OBJECTIVES

A Summarize the main types of clouds.

B Describe the conditions under which clouds with vertical development form.

C Show how to predict the base and highest possible top of cumulus clouds.

D Describe the conditions under which layer clouds form.

III Clouds

Topic 10 The Origin of Clouds

Clouds are simply high fogs, mist, or haze. They form when air above the surface cools below its dew point. The shape of a cloud depends on the air movement that forms it. If air movement is mainly horizontal, clouds form in layers. They are called *stratiform clouds.* If air movement is mainly vertical, clouds grow upward in great piles. These are called *cumuliform clouds.*

At temperatures above freezing, clouds are made entirely of water droplets. Below freezing, clouds are usually mixtures of snow crystals and supercooled water. **Supercooled water** is water that has cooled below 0°C without freezing. When supercooled droplets encounter something to freeze on, such as an airplane or ice nuclei, they form snow and ice crystals. Below a temperature of about −18°C, clouds are almost entirely snow and ice crystals.

Figure 27.7 and the table below show the four families of clouds. The average height range given in the table is for middle latitudes. The heights are measured above the surface, not above sea level. Clouds reach higher altitudes in equatorial areas and lower altitudes in polar areas.

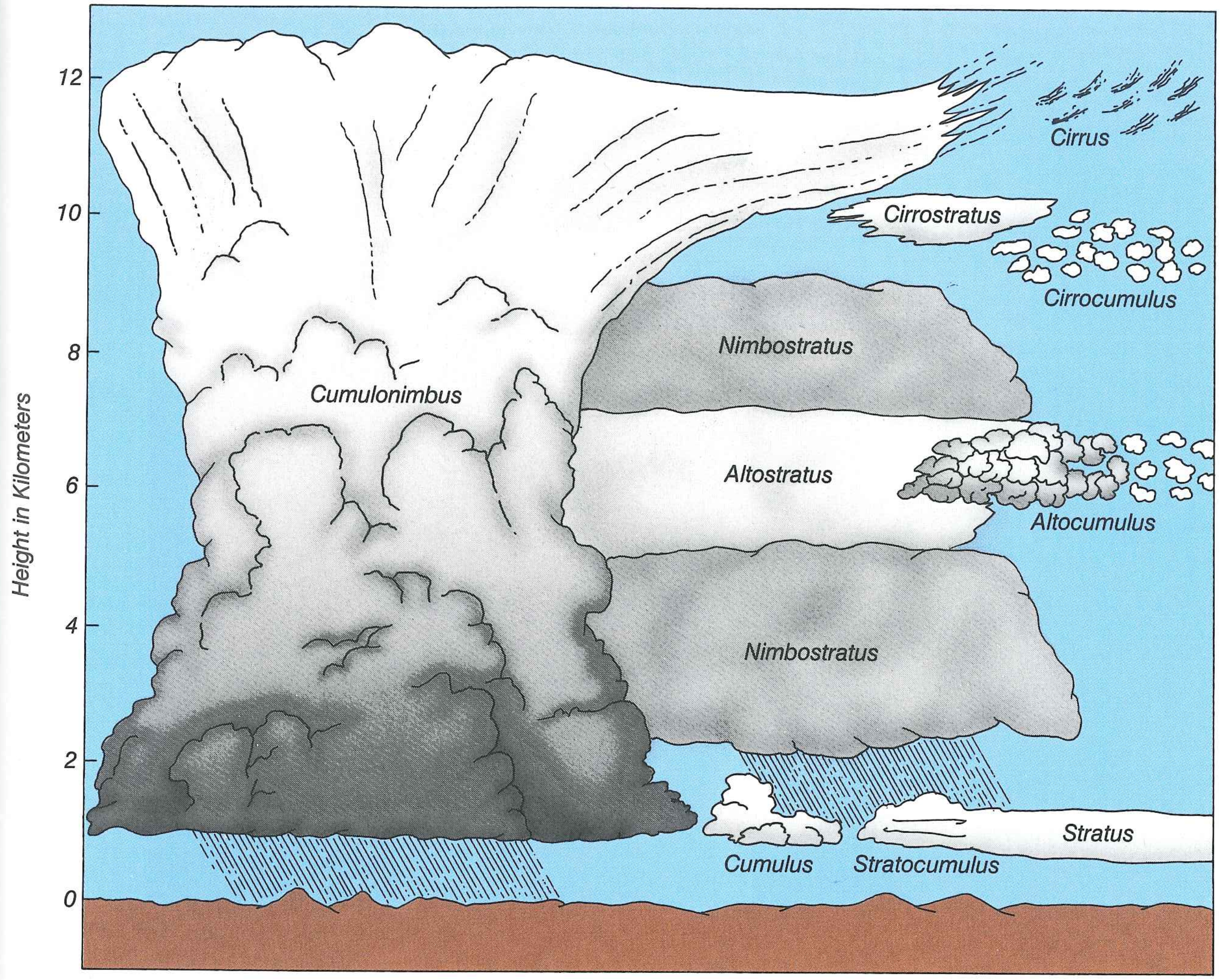
Classification of Clouds

Family	Average Height Range	Types	Symbol
High clouds	7000 to 13 000 meters	Cirrus	Ci
		Cirrostratus	Cs
		Cirrocumulus	Cc
Middle clouds	2000 to 7000 meters	Altostratus	As
		Altocumulus	Ac
Low clouds	500 to 2000 meters	Stratocumulus	Sc
		Stratus	St
		Nimbostratus	Ns
Vertical development	500 to 13 000 meters	Cumulus	Cu
		Cumulonimbus	Cb

Topic 11 Cloud Names and Their Meanings

The table includes three simple cloud names—cirrus, stratus, and cumulus. These three names represent the three main cloud types. All the other clouds are combinations or variations of these types.

Cirrus clouds are thin, feathery, or tufted. They are so high that they are always made of ice crystals. All of the high family of clouds

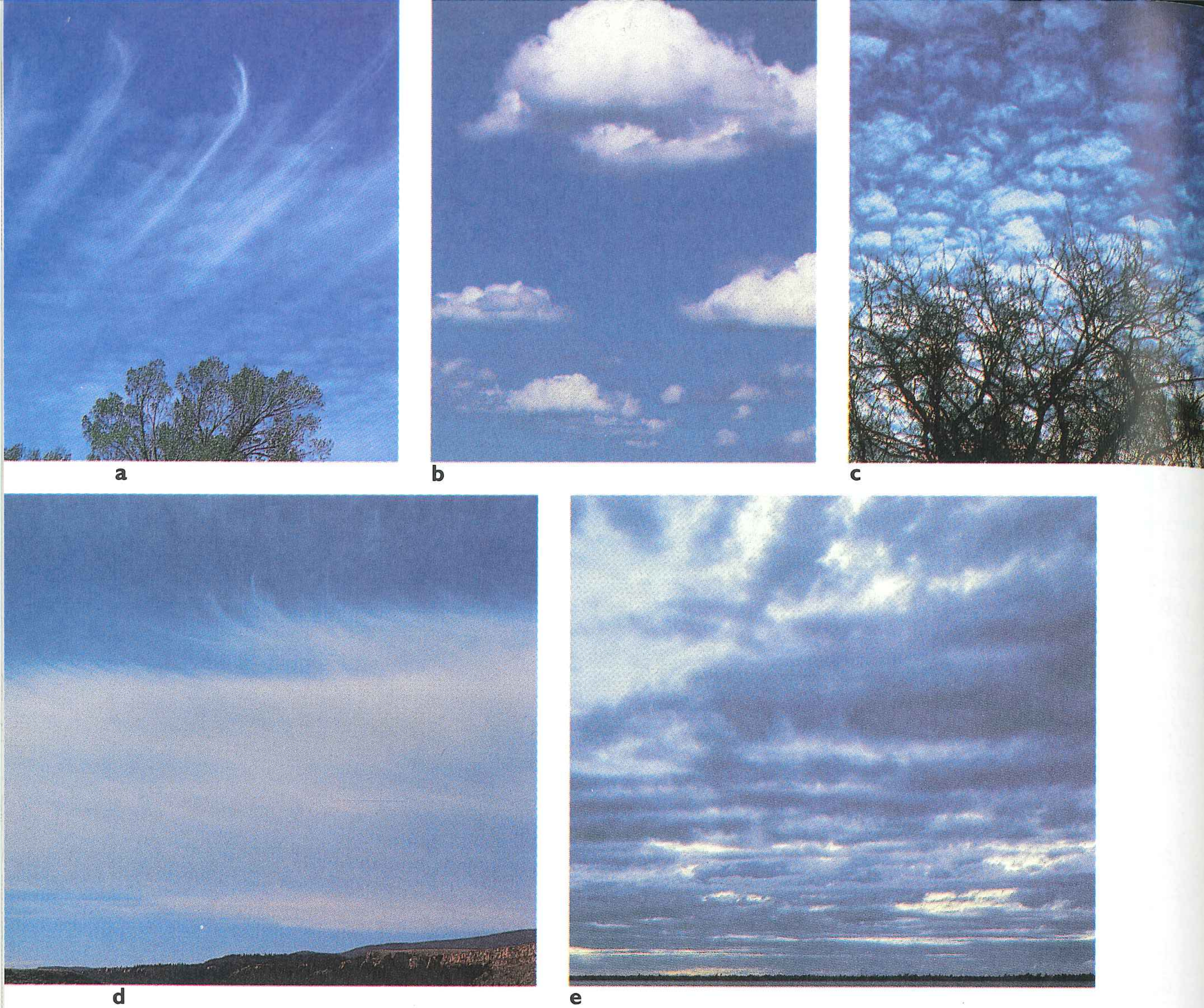


27.7 Cloud types. Cumulus and cumulonimbus belong to the family of clouds of vertical development.

are of the cirrus type. **Stratus** clouds are low sheets or layers of cloud. **Cumulus** clouds are formed by vertically rising air currents. They are piled in thick, puffy masses.

Cirrostratus are high, thin, smooth or fibrous sheets of ice-crystal clouds. They sometimes cause halos, or rings, around the sun or moon. Cirrostratus clouds often mean the approach of rain or snow. *Stratocumulus* clouds are layers made up of round puffs. They often cover the whole sky, especially in the winter. *Cirrocumulus* clouds are small globular patches of cloud made of ice crystals.

The prefix *alto* (high) and the word *nimbus* (rain cloud) are used in cloud names. *Altocumulus* clouds are like stratocumulus clouds. Their puffs look smaller because they are farther away (higher). *Altostratus* clouds are stratus clouds that occur at a higher level. They are gray or bluish and produce no halo around the sun or moon. *Nimbostratus* clouds are dark, gray layers of cloud that produce steady rain.



27.8 Variety of cloud types: (a) cirrus, (b) cumulus, (c) altocumulus, (d) cirrostratus, (e) stratocumulus

Topic 12 Dry- and Moist-Adiabatic Lapse Rates

The shapes of clouds show how the air is moving through them. For example, the air in stratiform clouds flows mostly horizontally. Air in a growing cumulus cloud moves upward because it is buoyant. The air is buoyant because its temperature is warmer than the surrounding air. To what height will the cumulus cloud be warmer and more buoyant? To answer this question, it is necessary to know how temperature changes as air rises in a cloud.

Rising dry air cools at a rate of 1°C for every 100 meters (see Chapter 26, Topic 10). This is the dry-adiabatic lapse rate. The cooling is caused only by the air expanding. The air expands as it rises because it is surrounded by lower pressure. Similarly, sinking air is compressed as it encounters higher pressure. This raises the temperature at the same rate, 1°C for every 100 meters. Thus, if an air parcel rises 100 meters and then sinks 100 meters its final temperature will be the same as its starting temperature.

Air rising in a cloud does not cool as fast as rising dry air does. On the average, it cools at 0.6°C for every 100 meters. Why does it cool at a slower rate? The condensing water releases heat to the air, which makes the air cool more slowly. In the same way, sinking air in clouds warms 0.6°C for every 100 meters because the evaporation of cloud droplets slows its warming. Meteorologists call the rate of temperature change of a rising or sinking saturated parcel the **moist-adiabatic lapse rate**.

Topic 13 Clouds with Vertical Development

Cumulus clouds and other clouds with vertical development form when rising air currents are buoyant, or lighter than the surrounding air. How can this happen when air cools as it rises? It can, if the temperature of the surrounding air decreases even faster with height. Suppose a cloud is rising through a layer of air with a lapse rate of 1°C for each hundred meters. Since the air in the cloud is cooling at only 0.6°C for each 100 meters, it will be 0.4°C warmer than the surrounding air after rising 100 meters, 0.8°C warmer after rising 200 meters, and so on. The rising air in the cloud is warmer than the surrounding air even though it gets cooler as it rises. Since the cloud is warmer, it is also lighter or less dense. That is, the air in the cloud is buoyant. The cloud can continue to grow. Meteorologists say that the air surrounding the cloud is *unstable*.

If a shallow layer of air is unstable, cumulus clouds can form. If a deep layer of air is unstable, thunderclouds, or **cumulonimbus** clouds, might form. From these come lightning, thunder, and heavy showers. Violent thunderstorms can have hail, strong winds, and even tornadoes.

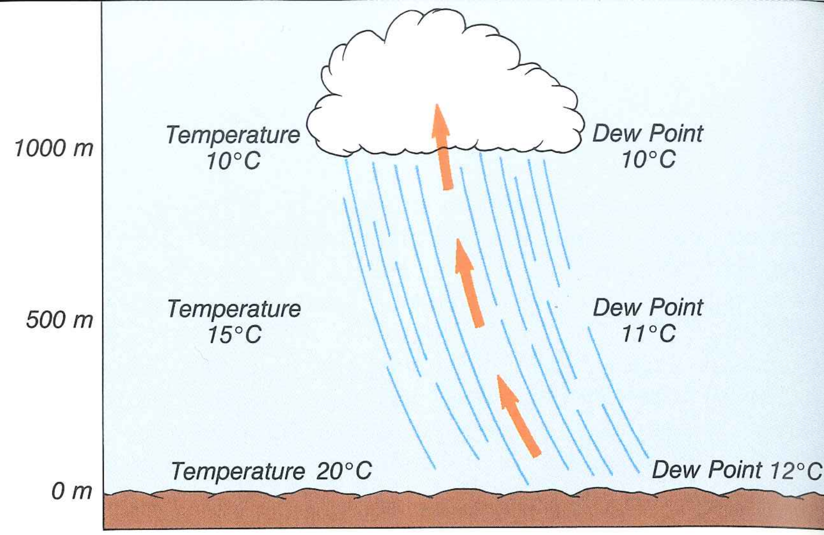
27.9 Cumulonimbus cloud

Topic 14 Cumulus and Cumulonimbus Clouds

Rising buoyant air currents form cumulus clouds. These clouds often appear in the late morning or early afternoon on bright sunny days. They have flat bases and billowy tops. Their shape reveals how these clouds form and grow.

Cumulus clouds form over heated ground. The ground is warm enough so that rising air remains bouyant even though it is cooling at the dry-adiabatic lapse rate. The flat cloud base shows where the water vapor began to condense. This height is called the **condensation level.** Here the temperature is about equal to the dew point (Topic 6).

Suppose the temperature and dew point of the air at the ground are known. Then the condensation level can be found. For dry air



27.10 The condensation level of rising air can be predicted if its temperature and dew point are known. Rising air cools at a rate of 1°C per 100 meters. At the same time, however, its dew point changes, dropping 0.2°C per 100 meters. Where air temperature and dew point meet, condensation begins.

the rate of cooling by expansion is 1°C for every 100 meters. As the air rises, its dew point falls at a rate of 0.2°C for every 100 meters.

Here is an example: At the surface the air temperature is 20°C, the dew point is 12°C, and the difference between these temperatures is 8°C. However, 100 meters higher the air temperature is 19°C and the dew point is 11.8°C. The difference is only 7.2°C. The two temperatures continue to approach each other at a rate of 0.8°C for each 100-meter rise in altitude.

To find where the dew point will reach the air temperature, divide 8°C (the difference between the air temperature at ground level and the dew point) by 0.8°C (the amount per 100 meters at which the dew point approaches the air temperature).

$$\frac{8°\text{C}}{0.8°\text{C}} = 10$$

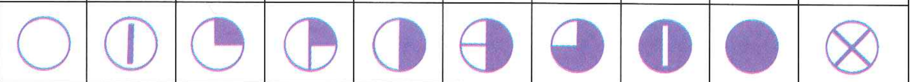
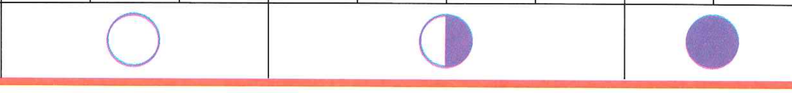
Thus, 10 multiplied by 100 is the rise necessary in meters (1000 meters) for the beginning of condensation. This level is known as the *lifting condensation level.* It is of great importance in forecasting changes in the weather. A typical value over land in summer is around 1000 meters.

Meteorologists can also estimate the highest possible cloud top. They know that the temperature of the rising air in the cloud starts at the cloud-base temperature and falls with height at the moist-adiabatic lapse rate. They have measurements of the temperature of the surrounding air. The height of the cloud top will be close to the height where the cloud temperature and air temperature are equal. Here, the cloud is no longer buoyant. The rising air spreads out, forming the flat anvil-shaped top characteristic of cumulonimbus clouds.

Topic 15 Layer Clouds

Layer clouds form in stable air, where motions are mainly horizontal. The atmosphere is *stable* when the lapse rate of the air surrounding the clouds is smaller than the moist-adiabatic lapse rate. For example, suppose the temperature of the surrounding air is uniform throughout a thick layer. A cloudy rising current would be

Symbols Showing Percentage of Sky Covered

Tenths of Sky covered	0	1	2–3	4	5	6	7–8	9	10	Sky Obscured
National Weather Service Weather Maps										
Newspaper Maps										

cooler than the surrounding air as soon as it started rising and cooling. Being colder and therefore heavier than the surrounding air, the air current would sink back down to where it started. In this case, the air cannot easily move up or down and tends to spread out in layers.

Clouds can form in stable air in two ways. First, the air can be forced slowly upward to its condensation level. Air is forced upward when it moves up rising terrain, such as a mountainside, or over a layer of colder, denser air. And second, layer clouds form if radiation or mixing cools a layer of air to its dew point.

27.11 These symbols are used on weather maps to show how much of the sky is covered by clouds.

TOPIC QUESTIONS

Each topic question refers to the topic of the same number.

10. **(a)** How are clouds formed? **(b)** What kind of air motions occur in stratiform clouds? Cumuliform clouds? **(c)** At what temperatures do clouds consist of only liquid water? Of only snow and ice? Of both ice and water? **(d)** What is supercooled water? **(e)** List the four families of clouds.

11. Name and describe the three main cloud types.

12. **(a)** Why does rising air cool? Why does sinking air warm? **(b)** Give the numerical value of the dry-adiabatic lapse rate and the moist-adiabatic lapse rate. **(c)** Why is the moist-adiabatic lapse rate smaller?

13. **(a)** Under what conditions do clouds with vertical development form? **(b)** Compare the lapse rate inside and outside the cloud if the air is unstable. **(c)** How does unstable air affect the buoyancy of the rising air in the cloud? **(d)** What kind of cloud forms when the air is unstable through a deep layer?

14. **(a)** How is a cumulus cloud formed? **(b)** How do meteorologists estimate the height of the cloud base? What is this height called? **(c)** Explain how meteorologists estimate the level of the highest possible cloud tops.

15. **(a)** Under what conditions do layer clouds form? **(b)** Compare the lapse rate inside and outside layer clouds.