WEATHER

GAYLE PICKWELL

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BY GAYLE PICKWELL, Ph.D.

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PREFACE

Weather has been written and illustrated with the average individual and the interested student in mind. There are no undefined technical terms. Throughout, everyday weather features have been stressed. The final chapter on *Learning the Weather* will present a few of the multitude of fascinating experiments and devices that will make the learning of weather more significant.

Illustration No. 32, *Lightning,* was taken by Mr. Frank Thorne. The author is indebted to him for his kind permission to use it. All other photographs used as illustrations were taken by the author. The pictures were secured in New York, Illinois, Nebraska, Wyoming, Utah, Nevada, Washington, California, and Arizona. In spite of this wide range of locality, many of the weather characteristics displayed may be observed during the year at any place.

The Airways Weather Service at the Oakland Airport most graciously supplied the information regarding the aviation work of the U. S. Weather Bureau. The author is indebted to Miss Ebba Swanson, to Mrs. Alice Addicott, and to Miss Emily Smith for their assistance in outlining work in *Learning the Weather.* These three individuals, in their various positions, presented the subject of weather successfully in elementary grades and in college work. Their contributions greatly enhance such value as *Weather* may have.

GAYLE PICKWELL

San Jose, California

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WEATHER

CHAPTER I

WHY STUDY WEATHER

WEATHER MAY BE SPECTACULAR AND DISASTROUS

WEATHER has supplied to newspapers, during the past few years, the material for the biggest and blackest headlines since the World War. During the summer of 1934 the Middle West experienced the longest hot and dry season in the memory of man. Winds raised the worst dust storms of history to blow "black blizzards" out of the "dust bowl" of central United States, in the spring of 1935. In the late spring of 1935 floods closely related to the conditions that followed the "black blizzards" raised the Republican River and drowned more than a hundred people in Nebraska, in a region where people had never been drowned by floods before. As this is written in the summer of 1936, a drouth and fierce heat again work havoc in the Middle West.

January and February, 1936, presented to regions east of the Rockies the longest periods of subzero weather and the greatest snowfall, in many a locality, that had ever been experienced; and brought a new term, "polar front," to the public attention. This same snow mantle, extending to the Atlantic, was melted abruptly by a succession of rains in March, 1936, to bring floods of vast and disheartening proportion to the East. In April of 1936, tornadoes swept through the Southeast to take 400 lives and to leave dire destruction. Not even the calamities of depression have equalled in blackness the headlines produced by weather such as this. And though one cannot have experienced such weather or have read the account of such weather without asking himself "why?" still the interest in weather is not limited to the spectacular.

MAN IS EXPLORING THE STRATOSPHERE ABOVE THE REALM OF WEATHER

On November 11, 1935, Captain Albert W. Stevens and Captain Orvil A. Anderson were lifted in the gondola of the world's greatest balloon, Explorer II, to a height of 72,395 feet. This was the highest point ever reached by man. At this great height the sun was white and 20 per cent brighter than at the ground level; the sky was almost black, and the temperature 80 degrees below zero. Cosmic rays bombarded with equal violence from directly above and from the sides, and photographed themselves on photographic plates wrapped in black paper; 96 per cent of all the atmosphere was below the balloon; twelve gallons of air, collected at that elevation, were equal only to two quarts, when reduced to the pressure at sea level. The ultra violet rays, which are so necessary for health when they have been screened by the ozone of high elevation and by the lower air, were so unobstructed that they would have caused death to any man had he been exposed to them for more than a few minutes; but spores of fungi were present and living at that great height.

The stratosphere, on the basis of constancy of temperature, began for Stevens and Anderson at about 35,000 feet elevation, where their thermometer reached a temperature of 70 degrees below zero and fluctuated within ten degrees of this point up to the "ceiling" and down to 35,000 feet again. The stratosphere for them, therefore, extended from 35,000 elevation on to the highest point attained.

This venturing into the upper atmosphere was first begun by airplane when Soucek reached 43,166 on June 4, 1930, to be followed by Donati, who reached the highest point ever attained by a heavier than air machine, 47,672 feet, on April 12, 1934. The real exploration of the stratosphere, however, has been left to balloons. The adventures of the Piccards made the whole world stratosphere conscious when, on October 23, 1934, Mr. and Mrs. J. Piccard reached a height of 57,579 feet. There have been other stratosphere explorations, but Explorer II reached an elevation several thousand feet above all others.

Stratospheric exploration as yet has shown no very clear relationship to the problems of weather. However, many exciting things are discovered and since the stratosphere is part of our sky, our sky which is responsible for our weather, some of the significant things learned will be considered here briefly. It will be remembered that Mount Everest in the Himalayas, the world's highest mountain, stands, at its top, 29,194 feet above the level of the sea. Explorer II climbed to an elevation nearly two and one-half times as high as this world's highest mountain, 13.71 miles above the level of the sea and over 13 miles above the South Dakota plains over which the balloon made its ascent. Nowadays 13 miles is a very inconsequential distance in a linear line at the surface of the earth. We span it with a modern car in a very few minutes, but let us note what amazing things are experienced if that distance is covered vertically into the sky.

The cloud layers that start with the fogs which may be near sea level and run through a succession of stratus, nimbus, cumulus, cumulo-nimbus, alto-cumulus, alto-stratus, cirro-stratus, and cirrus, all lie far below the elevation which was reached by Explorer II. Even highest cirrus only now and then extends above 30,000 feet (see under clouds in Chapter III, *Signs of the Weather*). Stevens and Anderson went more than twice that high. The clouds and the winds of our weather lie in the troposphere. The troposphere is characterized by all the things that make our weather: ascending air currents, winds, cyclones ("highs" and "lows"), storms, and temperature changes. The stratosphere begins above the troposphere and it is characterized by uniform temperature, by mild winds, and no clouds. At the equator the stratosphere may not begin short of ten miles of elevation, but its average is six and one-half miles.

Problems involved in exploring the stratosphere, such as the necessity to have a gondola sealed tightly and with its own supply of air (for no human being can live in the extremely thin air of high elevations), the problems of the manipulation of the gigantic balloon, both on its ascent and descent, the problems of the many complicated and exciting scientific instruments that are used in making studies of the stratosphere, are items that should be covered in other readings such as may be found under *Further Helps in Learning the Weather* in Chapter VI.

MAN IS DOING SOMETHING ABOUT THE WEATHER

Man may not be able to stop the wind, but great projects are afoot to stop "black blizzards," the havoc wrought by winds. This will be accomplished by re-establishing grass and range conditions where grass and range should always have been. Perhaps the grass over large areas will temper the heat and so make drouths less destructive. Man has not yet learned how to make rain, and he has not yet learned how to stop it, but new sod and new forests may prevent destructive floods when rains continue. These greatest of all weather projects are still matters for the future, but man is doing many lesser things about the weather. He long ago learned to irrigate because it didn't rain enough, and, today, irrigation projects are tremendous. Long ago he looked at the sky and made a forecast of the weather, perhaps with hay cutting in mind. Today, forecasting and many other phases of weather work are being carried out scientifically as man does something about the weather.

The Work of the United States Weather Bureau. The greatest agency in the world in the matter of weather is our own Weather Bureau. Its work includes many activities. A few of them will be given here. There are, first of all, five forecast centers: Washington, D.C., Chicago, New Orleans, Denver, and San Francisco. In addition to these, there are about 300 regular observing stations in the United States, Canada, Alaska, and the West Indies, each with a full-time weather man in charge. Each of these stations reports twice daily the conditions of its weather. In addition to these regular stations, a variable number of weather reports are received by radio from ships at sea. These twice-daily reports furnish the basis for the best known of weather activities, that of forecasting or weather prediction.

Weather forecast or weather prediction is available throughout the day to any who may call a weather station. Nearly every daily newspaper in the United States prints this forecast. The forecast is telegraphed daily to nearly 2000 distributing points, and mailed to nearly 90,000 addresses. More than 100 radio stations use it daily. These forecasts have been shown to be correct from 85 to 90 per cent of the time. The weather that your newspaper predicts, therefore, has nine chances out of ten of being correct. Remember, when you say "the weather man was wrong," you have forgotten he was right nine times, and wrong only one time out of ten.

After weather forecasting, the Weather Bureau is best known for its daily weather maps. These are printed every morning by about 45 of the larger stations and are widely mailed to subscribers. In addition to forecasts and weather maps, there are forecast bulletins from about 90 stations; 400 points along the Atlantic, Pacific, and Gulf states display storm warnings; and many stations issue cold wave warnings, and warnings of frost and freezing weather. Most recently developed, and, in many ways, the most interesting, is the work of the Weather Bureau in connection with aviation, airplanes, and the airways.

The work of the Weather Bureau in connection with aviation is done by the Aerological Division in close co-operation with the Department of Commerce. In this work, weather information is broadcast every hour from many airports for pilots in the air. Pilots in flight may secure special weather information at any time by radio. The pilots assist in collecting this weather information as they fly their routes. From leading airports, pilot balloons are sent aloft four times daily and observed from the ground, to obtain wind direction and wind velocity at various elevations. A special airplane flight is made daily to heights of 20,000 feet to secure weather information to assist pilots. A machine to record humidity, temperature, and air pressure automatically, is attached to the wing of this airplane. This device is called a meteorograph. Information regarding the weather is supplied by many observers along the airways. Some of these observers live in mountain fastnesses, and others in the bleakness of the desert. Their work has become indispensable for the safety and the success of air travel.

WEATHER PRODUCES BEAUTY

Many of the striking beauties of nature are the result of the work of weather. Only a few of them can be mentioned here: consider a cloud, consider the pattern the frost will make upon a window pane, consider the beauty of a sunset, the rhythm demonstrated by wind over a field of waving grain, the thrill of a rainbow, the exhilaration of a shower, and the satisfaction that comes in living as a "high" brings its sparkling, clear air.

WEATHER BRINGS SATISFACTION IN ITS LEARNING

Every year, every month, every day, every hour, the weather about us presents material of interest. The sun shines, clouds fly, winds blow, rains fall. One of the most fascinating phases of all knowledge lies in answering for these the "why." A sense of accomplishment and genuine satisfaction attend the learning of weather. A feeling of satisfaction attends when one is able to understand the drama of hail, for instance, and to be able to forecast weather with the accuracy of the intelligent amateur. In time, weather becomes a matter of interesting discussion and not merely a stop-gap for an uninteresting conversation.

CHAPTER II

WHAT MAKES THE WEATHER

"It's beastly weather," you growl, when the air in the form of wind is blowing a "black blizzard." "I'm chilled to the marrow of my bones," you shiver, meaning that the air has a temperature that isn't pleasant. "Oh, I wish it would quit raining," you complain, with a picnic in mind, as the same air gives up some of its water. But winds die, rains cease, the air becomes warmer, and the sun shines. Then you are prompted to say, "Isn't the sun grand? It's a perfect day!" The air, the water that air contains, and the sun—these make weather. All are necessary for weather, but the sun stands first.

THE SUN

The sun and the seasons. The sun is more than 90,000,000 miles away, but it controls, directly or indirectly, everything that surrounds us and nearly everything we do. It is necessary for all green plants; and so, in the final analysis, for all life and hence, for all of our foods and all of our clothing. The sun, with the things the sun can do, dictates the places we may live and the homes we build. The sun has a diameter of 800,000 miles (it would be necessary to place a hundred earths side by side to extend that far); it has a surface temperature of 10,000 degrees Fahrenheit; 140,000 horse power of energy is being emitted constantly from each square yard of its surface, but only one two-billionth part of this great energy travels the ninety million miles to reach our earth; yet that part is sufficient to perform the many, many things the sun accomplishes here. With its handmaidens, air and water, the sun presents weather, one of its most impressive accomplishments.

At times when the light of the sun is broken by its passage through cloud fragments (as in Illustration 1), it spreads out in the beautiful fan-like "water drawing" effect, which scientists call "crepuscular rays." Of course water is not streaming up the spectacular rays, for the effect is brought about by the lighting of dust particles or moisture particles along the paths of the beams. The shadows between the beams serve to set them out. Incidentally, the rays do not converge at the top though they seem to do so; they are as far apart there as they are below. This illusion is brought about because the rays are farther away at the top than at the bottom; and so they seem to come together as do any parallel lines that stretch away from the eye. Remember the effect of railroad rails that seem to come together as they extend into the distance.

The rays from the sun do not strike all places on the earth's surface with equal directness or with equal force. The rays from the sun are parallel, one to the other (as was noted in connection with Illustration 1), and the space covered by any ray is smallest and the light most intense, therefore, when the sun is directly overhead. The fact that the sun's rays are less intense when they must cover more surface is obvious when we remember the cool of late afternoon when the sun is low in the west. To illustrate the difference in the amount of area covered between two parallel lines, such as rays from the sun, draw a horizontal line on a sheet of paper to represent the surface of the earth. Bring two parallel lines down to this "earth's" surface from above, at right or ninety degree angles to it. Then bring two similar parallel lines at an angle of about twenty-five degrees to the "earth's" surface. The space between our twenty-five degree lines where they strike is much greater than the space between the parallel lines that strike at right angles, as you can see. So the intensity of the energy of the sun varies during a day because of the difference in the angle of the rays with the attendant difference in the amount of surface each ray must cover. This difference in the angle of the sun's rays makes the regions of the earth different from pole to pole. Finally, because the angle of the rays differs at any one place from month to month, it also makes our seasons.

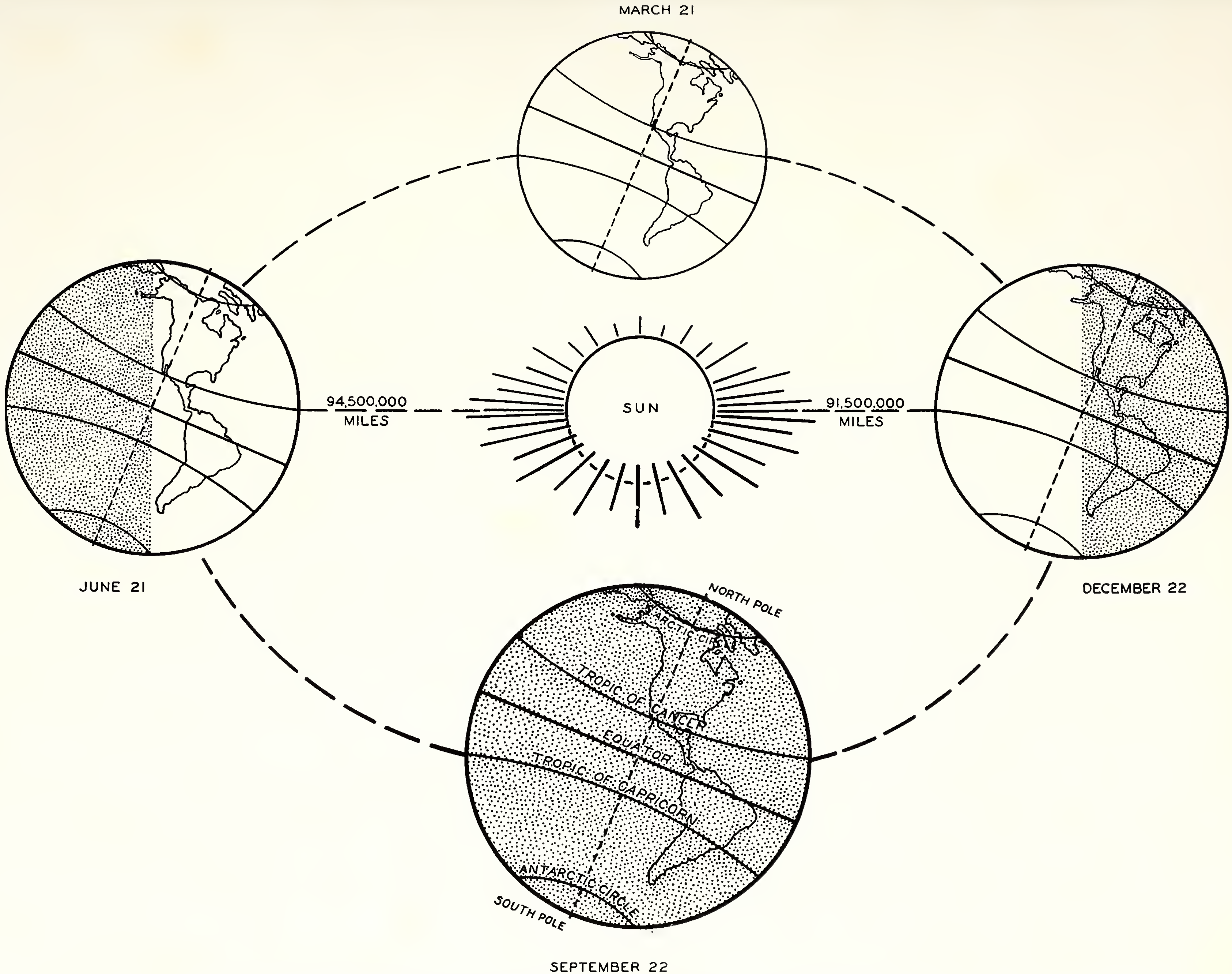
The earth has two constant motions: it turns around and around like a spinning top, with the poles forming the ends of the top; and it travels around the sun in a journey of nearly 600 million miles in the course of a year. Night and day result because of the earth's spinning; seasons result because of the positions the earth assumes as it travels around the sun.

To understand seasons, let us consider the region in which the earth moves to be something like a great floor in space. The sun is near the center of this floor. The earth moves around the outer edge of this floor (scientists call it the "plane of the ecliptic"). Consider the earth as a gyroscopic top, a top that whirls so fast (a thousand miles an hour at the equator), that it holds one position constantly as any true gyroscope does. The axis of the earth, a line extending from pole to pole, is not at right angles (90 degrees) to the floor, and thus standing "straight up and down," but is at 66½ degrees and forever leans.

If our earth were "straight up and down" to its floor or plane of the ecliptic, we should have at all times and everywhere a condition of equal days and nights, like that of March 21 or September 21 (with us early spring or early fall). But the "leaning" earth brings about the other seasons because as it spins around the sun on its great floor, it is "broadside" to the sun only on March 21 and September 21. As it moves from March 21 to June 21, the daylight becomes longer north of the equator, for the angle of the axis of the earth turns more and more of the northern hemisphere toward the sun (see Drawing 2). Following June 21, the daylight decreases with every day because the axis of the earth presents the southern hemisphere to longer and longer periods of sun. Northern and southern hemispheres have the same light again on September 21, and the southern hemisphere increases in daylight from that time to December 22, when, we are accustomed to say, we have our "shortest days." Light increases to the north again from December 22, through that day when daylight and dark are equal everywhere on March 21 (not only in the north, but everywhere), until the "longest days" are reached on June 21. Scientists express this by explaining that "the earth presents an agle of 66½ degrees to the plane of the ecliptic and maintains a constant parallelism of axis in the circuit of the sun."

The cause of the seasons can be illustrated in a very simple way with two apples and a pencil. Put one apple on the center of a table and call it the "sun." Put the pencil through the other apple, which is the "earth," from stem end to blossom end. Call the stem end the "north pole," the blossom end the "south pole." The pencil represents the axis of the earth, the table the

1. THE SUN "DRAWS WATER"



2. THE POSITION OF THE EARTH WITH RESPECT TO THE SUN AT THE BEGINNING OF EACH OF THE SEASONS

plane of the ecliptic. Lean the "earth" apple at an angle of 66½ degrees to the table (see the angle of the earth's axis in Drawing 2 as an example). Hold the "earth" apple in that position and move it around the "sun" apple. It is obvious now that the rays of light from the "sun" will strike with variable directness various parts of the "earth" apple as it moves about the apple "sun."

Drawing 2 shows several other things of interest with regard to the earth, the sun, and the seasons. Note that the angle of the axis of the earth with respect to the sun gives the entire arctic circle darkness for a full twenty-four hour day on December 22. The light in this region increases from this date until, on June 21, the entire arctic region has sunlight for a full twenty-four hour day. Of course the same thing happens at the antarctic, but the seasons are just the reverse of the arctic.

It is the position of the sun at the solstices (summer solstice, June 21, winter solstice, December 22) that determines the boundaries of the arctic and antarctic circles, the tropics of Cancer and of Capricorn. At equinox (equal day and night, March 21 and September 21) the sun is exactly above the equator. It is interesting also to note that the plane of the ecliptic is not a perfect circle but is ellipsoid, almost egg-shaped. The earth is four million miles nearer the sun on December 22 than on June 21, but the angle of the earth's axis gives winter to our northern regions in spite of that.

Earthly bodies influenced by the sun. On the earth, the influence of the sun, great or small, affects chiefly three great substances there: the land, the great bodies of water, and the air. Land, under the influence of the sun, warms quickly and intensely. This fact accounts for the very high temperatures of the interiors of the great continents, accounts for the great heat of interior Siberia, of interior United States, of the great Sacramento-San Joaquin Valley of California, and of the deserts of the Southwest. Likewise, land cools quickly when the sun's heat is withdrawn; and so great land masses will have, in winter, the coldest weather of the earth. Temperatures that go above 100 degrees Fahrenheit in summer in Central United States will drop to 20 or 30 degrees below zero in winter. Asia, the greatest land mass of all, has in central Siberia the coldest weather of all, colder even than the poles, for temperatures as low as 90 degrees below zero have been recorded there.

In contrast to the land, the oceans respond more slowly to the energy of the sun. Water responds slowly to heat for it requires four times as much energy to raise a given amount of water one degree as to raise a like amount of the soil of the land one degree. Furthermore, water does not give up its heat as readily as air or land. Surface water also transmits heat to the water below much more readily than surface soil transmits heat to deeper soil, or than air does to unheated air regions above or below. These three characteristics of water (slowness to acquire heat, slowness in parting with heat, and rapid heat transmitting power) give to great water masses a more uniform temperature than to land masses. For example, the temperature of surface ocean water varies only from 90 degrees Fahrenheit at the equator to 28 degrees at the poles, whereas land masses will vary from temperatures well above 100 degrees Fahrenheit, to 60 or 70 degrees below zero. The Pacific Ocean is shown in Illustration 3. Its temperature change from winter to summer is only a few degrees. To it the equable and mild temperature of the West Coast must be attributed.

The sun is the mighty instigator of weather. Yet the heat of the sun is varied and modified by many things: by the shape of the earth, by the position of the axis of the earth with respect to the sun at various seasons, by the spinning of the earth in day and night, and by the land and sea masses that cover the surface of the earth. These variations in the sun's energy give us our variations in weather.

THE AIR

We humans live at the bottom of an ocean that surrounds the earth. Our ocean is not very deep, but we, confined perpetually to its bottom, only occasionally appreciate its shallowness. Yet when we climb a high mountain our heart thumps in protest because we have gone from that portion of our ocean where the density is best suited for us. Two or three miles above our ocean's bottom, as an airplane ride will prove, we come to regions where temperatures are lower than bottom dwellers like. We humans roam far and wide over our ocean's bottom and pride ourselves upon our superior ability, but we are still confined to our ocean's bottom, never going far below it and even today going but a short way above it. The ocean that shuts us in is air.

Structure of the air. The air at the earth's surface is composed of several different gases: of the sluggish and inert nitrogen there is about 75 per cent; of the very active oxygen there is about 20 per cent; of carbon dioxide, most important of all gases to plants, there is usually .03 per cent; of argon, there is 1 per cent; of several other gases there are traces. Dust particles are present and vary in number. There is also, and most important in our study of weather, a variable amount of water vapor. How it gets there and how it ultimately forms our clouds, rains, dew, frost, fog, hail, and snow, will be shortly discussed.

The structure of the air at the earth's surface is very little different from that of the air at the limit of clouds, some six or eight miles up, except that at these altitudes it is much thinner. Since our weather is produced in the cloud zone, the air above this zone, interestingly different though it may be, need not concern us here.

Weight and pressure of the air. Air is a gas, but it has substance, a substance that responds to gravity and is attracted to the earth, like a ball or a rock, and this gives it weight. The weight of all the air above any given point produces a pressure. Since air is a gas, however, this pressure is exerted in all directions, not only from above, but from the sides and even from below if air may get beneath. Because this air pressure, that results from its weight, is equally distributed on all sides on an object such as the body of a human being, we are not aware of it because we have become adjusted to it. However, if we make it possible for the air to exert its weight pressure on only one point, instead of on all points, we soon learn that it exists. The best known example of the work of air pressure is the drinking of lemonade through a straw. One does not really "suck up" the lemonade, one merely reduces the air pressure on the lemonade at the lower end of the straw by drawing off a little bit of air. The air pressure exerted on the lemonade in the glass forces it up the straw and into one's mouth in the air's effort to equalize the pressure.

If all the air pressure is removed from directly above a column of water (like a giant sucking through a mighty straw), the surrounding air pressure at sea level will support about thirty feet of water, but no more. If our giant has a straw longer than thirty feet, he will draw himself purple in the face without getting a drop to drink.

The little bucket pumps which have a sucking cylinder at the top will not work unless the water is within thirty feet or less. Such a pump is dependent upon air pressure on the water of the well to force it up the pipe, just as is our thirsting giant who tries to drink through a straw too long.

The air pressure at sea level, if you can make it felt on only one surface, exerts a weight of 14.7 pounds per square inch. This pressure is sufficient to support about thirty feet of water, as has been noted, or thirty inches of mercury. Even at sea level, the air pressure varies slightly with changing weather conditions; and so the variation of mercury, slightly above or slightly

3. THE PACIFIC OCEAN IS RESPONSIBLE FOR THE MILD WEATHER OF THE WEST COAST

below its normal thirty inch height, becomes a barometer and is an important means of weather forecasting. The thirty feet of water in a glass tube would do as well were it not so inconvenient and so liable to freeze.

The weight pressure of the air becomes less at elevations above sea level, to such an extent, and so rapidly, that up about six and one-half miles, which is the upper limit of most clouds, it has but 22 per cent of its sea level weight. Any one who has climbed a mountain slope, or dropped rapidly down it in an automobile, has experienced this change of air pressure by queer sensations in his middle ear. These sensations are relieved by swallowing and so opening the auditory tube from mouth to middle ear so that the air pressure may be equalized on both sides of the ear drum. Rides in airplanes produce the same effects, and likewise riding up or down for several floors in an express elevator.

Heating of the air. The changes in the air are brought about by the sun. The sun influences the air by heating it. Air is heated by the sun in several different ways. First, the air over the oceans is warmed to the temperature of the water wherever the lower layers of the air come into contact with it. Furthermore, the ocean reflects about forty per cent of the sun's energy and this reflected energy heats the air above the water. On the other hand, though ground reflects but little of the sun's energy, it radiates the heat it receives from the sun almost entirely to the air during the day or the night. This radiation from the ground results in far more radical heating of the air over the land than over the ocean. The air receives very little heat directly from the sun for it transmits its energy too readily. Only where the air is very dusty does it acquire heat directly and even then in very small quantities. It follows then that the temperature of the air results chiefly from its contact with the earth (with the water or the land).

It is common experience that if one end of a metal bar is heated the other end will eventually become hot too. This type of heat transmission is called "conduction." It is equally well known that some substances conduct heat much more readily than others. For instance, aluminum conducts heat more readily than iron; wood conducts heat much more slowly than either (hence wooden handles on cooking utensils); and water conducts heat much more readily than soil. Air is one of the poorest conductors of all, and if other causes did not contribute, the air heated or cooled by its contact with water or soil would never be more than a few feet in thickness. But air is a gas and as a gas it can move. It is the nature of both liquids and gases to attempt always to adjust their temperature differences. If the air near the surface of the ground is heated, it expands, becomes lighter, and rises as colder and heavier air forces in to take its place. This forcing upward of water or air that is heated is called "convection."

Land and sea breezes. One of the best known examples of convection and movement of the air, due to heating, is that which produces land and sea breezes. During the day the land becomes much warmer, under the influence of the sun, than the ocean water. The warmed land heats the air that lies above it. This warmed air is forced to rise by the movement of colder, heavier air that replaces it. If the sea is near it will supply this colder air in the form of a sea breeze. Along much of the Pacific Coast such a breeze starts with almost clocklike regularity, about 1.00 P.M. during the summer and every day that is very warm. Along the Pacific Coast and in the valleys of the coast range mountains, the sea breeze is accompanied regularly by the famous ocean or advection fogs that do much to make the summer climate of this region (see Illustration 4).

A peculiar condition of cold water, upwelling from the depths, exists offshore near the Pacific Coast of the United States. As the sea breeze swings landward, laden with water, it strikes this colder region and some of its water condenses into the fog cloud that sweeps onto the land to give the West Coast its characteristic summer fog. When the days have been especially warm in the coastal valleys, and the sea breeze correspondingly strong, this sea fog will fill the valleys. The under surface of the fog will be dissolved away by the warmed air that continues to rise from the heated land; and so the fog will not be at ground level, but will have a smooth grey "ceiling" several hundred feet high. Though the sea breeze began at 1.00 P.M., the fog it brings may not reach the mountain valleys until the night. The next morning, with the grey blanket overhead, people will shiver and say, "doesn't it look like rain?" though they know that it will not rain. On the mountain slopes one may look down upon this advection or sea fog that resembles, from above, an angry but motionless sea. In the bright sun one breathes deeply and hesitates to go back again to the chilly world beneath the fog that the sea breeze has brought.

At night the land rapidly radiates its heat to space and becomes colder than the ocean water near by (though this is delayed and may not occur if a fog blankets the land). The colder air of the land at night slips seaward to push up the warmer ocean air. This makes the land breeze that is experienced on the ocean at night near the land.

Dust whirls and cumulus clouds. There are other evidences that air is forced up when heated. Frequently in our western deserts or wherever there is a large area of dusty surface, dust whirls will be seen rising on bright, quiet days. Air near the surface is heated greatly and is forced to rise in a column. Cold air rushes in, and, swinging to one side or the other, due to irregularities of the ground, throws the column into a whirl. The great, barren, alkaline sinks of Nevada or of Utah often will have these queer columns, hundreds of feet high, marching slowly one after the other across the grotesque landscape (see Illustration 28).

Cumulus clouds, those flat-bottomed, high-domed mounds that occur in fair weather (see Illustration 20), are formed on the top of ascending columns of air. Just why clouds form at the top of these columns will be explained in Chapter II, *Signs of the Weather.*

The cooling of the air. Air when warmed becomes lighter and is forced up as colder and heavier air replaces it. As it rises it cools. It cools chiefly because of two reasons: it mixes with the air above, and this air is much cooler because only the air near the ground will be appreciably heated by the sun, and the air above has radiated its heat to space; and also it cools because air expands as it rises, since air above is less dense than air nearer the earth, and a gas cools as it expands (conversely it heats as it is compressed or, in this case, as it falls). At night, air very near the ground may be cooler than the air just above, because the ground rapidly radiates its heat to space, and the air is chilled as the ground cools; but for the most part there will be a gradual lowering of temperature from the surface up. This cooling, accompanying increase of elevation, averages 1 degree Fahrenheit for each 300 feet and it is called the "temperature gradient."

The decrease of temperature of air with elevation continues at the rate of 1 degree for each 300 feet until a height of nearly seven miles is reached. Here the temperature will average about 55 degrees below zero. Above seven miles, for an unknown distance, the temperature of the air will remain the same, or about 55 degrees below zero (the stratospheric temperature during the flight of Explorer II, November 11, 1935, above South Dakota, was 80 degrees below zero). This great region of constant atmospheric temperature is called the "isothermal region" or "stratosphere." Why the temperature of the stratosphere does not vary, as does that of the lower atmosphere, is not certainly known. These temperature facts have been learned chiefly by the use of "sounding" balloons, or small balloons

4. THE ADVECTION OR SEA FOG, BROUGHT TO PACIFIC COAST VALLEYS BY THE SEA BREEZE

sent aloft accompanied only with instruments to record the conditions of the atmosphere through which they travel. Today, stratosphere balloons are accompanied by human beings. Since our weather develops almost entirely in the first seven miles of air, and since here there is a temperature gradient, this region will interest us chiefly in this book.

The average temperature gradient, or drop of 1 degree Fahrenheit for each 300 feet of altitude, represents the average condition of the atmosphere when it is quiet and has no convection. A given body of air, that may be heated at the earth's surface, will rise and cool, not at the rate of 1 degree for each 300 feet, but 1.6 degrees for each 300 feet. This rate of cooling for rising and expanding air is called the "adiabatic" rate of temperature change. Any mass of air that is warmer than surrounding air will be forced to continue to rise and to cool at this rate until it has cooled to the temperature of surrounding air or until the water it contains begins to form into cloud, in which case latent heat is released and it rises still higher.

For instance, let us suppose that the normal gradient begins at 50 degrees Fahrenheit at the surface of the earth at 9.00 A.M. and that the temperature at 3000 feet is 40 degrees Fahrenheit (a drop of 1 degree for each 300 feet). At 11.00 A.M. the earth has heated under the influence of the sun and it warms the surface air until the temperature has risen to 60 degrees Fahrenheit. Since the air is warmer than the normal temperature gradient will allow, it will, accordingly, rise. It cools at the rate of 1.6 degrees for each 300 feet and the normal gradient also lessens at 1 degree for each 300 feet, and, therefore, the heated air will rise almost to 5000 feet before its temperature will be, once again, the same as that of the surrounding air.

If, therefore, air becomes colder or warmer than the normal gradient of the place, it undergoes convection, that is, lifting or settling. Usually heated air will mix with surrounding air and so lose its heat before it reaches the theoretical level. Again, the cooling may cause the moisture of the air to condense out into cloud and this adds another factor. Indeed, it is the adiabatic cooling that forms our cumulus clouds as will be shown later.

Impressive Mount Rainier, in Illustration 5, exhibits the cooling of air brought about by elevation. At Bear Prairie Point, where the picture was taken, the elevation is about 2500 feet and is wet enough and warm enough for a jungle-like growth of ferns and a heavy forest of great trees. The top of Rainier, however, extends to a height of 14,400 feet, into air where the temperature is forever like that of the arctic. Here is a little problem: if the air is at a normal gradient (that is at a temperature everywhere that will bring about no movement of air), and the temperature at Bear Prairie is 60 degrees Fahrenheit, what is the temperature at Rainier's summit? (The average drop is 1 degree for each 300 feet elevation, remember.)* Another and harder problem is this: suppose that the air at Bear Prairie Point has become very warm, say 90 degrees Fahrenheit, and is forced to rise. As it rises it cools at the adiabatic rate (1.6 degrees for each 300 feet in elevation). How high must it rise before it cools to the temperature of the normal gradient, presuming that no other factors interfere?†

Dust particles of the air and sky colors. The blue sky is caused by dust particles. The haze of summer days is caused by dust particles, and frequently in the West by smoke particles of forest fires. Sunset colors are caused by dust particles in the air. These colors are due to the action of the dust particles on the different light rays that come from the sun.

The sunlight, as the spectrum shows, is composed of rays of many different colors. The visible light rays, when combined together, give us white light. There are rays which our eyes

*The temperature at Rainier's summit will be 20.33 degrees Fahrenheit.

†The air must rise 15,000 feet above Bear Prairie Point before it cools to the normal gradient.

cannot see, such as infra-red and ultra-violet, but the rays which we can see give us atmospheric colors. Of these there is a gradation from very short rays of about two-millionths of an inch, to much longer rays, about ten times as long, or twenty-millionths of an inch. The shortest visible rays are violet and blue, the longest are red and yellow. In a very clear sky, with a minimum of dust particles present, only the blue is refracted by them. This sorting out of the blue gives us our blue sky. If there were no dust particles the sky would be black, stars and moon would shine brightly at midday, shadows would be very dense.

As dust particles increase, the blue is lost and the sky becomes gray instead. Toward the horizon the sky is always gray, except on very clear days, because the light there is coming through much more air than the light from directly overhead, and consequently it comes through more dust particles.

The sorting of light rays by the dust particles is most obvious and most pronounced in sunset colors. To have the most vivid sunsets there must be clouds overhead to reflect the colors. If clouds are there, the colors are usually as follows: blue, purple, yellow, orange, pink, deep red, and finally blue-black or brown. These colors are sorted out from the shortest to the longest rays and the longest exhibit of their abilities to penetrate more and more dust particles as the sun sinks lower and lower.

One must not leave the matter of the dust of the air without mentioning that dust seems to be necessary for rain. A tiny dust particle forms a nucleus about which the condensing water vapor forms to make the raindrop. We are told that the pea soup fogs of London are aggravated to that intensity because of the tremendous amount of soft coal smoke particles in the air for the tiny water particles to cluster about.

Wind belts of the earth. Air rises when it is warmed because colder air pushes in beneath to take its place, and thus winds are formed. Winds result from uneven heating of the air. In any one place, the winds, though they may seem to blow at times from various directions of the compass, come in general from one direction. There is a region near the equator where the air, rising regularly because of the great heat received there, seems very quiet at the surface. This is the belt of calms or, as the sailors know it, the doldrums. On each side of the equator, for a region extending many hundreds of miles to the north and to the south, the winds blow constantly into the belt of calms and force up this warmer air. These are the trade winds. The trade winds do not blow directly toward the equator, but from northeast to southwest on the north side, and from southeast to northwest on the south side. Since, thus, they blow partly from the east they are often called the "easterlies."

The year-round warmest region on the surface of the earth is near the equator. Here the air rises. The trade winds rush in to push up this air. The warmed air of the equator moves up and either north or south and is gradually cooled as it moves. A portion of it moves on to the poles, but much of it settles just north of the tropic of Cancer and just south of the tropic of Capricorn (about 30 degrees north and 30 degrees south latitude). In the terminology of the wind belts of the earth, these regions are called the "horse latitudes." The air that settles here is dry air, for it long before gave up its moisture above the equator. Hence it follows that many of the deserts of the world lie in the horse latitudes. Such is true of the Sahara, the Arabian and Persian deserts and much of the dry regions of southern United States and northern Mexico. The deserts of South Africa, South America, and Australia are in the horse latitudes that occur south of the equator.

Between the horse latitudes and the arctic or antarctic circles there are broad regions, the temperate zones, which, in the north, include all of

5. THE SNOW AND ICE OF MOUNT RAINIER SHOW THE LOWERING OF TEMPERATURE WITH ELEVATION

the United States and nearly all of Canada. Here the winds blow persistently from the west. North of the equator they blow from northwest to southeast. South of the equator they blow from southwest to northeast. These are the "westerlies." These are the winds that will concern us most.

Above the arctic or below the antarctic circles the winds are various, blowing frequently from the cold poles to the warmer regions that lie to the south or north. Winds of the earth would blow directly north or south if the earth did not revolve, but since it does the wind belts are thrown into diagonals, some of which are nearly due east and west.

Air is a relatively thin layer of various gases over the surface of the earth. Its past has seen changes, as its future undoubtedly will. Air has weight and varies in density altitudinally. Air, responding to the energy of the sun, moves. Since the energy of the sun varies, the movements of the air vary accordingly to form wind belts on the earth. The air carries dust particles and these dust particles sort out, into various patterns at different times of the day, the sunlight that passes through them. Above all in importance, air can hold water.

WATER

The sun and air together would give us a weather of temperature change and winds; but without water in the air, there would be no clouds, no dew, no frost, no rain, no snow. It follows, then, that the third great factor of weather is water. All weather, in fact, is bound up inextricably with sun, air, and water. To us, as living beings, all three must always be present.

Source of water vapor. The water that enters the air is in the form of invisible vapor. This water vapor can come from the soil, from streams and lakes, in large quantities from plants and trees; but the biggest source is the ocean. On the West Coast the great Pacific (Illustration 3) supplies nearly all the water that falls in the winter's rains of this region. In the Middle West most of the moisture of the air comes from the Gulf of Mexico, and along the eastern seaboard the Atlantic furnishes the water for the clouds.

Air, passing over water in any form, will pick up a certain amount of it in invisible vapor. The amount of water that the air holds depends on three things: the length of contact of the air with water, the temperature of the water and the temperature of the air. If air has had a long voyage over the surface of a large body of water, then the air near the water will be filled with water vapor to its capacity. This is true of air traveling near the level of the ocean. If, however, air has been passing over regions where water is present, if at all, in very small quantities, then the air may be nearly dry.

Absolute and relative humidity. The ability of air to hold water increases as its temperature increases, so much so that air at a freezing temperature can hold only about one-tenth as much water as air at 100 degrees Fahrenheit. The actual amount of water vapor in a given quantity of air at any temperature is called the "absolute humidity."

Since the capacity of air to hold water depends upon its temperature, it follows that warm air can hold more water vapor than colder air. It thus comes about that air, blowing over a heated desert, may have actually as much water vapor in it as very cold air blowing over a large body of water. However, the desert air is capable of holding much more water than the cold air, and so we speak of the desert air as dry air or as having a very low "relative humidity." Relative humidity is the per cent of water vapor that air actually holds compared to what it might hold. Let us suppose, for instance, that the temperature of the air is 70 degrees Fahrenheit. If the air at that temperature were completely saturated with water, its relative humidity would be 100 per cent. However it is found that the air has only two grains of water per cubic foot, whereas, at 70 degrees it could hold about eight. The relative humidity is, therefore, only one-fourth of the possible capacity, or 25 per cent.

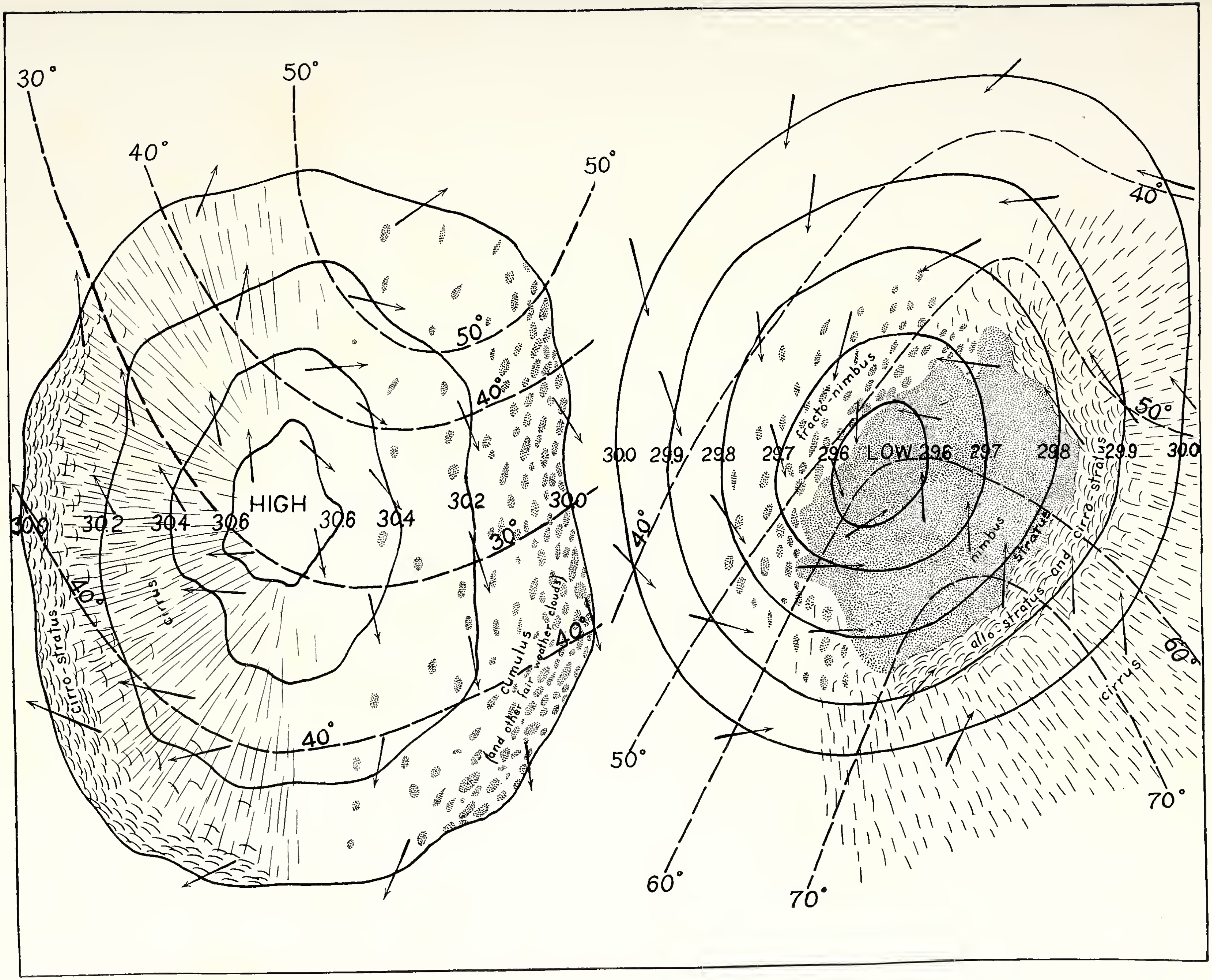
The human body is so constructed, that to be comfortable, evaporation must always be possible from the surface of the body. Quite naturally, as relative humidity increases, the air becomes more nearly saturated with water and is reluctant to take up more. Under these conditions evaporation from the surface of the human body proceeds very slowly and we humans feel uncomfortable. If the temperature is high, so that we perspire, a high relative humidity makes us doubly uncomfortable, for it is the evaporation of perspiration that cools us. It is because the relative humidity is low that the high temperatures of the Sacramento-San Joaquin Valley and desert regions are endurable. It is a high relative humidity with a high temperature that gives us "muggy" weather. High relative humidity it is that makes people say so often "it isn't the temperature, it's the humidity."

CYCLONES AND ANTICYCLONES

Tropical cyclones. In the discussion of the wind belts of the earth, it was noted that there were regions of doldrums, trade winds, and westerlies. In general the winds of these regions blow from the directions as noted but many things enter in to modify them and to make for irregularities. In the belt of calms or doldrums, for instance, the intense heating of regions of the air will at times cause a violent updraft in some locality, usually over the ocean. This great updraft begins to whirl because the earth is rotating. In the northern hemisphere, the whirl is counterclockwise; in the southern hemisphere, the whirl is clockwise. In this whirling updraft of air, clouds form because the moist surface air is soon lifted and cooled beyond a point where it can hold its water vapor in invisible form. Water, in condensing, liberates latent heat. This liberation of heat causes the air to rise still more. All in all, the whirl becomes very violent, rain falls in torrents near the center of the whirl, a calm center is formed, much as whirling water leaves a hole in its center, and the whole storm sweeps along at many miles per hour. This type of storm, originating in the doldrums near the equator, is called a "tropical cyclone."

Tropical cyclones have long been the dread of the sailor of the warm seas; and even for the residents of the islands and mainlands near their places of origin they are often disastrous storms. Tropical cyclones originate usually only a short distance north of the equator, but their paths frequently carry them far to the north. It was a tropical cyclone that caused the great havoc in Galveston, Texas, on September 8, 1900, when thousands of lives were lost and millions of dollars worth of property destroyed. This storm originated southeast of Haiti, but before it was finished, its mad course had swung west to Galveston, had gone inland and finally passed off the New England coast. The tropical cyclone of Galveston caused great damage by the terrific wind that accompanied it (the Weather Bureau's wind gauge was blown away after the gale had reached 100 miles per hour), and by the great tidal wave the wind raised. The months of tropical cyclones are August and September and it is rare that a year passes without one or more of these storms striking with violence some portion of the mainland that surrounds the Gulf of Mexico, and east to the eastern coast of Florida and even to Bermuda. A recent disastrous example that destroyed many lives, was the Labor Day storm that struck the Florida Keys in 1935. In Florida and the West Indies these storms are known as "hurricanes," and in other parts of the world as "typhoons." That part of any book which describes in detail the characteristics and structure of a tropical cyclone will be the most thrilling.

Extratropical cyclones (Drawing 6). Tropical cyclones need not concern us greatly for they



6. DIAGRAMS OF THE CYCLONE OR "LOW," AND OF THE ANTICYCLONE OR "HIGH"

occur in their hurricane form only in the tropical regions and on the borders of the Gulf states. They do not invade the temperate zones in their true tropical character. In these regions another type of cyclone occurs. It is called the "extratropical cyclone." Our region of westerly winds is subject to whirls of the atmosphere, just as in the tropical region, but here our whirls are never so violent and they are far more regular in occurrence. Indeed, throughout the year in most of the United States, and throughout the winter on the West Coast, there is a constant and persistent succession of cyclones above our heads. The cyclones bring us clouds and rain, bring us weather's variations.

The "low" (Drawing 6). The surface of the earth and sea, and the air that lies near these surfaces, are regularly heated by the sun. Surrounding colder air pushes this warmed air up and the push of colder air toward the warmed areas creates wind. The winds, blowing into such a region, swing along the surface over oceans or over the ground, and pick up moisture in the form of water vapor. As they move toward the warmed area, these winds become warmed and their capacity for water becomes greater. Such winds, if the earth did not revolve, would blow directly to the regions of greatest warmth. But the earth does revolve and so the inblowing air is thrown into a whirl. In the westerlies of the northern hemisphere, this whirl is counterclockwise; in the westerlies of the southern hemisphere the whirl is clockwise. The wind thus blows spirally into a center to force up the warmer air there. Near the center of this region (more especially on the southeast quadrant), rain occurs. The reasons for rain are obvious, since the warmed, moisture laden air is certain to cool as it rises, to form clouds, and to cause rain as a consequence. This region of rising air with its rain (or snow), and great spirally inblowing winds, is an "extratropical cyclone." On the weather maps it is merely labeled "low."

The word "low" of an extratropical cyclone refers to the pressure of air as determined by the barometer. If air is rising in any large area, the air pressure is proportionately less than in regions where it is falling; hence the mapped extratropical cyclone presents rings of barometric pressure which show less and less pressure as the center is approached. This cyclone or "low" may be several hundred or even several thousand miles in diameter. Each day it moves rather steadily from west to east, often covering five hundred miles in its daily advance. Again, at times, it may be blocked by mountain ranges and remain for days in one locality. It is then said to be "stagnant."

As the "front" of the cyclone approaches, the thermometer steadily rises (it may fall in summer), and the barometer steadily falls. Extending out from the cyclone are thin layers of cirrus and cirro-stratus clouds. As the cyclone passes overhead, the clouds thicken, rain falls perhaps for a day, perhaps for two or three days. Then the rain clouds break. The barometer rises and the thermometer falls (it may rise in summer). The last showers come with the wind swinging from east, southeast, or northeast to the northwest, west, or southwest. A "low" has come and gone.

Many of the "lows" that produce the weather of North America arise in the Pacific Ocean. Especially is this true from October to June. Regularly, week after week, "lows" form in the Gulf of Alaska and then swing south and east. They strike southwestern Canada and northwestern United States, bring heavy rain to this region, and then pass inland to bring rain or snow to the interior across southern Canada, northern United States, finally to pass off the New England coast. As they pass the great Rocky Mountain barrier, they lose the moist winds from the Pacific Ocean and their rains are slight until they come into the influence of air from the Gulf of Mexico, the Great Lakes, and finally, in the far east, from the Atlantic Ocean (see Drawings 7, 8, and 9). Other "lows" originate in the Pacific south of the Gulf of Alaska to bring rain to central and southern California. These "lows," in the winter, march across the great barriers of Sierra Nevada and Rocky Mountains to leave light snows in these regions and then, in the Middle West, to receive the moist winds from the Gulf of Mexico and make great layers of snow there, and on to the east to pass off New England again. "Lows" less frequently form in southwestern United States and swing across the continent in a great diagonal to New England. These are the "lows" that give most rain to such states as Oklahoma, Kansas, Nebraska, and Iowa. They receive their water in these regions from the southerly winds that blow into them from the Gulf of Mexico. "Lows" also form in the Texas-Louisiana region (such as those that brought the floods of early March, 1936, to eastern United States) and in the Florida region, to swing northeast to New England. Even the hurricanes that strike Florida and lose their violence as they move northward out of tropical ocean regions, eventually move into the Atlantic off the northeastern portion of the United States. The persistency with which these "lows" pass off the New England area gives to this region its consistent alternately fair and stormy weather.

Not all "lows" or cyclones bring rain, though all of them bring clouds. And after each cyclone, there comes a period of fair weather with crisp and stimulating air. The fair weather period denotes that we are in the "anticyclone," or "high."

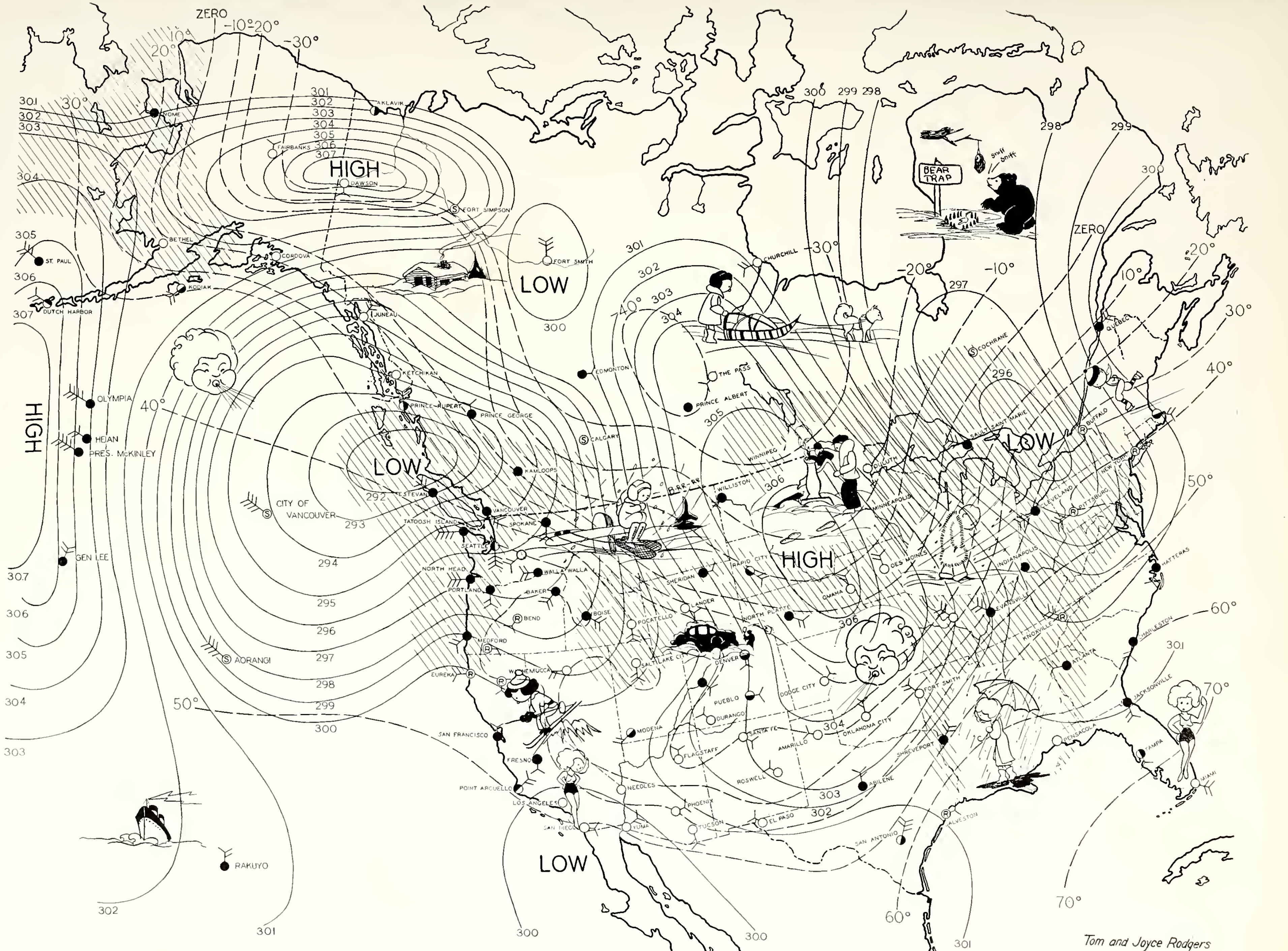
The "high" (Drawing 6). Air cannot forever rise; it must eventually fall again. In the low pressure area or cyclone, air is blowing into a central area where it is rising. As the air rises, it gives up its moisture in the form of rain or snow, and continues to rise into the colder upper regions. High aloft, above the cyclone, the air spreads out in all directions, carrying thin clouds out to mark the approach of the cyclone; finally it settles as cold, dry air, beyond the margins of the "low." This settling, cold air also whirls, though usually not in circles so pronounced as those of the warm air of the "low." Because the air is settling, it whirls in a direction opposite to that of the "low," that is clockwise instead of counterclockwise. The falling air makes the anticyclone or "high."

Where air is falling its weight must be greater than where rising, therefore at the center of such a region the highest barometer pressure will exist. Around the region of highest pressure concentric circles of barometer pressure will lie; the pressure of these is less and less as one proceeds from the center out. On the weather map the anticyclone will be labeled merely "high." On the eastern "front" of the "high" the temperature falls sharply in winter, to remain low until the center is past. The "front" of the "high" of summer is usually accompanied by rising temperature.

When the storm has gone and we are entering a "high," the day dawns crisp and clear. Shortly thereafter cirrus wisps form across the sky. These thicken to alto-cumulus mounds and then all disappears under the heat of the sun. By ten o'clock cotton mounds appear in the sky; and, as the northwest wind freshens, these cumulus clouds are torn under its boisterousness and driven helter-skelter over the landscape. Night falls with the wind abated and the sky again clear. The next day may be cloudless with but a faint breeze from the north. By the third day, though, faint cirrus clouds appear in the west and the wind swings easterly. The thermometer begins to climb again, the barometer falls, and sultriness pervades the air. Our anticyclone is passing to the east, a cyclone is approaching. Our "high" has gone, again there comes the "low" (see Drawings 6, 7, 8, 9, 10).

CYCLONES AND SEASONS

Drawings 7, 8, 9, and 10 are drawings of actual weather maps of winter, late spring, mid-



7. A WEATHER MAP OF WINTER

summer, and autumn, animated to give a graphic impression of the weather conditions of various regions at these seasons in North America. These drawings are based on weather maps of the United States Weather Bureau for specific dates during the four seasons. Before describing the seasonal maps individually, brief explanation should be given of the nature of weather maps and the methods used in their making.

The weather map. Each morning, for the information necessary in map making, about three hundred regular weather stations in North America and the West Indies report by telegraph (remote stations and a variable number of ships at sea report by radio), to several collecting centers, the conditions at their locations. In order that all of these reports may be made of conditions at the same time, stations in the east report the conditions of 8.00 A.M. Eastern Standard Time (75th Meridian Time), in the Middle West of 7.00 A.M. Central Time, from the Rocky Mountains and the Great Basin of 6.00 A.M. Mountain Time, from the Far West of 5.00 A.M. Pacific Time. Ships reporting from the Pacific by radio report at 4 A.M. 120th Meridian Time (Pacific Time). All of the regular weather stations report four things: air pressure (barometric reading); temperature (at the time of the report, and the highest and lowest for the preceding twenty-four hours); weather condition (clear, partly cloudy, rain, snow, and fog); wind at the time of the report (direction and velocity); and the amount of rainfall for the twenty-four hours preceding the report.

Each station or ship making a report which is used on the map is located by a circle which represents the head of an arrow. The head of the arrow is shown clear if the weather reported was clear; if the circle is half black, the weather reported was partly cloudy; if all black then the weather was cloudy; if the letter "R" appears then it was raining; if the letter "S," it was snowing; if the letter "F," it was foggy. The arrows show the direction the wind was blowing (they fly with the wind) and the number of feathers (or diagonal lines) on the arrow indicates the wind velocity based on the Beaufort Scale.

The Beaufort Scale follows: 1 feather on the arrow indicates a wind of 1 to 3 miles per hour; 2 feathers, 4 to 7 miles per hour; 3 feathers, 8 to 12 miles per hour; 4 feathers, 13 to 18 miles per hour; 5 feathers, 19 to 24 miles per hour; 6 feathers, 25 to 31 miles per hour; 7 feathers, 32 to 38 miles per hour; 8 feathers, 39 to 46 miles per hour; 9 feathers, 47 to 54 miles per hour; 10 feathers, 55 to 63 miles per hour; 11 feathers, 64 to 75 miles per hour; 12 feathers, over 75 miles per hour.

The heavy lines of a weather map are drawn through the regions which have the same barometric pressure (the lines are called "isobars"). These lines are drawn to indicate each tenth of an inch difference in the barometric pressure as indicated by the mercury barometer. The dotted lines are drawn through regions of the same temperature as recorded by Fahrenheit thermometers (these lines are called "isotherms"), and are drawn at ten degree intervals. Regions which have had rain during the twenty-four hours preceding the report are shown shaded with diagonal lines. With this explanation behind us, let us examine the seasonal maps.

A weather map of winter (Drawing 7). This map follows the actual conditions as reported for December 26, 1934, but it will do equally well for any typical midwinter day.

Find the reporting station nearest your home and learn the conditions of the weather there on the day this map was made. What was the condition of the sky, the direction and the velocity of the wind, the air pressure, the temperature, and the condition with regard to rainfall (or snow), for the previous twenty-four hours? If a little figurine is near, does it indicate the condition of the weather properly?

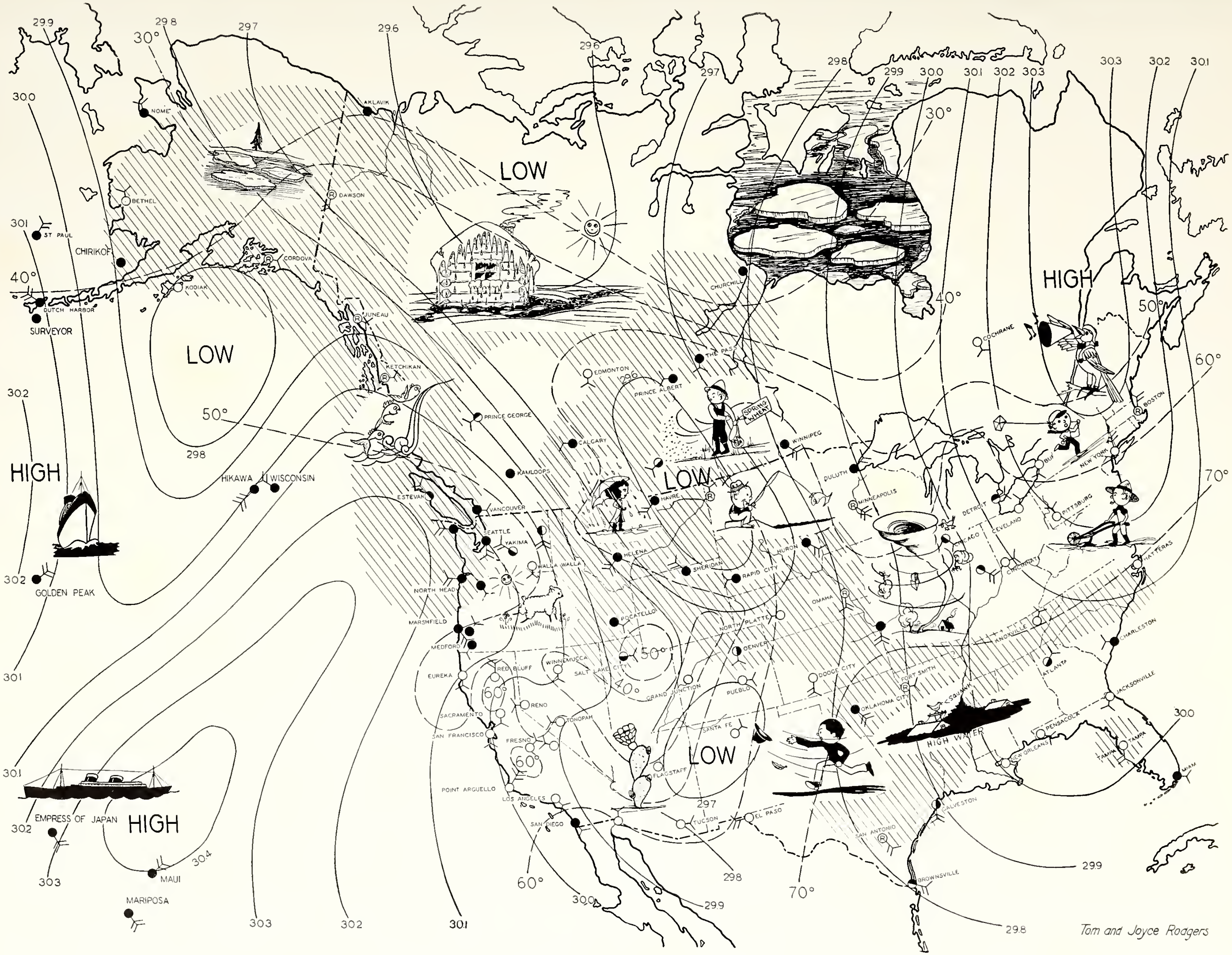
Now look at the map as a whole and note the "highs" and the "lows." The wind is blowing into the "lows" and out of the highs" (counterclockwise into the "lows," and clockwise out of the "highs"). Note that the isotherms (temperature lines) run to the north on the eastern margins or "fronts" of the "lows" to show that temperature rises as the "low" comes on. The isotherms run radically to the south on the eastern "front" of the "high" that occupies most of central North America. The thirty-below-zero line swings south to come to the border of the United States in the region of North Dakota. This winter map indicates that the interior of great land masses, such as the United States, experiences more intense cold in winter than regions near the sea (and on the summer map you will see that the exact reverse is true).

In January and early February of 1936, this same region of central North America experienced cold more severe than this map shows, the coldest weather for the longest extent of time ever recorded there. The influence of the warm Pacific Ocean is very marked, for the isotherms run far to the north on its shores, and winter rains are well advanced in this region. To see a radical change of temperature in a relatively short distance, count the isotherms from the Gulf of Alaska to Dawson, Yukon Territory (from 50 degrees above zero to 30 degrees below). Incidentally, how many ships reported by radio from the Pacific Ocean?

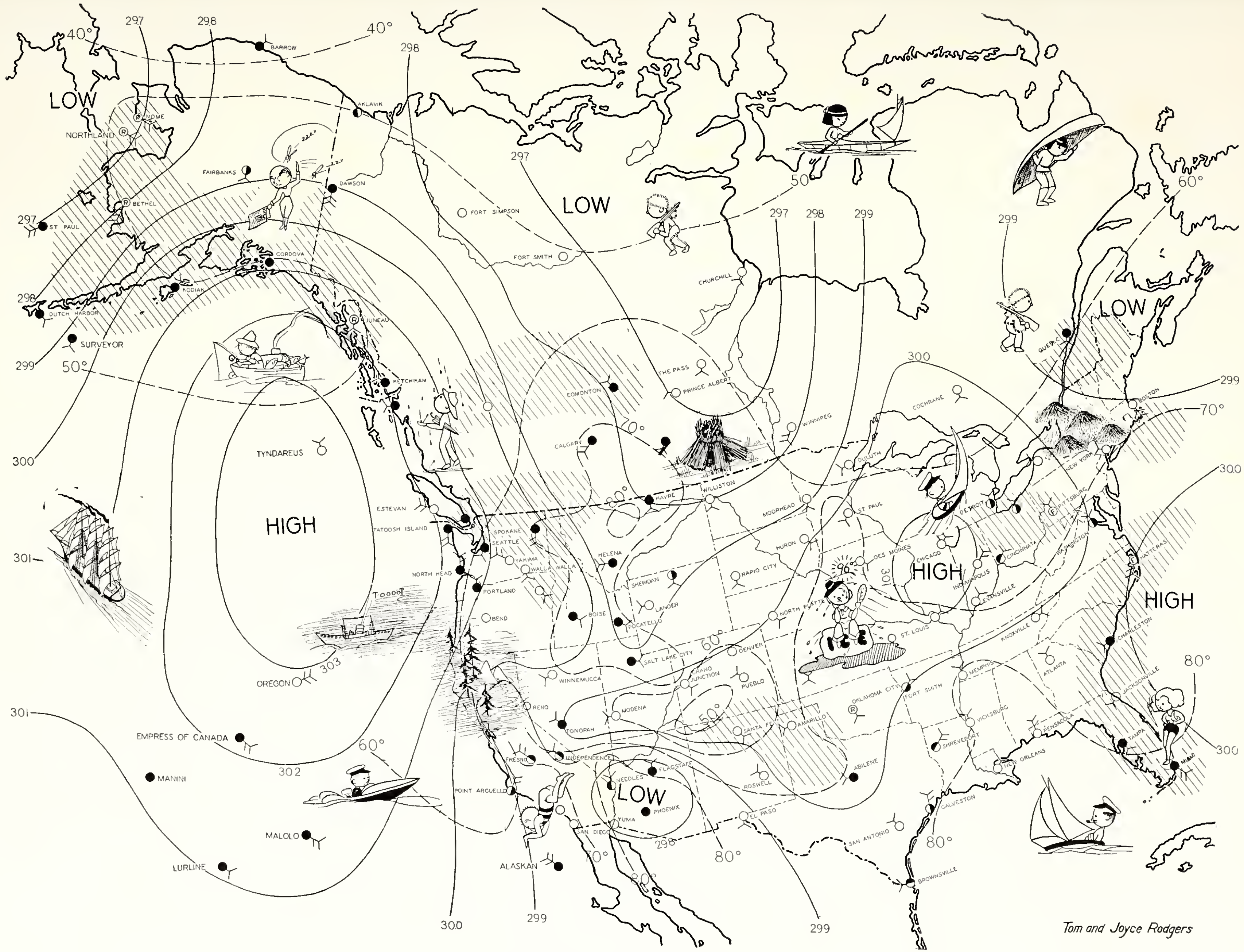
A weather map of spring (Drawing 8). This is the actual weather map of June 1, 1935. Though its date is that of relatively late spring, the weather conditions it displays are typically spring. The wild flowers of the deserts and of the Far West will have passed their prime in April. Lambs will be two or three months old. Northern snow will have melted, and the breaking ice will be out of the northern rivers and bays, though it is still frosting in northern Canada and at Point Barrow, Alaska. Spring wheat planting in Canada was done in April and May. Birds are still singing; many of them are busy with second families. Floods of the Middle Western rivers that were caused by spring rains which melted winter's snows (such as the terrible floods of Pennsylvania and New England in mid-March, 1936) will have abated, to be caused anew by thunderstorms. Kite flying will have passed its prime, but gardening still flourishes everywhere. The season for tornadoes in the Middle West is still present.

Compared with the winter map, this map of spring is noteworthy in that its cyclones are not nearly so intense. The middle portion of the continent has warmed remarkably, so that its weather this day is warmer than the Pacific Coast. The "low" that centered over Nebraska and the Dakotas has left a trail of rain behind it, and we know that weather there is "muggy," damp and hot. That "high" lying off the California coast is bringing the persistent fair weather with the northwest ocean wind for which the state is noted. An extensive "high" with fair weather is present over all of Eastern United States. That "low," developing over Texas, will become more intense as the Gulf of Mexico winds begin to enter it, and it will combine with the "low" above to bring heavy, late spring rains to all the East.

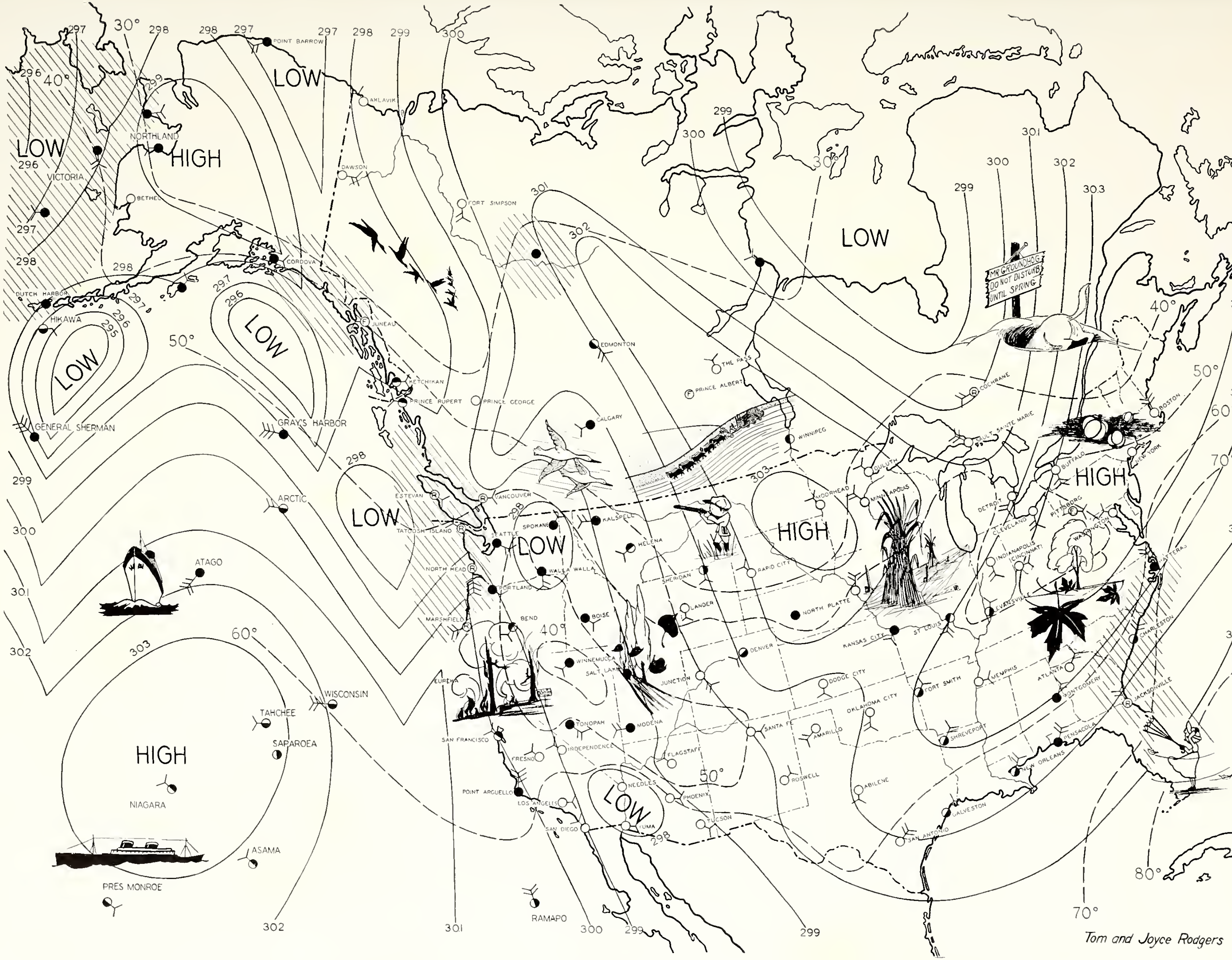
A weather map of summer (Drawing 9). This is the weather map of July 16, 1935. How different it is from the winter map! Notice how the isotherms run to the north in the Middle West, and to the south on the Pacific Coast, just the reverse of winter. The temperatures on which the isotherms are based were taken at 8.00 A.M. in the East, and at 7.00 A.M. in the Middle West, almost the coolest portion of the day. Let's see what the highest temperature for the preceding twenty-four hours was for some middle Western cities. Des Moines, Iowa, 88; Omaha, Nebraska, 90; Chicago, Illinois, 70 (comparatively cool); Dodge City, Kansas, 96. Strange to say it was hotter in Utah, Idaho, and Montana this day than in the Middle West. It was 100 at Boise, Idaho and Salt Lake City, Utah; 102 at Havre, Montana. The record breaking dry and hot sum-



8. A WEATHER MAP OF SPRING



9. A WEATHER MAP OF SUMMER



10. A WEATHER MAP OF FALL

mer of 1934* gave to the Middle West its unbelievably high temperatures, day after day; 1935 was more reasonable, but still this summer map shows the summer extremes (as the winter map showed the winter extremes), which the interior of a large continent will produce.

One must not leave the matter of high temperature without mentioning the high points of some other hot places. In Needles, California (the eastern border of the Mohave Desert), 106; Phoenix, Arizona, 110; Fresno, California (in the San Joaquin Valley), 106.

The summer convection fogs, or sea fogs, are promoting the Redwoods of the northern California coast. People of Alaska are swatting mosquitoes. Harvesting is well advanced in the wheat belt. The Indians and Eskimos of northern Canada are laying in their winter food. Hay is being made in New York, and of course there is sea bathing in Florida and California, though the sea water is very little warmer than in January.

A weather map of fall (Drawing 10). This is the weather map for October 2, 1934. October gives the most uniform and equable weather over the whole of North America that is experienced at any time of the year. This weather map displays this fact in an impressive way. The limited number of isobars showing very little difference in air pressure from place to place, and no pronounced cyclones as a consequence, is the outstanding feature of the map. By following the isotherms, one notes that large areas have the same temperatures. Isotherms almost nowhere run radically north or south. The temperatures now, for almost the only time in the year, are very nearly the same throughout the United States. It follows that nowhere is there a high wind.

The relative humidity is at its lowest in the Far West at this time. Forest litter and bark of trees are at their driest, and forest fires are a serious menace in this region. They make the air everywhere a hazy blue. Leaves are showing autumnal colors throughout the nation. Birds migrate toward the southlands. Gunners feel the itch to shoot. Belated wheat and oat harvesting continues in Canada. Fodder is in the shock in the corn regions. Pumpkins foretell of Hallowe'en. The fat ground hog (woodchuck) prepares for winter hibernation. This is the season of the year's calmest and most pleasant weather.

*Here are the high points for the same localities on July 17, 1934: Des Moines, Iowa, 96; Omaha, Nebraska, 104; Chicago, Illinois, 74; Dodge City, Kansas, 102.

CHAPTER III

SIGNS OF THE WEATHER

CLOUDS

I am the daughter of earth and water,
And nursling of the sky;
I pass through the pores of the ocean and shores;
I change, but I cannot die.
The Cloud, Shelley

What makes a cloud. Clouds are formed whenever the air is unable longer to hold in invisible form its water vapor. The capacity of air to hold its water vapor in invisible form depends upon the amount of such vapor and the temperature of the air. At lower temperatures, the air can hold less water and at higher temperatures more water. Thus it follows that clouds result because air, with a certain amount of water vapor, has been cooled below a point where it can retain all of that water in invisible form. Clouds are the result of cooling of the air.

Air may be cooled in various ways. The most important air cooling is brought about by the pushing of the air, that has been heated because of its position near the surface of the earth, into colder regions aloft. When a cyclone or "low" is approaching, great masses of surface air blow into the cyclone from all sides; the air from the south and east is warmer and more moist, and this, in rising, becomes cooled below its dew point and forms the great, extensive clouds of a storm period. Smaller masses of air may be heated near the surface of the earth under a fair-weather sun, and these rise to form the cumulus clouds. Again, the air may be cooled, and clouds formed, by the lifting of air to cross a high mountain; by the radiation of heat into the clear sky at night, bringing about the morning cirrus types and low fogs; by the throwing of air into waves (at the crests of the waves clouds form because the crests are higher and colder); by the passage of moist ocean air over colder water, forming thus the sea fogs of the Maine and the West Coast.

A high, cold mountain, such as Mount Rainier (Illustration 11 and Illustration 5), illustrates graphically the cause of cloud formation. The air from the western lowlands of the state of Washington is usually warm and moisture-laden. As this air is forced by the persistent westerly winds to cross the cold elevations of Mount Rainier, it cools at the rate of 1.6 degrees Fahrenheit for each 300 feet of ascent. As the air cools, its ability to hold water in invisible form decreases, until on the high cold flanks of the mountain the water begins to condense out in a cloud.

Only a few cloud fragments are shown in

11. CLOUDS FORMING ON MOUNT RAINIER

Illustration 11, but at times the entire top of the mountain will be enveloped in a dense cloud mantle. Air that is forced to rise in a "low," or cyclone, forms clouds similarly; and such a "low," crossing Mount Rainier, gives to the mountain a tremendous deposit of snow. Both the snow and the glaciers of Illustration 11 are the children of the clouds.

The names of clouds. Clouds have always been a part of the world in which man lives, and yet no attempt was made to name clouds until the beginning of the 19th century. The Frenchman, Lamarck, gave to clouds their first names in 1801, but his French terms were superseded in 1803 by the simple Latin names given by the Englishman, Luke Howard. Howard used four terms to name his clouds. They were: "cirrus," "stratus," "cumulus," and "nimbus." "Cirrus" means "lock" or "curl" and refers to the high, white, delicate wisps of cloud. "Stratus" means a "spreading out" or "layer" and is applied to any cloud which smoothly overcasts the sky. "Cumulus" means a "heap" and is applied to the mound-like clouds, so frequently seen on fair days, that have flat bases and white, billowing upper reaches. "Nimbus" means literally a "rain cloud" and was the name applied by Howard to any layer cloud from which rain or snow is falling.

The names given by Howard are still in use to describe the four basic types; but many names for the intermediate and modified types have been suggested, so many indeed that International Meteorological Committees have ruled upon and accepted certain terms to get uniformity in cloud names and cloud descriptions. The first such cloud report was accepted by the International Meteorological Conference of 1891. Since then International Committees have published cloud names, photographs, and descriptions.

Thirteen cloud names are now in use. These are the four names proposed by Howard, plus names which describe combinations of these four basic types, plus names of cloud forms which are very high, plus names of clouds that are broken by the wind. Thus we have cirrus, stratus, cumulus, nimbus; cirro-stratus, cirro-cumulus, strato-cumulus, cumulo-nimbus; alto-stratus; alto-cumulus; fracto-stratus, fracto-cumulus, and fracto-nimbus. If we remember the definitions for the basic types, and also that "alto" means high and "fracto" means wind-broken, then we find that all of the terms are at once self-explanatory.

Cirrus (Illustration 12 and also present in Illustrations 3 and 17). This most delicate of all clouds is displayed across the sky in detached portions that may be thread-like, feather-like, whisk broom-like, curled or tufted. To types of this cloud are given the popular names of "witch's broom," and "mare's tail." It is the highest of all clouds, forming most frequently at 32,000 feet, but ranging from 18,000 to 52,000 (over nine miles at the highest). It is always white and composed of ice crystals.

The cirrus cloud is formed in the air that is forced to the highest levels in a "low," or in a thunderstorm. Most of the moisture of the "low," or thunderstorm, condenses out in heavy clouds at comparatively low elevation, but the great height to which the air may ascend, and the inability of the thin and cold air to hold more than the minutest trace of water in invisible form at these elevations, forms the delicate cirrus cloud. The air that has been forced up in the "low," or in the thunderstorm, spreads out in all directions at the top and the high winds aloft carry the cirrus cloud in advance of the "low" (as well as to the rear), and often in advance of an approaching thunderstorm. This cloud may form at night, too, by the radiation to space of the heat of high air; and so the cloud may appear in the morning as cirrus or cirro-cumulus, shortly to disappear again as it reabsorbs heat from the sun.

If the sky is brightly blue above the cirrus cloud, then a "high" is at hand and the cloud may be expected to disappear during the morning, to leave a spotless sky. If the sky is gray-blue, then the cirrus may be expected to thicken to cirro-stratus, for a "low" with its heavier clouds and probably rain or snow is on the way.

Cirro-stratus (Illustration 13, and also present in Illustrations 3 and 33). When the fibrous cirrus forms into a layer of thin, white cloud like a veil, it is then cirro-stratus. When it overcasts the sky in a smooth layer, it presents an appearance of milky haze. The moon and the sun shine through it, but about them the cloud produces halos. This cloud is formed by causes similar to those that form cirrus, and at similar great elevations (it averages about 30,000 feet rather than 32,000). It is composed also of ice crystals.

Cirro-stratus is almost a positive indicator that a "low" is approaching, and that one may expect rain or snow within twenty-four hours, or sooner, after its appearance. As the storm area comes nearer, the cirro-stratus thickens to alto-stratus.

Alto-stratus (The cloud above the fog of Illustration 25). The thickening and formation of cloud at an elevation somewhat lower than cirro-stratus bring about alto-stratus. It is a thin, gray cloud, uniform in structure, and not showing the fibrous character of cirrus or cirro-stratus. The sun and the moon shine through it, though feebly, and about them the cloud produces coronas. The average height of the cloud is about 20,000 feet, but it ranges from 6,000 to 50,000 and so has the widest altitudinal range of all clouds. It is composed frequently of water particles, though its highest forms must be ice crystals.

This is the normal cloud to expect as the center of a "low" approaches. It follows regularly on the heels of cirro-stratus, but since clouds are forming at lower and lower levels by the uplifted air of the areas nearer the center of the "low," this cloud averages lower than the cirrus types. Like cirrus, alto-stratus may at times be formed at night by the radiation of heat to space of upper atmospheric levels and the formation of cloud there. This is the explanation for the alto-stratus above the advection fog of Illustration 25.

If alto-stratus forms as explained for Illustration 25, then it may be expected to dissolve under the sun to leave cirrus forms and finally a clear sky. If it results from the formation of a thicker and lower cloud following cirro-stratus, then one may expect true stratus shortly, to be followed by nimbus and rain or snow.

Stratus (Illustration 14, and present also in Illustrations 18 and 26). Since the word "stratus" means "layer," any uniform blanket of cloud may be termed stratus. Pure stratus is so uniform that it photographs as a smooth grey sky and shows no structure. Illustration 14, therefore, is not pure stratus because it shows some unevenness, but pure stratus is meaningless in an illustration. This, the commonest cloud, is always gray, conceals the sun or moon, and is comparatively low (it averages about 2100 feet, but may occur as low as 400 or as high as 6000). It is composed of water particles in summer usually, but of ice crystals in cold weather.

Pure stratus is the cloud that covers us as the center of the "low" nears. It is the result of the pushing aloft of the moist air there. The advection fogs of the West give also the appearance of stratus from below, but they are formed by the passage of moist air over cold ocean water as is explained later.

If stratus is an advection fog, it dissolves under the sun to form first fracto-stratus, and this goes, leaving a clear sky. The stratus of a "low" may be expected to thicken to nimbus, to provide rain or snow. If the "low" is passing, the nimbus may give way again to stratus, though this is usually wind broken and therefore fracto-stratus. Rain does not necessarily follow stratus, though this is the usual sequence.

Nimbus (Illustration 15, and also present in Illustration 38). This, the rain cloud, is officially defined as "a thick layer of dark clouds without

12. CIRRUS CLOUDS

13. CIRRUS CLOUDS FORMING CIRRO-STRATUS (CIRRUS IN A LAYER)

14. STRATUS OR LAYER CLOUD

shape and with ragged edges." From this cloud, steady rain or snow usually falls. As in the case of pure stratus, a photograph of nimbus with a camera situated in such a rain would be impossible, for the sky would be uniform and blank. Illustration 15 solves this problem, however, by showing an oncoming nimbus cloud, the front margins of which show the ragged outline typical of the rain cloud, and the cloud some miles beyond across the valley and in the mountains of the opposite side shows the falling rain. Not every cloud that rains is nimbus, for we shall see that rain may fall from strato-cumulus and from one or two other types under certain circumstances; but nimbus is the typical rain cloud, the cloud from which all heavy rains fall. Since the cloud rains or snows, it is composed of water particles or ice crystals. It varies greatly in height, from an average of 3600 feet to a maximum height of 18,000 feet. It may, however, be as low as a few hundred feet.

The "low" is first heralded by cirrus, to be followed in succession by cirro-stratus, alto-stratus, and stratus. Following stratus comes the nimbus. Nimbus is the logical answer to the uplift of moist, warm, surface air near the center of the "low" (more typically on the southeast quadrant as shown by Drawing 6). This air is so heavily laden with water that it forms cloud at a low elevation as it rises, and begins to rain with any further rise of the cloud into colder levels.

The nimbus cloud is the answer to the warnings posted by cirrus, cirro-stratus, alto-stratus, and stratus. The passing of nimbus will be followed by fracto-nimbus, fracto-stratus, and the events that accompany the onset of clear weather.

Fracto-nimbus (Illustration 16, and present also in Illustrations 29 and 30). As the center of the "low" passes, the wind changes, often abruptly, from northeast, east, or southeast to southwest or northwest (depending on the position of the region with respect to the center of the "low," as shown by Drawing 6). The boisterous southwest or northwest wind tears the under surface of the nimbus cloud and sends fragments of it scurrying to the east. To these cloud fragments on the under surface of the nimbus cloud the sailors give the name of "scud." The last of the rain comes in gusts with the forming of the scud. This cloud, formed from nimbus, lies at the same elevations as nimbus, and is similarly formed.

One may expect fracto-nimbus shortly to show patches of blue sky with alto-stratus, cirro-stratus or cirrus clouds above the scud. The last of the rainy squalls will soon pass, and the general cloud will be replaced by fracto-stratus.

Fracto-stratus (Illustration 1). Following nimbus and fracto-nimbus in the sequence of events that attends the movement of a "low," the last general cloud is fracto-stratus. The same wind that comes out of the southwest or northwest to make the scud on the under surface of the nimbus cloud will continue to rupture the layer cloud that remains after the rain has ceased. This is fracto-stratus. It is a grey cloud that frequently, through its breaks, will show layers of alto-stratus, cirro-stratus, or cirrus at upper levels. Since it follows nimbus and fracto-nimbus closely, its structure and elevation will be the same as nimbus.

Fracto-stratus only rarely precedes the stratus and nimbus on the eastern edge of a "low." So, since it usually appears after nimbus, one may expect this cloud shortly to clear away to leave a clear sky or a sky with cirrus tufts. Even if it is the result of the dissolving advection fog of West Coast valleys, a clear sky will follow its breaking.

The clearing sky (Illustration 17). Cirrus, cirro-stratus, stratus, nimbus, fracto-nimbus, and fracto-stratus herald the approach of a "low," and accompany it on its eastern half to make the gray day, the rain, and the breaking rain cloud. Clearing weather toward the western portion of the "low" (see Drawing 6), is accompanied by a chaotic cloud group to produce the weather man's "unsettled weather." The last of the stratus will break away to show cirrus clouds in the upper sky (upper left portion of Illustration 17). The vivid sun promptly begins to warm the wet earth and at times, before the last of the stratus clouds have gone (upper right and extending in an arm toward the left in Illustration 17), the warmed and moist surface air, as it rises, will be forming cumulus clouds (on the lower half of Illustration 17).

Alto-cumulus (Illustration 18, and also Illustration 19). Alto-cumulus is a small, high, white cloud that may approach its neighbor so closely that the outlines are confused and the sky seems to be filled with closely packed cloud mounds. Again, as in Illustration 18, the clouds may be somewhat scattered and their edges torn into irregular fringes by a strong wind blowing at their great altitude. The average elevation of this cloud is about 15,000 feet, but it occurs as low as 7000, and as high as 36,000 feet. It is composed most frequently of ice crystals. A common name applied to it is "sheep-herd cloud."

This cloud is formed usually on crests of high air waves and so may be arranged in rows. It is a cloud of the upper levels, and Illustration 18 shows that it is far above the dark stratus cloud that stands above the Pacific Ocean. It is a fair weather cloud and forms on the first day following rain, or may show itself above the breaking stratus as in Illustration 18. Though it is usually a morning cloud, this picture shows it as the sun is setting over the ocean.

Cirro-cumulus and alto-cumulus (Illustration 19). Cirro-cumulus is a small, white flake of a cloud. Often it appears with its neighbors in close-ranked rows across the sky. The sun and the moon shine through the rows of cirro-cumulus to show their thinness, whereas the heavier alto-cumulus (the larger clouds on the right in Illustration 19) obscure the sun or the moon. Cirro-cumulus, however, is formed, as is alto-cumulus, by waves in the upper atmosphere. Each wave's crest reaches high enough so that its meager water vapor is condensed out in cloud. Its average height is about 22,000 feet, but it may occur at 12,000 and sometimes as high as 50,000 feet. Because it forms so high, it is composed always of ice crystals. Sailors know cirro-cumulus as "mackerel sky."

Cirro-cumulus is nearly always a fair weather cloud and makes its appearance usually in the morning the first or second day following a storm period. One can expect it to dissolve away during the morning to leave a spotless and intensely blue sky.

Cumulus (Illustration 20, and also Illustrations 17, 37, and 52).

They come, most fitting sequel of the storm,
Cloud puffs with atmospheric leaven,
Into the days that follow dark and rain.
They float, ginned by the northwest wind to form
Cotton balls of heaven,
Beneath blue sky and over fields of grain.

They skirmish, long rows of sails on foam,
White-fringed by the sun,
Deployed like ancient caravels upon an azure sea.
They romp, tresses swirling with the wind as comb,
Cloud children in wild fun,
With their clean but ragged shadows on the lea.

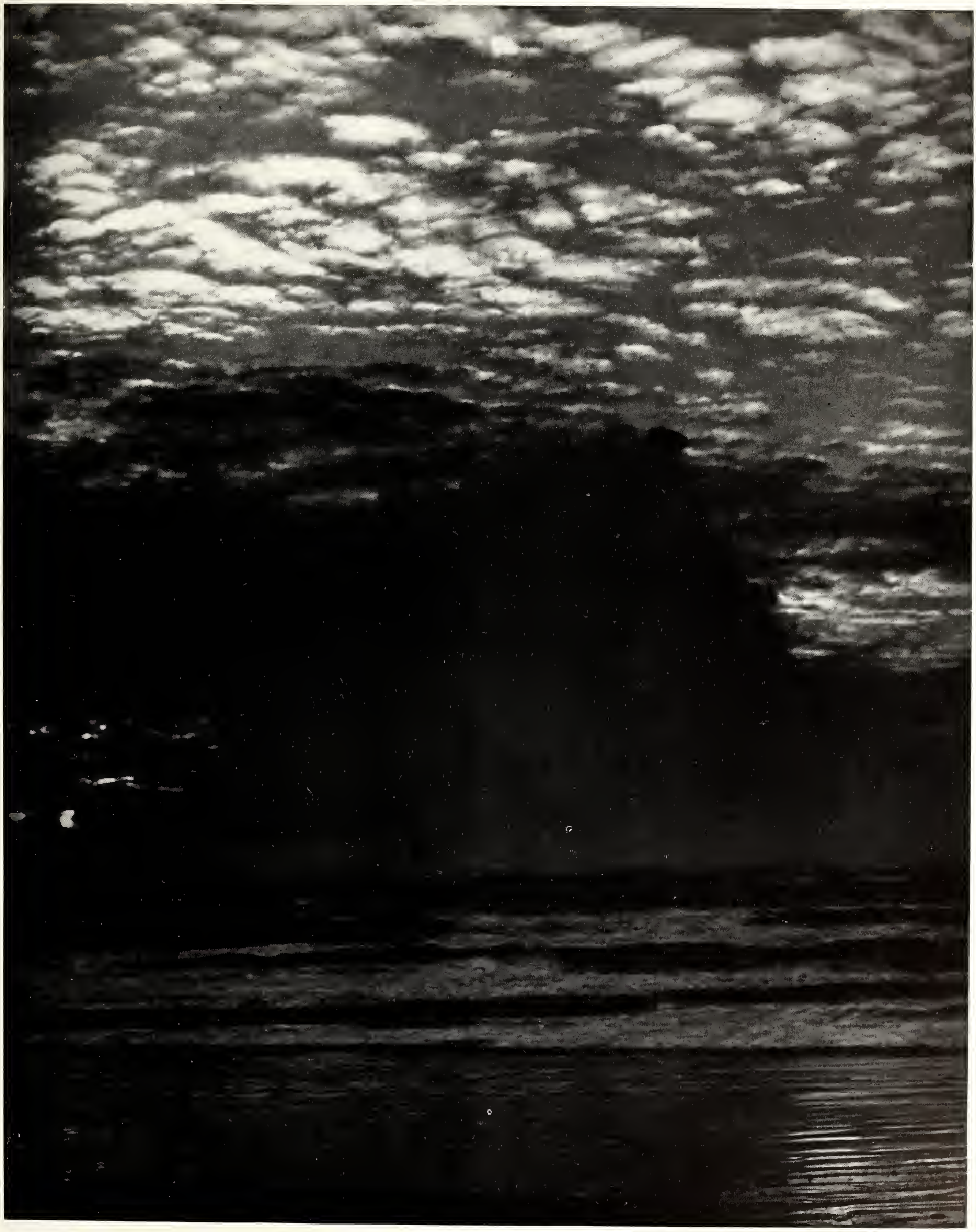
They drift, motile banks of pure sky snow,
Made—not melted—by the sun,
Across the blue and o'er an earth ablaze with June.
They disappear at ev'n for to them the night is foe;
Fading softly one by one;
Gone, when the day is done, too soon!

This, the "woolpack," is the best known and most beloved of all clouds. Its beauty accompanies the days of brilliantly blue sky and the good spirits that always attend the air pressure of the

15. NIMBUS OR RAIN CLOUD

16. FRACTO-NIMBUS OR WIND-BROKEN RAIN CLOUD

17. THE CLEARING SKY



18. ALTO-CUMULUS OR HIGH CUMULUS CLOUDS (UPPER PORTION) AND STRATUS CLOUDS (CENTER)

19. CIRRO—CUMULUS (LEFT HALF), AND ALTO-CUMULUS CLOUDS (RIGHT HALF)

20. CUMULUS CLOUDS

"high." In the first two or three days following the rain of the "low," cold air descends as the eastern margin of the "high" extends above the wet ground. The sun is brilliant and intense. Quickly it heats the ground, the ground heats the surface air, and this air, moisture laden, is forced to rise. Since cold air is descending everywhere, the moist air rises but a comparatively short distance before it, too, becomes chilled, reaches the saturation point and begins to condense out its excess water in cloud. Thus is formed the cumulus clouds. (The alternately descending and ascending columns of air that accompany conditions that form cumulus clouds give the "rough" air that destroys much of the pleasure of airplane riding.)

The cumulus cloud, if unmodified by wind, is a rounded, billowy mass with a flat base. It is a comparatively low cloud with the base sometimes as low as a few hundred feet from the ground, and the base average about 4000 feet. The top of the cumulus may be as low as 3000, but will average about 6000, and on rare occasions towers to much greater heights. Away from the sun the cumulus cloud is all white; toward the sun it shows a dark center with brilliant margins. Normally, it is composed of water particles.

Cumulus clouds are fair weather clouds. Such clouds may become thick enough nearly to fill the sky and so form strato-cumulus. If the northwest wind that usually accompanies them is strong, then these clouds are wind whipped into fracto-cumulus. Only in the mountainous regions or in the sultry air of the summer of the Middle West or East is the cumulus likely to tower up in the spectacular thunderhead, the cumulo-nimbus. Usually cumulus clouds will disappear at nightfall to leave a clear sky. Only on rare occasions are cumulus clouds observed at night.

Strato-cumulus (Illustration 21, and also Illustration 22). Toward noon on the fair weather day that produces cumulus clouds, these clouds may become so numerous that they nearly fill the sky. Their flat bases join to form a dark layer with only infrequent areas of blue sky between. Rolls of grey clouds showing somewhat lighter margins may reach from horizon to horizon. These are strato-cumulus clouds, cumulus clouds that form a layer. Superficially they look like fracto-stratus, but unlike that cloud they show rounded rather than ragged edges. Then, too, the conditions of the day are greatly different and this will serve to assist in their identity.

Since strato-cumulus clouds form toward noon, or shortly after noon, they will have risen somewhat higher than the cumulus clouds that preceded them (it is this continued lifting that forms the greater cloud mass of strato-cumulus as compared with cumulus). Their average elevation will be about 8000 feet, with base between that and 4500, and tops usually not above 16,000. They are usually composed, as are cumulus clouds, of water particles.

Though light showers may fall from strato-cumulus clouds, one may expect them to thin to cumulus or fracto-cumulus by mid-afternoon, and to leave a clear sky at night.

Rain flurries from strato-cumulus clouds (Illustration 22). Strato-cumulus clouds nearly fill the sky in Illustration 22, and through the center of the picture over the valley rain is falling. Since these clouds occur during the first days of the "high," weather men call the showers "high pressure flurries." The flurry is most frequent from the strato-cumulus clouds of winter, and at that time it contributes skifts of snow. Since the northwest wind may be blowing a blizzard by drifting the snow that fell during the previous day, these skifts add to the drifts that the blizzard has piled.

Fracto-cumulus (Illustration 23, present also in Illustrations 5, 11, 28, and 49). Since cumulus clouds form in the days following the passage of the "low," days wherein the air blows out of the following "high" from the west, it is seldom that these clouds are allowed to retain their rounded, billowy forms for long. If the air is reasonably quiet, the cumulus clouds may form strato-cumulus by noon, but far more frequently a rising wind blows more and more heavily at this time of the day, and the clouds are flattened and frayed into the wind-torn fracto-cumulus clouds. Normally cumulus clouds may be expected to become fracto-cumulus by midday because of the rising wind.

With the exception of their ragged edges, fracto-cumulus clouds have all the characteristics of true cumulus. With the dying of the wind and sun in late afternoon, they also die to leave a spotless sky.

The "high" is first advertised by fracto-nimbus and fracto-stratus. It is ushered in by beautiful cirrus on the morning following the rain, beautiful because the sky is so blue. This same morning, or the very next morning, may show cirro-cumulus and alto-cumulus. During the warmer portions of these first days, the cumulus clouds will fly. They begin to form about 10.00 A.M., become strato-cumulus by noon or shortly after, and fracto-cumulus by mid-afternoon. From them there may fall a "high pressure flurry." The two or three days that follow this succession of clouds will be cloudless, for these are the days of the "high," but by the end of the third or the fourth day one may expect cirrus or cirro-stratus to appear in announcement of the oncoming "low" (see Drawing 6).

Cumulo-nimbus (Illustration 24). Cumulo-nimbus is the thunderhead. Excepting only the cloud of the tornado, it is the most spectacular of all clouds. It towers into the air mountain high, and is provided with parapets, turrets, and domes like a weird castle. In its fantastic outline one may imagine the faces of giants and ungainly beasts. The base is dark, with detached clouds like scud floating out from it. The top may be spread out like an anvil, with cirrus-like clouds streaming away from the anvil's margin.

In its formation, cumulo-nimbus seems to be an exaggerated cumulus cloud. It forms from local, rising (convection) currents of warmed and moist air, as does the cumulus. It differs from typical cumulus in several respects, however. It occurs only during spring and summer, whereas some of the most magnificent cumulus clouds may occur during the winter. In the sultry and humid weather that accompanies the summer "low," the cumulo-nimbus rises, whereas the true cumulus is a fair weather cloud, a cloud of the "high." Cumulo-nimbus occurs over much of the United States, but it is most turbulent and most destructive in the Middle West. In the Far West it appears only above the mountains.

In the sultry air of a late afternoon summer day, one may watch the cumulo-nimbus form. In the beginning it appears in the murky sky to the west as a poorly defined cumulus cloud. This cloud rapidly increases in size and other similar clouds begin to form in its vicinity. All of the clouds may be drawn together by the great updraft of air that forms them. After this there is but one cloud, and vastly larger. As the cloud towers higher and higher, its base becomes dark, and mutterings of thunder disturb the quiet air. If the cloud lies to the southwest of the observer, it will approach him steadily, to become more and more ominous. Rain may be noted falling like a sheet while the cloud is still at some distance. Scud or "squall" clouds may be seen fringing its margin. As the cloud swings overhead, the first rain falls in big splattering drops. The light of day fades out as if the curtain of night were suddenly rung down. Lightning displays itself in blinding streaks of light, with thunder crashes following each flash too soon. Big rain drops may increase and be accompanied by hail that rattles on roofs and roads in a fearful staccato of sound. Hail diminishes in quantity, and rain then falls in torrents. Surprisingly soon, however, the time interval between lightning flash and crash of thunder becomes longer and longer. The rain suddenly lessens, the thunder becomes again a distant mutter, and a wind, cool and fresh, comes out of the west. Wind and rain soon die. Light comes again to the darkened earth, and the setting sun, as if in reassurance,

21. STRATO-CUMULUS CLOUDS, OR CUMULUS CLOUDS FORMING A LAYER

22. RAIN FLURRIES FROM STRATO-CUMULUS CLOUDS

23. FRACTO-CUMULUS CLOUDS, OR WIND-BROKEN CUMULUS CLOUDS

24. CUMULO—NIMBUS, THE THUNDERHEAD CLOUD

shows a rainbow on the dark cloud in the east. Deep breaths are taken of the freshened air, for cumulo-nimbus, with its thunderstorm, has come and gone.

Advection, coast or sea fog (Illustration 25, and also Illustrations 4 and 34). Fog is a cloud that forms at the ground or very near it. When air at the ground level becomes cooled for any reason beyond the dew point, it may deposit the moisture it cannot hold in dew or frost. If the cooling below the dew point extends for a distance above the immediate surface, then fog will form in addition to dew. There are two distinct types of fogs, and, of course, several variations of each of these. One is the fog that develops in quiet air immediately above the point where the cooling occurs. This is called "radiation" fog. It is the common fog over lakes, streams, ponds, or in cool and moist hollows of the earth, in spring, summer, or in fall (in winter in the Far West). The other is the "advection" fog which is formed by the movement of warmed and moist air of one place, over surface conditions of another place that are colder—cold enough to lower the moist and warmed air below the dew point—so that some of the moisture condenses out in the fog cloud. Since the advection fog is produced usually by conditions that occur at sea, it is commonly called a sea or coast fog, even though it drifts over the land.

There are two regions in North America that experience frequently the advection fog. One of these is the California coast, the other the Maine and Newfoundland coast. Off the coast of Maine and Newfoundland the arctic current strikes the margins of the Gulf Stream; cold water strikes warm water. The air above the cold water is cold, that above the warm water is warm and moist. The mixture of the air above these ocean currents produces a dense fog, for the temperature of the moist air above the Gulf Stream is reduced below the dew point, or beyond the saturation point. This fog is a persistent problem for ships at sea, and as the air blows into a "low" standing over the Maine-Newfoundland coast, it brings the fog inland.

The advection fog of the California coast, though similar, differs in some important respects. The cause of the upwelling of cold water along the Pacific Coast is not certainly known, but the warmer water is supplied by the Japan Drift from the north. During nearly every brilliantly sunny day, the valleys of the California coast range mountains, and especially the great Sacramento-San Joaquin Valley of the interior, become very warm to intensely hot. The sea breeze rushes in to push up this heated air, and as the moist sea air crosses the cold area of water just offshore, fog is formed. The fog is carried inland to make a blanket for all the coast, and often it fills the coast range valleys, too.

The sea wind and the sea fog of the West occur only now and then during the months of November to April, for the land does not heat sufficiently to promote the sea wind during that time. From April to November, however, and especially in July, August, and September, the sea fog is a very frequent weather condition for all of coastal California, and for all valleys near the coast. As this fog moves inland its lower levels are dissolved away by the warm land, and so from beneath its base it looks just like a stratus cloud, for it lies several hundred feet above. Because of this, the Californian is inclined to call it "high" fog. Before this fog can penetrate to the Sacramento-San Joaquin Valley where the chief cause for its existence arises, it has all dissolved away in the hot and dry air, to leave only the persistent wind that brought it landward. Even on the coast and coastal valleys the morning sun will remove the fog by 10.00 A.M., but it will come again to the coast by the midafternoon and fill the valleys during the night.

One may see the advection or sea fog from above by climbing the mountains that surround the coast range valleys. From this view the fog, lying below, looks like a turbulent sea that is sending its misty arms into every canyon and ravine of the hills.

Radiation fog (Illustration 26, and also Illustration 27). This, the usual fog, is not formed by colder or warmer air flowing into a region, nor is it carried from the place of its formation to another (as is the advection fog), but is formed by the conditions that prevail where it appears. Air will become heavily supplied with moisture if it is in contact, for instance, with wet soils, a lake, stream, or pond. If there is no wind, the quiet air will tend to take up more and more water. During the night this same air becomes cooled by the radiation of its heat to air above and to space. And though the radiation of heat is no more rapid at night than in the day, there is no sun to replace the loss. The air often becomes cooled so much, therefore, that its temperature drops below the point at which it can hold all of its moisture in invisible form. Dew results where such air is in contact with the ground, and fog results above the ground if sufficient air is involved. This is the radiation fog.

In early September, 1935, heavy rains fell throughout the Middle West. Each night for several days that followed the rains, fogs formed in the depressions between the gently rolling loess hills of eastern Nebraska. When traveling over the highways in an automobile, one would drop into the dense blanket at the base of each hill, and leave it behind as the hill's summit was approached. Fog formed in the hollows because there was no movement of air there, to mix it with the higher and dryer air.

California coastal regions experience regularly throughout the summer the sea or advection fog. This region has little or no fog during the winter, for there is no strong onshore wind (since the land does not become hot) to bring the sea fog; and the ocean does not allow sufficient cooling along the shore for radiation fogs to form. In California valleys, however, and especially in the great Sacramento-San Joaquin Valley, dense radiation fogs follow every period of winter rain.

Cities that burn great quantities of soft coal may expect denser fogs than surrounding regions whenever conditions are suitable for fogs, because of the city's smoke. Every visible water particle, whether it be as small as the water particle of a fog, or water in the form of a large raindrop, requires a small particle or "nucleus" about which to form. This nucleus may be a minute dust particle or it may be a smoke particle. The tremendous smoke of London is in part responsible for the dense fogs of that city.

Radiation fog makes the white banner along the flanks of the Santa Lucia Mountains of Illustration 26. During the rainy season in California, such a fog forms frequently along the bases of the mountain ranges at night. In addition to the radiation of heat from the wet air at the base of the mountain, cool air is added from the summits of high mountains to accentuate the formation of fog at the mountain's base. When the sun begins to warm the air in the valley, and at the mountain's base in the morning, air begins to rise up the slopes. If a fog has formed, it, also, is carried slowly up.

Incidentally, a stratus cloud covers the sky above the fog and mountains of Illustration 26.

"Frost smoke" (Illustration 27). Most of the advection fogs are formed by the movement of warm and moist air over colder water, land, or snow. A surprising fog is sometimes formed under circumstances that are just the reverse of these, i.e., very cold air flowing over regions that are warmer. In the case of "frost smoke," cold air flowing over water causes a condensation of the water vapor in the air just above the water's surface.

Illustration 27 shows "frost smoke" arising from Lake Michigan, like steam from a boiling cauldron. The temperature of the water was not much above freezing, as the rim of heavy ice at the shore and the ice particles in the water attest, but the temperature of the air was ten degrees below zero when the picture was made; so the water and the air just above it were com-

25. ADVECTION, COAST, OR SEA FOG BELOW, ALTO-STRATUS OR HIGH STRATUS CLOUDS ABOVE

26. A BANNER OF RADIATION FOG, WITH STRATUS CLOUDS ABOVE

27. ICE, ICICLES, AND "FROST SMOKE" ON LAKE MICHIGAN

28. A "DUST DEVIL" BENEATH FRACTO-CUMULUS CLOUDS ON A UTAH DESERT

paratively very warm. As the below-zero-cold blast flowed over the Lake, it chilled the air at the surface of the water, chilled it below its dew point, or point at which it could hold all of its moisture in invisible form, and then the Lake seemed to steam. The "steam" or "frost smoke," strange to say, is composed of tiny ice crystals. "Frost smoke" is a picturesque name for a picturesque fog.

WINDS

In Chapter III, "The Work of the Weather," the work of winds will be considered in some detail. At this time, in connection with "Signs of the Weather," only one or two forms of wind will be considered, and they because they make themselves strikingly visible and are truly "signs of the weather."

"Dust Devils" (Illustration 28). When the sun shines brightly, as on days with cumulus clouds, strong convection columns of air arise from the heated earth. This air is pushed up by colder and heavier air that is falling to replace the warmer and lighter air. The column of rising air moves forward with the general direction of the surface breeze (usually from southwest to northeast), and any slight irregularity will start it into a whirl. After it is formed, the "dust devil" marches slowly and solemnly across the Southwest deserts where they are most conspicuous, sometimes carrying a column of dust to a height of several hundred feet. When the "devil" is not moved too rapidly by the surface breeze, it may tower into the air like a slender chimney. On the dusty old lake beds of Nevada, "Dust Devils" may follow one another in a march across the land until several are in view at the same time. The "dust devil" of Illustration 28, beneath the fracto-cumulus clouds, was taken on the desert at the south end of the Great Salt Lake, in Utah.

"Dust Devils" occur everywhere, they are merely more conspicuous and more spectacular in the desert regions. They are called "whirlwinds" or "dustwhirls" in regions other than the deserts, but they form just the same; they pick up dust and papers, scurry across the roads and along the city streets in the same manner as those formed beneath a desert sun.

The tornado (Illustrations 29 and 30). The writer had the rare but perhaps not enviable opportunity to witness and to photograph the tornado of these illustrations. The account of this experience with one of the most spectacular and most devastating of winds follows:

The day was not sultry when this tornado appeared for it was too early in the spring (April 6), but it was warm and pleasant. Though clouds had appeared during the morning, they cleared at noon to show a sky with a bright sun that continued to shine throughout most of the afternoon. Toward sundown a very heavy, green-black cloud, like a cumulo-nimbus, rolled over from the southwest and began to hail. The hail came gently at first and then in great hard balls. For several minutes this continued, then came a cessation and the sun burst forth from its low position in the west (it was 6.00 P.M.), illuminating the edges of the ragged cumulus and fracto-nimbus clouds to a brilliant white. But the heavy green-black cloud above our heads was more ominous than before. Someone in the house glanced out at the sky and saw the tornado.

The tornado was unmistakable even to us who had never seen one before. It looked like a great thick rope hanging in a long loose arch from the cloud immediately above. The tornado was black and ragged at its upper end, but it faded out until the lower lengths were the color of escaping steam. A southeast wind had swung the foot away to the west of the mother cloud, so that though the head of the tornado was directly above our heads, the foot on the earth was nearly a mile away. At the head could be seen the funnel mass of cloud, rapidly spiraling; at the foot a dust cloud arose and fell, to rise and fall again as the tornado raced over meadow and over cultivated field. The column of steam-like cloud could be seen reaching through this dust cloud to the ground.

The mother cloud was traveling northeastward, but the southeast surface wind moved the foot of the tornado to the northwest. As a consequence, the tornado became longer and longer. Loops appeared in it (the beginning of such a loop may be seen in Illustration 30), the loops moved up the long cloud to appear like coils, and then the tornado broke. With the breaking of the steam-like cloud, the tornado disappeared, but the dust cloud at the base continued its whirl for nearly a mile before it, too, disappeared. From the green-black cloud there now fell a heavy rain, but the tornado had gone.

This tornado was longer than most, but the foot was narrower than most, for it was never more than 300 feet wide, and at times only 100 feet. The devastation it accomplished wherever this narrow foot struck was as appalling as if it were the largest, those that cover 1000 feet. It made a path seven miles long in the ten minutes of its life, and though it moved through open country it damaged every building it struck, and completely demolished one house.

An hour after the tornado, we put chains on our car and plowed through the mud the rain had made to visit the path of the storm. One new house, struck as the storm was ending, had been lifted from its foundation and set down again askew. Another, a half mile to the south, had been wrecked completely, the boards all torn asunder and the wreckage scattered for a distance of several hundred yards along the path of the storm. Mrs. George Lenz, the wife of the farmer who lived at the place, was in this house when the tornado struck. She had been in the yard caring for some baby chicks when she was attracted by the roar of the tornado. She ran to the house to be with her baby who was sleeping on a bed. Mr. Lenz, who had been at some distance watering cattle, found Mrs. Lenz unconscious, but not seriously injured, in an orchard some hundred yards from where the house had stood. The baby, uninjured, was in the mother's arms. When we arrived, Mrs. Lenz was being assisted to a neighbor's home.

Incidentally, the foot of the tornado, as shown in the illustration, was in the process of demolishing the Lenz home when the picture was taken.

A tornado is a powerful whirl that is started by convection currents, not at the ground level as in the case of a "dust devil," but in the cloud level, some thousands of feet above. Convection currents must be especially powerful aloft to start the tornadic whirl; such conditions occur only on the east or southeast margin of a "low," and most frequently in March, April, or May when cold air aloft is in marked contrast to the earth-warmed air of sunny days. The whirling mass of air with its funnel-shaped cloud may extend only slightly beyond the cloud which forms it, and so never reach the earth. But too frequently the rotating air will involve the air below it, and so set up a whirling column that extends down, down until the earth is reached. Hail is formed by the same violent, turbulent uplift and descent of air that starts the tornado. Indeed, hail seems always to accompany a tornado, to precede it, or to follow it, though a tornado does not necessarily always accompany hail.

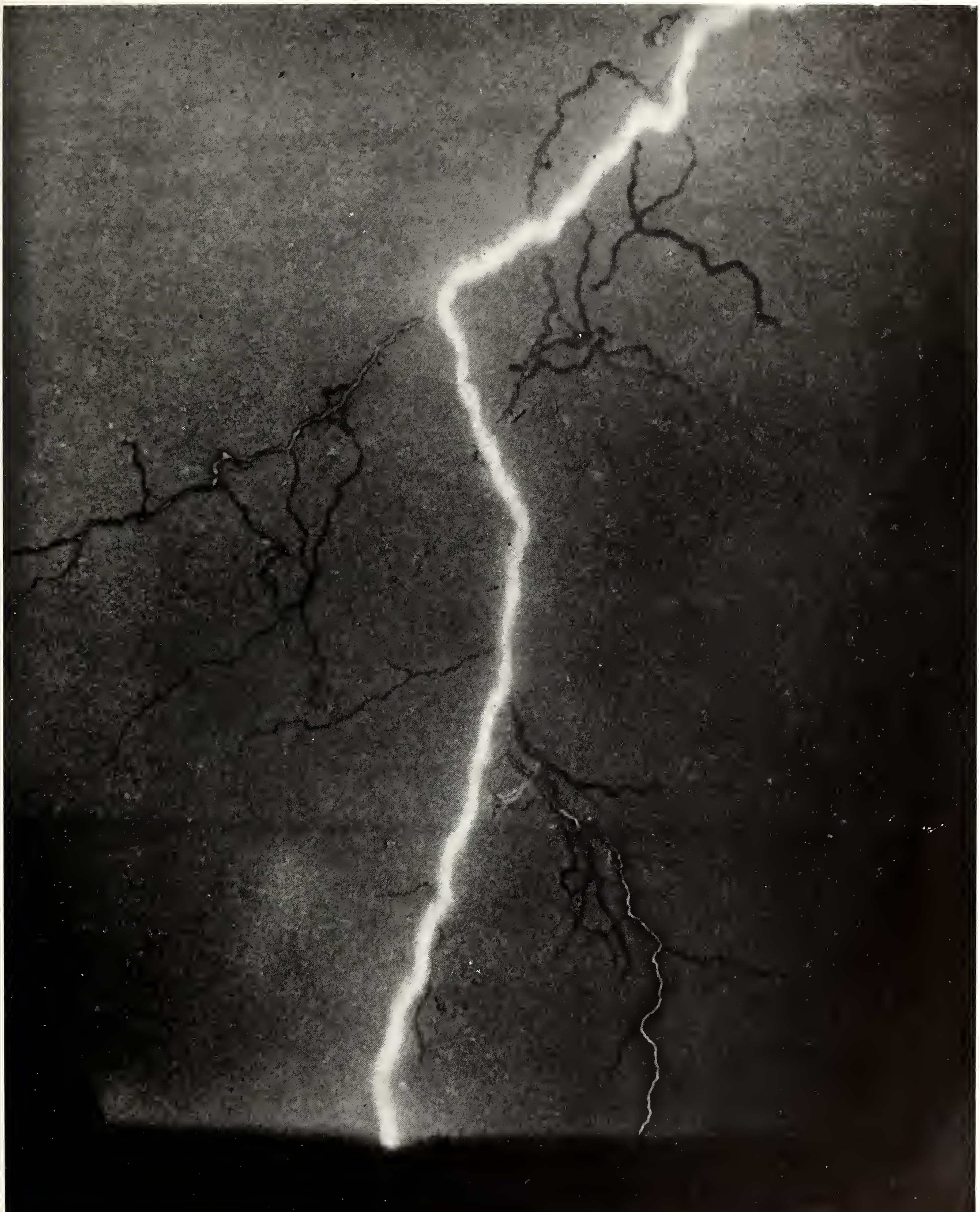
The visible part of a tornado is the cloud that is formed about the axis of whirling winds. These winds rotate so violently (from 300 to 500 miles per hour it is estimated), that they greatly reduce the air pressure toward the center of the whirl; this reduction causes the air there to expand and to cool; and the cooling forms a visible cloud.

The destruction caused by tornadoes is tremendous (the tornadoes of Mississippi, Georgia, Tennessee, Arkansas, and South Carolina on April 6, 1936, killed more than 400 people and did $20,000,000 damage). The unbelievably high winds destroy everything in their path. And when the storm passes through a city (as at Gainesville, Georgia, on April 6, 1936) the result

29. THE UPPER PORTION OF THE TORNADO CLOUD OF APRIL 6, 1919, AT ELMWOOD, NEBRASKA

30. THE LOWER PORTION OF THE TORNADO CLOUD OF APRIL 6, 1919, AT ELMWOOD, NEBRASKA

31. A "CYCLONE CAVE" AT A RURAL SCHOOL IN EASTERN NEBRASKA



32. LIGHTNING

is appalling. The vacuumlike center of the storm causes the internal pressure of the air in buildings to burst the walls open as it passes over. The force of the winds will lift and carry away objects as heavy as a locomotive. In addition to the great destruction, the tornado does freakish things: it drives straws into boards, and takes the feathers off chickens. The tornado here illustrated killed a horse by driving a corn cob into the front of its head.

As might be guessed, tornadoes are most frequent in the Middle West where the great interior produces the greatest weather extremes and the greatest weather turbulence. They may begin in late winter in the states that border the Gulf, and as the season advances they occur farther and farther to the north. They are most frequent in March, April, and May, but have occurred during every month of the year. The Atlantic seaboard and New England experience them rarely, and they are almost unknown west of the Rocky Mountains.

One thing more must be mentioned in connection with the tornado of Illustrations 29 and 30. These pictures were hurriedly taken with a little box camera, the only camera available. Since the upper portion of the tornado was directly overhead, and the foot more than a mile away, two exposures (the only two left in the camera) were required to get it all. Thus the two pictures represent the same tornado, and since they were taken quickly, one after the other, when the upper part is fitted to the lower, the whole picture gives exactly the appearance of the entire cloud.

The "cyclone cave" (Illustration 31). Escape from a tornado is not always possible, for though the storm occurs usually in the afternoon or early evening when it is visible, occasionally it occurs at night. Since a tornado is a feature of violent cumulo-nimbus clouds and occurs only on the eastern and southeastern margin of a "low," one who is weather intelligent may also be tornado intelligent. If in the open, one may side-step a tornado even if only a few seconds of warning are given, for the cloud nearly always travels to the northeast (the tornado of Illustrations 29 and 30 was an exception for its foot traveled northwest, though the upper part traveled northeast), and if it is not to the southwest when first noted it will be likely to pass to one side anyway. If it is directly to the southwest, then one should run as fast as possible to the southeast or northwest. People in the Middle West, in the tornado belt, rarely try to side-step a tornado, but rely on their basements or outdoor cellars which they call "cyclone caves." The rural schools of eastern Nebraska have these "cyclone caves" as a permanent adjunct to the school building. In Illustration 31, the "cyclone cave" of the Fairview School is shown. It is a nicely bricked and plastered cellar with a ventilator and with its door situated just a few feet from the schoolhouse door. But after all, tornadoes cover such a narrow strip of ground that the chances of ever being struck by one, even in the region of "cyclone caves," is very slight indeed.

Lightning (Illustration 32). Cumulo-nimbus, the thunderhead, with its great, piling, turbulent cloud may bring torrents of rain; it may bring hail; now and then it produces a tornado; and certainly thunder will accompany it; and, of course, the thing that causes thunder, the lightning. The violent convection or uplift of air in the cumulo-nimbus soon causes raindrops to form. These drops are carried up with the ascending air and grow larger and larger as they go. These drops may break up, or fall to earth. The smaller drops near the cloud's top carry a negative electrical charge, the larger near the cloud's base carry a positive charge. The earth has a negative charge. Eventually the difference in charge will cause a lightning flash from the base of the cloud to the top, or from the cloud to the earth, to equalize the electrical potential.

The lightning of Illustration 32 is the best known form of lightning, the sinuous or zigzag flash between cloud and earth. "Sheet lightning" is caused by the lighting of a cloud with the flash concealed. "Heat lightning" is the flickering of lightning along the horizon in a muggy evening, caused by a thunderhead beyond the horizon. Lightning is of common occurrence throughout the spring and summer (the season for cumulonimbus), in most of the United States. On the West Coast it occurs, if at all, chiefly in the winter or above the high mountains in summer.

Illustration 32 presents a problem for which the entire solution is not apparent. This picture shows some of the so-called "black" lightning. Black lightning is something the eye never sees, but the camera does. This picture, taken by Frank Thorne in eastern Colorado, was done in the usual way by opening the camera lens, waiting for the flash and then closing the lens. It is suggested that some of the flashes appear black because the expanded air about them has refracted their light and so to the camera they showed black against the lighted cloud behind.

CHAPTER IV

THE WORK OF THE WEATHER

THE WORK OF WINDS

WIND does much work. It does such impressive things as the making of the "lows" and the "highs," with all their attendant weather. It does many lesser things, such as causing the movement of leaves and plant seeds, the turning of windmills, the flying of kites, and the drying of clothes. In discussing the work of the wind, however, some things that result most impressively from its blowing will be briefly considered.

Sand dunes and loess hills (Illustration 33). A surprisingly large part of the surface of the earth has been modified by the work of winds. The surface of all desert areas with their dunes, sand-etched rocks, and desert pavements are largely the creations of winds. In the United States, wherever there is sand, the wind lifts it up to drop it down again to show the handiwork of wind. Sand exists over large areas in the northern and western parts of Nebraska, for instance, and the whole Sand Hill region there has been molded by the wind. Sand exists on much of the Atlantic Coast, along the south end of Lake Michigan, and in long stretches along the Pacific, as well as in the deserts of the Southwest. Where there is sand, there the wind plays a hand in forming it into the mounds called dunes.

Illustration 33 is of the dune region at Oceano, California. The waves wash the sand of the ocean's bottom onto the beach, and there it dries as the tides run out. The stiff sea breeze, that blows persistently landward during the afternoons much of the year, lifts the dry sand and carries it shoreward to sort it out in coarse sand dunes near the water, and dunes of finer sand farther from the water. Here the wind makes a desert of sand beside an ocean of water.

Dunes are obvious creations of wind, but it becomes a surprise to be told that large areas of the earth's surface, far from sand, were also formed by wind. The surface of extensive areas of eastern China and of north central Europe has been built by the blowing of soil much finer than sand. Such wind-built soil is called "loess." Coming nearer home, we learn that much of the great Mississippi Valley region is also loess, wind-formed soil. The winds that formed the loess blew it into hills like great dunes; and a traveler over any of the several states in this area is impressed with the continual rise and fall of the gentle hills that form most of this region. In eastern Nebraska, for instance, all of the land is of this rolling type, the only flat areas being the flood plains along the margins of the rivers. The highest loess dunes were formed along the banks of these same rivers and these are called "bluffs." It is believed that the blowing of the loess occurred before the ground was covered with vegetation, after the retreat of the last great ice sheet, which extended as far south as central Kansas. Man today, by laying the ground bare again in winter wheat raising in the Panhandle of Texas, in Oklahoma, western Kansas, eastern Colorado, western Nebraska, and western South Dakota, makes possible the "black blizzards," created by the wind as in the days when the loess was first deposited.

The sea breeze and Redwoods (Illustration 34). The most magnificent forest in the world owes its existence to a wind! That forest is the Redwood belt that extends for more than 400 miles along the coast of California, from the region of the Big Sur on the south to southwestern Oregon on the north. The wind upon which its existence depends is the sea breeze that comes landward regularly each afternoon through much of the year, bringing with it the ocean fog. The fine needle foliage of the Redwoods traps the fog particles as they drift through the trees, collects them, assembles them into large drops, and lets the drops fall to the ground like a slow rain. The fog furnishes, thus, a bountiful water supply to the Redwoods during the long season from May to October when no true rain falls. So dependent upon the sea fog are the Redwoods that they natively occur only where the fog may reach them, and never more than thirty miles from the Pacific Ocean.

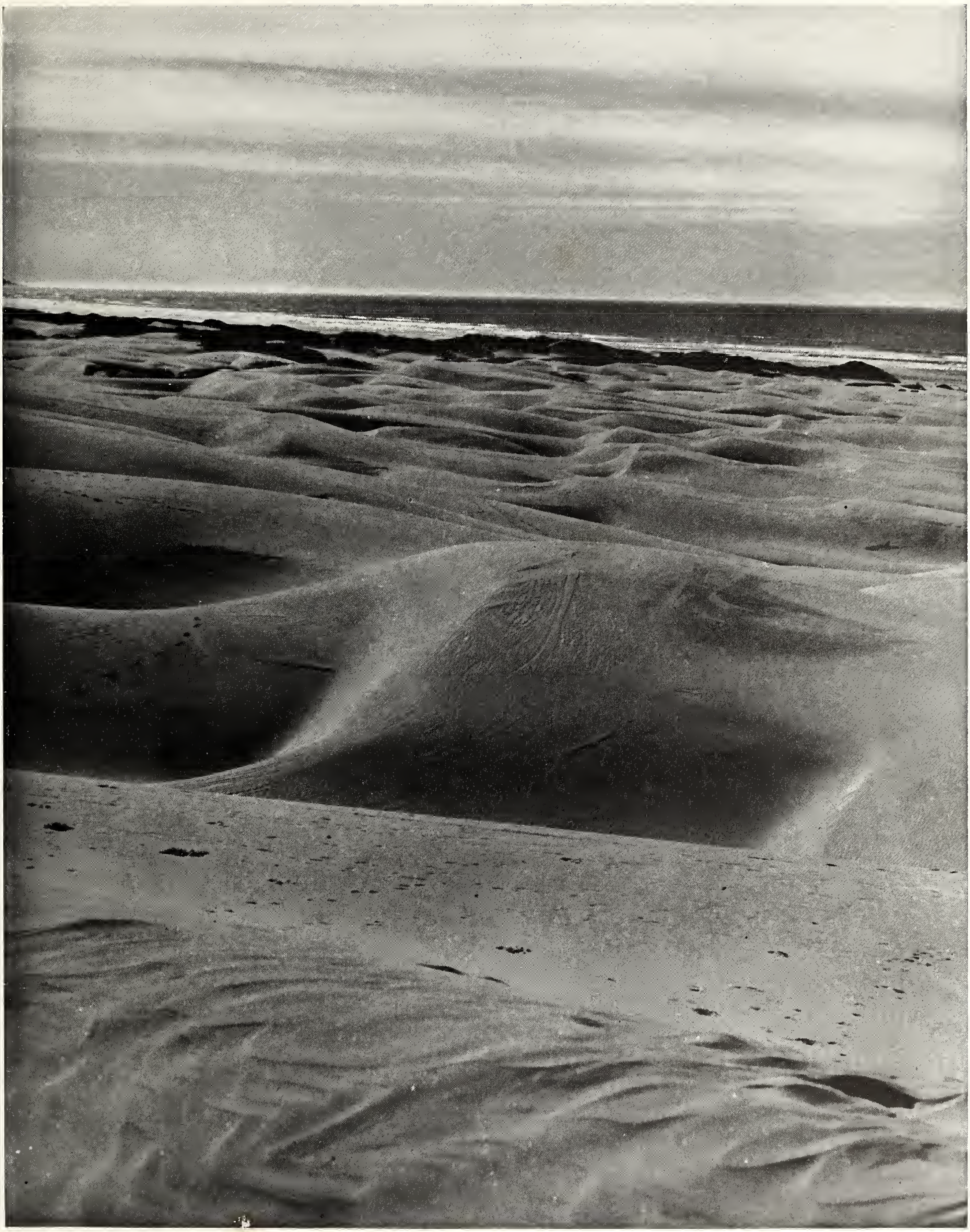
In Illustration 34, the sea fog (advection fog), is drifting up the San Lorenzo Valley in the Santa Cruz Mountains, like a mighty river flowing uphill. At the top of the valley it cascades as a waterfall over a ridge and through a grove of Redwoods—Redwoods that are there because the sea breeze brings them their fog.

THE WORK OF WATER

Rain, and the work of rain. Cloud particles form around very minute dust particles. It can be demonstrated that clouds will always form more readily where atmospheric dust is present in large quantities. The amount of this atmospheric dust varies from 100,000 particles per cubic centimeter in a city, to only about 500 particles per cubic centimeter over some of the oceans. The dust particles form so-called "nuclei" about which the water vapor collects and condenses. But hundreds of cloud particles, minute droplets of water, are necessary to form one raindrop.

Why does it rain? That is a question difficult to answer. Our greatest air physicist, Dr. W. J. Humphreys, of the United States Weather Bureau, admits the difficulties in explaining why it rains, but gives an explanation of which the following is the gist: Clouds form during vertical convection or uplift of air masses. Each of the innumerable cloud particles requires a dust particle as a nucleus about which to form. The formation of a cloud removes a large percentage of the free dust particles from the air. The cloud particles are heavier than the surrounding air and do not rise as fast as the air in which they were formed; they may even sink a little. The cloud particles are formed as the excess moisture after the air had passed its saturation point. This saturated air continues to rise and forms more cloud as it reaches colder regions. The number of dust particles becomes greatly reduced as the air rises and leaves cloud behind, for every cloud particle has sifted out a dust particle. But the water vapor continues to condense out in cloud, because the saturated air continues to rise. This condensing water vapor at the higher elevations must gather about the remaining dust particles, and since they are fewer in number, the water droplets must be larger. These larger droplets are of drizzle size. They become electrified and unite when they collide. These collisions form raindrops, and raindrops are usually heavy enough to fall to earth. Thus it rains (in Illustration 22 one may see rain falling).

Of all the work of weather, the work of rain, aided by the melting of snow, is most impres-



33. SAND DUNES ALONG THE PACIFIC OCEAN, AT OCEANO, CALIFORNIA

34. SEA FOG DRIFTING THROUGH THE REDWOODS

sive. To the work of rain must be attributed the formation of most of the surface of the earth, for though land is raised from the sea by the foldings of the earth itself, the rain wears it down and carries it back to the sea to be lifted again as the ages pass. Long chapters in large books are necessary to explain all of the work of rain, but only one can be considered here: the formation and the course of a river (Illustrations 35, 36, 37, and 38).

Illustration 35 shows the crest of a hill. Rain that falls here runs down the slope and converges toward the lowest point. This forms gutters in the soil. All of the gutters come together, and unite to form one deep gully. This is the head, the beginning of a stream. Here, in graphic form, is displayed the work of rain as it carries away the surface soil in the beginning of its march to the sea.

Illustration 36 is a canyon creek in flood. Dozens of separate gutter systems and their gulleys have united their rain and their silt to make this stream. The stream is not large, even in flood, but it and its associate run-off gulleys have cut, during the thousands of years in which it has carried the water of rain, a canyon several hundred feet deep. So industrious is the water of rain that much of this canyon has been cut through solid rock.

Illustration 37 gives a view into the canyon of the Kaweah River, in Sequoia National Park, California. Here are canyon walls, cut to a depth of not a few hundred, but several thousand feet, by the work of water of rain. The dome that stands in the upper right is of granite, but even the hardness of granite has given way in a spectacular fashion to the wearing of rain and of melted snow. To show that a little of the rain is held for the growth of plants, the California Buckeyes fill the center of the picture, and flaunt their spikes of white blossoms.

Hill crest gutters form gulleys, the gulleys converge into creeks, the creeks form rivers that cut great canyons, and finally the river flows out on the valley floor, with its waters sluggishly meandering. The valley itself has been made largely by the depositing of the soil that was cut away from the bordering hills by the headwaters of the river and all of its tributaries. The river of Illustration 38 is the Salinas River of the Salinas Valley in California. Its wide and sandy bottom, its meandering course, make it much like the rivers of the Middle West. It differs from most rivers, however, in that the long dry season of California reduces its water so that for several months during late summer and fall no visible water flows. Its sand bed conceals the water that flows slowly through it. Because these great rivers may show no surface water for a long period, though water still flows, they are aptly called the "upside-down rivers." A little visible water is beginning to flow in the Salinas of this picture, for the photograph was taken in December and winter rains had begun (the sky is filled with a nimbus cloud).

The water of the Salinas goes to the sea, and with it we complete the most impressive story of rain, from the beginning to the end of its work in the building of a river.

Snow (Illustration 39 and also present in Illustrations 45 and 46). If the temperature at cloud levels, in which vigorous condensation is going forward, is below freezing, then the cloud particles will be ice crystals. The union of hundreds of these ice crystals, often into beautiful designs and configurations, will form snowflakes. Very frequently during spring, fall, and winter, the water that reaches the ground as rain began its descent as snow. On the other hand, when the temperature is at or below zero Fahrenheit, snow falls as very fine needles of ice and not as snowflakes. This is often called "dry snow."

Illustration 39 is of an April snow in New York state (Cornell University Campus, Ithaca, New York). Rain fell before the snow, as one may note since the Cascadilla Creek is in flood.

The rain gave way to snow, as frequently is the case in spring, but the snow was a "wet snow," the ideal snowball snow, that clung tenaciously to everything, to give ground, trees, and shrubs a mantle of white. Light snows frequently follow early spring rains as the center of the "low" passes to the east and the cold wind from the west or northwest underruns the warmer southeast wind that accompanied the rain. The last of the condensation, associated with this colder air, produces snow. Heavy snowfalls occur when the temperature is below freezing as the eastern margin of the "low" approaches. The very heaviest snows fall with the center of the "low" to the south and a cold northeast wind underrunning the warm and moist air that is flowing higher up from the southeast.

At low elevations, northeastern United States leads in the greatest depths of snow falling during a storm. On the high western mountains much greater depths in a single storm occur; sometimes several feet remain after the passage of a "low." In the higher regions, this snow does not melt appreciably from the first snowfall until May or June. Thus, storm after storm adds its mantle until the total depth may reach twelve feet in the Sierra Nevada Mountains, or even twenty-five feet on the flanks of the high mountains of Washington.

Sleet. Rain, that falls through a layer of air cold enough to freeze the drops, may reach the ground as pellets of ice. These pellets are sleet. Usually sleet is not simply frozen rain, but snow that has been partially melted and frozen again. To produce sleet of this type a variety of conditions must prevail in the atmosphere. First, the layer of air near the ground must be below freezing in temperature; next above it a layer of warmed air must exist. This condition is not unusual, for frequently the colder air near the earth's surface will have pushed aloft this warmed layer. The warm layer will have clouds forming in its upper limits and these clouds may be high enough and the temperatures low enough for snow to form. The snow falls into the warmed area and partially melts, to freeze again when the cold layer near the earth is reached.

Ice Storm (Illustration 40). If, after a long, intensely cold period that has reduced the temperature of the earth, of the trees, and all objects near the earth—if then it should rain—the rain freezes as it strikes the cold earth, or the cold objects near the earth. The result is a coating of ice. So heavy will the coating of ice become at times that it will break the branches from trees and break from their poles the telephone and power lines.

Ice storms are most severe in eastern United States. One of the most spectacular and disastrous occurred in New England November 26–29, 1931. They also occur, though in less severe form, in many states to the west. Illustration 40 was secured on the shores of Lake Michigan, at Evanston, Illinois, December 19, 1924. Southern states, most states of the Canadian border, and Far Western states experience them, if at all, in very mild form.

The ice storm is one of nature's most picturesque displays. If the storm was caused by a cold northwest wind accompanying the rain, which is often the case, the following day will dawn clear. The rays of the sun then glitter as if from myriads of glistening jewels as they strike the ice.

Hail (Illustration 41). Hail is the result of weather's most boisterous mood; it is formed in the most violent of storms. Hail may accompany a thunderstorm; indeed, hail almost never occurs except in a thunderstorm. Under the conditions that produce small but swiftly rising masses of air, as in a cumulo-nimbus or thunderhead cloud, rain may form in the lower cloud masses, but instead of falling to earth, be carried up by the vigorous ascending currents. Up, up it goes, until it reaches a region so cold that it freezes; and still up, collecting about itself a layer of snow. At last it literally is blown out of the ascending

35. GUTTERS FORMED BY RUN-OFF RAIN AT THE CREST OF A HILL

36. A CANYON CREEK IN FLOOD

37. THE GORGE OF THE KAWEAH RIVER IN THE SIERRA NEVADA MOUNTAINS

38. THE MEANDERING SALINAS RIVER, OF CALIFORNIA

39. A SPRING SNOW THAT FOLLOWED RAIN, AT ITHACA, NEW YORK

40. ICE STORM

41. HAIL

column of air and falls to one side of the cloud. But at lower levels it is sucked again into the uprush of air at the cloud's base. Up again it goes to become coated with water, which freezes in the higher regions. Again it becomes coated with snow. Again it falls. Again it is sucked in, to make the circle once more. Finally the hailstone, becoming too heavy for even the violent whirl of air, breaks through to come pounding to earth; to fall, usually, at the eastern edge of the thunderstorm. Its last great fall may wear it off until it may be teardrop in shape; but it still will show concentric circles of ice and snow, perhaps only one layer of each, perhaps two, perhaps three, perhaps four (the hailstones of Illustration 41 show two layers of ice and one of snow, but others were undoubtedly melted away in the last fall). And every layer means a tumultuous journey of thousands of feet upward, thousands of feet back and thousands of feet up again. Hailstones are the offspring of weather's wildest mood. Hailstones are the most dramatic of water's forms.

The western Middle West (Missouri, Kansas, Nebraska, Minnesota, and Iowa) have the greatest number and the most severe hail storms. This region of weather's greatest extremes may be expected to foster a weather extreme such as hail. Cheyenne, Wyoming, is credited with more hail than any other city in the United States, but some exceptionally large stones, big as baseballs with 25 layers of snow and ice, fell at Annapolis, Maryland, June 22, 1915. Hail falls more frequently in June than in any other month, the month when there is still a great range in upper and lower atmospheric temperatures. It is the July hail, however, that does greatest damage to the farmers of the corn belt, for at that season the corn crop may be stripped bare of its leaves or beaten entirely to earth. In the Far West hail is rare, and occurs, strange to say, most frequently in winter.

Dew (Illustration 42). The ice storm and hail are the most violent manifestations of the water in the air, but dew is the most gentle. On clear days the wind usually ceases at night, because the sun does not shine to cause convection currents, and there is therefore no longer a mixing of air at the surface. Into the valleys, into every depression, the heavy, cold air settles. Into the clear sky the earth radiates its heat. The air lying near the ground is thus greatly cooled. If the earth is moist, this air will have much water vapor. As the temperature decreases, the ability of this surface layer of air to hold its water decreases also. Eventually it becomes cooled to a point where it must lose some of its water, and this is deposited on the objects near the ground. If the objects are green plants, a little water is added from the plant surface, and this, together with that from the air, gathers into the glistening droplets of dew.

Frost (Illustration 43). If the temperature, during the conditions that might form dew, goes below the freezing point, then frost forms. The frost is spine-like and feathery if the temperature during the entire night is below freezing, but consists of frozen globules if dew formed first and then froze. It is this latter condition that is shown in Illustration 43.

Plants show dew or frost before other objects because of two reasons. They add to the water vapor in the air about them by the moisture they exude, and this makes the air there more quickly saturated. Also they have a greater proportion of surface to volume than most objects and so become cooled faster than a rock, for instance.

Since the air near the ground must radiate its heat to space during the night to form dew, it follows that dew will not form or form very sparsely if clouds blanket the sky. The clouds prevent the heat radiation to space and even radiate back some of the earth's heat. If a wind blows, it mixes the air and prevents the settling of cold air as a consequence, so dew does not form under these circumstances. Clouds and wind will accordingly prevent frost as well as dew, if the temperature that might otherwise form dew is near the freezing point.

In connection with dew and frost, a condition called "inversion of temperature" should be noted. It has been pointed out that normally, through a range in elevation, the temperature becomes progressively lower as greater height or elevation is attained; the mountain's top is colder than the mountain's foot. This does not hold true at night for the first few hundred feet of elevation, however, but rather just the reverse. The cold air sinks to the lowest point, breezes blow on the hills, dews and frost form in the low points, the higher points are free. This inversion of temperature at night is noticeable even where there is but little difference in elevation, as between the summit of a low hill and its base, as between the top of a house and the ground beside it. In the Far West these temperature inversions have strikingly influenced man's activities.

Because of temperature inversions and their relation to frost for instance, the difference of fifty to one hundred feet elevation in Santa Clara Valley, California, a great apricot and prune center, may mean that certain ranchers will be required to smudge against frost, while nearby neighbors never set out a pot. More impressively, the foothills all around the Valley rarely experience frost, while killing frosts occur frequently in the Valley itself. For this same reason, oranges are raised as far north as Oroville in the Sacramento-San Joaquin Valley, whereas at Fresno, 250 miles farther south, they are killed by the frosts. Oroville is in the foothills of the Sierra Nevada Mountains; Fresno is in the level valley.

Ice and icicles (Illustrations 44 and 27). Ice forms in fresh water when the temperature of the water falls below 32 degrees Fahrenheit. The effect of dissolved minerals in the water is to drop back the freezing point so that sea water does not freeze until 27 degrees Fahrenheit is reached. Since water gives up its heat tardily, large bodies of water are slow to freeze. Lake Michigan, for instance, shows the first ice at the shore line because the shallower water here is first to radiate enough of its heat to reach the freezing point (Illustrations 44 and 27 are of Lake Michigan, at Evanston, Illinois). This shore line ice gradually extends out into the Lake as cold weather continues. The waves, as they pound against this border of ice, splash over it to build it higher and higher above the water, and melt spectacular caverns along its margin. New ice, forming in the water, is churned into mushy fragments that do not form a solid sheet unless very quiet and very cold weather prevails.

Illustration 27 shows icicles forming in one of the icy caverns of Lake Michigan shore ice. Under the bright winter sun, the surface ice slowly melts and the resulting water trickles into the caverns where the temperature, below freezing, forms it into long daggers of ice. Icicles form at the eaves of roofs with a blanket of snow in similar fashion, though the snow may melt, in this case, because of the warmth that comes through the roof from below.

Mountains and snow (Illustration 45, and also Illustrations 5, 11, and 46). Mt. Hamilton, California, with its famous Lick astronomical observatory, is 4200 feet high. As mountains go it is not a high mountain, but in Illustration 45 it shows graphically the effect of elevation on temperature. At the point where the picture was taken the elevation is about 2000 feet, and at that elevation snow melted as fast as it fell, because the air there was above freezing. Five hundred feet higher, however, the temperature was enough lower for the snow to persist in the irregular border that can be seen. The temperature at this line is at or near 32 degrees Fahrenheit; if the temperature descends at the rate of about one degree for each 300 feet of elevation, what is the temperature at the observatory?

The lower temperature that is contributed by the elevation of a mountain and is so visibly ap-

42. DEW

43. FROST

44. ICE

45. THE TEMPERATURE OF ELEVATION, SHOWN BY THE SNOW AND THE SNOW LINE OF MOUNT HAMILTON, CALIFORNIA

parent in the snow that may cap it, is only part of the mountain's weather. The air pressure is also much less (approximately one inch of mercury for each 900 feet of elevation), so that water boils at less than 212 degrees Fahrenheit (the sea level boiling point), and more time is required to cook food by boiling. The westward slope of the mountain, by forcing air to rise to cross it, develops clouds more frequently than lowlands (see Illustration 11), and has, as a consequence, more rain or snow. In the Far West, summer thunderstorms are frequent over the mountains (see Illustration 24), but may occur not at all in the lowlands. Wind blows more violently on mountains (the strongest wind ever recorded, 231 miles per hour, was on Mt. Washington, New Hampshire, April 12, 1934). Most impressively for lowland dwellers, to the presence of mountains one must attribute cool evenings and nights, no matter how hot the day may become, for as night falls and surface heating of the earth ceases, the warm air there is replaced by the cold air that slips down from the mountain and underruns it.

Rivers of Ice (Illustrations 46, 47, and 48). We lived as youngsters among the loess hills of eastern Nebraska. Here a rock of any sort was a very rare object. As a consequence, we often gazed with great interest at a huge boulder that the creek had uncovered. This was the only rock within miles and it always aroused our curiosity. Curiosity was excited the more when it was later learned that the smooth and rounded boulder had been left there thousands of years before by the last great glacier, or ice sheet, that had brought the rock hundreds of miles from the north.

The most extensive of these ice sheets extended into northeastern Kansas, farther into Missouri and along the northern edge of the entire United States, and left its rocks and debris over the land as it melted away.

Throughout the Middle West, the blowing of the loess covered all of the glacial drift, to be uncovered only here and there by the work of streams. Where loess did not blow, as in Michigan and most of the New England states, the drifts or "moraines" were left exposed to make the material for rock piles and rock fences that the people of these states are forever building as they clear their land.

Still another significant thing these great continental sheets of ice did, that makes today one of the most impressive of all the age-long work of weather: they gouged out troughs and built the dams that made what we call today the Great Lakes; and also made most of the lakes of Minnesota, New York, and of New England.

The great continental ice sheets or glaciers were formed by an age-long fall of snow in the north that was greater than could be melted during the summer. The cause of these glaciers is an argued question, but now they are melted away to leave their drift and their ice-made lakes. Today, the only living glaciers in the United States are the montane types, those that exist on the flanks of the high mountains; and though they, too, are dying, they show in a striking way the work of snow that is compacted into slowly moving ice.

Illustration 46 shows the northeast face of mighty Mt. Rainier of Washington. That dirty "river" of the lower left-hand corner, divided into two white lanes that reach to the Mountain's summit, is Emmon's Glacier, the largest of the Mountain's many glaciers. As much as twenty-five feet of snow falls each winter on the flanks of Mt. Rainier at the 10,000 foot level, the region of the heaviest clouds, and lesser amounts of snow fall on the summit and on the lower levels. Of all this snow, only a part can melt during the summer, so the rest remains to have added to it the great weight of the next winter's snow. This piling of the snow, year after year, makes such weight that the bottom layers are compacted into ice, and the great pressure on the steep slopes causes the ice to slide slowly toward the mountain's base.

As the river of ice slowly moves (very slowly in winter, several feet a day in summer), it tears away the mountain's face, makes deep canyons along its course, and covers itself at the lower end with the broken rock of the mountain's walls (see Illustration 46).

At the glacier's snout its melting ice shows a sheer face nearly 75 feet high, but the face is black, black with the rocks the ice has ground from the mountain's walls (see Illustration 47). The ice slips down the mountain steadily, but nowadays it melts back more rapidly than it comes forward, and as it retreats it dumps its rock burden mounds at its snout, as did the old continental glaciers of the ancient day. These dumps are called moraines. Illustration 47 is the snout of Emmon's Glacier, and the sheer cliff across the center of the photograph is a wall of dirty ice, so dirty that it seems almost black. Above the snout, and all around the base of the snout are the moraines, evidence of the scouring work of glaciers.

From the snout of every glacier a river flows (Illustration 48, and also visible in Illustration 47). The river is made by the melting of the ice. The ice melts throughout most of the length of the glacier, even in winter, though less rapidly. The melting is brought about in part by the pressure on the lower ice by hundreds of feet of ice with its thousands of pounds above. The pressure creates heat, and the resultant water gushes forth in a river from the glacier's snout. Illustration 48 is the snout of Nisqually Glacier of Mt. Rainier. Its river can be heard nearly a half-mile above the snout as it roars beneath the ice, and the water that gushes forth is milk white with silt and is called "glacial milk."

THE WORK OF THE SUN

The sun without water in the Middle West (Illustration 49). During the summer of 1934, the Middle West experienced the dryest and hottest season ever recorded in that region. Headlines in a Nebraska paper, for instance, played up, day after day, news as follows: "State swelters again; Lincoln's highest is 110. Temperatures above 100 are reported for all parts of Nebraska. Corn has been wiped out; gardens practically gone!" These reports were of August 6, 1934, but similar news of devastating heat had been reported almost daily for months, for the hot weather began in May of that year. Here was the work of the sun at its worst, the sun without rain.

Hot weather in Nebraska is not unusual, it is to be expected as part of the seasonal extremes that a great interior region experiences; but the heat of 1934 exceeded by far that of any previously recorded year. May, for instance, had several days with maximum temperatures above 90 degrees Fahrenheit, as recorded at Omaha, Nebraska, and a high of 104 on May 31. June was an incredible scorcher, with June 1 ushered in with 102, attended with many days of 90 plus, and ushered out with temperatures of 104, 104, and 90 on June 28, 29, and 30. July exceeded even June's reputation, by starting with 100, going to 106 on July 5 and 25, to 110 on July 20 and 21, and having more than ten days with temperatures above 100 and twenty-five days with temperatures above 90. Temperatures in August continued above 90 until the 16th, with two or three highs above 100. The first relief from many weeks of unbelievable heat came on August 16 with a high of only 84. At last the hot spell had been broken!

The hot spell was broken, but devastation remained. As an example, note the heat and drouth killed trees of Illustration 49. This is a photograph taken in early September of the following year. The place is near Elmwood, in eastern Nebraska. Elmwood is about thirty-five miles from Omaha, the city at which the official weather reports of the preceding paragraph were obtained. Elmwood's weather was not greatly different from that of Omaha. In the picture, standing stark against the sky, are three dead

46. EMMON'S GLACIER ON MOUNT RAINIER

47. THE SNOUT OF EMMON'S GLACIER, MOUNT RAINIER

48. NISQUALLY RIVER FLOWING FROM THE SNOUT OF NISQUALLY GLACIER, MOUNT RAINIER

49. COTTONWOODS OF EASTERN NEBRASKA, KILLED BY THE HEAT AND DROUTH OF 1934

50. GIANT CACTUSES AND IRONWOOD IN THE DESERT NORTH OF YUMA, ARIZONA

51. A REDWOOD FOREST IN THE SANTA CRUZ MOUNTAINS OF CALIFORNIA

cottonwood trees, grim reminders of the work of the sun of the year before. This cottonwood is a native of the Middle West, hardened to the conditions of that land of extremes. But the summer of 1934 brought weather that these trees, nearly half a century old, could not endure. One may assume, that if cottonwoods died, all other trees suffered even more. Rapidly the farmers have cut their prize wood lots into firewood.

The heat was intense, but intense heat is closely related to lack of water, so drouth and heat are twins. The heat could not have been so destructive if rain had fallen normally, but intense heat does not occur when the ground is wet. The story is not complete, then, without noting the rainfall for the drouth months. Corn, the great crop of the Middle West, is never irrigated and requires for proper growth an average of about one inch of rain weekly. Here is the rain record for Omaha, Nebraska, in a great corn region. During April less than one-half inch fell in the entire month. The month of May had less. June was slightly better favored, for more than two inches fell. This June rain made possible a fair wheat crop. The entire month of July, unfortunately, was a repetition of April with about half an inch. The weather maps listed occasionally the fateful letter "T," meaning a trace of rain, less than one-hundredth of an inch. One who has not experienced it cannot know the exasperation and dismay that is felt with rain that is listed only as "T" when a real downpour is needed. July is the month that corn demands rain. Rain did not come, only blistering heat. As a result, the corn farmer said, at July's end, "it's just fodder, and poor fodder at that!" That is the most belittling term that can be used for corn. August, after July, was not greatly different with regard to rainfall. "T's" occurred several times on the Omaha weather reports, and a total of slightly over one inch of rain fell in addition. This slight rain could not help after the heat and drouth that had preceded, even though cooler weather began on August 16. Not until September was well advanced, did rains of any consequence fall.

Nebraska has merely served as an example of the work of sun without rain; the same or worse conditions existed throughout a vast region. The Dakotas, Nebraska, Kansas, Oklahoma, northern Texas, Missouri, Iowa, Minnesota, Illinois, and even regions farther east, all felt the effects of this summer, the most abnormal in man's memory.

The desert sun without water (Illustration 50). Ages of sun, with scanty rain, have made the deserts of the Southwest. Unlike the Middle West where a yearly rainfall of about thirty inches is normal, the deserts may expect five inches of rain or less yearly, with a sun that sends the mercury of thermometers to heights that are almost unbelievable. As a consequence, one does not expect to raise crops in the deserts without irrigation. The sun, the heat, and the drouth, therefore, cannot cause the calamity that occurred in the Middle West in 1934. It is interesting, however, to list some desert conditions of 1934 to compare with those as given for Omaha for the same period.

Illustration 50, with its barren plains and mountains, with its hardy plants of Desert Ironwood and Giant Cactus, is taken in the Sonoran Desert in Arizona, about thirty miles north of Yuma. The first day, with 100 degrees Fahrenheit at Yuma, occurred on April 27, 1934. Temperatures of 100 or above occurred daily from May 7th to 16th inclusive, with two days at 110. With the exception of about two weeks of "cool" weather during the last of May and early June, and an occasional day here and there, the remainder of the summer and up to the 20th of September, had daily temperature above 100, with the highest at 116 on July 11. During this long period the weather maps twice listed "T," a trace of rain!

The desert country, this region of sun without rain, does not have, in spite of its temperature, weather as uncomfortable as that experienced in the Middle West in 1934. The reasons are two: the dryer air evaporates perspiration more freely than the more humid air of the Middle West; and the nights are no hotter.

The sun with water (Illustration 51). All plant life is dependent upon the sun. But the sun alone makes a desert. So for plant life to be most luxuriant the sun and water are necessary together. One of the most impressive examples of the result of the sun's work, with the aid of water, is shown in a Redwood forest. Redwoods grow along the coast of California from the southwest corner of Oregon, south for about 400 miles. In this long but narrow belt, they receive from forty to sixty inches of winter rain. More important than the rainfall to the Redwoods is the frequent fog, that drifts over them during the spring, summer, and fall, from the nearby Pacific Ocean (see Illustration 34).

The weather that fosters the Redwood is one of famous mildness, never very hot, never very cold, and consistently wet. The cottonwoods of the Middle West may have attained an age of fifty years before an abnormally hot and dry summer killed them, but some of the Redwoods of Illustration 51 are perhaps more than a thousand years old. If the past will serve as an indicator of the future, then suitable weather may continue to promote the Redwoods for thousands of years yet.

Of all of the work of the weather in winds and water, in the sun without water, and the sun with water, the most appealing is an age-old forest.

CHAPTER V

WHAT MAN DOES ABOUT THE WEATHER

"Everybody complains about the weather, but nobody does anything about it."

Mark Twain.

TWAIN really was wrong, for man has attempted to do something about the weather for the past several thousand years. Rain making, for instance, is one of the most ancient of practices. Rain doctors were, and are, present in all savage tribes. Rain makers still ply their trade today among more civilized people. Their materials range from prayers, through incantations, to smoke, pyrotechnics, and cannon. They have a vast following, especially where much is dependent upon the weather. The savage rain doctor was considered the magician of his tribe. The modern rain maker is a present-day magician, however false he may seem to most, for though modern science to date has shown that little or nothing can be accomplished by the rain maker's methods, still it always does rain sooner or later and the rain maker says, "look at me." The rain maker worked, and it rained. What better proof is needed? Only the inexperienced rain maker sets a certain date in which it will rain, or specifies the amount of rain. In any case, man has done something about the weather!

Also from time immemorial, man has predicted the weather. Magicians naturally predicted weather as well as made it. Even today, though they do not claim to be magicians, there are many people who predict the weather. These amateur forecasters vary from those who predict the weather by the state of their rheumatism, to those intelligent observers who have learned the meaning of clouds, air pressure, and winds.

RECORDING AND PREDICTING THE WEATHER

Folklore weather prediction. The folklore that has grown up about weather and its prediction is extensive and amazing. Only a few words can be said about it here. As one would expect, weather folklore will be most pronounced among those people who are most concerned with weather. These are, first of all, the sailors, especially those of the sailing-vessel days, and secondly, the farmers.

The folklore that predicted the weather was, and still is, based on many things observable in the out-of-doors: naturally, the appearance of the sky; temperature, wind direction; and condition of the atmosphere. Perhaps the commonest weather prediction still heard is "it *feels* like rain"; or "it *looks* like rain." A person making such a remark, and there are millions of them, is an amateur weather forecaster. And it is well known that it truly may "look like rain," or that our feelings do express the weather, though the average person does not know why. Many proverbs have grown up in the field of folklore weather prediction based on the appearance of the sky. Thus, when clouds present a "mackerel sky," a high wind from the northwest is probable, hence "mackerel scales and mares' tails make tall ships carry low sails."

Folklore weather prediction does not stop with appearance of the sky, temperature, wind direction, condition of the atmosphere, or personal feelings. Some of the most persistent are those beliefs in the relation of phases of the moon to weather. So ancient and so firmly established are these beliefs that many planters today will not sow unless the moon is at the proper stage, for fear that otherwise rains and growing temperatures will not follow. Of course there has never been any scientific evidence that the moon has any tangible effect upon the weather of the earth.

The appearance of the moon and of the sun has for ages been a basis for weather prediction, and in many respects it is a logical basis for prediction. If halos or coronas surround sun or moon, one may feel fairly confident that rain or snow will follow in less than twenty-four hours. Halos indicate cirro-stratus clouds and coronas indicate alto-stratus clouds, and both are forerunners of an approaching storm area or "low," though occasionally they may follow a storm.

One phase of folklore weather prediction that is still confidently adhered to is that, on the basis of the weather of one season, one may predict the weather of the season to follow. Thus "a February spring is worth nothing," or "March damp and warm does farmer much harm." In many respects such a belief in seasonal weather prediction is well-founded; not because a damp and warm March foretells what April will be, but because in such a March many crops will start prematurely only to be damaged in the usual frosts of April.

Rural people have come to attach a weather forecast significance to the action and appearance of many things besides sky, sun and moon, or seasons. Farmers of the Middle West are confident that stock flies are more annoying and cling tighter just before a rain than at other times. The actions of horses, cattle, and dogs are presumed to have a relationship to impending weather. It is not at all improbable that they do. In fact a large proportion of weather folklore, though perhaps unreasoning, has come about from many years of observations of the relationship between conditions and the presumed causes. We, as a people, still foster the notion that if the ground hog sees his shadow on February 2nd, six weeks of bad weather will follow.

The finest of all summaries of folklore weather prediction is given in the following couplets.

SIGNS OF RAIN

The hollow winds begin to blow;
The clouds look black, the glass is low,
The soot falls down, the spaniels sleep,
And spiders from their cobwebs peep.
Last night the sun went pale to bed,
The moon in halos hid her head;
The boding shepherd heaves a sigh;
For see, a rainbow spans the sky!
The walls are damp, the ditches smell,
Closed is the pink-eyed pimpernel.
Hark how the chairs and tables crack!
Old Betty's nerves are on the rack;
Loud quacks the duck, the peacocks cry,
The distant hills are seeming nigh.
How restless are the snorting swine!
The busy flies disturb the kine,
Low o'er the grass the swallow wings,
The cricket, too, how sharp he sings!
Puss on the hearth, with velvet paws,
Sits wiping o'er her whiskered jaws;
Through the clear streams the fishes rise,
And nimbly catch incautious flies.
The glow-worms, numerous and light,
Illumed the dewy dell last night;
At dusk the squalid toad was seen,
Hopping and crawling o'er the green;
The whirling dust the wind obeys,

And in the rapid eddy plays;
The frog has changed his yellow vest,
And in a russet coat is dressed.
Though June, the air is cold and still,
The mellow blackbird's voice is shrill;
My dog, so altered is his taste,
Quits mutton-bones on grass to feast;
And see yon rooks, how odd their flight!
They imitate the gliding kite,
And seem precipitate to fall,
As if they felt the piercing ball.
'Twill surely rain; I see with sorrow,
Our jaunt must be put off tomorrow.

DR. EDWARD JENNER

Rules for amateur weather prediction. Anyone who has learned the merest rudiments of weather can be an amateur weather forecaster with fair success. Here are a few simple rules that will assist.

1. A falling barometer indicates an approaching "low" with a storm.
2. A rising barometer indicates the passing of the "low," the approach of a "high," and fair weather.
3. The passing of the "low," in summer, will be followed by warmer weather.
4. The passing of the "low," in winter, will be followed by colder weather, perhaps with a "cold front" blowing from the Far North, and with blizzards in regions east of the Far West.
5. Winds from the south or southeast foretell of a "low" coming from the west with its center to the north of the observer, and with rain to come within twenty-four hours or sooner.
6. Winds from the east or northeast foretell of a "low" coming from the west with its center to the west or to the south of the observer, usually with heavy, chilly rain, and subsequent cold weather, within a few hours.
7. Winds swinging from the southeast to the southwest indicate that the center of the "low" is to the east of the observer, and that fair weather will follow shortly.
8. Winds swinging from the east or northeast to the northwest also indicate that the center of the "low" has passed to the east of the observer, and that fair and colder weather will soon follow.
9. Cirrus and cirro-stratus clouds, coming from the west with a gray sky, indicate the approach of a "low," with accompanying storm.
10. A bright blue sky with cirrus wisps and with wind in the west or northwest will be followed by fair weather for twenty-four to forty-eight hours, or longer.
11. A bright blue sky with numerous cumulus clouds may be followed by strato-cumulus and rain or snow flurries during the middle of the day and early afternoon, but by fair weather at sundown.
12. Calm, humid, warm to hot days during spring and summer throughout the United States (excepting the lowlands of the Far West), may be expected to produce thunderstorms; the thunderstorms will be most violent, usually, in the Middle West.
13. Conditions of strong convection currents that produce thunderstorms may be expected to produce hail also.
14. Thunderstorms in the Far West may occur occasionally in the lowlands in winter, but in summer are restricted to the high mountains.
15. If the lightning of an approaching thunderstorm appears to the north, east, or south, the thunderstorm will not reach the observer.
16. If lightning of a thunderstorm appears to the northwest, west, or southwest, the thunderstorm will come nearer the observer, and perhaps pass overhead.
17. One can calculate the distance of the lightning flash, that produces the thunder, by counting seconds between flash and the

accompanying thunder and allowing five seconds for each mile the sound travels.

18. The thunderstorm travels on the average about twenty-five miles per hour; if the cloud is in the southwest, west, or northwest, one may estimate when the storm will strike by calculating the distance it is away (see number 17).
19. The cold northwest winds of fall and winter will produce snow squalls on the eastern and southern shores of large bodies of inland waters, such as the Great Lakes.
20. Extremely cold northwest winds over the Great Lakes will produce the fog known as "frost smoke."
21. Fogs will occur in all depressions, and over streams and lakes, following periods of rain in spring, late summer, and fall throughout the United States. These are radiation fogs.
22. Since rains in the Far West are largely restricted to winter, radiation fogs follow winter rains in that region. Westerners call these the "tule" fogs.
23. Advection, coast, or sea fogs may be expected along the northeastern shoreline of the United States during the summer whenever a "low" approaches that region, with winds blowing into it from the Atlantic.
24. Advection, coast, or sea fogs may be expected along the shoreline and in coast range valleys of California during the afternoon, night, and early morning following every day that is warm in the interior valleys, from April to November. Westerners call these "sea fogs," or "high fogs."
25. If in fall or spring the temperature falls at the end of a clear, calm day to 40 or 45 degrees Fahrenheit, one may expect frost in all low places by morning.
26. Frost will not form under the conditions of Number 25 if clouds cover the sky before morning, or if a wind of any sort blows during the night.
27. Dew will form every night (except under extremely dry conditions), if there is no wind and the sky is clear so that ground heat may be radiated to space.

The work of the U. S. Weather Bureau in weather prediction. A vast amount of work is done by the U. S. Weather Bureau in connection with weather, but its best known activity is weather forecasting. In obtaining the records necessary for weather prediction, each regular observing station is equipped with a number of weather-recording instruments. These are: barometers to record the pressure of the air; thermometers to record the temperature of the air; anemometers to record the velocity of the wind; rain and snow gauges to record the precipitation; wind vanes to record the direction of the wind; hygrometers to record the relative humidity of the air in many stations, and sunshine recorders. In the hands of the U. S. Weather Bureau these instruments have been highly developed, so much so that nearly all of them now write out a continuous record of temperature, pressure, wind velocity, wind direction, relative humidity, and amount of sunshine, on strips of paper on circular drums. Indeed, though the actual instruments may be on a roof far above the Weather Bureau room, the records will be constantly made and constantly visible on drums in the weather man's office. Some of these instruments may be observed at work in the kiosk that most regular Weather Bureau Stations will have on the ground near the office. With the records produced by these instruments, the daily forecasts and the daily weather maps are made (see Drawings 7, 8, 9, and 10, and material on "seasons," in Chapter II).

One cannot, in a few words, explain the many details of forecasting or predicting the weather (see Chapter I on *Work of the United States Weather Bureau,* and Chapter II on *Weather Maps*). In the first place, the United States Weather Bureau never attempts to forecast for more than a week in advance and gives specific weather outlook for only the next 36 hours. Many researches have been undertaken to determine if long-range weather prediction is possible, but, to date, the conclusion of most scientists is that there is no adequate basis upon which to predict weather for more than a few days at most.

The forecaster, then, looks upon his map. He knows that winds blow into a "low" and out of a "high." He knows that high pressure areas, with their cold fronts, move toward the southeast; and that low pressure areas with their warm fronts, toward the northeast. He knows also that these cyclones and anticyclones travel from west to east at a certain rate of speed; a rate that varies with certain conditions of which he also is aware. He knows, also, that rains usually occur in the southeast quadrant of a "low" and that whenever there is radical pressure change there will be high winds.

Recently a new phase of the science of weather forecasting has come into existence, and since it is introducing several new words into the field, it will be mentioned here. It has long been known that the great air eddies called "cyclones" or "lows," are accompanied by warm moist air that enters their south and east sides, and that colder, dryer air flows into their north and west sides. The interaction of these two streams of air is the cause of the weather conditions that accompany the cyclone, as has been noted. In connection with these conditions, there was first developed in Norway, through the work of Professor V. Jerknes and his associates, the "polar front" theory.

In the "polar front" idea it was contended that the cold air on the western face of a "low," or in a "high," might arise in polar regions. The air flowing northward on the eastern margin of a "low" might be tropical in origin. This work, begun by the Norwegians, has been investigated by the Massachusetts Institute of Technology, by the California Institute of Technology, and intensively by the U. S. Weather Bureau. This new feature of forecasting is called "air mass analysis." Such new terms as "polar Pacific" and "tropical Gulf," have thus come into common usage among weather men.

With his instruments and his expert knowledge, the weather man is now able to predict accurately all phases of the weather. His predictions are correct from 85 to 90 per cent of the time.

CONTROL OF THE WORK OF WEATHER

Man does countless things to control the weather. Think of the main reason for clothing and houses, for instance. Then there are electric fans, windmills, refrigerators, surfaced roads, enclosed automobiles, snow sheds, snow fences, lightning rods, windbreaks, air conditioning, and irrigation. Man is doing something about the weather with each of these methods in the control of the work of rain, wind, sun, and temperature. Two or three large projects in the control of the work of weather will be considered in some detail here.

The control of winds and floods. New terms connected with weather have crept into the newspapers during the past two or three years. These are terms of destruction, if not of doom. The terms are "dust bowl," and "black blizzard." Stranger than the terms is the fact that man has made possible the conditions of weather that have brought forward these dramatic words.

The white man, in conquering the West, has gone too far, as always. His cattle were first spread over the lush prairies, but the plow in turn pushed the cattle farther west. From prairies to bunch grass the range man was pushed; until his far ranging steers were foraging on the plains of western Kansas, Panhandle of Texas, western portions of Oklahoma, Kansas, Nebraska, the Dakotas, and eastern Colorado. The bunch grass of these regions was grazed too closely; but the grazing did not cause all the trouble, for after the cattle and sheep there have followed the tractor, the combine, and the truck. Now vast areas in these regions have been converted to the growing of wheat. Wheat, in this region, is winter wheat. That is, the land is prepared in the late summer, and sowed before cold weather. The small new wheat passes the winter in a dormant condition and the ground where it has been sowed is still largely bare by March and April of the following spring. In connection with this winter wheat growing it is necessary to summer fallow the ground every third or fourth year. Summer fallowing consists in keeping the ground bare and finely pulverized in the conservation of the scanty rainfall of this portion of the wheat belt. Thus it comes about that the lusty winds of April and May have great areas of bare ground from which to blow the surface. And blow it they do! During the spring of 1935, for instance, the April winds lifted countless millions of tons of the soil as they blew "black blizzards" out of the "dust bowl" that is the Panhandle of Texas, western Oklahoma, western Kansas, western Nebraska, and eastern Colorado. That soil of great value darkened the sun to the Atlantic seaboard and left behind it a land fast becoming a desert.

Floods and "black blizzards" do not at first thought seem to be related, but, strange to say, their relationship is close. In June of 1935, following the terrible winds of April that ruined millions of acres of wheat as they blew away top soil to depths of inches, there occurred the disastrous flood on the Republican River. The Republican River is normally a docile, meandering, smallish stream that heads in eastern Colorado, swings along the southern margin of Nebraska, and then turns into Kansas, finally to join the Kansas River, and so into the Missouri River. The farmers along the Republican had never known it to flood so seriously as to be a menace. Because of this they could not consider seriously the warnings of the impending flood. So they stayed at home while the yellow waters spread, overran the lands, and drowned them by scores. Day after day, during this tragic flood, the newspapers carried lists of the drowned, lists that seemed like war-time casualty records.

This great tragedy on the Republican came because man raises wheat where grass once grew. The grass retarded the run-off of the torrential rains that fall in that region, and the rivers did not rise in flood as they do now since the grass has gone. Winds lay bare the man-planted soil and little or nothing remains to check the run-off of water. "Black blizzards" may be expected to be followed by yellow floods.

Winds do not lift the soil of the East and carry it to the sea as do the winds of the great "dust bowl," but the destruction of the forests on the hills and on the mountains of the eastern seaboard has allowed the rain to erode away the old surface that once retained much of the rain that fell. Now, without an adequate check, the water of rain rushes into the streams of the East and makes floods for that region unlike any ever known before. Such a flood was that of March, 1936. This flood was the result of a peculiar set of circumstances, to be sure, for "lows" came up in succession from the southeast to provide rain that melted a heavy mantle of snow, but the floods would not have been so disastrous if man had not made them possible by his own folly. As it was, a second Johnstown flood raged on March 17 and 18 (the first flood resulted from the breaking of a dam, but not the second). The "lows" that caused this part of the Pennsylvania flood continued north and east until thirteen states had been visited with disaster, 200,000 people left homeless, and hundreds of millions of dollars of damage done. Paul Sears, who wrote the famous book *Deserts on the March,* says man made this flood more severe by his destruction of the old spongy top layers of soil throughout the region of the disaster.

Man has certainly done something about the weather in this case. With his shortsightedness he makes possible "black blizzards" and adds to the terrors and destructiveness of floods. This isn't what he had intended, in doing something about the weather; quite the reverse. The question still remains: Can man do something about the weather in the proper way? Authorities say he can. He can restore the forests to the eastern hills and mountains. New York State, for instance, has been developing a great program in this connection for several years, but has experienced difficulty because the good soil has gone and much of the virtue has been leached out of the remainder. The "dust bowl" can lose its black horrors if it is returned to the condition of grass and cattle. These are two of the most frequently heard suggestions whereby man can do something constructive about the weather. The program is difficult and the way is long. But who can tell? Maybe new sod and preserved water will even do something about summers too hot and too dry. Perhaps new .sod will stop floods, the rains of which now carry down from the skies in mud the dust of the "black blizzards."

Control of normal erosion. New forests to hold the soil, new grass roots to stop the blowing, represent gigantic projects that will require years for their development. But many lesser projects have been employed where soil must be tilled in the raising of foods. Cultivation around a hill, rather than up and down, brush staked in forming gulleys, and pastures established on slopes that erode badly are just a few of age-old methods used to hold the soil. One relatively new method of erosion control, developed by the United States Government, will be considered.

Illustration 52 displays in a disheartening fashion the havoc brought by normal erosion on a slope from which the old grass cover has been removed by cultivation. The soil of the picture is very sandy and erodes easily as a consequence, but since it lies in the region of cool coastal weather (Arroyo Grande, California), and can raise an excellent crop of peas without irrigation, it is also very valuable. The surface that Illustration 52 shows has been ruined by the guttering of rains. This could have been prevented.

Illustration 53 shows an erosion control project established not far from the region of Illustration 52. The erosion of this sandy but productive soil has been prevented as follows: shallow ditches are dug around the slope in great circles at intervals of two or three hundred feet (five of these concentric ditches can be counted in Illustration 53). The soil removed in digging these ditches is heaped along their lower edges. Run-off rain spills into these ditches before it has gathered much force and before it has eroded much soil. These circular ditches lead the water gently to the side of the field. At the side of the field a ditch, dug up and down the slope, leads the water to the bottom. This collecting ditch has dams at intervals, such as the one in the lower part of Illustration 53, and these dams check the water and prevent it from gaining the speed that causes bad washing. With a series of circular ditches on the slope and with vertical or lead-off ditches with dams on the margin of the field, it is possible to prevent the washing of the soil. The small amount of soil that is carried into the ditches is trapped and may be plowed out again and put back onto the ground. Several kinds of grasses and other deep-rooted plants are established along the rims of the ditches to assist in the erosion control.

Control of frost. Aside from the covering of new plants with paper bags, which is practised widely as a protection against frost, the greatest frost control occurs in California. In this State several crops require occasional protection against frost damage. Several winter-grown vegetables are capped with paper bags, but the most extensive control is practised in the orchards. The fruits most frequently protected are the citrous (lemons, oranges, and grapefruit), and such early blossoming fruits as the apricot and English walnut.

Citrous trees are evergreen, hold their fruits for very long periods, bloom throughout the year and most profusely in late winter. Frost at any time is damaging to them, but because they are raised where such frosts occur, if at all, only in the coldest months of the year, such as December and early January, they will need protection against frost only in these months. Apricots and English walnuts, on the other hand, have no leaves during the winter and may be grown in regions where winters are colder than those in which citrous fruits can be grown. Only after blossoming in early March and with the young fruits started do apricots and English walnuts need protection against frost. Protection is needed only in March and early April, for after the middle of April frost danger almost never occurs.

There is no protection against extreme cold, wherein winds below freezing may blow. In this region such conditions are very rare, however. The light frost is another thing, and against it the fruit grower has means of control. The most extensive method is orchard heating. The heating is done by burning a low grade oil in smudge pots. The smudge pots may be nothing but discarded oil cans, such as those of Illustration 54, or they may be elaborate devices with chimneys.

In orchard heating, the fruit grower's actions are somewhat as follows. If he lives in an important fruit area, he will be advised of possible dangerous temperatures by a fruit expert of the United States Weather Bureau. More than likely, however, he will have established his own warning device. This consists of a thermometer attached to a loud gong. When possible danger of frost has been forecast by the United States Weather Bureau, he will have filled his pots and placed them between the rows of orchard trees, about one pot per tree. He will then have gone to bed with hopes for the best. If the temperature drops to 35 degrees Fahrenheit, the gong will ring. If it rings before 5 A.M. he gets up and lights the pots. If the gong does not ring before 5 A.M. he does not fear, because the sun will be up and warming the orchard before the temperature has dropped to 32 degrees Fahrenheit, the damaging point.

It was formerly thought that the frost was prevented by two things in the lighting of the smudge pots: the burning oil provided heat, and the heavy pall of smoke was presumed to act as a cloud and blanket the orchards and so prevent the radiation of the heat to space. As a consequence, heavy smudging made a blanket of smoke over large areas, filled the air, drifted into the cities, damaged furnishings, and caused everyone to awake with a headache and blowing soot from his nostrils. Recently it has been demonstrated that the heat is the important phase of the protection and the smoke is not of great value. Because of this smokeless burners are gradually replacing the old smudge pots; but in many regions every night of frost during the frost damaging period will still be followed by a morning sky black with smoke.

Light frosts, such as these which occur in the fruit valleys of California, are nearly all due to temperature inversions (see Chapter IV, *The Work of the Weather,* under *Frost*), that is, the cold air of higher points has settled to the lowest points and has lifted the warmer air. Thus a region in California a few hundred feet above the lowest points of a valley may never experience frost, while the low regions will have frequent damaging frosts. This factor of temperature inversions makes interesting variations in the orchards raised even though the difference in elevations may be so slight as to be imperceptible. In Illustration 54, for instance, smudge pots are in the apricot orchard, but the cherries in blossom just beyond are not easily injured by frost and so they have no pots. In Santa Clara Valley, California, to avoid the expense of smudging, orchardists raise pears at the lowest points, cherries and prunes at the next elevation, and apricots and English walnuts at the highest or on the hills, though the range of elevation is not more than a few hundred feet.

Recently a new system has been promoted to avoid the expense and discomfort of smudging. This is the use of motors and airplane propellers to stir up the air, to bring forward the warmer air of slightly higher elevations and to destroy the effect of temperature inversion. This is perhaps man's newest method in doing something about the weather.

52. UNCONTROLLED EROSION ON CULTIVATED LAND

53. CONTROL OF EROSION ON CULTIVATED LAND

54. AN APRICOT ORCHARD WITH SMUDGE POTS FOR PROTECTION AGAINST FROST

CHAPTER VI

LEARNING THE WEATHER

WEATHER can become the most exciting of all studies. Many of its phases can be studied at school or at home. Weather is with us always, wherever we live and wherever we go. It becomes good fun to be able to note, and to be able to talk about it with intelligence. Here are a few projects to consider in its study.

HOW THE YOUNGER STUDENT LEARNS THE WEATHER

Learning the work of the sun. The sun is the most important factor in weather. Its work is best learned with a thermometer. There really is a lot of excitement in using a thermometer; let's experiment with one. First, read it as it hangs in the school or home. Place it outdoors next. If it is winter, how does the temperature outdoors compare with the temperature indoors? Lower or higher? The temperature, remember, is a record of the heat of the air, and the heat of the air comes from the sun. Why is the temperature outdoors lower in winter and higher in summer? Chapter II of this book will explain.

Now take the temperature outdoors early in the morning. Write down that reading. Take it next at noon. Write that down also. Take the temperature in the late afternoon, just before the sun sets. Which is the highest temperature? Which the lowest? The sun is the cause of the heat of the air, but can you explain why the temperatures are different?

Take the temperature in the shade. Next let the sun shine directly on the bulb. How do these two readings compare? In the shade the thermometer records only the temperature of the air. In the sun the bulb absorbs heat directly from the rays of the sun.

Generally, a thermometer is used to record the heat of the air. The air is heated, for the most part, by absorbing the heat from the ground. To understand why air is not heated directly, remember that heat comes from the sun's rays, and the rays pass through the air as they pass through clear glass (a window pane may be cool with the sun shining on it). When the rays reach the ground, or water, they are absorbed and so give up their heat. The ground in turn heats the air that lies above it. In summer, put the bulb of the thermometer on a rock that is in the sun, or on the surface of dry soil in the sun. Compare these temperatures with the temperature of the air, without allowing the sun to shine on the bulb. Do you see why the air is heated from the ground and not directly from the sun?

If snow is on the ground, take the temperature at the surface of the snow, and then several inches beneath the surface. Is it colder at the surface of the snow than several inches below the surface? Can you explain why? These are just a few suggestions for the use of a thermometer in learning the work of the sun.

Learning about the air. When air is warmed, it becomes thinner and lighter, and is forced up by heavier, colder air. Blow soap bubbles to prove this. Why do they float, or even rise? Why do they soon begin to fall? Blow them toward a stove or heat register. Why do they rise when they come near the stove or register? If they are strong bubbles they will rise to the ceiling over the stove or register, float along the ceiling and begin to fall when they reach the wall farthest from the source of heat. With the thermometer, take the temperature near the floor. Take the temperature near the ceiling. Where is the air colder? Can you make a diagram now to show the circulation of the air of the room? Show the temperatures of the air at each point on the diagram.

Air expands when it is heated and contracts or shrinks when it is cooled. This can be shown by the following simple experiment. Turn a milk bottle upside down in a pan with a little water. Heat the bottle by wrapping a hot towel around it. Note that some of the air bubbles out around the end of the bottle in the water. The warmed air is expanding. When the bottle becomes cold again, note that water has been drawn into the neck for a short distance. The air has shrunken.

Air has weight and its weight exerts pressure. The following experiments prove it. Suck water or lemonade through a straw. You really aren't drawing the water or lemonade up, but the pressure of the air on the liquid is forcing it into your mouth. You see, by sucking on the straw, you remove part of the air from within the straw. The air all around tries to replace it and pushes the lemonade or water into your mouth as it does so.

Fill a glass with water. Place a sheet of smooth stiff paper (such as the smooth side of an envelope) over it and turn it upside down with your hand on the paper. The hand may then be removed from the paper and the water will remain in the glass. You will discover that the slightest touch on the paper over the end of the upside-down-glass will cause the water to pour out. The water stays in the upside-down-glass, with only a sheet of paper to hold it in, because air has weight pressure. The pressure cannot be felt on the water except at the open end of the glass, and since a sheet of paper covers this, all of the pressure comes against the paper and holds it tightly. If you let a little air in by touching the paper, then the outside pressure no longer works evenly and the water spills. This is one of the simplest and most surprising of all weather experiments.

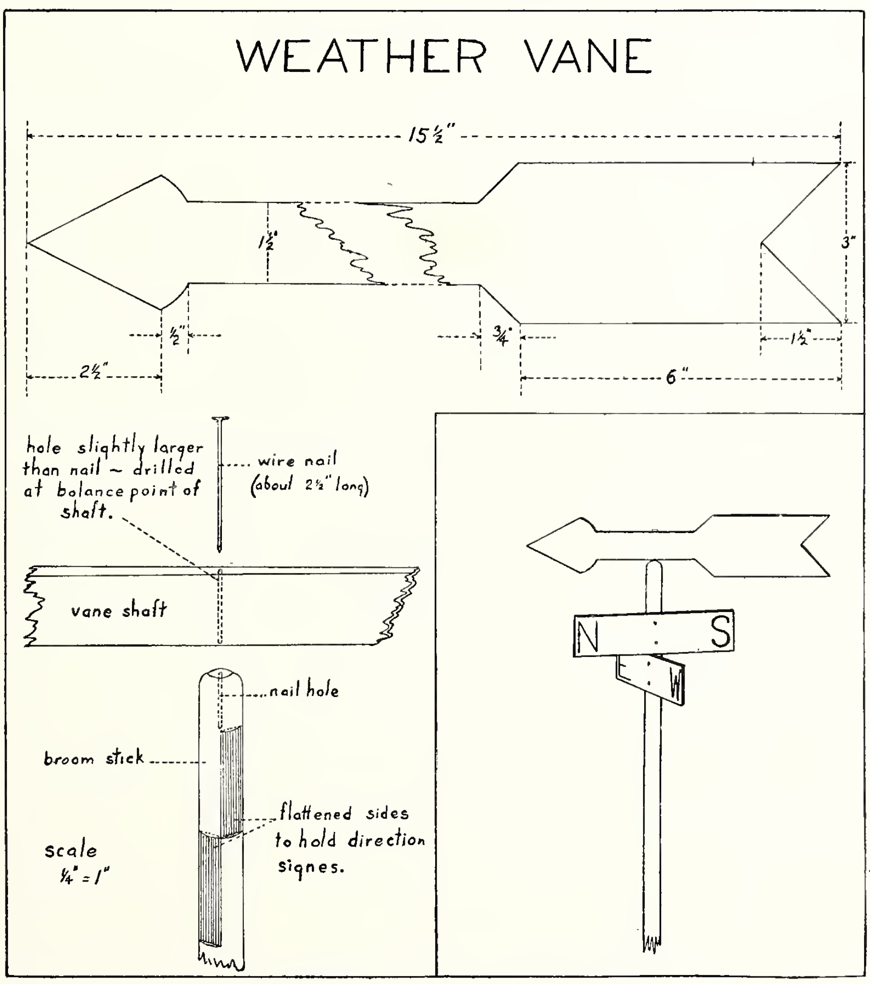
Here is another clever little experiment to show that air exerts pressure. Hard boil a large egg. Remove the shell carefully. Try to put it into a milk bottle. Usually, if it is a large egg, it cannot be put into the bottle without breaking it. You can use air pressure, though, and get it in. Drop a piece of burning paper into the milk bottle and while the paper burns put the egg into the mouth of the bottle. To your surprise, the egg will soon slide into the bottle as if it were being sucked in. This is the reason. The burning paper heats the air in the bottle and some of the warmed and expanded air pushes out past the egg. Very quickly, as the fire dies out and the air in the bottle cools, surrounding air forces down upon the egg to replace the thinner air in the bottle. The egg does not allow the air to slip by it into the bottle because it makes a stopper; so the egg is pushed in by the greater pressure of the outside air.

If you try to shake the egg out, you will find that it will not come. However, if you hold the bottle upside down and blow into the bottle with your mouth over the opening, the egg will pop into your mouth. You have compressed the air in the bottle and this air pushes the egg out. Hold the bottle upside down and run hot water over it and you accomplish the same result.

Air, when it moves, forms winds. To know the direction from which the wind blows, make a weather vane. Drawing 55 shows a simple weather vane. Only one or two words are necessary for its making. The vane can be made most easily from a shingle. The hole through the shingle, as shown in the figure, can be made by heating the nail, or a piece of wire, red hot, and using this to burn the hole through. To allow the vane to turn easily, place a bead on the nail between the shingle and the broom handle to serve as a washer. Put the vane in a position where the winds reach it, and also, if possible, where it can be seen from your window.

You can estimate the speed of the wind by the following table:

Smoke rises straight up	no wind
Smoke drifts	3 miles per hour or less
Leaves rustle, wind felt on face	slight breeze, about 5 miles per hour
Flags extend, leaves and twigs move constantly	gentle breeze, about 10 miles per hour
Dust is raised, small branches move	moderate breeze, about 15 miles per hour
Large branches move	strong breeze, 25–30 miles per hour
Whole trees in motion	high wind, about 35 miles per hour
Twigs and branches broken, walking is difficult	gale, from 40–60 miles per hour



55. Plans for a Wind or Weather Vane

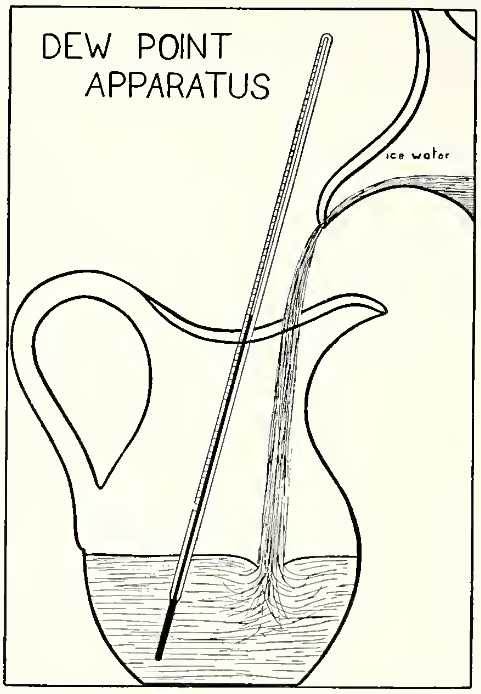
Air can hold water in invisible form. Steam from a teakettle is water, and it disappears into the air. Put a pan of water in the sun and note that the water soon evaporates into the air. Clothes become dry because the air takes up their water. Frost forms on the inside of window panes because the air of the room holds invisible water that condenses when it strikes the cold pane.

Learning the signs of the weather. Clouds, especially cumulus clouds and related forms, are among the most beautiful objects in nature. In their learning, one may use many of the lessons of art. Crayon and water color posters of the clouds of the day, with landscapes worked in, make beautiful and instructive projects. Lacking suitable clouds in nature, copy the clouds of *Weather* (such as pictures 1, 4, 11, 12, 13, 15, to 30). Give the proper cloud name to each picture. White clouds may be torn from white paper and pasted on blue backgrounds; or dark clouds from dark paper and pasted on blue. Cloud silhouettes may be cut from paper and pasted on the suitable background.

Learning the work of the weather. To learn of winds, and the work of winds, collect and post pictures. Illustrations 28 to 31, 33, and 34 of *Weather* provide a start. Newspapers every year have pictures of destruction caused by tornadoes, of snow piled by winter blizzards, of dust piles and dust-laden air, the result of "black blizzards."

The work of water can also be learned by collecting and posting pictures. Start with Illustrations 35 to 48 of *Weather.* Then find other pictures of snow, rivers, mountains with snow, hail, sleet, and ice storms. When it snows, collect some of the flakes on black paper or on black velvet to see their beautiful forms. If it hails, collect some of the stones and count the rings of snow and ice in each; then read about hail in Chapter IV, *The Work of the Weather.*

Such work of water and temperature as dew and frost can be demonstrated at home or at school with very simple methods. Use a small aluminum pitcher and pour ice water into it slowly (see Drawing 56). Stir the water with your thermometer. When the first film of water forms on the outer surface of the pitcher, the thermometer will give the dew point, or temperature at which dew will form under the conditions of the air at that time. Replace the water of the pitcher with ice. Over the ice place a handful of salt. Dew will form on the pitcher first, and later will freeze. Most frost is frozen dew and this experiment shows how frost is usually formed in nature.



56. Materials for Determining the Dew Point

The work of the sun is always shown when you fail to water the flowers. Illustrations 49 to 51 of *Weather* also show the sun's work. Can you collect other pictures of deserts, forests, and jungles to give more proof of the work of the sun?

In *learning what man does about the weather,* read the weather report and forecast in the daily newspaper. Collect pictures of irrigation projects, erosion control projects (such as Illustrations 52 and 53 of *Weather*), windbreaks, and snowsheds. Ask if any of your friends or classmates have lived where smudging is done in frost control (see Illustration 54).

No weather observation or experiment is complete until it is reported. To report it, lay out a sheet of paper with the following heads along the left-hand margin: "Date," "What experiment is to prove," "Materials used" (with drawings of materials), "How experiment was performed," "Results," "Why these results were obtained." Then write below each head the answers. Also, keep weather charts. The first chart may be of temperatures only, but later charts will include, in addition to "Temperature," "Wind velocity," "Wind direction" (as shown by the wind vane), "Condition of the sky" (clear, cloudy, or partly cloudy), and "Condition of the weather" (rain, snow, sleet, hail, dew, frost, fog).

These charts are very simply made. Each student may make his own by ruling a sheet lengthwise into the number of records that are to be kept (for instance, "Date," "Temperature," "Wind direction," "Wind velocity," "Condition of sky," "Condition of weather"), and by using each cross line for a day. Of course, the weather chart may be an elaborate blackboard diagram or big sheet of cardboard. If blackboard and cardboard charts are used, then committees should be appointed at weekly intervals to obtain the information for the chart.

HOW THE OLDER STUDENT LEARNS THE WEATHER

Learning the work of the sun. Seasons are the most pronounced of weather's characteristics. The position of the sun with respect to the earth produces the seasons. To demonstrate the seasons, secure two apples and a pencil. Put one apple on the center of a table and call it the "sun." Call the stem end of the other apple the "north pole," and the blossom end the "south pole." Thrust the pencil through this apple from north pole to south pole. Now with Drawing 2 before you, hold the apple by means of the pencil at the proper angle with respect to the table (which is the plane of the ecliptic), and move the apple around the sun. All seasons are illustrated as the apple travels around the sun. To carry out the proper number of days, the apple would be whirled 365 times in the circuit of the sun.

Of course you have a thermometer and have taken all the temperature readings that have been suggested earlier in this chapter. Now you will want to experiment with a thermometer you yourself have made. Construct the air thermometer in Drawing 57. The materials for this thermometer may be available in the science department of your school, or can be purchased inexpensively from a scientific apparatus company. Enough water is placed in the bulb nearly to fill the long neck when the bulb is turned over and the end thrust into the water of the bottle. Now, as the temperature of the room changes, the water of the tube will rise or fall. It will work in a fashion the reverse of the regular thermometer, for the water in the tube will fall as the temperature rises, and rise in the tube as the temperature drops. In any case, it will prove that the air of the bulb expands with heat and pushes the water out, and contracts with cold and allows more water to flow in. Your hand, your breath on the bulb, or a piece of ice against the bulb, will cause the level of the water in the tube to change.

An interesting experiment in connection with the work of the sun consists in obtaining the temperature on a warm day of a pan of dry soil, and of a pan of water, after both have stood for an hour or more in the sun. The soil will be much warmer than the water. Water warms much more slowly than soil, you will thus learn, and the water also evaporates under the heat of the sun and uses this heat in evaporating. Try the same experiment on a very cold day and you will get just the reverse results with the soil colder than the water. Several factors of weather are illustrated here. For instance, the reason for the more equable climate along a sea coast as compared with the interior of a large continent. Also, why evaporating water cools (as we cool with evaporating perspiration). Can you name other weather factors illustrated by this experiment?

Learning about the air. One of the most important characteristics of the air is that it has weight pressure. In the first of this chapter two or three simple experiments were described to prove it. Here is another. Secure a gallon oil can with a screw top. Remove the top, put a little water in the can, place the top on the can loosely, and heat the can over a stove, or over any burner. Steam will come from the can around the edges of the loose cover. While the can is still steaming, screw the cap down tightly and remove the can from the fire. The can will soon collapse if you do nothing more, but if you put it under a stream of cold water it will collapse promptly. The heated air of the can expanded, you see, and part of it was forced out. When the air in the can cooled it contracted, exerted less pressure on the inner walls of the can than the air outside, so the outside air collapsed the can because of its greater weight pressure.

A barometer is the most widely used and most instructive device to illustrate the weight pressure of air. Any older student with a few simple materials and about a pound of mercury can make it. All of the materials can be secured from a scientific supply house. The science department of any school will have catalogues of such houses. In addition to the mercury, you will need a glass tube of about 3/16 inch inside diameter and 31 inches long, a yard stick, a small dish, and a strip of metal, as shown in Drawing 57, for a support for the dish. Close one end of the glass tube by heating it over a burner (a laboratory burner, or the flame of a gas stove), and smooth the other end by heating it slightly.

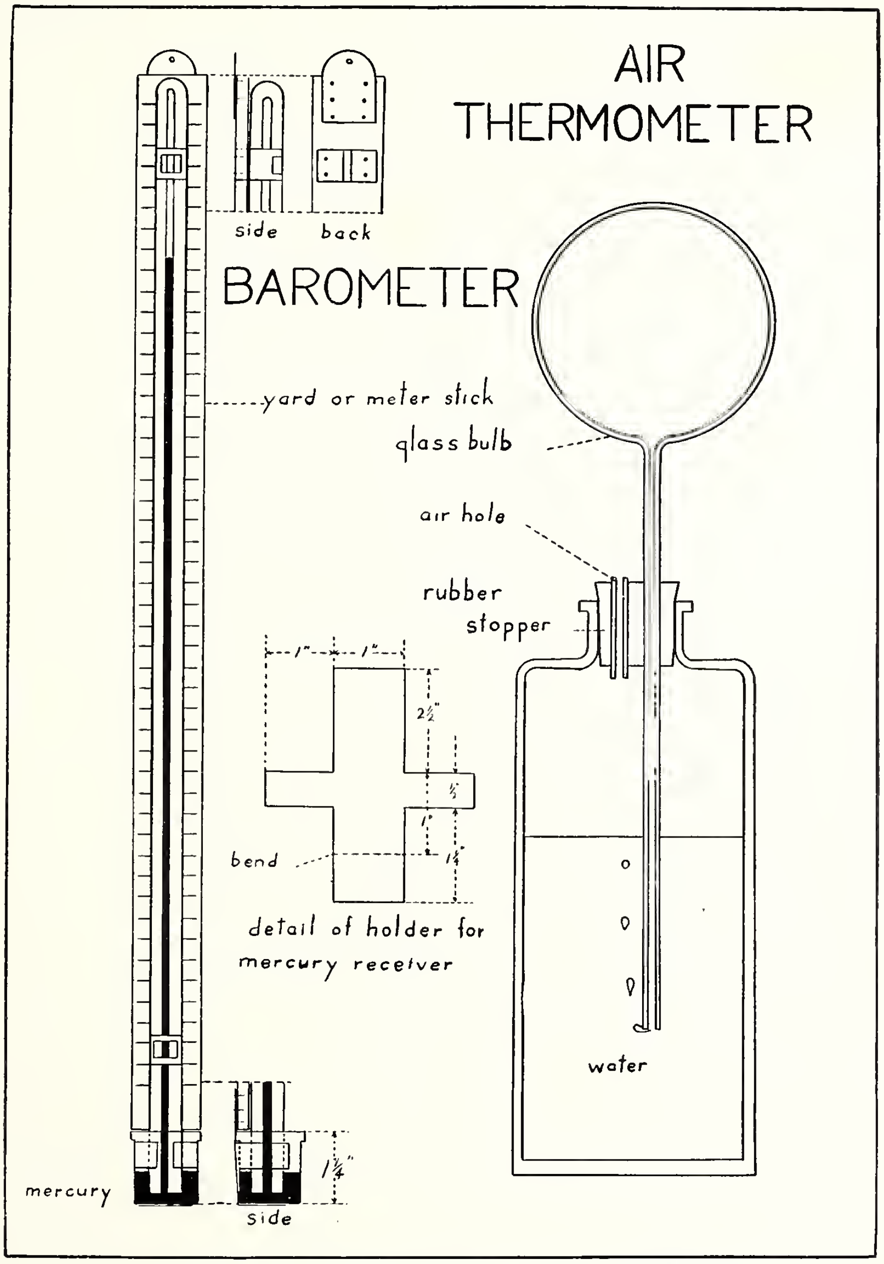
The support for the mercury dish should be made next. This support consists of a sheet of light metal 4½ inches long and 3 inches wide. The metal is cut as shown in Drawing 57 and then the top flap is fastened to the back of the meter stick, the side flaps are bent around to embrace the mercury dish, and the bottom flap supports the dish below. Light metal strips to hold the tube after it is filled with mercury are thrust through slits in the yard stick ready to be fastened to the back of the stick with light screws. The upper of these strips should have a window so that the mercury may be seen at its level.

Now we are ready to fill the glass tube with mercury. Do this with the aid of a small funnel, and over a large metal pan, for the mercury is easily spilled. When the tube is filled, hold a finger tightly over the open end and turn it upside down into the small dish which contains the remainder of the mercury. Fasten the tube in place and the barometer is complete.

At sea level the weight pressure of the air will support about 30 inches of mercury in a tube closed at the upper end because of its pressure on the exposed mercury in the dish at the base of the tube. Water would make a barometer as well as mercury, except for the inconvenience; since more than thirty feet of water would be necessary. The weight pressure of the air varies with the weather, and so the level of the mercury in the barometer rises and falls with the change of weather. The weight pressure is less in a "low," for the air is rising; the weight pressure is greater in a "high," for the air is falling. Thus a falling barometer indicates the approach of a "low," with its attendant storm; the rising barometer indicates the approach of a "high," with fair weather. The barometer, therefore, is the most valuable of all instruments in forecasting the weather.

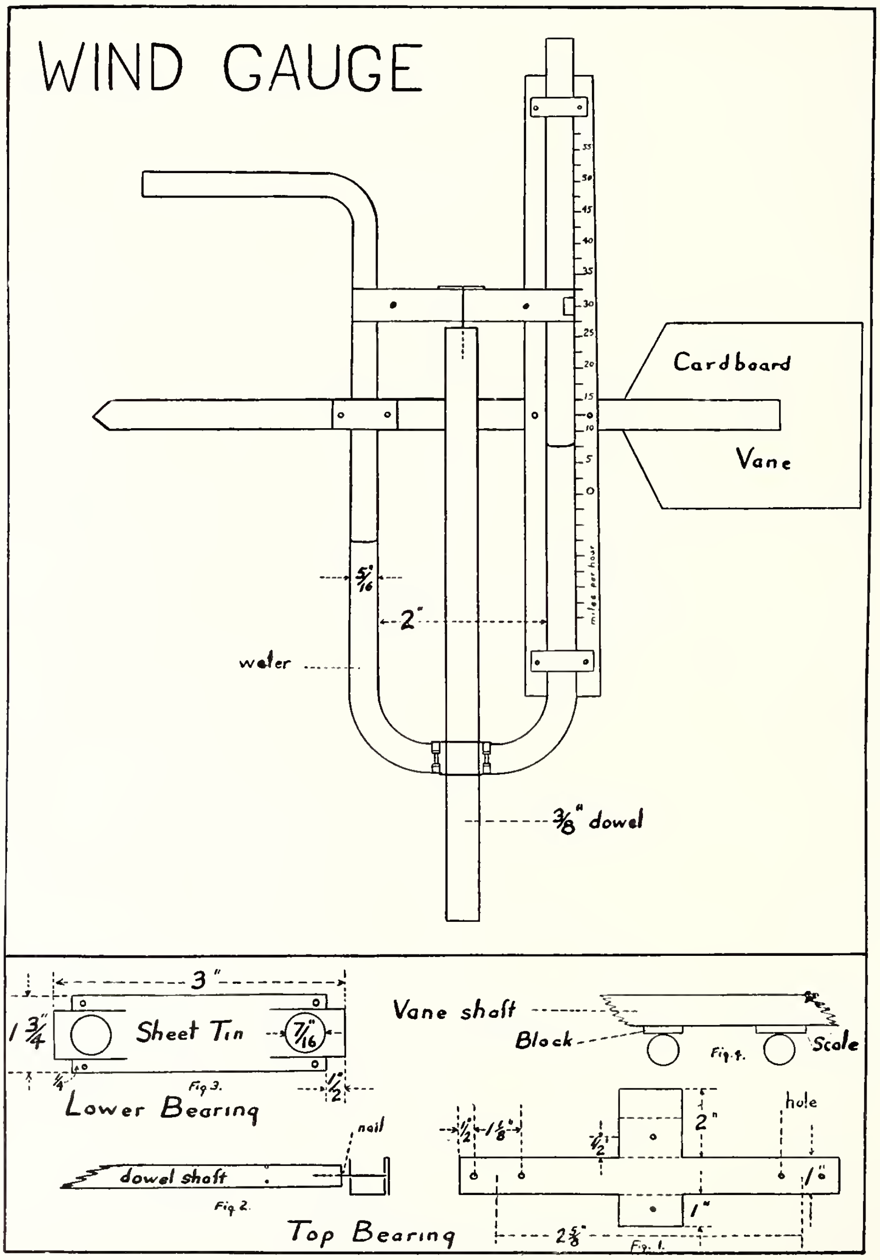
Incidentally, the weight pressure of the air is greater at sea level and there it maintains about 30 inches of mercury, as has been noted. At elevations above sea level the air supports less than 30 inches of mercury, so the barometer can be used to determine the elevation at any place. Since the weight pressure of the air lessens at the rate of about one inch of mercury for each 1000 feet, what is the elevation where you live as shown by the barometer?

Air heats when it is compressed and cools as it expands. These two facts are related to weather in several ways. First, the cooling by expansion is one of the two reasons for colder conditions at high elevations, such as mountain tops. The other reason for colder air at such places is, as we have learned, because air is



57. Plans for a Barometer and the Air Thermometer

heated from its contact with earth and once away from the earth the air has no source of heat. Air heating by compression is demonstrated in part by the extremely hot conditions of low deserts, such as the Colorado Desert or Death Valley. Also the warm winds called "chinook" or "foehn," that result in late winter from the blowing of air down a mountain slope, are largely warmed by the heat of compression. Here is a simple experiment to demonstrate that air heats when compressed. Work a bicycle or automobile tire pump vigorously in inflating a tire. Notice how warm the pump becomes at the base where the air compression is greatest. After the tire is



58. Plans for a Wind Gauge

tightly inflated, and is the same temperature as the room, take out the valve core and allow the air to escape rapidly. As the air flows out hold a thermometer at the valve. What about the temperature?

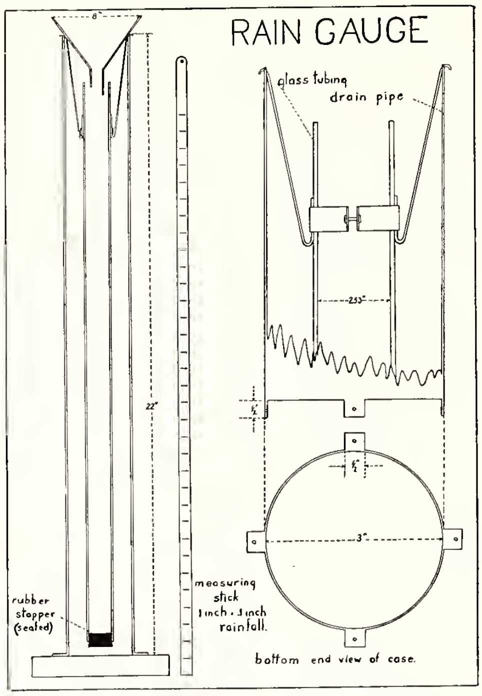
Air, when it moves, forms winds. You will have made a wind or weather vane as shown in Drawing 55, and know the table of approximate wind velocities as given earlier in this chapter. The ambitious student will want to make the device shown in Drawing 58 to secure more accurate readings of wind velocity. A glass tube, bent in the shape shown in Drawing 58 is the most important of the materials, the remainder can be left to the ingenuity of any older student. The following additional instructions in its making will be helpful. The top bearing of the wind gauge is made of light sheet metal of the dimensions shown in Drawing 58. The ends of this piece of metal are bent around the tube, as shown in the main drawing, and fastened with small bolts through the holes. The two middle flaps are bent back and the outer end of the top one of these is doubled back upon itself so that a nail, which is passed through the two holes, is held in place by this piece. The lower bearing is cut as shown in the illustration. This strip of metal is bent around the glass tubing, the small strips are bolted around the glass, and the shaft is passed through the large holes.

To get the proper readings for the wind gauge, hold it far out of the window of an automobile that is driven on a very smooth pavement (to avoid jolting of the water in the tube). Check car speedometer with level of the water in the tube beside the scale and the gauge will be fairly well calibrated. It is not recommended that you ride atop the car to be in the air currents that are not modified by the car body, though one weather student did this. After the wind gauge is calibrated, it should be set in the open where the air has a clean sweep.

Learning the signs of the weather. The lover of the weather will have his head up and his eyes frequently on the sky. To learn the clouds he sees there, he should compare them with the illustrations of this book. If a separate set of pictures is available, then each day the picture or pictures showing the clouds of the sky should be posted on a bulletin board.

To show that the study of weather can also employ arithmetic, here are a few of the problems presented by clouds. First, an easy one. The mountain beneath the cumulo-nimbus cloud of Illustration 24 is about 2000 feet high. What is the elevation at the top of the cumulo-nimbus cloud? Here is one a bit harder. It has rained during the night and the morning shows a bright blue sky. You know, however, that cumulus clouds will form during the day because the sun will start air to rise in convection currents. The temperature of the air is 50 degrees Fahrenheit. You want to know how high it must rise to form clouds. You use the materials shown in Drawing 56, and the methods described near by, and find that the dewpoint is 40 degrees Fahrenheit. Dewpoint is also the temperature at which a cloud would form if enough air is involved. The difference between the two temperatures is 10 degrees. Air cools at the rate of about 1.6 degrees Fahrenheit for each 300 feet as it rises, but it expands also and the amount of water vapor it carries does not increase. The expansion of the air as it rises drops the dewpoint, or cloud point back .33 degree for each 300 feet. The rate, therefore, at which air will reach the dewpoint, or cloud point, is 1.6 less .33, or 1.27 for each 300 feet. Our problem is to divide 10 degrees (the amount the surface air must drop in temperature before it will form a cloud) by 1.27 and multiply by 300. At what height will clouds form? Work this problem on several days.

Learning the work of the weather. The dewpoint and frost apparatus you have used; next let us make a rain gauge as shown in Drawing 59. The following materials are needed. The



59. Plans for a Rain Gauge

outer can of the gauge can be of any cheap material, such as galvanized iron, but the inner should be of brass or glass. In order to make careful measurements of slight rainfall, it is customary to increase it tenfold in the gauge. This is done with a collecting surface ten times that of the surface of the inner can. To collect heavy rains, the gauge should be not less than 20 inches deep, for as you see, 2 inches of rain will fill it. Drawing 59 shows a sample set of proportions. If the measuring stick is divided to tenths of an inch, then the reading will be in hundredths, as the U. S. Weather Bureau does it.

Learning what man does about the weather. You, as older students, will keep exact records of all experiments and observations as do the younger students, but you will do them more carefully. You will consider the same phases of the experiment ("Date," "What experiment is to prove," "Materials used," "How experiment was performed," "Results," and "Why these results were obtained"), and with your new instruments you will have data for a more complete weather chart.

Your chart will be divided into the following columns across the top: "Date," "Time of day," "Temperature," "Air pressure," "Rainfall," "Wind direction," "Wind velocity," "Condition of the sky" (clear, cloudy, or partly cloudy), and condition of the weather (rain, snow, sleet, hail, dew, frost, fog). Committees will be appointed to secure these different items and to keep the weather chart active.

You are ready now to learn to predict the weather. Refer to the *Rules for Amateur Weather Prediction,* in Chapter V, and see how accurate you can be. Make it a game. Several of you, having studied the conditions, make predictions for the next twenty-four hours, and, the following day, find who has come nearest the actual results.

Subscribe for a month's issue of daily weather maps. Under *Further Helps in Learning the Weather,* at the end of this chapter you will learn how to do so. These maps look complicated and uninteresting at first glance, but they can be as exciting as the best feature of a daily newspaper. For instance, see if the Weather Man agrees with you in his forecast for your region. Having studied the map, try to forecast the weather yourself for your own and for other regions. Put the maps in a row, day after day, and watch the movements of the "lows" and the "highs" from west to east. How far do they move each day, on the average? Follow the accounts of great storms, as the newspapers report them, and examine the weather maps of the same dates to see for yourself what the weather conditions were.

If there are irrigation, erosion control, or other projects near, visit them to see what man is doing about the weather. Lastly, make arrangements with the office of the U. S. Weather Bureau, if there is one near (a telephone directory will tell), and visit a regulation Weather Man at work among his remarkable instruments.

FURTHER HELPS IN LEARNING THE WEATHER

WHAT MAKES THE WEATHER

Brooks, Charles Franklin. *Why the Weather.* New York, Harcourt, Brace and Co., 1935. 295 pp., 52 figures. (An exceedingly interesting collection of weather notes and anecdotes.)

Hazeltine, K. S. and others. "Weather." *Science Guide for Elementary Schools.* Sacramento, California, State Department of Education, Vol. 1, Number 5, December, 1934. 34 pp., 12 figures. (A bulletin of weather material for California.)

Humphreys, W. J. and Talman, C. F. "Weather." *Merit Badge series 3816 of Boy Scouts of America.* New York, 1928.

Humphreys, W. J. *Physics of the Air.* New York, McGraw-Hill Book Company, 1929 (second edition). 654 pp., 226 figures. (The most comprehensive and exacting study of weather phenomena.)

Milham, W. I. *Meteorology.* New York, The Macmillan Company, 1921. 549 pp., 157 figures and 50 charts. (One of the best general books devoted to weather.)

Palmer, E. Lawrence. "The Earth and Its Weather." *Cornell Rural School Leaflets.* Ithaca, New York, State College of Agriculture. Vol. XV, Number 3, January, 1922. 53 pp., 33 figures.

Palmer, E. Lawrence. "Heat." *Cornell Rural School Leaflets.* Ithaca, New York, State College of Agriculture. Vol. XXVIII, Number 3, January, 1935. 30 pp., 21 figures.

Talman, Charles Fitzhugh. *A Book About the Weather.* New York, Blue Ribbon Books, Inc., 1935. (Previously published as *The Realm of the Air,* 1931.)

U. S. Weather Bureau. *Daily Weather Map.* (Issued daily except Sunday and holidays.) 20 cents per month, $2.40 per year. Apply nearest forecast center (Washington, D. C., Chicago, New Orleans, Denver, and San Francisco) and pay by money order drawn to the Superintendent of Documents.

U. S. Weather Bureau. *The Weather Bureau.* Washington, D. C., July, 1931. 34 pp., 11 figures. (Work of the Weather Bureau described. 5 cents.)

U. S. Weather Bureau. *Daily Weather Map with Explanations.* Washington, D. C. 8 pp. 5 cents.

SIGNS OF THE WEATHER

Humphreys, W. J. *Weather Proverbs and Paradoxes.* Baltimore, Williams and Wilkins Co., 1923. 125 pp. (Several illustrations from photographs. A remarkable collection of weather folklore.)

Humphreys, W. J. *Fogs and Clouds.* Baltimore, Williams and Wilkins Co., 1926. 104 pp., 92 figures. (An extensive collection of cloud pictures, with explanations.)

McFall, Kerbey. "Toilers of the Sky." *National Geographic Magazine,* Vol. XLVIII, Number 2, pp. 163–189. August, 1935. (Many cloud pictures.)

U. S. Weather Bureau. *Cloud Forms According to the International System of Classification.* Washington, D. C., 1928. 22 pp., 32 illus. 20 cents.

WORK OF THE WEATHER

Borah, Leo A. "Utah, Carved by Wind and Water." *National Geographic Magazine,* Vol. LXIX, Number 5, pp. 577–623. May, 1936.

Palmer, E. Lawrence. "Save the Soil." *Cornell Rural School Leaflets.* Ithaca, New York, State College of Agriculture, Vol. 24, Number 3, January, 1931. 36 pp., 28 figures.

Salisbury, Rollin D. *Physiography*. New York, Henry Holt and Company, 1924, 676 pp., 608 figures. (Much of land forms is the result of weather as this famous book shows.)

WHAT MAN DOES ABOUT THE WEATHER

Humphreys, W. J. *Rain Making and Other Weather Vagaries*. Baltimore, Williams and Wilkins Co., 1926. 157 pp. (Popular myths and superstitions of weather laid to rest.)

Palmer, E. Lawrence. "Save the Soil." *Cornell Rural School Leaflets*. Ithaca, New York, State College of Agriculture. Vol. 29, Number 4, March, 1936. 32 pp., 20 figures.

Sears, Paul B. *Deserts on the March*. Norman, Oklahoma, University of Oklahoma Press, 1935. 231 pp. (A recent book that discusses the work and the control of the work of the weather.)

Stevens, Captain Albert W., U. S. A. "Man's Farthest Aloft." *National Geographic Magazine,* Vol. LXIX, Number 1, pp. 59–94. January, 1936.

Stevens, Captain Albert W., U. S. A. "The Scientific Results of the World-Record Stratosphere Flight." *National Geographic Magazine,* Vol. LXIX, Number 5, pp. 693–712. May, 1936. (Exciting reports of a great stratospheric ascent.)

Young, Floyd D. *Frost and Prevention of Frost Damage*. Washington, D. C., U. S. Department of Agriculture, 1929, Farmers Bulletin 1588.

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