Weather Prediction
in Forest Fire Suppression

by

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INTRODUCTION

Forest protection agencies cannot, at present, look forward to a time when fires will be completely eliminated from the forest. Even with the maximum efficiency of public education, law enforcement, hazard reduction and other fire prevention activities, there will always be forest fires resulting from man's activities and from natural causes such as lightning, spontaneous combustion, or volcanic eruptions.

Wherever and whenever fire prevention fails to protect the forest, fire suppression must take over this job. The most vital element in successful fire suppression is time. It has been said that all disasterous forest fires could have been stamped out with the foot, had a man been there soon enough. This time element is the basis for fire preparedness. The value of fire preparedness depends largely upon predetermination of where and when fires will occur and what their behavior will be. It is in this function that weather prediction offers a solution to the problem.

PURPOSE

It is the purpose of this paper to determine, through a study of the fundamentals of weather forecasting and the application of weather forecasting to forest protection, the value of weather prediction in forest fire suppression. However, it is intended that this will in no way minimize the importance of fire prevention.

CLOUDS

The formation of clouds

Clouds are formed whenever air is unable to hold in invisible form its water vapor. The capacity of air to hold its water vapor in invisible form depends upon the amount of such vapor and the temperature of the air. At low temperatures, the air can hold less water than at high temperatures. Thus clouds result because air, with a given amount of water vapor, has cooled below a point where it can retain all of this water in invisible form.

Air may be cooled and clouds formed in various ways. The most important air cooling process is that of pushing of air, that has been heated because of its position near the surface of the earth, into colder upper regions of the atmosphere. When a cyclone or "low" is approaching, great masses of surface air blow into the cyclone from all sides; the air from the south and east is warmer and more moist, and this, in rising, becomes cooled below its dew point and forms the great, extensive clouds of a storm period. Smaller masses of air may be heated near the surface of the earth under a fair-weather sun, and these rise to form the cumulus clouds. The air may be cooled and clouds formed by the lifting of air across a high mountain; by the radiation of heat into the clear sky at night, bringing about the morning cirrus types and low fogs; by the throwing of air into waves where clouds form because the crests are higher and colder; by the passage of moist ocean air over colder water, forming sea fogs. (7)

The classification of clouds.

The Frenchman Lamarck was the first to name clouds in 1801, but his French terms were superseded in 1903 by the names given by the Englishman, Luke Howard. Howard used four terms to classify clouds, but the success of his classification was due to its simplicity and the descriptive Latin names which made his classification understood at once by scientific people of all languages.

Howard's classification was as follows:

1. Cirrus (Latin word meaning a whisp or ringlet of hair). This class included all types of delicately fibrous or feathery clouds.

2. Cumulus (Latin word meaning heap, pile or mass) included forms which are rounded or have a humpy appearance.

3. Stratus (Latin word meaning covering or spread out) included stratified, layered, or sheets of clouds.

4. Nimbus (Latin word meaning shower) a special type of cumulus cloud from which rain was descending. (2)

The Cloud Committee of the United States Weather Bureau has classified clouds into ten major types. These are the four names proposed by Howard, combinations of these four basic types, and combinations using the prefix "alto" which means high. The names, abbreviations, definitions, and descriptions of the ten types are:

Cirrus (Ci.) Detached clouds of delicate and fibrous appearance, often showing a feather-like structure, generally of whitish color. Cirrus clouds take the most varied shapes, such as isolated tufts, thin filaments, threads spreading out in the form of feathers, curved filaments ending in tufts, bands across the sky, etc. To variations of this cloud are given the popular names of "witch's broom," and "mare's tail." It is the highest of all clouds, forming most frequently at 32,000 feet, but ranging from 18,000 to 52,000 feet. It is almost always white and composed of ice crystals. (2)

The cirrus cloud is formed from air that is forced to highest levels in a "low", or in a thunderstorm. Most of the moisture of the "low", or thunderstorm, will condense out in heavy clouds at low levels, but the great height to which some of the air may ascend, and the inability of the thin and cold air to hold more than a trace of water vapor at high elevations, causes the formation of delicate cirrus clouds. The cirrus cloud may also form at night by radiation of heat into space, but clouds formed in this way usually disappear the next morning as heat is reabsorbed from the sun. (2) (7)

Cirro-stratus (Ci.-St.). A thin whitish sheet of clouds. When the fibrous cirrus forms into a layer of thin white cloud like a veil, it is then cirro-stratus. When it overcasts the sky in a smooth layer, it presents an appearance of milky haze. The moon and the sun shine through it, and in so doing produce halos. The cirro-stratus cloud is formed by causes similar to those that form cirrus, and like the cirrus, this cloud is composed of ice spicules. The average height is little less than that of the cirrus. (2)

Cirro-stratus is almost a positive indicator that a "low" is approaching, and that one may expect rain or snow within twenty-four hours, or sooner, after its appearance. As the storm area comes nearer, the cirro-stratus thickens to alto-stratus. (7)

Cirro-cumulus (Ci.-Cu.). Small globular masses or white flakes without shadows, or showing very light shadows arranged in groups and often in lines. This type of cloud often forms ripples such as formed of sand at the seashore. This formation is caused by waves in the upper atmosphere, which reach high enough so that the water vapor is condensed in the crest of the waves. Cirro-cumulus clouds vary in height from 12,000 to 50,000 feet and average around 22,000 feet. Like the cirrus and cirro-stratus cloud the cirro-cumulus is composed of ice crystals. "Mackerel sky" is a popular name for this formation. (2)

Cirro-cumulus is nearly always a fair weather cloud and makes its appearance usually in the morning the first or second day following a storm period. One can expect it to dissolve away during the morning to leave a spotless and intensely blue sky. (7)

Alto-stratus (A.-St.). A thick sheet of a grey or bluish color. This cloud forms a compact layer, uniform in structure. Thickening and formation of clouds at elevations somewhat lower than cirro-stratus brings about alto-stratus. The sun or moon will usually shine dimly through this cloud. Alto-stratus clouds form at from 6,000 to 50,000 feet, the largest altitudinal range of all clouds. It may be composed either of water or ice particles, depending upon the height at which it forms.

This is the normal cloud to expect as the center of a cyclonic depression approaches. It may or may not, depending upon its origin, indicate the approach of a "low" however. If it results from the formation of a thicker and lower cloud following cirra-stratus, then it does indicate an approaching storm, and will probably be followed by stratus, then nimbus and rain or snow. If it is the result of radiation of heat into space and forms at high levels, it may be expected to dissolve under the sun and leave cirrus forms followed by clear sky. (7)

Alto-cumulus (A.-Cu.). Large globular masses, white or greyish, partially shaded, arranged in groups or lines, and often so closely packed that their edges appear confused. This is a small, high, white, cumulus cloud appearing as closely packed cloud mounds. The average elevation of the alto-cumulus cloud is about 15,000 feet, but it may occur between 7,000 and 36,000 feet. Most frequently it is composed of ice crystals. The most popular common name applied to this type is "sheep-herd " cloud.

Formation of the cloud usually takes place on crests of high air waves giving it its arrangement in rows. It is a fair weather cloud and forms about the first day following rain. Though usually a morning cloud, it may occur in afternoon or evening.

Strato-cumulus (ST.-Cu.). Large globular masses or rolls of dark clouds often covering the whole sky, especially in winter. These are cumulus clouds which form a dark layer with only infrequent areas of sky showing between. They are similar to fracto-cumulus clouds, but unlike the fracto-cumulus they show rounded rather than ragged edges. This type usually forms toward noon or shortly after noon, and are in general somewhat higher than cumulus clouds that have preceded them. Their average height is about 8,000 feet, but they vary in height between 4,500 and 16,000 feet. They are usually composed of water particles. Though showers may fall from strato-cumulus clouds, they ordinarily thin to cumulus or fracto-cumulus by mid-afternoon, and leave a clear sky at night. Strato-cumulus clouds usually occur during the first days of a "high" and produce high pressure flurries in the form of rain or snow. (2)

Cumulus (Cu.). Thick clouds of which the upper surface is dome-shaped and exhibits protuberances, while the base is flat. Cumulus clouds appear as single clouds with flat horizontal bases and high everchanging rounded tops that resemble huge cauliflowers. They are formed the first two or three days following rain of a low pressure area. Cold air from the approaching high pressure area descends as the eastern margin of the high extends above the wet ground, the brilliant sun soon heats the ground, the ground heats surface air, and the warm moisture-laden air is forced up into the descending cold air. The alternately descending and ascending columns of air that accompany conditions that form cumulus clouds causes the formation of detached individual clouds.

The cumulus cloud is a comparatively low cloud averaging about 6,000 feet or more. This is a fair weather cloud which is usually revaporized during the heat of the day, leaving a clear sky at night. (7)

Cumulus-nimbus (Cu.-Nb.). Heavy masses of clouds rising in the form of mountains, turrets or anvils generally surmounted by a sheet or screen of fibrous appearance and having at its base a mass of clouds similar to nimbus. This is a cumulus cloud that has developed into a thunderhead. It towers to heights up to six miles, and is provided with parapets, turrets, and domes. In its fantastic outline many weird designs may be imagined. The base is dark and flat, with detached scud-like clouds floating out from the margins. It forms from local convection currents of warmed moist air, usually in sultry air of late afternoon summer days. The cloud usually appears in the murky sky to the west as a poorly defined cumulus cloud. This cloud rapidly increases in size and other similar clouds form in its vicinity. All of these may be drawn together by the great updraft of air caused by the warming of the air as water vapor is condensed out. As the cloud towers higher and higher and more and more vapor is condensed, the upper portion receives a negative charge of electricity and the lower portion a positive charge by a process in which rising water particles tend to carry a negative charge and falling particles tend to carry a positive charge. Whenever this difference in potential between the charged parts of the thundercloud or between the cloud and the ground becomes sufficiently great, an electric discharge occurs between them in the form of lightning. (2)

Nimbus (Nb.). A thick layer of dark clouds without shape and with ragged edges from which rain or snow usually falls. Not every cloud from which rain falls is nimbus as strato-cumulus and one or two other types cause precipitation under certain circumstances, but nimbus is the typical rain cloud from which all heavy rain falls. This cloud varies greatly in height, from a few hundred feet to 18,000 feet with an average of around 3,600 feet. The nimbus is characteristic of the passing of a low pressure area, and will ordinarily be followed by fracto-nimbus, fracto-stratus, and clear weather.

Stratus (St.). A uniform layer of cloud resembling a fog but not resting on the ground. This is the most common cloud formation. It is a comparitively low cloud averaging about 2,000 feet, but may occur as high as 6,000 or as low as 400 feet. It is the characteristic formation of an approaching low pressure area, and may be expected to thicken to nimbus. (7)

The prefix fracto (Fr.) is also combined with cumulus, nimbus, or stratus clouds to designate broken or wind blown formations. Thus, fracto-cumulus is a cumulus cloud that is torn by strong winds so that it has a ragged appearance. (2)

Cyclones.

In popular usage, the term "cyclone" is a much abused word; in popular usage it is often used to designate a tornado. A cyclone is defined as any area of low air pressure with counter-clockwise circulation of the air around it--clockwise in the Southern Hemisphere. The winds of a cyclone may be strong or even violent as in a tropical cyclone, generally termed "hurricane," or they may be gentle as in the typical extra-tropical cyclone which is so common in regions of the prevailing westerly winds. The study of cyclones and anti-cyclones, their development and degeneration, their sources, paths, rates of displacements, and their energy has been the fundamental problem of synoptic meteorology for many years. In the synoptic method, based on air-mass analysis, the interactions of the air masses are studied in as much detail as the observational material will permit. (2)

The tropical cyclone or hurricane.

The tropical cyclone is a storm typical of island regions of the tropics and of little importance in the United States. It is a storm of from 50 to 300 miles in diameter with very steep pressure gradients and with violent winds blowing circularly around a calm center of very low pressure.

Striking characteristics of the tropical cyclone are; the calm center, the violent circular winds, the steep pressure gradients, the down-pour of rain, and the slow rate of travel of the gigantic whirlwind as a whole. (2)

<u>The extra-tropical cyclone or "low."</u>

Extra-tropical cyclones are whirling storms of vast extent that occur in the regions of the prevailing westerly winds. They are characterized by an irregular whirl of gentle wind about a region of low barometric pressure that is not always well defined. The extra-tropical cyclone remotely resembles the tropical cyclone but has many points of marked difference:

1. They are extensive, being usually 1,000 to 15,000 miles in diameter. 1500

2. They are not symmetrical in shape; the isobars (lines passing through points of equal pressure) are usually irregular both in direction and spacing.

3. The temperature and rainfall are not uniformly distributed around the center.

4. A region of high pressure, around which gentle winds blow in a clockwise direction, is a counter part of the extra-tropical cyclone.

5. The velocity of travel of the low pressure area is as great or often much greater than the velocity of circulating winds within the area. It would therefore be impossible for the air to travel completely around the extra-tropical cyclone. (2)

Any region of low barometric pressure surrounded by regions of higher pressure is known as a "low" or "depression." The term "low" is used by the United States Weather Bureau to designate all depressions shown on their synoptic weather maps.

The barometric pressure at the center of a "low" varies from about 30 inches of mercury to about 28 inches, the average being about 29.5 inches. Isobars around a "low" are in most cases irregular, being neither circular nor concentric, but they are invariably roughly oval in form and often greatly elongated. (1)

The clouds accompanying a low usually cover the southeast quadrant and part of the northeast and southwest quadrants. The eastern edge of the "low" is rather extensively sirrus which gives way to cirro-stratus, to alto-stratus, to stratus and to nimbus toward the center or the sirrus gives way to cirro-cumulus, to alto-cumulus, to strato-cumulus, and to nimbus. The precipitating nimbus may cover as much as one quarter of the "low". Passing from the nimbus area west or northwest, the nimbus clouds give way to fracto-nimbus to fracto-stratus, or they may give way to fracto-nimbus to fracto-cumulus.

The anticyclone or "high."

The anticyclone or "high" is a region of high barometric pressure surrounded by regions of low pressure in which the winds blow clockwise--counter-clockwise in the Southern Hemisphere. The anticyclone is roughly oval in shape, but likely to assume various odd shapes. It is usually more extensive than the "low" and less intensive. As the isobars are farther apart than in the "low" the winds are lighter or sometimes calm. The weather of the "high is usually fair and the sky is usually clear. The temperature in the northeast and the southeast portions of the area tend to be cool, but in the southwest and northwest it is usually warmer. (2)

Movements of "highs" and "lows" in the United States.

The movement of both "highs" and "lows" across the United States is, in general, from west to east. The paths of thousands of "highs" and "lows" have been studied and general paths have been established, but each "low" or "high" takes its own individual path and no two are the same. In general, both "highs" and "lows" tend to swing southeast over Central United States and northeast over the eastern portion. (2)

The thunderstorm.

The thunderstorm is a convection shower accompanied by thunder and lightning. The conditions causing the development of the thunderstorm are:

1. A sufficient volume of moisture in a warm air so that the air will become saturated when the air is raised and cooled.

2. A mechanically produced lifting power sufficient to overcome the stabilizing forces at lower levels and carry the air to the equilibrium point.

Thunderstorms are most likely to occur on warm, sultry summer days when the air is still and very warm and the relative humidity is high. When an upward current of air is formed by convection in an atmosphere of high relative humidity, clouds are formed at an elevation that is sufficient to cool the air to the dew point. Clouds thus formed may tower to heights of five or six miles.

Thunderstorm electricity is built up by a process different from that forming ordinary atmospheric electricity. The theory developed by G. C. Simpson has gained wide acceptance from leading meteorologists. This theory is based on the breaking up of raindrops in the strong convection currents of rising air in the thundercloud. The raindrops, originally consisting of equal amounts of negative and positive charges, are split up in such a way that the outer and upper particles of the drop where most of the negative charge is carried are torn away in fine droplets, leaving the larger portion with a predominantly positive charge. The small negatively charged droplets tend to be carried by the strong convection currents to the upper and outer portions of the thundercloud formation, while the larger positively charged drops tend to settle to the lower and central portions of the cloud. Since the earth carries a slight negative charge, a strong potential is built up between the ground and the lower portion of the cloud, and a stronger potential is built up between the upper and lower portions of the cloud. When the difference in potential between the charged parts of the cloud or between the cloud and the earth becomes sufficiently great, an electric discharge occurs between them in the form of a long branching crooked spark. (3)

The basis of weather forecasts.

After many years of experience meteorologists continue to make forecasts as to future weather character and conditions upon the basis of synoptic weather maps. These maps give a graphic picture of the meteorological conditions for a given time throughout extensive regions of the earth's surface. Synoptic weather maps constitute the most sound logical and scientific basis for definite, specific, and exact weather forecasts.

The underlying fundamentals which must be recognized in modern weather forecasting from synoptic maps are:

1. Weather travels.
2. The character of weather is in general largely determined by atmospheric pressure distribution with modifications arising from movement into regions differing in some respect from the original environment.

The synoptic map consists of a territorial map covering a large region upon which is pictured areas of high and low pressure indicated by isobars (lines passing through points of equal pressure), areas of high and low temperature indicated by isotherms (lines passing through points of equal temperature), character of the sky indicated by symbols, direction and velocity of wind indicated by arrows and barbs on the arrows, areas of precipitation during the past 24 hours indicated by shaded areas. (12)

The method of forecasting weather from synoptic charts.

From the synoptic chart, the forecaster observes factual data which, although mostly expressed numerically on the map, are rather easily translated into a mental picture of the weather existing in various portions of the area being considered. This mental picture, together with similar pictures of weather changes which have taken place in that area during the preceding 12 and 24 hours, and a knowledge of the characteristics of the particular weather types being considered, creates in the mind of the experienced forecaster an impression of what changes in air pressure, wind, state of sky, etc. may be expected in the near future. The accuracy with which these changes are predetermined depend largely upon the forecaster's understanding of the behavior of the particular weather type and an understanding of the factors which determine its behavior. This understanding comes as much from experience as from study. (12)

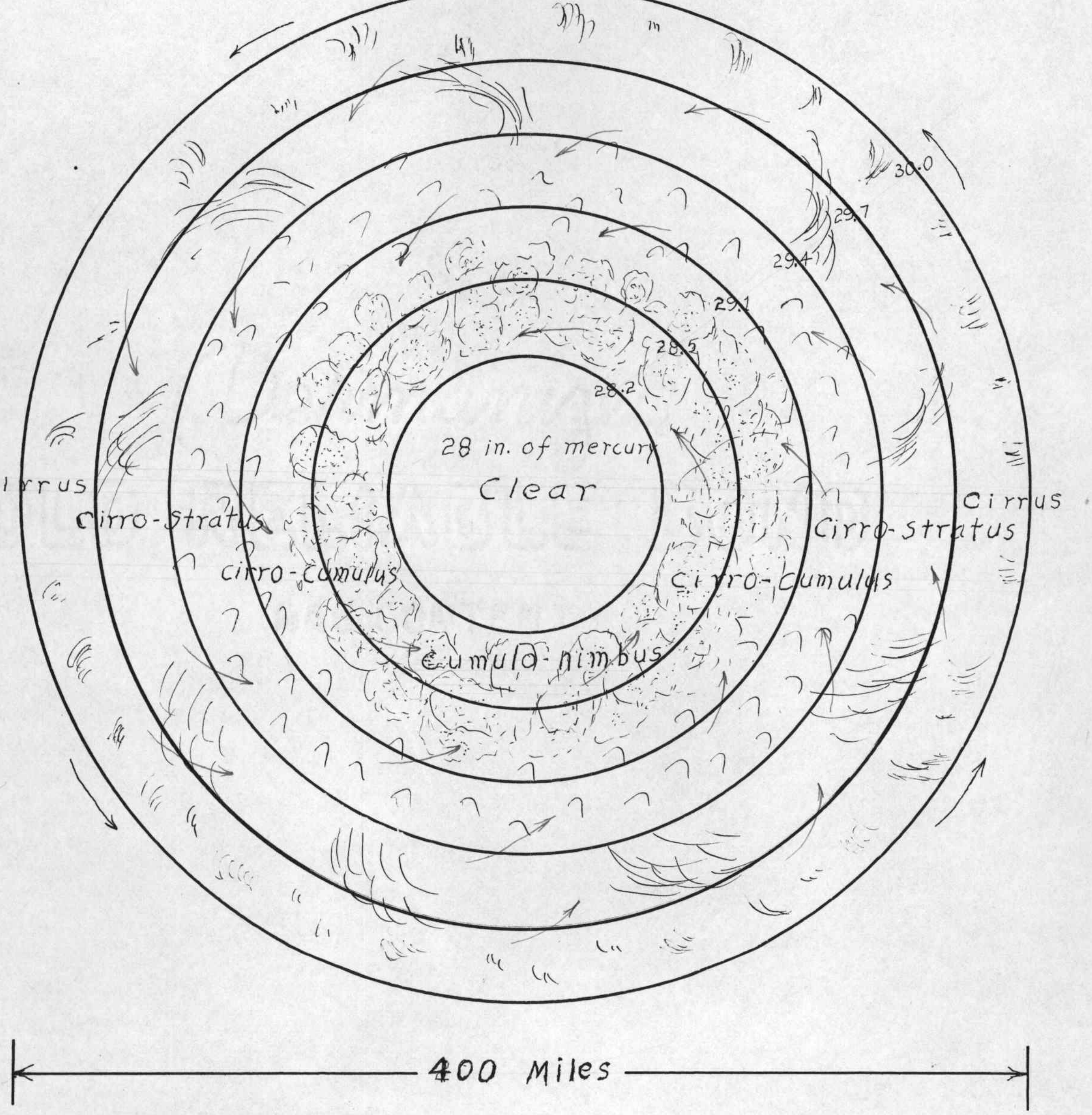

Figure 1. The tropical cyclone (Hurricane).

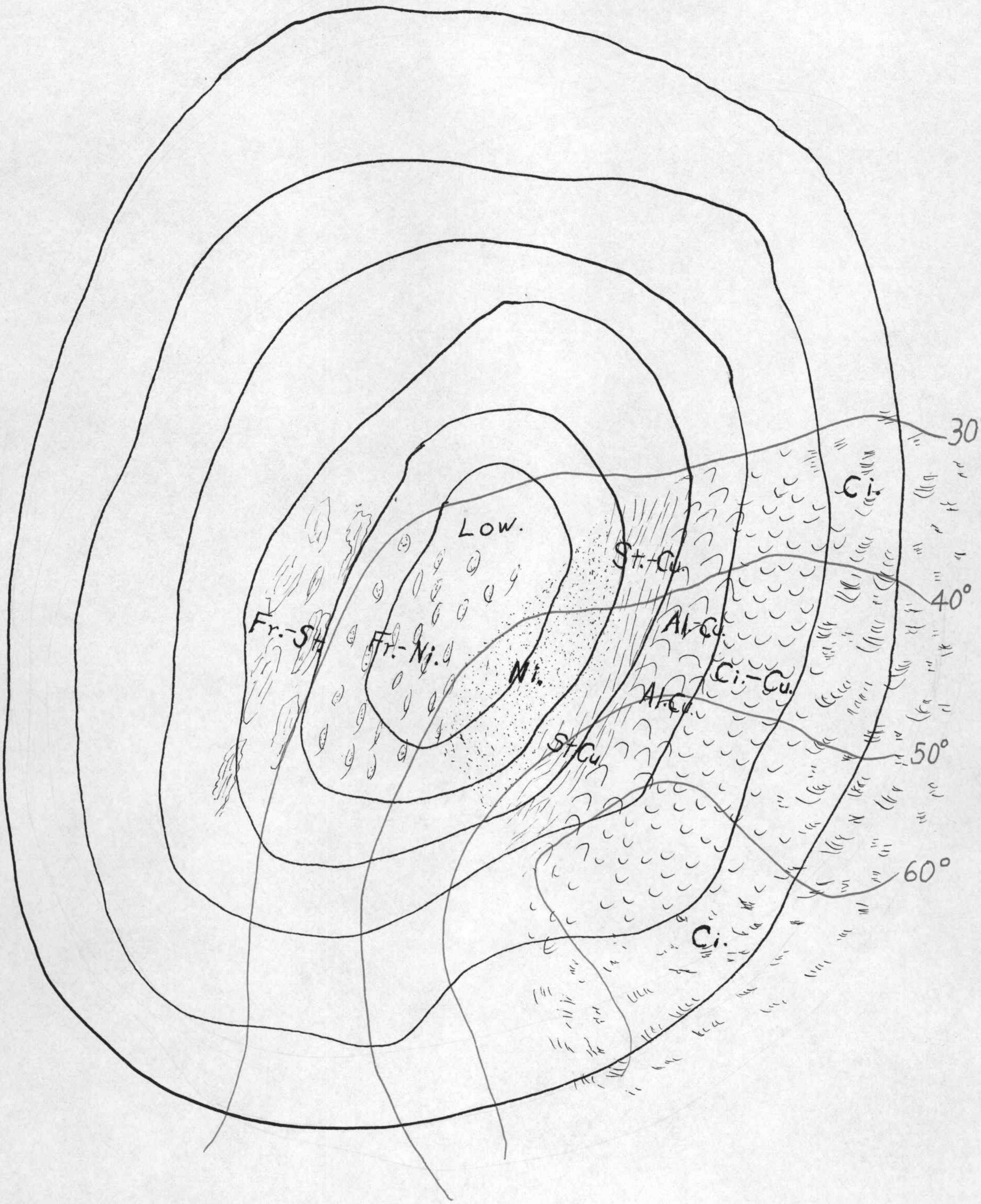

Figure 2. The extra-tropical cyclone (Low).

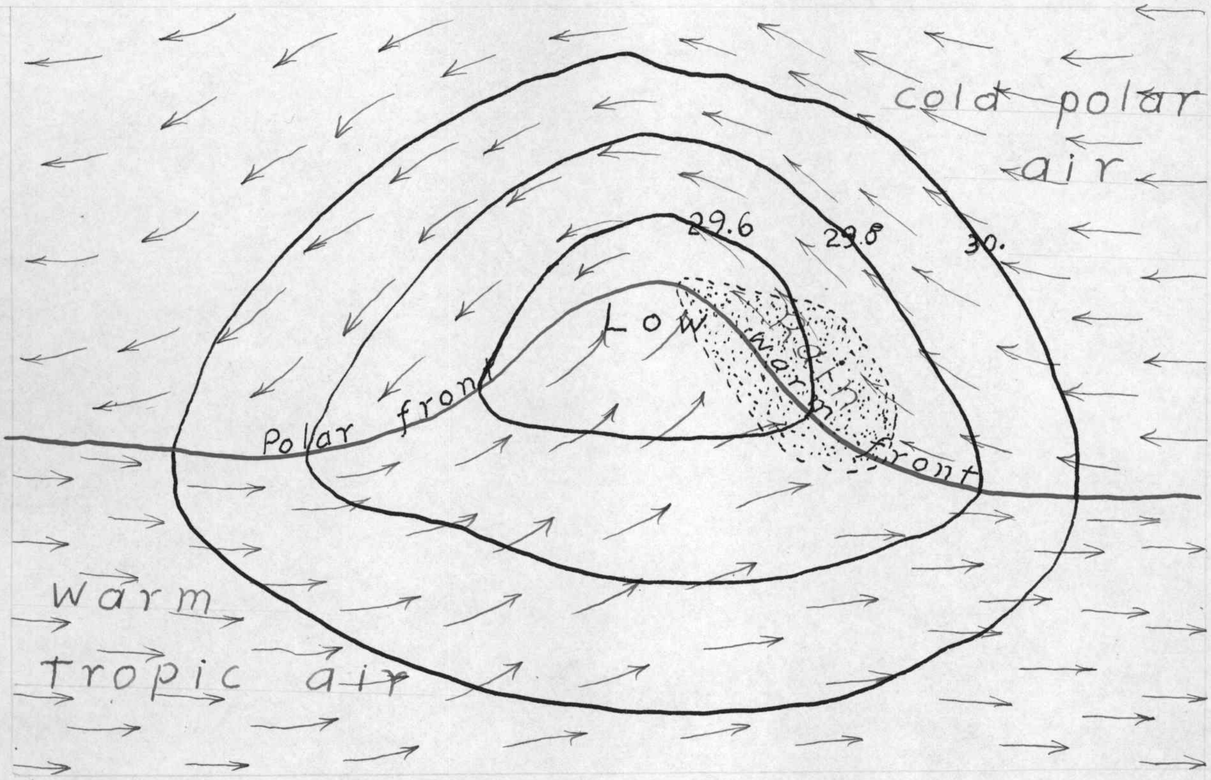

Figure 3. Early stage of the "low".

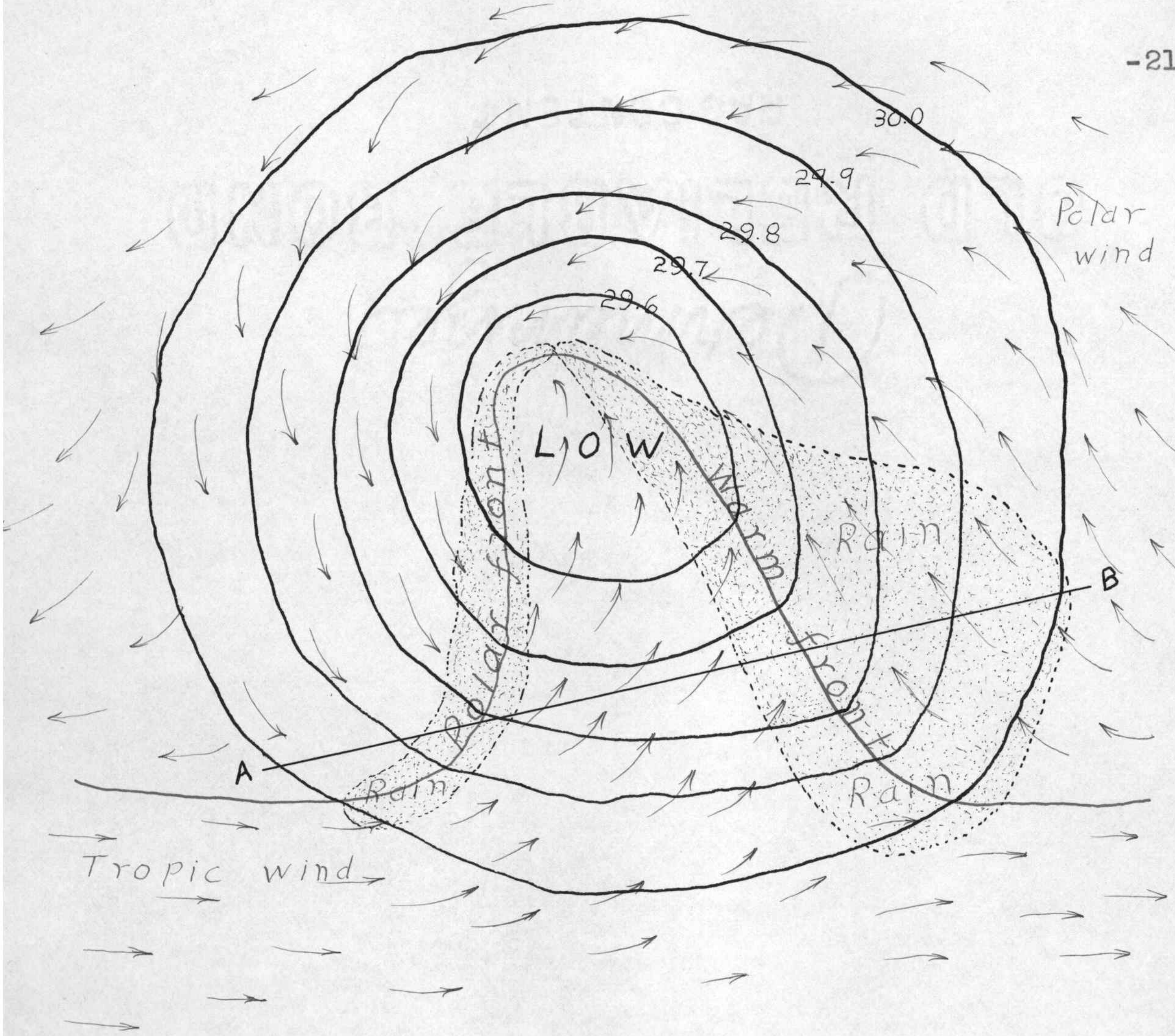

Figure 4. The well-developed "low".

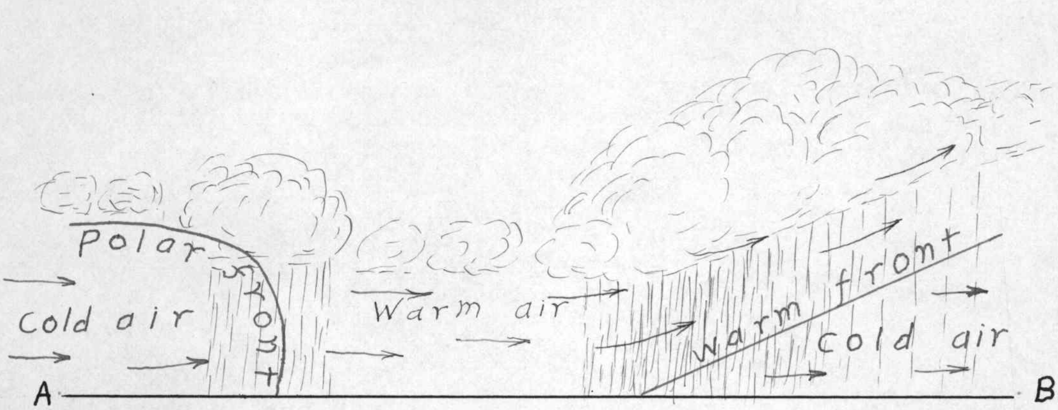

Figure 4a. Vertical section

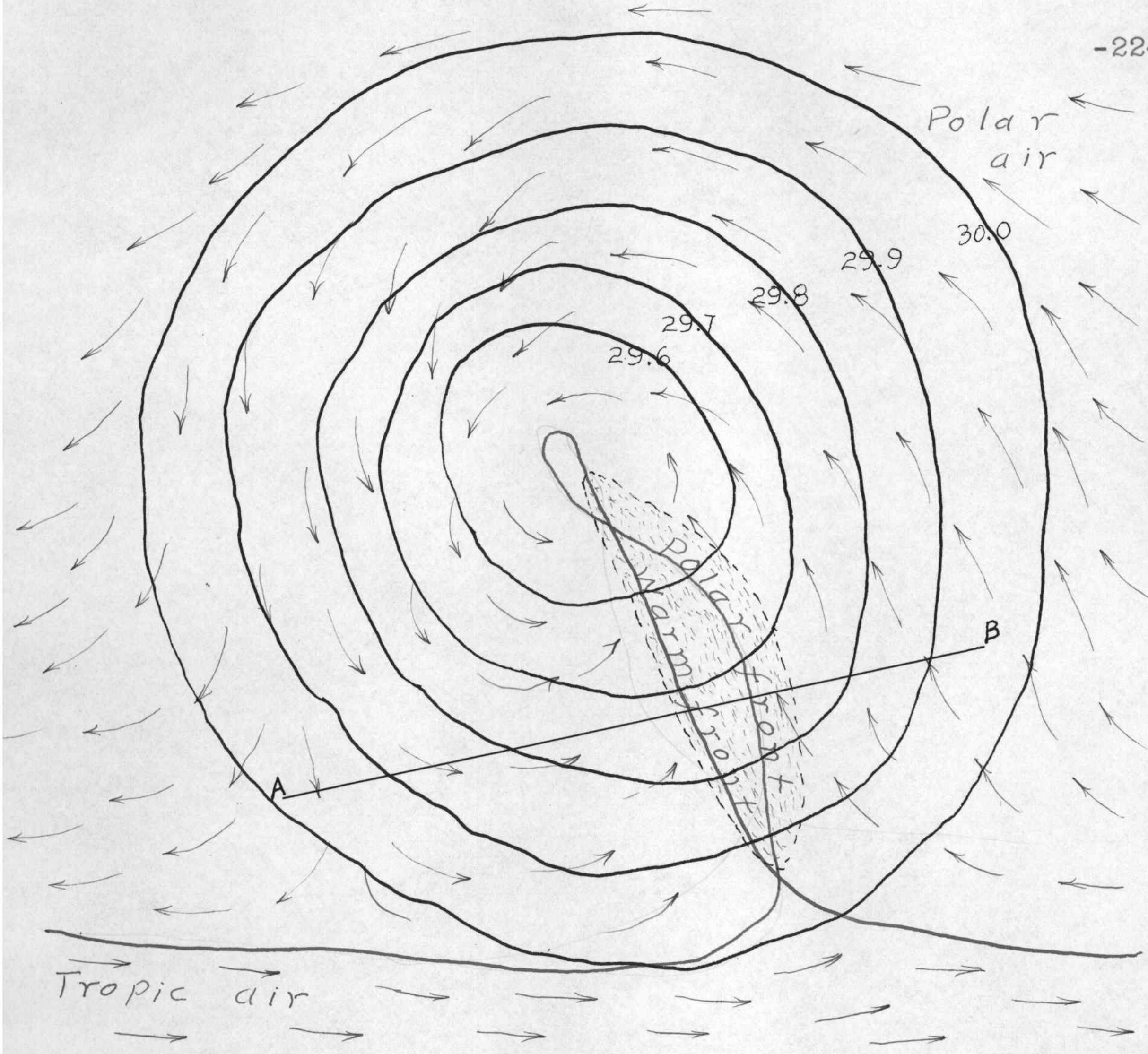

Figure 5. The late stage of the "low" (the oculated fron).

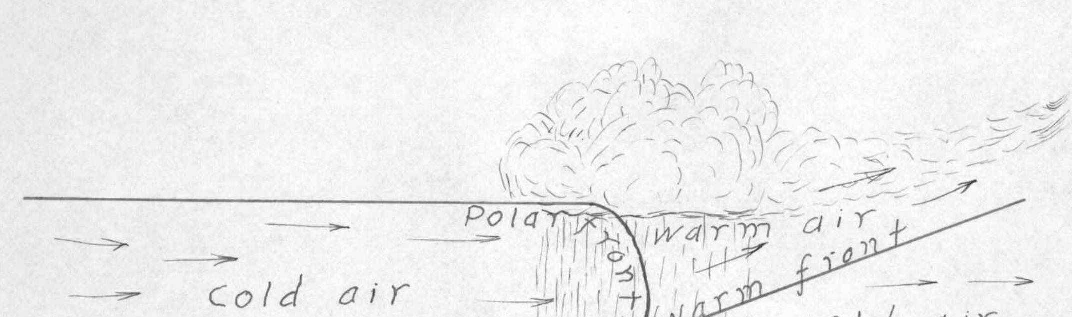

Figure 5a. Vertical Section

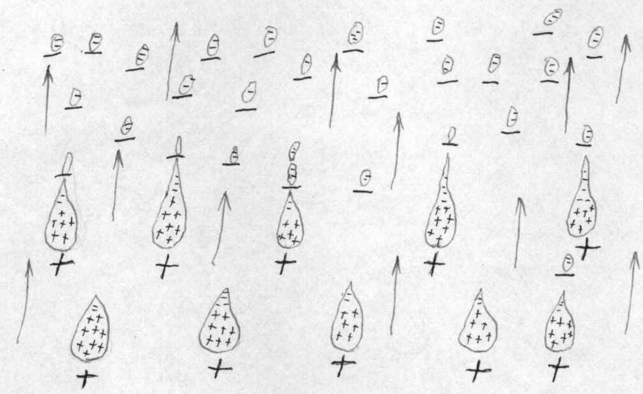

Figure 6. Charges developed by the convection current.

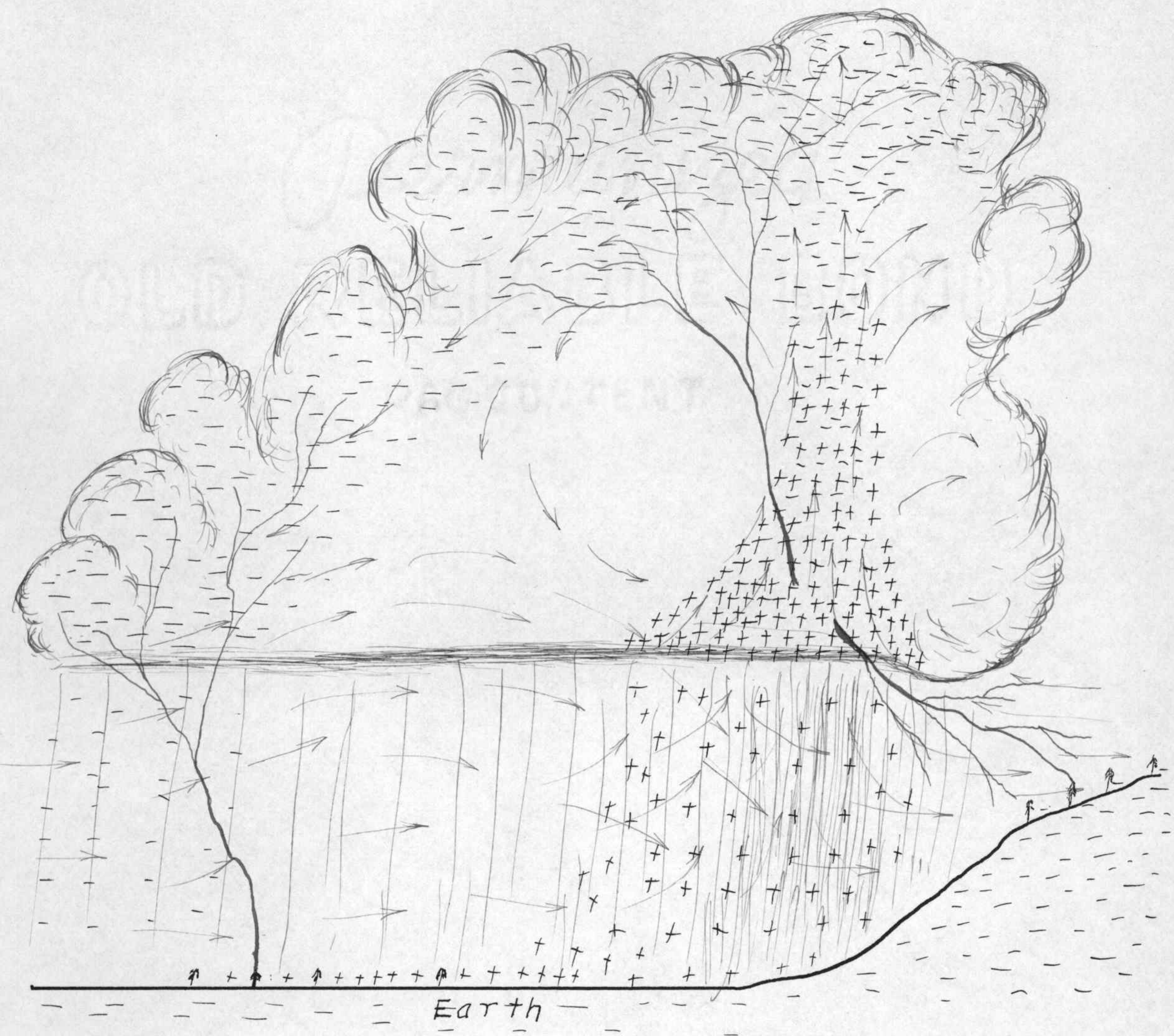

Figure 7. Plan of the thunderstorm.

THE APPLICATION OF WEATHER PREDICTION TO FIRE PROTECTION

Weather forecasts have been used for many years as an aid in protection of forests from fires. 1912 marked the first definite recognition of the need for specialized forecasts to meet the particular problems in forest protection. This recognition was largely a result of disastrous forest fires in Washington and Oregon which occurred in 1910 and 1912. The Forest Service and the Western Forestry and Conservation Association urged E. A. Beals, the district forecaster in Portland, Oregon to institute a forecasting program which would suit the needs of forest protection agencies. Arrangements were completed for collection of a small number of weather observations from forest areas, and for the issuing of special fire-weather forecasts for Oregon, Washington, Idaho, and California during the fire season of 1914.

The program required the establishment of meteorological stations and instruments within forest areas and a study of topography of local forests in order to make the forecasts applicable to small local areas. Weather predictions were confined to forecasting of wind, weather, and temperature conditions favorable to the starting and spread of forest fires.

This fire-weather warning proved of such great value to fire protection agencies in the western states that the practice of issuing special fire-weather forecasts was extended, principally to states west of the Mississippi River.

With the increasing extensive forecasting and with the increased experience in the work, it became evident that the program was quite inadequate to meet the need and was not in proportion to the values at stake.

In 1924, largely through the efforts of the Forestry and Conservation Association, C. I. Dague was assigned to Portland and G. W. Alexander was assigned to Seattle for meteorological work exclusively in fire-weather work. This marked the first step in the employment of specialized full-time personnel in fire-weather forecasting work. Thus the principle was definitely established that fire-weather forecasting is a highly specialized problem which requires full-time attention of trained meteorologists.

In 1926, Congress appropriated money which provided for a definite fire-weather unit in the Weather Bureau organization, and seven fire-weather districts were established during the next two years. The fire-weather districts were located as follows:

	District	Headquarters
1.	California	San Francisco
2.	Oregon	Portland
3.	Washington	Seattle
4.	Montana and northern Idaho	Spokane
5.	Southern Idaho	Boise
6.	Minnesota, Wisconsin and Michigan	Duluth
7.	New England and New York	Boston

A meteorologist was assigned to each district. His duties included establishing and maintaining a network of meteorological substations in the forest, to make daily weather reports, to issue warnings and forecasts as needed, and to engage in research with the idea of localizing forecasts and making them in more detail.

In 1929, a supplementary forecasting service was developed in California, based on previous experience, recognition of the needs of protection agencies, and the appreciation of the values at stake. L. G. Gray, who was then in supervision of the fire-weather work in California, saw the need for short period forecasts applicable to areas on which large fires were burning. He made arrangements for collecting weather data at the location of the fire, and the preparation of weather maps which included reports from nearby substations in surrounding areas. Short range forecasts were then issued stressing weather conditions of greatest importance to the particular problem. This work proved to be so valuable that the Weather Bureau was provided with a truck equipped with meteorological and radio equipment to be used as a mobile "on the ground" forecasting unit. The truck was equipped with a radio receiver, meteorological instruments, and all other facilities required for collection of weather data and preparation of weather maps. This mobile unit made the fire-weather forecaster an integral part of the fire-fighting organization, and available for consultation in formulation of suppression plans. This specially equipped mobile unit proved beyond question in 1929 and succeeding seasons the value of fire-weather prediction in direct suppression work, and in 1937, through increased appropriations, four additional units were assigned to other western states.

With continued improvement in the accuracy of forecasts, substation records covering a sufficient period of years to present conditions accurately as they exist are becoming of increasing importance. Lack of these records has been a handicap in the past, but there are now good records covering 12 or more years in all districts. Most of these records have been compiled in convenient form for use. These records have made it possible to determine seasonal, monthly, and ten-day normals of the various important weather elements.

In the western districts where lightning storms present the most serious single fire-weather problem, their accurate prediction, both with respect to place of starting and rate of spread is of incalculable importance. The knowledge of thunderstorm occurrence and behavior has been reflected in the increased accuracy and degree of localization of forecasts. (6)

SUMMARY

At present the correlation of synoptic weather maps, a knowledge of characteristics of particular weather types, and an understanding of the influence of local topography constitutes the most sound, logical and scientific basis for definite, specific, and exact weather forecasts.

The rules for forecasting cannot be stated simply, and it is extremely difficult to attain success in forecasting through formal study, but more and more, through the perfection of formula methods, forecasting is becoming a scientific process instead of the complicated correlation procedure requiring much experience and little scientific training. As yet, mathematical methods cannot be applied to all the factors of forecasting, but they can be used as an aid in prediction of future positions and developments of high pressure and low pressure areas and other features of weather change.

Weather forecasting was first officially adopted in forest protection in the Northwest in 1914, and has since developed both extensively and intensively. Essential substation records covering a sufficient period of years to determine seasonal, monthly, and ten-day normals of the various weather elements are continually being compiled in all districts. These records will be of increasing aid in the localization of forecasts.

In the western forests, lightning storms present the greatest fire-weather problem. Their accurate prediction, though very difficult to accompligh is of incalculable importance. Recent developments in formulae methods of forecasting have improved and localized thunderstorm forecasts.

The increasing use of airplanes and stratosphere sounding balloons is steadily increasing the accuracy of all weather forecasts. A knowledge of the qualities of the upper air is equally important in accurate forecasting to a knowledge of the surface air qualities.

CONCLUSIONS

Fire-weather forecasting is continually increasing in importance as a part of efficient fire suppression. It affords a sound scientific basis for predetermining where and when fires will start, and what their behavior will be. Perfection of formulae methods of forecasting, continued collection and analysis of weather data, development of superior instruments, and an increasing knowledge of weather characteristics and causes are gradually bringing about the increasing accuracy and value of the fire-weather forecast.

In recent years increasing attention has been paid to the influences of upper air upon the behavior of weather elements. This is the result of increased amount of observational data mada available through the use of airplanes. With the ever-increasing knowledge of the characteristics and structure of the upper atmosphere, ever-increasing accuracy and value of forecasts may be expected.

Progress in fire-weather forecasting is expected to continue through refinement of present methods and through development of new ones.

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