How the Daily Forecast is Made

By C. L. Mitchell and H. Wexler

MAKING the daily weather forecast is a highly expert job. Gradually the guesswork and the art have been reduced, and the process has become more and more scientific. To show how it is done, this article takes a single forecast made on a day in March 1939, gives some of the data the forecaster had available, and tells how he used it to predict what the weather would be during the next day over an area covering 16 States. This particular example was chosen because it was an "easy" one, though it may not seem so to the general reader.

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The forecasts of the weather to be expected during the next few days, issued daily by the Weather Bureau of the United States and the meteorological services of other countries, are made on the basis of the fact that existing weather conditions travel constantly, changing more or less as they move. By making observations of the weather simultaneously at a large number of places distributed over as large a part of the earth’s surface as possible, transmitting them immediately to a central station, and there preparing from them a map showing the existing weather over a particular region, it is possible to estimate how these existing conditions will move and change and hence what weather will be experienced in different areas in the immediate future.

For this purpose the United States Weather Bureau maintains about 350 stations distributed over the country. Observations from which to prepare maps and diagrams of many different kinds are taken simultaneously at these stations, and in addition reports are received from many places in Canada, Mexico, Central America, and the West Indies, from scores of ships at sea, from islands in the Pacific and Atlantic Oceans, and from the continents of Europe, Asia, and Africa. The data that are collected and charted include not only information about temperature, barometric pressure, wind, rain, and other conditions at the surface of the earth, but also reports obtained from soundings of the atmosphere up to altitudes of several miles at a large number of stations.

This organization has grown from small beginnings more than 70 years ago, when the Signal Corps of the United States Army inaugurated a meteorological service in response to the demand created by the success of pioneer efforts on the part of Cleveland Abbe to conduct such a service at the Cincinnati Observatory. The fact that weather conditions travel over the surface of the earth had been indicated more than a hundred years earlier by Benjamin Franklin’s discovery in 1743 that a storm experienced at Philadelphia in September of that year moved eastward across the country and was confirmed by subsequent studies on the part of many investigators during the eighteenth and nineteenth centuries.

After the invention of the electric telegraph, many saw the possibility of forecasting the weather by the obvious and simple process of telegraphing ahead what was coming. The synoptic map prepared from observations taken simultaneously at a network of stations over a large region, showing the weather conditions over this region at the time of the observations, was introduced early in the nineteenth century. Daily telegraphic maps were first issued in the United States by the Smithsonian Institution beginning in 1850, only 5 years after the opening of the first commercial telegraph line. France first issued daily telegraphic charts regularly in 1863, and other countries followed with similar maps in steady succession.

**DEVELOPMENT OF UPPER-AIR OBSERVATIONS**

During recent years the observing network has been enlarged, and the completeness and frequency of the observations have steadily increased; in particular upper-air data from aerological soundings have become more complete and more quickly available for current daily use. Long before weather forecasting was undertaken, upper-air explora-
tion had begun. In 1749 Alexander Wilson, of Glasgow, was raising thermometers on kites. In 1784 John Jeffries and the aeronaut Blanchard made the first balloon ascents for meteorological purposes. Thereafter progress was slow until 1852, when John Welsh, of Kew Observatory, England, made balloon ascents to 7,000 meters (over 4 miles), taking observations of temperature, pressure, and humidity. Between 1862 and 1866 James Glaisher carried out meteorological observations in a series of historic balloon ascents.

In the seventies in the United States the Signal Corps of the Army established the first high-mountaintop weather observatories on Mount Washington, N. H. (6,300 feet), and on Pikes Peak, Colo. (14,100 feet). The continuous observations at these stations when compared with similar observations at nearby lowland or valley stations threw a good deal of light on the upper-air structure of storms, which had previously been studied from surface conditions alone. The observations were studied more zealously by the European meteorologists than by the American, and their valuable results led to the establishment of a large number of mountain observatories in Europe. Attempts to use the daily telegraphed reports from the mountain stations in making daily forecasts were unsuccessful, for the reasons that an adequate working hypothesis as to the relation of upper-air conditions to surface weather was lacking and the mountaintop observations were not truly representative of the free atmosphere, owing to the disturbing influence of the mountain itself. The mountain observatories in this country were therefore closed, but active work on other methods of procuring upper-air data was continued.

As an indirect means of determining upper-air motions, classification of the forms of clouds and observations of their movements were industriously carried out by many observers, beginning in the early nineteenth century. The French naturalist, Lamarck, in 1801, was the first to attempt a classification, but the credit of classifying the clouds in a scientific manner belongs to Luke Howard. In 1803 he named the main classes—cirrus, stratus, cumulus, and nimbus. Many investigators used cloud observations in determining the courses of air currents aloft and the relation between cloud type and ensuing rain. Clement Ley's cloud studies in England (1865–78) gave the first adequate description of the upper windflow in cyclones and anticyclones. In this country the most elaborate summary of cloud observations was made by Clayton in his review of data of the Blue Hill Observatory of Harvard University, in Massachusetts. Clayton found that while cloud types gave definite warning of precipitation in the next few hours, they were of very little help for longer intervals.

In 1893 the first recording instruments, or meteorographs, were sent up on small free balloons by Hermite and Besançon in France. A year later instruments were sent up in box kites by Rotch and Fergusson in the United States. Pressure, temperature, and humidity were recorded by pens tracing curves on a sheet of paper fastened to a drum rotated by a clock. The record was evaluated after the meteorograph was recovered. Important investigations with the

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use of balloons or kites were made later by Teisserene de Bort in France, Assmann in Germany, Dines in Scotland, and Clayton in the United States.

In 1909 Rotch, at Blue Hill Observatory, made the first upper-wind observations by means of a theodolite (a telescope mounted so as to measure horizontal and vertical angles) with which he observed at regular intervals the elevation and horizontal (azimuthal) angles of a small balloon, called a pilot balloon. Knowing the rate of climb of the balloon, its horizontal path could be plotted and the wind direction and velocities at various heights found. Pilot-balloon observations are now taken several times daily at more than 100 stations in the United States.

So extensively had the program of upper-air research developed before the World War that 18 countries were actively participating in this type of work. However, for various reasons the data obtained were not available for current use in forecasting. The sounding balloon, while easy to use and capable of reaching great heights, suffered from the disadvantage that the record often could not be recovered until weeks and even months after the release. The kite could be released only under certain favorable wind and weather conditions, and usually reached a height of only a mile, while the sounding took several hours and required a mass of cumbersome equipment and the work of several men. Hence the upper-air data served only for statistical investigations.

The rapid development of the airplane during the World War resulted in a quick and easy means of obtaining observations up to 2 or 3 miles; and, what was just as important, the detailed-forecast requirements for aircraft operations served as a stimulus to the use of the upper-air data in forecasting.

After the war the airplane sounding was adopted in many countries. In the United States the Navy had already made such soundings as far back as 1917, and the Weather Bureau in cooperation with the Army made test soundings in 1918. Airplane soundings were made frequently at most of the Naval Air Stations in the 1920's. It was not until 1931, however, that the Weather Bureau began to replace the kite stations, which had at no time numbered more than six, by airplane stations. Four such stations were established in the summer of 1931, and together with soundings made by the Navy and one by the Massachusetts Institute of Technology the total number available was about a dozen. In July 1934, following the recommendations of the President's Science Advisory Board, Congress authorized an increase in the number of Weather Bureau airplane stations and the use of Army planes at other stations, so that the total number of airplane soundings—Weather Bureau, Navy, Army, and Massachusetts Institute of Technology—available for daily use was over 20. The number was gradually increased to about 30 in 1937.

Despite their advantages over the balloon and the kite soundings, the airplane soundings were expensive, and it was often impossible to take them during periods of disturbed weather, when they would have been most valuable. The latter objection applied also to the pilot-balloon soundings. Consequently, at about the time that the extended network of airplane stations was being established in the United States, research was being actively conducted both in this
country and abroad to develop a radio-meteorograph—radiosonde—consisting of a lightweight meteorograph and radio transmitter attached to a small balloon. Each of the three meteorological elements, pressure, temperature, and relative humidity, is measured by the meteorograph and indicated by radio signals, which are intercepted at the ground by a radio receiver. The radiosonde observations, besides being collected at the ground without loss of time, have the added value of being less expensive than airplane soundings and independent of bad flying weather, and they can be obtained at far greater heights.

The first successful radiosonde ascent was made before 1930 by the Russian meteorologist Moltchanoff at Sloutsk, near Leningrad. The first one in this country was made by Lange, of Blue Hill Observatory, in 1935. Bureau of Standards scientists devised a radiosonde that was first used by the Navy at Washington, D. C., in 1936 and then at Fairbanks, Alaska, during some special investigations of polar weather in 1937–38. In July 1938, 6 airplane stations of the Weather Bureau network changed over to radiosondes. Finally, in July 1939, all of the Weather Bureau and 3 of the 9 Navy airplane stations were replaced by radiosonde stations, making a total of about 30 in all.

Meanwhile the purely empirical methods, based on experience alone, to which weather forecasting, as developed in the nineteenth century, was at first limited, have in recent years been supplemented to an increasing extent by methods based on an understanding and an explicit application of the physical laws to which atmospheric phenomena conform. For this the development of the polar-front theory, described elsewhere in this volume (Rossby, p. 599; Reichelderfer, p. 128), has been largely responsible.

MAKING THE DAILY FORECAST

The object in weather forecasting is to provide the farmer, the city dweller, the shipper of perishable goods, the railroads, the public utilities such as gas, electric, and street-transportation companies, the aviator, and the owners and masters of all types of vessels from fishing and pleasure craft up to the largest passenger liner, and all others interested in the weather, with as accurate weather information as possible and with forecasts as far ahead as practicable. In order to do this it is necessary for the forecaster to know intimately what changes have taken place in the weather situation for the last day or two. When he has become well acquainted with the sequence of events and weather phenomena as shown on the principal weather chart and all the auxiliary charts and graphs that are prepared regularly, he is ready to project the present conditions into the future to the best of his ability with the aid of every scrap of information that will give a hint as to what will take place within the next 12, 24, 36, and even 48 hours.

There are now available every 6 hours detailed observations at the surface of the earth from hundreds of places in the United States, including Alaska, and Canada, and from Bermuda and scores of ships at sea; and every hour from most of the stations in the United States and southern Canada via the telegraphic typewriter, or teletype. In addition, twice-daily reports are received from parts of Mexico, Cen-
tral America, the West Indies, Greenland, the Azores, Europe, northern Africa, China, Japan, Siberia, the Philippines, Honolulu, and Midway, Wake, and a few other islands between Honolulu and the Philippines.

The data from a large number of stations in the United States, southern Canada, Mexico, Central America, the West Indies, and Bermuda and reports from ships in the adjacent waters are plotted on a single sheet—the principal weather chart—containing an outline map of this area. The rest of the reports are entered on a chart of the Northern Hemisphere and are utilized largely in the preparation of semiweekly weather outlooks. In preparing the daily forecasts, the surface observations are supplemented, as previously described, with pilot-balloon observations now made at nearly 100 stations in the United States and at a few stations in Alaska and southern Canada and with the observations from 35 to 40 radiosonde and airplane stations fairly well distributed over the United States and 2 in Alaska.

**The Principal Weather Chart**

The data entered on the principal weather chart enable the forecaster to locate all the areas of low barometric pressure (lows) and of high pressure (highs), and at least the principal fronts (dividing lines between air masses of different origin, density, and water-vapor content), as well as the directions and rates of movement of the centers of the highs and lows and of the fronts since they first made their appearance on the weather chart. He sees not only these important features of the map but also the type of weather produced by them at all reporting stations. The principal items that indicate the current condition are the temperature and the dewpoint (the temperature at which the water vapor in the air would begin to condense if the air were cooled), the proportion of sky covered by clouds, and the occurrence or nonoccurrence of precipitation at each station. To obtain an idea of the changes or movements, the 3-hour pressure change entered for each station on the principal chart must be utilized. Other data and information entered on a 12-hour pressure-change chart prove extremely helpful on many occasions.

It is of great importance in forecasting to know in as much detail as possible the vertical structure of the atmosphere, especially through the first 2 or 3 miles above the surface. Attention is given to the direction and velocity of the wind at the different stations at several levels up to 14,000 feet above sea level, as plotted on the pilot-balloon charts, and to the individual plotings of both airplane and radiosonde observations, especially those in areas (as shown on the principal weather chart) where important developments are occurring or are likely to occur. Meanwhile, specialists in interpretation of upper-air data have drawn cross sections of the atmosphere to a height of 5 kilometers (about 3 miles) or more and charts and diagrams showing the physical state of the atmosphere.

Close attention is also given to cloud observations from a very large number of stations, as entered on a cloud chart (not here reproduced). Lower clouds (such as stratus, strato-cumulus, cumulus, and cumulo-nimbus), the intermediate clouds (alto-stratus, alto-cumulus, cumulo-nimbus), the intermediate clouds (alto-stratus, alto-cumulus,

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4 The number in Alaska was increased to 7 late in 1940; and on April 1, 1941, all radiosonde stations in the United States began making 2 observations each day, at 1 a.m. and 1 p.m., eastern standard time.
and cirro-cumulus), and the high clouds (cirrus and cirro-stratus) are entered so as to indicate the direction of movement and the amount of sky covered by each type. The low clouds are entered in blue pencil and the intermediate and high clouds in red pencil. Of all types of cloud the alto-stratus, intermediate in height, is by far the most important, because this type indicates the so-called warm front (or up-glide) action of moist air that has reached the condensation level, and from these clouds all of our long-continued light-to-moderate precipitation comes.

Conclusions are drawn from careful consideration of the several charts and diagrams referred to and are checked and rechecked with each other; and if there appears to be a conflict between the determinations from different charts, a quick decision must be made as to which will be accepted. Having accomplished all of this in as systematic and complete a manner as possible in the short time available for the purpose and having made computations as to the rate and direction of movement of the fronts and the troughs of low pressure, the forecaster is ready to begin dictating State forecasts, forecasts for coastal waters, and a general forecast, and in addition a summary of weather conditions during the past 24 hours. In the forecasts an attempt is made to indicate the state of the sky as to amount of cloudiness (fair, increasing cloudiness, mostly cloudy, etc.); the occurrence of precipitation (rain, snow, showers, etc.); and any changes of importance in temperature (warmer, colder, much colder, etc.; if no material change in temperature is likely, the terms "little change in temperature" or "not much change in temperature" are used).

**AN EXAMPLE OF A DAILY FORECAST**

In order to show, in as much detail as practicable, the various steps leading up to the actual making of weather forecasts from synoptic charts and the type of reasoning involved in making the forecasts, the weather situation at 7:30 a.m., eastern standard time, on March 29, 1939, has been selected. Most of the charts and diagrams, actually made and utilized in analysis and prognosis (forecasting) are here reproduced.

The map selected is one without important complications; it is what is called an "easy" map from which to make forecasts that will verify well. It should not be inferred that map analysis and prognosis can be accomplished quickly and satisfactorily in all cases even by an experienced forecaster; the actions and interactions of the air masses are so complicated and the changes that occur in them over very large areas are so involved that the weather for a small area such as a State cannot now (and probably never will) be predicted with 100-percent accuracy in complicated weather situations for more than a few hours ahead. But very complicated weather situations would not be suitable for illustration and explanation to those who are not trained synoptic meteorologists.

All weather reports received by telegraph, radio, or cable are in code. Formerly a word code was used, but now they are mostly in a numeral code, each message consisting of several groups of five figures each. Reports received by teletype are either in numeral
code or in symbols and figures. As the reports are received at the
district forecast center they are immediately translated by a man who
is an expert in such work, and a “chart man” enters on each chart
the data required. Translation begins about 7:40 a.m. and 7:40
p.m. and is usually stopped about 9:15, so that the forecaster can
complete his analysis of the map and prepare to begin forecasting
at 9:30 or shortly thereafter. The forecasts are completed and dic-
tated within a few minutes and are immediately telegraphed to the
Weather Bureau stations in the States for which they have been
made. Copies are furnished to press associations and newspapers
without delay.

Description of Charts

The Principal (Surface) Weather Map.—The principal weather chart
for 7:30 a.m., March 29, 1939, is reproduced in figure 1; it shows
weather conditions at the surface. No names of places are printed
on the base map for the United States; the chart men must be able to
enter data instantly for each station, which is identified only by a
circle at the proper location. Since July 1, 1939, the stations have
been identified either by a group of three figures or by a two- or three-
letter designation, both in the coded reports and on the maps. The
following data for each station are entered
ou
this chart, but not all
arc reproduced in figure 1:

1. State of weather (amount of cloudiness, rain, snow, etc.).

2. Direction and force of wind (Beaufort scale).

3. Temperature and dew point.

4. The barometric pressure reduced to the value it would have at
sea level (in millibars, and tenths).

5. Pressure tendency and amount of change during last 3 hours.

6. Amount of rain or melted snow in inches and hundredths during
last 12 hours.

7. Miscellaneous data, such as thunderstorms, fog, and frost.

Long before the translation of all the reports is completed, the
forecaster begins to analyze the map; he draws as many isobars—
lines connecting places of equal pressure—as possible with the incom-
plete entry of data, finishing this work after the translation has been
completed or stopped. In order to analyze a weather map correctly
and without loss of time, it is necessary to refer to the completely
analyzed maps of 6 or 12 hours before; with the air masses properly
identified and the fronts properly placed on these previous maps, the
analysis of the current map is greatly facilitated.

There are two important sets of lines in figure 1. The lines in
black pencil on the original chart are the isobars, which are drawn for
each 3 millibars, or approximately 0.09 of an inch, difference in pres-
sure. The lines separating air masses are the fronts; on the original
chart the cold fronts are drawn in blue pencil, the warm fronts in
red, and the occluded fronts in purple. When the movements of the
air currents are such that colder air is advancing over regions occu-

\[ A \text{ millibar} = \frac{1}{4000} \text{ of the pressure that would be exerted per unit area by a column of mercury 29.531}
\text{ inches high at 32° F. in latitude 45°; it is a force of 1,000 dynes per square centimeter.} \]
Figure 1.—The principal weather chart for 7:30 a.m., March 29, 1939.
occupied by colder air, the discontinuity is called a warm front; the discontinuity formed when a cold front overtakes a warm front and displaces the warm air formerly between them to a higher level is known as an occluded front. The air masses are classified into tropical and polar, according to their place of origin. Each of these is further subdivided into continental and maritime, according to whether the source region was over land or ocean, and still further subdivided according to whether they are warmer or colder than the surface over which they are flowing. These characteristics are indicated by symbols to designate the different types; thus the symbol \( MT_k \) means air of maritime (\( m \)) tropical (\( T \)) origin and colder (\( k \)) than the surface over which it is moving; \( CP_k \) is air of continental (\( c \)) polar (\( P \)) origin, colder (\( k \)) than the surface over which it is moving; and \( MP_k \) is air of maritime polar origin, colder than the surface over which it is moving.

The portion of the front on this map that extends from near the mouth of the Rio Grande to eastern Arkansas is a cold front, and it separates the air of tropical origin, labeled \( MT_k \), from the air of continental polar origin, labeled \( CP_k \). Examination of the temperature and wind data for the stations in the tropical air shows temperatures of 66° to 72° F., and dew-point temperatures of 64° to 70°, with winds from a southerly direction. This air must have moved over a body of warm water for a considerable period of time in order to have picked up sufficient moisture to raise the temperature of the dew point to these high values. Immediately to the west of this front both the air temperature and the dew point rapidly fall off through the 50's and 40's with a temperature reading of 36° reported from Oklahoma City. Since this air mass to the west has undoubtedly come originally from a far-northern region, it is called polar air, and having moved southward from northern Canada, as its previous history showed, it is labeled \( CP_k \). As long as the cold air advances (usually in a southerly or easterly direction), the boundary, or line of discontinuity, between it and the warmer air ahead is called a cold front.

Attention is now turned to the part of the frontal system that extends from the center of the wave disturbance over Arkansas southeastward to the extreme southern portion of Georgia, thence eastward for about 500 miles, and thereafter northeastward over the Atlantic Ocean. As is usually the case with a cold front of great length, wave disturbances have developed. One is here shown northwest of the island of Bermuda, and another and more important one south of Newfoundland. It will be noted that the entire air mass south of this front is labeled \( MT_k \), being of tropical or subtropical origin, and the air masses to the north of the front are labeled \( CP_k \) and \( MP_k \), both being of polar origin but the latter having a trajectory, or path of movement, that took it over the ocean for several hundred miles, where the air gradually became warmer and more moist.

The entire front is called a cold front, except the portion extending from Arkansas to extreme southwestern Georgia and other portions over the ocean to the northeast or east of the wave disturbances; these parts of the front are called warm fronts because the warm air to the south is advancing northward at the surface while the cold air is retreating. The area within the "wave" portion of the front is called the warm sector. The waves move along the front, usually developing
into wave disturbances with closed isobars—that is, into systems in which a wind circulation has been set up around a center. As a rule the cold front to the southwest or west of a disturbance moves faster than the warm front and eventually overtakes it east or southeast of the center. When this happens the disturbance becomes occluded, and the warm sector gradually disappears, the warm air being forced upward over the colder air. When the supply of moist air is greatly lessened, or even cut off, by the occlusion process, there is much less condensation and lighter precipitation, and hence less energy for maintaining the disturbance; in most cases it moves more slowly and loses intensity.

Ordinarily, fair weather with little or no cloudiness is expected at and around the center of a high-pressure area (H), especially to the east of a line drawn north-south through its center, because over this area the air is of polar origin and not only was rather dry originally but is further dried because it is descending and becoming warmer by compression. The opposite process is involved ahead of moving disturbances (lows or cyclones) and behind moving highs (anticyclones). There, air is ascending, as it usually moves up the warm-front surface. Near the low a more violent upward motion occurs, caused by the advancing cold front. In its ascent the air is cooled because of expansion due to gradually lessened pressure. As soon as the condensation level is reached, the formerly invisible water vapor begins to condense into visible droplets, and clouds begin to form. When there is sufficient moisture in the air and the lifting of the air mass continues, especially if it is of tropical origin, precipitation occurs, and rain or snow will reach the ground unless the precipitation is light and the air sufficiently dry to cause it to evaporate before it reaches the ground.

On the surface map of 7:30 a.m., March 29, 1939, the weather is clear or is characterized by scattered high clouds of the cirrus type at most stations not only near and east of the north-south axis of the high centered near Lake Ontario but also west of the high center over the northern border States. Cloudiness has already set in over Ohio, southwestern Pennsylvania, and the western portions of Maryland and Virginia. Here the clouds observed are alto-cumulus and alto-stratus; and from these States to the center of the disturbance over Arkansas the sky is completely overcast with alto-stratus clouds from which precipitation is beginning to occur in Indiana and Kentucky, where also low clouds of the stratus type are observed. To the rear of the cold front the sky is overcast with low clouds over Texas and Oklahoma, and some light or drizzling rain is falling.

The Upper-Air Maps.—Turning to the upper-air data, one of the first things to be noted in looking at the 10,000-foot (3-kilometer) pilot-balloon map for the morning of March 29, 1939 (fig. 2), is the change in wind circulation as compared with the sea level map and the displacement or disappearance of the centers of high pressure and low pressure. The arrows on the chart fly with the wind, and the number of half feathers represents the wind velocity in the Beaufort scale, which uses numbers from 0 to 12; the temperature (centigrade) and the pressure in millibars are entered for airplane or radiosonde stations on the 6,000-, 10,000-, and 14,000-foot maps. (Of these three, only the 10,000-foot map is given here.) In addition, pressures for stations at high elevations in the West are entered on the 6,000-foot
FIGURE 2.—Chart showing upper-air data at 10,000 feet above sea level as gathered by pilot balloon for the morning of March 29, 1939.

map. Pressures for 5,000 feet above sea level, entered on the 6,000-foot map, range from 842 to 850 millibars, and those for 10,000 feet range from 690 to 705 millibars. On the principal map (fig. 1) they range from 1005.1 to 1031.5 millibars. Isobars on upper-air maps are drawn for the same interval (3 millibars) as on the surface map. In the free air the wind blows very nearly parallel to the isobars, so that if changes in the pressure field 24 hours ahead can be roughly approximated, both the direction and speed of the air movement aloft can be estimated with sufficient accuracy to be of much value in forecasting.

It will be noted that the low center at the surface in Arkansas is displaced to the northwest at higher levels. On the 6,000-foot map it is some distance northwest of the surface center; and the 10,000- and 14,000-foot maps show a further displacement northwestward. When a disturbance is moving eastward or northeastward at a more or less normal rate, the coldest average temperature of the air column in the lower layers is usually northwest of the low center; since this air is more dense and therefore heavier than the surrounding air, there is a more rapid decrease in pressure with altitude than over adjacent areas, so that the lowest pressure at, say, 5,000 feet above sea level is over this dense air to the northwest of the surface center. This pressure effect is still evident in many cases at 10,000 feet or higher, usually being manifest, not as a distinct cyclonic center, but as a trough in the isobaric pattern farther to the west and northwest than the center, either at the surface or at 6,000 feet. In old occluded lows, however, the cold air moves around the center even up to high levels, the warm sector having disappeared altogether, so that the lowest pressure and
more or less circular isobars are found over approximately the same area up to 4 miles or more above sea level.

As for highs, they rapidly disappear with height when they are moving cold highs, as in this case, and a short distance aloft the westerlies appear. The dome of polar air accompanying this high is subsiding, resulting in descent of air from aloft and a marked temperature inversion (increase of temperature with height) near the ground above the thin layer of air cooled excessively at night by radiation; in many instances the temperature actually rises many degrees in the first few hundred feet of ascent. Winds blow from some westerly direction, as a rule, when well above these highs; and the highest pressure aloft may be found far to the south, as is indicated on the 14,000-foot map of March 29.

In addition to the air temperature and dew point at each reporting station, we now have a fairly good picture of the distribution of pressure and of wind direction and velocity up to 14,000 feet above sea level, from the surface map and the upper-air maps. Also entered, on the cloud chart (not shown) for each station, are the types and directions of movement of clouds observed; the heavily shaded areas on the principal weather chart show where active precipitation is occurring at the time of observation, and the lightly shaded areas show the extent of the alto-stratus cloud.

The Isentropic Chart.- One of the auxiliary charts most recently developed is known as an isentropic chart. Instead of showing meteorological conditions over a surface at a given height above sea level, it shows conditions at each point at a height where the so-called potential temperature has a given selected value. The potential temperature is the temperature to which air would come, as a result of compression or expansion, if the pressure were changed from its actual value to 1,000 millibars without any heat being communicated to the air or lost by the air. A surface over which the potential temperature has the same value everywhere is called an isentropic surface; and the isentropic chart is a map of conditions over such a surface. In meteorological work the potential temperature is measured on a thermometric scale in which the freezing point of water under standard conditions is marked 273° (instead of 32° as on the Fahrenheit scale, or 0° as on the centigrade scale) and the boiling point is marked 373°; this scale is called the absolute temperature scale. Figure 3 is a map of the meteorological conditions on the isentropic surface over which the potential temperature is everywhere 301° Abs.

The observations from which figure 3 was drawn were obtained 3½ hours before those used in the surface map. Along the front over the Atlantic Ocean, the contour lines of the height of the isentropic surface, as well as the moisture lines, show a maximum gradient, or rate of decrease, as would be expected in the neighborhood of a front. Southeast of Newfoundland, where the first disturbance (area of low pressure) is located, there is a northward bulge of the moisture lines relative to the contour line, and a similar picture exists for the minor wave disturbance east of the Virginia Capes. In both disturbances condensation areas are indicated by the lines intersecting the isobars, and the surface reports indicate precipitation at these localities.

6 Absolute zero—the complete absence of heat—is -273° F.
FIGURE 3.—The flow pattern for an isentropic surface corresponding to a potential temperature of 301° Abs. for March 29, 1939.
Over the Southeastern States there is seen an "island" of dry air which has been cut off from its northern source by a moist current. Clear weather is associated with this dry island, and a portion of it is moving toward the southeast, evidently with down-slope motion, while another portion is flowing to the northeast and merging with the moist current moving up the Mississippi Valley; this latter (moist) current branches, that is, splits into two currents, one moving to the east in the form of a narrow tongue and the other to the west. Owing to the high moisture content of this air and the steep northerly slope of the surface, condensation is soon reached and is indicated by the shaded region. Note how this corresponds to the alto-stratus cloud and precipitation areas on the sea level map (fig. 1). In the west over Texas is shown a dry current cutting into the moist current, and this is responsible for the ending of the significant precipitation over Texas and Oklahoma. The drizzle occurring over these States is falling out of low-lying stratus clouds, as the Oklahoma City sounding shows.

The Cross-Section Charts.—In figures 4 and 5 are shown two cross sections through the disturbance over the Midwest. One (fig. 4) is a north-south section from Sault Ste. Marie, Mich., to Pensacola, Fla., showing very clearly the section of the sloping warm front that is found at the surface south of Nashville, Tenn.; the front is located about 500 meters (1,500 feet) above the ground at this station, as shown by the change in the wind from easterly at the ground to southerly above, and by the increase in temperature from 9° to 13° C. and in specific humidity (weight of water vapor in unit weight of the air) from 61. to 8.6 grams of water per kilogram of air. At Chicago this front is identified by similar changes in the vertical distribution of temperature and humidity, and this is true to a less marked degree at Sault Ste. Marie. Note how at all three stations the front is characterized by a constant potential temperature of about 293° Abs.

The second section (fig. 5) goes from El Paso, Tex., to Lakehurst, N. J., and passes just north of the center of the low. No tropical air is found at the ground in this section, but the trough of low pressure in the frontal surface coincides with the position of the surface cyclone. The slope of the warm front from Nashville to Lakehurst is much less steep than that in the north-south section, and this is one factor responsible for the lack of precipitation in this area.

The Pressure-Change Chart.—On the 12-hour pressure-change chart (not here reproduced) the sea level pressure is entered below the circle representing a station, and above this entry is written the change in pressure during the last 12 hours, corrected for the normal daily range. Except for some stations located along the coast, the barometer normally reads from 1 to 3 millibars higher at 7:30 a. m. than at 7:30 p. m., and this normal change, having nothing to do with weather conditions, is eliminated; the remainder of the changes are due to the horizontal movement (advection) of air masses of differing density and to other physical or dynamical processes that increase or decrease the total weight of the air column up to the upper limits of the atmosphere. There is also entered for each station the net amount of the change (increase or decrease) in atmospheric pressure during the 3 hours preceding the observation taken from the barograph, together
Figure 4.—Cross section through the disturbance over the Midwest, March 29, 1939, from Sault Ste. Marie, Mich., to Pensacola, Fla.

Figure 5.—Cross section through the storm of March 29, 1939, from El Paso, Tex., to Lakehurst, N. J.
with a slanting line indicating the slope of the trace on the barograph during this period.

The actual pressure and the amounts of abnormal change are entered in pencil on this chart, while for purposes of quick appraisal, the upward tendencies and slants are in red pencil and the downward tendencies and slants in blue pencil. Heavy blue lines are drawn separating areas on the map showing 12-hour increases in pressure from areas showing decreases. If these increases or decreases amount to 3 millibars or more, lighter lines are drawn (in red for increase and in blue for decrease) for each 3 millibars. On this particular map the greatest change both upward and downward is 9 millibars; therefore two light lines surround the station or stations with a change of 9 millibars, and the amount of this greatest change is entered in large figures in the appropriate color and preceded by a minus or plus sign, making this important feature stand out for quick inspection and appraisal. Where the 3-hour pressure tendency exceeds 1.5 millibars, a green dashed line is drawn around the area with 1.5 millibars or more change, and other dashed lines for multiples of 1.5 (3.0, 4.5, 6.0, etc.). These dashed green lines are called isallobars and the areas within them are often called isallobaric lows or isallobaric highs, as the case may be. An area of 12-hour pressure fall is called a katallobar, while an area of 12-hour pressure rise is called an anallobar. These isallobaric lows and highs, as well as katallobars and anallobars, are all very important in projecting weather into the future, and especially in predicting the pattern of the weather maps 12, 24, 36, and even 48 hours ahead. If the forecaster knows what the pressure distribution will be on future maps he will be able to forecast with a high degree of accuracy, provided he has made a correct analysis of the current map and upper-air data.

Preparing the Forecast

After the analysis of surface maps and upper-air maps and diagrams has been completed, the preparation of forecasts is begun. The first and one of the principal preliminary steps is the determination, as accurately as the data permit, of the location 24 hours hence of the centers of the highs and lows, the positions of the fronts (especially the cold fronts), and of the troughs of low pressure without fronts. In many cases a fairly satisfactory estimate of the direction and rate of movement may be made by simply measuring the movement during the last 12 or 24 hours and then extrapolating, or extending, this movement into the future. Several years ago, however, the Norwegian meteorologist Sverre Pettersen developed more refined extrapolation methods which have proved very helpful to the synoptic meteorologist in estimating these movements. Applying them to the center of the Arkansas low and to the trough containing a cold front that extends thence southwestward to southern Texas on the 7:30 a.m. map of March 29, 1939 (fig. 1), we find that after 24 hours the center of the disturbance should be over or close to Ohio, with the trough and cold front extending south-southwestward to the vicinity of Pensacola, Fla., while the movement of the high should take its center eastward to a position a short distance east of Nova Scotia.
These calculations were actually completed before the forecasts were made on the map of March 29; by extrapolation the same information was available for an additional 12 hours ahead. The map for 7:30 a.m., March 30, 1939 (not here reproduced) shows a close agreement with the calculations. On the basis of this estimate of the future locations of the fronts and other features, it was comparatively easy to estimate the advance of the precipitation area; and from our knowledge of the arrangement of surface air masses with respect to fronts, troughs, wedges, and centers, the forecaster was then able to predict quite well the wind directions and approximate rate of air movements, and the resultant changes in temperature, in the several States comprising his district.

In the making of the precipitation forecasts, the upper-air data are of prime importance. If the radiosonde or airplane observations show that stable air with little moisture (dry air) is likely to be over a particular locality during the forecast period, there is little likelihood of precipitation or even much cloudiness. In this case, however, the upper-air picture was very different. The individual plottings of radiosonde and airplane observations, as well as the isentropic chart and the cross sections, showed quite plainly the reason for so much cloudiness and active precipitation. The moist tongue on the isentropic chart (fig. 3) represents only a skin layer on a single selected equal potential-temperature, or isentropic, surface (in this case 301° Abs.); but the cross sections and plots of data for individual stations showed that this moist tongue was of considerable depth. Moreover, the wind data plotted on the isentropic chart indicated up-slope motion, and the air was so close to the condensation level that not much lifting was required to produce condensation, clouds, and precipitation.

The surface and cloud observations substantiated the conclusions reached by consideration of upper-air data. The 10,000-foot chart (fig. 2) indicated that there would be a further turning of the wind over the Lake region and the Atlantic States from westerly to a more southerly direction; and that air at this level and also for a considerable distance above and below would move from the vicinity of the lower Mississippi Valley, where the moisture content of the air was greatest, northeastward at an average rate of about 30 miles per hour. The expected movements of the centers of the low and the high and the trough containing the cold front over the west Gulf States, as well as the 12-hour and 3-hour pressure changes, all supported the indications of this comparatively rapid movement.

The official State forecasts issued on the morning of March 29, 1939, called for the extension of the rain area northeastward to Massachusetts and New Hampshire by 7:30 a.m. of the 30th, and the ending of the rain by the same hour in western Kentucky and western and southern Tennessee because of the passage of the cold front and the arrival of dry polar air. No rain was predicted for northern Michigan and northern Wisconsin because the wind at intermediate and higher levels was expected to continue to blow from west to east, preventing the moist air from the South from reaching that area; furthermore, inspection of the isentropic chart shows that the westerly wind was not up slope over the northern Lake region. These forecasts, together with those for changes in temperature, were well verified.
FORECASTING PROCEDURE

The forecaster begins his forecasting day about 8:15 a. m. by studying the circulation in the free air as shown by the pilot-balloon charts and drawing the isobars on the 6,000-, 10,000-, and 14,000-foot maps. This provides him with a fairly complete picture of the direction and rate of movement of the various air masses, information that is invaluable not only in his forecast later on, but also in his analysis of the surface synoptic weather map, which is begun between 8:30 and 8:45 a. m., at least a half hour before translation is finished.

Analysis, including the drawing of fronts and isobars, continues through translation and continuous entry of observations on the map upon which the forecaster is working. He sketches all or a part of a front or an isobar here and there over the map as entry of data progresses, gradually completing the lines in the East, while the chart man concentrates on entering data from western stations, then changing positions while data are entered for eastern stations and map construction shifts to the West. A lull in reports comes for the forecaster for a few minutes while those for Alaska, Greenland, and northern Canada are being translated and entered on a separate section of the map covering these areas; he is then able for the first time to survey and work on the entire main synoptic map and can refer to previous maps underneath the current one. The chart man soon returns for entry of late reports on the main map, while the forecaster at least partly constructs the chart for the northern areas.

Returning to the job of finishing the principal synoptic chart, the forecaster usually is compelled to call a halt on the translation and entry of late land and vessel reports in order to spend a few minutes in computations and in correlation of the conclusions (sometimes contradictory) reached from his brief study of the several charts and cross sections, before beginning dictation of the forecasts at or shortly after 9:30 a. m. All regular State forecasts, special forecasts, and weather synopses are completed by or shortly after 10 a. m. As soon as a State forecast is completed, it is telegraphed immediately, and by 10 a. m. all the Weather Bureau stations in the forecast district have received their State forecasts.

The actual time consumed in formulating and dictating the forecasts for the Washington forecast district, comprising 16 States and the District of Columbia, is seldom more than 15 to 20 minutes. The time-consuming work is the translation of the data and their entry on the several charts; at least 1 ½ hours is required for the translation and map drawing. The decoding and plotting of data from pilot balloon, radiosonde, and airplane observations begins much earlier than the translation of synoptic reports. This work, together with the drawing of isentropic charts and cross sections, requires much time, but when enough trained and experienced men are available it is usually well along or completed by 9:15 a. m.

WHAT A NEWSPAPER WEATHER MAP SHOWS

The daily newspaper weather map is a simplified form of the forecaster’s principal chart. Wind, temperature, state of weather, and pressure (isobars) are shown for selected cities. On this ele-
mentary chart, highs and lows and their movements from day to day are related in a useful way to the major changes in the weather in any locality, but especially in the northern part of the country. By a study of the map, the newspaper reader can get a fairly good idea of the wind, rain, snow, clouds, and temperature changes as related to the forms of isobars.

Ordinarily during a period of cold winter weather the low is preceded by cloudiness, rising temperature, easterly or southerly winds, and rain or snow and is followed by colder winds from west to north and the cessation of precipitation; the high is then in control, with fine, cold weather which persists until the influence of the next low is felt. But the march of weather has many variations from this simple sequence; these changes are shown in much greater detail on the forecaster’s chart. The newspaper reader who watches the map in connection with changes in his own locality may acquire a certain proficiency in anticipating the outstanding changes in the weather. The map enables him to develop a better appreciation of the reasons for the Weather Bureau forecasts, helps him to understand the weather data in the table near the map, and assists him in applying the forecasts and data to his individual needs.

Newspaper maps are prepared in Weather Bureau field offices for publication locally. The New York office makes the map used for distribution by wirephoto.