Severe Weather
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Esther Canja, Leslie A. Mack, Agricultural Engineering; Norton Strommen, NOAA
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UNIT 4 4-H WEATHER PROJECT

SEVERE WEATHER

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Member's Guide

4-H—Youth Programs
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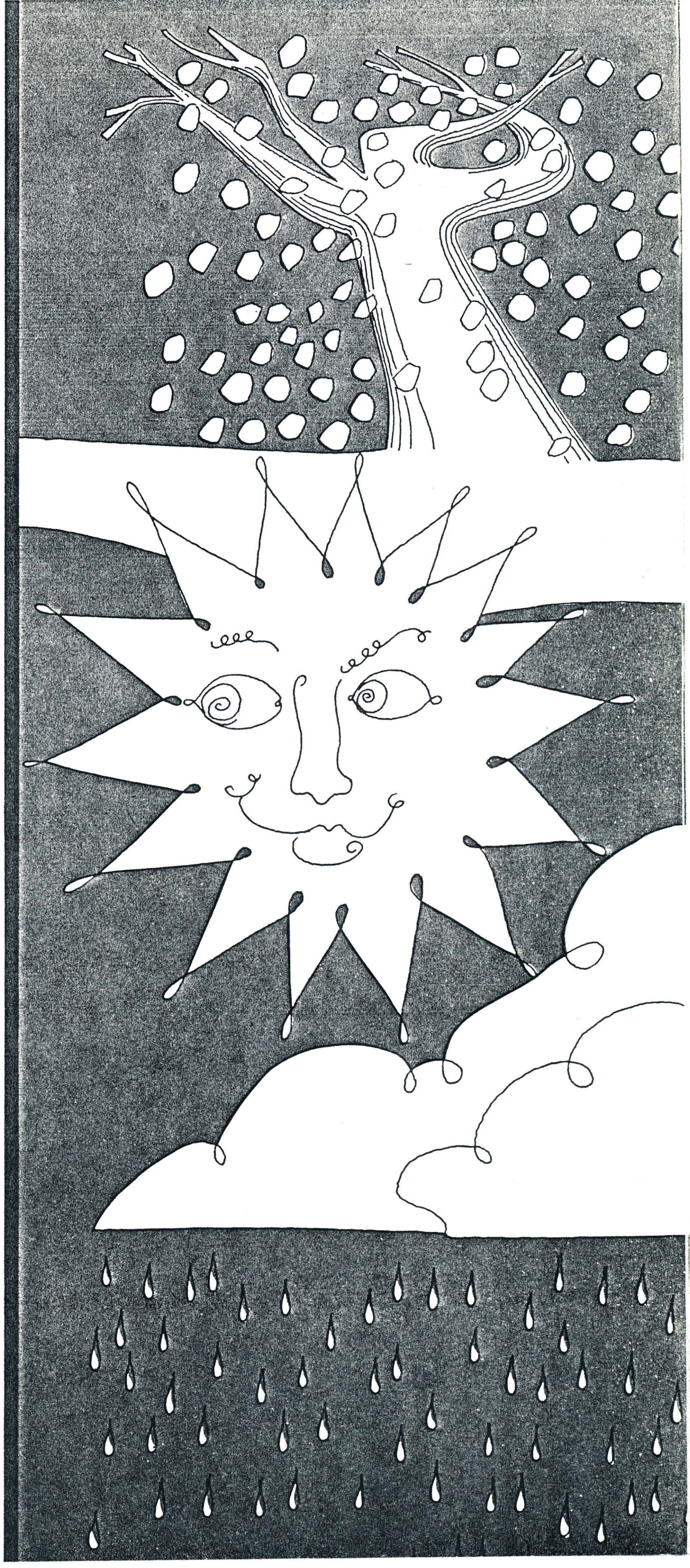
Agricultural Engineering Department

Cooperative Extension Service
Michigan State University



SEVERE WEATHER

INTRODUCTION

Until this century when man split the atom, weather, in its most extreme or violent forms, posed the greatest threat to the greatest number of people. Tornadoes, hurricanes, prolonged heat waves or severe cold, too much rain or too little, often meant death or major disaster for hundreds, possibly thousands, of people. They still do. But each year we learn a little better how to live with these plagues. We've come to recognize weather conditions that warn of impending disaster. And we've developed ways of protecting ourselves.

Nevertheless, though we understand *what* happens in severe weather, we are only on the threshold of understanding *why*. Why does rain fall? What triggers a tornado? Can a hurricane be weakened before it reaches land? No one really knows. The search for answers has never been more intense.

The whole field of meteorology, in fact, is bursting with significant research today. Equipped with such sophisticated tools as weather satellites, rockets for upper-air soundings, and computers, meteorologists are gaining insights into weather phenomena that have never been possible before. Some of the most respected old theories are being challenged. Even the theory of "cold fronts" and "warm fronts"—the very foundation of weather forecasting in our middle latitudes—is being re-evaluated. "Fronts" do exist; but is some other mechanism equally responsible, if not more so, for the development of our changeable middle-latitude weather? You are about to see that the answer is probably "yes".

This unit presents some of the latest information and the newest theories on weather extremes and those conditions under which they develop. Keep in mind that much of the material presented here was not even known before World War II. Within the next few years, as more secrets of the atmosphere are unveiled and weather data finally becomes available from every part of the world, many meteorologists look for major breakthroughs in our understanding of weather processes. They confidently expect that two "dreams"—long-range forecasting and weather control—will at last become realities. So it is that age-old meteorology has become one of the new pioneering sciences, hungry for inquiring minds and full of career opportunities.

One purpose of this unit is to give you some basic knowledge of how our atmosphere works so that you can understand, as well as use, new facts and theories. Another purpose is more immediate: storms and other extreme weather conditions threaten our well-being. The better we understand them, the more intelligently we can act to curb their ill effects, limit our losses, and very possibly save our lives.

SEVERE WEATHER

Exploring the Atmosphere

THE TROPOSPHERE

We live in a very shallow layer of atmosphere called the *troposphere.* The troposphere varies in height with latitude and seasons. At the poles, the troposphere may extend upward an average of four miles, but at the equator, great currents of warm air, streaming upward, push the top of the troposphere much higher, to an altitude of about ten miles. Almost all of the water vapor in the atmosphere is contained in the troposphere, and weather, as we know it, takes place only here. This entire layer—unlike any other—is marked by a great overturning and mixing of the air, which creates what airplane pilots call *turbulence.*

The troposphere has other characteristics which are important to us weatherwise. One is its density. About 80% of the atmosphere's mass is contained here (and almost two-thirds of that is packed into the first four miles!) Mountain climbers tackling the world's highest mountains (for example, Mt. Everest, 5½ miles high) must carry oxygen to supplement the thin air.

These same climbers, hobbling painfully back to earth with frost-bitten toes, can attest to another characteristic. Temperature in the troposphere decreases with height. This decline in temperature is called the *lapse rate* and averages about 3½ degrees for each 1000 feet of height.

BEYOND THE TROPOSPHERE

Scientists used to believe that the atmosphere grew progressively colder to its upper limits. The first hint that this might not be so came during World War I when scientists were asked to explain why an explosion could be heard 10 miles away, and even 50 miles away—but not at a distance of 30 miles. The only logical explanation: a layer of warm air in the upper atmosphere must have bent the sound waves so that they bypassed the middle distances.

The deduction was brilliant. A warm layer did exist, caused by a concentration of ozone in the stratosphere. Ozone absorbs ultraviolet rays from the sun. The concentrated ozone warms the upper regions of the stratosphere and at the same time keeps us on the earth's surface from "sunburning" to death.

Now that meteorologists can explore the upper air with rockets and satellites, they have found that the atmosphere is much like a three-decker sandwich with two extremely cold regions between three warmer ones. By the 1960's there had been so many discoveries about the atmosphere and such a variety of identifying names tagged to overlapping areas that the World Meteorlogical Organization decided to end the confusion. In 1962, they divided the atmosphere into layers by temperature tendencies. Major areas became:

Troposphere—in which the temperature is warm at the surface but decreases with height.

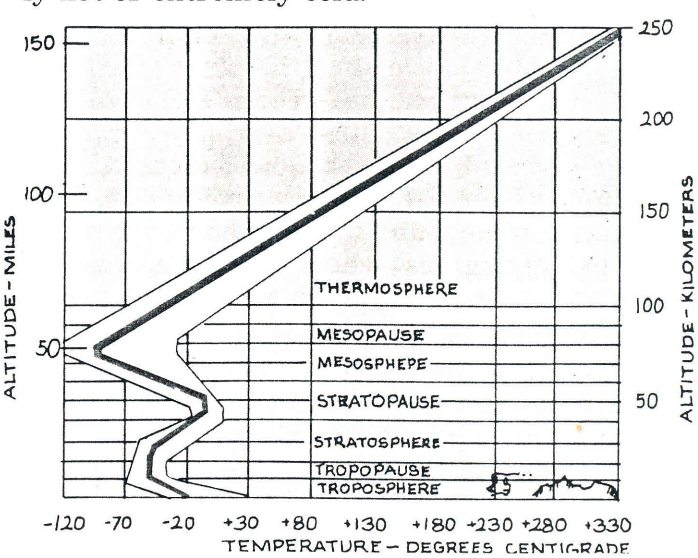
Stratosphere—in which the temperature is constant and then increases. The area above the ozone layer may be warmer than ground level.

Mesosphere—in which the temperature decreases until extremely cold (-200°F.)

Thermosphere—in which the temperature rapidly increases. This layer is heated by the presence of oxygen atoms, which like ozone (another form of oxygen), absorb high energy rays from the sun. Included in the thermosphere is a region of charged particles, sometimes called the **ionosphere**.

Exosphere—the outer fringes of our atmosphere, extending from about 350 miles above the earth. Once thought to be extremely cold, the exosphere is now known to be intensely hot.

Boundaries between these layers were named, respectively, the *tropopause*, *stratopause*, *mesopause*, and *thermopause.* As you can see from the illustration, these areas have a more constant temperature, either extremely hot or extremely cold.

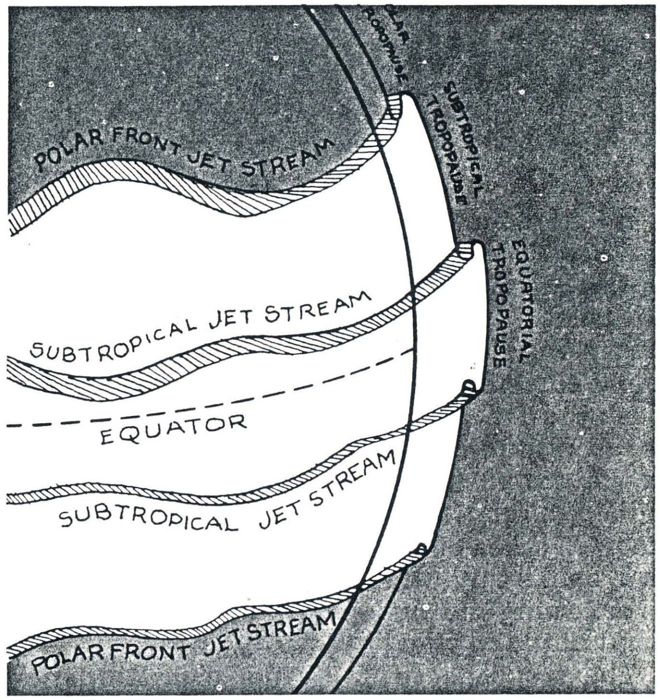


Every layer of the atmosphere is significant to us. Just as the ozone in the stratosphere protects us from the sun's scorching rays, ions in the thermosphere make radio communication possible. What more can you find out about the atmosphere? How do the layers differ? And how do their differing characteristics affect us? What were the layers formerly called?

If you should take a trip by plane while studying this weather unit, record what you observe. At what altitude are you flying? What kind of clouds do you observe? At what height? Approximately where in relation to some identifiable city or area below? Check your notes with a weather map for the same day. You'll be surprised by your new perspective.

Date ____________
Plane ____________

Time ____________
Altitude ____________
Location ____________
Speed ____________
Observations:
(Clouds, Turbulence, Visibility, Etc.)



A CLOSER LOOK AT THE TROPOPAUSE

The tropopause, stretching like a thin membrane between the troposphere and stratosphere plays many important weather roles. For one thing, its constant temperature retards the further upward development of clouds that have progressed this far (see page 3). Weather is trapped below.

The tropopause increases in height from the poles to the equator, but the slope is neither continuous nor gradual. There is an abrupt change, sometimes called a break or gap, at the Polar Front, where the lower Polar air and the higher Tropical air come together. A similar gap is often found over the horse latitudes (around 30 degrees) where the high equatorial tropopause and the lower subtropical tropopause meet.

In the late 1950's our country carried out testing of high-yield H-bombs in the equatorial Pacific, far away from inhabited areas. Months later, fallout from the bomb began to be detected throughout the middle latitudes, in a belt which included the United States, Britain, France and Russia. Later, when Russia conducted similar tests in remote areas of the Artic, the same thing happened. No matter where the H-bomb tests were carried out, the fallout seemed to find its way back to the middle latitudes. How was it possible?

The test bombs were so powerful that they blasted tons of fallout particles high into the stratosphere. Because there is so little vertical mixing of the air in the stratosphere, the fallout particles remained here for many months, slowly drifting around the earth. Eventually they settled through the tropopause gap at the Polar Front. There, caught by the winds and turbulent air of the troposphere, the minute but dangerously radioactive particles fell back to earth.

Bomber pilots on raids to Japan during World War II made another startling discovery in the upper portions of the troposphere. Around 20,000 feet they encountered winds so strong they could make no progress against them. These high-velocity winds came to be called the *jet stream*. In the years since World War II, jet streams have been found meandering around the globe in more or less continuous and narrow bands, generally over the polar and subtropical frontal zones. Even more significantly, scientists are finding that a jet stream is generally present aloft when weather is at its worst below.

The jet stream is only one feature of a great whirl of upper winds which may control most of our weather. Let's look at these winds next.

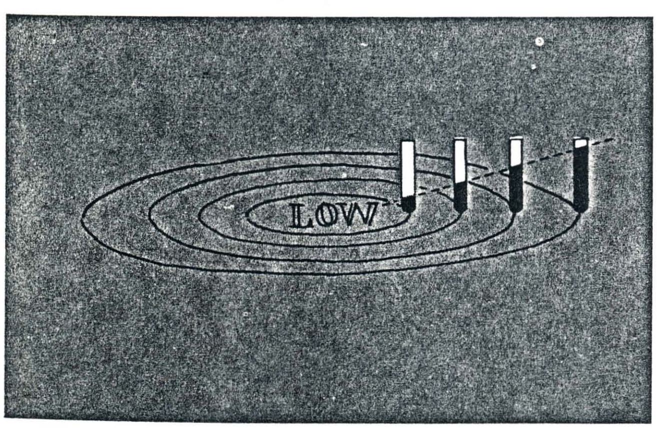
Winds Aloft

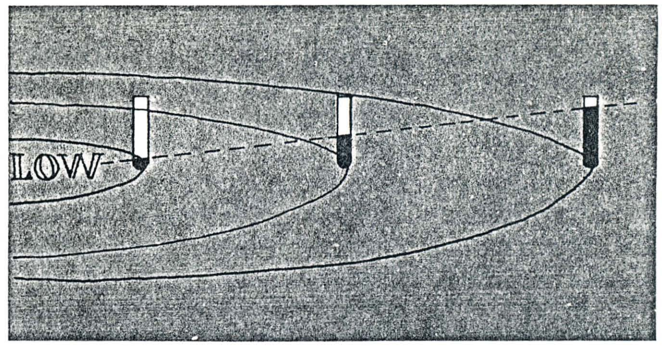
Take a look at the weather maps in your leader's guide and compare the upper winds (500 millibar map) with winds at the surface. On any of the surface maps you'll find winds moving in from every direction, sometimes whirling clockwise, sometimes counterclockwise, but generally blowing across the *isobars* (lines of equal pressure explained in Unit III). Now look at the winds aloft and notice how much swifter they are than those below. Instead of crossing the isobars, they seem to flow between them, like a river. Have you any idea why?

Winds—whether at the surface or aloft—are a balance of forces. Add a little more of one force, or take away another and you have a change in the wind's speed or direction. All of the differences you've noticed in the upper and surface winds can be explained by the interaction of just three forces: *pressure gradient*, *Coriolis effect*, and *friction*.

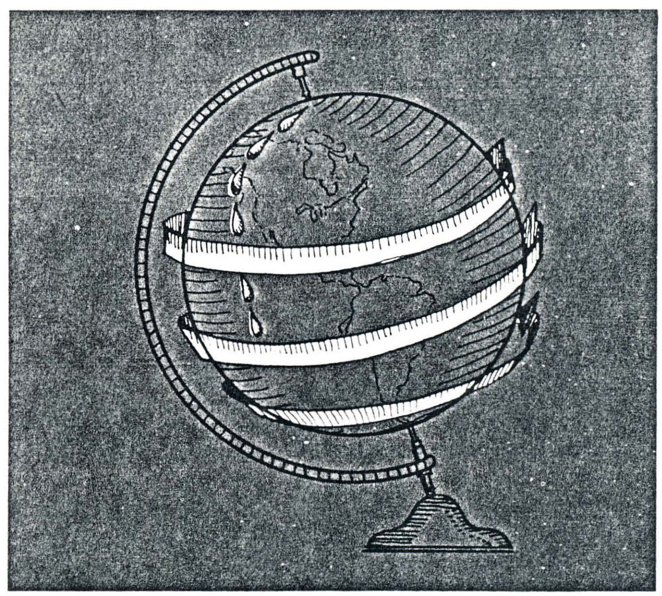
Pressure Gradient. We know from Unit III that air moves from high pressure to low pressure. The greater the pressure difference, the faster the wind. This difference is called pressure gradient or the barometric slope.

Try this. As you look at a weather map, picture a column of mercury at each isobar, corresponding to the pressure. Where the isobars are closely spaced, below, a line drawn from one mercury level to the next would show a sharp drop. Air rushes down the slope and across the isobars. Above, right, where the isobars are widely spaced, the slope is gradual and air moves more slowly. As you can see, closely spaced isobars will always indicate fast winds. Very wide spaces reveal a calm.





Coriolis Effect. The Coriolis effect is explained thoroughly in Unit II, but here's an experiment to refresh your memory. Start a globe spinning *slowly* in an eastward direction. Now let a drop of water trickle down from the north pole and watch its path. Because the earth rotates, the winds, like the drop of water, are deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. The deflection is most pronounced at the poles, diminishing to zero at the equator. Coriolis is also proportional to speed. The faster a parcel of air moves, the greater the Coriolis deflection will be.



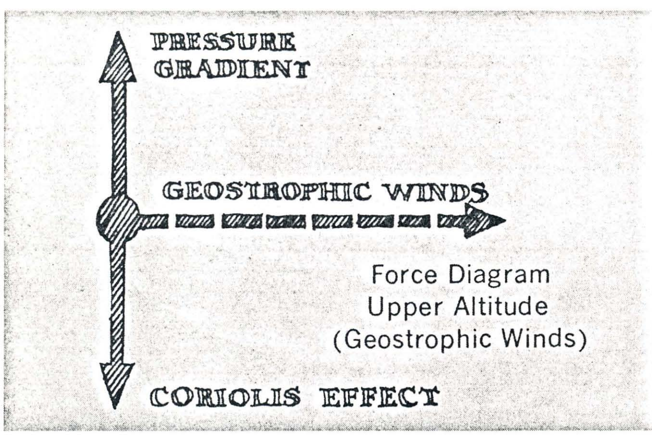
Friction. Friction is a force which holds back motion when one surface slides over another. Rough surfaces increase friction. Consider what happens then to surface air as it slides over the earth, held back by mountains, trapped in valleys, bumping along over ridges and gullies, forests and cities. The air slows down. Aloft, away from such obstructions, air can move much faster.

BALANCING THE FORCES

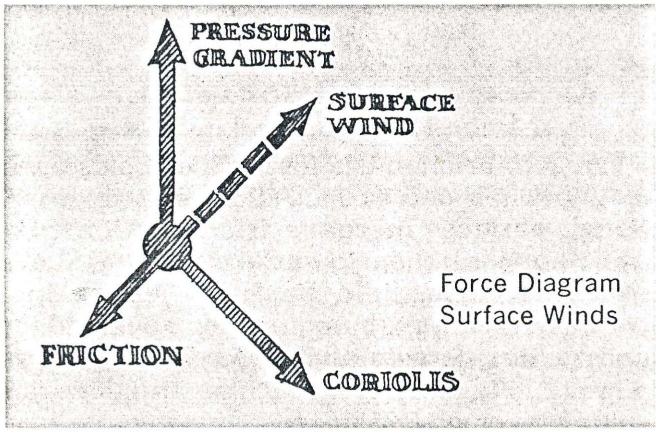
If the earth stood still, unequal heating by the sun would soon set up a pressure difference and start the air flowing between equator and poles. Cold, dense air at the poles would sink and slide southward, while at the equator the warm, light surface air would rise as high as possible and then "fall down" toward the poles.

Now let's start our earth spinning from west to east. Coriolis will deflect these northward and southward moving winds to the right. As the winds gather momentum and increase in speed, their deflection also increases. Soon the winds are blowing straight from the west and parallel to the isobars. These winds aloft are called the *geostrophic wind* and represent a balance between the pressure gradient force and Coriolis effect.

Winds above 2500 to 3500 feet can generally escape the effects of friction, but surface winds cannot. Friction upsets the fine balance of forces which exists aloft. The winds slow down; their deflection decreases. Instead of flowing between the isobars, surface winds flow across them, toward lower pressure.



Force Diagram
Upper Altitude
(Geostrophic Winds)



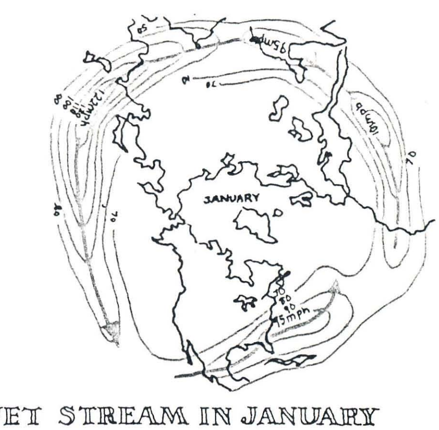
Force Diagram
Surface Winds

JET STREAM

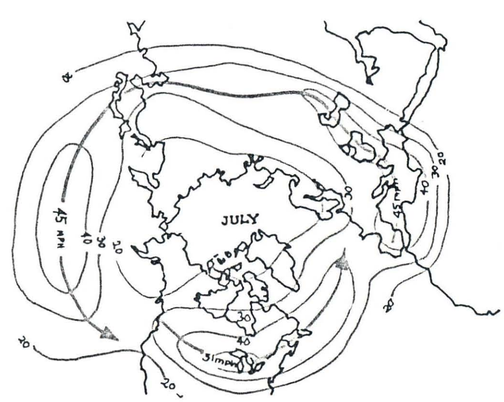
Within the fast-moving upper westerlies, there will often appear a core or "jet stream" of even swifter winds. The velocity of these core winds may exceed 200 miles an hour. Jet streams are frequently located in the vicinity of the tropopause and generally develop where the greatest temperature contrasts, both vertical and horizontal, exist. They fluctuate in height between 20,000 and 40,000 feet and are generally lower in winter than in summer. **Can you explain why?**

Jet streams will usually be found near the polar and subtropical frontal zones. The subtropical jet stream does not stray very far from 30 degrees latitude, but the polar jet stream moves with the Polar Front; south in the winter, north in the summer. These core winds tend to be much swifter in the winter. **Can you figure out why?** Whenever possible, airliners crossing the Pacific on their way to California will hitch a ride on a jet stream.

Jet streams are found in both hemispheres, but with a distinctive difference. In the Southern Hemisphere, the jet core and river of air surrounding it flows more directly eastward.



JET STREAM IN JANUARY



JET STREAM IN JULY

In the Northern Hemisphere, the great wind river meanders. A simple experiment will show you why:

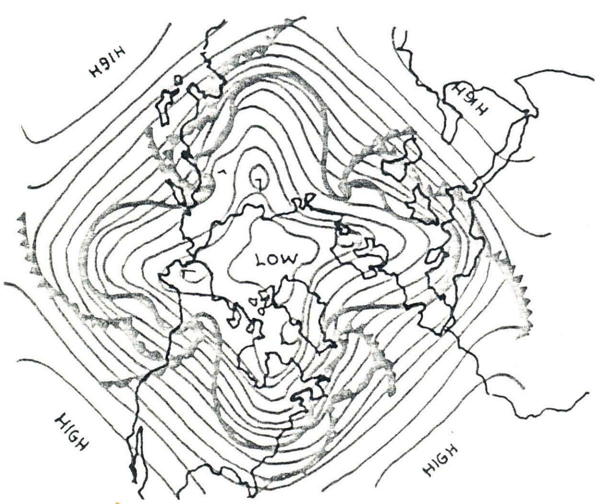
Pour about an inch of water in a bowl and start it spinning on a turntable (record player, revolving stool, etc.). Add a few drops of food coloring and notice the pattern which develops. Looks like the classic geostrophic wind pattern, doesn't it?

Now empty the bowl and add some kind of a barrier (stones, a block, etc.) so that a right angle is formed with one side of the bowl. This will represent the Southern Hemisphere which has relatively few land surfaces and only one high, extended mountain range, the Andes of South America. Barely cover the obstacles with water. Set the bowl spinning, add a few drops of coloring and observe as before. Where there are few land barriers to disturb the air, the upper westerlies tend to be most purely geostrophic.

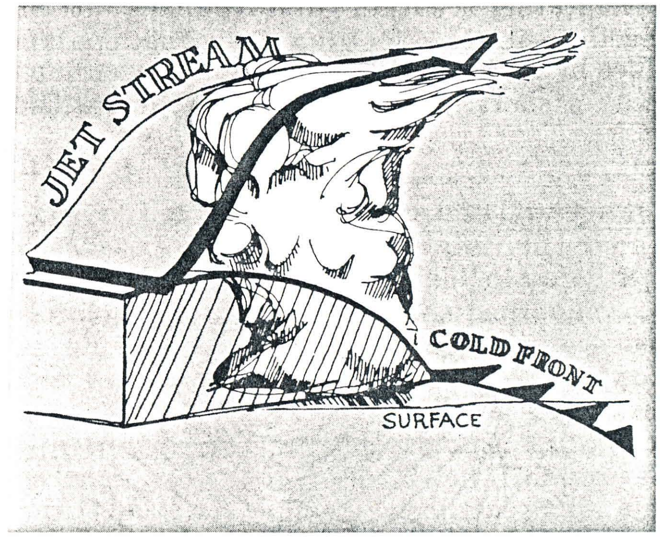
Repeat the experiment above, but add a second barrier opposite the first. What do you observe? In the Northern Hemisphere, the mountain ranges of Alaska, the Rockies and Sierras, the Alps and Himalayas all rear upward, blocking the flow of air. These and other obstacles, such as turbulent areas where warm and cold air masses come together, tend to throw the winds aloft into a series of waves with surprising consequences for weather below.

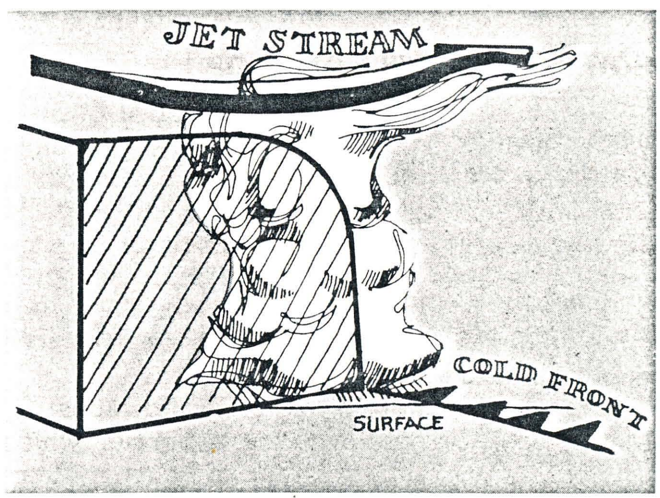
WAVES ALOFT AND WEATHER BELOW

How do these upper waves affect our weather? Let's take a look. Here is a global view of the upper air superimposed over a corresponding map of weather at the surface. The date: a rather typical winter day.



In this view Polar air has pushed southward in four long waves or *troughs*. These troughs are also called standing waves for they move very slowly and may remain in essentially the same position to two to three weeks or longer. Since Polar air is heavy and sinks, you might expect to find some of this mass of Polar air at the surface—and you would be right. Below, and in this case, along each advancing edge of Polar air is an old friend from Unit III, the cold front. A side view might look like this:



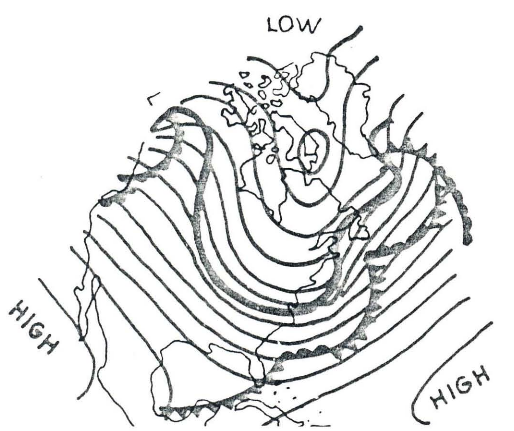


Scientists are finding that the advancing mass of cold air is not always wedge-shaped. At times the slope might be more nearly vertical as above.

Are you wondering why the cold fronts and cyclone families on the idealized map (left) have formed to the east of each upper level trough? The answer lies in smaller, faster-moving waves, also found aloft. These *short* *waves* ripple around the long-wave trough position, very much like small ocean waves ripple across a large ocean swell.

When a short wave moves toward the bottom of a long-wave trough, it slows down but intensifies. This is easy to understand if you have ever pinched a garden hose or stuck your thumb over part of the opening to increase the force of the flow. Short waves are similarly squeezed or constricted as they move through the bottom of a trough. Like a pinched flow of water, they intensify.

Migrating weather disturbances at the earth's surface,—for example, the cyclone families illustrated below—are always associated with a short wave aloft which has intensified.



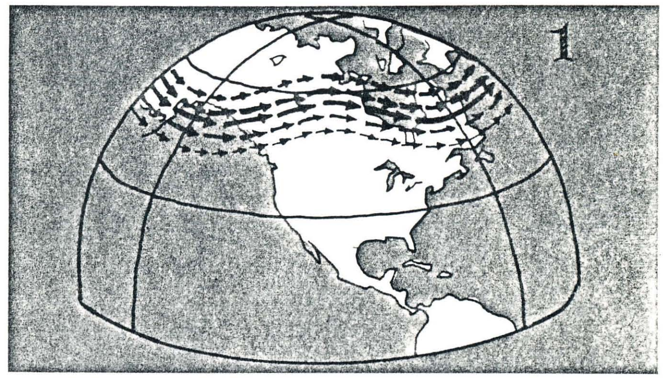
HOW LONG WAVES DEVELOP

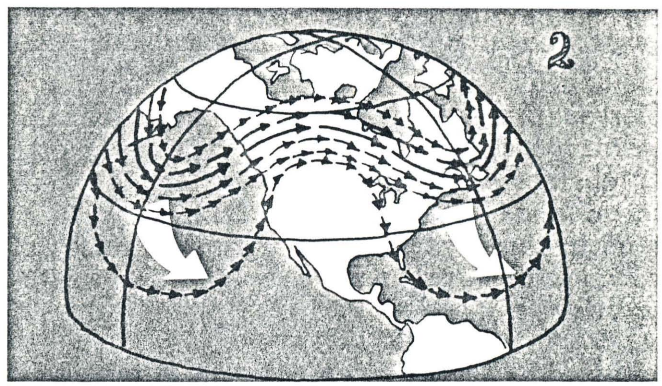
The upper westerlies go through a cycle of wave formation and each stage of development carries with it a special kind of weather. The entire *index cycle* takes from three to eight weeks to complete and occurs in summer as well as in winter. There are seasonal differences, however. In the winter the waves develop farther southward, storms are more vigorous, and the winds more intense.

Stage 1. The upper westerlies flow most directly west to east forming a barrier which prevents any great exchange of Polar or Tropical air. At the earth's surface, storms are not well developed, move rapidly, and produce very little weather.

Stage 2. The upper winds start to buckle, forming two to five or more long waves or troughs of low pressure. Some of the Polar air trapped in Stage 1 is now brought southward. At the same time, ridges of high pressure, Tropical air are pushed up between the troughs, bringing warm air northward.

At the surface, continental Polar air masses are building up (see Unit III) and begin to move south, where they interact with Tropical air. The map on page 9 is a good example of this second stage in which well developed storms and families of cyclones move across the middle latitudes, steered by the waves above. The jet stream is now in its most normal seasonal position.

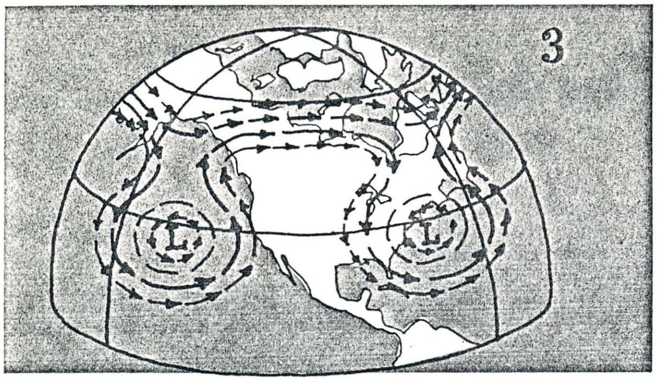


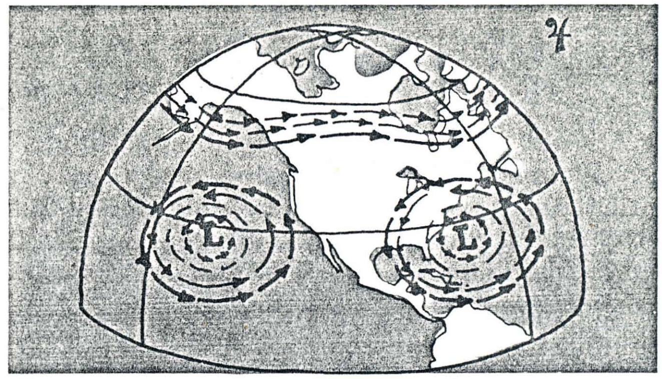


Stage 3. The waves deepen and extreme east-west temperature contrasts are found, especially in the winter.

Finally the waves become so deep that great masses of cold air with a jet stream are pinched off over southern latitudes. Masses of warm air are also cut off and isolated over northern latitudes. Topsy-turvy weather prevails, and Alaska might be warmer than Florida. Which of these cut-off cells do you think will dissipate first? The warm mass or the cold? Why? (Remember Unit I, Temperature?)

Stage 4. Gradually the upper winds return to the first or high-index stage. The cut-off Polar air warms up, at the same time cooling the warmer latitudes; the cut-off Tropical air cools, with a similar regulatory effect. In this way, Tropical regions are prevented from getting too hot; Polar regions are prevented from getting too cold, and the remarkable heat balance of our atmosphere is maintained.





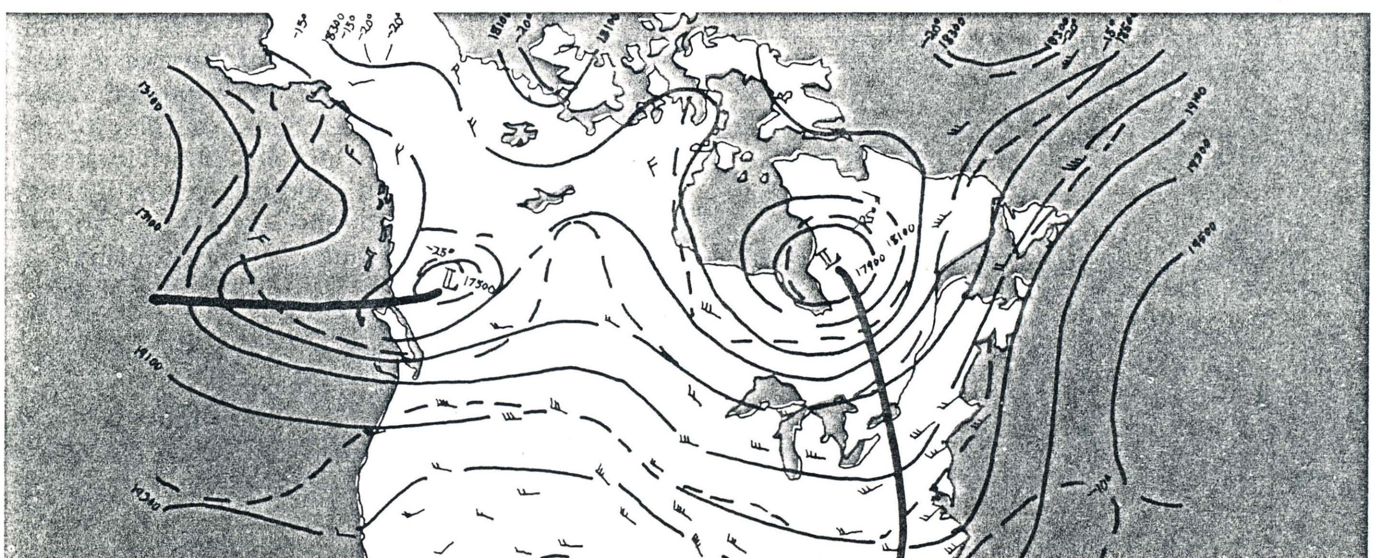
ANALYZING WEATHER

Reproduced below is an actual weather map, showing upper winds at the 500 mb level, in an average of about 19,000 feet. From the velocity of the winds and the latitude of the waves, can you figure out the season? In what stage of the index cycle does this appear to be? Outline the areas of maximum winds. How fast are they? The Low to the left will follow the band of swiftest winds. Will it move eastward? Southeastward? Where will it change direction? Where in Canada might you expect to find clear, bright weather? Where would you find a storm system?

Now would you like to know how accurate a forecaster you've become? This map of the upper air corresponds to the surface map for Monday, July 31, 1967, which is included in your leader's guide. Check the map and see how closely your expectations compare with the actual weather that day.

DISHPAN WEATHER

One of the clearest insights into how our atmosphere works has been obtained in laboratories with a rotating "dishpan" of water. By warming the outer edge of the pan and cooling an inner core, meteorologists have been able to reproduce every wave formation observed in the upper atmosphere, complete with troughs, ridges, jet streams, and even cyclones and anticyclones below. The procedure is basically simple, but suitable materials may be hard to find. If your club would like to try similar experiments, you'll find suggestions in your leader's guide.



Stable Vs. Unstable Air

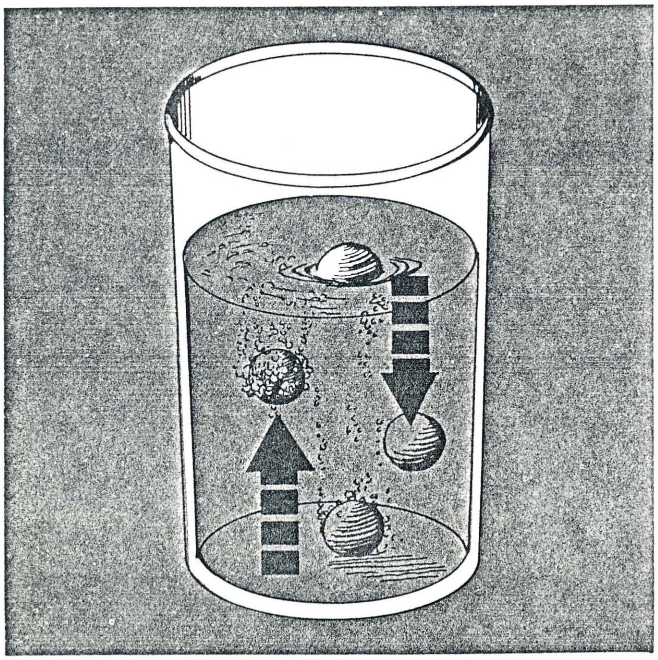
An old trick called "bobbing mothballs" gives us another good insight into how our atmosphere works. If you've never tried this experiment before, you'll have fun with it now. You'll need:

a drinking glass, about 2/3 full of water
four mothballs
baking soda
vinegar

Shake about one-half teaspoon of baking soda into the water and stir until dissolved. Drop the mothballs into the glass. Obviously each mothball sinks to the bottom.

Now add a little vinegar to the glass. The mothballs begin to rise. Some may remain suspended in the water for a while, but eventually, all will reach the top, fall back to the bottom of the glass, and in due time, bob up again.

Can you explain what happens? The vinegar and soda interact to form carbon dioxide. When bubbles of the gas attach themselves to a mothball, the mothball becomes a little bigger and lighter than before—in other words, less dense. To remain suspended in the water, the density of the bubble-enlarged mothball must equal the density of the water. Eventually, when the mothball acquires enough bubbles and is lighter than the water, the mothball will rise all the way to the top. Why doesn't it continue upward into the air? Can you also figure out why it sinks back to the bottom?



Parcels of air in the troposphere act very much like these mothballs, sometimes staying put, sometimes rising, sometimes sinking, depending on how the density of the parcel compares to the density of the surrounding air.

Stable air. Air is said to be stable if a displaced parcel of air will always return to its original position. In the experiment above, what would happen to the mothball if you tried to suspend it in water before adding the vinegar? It would sink right back to its original position, the bottom—just like stable air.

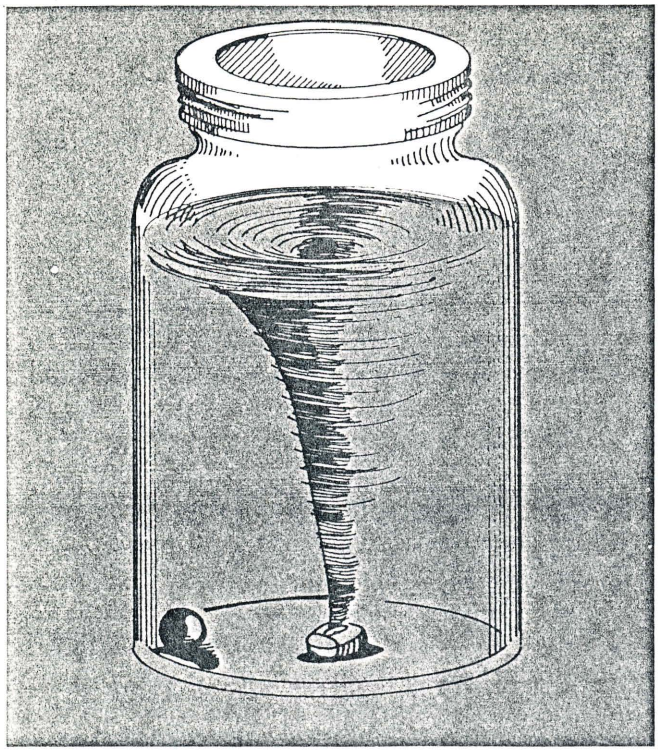
Neutrally stable air. Air is said to be neutrally stable if a displaced parcel of air is so similar to its environment that, like the suspended mothball, it remains where placed.

Unstable air. When a parcel of air is displaced and continues to move in the direction of its displacement, the atmosphere is said to be unstable. Unstable air, like the rising mothball, moves away from its original position.

AIR STABILITY AND WEATHER

Air stability has important weather consequences. In unstable conditions, warm air rises freely from the surface or is lifted and continues to rise. Cumulus-type clouds form and may develop into any number of severe weather conditions such as thunderstorms, squall lines or tornadoes. Stratus clouds, on the other hand, are a good indication of stable air. An air mass may be lifted—probably by frontal conditions—but does not continue upward. Under stable conditions, a layer of clouds may form; there may be drizzle, but no serious storm develops.

What makes one parcel of air denser than another? Temperature is important, but so is pressure. Cold air is denser than warm air, which means that cold air has more mass per unit volume. Since temperature declines with altitude in our troposphere, cold air generally overrides warm. Yet the air may not be unstable. The cold air at the higher altitude will have expanded because of the lower pressure and may, in fact, be less dense than the warm air at the surface. The atmosphere would be stable.



moister. Cover the jar, and grasping it with both hands, rotate it vigorously. The surprising results: a miniature tornado with a flicking tail, and even a trough at the top.

This experiment demonstrates the effects of *centrifugal force.* When a fluid (or air) is rotated, any mass with a heavier density will distribute itself as far away as possible from the center of *axis of rotation.* A tight vortex forms with the mass of lower density and pressure in the center. One question left unanswered by this experiment is: "What causes the vigorous rotation?" We'll come to that in the section on tornadoes.

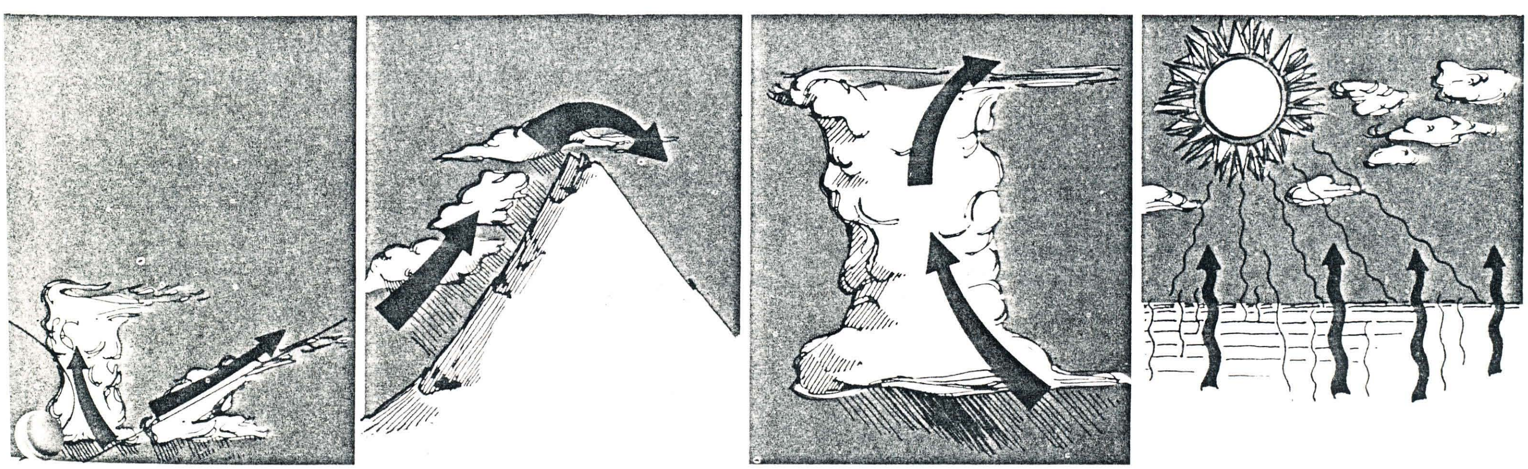
UNSTABLE AIR: STORMS — BEWARE!

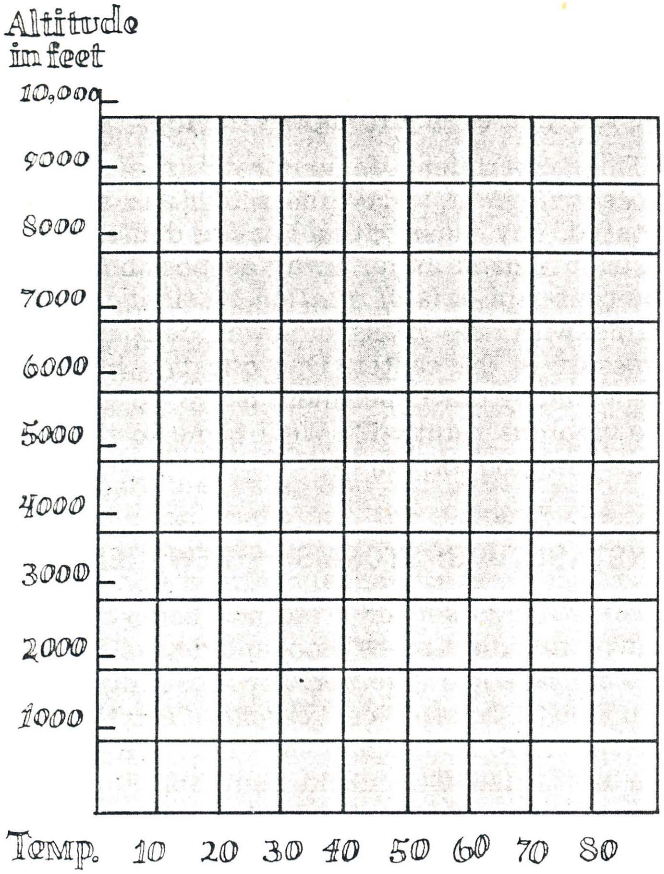
The stage is set for a storm whenever two contrasting air masses (cool and dry vs. warm and moist) come together. Their meeting place is called a *zone of convergence.* All that is needed is some mechanism which will cause the air to rise. This could be a frontal situation (explained in Unit III) whereby the air is lifted. Or some more localized condition might increase the contrast between the air masses, creating instability. Heating of the earth's surface is one of these localized conditions.

Let's assume a warm, humid day. The sun has been beating down on a plowed field. Finally, around 2 p.m. the air over the field has grown warmer than the surrounding air and is rising. If the rising air is 75° with a dewpoint of 64°, and the surrounding air at ground level is 70°, cooling at a steady lapse rate of 3½° for each 1000 feet, might a storm develop?

However, if there is an extreme temperature contrast between the cold air aloft and the warm surface air, the upper air may be so much denser that the top-heavy atmosphere overturns. Would you like to see for yourself why meteorologists are especially watchful when this situation develops?

You'll need a wide-mouth quart jar almost filled with water. Add a few drops of blue or green food coloring to show up the results better. Now drop in a marble. This will simulate a thick layer of dense air, cold and dry. Add with it a kernel of unpopped corn to represent a layer that is lighter, warmer and





On the temperature-altitude chart above, plot a *temperature profile*, using a solid line or a colored pencil. (Since the lapse rate is steady, your profile should be a straight line, starting with 70° at ground level, 66.5° at 1000 feet, 63° at 2000 feet, etc.)

Next, with a dotted line or second color, plot the changing temperature of the rising air. We know that as unsaturated air rises, it expands and cools adiabatically at a rate of 5½° per 1000 feet (see Unit II). In the same distance its dewpoint temperature decreases about 1°. This is because the expanded air holds less water vapor per cubic foot. In each 1000 feet, therefore, the rising air comes 4.5° closer to its surface dewpoint. Use this formula to find the condensation level of the rising air, or, in other words, the point at which a cloud will first appear:

$$\text{Condensation Level} = \frac{\textit{Surface Temperature} - \textit{Surface Dewpoint}}{4.5} \times 1000$$

Plot the resulting figure on your chart in a line with 64°.

When water vapor condenses, heat is given off. As air rises above the condensation level, it cools more slowly, at the moist adiabatic rate, about 3½° per 1000 feet. Plot the two temperature profiles to the limits of this chart, or if you'd like, continue to an altitude, say 20,000 feet, where the atmosphere's temperature no longer decreases. This would represent the tropopause and your first line would go straight up from that point. The cloud will grow as long as the second line, depicting the rising air, remains on the warm side of the first line.

If these temperatures did in fact exist, we can see from the chart that a cumulus cloud with its base at about 2000 feet could develop into a towering cumulonimbus extending the entire depth of the troposphere, halted finally by the constant temperature of the tropopause.

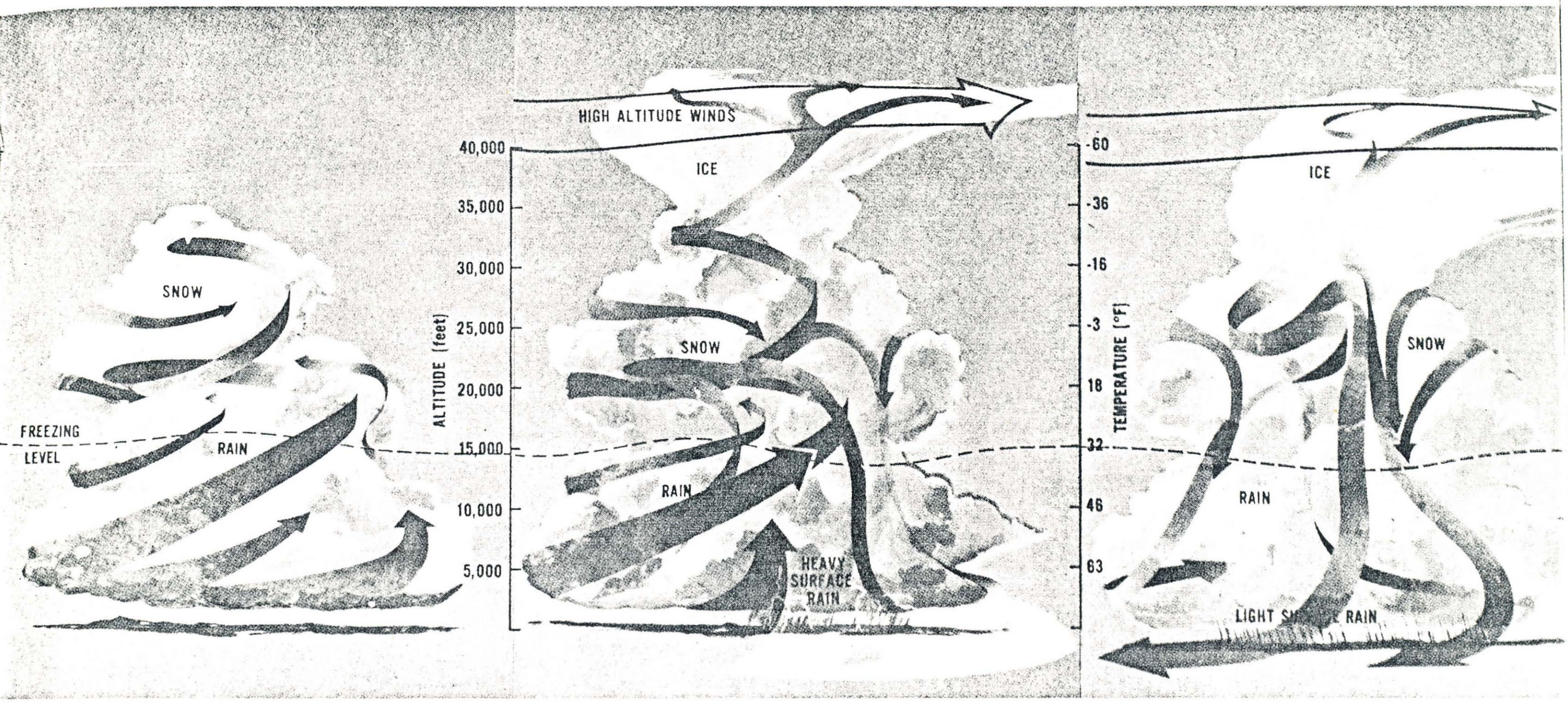
Suppose any of the following sets of temperature had been recorded in the atmosphere above our plowed field instead of the lapse rate given. Plot each of these sets as a separate temperature profile. Then, assuming the same parcel of 75° air with a dewpoint of 64°, can you figure out in each case (1) whether a cloud would develop and (2) how far?

A		B		C	
Alt.	Temp.	Alt.	Temp.	Alt.	Temp.
surface	70°	surface	70°	surface	70°
2000 ft.	68	2000 ft.	60	2000 ft.	55
4000	64	4000	54	4000	76
6000	60	6000	45	6000	50
8000	52	8000	38	8000	40
10000	44	10000	50	10000	28

TEMPERATURE INVERSIONS

Sometimes, as in the last chart above, we find a reversal of the normal lapse rate—that is, an actual warming of the air as we go aloft. This is called a *temperature inversion.* (See Units 2 and 3.) A temperature inversion acts like a lid, trapping smoke, dust and other pollutants in the air below. The atmosphere may become very hazy. When the concentration of pollutants is sufficiently large, a serious health hazard can result (see "Smog", Unit V).

Thunderstorms



Thunderstorms develop from cumulonimbus clouds which have grown in height beyond the freezing levels of the atmosphere. Some cumulonimbus, particularly during the summer, may reach heights of 50,000 feet, or approximately 10 miles. The prevailing upper altitude winds shear off the top of the higher clouds giving the thunderhead a characteristic anvil shape.

Inside the cumulonimbus are cells of rapidly moving air: some moving up, producing powerful updrafts; and some moving down, creating equally strong downdrafts. It is this turbulent churning air within the cells which is extremely dangerous to aircraft, should a pilot try to fly through such a storm. Velocities of the up and down drafts have been estimated to exceed 200 miles an hour.

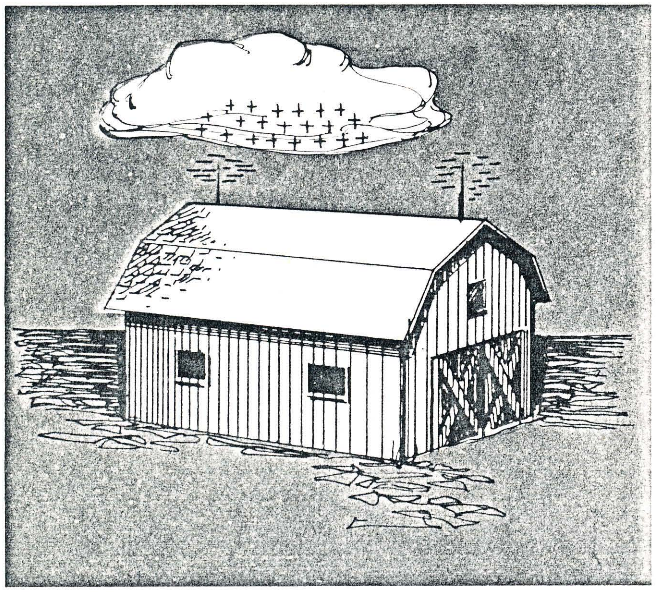
All the time these cells are developing, enormous stores of latent energy (heat from the condensation of water vapor) are building up within the cloud. What triggers the release of all this energy in the form of thunder, lightning, rain and possibly hail is still a bit of a mystery. Many scientists believe it is the formation of ice crystals in the freezing levels of the atmosphere. Water droplets, collecting around these crystals, grow heavy and fall. When this happens, the cloud begins to break down.

LIGHTNING

Lightning is a huge electrical spark between a positively charged and a negatively charged area. It is known that upper portions of a thundercloud are positively charged, middle sections around the freezing level generally are negative and bottom portions may carry either charge. Why this is so is also uncertain, but most scientists believe the powerful up and down air currents are responsible.

Raindrops caught in an updraft are carried above the freezing levels. Then, as snow or ice, they are brought down in a downdraft, collecting more water on this journey. In the process of moving up and down, the drops might be split apart many times by the strong drafts. It is believed that this splitting separates positive and negative charges within the drops and is responsible for the concentration of charges observed in various parts of the cloud.

Lightning can take place within the cloud, between two clouds, or between the cloud and the earth. As a charged portion of a cloud (for example, positive) passes over the earth, it will attract the opposite (negative) charge below. The attracted charge will tend to collect in any isolated projection above the earth's surface—a tree, the spire of a tall building, or any building standing alone. When enough of the charge has built up, lightning strikes.

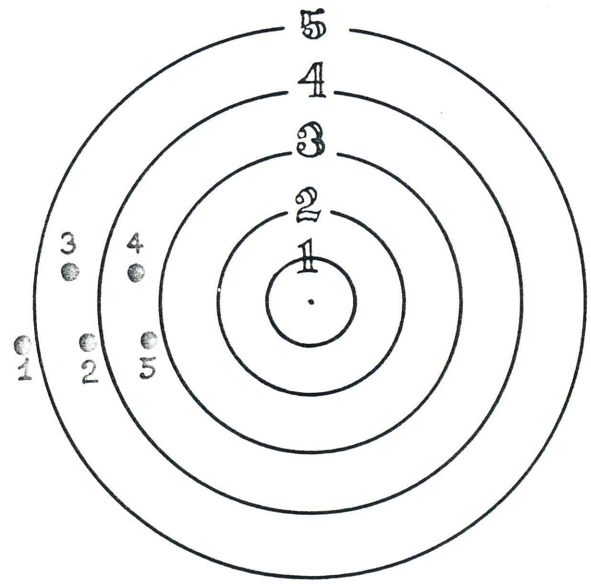


THUNDER

The tremendous heat of a lightning flash expands the air, producing a sound wave which we hear as thunder. Since light travels faster than sound, we always see the flash before we hear the thunder.

Here's an interesting project by which you can plot the path of a thunderstorm. The method is essentially the same as tracking storms by radar. On a piece of paper, draw a number of concentric circles, each an inch larger in radius than the preceding one. Mark the innermost circle 1 mile, the next 2 miles, etc. Also draw on your paper an arrow pointing north.

During a thunderstorm, place your paper so that the arrow does in fact point north. Every time you see a flash of lightning, count the seconds until you hear the thunder. While lightning is seen almost instantaneously, traveling 186,000 miles per second, the sound of thunder covers only 1,100 feet in the same time. Therefore, every five seconds which elapse indicate the storm is one mile away. Number each flash as it occurs and locate it by direction and distance on your chart. You can see whether the storm is moving toward you or away from you. Thunder generally cannot be heard more than 10 to 15 miles away, depending upon atmospheric conditions. You sometimes can see lightning 100 miles away.



PROTECTING YOURSELF IN A THUNDERSTORM

Now that you understand the dangers of a thunderstorm, what can you do to protect yourself and your family? Your friends?

1. Learn what you can about the conduction of electricity. How do lightning rods work? Should your home or farm buildings be protected with them?

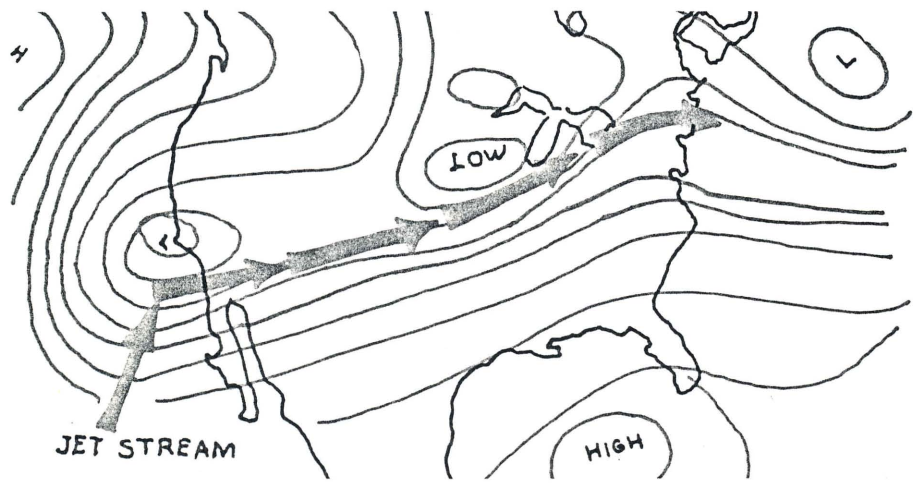
2. Ask your fire chief, county agent or others in the community for information on the best way to protect yourself from lightning. Is it safer indoors or out?

3. If you're in the woods, should you stay in the woods or search for a clearing? Is it safe to swim in a thunderstorm? On the basis of what you learn, make up a list of safety rules for your family and friends.

4. If someone near you were knocked unconscious by a bolt of lightning and you were the only person around, would you know what to do? Proper action could save his life. Learn from your local Red Cross chapter how to treat shock and burns and how to restore breathing.

Tornadoes

Surface Map
April 11, 1965



High Altitude Map

On April 11, 1965—Palm Sunday—meteorologists at the Weather Bureau's severe local storm forecasting center (SELS) in Kansas City grew increasingly alarmed as they plotted weather reports coming in from the south and west.

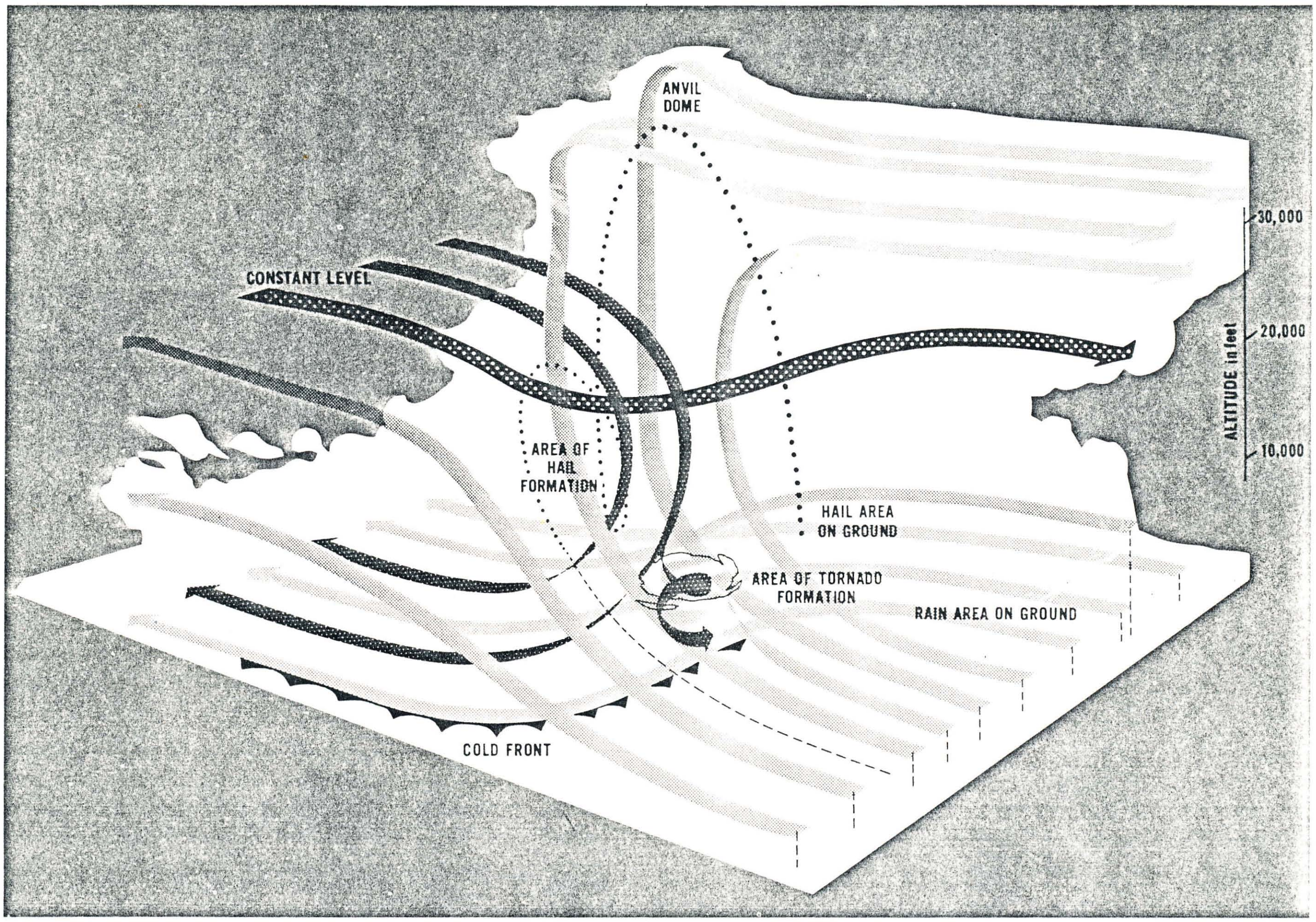
Streaming northeastward from the Gulf of Mexico was a mass of warm, moisture-laden air, ahead of a fast-moving, low-pressure area.

Moving in equally fast from the West was a mass of relatively dry and cooler air. Thunderstorms were beginning to form along the boundary of the two contrasting air masses (Surface map above.)

So far, the convergence of two air masses such as these was no unusual circumstance. It happens every spring. But then the meteorologists looked at the upper air map and knew that the Midwest was in for trouble. A much stronger than normal jet stream dominated the central United States and flowed over the area where thunderstorms were beginning to form. The winds aloft were reaching maximum speeds of 140 mph and more. Over Dodge City, Kansas, the winds were recorded at 185 miles an hour. (See high altitude map.)

Three meteorological conditions are necessary for tornado formation: a layer of warm, moist air; a layer of cool, dry air, and a strong jet stream aloft. On Palm Sunday, 1965, all three conditions were converging over the upper Mississippi and moving northeast.

At 12:45 p.m. the first two tornadoes struck, east of Cedar Rapids, Iowa. By 2 p.m. the storm center had taken a more easterly path, was still intensifying and moving forward at a fast pace, 50 miles an hour. Southern Illinois and central Indiana were now threatened. To make matters worse, upper air soundings showed that the jet stream was branching out, with strong currents headed upward over south-central Wisconsin and south-western



Michigan. At 3:15, weathermen at Chicago tracking one branch of the storm by radar, watched a whole colony of funnel-shaped clouds dancing over the earth within a 100-mile long line of thunderstorms, from DeKalb, Illinois to Madison, Wisconsin.

By the end of the day, the United States had experienced its worst tornado disaster in 40 years. At least 37 separate tornadoes touched down over a six-state area, including Iowa, Illinois, Wisconsin, Michigan, Indiana and Ohio. Southwestern Michigan around Coldwater was especially hard-hit. The destruction was incredible. Where seconds before a home might have stood, all that remained was rubble.

That day, 271 people died from the tornadoes. The death toll undoubtedly would have been higher had it not been for the SELS center which accurately plotted areas of convergence and issued warnings in advance. As it turned out, 33 of the 37 tornadoes were within tornado forecast areas.

WHAT IS A TORNADO?

A tornado is the most vicious storm known. Dipping down from heavy cumulonimbus, the funnel-shaped cloud hops and skips erratically across the countryside leaving behind a path of death and destruction. The usually counterclockwise winds whip around the funnel's small opening, so fast they cannot be measured. However, they are strong enough to toss houses around like toys or drive straw through trees. Their velocities have been estimated to exceed 500 miles an hour. Pressure inside a tornado is very low, almost a vacuum. A closed-up house will literally explode if a tornado passes overhead. Can you explain why?

Tornadoes are usually small, local storms. Their diameters might range from a few feet to about a mile. They normally travel at speeds of 20 to 25 miles per hour for distances of 10 to 15 miles, but a few exceptional tornadoes have covered as much as 300 miles and as fast as 50 miles per hour before dying out. When conditions are favorable, tornadoes are most likely to develop in the "warm sector" just ahead of a cold front (A on the surface weather map, page 15) or just ahead of the point of occlusion (B). The dotted area, enclosing the B position above is in fact where most of the Palm Sunday tornadoes struck.

Although tornadoes may occur anywhere in the world, they are overwhelmingly an American phenomena. Four Plains states—Texas, Oklahoma, Kansas, and Iowa—are struck so often by these vicious storms that they have been called "tornado alley". While tornadoes may develop at any time of the year, spring and summer are the favored seasons. Watch your newspaper and keep a record of where and when tornadoes are reported. In a typical year, they begin to develop over the central Gulf states around February, then, month by month, move progressively North and East. Can you explain why? When are tornadoes most apt to strike Michigan?

TORNADO IN THE LAB

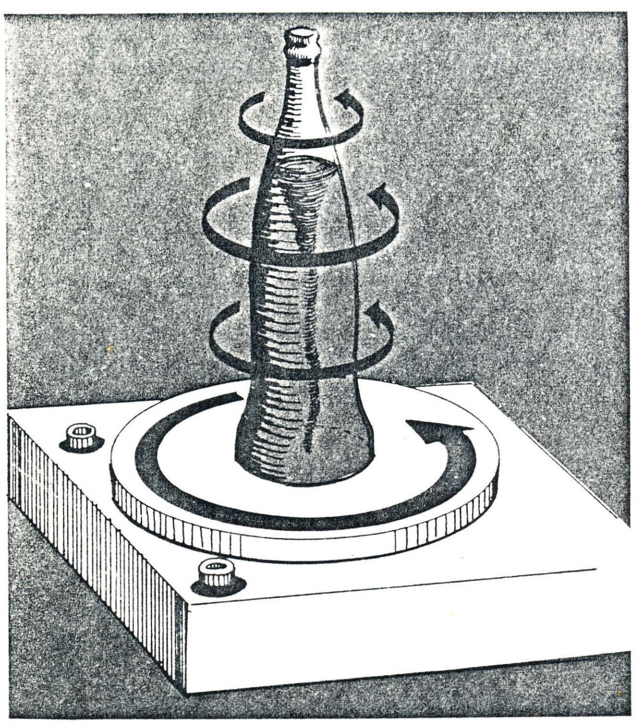
Here is another laboratory experiment by which meteorologists are studying tornadoes. You'll need:

an old record player without a spindle

an untinted bottle of soda water with the label removed

a few grains of sugar

Pour out an inch or so of the soda water. Place the bottle exactly on the center of the turntable and rotate at 78 rpm until the soda water is revolving at the same speed as the turntable. Now drop in a few grains of sugar. These grains (or any solid particles) represent the inflow of a denser mass, i.e. cold air. The results are quite dramatic.



PROTECTING YOURSELF IN A TORNADO

1. Does everyone in your family know the difference between a *tornado watch* and a *tornado warning*? Do they know what to do when either alert is sounded?
2. Look over your home with your family and find the place that would offer the greatest protection. If you don't have a storm cellar, the southwest corner of the basement might be best. Why? How might a sturdy table improve your protection? You can obtain more information on tornadoes and tornado protection from your 4-H leader, civil defense director, county extension agent, nearest weather bureau or state police post.
3. Don't trust instinct. Practice tornado drills with your family and make sure you will all *automatically* do the right thing. For example, in a tornado alert, you might instinctively close the windows to keep the furniture dry if you saw storm clouds approaching from the southwest. If a tornado did pass overhead, the house would surely explode. Opening the windows a little on the north and east sides would help equalize the pressure and might reduce damage to the house. Practice opening the proper windows and taking shelter in the safest place.
4. Many persons are cut or otherwise injured by flying debris in a tornado. A broader knowledge of first aid is good protection. Learn how to stop bleeding, or care for cuts, broken bones and other injuries. Learn how to transport the injured. Then practice your new skills with your friends.

TORNADO WATCH means

1. Conditions are favorable for a tornado, but don't panic.
2. Go about your normal business.
3. Keep tuned to local radio or TV for up-to-date information.
4. Be aware of tornado safety rules and have a shelter area or evasive action in mind.

TORNADO WARNING means

1. Tornadoes have been sighted.
2. Take cover fast. (It helps to have a portable radio with you so that you know when the all-clear has been sounded.)

Hurricanes

In September of 1965, just as the tornado-stricken Mid-western states were returning to normal, one of the worst tropical storms of all times blew in from the Caribbean Sea. It was a hurricane named 'Betsy'. Florida, sitting right in Betsy's path was forewarned and could prepare somewhat for the onslaught of 140 mph winds and massive tides. Still, Betsy claimed lives, ruined crops, flooded buildings, uprooted trees and ripped down power lines.

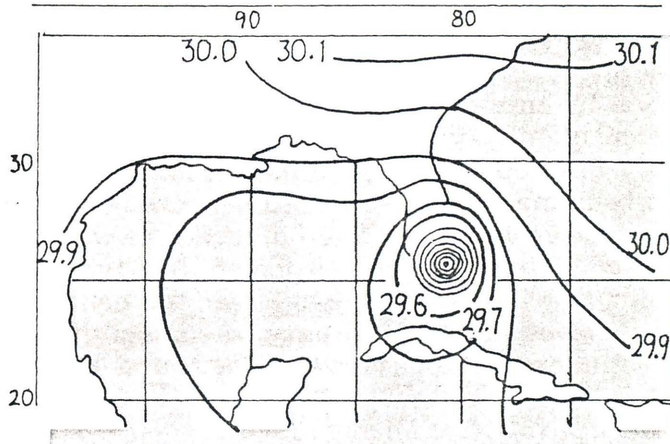
Then Betsy veered northwestward into the Gulf of Mexico. Louisiana and Mississippi felt her terrible fury next. The 90-mile-wide center or "eye" of the hurricane passed right over New Orleans, nearly half of which is below sea level. The dikes burst and a wall of water, 8 to 14 feet high, poured over the city. Property damage in Florida and the Gulf States climbed to 1.5 billion dollars from this one storm alone.

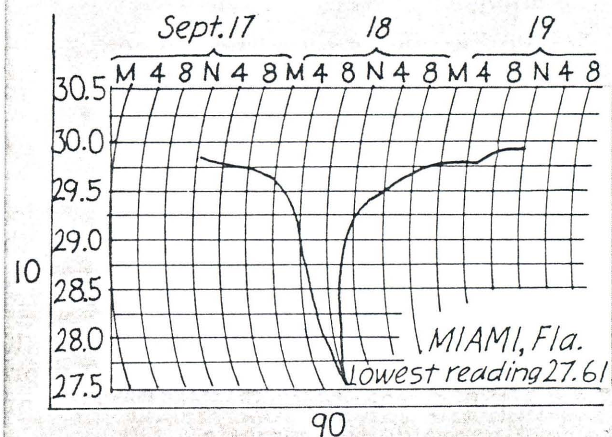
Every year one or more hurricanes batter coastal regions of the United States, from Texas to Florida and north to New England. Damages always add up to millions or billions of dollars. While there is no way known of diverting a hurricane from its path, many lives are being saved by early detection and plotting, forewarning and evacuation.

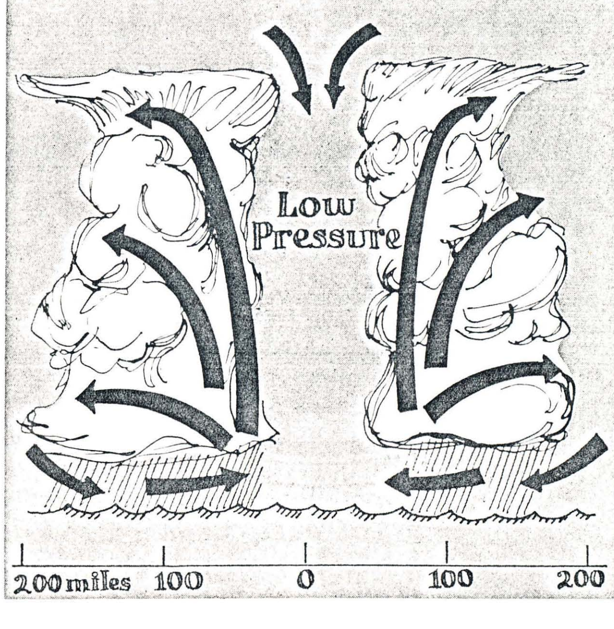
Here's a project you might want to undertake during the "hurricane season" this summer and fall, especially during August, September and October. Draw a map of the United States showing the Caribbean waters, Gulf of Mexico and Atlantic Ocean. Most of the hurricanes which affect us come from one of these three areas. Keep track of any hurricanes which develop. What land areas are involved? How extensive is the damage? Was evacuation necessary?

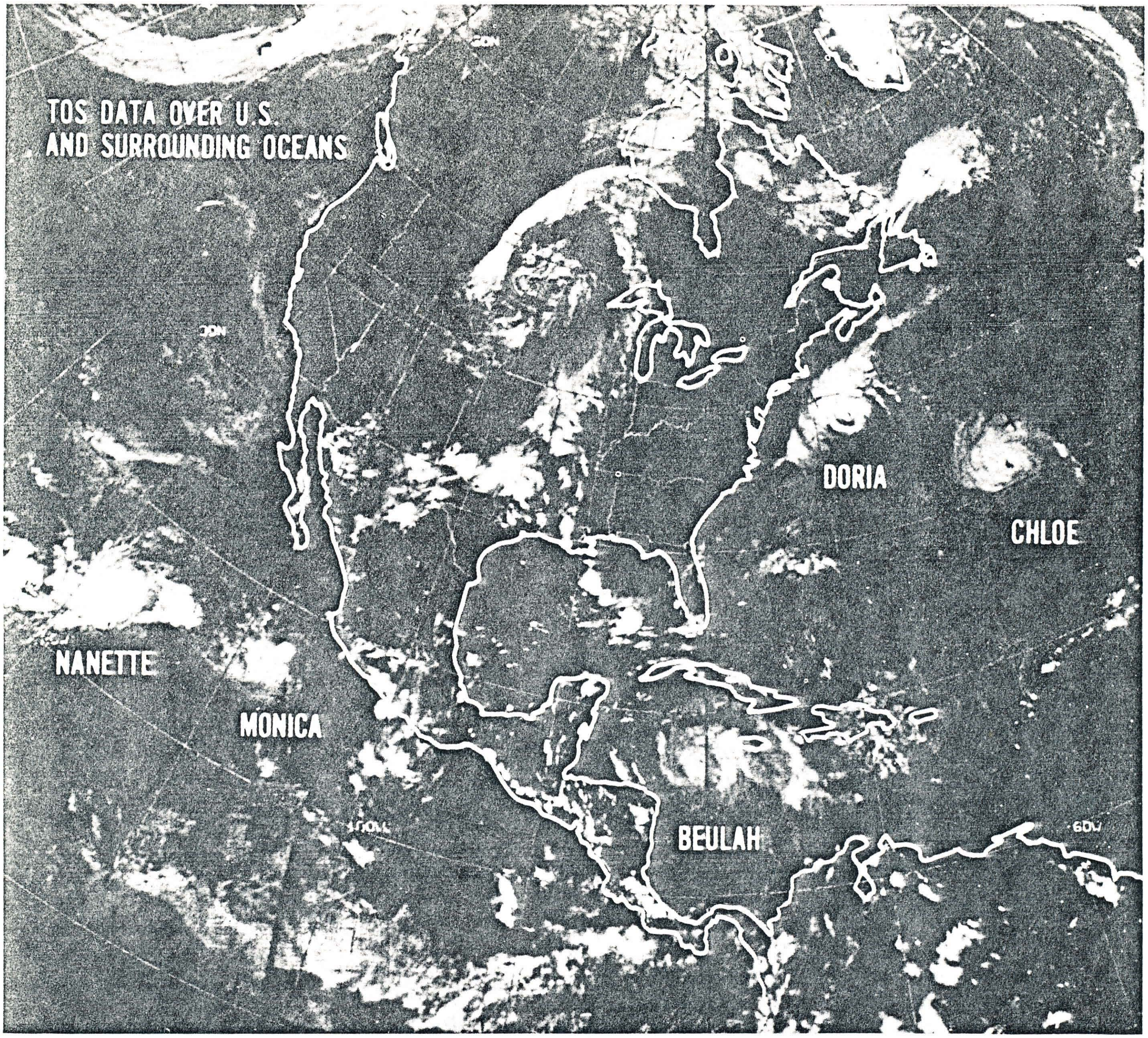
WHAT IS A HURRICANE?

A hurricane (or *typhoon*, as it is known in the western Pacific) is an intense storm which forms over tropical waters. It is characterized by high winds (75 miles an hour or more) rotating around a calm, central region called the *eye*. Many people are fooled when the eye passes over them. The winds die down, the sun comes out, and the storm may appear to be over. Then suddenly the winds pick up sharply from the opposite direction with the same smashing force as before. These winds are accompanied by torrential rains, high tides









and waves. Sometimes a wall of water builds up ahead of the hurricane and is sent cascading over the land.

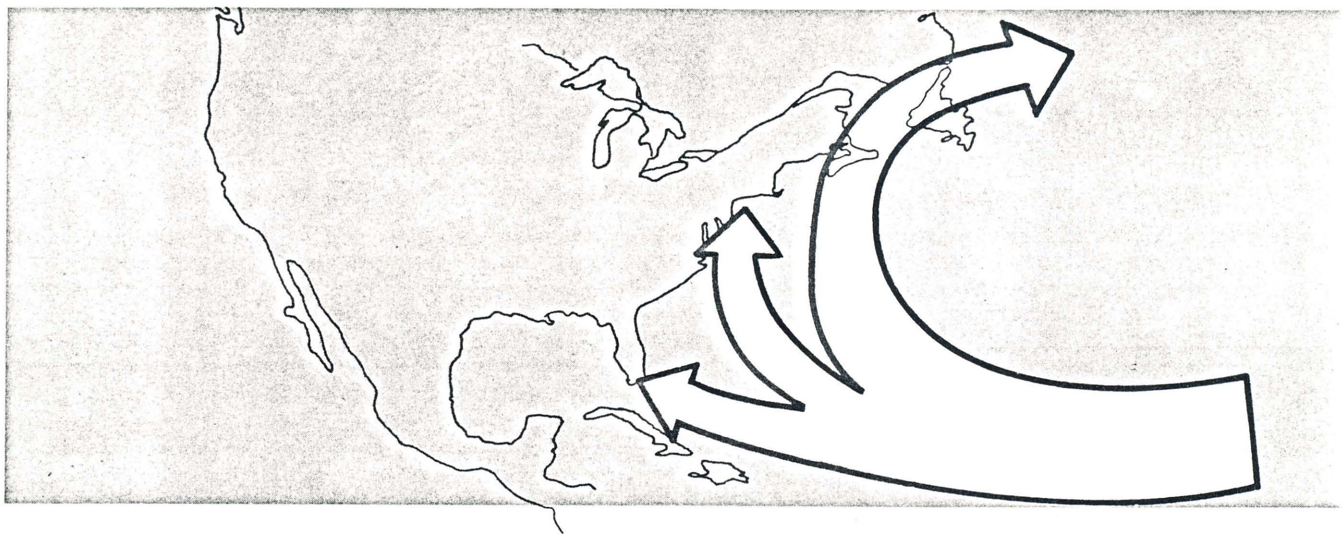
The path of the hurricane is usually slow and westerly at first. Then the hurricane picks up speed and intensifies before typically veering north or northeast and dying out.

The energy within a hurricane is enormous. The Weather Bureau has figured out that just one hour of hurricane energy would equal all of the electric power generated in our country during an entire year. The source of all this energy is latent heat, released when water vapor condenses. Moisture, then, is the fuel which propels a hurricane. All the time a hurricane brews over an ocean, it is sucking up energy. When moving over land, however, the hurricane loses its source of energy and rapidly begins to weaken.

PROBLEMS OF UNDERSTANDING A HURRICANE

If a hurricane is the most destructive of all storms, it is also the least understood. Until recently, observation of a hurricane has not been easy. Before World War II the only information of weather conditions over ocean areas had to come from ships at sea or observation stations on small islands. Many large ocean areas were never observed on a regular basis.

In 1943 the first airplane flight was made into a hurricane to record meteorological data. Imagine what an accomplishment that must



have been. Since then airplanes have been developed which are strong enough to penetrate to the eye of the hurricane. Flights to measure the wind, humidity, and temperature of a hurricane are now routine. When radar was adapted for weather use, meteorologists realized for the first time that the hurricane's winds whirled in a spiral formation.

Finally, in 1960, the first weather satellite, Tiros I, revealed unmistakably that the hurricane is a vigorous cyclone with winds spiraling counterclockwise in the Northern Hemisphere and clockwise in the Southern. Only since the advent of the weather satellite has weather data been available regularly from many tropical oceanic areas. Now an attempt is being made to obtain weather information at regular and frequent intervals from all formerly inaccessible areas. With this data now available, many questions about the hurricane and other tropical storms can be answered.

WHAT IS KNOWN ABOUT HURRICANES

Scientists know that hurricanes develop where the ocean is especially warm. The ocean heats the lower layer of air, the warm air rises and clouds form. The latitude where this is happening must be far enough away from the equator so that the Coriolis influence can take effect. Hurricanes rarely start within five degrees of the equator.

Now two special wind conditions must coincide. At the lower levels, the trade winds must flow into the area, forcing a gentle uplifting of air at the surface. Aloft, a trough must also be present. This combination will often continue to increase in intensity, moving eastward in its early stages as an area of thunderstorms, squalls or rain showers. It is not known why some tropical storms develop beyond this stage and become hurricanes while others die out. It is known that the trough aloft seems to steer the hurricane's movement.

CAN HURRICANES BE MODIFIED?

Hurricanes have some good aspects. They help preserve nature's heat and moisture balance by bringing both northward. Meteorologists would like to be able to weaken the hurricane's destructive capabilities while maintaining its beneficial effects. This is the goal of Project Stormfury, a joint undertaking of the Weather Bureau's ESSA (Environmental Science Services Administration) and the U.S. Navy. Watch your newspaper and science magazines for reports on how this current attempt to modify our weather is progressing.

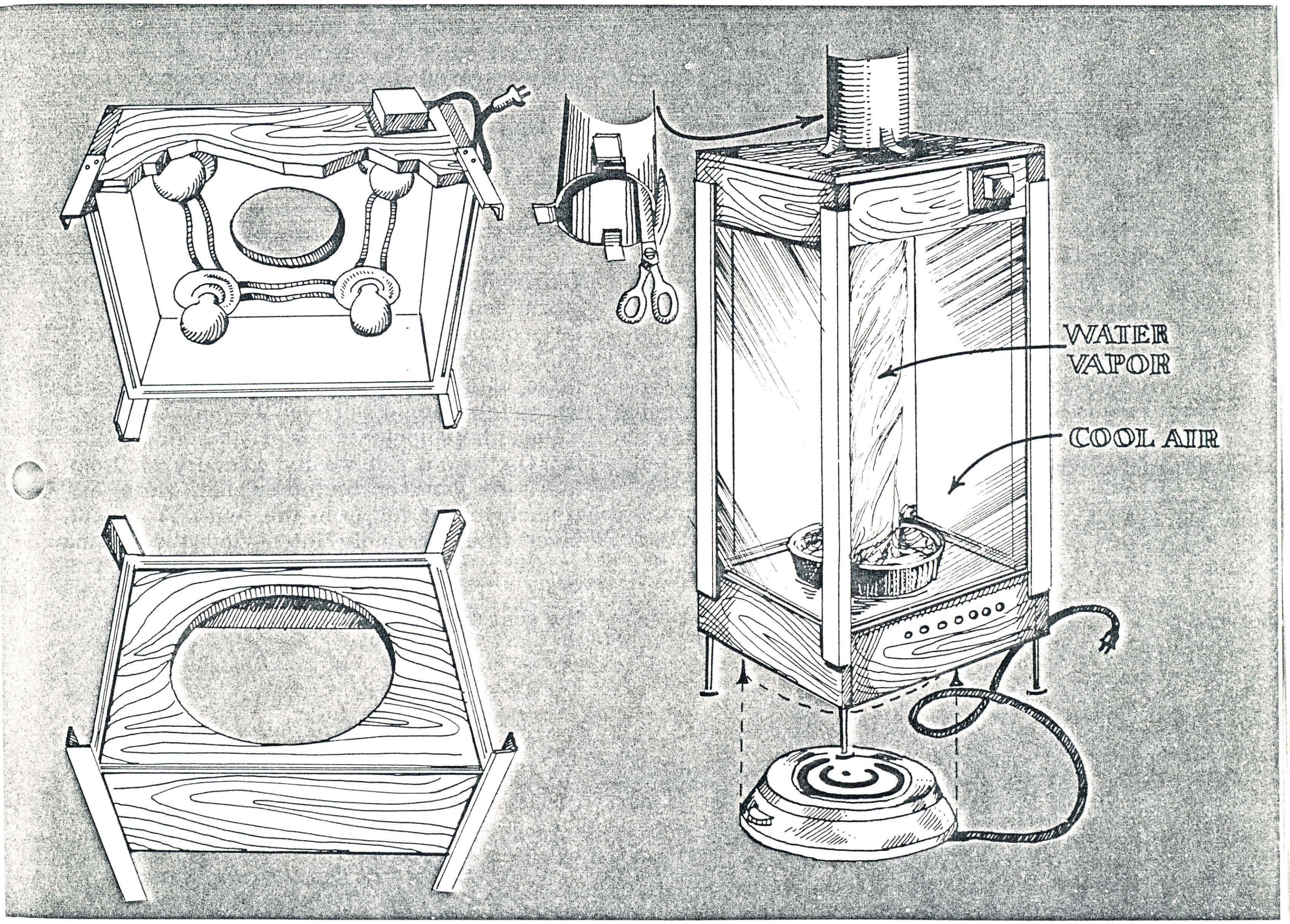
BUILD A MODEL HURRICANE

YOU'LL NEED

1 pc stovepipe, 6 in. diameter X 36 in.
4 light sockets (porcelain)
4 electric lamps — 25 watt
1 electric junction box and cover
8 pcs aluminum or plastic channel (for glass guides) 15-in. long
1 pie tin, 12 inch

4 pcs angle iron (or aluminum), 1 in. X 24 in.
4 pcs 3/4-inch plywood, 16 in. X 4-1/2 in.
4 pcs 3/4-inch plywood, 14-1/2 in. X 4-1/2 in.
2 pcs 3/8-inch plywood, 16 in. square
3 pcs glass - double weight, 14 inches X 20 in.
1 pc masonite, 14 in. X 20 in.
1 electric hot plate

4 doz finishing nails, number 4
16 finishing nails, number 6
24 wood screws, flat head, number 6 X 3/4 in.
4 lag screws, 1/4-in. X 4 in.
12 ft. lamp cord with plug
fasteners for channel—type and number depends on type of channel material selected.



The upper box is made of four 3.4-inch plywood sides and the 3/8-inch plywood for the top. Fasten together with finishing nails. Cut 6-inch diameter hole in top for stovepipe. Assemble lamp sockets as shown. Drill 1-inch hole in side and fasten junction box over hole. Fasten channel to edges of 3/4-inch plywood to serve as upper guides for glass and masonite.

The lower box is made similar to the upper one. Cut a 12-inch diameter hole for the pie tin. Fasten channels to top of box (on the 3/8-inch plywood) for glass and masonite guides. Cut off or bend flat outside lip of one guide to permit removal of masonite panel.

The Completed Generator is assembled using four 2-foot sections of 1-inch angle iron. Attach the angle irons to the bottom box, insert the glass and Masonite side pieces, and attach the upper box. The glass and Masonite should measure 14 inches by 20 inches. You can attach two drawer pulls to the piece of Masonite to make it easier to handle.

The Hurricane Generator. A real hurricane begins when the sun heats the ocean, producing a rising cloud of warm, moist air. In the hurricane generator, a cloud of water vapor is formed by heating water in a pan. Cool air enters at the sides of the generator, forcing the cloud to twist upward like a real hurricane.

The Direction of Spin is controlled by sliding the glass panels to the left or right. A Northern Hemisphere hurricane, above, twists counter-clockwise. A Southern Hemisphere hurricane, below, twists upward in a clockwise way.

To Start the Generator, take the Masonite wall off the apparatus and place a pie pan in the lower box. Fill the pan with water and put the Masonite wall back on. Slide the glass and Masonite walls to the left. Put the hot plate beneath the generator and turn it on. Note the twisting action of the cloud of water vapor. Then move the walls to the right to reverse the direction of the twisting.

Winter Storms

Who in Chicago, Illinois, or Lansing, Michigan, will forget the great snowstorm of 1967? The snowstorm, on January 26 and 27, was the deepest and most intense either city has ever experienced. At least 24 inches of snow fell, but the situation was made much worse with drifts of up to ten feet and more.

By the afternoon of the 26th, so much snow had fallen in Chicago that the metropolitan area was virtually paralyzed. Commuters trying to get home shivered in 60 mph winds and 20 degree temperatures waiting for buses that never arrived. The trains were also inoperable, their switches snowpacked and frozen.

Motorists fared no better. Cars quickly stalled and would not budge against the falling, drifting snow. Soon thousands and thousands of immovable cars, lined up bumper to bumper, were abandoned by their drivers who then set out on foot to find shelter.

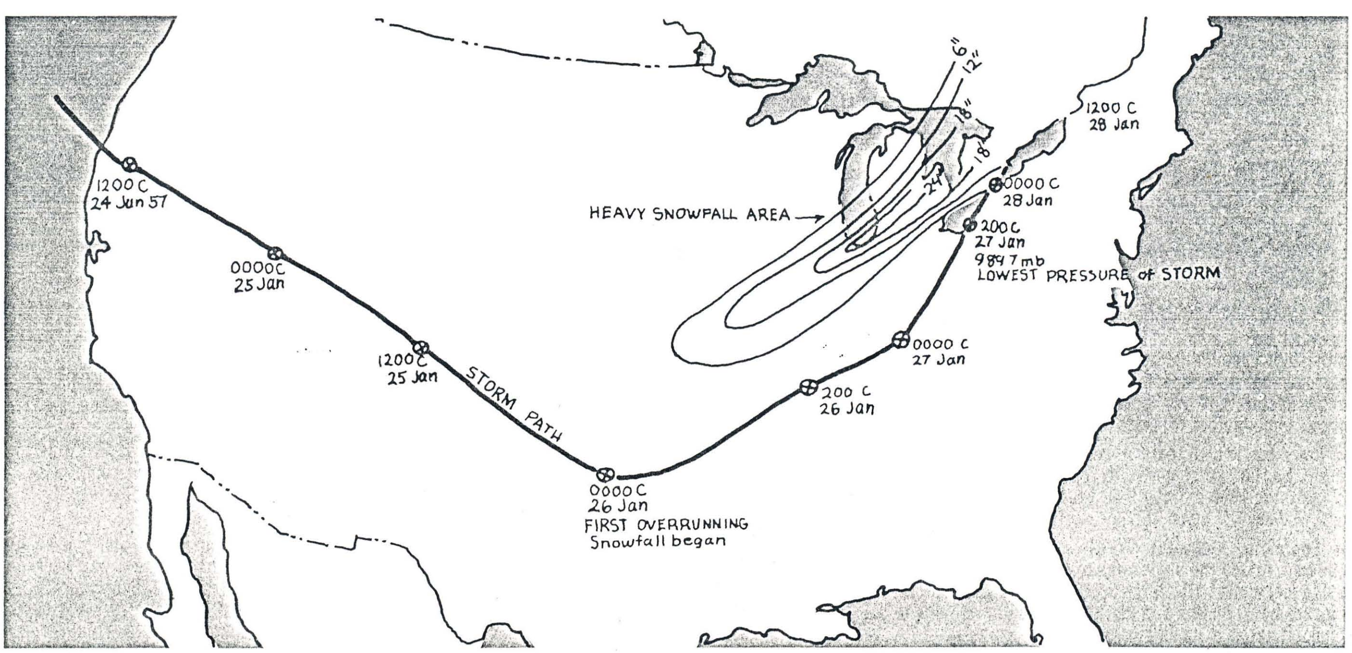
The next day, with the snow still falling, all means of transportation had come to a standstill. This, in a city the size of Chicago, was a catastrophe. Families ran short of food and could not get to a store. Those needing emergency medical care could not get to a hospital. Snow removal equipment could not keep ahead of the falling snow, then found their paths blocked by abandoned cars.

In Lansing, a similar situation existed, but on a smaller scale. For days the city was isolated. Schools remained closed for over a week. Even the mail could not get through.

WHAT HAPPENED

Although the length of the storm was a surprise, the basic meteorological conditions were quite typical of intense middle latitude storms of any season. In this case, a storm system had developed over the Pacific Ocean, but, moving inland, had lost most of its identity in crossing the Rockies and reached the Plains states as a weak, unorganized storm. This weak storm center moved over the southerly route. (See Storm Tracks, Unit 3.) Early on the 25th, it had moved into the Texas and Oklahoma panhandle area. At this point, the storm center began pulling into its circulation large quantities of moisture-laden air from the Gulf of Mexico. Meanwhile, to the north, a mass of continental Polar air from Canada was establishing itself over the midwest.

Does the combination start to sound familiar? On the one side we find cold, dry air from the north, and on the other side, warm, extremely moist air from the south. An upper level trough rapidly intensified the storm, steering it northeastward across the United States. This placed Chicago and Lansing at the center of the belt of heaviest snow. To the



south of the heavy snow band, a severe ice storm brought down power lines and blacked out cities for hours in southern Illinois.

BLIZZARDS

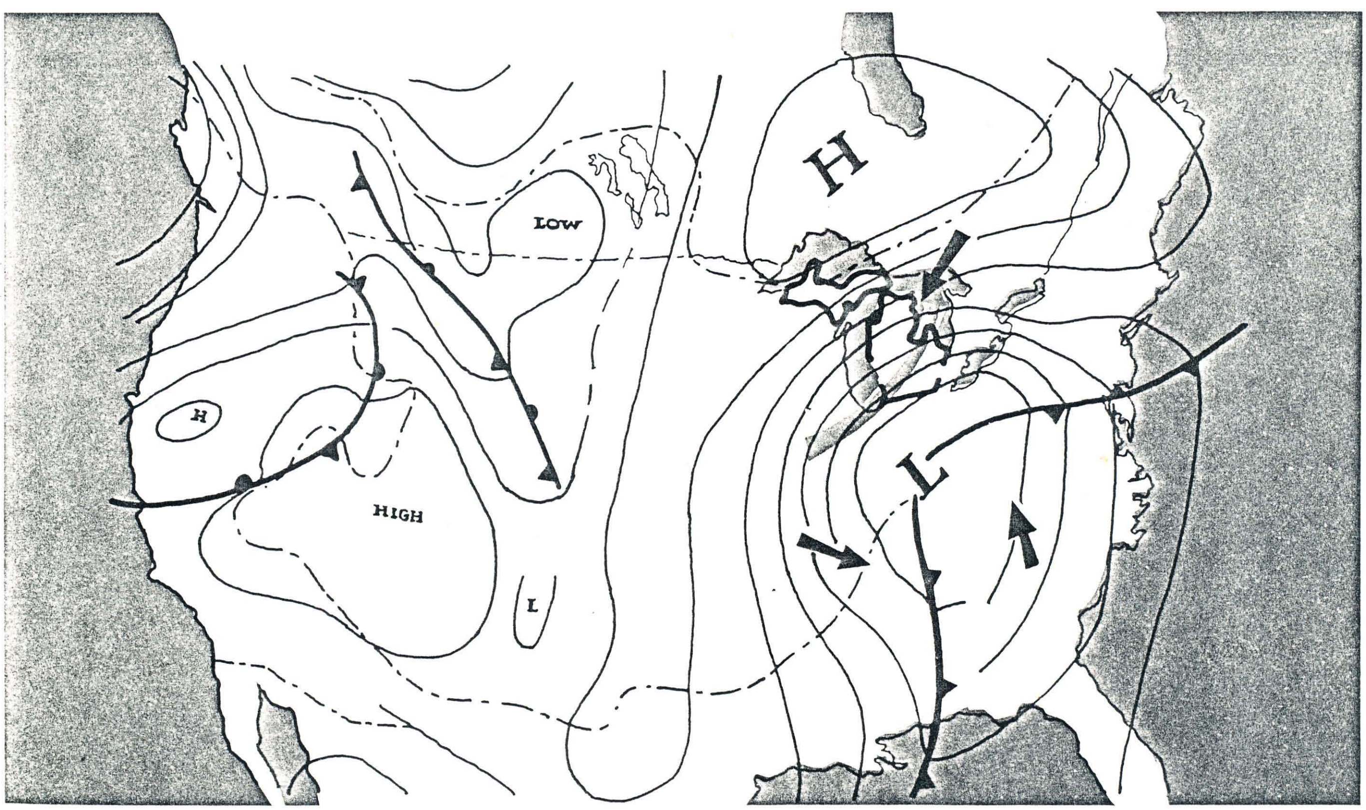
In a literal sense, blizzards are not "storms" but bitter winds which whip up snow that has already fallen. To anyone caught in a blizzard, however, the distinction would be unimportant. As high and as far as he could see, the air would be filled with swirling masses of fine, pulverized snow. Anyone caught without shelter in a genuine blizzard of gale winds, below zero temperatures, and driving snow would stand little chance of survival.

Western plains and prairies of the United States are most susceptible to blizzards, although the bitter winter winds do sweep down from Canada over the Middle West.

PROTECTING YOURSELF IN A WINTER STORM

Blizzards and other severe winter storms can strike in unexpected places, creating havoc for the unprepared. In Lansing and Chicago, some families were isolated for four and five days, blocked by huge snow drifts and impassable roads. If this should happen to your family, would you have enough food in the house? Would there be enough medicines and other supplies on hand for babies, diabetics, heart patients or other family members with special needs? What if gas or power lines were cut off? Could you keep warm? Cook food? Light the darkness?

1. Consider such problems with your family and figure out in advance how to handle them.
2. Build an emergency supply of foods that would not need cooking and that could last your family for a week. Your county extension agent or local civil defense director can give you many suggestions.
3. Prepare a first aid kit with an emergency supply of family medicines included.
4. Make sure your family would have a source of emergency light. This might be a box of candles, or flashlights with extra bulbs and batteries. You might want to rig up an emergency light from a car battery. Your county extension agent can give you plans.



Summing Up. . .

"Everyone talks about the weather, but no one does anything about it," Mark Twain quipped, a hundred years ago or more. It was a fair enough remark for his time. Little was known or done about the weather, nor was anyone particularly concerned, with the possible exception of countryfolk, who needed rain for their crops, and seamen who tried to steer clear of the storms.

Modern technology has radically changed this complacency. The more sophisticated our civilization becomes, the more vulnerable we are to bad weather. In our finely interrelated society, we need transportation, power, incoming goods and outside services, all of which may be cut off or disrupted by the weather. This is one reason for the increasing importance of meteorology and climatology in every facet of our modern life. We need to know "How does weather threaten us?" and "What can we do to protect ourselves?" As we have seen in this unit, meteorologists are coming up with many of the answers today and anticipate even more rapid progress in the near future.

Ironically, just as we are developing some understanding of weather processes and learning how to limit our losses in tornadoes, hurricanes and other natural disasters, we are creating two far more devastating weather related threats. Air pollution is one threat. Radioactive fallout is the other.

AT THE DOORSTEP OF OPPORTUNITY

By now you have discovered that weather is not all mystery and magic. In fact, it's a fascinating study and an even more fascinating vocation. As our knowledge of weather and meteorology increases, more challenging opportunities for careers will become available to anyone having the interest and qualifications. Dozens of exciting fields are open right today—meteorology, climatology, electronics, computers and data processing, mathematics, physics and a host of other professional, technical and clerical opportunities. And virtually all of these careers are open almost world-wide to both men and women—in government, industry and business. Maybe one of these careers is just what you are looking for. Read the booklet "The Challenge of Meteorology" in your leader's guide. You will open the door to an exciting and rewarding future.