CHAPTER 5

ATMOSPHERIC PHENOMENA

Atmospheric phenomena include all hydrometeors, lithometeors, photo-meteors, and electrometeors and their associated effects. As an observer, you have the opportunity to observe and record some of these phenomena on a daily basis; however, as an analyst you must understand how and why these phenomena occur and what effects they can have on naval operations. Some phenomena have little effect on naval operations, but others such as extensive sea fogs and thunderstorm activity can delay or cancel operations.

HYDROMETEORS

LEARNING OBJECTIVE: Identify the characteristics of hydrometeors (precipitation, clouds, fog, dew, frost, rime, glaze, drifting and blowing snow, spray, tornadoes, and waterspouts).

Hydrometeors consist of liquid or solid water particles that are either falling through or suspended in the atmosphere, blown from the surface by wind, or deposited on objects. Hydrometeors comprise all forms of precipitation, such as rain, drizzle, snow, and hail, and such elements as clouds, fog, blowing snow, dew, frost tornadoes, and waterspouts.

PRECIPITATION

Precipitation includes all forms of moisture that fall to Earth's surface, such as rain, drizzle, snow, and hail, etc. Dew, frost, clouds, fog, rime, glaze, spray, tornadoes, and waterspouts are not forms of precipitation, although they are hydrometeors. Precipitation is classified according to both form (liquid, freezing, and solid) and size (rate of fall). The size of precipitation drops determines their rate of fall to a large extent.

Rain

Precipitation that reaches Earth's surface as water droplets with a diameter of 0.02-inch (0.5 mm) or more is classified as rain. If the droplets freeze on contact with the ground or other objects, the precipitation is classified as freezing rain. Rain falling from convective clouds is referred to as rain showers. Showers are usually intermittent in character, are of large droplet size, and change rapidly in intensity.

Drizzle

Drizzle consists of very small and uniformly dispersed droplets that appear to float while following air currents. Sometimes drizzle is referred to as mist. Drizzle usually falls from low stratus clouds and is frequently accompanied by fog and reduced visibility. A slow rate of fall and the small size of the droplets (less than 0.5-mm) distinguish drizzle from rain. When drizzle freezes on contact with the ground or other objects, it is referred to as freezing drizzle. Drizzle usually restricts visibility.

Snow

Snow consists of white or translucent ice crystals. In their pure form, ice crystals are highly complex hexagonal branched structures. However, most snow falls as parts of crystals, as individual crystals, or more commonly as clusters and combinations of these. Snow occurs in meteorological conditions similar to those in which rain occurs, except that with snow the initial temperatures must be at or below freezing. Snow falling from convective clouds is termed snow showers.

Snow Pellets

Snow pellets are white, opaque, round (or occasionally conical) kernels of snow-like consistency, 0.08 to 0.2 inch in diameter. They are crisp, easily compressible, and may rebound or burst when striking hard surfaces. Snow pellets occur almost exclusively in snow showers.

Snow Grains

Snow grains consist of precipitation of very small, white, opaque grains of ice similar in structure to snow crystals. They resemble snow pellets somewhat, but are more flattened and elongated. When the grains hit hard ground, they do not bounce or shatter. Snow grains usually fall in small quantities, mostly from stratus clouds, and never as showers.

Ice Pellets

Ice pellets are transparent or translucent pellets of ice that are round or irregular (rarely conical) and have a diameter of .02 inch (.5 mm) or less. They usually rebound upon striking hard ground and make a sound on impact. Ice pellets are generally subdivided into two groups, sleet and small hail. Sleet is composed of hard grains of ice, which has formed from the freezing of raindrops or the refreezing of largely melted snowflakes; it falls as continuous precipitation. Small hail is composed of pellets of snow encased in a thin layer of ice that has formed from the freezing of either droplets intercepted by the pellets or water resulting from the partial melting of the pellets; small hail falls as showery precipitation.

Hail

Ice balls or stones, ranging in diameter from that of a medium-size raindrop to two inches or more are referred to as hail. They may fall detached or frozen together into irregular, lumpy masses. Hail is composed either of clear ice or of alternating clear and opaque snowflake layers. Hail forms in cumulonimbus cloud, and is normally associated with thunderstorm activity and surface temperatures above freezing. Determination of size is based on the diameter (in inches) of normally shaped hailstones.

Ice Crystals (Ice Prisms)

Ice crystals fall as unbranched crystals in the form of needles, columns, or plates. They are often so tiny they seem to be suspended in the air. They may fall from a cloud or from clear air. In a synoptic observation, ice crystals are called ice prisms. They are visible mainly when they glitter in the sunlight or other bright light; they may even produce a luminous pillar or other optical phenomenon. This hydrometeor is common in Polar Regions and occurs only at low temperatures in stable air masses.

PRECIPITATION THEORY

Several valid theories have been formulated in regard to the growth of raindrops. The theories most widely accepted today are treated here in combined form.

Raindrops grow in size primarily because water exists in all three phases in the atmosphere and because the air is supersaturated at times (especially with respect to ice) because of adiabatic expansion and radiation cooling. This means that ice crystals coexist with liquid water droplets in the same cloud. The difference in the vapor pressure between the water droplets and the ice crystals causes water droplets to evaporate and then to sublimate directly onto the ice crystals. Sublimation is the process whereby water vapor changes into ice without passing through the liquid stage. Condensation alone does not cause droplets of water to grow in size. The turbulence in cloud permits and aids this droplet growth processes. After the droplets become larger, they start to descend and are tossed up again in turbulent updrafts within the cloud. The repetition of ascension and descension causes the ice crystals to grow larger (by water vapor sublimating onto the ice crystals) until finally they are heavy enough to fall out of the cloud as some form of precipitation. It is believed that most precipitation in the mid-latitudes starts as ice crystals and that most liquid precipitation results from melting during descent through a stratum of warmer air. It is generally believed that most rain in the tropics forms without going through the ice phase.

In addition to the above process of droplet growth, simple *accretion* is important. In this process, the collision of ice crystals with super-cooled water droplets causes the droplets to freeze on contact with the ice crystals. As the droplets freeze on the ice crystals, more layers accumulate. This process is especially effective in the formation of hail. There are other factors that explain, in part, the growth of precipitation, but the above processes are the primary ones.

OTHER HYDROMETEORS

The hydrometeors that follow, are not precipitation; however, they are equally important.

Clouds

A cloud is a visible mass of minute water droplets (or ice particles) suspended in the atmosphere. It differs from fog in that it does not reach the surface of Earth. Clouds are a direct expression of the physical processes taking place in the atmosphere. An accurate description of both type and amount plays an important part in the analysis of the weather and in forecasting the changes that take place in the weather.

CLOUD FORMATION.—To be able to thoroughly understand clouds, the Aerographer's Mate must know the physical processes that form clouds. Three conditions must be met before clouds can form as a result of condensation—presence of sufficient moisture, hygroscopic or sublimation nuclei in the atmosphere, and a cooling process. Moisture is supplied to the atmosphere by evaporation and is distributed horizontally and vertically by the winds and vertical currents. The first task is to consider the hygroscopic and sublimation nuclei.

Hygroscopic nuclei are particles of any nature on which condensation of atmospheric moisture occurs. It can be said that hygroscopic nuclei have an affinity for water or that they readily absorb and retain water. The most effective hygroscopic nuclei are the products of combustion (sulfuric and nitric acids) and salt sprays. Some dust particles are also hygroscopic, but not effectively so. The presence of hygroscopic nuclei is a must; water vapor does not readily condense without their presence. Air has been supersaturated in laboratories to over 400 percent before condensation began when there were no hygroscopic nuclei present. On the other hand, condensation has been induced with relative humidity of only 70 percent when there was an abundance of hygroscopic nuclei.

The condensation, which results when all three mentioned conditions are fulfilled, is usually in the form of mist, clouds, or fog. Fogs are merely clouds on the surface of Earth.

In our industrial cities, where byproducts of combustion are abundant, the distinction between smoke, fog, and haze is not easily discernible. A combination of smoke and fog gives rise to the existence of the so-called smog characteristic of these industrial areas.

Little is known about the properties of sublimation nuclei, although it is believed they are essential for sublimation to occur at all. It is assumed sublimation nuclei are very small and very rare, possibly of a quartz or meteoric dust origin. All cirriform clouds are composed of ice crystals and are believed to be formed as a result of direct sublimation. In the atmosphere, water clouds, water and ice crystal clouds, and pure ice crystal clouds may coexist at the same time.

Next under consideration is the cooling process that may induce condensation. There are several processes by which the air is cooled: convective cooling by expansion, mechanical cooling by expansion, and radiation cooling. Any of the three methods may work in conjunction with another method, making it even more effective. The methods are as follows:

1. Convective cooling. The ascent of a limited mass of air through the atmosphere because of surface heating is called thermal convection. If a sample of air is heated, it rises (being less dense than the surrounding air) and decreases in temperature at the dry adiabatic lapse rate until the temperature and dew point are the same. This is the saturation point at which condensation begins. As the parcel of air continues to rise, it cools at a lesser rate—called the moist/saturation adiabatic lapse rate. The parcel of air continues to rise until the surrounding air has a temperature equal to, or higher than, the parcel of air. At this point convection ceases. Cumuliform clouds are formed in this way. Cloud bases are at the altitude of saturation and tops are at the point where the temperature of the surrounding air is the same as, or greater than, the temperature of the parcel of air.

2. Mechanical cooling. Orographic and frontal processes are considered mechanical means of cooling which result in cloud formation.

a. Orographic processes. If air is comparatively moist and is lifted over mountains or hills, clouds may be formed. The type of cloud depends upon the lapse rate (the rate of decrease in temperature with increase in height, unless otherwise specified) of the air. If the lapse rate is weak (that is, a low rate of cooling with an increase in altitude), the clouds formed are of the stratiform type. If the lapse rate of the air is steep (that is, a high rate of cooling with increasing altitude), the clouds formed are of the cumuliform type.

b. Frontal processes. In the previous unit, you learned that, at frontal surfaces, the warmer, less dense air is forced to rise along the surfaces of the colder air masses. The lifted air undergoes the same type of adiabatic cooling as air lifted orographically. The type of cloud formed depends on the lapse rate and moisture of the warm air and the amount of lifting. The slope of the front determines lifting; when the slope is shallow, the air may not be lifted to its saturation point and clouds do not form. When the slope steep, as with a fast-moving cold front, and the warm air is unstable, towering cumuliform cloud form.

3. Radiation cooling. At night Earth releases long-wave radiation, thereby cooling rapidly. The air in contact with the surface is not heated by the outgoing radiation, but rather is cooled by contact with the cold surface. This contact cooling lowers the temperature of the air near the surface, causing a surface inversion. If the temperature of the air is cooled to its dew point, fog and/or low clouds form. Clouds formed in this manner dissipate during the day because of surface heating.

CLOUD CLASSIFICATION.—The international classification of clouds adopted by most countries is a great help to both meteorological personnel and pilots. It tends to make cloud observations standard throughout the world, and pilots that can identify cloud types will normally take the necessary steps to avoid those types dangerous to their aircraft.

Clouds have been divided into etages, genera, species, and varieties. This classification is based primarily on the process that produces the clouds. Although clouds are continually in a process of development and dissipation, they do have many distinctive features that make this classification possible.

Etages.—Observations have shown that clouds generally occur over a range of altitudes varying from sea level to about 60,000 feet in the tropics, to about 45,000 feet in middle latitudes, and to about 25,000 feet in Polar Regions. By convention, the part of the atmosphere in which clouds are usually present has been vertically divided into three etages—high, middle, and low. The range of levels at which clouds of certain genera occur most frequently defines each etage.

Cirrus, cirrocumulus, and cirrostratus are always found in the high etage. Altocumulus and altostratus are found in the middle etage, but altostratus may often extend into the high etage. Nimbostratus is always found in the middle etage but may extend into the high, and especially the low etage. Cumulus, cumulonimbus, stratus, and stratocumulus are always associated with the low etage, but the tops of cumulus or cumulonimbus may extend into one or both of the two other etages.

The HIGH ETAGE extends from about 10,000 to 25,000 feet in polar regions, 16,500 to 45,000 feet in temperate regions, and 20,000 to 60,000 feet in tropical regions.

The MIDDLE ETAGE extends from about 6,500 to 13,000 feet in polar regions, 6,500 to 23,000 feet in temperate regions, and 6,500 to 25,000 feet in tropical regions.

The LOW ETAGE extends from near Earth's surface to 6,500 feet in all regions of Earth.

Genera (Types).—As a weather analyst, interpreter, and briefer, you will be viewing the state of the sky with distinctly different objectives in mind. A review of the various cloud types can help you to associate past observer experiences with synoptic conditions and trends.

High clouds. High clouds are described as follows:

1. Cirrus (CI). Cirrus are detached clouds of delicate and fibrous appearance, are generally white (cirrus are the whitest clouds in the sky), and are without shading. They appear in the most varied forms, such as isolated tufts, lines drawn across the sky, branching feather-like plumes, and curved lines ending in tufts. Since cirrus is composed of ice crystals, their transparent character depends upon the degree of separation of the crystals. Before sunrise and after sunset, cirrus may still be colored bright yellow or red. Being high altitude clouds, they light up before lower clouds and fade out much later. Cirrus often indicates the direction in which a storm lies.

2. Cirrocumulus (CC). Cirrocumulus, commonly called mackerel sky, looks like rippled sand or like cirrus containing globular masses of cotton, usually without shadows. Cirrocumulus is an indication that a storm is probably approaching. The individual globules of cirrocumulus are rarely larger than 1 degree as measured by an observer on the surface of Earth at or near sea level.

3. Cirrostratus (CS). Cirrostratus form a thin, whitish veil, which does not blur the outlines of the Sun, or the Moon but does give rise to halos. A milky veil of fog, thin stratus, and altostratus are distinguished from a veil of cirrostratus of similar appearance by the halo phenomenon, which the Sun or Moon nearly always produces in a layer of cirrostratus. The appearance of cirrostratus is a good indication of rain. In the tropics, however, cirrostratus is quite often observed with no rain following.

Middle clouds. Middle clouds are described as follows:

1. Altocumulus (AC). Altocumulus appear as a layer (or patches) of clouds composed of flattened globular masses, the smallest elements of the regularly arranged layer being fairly small and thin, with or without shading. The balls or patches usually are arranged in groups, lines, or waves. This cloud form differs from cirrocumulus by generally having larger masses, by casting shadows, and by having no connection with cirrus forms. Corona and irisation are frequently associated with altocumulus.

2. Altostratus (AS). Altostratus looks like thick cirrostratus, but without halo phenomena; altostratus forms a fibrous veil or sheet, gray or bluish in color. Sometimes the Sun or Moon is completely obscured. Light rain or heavy snow may fall from an altostratus cloud layer. Altostratus can sometimes be observed at

two different levels in the sky and sometimes in conjunction with altocumulus, which may also exist as two different layers in the sky.

3. Nimbostratus (NS). Nimbostratus appears as a low, amorphous, and rainy layer of clouds of a dark gray color. They are usually nearly uniform and feebly illuminated, seemingly from within. When precipitation occurs, it is in the form of continuous rain or snow. However, nimbostratus may occur without rain or snow reaching the ground. In cases in which the precipitation does not reach the ground, the base of the cloud is usually diffuse and looks wet. In most cases, nimbostratus evolve from altostratus layers, which grow thicker and whose bases become lower until they become a layer of nimbostratus.

Low clouds. Low clouds are described as follows:

1. Stratocumulus (SC). Stratocumulus appear as a layer (or patches) of clouds composed of globular masses or rolls. The smallest of the regularly arranged elements is fairly large. They are soft and gray with darker spots.

2. Stratus (ST). Stratus appears as a low, uniform layer of clouds, resembling fog, but not resting on the ground. When a layer of stratus is broken up into irregular shreds, it is designated as stratus fractus. A veil of stratus gives the sky a characteristically hazy appearance. Usually, drizzle is the only precipitation associated with stratus. When there is no precipitation, the stratus cloud form appears drier than other similar forms, and it shows some contrasts and some lighter transparent parts.

3. Cumulus (CU). Cumulus is dense clouds with vertical development. Their upper surfaces are dome shaped and exhibit rounded protuberances, while their bases are nearly flat. Cumulus fractus or fractocumulus resemble ragged cumulus in which the different parts show constant change.

4. Cumulonimbus (CB). Cumulonimbi are heavy masses of cumulus-type clouds with great vertical development whose cumuliform summits resemble mountains or towers. Tops may extend higher than 60,000 feet. Their upper parts are composed of ice crystals and have a fibrous texture; often they spread out in the shape of an anvil.

Cumulonimbi are the familiar thunderclouds, and their precipitation is of a violent, intermittent, showery character. Hail often falls from well-developed cumulonimbus. On occasion, cumulonimbus clouds display several readily apparent supplementary features. Examples are (1) mamma or hanging pouch-like protuberances on the under surface of the cloud; (2) tuba (commonly called the funnel cloud), resembling a cloud column or inverted cloud cone/pendant from the cloud base; and (3) virga, wisps or streaks of water or ice particles falling out of a cloud but evaporating before reaching Earth's surface as precipitation.

The Aerographer's Mate must learn to recognize the various cloud types and associated precipitation as seen from Earth's surface. Figure 5-1 shows the various types of clouds in a tier with each cloud type at its average height. Although one never sees all cloud types at once, quite frequently two or three layers of clouds of different types may be present simultaneously.

Species.—The following species of clouds are referred to frequently; others may be found in the *International Cloud Atlas* or in the newer publication, *Cloud Types for Observers.*

Castellanus. Clouds which present, in at least some portion of their upper part, cumuliform protuberances in the form of turrets. The turrets, which are generally taller than they are wide, are connected to a common base. The term applies mainly to cirrocumulus, altocumulus, and stratocumulus, but especially altocumulus.

Stratiformis. Clouds which are spread out in an extensive horizontal sheet or layer. The term applies to altocumulus, stratocumulus, and occasionally to cirrocumulus.

Lenticularis. Clouds having the shape of lenses or almonds, often elongated and having well-defined outlines. The term applies mainly to cirrocumulus, altocumulus, and stratocumulus.

Fractus. Clouds in the form of irregular shreds, which have a clearly ragged appearance. The term applies only to stratus and cumulus.

Humilis. Cumulus clouds of only a slight vertical extent; they generally appear flattened.

Congestus. Cumulus clouds which are markedly sprouting and are often of great vertical extent. Their bulging upper part frequently resembles cauliflower.

Varieties and Supplementary Features.—Cloud varieties are established mainly on the basis of the cloud's transparency or its arrangement in the sky. A detailed description of the nine varieties can be found in the *International Cloud Atlas.*

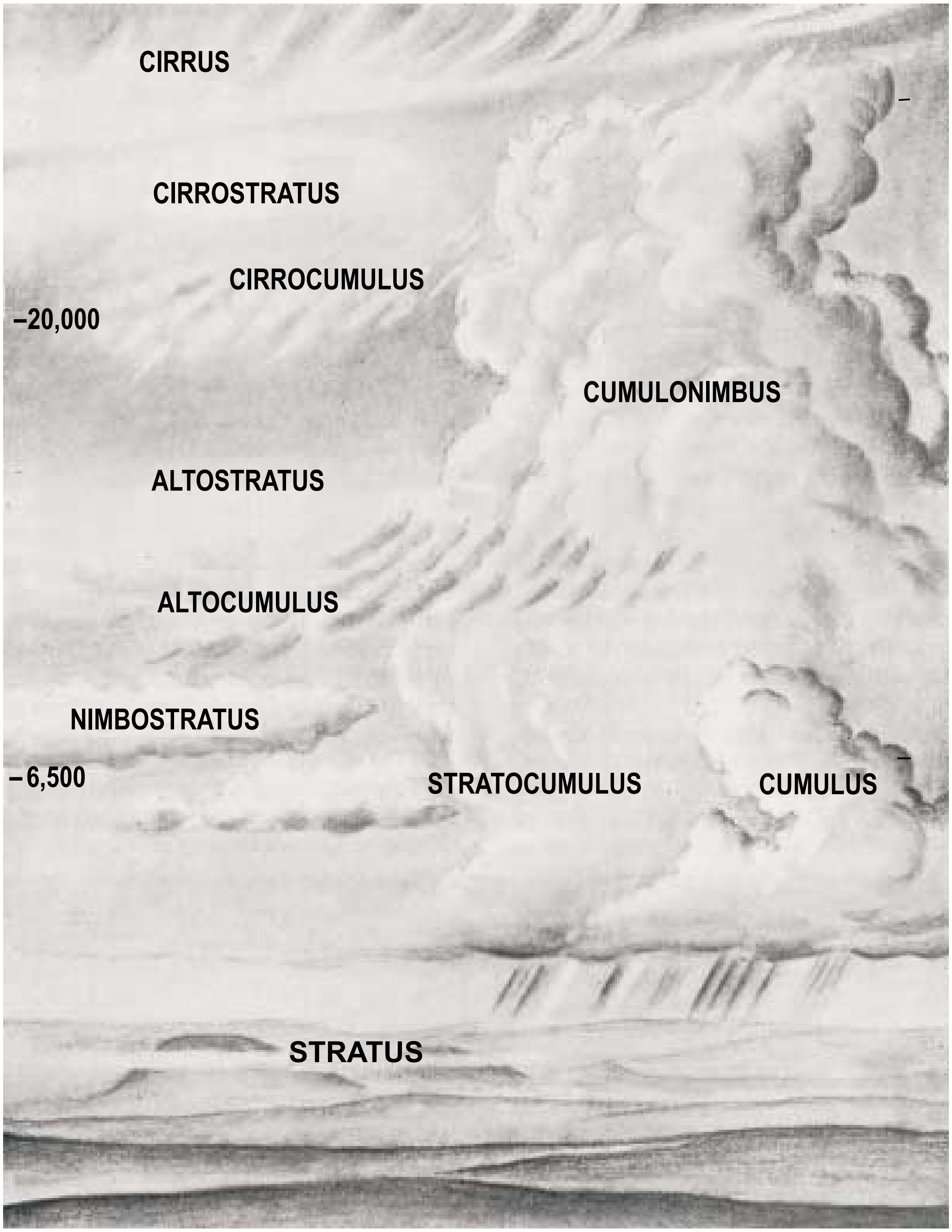


Figure 5-1.—Layer diagram of clouds at various levels.

Supplementary features and accessory clouds, like the varieties, aid in the clear identification of clouds. The most common supplementary features are mamma, tuba, and virga. They are defined and associated with the parent clouds in the general section.

Fog

Fog is a cloud on Earth's surface. It is visible condensation in the atmosphere. Fog varies in depth from a few feet to many hundreds of feet. Its density is variable resulting in visibility from several miles to near zero. It differs from rain or mist in that its water or ice particles are more minute and suspended and do not fall earthward.

The forecasting of fog is frequently a difficult task. In addition to knowledge of the meteorological causes of fog formation, it is necessary to have a thorough knowledge of local geography and topography. A slight air drainage (gravity induced, downslope flow of relatively cold air) may be enough to prevent fog formation, or a sudden shift in the wind direction may cause fog to cover an airfield.

The temperature to which air must be cooled, at a constant pressure and a constant water vapor content, in order for saturation to occur is the dew point. This is a variable, based upon the amount of water vapor present in the atmosphere. The more water vapor present, the higher the dew point. Thus, the dew point is really an index of the amount of water vapor present in the air at a given pressure.

Temperature and dew point may be made to coincide either by raising the dew point until it equals the temperature of by lowering the temperature to the dew point. The former results from the addition of water vapor to the air by evaporation from water surfaces, wet ground, or rain falling through the air. The latter results from the cooling of the air by contact with a cold surface underneath. There are several classifications of fog: radiation fog, advection fog, upslope fog, and frontal fog.

RADIATION FOG.—Radiation fog, which generally occurs as ground fog, is caused by the radiation cooling of Earth's surface. It is primarily a nighttime occurrence, but it often begins to form in the late afternoon and may not dissipate until well after sunrise. It never forms over a water surface. Radiation fog usually covers a wide area.

After sunset, Earth receives no heat from the Sun, but its surface continues to reradiate heat. The surface begins to cool because of this heat loss. As Earth cools, the layer of air adjacent to the surface is cooled by conduction (the transfer of heat from warmer to colder matter by contact). This causes the layer near Earth to be cooler than the air immediately above it, a condition called an inversion. If the air beneath the inversion layer is sufficiently moist and cools to its dew point, fog forms. (See fig. 5-2.) In case of a calm wind, this cooling by conduction affects only a very shallow layer (a few inches deep), since air is a poor conductor of heat. Wind of low speed (3 to 5 knots) causes slight, turbulent currents. This turbulence is enough to spread the fog through deeper layers. As the nocturnal cooling continues, the air temperature drops further, more moisture is condensed, and the fog becomes deeper and denser. If winds increase to 5 to 10 knots, the fog will usually thicken vertically. Winds greater than 10 knots usually result in the formation of low scud, stratus, or stratocumulus.

After the Sun rises, Earth is heated. Radiation from the warming surface heats the lower air, causing evaporation of the lower part of the fog, thereby giving the appearance of lifting. Before noon, heat radiated from the warming surface of Earth destroys the inversion and the fog evaporates into the warmed air. Radiation fog is common in high-pressure areas where the wind speed is usually low (less than 5 knots) and clear skies are frequent. These conditions permit maximum radiation cooling.

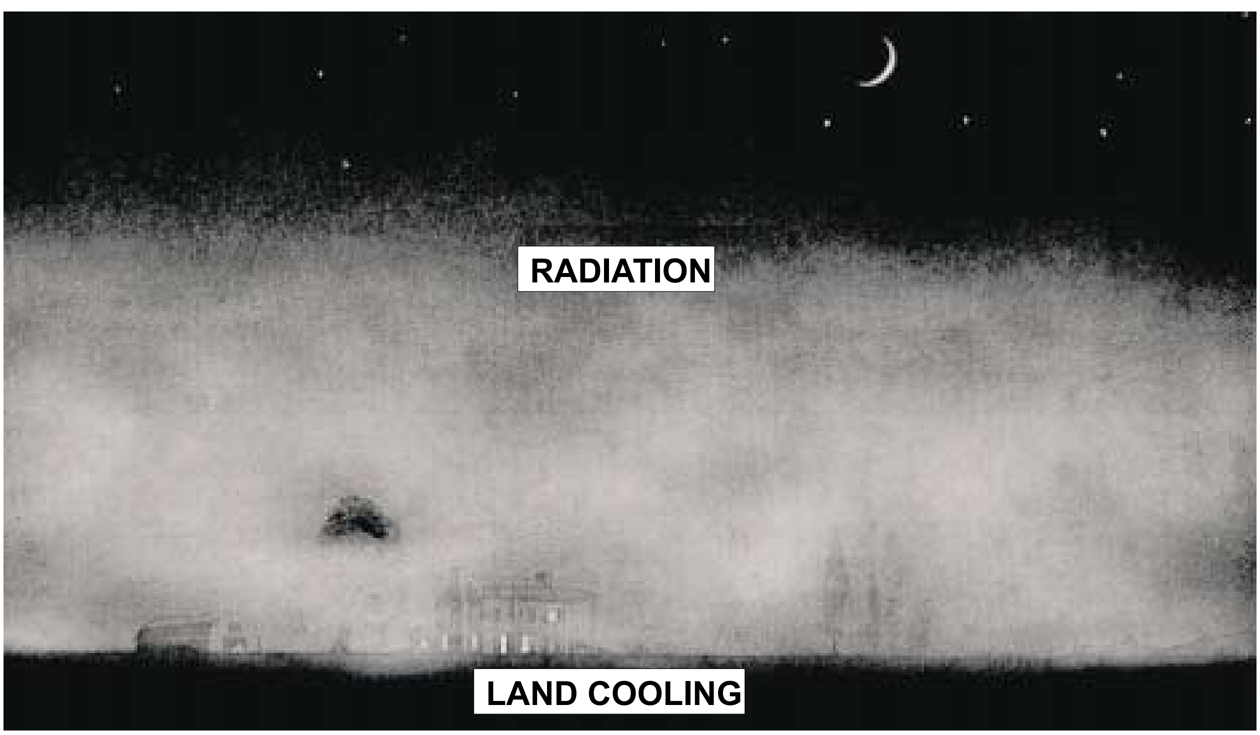


Figure 5-2.—Radiation fog.

ADVECTION FOG.—Advection fog is the name given to fog produced by air in motion or to fog formed in one place and transported to another. This type of fog is formed when warmer air is transported over colder land or water surfaces. Cooling from below takes place and gradually builds up a fog layer. The cooling rate depends on the wind speed and the difference between the air temperature and the temperature of the surface over which the air travels.

Advection fog can form only in regions where marked temperature contrasts exist within a short distance of each other, and only when the wind blows from the warm region toward the cold region. (See fig. 5-3.) It is easy to locate areas of temperature contrast on the weather map, as they are usually found along coastlines or between snow-covered and bare ground.

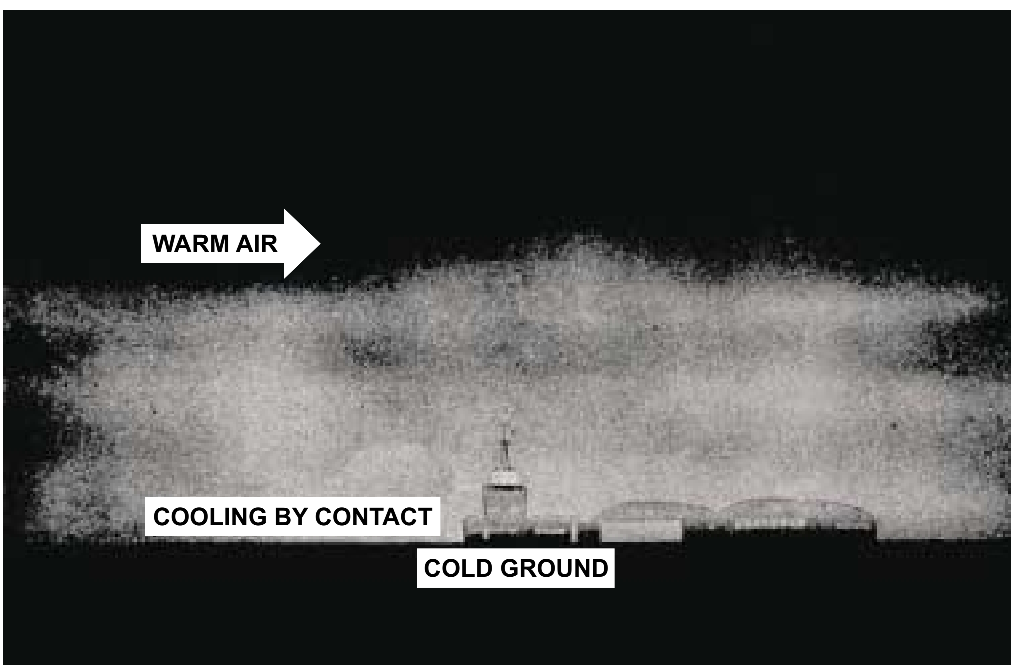
Sea Fog.—Sea fog is always of the advection type and occurs when the wind brings moist, warm air over a colder ocean current. The greater the difference between the air temperature and the ocean temperature, the deeper and denser the fog. Sea fog may occur during either the day or night. Some wind is necessary, not only to provide some vertical mixing, but also to move the air to the place where it is cooled. Most advection fogs are found at speeds between 4 and 13 knots. Sea fogs have been maintained with wind speed as high as 26 knots. They persist at such speeds because of the lesser frictional effect over a water surface. Winds of equal speed produce less turbulence over water than over land.

Sea fogs, which tend to persist for long periods of time, are quite deep and dense. Since the temperature of the ocean surface changes very little during the day, it is not surprising to hear of sea fogs lasting for weeks. A good example of sea fog is that found off the coast of Newfoundland.

Land Advection Fog.—Land advection fog is found near large bodies of water; that is, along seacoasts and large lakes. Onshore breezes bring maritime air over a land surface, which has cooled by radiation at night. (See fig. 5-4.) Also, fogs may form over the ocean and be blown over the land during either the day or the night. Another situation favorable to fog formation is one in which air flows from warm, bare ground to snow-covered ground nearby.

Land advection fog cannot exist with as high wind speed as the sea type because of the greater turbulence. It dissipates in much the same fashion as radiation fog. However, since it is usually deeper, it requires a longer time to disperse.

Steam Fog.—Steam fog occurs within air masses; but, unlike other air-mass fogs, which are formed by the cooling of the air temperature to the dew point, steam fog is caused by saturation of the air through evaporation of water. It occurs when cold air moves



AG5f0503

Figure 5-3.—Advection fog.

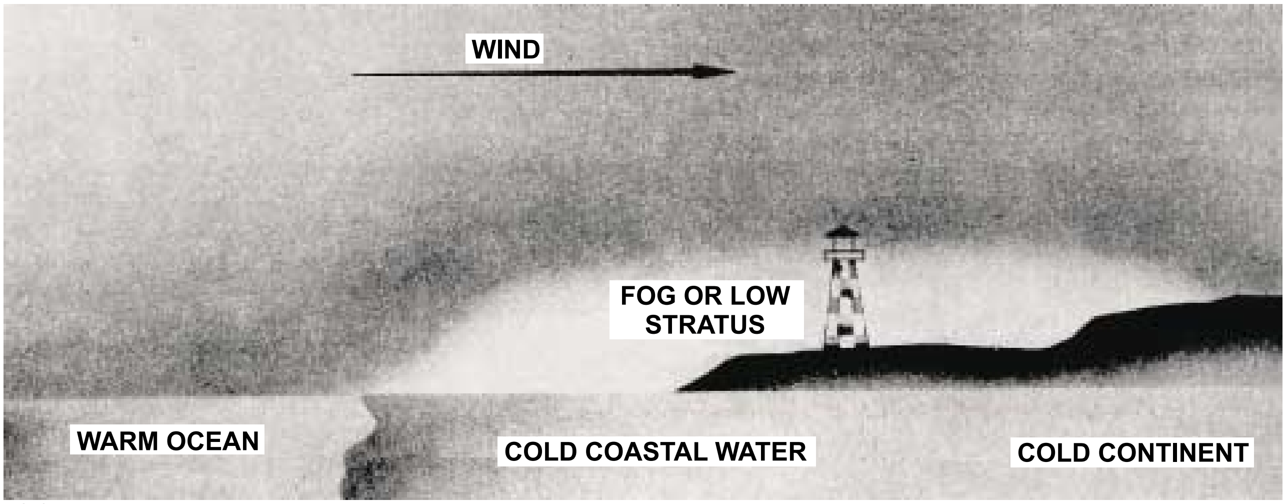


Figure 5-4.—Land advection fog caused by an onshore flow over cold coastal water.

over warm water. Evaporation from the surface of the warm water easily saturates the cold air, causing fog, which rises from the surface like smoke. It should be noted that the actual process of heating cold air over a warm surface tends to produce instability. The presence of an inversion above the surface prevents steam fog from rising very high; it is usually fairly dense and persistent.

This type of fog forms on clear nights over inland lakes and rivers in late fall before they freeze. It is prevalent along the Mississippi River and Ohio River at that time of year. Arctic sea smoke is the name given to steam fogs in the arctic region. It forms when cold air moves over a warmer water surface, which is most often found in breaks of the surface ice. It may also occur over the ocean surface following a cold frontal passage when the water is approximately 40°F warmer than the air passing over it.

Upslope Fogs.—Upslope fog is caused by adiabatic cooling of rising air. It is formed when moist, warm air is forced up a slope by the wind. The cooling of the air is almost entirely adiabatic, since there is little conduction taking place between the air and surface of the slope. The air must be stable before it starts its motion so that the lifting does not cause convection, or vertical currents, which would dissipate the fog.

Some wind speed is needed, of course, to cause the upslope motion. Upslope fog is usually found where the air moves up a gradual slope. This type of fog is deep and requires considerable time to dissipate. The most common fog of this type is called *Cheyenne fog* and is caused by the westward flow of air from the Missouri Valley, which produces fog on the eastern slope of the Rockies.

Frontal Fog.—Frontal fog is another hazard, which must be added to the list of weather problems associated with fronts. The actual fog is due to the evaporation of falling rain and occurs under the frontal surface in the cold air mass. This additional water vapor gradually saturates the air. Precipitation falls from the lifted warm air through the cold air. Evaporation from the rain continues as long as the temperature of the raindrops is higher than the temperature of the air, even though the cold air is already saturated. Naturally, the upper regions become saturated first because the temperature and dew point are lower at the higher altitude. As the evaporation from the rain continues, a layer of clouds begins to build down from the frontal surface. Eventually, this cloud layer extends to the ground and becomes fog.

During the day, there may be enough turbulence caused by solar heating to keep this cloud off the ground. However, after dark, because of dying convection currents and the nocturnal cooling of the air, the ceiling drops suddenly. It is this sudden closing in after dark that makes frontal fog so dangerous.

Cold fronts usually move so rapidly and have such narrow bands of precipitation and high wind speeds that *cold-front fog* is comparatively rare and short lived. *warm-front fog,* on the other hand, is fairly common. Since warm frontal systems are quite extensive, warm-front fog may cover a wide area. This type fog is also deep because it extends from the ground to the frontal surface. The clouds above the frontal surface also slow down the dissipating effect of solar heating.

These factors make the warm-front fog among the most dangerous. (See fig. 5-5.)

Dew

Dew does not actually fall; rather the moisture condenses from air that is in direct contact with the cool surface. During clear, still nights, vegetation often cools by radiation to a temperature at or below the dew point of the adjacent air. Moisture then collects on the leaves just as it does on a pitcher of ice water in a warm room. Heavy dew is often observed on grass and plants when there is none on the pavements or on large, solid objects. These objects absorb so much heat during the day or give up heat so slowly, they may not cool below the dew point of the surrounding air during the night.

Another type of dew is white dew. White dew is a deposit of white, frozen dew drops. It first forms as liquid dew, then freezes.

Frost

Frost, or hoarfrost, is formed by the process of sublimation. It is a deposit of ice having a crystalline appearance and generally assumes the form of scales, needles, feathers, or fans. Hoarfrost is the solid equivalent of dew and should not be confused with white dew, which is dew frozen after it forms.

Rime (Rime Icing)

Rime is a white or milky opaque granular deposit of ice. It occurs when supercooled water droplets strike an object at temperatures at or below freezing. Factors favoring the formation of rime are small drop size, slow accretion, a high degree of supercooling, and rapid dissipation of latent heat of fusion. Rime is a result of freezing drizzle and looks like frost in a freezer. Rime icing, which forms on aircraft, can seriously distort airfoil shape, therefore diminishing lift and performance. Rime icing is more likely to form in

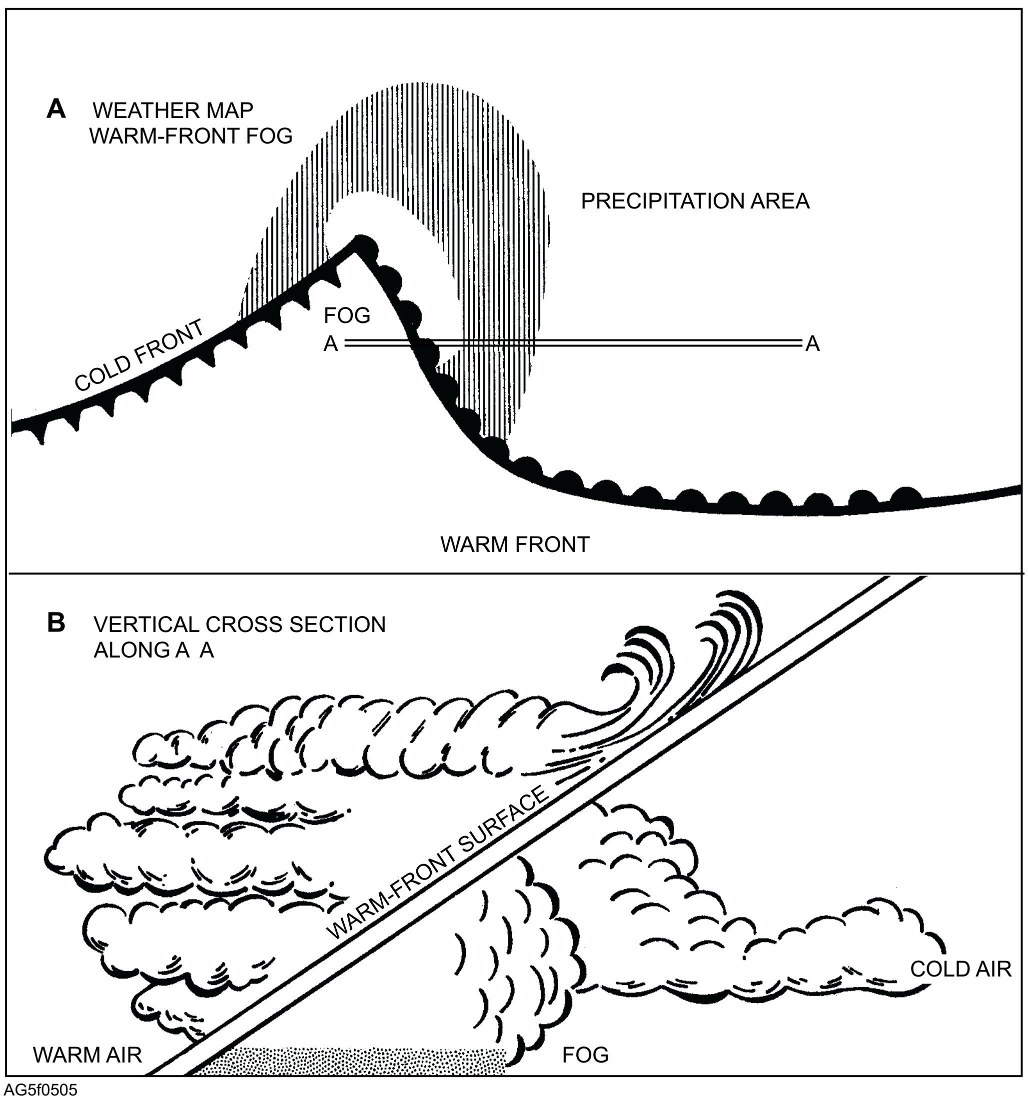


Figure 5-5.—Warm-front fog.

stratus-type clouds with temperatures between 0°C and minus 22°C. When formed in cumuliform-type clouds, temperatures range from minus 9°C to minus 15°C and are accompanied by clear icing which is then termed mixed icing.

Glaze (Clear Icing)

Glaze is a coating of ice, generally clear and smooth. It occurs when supercooled water droplets deposited by rain, drizzle, fog, or condensed water vapor strike an exposed object at temperatures at or below freezing. Factors favoring formation of glaze are large drop size, rapid accretion, slight supercooling, and slow dissipation of the latent heat of fusion. Glaze is denser, harder, and more transparent than rime and looks similar to an ice cube. Clear icing forms on aircraft and adds appreciably to the weight of the craft. This additional weight has an even greater effect in reducing the performance of the aircraft than does rime icing. Clear icing occurs in cumuliform-type clouds at temperatures between 0°C and a minus 9°C. It also occurs with rime icing in cumuliform clouds at temperatures between minus 9°C and minus 15°C.

Drifting and Blowing Snow

Drifting and blowing snow are the result of snow particles being raised from the ground by the wind. To classify wind-driven snow as drifting snow, the particles will only be lifted to shallow heights (less than 6 feet) and the horizontal visibility will remain at 7 miles or more at eye level (6 feet). When the wind drives snow to levels 6 feet or higher and the visibility is restricted to 6 miles or less, it is classified as blowing snow.

Spray and Blowing Spray

Spray and blowing spray occurs when the wind is of such force that it lifts water droplets from the water surface (normally the wave crests) and carries them into the air. To be classified as spray, the wind-driven water droplets will not obstruct visibility at eye level (6 feet on shore and generally 33 feet at sea). Blowing spray occurs when the water droplets are lifted in such quantities that they reduce visibility to 6 miles or less at eye level.

TORNADOES

A tornado is an extremely violent whirling storm with a small diameter, usually a quarter of a mile or less. The length of the track of a tornado on the ground may be from a few hundred feet to 300 miles; the average is less than 25 miles. When not touching the ground, it is termed *a funnel cloud* or *tuba.* The velocities of tornado winds are in the general range of 125 to 250 knots. A large reduction of pressure in the center due to the spiraling of the air seems to cause buildings in the path of the storm to explode. The speed of the storm over Earth's surface is comparatively slow—usually 22 to 34 knots.

Most of the tornadoes in the United States occur in the late spring and early summer in middle and late afternoon, and they are associated with thunderstorm activity and heavy rain. Tornadoes occur on all continents but are most common in Australia and the United States. They can occur throughout the year and at any time of day. Tornadoes have been observed with various synoptic situations but are usually associated with overrunning cold air. Statistics show that the majority of tornadoes appear about 75 to 180 miles ahead of a cold front along the prefrontal squall line. Figure 5-6 shows the various stages of development of a tornado.

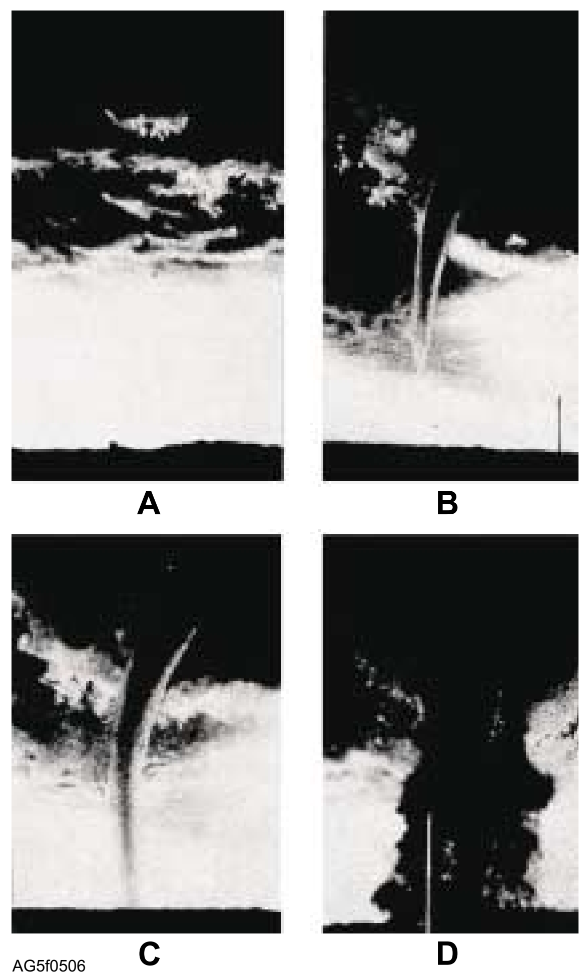


Figure 5-6.—Stages of development of a tornado.

A situation that is noticeably favorable to tornado activity is cold air advection aloft. When mP air moves across the United States, it becomes heated in the low levels in the western plateaus. The resulting density of the now warm mP air is then equal to or less than that of mT air moving northward over the Mississippi Valley. The mP air rides up over the mT air. The mP air still maintains low temperatures at higher altitudes causing extreme instability.

The following conditions may indicate possible tornado activity:

1. Pronounced horizontal wind shear. (Wind shear is the rate of change of wind velocity with distance.)

2. Rapidly moving cold front.

3. Strong convergent flow at the surface.

4. Marked convective instability.

5. Dry air mass superimposed on a moist air mass and abrupt change in moisture content, usually below 10,000 feet.

6. Marked convection up to the minus 10°C isotherm.

WATERSPOUTS

Waterspouts are tornadoes that form over ocean areas. This phenomenon consists of two types: tornado in origin and locally induced. The difference between the two types is significant in that the tornado type has potential for inducing substantial damage and injury over a broad area, while the local type has potential for causing only minor damage in a small area. The following information is provided to help you to better understand the two types of waterspouts.

Tornado Type

These waterspouts form at the cloud and extend down to the surface. They originate from severe convective cells associated with a cold front, squall line, or large convective cluster. Whenever the conditions for tornado development are present over coastal areas and the triggering mechanism extends into the adjacent maritime area, then potential for waterspout development is high. The tornado waterspout has a relatively short life span and usually stays over water. However, when one does come ashore, there is potential for it to assume the characteristics of a tornado; although its life span is limited, the initial intensity is sufficient to cause property damage and injury to personnel.

Local Type

These waterspouts originate from convective clouds of moderate vertical extent which form a line or a small cluster. Their existence is sensitive to wind and temperature in that surface winds of 20 knots or greater, or a cooling of the atmosphere by precipitation, dissipates them. Additionally, when local waterspouts come ashore, the friction induced by the land rapidly dissipates them. The biggest threat posed by these waterspouts is to small craft, recreational boating, and to support facilities such as harbor operations and marinas.

REVIEW QUESTIONS

Q5-1. Describe the major difference between rain and drizzle.

Q5-2. What altitude range do clouds occur in the tropics?

Q5-3. What is the altitude range of middle clouds in the temperate regions?

Q5-4. Describe the difference between sea fog and steam fog.

Q5-5. What criteria must be met for a hydrometeor to be classified as blowing spray?

LITHOMETEORS

LEARNING OBJECTIVE: Identify the characteristics of lithometeors (haze, smoke, dust, sand, and dust devils).

Lithometeors comprise a class of atmospheric phenomena of which dry haze and smoke are the most common examples. In contrast to hydrometeors, which consist largely of water, lithometeors are composed of solid dust or sand particles, or the ashy products of combustion.

HAZE

Haze is composed of suspended dust or salt particles that are so small that they cannot be individually felt or seen by the unaided eye. They reduce visibility and lend a characteristic opalescent appearance to the air. Haze resembles a uniform veil over the landscape that subdues all colors. This veil has a bluish tinge when viewed against a dark background and a dirty yellow or orange tinge when viewed against a bright background. Differences in air temperature may cause a shimmering veil over the landscape called optical haze.

SMOKE

Smoke is fine ash particles suspended in the atmosphere. When smoke is present, the disk of the Sun at sunrise and sunset appears red, and during the daytime has a reddish tinge. Smoke at a distance, such as from forest fires, usually has a light grayish or bluish color and is evenly distributed in the upper air.

DUST

Dust is finely divided solid matter uniformly distributed in the air. It imparts a tan or grayish hue to distant objects. The Sun's disk is pale and colorless or has a yellow tinge during the day. Blowing dust consists of dust raised by the wind to moderate heights above the ground and restricting horizontal visibility to less than 7 miles. When visibility is reduced to less than five-eighths of a mile but not less than five-sixteenths of a mile, it is classified as a dust storm and, if less than five-sixteenths of a mile, as a severe dust storm.

SAND

Fine particles of sand picked up from the surface by the wind and blown about in clouds or sheets constitute a troublesome lithometeor in some regions. Blowing sand consists of sand raised by the wind to moderate heights above the ground, which reduces horizontal visibility to less than 7 miles. When the visibility is reduced to less than five-eighths of a mile but not less than five-sixteenths of a mile, it is classed as a sandstorm and, if less than five-sixteenths of a mile, as a severe sandstorm.

DUST DEVILS

Dust devils, or whirling, dust-laden air, are caused by intense solar radiation, which sets up a steep lapse rate near the ground. They are best developed on calm, hot, clear afternoons and in desert regions. As the intense surface heating sets up a steep lapse rate, a small circulation is formed when the surrounding air rushes in to fill the area of the rising warm air. This warm ascending air carries dust, sand, leaves, and other small material to a height of a few hundred feet.

REVIEW QUESTIONS

Q5-6. Name one way that smoke is distinguished from haze.

Q5-7. When and where are dust devils usually observed?

PHOTOMETEORS

LEARNING OBJECTIVE: Identify the characteristics of photometeors and describe the characteristics of light, reflection, and refraction.

Photometeors are any of a number of atmospheric phenomena that appear as luminous patterns in the sky. While they constitute a variety of fascinating optical phenomena, photometeors are not active elements; that is, they generally do not cause adverse weather. However, many are related to clouds that do cause adverse weather. Therefore, they help in describing the state of the atmosphere.

LIGHT

Light, acting in conjunction with some of the elements of the atmosphere, produces a variety of atmospheric phenomena, such as halos, coronas, mirages, rainbows, and crepuscular rays. This lesson discusses the theories of light and the resulting photometeors.

Light is the portion of the electromagnetic spectrum that can be detected by the human eye. It travels at the same speed as all other electromagnetic radiation (186,000 miles per second). However, the characteristics of light are considerably different from other regions of the electromagnetic spectrum because of the differences in wavelength and frequency.

Sources of Light

There are two sources of light—natural and artificial. Nearly all natural light is received from the Sun. Artificial light is light such as that produced by electric lamps, fires, or fluorescent tubes. Luminous bodies are those bodies that which produce their own light, such as the Sun and the stars. Illuminated or non luminous bodies are those bodies which merely reflect the light they receive and are therefore visible because of this reflection. The Moon is an example of an illuminated body.

Theory

When light is emitted from a source, waves of radiation travel in straight lines and in all directions. Dropping a pebble into a pool of water can see a simple example of motion, similar to that of radiation waves. The waves spread out in expanding circles; similarly, light waves spread out in all directions to form a sphere. The boundary formed by each wave is called a *wave front.* Lines, or rays, drawn from the light source to any point on one of these waves indicate the direction in which the wave fronts are moving. Light radiates from its source in all directions until absorbed or diverted by coming in contact with some substance or object.

Wavelength

The wavelength of a light wave is the distance from the crest of one wave to the crest of the following wave. Wavelength, frequency (the number of waves which pass a given point in a unit of time), and speed are related by the simple equation:

$$C = \lambda F$$

Where:

C = speed
λ = wavelength
F = frequency

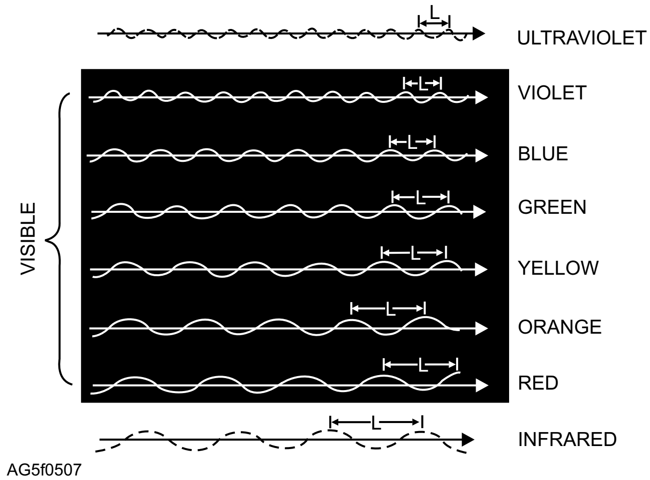


Figure 5-7.—Wavelength of various visible and invisible colors.

Because the speed of electromagnetic energy is constant, the frequency must increase if the wavelength decreases and vice versa.

Wavelength is measured in angstrom units (A). They may also be measured in millimicrons, or millionths of millimeters (mA). Figures 5-7 and 5-8 show the visible and invisible spectrum's colors in relation to their wavelengths. Figure 5-8 shows that the visible spectrum occupies only a small portion of the complete electromagnetic spectrum extending between 4,000 and 7,000 angstroms only.

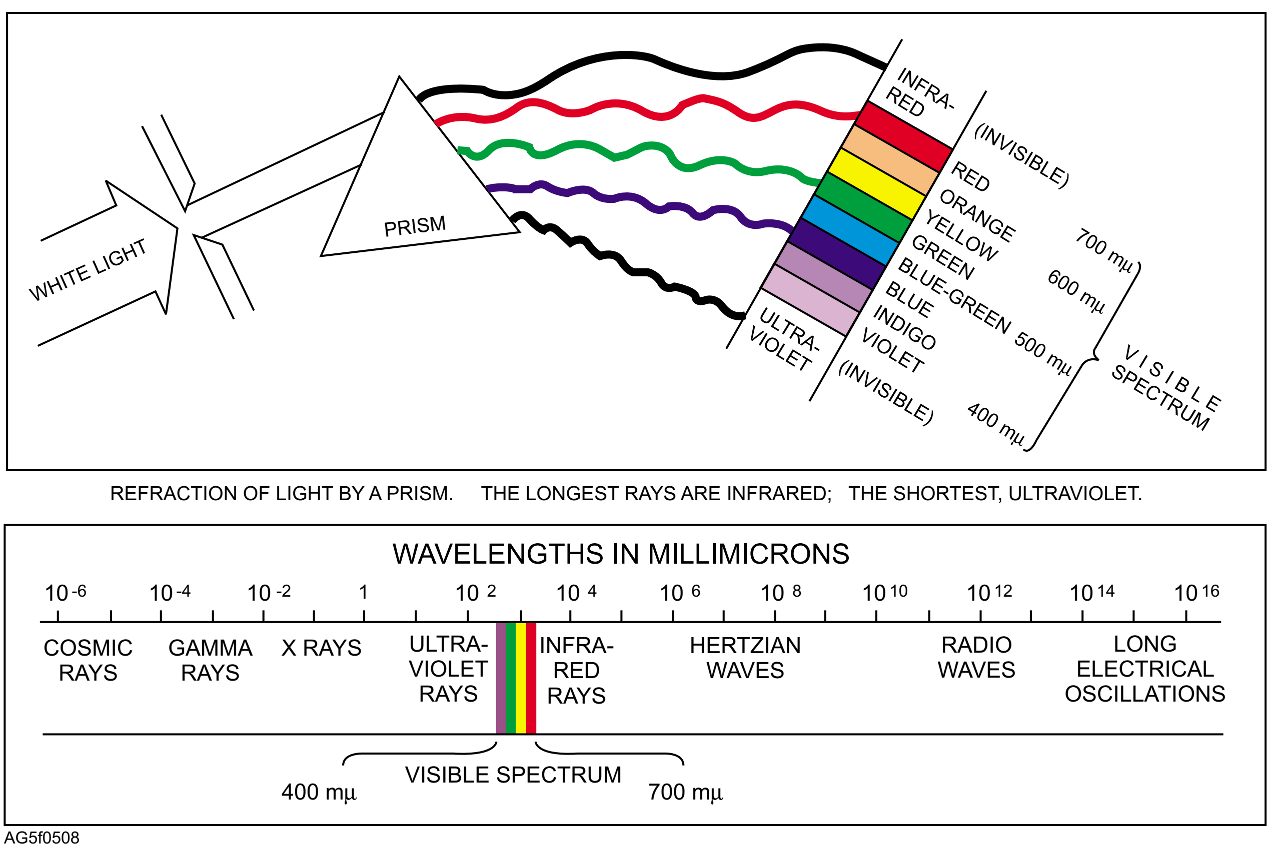


Figure 5-8.—Wavelengths and refraction.

Characteristics

When light waves encounter any substance, they are either reflected, absorbed, or refracted. (See fig. 5-9.) Substances that permit the penetration of clear vision through them and transmit almost all the light falling upon them, such as glass and air, are transparent. There is no known substance that is perfectly transparent, but many are nearly so. Those substances that allow the passage of part of the light but appear clouded and impair vision substantially, such as frosted light bulbs, are considered translucent. Those substances that do not transmit any light are termed opaque.

All objects that are not light sources are visible only because they reflect all or some part of the light reaching them from a luminous source. If light is neither refracted nor reflected, it is absorbed or taken up by the medium. When light strikes a substance, some absorption and some reflection always takes place. No substance completely refracts (transmits), reflects, or absorbs all the light that reaches its surface. Figure 5-9 illustrates this refraction, absorption, and reflection of light using a flat pane of glass.

Candlepower and Foot-candles

Illumination is the light received from a light source. The intensity of illumination is measured in foot-candles. A foot-candle is the amount of light falling upon a 1-square-foot surface, which is 1 foot away from a 1-candlepower light source.

REFLECTION

The term *reflected light* refers to those light waves that are neither transmitted nor absorbed but are thrown back from the surface of the medium they encounter. If a ray of light is directed against a mirror, the light ray that strikes the surface is called the *incident ray;* the one that bounces off is the *reflected ray* (see fig. 5-10). The imaginary line perpendicular to the mirror at the point

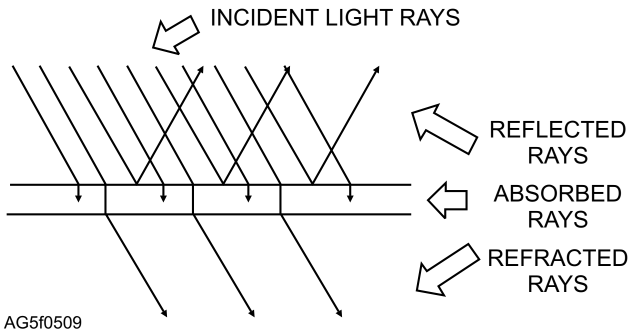


Figure 5-9.—Light rays reflected, absorbed, and refracted.

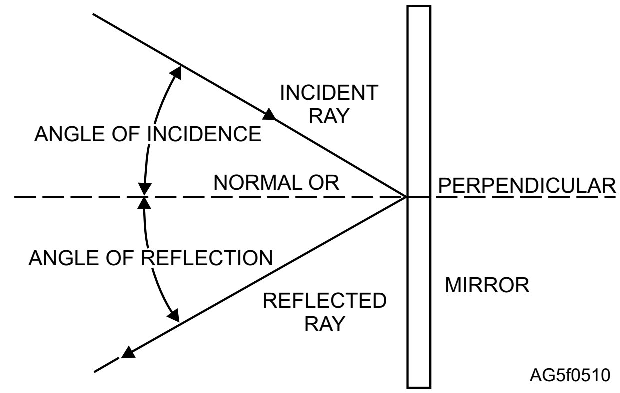


Figure 5-10.—Terms used to describe the reflection of light.

where the ray strikes is the *normal.* The angle between the incident ray and the normal is the *angle of incidence.* The angle between the reflected ray and the normal is the *angle of reflection.*

If the surface of the medium contacted by the incident light ray is smooth and polished, such as a mirror, the reflected light is thrown back at the same angle to the surface as the incident light. The path of the light reflected from the surface forms an angle exactly equal to the one formed by its path in reaching the medium. This conforms to the law of reflection, which states that the angle of incidence is equal to the angle of reflection.

Reflection from a smooth-surfaced object presents few problems. It is a different matter, however, when a rough surface reflects light. The law of reflection still holds but because the surface is uneven, the angle of incidence is different for each ray of light. The reflected light is scattered in all directions as shown in figure 5-11 and is called irregular or diffused light.

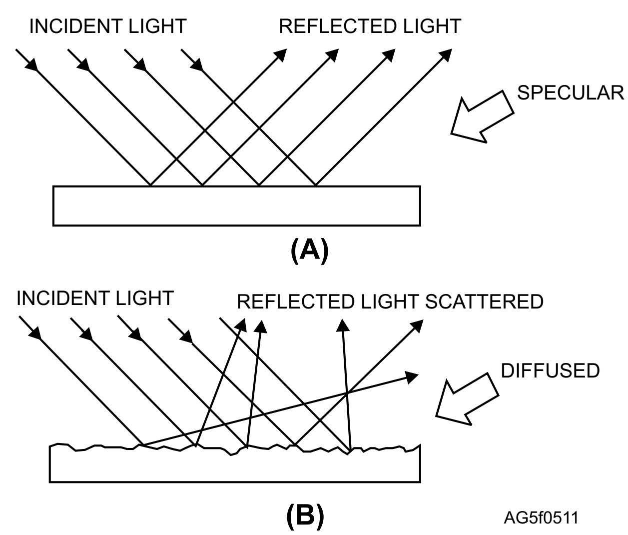


Figure 5-11.—Reflected light. (A) Regular (specular); (B) Irregular (diffused).

REFRACTION

The change of direction that occurs when a ray of light passes at an oblique angle (less than 90°) from one transparent substance *into* another substance of different density is called refraction. Refraction occurs because light travels at various speeds in different transparent substances of different densities. The greater the density of a substance, the slower the light travels through it.

Refraction (or change of direction) always follows a simple rule: when the light ray passes from one transparent substance into another of greater density, refraction is toward the normal. In this context, the normal means a line perpendicular to the surface of the medium at the point of entrance of the light ray. (See fig. 5-12.) In passing from one transparent substance into another of lesser density, refraction is away from the normal. (See fig. 5-13.)

When a ray of light enters a denser medium at an angle of 90°, as shown in figure 5-14, the wave fronts slow down but remain parallel. When this same light ray enters a *denser* medium at an oblique angle, the portion of the wave front that first enters the water moves slower than the other part of the wave front that is still in the air. Consequently, the ray bends toward the normal. (See fig. 5-12).

If the light ray enters a *less dense* medium at an oblique angle, the ray bends away from the normal as shown in figure 5-13. The portion of the wave front that enters the less dense substance travels faster than the other part of the wave front. Consequently, the ray bends away from the normal.

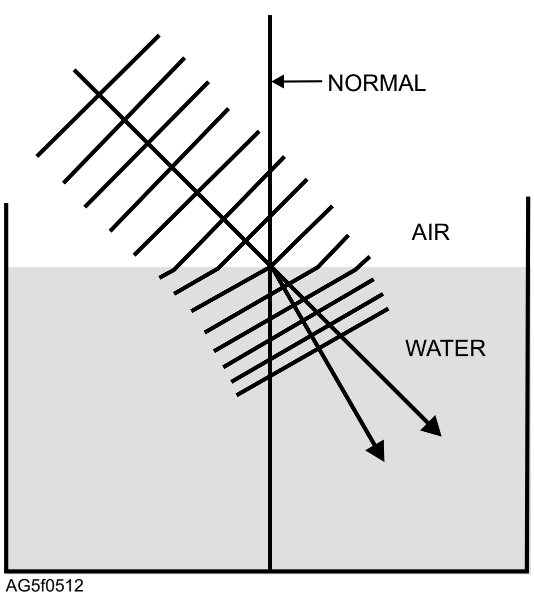


Figure 5-12.—Wave front diagram illustrating refraction of light at an air-water boundary. Ray is entering a more dense substance.

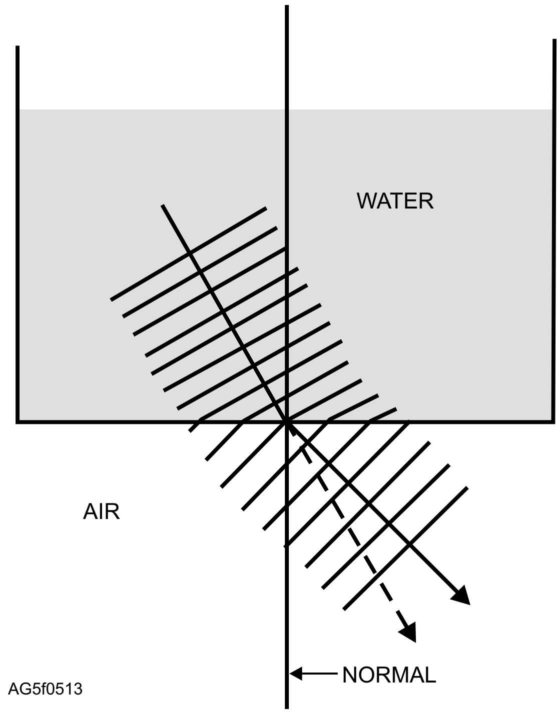


Figure 5-13.—Wave front diagram illustrating refraction of light at an air-water boundary. Ray is entering a less dense substance.

When a beam of white light is passed through a prism, as shown in figure 5-8, it is refracted and dispersed into its component wavelengths. Each of these wavelengths reacts differently on the eye, which then sees the various colors that compose the visible spectrum.

The visible spectrum ranges in color from violet at one end to red at the other end. (See fig. 5-8.) There are

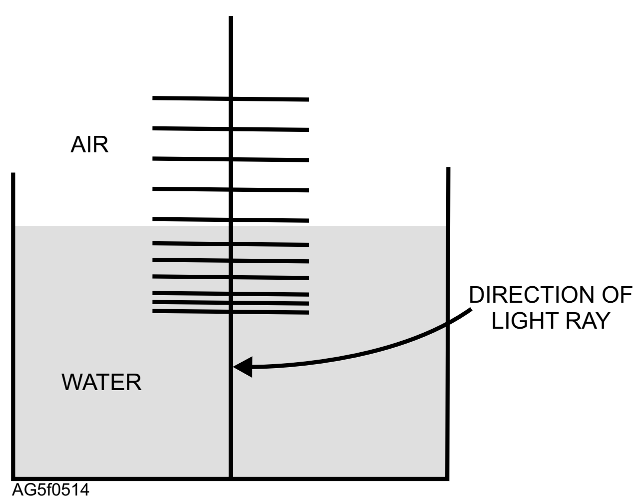


Figure 5-14.—Wave front diagram illustrating the difference in the speed of light in air and water.

six distinct colors in the spectrum: red, orange, yellow, green, blue, and violet. However, a mixture of these colors is also present.

ATMOSPHERIC OPTICAL PHENOMENA

LEARNING OBJECTIVE: Identify the characteristics of atmospheric optical phenomena (halos, coronas, rainbows, fogbows, mirages, looming, scintillation and crepuscular rays).

ATMOSPHERIC LAWS

Atmospheric optical phenomena are those phenomena of the atmosphere that can be explained in terms of optical laws. Some of the atmospheric elements, such as moisture, serve as a prism to break a light source down into its various component colors. The resulting phenomena can be spectacular as well as deceptive.

Halos

A halo is a luminous ring around the Sun or Moon. When it appears around the Sun, it is a solar halo; when it forms around the Moon, it is a lunar halo. It usually appears whitish (caused by reflection), but it may show the spectral colors, from refraction (red, orange, yellow, green, blue, indigo, and violet) with the red ring on the inside and the violet ring on the outside. The sky is darker inside the ring than outside. Halos are formed by *refraction* of light as it passes through ice crystals. This means that halos are almost exclusively associated with cirriform clouds. Refraction of light means that the light passes through prisms; in this case, ice crystals act as prisms. Some reflection of light also takes place.

Halos appear in various sizes, but the most common size is the small 22-degree halo. The size of the halo can be determined visually with ease. Technically, the radius of the 22-degree halo subtends an arc of 22°. This simply means that the angle measured from the observation point between the luminous body and the ring is 22°. Halos of other sizes are formed in the same manner.

Coronas

A corona is a luminous ring surrounding the Sun (solar) or Moon (lunar) and is formed by *diffraction* of light by water droplets. It may vary greatly in size but is usually smaller than a halo. All the spectral colors may be visible, with red on the outside, but frequently the inner colors are not visible. Sometimes the spectral colors or portions of them are repeated several times and are somewhat irregularly distributed. This phenomenon is called iridescence.

Rainbows

The rainbow is a circular arc seen opposite the Sun, usually exhibiting all the primary colors, with red on the outside. Diffraction, refraction, and reflection of light cause it from raindrops or spray, often with a secondary bow outside the primary one with the colors reversed.

Fogbows

A fogbow is a whitish circular arc seen opposite the Sun in fog. Its outer margin has a reddish tinge; its inner margin has a bluish tinge; and the middle of the band is white. An additional bow, with the colors reversed, sometimes appears inside the first.

Mirages

Mirages are images of objects that are made to appear displaced from their normal positions because of refraction. These images may be only a partial image of the object, and they may appear in either an upright or an inverted position, depending upon the atmospheric condition that exists at the time of observation. Mirages occur when adjacent layers of air have vastly different densities because of great temperature differences. Whether these layers exist side by side and horizontally or vertically determines the type of mirage.

Mirages are often seen in desert areas where air near the surface becomes very hot. Cool air overlies this hot layer resulting in a large difference in the densities of the two layers. Three types of mirages result from the refraction of light rays through layers of air with vastly different densities.

INFERIOR MIRAGE.—The inferior mirage, the most common of the three, appears as a mirrored image below the object being viewed by the observer. In this case, you can associate the word *inferior* with *beneath* or *below.*

SUPERIOR MIRAGE.—In the superior mirage, the mirrored image appears above the object being viewed. In this case, associate the word *superior* with *above* or *over.*

LATERAL MIRAGE.—Since the positions of above and below represent superior and inferior mirages respectively, the lateral mirage then appears to the side of the object being viewed.

Looming

Looming is similar to a mirage in that it brings into view objects that are over a distant horizon. Looming occurs when there is superrefraction in the lower atmosphere, which makes reflected light travel a path similar to the curvature of Earth. Objects over the horizon may be seen when light reflected from them takes this path. Looming is somewhat rare and is normally observed over flat surfaces, such as oceans and deserts.

Scintillation

Scintillation is caused by variations in atmospheric density near the horizon. It produces the appearance of rapid changes in the position, brightness, and color of distinct luminous objects, such as stars. Stars flickering and changing color near the horizon shortly after sunset are good examples of scintillation and are a reasonably common phenomenon.

Crepuscular Rays

Crepuscular rays are another common phenomena. They are simply sunbeams that are rendered luminous by haze and dust particles suspended in the atmosphere. They are seen before and after sunrise and sunset as they pass through small breaks or openings in or around clouds. The sunbeams are actually parallel but appear to diverge from the Sun.

REVIEW QUESTIONS

Q5-8. Name the two sources of light.

Q5-9. What is the difference between natural and artificial light?

Q5-10. What is the difference between reflection and refraction?

Q5-11. What is a mirage?

ELECTROMETEORS

LEARNING OBJECTIVE: Identify the characteristics of electrometeors (thunderstorms, lightning, auroras, and airglow).

An electrometeor is a visible or audible manifestation of atmospheric electricity. The more important electrometeors are thunderstorms, lightning, and auroras.

THUNDERSTORMS

The thunderstorm represents one of the most formidable weather hazards in temperate and tropical zones. Though the effects of the thunderstorm tend to be localized, the turbulence, high winds, heavy rain, and occasional hail accompanying the thunderstorm are a definite threat to the safety of flight operations and to the security of naval installations. The Aerographer's Mate must be acquainted with the structure of thunderstorms and the types of weather associated with them.

Formation

The thunderstorm represents a violent and spectacular atmospheric phenomenon. Lightning, thunder, heavy rain, gusty surface wind, and frequent hail usually accompany it. A certain combination of atmospheric conditions is necessary for the formation of a thunderstorm. These factors are conditionally unstable air of relatively high humidity and some type of lifting action. Before the air actually becomes unstable, it must be lifted to a point where it is warmer than the surrounding air. When this condition is brought about, the relatively warmer air continues to rise freely until, at some point aloft, its temperature has cooled to the temperature of the surrounding air. Some type of external lifting action must be introduced in order to raise the warm surface air to a point where it can rise freely. Many conditions satisfy this requirement; heating, terrain, fronts, or convergence may lift an air mass.

Structure

The fundamental structural element of the thunderstorm is the unit of convective circulation known as the convective cell. A mature thunderstorm contains several of these cells, which vary in diameter from 1 to 6 miles. By radar analysis and measurement of drafts, it has been determined that, generally, each cell is independent of surrounding cells of the same storm. Each cell progresses through a cycle, which lasts from 1 to 3 hours. In the initial stage (cumulus development), the cloud consists of a single cell, but as the development progresses, new cells form and older cells dissipate. The life cycle of the thunderstorm cell

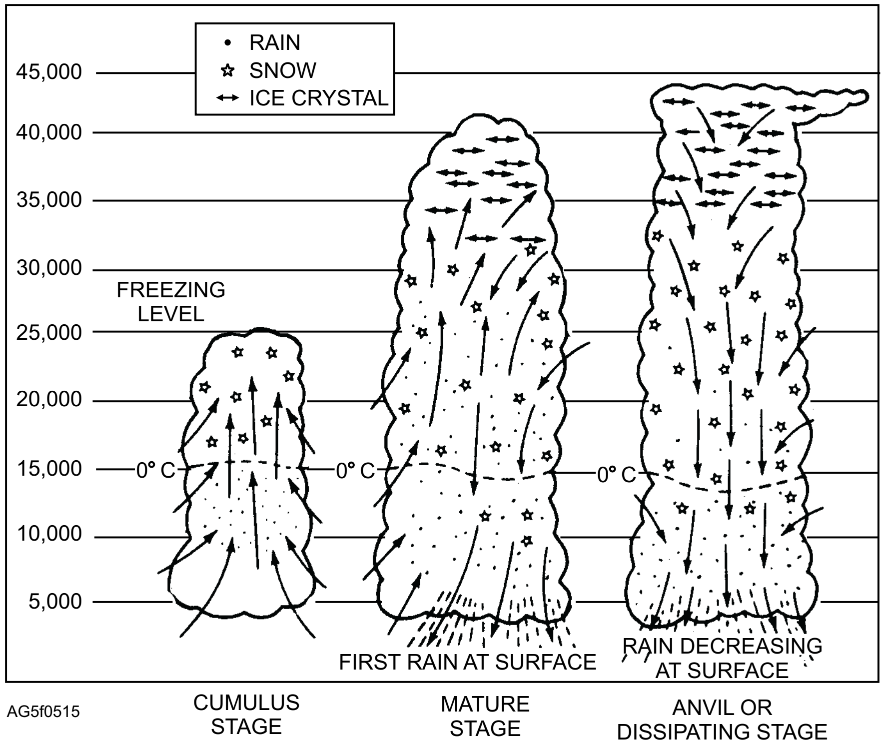


Figure 5-15.—Life cycle of a thunderstorm cell.

consists of three distinct stages; they are the cumulus. stage, the mature stage, and the dissipating or anvil stage. (See fig. 5-15.)

CUMULUS STAGE.—Although most cumulus clouds do not become thunderstorms, the initial stage of a thunderstorm is always a cumulus cloud. The chief distinguishing feature of this cumulus or building *stage is an updraft, which* prevails throughout the entire cell. Such updrafts vary from a few feet per second in the early cells to as much as 100 feet per second in mature cells.

MATURE STAGE.—The beginning of surface rain, with adjacent updrafts and downdrafts, initiates the mature stage. By this time the top of the average cell has attained a height of 25,000 feet or more. As the raindrops begin to fall, the frictional drag between the raindrops and the surrounding air causes the air to begin a downward motion. Since the lapse rate within a thunderstorm cell is greater than the moist adiabatic rate, the descending saturated air soon reaches a level where it is colder than its environment; consequently, its rate of downward motion is accelerated, resulting in a downdraft. (See fig. 5-16.)

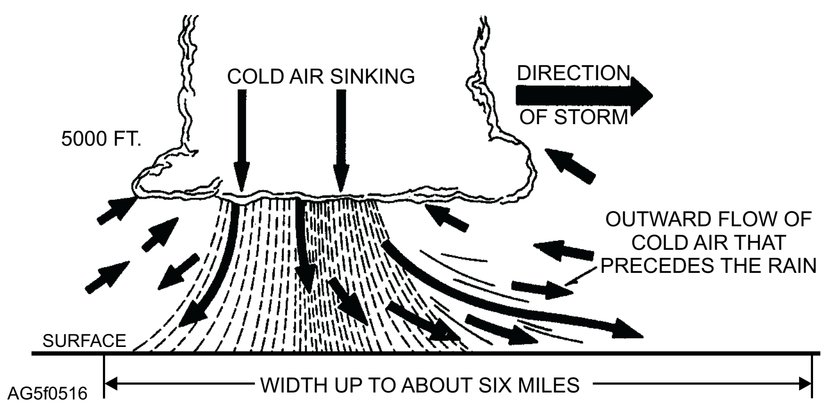


Figure 5-16.—Downdraft beneath a thunderstorm cell in the mature stage. Arrows represent wind flow. Dashed lines indicate rainfall.

A short time after the rain starts its initial fall, the updraft reaches its maximum speed. The speed of the updraft increases with altitude. Downdrafts are usually strongest at the middle and lower levels, although the variation in speed from one altitude to another is less than in the case of updrafts. Downdrafts are not as strong as updrafts; downdraft speeds range from a few feet per second to 40 feet per second or more. Significant downdrafts seldom extend to the top of the cell because, in most cases, only ice crystals and snowflakes are present, and their rate of fall is insufficient to cause appreciable downdrafts.

The mature cell, then, generally extends far above 25,000 feet, and the lower levels consist of sharp updrafts and downdrafts adjacent to each other. Large water droplets are encountered suspended in the updrafts and descending with the downdrafts as rain.

DISSIPATING (ANVIL) STAGE.—Throughout the life span of the mature cell, the falling raindrops are dragging down more and more air aloft. Consequently, the downdraft spreads out to take the place of the dissipating updraft. As this process progresses, the entire lower portion of the cell becomes an area of downdraft. Since this is an unbalanced situation and since the descending motion in the downdraft effects a drying process, the entire structure begins to dissipate. The high winds aloft have now carried the upper section of the cloud into the anvil form, indicating that gradual dissipation is overtaking the storm cell.

Vertical Development

Thunderstorms have been accurately measured as high as 67,000 feet and some severe thunderstorms attain an even greater height. More often the maximum height is from 40,000 to 45,000 feet. In general, air-mass thunderstorms extend to greater heights than do frontal storms.

Rising and descending drafts of air are, in effect, the structural bases of the thunderstorm cell. A draft is a large-scale vertical current of air that is continuous over many thousands of feet of altitude. Downdraft speeds are either relatively constant or gradually varying from one altitude to the next. Gusts, on the other hand, are smaller scaled discontinuities associated with the draft proper. A draft may be compared to a great river flowing at a fairly constant rate, whereas a gust is comparable to an eddy or any other random motion of water within the main current.

Thunderstorm Weather

The hydrometeors and turbulence of a thunderstorm that we observe and record at the surface are easily recognized. The weather within the thundercloud itself is another story. Visual observations from aircraft are difficult because of the speed with which they pass through the thunderclouds, and man has yet to devise an instrument that will measure all hydrometeors in the cloud. Let us look at those forms of precipitation turbulence and icing occurring with and within thunderclouds as we know them today.

RAIN.—Liquid water in a storm may be ascending if encountered in a strong updraft; it may be suspended, seemingly without motion, yet in an extremely heavy concentration; or it may be falling to the ground. Rain, as normally measured by surface instruments, is associated with the downdraft. This does not preclude the possibility of a pilot entering a cloud and being swamped, so to speak, even though rain has not been observed from surface positions. Rain is found in almost every case below the freezing level. In instances in which no rain is encountered, the storm probably has not developed into the mature stage. Statistics show that although heavy rain is generally reported at all levels of a mature storm, the greatest incidence of heavy rain occurs in the middle and lower levels of a storm.

HAIL.—Hail, if present, is most often found in the mature stage. Very seldom is it found at more than one or two levels within the same storm. When it is observed, its duration is short. The maximum occurrence is at middle levels for all intensities of hail.

SNOW.—The maximum frequency of moderate and heavy snow occurs several thousand feet above the freezing level. Snow, mixed, in many cases, with supercooled rain, may be encountered in updraft areas at all altitudes above the freezing level. This presents a unique icing problem: wet snow packed on the leading edge of the wing of the aircraft resulting in the formation of rime ice.

TURBULENCE.—There is a definite correlation between turbulence and precipitation. The intensity of associated turbulence, in most cases, varies directly with the intensity of the precipitation.

ICING.—Icing may be encountered at any level where the temperature is below freezing. Both rime and clear ice occur, with rime predominating in the regions of snow and mixed rain and snow. Since the freezing level is also the zone of greatest frequency of heavy turbulence and generally heavy rainfall, this particular altitude appears to be the most hazardous for aircraft.

SURFACE WIND.—A significant hazard associated with thunderstorm activity is the rapid change in surface wind direction and speed immediately before storm passage. The strong winds at the surface accompanying thunderstorm passage are the result of the horizontal spreading out of downdraft current from within the storm as they approach the surface of Earth.

The total wind speed is a result of the downdraft divergence plus the forward velocity of the storm cell. Thus, the speeds at the leading edge, as the storm approaches, are greater than those at the trailing edge. The initial wind surge, as observed at the surface, is known as the *first gust.*

The speed of the first gust is normally the highest recorded during storm passage, and the direction may vary as much as 180° from the previously prevailing surface wind. First-gust speeds increase to an average of about 16 knots over prevailing speeds, although gusts of over 78 knots (90 mph) have been recorded. The average change of wind direction associated with the first gust is about 40°.

In addition to the first gust, other strong, violent, and extremely dangerous downdraft winds are associated with the thunderstorm. These winds are referred to as *downbursts*. Downbursts are subdivided into *macrobursts* and *microbursts*.

Macrobursts.—Macrobursts are larger scale downbursts. Macrobursts can cause widespread damage similar to tornadoes. These damaging winds can last *5* to 20 minutes and reach speeds of 130 knots (150 mph) or more.

Microbursts.—Microbursts are smaller scale downbursts. A microburst can last 2 to 5 minutes and can also reach wind speeds in excess of 130 knots. Microbursts produce dangerous tailwinds or crosswinds and wind shear for aircraft and are difficult to observe or forecast.

Downbursts are not the same as first gusts. First gusts occur in all convective cells containing showers and are predictable and expected. Downbursts, however, do not occur in all convective cells and thunderstorms.

Classifications

All thunderstorms are similar in physical makeup, but for purposes of identification, they may be divided into two general groups, frontal thunderstorms and air-mass thunderstorms.

FRONTAL.—Frontal thunderstorms are commonly associated with both warm and cold fronts. The warm-front thunderstorm is caused when warm, moist, unstable air is forced aloft over a colder, denser shelf of retreating air. Warm-front thunderstorms are generally scattered; they are usually difficult to identify because they are obscured by other clouds.

The cold-front thunderstorm is caused by the forward motion of a wedge of cold air, into a body of warm, moist unstable air. Cold-front storms are normally positioned aloft along the frontal surface in what appears to be a continuous line.

Under special atmospheric conditions, a line of thunderstorms develops ahead of a cold front. This line of thunderstorms is the prefrontal squall line. Its distance ahead of the front ranges from 50 to 300 miles. Prefrontal thunderstorms are usually intense and appear menacing. Bases of the clouds are very low. Tornadoes sometimes occur when this type of activity is present.

AIR MASS.—Air-mass thunderstorms are subdivided into several types. In this text, however, only two basic types are discussed, the convective thunderstorm and the Orographic thunderstorm.

Convective.—Convective thunderstorms may occur over land or water almost anywhere in the world. Their formation is caused by solar heating of various areas of the land or sea, which, in turn, provides heat to the air in transit. The land type of convective thunderstorm normally forms during the afternoon hours after Earth has gained maximum heating from the Sun. If the circulation is such that cool, moist, convective, unstable air is passing over the land area, heating from below causes convective currents and results in towering cumulus or thunderstorm activity. Dissipation usually begins during the early evening hours. Storms that occur over bodies of water form in the same manner, but at different hours. Sea storms usually form during the evening after the Sun has set and dissipate during the late morning.

Both types of convective thunderstorms occur in Florida. The anticyclonic circulation around the Bermuda high advects moist air over the land surface of Florida in its easterly flow. Thunderstorms off the East Coast of Florida at night occur when this easterly flow passes over the warm axis of the Florida current. In those areas where the air is cooler than the water below it, the air is heated and convective currents (lifting) begin. Any nocturnal cooling of the easterly flow aloft aids in establishing the unstable lapse rate necessary for thunderstorm development. After sunrise, the air is heated and becomes warmer than the water, thereby destroying the balance necessary to sustain or build similar storms. As the day progresses, the land surface becomes considerably warmer than the air. Convective currents again result, and Florida’s common afternoon thunderstorms are observed. After sunset the land cools, convective currents cease, and the thunderstorms dissipate. The apparent movement of the storms to sea at night, and to shore during the day, is in reality the reformation of storms in their respective areas. As a general rule, convective thunderstorms are scattered and easily recognized. They build to great heights, and visibility is generally excellent in the surrounding area.

Orographic.—Orographic thunderstorms form in mountainous regions, particularly adjacent to individual peaks. A good example of this type of storm occurs in the northern Rocky Mountain region. When the circulation of the air is from the west, moist air from the Pacific Ocean is transported to the mountains where it is forced aloft by the upslope of the terrain. If the air is conditionally unstable, this upslope motion causes thunderstorm activity on the windward side of the mountains. This activity may form a long, unbroken line of storms similar to a cold front. The storms persist as long as the circulation causes an upslope motion. They tend to be more frequent during afternoon and early evening when convective lifting coincides with the mechanical lifting of the terrain.

LIGHTNING

Lightning is obviously the most spectacular of electrometeors and is directly related to the thunderstorm even though classified independently. It is the bright flash of light accompanying a sudden electrical discharge. Most lightning has its beginning in clouds; however, it generates from high structures on the ground and mountains, although much less frequently.

The thunderstorm changes the normal electric field, in which the ground is negatively charged with respect to the air above it. Because the upper portion of the thunderstorm cloud is positive and the lower part is negative, the negative charge induces a positive charge on the ground. The distribution of the electric charges in a typical thunderstorm is shown in figure 5-17. The

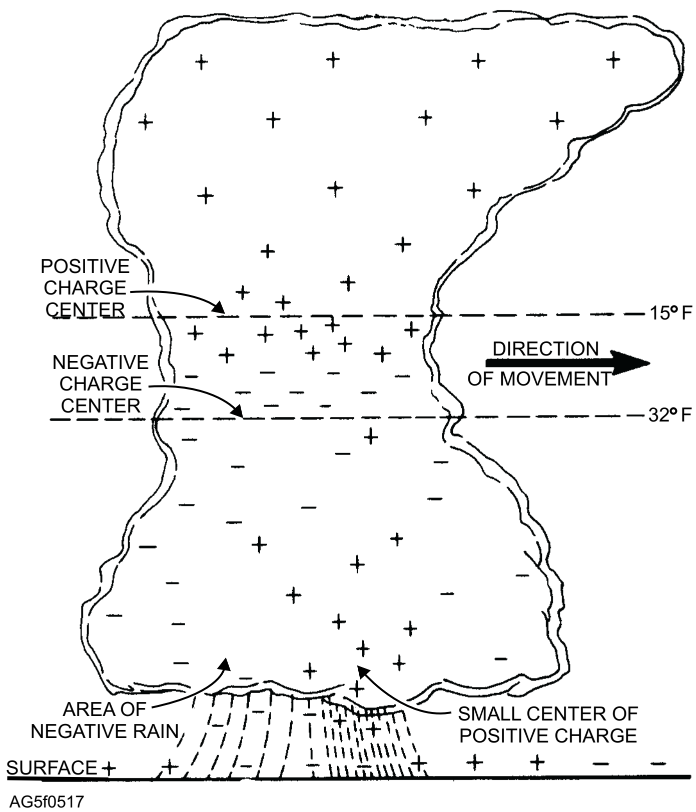


Figure 5-17.—Location of electric charges inside a typical thunderstorm cell.

lightning first occurs between the upper positive charge area and the negative charge area immediately below it. Lightning discharges are considered to occur most frequently in the area bracketed roughly by the 32°F and the 15°F temperature levels. However, this does not mean that all discharges are confined to this region; as the thunderstorm develops, lightning discharges may occur in other areas and from cloud to cloud, as well as from cloud to ground.

There are four main types of lightning. All can do considerable damage to aircraft, especially to radio equipment.

1. Cloud To Ground Lightning (CG). Lightning occurring between cloud and ground.

2. Cloud Discharges (IC). Lightning taking place within the cloud.

3. Cloud To Cloud Discharges (CC). Streaks of lightning reaching from one cloud to another.

4. Air Discharges (CA). Streaks of lightning passing from a cloud to the air that do not strike the ground.

AURORAS

Auroras are luminous phenomena, which appear in the high atmosphere in the form of arcs, bands, draperies, or curtains. These phenomena are usually white but may have other colors. The lower edges of the arcs or curtains are usually well defined while the upper edges are not. Polar auroras are caused by electrically charged particles, ejected from the Sun, which act on the rarefied (select) gases of the higher atmosphere. The particles are channeled by Earth's magnetic field, so auroras are observed mainly near the magnetic poles. In the Northern Hemisphere they are known as aurora borealis; in the Southern Hemisphere they are known as aurora australis.

AIRGLOW

Airglow is similar in origin and nature to the aurora; it, too, is an upper atmospheric electrical phenomenon. The main differences between airglow and aurora are that airglow is quasi-steady (quasi means seemingly) in appearance, is much fainter than aurora, and appears in the middle and lower altitudes.

REVIEW QUESTIONS

Q5-12. What is the diameter range of a mature thunderstorm cell?

Q5-13. During what stage of a thunderstorm is rain observed at the surface?

Q5-14. What is the difference between a macroburst and a microburst?

Q5-15. Describe the two different types of thunderstorms?