INTERSTATE AIR POLLUTION STUDY

BI-STATE DEVELOPMENT AGENCY

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PHASE II PROJECT REPORT

V METEOROLOGY AND TOPOGRAPHY

INTERSTATE AIR POLLUTION STUDY
PHASE II PROJECT REPORT

V. METEOROLOGY AND TOPOGRAPHY

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U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

Public Health Service

Bureau of Disease Prevention and Environmental Control
National Center for Air Pollution Control
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Copies of this report are available from the cooperating agencies listed on the cover of this report and from the National Center for Air Pollution Control, 1055 Laidlaw Avenue, Cincinnati, Ohio 45237.

FOREWORD

The Interstate Air Pollution Study was divided into two phases. Phase I, a general study of the overall air pollution problems in the St. Louis - East St. Louis Metropolitan area, was conducted to determine specific activities that would require further study in Phase II of the project. The effort was divided into two phases to provide a logical stopping point in the event that interest and resources for proceeding further might not materialize. The necessary impetus did continue, however, and the Phase II operation was also completed.

The Phase I operation resulted in a detailed report, designed primarily for use of the Executive Committee members and their agencies in making decisions concerning the Phase II project operation. A Phase I summary report was also prepared; it received wide distribution.

Numerous papers, brochures, and reports were prepared during Phase II operations, as were some 18 Memorandums of Information and Instruction concerning the project. All of these documents were drawn upon in the preparation of the Phase II project report. The Phase II project report consists of eight separate volumes under the following titles:

I. Introduction
II. Air Pollutant Emission Inventory
III. Air Quality Measurements
IV. Odors - Results of Surveys
V. Meteorology and Topography
VI. Effects of Air Pollution
VII. Opinion Surveys and Air Quality Statistical Relationships
VIII. Proposal for an Air Resource Management Program

CONTENTS

V. METEOROLOGY AND TOPOGRAPHY

GENERAL CLIMATOLOGY

The St. Louis area experiences the meteorological conditions typical of most Great Plains cities that are not influenced by major natural features such as mountains or large bodies of water. The winters are fairly brisk and stimulating as a rule and are seldom severe. Almost every winter has several periods of mild weather and occasional short spells of extreme cold. Summers are generally warm, whereas spring and fall are characterized by moderate temperatures.

Marked variations in day-to-day conditions are provided by changes from warm, moist air flowing up from the Gulf of Mexico during some periods to cool, dry air from the Northern Plains during others.

TOPOGRAPHY

The St. Louis area is gently rolling, generally with gradual undulations rather than sharply defined ridges and valleys. Although there are a few rises and drops of 100 feet in elevation over a short distance, the area within a 25-mile radius of downtown St. Louis is generally free of major orographic features that strongly influence meteorological variables. In general, elevations range from 480 feet above sea level in the downtown St. Louis area to about 550 feet at Lambert Field, 12 miles away, with a slight ridge rising to 600 feet in between. A flat area known as the American Bottoms, surrounded by a crescent-shaped bluff rising to an average of 640 feet above sea level, lies on the east side of the Mississippi River across from St. Louis. The boundary bluff extends from Alton, Illinois, on the north, to 10 miles east of the Mississippi at East St. Louis, to within 3 miles of the river opposite the mouth of the River des Peres on the south.

The average elevation of the Mississippi River is 400 feet above sea level, and of the American Bottoms, about 420 feet above sea level, about 60 feet below the main commercial area of St. Louis. At times, stagnation of a shallow pool of cool air in this basin during the night enhances radiation fog formation under clear skies in the early morning. These conditions are generally dissipated within a few hours after sunrise. Similar conditions exist in the Missouri River channel to the west and north of St. Louis, though the Missouri River bottom area is relatively small in extent.

METEOROLOGICAL PARAMETERS

Stability

Stability may be simply described as resistance to change. In the atmosphere it may be measured by the vertical variations (lapse rate) of temperature. Because of the interaction of pressure, temperature, and volume, a parcel of air lifted through the atmosphere experiences an increase in volume (hence a decrease in density) and a decrease in temperature. If the parcel is insulated from its surroundings or is moved quickly enough to prevent exchange of heat with its surroundings, its temperature decreases at the rate of 5.4°F for each 1,000-feet increase in elevation (0.98°C for each 100 meters). This condition is termed the adiabatic lapse rate. If, when released at its new position, the air mass is warmer than its surroundings, it continues to rise. If it is cooler than its surroundings it will tend to descend. If this tendency to rise or descend is such as to return the air mass to its level of origin, the atmosphere is stable; but if the tendency is to move it farther from its level of origin, the atmosphere is unstable. Thus, if the temperature in the atmosphere decreases with height more rapidly than the adiabatic lapse rate, the atmosphere is unstable.

If the temperature decreases less rapidly or even increases with height, the atmosphere is termed stable. Special terms are applied to these conditions. A decrease of temperature with height more rapid than adiabatic is described as superadiabatic and is an unstable condition. A decrease of temperature at the adiabatic lapse rate is called adiabatic, of course, and is a neutrally stable condition. A condition wherein the temperature does not vary with height is termed isothermal (iso means equal) and is quite stable. An increase of temperature with height is an inversion, which is most stable. Conditions between adiabatic and isothermal are sometimes called "lapse" or slightly stable. Each of the terms "superadiabatic," "lapse," and "inversion" covers a range of conditions. The boundaries separating these ranges are the adiabatic and isothermal conditions. These variations in lapse rate and stability are illustrated in Figure 1.

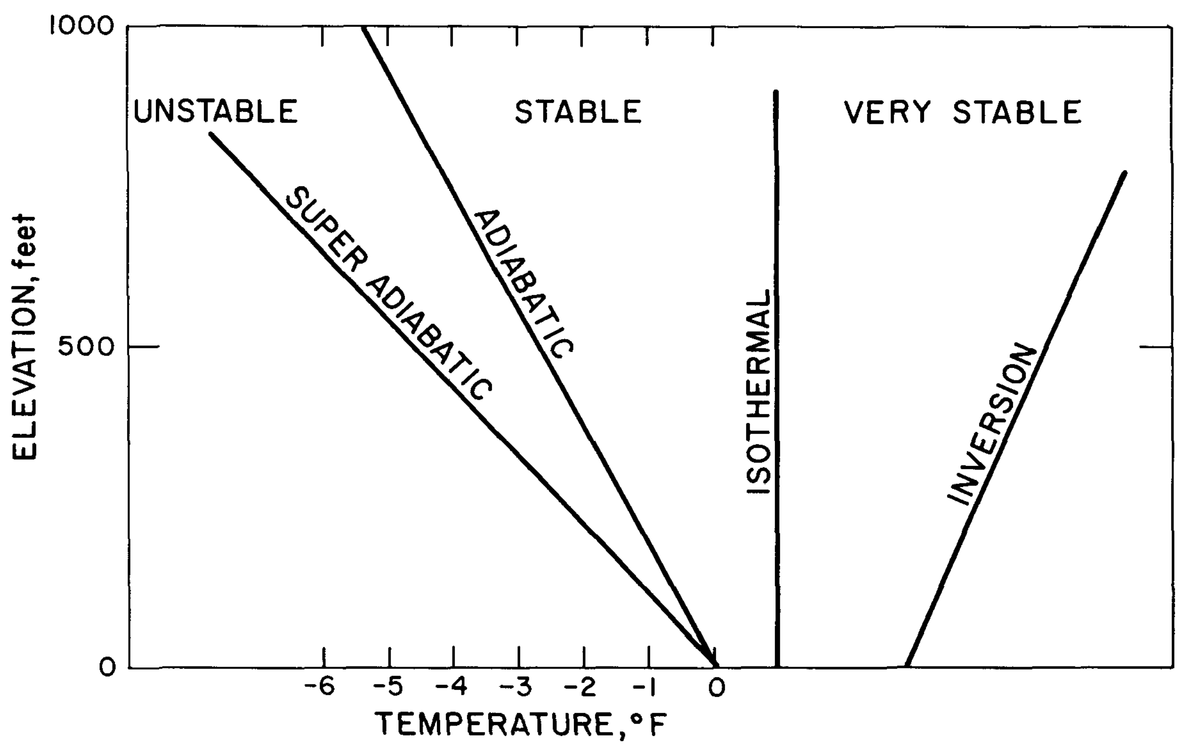


Figure 1. Lapse rates and stability.

A stable condition inhibits the creation of eddies and thus the diffusion of air pollutants, whereas an unstable condition supports the creation of eddies and accelerates the diffusion of air pollutants. These effects of variations in stability may be seen in smoke plumes, as illustrated in Figure 2.

Wind

The term "wind" includes both direction and speed. The principal effect of wind direction is readily apparent since it determines the part of a city that may be affected by the transport of pollution from given sources or areas. Wind speed and atmospheric stability largely govern the degree of dilution of effluent before reaching a given location downwind from a pollution source. Figures 3 through 6 are surface wind roses for particular months which characterize each of the four seasons. The radial bars on the wind roses indicate the direction from which the wind blows; for example, the southeast bar represents the wind that blows from the southeast. Figure 7 illustrates monthly average wind speeds at the surface and at 1,100 feet above St. Louis (500 meters above sea level) during the years 1950-1959, as well as seasonal average wind speeds within this layer.

Winds Aloft - 1,100 Feet Above St. Louis

The wind roses in Figures 8 through 15 for 500 meters above mean sea level (1,100 feet above St. Louis) were prepared from Weather Bureau pilot balloon (PIBAL) observations at Lambert Airport.[1] Again the radial bars on the wind roses indicate the direction from which the wind blows. This level was considered high enough to be generally uninfluenced by any surface features, and thus to present a picture of smooth airflow over the area. During the winter months, 1,100 feet is generally near the top of the mean maximum mixing layer and the airflow does not show very much diurnal variation in speed or direction; however, during the other months, turbulence from surface heating changes the wind regime with time of day so that at this level daytime wind speeds are generally lower than nighttime speeds.

AIR POLLUTION CLIMATOLOGY

The general weather conditions and climatology that have specific application to this study are summarized in Figures 16 and 17.[2] Table 1 summarizes and compares several climatological parameters for St. Louis as well as other large cities.

The principal effect of temperature on air pollution is that space heating is required in cold weather. Heating requirements are measured in degree-days. The heating degree-day is based on the premise that when the daily mean temperature falls below 65°F, space heating is generally required. The number of heating degree-days is defined as the number of degrees the mean temperature is below 65°F. Emissions from space-heating equipment are very nearly proportional to the number of degree-days; hence, degree-day data may be used to estimate daily and seasonal variations of pollutants emitted from such sources.

The annual distribution of degree-days is presented in Figure 16 with the monthly average maximum and minimum temperatures. Also presented in Figure 16 are the average number of days with thunderstorms, average number of days

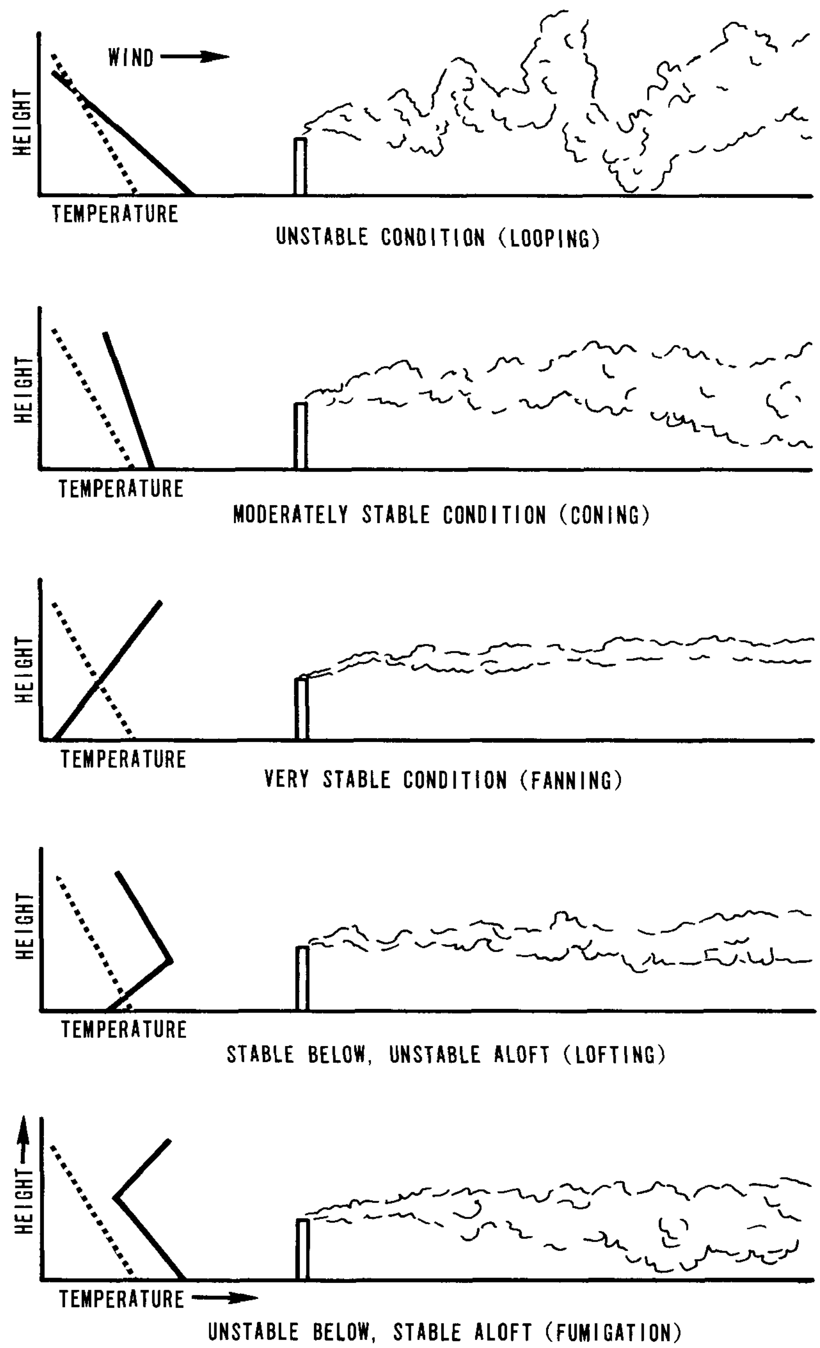


Figure 2. Schematic representation of stack gas behavior under various conditions of vertical stability (Dry adiabatic lapse rate shown by dashed line).

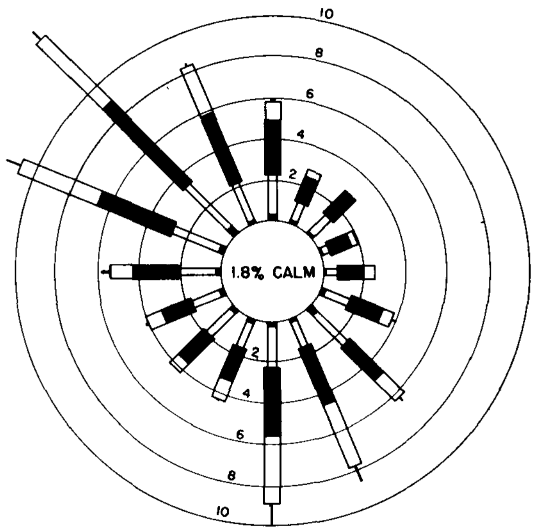
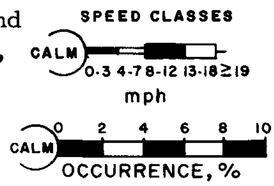


Figure 3. January surface wind rose for Lambert Airport, 1951-60.



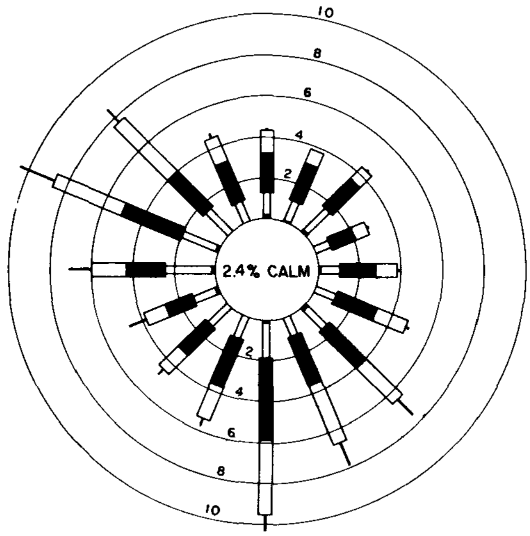


Figure 4. April surface wind rose for Lambert Airport, 1951-60.

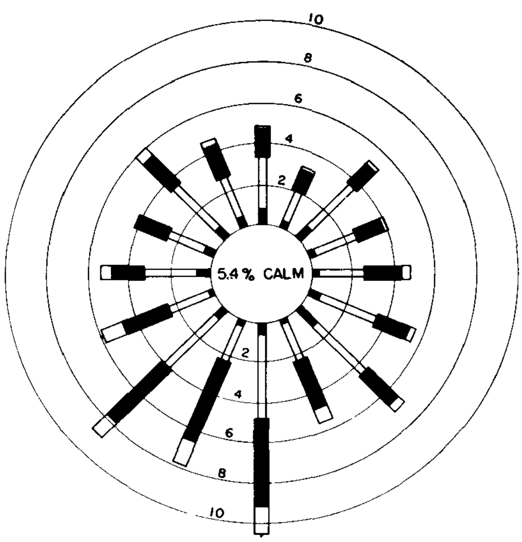


Figure 5. July surface wind rose for Lambert Airport, 1951-60.

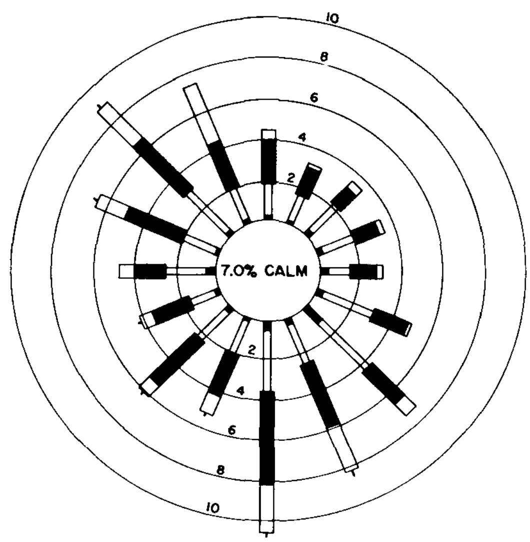


Figure 6. October surface wind rose for Lambert Airport, 1951-60.

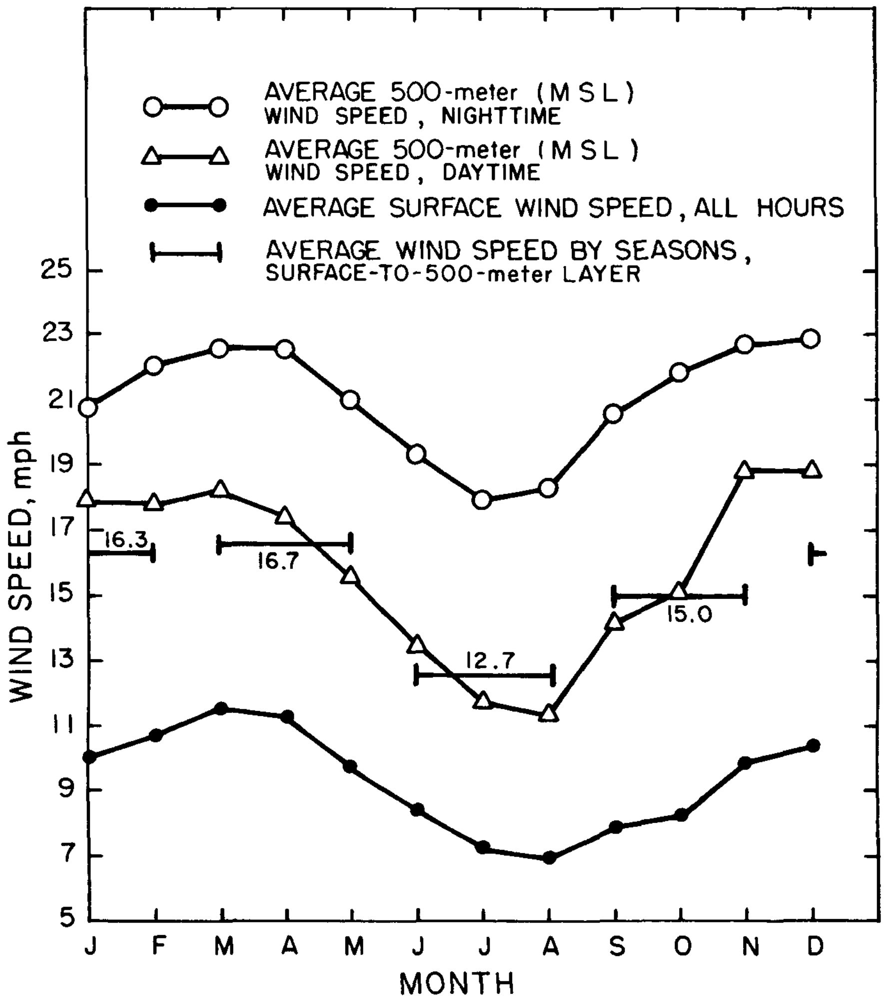


Figure 7. Wind speeds at Lambert Airport, averages for 1950-59.

measurable (0.01 inch or more) precipitation, and the normal monthly amount of precipitation. Thunderstorm days are of interest since a thunderstorm is associated with unstable conditions and strong vertical motions, which are effective in carrying pollutants aloft. Precipitation alone is less important, though there is some tendency for rain (or snow) to wash (or scour) pollutants out of the atmosphere. The number of thunderstorm days is greatest in the summer season. Spring and early summer are the best seasons for removal of pollutants from the atmosphere by wash-out, in view of the high number of days with rain.

Stability in the lowest layer of the atmosphere varies in a diurnal pattern, normally being stable at night and unstable in the afternoon. The height to which the unstable layer develops is defined as the maximum mixing depth, and, taken with wind speed, represents a volumetric indication of the dilution of air pollutants, since the scale and applications are generally area-wide. Holzworth[3] has computed mean maximum mixing depths from vertical temperature profiles (from radiosonde observations) for all places in the United States where data were available. These were interpolated for St. Louis from his maps (since the nearest radiosonde station to St. Louis is Columbia, Missouri). Figure 17 shows the monthly mean maxi-

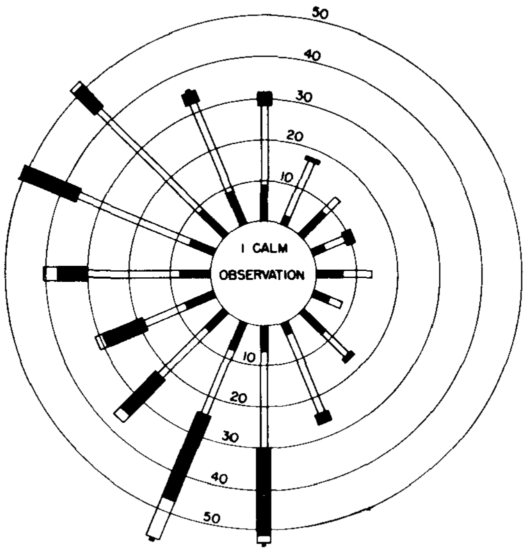


Figure 8. January wind rose 1,100 feet above surface at Lambert Airport, daytime, 1950-59, 504 observations.

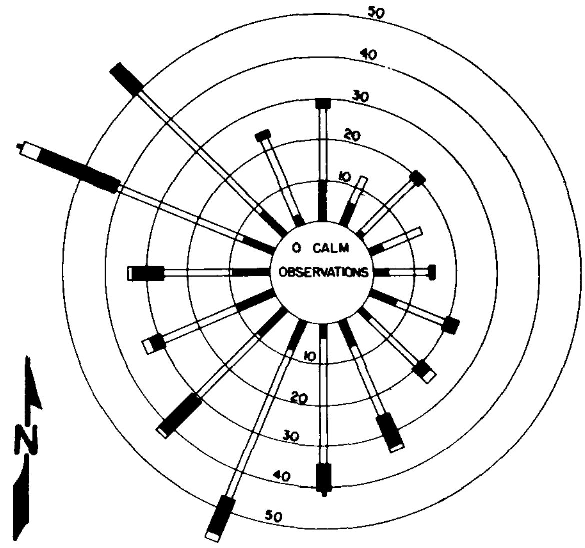
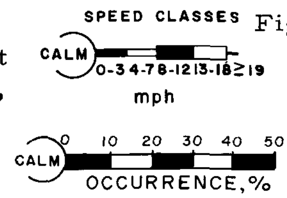


Figure 9. April wind rose 1,100 feet above surface at Lambert Airport, daytime, 1950-59, 540 observations.



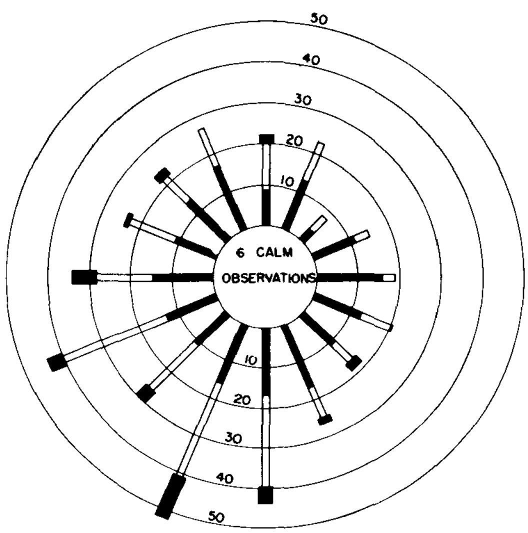


Figure 10. July wind rose 1,100 feet above surface at Lambert Airport, daytime, 1950-59, 440 observations.

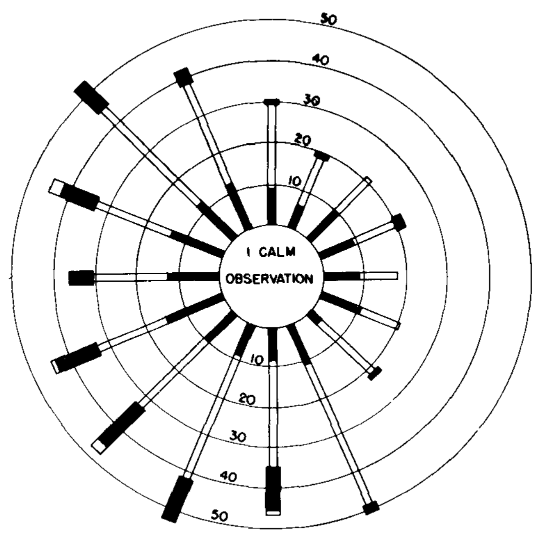


Figure 11. October wind rose 1,100 feet above surface at Lambert Airport, daytime, 1950-59, 578 observations.

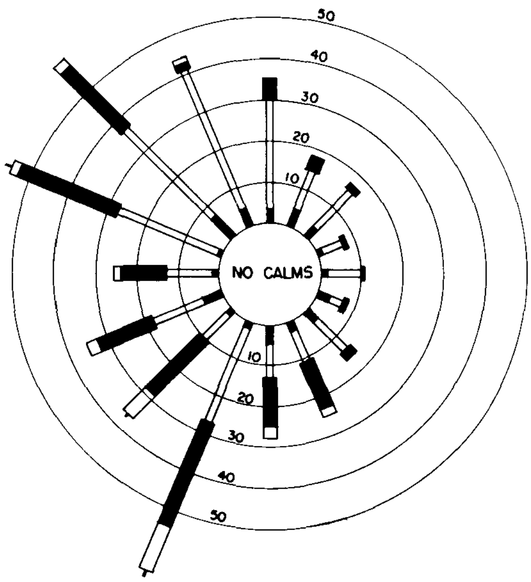
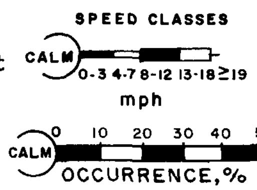


Figure 12. January wind rose 1,100 feet above surface at Lambert Airport, nighttime, 1950-59, 496 observations.



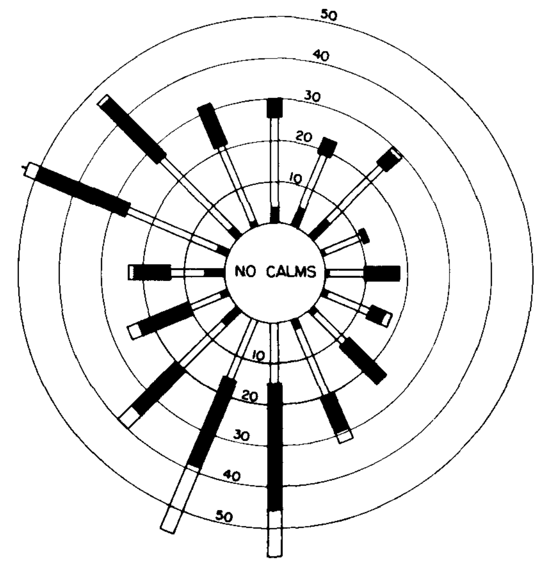


Figure 13. April wind rose 1,100 feet above surface at Lambert Airport, nighttime, 1950-59, 523 observations.

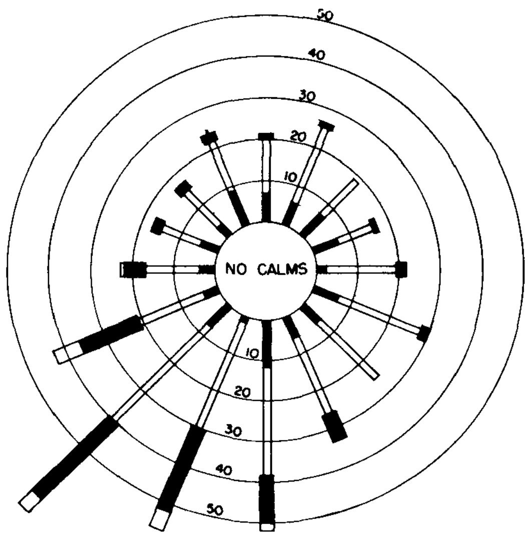


Figure 14. July wind rose 1,100 feet above surface at Lambert Airport, nighttime, 1950-59, 502 observations.

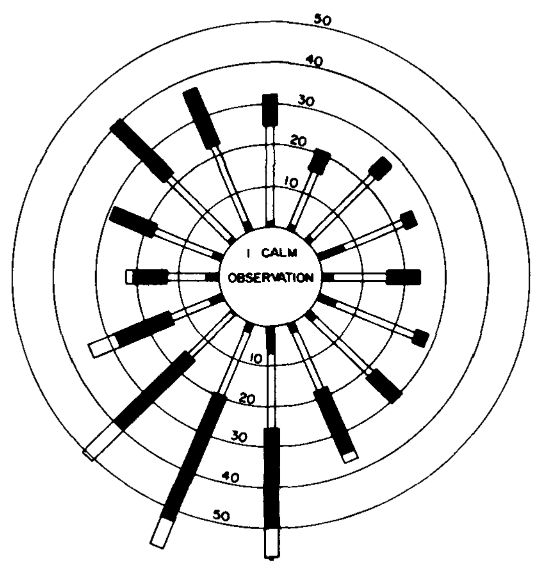


Figure 15. October wind rose 1,100 feet above surface at Lambert Airport, nighttime, 1950-59, 568 observations.

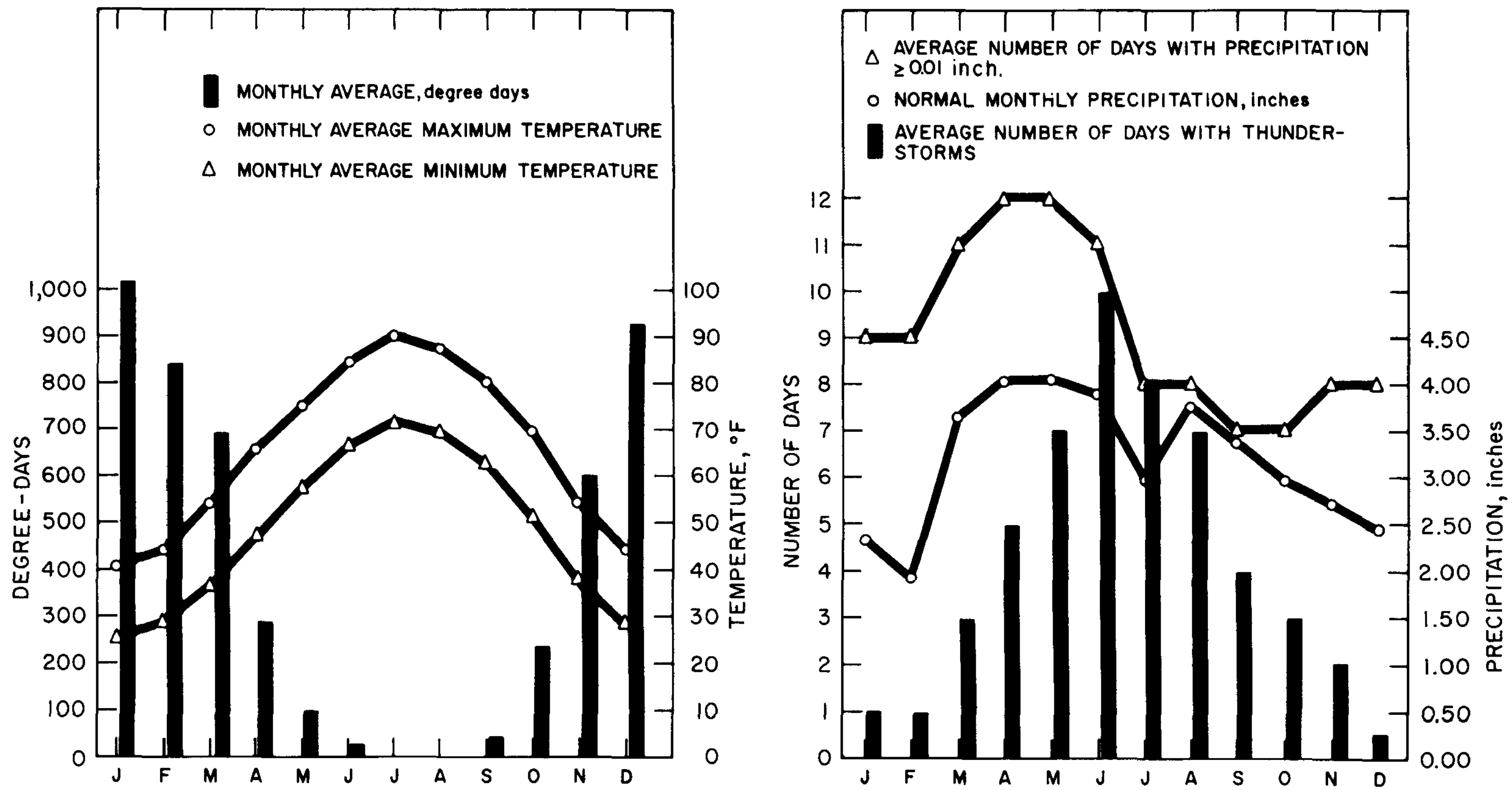


Figure 16. Normal data, Lambert Airport, 1931-60.

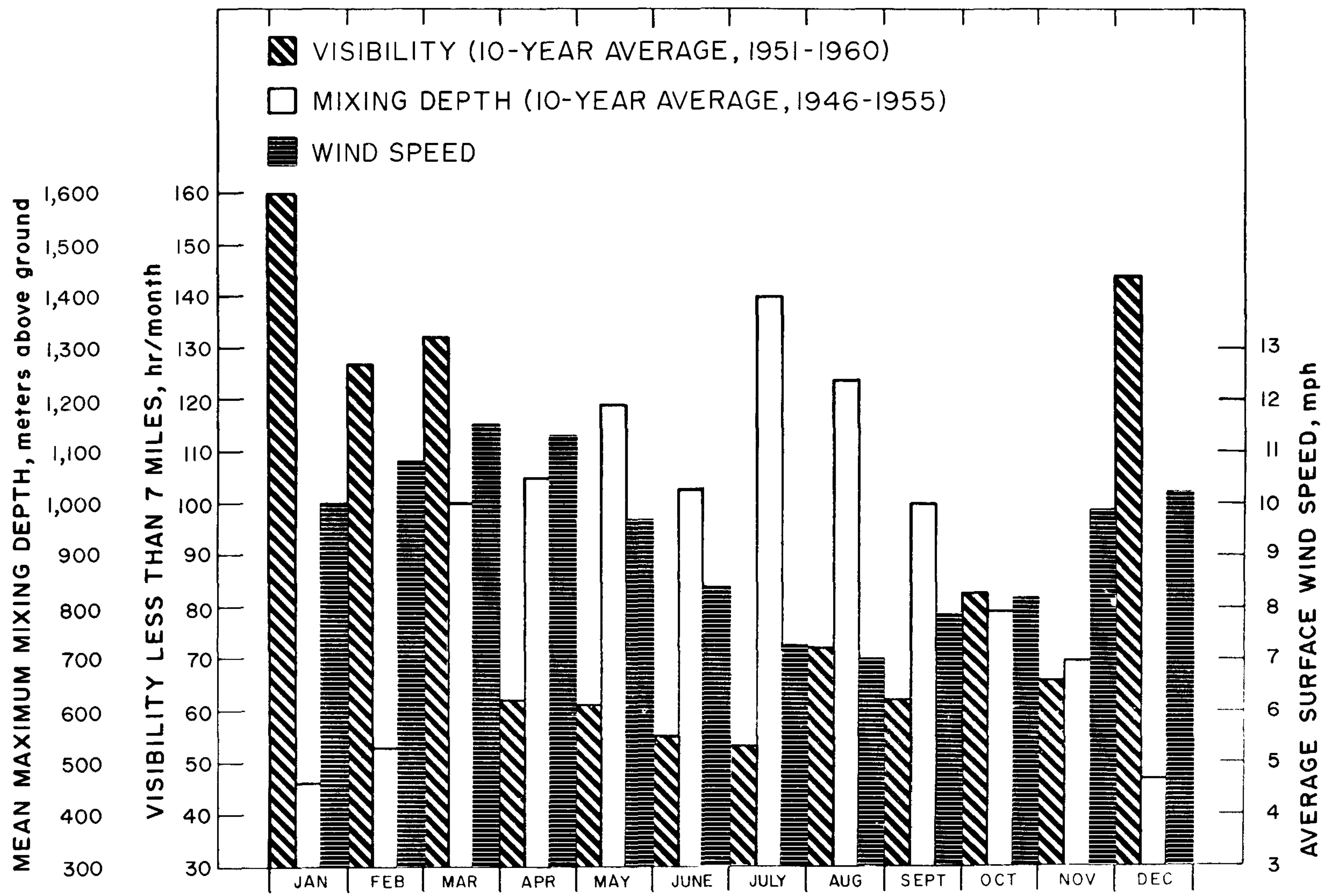


Figure 17. Visibility, mixing depth, and wind speed relationships.

Table 1. CLIMATOLOGICAL NORMALS FOR ST. LOUIS AND FOUR OTHER LARGE CITIES

City	Temperature, °F Mean maximum	Mean minimum	Record high	Record low	Degree-days	Yearly precipitation, inches	Cloud cover (tenths)	Mean hourly wind speed, mph	Percent possible sunshine
St. Louis	66.0	46.6	115	-23	4699	36.80	6.0	9.3	56
Chicago	59.3	40.8	105	-23	6310	32.72	6.2	10.1	58
Atlanta	72.2	52.2	103	- 9	2826	49.16	5.7	9.6	60
Denver	63.5	36.1	105	-30	6132	14.20	5.2	9.6	69
Dallas	76.6	56.4	111	- 3	2272	34.42	5.1	10.8	66

mum mixing depths for St. Louis associated with the average wind speed and with the number of hours visibility at Lambert Field is restricted to less than 7 miles. The large monthly variations in mixing depth are quite evident, with lowest values during the season of maximum heating. The combination appears to be related to restricted visibility.

The product of maximum mixing depth and average monthly wind speed at or near the surface gives a qualitative idea of atmospheric dilution for an area. Table 2 illustrates this idea for the St. Louis area by using the average wind speed from the surface to 1,100 feet above ground. This concept indicates that the atmosphere is least able to dilute pollutants during the fall and winter season when dilution is most necessary, though its application is limited to afternoon conditions.

The wind rose in Figure 18 illustrates the wind directions associated with visibility of less than 3 miles at Lambert Airport due to all causes during 1941-1950.[4] Visibility restrictions to less than 3 miles were present in 11 percent of the weather observations during this 10-year period at the airport. Since fog is normally associated with the lower wind speeds, it appears that visibility of less than 3 miles attributable to nonfog conditions, primarily smoke and haze, occurs most frequently with winds coming from the general direction of the city of St. Louis (from the southeast) and Granite City (from the east-southeast or east). The frequency of such visibility restrictions with winds from the east-southeast is about twice that expected from examining the surface wind roses (Figures 3, 4, 5, 6).

Frequency of temperature inversion is another useful climatological parameter for describing atmospheric dilution. Hosler's[5] data in Table 3 show seasonal percent frequency of inversion at or below 500 feet above ground. The percentage of total time during which inversions occur is highest in fall; therefore, the time during which pollutants can mix freely into a deep layer is a minimum during the fall. The very high frequency of nighttime inversions in summer and fall suggests that early morning pollutant levels will average much higher than early evening levels. Figures 19 to 22 illustrate the percentage of low wind speed classes (7 mph or less) recorded at 9 p.m. and 3 a.m. at the surface and are typical of conditions beneath an inversion. These low wind speeds show the poor dilution capabilities near the surface at night, especially when considered with the high inversion frequencies in summer and fall. Also, morning fumigation conditions occur when pollutants aloft in stable layers of air are mixed downward by turbulence

Table 2. ATMOSPHERIC DILUTION FACTOR

Month	Average wind speed, mph	Mean maximum mixing height, meters	Product (mph x meters)	Seasonal product average	Relative dilution factor
Dec.	15.8	460	7,400	Winter,	
Jan.	16.2	460	7,400		
Feb.	16.8	530	8,900	7,900	1.0
Mar.	17.4	1,000	17,400	Spring,	
Apr.	17.1	1,060	18,100		
May	15.1	1,200	18,100	17,900	2.3
June	13.7	1,040	14,400	Summer,	
July	12.3	1,400			
Aug.	12.2	1,250	15,200	15,600	2.0
Sept.	14.2	1,000	14,200	Fall,	
Oct.	15.1	800	12,800		
Nov.	15.6	700	10,900	12,600	1.6

Table 3. PERCENT FREQUENCY OF INVERSION OCCURRENCE AT COLUMBIA, MO.(16)

Season	9 p.m. (Central standard time)	9 a.m.	6 p.m.	6 a.m.	Total[a] time	Maximum[b]
Winter	53	38	27	52	31	61
Spring	54	4	1	67	31	62
Summer	84	5	5	78	35	86
Fall	80	24	20	66	43	85

[a] Percent total time.
[b] Percent of dates on which at least one observation showed an inversion.

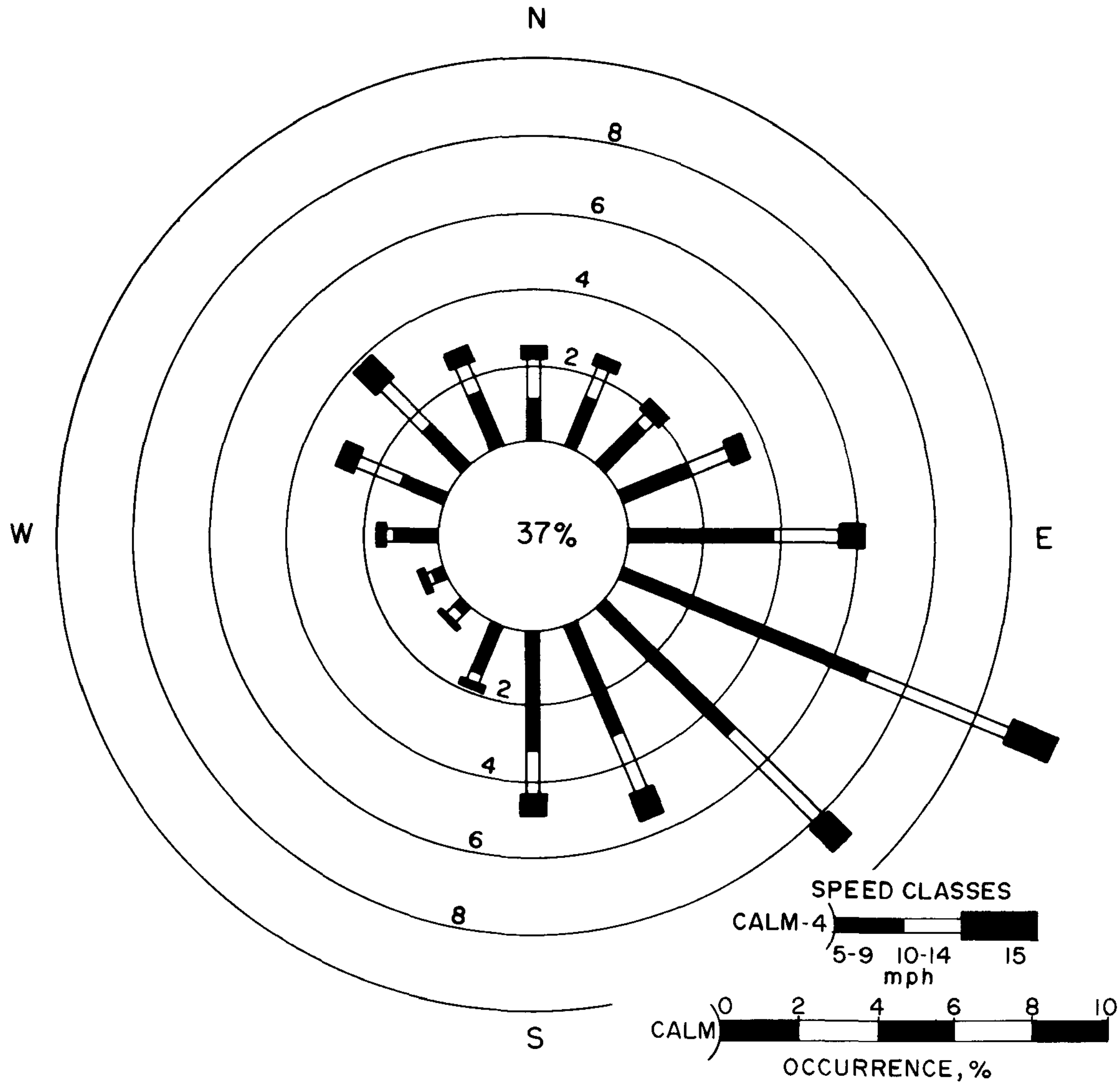


Figure 18. Wind rose for visibility of less than 3 miles from all causes at Lambert Airport, 1941-50.

from surface-heating and ground-pollutant concentrations are increased considerably for 1 to 2 hours.

Interpolation from Korshover's work,[6] indicates that St. Louis experienced nine cases when high pressure systems with very low wind speeds stagnated over the area for 4 or more consecutive days during the period 1936-1956. These cases resulted in 40 stagnation days, which occurred from April through October. Such stagnation days are usually associated with low wind speeds and restricted vertical diffusion.

Air pollution potential is defined as a set of weather conditions conducive to the accumulation of air pollutants in the atmosphere over a period of time. It is a condition that can be forecast with reasonable confidence when applied to large areas and a reasonable persistence. Miller and Niemeyer[7] indicate that 2 high

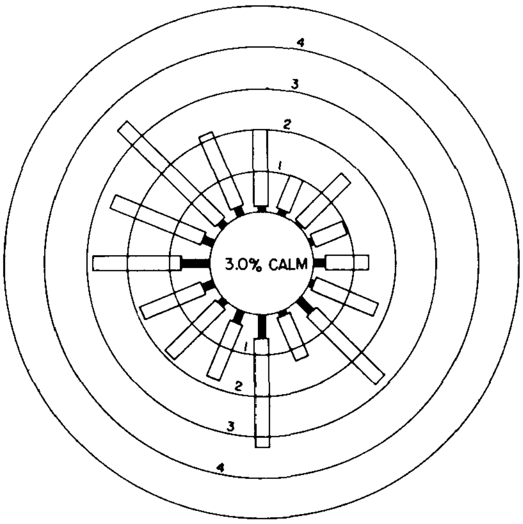
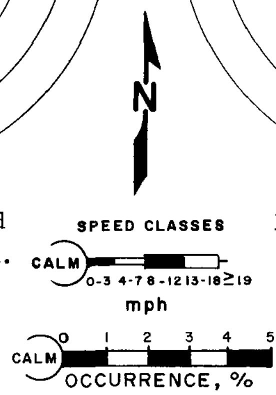


Figure 19. Winter low-speed surface wind roses, 9 p.m. and 3 a.m., Lambert Airport, 1951-60.



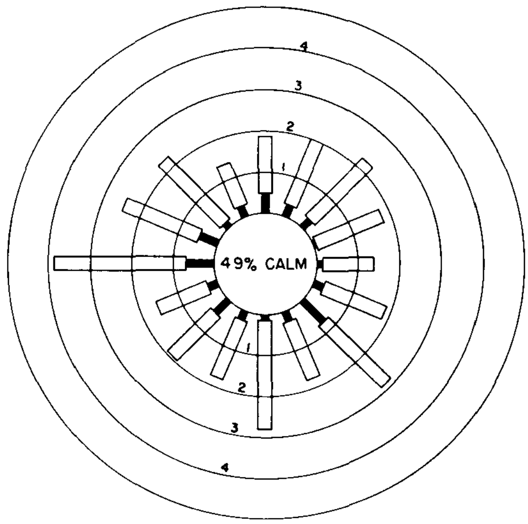


Figure 20. Spring low-speed surface wind roses, 9 p.m. and 3 a.m., Lambert Airport, 1951-60.

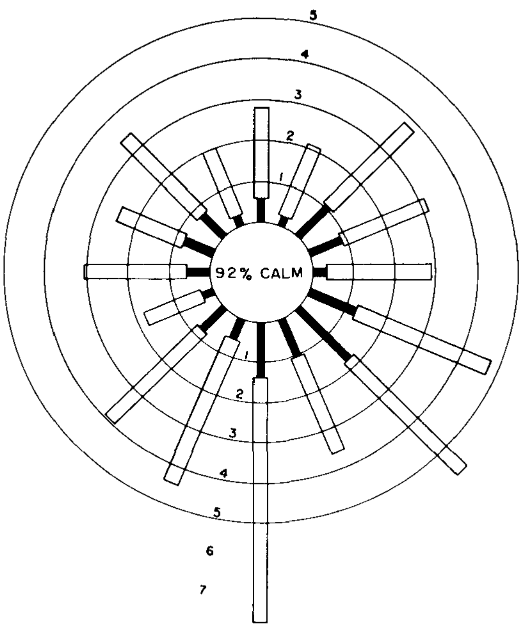


Figure 21. Summer low-speed surface wind roses, 9 p.m. and 3 a.m., Lambert Airport, 1951-60.

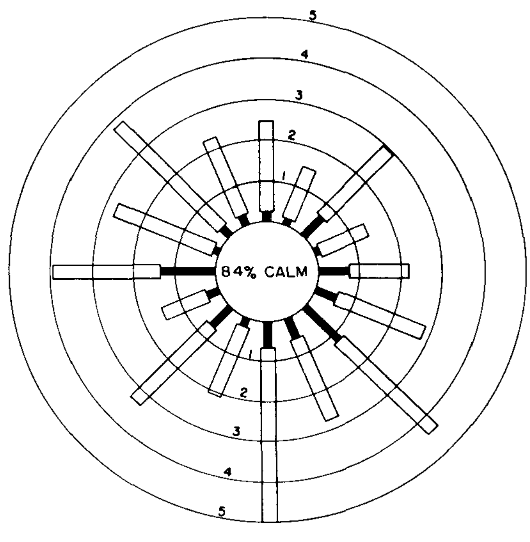


Figure 22. Fall low-speed surface wind roses, 9 p.m. and 3 a.m., Lambert Airport, 1951-60.

air pollution potential days occurred in St. Louis from August 1960 through July 1961. Their criteria for high air pollution potential are: (1) surface wind speeds less than 8 knots, (2) winds at no level below 500 mb (about 18, 000 feet) greater than 25 knots, (3) the existence of subsidence below 600 mb (about 14, 000 feet), and (4) persistence of these conditions for 36 hours or more over a minimum area equivalent to a 4-degree latitude - longitude square. Since July, 1961, these criteria were met only for a 3-day period, November 30 - December 2, 1962, and for 1 day in October 1964, when St. Louis was on the boundary of such an area on the 15th and 16th. Forecasts of high air pollution potential areas are issued daily over the Weather Bureau Service C teletype circuit by the Weather Bureau Research Station in Cincinnati, Ohio, and may be obtained from the Meteorologist-in-Charge at Lambert Airport.

URBAN AND TOPOGRAPHIC EFFECTS

Urban Heat Island Effects

Metropolitan areas impose their own effects upon the atmosphere. The city acts as a heat island, or heat reservoir, by storing up heat by absorption from the sun's rays during the day and releasing the stored heat at night. The heat island has two direct effects. Nighttime temperatures remain higher than in the surrounding countryside; and the nighttime inversion, which generally is based at the ground, is lifted to some distance above ground over the city itself. St. Louis is no exception to this rule. The heat island effect is illustrated in Figures 23 through 26, in which the average minimum temperatures for each of 4 months are mapped for several sites in and around the city. Note that in each case the minimum temperature at the KMOX-TV tower averages higher than at any of the outlying sites. Table 4 illustrates the inversion effect; average early morning temperatures for each of 4 months are given for various levels on the KMOX-TV tower. In each case the average minimum temperature at 125 feet was lower than the average temperature at 250 feet, and in three of the four cases, lower than the average temperature at 455 feet. In July and April the average condition was an inversion for both layers; in October, an isothermal layer above an inversion; and in January, a stable (between neutral and isothermal) layer above an inversion.

Although the existence of these urban "heat islands" has been well documented[8-11] and can be explained quite easily, their dimensions and total effect have not been defined. When the multitudinous variations affecting them are taken into account, a simple model likely to provide such information is not possible. Their vertical extent has been estimated[9] at about three times the average height of buildings, although this may be suspect in the case of a small cluster of tall buildings such as occurs in the downtown area of larger cities.

The factors involved in producing a heat island are many. Heat itself may be supplied by absorption of solar radiation during the day and reradiation at night, or by space heating during colder months. Low wind speeds are essential if the thermal stratification characteristic of a heat island is to be established and maintained. The presence of buildings reduces wind speeds. Clear skies intensify the effect since radiation from the countryside permits rapid cooling at night while radiation from building walls reflects back and forth to be absorbed eventually by the air, perhaps mostly by conduction from the warm surfaces.

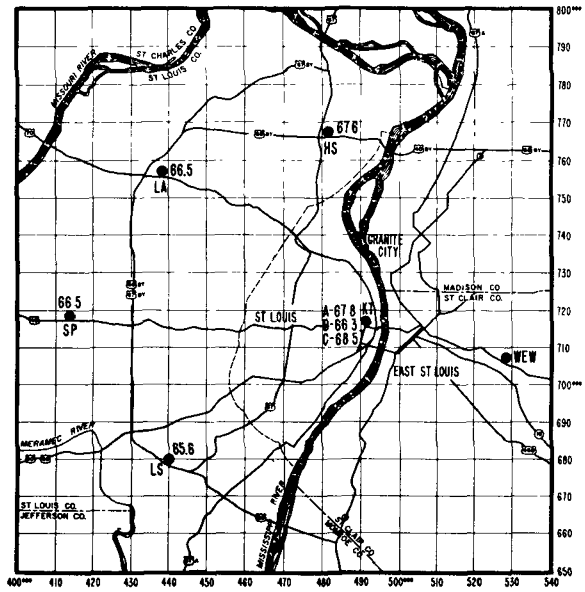


Figure 23. Average minimum temperature for July 1963.

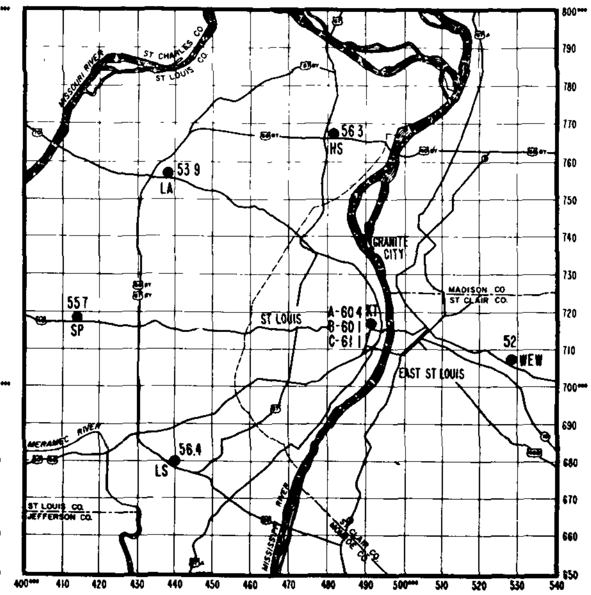


Figure 24. Average minimum temperature for October 1963.

HS–HAZELWOOD SCHOOL	SP–STATE POLICE STATION
LA–LAMBERT AIRPORT	KT–KMOX-TV TOWER
LS–LINDBERG SCHOOL	WEW–RADIO STATION (Oct only)

A OBSERVED MINIMUM TEMPERATURE AT 125 ft ABOVE GROUND

B. REDUCED TO GROUND LEVEL USING AVERAGE LAPSE RATE 125 TO 250 ft

C. REDUCED TO GROUND LEVEL USING ADIABATIC LAPSE RATE

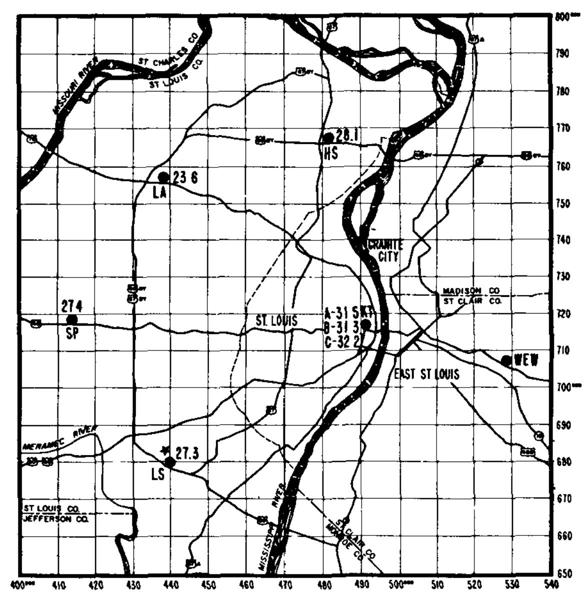


Figure 25. Average minimum temperature for January 1964.

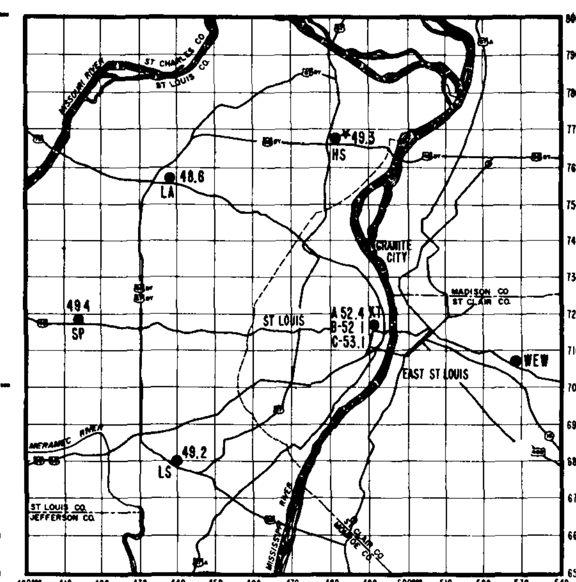


Figure 26. Average minimum temperature for April 1964.

Table 4. EARLY MORNING MINIMUM TEMPERATURES AT 125-FOOT LEVEL ON KNOX-TV TOWER
(Adiabatic Temperatures are Derived From 125-Foot Data for Comparison With Observed Data at Other Levels)

Height above street		Temperature, °F			
		1963		1964	
		July	Oct.	Jan.	Apr.
455 feet	Average, measured	69.5	60.7	31.1	52.9
	adiabatic	66.0	58.6	29.7	50.6
250 feet	Average, measured	69.3	60.7	31.7	52.7[a]
	adiabatic	67.1	59.7	30.8	51.7
125 feet	Average, measured	67.8	60.4	31.5	52.4
		Number of Inversions			
125 to 250 feet		31	23	21	20[a]
125 to 455 feet		26	16	19	22

[a]Data from 1 day were missing.

The heat island itself may be described as a "bubble" of air with a neutral to isothermal lapse rate or weak inversion inclosed in a general inversion, with the inversion layer deep enough to inclose the entire bubble. This is a subjective description, illustrated in Figure 27, and should be verified when possible by actual measurements. Some such measurements are available, but are not sufficiently detailed for a definite description.[8]

The circulation within the heat island itself must be described by inference since suitable measurements are not available. Arnold[12] has already provided a reasonable suggestion for the St. Louis area. The simplest model would be based on two assumptions, (1) a symmetrical warm area, warmer at the center than at the edges, and (2) no overriding wind flow. In this model the warm air would rise in the central area, flow outward along the surface of the bubble, lose heat to the surrounding atmosphere, sink to ground level at the outer edges, and return to the central area along the ground from all directions. This is also shown in Figure 27. There would be some exchange with the surrounding atmosphere due to mixing at the interface, but this would be minimal. This flow pattern would permit pollutants emitted in the central areas to eventually reach intermediate areas from the opposite direction. In reality, variations in terrain and heat sources (a factory might be a "hot spot") would introduce many modifications to this pattern, but it should be expected that pollutants emitted at almost any source within the bubble would reach the central area, and that average concentrations of any pollutant emitted within the bubble would increase with time until the condition is terminated or the source eliminated. A very light wind would perhaps distort the bubble without destroying it.

Termination of such a heat island, or rather the effect of its closed circulation, would come about either upon general warming of the surrounding area suf-

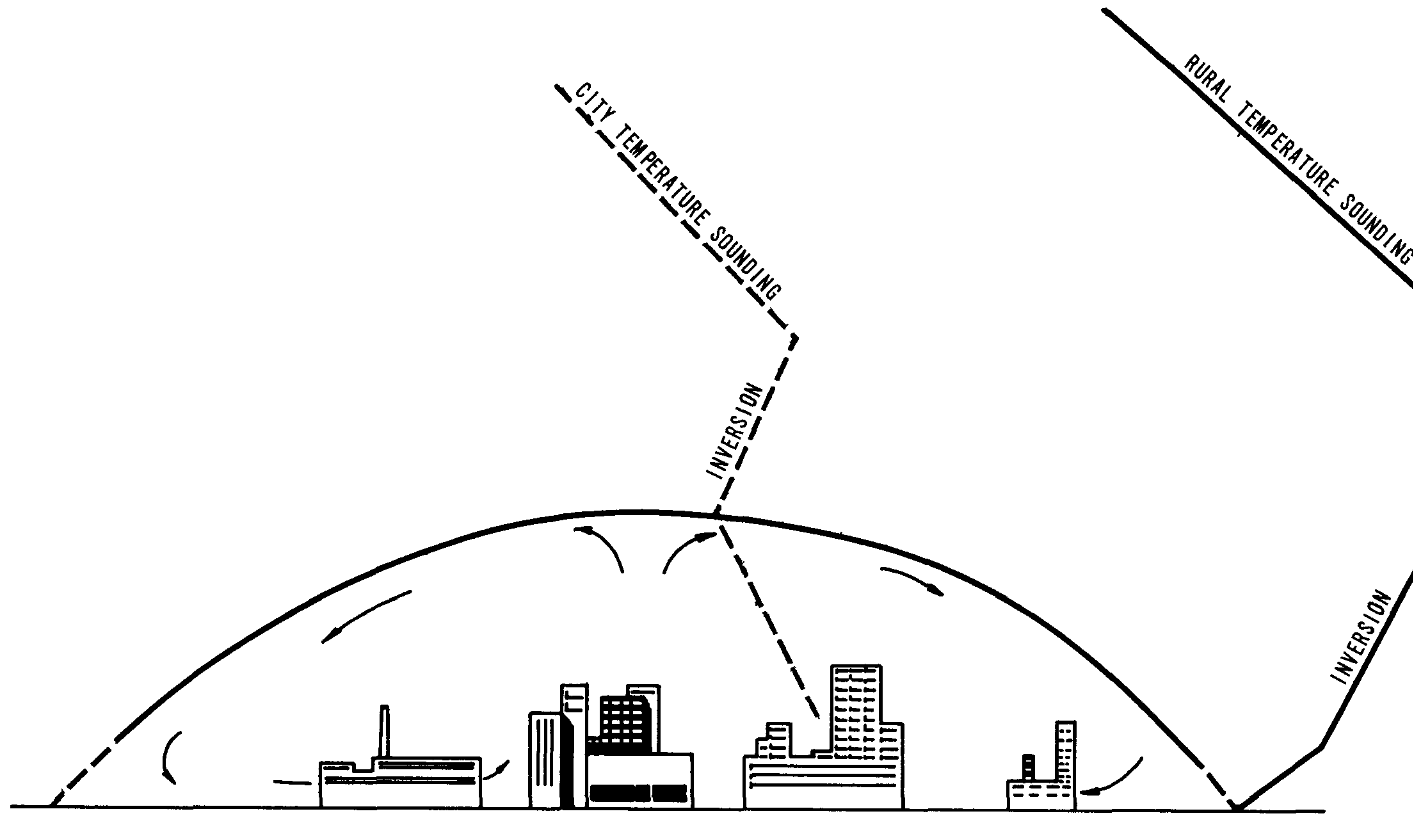


Figure 27. Idealize heat island "bubble," showing movement of air.

ficient to create a neutral or unstable condition, or upon an increase in wind speed sufficient to break down the interface between the more stable and less stable layers.

Topographic Effects

Topography also has an effect on weather conditions. Low-lying areas have consistently lower minimum temperatures than surrounding hills. As air cools and becomes more dense, it settles into low places. When low rural or suburban areas are next to a metropolitan area, this effect becomes dramatic. The American Bottoms across the Mississippi River from St. Louis, is such a low lying area. Inversions in this area are of great frequency and intensity. This local effect has been well discussed, for the fall season, by Dr. G. R. Arnold in his doctoral dissertation.[12]

Dr. Arnold set up an observing site for both temperature and wind at the WEW radio transmitter site, between East St. Louis and Caseyville, Illinois, about 5 miles east of the Mississippi River, and made observations from September 6 to December 6, 1963, inclusive. During this period there were only six dates on which no inversion was detected in observations made at either dawn or dusk.

Ten-degree or greater inversions (where the temperature aloft was at least 10°F warmer than at the surface) occurred on 45 percent of the mornings and 15°F inversions, on 25 percent of the mornings. On one occasion an inversion of 27°F was measured at dawn, and on another, a 17°F inversion was measured at dusk.

Most of these inversions were represented by cold air in the Bottoms. The elevation of the surrounding bluff and hills averages about 200 feet above the Bottoms. Of all the inversions Dr. Arnold measured, about 81 percent of the average temperature increase noted at 500 feet occurred in the first 200 feet, or within the confines of the valley.

The minimum temperature at the WEW site averaged about 7°F lower than at the Customhouse in St. Louis; only once was it as much as 3°F warmer, whereas on 27 occasions it was 10°F or more colder. (December data were not included.)

Evidence of a "counterflow" (wind reversal) was found in both meteorological data and soiling index measurements of suspended particulates. Although "There are no principal sources of smoke either south or east of WEW," by far the greater number of soiling index samples showing high pollutant values were obtained with winds from those directions. Visual observations of smoke from burning dumps or open fires showed the counterflow also. Figure 28 is reproduced from Arnold's treatise to illustrate the counterflow, which is similar to the heat island circulation postulated above.

The juxtaposition of the cold pool of air in the American Bottoms and the heat island of the City of St. Louis thus produces complex wind patterns, the effect of which are to retain effluents in the city and bottom area during night and early morning hours. Dr. Arnold presents seasonal evidence of a quasi-closed circulation within these areas. Unfortunately year-round data are not available, but there is little doubt that this condition occurs, in greater or lesser degree, in all seasons of the year.

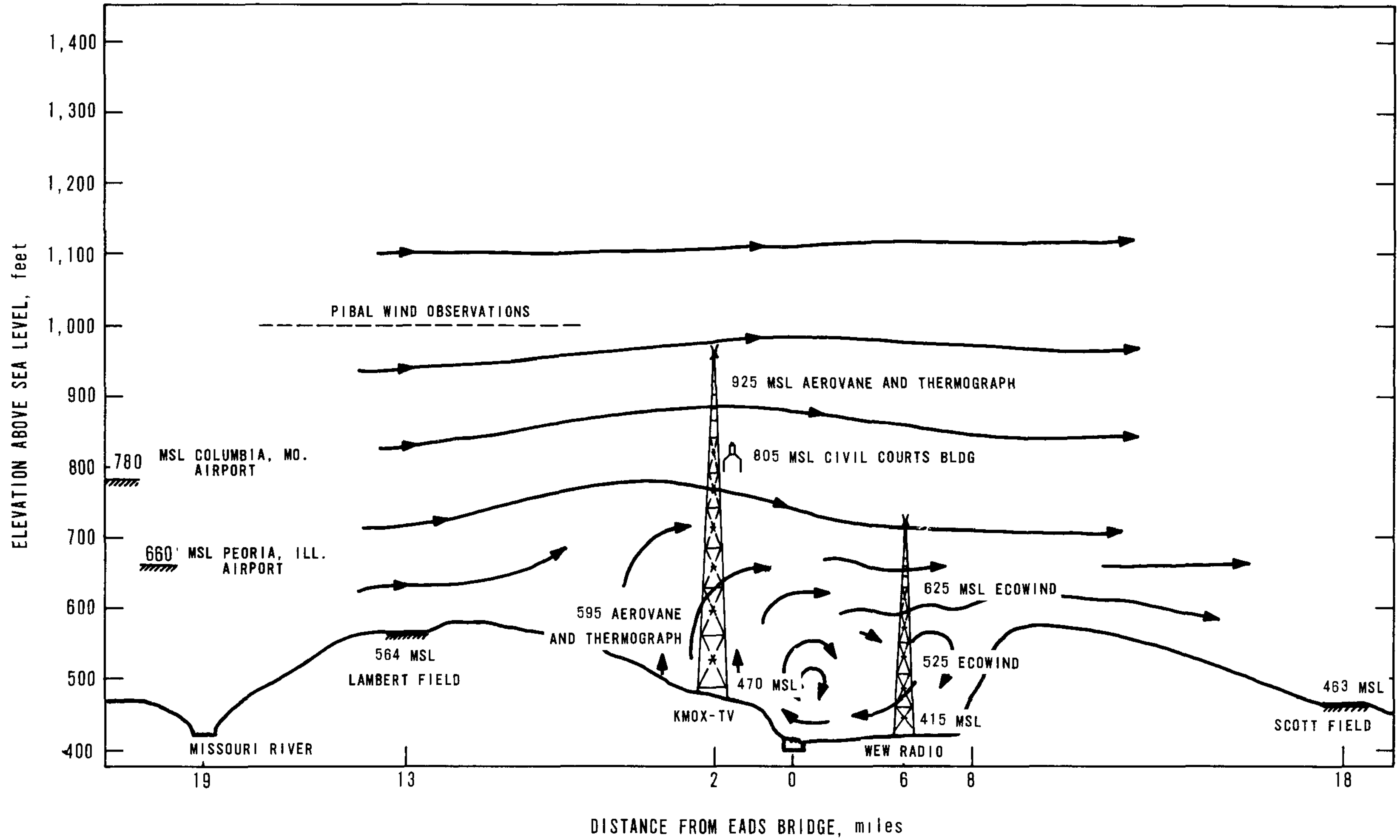


Figure 28. Vortex pattern in American Bottoms (after Arnold[12]).

METEOROLOGICAL INSTRUMENTATION IN THE ST. LOUIS AREA

Figure 29 shows the location of Weather Bureau Offices, Cooperative Climatological Stations, and special meteorological instrumentation sites in the St. Louis area. During the atmospheric dispersion field experiments, special equipment and instruments were used to determine more accurately the character of the atmosphere at low levels. Balloon-borne instruments were used to measure the variation of temperature with height, and pilot ballons were used to measure the variation of wind with height.

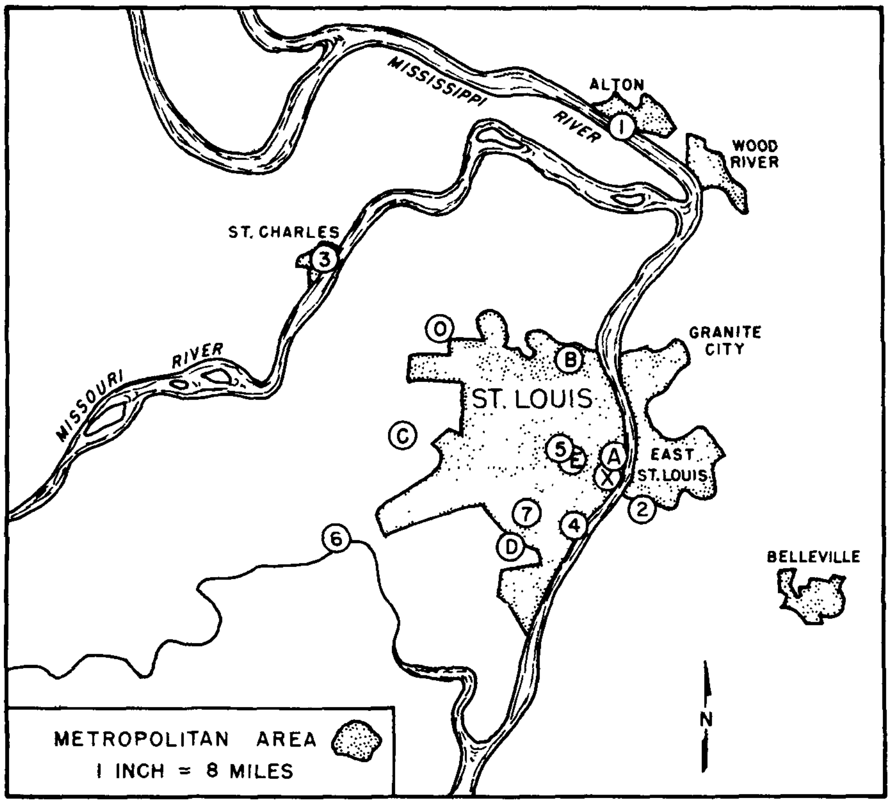
Table 5 lists the location of the Interstate Air Pollution Study meteorological sites and the instrumentation at each.

RESEARCH ASPECTS OF THE STUDY

In connection with the Interstate Air Pollution Study, detailed dispersion studies were conducted by the Meteorology Section, Laboratory of Engineering and Physical

Table 5. METEOROLOGICAL INSTRUMENTATION FOR ATMOSPHERIC DIFFUSION RESEARCH STUDY

Location	Height, ft	Instrumentation
KMOX-TV tower	125	Temperature sensor
		Aerovane (wind direction and speed)
		Anemometer (speed only)
	250	Temperature sensor
		Anemometer (speed only)
	393	Anemometer (speed only)
	455	Temperature sensor
		Aerovane
		Anemometer (speed only)
Hazelwood High School	6	Hygrothermograph
	10 ft above roof	Aerovane
Missouri State Police Radio Tower -	6	Hygrothermograph
Daniel Boone Expressway near Ballas Road	50	Aerovane
Lindbergh High School	6	Hygrothermograph
	10 ft above roof	Aerovane
Forest Park	3	Fluorescent particle dispensing equipment



Location	Instrumentation
1. Alton Dam No. 26.	Recording rain gauge and temperature
2. E. St. Louis Airport	Precipitation and temperature
3. St. Charles	Recording rain gauge and temperature
4. St. Louis River Forecast Center	Precipitation and temperature
5. St. Louis University	Precipitation and temperature
6. Valley Park	Precipitation
7. Webster Groves	Precipitation and temperature
0. Lambert Airport	Complete weather records
X. USWB City Office	Complete weather records
A. KMOX TV Tower	Instrumented for air pollution study
B. Hazelwood High School	Instrumented for air pollution study
C. State Police Radio Tower	Instrumented for air pollution study
D. Lindbergh High School	Instrumented for air pollution study
E. Forest Park	Dispensing site for tracer study

Figure 29. Climatological stations and specially instrumented meteorological sites in St. Louis area.[9,10]

Science, United States Public Health Service. The objective of this study was to describe quantitatively the dispersion of material emanating from various locations near and within an urban area, and to relate the dispersion to the causative atmospheric flow and turbulence.

The dispersion studies were of two types involving different techniques. In one study, fluorescent (tracer) particles were released under various meteorological conditions and their dispersion over the downwind area was measured. In the other study, an inventory of sources of sulfur dioxide was made and the distribution of this pollutant over the city was measured and correlated with meteorological data.

Meteorological measurement sites in Figure 29 provided continuous data, which has been reduced and placed on automatic data-processing cards. When these data are combined with the tracer dispersion data, a mathematical atmospheric dispersion model can be developed. The model itself is an expression relating the various pollution sources throughout the area, both by location and strength, and various meteorological parameters (principally wind direction, wind speed, and stability to the distribution of pollutants). Once completed and tested, the model will be useful in planning for the future, in estimating concentrations to be expected at any place, and in estimating the effect of new sources or changes in existing sources.

Work is not yet completed on dispersion studies. When it is, separate technical papers and reports will be prepared.

Tracer Studies

Studies in which tracer materials are deployed in the atmosphere have been conducted at various times and places over many years. From these studies, atmospheric diffusion coefficients have been determined with a reasonable degree of precision. Most of these studies have been over open and level countryside, and their applicability to the relatively complicated features of an urban area is not straightforward.

The initiation of the Interstate Air Pollution Study made it possible to conduct tracer studies over an urban area at minimum expense because of the facilities and equipment on hand. Additional meteorological instrumentation was installed on the KMOX-TV tower downtown, at Lindbergh High School, Missouri State Police Station C, and Hazelwood High School--all on the periphery of the urban area. Samplers were placed along seven arcs centered on two release points, Forest Park for use with westerly winds, and the Knights of Columbus Building at Grand and Potomac for southeasterly winds. These sites and the sampling arcs are shown in Figure 30. Over 300 sampling sites were selected; 30 to 50 were used in each experiment. They included trees, utility poles, public buildings, residences, and commercial structures.

The tracer material used was zinc cadmium sulfide, a fluorescent compound. Particle diameters ranged from 0. 5 to 5 microns and averaged about 3 microns (about 1/10, 000 inch). Particles of this size settle so slowly and respond so readily to random molecular motions in the air that their dispersion may be considered the same as that of a gas for studies of this type. Samplers were of three types: (1) rotorod samplers, consisting of an H-shaped collector rod kept spinning by a battery-

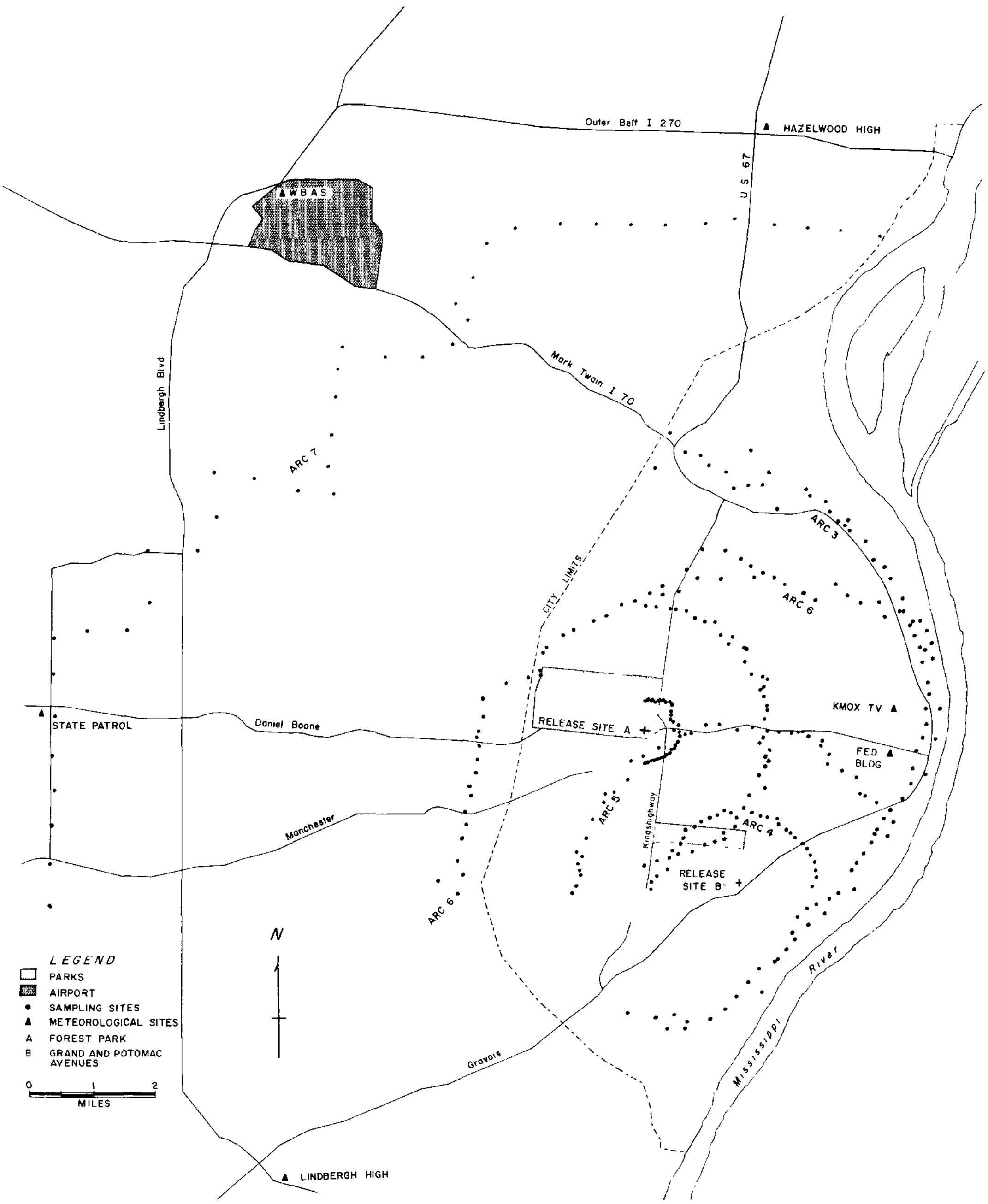


Figure 30. Sampling site locations used in tracer study.

powered motor (uprights were about 1/70 inch broad and 1-1/5 inches high, of metal with a light coating of silicone grease, and spinning on a radius of about one and one-fifth inches at 2,400 rpm); (2) membrane filter samplers, in which air is drawn through a membrane filter at a predetermined rate by an electrically-powered vacuum pump; and (3) a drum pulsed-sampler, in which air is drawn through a slit-orifice at a predetermined rate and impinges upon a metal drum (coated lightly with silicone grease), which rotates by 3-degree steps at variable but controlled intervals. The first two samplers provide estimates of total exposure to the cloud of particles (dosage), whereas the drum provides an estimate of the density of the cloud at various times as it passes over the sampling point.

In addition to the fixed meteorological network (Figure 30), a wind recorder was operated and pilot balloon observations were taken at the tracer release site. The wind recorder provided a continuous record of wind speed and direction near the ground, and the pilot balloon observations provided a measurement of the vertical variation of wind speed and direction at a particular time. Transponder-equipped tetroons[13] were released from the tracer release site during each experiment and followed by use of the Weather Bureau radar at Lambert Airport. Tetroons float at a predetermined height above ground and show visually where a parcel of air is going. Thus they enabled the research crew to follow the cloud of invisible particles. The transponder is an electronic device that enables a radar operator at a considerable distance to follow the tetroon by eliminating interfering radar echoes from buildings and other fixed objects. The radiosonde provides a record of the rate at which temperature and relative humidity change with altitude, and thus an estimate of atmospheric stability at the time of observation. Other meteorological data were obtained during many releases by radiosonde ascents, either free or tethered from the roof of the Federal Building at 12th and Market Streets. Tethered balloons were also used to carry Rotorod samplers to elevations of about 1,000 feet to obtain vertical profiles of the tracer cloud during 17 releases.

Seven series, totaling 43 experiments, were conducted between May 1963 and March 1965.

Limited assays of the sampling results were made during each test series to correct any obvious deficiencies in the sampling layout or procedures. After each test series, all samples were sent to Metronics, Inc. in Palo Alto, California, for actual sample assay. From 3 to 6 months was required to complete the sample counting and checking. These assay results, expressed as number of particles per sample, were analyzed together with the meteorological data to determine the dispersion patterns obtained under various meteorological conditions.

Examples of the results for two quite different conditions were selected for illustration. The ninth experiment, a release from Forest Park, was run during midday on September 12, 1963. The wind was blowing steadily and briskly from the northwest, and the pattern of concentrations was the reasonably familiar elongated ellipse (Figure 31), with the concentrations decreasing rapidly with distance from the source. In this case, all the various measurements of wind direction (the three outlying sites, two levels on the KMOX tower, the pilot balloon observations, the surface winds recorded at the release site, and the tetroon trajectory) were within 15 degrees of the mean direction of the tracer. The measured wind speeds, allowing for local differences due to differing instrument exposures, were also consistent and gave a good indication of the speed of travel of the tracer. Figure 32 shows the cross-plume concentration of particles in this experiment. The mean path of the tetroon clearly indicates the centerline of the cloud of particles. Figure 33 shows the time required for the cloud of particles to reach each sampling arc in the same experiment, and the duration of its passage at each arc. These data are from specific drum-type samplers, and the multiple peaks shown for the first two samples are undoubtedly due to the shifting of the cloud pattern in fluctuating winds. The time required for the tetroon to reach the sampling arc corresponds well with the time at which measurable concentrations were first in evidence.

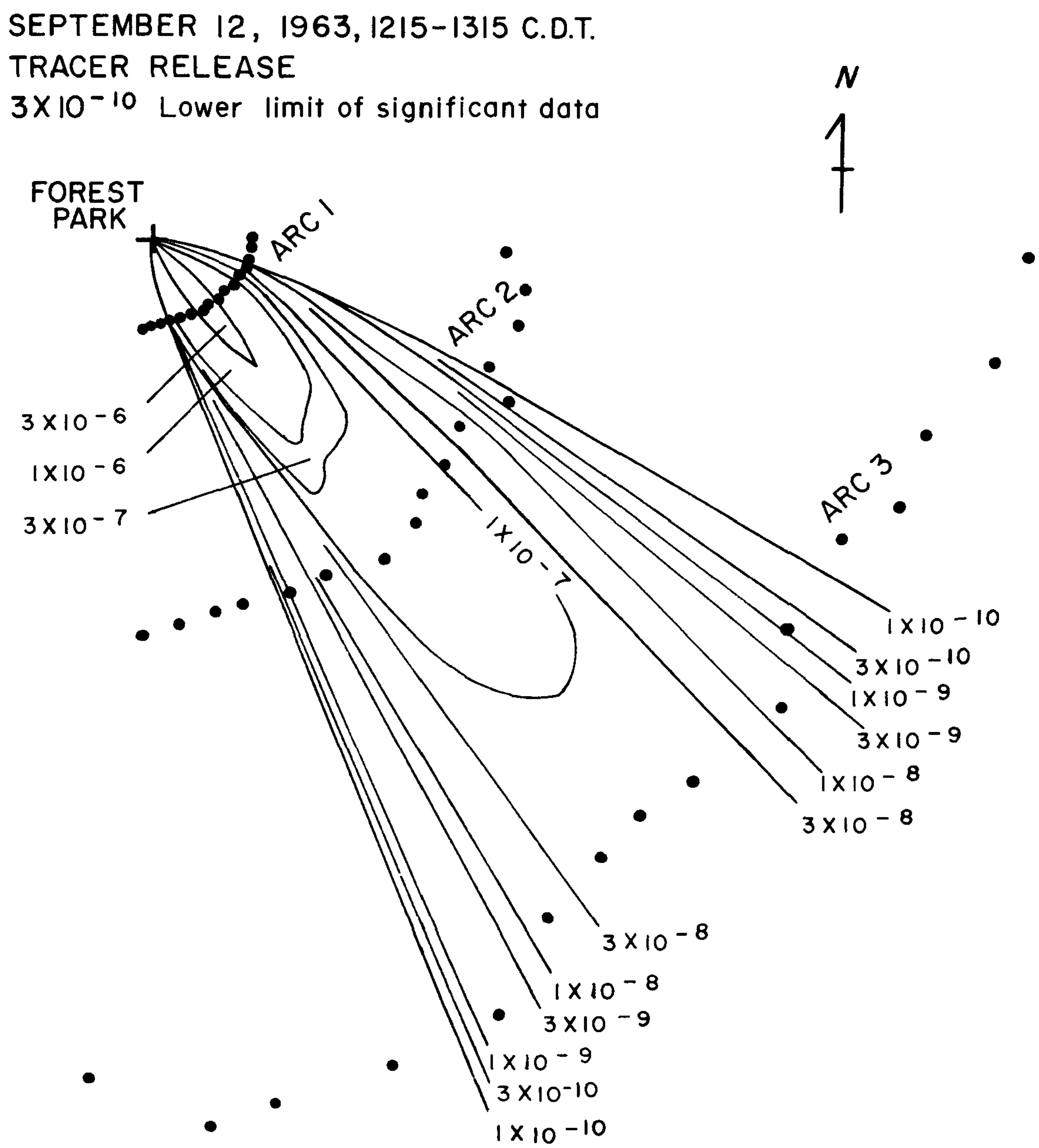


Figure 31. Pattern of relative concentration, in grams per cubic meter, for a daytime tracer experiment with steady winds (Concentrations based on emission rate of 1 gram per second).

To use dispersion data, a term must be found to describe the distribution of pollutants in a cloud or plume. Such a term is the statistical standard deviation (σ), defined as ". . . a number. . . which seems to measure the relative extent to which data are concentrated about the mean and which becomes larger as the data become more dispersed."[14] The value of this term, in both the horizontal (σ_y) and vertical (σ_z) planes as obtained from the above experiment is illustrated in Figure 34. In both planes the increase of σ with distance is clearly indicated.

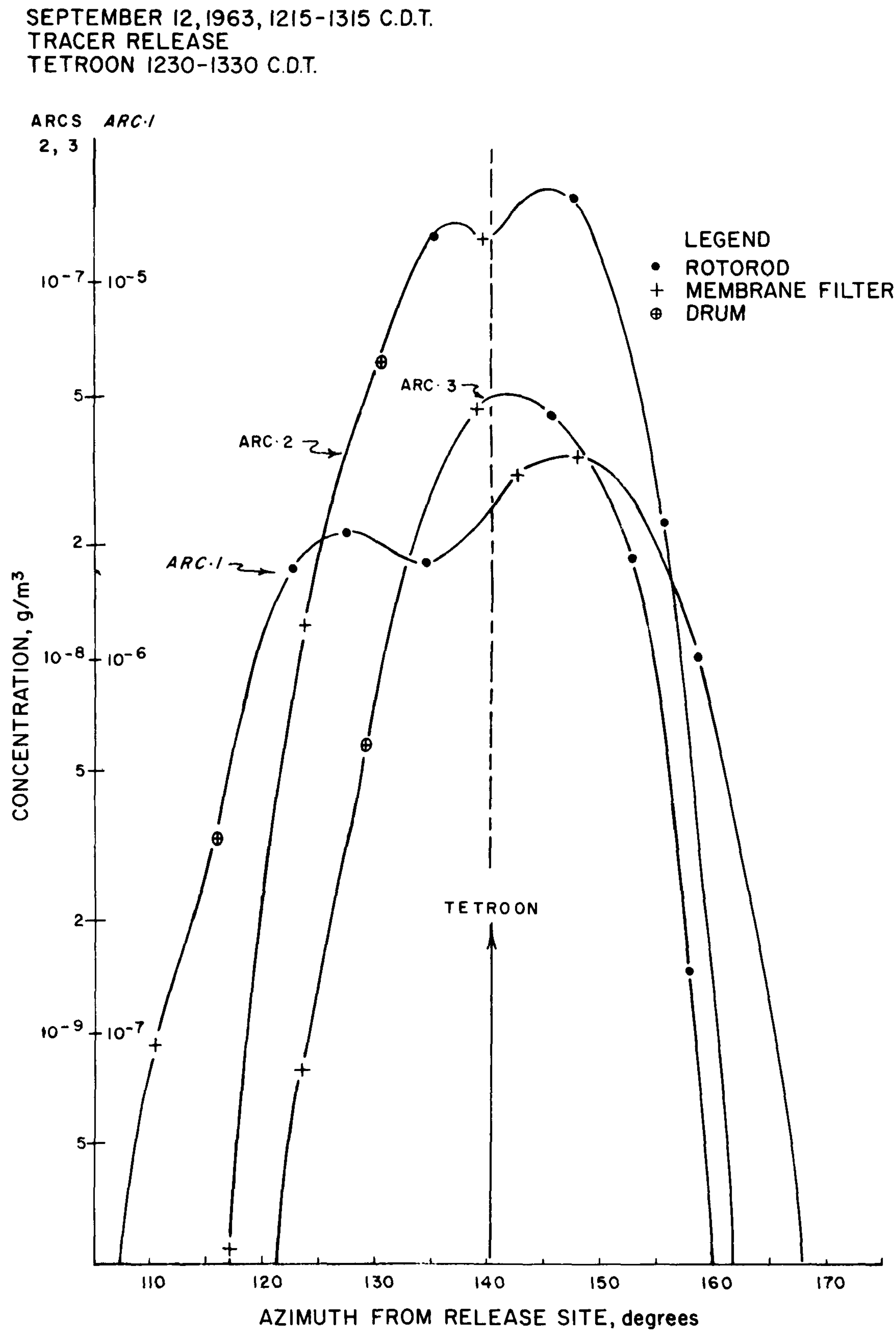


Figure 32. Crosswind relative dosage distributions along three sampling arcs, and mean direction of tetroon travel.

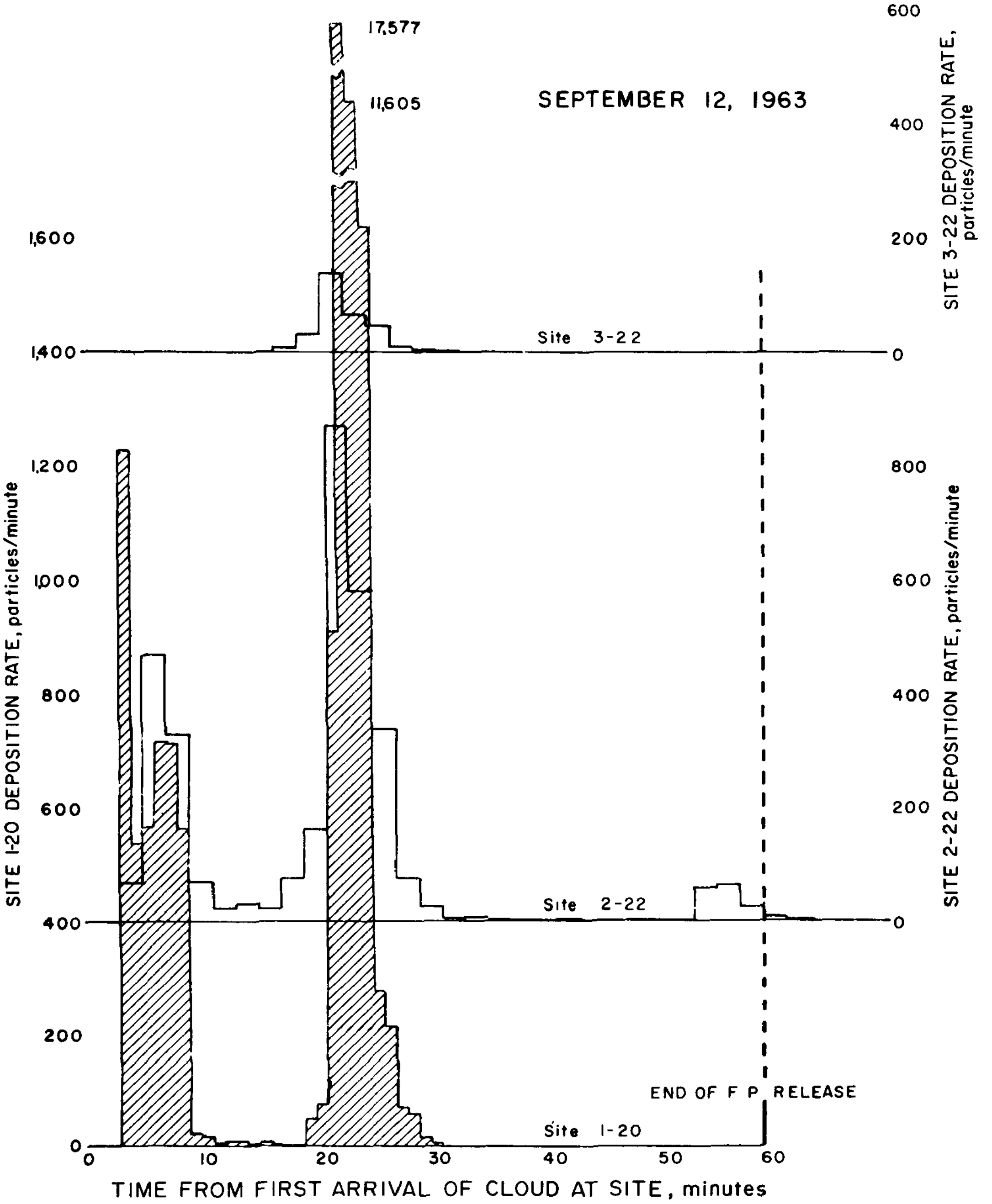


Figure 33. Sequences of dosages at three sites at approximately the same azimuth from tracer release site (Abscissa is adjusted for travel time to each sampling site according to mean tetroon speed).

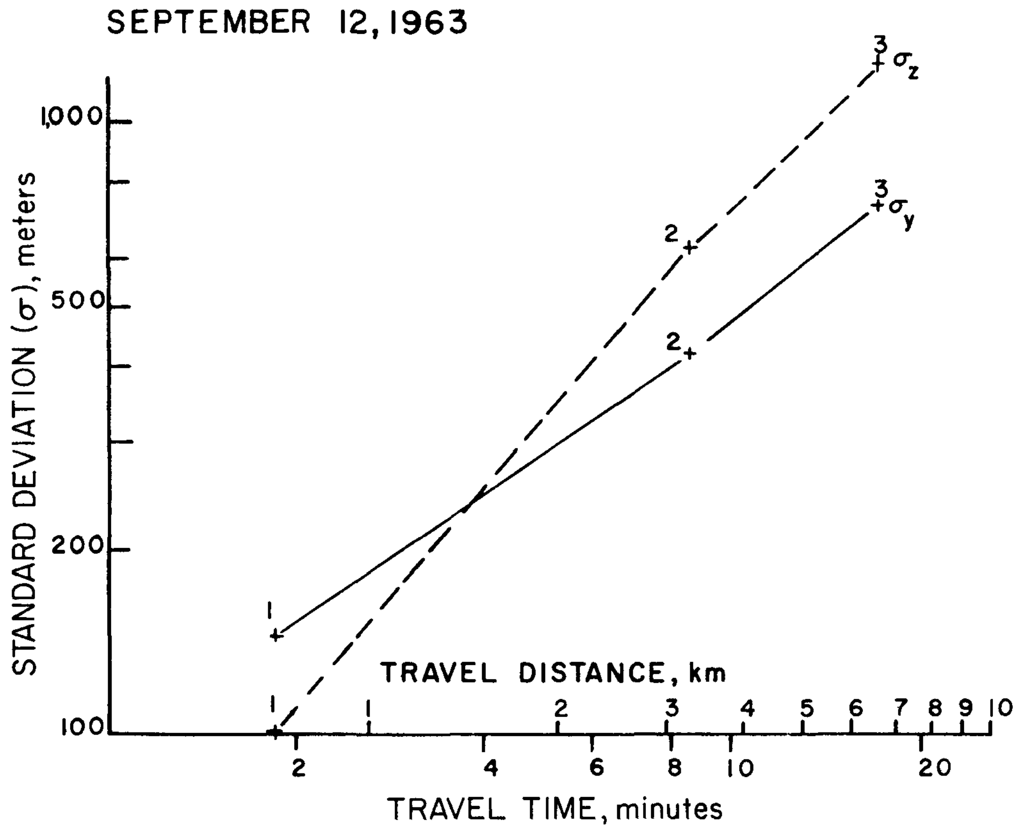


Figure 34. Measured crosswind standard deviations (σ_y) and derived vertical standard deviations (σ_z) of tracer distribution.

The 13th experiment, a release from the Knights of Columbus Building, was run during the evening of September 18, 1963, under considerably different meteorological conditions. The winds were much lighter than during the ninth experiment, and the observed wind directions varied considerably, both spatially and temporally. The overall picture was of a light easterly flow near the surface, veering to southerly or southwesterly as the southerly or southwesterly flow initially aloft worked down to the surface from higher elevations. A heat island flow, directed toward the more built-up parts of the city, was superimposed on the easterly flow, and the easterly flow itself decreased to yield essentially a calm at the surface before the southerly flow from aloft took over. It may be inferred from the wind data that at least the later portion of the tracer release drifted toward the west of the release site in an elongated cloud and stagnated. The upper parts of the cloud were gradually eroded away by the southerly flow aloft. With the arrival of the southerly flow at the surface, the remainder of the cloud moved away normal to its long axis and provided the bulk of the measured dosages over most of the sampling array (Figure 35).

Although some of the samplers probably were turned off while this drifting cloud was still passing the sampling sites, the shape of the dosage pattern shown is considered valid. The total (crosswind) dosage from this cloud, with any reasonable assumptions about the vertical extent of the cloud and its speed of translation, is low, however, in comparison with the total amount of tracer released.

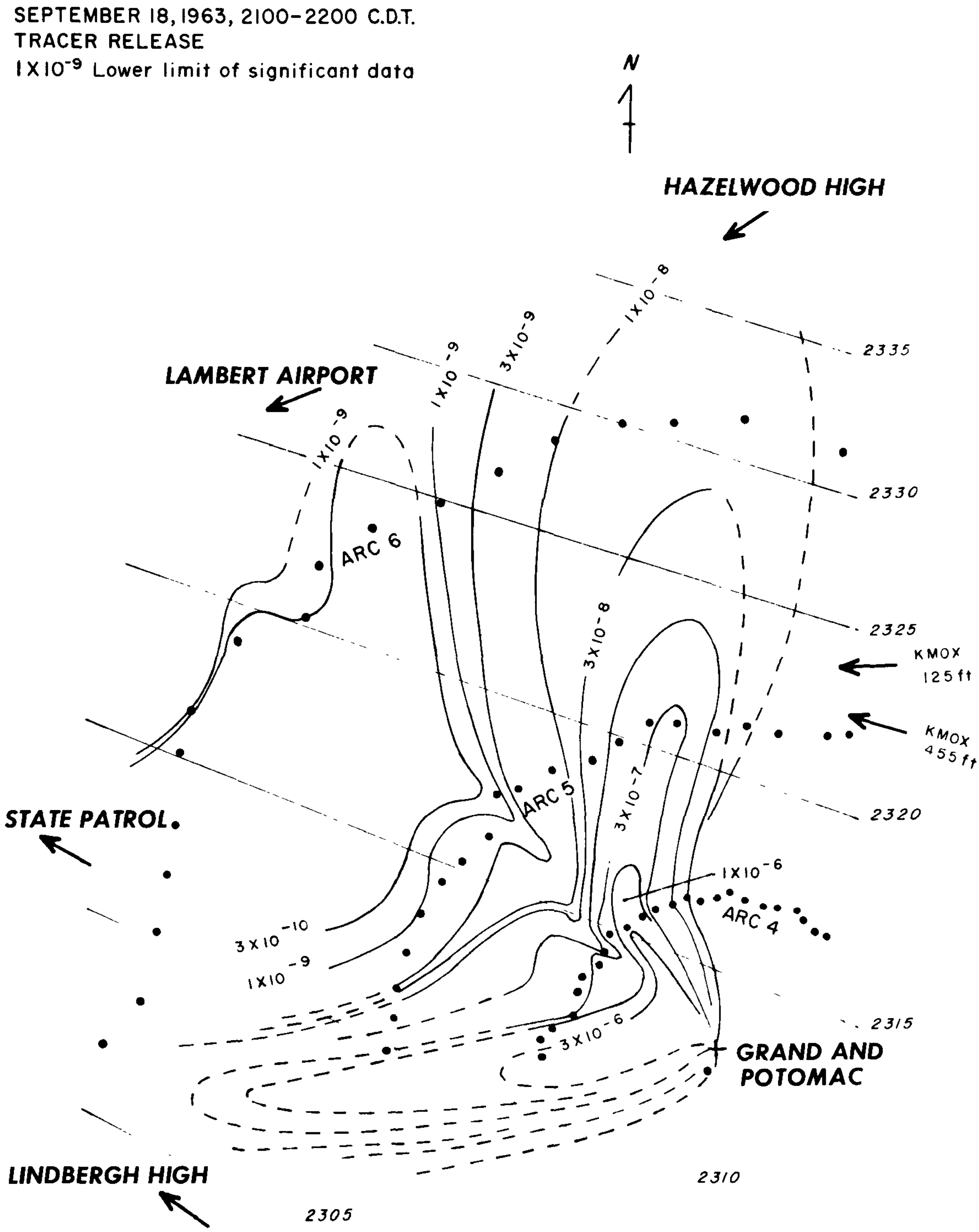


Figure 35. Pattern of relative concentration, in grams per cubic meter, for an evening tracer experiment with light and shifting winds (Arrows indicate mean wind directions at meteorological sites during time of tracer release. Thin solid lines indicate time when surface winds shifted from easterly to southerly, interpolated from meteorological sites).

Two aspects of the travel of the tracer may contribute to this apparent "loss" of material. First, an appreciable transport of the material within the southerly flow aloft must have occurred before the cloud at the surface passed; the sampling results indicate that the passage of the cloud aloft was of a duration comparable to the transit time of the surface cloud. Second, the earlier portion of the tracer release probably was carried westward around the end of the sampling arcs, and subsequently was carried northward a few miles west of the most distant arc, so that very little dosage from this portion of the release was observed anywhere.

With such a complex pattern of flow, there is no "standard" diffusion equation for which coefficients can be derived. Indeed, it is impossible to define a "mean wind direction" or a "mean wind speed," and it appears that the sampling results rather poorly define the geometry of the entire tracer cloud. Weather situations similar to this case are of more than routine interest, however, because situations like this are the type that lead to high concentrations of air pollutants. Any attempts to trace sources of pollutants with such a complex flow pattern are likely to be frustrating and inconclusive.

REPRESENTATIVENESS OF METEOROLOGICAL CONDITIONS DURING THE SURVEY

Since dispersion and, to some extent, emission of atmospheric pollutants are strongly dependent upon meteorological conditions, in a study of air pollution levels one must know whether meteorological conditions are representative of those usually encountered. With this knowledge one can estimate the concentrations that may be expected under average conditions and under other conditions as well.

Data used in the following discussion are from surface observations at Lambert Field and from temperature sensors mounted on the KMOX-TV transmitting tower in downtown St. Louis. Data are for the period beginning July 1, 1963, and ending June 30, 1964.

Surface Wind

The average wind speed for the year of the study was 10.0 mph, 0.7 mph in excess of the normal. Of 9 months showing an excess over normal, 4 were at least 10 percent above, and 3 of these were around 20 percent above normal. The remaining 3 months were below normal, although in no case by as much as 10 percent. The monthly variations of average wind speed and the normal values are shown in Figure 36. With the exception of March, April, June, and July, wind speeds were such that average concentrations of pollutants for the month should be considered representative, as far as the effect of wind speed alone is considered. For these 4 months, however, the measured values should be considered to be below average.

Wind roses are shown for July and October 1963, and for January and April 1964 in Figures 37 through 40, which correspond to the normal roses in Figures 6, 5, 3, and 4, respectively. In each case an excess frequency of winds from the southeasterly to southerly directions is noted, as is a deficiency in winds from the northwesterly to northerly directions and, except in January, a lower than normal frequency of calm hours. In many cases a greater-than-normal frequency of winds of the higher speed groups can be noted. Since the east-to-west and west-to-east

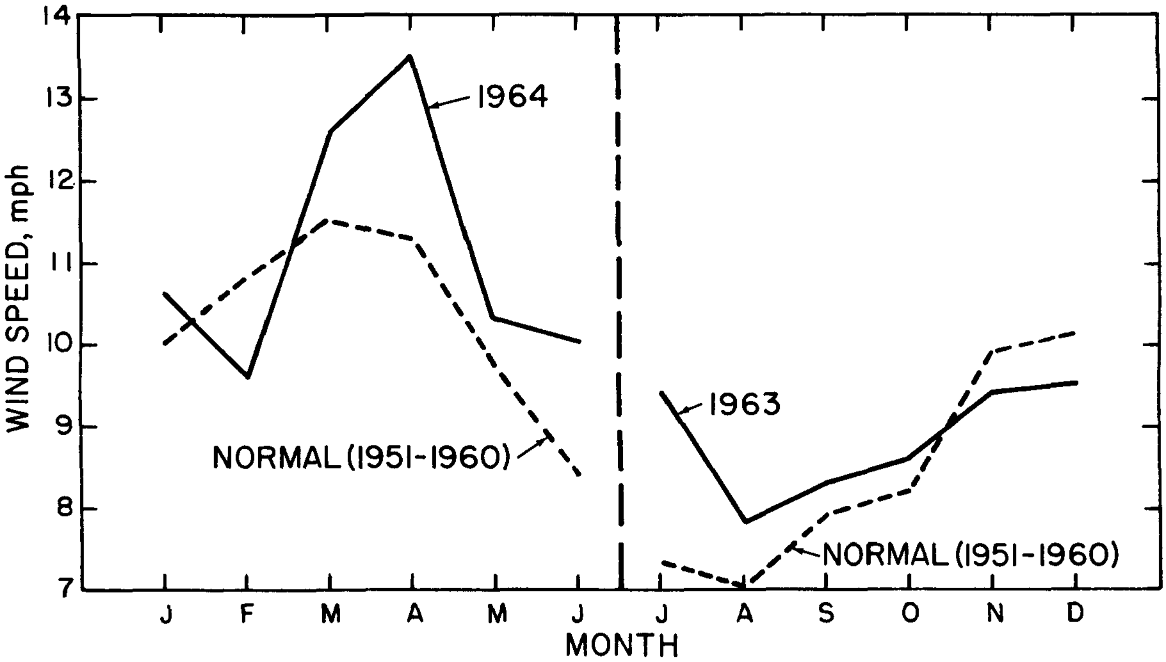


Figure 36. Average hourly wind speeds, Lambert Airport.

transport of pollutants is of interest because of the interstate air movement, the normal wind roses and wind roses for the study period were compared by cardinal sectors with some emphasis on the east and west sectors (Table 6). The frequency of all winds in these two sectors was very near normal except for deficiencies in October 1963 (west) and January 1964 (east). The frequency of low wind speeds (7 mph or less), however, was much below normal except for westerly winds in January 1964; the frequency of speeds of over 7 mph was near normal for westerly winds and appreciably above normal for easterly winds. Since pollutant concentrations generally bear an inverse relationship to wind speeds, it appears that for

Table 6. RELATIVE FREQUENCY OF WIND BY DIRECTION AND SPEED[a]

Direction[b]	Calm	North			East			South			West		
Speed[c]		All	> 7	≤ 7	All	> 7	≤ 7	All	> 7	≤ 7	All	> 7	≤ 7
January 1964	4.1	0.5	0.5	0.4	0.8	1.2	0.3	1.4	1.5	1.0	1.0	1.0	1.0
April 1964	0.2	0.5	0.4	0.7	1.0	1.3	0.4	1.2	1.4	0.2	1.0	1.1	0.5
July 1963	0.1	1.0	2.0	0.5	1.1	1.8	0.6	1.2	1.7	0.4	1.1	1.1	0.6
October 1963	0.7	0.7	0.6	0.8	1.1	1.4	0.8	1.6	1.8	1.2	0.7	0.8	0.7

[a] Tabular figures are the ratio of occurrences in the specified month to the average number of occurrences in the same month during the period 1951 - 1960.
[b] Directions are grouped by quadrants: N includes NNW and NNE; E includes NE through SE; S includes SSE and SSW; and W includes SW through NW.
[c] Speeds included are: All, all reported values not including calm; > 7, all occurrences of over 7 mph; and ≤ 7, all occurrences of 1 to 7 mph, inclusive.

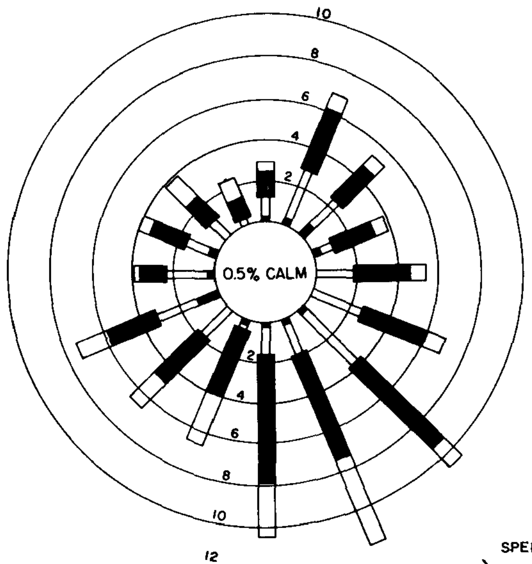
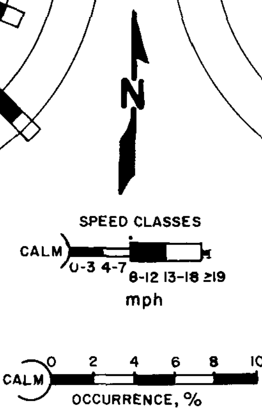


Figure 37. July 1963 surface wind rose for Lambert Airport.



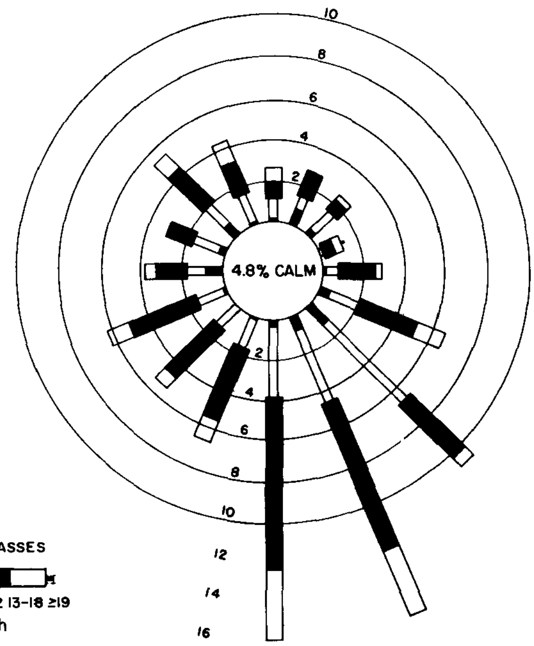


Figure 38. October 1963 surface wind rose for Lambert Airport.

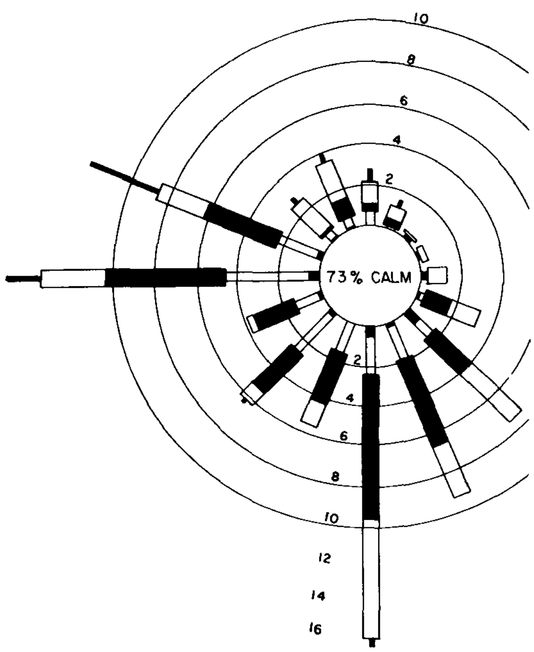


Figure 39. January 1964 surface wind rose for Lambert Airport.

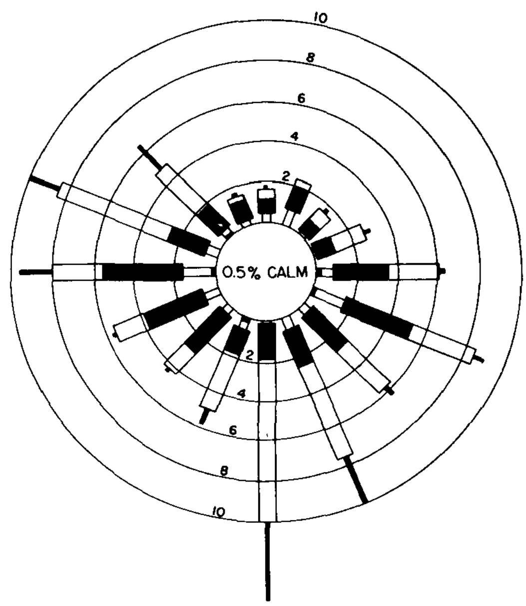


Figure 40. April 1964 surface wind rose for Lambert Airport

these 4 months, at least, east-west or west-east transport concentrations should have been below average.

In evaluating the wind roses for January and April, an additional factor must be considered. On January 1, 1964, the method of recording wind direction at airport stations was changed from entry by compass directions to entry by tens of degrees in azimuth. In adjusting these data, recorded for 36-directions, to the 16-point wind rose of previous data, a slight bias in favor of the cardinal directions (N, E, S, W) is introduced at the expense of adjacent directions. This bias, however, is much too small to account for the excessive frequency of south winds in January and April, or of the west wind in January (Table 7).

Wind Data for Pollution Roses

Since atmospheric pollutants are carried by air currents, relating their occurrence or concentration to wind speed and direction is a common practice, usually illustrated in the form of a "pollution rose." When the site at which wind data are obtained is considerably removed from either sources or receptors of air pollution a question arises as to its applicability. In the Interstate Air Pollution Study, measurements are available at Lambert Airport, Hazelwood High School, the State Police radio tower on the Daniel Boone Expressway, Lindbergh High School, and the KMOX-TV tower at two levels (Table 5). Of these only the airport location can be considered permanent.

Of the five locations listed, the most centrally located is the KMOX-TV tower. The two wind direction instruments on the tower are at 125 and 455 feet above street level (Table 5). Unfortunately neither instrument produced a complete record. For comparison with Lambert Field data wind roses for both levels on the KMOX-TV tower were prepared for the months of July and October 1963 (Figures 37-40), and January and April 1964 (Figures 41-48). The months of October and April are particularly deficient, with only 480 and 350 hours of data, respectively, for the upper level and only 649 hours of data for the lower level in April. The other data are complete enough, however, to provide a qualitative rose for comparison. The two highest speed classes used for airport data are combined into one for the tower data. The roses are generally similar with one pronounced exception. Compared with October airport data, the lower tower level shows a very marked excess of winds from west through northwest, and an equally marked deficiency of winds from east-southeast through south.

A more detailed and valid comparison can be made by use of Table 7, where total occurrences from each direction are expressed in percent of valid data for each of the three records. Because of the method of recording data, a slight bias is introduced. Lambert Airport data for July and October 1963 are recorded to 16 points; all other data used here are recorded to 36 points and converted to 16 points by combinations that group three points into one for the cardinal directions and two points into one for other directions. The presence of this bias should be recognized, though its effects are small enough to be disregarded here.

Of more interest where very local circulations are concerned is a difference in pattern between the two tower levels. For the 2 months with relatively complete records, the lower level shows an excess of winds from the easterly quadrant and a deficiency from the westerly quadrant (Table 8). Though based on incomplete

Table 7. COMPARISON OF WIND DIRECTION RECORDS FROM KNOX-TV TOWER AND LAMBERT AIRPORT - PERCENT FREQUENCIES

	July 1963			Oct. 1963			Jan. 1964			Apr. 1964		
	Tower*		Airport	Tower		Airport	Tower		Airport	Tower		Airport
	U	L		U	L		U	L		U	L	
N	2	5	3	9	5	3	4	4	3	1	0	2
NNE	4	5	7	8	4	3	3	2	1	2	1	2
NE	7	8	5	4	3	3	0	1	0	3	2	2
ENE	6	5	4	3	5	1	1	2	0	4	5	3
E	5	4	4	3	3	3	1	1	1	5	6	6
ESE	4	5	7	1	2	7	0	3	3	3	5	9
SE	3	8	11	3	3	11	2	5	8	1	5	6
SSE	11	13	12	2	5	15	13	10	9	5	7	10
S	22	18	11	18	8	16	23	22	17	22	17	13
SSW	10	7	7	21	9	7	7	7	6	15	11	6
SW	8	8	7	12	12	5	9	8	6	8	9	5
WSW	5	2	7	8	5	6	11	9	4	7	7	6
W	4	5	4	3	12	4	13	13	15	9	9	10
WNW	3	2	4	0	18	3	6	4	12	10	5	10
NW	3	2	4	1	10	5	3	1	3	3	5	6
NNW	3	3	3	4	3	4	3	4	4	0	4	2
C	0	0	0	0	1	5	1	2	7	0	0	0
Total observations	731	734	744	480	739	744	712	743	744	350	649	720

*U, upper level; L, lower level

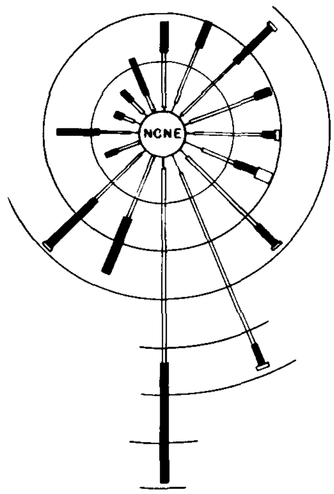


Figure 41. July 1963 wind rose for lower level of KMOX-TV tower, 734 observations.

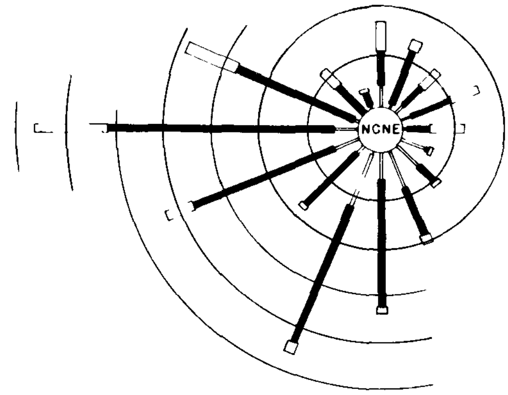
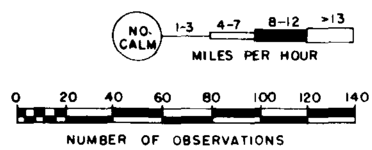
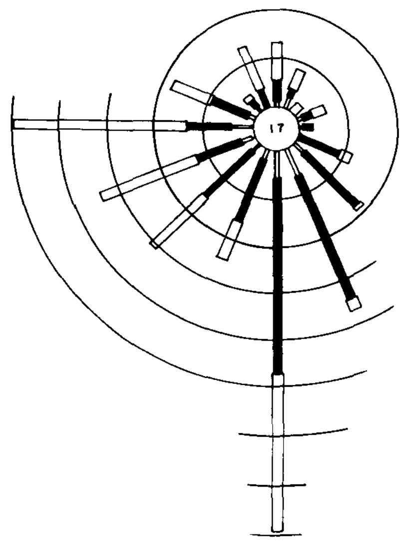
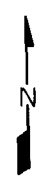


Figure 42. October 1963 wind rose for lower level of KMOX-TV tower, 739 observations.







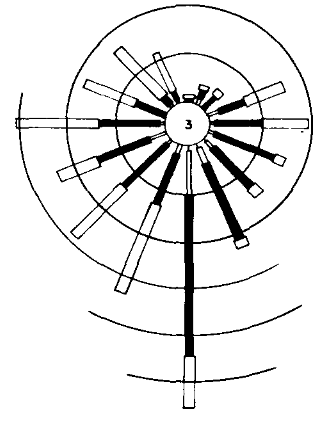


Figure 43. January 1964 wind rose for lower level of KMOX-TV tower, 743 observations.

Figure 44. April 1964 wind rose for lower level of KMOX-TV tower, 649 observations.

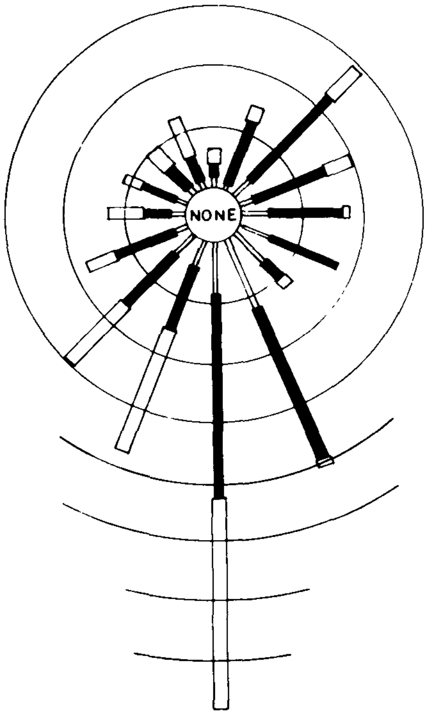


Figure 45. July 1963 wind rose for upper level of KMOX-TV tower, 731 observations.

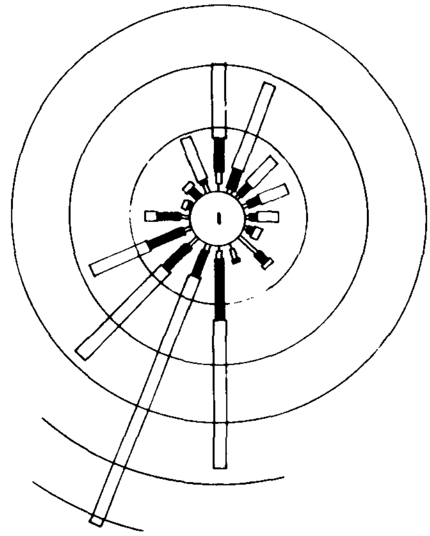
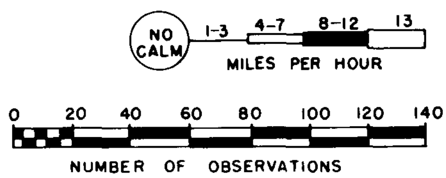
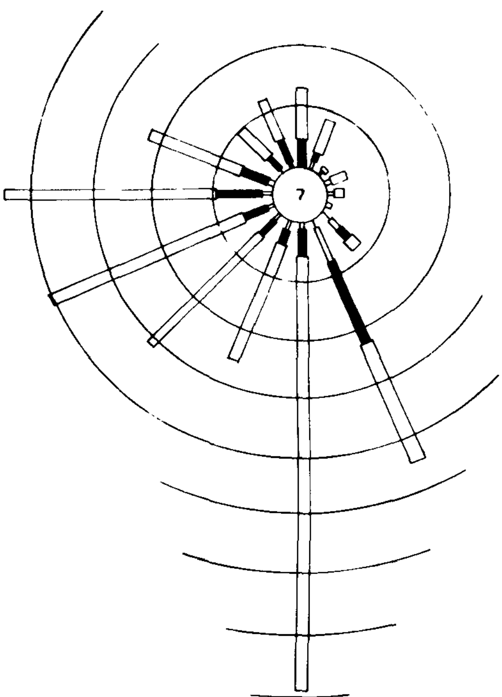
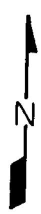


Figure 46. October 1963 wind rose for upper level of KMOX-TV tower, 480 observations.







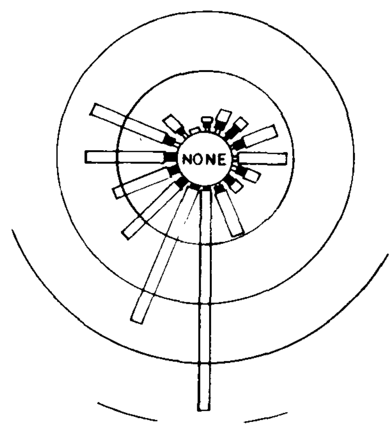


Figure 47. January 1964 wind rose for upper level of KMOX-TV tower, 712 observations.

Figure 48. April 1964 wind rose for upper level of KMOX-TV tower, 350 observations.

Table 8. NUMBER OF OCCURRENCES OF WIND DIRECTION FROM EAST AND WEST QUADRANTS, KNOX-TV TOWER

	July 1963		Jan. 1964	
	Lower	Upper	Lower	Upper
040° - 140°	215	182	89	36
220° - 320°	138	164	268	299

data for the upper level, an even more pronounced excess of west to northwest and deficiency of south and south southwest winds existed at the lower level in October 1963, according to Table 7. These effects are almost certainly due to the presence of the city and its action as a heat source.

The value of a pollution rose is dependent upon both its purpose and the data used in preparing it. To relate a specific source and a specific receptor, wind data should be obtained in the immediate vicinity from an instrument so located as to indicate motion between source and receptor. Even then, care must be taken to avoid possible eddies induced by nearby buildings or strong heat sources. Wind roses (Figures 41-48) and tabular comparisons (Tables 7 and 8) indicate that the tower data are influenced by local effects. Whether these effects influence only one or both levels cannot be determined from the data. The presence of the tower itself creates eddies reflected in the records as erroneous direction and/or speed information. These errors vary with both speed and direction and cannot be accurately assessed. The instruments at Lambert Airport, on the other hand, are well away from any terrain or heat island effects. In addition, the data are uninterrupted and there is assurance of continued operation. The records should be as representative of the general flow as can be obtained. Thus, for the overall study, and for future reference, the use of Lambert Airport wind data for constructing pollution roses is preferred.

Wind records from the other three locations are from temporary installations and also have periods of missing data. In addition, they are no more centrally located with respect to the areas of important sources and most affected receptors than is the airport. They were intended for use in the tracer studies (as were the KMOX-TV tower records); and although of possible application in a neighborhood problem, they are not suitable for use for overall pollution roses.

Temperature

Monthly degree-day totals for the study period are compared with normal totals in Figure 49. In most months of this study heating requirements appeared to be near normal. In October, requirements were about 65 percent below normal; however, December of 1963 was the coldest December of record in St. Louis, and heating requirements were about 145 percent of the normal for the month.

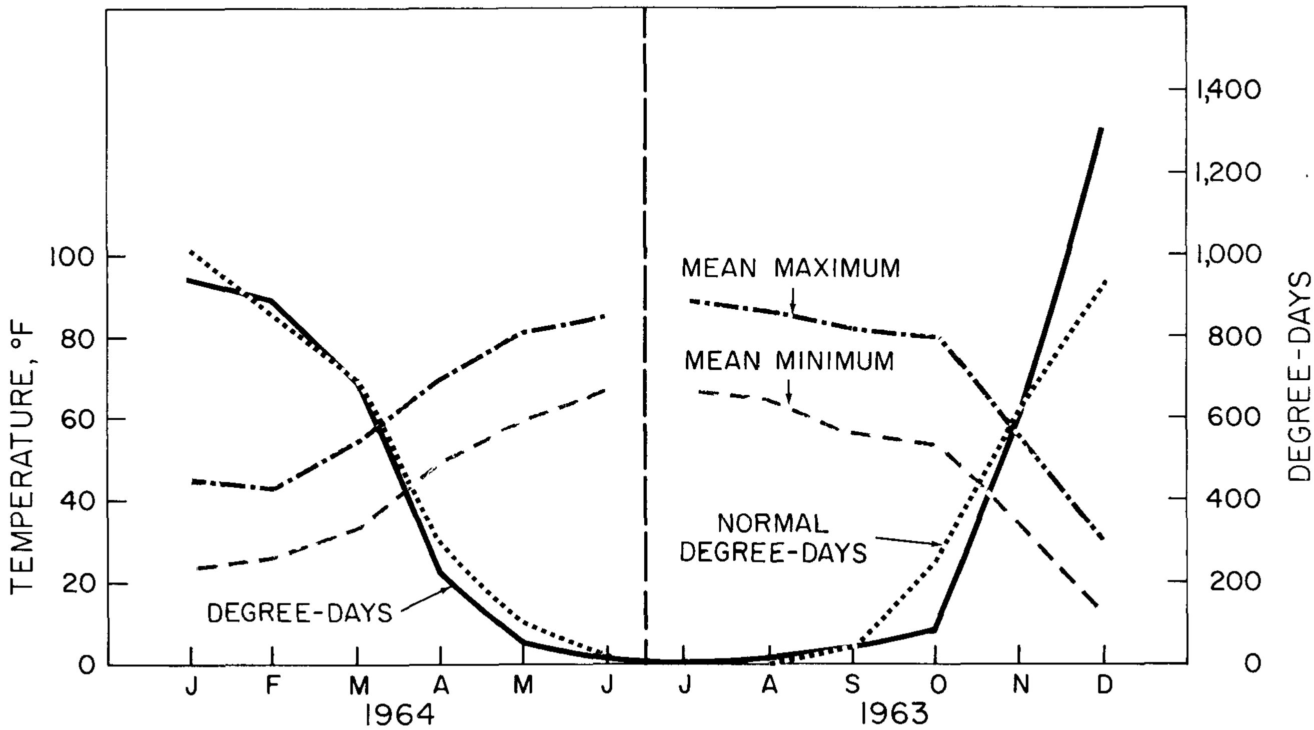


Figure 49. Monthly mean maximum and minimum temperatures, and monthly normal degree-days at Lambert Airport from July 1963 through June 1964.

Precipitation

Rain and snow are of interest in air pollution because of their effectiveness in reducing the pickup of dust particles from the earth's surface by the wind. A minor effect is the washout or scrubout of some particulate by rain or snow as they fall. Days with measurable precipitation and total monthly precipitation amounts are shown in Figure 50. The number of thunderstorm days is also shown. The occurrence of a thunderstorm signifies unstable air, usually at or near the surface, and consequently good dispersion conditions.

The study year as a whole was below normal in all three categories, total amount of precipitation, number of days with thunderstorms, and number of days with rain. The summer months were deficient in total precipitation and number of days with thunderstorms, with September 1963 and May 1964 also deficient in days with rain. February, March, and April 1964, were above normal in total precipitation; April was the only month above normal in all three categories. Other months were near normal in days with rain and days with thunderstorms, but December 1963 and January 1964 were both deficient in total precipitation.

Visibility

Visibility, the horizontal distance at which an object can be seen, is sometimes used as an indicator of air pollution; however, the frequency of visibilities restricted to less than 3 miles from all causes (including rain, snow, and fog) during the year of study, was only 6 percent compared with a normal of 11 percent. During only

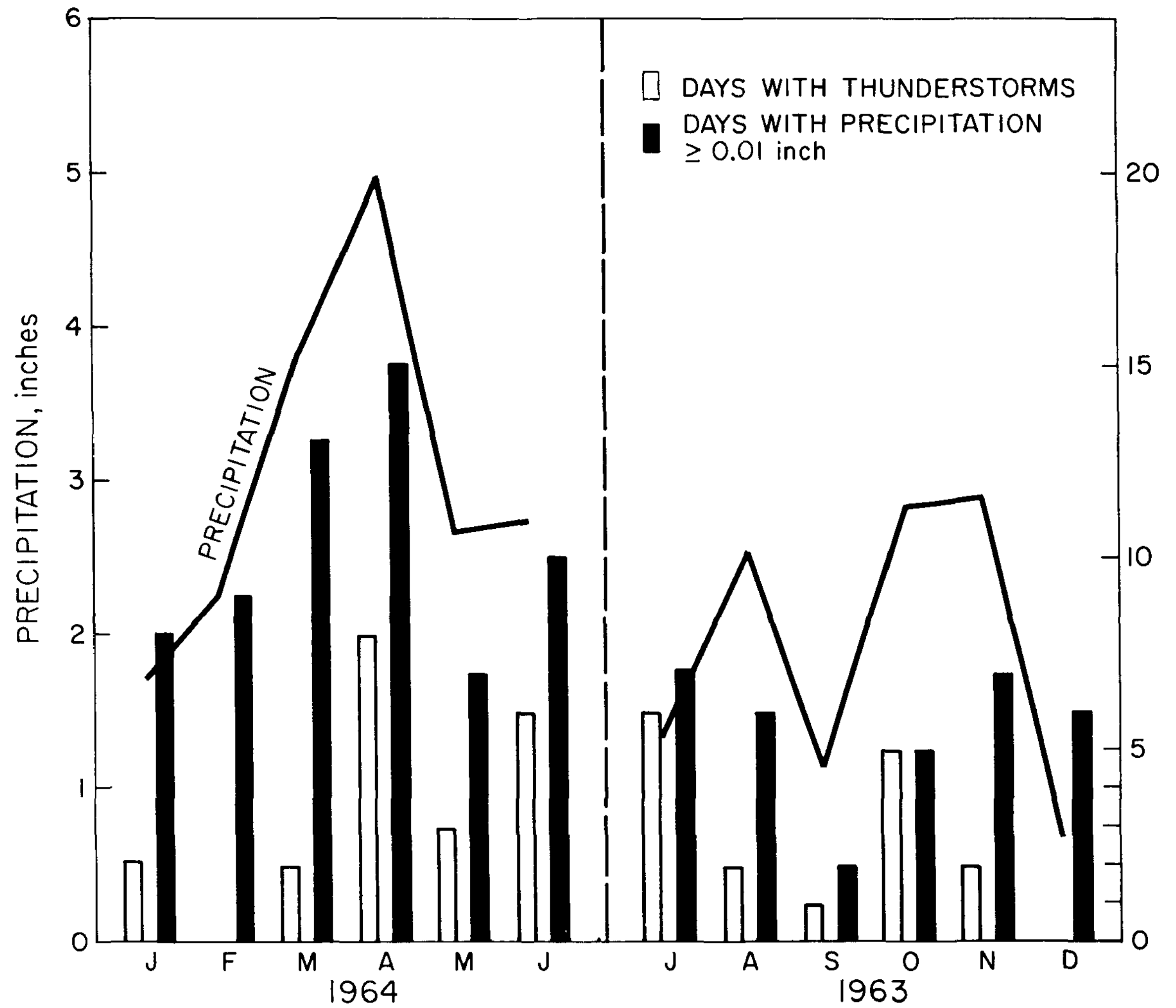


Figure 50. Monthly precipitation totals at Lambert Airport for July 1963 through June 1964.

4 months, November, January, February, and March, did as many as 10 percent of all hours show visibilities restricted to less than 3 miles by all causes. Thus visibilities would indicate that particulate concentrations were somewhat below normal at Lambert Airport.

SUMMARY

Inspection of Figures 36 and 49 indicates that 5 months of the period from July 1963 through June 1964 could not be considered representative. July, April, and June were much above normal in wind speed, therefore, diffusion conditions for the respective months were better than average. With an average wind speed slightly above normal and heating requirements much below normal in October, measurements of pollutants resulting from space heating would be expected to be below normal. Since space heating requirements are normally lower in October than in winter months, this departure may not be significant in the total pollution loading of the atmosphere. December, with an average wind speed slightly below normal, was much above normal in heating requirements and therefore in pollutants resulting from space heating. In all other months, both wind speed and heating requirements were near normal.

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