EPA/450/2-81/017c

U.S. Environmental Protection Agency

Air Pollution Training Institute

COURSE SI:422

3rd Edition

AIR POLLUTION CONTROL

ORIENTATION COURSE

****

Unit 3

Air Pollution Meteorology

EPA/450/2-81/017c

United States
Environmental Protection
Agency

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

EPA 450/2-81-017c
June 1981

Air

APTI
Course SI:422 3rd Edition
Air Pollution Control Orientation Course

Unit 3
Air Pollution Meteorology

Prepared By:
Northrop Services, Inc.
P. O. Box 12313
Research Triangle Park, NC 27709

Under Contract No.
68-02-2374
EPA Project Officer
R. E. Townsend

United States Environmental Protection Agency
Office of Air, Noise, and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, NC 27711

Guidance to the Student

This unit covers the fundamental aspects of air pollution meteorology, with major attention on horizontal and vertical air movement and the ways in which this movement affects the dispersion of pollutants. Successful completion of this unit will make you conversant with basic terms and concepts.

The unit, unlike all others in the course except *Sampling and Analysis*, has *no* accompanying tape. You should work through it just as you would read a book, going at your own speed and reviewing information whenever you feel the need. You will find reviews and questions interspersed throughout the unit. These are designed to help you learn the material efficiently, so even if you're confident that you understand what you've read, be sure to answer all the questions (without looking at the answers). After you have answered the questions, check your answers with the correct ones which appear on the following page.

The unit contains three lessons. Preceding each are learning objectives, which you should read, and following each are review questions. At the end of the unit, a review exam covers all material.

For further study of air pollution meteorology, the following courses of the Air Pollution Training Institute may be helpful:

SI:486 Elements of Air Pollution Meteorology (to be available in mid 1981)
411 Air Pollution Meteorology
423 Dispersion of Air Pollution: Theory and Model Application
452 Principles and Practice of Air Pollution Control

Lesson 1

Scales of Motion

Lesson Objectives

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

- list the four scales of motion
- identify the characteristics of each scale of motion
- list at least two phenomena associated with each scale of motion

Scales of Motion

Meteorological phenomena are classified according to the scope of their influence and their duration. These classifications are called **scales of motion**. and they provide categories for weather patterns lasting weeks or months. Figure 1-1 provides an outline of the scales of motion.

Scale/Description	Time	Phenomena
Macroscale: the atmosphere viewed on a hemisphere scale; major features affecting the planet.	Weeks/months	Changes in planetary climate or atmospheric composition, transport of dust from major volcanos, general circulation of the atmosphere (easterlies, trade winds).
Synoptic: Large-scale phenomena viewed in networks of stations 50 to 500 miles apart; features covering a continent or major part of one.	Days/weeks	High and low pressure areas; weather fronts; hurricanes, winter storms.
Mesoscale: Medium-scale weather patterns. Includes phenomena which cover a distance of approximately 10-100 miles.	Hours/days	Land and sea breezes; urban heat island; weather affecting an air quality control region, atmospheric stagnation advisory.
Microscale: Phenomena which occur around a specific point, up to a few hundred meters, especially in the layer next to the ground. Includes phenomena which cover a distance of approximately 10 miles or less.	Minutes	Behavior of a plume emitted from a single source; meteorological conditions affecting transport to a single receptor; depressed expressway segment.

Figure 1-1. Scales of motion.

The **macroscale** covers phenomena occurring over the entire globe, or at the very least, over a hemisphere. Air pollution meteorologists are not primarily concerned with macroscale phenomena, because the macroscale has little immediate application to day-to-day planning and forecasting. Macroscale phenomena are important to the student of meteorology, however, because they depict the "origin of weather."

The **synoptic** scale is familiar to most of us because we see national weather maps on television and in newspapers. These maps synopsize the weather conditions of a region for a specified period of time. Synoptic phenomena are observed by networks of stations approximately 50-500 miles apart. These observations are collected and analyzed at a central location. Such large-scale weather systems as high and low pressure systems and cold and warm fronts can then be plotted. The two networks of stations in the United States that deal with synoptic phenomena are the *National Weather Service* and the *National Air Sampling Network*. The National Weather Service is particularly important to the air pollution meteorologist. Its 800 stations across the country make weather observations each hour and send data to the National Meteorological Center in Maryland for analysis and synthesis. The center then sends back comprehensive information and forecasts to the local stations, which issue forecasts several times a day.

Mesoscale phenomena include medium-scale weather patterns ranging over distances of about 10-100 miles. Mesoscale phenomena are important in air pollution control because they influence dispersion of pollutants from a large source or over a metropolitan area of mesoscale size.

The **microscale** covers the meteorological effects occurring around an individual point source, especially in the atmospheric layer next to the ground. Such effects, which influence the air flow around an industrial plant or a monitoring device, are obviously fundamental to air pollution control.

To review quickly then, the macroscale includes fairly long-term phenomena covering a large part of the earth. The synoptic scale classifies phenomena influencing weather over a continent or a major part of one. Smaller-scale phenomena ranging from 10-100 miles are mesoscale. Finally, microscale phenomena occur in an area of 10 miles or less. Air pollution meteorologists are primarily concerned with microscale and mesoscale phenomena, but they use synoptic data to forecast air pollution transport and dispersion.

The following questions provide you with an opportunity to test your understanding of the scales of motion. If you need further review before answering them, look again at Figure 1-1.

Questions

1. List the four scales of motion
2. The distance encompassed by the mesoscale is
   a. 1000-10,000 miles
   b. less than 10 miles.
   c. 10-100 miles
3. Name the two scales of motion most important to the air pollution meteorologist

Classify the following situations according to the scale of motion applicable

4. Weather forecasters in an Eastern city note from National Weather Service reports that the high pressure system currently dominating the city's weather is likely to persist for 24 hours They notify local environmental protection agencies that an atmospheric stagnation advisory is now being issued. (The term "atmospheric stagnation advisory" is used to refer to a set of conditions which threaten to result in an air pollution episode.)
5. Weather stations are set up at certain points over the entire globe. These "benchmark" stations collect data about the climate and composition of the atmosphere which, when analyzed over long periods of time, can help scientists to determine if there are any significant changes occurring in the planetary climate or make-up of the atmosphere.
6. The scale of motion most applicable to the behavior of a smoke plume from an industrial stack is ______________.

Answers

1. You should have recalled the *macroscale*, *synoptic scale*, *mesoscale*, and *microscale*
2. (c): 10-100 miles
3. The mesoscale and the microscale
4. The forecasting of atmospheric stagnation advisories is an example of the use of *synoptic scale* information. In other words, it is necessary to look at data from a number of weather stations to determine the extent and probable movement of a large-scale weather system like a high pressure area. So, while an atmospheric stagnation advisory usually applies to a community, the actual forecasting uses synoptic observations.
5. This is an example of observations of *macroscale* phenomena. You may have been mislead by the fact that these observations are made at a number of stations. The benchmark stations, however, collect data for the entire globe over long periods of time.
6. Microscale.

If you answered all the questions correctly, go on to the next lesson. If you did not answer all the questions correctly, be sure to review the lesson before continuing

Lesson II

Wind and Stability: Their Effects on Air Pollution

Lesson Objectives

At the end of this lesson. you should be able to:

- state the rule for naming wind direction
- distinguish between geostrophic and surface wind
- identify the effects of common topographic features on wind flow
- define briefly. in your own words. the terms pressure gradient. vertical mixing. stable atmospheric conditions. unstable atmospheric conditions. inversion. measured lapse rate. dry adiabatic lapse rate
- identify the stability conditions in which looping. coning. and fanning plumes occur
- identify the atmospheric stability which would most likely occur under given weather conditions
- explain the importance of mixing height to air pollution control
- plot and interpret temperature profiles. using lapse rate data

Wind and Stabililty: Their Effects on Air Pollution

Now that you understand the scales of weather activity important to meteorologists, let's look at some of the specific meteorological phenomena that are part of our everyday weather and have a great effect on dispersion of air pollutants. This lesson will concentrate on two primary meteorological factors: *wind and stability*.

Wind

The dispersion of pollutants in the atmosphere is basically dictated by the amount of turbulence in the atmosphere around a source of air pollution. Wind, which is the ***horizontal motion of the atmosphere***, is a major source of turbulence and is therefore extremely important to air pollution meteorology.

The two most important characteristics of wind for our discussion are direction and speed. **Note that a wind is named for the direction from which it blows**. A north wind blows *from* the north, not *to* the north.

Wind speed can be an especially important factor in pollutant concentrations for a given area. Pollutant concentration at ground level is less when strong winds bring in fresh air to dilute the pollutants and to blow them away. Concentration is greater when low wind speed or calm conditions exist.

Pressure Gradient

Pressure gradient is the rate and direction of the pressure change between areas of high and low pressure. Pressure, in meteorological terms, is simply the weight of the atmosphere above a given point. The height and temperature of a column of air are determinants of atmospheric weight. Cool air weighs more than warm air. *Generally*, a high pressure air mass is relatively cool, heavy air, while a low pressure air mass is comparatively warm, light air. The pressure difference causes air to move from the area of high pressure to the area of low pressure. This movement is wind.

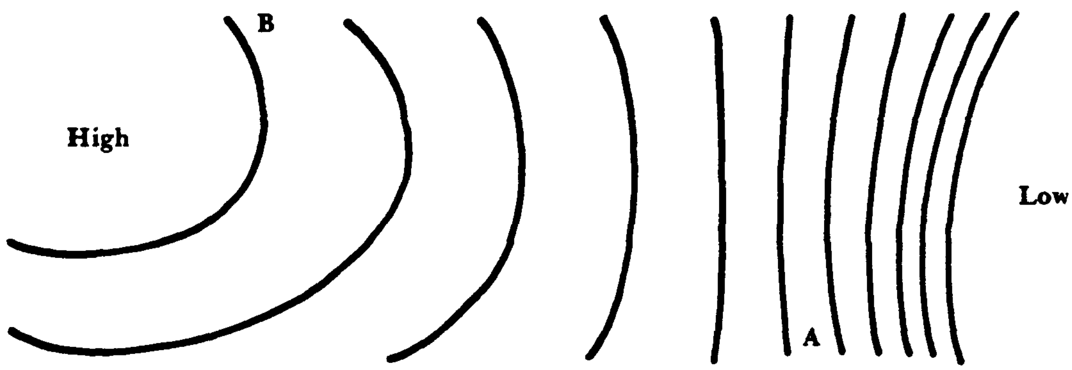


Figure 2-1. Pressure gradient.

In Figure 2-1 the solid lines are isobars or lines connecting points of equal pressure. Where the isobars are close together, the pressure change is rapid (point A) and the pressure gradient is "steep." Where the pressure gradient is steep, the wind speed is faster. Likewise, where the isobars are far apart (point B), the pressure gradient is not steep and the wind speed is slower.

Indicate the direction of the wind flow in the figure above by drawing an arrow.

The arrow you have drawn should point in the direction of the low pressure center because air in a high pressure area will always move in the direction of the low pressure area. The important point for you to remember is that the fundamental cause of wind (the horizontal movement of the atmosphere) is the pressure difference between areas of high pressure and areas of low pressure. The pressure gradient expresses the rate of that pressure change and whether pressure is increasing or decreasing.

Geostrophic Wind, Surface Wind, and Topographical Influences

Geostrophic wind is a term used to refer to wind resulting primarily from pressure gradient forces and the effects of the earth's rotation. Surface frictional forces do not affect this wind.

More important to us is the **surface wind**, which is air movement caused by a pressure gradient and affected by surface frictional forces. It is within the area of surface wind that air pollution is created and transported.

The following diagrams (Figure 2-2) illustrate some of the general kinds of effects that topographic influences can have on the wind.

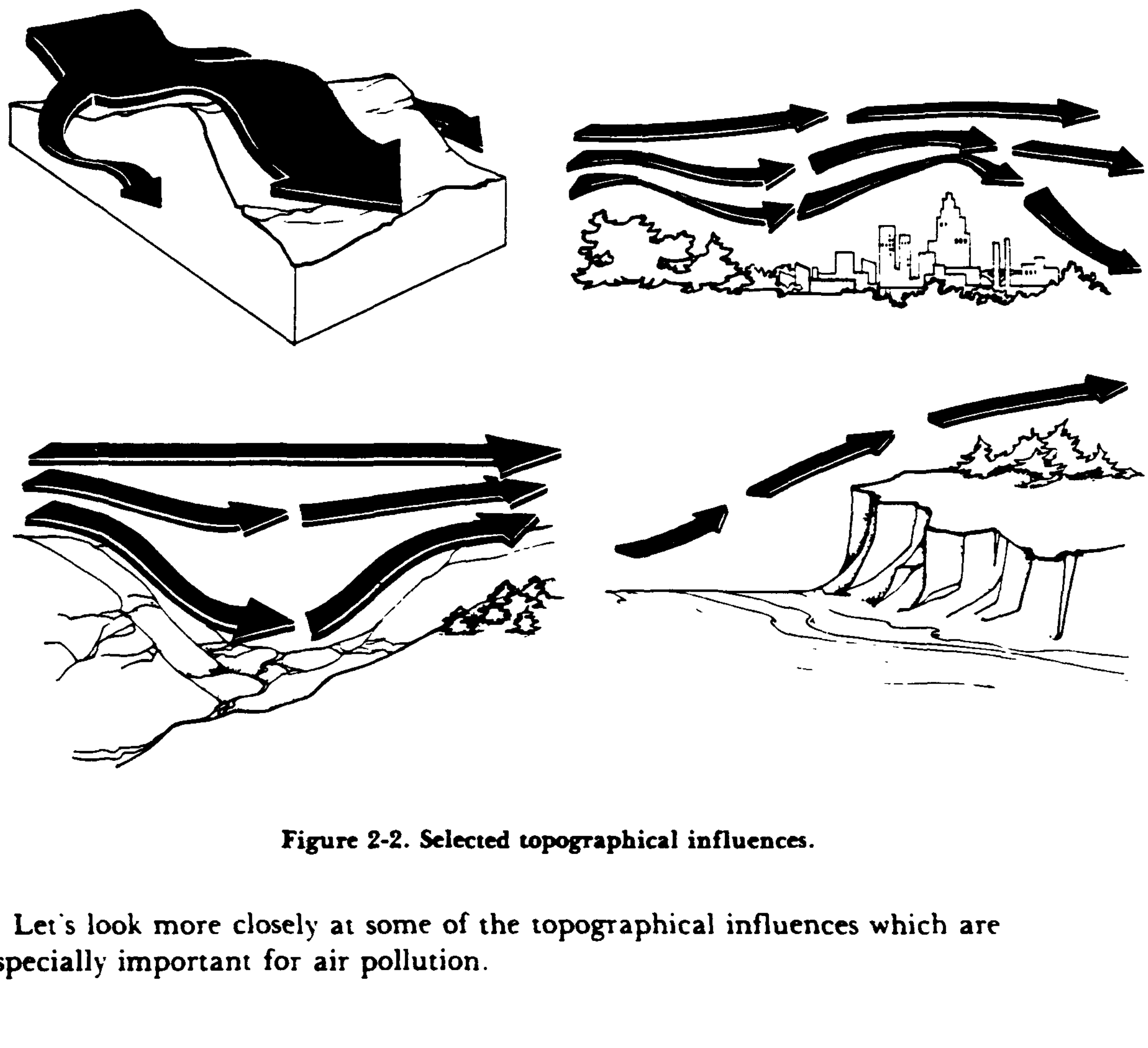


Figure 2-2. Selected topographical influences.

Let's look more closely at some of the topographical influences which are especially important for air pollution.

One topographical influence occurs where land and sea meet. During the day, air heats over land and rises; it cools and descends over water. So during the day, breezes flow from the water toward the land. These are called *sea breezes*. At night, the conditions are reversed, and the breezes flow from the land toward the water. These are *land breezes*. Note that the breezes are named for their origins, just as winds are named for the direction from which they blow.

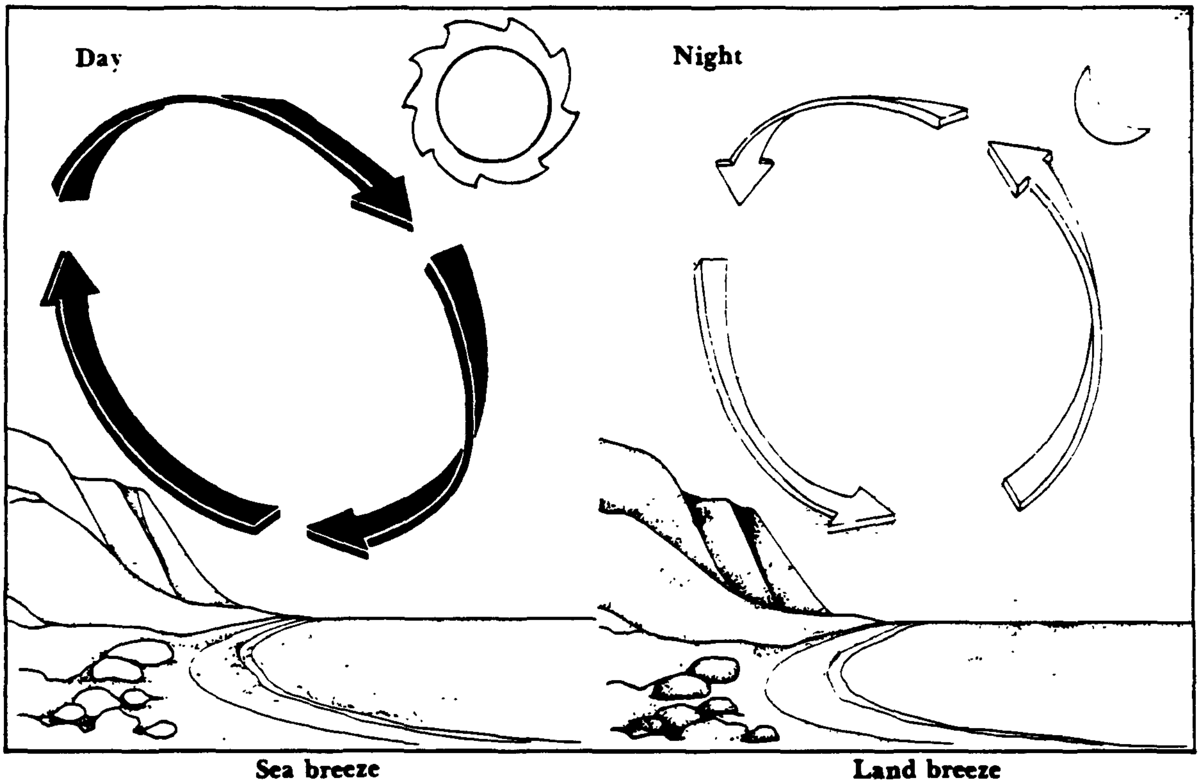


Figure 2-3. Land and sea breezes.

Valley and mountain breezes are similar to land and sea breezes (Figure 2-4).

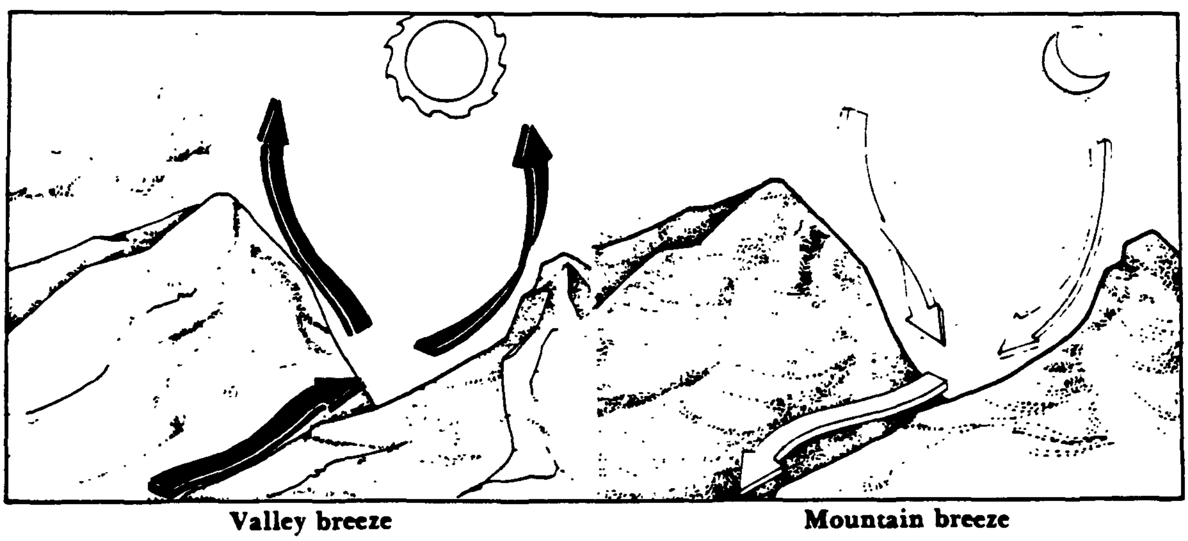


Figure 2-4. Valley and mountain breezes.

During the day, the air in contact with mountain slopes is usually warmer and lighter than the air farther from the slope, and it rises up the slopes. Such air movement is called a *valley breeze* or *valley wind*. At night, the air in contact with the mountain slopes becomes colder and denser than the air further away from the slopes and descends down the slopes. This air movement is called a *mountain breeze*.

The *bowl effect* is a variation on mountain and valley breeze phenomena. Here, a lower area is surrounded on all sides by higher terrain (Figure 2-5). At night, the mountain breeze fills the bowl with cooler air, and under certain conditions the air above the bowl remains warmer. This warmer air forms a lid which restricts vertical air movement and traps pollutants in the bowl. Denver, Colorado, Cheyenne, Wyoming, and Billings, Montana are cities in bowls.

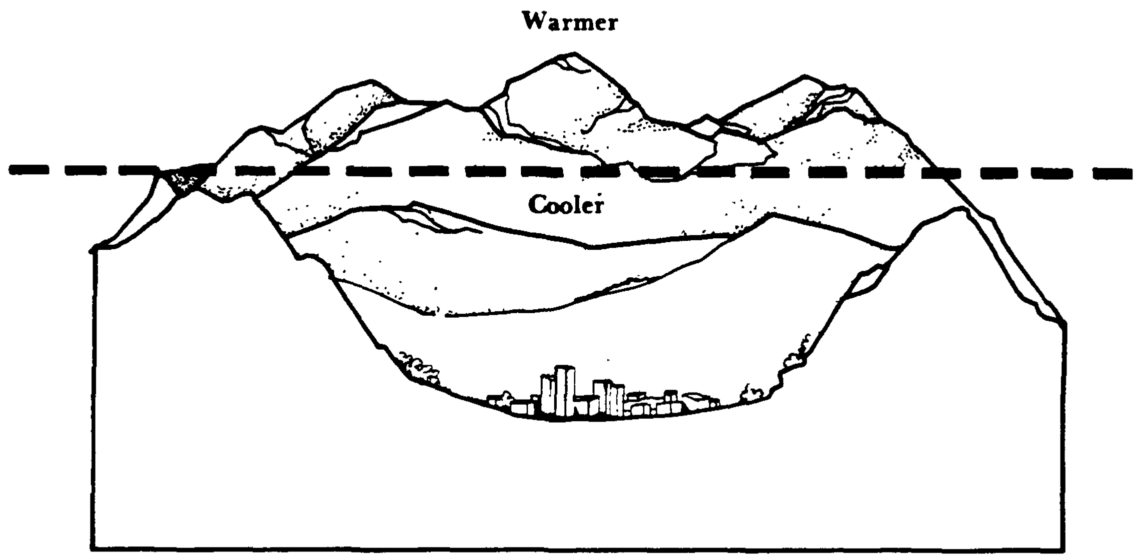


Figure 2-5. The bowl effect.

Another common topographical phenomenon is the *heat island* (Figure 2-6). Here the man-made surfaces of a city absorb heat more quickly than the surrounding countryside, and they retain the heat longer. The result is a dome of warmer air which forms over the city during the day and continues into the night. This dome acts as a kind of pump, continually pulling air into the city. On some nights, when the mixing depth (or volume of air in which pollutants can be mixed) is limited, pollutants tend to become trapped in the dome and reach relatively high concentrations.

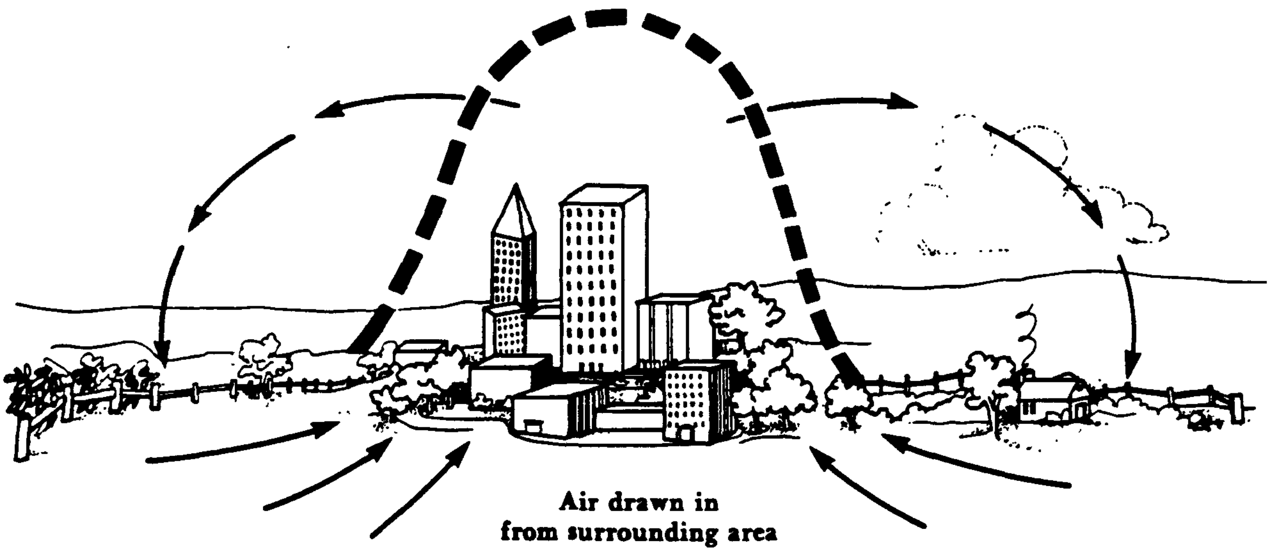


Figure 2-6. The heat island.

Although features of the earth's surface influence the behavior of the wind. we cannot always be sure that a given wind will behave in a predictable way around a particular topographical feature.

The case of the Magna. Utah steel reduction plant smoke plume serves as a classic example of the unpredictability of the effects of topography on wind (Figure 2-7).

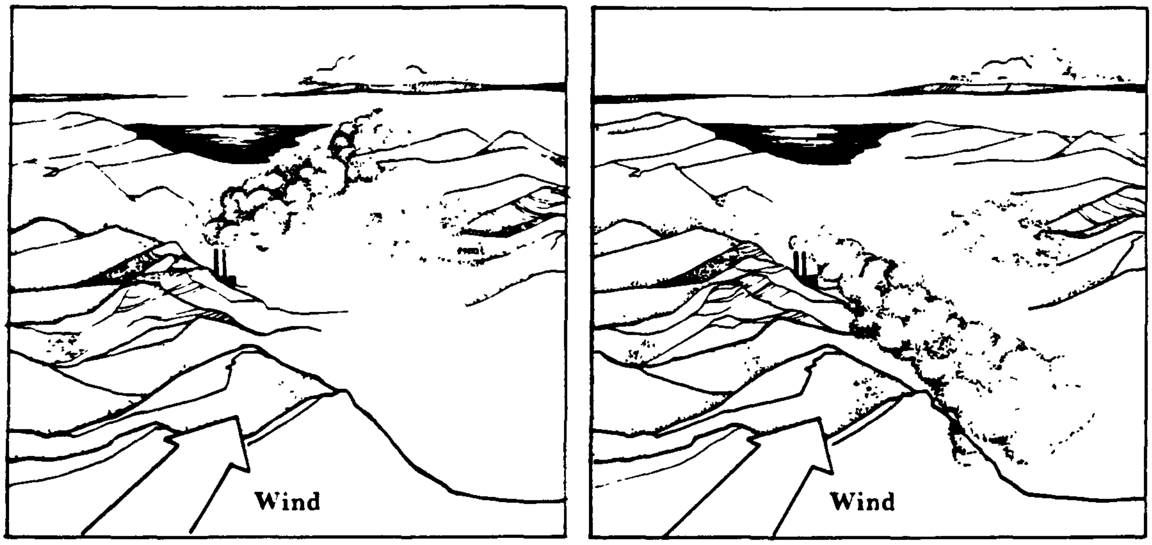


Figure 2-7. Unusual topographic effects.

One day in the late 1960's a surface wind of 35 knots and southwest direction caused the smoke plume from the Magna plant to be dispersed in a northeasterly direction. The very next day. the surface wind was again 35 knots from the southwest. but the smoke plume from the Magna plant was dispersed in a *southeasterly* direction. Since there was no detectable change in the meteorological conditions from one day to the next. meteorologists feel sure that the topography affected the transport of the plume. *How* the topography affected the plume transport is still not certain. However. if the effects of channeling. terrain downwash. or increased turbulence—all topographical effects—had been sampled it may have been possible to forecast the apparent changes from day to day.

As the Magna example shows. the forces affecting wind speed and direction are not simple phenomena. In this section. for the sake of clarity. we have discussed wind in fairly simple terms. The questions on the following page provide you an opportunity to test your understanding of *geostrophic wind*, *surface wind* and *topographic features* discussed in this lesson.

Questions

1. Charleston, South Carolina represents a typical land and sea relationship. Which of the following would characterize the predominant daily wind flow over this city?
   a. wind flows from the ocean to the land during the day, and from the land to the ocean at night.
   b. sea breezes at night, and land breezes during the day.
   c. land breezes during the day and the night.
   d. sea breezes during the day and the night.
2. New York City is often much warmer than the surrounding suburban counties The phenomenon can be explained by the
   a. geostrophic wind.
   b. bowl effect
   c. heat island effect.
   d. pressure gradient.
3. Land and sea breezes and mountain and valley breezes are similar in that they:
   a. occur only in California.
   b. are geostrophic winds.
   c. result from differential heating of surfaces of the earth between day and night
   d. occur at the same altitude.
4. The geostrophic wind is:
   a. above the influence of surface wind effects.
   b. at the earth's surface.
   c. determined by the pressure gradient and features at the earth's surface.
5. In a topographic bowl, higher pollutant concentrations are likely because.
   a. warmer air floods the bowl and is trapped by cooler air above
   b. the wind always flows down into the bowl.
   c. cooler air in the bowl is often trapped by warmer air above.
   d. the bowl forms an inverted heat island.

Answers

1. a. wind flows from the ocean to the land during the day. and from the land to the ocean at night.
2. c. heat island effect.
3. c. result from differential heating and cooling of surfaces of the earth between the day and night.
4. a. above the influence of the surface wind.
5. c. cooler air in the bowl is trapped by warmer air above.

Atmospheric Stability

In the last section you learned that wind is the horizontal motion of the atmosphere. **Atmospheric stability** is concerned with its *vertical* motion.

Stability is very important to the air pollution meteorologist, because the amount of vertical motion in the atmosphere over a polluted area is a crucial factor in determining how quickly and effectively the pollutants will be mixed in the air and dispersed. In our discussion of stability, we will ignore any effect of surface wind and look only at the basic principles of stability.

Characteristically during the day, the air near the earth's surface is warmer than that aloft. This is because the earth absorbs the sun's heat and then heats the air in contact with it. The warmer lighter air rises, and the cooler heavier air sinks and replaces it. This causes an overturning or vertical mixing in the air, which provides a large volume of air in which pollutants can disperse. Figure 2-8 represents atmospheric conditions in which air near the surface of the earth is warmer than the air at higher altitudes.

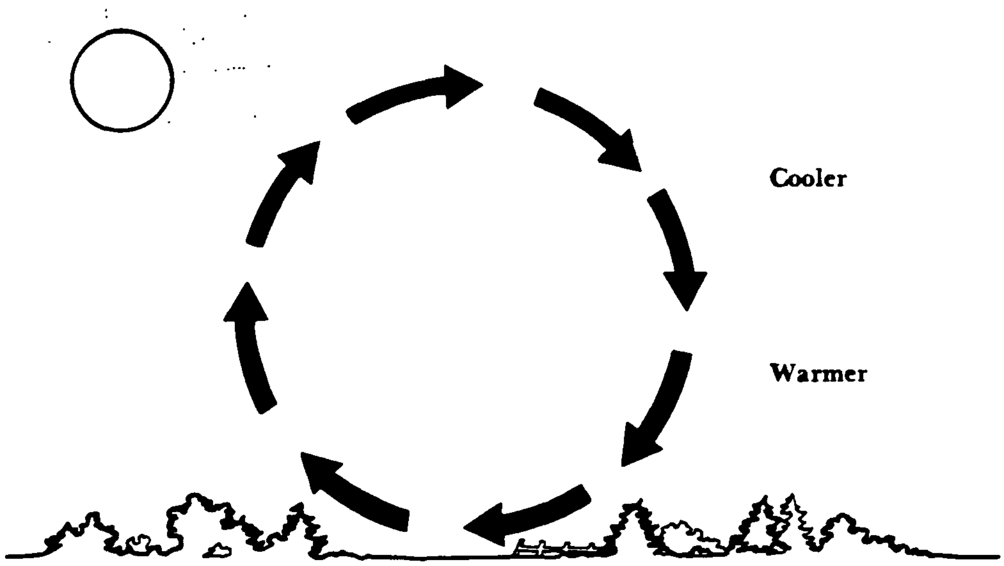


Figure 2-8. Unstable conditions.

In these circumstances, the atmosphere is unstable. *Unstable atmospheric conditions will cause vertical mixing.*

Stable atmospheric conditions usually occur when warmer air is above cooler air in the atmosphere, inhibiting vertical mixing (Figure 2-9). This situation is called an *inversion*. With little or no vertical mixing during an inversion, pollutants remain close to the surface and tend to be in higher concentrations.

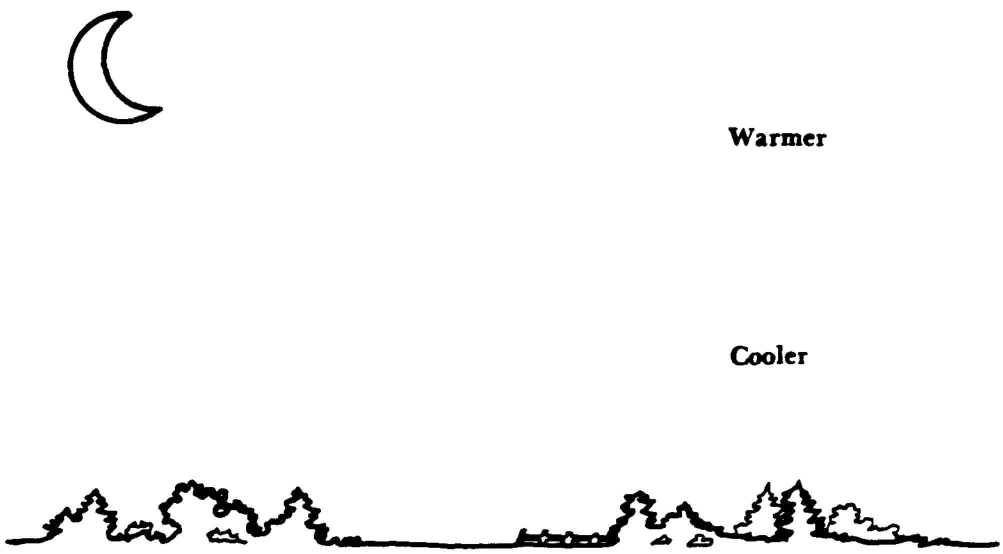


Figure 2-9. Stable conditions.

An index of vertical motion can be determined by investigating how air temperature changes with atmospheric height. This is usually done at a weather station by releasing an instrument called a radiosonde. The radiosonde carries sensors and a radio transmitter and sends back information about temperature, pressure, and humidity at various altitudes.

Radiosonde readings provide information on the **lapse rate**, which is the ***rate at which atmospheric temperature changes with height***. The lapse rate is the most important indicator of stability. Temperature profiles are used by meteorologists to describe lapse rate. The solid line in the profiles (Figures 2-10 and 2-11) represents the "measured" lapse rate or the "environmental" lapse rate. Meteorologists call the solid line symbol for measured lapse rate a *sounding*. The measured lapse rate is the actual rate of temperature change with height.

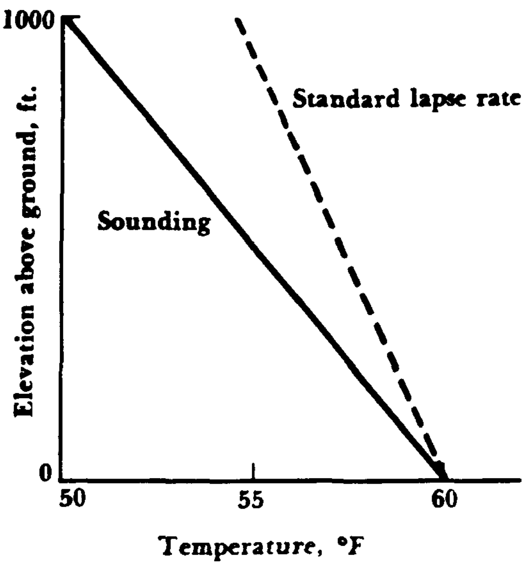


Figure 2-10. Unstable conditions.

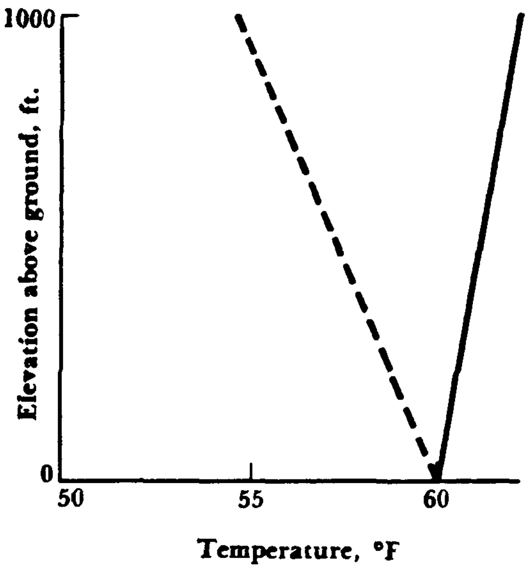


Figure 2-11. Stable conditions.

The dotted line represents the standard lapse rate, or the **standard dry adiabatic lapse rate**. This lapse rate is a 5.4 °F decrease in temperature per 1000 feet of altitude and is used as a reference standard. It is helpful to think of the standard lapse rate as the dividing line between stable and unstable conditions, or as the neutral condition. We can use this standard lapse rate as a reference because the temperature of the air normally decreases with height. At greater altitudes, there is less pressure, so the air increases in volume and decreases in temperature. The standard dry adiabatic lapse rate also assumes no moisture content in the air, since various moisture conditions will affect temperature conditions. The important thing to remember, though, is that this is a reference, or neutral, standard which divides stable and unstable atmospheric conditions.

Figure 2-10 represents a decrease in temperature with height that is greater than the standard lapse rate, so we know that this profile describes unstable conditions, the kind of conditions necessary for good dispersion.

Figure 2-11 represents an increase in temperature with height, or stable, inversion conditions. Any time there is an increase of temperature with height through an atmospheric layer, a temperature inversion is present and the layer is stable. These conditions are not conducive to good mixing.

Stability Practice Session

The following practice exercises are provided to give you an opportunity to plot temperature profiles and to think about the conditions they represent. They will introduce some new information about atmospheric stability, which will be explained in more detail later. This is not a test of your understanding of stability (that will come later); these are practice exercises designed to stimulate you to think about stability and to prepare you for the next stability topics. Please respond to each practice item.

1. Plot on the graph the temperature profile that represents the temperature conditions depicted in Figure 2-12.

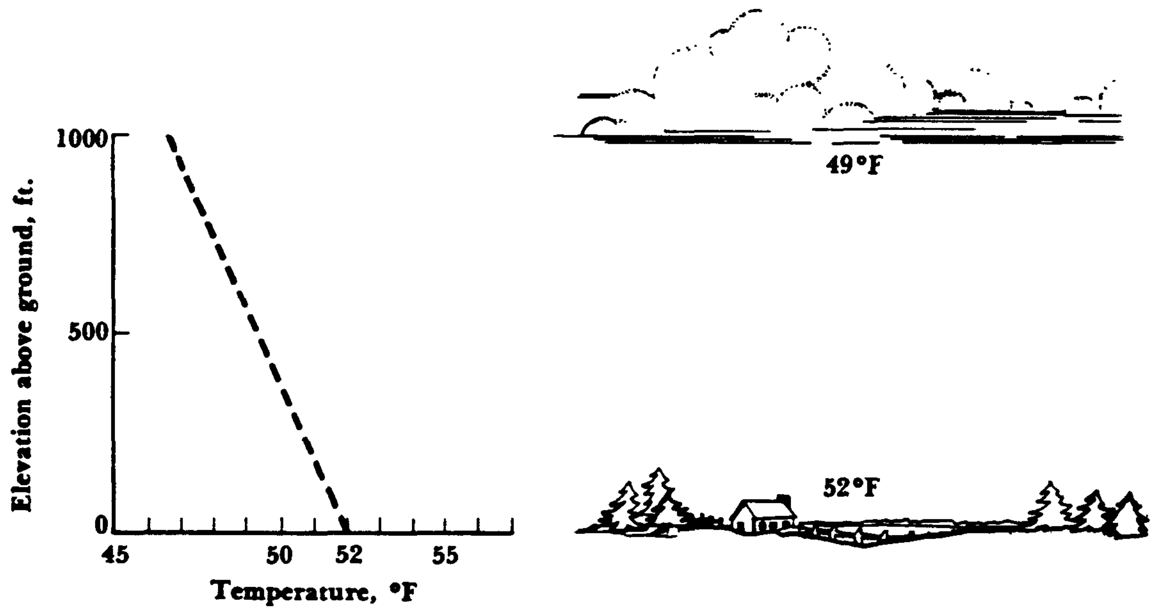


Figure 2-12.

2. The environmental lapse rate you've just plotted is representative of which kind of atmospheric conditions?
   a. a lot of vertical mixing—unstable
   b. very little vertical air motion, poor dispersion—stable
   c. some vertical motions, moderate dispersion—slightly stable
3. Can you deduce which is the most likely description of the weather conditions represented by the temperature profile you have just drawn?
   a. a clear day, the air near the surface is very warm because the earth is giving off heat it has absorbed from the sun.
   b. cloudy, the air near the ground stays nearly the same temperature as the air aloft.
   c. after sunset on a clear day; the air near the ground has cooled off more rapidly than the air aloft.

4. Plot on the graph the temperature profile that represents the temperature conditions depicted in Figure 2-13.

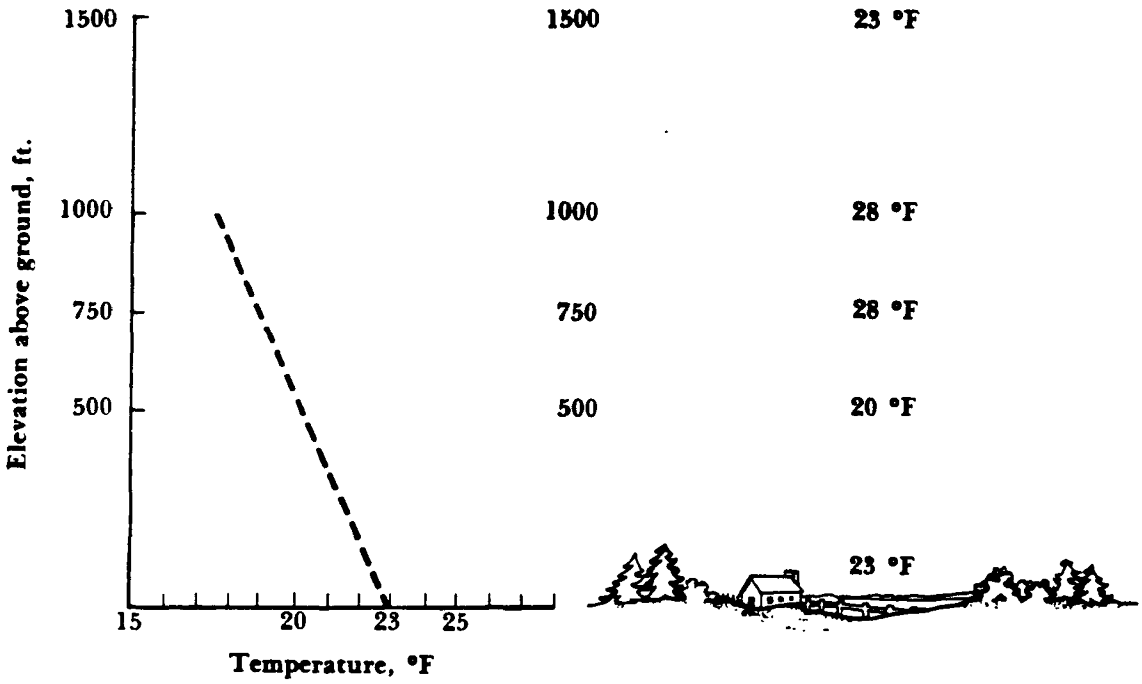


Figure 2-13

5. In the sounding you have just drawn, the atmosphere from the surface to 500 ft. is__________(stable/unstable); from 500 ft. to 750 ft. it is__________(stable/unstable).
6. The atmosphere is said to be "isothermal" when there is no change of temperature with height. Between which altitudes in Figure 2-13 is the lapse rate isothermal?
7. An inversion can occur near the surface or aloft. The conditions depicted in Figure 2-13 represent an inversion that is__________(elevated/not elevated) from an altitude of________feet to________feet.

8. Can you deduce from the temperature profile in Figure 2-14 which stability condition is being depicted by the environmental lapse rate? (Remember: the dotted line represents the dry adiabatic lapse rate: the solid line represents the measured lapse rate.)

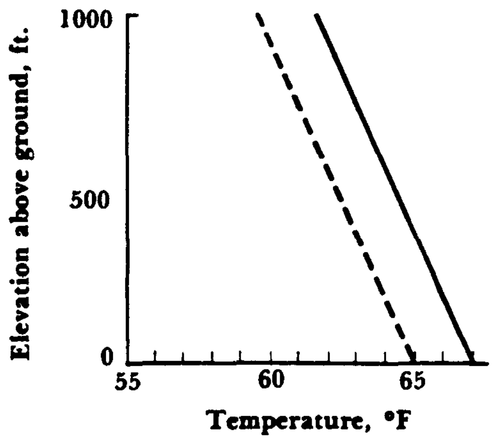


Figure 2-14.

9. The shape and behavior of a plume or stream of smoke emitted from a large source of pollution can tell us whether conditions are stable. unstable or neutral. Knowing what you do about how stability reflects the amount of vertical movement of the atmosphere. try to match each plume in Figure 2-15 with the graph of the atmospheric conditions that would give the plume its shape.

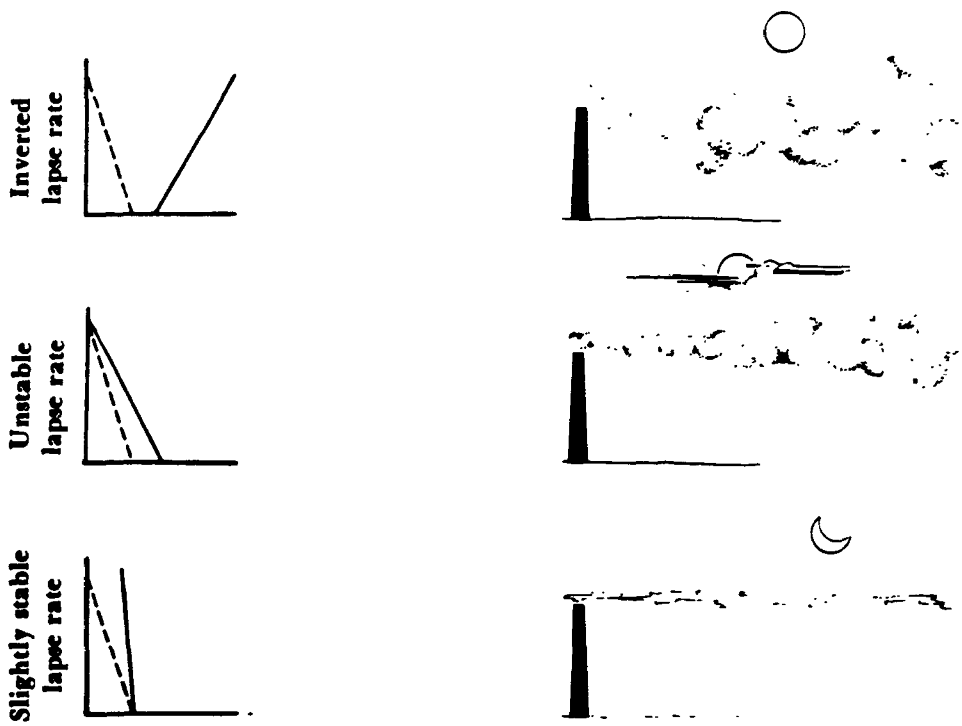
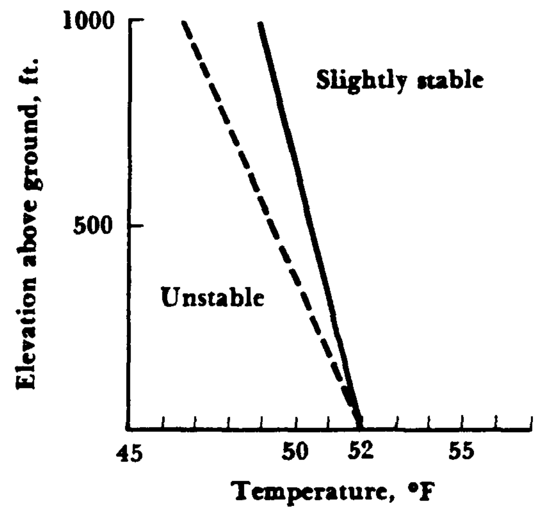


Figure 2-15.

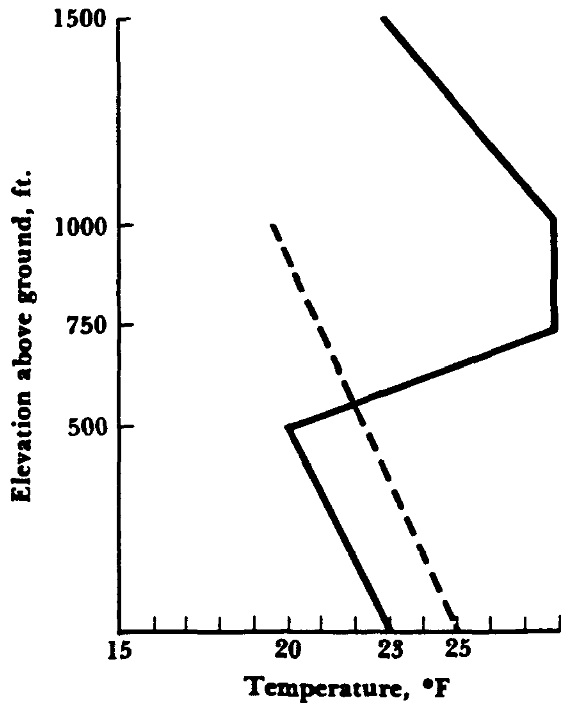
Answers to Practice Session

1. The temperature profile you drew in Exercise 1 should look like that below:



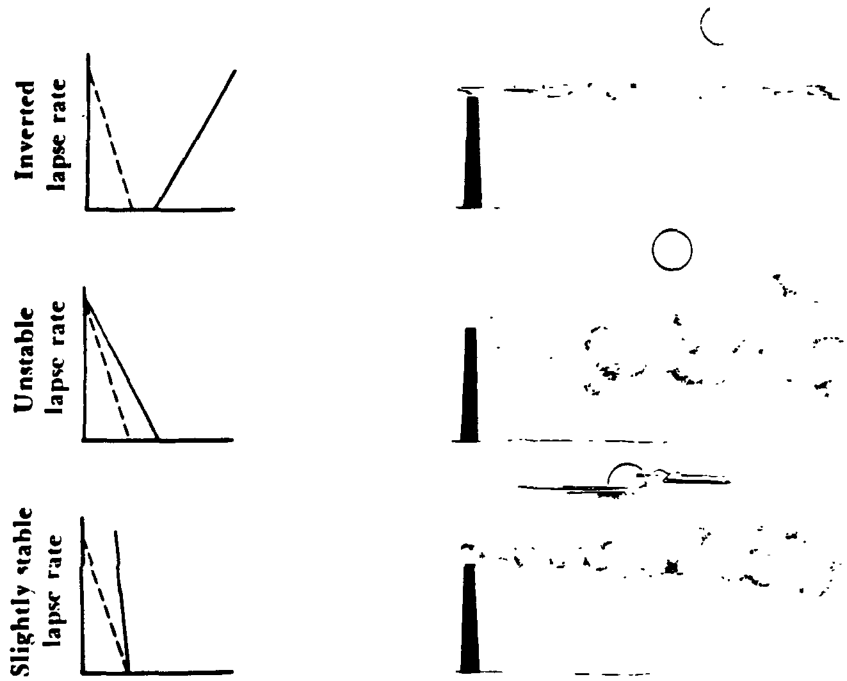
2. The lapse rate represents (c) a slightly stable atmosphere with moderate dispersion. Remember to think of the standard lapse rate (or dry adiabatic lapse rate) as the dividing line between stable and unstable conditions. Because the sounding falls to the right of the standard lapse rate, we know that it represents a stable atmosphere. It represents a *slightly stable* atmosphere and not a *very stable* atmosphere because a very stable atmosphere would be characterized by an increase in temperature with height.
3. (b) Cloudy, the air near the ground stays nearly the same temperature as the air aloft. The clouds in the drawing are the key. On a clear day, the earth absorbs the sun's heat, and that heat is conducted to the air near the surface. The cloud cover in the example prevents the sun's radiation from heating the earth very much, so there is less difference in temperature between the air at ground level and the air at 1000 feet. A subsequent section of the lesson will discuss daily weather conditions and atmospheric stability more fully.

4. The temperature profile should look like that depicted below.



5. The atmosphere from the surface to 500 feet is *slightly unstable* (because there is a decrease in temperature with height greater than the standard lapse rate). From 500 ft. to 750 ft. it is *stable* (because there is an increase in temperature with height).
6. Between the altitudes of *750 ft. and 1000 ft.* the lapse rate is isothermal.
7. The conditions depicted above represent an inversion that is *elevated* from an altitude of *500* ft. to *750* ft.
8. An environmental lapse rate that is equal to the standard lapse rate of 5.4° decrease/1000 ft. of altitude represents a *neutral* atmosphere—neither stable nor unstable. The important point for you to remember is that the standard or dry adiabatic lapse rate is the dividing line between stable and unstable atmospheric conditions.

9. The lapse rates and plume types should match as follows:



By now you should have a good feel for representing atmospheric stability in a temperature profile. You should also be developing an understanding of how stability affects the dispersion of air pollution.

If you responded incorrectly to questions 1, 2, 4, 5, 6, 7, or 8, please make sure you understand the correct answers before continuing. The subject matter of questions 3 and 9 are covered in the next two sections of this lesson.

Congratulations' You have reached the half-way mark' You may want to take a break at this point and return to the module later.

A caution: if you return to the module much later than a few hours, be sure to reread the objectives for the sections you've completed and review any content you are unsure about before continuing.

Smoke Plumes as Indicators of Stability

The practice exercise briefly introduced you to the fact that the shape and behavior of a plume or stream of smoke emitted from a pollution source can indicate whether conditions are stable or unstable.

Unstable conditions cause a great deal of mixing and overturning of the atmosphere. This condition results in "eddies", or areas with different mixing rates. Eddies determine the shape of the *looping plume* (Figure 2-16).

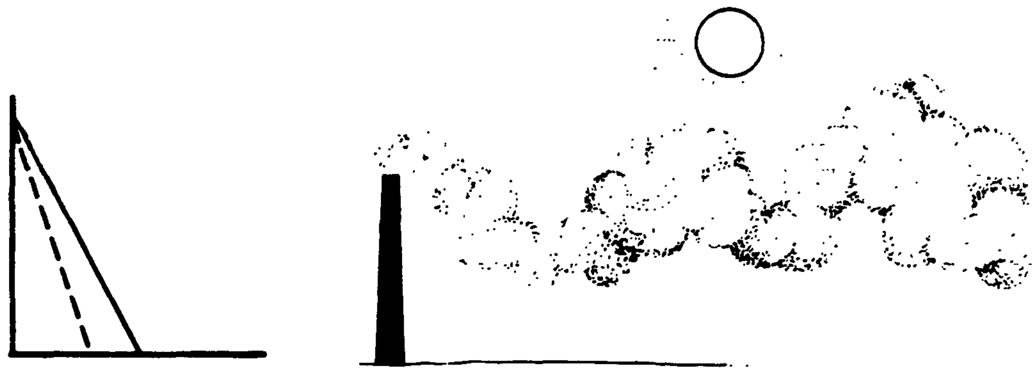


Figure 2-16. Looping plume.

When the atmosphere is slightly stable, the tendency for overturning decreases, and we see what is known as a *coning plume* (Figure 2-17). In this instance the amount of spreading out in the horizontal and vertical directions are about the same and dispersion is fairly good.

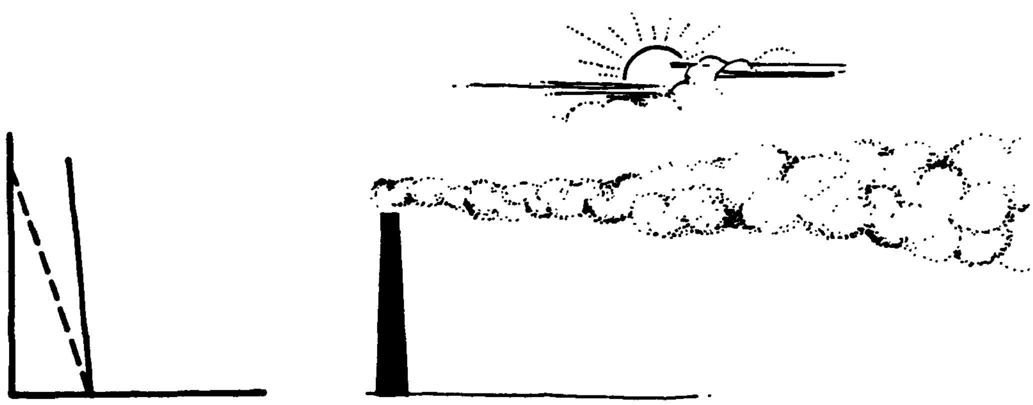


Figure 2-17. Coning plume.

In an inversion situation, the atmosphere resists vertical mixing, and a *fanning plume* results (Figure 2-18).

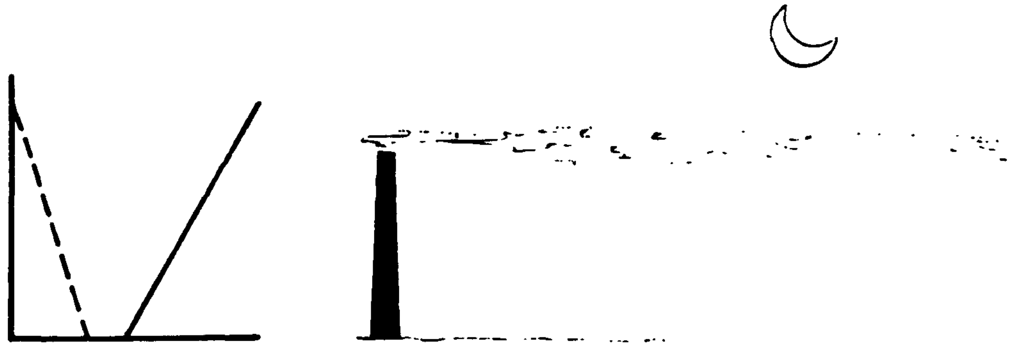


Figure 2-18. Fanning plume.

Inversions can occur near the surface or aloft. Emissions from ground-level sources will stay within the surface inversion layer. This situation frequently occurs early in the morning when the exhaust fumes from heavy traffic and other sources at the surface are trapped in a surface inversion.

Very high stacks (700 feet or more) can prevent high ground-level concentrations in an area where there are frequent surface inversions, since pollutants emitted above the inversion level will stay at that level or go upward but *not* touch the ground.

Horizontal dispersion is also taking place in the three examples given. It is now generally recognized that dispersion does not take place at the same rate horizontally as vertically. Ground-level concentrations are mainly a function of vertical mixing. Some factors that affect horizontal dispersion are: gravity waves, sound waves, wind shear, and turbulent eddies.

Do not continue to the next lesson until you understand the connection between plume shape and atmospheric stability and are able to identify the three plume types and the conditions each represents.

Daily Weather Conditions and Atmospheric Stability

One of the practice session items required you to relate weather conditions to atmospheric stability. Meteorologists are concerned with *typical* daily weather conditions that influence atmospheric stability.

For example:

On a clear day, by midafternoon, the air near the surface of the earth is very warm because the earth is conducting the heat absorbed from the sun to the air adjacent to it. There are unstable conditions because of the large difference between ground level temperature and the temperature aloft (Figure 2-19). Much mixing or overturning, called thermal turbulence, occurs under these conditions.

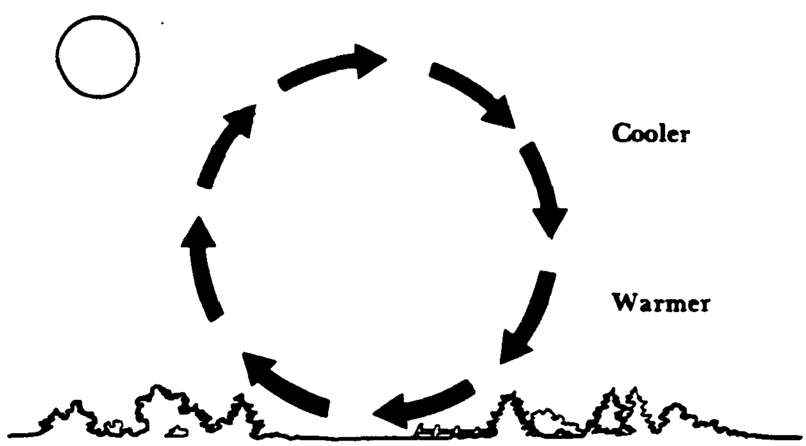


Figure 2-19. Unstable conditions.

A slightly different condition occurs when a cloud cover prevents the ground from absorbing as much heat (Figure 2-20). On cloudy days the air near the ground stays nearly the same temperature as the air aloft during the day and does not cool off as much at night. Under these conditions, there is moderate mixing and dispersion of pollutants.

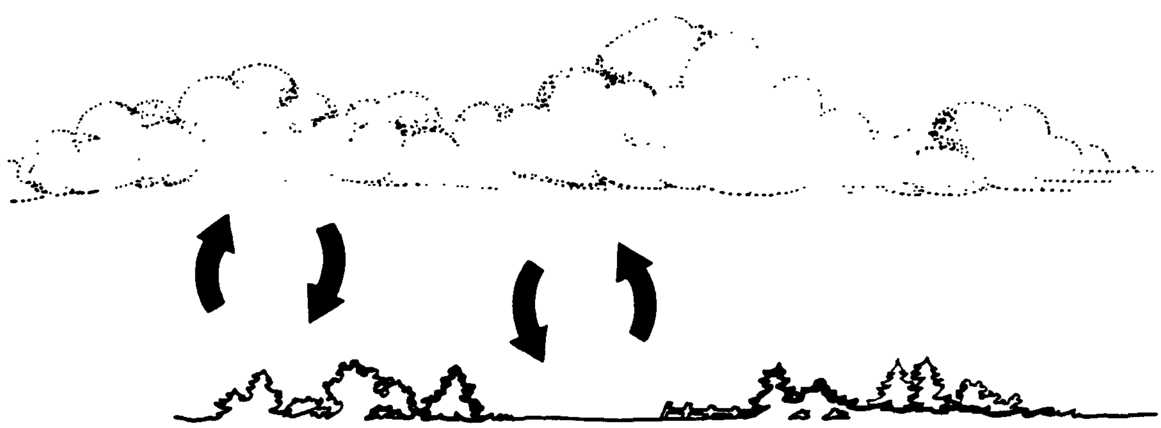


Figure 2-20. Slightly unstable conditions.

Can you deduce what will happen when the sun sets on a clear day? Here's a hint: the ground will begin to cool off much more rapidly than the air above it. Do not continue until you have thought this through.

Did your reasoning lead you to conclude that surface-based inversion would most likely result when the sun sets on a clear day? If so, you are correct and are becoming quite a sleuth!

When the sun sets on a clear day, the ground cools off much more rapidly than the air above it, and a layer of cool air forms near the ground. As the night continues, the cool layer of air extends further into the atmosphere. Pollutants emitted into this cool air remain near the surface of the earth, since they are trapped under the warm layer of air above them. Under these conditions, the temperature structure is inverted, and we have an *inversion*.

When the sun rises again on a clear day, the solar radiation quickly heats the earth's surface and subsequently warms the layer of air in contact with it. This air becomes warmer than the air above and begins to move upward, soon "burning off" the cold inversion layer. Usually, within two to three hours after sunrise, we will have returned to the "usual clear day" temperature structure like that depicted in Figure 2-19.

This typical diurnal cycle (unstable conditions during the daytime when the sun is shining; inversion conditions at night) may be altered by the presence of clouds, precipitation, or high winds. High winds cause mechanical turbulence near the earth and help break up the temperature stratification. When they occur, thermal turbulence during the day and nighttime inversions are less pronounced.

Figure 2-21 summarizes the typical daily weather conditions and their effects on stability. Of course, there are many variations from these "typical" conditions, and the varieties will influence the dispersion of pollutants.

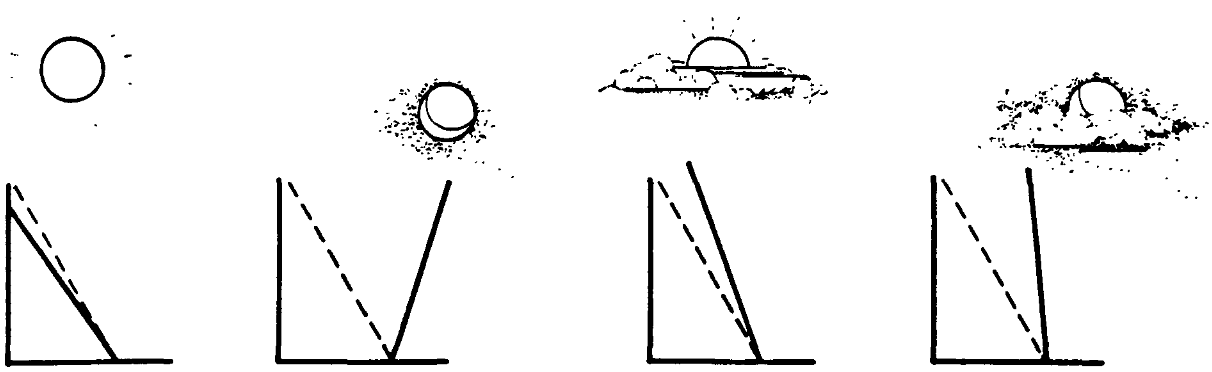


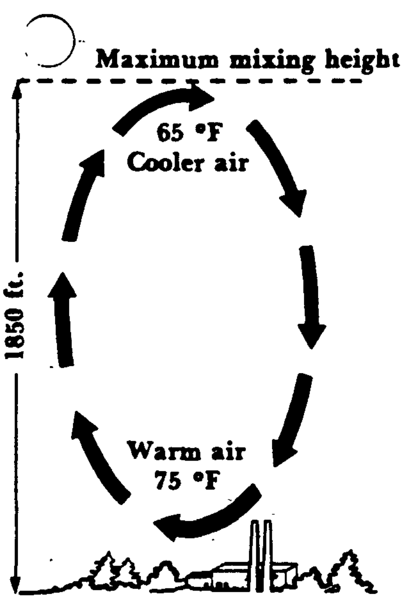
Figure 2-21. Summary of stability conditions.

Mixing Height

Variations in atmospheric stability during the course of a 24-hour period are important to the air pollution meteorologist because of his concern with the capability of the atmosphere to mix and dilute atmospheric pollutants.

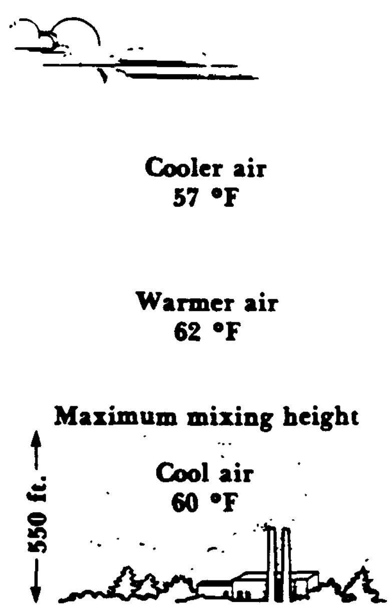
Mixing height (also called mixing depth) refers to the *maximum altitude to which effective vertical mixing occurs.*

The figures below represent mixing heights of 1850 feet and 550 feet.



Clear sunny day

Figure 2-22.



Inversion conditions on a cool morning

Figure 2-23.

If the same emissions of pollutants occurred in both of the situations illustrated, you would expect a much higher ground-level concentration of pollutants under inversion conditions, because there is a smaller volume of air within which the pollutants can be diluted. On a sunny, summer day, the mixing height may extend up to several thousand feet. In the winter, when less heat is received from the sun, the mixing height may be as low as a few hundred feet. The mixing height will also vary in the course of a day because of the daily variations in stability already discussed.

Wind speed and direction, lapse rate, and mixing height, as you can see, are *all* important influences on the volume of atmosphere in which pollutants can be mixed.

Morning and afternoon mixing heights are calculated each day for the major weather stations around the country. The mean, or average, wind speed is also calculated. Mixing height, wind speed, and pollutant emission rates are all major factors used to forecast ground level pollutant concentrations.

The map (Figure 2-24) shows the average annual afternoon mixing heights and the corresponding annual wind speed averages for some of the major cities in the country.

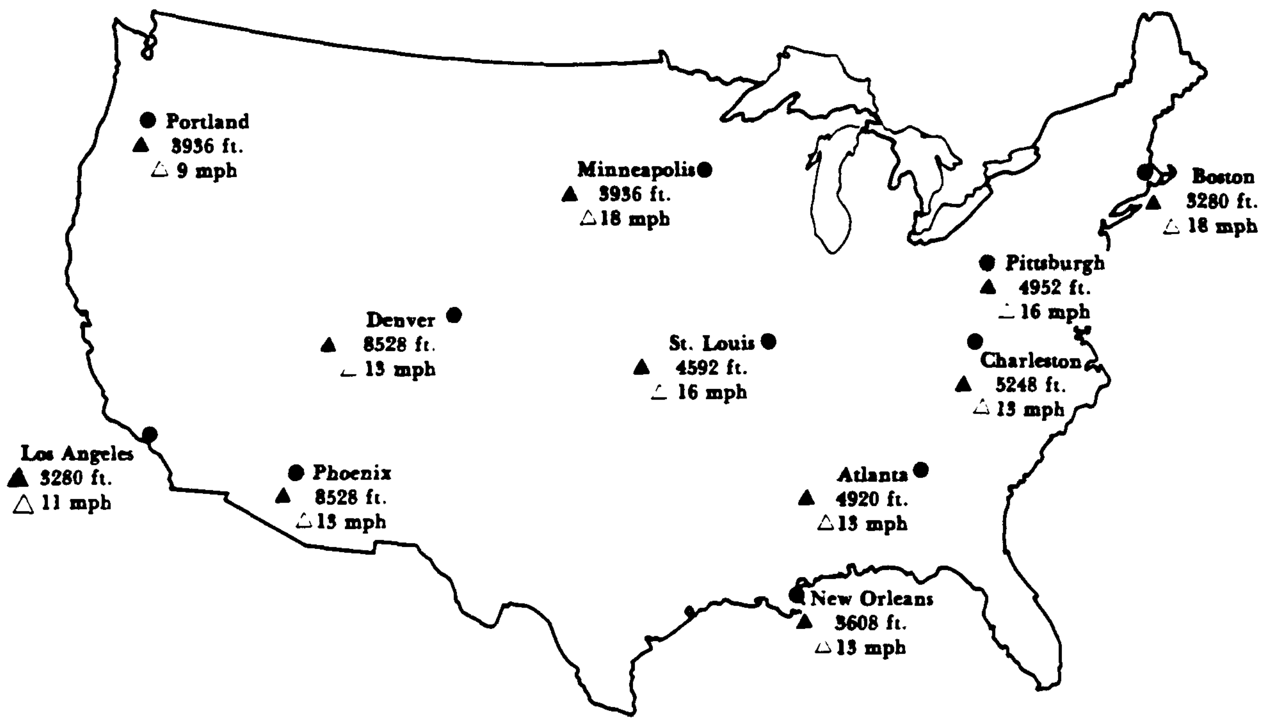


Figure 2-24.

The information given on the map does not tell the whole story about dispersion capacity over these cities, since these are annual averages. By studying data of this sort concerning vertical and horizontal atmospheric movement, and by looking at daily and seasonal atmospheric variation and its implications for pollutant dispersion, air pollution meteorologists have been able to identify areas of the country where weather conditions do not favor the dispersion of pollutants. Oregon and central California, the great basin in the Rocky Mountains, northern Minnesota, and the area around and including West Virginia are locations where atmospheric conditions tend to aggravate air pollution problems. Not every air pollution problem is related to meteorological conditions, however. The New York-New Jersey area, for example, has a serious air pollution problem, although its location provides some of the most favorable meteorological conditions for dispersion in this country. The problem there stems from the tremendous concentration of pollutant sources.

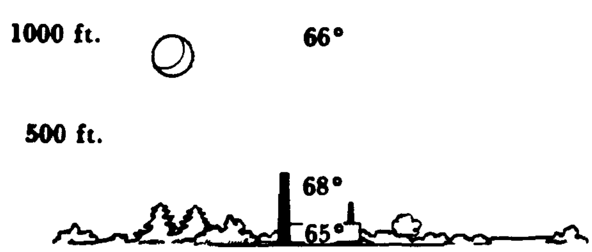
When conditions do not favor good atmospheric mixing and dispersion of pollutants, as during an inversion, an *air pollution episode* may occur. Episode is a term used to describe conditions in which especially high pollutant concentrations endure over a period of time and endanger health and/or property.

We've now covered *wind, topographic influences, atmospheric stability,* and *mixing height*. If you feel that you understand these subjects, go on to the review questions. If not, reread the section you're not sure about.

Questions

1. Complete the following statement: A wind is named for the direction__________
______________________________.

2. Billings, Montana and other cities located in topographical bowls have a problem with pollution becoming trapped below an inversion that forms a "lid" over the bowl. In a 24 hour period, if the atmospheric conditions followed a typical diurnal circle, the pollution level in Denver would be at its worst:
   a. during the afternoon
   b. during mid morning
   c. during early evening
   d. prior to sunrise
3. On a fall day by mid afternoon, the air temperature at the surface around Sneed's Cement Plant is 80 °F. The sky is clear, and the air temperature at 500 feet is 60 °F. Ground-level concentrations of pollutants in the vicinity of the plant are low, even though the plant has been emitting pollutants. What meteorological factor from the list below would most likely account for the low concentrations?
   a. vertical mixing
   b. precipitation
   c. high winds
   d. stable conditions
4. Early in the morning hours when there is heavy traffic on the highways, exhaust fumes from automobiles are frequently trapped close to the surface of the earth. Under *normal* circumstances, as the day progresses,
   a. surface winds will blow the pollution away
   b. the sun will "burn off" the inversion layer, allowing the pollutants a greater volume of air within which to dilute
   c. the ground level concentration will remain heavy until nightfall
   d. the mixing height will gradually decrease.
5. After sunset on a cloudless, summer day, the air near the ground begins to cool rapidly. The sky is still clear, and the winds die down until they are calm. By the time the lowest temperature for that night is reached, the temperature structure looks like that sketched below. What kind of dispersion would the emissions from the very short stack have?__________(good, moderate, poor). What kind of dispersion would you expect from the tall stack?__________(good, moderate, poor).



Answers

1. A wind is named for the direction *from which it blows* (or words of the same meaning).
2. *d. Prior to sunrise.* If a typical diurnal cycle is followed in the atmosphere over the "bowl," then the inversion that generally forms will disappear during the day. This is because of surface warming and vertical motion. Early evening is a poor answer because the inversion is not fully established and will not be at its lowest elevation.
3. *a. Vertical mixing.*
4. *b. The sun will "burn off" the inversion layer allowing the pollutants a greater volume of air with which the pollutants can be diluted.*

   The normal diurnal cycle is characterized by unstable daytime conditions and stable or inversion nighttime conditions. Early in the morning, before the sun has heated the earth's surface, surface inversion conditions frequently prevail. The cool layer of air near the earth's surface and pollutants within it, remain trapped under the warmer layer above until solar radiation is intense enough to heat the earth's surface. Once the surface is heated, it heats the surface air in contact with it. Usually, within 3 hours after sunrise the unstable temperature structure is restored.
5. *Poor; moderate*

   Emissions from the short stack would have poor dispersion since they are under the surface inversion. The emissions from the taller stack would show moderate dispersion, since they are above the low lying inversion layer, but still under only slightly stable atmospheric conditions.

If you answered all the questions correctly, go on to the next lesson. If you did not answer them all correctly, be sure to review the correct answers to those questions missed before continuing.

Lesson III

Other Meteorological Influences and Representation of Meteorological Information

Lesson Objectives

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

- cite effects of atmospheric water vapor which tend to cause air pollution to increase or decrease
- cite a mesoscale effect of solar radiation which reduces the dispersion of pollutants in the atmosphere
- describe the major characteristics of high and low pressure systems
- identify the typical effects of pressure systems on air pollution
- recognize the symbols for cold and warm fronts and interpret from them the direction of front movement
- interpret a wind rose

Other Meteorological Influences and Representation of Meteorological Information

We have examined in some detail the two meteorological factors that are of primary concern to the study of air pollution meteorology: wind and stability. We have also mentioned the role topography and other surface features of the earth can play in the transport of air pollution. Now let's look briefly at some other meteorological factors affecting air pollution

Solar Radiation

As you learned in Lesson II, solar radiation is a major factor in atmospheric stability. The radiant energy of the sun can also cause changes in chemicals already existing in the atmosphere, producing secondary pollutants called photochemical oxidants. The photochemical smog we hear so much about in connection with Los Angeles and many other cities results from the action of the sun on nitrogen oxides (nitric oxide—NO—and nitrogen dioxide—NO_2) and hydrocarbons already in the air.

The photochemical process occurs when NO_2 absorbs energy from the sun. This absorption causes NO_2 to separate into nitric oxide (NO) and atomic oxygen (O). Atomic oxygen—not to be confused with oxygen as it usually exists in the atmosphere as molecular oxygen O_2—is quick to react with other oxygen molecules and chemicals to produce a variety of chemical compounds, including ozone. Ozone is a dangerous substance in its own right, and it becomes the active agent in a series of complex chemical reactions which result in the production of other dangerous pollutants.

The important point for you to remember is that solar radiation is a meteorological force that can activate production of dangerous pollution in the atmosphere when certain pollutants are in the air.

Precipitation and Humidity

Precipitation and humidity can significantly affect air pollution concentrations. Precipitation (condensed water vapor) is a positive influence when it acts as a natural cleansing process, washing pollutant particles out of the air. Rain also cuts down on surface dust, and snow cover influences stability. High humidity (uncondensed water vapor) can be detrimental; just as solar radiation affects chemical processes that produce secondary pollutants, water vapor can combine with some gaseous pollutants to produce more potent and dangerous secondary pollutants. An example is the combination of sulfur dioxide (SO_2) and water (H_2O) to form the secondary pollutant sulfuric acid (H_2SO_4), which may fall to earth as "acid rain." Sulfuric acid is a highly corrosive substance that damages metals, building materials, and vegetation.

Solar radiation, precipitation, and humidity, like topography, are mesoscale and microscale phenomena that influence air pollution in combination with other factors in very complex ways.

Large Scale Weather Systems

Although macroscale and synoptic scale phenomena are not as important to the air pollution meteorologist as micro and mesoscale phenomena, he is concerned with the two most basic large-scale weather systems—**high pressure** and **low pressure systems**, or highs and lows, and the weather conditions typically characterizing them. Remember that pressure is basically the weight of the atmosphere above a point at ground level. In essence, a high pressure system is a dome of air in the atmosphere, and a low is a bowl (Figure 3-1). A high contains more air than a low and is thus heavier.

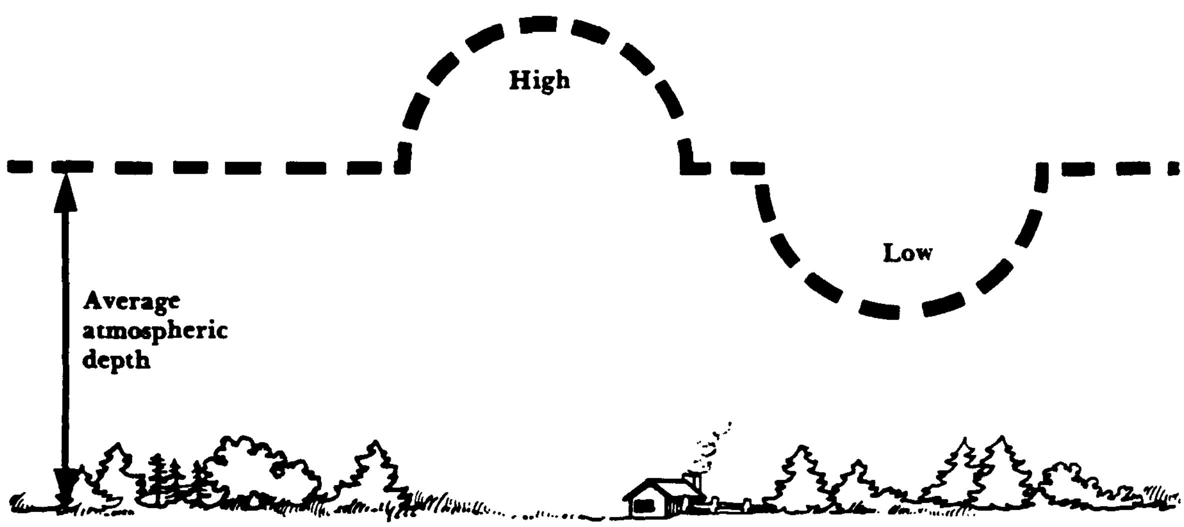


Figure 3-1. High and low pressure.

High and low pressure systems are determined by measuring barometric pressure at various observation points on the earth's surface. In the United States these barometric measurements are made regularly at the stations of the National Weather Service. Once air pressure values are obtained for the various observation points, they are submitted to a central station where the pressure systems are plotted on maps by drawing lines, called *isobars*, that connect locations of equal pressure. Since connecting all points on a map with the same pressure would result in a maze of lines, isobars are usually drawn at pressure intervals of 3-5 millibars. A millibar equals 1/1000 of a bar, which is a standard unit for measuring atmospheric pressure. Millibars are the units meteorologists commonly use to express atmospheric pressure.

As Figure 3-2 depicts, a low pressure system has its lowest pressure area in the center of the system, whereas a high pressure system has its highest pressure in the center.

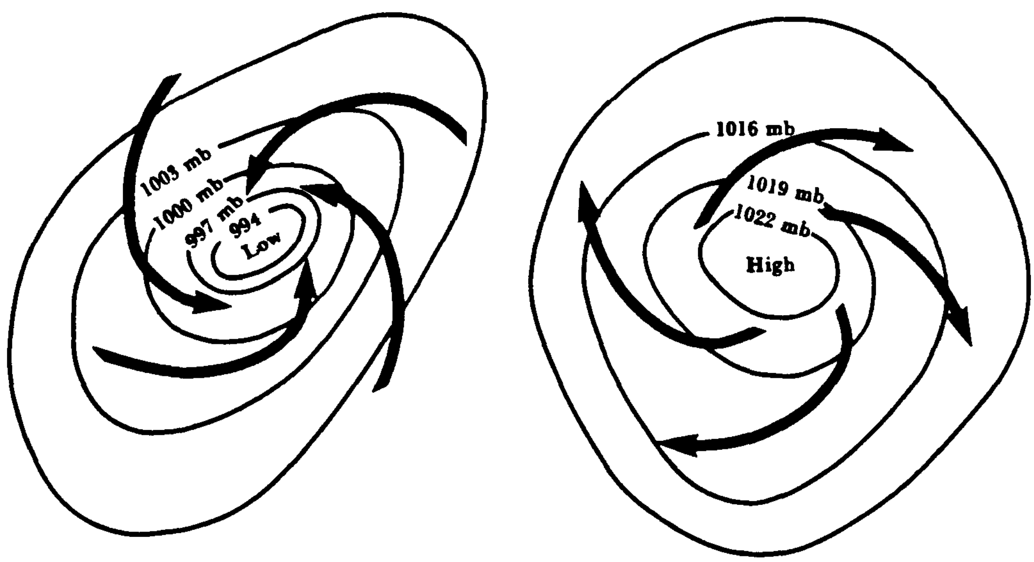


Figure 3-2. High and low pressure systems.

The figure also shows that wind moves from an area of higher pressure to an area of lower pressure. This means convergent air circulation or circulation *into* the center of a low pressure system and divergent air circulation or circulation *out* from the high pressure system. Lows are called *cyclones*, and highs are called *anti-cyclones*. The air in low pressure systems circulates counter-clockwise and circulates clockwise in highs.

Now, *remember that cold air is heavier than warm air*. With air temperature in mind, let's look at what typically happens around lows and highs.

As air moves into the low pressure system, it warms up and begins to rise. As it rises, it cools and water vapor condenses to produce clouds and precipitation. Low pressure systems are generally characterized by moderate to high wind speeds and tend to move more quickly than high pressure systems.

The conditions characterizing lows—cloudiness, precipitation, rapidly moving stormy weather and relatively high winds—are generally good for the dispersion of air pollutants.

Around a high pressure system the air tends to flow out of the high pressure area near the surface of the earth and air from aloft sinks to replace it. As the air sinks, its temperature rises, creating conditions unfavorable for cloud formation and precipitation. Clear skies result. High pressure systems usually cover a large area and move more slowly than lows.

The conditions characterizing highs—clear skies and relatively low wind speeds—tend to lead to relatively stagnant air, which is not generally favorable for the dispersion of air pollutants.

The table in Figure 3-3 summarizes conditions commonly associated with high and low pressure systems.

Meteorological factor	High (anticyclone)	Low (cyclone)
Pattern of circulation	Divergent (spiraling out)	Convergent (spiraling in)
Vertical air movement	Sinking, subsiding	Lifting, upward movement
Clouds	Clear skies, no precipitation	Clouds, precipitation
Winds	Calm or low winds circulating clockwise around center	Moderate to high winds circulating counter-clockwise around center
Size	Cover a large area, move slowly	Cover a relatively small area, move quickly
Pollutant dispersion	Relatively little dispersion; relatively high pollutant levels	Relatively great dispersion; relatively low pollutant levels

Figure 3-3. Summary of high and low systems.

Representation of Meteorological Information

Every discipline has its own language, jargon, and symbols. Meteorology relies very heavily on visual symbol systems to represent various weather phenomena. This lesson will look briefly at two visual tools that are indispensable to the meteorologist: the **weather map** and the **meteorological rose, or wind rose**.

Weather Maps

You learned in Lesson I that the National Weather Service's 800 stations across the country make weather observations each hour and transmit this data to the National Meteorological Center where they are analyzed and synthesized. The Center then plots the weather data on a map for the appropriate location in a systematic manner, following an international meteorological symbol system known as the "station model." Once the information is amassed and plotted on a map, the Center sends back comprehensive forecasts to local stations.

Look at the weather map segment (Figure 3-4) for a few moments. Notice the station model legend in the lower left corner.

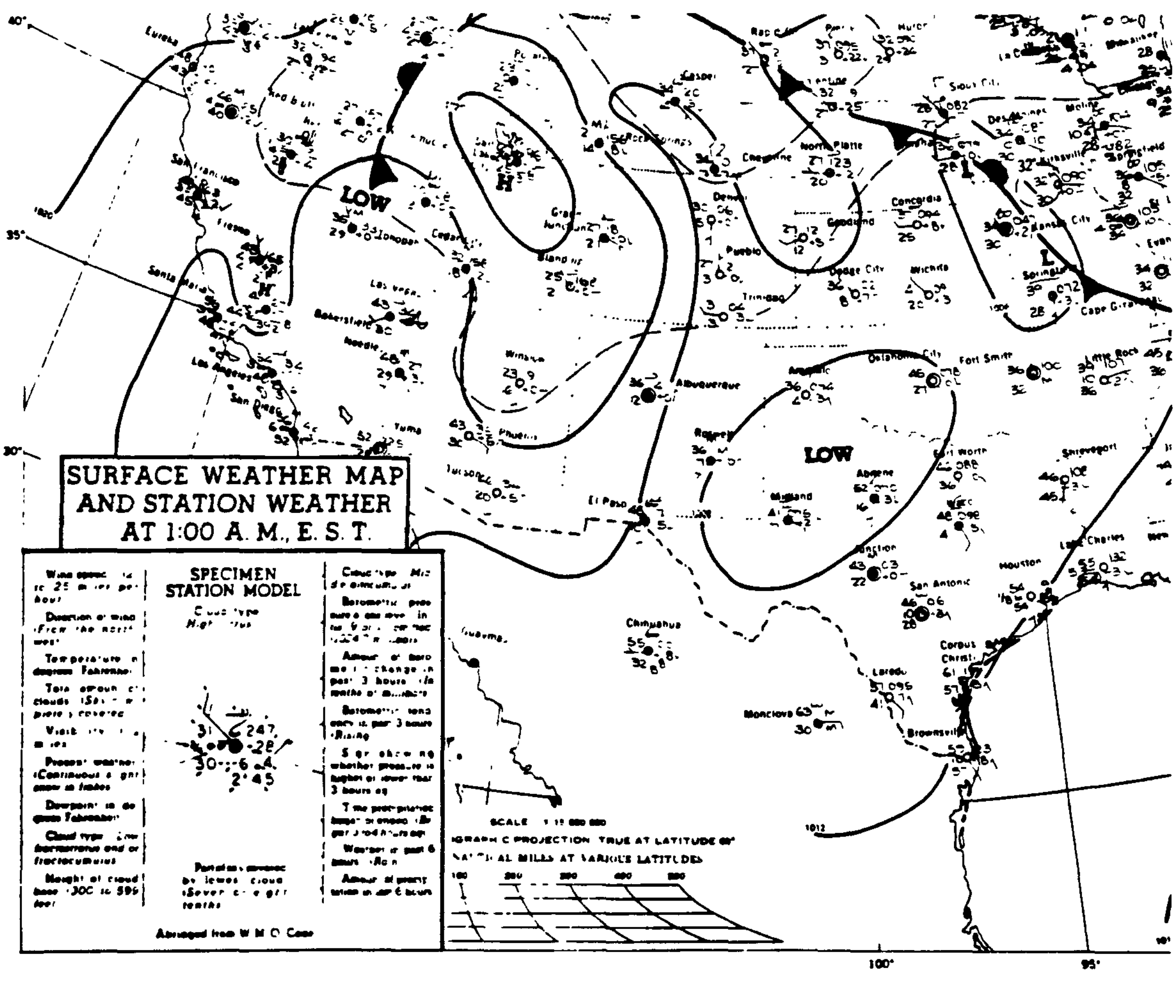
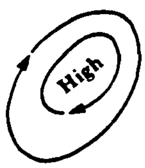
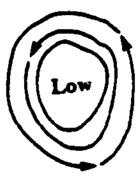


Figure 3-4. Station model weather map.

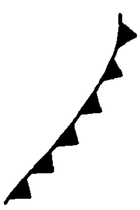
As you can see, a great deal of information is represented on a map. It has been said that the analyzed weather map represents more information than any other chart in existence. As you might imagine, the process of weather map analysis is very complex indeed. It is not the intention of this unit to teach weather map analysis. However, you will need to recognize and be familiar with some of the most important symbols on a weather map. These are discussed below:



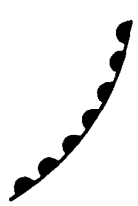


High pressure systems and low pressure systems are represented by lines called isobars, which join points of equal pressure. As you learned in the previous lesson, because joining all points on a map with the same pressure would result in a maze of lines, isobars are usually drawn at pressure intervals of 3-5 millibars. On weather maps the words *high* or *low* always appear in the center of the pressure system.

In daily weather reports we often hear about frontal systems, and/or cold and warm fronts. Fronts represent a zone of discontinuity between adjacent air masses possessing different temperatures. More simply put, a *front* is the *boundary between two different air masses.*



The symbol on the left represents a *cold* front. A cold front is defined as a front along which cold air replaces warm air. Black wedges are the standard cold front symbols and are always shown on the side toward which the front is moving; that's to say they point into the warm air. The air masses depicted by this front are moving from west to east (left to right on this page).



The symbol on the left represents a *warm front*. A warm front is defined as a front along which warm air replaces cold air. A warm front is indicated by black semicircles drawn on the side of the front toward which it is moving—that is to say in the direction of the cold air. The warm front depicted here is moving from east to west, (right to left). Fronts, the boundaries of air masses, clearly have a pronounced influence on weather change and for that reason are very important to meteorologists.

The station model legend given on every weather map will aid you in interpreting what is happening around a given weather station. You should be able to recognize the following symbols and notations without referring to the legend.

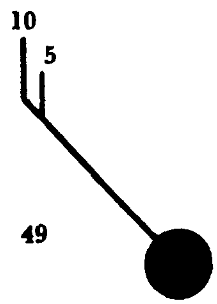


Figure 3-5. Station model notation.

The dots and circles that speckle a weather map denote the *weather stations* from which various meteorological information is reported. The flags emanating from the stations are wind direction symbols; they denote the direction from which the wind is blowing. In Figure 3-5, for example, the wind is blowing from the northwest, at 15 miles per hour. The flags denote wind speed. A short flag represents 5 miles/hour and a long flag represents 10 miles/hour.

On any weather map there will be a lot of numbers surrounding a station symbol. You should be able to immediately recognize the number in a 10 o'clock position as *temperature*. In Figure 3-5, 49 °F is the temperature.

Now turn back to the weather map (Figure 3-4) and practice identifying the symbols that have been discussed.

Wind Roses

Wind rose is a term used for one of a number of diagrams that show the distribution of wind direction recorded at a location over some predetermined time period. In this manner, it shows the prevailing wind direction. The most common form is a circle of 16 lines emanating from the center, one for each compass point. The length of the lines is proportional to the frequency of wind from that direction; and the frequency of calm conditions (no wind) is entered in the center. However, many variations exist. Some relate wind direction and other meteorological occurrences.

The wind rose depicted (Figure 3-6) is a 16-point wind rose portraying percentage of wind frequency from 16 directions: N, NNE, NE, ENE, E, etc. The number in the center represents the percentage of calms for the period of time the wind was observed, in this instance a period of one month. The numbers 5, 10, 15 designate percent frequency. We know from this wind rose, for example, that 10% of the time the wind was observed, there were calm conditions, and that 5% of the time the wind prevailed from the north. From what direction did the wind most frequently prevail during the month according to the wind rose in Figure 3-6? From which three directions did the wind least frequently blow? What percentage of time did a south wind occur?

Do not continue until you have responded to the questions.

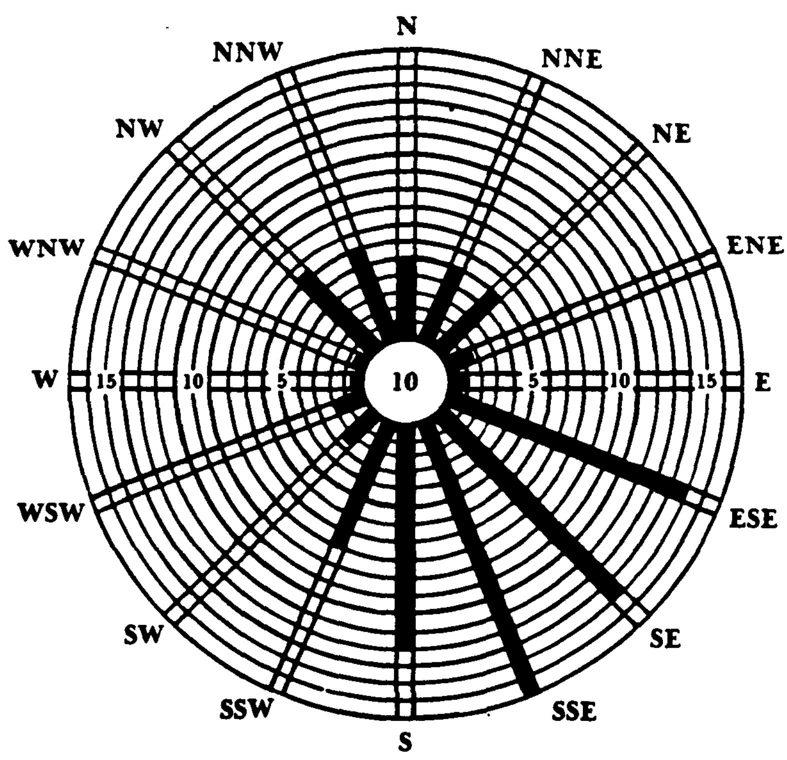


Figure 3-6. Wind rose.

The wind rose depicts that the wind most frequently blew from a *SSE* direction. According to the rose, the three directions from which the wind least frequently blew (about 1% of the time) were the *E*, the *W*, and the *WNW*. There was a south wind, according to the rose, 13% of the time.

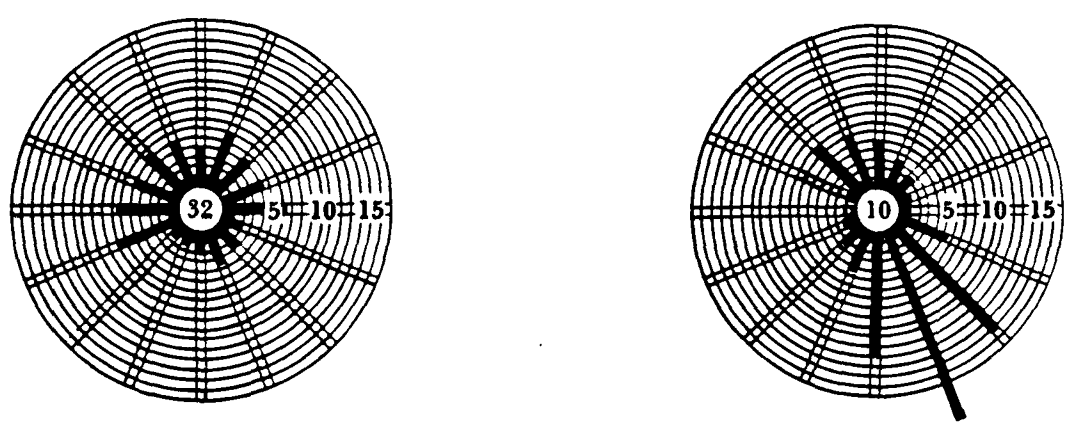
If you missed any of these questions, please review the discussion of wind roses and try answering the questions again. In addition to interpreting wind direction and calm frequency from a wind rose, you should keep in mind why wind roses are important to air pollution meteorology. You learned in Lesson II that both wind speed and direction are very important in air pollution control. Direction is important because it determines the receptors of pollutant emissions. Wind roses document wind direction over a considerable period of time for a location — a month, a year or several years — and, they are thus a valuable wind direction resource to the air pollution meteorologist.

Pollution Rose

A specialized type of wind rose that is especially important in air pollution meteorology is the **pollution rose**. A pollution rose portrays wind direction frequency *only* for winds having a certain amount of a particular pollutant concentration.

A sulfur dioxide pollution rose would show wind direction frequency only for winds containing a certain amount of SO_2 — concentrations greater than 200 $\mu g/m^3$, for example.

Since transport of pollutants depends in great part on wind flow, a pollutant-specific wind rose is very helpful in relating air pollutant and wind data. Figure 3-7 depicts a pollution rose and a wind rose for Seattle for a period of one month. Compare them.



Pollution rose **Wind rose**

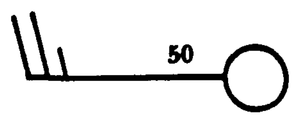
Figure 3-7. Pollution rose and wind rose for Boeing Field, Seattle, October, 1962.

In this lesson, specific meteorological factors—*solar radiation, precipitation*, and *humidity*—have been discussed in terms of the role each can play in affecting air pollution. We have also discussed large scale weather systems, the meteorological characteristics of each, and two indispensable meteorological tools.

Now test your understanding of this lesson by responding to the following questions.

Questions

1. From the symbols depicted below, answer the following questions:
   a. what is the wind speed?
   b. what is the temperature?
   c. what does the large circle represent?
   d. what is the wind direction?



2. Isobars are the curvilinear lines on weather maps which (list all which apply):
   a. join points of equal pressure.
   b. delineate areas of precipitation.
   c. delineate high and low pressure systems.
   d. show wind direction.
   e. show cold fronts.
   f. are drawn at pressure intervals of 3-5 millibars.
3. Provide a positive and a negative example of the effect water vapor in the atmosphere can have on air pollution.
4. A detrimental mesoscale effect of solar radiation on air pollution is:
   a. thermal turbulence.
   b. it causes the mixing depth to increase.
   c. photochemical smog.
   d. acid rain.
5. The longest spike emanating from a typical wind rose is along the WNW direction. 20 is the number in the center of the rose. The wind rose is depicting:
   a. predominant wind direction for a 20 month period was from the WNW.
   b. winds blew from the WNW at 20 mph.
   c. winds blew predominantly from the WNW. 20% of the observation time there were calm conditions.
   d. pollution most frequently blew from the WNW.
6. A pollution rose:
   a. is another name for a wind rose.
   b. is a type of wind rose showing wind direction frequency for winds having a certain amount of a particular pollutant concentration.

Answers

1. a. wind speed — 25 mph
   b. temperature — 50 °F
   c. large circle — National Weather Service Station
   d. wind direction — West
2. Isobars are the curvilinear lines on weather maps which
   a. join points of equal pressure
   c. delineate high and low pressure systems
   f. are drawn at pressure intervals of 3-5 millibars
3. a. Precipitation can act as a positive influence on air pollution by washing pollutant particles out of the air.
   b. A negative effect of water vapor is that it can combine with other pollutants in the air to produce more dangerous secondary pollutants. You may have provided the specific example of sulfur dioxide (SO_2) combined with water (H_2O) to form sulfuric acid (H_2SO_4), a highly corrosive substance.
4. c. photochemical smog
5. c. winds blew predominantly from the WNW. 20% of the observation time there were calm conditions.
6. b. is a type of wind rose showing wind direction frequency for winds having a certain amount of a particular pollutant concentration.

If you responded correctly to these questions, you're in fine shape. However, you may want to review any information you're not sure about before testing your knowledge of air pollution meteorology by taking the post-test.

Post-Test

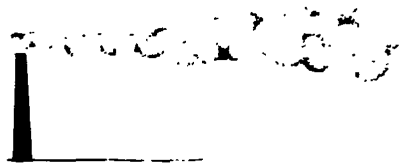
Classify the 3 following air pollution control situations according to the scale of motion each represents.

1. A tall stack is built for a fossil-fuel-fired steam generator that supplies electricity for a region. The plant is located in the lee of a hill, and wind flow over the hill causes emissions to downwash almost immediately after leaving the stack.
2. A city located at the foot of high mountains has a climate characterized by many sunny days and clear nights each year. This sets up a down-valley wind flow at night and an up-valley wind flow in the afternoon, creating a "recycling" of air. Thus there may be little actual change of air in this area for several days.
3. Industries were originally located in mountain valleys in the Appalachians where coal was cheap and plentiful and water was available. Emissions increased as these industries grew and prevailing down-valley winds at night frequently caused odor and smoke irritating to residents for miles down the valleys.

Choose the best explanation of the role wind, stability, topography or other meteorological factors play in the following situations:

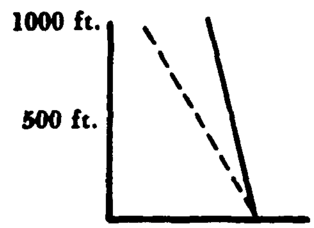
4. A factory emits the same amount of pollution on a clear summer day and on a cloudy, calm winter day. The ground level concentration of pollutants in the vicinity of the plant would most likely:
   a. be greater on the summer day because of the greater mixing height.
   b. be the same on both days.
   c. be greater on the winter day, because of the shorter mixing height.
   d. be mixed in a greater volume of air on the winter day.
5. On intermittent occasions during the year a large number of complaints are received by the air pollution control agency about unpleasant odors and smoke. In tracking down the source for this nuisance, the first meteorological factors which should be considered are:
   a. wind direction and mixing depth on the days that the complaints are received.
   b. topographical features of the area where the complaints originate.
   c. occurrence of heavy rainfall and high humidity on the days when the complaints are received.
   d. wind speed considerations on the days that the complaints are received.

6. The weatherman announces that a low pressure system, characterized by cloudy weather, occasional thunderstorms, and moderate winds, will be moving into the area. For the air pollution expert concerned with dispersion of pollutants, this weather pattern means:
   a. poor dispersion, since pollutants will be trapped under a layer of clouds.
   b. good dispersion, since there is likely to be a highly unstable atmosphere and a lot of vertical mixing.
   c. moderate to good mixing, with moderate winds, some precipitation, and a system which is likely to move through the area fairly quickly bringing new masses of air in which to mix pollutants.
   d. poor mixing since low pressure systems are often stagnant for several days.

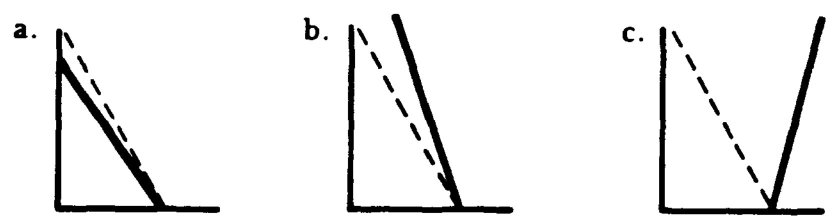


7. What is the most likely explanation of the conditions depicted in the sketch above?
   a. the atmosphere is unstable.
   b. the atmosphere is slightly stable.
   c. the atmosphere is inverted.
   d. the atmosphere is very unstable.
8. A plume observed from a pollution source is a fanning plume. Which environmental lapse rate would most likely produce this kind of plume?
   a. 6 °F decrease in temperature per 1000 feet of altitude
   b. 5.4 °F decrease in temperature per 1000 feet of altitude
   c. 3 °F decrease in temperature per 1000 feet of altitude
   d. 5.4 °F increase in temperature per 1000 feet of altitude
9. The best explanation of the conditions depicted below is:
   a. It is a sunny day and a high pressure system is moving through bringing high winds.
   b. It is early in the morning. The sun has just risen.
   c. It is a sunny day and unstable conditions prevail.
   d. It is about to rain.

10. The conditions depicted below are not very favorable for good dispersion of air pollution. The most likely reason for these conditions is:
   a. It is a clear day; the air near the surface is very warm because the earth is conducting heat absorbed from the sun. Conditions are unstable.
   b. It is cloudy; the air temperature near the ground is nearly the same as the air temperature aloft. Conditions are slightly stable.
   c. It is after sunset on a clear day; the air near the ground has cooled off more rapidly than the air aloft. Conditions are stable.
   d. It is a windy day.



11. It is 9:00 p.m. and a fanning smoke plume extends over a mile from a factory stack. What does the lapse rate most likely look like?

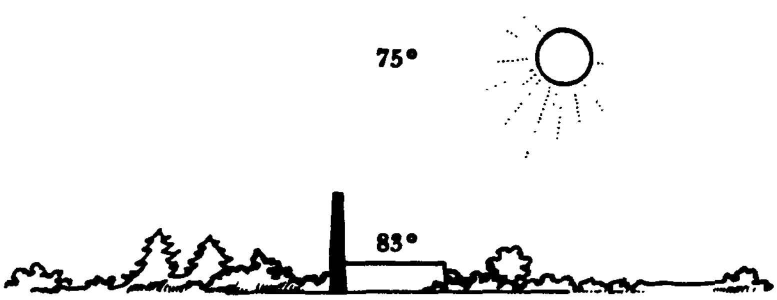


12. Los Angeles, located between the mountains and the ocean has many days of sunshine each year. Pollutants are shuttled back and forth between mountains and the ocean. The problem in Los Angeles can be said to be due to:
   a. the sun, in the formation of photochemical smog.
   b. the concentration of industrial and automotive pollutant sources.
   c. topographical features.
   d. all of the above.

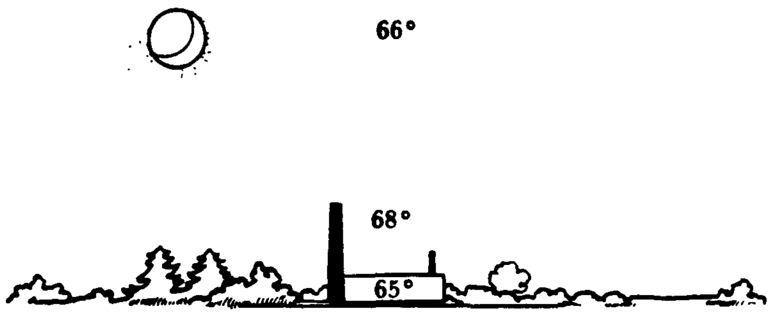
13. A heavy summer thunderstorm hits a midwestern town where dust from plowing and particles from grain storage processing and lumber mills have reached troublesome levels. In this case the rain:
   a. could be dangerous because it might form acids by reacting with the particles in the air.
   b. will affect the temperature at the earth's surface and thereby aggravate the surface pollutants.
   c. will have a favorable effect, since it will most likely wash the dust and particles out of the air.
   d. will not effect the particulate matter levels.
14. The formation of secondary pollutants can be activated by:
   a. water vapor.
   b. solar radiation.
   c. strong winds.
   d. both a and b.
15. Water vapor can act as a positive influence on air pollution when:
   a. it condenses as precipitation.
   b. combines with other chemicals in the atmosphere.
   c. it evaporates.
   d. it saturates the atmosphere.

Categorize the pollutant dispersion for the following situations as good, moderate, or poor.

16. It is a summer day with cloudless skies and light winds. The sun is hot and is warming the air near the surface. An industrial plant located in open country can expect what kind of dispersion for its emissions? (GOOD, MODERATE, POOR) (The diagram below represents the conditions.)

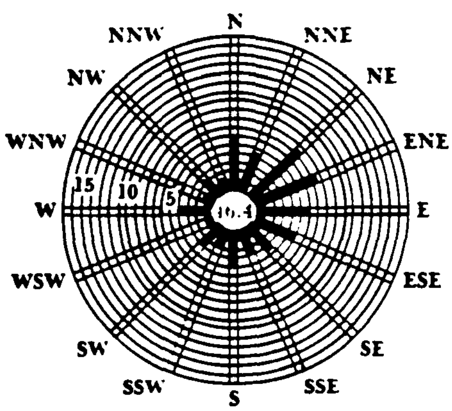


17. After sunset on this same day (see 16) the air near the ground begins to cool rapidly. The sky is still clear, and the winds die down until they are calm. By the time the lowest temperature for that night is reached, the temperature pattern looks like that below.
   a. What kind of dispersion would the emissions from the short stack have? (GOOD, MODERATE, POOR)
   b. What kind of dispersion would you expect from the tall stack?



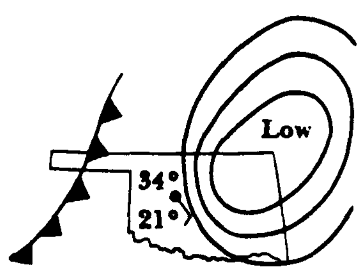
18. On a cloudy day in midwinter, the temperature is 53 °F at surface level and 52 °F at 1000 feet. Winds are light with occasional gusts. What kind of dispersion would you expect? (GOOD, MODERATE, POOR).

19.



The wind rose depicts the frequency of occurrence of wind direction. We know from the rose shown that:
   a. the wind blew from the east less frequently than from the north-northeast.
   b. the combined frequency of the west and west-southwest is 8%.
   c. the wind was calm 46.4% of the time.
   d. the winds blew more frequently from the southwesterly directions than from the northeasterly directions.

20.



Identify statements that are true about the basic symbols depicted in the abridged weather map of Oklahoma represented to the left:
   a. there is a low pressure center to the east of Oklahoma.
   b. a cold front has moved over Oklahoma from the southeast.
   c. the wind is blowing into the station from a SSE direction at 10 mph.
   d. a warm front is moving through from the west.
   e. the temperature at the station is 21 °F.
   f. the temperature at the station is 34 °F.

Answers

1. microscale
2. mesoscale
3. mesoscale
4. c.
5. a.
6. c.
7. b.
8. d.
9. c.
10. b.
11. c.
12. d.
13. c.
14. d.
15. a.
16. GOOD
17. a. POOR
    b. MODERATE
18. MODERATE
19. c.
20. a., c., and f.