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SOME OBSERVATIONS ON THE CYCLONIC PRECIPITATION OF FEBRUARY 22-23, 1925, IN THE CENTRAL AND EASTERN UNITED STATES

By R. H. WEIGHTMAN

[Read before the American Meteorological Society, May 2, 1925, Washington, D. C.]

The first step in predicting any phenomenon is to understand the physical processes underlying its occurrence. The precipitation problem, important to mankind and attractive because of its difficulty, has received, therefore, much attention from meteorologists.

The causes of condensation and resulting rainfall are, as purely physical matters, fairly well understood. This can not as yet be said of the meteorological aspects of rainfall, though our knowledge of them is increasing rapidly. J. Bjerknes and H. Solberg, in their treatise on "The Meteorological Conditions for the Formation of Rain," show that:

> Adiabatic cooling by expansion is the most effective cooling process at least for larger air masses. Expansion of atmospheric air will again mainly be due to ascending motion, which rapidly brings the air from layers of high pressure to layers of lower pressure. Horizontal motion may certainly also bring air from high to low pressure, but the resulting expansion will be much smaller than that attained by vertical displacement. The effect of pressure changes in a horizontal current can thus only in exceptional cases cause rain. The predominating influence of ascending air motion reduces the meteorological side of the problem of rain formation to the following principal one: What are conditions for development of strong ascending motion. The solution of this problem gives the explanation for the cause of the greatest part of the occurring rainfall.

While we may explain why precipitation occurred after we know what changes in pressure distribution, temperature lapse rates, and other conditions have taken place, it is very difficult at times to tell from our current maps when and where precipitation will ensue during the succeeding 24 hours, and much more difficult to forecast it for the next 36 to 48 hours. The earlier forecasters in this country recognized certain types of barometric distribution, accompanying wind circulation, and other factors as being the forerunners of precipitation and they issued many very accurate and valuable forecasts before the processes were understood. Later, the general physical processes were explained.

More recently, Prof. V. Bjerknes has described these processes in the language of mathematics, explained them on thermo-dynamical principles, showed the idealized barometric types that accompany them, and provided strikingly appropriate names for certain important features of the pressure and wind systems. To him belongs the distinction of having brought together the best thought of meteorologists in Europe and this country concerning the structure and rain-producing processes of storms, combining them with his own special contributions into a *rationale* which has been an inspiration to meteorologists the world over.

The visit last year of Prof. V. Bjerknes, his son, Dr. J. Bjerknes, and Mr. M. A. Giblett, a member of the forecasting staff at London, provided the inspiration for the present study.

Before proceeding with an analysis of the disturbances which form the subject of this paper, a brief résumé of the Bjerknes polar front theory will be given. According to this theory, a cyclone consists of two essentially different air masses (see fig. 1). We have a warm current of

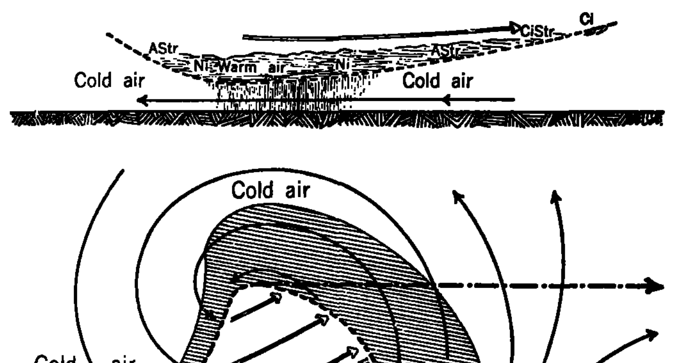

FIG. 1.—Bjerknes's ideal polar front system

south and southwest winds in the region of the cyclone and its trough, with cold air at the rear of the cyclone and also at its front. These air masses are separated by a fairly distinct boundary surface which passes through the center of the cyclone. This surface is inclined in the vertical always toward the cold side at an angle or slope of the order of from 1 to 50, up to 1 to 200, or a one-half of 1 per cent to a 2 per cent grade. The middle portion of figure 1 shows the plan of the surface air currents about a LOW.

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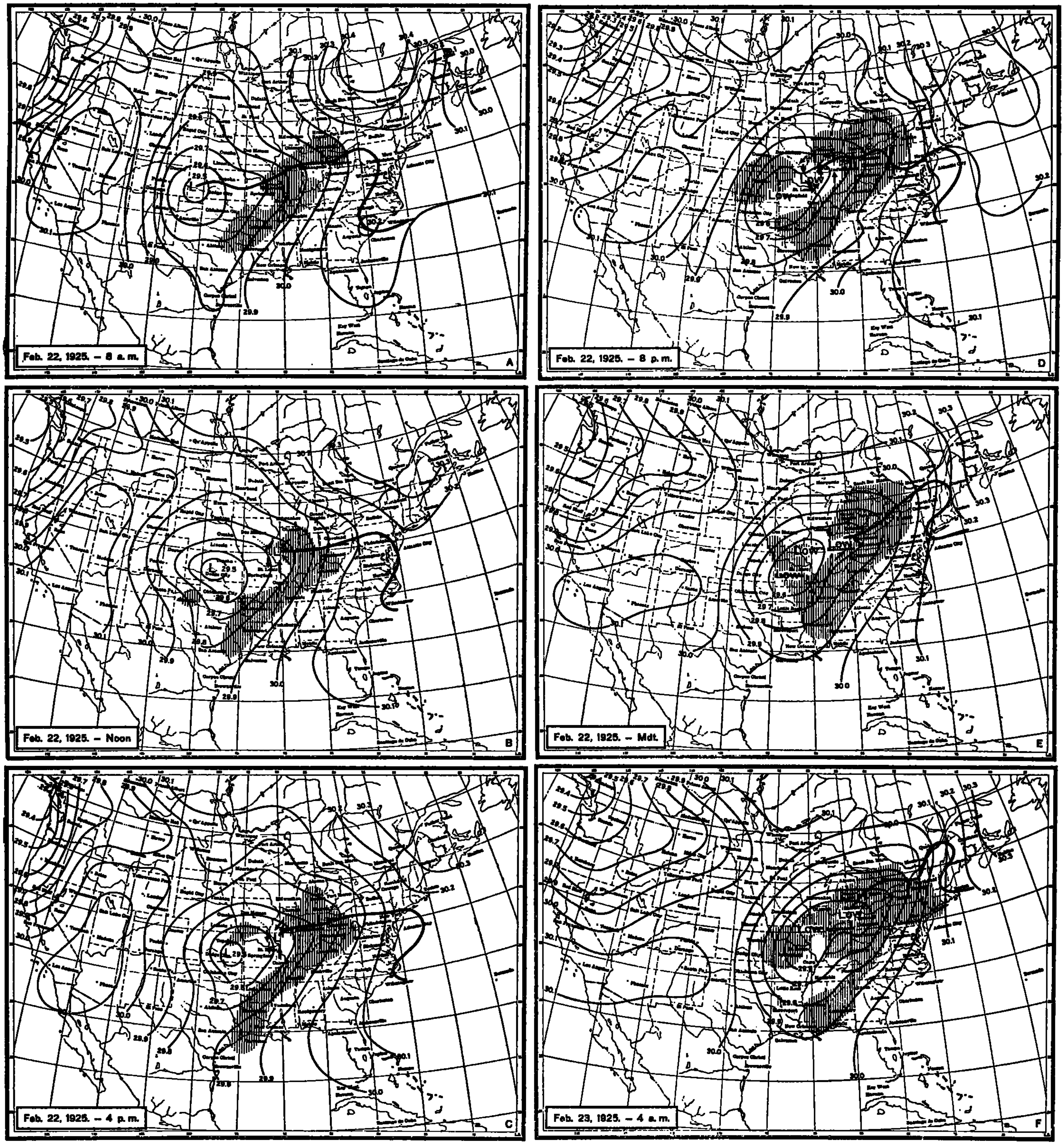

FIG. 2.—Weather maps of 8 a. m, February 22 to 8 p. m. February 23, 1925, with tracks of centers, and Bjerknes's diagram of secondary formation on cold front of the "Mother cyclone."

At the center of the LOW the warm and cold fronts meet. The upper portion of the figure shows a vertical east-west section through the cyclone north of the center. Here the air at the surface is from an easterly quarter, as we would expect in the northern quadrants of the LOW. Aloft the wind is from a southerly quarter and, being of equatorial origin, is relatively warm. It came originally from lower levels and lower latitudes, having undergone a forced ascent over the cold surface air with the result that there is considerable cloudiness and precipitation. The lower cut shows a vertical east-west section through the cyclone south of the center. At the left are seen the cold polar surface winds from the west and northwest underrunning the warm equatorial south and southwest winds, which latter persist aloft after the wind has changed to westerly at the surface. This

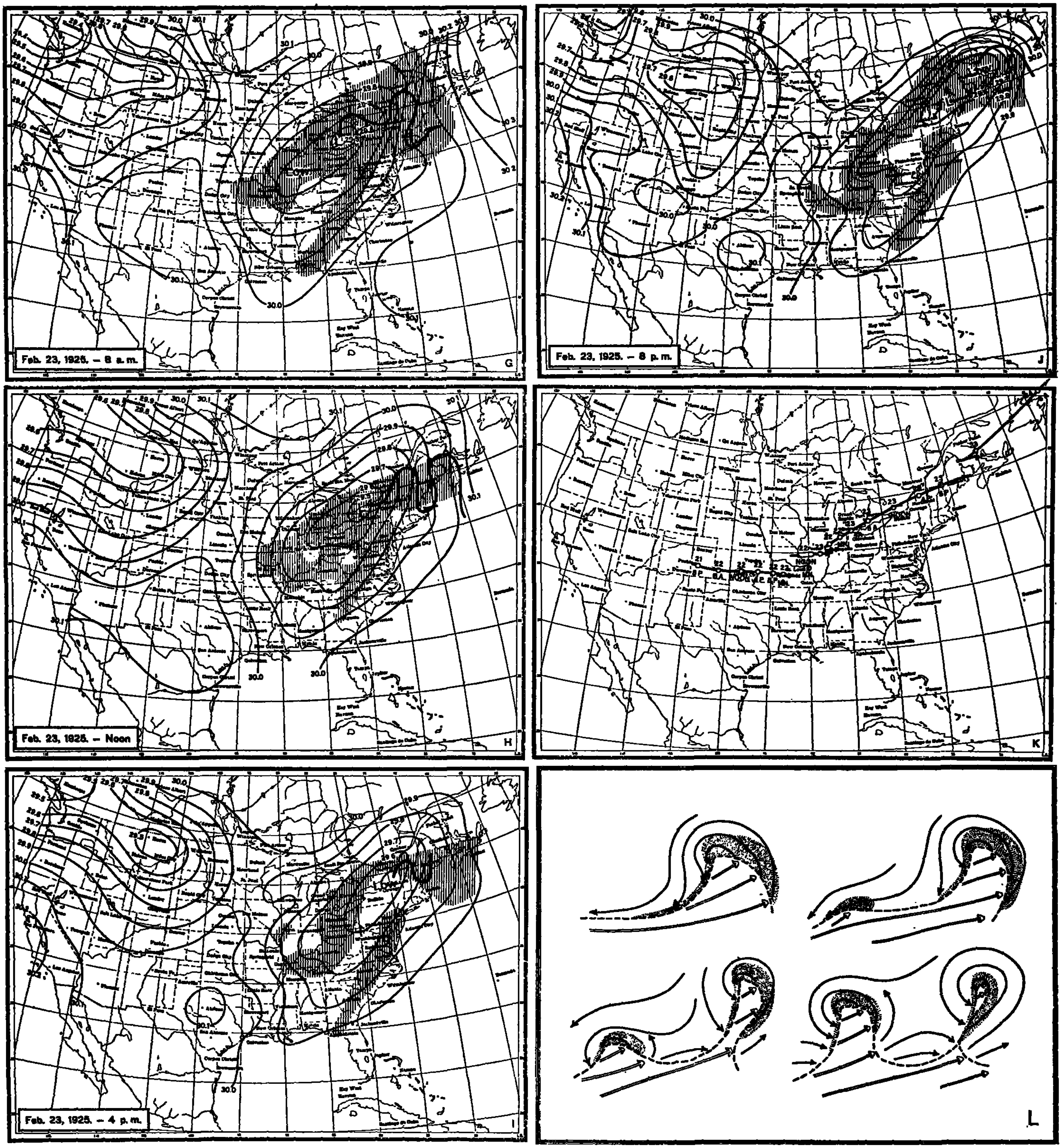

FIG. 2.—Continued

underrunning results in a forced ascent of the warm air from the south, with resulting cloudiness and heavy and, as a rule, brief showers. This front is called the "cold front," and is identical with the squall line or trough. At the right we have the relatively warm southwest winds overrunning the colder air to the east, giving rather widespread cloudiness and showers. In the central figure the broken line trending east and southeast from the LOW center shows the position of the warm front, while the cold front extends southwest from the center of lowest pressure. Hence, with the passing of the warm front, cold air at the surface gives place to warm. Between the warm and cold fronts, at and near which cloudiness and precipitation are in evidence, there is a region of warm air and relatively clear sky and sunshine, although cumulus clouds are to be expected because conditions are favorable to convection. On the cold front, warm air gives place to cold. It will be noted that a narrow band of showers occurs along and immediately west of the cold front due to the raising of the warm south or southwest current by the cold west and northwest current underrunning it, thereby adiabatically lowering its temperature below the dew point. On, and immediately ahead of the warm front, however, the area over which rain is falling is relatively large, the rain being due to the forcing of the warm south or southwest current up over the cold and dense currents from the east and northeast, thereby producing adiabatic cooling. In this country the warm front usually has less inclination than the cold front if the extent of the rain area may be taken as a criterion.

To carry out a study of the disturbances of February 22 and 23, 1925, working charts were prepared for intervals of four hours, showing the pressure and wind direction, together with the precipitation for the two hours preceding and the two hours following the time of the map. In the maps accompanying this paper, these two two-hour periods have been combined into one of four hours. The hatching on each map shows the area over which precipitation occurred in these four-hour intervals, beginning two hours before the time of the map and ending two hours after. For the more northern stations there is some uncertainty as to when precipitation occurred during the night hours, because during the cold season the tipping bucket is removed from the gauge and consequently no record is obtained on the triple register sheet at most stations. At stations where an automatic record was not available, recorded beginnings and endings of precipitation were used.

Let us now examine the series of maps, on each of which the warm front is indicated by the heavy line.

Figure 2A (*Feb. 22, 8 a. m.*).—In the disturbance central over western Kansas the greatest 12-hour pressure fall occurred over Missouri, and the isobars are bulging over the Ohio Valley and Lower Lake region.

Figure 2B (*Feb. 22, noon*).—The LOW center has moved to central Kansas, and the wind circulation (shown by heavy black arrows) indicates that a new center is becoming established on the warm front over northeastern Missouri.

Figure 2C (*Feb. 22, 4 p. m.*).—The LOW has moved to eastern Kansas, and the wind circulation over northeastern Missouri is more firmly established, while the warm front maintains approximately the same position.

Figure 2D (*Feb. 22, 8 p. m.*).—The original cyclone has moved to southwestern Missouri, and the circulation persists over northeastern Missouri, with a bending up of the isobars, indicating further the development of a secondary. There is also some evidence of another circulation developing over northern Indiana.

Figure 2E (*Feb. 22, midnight*).—Traces of the parent disturbance remain over southwestern Missouri where pressure is nearly stationary, though rising slightly. The center over northeastern Missouri has remained practically stationary, but pressure at the center has decreased a little, while the circulation over northern Indiana is more truly cyclonic in character and pressure had fallen slightly.

Figure 2F (*Feb. 23, 4 a. m.*).—The parent center has practically lost its identity, and the northeastern Missouri disturbance remains nearly stationary, while the one that was over northern Indiana has moved to extreme southeastern lower Michigan. Pressure has fallen at both centers.

Figure 2G (*Feb. 23, 8 a. m.*).—The northeastern Missouri center is now over central Illinois and filling up, while the Michigan disturbance has advanced to Lake Erie with slightly increased intensity.

Figure 2H (*Feb. 23, noon*).—The Illinois disturbance is no longer recognizable, while the center that was over Lake Erie has advanced to western Lake Ontario.

Figure 2I (*Feb. 23, 4 p. m.*).—The Ontario disturbance has advanced to extreme northeastern New York, and pressure at the center has risen slightly.

Figure 2J (*Feb. 23, 8 p. m.*).—The northern New York center is over Vermont and another center is apparently developing over New Brunswick. This new center by 8 o'clock the following morning was near Newfoundland, with greatly increased energy.

Figure 2K shows the tracks of these disturbances. Without the aid of the four-hour charts it would have been impossible to distinguish the several centers. It is apparent, therefore, that observations at intervals of less than 12 hours would be of great value in many cases. Were we to contemplate such a program at present, the considerable additional cost of telegraphing and of personnel would prohibit it, but it is believed that the time is coming when more frequent observations, say, every six hours, will become necessary because of their value for the making of shorter period forecasts for local interests, including aviation.

The meteorological situation on February 22 suggests a similarity to Bjerknes's idealized case for the formation of secondary cyclones. In describing this formation, Bjerknes presented the chart reproduced as Figure 2L. It will be seen that the eastern LOW advances and is followed by an anticyclone, thus leaving, in many cases, a line of discontinuity extending from the LOW center southwestward, south of the HIGH system. On this line and generally to the south or southwest of the HIGH the secondary develops.

In the present case, the line of discontinuity is traceable on the map of 8 p. m., February 21 (not reproduced), from the center of the LOW over the St. Lawrence Valley southwestward, south of the center of the HIGH. It may be considered that the LOW, which originated over Colorado, developed on this line of discontinuity, southwest of the high pressure area that was over Quebec on the morning of the 22d. The secondary depressions that later developed over northeastern Missouri, northern Indiana, and New Brunswick would have to be considered as developing *ahead of* the parent LOW and would seem to constitute a type that Bjerknes has not mentioned among his classes, or that perhaps is so rare in Europe that it was not thought worth discussing

So far we have considered in the main the development and movement of the centers of disturbance We are now prepared to take up the occurrence of precipitation.

Figure 2A (Feb. 22, 8 a. m.) shows an area of precipitation extending from northeastern Texas to lower Michigan. The rain extends along and north of the warm front from northeastern Missouri northeastward to lower Michigan. This precipitation is of the warm-front type, as we have relatively cold east and northeast surface winds, while aloft, as shown by observations at Royal Center, Ind., we have southwest winds at 2,500 meters, the highest elevation reached by the kites. In other words, warm air is forced to rise over the cold wedge at the surface. This is further confirmed by the temperatures shown by the morning kite flight at Royal

Center, which indicate practically no change with elevation up to 1,100 meters and a lapse rate above that level of about 0.56° C. per 100 meters, or nearly the saturated adiabatic at temperature 0° C.

The showers which are in progress over the area extending from southern Indiana to northeastern Texas, between the warm front and the trough which generally marks the cold front, occurred in a great many instances in connection with thunderstorms. They are of the cold-front type mentioned by Bjerknes and Solberg in *Geofysiske Publikationer*, III, No. 1, page 8, Figure 4b. In this type the colder air in the rear of the trough does not undermine the relatively warm air at the surface, but comes in first at some higher level and gradually works down to the surface, with the result that there is, temporarily, cold air over warm. Immediately preceding these showers surface temperatures were 20° or more above the seasonal average. East of this main rain area instability showers under quite different circumstances are in evidence at Meridian, Miss. This type occurs, when humidity conditions are propitious, in air of polar origin, the upper portion of which remains relatively cold, while the lower layers warm up under clear skies until the resulting unstable equilibrium produces local showers.

Returning now to the main shower area, the free-air data at Groesbeck, Tex. (see fig. 3), show that from the 20th to the 21st temperature rose from the surface up to

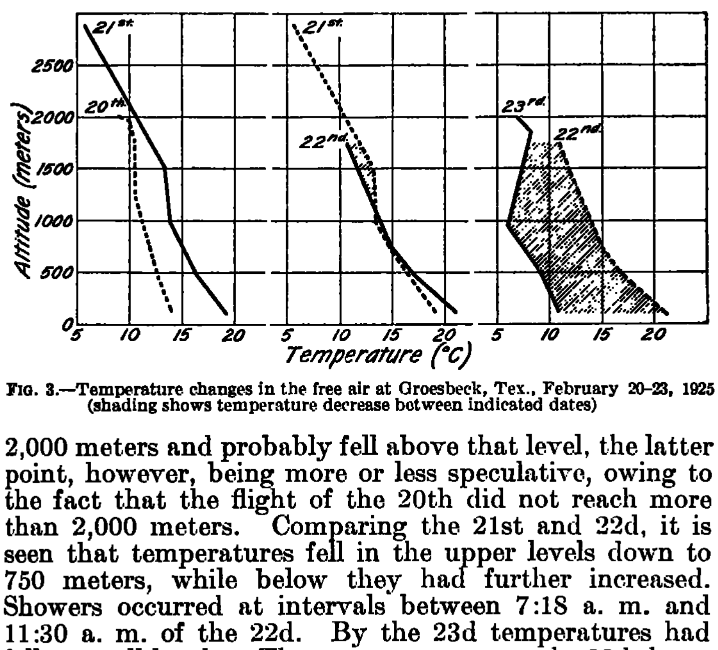

FIG. 3.—Temperature changes in the free air at Groesbeck, Tex., February 20–23, 1925 (shading shows temperature decrease between indicated dates)

2,000 meters and probably fell above that level, the latter point, however, being more or less speculative, owing to the fact that the flight of the 20th did not reach more than 2,000 meters. Comparing the 21st and 22d, it is seen that temperatures fell in the upper levels down to 750 meters, while below they had further increased. Showers occurred at intervals between 7:18 a. m. and 11:30 a. m. of the 22d. By the 23d temperatures had fallen at all levels. The vapor pressure on the 22d shows a rise at practically all levels up to 1,750 meters, the highest reached, being most marked above 1,000 meters. By the 23d vapor pressure had decreased greatly at all levels, indicating that all air above the station was of anticyclonic and polar origin. The lower temperatures came in first at the upper levels and at the same time as the winds in these levels shifted from south to southwest, the air of lower temperature apparently having had its origin in the anticyclone over the southern plateau. These temperatures and vapor-pressure conditions, together with the fact that the area of showers moved eastward in a narrow belt that was consistently covered by precipitation, would certainly indicate that the type of precipitation which prevailed was of the cold-front type described above. Further, there is every reason to suppose from all the facts available that the sequence of conditions experienced at Groesbeck was progressively experienced at stations to the eastward. Unfortunately no kite data are available for Due West, S. C., on the 22d and 23d, due to an enforced curtailment of the observational program.

Figure 2B (*Feb. 22, noon*) shows a rain area very similar to that of the 8 a. m. map. The first indication of a second area of cold-front rain is the light shower at Amarillo. Such light showers are typical of cold fronts along the eastern slope of the Rocky Mountains, because the winds attending them have a down-slope direction, and consequently a tendency to be warmed through increased pressure; hence it is only in cases of decided temperature contrasts that precipitation ensues.

Figure 2C (*Feb. 22, 4 p. m.*).—There are now two areas of warm-front rains, the first over northeastern Kansas and northwestern Missouri, associated with the principal LOW center over eastern Kansas, and the second extending along and north of the warm front from Illinois to lower Michigan and northern Ohio, associated with the new LOW center developing over northeastern Missouri. The belt of showers extending from Indiana to Texas maintains the same position relative to the LOW center.

Figure 2D (*Feb. 22, 8 p. m.*).—Warm-front rain extends along and north of the warm front from northern Illinois to western New York and the area of cold-front showers maintains the same position relative to the new LOW center, but has advanced slightly eastward. The secondary area of cold-front rain is in evidence over Kansas, northwestern Missouri, and southeastern Nebraska, although the rain in the last-named State is possibly a remainder of the warm-front rain of the preceding map, as indicated by the temperature trace sheet at Drexel, which shows a characteristic warm-front form. The Kansas rain is clearly of the cold-front type, as shown by the thermograph traces of the several stations.

Figure 2E (*Feb. 22–23, midnight*).—Warm-front rain in connection with the northeastern Missouri disturbance has ceased, probably due to the failure of the south or southwest warm current, but is spreading in connection with the new center developing over northern Indiana. The cold-front showers continue and extend from Ohio south-southwestward to the northwest portion of the East Gulf States, having advanced slightly eastward, while the secondary area of cold-front rain covers Missouri.

Figure 2F (*Feb. 23, 4 a. m.*).—Warm-front rain continues to spread eastward from the new LOW center over southeastern lower Michigan, and has reached western New England. The cold-front showers continue in a narrow band from Ohio and western Pennsylvania to the Middle Gulf States and also over Indiana and northeastern Kentucky. The secondary cold-front rain area has increased in size and extends from southern Lake Michigan to Missouri, the Chicago thermograph trace showing the advent of the cold front at that station about midnight.

Figure 2G (*Feb. 23, 8 a. m.*).—Shows the warm-front rain covering New England, while the belt of cold-front showers has advanced slowly eastward. Rain still continues over northern Indiana, southern Illinois, and Ohio. The *secondary* cold front rains are fairly continuous along and immediately in the rear of the cold front, and are confined to the area formerly occupied by the depressions. Such regions are, of course, the most active as far as temperature changes are concerned and are generally the regions of greatest pressure change.

Figure 2H (Feb. 23, noon).—Shows much the same distribution of precipitation as the preceding one, except that showers have temporarily ceased in southern Georgia. The whole system is advancing slowly eastward.

Figure 2I (Feb. 23, 4 p. m.).—Shows clearly the difference in the position of the warm-front rain and the two areas of cold-front showers; these areas are separate and distinct.

Figure 2J (Feb. 23, 8 p. m.).—Shows the same general conditions as the preceding figure, except that the whole system has advanced slowly eastward.

This study serves to give an insight into the several types of rainfall associated with the polar front theory, which, in this case, shows a quite orderly behavior. It should be remembered, however, that these LOWS showed remarkably small changes at the centers, the lowest pressure varying between 29.48 and 29.58 inches, not considering the diurnal variation. Further, they had a regularity of movement both with respect to direction and rate that is not usually encountered. The major currents associated with them were uniform and well established. Under such circumstances, forecasting is is not the trying task it sometimes is.

In cases where the movement is rapid, where the barometric changes at the center are marked, or where there is irregularity of direction and rate of movement, well-ordered rain areas are not the rule, and in such cases we have, of necessity, to depend on our ability to forecast the erratic behavior of the LOWS.

The Bjerknes system is used exclusively in Norway and to a considerable extent in the British Isles and other European countries. Since this system has proved so useful in Europe, it behooves us in the United States to study its newer features carefully in order that we may not overlook an opportunity of improving in any way our forecasting methods. Our problem is somewhat different from that of the European meteorologists, as shown by the following statement in the paper of J. Bjerknes and H. Solberg: "Life Cycle of Cyclones and the Polar Front Theory":

> A very large percentage of European cyclones are occluded ones, being dying remainders of previously strong Atlantic depressions. The predominance of occluded cyclones in Europe has led to the statistical result that cyclones usually have a cold core.

In the United States about 40 per cent of all disturbances that affect us develop within the continental confines or along the Atlantic or Gulf coasts. They are, therefore, new or increasing disturbances as distinguished from the dying or occluded cyclones of Europe. On this account it would seem that in this country we must continue to rely in the main on our established methods, with such improvement as can be made on them.

METEOROLOGICAL ASPECTS OF THE SAN FRANCISCO-HAWAII AIRPLANE FLIGHT

By THOMAS R. REED

[Weather Bureau, San Francisco, Calif., September 28, 1926.]

The nonstop flight essayed by naval airplanes from San Francisco to the Hawaiian Islands, August 31 to September 1, 1925, attracted nation-wide attention as being the longest nonstop ocean flight that had yet been attempted. Almost as interesting as the fact of the flight itself are some of the details of organization by which it was hoped to insure the success of the project. None of these details was more important than the meteorological preparations. The plans in this regard were thorough in the extreme. It was recognized from the outset that success would largely hinge on the character of weather encountered, particular dependence being placed on the prevalence of trade winds which normally are found over the greater part of the course between the southern California coast and Honolulu. The extent, duration, and force of these winds therefore constituted the first problem to be considered, since they were to decide the date of departure and the point on the California coast from which the flight would start.

The choice of sites for the commencement of the flight lay between San Francisco and San Diego, the former being finally decided upon in conference between Commander John Rodgers and Lieut. Allen T. Snody and the local officials of the Weather Bureau in San Francisco. San Diego, although farther from Hawaii in actual distance than San Francisco, nevertheless had a strong claim. Being some 5° nearer the Equator, San Diego is situated in the latitude of the summer trade winds, and while these winds are not found in the proximity of the southern California coast, it was believed that the trade-wind belt would be sooner entered if the departure were made from the southern city. Furthermore, the winds which would intervene between the coast and the point at sea where the favoring trades were looked for were known to be normally more adverse off the northern California coast than off the southern (see fig. 1). Their direction in both sectors would have a deflecting effect on the planes, but because of their greater strength in the North this effect was likely to be more consequential there than in the South, and might conceivably reach objectionable proportions if the west-east component happened to predominate. The north-south component of these winds caused no apprehension, as any drift arising therefrom would be a help in bringing the planes into the southern latitudes occupied by the northeast trades.

But whatever disadvantages were to be feared from possible west-east components of movement off the north and central coast were more than offset by the counterclaims of shorter mileage from San Francisco and the reasonable certainty of favorable local conditions for taking off. Due to the great fuel load, it was considered desirable that the planes should take off against a wind of at least 15 miles per hour. Another requisite was an adequate stretch of shallow water; the planes must have ample space in which to gain flying speed, and launching has been found to be most readily effected in very shallow water. Ideal conditions in these respects exist along the western shores of San Pablo Bay (as the northern reaches of San Francisco Bay are known), and this site was finally decided upon as the point of departure. Satisfactory test flights under full load were made there before the day of departure. On the final day both planes got off easily and within a few minutes of each other.

The next question to be considered was the date on which the flight should be attempted. Pressure was exerted to have it coincide with the opening of the Diamond Jubilee festival to be held in San Francisco beginning on September 5. Examination of data, however, led to the conviction that the most favorable winds, both locally and in the trade-wind belt would be found