APPENDIX C

W e a t h e r

Field behavior of NBC agents, smoke, and other obscurants depends upon weather variables, which are wind, temperature, vertical temperature gradients, humidity, and precipitation. The influence of each variable depends upon synoptic or general weather conditions. Local topography, vegetation, and soil affect these variables.

Weather also determines the effectiveness of agents and possible downwind hazards.

This appendix discusses weather elements and primary weather factors in further detail for you to work with your forecaster on how best to employ chemical agents, smoke, and other obscurants or to defend against NBC agent use.

Elements

This section will outline several basic weather elements that must be understood. The weather elements discussed will include the atmosphere, wind speed and direction, atmospheric turbulence, air and surface temperatures, humidity, dew point, clouds, precipitation, and atmospheric stability. In this section, each element will be discussed to provide the needed background information for the NBC staff officer.

Atmosphere

The sun is the fundamental source of energy for the earth and its atmosphere; its influence is felt in the radiant energy that is the basic source of heat to the atmosphere. The spherical shape of the earth causes the unequal absorption of this energy by the earth's surface and the atmosphere. The unequal heating results in a strong poleward transport of heat from the equator. Without the transport of heat by the atmosphere and the oceans, temperatures would be much colder at the poles and much warmer in equatorial regions.

A revolution of the earth around the sun takes one year or 365-1/4 solar days. Every fourth year is 366 days long, hence leap year. The revolution of the earth about the sun is associated with four seasonal changes. If the plane of the earth's orbit were in the plane of the equator, there would be only a small seasonal change. Figure C-1 shows an explanation of the four seasons. A season is one of the four quarters into which the year is divided. Figure C-1 shows that the earth wobbles (is

inclined) at an angle of approximately 23-1/2 degrees north and south from the equator. This wobble and revolution (tilt and movement) around the sun are responsible for the four seasons. The winter solstice (Tropic of Capricorn) occurs when the sun, with respect to the earth, is farthest south. Conversely, the summer solstice (Tropic of Cancer) occurs when the sun is farthest north. The two points midway between the solstices occur on the equator two times each year when the sun crosses the equator. Day and night everywhere are equal in length. These are known as the spring and autumnal equinoxes (about 21 March and 23 September). A year is divided into 12 months (or one-twelfth of a year). A month equals four weeks or 30 days. A season is composed of 91-1/4 days.

The atmosphere is the envelope of air that surrounds the earth and is bound to it by the earth's gravity. The atmosphere extends from the solid and liquid surfaces of the earth to an indefinite height. It may be subdivided vertically into a number of layers. The most common subdivision divides the atmosphere into a troposphere from the surface to about 10 to 20 kilometers, a stratosphere which extends to about 80 kilometers, and the ionosphere above that height. Each of these layers may be further subdivided.

In tropical latitudes, the troposphere extends from the surface to a height of 15 to 20 kilometers. In polar regions, it may be as low as 10 kilometers. The troposphere also contains about three-quarters of the atmospheric mass. It also contains nearly all of the atmospheric water vapor. Most

Figure C-1. Revolution of the earth and the seasons.

Figure C-2. Layered structure of the atmosphere.
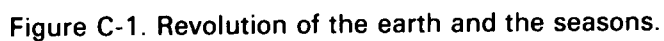
weather events are associated with the troposphere. The troposphere or "region of change" can be characterized by decreasing temperature with height, increasing wind speed with height, and considerable vertical wind motion. Weather changes in the troposphere are a function of the seasonal changes and the poleward transfer of heat. The troposphere may be subdivided into three vertical zones. These zones are the surface boundary layer, the planetary boundary layer, and the free atmosphere. The surface boundary layer extends from the air-earth interface to a height of 50 to 100 meters. The planetary boundary layer extends to heights of 500 to 1,500 meters over fairly level terrain and may be as thick as 3,000 meters over mountainous regions. Above the planetary layer is the free atmosphere. Figure C-2 illustrates the layered structure of the atmosphere.

The surface boundary layer and the planetary boundary layer—also known as the friction zone or Ekman layer—are of primary concern for NBC operations. Nearly all releases of chemical agents and smoke will be near the surface or within the bounds of the surface and planetary layers.

The following paragraphs discuss many of the characteristics of the surface and planetary boundary layers with respect to NBC and smoke operations.

Wind Speed and Direction

Wind is air in motion with respect to the surface of the earth. Vertical components of atmospheric motion are relatively small near the surface. Therefore, the term "wind" is used almost exclusively to define the horizontal speed and direction. NBC agents, smokes, and other obscurants, either deliberately or inadvertently released into the atmosphere, will travel downwind, that is, they will move in the general wind direction. Therefore, you must understand how the air moves in a given situation to be able to predict the dispersion behavior of agents. You need to understand how topography can affect the mean airflow near the surface. You should understand how obstacles such as buildings, hills, trees, and other vegetation generate gusts, updrafts, and downdrafts downwind of the obstructions. Also, you need some basic knowledge of the mean airflow within forests and other vegetative canopies.

The large-scale circulation of the atmosphere is driven by solar heating and radiation cooling and is affected by factors such as topography. Above the surface and planetary layers, large-scale air movements are determined by the general heat balance of the earth. Air is heated from below in the equatorial regions. It rises, loses heat near the poles, and sinks. Figure C-3 shows the general
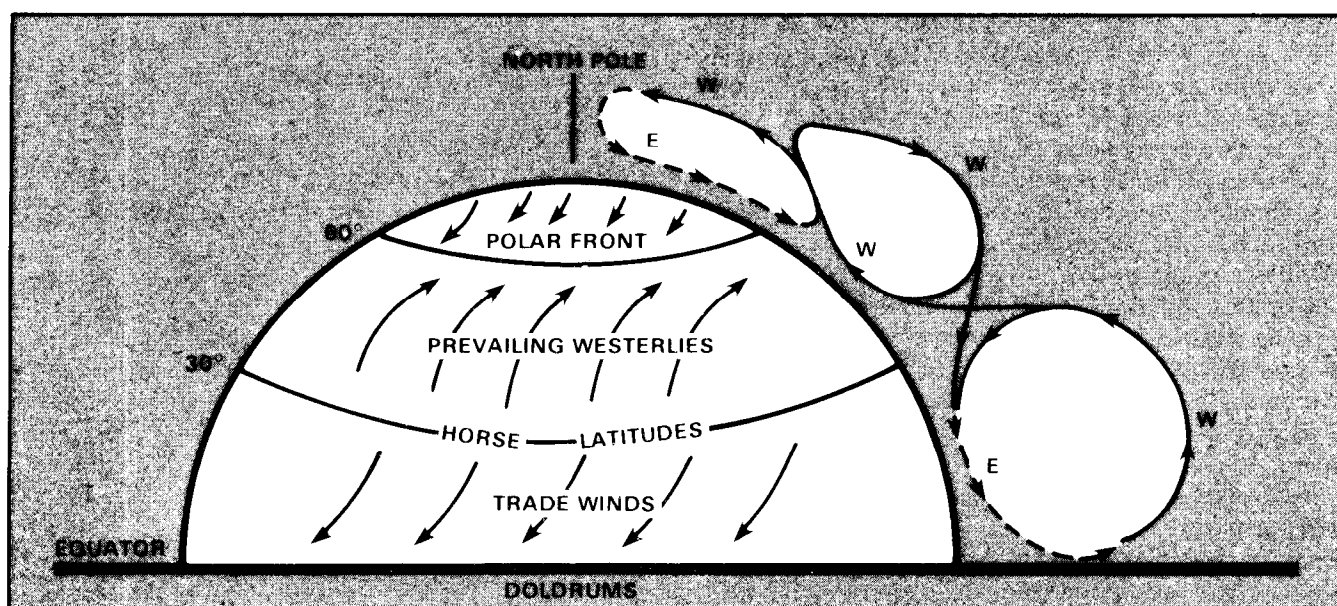

Figure C-3. General horizontal and vertical circulation, northern hemisphere.

circulation of the atmosphere on a rotating earth. In the temperate latitudes, observations show that the surface winds tend to blow from southwest to northeast. In polar latitudes, surface winds generally blow from northeast to southwest. The region between the polar and tropical air masses is the spawning ground for major mid-latitude storms. These storms generally move from west to east. They assist in transporting cold polar air southward and force the warm tropical air to rise and move northward.

It is important to know how wind direction is recorded and reported. Wind direction is the compass direction from which the wind blows. The normal flow of air is not steady. The direction will fluctuate about its mean value, randomly deviating from the prevailing direction. These fluctuations are usually larger in light wind conditions (5 knots or less) than with higher wind speeds. The basic principles governing wind change and how to interpret wind directions are important for the NBC staff officer to understand.

The US Air Force Air Weather Service meteorological forecasts for NBC operations give the direction from which the wind blows to the nearest 10 degrees measured from true north. Winds-aloft reports and aviation forecasts of upper winds also give the direction from which the wind blows to the nearest 10 degrees.

Field artillery ballistic meteorological (met) messages follow the form outlined in FM 6-40 and FM 6-15. Both field manuals give wind directions in increments of artillery mils. One degree of compass direction is equal to approximately 17.8 mils, or 360 degrees equal 6,400 mils. A ballistic met message lists direction to the nearest 100 mils, or about 5.5 degrees. For the recently adopted Standard Biological and Chemical Meteorological Message Quadripartite Standardization Agreement (QSTAG 388 and STANAG 2103), wind directions are reported to the nearest 10 mils measured from true north. In radioactive fallout and computer meteorological messages, direction is also in tens of mils. Line O of these messages refers to a surface value that may not be representative. For the ballistic met message or the computer message, line 1 gives the average wind for the lowest 200 meters of the atmosphere. Line 1 of the fallout message is for the lowest 2,000 meters of the atmosphere. An example of a fallout wind message is in Table C-1.

Table C-1. Fallout wind message.

WIND LAYER (10^3 meters)	WIND DIRECTION (mils)	WIND SPEED (knots)
0-2	1,240	9
2-4	1,420	13
4-6	1,600	18
6-8	1,780	13
8-10	1,960	9
10-12	2,310	9
12-14	2,850	13
14-16	3,200	13
16-18	3,560	18
18-20	3,740	14
20-22	3,820	18
22-24	3,910	27
24-26	3,910	26
26-28	3,910	34
30-Balloon Burst		

Figure C-4 shows the relationships governing the two basic methods of reporting wind directions. The figure also includes the generic method. This consists of the four major and four
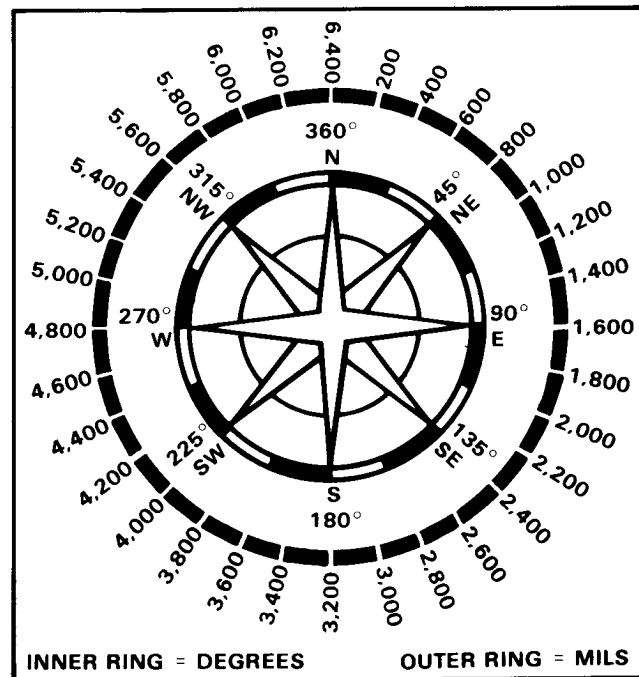

Figure C-4. Designating wind direction by compass points, degrees, and mils.

intermediate points of the compass, that is, north, northeast, east, southeast, south, southwest, west, and northwest.

Surface wind speeds and directions at any specific locale are caused by many factors and forces operating in the atmosphere. Wind speed and direction can be considered to be local phenomena and must be measured directly or observed to be useful for NBC operations and dispersion predictions.

Atmospheric Turbulence

Dispersion of NBC agents and screening smokes in the surface and planetary layers can be directly attributed to atmospheric turbulence. The interaction of weather systems on all scales at any locale results in a three-dimensional wind that varies continuously with time. These continuous fluctuations are defined as turbulence. Atmospheric turbulence results from four factors. These are (1) the mechanical or drag effects of objects such as vegetation, hills, and man-made structures protruding into the airstream; (2) the vertical rate of increase of wind speed plus the turning of the wind with height; (3) the vertical temperature structure of the atmosphere; and (4) the relative moisture content.

If the ground is rough, mechanical turbulence (Figure C-5) results, since the air passing over it rises and falls with the terrain relief or flows around obstacles, generating both vertical and horizontal turbulence. This turbulence is greater with high wind speeds because of the increase of drag. It also decreases with height.

The wind increases in speed and shifts in direction from the surface to the top of the planetary layer. This change of speed and direction with height is known as wind shear.

Atmospheric turbulence also depends upon the vertical temperature gradient. If air is carried upward, air pressure decreases, its volume increases, and there will be a corresponding decrease of temperature. If there is no exchange of heat between the ascending parcel and its surrounding environment, the process is labeled adiabatic.

There are four basic vertical temperature gradient conditions. These are adiabatic, superadiabatic, inversion, and isothermal.

Adiabatic conditions are an idealized state for the earth's atmosphere. The adiabatic lapse rate for such an atmosphere is a temperature decrease with height of 9.8°C per 1,000 meters.

If an ascending parcel of air arrives at some specified height warmer than its environment, then it will continue to rise. An ascending parcel that rises and is cooler than the surrounding air when the lifting process ceases will sink back to its original level. These two processes are known as thermal or static instability and stability, respectively.

If the air next to the ground during the daylight hours is heated by contact with the surface and by conduction until it is warmer than the air above, a heat-energy gradient exists

Figure C-5. Mechanical turbulence.

upward through the atmosphere. The warmer air tends to rise (see Figure C-6). Thus, there is a net upward flow of heat. This is known as convective turbulence. The larger the heat gradient, the greater the rate of convective mixing. Hence, the turbulent transfer is greater.

At night, mechanical turbulence is the dominating feature of the mean wind flow. At night, heat is extracted from the air and transferred to the ground. The cooling of the air next to the surface results in a temperature inversion, that is, an increase of temperature with height. The net result is an absence of buoyant motion or convective turbulence. Under inversion conditions, the mean wind flow shows a tendency to approach nonturbulent flow conditions.

On occasion, a layer of air will exhibit no temperature change with height. This is known as an isothermal condition. During the daylight hours, particularly in the first 100 meters or so of the atmosphere, lapse rates greater than adiabatic will exist. These are termed as being superadiabatic.

Knowledge of the vertical distribution of temperature is particularly important to NBC operations. The height above the ground to which an inversion exists is an important factor for determining the concentration or dosage of chemical agents. In addition, surface-based inversion heights or the height of elevated inversions plays an important role with respect to aerial spray releases or other elevated releases of agents. Dissemination above an inversion layer can result in little if any agent reaching the surface and/or a particular target area.

Atmospheric turbulence is the prime factor controlling the dispersion of NBC agents or screening smokes released into the atmosphere. Extreme turbulence dilutes an expanding puff or plume quite rapidly. Effective downwind distances are thus reduced drastically. You must remember that the most effective use of NBC agents and/or smoke will be in periods when turbulence is low and wind speeds are moderate.

Air and Surface Temperatures

Air temperature is the ambient temperature measured at about 1.5 meters above the surface. Ground temperature for NBC operations is the temperature of the surface(s) on which the agents come to rest. Ground temperatures may be many degrees warmer or cooler than the air temperature. The difference depends on the amount of radiational heating or cooling at the surface. Surface temperatures play a major role in how long liquid contamination on the surface is effective and how concentrated the vapor is above the liquid. Air temperature varies the rate of evaporation of liquid droplets in the atmosphere. Forecasts for NBC operations, therefore, should
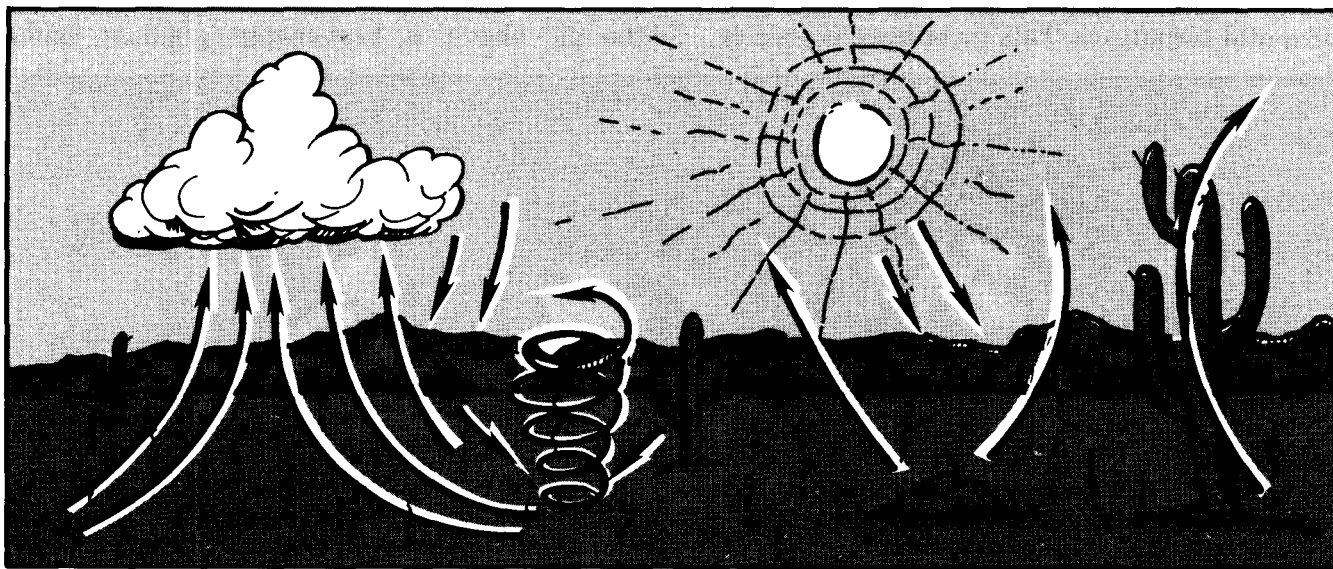

Figure C-6. Thermal turbulence.

include predicted temperatures to the nearest 3°C for air, soil, or water surfaces.

Humidity

In general, humidity is a generic term indicating a measure of the water vapor content of the atmosphere. Popularly, it is interpreted to be the same as relative humidity. Relative humidity expresses the percentage of water vapor actually contained in the air as compared to how much it would contain if saturated at the same temperature and pressure.

The surface and planetary boundary layers contain about half of all the atmospheric water vapor. Water vapor is one of the most important parts of the atmosphere. The amount in the air varies widely because of the great variety of sources of evaporation and "sinks" (condensation sites) that contribute to the hydrologic cycle. Water vapor is not only the raw material for clouds and rain; it also affects the transport of heat energy.

In warm air, high relative humidities indicate a large water vapor content. When air temperatures are low, high relative humidities do not indicate large water vapor contents, since cold air cannot hold as much water vapor as warm air.

For example, blister agents are more effective when both temperature and relative humidity are high. When the water vapor concentration is higher, people perspire more freely and skin becomes more sensitive to the effects of blister agents. Humidity is also an important consideration for use of smoke obscurants. The chemical smokes—hexachloroethane (HC), white phosphorus (WP), and red phosphorus (RP)—are aerosols that absorb water (hydroscopic) vapor from the atmosphere. As smoke particles absorb water vapor, this increases the screening power of the obscuring aerosols. For example, WP smoke screen effectiveness increases by at least 1/3 if the relative humidity increases from 30 to 50 percent.

Dew Point

Dew point is the temperature to which air must be cooled at constant pressure for it to become saturated. The dew point is convenient as an approximate measure of the water vapor present in the air. For example, if the air temperature is 16°C and the dew point is 10°C, the atmosphere would become saturated if the temperature fell to 10°C. As the temperature approaches the dew point, condensation occurs. Dew is one form condensation can take. When the difference between the temperature and the dew point is 2°C or less, fog will likely form. Forecasts for NBC operations should also include the dew point.

Clouds

Cloudiness is another variable that can influence the weather near the ground. If the sky is overcast, the amount of incoming solar radiation reaching the ground is greatly reduced. Effects on surface air temperatures and lapse rates also vary with the degree of cloudiness.

Classification of clouds is based on their form, appearance, and height. The following is a classification of clouds according to their height above ground.

Low clouds .2,000 meters

Middle clouds . . . . .2,000 meters to 6,000 meters

High clouds . . . . .6,000 meters and higher

Clouds of vertical . . . . .500 meters
development   to highest cloud level

Cloud coverage is the portion of the sky covered by clouds. Coverage is observed and forecast in eighths except in the United States where it is reported in tenths. For most purposes, the descriptions in Table C-2 will suffice.

The thickness of a cloud layer is estimated visually. Thin clouds are those through which the outline of the sun or moon can be seen. Thick clouds obscure the sun and look especially dark when the sun is behind them.

Persistent overcast low clouds usually indicate a neutral condition and small diurnal (daily) variations in weather factors near the ground.

Broken low clouds generally indicate a weak to moderately unstable (lapse) condition during the day and a weak to moderately stable (inversion) condition at night.

Thick, overcast middle clouds generally produce the same neutral conditions as overcast low clouds.

Broken middle clouds usually permit a moderate lapse (unstable) condition during the

Table C-2. Descriptions of cloud coverage.

SKY DESCRIPTION	SKY COVERAGE	INTERPRETATION EFFECTS ON AIR TEMPERATURE AND STABILITY
CLEAR	Less than 1/10 (or 1/8)	Few clouds; sunny day indicative of convective turbulence. Stable, cool nighttime conditions.
SCATTERED	1/10 to and including 5/10 (or 1/8 to and including 4/8)	Cloud effects disregarded if only high clouds present. For other cloud types, little effect upon air temperature or stability.
BROKEN	6/10 to and including 9/10 (or 5/8 to and including 7/8)	Usually smaller than average daily range in temperature. Predictions based upon rate of change indicated in recent reports, modified by the major tendency for rising temperatures until approximately 1400 hours, and decreasing temperatures in the evening and during the night.
OVERCAST	9/10 (or 7/8) to 10/10 (or 8/8)	Atmosphere probably moderately stable or neutral. Make temperature prediction from the trend indicated in the weather reports.

day and a moderate inversion (stable) condition at night.

High clouds, whether overcast or broken, tend to indicate a moderately unstable (lapse) condition during the day and a moderately stable (inversion) condition at night. High clouds are usually of low density and have a limited impact on incoming solar radiation.

Scattered clouds of all types and heights generally indicate a moderate to strong lapse (unstable) condition during the day and a moderate inversion (stable) condition at night.

A clear sky indicates a strong lapse (unstable) condition for most of the day and a strong inversion (stable) condition for most of the night if the surface wind is light or calm.

Weather clouds have no direct effect on chemical vapor or aerosol clouds, but they alter the temperature and stability categories.

Clouds have significant vertical development when their bases form at anywhere from a few hundred to 3,000 meters and extend upward from their bases to as high as 20,000 meters. Vertical development clouds originate from lapse (unstable) conditions beneath them. Under this type of cloud—regardless of its thickness or sky coverage—the temperature gradient may vary considerably. In general, vertically developed clouds over operational areas indicate that a chemical operation must contend with an unfavorable temperature gradient and turbulence. Additionally, when clouds have significant development there is strong likelihood of rain showers.

NOTE:
The AWS routinely reports cloud heights in feet and wind speeds in knots. However, cloud heights may also be reported in meters by other nations. However, kilometers per hour or miles per hour may also be used.

Precipitation

Rain and snow influence NBC operations and must be considered. Precipitation results when cloud droplets or ice crystals grow large enough to fall. It is usually accompanied by neutral or unstable conditions.

Heavy rains or snows reduce the effectiveness of agent clouds by diluting or washing chemical vapors or aerosols from the air, vegetation, and material. Air Weather Service synoptic weather forecasts predict the types, amounts, intensities, and general beginning and ending times of precipitation.

In tropical regions, afternoon showers tend to occur at about the same time each day. This tendency may also be influenced by seasonal factors, such as the monsoons. Such regularity is not common in temperate regions.

Precipitation causes some chemical agents to hydrolyze or to break down into less harmful compounds. Therefore, the amount of precipitation and the hydrolysis rate of some chemicals must be taken into account when considering the use of some chemical agents.

Atmospheric Stability

The criterion for describing the state of the atmosphere consists of dividing stability into three categories-stable (inversion), neutral, and unstable (lapse). Stable conditions are usually a nighttime condition that is assumed to exist from an hour before sunset to an hour after sunrise. The daylight hours from an hour after sunrise to an hour before sunset are presumed to be unstable. Neutral conditions are normally associated with high wind speeds greater than 15 knots or overcast sky conditions for all wind speeds, day or night. The atmosphere also tends toward neutral conditions at sunrise and sunset.

Determination of stability categories is based on the relationships between surface wind speed, incoming solar radiation, vertical transfer of heat in the surface and planetary boundary layers, cloud cover, and the time of day.

On a battlefield, NBC operations may be conducted without the benefit of forecasts or measured surface winds. As a contingency for unavailable wind information, the Beaufort wind

Table C-3. Beaufort wind scale.

BEAU-FORT NUMBER (FORCE)	MEAN WIND SPEED, KNOTS	WIND SPEED RANGE, MPH	DESCRIPTION OF WIND	SPECIFICATIONS FOR USE ON LAND
0	0	0-1	Calm	Calm; smoke rises vertically.
1	2	1-3	Light air	Direction of wind shown by smoke drift, but not by wind vanes.
2	6	4-7	Light breeze	Wind felt on face; leaves rustle; ordinary vane moved by wind.
3	11	7-12	Gentle breeze	Leaves and small twigs in constant motion; wind extends light flag.
4	16	13-18	Moderate breeze	Raises dust and loose paper; small branches are moved.
5	22	19-24	Fresh breeze	Small trees in leaf begin to sway; crested wavelets form on inland waters.
6	29	25-31	Strong breeze	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty.
7	36	32-38	Moderate gale	Whole trees in motion; inconvenience felt when walking against wind.
8	44	39-46	Fresh gale (or gale)	Breaks twigs off trees; generally impedes progress.
9	52	47-54	Strong gale	Slight structural damage occurs (chimney pots and slate removed).
10	60	55-63	Whole gale (or storm)	Seldom experienced inland; trees uprooted; considerable structural damage occurs.
11	69	64-72	Storm (or violent storm)	Very rarely experienced; accompanied by widespread damage.
12 or above	70 and above	73 and above	Hurricane *	Devastation occurs.

*The US uses 74 statute mph as the speed criterion for a hurricane.

scale may be used to estimate wind speeds and is given in Table C-3. The scale provides an estimate of mean wind speed, an associated range about the mean, and a description of the observed wind effect upon easily recognized features of a landscape, such as tree leaves and limbs. Table C-3 is easy to use, even by the inexperienced. It is based on a description of wind conditions and the general specifications for use on land.

Factors

This section outlines factors that must be considered for the analysis of NBC operations. Assessing some of these factors will be difficult under combat conditions because of the probability of very limited observations and intelligence concerning the battlefield and the target area.

The primary factors affecting a forecast are the synoptic (general weather) situation, climatology, topography, vegetation, and soil. In this section, each factor is discussed in relation to its influence on forecasting wind, temperature, relative humidity, and the stability category. All of these must be known in planning NBC and smoke operations. The forecaster needs hourly information about these factors. This person uses this information for analysis, applying established principles.

Some of these principles are described basically in this manual, but they encompass a large part of the whole field of meteorology. Only a trained meteorologist can be expected to understand and fully exploit these principles properly. However, under combat conditions, anyone making a weather analysis must try to collect information on the following items:
- Current general weather (synoptic) situation in the target area.
- Current upper air soundings close to or representative of the target analysis. This information normally comes from artillery meteorology sections. These sections at division and higher echelons transmit upper air data to the nearest AWS detachment.
- Current surface winds in the target area.
- Topography in and around the target area.
- Times of sunrise and sunset.
- Vegetation.
- Types of soil at the target.

The first three factors are constantly changing. The last four factors are relatively constant.

Synoptic Situation

The synoptic situation is the general weather situation over an extensive area. Normally, knowledge of the synoptic situation comes from observations taken at or near the same time to afford an accurate overall picture of weather conditions. You usually receive this information in a synoptic situation map. (See an example in Figure C-7.)

In tropical areas and often in summer in the mid-latitudes, the synoptic situation changes so little or so slowly from day to day, and the sky is so often clear, that the diurnal (daily) weather variations account for much of the weather and are useful in forecasting. However, in the colder seasons of the mid-latitudes, marked day-by-day changes in synoptic situations and weather are
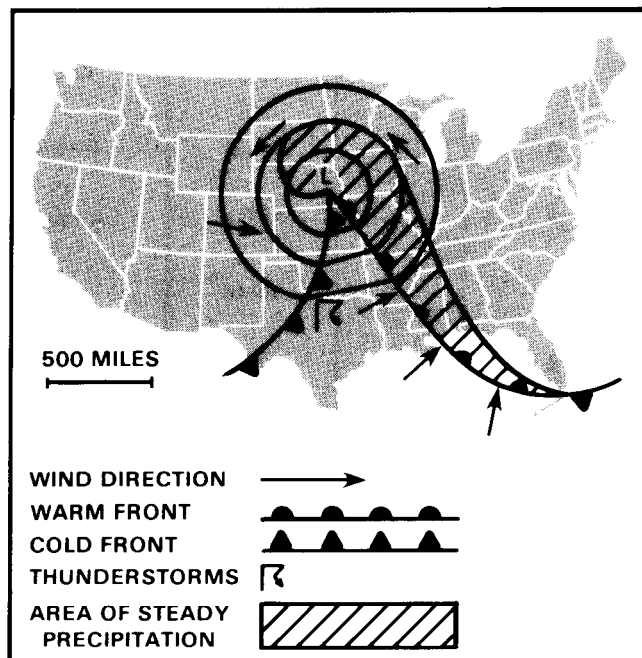

Figure C-7. Synoptic weather map.

the rule. These changes tend to obscure any daily pattern to weather elements.

Estimating changes in the general weather situation is feasible by using only local observations. It is possible to draw conclusions about changing conditions with only a general knowledge of weather prediction. For example, if the weather has been dominated by high pressure (clear skies with light winds), a trend (in the northern hemisphere) to falling pressure; rising winds from the northeast, east, and southeast; and high clouds lowering to middle or low overcast will indicate a storm or disturbance (low pressure system) is approaching and steady rain or snow may be expected in a few hours. A frontal passage followed by clearing skies and much colder air over the region is generally preceded by low overcast skies, precipitation, southerly winds, low pressure, a wind shift to the west or northwest, falling temperature, and rising pressure.

Wind speed, temperature, vertical temperature gradient, and percent of relative humidity normally follow typical day-night (diurnal) patterns as presented in Figure C-8. In Figure C-8 each vertical line represents two hours of time— between midnight to noon or noon to midnight. Low-level wind speeds experience diurnal variations (Figure C-8, A), There is a well-defined maximum wind speed in the afternoon at about the time of maximum lapse. The minimum wind speed, which is not so well-defined, occurs sometime during the night and continues until about sunrise, when the cycle begins again. Actual wind speeds, even when a diurnal variation is evident, vary with the synoptic situation, topography, and vegetation.

There is no diurnal change in wind direction except in valleys and in coastal areas where valley winds or land and sea breezes may influence wind direction and/or speed at certain hours.

Wind speed and direction may change with height. A contaminated cloud (released aloft or at the surface) will be acted upon by the winds in each layer as it passes through that layer. To predict the location and extent of the downwind hazard area, the effects of the wind must be considered within each layer as the material travels to the surface. The final hazard area characteristics (size, concentration, and cloud continuity) are determined by the collective action of each layer through which the cloud passes. (See Figure C-9 for
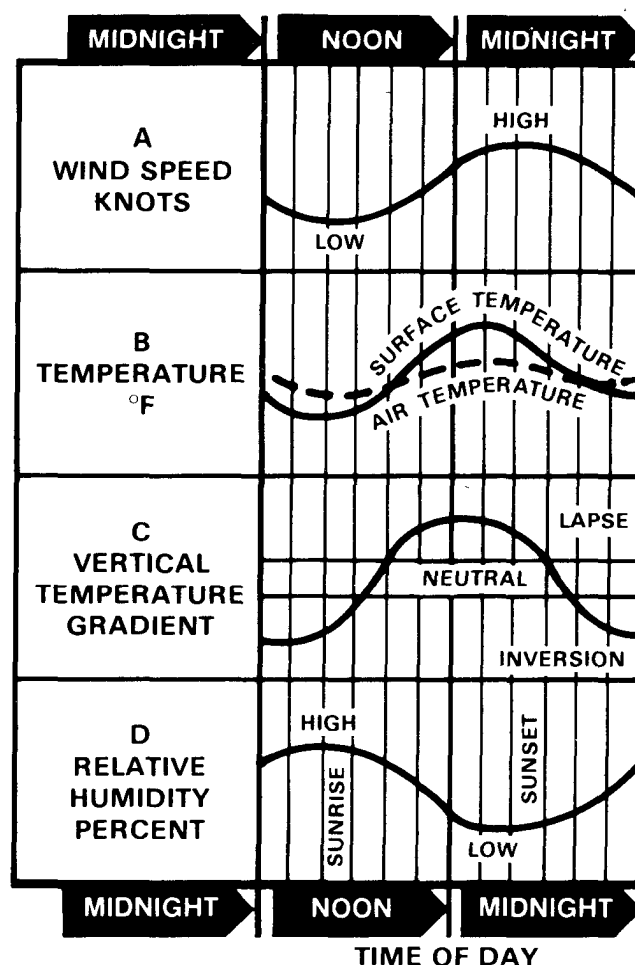

Figure C-8. Normal diurnal variations in weather conditions with reference to local times of sunrise and sunset.

an exaggerated example of this effect.)

Variations in wind speed and direction determine the lateral spread of a chemical agent cloud. The greatest lateral spread will occur under light wind conditions, because the wind direction is more likely to fluctuate at low wind speeds than high wind speeds. Lateral spread may approach 50 percent of the downwind distance the chemical cloud travels. With steady winds, lateral spread may be only about 15 percent of the distance traveled. Under average conditions, lateral spread is about 20 percent of the distance traveled.

Vertical temperature gradients are functions of the synoptic situation, cloudiness, and wind speed. With clear skies and light winds, strong inversion (at night) and lapse (during the day)

AIRBURST

100 M   WIND WEST 20 KNOTS

75 M   WIND SOUTH 15 KNOTS

50 M   WIND WEST 10 KNOTS

25 M   WIND NORTH 5 KNOTS

4 M   WIND EAST 3 KNOTS

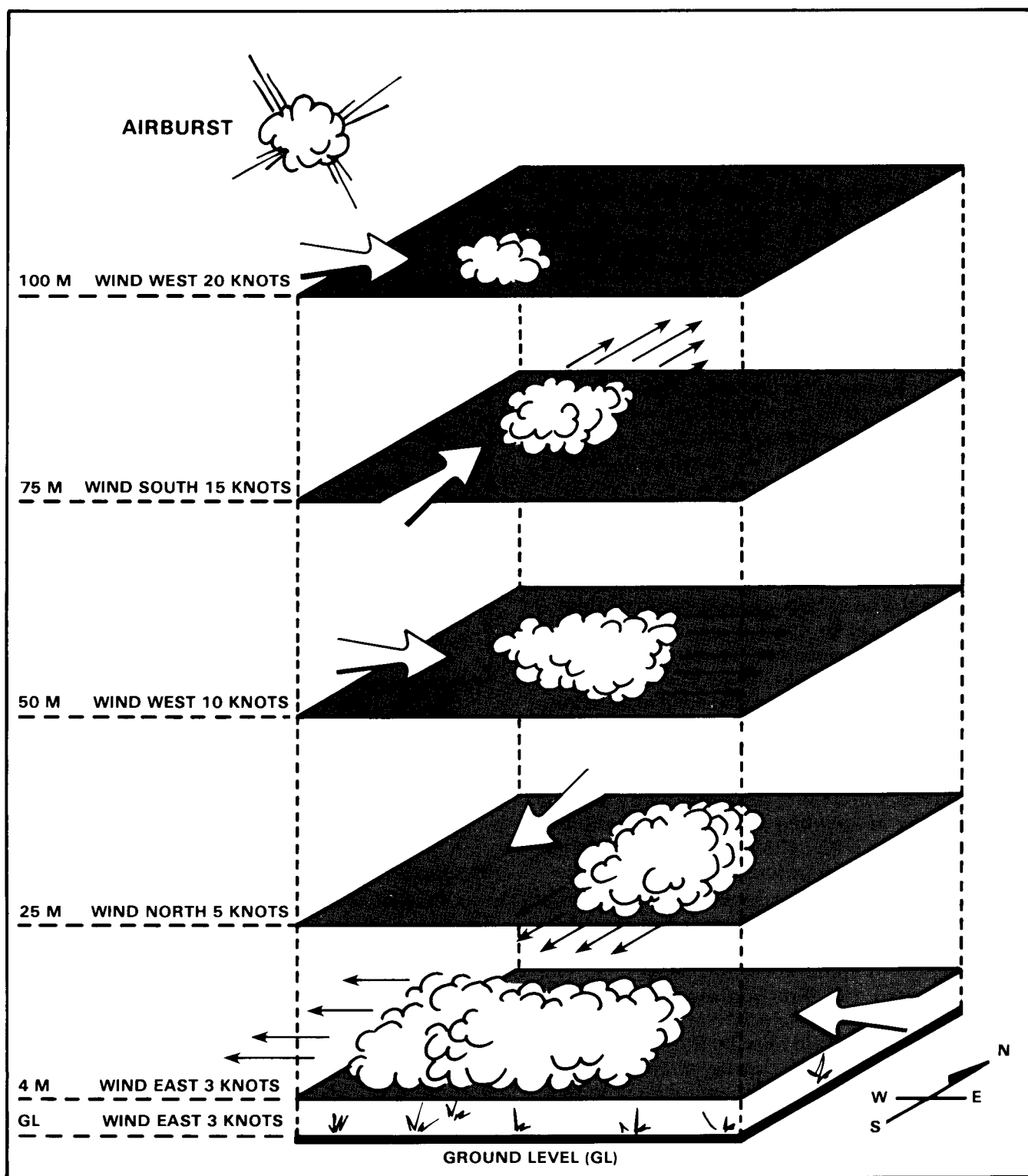GL   WIND EAST 3 KNOTS

GROUND LEVEL (GL)

N

W   E

S

Figure C-9. Vertical wind distribution and its influence on the downwind hazard area at the surface (assumes inversion condition and little turbulence).

conditions exist in the surface and planetary boundary layers.

Overcast skies indicate only a weak inversion at daybreak, with midday temperature gradients reaching values of only 1/5 to 1/4 as great as with clear skies. At night a gradient may form that will be only 1/10 that formed under clear skies.

With partly cloudy skies, temperature gradients are between the just-discussed 1/10 extremes. The temperature gradient is unaffected by cloudiness up to 3/10. With sky cover of 4/10 to 6/10, temperature gradients decrease by amounts of 1/10 to 1/5. With sky cover of 7/10 to 9/10, temperature gradients reduce by 1/5 to 1/2 of the values for clear skies.

There is a large diurnal variation in the type and degree of temperature gradient (Figure C-8, C). The variation is least in winter and decreases with increased cloudiness. In winter with overcast skies, the temperature gradient is substantially neutral throughout the day and night. When the ground is covered with snow or ice, an inversion is more probable than a neutral condition, and a lapse condition is rare regardless of clouds and time of day. The latter is especially true in polar regions.

As the wind speed increases, the strength of the inversion decreases. Ground inversions do not exist in winds over about 20 knots. Strong wind speeds tend to erase vertical temperature gradients at the surface. Strong lapse rates (unstable conditions) can result in variable and gusty winds.

Over the sea, diurnal variation in temperature gradients near the surface is almost absent. This is because of the sameness of the sea surface temperature at a given location.

In mid-latitudes, neither very stable nor very unstable conditions exist with precipitation. This may not be true in tropical or polar regions. With the formation of ground fog, a neutral or weak inversion condition is most probable in the lower layers.

The stability of the air layer above the surface boundary layer does not always indicate the temperature gradient in the lower layer. It is not possible to predict lapse conditions in the lower layer from observation or forecast strong lapse conditions aloft without considering the factors of wind, clouds, and ground temperature. A strong wind tends to stir up any stable air near the

ground and thus destroys or prevents formation of an inversion. A light wind favors the formation of inversions. Upper air soundings or radiosondes are thus very useful in forecasting weather.

The intelligence section furnishes the reported surface air temperatures. There is a pronounced diurnal trend of this temperature. The minimum temperature occurs just before dawn and the maximum in the early afternoon. The daily range in temperature increases in the lowest layer; thus, the greatest diurnal variation occurs at the surface of the earth. The diurnal range of temperature may be as great as 55°C over the desert or as small as 1°C over water; but the actual range depends upon cloudiness, vegetation, and the composition of the earth's surface.

With increasing cloudiness, outward radiation from the earth is blocked by the clouds and temperature ranges are reduced. The lower and denser the clouds, the greater their effect on modifying surface temperatures. Also, the percentage of sky covered by any particular type of cloud is a consideration. If clouds are high and scattered, the outward radiation is only about 4 percent less than that with clear skies; but if clouds are low and the sky is overcast, the outgoing radiation is approximately 90 percent less than with clear skies.

There is a diurnal trend of relative humidity in the surface layer of the atmosphere. (See Figure C-8, D.) The magnitude of the relative humidity is determined by the temperature and the absolute humidity. Maximum relative humidity occurs at the time of minimum temperature, during the early morning hours. Minimum relative humidity occurs in the afternoon, at the time of maximum temperature, if the absolute humidity remains unchanged.

If a pronounced change in weather is taking place, weather change influences the relative humidity more than does the temperature. Thus, if it is raining or there is fog, the relative humidity will be near 100 percent even though it is afternoon when relative humidity is normally at a minimum.

Climatology

Climatology is the science dealing with climate. Climate is a historical average of the

weather for a place or area over a given period. Current weather is a phase—a single element—in this average.

Personnel can use climatological summaries to determine expected weather conditions within certain probability limits to aid long-range planning. However, they should use current weather information to predict short-range conditions. Climatic and special data summaries are available for locations with weather records. The summaries can provide diurnal variations, frequencies, and correlations between elements. This information should be used as early as possible in the planning stage.

Climatological wind values at a given location are normally available for most cities and airfields but may not be available for small settlements or unpopulated areas. For these, you must estimate expected conditions, using data for nearby areas. Wind data can be obtained for specific hours of the day to show diurnal trends, or they can be averaged to show mean conditions.

An indication of the probability of different stability categories may be forecast from the climatological values of sky cover and wind for the area. Particular attention must be paid to the difference between day and night conditions, because the diurnal trend of temperature gradient under the two conditions varies widely, even though the climatological average of sky cover and wind may not.

Topography

Topography (terrain conditions) influences the wind, temperature gradient, temperature, and humidity.

A topographic (local) wind is usually described in terms of what would occur if the effects of the overall synoptic situation were eliminated. These winds may be thermally or gravitationally induced. Topography influences the wind by thermal effects and by physically diverting and altering the normal flow of wind. Figure C-10 makes use of arrows and fishhooks to show flow of the wind. Arrows and fishhooks are used in other figures to depict wind direction and motion. Air tends to follow the line of a valley. Also, air moving up a hillside does not leave the ground at the hilltop but tends to remain on the ground and travel down the other side of the hill, displaying the normal friction eddies (Figure C-10, A.)

Air crossing the crest of a hill tends to eddy (Figure C-10, B). The sharper the hillcrest and the steeper the drop on the leeward side, the more pronounced the eddy (Figure C-10, C). Heavily contoured terrain or mountainous regions tend to have sharp eddies and pronounced updrafts in the air above them. Mountain ranges may deflect the surface airflow for an appreciable distance. Steep hills split the wind so that there is an eddying around the hill as well as over it. In such cases, if the leeward side is very steep, providing shelter for the air in the valley, airflow in the valley tends to be very slight, speeds are low, and large-scale air movements are unlikely (Figure C-10, D).
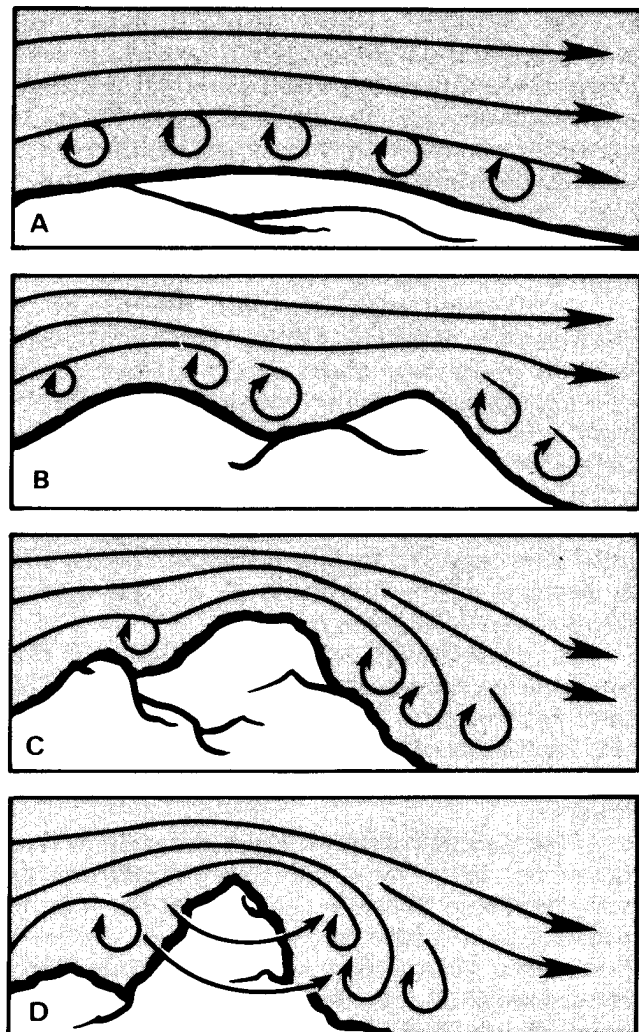

Figure C-10. Effects of terrain on wind.

Obstacles, such as buildings, large rocky outcrops, and groves of small trees, also cause eddies. Such eddies may influence the wind for a downwind distance 15 to 20 times the height of the obstacle producing the eddy. Beyond this distance, these obstacles have little influence (Figure C-11).
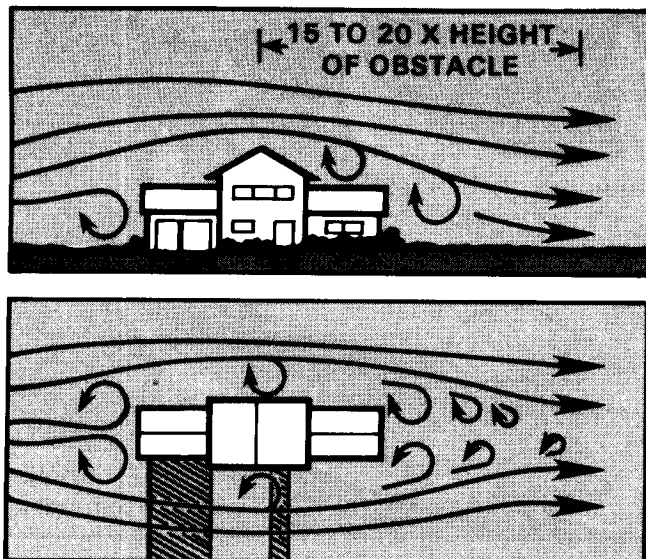

Figure C-11. Eddies around obstacles.

Air moving over a forest is turbulent where the uneven treetops disturb the air flowing over them (Figure C-12, A). Large eddies form where there is a sufficient opening or a well-defined tree line that permits the air to descend to the ground again (Figure C-12, B). The same turbulence may occur if the free air blows at right angles to a forested gully, although air in such gullies or in riverbeds is normally well protected from eddies and turbulence (Figure C-12, C).

Thermally induced topographic winds result from definite temperature differences. Examples of such winds are valley-mountain winds, slope winds, and land-sea breezes. Sea breezes and valley winds result from daytime heating of the earth's surface. Land and mountain breezes result from nighttime cooling of the ground.

Valley winds and slope winds usually are present at all latitudes where there are hills and mountains, regardless of weather conditions (see Figure C-13). However, they develop best with clear skies and weak winds aloft. In the tropics, where seasonal changes are small, such winds develop best during the dry season.

Valley winds develop best in large, broad, U-shaped valleys with gently sloping floors to high ridges, rather than in steep V-shaped valleys.
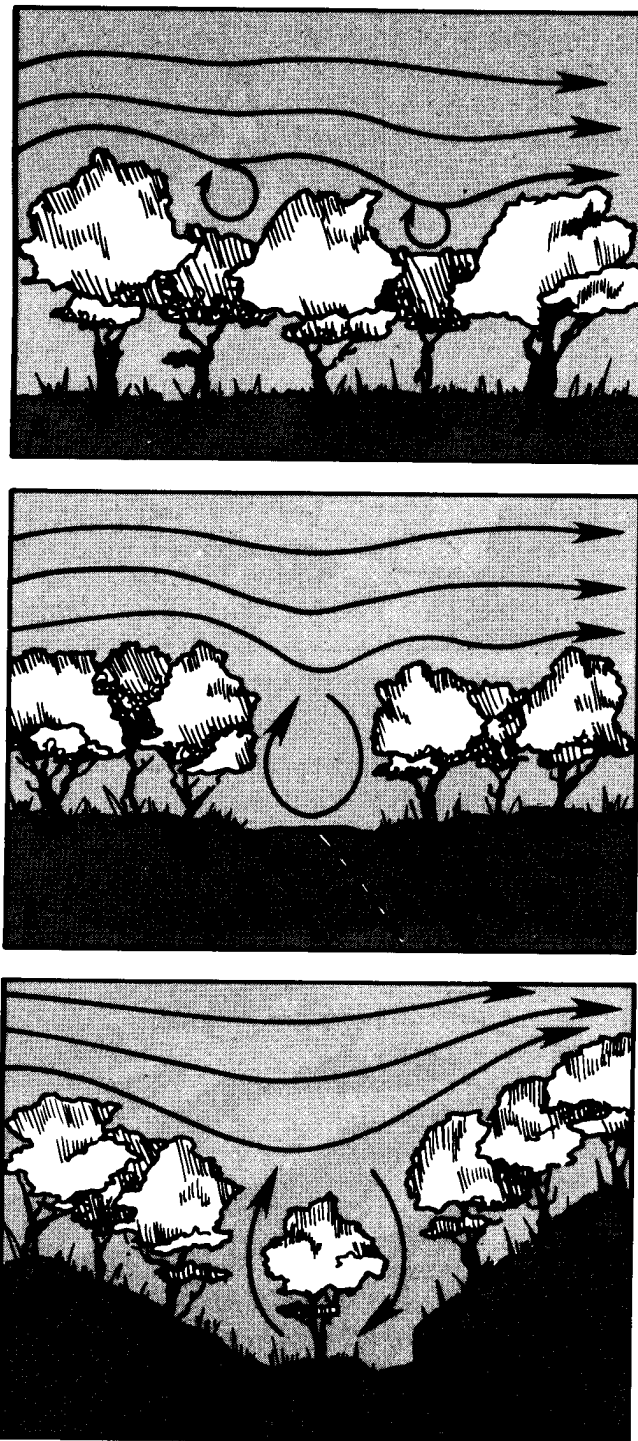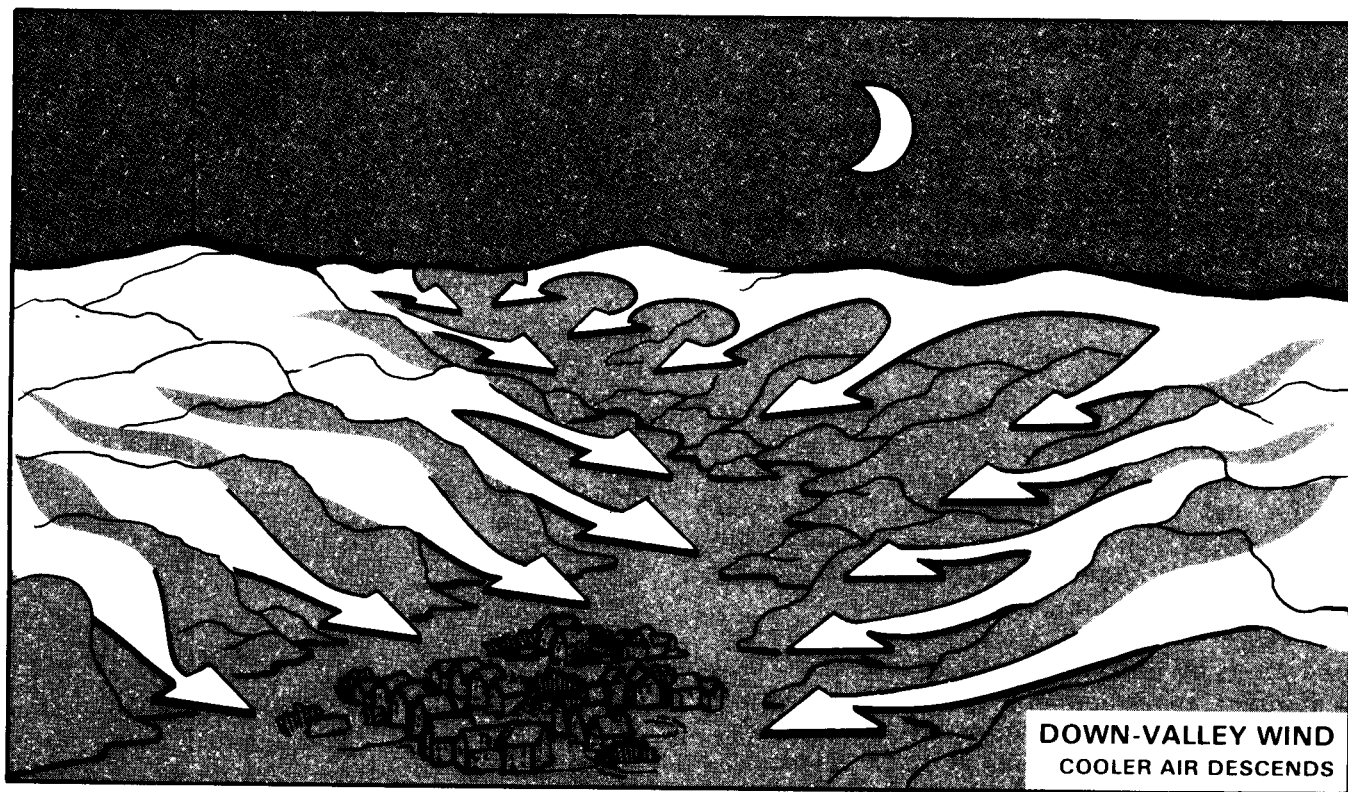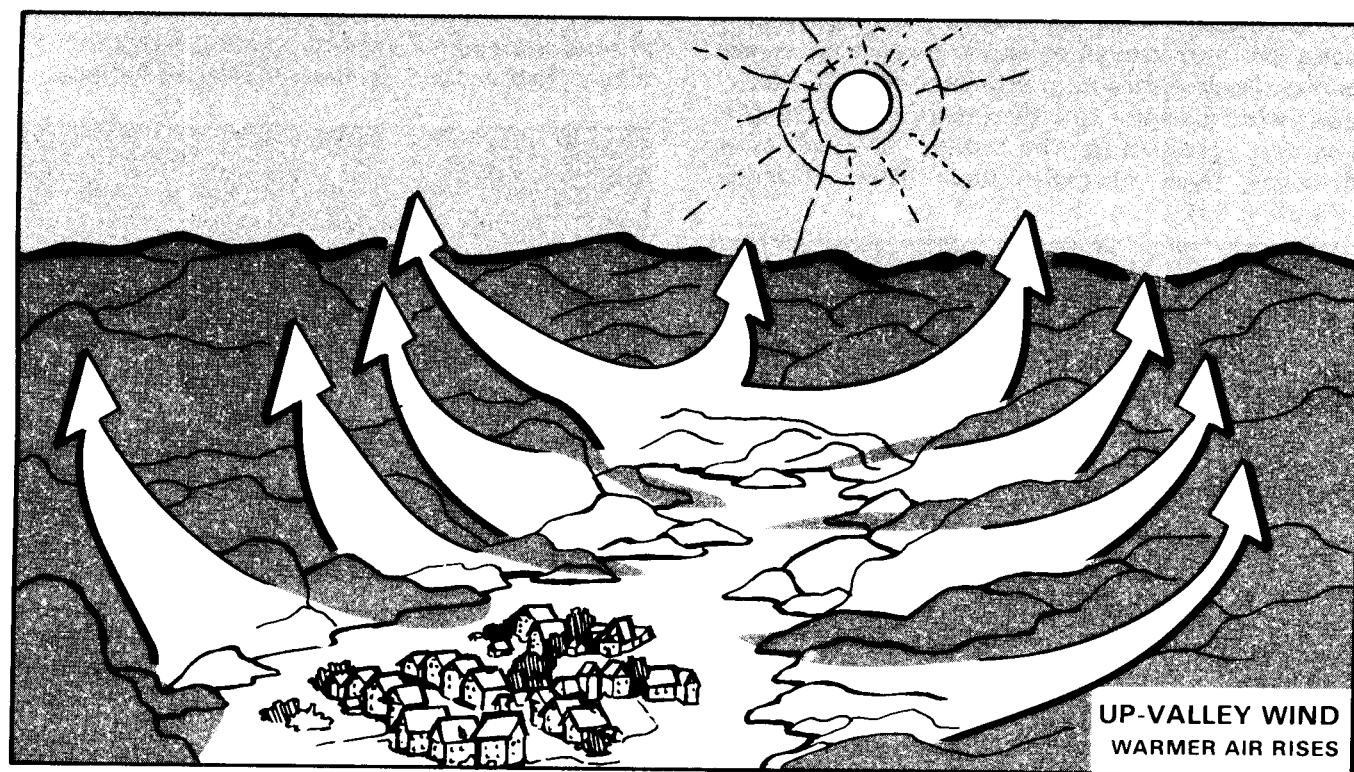

Figure C-12. Effects of forests on wind.

Figure C-13. Up-valley and down-valley winds.

Up-valley winds develop when air, heated by ground radiation, rises and moves up the valley under a layer of cooler air. This cooler air occupies approximately the upper third of the valley air mass. Up-valley winds begin one to four hours after sunrise, earlier in small valleys, and often not in large valleys until late morning. Maximum development is reached in the early afternoon in small or side valleys and at midafternoon in large valleys. Valley winds reach their maximum speed at about one-third of the ridge height. Minimum speed of valley winds occurs at the boundary of the valley system, immediately below the ridge top.

Up-valley winds have greater vertical depth than down-valley winds. Up-valley winds may fill an entire valley to the height of the surrounding ridges. These winds continue until about an hour before sunset.

Down-valley winds, resulting from cooler air flowing down along the cooling ground surface, set in one to three hours after sunset. With favorable conditions of light winds and clear skies, these winds persist until one to two hours after sunrise. They are shallower than up-valley winds, being only about 1/3 to 2/3 as deep. Their horizontal development is limited by the immediate surrounding hills.

The extent and intensity of topographic up-valley and down-valley winds are controlled by the shape of the valley, height of the ridges, sky cover, and gradient winds. Strong surface winds can obliterate topographic valley winds. Valley winds usually have slow air movements but may sometimes combine with another wind system, such as the sea breeze along a coastal valley, to cause a stronger wind. If the mouth of the valley is narrow, the down-valley wind accelerates and this effect may extend outward for several kilometers. The wind speed may increase to 30 knots or more and is difficult to predict.

Slope winds are thermally induced by hill and mountain sides. Upslope winds set in during the day and downslope winds at night (Figure C-14). On clear days, upslope winds begin 15 to 45 minutes after sunrise and stop about sunset, reaching a maximum speed around noon. It is very difficult to predict upslope winds.

Downslope winds usually begin 15 to 45 minutes after sunset and tend to persist throughout the night until shortly after sunrise. In the northern hemisphere, south-facing slopes have the most fully developed slope winds, both in
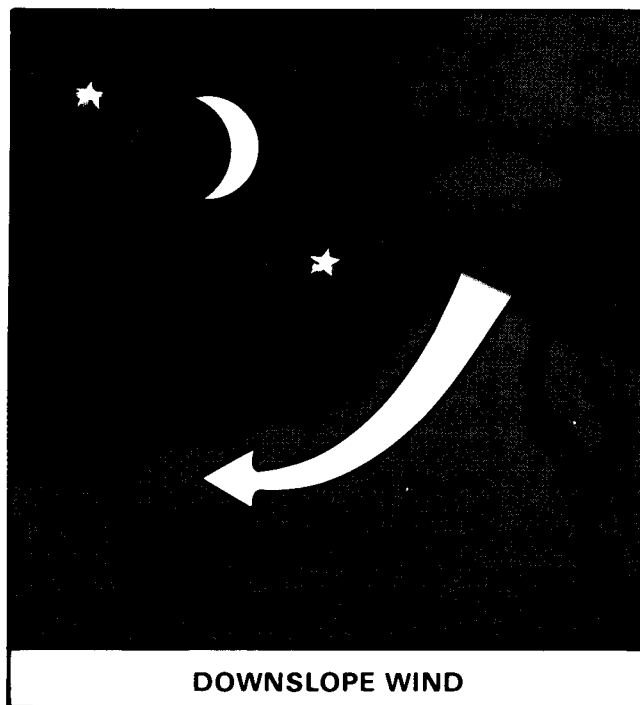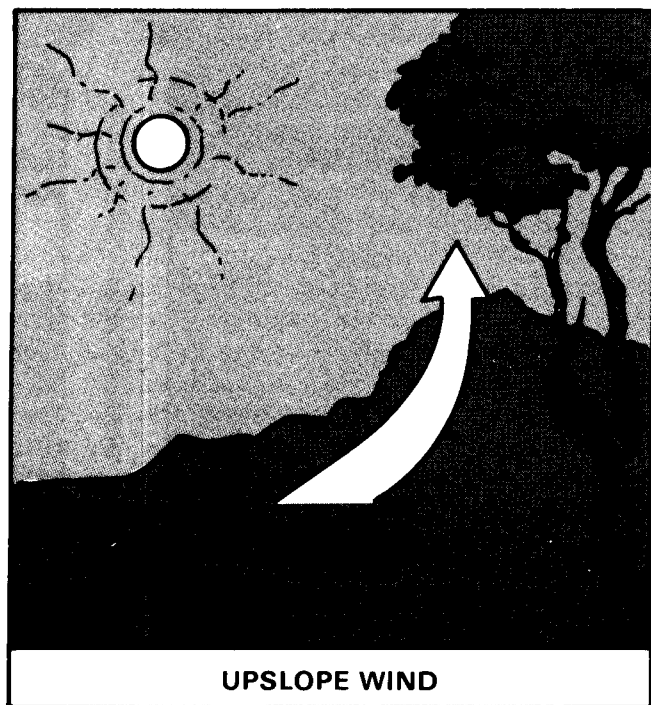

UPSLOPE WIND

DOWNSLOPE WIND

Figure C-14. Upslope and downslope winds.

vertical development and velocity. North-facing slopes have the least-developed slope winds. The maximum depth of slope winds is about 200 meters, which may be attained on large mountain slopes under conditions of clear skies and light gradient winds.

Land and sea breezes occur almost daily in tropical and mid-latitude regions on the coasts of all islands and continents. They occur because the land cools and heats more rapidly than the adjacent water. (See Figure C-15.) Breezes develop quickly during the dry season on clear days with light gradient winds, during any season, and even during bad weather. With little or no surface wind (0 to 4 knots), the sea breeze sets in about two hours after sunrise and increases to its maximum in midafternoon. The sea breeze stops one to two hours before sunset. The land breeze sets in shortly after sunset.

An off-land surface wind of 4 to 9 knots delays the onset of the sea breeze until late morning or midday. If the surface wind is off-land at 9 to 12 knots, the sea breeze will not set in until midafternoon. Under these conditions, the sea breeze starts several kilometers out to sea. It slowly progresses shoreward and arrives on land as a gusty, sharp wind shift. Surface winds of 13 knots or greater neutralize all but the strongest sea breezes.

With a strong surface wind from the sea toward the land, no real land and sea breezes exist. The effect of the land and sea breezes is then a force added to the surface wind. The sea breeze is discernible as a daytime strengthening of the wind, and the land breeze is observed as a nighttime weakening of the wind.

Sea breezes are deeper and stronger than land breezes. They usually begin about midmorning and begin to subside toward evening. Sea breezes establish at approximate right angles to the coast. Sea breezes increase in speed from their onset, with maximum speeds being reached in the afternoon, usually about one hour after the maximum land temperature is reached. Maximum speeds exist just above the surface and ordinarily are not more than 13 knots.

Sea breezes usually extend aloft from 200 to 500 meters, but they have been observed at over 700 meters. On extremely large islands, the movement of air in a sea breeze is quite appreciable
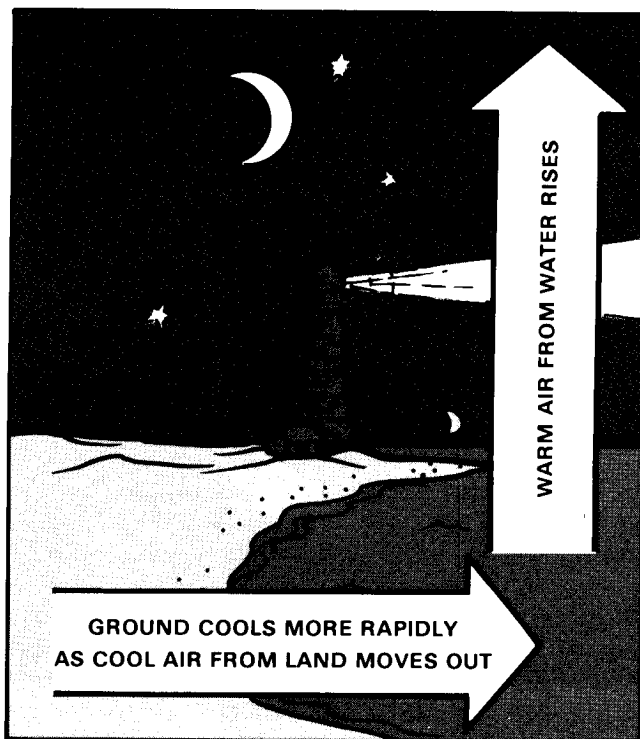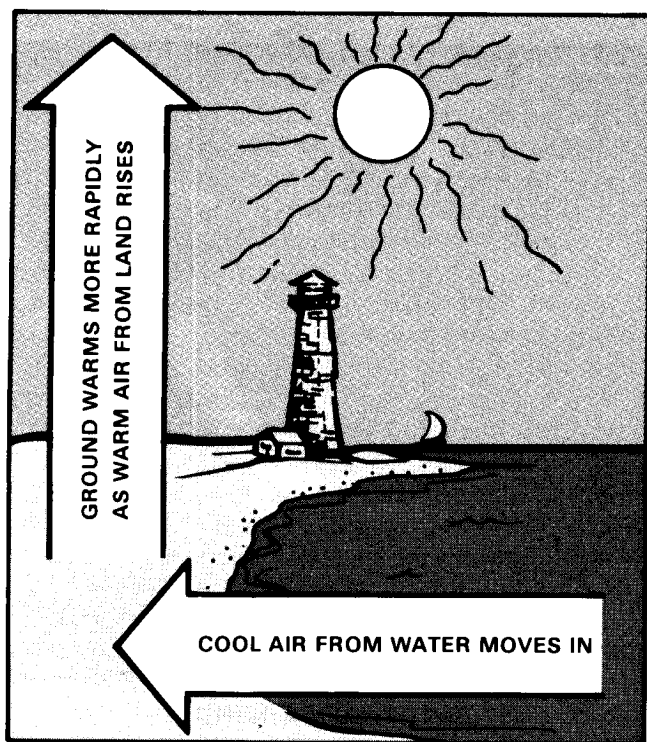

Figure C-15. Land and sea breezes.

at 15 to 20 kilometers from shore. Inland penetration of sea breezes depends on topography; and under favorable conditions such as valleys running inland, they may penetrate 35 to 50 kilometers. Sea breezes are nonturbulent when they first reach the shore but become more and more turbulent in passing over land.

A land breeze is considerably weaker and more shallow than a sea breeze. It usually influences a layer less than 200 meters thick. It starts about an hour after sunset and ends shortly after sunrise. On flat terrain, land breezes rarely exceed 3 knots, but, in combination with down-valley winds, they may attain considerable speed. Because of passage over ground, land breezes are inclined to be turbulent in nature; however, this turbulence is dampened by inversion (stable) conditions normally occurring during this period. Land breezes usually extend only 6 to 8 kilometers out to sea.

At sea, the stability of the surface boundary layer depends upon the relative temperatures of air and water. Warm air moving over cold water results in stable conditions, and cold air moving over warm water creates instability. In shallow water, such as in a lagoon, there is an appreciable warming of the water by the sun; lapse (unstable) conditions may exist in the lower levels but not to the extent of causing large convection currents.

On land, the main influence of topography is slope effects on stability. Since south-facing slopes receive the greatest amount of incoming solar radiation in the northern hemisphere, they develop lapse conditions stronger and more persistent than those on north-facing slopes. In the southern hemisphere, the north-facing slopes attain the strongest lapse conditions. Stable (inversion) conditions are always associated with light, nocturnal downslope or down-valley winds, and unstable (lapse) conditions accompany upslope or strong daytime up-valley winds.

Topography influences temperature by affecting the amount of incoming solar radiation that a parcel of land receives. This is determined primarily by the angle of the slope, direction of its exposure to the sun, latitude, and the season.

South-facing slopes receive the greatest direct incoming solar radiation in the northern hemisphere and reach maximum temperatures. For example, at a latitude of 45 degrees, a north-facing slope of 30 degrees receives no direct solar radiation from November through February. Temperatures are correspondingly lower than on south-facing slopes, which are exposed to solar radiation during these periods. Figure C-16 shows the solar loading situation for the northern hemisphere. The opposite situation occurs in the southern hemisphere.

Two sources of thermal energy affect air temperature. These sources are incoming solar radiation and heat being radiated outward from the earth. Incoming solar radiation peaks on a daily and a seasonal basis. The daily peak occurs one to two hours after noon when the sun is at its highest. The seasonal peak occurs during the summer solstice when the sun reaches its zenith in the summer sky. Incoming solar radiation also shows a seasonal minimum, at the winter solstice, but does not truly have a daily minimum. Instead, from about sunset to about sunrise, the value of the incoming solar radiation is zero. Maximum and minimum air temperature lags are illustrated in Figure C-17.

Relative humidity increases when influenced by nearby watery areas, such as swamps or lakes. Also, when winds move up a high mountain slope, the relative humidity tends to increase, as shown by frequent mountaintop clouds.

Vegetation and Wind

Leaves and branches produce drag on wind blowing through and across the vegetation. The denser the vegetation, the greater the decrease in wind speed. Also, the taller the vegetation, the greater the depth of the friction layer. Finally, the more uneven the top of the vegetation, the greater the turbulence induced in the wind flowing over the vegetation.

In scattered tall shrubs and scrub forests, the sparse vegetation produces only a moderate drag effect; thus, the wind speed is only slightly influenced. The predominant effect is a deflection of the airflow and changes in wind direction. When the vegetation is thick enough to be classified as medium-dense, the wind speed and direction at any given instant will differ from location to location.

In coniferous (evergreen) forests, high wind speeds at the surface are rare and wind direction is extremely variable. This also is true in medium-dense deciduous (seasonal, leafy) forests in full
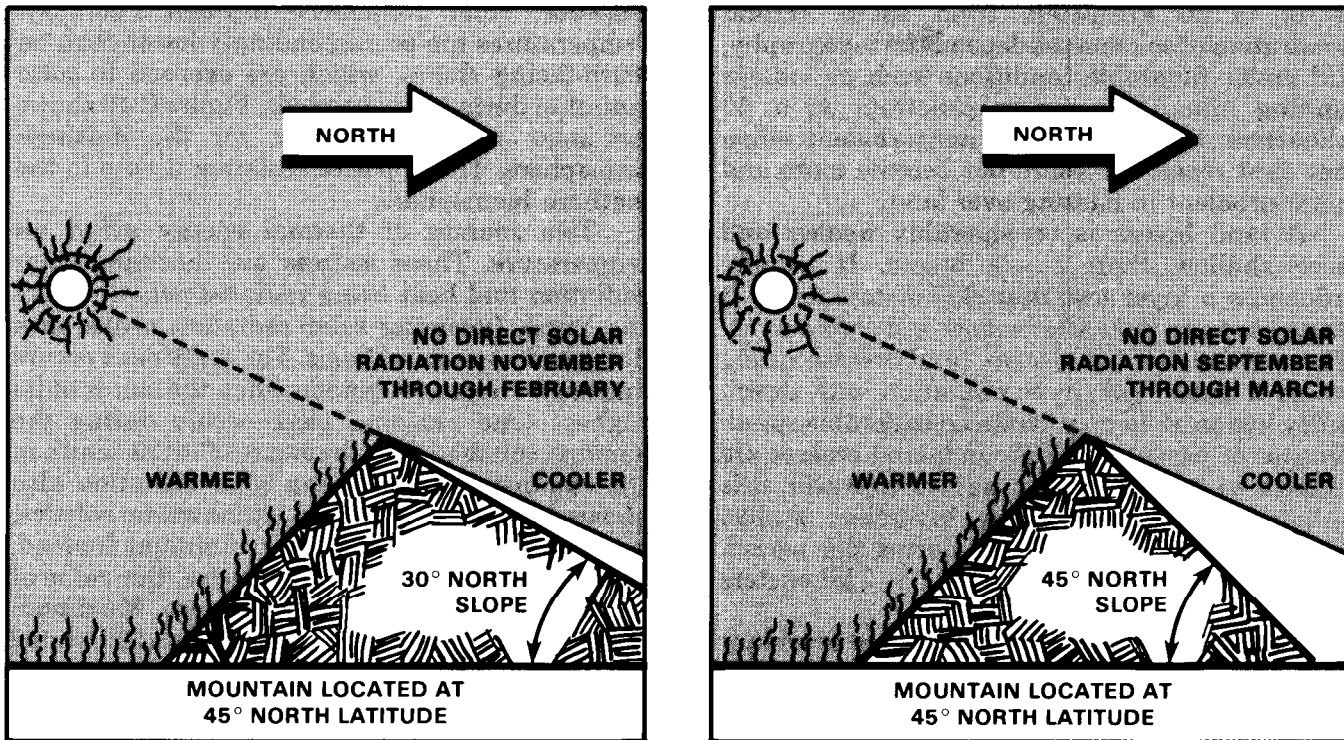
Figure C-16. Solar radiation on north-facing slopes.

leaf. Tropical jungles affect the mean wind flow even more adversely than do temperate latitude forests. The thick, luxuriant growth reduces surface wind speeds to extremely low values, and wind directions become meandering.

Vegetation and Temperature

Vegetation influences the temperature gradient by keeping much of the solar energy from penetrating to the ground. It has a blanketing or insulating effect, so that strong lapse or strong inversion conditions are not probable in heavily vegetated areas. The temperature gradient within or below vegetation approaches a neutral condition as the density of the vegetation increases.

In tall shrubs or scrub forests, shading affects the air adjacent to the ground, so that extreme surface temperatures are not reached and strong inversion or lapse conditions are relatively infrequent. In coniferous forests, moderate lapse and inversion conditions can and do occur. However, they are not as frequent or as marked as in the open. Temperature gradients in the forest

range from one-third to one-half of the values attained in the open. The tendency is toward neutral temperature gradients.

Vegetation influences temperature by raising the radiating level from the earth's surface to the top of the vegetation, which acts as the cooling and heating surface. Maximum and minimum values are, therefore, reached at or near vegetation top, while the temperatures below this level are modified. Since vegetation has an insulating effect, maximum temperatures are not as high and minimum temperatures are not as low as those in the open. The normal diurnal trend of temperatures continues, but the vegetation causes a time lag in reaching maximum and minimum values. The degree of these effects is determined by the density of the vegetation.

In grass, the lag in reaching maximum and minimum temperatures is small, and temperatures are not appreciably modified. In tall shrubs and scrub forests, also, the lag is slight; but temperatures at 1.5 meters are considerably moderated.

In coniferous and deciduous forests, the time lag between forest temperatures and temperatures
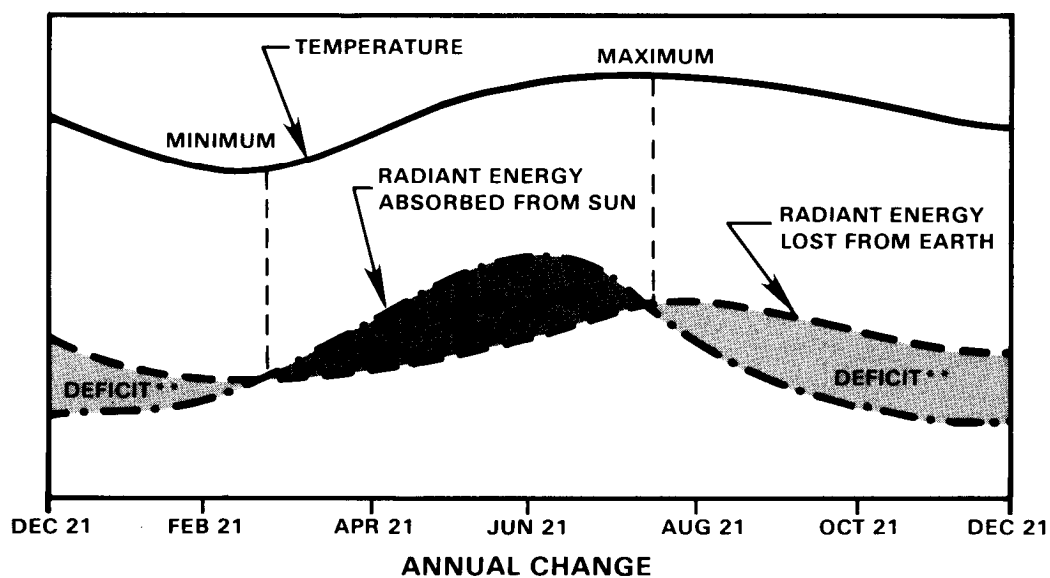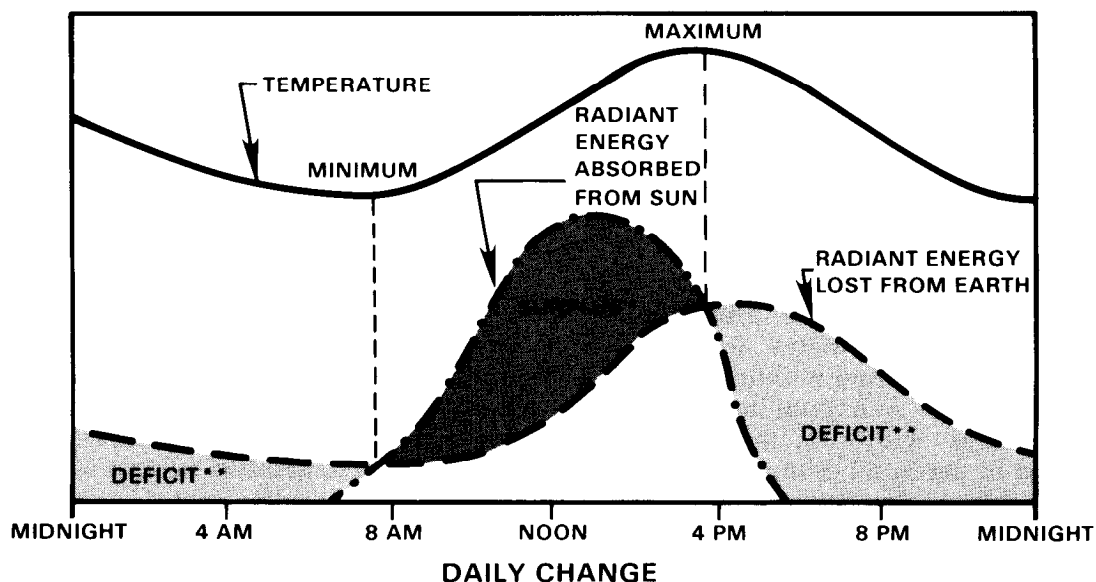
*SURPLUS—PERIOD DURING WHICH SURFACE AIR LAYER IS ABSORBING RADIANT ENERGY BOTH FROM THE
SUN AND THE RERADIATED ENERGY FROM THE EARTH. PERIOD OF PEAK AIR TEMPERATURES.

**DEFICIT—PERIOD DURING WHICH THE SURFACE AIR LAYER IS LOSING RADIANT ENERGY BOTH FROM THE
SUN AND THE RERADIATED ENERGY FROM THE EARTH'S SURFACE. PERIOD OF MINIMUM AIR
TEMPERATURES.

Figure C-17. Maximum and minimum air temperature lags.

in the open is approximately two hours. Forest temperatures are usually 5 to 6 degrees lower at midday than those at corresponding levels in the open. Temperatures in a forest at night are higher than nighttime temperatures in the open.

In a tropical jungle, the lag in reaching maximum temperatures is about one hour. Since the diurnal range of jungle temperature is so small in tropical climates (8°C), the difference between jungle and open temperatures is only 10 to 3°C.

There is a pronounced and regular trend of relative humidities in forests and jungles. Minimum relative humidities occur with maximum temperatures, and maximum relative humidities occur with minimum temperatures. Relative humidities within a forest average between 60 and 90 percent. During the night and forenoon, the relative humidity within a forest is about 5 percent higher than in the open; but in the afternoon, until about sunset, the relative humidity in the forest may be from 15 to 20 percent higher than in the open.

In canopied jungles on tropical islands or near windward tropical coasts, the relative humidity ranges from 65 to 95 percent and is almost always within 5 percent of the relative humidity in the open.

Soil

Soil influences ground burst munitions and ground contamination. Variations in soil types usually do not materially influence winds. The primary effect of soil on temperature gradient is due to the great range of temperatures attained at the soil surface. Compared to other natural surfaces, bare rock attains the highest daytime surface temperature and the lowest nighttime temperature. Bare soil, with the exception of sand, acts like rocks, but to a lesser extent.

On a snow-covered surface, snow is the critical factor in determining the temperature gradient. Inversions (stability) on snow-covered surfaces are strongest about sunrise; but during clear, cold, and calm weather, the temperature inversion is not always completely destroyed during the day. In polar regions, winter inversions may persist for days, or even weeks, because of the low sun or nearly complete darkness.

Soil and vegetation surface temperatures are important because they are a factor in determining the rate of evaporation of agents used for persistent effect. The primary factors in determining rate of evaporation of these agents are surface temperature and the rate at which the substance flows out to the radiating surface. This rate varies with the nature and texture of the surface. Heavy clay soil does not absorb as readily as porous sandy soil. The extent of absorption further depends upon the relative depth of the absorbing topsoils and subsoils, type of soil, and moisture content.

The soil also affects relative humidity values as it alters the temperature. Evaporation from wet soils tends to raise the relative humidity.