cause the perpetual warmth of the tropics and the extreme cold of the polar regions.

IX. *Steady motions under balanced forces.*—Whatever free motions may be continuously maintained against resistances by active forces, a state of steady motion under balanced forces must soon be established. If the active forces and the opposing resistances are constant the velocities in the steady state will always be constant regardless of the direction of motion. Changes of both velocity and direction must always accompany changes in amount or character of the active forces or resistances, except in the improbable case in which simultaneous changes in both force and friction just offset each other.

X. *Flow of air tends to minimum, or state of rest.*—The flow of masses of the air from places of higher to places of lower pressure obviously at once tends to reduce or dissipate the pressure gradient to fill up the low, after which friction stops the motion. Such flow also tends to reduce or remove temperature contrasts and any like causes which tend to create and maintain gradients. In other words, *all motions of the atmosphere due to temperature contrasts and pressure gradients tend automatically to the minimum of motions, or to a state of rest.* First, because even without friction the flow and intermixture must equalize temperatures and dissipate gradients or reduce these to a minimum. Second, the surging and oscillating motions of great complexity which conceivably might be set up and continue forever without friction, must by it be readily damped out or reduced to a steady state of the minimum motion.

XI. The motions of the air must satisfy the equations of continuity which require that the inflow and outflow for a given region shall be equal on the average.

XII. Hadley and others since assume, without adequake basis of proof, however, that the algebraic sum of all the frictional affects between the air and the earth for the entire surface of the globe is zero, because otherwise a change in the period of rotation of the earth on its axis should be in evidence.

The foregoing is believed to clearly state principles of great fundamental importance in dynamic meteorology. The whole difficult problem of the mechanics and thermodynamics of the atmosphere is comprehended in the steady winds and the changing motions, for which simply the conditions are stated in paragraphs IX and X.

The literature of mathematical meteorology in so far as it relates to atmospheric circulation is an effort to satisfy in mathematical terms principles IX and X.

THE GREAT CYCLONE OF MID-FEBRUARY, 1919.

By C. LeRoy Meisinger.

[Weather Bureau, Washington, D. C., Oct. 23, 1920.]

SYNOPSIS.

Between the 10th and 16th of February, 1919, the United States witnessed the passage of a cyclonic storm of more than usual intensity, with almost circular isobars, with a diameter sufficient to overreach the northern and southern borders of the country, and with a persistence which enabled it to retain its identity from the time it appeared in the western United States until it disappeared off Newfoundland. A study of this storm, based upon the upper-air data obtained at stations of the Meteorological Section of the Signal Corps and of the Weather Bureau, shows that the distribution of weather elements agrees closely with the usual conditions as described by Bjerknes. The influence of the storm extended at least as high as 3 kilometers, as shown by kites and pilot balloons. There were high wind velocities, both at the surface and aloft, which gave rise to widespread dust storms in the Middle West. Eight maps show the distribution of pressure and winds (surface and aloft) from the 12th to the 15th, inclusive.

INTRODUCTION.

It is not often that the endless procession of low-pressure areas, sweeping across the United States from west to east, reveals a member so strikingly symmetrical, so intense, so persistent, and so remarkable in the distribution of cloudiness and precipitation as that of February 10 to 16, 1919. Appearing on the morning of February 10 off the coast of British Columbia, it moved southeastward into the United States, and by the morning of the 11th was centered in northern Nevada. The morning of the 12th found it centered at Denver, the 13th in eastern Kansas, the 14th in central Illinois, the 15th in New England, and the 16th found it over the Atlantic east of Newfoundland. Its greatest intensity was observed on the morning of the 13th at Kansas City, where the sea-level pressure was 28.90 inches. Previous to this time it had been gradually deepening, and in the remainder of its journey across the United States it diminished very slowly until it approached the ocean, when it appeared to intensify slightly because of the warmer air, the lesser surface friction over the water, and the increasing latitude. With such a strong horizontal gradient of pressure, it was natural that there should be high winds; and with such active circulation that there should be a strong surface temperature gradient. Therefore, because of the almost ideal characteristics of this LOW, it has seemed worthy of study, not only as to surface weather, but also as to the winds aloft.

WEATHER AND WINDS.

Precipitation.—In several recent papers [1] on the general subject of forecasting weather, Prof. V. Bjerknes has outlined in a very lucid manner the way in which masses of cold and warm air interact in circulating about a barometric depression, based upon his observations in Norway. There are two distinct lines of discontinuity in the moving cyclone, *the steering line*, which is shaped like an inverted "S" and occurs in the eastern half of the depression, marking the front, at the surface, of a tongue of warm southerly air; and *the squall line*, which trails away from the center into the southwest quadrant of the cyclone, marking the rear of the intruding tongue of warm southerly air. Along the steering line the southerly air leaves the surface and overrides the easterly surface current in the northern part of the depression; along the squall line the cold northerly wind of the western side of the depression underruns the tongue of warm southerly air. Precipitation is closely related to these two lines: along the steering line the rain falls owing to the dynamic cooling of the southerly wind as it rises over the easterly, and along the squall line the rain falls from the southerly air, which is forced to ascend by the denser northerly wind. A third cause of rain is frequently operative also, namely, the convection caused by the convergence of winds within the tongue of southerly air.

The reason for outlining thus the observations of Prof. Bjerknes is to draw attention to the striking accord which exists in the performance of the cyclone in question. From the time the storm freed itself from the topographical hindrances of the Rocky Mountains the distribution of winds and precipitation during its eastward march conformed perfectly with the mechanical outline of Bjerknes. On the 12th, when the storm was centered

[1] The structure of the atmosphere when rain is falling. *Quar. Jour. Royal Meteorological Society*, April, 1920, pp. 119-140: abstract in Mo. Weather Rev., July, 1920, 48:401. The meteorology of the temperate zone and the general atmospheric circulation. *Nature* (London), June 24, 1920, pp. 522-524; abstract in later Review.

in Colorado, it had not yet attained sufficient control over the warm, moist air over the Gulf of Mexico to induce precipitation as usual in the region east of the center. But Texas, Louisiana, Arkansas, and Oklahoma were covered with clouds, and farther north, in Kansas, Missouri, and Illinois, the sky was partially covered. During the succeeding 24 hours, however, precipitation was general throughout the Mississippi Valley and Southern States. But at the time of observation (8 a. m., 75th mer. time) rain was falling along a strip extending from eastern Georgia and South Carolina northwestward into Indiana, Illinois, and Iowa. This was caused by ascending southerly winds, which at the surface were strong. Rain and snow were also falling in southern Kansas and Oklahoma along the squall line. This relative distribution of precipitation moved continuously forward into new regions of the country, owing to the eastward movement of the cyclonic center. The observations on the upper winds, which are given later, also show this eastward progression. It may be of interest to quote excerpts from the weather-map synopses prepared by Dr. Frankenfield on the mornings in question:

February 12:

Low pressure prevails generally this morning, except in the Pacific States, and there is a marked disturbance central over eastern Colorado. Precipitation continued general west and northwest of the storm center, but as yet there has been none to the eastward and southward. * * *

February 13:

The most severe storm of the present winter is central this morning over northwestern Missouri with a barometer reading of 28.90 inches at Kansas City. The storm influence covers the entire country east of the Rocky Mountains, and there are general rains in the Southern States, the great central valleys, and the southern upper Lake Region, and rains and snows in the Plains States. * * *

February 14:

The barometer is still abnormally low over the eastern half of the country, with a very slow movement of the center of disturbance, which is over Illinois this morning. General rains continue over the low area, with also considerable snow on its northern and western boundaries. * * *

Temperature.—The effect of the cyclone with respect to temperature was most marked on the 12th, 13th, and 14th, because on these dates the storm was so situated as to produce the greatest contrast of temperature between the front and rear. Before the storm was centered in Colorado the temperatures over the eastern half of the United States were quite even, the difference between the Gulf region and the Great Lakes being not over 11° C. The influence of the LOW upon the temperature became strongly marked, however, as soon as the storm crossed the Rockies.

A line drawn through the center of the depression in a general northwesterly direction lies nearly normal to the isotherms. Measuring along such a line on the several succeeding mornings we discover large differences in surface temperature. For example, on the 12th, between Galveston, Tex., and Yellowstone Park, Wyo., there was a difference of temperature of 20° C.; on the 13th, between Mobile, Ala., and Rapid City, S. Dak., there was a difference of 21° C.; and between Jacksonville, Fla., and Moorhead, Minn., on the 14th there was a difference of 25° C. By the next morning the center of the LOW was so far advanced that it is not possible to obtain temperatures in its southeast quadrant, but between Jacksonville and Moorhead the difference of temperature had increased to 28° C.

Following the storm low temperatures were prevalent over the eastern United States as a consequence of the northerly winds in the rear of the storm.

Upper air observations.—The upper air observations made at this time were largely in the hands of the Meteorological Section of the Signal Corps, which had stations at many of the flying fields and artillery camps. These observations were made with pilot balloons and clouds, the latter being non-instrumental. The Weather Bureau had at that time six kite stations, at several of which pilot balloon observations were also made. Pilot-balloon observing during the passage of a LOW is, owing to the widespread cloudiness and consequent early disappearance of the balloon, rather unsatisfactory. The data presented here and in the accompanying charts are gathered from the records of these Signal Corps stations and the aerological stations of the Weather Bureau. The cloud data from the regular stations of the Weather Bureau were not used because of the fact that the Signal Corps stations made more frequent complete observations, often every two hours; moreover, the meteorologists in charge of nearly all these stations submitted transcripts of their records during this period, which greatly facilitated the organization of the data. To have secured an equivalent amount of information from the original forms would have involved labor incommensurable with their value as additional material.

Over- and underrunning winds.—One of the interesting studies to be made with upper air wind data is that concerning the overrunning and underrunning of winds. An example is to be found on the morning of the 12th. The steering line, as shown by the very short wind arrows on Chart I in red, extends eastward from the center of low pressure through southern Nebraska and Iowa, across central Illinois to a point in central Indiana, where it was influenced by a secondary LOW centered over southern Lake Michigan. This line, according to Bjerknes, may be considered as the line along which the winds of southerly component leave the surface and rise up over the current of easterly winds. The kite observations at Drexel, Nebr., and Ellendale, N. Dak., afford interesting material. Drexel lies not over 50 kilometers north of the position of the steering line. Here there was observed a turning from ESE. to SE. at an altitude of 1,000 meters above sea level, or 604 meters above the station. With this shift of direction was associated an inversion of temperature, part of which may undoubtedly be attributable to the southerly wind, although the inversion was enhanced by the low temperature of the ground itself. The record shows a surface temperature of 0.6° C. (33.1° F.), a temperature at 104 meters above the station of 3.9° C. (38.8° F.), and at 604 meters above the station of 11.0° C. (51.8° F.). From a point 39 meters higher the temperature fell slowly for 500 meters and then more rapidly.

At Ellendale the same morning we find the wind becoming SE. from E. between 1,200 meters and 1,500 meters above sea-level, or between 706 and 956 meters above the station. Estimating the point on the steering line where the air, rising in a northwesterly direction, would reach Ellendale, we find the horizontal distance it would have to traverse to be about 600 kilometers. It is now possible to estimate the rate of ascent of the southerly air. Estimating the height of the point where the air left the surface as about 390 meters above sea level, it is found that the ratio of vertical to horizontal motion of the air at Drexel is about 1 to 71, and at Ellendale is about 1 to 500. Bjerknes, in Norway, using the formula of Margules,[2] finds that there is an "inclination, as a rule, of an order of magnitude between 1 in 50 and 1 in 100."

[2] Margules, Max: On the energy of storms. English translation by Cleveland Abbe, in the Mechanics of the Earth's Atmosphere, Smithsonian Misc. Coll., vol. 51, No. 4.

It is seen that this agrees with the value at Drexel, but not at Ellendale. The distance from the steering line to Ellendale, 600 kilometers, is a greater distance than Bjerknes has to deal with in Norway, whereas the distance to Drexel, 50 kilometers, is quite comparable with those in Norway.

When attention is paid to the moisture content and temperature of the air aloft in the occurrence of overrunning winds at various aerological stations, the amount of precipitation to be expected over the region in question can be computed. Supposing two stations, such as Drexel and Ellendale, show the progress aloft of an ascending layer of warm, moist air. The amount of rain that will fall out of a section of such a layer in traveling from Drexel to Ellendale will be equal to the difference in the amount of moisture contained as it passed over the two stations. This rainfall is, owing to the cooling of the air, largely as a result (1) of rising over the wedge of cold air at the surface, and (2) of rising on account of lateral convergence within the southerly wind itself. The amount of rainfall due to the first may be computed roughly from the cooling resulting from the rise of air up the slope from one station to the other. That due to the second would be approximately the difference between the total and that computed for the first. The placing of such data in the hands of the forecaster in time and in such a form as to be of service in his work should be of assistance in the forecasting of precipitation. In the case of February 12 the region wherein precipitation would ordinarily be expected was clear. The Drexel observation shows that both the lower and overrunning air were of low relative humidity, averaging about 50 per cent and 26 per cent, respectively. At Ellendale the values were about 92 per cent and 63 per cent, respectively. These data are sufficient to show why there was no precipitation. If there had been available, on the following day, data from a series of four or five stations, extending from Leesburg, Ga., through Royal Center, Ind., to northern Michigan, it would have been possible to compute the amount of rainfall over that region.

The charts show all the available aerological data. In red are given the surface wind directions (small arrows), the sea-level pressure, and the wind directions at 500 meters above sea level (large arrows). The charts present the morning and evening conditions for the four days February 12 to 15, inclusive. It should be remarked that in the case of the afternoon maps the upper air observations which represent conditions at about 3 p. m. (seventy-fifth meridian time) are plotted over barometric and surface wind conditions for 8 p. m. This discrepancy of five hours between the upper wind directions and the surface probably is not significant because of the moderate rate of movement of the depression. The data for the wind directions at the 1, 2, and 3 kilometer levels are shown in black arrows—solid for 1 kilometer, dashed for 2 kilometers, and dotted for 3 kilometers. Whenever two or all of these levels had wind of the same direction, the fact is indicated by two or three heads on the arrow. Wherever the observation is upon clouds alone, a black symbolic arrow, varied for the different cloud types, as shown in the legend, is placed as near the station as possible.

It is seen from the charts that the wind directions to at least 2 kilometers conform quite closely to the sea-level distribution of pressure. It is the normal thing for winds at 3 kilometers in cyclones to show quite a decided westerly tendency. Such is the case here where observations to that height were made. Since there were practically no observations in the northern part of the LOW, it is difficult to know whether the westerly tendency was also present there, where surface winds were easterly.

Mr. W. R. Gregg, in discussing this question, has pointed out the fact that at Drexel on the morning of the 12th the observations showed an easterly component as high as 3 kilometers; in fact, the wind was almost parallel to the sea-level isobars. Above this height, however, there was a veering to southwest. The easterly component at Ellendale, while still in evidence at 2 kilometers, had diminished considerably in strength. The temperatures at Ellendale, both at the surface and aloft, were lower than at Drexel, with the result that with increasing altitude there was a diminishing pressure gradient between the two stations. Indeed, at 2 kilometers above sea-level at both stations the pressure as recorded by the meteorographs was identical, 781 mm. Above this height the gradient was the reverse of that at the surface. Therefore, in all probability there was a shift to southwest slightly above 2,500 meters. This conclusion is also supported by the fact that the kite flight was a low one owing to diminishing winds.

Wind velocities.—Such steep horizontal pressure gradients as those indicated by the sea-level distribution of pressure may be expected to yield quite high velocities. It will be of interest to note the speeds actually observed both at the surface and aloft and compare them with the gradient velocity, which may be easily computed,[3] assuming the sea-level gradients to be influential at least as high as 500 meters. The fact that this cyclone is characterized so strongly by the smoothness and concentric nature of the isobars would suggest that the agreement between the observed and computed velocities should be close.

A few of the highest surface velocities recorded during the passage of the LOW are given in Table 1.

TABLE 1.—*Current and maximum*[1] *velocities of surface wind.*

Station.	Feb. 12.		Feb. 13.				Feb. 14.	
	8 p. m.		8 a. m.		8 p. m.		8 a. m.	
	Current.	Maximum.	Current.	Maximum.	Current.	Maximum.	Current.	Maximum.
	m/s.	*m/s.*	*m/s.*	*m/s.*	*m/s.*	*m/s.*	*m/s.*	*m/s.*
Cheyenne	17.0	20.6			11.6	21.5		
Huron					13.4	18.8		
North Platte			19.7	21.5	14.3	23.2		
Dodge City			17.0	18.8				
Wichita					18.8	23.2		
Oklahoma City					8.0	26.8		
Amarillo					6.3	17.9		
Abilene	18.8	20.6						
El Paso	17.9	26.8	11.6	19.7				
Del Rio			13.4	17.9				
San Antonio			8.0	18.8				
Milwaukee			13.4	16.1	16.1	21.5		
Terre Haute							11.6	21.5
Evansville					12.5	21.5		
Little Rock					14.3	17.9	13.4	17.9
Vicksburg							8.0	17.9
Memphis					17.9	23.2	9.8	25.0
Pensacola					10.7	19.7		

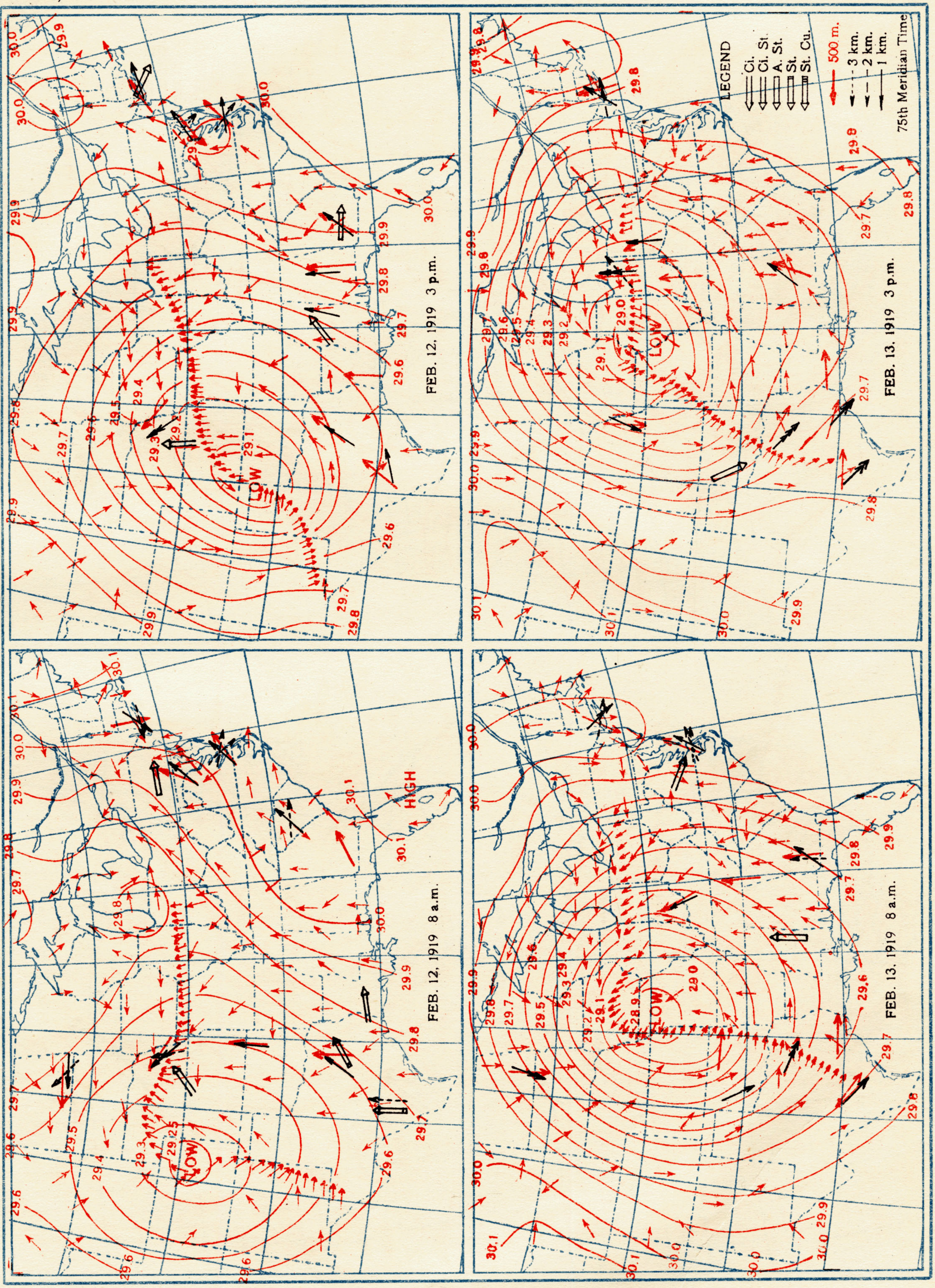
[1] The maximum for a five-minute period during the preceding 12 hours.

Comparisons between the computed velocity and the observed for several stations are presented in Table 2.

First, it is seen that practically all the differences in the 500-meter column are of negative sign, indicating that, on the whole, the velocities at 500 meters were less than those computed. The 1,000-meter column, on the other hand, shows a positive tendency, indicating that the observed speeds were, on the whole, greater than the computed values. From this it may be inferred that the gradient velocity occurred between the 500-meter and 1,000-meter elevations above sea-level, or between 350 meters and 600 to 1,000 meters above the stations.

[3] Humphreys, William J.: The physics of the air. Franklin Institute, Philadelphia, 1920, pp. 139, 140. Cf. Marvin, C. F: The law of the geoidal slope and fallacies in dynamic meteorology, this REVIEW, pp. 570–573.

C. L. M. **Chart I. Winds at various Heights and Pressure at Sea-level.**



C. L. M. **Chart II. Winds at various Heights and Pressure at Sea-level.**

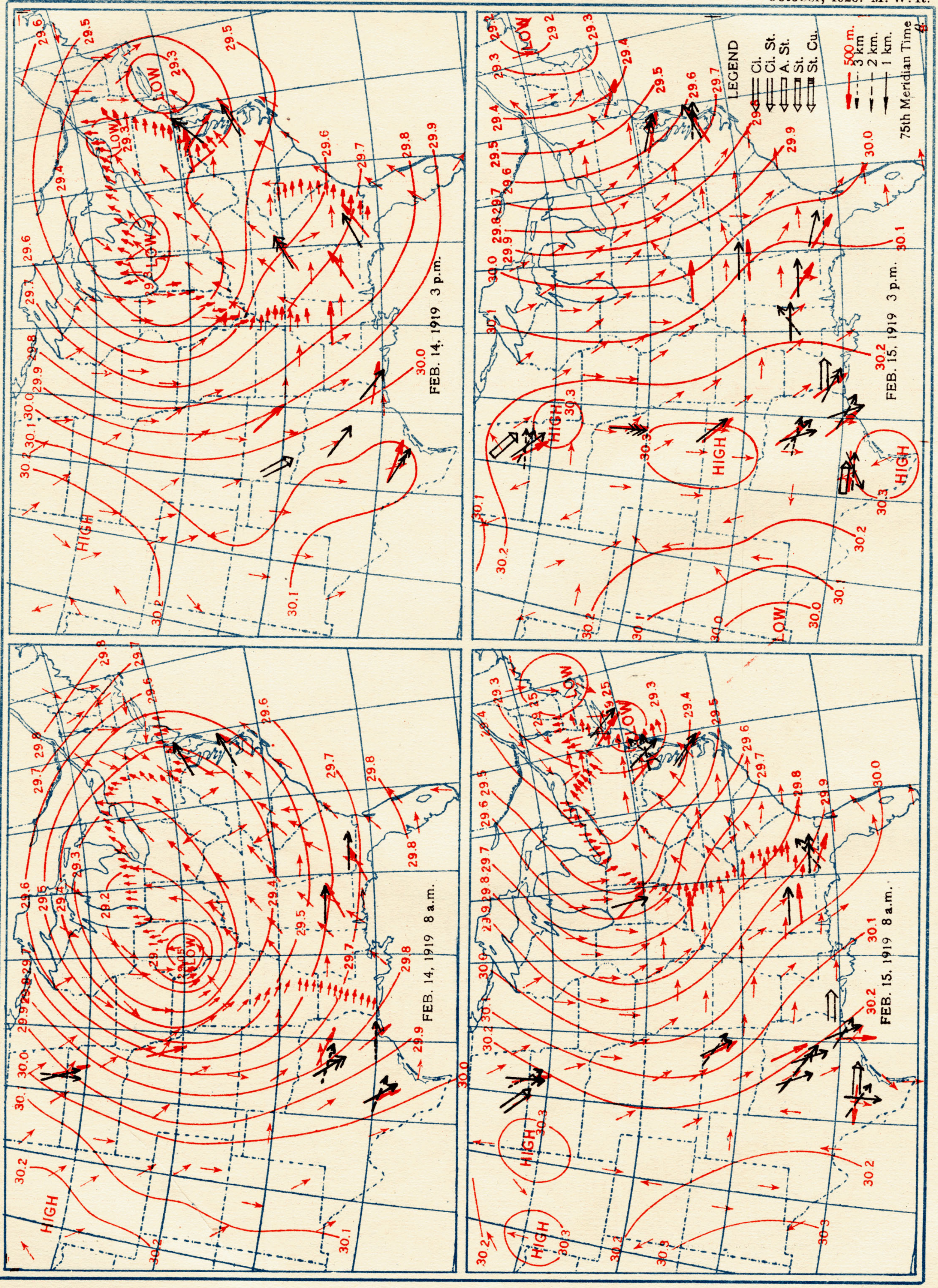


Table 2.—*Comparison of observed and computed wind velocities.*

Date.	Time.	Station.	Computed velocity.	Observed velocity.		Observed minus computed.	
				500 meters.	1,000 meters.	500 meters.	1,000 meters.
	A. M.		m/s.	m/s.	m/s.	m/s.	m/s.
Feb. 12...	8	Ellendale.....	22	[1] 10	10	−12	−12
		Drexel.........	13	[1] 12	14	− 1	+ 1
		Broken Arrow	20	[1] 24	30	+ 4	+10
		Groesbeck.....	20	21	28	+ 1	+ 8
Mean difference						− 2	+ 7
Feb. 13...	8	Ellendale.....	22	[1] 14	15	− 8	− 7
		Groesbeck.....	28	13	20	−15	− 8
		San Antonio..	11	19	18	+ 8	+ 7
		Leesburg......	23	21	22	− 2	− 1
Mean difference						− 4	− 2
Feb. 14...	8	Ellendale.....	16	[1] 20	21	+ 4	+ 5
		Groesbeck.....	17	16	16	− 1	− 1
		Leesburg......	17	16	20	− 1	+ 3
Mean difference						+ 1	+ 2
Feb. 15...	8	Royal Center..	16	[1] 13	15	− 3	− 1
		Montgomery..	15	10	11	− 5	− 4
		Fort Monroe..	13	16	20	+ 3	+ 7
Mean difference						− 2	+ 1

[1] The data for Ellendale, Drexel, Broken Arrow, and Royal Center are given for a level 350 meters above the station, instead of 500 meters above sea level because of the fact that they are over 200 meters above sea level, and thus the 500 meter above sea-level elevation would be so near the surface at those statons as to include considerable influence of friction. All other values in the table are for the heights indicated above sea-level.

The large negative departure of Ellendale on the 12th is probably to be accounted for by the decreasing gradient pointed out above. Conversely, the excess of observed over computed velocities at Broken Arrow and Groesbeck can be explained on the basis of an increasing gradient aloft, which is produced by the smaller vertical decrease of pressure in the heated air of southern latitudes.

It is also evident that the best agreement occurred in those cases where the homogeneous northerly winds were blowing, on the 14th and 15th. The greatest discrepancies, on the other hand, occur where the winds are not homogeneous—that is, where there is over- and under-running of winds. The reason for these discrepancies is probably as follows: In the case where a cold easterly or northeasterly wind at the surface is wedging itself under a southerly current, there is a region, bounded on the south by the steering line, in which the reduction of pressure to sea-level is influenced by the temperature argument. That is to say, the temperature at stations north of this line is abnormally low owing to the importation of cold air, with the result that the reduced pressures are somewhat greater than they should be. Thus, the weather map indicates a gradient wind which does not exist. The mention of this point must naturally lead to the repetition here of a point which was made in an earlier paper,[4] namely, that if we are to be able to forecast winds aloft for the use of aviation, or, as in this case, to determine the gradient velocity from computation based upon isobaric maps, those maps *must* represent the pressure distribution at the level under consideration. Sea-level maps do not represent such a level, and it is only a fortunate circumstance which permits us to approximate the speed of the winds at a few hundred meters above the surface with a fair degree of accuracy.

Clouds.—The following table gives for four stations the succession of clouds as observed during the passage of the LOW. These observations were made at Signal Corps stations every two hours, from 6 a. m. to 8 or 10 p. m. The stations presented here, Kelly Field, Tex.; Ellington Field, Tex.; Gerstner Field, La.; and Hazelhurst Field, Long Island, N. Y., are not as well distributed with respect to the depression as one might wish, but they serve as good examples of the succession of clouds in the particular portions of the storm in which they were located.

Table 3.—*Succession of clouds as observed at two-hour intervals during the passage of the* LOW *at Kelly Field, Ellington Field, Gerstner Field, and Hazelhurst Field, given in amount (tenths of sky covered), kind, and direction.*

Station.	Date.	Time.								
		6 a. m.	8 a. m.	10 a. m.	12 noon.	2 p. m.	4 p. m.	6 p. m.	8 p. m.	10 p. m.
Kelly Field (San Antonio), Tex.	Feb. 10	4 St.......SW	10 St........S	10 St.......SW	10 Nb........S	10 St.........S	10 St.......SW	10 St.......SW	10 St. Cu.....S	10 St. Cu.....S
	Feb. 11	Dn. fog (?).....	Dn. fog......S	Dn. fog....SW	10 St.......SW	10 St.......SW	10 St.......SW	10 St. Cu.....S	10 St. Cu.....S	10 St. Cu.....S
	Feb. 12	10 St. Cu....S	10 St. Cu.....S	Few A. Cu..SW 9 St. Cu......S	Few A. Cu..SW	1 St. Cu....SW	2 f St.......SW	None..........	None..........	None.
					Few Cu....SW	Few Cu....SW	Dust...........			
	Feb. 13	None..........	None..........	None..........	None..........	None..........	None..........	None..........	None..........	None.
	Feb. 14	None..........	None..........	None..........	None..........	None..........	None..........	None..........	None..........	None.
	Feb. 15	4 Ci........W	9 Ci. St.....W	9 A. St.......W	6 A. St.....SW	8 A. St.....SW	10 A. St.....W Few A. Cu..W	10 A. St.....W Few A. Cu..W	10 A. St.....W	10 A. St.....W
	Feb. 16	10 A. St.....S	10 A. St.....S	10 A. St......S	10 A. St....SW	10 A. St......S	10 A. St......S	10 A. St....SE	10 Nb.?........	10 St. ?
Ellington Field (Houston), Tex.	Feb. 10	3 St. Cu.....W	8 St. Cu.....W	Few Cu...SW	6 Cu.......SW	10 St. Cu...SW	10 St. Cu...SW	10 St. Cu...SW	10 St. Cu...SW	
	Feb. 11	10 St....WSW	10 St....WSW	10St.Cu. WSW	8 St.Cu..WSW	6 Cu.........W	7 Cu.........W	8 St.Cu..WSW	6 A. Cu....SW	
	Feb. 12	10 St.........S	10 St.........S	10 St.........S	10 St.........S	10 St.........S	10 St.........S	10 St.........S	10 St.........S	
	Feb. 13	10 St.........W	10 St.........W	10 St.........W	Lt. haze....W	Lt. haze....W	Lt. haze....W	Lt. haze....W	Lt. haze....W	
	Feb. 14	Lt. fog......W	Lt. fog......W	Lt. haze....W	Lt. haze....W	Lt. haze....W	Lt. haze....W	Lt. fog..WNW	Lt. fog.......W	
	Feb. 15	Few A. St..W	Few A. St...W	5 A. St......W	7 A. St......W	6 A. St......W	6 A. St......W	3 A. St......W	Few A. St...W	
	Feb. 16	9 A. St....SW 1 A. Cu....SW	9 A. St.....SW 1 A. Cu....SW	10 A. St....SW	10 A. St....SW	10 A. St....SW	10 A. St....SW	10 St.Cu. WSW	10 St.Cu. WSW	
Gerstner Field (Lake Charles), La.	Feb. 10	10 A.St. WNW	3 Ci. St..WNW 5 A.St..WNW	3 Ci. St..WNW	Few A. St...W	2 A. St.......W	2 A. St.......W Few St.Cu.SSE	1 A. St......W	10 A. St . WSW	10 A.Cu. WSW
	Feb. 11	1 Cu.........W Lt. fog.......E	10 St.........W Lt. fog.......W	3 Cu..........W	8 Cu.......SW	8 Cu.......SW	4 Cu.......SW	Few A.St.WSW 2 St.........W	10 St.........W	10 St.........W Lt. fog.....SW
	Feb. 12	9 A.St...WSW 1 St.......SSW	4 A.Cu..WSW 3 Ci. St..WSW	1 A. Cu..WSW 3 St.Cu...SSW	10 St. Cu.....S	7 St. Cu....SW 3 St.......SSE	3 St. Cu....SW 7 St.......SSE	10 St......SSW	10 St......SSW	10 St.....SSW
	Feb. 13	3 A. St...W(?)	Lt. haze.......	Lt. haze.......	Lt. haze.......	Lt. haze.......	Lt. haze.......	None..........	None..........	None.
	Feb. 14	Lt. haze.......	Lt. haze.......	Lt. haze.......	None..........	Few St. Cu..W	None..........	None..........	None..........	None.
	Feb. 15	None..........	Few Ci.....W	1 Ci.........W	8 Ci.........W	9 Ci.........W	9 Ci. St......W Few Ci..Cu..W	8 Ci. St......W Few Ci. Cu..W	8 Ci. St......W	8 Ci.St......W
	Feb. 16	3 Ci. St......W 1 Ci. Cu......W	2 Ci. St......W 7 A. Cu......W	9 Ci. St......W 1 Ci. Cu......W	8 Ci. St......W	9 Ci. St......W Few Ci. Cu..W	2 Ci. St......W 6 A. Cu......W	10 A. St......W	8 A. St......W 2 St. Cu.....W	8 A. St......W 2 St. Cu.....W
Hazelhurst Field (Mineola), N. Y.	Feb. 10	3 Ci. St......W	4 Ci. St......W	1 Ci. St......W	1 A. Cu......W	2 A. Cu....NW	2 A. Cu....NW 2 St. Cu......N	1 St. Cu......N	None	None.
	Feb. 11	None..........	None..........	None..........	None..........	None..........	None..........	2 Ci. St....SW	7 Ci. St....SW	10 Ci. St...SW
	Feb. 12	10 St.......NE	10 A. St.....W	10 St.......SW	10 St.......SW	10 St......NW	10 St......NW	10 St......NW	10 St.......SW	10 St.......SW
	Feb. 13	3 Ci. St......W	2 Ci. St....NW 3 Ci. Cu....NW	3 Ci. St......W	3 Ci. St......W	7 A. St.......W	10 A. St......W	10 St.......NE	10 St.......NE	10 St.......NE
	Feb. 14	10 St.........E	10 St.........E	10 St.........E	10 St.........E	10 St.........E	10 St. E..........	10 St.........E	10 St.......NE	10 St.......NE
	Feb. 15	10 St.......NW	10 St.......NW	10 St.......NW	10 St.......NW	10 St.......NW	10 St.Cu. WNW	10 St. Cu....W	10 St. Cu....W	10 St. Cu....W
	Feb. 16	10 St. Cu..NW	9 St. Cu...NW	6 St. Cu....NW	Few St.Cu. NW	Few St.Cu. NW	None..........	None..........	None..........	None.

[4] Meisinger, C. LeRoy: Preliminary steps in the making of free-air pressure and wind charts. Mo. Weather Rev., May, 1920, 48: 251–263.

Dust storms.—In the Middle West, about the middle of the period in question, dust storms were reported from many stations, and by noting the dates upon which dust was observed a fair idea of its progress can be obtained. The Signal Corps meteorological station at Fort Sill, Okla., reports that on the morning of the 12th, with a surface wind of 5.4 meters per second from the southeast and a wind of 17.9 meters per second from the southwest at an altitude of 700 meters above the station, the dust began to fill the air. The barometer was falling rapidly. This condition continued until about 2:30 p. m., at which time the air was filled with dust and the the sky was obscured. The moon that night was seen through a very heavy layer of dust. The station at Kelly Field (San Antonio), Tex., reported: "A severe wind and dust storm approached this field from the west about 3:15 p. m. The extreme velocity measured at this station on the surface was 13.4 meters per second at 3:20 p. m. No rain fell in the immediate vicinity, although it was observed raining 3 or 4 miles to the northwest at 3:07 p. m." Other stations reporting the phenomenon were Gerstner Field (Lake Charles), La., and Payne Field (West Point), Miss. The report from the former station on the 13th says: "A light haze became visible about 7 a. m. It was rather high, but gradually became lower and thickened. By 11 a. m. it had reached the surface. About 2 p. m. it became heavy and the dust particles were larger. They began to settle on objects where the air was quiet, and they irritated the nasal passages. About 4 p. m. the wind changed from WSW., where it had been most of the morning and early afternoon, to W. and WNW. The haze was dissipated rapidly and had disappeared by 4:30 p. m. At night a large diffused light area around the moon showed the presence of an unusual amount of dust in the air." The latter station, Payne Field, noted a "dry fog" or haze on the 13th. The sun was visible through it, but it is described as "silver white."

At various stations in Iowa and Illinois the dust was observed. At Alexander, Ill., the dust was accompanied by rain, causing the precipitation of what was described as "red mud." This occurred on the morning of the 13th. At Des Moines and at St. Charles, Iowa, samples of the dust were collected and were subjected to examination by Jacques W. Redway, of Mount Vernon, N. Y. Concerning the Des Moines specimen he says:

> * * * The essential part of the content consists of rounded grains of white quartz sand, and reddish, jaspery quartz sand. A few particles of crystalline fragments resembling calcite are in evidence. * * * It is difficult to account for the spherules of iron. They were not noticeable at first, but the pole of a magnet collected a considerable number of them. Meteoric iron has not been much in evidence in atmospheric dust since 1914; moreover, the spherules in the Des Moines specimen are materially different from any hitherto collected at this laboratory. In color and appearance they much resemble emery-wheel dust. Similar spherules are sometimes blown out of smelter stacks when a strong blast is employed. According to Mr. Reed (Weather Bureau official at Des Moines), there are no smelters in the vicinity of Des Moines. Mr. Reed also noticed that some of the dust clung to the ironwork of his instrument supports.

A later letter from Mr. Reed stated that while there are no smelters in that vicinity there are several small foundries, one of which is four or five blocks southwest of the station. It is possible that the iron particles may have come from that source.

It seems probable that this dust may have been picked up by the high winds in the southwest, carried eastward and spread through the atmosphere in the rear and southern portions of the storm.[5]

CONCLUSION.

This study again brings to our attention the absolute necessity for aerological data. One can not be content to study weather without a knowledge of what is going on in the third dimension. This paper has pointed out how current aerological data can be put to good use in forecasting precipitation; but the greatest good can not be realized until there exists an adequate number of aerological stations in the United States. These upper-air data are indispensable and the establishment of more stations is certain to lead to an ever increasing return upon the investment.

[5] Winchell, A. N., and Miller, E. R.: The dustfalls of March, 1918. MONTHLY WEATHER REVIEW, November, 1918, 46:502-506.

ECONOMIC RESULTS OF DEFICIENT PRECIPITATION IN CALIFORNIA.

By ANDREW H. PALMER, Meteorologist.

[Weather Bureau, San Francisco, Calif., October, 1920.]

SYNOPSIS.

Because of markedly deficient precipitation in northern and central California during the past four rainy seasons serious loss resulted during the dry season of 1920. Streams reached the lowest stages on record. The Sacramento River at Sacramento fell below mean sea level, and the current of the stream was reversed in direction. The saline waters of San Francisco Bay encroached upon rich agricultural lands of the delta region, reducing the vegetable crops, drove the dairy industry to other regions, and threatened irreparable damage to alluvial soils through the infiltration of salt water through seepage. For domestic use fresh water had to be transported on barges across the bay. The teredo, or "ship worm," a minute salt-water organism, did great damage to wooden structures. In the interior valleys the water problem has passed from one of too much water to one of too little. The average yield per acre of many crops was reduced in 1920 because of deficient moisture. Rice growers felt the drought keenly, because of the large water requirements of rice. Litigation over water rights has ensued, and additional legislation is apparently needed to meet new conditions. Hydroelectric power shortage resulted in power restrictions and higher rates for electricity, thus raising the cost of living. Wells went dry because of the lowered level of ground water. Forest fires were more frequent and destructive than in past years, owing to the parched condition of the forests. Partial relief from the drought came as a result of copious showers in October, 1920. The storage and utilization of fresh water is one of the most important problems confronting California to-day.

INTRODUCTION.

Comparatively few people residing in the central and eastern portions of the United States appreciate the value of the generous precipitation received in those regions. In the West and Southwest, and particularly in California, water is wealth, and irrigation water is aptly termed "the lifeblood of the State." Since successful agriculture requires a minimum of 15 to 20 inches of water a year, vast regions in the West, where the annual precipitation is normally below those amounts, are largely dependent upon artificial irrigation. Most of these irrigation systems receive their supplies from the relatively heavy precipitation of the mountain regions, and the water is conducted through artificial canals from streams or from natural or artificial reservoirs. In designing such systems due allowance is made for abnormally heavy or deficient precipitation. But when abnormally light precipitation recurs for three or four consecutive years the inevitable water shortage brings economic results which cause a community to recognize the necessity of an adequate water supply.