United States
Environmental Protection
Agency

Air Pollution Training Institute
MD 20
Environmental Research Center
Research Triangle Park NC 27711

EPA 450/2-81-014
April 1981

Air

EPA

APTI Course 411 Air Pollution Meteorology

Student Workbook

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Office of Air, Noise, and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, NC 27711

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INTRODUCTION

The Air Pollution Training Institute has developed Course 411 Air Pollution Meteorology to train meteorologists, engineers, and physical scientists responsible for measuring and evaluating meteorological factors that affect the dispersion and concentration of pollutants in the atmosphere. Meteorological factors and the role they play in the transport and dispersion of air pollution are presented. You will have an opportunity to calculate estimates of continuous-release pollutant concentrations and become familiar with meteorological instruments. Discussions will be held to enable you to evaluate air pollution control strategies, and the planning and interpretation of surveys.

This workbook is designed to provide you with a guide to the lecture materials. Included herein are the course goal, course objectives, and lesson objectives and outlines.

A Study Guide lists reading assignments, homework assignments, and class exercises associated with this course. The homework problems and class exercises are included in this workbook.

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COURSE GOAL AND OBJECTIVES

Course Goal

The purpose of Course 411 Air Pollution Meteorology is to familiarize you with meteorological factors and their role in the transport and dispersion of air pollution, with calculation methods for continuous-release pollutant concentrations, and with meteorological instruments.

Course Objectives

Upon completion of this course, you should be able to:

1. describe the effect that solar radiation has on the earth's surface and its resulting influence in the atmosphere.
2. identify statements that correctly explain how the topography of an area, relevant meteorological factors, and the location of sources collectively effect the transport and dispersion of source emissions.
3. calculate an estimate of plume rise, given relevant meteorological and source parameters for a particular site, using the methods suggested by Briggs.
4. calculate an air pollution concentration estimate for a given source emission at a given receptor site using the Pasquill-Gifford method.
5. choose the proper method of siting an anemometer from a list of relevant meteorological information, topography, and location of sources.
6. choose the most appropriate meteorological instrument for site conditions, given relevant meteorological information, topography, and source location.
7. decide which factors must be considered in site selection for a proposed new source given sufficient geographical, topographical, instrumentational, climatological, and source data about a general location and facilities and justify this decision in a report.

STUDY GUIDE

A. Reading Assignments

The following reading assignments should be completed as indicated:

1. Before course begins:
   411 Student Manual, Section One, pages 1-1 to 1-21
   Section Two, pages 2-1 to 2-28
   Turner, *Workbook of Atmospheric Dispersion Estimates*
   Briggs, *Plume Rise*
2. Monday Night:
   411 Student Manual, Section Three, pages 3-1 to 3-45
   Section Seven, pages 7-1 to 7-8
   Appendix, pages 9-7 to 9-8
3. Tuesday Night:
   411 Student Manual, Section Seven, pages 7-27 to 7-35
   Section Six, pages 6-1 to 6-38
   Section Five, pages 5-23 to 5-34
4. Wednesday Night:
   411 Student Manual, Section Five, pages 5-1 to 5-22
   Section Four, pages 4-1 to 4-12
   Section Seven, pages 7-9 to 7-26
5. Thursday Night:
   Be prepared to present team answer to Site Analysis Exercise.
   Review all materials to prepare for posttest.

B. Homework Problems

The following assignments should be completed and turned in as indicated:

1. Homework Problem Set A: Due Wednesday Morning
   Stability Analysis, Meteorological Roses, and Mixing Depth
2. Homework Problem Set B: Due Thursday Morning
   Effective Stack Height and Dispersion Estimates

C. Class Exercises

The following exercises are to be completed by instructors and students during class as indicated:

1. Class Exercise 1: Tuesday Afternoon
   Dispersion Estimates Calculations
2. Class Exercise 2: Wednesday Afternoon
   Meteorological Data Reduction and Sigma y Calculation
3. Class Exercise 3: Thursday Afternoon
   Site Analysis

LESSON 1:
Registration, Course Information, and Pretest

Lesson Goal: The purpose of this lesson is to familiarize you with the course structure and objectives, to have you meet instructors and other students, to conduct the pretest, to present pertinent logistical information, and to obtain registration information.

Lesson Objectives: At the end of this lesson, you should be familiar with the basic content and structure of this course. There are no testable objectives for this lesson.

Lesson Outline:

I. Introduction

II. Course Structure and Requirements

III. Registration

IV. Pretest

LESSON 2:
Radiation, General Circulation, and Meteorological Scales of Motion

Lesson Goal: The purpose of this lesson is to familiarize you with the complex interaction of the sun's radiation and the earth's atmosphere and surface, the global circulatory patterns, and the meteorological scales of motion.

Lesson Objectives: At the end of this lesson, you should be able to:

1. explain the interaction between solar radiation and the earth's surface as it affects air pollution.
2. name the four meteorological scales of motion and describe the relative horizontal and vertical distances that characterize each of them.

Lesson Outline:

I. Role of Meteorology in the Source-Receptor Relationship

II. Radiation

- A. solar radiation
- B. radiation from earth's surface
- C. heat transfer processes
- D. selective absorption in atmosphere
- E. terrestrial reflectivity of atmosphere

III. Radiation Balance

- A. annually
- B. daytime
- C. nighttime

IV. Radiation Excess vs. Deficits

- A. radiation absorbed vs. reradiated globally
- B. heat exchange mechanisms

V. General Circulation of Atmosphere

A. nonrotating earth case

B. rotating earth

C. tri-cellular circulation pattern

D. zonal vs. meridional circulation

VI. Meteorological Scales of Motion

A. microscale

B. mesoscale

C. synoptic scale

D. macroscale

LESSON 3:
Winds, Temperature, Pressure Systems, and Fronts

Lesson Goal: The purpose of this lesson is to familiarize you with the physical processes that cause wind, the role of temperature in meteorology, and the types and characteristics of fronts.

Lesson Objectives: At the end of this lesson, you should be able to:

1. name the forces that cause wind.
2. recall the scales of temperatures used and the role of temperature in meteorology.
3. recall the types of fronts and the characteristics of each type.

Lesson Outline:

I. Awareness of Weather and Its Effects
   - A. radio-tv forecasts
   - B. planning and probability forecasts
   - C. reading surface weather charts

II. Motion Picture: "General Circulation of the Atmosphere"

III. Wind
   - A. definition
   - B. equations of motion
   - C. types of wind

IV. Temperature
   - A. definition
   - B. scales
   - C. importance of temperature

V. Fronts
   - A. definition
   - B. types of fronts
   - C. frontal characteristics

LESSON 4:
Atmospheric Stability and Atmospheric Stability Analysis

Lesson Goal: The purpose of this lesson is to familiarize you with atmospheric stability, the characteristics and factors of stability, and the applications of atmospheric stability to air pollution meteorology.

Lesson Objectives: At the end of this lesson, you shold be able to:

1. define atmospheric stability.
2. identify three classes of stability.
3. identify the four types of temperature profiles and the stability each profile depicts.

Lesson Outline:

I. Introduction

II. Atmospheric Stability

- A. definition
- B. effect of stability on vertical motion
- C. effect of stability on an air parcel

III. Atmospheric Lapse Rate

IV. Adiabatic Diagram

- A. composition
- B. examples

V. Environmental Lapse Rate

- A. definition
- B. measure of lapse rate
- C. temperature profiles
- D. factors that complicate stability
- E. pseudo-adiabatic lapse rate

VI. Determining the Stability of a Layer

A. lifting air parcel

B. subsidence

VII. Pseudo-Adiabatic Diagram

VIII. Mixing Depth

A. definition

B. calculation

C. examples

Attachment 4-1. Derivation of the dry adiabatic lapse rate.

The first law of thermodynamics is a statement of the law of conservation of energy for a thermodynamic system. Thus,

$$dH = dU + dW \tag{1}$$

Where, dH = infinitesimal amount of heat is added per unit mass
dU = change in internal energy per unit mass
dW = work done by unit mass of the system

By integrating the equation of state, $p\alpha = RT$, gives the following result,

$$pd\alpha + \alpha dp = RdT \tag{2}$$

But remember that $dU = C_v dT$ and $dW = pd\alpha$

Where, C_v = the specific heat of air at constant volume

Substituting into the first law of thermodynamics gives,

$$dH = C_v dT + pd\alpha \tag{3}$$

Then, substituting for $pd\alpha$ from (2) into (3) gives,

$$dH = (C_v + R)dT - \alpha dp \tag{4}$$

However, for an isobaric process, $dp = 0$, so that equation (4) becomes,

$$\left.\frac{dH}{dT}\right|_{p=\text{constant}} = C_v + R \tag{5}$$

But, $$\left.\frac{dH}{dT}\right|_{p=\text{constant}} = C_p, \text{ so that } C_p = C_v + R,$$

Therefore, $$dH = C_p dT - \alpha dp \tag{6}$$

However, $\alpha = RT/p$, from equation of state, so that for unit mass,

$$dH = C_p dT - \frac{RTdp}{Mp} \tag{7}$$

Now, if the process is adiabatic, which means that heat is not added or removed from the parcel, then:

$$dH = C_p dT - \frac{RTdp}{Mp} = 0 \tag{8}$$

Then, rewriting equation (8) gives,

$$\frac{dT}{dp} = \frac{RT}{C_p Mp} \tag{9}$$

From the relationship of pressure to height by using the hydrostatic equation,

$$dp = -\varrho g dz \tag{10}$$

If you make a substitution for denisty, ϱ, through the equation of state into (10), then

$$dp = -\frac{pM}{RT} g dz \tag{11}$$

Substituting for dp into equation (9) gives,

$$\frac{dT}{-\frac{Mp}{RT} g dz} = \frac{RT}{C_p Mp} \tag{12}$$

Therefore, after clearing the equation,

$$\frac{dT}{dz} = -\frac{g}{C_p} \tag{13}$$

Where, g = gravitational constant, 9.806 m/s/s
C_p = the specific heat of air at constant pressure

Equation (13) is for the dry adiabatic lapse rate, Γ_d. Water vapor in the atmosphere is ignored in this derivation.

The value of the dry adiabatic lapse rate is:

− 5.4 °F per 1000 feet, or

− 9.8 °C per kilometer, or

− 0.0098 °C per meter

Example

An example of the dry adiabatic lapse rate is shown on slide 411 4-4 in the lecture series.

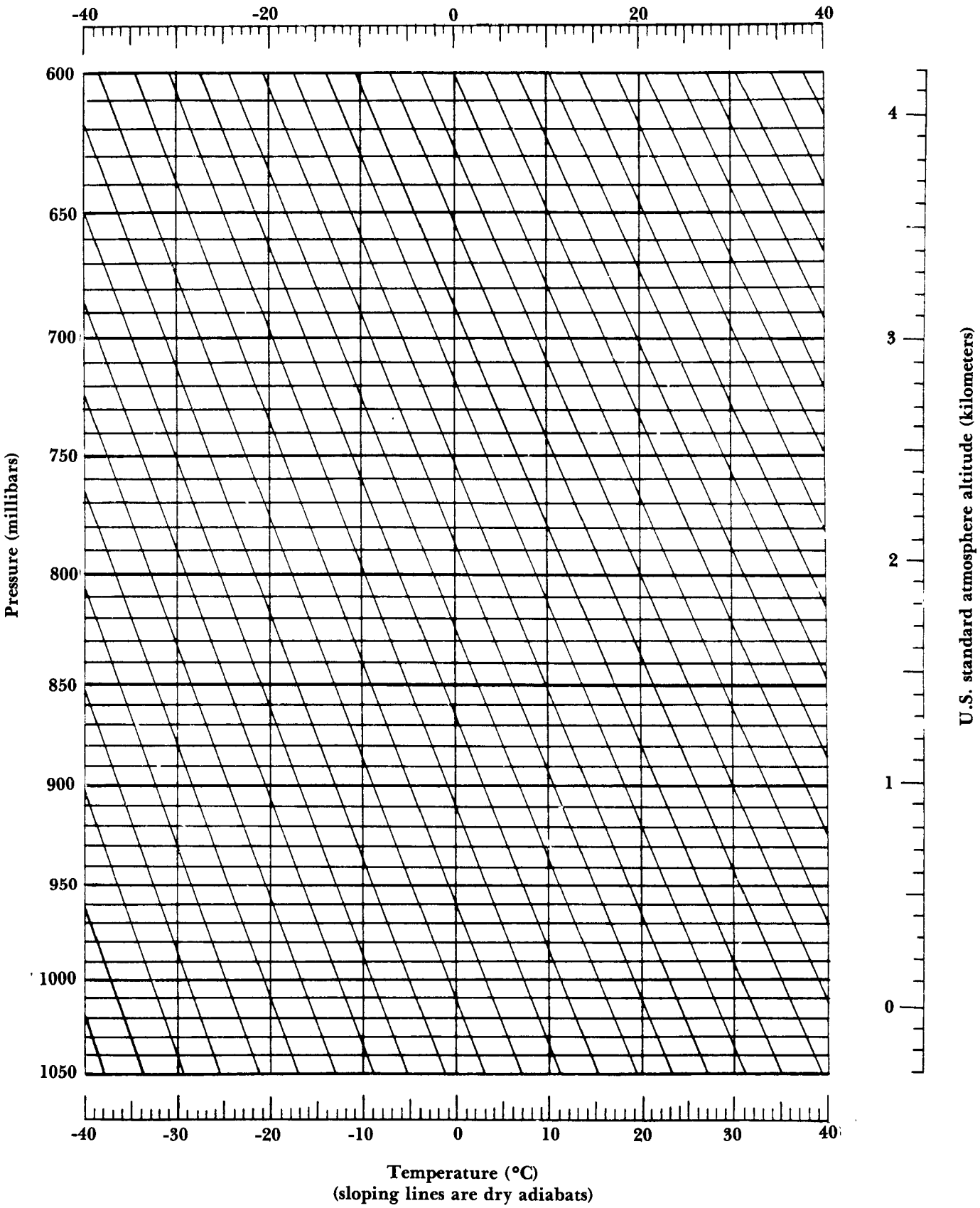


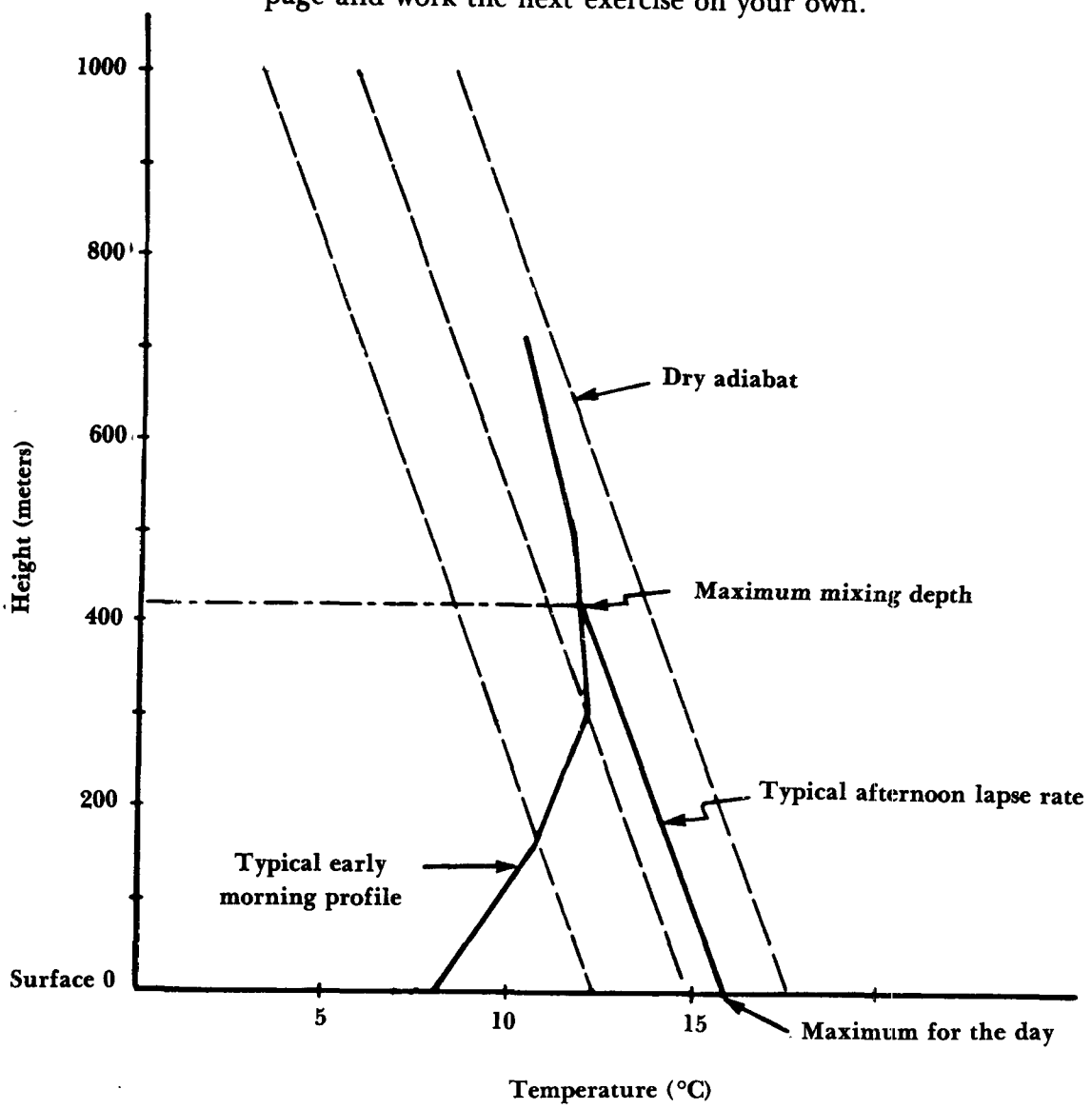
Figure 4-1. Adiabatic diagram

Maximum Mixing Depth
Example 1

The maximum mixing depth for a day can be estimated from a temperature profile by following these steps:

1. Plot the maximum surface temperature for the day on the morning profile. (e.g., 16°C)
2. From this point draw a line parallel to a dry adiabat to the point where it intersects the morning profile.
3. Read the height above ground at this point. This is the maximum mixing depth (MMD) for the day.
4. The MMD on the example profile below is approximately _____ meters.

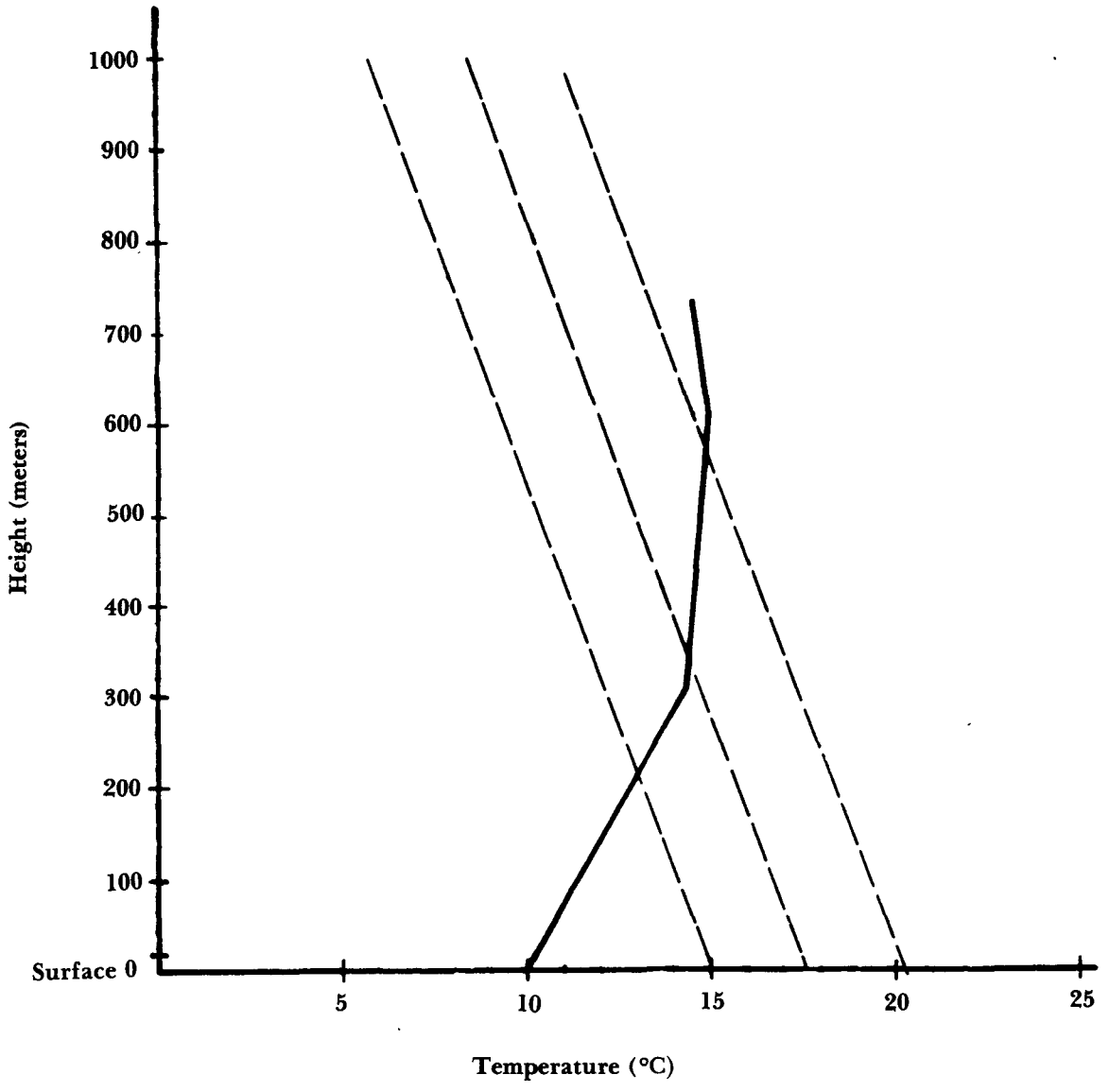
Now that you have worked this one, please turn page and work the next exercise on your own.



Maximum Mixing Depth
Example 2

Another typical early morning profile is shown below. If the maximum surface temperature for the day is 20 °C, what would you expect the maximum mixing depth to be?

_____ meters



LESSON 5:
Effects of Meteorological Factors on the Transport and Dispersion of Air Pollution

Lesson Goal: The purpose of this lesson is to familiarize you with the effect that wind, atmospheric stability, and fronts have on the transport and dispersion of air pollution.

Lesson Objectives: At the end of this lesson, you should be able to:

1. describe the effect of wind on the transport and dispersion of air pollution.
2. name the two types of turbulence and the causes of each type.
3. describe the relationship among stability, turbulence, and dispersion of air pollution.

Lesson Outline:

I. Introduction

II. Wind

- A. direction
- B. speed

III. Variability

- A. determination
- B. eddy
- C. mechanical turbulence
- D. thermal turbulence
- E. wind records and turbulence

IV. Relationship between Turbulence and Atmospheric Stability

- A. vertical temperature measurements
- B. stability categories

V. Variations of Wind with Height

A. speed increases

B. direction changes

VI. Diurnal Variations of Wind

A. day/night/day change

B. reasons

LESSON 6:
Influence of Topography on Atmospheric Motion

Lesson Goal: The purpose of this lesson is to familiarize students with the various ways the physical shape of the earth's surface influences atmospheric motion and the resultant shape and dispersion of various plumes from sources.

Lesson Objectives: At the end of this lesson, you should be able to:

1. state the basic effects that topography has on atmospheric motion.
2. distinguish between thermal and geometric types of topographical influences.
3. identify both thermal and geometric influences for each of the four types of topographical shapes.
4. identify plume dispersion characteristics given a particular topographical shape.

Lesson Outline:

I. Introduction

II. Types of Topographical Terrain

- A. planar
- B. mountain/hill
- C. valley
- D. urban areas
- E. land-water interface

III. Dispersion Characteristics of Topographical Types

- A. flat
- B. mountain/valley
- C. urban
- D. land-water interface

Attachment 6-1. Climatic changes produced by cities.

Element	Comparison with rural environs
Contaminants	
dust particles	10 times more
sulfur dioxide	5 times more
carbon dioxide	10 times more
carbon monoxide	25 times more
Radiation	
total on horizontal surface	15 to 20% less
ultraviolet, winter	30% less
ultraviolet, summer	5% less
Cloudiness	
clouds	5 to 10% more
fog, winter	100% more
fog, summer	30% more
Precipitation	
amounts	5 to 10% more
days with 0.2 inches	10% more
Temperature	
annual mean	1 to 1.5°F more
winter minima	2 to 3.0°F more
Relative Humidity	
annual mean	6% less
winter	2% less
summer	8% less
Wind Speed	
annual mean	20 to 30% less
extreme gusts	10 to 20% less
calms	5 to 20% more

Taken from, "Symposium: Air Over Cities," SEC Technical Report A62-5, Public Health Service, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, 1961.

LESSON 7:
Wind Roses and Air Pollution Roses

Lesson Goal: The purpose of this lesson is to familiarize you with the various methods used to construct wind roses and display wind data, and to identify uses for wind and air pollution roses.

Lesson Objectives: At the end of this lesson, you should be able to:

1. identify the uses of wind roses and air pollution roses.
2. identify the different methods of constructing wind roses and air pollution roses.
3. choose correct statements that identify biases present in wind data summaries.

Lesson Outline:

I. Tabulations of Data and Wind Roses

- A. older attempts at wind roses
- B. current wind roses in use
- C. data summaries available

II. Methods of Construction

- A. wind roses
- B. air pollution roses

III. Biases in Wind Data Tabulations

- A. wind speed bias
- B. wind direction
- C. example of bias

IV. Correcting Biases by Statistical Means

- A. decalming roses
- B. debiasing roses

V. Applications of Wind Roses to Air Pollution

- A. air pollution roses
- B. visibility roses

Table B. Wind direction and speed occurrences.

Direction	Hourly observations of wind speed (in miles per hour)										Av. speed
	0-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	47 over	Total	
N		11	5							16	6.7
NNE		6	3							9	7.1
NE	2	17	8							27	6.8
ENE	2	15	5							22	6.5
E		8	3							11	6.7
ESE	1	7	4							12	6.8
SE	2	9	2							13	6.3
SSE	2	2	4							8	6.6
S	2	10	1							13	5.5
SSW	5	11	4	2						22	6.5
SW	5	11	5	3						24	6.8
WSW	3	14	12	1						30	6.9
W	6	23	33	22	1	1				86	10.1
WNW	4	52	99	73	14	2				244	11.2
NW	1	18	35	76	30	2				162	14.4
NNW	2	2	1	1						6	7.2
Calm	39									39	0.0
Total	76	216	224	178	45	5				744	9.9

Table F. Occurrences of weather by wind direction.

Wind Dir	Ceiling (ft)									Visibility (mi)						Weather types								
	0	100-200	300-400	500-900	1000-1900	2000-2900	3000-4900	5000-9500	Over 9500	0-1/8	3/16-3/8	1/2-3/4	1-2 1/2	3-6	7 and over	Rain	Freezing rain	Drizzle	Snow Sleet	Hail	Fog	Fog with smoke	Smoke or haze	Thunderstorm
N									16					9	7								9	
NNE					1				8				1	3	5								4	
NE					1				26				11	7	9						2	2	18	
ENE				1	1			1	19				5	12	5						1	1	17	
E					1				10				2	4	5								6	
ESE			2				1	1	8			1	1	3	7			2			2		3	
SE							1	2	10					1	12	1							1	
SSE			1		1				6				1	1	6						1	1	2	
S			1	1	2	1			8				1	2	10						1	1	3	
SSW			2			4	4	1	11			1	1	3	17						2	2	5	
SW		1	1	1	2	1	2		16			2		2	20						2	2	4	
WSW				5	2	4	2	1	16					1	29			1					1	
W				9	6	4	5	1	61					6	80			1			1		5	
WNW	1	3	1	14	4	1	1	4	215	1	1	5	10	37	190	2		2			22	11	42	
NW		4	1	1		2	1	3	150			3	4	25	130			2			7	3	28	
NNW					1				5					1	5								1	
Calm				7	1				31				3	10	26			1			4	2	11	
Total	1	8	9	39	23	17	17	14	616	1	1	12	40	127	563	3		9			45	25	160	

Figure 7-1. Local climatological data (LCD).

LESSON 8:
Fundamentals and Applications of Basic Statistics

Lesson Goal: The purpose of this lesson is to familiarize you with the fundamentals of statistics and the applications of statistics to meteorological data.

Lesson Objectives: At the end of this lesson, you should be able to:

1. choose appropriate statements that give the meanings of the arithmetic and geometric mean, standard deviation, and frequency distribution.

2. solve problems that illustrate the arithmetic and geometric mean, standard deviation, and frequency distribution using meteorological data.

Lesson Outline:

I. Definitions of Statistical Terms and Symbols

   A. population

   B. sample

   C. frequency distribution

   D. measures of central tendency

   E. measures of dispersion

II. Basic Formulas

   A. frequency distribution

   B. measures of central tendency

   C. measures of dispersion

III. Applications of Statistics to Meteorology

Wind speed categories					
Category	Wind speed	Frequency: F_i		Relative frequency: F_i/n	
1	0-3	50	Frequency distribution	0.065	Relative frequency distribution
2	4-7	167		0.225	
3	8-12	268		0.360	
4	13-18	193		0.260	
5	19-24	52		0.070	
6	25-31	14		0.020	
		744	Total	1.000	Total

Figure 8-1. Wind data for Cincinnati, Ohio.

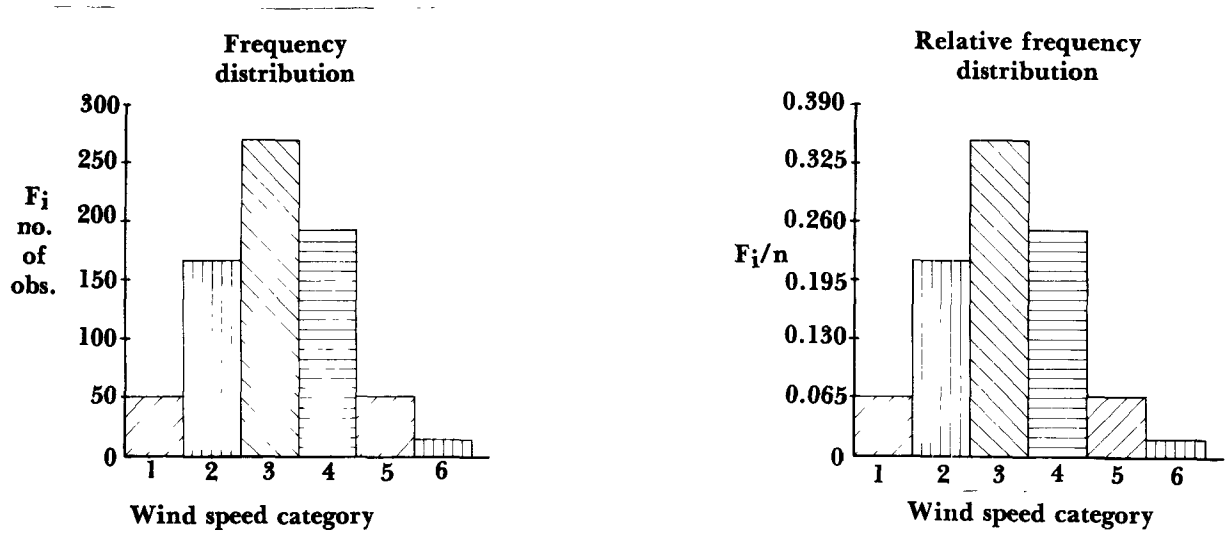


Figure 8-2. Frequency of occurrence.

Cat	F_i	
1	50	Cumulative frequency distribution
2	217	
3	485	
4	678	
5	730	
6	744	

Cat	F_i/n	
1	0.065	Relative cumulative frequency distribution
2	0.290	
3	0.650	
4	0.910	
5	0.980	
6	1.000	

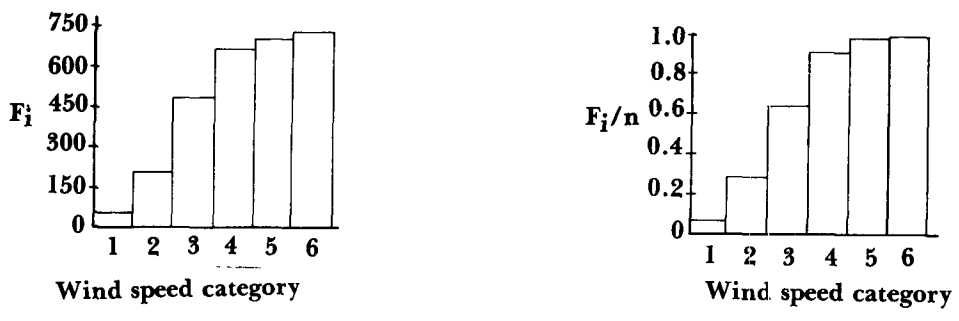


Figure 8-3. Cumulative frequency distributions.

Attachment 8-1. Wind speed: standard deviation.

The method of finding the standard deviation of the sample is:

$$S^2 = \frac{\Sigma(X_i - \bar{X})^2}{n-1}$$

the square root of the variance:

$$S = \sqrt{\frac{\Sigma(X_i - X)^2}{n-1}}$$

Example:

Cincinnati wind data gave the following wind speeds:

$\bar{X} = 10.3$ mph

$n = 31$ days

Then, $(X_i - \bar{X})^2$

1.44
1.69
2.25
0.64
1.21
4.84
.
.
.
.
.
29.16
23.03
51.84
6.25
5.76
$\Sigma =$ 275.71

Substituting into the equation for variance found above:

$$S^2 = \frac{275.71}{30} = 9.19$$

Then, taking the square root of the variance is

$S = \sqrt{9.19} = 3.03$ mph

Attachment 8-2. Wind direction: standard deviation.

Example:

Research Triangle Park wind direction trace gave the following data:

$\bar{\theta} = 120°$ (over a 4 hour average)

θ_i = a 15 minute average of θ

$n = 16$

and,

Nr.	$\Sigma(\theta_i - \theta)^2$	θ_i	$(\theta_i)^2$
1	100	130	16,900
2	0	120	14,400
3	25	115	13,225
4	25	115	13,225
5	625	095	9,025
6	100	110	12,100
7	100	110	12,100
8	625	095	9,025
9	100	115	13,225
10	400	140	19,600
11	25	115	13,225
12	25	115	13,225
13	100	110	12,100
14	625	145	21,025
15	1225	155	24,025
16	1225	155	24,025
	5325	1940	240,550

$S^2 = \frac{5325}{15} = 355$ which is the variance of the direction

Taking the square root of the variance gives the following result:

$S = \sqrt{355} = 19°$

Attachment 8-3. Long term/short term methodology.

A. The Difference Method:

$\overline{x}(a,n) - \overline{X}(S,n) = d$

$\overline{x}(a,N) = d + \overline{X}(S,N)$

Where, $\overline{x}$ = average of quantity at "a" being reduced
$\overline{X}$ = average of quantity at "S"
S = long-term climatological station
N = normal period of observation at "S"
n = short period of observation at "a"
a = short-term observation station
d = difference between quantity at "a" and "s"

Meteorological uses of the Difference Method:

wind direction
lapse rate
temperatures
cloudiness
number of days with haze/smoke
snow covered duration

Example: using wind direction

$240° - 260° = -20°$

$\overline{x}(a,N) = -20° + 290° = 270°$

B. The Ratio Method:

$\overline{x}(a,n) = q = \overline{x}(a,N)$

$\overline{X}(S,n)' \overline{X}(S,N)$

$\overline{x}(a,N) = q\overline{X}(S,N)$

Where $\overline{x}$ = n-year average at "a"
$\overline{X}$ = n-year average at "S"
$\overline{x}(a,N)$ = normal period average at "a"
$\overline{X}(S,N)$ = normal period average at "S"
q = quasi-constant ratio

Meteorological uses of the Ratio Method:

wind speed
precipitation
snow depth

Example: using wind speed

$$\frac{3.1}{4.3} = 0.72 = \frac{\overline{x}}{5.2}$$

$\overline{x} = 3.7$

LESSON 9:
Problem Set A
Atmospheric Stability Analysis and Meteorological Roses

Lesson Goal: At the end of this problem session, you will be familiar with the appropriate methods of calculating maximum mixing depth, determining atmospheric stability, and plotting air pollution roses.

Lesson Objectives: At the end of this lesson, you should be able to:

1. determine the stabilities of a specified atmospheric sounding using the method given in Atmospheric Stability Analysis, Lesson 4.

2. plot an air pollution rose for a specified local climatological data sheet location.

3. determine the maximum mixing depth for a specified atmospheric sounding.

PROBLEM A1.
Atmospheric Stability Analysis

Plot on adiabatic diagram (Figure A1-1.)
The 1200Z (0700L EST) radiosonde observation was:

	Pressure (mb)	Temperature (°C)	Dew Point (°C)	Height—MSL meters
SFC	982	16.2	15.2	297
	966	23.2	15.2	297
	909	19.0	10.0	
	900	19.1	7.3	
	883	19.2	3.2	
	850	16.8	0.2	1540
	786	12.5	− 7.2	
	756	13.8	−10.2	
	700	10.8	−15.5	3172

The winds reported were:

Height above surface (ft)	Direction (degrees)	Speed (kts)
Sfc	200	3
2000	210	11
3000	210	7
4000	240	4
5000	270	5
6000	270	7
7000	270	8
8000	270	9
9000	270	5
10000	250	7

What are the heights above ground level of the bases and tops of the inversion layers? The maximum recorded temperature for the day was 86°F. What do you estimate the maximum mixing depth (MMD) was on this day? What is the 1200Z average wind speed through the afternoon maximum mixing depth?

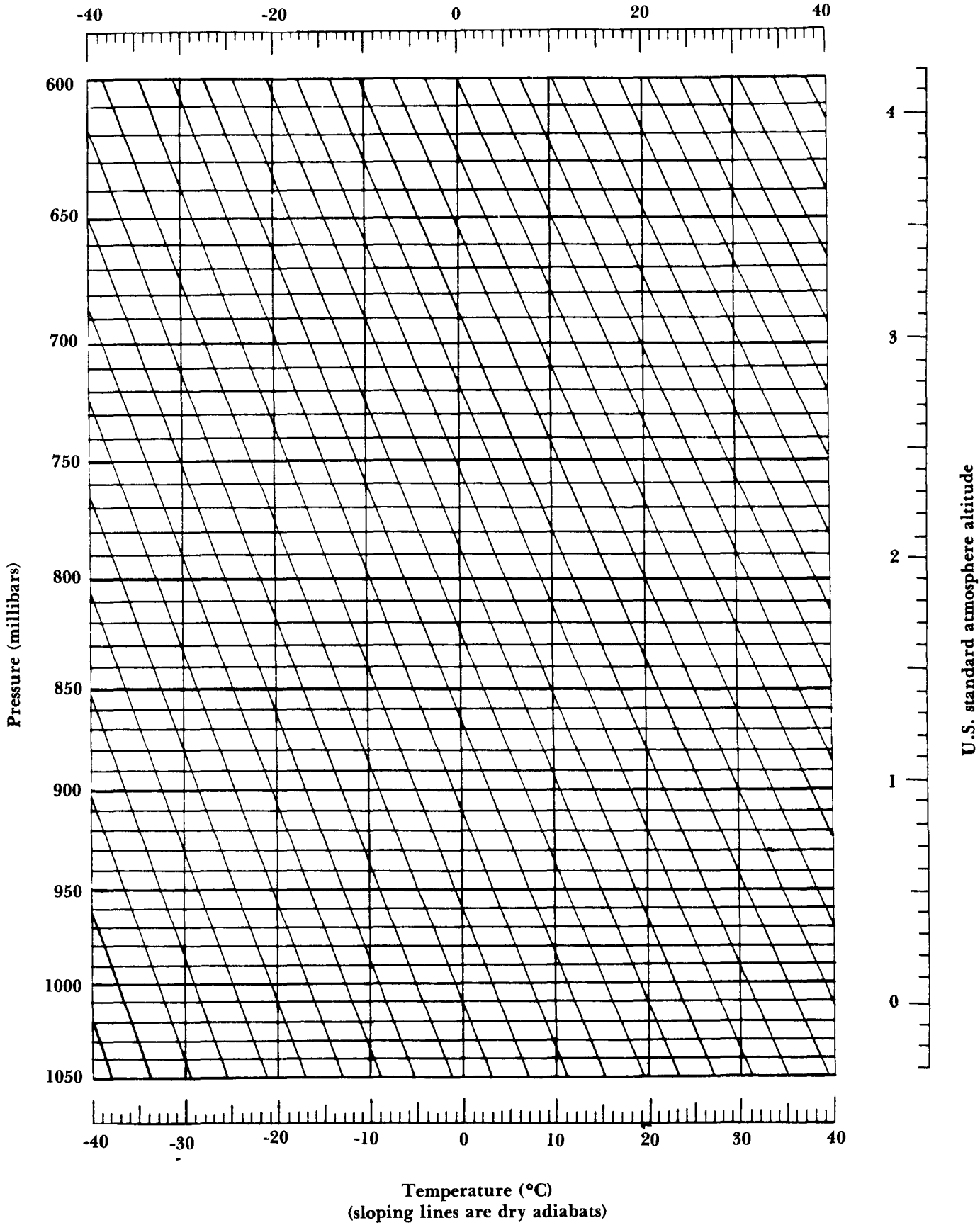


Figure A1-1. Adiabatic diagram.

PROBLEM A2.
Meteorological Roses

From the Local Climatological Data Supplement (LCD) provided (see Figure A2.1), construct an air pollution rose from Table F that shows the percent frequency of restricted visibility observations due to haze or smoke for at least 3 wind directions.

The worksheet for constructing the rose is Figures A2.2 and the graph is Figure A2.3.

Table B. Wind direction and speed occurrences.

Direction	Hourly observations of wind speed (in miles per hour)										Av. speed
	0-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	47 over	Total	
N		11	5							16	6 7
NNE		6	3							9	7.1
NE	2	17	8							27	6.8
ENE	2	15	5							22	6.5
E		8	3							11	6.7
ESE	1	7	4							12	6.8
SE	2	9	2							13	6.3
SSE	2	2	4							8	6.6
S	2	10	1							13	5.5
SSW	5	11	4	2						22	6.5
SW	5	11	5	3						24	6.8
WSW	3	14	12	1						30	6.9
W	6	23	33	22	1	1				86	10.1
WNW	4	52	99	73	14	2				244	11.2
NW	1	18	35	76	30	2				162	14.4
NNW	2	2	1	1						6	7 2
Calm	39									39	0.0
Total	76	216	224	178	45	5				744	9.9

Table F. Occurrences of weather by wind direction.

Wind Dir	Ceiling (ft)									Visibility (mi)						Weather types								
	0	100-200	300-400	500-900	1000-1900	2000-2900	3000-4900	5000-9500	Over 9500	0-1/8	3/16-3/8	1/2-3/4	1-2 1/2	3-6	7 and over	Rain	Freezing rain	Drizzle	Snow Sleet	Hail	Fog	Fog with smoke	Smoke or haze	Thunderstorm
N									16					9	7								9	
NNE					1				8				1	3	5								4	
NE					1				26				11	7	9						2	2	18	
ENE				1	1			1	19				5	12	5						1	1	17	
E					1				10				2	4	5								6	
ESE			2				1	1	8			1	1	3	7			2			2		3	
SE							1	2	10					1	12	1							1	
SSE			1		1				6				1	1	6						1	1	2	
S			1	1	2	1			8				1	2	10						1	1	3	
SSW			2			4	4	1	11			1	1	3	17						2	2	5	
SW		1	1	1	2	1	2		16			2		2	20						2	2	4	
WSW				5	2	4	2	1	16					1	29			1					1	
W				9	6	4	5	1	61					6	80			1			1		5	
WNW	1	3	1	14	4	1	1	4	215	1	1	5	10	37	190	2		2			22	11	42	
NW		4	1	1		2	1	3	150			3	4	25	130			2			7	3	28	
NNW					1				5					1	5								1	
Calm				7	1				31				3	10	26			1			4	2	11	
Total	1	8	9	39	23	17	17	14	616	1	1	12	40	127	563	3		9			45	25	160	

Figure A2-1. Local climatological data (LCD).

The air pollution or restricted visibility rose may be constructed by at *least* three methods using the Local Climatological Data Summaries (LCD).

Method A	Method B	Method C
$\frac{N_{HK}}{OBS}$ = _____%	$\frac{N_{HK}}{OBS_{HK}}$ = _____%	$\frac{N_{HK}}{OBS_{N}}$ = _____%
$\frac{NNE_{HK}}{OBS}$ = _____%	$\frac{NNE_{HK}}{OBS_{HK}}$ = _____%	$\frac{NNE_{HK}}{OBS_{NNE}}$ = _____%
$\frac{NE_{HK}}{OBS}$ = _____%	$\frac{NE_{HK}}{OBS_{HK}}$ = _____%	$\frac{NE_{HK}}{OBS_{NE}}$ = _____%
⋮		
$\frac{CALM_{HK}}{OBS}$ = _____%	$\frac{CALM_{HK}}{OBS_{HK}}$ = _____%	$\frac{CALM_{HK}}{OBS_{CALM}}$ = _____%
TOTAL = _____%	**TOTAL** = _____%	**TOTAL** = _____%
$\frac{\text{Numerator from row in Table F}}{\text{Denominator from total in Table B}}$	$\frac{\text{Numerator from row in Table F}}{\text{Denominator from total in Table B}}$	$\frac{\text{Numerator from row in Table F}}{\text{Denominator from total in Table B}}$

Figure A2-2. Air pollution wind rose worksheet.

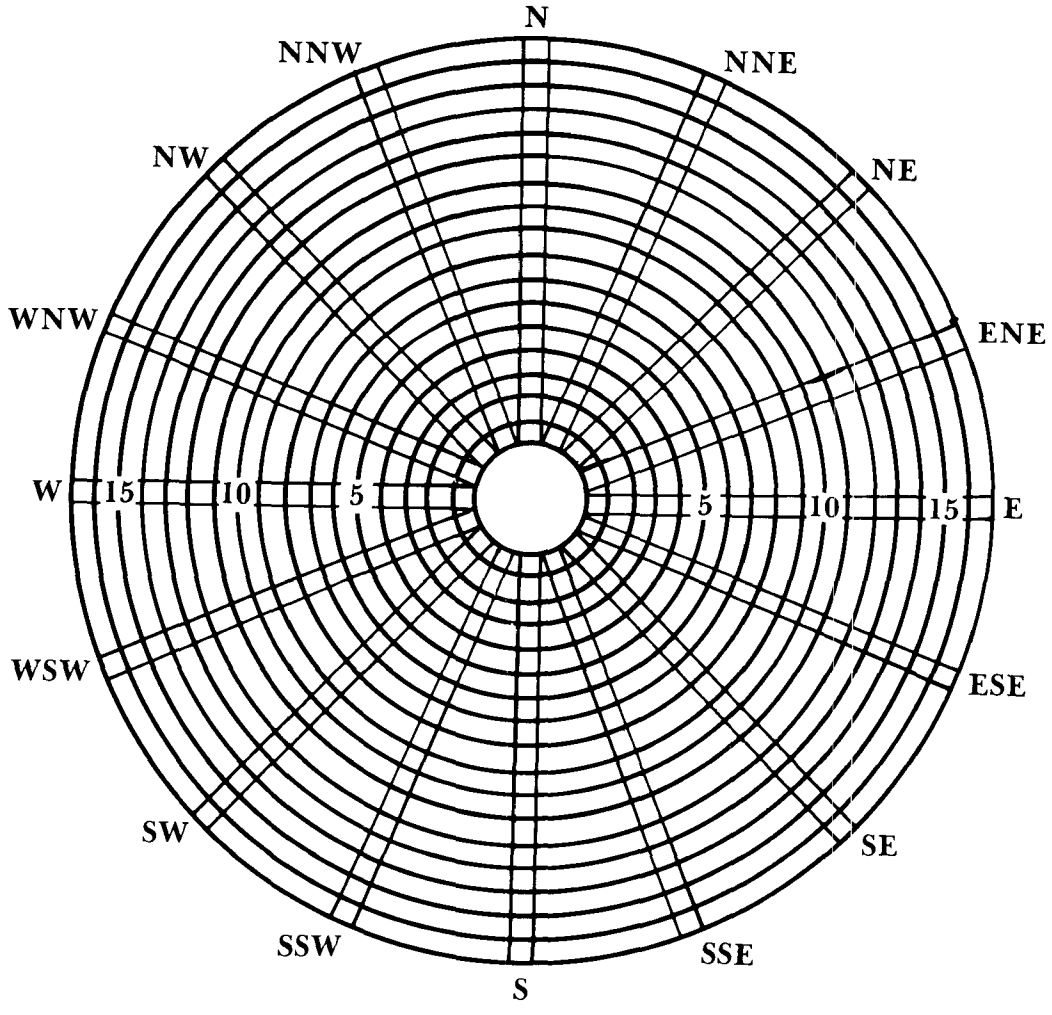


Figure A2-3. Air pollution wind rose graph.

LESSON 10:
Effective Stack Height

Lesson Goal: The purpose of this lesson is to familiarize you with the engineering and meteorological factors that determine plume rise; with the current plume rise equations used and their applications; and with the plume rise of larger power plants.

Lesson Objectives: At the end of this lesson, you should be able to:

1. identify the engineering and meteorological factors that determine plume rise.
2. calculate current plume rise equations and identify their applications.

Lesson Outline:

I. Important Engineering Factors

A. height of stack

B. diameter of stack

C. exit velocity

D. temperature of effluent

II. Meteorological Factors

A. wind speed

B. lapse rate

C. ambient air temperature

D. atmospheric pressure

E. density

F. gravity

III. Current Plume Rise Equations

A. composition

B. approaches to plume rise equations

C. current formulas

IV. Slide Sequence of Plumes and Stacks

V. Modifications for Large Power Plants

A. Pooler

B. LAPPES

LESSON 11:
Basic Principles of Turbulence and Dispersion

Lesson Goal: To familiarize you with the causes and typical locations of turbulence, with dimensionless numbers used in investigating turbulence, and with the effects that turbulence has on plume dispersion.

Lesson Objectives: At the end of this lesson, you should be able to:

1. define turbulence.
2. identify the reasons for turbulent production.
3. identify typical locations where turbulence is often found.
4. identify the effect of turbulence on the dispersion of a specified plume.
5. identify the recommended dimensionless numbers used in turbulence investigations.

Lesson Outline:

I. Factors Influencing Dispersion

A. wind speed

B. wind direction

C. mixing height

D. plume height

E. turbulence

II. Definitions of Turbulence

A. flying

B. physical science

C. circulation

D. simple

III. Reasons for Turbulent Production

A. mechanical turbulent production (shear)

B. thermal turbulent production (heat)

IV. Effects of Turbulence

A. mixing length theory

B. turbulent energy

C. momentum transfer

V. Typical Locations of Turbulence

A. near ground

B. near clouds

C. around obstructions

D. jet stream

VI. Dimensionless Numbers

A. Richardson number, R_i (gradient)

B. Richardson number, R_B (bulk)

C. comparison of factors

VII. Properties of Turbulence

A. thermal turbulent energy

B. mechanical turbulent energy

C. frequencies

D. eddy size increases with height

VIII. Gaussian Dispersion Estimates

A. normal frequency curve

B. binormal in x and y

C. assumptions

D. determination of sigmas

E. applications

LESSON 12:
Atmospheric Dispersion Estimates

Lesson Goal: The purpose of this lesson is to familiarize you with the methods of solving dispersion estimate problems found in air pollution using the *Workbook of Atmospheric Dispersion Estimates (WADE)* by D.B. Turner.

Lesson Objectives: At the end of this lesson, you should be able to:

1. select from the *Workbook of Atmospheric Dispersion Estimates* the appropriate formula and procedure for calculating dispersion concentrations given a specific air pollution situation with appropriate source data, atmospheric factors, and receptor locations.

2. use the graphs and tables in the *Workbook of Atmospheric Dispersion Estimates* to determine the appropriate data to use in the proper formula given the physical description and meteorological data about an air pollution problem.

Lesson Outline:

I. Estimates of Atmospheric Dispersion

   A. coordinate system

   B. dispersion equations

   C. standard deviations of wind directions

II. Effective Height of Emission

   A. plume rise (Holland's equation)

   B. estimating required stack height

   C. effects of evaporative cooling

   D. effect of aerodynamic downwash

III. Special Topics

A. inversion, breakup, fumigation

B. plume trapping

C. comparisons of ground-level concentration to effective stack height concentration from elevated sources

D. total dosage

E. crosswind-integrated concentrations

F. sampling times

G. topography

H. area sources

IV. Example Problems

V. Appendices

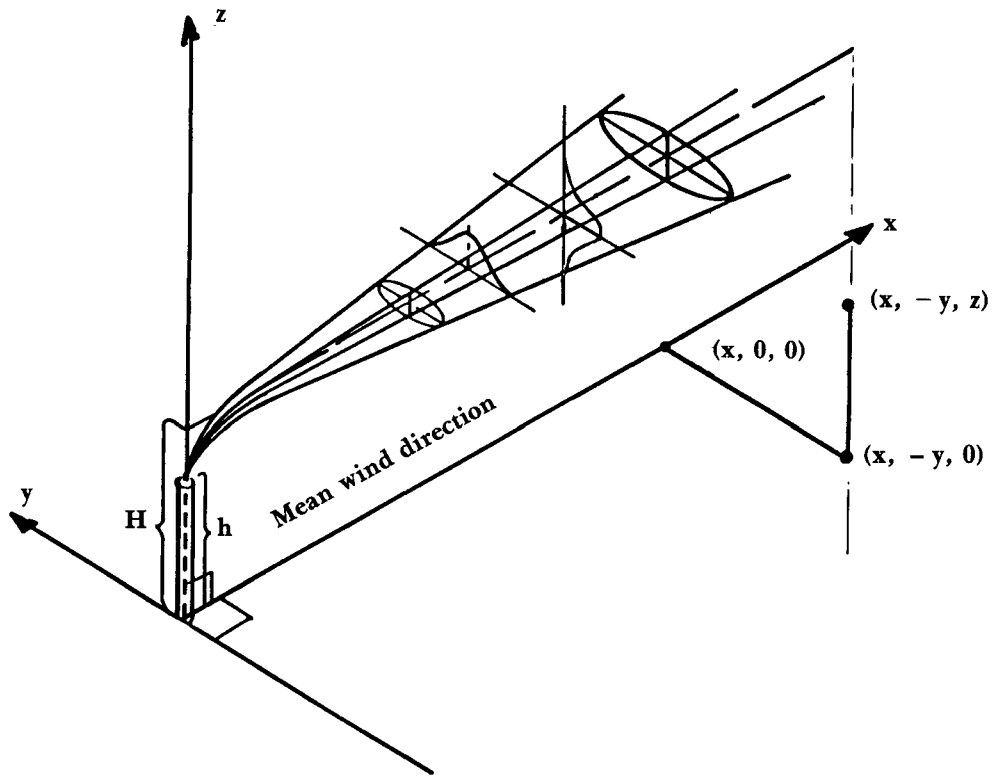


Figure 12-1. Coordinate system showing Gaussian distributions in horizontal and vertical.

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

$\sigma_y \ \sigma_z =$ standard deviation of plume width and height

Figure 12-2. Generalized Gaussian equation.

$$\text{Downwind Concentration (point source)} = \frac{\text{Source emission rate}}{\pi \begin{bmatrix}\text{Average}\\ \text{wind}\\ \text{speed}\end{bmatrix} \begin{bmatrix}\text{Horizontal}\\ \text{plume}\\ \text{spread}\end{bmatrix} \begin{bmatrix}\text{Vertical}\\ \text{plume}\\ \text{spread}\end{bmatrix} \begin{bmatrix}\text{Effective}\\ \text{emission}\\ \text{height}\end{bmatrix} \begin{bmatrix}\text{Receptor}\\ \text{location}\\ \text{distance}\end{bmatrix}}$$

$$\text{Ground level source/ground level receptor} = \frac{\text{Source emission rate}}{\pi \begin{bmatrix}A\\ W\\ S\end{bmatrix} \begin{bmatrix}H\\ P\\ S\end{bmatrix} \begin{bmatrix}V\\ P\\ S\end{bmatrix}}$$

$$\text{Elevated source/ground level receptor} = \frac{\text{Source emission rate}}{\pi \begin{bmatrix}A\\ W\\ S\end{bmatrix} \begin{bmatrix}H\\ P\\ S\end{bmatrix} \begin{bmatrix}V\\ P\\ S\end{bmatrix} \begin{bmatrix}E\\ E\\ H\end{bmatrix}}$$

$$\text{Elevated source/ground level receptor} = \frac{\text{Source emission rate}}{\pi \begin{bmatrix}A\\ W\\ S\end{bmatrix} \begin{bmatrix}H\\ P\\ S\end{bmatrix} \begin{bmatrix}V\\ P\\ S\end{bmatrix} \begin{bmatrix}E\\ E\\ H\end{bmatrix} \begin{bmatrix}R\\ L\\ D\end{bmatrix}} \quad \text{(not on plume centerline)}$$

Figure 12-3. Generalized Gaussian diffusion equations.

$$\text{Downwind concentration (area source)} = \frac{\text{Area source emission rate}}{\pi \begin{bmatrix}\text{Average}\\ \text{wind}\\ \text{speed}\end{bmatrix} \begin{bmatrix}\text{Adjusted}\\ \text{horizon}\\ \text{plume}\\ \text{spread}\end{bmatrix} \begin{bmatrix}\text{Vertical}\\ \text{plume}\\ \text{spread}\end{bmatrix} \begin{bmatrix}\text{Effective}\\ \text{emission}\\ \text{height}\end{bmatrix} \begin{bmatrix}\text{Receptor}\\ \text{location}\\ \text{distance}\end{bmatrix}}$$

$$\text{Downwind concentration (line source)} = \frac{\text{Line source emission rate}}{\sqrt{2\pi} \begin{bmatrix}A\\ W\\ S\end{bmatrix} \begin{bmatrix}V\\ P\\ S\end{bmatrix}}$$

$$\text{Seasonal/annual average concentration} = \sum_{s=1}^{S} \sum_{n=1}^{N} \frac{\text{[Source emission rate] [Frequencies of w/s, w/d, stability]}}{\sqrt{2\pi} \begin{bmatrix}A\\ W\\ S\end{bmatrix}_N \begin{bmatrix}V\\ P\\ S\end{bmatrix}_S \begin{bmatrix}\text{Downwind}\\ \text{distance}\\ \text{factor}\end{bmatrix} \begin{bmatrix}E\\ E\\ H\end{bmatrix}_S}$$

Figure 12-4. Special forms of Gaussian diffusion equation.

Attachment 12-1. Dispersion Estimate Suggestion No. 1, November 7, 1972 (Model Application Branch)

Subject: Estimation of 3-hour and 24-hour average concentrations

In order to obtain some degree of uniformity in performing calculations of air pollution concentrations from point sources among EPA's air pollution meteorologists, the following suggestions are made:

Calculate plume rise by using methods suggested by Briggs (1970) as modified by his discussion (1972).

Assume that estimates made using equations (excluding equation 5.12, page 38) and sigmas suggested by the *Workbook of Atmospheric Dispersion Estimates (WADE)* are valid for averaging times up to one hour.

To make an estimate of concentrations for a longer averaging time such as 3-hours or 24-hours, perform calculations for each hour of the period and average the hourly concentrations to obtain the concentration for the longer averaging time. Since interest is frequently on the maximum concentration during this period, the difficulty is in designating the location (azimuth and range) of the receptor that will receive the maximum impact from the source. If conditions are relatively stationary during this period, the mean direction and the distance of maximum for this stability and wind speed can be used for an estimate of this location. For changing conditions, calculations may need to be made at several receptors to approximate the maximum.

Because of interest in the estimation of short period maximum concentrations (3-hour to 24-hour) with a frequency of occurrence of once per year, a computational scheme was recently developed by the Model Application Branch with assistance from the Computer Techniques Group, Division of Meteorology to estimate the maximum 24-hour concentration for a year for single sources. This computational scheme can be considered a "brute force" approach as concentrations for each hour of the year 1964 (the only year that data from Asheville is readily available for 24 hours per day with wind direction to 10°) are calculated and the 24-hour concentration for each day is determined. Concentrations at 180 receptors (36 azimuths and 5 ranges) are found. An *Interim User's Guide* has been made available for this system. It is anticipated that technical review will require some modification to the calculations. Validation using air quality data near a point source is desirable, if suitable data can be found. A final *User's Guide* will be prepared and distributed by the Model Application Branch within the next several months.

Briggs, Gary A., 1971. Some Recent Analyses of Plume Rise Observations, pp. 1029-1032, in *Proceedings of the Second International Clean Air Congress,* edited by H.M. Englund and W.T. Berry, New York: Academic Press.
Briggs, Gary A., 1972. Discussion on Chimney Plumes in Neutral and Stable Surroundings, *Atmospheric Environment* 6: 507-510.

Lesson 13:
Class Exercise 1
Atmospheric Dispersion Estimates

Lesson Goal: The purpose of this lesson is to reinforce the material presented in Lesson 12.

Lesson Objectives: At the end of this lesson, you should be able to:

1. work dispersion estimate problems, given adequate information about particular situations.
2. identify the different forms of the Gaussian equation and explain their application to dispersion estimate situations.

Lesson Outline:

I. Examples of Dispersion Estimates Problems

A. stability (Figure 13-1.)

B. centerline concentration from an elevated source, sunny summer afternoon (Figure 13-2.)

C. centerline concentration from ground-level source (Figure 13-3.)

D. centerline concentration from an elevated source, cloudy day, Stability D (Figure 13-4.)

E. off centerline concentration (Figure 13-5.)

Example Problems (Figures 13-1.—13-5.)
Student Worksheets

Given: Sunny summer afternoon

Windspeed_____

Insolation is_____

Stability class is_____

Figure 13-1. Stability: sunny summer afternoon.

Given: Sunny summer afternoon,
$\bar{u} = 4$ m/s, elevated source
$H = 20$ m $\quad Q = 100$ g/s

$$\chi = \frac{Q}{\pi\, \sigma_y\, \sigma_z\, \bar{u}} \exp^{-\frac{1}{2}\left[\frac{H^2}{\sigma_z^2}\right]} \exp^{-\frac{1}{2}\left[\frac{y^2}{\sigma_y^2}\right]}$$

Receptor distance	**200m**	**1000m**
Stability =		
Q =		
$\bar{u}$ =		
σ_y =		
σ_z =		
H =		
y =		
$\exp^{-\frac{1}{2}\left[\frac{H^2}{\sigma_z^2}\right]}$ =		
$\exp^{-\frac{1}{2}\left[\frac{y^2}{\sigma_y^2}\right]}$ =		
χ =		

Figure 13-2. Receptor distance: sunny summer afternoon.

Given: Clear night, $\bar{u} = 2$ m/s,
ground—level source
$Q = 100$ g/s

$$\chi = \frac{Q}{\pi \sigma_y \sigma_z \bar{u}} \exp - \tfrac{1}{2} \left[\frac{H^2}{\sigma_z^2}\right] \exp - \tfrac{1}{2} \left[\frac{y^2}{\sigma_y^2}\right]$$

Receptor distance	200m	1000m
Stability =		
Q =		
$\bar{u}$ =		
σ_y =		
σ_z =		
H =		
y =		
$\exp - \tfrac{1}{2} \left[\frac{H^2}{\sigma_z^2}\right]$ =		
$\exp - \tfrac{1}{2} \left[\frac{y^2}{\sigma_y^2}\right]$ =		
χ =		

Figure 13-3. Receptor distance: clear night.

Given: Stability "D",
$\bar{u} = 4$ m/s, elevated source,
$H = 20$ m $Q = 100$ g/s

$$\chi = \frac{Q}{\pi \sigma_y \sigma_z \bar{u}} \exp - \tfrac{1}{2} \left[\frac{H^2}{\sigma_z^2}\right] \exp - \tfrac{1}{2} \left[\frac{y^2}{\sigma_y^2}\right]$$

Receptor distance	200m	1000m
Stability =		
Q =		
$\bar{u}$ =		
σ_y =		
σ_z =		
H =		
y =		
$\exp - \tfrac{1}{2} \left[\frac{H^2}{\sigma_z^2}\right]$ =		
$\exp - \tfrac{1}{2} \left[\frac{y^2}{\sigma_y^2}\right]$ =		
χ =		

Figure 13-4. Receptor distance: stability "D".

Given: Stability B,
$\bar{u} = 4 m/s$, ground—level source
concentration 50 meters
off centerline, $Q = 100$ g/s

$$\chi = \frac{Q}{\pi \sigma_y \sigma_z \bar{u}} \exp^{-\frac{1}{2}\left[\frac{H^2}{\sigma_z^2}\right]} \exp^{-\frac{1}{2}\left[\frac{y^2}{\sigma_y^2}\right]}$$

Receptor distance	**200m**	**1000m**
Stability =		
Q =		
u =		
σ_y =		
σ_z =		
H =		
y =		
$\exp^{-\frac{1}{2}\left[\frac{H^2}{\sigma_z^2}\right]}$ =		
$\exp^{-\frac{1}{2}\left[\frac{y^2}{\sigma_y^2}\right]}$ =		
χ =		

Figure 13-5. Receptor distance: stability "B".

LESSON 14:
Introduction to the Guideline on Air Quality Models, EPA-450/2-78-027

Lesson Goal: The purpose of this lesson is to familiarize you with the *Guideline on Air Quality Models* and the air quality models recommended by the guideline for use in air pollution dispersion modeling.

Lesson Objectives: At the end of this lesson, you should be able to:

1. recall the models that are recommended for use in air quality modeling.
2. recall the uses of the *Guideline* as it applies to new source reviews, prevention of significant deterioration, and control strategies.

Lesson Outline:

I. Atmospheric Dispersion Modeling

A. important in new source reviews, control strategy analysis, and prevention of significant deterioration

B. mathematical set of equations

C. predictive tool

II. *Guideline on Air Qualty Models*

A. origin

B. general description

C. status and uses

D. recommended modeling procedures

III. *Workbook for Comparisons of Air Quality Models*

A. purpose

B. principal contents

C. use (practical)

Table 14-1. Models applicable to specific pollutants, sources, and averaging times.

Point Sources SO_2 and PM All Averaging Times	Multi-sources SO_2 and PM Annual Average	Multi-sources SO_2 and PM Short-term Averages	NO_2 Annual Average	O_X 1-hour Average	CO 1 and 8-hour Averages
CRSTER RAM PTXXX models ISC VALLEY	AQDM TCM CDM/CDMQC Rollback	Rollback TEM RAM CDMQC AQDM	Rollback CDM	EKMA Rollback	Rollback HIWAY PAL Holzworth APRAC-1A APRAC 2

LESSON 15:
Selected Meteorological Instruments

Lesson Goal: The purpose of this lesson is to familiarize you with various meteorological instruments that are used for atmospheric sampling.

Lesson Objectives: At the end of this lesson, you should be able to:

1. recognize four meteorological instrument requirements.
2. identify a meteorological instrument by name given a picture.
3. identify statements that correctly site an anemometer at a specific location.

Lesson Outline:

I. Instrument Requirements

A. durable

B. inexpensive

C. convenient

D. simple

E. sensitive

F. accurate

II. Speed and Direction Instruments

A. instruments

B. recorders

C. correct siting

III. Other Meteorological Instruments

A. heat

B. radiation

C. visibility

D. humidity

E. precipitation

F. aircraft-borne instruments

Attachment 15-1. Meteorological instrumentation: advantages and disadvantages.

I. Primary Instrumentation

A. anemometers

1. cup and propeller
   a. advantages
      1. linear relationship between sensor output and wind speed
      2. calibration unaffected by changes in temperature, pressure, or humidity
      3. measure wide range of wind speeds from 0.25 m/s to 50 m/s
      4. long-term stability of calibration
      5. sensor output easily adapts to remote indicator
      6. wind speed data recording in either analog or digital form
      7. generally requires little maintenance
   b. disadvantages
      1. higher average wind speeds in gusty winds
      2. higher starting speeds unless made of light materials
      3. error produced in periods of heavy precipitation
2. hotwire
   a. advantages
      1. instantaneous readout of speed
      2. used in wind tunnel
   b. disadvantages
      1. not linear in relationship
      2. dust deposits require frequent cleaning
      3. rain or snow causes large errors
      4. zero shift in circuit causes large errors
3. pressure-plate
   a. advantages—none
   b. disadvantages
      1. nonlinear drag
      2. orientation into wind
4. bridled cup
   a. advantages—none
   b. disadvantages
      1. distorts wind speed
      2. inaccuracy at low speeds
5. dyne
   a. advantages—linear relationship
   b. disadvantages—oriented into wind
6. UVW
   a. advantages—yields component wind speed in axial direction (x, y, z)
   b. disadvantages
      1. requires complex data reduction
      2. certain wind directions cause mutual interference
      3. serious error in heavy precipitation

Attachment 15-1. Meteorological instrumentation: advantages and disadvantages, continued.

B. wind vanes

1. flat plate
   a. advantages
      1. fast response
      2. high accuracy of wind fluctuations at low speeds
   b. disadvantages—heavy material gives higher indications of wind fluctuations
2. splayed vane
   a. advantages
      1. durable and reliable
      2. follows very small changes in wind fluctuation
   b. disadvantages—higher mass than flat plate
3. airfoil vane
   a. advantages
      1. durable and reliable
      2. follows small changes in wind fluctuation
   b. higher mass than flat plate

II. Secondary Instrumentation

A. temperature

1. unaspirated and unshielded thermometers
   a. advantages—none
   b. disadvantages—serious error in ambient temperature readings
2. aspirated and shielded thermometers
   a. advantages—accurate ambient readings
   b. disadvantages—none

LESSON 16:
Meteorological Data Reduction and Sigma y Calculation

Lesson Goal: The purpose of this lesson is to familiarize you with the method of reducing meteorological data from analog strip charts and with how to use the results to calculate a sigma y that is representative of the data.

Lesson Objectives: At the end of this lesson, you should be able to:

1. reduce meteorological data from an analog strip chart of wind fluctuations using the method prescribed by Pasquill.
2. use the results from the reduction of wind data to calculate a representative sigma y.

Lesson Outline:

I. Determining Turbulence: Background

A. earlier theories
1. Fickian
2. von Helmholtz
3. Prandtl
4. Taylor

B. current theories
1. Panofsky
2. Draxler

II. Sigma Development

A. Porton, England

B. calculation of sigma

III. Data Reduction Exercise

LESSON 17:
Class Exercise 2
Meteorological Data Reduction and Sigma y Calculation Exercises

Lesson Goal: The purpose of this lesson is to reinforce the material presented in Lesson 16.

Lesson Objectives: At the end of this lesson, you should be able to:

1. reduce meteorological data from an analog strip chart of wind fluctuations using the method prescribed by Pasquill.
2. use the results from the reduction of wind data to calculate a representative sigma y.

Lesson Outline:

I. Background

A. wind vanes

B. standard notation

C. Taylor's Theory

D. Hay and Pasquill (1959)

E. Pasquill (1974)

II. Data Reduction Exercise

A. relationship of terms to a wind reduction trace

B. assignment of specific instrument trace

III. Exercise Review

Attachment 17-1. Meteorological data reduction exercise worksheet.

Instrument: _____

Time period: _____ Date: _____ 19 _____

Period	Time (min)	Wind speed (mph)	$\bar{\theta}$ (deg)	$\bar{\theta}_s$ (deg)	$[\bar{\theta}_s - \bar{\theta}]$ (deg)	$[\bar{\theta}_s - \bar{\theta}]^2$ (deg)
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						
27						
Total						

Attachment 17-2. Calculation of $\sigma_{\theta_{\tau,s}}$ and σ_y

1. The average wind speed over the period of record:_____

   $\bar{u}$ = w.s. (wind speed average) = _____mph = _____m/s

2. The average wind direction over the period of record:_____

   θ_s = w.d. (wind direction average) = _____

3. $\sigma_{\theta_{\tau,s}} = \sqrt{\dfrac{\Sigma\,(\theta_s - \theta)^2}{N-1}} = \sqrt{_____} = \sqrt{_____} = _____$

4. $\sigma_{\theta_{\tau,s}}$ = _____ degrees = _____ radians*

   *multiply degrees by 0.0175 to equal radians

5. The applicable downwind distance = x, where:

   $$\beta = \frac{x}{\bar{u}s}$$

   τ = sampling period = _____ minutes

   s = averaging time = _____minutes = _____seconds

   Then: x = (β)(u)(s)
   x = (4.0) (_____) (_____) = _____ meters
   x = _____meters

   Therefore: $\sigma_y = \sigma_{\theta_{\tau,s}}$ (x)

   σ_y = (_____) (_____) = _____ meters

6. What type of stability is indicated with a σ_y of this magnitude? _____
   (See manual)

LESSON 18:
Problem Set B
Effective Stack Height and Dispersion Estimates

Lesson Goal: The purpose of this lesson is to provide practice problems to familiarize you with appropriate methods of calculating effective stack height and dispersion estimates.

Lesson Objectives: At the end of this lesson, you should be able to:

1. calculate the plume rise using Briggs method to determine effective stack height.
2. calculate the concentrations downwind using the *Workbook of Atmospheric Dispersion Estimates* by Turner.

PROBLEM SET B
Effective Stack Height and Dispersion Estimates

1. An electric generating power plant has an eighty meter high stack that is 3.5 meters in diameter. The effluent gases are emitted at an exit velocity of 15 meters per second. The gas temperature is 93 °C and the ambient air temperature is 20 °C. Use the Davidson-Bryant equation to find the effective stack height when the wind speed is 4 meters per second.

2. Use the conditions stated above and an atmospheric pressure of 1010 millibars. Use the Holland equation to calculate the effective stack height.

3. Briggs has published plume rise equations that have been incorporated into dispersion calculations involving elevated emissions sources. The equations (modified for distance criteria) are:

$$\Delta h = 1.6(F)^{1/3}(u)^{-1}(x)^{2/3};\ \text{if } x < x_f$$
$$\Delta h = 1.6(F)^{1/3}(u)^{-1}(x_f)^{2/3};\ \text{if } x \geq x_f$$
$$x^* = 14(F)^{5/8};\ \text{when } F < 55\ m^4/s^3$$
$$x^* = 34(F)^{2/5};\ \text{when } F \geq 55\ m^4/s^3$$
$$x_f = 3.5x^*$$

Where: Δh = plume rise, in meters
Q_H = heat emission, in calories per second
F = buoyancy flux = $3.7X10^{-5}(Q_H)$, in meters^4 per second^3
u = wind speed, in meters per second
x = downwind distance, in meters
x^* = distance of transition from first stage of rise to the second stage of rise, in meters
x_f = distance to final rise, in meters

For the power plant described in problems 1 and 2 given the heat emission is 2,440,000 calories per second, find the plume rise at 350 meters and at 1750 meters downwind.

4. The power plant described on the previous page burns 12 tons of 2.5% sulfur content coal per hour. The effective stack height is 120 meters and the winds are 2 meters per second. At one hour before sunrise, the sky is clear. Using the information provided, fill in the table of values from 100 meters to 100 kilometers as given in Figure 18.6 below. What is the approximate distance of the maximum concentration, χmax, under these conditions?

x (km)	σ_y (m)	σ_z (m)	$\frac{Q}{\pi \sigma_y \sigma_z \bar{u}}$	$\frac{H}{\sigma_z}$	$e^{-\frac{1}{2}\left[\frac{H}{\sigma_z}\right]^2}$	χ (g/m³)
0.1						
1.0						
5.0						
10.0						
20.0						
25.0						
30.0						
50.0						
70.0						
100.0						

Figure 18-6. Effective stack height and dispersion worksheet.

5. It is estimated that 80 grams per second of sulfur dioxide is being emitted from a petroleum refinery from an average effective stack height of 60 meters. At 8 a.m. on an overcast winter morning with the surface wind of 6 meters per second, what is the ground level concentration directly downwind from the refinery at a distance of 500 meters?

6. A maximum concentration of 1.7×10^{-3} grams per cubic meter is measured 600 meters directly downwind of a source that has an effective stack height of 50 meters. The stability category is "C". What is the probable source strength, χ, in grams per second, if the mean wind speed is 5 meters per second?

LESSON 19:
Air Pollution Climatology, Stagnation, and Forecasting

Lesson Goal: The purpose of this lesson is to familiarize you with air pollution climatology, atmospheric stagnation, and the forecasting of air pollution.

Lesson Objectives: At the end of this lesson, you should be able to:

1. identify areas of the United States that have the greatest percentage of atmospheric stagnation periods.
2. identify correct statements describing the causes of atmospheric stagnation.

Lesson Outline:

I. Anticyclones
   - A. location
   - B. preferred tracks
   - C. stagnation
   - D. empirical studies of stagnation

II. Inversion Frequencies

III. Mixing Depth
   - A. morning radiosonde
   - B. forecast maximum afternoon temperature

IV. Wind Speed
   - A. highest seasonal average surface winds
   - B. lowest seasonal average surface winds

V. Urban Ventilation
   - A. mixing height average
   - B. wind speed average

VI. Wind Persistence

A. data

B. sectors (16)

C. percentages

D. hours

VII. Episode-Days of Limited Dispersion (Holzworth)

VIII. Forecasting Atmospheric Stagnation

A. definition

B. appropriate features

IX. NWS Guidelines and ASA Criteria

LESSON 20:
Natural Removal Processes in the Atmosphere

Lesson Goal: To familiarize you with eight natural processes present in the atmosphere that remove air pollution.

Lesson Objectives: At the end of this lesson, you should be able to:

1. list the eight natural removal processes that are present in the atmosphere.
2. choose statements about the atmosphere that identify the effects of specific natural removal processes.

Lesson Outline:

I. Introduction

II. Gravitational Settling

III. Absorption

IV. Adsorption

V. Impaction

VI. Rainout

VII. Washout

VIII. Coagulation

IX. Vegetation and Minerals

LESSON 21:
Class Exercise 3
Site Analysis

Lesson Goal: The purpose of this lesson is to familiarize you with the numerous factors that are involved in conducting a meterological survey. This lesson essentially ties together all the information and knowledge gained during the previous lessons.

Lesson Objectives: At the end of this lesson, you should be able to:

1. identify at least six meteorological factors that are used in conducting a meteorological survey.

2. conduct a simplified meteorological survey, given a specific location with physical information, meteorological data, and source information.

Lesson Outline:

I. Review Previous Lessons

II. Introduce Class Exercise 3

Class Exercise 3
Site Analysis

Problem Statement:

A new coal burning electric generating power plant is to be built on the shore of Lake Winnemucca, a deep lake that is 40 miles long and 25 miles wide with the longer axis oriented north-south. It is located at 45 degrees North Latitude in the North Central part of the United States. It should be assumed that the lake does not freeze over in the winter. The coal to be used by the power plant will be transported by lake steamers and barges, and will enter the lake by the Metro River that empties into the lake from the east shore. The sulfur content of the coal used will average from 2 to 2½ percent. (See Figure 21-1.)

The current plan is to install 99.5 percent efficiency electrostatic precipitators for particulates as an integral part of the plant construction. The average source strength is expected to be $4X10^3$ grams per second of SO_2 and $5X10^5$ grams per hour of particulates after control. The effective emission height under neutral stability conditions is expected to be 250 meters. The physical stack height is 100 meters. The wind under neutral conditions is 5 meters per second.

The terrain in the vicinity of the lake is quite flat with the highest elevations to the southeast rising only 300 feet above the lake level within 10 miles of the lake. The area between Urbana and Metropolis is forested, primarily state-owned land, while that between Urbana and Gotham is primarily devoted to agriculture. A few small towns are located between Urbana and Gotham that have some associated local commerce and manufacturing plants. The area, however, can still be characterized as rural.

The major population centers in the vicinity of the lake are: Metropolis, a city of approximately 100,000 on the eastern shore of the lake where the Metro River empties into it; Urbana, a town of 50,000 on the southwestern shore of the lake; and Gotham, a city of approximately 200,000 located on the northwestern shore of the lake where the lake flows into the Frasier River that flows to the northwest.

Annual wind frequency information is available for the three largest cities and is given in the attached tables and wind roses. Mean monthly and annual precipitation amounts are also given. From a large-scale study taken two years ago, the frequency of inversions below 500 feet are estimated on an annual basis to be: Metropolis, 20 percent; Urbana, 25 percent; and Gotham, 29 percent.

The problem stated above is a generalized situation that could exist. It is intended to apply only to the meteorology that has been discussed, not to engineering problems, cost factors, etc.

What *meteorological factors* should be considered in evaluating your site on the lake shore when locating the power plant in order to avoid problems of air pollution? You should design a *meteorology survey* for a site report that would answer your company's management questions. Include in your report the types of measurements needed to generate data on which to base your particular recommendations. If you recommend against building on the site, what contingency control strategies would you suggest adopting in case your are overruled by the management of the power company?

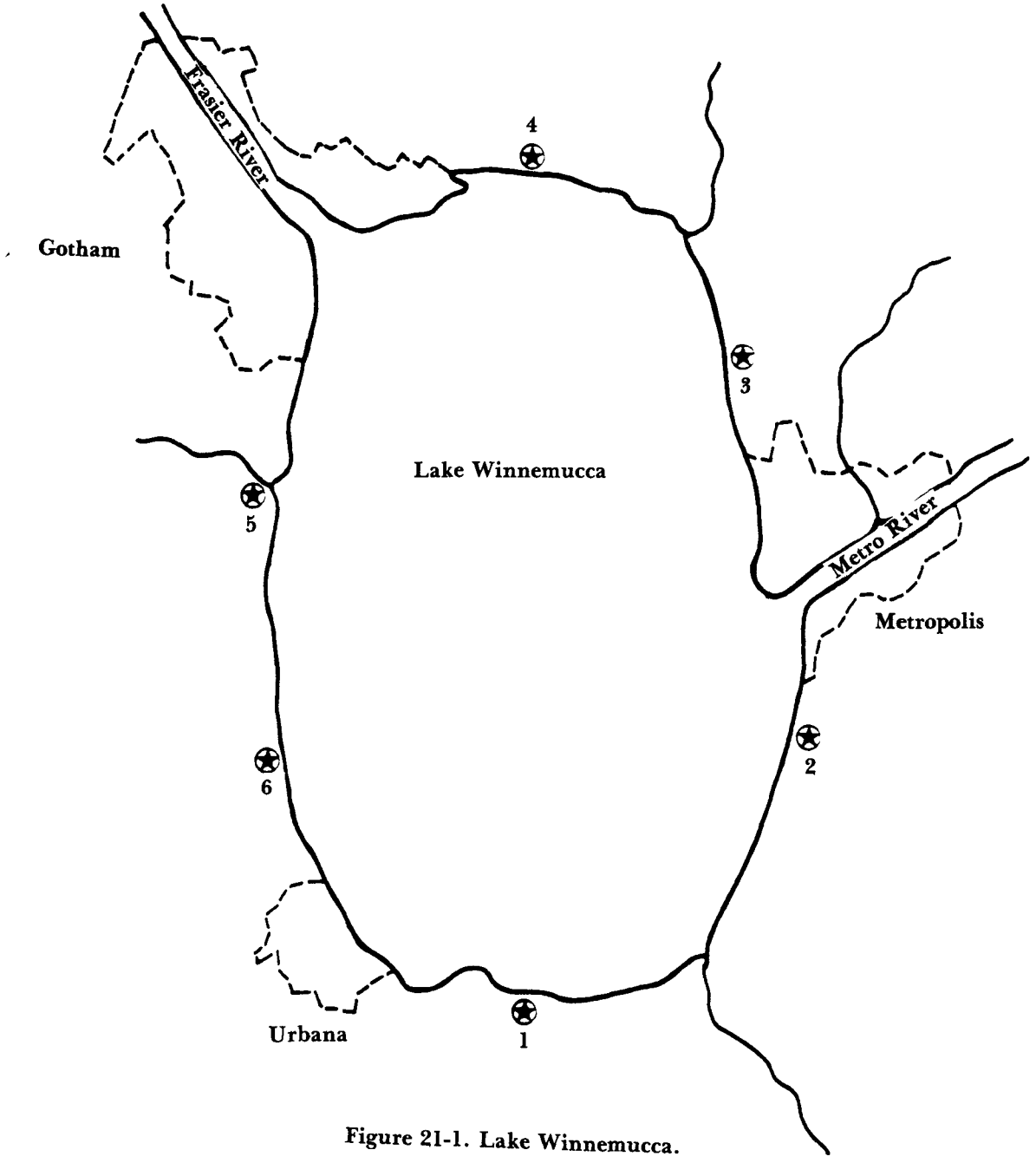


Figure 21-1. Lake Winnemucca.

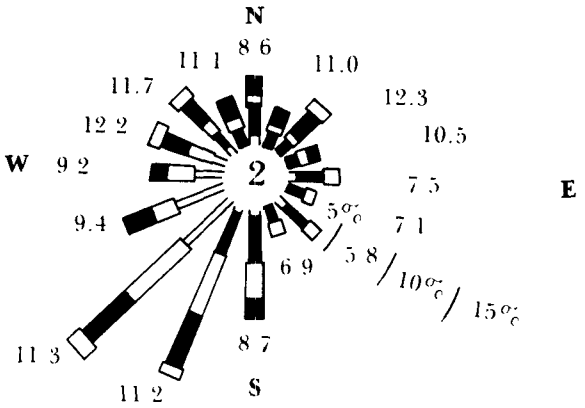


Figure 21-2. Gotham.

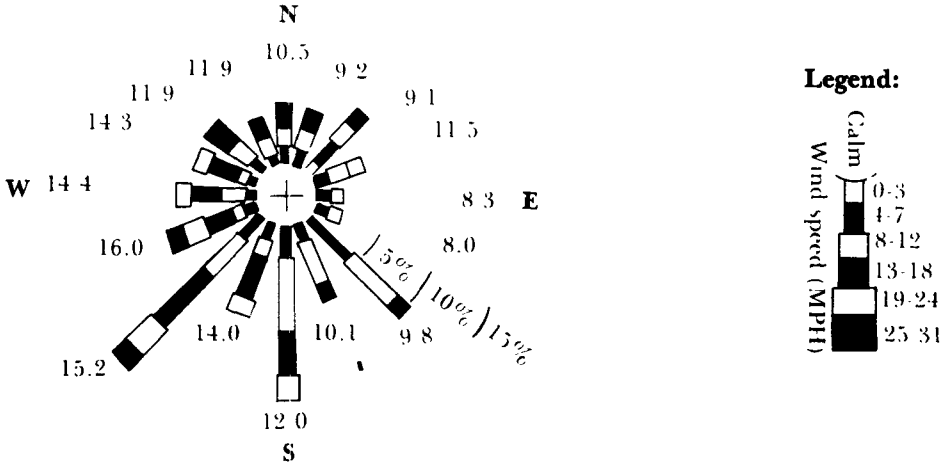


Figure 21-3. Metropolis.

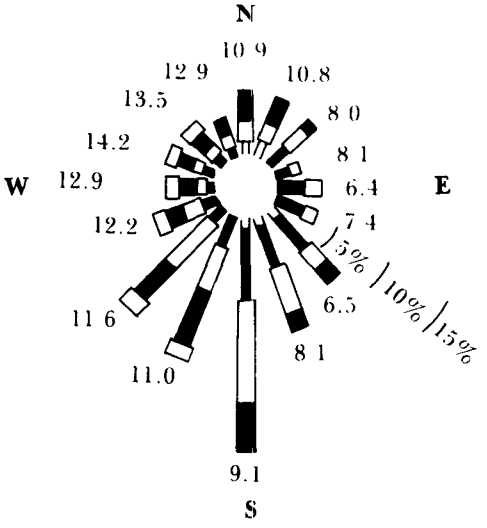


Figure 21-4. Urbana.

Table 21-1. Percentage frequencies of annual wind direction and speed.

Period of record: Jan. 1956 to Dec. 1960. + indicates more than 0 but less than 0.5. Values are to nearest whole percent not adjusted to make their sums equal to total percentages.

Metropolis

	Speed (miles/hour)									
	0-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	Total	Av. Speed
N	+	1	2	1	+	+			4	10.5
NNE	+	1	2	1	+	+			3	9.2
NE	1	2	2	1	+				6	9.1
ENE	+	1	2	1	+				3	11.5
E	+	1	1	+	+				3	8.3
ESE	+	1	1	+					2	8.0
SE	1	3	5	1	+				10	8.8
SSE	+	1	4	1	+	+			7	10.1
S	+	2	6	3	2	+			14	12.0
SSW	+	1	23	1	+	+	+		8	14.0
SW	+	2	4	5	3	1	+	+	15	15.2
WSW	+	1	1	2	2	1	+		7	16.0
W	+	+	2	2	1	+	+		6	14.4
WNW	+	+	1	2	1	+			5	14.3
NW	+		+	1		2	1		5	14.3
NW	+	1	2	2	+	+	+		5	11.9
NNW	+	+	2	1	+	+			3	11.9
Calm	+								+	
Total	4	17	40	24	11	3	1	+	100	12.5

Urbana

	Speed (miles/hour)									
	0-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	Total	Av. Speed
N	+	1	2	2	+	+			6	10.9
NNE	+	1	2	2	+				5	10.8
NE	+	2	2	1					4	8.0
ENE	+	1	1	+					2	8.1
E	+	2	1	+					4	6.4
ESE	+	2	1	+					4	7.4
SE	1	3	2	1	+				6	6.5
SSE	1	3	4	1	+				8	8.1
S	1	5	8	3	+	+			17	9.1
SSW	+	2	4	4	1				11	11.0
SW	+	1	5	3	1	+			10	11.6
WSW	+	1	2	1	1	+			5	12.2
W	+	+	1	1	1	+			4	12.8
WNW	+	1	1	1	1	+			4	14.2
NW	+	+	1	1	1	+			4	13.5
NNW	+	+	1	1	+	+			3	12.9
Calm	2								2	
Total	9	25	37	23	6	1			100	9.9

Table 21-1. (continued).

Gotham

	Speed (miles/hour)									
	0-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	Total	Av. Speed
N	1	2	1	1	+	+			5	8.6
NNE	+	1	1	1	+				4	11.0
NE	+	1	1	2	1	+			5	12.3
ENE	+	1	1	1	+	+			4	10.5
E	1	2	1	+	+				4	7.5
ESE	+	1	1	+	+				2	7.1
SE	1	2	1	+					3	5.8
SSE	+	1	1	+					3	6.9
S	1	3	3	1	+	+			8	8.7
SSW	1	3	5	4	1	+			15	11.2
SW	1	4	6	4	1	+	+		17	11.3
WSW	1	3	2	2	+	+			9	9.4
W	+	2	2	1	+				5	9.2
WNW	+	1	2	2	1	+			6	12.2
NW	1	1	1	2	1	+			5	11.7
NNW	+	1	1	1	+				4	11.1
Calm	2								2	
Total	11	28	30	23	7	1	+		100	10.0

Table 21-2. Normal precipitation amounts by month period of record 1921-1950.

	Gotham	Urbana	Metropolis
January	2.25	2.36	2.78
February	1.86	2.12	2.59
March	2.86	2.89	2.72
April	3.25	2.73	2.55
May	2.95	2.73	2.47
June	3.55	3.05	2.70
July	2.65	3.04	2.43
August	2.69	2.64	2.54
September	3.02	3.13	3.01
October	2.32	2.42	2.49
November	2.15	2.66	3.09
December	2.29	2.29	2.92
Total	31.84	32.06	32.29

Table 21-3. Summary data sheet for Lake Winnemucca.

	1	2	3	4	5	6
Distance (mi.)						
Gotham	12	20	33	27	20	5
Urbana	20	1	7	20	30	34
Metropolis	25	23	20	2	2	19
Wind Toward (%)						
Gotham	25	17	15	21	5	9
Urbana	6	17	8	3	9	4
Metropolis	15	5	13	37	12	11
Lake	56	38	42	35	38	18
Speed						
Mean	—	—	—	max.	max.	—
% Above 12 mph	72	66	63	61	61	78
Inversions (%)	27	25	24	20	20	29

Table 21-4. National Ambient Air Quality Standards.

Criteria Pollutant	Primary	Secondary
1. Sulfur Oxides	A. 80 $\mu g/^3$ (0.03 ppm) annual arithmetic mean B. 365 $\mu g/m^3$ (0.14 ppm) 24-hr concentration*	A. 60 $\mu g/m^3$ (0.02 ppm) annual arithmetic mean B. 260 $\mu g/m^3$ (0.1 ppm) 24-hr concentration* C. 1,300 $\mu g/m^3$ (0.5 ppm) 3-hr concentration*
2. Particulate Matter	A. 75 $\mu g/m^3$ annual geometric mean B. 260 $\mu g/m^3$ 24-hr concentration	A. 60 $\mu g/m^3$ annual geometric mean B. 150 $\mu g/^3$ 24-hr concentration*
3. Carbon Monoxide	10 $\mu g/m^3$ (9 ppm) maximum 8-hr concentration*	Same as primary
4. Oxidants	200 $\mu g/m^3$ (0.12 ppm) maximum 1-hr concentration*	Same as primary
5. Hydrocarbons	160$\mu g/m^3$ (0.24 ppm) maximum 3-hr (6am to 9am) concentration*	Same as primary
6. Nitrogen Dioxide	100 $\mu g/m^3$ (0.05 ppm) annual arithmetic mean	Same as primary
7. Lead	1.5 $\mu g/m^3$/calendar quarter	

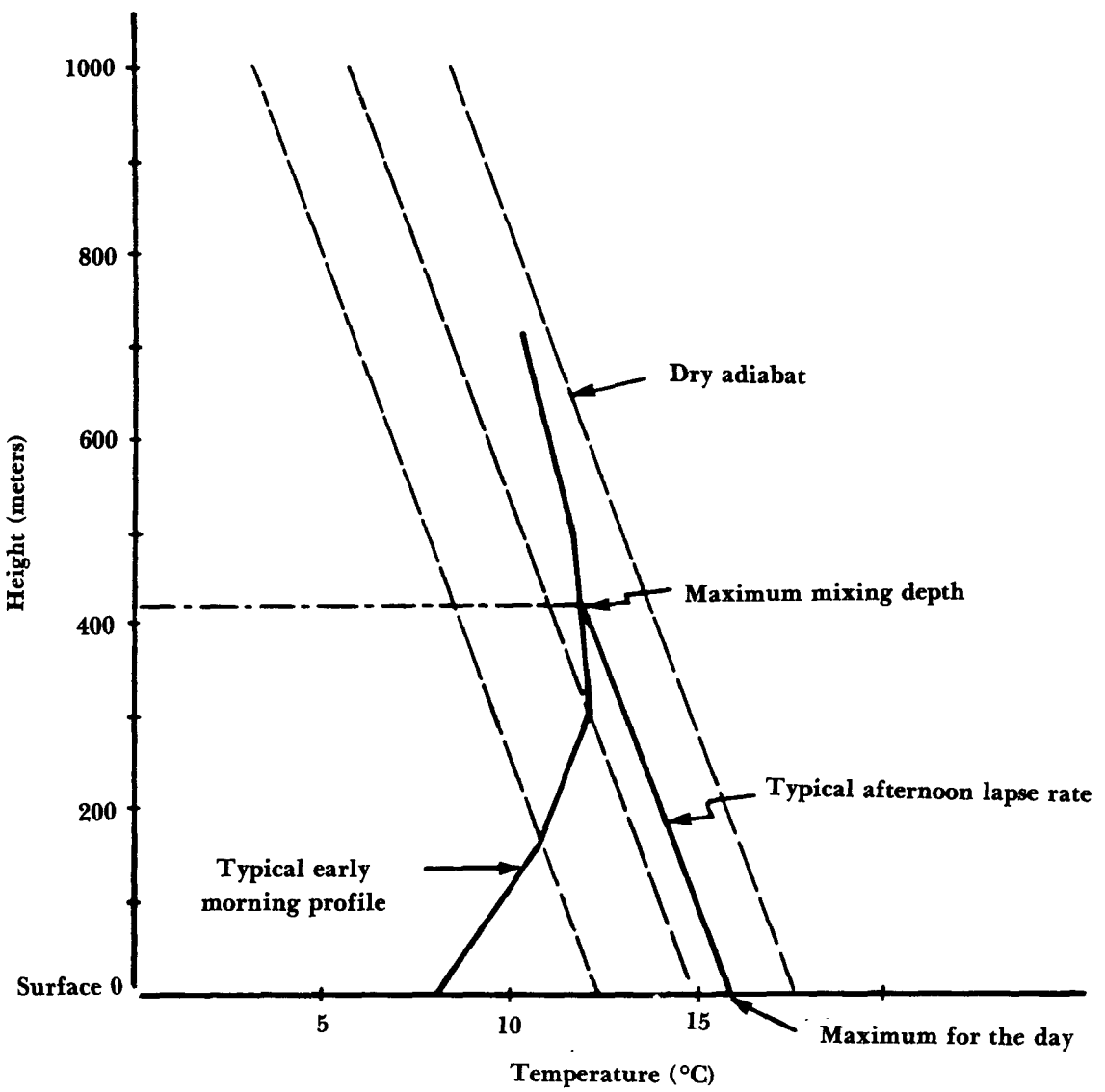
*Maximum value not to be exceeded more than once per year.

APPENDIX

Maximum Mixing Depth Example 1
(Solution)

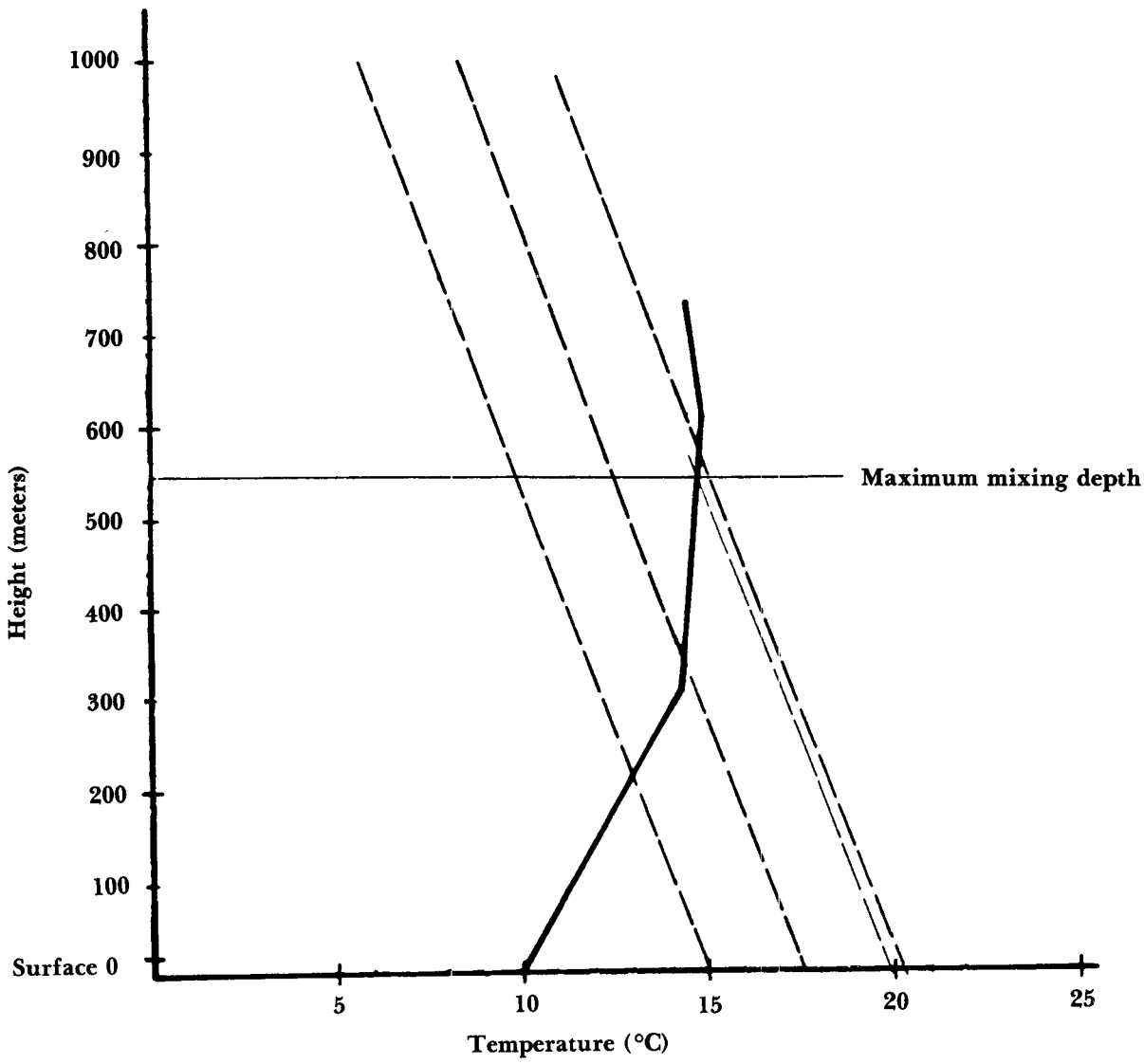
The maximum mixing depth for a day can be estimated from a temperature profile by following these steps:

1. Plot the maximum surface temperature for the day on the morning profile. (e.g., 16°C)
2. From this point draw a line parallel to a dry adiabat to the point where it intersects the morning profile.
3. Read the height above ground at this point. This is the maximum mixing depth (MMD) for the day.
4. The MMD on the example profile below is approximately 420 meters.



Maximum Mixing Depth Example 2
(Solution)

Another typical early morning profile is shown below. If the maximum surface temperature for the day is 20 °C, what would you expect the maximum mixing depth to be?
__550____ meters



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Project Officer for this manual is R.E. Townsend, EPA-ERC, RTP, NC 27711

16. ABSTRACT

This student workbook is designed for use in the Air Pollution Training Institute Course 411, "Air Pollution Meteorology." It contains introductory material, lesson outlines, problem sets, and class exercises.

This publication is intended for use in conjunction with the Course 411 Instructor's Guide (EPA 450/2-81-013) and the Student Manual.

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