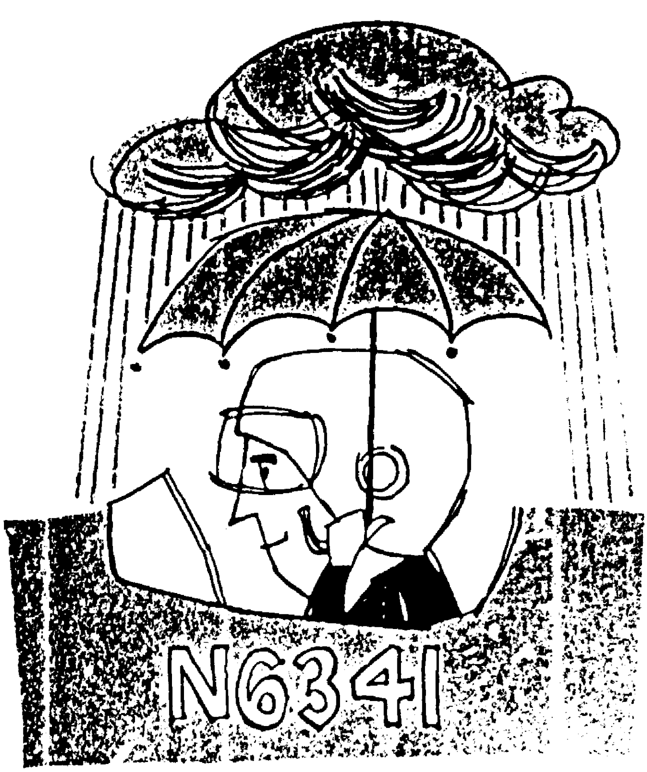

Chapter 5
MOISTURE, CLOUD FORMATION, AND PRECIPITATION

Imagine, if you can, how easy flying would be if skies everywhere were clear! But, flying isn't always that easy; moisture in the atmosphere creates a variety of hazards unmatched by any other weather element. Within Earth's climatic range, water is in the frozen, liquid, and gaseous states.

WATER VAPOR

Water evaporates into the air and becomes an ever-present but variable constituent of the atmosphere. Water vapor is invisible just as oxygen and other gases are invisible. However, we can readily measure water vapor and express it in different ways. Two commonly used terms are (1) relative humidity, and (2) dew point.

RELATIVE HUMIDITY

Relative humidity routinely is expressed in percent. As the term suggests, *relative humidity* is "relative." It relates *the actual water vapor present to that which could be present.*

Temperature largely determines the maximum amount of water vapor air can hold. As figure 32 shows, warm air can hold more water vapor than cool air. Figure 33 relates water vapor, temperature, and relative humidity. Actually, relative humidity expresses the degree of saturation. Air with 100% relative humidity is saturated; less than 100% is unsaturated.

If a given volume of air is cooled to some specific temperature, it can hold no more water vapor than is actually present, relative humidity becomes 100%, and saturation occurs. What is that temperature?

DEW POINT

Dew point is the temperature to which air must be cooled to become saturated by the water vapor already present in the air. Aviation weather reports normally include the air temperature and dew point temperature. Dew point when related to air temperature reveals qualitatively how close the air is to saturation.

TEMPERATURE–DEW POINT SPREAD

The difference between air temperature and dew point temperature is popularly called the "spread." As spread becomes less, relative humidity increases, and it is 100% when temperature and dew point are the same. Surface temperature-dew point spread is important in anticipating fog but has little bearing on precipitation. To support precipitation, air must be saturated through thick layers aloft.

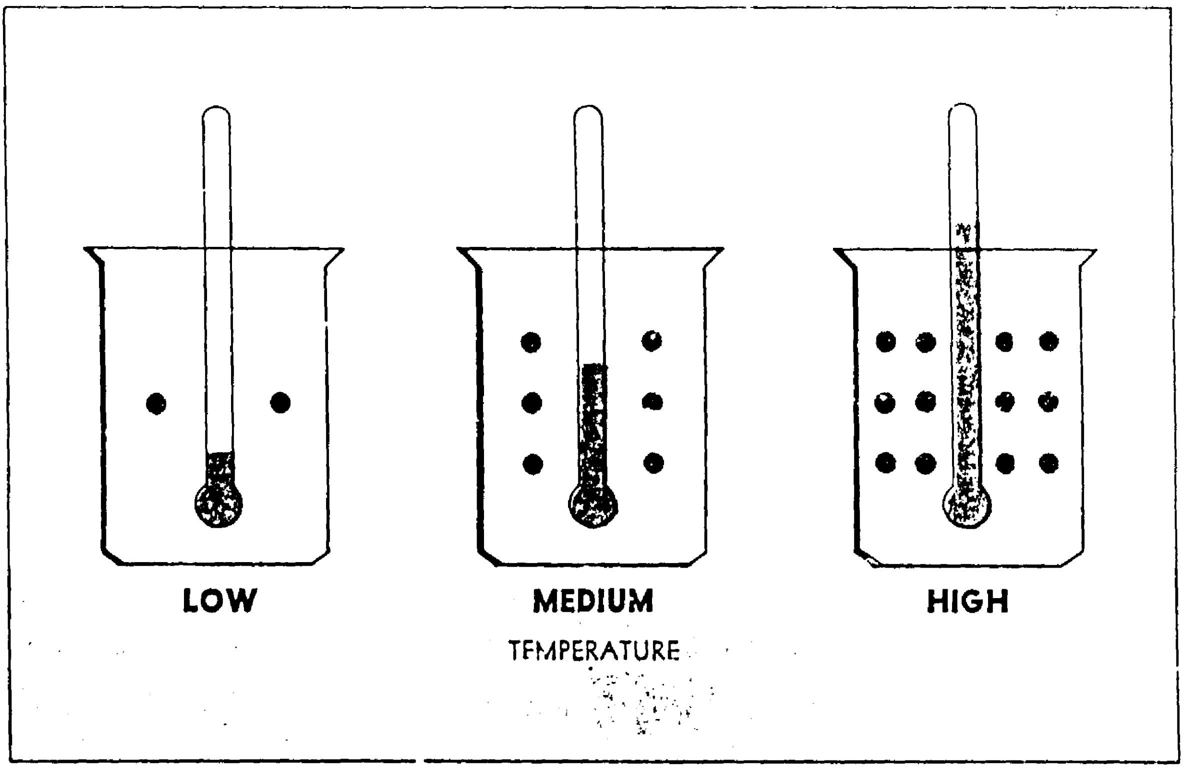

FIGURE 32. Blue dots illustrate the increased water vapor capacity of warmer air. At each temperature, air can hold a specific amount of water vapor—no more.

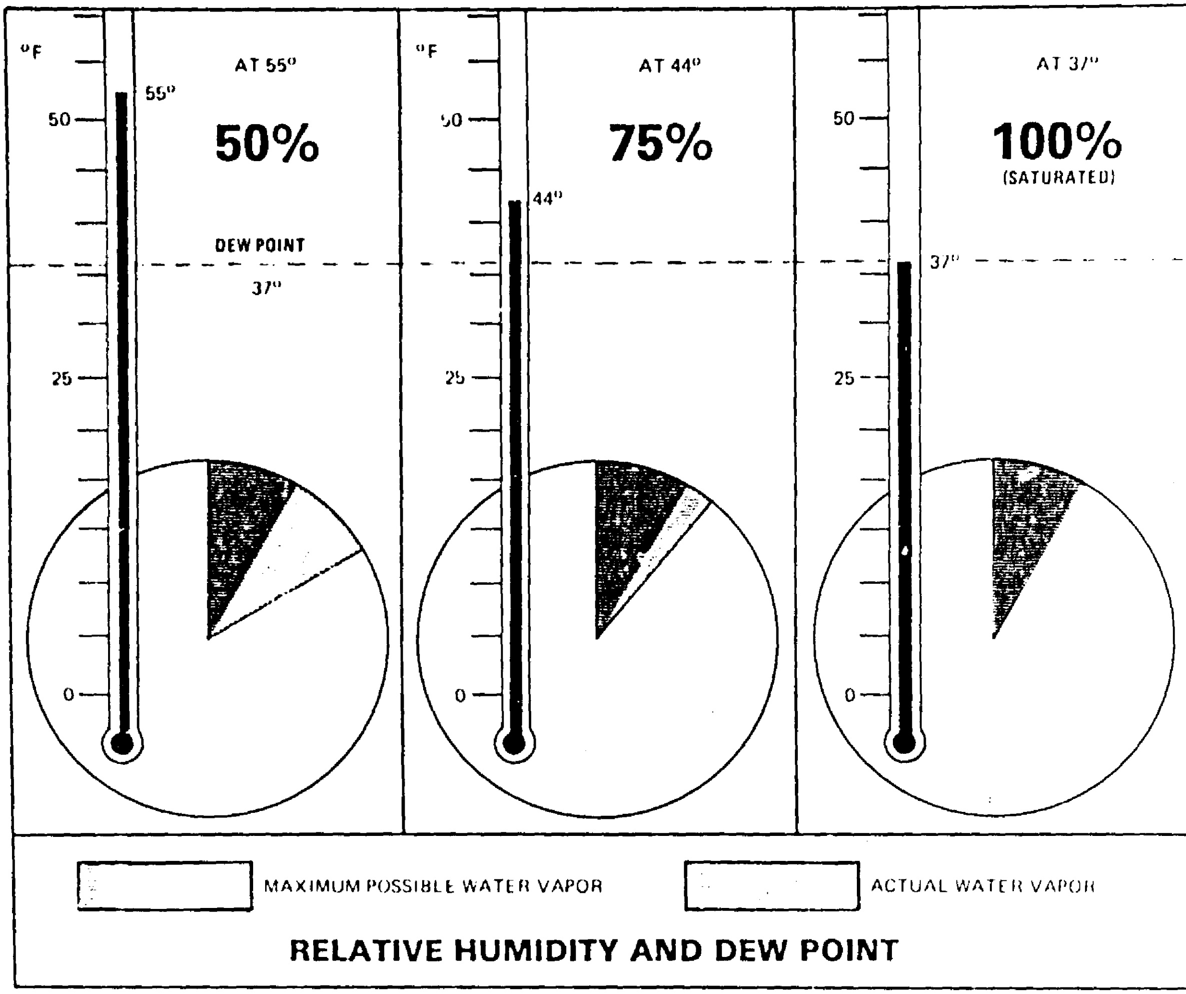

FIGURE 33. Relative humidity depends on both temperature and water vapor. In this figure, water vapor is constant but temperature varies. On the left, relative humidity is 50%; the warmer air could hold twice as much water vapor as is actually present. As the air cools, center and right, relative humidity increases. As the air cools to 37° F, its capacity to hold water vapor is reduced to the amount actually present. Relative humidity is 100% and the air is now "saturated." Note that at 100% humidity, temperature and dew point are the same. The air cooled to saturation, i.e., it cooled to the dew point.

Sometimes the spread at ground level may be quite large, yet at higher altitudes the air is saturated and clouds form. Some rain may reach the ground or it may evaporate as it falls into the drier air. Figure 34 is a photograph of "virga"—streamers of precipitation trailing beneath clouds but evaporating before reaching the ground. Our never ending weather cycle involves a continual reversible change of water from one state to another. Let's take a closer look at change of state.

CHANGE OF STATE

Evaporation, condensation, sublimation, freezing, and melting are changes of state. Evaporation is the changing of liquid water to invisible water vapor. Condensation is the reverse process. Sublimation is the changing of ice directly to water vapor, or water vapor to ice, bypassing the liquid

FIGURE 34. Virga. Precipitation from the cloud evaporates in drier air below and does not reach the ground.

state in each process. Snow or ice crystals result from the sublimation of water vapor directly to the solid state. We are all familiar with freezing and melting processes.

LATENT HEAT

Any change of state involves a heat transaction with no change in temperature. Figure 35 diagrams the heat exchanges between the different states. Evaporation requires heat energy that comes from the nearest available heat source. This heat energy is known as the "latent heat of vaporization," and its removal cools the source it comes from. An example is the cooling of your body by evaporation of perspiration.

What becomes of this heat energy used by evaporation? Energy cannot be created or destroyed, so it is hidden or stored in the invisible water vapor. When the water vapor condenses to liquid water or sublimates directly to ice, energy originally used in the evaporation reappears as heat and is released to the atmosphere. This energy is "latent heat" and is quite significant as we learn in later chapters. Melting and freezing involve the exchange of "latent heat of fusion" in a similar manner. The latent heat of fusion is much less than that of condensation and evaporation; however, each in its own way plays an important role in aviation weather.

As air becomes saturated, water vapor begins to condense on the nearest available surface. What surfaces are in the atmosphere on which water vapor may condense?

CONDENSATION NUCLEI

The atmosphere is never completely clean; an abundance of microscopic solid particles suspended in the air are condensation surfaces. These particles, such as salt, dust, and combustion byproducts

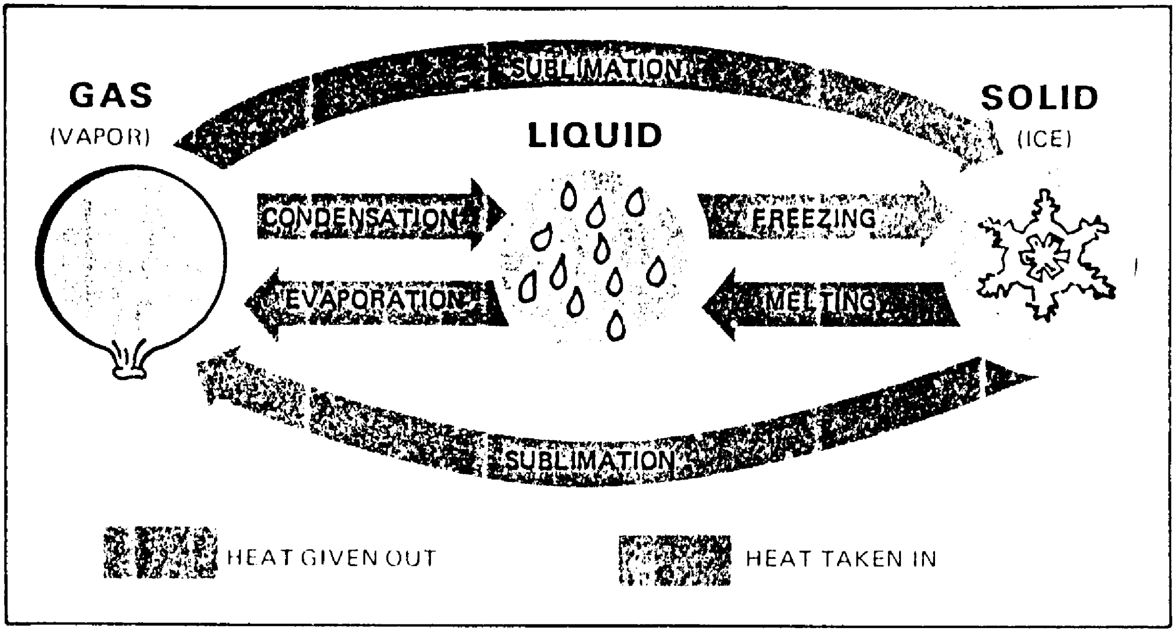

FIGURE 35. Heat transactions when water changes state. Blue arrows indicate changes that absorb heat. The absorbed heat remains hidden, or "latent" until a reverse change occurs. The red arrows show changes that release latent heat back to the surroundings. The heat exchange occurs whenever water changes state even when there is no change in temperature. These heat exchanges play important roles in suppressing temperature changes and in developing instability.

are "condensation nuclei." Some condensation nuclei have an affinity for water and can induce condensation or sublimation even when air is almost but not completely saturated.

As water vapor condenses or sublimates on condensation nuclei, liquid or ice particles begin to grow. Whether the particles are liquid or ice does not depend entirely on temperature. Liquid water may be present at temperatures well below freezing.

SUPERCOOLED WATER

Freezing is complex and liquid water droplets often condense or persist at temperatures colder than 0° C. Water droplets colder than 0° C are supercooled. When they strike an exposed object, the impact induces freezing. Impact freezing of supercooled water can result in aircraft icing.

Supercooled water drops very often are in abundance in clouds at temperatures between 0° C and −15° C with decreasing amounts at colder temperatures. Usually, at temperatures colder than −15° C, sublimation is prevalent; and clouds and fog may be mostly ice crystals with a lesser amount of supercooled water. However, strong vertical currents may carry supercooled water to great heights where temperatures are much colder than −15° C. Supercooled water has been observed at temperatures colder than −40° C.

DEW AND FROST

During clear nights with little or no wind, 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 often collects on grass and plants when none collects on pavements or large solid objects. These more massive objects absorb abundant heat during the day, lose it slowly during the night, and cool below the dew point only in rather extreme cases.

Frost forms in much the same way as dew. The difference is that the dew point of surrounding air must be colder than freezing. Water vapor then sublimates directly as ice crystals or frost rather than condensing as dew. Sometimes dew forms and later freezes; however, frozen dew is easily distinguished from frost. Frozen dew is hard and transparent while frost is white and opaque.

To now, we have said little about clouds. What brings about the condensation or sublimation that results in cloud formation?

CLOUD FORMATION

Normally, air must become saturated for condensation or sublimation to occur. Saturation may result from cooling temperature, increasing dew point, or both. Cooling is far more predominant.

COOLING PROCESSES

Three basic processes may cool air to saturation. They are (1) air moving over a colder surface, (2) stagnant air overlying a cooling surface, and (3) expansional cooling in upward moving air. Expansional cooling is the major cause of cloud formation. Chapter 6, "Stable and Unstable Air," discusses expansional cooling in detail.

CLOUDS AND FOG

A cloud is a visible aggregate of minute water or ice particles suspended in air. If the cloud is on the ground, it is fog. When entire layers of air cool to saturation, fog or sheet-like clouds result. Saturation of a localized updraft produces a towering cloud. A cloud may be composed entirely of liquid water, of ice crystals, or a mixture of the two.

PRECIPITATION

Precipitation is an all inclusive term denoting drizzle, rain, snow, ice pellets, hail, and ice crystals. Precipitation occurs when these particles grow in size and weight until the atmosphere no longer can suspend them and they fall. These particles grow primarily in two ways.

PARTICLE GROWTH

Once a water droplet or ice crystal forms, it continues to grow by added condensation or sublimation directly onto the particle. This is the slower of the two methods and usually results in drizzle or very light rain or snow.

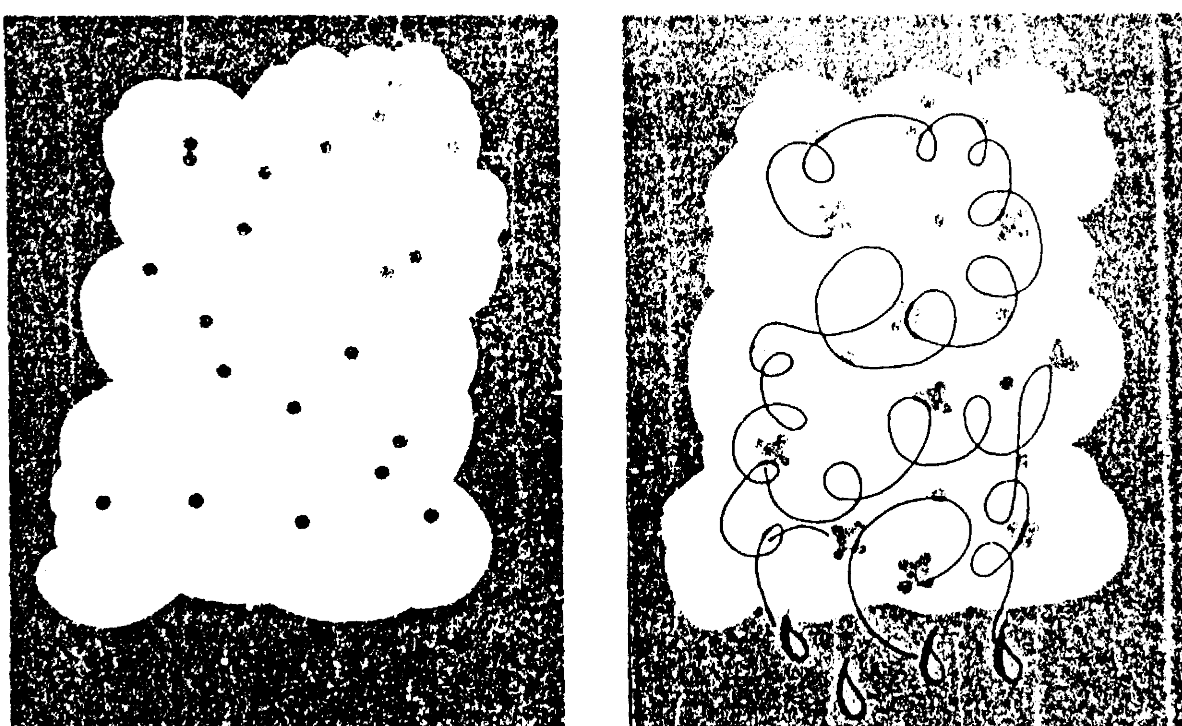

FIGURE 36. Growth of raindrops by collision of cloud droplets.

Cloud particles collide and merge into a larger drop in the more rapid growth process. This process produces larger precipitation particles and does so more rapidly than the simple condensation growth process. Upward currents enhance the growth rate and also support larger drops as shown in figure 36. Precipitation formed by merging drops with mild upward currents can produce light to moderate rain and snow. Strong upward currents support the largest drops and build clouds to great heights. They can produce heavy rain, heavy snow, and hail.

LIQUID, FREEZING, AND FROZEN

Precipitation forming and remaining liquid falls as rain or drizzle. Sublimation forms snowflakes, and they reach the ground as snow if temperatures remain below freezing.

Precipitation can change its state as the temperature of its environment changes. Falling snow may melt in warmer layers of air at lower altitudes to form rain. Rain falling through colder air may become supercooled, freezing on impact as freezing rain; or it may freeze during its descent, falling as ice pellets. Ice pellets always indicate freezing rain at higher altitude.

Sometimes strong upward currents sustain large supercooled water drops until some freeze; subsequently, other drops freeze to them forming hailstones.

PRECIPITATION VERSUS CLOUD THICKNESS

To produce significant precipitation, clouds usually are 4,000 feet thick or more. The heavier the precipitation, the thicker the clouds are likely to be. When arriving at or departing from a terminal reporting precipitation of light or greater intensity, expect clouds to be more than 4,000 feet thick.

LAND AND WATER EFFECTS

Land and water surfaces underlying the atmosphere greatly affect cloud and precipitation development. Large bodies of water such as oceans and large lakes add water vapor to the air. Expect the greatest frequency of low ceilings, fog, and precipitation in areas where prevailing winds have an over-water trajectory. Be especially alert for these hazards when moist winds are blowing upslope.

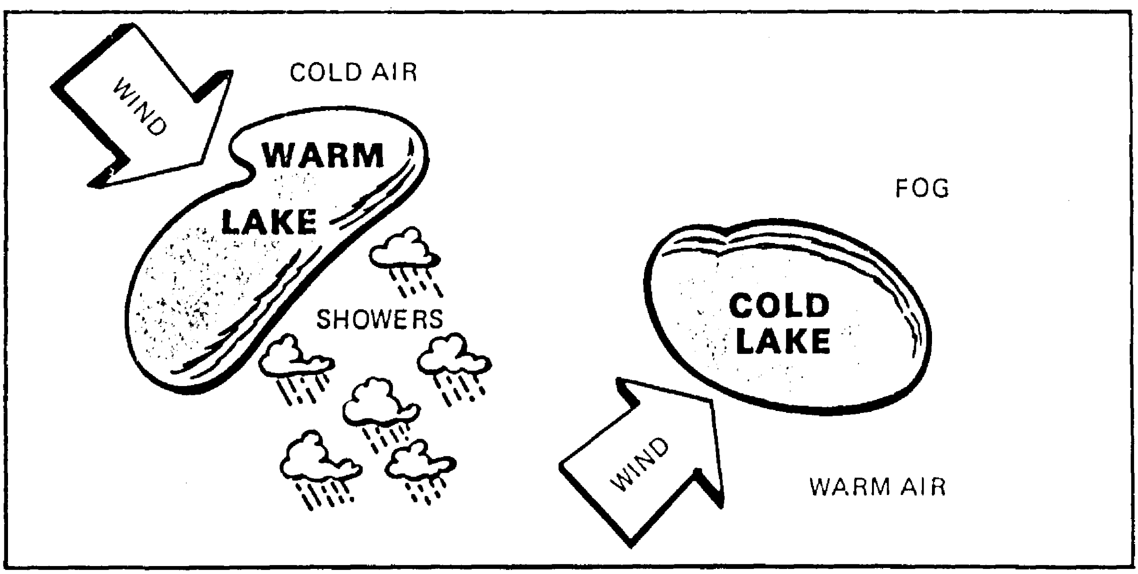

FIGURE 37. Lake effects. Air moving across a sizeable lake absorbs water vapor. Showers may appear on the leeward side if the air is colder than the water. When the air is warmer than the water, fog often develops on the lee side.

In winter, cold air frequently moves over relatively warm lakes. The warm water adds heat and water vapor to the air causing showers to the lee of the lakes. In other seasons, the air may be warmer than the lakes. When this occurs, the air may become saturated by evaporation from the water while also becoming cooler in the low levels by contact with the cool water. Fog often becomes extensive and dense to the lee of a lake. Figure 37 illustrates movement of air over both warm and cold lakes. Strong cold winds across the Great Lakes often carry precipitation to the Appalachians as shown in figure 38.

A lake only a few miles across can influence convection and cause a diurnal fluctuation in cloudiness. During the day, cool air over the lake blows toward the land, and convective clouds form over the land as shown in figure 39, a photograph of Lake Okeechobee in Florida. At night, the pattern reverses; clouds tend to form over the lake as cool air from the land flows over the lake creating convective clouds over the water.

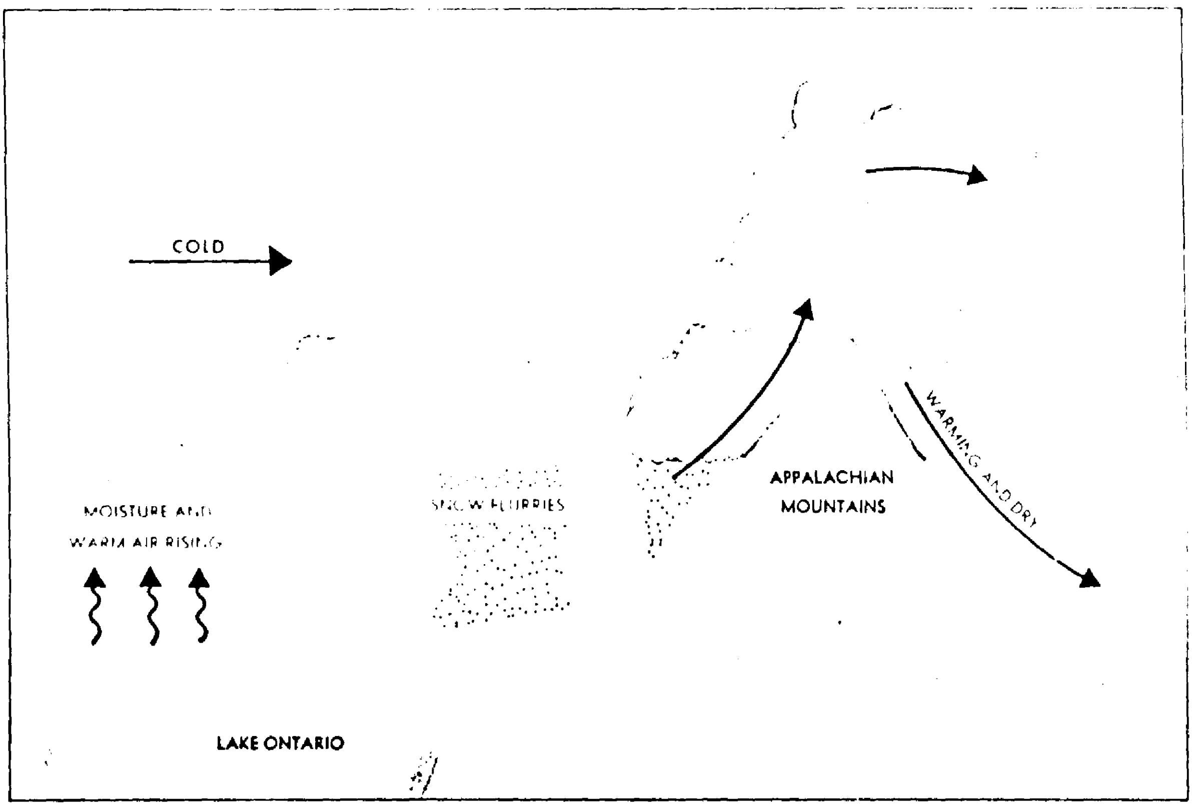

FIGURE 38. Strong cold winds across the Great Lakes absorb water vapor and may carry showers as far eastward as the Appalachians.

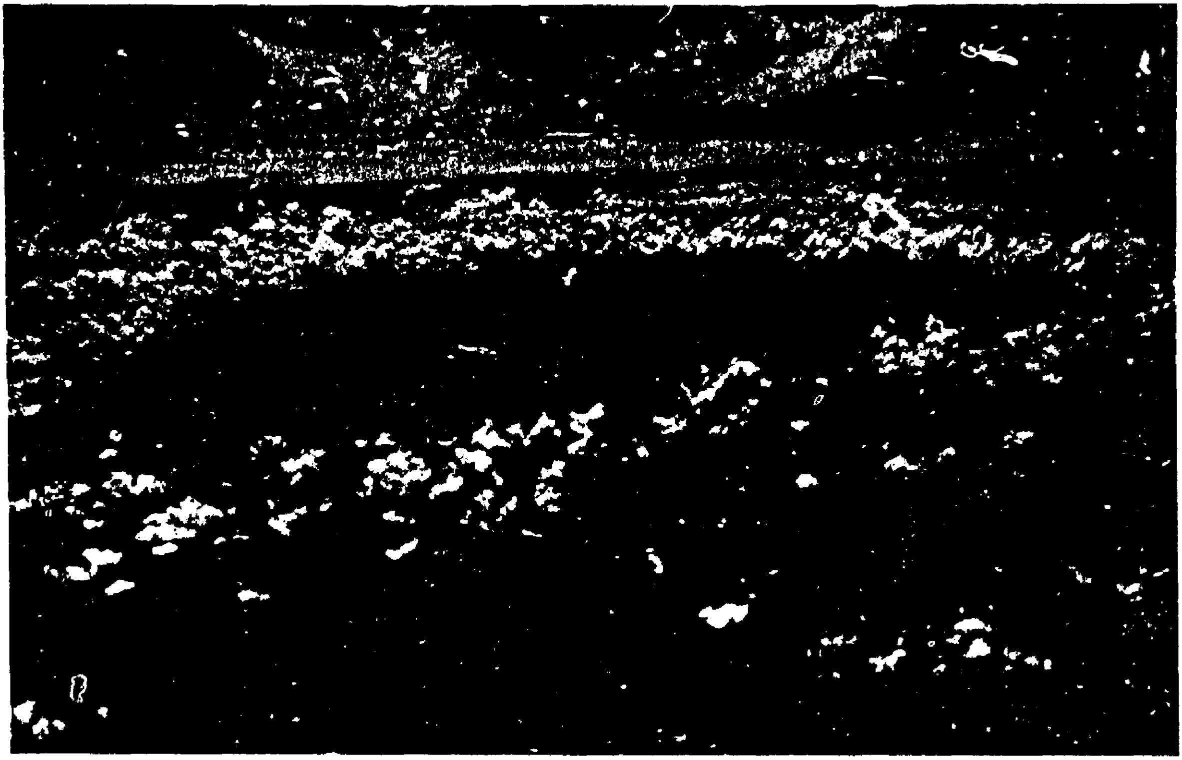

FIGURE 39. A view of clouds from 27,000 feet over Lake Okeechobee in southern Florida. Note the lake effect. During daytime, cool air from the lake flows toward the warmer land forming convective clouds over the land.

IN CLOSING

Water exists in three states—solid, liquid, and gaseous. Water vapor is an invisible gas. Condensation or sublimation of water vapor creates many common aviation weather hazards. You may anticipate:

1. Fog when temperature-dew point spread is 5° F or less and decreasing.
2. Lifting or clearing of low clouds and fog when temperature-dew point spread is increasing.
3. Frost on a clear night when temperature-dew point spread is 5° F or less, is decreasing, and dew point is colder than 32° F.
4. More cloudiness, fog, and precipitation when wind blows from water than when it blows from land.
5. Cloudiness, fog, and precipitation over higher terrain when moist winds are blowing uphill.
6. Showers to the lee of a lake when air is cold and the lake is warm. Expect fog to the lee of the lake when the air is warm and the lake is cold.
7. Clouds to be at least 4,000 feet thick when significant precipitation is reported. The heavier the precipitation, the thicker the clouds are likely to be.
8. Icing on your aircraft when flying through liquid clouds or precipitation with temperature freezing or colder.