WEATHER FORECASTING

U. S. Department of Commerce
Weather Bureau
1952

This is a revision of the publication formerly issued as Bulletin No. 42, under the title "Weather Forecasting with Introductory Note on Atmospherics." It will no longer be identified by number.

U. S. DEPARTMENT OF COMMERCE
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WEATHER FORECASTING

Washington, D. C.

1952

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price 20 cents

Preface

The purpose of this booklet is to present for popular reading the elementary principles of weather forecasting and some of the basic facts and theories of meteorology which are essential for an understanding of forecasting methods. In so doing, the technical terms and precise style of the textbook have been avoided so far as possible.

Originally the subject matter appeared in a series of newspaper articles by George S. Bliss, then in charge of the Weather Bureau Office at Philadelphia but since retired. Many years ago it was made into Bulletin No. 42, which proved to be very popular. By 1940 it had gone through six editions, each revised to keep pace with changes in forecasting methods.

Since 1940 there have been many developments in the art of forecasting and in the science of meteorology, and it has become necessary to prepare this new publication. An attempt has been made to preserve the simplicity of the original bulletin, but as time passes it becomes increasingly difficult to present a simple explanation of weather forecasting methods, chiefly because of the third dimension which has been added and developed in recent years. Therefore, this bulletin is not presented as a comprehensive discussion of the subject either from the standpoint of the science of meteorology or the art of prediction. Little is included, for example, on the subject of clouds, the use of the barometer and other instruments, prediction for extended periods of five to thirty days, and other subjects which are adequately treated in other bulletins issued by the Weather Bureau. The reader can obtain lists of other publications by addressing an inquiry to Chief, U. S. Weather Bureau, Washington 25, D. C.

I. R. TANNEHILL,
Chief, Synoptic Reports and Forecasts.

U. S. Weather Bureau.
Washington, D. C.
February 1952.

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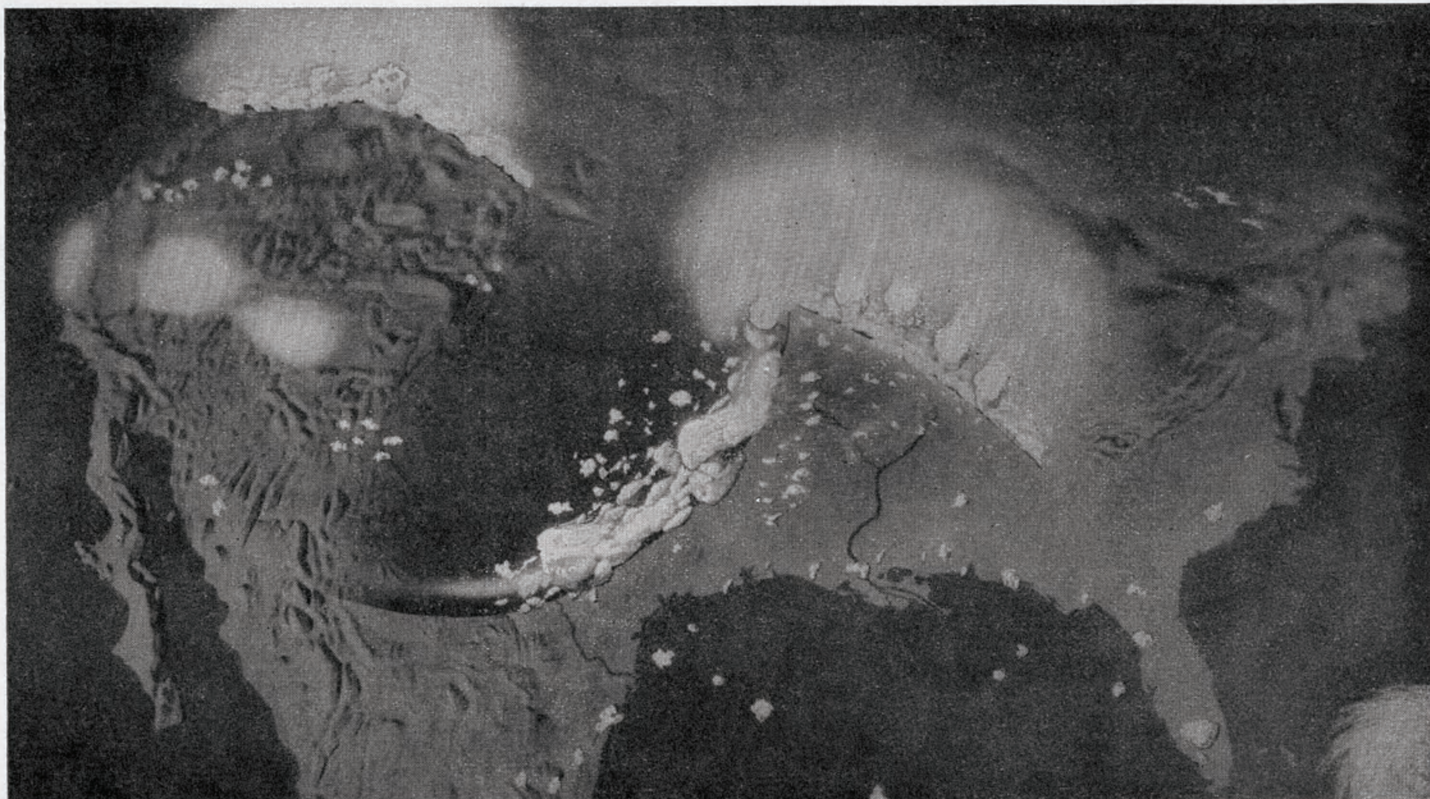

FIGURE 1.—An imaginary bird's-eye view of clouds and storms as seen from a great height over the United States.

WEATHER FORECASTING

I. Introduction

If it were possible for a person to rise by plane or rocket to a height where he could see the entire country from the Atlantic to the Pacific and from bordering Canadian Provinces to Mexico and the West Indies, he would be a long distance above the highest clouds. All weather disturbances that we know as storms would be far beneath him. Sometimes large areas including several States would be shut off from his view by clouds; other areas would be partly hidden by thin or scattering clouds; while in still other areas the view would be clear and beautiful. Figure 1 is an imaginary view of this kind.

In the clouded portions he would note, at times, violent disturbances, with flashes of lightning. Here and there would be a disturbance in which the clouds would appear to rotate about a center. When such disturbances were many miles in diameter and located over the Tropics he would know them to be hurricanes. But if they were only a few hundred feet in diameter and were in the interior of the country and he were not too high above the earth, he might recognize them as tornadoes, the most frightful and destructive of all local storms.

After the storms had passed and the clouds had cleared away he would be able to see flooded areas and swollen streams, due to the heavy downpours of rain and at times he could see the devastation wrought by terrific winds. After the passage of storms in winter he could see snow spread over the landscape like a white mantle.

If it were possible several times every day (and night) to rise to such a height, it might seem at first that it would solve the problem of weather forecasting. It might be thought that one with such a view surely could gain a better knowledge of storms and their movements and developments than would be possible for a person located on the ground, where he would have a narrow field of vision. The person aloft could map the storm areas at each observation. He could indicate the apparent energy of storms by means of numbers, and by comparing the maps from time to time he would know their directions and rates of movement. He could note the increase or decrease in their areas as they moved across the country, and it might seem to be a simple matter to send reports in advance to the areas likely to be affected during the ensuing 24 or 36 hours.

A careful study of such conditions, however, would soon show that since storms are moving disturbances in the atmosphere, and since they do not move at constant rates and in regular paths, it would be impossible to predict exactly the areas that they would cover in a given time. Each day there would be zones of uncertainty some distance ahead of the several storms, due to the difficulty of estimating exactly how far each would move. There would also be zones of uncertainty along the sides of their paths, owing to their irregular form and the impossibility of outlining them with precision.

If the error due to the zones of uncertainty did not average more than 15 or 20 percent in the forecasts, the information would still seem to be valuable. It would still compare favorably in accuracy and reliability with the advice that the public accepts and uses in other professional fields and in industrial and commercial activities. A logical conclusion would be that since such advices were the best that it was humanly possible to give, they should be accepted and used with that understanding.

Difficult as such an achievement seems at first thought, it is a fact that all of the principal nations maintain a weather service based upon surveys more accurate and detailed than would be possible by the suggested bird's-eye view. Such a survey is called "synoptic" or broad view.

The field of synoptic observation in the United States regularly covers North America, the West Indies, and the ocean areas immediately adjacent to the continent. In this area there are about 750 weather offices which send their reports every 6 hours at 1:30 a. m. and p. m., and 7:30 a. m. and p. m., Eastern Standard Time, and many of them report hourly. Cooperative arrangements are maintained between countries in North America for the exchange of the reports. Approximately 150 additional reports are received each 6 hours from ships in the Atlantic and Pacific Oceans. Telephone, telegraph, radiotelegraph, land-line teletypewriter, and radioteletypewriter are used in collecting the reports. Distribution within the United States to Weather Bureau offices is made by land-line teletypewriter circuits. The reports are entered on maps to give a synoptic picture of the weather.

In addition to reports from all of North America, the Weather Bureau has agreements with other countries in the Northern Hemisphere for the exchange of weather information. Reports from about 2,000 stations in Europe, Asia, North Africa, and northern South America are received and used to give a synoptic picture of the weather situation around the hemisphere.

The picture obtained by plotting reports of surface conditions is supplemented by upper-air information including wind direction and speed at various heights from about 350 stations in North America and about the same number of stations in the rest of the Northern Hemisphere. These reports are taken every 6 hours. In addition, observations of upper air temperature, pressure, and humidity are taken twice daily and in some cases four times daily by radiosonde at about 100 stations in North America and 50 or 60 more are received from other areas in the Northern Hemisphere.

The "synoptic" picture comes from almost 3,000 pairs of eyes looking around and up as compared with one person looking down as in the bird's-eye view, and the details are multiplied accordingly. Before we study a synoptic map of the weather in connection with weather forecasting, however, we shall review briefly certain basic facts about the nature and behavior of the atmosphere.

II. The Atmosphere

The atmosphere is composed of a mixture of gases which surrounds or envelops the whole earth. The principal constituents of dry air are oxygen and nitrogen in about the proportionate volumes of 21 percent of the former to 78 percent of the latter. The remaining part, approximately 1 percent, consists of several gases, most of which is argon. These percentages apply to dry air, but the free air is not dry. Water vapor, which is really water in a gaseous form, is always present, but in variable quantity. It may comprise up to 5 percent of the total weight of a given volume of air.

Air is acted upon by the force of gravity, as is any other substance. This force pulls the air toward the earth. Gases are easily compressed, and therefore the lowest layers have the greatest density, because they are compressed by the weight of all that which lies above. With increase of distance above sea level this pressure decreases steadily by the weight of air that is left below, thus diminishing gradually to nothing.

So much of the atmosphere is compressed into the lower layers that one-half of its total mass lies below an elevation of 3½ miles, although traces of its gases have been revealed at an altitude of more than 200 miles. Only about one one-hundred-and-fiftieth of the atmosphere lies above an altitude of 21 miles, so we may realize that this gaseous envelope is relatively very thin as compared with the diameter of the earth.

Exploration of the upper air by kites, balloons, rockets, and aircraft has shown that there are several distinctive layers. The lowest, the

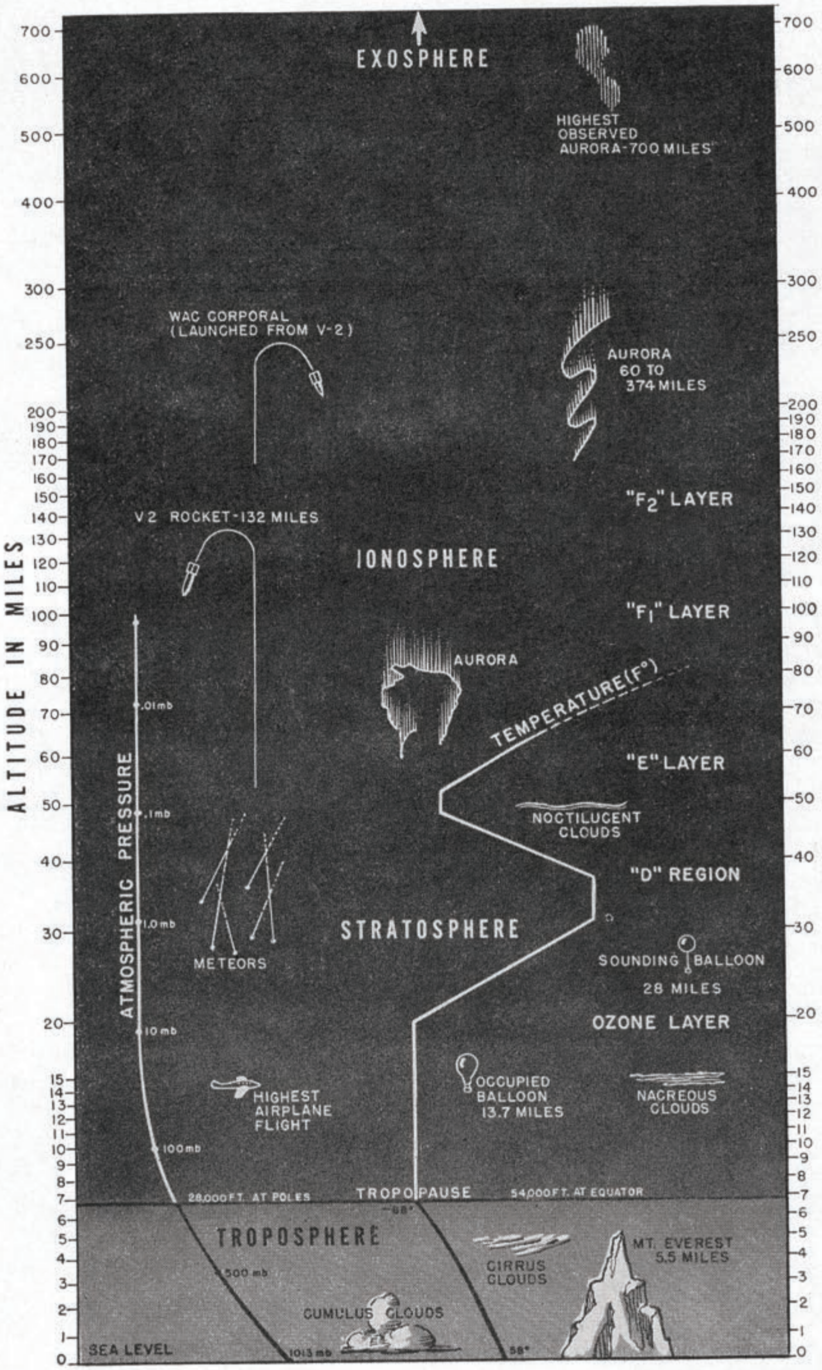

FIGURE 2.—A schematic cross section of the atmosphere.

troposphere, extends from ground level up to a height of 6 or 7 miles, in middle latitudes. Nearly all clouds and storms are contained in this layer. Usually its winds increase and its temperature falls steadily with increasing height to the top or *tropopause*, above which lies the *stratosphere* where the temperature ceases to fall with height. Higher up is the *ionosphere* and at the outer limit is the *exosphere*. Various other names have been suggested for the several higher layers, but they are not important in weather forecasting and a discussion of these details is beyond the scope of this bulletin. The schematic cross section (fig. 2) shows the relative heights of these layers of the atmosphere and the altitudes of mountains and clouds, heights reached by aircraft, balloons, and rockets, the regions of auroras, and other phenomena, and the variation of temperature with height.

The air holds in suspension many things, such as bacteria and dust particles, most of which serve a useful purpose. Only a small fraction of the bacteria is of the disease-breeding types. The dust particles in the air aid in diffusing the sunlight and thus help to give a uniform illumination. The dust also plays a part in the condensation of water vapor into clouds, as will be explained in chapter V. We have seen, however, that the atmosphere has weight and exerts pressure. How the pressure is measured is explained in the next chapter.

III. Atmospheric Pressure

Air pressure at any given point is merely the result of the combined weight of all the atmosphere overlying that point. The average pressure at sea level is about 15 pounds per square inch. Pressure varies as the amount of air above a place changes, but the total variation at any locality is only on rare occasions greater than one pound per square inch. However, variations in the pressure of the atmosphere, though rather small, are intimately associated with atmospheric disturbances, as we shall see later in taking up a study of the weather map.

The gases press equally in all directions at any given point, and consequently an open vessel, or any substance which the air can freely permeate, sustains no appreciable strain because it stands in the gases in much the same manner as does a vessel in water when it has been filled and sunk. If we should take an airtight tank or barrel at sea level, seal it, and exhaust all of the air from within, thus removing the support from that direction, the outer walls would then have to sustain the full pressure of the atmosphere (about 2,100 pounds per square foot) or collapse. On the other hand, if we should take the tank which is withstanding the full atmospheric pressure upon its outer walls,

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and should allow it to fill with air, the pressure would again be the same from within as from without and the tank would sustain no crushing pressure from the outside, as it did when there was no support from within.

Thus it is readily understood that by reducing or entirely removing the air pressure from one direction it becomes perceptible and measurable from the other directions. Barometers are instruments designed to utilize this principle and are capable of measuring the atmospheric pressure. They are of two principal kinds, mercurial and aneroid. A mercurial barometer in its simplest form consists of a glass tube about 34 inches in length and sealed at one end. The tube is filled with mercury to expel the air and is then inverted, with the open end dipping in a cup of mercury. Some of the mercury flows out and leaves a vacuum in the upper end of the tube, thus removing all pressure from the top of the mercurial column. Mercury will then remain high enough in the tube (about 30 inches at sea level) to balance the air pressure on the exposed surface of mercury in the cup. It was on this principle that the barometer was invented in 1643 by Torricelli, a pupil of Galileo.

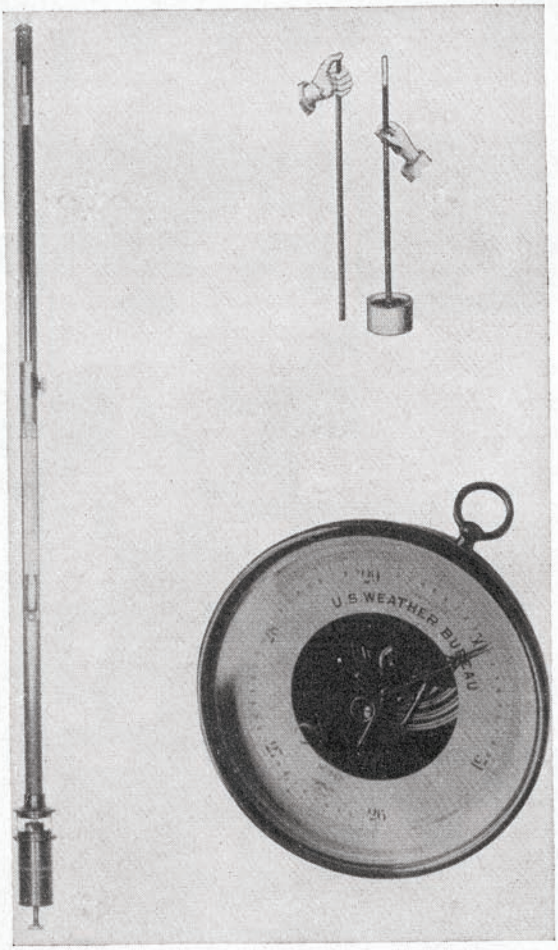

FIGURE 3.—Upper right, the experiment with a tube filled with mercury in the manner of Torricelli; left, a modern mercurial barometer; and lower right, an aneroid barometer.

A barometer can be constructed by using water or some other liquid instead of mercury, but since the atmospheric pressure is equal to a layer of water about 34 feet in height, it becomes evident that the glass tube would have to rise more than 34 feet above the surface of the water in the cup. Mercury, because of its high specific gravity, is much more practical.

A standard barometer consists of the above-described simple instrument encased in metal for better protection. A scale and vernier are attached near the upper end of the tube to give accurate readings of the height of the mercurial column. An ivory point marks the zero of the scale, or the point to which the surface of the mercury in the cup must be set before making a reading.

Aneroid barometers are intended to be moved from place to place and are much less reliable than the mercurial instruments which are moved only with extreme care to avoid damage. Aneroids use the principle of the spring scale and are graduated on the dial to correspond in pressure with inches on the scale of the mercurial instruments. The better grades are usually accurate to within one one-hundredth, or two one-hundredths of an inch, but the great majority of those offered on the market for popular use are of medium or inferior quality. Most of them bear the legends "Fair," "Rain," and "Stormy" on the dial. These legends not only have no real significance but are actually misleading. Chapter XV of this pamphlet tells how to use barometer readings in forecasting the weather from local indications.

If the indications of barometers were given in pounds instead of the height of the mercurial column in inches and fractions of inches, the instruments would seem less mysterious to the average person. Actually, there is international agreement that the pressure of the atmosphere, when given in weather reports in all parts of the world, will be expressed in millibars. The millibar is a unit of pressure in a universal system (C. G. S.) equal to, roughly, three one-hundredths of an inch of mercury.

Barometers fluctuate continuously with the passage of "Highs" and "Lows" across the country. The change from high to low is not so great as is commonly supposed, but it is very significant. The variations usually are greatest in winter, because atmospheric disturbances are most intense and energetic during that season of the year, but more so in northern than in southern States. It is unusual for a barometer to change as much as an inch in 24 hours, and such a change indicates an energetic disturbance moving at a rapid rate. The extreme range is also less than one might suppose. In 66 years of government weather records in Philadelphia, for example, the highest barometer was 31.02 inches (1050.5 millibars) and the lowest was 28.54 inches (966.5 millibars), thus making the extreme range 2.48 inches (84 millibars). This indicates a difference in pressure little more than one pound per square inch, or, in other words, it corresponds to a change in pressure such as one would experience in rising from sea level to an altitude of 2,350 feet.

IV. Heating and Cooling of the Atmosphere

It has been found that oxygen and nitrogen, the chief atmospheric gases, absorb very little of the sun's radiation on its way downward to the earth, and that most of the absorption is by water vapor, although the dust particles are also a factor. From the fact that one-half of the atmospheric gases, water vapor included, lie below an elevation of 3½ miles it becomes evident that the greater part of the absorption must take place near the bottom of the atmosphere. For that reason alone we might expect the lower layers of air to be the warmest. In addition, solar radiation which reaches the earth is only partly absorbed, while the remainder is reflected and is largely taken up during its outward passage, mostly in the moist lower air.

Again, the heat that is absorbed by the earth's surface is being constantly radiated back into space. This radiated heat is in turn absorbed by the moist lower air in the same manner as that which is reflected from the earth's surface.

There is another reason for the difference in temperatures in the upper and lower air. If a portion of the surface air is warmed, it becomes lighter than the air surrounding it and is forced upward. As the air ascends the pressure upon it decreases and it expands. The ascending air does work by expanding and pushing aside the surrounding air masses and suffers a loss of some of its total heat. Dry air, in fact, steadily cools on the average at the rate of about 1° F. for every 180 feet of ascent. Conversely, when air from higher levels descends because it is heavier than surrounding air masses the pressure on it increases and it is compressed. In this instance work is performed upon the air by the surrounding air, and thus its temperature is raised at the rate of about 1° F. for each 180 feet of descent.

If this ascending and descending action were complete and continuous, and if it were the only factor in heating and cooling, the temperature in the free, unsaturated air would decrease with elevation everywhere at the rate of 1° F. per 180 feet. However, the action is neither complete nor continuous, and the other factors which ordinarily enter into the processes of heating and cooling operate to materially reduce the rate given. In fact, at night, and especially on nights when the wind movement is light, it is not uncommon to have a local condition in which the temperature increases with elevation for short distances.

We now come to an explanation of some of the conditions which cause irregular changes in temperature from day to day or within shorter periods of time. To understand this one must know that the atmosphere is not heated uniformly, but very unequally. For example, a water surface reflects a large portion of the solar heat that reaches it, while the remainder goes to greater or less depths and is absorbed. The temperature of the water, especially clear water, is raised but little and very slowly for two reasons: First, the heating effect is distributed throughout the depth to which the radiation goes; and, second, as is well known, a larger amount of heat is needed to raise a given amount of water a given number of degrees than is required for almost any other substance for a similar change.

As the water heats up slowly, so, for much the same reasons, it cools slowly, while in the case of land the surface does not allow the rays to penetrate and does not reflect much of the energy back to the atmosphere. Consequently, land heats and cools rapidly. Thus the changes in temperature are greater and more rapid over the land than over the water. The contrast is not so noticeable in coast districts because of the equalizing effect of the land and sea breezes, but is very marked over the interior of the continents as compared with places far out over the oceans. This difference in the rates of heating and cooling causes the temperatures of adjacent areas to differ, and this in turn is, for example, the cause of the land and sea breezes.

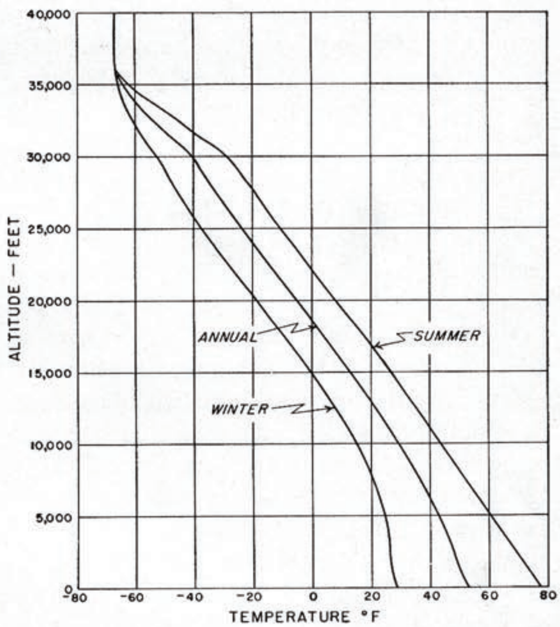

FIGURE 4.—Mean free-air temperature at about latitude 40° N. in the United States.

A further discussion of temperature changes is contained in chapter X on air mass and frontal analysis and in chapter XI on weather forecasting. In general, the amount of temperature change is dependent chiefly upon differences in temperature of the air masses, while the rate of change is also affected or partly determined by the rapidity of the air movement. For example, a cold wave is caused by a large mass of intensely cold air replacing warmer air very rapidly.

Most of the changes in weather involve cloudiness, and depend in other ways on the moisture in the atmosphere which is the subject of the next chapter.

V. Atmospheric Moisture

Heat causes water to acquire the properties of a gas. When applied to a water surface, heating results in a part of the water turning into a vapor. The heat that is expended in this process, which is called evaporation, is rendered latent or imperceptible so far as temperature effects are concerned until the vapor is again condensed into visible water particles. When this happens, the heat reappears. This explains why evaporation from a moist surface has a cooling effect, and it logically follows that the more rapid the rate of evaporation the faster will the heat become latent and the greater will be the cooling of the surface from which the heat is drawn.

We commonly speak of moist and dry air with the implied meaning that the atmosphere takes up vapor much as a sponge takes up water, but the fact is that the vapor occupies space without regard to the other gases. At any given temperature the same amount of vapor can be diffused through a vacuum as through an equal space occupied by air. In other words, the amount of vapor that can occupy a given space depends entirely on the temperature. The amount can be approximately doubled with each increase of 20° F. within the ordinary ranges experienced in the free air. Thus by raising the temperature from zero to 80° F., the capacity of a given space for moisture is increased almost sixteenfold.

Water vapor is invisible until the space which it occupies is saturated; i. e., supplied to the limit of its capacity at that temperature, after which any additional moisture becomes visible, sometimes as small particles on the surface of things, and sometimes as fog, or cloud. Also a reduction in temperature under saturated conditions will cause condensation by reducing the capacity of the space for vapor.

Night fog, or ground fog, as it is sometimes called, is caused by the radiation of heat from the surface of the ground and nearby air layers, which often lowers the temperature to a point where a part of the moisture near the ground condenses and becomes visible. The temperature at which condensation begins is called the "dew point."

At times there may be present in the atmosphere only one-half or three-fourths of the amount of moisture needed for saturation. The ratio of this amount to the amount necessary for saturation, is termed relative humidity. Thus we may say that the relative humidity is 50 percent, meaning that one-half as much moisture is present as would be needed for saturation.

During a period of high temperatures and light winds the weather conditions become oppressive if there is much moisture present, or, in other words, if the relative humidity is high. At such times the perspiration is evaporated from our bodies slowly and does not produce enough of a cooling effect. When we fan ourselves we reduce the body heat by increasing the rate of evaporation; that is, the vapor accumulating near the body is removed and the space can take more moisture.

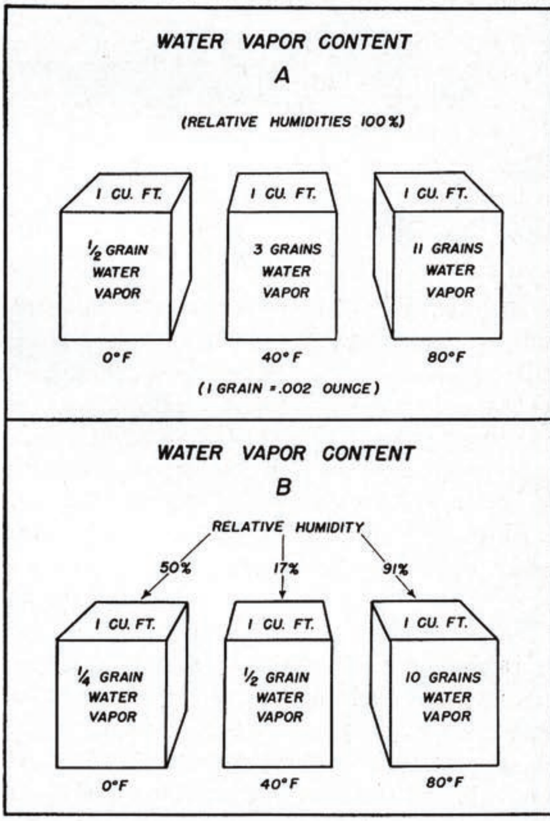

FIGURE 5.—Above (A), three cubic-foot samples of air at different temperatures showing in each case the amount of moisture necessary for saturation (100 percent relative humidity); below (B), three cubic-foot samples of air showing relative humidity with the temperature and moisture content indicated in each case.

Condensation of moisture seems to require some solid substance upon which the invisible particles can collect and coalesce into visible ones. Thus moisture condenses on the outside of a pitcher of ice water. The cold pitcher reduces the temperature of the adjacent air below the dew point, and the surface of the pitcher forms the substance upon which the moisture can collect.

In the case of free air in the atmosphere, cooling below the point of saturation, or dew point, will also result in condensation. In this case the moisture collects around minute foreign particles, termed condensation nuclei, and each water droplet is found to contain at least one such nucleus. This is true whether the condensation takes place near the ground as fog or at high altitudes as clouds.* Air which is entirely free from these nuclei can be cooled in a chamber far below its dew point without apparent condensation, but upon admitting a little puff of smoke or fine dust the moisture condenses into fog immediately.

Condensation nuclei are composed of many kinds of small particles. Sea salt particles enter the air over the oceans and subsequently drift over the continents. Fine dust particles are swept up from the land and carried thousands of miles. Finally, smoke and industrial waste fumes contribute substantially to the total in and downwind from civilized areas. The concentration of nuclei varies considerably over the globe. In the United States there appears to be a sufficient number at all times for effective condensation. In certain other places, including polar regions, the number appears to be rather deficient, and often one cannot see one's breath unless additional nuclei are supplied to the surrounding air from smoke, etc.

VI. Dew, Frost, Rain, Snow, Hail, Sleet

During clear, still nights vegetation often cools by radiation to a temperature below the dew point of the adjacent air and moisture collects on the leaves in precisely the same manner as it does on a pitcher of ice water. It often happens that when heavy dew is observed on grass and plants there will be none on the pavements or on large solid objects which absorb so much heat during the day that they do not cool below the dew point of the air at night.

Dew does not "fall"; the moisture comes from the air in direct contact with the cooled surfaces. When the condensation takes place upon any surface the temperature of which is below the freezing point, it forms frost instead of dew.

Rain, snow, hail, and sleet are all condensed moisture from the upper air, and their differences in character are due to the conditions under which they are formed. Dew, frost, and low fog are caused chiefly by cooling from radiation, while rain, snow, hail, and sleet are formed from water vapor condensed by the process of cooling that ordinarily attends the expansion of rising air currents.

Clouds are formed when the air is lifted upward and cools below the dew point. Droplets form on the condensation nuclei and are usually very small—about 1/1,000 of an inch in diameter. These droplets, being very light, are supported by the air and float along instead of falling to the ground. Sometimes air is lifted by converging winds over large areas, producing solid overcast skies. In other cases local currents predominate and form individual cumulus clouds.

*For a description of clouds, see *Cloud Forms*, U. S. Weather Bureau, Washington.

In order for cloud droplets to fall as precipitation—rain, snow, etc.—they must grow enormously, since the average raindrop contains a million times the water of a cloud droplet. Two processes are believed to contribute to this growth. When the top of the cloud becomes colder than freezing it is usually noticed that the droplets do not readily freeze, but become "supercooled." As the cloud reaches higher altitudes, however, some ice particles form and these grow at the expense of the supercooled droplets, the moisture leaving the droplet surfaces and condensing on the ice particles. Following this initial growth, the ice crystals begin to fall and their further growth results from collision and coalescence with other drops and ice crystals. If temperatures are below freezing all the way to the ground, the elements fall as snow flakes. If it is warm in the lower levels the snow flakes melt and form rain drops. In some cases rain falls from clouds which do not reach freezing heights, and here the coalescence process alone produces the rain drops.

The moisture conditions of the air below the cloud are also important in determining precipitation. When this air is almost saturated, raindrops or snowflakes fall to the ground with little change, but when the air is very dry, rain sometimes completely evaporates before reaching the ground. It is not uncommon on a warm summer afternoon, especially in the southwestern States, to note rain falling from a cloud and gradually evaporating until it can no longer be seen, and later when the cloud passes overhead to note that no rain reaches the ground.

The difference between rain and snow is similar to that between dew and frost. When condensation in the free air occurs with the temperature below freezing, the moisture may condense into minute ice crystals or into snowflakes. When snowflakes are examined under a microscope they, or their parts, are found to form regular six-sided figures in an almost endless variety of geometrical designs.

Snowflakes pile up on the ground to considerable depth but the water content of unpacked snow is rather low. Under ordinary conditions it takes from 8 to 12 inches depth of snow to equal 1 inch depth of water.

True hail occurs only in warm weather and usually with thunderstorms when strong vertical air currents are present. When a hailstone is sliced through the center it is found to be made up of concentric layers of snow and ice. It is therefore reasoned that the hailstone is started by a raindrop being carried up where the expanding air around it is cooled below the freezing point. The raindrop is frozen, and then, falling back into a warmer layer of cloud and rain, immediately collects a coating of water, only to be carried by another gust of rising air back into the higher layers and frozen. This process is continued by separate gusts of rising air until the hailstone becomes

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so large that it can no longer be held aloft, when it falls to the earth. Sometimes several hailstones touch and freeze together, falling to the earth as a large, irregular chunk of ice.

During the winter season rain sometimes falls through a layer of air where the temperature is slightly above freezing and afterward falls through colder air and reaches the earth as frozen raindrops or ice pellets. This form of precipitation is not hail but sleet.

After a prolonged or severe cold spell it sometimes rains before the temperature of the ground and the lower air have risen above the freezing point. The rain then freezes to everything that it touches and forms a coating of ice. This ice is often erroneously called "sleet." Meteorologists use the term "glaze" for the ice coating, while the storm which produces it is called an "ice storm." When the ice coating becomes heavy enough, much damage may result by the breaking down of wires, branches of trees, shrubs, vines, etc.

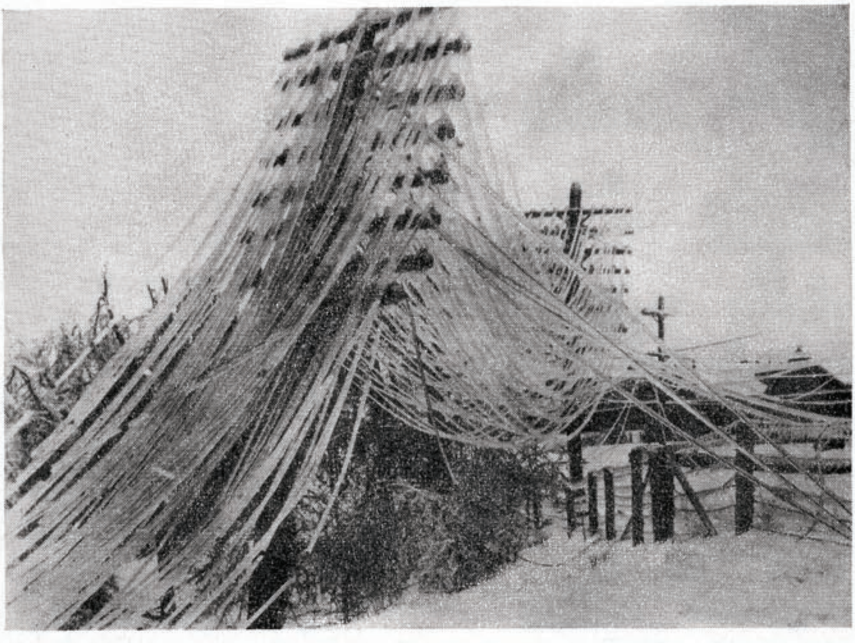

FIGURE 6.—When rain freezes to everything it touches, forming a coating of ice, it is called "glaze" and the storm which produces it is called an "ice storm."

VII. Circulation of the Atmosphere

Cold air is heavier than warm air under corresponding conditions because heat expands the atmosphere and makes it less dense. We can see this principle illustrated in the hot-air balloon which rises because the heated air in the sack is lighter, volume for volume, than the colder surrounding air, and it is forced upward in the same way that a cork when released under water is forced to the surface. In general, the greater the difference in temperature of adjacent masses of air the more vigorous will be the atmospheric disturbance.

At any given place on the earth's surface, especially in the temperate zones, the wind is likely to blow from any point of the compass; but, in general, particularly in lower latitudes, it is likely to blow more frequently from certain directions than from others. The prevailing direction is determined by the average distribution of temperature and barometric pressure over the globe; it may vary from season to season at a given place. The principal causes of the general atmospheric circulation are the heating of the earth in equatorial regions and the cooling in polar regions which tend to set up a circulation of air between high and low latitudes.

The circulation which actually results is profoundly influenced by the rotation of the earth and by the distribution of continents and oceans. In middle latitudes the circulation is highly irregular, and characterized by a constant succession of disturbances. In low latitudes, especially over the oceans, the winds blow with remarkable constancy and regularity; they are called "trade" winds.

The trade winds begin about 30° on either side of the thermal equator and flow from the northeast in the Northern Hemisphere and from the southeast in the Southern Hemisphere, and under the influence of earth rotation gradually become more and more easterly as they approach the Equator. The thermal equator shifts slightly north and south of the true Equator with change of seasons.

The circulation of the atmosphere comprises a complex and ever-varying system of interacting currents by which great quantities of air move from place to place over long distances. Sometimes, for example, vast masses of Arctic air move down from Canada and spread over the Great Central Valleys as a cold wave; the density of these cold air masses causes high barometric pressure, and they appear on the weather map as "Highs," or anticyclones, around which the winds circulate in general in a clockwise direction in the Northern Hemisphere. Widespread storms, accompanied by rain or snow, are wind systems of relatively low barometric pressure, or "Lows," around which the winds circulate in a counterclockwise direction in the Northern Hemisphere; they are technically called extratropical cyclones in temperate latitudes. When "Lows" appear in the Tropics and develop into severe storms, they are known as hurricanes in the West Indies and as typhoons in the Far East; these tropical cyclones are smaller in diameter than most of the extratropical ones, and usually are much more energetic. While in low latitudes of the Northern Hemisphere, they drift in a westerly direction, then northwesterly and northerly, and gradually curve toward the northeast. On drifting into temperate regions they usually increase somewhat in area and lose in-

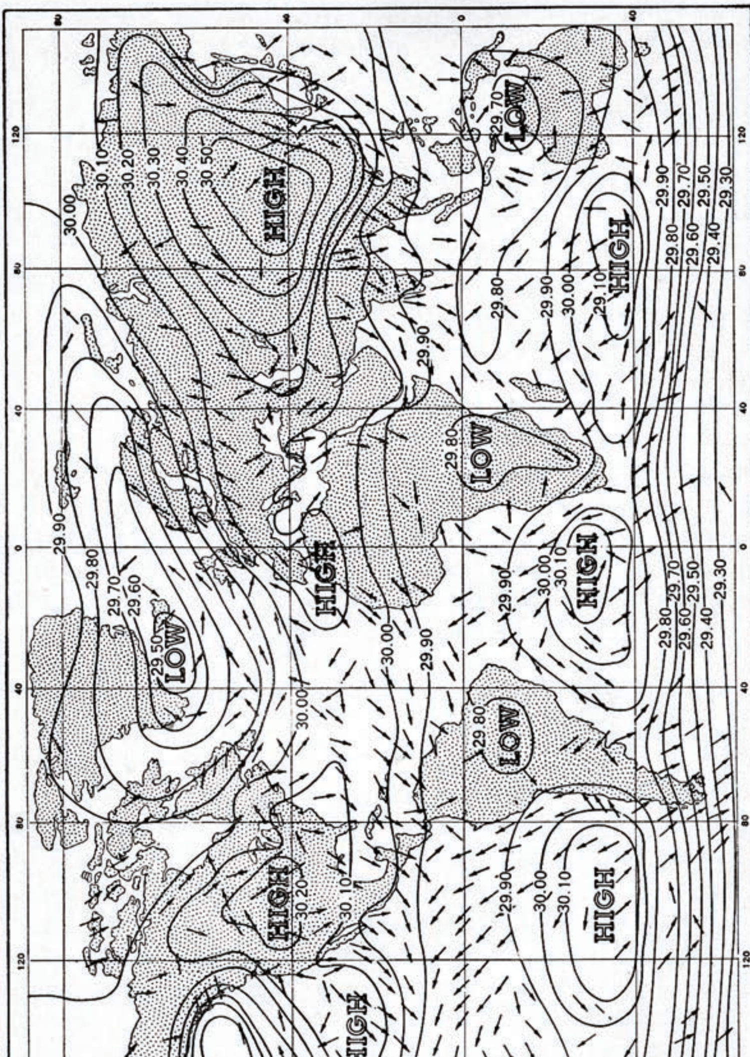

FIGURE 7.—The average distribution of pressure and wind over the earth in January.

tensity. Because of the effect of earth rotation, "Lows" in the Southern Hemisphere have clockwise wind systems and "Highs," counterclockwise.

VIII. An Atmospheric Survey

Of course it is impossible at present for any one to attain a height from which he could view such a vast region as the whole continent of North America. As suggested in the introductory remarks, however, there is a much more effective way to take an atmospheric survey; namely, by observing the conditions near at hand at a large number of places, and then piecing these observations together on a map. This is the synoptic method generally employed by meterological offices.

Every 6 hours near or shortly after 1 and 7 o'clock a. m., and p. m., 75th meridian time, the observers in all parts of the world simultaneously begin the work of taking the observations. The sky is observed and the clouds are classified; the barometers are read and corrections are applied to obtain the corresponding values for sea level, so that all reports may show pressures for the same level; the direction and speed of the winds are noted: the rainfall, or snowfall, if any, is measured; the current temperature and the extremes since the last previous observation are taken from the several thermometers; the moisture content of the air is calculated: the visibility and height of cloud are determined; and all other phenomena, such as thunderstorms, fog, smoke, halos, etc., are carefully noted.

Each observer then condenses the information into a numerical message in the International Code. The message is composed of 6 or more 5-figure groups which, if expanded into descriptive language, would comprise from 60 to 100 words. These messages are readily decoded in any country in the world.

This work consumes about 20 minutes after which the coded messages are transmitted to collection centers and exchanged internationally. At each receiving office the messages are decoded as fast as they are received and the conditions reported are transcribed by figures and symbols (the weatherman's international shorthand) upon an outline map covering the area from which reports are received. This map, known as a manuscript map, is especially designed for the entry and study of weather data contained in the reports. The location of each observing station is indicated by a small circle. Data in each station report are entered at the respective station circle in accordance with a definite pattern that is used throughout the world. This arrangement is known as the station model.

After all the reported data have been entered on the manuscript map the forecaster can see a broad picture of existing weather conditions over a very large geographical area. He improves the picture by connecting points of equal pressure with smoothed solid lines called isobars, and by marking boundaries or "fronts" between different masses of air.

Isobars are drawn at intervals of three millibars; e. g., through all points reporting a barometric pressure of 1020 millibars with successive isobars through points 1023, 1026 millibars, etc., toward regions of higher pressures and successive isobars through points reporting 1017, 1014 millibars, etc., toward regions of lower pressures. The centers of these regions are marked "High" or "Low," respectively. The picture can be made more graphic by shading or outlining areas over which precipitation is occurring at the time of observation.

All operations from weather observations to completion of the current weather map are carried out at high speed but with care to assure accuracy and in accordance with closely coordinated schedules. In less than 2 hours from the time the observations are taken the various forecasters are, figuratively speaking, standing on eminences overlooking the entire field of observation and are prepared to give out information regarding the weather conditions in any region. Such information, be it remembered, is not prospective or in any way in the nature of a forecast, but represents the actual observed conditions.

Manuscript weather maps are designed to serve as the chief tools of the forecaster. The principal map shows conditions at the surface of the earth but, in the main forecasting offices, a number of auxiliary maps are drawn showing conditions at various levels in the upper air. These maps present, as accurately and as extensively as is possible, a synoptic picture of existing weather. The forecaster compares this picture with those of the several preceding six-hourly intervals and studies the movements and actions of pressure systems and notes the changes in temperature and moisture that are taking place within the masses of air as they move over various types of terrain. Following this study he makes his forecasts. Before discussing the analysis of the weather and the forecast procedures, however, we shall examine two sample weather maps.

IX. A Short Study of the Weather Map

Following are two illustrations of the weather map for consecutive dates. These maps were abridged from official manuscript maps; they contain only a portion of the data regularly plotted and show a reduced network of reporting stations. They are intended to bring out rather simply the pressure pattern in a well-developed "Low," its movement and changes during a 24-hour period, and also how the temperatures, cloudiness, and other features of the low pressure system change during this time. In order that we may be able to interpret the weather map and make simple forecasts, we must study first some of these principal features.

As explained in the preceding chapter, the solid lines are called isobars, meaning lines of equal barometer readings. They outline the atmospheric disturbances and locate their centers, and thus constitute the most prominent feature of the map. The broad lines having triangles or half circles at intervals along their extent are the "fronts." A description of the structure and characteristics of fronts, as shown on these maps, will be found in the next chapter.

Bearing in mind that the arrows are inscribed to fly with the wind, a careful inspection of the areas having "Low" marked at the center will reveal the fact that the surface winds blow toward these centers, not directly, but spirally, and in a counterclockwise direction. Some places will be noted where the surface winds do not conform to this rule, being temporarily deflected by topography or other local conditions. However, the more intense and energetic the "Low" becomes, the more nearly will the winds conform to the general rule, as the forces in the atmospheric eddy become strong enough to overcome local influences.

It will readily be seen that when a "Low" is approaching any locality it will appear to the local observer to be coming from nearly the opposite direction, simply because the winds blow spirally around the center instead of with the direction of the "Low's" movement. Thus, the "Lows" that are commonly called "northeasters" along the north Atlantic coast usually move up from the south or southwest.

Now, an examination of the areas marked "High" at the center will show that the winds are blowing in a direction opposite to those around the "Lows"; that is, spirally outward from the center with a clockwise rotation. Thus, considering the circulation of winds around both the "High" and "Low" centers, it is readily seen that there is a gradual transfer of air at the surface from areas of high pressure to those of low pressure.

This transfer of air means that there is a slow sinking of air in "Highs" as air descends from upper levels to replace air at the surface as it flows outward. Conversely, there is ascent of air over "Lows" where it is pushed upward by converging winds. Reasoning then that descending air is being warmed by virtue of the resultant increase in pressure, and that rising air is cooled by expansion, as the result of its transport to higher levels where pressures are lower, we can deduce that, in a general way, there should be a definite tendency for clear skies in "Highs," and that cloudiness and precipitation should be found for the most part in and around "Lows" where winds are converging and the air is being forced upward. A glance at figures 8 and 9 will show that such a deduction holds true in this instance.

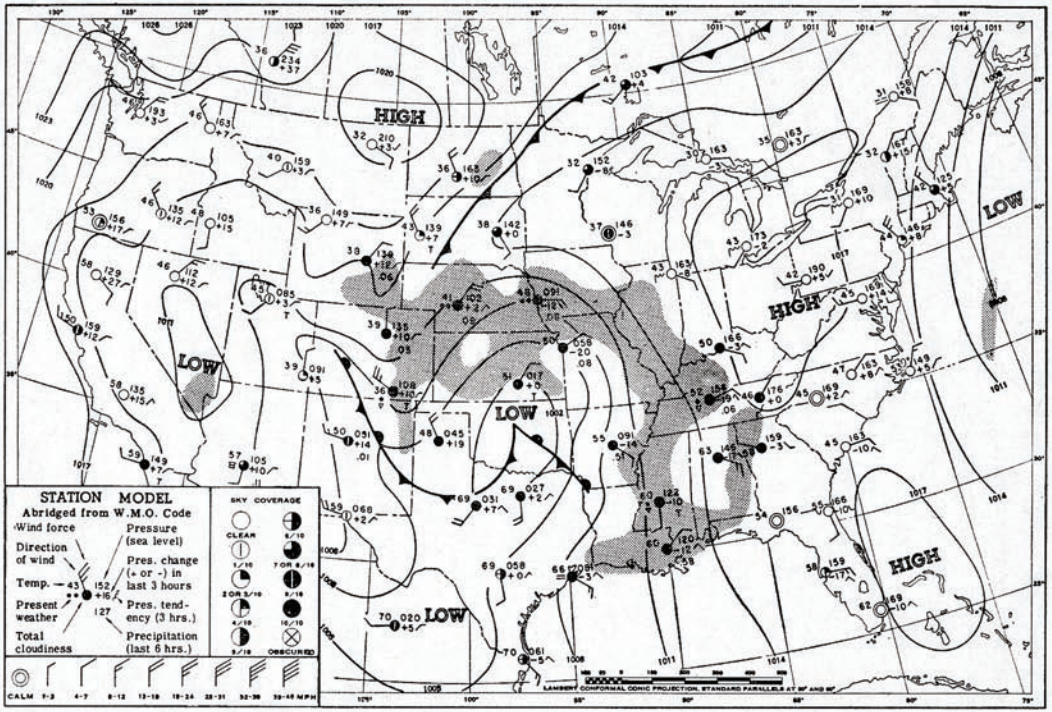

FIGURE 8.—Synoptic weather map of surface conditions on the morning of April 6 showing "Low" centered over Oklahoma. Abridged data are shown only for selected stations. Shading shows area over which precipitation is occurring at time of observation. See figure 9 for map for following day.

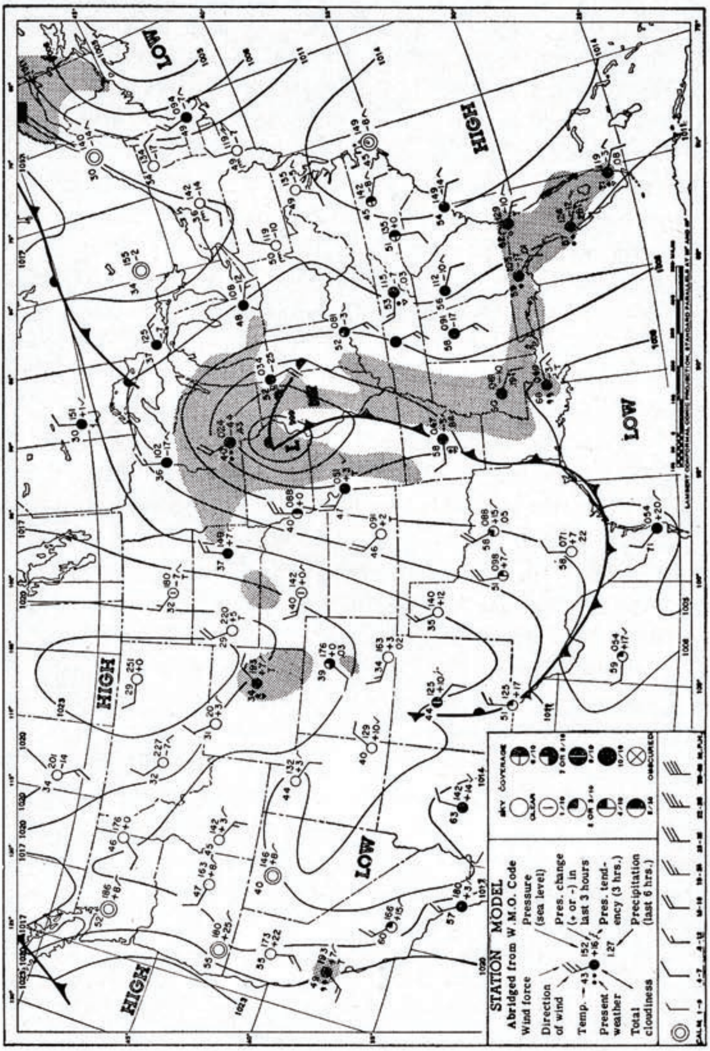

FIGURE 9.—Synoptic weather map of surface conditions on morning of April 7. The "Low" is now centered over eastern Iowa; the "High" over Montana has strengthened; and cold weather has extended southeastward across Texas.

Now, let us look first at figure 8. We see a large, well defined, low pressure system covering the south-central Plains States with a center developing over Oklahoma. The characteristic counterclockwise circulation is shown by the wind arrows at surrounding stations. The fronts extending outward from the center of the "Low" mark the boundaries between the two types of air that have produced this disturbance. We notice a sharp difference in wind directions on opposite sides of the fronts and a difference in temperatures between stations to the rear of the cold front and those in the warm sector between the forward edge of the cold front and the warm front.

Looking now at current weather conditions we see that precipitation is occurring at weather stations within a narrow belt extending northward from the lower Mississippi Valley then westward, and following, in a general way, the cyclonic (counterclockwise) circulation attending the "Low." In this case the precipitation is the result of the lifting and cooling of the warm, moist air as it moves northward then westward from the Gulf region.

In figure 9 we see the same "Low," now centered over Eastern Iowa and considerably more active than the day before as indicated by the more compact counterclockwise circulation and higher wind speeds. It will be noticed also that the "High" centered over eastern Montana has intensified during the twenty-four hour interval between maps and that the cold air has pushed southward to the West Gulf. Precipitation is occurring closer into the center of the "Low" than was the case at the time of the earlier map shown in figure 8. This is due to the more rapid movement of the air out of the warm sector upward over the colder, denser air beyond the warm front.

The warm and cold fronts mentioned in the foregoing description are essential elements in the structure of the "Lows" with which they are associated and play a leading part in the origin, development and eventual disappearance of such atmospheric disturbances. More complete information on this subject will be found in the next chapter.

X. Air-Mass and Frontal Analysis

The daily weather maps studied in the preceding chapter show conditions at the earth's surface. It is necessary also for the weather forecaster to have information regarding conditions at upper levels before he can understand fully what is taking place on the surface map. For the upper levels the air currents are mapped with data secured by small helium-filled rubber balloons called pilot balloons. They are optically tracked in flight by instruments called theodolites until they pass out of range of vision or are lost in clouds. Data are secured also by another device, the radiosonde, which has come into everyday, practical use in recent years. This instrument, which is carried aloft by a balloon, may properly be called a "robot reporter." As it rises it emits radio signals that can be translated into atmospheric pressure, temperature, and humidity. These signals are automatically copied by a recording instrument at the surface of the earth. From the pressures and temperatures, altitudes are computed. This instrument is very small and light; it can be carried to great heights by the balloon, and soundings can be made in all kinds of weather.

A more recent method developed during the war and now employed quite generally uses radio direction-finding equipment to track the balloon-borne radiosonde after it passes out of sight into clouds. By this means upper wind information is available to greater heights and is received simultaneously with pressure, temperature, and humidity data. Observations of winds aloft made by these techniques are known as rawinsondes. Another recent development in upper wind observation uses radar to track a target carried aloft with the radiosonde balloon but this method is not yet in general use.

The information obtained by pilot balloons and radiosondes has added a third dimension to the daily weather map and we can now find out what takes place in the upper air and how it affects the weather that occurs at the surface of the earth. We can follow the different air streams as they cross the country. In the study of these moving masses of air from different localities it has been found that they tend to retain many of the characteristics of their source regions. Cold, dry air from Canada remains dry but warms slowly. Warm moist air from the Gulf of Mexico continues moist and may become warmer or cooler, depending on conditions over the continent. As time goes on, of course, air masses gradually become more and more modified by the conditions encountered during thir progress.

One important point is that when air masses from widely separated places of origin, and with distinctly different properties, are brought into contact with one another, these bodies of air do not freely mix, but tend to retain their identities. Throughout much of their history they remain separated from one another by more or less well-defined surfaces of discontinuity or transition zones in temperature, humidity, and wind velocity until eventually they are subject to mixture, dissipation, and ultimate disappearance as separate bodies.

It is at these so-called frontal surfaces that the processes involved in weather phenomena are in general most active, although many important phenomena also frequently take place within the body of an air mass. A "Low," for example, is formed essentially of two great atmospheric currents, one of warm air and the other of cold air. A disturbance develops at the boundary between them. The warm current advances against and flows up over the cold current, while in the rear of the disturbance the cold air sweeps under the warm current (figs. 10

and 11). In the regions where warm air is forced to ascend, the cooling may lead to condensation, clouds, and rain or snow. Figure 11 shows in the middle a warm, moist current of south or southwest winds, constituting the "warm sector," with cold air at the rear and in front. The warm and cold air masses are separated by fairly distinct boundary surfaces, shown by the broken lines, which pass through the "Low" center; the cold front marks the line where the cold air is replacing warm air, and the warm front where warm air is replacing the cold air.

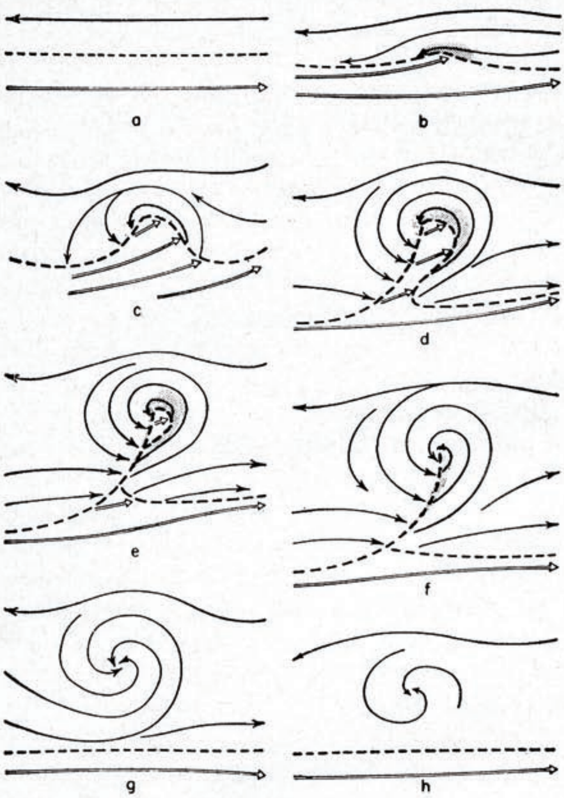

FIGURE 10.—In the above diagram the sequence, a, b, c, etc., shows the formation of a wave disturbance (a and b) on the boundary between a cold and a warm current; development of a cyclone (c and d); occlusion (e and f); and dissipation (g and h).

The upper portion of figure 11 shows a vertical east-west section through the "Low" north of the center. Here the air at the surface is moving from an easterly or northerly quarter and is quite cold, as is generally found in the northern quadrants of a "Low." Aloft the wind is from the southwest and, being of tropical origin, is relatively warm and humid. It came originally from lower levels and low latitudes, having undergone a forced ascent over the cold wedge of surface air with the result that there is considerable cloudiness and precipitation, due to cooling by expansion incident to ascent.

The lower portion of figure 11 shows another vertical east-west section through the "Low" south of the center. At the left are seen the cold, polar, surface winds from the west and northwest underrunning the warm, moist, tropical winds from the south and southwest, which latter persist aloft after the winds have changed to westerly at the surface. This under-running results in forced ascent of warm, moist air from the south with resulting cloudiness and showers which are occasionally heavy and, as a rule, brief. This is the cold front, which is generally identified with squally weather, where the wind changes suddenly to a westerly quarter. At the right of the section there is the relatively warm southwest wind aloft over-running the colder surface air from the east, giving widespread cloudiness and precipitation.

In the central part of figure 11 the line trending southeast from the "Low" center shows the position of the warm front while the cold front extends southwestward from the center of lowest pressure. Between the warm front and the cold front, at and near which cloudiness and precipitation are in evidence, there is usually a region of warm air and relatively clear sky and sunshine, although cumulus clouds are to be expected, and at times scattered local showers. It will be noted that a narrow band of showers is pictured along and immediately behind the cold front, which showers, however, are entirely absent in some cases.

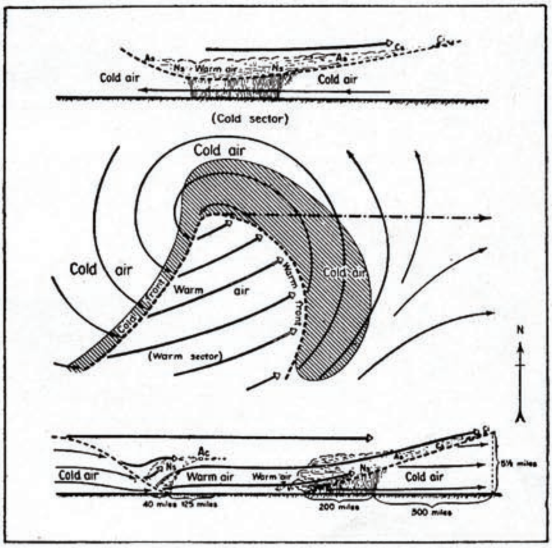

FIGURE 11.—Idealized extratropical cyclone formed by the process illustrated in figure 10, with vertical east-west cross sections through the northern part (above) and the southern part (below).—*After Bjerknes.*

At and immediately ahead of the warm front, on the other hand, the area over which rain is falling is relatively broad, the rain being due to the upflow of the warm, moist south and southwest winds over the cold, dense current from the east and southeast.

When a cold front advances rapidly the warm sector of a "Low" is sometimes squeezed between the cold air ahead and the oncoming mass of cold air in the rear. The warm air is pushed aloft and one of three things will happen to the "Low":

1. If the cold air in the rear is colder than the cold air in advance, the cold front will push under the air ahead of the front. This is called a "cold-front type occlusion" and is accompanied by precipita-

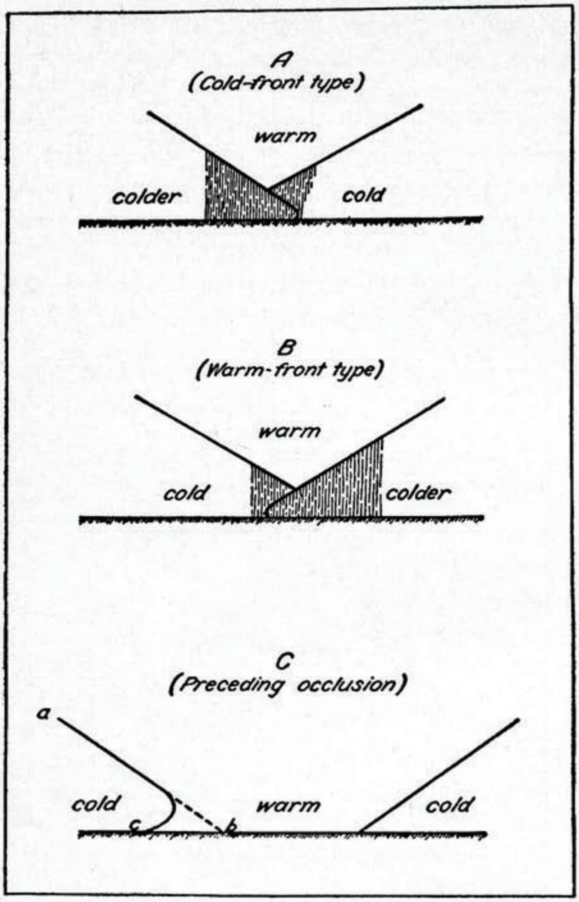

FIGURE 12.—Types of occlusions.

tion near and behind the surface front. 2. If the cold air in the rear is not as cold as the air being overtaken, it will slide upward over the cold air in front. This condition is called a "warm-front-type occlusion" and generally produces precipitation in advance of the surface front. 3. If there is little or no difference in temperature between the two cold air masses a "neutral-type occlusion" results. In this case precipitation occurs along the front and the low-pressure system dissolves.

Low-pressure systems have a regular life history; they develop, increase in intensity for a while, and later die out. They frequently occur in families on surfaces of discontinuity separating cold, polar air from warm, tropical air. The point where the development takes place is where a bend or wave develops in the line or surface of discontinuity (fig. 10), generally to the south or southwest of the anticyclone that follows the parent "Low." The family, or series, may consist of 2, 3, or even 4 individual "Lows," each one starting successively farther and farther to the south and east.

XI. Weather Forecasting

We can now begin to apply the elementary principles of weather analysis and begin to use weather maps to anticipate the movements and developments of atmospheric disturbances.

Many changes occur in the pressure systems and fronts during their progress across the country. The precipitation (rain, snow, hail, sleet, etc.) areas usually increase or decrease in size and change their form. Also, the temperature distribution around pressure centers changes, and the disturbances change in intensity. For example, when a "Low" is central over Idaho it is easy to understand why the precipitation within it will ordinarily be light; the air which flows into the "Low" from all sides is comparatively dry. Even the air currents from the Pacific are dry on reaching Idaho, because cooling by expansion takes place as they are forced to rise over the Cascade Mountains, thus precipitating a large portion of the original moisture. Once the center of the "Low" has crossed the Rocky Mountains, however, and has moved down the eastern slope into the Central Valleys the rainfall begins to increase in extent and amount because of increasing moisture in the air masses.

The increase in moisture is due partly to increased evaporation from moister regions, but primarily because in this stage the air masses in the front of the "Low" have moved from the Gulf and South Atlantic regions into the Central Valleys. As a result of the greater amount of moisture available, the precipitation area is likely to expand.

Weather forecasters watch these movements and developments by means of weather maps of the surface conditions and the upper air, in order to anticipate the changes that will occur within the disturbances, to estimate the expanse of territory that will be covered, and the time that given points will be reached by weather and temperature changes. By this means they make an estimate of the weather and temperature conditions that may reasonably be expected in each locality during the ensuing 36 to 48 hours.

One of the fundamental principles on which all weather forecasting for middle latitudes is based is the fact that atmospheric disturbances travel in a general easterly direction. Apart from the surface winds and isobars, there is an immense mass transport of the atmosphere from west to east across Canada and most of the United States. This is a part of the general or planetary circulation of the earth's atmosphere, and to a large extent the pressure systems and fronts, which are merely disturbances in this general circulation, are carried along and show a progressive eastward movement from day to day. As we find from experience that this eastward movement may vary anywhere between north and south directions, at the same time these pressure formations are constantly undergoing an increase or decrease in intensity, it becomes apparent that the problem of forecasting is immensely complicated.

About 60 percent of the "Lows" come into the United States in the extreme Northwest, and a large proportion of them move eastward along the northern border, across the Great Lakes, and finally pass off the north Atlantic coast. Some of these disturbances move far to the southward, however, and when the warm moist air begins to flow inland from the Gulf region they usually recurve to the northeast and then increase rapidly in intensity.

The low-pressure systems that are first seen over the southern Plains or come into the southern States from the Gulf of Mexico generally drift northeastward and pass off the north Atlantic coast. They are usually more intense and energetic than those which cross the country along the northern border. For example, we may conceive a well-developed "Low" to be central over northern Texas and moving toward the New England States. During the entire time that it is crossing the Central Valleys it is drawing warm air masses, heavily laden with moisture, from the Gulf of Mexico. As the storm moves farther to the northeastward and the moisture supply from the Gulf begins to decrease, the deficiency is partly made up by moisture-laden currents from the Great Lakes and the Atlantic Ocean. Thus it is that heavy rains may, and generally do, accompany these "Lows" throughout their entire course.

Although the direction and rate of movement of pressure systems vary with the season, there is no great regularity about them. Only in the averages do they show this regular seasonal effect. Some move with great rapidity and others move slowly or remain stationary. For his estimate of future motion of a low pressure system, the forecaster watches the upper air currents, the previous rate and direction of travel of the system, and the changes in pressure in the region in which it is located.

Predicting the speed and direction of travel of low- and high-pressure systems, however, accounts for only a part of the problem of weather forecasting. It still remains to determine what temperature changes will occur with their passage, whether precipitation will be produced, and, if so, where and when it will fall, the amount and height of cloudiness, the visibility, humidity, and other features of the coming weather. It is in this phase of the problem that greatest advance has been made in recent years owing largely to information obtained from upper levels. Meteorologists and forecasters have come to look upon each "Low" as a complicated machine having a rather definite structure, obeying well-recognized physical laws, and undergoing a characteristic life history.

At least two different air masses are necessary for the maintenance of a low-pressure system, and it is the interaction of these contrasting air masses that furnishes the energy to keep it going. Cold air from northerly directions flows into the "Low" in its western quadrants, while warm air, bearing abundant supplies of moisture, flows in from lower latitudes with southerly winds. These two opposing cur-

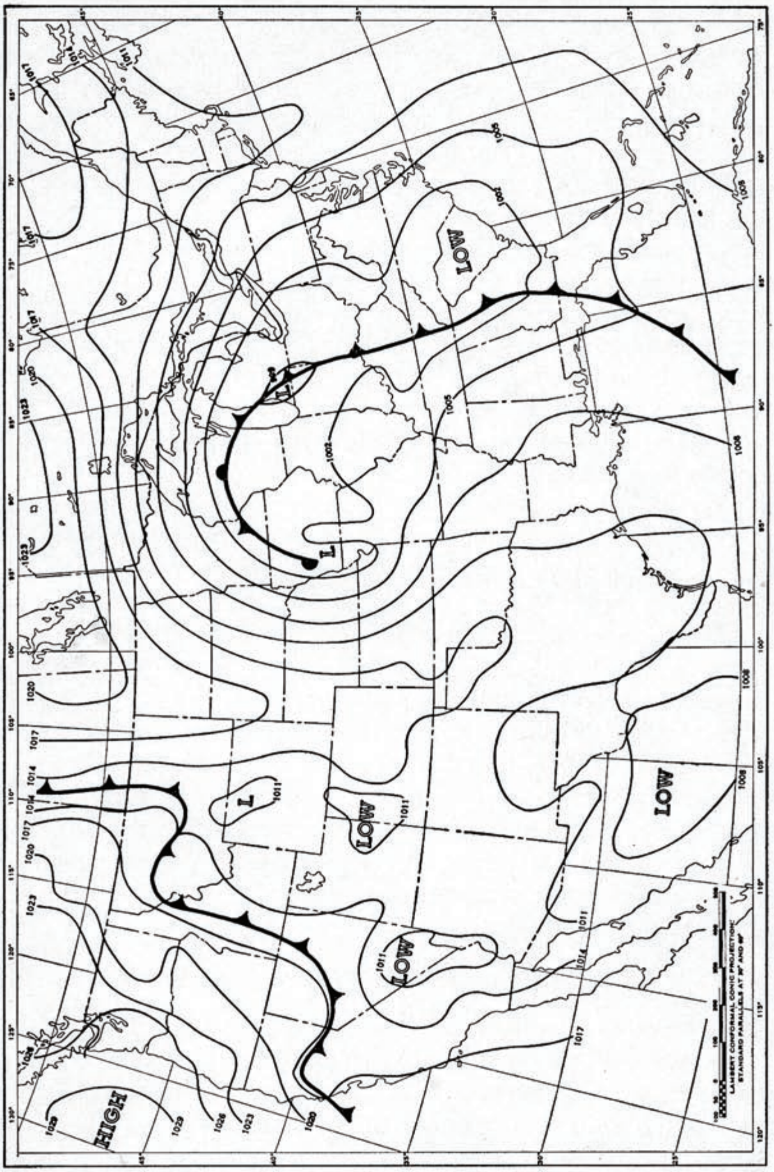

FIGURE 13.—Prognostic chart for the morning of April 8 based on the synoptic situation shown in figure 9.

rents, meeting at a surface of discontinuity, are clearly seen in the weather map reproduced in figure 8. Rain or snow in the northeastern quadrant of the "Low" is brought about by precipitation of moisture from the warm air riding up over the colder, denser air ahead of the warm front. Such condensation liberates large amounts of heat energy, which helps to perpetuate the system. However, there are exceptions; in some cases no precipitation occurs in advance of the center, since the warm air is not lifted high enough to produce saturation. Likewise, precipitation generally, but not always, falls a short distance behind the cold front.

This brings up the question whether the precipitation will be in the form of rain or snow. This is determined principally from charts showing the wind directions and speeds at various levels in the upper atmosphere, and also the temperature and moisture conditions. With this information it is possible to determine the steepness of the frontal surfaces, the amount of lifting required to produce saturation in the moist air, and whether or not the temperatures will be favorable for rain or snow.

At present, the principal tool in forecasting precipitation and other conditions is the prognostic chart. After study and analysis of the various charts, a map of surface pressure, systems and fronts as they will probably exist 24 to 48 hours later, and charts of probable future conditions on isobaric surfaces aloft (700 millibars, 500 millibars, etc.) are drawn. From these maps of future conditions the forecasts are made with due regard for the physical processes involved. A Central Analysis Unit at Washington prepares analyses and prognostic charts for the entire country and adjacent areas and transmits them to field offices by teletypewriter (code) and facsimile. District and local offices make forecasts for their respective areas, using the facsimile or coded maps received from the analysis center or their own maps prepared locally, or in some cases a combination of the two, depending on the facilities available.

XII. Hurricanes, Cold Waves, Tornadoes

The storms that occasionally move up from the Tropics to our southern coasts in late summer or early autumn are called hurricanes. They differ in many respects from the ordinary low-pressure systems. They are smaller in area and more intense and energetic. Their movement of translation in southern latitudes is slow, while the winds within the disturbances are generally violent and destructive. The accompanying rainfall is usually torrential in character. The rapid release of latent heat due to the great condensation of moisture appears to be one source of their tremendous energy.

In tropical regions these disturbances generally have a central area of comparative calm with a clear sky, called by sailors the "eye of the storm." Hurricanes usually approach the southeastern United States from the east and, upon reaching our southern coast districts, are likely to turn to the northwest and finally northeast, with decrease in intensity and increase in the movement of translation, while the "eye of the storm" gradually disappears. While these disturbances are in the tropical region they have no accompanying area of high barometric pressure, as the northern disturbances generally do; the temperatures are practically the same in all of the quadrants and the rainfall distribution is comparatively uniform. When they move into temperate latitudes their source of heat and moisture becomes the same as that of the extratropical disturbances, and their character changes accordingly.

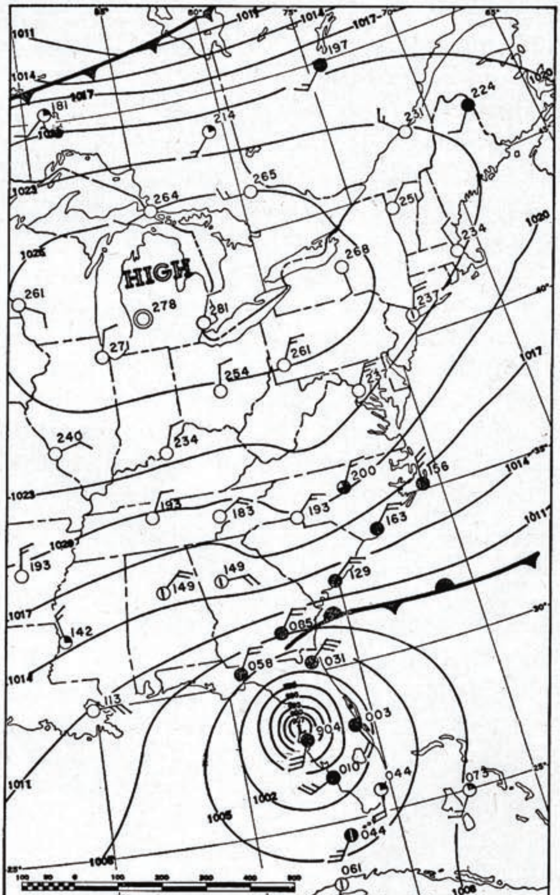

FIGURE 14.—Part of a weather map showing a hurricane centered near Tampa, Fla.

When a hurricane makes its appearance over southern waters it is customary for the Weather Bureau to request frequent reports from all observation points in its vicinity, and to watch its movements as closely as possible in order to issue warnings ahead of it. Reports come by radio from a large number of cooperating merchant ships and from many observing stations on the islands. In addition, military aircraft are used to reconnoiter the storm's center and report back to the forecast office. By this means, timely warnings and advices are issued and broadcast widely by radio.

Cold waves are caused by sudden outbreaks of cold, polar air which rapidly spread southward, displacing warmer air masses and causing large falls in temperature. They occur chiefly during the winter months, when the atmospheric disturbances are most energetic and the accompanying temperature changes are consequently most rapid and pronounced. If a rapid fall in temperature occurs in summer, it is usually from a point much above the normal to a point considerably below the normal, but seldom with injurious conditions, or with temperatures low enough to constitute a cold wave. In issuing warnings of cold waves, the Weather Bureau requires that the lower limit must under any circumstances reach frost temperatures, while at some places and in some seasons of the year it must fall to 0° F.

The pressure conditions most favorable for a cold wave require that an energetic and rapidly moving "Low" shall be quickly followed by an energetic "High." The most widespread and sweeping cold waves occur when the "Lows" move northeastward from the southern States and the "Highs" from the far Northwest spread down across the Plains States and the great central valleys in the rear of the "Lows."

When a cold wave occurs in the northeastern portion of the country the "Low" may move northeastward from the Ohio Valley or it may move up along the Atlantic coast, but it is necessary that the crest of the following "High" shall remain well to the northward until it reaches the Great Lakes, or else that it shall move southward from the Hudson Bay region. However, in this portion of the country, it sometimes happens that a cold wave occurs in the western quadrants of an energetic "Low" with no well-defined high pressure following it. In all events a cold wave is accompanied by a rapid rise in barometric pressure as the "High" moves in.

The most energetic of all air movements are tornadoes, which are local disturbances of a funnel-like character, the central core or vortex seldom being more than 150 or 200 yards in diameter. Not all of them are violently destructive, but some of them have a power for destruction that is almost unbelievable to one who has not seen it. Large frame buildings are literally torn into splinters. In some cases the largest piece remaining of a house or barn could be carried away by two men. Buildings of brick and stone are sometimes wrecked, and in some cases almost leveled to the ground. Instances have been noted where portions of brick buildings were removed and scattered as if by a huge projectile. Railroad boxcars, both empty and loaded, are blown 50 to 75 feet from the track and wrecked. In fact, few things above the level of the ground seem to be able to withstand the full fury of a tornado.

It has not been possible to measure the strongest wind in a tornado because they seldom occur in any one locality, and instrumental equipment is invariably wrecked. However, the results of a storm sometimes afford a basis for estimating wind velocities, and it is certain that they sometimes exceed 300 miles per hour.

FIGURE 15.—A tornado.

XIII. A Study of Map Types

The use of map types in forecasting is frequently suggested and has often been tried, but with only limited success. Weather maps, like human faces, seem to come in an almost endless variety, and rarely, if ever, do we find two which may be classified as duplicates. However, like human faces, they may be classified into certain types in which those belonging to each type will have certain general characteristics in common.

Many persons have conceived the idea that, if a very large number of maps were to be collected and classified, the problem of forecasting might be resolved by the simple method of selecting a map of corresponding type and by forecasting developments in exact accordance with those which followed in the case of the type map. Experience has shown that so many factors enter into the classification that such experiments are nearly always disappointing. When maps have been classified in accordance with the pressure and temperature distribution, and then further classified by months, it is found that in maps of corresponding types the precipitation areas vary greatly. This is due to the fact that the air currents involved in the disturbances may have come from different source regions and therefore vary greatly in moisture content.

For example, suppose we have two maps in which pressures and temperatures and their distribution are practically identical. In each there is a "Low" centered over Arkansas, these areas being of the same size, formation, and apparent energy, while the conditions in the remainder of the country are also alike on the two maps. In the one instance the "Low" has moved from Colorado and is recurving to the northeast, while in the other the "Low" has moved from Texas and is proceeding in a nearly straight path. The Colorado "Low" has come from a cool and elevated region, and the air which has passed through it has been comparatively dry. The Texas "Low" has passed through a low, flat country, and during its entire course has drawn warm, moist air from the Gulf region. It is easy to understand that the difference in the moisture content in these cases will have a marked effect on the size and intensity of the rainfall areas. Also, the act of recurving has a retarding effect on the movement of translation of the Colorado "Low," while the one from Texas suffers no such handicap. Thus we see how two maps of apparently the same type may vary greatly in their subsequent movements and developments.

The classification of a large number of maps indicates that a storm's characteristics are determined primarily by the portion of the country in which it makes its first appearance, and that this has a controlling influence on its movements and developments throughout its entire course. In an intelligent study of any map it therefore becomes necessary to take this factor into consideration. The study of maps with regard to type has been beneficial in many ways, however, chiefly because it has established certain general characteristics that maps of each type have in common. For example, the average movements of "Lows" classified in accordance with place of origin or first appearance are shown in figure 16.

XIV. Extended Periods, or "Spells" of Weather

When the atmospheric disturbances move in such a manner that low barometric pressure prevails in the southern and high pressure in the northern States for many successive days, or sometimes for several weeks, the prevailing winds in the Central Valleys and the eastern States are from northerly directions. This means that currents of cold air are constantly flowing from Canada and are spreading over those regions, and the temperatures remain abnormally low until the prevailing movement of the air changes to another direction. In such cases there is likely to be much precipitation.

Conversely, temperatures sometimes rise quite rapidly in the nature of a warm wave, but a more common condition is one in which it rises steadily for several days and the warm period extends over a week or more, sometimes for several weeks. Such a condition results when the pressure gradients are the reverse of those cited above, or, in other words, the pressure is high in the south and southeast and low in the

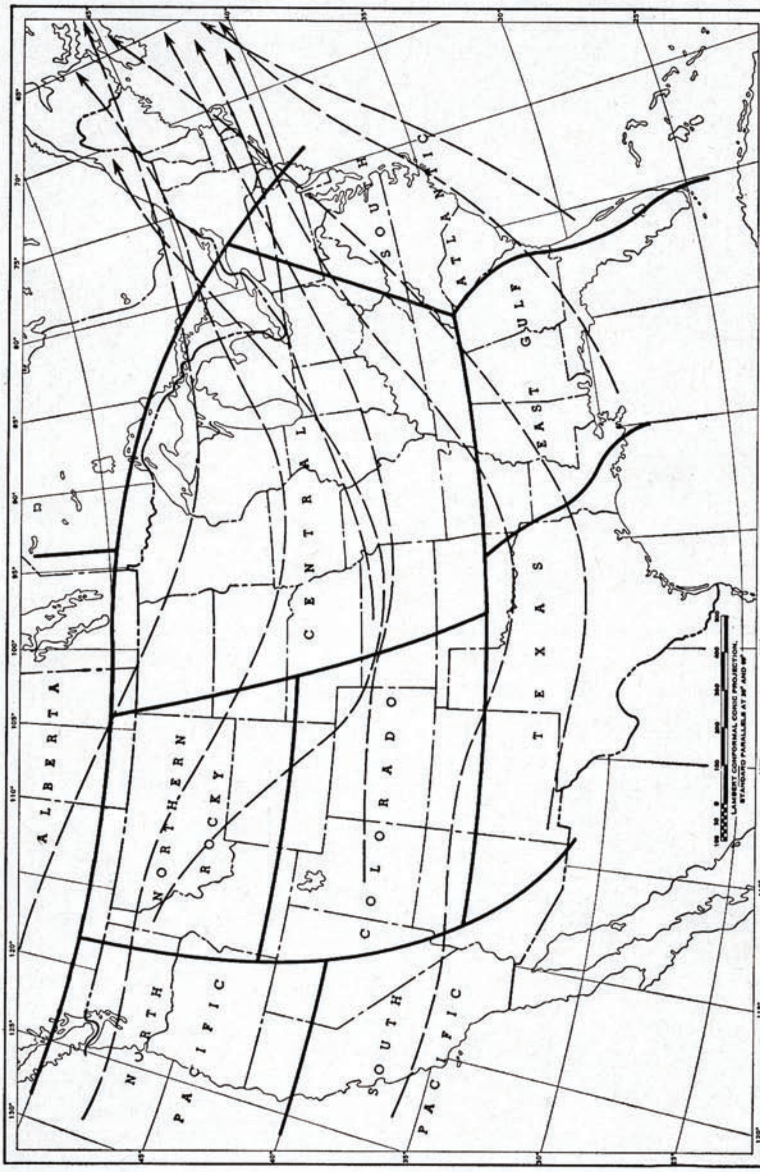

FIGURE 16.—Regions of origin of the storms of the United States, and the average January track of each type.—*By Bowie and Weightman.*

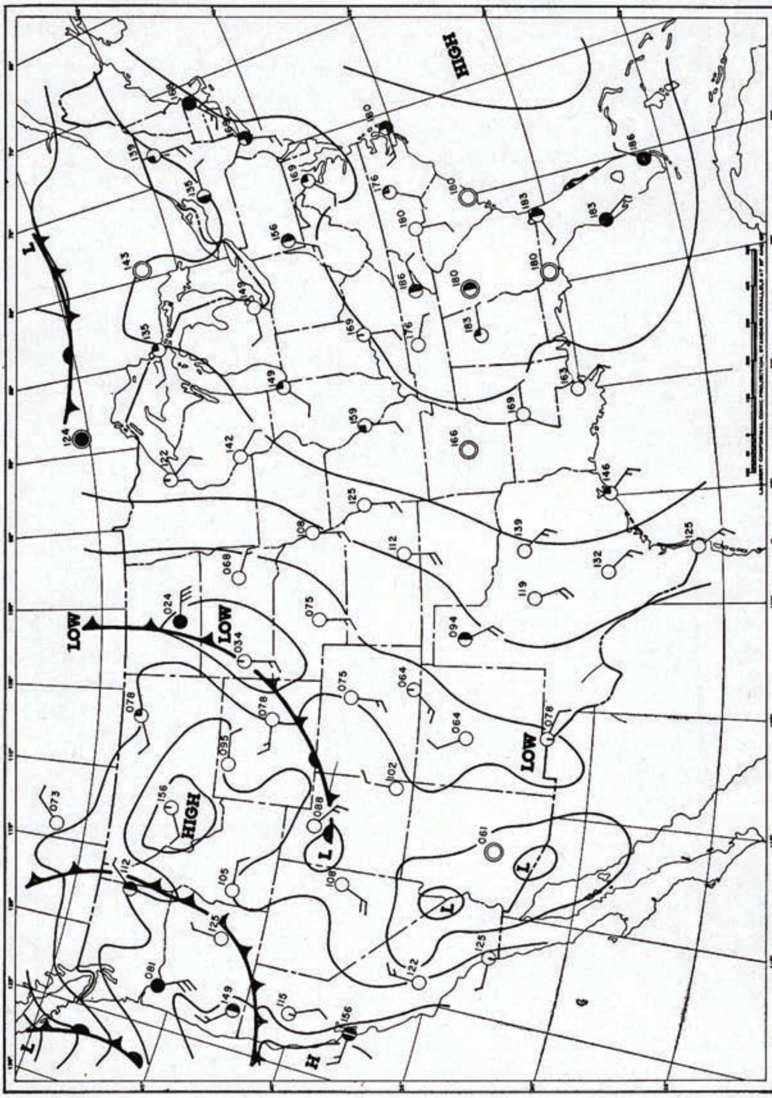

FIGURE 17.—Surface conditions during a warm spell in eastern United States.

north and northwest, and the prevailing winds are from southerly directions. Precipitation in these cases is usually below normal.

During the summer season the pressure sometimes builds up over the southeastern States as an extension of the Atlantic "High," while low-pressure areas succeed one another along the northern border with no well-defined intervening high-pressure areas. Under such conditions vast masses of tropical air move to the northward from the Gulf region and spread over the Central Valleys and the Plains States, and excessive heat prevails in those regions until the pressure changes and the tropical air masses are replaced by others from cooler regions.

By mapping the entire Northern Hemisphere the Weather Bureau is enabled to forecast general conditions for 5 days in advance with a creditable degree of accuracy, and outlooks for 30 days are issued experimentally. At the present time there is nothing known which justifies any person in venturing forecasts for a longer period. Five-day forecasts are not subdivided into definite 12- and 24-hour periods, but must necessarily be more or less generalized. Beyond 48 hours it is only possible to say if it will be generally fair or rainy, and if the temperature will be seasonable or otherwise.

XV. Forecasting From Local Indications

Though there has been much exaggeration of the ability of mariners to forecast weather changes from local observation, they are somewhat more adept than people in other occupations. This is not because the signs are so much more pronounced over the ocean than over the land, but is primarily because the mariner for many years had no other source of information and of necessity learned to interpret their significance. On land a heavy storm is not so often a matter of life or death as on the ocean, and consequently while most people recognize a few signs, they rarely follow them out in a systematic manner to determine their reliability.

Weather changes are not usually heralded definitely by local indications for periods longer than a few hours in advance; indeed many local storms give scarcely an hour's notice of their coming. Another difficulty is that very few local signs apply with equal force to all parts of the country. Indications along the Pacific coast differ materially from those along the Atlantic coast, the Gulf coast, or the interior of the continent, and in the interior there is a great difference between indications in the Rocky Mountain region, and the central valleys or the Great Lakes. Many signs which might be considered reliable in the Ohio Valley would be valueless in the drier regions of the far Southwest.

In order that the laymen may formulate such local rules as may be distinctly applicable to the locality in which he lives, he should proceed in a careful and systematic manner to record and correlate his observations. Weather proverbs will not be found to be generally applicable, and only those which, when analyzed, are found to be based upon scientific fact and principles will be worth considering.

Proverbs pertaining to the condition of the atmosphere, the appearance of the sky, the character and movements of the clouds, and the direction and force of the winds are, generally speaking, all that are worth testing out for any particular locality.

Proverbs regarding the actions of birds and animals are of little value. Changes in the atmospheric conditions are responsible for their peculiar actions and they are affected by the weather which is taking place and not by weather to come.

Sayings which pertain to the moon and the planets are useless and those which apply to forecasts for coming seasons are entirely without foundation. For example, peculiar growths and developments in vegetation are the results of weather conditions that have passed and have no connection with those to come. The character of the musk-rat's house or the beaver's dam is the direct result of the stage of the water at the time the structures were made.

Inasmuch as the barometric pressure is the main feature of the weather map having prognostic value, and is sometimes considered to be of as much importance to the forecaster as all of the other information combined, it is equally as essential that the local observer should be equipped with some means by which to detect changes in atmospheric pressure. Pressure changes used in connection with the wind direction will give him the best key to the local situation. There are certain wind-barometer indications that are generally applicable to all parts of our country; e. g., the following statements:

> "When the wind sets in from points between south and southeast and the barometer falls steadily, a storm is approaching from the west or northwest, and its center will pass near or north of the observer within 12 to 24 hours, with wind shifting to northwest by way of south and southwest. When the wind sets in from points between east and northeast and the barometer falls steadily, a storm is approaching from the south or southwest, and its center will pass near or to the south of the observer within 12 to 24 hours, with wind shifting to northwest by way of north. The rapidity of the storm's approach and its intensity will be indicated by the rate and the amount of the fall in the barometer."

A series of local observations, when compared and classified, will soon reveal certain well-defined relations that will enable the observer to begin compilation of a list of reliable indications. The list will increase with experience, and established rules will be modified by noting the most common exceptions. Some indications which are reliable for one season of the year will need to be materially changed in order to apply to a different time of the year.

The observer should remember that all weather changes are the results of physical conditions occasioned by the unequal heating of the atmosphere and modified by the character of the surrounding country. Everything savoring of astrology, or of the mysterious in general should be entirely rejected, and he should proceed with his work as far as possible on a purely physical and scientific basis.

Wind and barometer indications for the United States have been generally summarized in the following table, which is as reliable as any other set of local rules.

Wind direction	Barometer reduced to sea level	Character of weather indicated
SW. to NW	30.10 to 30.20 and steady	Fair, with slight temperature changes for 1 to 2 days.
SW. to NW	30.10 to 30.20 and rising rapidly	Fair, followed within 2 days by rain.
SW. to NW	30.20 and above and stationary	Continued fair, with no decided temperature change.
SW. to NW	30.20 and above and falling slowly	Slowly rising temperature and fair for 2 days.
S. to SE	30.10 to 30.20 and falling slowly	Rain within 24 hours.
S. to SE	30.10 to 30.20 and falling rapidly	Wind increasing in force, with rain within 12 to 24 hours.
SE. to NE	30.10 to 30.20 and falling slowly	Rain in 12 to 18 hours.
SE. to NE	30.10 to 30.20 and falling rapidly	Increasing wind, and rain within 12 hours.
E. to NE	30.10 and above and falling slowly	In summer, with light winds, rain may not fall for several days. In winter, rain within 24 hours.
E. to NE	30.10 and above and falling rapidly	In summer, rain probable within 12 to 24 hours. In winter, rain or snow, with increasing winds, will often set in when the barometer begins to fall and the wind sets in from the NE.
SE. to NE	30.00 or below and falling slowly	Rain will continue 1 to 2 days.
SE. to NE	30.00 or below and falling rapidly	Rain, with high wind, followed, within 36 hours, by clearing, and in winter by colder.
S. to SW	30.00 or below and rising slowly	Clearing within a few hours, and fair for several days.
S. to E	29.80 or below and falling rapidly	Severe storm imminent, followed, within 24 hours, by clearing, and in winter by colder.
E. to N	29.80 or below and falling rapidly	Severe northeast gale and heavy precipitation; in winter, heavy snow, followed by a cold wave.
Going to W	29.80 or below and rising rapidly	Clearing and colder.

As a rule, winds from the east quadrants and falling barometer indicate foul weather; and winds shifting to the west quadrants indicate clearing and fair weather, but there are exceptions and in some parts of the country this rule does not apply. In any case the local weather observer should not ignore the official forecasts and it is especially important that he give heed to special warnings issued by the Weather Bureau. He may modify them for his own use, in accordance with his local observations, and he may watch developments and see how the official forecasts are working out, but dangerous weather oftentimes comes very quickly with little or no indication except on the weather map.

U. S. GOVERNMENT PRINTING OFFICE: 1952