TOPIC VII
ENERGY EXCHANGES IN THE ATMOSPHERE

Our local weather is determined by atmospheric patterns that are part of a global system.

CHAPTER 10
Weather

You will know something about weather and its causes if you can:

1. Identify the relationships among the atmospheric variables.
2. Explain how these relationships are used to predict changes in weather.
3. Explain how major weather systems develop and transfer energy in the atmosphere.

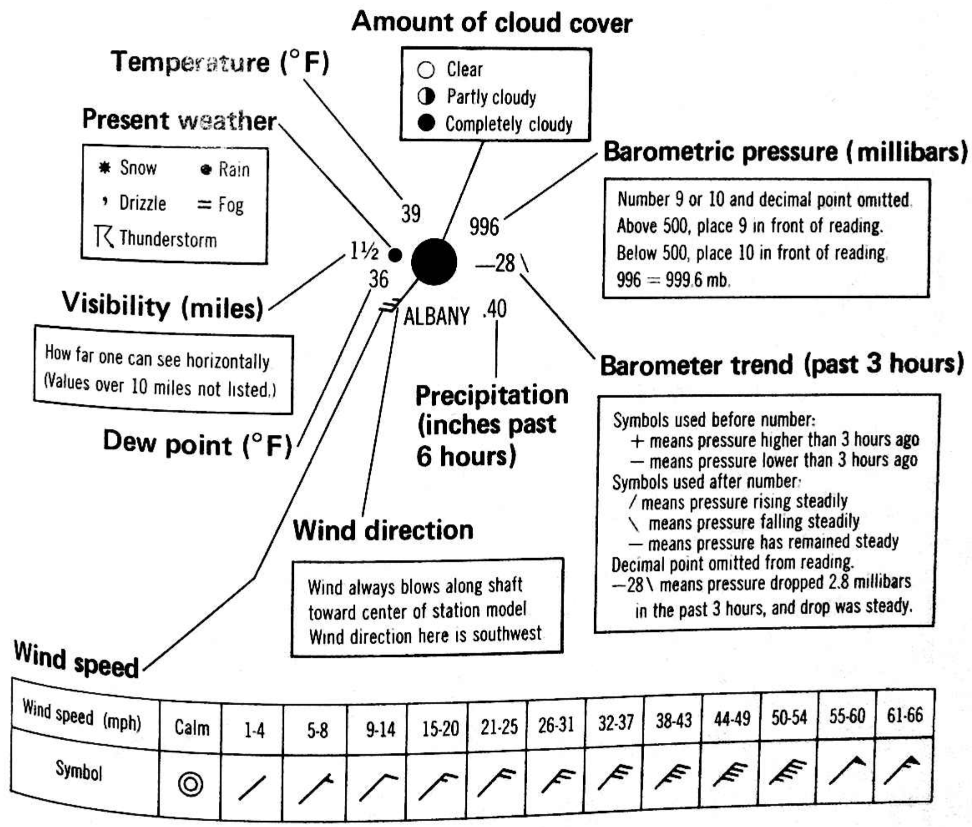
In this chapter and in Chapter 11 we will be concerned with that old reliable topic of conversation–weather. What makes weather interesting is that, in our part of the world, it is always changing. We would like to know what the weather is going to be this afternoon, tomorrow, and next weekend. If we're going to have any hope of doing that, we have to study the atmosphere and the kinds of changes that occur there.

ATMOSPHERIC VARIABLES

We know from our own experience that conditions in the atmosphere change frequently. The temperature and the pressure of the air can change. Winds may blow at various speeds and from various directions. There may be different kinds and amounts of clouds and of precipitation. The air may feel dry or damp. These properties of the air that change from time to time are called *atmospheric variables*. We can define *weather* as a description of the atmospheric variables at a particular place during a certain short period of time.

Relationships Among the Atmospheric Variables. In the section of Chapter 2 called "A Weather Watch" (beginning on page 22) there is a brief description of some of the atmospheric variables that you can observe with simple instruments. Weather scientists, or *meteorologists*, have been observing and recording these and many other variables at hundreds of places on the earth and for long periods of time. The National Weather Service makes such records today in a form called a station model. Figure 10-1 shows a typical station

Figure 10-1. A sample station model.



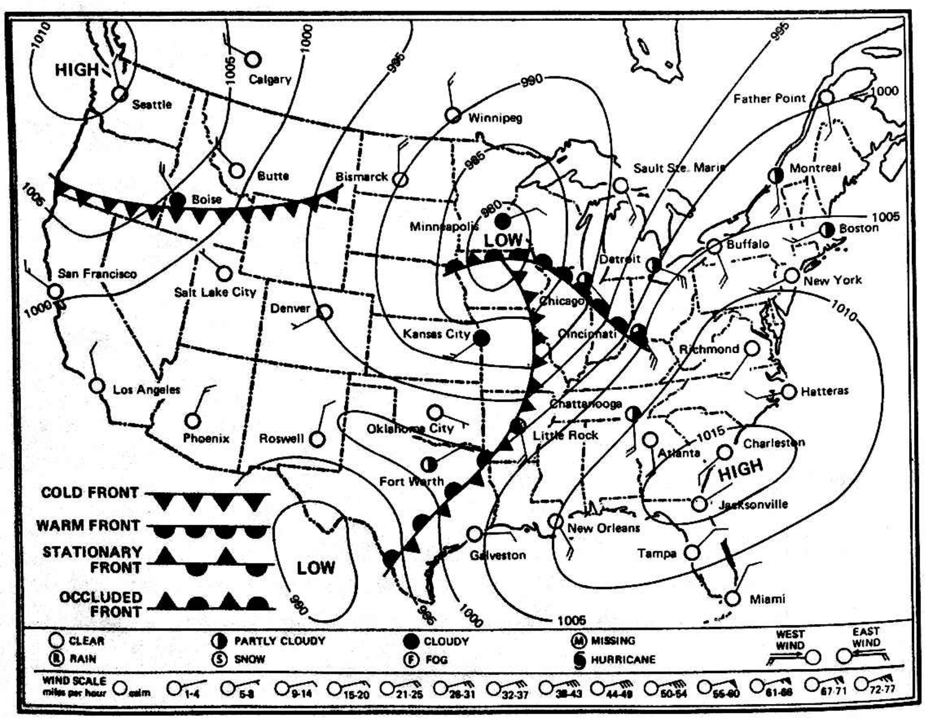
model, along with an explanation of the symbols used.

We need to mention that at the time this is being written (1976), the National Weather Service is still reporting weather measurements in English units, such as wind speeds in miles per hour, temperatures in °F, and air pressures in inches of mercury. These are the units used at this time in weather reports on radio and television and in newspapers. However, since conversion to the use of metric (SI) units is gradually taking place in the United States, we will use SI units, for the most part, in this chapter. The basic principles of weather observations and predictions will, of course, remain the same, whatever the system of units may be.

Weather Maps. To get back to our story, look at Figure 10-2. This is a simplified weather map for the United States, showing a few of the observations for some of the weather stations around the country. In addition to the station model symbols, the map has a pattern of numbered lines running across it. You will recognize this pattern as a field map, which we discussed in Chapter 5.

This map illustrates the fact that one field map looks pretty much like another. Just by looking at it you can't tell what field quantity is being shown. It could be an elevation field, as in a topographic map; it could be the odor field of a giant national hamburger festival, similar to the much smaller field map on page 59. In this case it is an air pressure field map. Each isoline on this map passes through points that have the same air pressure, as indicated by the number

Figure 10-2. Typical weather map of the United States.



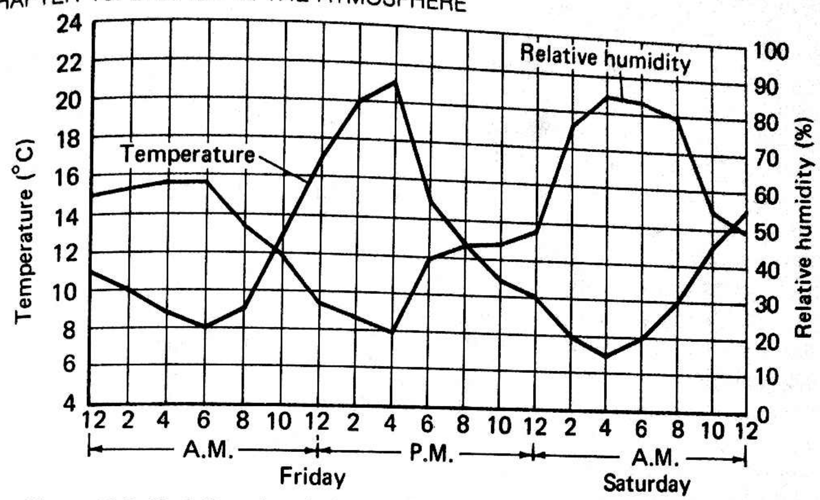


Figure 10-3. Variations in relative humidity and temperature over a period of two days.

on the isoline. Isolines that show points of equal air pressure are called *isobars*. The isobars on the map in Figure 10-2 are labeled in millibars (mb), a metric unit of pressure that has been used in recent years*.

You will notice areas on the map labeled HIGH and LOW. Just as contour lines of increasing elevation "close in" around a mountain peak, so isobars of increasing air pressure close in around regions of maximum pressure, called *highs*. Similarly, isobars of decreasing pressure close in around *lows*, or regions of minimum pressure.

On this weather map you can also see heavy lines with triangular or semicircular bumps along one side or the other. These lines are symbols for *fronts* between air masses. We will have more to say about fronts, air masses, highs and lows, and other details of weather maps as we go along.

Relationships Among Weather Variables. Weather records may be interesting in themselves. But they do not have much practical or scientific value unless they can be used to draw inferences about the causes of weather and to predict future changes in the weather. Meteorologists have studied their records for many years in order to find relationships among the atmospheric variables. Today, computers are used to analyze vast quantities of data for this purpose. From such studies it is possible to state that certain combinations of conditions usually lead to certain other conditions at a later time. Unfortunately, we still cannot predict the weather with absolute certainty. But we can state the *probability of occurrence* of certain changes in the weather.

One way of looking for relationships is to plot two or more variables on the same graph. Figure 10-3, for example, is a graph of observations of relative humidity and temperature for

*The official unit of pressure in the SI (metric) system is the *pascal*. The pascal is a very small unit (1/100 millibar), so the recommended unit for air pressure measurements is the kilopascal (1000 pascals). One kilopascal (kPa) equals 10 millibars. A pressure of 1000 mb equals 100 kPa.

a period of 36 hours. It can be seen that there appears to be an inverse relationship between these two variables. If such a pattern is frequently observed, we can say there is a high probability of its occurrence.

Another method is to keep a record of observations in the form of a table that shows how often one variable occurs along with another. For example, the two variables might be cloudiness and wind direction. Figure 10-4 shows the results an observer obtained over a period of 30 days. Each day he recorded the combination of wind direction and cloudiness as a "hatch mark" in the corresponding box of the table. For example, he noted clear skies combined with westerly winds on 10 days.

A table like this is called a *contingency table*. From the contingency table, you can calculate the probability that westerly winds will be accompanied by clear skies. The table shows that there were 23 days with westerly winds, and the skies were clear on 10 of those days. Therefore, when the winds were westerly, it was clear 10/23 or 43% of the time. This could be taken as the probability of these two conditions occurring together. In similar fashion, many other probabilities of occurrence of weather conditions could be inferred.

Figure 10-4. A contingency table. This table is a record of daily observations of two weather variables—wind direction and cloud cover—over a period of 30 days. Each day the observed combination of the two variables was marked off in the corresponding box of the table. Wind direction was considered to be either generally easterly or generally westerly. This table could have been expanded to record wind direction more precisely—for example, northeasterly, southeasterly, southwesterly, northwesterly. In that case it would probably be necessary to make observations over a longer period in order to get meaningful probabilities.

WIND DIRECTION	DEGREE OF CLOUDINESS			TOTALS
	Clear	Partly cloudy	Cloudy	
Easterly	1	2	4	7
Westerly	10	8	5	23
COLUMN TOTALS	11	10	9	30

CONDITION	PROBABILITY
Clear with easterly winds	1/7 = 0.14 or 14%
Partly cloudy with easterly winds	2/7 = 0.29 or 29%
Cloudy with easterly winds	4/7 = 0.57 or 57%
Clear with westerly winds	10/23 = 0.43 or 43%
Partly cloudy with westerly winds	8/23 = 0.35 or 35%
Cloudy with westerly winds	5/23 = 0.22 or 22%

What are some of the relationships among weather variables that have been discovered? If you have been conducting a Weather Watch, you can probably find several in your own data. In the following pages we will discuss the most common of these relationships.

SUMMARY

1. Weather is the condition of the atmospheric variables at a given location for a certain short period of time.
2. Weather conditions for a given time and place can be described by the symbols of a station model on a weather map.
3. Weather predictions are based on a probability that the atmospheric variables will change in a certain way.

SOME COMMON WEATHER RELATIONSHIPS

Temperature Variations. In Chapter 9 (page 144) we learned that the average temperature at a given location depends, basically, on the total amount of the sun's radiation received by an area. This, in turn, is determined by the intensity and duration of insolation. The greater the intensity and the more hours of insolation there are, the higher the average temperature of the location.

Intensity and duration of insolation are directly related to daily and seasonal cycles. But they are also modified by various atmospheric factors. For example, if an area is covered by a heavy blanket of clouds, incoming sunlight is reflected by the clouds back into space. Therefore, the amount of insolation received at ground level is decreased, and the temperature at ground level is lower than it would have been without the clouds. Heavy air pollution also cuts down the amount of insolation received at ground level. Cloudiness and even the amount of pollutants that remain in the air are affected by other atmospheric variables.

Pressure Variations. If you watch weather reports on television, you know that they include a lot of talk about highs and lows, sometimes called high-pressure and low-pressure *systems*. They usually tell you what is likely to happen as one of these systems reaches your area. If you have been making the observations and measurements that we discussed in the Weather Watch section of Chapter 2, you have probably had a chance to see what happens for yourself.

A weather report predicting what will happen when a high-pressure system moves into an area might go something like this:

> . . . So, as this high-pressure system moves down from Canada, the rain will end and temperatures will drop. Clear but cold nights can be expected, with daytime high temperatures never getting much above. . . .

This is an example of a relationship that is often observed between atmospheric pressure and temperature—as pressure increases, temperature decreases. A high-pressure system, then, usually contains cooler air than the surrounding regions. In the same way, a low-pressure system usually contains warmer air than the surrounding regions. So, high pressure is usually associated with cooler air, and low pressure with warmer air. The relationship between temperature and pressure is an inverse one. As temperature increases, pressure decreases, and vice versa.

Atmospheric pressure is also affected by the moisture content of the air, and this is also an inverse relationship. The more moisture there is in the air, the lower the atmospheric pressure. The less water vapor present, the greater the atmospheric pressure.

So, high-pressure systems are associated with cooler, drier air, while low-pressure systems are associated with warmer, moister air. Again, these are occurrences of high probability, not guaranteed to occur at all times.

Humidity. We know that the air can feel crisp and dry on a cold winter day, or it can feel damp and "humid." A hot summer day can also feel either dry or humid. We also know from experience that precipitation is more likely to occur when the air feels damp than when it feels dry. Just what is it that we are "feeling" at these times?

We might think that what we are feeling is the *amount* of moisture (water vapor) in the air. This, however, would not be the whole story. The amount of moisture in the air is certainly an important factor. But the degree of dampness or "humidity" that we feel actually depends on how close the air is to being *saturated* with moisture. Warm air can hold more moisture than cold air. Therefore, warm air will feel much drier than cold air with the same amount of moisture content. What counts is not just the amount of moisture in the air, but how close this amount is to causing the air to be saturated.

As stated on page 26, the "closeness to saturation" is described by the *relative humidity* of the air. The relative humidity is the ratio between the amount of moisture in the air and the amount that could be present at the existing temperature. It is usually stated as a percent.

Dew-point Temperature. The dew-point temperature is one of the simplest ways of describing the moisture content of the air. Recall from page 26 that the dew point is the temperature to which we would have to cool the air to make it saturated. It is at this temperature that water would begin to condense out of the air. Therefore, the probability of precipitation will depend on how close the actual air temperature is to the dew-point temperature. If the difference is small, it won't take much change in conditions to reach saturation and start condensation. If the difference is large, the probability of precipitation in the immediate future is small.

It is also important to observe whether the difference between the two temperatures is getting larger or smaller. Only if the difference is getting smaller can we say that the probability of precipitation is increasing. This difference can become smaller in either of two ways. The moisture content of the air can be increasing, thus raising the dew point closer to the air temperature. Or the air temperature can be dropping, thus bringing it down closer to the dew point. (Of course,

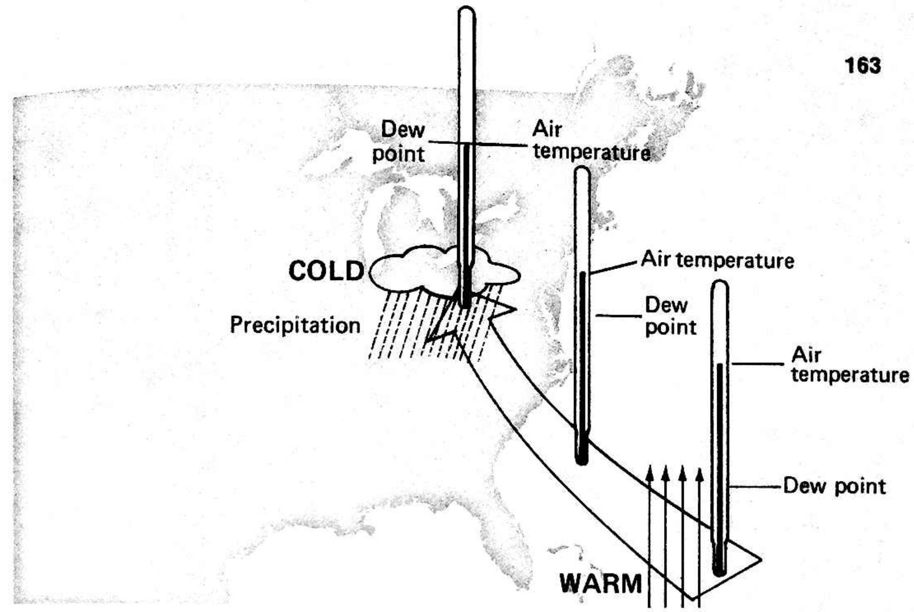


Figure 10-5. Changes in temperature and dew point in a moving mass of warm air. As warm air passes over the ocean, evaporation increases its water vapor content and raises its dew point. When the air passes over cooler land to the north, its temperature drops. If the air temperature drops to the dew point, precipitation is likely.

both of these effects could be occurring at the same time.)

An example of this relationship is common along the eastern coast of the United States (see Figure 10-5). Warm air moving up from the southeast over the Atlantic Ocean absorbs moisture by evaporation from the ocean, thus raising its dew point. Then the air temperature begins to drop as the air passes over the land farther north. Rain is often the result of such a sequence of events. Later in this chapter we will see that this is an example of the passage of a warm front.

Air Movement. *Wind* is a horizontal movement of air over the surface of the earth. Do you know what makes winds blow and why some winds are light breezes, while others can blow the roof off your school?

A portion of the weather map on page 158 is repeated here in Figure 10-6. Look at the isobars on this map.

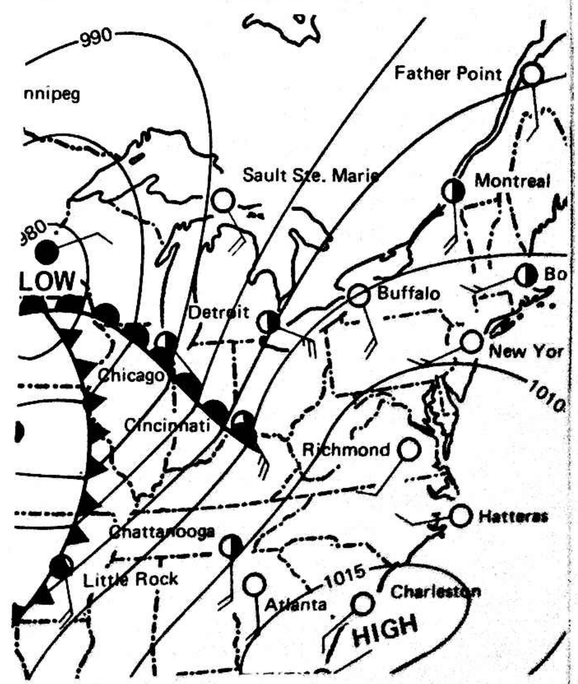


Figure 10-6. Pressure gradients and wind speeds.

In some places they are close together. At other places they are more widely separated. You recall that the spacing of the isolines on a field map indicates the *gradient* of the field, that is, the rate at which the field quantity changes as you go from one point to another. Where the isolines are closely spaced, the gradient is steep. Where they are far apart, the gradient is moderate or gentle. On this map the spacing of the isobars shows us where the *pressure gradient* is large (steep) and where it is small (gentle).

Now look at the wind arrows on the map. They show the speed and direction of the wind at each station. (Refer to the station model on page 157 to recall how to read the wind speed from these symbols.) Notice first of all that the winds seem to be blowing generally away from the high and toward the low. Secondly, the wind speed is generally greater where the pressure gradient is greater. You will see similar relationships on any weather map you examine.

We can infer, then, that it is differences in air pressure that cause winds to blow, and the greater the difference over a given distance, the faster the winds will blow.

Very strong winds often occur around major storm centers, such as hurricanes. In the center of a hurricane the atmospheric pressure is extremely low. So the difference in pressure between the storm center and the air around it is unusually great, and the pressure gradient is very steep. It is this great difference in pressure within a relatively small area that accounts for the winds of very high speed that accompany these storms.

Local Conditions. As you watch or listen to your local weather forecast, you should become aware of some characteristics of your area that seem to affect the local weather pattern. For example, if you live near a large lake, you have probably heard of the *lake effect*. Because a mass of air may pick up water vapor over the lake, your particular area may be hit by more severe storms than nearby areas. But living near a lake does have its advantages, because in hot weather the air near the lake will be cooler than the air in surrounding areas.

A range of mountains or high land may also have a strong influence on the weather. Any change in landscape is going to affect the steady flow of air and the moisture patterns.

If you live in a fair-sized city, you've probably heard many weather reports that go something like this:

> . . . High today in the city will be about 90°. Temperatures in the outlying areas in the low 80's.

A forecast like this bears out what every city-dweller has always known —that it's hotter in the city than it is in nearby suburbs or rural areas. Meteorologists refer to this phenomenon as an *urban heat island*. Figure 10-7 shows how this might look on a map of the temperature field around a large city.

There are three basic reasons for this effect: (1) Heat produced by the burning of fuel (to heat homes and offices, run factories, operate cars and trucks, etc.) warms the atmosphere. (2) Man-made materials, such as brick, concrete, and asphalt, heat up more rapidly than open fields or forests, and therefore reradiate energy into the atmosphere at a greater rate. (3) Heat that should have been reradiated back into space is trapped by layers of atmospheric pollution. As a result of these processes, the presence of large cities changes the temperature pattern of an area.

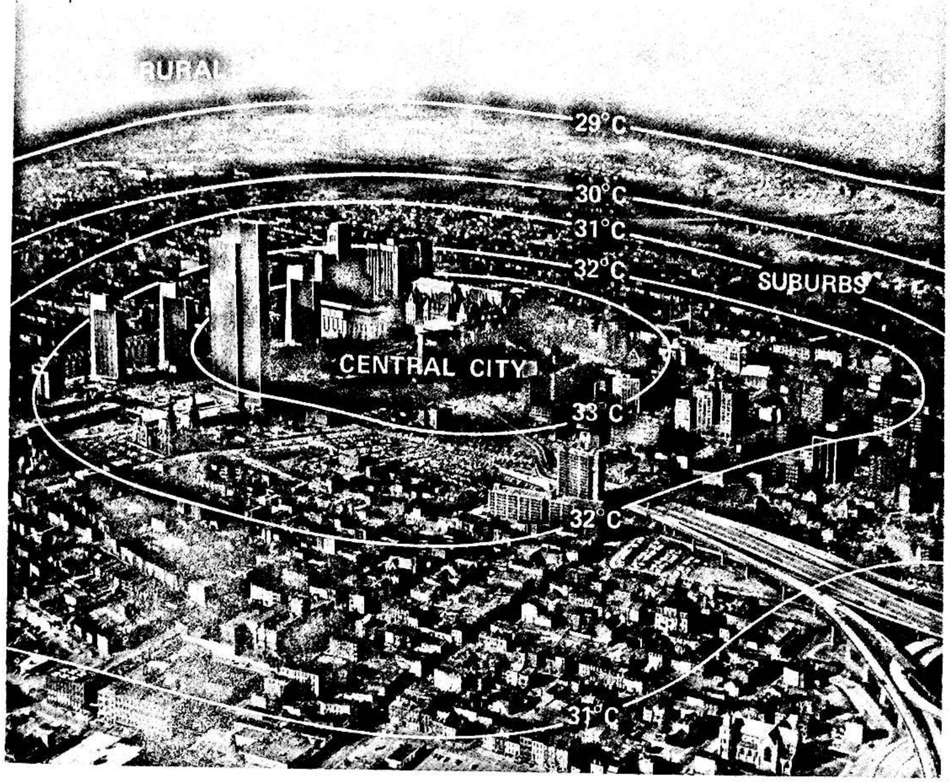


Figure 10-7. Urban heat island. The heat given off by large cities changes the temperature pattern of an area.

Large cities not only heat the atmosphere, but they produce great quantities of carbon dioxide. You should recall from page 149 that carbon dioxide is a good absorber of the energy reradiated at infrared wavelengths by warm surfaces. So an increase in the carbon dioxide content of the atmosphere also contributes to the heating of the atmosphere.

Atmospheric Transparency. Have you ever been fascinated by the dancing specks that can be seen in a shaft of sunlight coming through a window? These are dust particles—tiny bits of material that are always present in the air. We are conscious these days of the large amounts of smoke particles and other pollutants that our factories, power plants, and even our homes are pouring into the air. But even without these sources, the air would always contain dust from natural sources—bits of decayed leaves, microscopic hairs from the wing of a butterfly, wind-blown soil, and countless others. The air may also contain very small droplets of water, which are almost invisible to the eye.

All of these components of the air affect its *transparency*, and the transparency of the air varies greatly from day to day and from place to place. But the atmosphere tends to clear itself periodically. As we will see in the next chapter, dust particles act as centers around which water vapor can condense to form raindrops and snowflakes. Thus a rainstorm literally washes the air and leaves it cleaner than before.

But how much man-made pollution can the atmosphere handle? Will we come to a point at which it can no longer clean itself by processes like precipitation? This is a serious problem for the future—and the future may not be so far away!

Other Variables. We have seen that some of the atmospheric variables show a simple relationship that is either direct or inverse. For example, the average air temperature shows a direct relationship to intensity of insolation—as the intensity increases, so does the average temperature. Air pressure and moisture content show an inverse relationship—generally, the more humid the air, the lower its pressure. Some of the simple relationships we have observed are illustrated graphically in Figure 10-8.

Other variables, on the other hand, are not related in either a simple direct or a simple inverse manner. Their interrelationships are much more complex. Also, the effects of geographical characteristics, such as lakes and mountains, of cities, and of other local conditions on local weather patterns are complex.

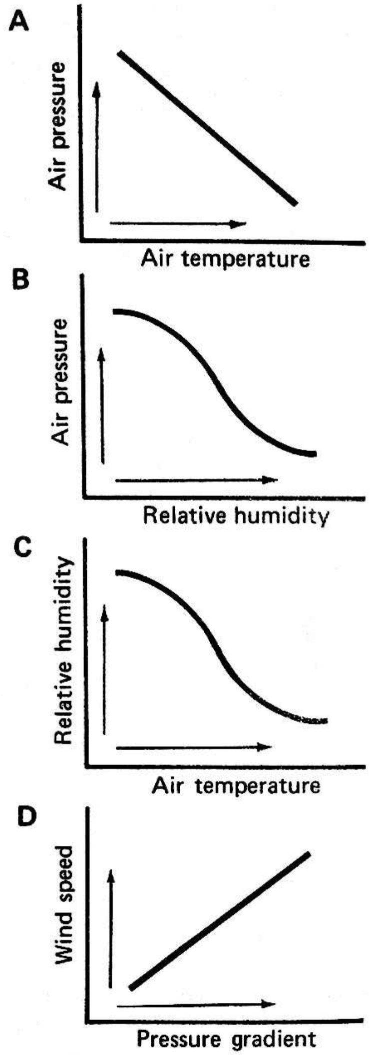


Figure 10-8. Some simple relationships between weather variables. Inverse relationships are illustrated in *A*, *B*, and *C*. A direct relationship is illustrated in *D*.

SUMMARY

1. Temperature at a given location basically depends on the intensity and duration of insolation. However, it can also be affected by various atmospheric factors.
2. Changes in atmospheric pressure are closely associated with changes in air temperature and water-vapor content.
3. Changes in the dew-point temperature indicate changes in atmospheric moisture.
4. As the difference between air temperature and dew-point temperature decreases, the probability of precipitation increases.

5. Wind is a horizontal movement of air over the surface of the earth.
6. Winds are caused by differences in atmospheric pressure.
7. Wind speed is directly related to the pressure field gradient.
8. In many places, local conditions, including geographical features, have a variety of complex effects on the local weather pattern.
9. Some atmospheric variables are related in a simple direct or inverse manner.

AIR MASSES

If you watch weather reports on television, you're probably familiar with the term *air mass*. An air mass is a large body of air that shows the same temperature and humidity characteristics throughout at a given altitude. That is, within the air mass, all points at the same altitude show pretty much the same temperature and humidity. As you will see, air masses are of basic importance in modern weather forecasting.

The size of an air mass can be equal to that of a fair portion of an entire continent or ocean. An air mass can extend upward to an altitude of 3 to 6 km. An air mass has definite boundaries, and it differs in temperature and humidity from adjacent air masses.

Source Regions. The characteristics of air masses are determined by the region over which they form. Such regions are called *source regions*. An air mass forms when a large body of air remains over an area long enough to pick up the temperature and humidity characteristics of that area. This body of air can be *stagnant* (unmoving), or it can be moving very slowly.

An air mass formed over land will usually be dry. An air mass formed over water will usually be moist. An air mass formed at high latitudes will have a relatively low temperature. An air mass formed at low latitudes will have a relatively high temperature.

Since air-mass characteristics are determined by the source region, air masses are classified and labeled according to their source area. The first factor considered in classifying an air mass is whether it is formed over land or water. The second factor is the latitude at which it forms (see Figure 10-9).

Air masses formed over land are called *continental* (*c*), while those formed over water are called *maritime* (*m*). Air masses formed at high latitudes are called *polar* (*P*), while those formed at low latitudes are called *tropical* (*T*). As you can see in Figure 10-9, the abbreviations referring to latitude are capital letters, while those for land and water are lower case. For example, an air mass formed over the North Atlantic Ocean would be designated as an *mP* air mass.

Sometimes an air mass can be modified by the area over which it travels. Suppose an air mass forms over central Canada. This would be a *cP* air mass because it formed at high latitudes over land. If this relatively dry air mass travels in a southeasterly direction, it will pass over the Great Lakes. It may then pick up moisture evaporating from the lakes and become a relatively moist air mass.

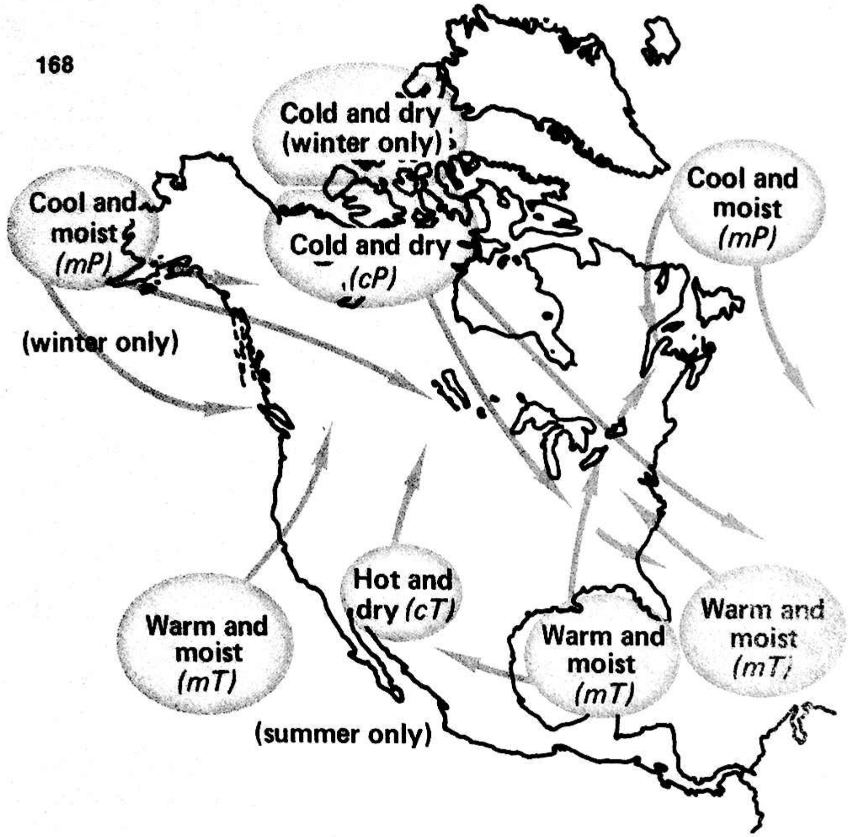


Figure 10-9. Source regions of air masses that affect the weather of the continental United States.

Highs and Lows. Air masses can be of two basic types, depending on their pressure and the direction of circulation of their winds. Low-pressure air masses are called *lows*, or *cyclones*. To most people, the term *cyclone* means a severe tropical storm. To a meteorologist, the term refers to a low-pressure system.

In a low, or cyclone, the pressure is lowest in the center of the system. You might expect the winds to blow in toward the center, directly at right angles to the isobars. However, as explained on page 96, winds in the Northern Hemisphere are deflected to the right by the Coriolis effect. As a result, the winds around a low blow nearly parallel to the isobars, in a *counterclockwise* direction in the Northern Hemisphere. If you examine a weather map, you will see the wind arrows following this pattern around the lows. The result is a counterclockwise rotation of the entire air mass.

High-pressure systems are called *highs*, or *anticyclones*. In a high, the pressure is greatest in the center of the system. You would expect winds to blow outward across the isobars. However, the Coriolis effect again deflects the winds to the right and the result is a *clockwise* circulation or rotation of the air mass.

In the Southern Hemisphere the Coriolis effect deflects winds to the left. Thus the general circulation around highs and lows is the opposite of that in the Northern Hemisphere—that is, highs have a counterclockwise circulation and lows have a clockwise circulation.

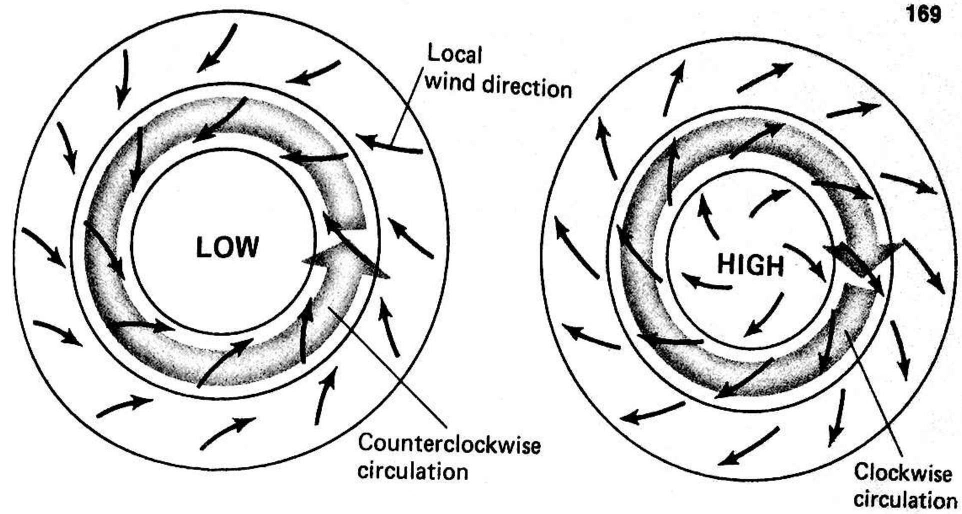


Figure 10-10. Circulation of winds in high- and low-pressure air masses.

SUMMARY

1. Air masses are identified on the basis of their pressure, moisture, and temperature.
2. At any given altitude within an air mass, the temperature field and the humidity field are nearly uniform.
3. The characteristics of an air mass are determined by the region over which it forms.
4. In a low-pressure air mass (a cyclone) the circulation is counterclockwise and in toward the center in the Northern Hemisphere.
5. In a high-pressure air mass (an anticyclone) the circulation is clockwise and outward from the center in the Northern Hemisphere.

FRONTS

The interface where two air masses with different characteristics meet is called a *front*. The interface between the two air masses is fairly distinct, and the two masses of air do not mix together to any great extent. Generally, a front forms when one air mass moves into an area occupied by another air mass of differing characteristics. Weather conditions at fronts are generally unstable, and precipitation is often associated with the passing of a front

Cold Fronts. A cold front forms when a cold air mass moves into an area occupied by a warmer air mass. Cold air masses generally move more rapidly than warm ones. As the cold air mass moves forward, it remains close to the ground because it is more dense than the warm air mass ahead of it. The warm air is therefore forced to rise, as shown in Figure 10-11.

The first sign of an approaching cold front may be the appearance of towering dark clouds in the distance

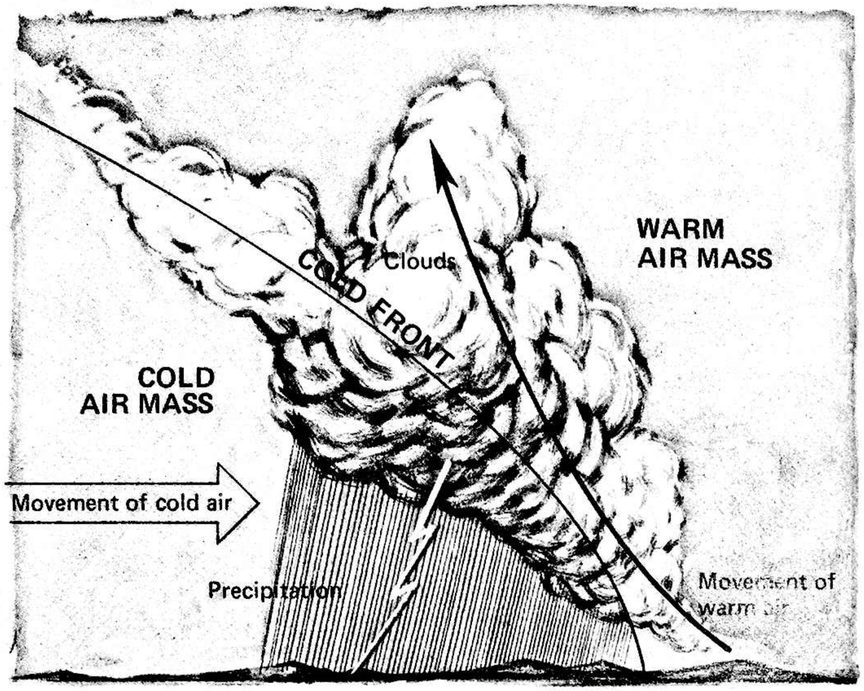


Figure 10-11. A cold front.

followed by an increase in wind speed (due to an increased pressure gradient). The warm air in the area is forced upward by the advancing cold front. This air cools as it rises until it reaches the dew point. Clouds form, and if condensation is great enough, precipitation will occur. The precipitation that does occur is generally brief, but it can be quite heavy. Thunderstorms are common.

When the front passes, the winds change direction sharply, the pressure rises, and the temperature drops. Small puffy clouds may be left in an otherwise clear sky.

Weather Variables During the Passage of a Cold Front. How would the passing of a cold front look to a meteorologist as he examines the data from his recording instruments? Figure 10-12 shows the variations in air pressure, air temperature, dew point, and relative humidity that were observed in a typical case. To interpret these records, remember that the dew point is the temperature at which the air becomes saturated and the relative humidity becomes 100%. The dew point measures the amount of water vapor in the air, and the relative humidity indicates how close the air is to being saturated.

Looking at the start of the record early Monday morning, we see that the air was moderately warm and humid. The dew point was close to the air temperature and consequently the relative humidity was high. We see, also, that the temperature dropped somewhat during the hours before sunrise, and rose after sunrise—the

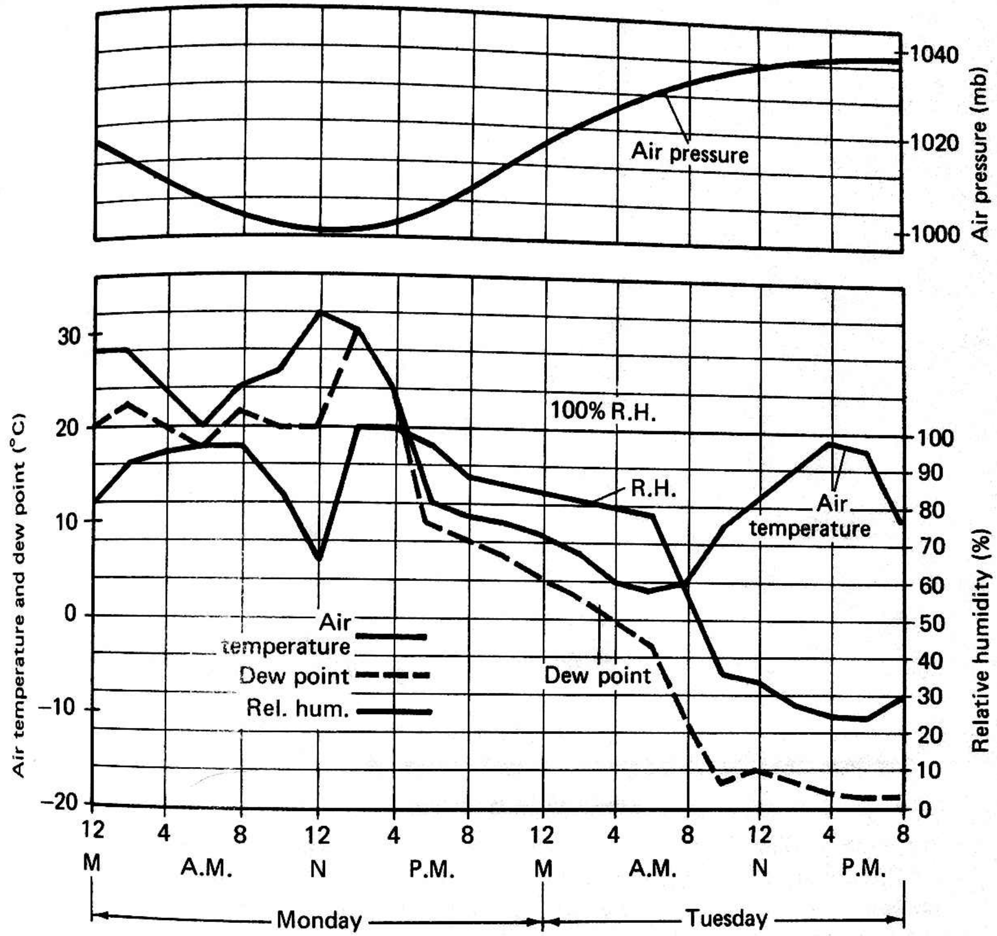


Figure 10-12. Changes in weather variables during the passage of a cold front.

usual pattern described in Chapter 9 (page 145). We also see the inverse relationship between relative humidity and air temperature that we noted in Figure 10-3 on page 157. Air pressure was decreasing during this period.

This pattern continued until noon on Monday. Then something apparently happened to upset it. The temperature began to drop, and it dropped sharply throughout the afternoon. Also, between noon and 2 P.M. the dew point rose. By 2 P.M., air temperature and dew point were equal, the air was saturated, and the relative humidity was 100%. We can infer that it started raining around noon, and that evaporation of the falling raindrops added water vapor to the air until it became saturated. The air pressure was increasing during this period.

Air temperatures continued to fall through the night, but the dew point decreased even more rapidly. By late

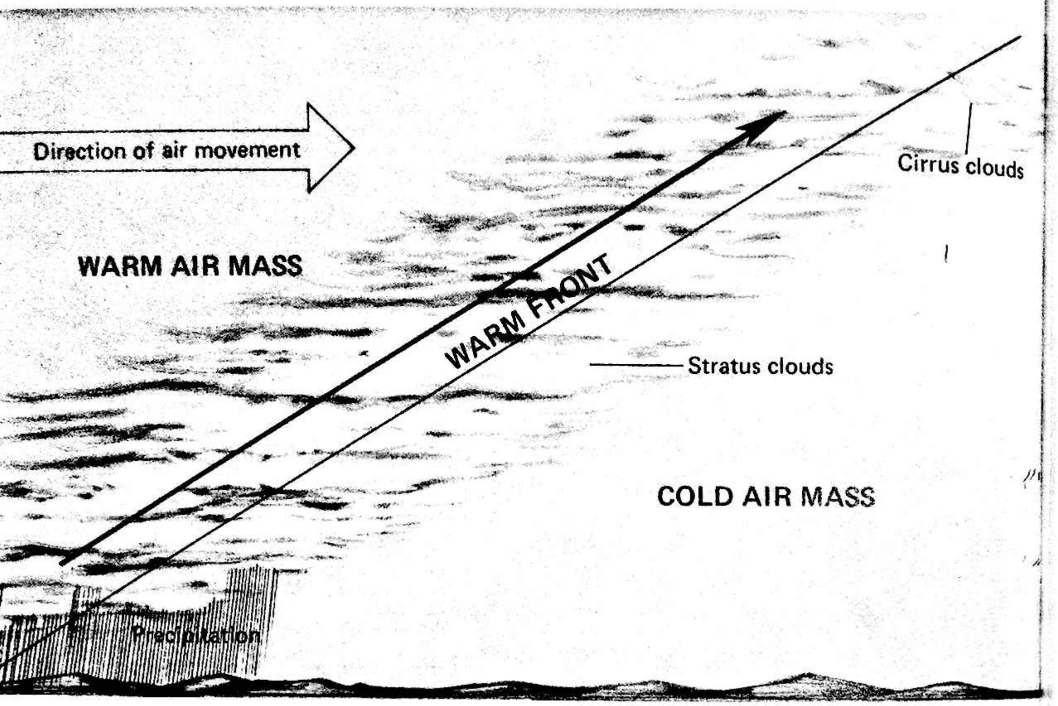


Figure 10-13. A warm front.

afternoon on Tuesday, the dew point and the relative humidity had both dropped to low levels. The mid-afternoon high temperature was lower than the lowest temperature of early Monday morning. The air pressure had increased considerably. From all this data it can be quite safely inferred that a cold front went by at about noon on Monday and a cool, dry, high-pressure air mass had moved in. Time elapsed: Less than 24 hours.

Warm Fronts. A warm front forms when a warm air mass moves into an area occupied by a cooler air mass. The cool air remains close to the ground, and the warmer air is forced to rise over it as it moves into the area (see Figure 10-13).

As the warm air rises, it cools. When it cools to the dew point, condensation begins. The arrival of a warm front is marked by the appearance of high, thin, wispy clouds and a gradual decrease in air pressure. As the warm air mass moves into the area, the cloud mass thickens and becomes lower. A light rain or snow begins and continues to fall for a considerable time, sometimes more than 24 hours. Gradually, the precipitation slows, then stops. As the front passes, the wind direction changes, the pressure stops dropping, and the temperature rises.

Figure 10-14 is a graph showing the passage of a warm front as recorded on meteorological instruments. About

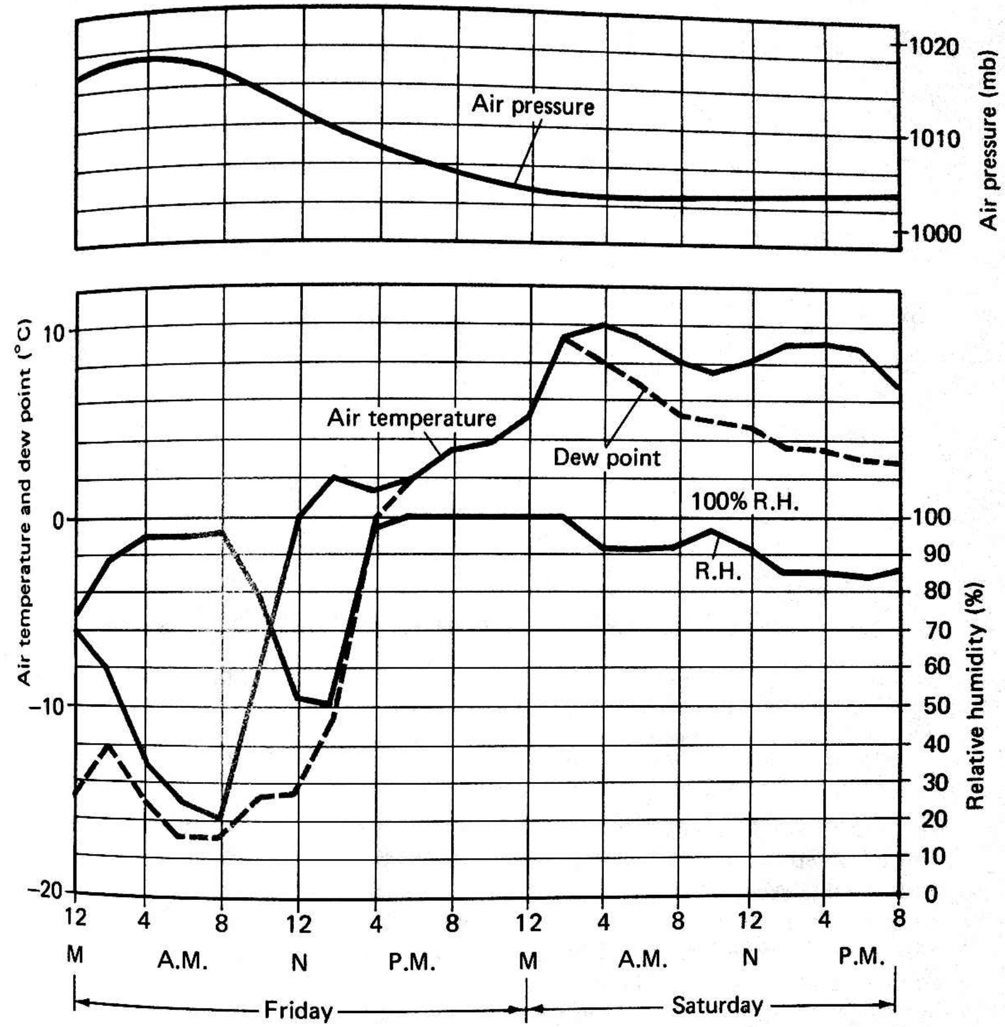
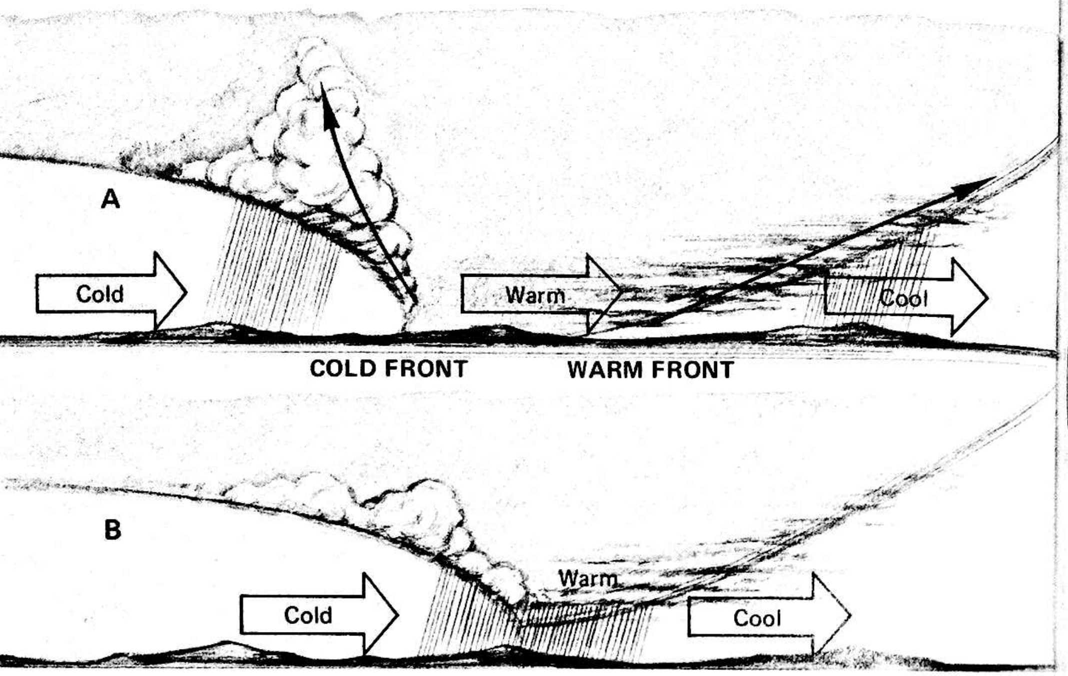


Figure 10-14. Changes in weather variables during the passage of a warm front.

8 A.M. on Friday, the temperature began to rise abruptly, and at first the relative humidity decreased. But within a few hours the dew point also rose sharply. By about 6 P.M. dew point and air temperature became equal, and relative humidity was 100%. Although the air temperature continued to rise through the night, the air remained saturated. It can be inferred that precipitation occurred from late afternoon to 2 A.M. that night. Air temperatures on Saturday were much higher than on Friday, and relative humidity remained quite high. A warm front had passed through between 2 P.M. and 4 P.M. on Friday, and a warm, moist air mass had arrived.

Notice that the effects of the warm front are still occurring more than 24 hours after the start of the passage of



OCCLUDED FRONT

Figure 10-15. Formation of an occluded front. An occluded front forms when a warm air mass is lifted completely off the ground by a faster-moving cold air mass.

the front. If you compare this with the time involved in the passage of a cold front, you'll see that there's quite a difference between them. Cold fronts move through an area relatively quickly, and sometimes violently, as in a thunderstorm. The passage of a warm front is often long and drawn out, taking days before the change is completed.

Stationary Fronts. A stationary front is formed when two adjacent air masses with different characteristics remain in the same positions for a considerable length of time. The weather along a stationary front is similar to that along a warm front.

Occluded Fronts. An occluded front forms in a series of stages. It begins with a stationary front between a cold and a warm air mass, with air moving in opposite directions along the front. Then the cold air begins to turn and move in under the warm air, forming a cold front, as shown at the left of Figure 10-15 *A*. At the same time, the warm air advances in the same general direction, forming a warm front (see right side of Figure 10-15 *A*). At the warm front the warm air rides up over the cold air ahead of it. However, the cold front advances faster than the warm front and finally overtakes it. The result is that the warm air mass is lifted entirely off the ground (Figure 10-15 *B*). This situation is called an occluded front.

Figure 10-16 shows how an occluded front might look on a weather map. Occluded fronts are as-

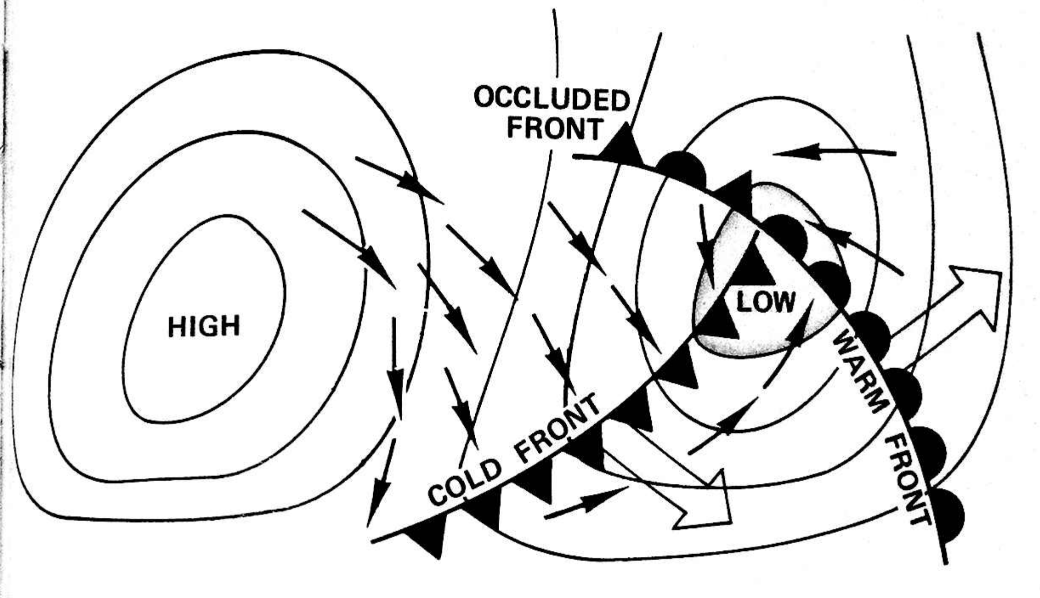


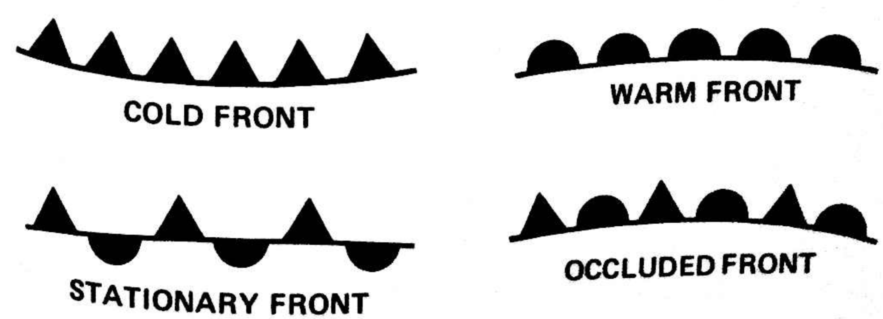
Figure 10-16. Relationships of air masses and pressure systems during formation of an occluded front.

sociated with the formation of low-pressure air masses, or lows, in the mid-latitude. They usually result in heavy precipitation.

Mapping Fronts. Since fronts, or the interfaces between air masses of different characteristics, generally bring changes in the weather, they are of great importance on weather maps. Figure 10-17 illustrates how fronts are shown on weather maps. You can see that a line is drawn along the front, and that the type of front involved is indicated by symbols on the front line.

Tracks of Fronts and Air Masses. In the late 1700's Benjamin Franklin began to keep records of major storms affecting the east coast of the United States. He found that there was a pattern to the movement of these storms.

Figure 10-17. Fronts on a weather map. The positions of fronts are shown by lines on the map, while the type of front is shown by symbols on the front line.



They seemed to move in a northeast direction much of the time. Franklin could not do much with his records, because in those days the storms traveled faster than the news. It was not until the invention of the telegraph in the mid-1800's that weather conditions in one place could be used to predict future conditions in another location.

Using information collected over the years, the paths, or *tracks*, and rates of movement of air masses and fronts can now be predicted quite accurately. Some of the major tracks are shown in Figure 10-9. Knowing the tracks of the fronts and air masses helps meteorologists to forecast weather.

Jet Streams. During World War II, American bomber pilots flying westward in missions over Japan sometimes found strong headwinds at altitudes above 6 km. Some of these winds were strong enough to cancel out completely their plane's forward speed, so that the plane was actually standing still relative to the ground! Flying eastward over the Pacific, the winds were such that planes sometimes doubled their actual flying speed relative to the ground.

These fast-moving streams of air are called *jet streams*. Jet streams appear to be streams of fast-moving air very high in the atmosphere. They occur in many parts of the world and seem to be associated with great waves in the upper atmosphere.

The speeds and positions of the jet stream change with the seasons, and there is even some change from day to day. But certain characteristics do hold fairly constant. The jet streams are found at altitudes of from 6 to 12 km. They are about 500 km wide, and wind speeds near the center range up to 500 km/hr. Jet streams are only several kilometers in thickness.

Meteorologists now think that the day-to-day changes in our weather are strongly influenced by the movements of the jet streams.

SUMMARY

1. The interface where two air masses of different characteristics meet is a front.
2. Weather conditions at fronts are generally unstable. Precipitation often occurs with the passage of a front.
3. The four basic types of fronts are cold fronts, warm fronts, stationary fronts, and occluded fronts.
4. The tracks and rates of movement of air masses and fronts can be predicted with considerable accuracy.
5. Jet streams are fast-moving streams of air in the upper atmosphere.
6. Jet streams may influence day-to-day changes in the weather.

STORMS

Storms are the most spectacular and violent forms of weather. Because storms can be so destructive, they are of great interest to meteorologists. However, until the development of satellites, storms for the most part had to be studied from the ground, and this greatly limited the amount of information that could be obtained about them. Now, with weather satellites, scientists can follow a storm from its initial stages of development until it dies out. Perhaps they will eventually learn to control storms in some way, and to prevent some of the damage done by storms each year.

Let's take a look at three common types of storms: thunderstorms, tornadoes, and hurricanes.

Thunderstorms. The photograph in Figure 10-18, taken from a satellite, shows the Florida peninsula on a typical day in late August. There are thunderstorms in all stages of development in this local region. Over the earth as a whole, it is estimated that more than 2,000 thunderstorms occur *every hour*.

Thunderstorms are generally associated with high temperatures. They occur most frequently in the afternoon over land areas. Thunderstorms are made up of units called *cells*. A cell has a definite life cycle that generally lasts only about an hour. But because a storm may be made up of several cells in various stages of development, it may last much longer than an hour.

Figure 10-18. Thunderstorms forming over the Florida Peninsula, as photographed from a satellite.

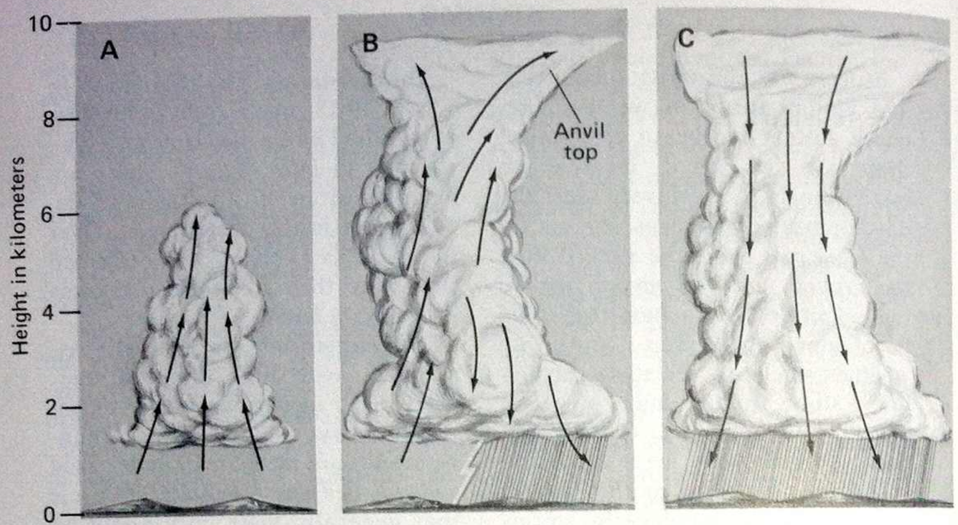


Figure 10-19. A storm cloud.

In the first stages of cell development, parcels of warm, moist air near the ground rise rapidly upward, like air bubbles in a liquid. As the air rises, it cools until the dew-point temperature is reached, and a dark, cumulus storm cloud begins to form. Even though the rising air cools off, it remains warmer than the still air around it, and so it continues to rise. When condensation occurs, large amounts of heat are released; this further warms the rising air, and the upward currents become much stronger. There is heavy precipitation from the condensation, which produces a strong downdraft of air. So within the storm there are areas of strong upward and downward movements of air.

The parcels of warm air continue to rise until they reach heights of 6 to 12 km. At these altitudes condensation decreases, and the temperature of the rising air drops until it is the same as the surrounding air. At this point the mass of air spreads out sideways, forming a flat top on the storm cloud (see Figure 10-19). This is often called an *anvil top* because it resembles the shape of a blacksmith's anvil.

Lightning and thunder occur when the storm clouds become electrically charged. Generally, the top part of the cloud becomes positively charged, while the bottom parts develop both positively and negatively charged areas. The charge builds up until a great spark, or arc, of electricity is discharged between the cloud and an oppositely charged object. This can be another part of the same cloud, another cloud, or the ground. Lightning strokes between a cloud and the ground can be 10 km or more in length.

The tremendous electrical current in the lightning stroke heats the air along its path. The great heat causes the air along the path to expand, and produces a shock wave of sound much like the sonic boom of a jet

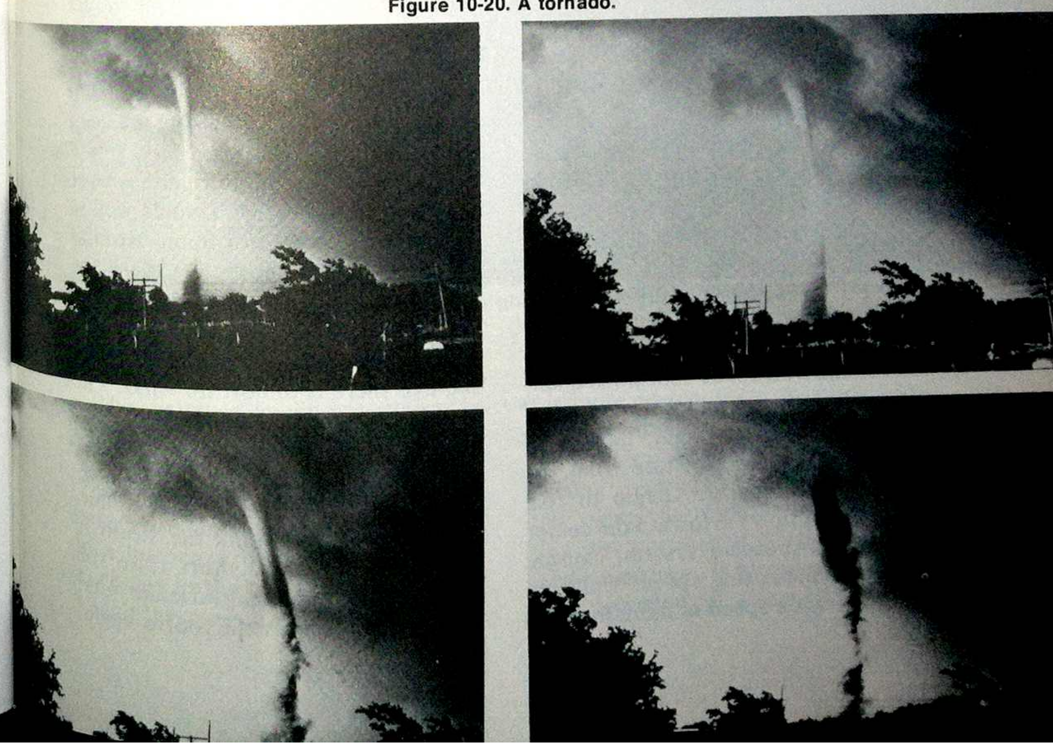
plane breaking the sound barrier. This sound wave is thunder.

The thunder from a single lightning stroke is usually drawn out in a series of rolls and rumbles, sometimes beginning with a loud crack when the lightning has struck nearby. The reason for the prolonged sound of thunder is that the sound from different parts of the stroke have different travel times, depending on their distance from the observer. Echoes from surrounding hills also add to the combined sound effects.

Tornadoes. Thunderstorms are frightening enough in themselves, but in certain parts of the United States there is always the danger that a squall line of thunderstorms may become the birthplace of a *tornado*, or *twister*, the most violent of all storms. Thunderstorms occur along both warm and cold fronts, but those along cold fronts are generally more violent and more likely to produce tornadoes. Tornadoes have occurred all over the United States, but they are most frequent in Iowa, Kansas, Oklahoma, and Arkansas.

A tornado appears as a funnel-shaped cloud that hangs down out of the towering clouds of a thunderstorm (see Figure 10-20). At the center of the tornado is the *vortex*, an area in which the atmospheric pressure is extremely low. Outside the vortex are winds that swirl in a counterclockwise direction (in the Northern Hemisphere) at speeds that may reach 800 km per hour. Tornadoes are small, some not more than 100 meters in diameter, but the enormous strength of their winds and the sudden and drastic drop in pressure within the vortex leave total destruction in their paths. The sudden drop in pressure may cause buildings

Figure 10-20. A tornado.



to explode or roofs to blow off when the air inside expands suddenly.

Tornadoes generally move in a northeasterly direction at speeds of 40 to 65 km per hour. Most tornadoes last for less than 1 hour. The path of a tornado along the ground is usually from 25 to 65 km long, although some are longer. Very peculiar things have happened to people, animals, and objects caught in the middle of a tornado. Cars, trucks, roofs, and other very large objects are often carried a considerable distance by the winds of a tornado.

Tornadoes leave a path of destruction several hundred meters wide. But the path may be twisted so that one house on a street is completely demolished, while the house next door is untouched. In areas where tornadoes are common, people have underground storm cellars, which provide the best protection against injury.

Hurricanes. The location: 15° north latitude, 65° west longitude, in the eastern Caribbean. The time: late August. A hurricane is born.

A hurricane, which is also called a *tropical cyclone* or *typhoon,* begins as a tightly formed low-pressure system over an ocean. The hurricane characteristics may begin to develop when a high-pressure system forms high in the atmosphere above the low.

The build-up of a hurricane involves the transfer of enormous quantities of energy. Around the center of the low-pressure system, masses of warm air, full of moisture from the warm ocean surface, begin to rise rapidly. Air flows in toward the center of the low-pressure system, causing winds of increasing speed. Until the winds reach a speed of more than 120 km per hour, the system is called a *tropical storm*. But when they exceed this speed, the storm becomes a full-fledged hurricane.

As the air rises, it cools. Towering thunderstorm clouds form. When the rising air cools to the dew point, condensation begins, and with the condensation come torrential rains. Condensation releases tremendous quantities of heat, which further warms the rising air. This creates a warm core in the hurricane. The pressure difference between the storm center and the surrounding air is intensified, wind speeds increase, more moisture is pulled into the system, more condensation occurs, and more heat is released—the entire process gains energy.

The whole hurricane system usually moves in a northwesterly direction at speeds of 15 to 18 km per hour. Figure 10-21 shows how a hurricane might look on a weather map several days after it first formed. Figure 10-22 is a photograph of a hurricane taken from a satellite. Such photographs are used to keep track of hurricanes.

A fully developed hurricane is over 650 km in diameter with winds well in excess of 120 km per hour. Around the center of the hurricane there are rising columns of warm air. But in the center itself the air is descending. This center is the *eye* of the hurricane. In the eye there is almost no wind. The clouds are broken and patchy, and the sky may even be blue. The eye may be as much as 30 to 50 km in diameter. When you are in the eye of a hurricane, you might think the storm is over. But within a short time the "other side" of the hurricane hits, and you're back in the storm again.

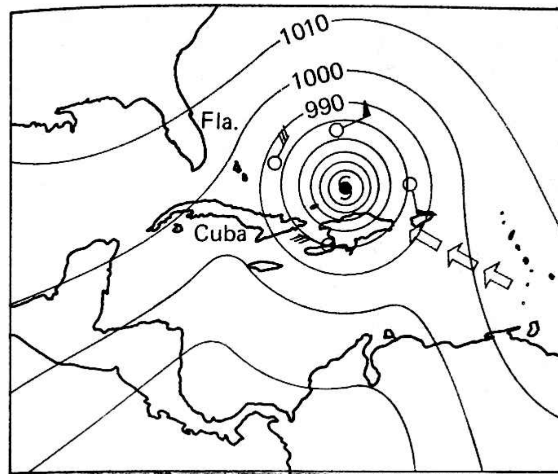


Figure 10-21. A hurricane on a weather map.

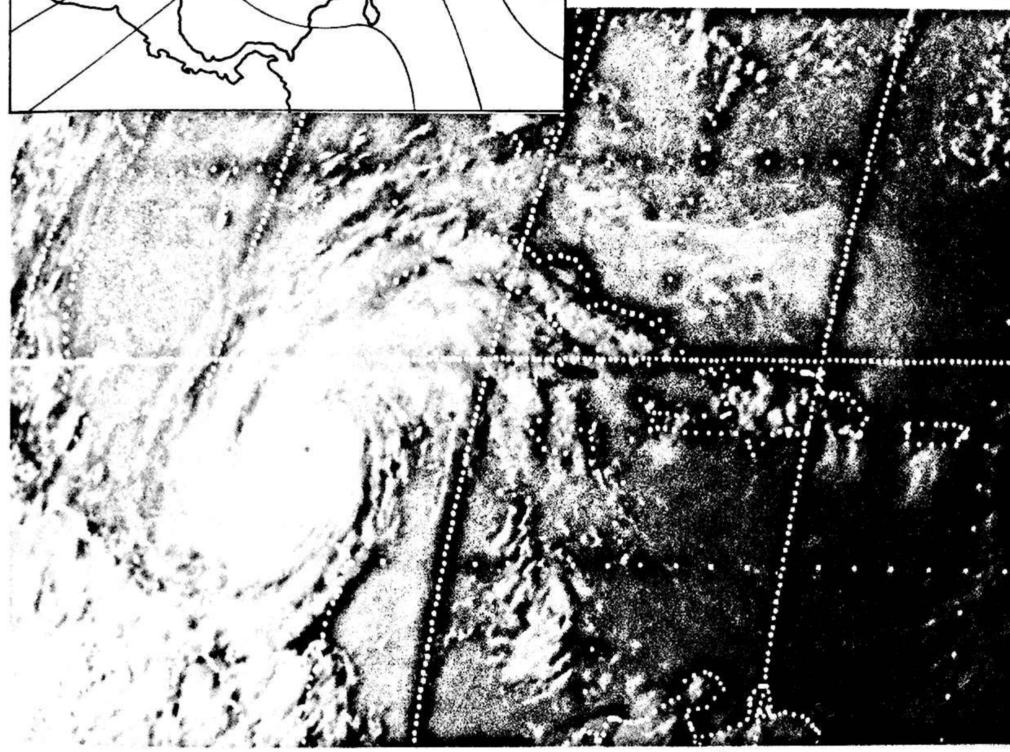


Figure 10-22. A hurricane as photographed from a satellite.

But now the winds are blowing from the opposite direction.

The decrease in air pressure as a hurricane moves through an area is about the same as that in a tornado. The low pressure of the tornado causes tremendous damage, but that of a hurricane does not. The difference lies in the length of time during which the pressure drop occurs. In a tornado, the time is measured in minutes, or even seconds. In a hurricane, it is more on the order of hours.

After a number of days, a hurricane dies out. It may smash its way inland, causing great damage as it goes, or it may swing out to sea. In both cases it dies out because it loses its main need—moisture. It requires the constant upwelling of warm, moist air.

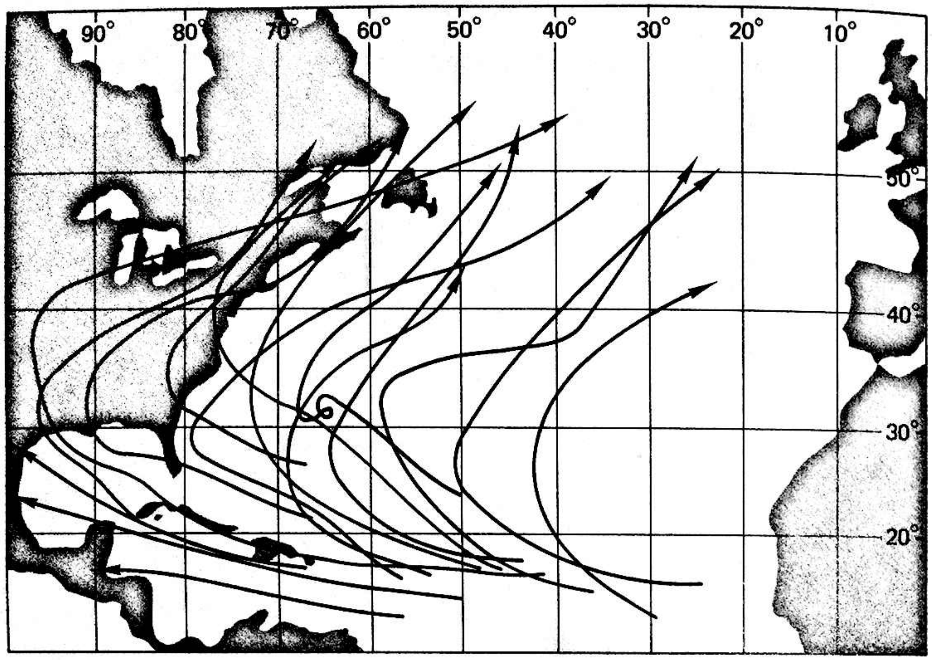


Figure 10-23. General pathways of hurricanes around the eastern United States.

Traveling over land or over the colder northern water cuts off the supply. Figure 10-23 shows typical pathways for hurricanes around the eastern United States.

In this chapter we have moved from the small day-to-day changes in the atmosphere to the most violent and complex of storms. It is this constant changing of atmospheric conditions that makes the science of meteorology such a challenging field. Meteorology is a study of change—and an attempt to understand and predict the course of change in the tremendous energy systems at work in the atmosphere.

SUMMARY

1. Tremendous amounts of energy are transferred within the atmosphere by storms.
2. Thunderstorms are generally associated with high temperatures. They occur most frequently in the afternoon over land areas.
3. Lightning occurs when storm clouds become electrically charged.
4. Thunder is a shock wave of sound. It is caused by the heating and expansion of air in the path of a lightning stroke.
5. Tornadoes are small, short-lived, very violent storms associated with thunderstorms.
6. Hurricanes form over warm oceans.
7. Hurricanes die out as they travel over land or the colder northern oceans, because their supply of moisture is cut off.

REVIEW QUESTIONS

Group A

1. Define the term *weather*.
2. What is a *station model*?
3. What are weather predictions based on?
4. What factors affect temperature at a given location?
5. What factors affect atmospheric pressure?
6. What does a change in dew-point temperature indicate?
7. What happens to the probability of precipitation as the difference between air temperature and dew-point temperature increases? Decreases?
8. What is *wind*?
9. What causes winds?
10. To what factor is wind speed related?
11. Name some of the local conditions, including geographic features, that can affect the local weather pattern.
12. Which atmospheric variables are related in a simple manner? Specify whether these relationships are direct or inverse.
13. What three characteristics are used in identifying air masses?
14. What determines the characteristics of an air mass?
15. What is the direction of circulation in a low-pressure air mass in the Northern Hemisphere?
16. What is the direction of circulation in a high-pressure air mass in the Northern Hemisphere?
17. What is a *front*?
18. How does the passage of a front generally affect weather conditions?
19. What are the four basic types of fronts?
20. What are jet streams and why are they important?
21. What is the importance of storms in terms of energy in the atmosphere?

Group B

1. A. pressure B. temperature C. cloud cover
   D. dew point E. visibility F. precipitation
   G. wind speed H. wind direction
   The variables listed above are those shown on the station model on page 157. Choose:
   a. One pair that you would expect to show a *direct* relationship on a contingency table or a graph.
   b. One pair that would show an *inverse* relationship on a contingency table or a graph.
2. Explain how some or all of the variables in Question 1 would change under the following conditions:
   a. The weather changes from warm and humid to cool and dry.
   b. The weather changes from cool and dry to warm and humid.
   (If you would like, organize your answer into a table, using one column for the change listed in 2-a and another column for the change listed in 2-b.)
3. Describe the probable origin, path, and effect on your area of an air mass as it moves from its source region to your location, bringing: (a) warm, moist air, (b) cool, dry air.