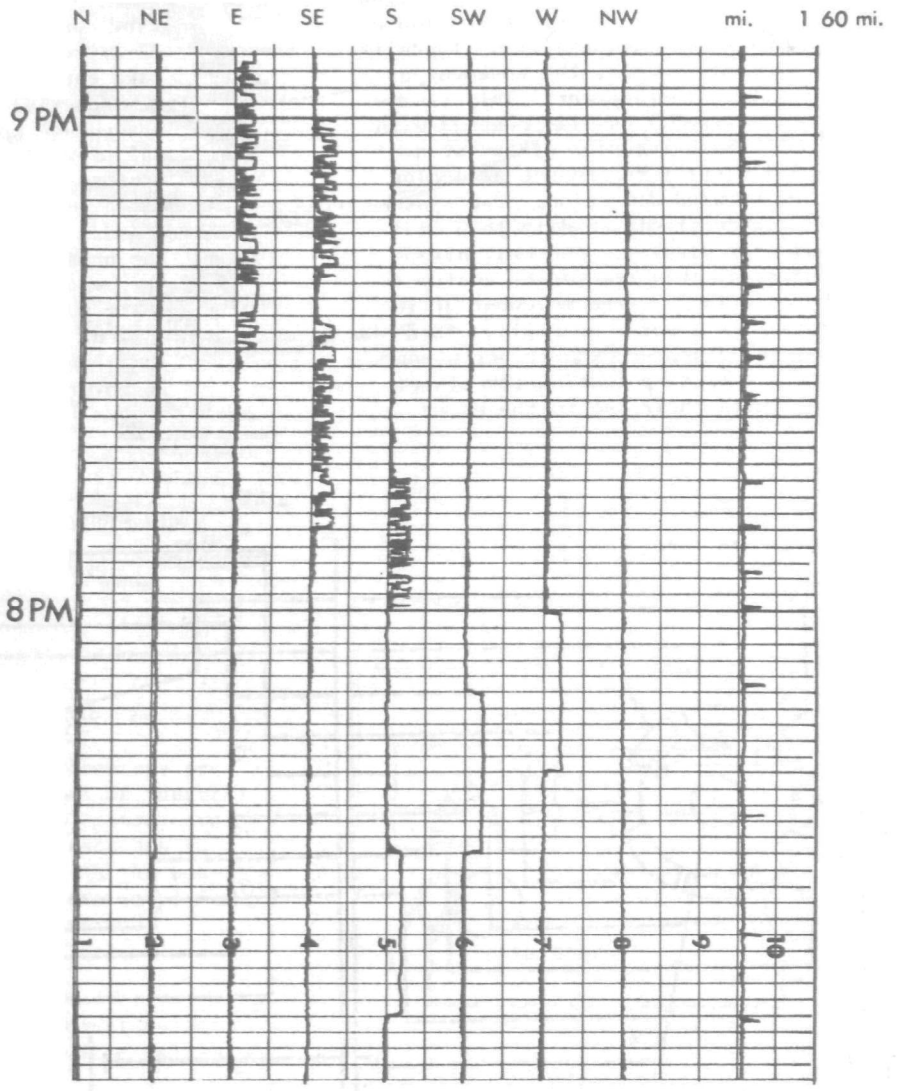


Figure 15 shows a visual display utilizing lights. An intermediate direction would be indicated by the activation of two adjacent lights.

Figure 16 illustrates a chart record produced by this type of transducer system. An intermediate direction would be indicated by the activation of two adjacent pens.

The friction inherent in the commutator transducer as well as the crude method of display make this transducer most applicable to operations involving only the acquisition of average wind direction.

Special Types

a Bi-directional Vanes (Bivanes)

This type of instrument is designed to rotate around a vertical axis to measure the aximuth angle of the wind, as does a conventional wind vane. It also can move in the vertical to measure the elevation angle of the wind. Because the vertical motions of the atmosphere are frequently of a different character than the horizontal motions (anisotropic turbulence), measurement of both the horizontal and vertical motions are desirable. This is particularly true under stable conditions when the vertical motion is almost absent, but horizontal changes in wind direction may be appreciable. Micropotentiometers are usually used to produce an analog record of both angles. The total wind speed can be measured by replacing the counterweight with a propeller anemometer. Figure 17 shows two typical anemometer bivanes.

B Airborne Sensors

Fixed location wind velocity sensors measure the wind at a fixed height as it varies with time. Most airborne sensors are used to average wind velocity through a given depth of the atmosphere at a particular time.

1 Pilot Balloon (pibal)

This method of measuring wind velocity uses a gas-filled free balloon (Figure 18) which is tracked visually through a theodolite. The theodolite is an optical system used to measure the azimuth and elevation angle of the balloon.

a Single Theodolite Pibals

When only one theodolite is used, the balloon is inflated to have a given amount of free lift. The elevation and azimuth angles are used with the assumed ascent rate to compute wind directions a speeds aloft. A theodolite is shown in Figure 19.

b Double Theodolite Pibals

By this method, the ascent rate of the balloon is not assumed, but calculated from the elevation and azimuth angles of the two theodolite observations taken simultaneously.

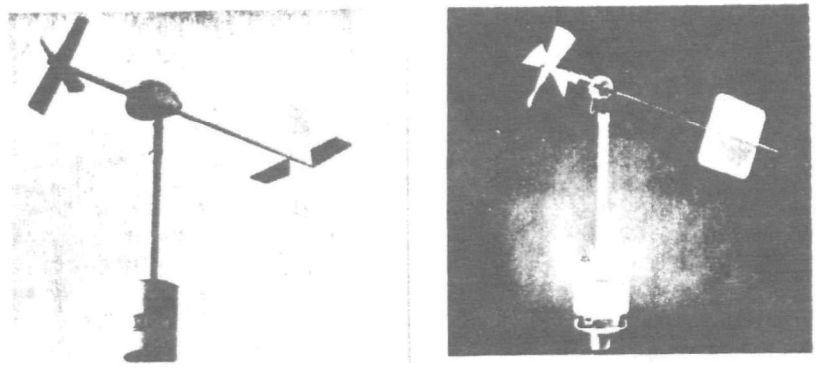


Figure 17 - Anemometer Bivanes

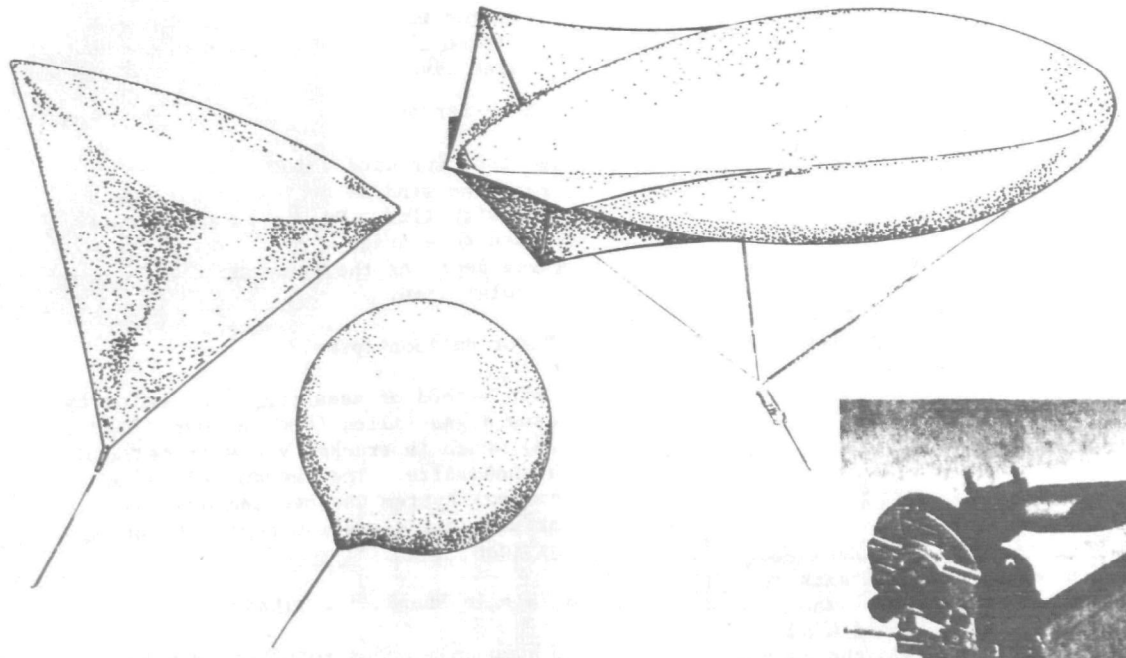


Figure 18 - Meteorological Balloons
(L to R - Tetroon, Pilot Balloon, Kytoon)

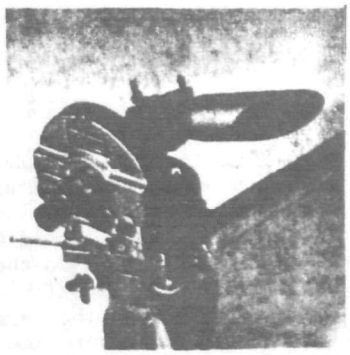


Figure 19 - Theodolite

The two theodolites are set a known distance apart (the baseline). Two types of pilot balloons frequently used reach 3000 ft. within 5 minutes and 8 minutes respectively after release. If detailed structure of winds with height is to be determined, readings of azimuth and elevation angle must be read every 15 or 30 seconds.

2 Rawinsonde

This method of measuring wind velocity aloft also uses a gas-filled free balloon, but it is tracked either by radio direction finding apparatus, or by radar. The former method is the most frequently used in the U.S. The radio transmitter carried by the free balloon is usually used to transmit pressure, temperature and humidity information to the ground (radiosonde). The radio direction finding equipment determines the elevation angles and azimuth angles of the transmitter. The height is determined by evaluation of the temperature-pressure sounding. Using radar the slant range is available for determining height. Soundings taken with this type of equipment are made on a routine basis for supporting forecasting and aviation activities. The ascension rate of these balloons is on the order of 1000 feet/minute, so they do not yield as detailed information on winds in the lowest part of the atmosphere as is desired for many air pollution meteorological purposes.

3 Rocket Smoke Plumes

A system using a cold propellant, recoverable rocket to emit a vertical smoke trail to an altitude of 1200 feet has been developed. (Gill, Bierly, and Kerawalla). This smoke trail is photographed simultaneously at short time intervals by two cameras 2000 feet from the launch site and at right angles to each other. The difference in position of the smoke trail from two successive photographs is a measure of one component (north-south for example) of the wind and can be determined at any number of heights from ground level to 1200 feet. Another system has been reported by Cooke (1962).

4 Constant Level Balloons

Unlike the previous airborne sensors for wind velocity which obtain average measurements through a vertical layer, constant level balloons are used to determine the trajectory or path of an air parcel during a given time interval. In order to maintain a constant altitude (more accurately to fly along a constant air density surface) the balloon must maintain a constant volume. A tetrahedron shaped balloon (tetroon) of mylar has been used for this purpose (Figure 18). These have been tracked visually and by radar. (Angell & Pack, 1960).

III TEMPERATURE LAPSE RATE

The vertical structure of temperature gives an indication of the stability and turbulence of the atmosphere.

A Temperature Difference Measurements

One method of estimating the vertical structure of temperature is by measuring the difference in temperature between sensors mounted at different heights. This, of course, gives an average condition between any two particular sensors.

1 Heights of Sensors

Because of the pronounced influence of the earth's surface on the atmosphere's temperature, it may be desirable to measure temperature difference at closer intervals near the ground than at higher levels. For example, a 300 foot tower might have sensors at 5 feet, 25 feet, 50 feet, 100 feet, 200 feet, and 300 feet. The height differences at the upper levels should be about equal so that the height of inversions may be determined. Radio and television towers are good supports for temperature difference sensors (as well as wind sensors) and stations usually are willing to allow sensors to be mounted upon their towers. Of course, sensors must be kept below the level of the transmitting antenna.

2 Sensors

Resistance thermometers of copper or nickel may be used for temperature difference systems. Thermo-couples of copper-constantan or iron-constantan also make reliable sensors. Resistance thermometers and thermocouples do not have to be frequently calibrated and may be expected to provide good service for 10 to 20 years if properly installed. Thermistors are not generally recommended because they may be quite variable from unit to unit and they may require recalibration more frequently than the other two types of sensors. Rapid response is usually not desired in measuring temperature differences. Rather, averages on the order of 5 minutes are desired. If the sensors are 1/2 to 5/8 inch in diameter, they will respond slowly enough to give an average temperature.

3 Shielding and Ventilating

Guidelines for the exposure of temperature sensors are covered in the following section.

4 Recorders

Generally multiple point (10 or 20 points) recorders are used for recording temperature differences. Thus, one recorder may be used for the entire system. The recorder is connected to one sensor for about 30 seconds, prints and then switches to another level. If a 6 minute cycle is used (print for each level every 6 minutes) there will be 10 readings every hour and an hourly average may easily be obtained by adding the 10 readings and shifting the decimal point 1 place. The sensors are usually wired so that the temperature differences are obtained directly rather than determining the temperature at each level.

B Balloon-borne Sensors

Temperature sensors may be lifted by either free or captive balloons. By this method, temperature, not temperature difference, is measured.

1 Radiosonde

The method of radiosonde (radio-soundings) observations is used routinely for temperature, pressure and humidity soundings of the upper air. A free balloon carries the sensors and a radio transmitter aloft. Cycling from sensor to sensor is by means of an aneroid barometer and consequently is a function of pressure. Observations are normally made twice daily at 0000 GCT and 1200

GCT at approximately 70 stations in the contiguous U.S. The ascent rate of the balloon is about 1000 ft/minute. Generally only 4 to 6 temperature readings are recorded within the lower 3000 feet so the vertical temperature information is not too detailed. It is still of considerable use when more detailed information is not available.

2 T-Sonde

This system consists of a temperature sensor and radio transmitter which is carried aloft by a free rising balloon. The main difference between this system and the radiosonde system is that only temperature is measured. Ten to twelve measurements are taken within the lower 3000 feet of the atmosphere, thus giving more detailed structure of temperature with height.

3 Tethered Kite Balloon

Using a captive balloon system to make vertical temperature measurements has the advantages of complete recovery of all components of the system, and as detailed a temperature sounding as is desired may be made by control of the level of the sensor. A balloon having fins is much easier to control and gives greater lift in slight winds than a spherical balloon. See Figure 18. Most kite balloons can be used in winds less than 15 knots. For air pollution meteorology purposes, the light wind periods are of greatest interest anyway. Because of hazards to aircraft, prior permission from the FAA is required for flights exceeding 500 feet above ground.

For additional precautions when using captive balloons, the reader is referred to the section on "Exposure of Airborne Instruments".

Several methods of relaying the observations to the ground have been used.

a Wiresonde

Using this system, a resistance thermometer is carried aloft by a kite balloon whose mooring cable contains wires connecting the sensor with a wheatstone bridge on the ground which is used to measure the resistance.

b Modified Radiosonde Transmitter

Another system uses a modified radiosonde transmitter to measure temperature and humidity. The signal is transmitted to the ground receiver and recording equipment by the same method used in the radiosonde. Cycling from one sensor to another is by a battery driven timing device. The temperature sensor is shielded from the sun by the styrofoam plastic and is aspirated by a small motor driven fan. The mooring of this system is by nylon cable marked at intervals to indicate the height of the sensor.

C Aircraft Borne Sensors

In some cases, light aircraft or helicopters have been used for obtaining temperature lapse rate measurements. Although there are complete systems commercially available for this method of temperature lapse rate measurement, one can use standard temperature sensors (thermisters, resistance thermometers, etc.) and recorders as long as the exposure guidelines presented in the next section are followed.

IV THE MEASUREMENT OF SECONDARY METEOROLOGICAL PARAMETERS

A Precipitation

Because large particles and water soluble gases may be removed from the atmosphere by falling precipitation, measurements of this element may be needed. Chemical or radioactive analysis of rain water may also be desired.

1 Standard Rain Gauge

The standard rain gauge consists of a metal funnel 8 inches in diameter, a measuring tube having 1/10 the cross-sectional area of the funnel, and a large container of 8 inches diameter (Figure 20). Normally precipitation is funneled into the measuring tube. The depth of water in the tube is measured using a dip stick having a special scale (because of the reduction in area). Measurements with this instrument, since they are made manually, give only accumulation since the last measurement.

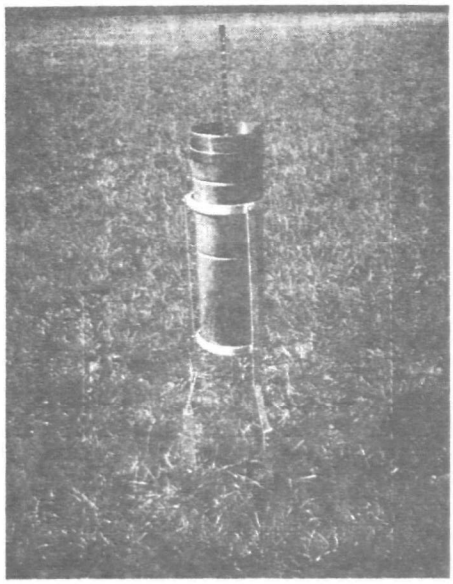


Figure 20 - Standard Rain Gauge

2 Recording Rain Gauge

The recording (or weighing) bucket rain gauge does give detailed time resolution of occurrence, and amount of precipitation as a strip chart, with one revolution per day, is used. The gauge consists of a bucket (to hold the precipitation) on a scale, which weighs the precipitation and moves the pen arm, recording the total accumulation on the chart, calibrated in inches. (Figure 21)

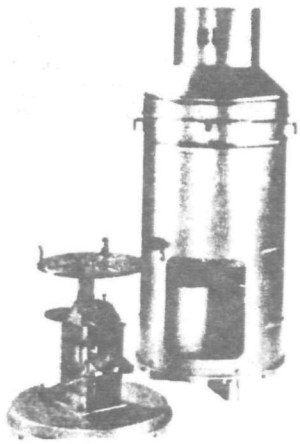


Figure 21 - Weighing Bucket Rain Gauge

3 Tipping Bucket Rain Gauge

This precipitation gauge has a bucket with two compartments beneath the collecting funnel. (Figure 22). When one side of the bucket collects a given amount (usually 0.01 inch) of precipitation, the bucket tips and empties the precipitation, collecting the next portion in the other side. The bucket movements are recorded on a chart. The number of bucket movements and the time they occur indicate the rainfall amount and rate. This type instrument is not suitable for measuring snow.

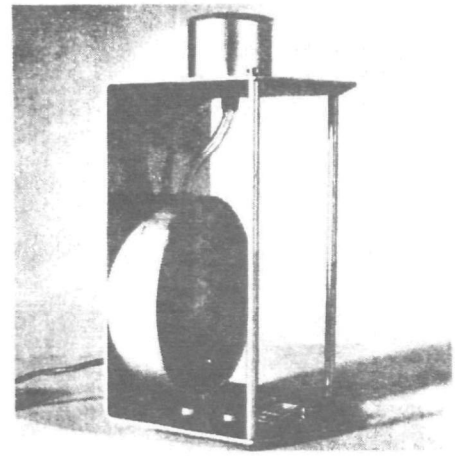


Figure 22 - Tipping Bucket

4 Precipitation Collector

For research purposes, it is desirable to analyze rainfall as to its chemical and radioactive constituents. Since it is desirable to include only precipitation samples, and not material that may fall into the collector during dry periods, a collector which opens only during periods of precipitation has been developed. The sensor (Figure 23) has two sets of adjacent wires. A raindrop falling between the wires completes an electrical circuit which removes the cover from a polyethylene container. A small heat source dries the sensor so that the circuit will be broken when precipitation ceases and also so that dew will not form and open the collector. This instrument is illustrated in Figure 24.

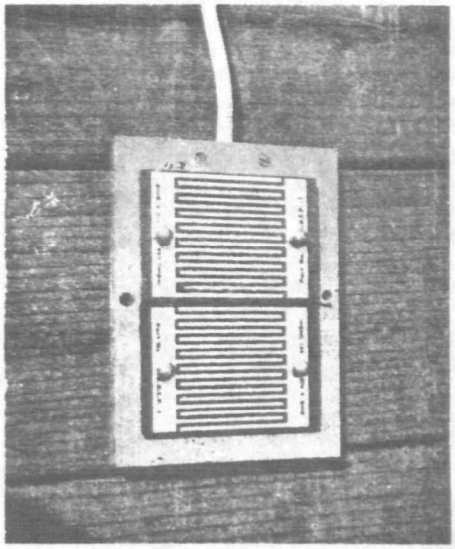


Figure 23 - Rain Detector for Automatic Precipitation Collector

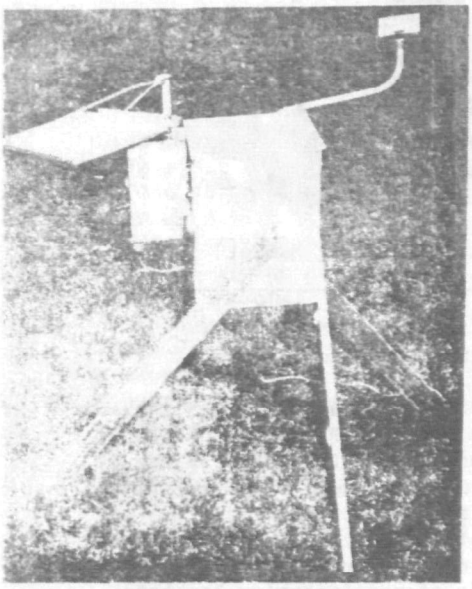


Figure 24 - Automatic Precipitation Collector (Open)

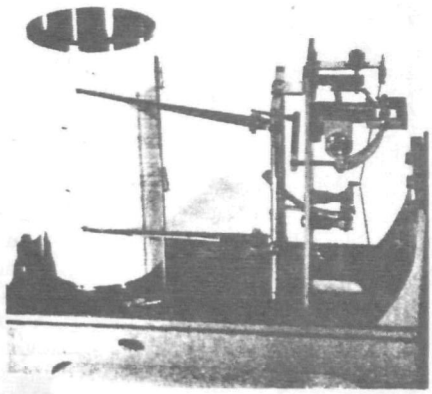


Figure 25 - Hygrothermograph

B Humidity

Because of its influence upon certain chemical reactions in the atmosphere and its influence upon visibility, it may be desirable to measure humidity in connection with an air pollution investigation. Also, some air pollutants affect receptors differently with different humidities, so measurement may be of importance in this respect.

1 Hygrothermograph

This instrument measures both temperature and humidity, activating pen arms to give a continuous record of each element upon a strip chart. The chart generally can be used for 7 days. The humidity sensor generally used is human hairs which lengthen as relative humidity increases and shorten with humidity decreases. Temperature measurements are usually made with a bourdon tube, a curved metal tube containing an organic liquid. The system changes curvature with changes in temperature, activating the pen arm. A hygrothermograph is shown in Figure 25.

2 Psychrometers

Humidity measurement by a psychrometer involves obtaining a dry bulb temperature and a wet bulb temperature from a matched set of thermometers. One thermometer bulb (wet bulb) is covered with a muslin wick moistened with distilled water. There must be enough air

motion to cause cooling of the wet bulb due to evaporation of the water on the wick. A motor driven fan may be used to draw air at a steady rate past the moistened wick while a reading is taken. A sling psychrometer has both thermometers mounted on a frame which is whirled through the air to cause cooling by evaporation. Relative humidity is determined from the dry and wet bulb readings through the use of tables. Continuous measurements of humidity are not obtained using psychrometers.

C Radiation

The influence of the sun's radiation upon the turbulence of the atmosphere and upon certain photochemical reactions is sufficient to make measurements of radiation of importance. In addition, radiation may be reduced due to particulate pollution in the atmosphere. Particularly for research purposes, it may be desirable to measure this effect by comparisons between urban and non-urban stations similarly instrumented.

1 Total Radiation

The direct radiation from the sun plus the diffuse radiation from the sky may be measured by pyranometers. These instruments are mounted so that the sensor is horizontal and can receive the radiation throughout the hemisphere defined by the horizon. The instrument illustrated in Figure 26 is of this type.

Figure 26 - "Black and White" Pyranometer

2 Direct Solar Radiation

Normal incidence pyrheliometer -

The direct solar radiation may be measured continuously by using the pyrheliometer shown in Figure 27 mounted upon an equatorial mount (Figure 28) to keep it pointed toward the sun. By using filters, different spectral regions of radiation may be determined.

3 Net Radiation

The difference between the total incoming (solar plus sky) radiation and the outgoing terrestial radiation may be

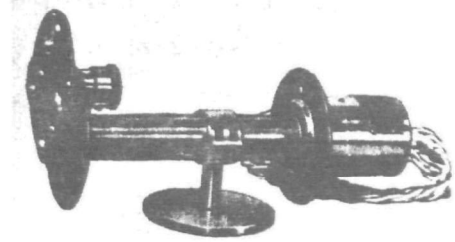


Figure 27 - Pyrheliometer

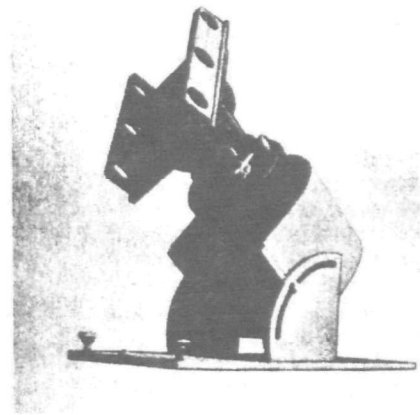


Figure 28 - Equatorial Mount

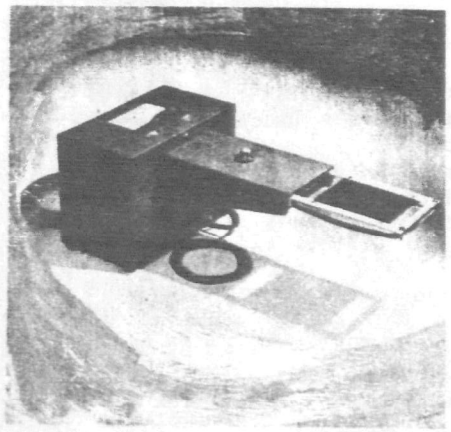


Figure 29 - Net Radiometer

useful in determining the stability, and hence, the turbulent character, of the lowest portion of the atmosphere. A net radiometer is shown in Figure 29.

D Visibility

Visibility, in addition to being affected by precipitation, is affected by humidity and air pollution. Frequently, visibility is estimated by human observer. An instrument to measure visibility, called a transmissometer, measures the transmission of light over a fixed baseline, usually on the order of 500 to 750 feet. An intense light source from the projector is focused on a photocell in the detector. The amount of light reaching the photocell over the constant baseline distance is assumed to be proportional to visibility. The transmissometer is restricted to estimating visibility in one direction only.

A transmissometer is also limited in that the light transmission it detects is affected mainly by liquid droplets in the air. It does not detect, to any great efficiency, the particulate matter in the atmosphere. The projector is shown in Figure 30 and the detector in Figure 31. A relatively new instrument, called a nephelometer, has been developed that will indicate visibility as it is affected by particulate matter in the atmosphere. An integrating nephelometer is shown in Figure 32.

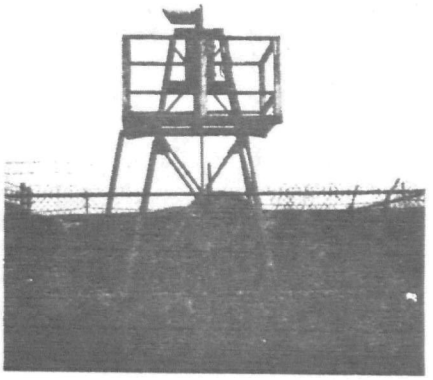


Figure 30 - Transmissometer Detector

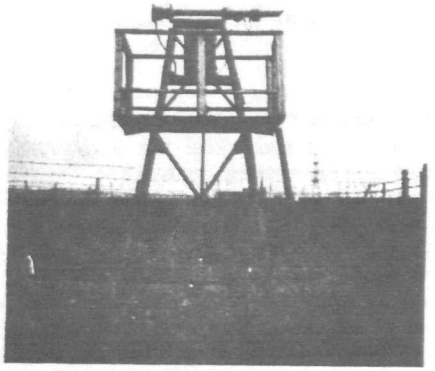


Figure 31 - Transmissometer Receiver

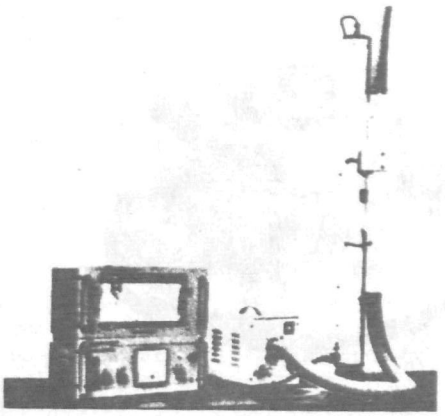


Figure 32 - Integrating Nephelometer

V. REMOTE SENSING TECHNIQUES

Remote sensing is based on measurements of the interaction of waves with the medium under study. Sensing systems make use of acoustic, radio or optical waves and may be termed passive using waves of natural origin, or, in greater use, active using man-made waves. Seven atmospheric parameters are most often measured as a function of time, including: wind, temperature, humidity, cloud particles, precipitation, aerosols and gaseous pollutants. Information which may be obtained as described by Little (1972), varies in complexity from the integrated value of the parameter along a line through the whole atmosphere, a line integral, to its full 4 dimensional distribution in time and space, the flux.

A. Wind Sensing

1 Laser/lidar - the scintillation of light from a laser beam has been used to measure the transverse component of the wind across the signal pathlenth. Relatively long pathlengths (100m to several km) can be used to obtain an average line integral of the wind velocity. Somewhat lower velocities are measured when compared to anemometer cup readings due to the space averaging of the laser system (Dickson, 1975). Two orthogonal systems would yield horizontal velocity.

2 Bistatic Acoustic Radar - acoustic energy is scattered by turbulent fluctuations of temperature and wind velocity. When two transmitters are used and one is tilted 22° toward the basic transducer the receiver picks up the Doppler shift in signal scattered back at 158°. Scattering at this angle is due to small scale velocity variations which can be translated to wind velocity components.

3 Radio/radar - radio waves interact more weakly in a clear atmosphere than do optical or acoustic waves. The back scattering radar cross section is very low although high power pulsed Doppler radars or FM-CW systems have been used to demonstrate a feasibility for determining winds. At the present hydrometeors or artificial chaff must be present for acceptable results. Research on CW forward scatter radars is reported by Birkemeier, et.al. (1973).

B. Temperature Profiles

1 Laser/lidar - by measuring the ground level atmospheric pressure at a laser site and assuming that the hydrostatic equation can be used to predict pressures aloft, temperature profiles can be derived from the Raman backscatter from nitrogen. Lidar systems have been used qualitatively to infer temperature structure, primarily temperature discontinuities such as inversion layers, due to local maximum in aerosol distributions (Infossi, et.al., 1974).

2 Monostatic Acoustic Radar - when backscattered acoustic energy is received from a co-located source the scattering due to thermal fluctuations is detected. Commercial systems generate sound bursts of about 70 dBA at a frequency of 1600 Hz with electrical power input of 35 to 140 W and a repetition rate of one pulse per 7 seconds when measuring the lowest 500 m layer (Tombach, et. al. 1973). The acoustic system does not directly measure the temperature profile but the echo signals represent energy scattered by turbulent fluctuations; from this data inferences regarding stability, turbulence and inversions are made.

3 Radio Acoustic Sounding System (RASS)- this system is a hybrid device which uses an acoustic transducer to send a burst of sound upward into the atmosphere and a Doppler radar to track the sound wave and determine its propogation speed. Errors due to vertical velocities are overcome by averaging the signals over several minutes and temperature profiles up to 3km on a real-time, continuous basis are possible (North et.al., 1973).

4 Microwave Radiometers - passive ground-based radiometers can measure thermal emission in any frequency band where gaseous constituents strongly absorb. One technique is based on detecting natural thermal radiation of oxygen molecules in the atmosphere at 54 or 55 GHz, depending on the upper height desired for the profile. Since a line profile is obtained, the distribution of the parameter along a line of known length, the smoothed record, makes determination of sharp discontinuities, eg. inversions, quite difficult (Westwater and Snider, 1975). Profiles can be obtained from the surface to about 5km.

C. Mixing Depth

1 Laser/lidar - backscattered laser light measurements are very useful in providing

continuous records of changes in the depth of the surface mixed layer. Plumes from pollution point sources are also easily "tracked" by lidar techniques in stable, neutral and unstable atmospheric conditions.(Bacci, et.al. 1974)

2 Acoustic sounder - the depth of the mixed layer is one of the most easily obtained outputs from a monostatic system. The inversion that caps the mixed layer can be monitored as displayed on a simple facsimile recorder (Wyckoff, et.al, 1973). A list of applications for acoustic sounders is provided by Thomson (1975) together with an extensive list of references.

3 Radio/radar - FM/CW radars, discussed above are very useful in detecting marine inversion layers. Beran and Hall (1974) attribute most of the signal returned to such radars by changes in refractive index to humidity discontinuties rather than temperature.

D, Meteorological Satellite Techniques

There are several methods for determining temperature profiles from radiometric observations on board satellites. The three major atmospheric windows (minimum molecular absorption) for sensing surface temperatures and three major absorption bands due to constituents uniformly distributed in the atmosphere can be used to construct vertical temperature profiles. The three bandwidths used aboard spacecraft are 4.3 μm, 15 μm and 5mm. Smith (1972) discusses several methods used to derive temperature profiles from NIMBUS data. The major drawback is the deep layer averaging technique which negates resolution of temperature discontinuities in the lower few km. Hopefully, NASA's next research and development satellite, NIMBUS G, to be launched in 1978 as NIMBUS 7,will incorporate advances to minimize this drawback. Its primary mission is to detect, identify, map and measure air and ocean pollution. (Heins, et.al., 1975).

REFERENCES

1 Hewson, E. W. "Meteorological Measurements" in Air Pollution, Vol. II New York, Academic Press. pp 329-387.

2 Slade, D. H., Editor "Meteorology and Atomic Energy-1968" U.S. AEC, Division of Technical Information. pp 257-300.

3 Middleton, W.E.K., and Spilhaus, A.F. Meteorological Instruments, Toronto, University of Toronto Press, pp 141-165. 1953.

4 Lockhart, T. J. "Bivanes and Direct Turbulence Sensors." Meteorology Research Inc. MRI 170 Pa 928. June 1970.

5 Stern, A. C., Editor "Air Pollution" Second Edition Vol. II New York, Academic Press. 1968. pp 334-347.

6 Doebelin, E. O. "Measurement Systems: Application and Design. "McGraw-Hill Co., New York, Chapter 7.

7 Stein, P. K. "Classification Systems for Transducers and Measuring Systems." Symposium on Environmental Measurements, U.S. Dept. HEW, July 1964. pp 65-68.

8 Angell, J. K. and Pack, D. H. "Analysis of Some Preliminary Low-Level Constant Level Balloon, (Tetroon) Flights." Mon. Wea. Rev. 88, 7, 235-248. 1960.

9 Hewson, E. W., and Gill, G. C. In report submitted to the Trail Smelter Arbitral Tribunal by R. S. Dean and R. E. Swain, U.S. Bur. Mines Bull, 453, 155-160. 1944.

10 Cooke, T. H. "A Smoke-Trail Technique for Measuring Wind." Quart. J.Roy. Meteorol. Soc. 88, 83-88. 1962.

11 George, D. H. and Zeller, K. F. "Visibility Sensors in Your Air Quality Program." Pres. Second Joint Conf. on Sensing of Env. Pollutants, December, 1973.

12 Monteith, J. L. Survey of Instruments For Micrometeorology, IBP Handbook No. 22. Blackwell Scientific Publications. 1972 Dist. by F. A. Davis Co. 1915 Arch St. Phila. Pa.

13 Pendergast, M.M. A Cautionary Note Concerning Aerodynamic Flying of Bivane Wind Direction Indicators. J. App. Meteor. Bol. 14, No. 4. 626-627, June 1975.

14 Little, C. G. Status of Remote Sensing of the Troposphere. Bull. AMS, Vol. 53. No. 10. 936-949, October 1972.

15 Dickson, C. R. Intercomparison of Standard Anemometry Techniques. NOAA Manuscript June 1975.

6-26

16 Birkemeier, W. P. etal. Wind Measurements Using Forward-Scatter C.W. Radar. J. App. Meteor. Vol. 12, No. 6., 1044-1053, September 1973.

17 Anfossi, D. Bacci P. and Longhetto, A. An Application of Lidar Technique to the Study of the Nocturnal Radiation Inversion. Atmos. Env. Vol. 8, No. 6, 537-541, June 1974.

18 Tombach, I., Mac Cready, P. B. and Baboolal, L. Use of a Monstatic Acoustic Sounder in Air Pollution Diffusion Estimates. Pres. Second Joint Conf.-Sensing of Environmental Pollutants. December 1973.

19 North, E. M. Peterson, A. M. and Parry, H. D. RASS, a Remote Sensing System for Measuring Low-Level Temperature Profiles. Bull. AMS, Vol. 54, No. 9,912-919, September 1973.

20 Westwater, E. R., Snider, J. B., and Carlson, A. V. Experimental Determination of Temperature Profiles by Ground-Based Microwave Radiometry. J. App. Meteor. Vol. 14, No.4, 524-539, June 1975.

21 Bacci, P. Elesei, G. and Longhetto, A. Lidar Measurements of Plume Rise and Dispersion at Ostiglia Power Station. Atmos. Env. Vol.8, No.11, 1177-1186, November 1974.

22 Wyckoff, R. J.,Beran, D. W. and Hall, F.F., Jr. A Comparison of the Low-Level Radiosonde and the Acoustic Echo Sounder for Monitoring Atmospheric Stability. J. App. Meteor. Vol, 12, No. 7, 1196-1204, October 1973.

23 Thomson, D. W. ACDAR Meteorology: The Application and Interpretation of Atmospheric Acoustic Sounding Measurements. Pres. Third Symposium on Meteorological Observations and Instrumentation. AMS. Washington, D.C. February 1975.

24 Beran, D. W. and Hall, F. F., Jr. Remote Sensing for Air Pollution Meteorology, Bull, AMS, Vol. 55, No. 9, 1097-1105, September, 1974.

25 Smith, W. L. Satellite Techniques for Observing the Temperature Structure of the Atmosphere. Bull. AMS, Vol. 53, No.11, 1074-1082, November 1972.

26 Heins, C. F. Johnson, F. D.,Mangold, E. C. Spectroscopic Instruments, Satellites,and Computers: New Directions for Monitoring the Environment. Env. Science & Tech. Vol. 9, No. 8, 720-725, August 1975.

Exposure of Instruments

Ronald C. Hilfiker

Exposure of Surface Instruments

INTRODUCTION

Exposure of instrumentation is undoubtedly one of the most important steps in any air pollution study. It is absolutely necessary to locate the instrumentation in such a manner that the measurements are representative of the area in which one is interested. In some cases, such as street level measurements in a city, it is desirable to obtain measurements of extremely local phenomena, but generally in air pollution meteorology, measurements that are representative of a fairly large area are desired. In this latter case, extreme care must be taken to ensure that the parameter being measured is not influenced by nearby obstacles.

An example of the effect of a building on regional wind flow is shown in Figure 1.

Figure 1a shows two identical aerovanes mounted on a tower approximately 20 feet south of a 12 foot high building. The only difference in exposure between the two aerovanes is the 6 foot difference in height. It can be seen from Figure 1b that when the wind is blowing from the west, both sensors are apparently free of building influence, with both wind traces indicating typical mechanical type turbulence. However, when the wind shifts to the north-west, the turbulence characteristics change markedly in the wind flow being sensed by the Bendix aerovane at the 6 foot level. At the 12 foot level, the Belfort aerovane continues to indicate typical mechanical type turbulence. Which trace is indicative of the regional wind flow? It is the purpose of this chapter to explore the concepts needed to answer this question.

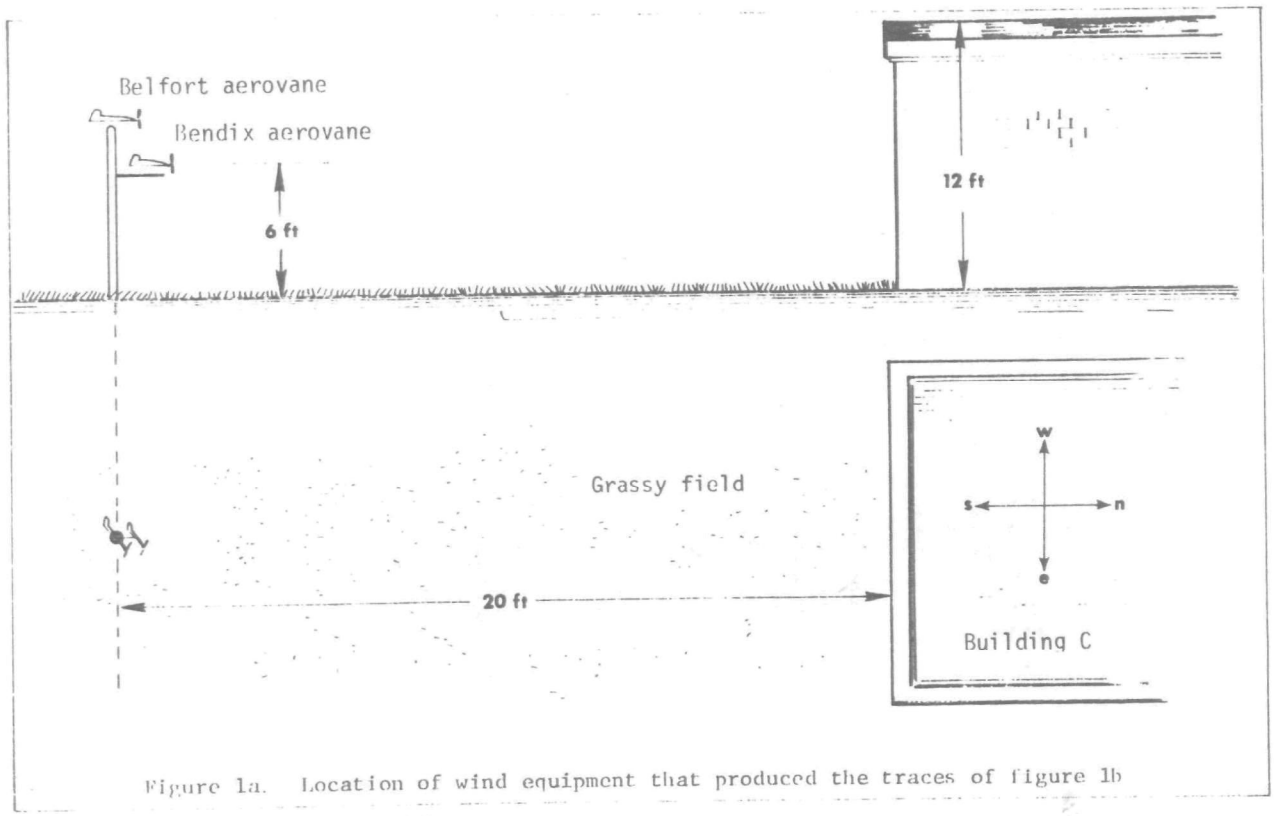


Figure 1a. Location of wind equipment that produced the traces of figure 1b

Ronald C. Hilfiker
Environmental Research
and Technology, Inc.
Concord, MA 01742

PA.ME.mm.13b.9.71

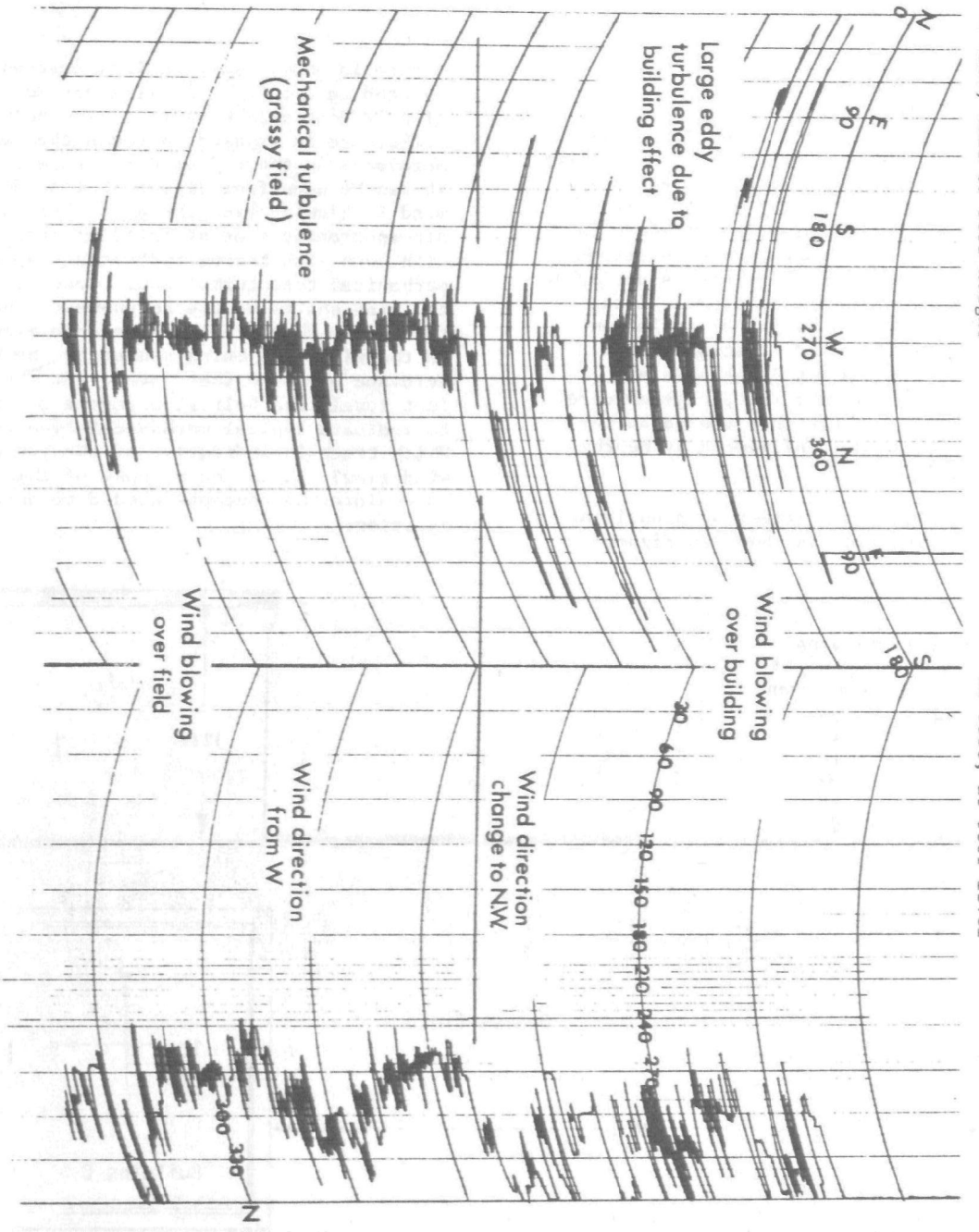


Figure 1b Wind trace produced by the aerovanes of figure 1a

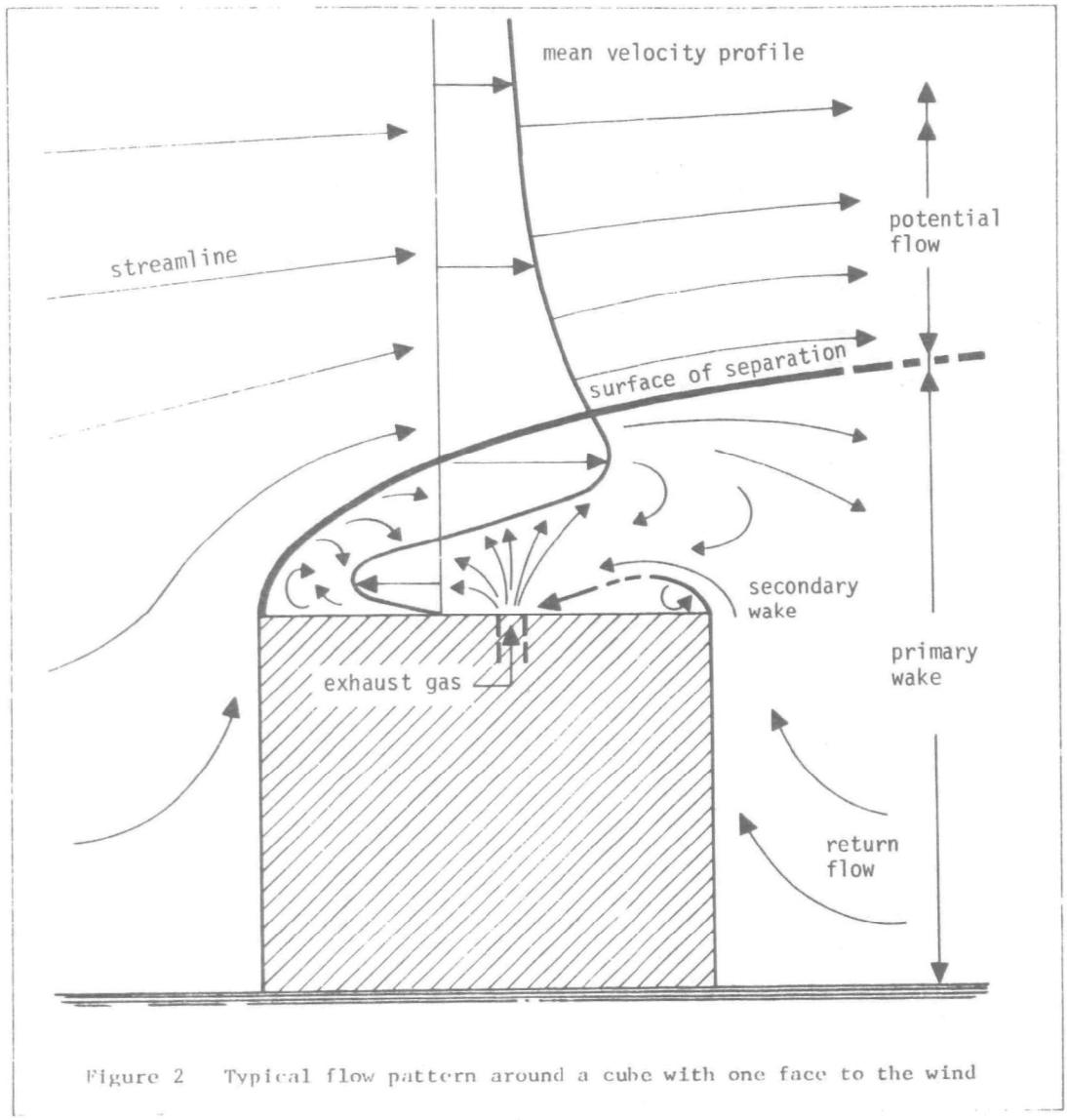


Figure 2 Typical flow pattern around a cube with one face to the wind

ANEMOMETERS AND WIND VANES

In recent years, an attempt has been made at standardizing the height above ground at which "surface wind" measurements will be taken. The World Meteorological Organization (WMO) and the National Oceanic and Atmospheric Administration (NOAA) have agreed on 10 meters for this standard height. Ideally the measurements would be taken over level, open terrain, but very rarely do these conditions exist in an air pollution survey area. What rules of thumb or guidelines can be followed if obstructions are present in the vicinity of the spot where wind measurements are to be taken?

Figure 2 illustrates a typical flow pattern around a cube that has one face normal to the wind flow. From Figure 2 several things can be noted:

1) The flow is disturbed on the upwind and downwind sides of the obstruction.

2) The flow is disturbed above the building to a height of about 1 to 1 1/2 building heights above the roof.

3) Very near the roof of the building a reverse flow occurs.

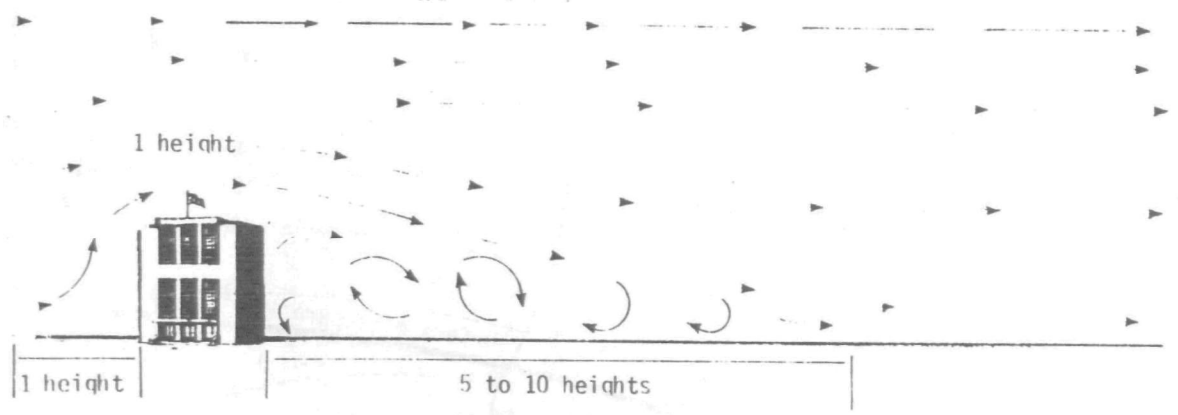


Figure 3 Building effect on wind

Figure 3 shows a more extensive view of the disruption in the ambient air flow around an obstruction. From Figure 3, one can formulate three rules of thumb for locating a wind system around an obstruction while keeping the sensor located in the ambient air flow:

1) The sensor must be located a distance upwind of the building equal to the building height.

2) If the sensor is to be located on the roof of the building it must be at least one building height above the roof.

3) The sensor must be located a distance of 5 to 10 building heights in the downwind direction.

These guidelines would apply most directly to a cubical obstruction standing by itself on open, level terrain. As the shape of the obstruction changes or as more obstructions become involved, the problem becomes much more complex. For example, suppose that it is desired to make measurements of the ambient air flow in the downtown area of a large city. Most probably the above guidelines could not be met because of the close proximity of the obstructions in a downtown area. A modification of these guidelines must be used. The sensor should be mounted on the roof of the tallest structure available, a distance above the roof determined by the proximity of taller buildings (using Guidelines 1 and 3), and the height of the building above the surrounding structures (utilizing Guideline 2). The exact height at which to locate the sensor would depend on the particular case.

In locating wind sensors in rough terrain or in valley situations, it will be necessary to determine if local effects such as channeling, slope and valley winds, etc., are of greatest importance, or whether flow above these influences is the parameter to be sensed. As in the urban situation, if the study centers upon elevated pollution sources, it may be desirable to avoid the local influences. However, if pollution from ground level sources is being emphasized, local influences may be of great importance. Remember that topographic influences such as hills, ridges, etc., produce flow patterns similar to those shown in Figures 2 and 3.

TEMPERATURE

As with wind sensors, thermometers are usually placed at a standard height above ground. This standard height has been set, by international agreement, at 1.25 to 2 meters (4-6.5 feet) above a grassy surface. Environmental considerations produce the following three rules of thumb for exposure of temperature sensors.

1) The sensor must be shielded from direct solar radiation.

2) The sensor must be well ventilated at a constant ventilation rate. (not less than 4-5 m/sec.)

3) The sensor must be uninfluenced by nearby features that might affect temperature.

If the sensor is of the thermocouple or thermister type, the aspirated shield of Figure 4 will fulfill the requirements of (1) and (2) above.

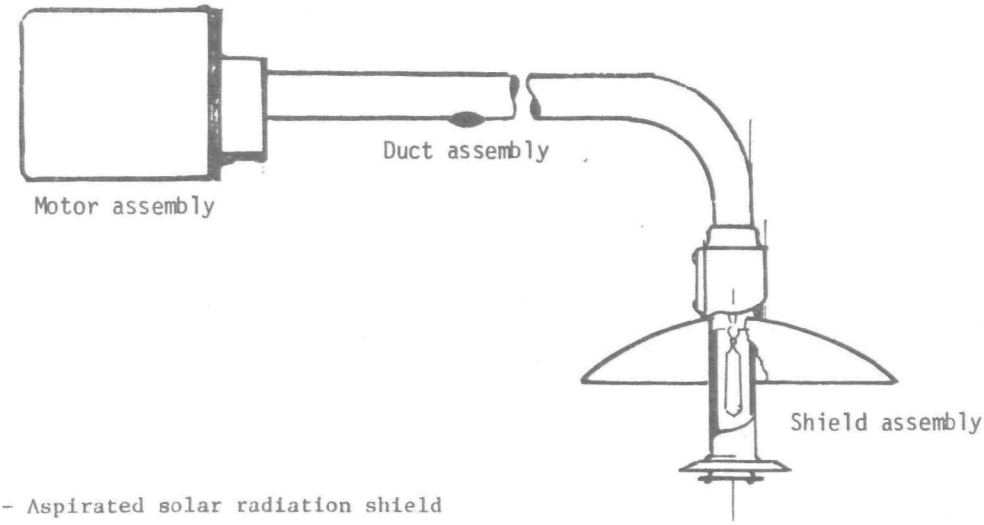


Figure 4 - Aspirated solar radiation shield

If a standard thermometer is to be exposed, the cotton region shelter of Figure 5 will fulfill requirement (1) above. Ventilation will be natural and therefore variable in rate so the requirement of rule (2) is not met exactly, but for standard thermometers, the error or effect is negligible.

If the shelter of Figure 5 is to be used, care should be taken to orient the door towards the north to eliminate solar heating of the thermometers while taking a reading. The thermometers should also be located as close to the center of the shelter as possible.

Requirement (3) above ensures that ambient air temperature is being measured, and not the temperature of a micro-environment such as the air very near the south side of a brick building or near an asphalt roadway or parking lot.

RELATIVE HUMIDITY

Since relative humidity is not only a function of the amount of water vapor in the atmosphere, but is also dependent on temperature, exposure criteria outlined for temperature should also be observed for relative humidity.

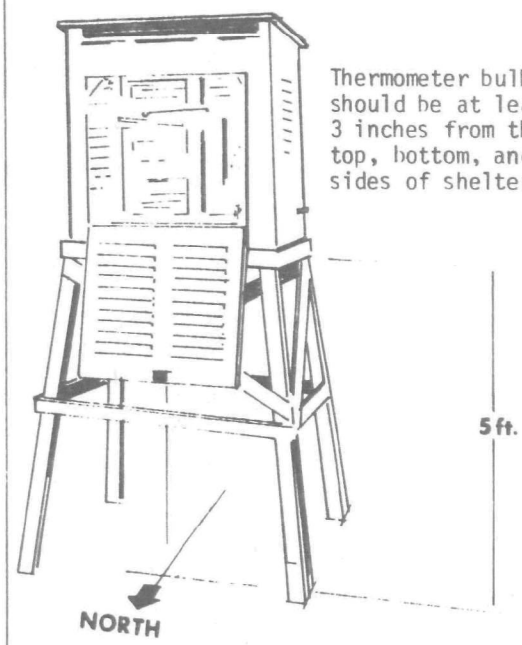


Figure 5 - Cotton region type instrument shelter

PRECIPITATION

The previous section describes the design and operation principles of rain gauges. Care must be taken in the exposure of a rain gauge to ensure that the collection efficiency of the gauge is not reduced. Wind and its associated turbulence are the two most important factors that would tend to change the collection efficiency of the gauge. If the wind blows the rain into the gauge on a slant, the collection area is changed and therefore the efficiency would be changed producing an error in the indicated rainfall. If considerable turbulence exists around the gauge, the rainfall itself will be disturbed, again producing errors in the indicated rainfall. These considerations produce the following guidelines:

1) The gauge should be free of overhanging obstructions.

2) The gauge should be a sufficient distance from obstacles to avoid local eddys.

3) The gauge should be sheltered from the possiblity of high wind speeds at the gauge.

Ideally, all three criteria could be met if the gauge was located in a clearing in a woods or orchard where the diameter of the clearing is about equal to the height of the surrounding trees. A windshield, such as the one shown in Figure 6, can also be installed to reduce the distortion of the air flow around the gauge.

RADIATION

Solar radiation measurements require exposure that will insure no obstructions between the sun and the sensor during any part of the year, and in the case of total solar radiation (direct and diffuse) as clear a view as possible of the entire sky is necessary.

The measurement of net radiation requires that the sensor be placed far enough away from the earth's surface to receive terrestial radiation over a representative area, yet not far enough from the surface to receive radiation from a thick air layer above the surface. For net radiation measurements, a height between 1 and 2 meters (3 to 6 feet) is generally recommended.

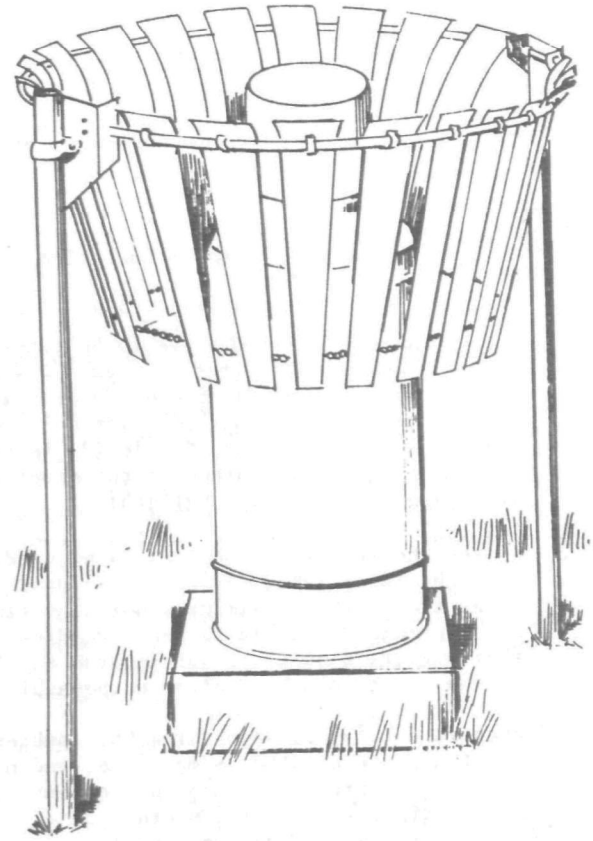


Figure 6 - Shielded rain gauge

A good discussion of the problems resulting from and solutions for removal of dew and frost formation may be found in:

Peterson, J. T., Flowers, E. C. and Rudisill, J. H. Dew and Frost Deposition on Pyranometers. J. Applied Meteor. Vol. 12, No. 7: 1231-1233, October, 1973.

Exposure of Instruments on Towers or Stacks

INTRODUCTION

In striving to meet the exposure criteria outlined in the last section, it is often necessary to mount meteorological sensors on towers or masts. Unless these sensors are mounted properly, errors will be introduced in the measurements due to the influence of the tower on the parameter being sensed. It is the purpose of this section to set forth guidelines to eliminate these tower induced errors.

WIND SYSTEMS

If a wind system (anemometer and vane) are to be mounted on top of a tower, little concern is needed as to exposure. If, however, wind equipment is to be installed on the side of the tower, precautions should be taken to ensure that the wind measurements are not influenced by the tower. An analysis by Gill and Olsson (1967) has shown that the turbulence in the wake of lattice-type towers is moderate to severe, and that in the wake of solid towers and stacks is extreme, often with reversal of flow.

Another study by Moses and Daubek (1961) revealed that the air flow on the lee side of a tower may be reduced to about one-half its true value under light wind conditions and about 25% for higher winds (10-14 mph). The study also revealed that when the wind blowing toward the anemometer made an angle of 20 to 40° with respect to the sides of the tower adjacent to the anemometer, the measured wind speed exceeded the true wind speed by about 30%.

These studies illustrate the necessity of proper exposure.

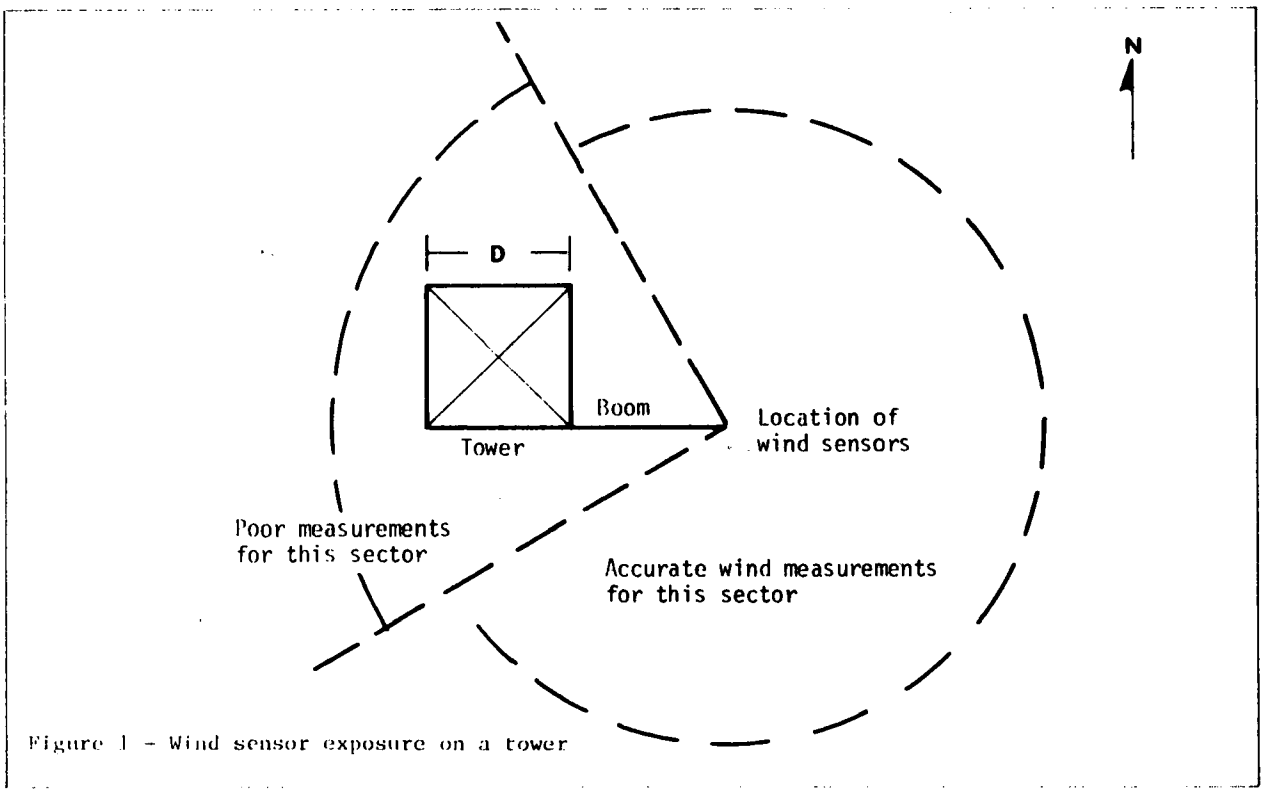


Figure 1 - Wind sensor exposure on a tower

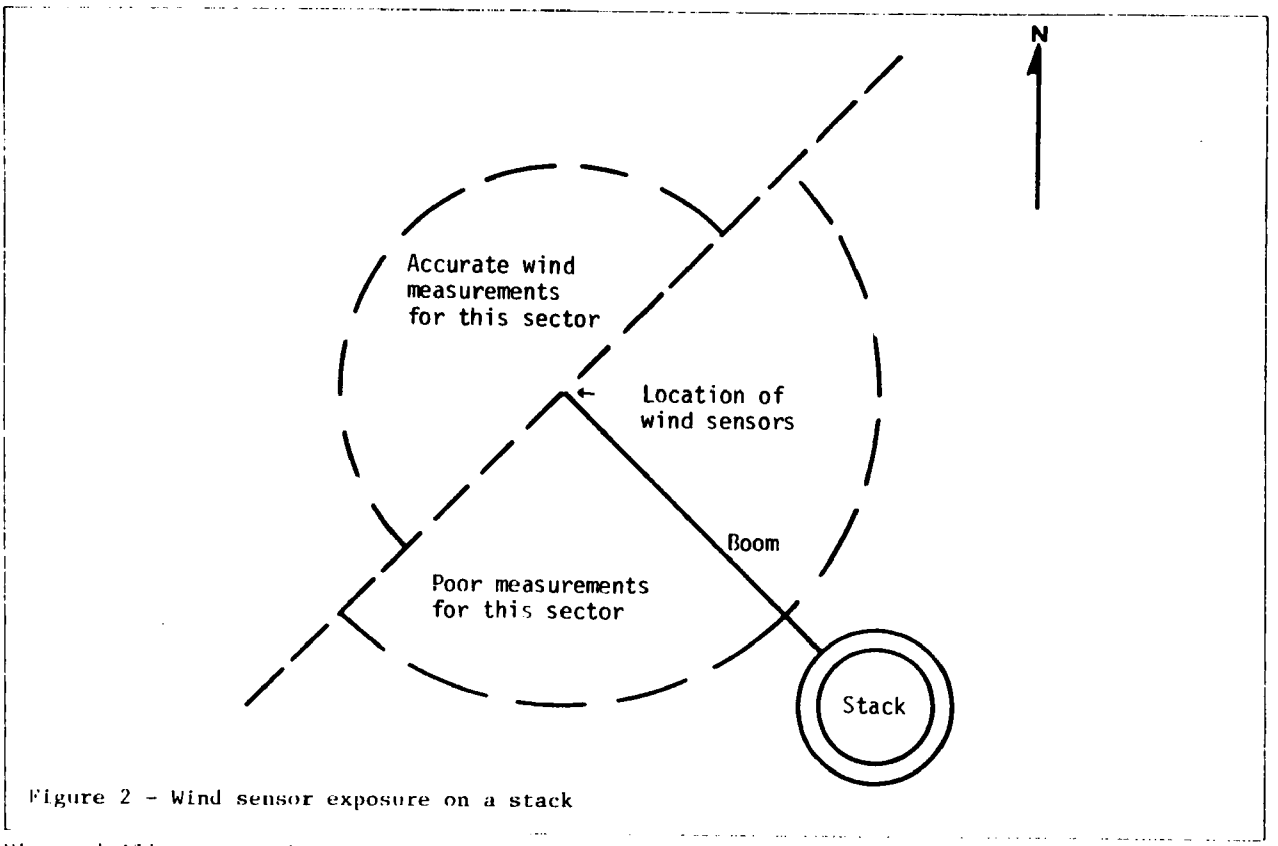


Figure 2 - Wind sensor exposure on a stack

Figure 1 illustrates the correct exposure of a wind sensor on an open tower. The following exposure criteria should be observed:

1) The boom should extend outward from a corner of the tower into the wind direction of primary concern.

2) The boom should place the sensor out from the tower a distance not less than the length of a side of the tower. (Length D in Figure 1)

3) The wind sensors should be located at heights of minimum tower density, and above or below horizontal cross members.

If the above guidelines are followed, the following accuracies can be expected:

1) For a boom length of 1D, measurements of wind speed are true within $\pm$ 10% for a 310° sector of arc.

2) For a boom length of 2D the wind speed is accurate within $\pm$ 10% for a 330° sector of arc.

3) For these two arcs, wind direction is accurate to within approximately $\pm$ 5%.

With a boom length of 1 -2D, wind speed and direction measurements within $\pm$ 5% can only be obtained for a 240 - 270° sector of arc. This is the case illustrated in Figure 1.

It has been found in practice that the maximum practical boom length is about 20-30 feet. If the wind sensors are to be mounted on very large towers (TV towers or fire look-out towers), the sector of arc yielding accurate wind measurements may drop to 180° due to the fact that the boom length may be less than 1D.

In any case, if accurate wind measurements are required for an arc sector greater than that produced by the above exposure criteria, it is recommended that two sets of speed and direction sensors be placed at 180° apart in the manner prescribed in the above guidelines.

EXPOSURE OF WIND SENSORS ON CLOSED TOWERS OR STACKS

Preferably, closed towers or stacks should not be used to support meteorological sensors. If a stack must be used, the following exposure guidelines should be observed:

1) The boom should place the sensor out from the stack a distance not less than 2 stack diameters.

2) Instruments should never be located within 2-5 stack diameters of the top of an active stack.

Figure 2 illustrates the correct exposure of a wind sensor on a stack. If the above guidelines are used one can expect accurate wind measurements (± 5 to 10% of true value) through an arc of only 180° as shown in Figure 2. As with towers, if accurate wind measurements through a full 360° of Azimuth are desired, it is recommended that two sets of wind systems be used. These two systems should be located 180° apart, and exposed according to the above guidelines.

TEMPERATURE SYSTEMS

Temperature sensors should also be exposed on booms out from the tower structure to assure that the temperature of the air sampled is not influenced by thermal radiation from the tower itself. Temperature sensors should never be mounted on stacks.

Booms for temperature sensors need not be as long as for wind sensors, but generally, both wind and temperature sensors are located on the same boom at about the same distance from the tower. The temperature sensors themselves must be shielded and ventilated as described in the previous section.

SPACING OF WIND AND TEMPERATURE SYSTEMS

Figure 3 illustrates a typical spacing of wind and temperature systems on a tower. Wind sensors are normally spaced at logarithmic height intervals (10,20,40,80, 160 meters) because of the normally logarithmic change of wind speed with height.

Temperature measurements should be made at close intervals near the ground, and at approximately equal intervals at greater heights as shown in Figure 3. A logarithmic spacing is not necessary since temperature profiles become approximately linear a short distance from the surface.

With both wind and temperature, provisions must be made for swinging or telescoping the boom in order to service the sensors. Provisions also must be made for orienting the wind vane correctly when the boom is in the service position.

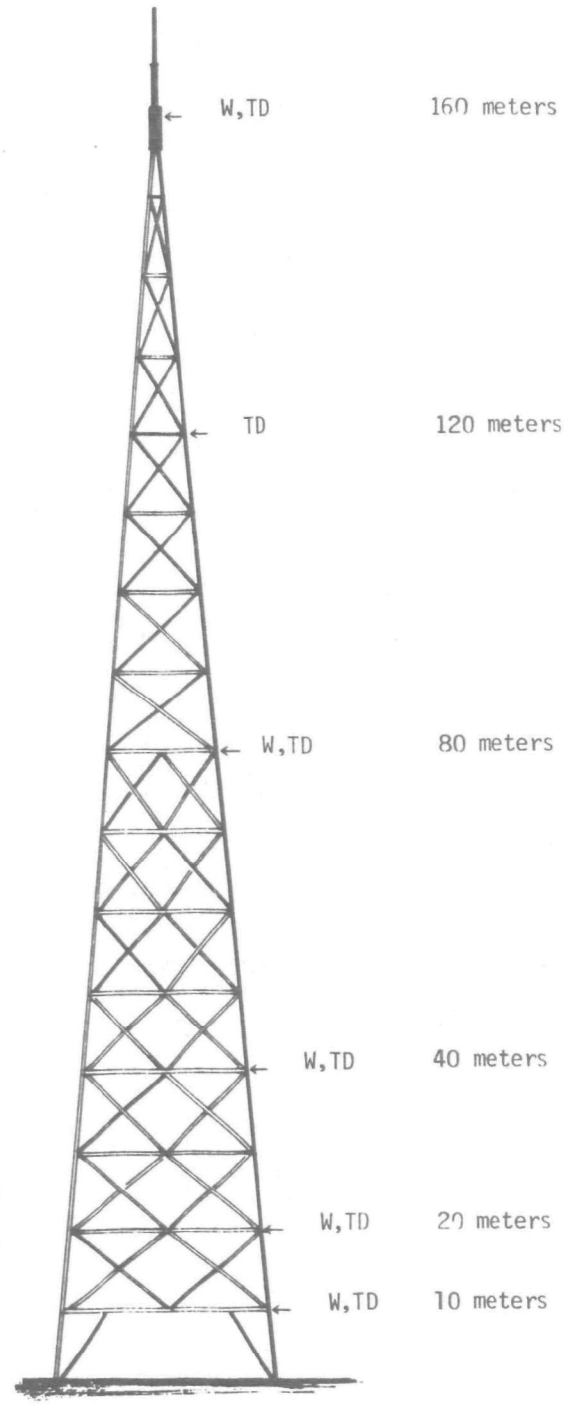


Figure 3 - Vertical spacing on a tower

Exposure of Airborne Instruments

INTRODUCTION

The measurement of meteorological parameters aloft may require the use of such devices as balloons, aircraft, rockets, etc. With many of these methods, surface-based receiving and recording instrumentation is necessitated. Therefore, a discussion of the exposure of airborne instruments must also include a discussion of the exposure of the surface-based support equipment.

EXPOSURE OF SURFACE BASED SYSTEMS

The measurement of wind aloft by balloon tracking may involve the use of radar or radio direction-finding equipment. Sites for radio and radar equipment should be on relatively high ground with the horizon as free from obstructions as possible. Of greatest importance to free balloon launchings is that there be no nearby obstructions to hinder the flight of the balloon. The operation of captive balloons (wiresondes) should be carried out only in open areas and never near power lines. Particular care should be taken to properly ground all captive balloon equipment and operations should be carried out only during periods of minimal atmospheric electrical potential. It should be noted that FAA authorization is necessary for most captive balloon operations.

EXPOSURE OF AIRCRAFT MOUNTED SYSTEMS

The main exposure problem associated with measurements from an aircraft is the fact that the sensors must be exposed to undisturbed air. Fixed wing propellor slipstreams and helicopter downwash must be avoided. For temperature measurements, engine and cabin heat must also be avoided, and a correction must be made for airspeed. Vibration of receiving and recording instrumentation in the aircraft may also be a problem.

The following guidelines are suggested for exposure of aircraft mounted sensors:

1) On fixed wing aircraft, sensors are most effectively mounted on the wingtips, forward of the wing not less than two feet.

2) On a helicopter, sensors are most effectively mounted on the forward tip of one of the skids, provided a forward speed of about 15 m/sec is maintained. This forward speed would project the downwash behind the sensor.

3) To reduce recorder vibrations, mountings of sponge rubber or plastic should be used.

REFERENCES:

Exposure of Meteorological Instruments

1) Gill, G.C., Olsson, L.E., Sela, J., and Suda, M., "Accuracy of Wind Measurements on Towers or Stacks", Bulletin of the A.M.S., Vol. 48, No. 9, Sept 1967 pp 665-674

2) Moses, H., and Daubek, H.G., "Errors in Wind Measurements Associated with Tower-mounted Anemometers", Bulletin of the A.M.S., Vol. 42, No. 3, 1961 pp 190-194

3) Haugen, D.A., Kaimal, J.C., Readings C.J., and Rayment, R. A Comparison of Balloon-Borne and Tower-Mounted Instrumentation for Probing the Atmospheric Boundary Layer. J. App. Meteor. Vol. 14, No. 4, 540-545, June 1975.

SECTION SEVEN

FURTHER APPLICATIONS OF METEOROLOGY TO AIR POLLUTION

Air Pollution Weather Forecasts
Air Pollution Surveys
Site Selection for a Pollutant Source
Atmospheric Tracers and Urban Diffusion Experiments
Meteorological Models for Urban Areas
Sources of Meteorological Data

AIR POLLUTION WEATHER FORECASTS

J.L. Dicke

A program to provide air pollution weather forecasts has been in effect on a year-round basis since August 1960, for the eastern U.S. and since October 1963, for the contiguous 48 states. The purpose of the program is to forecast meteorological conditions which are favorable for the accumulation of contaminants in the atmosphere. These forecasts are disseminated to public and private interests by the National Weather Service, NOAA.

I DEFINITION

A high potential for community air pollution has been defined as a set of weather conditions conducive to the accumulation of atmospheric pollutants over 36 hours or more and over an area of about 58,000 nautical mi^2 (76,000 statute mi^2) or more. Niemeyer, (6) Boettger, (1) and others have found that such conditions (e.g., hourly surface wind speeds generally not exceeding 7kt., winds aloft not exceeding 25kt., and subsidence below 600mb) occur when high pressure exists at the surface and there is a warm-core ridge aloft. This is the basic synoptic weather situation that the air pollution forecaster attempts to anticipate. The warm core ridge aloft is extremely important since it is indicative of a slow-moving surface pressure system. If the surface anticyclone becomes quasi-stationary, as it often does in such situations, perturbations aloft and at the surface are forced to move around the system. While poor dispersion also occurs during other types of weather situations, the warm-core anticyclone is considered the "text book" model of stagnation.

II. BACKGROUND

ESSA meteorologists assigned to the U. S. Public Health Service began issuing routine, operational forecasts of high air pollution potential for the area east of 105°W longitude in August, 1960. During the first year of this operation, 12 cases of air pollution potential occurred; of these, 10 were forecast (Miller and Niemeyer). (4)

In a climatological study of air pollution potential for the western United States, Holzworth, (3) also found that the large-scale synoptic feature most conducive to poor air quality was the quasi-stationary anticyclone. This study and the initial success of the forecast program for the eastern United States provided the background for a research program to extend the forecast area to include the western United States. An experimental forecasting program for the western United States was started in September 1961, The program was successful and on October 1, 1963 the operational forecast area for air pollution potential advisories was expanded to include all of the contiguous United States. Specialized forecast guidance for Alaska has been provided by the National Meteorological Center since early 1972.

An isoline analysis of the total number of high air pollution potential (stagnation advisory) days forecast from the start of the program through April 3, 1970 is given in Figure 1. The area in the eastern half of the United States with the maximum number of air pollution potential days is located along the Appalachian Mountains. The respective area for the western United States is found over central California.

The initial success of the forecasting program (prior to 1962) was due mainly to the individual forecaster's judgement based on experience. While the necessity for some forecasting judgement has always been required, especially when fixing the boundaries of high air pollution potential areas, it was recognized that the consistency and reliability of the forecasts could be improved by employing objective forecasting aids. Such an aid was developed for the eastern United States by V. D. Urban (unpublished) and for the western United States by Miller. (4)

Since these forecasting methods have been developed, many additional refinements have been introduced. The forecast program is by no means in its ultimate form, as continuing research is directed toward the development of more useful forecasts and more accurate forecasting techniques especially at the National Weather Service Forecast Office (WSFO) level.

III. GENERAL PROCEDURES AT NMC

A. The Aviation Weather Branch of the Forecast Division at the National Meteorological Center (NMC) provides several services in fulfilling its responsibilities within the National Weather Service (NWS) Air Pollution Weather Forecast Program. Forecasters in Washington, D. C. provide large-scale meteorological guidance used by field offices and prepare three major "products."

*Supervisory Meteorologist , NOAA
Meteorology & Assessment Division, EPA
Research Triangle Park, N. C. 27711

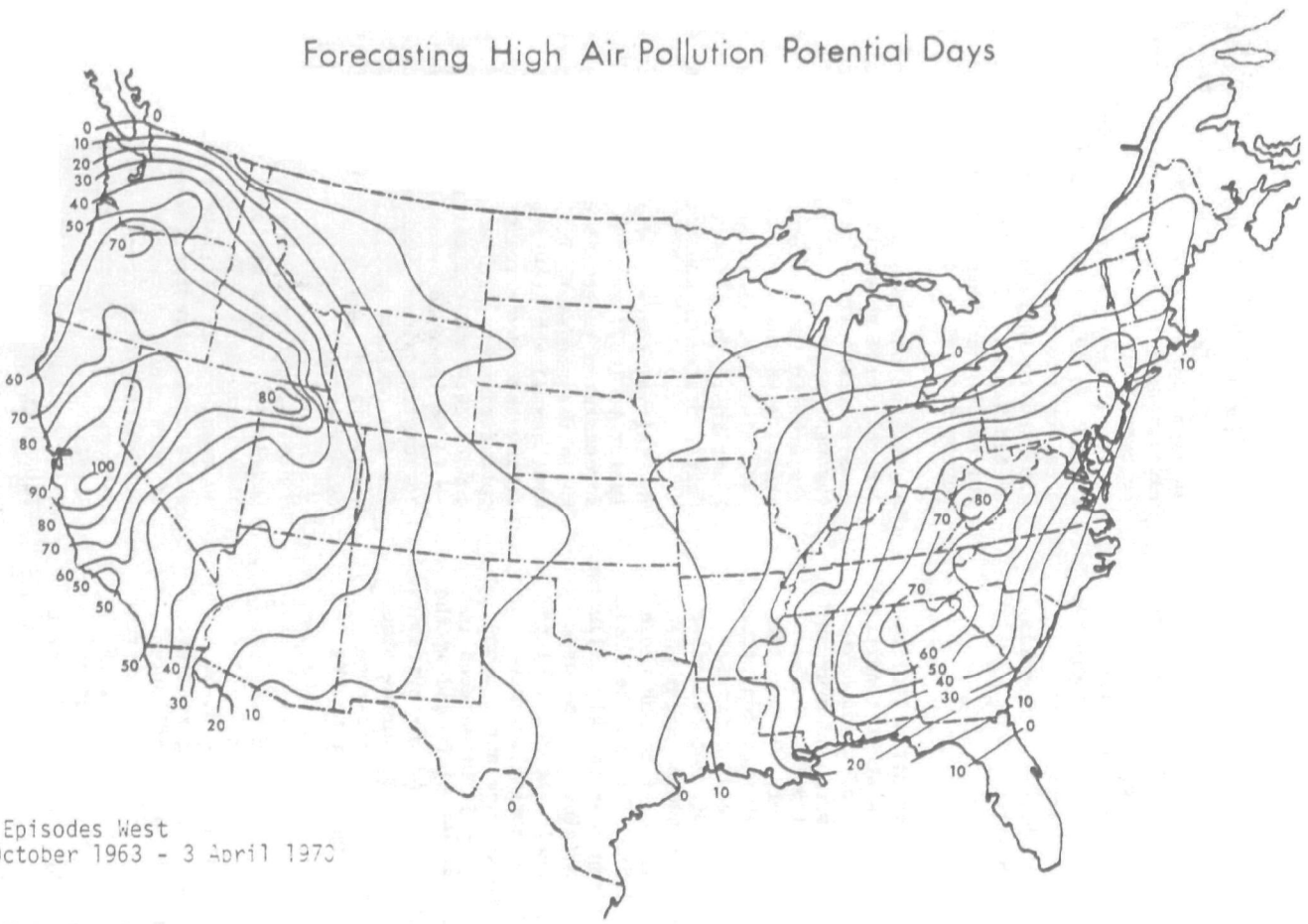

Forecasting High Air Pollution Potential Days
39 Episodes West
1 October 1963 - 3 April 1970
75 Episodes East
1 August 1960 - 3 April 1970

Figure 1.

1. Air Stagnation Guidance Charts are issued once daily in the morning on FOFAX as shown in Fig. 2.

2. Air Stagnation Narratives FKUS 2 are plain language teletypewriter messages issued several times daily on Service C as shown in Fig. 3.

3. Air Stagnation Data FKUS 1 is a computer produced teletypewriter message issued once daily on Service C as shown in Table 1.

4. A log of Air Stagnation Advisories (ASA) as issued by each WSFO is maintained at NMC.

The issuance or termination of an ASA is not the responsibility of NMC but recommendations and advice are available to WSFO meteorologists.

B. Forecast Stagnation Charts

The 4 charts in Fig. 2 are a "man-machine mix" product. A computer forecast of various parameters affecting stagnation is generated and the patterns are then modified by the forecaster as required to produce the final facsimile product. The computer evaluates vorticity, 12-hour vorticity change, 12-hour 5000 ft. temperature change, 5000 ft. wind speed and precipitation probability for each radiosonde station. If specific criteria are met the station is evaluated again, using more critical criteria. Those stations remaining after the second evaluation are printed out and subjectively evaluated by the forecaster in terms of reliability of boundary layer wind speed input, vorticity prognoses, forecast precipitation areas, frontal locations and their movement, stability index values, and upper flow patterns. The final results are transposed to facsimile charts for transmission at 1227 GMT (0727 EST) daily. Mixing height data are not input to this product.

C. Air Stagnation Narratives - FKUS2

The purpose of these narratives is to provide the WSFO's with

1. An explanation of forecast stagnation patterns stressing areas of probable deterioration or improvement of dispersion conditions.

2. Outlooks and guidance for dispersion problems.

3. NMC Forecaster estimate of general dispersion conditions and trends in stagnation areas.

A narrative is issued in the morning to coincide with the facsimile transmission and another is transmitted as an update shortly after noon. The afternoon narrative is filed as early as possible, between 1500-1530 EST, and also contains a brief summary of ASA's that are in effect as received from the WSFO's.

D. Air Stagnation Data - FKUS 1

This message is sent by NMC computer on Service C teletype and contains a list of mixing height and transport wind data for selected stations. The heights are in decameters, wind speeds in meters per second. Table 1 is an example partial listing of the daily transmission at 1720 Z (1220 EST).

IV. THE AIR POLLUTION FIELD FORECASTING PROGRAM

A. Weather Service Forecast Offices (WSFO)

The 43 WSFO's are responsible for issuing air pollution weather forecasts covering their respective areas and have assigned either a Focal Point or Program Leader to this task. Three basic air pollution products are issued by the WSFO:

1. Air Stagnation Advisory - (ASA)-FKUS4

This is the basic product issued to air pollution control agencies and the public as shown in Figure 4. An ASA is issued when locally established critical values of transport wind, mixing height and other parameters are forecast to be reached and are expected to persist for at least 36 hours, causing a probable significant decrease in air quality. Most forecasters use some type of air stagnation check sheet to assist them in arriving at a decision. Morning and afternoon mixing depth and transport wind speeds are evaluated and forecast, based on local data and a variety of NMC products.

At night as the atmosphere traverses an urban area, it usually acquires a significant amount of heat from urban sources, causing the temperature of the air over the city to be somewhat warmer than that upwind of the city. This phenomenon is called the urban "heat island".[2] An important effect of the urban heat island is

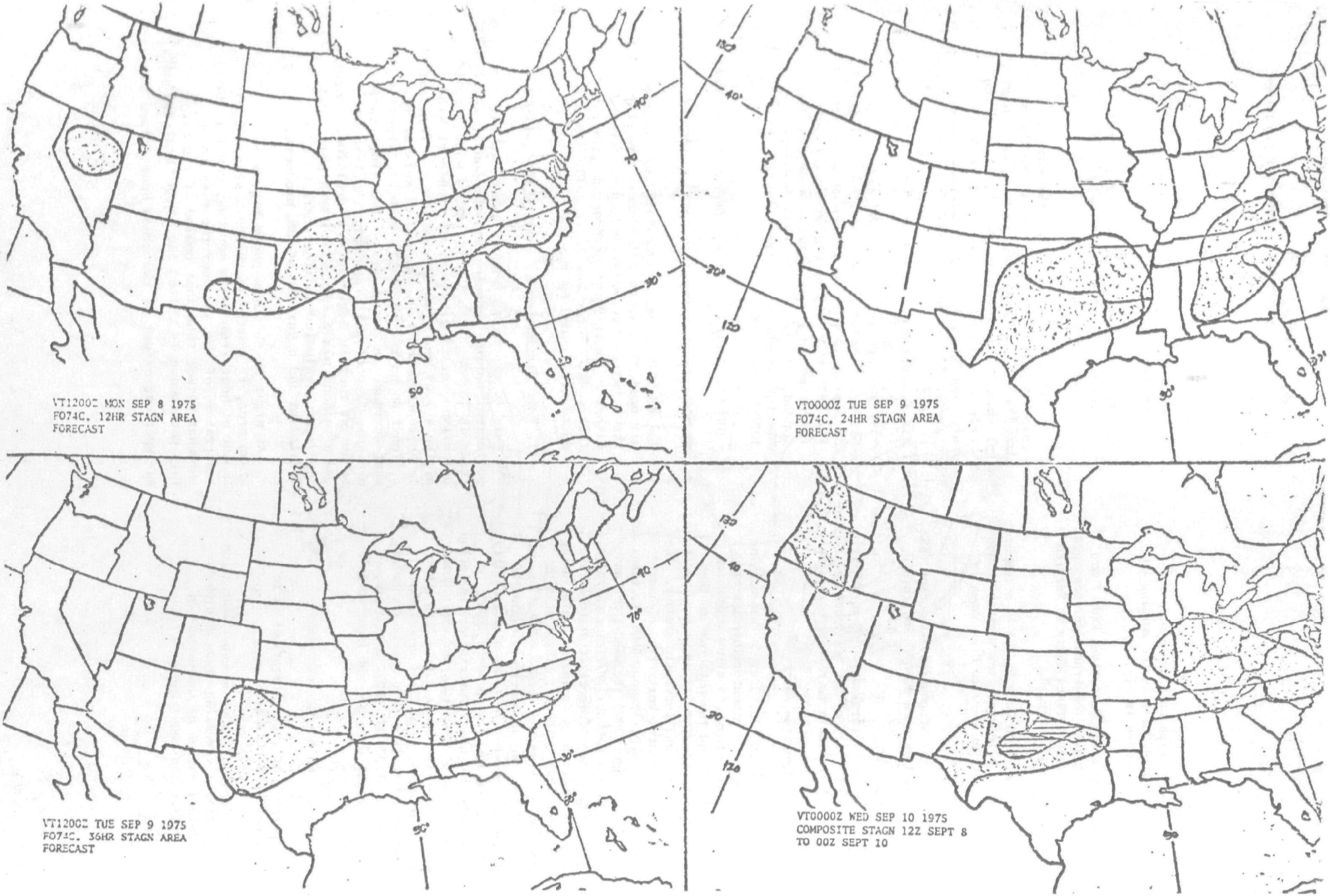


FIGURE 2. Sample Facsimile Transmission from NMC. Hatched Area Over South Oklahoma and NE Texas is Forecast to Remain Under Stagnation Conditions During All Four Periods (36hr.)

Table 1. Air Stagnation Data and Code

```
Z CZ C WBC626
FKUS1 KWBC 191720
AIR STAGNATION DATA
.
.
.
725 62  109042 002051 222133    72572 176060 004026 255037
725 76  177018 143019 236048    72583 238046 024067 307069
725 97  195021 004000 249029    72606 078021 076058 073058
726 37  062026 045051 091062    72645 119129 036028 132337
726 54  055153 180232 188232    72655 039093 163156 180156
726 62  205166 184205 196205    72681 204068 999999 999999
726 94  192056 003015 113024    72712 167046 028031 153074
727 34  104102 080067 075067    72747 067100 149094 221100
727 64  002154 107196 132196    72768 129164 108127 134139
727 75  151115 010046 241068    72785 247038 017031 256059
.
.
.
```

Explanation of the Code

IIiii MyMyMy$\overline{W}$y$\overline{W}$y$\overline{W}$y MnMnMn$\overline{W}$n$\overline{W}$n$\overline{W}$n MxMxMx$\overline{W}$x$\overline{W}$x$\overline{W}$x

IIiii The block number and station number.

MyMyMy The afternoon mixing height for "Yesterday Afternoon" in decameters.

$\overline{W}$y$\overline{W}$y$\overline{W}$y The average wind speed within the mixing height for "Yesterday Afternoon" in meters per second and tenths of meters per second.

MnMnMn The morning mixing height for "This Morning" in decameters.

$\overline{W}$n$\overline{W}$n$\overline{W}$n The average wind speed within the mixing height for "This Morning" in meters per second and tenths of meters per second.

MxMxMx The afternoon mixing height for "This Afternoon" in decameters.

$\overline{W}$x$\overline{W}$x$\overline{W}$x The average wind speed within the mixing height for "This Afternoon" in meters per second and tenths of meters per second.

FKUS2 KWBC 121240

AIR STAGNATION NARRATIVE

REFAX F074C.
POOR DISPERSION CONDS OVR BAY AREA AND INTERIOR VLYS OF CALIF WITH AFTN DIURNAL ITG IMPROVING DISPERSION IN VLYS...
DETERIORATION LIKELY OVR WEST COAST DURG WKEND AS PAC BLOCK BECOMES BETTER ESTABLISHED...

LGT TRANSPORT WNDS WILL REMAIN NORTHERN ALA THRU SWRN VA UNDER WK SFC RDG... OTHERWISE GENERALLY ADEQUATE DISPERSION OVR MOST OF U.S. DURING FCST PERIOD... CLIFFORD

Figure 3 Air Stagnation Narrative August 12, 1975

Figure 4.

FKUS4 RWRC Ø41ØØ
AIR STAGNATION ADVISORY NUMBER ONE
NATIONAL WEATHER SERVICE...MEMPHIS TENNESSEE
ISSUED 12 NOON THURSDAY SEPTEMBER 4 1975

AN AIR STAGNATION ADVISORY IS ISSUED FOR ALL OF TENNESSEE AND THE ADJOINING COUNTIES OF CRITTENDEN IN ARKANSAS AND DESOTO IN MISSISSIPPI.

STAGNANT HIGH PRESSURE OVER THE AREA IS EXPECTED TO CONTINUE THRU FRIDAY CAUSING GENERALLY POOR DISPERSION CONDITIONS. LIGHT WINDS AND A STRONG NIGHTIME TEMPERATURE INVERSION ARE ALLOWING SMOKE.. DUST AND GASES TO CONCENTRATE NEAR THE GROUND.

TEMPORARY IMPROVEMENT IN AIR QUALITY IS EXPECTED THIS AFTERNOON BUT A RETURN TO STAGNANT CONDITIONS WILL OCCUR AGAIN TONIGHT.

THE NEXT ADVISORY WILL BE ISSUED BY 2 PM FRIDAY.

Figure 5.

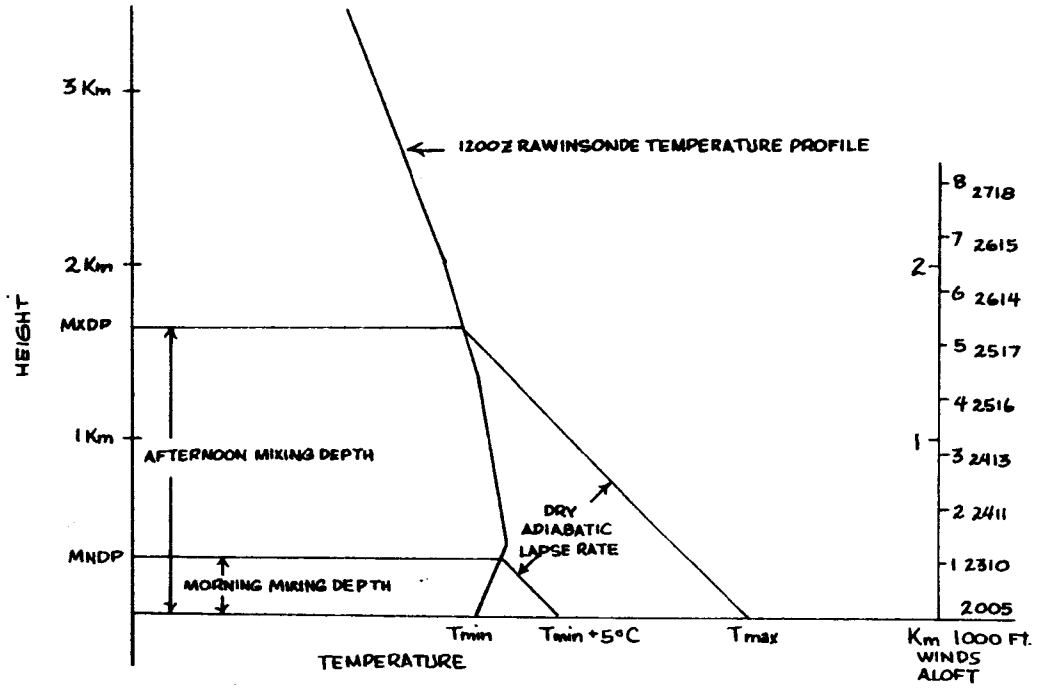


Figure 6.

FKUS4 RWRC Ø51700

TERMINATION OF AIR STAGNATION STATEMENT

NATIONAL WEATHER SERVICE FORECAST OFFICE MEMPHIS TENNESSEE
ISSUED 12 NOON FRIDAY SEPTEMBER 5 1975

THE AIR STAGNATION ADVISORY FOR TENNESSEE AND THE ADJOINING COUNTIES OF CRITTENDEN IN ARKANSAS AND DESOTO IN MISSISSIPPI WILL BE ENDING THIS AFTERNOON.

WINDS WILL BE INCREASING TODAY AND SHOWERS ARE EXPECTED THIS AFTERNOON THRU SATURDAY THAT WILL HELP IN CLEANSING THE AIR. STAGNANT CONDTIONS MAY PERSIST AGAIN SATURDAY MORNING IN PARIS OF EAST TENNESSEE BUT GOOD DISPERSION CONDITIONS ARE EXPECTED BY AFTERNOON ALONG WITH THE PROBABILITY OF SHOWERS.

THIS WILL BE THE LAST STATEMENT FOR THE CURRENT AIR STAGNATION EPISODE.

to establish a lapse rate over the city that is usually more unstable than the lapse rate over the rural area upwind of the city. The net result is a mixing layer over the city at night that may be as high as several hundred meters.

To simulate this effect, 5°C is added to the airport minimum temperature during the night. Then the height is determined where the dry adiabatic lapse rate from this surface temperature intersects the temperature - height profile observed (by rawinsonde) at 1200 GMT. This height is called the morning urban mixing depth (MNDP) and represents a rough value of mixing depth during the morning period over an urban area (See Figure 5).

To determine the greatest depth of the mixing layer (MXDP) that is expected during the day and the same procedure is repeated using the forecast maximum surface temperature.

The average wind speed through the mixing layer for the morning and afternoon periods is calculated by taking the arithmetic average through the mixing layer of the wind speeds aloft. For the morning period the speeds observed at 1200 GMT are used, but for the afternoon period forecast speeds are used.

A new ASA should be issued at least every 24 hours under continued stagnation. When conditions are forecast to improve sufficiently, and there is a definite indication of improving air quality a termination statement should be issued, coordinated with the local air pollution control agency. (Fig. 6)

Final responsibility for deciding whether to issue an ASA rests with the forecaster; however, under certain circumstances, the forecaster may decide that public issuance of an ASA would not be in the public interest such as:

a) If the public issuance of an ASA is likely to cause confusion. This might happen when public statements concerning an episode are issued by more than one agency.

b) An air stagnation situation exists, or is forecast but air quality is not expected to deteriorate sufficiently to arouse the public.

c) If, after close coordination with the local control agency, it is determined that appropriate warnings and control action will/is being taken.

2. Special Dispersion Statement - (SDS) -FKUS4

When the forecaster has determined that a potential air pollution situation exists but he has decided not to issue an ASA, a Special Dispersion Statement will be issued for the control agency. The main difference between an ASA and an SDS is that the SDS is not normally issued to the public. NMC receives and logs all ASA and SDS messages.

3. The Dispersion Outlook - FKUS3

At some WSFO's the Meteorologist-in-Charge (MIC) has determined through consultation with the local control agency that routine meteorological information on a daily basis will be transmitted to the agency. The format, content and time of issuance are specified locally, and are not usually sent to NMC.

B. NWS Low Level Sounding Program

The special observational units established by NWS several years ago originally known as Environmental Meteorological Support Units Units (EMSU), to provide surface and upper air data in major metropolitan areas have been curtailed. However, the following units are still operational:

LIST OF CURRENT NWS LOW LEVEL SOUNDING PROGRAM

Location	Program
New York, New York	Afternoon sounding on-call
Philadelphia, Pennsylvania	All observations on call
Pittsburgh, Pennsylvania	1 per day, Mon.-Fri.
Charleston, West Virginia	1 per day routine weekdays, second observation on-call
Birmingham, Alabama	1 per day routine, second observation on-call
Houston, Texas	2 per day, Mon.-Fri.
Los Angeles, California	2 per day, 7 days a week routine
El Monte, California	2 per day routine Mon.-Fri. except occasionally omit afternoon sounding on well-ventilated days

V EPA and Regional Office Activities

The EPA requires that emergency action plans, prepared by state air pollution control authorities as a part of their implementation plan, contain, as a criteria to trigger preplanned episode reduction schemes, definite procedures for receiving an ASA, or equivalent report stating that a condition of atmospheric stagnation will exist for the next 36 hours. Additional information is contained in the "Guide for Air Pollution Episode Avoidance" (1971) and two related publications (1971). The program responsibilities and organization vary, somewhat, within each EPA Regional Office and information should be obtained by direct contact.

REFERENCES

1. Boettger, C. M. Air Pollution Potential East of the Rocky Mountains, Fall 1959 Bulletin of the American Meteorological Society. 42:615-620. No. 9, September, 1961.

2. DeMarrais, G. A. Vertical Temperature Difference Observed Over an Urban Area. Bulletin of the American Meteorological Society. 42: 548-554. No18, August, 1961.

3. Holzworth, G. C. A Study of Air Pollution Potential for the Western United States. Journal of Applied Meteorology. 1:366-382. No. 3, September 1962.

4. Miller, M. E. Semi-Objective Forecasting of Atmospheric Stagnation in the Western United States. Monthly Weather Review. 92: 23-32, No. 1, January, 1964.

5. Miller, M. E. and Niemeyer, L. E. Air Pollution Potential Forecasts - A Year's Experience. Journal of the Air Pollution Control Association. 13: 205-210, No. 5.

6. Niemeyer, L. E. Forecasting Air Pollution Potential. Monthly Weather Review. 88: 88-96. No. 3., March. 1960.

7. Miller, M. E. Forecasting Afternoon Mixing Depths and Transport Wind Speeds. Monthly Weather Review. 95: 35-44. No.1 January, 1967.

8. NOAA, National Meteorological Center. Air Pollution/Stagnation Procedures. Aviation Weather Branch Note. Draft January 1974.

9. Nudelman, H. I. and Frizzola, J. A. An Air Pollution Incident Due to a Stationary Front. JAPCA Vol. 24, No. 2, 140-144, February 1974.

10. Stephens, E. R. Chemistry and Meteorology in an Air Pollution Episode. JAPCA Vol. 25, No. 5, 521-524, May 1975.

11. Gross, E. The National Air Pollution Potential Forecast Program. ESSA Technical Memorandom WBTMNMC 47, May, 1970.

12. Guide for Air Pollution Episode Avoidance. EPA, Office of Air Programs Publ. No. AP-76, May, 1971.

13. Guide for Control of Air Pollution Episodes in Medium-Sized Urban Areas. EPA, Office of Air Programs Pub. No. AP-77, June 1971.

14. Guide for Control of Air Pollution Episodes in Small Urban Areas. EPA, Office of Air Programs Pub. No. AP-78, June, 1971.

15. National Weather Service Operations Manual. C-30 "Air Pollution Weather Forecasts". June 19, 1975.

AIR POLLUTION SURVEYS

P. A. Humphrey*
J. A. Tikvart*

I DEFINITION AND PURPOSE OF AIR POLLUTION SURVEYS

A An air pollution survey is a critical examination of a given geographical area for the purpose of determining the nature, sources, extent, and effects of air pollution and their interrelationships. This includes:

1 Evaluating the character and magnitude of existing problems.

2 Estimating the potential for future problems or for the deterioration of a present problem.

3 Obtaining knowledge and understanding for the development of abatement and control measures.

B Brief inspections by enforcement officials and evaluations of combustion equipment or air and gas cleaning equipment do not qualify as surveys.

II TYPE AND SCOPE OF SURVEYS

A Local Source Problems (Determination of the extent to which a source affects the local ecology).

1 Large source with voluminous emissions.

2 Small source with emissions especially noxious or detrimental to the surrounding area.

B Site Selection Surveys

1 Sites for the construction of new industry.

2 Community planning and zoning

a Impact of a proposed plant or group of plants.

b Industrial park location.

C Area Surveys. Table 1 lists selected surveys not included in Tables 1 and 2 of Rossano (1962).

1 Appraisals involving little or no air sampling using available data.

a Determine current status of air pollution.

b Estimate future potential.

c Offer recommendations for prevention or abatement.

2 Small-scale intensive investigations (Sampling at one or more locations for a period of one to several weeks).

a Provides order-of-magnitude figures of levels and fluctuations of pollutant concentrations.

b Focuses attention of community on its growing problem and may provide opportunity for training.

3 Community air pollution surveys (Large-scale study involving considerable field and laboratory activities over a period of one or more years).

D Research Studies

1 Especially designed studies of an experimental nature.

a Meteorological transport and diffusion.

b Abatement procedures and control devices.

2 Post air pollution episode investigations.

*Supervisory Meteorologists, NOAA
Meteorology & Assessment Division, EPA
Research Triangle Park, N. C. 27711

PA.MT.mm.15b.6.67

III THE COMMUNITY AIR POLLUTION SURVEY

A Planning and Development

1 State the problem

a Human health, animal and/or vegetation effects, materials deterioration

b Pollutants responsible

c Meteorology and topography effects on transport

2 Define the depth of the survey

a Geographic area

b Money and personnel

1) "paper" study - one man and secretary

2) pollutant sampling and analyses program - interdisciplinary professional staff

c Time - short period or long term.

B Operations

1 Air pollutant source measurements (Emission inventory)

a Paper estimate

b Questionnaire and/or plant visit

c Source sampling

2 Meteorological and topographic studies

a Climatology

b Tracer experiments

c Mathematical diffusion model

3 Air sampling and analysis

a Time considerations in sampling

b Geographical (or geometrical) considerations

1) Wind trajectories

2) Concentric circles

3) Network

4) Mobile stations

5) Three-dimensional measurements

c Design of aerometric stations

4 Measurement of effects

a Biologic

1) Impairment of health

2) Odor nuisance

3) Reduction of solar radiation and visibility

4) Eye irritation

b Economic

1) Corrosion of metals

2) Deterioration of fabrics

3) Damage to paint

4) Soiling

5) Reduction of solar radiation and visibility

5 Photographic studies

a Ordinary ground and aerial photography

b Time lapse photography

c New photographic techniques

6 Analysis of data

7 Public relations and information

C Evaluation and Report

1 Interpretation

2 Evaluations, pro and con

3 Presentation of concise, attractive and easily understood report.

Table 1. Selected List of Air Pollution Appraisals and Investigations of Limited Scope

DESIGNATION	DATE	RESPONSIBLE ORGANIZATION	SCOPE
Air Pollution in Maricopa County (Winter 1959-60) Arizona	1960	Maricopa County Health Dept. Division of Environmental Health Sanitation Bureau of Public Health Engineering	-
Preliminary Report Air Pollution Surveillance Study Tucson, Arizona	1960	University of Arizona Tucson, Arizona	-
Air Pollution in Greater Elmira, New York	1960	New York State Air Pollution Control Board Albany, New York	-
A Pilot Study of Air Pollution in Washington, D. C.	1960	Washington, D. C., Dept. of Public Health and U.S. Dept. of HEW Public Health Service	-
The Atmosphere Over Philadelphia, Its Behavior and Contamination	1950	Drexel Institute of Technology	Detailed analysis of 10 years of weather records for Philadelphia and discussion of high and low high volume air sampler and AISI sampler concentrations as related to meteorological conditions.
Report on Sampling Survey - Hudson, New York	1960	New York State Dept. of Health Bureau of Air Pollution Control Services, in Conjunction with The Columbia County Health Dept.	Five AISI tape samplers, and two wind speed and direction recording systems were used to evaluate levels of soiling contaminants and to attempt to correlate wind directions and possible contaminant sources in and around the survey area. The sampling period was approximately 3 months.
Fresno Air Pollution Study	1960	Air and Industrial Hygiene Laboratory Bureau of Air Sanitation Dept. of Public Health State of California	Survey covers two periods of one week duration in the months of September and December. Sampling was done for oxidant, nitric oxide, nitrogen dioxide, carbon mononide, sulphur dioxide, hydrocarbons and particulate matter. Meteorological data including some temperature soundings are used in evaluating results.
Air Pollution in Lynchburg, Virginia	1961	Public Health Service (Region III)	Same as for state-wide air pollution appraisals.
Denver Metropolitan Area Air Sampling Survey	1961	Colorado State Dept. of Public Health	Survey covers 6-month period, with sampling of airborne particulate matter on 50 selected days. Field equipment included 6 AISI automatic strip filter paper samplers and 3 high volume filter paper samplers. Soiling characteristics, weight of suspended particulate matter and weight of benzene soluble organic matter in the suspended particulates was determined. Four gaseous pollutants were measured at a single station.

Table 1. (Cont'd) Selected List of Air Pollution Appraisals and Investigations of Limited Scope

DESIGNATION	DATE	RESPONSIBLE ORGANIZATION	SCOPE
In Quest of Clean Air for Berlin, New Hampshire	1962	Field Studies Branch Division of Air Pollution U.S. Public Health Service in cooperation with State of New Hampshire Department of Health and City of Berlin New Hampshire Health Dept.	A two-month study with 10 instrumented air quality stations and three meteorological stations for the purpose of appraising nature, sources, extent, and effects of air pollution in Berlin, N.H. The major source of air pollutants is paper pulping and ancillary operations, including steam generations, of a single company.
A Pilot Study of Air Pollution Providence, Rhode Island	1962	Technical Assistance Branch Division of Air Pollution USPHS, in cooperation with Division of Air Pollution and Mechanical Equipment and Installations City of Providence	Survey covers two equal periods of 15 sampling days each at one station. Particulate pollutant measurements include soiling index, total suspended particulates and dustfall and gaseous pollutants measurements include those for sulfur dioxide, total oxidants, nitric oxide-nitrogen dioxide and carbon monoxide. The normalcy of the meteorological conditions during the sampling period is considered and air pollution potential for the city is discussed.
Air Pollution Measurement Study in Richmond, Virginia	1962	Richmond's Bureau of Air Pollution Control Virginia's State Dept. of Health and U.S. Public Health Service	Measurements of particulate matter concentrations by AISI Smoke Sampler, sulfur dioxide and oxidant levels, for a one-week period in January. Results are discussed in terms of wind speed and sunshine.
A Qualitative Survey of Atmospheric Pollution Potentials in Tiffin, Ohio	1962	Ohio Dept. of Health Division of Industrial Hygiene	Same as for state-wide air pollution appraisals.
A Pilot Study of Air Pollution in Birmingham, Alabama	1962	Technical Assistance Branch Division of Air Pollution U.S. Public Health Service in cooperation with Jefferson County Dept. of Health Alabama	Survey covers two, 3-week periods during the summer and fall. Air samples were collected for measurement of dustfall, suspended particulates, smoke shade, sulfur dioxide, nitrogen oxides, total oxidants, carbon monoxide and hydrogen sulfide. Meteorology is used in a discussion of air pollution potential.
A Pilot Study of Air Pollution in Jacksonville, Florida	1962	Technical Assistance Branch Division of Air Pollution U.S. Public Health Service in cooperation with Florida State Board of Health	Emission inventory data, meteorology and other information were used to determine if there is a general air pollution problem. To aid in accomplishing the objective gaseous and particulate pollutants were measured for one week in a downtown park. Also, there was an investigation to determine if fluorides and sulfur dioxide could be damaging vegetation. To accomplish the second objective, some additional sampling was conducted in the area where vegetation damage had occurred.

Table 1. (Cont'd) Selected List of Air Pollution Appraisals and Investigations of Limited Scope

DESIGNATION	DATE	RESPONSIBLE ORGANIZATION	SCOPE
Management of Dade County's Air Resources	1962	Technical Assistance Branch Division of Air Pollution and Dade County Dept. of Public Health	Existing data on population, agriculture, meteorology, sources of pollutants, present air quality, and details of a proposed refinery are used to estimate Dade County's air resources.
A Study of Denver Air Pollution	1962	Dept. of Atmospheric Science Colorado State University	This is a continuation and expansion of the above survey. It is primarily of a meteorological nature. Wind direction, wind speed and temperature observations were made at 5 special project stations and similar data was available from 6 stations maintained by cooperating agencies. These observations were supplemented by ground and aerial photography, by visual observations and measurements of turbidity. Observational results during 5 air pollution episodes are described.
Air Pollution in the National Capital Area		U.S. Dept. of HEW Public Health Service Maryland State Dept. of Health Virginia Dept. of Health	Uses available data on topography, meteorology, sources of pollution and summarizes information on air pollution measurements from 1931 to date.
Illinois	1956	Same as in Stern's Book, Page 591, (Vol. I)	Same as in Stern's Book, Page 591, (Vol. I)
Colorado	1962	" "	" "
Georgia	1962	" "	" "
South Dakota	1962	" "	" "
Kansas	1962	" "	" "
Air Resources of Utah	1962	Utah Legislative Council Air Pollution Advisory Committee	" "
The Program for Appraisal of the Air Quality of Maryland	1962	Maryland State Dept. of Health	Appraisal of air pollution potential, discussion of 8 station air pollution network. Measurements from high volume samplers, automatic smoke samplers and dustfall jars is presented.

REFERENCES

51 Rossano, A. T., Jr. The Air Pollution Survey in Air Pollution. Vol. I. Editor, Stern, A.C. New York. Academic Press. pp 589-619. 1962.

52 Maricopa County Health Department. Division of Environmental Sanitation. Bureau of Public Health Engineering. AIR POLLUTION IN MARICOPA COUNTY. Winter 1959-60.

53 Mees, Quentin M., and Wortman, Robert L. Preliminary Report Air Pollution Surveillance Study. Bulletin No. 13. Civil Engineering Series No. 6. University of Arizona. Tucson, Arizona. August, 1960.

54 New York State Air Pollution Control Board. Air Pollution in Greater Elmira. Albany, New York. 1960.

55 Washington, D.C. Dept. of Public Health. U.S. Public Health Service. A Pilot Study of Air Pollution in Washington, D.C. Washington, D.C. Dec. 1960.

56 Davis, Francis K. The Atmosphere Over Philadelphia. Its Behavior and Contamination. Drexel Institute of Technology. Philadelphia 4, Pa. 56 pp. October, 1960.

57 Blanchard, G.E. Report on Sampling Survey-Hudson, New York. New York State Department of Health. Bureau of Air Pollution Control Services, in conjunction with the Columbia County Health Department. 29 pp. 1960.

58 State of California. Dept. of Public Health. Fresno Air Pollution Study. Berkeley, California. July, 1960.

59 Dyksterhouse, G. Dept. of HEW. Public Health Service. Region III. Charlottesville, Virginia. Air Pollution in Lynchburg, Virginia. Public Health Service. Washington, D.C. 1961.

60 Colorado State Dept. of Public Health. Denver Metropolitan Areas Air Sampling. 21 pp. Denver 20, Colorado. 1961.

61 Kenline, P.A. In Quest of Clean Air for Berlin, New Hampshire. Dept. of HEW. Public Health Servie. State of New Hampshire Health Dept. City of Berlin. Robert A. Taft Sanitary Engineering Center. 51 pp. Cincinnati, Ohio. 1962.

62 High, M.D., Slater, R.W., and Constantino, G.G. U.S. Dept. HEW. Public Health Service and Division of Air Pollution. City of Providence, R.I. A Pilot Study of Air Pollution in Providence, Rhode Island. (SEC TR A62-15). Robert A. Taft Sanitary Engineering Center. 44 pp. Cincinnati, Ohio. 1962.

63 Richmond's Bureau of Air Pollution Control. Virginia's State Dept. of Health and U.S. DHEW. Public Health Service. Air Pollution Measurement Study in Richmond, Virginia, January 18-24, 1962. 17 pp. Washington, D.C. 1962.

64 Foris, J. Jr., and Foreman, D.L. A Qualitative Survey of Atmospheric Pollution Potentials in Tiffin, Ohio. Ohio Dept. of Health. Division of Industrial Hygiene. 42 pp. 1962.

65 Hochheiser, S., Horstman, S.W., and Tate, G.M. Dept. of HEW. Public Health Service and Bureau of Sanitation. Jefferson County Dept. of Health. A Pilot Study of Air Pollution in Birmingham, Alabama. Robert A. Taft Sanitary Engineering Center. 54 pp. Cincinnati, Ohio. 1962.

66 Sheehy, J.P., et al. Dept. of HEW. Public Health Service. Florida State Board of Health. University of Florida. A Pilot Study of Air Pollution in Jacksonville, Florida, August - September, 1961. Robt. A. Taft Sanitary Engineering Center. 84 pp. Cincinnati, Ohio. 1962.

67 Mathews, D.S., and Schueneman, J.J. Dept. of HEW. Public Health Service. Management of Dade County's Air Resources. Robt. A. Taft Sanitary Engineering Center. Cincinnati, Ohio 39 pp. 1962.

68 Riehl, H., and Crow, L. A Study of Denver Air Pollution. Technical Paper No. 33. Dept. of Atmospheric Science. Colorado State University. Fort Collins, Colorado. (CER 62 HR 37). 15 pp. 1962.

69 Welsh, G.B. U.S. Dept of HEW. Public Health Service. Maryland State Dept. of Health. Virginia Dept. of Health. Air Pollution in the National Capital Area. Division of Air Pollution. PHS., Washington 25, D.C. 42 pp. 1962.

70 Illinois Dept. of Public Health. Something in the air--A Report on Air Pollution in Illinois. Springfield,Ill. Aug., 1956.

71 Palomba, J., Jr., and Wromble, R.F. Colorado State Dept. of Public Health. Dept. of HEW. Public Health Service. An Appraisal of Air Pollution in Colorado. Colorado State Dept. of Public Health. Denver, Colorado. 27 pp. 1962.

72 Lewis, R.P., et al. State of Georgia. Dept. of Public Health and U.S. Dept. of Health, Education, and Welfare. Public Health Service. Air Pollution in Georgia. Atlanta, Georgia. 35 pp. 1962.

73 Carl, C.E., and Christensen, G.L. South Dakota State Department of Health and U.S. Dept. of HEW. Public Health Service. Appraisal of Air Pollution in South Dakota. South Dakota State Dept. of Health. Pierre, South Dakota. 67pp. 1962.

74 Metzler, D.F., Strella, G.G., and Doughty, L.C. Kansas State Board of Health and Dept. of HEW, PHS. The Air Resources of Kansas. Kansas State Board of Health. Topeka, Kansas. 91 pp. 1962.

75 Utah Legislative Council. Air Pollution Advisory Committee. Air Resources of Utah. Salt Lake City, Utah. 32 pp. 1962.

76 Maryland State Dept. of Health. The Program for Appraisal of the Air Quality of Maryland. Div. of Occupational Health. Bureau of Environmental Hygiene. Maryland State Dept. of Health. Baltimore, Maryland. 12 pp. 1962.

77 Keagy, D.M., and Leavitt, J.M. Dept. HEW Public Health Service. A Review of the Air Pollution Problem in Salt Lake Valley, Utah. Cincinnati, Ohio. 1959.

78 DeMarrais, G.A. Dept. HEW Public Health Service. Meteorology for Land Development Planning in the Tulsa Metropolitan Area. Cincinnati, Ohio. 1961.

79 Welsh, G.B. Dept. HEW Public Health Service. An Appraisal of Air Pollution in Spartanburg, South Carolina. Cincinnati, Ohio. 1962.

80 Mecham, R.L., Ameen, J.S. and Slater, R.W. Dept. HEW Public Health Service. A Pilot Study of Air Quality in Winston-Salem, North Carolina. Cincinnati, Ohio 1963.

81 Watkins, C.R. and Wunderle, J.A. Ohio Dept. of Health. An Appraisal of Air Pollution in Dover, Ohio. Columbus, Ohio.

82 Faith, W.L. and Middleton, W.C. The Air Resources of Clark County, Nevada. 1963.

83 State of New York, Air Pollution Control Board. Air Pollution in Erie County, Albany, New York, 101 pages. 1963.

84 Oregon State Sanitary Authority. Air Pollution in Portland Metropolitan Area, Portland, Oregon, 43pages. 1963.

85 Hochheiser, S., Burchett, M., Dunsmore, H.J. Air Pollution Measurments in Pittsburgh, January-February, 1963. Robt. A. Taft Sanitary Engineering Center, Cincinnati, Ohio, 50 pages, Nov. 1963.

86 U.S. Public Health Service, Division of Air Pollution and Indiana Air Pollution Control Board. The Air Pollution Situation in Terre Haute, Indiana With Special Reference to the Hydrogen Sulfide Incident of May-June, 1964. Robt. A. Taft Sanitary Engineering Center, Cincinnati, Ohio. 28 pages. 1964.

87 U.S. Public Health Service, Division of Air Pollution. A Study of Air Pollution in the Interstate Region of Lewiston, Idaho, and Clarkston, Washington. Robt. A. Taft Sanitary Engineering Center, Cincinnati, Ohio, 247 pages. 1964.

88 Hochheiser, S. and Wetsel, R.E. Air Pollution Measurements in Indianapolis, June-July, 1963. Robt A. Taft Sanitary Engineering Center, Cincinnati, Ohio. 64 pp. July, 1964.

89 Welsh, G.B. and Kreichelt, T.E. Clean Air for Chattanooga. U.S. Public Health Service, Division of Air Pollution and Tennessee Dept. of Public Health. Robt. A. Taft Sanitary Engineering Center. 73 pp. July, 1964.

90 Weedfall, R.O. Climatological Aspects of Air Pollution in West Virginia. Environmental Data Service Technical Memorandum 3. U.S. Dept. Commerce-ESSA. 13 pp. January 1967.

For later surveys and related investigations refer to Section V Air Pollution Publications-A Selected Bibliography 1963-1966, and Section IX (a) Air Pollution Publications-A Selected Bibliography with Abstracts, 1966-1968. Public Health Service Publication No. 979.

SITE SELECTION FOR A POLLUTANT SOURCE

D. H. Pack*

The question of pollution source siting is perhaps the most challenging problem in the entire pollution field because, if done properly, it can eliminate or very much reduce the problem before it begins. The scope of pollution source siting ranges from determining specific locations of exhaust vents or air intakes on roofs of buildings to the design of a model community with its parks, industrial areas, etc. The conventional viewpoint, "Here is a large plant - where shall we put it?" is far too restrictive. There is something to be gained from the use of meteorology over the whole gamut of source location including determining the best relationship of the meteorology to the effluent type and the sources of pollution.

One should look into the philosophy of what we are trying to do. Air pollution is important only because of people. Air pollution that does not effect man, his animals and plants is of very little concern to us. The major reason for interest in air pollution results from urbanization and insufficient room for pollutants to be distributed.

Many of us, the technicians and specifically the meteorologists, are too apt to look at a problem and say, "Here is the solution." When presenting this solution to management, government or whoever is responsible for making decisions on pollution, we may be sure it will not be used if it is based solely on one narrow discipline. Such a solution may be uneconomical or it may be politically or psychologically impossible. For these reasons, it is incumbent on every individual that, if the data permit, he offer a variety of solutions and be able to discuss the consequences of adopting any particular one so that when a decision is made, some rational use will have been made of the environment to dilute material. We are not talking about absolute solutions; there is just too much involved for that.

Air pollution problems are now so complex that the air pollution control officer, chemist, meteorologist, etc., probably cannot know all the various factors that must be brought to bear on pollution siting. The astute individual will go to his counterpart beforehand for consultation or advice. We must require ourselves to be flexible and ingenious in providing advice since we are generally consultants not management. As a consultant, we must know as much about the problem as we can, bring to bear all the tools we can lay our hands on, and present a series of alternative answers. Several areas which must be considered are:

I Can weather be designed out of problem?

II What is the scope for site choice?

A Unlimited

B Restricted to specific large area (e.g., size of a state)

C Two or three alternate but fixed locations

D One location

III What is the pollution problem?

A What is the nature of the pollutant?

1 Toxic

a Maximum Allowable Concentration (MAC)

b Permissible chronic concentrations?

c Method of uptake

Inhalation

Ingestion

Via food chain

*Certified Consulting Meteorologist
McLean, VA.

2 Nuisance

a Odors

b Dust (can be more than nuisance)

c Soot

3 Environmental behavior

a Decay with time

Photolysis

Radioactive decay

b Deposition

c Reactions (e.g., SO_2 - H_2SO_4)

d Synergistic effects in presence of other materials

B Single or Multiple Source

C Area, point, surface, elevated source? (If elevated how high?)

D Release Characteristics

1 Temperature, velocity, gas, particulate size, etc.

2 Seasonally influenced?

3 Continuous or intermittent - If intermittent what are return periods, hold-up facilities, etc.?

4 The potential source (i.e., the accident problem)

Nuclear reactors, chemical storage areas, etc. (operation chlorine)

E What is "downwind?" (Receptor characteristics)

1 Permanent populations (e.g., residential areas)

2 Transient populations (daytime work force, seasonal populations as at resorts, etc.)

3 Vegetation types (sensitive to potential pollutant? pine trees-SO_2)

4 Animals (milk shed and I^{131})

F Control Possibilities and Plans (Evaluation and cost analyses)

1 Full time control

2 Part time

a Operational characteristics - how much lead time required?

b Hold-up facilities (what is needed?)

3 Meteorological control (generally considered last resort for commercial operations) common practice in AEC, DOD

IV What is the meteorological problem?

A Area Patterns

1 Seasonal changes and variations

2 Synoptic changes and variations

B Local Patterns

1 Terrain controlled anomalies

a Mountain-valley circulations

b Sea and lake shore circulations

c Channelled flow

2 Urban effects (if any)

C Estimation of Effects of Pollution - Transport and Diffusion Vs. Ventilation (Volumetric Approach)

1 Single source

a Close in (0-5 miles) in open terrain - transport and diffusion

b Long distances and in urban areas - ventilation

c Massive single source - combine T and D and ventilation

2 Multiple sources

a Transport and diffusion (e.g., Nashville model, receptor models) - requires source inventory

b Ventilation - (e.g., Duckworth, Bell in California)

V METEOROLOGICAL TOOLS

A Area Data

1 Published summaries

Examples - airways atlas, inversion study, mixing depth study, stagnation studies, climatologies of particular places.

2 Special unpublished tabulations - U.S. Weather Bureau, National Weather Records Center

B Local Data - Available from Many Sources

1 Summarized and published

a Local climate data - WB

b Station climatologies

2 Special studies

a Reactor hazard studies (particularly as sources of data)

b Industrial studies

c Military installations

3 Local non-WB observations

a Military

b Commercial (e.g., approximately 100 recording anemometers have been located between Richmond, Va. and New York City)

C Special On-Site Studies

1 Short term "scoping" studies

2 Longer term (1-2 year) studies

3 Permanent (or quasi-permanent) programs

4 Data collection

a Wind

Frequency, fluctuation characteristics, spatial variations

b Wind and temperature gradient

c Multiple station studies

d Tracer studies

1) Balloons (e.g., Sakagami, Gifford, Pack at Shippingport, Pa.)

2) Controlled release and sampling of gases and/or particulates (SO_2, FP, Uranine)

3) Sources of opportunity - particularly use of smoke photos

4) Tetroons - for long range trajectories or major pollution problems

VI SPECIAL PROBLEMS

A Conspicuous Sources

B Adding Sources to "Saturated" Atmosphere

C Long Range Travel Problems (single source such as western states smelters)

D Recirculation of Pollutants

E Controlled Release - When and How Much

F The Rare or "One-Shot" Pollution Problem (e.g., Nuclear Reactor Accidents)

VII PROBABILITIES AND PERSISTENCE IN POLLUTION SOURCE SITING

A Lapse Rate

1 Large area - stagnation episodes

2 Point source - (Hosler's Monthly Weather Review study)

Inversion Duration Probability (hours)

	50%	10%	1%
Hanford, Wash.	13	17	22
Shippingport, Pa.	4.5	15	24
Middletown, Conn.	14	19	27
Idaho Falls, Ida.	16	19	22

B Wind

22 1/2° Sector
Direction Duration Probability (hours)

	50%	10%	Max.
Laredo, Texas	2.2	6.7	36
Denver, Colo.	2.0	6.3	22
San Diego, Calif.	2.7	4.0	35

112 1/2° Sector
Direction Duration Probability (hours)

	50%	10%	Max.
Laredo, Texas	4.6	40	300
Denver, Colo.	3.6	16	49
San Diego, Calif.	1.5	18	140

REFERENCES

1 Hosler, C.R., Pack, D.H., and Harris, T.B. Meteorological Investigation of Diffusion in a Valley at Shippingport, Pa. Special Projects Section, OMR, U.S. Weather Bureau, Washington, D.C. April, 1959.

2 Landsberg, H.E. Weather-A Factor in Plant Location. Industrial Development and Manufacturers Record, Conway Publishers, Inc., Atlanta, Ga. May 1961.

3 Munn, R.E. The Application of an Air Pollution Climatology to Town Planning. Int. J. Air and Water Pollution 1:276-287, 1959.

4 Pack, D.H. The Air Environment and Pollution Engineering. Presented at 133rd Meeting AAAS, December 29, 1966.

5 U.S. Navy Weather Research Facility. Climatology and Low Level Air Pollution Potential from Ships in Selected New England Ports. Norfolk, Virginia, May 1966.

ATMOSPHERIC TRACERS AND URBAN DIFFUSION EXPERIMENTS

J. L. Dicke*

I ATMOSPHERIC TRACERS

Dispersion of pollutants by atmospheric diffusion and transport processes has received considerable theoretical treatment and there are several operational techniques available for empirical studies of diffusion on various distance scales. Figure 1 lists some of the tracers and the distances over which they have been used. Another class of tracer materials now being developed includes various halogenated compounds such as Freon 12, sulfur hexafluoride (SF_6) and bromotrifluoromethane.[7]

The suitability of any material for a tracer may be assessed by its ability to meet a number of requirements, several of which have been enumerated by Leighton.[4]

1 The material must possess a specific property, not duplicated by any other substance normally present in the atmosphere, which will permit its detection in extremely small amounts.

2 There should be a simple, rapid, sensitive and convenient method for the quantitative determination of the small amount of material.

3 The material should be available at reasonable expense in uniform lots large enough for the desired use and it should not deteriorate during storage.

4 The tracer should be readily and quantitatively dispersible into the atmosphere at controlled rates.

5 The tracer should be stable while in the atmosphere and its dispersion by atmospheric turbulence should be essentially that of an inert gas.

6 The tracer material should retain its specific property at least through the sampling and assessment operations.

7 The tracer should be safe to handle and non-toxic to man, animals and plants.

Atmospheric tracers can be used for a variety of experiments: To prove transport of material from one location to another such as in the New York - New Jersey area where fluorescent particles (FP) and balloons were used to prove interstate transport of air pollution.[8] To obtain empirical data on a practical problem such as penetration of chemical agents into forests or cities without using the actual chemical.[2] To investigate the actual urban area effects on dispersion parameters[6] and to evaluate σ_y and various topographic influences.[3] Recently Niemeyer and McCormick[5] have shown that both SF_6 and FP can be used as tracers to obtain quantitative diffusion data over ranges in excess of 100 km, for which precise knowledge of dispersion is now almost non-existant.

II URBAN DIFFUSION EXPERIMENTS

A St. Louis

Diffusion studies to provide direct experimental values of dispersion parameters over urban areas were first conducted in St. Louis in 1962 and 1963.[6] FP was disseminated in a series of trials under a wide range of meteorological conditions to determine the effects of the urban area on dispersion. Several sampling arcs were laid out as in Figure 2 and instrumented with rotorod, drum-pulsed, and membrane filter samplers, Figure 3, to collect the FP both on a total and sequential time basis.

*Supervisory Meteorologist , NOAA
Meteorology & Assessment Division, EPA

PA.ME.19.6.67

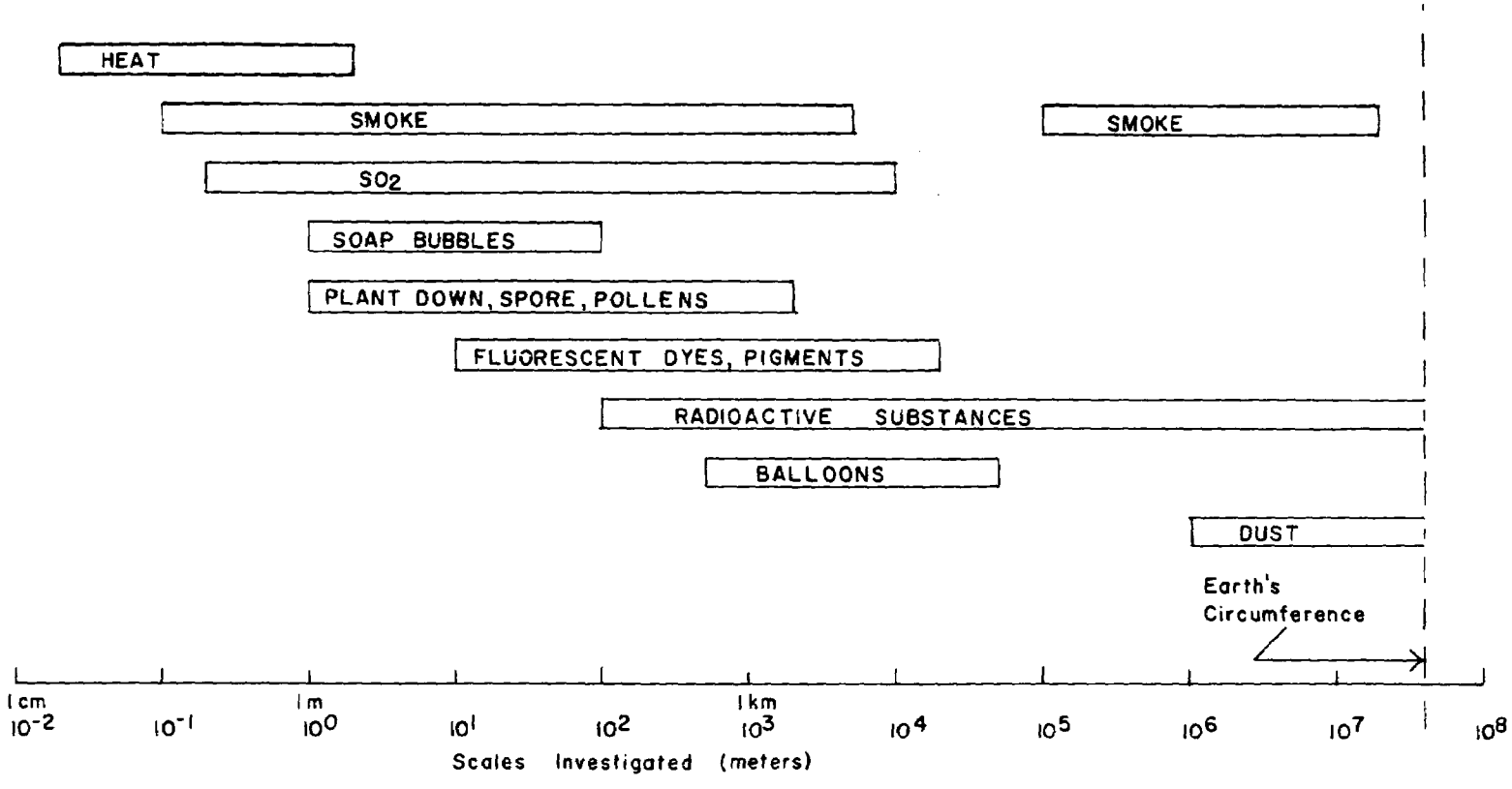


Figure 1. TRACERS USED IN ATMOSPHERIC TURBULENCE AND DIFFUSION

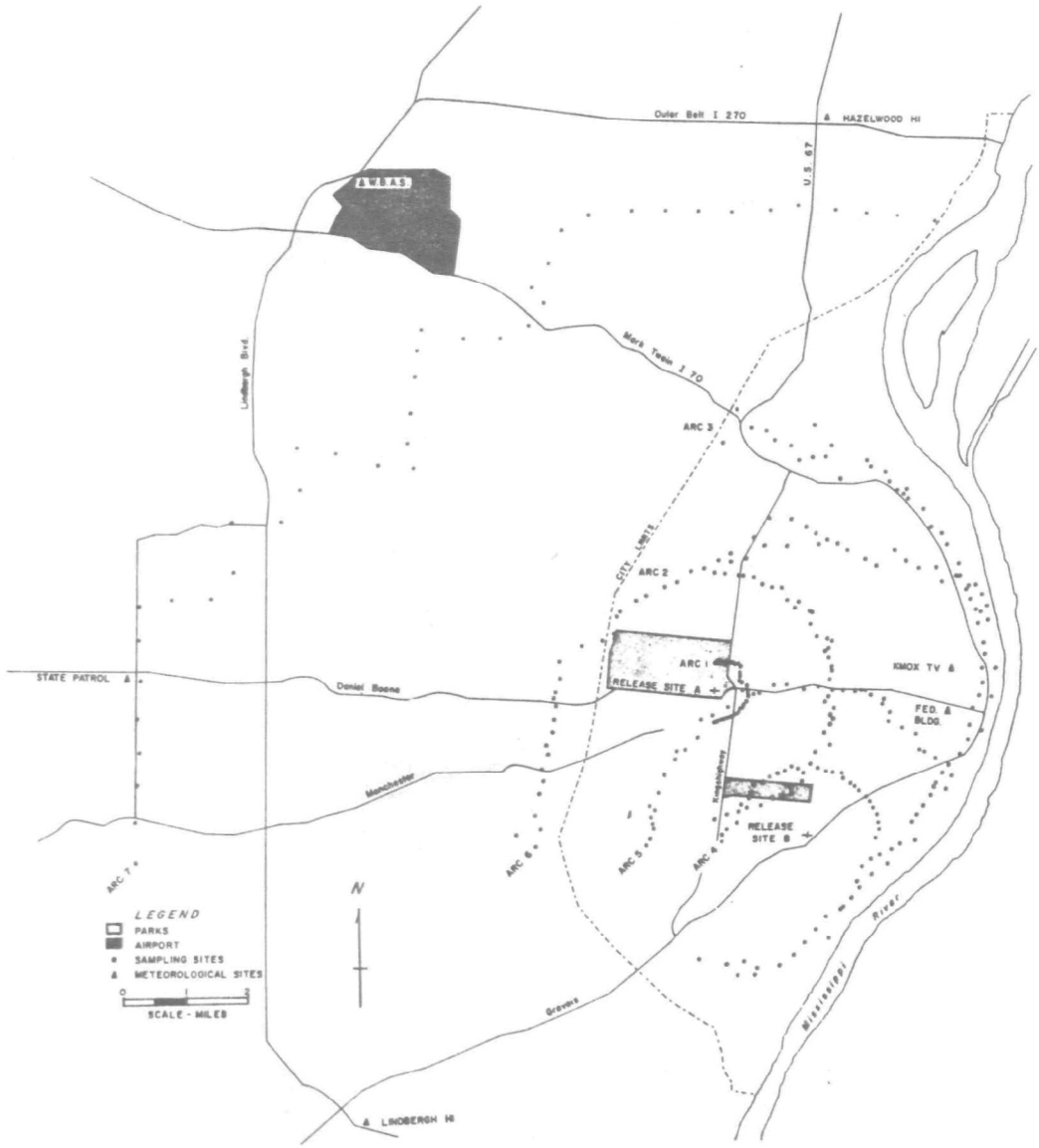
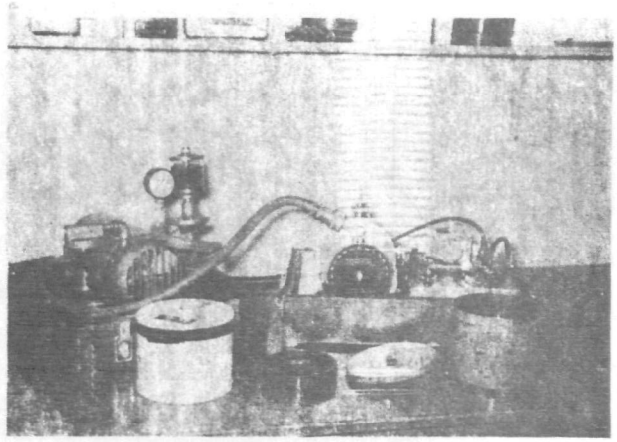
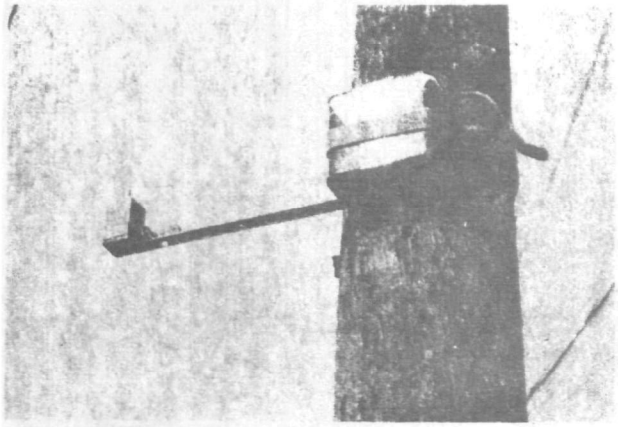


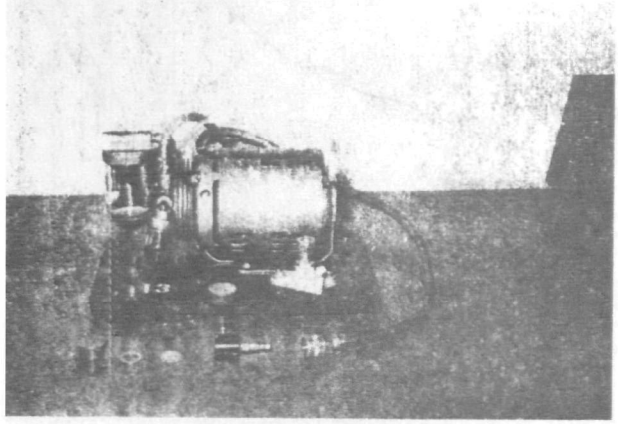
Figure 2. ST. LOUIS, MISSOURI, DIFFUSION STUDY MAP



a) Drum Sequential Sampler



b) Rotorod Sampler



c) Membrane Filter Sampler

Figure 3. FP SAMPLING EQUIPMENT

Tentative results of this study indicate that horizontal dispersion (σ_y) over a city is not markedly different from dispersion over open country, provided that an initial plume dimension comparable to the size of a city building is assumed. The vertical dispersion (σ_z) over a city during the daytime is comparable to that observed over open country. Vertical dispersion during the evening over an urban area is much greater than that observed over open country; the data suggest the formation of a slightly unstable layer of air over the city as the cool air flowing in from the country is warmed from below.

B Cincinnati

The diffusion studies in Cincinnati[5] have had two objectives: first to develop sampling and analysis techniques for several halogenated atmospheric tracers and second to obtain quantitative diffusion data over the range of one to several hundred kilometers.

Short range experiments on the grounds of the Gest Street Facility of NCAPC over distances up to 200 meters were conducted using two or three halogenated gaseous compounds together with FP. Rotorods and sequential drum samplers were used to collect the FP while the gases were collected in Saran bags for gas chromatographic analysis. The results showed that the halogenated gases were satisfactory tracer materials.

The long range experiments were conducted over the rolling terrain of northern Kentucky and southern Ohio. Meteorological conditions were chosen such that steady southerly winds would persist for at least six hours at high enough speeds to move the tracer cloud across the sampler arcs before marked diurnal stability changes occurred. Two or three sampling arcs were spaced about 30 to 40 kilometers apart depending on available highways. The centerline of each arc was determined by predicting the trajectory of a transponder-equipped tetroon which was released from the tracer dissemination site shortly before the tracers were released and tracked by radar.

Another objective of these tests has been to determine the magnitude of non-meteorological errors. This has been shown to be as high as 50%. The primary causes for errors lie in the analytical techniques, loss of particulate tracer strength, sampling errors and uncertainties in source strength.

The preliminary results indicate that the horizontal dispersion (σ_y) values are within 10-15% of the σ_y values for neutral stability conditions as presented in Section III of this manual. In addition the feasibility of using a gaseous tracer over a 75 mile range has been demonstrated.

REFERENCES

1 Dumbauld, R.K. Meteorological Tracer Technique for Atmospheric Diffusion Studies. J. Appl. Meteor. 1:437-443, December 1962.

2 Hilst, G.R. and Bowne, N.E. A Study of the Diffusion of Aerosols Released From Aerial Line Sources Upwind of an Urban Complex. Vols. I & II. The Travelers Research Center, Inc. July 1966.

3 Högström, U. An Experimental Study on Atmospheric Diffusion. Tellus 16:205-251, May 1964.

4 Leighton, P.A., Perkins, W.A., Grinnel, S.W. and Webster, F.X. The Fluorescent Particle Atmospheric Tracer. J. Appl. Meteor. 4:334-348, June 1965.

5 Niemeyer, L.E. and McCormick, R.A. Some Results of Multiple-Tracer Diffusion Experiments at Cincinnati. Pres. 60th Annual Meeting, APCA, Cleveland, Ohio, June 11-16, 1967.

6 Pooler, F., Jr. A Tracer Study of Dispersion Over a City. JAPCA, 16:677-681, December 1966.

7 Saltzman, B.E., Coleman, A.I., and Clemons, C.A.; Halogenated Compounds as Gaseous Meteorological Tracers. Anal. Chem. 38: 753-758, May 1966.

8 U.S. Public Health Service. Technical Report. New York-New Jersey Air Pollution Abatement Activity. 1967.

9 Raynor, G.S., Cohen, L.A., Hayes, J.V. and Ogden, E.C. Dyed Pollen Grains and Spores as Tracers in Dispersion and Deposition Studies. J. Appl. Meteor. 5 728-729. October 1966.

10 Morton, J.D. Comments on Raynor et al paper above. J. Appl. Meteor. 6. 725. August 1967.

11 Mc Elroy, J.L., and F. Pooler, Jr.; St. Louis Dispersion Study, Vol. I Instrumentation, Procedures, and Data Tabulations. National Air Pollution Control Administration Report APTD-68-12. August 1968.

12 Friend, J. P. and Charlson, R.J. Double Tracer Techniques for Studying Air Pollution. Env. Science and Tech. 3: 1181-1183. November 1969.

13 Nickola, P. W., Ludwick, J. D., and J. V. Ramsdell, Jr. An Inert Gas Tracer System for Monitoring the Real-Time History of a Diffusing Plume or Puff. J. App. Meteor. Vol.9, No. 4, pp. 621-626 Aug. 1970.

14 Sandberg, J. S., Walker, W. S., and Thuillier, R. C. Fluorescent Tracer Studies of Pollutant Transport in the San Francisco Bay Area. JAPCA 20:9, 593-598, 1970.

15 Angell, J. K., Hoecker, W. H., Dickson, C. R. and Pack, D. H. Urban Influence on a Strong Daytime Air Flow as Determined from Tetroon Flights. J. App. Meteor. Vol. 12, No. 4, 924-936, September 1973.

16 Drivas, P. J. and Shair, F. H. A Tracer Study of Pollutant Transport and Dispersion in the Los Angeles Area. Atmos. Env. Vol. 8, No. 11, 1155-1163. November 1974.

17 Raynor, G. S., Smith, M. E., and Singer, I.A. Temporal and Spatal Variation in SO_2 Concentrations on Suburban Long Island N. Y. JAPCA VOL. 24. No. 8, 586-590. June, 1974.

18 Raynor, G. S., Smith, M. E., and Singer, I. A. Meteorological Effects on SO_2 Concentrations on Suburban Long Island N.Y. Atmos. Env. Vol. 8, No. 12, 1305-1320, December 1974.

19 Gloria, H. R., Bradburn, G., Reinisch, R. F., Pitts, J. N. Behar, J. V., and Zafonte, L. Airborne Survey of Major Air Basins in California. JAPCA Vol. 24, No.7, 645-652, July 1974.

20 Lee, R. E. Jr., Caldwell, J., Akland, G. G., and Bachhauser, R. The Distribution and Transport of Airborne Particulate Matter and Inorganic Components in Great Britain. Atmos. Env. Vol. 8, No. 11, 1095-1109, November 1974.

21 Breeding, R. J., Haagenson, P. L., Anderson, J. A. and Lodge, P. J. Jr. The Urban Plume as Seen at 80 and 120 km. by Five Different Sensors. J. App. Meteor. Vol. 14, No. 2, 204-216, March 1975.

22 Loveland, W. D., Hewson, E. W. and Shum, Y.S. The Use of Artificial Activable Trace Elements to Monitor Pollutant Source Strengths and Dispersal Patterns. Paper #74-70, 67th Annual Meeting of the APCA, Denver, CO, June, 1974.

23 Drivas, P. J. and Shair, F. H. Dispersion of an Instantaneous Cross-wind Line Source of Tracer Released from an Urban Highway. Atmos. Env. Vol. 8, No. 5, 475-485, May 1974.

METEOROLOGICAL MODELS FOR URBAN AREAS

D. B. Turner
J. L. Dicke

I DEFINITION OF A DISPERSION MODEL

A A dispersion model is a mathematical description of the meteorological transport and dispersion processes combined with:

1 The necessary meteorological parameters during a particular period, and

2 An inventory of emissions to the atmosphere of the pollutant of interest to yield,

Estimates of concentrations of the particular pollutant for specific locations and time periods.

B To verify a model actual concentrations of the particular atmospheric pollutant must be measured for comparison with those calculated.

C Considering the structure of a model:

1 The mathematical description may be a dispersion equation such as the Gaussian or bivariate normal equation with additional provisions for considering wind direction.

2 The meteorological input parameters usually include wind direction, wind speed and stability. The environmental temperature lapse rate and a vertical limit to mixing may also be incorporated.

3 The emission inventory will include the locations of and amounts emitted from all sources of the pollutant of interest for the time periods needed.

II TYPES AND USES OF MODELS

A Short-time period model (1 hour to 1 day)

1 Diffusion Calculations - Estimate concentrations where it is impractical to sample such as over rivers or lakes or at distances above the ground.

*2 Control - Determine the amount of decrease required for pollutant sources under particular conditions or the necessary decrease in sources required when a predetermined alert level has been reached.

*3 Sampling - Location of mobile sampling teams when a pollution alert occurs.

B Climatological model (long time periods: months of years, or particular times of day for each season over a number of years).

1 Control - Aid in developing emission standards based on air quality standards.

2 Sampling - Locate permanent samplers strategically.

3 Planning - Location of sources with respect to source emission amounts and potential receptors.

III URBAN AIR POLLUTION DIFFUSION MODELS AND RESULTS

A Pooler - Nashville, Tennessee

Spatial distribution of SO_2 concentrations for periods of a month.

1 The Weather Bureau airport wind rose was used with a diffusion equation assuming a mean stability.

2 SO_2 calculations and observations were compared at about 120 locations for five months (600 comparisons).

*A2 and 3 both require forecasts of mesometeorological parameters.

*Supervisory Meteorologists, NOAA
Meteorology & Assessment Division, EPA
Research Triangle Park, NC 27711

EPA-MD-ed-27a-9-75

3 50% of the observed concentrations were between 0.8 and 1.25 times those calculated. 95% were within a factor of two.

B Turner - Nashville, Tennessee

Spatial distribution of SO_2 concentrations for 2-hour and 24-hour periods.

1 Mean wind velocity and atmospheric stability were determined for each 2-hour period.

2 24-hour concentrations were obtained from averaged 2-hour concentrations and 35 24-hour periods were modeled. SO_2 calculations and observations were compared at 32 locations on a 24-hour basis and at seven locations on a 2-hour basis. (1000 24-hour comparisons).

3 58% within 1pphm (error of measurement) 70% within a factor of 2.

C Clarke - Cincinnati, Ohio

Temporal variations of several pollutants at a single receptor location.

1 Sources over four ranges of distance from the single receptor location.

2 Solutions obtained by graphical techniques.

3 Comparison of 24-hour concentrations

Pollutant	Number of data pairs	Correlation	Number within a factor of 2
SO_2	24	0.71	63%
NO_x	19	0.67	95%
SO_2	19	0.81	47%

D Miller and Holzworth - Los Angeles, Nashville, Washington, D.C.

Average NO_x concentrations over Los Angeles and SO_2 concentrations over Nashville. Point NO_x concentrations at the Washington, D.C., CAMP station.

1 Minimum (afternoon) and maximum (morning) average concentrations over the urban area.

2 Results

Afternoon	Number	Correlation coefficient	
Los Angeles	36	.88	
Nashville	31	.83	
Washington	41	.83	
Morning			
Los Angeles	35	.80	over estimated
Nashville	31	.84	

3 Sequel comparing the statistical and analytical results for NO_x (Miller, 1967).

E Other

1 Szepesi - Hungary

2 Koogler - Jacksonville, Florida

3 Fortak - Bremen, Germany

4 Nester - Germany

5 Zimmerman - Ankara, Turkey

6 Martin - Air Quality Display Model (AQDM). NTIS PB 189-194

7 EPA Guidelines - Air Quality Implementation Plan Program (IPP) 2 Vols. NTIS PB198-299 PB 198-300.

IV CURRENT ACTIVITY IN MODELING

There are a number of more recent AQS modeling developments that can be classified into the four types summarized below and in Table 1. These approaches have the following common characteristics:

(1) All are adaptable to photoreactive pollutants;
(2) All are time-dependent; and
(3) Diffusion is treated by K-theory (concentration flux proportional to gradient) in all models that include diffusion.

The basic formulations of each modeling approach are summarized in the table, as are the advantages and disadvantages. The definitions of the terms in the equations are as follows:

c_i = mean concentration of chemical species i

$\vec{v}$ = vector mean wind

K_h, K_v = horizontal and vertical eddy diffusivities

x,y,z = component directions

R_i = rate of generation of species i by reactions

S_i = rate of emission of species i

V = cell volume

$\vec{v}'$ = vector effective mean transport wind (includes turbulent transport)

A. The fixed cell, finite difference models compute concentrations over a grid of cells in three dimensions, using finite-difference integration techniques to solve the classical equations of conservation of mass, including local change, advection, diffusion, reactions, and emissions. For n species or pollutants, there are n equations coupled through a reaction term.

B. The moving-cell models use a Lagrangian approach, in which a moving "cell" or "parcel" is advected along a wind trajectory. In this way, advection disappears from the equations. One variation of this approach assumes instantaneous uniform mixing within the parcel and thus neglects vertical diffusion. Both versions neglect horizontal diffusion.

C. The particle-in-cell is a novel approach in which pollutant mass is represented by "particles" which are advected in accordance with an effective transport velocity that includes both the mean and turbulent transports. Concentrations are computed according to the numbers of particles located in each cell of an Eulerian, or fixed-coordinate, grid at any given time.

D. The multiple-box models utilize an Eulerian array of well-mixed cells that can be quite large and variable in size to give spatial resolution only where needed. One version of this model does include terms for horizontal diffusion. This type of formulation is a variation of the basic finite-difference grid formulation and thus also is influenced by artificial diffusion produced when the equations are integrated.

Several of these models are now in advanced stages of development and evaluation. The eventual choice of which is the heat approach for a particular application will of course depend heavily upon the relative weight given to resolution and accuracy on the one hand, and computational efficiency on the other.

E. Line Source - Transportation Models

The Gaussian equation can be used to model non-reactive pollutant concentrations resulting from mobile sources, especially carbon monoxide. Stanford Research Institute researches[44] have developed the APRAC-1A Urban Diffusion Model Computer Program for EPA for determining hourly averages of this pollutant. HIWAY is a computer model developed within EPA for calculating non-reactive pollutant concentrations and is described briefly, in F. below. A research project funded by the Federal Highway Administration and performed by the California Division of Highways has resulted in a series of eight Air Quality Manuals[36]. Volume IV and its appendix, Mathematical Approach to Estimating Highway Impact on Air Quality, include techniques for calculating carbon monoxide concentrations without using a computer and is designed for use in meeting the requirements of Environmental Impact Statements. The manuals were prepared as interim reports and the methods procedures are presently being validated by extensive field measurements. Modifications and refinements will be published in future reports by the FHWA. The bulk of transportation generated air quality simulation research and development will be handled by the Transporation Systems Center of DOT in Cambridge, Mass. A state of the art survey has been prepared by Darling[37] which is quite comprehensive.

F. User's Network for Applied Modeling of Air Pollution (UNAMAP)

In May 1973 UNAMAP was developed so that both EPA and non-EPA users could utilize current air quality simulation models. The models involved are all in the form of computer programs accessible

from remote terminals connected to a central computer facility by telephone. EPA users can access the models through the UNIVAC computer at RTP. Non-EPA users may access the models via Computer Sciences Corporation (CSC) commercial teleprocessing network, INFONET. CSC has a GSA contract for teleprocessing services and users pay for their service through a direct agreement with CSC. Those interested in accessing UNAMAP via INFONET may contact Mr. Michael Welsh of CSC by telephone (404) 633-6174 for more details.

Currently, UNAMAP consists of the following models:

1) APRAC - The Stanford Research Institute APRAC-1A model computes the hourly averages of carbon monoxide as a function of extraurban diffusion from automotive sources in upwind cities, intraurban diffusion from roadway sources, and local diffusion within a street canyon. The model requires an extensive emission or traffic inventory for the city of interest. Requirements and technical details are documented in "User's Manual for the APRAC-1A Urban Diffusion Model Computer Program" which is available from NTIS* (accession number PB-213-091).

2) HIWAY is an interactive program which computes the short term (hourly) concentration of non-reactive pollutants downwind of roadways. It is applicable when uniform wind conditions and level terrain exist. It is best suited for at-grade highways, but also can be applied to depressed highways (Cut sections). NTIS PB 239-944

3) CDM - The Climatological Dispersion Model (CDM) determines long term (seasonal or annual) quasi-stable pollutant concentrations at any ground level receptor using average emission rates from point and area sources and a joint frequency distribution of wind direction, wind speed, and stability for the same period. This model differs from the Air Quality Display Model (AQDM) primarily in the way in which concentrations are determined from area sources, the use of Briggs' plume rise, and the use of an exponential increase in wind speed with height dependent upon stability. CDM uses a separate data set for the area of interest. NTIS PB 227-346-AS

4) PTMAX is an interactive program which performs an analysis of the maximum, short-term concentration from a point source as a function of stability and wind speed.

5) PTDIS is an interactive program which computes short-term concentrations downwind from a point source at distances specified by the user.

6) PTMTP is an interactive program which computes, at multiple receptors, short term concentrations resulting from multiple point sources.

All the interactive models are documented as the programs are executed. The CDM model requires a source listing for a user to understand the data set formats. Manuals for the PTXXX models are in preparation.

The models listed in the previous paragraph are installed on INFONET and ready for access. Other models will be added as they are validated. This inventory will eventually include models in the area of photochemistry, estimating concentrations in areas of complex terrain, and estimating concentrations under stagnation conditions.

G. Selected EPA Models Under Development

1. RAM- Real-time Air Quality-simulation Model. This short-term Gaussian steady-state model estimates concentrations of stable pollutants from urban point and area sources. Hourly meteorological data are used. Hourly concentrations and averages over a number of hours can be estimated. Briggs' plume rise is used. Pasquill-Gifford dispersion equations with dispersion parameters thought to be valid for urban areas are used in the model. Concentrations from area sources are determined using the method of Hanna, that is, sources directly upwind are considered representative of area source emissions affecting the receptor. Special features of the model include determination of receptor locations downwind of significant sources and determination of locations of uniformly spaced receptors to ensure good area coverage with a minimum number of receptors. A users' guide is being prepared within the Meteorology and Assessment Division.

*) NTIS -- National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia 22151

Table 1. Principal types of time-dependent air quality simulation models.

A. FIXED-CELL, FINITE-DIFFERENCE MODEL

Basic Equation:

$$\frac{\partial c_i}{\partial t} + \vec{v} \cdot \nabla c_i = \frac{\partial}{\partial x} K_h \frac{\partial c_i}{\partial x} + \frac{\partial}{\partial y} K_h \frac{\partial c_i}{\partial y} + \frac{\partial}{\partial z} K_v \frac{\partial c_i}{\partial z}$$

$$+ R_i(c_1,\ldots,c_n) + S_i \quad (i = 1,2,\ldots,n)$$

Type: Eulerian (fixed coordinate)

Investigators: Seinfeld et al.
Eschenroeder and Martinez

Advantages: Produces urban-wide concentration patterns.
Physically more realistic than most.

Disadvantages: Artificial diffusion is inherent.
Chemical computations performed in Eulerian frame.

Computer Time Requirements: Large

B. MOVING-CELL MODEL

Basic Equation:

$$\frac{\partial c_i}{\partial t} = \frac{\partial}{\partial z} K_v \frac{\partial c_i}{\partial z} + R_i + S_i \qquad (1)$$ Vertically inhomogeneous

$$\frac{\partial V c_i}{\partial t} = V R_i (c_1,\ldots,c_n) + V S_i \qquad (2)$$ Vertically homogeneous

Type: Quasi-Lagrangian (trajectory)

Investigators: Eschenroeder and Martinez
Wayne et al.

Advantages: Traces concentration history along an air trajectory.

Disadvantages: Difficult to obtain urban-wide patterns.
No horizontal diffusion or convergence.
Errors accumulate.

Computer Time Requirements: Modest

C. PARTICLE-IN-CELL MODEL

Basic Equation:

$$\frac{\partial c_i}{\partial t} + \nabla \cdot (\vec{v}' c_i) = R_i + S_i$$

Type: Moving particles represent pollutant mass

Investigators: Sklarew
Hotchkiss and Hirt

Advantages: No artificial diffusion.
Effective display of concentration pattern.

Disadvantages: Discrete mass represented by each particle limits accuracy.
Large core storage required.

Computer Time Requirements: Large

D. MULTIPLE-BOX MODEL

Basic Equation:

$$\frac{\partial c_i}{\partial t} + \vec{v} \cdot \nabla c_i = R_i + S_i$$

Type: Well-mixed cell

Investigators: Reiquam
MacCracken et al.

Advantages: Sizes and shapes of cells are variable.
Involves only ordinary differential equations.

Disadvantages: Neglects diffusion (Reiquam)
Neglects vert. diffusion (MacCracken)
Artificial diffusion can be significant.

Computer Time Requirements: Generally modest.

2. SCIM- Sampled Chronological Input Model. This short-term Gaussian steady-state model estimates concentrations of stable pollutants from urban point and area sources for hourly periods. An estimate of the frequency distribution of hourly concentrations over a long period, such as a year, can be obtained. This is accomplished by calculating hourly concentrations for a sample of hours over the period-not for every hour. This model was developed by contract by GEOMET, and CPU requirements are large. The model is UNIVAC compatible. Distribution of a users' guide will be made through NTIS when extensive modifications have been accomplished to permit greater versatility.

3. MX24SP- Power Plant Model- This steady-state Gaussian plume model estimates the maximum 24-hour concentration of stable pollutants that occurs during a year resulting from emissions from a single plant having one or more stacks. Estimates of hourly concentrations are made at 180 receptors (5 distances by 36 azimuths) using meteorological data for one year. Concentrations are averaged, midnight to midnight, each day. The annual concentration at each receptor, as well as the maximum 24 hour concentration of all receptors are included as outputs. A draft users' guide is being prepared. Improvements in techniques to estimate hourly stability and hourly mixing height will be made before making the model generally available.

4. PAL- Point, Area, Line source model. This short-term Gaussian steady state model estimates concentrations of stable pollutants from point, area, and line sources. Computations from area sources include effects of the edge of the source. This requires considerable computer time. The model is not intended for application to entire urban areas but for smaller scale analysis of such sources as shopping centers, airports, and single plants. Hourly concentrations are estimated and average concentrations from 1 hour to 24 hours can be obtained. No users' guide has been prepared yet.

5. C8M3D- This model treats sources and receptors in the same basic manner as AQDM. However, topographic input with respect to source and receptor elevations is accepted and utilized in the computations for stable conditions. If the source and receptors are in rural areas, calculations are made for all six stability categories, in contrast to AQDM where urban assumptions preclude estimates for stable conditions. In addition, in C8M3D, the plume centerline does not approach closer than 10 m of an elevated receptor location. Preparation of a user's guide has only recently begun.

6. SAI- Photochemical Model The SAI model is a photochemical dispersion model. It not only considers the transport and dispersion of pollutants but also the transformation of HC and NO_x into photochemical oxidant pollutants. It estimates the hourly concentration variations in these pollutants; CO, HC, NO, NO_2, and O_x. The mathematical formulation for this model is considerably different from that discussed for the other dispersion models. This model uses finite difference techniques over a grid of area sources to solve the classical equations of conservation of mass which include local change, advection, diffusion, photochemical reaction and emission. To this date it has only been applied to areas in California.

   This model is one of the better sophisticated photochemical models currently available. The reliability of this model is being thoroughly examined and data from the Regional Air Pollution Study (RAPS) will be used extensively in further development.

Photochemical Air Quality Simulation Models

K. L. Demerjian, and G. Smiley. National Environmental Research Center, Research Triangle Park, N. C. Meteorology Lab; Feb. 73, 1 reel mag tape EPA/DF-74/001 Specify tape recording mode desired: 9 track, 800 or 1600 bpi, odd parity, EBCDIC: or 7 track, 556 or 800 bpi, odd or even parity, BCD. Documentation available. PB-238 823/9WP Mag Tape $97.50: Foreign $122.50

This tape contains the FORTRAN code and data for three photochemical air quality models include: S. D. Reynolds (1973) - Urban Airshed Photochemical Simulation Model Study. Volume II: User's Guide and Description of Computer Programs. EPA Report R4-73-03f. NTIS No. PB-234978/9WP. July,J.R. Martinez (1972). Users Guide to Diffusion/Kinetics (DIFKIN)Code.EPA Report R4-73-012b. Oct.NTIS No.PB-22043/0,A. Kokin. L.G. Wayne and M. Weisburd (1973)-Controlled Evaluation of the Reactive Environ. Simulation Model (REM)-Volume II: User's Guide, EPA Report R4-73013b, NTIS No.PB-220457/6.

REFERENCES

1 Clarke, J.F. A Simple Diffusion Model for Calculating Point Concentrations from Multiple Sources. J. Air Poll. Control Assoc. 14, 9, 347-352, September 1964.

2 Davidson, B. A Summary of the New York Urban Air Pollution Dynamics Research Program. J. Air Poll. Control Assoc.17, 3, 154-158, March 1967.

3 Fortak, H. Rechnerische Ermittlung Der SO_2-Grundbelastung aus Emission Daten (calculated values of ground-level SO_2 concentrations from emission data) Institute for Theoretical Meteorology, Free Univ. of Berlin. February 28, 1966.

4 Koogler, J.B., Sholtes, R.S., Danis, A.L. and Harding, C.I. A Multivariant Model for Atmospheric Dispersion Predictions. J. Air Poll. Control Assoc. 17, 4, 211-214, April 1967.

5 Miller, M.E. A Note on Comparison of Statistical and Analytical Results for Calculating Oxides of Nitrogen Concentrations J. Air Poll. Control Assoc. 17, 4, 232-234, April 1967.

6 Miller, M.E. and Holzworth, G.C. An Atmospheric Diffusion Model for Metropolitan Areas. J. Air Poll. Control Assoc. 17, 1, 46-50, January 1967.

7 Nester, K. Frequency Distribution of the Maximum Concentrations of Stack Gases Based on Synoptic Weather Observations. Report No. 2 on Research Project 36/65, Institute for Meteorology, Darmstadt Technological College. February 15, 1966.

8 Pooler, F., Jr. A Prediction Model of Mean Urban Pollution for Use With Standard Wind Roses. Int. J. Air and Water Poll. 4, 3/4, 199-211, Sept. 1961.

9 Szepesi, D.J., A Model for the Long-Term Distribution of Pollutants Around a Single Source, Idojaras (Budapest) 68, 257-269, September-October, 1964.

10 Turner, D.B. A Diffusion Model for an Urban Area. J. Appl. Meteor., 3, 1, 83-91, February 1964.

11 Hilst, G.R. An Air Pollution Model of Connecticut. The Travelers Research Center, Inc. Pres. IBM Scientific Symposium October 24, 1967. 33 pp.

12 Montgomery, T.L. and Corn, M. Adherence of SO_2 Concentrations in the Vicinity of a Steam Plant to Plume Dispersion Models. JAPCA 17:513-517, August 1967.

13 Plato, P.A., Menker, D.F., and Dauer, M. Computer Model for the Prediction of the Disperison of Airborne Radioactive Pollutants. Health Physics 13: 1105-1115, 1967.

14 Slade, D.H. Modeling Air Pollution in the Washington, D.C. to Boston Megalopolis. Science 157:3794 ppl 1304-1307. September 15, 1967.

15 Symposium on Urban Air Pollution at the BP Research Centre. Atmos. Envir. 2, 6:617-620, November 1968.

16 LeBlanc, L.L. Finite-Difference Methods Used in Models of the Atmospheric Boundary Layer. Air Weather Service (MAC) USAF Tech. Rep. 206, 13 pp. June 1968.

17 Moroz, W.J. Weather and Pollution A Survey of Modelling Techniques. Pres. APCA Annual Meeting, June 25, 1968.

18 Martin, D.O. An Urban Diffusion Model for Estimating Long Term Average Values of Air Quality. JAPCA 21, 1, pp. 16-19. January, 1971.

19 Frenkiel, F.N., 1956 Atmospheric Pollution in Growing Communties - Smithsonian Report for 1956, pp 269-299.

20 Moses, Harry, 1969. Mathematical Urban Air Pollution Models, Argonne National Laboratory Anl/es-RPY-001, 69 pp., April 1969.

21 Bowne, N.E., 1969 A Simulation Model for Air Pollution over Connecticut, JAPCA 19, 8 pp 570-574, Aug. 1969.

22 Guidelines for the Development of Air Quality Standards and Implementation Plans - National Air Pollution Control Administration, May 1969.

23 Proceedings of Symposium on Multiple Source Urban Diffusion Models. Ed., A.C. Stern, Air Pollution Control Office Pub. No. AP-86, 1970.

24 Lamb, R. G., and Neiburger, M., An Interim Version of a Generalized Urban Air Pollution Model. Atmos. Environment, Vol. 5 239-264, 1971.

25 Lamb, R. G. The Representation of Atmos. Motions in Urban Diffusion Models. Paper presented at Conference on Air Pollution Meteorology, Raleigh, N.C. April, 1971.

26 Eschenroeder, A., and Martinez, J. R. An Extension of K-Theory to Describe Photochemical Air Pollution. Paper presented at Conference on Air Pollution Meteorology, Raleigh, N. C. April, 1971.

27 Shir, C. C. and Shieh, L. J. A Generalized Urban Air Pollution Model and Its Application to the Study of SO_2 Distribution in the St. Louis Metropolitan area. J. Appl. Meteor. Vol. 13, No.2, 185-204, March 1974.

28 Hanna, S. R. A Simple Method of Calculating Dispersion from Urban Area Sources. JAPCA 21:12 pp. 774-777, December 1971.

29 Halpern, P., Simon, C., and Randall, L., Source Emissions and the Vertically Integrated Mass Flux of Sulfur Dioxide across New York City. J. Appl. Meteor. 10:4 pp 715-724 August 1971.

30 Hotchkiss, R. S., and C. W. Hirt, 1972: Particulate transport in highly distorted three-dimensional flow fields. Proc. of the 1972 Summer Computer Simulation Conf., San Diego, Calif., June 1972.

31 Johnson, W. B., F. L. Ludwig, W. F. Dabberdt, and R. J. Allen, 1972: An urban diffusion simulation model for carbon monoxide. Proceedings, 1972 Summer Computer Simulation Conference, San Diego, Calif., June 14-16.

32 Martinez J. R. User's Guide to Diffusion Kinetics (DIFKIN) Code. EPA-R4-73-013b, October, 1972.

33 McCracken, M. C., T. V. Crawford, K. R. Peterson, and J. B. Knox, 1971: Development of a multibox air pollution model and initial verification for the San Francisco Bay area. Report No. UCRL-73348, Lawrence Radiation Laboratory, Livermore Calif.

34 Reiquam, H., 1970: An atmospheric transport and accumulation model for airsheds. Atmos. Envir., 4, 233.

35 Wayne, L., R. Danchick, M. Weisburd, A. Kokin, and A. Stein, 1971: Modeling photochemical smog on a computer for decision-making. J. Air Poll. Control Assoc., 21, 334-340.

36 Beaton, J. L. et al. Air Quality Manual, Vols. I-VIII. California Division of Highways, Report Nos. FHWA-RD- 72-33 thru 40. April 1972 Interim Report.

37 Darling, E. M., Jr. Computer-Modeling of Transportation-Generated Air Pollution. Report No. DOT-TSC-OST-72-20 Transportation Systems Center, 55 Broadway, Cambridge, Ma. 02142. June 1972 Final Report.

38 Calder, K. L. A Climatological Model for Multiple Source Urban Air Pollution In Ref. 27 above.

39 Bowne, N. E. Diffusion Rates. JAPCA Vol. 24 No. 9, 832-835, September 1974.

40 Carpenter, S. B. et. al. Principal Plume Dispersion Models: TVA Power Plants JAPCA 21:8 pp. 491-495. Aug. 1971.

41 Lantz, R. B. Application of a Three-Dimensional Numerical Model to Air Pollutant Calculations Paper 72-141 Pres. APCA Annual Meeting, Miami, Fla. June 1972.

42 Sklarew, R. C., et. al. Mathematical Modeling of Photochemical Smog using the PICK Method. JAPCA 22:11 pp. 868-869, Nov. 1972.

43 Johnson, W.B. The Status of Air Quality Modeling. Proceedings, Interagency Conference on the Environment, Livermore Laboratory, Calif., October 1972.

44 Mancuso, R. L. and F. L. Ludwig. User's Manual for the APRAC-1A Urban Diffusion Model Computer Program. Stanford Research Institute, Menlo Park, Ca. 94025. Sept. 1972. Available as PB-213-091 from NTIS.

45 Busse, A. D. and Zimmerman, J. R. User's Guide for Climatological Dispersion Model. EPA-R4-73-024. Avail. from NTIS. PB 227-346 AS. December 1973.

46 Zimmerman, J. R. and Thompson, R. T. User's Guide for HIWAY A Highway Air Pollution Model. EPA-650/4-74-008. Avail. from NTIS. PB 239-944, February 1975.

47 Turner, D. B. and Busse, A. D. User's Guides to the Interactive Versions of Three Point Source Dispersion Programs: PTMAX, PTDIS, and PTMTP. NOAA Manuscript, June 1973.

48 U. S. EPA Guidelines for Air Quality Maintenance Planning & Analysis Vol. 12: Applying Atmospheric Simulation Models to Air Quality Maintenance Areas EPA-450/4-74-013, September 1974.

49 U. S. EPA Users Network for Applied Modeling of Air Pollution (UNAMPAP) Magnetic Tape Avail. from NTIS as PB 229-771, $175 domestic, $219 foreign orders.

50 NATO Committee on the Challenges to Modern Society. Proceedings of the Second Meeting of the Expert Panel on Air Pollution Modeling, 1971, 15 papers. Proceedings of the Third Meeting, 1972, 20 papers.Proceedings of the Fourth Meeting 1973, 8 papers.Proceedings of the Fifth Meeting, 1974, 34 papers. Documents avail. from APTIC, EPA, RTP N.C. 27711.

51 Brier, G. W. Statistical Questions Relating to the Validation of Air Quality Simulation Models. EPA-650/4-75-010, March 1975.

52 Pasquill, F. Some Topics Relating to Modeling of Dispersion in Boundary Layer. EPA-650/4-75-015, April 1975.

53 Reynolds S. D., Roth, P. M. and Seinfeld, J. H. Mathematical Modeling of Photochemical Air Pollution-I. Formulation of the Model. Atmos. Env. Vol. 7, No. 11, 1033-1061, November 1973.

54 Roth. P. M., Roberts P. J. Liu, M. K. Reynolds, S. D. and Seinfeld, J. H. Mathematical Modeling of Photochemical Air Pollution-II. A Model and Inventory of Pollutant Emissions. Atmos. Env. Vol. 8, No. 2, 97-130, February 1974.

55 Reynolds, S. D. Liu, M. K., Hecht, T. A., Roth, P. M. and Seinfeld, J. H. Mathematical Modeling of Photochemical Air Pollution-III. Evaluation of the Model. Atmos. Env. Vol. 8, No. 6, 563-569, June 1974.

56. Hanna, S. R. A Simple Dispersion Model for the Analysis of Chemically Reactive Pollutants. Atmos. Env. Vol. 7, No. 8, 803-817, August 1973.

57 Ragland, K. W. and Peirce, J. J. Boundary Layer Model for Air Pollutant Concentrations Due to Highway Traffic. JAPCA, Vol. 25, No. 1, 48-51, January 1975.

58 Nicholson, S. E. A Pollution Model for Street-Level Air. Atmos. Env. Vol. 9, No. 1, 19-31, January 1975.

59 Wang, I. T. and Rote, D. M. A Finite Line Source Dispersion Model for Mobile Source Air Pollution JAPCA Vol. 25, No. 7, 730-733, July 1975.

SOURCES OF METEOROLOGICAL DATA

D. B. Turner*
J. L. Dicke*

It is necessary in the consideration of most air pollution problems to obtain meteorological information. Frequently a special observational program must be initiated. There are also situations where current or past meteorological records from a Weather Service station will suffice. The following outline provides a brief insight into the types of observations taken at Weather Service stations and some of the summaries complied from this data.

I OBSERVATIONS AND RECORDS

A Surface

1 First order stations

There are 200 Weather Bureau stations where 24 hourly observations are taken daily. The measurements taken are: dry bulb temperature and wet bulb temperature (from which dew point temperature and relative humidity are calculated), pressure, wind direction and speed, cloud cover and visibility. These observations are transmitted each hour on weather teletype circuits and are entered on a form with one day to each page. The original is sent to the National Climatic Center (NCC) in Asheville, North Carolina, and a duplicate maintained in the station files. Each station also maintains a climatological record book where certain tabulations of monthly, daily, and hourly observations are recorded. (See Part Two).

2 Second order stations

These stations usually take hourly observations similar to the first order stations above but not throughout the entire 24 hours of the day.

3 Military observations

Many military installations, especially Air Force Bases, take hourly observations. These are transmitted on military teletype circuits and therefore not available for general use. No routine publications of these data is done. Records of observations are sent to NCC where special summaries can be made by use of punched cards.

4 Supplementary airways reporting stations

These stations are at smaller airports. The observations are not at regular intervals, usually being taken according to airline schedules at the airport. These observations are not published and not on punched cards. Original records are sent to NCC,however.

5 Cooperative stations

There are about 10,000 of these stations manned for the most part by volunteer observers. The observations are taken once each day and consist generally of maximum and minimum temperatures and 24 hour rainfall. Observations are recorded on a form with one month to a page. The original is sent to NCC, a carbon sent to the state climatologist, and a carbon maintained at the station. A few cooperative stations have additional data on evaporation and wind. However, the wind observations are taken at only a few inches off the ground and are of use mainly in connection with the evaporation measurements.

6 Fire weather service stations

There are a number of special stations maintained during certain times of the year in forested regions where measurements of wind, relative humidity, and cloud cover are taken. These are not generally on punch cards or summarized.

B Upper Air

There are between 60 and 70 stations in the contiguous United States where upper air observations are taken twice daily (at 0000 GCT and 1200 GCT) by radiosonde balloon and radio direction-finding equipment. The measurements made are temperature, pressure, and relative humidity with height and wind speed and direction. Since these data are obtained primarily for knowledge of the large scale meteorological pattern and have relatively little refine-

*Supervisory Meteorologists, NOAA
Meteorology & Assessment Division, EPA

ment in the lower 2 to 3 thousand feet of the atmosphere, they are of limited use in air pollution meteorology. These observations are transmitted by teletype and original records sent to NCC where these data are published. (See Part Two).

II CLIMATOLOGICAL DATA

There are a number of routine and special publications available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402, that are useful in air pollution. A number of these are listed in Price List 48, available from the Superintendent of Documents.

Of principal interest in air pollution are the elements of wind and stability in relation to transport and diffusion, degree days in relation to source emissions from space heating, solar radiation which affects stability and atmospheric reactions, and precipitation affecting removal of pollutants. Following are listed the publications of main interest in air pollution. For more detailed information on these and other publications see "Selective Guide to Published Climatic Data Sources prepared by U.S. Weather Bureau" published in 1969.

A Routinely Prepared Data

1 Daily Weather Maps - Weekly Series

The charts in this 4-page, weekly publication are a continuation of the principal charts of the former Weather Bureau publication. "Daily Weather Map." All of the charts for 1 day are arranged on a single page of this publication. They are copied from operational weather maps prepared by the National Meteorological Center, National Weather Service. The Surface Weather Map presents station data and the analysis for 7:00 a.m. EST.

The 500-Millibar Height Contours chart presents the height contours and isotherms of the 500-millibar surface at 7:00 a.m. EST.

The Highest and Lowest Temperatures chart presents the maximum and minimum values for the 24-hour period ending at 1:00 a.m., EST.

The Precipitation Areas and Amounts chart indicates by means of shading areas that had precipitation during the 24 hours ending at 1:00 a.m., EST.

The publication is for sale by the Public Documents Department U.S. Government Printing Office, Washington, D.C. 20402. Annual subscription $7.50 Domestic airmail $5.20 additional. Single copy price is 15 cents.

2. Local Climatological Data (LCD)

These data are published individually for each station and include 3 issues discussed below. The subscription price is $1.50 per year for all three issues.

a Monthly Issue LCD

This issue, illustrated in Figure 1, gives daily information on a number of meteorological variables and monthly means on temperature, heating degree days, pressure and precipitation. On the reverse side are tabulated observations at 3-Hourly Intervals; see Figure 2. Tabulation of observations for each hour of the day was discontinued after December 31, 1964. This publication is usually available between the 10th and 15th of the following month.

b LCD Supplement (monthly)

This issue is available only for stations having 24 hourly observations daily until December 31, 1964 when publication was stopped. It contains frequency tables illustrated in Fig. 3. For air pollution investigations, Tables B,E,F, and G would be of greatest interest (Frederick, 1964). The Supplement is usually available from 20 to 40 days after the end of the month.

c LCD with Comparative Data (annual)

This issue, published annually, has a table of climatological data for the current year and a table of normals, means, and extremes for a longer period of record. This issue is usually available between 45 and 60 days after the end of the year.

3 Northern Hemisphere Data Tabulations

This publication, issued daily, contains approximately 30 pages of surface synoptic observations and upper air observations. The surface data are for one hour only (1200 GCT). In this publication the radiosonde information is of principal interest in air pollution meteorology.

A portion of a page of radiosonde data is illustrated in Figure 4. The data are available only in microforms. The subscription price is $5.00 per month, separate daily copies 25 cents. This publication is usually available 8 to 10 months after the date of the observations.

4 Climatological Data - National Summary

This publication of approximately 50 pages, issued monthly, contains a narrative summary of weather conditions, climatological data (similar to those given in each station's LCD) in both English and metric units, mean monthly radiosonde data, and solar radiation data. Also included are a number of maps of the United States showing spatial distribution of temperature, precipitation, solar radiation and winds. The mean radiosonde and solar radiation data are the main interests of this publication in air pollution meteorology. A portion of a page of mean radiosonde data is illustrated in Figure 5. An annual issue of this publication is also available. Subscription prices are 20 cents for monthly and 40 cents for annual issues; yearly, including monthly and annual; $2.50. Monthly issues are available from 4 to 6 months after the month of observation.

5 Climatological Data (by State)

This summary, issued monthly and annually contains data mainly on temperature and precipitation. This will only occasionally be of use to the air pollution meteorologist. Subscription price is 20 cents per monthly or annual copy or $2.50 per year for both monthly and annual issues. This publication is usually available 2 to 4 months from the month of observation.

6 Selected climatic maps

This publication consists of 30 U.S. maps of various meteorological parameters such as: maximum and minimum temperature, heating and cooling degree days, precipitation, relative humidity, solar radiation, and surface wind roses for January and July together with the annual wind rose. Wind data are presented for 74 locations within the contiguous U.S. A list of the basic Climatic Maps from which the generalized maps of this publication are taken is included.

B Summaries

1 Summary of Hourly Observations

This series of publications, Climatography of the United States, No. 82- , Decennial Census of United States Climate, has been prepared for over 100 Weather Bureau stations where 24 hourly observations are recorded each day. One issue is prepared for each station. Where records are sufficiently long the ten year period 1951 - 1960 has been considered. For others the 5 year period 1956 - 1960 has been summarized. This series supersedes the series, "Climatography of the United States" No. 30- , a 5 year summary published in 1956. A set of tables similar to tables A through E in the LCD Supplement are given for each month (See Figure 6) and for the entire period (See Figure 7). The price of this publication is 10 cents per copy and is prepared separately for each station. This series was temporarily discontinued as of May 1, 1965.

2 Climatic Guide

This series of climatological publications contains a wealth of climatological information useful to the air pollution meteorologist fortunate enough to have had one prepared for his city. Of major interest to air pollution meteorologists, are tables of wind frequencies, solar radiation and degree days.

The guides that have been published and the year of issue are:

Baltimore, Maryland	1956
New York City	1958
Seattle, Washington	1961
Chicago, Illinois	1961
Houston, Galveston, Texas	1962

The price of this publication varies between 30 and 40 cents per copy.

3 Climatic Summary of the United States-Supplement for 1931 - 1952.

This summary, issued separately by state, contains tables of monthly and annual precipitation, snowfall, and temperature by stations in the state. The price of this publication ranges from 20 cents to 70 cents per copy.

4 Terminal Forecasting Reference Manual

This manual, published by station, des-

cribes the weather conditions at the station, contains information on local topography, visibility effects due to fog and smoke, ceiling, precipitation, special weather occurrences, and mean wind and visibility conditions. Numerous charts are included summarizing the above elements. Of special interest are surface wind roses by month and a wind rose chart related to restricted visibility conditions. A topographic and smoke source map for the station is included. The price per copy is 10 cents.

5 Key to Meteorological Records Documentation

This series of publications was established to provide guidance information to those making use of observed data. A recent addition to this series No. 4. 11, "Selective Guide to Published Climatic Data Sources prepared by U.S. Weather Bureau" (1969) all is extremely useful to anyone contemplating use of climatic data. The addresses of the state climatologists are given inside the back cover.

The series No. 1. 1 title Substation History and issued by state contains information regarding history of station locations, type and exposure of measuring instruments, location of original meteorological records, where published, and dates of first and last observations. The price of this publication per state is $1.50.

III. NATIONAL CLIMATIC CENTER

The National Climatic Center was established in Asheville, North Carolina, in 1951 as the national archives for weather records. The files at the center contain 100,000 cubic feet of original records,more than thirty thousand reels of magnetic tape, and over 230,000,000 punched cards (Crutcher, 1964). In order to take a minimum of storage space, some of the punched cards have been microfilmed using FOSDIC (Film Optical Sensing Device for Input to Computers). This places the images of 12,000 punched cards on 100 ft. of 16 mm.film. An optical reader in combination with a card punch is used to recover the data. A reader to transfer data directly to magnetic tape is under development. For preparation of summaries, the Climatic Center has a RCA Spectra 70/45. Original manuscripts can be copied by microfilm, photocopy, xerox, microprints or micro-cards and furnished to users at the cost of reproduction. Special summaries are also prepared at cost for individuals or companies. A cost estimate for a specific job will be prepared on request. Inquiries may be addressed to Director, National Climatic Center, NOAA, Federal Building, Asheville, N.C., 28801.

Magnetic tape and punched cards can also be furnished to users with their own data processing equipment. Examples of three types of punched cards, the Hourly Surface Observation, Type 1; the Summary of the Day Card, Type 3; and the Winds Aloft Observations, Type 4 are shown in Figure 8. However, coding procedures for cards change, such as reporting winds to the nearest 10° (36 points) on January 1, 1964 and thereafter. Previously, winds were reported to 16 points of the compass. If a period of study spans one of these changes considerable difficulty may be encountered. A publication indicating some of the work of the NCC is: Climatology at Work (1960).

The NCC prepares special tabulations and summaries including the STAR Program (STability ARray) which presents wind distribution by Pasquill stability class. As of June 1, 1973 the STAR program had been compiled for 200 U.S. locations. The data are presented in terms of monthly seasonal or annual frequencies. Typical costs are given below:

STAR PROGRAM

One Year

	8 obs/day	24 obs/day
Monthly and Annual	$75	$100
Seasonal and Annual	50	75
Annual	45	70

Five Years

	8 obs/day	24 obs/day
Monthly and Annual	$125	$175
Seasonal and Annua	100	150
Annual	90	125

Reproduction costs for Tables already run:

Monthly and Annual	$45
Seasonal and Annual	22
Annual	7

STAR tabulations can be furnished on tapes at a cost of $60 per reel. The information can then be used in such EPA dispersion models as AQDM/IPP or CDM.

Inquiries should also be directed to NCC regarding inversion studies and morning and afternoon mixing height - transport wind speed tabulations which have already been prepared for specific locations. To initiate such a study based on a five year period of record would cost $500 to $600 per station. Refer to Holzworth (1974).

The NCC archives the low level sounding data, surface to 700 mb., from all Environmental Meteorological Support Units (EMSU). Copies of the Adiabatic Charts (WBAN-31D) and Wind Computation Sheets (WBAN-20) are available on microfilm. Mandatory, Standard and Significant Level data are also available on magnetic tape, as are half-minute wind observations.

The network originally consisted of the following stations.

City	Site Code	Begin
St. Louis, Mo.*	L0010	Apr. 1969
Chicago, Ill.*	L0020	Apr. 1969
Washington, D. C.	L0030	May 1969
New York, N. Y. **	L0040	June 1969
Philadelphia, Pa.**	L0050	June 1969
Cleveland, Ohio	L0060	Apr. 1971
Louisville, Ky.	L0070	Apr. 1971
Denver, Colo.	L0080	Apr. 1971
ElMonte, Cal.*	L0090	Apr. 1971
Los Angeles, Cal. *	L0100	May 1971
San Jose, Cal.	L0110	Aug. 1971
Boston, Mass.	L0120	Aug. 1971
Houston, Tex.*	L0130	Aug. 1971
Seattle, Wash.	L0140	Sep. 1971
Pittsburgh, Pa.*	L0150	Nov. 1971
Detroit, Mich.	L0160	Jul. 1972
Charleston, W. Va.*	L0170	Jul. 1972
Birmingham, Ala.*	L0180	Aug. 1972

*stations taking at least one sounding Monday through Friday as of August 1975.

**stations taking soundings only "on-call" as of August 1975.

In the past the state climatologist provided assistance on all matters relating to climatology and weather records for interested parties in the last of these positions. Persons requiring climatological records or similar assistance should contact either the nearest National Weather Service Office or Regional Headquarters or contact NCC directly. Please refer to the material beginning on page 7-52 which describes a NOAA perspective on the state climatological services, especially prepared by Arthur R. Hull, Deputy Director for Climatology, Environmental Data Service, NOAA. Please refer to 7-52 for the status of state climatological services.

REFERENCES

1. Barger, G. L., Editor, Climatology at Work Superintendent of Documents, Government Printing Office, Washington, D. C., 20402 1960. 65 cents.

2. Crutcher, H. L. The National Weather Records Center. Seminar on Human Biometeorology, Public Health Service Publication No. 999-AP-25. 1967.

3. Frederick, R. H. Weather Data for Air Pollution-Available, Analyzed and Inexpensive. J. of Air Pollution Control Assoc. 14:2, 60-65. 1964.

4. Selective Guide to Climatic Data Sources. Key to Meteorological Records Documentation No. 4. 11. Prepared by Staff, NCC, Asheville, N. C. Superintendent of Documents, Government Printing Office, Washington, D. C. 20402. 1969 $1.00

5. Superintendent of Documents, Selected Climatic Maps of the United States. U. S. Government Printing Office, Washington, D. C. 20402. 25 cents.

6. U. S. Superintendent of Documents. Weather Astronomy, and Meteorology. Price List 48. Government Printing Office. Washington, D. C., 20402.

7. U. S. Navy, NAVAER 50-1C-534. Guide to Standard Weather Summaries. January 1959 with Change No. 1, 15 July 1960.

8. U. S. Dept. of Commerce, Weather Bureau. Inventory of unpublished tabulations. Washington, D. C. 1954.80 cents.

9. Hull, A. R. The Federal Environmental Data System. Bull. Amer. Meteoro. Soc. Vol. 55 No. 7-765. July 1974.

10. Program and Abstracts: Climatology Conference and Workshop, October 8-11, 1974, Asheville N. C. Bull. Amer. Meteorology Soc. Vol. 55. No. 7; 859-875, July 1974.

11. Holzworth, G. C. Summaries of the Lower Few Kilometers of Rawinsonde and Radiosonde Observations in the United States, Paper presented at Climatology Conference and Workshop, Asheville, N. C. October, 1974.

LOCAL CLIMATOLOGICAL DATA

U. S. DEPARTMENT OF COMMERCE -- JOHN T. CONNOR, Secretary

ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION -- ENVIRONMENTAL DATA SERVICE

GREATER CINCINNATI AIRPORT
BOONE COUNTY, KENTUCKY
DECEMBER 1966

Latitude 39° 04' N Longitude 84° 40' W Elevation (ground) 869 ft. Standard time used: EASTERN

Date	Temperature (°F) Maximum	Minimum	Average	Departure from normal	Average dew point	Degree days (Base 65°)	Weather types shown by code 1-9 on dates of occurrence 1 Fog, Heavy Fog, or Thunderstorm 2 3 4 5 6 7 8 9 Blowing Snow, Sand, Dust, Duststorm, Sandstorm, Heavy Drifting Snow	Snow, Sleet, or Ice on ground at 07AM (In.)	Precipitation Total (Water equivalent) (In.)	Snow, sleet (In.)	Avg. station pressure (In.) Elev. 877 feet m.s.l.	Wind Resultant direction	Resultant speed (m.p.h.)	Average speed (m.p.h.)	Fastest mile Speed (m.p.h.)	Fastest mile Direction	Sunshine Total (Hours and tenths)	Percent of possible	Sky cover (Tenths) Sunrise to sunset	Midnight to midnight	Date
1	33	17	25	-12	26	40		T	.01	.1	29.15	29	9.1	11.9	16	33			10	10	1
2	19	15	17	-19	9	48		T	T	T	29.34	31	10.5	11.6	15	27			10	9	2
3	21	9	15	-21	8	50	8	T	0	0	29.64	06	7.5	8.8	12	10			1	9	3
4	35	14	25	-11	15	40		T	0	0	29.54	13	8.7	9.5	15	16			10	7	4
5	39	35	37	2	35	28	1	0	.31	0	29.25	22	10.4	11.4	17	22			10	10	5
6	58	38	48	13	47	17	1	0	.17	0	29.06	19	12.4	12.5	18	20			10	10	6
7	62	54	58	23	55	7	1	0	.23	0	28.90	20	15.2	15.6	21	20			10	10	7
8	65	60	63	28	58	2		0	.10	0	28.87	20	16.2	16.5	29	20			9	10	8
9	61	42	52	18	51	13	1	0	1.16	0	29.98	02	3.7	10.4	16	03			10	10	9
10	43	31	37	3	36	28	1	0	.63	1.0	29.05	01	10.2	11.4	20	35			10	10	10
11	34	30	32	-2	28	33		1	T	T	29.44	36	8.2	9.1	14	33			10	10	11
12	32	26	29	-5	23	36	8	T	T	T	29.51	07	9.8	10.1	12	07			10	10	12
13	32	24	28	-6	23	37	8	T	T	T	29.35	04	1.8	6.9	12	11			9	8	13
14	32	24	28	-5	24	37	1 8	0	0	0	29.30	24	8.2	8.9	13	29			9	8	14
15	46	24	35	2	25	30	1 8	0	0	0	29.37	19	8.2	8.3	13	20			2	1	15
16	52	33	43	10	27	22		0	0	0	29.28	23	9.4	9.6	14	25			5	3	16
17	52	33	43	10	30	22		0	0	0	29.15	22	10.0	10.2	17	24			7	4	17
18	55	30	43	10	35	22	1 8	0	0	0	29.04	27	4.3	7.3	12	03			1	2	18
19	42	27	35	2	31	30	1 8	0	0	0	28.95	15	5.2	7.8	13	16			9	8	19
20	43	34	39	6	30	26	8	0	T	0	28.82	30	10.7	11.1	18	29			10	9	20
21	43	32	38	5	30	27		0	0	0	28.96	12	6.3	7.3	13	14			10	10	21
22	38	25	32	-1	26	33	1 8	0	0	0	29.17	02	10.0	10.1	16	01			9	6	22
23	28	22	25	-7	12	40		0	0	0	29.23	04	14.6	15.1	20	02			10	10	23
24	31	18	25	-7	14	40		T	T	T	29.12	33	7.9	9.8	16	31			10	7	24
25	35	16	26	-6	13	39		T	0	0	29.16	26	10.3	10.9	20	29			0	0	25
26	34	12	23	-9	12	42		0	0	0	29.34	29	4.2	4.9	13	30			3	2	26
27	34	13	24	-8	14	41	1 4 6 8	0	.11	T	29.38	13	4.6	5.9	14	11			9	7	27
28	40	30	35	7	32	30	1 4 6	T	.57	.3	28.84	20	8.3	15.1	23	27			10	9	28
29	31	21	26	-4	17	39		T	.02	.2	28.92	26	17.3	17.3	25	27			9	7	29
30	37	15	26	-4	18	39		T	0	0	29.24	22	7.4	7.8	14	26			2	1	30
31	39	21	30	-2	25	35	2	0	T	T	29.09	19	6.5	7.9	14	21			10	9	31
Sum	1254	825				969	Total		Total	Total	For the month:						Total	% for month	Sum	Sum	
Avg.	40.5	26.6	Avg. 33.6	Dep. 0.3	Avg. 27	Season to date Total 2069	Dep. -14	Temperature: Number of days Max. ≤ 32° 51	Min. ≥ 90° 8	Min. ≤ 32° 0	Min. ≤ 0° 23	Dep. 0.56	3.31	1.6	29.10	24	2.6	10.3	Date: 08	Possible		Avg. 7.9	Avg. 7.0

Greatest in 24 hours and dates				Greatest depth on ground of snow, sleet or ice and date	
Precipitation		Snow, Sleet			
1.36	9-10	1.0	10	1	11+

* Extreme for the month. May be the less of more than one occurrence.
- Below zero temperatures or negative departure from normal.
T In columns 9, 10, and 11 and in the Hourly Precipitation table indicates an amount too small to measure.
X Heavy fog — visibility ¼ mile or less.
§ 70° at Alaskan stations.
+ Also on an earlier date, or dates.

HOURLY PRECIPITATION (Liquid in Inches)

Date	A. M. Hour ending at 1	2	3	4	5	6	7	8	9	10	11	12	P. M. Hour ending at 1	2	3	4	5	6	7	8	9	10	11	12	Date
1																		T	T	T	.01	T	T	T	1
2	T	T	T	T																					2
3																									3
4																									4
5		T	T	T	.03	.04	.11	.05	T	T	T								T	T	T	T	.01	.07	5
6	.07	.06	.03	.01	T	T	T	T				T	T				T	T	T			T	T		6
7		T	T	.01	.01	.03	.03	.02	.05	.05	.01	T								.02	T				7
8														T	T					.01	.09	T	T	T	8
9	.01	.01	.04	.05	.09	.11	.07	.03	.05	.09	.07	.05	.13	.07	.02	T	T	T	.01	T	.03	.05	.12	.10	9
10	.04	.10	.08	.08	.04	.03	.08	.03	.02	T	T	T	T	T				.01	.05	.04	.01	T	T	T	T	10
11				T	T					T	T				T	T	T							T	11
12	T	T					T	T		T	T	T	T	T											12
13							T	T																	13
14																									14
15																									15
16																									16
17																									17
18																									18
19																		T	T						19
20									T	T			T	T											20
21																									21
22																									22
23																									23
24				T	T	T	T	T	T	T	T	T	T	T	T	T	T	T								24
25																									25
26																									26
27																						.02	.04	.05	27
28	.04	.02	.04	.05	.04	.03	.01	.01	.04	.07	.11	.07	.04	T		T									28
29		T	T	T	T	T	T	T	T	.01	.01	T	T	T	T										29
30																									30
31								T	T									T	T					T	31

Data in columns 6, 12, 13, 14, and 15 are based on 8 observations per day at 3-hour intervals. Wind directions are those from which the wind blows. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. Figures for directions are tens of degrees from North; i.e., 09 = East, 18 = South, 27 = West, 36 = North, and 00 = Calm. When directions are in tens of degrees in Col. 17, entries in Col. 16 are fastest observed 1-minute speeds. If the / appears in Col. 17, speeds are gusts. Any errors detected will be corrected and changes in summary data will be annotated in the annual Summary if published.

AVERAGES BY HOURS

Hour (Local time)	Sky cover (in tenths)	Sunrise pres. (In.)	Dry bulb (°F)	Wet bulb (°F)	Rel. hum. (%)	Dew point (°F)	Wind speed (m.p.h.)	Resultant wind Direction	Resultant wind Speed (m.p.h.)
01	6	29.17	31	30	82	28	9.3	24	2.1
04	6	29.18	30	29	83	25	9.5	23	1.9
07	6	29.18	30	29	84	25	9.7	22	2.1
10	8	29.21	32	31	81	27	10.7	23	3.1
13	8	29.17	37	34	71	28	12.2	24	4.6
16	6	29.15	38	34	68	28	11.3	25	3.9
19	7	29.16	35	32	74	27	9.6	24	1.4
22	6	29.18	33	31	78	26	9.8	25	1.6

Subscription Price: Local Climatological Data $1.00 per year including annual Summary if published. Single copy: 10 cents for monthly Summary; 15 cents for annual Summary. Checks or money orders should be made payable and remittances and correspondence should be sent to the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402.

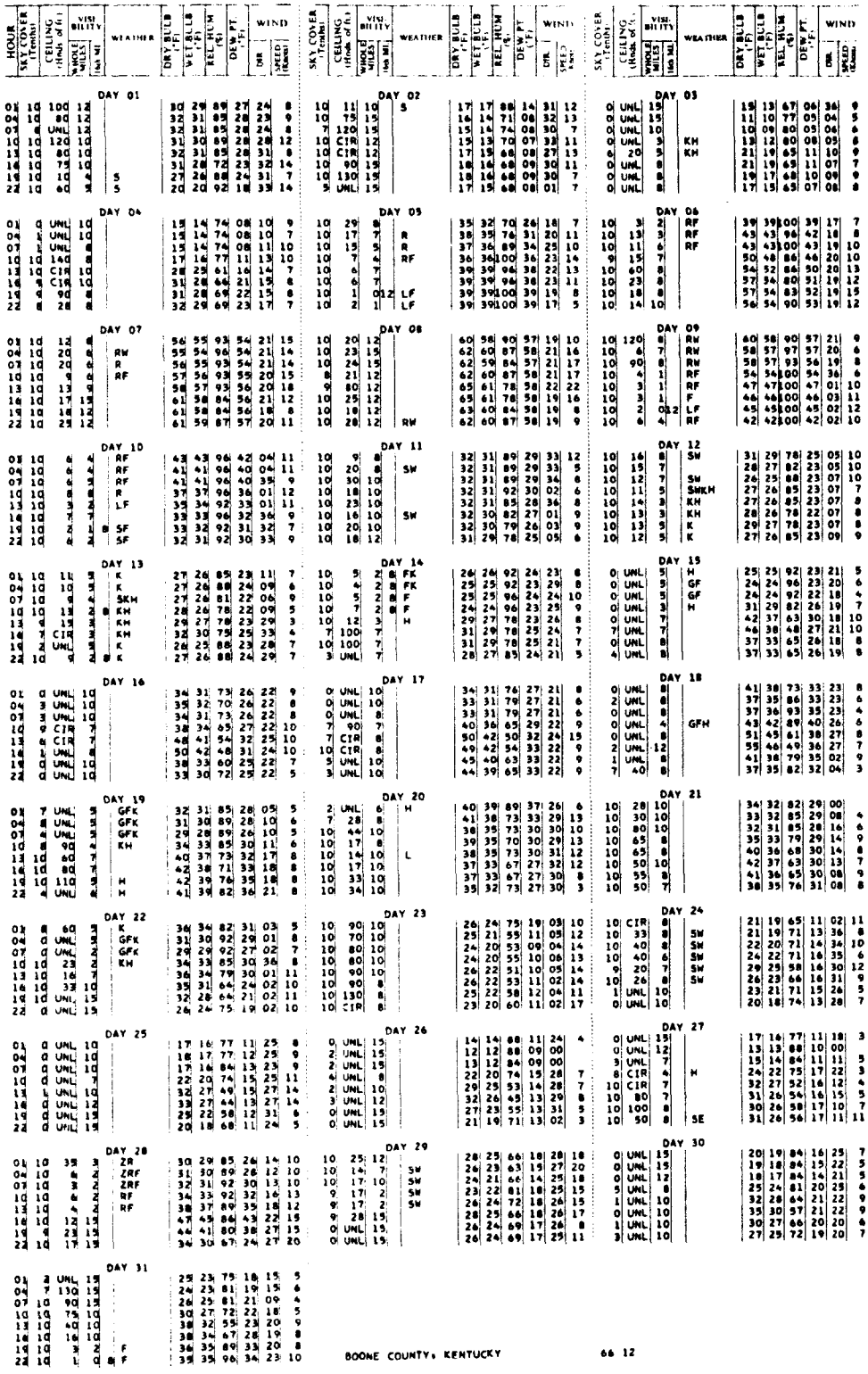
I certify that this is an official publication of the Environmental Science Services Administration, and is compiled from records on file at the National Weather Records Center, Asheville, North Carolina, 28801.

Director, National Weather Records Center

USCOMM - ESSA - ASHEVILLE 500

FIGURE 1

OBSERVATIONS AT 3-HOUR INTERVALS



BOONE COUNTY, KENTUCKY 66 12

FIGURE 2

REFERENCE NOTES

CEILING COLUMN—
UNL indicates an unlimited ceiling.
CIR indicates a cirriform cloud ceiling of unknown height.

WEATHER COLUMN—

*	Tornado
T	Thunderstorm
Q	Squall
R	Rain
RW	Rain showers
ZR	Freezing rain
L	Drizzle
ZL	Freezing drizzle
S	Snow
SP	Snow pellets
IC	Ice crystals
SW	Snow showers
SG	Snow grains
E	Sleet
A	Hail
AP	Small hail
F	Fog
IF	Ice fog
GF	Ground fog
BD	Blowing dust
BN	Blowing sand
BS	Blowing snow
BY	Blowing spray
K	Smoke
H	Haze
D	Dust

WIND COLUMNS—

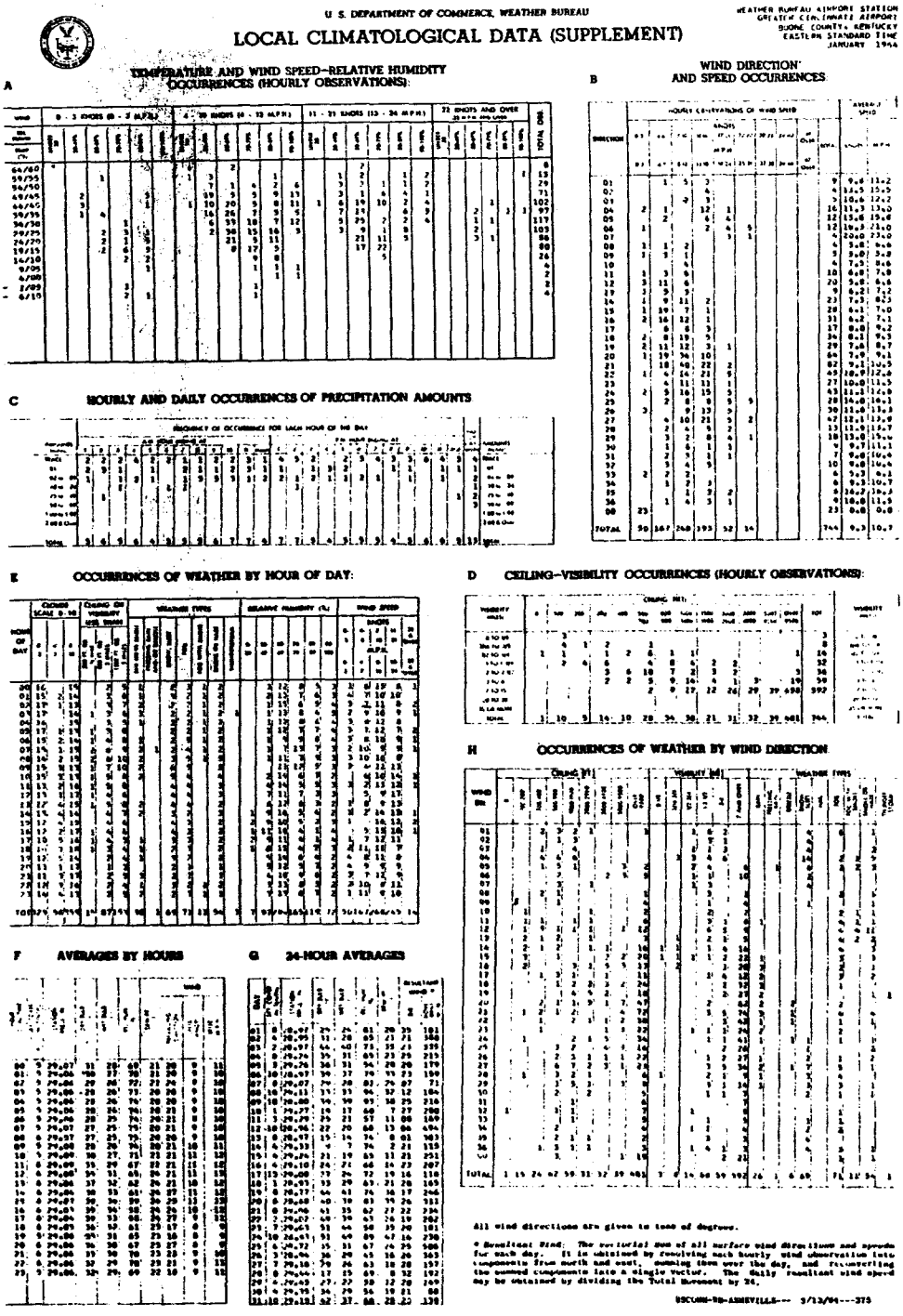
Directions are those from which the wind blows, indicated in tens of degrees from true North; i. e., 09 for East, 18 for South, 27 for West. Entry of 00 in the direction column indicates calm.

Speed is expressed in knots; multiply by 1.15 to convert to miles per hour.

ADDITIONAL DATA

Other observational data contained in records on file can be furnished at cost via microfilm or microfiche copies of the original records. Inquiries as to availability and costs should be addressed to:

Director
National Weather Records Center
Federal Building
Asheville, N. C. 28801



U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU

LOCAL CLIMATOLOGICAL DATA (SUPPLEMENT)

WEATHER BUREAU AIRPORT STATION
GREATER CINCINNATI AIRPORT
BOONE COUNTY, KENTUCKY
EASTERN STANDARD TIME
JANUARY 1954

A TEMPERATURE AND WIND SPEED—RELATIVE HUMIDITY OCCURRENCES (HOURLY OBSERVATIONS)

B WIND DIRECTION AND SPEED OCCURRENCES

C HOURLY AND DAILY OCCURRENCES OF PRECIPITATION AMOUNTS

D CEILING—VISIBILITY OCCURRENCES (HOURLY OBSERVATIONS)

E OCCURRENCES OF WEATHER BY HOUR OF DAY

F AVERAGES BY HOURS

G 24-HOUR AVERAGES

H OCCURRENCES OF WEATHER BY WIND DIRECTION

All wind directions are given to tens of degrees.

* Resultant Wind: The vectorial sum of all surface wind directions and speeds for each day. It is obtained by resolving each hourly wind observation into components from north and east, summing them over the day, and recompositing the summed components into a single vector. The daily resultant wind speed may be obtained by dividing the total movement by 24.

USCOMM-WB-ASHEVILLE--- 3/13/54---375

FIGURE 3

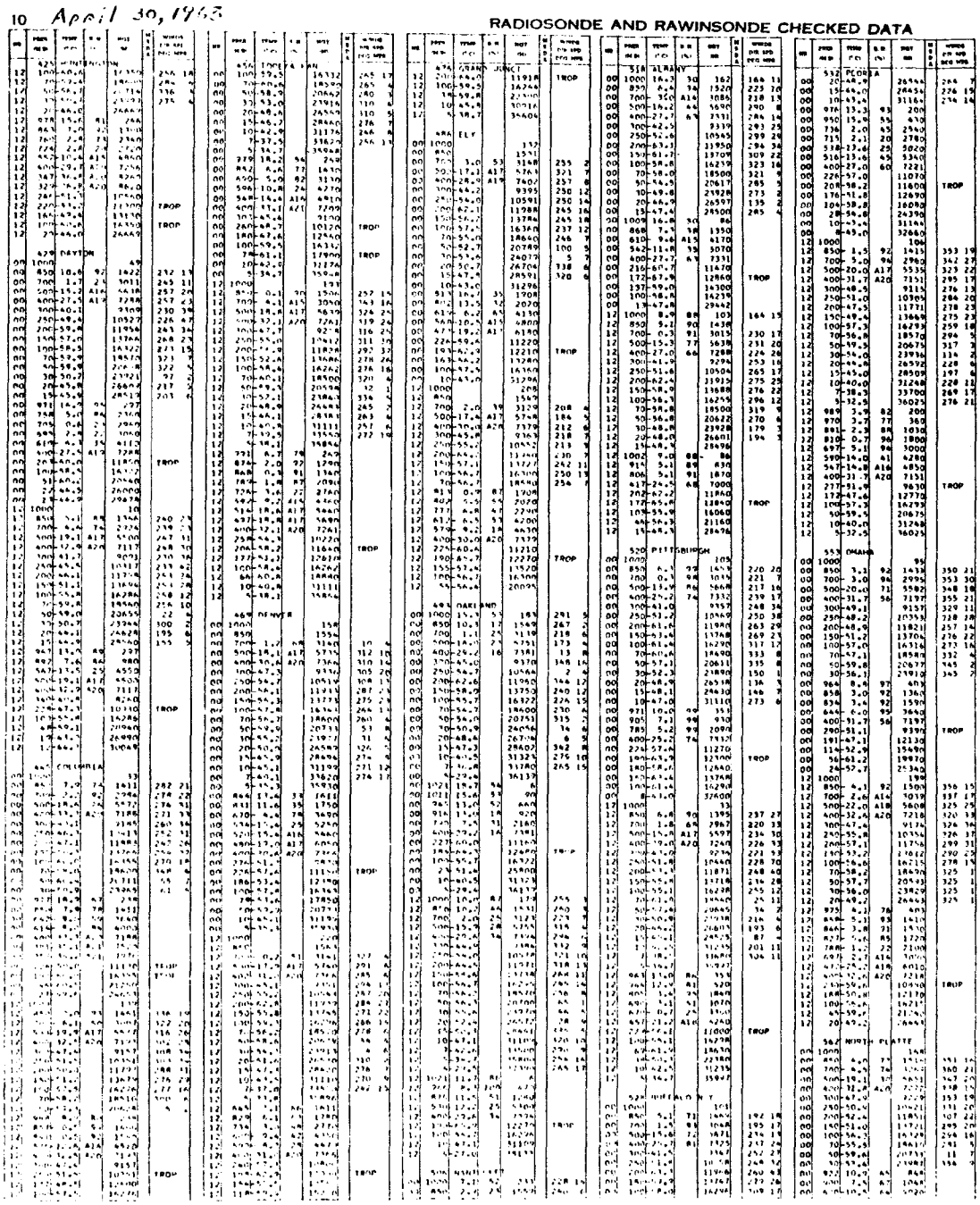
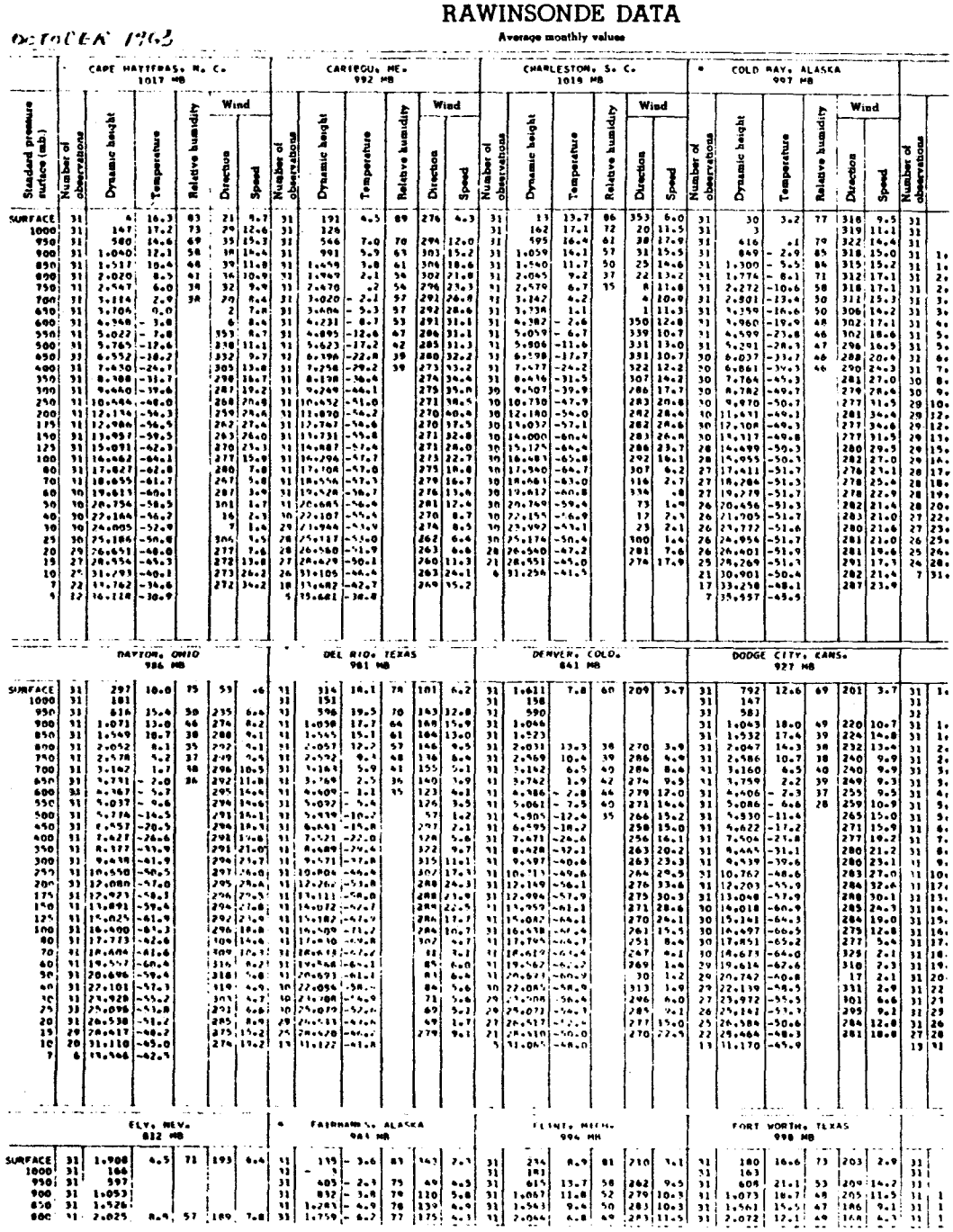


FIGURE 4



RAWINSONDE DATA

OCTOBER 1963

Average monthly values

CAPE HATTERAS, N. C. 1017 MB

Standard pressure surface (mb)	Number of observations	Dynamic height	Temperature	Relative humidity	Wind Direction	Wind Speed
SURFACE	31	4	16.3	83	21	9.7
1000	31	147	17.2	73	29	12.6
950	31	580	14.6	69	35	15.3
900	31	1,040	12.1	58	38	14.4
850	31	1,517	10.4	46	39	11.8
800	31	2,020	8.5	41	36	10.9
750	31	2,547	6.0	38	32	9.9
700	31	3,114	2.9	38	29	8.4
650	31	3,704	0.0		2	7.8
600	31	4,346	- 3.8		6	8.4
550	31	5,022	- 7.8		353	8.7
500	31	5,765	-12.6		338	11.1
450	31	6,552	-18.2		332	9.7
400	31	7,430	-24.1		305	13.8
350	31	8,388	-31.7		298	16.7
300	31	9,440	-39.6		287	19.2
250	31	10,646	-48.0		268	20.8
200	31	12,134	-56.3		259	23.6
175	31	12,986	-56.5		262	27.6
150	31	13,957	-59.5		263	26.0
125	31	15,093	-62.3		270	25.3
100	31	16,462	-64.1		277	15.9
80	31	17,827	-62.8		280	7.8
70	31	18,655	-61.7		267	5.8
60	30	19,613	-60.1		287	3.9
50	30	20,754	-58.5		301	1.7
40	30	22,164	-56.2		16	2.3
30	30	24,005	-52.9		7	1.6
25	30	25,186	-50.8		306	1.5
20	29	26,651	-48.8		277	7.6
15	27	28,554	-46.3		272	13.8
10	25	31,193	-40.1		273	26.2
7	22	33,762	-36.6		272	34.2
5	22	36,124	-38.9			

CARIBOU, ME. 992 MB

Standard pressure surface (mb)	Number of observations	Dynamic height	Temperature	Relative humidity	Wind Direction	Wind Speed
SURFACE	31	191	4.5	89	276	4.3
1000	31	326				
950	31	546	7.0	70	294	12.0
900	31	991	5.9	69	303	15.2
850	31	1,449	3.8	61	306	18.6
800	31	1,949	2.1	56	302	21.8
750	31	2,470	.2	56	296	23.3
700	31	3,020	- 2.1	57	292	26.9
650	31	3,606	- 5.3	57	292	28.6
600	31	4,231	- 8.7	53	291	31.1
550	31	4,895	-12.6	62	286	31.1
500	31	5,623	-17.2	62	285	31.3
450	31	6,396	-22.8	38	280	32.2
400	31	7,258	-29.2	39	273	33.2
350	31	8,198	-36.6		274	36.4
300	31	9,269	-44.1		275	35.8
250	31	10,492	-51.0		271	38.5
200	31	11,870	-54.2		270	40.4
175	31	12,767	-54.6		270	37.5
150	31	13,731	-55.8		271	32.8
125	31	14,867	-57.4		271	28.0
100	31	16,294	-57.7		273	22.7
80	31	17,708	-57.8		275	18.8
70	31	18,556	-57.3		279	16.7
60	31	19,528	-56.7		276	13.6
50	31	20,685	-56.6		281	12.4
40	30	22,107	-55.6		270	8.7
30	29	23,944	-53.9		274	8.5
25	28	25,187	-53.0		262	6.4
20	28	26,580	-51.9		263	6.6
15	27	28,429	-50.1		260	11.3
10	26	31,105	-44.4		263	24.1
7	18	33,682	-42.7		269	35.2
5	5	35,681	-38.8			

CHARLESTON, S. C. 1015 MB

Standard pressure surface (mb)	Number of observations	Dynamic height	Temperature	Relative humidity	Wind Direction	Wind Speed
SURFACE	31	13	13.7	86	353	6.0
1000	31	162	17.1	72	20	11.5
950	31	595	16.4	62	38	17.9
900	31	1,059	14.1	57	31	15.5
850	31	1,540	11.7	50	25	14.6
800	31	2,045	9.2	37	22	13.2
750	31	2,579	6.7	35	8	11.8
700	31	3,147	4.2		4	10.9
650	31	3,758	1.1		1	11.3
600	31	4,382	- 2.6		350	12.8
550	31	5,059	- 6.7		339	10.7
500	31	5,806	-11.6		331	13.0
450	31	6,598	-17.7		331	10.7
400	31	7,477	-24.2		322	12.2
350	31	8,436	-31.5		307	14.2
300	31	9,507	-39.9		286	17.7
250	30	10,730	-47.9		283	20.8
200	30	12,180	-54.0		282	24.6
175	30	13,037	-57.1		282	24.6
150	30	14,000	-60.4		283	26.8
125	30	15,125	-64.4		288	23.7
100	30	16,681	-65.8		292	16.1
80	30	17,940	-64.7		307	6.2
70	30	18,681	-63.0		116	2.7
60	30	19,612	-60.8		334	.8
50	30	20,749	-59.4		73	1.9
40	30	22,155	-56.9		12	2.9
30	30	23,992	-53.1		23	2.1
25	30	25,174	-50.4		100	1.6
20	28	26,540	-47.2		281	7.6
15	21	28,551	-44.0		274	17.9
10	6	31,254	-41.5			

COLD BAY, ALASKA 987 MB

Standard pressure surface (mb)	Number of observations	Dynamic height	Temperature	Relative humidity	Wind Direction	Wind Speed
SURFACE	31	30	3.2	77	318	9.5
1000	31	3			319	11.1
950	31	416	.1	70	322	14.4
900	31	849	- 2.9	85	318	15.0
850	31	1,300	- 5.5	84	315	15.2
800	31	1,774	- 8.1	71	312	17.1
750	31	2,272	-10.6	58	310	17.1
700	31	2,801	-13.4	50	312	15.3
650	31	3,359	-16.6	50	306	14.2
600	31	3,960	-19.9	48	302	17.1
550	31	4,599	-23.8	46	302	18.6
500	31	5,291	-28.3	47	296	16.5
450	30	6,037	-33.7	46	288	20.4
400	30	6,861	-39.3	46	290	24.3
350	30	7,764	-45.3		281	27.0
300	30	8,782	-49.7		279	28.6
250	30	9,970	-50.7		277	31.5
200	30	11,431	-49.1		281	34.6
175	30	12,108	-49.3		277	34.6
150	30	12,917	-49.8		277	31.5
125	28	14,099	-50.3		280	29.5
100	28	15,955	-50.1		282	27.0
80	27	17,411	-51.7		276	21.1
70	27	18,286	-51.3		278	25.4
60	27	19,279	-51.7		278	22.9
50	26	20,456	-51.3		282	21.6
40	26	21,905	-51.7		283	21.0
30	26	23,777	-51.6		280	21.6
25	26	24,956	-51.7		281	21.0
20	26	26,401	-51.9		281	19.6
15	25	28,269	-51.7		291	17.1
10	21	30,901	-50.4		282	21.6
7	17	33,258	-48.1		287	23.9
5	7	35,557	-45.5			

DAYTON, OHIO 986 MB

Standard pressure surface (mb)	Number of observations	Dynamic height	Temperature	Relative humidity	Wind Direction	Wind Speed
SURFACE	31	297	10.0	75	59	4.6
1000	31	381				
950	31	838	15.4	58	235	6.6
900	31	1,371	13.9	46	276	8.2
850	31	1,949	10.7	38	288	9.1
800	31	2,552	8.1	35	292	9.1
750	31	3,178	5.2	37	289	9.5
700	31	3,842	1.7	38	296	10.5
650	31	4,541	- 2.0	36	292	11.8
600	31	5,267	- 5.7		295	14.4
550	31	6,037	- 9.6		294	14.6
500	31	6,874	-14.5		291	14.1
450	31	7,757	-20.5		294	13.3
400	31	8,727	-26.6		293	14.8
350	31	9,787	-33.9		293	21.0
300	31	10,938	-41.9		296	21.7
250	31	12,550	-50.5		297	26.0
200	31	14,088	-57.0		295	28.4
175	31	14,923	-58.1		294	29.5
150	31	15,891	-59.4		294	27.8
125	31	17,025	-61.9		292	21.9
100	31	18,400	-61.3		296	18.8
80	31	19,773	-62.6		104	14.6
70	31	20,606	-61.6		109	10.3
60	31	21,527	-60.4		316	8.2
50	31	22,696	-59.4		318	5.8
40	31	24,101	-57.3		319	4.9
30	31	25,928	-55.2		303	4.7
25	31	27,096	-53.8		291	6.8
20	31	28,538	-51.2		285	8.9
15	29	30,617	-48.2		275	13.2
10	20	33,110	-45.0		276	19.2
7	6	35,566	-42.9			

DEL RIO, TEXAS 981 MB

Standard pressure surface (mb)	Number of observations	Dynamic height	Temperature	Relative humidity	Wind Direction	Wind Speed
SURFACE	31	314	18.1	78	101	6.2
1000	31	151				
950	31	596	19.5	70	163	12.8
900	31	1,058	17.7	64	168	15.9
850	31	1,555	15.1	61	164	13.0
800	31	2,057	12.2	57	146	9.5
750	31	2,592	9.4	48	136	8.4
700	31	3,163	5.9	41	155	9.1
650	31	3,769	2.5	36	140	9.9
600	31	4,409	- 1.1	35	123	9.1
550	31	5,092	- 5.4		126	9.5
500	31	5,839	-10.2		57	5.2
450	31	6,661	-15.8		297	2.1
400	31	7,571	-22.0		178	5.6
350	31	8,589	-29.4		322	9.7
300	31	9,771	-37.8		315	11.1
250	31	10,906	-46.6		307	13.1
200	31	12,262	-53.8		288	24.3
175	31	13,111	-58.0		288	23.9
150	31	14,072	-62.7		289	22.5
125	31	15,182	-67.9		284	17.7
100	31	16,509	-71.2		286	10.7
80	31	17,910	-69.8		307	4.7
70	31	18,613	-67.2		81	3.1
60	31	19,568	-64.1		85	6.0
50	31	20,693	-61.4		81	6.4
40	30	22,054	-58.-		84	5.6
30	30	23,788	-54.9		71	5.6
25	29	25,079	-52.-		69	5.7
20	28	26,511	-49.6		69	3.7
15	25	28,478	-46.-		279	9.1
10	21	31,122	-41.8			

DENVER, COLO. 841 MB

Standard pressure surface (mb)	Number of observations	Dynamic height	Temperature	Relative humidity	Wind Direction	Wind Speed
SURFACE	31	1,611	7.8	60	209	3.7
1000	31	158				
950	31	590				
900	31	1,046	13.3	38	270	3.9
850	31	1,523				
800	31	2,031	10.4	39	286	4.9
750	31	2,569	7.4	42	284	8.6
700	31	3,142	4.2	42	274	9.5
650	31	3,742	1.9	42	279	12.0
600	31	4,386	- 2.8	46	271	14.6
550	31	5,061	- 7.5	40	271	14.6
500	31	5,805	-12.4	35	266	15.2
450	31	6,595	-18.2		258	15.0
400	31	7,473	-26.6		256	16.1
350	31	8,428	-32.1		260	20.2
300	31	9,497	-40.6		263	23.3
250	31	10,713	-49.6		264	29.5
200	31	12,149	-56.1		276	33.6
175	31	12,996	-57.9		275	30.3
150	31	13,959	-61.1		271	28.6
125	31	15,087	-64.1		270	26.1
100	31	16,638	-67.4		261	15.5
80	31	17,799	-64.7		251	8.4
70	31	18,617	-63.4		247	4.1
60	31	19,562	-62.2		269	1.4
50	31	20,681	-60.9		30	1.2
40	30	22,085	-58.9		313	1.9
30	30	23,888	-56.4		296	4.0
25	29	25,073	-54.1		285	9.1
20	28	26,517	-51.-		277	15.0
15	21	28,410	-50.0		270	22.5
10	5	31,085	-48.0			

DODGE CITY, KANS. 927 MB

Standard pressure surface (mb)	Number of observations	Dynamic height	Temperature	Relative humidity	Wind Direction	Wind Speed
SURFACE	31	792	12.6	69	201	3.7
1000	31	147				
950	31	583				
900	31	1,043	18.0	49	220	10.7
850	31	1,532	17.4	39	226	14.8
800	31	2,047	14.3	38	232	13.4
750	31	2,586	10.7	38	240	9.9
700	31	3,160	6.5	40	240	9.9
650	31	3,759	2.2	39	249	9.3
600	31	4,406	- 2.3	37	255	9.5
550	31	5,086	- 6.6	28	259	10.9
500	31	5,830	-11.4		265	15.0
450	31	6,622	-17.2		271	15.9
400	31	7,504	-24.8		277	19.2
350	31	8,445	-31.1		280	21.2
300	31	9,539	-39.6		280	23.1
250	31	10,767	-48.6		283	27.0
200	31	12,203	-55.9		284	32.6
175	31	13,048	-57.9		288	30.1
150	30	14,018	-60.9		285	24.3
125	30	15,141	-64.3		284	19.0
100	30	16,497	-66.5		275	12.8
80	30	17,851	-65.2		277	5.6
70	30	18,673	-64.0		325	2.1
60	30	19,616	-62.6		310	2.3
50	29	20,742	-60.8		17	2.1
40	29	22,139	-58.5		331	2.9
30	27	23,972	-55.5		301	6.6
25	26	25,142	-53.3		295	9.2
20	25	26,584	-50.6		284	12.8
15	22	28,464	-48.3		281	18.8
10	13	31,170	-45.9			

ELY, NEV. 832 MB

Standard pressure surface (mb)	Number of observations	Dynamic height	Temperature	Relative humidity	Wind Direction	Wind Speed
SURFACE	31	1,908	4.5	71	193	6.4
1000	31	166				
950	31	597				
900	31	1,053				
850	31	1,526				
800	31	2,025	8.4	57	189	7.8

FAIRBANKS, ALASKA 981 MB

Standard pressure surface (mb)	Number of observations	Dynamic height	Temperature	Relative humidity	Wind Direction	Wind Speed
SURFACE	31	119	- 3.6	83	143	2.1
1000	31	5				
950	31	485	- 2.9	75	49	4.5
900	31	852	- 3.8	79	110	5.8
850	31	1,283	- 4.9	78	139	4.9
800	31	1,759	- 8.2	77	175	4.3

FLINT, MICH. 996 MB

Standard pressure surface (mb)	Number of observations	Dynamic height	Temperature	Relative humidity	Wind Direction	Wind Speed
SURFACE	31	234	8.9	81	210	9.1
1000	31	181				
950	31	615	13.7	58	262	9.5
900	31	1,067	11.8	52	279	10.3
850	31	1,543	9.4	50	283	10.3
800	31	2,044	6.8	49	283	11.5

FORT WORTH, TEXAS 998 MB

Standard pressure surface (mb)	Number of observations	Dynamic height	Temperature	Relative humidity	Wind Direction	Wind Speed
SURFACE	31	180	16.6	73	203	2.9
1000	31	163				
950	31	609	21.1	53	209	14.7
900	31	1,073	18.7	48	205	11.5
850	31	1,561	15.5	47	186	9.1
800	31	2,072	12.1	49	166	6.3

FIGURE 5

CINCINNATI, OHIO
Greater Cincinnati AP Boone Co., Ky.

SEPTEMBER
7200 Obs.

A TEMPERATURE AND WIND SPEED–RELATIVE HUMIDITY OCCURRENCES:

WIND	0-4 MPH						5-14 MPH						15-24 MPH						25 MPH AND OVER						TOTAL OBS
00/ 00	3						1						2												6
99/ 99	19	1					6						2												24
96/ 90	3	22					35	69	4				5	8						1	1				126
89/ 85	6	37	19				40	117	34				6	44	8					1	1				315
84/ 80	10	40	32	5			44	179	105	12			3	36	46	2					1				518
79/ 75	12	48	62	27	12		54	192	206	87	26	1	3	43	60	29	4				2				866
74/ 70	9	52	74	45	48	30	37	231	271	121	179	109	5	90	96	34	32	8			1	1			1313
69/ 65	6	26	77	50	54	70	20	216	296	186	139	195	7	17	25	33	25	22		1					1464
64/ 60		19	66	58	79	73	8	97	239	152	154	154	1	11	18	8	7	14							1147
59/ 55		7	57	49	55	84		50	138	111	122	56		6	10	3		2							712
54/ 50		3	17	30	65	48		9	75	70	75	28		3	3	3	3								432
49/ 45			12	19	34	33			37	33	35	16			2										219
44/ 40				2	3	14			7	24	7	3			1										61
39/ 35					2																				2
TOTAL	82	225	396	284	346	324	247	1140	1612	796	738	560	32	200	211	92	73	46		2	5	1			7200

B PERCENTAGE FREQUENCIES OF WIND DIRECTION AND SPEED:

DIRECTION	HOURLY OBSERVATIONS OF WIND SPEED (IN MILES PER HOUR) 0-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	47 Over	TOTAL	AV SPEED
N	.4	2.8	2.3	.5	+					6.0	7.7
NNE	.4	2.2	2.3	.7						5.8	8.2
NE	1.1	3.9	3.1	1.0						9.2	7.5
ENE	.8	3.1	2.3	.6						6.8	7.2
E	.8	2.3	1.6	.1						4.7	6.5
ESE	.5	1.8	1.7	.2	+					4.2	7.3
SE	.7	1.5	1.3	.2						3.8	7.0
SSE	.6	1.5	1.8	.3						4.2	7.5
S	1.1	2.8	3.2	.9						8.0	7.9
SSW	.7	3.4	5.0	3.4	.5	.1				13.0	10.2
SW	.5	2.0	3.7	3.0	.4					9.7	10.6
WSW	.3	1.1	2.0	1.3	.2					4.8	10.3
W	.3	.9	1.1	.6	.1	+				2.9	9.4
WNW	.2	1.0	1.5	.9	.1	+				3.7	9.9
NW	.4	1.5	1.5	.7	+					4.1	8.3
NNW	.2	1.3	1.6	.6	+	+				3.8	9.0
CALM	5.4									5.4	
TOTAL	14.5	33.2	36.0	15.0	1.3	.1	+			100.	8.1

C OCCURRENCES OF PRECIPITATION AMOUNTS:

INTENSITIES	FREQUENCY OF OCCURRENCE FOR EACH HOUR OF THE DAY — A.M. HOUR ENDING AT: 1 2 3 4 5 6 7 8 9 10 11 NOON	P.M. HOUR ENDING AT: 1 2 3 4 5 6 7 8 9 10 11 MID	NO. DAYS WITH
TRACE	10 15 13 19 15 10 21 27 25 18 11 12	15 11 11 14 14 9 10 13 19 13 17 8	94
01 TO 02 IN	2 3 3 2 3 3 4 3 4 1 3 5	5 4 4 4 3 2 4 2 2 4 1 3	34
03 TO 05 IN	6 6 2 3 6 8 6 4 3 3 3 6	4 3 5 7 3 3 4 1 2 4 4 6	24
06 TO 09 IN	1 4 3 4 4 1 2 1 1 1 3 3	2 2 2 2 1 1 2 2 1 2 3 3	14
10 TO 14 IN	1 1 1 3 1 1 1	2 1 1 2 1 1	6
15 TO 19 IN	1	1	1
20 TO 24 IN			
25 TO 49 IN	1	1 1 1 1	5
50 TO 99 IN			
100 TO 199 IN			
200 IN AND OVER			
TOTAL	21 26 23 30 29 22 33 36 34 27 22 25	31 24 29 28 19 19 18 19 23 23 28 21	301

D PERCENTAGE FREQUENCIES OF CEILING–VISIBILITY:

VISIBILITY (MILES)	CEILING (FEET) 0	100-200	300-400	500-900	1000-1900	2000-2900	3000-4900	5000-9900	OVER 10000	TOT
0 TO 1/8	.2		+		+			+	.2	.5
3/16 TO 3/8		+							.2	.2
1/2 TO 7/8		.1	.1	+	+	+	+	.2	.3	.9
1 TO 2 1/2	+	.1	.4	.3	.1	.1	.2	.1	1.1	2.5
3 TO 6			.2	1.2	.8	.4	.6	1.0	8.1	12.2
7 TO 10			.1	1.1	2.8	2.4	3.6	6.3	77.7	94.2
20 TO 30										
35 OR MORE										
TOTAL	.2	.2	.8	2.6	3.7	2.9	4.4	7.6	87.8	100

E PERCENTAGE FREQUENCIES OF SKY COVER, WIND, AND RELATIVE HUMIDITY:

HOUR OF DAY	CLOUDS SCALE 0-10: 0-3	4-7	8-10	WIND SPEED (IN MPH): 0-3	4-12	13-24	25-A OVER	RELATIVE HUMIDITY (%): 0-29	30-49	50-69	70-89	80-89	90-100
00	64	8	28	20	72	8	+	+	4	33	30	17	15
01	63	10	27	19	73	8	+	+	4	27	30	23	16
02	64	6	29	20	73	6			3	21	28	30	19
03	62	8	30	20	75	5			2	18	22	36	21
04	57	11	32	19	75	6			1	14	19	35	31
05	56	12	33	24	70	6			1	11	22	33	33
06	45	15	40	28	65	7				11	16	31	42
07	42	12	46	26	67	9			+	13	17	34	36
08	46	12	42	14	68	19			2	27	28	22	21
09	47	12	41	7	68	25			9	48	20	11	12
10	49	13	38	5	67	27		1	27	43	12	11	6
11	45	18	37	5	67	28		3	40	36	10	6	5
12	42	18	40	5	65	30		3	48	27	8	7	5
13	40	20	40	7	58	35	1	2	51	22	7	6	5
14	40	19	41	5	58	36	1	2	50	18	7	6	5
15	39	20	41	8	58	34		2	51	15	9	5	5
16	37	22	41	8	65	27	+	2	49	15	7	6	5
17	45	18	39	7	74	19	+	1	52	19	6	5	5
18	48	15	37	13	75	12	+	1	47	28	9	5	5
19	48	15	37	15	78	7		2	37	39	9	9	6
20	56	11	33	20	72	8		1	20	46	15	11	6
21	61	11	28	18	73	9		1	12	53	15	13	6
22	64	10	26	16	75	9		+	8	49	21	12	9
23	66	8	27	20	70	10		+	6	41	27	12	15
AVG	51	14	35	14	69	16	+	5	22	28	16	14	13

FIGURE 6

CINCINNATI, OHIO
Greater Cincinnati AP Boone Co., Ky.

AERIAL
87,672 Obs.

A TEMPERATURE AND WIND SPEED–RELATIVE HUMIDITY OCCURRENCES:

WIND DIR. (tens of degrees)	0-4 M.P.H.						5-14 M.P.H.						15-24 M.P.H.						25 M.P.H. AND OVER						OBS. TOTAL
	0-9	10-19	20-29	30-39	40-49	50-59	0-9	10-19	20-29	30-39	40-49	50-59	0-9	10-19	20-29	30-39	40-49	50-59	0-9	10-19	20-29	30-39	40-49	50-59	
04/ 10	+						+	+						+												1
09/ 15	2	1					2	5	+				1	2												13
14/ 20	3	10	2				8	45	13				2	9	2					+						94
19/ 25	3	21	17	+			14	92	73	2	+		2	19	18	+				+	+	+				261
24/ 30	4	27	34	11	1	+	28	116	127	31	5	+	3	23	37	9	1			+	1	1				447
29/ 35	4	26	38	28	21	8	20	108	143	91	61	7	7	24	33	19	5	+	+	1	2	+	+	+	+	640
34/ 40	5	18	46	38	49	51	18	96	137	91	125	106	8	22	32	14	14	6	+	1	1	2	+	1		879
39/ 45	4	14	39	36	41	60	20	81	134	90	99	117	6	20	28	17	15	15	1	1	3	2	+	+	+	843
44/ 50	3	14	29	32	39	36	16	71	114	77	87	83	8	22	32	17	19	16	1	3	3	1	3	1	1	726
49/ 55	2	12	22	22	30	25	15	79	100	55	70	62	6	30	27	18	22	23	1	2	3	1	2	2	2	639
54/ 60	3	10	19	15	23	20	12	77	101	57	64	75	7	23	26	14	19	20	1	2	2	+	1	1	1	611
59/ 65	1	12	21	16	17	13	6	77	119	57	61	72	3	27	35	13	17	17	+	2	1	1	1	1	+	599
64/ 70	1	10	18	13	14	12	3	62	135	68	78	73	2	27	47	19	23	19		+	3	1	1	1	+	627
69/ 75		8	25	17	14	24	1	48	153	88	87	98	+	13	51	26	28	20		+	3	1	1	1	+	698
74/ 80		7	29	21	20	16		22	141	106	109	94		9	47	30	33	22		+	2	2	1	+	+	711
79/ 85		5	21	15	18	9	+	8	109	87	74	23		4	36	26	16	4			1	1	+			460
84/ 90		2	16	12	11	4		7	62	52	32	7		2	22	15	6	1								249
89/ 95		1	7	7	8	+		6	36	26	12	1		2	14	7	1	+				+				131
94/ 00			4	3	3	+		1	20	19	6			1	9	4	1					+				68
99/ 05			2	1	2			1	11	11	4			1	6	2	+									44
04/ 10			2	1	1			+	5	5	1			+	2	1										18
10-11/ 25-26			+	+					3	3	2				+											8
25-26/ 10-11									+	1	1															2
TOTAL	34	198	390	294	318	293	159	998	1728	1013	948	818	54	303	505	242	220	169	4	14	25	12	11	4	0	8767

In Tables A and C, occurrences are for the average year (10-year total divided by 10). Values are rounded to the nearest whole number, but not adjusted to make their sums exactly equal to column or row totals. "+" indicates more than 0 but less than 0.5.

B PERCENTAGE FREQUENCIES OF WIND DIRECTION AND SPEED:

DIRECTION	HOURLY OBSERVATIONS OF WIND SPEED (in miles per hour)									TOTAL	AV SPEED
	0-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	47 & OVER		
N	.5	2.0	1.9	.7	+	+				5.2	8.2
NNE	.4	1.8	2.0	1.0	.1	+				5.1	9.0
NE	.7	2.3	2.2	.9	+					6.1	8.2
ENE	.5	2.0	2.0	.7	.1	+				5.4	8.2
E	.5	1.5	1.3	.3	+					3.6	7.5
ESE	.3	1.1	1.5	.4	+	+				3.1	8.2
SE	.4	1.2	1.3	.4	+	+				3.4	8.1
SSE	.3	1.2	1.7	.8	.1	+				4.0	9.3
S	.7	2.5	3.0	1.3	.2	.1	+		+	8.0	9.2
SSW	.6	2.8	4.9	3.7	1.0	.2	+	+		13.3	11.3
SW	.6	2.2	4.0	3.3	.8	.1	+			11.3	11.4
WSW	.3	1.4	2.8	2.5	.9	.1	+	+		7.6	11.7
W	.3	1.1	1.9	1.8	.3	.1	+			5.3	11.2
WNW	.3	1.3	2.3	2.2	.5	.1	+			6.6	11.5
NW	.3	1.2	1.7	1.2	.2	+	+			4.6	10.1
NNW	.2	1.1	1.4	.8	+	+	+			3.5	9.4
CALM	4.0									4.0	
TOTAL	10.8	26.6	35.6	22.2	3.9	.7	.1	+	+	100	9.6

C OCCURRENCES OF PRECIPITATION AMOUNTS:

INTENSITIES	FREQUENCY OF OCCURRENCE FOR EACH HOUR OF THE DAY																								NO. DAYS WITH
	A.M. HOUR ENDING AT												P.M. HOUR ENDING AT												
	1	2	3	4	5	6	7	8	9	10	11	NOON	1	2	3	4	5	6	7	8	9	10	11	MID.	
TRACE	36	38	38	38	42	40	41	44	36	41	41	38	39	39	39	40	36	36	32	37	35	38	38	35	84
01 TO 02 IN.	7	8	9	10	7	8	8	6	10	10	7	8	8	7	6	6	8	7	7	7	6	8	8	8	13
02 TO 05 IN.	13	11	12	15	14	14	12	12	15	13	13	13	15	12	12	11	11	12	13	14	12	12	12	14	41
05 TO 10 IN.	4	4	6	4	4	5	5	6	3	5	5	6	4	5	5	5	5	4	4	2	4	4	5	5	27
10 TO 15 IN.	+	1	1	1	1	2	1	1	1	1	+	1	+	1	+	1	1	+	1	1	1	1	1	1	21
15 TO 20 IN.	+	+	1	+		+	+	+	1	+	+	+	+	+	1	+	1	+	+	+	+	+	+	+	19
20 TO 25 IN.												+			+	+	+		+		+				7
25 IN. AND OVER																								+	1
TOTAL	60	62	66	66	67	66	66	66	65	68	65	63	63	62	61	62	60	60	58	61	60	62	62	62	193

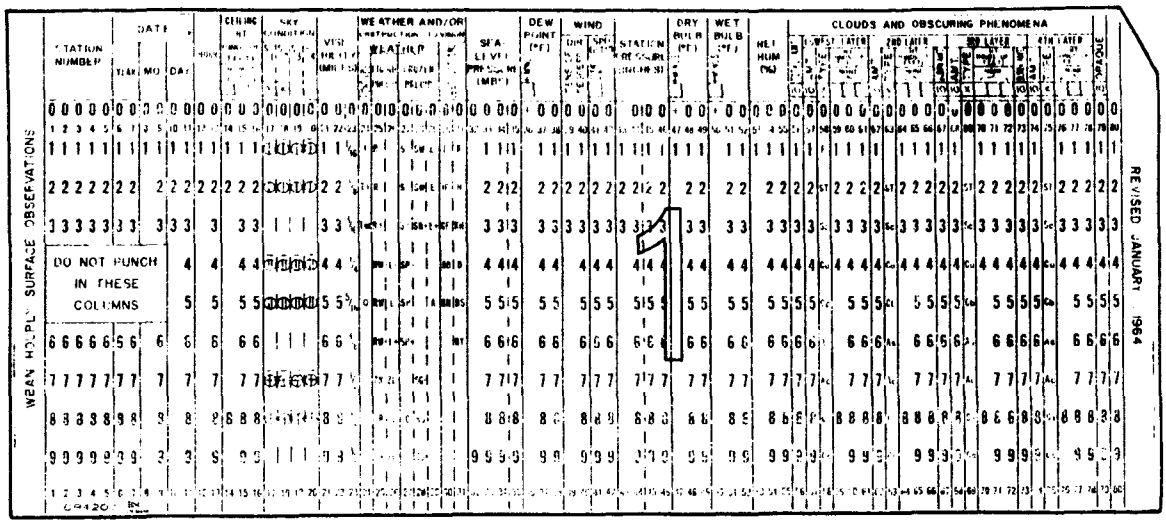
D PERCENTAGE FREQUENCIES OF CEILING–VISIBILITY:

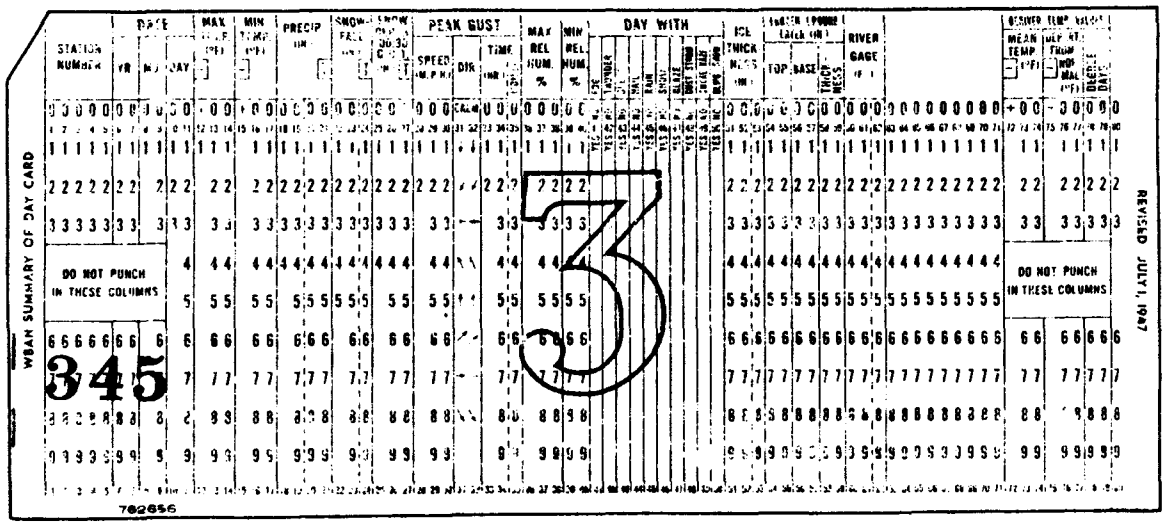
VISIBILITY (miles)	CEILING (feet)										
	0	100-200	300-400	500-900	1000-1900	2000-2900	3000-4900	5000-9900	OVER 10000	TOP	
0 TO 1/8	.3	.1	+	+	+	+	+	+	+	.1	.5
3/16 TO 3/8	.1	.2	+	+	+	+	+	+	+	.2	.4
1/2 TO 3/4	+	.3	.3	.2	+	+	+	+	+	.1	1.0
1 TO 2 1/2	+	.3	1.2	1.6	.6	.2	.2	.2	1.6	6	6.3
3 TO 6			+	.3	2.2	2.1	.9	1.2	1.3	6.6	14.9
7 TO 15			+	.1	1.2	5.8	4.3	8.2	7.5	53.7	77.9
20 TO 30											
35 OR MORE											
TOTAL	.6	.9	1.5	2.1	3.9	7.1	5.5	7.6	9.0	61.8	100

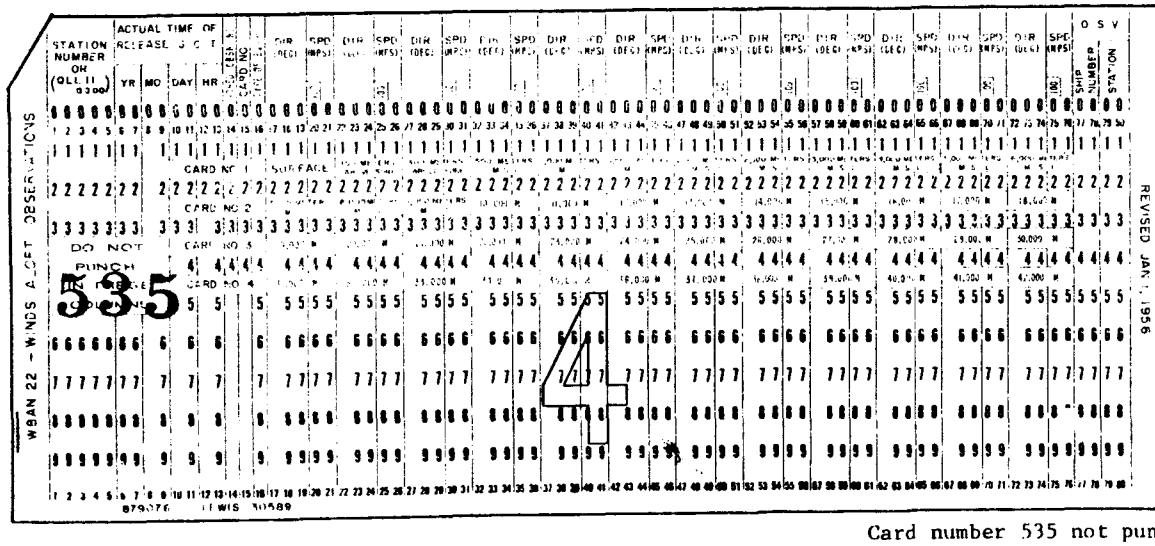
E PERCENTAGE FREQUENCIES OF SKY COVER, WIND, AND RELATIVE HUMIDITY:

HOUR OF DAY	CLOUDS (SCALE 0-10)			WIND SPEED (M. P. H.)				RELATIVE HUMIDITY (%)					
	0-2	3-7	8-10	0-3	4-12	13-24	25-& OVER	0-29	30-49	50-69	70-79	80-89	90-100
00	45	8	47	14	68	17	1	+	6	30	24	22	17
01	45	8	47	13	68	18	1	+	5	27	25	23	19
02	45	8	47	15	67	18	+	+	4	24	26	26	22
03	43	9	48	16	67	17	+	+	3	22	23	28	24
04	42	8	50	15	67	17	+	+	3	19	21	29	27
05	38	10	51	17	65	17	+	+	2	18	21	29	30
06	35	10	55	17	64	18	1	+	2	16	22	30	30
07	33	9	58	14	69	20	+	+	2	19	24	31	25
08	32	11	57	11	62	26	1	+	5	28	26	25	16
09	33	11	56	7	60	32	1	+	9	37	26	17	13
10	31	13	55	6	57	36	1	1	17	41	17	13	10
11	30	15	56	6	54	39	1	3	26	40	13	10	8
12	27	17	56	5	52	41	1	5	32	36	11	9	7
13	26	17	57	5	50	44	2	7	34	33	10	8	6
14	26	17	57	6	50	42	2	9	39	30	8	7	6
15	26	17	57	5	52	41	2	11	39	28	9	7	6
16	24	17	59	6	56	37	1	11	38	29	9	7	6
17	28	14	58	6	62	31	1	9	37	30	10	7	7
18	31	12	56	9	67	24	1	9	33	34	12	8	8
19	34	12	54	12	69	19	1	9	27	38	13	10	9
20	38	11	51	16	68	18	+	1	18	40	17	14	11
21	42	10	48	19	67	18	+	1	14	39	20	15	12
22	44	9	47	16	67	18	1	+	10	37	21	18	14
23	45	9	46	14	67	18	1	+	8	33	23	20	15
AVG	35	12	53	11	62	26	1	3	17	30	18	17	15

FIGURE 7







Card number 535 not punched after December 31, 1964.

FIGURE 8

PART TWO

Climatography of the United States
Series No. 82

This series, Decennial Census of United States Climate - Summary of Hourly Observations, is incomplete, although work on it has been temporarily discontinued. It is generally based on ten years of data. Similar summaries, based on five years of record are contained in Climatography of the United States, Series No. 30.

It has been issued for the stations listed. The second part of the series number indicates the State in which the station presented is located; for example, all stations in New York State carry the number 82-30.

The list of numbers and stations is:

82-1 Alabama
Birmingham
Mobile
Montgomery

82-2 Arizona
Phoenix
*Tucson

82-3 Arkansas
Little Rock

82-4 California
*Bakersfield
Burbank
Fresno
Los Angeles
Oakland
Sacramento
San Diego
San Francisco

82-5 Colorado
*Colorado Springs
Denver

82-6 Connecticut
*Hartford

82-7 Delaware
Wilmington

82-8 Florida
Jacksonville
Miami
*Orlando
*Tallahassee
Tampa
*West Palm Beach

82-9 Georgia
Atlanta
Augusta
*Macon
Savannah

82-10 Idaho
Boise

82-11 Illinois
*Chicago (O'Hare)
Chicago (Midway)
Moline
Springfield

82-12 Indiana
Evansville
Fort Wayne
Indianapolis
*South Bend

82-13 Iowa
Des Moines
Sioux City

82-14 Kansas
Topeka
Wichita

82-15 Kentucky
*Lexington
Louisville

82-16 Louisiana
Baton Rouge
Lake Charles
New Orleans
Shreveport

82-17 Maine
Portland

82-18 Maryland
Baltimore

82-19 Massachusetts
Boston

82-20 Michigan
Detroit (City AP)
*Flint
Grand Rapids

82-21 Minnesota
Duluth
Minneapolis

82-22 Mississippi
Jackson

82-23 Missouri
Kansas City
St. Louis
Springfield

82-24 Montana
Great Falls

82-25 Nebraska
Omaha

82-26 Nevada
*Las Vegas
*Reno

82-28 New Jersey
Newark

82-29 New Mexico
Albuquerque

*5 Year Summary Only

82-30 New York

Albany	New York (Int'l)
*Binghamton	New York (La Guardia)
Buffalo	Rochester
	Syracuse

82-31 North Carolina

Charlotte	Raleigh
Greensboro	*Winston-Salem

82-32 North Dakota

Bismarck	Fargo

82-33 Ohio

Akron-Canton	Columbus
Cincinnati	Dayton
Cleveland	Youngstown

82-34 Oklahoma

Oklahoma City
Tulsa

82-35 Oregon

Medford	Portland
*Pendleton	*Salem

*Not Prepared

82-36 Pennsylvania

Harrisburg	*Pittsburgh
Philadelphia	*Scranton

82-37 Rhode Island

Providence

82-38 South Carolina

Charleston	Columbia

82-39 South Dakota

Huron	*Rapid City

82-40 Tennessee

Chattanooga	Memphis
Knoxville	Nashville

82-41 Texas

Amarillo	Galveston
Austin	Houston
Brownsville	Laredo
Corpus Christi	*Lubbock
Dallas	*Midland
El Paso	San Antonio
*Fort Worth	*Waco
	*Witchita Falls

82-42 Utah

Salt Lake City

82-43 Vermont

*Burlington

82-44 Virginia

Norfolk	*Roanoke

Richmond

82-45 Washington

Seattle-Tacoma AP
Spokane

82-46 West Virginia

*Charleston

82-47 Wisconsin

*Green Bay	Milwaukee

Madison

82-48 Wyoming

*Casper

82-49 Alaska

*Anchorage
*Cold Bay
*Fairbanks
*King Salmon

82-50

Washington, D. C.

82-51 Hawaii

*Hilo
Honolulu
*Wake Island (Pacific)

82-52 Puerto Rico

San Juan

*5 Year Summary Only

STATUS OF STATE CLIMATOLOGICAL SERVICES*

The National Oceanic and Atmospheric Administration (NOAA) and most of the States have taken steps to ensure continuation of basic climatological services to the user public, now that NOAA's National Weather Service (NWS) State Climatologist program has been terminated.

For its part, NOAA has increased the service capabilities of the Environmental Data Services' National Climatic Center (NCC) and has realigned the climatological service function of NWS. Many States are providing personnel and facilities to carry on some or all of the services previously provided by the State Climatologists.

1. The National Climatic Center

NCC, the collection center and custodian of all United States weather records, has developed special programs to respond to increased user requests. The recently established Information Services Division has been restructured and equipped with an expanded telephone and intercom system to make it possible for NCC climatologists to respond simultaneously to eight user requests.

NCC, located in the Federal Building, Asheville, N. C. 28801, has established a toll free telephone line from the Washington, D. C. Area. The number is 427-7919. NCC's regular numbers are: FTS (704) 254-0683; Commercial (704) 258-2850, Ext. 683.

User requests to NCC should specify the data required, stations or geographical limits involved, desired carrier medium (magnetic tape, punched cards, microforms, hard copy), and other pertinent information such as a description of the problem for which the data are required. NCC personnel and the requester will consult on content and specifications, but nongovernment users who require assistance in specifying their needs or applications of data will be referred to private meteorological consultants.

In addition to the routine climatological service, the NCC, in a cooperative effort with EPA, has developed several computer programs aimed at helping the air pollution engineer or meteorologist. These include stability arrays for use in the Air Quality Display Model (AQDM) and the Climatological Dispersion Model (CDM), mixing height studies, inversion statistics, etc. Tabulations can be prepared for any station for which there is sufficient meteorological data available. All work at NCC is performed on a reimbursable basis. The requester is provided a cost estimate before work begins.

2. National Weather Service

NCC has supported the NWS offices by assembling climatic reference handbooks that are used to respond to user requests. One handbook is located at each of the 300 NWS offices throughout the 50 states. The books contain worldwide, national, and regional, State, district, and local climatic data and provide the on-station NWS meteorologist with reference materials needed to answer local queries.

In addition to standard climatic data, the handbooks also contain resort area climatic summaries, worldwide weather extreme statistics, information on the use of weather records in litigation, monthly ocean and lake temperature averages for selected stations, and the NOAA fee schedule for reproduction of weather records. The handbooks will be updated periodically.

NWS field offices respond to local user requests for climatological data using the handbooks and materials in their files. If the requested materials or information are not available at the office, the requests are forwarded to NCC. If the problem requires analysis or interpretation of the data, the requester will be referred to private consultants.

NWS offices prepare storm data and weekly weather summaries for weekly weather and crop reports like the Weekly Weather and Crop Bulletin published jountly with the Statistical Reporting Service of the U. S. Department of Agriculture.

3. The States

Efforts in the States to ensure continuation of basic climatological services range from assuming the total State Climatologist program, to assuming none of it.

Alaska, Arizona, California, Colorado, Massachusetts, Michigan, Minnesota, New York, Texas, Wisconsin, and Utah have assumed responsibility for the major portion of the State Climatologists program.

Connecticut, Illinois, Indiana, Kansas, Louisiana, Maine, Maryland, Missouri, Nebraska, New Hampshire, North Dakota, Ohio, Oklahoma, Rhode Island, South Dakota, Vermont, and West Virgina have an agency offering some of the services, including public services, previously provided by the State Climatologists.

Alabama, Delaware, Florida, Georgia, Hawaii, Montana, Nevada, New Jersey, Oregon, South Carolina, Tennessee, Virginia, and Wyoming are receiving some materials previously sent to the State Climatologists and are making these materials available to researchers but not the public.

In many States, climatological files are located at (and new materials will be sent to) the State Universities, which will provide service to requesters. Arizona, for example, has established a Laboratory of Climatology at its State University.

In Arkansas, Idaho, Iowa, Kentucky, Mississippi, New Mexico, North Carolina, Pennsylvania, and Washington, as well as the Commonwealth of Puerto Rico, no State action has yet been taken. NWS offices are receiving all the material previously sent to the State Climatologists and are responding to requests that can be answered by material available in the Services Offices.

NOAA hopes that eventually all of the States will will be able to provide climatological services to their residents. For States not able to do this, however, NOAA's NWS field offices and NCC stand ready to provide basic climatological data and information services for the user community.

*This information was provided by Arthur R. Hull, Deputy Director, Environmental Data Service, NOAA, in collaboration with W. D. Bartlett, Richard M. Davis and H. L. Suits as of September, 1975.

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE
Silver Spring, Md. 20910

NATIONAL WEATHER SERVICE OFFICES AND STATIONS

Eighteenth Edition — January 1978

1.0 General: The purposes of this publication are: to list all first- and second-order offices and stations operated by, or under the supervision of, the National Weather Service; to show the type and location of each station; and, to indicate briefly the nature of the observational program provided by each station. ("First-order" refers to a station manned by full-time Weather Service employees; "second-order" refers to all other stations that are supervised by the National Weather Service.)

2.0 Explanation of Entries: The data provided are extracted from the "Station Information File," which is maintained by the Resources Management Staff; the information is supplied by stations on WS Forms A1 and A3. The Resources Management Staff (Wx3) should be advised of any error, by memorandum through the Regional Headquarters or by revised WS Forms A1 or A3 if the station's file copy indicates an error.

2.1 Station Identification and Location Data:

CODE		TYPE OF STATION
10	WSO	- Weather Service Office
20	NC	- National Center
30	FAA	- Federal Aviation Administration
40	WSFO	- Weather Service Forecast Office
60	RFC	- River Forecast Center
70	WSMO	- Weather Service Meteorological Observatory
80	ADMO	- Administrative Office
90	CUA	- Cooperative Upper-Air Unit

01	AMOS	- Automatic Meteorological Observing Station (including full and partial parameter automatic stations)
02	SAWRS	- Supplementary Aviation Weather Reporting Station (SAWRS, SR)
03	B	- Basic Contract Observing Station (Basic, BC)
04	FSS	- Flight Service Station (FSS), FAA
05	TWR/LAWRS	- Control Tower/Limited Aviation Weather Reporting Station (TWR, LAWRS or LWRS), FAA
07	S	- Synoptic Observing Station
08	S/B	- Combined Synoptic and Basic Contract Observing Station
09	CG	- Coast Guard or Marine Reporting Station (MARS)

Examples of some possible combined types are:

11	WSO-AMOS	26	NC/RFC
12	WSO-SAWRS	31	FSS-AMOS
13	WSO-BASIC	32	FSS-SAWRS or TWR/LAWRS-SAWRS
14	WSO-FSS	33	FSS-BASIC or TWR/LAWRS-BASIC
15	WSO-TWR/LAWRS	46	WSFO/RFC
16	WSO-RFC	76	WSMO/RFC

STATION NAME - Where two or more stations are collocated (located in the same building or stations have the same latitude and longitude) and the station "Code" does not identify all stations, the "type" of station is added to the "Name". Example:

Code	Station Name
01	Ft. Dodge - AMOS/SAWRS
11	Valentine - BASIC

AIRPORT NAME - The airport name may not always be repeated if it is identical to the station name.

CALL Letters assigned as location identifiers for Weather Service Offices and Stations.

NO. Refers to the International Index Number.

LAT. Latitude to the nearest whole minute; North, unless South is indicated.

LONG. Longitude to the nearest whole minute; West, unless East is indicated.

ELEV. Elevation to the nearest whole foot.

ELT. Elevation type:

0 = elevation of the station (HP);
1 = elevation of the field (HA), highest usable portion of the landing area of an airport;
2 = elevation of the ground (H) beneath the instrument shelter or the observing station.

2.2 Observational Data:

Synoptic Observations

S - Synoptic (6- and 3-hourly)
0-8 = Number of observations per day

C - Completeness and frequency of reports
1 = Complete all elements coded and reported, daily
2 = Abbreviated, some elements not reported, daily

3 = Complete, seasonal
4 = Abbreviated, seasonal
5 = Complete, encoded from aviation weather report and supplemental information
6 = Abbreviated, encoded from aviation weather report

Aviation Observations, Observations by Marine Reporting Stations, and Observations by Automatic Stations

AV - Number of record observations per day
1 - 24 = Number per day
25 = On call only

F - Frequency during period of day
1 = Consecutive hourly
2 = Not consecutive hours
3 = Two-hourly
4 = Three-hourly
5 = Six-hourly
6 = Consecutive hourly, less than 24 hours, plus 2-, 3- or 6-hourly
7 = Every 20 minutes (by full parameter AMOSs)
9 = Irregular schedule

D - Day-to-Day
1 = Daily
2 = Less than 7 days a week

A - Additive data appended to aviation weather observations at 3- and 6-hourly times
0 - 8 = Number (times) per day
9 = Non-standard format or times
A = Aviation weather reports, not transmitted on aviation weather circuits

T - Time of Transmission
1 = Observation transmitted in regular sequence collection
2 = Observation transmitted in a scan period

Upper-Air

P = Pibal)
W = Rawin)
U = Radiosonde) 1 - 4 = Number per day
L = Low-level soundings)

Radar

RR - Radar Observations from:

Code	Equipment
X1	WSR-1 or 1A
X3	WSR-3
XM	WSR-4
XD	DECCA
X5	WR-100-5 or MR-782
XP	SP1M
XS	Special
57	WSR-57
65	WSR-57M
4C	WSR-74C
4S	WSR-74S
FA	FAA-owned

STATION INVENTORY
FIRST- AND SECOND-ORDER STATIONS

REGION	WSO	WSFO	WSMO	NC/ RFC	WSO/ FSS	WSO/ TWR	WSO/ SAWRS	WSO/ AMOS	WSO/ BASIC	AMOS	WSMO AMOS	CUA	WS/A
0	0	0	0	0	0	0	0	0	0	0	0	13	0
1	48	12	14	4	1	2	0	2	0	3	0	0	56
2	50	13	16	5	1	1	0	2	0	18	0	0	58
3	51	14	6	1	1	1	0	1	1	19	1	0	65
4	44	9	8	3	4	1	2	1	0	10	4	0	49
5	14	3	1	1	3	0	0	1	0	13	0	0	19
6	10	1	1	0	0	1	0	0	0	0	0	0	8
7	1	0	0	0	0	0	0	0	0	0	0	19	0
TOTAL	218	52	46	15	10	6	2	7	1	63	5	32	255

HOURLY OBSERVATIONS TABLE

24-HRLY	167	31	13	2	9	2	0	7	0	43	5	0	226
<24-HRLY	12	0	6	0	1	4	2	0	1	17	0	1	17

REGION	AREA	REGION	AREA
0	Central and South America, and Other	4	Western
1	Eastern	5	Alaska
2	Southern (Virgin Islands, San Juan, and Gulf of Mex.)	6	Pacific
3	Central	7	Mexican, Caribbean, and West Indies

Notes: 1. WSO/AMOS count includes 2 WSO/AMOS/BASIC stations and 1 WSO/AMOS/LAWRS station.
2. AMOS count includes 4 AMOS/BASIC stations, 4 AMOS/SAWRS stations, and 1 AMOS/BASIC/SAWRS station.
3. WS/A indicates the number of Weather Service offices (WSOs, WSFOs, WSMOs, RFCs) located at airports.

Hourly Observations Table: (Aviation observations, CG/MARS observations, and observations by AMOSs)
24-HRLY = Number of stations that take observations 24 hours per day.
<24-HRLY = Number of stations that take observations less than 24 hours per day.
(Stations that are "on call" to take observations are not included.)

STATION INVENTORY
FIRST- AND SECOND-ORDER STATIONS

REGION	FSS	TWR	FSS/ TWR	FSS/ WSMO	FSS/ AMOS	FAA/ BASIC	FAA/ SAWRS	SAWRS	WSMO/ SAWRS	BASIC	SYNOPTIC	SYNOP/ BASIC	MARS	WS/A
0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
1	36	28	0	0	0	0	5	81	0	6	7	1	73	0
2	52	27	2	0	2	4	8	42	0	8	0	0	29	0
3	51	22	0	1	1	2	13	106	1	26	6	1	30	2
4	39	40	0	0	1	3	5	19	1	46	2	0	65	1
5	11	1	0	0	4	0	0	12	0	38	0	0	10	0
6	0	1	0	0	0	0	0	3	0	5	19	2	6	0
7	0	0	0	0	0	0	0	0	0	0	3	0	0	0
TOTAL	189	119	2	1	8	9	31	264	2	129	38	4	213	3
HOURLY OBSERVATIONS TABLE														
24-HRLY	172	24	1	0	8	4	1	2	0	6	0	0	0	0
<24-HRLY	17	93	1	0	0	5	27	142	2	123	2	4	194	2

REGION	AREA	REGION	AREA
0	Central and South America, and Other	4	Western
1	Eastern	5	Alaska
2	Southern (Virgin Islands, San Juan, and Gulf of Mex.)	6	Pacific
3	Central	7	Mexican, Caribbean, and West Indies

Notes:
1. FSS/AMOS count includes 1 AMOS/LAWRS station.
2. FAA/BASIC count includes 2 LAWRS/BASIC and 7 FSS/BASIC stations.
3. FAA/SAWRS count includes 6 TWR/SAWRS, 23 LAWRS/SAWRS, and 2 FSS/SAWRS stations.
4. BASIC count includes 5 BASIC/SAWRS stations.
5. WS/A indicates the number of Weather Service offices (WSOs, WSFOs, WSMOs, RFCs) located at airports.

Hourly Observations Table: (Aviation observations, CG/MARS observations, and observations by AMOSs)
24-HRLY = Number of stations that take observations 24 hours per day.
<24-HRLY = Number of stations that take observations less than 24 hours per day.
(Stations that are "on call" to take observations are not included.)

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
ALABAMA														
ANNISTON	ANB/CALHOUN CO	4	ANB	0	3335	8551	618	0	00	24	11	81	0000	
AUBURN	AUBURN-OPELIKA	2	AUO	0	3237	8526	774	1	00	25	91	0	0000	
AUBURN-ESSC		10	AUBA1	0	3235	8530	652	0	00	0	00	0	0000	
BIRMINGHAM	MUNICIPAL	70	BHM	72228	3334	8645	630	0	41	24	11	81	0001	
BIRMINGHAM		40	BIRA1	0	3327	8651	0	0	00	0,	00	0	0000	
CENTREVILLE		70	CKL	72229	3254	8715	458	0	00	0	00	0	0220	65
DOTHAN	AIRPORT	4	DHN	0	3119	8527	353	0	00	24	11	81	0000	
GADSDEN	MUNICIPAL	2	GAD	0	3358	8605	564	1	00	16	11	2	0000	
HUNTSVILLE	HSV-MADISON CO	10	HSV	72323	3439	8646	644	0	00	24	11	81	0000	4C
MOBILE	AEROSPACE	2	BFM	0	3038	8804	261	0	00	11	11	A0	0000	
MOBILE	MUN BATES FIELD	10	MOB	72223	3041	8815	221	0	41	24	11	81	0000	4C
MOBILE POINT LS		9	8R1	0	3014	8802	18	2	00	4	91	1	0000	
MONTGOMERY	DANNELLY FIELD	10	MGM	72226	3218	8624	202	0	41	24	11	81	0000	4C
MUSCLE SHOALS	AIRPORT	4	MSL	0	3445	8737	562	0	00	24	11	81	0000	
TUSCALOOSA-FSS/BASIC	MUNICIPAL	33	TCL	0	3314	8737	186	0	00	24	11	81	0000	
ALASKA														
ALASKAN STAR	DRILLING RIG HELPT	2	EZR	0	5942	14307	63	0	00	25	91	0	0000	
ANCHORAGE	MERRILL FIELD	4	MRI	0	6113	14950	135	1	00	24	11	1	0000	
ANCHORAGE	INTERNATIONAL	70	ANC	70273	6110	15001	132	0	41	24	11	81	0220	
ANCHORAGE RH		80	ANCA2	0	0	0	0	0	00	0	00	0	0000	
ANCHORAGE-WSFO/RFC		46	ANC	0	6113	14957	0	0	00	0	00	1	0000	
ANGOON		3	AGN	70383	5730	13435	15	2	00	10	11	1	0000	
ANIAK-AMOS/B/SAWRS	AIRPORT	1	ANI	70232	6135	15932	86	0	00	24	71	51	0000	
ANNETTE	ANNETTE ISLAND	10	ANN	70398	5502	13134	110	0	31	18	11	61	0220	
ATTU	CASCO COVE	9	ATU	70409	5250	17311E	70	2	00	8	41	1	0000	
BARROW	W. POST-W. ROGERS	10	BRW	70026	7118	15647	13	0	41	24	11	81	0220	
BARTER ISLAND	AIRPORT	10	BTI	70086	7008	14338	50	0	41	24	11	81	0220	
BETHEL	AIRPORT	10	BET	70219	6047	16148	150	0	41	24	11	81	0220	
BETTLES	AIRPORT	4	BTT	70174	6655	15131	643	0	41	24	11	81	0000	
BIG DELTA-AMOS/FSS	AIRPORT	31	BIG	70267	6400	14544	1274	0	00	24	71	51	0000	
BIG RIVER LAKES		3	5B1	0	6049	15218	40	2	00	14	21	1	0000	
BIORKA ISLAND LN		9	Z21	0	5651	13533	50	2	00	8	41	1	0000	
CAPE DECISION LS		1	CDE	70388	5600	13408	50	0	00	24	71	1	0000	
CAPE HINCHINBROOK LS		1	5HN	70279	6014	14639	185	0	00	24	71	1	0000	
CAPE POLE		3	Z27	0	5558	13348	50	2	00	8	21	1	0000	
CAPE SARICHEF LN	AIRPORT	9	CSH	0	5436	16456	175	0	00	8	41	1	0000	

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
CAPE SPENCER LS		1	CSP	70365	5812	13638	88	0	00	24	71	81	0000	
CAPE ST ELIAS LS		1	SCE	70360	5948	14436	58	0	00	24	71	1	0000	
CHANDALAR LAKE	AIRPORT	3	WCR	0	6730	14829	1920	1	00	7	21	2	0000	
CIRCLE CITY	AIRPORT	3	CRC	0	6551	14405	598	1	00	8	61	1	0000	
COLD BAY	AIRPORT	10	CDB	70316	5512	16243	103	0	41	24	11	81	0220	
CORDOVA	MILE 13	4	CDV	70296	6030	14530	42	0	00	24	11	81	0000	
DEADHORSE	AIRPORT	4	SCC	0	7012	14828	60	0	00	24	81	1	0000	
DILLINGHAM-AMOS/FSS	AIRPORT	31	DLG	70321	5903	15831	95	0	00	24	71	61	0000	
DOLLY VARD. PLATFORM		9	Z56	0	6048	15138	100	0	00	2	90	0	0000	
DUTCH HARBOR	AIRPORT	3	DUT	70489	5354	16632	12	1	00	10	61	2	0000	
ELDRED ROCK		1	ERO	70364	5858	13513	55	0	00	24	71	1	0000	
ELFIN COVE		3	ELV	0	5812	13640	20	2	00	10	61	1	0000	
EMMONAK	AIRPORT	3	ZZD	0	6246	16431	10	1	00	10	61	1	0000	
FAIRBANKS-WSFO		40	FAI	0	6450	14742	0	0	00	0	00	0	0000	
FAIRBANKS-WSO	INTERNATIONAL	10	FAI	70261	6449	14752	454	0	41	24	11	81	0220	
FAREWELL	AIRPORT	4	FWL	70248	6230	15353	1503	0	00	8	12	31	0000	
FIVE FINGER LS		9	FIV	70385	5716	13337	35	0	00	10	21	2	0000	
FIVE MILE (CAMP)	FIVE MILE CAMP	2	FVM	0	6556	14950	509	1	00	11	11	1	0000	
FT. YUKON-AMOS/BASIC	AIRPORT	1	FYU	70194	6634	14516	431	0	00	24	71	1	0000	
FUNTER BAY		3	FNR	0	5815	13454	5	2	00	8	21	11	0000	
GALBRAITH		2	GBH	0	6829	14929	2661	1	00	11	11	2	0000	
GAMBELL	AIRPORT	2	GAM	0	6346	17145	31	0	00	25	92	2	0000	
GULKANA-AMOS/FSS	INTERMEDIATE FD	31	GKN	70271	6209	14527	1579	0	00	24	71	51	0000	
GUSTAVUS	AIRPORT	3	GST	70367	5825	13544	29	0	00	10	21	1	0000	
HAINES		3	Z26	0	5914	13526	31	2	00	8	21	1	0000	
HAPPY VALLEY CAMP	HAPPY VALLEY	2	HVY	0	6910	14850	938	1	00	11	11	1	0000	
HAYES RIVER		3	5HR	0	6159	15205	1000	2	00	10	21	1	0000	
HEALY		3	5EA	0	6353	14901	1475	2	00	10	11	1	0000	
HOMER	MUNICIPAL	14	HOM	70341	5938	15130	73	0	11	24	11	81	0000	
ILIAMNA-AMOS/FSS	AIRPORT	31	ILI	70340	5945	15455	160	0	00	24	71	31	0000	
JOHNSTONE POINT		3	JOH	0	6029	14636	25	2	00	3	22	1	0000	
JUNEAU-WSFO		40	JNU	0	5818	13425	0	0	00	0	00	0	0000	
JUNEAU-WSO	MUNICIPAL	10	JNU	70381	5822	13435	24	0	41	24	11	81	0000	
KAKE		3	KAE	0	5658	13357	30	2	00	8	61	1	0000	
KENAI	MUNICIPAL	4	ENA	70259	6034	15115	95	0	00	24	11	81	0000	
KETCHIKAN	INTERNATIONAL	4	KTN	70395	5521	13142	96	0	00	24	11	1	0000	
KING SALMON	AIRPORT	10	AKN	70326	5841	15639	49	0	41	24	11	81	0220	
KODIAK	AIRPORT	10	ADQ	70350	5745	15230	111	0	41	24	11	81	0220	
KOTZEBUE	RALPH WIEN	14	OTZ	70133	6652	16238	16	0	31	24	11	81	0220	
LAZY MOUNTAIN		3		0	6138	14902	790	2	00	3	11	11	0000	
LEVEL ISLAND		3	LVD	0	5628	13306	30	0	00	8	21	1	0000	
LONELY		2	LNI	0	7055	15315	22	0	00	13	11	1	0000	
MANLEY HOT SPRINGS	AIRPORT	3	MLY	70179	6500	15039	280	0	00	10	61	1	0000	
MCCARTHY	AIRPORT	3	MXY	0	6126	14255	1531	1	00	13	61	21	0000	
MCGRATH	AIRPORT	10	MCG	70231	6258	15537	338	0	41	24	11	81	0220	

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
MIDDLETON IS		1	MDO	70343	5926	14620	45	0	00	24	71	1	0000	
MINCHUMINA	AIRPORT	3	MHM	70246	6354	15216	701	0	00	12	21	31	0000	
NENANA	MUNICIPAL	1	ENN	70260	6433	14905	360	1	00	24	71	1	0000	
NIKOLSKI		1	IKO	70482	5257	16851	710	2	00	24	71	1	0000	
NOME	MUNICIPAL	10	OME	70200	6430	16526	22	0	41	24	11	81	0220	
NORTHWAY	AIRPORT	4	ORT	70291	6258	14156	1721	0	00	24	11	81	0000	
OCEAN BOUNTY		2	OBY	0	5951	14217	75	1	00	16	11	1	0000	
OCEAN CAPE LN		9	50C	0	5931	13946	0	0	00	25	91	0	0000	
OCEAN RANGER	DRIL. PLATF. HELIPAD	2	OCV	0	5931	15239	83	2	00	13	11	1	0000	
PALMER	MUNICIPAL	4	PAQ	70274	6136	14905	232	1	00	8	11	31	0000	
PAXSON	PAXSON FIELD	3	5PX	0	6302	14530	2700	2	00	10	61	11	0000	
PETERSBURG	AIRPORT	3	PSG	70386	5648	13257	107	1	00	12	11	1	0000	
PHILLIPS PLATFORM		9	Z69	0	6104	15057	105	2	00	2	91	0	0000	
PLATFORM DILLON		9	Z72	0	6044	15131	0	0	00	2	91	0	0000	
POINT RETREAT		1	PRT	0	5825	13457	20	0	00	24	71	0	0000	
PORT ALSWORTH		3	Z30	0	6012	15418	260	2	00	13	21	11	0000	
PORT CLARENCE LN		9	KPC	70119	6515	16652	18	0	00	8	21	61	0000	
PROSPECT CREEK	AIRPORT	2	PPC	0	6649	15039	1099	1	00	11	11	1	0000	
PRUDHOE BAY	AIRPORT	2	PUO	0	7015	14820	41	0	00	12	11	1	0000	
PT HEIDEN-AMOS/BASIC	AIRPORT	1	PTH	70333	5657	15837	95	1	00	24	71	1	0000	
PUNTILLA		3	PTI	70249	6206	15245	1837	1	00	11	61	1	0000	
RUBY		3	RBY	0	6445	15529	200	2	00	10	11	1	0000	
SAVOONGA	AIRPORT	2	SVA	0	6342	17028	53	1	00	25	92	1	0000	
SEWARD		3	SWD	70277	6007	14927	60	0	00	14	21	1	0000	
SISTERS ISLAND		3	SSR	0	5810	13515	35	2	00	9	11	1	0000	
SITKA	AIRPORT	4	SIT	70371	5704	13521	67	0	00	24	11	81	0000	
SKAGWAY	AIRPORT	3	SGY	70362	5928	13518	18	0	00	10	61	41	0000	
SKWENTNA	AIRPORT	3	SKW	70255	6158	15112	158	0	00	10	61	11	0000	
SLANA		3	5SZ	0	6242	14359	2191	2	00	16	11	31	0000	
SNOWSHOE LAKE		3	5SO	0	6202	14640	2410	0	00	3	21	1	0000	
ST MARY'S	AIRPORT	2	KSM	0	6204	16318	311	1	00	25	91	0	0000	
ST PAUL ISLAND	AIRPORT	10	SNP	70308	5709	17013	28	0	41	24	11	81	0220	
SUMMIT	AIRPORT	1	UMM	70264	6320	14908	2409	1	00	24	71	41	0000	
SUTTON 2 EAST		3		0	6143	14850	500	2	00	6	61	22	0000	
TALKEETNA	AIRPORT	14	TKA	70251	6218	15006	356	0	22	13	61	81	0000	
TANANA	RALPH M CALHOUN MEML	4	TAL	70178	6510	15206	220	0	00	16	11	51	0000	
TOK LN		9	Z12	0	6319	14243	1645	1	00	5	61	21	0000	
UMIAT-BASIC/SAWRS	AIRPORT	3	UMT	70162	6922	15208	265	1	00	15	21	21	0000	
UNALAKLEET	AIRPORT	11	UNK	70207	6353	16048	21	0	31	24	71	61	0000	
VALDEZ		10	VWS	70275	6108	14621	31	0	41	24	11	81	0000	
VALDEZ	MUNICIPAL	5	VDZ	0	6108	14615	111	1	00	9	11	1	0000	
WALES	AIRPORT	3	WAA	70116	6537	16803	17	0	00	3	21	1	0000	
WHITTIER		3	5WT	0	6046	14841	153	0	00	24	11	21	0000	
WILLOW	AIRPORT	3	Z22	0	6145	15003	220	1	00	12	61	21	0000	
WRANGELL	AIRPORT	3	WRG	70387	5629	13222	43	0	00	24	11	1	0000	

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
YAKATAGA	INTERMEDIATE	3	CYT	70298	6005	14230	35	0	00	10	61	51	0000	
YAKUTAT	STATE	10	YAK	70361	5931	13940	31	0	41	24	11	81	0220	
ARIZONA														
DEER VALLY-PHOENIX	MUNICIPAL	5	DVT	0	3341	11205	1540	0	00	16	11	0	0000	
DOUGLAS	BISBEE-DUG INTNL	4	DUG	0	3128	10936	4107	0	00	24	11	81	0000	
FLAGSTAFF	PULLIAM	10	FLG	0	3508	11140	7018	0	00	24	11	81	0000	
GOODYEAR	PHOENIX-LITCHFIELD	5	GYR	0	3325	11223	968	0	00	17	11	0	0000	
GRAND CANYON-LAWR/SR	NATIONAL PARK	32	GCN	0	3557	11209	6621	0	00	11	11	1	0000	
KINGMAN	MOJAVE COUNTY	1	IGM	72370	3516	11357	3389	0	00	24	71	81	0000	
LAKE HAVASU CITY	AIRPORT	2	LHU	0	3427	11422	482	1	00	1	00	22	0000	
PAGE-AMOS/SAWRS	AIRPORT	1	PGA	72371	3656	11127	4279	0	00	24	71	2	0000	
PAYSON		3	0E4	0	3414	11120	4913	2	00	7	21	22	0000	
PHOENIX	SKY HARBOR INTNL	40	PHX	72278	3326	11201	1107	0	41	24	11	81	0000	4C
PRESCOTT	MUNICIPAL	4	PRC	0	3439	11226	5052	0	00	24	11	81	0000	
SAFFORD		3	E74	0	3249	10941	2954	2	00	5	21	22	0000	
SCOTTSDALE	MUNICIPAL	5	SDL	0	3337	11155	1479	1	00	17	11	0	0000	
SHOWLOW		3	E03	0	3415	11002	6440	0	00	5	21	2	0000	
TUCSON	INTERNATIONAL	10	TUS	72274	3207	11056	2555	0	41	24	11	81	0220	
WINSLOW	MUNICIPAL	10	INW	72374	3501	11044	4883	0	41	24	11	80	0220	
YUMA	INTERNATIONAL	14	YUM	72280	3239	11436	206	0	31	24	11	81	0000	
ARKANSAS														
EL DORADO	MUNICIPAL	4	ELD	0	3313	9248	285	0	00	24	11	81	0000	
FAYETTEVILLE	DRAKE	4	FYV	0	3600	9410	1259	0	00	24	11	81	0000	
FT SMITH	MUNICIPAL	10	FSM	72344	3520	9422	463	0	41	24	11	81	0000	4C
HARRISON	BOONE COUNTY	4	HRO	0	3616	9309	1385	0	00	24	11	81	0000	
HOT SPRINGS	MEMORIAL	5	HOT	0	3429	9306	555	0	00	17	11	1	0000	
JONESBORO-FSS/BC	MUNICIPAL	33	JBR	0	3550	9039	274	0	00	24	11	81	0000	
LITTLE ROCK	NORTH LITTLE ROCK	40	1M1	72340	3450	9215	542	0	41	0	00	0	0220	57
LITTLE ROCK	ADAMS FIELD	4	LIT	0	3444	9214	257	0	00	24	11	81	0000	
PINE BLUFF-FSS-LAWRS	GRIDER FIELD	35	PBF	0	3410	9156	214	0	00	17	11	11	0000	
TEXARKANA	MUNICIPAL WEBB FIELD	5	TXK	0	3327	9400	399	0	00	24	11	41	0000	
WEST MEMPHIS	MUNICIPAL	5	AWM	0	3508	9014	212	1	00	17	11	0	0000	
CALIFORNIA														

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
ANACAPA ISLAND		9	L46	0	3401	11922	139	2	00	3	41	0	0000	
ARCATA	AIRPORT	4	ACV	0	4059	12406	225	0	00	24	11	81	0000	
BAKERSFIELD	MEADOWS FIELD	14	BFL	72384	3525	11903	492	0	21	24	11	81	0000	
BEAUMONT		3	BUO	0	3356	11657	2600	2	00	7	21	31	0000	
BISHOP	AIRPORT	12	BIH	72480	3722	11822	4145	0	00	14	11	51	0000	
BLUE CANYON	AIRPORT	71	BLU	0	3917	12042	5283	0	00	24	71	31	0000	
BLUNTS REEFS		1	84Q	0	4026	12430	0	0	00	25	91	0	0000	
BLYTHE	RIVERSIDE CO	4	BLH	0	3337	11443	392	0	00	24	11	81	0000	
BODEGA BAY		9	92Q	0	3319	12303	10	2	00	8	40	0	0000	
BURBANK	HOLLYWOOD-BUR	5	BUR	0	3412	11822	775	0	00	24	11	1	0000	
BURNEY		3	BNY	0	4053	12140	3141	0	00	1	91	2	0000	
CABRILLO BEACH		9	L14	0	3343	11817	25	0	00	2	91	0	0000	
CAMPO		3	CZZ	0	3237	11628	2630	2	00	6	21	22	0000	
CARLSBAD	PALOMAR	5	CRQ	0	3308	11717	328	1	00	16	11	0	0000	
CHICO-LAWRS/SAWRS	MUNICIPAL	32	CIC	0	3948	12151	272	0	00	14	11	2	0000	
CHINO	AIRPORT	5	CNO	0	3358	11738	692	0	00	17	11	A0	0000	
CONCORD	BUCHANAN FD	5	CCR	0	3759	12203	60	0	00	17	11	2	0000	
CRESCENT CITY-FSS/BC	MCNAMARA	33	CEC	0	4147	12414	57	0	00	19	21	81	0000	
DAGGETT	SAN BERNARDINO CO	4	DAG	0	3452	11647	1929	0	00	24	11	81	0000	
DAVIS POINT		9	52Q	0	3803	12216	60	2	00	25	90	0	0000	
EL MONTE	AIRPORT	5	EMT	0	3406	11802	330	0	00	17	11	A0	0000	
EL MONTE-EMSU	AIRPORT	72	EMT	74704	3405	11802	295	0	00	5	22	10	0002	
EUREKA		10	EKA	72594	4048	12410	60	0	41	0	00	0	0000	
FARALLON IS LS		9	50Q	0	3742	12300	30	0	00	3	90	30	0000	
FRESNO	FCH-CHANDLER DOWNTWN	5	FCH	0	3644	11949	278	1	00	17	11	1	0000	
FRESNO	AIR TERMINAL	10	FAT	72389	3646	11943	327	0	41	24	11	81	0000	
FULLERTON	MUNICIPAL	5	FUL	0	3352	11758	96	1	00	17	11	2	0000	
HAWTHORNE	MUNICIPAL	5	HHR	0	3355	11820	63	0	00	17	11	2	0000	
HAYWARD	AIR TERMINAL	5	HWD	0	3739	12207	47	1	00	17	11	2	0000	
HERMOSA BEACH		9	4L7	0	3552	11824	25	0	00	4	21	0	0000	
HUMBOLDT BAY		9	88Q	0	4046	12414	10	2	00	8	40	0	0000	
HUNTINGTON BEACH		9	6L9	0	3339	11800	118	0	00	2	31	0	0000	
IMPERIAL	COUNTY	4	IPL	0	3250	11534	48	0	00	24	11	81	0000	
INYOKERN	KERN CO NO 8	2	IYK	0	3540	11750	2426	0	00	25	11	A2	0000	
LANCASTER	WM. J. FOX	4	WJF	0	3444	11813	2347	0	00	24	11	81	0000	
LAVERNE	BRACKETT FIELD	5	POC	0	3406	11747	1000	1	00	16	11	A0	0000	
LIVERMORE	MUNICIPAL	5	LVK	0	3742	12149	397	0	00	15	11	2	0000	
LONG BEACH	LBARPT-DAUGHERTY	10	LGB	72297	3349	11809	40	0	00	24	11	81	0000	
LONG BEACH		9	L97	0	3245	11825	78	0	00	8	41	0	0000	
LOS ANGELES-WSFO		40	LAXC1	0	3403	11827	310	1	00	0	00	0	0000	
LOS ANGELES-WSO	INTERNATIONAL	10	LAX	72295	3356	11824	104	0	82	24	11	81	0002	4C
MAMMOTH LAKES	AIRPORT	2	MMH	0	3738	11851	7128	0	00	25	90	A0	0000	
MARINA DEL REY		9	2L6	0	3358	11826	10	0	00	2	21	0	0000	
MARYSVILLE	YUBA CO	4	MYV	0	3906	12134	73	0	00	24	11	81	0000	
MERCED	MUNICIPAL	5	MCE	0	3717	12031	153	1	00	13	11	A0	0000	

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
MISSION BEACH		9	L58	0	3246	11714	35	0	00	1	01	0	0000	
MODESTO-LAWRS/SAWRS	HARRY SHAM FIELD	32	MOD	0	3738	12057	140	0	00	19	11	2	0000	
MONTAGUE	SISKIYOU CO	4	SIY	0	4147	12228	2655	0	00	19	11	21	0000	
MONTEREY	MRY PENINSULA	5	MRY	0	3635	12151	220	0	00	24	11	1	0000	
MOSS LANDING		9	54Q	0	3648	12148	16	2	00	6	40	0	0000	
MT SHASTA		11	MHS	0	4119	12219	3587	0	00	24	71	31	0000	
MT WILSON		3	MWS	72289	3414	11804	5707	2	01	4	21	41	0000	
NAPA	COUNTY	5	APC	0	3813	12217	56	0	00	17	11	2	0000	
NEEDLES	AIRPORT	4	EED	0	3446	11437	887	0	00	8	11	31	0000	
NEEDLES		3	4ED	0	3450	11436	550	0	00	8	61	61	0000	
NEWPORT BEACH		9	3L3	0	3336	11753	10	0	00	5	41	0	0000	
OAKLAND-UAU	INTERNATIONAL	70	OAK	72493	3745	12213	18	0	00	0	00	0	0220	
OAKLAND-WSO/FSS	METROP OAK INTNL	14	OAK	72493	3744	12212	7	0	00	24	11	81	0000	
OCEANSIDE HARBOR		9	L34	0	3313	11724	30	0	00	3	41	2	0000	
ONTARIO	INTERNATIONAL	4	ONT	0	3403	11737	960	0	00	24	11	81	0000	
OXNARD	VENTURA CO	5	OXR	0	3412	11912	43	1	00	17	11	A1	0000	
OXNARD (CHANNEL IS)		9	L79	0	3410	11913	8	0	00	3	61	0	0000	
PALM SPRINGS	MUNICIPAL	5	PSP	0	3350	11630	480	0	00	17	11	2	0000	
PALMDALE	AIRPORT	5	PMD	0	3438	11805	2538	0	00	18	11	0	0000	
PALMDALE-RADAR		10	PMD	72382	3436	11805	2549	2	00	0	00	0	0000	FA
PALO ALTO	AIRPORT	5	PAO	0	3728	12207	2	1	00	17	11	A0	0000	
PASO ROBLES	COUNTY	4	PRB	0	3540	12038	817	0	00	24	11	81	0000	
PIGEON POINT LS		1	93Q	0	3711	12224	0	0	00	8	41	0	0000	
PILLAR POINT		9	53Q	0	3730	12230	130	2	00	8	40	0	0000	
POINT ARENA LS		9	89Q	0	3857	12344	63	0	00	8	40	0	0000	
POINT BLUNT LS		9	91Q	0	3751	12225	240	1	00	5	90	1	0000	
POINT BONITA LS		9	94Q	0	3749	12232	0	0	00	8	40	0	0000	
POINT LOMA		9	L13	0	3240	11729	364	2	00	3	40	0	0000	
PORT CHICAGO		9	99Q	0	3802	12202	10	2	00	8	41	0	0000	
PT ARGUELLO LN		9	L96	0	3434	12040	76	2	00	8	40	0	0000	
PT PIEDRAS BLANCAS		1	87Q	72390	3540	12117	69	0	00	24	71	2	0000	
PT. PINOS (REMOTED)		9	95Q	0	3638	12156	20	2	00	8	40	1	0000	
RED BLUFF	MUNICIPAL	14	RBL	72591	4009	12215	353	0	72	24	11	81	0000	
REDDING-LAWRS/SAWRS	MUNICIPAL	32	RDD	0	4030	12218	536	1	00	16	11	1	0000	
REDDING-WSO/FW		10	FRDC1	0	0	0	0	0	00	0	00	0	0000	
RIO VISTA		9	98Q	0	3809	12142	0	0	00	4	40	0	0000	
RIVERSIDE	MUNICIPAL	5	RAL	0	3357	11727	816	1	00	16	11	A0	0000	
RIVERSIDE-WSO/AG		10	RIVC1	0	3358	11720	1082	1	00	0	00	0	0000	
SACRAMENTO	METROPOLITAN	5	SMF	0	3842	12136	33	0	00	24	11	1	0000	
SACRAMENTO	EXECUTIVE	4	SAC	72483	3831	12130	25	0	00	24	11	80	0000	
SACRAMENTO-WSO/RFC		16	SACC1	0	3835	12130	25	1	00	0	00	0	0000	57
SALINAS	MUNICIPAL	4	SNS	0	3640	12136	77	0	00	24	11	81	0000	
SAN CARLOS	AIRPORT	5	SQL	0	3731	12215	2	1	00	17	11	A0	0000	
SAN DIEGO	BROWN	3	SDM	0	3234	11659	524	1	00	12	11	A0	0000	
SAN DIEGO	INTL LINBERGH FIELD	10	SAN	0	3244	11710	28	0	00	24	11	81	0000	

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
SAN DIEGO	GILLESPIE	5	SEE	0	3249	11658	437	0	00	16	11	2	0000	
SAN DIEGO	MONTGOMERY FIELD	70	MYF	72290	3249	11708	408	0	41	0	00	11	0220	
SAN DIEGO	MONTGOMERY FIELD	3	MYF	0	3249	11709	417	1	00	16	11	A0	0000	
SAN FRANCISCO (PBS)		9	51Q	0	3745	12241	15	2	00	8	40	0	0000	
SAN FRANCISCO-WSFO		40	RDWC1	0	3729	12212	4	2	00	0	00	0	0000	
SAN FRANCISCO-WSO	INTERNATIONAL	10	SFO	72494	3737	12223	18	0	41	24	11	81	0000	
SAN JOSE	REID/HILLVIEW	5	RHV	0	3720	12149	133	1	00	17	11	A0	0000	
SAN JOSE	MUNICIPAL	5	SJC	0	3722	12156	56	1	00	24	11	1	0000	
SAN LUIS OBISPO	COUNTY	2	SBP	0	3514	12038	208	1	00	7	91	A0	0000	
SAN MATEO LN		9	L98	0	3323	11735	76	2	00	8	40	0	0000	
SAN PEDRO		2	4SP	0	3345	11816	15	0	00	25	90	0	0000	
SANDBERG		71	SDB	72383	3445	11844	4523	0	25	24	71	31	0000	
SANTA ANA	ORANGE COUNTY	5	SNA	0	3341	11752	54	1	00	18	11	2	0000	
SANTA BARBARA	MUNICIPAL	4	SBA	0	3426	11950	20	0	00	24	11	81	0000	
SANTA BARBARA HARBOR		9	P44	0	3425	11942	27	0	00	8	41	0	0000	
SANTA CATALINA	CATALINA	3	AVX	0	3324	11825	1580	0	00	4	21	2	0000	
SANTA CATALINA	PEE BEACH SEAP BASE	2	LII	0	3320	11819	20	2	00	25	21	22	0000	
SANTA CATALINA IS		9	L27	0	3320	11820	10	2	00	3	21	0	0000	
SANTA CRUZ		9	85Q	0	3658	12200	0	0	00	3	40	0	0000	
SANTA MARIA	PUBLIC	12	SMX	72394	3454	12027	238	0	21	19	11	31	0000	
SANTA MONICA	MUNICIPAL	5	SMO	0	3401	11827	175	1	00	17	11	2	0000	
SANTA MONICA PIER		9	1L2	0	3400	11829	15	0	00	3	41	0	0000	
SANTA ROSA	SONOMA COUNTY	5	STS	0	3831	12249	148	0	00	17	11	2	0000	
SCRIPPS PIER		9	L21	0	3252	11715	15	0	00	1	61	0	0000	
SHELTER COVE		3	087	0	4002	12404	403	2	00	4	21	41	0000	
SOUTH LAKE TAHOE	LAKE TAHOE	5	TVL	0	3854	12000	6273	0	00	17	11	12	0000	
STOCKTON	METROPOLITAN	10	SCK	72492	3754	12115	27	0	41	24	11	81	0000	
SUSANVILLE	MUNICIPAL	3	SVE	0	4023	12034	4199	0	00	5	21	1	0000	
TAHOE CITY		9	Q67	0	3911	12007	6233	2	00	25	90	0	0000	
TERMINAL ISLAND		9	L82	0	3344	11816	33	0	00	8	41	0	0000	
THERMAL	AIRPORT	4	TRM	0	3338	11610	112	0	00	24	11	80	0000	
TORRANCE	MUNICIPAL	5	TOA	0	3348	11820	101	1	00	15	11	2	0000	
TRINIDAD HEAD		1	96Q	0	4103	12409	358	2	00	25	91	0	0000	
TRUCKEE	TRUCKEE-TAHOE	3	4TA	0	3919	12008	5897	0	00	5	21	2	0000	
UKIAH	MUNICIPAL	4	UKI	0	3908	12312	620	0	00	24	11	81	0000	
VAN NUYS	AIRPORT	5	VNY	0	3413	11829	799	1	00	24	11	1	0000	
VANDENBERG AFB		70	VBG	72393	3445	12034	325	0	00	0	00	0	0220	
VENTURA HARBOR		9	P43	0	3415	11915	24	0	00	8	41	0	0000	
VISALIA	MUNICIPAL	2	VIS	0	3619	11924	292	1	00	13	11	2	0000	
ZUMA BEACH		9	OL3	0	3401	11849	20	0	00	3	41	0	0000	

COLORADO

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
AKRON	WASHINGTON COUNTY	4	AKO	0	4010	10313	4621	0	00	24	11	81	0000	
ALAMOSA	MUNICIPAL	13	ALS	72462	3727	10552	7541	0	00	21	11	71	0000	
ASPEN		3	3V9	0	3917	10652	7446	0	00	6	41	20	0000	
ASPEN-LAWRS/SAWRS	SARDY FLD	32	ASE	0	3913	10652	7742	0	00	16	21	1	0000	
BROOMFIELD	JEFFERSON COUNTY	5	BJC	0	3954	10507	5648	1	00	17	11	A0	0000	
COLORADO SPRINGS	MUNICIPAL	10	COS	72466	3849	10443	6170	0	00	24	11	81	0000	
CORTEZ	MONTEZUMA COUNTY	2	CEZ	0	3718	10838	5914	1	00	15	11	2	0000	
CRAIG		1	2V0	72570	4030	10732	6191	0	00	24	71	0	0000	
DENVER	STAPLETON INTNL	40	DEN	72469	3945	10452	5332	0	41	24	11	81	0220	
DURANGO		3	4V5	0	3717	10752	6600	0	00	5	21	2	0000	
DURANGO	DRO-LA PLATO CO	2	DRO	0	3709	10745	6884	1	00	17	11	2	0000	
EAGLE	COUNTY	4	EGE	0	3939	10655	6513	0	00	24	11	81	0000	
ENGLEWOOD	ARAPAHOE COUNTY	5	APA	0	3934	10450	5872	0	00	17	11	2	0000	
FRASER		3	4FC	0	3957	10550	8560	2	00	12	31	41	0000	
FT COLLINS		3	FCL	0	4035	10505	5004	0	00	13	31	41	0000	
GRANBY	GRAND COUNTY	2	GNB	0	4005	10555	8220	2	00	25	90	A0	0000	
GRAND JUNCTION	WALKER FIELD	10	GJT	72476	3907	10832	4839	0	41	24	11	81	0220	
GUNNISON	COUNTY	2	GUC	0	3833	10655	7668	0	00	11	11	2	0000	
GUNNISON		3	2V9	0	3833	10656	7707	0	00	9	21	22	0000	
HAYDEN	YAMPA VALLEY	2	HDN	0	4030	10715	6600	2	00	8	11	2	0000	
LA JUNTA	MUNICIPAL	4	LHX	0	3803	10331	4215	0	00	24	11	81	0000	
LAMAR		3	4LJ	0	3807	10236	3620	0	00	8	41	82	0000	
LAMAR	MUNICIPAL	2	LAA	0	3804	10241	3703	1	00	4	11	A0	0000	
LEADVILLE		3	LXV	0	3913	10618	10060	0	00	8	41	42	0000	
LIMON		70	LIC	0	3911	10342	5562	0	00	8	41	82	0000	65
MONTROSE		3	6V8	0	3830	10754	5669	0	00	6	21	12	0000	
MONTROSE	COUNTY	2	MTJ	0	3830	10753	5759	1	00	14	11	2	0000	
PUEBLO	MEMORIAL	10	PUB	72464	3817	10431	4720	0	41	24	11	81	0000	
RIFLE		3	1V1	0	3932	10748	5400	2	00	8	41	41	0000	
SALIDA	HARRIET ALEXANDER	3	0V2	0	3832	10603	7488	0	00	12	31	42	0000	
STEAMBOAT SPRINGS	MUNICIPAL	2	SBS	0	4031	10652	6879	1	00	25	90	A0	0000	
STERLING	CROSSON FIELD	2	STK	0	4037	10316	4037	1	00	25	91	0	0000	
TRINIDAD	LAS ANIMAS CO	4	TAD	0	3715	10420	5743	0	00	24	11	81	0000	
CONNECTICUT														
BLOOMFIELD		60	HFDC3	0	4150	7244	58	2	00	0	00	C	0000	
BRIDGEPORT	IGOR I SIKORSKY MEM	10	BDR	72504	4110	7308	17	0	41	24	11	41	0000	
CHESTER	AIRPORT	2	3B9	0	4123	7230	409	1	00	3	21	A0	0000	
DANBURY	MUNICIPAL	5	DXR	0	4122	7329	437	0	00	17	11	2	0000	
EAST HARTFORD	RENTSCHLER	2	EHT	0	4145	7237	88	0	00	17	11	A0	0000	
GROTON-LAWRS/SAWRS	TRUMBULL	32	GON	0	4120	7203	20	0	00	17	11	2	0000	
HARTFORD-TWR/SAWRS	HARTFORD-BRAINARD	32	HFD	C	4144	7239	35	C	00	17	10	1	0000	

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
HARTFORD-WSO	BRADLEY INTNL	10	BDL	72508	4156	7241	179	0	41	24	11	41	0000	40
LITTLE GULL IS LS		9	32N	0	4112	7206	20	0	00	8	40	0	0000	
MERIDEN	MRDN-MARKHAM MUN	2	4B4	0	4131	7250	102	0	00	3	21	A0	0000	
NEW HAVEN		9	N11	0	4116	7254	9	2	00	8	41	0	0000	
NEW HAVEN	TWEED NEW HAVEN	5	HVN	0	4116	7253	13	0	00	19	11	1	0000	
NEW LONDON LEDGE LS		9	18N	0	4118	7205	25	0	00	8	40	0	0000	
OXFORD	WATERBURY-OXFORD	2	OXC	0	4129	7308	727	1	00	16	11	A0	0000	
STRATFORD	SIKORSKY AIR. HELPT.	2	JSD	0	4115	7305	85	0	00	10	61	0	0000	
DELAWARE														
GEORGETOWN	GEORGETOWN	2	GED	0	3842	7522	51	0	00	0	00	0	0000	
INDIAN RIVER		9	61N	0	3837	7504	0	0	00	8	40	0	0000	
WILMINGTON	GREATER	10	ILG	0	3940	7536	80	0	00	24	11	81	0000	
FLORIDA														
APALACHICOLA	MUNICIPAL	10	AQQ	72220	2944	8502	20	0	00	8	42	81	0220	57
BARTOW	MUNICIPAL	2	BOW	0	2757	8147	126	0	00	10	11	2	0000	
CAPE SAN BLAS LN		9	1J4	0	2941	8522	6	2	00	8	41	1	0000	
CEDAR KEY		1	CDKF1	0	2909	8303	5	2	00	8	41	1	0000	
CRESTVIEW	BOB SIKES	4	CEW	0	3047	8631	185	0	00	24	11	1	0000	
CROSS CITY	AIRPORT	1	CTY	72212	2937	8306	42	0	00	24	71	1	0000	
DAYTONA BEACH	REGIONAL	10	DAB	0	2911	8103	41	0	00	24	11	81	0000	57
DESTIN		1	DSTF1	0	3023	8627	17	2	00	8	41	0	0000	
DRY TORTUGAS LS		9	X85	0	2438	8255	4	2	00	8	41	0	0000	
EGMONT KEY LS		9	X91	0	2736	8246	5	2	00	4	41	1	0000	
FT LAUDERDALE	EXECUTIVE	5	FXE	0	2612	8010	14	1	00	17	11	A0	0000	
FT LAUDERDALE	FLL-HOLLYWD INTL	5	FLL	0	2604	8009	10	0	00	24	11	1	0000	
FT MEYERS FSS	PAGE FIELD	4	FMY	0	2635	8152	12	0	00	24	11	81	0000	
FT MEYERS-WSO		10	FMY	0	2639	8152	12	0	00	0	00	0	0000	
FT. PIERCE		9	X82	0	2728	8018	25	0	00	8	41	1	0000	
GAINESVILLE	MUNICIPAL	4	GNV	0	2941	8216	165	0	00	24	11	81	0000	
HOLLYWOOD	NORTH PERRY	5	HWO	0	2600	8014	9	1	00	17	11	A0	0000	
ISLAMORADA		9	X84	0	2457	8035	5	2	00	8	41	0	0000	
JACKSONVILLE	INTERNATIONAL	10	JAX	72206	3030	8142	31	0	41	24	11	81	0000	
JACKSONVILLE	CRAIG FIELD	4	CRG	0	3020	8131	41	1	00	24	11	A1	0000	
KEY WEST	INTERNATIONAL	10	EYW	72201	2433	8145	21	0	41	24	11	81	0220	57
LAKE WORTH INLET		9	X81	0	2646	8003	3	2	00	8	41	1	0000	
LAKELAND-WSO/AG		10	LAL	0	2802	8157	227	0	00	0	02	0	0000	
MARATHON		9	X88	0	2443	8107	0	0	00	8	41	1	0000	

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
MARATHON	AIRPORT	2	MTH	0	2443	8105	8	0	00	3	41	0	0000	
MARCO ISLAND	AIRPORT	2	X94	0	2560	8140	7	0	00	3	21	0	0000	
MELBOURNE	REGIONAL	4	MLB	0	2806	8038	27	0	00	24	11	1	0000	
MIAMI	DADE-COLLIER	5	TNT	0	2552	8054	10	0	00	10	11	A0	0000	
MIAMI	NEW TAMIAMI	4	TMB	0	2539	8026	10	1	00	24	11	A0	0000	
MIAMI	OPA LOCKA	5	OPF	0	2554	8017	9	1	00	18	11	A0	0000	
MIAMI-NHC/WSFO		20	MIAF1	0	2543	8017	65	0	00	0	00	10	0000	57
MIAMI-WSMO	INTERNATIONAL	70	MIA	72202	2549	8017	12	0	41	24	11	81	0000	
NAPLES	MUNICIPAL	2	APF	0	2609	8147	8	0	00	7	31	0	0000	
ORLANDO	INTERNATIONAL	10	MCO	72205	2826	8119	106	0	41	24	11	81	0000	
ORLANDO-FSS/LAWRS	HERNDON	35	ORL	0	2833	8120	119	0	00	24	11	1	0000	
PANAMA CITY-LAWRS/SR	BAY CO	32	PFN	0	3012	8541	20	0	00	18	11	2	0000	
PENSACOLA	SHERMAN FIELD	10	NPA	0	3020	8718	32	2	00	0	00	0	0000	57
PENSACOLA	REGIONAL	4	PNS	0	3028	8712	0	0	00	24	11	81	0000	
POMPANO BEACH	AIRPARK	5	PMP	0	2615	8007	20	0	00	14	10	0	0000	
PONCE DE LEON INLET		9	1J3	0	2904	8055	9	2	00	8	41	1	0000	
PUNTA GORDA	CHARLOTTE COUNTY	2	PGD	0	2655	8159	25	0	00	13	11	2	0000	
SANFORD	AIRPORT	2	SFB	0	2847	8115	5	0	00	12	11	A1	0000	
SANTA ROSA IS		9	1J5	0	3019	8715	6	2	00	8	41	1	0000	
SARASOTA-TWR/SAWRS	SRQ BRADENTON	32	SRQ	0	2724	8233	24	1	00	18	11	1	0000	
SO MELBOURNE BEACH		1	MEBF1	0	2803	8033	18	2	00	8	41	0	0000	
ST PETERSBURG	ALBERT WHITTED	5	SPG	0	2746	8238	7	1	00	17	11	A0	0000	
ST PETERSBURG	PIE-CLEARWATER	4	PIE	0	2755	8241	11	1	00	24	11	1	0000	
TALLAHASSEE	MUNICIPAL	10	TLH	72214	3023	8422	68	0	41	24	11	81	0000	
TAMPA	INTERNATIONAL	70	TPA	72211	2758	8232	0	0	41	24	11	81	0000	
TAMPA BAY AREA		10	TBW	72210	2742	8224	43	0	00	0	00	1	0220	57
TITUSVILLE	TI-COCOA	2	TIX	0	2831	8048	35	0	00	14	12	1	0000	
TURKEY POINT		1	TUPF1	0	2955	8429	10	2	00	8	41	1	0000	
VENICE LORAN		9	X90	0	2705	8227	12	2	00	5	41	1	0000	
VERO BEACH	MUNICIPAL	4	VRB	0	2739	8025	28	0	00	24	11	81	0000	
WEST PALM BEACH	PALM BEACH INTNL	10	PBI	72203	2641	8007	21	0	41	24	11	81	0220	
WEST PALM BEACH	SIKORSKY HELIPORT	2		0	2654	8019	29	1	00	10	11	0	0000	
GEORGIA														
ALBANY	DOUGHERTY COUNTY	4	ABY	0	3132	8411	193	0	00	24	11	1	0000	
ALMA	BACON COUNTY	4	AMG	0	3132	8231	206	0	00	17	11	61	0000	
ATHENS	MUNICIPAL	10	AHN	72311	3357	8319	811	0	41	24	11	81	0220	65
ATLANTA	DEKALB-PEACHTREE	5	PDK	0	3353	8418	1002	1	00	17	11	A0	0000	
ATLANTA	CHARLEY BROWN FULTON	4	FTY	0	3347	8431	844	0	00	24	11	41	0000	
ATLANTA-WSFO/RFC		46	ATL	72219	3339	8425	1034	0	41	24	11	81	0000	4C
AUGUSTA	BUSH FIELD	10	AGS	72218	3322	8158	148	0	41	24	11	81	0000	4C
BRUNSWICK	MCKINNON	4	SSI	0	3109	8123	24	0	00	24	11	81	0000	

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
BRUNSWICK-LAWRS/SR	GLYNCO JETPORT	32	GDL	0	3115	8128	26	1	00	25	92	0	0000	
COLUMBUS	METROPOLITAN	10	CSG	0	3231	8456	394	0	00	24	11	81	0000	
MACON	LEWIS B WILSON	10	MCN	72217	3242	8339	362	0	41	24	11	81	0000	4C
MACON-WSO/FORESTRY		10		0	3248	8333	425	2	00	0	00	0	0000	
MOULTRIE	MGR-THOMASVILLE	2	MGR	0	3105	8348	290	1	00	15	11	A0	0000	
ROME	RUSSELL FIELD	11	RMG	0	3421	8510	643	0	00	24	11	41	0000	
SAVANNAH	MUN APT TRAVIS F	10	SAV	72207	3208	8112	51	0	41	24	11	81	0000	
ST SIMON ISLAND		9	1J1	0	3108	8122	5	2	00	8	41	1	0000	
TYBEE		9	1J2	0	3201	8051	10	2	00	8	41	1	0000	
VALDOSTA	MUNICIPAL	4	VLD	0	3047	8317	223	0	00	24	11	1	0000	
WAYCROSS	WARE CO	70	AYS	72213	3115	8224	152	0	00	0	00	A0	0220	65
HAWAII														
HAINA		7	HAIH1	91199	2006	15528	415	2	22	0	00	0	0000	
HILO	GEN. LYMAN FIELD	10	ITO	91285	1943	15504	36	0	41	24	11	81	2220	
HONOLULU RH		80	PHNL	0	0	0	0	0	00	0	00	0	0000	
HONOLULU-WSFO	INTERNATIONAL	40	HFO	91182	2120	15756	15	0	41	24	11	81	4000	
KAANAPALI	AIRPORT	8	PHKP	91189	2056	15642	8	2	42	10	11	1	0000	
KAHULUI	AIRPORT	15	OGG	91190	2054	15626	67	0	31	16	11	61	3000	
KAILUA HEIGHTS		3	6KI	0	1936	15558	500	2	00	3	51	12	0000	
KAPOHO		9	6KB	0	1930	15449	10	2	00	3	51	30	0000	
KE-AHOLE	AIRPORT	5	KOA	0	1945	15603	54	0	00	17	11	1	0000	
KEAWAKAPU BEACH		7	KEBH1	91191	2042	15627	15	2	31	0	00	0	0000	
KILAUEA POINT		9	0Z5	91164	2214	15924	186	0	00	3	90	30	0000	
KOKEE		7	KOKH1	91161	2209	15939	4200	2	42	0	00	0	0000	
KOLOA LN (MAKAHUENA)		9	1Z4	91166	2152	15927	52	2	00	4	51	40	0000	
LANAI CITY	AIRPORT	3	LNY	0	2048	15657	1308	0	00	10	11	11	0000	
LIHUE	AIRPORT	10	LIH	91165	2159	15921	148	0	41	24	11	81	2220	
MOLOKAI	AIRPORT	3	MOLH1	91186	2109	15706	451	0	00	11	11	41	0000	
PAHALA		3	P41	0	1912	15529	900	2	00	3	51	2	0000	
SOUTH KONA		7	SKOH1	91293	1906	15545	2650	2	32	0	00	0	0000	
UPOLU POINT LN		9	1Z2	91195	2015	15553	61	2	12	3	51	31	0000	
WAIALEE		7	WAIH1	91169	2141	15802	38	0	41	0	00	0	0000	
WAIMEA KOHALA	AIRPORT	3	MUE	0	2000	15540	2679	0	00	5	12	1	0000	
IDAHO														
BOISE	AIR TERM/GOWEN FLD	40	BOI	72681	4334	11613	2868	0	41	24	11	81	0220	
BURLEY	MUNICIPAL	4	BYI	0	4232	11346	4157	0	00	24	11	81	0000	
GOODING	MUNICIPAL	3	GNG	0	4255	11446	3729	0	00	12	21	51	0000	

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
GRANGEVILLE		3	S80	0	4555	11606	3304	0	00	4	51	42	0000	
HAILEY-BASIC/SAWRS	FRIEDMAN MEMORIAL	3	SUN	0	4330	11418	5315	1	00	11	11	62	0000	
IDAHO FALLS	FANNING FIELD	4	IDA	0	4331	11204	4744	0	00	24	11	81	0000	
LEWISTON-WSO/LAWR/SR	NEZ PERCE CO	15	LWS	72783	4623	11701	1436	0	31	20	11	61	0000	
MALAD CITY		3	MLD	0	4210	11219	4495	0	00	16	21	81	0000	
MULLAN		3	S06	0	4728	11548	3317	0	00	16	21	82	0000	
POCATELLO	MUNICIPAL	10	PIH	72578	4255	11236	4478	0	41	24	11	81	0000	
SALMON	MUNICIPAL	3	SMN	0	4507	11353	4055	0	00	11	61	62	0000	
STREVELL		3	4SV	0	4201	11315	5290	2	00	6	21	42	0000	
TWIN FALLS	JOSLIN	2	TWF	0	4229	11429	4150	1	00	16	11	1	0000	
TWIN FALLS-WSO/AG		10	TWFI1	0	4233	11421	3922	2	00	0	00	0	0000	
ILLINOIS														
ALTON	CIVIC MEMORIAL	5	ALN	0	3853	9003	545	1	00	17	11	2	0000	
AURORA	MUNICIPAL	5	ARR	0	4146	8828	706	1	00	13	11	0	0000	
BLOOMINGTON-LAWRS/SR	BMI-NORMAL	32	BMI	0	4029	8857	875	1	00	15	11	2	0000	
CAIRO		10	CIR	0	3700	8910	357	0	00	0	00	0	0000	
CARBONDALE-LWRS/SR	SOUTHERN ILLINOIS	32	MDH	0	3747	8915	416	0	00	13	11	2	0000	
CENTRALIA	MUNICIPAL	2	ENL	0	3831	8905	534	1	00	25	92	A0	0000	
CHAMPAIGN	UNIV OF ILL-WILLARD	5	CMI	0	4002	8817	763	0	00	24	11	1	0000	
CHICAGO DUNNE CRIB		9	DUK	74465	4147	8732	579	2	00	9	21	0	0000	
CHICAGO-DUPAGE	DUPAGE CO	4	DPA	0	4155	8815	767	0	00	24	11	1	0000	
CHICAGO-MEIGS	MEIGS	5	CGX	0	4152	8737	592	1	00	17	11	1	0000	
CHICAGO-MIDWAY	MIDWAY	10	MDW	72534	4147	8745	623	0	41	24	11	81	0001	
CHICAGO-OHARE	OHARE INTNL	10	ORD	72530	4159	8754	674	0	00	24	11	81	0000	
CHICAGO-WHEELING	PALWAUKEE	5	PWK	0	4207	8754	698	0	00	0	00	0	0000	
CHICAGO-WSFO		40	CHI	0	4160	8753	0	0	21	0	00	0	0000	
DANVILLE-LAWRS/SAWRS	VERMILION CO	32	DNV	0	4012	8736	695	1	00	25	90	A0	0000	
DECATUR	AIRPORT	4	DEC	0	3950	8852	679	0	00	24	11	1	0000	
DIXON	WALGREEN FIELD	2	C73	0	4150	8927	786	1	00	25	90	A0	0000	
EAST ST LOUIS	BI-STATE PARKS	5	CPS	0	3834	9009	413	1	00	13	11	2	0000	
ELGIN	AIRPORT	2	C06	0	4204	8817	790	1	00	25	90	A0	0000	
FREEPORT	ALBERTUS MUNICIPAL	2	FEP	0	4215	8935	847	1	00	25	90	0	0000	
GALESBURG-TWR/SAWRS	MUNICIPAL	32	GBG	0	4056	9026	803	0	00	14	11	A0	0000	
KANKAKEE	GREATER KANKAKEE	2	3KK	0	4104	8751	623	1	00	25	90	A0	0000	
LANSING	MUNICIPAL	2	3HA	0	4132	8732	614	0	00	25	90	0	0000	
LAWRENCEVILLE	LWV-VINCENNES	2	LWV	0	3846	8736	428	1	00	25	90	A0	0000	
MACOMB	MUNICIPAL	2	MQB	0	4031	9039	701	1	00	25	90	A0	0000	
MARION	WILLIAMSON CO	5	MWA	0	3745	8900	471	1	00	16	61	A0	0000	
MARSEILLES		71	MMO	0	4122	8841	733	2	00	24	71	42	0000	57
MATTOON	COLES CO MEM	2	MTO	0	3929	8817	721	1	00	9	11	2	0000	
MOLINE	QUAD-CITY	10	MLI	72544	4127	9031	594	0	41	24	11	41	0000	4C

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
MT VERNON	MT VN-OUTLAND	2	MVN	0	3819	8852	479	0	00	16	11	2	0000	
OLNEY	OLNEY NOBLE	2	OLY	0	3843	8811	471	1	00	25	90	AO	0000	
PEORIA	GREATER PEORIA	10	PIA	72532	4040	8941	662	0	41	24	11	81	0220	
QUINCY	BALDWIN FIELD	4	UIN	0	3956	9112	766	0	00	24	11	81	0000	
ROCKFORD	GREATER RFD	10	RFD	72543	4212	8906	743	0	00	24	11	81	0000	
SALEM	LECKRONE	70	SLO	72433	3839	8858	581	0	00	0	00	0	0220	
SPRINGFIELD	CAPITAL	10	SPI	72439	3950	8940	613	0	41	24	11	41	0000	
STERLING-ROCK FALLS	WHITESIDE COUNTY	2	SQI	0	4144	8941	645	1	00	17	11	AO	0000	
INDIANA														
ANDERSON	MUNICIPAL	2	AID	0	4006	8537	919	1	00	16	11	AO	0000	
BLOOMINGTON-LWRS/SR	MONROE CO MUNICIPAL	32	BMG	0	3908	8637	847	1	00	25	90	AO	0000	
ELKHART	MUNICIPAL	2	EKM	0	4143	8559	777	1	00	25	90	AO	0000	
EVANSVILLE	DRESS REGIONAL	10	EVV	72432	3803	8732	388	0	41	24	11	81	0000	57
FT WAYNE	BAER FIELD	10	FWA	72533	4100	8512	828	0	41	24	11	81	0000	4C
GARY	MUNICIPAL	2	GYY	0	4137	8725	616	0	00	25	90	AO	0000	
INDIANAPOLIS	EAGLE CREEK	2	I14	0	3950	8618	820	1	00	25	90	AO	0000	
INDIANAPOLIS	INTERNATIONAL	40	IND	72438	3944	8616	808	0	41	24	11	81	0000	4C
KOKOMO	MUNICIPAL	2	OKK	0	4032	8604	827	1	00	25	91	0	0000	
LAFAYETTE-ESSC		10	LFYI3	0	4028	8700	0	0	00	0	00	0	0000	
MARION	MUNICIPAL	2	MZZ	0	4029	8541	859	1	00	8	12	AO	0000	
MICHIGAN CITY	AIRPORT	2	MGC	0	4142	8649	650	1	00	25	90	AO	0000	
MICHIGAN CITY		9	18C	0	4143	8655	579	2	00	12	30	0	0000	
MUNCIE-LAWRS/SAWRS	DEL CO JOHNSON FD	32	MIE	0	4014	8523	947	0	00	17	11	AO	0000	
SOUTH BEND	MICHIANA REGIONAL	10	SBN	72535	4142	8619	773	0	41	24	11	81	0000	
TELL CITY	PERRY COUNTY MUN	2	TEL	0	3801	8641	659	1	00	25	92	0	0000	
TERRE HAUTE	HULMAN	4	HUF	0	3927	8718	593	0	00	24	11	1	0000	
VALPARAISO	PORTER COUNTY MUN	2	VPZ	0	4127	8700	768	1	00	25	90	AO	0000	
WARSAW	MUNICIPAL	2	ASW	0	4117	8551	842	1	00	25	90	AO	0000	
WEST LAFAYETTE	PURDUE UNIVERSITY	4	LAF	0	4025	8656	637	0	00	24	11	81	0000	
IOWA														
BURLINGTON	MUNICIPAL	4	BRL	0	4047	9107	702	0	00	24	11	1	0000	
CEDAR RAPIDS	MUNICIPAL	4	CID	0	4153	9142	871	0	00	24	11	81	0000	
CLINTON	MUNICIPAL	2	CWI	0	4150	9020	707	1	00	25	11	AO	0000	
DAVENPORT	MUNICIPAL	2	DVN	0	4137	9036	753	1	00	25	90	AO	0000	
DES MOINES	MUNICIPAL	40	DSM	72546	4132	9339	963	0	41	24	11	41	0000	57
DUBUQUE	MUNICIPAL	15	DBQ	72547	4224	9042	1080	0	21	14	11	51	0000	
FORT MADISON	MUNICIPAL	2	K27	0	4040	9120	724	1	00	25	90	AO	0000	

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
FT. DODGE-AMOS/SAWRS	MUNICIPAL	1	FOD	0	4233	9411	1165	0	00	24	71	A1	0000	
IOWA CITY	MUNICIPAL	2	IOW	0	4138	9133	661	1	00	25	90	AO	0000	
KEOKUK	MUNICIPAL	2	EOK	0	4028	9126	670	1	00	25	90	AO	0000	
LAMONI		3	30I	0	4037	9356	1122	0	00	16	61	82	0000	
MASON CITY	MUNICIPAL	4	MCW	0	4309	9320	1225	0	00	24	11	81	0000	
OTTUMWA	INDUSTRIAL	4	OTM	0	4106	9227	850	0	00	24	11	81	0000	
POCAHONTAS	MUNICIPAL	2	OK2	0	4244	9438	1222	1	00	25	92	0	0000	
SIOUX CITY	MUNICIPAL	10	SUX	72557	4224	9623	1103	0	41	24	11	41	0000	
SPENCER		8	3SE	72650	4310	9509	1339	0	72	19	11	2	0000	
SPENCER	MUNICIPAL	2	SPW	0	4310	9512	0	0	00	25	92	0	0000	
WATERLOO	MUNICIPAL	10	ALO	72548	4233	9224	878	0	00	24	11	81	0000	4C
KANSAS														
CHANUTE	MUNICIPAL	4	CNU	0	3740	9529	1011	0	00	24	11	81	0000	
CONCORDIA	BLOSSER MUN	10	CNK	72458	3933	9739	1484	0	41	24	11	81	0000	4C
DODGE CITY	MUNICIPAL	10	DDC	72451	3746	9958	2592	0	41	24	11	81	0220	
ELKHART		1	1K5	72460	3700	10153	3616	0	00	24	71	41	0000	
EMPORIA	MUNICIPAL	4	EMP	0	3820	9612	1212	0	00	24	11	81	0000	
GARDEN CITY	MUNICIPAL	74	GCK	0	3756	10043	2882	0	00	25	90	AO	0000	65
GOODLAND	RENNER FIELD	10	GLD	72465	3922	10142	3688	0	41	24	11	81	0000	4C
GREAT BEND	MUNICIPAL	2	GBD	0	3821	9852	1890	1	00	25	90	AO	0000	
HAYS	MUNICIPAL	2	HYS	0	3851	9916	1998	1	00	3	91	AO	0000	
HILL CITY-FSS/BASIC	MUNICIPAL	33	HLC	0	3923	9950	2221	0	00	19	21	81	0000	
HUTCHINSON-LAWRS/BC	MUNICIPAL	33	HUT	0	3804	9752	1524	0	00	21	11	1	0000	
KANSAS CITY	FAIRFAX	5	KCK	0	3909	9435	745	0	00	25	90	AO	0000	
LAWRENCE	MUNICIPAL	2	3LA	0	3000	9513	832	2	00	25	91	0	0000	
LIBERAL	MUNICIPAL	2	LBL	0	3703	10058	2887	1	00	10	11	AO	0000	
MANHATTAN-FSS/SAWRS	MUNICIPAL	32	MHK	0	3909	9640	1070	0	00	16	11	1	0000	
MEDICINE LODGE		1	P28	0	3718	9835	1536	0	00	24	71	41	0000	
OLATHE	JOHNSON COUNTY	5	OJC	0	3851	9444	1126	0	00	16	11	AO	0000	
PARSONS	TRI CITY	2	PPF	0	3720	9530	899	1	00	3	91	AO	0000	
RUSSELL	MUNICIPAL	4	RSL	0	3852	9849	1869	0	00	24	11	81	0000	
SALINA	MUNICIPAL	4	SLN	0	3848	9739	1282	0	00	24	11	81	0000	
TOPEKA	PHILIP BILLARD MUN	40	TOP	72456	3904	9538	885	0	41	24	11	41	0220	4C
TOPEKA	FORBES FIELD	2	FOE	0	3857	9540	1064	0	00	25	90	0	0000	
WICHITA	MID-CONTINENT	10	ICT	72450	3739	9726	1340	0	41	24	11	81	0000	57
KENTUCKY														
BOWLING GREEN	BWG WARREN COUNTY	4	BWG	0	3658	8626	536	0	00	24	11	81	0000	

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
FRANKFORT	CAPITAL CITY	2	FFT	0	3811	8455	804	1	00	25	92	0	0000	
LEXINGTON	BLUE GRASS FIELD	10	LEX	72422	3802	8436	989	0	41	24	11	81	0000	
LONDON	ROSCOE E MAGEE MEM	4	LOZ	0	3705	8405	1211	0	00	24	11	81	0000	
LOUISVILLE	STANDIFORD FIELD	40	SDF	72423	3811	8544	488	0	41	24	11	81	0000	4C
LOUISVILLE	BOWMAN FIELD	4	LOU	0	3814	8540	556	0	00	24	11	A0	0000	
MADISONVILLE	MUNICIPAL	2	2IO	0	3721	8724	438	1	00	25	90	A0	0000	
OWENSBORO	DAVIESS CO	5	OWB	0	3745	8710	417	0	00	17	11	2	0000	
PADUCAH	BARKLEY	4	PAH	0	3704	8846	413	0	00	24	11	81	0000	
PIKEVILLE		3	5I3	0	3729	8231	700	0	00	7	21	32	0000	
LOUISIANA														
ALEXANDRIA FSS	ESLER REGIONAL	4	ESF	0	3124	9218	118	0	00	17	11	51	0000	
ALEXANDRIA-WSO		10	ESF	0	0	0	78	2	00	0	00	0	0000	
BATON ROUGE	RYAN MUNICIPAL	10	BTR	72230	3032	9109	76	0	00	24	11	81	0000	XS
BOOTHVILLE		70	BVE	72232	2920	8924	2	0	00	18	21	61	0220	
CALCASIEU RBS		9	8R6	0	2947	9321	5	2	00	8	41	1	0000	
FORT POLK	USA AIRFIELD	2	POE	0	3103	9311	330	1	00	15	12	A0	0000	
GRAND ISLE		9	8R5	0	2916	8957	0	0	00	8	40	0	0000	
HOUMA	HOUMA-TERREBONNE	2	HUM	0	2934	9040	11	0	00	25	92	2	0000	
INTRACOASTAL CITY	AIRPORT	2	7R4	0	2947	9208	3	0	00	13	11	2	0000	
LAFAYETTE	REGIONAL	4	LFT	0	3012	9159	42	0	00	24	11	81	0000	
LAKE CHARLES	MUNICIPAL	10	LCH	72240	3007	9313	32	0	41	24	11	81	0220	57
LEEVILLE	GULF LEEVILLE HELI.	2	7R2	0	2913	9014	22	0	00	25	91	2	0000	
MONROE	MUNICIPAL	4	MLU	0	3231	9203	81	0	00	24	11	81	0000	
NEW IBERIA	ACADIANA REGIONAL	2	ARA	0	3002	9153	25	1	00	25	91	0	0000	
NEW ORLEANS	INTNL/MOISANT FLD	70	MSY	72231	2959	9015	30	0	41	24	11	81	0000	
NEW ORLEANS	LAKEFRONT	5	NEW	0	3002	9002	9	1	00	24	11	1	0000	
NEW ORLEANS-WSFO		40	MSYL1	0	2957	9005	177	0	00	0	00	0	0000	
SHREVEPORT	DOWNTOWN	4	DTN	0	3231	9345	179	0	00	24	11	A0	0000	
SHREVEPORT	REGIONAL	10	SHV	72248	3228	9349	259	0	41	24	11	81	0000	4C
SLIDELL-WSMO/RFC		76	SIL	0	3017	8946	17	2	10	0	00	0	0000	57
SOUTHWEST PASS LS		9	8R3	0	2855	8926	0	0	00	8	40	0	0000	
MAINE														
AUBURN	AUBURN-LEWISTON MUN	2	LEW	0	4403	7017	271	1	00	14	11	A0	0000	
AUGUSTA	STATE	4	AUG	0	4419	6948	360	0	00	24	11	81	0000	
BANGOR	INTERNATIONAL	4	BGR	0	4448	6849	192	0	00	24	11	81	0000	
BAR HARBOR	AIRPORT	2	BHB	0	4427	6822	84	1	00	25	90	A0	0000	
BEAR ISLAND LS		9	9B5	0	4417	6816	0	0	00	5	41	0	0000	

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
BRUNSWICK	NAVAL AIR STATION	70	NHZ	74392	4354	6956	72	2	00	0	00	0	0000	57
CAPE NEDDICK LS		9	27B	0	4310	7036	0	0	00	5	40	0	0000	
CARIBOU	MUNICIPAL	10	CAR	72712	4652	6801	628	0	31	17	11	31	0220	
DUCK ISLAND LS		9	14B	0	4409	6815	0	0	00	8	40	0	0000	
EASTPORT		7	EPO	72608	4455	6700	75	0	31	0	00	0	0000	
GOAT ISLAND LS		9	0B9	0	4320	7024	0	0	00	5	31	0	0000	
GREENVILLE		1	6B2	72619	4528	6935	0	0	00	24	71	1	0000	
HERON NECK LS		9	16B	0	4402	6852	0	0	00	8	41	0	0000	
HOULTON	INTERNATIONAL	4	HUL	0	4608	6747	476	0	00	24	11	81	0000	
MANANA ISLAND FSS		9	18B	0	4346	6920	0	0	00	8	41	0	0000	
MATINICUS ROCK LS		9	19B	0	4347	6851	0	0	00	8	40	0	0000	
OLD TOWN	DEWITT FIELD OLD MUN	2	OLD	0	4457	6840	126	1	00	25	90	A0	0000	
PORTLAND HEAD LS		9	2B8	0	4337	7012	0	0	00	5	41	0	0000	
PORTLAND-WSFO		40	PWMM1	0	4339	7016	0	0	00	0	00	0	0000	
PORTLAND-WSMO	INTNL JETPORT	70	PWM	72606	4339	7019	63	0	41	24	11	41	0220	
PRESQUE ISLE	MUNICIPAL	2	PQI	0	4642	6803	534	1	00	12	11	2	0000	
ROCKLAND		9	20B	0	4406	6906	0	0	00	8	41	0	0000	
ROCKLAND	KNOX COUNTY	2	RKD	0	4404	6906	55	1	00	6	21	A0	0000	
RUMFORD		7	RUM	72618	4432	7032	674	0	41	0	00	0	0000	
SEGUIN ISLAND LS		9	23B	0	4343	6946	0	0	00	8	41	0	0000	
WATERVILLE	LAFLEUR	2	WVL	0	4432	6940	332	1	00	4	21	A0	0000	
WEST QUODDY HEAD LS		9	24B	0	4448	6657	0	0	00	8	41	0	0000	
MARYLAND														
ABERDEEN	PHILLIPS AAF	2	APG	0	3928	7610	57	0	00	25	90	A0	0000	
ANNAPOLIS		9	61W	0	3855	7628	0	0	00	8	41	0	0000	
BALTIMORE	BAL-WASHINGTON INTNL	10	BAL	72406	3911	7640	155	0	41	24	11	41	0000	
COVE POINT LS		9	66W	0	3823	7623	3	2	00	6	41	0	0000	
CRISFIELD ANT		9	W06	0	3759	7552	8	2	00	5	41	0	0000	
CUMBERLAND	MUNICIPAL	2	CBE	0	3936	7846	790	1	00	25	92	A0	0000	
EASTON	AIRPORT	2	ESN	0	3849	7605	75	0	00	0	00	0	0000	
GAITHERSBURG	MONTGOMERY CO. AIRPK	2	GAI	0	3909	7710	540	0	00	25	90	0	0000	
HAGERSTOWN-LAWRS/SR	REGIONAL	32	HGR	0	3941	7744	704	1	00	17	11	2	0000	
KENTMORR MARINA		9	OW4	0	3855	7622	0	0	54	0	00	0	0000	
MIDDLE RIVER	GLENN L MARTIN STATE	2	MTN	0	3920	7625	61	0	00	25	91	0	0000	
OCEAN CITY	AIRPORT	2	N80	0	3820	7505	12	0	00	25	90	A0	0000	
OCEAN CITY		9	W3C	74595	3820	7505	17	0	00	8	40	0	0000	
PATUXENT RIVER	NAVAL AIR STATION	70	NHK	72404	3817	7625	45	2	00	0	00	0	0000	57
SALISBURY	WICOMICO CO	4	SBY	0	3820	7530	60	0	00	24	11	81	0000	
STILLPOND		9	67W	0	3920	7606	0	0	00	8	41	0	0000	
THOMAS POINT LS		9	65W	0	3854	7626	0	0	00	8	41	0	0000	
WASHINGTON-NMC/WSFO		20	WBC	0	3851	7656	289	2	00	0	00	0	0000	

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
MASSACHUSETTS														
BEDFORD	L G HANSCOM FIELD	5	BED	0	4228	7131	133	0	00	16	11	2	0000	
BEVERLY	MUNICIPAL	5	BVY	0	4235	7055	108	0	00	17	11	A1	0000	
BOSTON	LOGAN INTERNATIONAL	40	BOS	72509	4222	7102	29	0	41	24	11	81	0000	
BOSTON LS		9	29B	0	4219	7053	0	0	00	8	41	0	0000	
BRANT POINT		9	45B	0	4117	7005	0	0	00	8	40	0	0000	
BUZZARDS BAY ENTR LS		9	33B	0	4123	7102	0	0	00	8	40	80	0000	
CAPE COD CANAL		9	30B	0	4147	7030	0	0	00	8	41	0	0000	
CHATHAM		9	31B	0	4140	6957	0	0	00	8	41	0	0000	
CHATHAM		70	CHH	74494	4140	6958	53	0	82	0	00	0	0220	65
GLOUCESTER		9	34B	0	4235	7040	0	0	00	8	41	0	0000	
GREAT BARRINGTON	AIRPORT	2	GBR	0	4211	7324	742	0	00	25	90	C	0000	
HYANNIS	BARNSTABLE MUNICIPAL	5	HYA	0	4140	7017	52	1	00	17	11	31	0000	
LAWRENCE	MUNICIPAL	2	LWM	0	4243	7107	155	2	00	3	90	0	0000	
MARTHAS VINEYARD	AIRPORT	2	MVY	0	4124	7036	78	0	00	12	11	2	0000	
MENEMSHA		9	32B	0	4121	7046	0	0	00	8	41	0	0000	
MERRIMAC RIVER		9	35B	0	4249	7052	0	0	00	8	40	0	0000	
MILTON-BLUE HILL		70		0	4213	7107	640	0	00	0	00	0	0000	
NANTUCKET	MEMORIAL	5	ACK	0	4115	7004	12	0	00	17	11	81	0000	
NEW BEDFORD	MUNICIPAL	5	EWB	0	4141	7058	79	1	00	17	11	2	0000	
NORWOOD	MEMORIAL	5	OWD	0	4211	7111	50	1	00	13	11	1	0000	
OCEAN VICTORY		2		0	4051	6729	70	0	00	4	41	0	0000	
PITTSFIELD	MUNICIPAL	2	PSF	0	4226	7318	1169	0	00	4	21	12	0000	
PROVINCETOWN	MUNICIPAL	2	PVC	0	4204	7013	8	1	00	6	2M	A0	0000	
RACE POINT		9	36B	0	4205	7012	0	0	00	8	41	0	0000	
SCITUATE		9	37B	0	4212	7043	0	0	00	8	41	0	0000	
WESTFIELD	BARNES MUNICIPAL	5	BAF	0	4210	7243	273	0	00	16	11	2	0000	
WORCESTER-LAWRS	MUNICIPAL	11	ORH	0	4216	7152	1017	0	00	24	11	61	0000	4C
MICHIGAN														
ALPENA	PHELPS COLLINS FIELD	10	APN	72639	4504	8334	693	0	00	24	11	81	0000	4C
ANN ARBOR	MUNICIPAL	5	ARB	0	4213	8345	839	1	00	13	11	A0	0000	
ANN ARBOR-WSFO		40	ARB	0	4216	8344	0	0	00	0	00	0	0000	
BAD AXE	HURON CO MEMORIAL	2	76D	0	4347	8259	763	1	00	25	90	A0	0000	
BATTLE CREEK	KELLOGG	5	BTL	0	4218	8514	939	0	00	24	11	1	0000	
BELLAIRE	ANTRIM COUNTY	2	ACB	0	4459	8512	640	0	00	25	90	A0	0000	
BELLE ISLE		9	31G	0	4220	8258	580	2	00	12	30	0	0000	
BENTON HARBOR (LWRS)	ROSS FIELD	32	BEH	0	4208	8626	643	1	00	16	11	2	0000	

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
CADILLAC	MUNICIPAL	2	CAD	0	4415	8528	1305	1	00	25	90	0	0000	
DETOUR VILLAGE		1	P55	0	4559	8354	608	2	00	12	31	0	0000	
DETROIT	WILLOW RUN	5	YIP	0	4214	8332	777	0	00	24	11	1	0000	
DETROIT	CITY	4	DET	0	4225	8301	626	0	00	24	11	1	0000	
DETROIT RIVER LS		9	18G	0	4200	8309	571	2	00	12	30	0	0000	
DETROIT-WSO	METROPOLITAN	10	DTW	72537	4214	8320	664	0	41	24	11	81	0000	57
EAGLE HARBOR LS		9	31Y	0	4728	8810	607	2	00	12	30	0	0000	
ESCANABA		7	ESC	72648	4544	8703	612	0	72	0	00	0	0000	
ESCANABA	DELTA COUNTY	2	ESC	0	4544	8705	608	1	00	17	11	2	0000	
FLINT	BISHOP	10	FNT	72637	4258	8344	766	0	41	24	11	81	0220	
FRANKFORT		9	14C	0	4438	8615	572	2	00	12	30	0	0000	
GAYLORD	OTSEGO COUNTY	2	GLR	0	4501	8442	1335	1	00	25	90	A0	0000	
GRAND MARAIS		9	27Y	0	4641	8559	600	2	00	12	30	0	0000	
GRAND RAPIDS	KENT CO	10	GRR	72635	4253	8531	803	0	41	24	11	81	0000	
HOLLAND	TULIP CITY	2	C19	0	4245	8607	680	1	00	25	90	A0	0000	
HOUGHTON	COUNTY	4	CMX	0	4710	8830	1079	0	00	24	11	81	0000	
HOUGHTON LAKE	ROSCOMMON COUNTY	10	HTL	72638	4422	8441	1160	0	41	24	11	81	0000	4C
IRON MOUNTAIN	FORD	2	IMT	0	4549	8807	1174	1	00	16	11	2	0000	
IRONWOOD	GOGEBIC CO	2	IWD	0	4632	9008	1246	1	00	16	11	2	0000	
JACKSON	REYNOLDS	4	JXN	0	4216	8428	1020	0	00	24	11	81	0000	
KALAMAZOO	MUNICIPAL	5	AZO	0	4214	8533	874	1	00	24	11	1	0000	
LANSING	CAPITAL CITY	10	LAN	72539	4247	8436	874	0	00	24	11	81	0000	
LUDINGTON	MASON COUNTY	2	LDM	0	4358	8625	642	1	00	25	90	A0	0000	
LUDINGTON LS		9	17C	0	4357	8628	597	2	00	12	30	0	0000	
MANISTEE	MBL-BLACKER	2	MBL	0	4416	8615	620	1	00	16	11	2	0000	
MANISTIQUE	SCHOOLCRAFT COUNTY	2	ISQ	0	4559	8611	684	1	00	25	90	A0	0000	
MANITOU ISLAND LS		9	33Y	0	4725	8735	609	2	00	12	30	0	0000	
MARQUETTE		10	MQUM4	72743	4634	8724	734	0	31	0	00	0	0000	
MARQUETTE	MQT COUNTY	4	MQT	0	4632	8734	1425	0	00	24	11	81	0000	
MARQUETTE LS		9	34Y	0	4633	8723	644	2	00	12	30	0	0000	
MENOMINEE	COUNTY	2	MNM	0	4507	8738	621	1	00	16	11	2	0000	
MUSKEGON	COUNTY	10	MKG	72636	4310	8615	633	0	41	24	11	81	0000	4C
MUSKEGON LS		9	19C	0	4314	8620	598	2	00	12	30	0	0000	
NORTH MANITOU SHOALS		9	28Y	0	4501	8557	581	2	00	12	30	0	0000	
PASSAGE ISLAND LS		9	35Y	0	4813	8822	656	2	00	12	30	0	0000	
PELLSTON	EMMET COUNTY	4	PLN	0	4534	8448	715	0	00	24	11	81	0000	
POINT BETSIE LS		9	36Y	0	4442	8615	0	0	00	5	30	0	0000	
PONTIAC-TWR/SAWRS	OAKLAND-PONTIAC	32	PTK	0	4240	8325	980	1	00	18	11	2	0000	
PORT HURON	ST CLAIR	2	PHN	0	4255	8232	648	1	00	25	90	A0	0000	
PORT HURON		9	33G	0	4300	8225	581	2	00	12	30	0	0000	
PORTAGE		9	32Y	0	4714	8838	624	2	00	12	30	0	0000	
ROCK OF AGES LS		9	37Y	0	4752	8919	602	2	00	12	30	0	0000	
SAGINAW	TRI CITY	4	MBS	0	4332	8405	670	0	00	24	11	81	0000	
SAGINAW RIVER		9	30G	0	4338	8351	580	2	00	12	30	0	0000	
SAULT STE MARIE	CITY-COUNTY	10	SSM	72734	4628	8422	724	0	41	24	11	81	0220	

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
SAULT STE MARIE ANT		9	44Y	0	4630	8420	577	1	00	12	31	0	0000	
SEUL CHOIX POINT		1	P75	0	4555	8555	618	0	00	24	71	21	0000	
ST CLAIR SHORES		9	41Y	0	4228	8226	575	2	00	12	31	A0	0000	
ST IGNACE		9	38Y	0	4551	8443	579	2	00	12	30	0	0000	
ST JOSEPH		9	20C	0	4207	8629	579	2	00	12	30	0	0000	
STANNARD ROCK		1	STRM4	0	4710	8715	600	2	00	8	41	0	0000	
TAWAS POINT LS		9	39Y	0	4415	8326	583	2	00	12	30	0	0000	
THREE RIVERS	MUN DR. HAINES	2	HAI	0	4158	8536	830	1	00	25	91	0	0000	
THUNDER BAY IS LS		9	40Y	0	4502	8312	583	2	00	12	30	0	0000	
TRAVERSE CITY	CHERRY CAPITAL	4	TVC	0	4444	8535	630	0	00	24	11	81	0000	
WHITEFISH POINT		1	42Y	0	4646	8457	604	2	00	12	21	0	0000	
MINNESOTA														
ALEXANDRIA	MUNICIPAL	4	AXN	0	4552	9523	1431	0	00	24	11	81	0000	
BEMIDJI	MUNICIPAL	7	BJI	72755	4730	9456	1377	0	82	17	11	1	0000	
BRAINERD	CROW WING COUNTY	2	BRD	0	4624	9408	1226	1	00	16	11	2	0000	
CLOQUET	COQ-CARLTON	2	49D	0	4642	9230	1278	1	00	25	90	A0	0000	
DETROIT LAKES	AIRPORT	2	DTL	0	4650	9553	1396	1	00	25	90	A0	0000	
DULUTH	INTERNATIONAL	10	DLH	72745	4650	9211	1417	0	41	24	11	41	0000	4C
DULUTH HARBOR		9	30Y	0	4646	9205	610	2	00	12	30	0	0000	
ELY	MUNICIPAL	2	ELO	0	4749	9150	1455	1	00	25	92	0	0000	
EVELETH	EVM-VIRGINIA MUN	2	EVM	0	4726	9230	1385	1	00	25	90	A0	0000	
FAIRMONT	MUNICIPAL	2	FRM	0	4339	9425	1161	1	00	14	11	2	0000	
GRAND RAPIDS	ITASCA COUNTY	2	GPZ	0	4713	9331	1326	1	00	25	90	A0	0000	
HIBBING	CHISHOLM HIBBING	4	HIB	0	4723	9251	1357	0	00	24	11	81	0000	
INTERNATIONAL FALLS	FALLS INTERNATIONAL	10	INL	72747	4834	9323	1183	0	41	24	11	41	0220	
MANKATO	MUNICIPAL	2	MKT	0	4413	9355	1020	0	00	14	11	2	0000	
MARSHALL	MUNICIPAL-RYAN FIELD	2	MML	0	4427	9549	1179	1	00	25	90	0	0000	
MINNEAPOLIS	MSP-ST PAUL INTNL	40	MSP	72658	4453	9313	838	0	41	24	11	81	0000	57
MINNEAPOLIS	CRYSTAL	5	MIC	0	4504	9321	869	1	00	16	11	A0	0000	
MINNEAPOLIS	FLYING CLOUD	5	FCM	0	4450	9327	905	1	00	17	11	A0	0000	
NEW ULM	MUNICIPAL	2	ULM	0	4419	9430	1005	1	00	25	90	A0	0000	
ORR	MUNICIPAL	2	ORB	0	4801	9251	1310	1	00	0	00	0	0000	
PEQUOT LAKES		1	P39	0	4635	9419	1280	0	00	24	71	31	0000	
REDWOOD FALLS	MUNICIPAL	4	RWF	0	4433	9505	1030	0	00	24	11	81	0000	
ROCHESTER	MUNICIPAL	10	RST	72644	4355	9230	1320	0	41	24	11	41	0000	4C
ST CLOUD	MUNICIPAL	10	STC	72655	4533	9404	1024	0	31	18	11	60	0220	
ST PAUL	DOWNTOWN	5	STP	0	4456	9304	704	0	00	16	11	A0	0000	
THIEF RIVER FALLS	PUBLIC	2	TVF	0	4804	9611	1116	1	00	17	11	2	0000	
WARROAD	MUNICIPAL	1	D45	0	4856	9521	1075	0	00	24	71	31	0000	
WILLMAR	MUNICIPAL	2	ILL	0	4507	9505	1130	1	00	25	90	A0	0000	
WINONA	MUN-MAX CONRAD	2	ONA	0	4405	9142	656	1	00	13	12	A0	0000	

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
WORTHINGTON	MUNICIPAL	2	OTG	0	4339	9535	1574	1	00	16	11	2	0000	
MISSISSIPPI														
COLUMBUS	GOLDEN TRIANGLE	2	GTR	0	3327	8836	264	1	00	15	11	A2	0000	
GREENVILLE-LWRS/SR	INTERNATIONAL	32	GLH	0	3329	9059	131	0	00	17	11	2	0000	
GREENWOOD	GRNWD-LEFLORE	4	GWO	0	3330	9005	133	0	00	24	11	81	0000	
GULFPORT-LAWRS/SAWRS	MUNICIPAL	32	GPT	0	3024	8904	28	1	00	18	11	2	0000	
JACKSON	A. C. THOMPSON FIELD	40	JAN	72235	3219	9005	331	0	41	24	11	81	0220	57
LAUREL/HATTIESBURG	PINE BELT REG.	2	PIB	0	3128	8920	298	1	00	18	61	2	0000	
MCCOMB	PIKE CO	4	MCB	0	3111	9028	422	0	00	24	11	81	0000	
MERIDIAN	KEY FIELD	10	MEI	72234	3220	8845	310	0	41	24	11	81	0000	4C
NATCHEZ	NATCHEZ-ADAMS COUNTY	2	HEZ	0	3137	9117	272	1	00	15	11	2	0000	
OXFORD	UNIVERSITY	2	UOX	0	3423	8933	451	1	00	8	21	2	0000	
PASCAGOULA	JACKSON COUNTY	2	PGL	0	3023	8830	16	1	00	3	91	0	0000	
PASCAGOULA		9	8RO	0	3022	8834	3	2	00	8	41	1	0000	
SHIP ISLAND		9	9R8	0	3015	8858	0	0	00	3	21	0	0000	
STONEVILLE-ESSC		10	STMV6	0	3325	9055	127	2	00	0	00	0	0000	
TUPELO	MUNICIPAL	2	TUP	0	3416	8846	361	1	00	16	11	2	0000	
VICKSBURG-WSO/COE		10		0	3221	9053	229	2	00	0	00	0	0000	
MISSOURI														
CAPE GIRARDEAU	MUNICIPAL	4	CGI	0	3714	8934	352	0	00	24	11	81	0000	
CHESTERFIELD	SPIRIT OF ST. LOUIS	5	SUS	0	3840	9039	462	1	00	16	11	A0	0000	
CHILICOTHE	MUNICIPAL	2	K48	0	3947	9330	765	2	00	0	00	0	0000	
COLUMBIA	REGIONAL	10	COU	72445	3849	9213	898	0	41	24	11	41	0000	4C
JEFFERSON CITY	MEMORIAL	2	JEF	0	3836	9210	547	1	00	17	11	A0	0000	
JOPLIN	MUNICIPAL	4	JLN	0	3710	9430	985	0	00	24	11	81	0000	
KAISER	LEE C FINE MEMORIAL	2	AIZ	0	3806	9233	869	1	00	25	90	A2	0000	
KANSAS CITY	INTERNATIONAL	70	MCI	72446	3917	9443	1025	0	41	24	11	41	0000	
KANSAS CITY	MUNICIPAL	4	MKC	0	3907	9436	750	0	00	24	11	1	0000	
KANSAS CITY RH		80	KACM7	0	0	0	0	0	00	0	00	0	0000	
KANSAS CTY-NSSFC/RFC		26	MCIM7	0	3906	9435	1355	0	00	0	00	0	0000	57
KIRKSVILLE	CLARENCE CANNON MEM	3	IRK	0	4006	9233	965	0	00	16	21	81	0000	
MALDEN	MUNICIPAL	2	MAW	0	3636	9000	295	1	00	25	92	0	0000	
MONETT		70	UMN	72349	3653	9354	1435	0	82	0	00	0	0220	65
POPLAR BLUFF	EARL FIELDS MEMORIAL	2	M15	0	3646	9019	330	1	00	25	90	A0	0000	
POPLAR BLUFF		1	P02	72330	3646	9028	480	0	00	24	71	41	0000	
SPICKARD		1	P35	72540	4015	9343	888	0	00	24	71	31	0000	
SPRINGFIELD	MUNICIPAL	10	SGF	72440	3714	9323	1270	0	41	24	11	81	0000	

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
ST JOSEPH	ROSECRANS MEM	5	STJ	72449	3946	9455	818	0	00	17	11	1	0000	
ST LOUIS-WSFO		40	SJOM7	0	3848	9034	545	2	00	0	00	0	0000	57
ST LOUIS-WSMO	LAMBERT-STL INTL	70	STL	72434	3845	9023	564	0	41	24	11	81	0000	
VICHY	ROLLA NATIONAL	4	VIH	0	3808	9146	1137	0	00	24	11	81	0000	
WEST PLAINS		7	H63	0	3644	9151	1011	0	41	0	00	0	0000	
MONTANA														
BAILEY'S LANDING		9	08S	0	4804	11413	2898	2	00	2	90	0	0000	
BILLINGS	LOGAN FIELD	10	BIL	72677	4548	10832	3570	0	41	24	11	81	0000	4C
BOZEMAN	GALLATIN FIELD	4	BZN	0	4547	11109	4449	0	00	24	11	81	0000	
BROADUS		3	4BQ	0	4526	10524	3032	0	00	4	51	42	0000	
BUTTE	B MOONEY SILVER BOW	4	BTM	0	4557	11230	5533	0	00	24	11	81	0000	
CUTBANK	MUNICIPAL	4	CTB	0	4836	11222	3838	0	00	24	11	81	0000	
DILLON	BEAVERHEAD COUNTY	3	DLN	0	4515	11233	5222	0	00	16	21	81	0000	
DRUMMOND		3	3DU	0	4640	11309	3943	2	00	14	11	52	0000	
FORT PECK MARINA		9	37S	0	4759	10628	2259	2	00	25	90	0	0000	
GLASGOW	INTERNATIONAL	10	GGW	72768	4813	10637	2298	0	41	24	11	81	0220	
GLENDIVE	DAWSON COMMUNITY	2	GDV	0	4708	10448	2476	1	00	25	90	2	0000	
GREAT FALLS-WSFO		40	GFLM8	0	4730	11112	0	0	00	0	00	0	0000	
GREAT FALLS-WSMO	INTERNATIONAL	70	GTF	72775	4729	11122	3657	0	41	24	11	81	0220	
HARLOWTON		3	3HT	0	4626	10950	4160	2	00	6	21	1	0000	
HAVRE	CITY COUNTY	10	HVR	72777	4833	10946	2599	0	41	24	11	41	0000	
HELENA	AIRPORT	10	HLN	72772	4636	11200	3898	0	41	24	11	81	0000	
KALISPELL	GLACIER PARK INTNL	10	FCA	72779	4818	11416	2973	0	41	24	11	81	0000	
LEWISTOWN	MUNICIPAL	4	LWT	0	4703	10927	4146	0	00	24	11	81	0000	
LIVINGSTON	MISSION	4	LVM	0	4542	11026	4618	0	00	16	11	81	0000	
MILES CITY	MUNICIPAL	4	MLS	0	4626	10552	2634	0	00	24	11	81	0000	
MISSOULA	JOHNSON-BELL FIELD	10	MSO	72773	4655	11405	3189	0	41	24	11	81	0000	57
MONIDA		3	MQM	0	4434	11219	6785	2	00	10	21	2	0000	
SIDNEY	SDY-RICHLAND MUN	2	SDY	0	4743	10411	1979	0	00	25	90	2	0000	
THOMPSON FALLS		3	3TH	0	4736	11522	2380	2	00	6	21	2	0000	
WEST YELLOWSTONE	YELLOWSTONE	2	WYS	0	4441	11107	6644	1	00	14	11	2	0000	
WEST YELLOWSTONE		3	WEY	0	4439	11106	6669	0	00	8	41	82	0000	
WOLF POINT	INTERNATIONAL	2	OLF	0	4806	10534	1985	1	00	7	11	2	0000	
NEBRASKA														
AINSWORTH	MUNICIPAL	3	ANW	0	4235	9959	2587	1	00	13	11	1	0000	
ALLIANCE	MUNICIPAL	72	AIA	0	4203	10248	3930	1	00	18	11	1	0000	4S
BEATRICE	MUNICIPAL	3	BIE	0	4019	9645	1310	0	00	13	11	11	0000	

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
BROKEN BOW	MUNICIPAL	3	BBW	0	4126	9939	2538	1	00	13	11	2	0000	
BURWELL		3	K20	0	4147	9908	2180	0	00	4	21	2	0000	
CHADRON	MUNICIPAL	4	CDR	0	4250	10305	3315	0	00	24	11	81	0000	
COLUMBUS	MUNICIPAL	2	OLU	0	4126	9721	1443	1	00	13	11	1	0000	
GRAND ISLAND	HALL COUNTY REGIONAL	10	GRI	72552	4058	9819	1856	0	41	24	11	81	0000	65
HASTINGS	MUNICIPAL	2	HSI	0	4036	9826	1944	1	00	9	11	0	0000	
IMPERIAL		3	6V1	0	4032	10138	3284	0	00	16	21	81	0000	
KEARNEY	MUNICIPAL	2	EAR	0	4044	9900	2130	1	00	15	11	1	0000	
LEXINGTON	MUNICIPAL	2	LXN	0	4047	9946	2410	0	00	25	91	0	0000	
LINCOLN	MUNICIPAL	10	LNK	72551	4051	9645	1189	0	00	24	11	81	0000	
MCCOOK-BASIC/SAWRS	MUNICIPAL	3	MCK	0	4013	10035	2579	1	00	15	11	22	0000	
MULLEN		3	MHN	0	4203	10103	3260	1	00	12	11	12	0000	
NORFOLK	KARL STEFAN MEMORIAL	10	OFK	72556	4159	9726	1551	0	31	24	11	31	0000	4C
NORTH PLATTE	LEE BIRD FIELD	10	LBF	72562	4108	10041	2787	0	41	24	11	81	0220	4C
OMAHA FSS	EPPLEY AIRFIELD	4	OMA	72550	4118	9554	982	0	00	24	11	41	0000	
OMAHA-WSFO	NORTH OMAHA	40	3NO	72553	4122	9601	1331	0	00	0	00	0	0220	4C
SCOTTSBLUFF	COUNTY	10	BFF	72566	4152	10336	3958	0	00	24	11	81	0000	
SIDNEY-AMOS/FSS	MUNICIPAL	31	SNY	72561	4106	10259	4306	0	00	24	71	61	0000	
VALENTINE-BASIC	MILLER FIELD	11	VTN	72567	4252	10033	2598	0	00	24	71	81	0000	
NEVADA														
AUSTIN		3	U31	0	3930	11705	6608	0	00	4	21	0	0000	
BATTLE MOUNTAIN	LANDER COUNTY	3	BAM	0	4037	11652	4532	1	00	13	11	41	0000	
CALIENTE		1	P38	72487	3737	11431	4381	0	00	24	71	81	0000	
ELKO		10	EKLN2	0	4050	11546	5060	2	00	0	00	0	0000	
ELKO	MUNICIPAL	4	EKO	0	4050	11547	5077	0	00	24	11	81	0000	
ELY	YELLAND FIELD	10	ELY	72486	3917	11451	6262	0	41	24	11	81	0220	
LAS VEGAS	MCCARRAN INTNL	10	LAS	72386	3605	11510	2180	0	41	24	11	81	0000	4C
LOVELOCK	DERBY	4	LOL	0	4004	11833	3904	0	00	24	11	81	0000	
OWYHEE		3	OWY	0	4157	11606	5401	0	00	7	21	71	0000	
PYRAMID LAKE		9	963	0	3957	11937	3880	2	00	2	90	0	0000	
RENO	INTERNATIONAL	40	RNO	72488	3930	11947	4400	0	41	24	11	81	0000	
TONOPAH	MUNICIPAL	4	TPH	0	3804	11705	5434	0	25	24	11	81	0000	
TONOPAH		2	TNX	0	3747	11646	5540	0	00	0	91	0	0000	
WINNEMUCCA	MUNICIPAL	10	WMC	72583	4054	11748	4314	0	41	24	11	81	0220	
YUCCA FLAT		70	UCC	72385	3657	11603	3926	0	00	24	11	82	0220	
NEW HAMPSHIRE														
BERLIN	MUNICIPAL	7	BML3	72616	4435	7111	1158	1	32	25	10	AC	0000	

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
BOON ISLAND LS		9	12B	0	4307	7029	0	0	00	8	41	0	0000	
CONCORD	MUNICIPAL	10	CON	72605	4312	7130	346	0	41	24	11	81	0000	
ISLES OF SHOALS LS		9	26B	0	4258	7037	0	0	00	8	41	0	0000	
KEENE	DILLANT-HOPKINS	2	EEN	0	4254	7216	487	1	00	16	11	2	0000	
LACONIA	MUNICIPAL	2	LCI	0	4334	7126	546	2	00	12	11	2	0000	
LEBANON	REGIONAL	4	LEB	0	4338	7219	570	0	00	24	11	81	0000	
MANCHESTER	GRENIER FLD/MHT MUN	5	MHT	0	4256	7126	233	1	00	19	11	1	0000	
MT WASHINGTON		8	MWN	72613	4416	7118	6267	0	82	8	41	2	0000	
PORTSMOUTH HARBOR		9	25B	0	4304	7043	0	0	00	8	40	0	0000	
ROCHESTER	SKY HAVEN	2	6B1	0	4317	7056	322	1	00	25	90	0	0000	
WHITEFIELD	REGIONAL	2	HIE	0	4422	7133	1072	2	00	9	11	A0	0000	
WOLFEBORO		7	WOLN3	72613	4346	7114	720	0	21	0	00	0	0000	
NEW JERSEY														
ATLANTIC CITY	BADER FIELD	2	AIY	0	3921	7438	11	2	00	25	90	A0	0000	
ATLANTIC CITY	NAFEC POMONA	10	ACY	72407	3927	7434	67	0	41	24	11	41	0000	57
ATLANTIC CITY		9	55N	0	3923	7425	12	2	00	8	40	1	0000	
BARNEGAT LAS		9	N78	0	3946	7406	5	2	00	8	40	0	0000	
BEACH HAVEN		9	BEAN4	0	3944	7412	5	2	00	1	91	0	0000	
CAPE MAY	COUNTY	2	WWD	0	3901	7457	22	1	00	5	11	A0	0000	
CAPE MAY ANT		9	N91	0	3857	7453	5	2	00	8	41	1	0000	
FAIRFIELD	ESSEX COUNTY	5	CDW	0	4053	7417	175	0	00	9	61	0	0000	
FARMINGDALE	MONMOUTH COUNTY	2	BLM	0	4011	7407	155	0	00	3	21	A0	0000	
MANASQUAN INLET		9	54N	0	4006	7401	0	0	00	0	00	0	0000	
MILLVILLE	MUNICIPAL	4	MIV	0	3922	7504	76	0	00	24	11	81	0000	
MORRISTOWN	MUNICIPAL	5	MMU	0	4048	7425	187	1	00	17	11	A0	0000	
NEW BRUNSWICK-WSO/AG		10	NBKN4	0	4029	7426	0	0	00	0	00	0	0000	
NEWARK	INTERNATIONAL	10	EWR	72502	4042	7410	30	0	00	24	11	81	0000	
ROBBINSVILLE	TRENTON-TRA	2	TRA	0	4013	7436	119	0	00	25	90	A0	0000	
SANDY HOOK		9	56N	0	4028	7401	15	2	00	8	41	0	0000	
TETERBORO	AIRPORT	3	TEB	0	4051	7403	7	1	00	24	11	1	0000	
TRENTON		10	TRTN4	0	4013	7446	190	0	00	0	00	0	0000	
TRENTON	MERCER CO	5	TTN	0	4017	7449	213	1	00	24	11	2	0000	
WILDWOOD		9	52N	0	3900	7449	7	2	00	25	91	0	0000	
NEW MEXICO														
ALAMOGORDO	MUNICIPAL	2	ALM	0	3250	10600	4197	1	00	9	12	A2	0000	
ALBUQUERQUE-RADAR		70	ZAB	0	3510	10634	5318	2	00	0	00	0	0000	FA
ALBUQUERQUE-WSFO	INTERNATIONAL	40	ABQ	72365	3503	10637	5314	0	41	24	11	81	2220	

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
CARLSBAD	CAVERN CITY AIR T	4	CNM	0	3220	10416	3261	0	00	24	11	81	0000	
CHAMA		3	E33	0	3654	10635	7750	0	00	1	00	0	0000	
CLAYTON	MUNICIPAL	11	CAO	72360	3627	10309	4972	0	00	24	71	31	0000	
CLINES CORNER		1	P70	0	3455	10535	6874	2	00	8	41	0	0000	
CORONA	LINCOLN COMPRESS	3	4CR	0	3406	10541	6500	2	00	1	01	12	0000	
DEMING	MUNICIPAL	4	DMN	0	3215	10742	4324	0	00	24	11	81	0000	
FARMINGTON CST	MUNICIPAL	5	FMN	0	3645	10814	5502	0	00	24	11	41	0000	
GALLUP	MUNICIPAL	4	GUP	0	3531	10847	6468	0	00	24	11	81	0000	
GRANTS	GNT-MILAN MUN	3	GNT	0	3510	10754	6520	0	00	2	21	2	0000	
HOBBS	LEA CO	5	HOB	0	3241	10312	3666	0	00	17	11	31	0000	
LAS CRUCES	MUNICIPAL	3	LRU	0	3217	10655	4454	2	00	1	01	2	0000	
LAS VEGAS	MUNICIPAL	4	LVS	0	3539	10509	6875	0	00	24	11	81	0000	
LOS ALAMOS	MUNICIPAL	2	Q03	0	3553	10617	7150	2	00	24	11	2	0000	
MORIARTY		3	4MY	0	3459	10603	6220	2	00	1	11	12	0000	
ROSWELL	INDUSTRIAL AIR CTR	14	ROW	72268	3318	10432	3669	0	11	24	11	81	1000	
SANTA FE	SAF COUNTY MUNICIPAL	5	SAF	0	3537	10605	6308	0	00	17	11	31	0000	
SILVER CITY	SVC-GRANT COUNTY	2	SVC	0	3238	10810	5443	1	00	7	11	2	0000	
SOCORRO		3	ONM	0	3404	10654	4617	2	00	2	21	12	0000	
TAOS		3	E23	0	3625	10534	6965	2	00	1	01	12	0000	
TORREON		3	4SL	0	3548	10711	6700	2	00	1	01	2	0000	
TRUTH OR CONSEQUENCE	MUNICIPAL	31	TCS	0	3314	10716	4858	0	00	24	71	31	0000	
TUCUMCARI	MUNICIPAL	4	TCC	0	3511	10336	4039	0	00	24	11	81	0000	
NEW YORK														
ALBANY	COUNTY	40	ALB	72518	4245	7348	292	0	41	24	11	41	0220	4C
AMBROSE LS		9	N28	74499	4027	7349	94	0	00	8	40	0	0000	
AMITYVILLE	ZAHNS	2	AYZ	0	4042	7324	54	1	00	10	11	A0	0000	
BAY SHORE (FIRE IS)		9	45N	0	4038	7316	15	2	00	8	41	0	0000	
BETHPAGE	GRUMMAN	2	BPA	0	4044	7329	168	0	00	12	12	A0	0000	
BINGHAMTON	BROOME CO	10	BGM	72515	4213	7559	1629	0	41	24	11	41	0000	4S
BUFFALO		9	19G	0	4253	7853	0	0	00	12	30	0	0000	
BUFFALO	GRTR BUFFALO INT	40	BUF	72528	4256	7844	706	0	41	24	11	81	0220	57
CALVERTON	PECONIC RIVER	2	CTO	0	4055	7247	75	1	00	9	12	A0	0000	
DANSVILLE	MUNICIPAL	7	DSV	72523	4234	7743	686	0	31	0	00	0	0000	
EATONS NECK		9	34N	0	4057	7324	0	0	00	8	41	0	0000	
ELMIRA	CHEMUNG CO	4	ELM	0	4210	7654	954	0	00	24	11	81	0000	
EXECUTION ROCKS LS		9	N84	0	4053	7344	25	0	00	8	40	0	0000	
FARMINGDALE	REPUBLIC	5	FRG	0	4044	7326	134	0	00	17	11	2	0000	
GLENS FALLS	WARREN CO	4	GFL	0	4321	7337	333	0	00	24	11	81	0000	
ISLIP	LONG IS/MACARTHUR	4	ISP	0	4047	7306	108	0	00	24	11	81	0000	
ITHACA	TOMPKINS CO	2	ITH	0	4229	7628	1098	0	00	19	11	A0	0000	
JAMESTOWN	MUNICIPAL	2	JHW	0	4209	7915	1723	1	00	18	11	2	0000	

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
MASSENA	RICHARDS MUNICIPAL	4	MSS	0	4456	7451	208	0	00	24	11	81	0000	
MONTAUK POINT LS		9	48N	0	4104	7156	3	2	00	8	41	0	0000	
MONTGOMERY	ORANGE COUNTY	2	MGJ	0	4130	7415	375	0	00	25	90	A0	0000	
MONTICELLO	SULLIVAN CTY INTL	2	MSV	0	4142	7448	1413	0	00	14	11	A0	0000	
MORICHES		9	49N	0	4047	7245	4	2	00	8	41	0	0000	
NEW YORK		40	NYC	0	4051	7355	87	0	00	0	00	0	0000	57
NEW YORK	PAN AM HELIPORT	2	JPB	0	4045	7359	853	1	00	25	92	0	0000	
NEW YORK (FT TOTTEN)		70	NFTN6	74486	4047	7346	26	0	00	0	00	0	0220	
NEW YORK JFK	KENNEDY INTNL	10	JFK	74486	4039	7347	22	0	41	24	11	1	0000	
NEW YORK LGA	LAGUARDIA FIELD	10	LGA	72503	4046	7354	31	0	41	24	11	81	0000	
NEW YORK RH		80	GARN6	0	0	0	0	0	00	0	00	0	0000	
NEWBURGH	STEWART	2	SWF	0	4130	7406	471	0	00	17	11	1	0000	
NIAGARA		9	13G	0	4316	7904	0	0	00	12	30	0	0000	
NIAGARA FALLS	INTERNATIONAL	5	IAG	0	4306	7857	590	1	00	24	11	1	0000	
OGDENSBURG	INTERNATIONAL	2	OGS	0	4441	7528	300	0	00	18	12	A0	0000	
ONEONTA	MUNICIPAL	2	N66	74484	4231	7504	1775	0	00	25	91	A0	0000	
OSWEGO		9	28G	0	4328	7631	255	0	00	12	41	0	0000	
PLATTSBURG	CLINTON CO	2	PLB	0	4441	7331	371	1	00	17	11	A0	0000	
POUGHKEEPSIE	DUTCHESS CO	4	POU	0	4138	7353	162	0	00	24	11	81	0000	
ROCHESTER	ROC-MONROE CO	10	ROC	72529	4307	7740	555	0	41	24	11	41	0000	
ROCHESTER LS		9	26G	0	4315	7736	0	0	00	12	41	0	0000	
ROCKAWAY		9	50N	0	4034	7353	10	2	00	8	41	0	0000	
SARANAC LAKE	ADIRONDACK	2	SLK	0	4423	7412	1659	1	00	9	11	2	0000	
SCHENECTADY	COUNTY	2	SCH	0	4251	7357	378	1	00	16	11	A0	0000	
SHORT BEACH		9	51N	0	4035	7333	2	2	00	8	41	0	0000	
SYRACUSE	SYR HANCOCK INTNL	10	SYR	72519	4307	7607	408	0	41	24	11	81	0000	
UTICA	ONEIDA CO	4	UCA	0	4309	7523	744	0	00	24	11	81	0000	
WATERTOWN	INTERNATIONAL	4	ART	0	4400	7601	333	0	00	24	11	81	0000	
WESTHAMPTON BEACH	SUFFOLK COUNTY	2	FOK	0	4051	7238	67	1	00	0	00	0	0000	
WHITE PLAINS	WESTCHESTER CO	3	HPN	0	4104	7343	443	0	00	24	11	41	0000	
NORTH CAROLINA														
ASHEVILLE	MUNICIPAL	10	AVL	72315	3526	8233	2170	0	41	24	11	81	0000	
CAPE HATTERAS		10	HAT	72304	3516	7533	11	0	41	24	11	41	0220	65
CAPE LOOKOUT		9	77W	0	3436	7632	13	2	00	8	40	0	0000	
CHARLOTTE	DOUGLAS MUN	10	CLT	72314	3513	8056	769	0	41	24	11	81	0000	
ELIZABETH CITY	CG AIR BASE MUN	4	ECG	74694	3616	7611	13	0	00	15	11	61	0000	
FAYETTEVILLE	MUN GRANNIS FD	5	FAY	0	3500	7853	196	0	00	24	11	1	0000	
FRYING PAN LS		9	46W	74699	3329	7735	0	0	00	8	40	0	0000	
GREENSBORO	GSO HI PT WSTN SALEM	10	GSO	72317	3605	7957	886	0	41	24	11	41	0220	
GREENVILLE	PITT-GREENVILLE	2	PGV	0	3538	7723	30	0	00	7	11	0	0000	
HICKORY	MUNICIPAL	4	HKY	0	3545	8123	1188	0	00	24	11	81	0000	

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
HOT SPRINGS		3	HSS	0	3554	8249	1480	2	00	7	11	2	0000	
JACKSONVILLE	ALBERT J ELLIS	2	OAJ	0	3450	7737	94	1	00	15	11	A0	0000	
KINSTON	STALLINGS	2	ISO	0	3519	7738	93	1	00	18	11	A0	0000	
NEW BERN	SIMMONS-NOTT	4	EWN	0	3505	7703	24	0	00	24	11	81	0000	
OAK ISLAND		9	78W	0	3353	7801	0	0	00	8	40	0	0000	
OCRACOKE		9	45W	0	3507	7559	6	2	00	8	40	0	0000	
OREGON INLET		9	79W	0	3546	7531	0	0	00	8	20	2	0000	
RALEIGH	RALEIGH-DURHAM	40	RDU	72306	3552	7847	441	0	41	24	11	41	0000	4C
ROCKY MOUNT-WILSON	AIRPORT	4	RWI	0	3551	7753	158	0	00	24	11	81	0000	
SOUTHERN PINES	PINEHURST-SOPINES	2	SOP	0	3514	7924	0	0	00	10	11	0	0000	
WILMINGTON	NEW HANOVER CO	10	ILM	0	3416	7755	38	0	00	24	11	81	0000	57
WINSTON SALEM (LWRS)	SMITH REYNOLDS	32	INT	0	3608	8014	978	0	00	24	11	1	0000	
WRIGHTSVILLE BEACH		9	1W9	0	3411	7749	10	2	00	25	90	0	0000	
NORTH DAKOTA														
BISMARCK	MUNICIPAL	40	BIS	72764	4646	10045	1660	0	41	24	11	81	0220	4C
DEVILS LAKE	MUNICIPAL	2	DVL	0	4807	9854	1450	1	00	9	11	2	0000	
DEVILS LAKE		7	DVLN8	72757	4807	9852	1478	0	31	0	00	0	0000	
DEVILS LAKE		1	P11	72758	4806	9852	1438	0	00	24	71	41	0000	
DICKINSON	MUNICIPAL	4	DIK	0	4647	10248	2583	0	00	24	11	81	0000	
FARGO	HECTOR	10	FAR	72753	4654	9648	899	0	41	24	11	41	0000	4S
GRAND FORKS	INTERNATIONAL	4	GFK	0	4757	9711	832	0	00	24	11	81	0000	
JAMESTOWN	MUNICIPAL	4	JMS	0	4655	9841	1494	0	00	24	11	81	0000	
MINOT	INTERNATIONAL	4	MOT	0	4816	10117	1714	0	00	24	11	81	0000	
ROSEGLEN		1	P24	72765	4745	10150	2047	0	00	24	71	41	0000	
WILLISTON	SLOULIN FD INTNL	10	ISN	72767	4811	10338	1905	0	41	24	11	81	0000	4C
OHIO														
AKRON	MUNICIPAL	5	AKR	0	4102	8128	1052	0	00	7	11	A0	0000	
AKRON	AKRON CANTON REG	10	CAK	72521	4055	8126	1236	0	41	24	11	81	0000	4C
ASHTABULA LS		9	20G	0	4155	8048	586	0	00	12	30	0	0000	
CINCINNATI	MUN LUNKEN FD	4	LUK	0	3906	8426	497	0	00	24	11	41	0000	
CINCINNATI-RFC		60	CINO1	0	3907	8430	0	0	00	0	00	0	0000	
CINCINNATI-WSMO	ABBE OBSERVATORY	70	CNNO1	0	3909	8431	627	0	00	0	00	0	0000	
CINCINNATI-WSO	GR CINCINNATI	10	CVG	72421	3903	8440	877	0	41	24	11	81	0000	57
CLEVELAND	CUYAHOGA CO	5	CGF	0	4134	8129	889	1	00	17	11	1	0000	
CLEVELAND	HOPKINS INTNL	40	CLE	72524	4125	8152	805	0	41	24	11	41	0000	4C
CLEVELAND	BURKE LAKEFRONT	5	BKL	0	4131	8141	584	1	00	17	11	1	0000	
COLUMBUS	PORT COLUMBUS INTL	10	CMH	72428	4000	8253	833	0	41	24	11	81	0000	4C

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
COLUMBUS	BOLTON FIELD	2	2I4	0	3954	8308	952	0	00	17	11	A0	0000	
COLUMBUS	OHIO STATE UNIV.	5	OSU	0	4005	8304	904	0	00	17	11	A0	0000	
DAYTON-WSMO		70	DAN01	72429	3952	8407	979	0	00	0	00	0	0220	
DAYTON-WSO	J M COX DAY MUN	10	DAY	72429	3954	8412	1003	0	41	24	11	81	0000	
ELYRIA	LORAIN COUNTY REG	2	22G	0	4121	8211	794	1	00	25	90	A0	0000	
FINDLAY	AIRPORT	4	FDY	0	4101	8340	803	0	00	24	11	81	0000	
GALION	AIRPORT	2	GQQ	0	4044	8245	1295	1	00	25	91	0	0000	
HAMILTON	AIRPORT	2	HAO	0	3922	8431	674	0	00	25	90	A0	0000	
JEFFERSON	ASHTABULA	2	7G2	0	4147	8042	923	0	00	12	11	A0	0000	
LIMA	ALLEN COUNTY	2	AOH	0	4042	8402	975	1	00	15	00	A0	0000	
LORAIN		9	27G	0	4128	8211	580	0	00	12	30	0	0000	
MANSFIELD	LAHM MUNICIPAL	15	MFD	0	4049	8231	1312	0	00	24	11	41	0000	
MARBLEHEAD LS		9	21G	0	4133	8244	644	0	00	12	30	0	0000	
MIAMISBURG	DAYTON GENERAL	2	MGY	0	3935	8413	961	1	00	25	91	0	0000	
OXFORD	MIAMI UNIVERSITY	2	OXD	0	3930	8447	1025	0	00	25	90	0	0000	
TOLEDO		9	24G	0	4142	8327	0	0	00	12	31	0	0000	
TOLEDO	TOL EXPRESS	10	TOL	72536	4136	8348	692	0	41	24	11	81	0000	
WILLOUGHBY	LOST NATION	2	LNN	0	4141	8124	651	0	00	4	21	A0	0000	
YOUNGSTOWN	MUNICIPAL	10	YNG	72525	4116	8040	1186	0	41	24	11	81	0000	
ZANESVILLE	MUNICIPAL	4	ZZV	0	3957	8154	902	0	00	24	11	81	0000	
OKLAHOMA														
ARDMORE-LAWRS/BASIC	MUNICIPAL	33	ADM	0	3418	9701	772	0	00	24	11	1	0000	
BARTLESVILLE	PHILLIPS	2	BVO	0	3645	9600	723	0	00	12	11	A2	0000	
CLINTON .(BURNS FLAT)	CLINTON SHERMAN	5	CSM	0	3521	9912	1923	1	00	12	12	1	0000	
ENID	WOODRING FIELD MUN	2	WDG	0	3623	9748	1163	1	00	7	91	A0	0000	
GAGE	INTERMEDIATE FLD	4	GAG	0	3618	9946	2202	0	00	24	11	81	0000	
HOBART	MUNICIPAL	4	HBR	0	3500	9903	1570	0	00	24	11	81	0000	
LAWTON	MUNICIPAL	2	LAW	0	3434	9825	1108	0	00	19	11	A0	0000	
MCALESTER	MUNICIPAL	4	MLC	0	3453	9547	770	0	00	24	11	81	0000	
OKLAHOMA CITY	WILEY POST	4	PWA	0	3532	9738	1299	1	00	24	11	A1	0000	
OKLAHOMA CITY	WILL ROGERS WORLD	40	OKC	72353	3524	9736	1304	0	41	24	11	81	0220	57
PONCA CITY	MUNICIPAL	4	PNC	0	3644	9706	998	0	00	24	11	81	0000	
RICH MOUNTAIN		1	PGO	72341	3441	9437	2660	0	00	24	71	41	0000	
TULSA	RIVERSIDE	5	RVS	0	3602	9559	680	0	00	16	11	A0	0000	
TULSA	INTERNATIONAL	10	TUL	72356	3612	9554	676	0	41	24	11	81	0000	4C
TULSA-RFC		60	TUL02	0	3609	9600	703	2	00	0	00	0	0000	
OREGON														

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
ASTORIA	CLATSOP CO	10	AST	72791	4609	12353	22	0	41	24	11	81	0000	
BAKER	MUNICIPAL	4	BKE	0	4450	11749	3373	0	00	24	11	81	0000	
BONNEVILLE DAM		9	20S	0	4538	12157	60	2	00	25	90	0	0000	
BROOKINGS		3	4BK	0	4203	12417	85	0	00	7	21	72	0000	
BURNS		70	4BW	72683	4335	11903	4170	0	62	16	21	62	0000	
CAPE BLANCO LN		9	92S	0	4250	12434	188	0	00	4	41	10	0000	
CASCADE LOCKS	AIRPORT	3	CZK	0	4541	12153	158	2	00	6	31	2	0000	
CHETCO RS		9		0	4209	12416	0	0	00	6	41	0	0000	
COOS BAY		9	83S	0	4321	12420	75	2	00	4	41	0	0000	
CORVALLIS-WSO/AG		10		0	4438	12312	225	2	00	0	00	0	0000	
EUGENE	MAHLON SWEET FLD	10	EUG	72693	4407	12313	373	0	82	24	11	81	0000	
HILLSBORO	PORTLAND-HLSBORO	5	HIO	0	4532	12257	199	1	00	24	11	1	0000	
KLAMATH FALLS	MUNICIPAL	10	LMT	0	4209	12144	4102	0	00	0	00	0	0000	
LA GRANDE	MUNICIPAL	2	IGD	0	4518	11806	2713	0	00	4	42	0	0000	
LAKEVIEW		3	4LW	0	4213	12021	4764	0	00	7	41	72	0000	
MEACHAM	EMERGENCY	1	MEH	0	4531	11824	3726	0	00	24	71	81	0000	
MEDFORD	MFR-JACKSON CTY	10	MFR	72597	4222	12252	1329	0	41	24	11	81	0220	65
NEWPORT		3	JNW	0	4438	12403	159	0	00	8	41	1	0000	
NORTH BEND	MUNICIPAL	4	OTH	0	4325	12415	17	0	00	24	11	81	0000	
PACIFIC CITY		9	51S	0	4512	12357	10	2	00	1	01	10	0000	
PENDLETON	MUNICIPAL	10	PDT	72688	4541	11851	1495	0	41	24	11	41	0000	
PORTLAND-RFC		60	PDX03	0	4532	12240	0	0	00	0	00	0	0000	
PORTLAND-WSFO	INTERNATIONAL	40	PDX	72698	4536	12236	39	0	41	24	11	81	0000	40
PORTLAND-WSO/FW		10		0	4531	12241	95	0	00	0	00	0	0000	
REDMOND	ROBERTS	4	RDM	0	4416	12109	3084	0	00	24	11	81	0000	
ROSEBURG-BASIC/SAWRS	MUNICIPAL	3	RBG	0	4314	12322	510	0	00	13	11	1	0000	
SALEM	MCNARY FIELD	10	SLE	72694	4455	12301	201	0	41	24	11	41	0220	
SALEM-WSO/FW		10	SAL03	0	4455	12300	0	0	00	0	00	0	0000	
SEASIDE		9		0	4560	12355	0	0	00	25	90	0	0000	
SEXTON SUMMIT-BASIC		71	SXT	0	4237	12322	3841	0	00	24	71	31	0000	
SIUSLAW RIVER		9	85S	0	4400	12407	40	2	00	4	41	0	0000	
THE DALLES	MUNICIPAL	4	DLS	0	4537	12109	210	0	00	17	11	61	0000	
TILLAMOOK BAY		9	88S	0	4534	12355	50	2	00	5	40	0	0000	
TROUTDALE-AMOS/LAWRS	AIRPORT	31	TTD	0	4533	12224	32	0	00	24	11	1	0000	
UMPQUA RIVER		9	90S	0	4341	12410	135	2	00	5	40	0	0000	
YAQUINA BAY		9	95S	0	4437	12403	0	0	00	6	40	0	0000	
YOUNGS BAY BRIDGE		9		0	4611	12352	0	0	00	25	90	0	0000	
PENNSYLVANIA														
ALLENTOWN	A BETHLEHEM EASTON	10	ABE	72517	4039	7526	385	0	41	24	11	81	0000	
ALTOONA	BLAIR CO	4	AOO	0	4018	7819	1469	0	00	24	11	81	0000	
BEAVER FALLS	BEAVER COUNTY	2	G01	0	4046	8024	1252	1	00	2	42	0	0000	

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
BRADFORD	REGIONAL	4	BFD	0	4148	7838	2150	0	00	24	11	81	0000	
DUBOIS	JEFFERSON CO	4	DUJ	0	4111	7854	1824	0	00	24	11	81	0000	
ERIE	INTERNATIONAL	10	ERI	72526	4205	8011	737	0	00	24	11	81	0000	4C
ERIE HARBOR		9	25G	0	4207	8005	578	2	00	12	11	0	0000	
FRANKLIN	CHESS LAMBERTON	2	FKL	0	4123	7952	1540	1	00	13	11	2	0000	
HARRISBURG	CAPITOL CITY	4	CXY	0	4013	7651	351	0	00	24	11	41	0000	
HARRISBURG-WSO/RFC		16	HRBP1	0	4016	7653	0	0	00	0	00	0	0000	4C
JOHNSTOWN-FSS/SAWRS	JST-CAMBIA CO	32	JST	0	4019	7850	2294	0	00	16	11	1	0000	
LANCASTER	MUNICIPAL	5	LNS	0	4008	7618	464	0	00	16	11	AC	0000	
LATROBE	AIRPORT	3	LBE	0	4017	7924	1161	0	00	16	11	A1	0000	
MIDDLETOWN	HARSBG INTL OLMSTEAD	5	MDT	0	4012	7646	318	0	00	24	11	1	0000	
PHILADELPHIA	N PHILADELPHIA	3	PNE	0	4005	7501	119	0	00	24	11	1	0000	
PHILADELPHIA EMSU		70	PLDP1	72408	3955	7511	1	0	00	0	00	0	0000	
PHILADELPHIA-AMBLER	WINGS FIELD	2	N67	0	4006	7516	320	0	00	25	92	0	0000	
PHILADELPHIA-WSFO		40	PHLP1	0	3957	7509	35	2	00	0	00	0	0000	
PHILADELPHIA-WSO	INTERNATIONAL	10	PHL	72408	3953	7515	28	0	41	24	11	81	0000	
PHILIPSBURG	MID-STATE	4	PSB	0	4053	7805	1914	0	00	24	11	81	0000	
PITTSBURGH	ALLEGHENY CO	4	AGC	0	4021	7956	1273	0	00	24	11	1	0000	
PITTSBURGH	GREATER PITTS INTL	10	PIT	72520	4030	8013	1225	0	41	24	11	81	0000	
PITTSBURGH-MN TWNSHP		70	PTBP1	72520	4032	8014	1183	0	00	0	00	0	0220	65
PITTSBURGH-WSFO		40	PITF	0	4027	8000	1017	0	00	0	00	0	0000	
READING	MUN, GEN SPAATZ FLD	5	RDG	0	4023	7558	353	0	00	24	11	1	0000	
THOMASVILLE	YORK AIRPORT	2	THV	0	3955	7652	486	1	00	25	92	0	0000	
TOBYHANNA		3	7TB	0	4111	7525	1920	2	00	8	41	2	0000	
UNIVERSITY PARK	AIRPORT	2	N36	0	4051	7751	1220	1	00	4	22	A0	0000	
WILKESBARRE SCRANTON	AIRPORT	10	AVP	72513	4120	7544	948	0	41	24	11	81	0000	
WILLIAMSPORT	IPT-LYCOMING CO	14	IPT	72514	4115	7655	525	0	00	24	11	81	0000	
RHODE ISLAND														
BLOCK ISLAND-BASIC	BID STATE	11	BID	0	4110	7135	118	0	00	24	71	31	0000	
NEWPORT	STATE	2	2B4	0	4132	7117	180	0	00	25	90	A0	0000	
POINT JUDITH		9	PJI	0	4122	7129	2	2	00	0	00	0	0000	
PROVIDENCE	T F GREEN STATE	10	PVD	72507	4144	7126	62	0	41	24	11	81	0000	
SMITHFIELD	NOTH CENTRAL STATE	2	SFZ	0	4155	7129	451	0	00	2	21	0	0000	
WESTERLY	STATE	2	WST	0	4121	7148	81	1	00	10	11	A0	0000	
SOUTH CAROLINA														
ANDERSON	COUNTY	4	AND	0	3430	8243	773	0	00	24	11	61	0000	
CHARLESTON	MUNICIPAL	10	CHS	72208	3254	8002	48	0	41	24	11	81	0220	57

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
CHARLESTON		9	86J	0	3246	7951	9	2	00	5	41	1	0000	
CLEMSON-WSO/AG		10	CLMS1	0	3441	8249	819	2	00	0	00	0	0000	
COLUMBIA	METROPOLITAN	40	CAE	72310	3357	8107	225	0	41	24	11	41	0000	4C
COLUMBIA	OWENS FIELD	2	CUB	0	3358	8100	210	1	00	25	90	0	0000	
FLORENCE	CITY-COUNTY	4	FLO	0	3411	7943	151	0	00	24	11	81	0000	
FOLLY BEACH LN		9	84J	0	3241	7953	10	2	00	4	40	0	0000	
GEORGETOWN LS		9	85J	0	3313	7911	0	0	00	5	40	0	0000	
GREENVILLE	MUNICIPAL DT	5	GMU	0	3451	8221	1040	0	00	17	11	A0	0000	
GREENVILLE-SPRTNBG	GRNV-SPA JET AGE	10	GSP	72312	3454	8213	971	0	41	24	11	41	0000	
GREENWOOD	COUNTY	2	GRD	0	3415	8209	631	1	00	25	92	0	0000	
HILTON HEAD IS	AIRPORT	2	49J	0	3213	8042	20	2	00	25	90	A0	0000	
MYRTLE BEACH NORTH	AIRPORT	4	CRE	0	3349	7843	33	1	00	9	11	21	0000	
SPARTANBURG	DT MEMORIAL	5	SPA	0	3455	8157	824	0	00	16	11	A0	0000	
SOUTH DAKOTA														
ABERDEEN	REGIONAL	10	ABR	72659	4527	9826	1300	0	41	24	11	81	0000	
BROOKINGS	MUNICIPAL	2	BKX	0	4418	9648	1637	1	00	14	11	2	0000	
CHAMBERLAIN		1	CHB	0	4348	9919	1740	0	00	24	71	0	0000	
HURON	REGIONAL	10	HON	72654	4423	9813	1289	0	41	24	11	81	0220	65
LEMMON		3	Y22	0	4556	10210	2602	0	00	4	51	42	0000	
MITCHELL	MUNICIPAL	2	MHE	0	4346	9802	1302	1	00	17	11	2	0000	
MOBRIDGE		3	Y26	0	4532	10026	1664	0	00	8	41	82	0000	
PHILIP	AIRPORT	3	PHP	0	4403	10136	2212	0	00	17	21	81	0000	
PICKSTOWN		7	PKSS2	72652	4304	9832	1485	0	41	0	00	0	0000	
PIERRE	MUNICIPAL	4	PIR	0	4423	10017	1726	0	00	24	11	81	0000	
RAPID CITY	REGIONAL	10	RAP	72662	4403	10304	3168	0	41	24	11	81	0220	4C
REDIG		1	REJ	72661	4516	10332	3035	0	00	24	71	0	0000	
SIOUX FALLS	FOSS FIELD	40	FSD	72651	4334	9644	1427	0	41	24	11	81	0000	4C
WATERTOWN	MUNICIPAL	4	ATY	0	4455	9709	1740	0	00	24	11	81	0000	
YANKTON	GURNEY MUN	2	YKN	0	4255	9723	1303	1	00	13	11	2	0000	
TENNESSEE														
BRISTOL	TRI-CITY	10	TRI	72318	3629	8224	1525	0	00	24	11	81	0000	65
CHATTANOOGA	LOVELL	10	CHA	72324	3502	8512	688	0	41	24	11	81	0000	
CLARKSVILLE	OUTLAW FIELD	2	CKV	0	3637	8725	545	1	00	18	11	A2	0000	
CROSSVILLE	MEMORIAL	4	CSV	0	3557	8505	1870	0	00	24	11	81	0000	
DYERSBURG	MUNICIPAL	4	DYR	0	3601	8924	345	0	00	17	11	61	0000	
JACKSON	MCKELLAR	4	MKL	0	3536	8855	422	0	00	24	11	81	0000	
KNOXVILLE	MCGHEE-TYSON	10	TYS	72326	3549	8359	980	0	41	24	11	81	0000	

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
KNOXVILLE	DOWNTOWN ISLAND	5	DKX	0	3558	8353	833	1	00	14	11	A0	0000	
MEMPHIS-WSFO	INTERNATIONAL	40	MEM	72334	3503	9000	284	0	41	24	11	81	0000	
MEMPHIS-WSMO	NAVAL AIR STATION	70	NQA	0	3521	8952	389	0	00	0	00	0	0000	65
NASHVILLE-WSMO		70	NSHT1	72327	3615	8634	591	0	00	0	00	0	0220	65
NASHVILLE-WSO	METROPOLITAN	10	BNA	72327	3607	8641	605	0	41	24	11	81	0000	
TEXAS														
ABILENE	MUNICIPAL	10	ABI	72266	3225	9941	1790	0	41	24	11	81	0000	40
ALICE	INTERNATIONAL	4	ALI	0	2744	9802	180	0	00	24	11	81	0000	
AMARILLO	AMA AIR TERMINAL	10	AMA	72363	3514	10142	3604	0	41	24	11	81	0220	57
AUSTIN	MUNICIPAL	10	AUS	72254	3018	9742	621	0	41	24	11	81	0000	40
BROWNSVILLE	INTERNATIONAL	10	BRO	72250	2554	9726	20	0	41	24	11	81	0220	57
BROWNWOOD	MUNICIPAL	2	BWD	0	3148	9857	1386	0	00	8	11	2	0000	
CHILDRESS	MUNICIPAL	4	CDS	0	3426	10017	1952	0	00	24	11	81	0000	
CLEAR LAKE CITY	METRO STOLPORT	2	CLC	0	2933	9508	39	0	00	25	90	A0	0000	
COLLEGE STATION	EASTERWOOD	4	CLL	0	3035	9622	328	0	00	24	11	81	0000	
COLLEGE STATION ESSC		10	CLL	0	3036	9620	0	0	00	0	00	0	0000	
CORPUS CHRISTI	INTERNATIONAL	10	CRP	72251	2746	9730	44	0	41	24	11	81	0000	40
COTULLA-FSS/BASIC	MUNICIPAL	33	COT	0	2827	9913	479	0	00	24	11	81	0000	
DALHART	MUNICIPAL	4	DHT	0	3601	10233	3997	0	00	24	11	81	0000	
DALLAS	LOVE FIELD	4	DAL	72258	3251	9651	488	0	00	24	11	41	0000	
DALLAS	ADDISON	5	ADS	0	3258	9650	643	1	00	17	11	A0	0000	
DALLAS	REDBIRD	5	RBD	0	3241	9652	660	1	00	16	11	A0	0000	
DALLAS/FT WORTH	DAL/FT WORTH REG	70	DFW	72259	3254	9702	596	0	41	24	11	81	0000	
DEL RIO	INTERNATIONAL	10	DRT	72261	2922	10055	1027	0	41	24	11	81	0220	
EL PASO	INTERNATIONAL	10	ELP	72270	3148	10624	3916	0	41	24	11	81	0220	
FREEPORT		9	8R8	0	2857	9518	4	2	00	8	40	1	0000	
FT WORTH	MEACHAM	4	FTW	0	3249	9721	706	0	00	24	11	1	0000	
FT WORTH RH		80	FTRT2	0	0	0	0	0	00	0	00	0	0000	
FT WORTH-WSFO/RFC		46	FTWT2	0	3245	9720	616	2	00	0	00	0	0000	
GALVESTON		10	GLS	72242	2918	9448	54	0	41	0	00	0	0000	57
GALVESTON-AMOS/FSS	SCHOLES FIELD	31	GLS	0	2916	9452	9	0	00	24	71	1	0000	
GREENVILLE	MAJORS FIELD	2	GVT	0	3304	9604	544	1	00	9	12	A2	0000	
GUADALUPE PASS		1	GDP	72262	3150	10448	5460	0	00	24	71	1	0000	
HARLINGEN-LAWRS/SR	INDUSTRIAL AIR PARK	32	HRL	0	2613	9740	35	1	00	17	11	A0	0000	
HONDO		70	HDO	0	2921	9910	990	0	00	0	00	0	0000	65
HOUSTON	WM P HOBBY	4	HOU	0	2939	9517	47	0	00	24	11	1	0000	
HOUSTON AREA-WSO		10	HOST2	72243	2925	9513	42	2	00	0	00	0	0001	
HOUSTON-WSMO	INTERCONTINENTAL	70	IAH	72243	2958	9521	108	0	41	24	11	81	0000	
JUNCTION-AMOS/BASIC	KIMBLE CO	1	JCT	74740	3030	9945	1713	0	03	24	71	32	0000	
KILLEEN	MUNICIPAL	2	ILE	0	3105	9741	846	0	00	25	90	A0	0000	
LAKE JACKSON	BRAZORIA COUNTY DOW	2	LJN	0	2902	9527	12	0	00	25	90	A0	0000	

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
LAREDO-LAWRS/SAWRS	INTERNATIONAL	32	LRD	0	2732	9927	504	0	00	17	11	A1	0000	
LONGVIEW	GREGG CO	5	GGG	0	3223	9443	373	0	00	24	11	1	0000	
LONGVIEW-WSMO		70	GGG	72247	3221	9439	407	0	00	0	01	0	0220	4S
LUBBOCK-WSFO	REGIONAL	40	LBB	72267	3339	10149	3241	0	41	24	11	81	0000	4C
LUBBOCK-WSO/AG		10	LBKT2	0	3339	10151	3245	2	00	0	00	0	0000	
LUFKIN	ANGELINA CO	4	LFK	0	3114	9445	316	0	00	24	11	81	0000	
MARFA-AMOS/BASIC	MUNICIPAL	1	MRF	72264	3022	10401	4858	0	00	6	71	52	0000	
MCALLEN	MILLER INTNL	4	MFE	0	2611	9814	112	0	00	24	11	81	0000	
MIDLAND	REGIONAL AIR TERM	10	MAF	72265	3157	10211	2862	0	41	24	11	81	0220	65
MINERAL WELLS	MUNICIPAL	4	MWL	0	3247	9804	972	0	00	17	11	61	0000	
NACOGDOCHES	EAST TEXAS REGIONAL	2	OCH	0	3135	9442	372	0	00	25	91	2	0000	
PALACIOS	MUNICIPAL	4	PSX	0	2843	9615	15	0	00	24	11	81	0000	
PARIS	COX FIELD	2	PRX	0	3338	9527	547	1	00	25	91	2	0000	
PLAINVIEW	HALE CO	5	PVW	0	3410	10143	3372	1	00	17	11	2	0000	
PORT ARANSAS		9	9R1	0	2750	9704	4	2	00	8	41	1	0000	
PORT ARTHUR	JEFFERSON CO	15	BPT	72241	2957	9401	22	0	00	24	11	51	0000	
PORT ISABEL		9	9R3	0	2604	9710	15	2	00	8	41	1	0000	
PORT O'CONNOR		9	8R9	0	2826	9626	10	2	00	8	41	1	0000	
SABINE (PSS)		9	8R7	0	2944	9352	0	0	00	8	40	0	0000	
SAN ANGELO	MATHIS	10	SJT	72263	3122	10030	1908	0	41	24	11	81	0000	4C
SAN ANTONIO	INTERNATIONAL	40	SAT	72253	2932	9828	794	0	41	24	11	81	0000	
SAN ANTONIO	STINSON FLD MUN	5	SSF	0	2920	9829	577	1	00	10	11	A0	0000	
SANDERSON		1	P07	74730	3010	10225	2838	0	00	24	71	41	0000	
SEA RIM STATE PARK		9		0	2941	9402	3	2	00	25	90	0	0000	
STEPHENVILLE	CLARK FIELD	70	SEP	72260	3213	9811	1318	0	00	0	00	0	0220	65
TEMPLE	DRAUGHON MILLER	2	TPL	0	3109	9725	682	1	00	18	11	1	0000	
TYLER	POUNDS FIELD	5	TYR	0	3222	9524	551	0	00	24	11	41	0000	
VICTORIA	REGIONAL	10	VCT	72255	2851	9655	117	0	41	24	11	81	0220	XS
WACO	MADISON COOPER	10	ACT	72256	3137	9713	508	0	41	24	11	81	0000	4C
WICHITA FALLS	MUNICIPAL	10	SPS	72351	3358	9829	1030	0	41	24	11	81	0000	4C
WINK	WINKLER CO	4	INK	0	3147	10312	2820	0	00	24	11	81	0000	
UTAH														
BLANDING		3	4BL	0	3737	10928	6132	0	00	8	21	81	0000	
BRYCE CANYON-FSS/BC	AIRPORT	33	BCE	0	3742	11209	7589	0	00	18	21	81	0000	
BULLFROG MARINA		3	U17	0	3730	11042	3643	2	00	4	21	2	0000	
CEDAR CITY	MUNICIPAL	4	CDC	0	3742	11306	5618	0	00	12	11	41	0000	
DELTA		3	U24	0	3920	11235	4626	0	00	16	21	81	0000	
GREEN RIVER		3	U28	0	3900	11009	4069	0	00	7	61	41	0000	
HANKSVILLE		3	4HV	0	3822	11043	4312	0	00	12	21	82	0000	
LOGAN	LOGAN-CACHE	2	LGU	0	4147	11151	4453	0	00	25	92	2	0000	
MILFORD	MUNICIPAL	70	MLF	0	3826	11301	5033	0	00	11	11	41	0000	

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
OGDEN	MUNICIPAL	5	OGD	0	4111	11201	4455	1	00	17	11	1	0000	
PRICE	CARBON COUNTY	1	PUC	72470	3937	11045	5901	0	00	24	11	81	0000	
ROOSEVELT		3	U67	0	4018	10959	5106	0	00	4	21	1	0000	
SALT LAKE CITY RH		80	SLCU1	0	0	0	0	0	00	0	00	0	0000	
SALT LAKE CITY-RADAR	INTERNATIONAL	10	ZLC	0	4046	11157	4220	2	00	0	00	0	0000	FA
SALT LAKE-WSFO/RFC	INTERNATIONAL	46	SLC	72572	4046	11158	4227	0	41	24	11	41	0220	
ST GEORGE	MUNICIPAL	2	SGU	0	3706	11336	2910	0	00	24	11	2	0000	
VERNAL	MUNICIPAL	2	VEL	0	4027	10931	5259	0	00	10	11	2	0000	
WENDOVER	AF AUX FIELD	1	ENV	72581	4044	11402	4239	0	00	24	71	31	0000	
VERMONT														
BURLINGTON	INTERNATIONAL	10	BTV	72617	4428	7309	340	0	41	24	11	81	0000	
MONTPELIER	EDWARD F KNAPP	4	MPV	0	4412	7234	1165	0	00	24	11	81	0000	
NEWPORT	STATE	2	EFK	0	4453	7214	930	1	00	5	11	A0	0000	
NEWPORT		7	NPTV1	72612	4456	7212	766	0	41	0	00	0	0000	
RUTLAND	STATE	2	RUT	0	4332	7257	787	1	00	14	12	2	0000	
SPRINGFIELD	STATE	2	VSF	0	4320	7231	575	1	00	3	21	A0	0000	
ST JOHNSBURY		1	STJV1	72614	4425	7201	711	0	00	24	71	1	0000	
WILMINGTON		7	WMTV1	74483	4253	7253	0	0	21	0	00	0	0000	
VIRGINIA														
CAPE HENRY LS		9	62W	0	3656	7600	0	0	00	8	41	0	0000	
CHARLOTTESVILLE	CHO ALBEMARLE	5	CHO	0	3808	7827	640	1	00	24	11	1	0000	
CHESAPEAKE LS		9	W39	74589	3654	7543	0	0	00	8	41	80	0000	
DANVILLE	MUNICIPAL	4	DAN	0	3634	7920	590	0	00	16	11	61	0000	
HOT SPRINGS	INGALLS FIELD	2	HSP	0	3757	7949	3801	0	00	9	11	2	0000	
LYNCHBURG	MUN PRESTON GLEN FLD	15	LYH	72410	3720	7912	937	0	31	18	11	41	0000	
MANASSAS	MUNICIPAL	2	W10	0	3844	7731	181	0	00	25	90	A0	0000	
MILFORD HAVEN		9	63W	0	3729	7619	0	0	00	8	41	0	0000	
NEWPORT NEWS	PATRICK HENRY INTL	4	PHF	0	3708	7630	51	0	00	24	11	81	0000	
NORFOLK	ORF REGIONAL	10	ORF	72308	3654	7612	30	0	41	24	11	41	0000	
PARRAMORE BEACH		9	64W	0	3732	7537	0	0	00	8	40	0	0000	
RICHMOND	R E BYRD INTNL	10	RIC	72401	3730	7720	177	0	41	24	11	41	0000	
ROANOKE	MUNICIPAL	10	ROA	72411	3719	7958	1176	0	41	24	11	41	0000	
SMITH POINT LS		1	W71	0	3753	7611	0	0	00	25	91	0	0000	
STAUNTON	SHENANDOAH VALLEY	2	SHD	0	3816	7851	1192	1	00	18	11	1	0000	
VOLENS-RADAR		70	7VM	0	3657	7859	607	2	00	0	00	0	0000	4S
WALLOPS IS-UAU		70	WALV2	72402	3751	7529	9	2	32	9	11	A0	0220	
WALLOPS STATION	NASA WBSF	10	WAL	0	3756	7528	48	0	00	12	12	42	0000	

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
WASHINGTON DULLES	DULLES INTNL	10	IAD	72403	3857	7727	323	0	41	24	11	41	0000	
WASHINGTON NATIONAL	NATIONAL	10	DCA	72405	3851	7702	65	0	41	24	11	81	0000	
WASHINGTON-UAU		70	STNV2	72403	3859	7728	276	0	00	0	00	0	0220	
WINCHESTER	MUNICIPAL	2	W16	0	3908	7808	710	0	00	25	90	A0	0000	
WISE	LONESOME PINE	2	LNP	0	3659	8232	2677	0	00	5	91	0	0000	
WASHINGTON														
ALKI POINT LS		9	91S	0	4731	12225	0	0	00	25	90	0	0000	
AUBURN-RADAR		10	ZSE	0	4717	12211	291	2	00	0	00	0	0000	FA
BELLINGHAM	MUNICIPAL	4	BLI	0	4848	12232	159	0	00	24	11	81	0000	
BREMERTON-BC/SAWRS	KITSAP CO	3	PWT	0	4729	12246	443	0	00	10	11	2	0000	
CAPE DISAPPOINTMENT		9	82S	0	4617	12403	180	2	00	4	90	0	0000	
CAPE FLATTERY LS		9	93S	0	4823	12444	86	0	00	7	40	0	0000	
COLVILLE		3	63S	72787	4832	11753	1862	0	00	4	51	42	0000	
EPHRATA	MUNICIPAL	4	EPH	0	4719	11931	1259	0	00	17	11	81	0000	
EVERETT	PAINE FIELD	5	PAE	0	4755	12217	647	0	00	17	11	1	0000	
FRIDAY HARBOR	FRIDAY HARBOR	9	S19	0	4830	12300	0	0	00	25	90	0	0000	
GRAYS HARBOR		9	84S	0	4655	12406	17	2	00	7	40	0	0000	
HANFORD		7	HNDW1	72784	4634	11936	733	0	31	0	00	0	0000	
HOQUIAM	BOWERMAN FIELD	4	HQM	0	4658	12356	15	0	00	24	11	81	0000	
MOSES LAKE	GRANT COUNTY	5	MWH	0	4712	11919	1196	0	00	17	11	2	0000	
MUKILTEO LS		9	98S	0	4757	12218	15	2	00	6	41	0	0000	
NEW DUNGENESS LS		9	96S	0	4810	12306	15	2	00	6	41	0	0000	
OLYMPIA	AIRPORT	10	OLM	0	4658	12254	200	0	00	24	11	81	0000	
OLYMPIA-WSO/FW		10	FOLW1	0	0	0	0	0	00	0	00	0	0000	
OMAK		7	40M	72789	4826	11932	1232	0	82	8	41	81	0000	
PACIFIC BEACH		9	NIX	0	4713	12412	60	2	00	25	91	0	0000	
PASCO-LAWRS-SAWRS	TRI-CITIES	32	PSC	0	4616	11907	442	0	00	18	11	1	0000	
POINT NO POINT LS		9	97S	0	4755	12232	12	2	00	6	41	0	0000	
POINT ROBINSON LS		9	99S	0	4723	12222	10	2	00	6	40	0	0000	
POINT WILSON LS		9	53S	0	4809	12245	0	0	00	8	40	0	0000	
PORT ANGELES	FAIRCHILD INTNL	3	CLM	0	4807	12330	290	0	00	12	11	41	0000	
PORT ANGELES AS	AIR STATION	9	NOW	74201	4808	12324	29	0	00	6	41	31	0000	
PULLMAN	PUW-MOSCOW	2	PUW	0	4645	11707	2551	1	00	17	11	12	0000	
QUILLAYUTE	AIRPORT	70	UIL	72797	4757	12433	205	0	41	24	11	81	0220	
QUILLAYUTE RIVER		9	87S	0	4754	12438	0	0	00	4	40	0	0000	
RENTON	MUNICIPAL	5	RNT	0	4730	12213	29	1	00	17	11	A0	0000	
RICHLAND	MUNICIPAL	2	RLD	0	4618	11918	393	0	00	13	61	0	0000	
SEATTLE	FIELD/KING CO. INTL	5	BFI	0	4732	12218	30	0	00	24	11	1	0000	
SEATTLE (TACOMA)-WSO	INTERNATIONAL	10	SEA	72793	4727	12218	450	0	41	24	11	81	0000	
SEATTLE-WSFO		40	SEAW1	0	4736	12220	14	2	00	0	00	0	0000	
SHELTON		3	SHN	0	4715	12309	278	2	00	6	11	A1	0000	

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
SMITH ISLAND LS		9	86S	0	4819	12251	0	0	00	7	90	0	0000	
SPOKANE	INTERNATIONAL	10	GEG	72785	4738	11732	2365	0	41	24	11	81	0220	
SPOKANE	FELTS	4	SFF	0	4740	11720	1968	0	00	24	11	1	0000	
STAMPEDE PASS		71	SMP	0	4717	12120	3967	0	00	24	71	61	0000	
TACOMA	INDUSTRIAL	5	TIW	0	4716	12235	292	1	00	9	11	2	0000	
TOLEDO-FSS/BASIC	WINLOCK MUNICIPAL	33	TDO	0	4629	12248	379	0	00	17	11	61	0000	
WALLA WALLA	CITY-COUNTY	4	ALW	0	4606	11817	1207	0	00	24	11	81	0000	
WALLA WALLA-WSO/AG		10	WLAW1	72788	4602	11820	991	0	00	0	00	0	0000	
WENATCHEE	PANGBORN	4	EAT	0	4724	12012	1255	0	00	24	11	81	0000	
WENATCHEE-WSO/AG		10	EATW1	0	4726	12021	800	0	00	0	00	0	0000	
WEST POINT LS		9	43S	0	4740	12226	12	2	00	6	41	0	0000	
WILLAPA BAY LS		9	89S	0	4642	12358	25	2	00	7	40	0	0000	
YAKIMA	AIR TERMINAL	10	YKM	72781	4634	12032	1066	0	41	24	11	81	0000	
WEST VIRGINIA														
BECKLEY	RALEIGH COUNTY MEM	10	BKW	72412	3747	8107	2514	0	82	24	11	81	0000	
BLUEFIELD	MERCER COUNTY	4	BLF	0	3718	8113	2867	0	00	24	11	81	0000	
CHARLESTON	KANAWHA	40	CRW	72414	3822	8136	951	0	41	24	11	81	0000	4C
CHARLESTON EMSU		70	CSTW2	72414	3823	8146	598	2	00	0	00	0	0001	
CLARKSBURG	BENEDUM FIELD	5	CKB	0	3918	8014	1256	0	00	8	11	1	0000	
ELKINS	EKN-RANDOLPH CO	10	EKN	72417	3853	7951	1997	0	00	16	11	51	0000	
HUNTINGTON	TRI-STATE	10	HTS	72425	3822	8233	838	0	41	24	11	81	0220	
KEARNEYSVILLE-WSO/AG		10	KRYW2	0	3923	7753	550	2	00	0	00	0	0000	
LEWISBURG	GREENBRIER VALLEY	2	LWB	0	3752	8024	2302	1	00	15	11	2	0000	
MARTINSBURG	EASTERN WV REGIONAL	4	MRB	0	3924	7759	534	0	00	24	11	81	0000	
MORGANTOWN	MUNI-W L B HART FLD	4	MGW	0	3939	7955	1253	0	00	24	11	81	0000	
PARKERSBURG		10	PKB	0	3916	8134	637	0	00	0	00	0	0000	
PARKERSBURG	WOOD COUNTY	4	PKB	0	3921	8126	864	0	00	24	11	81	0000	
WHEELING	HLG OHIO COUNTY	5	HLG	0	4011	8039	1201	0	00	24	11	1	0000	
WHITE SULPHUR SP	GREENBRIER	2	SSU	0	3746	8020	1801	1	00	11	11	2	0000	
WISCONSIN														
APPLETON-TWR/SAWRS	OUTAGAMIE CO	32	ATW	0	4416	8831	918	1	00	17	11	A0	0000	
ASHLAND	JFK MEMORIAL	2	ASX	0	4633	9055	826	1	00	25	90	A0	0000	
DEVILS IS LS		9	29Y	0	4705	9044	629	2	00	12	30	0	0000	
EAU CLAIRE	MUNICIPAL	4	EAU	0	4452	9129	895	0	00	24	11	81	0000	
FOND DU LAC	COUNTY	2	FLD	0	4346	8829	809	1	00	25	90	A0	0000	
GREEN BAY	AUSTIN STRAUBEL	10	GRB	72645	4429	8808	702	0	41	24	11	81	0220	
HAYWARD	AIRPORT	2	HYR	0	4601	9127	1213	1	00	25	92	A0	0000	

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
JANESVILLE-LAWRS/SR	ROCK COUNTY	32	JVL	0	4237	8902	808	1	00	17	11	2	0000	
KENOSHA	MUNICIPAL	2	ENW	0	4236	8755	729	1	00	25	90	A0	0000	
KENOSHA		9	16C	0	4235	8745	730	2	00	12	30	0	0000	
LACROSSE		10	LCRW3	0	4352	9114	0	0	00	0	01	2	0000	
LACROSSE	MUNICIPAL	4	LSE	0	4352	9115	663	0	00	24	11	81	0000	
LAND O LAKES	MUNICIPAL	2	LNL	0	4609	8913	1706	1	00	25	90	A0	0000	
LONE ROCK	TRI COUNTY	4	LNR	0	4312	9011	721	0	00	17	11	61	0000	
MADISON	DANE COUNTY REGIONAL	10	MSN	72641	4308	8920	866	0	41	24	11	51	0000	X3
MANITOWOC	MUNICIPAL	2	MTW	0	4408	8740	651	1	00	15	11	2	0000	
MARSHFIELD	MUNICIPAL	2	MFI	0	4438	9011	1261	1	00	25	90	A0	0000	
MILWAUKEE		9	15C	0	4301	8757	595	2	00	12	30	0	0000	
MILWAUKEE	GEN. MITCHELL FIELD	40	MKE	72640	4257	8754	693	0	41	24	11	41	0000	
MILWAUKEE	TIMMERMAN	5	MWC	0	4307	8803	745	1	00	16	11	2	0000	
MOSINEE	CENTRAL WISCONSIN	2	CWA	0	4447	8940	1273	1	00	19	11	2	0000	
NEENAH		70	EEW	0	4413	8833	907	0	00	0	00	0	0000	65
OSHKOSH-TWR/SAWRS	WITTMAN FIELD	32	OSH	0	4400	8834	805	1	00	18	11	2	0000	
PARK FALLS		7	PKF	72741	4556	9027	1539	0	82	0	00	0	0000	
RHINELANDER	ONEIDA CO	2	RHI	0	4538	8927	1608	1	00	15	11	2	0000	
SHEBOYGAN	SBM COUNTY MEMORIAL	2	SBM	0	4346	8751	746	1	00	25	91	A0	0000	
SHEBOYGAN		9	21C	0	4345	8742	631	2	00	12	30	0	0000	
STEVENS POINT	MUNICIPAL	2	STE	0	4433	8932	1110	1	00	20	91	A0	0000	
STURGEON BAY	DOOR CO CHERRYLAND	2	SUE	0	4450	8725	718	1	00	25	90	A0	0000	
TWO RIVERS		9		0	4408	8733	577	2	00	0	00	0	0000	
WAUKESHA	COUNTY	2	UES	0	4302	8814	90	1	00	9	11	0	0000	
WAUSAU	MUNICIPAL	4	AUW	0	4455	8937	1196	0	00	24	11	81	0000	
WEST BEND	MUNICIPAL	2	ETB	0	4325	8808	888	1	00	25	90	A0	0000	
WISCONSIN RAPIDS	ALEXANDER FIELD	2	ISW	0	4422	8950	1019	1	00	25	90	A0	0000	
WOODRUFF	LAKELAND	2	ARV	0	4556	8944	1628	1	00	25	90	A0	0000	
WYOMING														
BIG PINEY		1	BPI	0	4234	11006	6970	1	00	24	71	1	0000	
CASPER	NATRONA CTY INTNL	10	CPR	72569	4255	10628	5290	0	41	24	11	81	0000	
CHEYENNE	MUNICIPAL	40	CYS	72564	4109	10449	6141	0	41	24	11	81	0000	4C
CODY-AMOS/SAWRS	MUNICIPAL	1	COD	72670	4431	10901	5096	1	00	24	71	1	0000	
DOUGLAS		3	4DG	0	4245	10523	4853	0	00	16	21	82	0000	
EVANSTON	MUNICIPAL	3	EVW	0	4120	11100	6600	0	00	24	11	81	0000	
GILLETTE-AMOS/SAWRS	CITY/COUNTY	1	GCC	72665	4421	10532	4363	1	00	24	71	40	0000	
JACKSON	MUNICIPAL	2	JAC	0	4336	11044	6444	1	00	12	11	2	0000	
LANDER	HUNT FIELD	10	LND	72576	4249	10844	5558	0	41	24	11	41	0220	
LARAMIE	GEN BREES	4	LAR	0	4119	10541	7272	0	00	24	11	81	0000	
MOORCROFT		3	4MC	72663	4416	10457	4282	0	00	4	51	42	0000	
RAWLINS	MUNICIPAL	4	RWL	0	4148	10712	6743	0	00	24	11	81	0000	

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
RIVERTON	MUNICIPAL	2	RIW	0	4303	10827	5509	1	00	13	11	2	0000	
ROCKSPRINGS	MUNICIPAL	4	RKS	0	4136	10904	6745	0	00	24	11	81	0000	
SHERIDAN	SHERIDAN COUNTY	14	SHR	72666	4446	10658	3968	0	31	24	11	51	0000	
WORLAND	MUNICIPAL	4	WRL	0	4358	10758	4210	0	00	24	11	81	0000	
CARIBBEAN AND WEST INDIES														
AGUADILLA	BORINQUEN	2	BQN	0	1830	6708	241	0	00	11	11	1	0000	
BARBADOS	SEAWELL INTNL	90	MKPB	78954	1304	5930	153	0	00	0	00	0	0220	
BASSETERRE/ST KITTS		7	MKPK	78857	1717	6244	29	0	86	0	00	0	0000	
CAPE SAN JUAN LN		9	X93	0	1823	6537	220	2	00	8	41	0	0000	
CASTRIES/ST LUCIA		7	MKPL	78946	1402	6101	181	0	86	0	00	0	0000	
CHARLOTTE AMALIE	TRUMAN	5	STT	0	1820	6458	221	0	00	16	11	1	0000	
CHRISTIANSTED	ALEX HAMILTON	5	STX	0	1742	6448	55	0	00	15	11	1	0000	
CURACAO	DR. ALBERT PLESMAN	90	MACC	78988	1212	6858	27	0	00	0	00	80	0220	
GRAND CAYMAN	OWEN ROBERTS	90	MKCG	78384	1918	8122	6	0	31	15	11	20	0220	
KINGSTON	NORMAN MANLEY	90	MKJP	78397	1756	7647	24	0	00	0	00	0	0220	
MAYAGUEZ-LAWRS/SAWRS	AIRPORT	32	MAZ	0	1815	6709	29	0	00	19	61	1	0000	
POINT BORINQUEN LS		9	BQN	0	1830	6708	232	2	00	4	41	0	0000	
POINT TUNA LS		9	X92	0	1759	6553	67	2	00	4	41	0	0000	
PONCE	MERCIDITA	5	PSE	0	1801	6634	49	0	00	17	11	1	0000	
PORT PONCE LAS		9	X69	0	1758	6637	0	0	00	3	41	0	0000	
ROSEAU/DOMINICA		7	MKPD	78907	1518	6124	237	0	36	0	00	0	0000	
SAN ANDRES IS		90	MCSP	80001	1235	8142	0	0	00	0	00	0	0220	
SAN JUAN	ISLA VERDE INTNL	40	MJSJ	78526	1826	6600	62	0	82	24	11	81	0220	XP
SANTO DOMINGO		90	MDSD	78486	1828	6953	14	0	00	0	00	0	0220	
SINT MAARTEN	JULIANA	90	MACM	78866	1803	6307	10	0	00	0	00	0	0110	
ST THOMAS (LAS)		9	X70	0	1821	6455	0	0	00	2	41	0	0000	
SWAN ISLAND		10	MHIC	78501	1724	8356	35	0	62	6	11	0	0220	
TRINIDAD	PIARCO INTL	90	MKPP	78970	1035	6121	31	0	00	0	00	0	0220	
CENTRAL AMERICA														
BLUEFIELDS		7	MNBL	78745	1159	8347	25	2	52	0	00	0	0000	
GUATEMALA CITY	LA AURORA	90	MGGT	78641	1435	9031	1489	0	00	0	00	0	0110	
PUERTO CABEZAS		90	MNPC	78730	1402	8324	22	2	52	0	00	0	2000	
SAN JOSE		90	MROC	78762	959	8413	939	0	00	0	00	0	0110	
TEGUCIGALPA	TONCONTIN	90	MHTG	78720	1402	8715	999	0	60	0	00	0	0110	
OCEAN														

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
OIL RIG A(ATL OCEAN)		2		0	4056	6818	0	0	00	25	90	0	0000	
PACIFIC ISLANDS														
AILINGLAPALAP MI		7		91367	716	16850E	9	0	41	0	00	0	0000	
FR FRIGATE SHOALS LN		9	1Z6	91155	2352	16617	6	0	41	0	00	0	0000	
GUAM MARIANA IS		70	PGAC	91217	1333	14450E	365	0	31	5	21	22	1220	
JALUIT/JABOR IS MI		7		91369	555	16939E	9	0	41	0	00	0	0000	
JOHNSTON ISLAND		10	PJON	91275	1644	16931	17	0	41	24	11	82	2220	
KAPINGAMARANGI ECI		7		91434	105	15448E	13	0	41	0	00	0	0000	
KOROR WCI		10	PTRO	91406	720	13429E	109	0	31	19	11	70	1110	
KOSRAE (LELE IS) ECI		7	PTSA	91356	520	16302E	13	0	41	0	00	0	0000	
KWAJALEIN	BUCHOLZ	8	PKWA	91366	844	16744E	26	0	41	19	11	72	0110	
MAJURO	MARSHAL IS INTL	2		0	704	17116E	6	1	00	25	90	A0	0000	
MAJURO		10	PKMJ	91376	705	17123E	10	0	41	19	11	70	2110	
MILI MARSHALL IS		7		91378	605	17144E	14	0	41	0	00	0	0000	
NUKUORO ECI		7		91425	351	15301E	12	0	41	0	00	0	0000	
PAGO PAGO	INTERNATIONAL	10	NSTU	91765	1420S	17043	10	0	41	24	11	81	2220	
PINGELAP ECI		7		91353	613	16042E	14	0	41	0	00	0	0000	
PONAPE ECI		10	PTPN	91348	658	15813E	151	0	31	18	11	60	2110	
PONAPE ECI	INTERNATIONAL	2	PNI	0	659	15813E	10	0	00	15	11	0	0000	
PULUWAT IS ECI		7		91324	721	14912E	15	0	41	0	00	0	0000	
SAIPAN	INTL-ISLEY FIELD	2	PGSN	0	1507	14544E	215	0	00	13	11	2	0000	
SAIPAN LN		9	2Z4	91232	1508	14542E	12	0	41	0	00	0	0000	
SATAWAN ECI		7		91338	520	15344E	15	0	41	0	00	0	0000	
TOBI WCI		7		91410	301	13111E	15	0	41	0	00	0	0000	
TRUK ECI	AIRPORT	10	PTKK	91334	728	15151E	8	0	31	20	11	70	1110	
ULITHI/FALALOP I WCI		7		91203	1002	13948E	16	0	31	0	00	0	0000	
UTIRIK MARSHALL IS		7		91258	1114	16951E	9	0	41	0	00	0	0000	
WAKE ISLAND	AF BASE	10	PWAK	91245	1917	16639E	12	0	41	24	11	82	0220	
WOLEAI WCI		7		91317	723	14355E	12	0	41	0	00	0	0000	
WOTJE MARSHALL IS		7		91371	928	17015E	9	0	41	0	00	0	0000	
YAP WCI	AIRPORT	10	PTYA	91413	929	13805E	56	0	31	19	11	70	1110	
SOUTH AMERICA														
ANTOFAGASTA	CERRO MORENO	90	SCFA	85442	2325S	7028	449	0	00	0	00	0	0220	
ASUNCION		90		86218	2043S	6155	101	0	00	0	00	0	0110	
BOGOTA	ELDORADO	90	MCBO	80222	442	7409	8422	0	00	0	00	0	0220	

WEATHER SERVICE OFFICES AND STATIONS

STATION NAME	AIRPORT NAME	TYPE	CALL	NO.	LAT.	LONG.	ELEV.	ELT.	SC	AV	FD	AT	PWUL	RR
IQUITOS	CORONEL FRAN SEC VIG	90		84377	345S	7315	0	0	00	0	00	0	0110	
ISLA DE PASCUA	MATAVERI	90	NEIP	85469	2710S	10926	135	2	00	0	00	0	0110	
LA PAZ	J. F. KENNEDY INTL	90		85201	1630S	6811	0	0	00	0	00	0	0110	
LIMA		90	SPIM	84628	1201S	7702	442	0	00	0	00	0	0110	
PUERTO MONTT	EL TEPUAL INTNL	90	SCTE	85799	4126S	7307	365	0	00	0	00	0	0220	
QUINTERO	CHILEAN AFB	90	SCER	85543	3247S	7132	23	0	00	0	00	0	0220	
MEXICO														
CHIHUAHUA		90	CUU	76225	2842	10604	4684	2	00	0	00	0	0220	
EMPALME		90	GYM	76256	2757	11048	36	2	00	0	00	0	0220	
GUADALUPE IS		90	IGP	76151	2853	11818	15	2	00	0	00	0	0220	
LA PAZ B C	AIRPORT	90	LAP	76405	2410	11018	33	2	00	0	00	0	2000	
MANZANILLO		90		76654	1904	10420	2	0	00	0	00	0	0110	
MAZATLAN		90	MZT	76458	2312	10625	9	0	00	0	00	0	0220	
MERIDA	INTERNATIONAL	90	MID	76644	2057	8940	33	2	00	0	00	0	0220	
MEXICO CITY	INTERNATIONAL	90	MEX	76679	1926	9905	7331	2	00	0	00	0	0220	
MONTERREY	GEN MAR. ESCO. INTL	90	MTY	76394	2552	10012	1476	0	00	0	00	0	0220	
SOCORRO IS		90		76723	1843	11057	115	2	00	0	00	0	1110	
VERACRUZ		90	VER	76692	1909	9607	43	2	00	0	00	0	0220	
GULF OF MEXICO														
EUGENE ISLAND B-333		1	VUW	0	2815	9150	0	0	00	8	41	1	0000	
GRAND ISLE B95-GULF		1	P26	0	2830	9007	90	0	00	8	41	1	0000	
HIGH IS B-A323-GULF		2	5R0	0	2813	9345	85	0	00	13	11	2	0000	
MAIN PASS B68-GULF		1	P21	0	2940	8853	0	0	00	8	41	1	0000	
SO MARSH IS B23-GULF		2	7R8	0	2853	9154	90	0	00	13	11	2	0000	
TENNECO PLATFORM		1	P00	0	2800	9300	0	0	00	8	71	41	0000	
VERMILION B131-GULF		1	P22	0	2904	9211	75	0	00	8	41	1	0000	
VERMILION B215-GULF		1	P25	0	2842	9219	0	0	00	8	41	1	0000	
VERMILION B245-GULF		2	9R9	0	2835	9227	84	0	00	13	11	2	0000	
WEST CAMERON B-533		1	P30	0	2820	9301	80	0	00	8	41	1	0000	

SECTION EIGHT

ASSISTANCE IN AIR POLLUTION METEOROLOGY

Assistance in Meteorologic Problems
Sources of Air Pollution Literature

ASSISTANCE IN METEOROLOGIC PROBLEMS

J. L. Dicke*

REFERENCES

Abstracts

Air Pollution Abstracts
U. S. Environmental Protection Agency
Research Triangle Park, N. C. 27711
U. S. Government Printing Office
Washington, D. C. 20402

Meteorological and Geoastrophysical Abstracts
American Meteorological Society
45 Beacon Street
Boston Mass, 02108

Public Health Engineering Abstracts
Superintendent of Documents
U.S. Government Printing Office
Washington, D.C. 20402

Periodicals

Atmospheric Environment (formerly International Journal of Air and Water Pollution)
Pergamon Press
Maxwell House, Fairfield Park
Elmsford, N. Y. 10523

Bulletin of the American Meteorological Society
American Meteorological Society (See above)

Journal of Applied Meteorology
American Meteorological Society
(See above

Journal of the Atmospheric Sciences (formerly Journal of Meteorology)
American Meteorological Society
(See above)

Journal of the Air Pollution Control Association
Air Pollution Control Association
4400 Fifth Ave.
Pittsburgh, PA. 15253

Monthly Weather Review
American Meteorological Society
(See above)

Nuclear Safety. A Quarterly Technical Progress Renewal Prepared for Division of Technical Information, USAEC
Superintendent of Documents
U. S. Government Printing Office
Washington, D. C. 20402

Quarterly Journal of the Royal Meteorological Society
Royal Meteorological Society
49 Cromwell Road
London S. W. 7 England

Public Health Reports
U. S. Department of Health, Education and Welfare
Public Health Service
Washington, D. C.

Weather
Royal Meteorological Society
(See above)

Weatherwise
American Meteorological Society
(See above)

Books

American Meteorological Society, On Atmospheric Pollution, Meteorological Monographs, 1, 4, Nov. 1951.

Byers, H. R. General Meteorology, McGraw-Hill, New York, 3rd ed. 1959.

Encyclopedia of Instrumentation for Industrial Hygiene
University of Michigan, Ann Arbor, 1956.

Frenkiel, F. N.; and Sheppard, P. A. editors, Atmospheric Diffusion and Air Pollution,
Academic Press, London, 1959.

Geiger, R. (Translated by Scripta Technica Inc.) The Climate Near the Ground
Rev. ed., Harvard University Press
Cambridge, Mass. 1965.

Haltiner, G. J.; and Martin, F. L. Dynamical and Physical Meteorology.
McGraw-Hill, New York. 1957

Hess, S. L. Introduction to Theoretical Meteorology.
Henry Holt, New York, 1959.

Hewson, E. W.: and Longley, R. W. Meteorology, Theoretical and Applied
Wiley, New York. 1944.

*Supervisory Meteorologist, NOAA
Meteorology & Assessment Division, EPA

PA.ME.23 c.2.75

Leighton, P. A. Photochemistry of Air Pollution.
Academic Press, New York. 1961.

Magill, P. L.; Holden, F. R.; and Ackley, C. editors, Air Pollution Handbook.
McGraw-Hill, New York. 1956.

Malone, T. F. editor, Compendium of Meteorology,
American Meteorological Society
Boston, 1951.

McCabe, L. C. editor. Air Pollution: Proceedings of the United States Technical Conference on Air Pollution.
McGraw-Hill, New York. 1952.

Meade, P. J. Meteorological Aspects of the Peaceful Uses of Atomic Energy, Part 1.
Tech. Note No. 33, World Meteorological Organization, Geneva. 1960.

Munn, R. E. Descriptive Micrometeorology.
Academic Press, New York. 1966.

Pasquill, F. Atmospheric Diffusion 2nd. Ed.
John Wiley & Sons, London, 1974.

Priestley, G. H. B.:McCormick, R. A.: and Pasquill, F. Turbulent Diffusion in the Atmosphere.
Tech. Note No. 24. World Meteorological Organization, Geneva, 1958.

Priestly, C. H. B. Turbulent Transfer in the Lower Atmosphere.
University of Chicago Press, Chicago, 1959.

Scorer, R. S. Natural Aerodynamics.
Pergamon Press. London. 1958.

Munn, R. E. Biometeorological Methods
Academic Press, Inc. New York, 1970.

Stern, A. C. editor. Air Pollution, A Comprehensive Treatise, 3 Vols.
Academic Press, New York. 1968.

Sutton, O. G. Micrometeorology.
McGraw-Hill, New York, 1953.

U. S. Atomic Energy Commission, Handbook on Aerosols,
Govt. Printing Office, Washington, 1950.

U. S. Atomic Energy Commission, Meteorology and Atomic Energy. 1968
TID-24190, NTIS, U. S. Department Commerce, Springfield, Virginia 22161, $6.

World Health Organization, Air Pollution,
Columbia University Press
New York. 1961.

PROFESSIONAL METEOROLOGICAL CONSULTANTS

Professional meteorologists advertise their services in the Professional Directory section of the Bulletin of the American Meteorological Society. In the July 1975 Bulletin, 63 such firms and individuals were listed. The American Meteorological Society has in the last several years instituted a program of certifying consulting meteorologists. Of the 63 professional services listings in the Bulletin, 40 Certified Consulting Meteorologists are listed. A total of 140 meteorologists gists are currently certified.

LOCAL U.S. NATIONAL WEATHER SERVICE OFFICE

A wealth of meteorological information and experience is available at the local city or airport Weather Service Office pertaining to local climatology, pecularities in local micro-meteorological conditions including topographic effects, and exposure and operating characteristics of meteorological instruments. The Air Stagnation Advisories are received here by teletype from the National Meteorological Center. Often the public telephones the Weather Service with air pollution complaints which the meteorologists may have traced back to a specific source by examing local wind circulations. Through personal contact with the meteorologist-in-charge (MIC) specific, localized forecasts may be arranged to support a short-term air pollution investigation or sampling program.

CONTRACT WORK

Many universities do contract work for private organizations and for government agencies on meteorological problems and also on air pollution surveys.

EPA REGIONAL OFFICES

A contact person has been designated in each of the ten EPA Regional Offices to provide technical assistance consultation and special support services in air pollution meteorology, at the regional level.

Region I -Mr. V. J. Descamps (Boston)
Region II -Mr. Ray Warner (New York)
Region III-Dr. Peter L. Finkelstein (Phil.)

Assistance in Meteorologic Problems

Region IV -Mr. Lewis H. Nagler (Atlanta)
Region V -Mr. Edward W. Klappenbach (Chicago)
Region VI -Dr. F. Hall (Dallas)
Region VII -Mr. Keith Tipton (Kansas City)
Region VIII -Mr. Donald Henderson (Denver)
Region IX -Ms. Charlotte J. Hopper (San Fran.)
Region X -Mr. Dean A. Wilson (Seattle)

SOURCES OF AIR POLLUTION LITERATURE

Publications Abstracting Air Pollution Literature

1. Air Pollution Abstracts
   Air Pollution Technical Information Center
   U. S. EPA Research Triangle Park,
   N. C. 27711

2. Air Pollution Titles
   Center for Air Environment Studies
   The Pennsylvania State University
   226 Fenske Laboratory
   University Park, PA 16802

3. Air/Water Pollution Report
   Business Publishers, Inc.
   P. O. Box 1067
   Silver Spring, MD. 20910

4. Applied Science and Technology Index
   The H. W. Wilson Company
   950 University Avenue
   New York 52., New York

5. Atmospheric Environment, Microforms
   Int'l Marketing Corp. Inc. (Distributors)
   380 Saw Mill River Rd.
   Elmsford, N. Y. 10523

6. Chemical Abstracts Service
   The Ohio State University
   Columbus, OH 43210

7. Engineering Index
   Engineering Index, Inc.
   345 East 47th Street
   New York, New York 10017

8. Environment Information ACCESS
   Environment Information Center, Inc.
   124 East 39th St.
   New York, N. Y. 10016

9. Meteorological and Geoastrophysical Abstracts
   American Meteorological Society
   45 Beacon Street
   Boston, Massachusetts 02108

10. Monthly Catalog of United States Government Publications
    Superintendent of Documents
    U. S. Government Printing Office
    Washington, D. C. 20402

11. Public Health Engineering Abstracts
    Superintendent of Documents
    U. S. Government Printing Office
    Washington, D. C. 20402

12. Index Medicus
    U. S. Government Printing Office
    Washington, D. C. 20402

13. Readers' Guide to Periodical Literature
    The H. W. Wilson Company
    950 University Avenue
    New York, New York 10452

14. Weekly Government Abstracts
    Category 68. Environmental Pollution and Control.
    NTIS
    5285 Port Royal Road
    Springfield, Va. 22161

15. Pollution Abstracts
    620 S. Fifth St.
    Louisville, KY 40202

16. Government Reports Announcements & Index
    National Technical Information Service
    Springfield, Va. 22161

17. Chemical Titles
    Chemical Abstracts Service
    The Ohio State University
    Columbus OH. 43210

SOURCES OF AIR POLLUTION LITERATURE

Periodicals

1. Air Conditioning, Heating & Refrigeration News
Business News Publishing Company
P. O. Box 6000
Birmingham, Michigan 48012

2. American City
Berkshire Common
Pittsfield, MA 01201

3. American Industrial Hygiene Association Journal
66 S. Miller Road
Akron, OH 44313

4. American Journal of Public Health and Nation's Health
American Public Health Association, Inc.
1015 18th St. N. W.
Washington, D. C. 20036

5. Archives of Environmental Health
American Medical Association
535 N. Dearborn Street
Chicago, Illinois 60610

6. Atmospheric Environment
Pergamon Press
Maxwell House, Fairview Park
Elmsford, N. Y. 10513

7. Chemical Engineering
McGraw-Hill Publishing Company, Inc.
McGraw-Hill Building
1221 Ave. of the Americas
New York, N. Y. 10020

8. Chemical Engineering Progress
American Institute of Chemical Engineers
345 E. 47th Street
New York, New York 10017

9. Environmental Pollution-An Int'l. Journal
Applied Science Publishers Ltd.
Ripple Road, Barking Exsex
England

10. Boundary Layer Meteorology.
R. E. Munn (Ed.) D. Reidel Pub. Co.
Dordrecht, Holland

11. Heating, Piping and Air Conditioning
Reinhold Publishing Company
614 Superior Ave. West
Cleveland, OH 44113

12. Industrial and Engineering Chemistry
American Chemical Society
1155 Sixteenth Street, N. W.
Washington, D. C. 20036

13. Industrial Hygiene Digest Industrial Health Foundation
5231 Centre Ave.
Pittsburgh, Pennsylvania 15232

14. Journal of Environmental
American Society of Agronomy Quality
677 S. Segoe Road
Madison, Wisconsin 53711

15. Industrial Wastes
Scranton Publishing Company, Inc.
4345 Wabash
Chicago, Illinois 60605

16. Journal of the Air Pollution Control Association
Air Pollution Control Association
4400 Fifth Avenue
Pittsburgh, Pennsylvania 15253

17. Water, Air, and Soil Pollution
D. Reidel Publishing Company
Dordrecht, Holland

18. Mechanical Engineering
American Society of Mechanical Engineers
345 E. 47th Street
New York, New York 10017

19. The Oil and Gas Journal
P. O. Box 1260
Tulsa, Oklahoma 74101

20. Public Health Reports
U. S. Department of Health, Education, and Welfare
Health Services Administration
Superintendent of Documents
U. S. Government Printing Office
Washington, D. C. 20402

21. Pollution Monitor
Wealdon Press, Ltd.
P. O. Box No. 8
Tonbridge, Kent.
TN1105X, England

22. Smokeless Air
National Society for Clean Air
Field House, Breams Building
London E. C. 4, England

23. Transactions of the American Society of Mechanical Engineers
Journal of Engineering for Power (Series A of the Transactions of the ASME
Journal of Engineering for Industry (Series B)
Journal of Heat Transfer (Series C)
Journal of Basic Engineering (Series D)
Journal of Applied Mechanics (Series E)
American Society of Mechanical Engineers
345 East 47th Street
New York, New York 10017

24. Transactions of Institution of Chemical Engineers
Institution of Chemical Engineers
16 Belgrave Square
London S. W. 1, England

25. Environmental Science and Technology
American Chemical Society
1155 Sixteenth Street N. W.
Washington, D. C. 20036

26. World Meteorological Organization-List of available publications.
WMO Publications Center
UNIPUB Inc.
P. O. Box 433
New York, New York 10016

Bibliographies

1. Air Pollution Technical Publications of the U. S. EPA. Listing by Air Pollution Technical Information Center Research Triangle Park, N.C. July 1974 (Reprinted June 1975). Beginning July 1975 only new entries will be published semi-annually.

2. Carbon Monoxide - A Bibliography with Abstracts. U. S. Dept. HEW, Public Health Service. Publication No. 1503. 1966.

3. Sulfur Oxides and other Compounds - A Bibliography with Abstracts, U. S. Dept. HEW Public Health Service, Publication No. 1093. 1965.

4. Nitrogen Oxides: An Annotated Bibliography NAPCA Pub. No. AP-72, August 1970.

5. Hydrocarbons and Air Pollution: An Annotated Bibliography. Pub. No. AP-75 (Parts I, II), October 1970.

6. Photochemical Oxidants and Air Pollution: An Annotated Bibliography. Pub. No. AP-88 (Parts 1, 2), March 1971.

7. Asbestos and Air Pollution: An Annotated Bibliography. GPO No. EP 4.9:82 February 1971

8. Beryllium and Air Pollution: An Annotated Bibliography. GPO No. EP 4.9.83 February 1971

9. Chlorine and Air Pollution; An Annotated Bibliography GPO No. EP 4.9.99 July 1971.

10. Hydrochloric Acid and Air Pollution: An Annotated Bibliography GPO No.EP 4.9.105 July 1971.

11. Odors and Air Pollution; An Annotated Bibliography. GPO No. EP 4.9. 113 October 1972.

12. Mercury and Air Pollution: A Bibliography with Abstracts. GPO No. EP 4.9.114 October 1972.

13. Lead and Air Pollution: A Bibliography with Abstracts. EPA-450/1-70-001, January 1974.

APPENDIX

Glossary
Elementary Statistical Description of Data
Index
Units of Measure for Dimensional Systems
Values and Logarithms of Exponential Functions
Conversion Factors
- Temperature, Pressure
- Length, Area
- Volume, Flow
- Weight, Concentration
- Velocity, Emission Rates
- International Atomic Weights

GLOSSARY

Most of the definitions of the following terms are taken from the "Glossary of Meteorology" (1959).

actinometer - The general name for any instrument used to measure the intensity of radiant energy, particularly that of the sun.

adiabatic process - A thermodynamic change of state of a system in which there is no transfer of heat or mass across the boundaries of the system.

advection - The process of transport of an atmospheric property solely by the mass motion (velocity field) of the atmosphere. The description of predominantly horizontal large scale motions of the atmosphere.

aerometric - Pertaining to the science of measuring properties of the air.

air drainage - General term for gravity-induced, downslope flow of relatively cold air. Winds thus produced are called gravity winds.

air mass - A widespread body of air, the properties of which can be identified as a) having been established while that air was situated over a particular region of the earth's surface (air-mass source region), and b) undergoing specific modifications while in transit away from the source region. An air mass is often defined as a widespread body of air that is approximately homogeneous in its horizontal extent, particularly with reference to temperature and moisture distribution; in addition, the vertical temperature and moisture variations are approximately the same over its horizontal extent. The stagnation or long-continued motion of air over a source region permits the vertical temperature and moisture distribution of the air to reach relative equilibrium with the underlying surface.

air pollution - The presence, in the ambient atmosphere, of substances put there by the activities of man in concentrations sufficient to interfere directly or indirectly with his health, safety, or comfort, or with the full use and enjoyment of his property.

air pollution meteorology - The study of atmospheric phenomena that influence or are influenced by air pollutants.

albedo - The ratio of the amount of electromagnetic radiation reflected by a body to the amount incident upon it, commonly expressed as a percentage. The albedo is to be distinguished from the reflectivity, which refers to one specific wavelength (monochromatic radiation).

anemometer - The general name for instruments designed to measure the speed (or force) of the wind.

anticyclone - An atmospheric anticyclonic circulation (clockwise in the northern hemisphere), a closed circulation. With respect to the relative direction of its rotation, it is the opposite of a cyclone. Because anticyclonic circulation and relative high atmospheric pressure usually coexist, the terms anticyclone and high are used interchangeably in common practice.

backing - 1) According to general internationally accepted usage, a change in wind direction in a counterclockwise sense (e.g. south to southeast to east) in either hemisphere of the earth; the opposite of veering.

2) According to widespread usage among U.S. meteorologists, a change in wind direction in a counterclockwise sense in the northern hemisphere, clockwise in the southern hemisphere.

Beaufort wind scale - A system of estimating and reporting wind speeds, invented in the early nineteenth century by Admiral Beaufort of the British Navy. It was originally based

on the effects of various wind speeds on the amount of canvas that a full-rigged frigate of the period could carry, but has since been modified and modernized.

bivane - A bi-directional wind vane; a sensitive wind vane used in turbulence studies to obtain a record of the horizontal and vertical components of the wind. The instrument consists of two lightweight airfoil sections mounted orthogonally on the end of a counter-balanced rod which is free to rotate in the horizontal and vertical planes. The positions of the rod may be recorded by electrical techniques.

bridled-cup anemometer - A combination cup anemometer and pressure-plate anemometer, consisting of an array of cups about a vertical axis of rotation, the free rotation of which is restricted by a suitable spring arrangement. By proper adjustment of the force constant of the spring, it is possible to obtain an angular displacement which is proportional to wind velocity. A bridled-cup anemometer is frequently used to measure high wind speeds.

buoyancy - That property of an object that enables it to ascend through or remain freely suspended in a compressible fluid such as the atmosphere. Quantitatively, the ratio of the specific weights of the fluid and the object.

calm - The absence of apparent motion of the air.

Campbell-Stokes recorder - A sunshine recorder which consists of a spherical lens which burns an image of the sun upon a specially prepared card. The depth and breadth of the trace may be interpreted in terms of intensity of the sun.

cascade impactor - A low speed impaction device for use in sampling both solid and liquid atmospheric suspensoids. Four pairs of jets and sampling plates work in series and are designed so that each collects particles in one size range.

climate - "The synthesis of the weather"; the long-term manifestations of weather, however they may be expressed. More rigorously, the climate of a specified area is represented by the statistical collective of its weather conditions during a specified interval of time (usually several decades).

climatology - The scientific study of climate. In addition to the presentation of climatic data, it includes the analysis of the causes of differences of climate, and the application of climatic data to the solution of specific design or operational problems.

condensation nucleus - A particle, either liquid or solid, upon which condensation of water vapor begins in the atmosphere.

convection - As specialized in meteorology, atmospheric motions that are predominantly vertical, resulting in vertical transport and mixing of atmospheric properties.

coriolis force - A force per unit mass on moving particles arising solely from the earth's rotation. It acts as a deflecting force, normal to the velocity, to the right of motion in the northern hemisphere and to the left in the southern hemisphere.

dew point - (or dew point temperature) - The temperature to which a given parcel of air must be cooled at constant pressure and constant water vapor content in order for saturation to occur.

diffusion - In meteorology, the exchange of fluid parcels (and hence the transport of conservative properties) between regions in space, in the apparently random motions of a scale too small to be treated by the equations of motion.

Dines anemometer - A pressure-tube anemometer in which the pressure head on the windward end of a weather vane is kept facing into the wind. Another head develops suction independent of wind direction. The pressure difference between the two heads is proportional to wind speed squared and is measured by a float manometer.

direct solar radiation - That portion of the radiant energy received at an instrument direct from the sun as opposed to diffuse sky radiation or radiation from any other source.

dispersion - The process by which radiation is separated into its component wavelengths. Dispersion results when an optical process such as diffraction, refraction, or scattering varies according to wavelength.

diurnal - Daily, especially pertaining to actions which are completed within twenty-four hours and which recur every twenty-four hours; thus, most reference is made to diurnal cycles, variations, ranges, etc.

downwind - The direction toward which the wind is blowing; with the wind.

dry-adiabatic lapse rate - A special process lapse rate of temperature, defined as the rate of decrease of temperature with height of a parcel of dry air lifted adiabatically through an atmosphere in hydrostatic equilibrium, numerically equal to 9.767°C per km., or 5.4°F per thousand feet.

eddy - 1) By analogy with a molecule, a "glob" of fluid within the fluid mass that has a certain integrity and life history of its own; the activities of the bulk fluid being the net result of the motion of the eddies.

2) Any circulation drawing its energy from a flow of much larger scale, and brought about by pressure irregularities as in the lee of a solid obstacle.

eddy diffusion - (or turbulent diffusion) - The diffusion of a conservative property by eddies in a turbulent flow.

Ekman layer - (sometimes called spiral layer) - The layer of transition between the surface boundary, where the shearing stress is constant, and the free atmosphere where the atmosphere is treated as an ideal fluid in approximate geostrophic equilibrium.

Eulerian coordinates - Any system of coordinates in which properties of a fluid are assigned to fixed points in space at a given time without attempting to identify individual parcels from one time to the next.

exchange coefficients - Coefficients of eddy flux in turbulent flow. The hypothesis states that the mean eddy flux per unit area of a conservative quantity is proportional to the gradient of the mean value of the quantity.

free atmosphere - (sometimes called free air) - That portion of the earth's atmosphere, above the planetary boundary layer, in which the effect of the earth's surface friction on the air motion is negligible, and in which the air is usually treated (dynamically) as an ideal fluid. The base of the free atmosphere is usually taken as the geostrophic wind level.

friction layer - 1) Same as planetary boundary layer.

2) Same as surface boundary layer.

geostrophic wind - That horizontal wind velocity for which the coriolis acceleration exactly balances the horizontal pressure force. The geostrophic wind is thus directed along the contour lines on a constant pressure surface (or along the isobars in a geopotential surface) with low elevations (or low pressure) to the left in the northern hemisphere and to the right in the southern hemisphere.

greenhouse effect - The heating effect exerted by the atmosphere upon the earth by virtue of the fact that the atmosphere (mainly, its water vapor) absorbs and remits infrared radiation. In detail: the shorter wavelengths of isolation are transmitted rather freely through the atmosphere to be absorbed at the earth's surface. The earth then re-emits this long-wave (infrared) terrestrial radiation, a portion of which is absorbed by the atmosphere and again emitted. Some of this is emitted downward back to the earth's surfact. It is essential, in understanding the

concept of the greenhouse effect, to note that the important additional warming is due to the counter-radiation from the atmosphere. The glass panes of a greenhouse function in this manner exactly analogously to the atmosphere in maintaining high greenhouse temperatures, hence the name.

gust - A sudden brief increase in the speed of the wind. According to the U. S. weather observing practice, gusts are reported when the peak wind speed reaches at least 16 knots and the variation in wind speed between the peaks and lulls is at least 9 knots. The duration of a gust is usually less than 20 seconds.

haze - Fine dust or salt particles dispersed through a portion of the atmosphere, a type of lithometeor. The particles are so small they cannot be felt or individually seen by the naked eye.

hot-wire anemometer - An anemometer which utilizes the principle that the convection of heat from a body is a function of ventilation. Wind speed is determined by measuring either the current required to maintain the hot wire at a constant temperature or the resistance variation while a constant current is maintained.

illuminometer - Same as photometer.

instability - A property of the steady state of a system such that certain disturbances or perturbations introduced into the steady state will increase in magnitude.

inversion - A departure from the usual decrease or increase with altitude of the value of an atmospheric property; also, the layer through which this departure occurs.

inversion, temperature - A layer in which temperature increases with altitude. The principal characteristic of an inversion layer is its marked static stability, so that very little turbulent exchange can occur within it. Strong wind shears often occur across inversion layers, and abrupt changes in concentrations of atmospheric particulates and atmospheric water vapor may be encountered on ascending through the inversion.

isokinetic sampling - A technique for collecting airborne particulate matter in which the airstream entering the collector has a velocity equal to the air passing around and outside the collector.

kytoon - A captive balloon used to maintain meteorological equipment aloft at an approximately constant height. It is streamlined and combines the aerodynamic properties of a balloon and a kite.

lapse rate - The decrease of atmospheric temperature with height. The term applies ambiguously to the environmental lapse-rate and the process lapse-rate, and the meaning must often be ascertained from the context.

lapse rate, environmental - The rate of decrease of temperature with elevation. The environmental lapse rate is determined by the distribution of temperature in the vertical at a given time and place and should be carefully distinguished from the process lapse rate, which applies to an individual air parcel.

lapse rate, process - The rate of decrease of temperature of an air parcel as it is lifted. In the atmosphere the process lapse rate is usually assumed to be either the dry-adiabatic lapse rate or the saturation-adiabatic lapse rate.

mesometeorology - That portion of the science of metoerology concerned with the study of atmospheric phenomena on a scale larger than that of micrometeorology, but smaller than the cyclonic scale.

meteorology - The study dealing with the phenomena of the atmosphere. This includes not only the physics, chemistry, and dynamics of the atmosphere, but is extended to include many of the direct effects of the atmosphere upon the earth's surface, the oceans, and life in general. The goals often ascribed to meteorology are the complete understanding, accurate prediction, and artificial control of atmospheric phenomena.

micrometeorology - That portion of the science of meteorology that deals with the observation and explanation of the smallest-scale physical and dynamic occurrences within the atmosphere. So far, studies in this field are confined to the surface boundary layer of the atmosphere; that is, from the earth's surface to an altitude where the effects of the immediate underlying surface upon air motion and composition become negligible. To date, the bulk of the work in this field has centered around the evaluation of low level atmospheric turbulence, diffusion, and heat transfer.

Mie Theory - A mathematical-physical theory of scattering of electromagnetic radiation which is not restricted to scattering by particles small compared to the wavelength of the scattered radiation but is valid for all ratios of diameter to wavelength.

mixing length - A mean length of travel characteristic of a particular motion over which an eddy maintains its identity; analogous to the mean free path of a molecule.

photometer - (also called illuminometer) - An instrument for measuring the intensity of light or the relative intensity of a pair of lights. If the instrument is designed to measure the intensity of light as a function of wavelength, it is called a spectro-photometer. Photometers may be divided into two classes: photoelectric photometers in which a photoelectric cell is used to compare electrically the intensity of an unknown light with that of a standard light; and visual photometers in which the human eye performs the function of a photo cell. A photometer used to measure the intensity of a distant light is referred to as a telephotometer or transmissometer.

planetary boundary layer - (also called friction layer, atmospheric boundary layer) - That layer of the atmosphere from the earth's surface to the geostrophic wind level including, therefore, the surface boundary layer and the Ekman layer. Above this layer lies the free atmosphere.

potential temperature - The temperature a parcel of dry air would have if brought adiabatically from its initial state to the standard pressure of 1000 mb.

prevailing wind - The wind direction most frequently observed during a given period.

pyrheliometer - General term for the class of actinometers which measure the intensity of direct solar radiation.

radiational cooling - The cooling of the earth's surface and adjacent air, accomplished whenever the earth suffers a net loss of heat due to terrestrial radiation.

radiosonde - A balloon borne instrument for the simultaneous measurement and transmission of meteorological data. The instrument consists of transducers for the measurement of pressure, temperature and humidity; a modulator for the conversion of the output of the transducers to a quantity which controls a property of the radio frequency signal; a selector switch which determines the sequence in which the parameters are to be transmitted; and a transmitter which generates the radio-frequency carrier.

Rayleigh scattering - Any scattering process produced by spherical particles whose radii are smaller than about one-tenth the wavelength of the scattered radiation. The scattering coefficient varies inversely with the fourth power of the wavelength.

relative humidity - The dimensionless ratio of the actual vapor pressure of the air to the saturation vapor pressure.

resultant wind - In climatology, the vectorial average of all wind directions and speeds for a given level at a given place for a certain period, as a month.

saturation-adiabatic lapse rate - A special case of process lapse rate, defined as the rate of decrease of temperature with height of an air parcel lifted in a saturation adiabatic process through an atmosphere in hydrostatic equilibrium. Owing to the release of latent heat, this lapse rate is less than the dry adiabatic lapse rate.

shear, wind - The local variation of the wind vector or any of its components in a given direction.

streak line - A line within a fluid which, at a given instant, is formed by those fluid particles which at some previous instant have passed through a specified fixed point in the fluid.

streamlines - A line whose tangent at any point in a fluid is parallel to the instantaneous velocity of the fluid at that point.

subsidence - A descending motion of air in the atmosphere, usually with the implication that the condition extends over a rather broad area.

surface boundary layer - (Also called surface layer, friction layer, atmospheric boundary layer, ground layer.) - That thin layer of air adjacent to the earth's surface extending up to the so-called anemometer level (the base of the Ekman layer). Within this layer the wind distribution is determined largely by the vertical temperature gradient and the nature and contours of the underlying surface; and shearing stresses are approximately constant.

synoptic - In meteorology, this term has become somewhat specialized in referring to the use of meteorological data obtained simultaneously over a wide area for the purpose of presenting a comprehensive and nearly instantaneous picture of the state of the atmosphere.

trajectory - A curve in space tracing the points successively occupied by a particle in motion. (a path).

turbulence - A state of fluid flow in which the instantaneous velocities exhibit irregular and apparently random fluctuations so that in practice only statistical properties can be recognized and subjected to analysis.

The satisfactory treatment of this phenomena in the atmosphere is perhaps the outstanding unsolved problem of theoretical meteorology.

valley breeze - A wind which ascends a mountain valley (up-valley wind) during the day; the daytime component of a mountain and valley wind system.

veering - 1) According to general international usage, a change in wind direction in a clockwise sense (e. g., south to southwest to west) in either hemisphere of the earth; the opposite of backing.

2) According to widespread usage among U. S. meteorologists, a change in wind direction in a clockwise sense in the northern hemisphere, counterclockwise in the southern hemisphere.

wind rose - Any one of a class of diagrams designed to show the distribution of wind direction experienced at a given location over a considerable period. The most common form consists of a circle from which sixteen lines emanate, one for each compass point. The length of each line is proportional to the frequency of wind from that direction; and the frequency of calm conditions is entered in the center.

wind vane - An instrument used to indicate wind direction.

wiresonde - An atmospheric sounding instrument which is supported by a captive balloon and used to obtain temperature and humidity data from the ground level to a height of a few thousand feet. Height is determined by means of a sensitive altimeter, or from the amount of cable released and the angle which the cable makes with the ground. The information is telemetered to the ground through a wire cable.

REFERENCE

Huschke, R. E., Editor. Glossary of Meteorology. Amer. Meteorol. Soc. Boston, Massachusetts. 1959.

ELEMENTARY STATISTICAL DESCRIPTION OF DATA

I DESCRIPTION OF DATA

Certain terms are used to describe data obtained in a study.

A Mean

The sum of all the observations divided by the number of observations is the mean.

$$\bar{X} = \frac{\Sigma X_i}{N} \qquad (1)$$

where:

$\bar{X}$ = mean of the observations

X_i = value of an individual observation

N = number of observations

B Geometric Mean

The Nth root of the product of all the observations is the geometric mean.

$$\bar{X}_g = \sqrt[N]{(X_1)(X_2)\ldots(X_N)} \qquad (2)$$

or:

$$\text{Log } \bar{X}_g = \frac{1}{N} \Sigma \log X_i \qquad (3)$$

where:

$\bar{X}_g$ = geometric mean

C Median

The median is the middle value of any group of observations. If the data are arranged from smallest to largest value, the median is the $\left(\frac{N+1}{2}\right)$th term. It can be said of the median that 50% of the data are equal to or greater than its value; 50% are equal to or less than this value.

D Range

The range is the difference between the smallest and largest observations of a series.

E Variance

The variance is defined as the sum of the squares of the deviations of the observations from their mean, divided by one less than the total number of observations.

$$s^2 = \frac{\Sigma (X_i - \bar{X})^2}{N - 1} \qquad (4)$$

where:

s^2 = variance

An equivalent formula for s^2 which is simpler to use for computations is:

$$s^2 = \frac{\Sigma X_i^2 - \frac{(\Sigma X_i)^2}{N}}{N - 1} \qquad (5)$$

F Standard Deviation

The standard deviation is defined as the positive square root of the variance.

$$s = \sqrt{\frac{\Sigma (X_i - \bar{X})^2}{N - 1}} \qquad (6)$$

where:

s = standard deviation or, from equation (5):

$$s = \sqrt{\frac{\Sigma X_i^2 - \frac{(\Sigma X_i)^2}{N}}{N - 1}} \qquad (7)$$

Note: The variance and standard deviation are meaningful measures of variation only if the data are normally distributed.

G Correlation Coefficient

The correlation coefficient is a measure of the linear dependence between two variables. By mathematical definition the correlation coefficient can vary in magnitude from -1 to +1.

The equation of the correlation coefficient is given by:

$$r = \frac{N\Sigma X_i Y_i - \Sigma X_i \Sigma Y_i}{\sqrt{\left[N\Sigma X_i^2 - (\Sigma X_i)^2\right]\left[N\Sigma Y_i^2 - (\Sigma Y_i)^2\right]}}$$

where:

- r = correlation coefficient
- ΣX_i = sum of measurements of first variable
- ΣY_i = sum of measurements of second variable
- N = number of measurements

H Linear Regression Line

If the relation between two variable is significant, a further test is whether the data can be represented by a straight line in the form $y = a + bx$. To solve for the constants a and b the equations are:

$$a = \frac{\Sigma X_i^2 \Sigma Y_i - \Sigma X_i \Sigma X_i Y_i}{N\Sigma X_i^2 - (\Sigma X_i)^2}$$

and:

$$b = \frac{N\Sigma X_i Y_i - \Sigma X_i \Sigma Y_i}{N\Sigma X_i^2 - (\Sigma X_i)^2}$$

where:

- b = slope of regression line
- a = intercept of regression line

REFERENCES

1 Brownlee, K. A. Industrial Experimentation. Chemical Publishing Company., Inc. Brooklyn, New York. 1953.

2 Burington, R. S. and May, D. C. Handbook of Probability and Statistics With Tables. Handbook Publishers, Inc. Sandusky, Ohio. 1953.

3 Dixon, W. J. and Massey, F. J., Jr. Introduction to Statistical Analysis. 2nd Edition. McGraw-Hill Book Co., Inc. New York. 1957.

4 U. S. Public Health Service Publication No. 978. Air Pollution Measurements of the National Air Sampling Network, Analysis of Suspended Particulates 1957-1961. Robt. A. Taft Sanitary Engineering Center, Cincinnati, Ohio. 1962.

INDEX

A

Absorption
  by aerosols 5-5
  by gases 5-5
Abstracts - air pollution
  and meteorology 8-1, 8-5
Actinometer 9-1
Adiabatic diagram 1-9, 1-22
Adiabatic lapse rate 1-4
Adiabatic process 9-1
Advection 9-1
Afternoon mixing depth (MXDP) 7-3
Air drainage 9-1
Air mass 1-6, 9-1
Air pollution potential 1-10, 4-2
  climatology 4-6, 7-1, 7-3
  criteria 7-6
  definition of high potential 7-1
  forecasting 7-1, 7-6
  mixing depth calculations 7-3, 7-6
Air quality cycles 5-23, 5-31
  analysis methods 5-28, 5-31
  annual 5-23
  averaging time 5-25, 5-27
  daily 5-23
  nitrogen dioxide 5-24
  oxidant 5-24
  sampling time 5-25
  sulfur dioxide
Aircraft-borne sensors 6-12, 6-13
Albedo 1-1, 9-1
  fog 2-12
Anemometer 6-1, 6-4, 9-1
  bridled cup 6-1, 6-7
  cup 6-1
  propeller 6-2, 6-3
Anticyclone 1-5, 1-6, 9-1
  stagnating 4-2, 4-4
  subtropical 4-1
  tracks 4-1, 4-3
Area conversion factors 9-28
Atmospheric chemistry 5-9, 5-12
Atmospheric tracers 7-31, 7-32
Atomic weights 9-36
Austausch coefficient 3-13
Autocorrelation coefficient 3-10, 3-11
  Eulerian 3-14
  Lagrangian 3-13, 3-14
Average wind speed (AWS) 7-3
Averaging time for survey 5-25, 5-27

B

Backing 3-21, 9-1
Beaufort wind scale 9-1
Bibliographies 8-7
Bi-directional vane (Bivane) 3-19, 6-7, 9-2
Booklist - air pollution meteorology 8-1, 8-2
Boyle's law 2-14
Bridled cup anemometer 9-2
Buoyancy 9-2

C

Campbell-Stokes recorder 9-2
Cascade impactor 9-2
Centripetal acceleration 1-5
Chemistry, atmospheric 5-9, 5-12
Climate 9-2
Climatology 9-2
Climatology, air pollution 4-1, 4-6
  air pollution potential 4-6
  anticyclones
    stagnating 4-2, 4-4
    subtropical 4-1
    tracks 4-1, 4-3
  cyclones
    tracks 4-1, 4-3
  frontal trapping 4-6
  Holzworth, G. C. 4-2, 4-4, 4-5, 4-6
  Hosler, C. R. 4-2, 4-4
  inversion frequency 4-2, 4-5
  Klein, W. H. 4-1
  Korshover, J. 4-2
  maximum mixing depth 4-4, 4-5
  Visher, S. S. 4-1, 4-4
  wind speed 4-5
Cloudiness
  urban vs. rural 5-2
Clouds 1-5, 1-6
Concentration
  conversion factors 9-32
Condensation 1-5, 1-6
Condensation nucleus 1-6, 1-7, 9-2
Coning 2-5, 2-6
Constant level balloon 6-6
Consultants 8-2
Convection 9-2

Conversion factors 9-26 — 9-37
area 9-28
concentration 9-32
emission rate 9-34
flow 9-30
length 9-33
pressure 9-25
temperature 9-26
velocity 9-35
volume 9-29
weight 9-31
Coriolis force 1-2, 1-5, 9-2
Correlation coefficient
space 3-10
defined 9-8
Correlogram 3-10
Eulerian 3-14
Lagrangian 3-14
Crystallization 1-5
Cumulative frequency distribution 5-28
Cycles
annual 5-23, 5-25
daily 5-23
nitrogen dioxide 5-24
oxidant 5-24
sampling time 5-25
sulfur dioxide 5-24, 5-25
Cyclone 1-5, 1-6
tracks 4-2, 4-3

D

Data, meteorological 7-37
National Weather Records Center 7-41, 7-42, 7-44
observing stations
cooperative 7-37
fire weather 7-37
first order 7-37
military 7-37
second order 7-37
upper air 7-37
publications
climatological data-national summary 7-39
climatological data-state 7-39
daily weather map 7-38
local climatological data 7-38
northern hemisphere data tabulations 7-38
National Weather Service Offices and Stations 7-53
Davidson-Bryant equation 3-41
Decennial Census of United States Climate 2-17, 7-50
Dew point 1-5, 9-2
Diffusion (also see Turbulence) 2-1, 3-1, 3-36
defined 3-12, 9-2
horizontal turbulent diffusion 3-3, 3-5
influence of cities 3-3
influence of weather systems 3-3
vertical turbulent diffusion 3-2, 3-3
Diffusion computations 3-17, 3-35
accuracy 3-22
areas within concentration isopleths 3-21
assumptions 3-19
calculation of off-axis concentrations 3-21
centerline concentration from ground level source 3-20
continuous point source 3-18
elevated source 3-18, 3-19
estimation by graphical means 3-21
estimation of vertical and horizontal dispersion 3-20, 3-24, 3-25
estimation of wind speed 3-20
general equation 3-13, 3-17, 3-18, 3-19
ground level concentration 3-18
from an elevated source 3-20, 3-21
nomograms 3-28, 3-32
plotting ground-level concentration isopleths 3-21
source at ground level 3-18
under vertically limited convection 3-20
use of stability categories for sigma 3-19
Diffusion experiments, urban
Cincinnati 7-25
St. Louis 7-21 — 7-25

Diffusion theory (see also Turbulence and diffusion theory)
  Fickian 3-13
  generalized Gaussian diffusion equation 3-17, 3-18
  statistical 3-2, 3-10, 3-13
  transfer theory 3-12, 3-13
    general diffusion equation 3-13
  virtual diffusivity ("K" theory) 3-2
Dilution 2-1
Dines anemometer 9-2
Direct solar radiation 9-3
Dispersion 9-3
Diurnal 9-3
Downwash
  near building 3-41
  near stack 3-40, 3-41
Downwind 9-3
Dry adiabat 1-9
Dry adiabatic lapse rate 9-3

E

Eddy 9-3
Eddy diffusion 9-3
Eddy diffusivity 3-13
Eddy energy 3-9, 3-10
Eddy velocity 3-9
Effective stack height 3-40, 3-43
  defined 3-39
  effect of aerodynamic downwash 3-40, 3-41 3-43
  effect of evaporative cooling 3-40
  formulae 3-39, 3-40
    corrections and limitation 3-40
  Davidson-Bryant 3-39
  Holland 3-40
  Lucas 3-40
  inversion - breakup fumigation equation 3-42
  rules-of-thumb 3-40, 3-41
  wind tunnel models 3-41
Ekman layer 9-3
Emission rate
  conversion factors 9-34
Energy spectrum 3-11
Equation of continuity 3-18
Equation of state 2-14
Eulerian coordinates 9-3
Eulerian system 3-9, 3-14
Evaporation 1-5
Exchange coefficient (Austausch) 3-13
Exposure of instruments 6-21, 6-25
  airborne instruments 6-24, 6-25
  stack-mounted instruments 6-23, 6-24
  surface instruments 6-21, 6-22
  tower instruments 6-22, 6-23
Extinction coefficient 5-5

F

Fanning 2-5, 2-6
Flow
  conversion factors 9-30
Flux 3-13
Fog 2-11, 2-12
  London, 1952 5-18-5-20
  radiation 2-12
  urban vs. rural 3-2, 5-3
Free atmosphere 9-3
Friction layer 9-3
Frictional flow 1-5
Frontal trapping 2-3, 4-6
Fronts 1-5, 1-6, 2-3
Fumigation 2-5, 2-6, 2-11, 3-39

G

Gay-Lussac's law 2-14
Gas constant 2-14
Gaussian diffusion equation 3-17
General circulation 1-2
  Palmen's model 1-2
Geometric mean 9-7
Geostrophic wind 1-5, 3-20, 9-3
Glossary 9-1, 9-6
Gravitational settling 5-13
"Greenhouse effect" 1-1, 9-3
Gust 9-4
Gust accelerometer 6-7
Gustiness of the wind 3-6

H

Haze 9-4
Heat of condensation 1-5
High pressure area 1-5, 1-6
Holland equation 3-40
Hot wire anemometer 9-4
Humidity
  urban vs. rural 5-1
Hygrothermograph 6-16

I

Illuminometer 6-15, 9-4
Impaction 5-13, 5-15, 5-16
Insolation 3-19, 3-20
Instability 9-4
Instruments, meteorological 6-1, 6-26
  aircraft-borne sensors 6-12, 6-13
  anemometers 6-1, 6-4
    bridled cup 6-2, 6-7
    cup 6-1
    propeller 6-2, 6-3
  bi-directional vane (bivane) 6-7
  constant level balloon 6-6
  exposure 6-8, 6-21, 6-25
    airborne 6-24, 6-25
    stack-mounted 6-23, 6-24
    surface 6-21, 6-22
    tower 6-22, 6-23
  gust accelerometer 6-7
  hygrothermograph 6-16
  illuminometer 6-15
  net radiometer 6-15
  pilot balloon (pibal) 6-5
  precipitation collector 6-18
  psychrometer 6-16
  pyranometer 6-13, 6-14
  pyrheliometer 6-13, 6-14
  radiosonde 6-11, 6-12
  rain gauges 6-17, 6-18
    recording 6-17
    standard 6-17
    tipping bucket 6-18
  rawinsonde 6-5
  resistance thermometer 6-8
  rocket 6-5
  shielding for temperature sensors 6-8, 6-11
  sun photometer 5-6, 6-14
  T-sonde 6-12
  temperature-difference measurements 6-8, 6-13
  tethered balloon 6-12, 6-13
  tetroon 6-6
  thermistor 6-8
  thermocouple 6-8
  transmissometer 6-15
  turbulence measurements 6-6, 6-13
  wind vanes 6-4, 6-5
    aerodynamic shape 6-4
    flat-plate 6-4
    splayed 6-4
  wiresonde 6-12
Inversion 1-2
  above valley 2-12
  advection 1-9
  defined 9-4
  frequency 4-2, 4-4
  frontal 1-9
  radiation 1-9, 1-10
  subsidence 1-9, 1-10
  urban vs. rural 5-1
Inversion breakup 3-39
Isobars 1-5
Isokinetic sampling 9-4
Isotropy 3-11

J

Jet stream 1-2, 1-5

K

Kinematic viscosity 5-13
Kytoon 9-4

L

Lagrangian system 3-9, 3-10, 9-4
Lake breeze 2-10
Land breeze 2-10
Lapse rate
  defined 9-4
  dry adiabatic 1-4, 1-9, 2-2
  effect on turbulence 3-2, 2-2
  environmental 1-4, 9-4
  inversion 1-4, 1-9
  isothermal 1-4, 2-2
  process 1-4, 9-4
  pseudoadiabatic 1-5
  sub-adiabatic 1-4, 1-9
  super-adiabatic 1-4, 1-9
  urban effect upon 3-3
Large power plants 3-41
Length
  conversion factors 9-33
Linear regression line 9-8
Local
Climatological Data (LCD) 7-38, 7-42, 7-43
  Supplement 2-16, 7-44

Lofting 2-5, 2-6
London smog 5-9
Looping 2-5, 2-6
Los Angeles smog 5-9
Low pressure area 1-5, 1-6

M

Maximum mixing depth 1-10, 1-11
climatology 4-4, 4-5
Mean 5-28, 9-7
Median 5-28, 9-7
Mesometeorology 9-4
Micrometeorology 9-5
Mie theory 9-5
Millibar 2-15
Mixing depth 1-10, 7-3, 7-6
Mixing length 9-5
Mode 5-28
Models - meteorological
diffusion 4-6, 7-37 7-27
components 7-27
examples
Clarke-Cincinnati 7-28
Miller and Holzworth 7-28
Pooler-Nashville 7-27
Turner-Nashville 7-28
types 7-31
Morning urban mixing depth (MNDP) 7-3

N

National Climatic Center 7-37 — 7-40

Natural removal processes 5-13, 5-20
gravitational settling 5-13
impaction 5-13, 5-15, 5-16
rainout 5-13, 5-16, 5-17
tilted plume model 5-15
washout 5-13, 5-18
Net radiometer 6-15
Nitrogen dioxide 5-10

O

Olefins 5-10
Organic compounds 5-10
Ozone 5-9, 5-10

P

Particulates
reactions 5-11
"Peak-to-mean" ratio 2-7
Periodicals - air pollution and meteorology 8-1, 8-6, 8-7
Photochemical reactions 5-9
Photometer 5-5, 5-6, 6-14, 9-5
Pibal 6-5
Pilot balloon 6-5
Planck's law 1-1
Planetary boundary layer 9-5
Pollution concentration variation
due to meteorological variations 2-7
variation due to sampling time 2-7
Pollution wind rose 2-18
Potential temperature 9-5
Precipitation 1-6, 1-7
urban vs. rural 5-1
Precipitation collector 6-18
Pressure
conversion factors 9-27
units 2-14
Pressure gradient force 1-5
Prevailing wind 9-5
Psychrometer 6-16
Pyranometer 6-13, 6-14
Pyrheliometer 6-13, 6-14, 9-5

R

Radiation 1-1
solar 5-9
urban vs. rural 5-2
Radiational cooling 9-5
Radiosonde 1-9, 6-11, 9-5, 6-12
Radon 3-2
Rain gauges 6-17, 6-18
recording 6-17
standard 6-17
tipping bucket 6-18
Rainout 5-16, 5-17
Range 5-28, 9-7
Rawinsonde 6-5
Rayleigh scattering 5-5, 9-5
Reflectivity 1-1
Regression 9-8

Relative humidity 9-5
effect on atmospheric chemistry 5-10, 5-12
effect on turbidity 5-6
urban vs. rural 5-1
Removal processes 5-13, 5-20
gravitational settling 5-13
impaction 5-13, 5-15, 5-16
rainout 5-13, 5-16, 5-17
tilted plume model 5-15
washout 5-13, 5-18
Resistance thermometer 6-8
Resultant wind 9-5
Reynolds number 5-13, 5-14
Rocket 6-5
Roughness element 2-2, 5-2
Roughness, surface 2-2

S

Sampling time for survey 5-25
Saturation-adiabatic lapse rate 9-5
Scattering 5-5
Sea breeze 2-10
Secondary pollution 5-9, 5-11
reaction rate 5-11
Selection of sites 7-17
Shear, wind 9-6
Shielding for temperature sensors 6-8
Sigma 3-13, 3-19
estimation from stability 3-19
measurement 3-19
Site selection 7-17
Smog
London, 1952 5-18, 5-20
London type 5-9
Los Angeles 5-9
oxidizing 5-9
reducing 5-9
Snow
urban vs. rural 5-2
Solar radiation
impinging on earth 1-1
photochemical effect 5-12
urban vs. rural 5-2, 5-3
Sounding 1-9,1-21
Sources
area 3-2
continuous point 3-1
instantaneous point 3-1
isolated line 3-1
virtual "image" 3-17
Spectral density 3-11
Spectrum
energy or power 3-11
Stability, atmospheric 1-3
Stability categories 3-19, 3-23
Stagnating anticyclones 4-2, 4-4
Standard deviation 3-13, 3-19
defined 9-7
measurement 3-19
Stark-Einstein law 5-11
State climatologists 7-34
Statistics 9-7, 9-8
use in analysis of data 5-28
Stokes' law 5-13, 5-14
Stratosphere 1-3
Streak line 9-6
Streamline 9-6
Sublimation 1-5
Subsidence 1-4, 9-6
Sulfur dioxide 5-9, 5-10
Sulfuric acid 5-10
Sun photometer 5-5, 5-6, 6-14
Surface boundary layer 9-6
Surveys 7-9,
area 7-9
local source 7-9
operations 7-10
planning 7-10
purpose 7-9
research 7-9
site selection 7-9
Synoptic 9-6
Synoptic climatology 4-1

T

Temperature
conversion factors 9-24
diurnal variation with height 3-4
horizontal variation 1-3
urban vs. rural 5-1
variation with height 1-2
Terminal velocity 5-14
Tethered balloon 6-12, 6-13
Tetroon 6-6
Thermistor 6-8
Thermocouple 6-8
Tilted plume model 5-15
Topographic influences on
transport and diffusion 2-9, 2-12
influence of hills and valleys 2-9, 2-11, 2-12
land-water differences 2-10, 2-11

Tracers, atmospheric 7-21, 7-22
Tracks
anticyclone 4-1, 4-3
cyclone 4-2, 4-3
Trajectory 9-6
Transmissivity 5-5
Transmissometer 6-15
Trapping 2-5, 2-6
Travel time (T) 2-1, 3-15
Tropopause 1-3
Troposphere 1-2, 1-3
T-sonde 6-12
Turbidity
defined 5-5
network 5-6, 5-7
sun photometer 5-5, 5-7
Turbulence 2-1, 3-1, 3-12
defined 3-2, 3-9, 9-6
diurnal variation 2-3
effects of verticla temperature distribution 3-2, 3-3
Homogeneous 3-10, 3-13
intensity 3-9
isotropic 3-11
measurements 6-6, 6-13
mechanical 2-1, 2-2
relation to atmospheric stability 2-2
relation to wind records 2-2
sampling duration T 3-12
sampling periods (statistical theory) 3-11, 3-12
sampling time (s) 3-12
stationary 3-12, 3-13
statistical properties 3-12
thermal 2-2
Turbulence and diffusion theory
Fick, A. 3-13
Gifford, F. A. 3-19
Hay, J. S. and Pasquill, F. 3-14
Hilsmeier, W. F., and Gifford, F. 3-21
Kolmogoroff, A. N. 3-11
Meade, P. J. 3-19
Mickelesen, W. R. 3-14
mixing length 3-9
Pasquill, F. 3-15, 3-19
Prandtl, L. 3-9
Roberts, O. F. T. 3-13
sililarity 3-11
Smith, F. B. 3-13
statistical 3-10, 3-12
Sutton, O. G. 3-14
Taylor, G. I. 3-10, 3-11, 3-13
von Karman, T. 3-11
Turbulent (or eddy) velocity 3-9
Turbulent wake 3-39

U

Units of measurement 9-23
Urban diffusion experiments
Cincinnati 7-25
St. Louis 7-21 — 7-25
Urban dispersion model 7-27
components 7-27
types 7-27 — 7-31
Urban effect upon meteorological parameters 5-1, 5-7
cloudiness 5-2
humidity 5-1
radiation 5-2
rain 5-1
snow 5-2
temperature 5-1
visual range 5-3
wind 5-2

V

Valley breeze 9-6
Valley effects 2-9, 2-10, 9-6
Variance 9-7
Veering 9-6
Velocity
conversion factors 9-33
Visual range
urban vs. rural 5-3
Volume
conversion factors 9-27
Vorticity 7-6

W

Washout 5-13, 5-18
Water vapor 1-4, 1-5

National Weather Service 7-47

Weight
- conversion factors 9-31

Wind
- backing 3-21
- channeling 2-9
- climatology of low speeds 4-5
- direction 2-1
- diurnal variation 3-4, 3-5
- fluctuations 3-5, 3-6
- gustiness 3-6
- persistence 4-6
- slope 2-9, 2-10
- speed 2-1
- urban vs. rural 5-2
- valley 2-9, 2-10
- variability 2-1
- veering 2-2, 3-21

Wind rose 2-16, 2-27
- Baille 2-26
- defined 2-16, 9-6
- distribution of calms 2-22
- removal of bias 2-22

Wind vane 6-4, 6-5, 9-6
- aerodynamic shape 6-4
- flat plate 6-4
- splayed 6-4

Wiresonde 6-12, 9-6

ABSOLUTE	GRAVITATIONAL			ENGINEERING		Dimensional System
	FORCE-LENGTH-TIME			FORCE-MASS-LENGTH-TIME		
English	Metric	English		Metric	English	Systems of Units of Measurement ←
ft - lb_m - sec poundal - °R	cm - gm_f - sec - °K	ft - lb_f sec - °R	ft - lb_f - sec slug - °R	cm - gm_f - gm_m sec - °K	ft - lb_f - lb_m sec - °R	
$\frac{ft}{sec^2}$	$\frac{cm}{sec^2}$	$\frac{ft}{sec^2}$	$\frac{ft}{sec^2}$	$\frac{cm}{sec^2}$	$\frac{ft}{sec^2}$	
poundal / gm_f	gm_f / lb_f	lb_f		gm_f	lb_f	
$\frac{ft}{sec^2}$	$\frac{cm}{sec^2}$	$\frac{ft}{sec^2}$	$\frac{ft}{sec^2}$	$\frac{cm}{sec^2}$	$\frac{ft}{sec^2}$	
(1) $\frac{lb_m\text{-}ft}{poundal\text{-}sec^2}$	(1) dimensionless	(1) dimensionless	(1) $\frac{slug\text{-}ft}{lb_f\text{-}sec^2}$	981 $\frac{gm_m\text{-}cm}{gm_f\text{-}sec^2}$	$\frac{32.2\ lb_m\text{-}ft}{lb_f\text{-}sec^2}$	
lb_m	$\frac{gm_f\text{-}sec^2}{cm}$	$\frac{lb_f\text{-}sec^2}{ft}$	slug	gm_m	lb_m	
$\frac{lb_m}{ft^3}$	$\frac{gm_f\text{-}sec^2}{cm^4}$	$\frac{lb_f\text{-}sec^2}{ft^4}$	$\frac{slug}{ft^3}$	$\frac{gm_m}{cm^3}$	$\frac{lb_m}{ft^3}$	
$\frac{4.97X10^4\ poundal\text{-}ft}{(lb_m\text{-}mole)\ °K}$	$\frac{8.31X10^7\ gm_f\text{-}cm}{\left(\frac{gm_f\text{-}sec^2}{cm}\text{ - mole}\right)°K}$	$\frac{4.97X10^4\ lb_f\text{-}ft}{\left(\frac{lb_f\text{-}sec^2}{ft}\text{ -mole}\right)°R}$	$\frac{4.97X10^4\ lb_f\text{-}ft}{(slug\text{-}mole)\ °R}$	$\frac{8.47\ X\ 10^4\ gm_f\text{-}cm}{(gm_m\text{-}mole)\ °K}$	$\frac{1544\ lb_f\text{-}ft}{(lb_m\text{-}mole)\ °R}$	
$\frac{lb_m}{(lb_m\text{ - mole})}$	$\frac{gm_f\text{-}sec^2}{cm\left(\frac{gm_f\text{-}sec^2}{cm}\text{-mole}\right)}$	$\frac{lb_f\text{-}sec^2}{\left(\frac{lb_f\text{-}sec^2}{ft}\text{-mole}\right)ft}$	$\frac{slug}{(slug\text{-}mole)}$	$\frac{gm_m}{(gm_m\text{ - mole})}$	$\frac{lb_m}{(lb_m\text{-mole})}$	
$\frac{poundal}{ft^2}$	$\frac{gm_f}{cm^2}$	$\frac{lb_f}{ft^2}$	$\frac{lb_f}{ft^2}$	$\frac{gm_f}{cm^2}$	$\frac{lb_f}{ft^2}$	
poundal / gm_f		lb_f	lb_f	gm_f	lb_f	
$\frac{poundal}{ft^3}$	$\frac{gm_f}{cm^3}$	$\frac{lb_f}{ft^3}$	$\frac{lb_f}{ft^3}$	$\frac{gm_f}{cm^3}$	$\frac{lb_f}{ft^3}$	
$\frac{lb_m}{ft\text{-}sec}$	$\frac{gm_f\text{-}sec}{cm^2}$	$\frac{lb_{f\text{-}sec}}{ft^2}$	$\frac{lb_f\text{-}sec}{ft^2}$	$\frac{gm_m}{cm\text{-}sec}$	$\frac{lb_m}{ft\text{-}sec}$	
$\frac{ft^2}{sec}$	$\frac{cm^2}{sec}$	$\frac{ft^2}{sec}$	$\frac{ft^2}{sec}$	$\frac{cm^2}{sec}$	$\frac{ft^2}{sec}$	
4	5	6	7	8	9	

DIMENSIONAL SYSTEMS AND SELECTED SYSTEMS OF UNITS OF MEASUREMENT

Table 1. Common Systems of Units of Measurement for the Various Dimensional Systems

Item	Symbol	Definition	Dimensions	MASS-LENGTH-TIME		
				Metric		
				$\frac{cm - gm_m}{sec^2 - {}^\circ K}$	$\frac{cm\text{-}gm_m}{dyne\text{-}sec^2 - {}^\circ K}$	$\frac{ft - lb_m\text{-}sec^2}{{}^\circ R}$
acceleration	a		$\frac{length}{(time)^2}$	$\frac{cm}{sec^2}$	$\frac{cm}{sec^2}$	$\frac{ft}{sec^2}$
force	F		$\frac{(mass)(length)}{(time)^2}$	$\frac{gm_m - cm}{sec^2}$	dyne	$\frac{lb_m\text{-}ft}{sec^2}$
local acceleration due to gravity	g		$\frac{length}{(time)^2}$	$\frac{cm}{sec^2}$	$\frac{cm}{sec^2}$	$\frac{ft}{sec^2}$
dimensional constant	g_c		variable	(1) dimensionless	(1) $\frac{gm_m\text{-}cm}{dyne\text{-}sec^2}$	(1) dimensionle
mass	m		mass	gm_m	gm_m	lb_m
density	ρ	$\frac{mass}{volume}$	$\frac{mass}{(length)^3}$	$\frac{gm_m}{cm^3}$	$\frac{gm_m}{cm^3}$	$\frac{lb_m}{ft^3}$
universal gas constant	R	$\frac{(force)(length)}{(mass\text{-}mole)(temp)}$	$\frac{(mass)(length)^2}{(time)^2(mass\text{-}mole)(temp)}$ $\left[\frac{\frac{(force)(length)}{(length)}}{\frac{(force)(time)^2}{(length)} - mole}\right](temp)$ $\frac{(force)(length)}{(mass\text{-}mole)(temp)}$	$\frac{8.31X10^7\ gm_m\text{-}cm^2}{sec^2(gm_m\text{-}mole)^\circ K}$	$\frac{8.31X10^7\ dyne\text{-}cm}{(gm_m - mole)\text{-}^\circ K}$	$\frac{4.97X10^4\ lb_m\text{-}ft}{sec^2(lb_m\text{-}mole)^\circ}$
molecular weight	M	$\frac{mass}{(mass - mole)}$	$\frac{mass}{(mass - mole)}$ $\left[\frac{\frac{(force)(time)^2}{(length)}}{\frac{(force)(time)^2}{(length)} - mole}\right]length$	$\frac{gm_m}{gm_m - mole}$	$\frac{gm_m}{(gm_m\text{-}mole)}$	$\frac{lb_m}{(lb_m\text{-}mole)}$
pressure	P	$\frac{force}{area}$	$\frac{mass}{(length)(time)^2}$	$\frac{gm_m}{cm\text{-}sec^2}$	$\frac{dyne}{cm^2}$	$\frac{lb_m}{ft\text{-}sec^2}$
weight	W	force due to gravity	$\frac{(mass)(length)}{(time)^2}$	$\frac{gm_m\text{-}cm}{sec^2}$	dyne	$\frac{lb_m\text{-}ft}{sec^2}$
specific weight	w	$\frac{weight}{volume}$	$\frac{mass}{(length)^2(time)^2}$	$\frac{gm_m}{cm^2 - sec^2}$	$\frac{dyne}{cm^3}$	$\frac{lb_m}{ft^2 - sec^2}$
viscosity	μ	$\frac{mass}{(length)(time)}$	$\frac{mass}{(length)(time)}$	$\frac{gm_m}{cm - sec}$	$\frac{gm_m}{cm\text{-}sec}$	$\frac{lb_m}{ft\text{-}sec}$
kinematic viscosity	ν	$\frac{viscosity}{density}$	$\frac{(length)^2}{time}$	$\frac{cm^2}{sec}$	$\frac{cm^2}{sec}$	$\frac{ft^2}{sec}$
			Column number	1	2	3

VALUES AND LOGARITHMS OF EXPONENTIAL FUNCTIONS

Note: If $0 < x < .01$ the value for e^{-x} can be found by the use of $(1-x)$ or the value for e^{x} can be found by the use of $(1+x)$.

x	e^x		e^{-x}	x	e^x		e^{-x}
	Value	Log_{10}	Value		Value	Log_{10}	Value
0.00	1.0000	.00000	1.00000	0.50	1.6487	.21715	.60653
0.01	1.0101	.00434	.99005	0.51	1.6653	.22149	.60050
0.02	1.0202	.00869	.98020	0.52	1.6820	.22583	.59452
0.03	1.0305	.01303	.97045	0.53	1.6989	.23018	.58860
0.04	1.0408	.01737	.96079	0.54	1.7160	.23452	.58275
0.05	1.0513	.02171	.95123	0.55	1.7333	.23886	.57695
0.06	1.0618	.02606	.94176	0.56	1.7507	.24320	.57121
0.07	1.0725	.03040	.93239	0.57	1.7683	.24755	.56553
0.08	1.0833	.03474	.92312	0.58	1.7860	.25189	.55990
0.09	1.0942	.03909	.91393	0.59	1.8040	.25623	.55433
0.10	1.1052	.04343	.90484	0.60	1.8221	.26058	.54881
0.11	1.1163	.04777	.89583	0.61	1.8404	.26492	.54335
0.12	1.1275	.05212	.88692	0.62	1.8589	.26926	.53794
0.13	1.1388	.05646	.87809	0.63	1.8776	.27361	.53259
0.14	1.1503	.06080	.86936	0.64	1.8965	.27795	.52729
0.15	1.1618	.06514	.86071	0.65	1.9155	.28229	.52205
0.16	1.1735	.06949	.85214	0.66	1.9348	.28664	.51685
0.17	1.1853	.07383	.84366	0.67	1.9542	.29098	.51171
0.18	1.1972	.07817	.83527	0.68	1.9739	.29532	.50662
0.19	1.2092	.08252	.82696	0.69	1.9937	.29966	.50158
0.20	1.2214	.08686	.81873	0.70	2.0138	.30401	.49659
0.21	1.2337	.09120	.81058	0.71	2.0340	.30835	.49164
0.22	1.2461	.09554	.80252	0.72	2.0544	.31269	.48675
0.23	1.2586	.09989	.79453	0.73	2.0751	.31703	.48191
0.24	1.2712	.10423	.78663	0.74	2.0959	.32138	.47711
0.25	1.2840	.10857	.77880	0.75	2.1170	.32572	.47237
0.26	1.2969	.11292	.77105	0.76	2.1383	.33006	.46767
0.27	1.3100	.11726	.76338	0.77	2.1598	.33441	.46301
0.28	1.3231	.12160	.75578	0.78	2.1815	.33875	.45841
0.29	1.3364	.12595	.74826	0.79	2.2034	.34309	.45384
0.30	1.3499	.13029	.74082	0.80	2.2255	.34744	.44933
0.31	1.3634	.13463	.73345	0.81	2.2479	.35178	.44486
0.32	1.3771	.13897	.72615	0.82	2.2705	.35612	.44043
0.33	1.3910	.14332	.71892	0.83	2.2933	.36046	.43605
0.34	1.4049	.14766	.71177	0.84	2.3164	.36481	.43171
0.35	1.4191	.15200	.70469	0.85	2.3396	.36915	.42741
0.36	1.4333	.15635	.69768	0.86	2.3632	.37349	.42316
0.37	1.4477	.16069	.69073	0.87	2.3869	.37784	.41895
0.38	1.4623	.16503	.68386	0.88	2.4109	.38218	.41478
0.39	1.4770	.16937	.67706	0.89	2.4351	.38652	.41066
0.40	1.4918	.17372	.67032	0.90	2.4596	.39087	.40657
0.41	1.5068	.17806	.66365	0.91	2.4843	.39521	.40252
0.42	1.5220	.18240	.65705	0.92	2.5093	.39955	.39852
0.43	1.5373	.18675	.65051	0.93	2.5345	.40389	.39455
0.44	1.5527	.19109	.64404	0.94	2.5600	.40824	.39063
0.45	1.5683	.19543	.63763	0.95	2.5857	.41258	.38674
0.46	1.5841	.19978	.63128	0.96	2.6117	.41692	.38289
0.47	1.6000	.20412	.62500	0.97	2.6379	.42127	.37908
0.48	1.6161	.20846	.61878	0.98	2.6645	.42561	.37531
0.49	1.6323	.21280	.61263	0.99	2.6912	.42995	.37158
0.50	1.6487	.21715	.60653	1.00	2.7183	.43429	.36788

VALUES AND LOGARITHMS OF EXPONENTIAL FUNCTIONS

(continued)

x	e^x		e^{-x}	x	e^x		e^{-x}
	Value	Log_{10}	Value		Value	Log_{10}	Value
1.00	2.7183	.43429	.36788	1.50	4.4817	.65144	.22313
1.01	2.7456	.43864	.36422	1.51	4.5267	.65578	.22091
1.02	2.7732	.44298	.36060	1.52	4.5722	.66013	.21871
1.03	2.8011	.44732	.35701	1.53	4.6182	.66447	.21654
1.04	2.8292	.45167	.35345	1.54	4.6646	.66881	.21438
1.05	2.8577	.45601	.34994	1.55	4.7115	.67316	.21225
1.06	2.8864	.46035	.34646	1.56	4.7588	.67750	.21014
1.07	2.9154	.46470	.34301	1.57	4.8066	.68184	.20805
1.08	2.9447	.46904	.33960	1.58	4.8550	.68619	.20598
1.09	2.9743	.47338	.33622	1.59	4.9037	.69053	.20393
1.10	3.0042	.47772	.33287	1.60	4.9530	.69487	.20190
1.11	3.0344	.48207	.32956	1.61	5.0028	.69921	.19989
1.12	3.0649	.48641	.32628	1.62	5.0531	.70356	.19790
1.13	3.0957	.49075	.32303	1.63	5.1039	.70790	.19593
1.14	3.1268	.49510	.31982	1.64	5.1552	.71224	.19398
1.15	3.1582	.49944	.31664	1.65	5.2070	.71659	.19205
1.16	3.1899	.50378	.31349	1.66	5.2593	.72093	.19014
1.17	3.2220	.50812	.31037	1.67	5.3122	.72527	.18825
1.18	3.2544	.51247	.30728	1.68	5.3656	.72961	.18637
1.19	3.2871	.51681	.30422	1.69	5.4195	.73396	.18452
1.20	3.3201	.52115	.30119	1.70	5.4739	.73830	.18268
1.21	3.3535	.52550	.29820	1.71	5.5290	.74264	.18087
1.22	3.3872	.52984	.29523	1.72	5.5845	.74699	.17907
1.23	3.4212	.53418	.29229	1.73	5.6407	.75133	.17728
1.24	3.4556	.53853	.28938	1.74	5.6973	.75567	.17552
1.25	3.4903	.54287	.28650	1.75	5.7546	.76002	.17377
1.26	3.5254	.54721	.28365	1.76	5.8124	.76436	.17204
1.27	3.5609	.55155	.28083	1.77	5.8709	.76870	.17033
1.28	3.5966	.55590	.27804	1.78	5.9299	.77304	.16864
1.29	3.6328	.56024	.27527	1.79	5.9895	.77739	.16696
1.30	3.6693	.56458	.27253	1.80	6.0496	.78173	.16530
1.31	3.7062	.56893	.26982	1.81	6.1104	.78607	.16365
1.32	3.7434	.57327	.26714	1.82	6.1719	.79042	.16203
1.33	3.7810	.57761	.26448	1.83	6.2339	.79476	.16041
1.34	3.8190	.58195	.26185	1.84	6.2965	.79910	.15882
1.35	3.8574	.58630	.25924	1.85	6.3598	.80344	15724
1.36	3.8962	.59064	.25666	1.86	6.4237	.80779	.15567
1.37	3.9354	.59498	.25411	1.87	6.4883	.81213	.15412
1.38	3.9749	.59933	.25158	1.88	6.5535	.81647	.15259
1.39	4.0149	.60367	.24908	1.89	6.6194	.82082	.15107
1.40	4.0552	.60801	.24660	1.90	6.6859	.82516	.14957
1.41	4.0960	.61236	.24414	1.91	6.7531	.82950	.14808
1.42	4.1371	.61670	.24171	1.92	6.8210	.83385	14661
1.43	4.1787	.62104	.23931	1.93	6.8895	.83819	.14515
1.44	4.2207	.62538	.23693	1.94	6.9588	.84253	.14370
1.45	4.2631	.62973	.23457	1.95	7.0287	.84687	.14227
1.46	4.3060	.63407	.23224	1.96	7.0993	.85122	.14086
1.47	4.3492	.63841	.22993	1.97	7.1707	.85556	.13946
1.48	4.3929	.64276	.22764	1.98	7.2427	.85990	.13807
1.49	4.4371	.64710	.22537	1.99	7.3155	.86425	.13670
1.50	4.4817	.65144	.22313	2.00	7.3891	.86859	.13534

VALUES AND LOGARITHMS OF EXPONENTIAL FUNCTIONS
(continued)

x	e^x		e^{-x}	x	e^x		e^{-x}
	Value	Log_{10}	Value		Value	Log_{10}	Value
2.00	7.3891	.86859	.13534	2.50	12.182	1.08574	.08208
2.01	7.4633	.87293	.13399	2.51	12.305	1.09008	.08127
2.02	7.5383	.87727	.13266	2.52	12.429	1.09442	.08046
2.03	7.6141	.88162	.13134	2.53	12.554	1.09877	.07966
2.04	7.6906	.88596	.13003	2.54	12.680	1.10311	.07887
2.05	7.7679	.89030	.12873	2.55	12.807	1.10745	.07808
2.06	7.8460	.89465	.12745	2.56	12.936	1.11179	.07730
2.07	7.9248	.89899	.12619	2.57	13.066	1.11614	.07654
2.08	8.0045	.90333	.12493	2.58	13.197	1.12048	.07577
2.09	8.0849	.90768	.12369	2.59	13.330	1.12482	.07502
2.10	8.1662	.91202	.12246	2.60	13.464	1.12917	.07427
2.11	8.2482	.91636	.12124	2.61	13.599	1.13351	.07353
2.12	8.3311	.92070	.12003	2.62	13.736	1.13785	.07280
2.13	8.4149	.92505	.11884	2.63	13.874	1.14219	.07208
2.14	8.4994	.92939	.11765	2.64	14.013	1.14654	.07136
2.15	8.5849	.93373	.11648	2.65	14.154	1.15088	.07065
2.16	8.6711	.93808	.11533	2.66	14.296	1.15522	.06995
2.17	8.7583	.94242	.11418	2.67	14.440	1.15957	.06925
2.18	8.8463	.94676	.11304	2.68	14.585	1.16391	.06856
2.19	8.9352	.95110	.11192	2.69	14.732	1.16825	.06788
2.20	9.0250	.95545	.11080	2.70	14.880	1.17260	.06721
2.21	9.1157	.95979	.10970	2.71	15.029	1.17694	.06654
2.22	9.2073	.96413	.10861	2.72	15.180	1.18128	.06587
2.23	9.2999	.96848	.10753	2.73	15.333	1.18562	.06522
2.24	9.3933	.97282	.10646	2.74	15.487	1.18997	.06457
2.25	9.4877	.97716	.10540	2.75	15.643	1.19431	.06393
2.26	9.5831	.98151	.10435	2.76	15.800	1.19865	.06329
2.27	9.6794	.98585	.10331	2.77	15.959	1.20300	.06266
2.28	9.7767	.99019	.10228	2.78	16.119	1.20734	.06204
2.29	9.8749	.99453	.10127	2.79	16.281	1.21168	.06142
2.30	9.9742	.99888	.10026	2.80	16.445	1.21602	.06081
2.31	10.074	1.00322	.09926	2.81	16.610	1.22037	.06020
2.32	10.176	1.00756	.09827	2.82	16.777	1.22471	.05961
2.33	10.278	1.01191	.09730	2.83	16.945	1.22905	.05901
2.34	10.381	1.01625	.09633	2.84	17.116	1.23340	.05843
2.35	10.486	1.02059	.09537	2.85	17.288	1.23774	.05784
2.36	10.591	1.02493	.09442	2.86	17.462	1.24208	.05727
2.37	10.697	1.02928	.09348	2.87	17.637	1.24643	.05670
2.38	10.805	1.03362	.09255	2.88	17.814	1.25077	.05613
2.39	10.913	1.03796	.09163	2.89	17.993	1.25511	.05558
2.40	11.023	1.04231	.09072	2.90	18.174	1.25945	.05502
2.41	11.134	1.04665	.08982	2.91	18.357	1.26380	.05448
2.42	11.246	1.05099	.08892	2.92	18.541	1.26814	.05393
2.43	11.359	1.05534	.08804	2.93	18.728	1.27248	.05340
2.44	11.473	1.05968	.08716	2.94	18.916	1.27683	.05287
2.45	11.588	1.06402	.08629	2.95	19.106	1.28117	.05234
2.46	11.705	1.06836	.08543	2.96	19.298	1.28551	.05182
2.47	11.822	1.07271	.08458	2.97	19.492	1.28985	.05130
2.48	11.941	1.07705	.08374	2.98	19.688	1.29420	.05079
2.49	12.061	1.08139	.08291	2.99	19.886	1.29854	.05029
2.50	12.182	1.08574	.08208	3.00	20.086	1.30288	.04979

VALUES AND LOGARITHMS OF EXPONENTIAL FUNCTIONS

(continued)

x	e^x		e^{-x}
	Value	$\log_{10}$	Value
3.00	20.086	1.30288	.04979
3.05	21.115	1.32460	.04736
3.10	22.198	1.34631	.04505
3.15	23.336	1.36803	.04285
3.20	24.533	1.38974	.04076
3.25	25.790	1.41146	.03877
3.30	27.113	1.43317	.03688
3.35	28.503	1.45489	.03508
3.40	29.964	1.47660	.03337
3.45	31.500	1.49832	.03175
3.50	33.115	1.52003	.03020
3.55	34.813	1.54175	.02872
3.60	36.598	1.56346	.02732
3.65	38.475	1.58517	.02599
3.70	40.447	1.60689	.02472
3.75	42.521	1.62860	.02352
3.80	44.701	1.65032	.02237
3.85	46.993	1.67203	.02128
3.90	49.402	1.69375	.02024
3.95	51.935	1.71546	.01925
4.00	54.598	1.73718	.01832
4.10	60.340	1.78061	.01657
4.20	66.686	1.82404	.01500
4.30	73.700	1.86747	.01357
4.40	81.451	1.91090	.01227
4.50	90.017	1.95433	.01111
4.60	99.484	1.99775	.01005
4.70	109.95	2.04118	.00910
4.80	121.51	2.08461	.00823
4.90	134.29	2.12804	.00745
5.00	148.41	2.17147	.00674
5.10	164.02	2.21490	.00610
5.20	181.27	2.25833	.00552
5.30	200.34	2.30176	.00499
5.40	221.41	2.34519	.00452
5.50	244.69	2.38862	.00409
5.60	270.43	2.43205	.00370
5.70	298.87	2.47548	.00335
5.80	330.30	2.51891	.00303
5.90	365.04	2.56234	.00274
6.00	403.43	2.60577	.00248
6.25	518.01	2.71434	.00193
6.50	665.14	2.82291	.00150
6.75	854.06	2.93149	.00117
7.00	1096.6	3.04006	.00091
7.50	1808.0	3.25721	.00055
8.00	2981.0	3.47436	.00034
8.50	4914.8	3.69150	.00020
9.00	8103.1	3.90865	.00012
9.50	13360.	4.12580	.00007
10.00	22026.	4.34294	.00005

CONVERSION FACTORS

Page

TEMPERATURE.....9-26

PRESSURE.....9-27

AREA.....9-28

VOLUME.....9-29

FLOW.....9-30

WEIGHT.....9-31

CONCENTRATION.....9-32

LENGTH.....9-33

EMISSION RATES.....9-34

VELOCITY.....9-35

LOGARITHMS

10-99 to Base 10..... 9-36 — 9-37

International
Atomic Weights..... 9-38

CONVERSION FACTORS - TEMPERATURE

Given Units \ Desired Units	^{o}F	^{o}C	^{o}R	^{o}K
Degrees Fahr.		.5555 x (^{o}F - 32)	^{o}F + 460	.5555 x (^{o}F-32) + 273
Degrees Centigrade	1.8^{o}C + 32		1.8^{o}C + 492	^{o}C + 273
Degrees Rankin	^{o}R - 460	.5555 x (^{o}R - 492)		.5555 x (^{o}R-492) + 273
Degrees Kelvin	1.8(^{o}K-273) + 32	^{o}K - 273	1.8(^{o}K-273)+492	

CONVERSION FACTORS - PRESSURE

Given units \ Desired units	$\frac{gm_m}{cm\text{-}sec^2}$	$\frac{dynes}{cm^2}$	$\frac{\#_m}{ft\text{-}sec^2}$	$\frac{poundals}{ft^2}$	$\frac{gm_f}{cm^2}$	$\frac{\#_f}{ft^2}$	$\frac{\#_f}{in^2}$	"Atmospheres
$\frac{gm_m}{cm\text{-}sec^2}$	1	1	6.7197×10^{-2}	6.7197×10^{-2}	1.0197×10^{-3}	2.0885×10^{-3}	1.4504×10^{-5}	9.8692×10^{-7}
$\frac{dynes}{cm^2}$	1	1	6.7197×10^{-2}	6.7197×10^{-2}	1.0197×10^{-3}	2.0885×10^{-3}	1.4504×10^{-5}	9.8692×10^{-7}
$\frac{\#_m}{ft\text{-}sec^2}$	14.882	14.882	1	1	1.5175×10^{-2}	3.1081×10^{-2}	2.1584×10^{-4}	1.4687×10^{-5}
$\frac{poundals}{ft^2}$	14.882	14.882	1	1	1.5175×10^{-2}	3.1081×10^{-2}	2.1584×10^{-4}	1.4687×10^{-5}
$\frac{gm_f}{cm^2}$	980.665	980.665	65.898	65.898	1	2.0482	1.4223×10^{-2}	9.6784×10^{-4}
$\frac{\#_f}{ft^2}$	478.80	478.80	32.174	32.174	4.8824×10^{-1}	1	6.9444×10^{-3}	4.7254×10^{-4}
$\frac{\#_f}{in^2}$	6.8948×10^4	6.8948×10^4	4.6331×10^3	4.6331×10^3	70.307	144.00	1	6.8046×10^{-2}
"Atmospheres"	1.0133×10^6	1.0133×10^6	6.8087×10^4	6.8087×10^4	1.0332×10^3	2.1162×10^3	14.696	1

To convert a value from a given unit to a desired unit, multiply the given value by the factor opposite the given units and beneath the desired units.

CONVERSION FACTORS - AREA

Given Units \ Desired Units	Square Inch	Square Feet	Square Yard	Square Mile	Acre	Square Centimeter	Square Decimeter	Square Meter	Square Kilometer
Square Inch	1	6.9444×10^{-3}	77.1605×10^{-5}	2.49×10^{-10}	15.94×10^{-6}	6.452	6.452×10^{-2}	6.452×10^{-4}	6.452×10^{-10}
Square Foot	144	1	0.1111	3.587×10^{-8}	2.296×10^{-5}	929.0341	929.0341×10^{-2}	929.0341×10^{-4}	929.0341×10^{-10}
Square Yard	1296	9	1	3.228×10^{-7}	2.066×10^{-4}	83.61×10^{2}	83.61	83.61×10^{-2}	83.61×10^{-8}
Square Mile	40.144×10^{8}	2.788×10^{7}	3.098×10^{6}	1	640	2.589998×10^{10}	2.589998×10^{8}	2.589998×10^{6}	2.589998
Acre	62.73×10^{7}	4.3560×10^{4}	4840	15.625×10^{-4}	1	4046.873×10^{4}	4046.873×10^{2}	4046.873	4046.873×10^{-6}
Square Centimeter	15.5×10^{-2}	10.764×10^{-4}	1.1960×10^{-4}	3.8610×10^{-11}	2.471×10^{-8}	1	1×10^{-2}	1×10^{-4}	1×10^{-10}
Square Decimeter	15.5	10.764×10^{-2}	1.1960×10^{-2}	3.8610×10^{-9}	2.471×10^{-6}	1×10^{2}	1	1×10^{-2}	1×10^{-8}
Square Meter	15.5×10^{2}	10.764	1.1960	3.8610×10^{-7}	2.471×10^{-4}	1×10^{4}	1×10^{2}	1	1×10^{-6}
Square Kilometer	15.5×10^{8}	10.764×10^{6}	1.1960×10^{6}	3.8610×10^{-1}	2.471×10^{2}	1×10^{10}	1×10^{8}	1×10^{6}	1

To convert a value from a given unit a desired unit, multiply the given value by the factor opposite the given units and beneath the desired unit

CONVERSION FACTORS – VOLUME

Given Units \ Desired Units	Cubic Yard	Cubic Foot	Cubic Inch	Cubic Meter	Cubic Decimeter	Cubic Centimeter	Liter
Cubic Yard	1	27	4.6656×10^{4}	0.764559	764.559	7.64559×10^{5}	764.54
Cubic Foot	3.7037×10^{-2}	1	1728	2.8317×10^{-2}	28.317	2.8317×10^{4}	28.316
Cubic Inch	2.143347×10^{-5}	5.78704×10^{-4}	1	1.63872×10^{-5}	1.63872×10^{-2}	16.3872	1.63868×10^{-2}
Cubic Meter	1.30794	35.314445	6.1023×10^{4}	1	1000	1×10^{6}	999.973
Cubic Decimeter	1.3079×10^{-3}	3.5314×10^{-2}	61.023	0.001	1	1000	.99997
Cubic Centimeter	1.3079×10^{-6}	3.5314×10^{-5}	6.1023×10^{-2}	1×10^{-6}	1×10^{-3}	1	9.99973×10^{-4}
Liter	1.3080×10^{-3}	3.5316×10^{-2}	61.025	1.000027×10^{-3}	1.000027	1000.027	1

To convert a value from a given unit to a desired unit, multiply the given value by the factor opposite the given units and beneath the desired units.

CONVERSION FACTORS – FLOW

Given Units \ Desired Units	$\frac{M^3}{sec}$	$\frac{M^3}{min}$	$\frac{M^3}{hour}$	$\frac{ft^3}{sec}$	$\frac{ft^3}{min}$	$\frac{ft^3}{hour}$	$\frac{L}{sec}$	$\frac{L}{min}$	$\frac{cm^3}{sec}$	$\frac{cm^3}{min}$
$\frac{M^3}{sec}$	1	60	3600	35.3144	21.1387 $\times 10^{2}$	12.7132 $\times 10^{4}$	999.973	59.998 $\times 10^{3}$	1×10^{6}	6×10^{7}
$\frac{M^3}{min}$	0.0167	1	60	0.5886	35.3144	21.189 $\times 10^{2}$	16.667	999.973	16.667 $\times 10^{3}$	1×10^{6}
$\frac{M^3}{hour}$	2.778 $\times 10^{-5}$	16.667 $\times 10^{-3}$	1	98.99 $\times 10^{-4}$	0.5886	35.3144	27.777 $\times 10^{-2}$	16.667	2.777 $\times 10^{2}$	1.666 $\times 10^{4}$
$\frac{ft^3}{sec}$	28.317 $\times 10^{-3}$	1.699	101.94	1	60	3600	28.316	16.9896 $\times 10^{2}$	2.8317 $\times 10^{4}$	1.699 $\times 10^{6}$
$\frac{ft^3}{min}$	4.7195 $\times 10^{-4}$	28.317 $\times 10^{-3}$	1.699	16.667 $\times 10^{-3}$	1	60	47.193 $\times 10^{-2}$	28.315	4.7195 $\times 10^{2}$	2.8317 $\times 10^{4}$
$\frac{ft^3}{hour}$	7.8658 $\times 10^{-6}$	4.7195 $\times 10^{-4}$	28.317 $\times 10^{-3}$	2.778 $\times 10^{-4}$	16.667 $\times 10^{-3}$	1	7.866 $\times 10^{-3}$	0.4719	78.658	4.7195 $\times 10^{2}$
$\frac{L}{sec}$	1.000027 $\times 10^{-3}$	6.00016 $\times 10^{-2}$	3.6	35.316 $\times 10^{-3}$	2.11896	127.138	1	60	1000.027	16.667 6.00016×10^{4}
$\frac{L}{min}$	1.6667 $\times 10^{-5}$	1.000027 $\times 10^{-3}$	6.00016 $\times 10^{-2}$	5.886 $\times 10^{-4}$	35.316 $\times 10^{-3}$	2.11896	1.6667 $\times 10^{-2}$	1	16.667	1000.027
$\frac{cm^3}{sec}$	1×10^{-6}	6×10^{-5}	3.6×10^{-3}	3.5314 $\times 10^{-5}$	2.1189 $\times 10^{-3}$	1.271 $\times 10^{-3}$	9.99973 $\times 10^{-4}$	5.9998 $\times 10^{-2}$	1	60
$\frac{cm^3}{min}$	1.6667 $\times 10^{-8}$	1×10^{-6}	6×10^{-5}	5.886 $\times 10^{-7}$	0.3531 $\times 10^{-4}$	2.11887 $\times 10^{-3}$	5.9998 $\times 10^{-2}$	9.99973 $\times 10^{-4}$	16.667 $\times 10^{-3}$	1

To convert a value from a given unit to a desired unit, multiply the given value by the factor opposite the given units and beneath the desired unit.

CONVERSION FACTORS WEIGHT

Desired Units / Given	Micro-gram	Multi-gram	gram	Kile-gram	grain	Ounce (avdp)	Pound (avdp)	Ton (U.S. short)	Tonne (metric)
Micro-gram	1	1×10^{-3}	1×10^{-6}	1×10^{-9}	15.4124×10^{-6}	3.5274×10^{-8}	2.2046×10^{-9}	1.1023×10^{-12}	1×10^{-12}
Milli-gram	1×10^{3}	1	1×10^{-3}	1×10^{-6}	15.4324×10^{-3}	3.5274×10^{-5}	2.2046×10^{-6}	1.1023×10^{-9}	1×10^{-9}
gram	1×10^{6}	1×10^{3}	1	1×10^{-3}	15.4324	3.5274×10^{-2}	2.2046×10^{-3}	1.1023×10^{-6}	1×10^{-6}
Kilogram	1×10^{9}	1×10^{6}	1×10^{3}	1	15.4324×10^{3}	35.274	2.2046	1.1023×10^{-3}	1×10^{-3}
grain	64.799×10^{3}	64.799	64.799×10^{-3}	64.799×10^{-6}	1	22.857×10^{-4}	1.4286×10^{-4}	7.143×10^{-8}	64.799×10^{-9}
Ounce (avdp)	28.349×10^{6}	28.349×10^{3}	28.349	28.349×10^{-3}	437.5	1	62.5×10^{-3}	3.125×10^{-5}	28.349×10^{-6}
Pound (avdp)	453.59×10^{6}	453.59×10^{3}	453. 59	453.59×10^{-3}	7000	16	1	5×10^{-4}	453.59×10^{-6}
Ton (U.S. short)	905.185×10^{9}	907.185×10^{6}	907.185×10^{3}	907.185	14×10^{6}	3.2×10^{4}	2000	1	0.907185
Tonne (metric)	1×10^{12}	1×10^{9}	1×10^{6}	1×10^{3}	1.543×10^{7}	3.5274×10^{4}	2204.62	1.10231	1

CONVERSION FACTORS - CONCENTRATION

Given Units \ Desired Units	$\frac{\mu g}{M^3}$	$\frac{\mu g}{M^3}$	$\frac{\mu g}{L}$	$\frac{oz}{ft.^3}$	$\frac{lbs.}{ft.^3}$	$\frac{grams}{ft.^3}$	$\frac{lbs.}{1000\ ft.^3}$	$\frac{grains}{ft.^3}$
$\frac{\mu g}{M^3}$	1	1000	1.000027	9.989×10^{-7}	6.243×10^{-8}	2.8317×10^{-5}	6.243×10^{-5}	4.37×10^{-4}
$\frac{\mu g}{M^3}$	1×10^{-3}	1	1.000027×10^{-3}	9.989×10^{-10}	6.243×10^{-11}	2.8317×10^{-8}	6.243×10^{-8}	4.37×10^{-7}
$\frac{\mu g}{L}$	.999973	9.99973×10^{2}	1	9.988×10^{-7}	6.242×10^{-8}	2.8316×10^{-5}	6.242×10^{-5}	4.37×10^{-4}
$\frac{oz}{ft.^3}$	1.00115×10^{6}	1.00115×10^{9}	1.00118×10^{6}	1	62.5×10^{-3}	28.349	62.5	4.375×10^{2}
$\frac{lbs.}{ft.^3}$	1.602×10^{7}	1.602×10^{10}	1.602×10^{7}	16	1	453.59	1×10^{3}	7×10^{3}
$\frac{grams}{ft.^3}$	3.531×10^{4}	3.531×10^{7}	3.531×10^{4}	3.5274×10^{-2}	2.20462×10^{-3}	1	2.2046	15.43
$\frac{lbs.}{1000\ ft.^3}$	1.602×10^{4}	1.602×10^{7}	1.602×10^{4}	1.6×10^{-2}	1×10^{-3}	453.59×10^{-3}	1	7
$\frac{grains}{ft.^3}$	2.288×10^{3}	2.288×10^{6}	2.288×10^{3}	2.2857×10^{3}	1.4286×10^{-4}	6.4799×10^{-2}	14.286	1

To convert a value from a given unit to a desired unit, multiply the given value by the factor opposite the given units and beneath the desired unit.

CONVERSION FACTORS - LENGTH

Desired Units / Given Units	Inch	Foot	Yard	Mile	Micron	Millimeter	Centimeter	Meter	Kilometer
Inch	1	83.33 x 10^{-3}	27.778 x 10^{-3}	1.578 x 10^{-5}	2.54 x 10^{4}	25.4	2.54	2.54 x 10^{-2}	2.54 x 10^{-5}
Foot	12	1	3333	1.894 x 10^{-4}	30.48 x 10^{4}	304.8	30.48	30.48 x 10^{-2}	30.48 x 10^{-5}
Yard	36	3	1	5.682 x 10^{-4}	91.44 x 10^{4}	914.4	91.44	91.44 x 10^{-2}	91.44 x 10^{-5}
Mile	6.3360 x 10^{4}	5280	1760	1	1.6094 x 10^{9}	1.6094 x 10^{6}	1.6094 x 10^{5}	1.6094 x 10^{3}	1.6094
Micron	3.937 x 10^{-5}	32.808 x 10^{-7}	10.94 x 10^{-7}	62.137 x 10^{-11}	1	1 x 10^{-3}	1 x 10^{-4}	1 x 10^{-6}	1 x 10^{-9}
Millimeter	3.937 x 10^{-2}	32.808 x 10^{-4}	10.94 x 10^{-4}	62.137 x 10^{-8}	1 x 10^{3}	1	0.1	1 x 10^{-3}	1 x 10^{-6}
Centimeter	3.937 x 10^{-1}	32.808 x 10^{-3}	10.94 x 10^{-3}	62.137 x 10^{-7}	1 x 10^{4}	10	1	1 x 10^{-2}	1 x 10^{-5}
Meter	39.37	32.808 x 10^{-1}	10.94 x 10^{-1}	62.137 x 10^{-5}	1 x 10^{6}	1 x 10^{3}	1 x 10^{2}	1	1 x 10^{-3}
Kilometer	3.937 x 10^{4}	32.808 x 10^{2}	10.94 x 10^{2}	62.137 x 10^{-2}	1 x 10^{9}	1 x 10^{6}	1 x 10^{5}	1 x 10^{3}	1

To convert a value from a given unit to a desired unit, multiply the given value by the factor opposite the given units and beneath the desired units.

CONVERSION FACTORS - EMISSION RATES

Given units \ Desired units	gms/sec	gms/min	kg/hr	kg/day	lbs/min	lbs/hr	lbs/day	tons/hr	tons/day	tons/yr
gms/sec	1.0	60.0	3.6	8.640 X 10	1.3228 X 10^{-1}	7.9367	1.9048 X 10^{2}	3.9683 X 10^{-3}	9.5240 X 10^{-2}	3.4763 X 10
gms/min	1.6667 X 10^{-2}	1.0	6.0 X 10^{-2}	1.4400	2.2046 X 10^{-3}	1.3228 X 10^{-1}	3.1747	6.6139 X 10^{-5}	1.5873 X 10^{-3}	5.7938 X 10^{-1}
kg/hr	2.7778 X 10^{-1}	16.667	1.0	2.4000 X 10	3.6744 X 10^{-2}	2.2046	5.2911 X 10	1.1023 X 10^{-3}	2.6456 X 10^{-2}	9.6563
kg/day	1.1574 X 10^{-2}	6.9444 X 10^{-1}	4.1667 X 10^{-2}	1.0	1.5310 X 10^{-3}	9.1860 X 10^{-2}	2.2046	4.5930 X 10^{-5}	1.1023 X 10^{-3}	4.0235 X 10^{-1}
lbs/min	7.5598	4.5359 X 10^{2}	2.7215 X 10	6.5317 X 10^{2}	1.0	60.0	1.44 X 10^{3}	3.000 X 10^{-2}	7.2000 X 10^{-1}	2.6280 X 10^{2}
lbs/hr	1.2600 X 10^{-1}	7.5598	4.5359 X 10^{-1}	1.0886 X 10	1.6667 X 10^{-2}	1.0	24.0	5.0000 X 10^{-4}	1.2000 X 10^{-2}	4.3800
lbs/day	5.2499 X 10^{-3}	3.1499 X 10^{-1}	1.8900 X 10^{-2}	4.5359 X 10^{-1}	6.9444 X 10^{-4}	4.1667 X 10^{-2}	1.0	2.0833 X 10^{-5}	5.0000 X 10^{-4}	1.8250 X 10^{-1}
tons/hr	2.5199 X 10^{2}	1.5120 X 10^{4}	9.0718 X 10^{2}	2.1772 X 10^{4}	3.3333 X 10	2.0 X 10^{3}	4.8000 X 10^{4}	1.0	24.0	8.7600 X 10^{3}
tons/day	1.0500 X 10	6.2999 X 10^{2}	3.7799 X 10	9.0718 X 10^{2}	1.3889	8.3333 X 10	2.0 X 10^{3}	4.1667 X 10^{-2}	1.0	365.0
tons/yr	2.8766 X 10^{-2}	1.7260	1.0356 X 10^{-1}	2.4854	3.8052 X 10^{-3}	2.2831 X 10^{-1}	5.4795	1.1416 X 10^{-4}	2.7397 X 10^{-3}	1.0

To convert a value from a given unit to a desired unit, multiply the given value by the factor opposite the given units and beneath the desired units.

CONVERSION FACTORS - VELOCITY

Given units \ Desired units	m/sec	ft/sec	ft/min	km/hr	mi/hr	knots	mi/day
m/sec	1.0	3.2808	1.9685 X 10^{2}	3.6	2.2369	1.9425	5.3687 X 10
ft/sec	3.0480 X 10^{-1}	1.0	60	1.0973	6.8182 X 10^{-1}	5.9209 X 10^{-1}	1.6364 X 10
ft/min	5.0080 X 10^{-3}	1.6667 X 10^{-2}	1.0	1.8288 X 10^{-2}	1.1364 X 10^{-2}	9.8681 X 10^{-3}	2.7273 X 10^{-1}
km/hr	2.7778 X 10^{-1}	9.1134 X 10^{-1}	5.4681 X 10	1.0	6.2137 X 10^{-1}	5.3959 X 10^{-1}	1.4913 X 10
mi/hr	4.4707 X 10^{-1}	1.4667	88.0	1.6093	1.0	8.6839 X 10^{-1}	24
knots	5.1479 X 10^{-1}	1.6890	1.0134 X 10^{2}	1.8533	1.1516	1.0	2.7637 X 10
mi/day	1.8627 X 10^{-2}	6.1111 X 10^{-2}	3.6667	6.7056 X 10^{-2}	4.1667 X 10^{-2}	3.6183 X 10^{-2}	1.0

To convert a value from a given unit to a desired unit, multiply the given value by the factor opposite the given units and beneath the desired units

LOGARITHMS TO BASE 10

N	0	1	2	3	4	5	6	7	8	9	Proportional Parts 1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4	8	12	17	21	25	29	33	37
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4	8	11	15	19	23	26	30	34
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	10	14	17	21	24	28	31
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3	6	10	13	16	19	23	26	29
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15	18	21	24	27
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3	6	8	11	14	17	20	22	25
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3	5	8	11	13	16	18	21	24
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	2	5	7	10	12	15	17	20	22
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12	14	16	19	21
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11	13	16	18	20
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7
N	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

The proportional parts are stated in full for every tenth at the right-hand side. The logarithm of any number of four significant figures can be read directly by adding the proportional part corresponding to the fourth figure to the tabular number corresponding to the first three figures. There may be an error of 1 in the last place.

LOGARITHMS TO BASE 10

(continued)

N	0	1	2	3	4	5	6	7	8	9	Proportional Parts 1	2	3	4	5	6	7	8	9
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	4
N	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

The proportional parts are stated in full for every tenth at the right-hand side. The logarithm of any number of four significant figures can be read directly by adding the proportional part corresponding to the fourth figure to the tabular number corresponding to the first three figures. There may be an error of 1 in the last place.

INTERNATIONAL ATOMIC WEIGHTS

BASED ON CARBON - 12

	Symbol	Atomic Number	Atomic Weight		Symbol	Atomic Number	Atomic Weight
Actinium	Ac	89	[227] *	Mercury	Hg	80	200.59
Aluminum	Al	13	26.9815	Molybdenum	Mo	42	95.94
Americium	Am	95	[243] *	Neodymium	Nd	60	144.24
Antimony	Sb	51	121.75	Neon	Ne	10	20.183
Argon	Ar	18	39.948	Neptunium	Np	93	[237] *
Arsenic	As	33	74.9216	Nickel	Ni	28	58.71
Astatine	At	85	[210] *	Niobium	Nb	41	92.906
Barium	Ba	56	137.34	Nitrogen	N	7	14.0067
Berkelium	Bk	97	[249] *	Nobelium	No	102	[254] *
Beryllium	Be	4	9.0122	Osmium	Os	76	190.2
Bismuth	Bi	83	208.980	Oxygen	O	8	15.9994 [a]
Boron	B	5	10.811 [a]	Palladium	Pd	46	106.4
Bromine	Br	35	79.909 [b]	Phosphorus	P	15	30.9738
Cadmium	Cd	48	112.40	Platinum	Pt	78	195.09
Calcium	Ca	20	40.08	Plutonium	Pu	94	[242] *
Californium	Cf	98	[251] *	Polonium	Po	84	[210] *
Carbon	C	6	12.01115 [a]	Potassium	K	19	39.102
Cerium	Ce	58	140.12	Praseodymium	Pr	59	140.907
Cesium	Cs	55	132.905	Promethium	Pm	61	[147] *
Chlorine	Cl	17	35.453 [b]	Protactinium	Pa	91	[231] *
Chromium	Cr	24	51.996 [b]	Radium	Ra	88	[226] *
Cobalt	Co	27	58.9332	Radon	Rn	86	[222] *
Copper	Cu	29	63.54	Rhenium	Re	75	186.2
Curium	Cm	96	[247] *	Rhodium	Rh	45	102.905
Dysprosium	Dy	66	162.50	Rubidium	Rb	37	85.47
Einsteinium	Es	99	[254] *	Ruthenium	Ru	44	101.07
Erbium	Er	68	167.26	Samarium	Sm	62	150.35
Europium	Eu	63	151.96	Scandium	Sc	21	44.956
Fermium	Fm	100	[253] *	Selenium	Se	34	78.96
Fluorine	F	9	18.9984	Silicon	Si	14	28.086 [a]
Francium	Fr	87	[223] *	Silver	Ag	47	107.870 [b]
Gadolinium	Gd	64	157.25	Sodium	Na	11	22.9898
Gallium	Ga	31	69.72	Strontium	Sr	38	87.62
Germanium	Ge	32	72.59	Sulfur	S	16	32.064 [a]
Gold	Au	79	196.967	Tantalum	Ta	73	180.948
Hafnium	Hf	72	178.49	Technetium	Tc	43	[99] *
Helium	He	2	4.0026	Tellurium	Te	52	127.60
Holmium	Ho	67	164.930	Terbium	Tb	65	158.924
Hydrogen	H	1	1.00797 [a]	Thallium	Tl	81	204.37
Indium	In	49	114.82	Thorium	Th	90	232.038
Iodine	I	53	126.9044	Thulium	Tm	69	168.934
Iridium	Ir	77	192.2	Tin	Sn	50	118.69
Iron	Fe	26	55.847 [b]	Titanium	Ti	22	47.90
Krypton	Kr	36	83.80	Tungsten	W	74	183.85
Lanthanum	La	57	138.91	Uranium	U	92	238.03
Lead	Pb	82	207.19	Vanadium	V	23	50.942
Lithium	Li	3	6.939	Xenon	Xe	54	131.30
Lutetium	Lu	71	174.97	Ytterbium	Yb	70	173.04
Magnesium	Mg	12	24.312	Yttrium	Y	39	88.905
Manganese	Mn	25	54.9380	Zinc	Zn	30	65.37
Mendelevium	Md	101	[256] *	Zirconium	Zr	40	91.22

* Value in brackets denotes the mass number of the isotope of longest known half life (or a better known one for Bk, Cf, Po, Pm, and Tc).

[a] Atomic weight varies because of natural variation in isotopic composition: B, ±0.003; C, ±0.00005; H_2, ±0.00001; O, ±0.0001; Si, ±0.001; S, ±0.003.

[b] Atomic weight is believed to have following experimental uncertainty: Br, ±0.002; Cl, ±0.001; Cr, ±0.001; Fe, ±0.003; Ag, ±0.003. For other elements, the last digit given for the atomic weight is believed reliable to ±0.5. Lawrencium, Lw, has been proposed as the name for element No. 103, nuclidic mass about 257.