AVIATION WEATHER DISSEMINATION

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STUDY SCHEDULE NO. 57

For each study step, read the assigned pages first at your usual speed, then reread slowly one or more times. Finish with one quick reading to fix the important facts firmly in your mind. Study each other step in this same way.

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AVIATION WEATHER DISSEMINATION

Weather and Aviation

WEATHER affects all of us, but not in the same degree. A sudden storm, for instance, is merely an annoyance to a city dweller who is caught in it unprepared. It may be more serious to a farmer—in fact, it may mean a considerable financial loss if it ruins an unharvested crop. But to an aviator, a storm is not merely an inconvenience or a financial loss—to him, it can mean a grim battle with sudden death.

A knowledge of what the weather will be is therefore a vital necessity to the air transport industry. Much of the recent progress in meteorology, and the vast increase in the number of weather stations, is a direct result of this need for more and better weather information. Conversely, it is not going too far to say that meteorological progress is what has made modern aviation possible.

Meteorology, or, perhaps more properly, *aerology*, is the name given to the study of weather in all its phases—the physics of the atmosphere. Meteorology is as yet primarily an empirical science, since its conclusions, in the form of forecasts, are drawn from great masses of observational data rather than from pure theory. The accuracy of a forecast depends both upon the accuracy and the amount of informa-

Courtesy U. S. Weather Bureau

These clouds are predominantly cirro-cumulus. A cirrus mass is associated with them.

tion available, and upon the individual skill and experience of the forecaster, much as a physician's diagnosis depends upon his experience and skill in interpreting symptoms and test results. Therefore the accumulation of weather data covering large areas at frequent, periodic intervals is of first importance.

This gathering of raw data is called *weather observation*. The transmission of current weather data and forecasts to interested persons and agencies is called *weather dissemination*. You can see that rapid, accurate communication is essential if the services of meteorology are to be of much value. A most important service of marine and aircraft radio communication systems is receiving and transmitting weather information. Therefore the radio man should be well versed in the nomenclature, symbology, and interpretation of the weather information he must handle.

It is the purpose of this Lesson to describe briefly the meteorological factors affecting air navigation and the systems that have been developed for making accurate weather information available to the airman.

FLIGHT WEATHER ELEMENTS

Weather is perhaps the greatest single hazard encountered in air navigation. The United States Government early recognized this and in 1926 passed the Air Commerce Act, which charged the U. S. Weather Bureau with the responsibility of furnishing an adequate meteorological service for aviation in order "to promote the safety and efficiency of air navigation in the United States and above the high seas." Although modern aircraft are considerably more airworthy in bad weather than 1926 vintage aircraft, weather conditions still have so much effect on the safety of flight that all aircraft movements are rigidly regulated by law in accordance with weather minimums defined by the Civil Aeronautics Administration.

Weather Hazards. Weather consists essentially of disturbances in the blanket of air that surrounds the earth. As you might expect, practically all these disturbances influence air navigation to some extent.

The most dangerous flight conditions due to weather are, in general, (1) *low visibility*, (2) *low ceiling*, (3) *air turbulence and high winds*, (4) *ice formation on the aircraft*, and (5) *the possibility of lightning damage*. Many times several, or even all, these conditions are simultaneously present.

Low visibility may be caused by cloud formations, fog, precipitation, smoke, haze, or blowing snow or dust. *Low ceiling* (which frequently accompanies low visibility) results from the same general conditions as those limiting horizontal visibility. These conditions in themselves are in the main dangerous only during take-off and landing, when it is important that visibility in all directions be unrestricted. However, even at cruising altitudes, an "instrument" flight necessitates more vigilance on the part of pilots, flight dispatchers, and airways traffic control personnel than if the ceiling and the visibility are unlimited. Also, instrument landings require much more time to execute than normal contact approaches and greatly complicate the traffic situation at busy airports.

Aside from discomfort to passengers occasioned by *air turbulence*, extremely turbulent air conditions, such as those existing in severe thunderstorms,

line squalls, hurricanes, tornadoes, gales, etc., can cause loss of control of the aircraft or even mechanical damage due to the unusually high stresses. Also, a high wind can blow an aircraft miles off course, or a strong unexpected head wind may greatly increase the expected fuel consumption. For these reasons, knowledge of upper air conditions is necessary to plan a flight efficiently. One of the most recent and most important services of meteorology to aviation is the determination of "winds aloft" to assist pilots in selecting favorable flight altitudes.

Aircraft icing is one of the chief dangers to safe operation of aircraft, despite the use of mechanical or other de-icing devices. Icing results when liquid water is present in the air at temperatures below freezing (supercooled). The temperature range in which liquid water in the super-cooled state is most frequently observed is between 0° and —18° C. Therefore, any cloud area or frontal zone having temperatures below 0° C. is a potential icing zone. The dangers of ice formation on aircraft are (1) that the ice builds up on propellers and wings, deforms the airfoil surfaces, and therefore causes increased drag and decreased lift, and (2) that, because of the added weight of ice and the altered aerodynamic properties of the airfoils, the speed at which the aircraft will stall increases considerably. Although the present trend toward higher flight levels decreases the danger of icing during flight, the danger of icing during landings or take-offs still remains. Particularly severe icing conditions result when warm rain falls through a very cold layer near the ground; freezing rain, in such cases, will produce impossible flying conditions. Wet snow, particularly at slow speeds, also constitutes a hazard, because it accumulates on airfoils in a fashion similar to that of ice. The prediction of icing areas is another important service of aviation meteorology.

The dangers of *lightning*, although much decreased by modern metal aircraft construction, cannot be entirely ignored. Radio antennas or equipment may be damaged by a stroke, thus disrupting communication, or the compensation of the magnetic compass may be upset by the magnetic effect of lightning stroke currents through the ship's body or engines. Pilots may be temporarily blinded by lightning flashes and lose control. The danger of serious mechanical damage to an all-metal aircraft, however, is not great, since the occupants and apparatus within the metal skin are protected by an almost perfect electrostatic shield.

In addition to these possibly dangerous conditions, other general weather factors are important in flight planning and operation. For example, the direction and character of the ground wind are important in the landing operation, and knowledge of the barometric pressure is necessary to insure proper setting of the altimeter.

However, it is not enough merely to inform pilots of weather along the airway before take-off. Weather changes continuously and sometimes with great rapidity, and weather trends cannot yet be charted with positive certainty. Therefore it is necessary that aircraft be kept informed of weather conditions while in flight. This necessitates a vast, coordinated system of weather observing stations linked with radio communications stations. The development of this system is an accomplishment of the Weather Bureau and the C.A.A.

FEDERAL AIRWAYS WEATHER SERVICE

To analyze the weather along an airway accurately, it is necessary to have weather data available from large areas on either side of the airway. As a result, there now exists a government-maintained network of surface and upper-air weather observation stations manned by trained observers and equipped for rapid transmission of reports. Some idea of the magnitude of this system is given by the fact that it serves approximately 35,000 miles of airways in the United States, Alaska, and Hawaii. The observing network consists of about 800 Weather Bureau stations distributed along the airways and several hundred off-airway stations. Approximately 100 of these stations are equipped for taking upper-air soundings with pilot-balloon or radiosonde equipment. Further, observations of upper-air temperature and humidity are made by aircraft at several Weather Bureau stations and Naval (Bureau of Aeronautics) stations. Reports are collected from airway stations by radio and teletype and from off-airway stations by telegraph and telephone and are relayed to required points along the airways by C.A.A. radio and teletype circuits. At certain major terminals, all this information is collected and consolidated on weather maps, upper air charts, and diagrams by a technical staff. Meteorologists then analyze the weather trends and issue short-period general and regional forecasts.

The vast mass of data, when finally consolidated and analyzed, is available to airmen in the following forms:

(1) Weather maps, issued every 6 hours. These weather maps are prepared by the Weather Bureau for general use by all interested agencies, including aviation.

(2) General and regional weather forecasts covering, respectively, 24-hour and 4-to-6-hour periods. These forecasts are relayed to airway stations by C.A.A. teletype.

(3) Hourly teletype reports for each airway station at C.A.A. stations.

(4) Every thirty minutes (or more frequently if conditions warrant) radiotelephone broadcasts from the network of C.A.A. range and weather stations.

In addition to these government services, each airline usually maintains its own staff of meteorologists, who make intensive studies of local conditions, terrain, etc., along the airway and issue weather forecasts based on the data collected by the government services. Airline meteorological staffs usually issue special traffic forecasts to inform airlines personnel of probable operations, general forecasts for the information of dispatchers, and flight forecasts for each flight. These forecasts are handled via company ground station radio and over teletype lines.

Weather Observing

An important duty of the airline radio operator is transmission of weather information to aircraft in flight. The radio man, therefore, must be able to read rapidly and accurately the weather reports from teletyped weather sequences. In addition, he should have some knowledge of weather observing and the elements of meteorology, since he may be called upon in case of emergency to make spot observations of weather conditions in the immediate vicinity of an airport. An alert radio man always studies weather conditions over the entire airline when he first comes on watch, both to help him plan his watch more efficiently and to enable him to converse intelligently with dispatchers and flight personnel about weather conditions.

The meteorological elements used to describe the state of the weather at given observing stations are: (1) ceiling, (2) sky condition, (3) visibility, (4) weather (precipitation, etc.), (5) obstructions to vision, (6) barometric pressure, (7) temperature, (8) dew point, and (9) wind direction and velocity.

CEILING

"Ceiling zero" is an expression that laymen have learned means dangerous flying because it necessitates instrument landing approaches or even "blind" landings—procedures that contain an element of risk despite modern radio aids to navigation.

The "ceiling" is the distance from the ground to the *lowest* layer of clouds (or other obscuring phenomena) that is of sufficient density to block visibility to higher altitudes. Clouds that are thin or that only partially cover the sky are not counted; the ceiling layer must be thick enough to block vision. The ceiling may be broken as long as it covers more than half the sky. The obscuring phenomena other than clouds are precipitation (rain, sleet, hail, snow), fog, haze, etc. With any of these obscuring phenomena, the ceiling is the vertical distance upward to the limit of visibility. Notice that this is not the *bottom* of the layer except in rare instances—most layers can be penetrated an appreciable distance before enough of the cloud or obscuring phenomena is present to cut off vision.

Of course, this works the other way—in addition to being the distance upward that can be viewed from the ground, the ceiling is also the height at which the ground can just be seen from an airplane. Therefore, a way of determining the ceiling is from airplane pilots flying overhead who report their altitude and whether or not they can see the ground.

It is obvious that an accurate determination of ceiling height (particularly low ceilings) is of great importance. An error of 100 feet may be serious if the ceiling is low. An experienced observer can make a fairly accurate estimate of ceiling height; however, to eliminate errors of judgment, instruments are used to measure ceilings. Balloons are used for daylight measurements, and a spot of light is thrown vertically on the clouds by a special light projector for night observations. The projector is located a known distance—usually 500 feet—from the observer's station and the angle to the light spot on the clouds is measured by an angle-measuring instrument called the "clinometer." The ceiling height corresponding to the measured angle is then determined from a table.

Below 50 feet, the ceiling is reported as "zero"; between 50 and 5000 feet, the ceiling is reported to the nearest 100 feet; above 5000 feet, it is reported to the nearest 500 feet.

SKY CONDITION

Sky condition refers to the extent and configuration of any clouds present. The general descriptive terms used to describe the sky are:

(1) *Clear:* No clouds present, or sky less than 0.1 covered.

(2) *Scattered clouds:* Sky 0.1 to 0.5 covered.

(3) *Broken clouds:* Sky between 0.5 and 0.9 covered.

(4) *Overcast:* Sky over 0.9 covered.

Clouds are masses of condensed water vapor (or ice crystals) suspended in the atmosphere. They are formed when air containing moisture is cooled below the dew point (that temperature at which the air is saturated with water vapor, and condensation begins); the excess water vapor then condenses—usually around dust particles known as "condensation nuclei"—and forms visible droplets. The cooling of the air mass may result from (1) contact with a cold surface, (2) mixing with other and cooler air masses, or (3) cooling by expansion of a rising warm air mass. Fog and clouds are essentially alike and differ only in location; a fog is merely a cloud formed in contact with the earth.

Clouds are important indicators of weather and for that reason have been carefully studied and classified as to type and altitude. The generic names of the four main cloud types are Latin derivatives and are indicative of the shape and appearance of the cloud: (1) *cirrus*—"a lock of hair," (2) *cumulus,* which means "pile," (3) *stratus,* which means "layer," and (4) *nimbus,* which means "storm." Many clouds are combinations of two basic types and are therefore given combination names, such as "cirrocumulus," "stratocumulus," etc.; each name is actually a description that makes cloud recognition comparatively simple. Certain other descriptive prefixes, such as *alto,* meaning "high," and *fracto,* meaning "broken," are also used to distinguish cloud forms.

TABLE 1—Cloud Heights

Classification	Cloud Name	Mean Lower Level (feet)	Mean Upper Level (feet)
I. HIGH CLOUDS	1. Cirrus 2. Cirrocumulus 3. Cirrostratus	20,000	———
II. MIDDLE CLOUDS	4. Altocumulus 5. Altostratus	6500	20,000
III. LOW CLOUDS	6. Stratocumulus 7. Stratus 8. Nimbostratus	Close to surface	6500
IV. CLOUDS WITH VERT. DEVELOPMENT	9. Cumulus 10. Cumulonimbus	1600	

Courtesy U. S. Weather Bureau

FIG. 1. These thin, white, high clouds are tufted cirrus. Other cloud types are shown on other pages of this Lesson.

A further classification of clouds may be made on the basis of the altitude at which they normally form. These are shown in Table 1. Notice that the altitudes are *mean* (average) altitudes; actual cloud heights may vary widely from the figures given. The ten cloud forms listed are the ten recognized genuses; special forms of these generic types are further subdivided into species and varieties.

One of these ten main types of clouds is shown in Fig. 1. (If you are interested in learning more about clouds and other weather phenomena than we have covered in this book, write the Superintendent of Documents, Government Printing Office, Washington 25, D. C., asking for a free price list of publications on weather.)

Cirrus (Ci). Detached clouds, delicate and fibrous-appearing, often showing a featherlike structure, generally white and without shading. May appear as isolated tufts, branching featherlike plumes or curved lines ending in tufts; often arranged in bands that cross the sky like meridian lines and appear to converge at a point on the horizon because of perspective. Because of their great altitude, cirrus clouds are composed of ice crystals.

Cirrostratus (CiS). A thin, whitish veil, sometimes completely covering the sky and giving it a milky appearance and at other times showing a fibrous structure with disordered filaments. Cirrostratus is not thick enough

Courtesy U. S. Weather Bureau

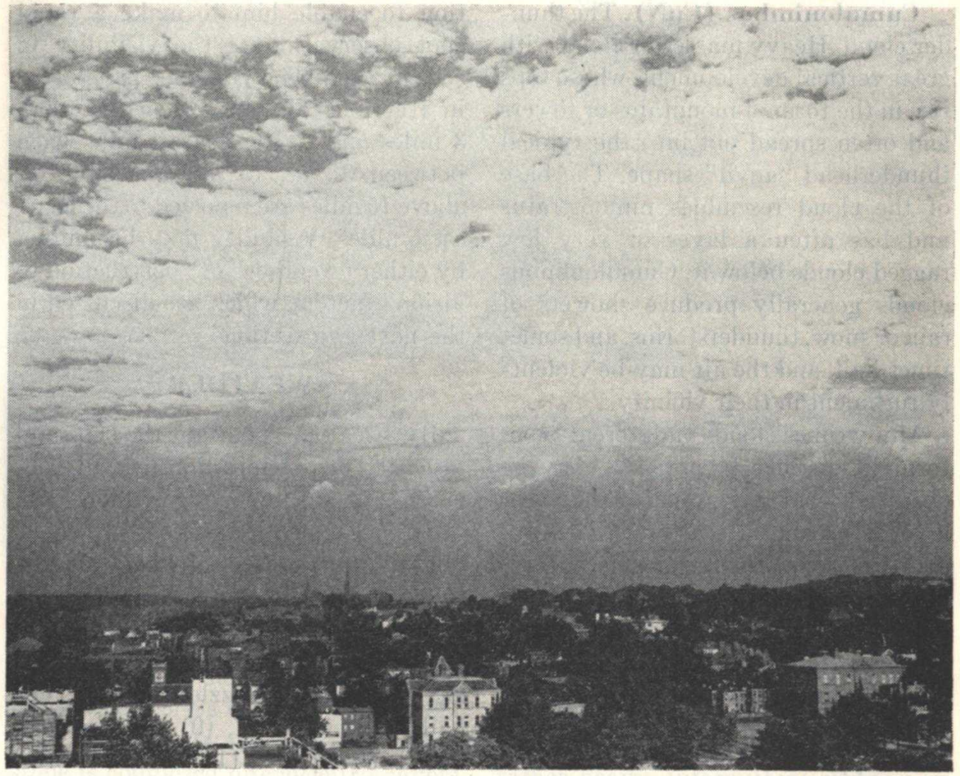
The thin, white veil in the lower part of this picture is cirrostratus; it spreads apart into cirrus in the upper part.

to blur the outline of the sun or moon, but gives rise to halos. This cloud is closely associated with cirrus, and if cirrus changes to cirrostratus it is an indication of an approaching weather disturbance.

Cirrocumulus (CiCu). Small globular masses or flakes, white and without shadows, often arranged in groups or lines resembling sand ripples on the seashore. Real cirrocumulus is uncommon; it is a degraded form of cirrus or cirrostratus.

Altocumulus (ACu). A layer (or patches) composed of laminae or rather flattened globular masses arranged in groups, lines, or waves, following one or two directions and sometimes so close together that their edges join. At its greatest height, altocumulus made up of separate elements resembles cirrocumulus; it may be distinguished from cirrocumulus in that it is not connected with or evolved from cirrus or cirrostratus.

Altostratus (As). A striated or fibrous veil, more or less bluish or grey in color. This cloud is like thick cirrostratus but does not cause halo; the sun or moon shows vaguely through the veil. Rain or snow may fall from altostratus. A cloud layer that has no fibrous structure and in which rounded cloud masses may be seen, is classed as altocumulus or nimbostratus rather than altostratus.



Courtesy U. S. Weather Bureau

These are altocumulus clouds of a special type, called altocumulus castellatus.

Stratocumulus (SCu). Large globular masses or rolls of dark cloud, frequently covering the entire sky (especially in winter) and occasionally giving it a wavy appearance. The elements of stratocumulus often tend to fuse together completely and can, in certain cases, change into nimbostratus or stratus. If this happens, the lower surface of the cloud no longer has a clear-cut boundary. Thickness 1200-4000 feet.

Stratus (St). A uniform layer of cloud, resembling fog, but not resting upon the ground. When this very low layer is broken up into irregular shreds by wind, it is called fractostratus. Stratus may give a drizzle, that is, small drops very close together, whereas nimbostratus gives continuous rain composed of drops of some size. These clouds are frequently associated with icing conditions in winter.

Nimbostratus (NS). A low, dark, amorphous layer of cloud, usually having ragged edges. If it gives precipitation, it is in the form of continued rain or snow. Thickness 500 to 4000 feet.

Cumulus (Cu). Thick clouds with vertical development; the upper surface is dome shaped and exhibits rounded protuberances, whereas the base is more nearly horizontal. Cumulus clouds normally have clear cut edges, and sunlight falling on them causes deep contrasts of light and shade. These clouds are caused by ascending currents of warm air.

Cumulonimbus (CuN). The thunder cloud. Heavy masses of cloud with great vertical development, whose tops rise in the form of mountains or towers and often spread out into the typical thunderhead "anvil" shape. The base of the cloud resembles nimbostratus and has often a layer of very low ragged clouds below it. Cumulonimbus clouds generally produce showers of rain or snow, thunderstorms, and sometimes hail, and the air may be violently turbulent in their vicinity.

Many times clouds of different types form in distinct layers that may be observed from the ground if the lower layer is broken or scattered. The layers, together with their levels, are reported in standard symbols. These are discussed in the following section.

During the passage of a typical cyclonic storm, there is a definite, orderly sequence of events, and certain cloud types are associated with certain areas and stages of the storm. A very creditable job of short-term forecasting can be done merely from local observations and a knowledge of a typical storm sequence. Since changing cloud forms are indicative of the weather sequence, a more detailed study of clouds and cloud changes as applied to weather forecasting will repay the student further interested in meteorology.

VISIBILITY

Visibility is the greatest horizontal distance at which prominent objects may be seen and identified by the unaided eye. It is obviously of great importance in navigating an aircraft, particularly during the landing operation. The airline radio man should ascertain the distances to a series of landmarks in the vicinity of his station to enable him to make a rapid spot observation of the visibility in case of need. The visibility is reported in fractions of miles when less than 3 miles and to the nearest mile when between 3 and 15 miles. Visibilities above 15 miles are reported to the nearest 5 miles. Visibility may be limited by either "weather" or "obstruction to vision" factors, which are discussed in the next two sections.

WEATHER

By "weather" is meant the type and intensity of precipitation actually occurring at the reporting station. The intensity of precipitation is stated as "light," "moderate," or "heavy"; the types of precipitation used to describe the state of the weather are (1) rain, (2) snow, (3) freezing rain, (4) drizzle, (5) freezing drizzle, (6) sleet, (7) hail, (8) small hail, (9) snow pellets, (10) snow squalls, (11) thunderstorm, (12) rain squalls, (13) snow showers, (14) rain showers, and (15) tornado. Since most of these terms are self-explanatory, only those that may need some clarification will be discussed in detail.

Rain, snow, hail, and sleet are all condensed moisture from the upper air, and their differences in character are due to the different conditions under which they are formed. The difference between rain and snow is similar to that between dew and frost. When condensation occurs at temperatures above freezing, liquid rain results; if the temperature is below freezing, the moisture condenses into minute ice crystals or into snowflakes. Under ordinary conditions, it takes from 8 to 12 inches of snow to equal one inch of water.

True hail occurs only in warm

Courtesy U. S. Weather Bureau

The clouds in the upper sky are altostratus; there are altocumulus clouds beneath them.

weather and is usually accompanied by thunderstorms in which strong vertical air currents are present. A hailstone is composed of concentric layers of ice and snow; one theory of its formation is that a raindrop has been carried aloft into freezing temperatures several different times by the ascending air currents before becoming heavy enough to fall to earth. During winter, rain sometimes forms in a layer of air where the temperature is slightly above freezing and then falls through colder air and reaches the ground as frozen raindrops or ice pellets. This form of precipitation is not hail, but sleet.

After a cold spell, it sometimes rains before the ground temperature and the temperature of the lower air strata have risen above freezing. The rain then instantly freezes to objects it strikes and forms a coating of ice known as "glaze." Such precipitation should be reported as "freezing rain" instead of "sleet." Freezing rain is very dangerous to aircraft in flight because it gives rise to severe icing conditions.

Rain or snow squalls are sudden, rather heavy, intermittent showers of rain or snow accompanied by strong, gusty winds. They are usually thundersqualls in the summer, but in winter occur along a wind-shift line and are evidence of turbulent conditions that may be hazardous to aircraft.

OBSTRUCTIONS TO VISION

In addition to the various types of precipitation mentioned in the preceding section, the following factors are reported as obstructions to vision: (1) haze, (2) fog, (3) smoke, (4) dust, and (5) blowing or drifting snow and blowing dust or sand. If the visibility is six miles or less, and if there is precipitation but it does not alone constitute the visibility-limiting factor, one of these factors will be reported.

Haze is a condition of poor visibility due to atmospheric pollution (smoke, dust particles, or other dry precipi-

Courtesy U. S. Weather Bureau

Clouds of this sort, often seen on windy days, particularly in the fall, are stratocumulus.

tates), minute water droplets (water haze or nebula), or irregular air density (optical haze). Haze is characteristic of protracted dry periods and gives a milky or bluish appearance to the sky. Smoke and dust may limit the visibility many thousands of feet in the air, and are therefore not necessarily surface phenomena.

Fog is a dangerous visibility-limiting factor. Fog forms when the temperature of the atmosphere falls below the dew point, at which time moisture in the air condenses and collects around particles, such as dust, to form extremely fine droplets suspended in the atmosphere. These droplets have no visible downward motion. Essentially, a fog is a cloud that reaches to ground level—the only difference between a fog and a cloud is that the base of fog is at the earth's surface, and the base of a cloud is above the surface. Fog is easily distinguished from haze by its dampness and gray color.

If the fog does not reach upward to join with the base of clouds that may be above it, and if it conceals less than .6 of the sky (the sky above an angle of 36° is observable) it should be reported as *ground fog* rather than *fog*. Essentially, the difference is that with a ground fog, it is possible to see through it to the sky because it is a low-lying layer.

The primary difference between ground fog and ordinary fog is in the method of formation of the fog layer. Ground fog is formed whenever so much heat is radiated from the ground and adjacent layers of air that the temperature becomes low enough to permit condensation. This ground fog, sometimes called radiation fog, is invariably shallow and clears or "burns off" shortly after sunrise. The more general kind of fog is formed by the movement of a layer of warm, moist air over a cold surface, and may reach altitudes as great as 5000 feet. This general fog, sometimes called advection fog, may persist for long periods, at least until the higher air strata have been sufficiently warmed to dissipate the layer.

Fog is always reported as an obstruction to vision, and of course has much to do with the limits of visibility in both the vertical and horizontal directions.

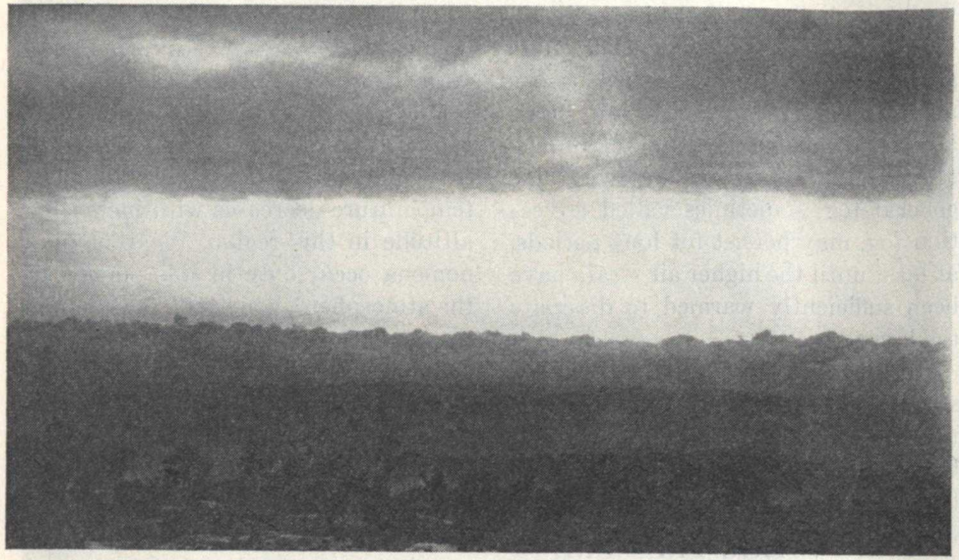
BAROMETRIC PRESSURE

Traces of atmospheric gases have been found as far as 200 miles above the earth's surface, but since only about one one-hundred-and-fiftieth of the atmosphere is found above about 21 miles, you can see that the atmosphere is in reality very thin compared with the earth's diameter. Up to about 7 miles above the earth's surface, the composition of the atmosphere is considered to be relatively constant. The temperature decreases with increasing altitude in this region. Weather phenomena occur only in this portion of the atmosphere, which is known as the *troposphere*.

That portion of the atmosphere above 7 miles is known as the *stratosphere*. In this portion, the composition and properties of which are but little known, the temperature remains relatively constant. Because of contemplated stratosphere aircraft and rocket developments, the stratosphere is at present the object of intensive research, and it is likely that knowledge of its properties will soon be as important as knowledge of the tropo-

Courtesy U. S. Weather Bureau

These are low stratus clouds enveloping the top of a small island.



Courtesy U. S. Weather Bureau

A layer of nimbostratus clouds.

sphere is at the present time.

The tendency of the atmosphere to escape into space is overcome by the earth's attraction, gravity. Therefore, the weight of the air causes it to exert a uniform pressure in all directions. Since gas is readily compressible, the pressure decreases with altitude. At the earth's surface (sea level) it amounts to about 14.7 pounds per square inch, which is equivalent to the pressure exerted by a layer of water about 34 feet thick, or a layer of mercury about 30 inches thick. Since the pressure of the air is the chief factor in studying its movements and disturbances, accurate measurement of pressure variations is of great importance, particularly since the extreme range of variation is small. The instrument used to measure atmospheric pressure is known as the barometer.

A knowledge of the barometric pressure is also of importance in correctly setting the altimeter, which is operated by the atmospheric pressure and calibrated in feet of altitude. Therefore a knowledge of the pressure changes along the flight course is necessary so that the altimeter may be adjusted to indicate the correct altitude, regardless of pressure variations along the route.

TEMPERATURE

Temperature is one of the most important meteorological elements, since many weather phenomena are directly dependent upon the amount of heat contained in the atmosphere. Temperature is measured by a thermometer graduated either in degrees Fahrenheit (°F) or degrees Centigrade (°C); water freezes at 32°F or 0°C and boils at 212°F or 100°C under normal atmospheric pressure. The conversion from degrees Fahrenheit to degrees Centigrade, or vice versa, is given by the relationships:

$$°F = 9/5(°C) + 32$$
$$°C = 5/9(°F) - 32$$

The Centigrade scale is universally used in European countries and in most scientific work; temperature readings in the United States are given in degrees Fahrenheit.

DEW POINT

The expression "dew point" means the temperature at which, without change of pressure, the air is saturated with vapor, and condensation begins. In practice, the dew point is measured with an instrument known as the psychrometer.

A usual form of psychrometer is a device containing both dry- and wet-bulb thermometers that is ventilated by being whirled manually. The so-called aspiration psychrometer is perhaps the most accurate. It consists of two parallel, double-walled tubes, silvered to minimize radiation, that are united into a common duct and surmounted by a ventilating fan. The tubes contain wet- and dry-bulb thermometers, respectively. The observer need note only the air temperature, the wet-bulb depression (difference between wet- and dry-bulb temperature readings), and the barometric pressure. The actual dew point temperature is then obtained from a table.

The dew point is of great value to the meteorologist making forecasts, since it enables him to predict fog formation by noting the trend of dew point with respect to temperature.

WIND

Wind direction and velocity are factors of importance to the meteorologist predicting weather trends; also, the velocity, direction, and character of the surface wind are of concern to the aircraft pilot during take-off and landing operations. The pilot of an aircraft about to land always requests a wind check from the ground station radio operator so that he may properly select his runway (to land into the wind) and plan his landing.

Wind velocity is usually measured with a device known as the anemometer. A common type is the Robinson cup-type anemometer, which consists of three metal arms rigidly secured together to form an equilateral "Y" and bearing at their extremities hollow, hemispherical cups, usually made of duralumin. The cup system is rotated by a wind, just as a turbine is by flowing water, and operates a revolution counter, which may be either electrical or mechanical. The entire system is calibrated so that revolutions of the spindle may be translated into wind velocity in miles per hour.

The wind direction is also important, and every airport is equipped with a wind cone or "sock," lighted at night, for visual observation of wind direction from the air. For the more accurate observation required for meteorological purposes, however, a wind vane is used. At aeronautical stations the wind vane is usually connected, either electrically or mechanically, to indicate the wind direction on a calibrated dial or to inscribe a continuous record on a chart. The wind direction is always reported as the direction from which the wind is blowing.

Teletyped Weather Messages

In order to facilitate rapid distribution and transmission of the vast amount of weather data accumulated by the observers, a standard teletype procedure using symbols and abbreviations is used. The order in which weather information is transmitted over the teletype network is as follows:

(1) STATION IDENTIFICATION
One space
(2) TYPE OF REPORT
One space
(3) TIME GROUP
One space
(4) CEILING
(5) SKY
(6) VISIBILITY
(7) WEATHER
(8) OBSTRUCTIONS TO VISION
} Transmitted as one group.
One space
(9) BAROMETRIC PRESSURE
Slanting line
(10) TEMPERATURE
Slanting line
(11) DEW POINT
(12) WIND
Slanting line
(13) ALTIMETER SETTING
Slanting line
} Transmitted as one group.
One space
(14) REMARKS

A typical teletype weather sequence is reproduced in Fig. 2 for practice purposes; the rest of this section is devoted to detailed study of the individual elements of the weather message form. If you become an airline radio man, you must learn to read such weather sequences as readily as you do a printed page.

(1) STATION IDENTIFICATION. This element is a three-letter group representing the name of the station originating the report. For stations having radio range facilities, the station designation is the same as the range station identifying signal (DCA = Washington, CHI = Chicago, MSP = Minneapolis, etc.)

(2) TYPE OF REPORT. This is indicated by the abbreviation "S" meaning "special observation" or "L" meaning "local extra observation" if such observations are taken. This key is omitted if the observation is a regular hourly sequence report.

(3) TIME GROUP. The time group is transmitted only if the observation is of the S or L type, and is omitted on regular sequences in which the date and time appear in the sequence heading. The time group consists of a group of figures denoting the time on the 24-hour system followed without break by a letter specifying the local time zone, e.g., 0958E is 9:58 a.m. EST, 2330C is 11:30 p.m. CST.

(4) CEILING. The ceiling is given by figures representing hundreds of feet. Below 51 feet the ceiling is considered to be "zero" and is represented by the figure naught (0).

To specify the ceiling further, the number giving the ceiling height is preceded by a single letter: M (measured ceiling), E (estimated), W (indefinite ceiling), P (precipitation ceiling), A (ceiling reported by aircraft), B (balloon ceiling). The letter V after the ceiling number indicates that the ceiling is variable. Thus E15V is "estimated 1500 feet, variable," and A18 is "ceiling 1800 feet, reported by aircraft." Since the ceiling is from the local ground level, and an aircraft altimeter indicates height above sea level, an aircraft reading must be corrected before being used, by subtracting from it the altitude of the field above sea level. Furthermore, the aircraft should be within 1½ miles of the observation point at the time of reporting.

Since the ceiling represents the height beyond which vision is blocked, any sky condition lower than this, if reported under "sky" will *precede* the ceiling report instead of following it. Examples are given below, under "sky."

(5) SKY. The sky condition is given by one of the symbols in Table 2. The three basic cloud symbols are for scattered, broken, or overcast conditions. A plus (+) or minus (—) sign preceding the cloudiness symbol indicates "dark" or "thin" respectively. The symbol is preceded by a figure giving the height of the layer.

Since clouds exist in layers, the lowest layer is given first, then succeeding higher layers in order. If there are thin or scattered lower layers, then the ceiling height is *above* the lowest layer in the sky report, so it may move out of the position ahead of the sky report to become part of the sky report. (The ceiling is always above any scattered clouds; by definition it must correspond to the lowest broken or overcast layer). For example:

(A) E30⦷50⊕
(B) 20⦶M60⦷

In the example (A) we have an estimated (E) ceiling at 3000 feet because of broken clouds, and an overcast (observable through the breaks) at 5000 feet. In example (B) we have

```
0
 AVP 20⦶E50⊕5SW-- 112/27/21↗12/981/ 605
BDL E80⦷200⦷9 078/31/19↗3/974
BOS E120⦷200⦷8 069/32/17→↘7/972/ 512 0705 85483
0
PKL S2 E18⊕4S- 112/21/19→↘22/ 603 5//6
CHW A22⊕10S-- 195/26/19→↗13/006/SB00/ 303 5//6
 EVR ○15 227/46/26→↘9/019/ 620
```

FIG. 2. This illustration was extracted from an actual teletype weather report. Station AVP reports scattered clouds at 2000 feet, an estimated ceiling at 5000 feet in an overcast, visibility of 5 miles, very light snow showers (just a few flakes), barometric pressure of 1111.2 millibars, temperature of 27°, dew point 21°, wind from southwest at 12 miles per hour, altimeter setting 29.81 inches; the "remarks" code group 605 can be interpreted from tables furnished to operators. Station BDL has an estimated ceiling at 8000 feet in broken clouds, with another broken cloud layer at 20,000 feet, visibility is 9 miles, pressure is 1007.8 millibars, temperature is 31°, dew point 19°, wind from southwest at 3 miles per hour, altimeter 29.74 inches. Practice reading the report of station BOS yourself (ignore the three groups of figures in the "remarks" section). The report of PKL is a special one—the second of the series (S2), and the lowest cloud group, estimated at 1800 feet, is the ceiling. Determine the weather and wind directions by using the lists under "Weather," and Table 3. The ceiling at CHW is one reported by an aircraft (A). At EVR, the sky is clear, so there is no reported ceiling; the figures after the "clear sky" symbol give the visibility. Practice reading the other values. None of these examples reported any obstructions to vision other than the "weather" condition. If such obstructions existed, the proper symbol would be added under "sky" and the type of obstruction would follow the "weather."

Table 2—Sky Symbols

X	Obscuration	Sky completely hidden by precipitation or obstructions to vision.
—X	Partial Obscuration	0.1 to less than 1.0 sky hidden by precipitation or obstructions to vision.
○	Clear	Less than 0.1 total sky cover. This symbol is not used in combination.
⦶	Scattered	0.1 to less than 0.6 sky cover.
⦷	Broken	0.6 to 0.9 sky cover.
⊕	Overcast	More than 0.9 sky cover. This symbol is used in combination with a lower overcast symbol only if the latter is classified thin.

Symbols for thin (—) and dark (+) are added when appropriate.

Sky cover may refer either to the amount of sky covered by a particular layer or to the amount covered by all layers. Thus several combinations of the above symbols are possible.

scattered clouds at 2000 feet, and a measured (M) ceiling at 6000 feet because of broken clouds. There are two clues here—the scattered clouds never form the ceiling, and the letter preceding the proper height is one of those listed under "ceiling" above.

When the sky is clear—there are no clouds or other obscuration, the "clear sky" symbol is used; this automatically also indicates an unlimited ceiling. On the other hand, the symbol (X) indicates an obscurement such as precipitation, fog, haze, etc., that usually prevents determining the height of any cloud layers. The ceiling figure shows how far it is possible to see upward into this obscurement.

(6) VISIBILITY. Visibilities up to 3 miles are given by a figure representing the value in fractions of a mile. For distances between 3 and 15 miles, it is given to the nearest mile, and above 15 miles it is given to the nearest 5 miles. "Zero" visibility is indicated by the figure naught (0). If the visibility is 3 miles or less and is changeable or fluctuating, the letter V is entered between the values reached. Thus, 1V2 means visibility varies between one and two miles.

(7) WEATHER. The weather element of the report, when appropriate, is indicated by the following symbols:

R	Rain
S	Snow
ZR	Freezing rain
L	Drizzle
ZL	Freezing Drizzle
E	Sleet
A	Hail
AP	Small hail
SP	Snow pellets
SQ	Snow squall
RQ	Rain squall
T	Thunderstorm
SW	Snow shower
RW	Rain shower
	TORNADO

A minus sign (—) following the weather symbol means "light," a plus sign (+) signifies "heavy." No qualifying sign following the weather symbol is interpreted as "moderate." Thus R— is "light rain," ZR+ is "heavy freezing rain," and the symbol R without sign is interpreted as "moderate rain." TORNADO is always written out in full, followed by its direction from the station.

(8) OBSTRUCTIONS TO VISION. Obstructions to vision, when present, are indicated by the following symbols:

F	Fog
GF	Ground Fog
K	Smoke
D	Dust
BS	Blowing Snow
GS	Drifting Snow
BD	Blowing Dust
BN	Blowing Sand
IF	Ice Fog
H	Haze

Plus and minus are not used with these symbols; the intensity is indicated by its effect on the visibility figure in the report.

(9) BAROMETRIC PRESSURE. The barometric pressure is given by a three-figure group; the first two figures represent tens and units of millibars,* respectively, and the third figure represents tenths of millibars. Thus a pressure of 980.5 millibars would be sent as "805" and a pressure of 1015.3 millibars would be transmitted as "153." This element of the report is sent only by stations equipped with mercury barometers.

(10) TEMPERATURE. The temperature is given in figures to the nearest degree Fahrenheit. Temperatures below zero are indicated by a minus (—) sign preceding the temperature figure.

*The millibar is the meteorological unit of pressure and is equal to 1000 dynes/cm².

(11) DEW POINT. The dew point is given in figures to the nearest degree Fahrenheit. It is separated from the temperature by an oblique (slant mark). Dew points below zero are also indicated by a minus (—) sign.

(12) WIND. The wind *direction* is indicated by arrows as shown in Table 3. The wind *velocity* is indicated immediately following the direction symbol by figures giving its velocity in miles per hour; if there is no wind, the letter "C" for "calm" is used.

When the wind velocity is estimated rather than measured, the letter "E" is used immediately following the figures. There should be no space or slanting line between the E and the figures. Of course, the wind speed is not al-

Table 3—Wind Directions

↓	North.
↓↙	North-northeast.
↙	Northeast.
←↙	East-northeast.
←	East.
←↖	East-southeast.
↖	Southeast.
↑↖	South-southeast.
↑	South.
↑↗	South-southwest.
↗	Southwest.
→↗	West-southwest.
→	West.
→↘	West-northwest.
↘	Northwest.
↓↘	North-northwest.

NOTE: The teletypewriter at airways stations is equipped with eight arrows for wind directions from eight points of the compass—north, northeast, east, etc.

ways a steady value. When the wind speed increases and decreases intermittently with at least a 10-mile-per-hour variation between peaks and lulls, and its peak speed is at least 19 miles per hour, and the time interval between peaks and lulls does not exceed twenty seconds, the wind is said to be "gusty." If the same condition exists with the peaks lasting for two or three minutes or more, the condition is described as a "squall." Squalls are reported by the letter "Q" immediately following the wind speed, in turn followed by the peak speed observed during the fifteen minutes before the report is turned in. If the wind is gusty but no squall is evident, a plus sign (+) is used immediately after the wind speed, followed by a figure representing the peaks of the gusts.

For example:

→25Q40

means the wind is from the west at 25 miles per hour, with squalls having peaks of 40 miles per hour. Similarly,

→25+40

says the same except the wind peaks are gusts rather than squalls.

The wind direction is also a variable. As the weather changes, the direction and the speed of the wind may both change. A wind shift is indicated by an additional entry immediately following the wind data in the report. The additional entry shows the direction of the wind *before* the shift, and the local time of the shift. For example:

↘25+30↗1710C

would be interpreted as saying that the wind is now coming from the northwest at 25 miles per hour, with peak gusts of thirty miles, and that the wind shifted from southwest to northwest at 1710 (10 minutes past 5 P.M.) Central Standard time.

(13) ALTIMETER SETTING. The altimeter setting is sent as a group of three figures representing the pressure in inches of mercury. The first figure indicates units and the last two indicate the tenths and hundredths, respectively. Thus, a pressure of 30.00 inches would be sent as 000; 29.89 inches would be sent as 989.

(14) REMARKS. Special information, such as remarks concerning whether the barometer reading is rising or falling, cloud types and directions, field conditions, radio range information, or additional weather information are transmitted at the end of the regular weather message in authorized English abbreviations and teletype symbols An elaborate code of abbreviations and symbols is in use to shorten message lengths; special tables listing these code groups are furnished to the operators.

Missing Elements. Elements normally sent, but for some reason missing from the report, are indicated by substituting the letter "M" for the missing data. However, stations not regularly reporting certain data merely omit the elements not observed and report the other elements in proper order.

Elements of Meteorology

The atmospheric disturbances that we call weather are caused by uneven heating of the atmosphere by solar and terrestrial radiation. This uneven heating occurs for a variety of reasons. For example, the sun's rays are more direct at the equator than at the poles, and therefore equatorial regions are warmer than polar areas. Also, during daylight the solar radiation does not heat air over water areas at the same rate as it heats air over land areas; and on land, there are differences in the rate of heating of air over forest areas and plains regions. These differences in heating result from variations in surface absorption and radiation from the earth, and from the varying moisture content of the air over various regions of the earth (since most of the absorption of solar radiation by the atmosphere is due to the water vapor present and not to the atmospheric gases, which are relatively poor absorbers).

Portions of air that have been heated more rapidly than air in surrounding regions become less dense, and therefore lighter, and are forced to rise because of the pressure of the adjacent, colder, and more dense air masses. This air expands as it rises because of the decreased pressure upon it, and, in the process of expanding, performs work against the surrounding air masses and therefore loses heat and cools as it rises. Conversely, cool air from higher levels descends, and, as it descends, the pressure upon it increases and compresses the cool air. Work is there-

Courtesy U. S. Weather Bureau

Cumulus clouds, showing a tendency toward cumulonimbus at the center.

fore done upon the descending cool air, warming it. These rising currents of warm air and descending currents of cool air are known as convection currents.

The theoretical rate of cooling of rising, warm air, or heating of descending, cool air, is about 1°F per 180 feet, and if the ascending and descending convective action were complete and the only factor entering into the heating and cooling process, the temperature in the free, unsaturated air would decrease everywhere at the rate of 1°F per 100 feet. However, the factors we mentioned a little earlier reduce this rate considerably by an amount that differs for different locations and different conditions. Knowledge of the rate (called the "lapse rate") at which air temperature decreases with altitude is an important item in weather forecasting.

The unequal heating of the atmosphere, with the resultant development of large areas of "low" and "high" pressure, coupled with the deflecting forces due to the earth's rotation, cause the large-scale, or *general*, circulation of the atmosphere. On a smaller scale, local variations cause local weather disturbances.

CIRCULATION OF THE ATMOSPHERE

Since unequal pressures cannot exist side by side in a gas, differences in atmospheric pressure at the earth's surface are immediately followed by a movement of surface air from the area of high pressure to that of low pressure. This air movement is what we call wind. The pressure differences that cause the wind, result from temperature differences, which in turn result from unequal rates of heating or cooling of different portions of the atmosphere. In general, the greater the temperature difference between adjacent volumes of air, the more violent the wind. The "prevailing" direction of the wind at any place on the globe is determined mainly by the average pressure distribution over the earth. The averages of barometric pressure readings taken over long periods of years show well-defined belts of high pressure encircling the globe in both the north and south hemispheres; the belt in the northern hemisphere centers at about 35° N. latitude, while that in the southern hemisphere has its center at about 30° S. latitude. The equatorial and polar pressures are, in general, lower, and we would therefore expect a flow of air from both high pressure regions

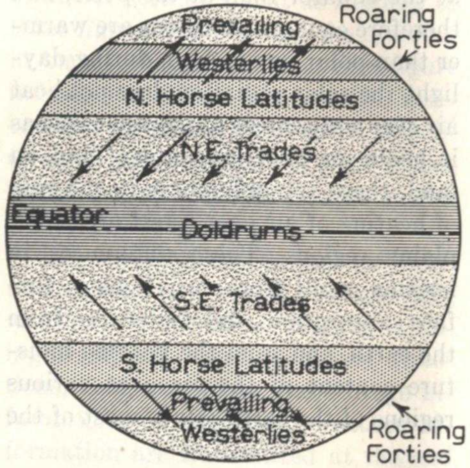


FIG. 3. This is a highly idealized picture of the prevailing surface winds of the earth. The doldrums is an equatorial belt of generally calm winds and low pressure; the horse latitudes are regions of high pressure; the roaring forties are stormy tracts of ocean between the 40th and 50th parallels of latitude. The wind directions shown are much modified by the distribution of land and water and by other local conditions.

toward the polar and equatorial regions, in a north-south direction. However, the earth rotates from west to east, and the rotational forces deflect the flow so that the wind system shown in Fig. 3 results. The wind directions shown are much idealized; in reality, the distribution of land and sea areas, local conditions, and seasonal changes greatly modify the idealized general circulation of the atmosphere. In low latitudes, however, the trade winds blow with remarkable constancy, especially over ocean areas; in middle latitudes the circulation is highly irregular, and is characterized by a constant succession of disturbances that give the north temperate latitudes their variable weather.

The air motions that make up the circulation of the atmosphere are complex and variable. They may either transport vast quantities of air over great distances or cause brief, local disturbances. The general circulation may be regarded as a background upon which are superimposed many smaller disturbances, just as eddies or cross currents are formed in a stream. The moving wind systems, in particular—the regular procession of "high" and "low" pressure systems that move in an easterly direction across the United States and cause our variable weather sequence—are important *secondary* circulations.

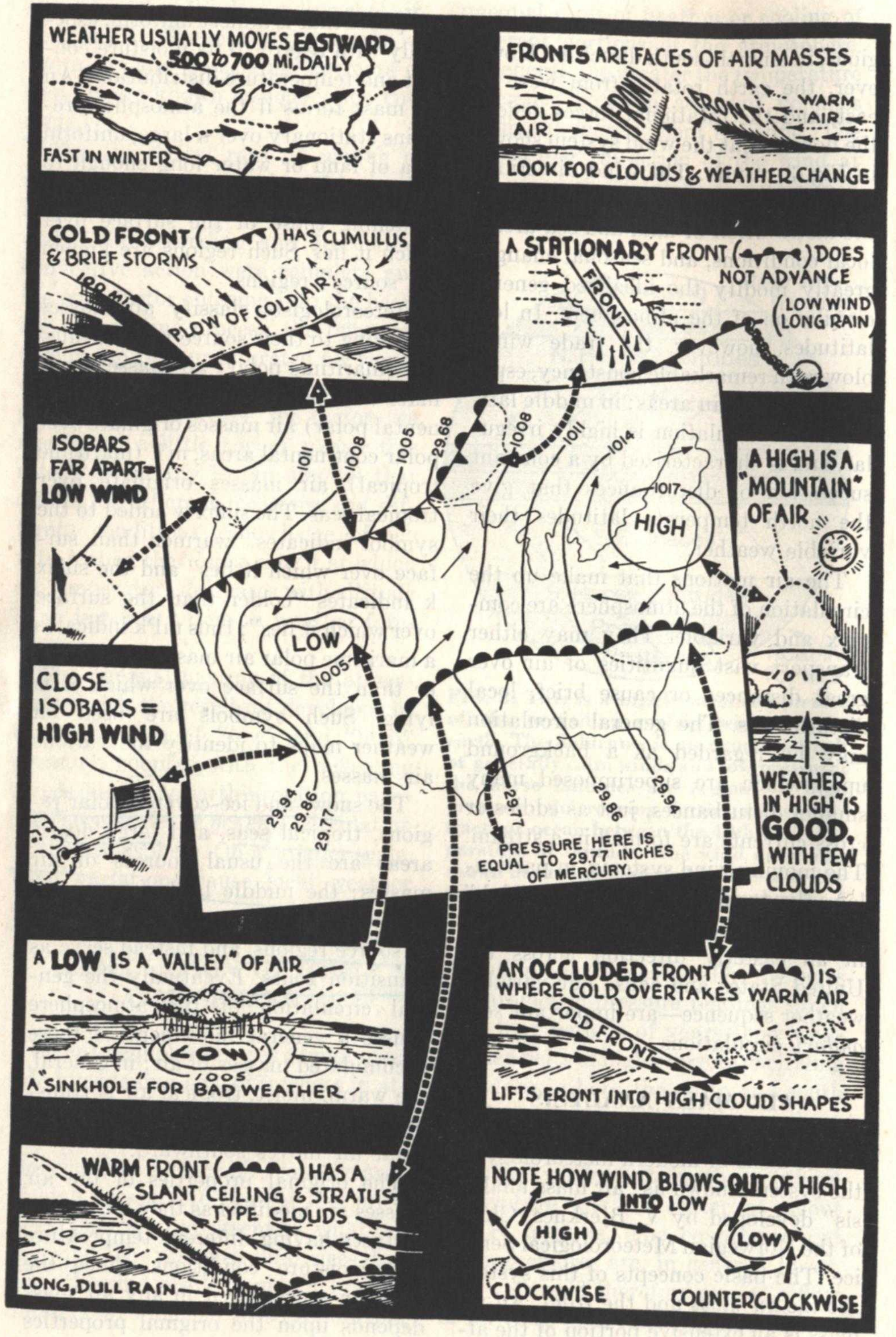
AIR MASS ANALYSIS

The basis of modern meteorology is the system known as "air mass analysis" developed by V. Bjerknes, Chief of the Norwegian Meteorological Service. The basic concepts of this system are the *air mass* and the *front*. An air mass is an extensive portion of the atmosphere that is almost uniform, especially with regard to its moisture content and temperature distributions. An air mass forms if the atmosphere remains stationary over a large, uniform area of land or water long enough to take on uniform characteristics approaching those of the surface over which it lies. Such regions are known as "source" regions.

Meteorologists classify air masses according to their source region; thus, mP (maritime polar) air masses originate over polar sea areas, cP (continental polar) air masses originate over polar continental areas, mT (maritime tropical) air masses originate over tropical seas. The suffix w added to the symbol indicates "warmer than surface over which it lies" and the suffix k indicates "colder than the surface over which it lies"; thus mPk indicates a maritime polar air mass that is colder than the surface over which it is lying. Such symbols are used on weather maps to identify the various air masses.

The snow- and ice-covered polar regions, tropical seas, and large desert areas are the usual sources of air masses; the middle latitudes are not sufficiently uniform physically to act as source regions, and instead serve as transition zones. Eventually the general circulation of the atmosphere causes a general movement of these accumulated masses of air; in general, the warm, moist, tropical air is transported northward and the cold, dry, polar air moves southward.

The original properties of the air masses are modified as they move over surfaces having different temperature and moisture conditions. Since the weather encountered in any air mass depends upon the original properties



Courtesy Popular Science Monthly

Courtesy U. S. Weather Bureau

This picture shows the nose of a cold front. The front is about 5 to 6 miles in length and ¾ mile in depth.

of the air and the degree of modification it has undergone during its travel, it is necessary for the meteorologist to follow the life histories of the various air masses that appear on the weather map. Eventually a cold air mass and a warm mass collide; when this happens, the masses do not immediately mix freely and lose their individual identities, but rather remain separated from each other for some time. The areas in which the two masses are in contact are called "fronts." There is a more or less abrupt change in the properties of the air on either side of the front between two air masses, and therefore it is in the frontal areas that the principal weather changes occur.

Fronts are classified into four main types: (1) the *cold front*, along which cold air replaces warm air at the surface, (2) the *warm front*, along which warm air replaces cold air at the surface, (3) the *occluded front*, which results when a cold front overtakes a warm front, and (4) the *stationary front*, which has little or no horizontal movement. See Fig. 4.

The passage of a cold front is usually very noticeable because of the relatively great temperature contrast between the two air masses. The frontal line is usually accompanied by squalls, turbulence, and a definite and sharp wind shift. As the front passes, the temperature and humidity decrease,

FIG. 4. The figure at the left illustrates the meanings of the most important meteorological terms.

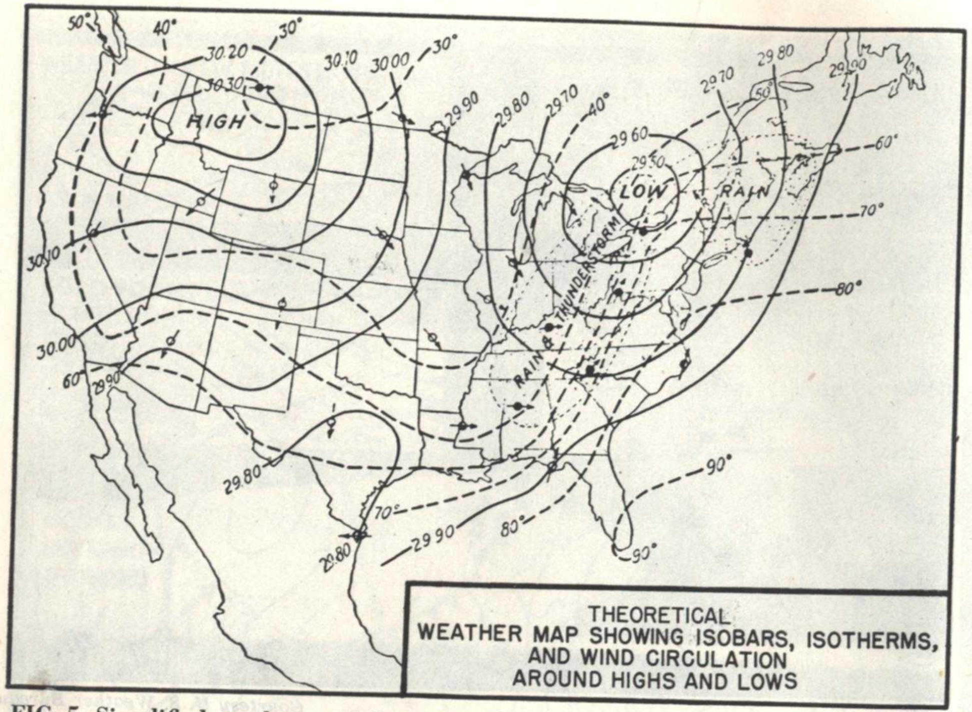


FIG. 5. Simplified weather map showing isobars (lines of equal barometric pressure), isotherms (lines of equal temperature) and wind circulation, which is counterclockwise around the low pressure area and clockwise around the "high" or anticyclone. Note also that a precipitation area accompanies the low pressure area.

the barometer rises noticeably, and the visibility and ceiling improve rapidly. The cold front was recognized years before the development of the polar-front theory and was called the "wind-shift line" or "squall line."

The warm front is not as sharply defined as the cold front; since warm air is moving upward over the wedge of cold air, the warm front usually forms a uniform cloud layer that extends well in advance of the frontal line. Precipitation may begin some distance ahead of the front, and is usually of the slow, steady type. As the front passes, and the warm air replaces the cold air at the surface, there is often a noticeable temperature increase; however, the changes are much less pronounced than for the cold front.

AIR-MASS ORIGIN OF "LOWS" AND "HIGHS"

The secondary circulation, particularly in temperate latitudes, is marked by a sequence of traveling wind systems, the barometric "lows" and "highs" on the weather map, such as those that regularly proceed in a general easterly direction across the United States (Fig. 5). The "low" or cyclonic system is a region of low barometric pressure about which winds circulate in a counterclockwise direction in the northern hemisphere; the air moves in toward the center of the low and is carried upward and removed at the top. The "high" or anticyclonic system is a region of high barometric pressure around which winds circulate in a clockwise direction in the northern

hemisphere; air flows outward from the high pressure center and is supplied from the top. Generally fair weather is popularly associated with anticyclones, and storm conditions with the lows.

Experience has shown that cyclonic and anticyclonic systems are primarily the result of interaction between different air masses, and often result from the instability of a frontal system. Closer study of the formation of a typical disturbance will illustrate some of the basic principles of meteorology.

Fig. 6 indicates the development of a barometric depression or "low." Assume first a current of warm air moving from the west and to the south of a current of cold air moving from the east, the two currents being separated by a definite frontal line (Fig. 6A). Then some local disturbance or irregularity of flow causes a wave to form, as shown on Fig. 6B; if the system is unstable, the wave deepens (Fig. 6C). Cold fronts are dynamically unstable and are therefore subject to this process, known as "cyclogenesis," whereas warm fronts are generally more stable and therefore less likely to form cyclonic systems.

The eastern portion of the wave system, where warm air is advancing and meeting colder air, is now a warm front, and the western portion, where cold air is replacing warm air at the

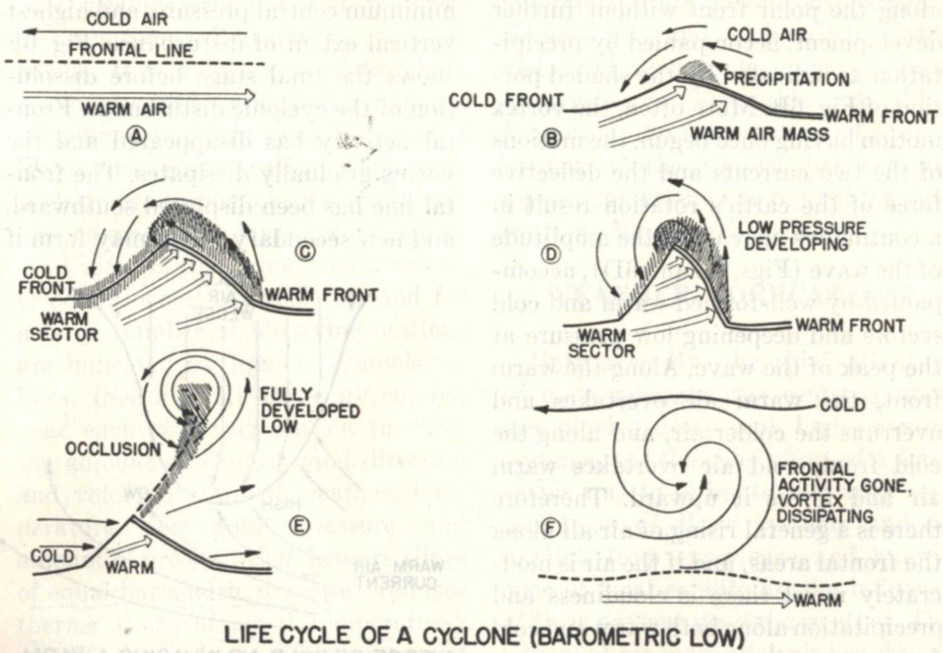


FIG. 6. If an unstable wave forms on a major air-mass boundary it increases in amplitude as it travels along the front and develops a low-pressure vortex. Stage (a) shows the original condition, and stage (b) shows the wave developing. Stage (c) is the "young wave cyclone" stage and is characterized by a broad warm-front sector and pronounced cold-front. The speed of the disturbance is usually greatest at this stage and decreases as the vortex forms. The cold front travels faster than the warm front and gradually overtakes it, forming an occlusion as shown in stage (e). This stage has the greatest intensity and minimum central pressure. Stage (f) shows the gradual dissipation of the system; frontal activity has disappeared, and the frontal line has been shifted southward.

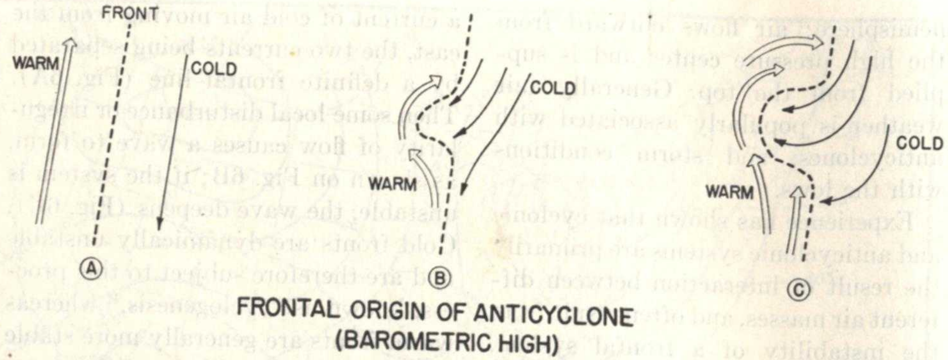


FIG. 7. If a warm current is moving northward on the west side of a cold current moving south, and a northward bulge develops in the frontal surface between the currents, the bulge, aided by the deflection to the right due to the earth's rotation, will tend to initiate anti-cyclonic circulation (clockwise), and build up high pressure at the center.

surface, is a cold front. Sometimes the wave thus originated merely moves along the polar front without further development, accompanied by precipitation as indicated by the shaded portion of Fig. 6B. More often, the vortex motion having once begun, the motions of the two currents and the deflective force of the earth's rotation result in a continuous increase in the amplitude of the wave (Figs. 6C and 6D), accompanied by well-formed warm and cold sectors and deepening low pressure at the peak of the wave. Along the warm front, the warm air overtakes and overruns the colder air, and along the cold front, cold air overtakes warm air and forces it upward. Therefore there is a general rising of air all along the frontal areas, and if the air is moderately moist there is cloudiness and precipitation along both warm and cold fronts.

The cold front usually advances more rapidly than the warm front, and therefore as the depression develops, the warm sector is slowly reduced in size. The cold front may overtake the warm front, as shown in Fig. 6E, and form an occlusion; in this stage, the vortex is fully formed and the cyclone has its greatest intensity, minimum central pressure, and highest vertical extent of disturbance. Fig. 6F shows the final stage before dissolution of the cyclonic disturbance. Frontal activity has disappeared and the vortex gradually dissipates. The frontal line has been displaced southward, and new secondary waves may form if

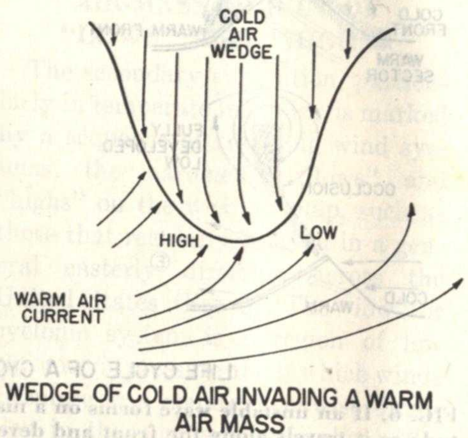


FIG. 8. The wedge of cold air has forced itself into a warm air mass, thereby partially obstructing the flow and building up a high pressure area on its west side and a depression on its eastern edge. Once started, the disturbances are maintained and further developed by the energies of the respective air masses.

the initiating forces are present.

(Although the name "cyclone" is popularly applied to a violent storm, meteorologists use the word for any extensive horizontal movement of the air around a low-pressure area. This may be a violent storm—a hurricane, for example—but it may also be moderate in character.)

Highs are formed either by irregularities along a polar front, as are lows, or by surges of cold, dense air toward the equator (see Figs. 7, 8). Since high pressure areas generally closely follow well-developed low pressure areas, it seems likely that both cyclonic and anticyclonic systems are often started by the method shown in Fig. 8.

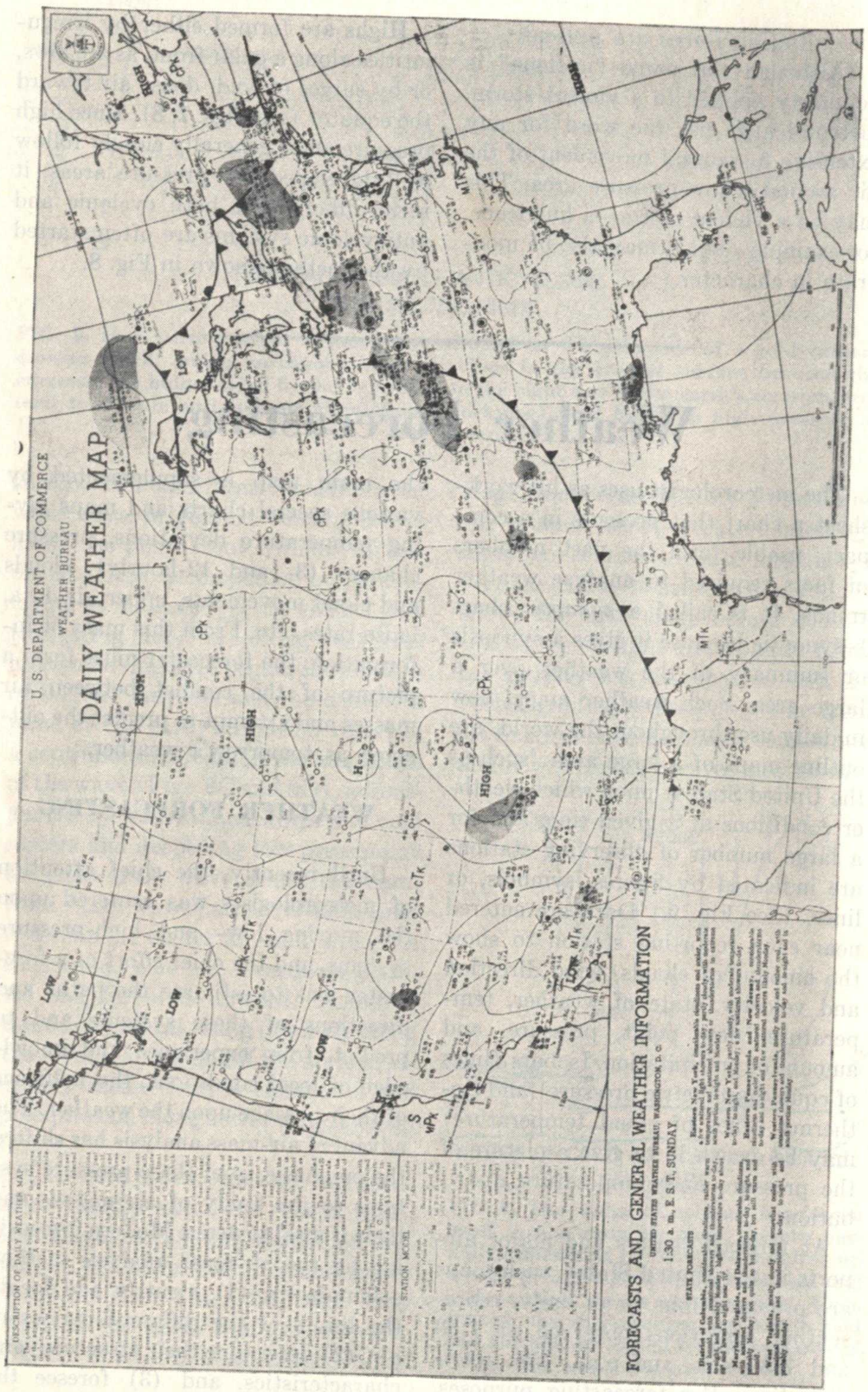
Weather Forecasting

The meteorologist uses as his worksheet a chart that presents in a compact, usable form the vast numbers of facts required to analyze weather trends. It is called a *synoptic* chart—synoptic because it gives a synopsis or summary of the weather over a large area. Such weather maps, now in daily use throughout the world, are outline maps of a large area (such as the United States) upon which weather conditions at a given time and for a large number of observing stations are indicated by figures, symbols, or lines. (See Fig. 9.) Data are entered near each reporting station to show the amount of clouds, wind direction and velocity, state of weather, temperature, dew point, pressure, and amount of precipitation. Isobars (lines of equal barometric pressure) and isotherms (lines of equal temperature) may be drawn in to give a picture of the pressure and temperature distribution.

At forecast centers and major airports in the United States, such maps are prepared four times daily, representing conditions observed at 1:30 and 7:30 a.m. and p.m., 75th meridian time. For forecasting purposes, the main map is supplemented by various special charts and maps giving temperature deviations, pressure changes (3- and 12-hourly), clouds and cloud movements, upper air data, lapse rates, etc. From this mass of information, the forecaster must form a picture of the conflict between air masses and attempt to predict the outcome as tomorrow's weather.

WEATHER FORECASTING

Until recently, the chief attention of meteorologists was centered upon the moving low- and high-pressure systems, and the chief effort of a forecaster was to estimate the paths and directions of these systems and to predict, from experience and knowledge of local conditions, the influence of their passage upon the weather. The advent of air-mass analysis has shifted the emphasis from these pressure systems to the study of air masses and their frontal systems. Modern forecasting by the air-mass analysis method attempts to: (1) identify and locate the limits of the different masses of air, (2) determine their structures and characteristics, and (3) foresee the



Courtesy U. S. Weather Bureau

FIG. 9. At left is a typical daily weather map issued by the Weather Bureau. Notice fronts shown near the eastern Canadian border and in the southeastern region. Shaded areas indicate precipitation.

weather changes as one mass is displaced by another. The forecaster must know the physical properties of the air masses (temperature, humidity, and lapse rate at different levels, etc.) and the location, structure, and movement of the fronts along which the different masses meet.

The fronts are located on the map by noting abrupt changes in surface temperature, dew point, and wind direction, pressure tendencies during the 3 hours preceding the observation, and the types of clouds and precipitation. In general, cold fronts are more distinct and easier to locate exactly than warm fronts. The next step is to estimate the future movement and intensity change of the pressure systems and their accompanying fronts. In doing this, the forecaster usually relies mostly on experience unless sufficient information is available to permit him to use mathematical methods. The prediction of movement can usually be made with a good degree of accuracy. The forecasting of precipitation presents greater difficulties, because it requires an intimate knowledge of the structure and activity of the air masses and fronts. Since it is not yet possible to determine these factors in sufficient detail, the exact precipitation area and amount of precipitation cannot yet be predicted with any great degree of certainty unless precipitation has already begun in the frontal system, in which case its spread in the direction of movement of the front is likely. Wind directions and velocities are predicted from the pressure distribution, and temperature may be predicted from the temperature characteristics of the air mass expected to arrive, subject, of course, to modifications enroute.

It is safe to say that the three-dimensional system of air-mass analysis will provide increasingly accurate forecasts as more details on the upper atmosphere become available.

Upper-Air Observations

From what has been said, you can see that the air-mass analysis methods of modern meteorology require an accurate knowledge of upper-air conditions in addition to the surface data. Most important from a forecasting standpoint are (1) barometric pressure, (2) upper air temperature, (3) humidity, and (4) direction and velocity of winds aloft. Also, of course, the pilot is interested in the actual weather conditions existing aloft, since knowledge of upper air data will help him select favorable winds or ice-free altitudes. Modern trends toward greater flight altitudes and stratosphere equipment have made investigation of the physical conditions in the outer reaches of the atmosphere increasingly important.

Various methods and instruments are used to secure the necessary data on upper-air conditions. We shall describe three of these methods briefly.

BALLOON OBSERVATIONS

The direction and intensity of winds aloft are usually measured by watching the flight of a pilot balloon. A properly inflated spherical balloon, when released, rises at a substantially constant rate and drifts freely with the winds through which it passes. If the balloon's position in space can be determined with respect to the point of release at regular intervals during its ascent, the velocity and direction of the wind at various levels can be determined. Obviously, this method is effective only up to the cloud level and is useless if visibility from the ground is impaired.

Helium-inflated standard balloons (6 or 12 inches in diameter, prior to inflation) are used; they are inflated to give some standard ascension rate such as 200 meters per minute. At night a small paper lantern containing a light is tied to the balloon. A theodolite, a surveying instrument that can measure vertical and horizontal angular deflections, is used to track the balloon, and the wind direction and velocity at various levels are then computed from the ascension rate and from the angular deflections observed.

THE AEROMETEOROGRAPH

The aerometeorograph is a somewhat complex mechanical device that is carried aloft by an aircraft and automatically records upon a chart the barometric pressure, relative humidity, and temperature of the air through which it passes. The wind cannot be recorded from a moving aircraft. Although accurate data are furnished, this system has a number of disadvantages: (1) the plane can make its weather observation flight only during flying weather, (2) the maximum altitude attainable is seldom greater than 17,000 feet, and (3) the cost per flight is rather high.

RADIOSONDE

The radiosonde system consists of a combination meteorograph-radio transmitter carried aloft by a free balloon. The device is so arranged that during its ascent radio signals are transmitted back to a ground station receiver-recorder system. The radio signals, when properly interpreted, give an almost continuous record of the temperature and humidity at various altitudes. In clear weather the balloon carrying the radiosonde can be tracked with a theodolite to secure upper-air wind data; radio direction-finding equipment for tracking the balloon during conditions of poor visibility is also coming into use. Aluminum foil is attached to the balloon to form a reflector, so radar can be used to track its flight.

The advantages of the radiosonde are that it furnishes accurate, consistent weather data under all weather conditions up to altitudes of 10-12 miles at a reasonably low cost. The instrument is equipped with a parachute that releases when the balloon bursts. This sometimes permits it to be recovered, but a high percentage of undamaged recoveries is unlikely, and the instruments are considered to be expendable.

The complete radiosonde system consists of (1) a light-weight v.h.f. transmitter, (2) a compact meteorograph coupled to the transmitter for transmission of weather data signals, (3) a balloon about 5 feet in diameter, (4) a v.h.f. radio receiver and record-

ing equipment for receiving and recording the signals, and (5) radio direction-finding equipment for tracking the balloon to ascertain wind conditions. The instrument will indicate temperatures between 60°C and —90°C and relative humidities between 15% and 100%.

The circuit of a radiosonde is shown in Fig. 10. The radio section of the circuit consists of two oscillators, marked MO and HO, that use a single 1G6GT/G twin-triode. Triode MO operates as a grid-leak-condenser modulating oscillator, generating a frequency of 1 mc. and blocking automatically at an audio rate. The rate at which it blocks depends on the resistance included in its grid circuit; this resistance consists of R_1 plus other resistances included in the circuit by operation of the mechanical components of the apparatus. (The operation of these components will be taken up in a moment.) The rate may vary between 0 and 200 cycles.

Oscillator HO, a tuned-line v.h.f. oscillator, operates at a frequency of 72.7 mc. Its output is coupled to a half-wave dipole. The two oscillators are so connected that oscillator HO is shut off when oscillator MO operates; this occurs because operation of MO creates a voltage across resistor R_5 that blocks the grid of HO. Thus, oscillator HO is modulated at the same rate as oscillator MO, because it operates only when the latter is blocked. This system is used because it is desired to transmit on the v.h.f. band, but it is easier to moduate the relatively low-frequency MO oscillator.

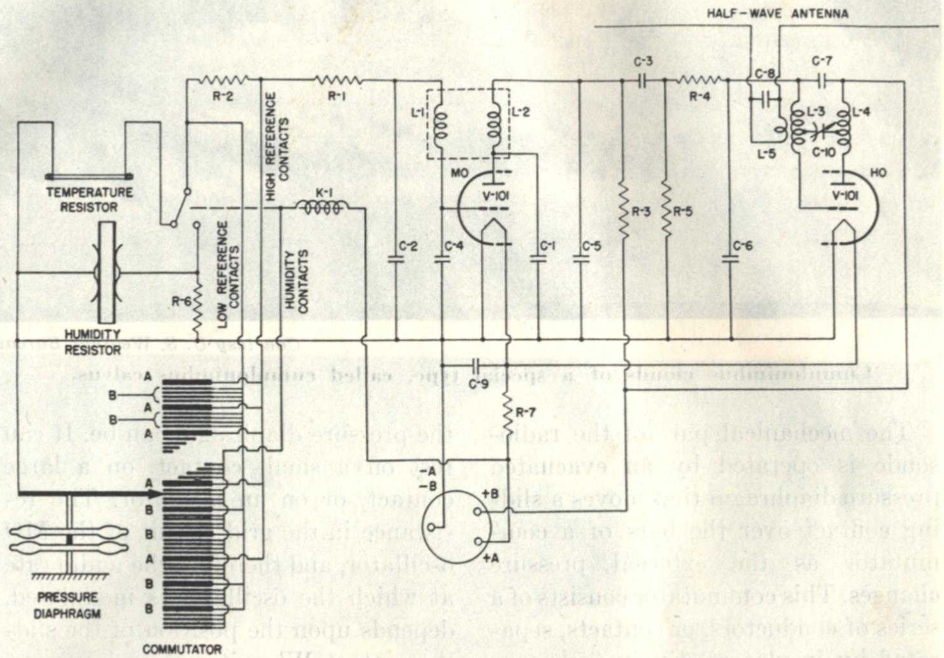
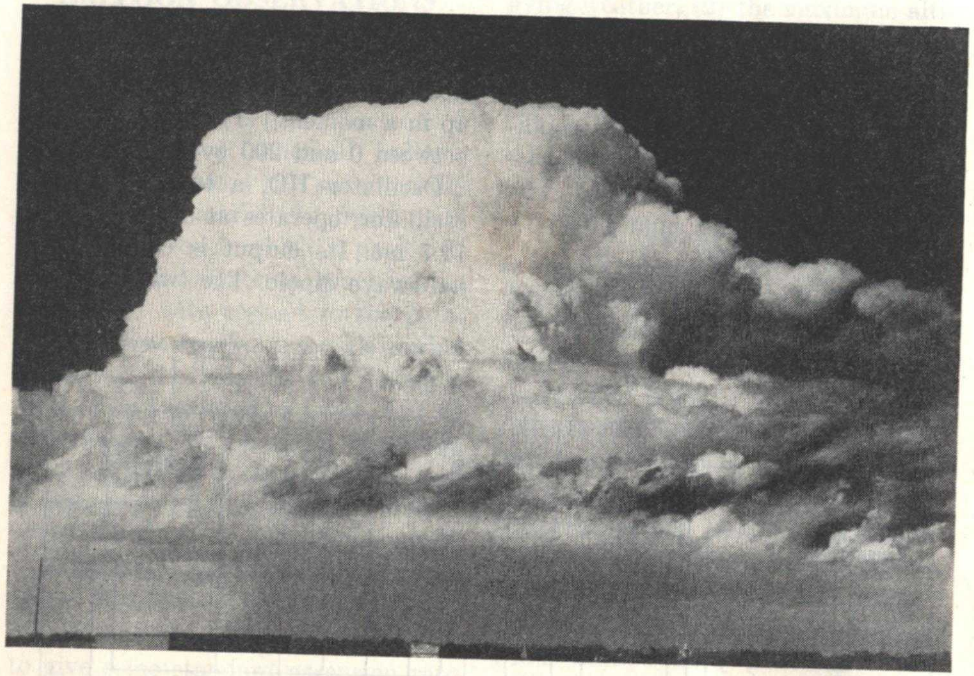


FIG. 10. Schematic diagram of the radiosonde transmitter. Movement of the pressure diaphragm as the balloon ascends slides a contact over the commutator, thereby determining what signal is transmitted.



Courtesy U. S. Weather Bureau

Cumulonimbus clouds of a special type, called cumulonimbus calvus.

The mechanical part of the radiosonde is operated by an evacuated pressure diaphragm that moves a sliding contact over the bars of a commutator as the external pressure changes. This commutator consists of a series of conductors, or contacts, separated by insulators. Every fifth contact is larger than the intermediate ones. The break in the commutator shown in the diagram indicates several more groups of contacts that were left out because of lack of space. The other main parts of this section of the sonde are a resistor that changes in resistance when the temperature changes, a resistor that changes in resistance when the humidity changes, two fixed resistors (R_2 and R_6), and a two-position relay.

As you can see from the diagram, there are three possible positions in which the sliding contact attached to the pressure diaphragm can be. It can rest on a small contact, on a large contact, or on an insulator. The resistance in the grid circuit of the MO oscillator, and therefore the audio rate at which the oscillator is modulated, depends upon the position of the sliding contact. When it is on an insulator, relay K_1 is not energized, and the resistance in the grid circuit of MO consists of R_1, R_2, and the temperature resistor. Since the first two of these are fixed in resistance, the rate at which MO is modulated depends upon the resistance of the temperature resistor. Since this last depends upon the temperature, the audio modulation of the signal transmitted by the radiosonde under these conditions indicates the temperature.

The action of the radiosonde when the sliding contact is on one of the commutator contacts depends upon the circuit connections. As you can see, the small contacts at the lower end of the commutator in the diagram are connected to the operating coil of relay K_1. When the sliding contact is on one of these contacts, K_1 is energized; the resistance in the grid circuit of MO then consists of R_1, R_2, and a parallel combination of R_6 (a fixed resistor) and the humidity resistor. Since this last is the only variable resistor in the circuit, the modulation of MO and HO when the sliding contact is in this position indicates the humidity of the air surrounding the humidity resistor.

When the sliding contact is on other commutator contacts, the resistance in the grid circuit of MO consists of either R_1 alone, or of R_1 plus R_2, depending on which commutator contact is touched by the sliding contact. Since both of these are fixed resistors, the modulation produced will have either of two fixed audio frequencies.

Now that we've seen how the individual circuits of the radiosonde operate, let's trace briefly the operation of the device during a flight.

Let's assume that the barometric pressure on the ground when the balloon is released is high enough to compress the pressure diaphragm completely. This places the sliding contact on the lowest commutator contact in the diagram. This is a "humidity contact," so the device broadcasts a 72.2 mc. signal modulated by an audio note that indicates the humidity of the surrounding air.

As the balloon rises, the air pressure

Courtesy U. S. Weather Bureau

Cumulus clouds of this sort, broken by wind, are called fractocumulus.

drops. This allows the pressure diaphragm to expand slightly, moving the sliding contact to an inter-contact insulator. The broadcast signal of the sonde is now modulated by an audio note whose frequency indicates the air temperature.

A further rise moves the sliding contact to a humidity contact, then to an insulator, and so on. Signals indicating humidity and temperature are broadcast alternately until the sliding contact touches the first large commutator contact (marked B on the diagram). The broadcast signal is then modulated by a fixed tone that indicates the slider is on a B contact.

This sequence of signals continues as the balloon rises. From time to time the slider touches a contact marked A; this produces a fixed tone of a frequency different from that produced by touching a B contact. Humidity signals are no longer given when the balloon gets so high that the humidity is approximately zero. Instead, as the diagram shows, all the upper contacts of the commutator are connected as A and B contacts. Thus, the radiosonde transmits only A, B, and temperature signals in the upper reaches of its flight.

The A and B signals are used as references by which the altitude of the balloon is determined. The signals by themselves show nothing about the altitude, since they have fixed tones that are the same at any altitude, but the sequence in which they are received shows how high the balloon is. The signals transmitted by the radiosonde are received and demodulated by a ground receiver, and the audio components are recorded continuously and automatically on a moving paper tape. Since the ground operator knows both the sequence in which the A and B signals should be transmitted and the altitude at which any particular signal in the sequence should be transmitted, it is simple matter for him to mark the A and B signals on the tape to indicate the altitudes at which the various temperatures and humidities are found.

Lesson Questions

Be sure to number your Answer Sheet 57RC-1.

Place your Student Number on *every* Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next Lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time or you may run out of Lessons before new ones can reach you.

1. What does the term "ceiling" mean in a weather report?
2. What is the difference between a cloud and fog?
3. What is the name of that part of the atmosphere in which weather phenomena occur?
4. What instrument is used to measure atmospheric pressure?
5. What is an anemometer?
6. What does the weather symbol RQ+ mean in a teletyped weather message?
7. What is the "lapse rate"?
8. What is the meteorological meaning of "front"?
9. What are pilot-balloon position observations used for?
10. What information does a radiosonde transmit?

HOW DO YOU FEEL?

A theory has been advanced (and to a large extent scientifically proved) that people feel good and feel bad in *cycles.*

Psychologists say that for a certain number of days you will be "sitting on top of the world." Then for a longer period of time you will feel about average. Then for a while you may be depressed—"in the dumps"—have the "blues."

Then the cycle starts over again. It is claimed you can keep a record of the way you feel, and predict accurately about when you will be feeling grand—or when you will be depressed. Be this as it may, we DO know that no matter how black things look at times, conditions *always* seem to improve. It's a very, very true saying that "every cloud has a silver lining." Perhaps this old saying is really based on the scientific theory I mentioned above.

And since you and I both know that we are *bound to* "snap out" of periods of depression, let's resolve never to make important decisions while feeling "low."

Don't fuss with a friend—don't quit a good job—don't give up a worthwhile ambition just because you are in a "depressed cycle." Tomorrow, or next week, you'll feel better!

J. E. SMITH