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THE PREPARATION AND SIGNIFICANCE OF FREE-AIR PRESSURE MAPS FOR THE CENTRAL AND EASTERN UNITED STATES

BY

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THE PREPARATION AND SIGNIFICANCE OF FREE-AIR PRESSURE MAPS FOR THE CENTRAL AND EASTERN UNITED STATES.[1]

By C. LeRoy Meisinger, Meteorologist.

PREFACE.

My interest in the question of drawing charts of the free-air distribution of barometric pressure was aroused during the World War by Dr. Charles F. Brooks, then instructor in the Signal Corps School of Meteorology at College Station, Tex.; but it was not until the autumn of 1919 that the opportunity was afforded of approaching the problem in the more auspicious atmosphere of the Central Office of the Weather Bureau at Washington. Since that time the various ramifications of the problem have become apparent one by one. Increasing familiarity with the technique of barometric reduction and other practices pertaining to forecasting the weather, and discussions with representatives of other meteorological services, have served to develop the conviction that barometric maps of free-air levels should have a direct and important bearing upon accurate forecasting for aviation interests and, with experience, upon the general forecasting of weather.

It is true that this study has been confined to the eastern United States, where the problem of barometric reduction to sea level is not serious. But even if upper-air maps are not needed to avoid reduction difficulties, nevertheless they should serve valuable ends in removing uncertainty from the surmises regarding free-air conditions, especially when aerological observations are not available. Moreover, they would link up such free-air observations as are obtainable by relating them to the general barometric situation aloft.

Preliminary studies relative to the history of barometry in the United States led at once to the West, to the rugged Rockies in whose lofty fastnesses lurks that formidable barometric *bête noire* in a lair from which he has never yet been driven. Abbe, Ferrel, and Bigelow made significant efforts to exterminate this annoying and dangerous monster; but he is still abroad. The forecasters are eminently desirous of his capture, and a symposium on Plateau reductions at the Toronto meeting of the American Meteorological Society clearly indicates that the challenge still exists for some doughty meteorological nimrod to shoulder his hypsometric blunderbuss and sally forth. Whether the attack can best be made from the air is a question for further consideration.

This study aims to carry the process of free-air reduction to the point where it can be performed at meteorological stations with a facility equal to that with which sea-level reductions are performed at present. The process is fully explained, the accuracy of the resulting maps is supported by much evidence, and a few specimen maps are drawn. The real test of the value of these maps can not be made by the author; that demonstration must rest with the forecaster, experienced, as he is, with daily weather controls, and sympathetic, as he must be, with the new charts, which will reveal to him pictures hitherto apparent only as fragmentary impressions. It is hoped that such a trial will lead to a more adequate conception of the processes at work in the lower levels of the atmosphere and a deeper appreciation of three-dimensional weather.

I am indebted to the Chief of Bureau and various members of the Weather Bureau staff for much helpful discussion and criticism and for assistance in gathering data. Dr. S. Fujiwhara and Dr. R. Sekiguchi contributed valuable information concerning the use and construction of free-air pressure charts in Japan. My wife spent many hours patiently assisting in the more tedious portions of the work—conversion of units, tabulation, and pressure reduction. To all these I wish to express my sincere thanks.

C. L. M.

Washington, D. C., *July 20, 1922.*

[1] A thesis presented to the Faculty of Graduate Studies, George Washington University, in part satisfaction of the requirements for the degree of Doctor of Philosophy.

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Part I.—THE HISTORY AND PROBLEMS OF AMERICAN BAROMETRY.

INTRODUCTION.

Since its inception, the principal function of the weather service in the United States has been the forecasting of weather; and the forecaster has based his predictions, in large part, upon the synoptic weather map. It is obvious, therefore, that the accuracy of the forecast is dependent, in no small measure, upon the truthful depiction of the distribution of the meteorological elements. But, of all these elements, there is none whose correct representation is more essential than that of barometric pressure, for the relationship is close between pressure and the distribution of temperature, wind, and precipitation. Hence, if the pressure be not accurately represented, the forecaster may be misled; or, if he *is* aware of the falsity of certain isobaric configurations (as he often is in considering the western United States), it is incumbent upon him to allow for them as best he can when a host of other details are demanding his attention. For this reason, if for no other, it is imperative that the system of pressure reductions be brought, as soon as practicable, into its most accurate and satisfactory form. Thus, the history of barometric reduction in the United States is the record of successive attempts at improvement.

But, if the pressure distribution is that which demands the greatest accuracy of representation, it is at once the one which affords the greatest difficulty. Wind, temperature, and precipitation appear on the weather map just as they are observed. The barometric reading, however, is not alone dependent upon the march of pressure formations in the atmosphere, but is a function of the station altitude also. Thus, one barometric reading is not comparable with another at some other station unless the two are at precisely the same level,—instrumental and other corrections being equal. As a consequence of this relation between altitude and pressure, it is necessary to reduce the station pressure to some datum level upon which the effect of altitude differences does not appear. While the theoretical relations involved in the reduction of pressure from one level to another are well understood, there are certain considerations of a practical nature which render the selection of a suitable reduction level a problem of considerable difficulty.

The datum level at present in use is mean sea level, and the methods involved in the reduction, at least in the United States and Canada, are those devised by Bigelow about 20 years ago.[1] This work, comprising a huge volume of tables, charts, and discussion, recounts in considerable detail the various methods or steps which preceded it. Without going into great detail with respect to these steps, it will be instructive from an historical standpoint to examine them and observe the evolution of ideas concerning this important subject.

BAROMETRY IN THE UNITED STATES.

The Guyot tables.—The first reductions of station barometric pressure observations to sea level were performed by means of the Guyot tables.[2] The method consisted in reading from the Tables XIX or XIX′ (metric or English) the height of a column of air corresponding (1) to a certain barometric interval, a millimeter, or a tenth of an inch, of mercury, at station pressure and temperature; and (2) the same interval at approximate sea-level pressure and a temperature computed for sea level from an assumed gradient of 1° C. per 185 meters. The mean of the two values thus obtained was divided into the altitude of the station and the result represented a certain number of millimeters or tenths of an inch that should be added to the station pressure in order to obtain the pressure at sea level. Being at the outset an extremely rough and approximate method, it was rendered unserviceable by the practice of the Signal Service of using surface conditions only instead of making some effort to secure a temperature argument that might have represented an air column *had there been one.* The result was that, in the plateau region of the West, the fictitious isobars were of a migratory character that rendered them wholly useless for forecasting. Indeed, the isobars in that region were not even drawn on the daily map.

This method of reduction was used by the Signal Service from 1870 to June 1, 1881, when a method of monthly constants was adopted.

The Abbe-Upton monthly constants.—A complete discussion of this method of reduction, which represents the initial work of Upton and a revision by Prof. Cleveland Abbe,[3] reveals the fact that the shortcomings of the method were realized but that it represented a distinct advance over the method in use up to that time. The monthly constants consisted of a table for each station for the 12 months, containing a certain pressure correction to be applied to the observed barometric reading *regardless of local conditions.* They were computed from a temperature record of only two years and, in some

[1] Bigelow, Frank H.: Report on the barometry of the United States, Canada, and the West Indies. *Report of the Chief of the Weather Bureau, 1900-1901*, Vol. II.

[2] Guyot, Arnold: *Tables, meteorological and physical, prepared for the Smithsonian Institution*, 3d ed. Washington, 1859. Cf., pp. D-88-93.

[3] Abbe, Cleveland: Appendix 61, *Report of the Chief Signal Officer*, 1882, Part 1, pp. 826-846.

cases, for stations where the altitude of the barometer had been but imperfectly determined. The constants were based upon a discussion of the variation of temperature with altitude, latitude, and longitude, the temperatures used being those of the stations themselves, since no free-air soundings were then available. It has been shown since that such gradients were quite erroneous and that station surface temperatures were unreliable as substitutes for free-air data; but, while having the merit of being an attempt in the proper direction, the method, as Bigelow says, "gives a sort of average barometric reduction * * * yet avoids the very essence of the plateau problem which it is desirable to elucidate."

In the period from June 1, 1881, to July 10, 1886, at which time the method was abandoned, there were six revisions of the constants, the last two of which were made by Ferrel.

Ferrel's tables.—Ferrel's system of reductions may be regarded as the most scientific treatment of the problem devised up to that time. Bigelow remarks that the exposition of the method [4] is, unfortunately, obscurely written and that this fact had much to do with its ultimate displacement by what he [Bigelow] considered a less valuable method. However, the Ferrel system took into account the effect of diurnal variations of station temperature upon the reduced pressure and introduced, as a temperature argument, the mean of twice the current and the two preceding daily observations (this at a time when observations were taken thrice daily, at 7 a. m., 3 p. m., and 11 p. m., 75th meridian time), plus a correction which was a function of the station elevation and an assumed temperature gradient.

Ferrel introduced, moreover, a plateau correction factor designated by him $C\Delta\theta H$, in which C was a constant derived from a least square analysis of the data,—its value was 0.001; $\Delta\theta$ was the departure from the annual mean temperature, and H was the altitude in thousands of feet. This plateau factor is of importance because it was extensively employed by Bigelow, as will be shown later. These considerations show that Ferrel had a correct comprehension of the problems of plateau barometry. The computation of the temperature argument was cited as a practical obstacle because of the valuable time consumed at the observation time; but it seems that the obscure explanation, with the consequent failure of observers to understand it fully, was the real occasion for yielding to the Hazen system that followed.

The Ferrel reduction method was in force from July 10, 1886, to July, 1887.

Ferrel and Hazen methods combined.—Before Ferrel published his method in 1886 another system had been proposed by H. A. Hazen, but Ferrel does not mention it, nor does he make use of any of the principles involved. Hazen's paper appeared in 1882,[5] and in July, 1887, the Hazen reductions were first employed at some stations of the Signal Service. This situation continued for almost four years, Hazen's tables coming into greater favor and Ferrel's at the same time losing ground, until in January, 1891, the latter method was completely abandoned and the former adopted at all stations.

The Hazen reductions.—If one were to accept without question the view of Bigelow upon the wisdom of the change from the Ferrel to the Hazen reductions, one should necessarily regard it as a most unfortunate occurrence; but the growth of the new tables in the favor of the forecasters and observers of the time bespeaks strongly the fact that, whatever the scientific deficiencies of the method, there was much that was valuable from a practical standpoint. Even at the time of the present writing one hears occasionally words of commendation of the Hazen system from those who were members of the Signal Service at that time.

Scientifically, the difficulty was with the temperature argument, just as it was in previous methods and just as it is to-day in the method devised by Bigelow. The conclusions of Hazen were based largely upon a study of temperature and pressure changes occurring simultaneously between the summit of Mount Washington, N. H., and the lower stations, Burlington, Vt., and Portland, Me. He also employed data obtained by Guyot in the Swiss Alps. The weakness of the conclusions lies in his lack of faith in the Laplacian hypsometric formula based upon the failure of the observed values of the mean temperature of the air column (means of temperatures at the upper and lower stations named above) to agree with that obtained by inverting the Laplacian formula and solving for the temperature term. In view of present-day knowledge of temperature gradients and the difference between free-air temperatures and temperatures at surface stations at the same elevation, this discrepancy is not surprising. Hazen summarizes his conclusions as follows:

> I have attempted to show, first, that there are objections to the determination of the mean temperature of the air column by the inverted formula of Laplace; second, that the temperatures seem to diminish according to an arithmetical progression as we ascend above the earth's surface, and hence that the hypothesis that the mean of the observed temperatures at the base and summit of a mountain will give the true mean temperature of the air column is valid; and, third, that while the change in air pressure at the summit of a mountain, as brought about by the varying temperature of the seasons, is uniform the effect of the change of temperature upon the air column during the day hours is inappreciable, but is very manifest when we consider the temperature changes from one day to the next.

His case is further weakened, scientifically, by attempting to apply to the plateau conclusions reached from data obtained on an isolated mountain peak.[6] To overcome

[4] Ferrel, William: Report on reduction of barometric pressure to sea level and standard gravity. *Report of the Chief Signal Officer*, 1886, Appendix 23, pp. 221-232.

[5] Hazen, H. A.: The reduction of air pressure to sea level at elevated stations west of the Mississippi River. *Professional Papers of the Signal Service, No. VI.* Washington, 1882.

[6] Cf. Hann, J. von: *Lehrbuch der Meteorologie*, 3d Ed., pp. 126-127.

certain persistent isobaric irregularities associated with reductions at certain stations, obviously local effects, Hazen made arbitrary corrections of a "cut and try" nature to the observed temperatures at those stations. His final tables consisted of (1) a certain general table containing pressure increments to be added to observed pressures to obtain sea-level pressure, with arguments of mean temperature of the air column and altitude; and (2) a small correction table, peculiar to each station, containing local corrections to the reduced pressure as a function of the mean temperature of the preceding 24 hours. It should also be remarked that in computing the general table the value of pressure at sea level was taken to be 30 inches, thus rendering his solution that of a special case.

It is clear that the faults so vigorously pointed out by Bigelow are, indeed, genuine deficiencies in the method; but the fact that the horizontal sea-level pressure gradients determined by it were said to be satisfactory to the forecasters, defends it, to a slight degree, in spite of its bold empiricism.

Bigelow's conclusions from the three preceding methods.—Before passing to the further steps in the history of American barometry, it is worth while to present the concise and reasonable conclusions of Bigelow regarding the three methods outlined above, conclusions which afforded a basis or groundwork upon which he proceeded, after a while, to build the system of barometry at present in use. These conclusions are as follows:[7]

(1) That the Upton, Ferrel, and Hazen systems are too much specialized, and do not possess the flexibility required by the plateau barometric phenomena; (2) that the gradient system connecting the surface and the mean air column temperature must be carefully determined under the extreme as well as under the mean conditions prevailing in the atmosphere; (3) that a special correction must be applied for the plateau stations in order to reduce the Laplacian tables to barometric reductions in the elevated regions west of the Mississippi Valley. The second and third conditions interact upon each other locally, and constitute the peculiar difficulty in making up general tables which will give us balanced, smooth-gradient barometric lines at the sea level under the plateau.

The Hazen tables were replaced by the Bigelow system at the beginning of 1902, but, in the meantime, there was another, unpublished, attempt at solving the problem.

Morrill's tables.—The tables devised by Park Morrill were the outcome of the deliberations of a board consisting of Messrs. Abbe, Marvin, Hazen, Henry, and Morrill. The board, in general, desired to improve upon the empirical method of Hazen, although it is stated that Professor Hazen filed a minority report. This board was convened on May 11, 1895.

The Morrill tables provided a flexibility of temperature argument, using the gradients 0.150° F. per hundred feet of elevation in winter, 0.250° F. in summer, and 0.200° F. in spring and autumn, and for the annual mean. This was, of course, an improvement over the constant gradient employed by Ferrel. But, while there was general recognition of the fact that local modifications must necessarily be made to the Laplacian formula at various plateau stations, the first barometry board did not undertake to investigate the complicated problem of local topographic and other peculiarities that might exercise an effect upon station temperatures. The Morrill tables had the disadvantage of being too complicated for rapid use on stations, and, for that reason, probably would never have come into general use.

The majority and minority reports of the first barometry board were submitted to Professor Bigelow for review and discussion, and this led to the formation in December, 1896, of a second barometry board consisting of Maj. H. H. C. Dunwoody, Professor Bigelow, and Mr. Morrill. Only Professor Bigelow remained to finish the work, however, owing to Major Dunwoody's military assignment and Mr. Morrill's death. The well-known *Barometry Report* of Bigelow was the result.

Bigelow's system of barometric reductions.—The unnecessarily ponderous bulk of Professor Bigelow's report, combined with the apparent complexity of the discussion and the forbidding multiplicity of charts and tables, have contributed almost entirely to the lack of general understanding of the basic principles of the work. It is not within the scope of this paper to present a detailed analysis or a comprehensive critique of this important volume; it is rather the purpose here to set forth simply and directly certain fundamental propositions employed in Bigelow's reductions and to reveal what appear to be merits or fallacies in the various steps of the author's development.

First, an attempt was made to secure an accurate sea-level distribution of mean temperature (whatever that may mean!) in the plateau region. This was accomplished by (1) selecting 37 points so located that the several stations in the immediate neighborhood of each could be averaged together and the average altitude, temperature, and pressure considered characteristic of the individual points; (2) grouping these 37 points by altitude, i. e., by altitude zones of 1,000 feet depth; (3) reducing these temperature means by a gradient of 0.300 °F. per hundred feet of elevation to the middle of each zone, to 500 feet, 1,500 feet, 2,500 feet, etc., above the level of the sea; (4) reducing these temperatures to 18 chosen intersections of meridians and parallels of latitude; (5) drawing an altitude-temperature curve for each of these points and extrapolating to sea level; (6) working successively from vertical to horizontal distribution of temperature to obtain, eventually, a "system of balanced isothermal lines" at sea level. These steps, according to Bigelow, enable one to "begin on the sea-level plane at the geographical position of the station and by interpolation ascend to any altitude we please with the assurance that we are dealing with substantial data." It should be noted that, in spite of Bigelow's confidence in these data, they are, at the end, far removed from the original source and have experi-

[7] Loc. cit., p. 51.

enced no little smoothing. Moreover, the treatment of station temperatures as if they were free-air temperatures and the use of a constant gradient are also sources of error. Since, however, the reduction by means of the constant gradient is, in no case, through a greater distance than 500 feet, the resulting error is perhaps inconsequential.

Adjusted vertical temperature curves for each 10° of longitude and each 5° of latitude throughout the plateau were obtained and from them normal monthly vertical gradients and mean temperatures of the air column derived.

The monthly mean charts of sea-level pressure which appear to occupy a place of fundamental importance in the treatise, owing to their relation to the discussion of abnormalities at certain stations, were determined by two approximations. First, maps of sea-level pressure were made by reducing the normal station pressure to sea level by means of the mean temperature of the air column obtained as described above. Such maps revealed persistent irregularities or departures from the "balanced" system of 260 stations. It should be added that the factor $C\Delta\theta H$, mentioned in the discussion of Ferrel's work, was applied to all stations in this first approximation.

The differences between these reduced pressures and the pressures indicated by the map were tabulated and designated ΔA. It was suspected that such discrepancies might be the result of incorrect determinations of the station elevation, but investigation showed that this did not sufficiently account for the magnitude of ΔA. It was an illusory discrepancy and one that resisted explanation. Bigelow said that it might be, in addition to erroneous station altitudes, (1) a permanent topographic effect, (2) a local gravity variation, (3) a variation in the plateau reduction constant of Ferrel, or (4) erroneous mean station temperature. Not being able to explain it satisfactorily, he simply removed the troublesome quantity and corrected the reductions accordingly. At certain stations it was necessary to charge further discrepancies to anomalous values of θ, and the temperature argument was correspondingly adjusted. Station normals were now recomputed, the above corrections being included, and the result was a series of monthly normal sea-level pressures, which were adopted as standard.

There is the further and more interesting problem of the actual day-to-day pressure reductions. The problem, from Bigelow's standpoint, divided itself into two distinct phases, (1) that dealing with low-surface temperatures, and (2) that concerned with high-surface temperatures. Each of these was given a different treatment and will, therefore, be discussed separately.

The reasoning Bigelow used with reference to the cold-wave conditions in the plateau is especially interesting. What is really needed in the weather map is the actual distribution of pressure and not a fictitious distribution upon some level thousands of feet below the level of the ground. How, then, may the pressure occurring over half a mile above sea level be shown on the sea-level chart? Bigelow reasoned that if the average height of the plateau is 3,500 feet the distribution of pressure appearing on the sea-level map should be the same as that at 3,500 feet. Accordingly 50 dates upon which cold-wave conditions prevailed in the plateau were carefully selected and maps were drawn for each of the dates for the 3,500-foot level, a reduction that could be performed with fair accuracy owing to the short air columns. Now, having the distribution of pressure that he desired to reproduce upon the sea-level map, it was only necessary to erase the numbers of the isobars of the upper level and join them up with the sea-level isobars to the east and west of the plateau, invert the hypsometric formula and solve for the temperature argument that would obtain under such conditions of upper and lower pressure. This rather astonishing procedure seems sufficiently important to warrant quoting from Bigelow concerning it. On page 774 of the *Barometry Report* we find the following:

> Furthermore, besides drawing the isobars on the 3,500-foot plane the low-level stations in the Pacific districts and also on the Rocky Mountain slope to the Mississippi Valley—that is, west and east of the plateau—were reduced to sea level. Through these low-level stations the isobars were drawn independently of those on the 3,500-foot plane. Next we assumed that the configuration on the 3,500-foot plane is the one which should appear on the sea level, and this was accomplished by abandoning the numbering of the lines on the 3,500-foot level and joining them up with the lines on the sea level one by one, as was very easily done. Then the depressed configuration was renumbered from the sea-level isobars. The result is a sea-level configuration reproducing the natural one at the mean height of the plateau stations in connection with the low-level isobars, about whose reduction to sea level no question can be raised.

On the page following this passage a map is given in which the 3,500-foot isobars are shown in red and the sea-level isobars in black. Concerning the junction of the two systems he says, on page 775: "The two systems flow together harmoniously and generally with very little disturbance of the lines at the junctions of them."

The values of θ thus obtained were classified by 10° groups of surface temperatures and were ready to incorporate into reduction tables.

The second part, having to do with high temperatures, was handled by reference to the difference between surface temperature and sea-level temperature as derived from the first set of maps mentioned above. As a first approximation (cf. pp. 781–784) the relation

$$\theta = (t + t_0)/2$$

was employed, θ being the mean temperature of the air column, t being the surface temperature, and t_0 being the sea-level temperature. A mean value was obtained for each month.

These data being plotted on a set of axes whose horizontal argument was θ and whose vertical argument was θ–t, it was possible to draw a smooth curve from which new values of θ, now designated (θ), were read off for various values of θ–t. With (θ) for a temperature

argument, the station pressure was reduced to sea level, using what was deemed a satisfactory value of the vapor pressure. The reduced pressure corrected for the plateau by Ferrel's plateau factor gave the sea-level pressure B_0. These values of B_0 were plotted for all stations and the isobars smoothly drawn. New sea-level values were now interpolated from the map and designated B_m; by knowing the effect upon sea-level pressure of a change of 1° in the mean temperature of the air column, a quantity called ΔB, it was possible to arrive at an additional thermal quantity $\Delta\theta$ by dividing $(B_m - B_0)$ by B. If, now, $\Delta\theta$ is added to the curve of the first approximation, a new series of points will result, which, when smoothed, will yield the new quantity $(\Delta\theta)$. A new reduction to sea level is performed with the temperature argument $(\theta) + (\Delta\theta)$, the values are plotted again and the interpolations made as before. The outstanding differences are applied to the station normal pressures and the value B_n obtained. This is, indeed, a veritable labyrinth of approximations and smoothings, requiring perseverance upon the part of the reader. In order to make the process somewhat clearer, the following portion of Bigelow's Table 52 and his diagram "Chart 35" (opposite p. 782), here Table 1 and Figure 1, are reproduced.

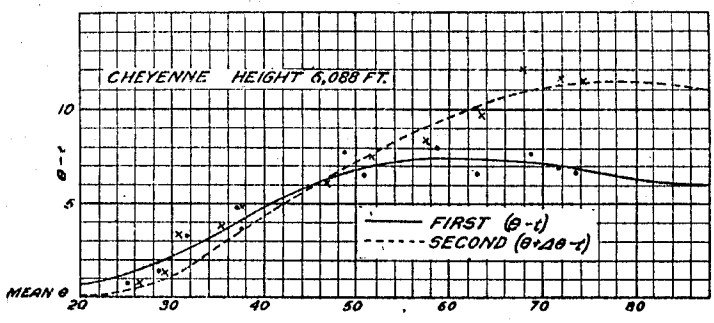


FIG. 1.—Bigelow's method of determining the relation between θ and t. (Adapted from chart 35, page 782, of the *Barometry Report*.)

TABLE 1.—*Portion of Bigelow's Table 52, showing the computation of the second approximation* $(\theta+\Delta\theta)$.[1]

[Cheyenne, height, 6,088 feet.]

		January.	February.	March.	Line.
Surface	t	25.0	27.3	32.8	1
Sea level	t_0	26.4	29.9	42.3	2
Mean	θ	25.7	28.6	37.6	3
Difference	$\theta-t$	0.7	1.3	4.8	4
Mean	(θ)	26.6	29.3	35.6	5
Sea level	B_0	30.041	30.009	29.952	6
First map	B_m	30.050	30.020	29.950	7
	B_m-B_0	+ .009	+ .011	− .002	8
	$+1°\Delta\theta=\Delta B$	− .012	− .012	− .012	9
	$\Delta\theta$	−0.8	−0.9	+0.2	10
Adopted	$(\Delta\theta)$	−1.0	−1.0	−0.4	11
	$(\theta)+(\Delta\theta)$	25.6	28.3	35.2	12
	B_0	30.056	30.024	29.955	13
Second map	B_m	30.050	30.030	29.960	14
	B_m-B_0	− .006	+ .006	+ .005	15

[1] Bigelow's tables included the entire year. This table is restricted to the first three months since its purpose is simply to illustrate Bigelow's method.

For the reader's convenience, the following synopsis of the symbolic relations involved in the second column, together with reference to the line in Table 1 and to the drawing, Figure 1, which is copied from Bigelow, except as modified by the insertion of points marked by dots and crosses, is given below:

Line 3, $\theta=(t+t_0)/2$. Values of θ (ordinates) are plotted against $\theta-t$ (abscissæ) throughout the year, in dots.

Line 5, (θ)=smooth curve drawn through these dots.

Line 10, $\Delta\theta=(B_m-B_0)\Delta/B$. Values of $\Delta\theta$ were added to $(\Delta\theta)$ for each month and plotted by crosses.

Line 11, $(\Delta\theta)$=smooth curve drawn through these crosses.

This indicates, as concisely as seems practicable, the method by which the relation between the mean temperature of the air column and the surface temperature was determined for the higher surface temperatures. Now, combining the results obtained by this method with those obtained by the previously explained device for low temperatures, it was possible to include in the station reduction tables a certain temperature factor applicable over the entire range of temperatures likely to occur at a given station. The station reduction tables as used to-day contain sea-level pressure for the arguments of station pressure and a temperature that is the mean of the current and the preceding 8 o'clock temperatures. In this way the station observer need not concern himself with the probable mean temperature of the air column.

While it is undoubtedly true, as Bigelow says, that the plateau problem is difficult, one can not but be impressed with certain questionable procedures that have found their way into the work in spite of frequent protestations of their validity. A certain amount of smoothing is necessary in handling meteorological data, it can not be denied, yet there is a danger of too much smoothing, a danger in trying to make natural phenomena conform to a smooth standard of behavior which the worker, in his enthusiasm, may visualize.

It is too much to say that this *has* been done in the *Barometry Report*, yet it seems that the charge of empiricism which the author so vigorously turns upon the Hazen reductions might well be focused upon such spots in the *Barometry Report* as the doing away with the discrepancy ΔA and the deliberate projection of the 3,500-foot isobaric distribution upon sea level by a mere change of the numbers of the isobars. Whatever may be the validity of these steps, it appears that the whole system of plateau reduction is suffering from a certain disorder—perhaps to a smaller degree than it did in the hands of earlier students, but, nevertheless, to a degree which causes discomfort to those who must forecast from the maps. The fact of the great distance between the surface of the earth and the level of the sea in these districts, however, suggests that, as long as sea level is retained as a reduction level, the disorder will be practically irremediable.

THE DIFFICULTIES OF SEA-LEVEL REDUCTION.

Common characteristics of the several methods.—With these summaries of the several methods of reduction before one, it is possible to view them in perspective, as

it were, and see what characteristics were common to each. In the first place we see that sea level was the universal reduction level. This was probably the result of the lack of knowledge of free-air conditions in those early days. Had a real air column been involved, it would have been difficult to satisfy the temperature argument; but where the air column was fictitious there was greater latitude and freedom of assumption. In fact, it was possible to assign to the air column any temperature that seemed to satisfy the requirements for smooth isobars. This idea has been perpetuated, and each succeeding method of reduction has regarded the level of the sea as a fundamental reduction surface, thus retaining a feature which, in the plateau, has always been regarded as unsatisfactory until a day when aerological data are quite plentiful.

Secondly, the question of what temperature argument to use has been the point about which most of the contention has occurred. Students have universally recognized the physical absurdity of assigning some temperature value to a reduction column that has no reality, for it is impossible to say with certainty what the free-air temperature would be at a given point if the continent were removed. In fact, no attempt has been made to say that this temperature value *does* represent that. The treatment of the temperature argument has become a contest in the manipulation of data from which Bigelow, with his undeniably ingenious devices, has emerged the victor.

Thirdly, there were residual errors—mysterious quantities that asserted themselves at various stations in the plateau and elsewhere. Ferrel recognized them and tried to do away with them by making corrections; Hazen found them lurking in his tables and with persistent effort subtracted a little here and added a trifle there until his isobars were fairly smooth; Bigelow discovered them also and taxed his ingenuity to explain them, but ended by adopting certain of Ferrel's corrections and devising some of his own. *In this way the skeleton has been kept in the closet until it has been nearly forgotten.*

These three points, then, suggest themselves as the outstanding common features of the barometry methods—the heritage of sea level as a reduction level, the inherent physical difficulty of satisfying the temperature argument, and the difficulty of trying to obliterate certain irritating and persistent discrepancies. These last two are children of the first, and as long as efforts are made to reduce to sea level they will be lively participants in the discussion.

The plateau temperature.—It will be seen from the sketch of Bigelow's method that his manner of dealing with the temperature question is clever, however encumbered with difficulties. The tables are so computed that the plateau temperature correction (additive to the surface temperature argument) is already included, and the observer needs not think of it in making his reduction. This correction varies only with surface temperature. It is always higher than the surface value to which it corresponds or, in other words, the differences between the mean temperature of the air column and the surface temperature is always positive, a conclusion that kite data have proved untenable in the free air. When the morning temperature argument for the surface is calculated, the current temperature is added to the temperature 12 hours preceding and the sum divided by 2. The resulting value is, therefore (assuming a normal diurnal march), higher than the current value. If the evening observation is considered, the mean is lower than the current observation; but at either time the temperature of the plateau column is assumed to be higher. The diurnal march of temperature in the free air permits of no such conclusion, for while the mean temperature in the late afternoon and early evening *should* be higher than the temperature at a certain elevation in the free air morning observations at nearly all aerological stations show an inversion of temperature often effective, especially in winter, as high as stations in the plateau region. In such a case the mean temperature of the air column is likely to be lower than that of a point in the free air within these altitude limits.

The surface temperature.—In addition to such discrepancies as may occur in the plateau temperature, there are serious errors introduced by the irregular march of temperature at the surface. These are errors to which the deficiencies of the present plateau map are usually attributed. They are the result, in the main, of chinooks, of masses of cold, stagnant air captured in topographic basins, of peculiar radiation effects, or of other phenomena resulting from topographic irregularities, all of which abound in this region. The presence of "reduction LOWS" and "reduction HIGHS" is well known to those familiar with the weather map. It is not necessary to go into detail in pointing out their origin. A little calculation shows the effect upon sea-level pressure of the irregular diurnal temperature march.

For instance, in the case of a station whose altitude is 1,500 meters, let us assume that between the evening and morning observations, i. e., during the night, the station pressure rises 5 mb. It is found that this rise will be reproduced on the sea-level map if (to cite a specific case) the temperatures at three consecutive observations beginning with the morning observation of a certain day are $-13°$, $7°$, and $-9.8°$ C. If during the night there is a variation of the diurnal march so that the three temperatures are $-13°$, $7°$, and $5.4°$ C., the 5 mb. rise of pressure at the station will be completely obliterated at sea level.

It is possibly true that the effect would be local and might be easily recognized; but smaller effects, which occur more often, might give rise to abnormally steep or slight horizontal pressure gradients on the sea-level map, and these would be more difficult to recognize and more misleading. This would be especially true in cases where effects of opposite sign in surface temperature distribution came into play, as, for example, stagnation with strong nocturnal radiation in one place and

a chinook in another several hundred miles distant. It should not be necessary for forecasters and students constantly to be making allowances for such effects. The map should be correct.

The possibilities of free-air reduction.—The whole difficulty lies, from a physical standpoint, in the selection of of sea level as a reduction level. If we are to have accurate maps of the plateau region, we must get away from sea level. Prof. Cleveland Abbe recognized this in 1882 and said:[8]

> If the reduced pressure agrees with the isobars based on much lower stations, the reduction is considered to be plausible; but over an extended plateau this criterion fails, and, in fact, for all cases the only natural method of reduction would seem to consist in an attempt to reduce upward through the actually existing atmosphere (whose temperature and moisture can be observed) to a uniform altitude; but even in the case of the fluctuations of pressure, temperature and moisture will render the problem sufficiently difficult.

But, while the characteristic difficulties of sea-level reduction are such as to set up a permanent and forbidding barrier, the question of reducing to upper levels becomes more and more promising with the accumulation of aerological data. The merit of free-air pressure maps lies in the fact that they are representations of *real* conditions. The mean temperature of the air column, that troublesome quantity which has afforded so much difficulty in the past, is now an observable quantity, as is the moisture.

Not only do we owe it to the plateau region to devise more trustworthy pressure reductions but also to the newer problems of aeronautical meteorology, the forecasting of free-air winds for the use of aviation. It is well known that the sea-level distribution of pressure can be relied upon as an index to upper winds only within narrow limits a few hundred meters above the earth's surface even in low, relatively smooth country like that east of the Mississippi River. Below this level, where sea-level gradients may be assumed to hold, surface friction deflects the wind and retards speed; above it, the distribution of pressure may depart from that at lower levels and thus produce a different circulation. Hence if we may know this upper pressure we may foretell the winds with greater certainty.

For these two reasons, (1) that we may improve plateau barometry and (2) that we may perfect aeronautical barometry, we should make some attempt to investigate the possibilities of free-air reduction. The field of this paper has been restricted to the eastern United States because that region is the source of practically all the available aerological data; hence it is the aeronautical phase that will be stressed. But in the background, awaiting its hearing, is the plateau problem.

[8] *Loc. cit.*, p. 826.

Part 2.—BAROMETRIC HYPSOMETRY AND MAPS OF THE FREE AIR.

THE HYPSOMETRIC FORMULA AND ITS TERMS.

Historical note.—From the day, in the autumn of 1648, when Perier, brother-in-law of Pascal, aided by the civil and ecclesiastical authorities of Clermont, ascended the Puy de Dome with a mercurial barometer and confirmed Pascal's suggestion that the mercury must stand lower on the mountain top than in the valley, the problem of the rate of decrease of pressure with increase of altitude has been of keen interest to investigators. The early volumes of the *Philosophical Transactions* abound with quaint reports of the studies of Boyle, Hook, Beal, Halley, Derham, and others, upon this important problem. Halley, for instance, believed that the equation expressing the altitude-pressure relation was hyperbolic in form; Robert Hook suspected that it would be worth while "to inquire if the mercury do not shrink and swell with cold and heat"; but it was Deluc, in 1772, who first approximated the Laplacian hypsometric formula. Deluc's equation is as follows:

$$dh = (\log B - \log b)[1 + (c - 16.75)/215],$$

in which dh is the difference in height of the two stations in *toises* (6.3946 feet), B and b are the readings of the two barometers in French inches (1.0657 English inches), and c is the mean temperature of the air column (Reaumer scale, usually) or, more strictly, the mean of the temperatures at the two stations.

The formula of Deluc was subjected to scholarly criticism by Sir George Shuckburgh about 1778. Deluc's equation seemed to give values consistently small, and Sir George was not favorable to the logarithmic method. He recognized, moreover, the necessity for reduction to a standard temperature—he advocated 31.24° F.—and suspected, but could not decide concerning, the necessity for a latitude correction. He gave the following short equation for the difference in height between two stations:

$$dh = 30\alpha\beta/A$$

where α is the difference of the two barometers in tenths of an inch, β is a value representing altitude change per tenth of an inch at a given temperature, and A is the average height of the barometer at the lower station, also in inches.

About the beginning of the nineteenth century, however, Laplace subjected the problem to mathematical analysis and derived the formula, which, with certain modifications, is the one in use to-day.[1]

The hypsometric formula.—The hypsometric formula has been so frequently discussed that, for the present purpose, a simple statement of it must suffice.[2] Instead of expressing the difference in altitude between the two stations as a function of the barometric pressure at the two stations, the mean temperature of the air column, and the vapor pressure it is necessary to express the pressure at one of the levels as a function of the remaining elements, including the difference in altitude. The ordinary statement of this relation, in metric units, is as follows:

$$\text{Log } b = \log B - Z/[18400(1 + 0.00367\theta + 0.378\ e/b)]$$

in which b and B are the respective barometric readings at the upper and lower stations; Z is the length of the air column; θ is the mean temperature of the air column, and $\frac{e}{b}$ is the ratio of the partial pressure of the water vapor to the total pressure.

Doctor Humphreys has given the amount of error resulting from certain errors in the various terms, and it is seen that by far the greatest errors arise from incorrect values of θ.[3] The effect of water vapor, however, is not negligible and, except as otherwise stated, has been considered in what follows.

It is convenient to regard the vapor pressure effect in terms of the equivalent effect of temperature. This is easily accomplished by the equation

$$\Delta\theta_w = 0.378\frac{e}{b}/0.00367,$$

$\Delta\theta_w$ being the temperature effect in the air column equivalent to that of the existing water vapor. Hence, upon substituting in the first equation, it becomes:

$$\text{Log } b = \log B - Z/18400\ [1 + 0.00367\ (\theta + \Delta\theta_w)]$$

In future references to θ the quantity referred to will be the *virtual* temperature, $\theta + \Delta\theta_w$,—that is, the mean temperature of the air column including the equivalent thermal effect of the water vapor present.

It will be worth while to consider briefly the various terms that enter into the equation in order to see how

[1] Laplace: *Mécanique céleste*, Liv. X, Ch. IV; Bowditch's translation, Vol. IV, pp. 565–572.

[2] Cf. Abbe, Cleveland: *loc. cit.*, pp. 829–834; Ferrel, William: Barometric hypsometry and reduction of the barometer to sea level. *Meteorological Researches*, Pt. III, Appendix 10, *Coast and Geodetic Survey Report for 1881*, pp. 2–46; Ruhlmann, Richard: *Die barometrischen Höhenmessungen und ihre Bedeutung für die Physik der Atmosphäree* Leipzig, 1870; Plantamour, E.: *Mesures hypsométriques dans les Alpes exécutées à l'aid. du baromètre.* Genève, 1866; Williamson, R. S.: On the use of the barometer on surveys and reconnaissances. *Professional Papers of the Corps of Engineers of the Army*, No. 15, 1868; Whitney, J. D.: *Contributions to barometric hypsometry: with tables for use in California.* Cambridge, 1874; Bigelow, F. H.: *loc. cit.*, pp. 57–72; *Smithsonian Meteorological Tables*, 4th Ed., pp. xxxix-xli; Humphreys, W. J.: *Physics of the air*, Philadelphia, 1920, pp. 61–70. These are only a few of the available discussions of the hypsometri formula.

[3] *Loc. cit.*, pp. 66–67.

they are measured and to learn of their physical significance. These terms are B, h, $\frac{e}{b}$, and θ and will be considered in order.

Surface pressure.—The mercurial barometer is subject to certain errors which are inherent in the instrument or follow as a result of its position. The observed reading of the height of the mercurial column must be corrected for these errors before the value B is obtained. The instrumental errors are owing (1) to capillarity, the depression of the mercurial column resulting from the small bore of the glass tube; (2) to imperfect vacuum above the mercury; (3) to imperfect adjustment of the scale; (4) to the effect of temperature upon the scale and the mercury; and, of less importance, (5) to chemical impurity of the mercury, which would result in a variation of density.[4]

Errors of surface pressure, for which there must be a correction in order to make one barometer comparable with another at some distance, are the result of the variations of gravity with altitude and latitude. The former is a very small quantity, small enough to be negligible in ordinary computations involving the lower atmosphere. The latter, however, must be taken into account. The force of gravity equal to 980.665 dynes has been adopted as standard, and all barometric readings are corrected to standard gravity.[5]

The above corrections applied to the observed reading of the station barometer give a pressure value which, when converted into units of force, such as millibars, is called B in the equation.[6]

Length of the air column.—The length of the air column in reducing pressure to upper levels is a function of the altitude of the station above sea level. Station altitudes, or, more specifically, the altitude of the barometer cistern above mean sea level, is, at Weather Bureau stations, accurately determined by some authorized agency, such as the United States Coast and Geodetic Survey or the Engineer Corps of the Army. The value Z is therefore merely the difference between the altitude of the chosen reduction level and the altitude of the barometer, both referred to mean sea level. This quantity is in all cases very accurately known.

Vapor pressure.—The distribution of water vapor in the free air is irregularly variable, especially in the lower atmosphere. Appearing, as it does, in the equation in a ratio with the total pressure, it constitutes a very small quantity when converted into its equivalent thermal effect. Since it is so small and exerts so little influence upon the pressure at upper levels, it is permissible to use monthly means from the data obtained at the several aerological stations in the United States. These values have been determined up to levels much higher than will be required for this paper.[7]

Mean temperature of the air column.—There is scarcely a meteorological element that is more irregularly variable with change of altitude than temperature. The term representing the mean temperature of the air column is, indeed, the "Achilles heel" of hypsometry; it has been the point of greatest vulnerability in methods for reduction downward, and plays an equally conspicuous rôle in methods for reducing upward.

The value of θ that would be ideal may be defined as a mean determined by integrating the current vertical temperature curve throughout the length of the air column under consideration. But this is manifestly impracticable. The equipment necessary for the observation of free-air temperatures can not be provided for the individual stations; and, if it could, the time required for the reduction of observations would render the plan ineffectual for the forecasting of weather. *The present problem, therefore, becomes that of finding some clue, or index, observable at the surface, that will lead to a close approximation of the mean temperature of the air column.* When one considers the almost infinite variety of surface and free-air conditions that bear directly upon the temperature of the air column, the search seems, at the outset, rather unpromising; but, as will be shown later, the way is opened through the use of the surface-wind direction as a basis of classification.

FREE-AIR MAPS BY VARIOUS INVESTIGATORS.

The recognition of the importance of accurate maps of the free air has been a development of the last 50 years. Serious and important studies of dynamic meteorology demanded such charts as aids in the consideration of the general circulation of the atmosphere. These charts were necessarily concerned with average conditions. More recently, however, the question of whether or not daily current charts of the pressure at given levels might be of value in forecasting has been raised with the result that attempts have been made to produce such charts. Some of these attempts will be reviewed.

Teisserenc de Bort.—As far as can be ascertained, the first free-air pressure maps were drawn by Teisserenc de Bort about 1885. These charts [8] showed the mean iso-

[4] Cf. Marvin, C. F.: Barometers and the measurement of atmospheric pressure. *Circular F*, Instrument Division, Weather Bureau, Dept. of Agr., Washington.

[5] The best determinations of the value of the acceleration of gravity are found to be subject to certain variations of an irregular character, and these irregularities are attributed to topographic effects, isostatic compensation, or gravity anomaly. This value, when originally adopted, was supposed to represent the value of g at sea level in latitude 45°, but later determinations show it to be slightly in error. So long as all barometers are reduced to it, it serves just as well.

[6] When the English units are used, the barometric pressure is given in terms of the height of the mercury column in inches, although, as is obvious from the formula, this is not necessary in the computation.

[7] Gregg, W. R.: An aerological survey of the United States. Part I. Results of observations by mean of kites. Mo. Weather Rev. Supplement No. 20, Washington, 1922.

[8] Teisserenc de Bort, Leon: Étude sur la circulation général de l'atmosphère. *Annales du Bureau Central Météorologique de France*, 1885, Part IV, Météorologie général, seconde partie, pp. 35–44. This work contains the original maps discussed above. They have subsequently appeared in many papers and discussions of the question of atmospheric circulation. Cf. *ibid.*: Étude sur la synthèse de la repartition des pressions à la surface du globe. *Annales du Bureau Central Météorologique de France*, 1887, Part I, Memoires, p. C. 13; *Report on the present state of our knowledge respecting the general circulation of the atmosphere.* London, 1893. Hildebrandsson, H. and Teisserenc de Bort, L.: *Les bases de la météorologie dynamique historique-etat de nos connaissances.* Paris, 1900, pp. 213–214, tome II. These charts were drawn on the Mercator projection, but were redrawn by Bigelow on circular projections of the Northern Hemisphere, and appear facing p. 443 of the Report on the international cloud observations. *Report of the Chief of the Weather Bureau for 1898–99*, vol. 2. One of these maps on the circular projection has been published by Prof. C. F. Marvin in The law of the geoidal slope and fallacies in dynamic meteorology. Mo. Weather Rev., October, 1920, p. 578.

baric distribution for January and July at sea level, 1,467 meters, 2,859 meters, and 4,000 meters above sea level. The two irregular altitudes correspond to the altitudes of the two French observatories on the Puy de Dome and the Pic du Midi. They correspond also, according to the author, to the average height of the bases of cumuli in winter and summer, respectively. The 4,000-meter level corresponds to the alto-cumulus level.

Surface data were, of course, fundamental in the computation of the maps. The temperature arguments were computed upon the basis of a January gradient of 1° C. per 200 meters and a July gradient of 1° C. per 160 meters, these gradients being based upon mountain and manned-balloon observations. The author recognized the fact that there must be considerable departures from the computed values in certain places, but contended that the charts probably show quite accurately the relative distribution of normal pressure over the world.[9] Support is given this contention in later writings in the *Bases de la météorologie dynamique*,[10] in which it is said that the mean direction of the upper winds as shown by clouds is not in direct relation to the mean barometric distribution at the surface of the earth, but, in tracing on the same chart these upper currents and the isobars, determined by M. Teisserenc de Bort for the altitude of 4,000 meters, the relation is very satisfactory.

Köppen.—Relative to the question of the form of isobars at upper levels, Köppen, in 1888, contributed an important paper.[11] It presents an ingenious manner of taking into consideration, without computation, the relative effects upon the free-air pressure distribution of the sea-level pressure and surface temperature. Beginning with ideal systems of circular isobars and parallel east-west isotherms, he shows how the free-air isobars may be approximately traced by drawing lines connecting the intersections of the lower isobars and isotherms. He shows the effect of decreasing the distance between isotherms and proceeds to the case of circular isobars and a rather idealized cyclonic distribution of temperature. The last figure gives the free-air isobars determined in this manner for a certain date over the eastern United States and the western Atlantic. These maps show the characteristic shifting of the centers of action in the free air toward regions of lower temperature; but while the device may be considered to have a reasonably sound basis in theory it is not believed that in practice its usefulness would extend beyond that of a hastily drawn sketch map.

Bigelow.—As a part of his *Barometry Report* mentioned earlier, Bigelow attempted to draw day-to-day maps of the pressure distribution at 3,500 feet and 10,000 feet above sea level. He did this for some time, but there is no evidence that the maps yielded results of conclusive value for forecasting. There are at least three reasons why nothing conclusive resulted from the experiment: (1) The maps were not studied sufficiently long to give the necessary experience to the forecaster; (2) the comparison of forecasts from the upper-air maps with those from sea-level charts was not continued over sufficient length of time; or (3) the maps were inherently in error. The first two points lie without the province of this paper, but the third, that dealing with the method of construction, is of especial interest.

The preliminaries of Bigelow's upward reductions consisted in the making of three series of charts showing, respectively, the monthly mean temperature in the United States at sea level 3,500 feet and 10,000 feet. The sea-level temperatures, as previously explained (cf., p. 9), were based upon the extrapolation to sea level of vertical gradients obtained in studying station temperatures in groups. The 10,000-foot temperatures were based upon cloud studies and gradients from European balloon ascensions[12] and kite flights in the United States.[13] The 3,500-foot temperatures were interpolated between sea level and 10,000 feet[14] in the eastern United States and were taken directly from the vertical gradients. Assuming the temperature gradients from which these charts were drawn to be satisfactory (subsequent aerological observations have probably yielded more reliable data), how are these monthly mean temperatures treated in order to use them from day to day?

The following relations were assumed to hold between station temperature and the mean temperature of the air column:

$$t-\theta_1=(t-t_1)/2,$$

and

$$t-\theta_2=(t-t_2)/2,$$

in which t is the station temperature, t_1 and t_2 the normal temperatures on the 3,500-foot and 10,000-foot levels, respectively, and θ_1 and θ_2 the mean temperatures of the air column from sea level to the respective levels.

In this way it was possible to obtain a mean temperature which varied with surface temperature and which could be incorporated into reduction tables with ease. The pressures used by Bigelow for the computation of the monthly *normal* pressures at the two upper levels were those previously obtained for sea level and were not station normals. The reduction tables for day-to-day use were, however, computed on the basis of the equations given above.[15] Perhaps these equations for

[9] In the *Report of the seventh meeting of the International Commission for the Investigation of the Upper Air*, Bergen, 1921, pp. 15–17, appears an abstract of a paper presented by Sir Napier Shaw, in which he discussed the distribution of pressure and other elements in the free air over the Northern Hemisphere during the month of July. It is understood that Sir Napier has drawn the free-air isobars upon concentric glass hemispheres representing different levels, thus providing a graphic means of studying the variations with altitude.

[10] Hildebrandsson, H: Sur la direction moyenne des courants superieurs de l'atmosphère au-dessus de la surface terrestre. *Memoires, Congres météorologique international*, Paris, 1889; and Über den Werth der Messungen von Zugrichtung und Höhe der Wolken für die meteorologische Wissenschaft. *Archiv der Deutschen Seewarte*, 1891, No. 5.

[11] Köppen, W.: Über die Gestalt der Isobaren in ihrer Abhängigkeit von Seehöhe und Temperatur-Verteilung. *Meteorologische Zeitschrift*, December, 1888, pp. 470–481.

[12] Bigelow, F. H.: Report on the international cloud observations. *Report of the Chief of the Weather Bureau, 1898–99.*

[13] Frankenfield, H. C.: Vertical gradients of temperature, humidity, and wind direction. *Weather Bureau Bulletin F*, Washington, 1899.

[14] See *Barometry Report*, p. 418.

[15] *Ibid.*, pp. 638–639.

determining the mean temperature of the air column may justly be criticized as being insufficiently flexible to account for the various and frequent irregularities known to exist in the vertical temperature gradient. But it must also be remembered that it is rather hazardous to devise schemes for estimating free-air temperatures in the utter absence of any kind of aerological data. It would seem, nevertheless, that a method which would not carry the data through so many transformations that its original form is hardly recognizable should be available.

In this connection a further difficulty arises in the discussion of temperature gradients. It will be remembered that Bigelow so contrived his reduction to sea level that, in the plateau, the sea-level map was, in reality, the replica of the actual pressure at 3,500 feet, and he devised temperature arguments that would produce approximately this effect (cf., p. 101). Independently, he devised temperature arguments, as has been shown, for reduction to the 3,500-foot level. In the last analysis, it would appear that his two maps should be identical; whether they were or not is of less consequence than the circuitous reasoning. We know, moreover, that certain plateau gradients appearing on the sea-level map are erroneous, and if the 3,500-foot map showed an identical configuration, we should be forced to the conclusion that it, also, was erroneous. It would be preferable, indeed, to suppose that the 3,500-foot map were the more accurate because of the shorter reduction column. But the reader may have his own opinions concerning the validity of these arguments.

Maps were drawn by Bigelow for these two upper levels for approximately a year; they were studied by him and certain precepts for forecasting were derived from the study,[16] but their value was, as mentioned before, never successfully demonstrated.

Sandström.—In 1906, J. W. Sandström [17] published a treatise in which the reduction, not to levels equidistant from sea level but to levels of equal gravity potential, was discussed. This was essentially an application of the Bjerknes theory of solenoids. These equipotential surfaces do not, however, vary greatly from parallelism with sea level until very great heights are reached. The system proposed by Sandström depended upon actual aerological observations by kites, and this introduced a barrier of practicability mentioned earlier. Sufficient data would not be available and if they were it would be difficult to work them up in time to be of great assistance to the forecaster. "Certainly within one and a half hours after the descent of the last kite," says the author, "these maps could be drawn and finished at the Central Office of the Weather Bureau." But that would require too much time.

Dietsch.—In connection with the wind changes with altitude in cyclones, Marie Dietsch [18] has found it necessary to draw maps of the 1 and 2 kilometer levels over north Germany. These were constructed, using a gradient of 0.5° C. per 100 meters in all parts of the cyclone. The use of a constant gradient over so large an area as even half the United States would certainly lead to considerable inaccuracy. In spite of this, however, very satisfactory agreement between observation and computation at the 1-kilometer level was found.

Fujiwhara.—Since about 1919, maps of pressure at 3 kilometers above sea level over the Japanese Empire have been drawn daily and used as auxiliaries to forecasting.[19] The ingenious manipulation of the hypsometric formula by which the reductions are accomplished is due to Dr. S. Fujiwhara, of the Central Meteorological Observatory at Tokyo.

At first the method seems astonishing, for it consists in adding millimeters of mercury at sea level directly to centigrade degrees of station temperature and obtaining in the sum a value which is approximately twice as great as the pressure in millimeters at the 3-kilometer level. It is only approximate and no more is claimed for it, yet it is said by Doctor Fujiwhara that the gradients so indicated are very useful in meteorological work in Japan. Considerable work has been done with these charts by Drs. R. Sekiguchi and Horiguchi, but, except for a paper by the former,[20] but little has been published in other than the Japanese language.[21]

This clever artifice depends upon the fact that at approximately 3 kilometers above sea level the effect of 1 mm. rise in the sea-level pressure is equal to that of an increase of 1° C. in the mean temperature of the air column. Since an increase of either of these elements produces a rise in pressure at the upper level, they can be added together, and the result is a kind of index number, which, when divided by 2, gives the approximate pressure at the upper level.

Leaving vapor pressure out of consideration in the hypsometric formula, the problem is essentially this: To find at what level a certain change of pressure Δb may be produced either by a change in pressure at sea level ΔB or a change in the mean temperature of the air column $\Delta\theta$. This level is given by the equation

$$h = K \log [(B+\Delta B)/B]\,[1+\alpha(2\theta+\Delta\theta)+\alpha^2\theta(\theta+\Delta\theta)]/\alpha\Delta\theta,$$

where h is the altitude in question, K is the barometric constant 18,400, and α is the coefficient of expansion of gases, the other symbols having been explained before. This equation follows easily when one equates the

[16] Bigelow, F. H.: The circulation in cyclones and anticyclones with precepts for forecasting by auxiliary charts on the 3,500-foot and 10,000-foot planes. Mo. Weather Rev., May, 1904, p. 216.

[17] Sandström, J. W.: On the construction of isobaric charts for high levels in the earth's atmosphere and their dynamic significance. *Transactions of the American Philosophical Society*, N. S. Vol. XXI, Part I, pp. 31–96.

[18] Dietsch, Marie: Untersuchungen über die Änderungen des Windes mit der Höhe in Zyklonen. *Veröffentlichungen des Geophysikalischen Instituts der Universität Leipzig*, Band II, Heft 5, 1918, pp. 197–234. Abstract in Mo. Weather Rev., July, 1920, p. 402, by W. R. Gregg.

[19] Fujiwhara, S.: Pressure maps at 3 kilometers in Japan. Mo. Weather Rev., October, 1921, pp. 571–572.

[20] Sekiguchi, R.: Free-air pressure maps as forecasting aids in Japan. Mo. Weather Rev., May, 1922, pp. 242–243.

[21] Cf. Nakamura, S.: Upper air currents and volcanic ashes from Asama. *Journal of the Meteorological Society of Japan*, February, 1921.

hypsometric effect of increasing B by the amount ΔB to the effect of increasing θ by $\Delta\theta$. Using millimeters as the pressure unit, the level is about 3 kilometers above sea level. If the pressure is given in millibars, h would be approximately 2 kilometers, varying in a nearly linear manner within the ordinary range of sea-level pressure but increasing about 150 meters with each 10° C. rise in temperature.

Now what has been the treatment of θ in Japanese practice? Doctor Fujiwhara's own words will give this most concisely:

> This [the above argument] holds if the lapse rate is uniform. When the lapse rate is not uniform, we ought to make some allowance for it, so that
>
> $$(p_3-P_3)=0.67(p_0+t_m+\tau)-\text{a constant},$$
>
> (p_3-P_3) being the current pressure departure from the normal at 3 kilometers, p_0 sea-level pressure, t_m the mean temperature of the air column, and the small correction under discussion. For our purpose τ can be obtained by rough estimation. From the results of actual observation of the upper-air temperature we can make a table for τ corresponding to various circumstances, e. g., fair weather, rainy, near the surface of discontinuity, morning, evening, summer and winter, continental, oceanic, etc.

The following quotation from the discussion will point out some of the reasons why this method would not be practicable in the United States in spite of its apparent success and usefulness in Japan:

> * * * The extensive continental area [of the United States] produces strong seasonal variations between inland and coastal regions, and the elevation differences between the east and the west, the extremely variable nature of the surface covering, and topographic irregularities result in a complex of temperature conditions that would make it difficult, if not impossible, to tabulate, as they do in Japan, the probable variation from the uniform lapse rate.

Doctor Sekiguchi has remarked that the reductions at inland stations in Japan were often so unsatisfactory that they were neglected and only the coastal stations used. Fortunately, Japan's geographical characteristics permit of this since the distance from west to east is not great. But the great extent of the United States would not permit of such a convenient liberty.

Summary.—Of all the methods for the construction of free-air maps, those by Teisserenc de Bort, Köppen, Sandström, Dietsch, and Fujiwhara are least applicable to the United States, either because of their statistical nature, their impracticability, or because of inherent geographical characteristics of the United States as compared with those of the countries in which they have been employed. Naturally Bigelow's work, because it was intended for application in the United States, comes nearest to usefulness, but it has several features which render its accuracy questionable, and its attempted application did not appear to yield convincing results. The maps of Fujiwhara clearly demonstrate their usefulness and promise for, in Japan, they are regularly used by the forecaster. From such an example we may draw our inspiration for an attempt, which, in the light of modern aerological data, may yield satisfactory results.

Part 3.—SURFACE WIND DIRECTIONS AS INDICES TO TEMPERATURES IN THE FREE AIR.

THE INDEX.

The need for an index.—It has been shown in the foregoing that in reducing to upper levels three elements are accurately known—(1) the vertical distance between the station and the reduction level, (2) the surface pressure, and (3) the surface temperature. There are two elements to be determined, (1) the mean temperature of the air column, and (2) the mean vapor pressure of the air column. The mean temperature affords the greater problem, for the water vapor effect is less influential. If the mean temperature can not be observed, it is imperative that some index, *observable at the surface,* be employed. What shall this index be?

The qualifications of an index.—There are two qualifications to which such an index must conform: (1) It must have a direct physical relation to the temperature in the the free air, and (2) it must be one of the weather elements regularly observed at stations. The first of these qualifications is *scientifically* pertinent; the second is *practical.* It is often inadvisable to infuse too much of the purely practical into the preliminary research relative to such a problem as this; but in this case it seems evident that the factors of simplicity and practicability are inseparable from the scientific solution of the problem. For that reason it is desirable to impose this qualification upon whatever element is selected.

WIND DIRECTION.

Comparison of wind direction and atmospheric pressure as temperature controls in the lowest levels.—A careful consideration of the various elements observed regularly at meteorological stations will invariably eliminate all but one (excluding temperature and pressure, which are essential to the formula as stated above), and that one is *wind direction.* Surface pressure and temperature do, however, call for a word in this connection. Leaving the question of the cause of irregular barometric fluctuations, i. e., the cyclones and anticyclones of extratropical latitudes out of consideration, it is sufficient to say that temperature changes in the lowest levels of the atmosphere (only the lowest 2 kilometers will be considered here) are the result of the importation of warmer or cooler air. Such importation is the result of the blowing of the wind, and the blowing of the wind is the result of a pressure gradient, however established.

Many important discussions have centered about the cause of temperature changes in the free air, some meteorologists adhering to the belief that such changes are essentially dynamic in character,[1] and others that the changes result through the importation of air of different temperature.[2] But these discussions concern themselves with conditions at higher levels than are of interest here. It is generally agreed, it seems, that in the United States the temperature, owing to the continental character of the weather controls, at least below 3 kilometers, is more strongly related to the source of the air (hence to wind direction) than to such effects as dynamic and radiational heating and cooling.

In 1919, correlation coefficients were worked up by W. S. Cloud, at that time assistant in the Aerological Division of the Weather Bureau, showing the relation between temperature, pressure, and the south component of the wind at the surface and at 3 kilometers, based upon approximately 200 observations. These gave values opposite in sign to those determined in Europe, and led Mr. Gregg to conclude that the factor of continentality with the attendant marked effects of wind direction was the cause of the obliteration of such dynamic effects as were pointed out by W. H. Dines, in England. Mr. Gregg states, in conclusion: "These figures [Cloud's correlation coefficients] confirm the conclusions already given, viz, that in the United States, particularly in the interior portions, wind direction exerts a greater influence on the air temperature than does the sea-level pressure." One may attribute wind direction to pressure distribution, but, in such event, the relation is, at best, only indirect between pressure and temperature, whereas between wind direction and temperature it is direct. This disposes of the measured element of surface barometric pressure as an index to upper temperatures.

Wind direction and temperature at the surface in relation to free-air temperatures.—Similarly, there is a good correlation in the United States, between surface temperature and wind direction. This holds at least as high as 3 kilometers. While, in considering seasonal or monthly normals, there appears to be a certain relation between temperature at the surface and at some free-air level, it is obvious that such a relation can not be expected to hold uniformly under day-to-day conditions. The vertical distribution of temperature is not constant, nor even regularly variable, but one which varies with type of weather, time of day, topography, etc. It is apparent, then, that if the relation between surface temperature and free-air temperature were used, it would have to be classified according to some other condition more repre-

[1] Dines, W. H.: The characteristics of the free atmosphere. *Geophysical Memoires, No. 13,* Brit. Meteorological Off., 1919. Abstract Mo. WEATHER REV., September, 1919, pp. 644-647, by W. R. Gregg.

[2] Gregg, W. R.: Vertical temperature distribution in the lowest 5 kilometers of cyclones and anticyclones. Mo. WEATHER REV., September, 1919, pp. 647-649.

Douglas, C. K. M.: Temperature variations in the lowest 4 kilometers. *Quarterly Journal of the Royal Meteorological Society,* January, 1921, pp. 23-46.

sentative of the type of weather. Wind direction would offer such a classification for reasons given above. Thus, it seems that wind direction stands as the logical element by which temperatures in the free air in the United States may be judged most readily; both surface pressure and temperature are but indirectly related to free-air temperature, while wind direction at the surface—the consequence of both these elements—is directly related.

General pressure distribution as an index.—It has been suggested that the position of the station with reference to the distribution of pressure should be the criterion for the estimation of temperatures aloft. It is believed, however, that this criterion fails with respect to the qualification of practicality. An observer *must* be able, without knowledge of widespread conditions, to apply whatever criterion is adopted. Obviously, it is not until all the observations are collected upon the synoptic chart that one can determine the station's location with respect to the quadrant of the cyclone or anticyclone. Hence, this suggestion is, for current reductions, entirely impractical. If it were possible, as it is in statistical summaries, there is the additional drawback of being unable to assign the station definitely to a proper barometric situation.[3] Wind direction, however, being a direct result of the barometric situation, affords a satisfactory and simple expedient, and such classification is, in the last analysis, classification by pressure distribution.

The time element in wind direction.—One point has been raised in discussion that is worthy of careful consideration. Suppose at a certain observation the temperature is −15° C. and the wind south, of moderate velocity, but that it has changed to south only within the last hour. The observer using his observations as the fundamental data computes the probable mean temperature of the air column upon the basis of a south wind at the surface. Suppose, moreover, that the wind blows steadily from the south for 24 hours and in that time the surface temperature has risen to 0° C. under its influence. The mean temperature of the air column will be quite different in the two cases, as is the surface temperature; but, since the south wind was blowing at both observations, the observer will consider that the difference between the mean temperature of the air column and the surface temperature is the same at these times. Is such a device justified? This is a question of genuine importance for an answer to which one must look to the testimony of observations. The only answer that the writer can give at this time is based upon some statistical data gathered from the aerological stations at Mount Weather, Va., Drexel, Nebr., and Ellendale, N. Dak., and published in connection with preliminary considerations of this question of reduction upward.[4]

If there is a marked difference between the air column temperature when the wind has just set in and after it has been blowing for a considerable time, the probable variation or standard deviation of the individual cases from the mean should be large. In other words, if the probable variation is small, the individual observations must agree closely with the mean, and the time interval between onset and observation must be of slight importance. It was found that, taking the observations as a whole, at the three stations mentioned, the probable variation of the mean temperature of the air column from the mean in reducing to 1 kilometer above sea level (roughly, an air column of 700 meters) is only 1.3° C.; to 2 kilometers it is only 1.8° C., being slightly greater at inland than at coastal stations. In terms of pressure at ordinary conditions these variations are of the order of 0.5 mb. and 1.2 mb. at the two levels, respectively. It is believed that errors of this order of magnitude would not be serious, especially if they are distributed over considerable areas rather than localized. This is not to say that the consideration of the time factor would not reduce the probable variation, but it seems that the labor and tedium of this further classification would hardly be justified by the degree of increased accuracy.

The turning of wind with altitude.—The argument may be advanced that a certain wind direction at the surface does not necessarily indicate the turning of the upper wind and that, using the argument that importation is the chief factor in determining temperatures below 3 kilometers, an upper temperature may be quite different at two observations when the surface temperature and wind direction are the same; but the same argument advanced above will hold here. If such cases do occur (and they undoubtedly do), they are not frequent enough to exercise appreciable effects upon the reduced pressure.

But there is another way to approach the problem and that is to study the results of aerological observations which have lately been summarized for the eastern and central United States by the Weather Bureau Aerological Division.[5]

We know that, as greater and greater elevations are attained by kites, pilot balloons, and other means, there is frequently and usually a turning of the wind, sometimes to the right and sometimes to the left. It is not of much importance whether this turning is much or little, *so long as it is the same under similar surface conditions.*

It follows, therefore, that if the turning is not the same under all conditions, the deviation from surface direction should be small, if surface direction is to be a reliable index. In other words, surface wind direction may be regarded as a satisfactory guide to upper temperatures (1) if turning with altitude is constant, or nearly so, or (2) if deviation from surface direction is small. Mr. Gregg has arranged tables extremely convenient for this test.[6] In Table 10c is given the average deviation in

[3] Except in the case of special investigations, such as the study of the dynamics of cyclones and anticyclones, this classification has been abandoned by the United States Weather Bureau in favor of classification by surface wind direction.

[4] Meisinger, C. LeRoy: Preliminary steps in the making of free-air pressure and wind charts. Mo. Weather Rev., May, 1920, pp. 255-267.

[5] Aerological Survey of the United States. Mo. Weather Rev. Supplement No. 20.

[6] *Ibid.*, pp. 56 and 68.

degrees of the free-air winds from surface direction at different elevations above the several kite stations. In Table 15c is given the average percentage frequency of clockwise and counterclockwise turning for the same elevation and the same stations. The curves in the accompanying Figure 2 are carried to the 3-kilometer level in order that the proper trend at the 2-kilometer level may be shown.

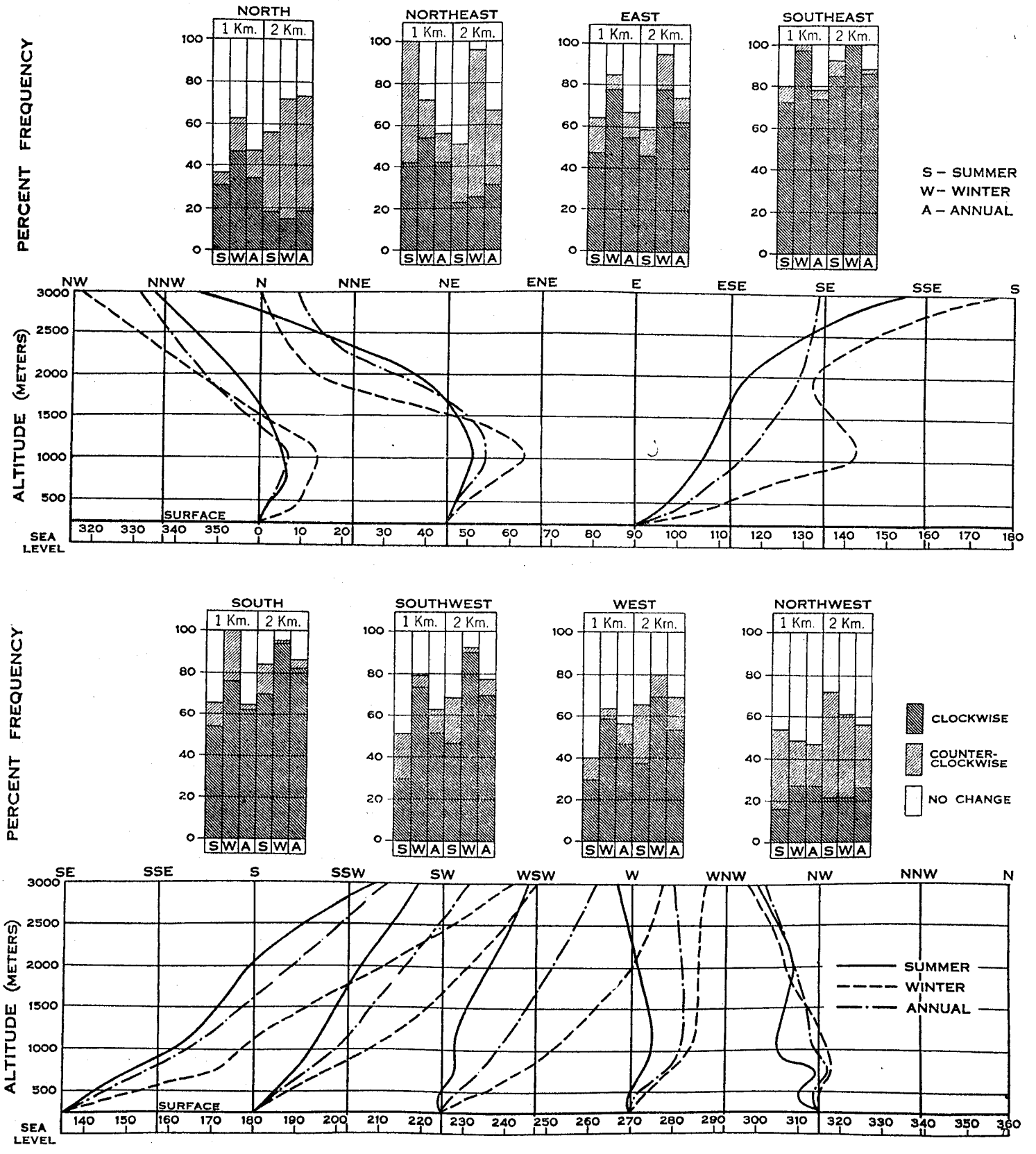


FIG. 2.—Summer, winter, and annual average turning of winds with altitude from the eight surface directions, and the percentage frequency of clockwise and counterclockwise turning.

It will be seen that the average elevation of the six stations is 250 meters, and that the elevations are given above sea level. For each wind direction at the surface (8 points) there are three curves—summer, winter, and annual deviation. The small numbers just below the surface level indicate the wind direction in degrees, measuring clockwise from north, while the wind directions indicated near the 3-kilometer level are for 16 compass points. Above each of the eight points of the surface wind are shown frequency polygons of the average clockwise and counterclockwise turning expressed as percentages of the total observations. The darker shading indicates clockwise, and the lighter shading counterclockwise turning, while the unshaded portion indicates no turning at all. The deviation curves for the southeast wind, owing to their marked and rapid turning toward the west, are to be found in the lower tier at the left.

It will now be instructive to examine these curves with special reference to the consideration set forth above. In the first place, what of the constancy of turning? For this we may study the eight polygons. Taking a broad survey of the eight graphs, we find that there is a marked seasonal difference, as well as a difference between the several directions. The outstanding features of the polygons may be enumerated as follows:

(1) There is more frequent turning of winds from surface direction, in all seasons at the 2-kilometer level than at the 1-kilometer level. This is a well-known fact, but a short table of the percentage of times there is *no* change is of interest, the annual average only being considered.

TABLE 2.—*Percentage frequency of no turning of wind with altitude (annual average).*

Elevation.	N.	NE.	E.	SE.	S.	SW.	W.	NW.
1 km	53	44	33	22	35	38	44	53
2 km	27	33	16	12	14	23	31	44

It is clear from this table that northerly winds are the deepest and most likely to persist up to the 2-kilometer level, while east, southeast, and south winds are most likely to turn below this level.

(2) At the 1-kilometer level, clockwise turning occurs most frequently with southeast winds and least frequently with northwest winds, the transition from one to another being quite gradual.

(3) At the 1-kilometer level, counterclockwise turning occurs most frequently with northwest and north winds, and least frequently with southeast and south winds, the frequency of clockwise turning being rather small.

(4) At the 2-kilometer level, clockwise turning occurs most frequently with southeast winds and least frequently with northwest or north winds

(5) At the 2-kilometer level counterclockwise turning occurs most frequently with north and northeast winds and least frequently with southeast winds, the frequency, relative to clockwise turning being considerably greater, especially with northerly winds, than is the case at the 1-kilometer level.

(6) The first precept—that concerning the greatest constancy of turning—is fulfilled by southerly winds, especially southeast.

Let us now examine the portion of the diagram dealing with the average deviations from surface direction, bearing especially in mind the importance of the *amount* of the deviation and its relation to the constancy of turning discussed above. The following features appear worthy of consideration:

(1) At the 1-kilometer level all winds except northwest deviate clockwise. With northwest winds the winter deviation is clockwise also by a very small amount, but the summer and annual curves tend counterclockwise.

(2) At the 1-kilometer level the maximum deviation in the clockwise direction occurs with east and southeast winds. In winter this deviation amounts to more than 45°.

(3) At the 1-kilometer level the clockwise deviation is much less in summer than in winter; with northwest winds, mentioned in (1), the summer deviation is counterclockwise.

(4) At the 2-kilometer level all winds, excepting north, northeast, and northwest, deviate clockwise; in the three exceptions the deviations are decidedly counterclockwise.

(5) At the 2-kilometer level the maximum clockwise deviation occurs with southeast winds, where, in winter, it amounts to as much as 75°.

(6) At the 2-kilometer level the maximum counterclockwise deviation occurs with northeast winds, where, in winter, it amounts to about 30°.

(7) At the 2-kilometer level the clockwise deviation is more pronounced in winter than in summer. This is also true in the case of the three northerly winds mentioned in (4) with respect to counterclockwise deviation.

(8) The second precept, that concerned with the occurrence of the smallest average deviation, is fulfilled with the northwest wind.

It thus appears that the earlier contention that wind direction is a reliable index to upper temperatures is verified by these considerations. It was seen from the frequency polygons that the turning is most frequently the same aloft when the winds are southerly, but that the average deviation from surface direction is least when the winds are northerly. *The greatest average deviation occurs with greatest reliability of turning; the least deviation occurs with the least reliability of turning.*

The conclusion is, therefore, that the available statistical evidence is decidedly favorable to the use of surface wind direction in the capacity of an index to the thermal conditions aloft.

The annual average and its relation to summer and winter means.—It may not be amiss to digress for a moment to discuss a point which first became obvious when the diagrams of average deviation were drawn, namely, that the curves representing annual average deviation conform in nearly all directions more closely to the summer curve than to the midway position between summer and winter. This would lead to the suggestion that, as far as wind

directions are concerned, the winter season is a brief but characteristic condition, while the turning of winds in spring and autumn is sufficiently like that of summer to swing the annual average in that direction. But this conclusion should be tested by an independent method.

Upon the suggestion of W. R. Gregg, a comparison of the horizontal gradient of pressure in the free air between Ellendale, N. Dak., and Groesbeck, Tex., in the several seasons has been made. The mean pressures for the four seasons were set down and the difference taken. These differences are proportional to the pressure gradient between them. The annual mean gradient, obtained by averaging the 12 months, is compared with the mean of the summer and winter gradients. These comparisons are brought together in the following table:

TABLE 3.—*Pressure differences between Ellendale and Groesbeck in different seasons (mb.).*

Season.	1 kilometer.			2 kilometers.		
	Ellendale.	Groesbeck.	Difference.	Ellendale.	Groesbeck.	Difference.
Winter	896.2	904.1	7.9	788.0	800.5	12.5
Spring	898.0	901.6	3.6	793.0	800.3	7.3
Summer	902.3	905.5	3.2	801.8	806.0	4.2
Autumn	899.9	904.7	4.8	796.0	803.7	7.7
Annual	899.1	904.1	5.0	794.8	802.8	8.0
(Winter+summer)/2	.....	.....	5.6	.....	.....	8.4
Difference	.....	.....	0.6	.....	.....	0.4

This table shows conclusively that the average pressure gradients for the whole year do not lie halfway between summer and winter but are more nearly like those of summer. This can be said of all wind directions and explains the curves in Figure 2.

Conclusions.—To return now to the question of the relations between surface wind and upper-air temperature conditions, let us review the evidence and state the conclusions. A consideration of the various weather elements regularly observed on stations indicates that surface wind direction is the one which bears a direct physical relation to temperature conditions in the free air below 2 or 3 kilometers. This is abundantly confirmed by (1) Cloud's correlation coefficients between temperature and the south component of the wind at the surface and at 3 kilometers; (2) a study of the average seasonal and annual deviations from surface direction with altitude and the percentage frequency of clockwise and counterclockwise turning. Upon this basis it seems that a classification of the difference between the mean temperature of the air column and surface temperature by surface wind directions and months is entirely warranted. Certain sub-classifications might be made, but these would, at once, demand a larger quantity of data, and render the final reduction tables unwieldy.

Part 4.—Δ AND ITS EVALUATION.

THE CHARACTER OF THE DATA.

Introduction.—The character of the data and their sources, the plan of the attack, and the preliminary results have appeared in previous papers [1] and have been presented orally at meetings of the American Meteorological Society at St. Louis (1919), Chicago (1920), Washington (1920, 1921, and 1922), and Toronto [2] (1921). For that reason only the briefest outline of this previous work will be given here, with such detail as seems pertinent, together with such modifications and improvements in the method as experience has suggested.

The work was begun in the autumn of 1919 upon the basis of the then unjustified assumption that surface wind direction is a dependable index to free-air temperature. The data presented in Part 3 were not available at that time, and it was necessary to go to the original sources to seek the information without any assurance that this basic assumption was sound. But, as already shown, the preliminary results justified the assumption and subsequent aerological investigations have abundantly confirmed it.

The aerological stations.—The data were drawn from the seven kite stations of the Weather Bureau, two of which have since been discontinued. They comprise four stations in an approximately north-south line in the Middle West—Ellendale, N. Dak.; Drexel, Nebr.; Broken Arrow, Okla.; and Groesbeck, Tex.;—a station at Royal Center, Ind.; one at Leesburg, Ga.; and one at Mount Weather, Va. The last two stations are no longer in operation, the former having been replaced about the end of 1920 by one more satisfactorily located at Due West, S. C., and the latter discontinued in 1914, after seven years of active work. The preliminary studies were concerned only with Mount Weather, Ellendale, and Drexel, but the present paper has been based upon all flights occurring about 8 a. m., 75th meridian time, at all stations up to the beginning of 1921. The data at Due West have not been considered because this station has been established so recently that the means of the difference between the surface temperature and the mean temperature of the air column would not be very reliable. Moreover, Due West affords an interesting opportunity to test the accuracy of the computed pressure maps.

The total number of kite observations examined and tabulated is over 5,000 when all stations are considered, It is seen that even when this number is subdivided and apportioned to the several stations and further divided by classification into months and wind directions the numbers of observations upon which the means are based are large enough to justify a considerable degree of confidence. For some wind directions the number is larger than for others, but, fortunately, in such cases the number of observations is a fair index of the frequency of occurrence of such winds, and the low reliability of certain values is offset statistically by the paucity of occurrences.

The reduction levels.—Two free-air levels, 1 and 2 kilometers above sea level, respectively, were chosen. There are several reasons why these particular levels seemed most desirable, namely, (1) the largest amount of aerological data was available for these lower levels, since the number of kite flights that reached altitudes greater than 2 kilometers above sea level falls off rapidly; (2) it is at about these levels that the greatest amount of flying takes place, hence maps of pressure there would be of the greatest benefit to aviators; and (3) above 2 kilometers the tendency for isobars to lie prevailingly from west to east becomes apparent. The weaker pressure formations may not extend above that height, yet they may have a profound influence upon the surface weather.

Below 1 kilometer, the effect of surface-induced turbulence may, and does, have considerable influence in deflecting winds from the gradient direction and in preventing them from attaining gradient speed. Thus, the 1 and 2 kilometer levels seem acceptable as trial levels for pressure reductions.

The time of observation.—In selecting the flights from which the data were obtained, an attempt was made to take only those representative of conditions about 8 a. m., 75th meridian time. The average time of kite flights at various aerological stations is about 10 a. m., but flights occurring much later or much earlier than 8 a. m. were not included in this study. The purpose in using only those observations was to get temperature relations that would be applicable to the regular morning observations at Weather Bureau stations. Therefore, while it is undoubtedly true that the mean time of the observations contained herein is not precisely 8 a. m., it must lie within a few minutes of that time, and, for all practical purposes, the change in temperature owing to this time difference would be negligible.

Owing to the small number of flights occurring during the evening hours, no attempt has been made to prepare

[1] Meisinger, C. LeRoy: *Loc. cit.;* also Progress in making free-air pressure and wind charts. Mo. Weather Rev., April, 1921, pp. 238–239.

[2] *Ibid.:* The Toronto symposium on pressure reductions. Mo. Weather Rev., December, 1921, pp. 655–657; *cf.* also The symposium on pressure reductions at the Toronto meeting. *Bulletin of the American Meteorological Society,* February, 1922, pp. 22–24.

similar data for the 8 p. m. observation. Work must, however, be done along this line, possibly as the next step in this research.

The rôle of wind speed.—No classification by surface wind speed has been attempted. It is not unlikely that a study to determine the relation between winds of various speeds from the same direction and the mean temperatures of the air column would be of interest and value. To introduce this element, would, however, involve an undesirable complexity of arrangement. It is obvious that the figures given herein apply to conditions when there is sufficient wind to raise a kite, the average intensity of which is placed at about 5 meters per second at the surface. As the kite ascends to higher levels, greater speed is necessary to support the kite, owing to the decreased density of the air and the increased weight of kite wire. This varies, of course, with the size and type of kite.

The matter of the treatment of the vertical temperature gradient in calms is thus brought to the attention. The question is pertinent and one which could best be answered by an ample series of captive balloon ascents. Such data are not available and it is proposed in this study to use temperature data corresponding to the mean of all wind directions when there is a surface calm at a station over which pressure is desired.

The data.—The collection of data consisted in going over the individual kite flights and determining the mean temperature of the air column, finding its difference from the surface temperature, and classifying this difference by wind direction (eight points) and by months. The record sheets of the flights prepared in the Aerological Division of the Weather Bureau give the conditions of temperature, pressure, vapor pressure, etc., at frequent altitude stages, and the simultaneous surface conditions. In determining the mean temperature of the air column between the surface and a chosen level, say 1 kilometer above sea level, it was necessary to weight the mean temperatures of several layers intervening according to the depth of each layer. In this way, the mean temperature of the required air column was the weighted mean of several layers whose mean temperature could be very accurately determined. Inspection of the vertical curves of temperature indicates that, when carefully performed, this method of integration is sufficiently accurate.

Definition of Δ.—Experience has indicated that confusion may arise in the use of the rather prolix expression "difference between the mean temperature of the air column and the surface temperature," a phrase that has been used a great deal. A symbol for this quantity is desirable since it will be necessary to refer to it again and again. Consequently from the following relation,

$$t+\Delta=\theta,$$

in which t represents the surface temperature, θ the mean temperature of the air column, and Δ the difference between the two, it appears that Δ will fulfill this need satisfactorily.[3] It will be used throughout this paper.

Probable variation of Δ.—Part 3 contained a statement regarding the probable variations of the values of Δ determined in preliminary work on data from Ellendale, Drexel, and Mount Weather. A short résumé of these errors is important here because the results of that statistical treatment of the three stations are probably applicable to the others.

In the first place, after obtaining mean values of Δ for each month and wind direction, the magnitude of the departures of individual records from the mean was found to have little or no variation with season or wind direction. In other words, the residuals appear to be accidental and distribute themselves according to the Gaussian normal error curve. Indeed, after considering the possibilities of seasonal, geographical, and other causes of systematic variations of residuals, the conclusions were summarized as follows:

> Therefore it appears that the errors are not systematic; and that they are indiscriminately scattered * * * in such a manner that they may be considered as accidental. At any rate, if one were willing to admit the slightest effect of external influences in the distribution of the magnitudes of the residuals, it is plainly seen that such effect must be so small as to be hidden by the accidental variation.

Table 4, which is a composite of matter contained in Tables 9 and 11 of the earlier paper,[4] gives at a glance the summary of this statistical study:

TABLE 4.—*Summary of statistical investigation of preliminary data.*

Station.	Level.	σ	E.	
	km.	°*C.*	°*C.*	*mb.*
Mount Weather	1	1.8	1.2	0.49
	2	2.5	1.6	1.15
Drexel	1	2.1	1.4	0.58
	2	3.1	2.0	1.43
Ellendale	1	2.2	1.4	0.58
	2	2.7	1.8	1.29

The column headed σ gives the standard deviation for each of the three stations expressed in degrees centigrade. The probable variation E is defined as 0.6745σ. This is given both in units of temperature and in the equivalent variation in pressure reduced to the upper level. It is seen that the error at the upper level is, roughly, twice that at the lower, probably due to the combination of the effects of a longer air column and the smaller number

[3] A clear distinction should be made by the reader between the term Δt commonly used in aerology and the symbol Δ used in this paper. The former is a symbol used to denote the *rate of change of temperature with altitude.* It is called the vertical temperature gradient or lapse rate and usually is the amount of temperature change per altitude change of 100 meters. Its sign is *positive* when temperature *falls* with increase of altitude and *negative* in the case of *inversion.* The following quotation from the recommendation of the Subcommission on International Publications at Monaco, in 1909, gives the basis for this usage:

"La Sous-Commission recommande d'adopter, pour la définition du signe du gradient vertical de la température, le systeme ou le gradient sera positif lorsque la température diminue à mesure que la hauteur augmente, et que le gradient sera négatif dans la cas contraire." (*Sixième Reunion de la Commission Internationale pour l'aerostation scientifique à Monaco du 31 Mars au 6 Avril, 1909.* Strasbourg, 1910.)

On the other hand, the symbol Δ does not represent a lapse *rate;* it represents an actual *difference of temperature* between two points in a vertical in the atmosphere, one at the surface and the other in the free air at a level representative of the air column in question. Hence, when the temperature *falls* with altitude, the value of Δ is *negative,* and when temperature *rises* the sign is *positive.* Owing to this difference of sign, it is imperative that Δt and Δ be not confused.

[4] Pp. 260 and 262.

of observations. It is possible, though not certain, that the addition of the data for the year 1921 would decrease the magnitude of these values. At any rate, the probable variation is small enough that it may be regarded as satisfactory. Assuming that the examination of the data from these three stations affords information sufficiently representative, no further statistical examination of the data have been made.

CHARACTERISTICS OF Δ AT THE AEROLOGICAL STATIONS.

Local monthly variations of Δ with wind direction.—Having obtained from the original sources the values of Δ and classified them in the manner described, it seemed that a graphical representation of the data would display the chief characteristics of the variations. Hence the isopleths showing lines of equal value of Δ for the several stations and both levels were drawn. The ordinates are wind directions and the abscissæ are the months. The data were plotted in such a way that the vertical lines in the figures indicate the beginning of the months. In this respect the diagrams are different from those given as Figures 5 to 10, page 257, of the preliminary paper, where the vertical lines correspond to the middle of the month. According to the present arrangement it is very easy to read off directly from the charts the value of Δ for any set of conditions. For this reason and because additional data have been included, the preliminary diagrams are now obsolete and are superseded by those in the present paper. The isopleths are somewhat smoothed, but in all cases the smoothing was carried out with proper regard from the character of the data upon which the value at the point in question was based. Marked irregularities were infrequent, however, and the greater part of the values fitted easily and gracefully into the smooth system.

The testimony of the isopleths.—It will be instructive to study the isopleths with a view to interpreting in terms of the physical processes involved the phenomena they show. Figures 3 to 16 are the isopleths for the several stations and levels.

The following points are apparent:

(1) The highest and lowest values, as well as the range for both levels, are greater at the northern interior stations than at the southern coastal stations.

(2) There is a southerly component in the surface wind when Δ is highest at both levels at all stations except the 1-kilometer level at Leesburg.

(3) The highest values occur in the winter months, December to February, inclusive.

(4) In general there is a northerly component in the surface wind when Δ is lowest. (There are significant but explainable exceptions.)

(5) The lowest values of Δ occur in all cases during the months of late spring and early summer, there being a tendency for the time of this occurrence to be later at the southeastern stations than at the western and northern stations.

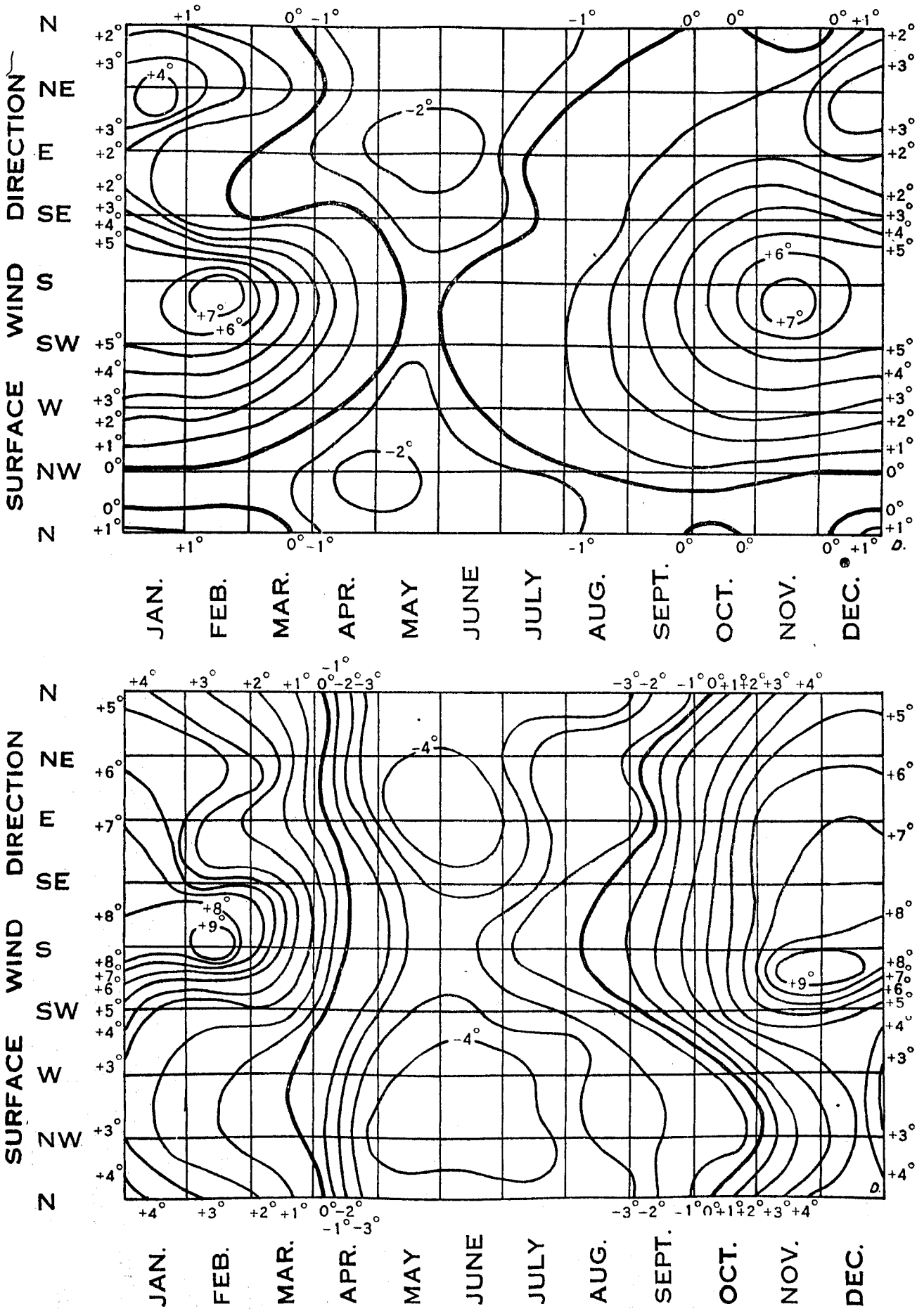
(6) There is a slight tendency for the lowest values of Δ to occur later when the 2-kilometer level rather than the 1-kilometer is considered.

The interpretation of the testimony.—These observations are in accord with deductions based upon the interrelations of the factors of *wind direction* (surface and aloft), *seasonal variation of temperature*, and *geographical location*. The six features mentioned above are composites of these three effects. Nevertheless, it is more direct to consider the several points separately, unraveling so far as possible the three threads.

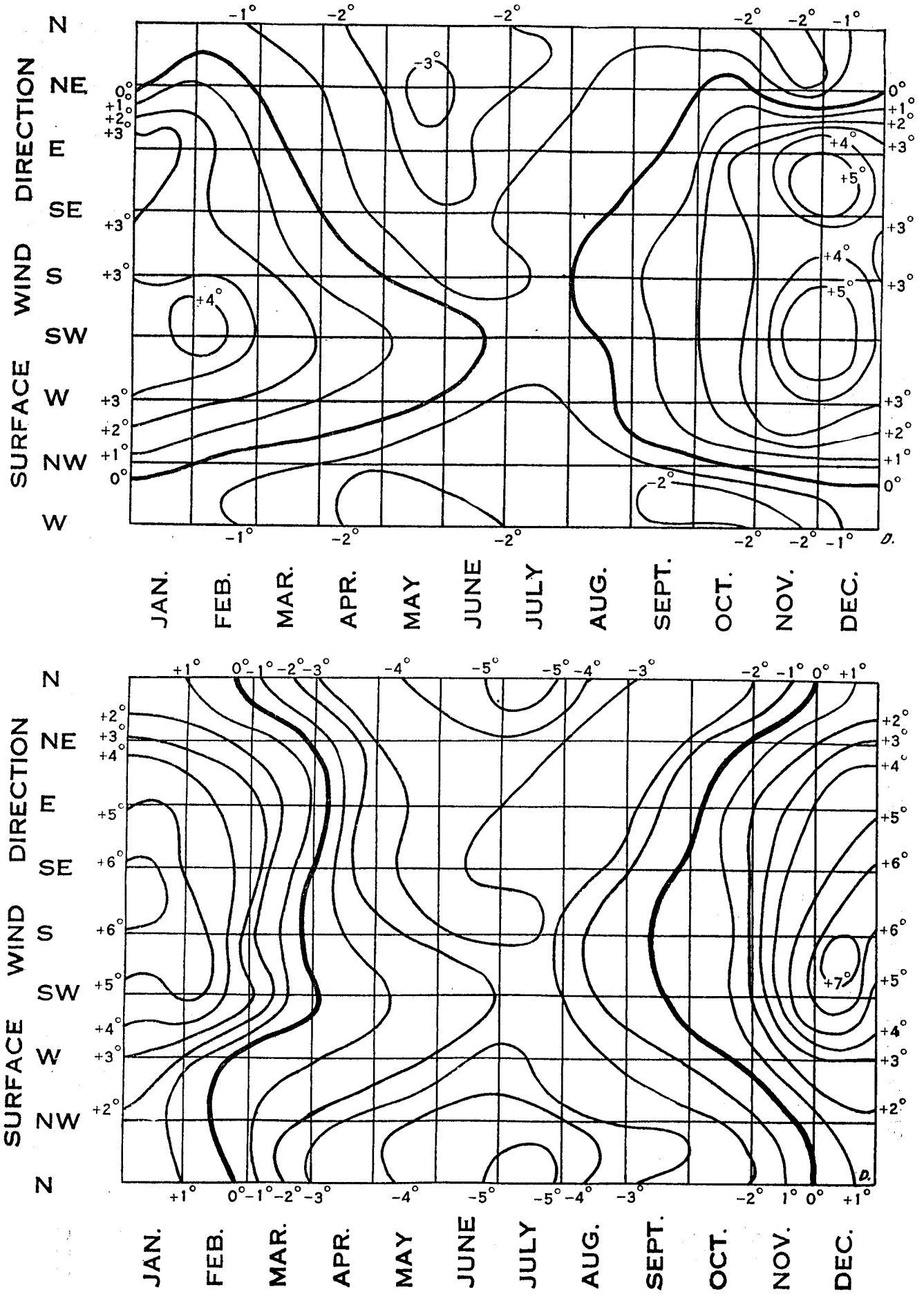
(1) When the annual march of Δ is considered for the several stations, the maxima and minima of the curves are higher at the interior than at the coastal stations. The range also is greater. This effect is largely geographical. It is well known that stations in the northern Great Plains experience higher temperatures in summer and lower temperatures in winter at the surface than those in eastern districts and lower latitudes, the temperatures of the latter regions being moderated by the Atlantic Ocean and the Gulf of Mexico.[5] Water being a poorer radiator and absorber than land responds with less flexibility to the seasonal variation of insolation. It not only is warmer in winter than the adjacent land and cooler in summer, but it exerts a profound influence upon the climate of the coasts. The higher absolute values of the vertical temperature differences in the interior is the result of a marked tendency, especially during the winter months, for an inversion to occur. This effect is augmented to be sure by the fact that the observations refer only to morning hours. Nevertheless at Ellendale, even in summer, there is a strong tendency toward an inversion of temperature.

(2) The presence of a southerly component in the surface wind when the highest values of Δ occur is to be explained upon the basis of wind direction and the effect of importation. The presence of the southerly component is not to be accepted without consideration of the turning of wind with altitude, for the temperatures at some free-air level are dependent upon the temperature of the region whence the air at that level came. Figure 2 showed that, within the lowest 3 kilometers, the tendency for all winds from east through south around to southwest was to become westerly through clockwise turning with increase of altitude. The effect is most pronounced with easterly winds because they have the greatest angle through which to turn to become westerly. Hence, in the case of stations showing an east-southeast wind at the surface when the value of Δ is greatest, it is necessary to examine the general region to the south and even to the southwest of the station, rather than the southeast, in order to ascertain whether or not such a value can be explained by importation. Thus, at all stations, with the exception of the northeast

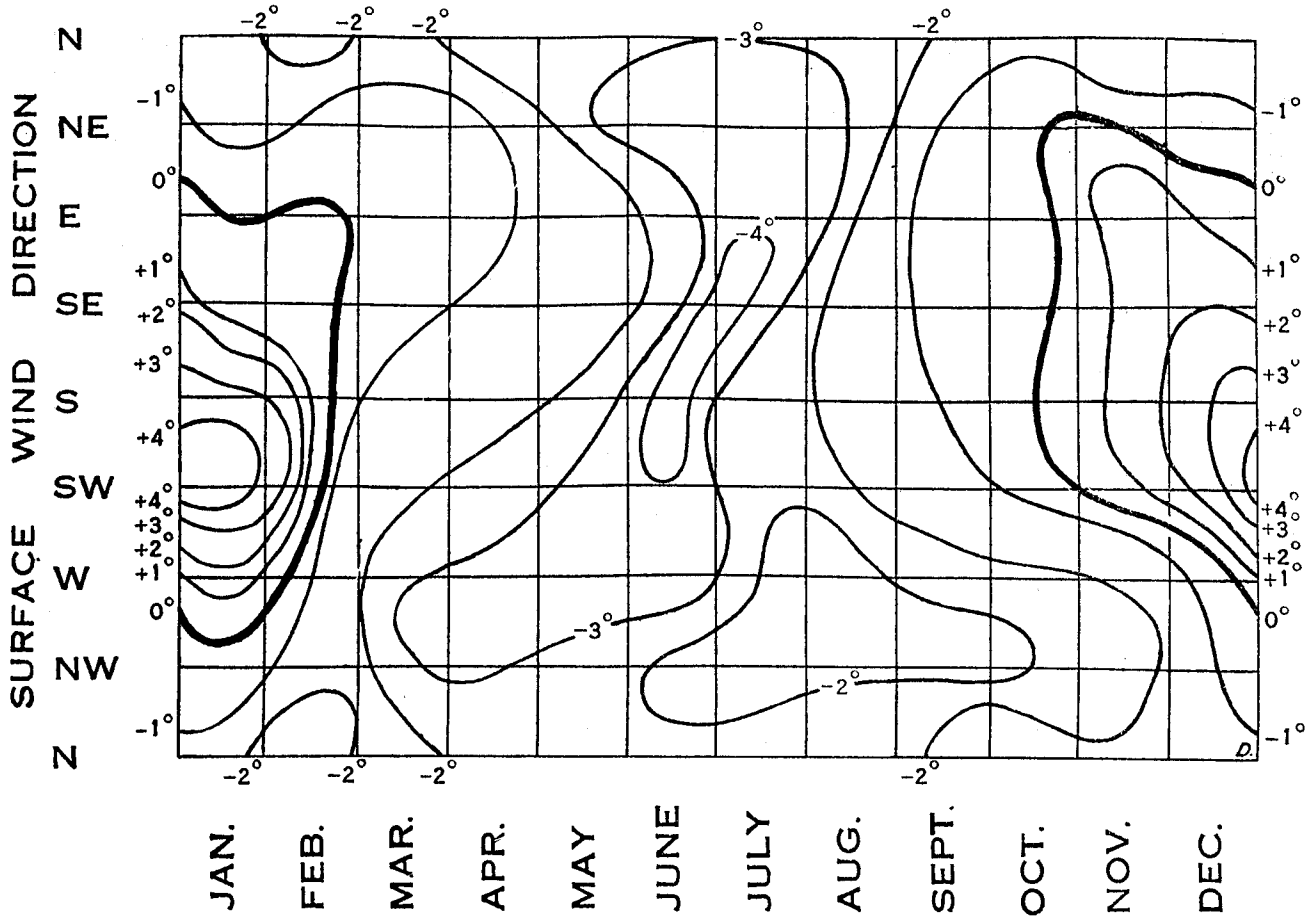
[5] Ward, Robert DeC.: Some characteristics of United States temperatures. Mo. WEATHER REV., November, 1921, pp. 595-606. The mean monthly isotherms follow the shore lines of the Atlantic and the Gulf in spite of prevailing offshore winds.

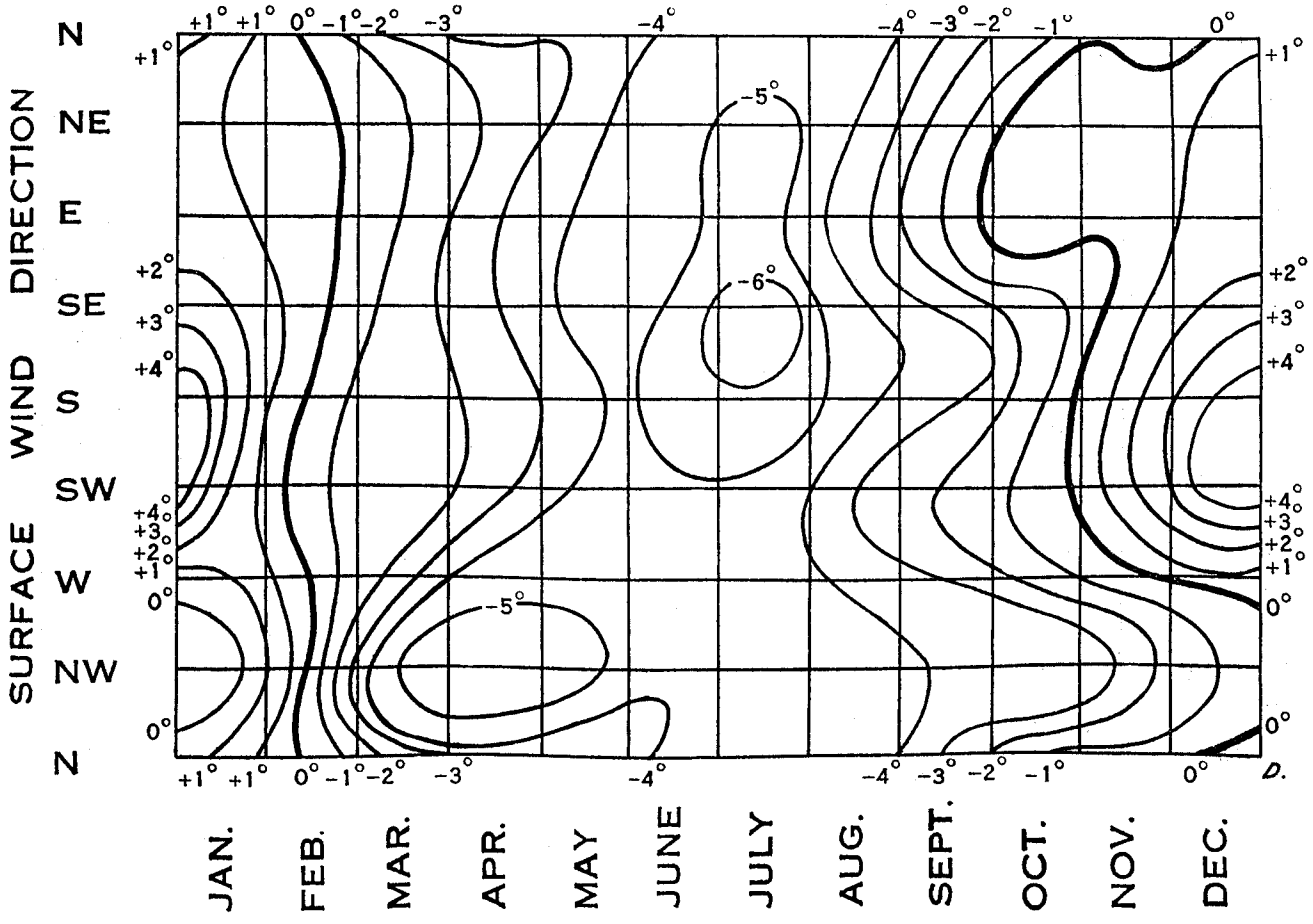


FIGS. 3-4. Isopleths for Ellendale, N. Dak., for the 1 and 2 kilometer levels (upper and lower diagrams, respectively).

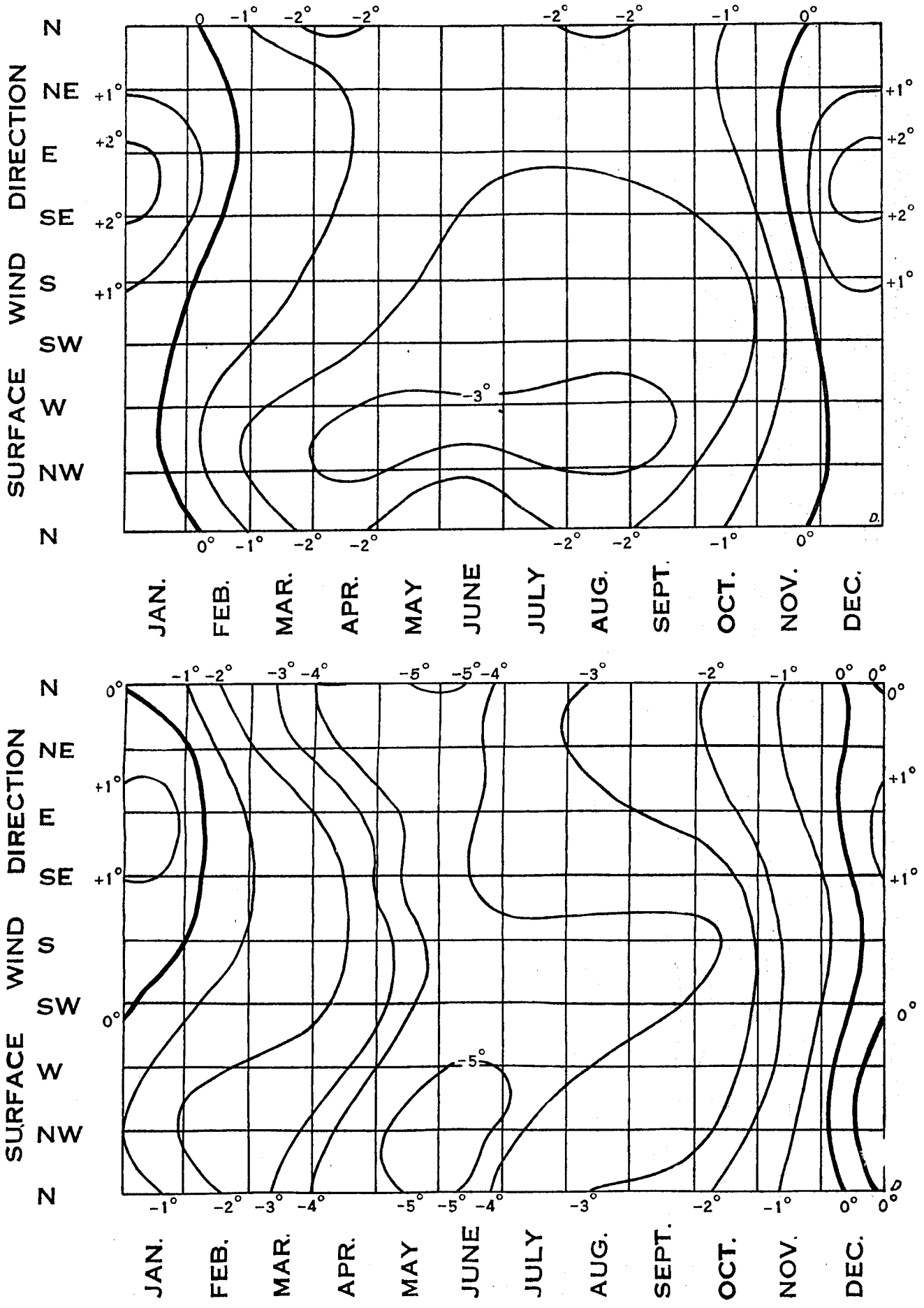


FIGS. 5-6.—Isopleths for Drexel, Nebr., for the 1 and 2 kilometer levels (upper and lower diagrams, respectively).

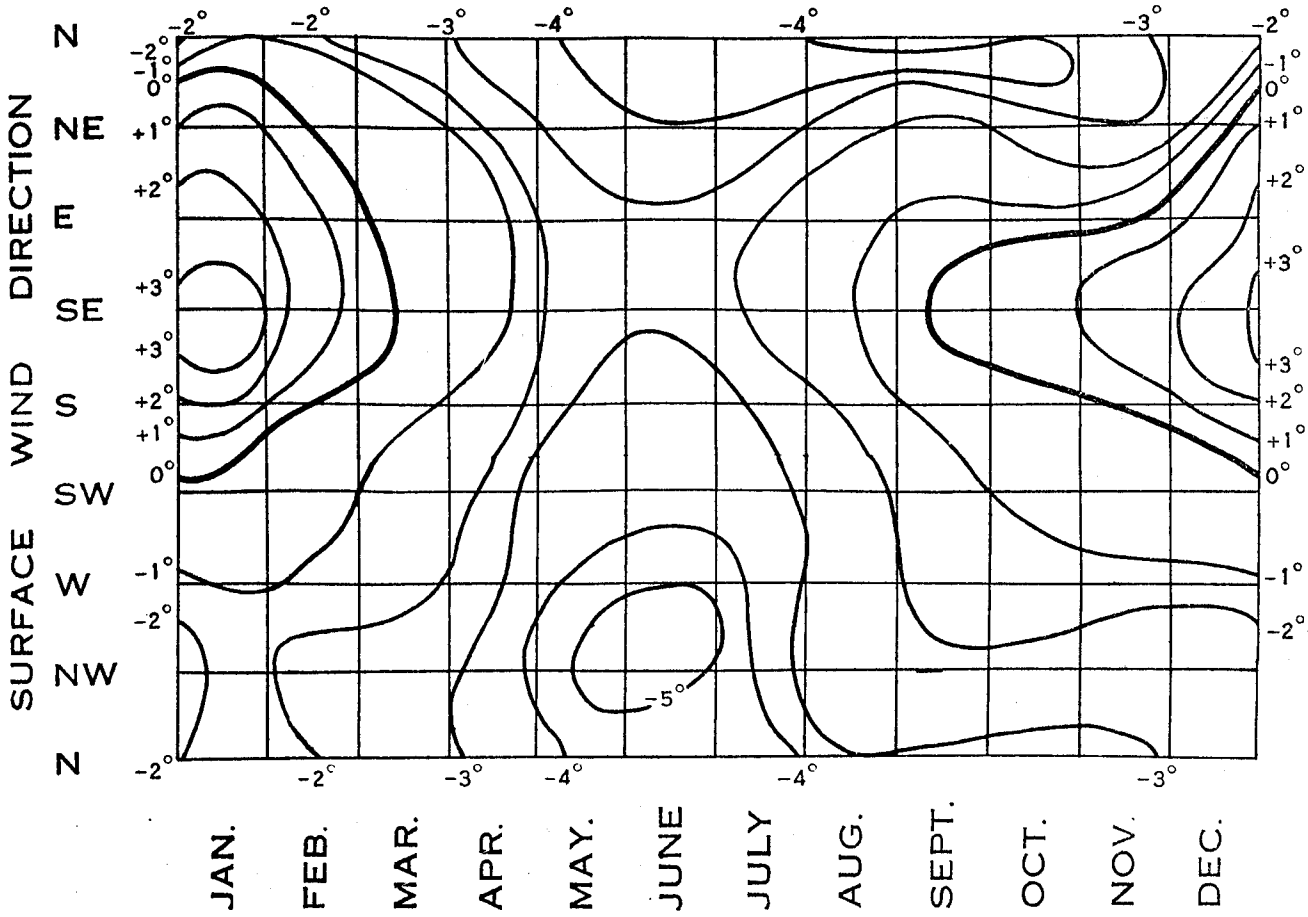


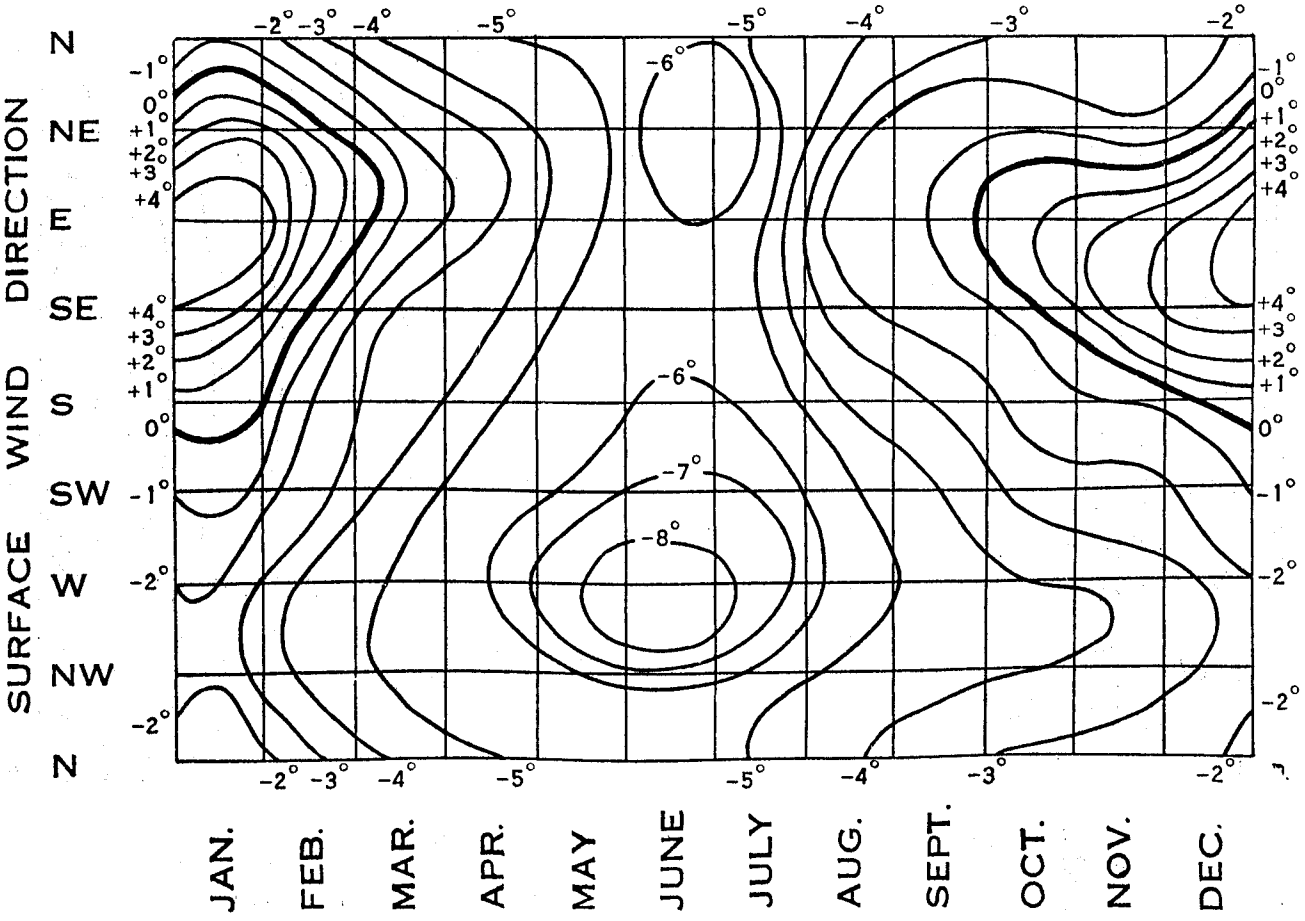


FIGS. 7–8.—Isopleths for Broken Arrow, Okla., for the 1 and 2 kilometer levels (upper and lower diagrams, respectively).

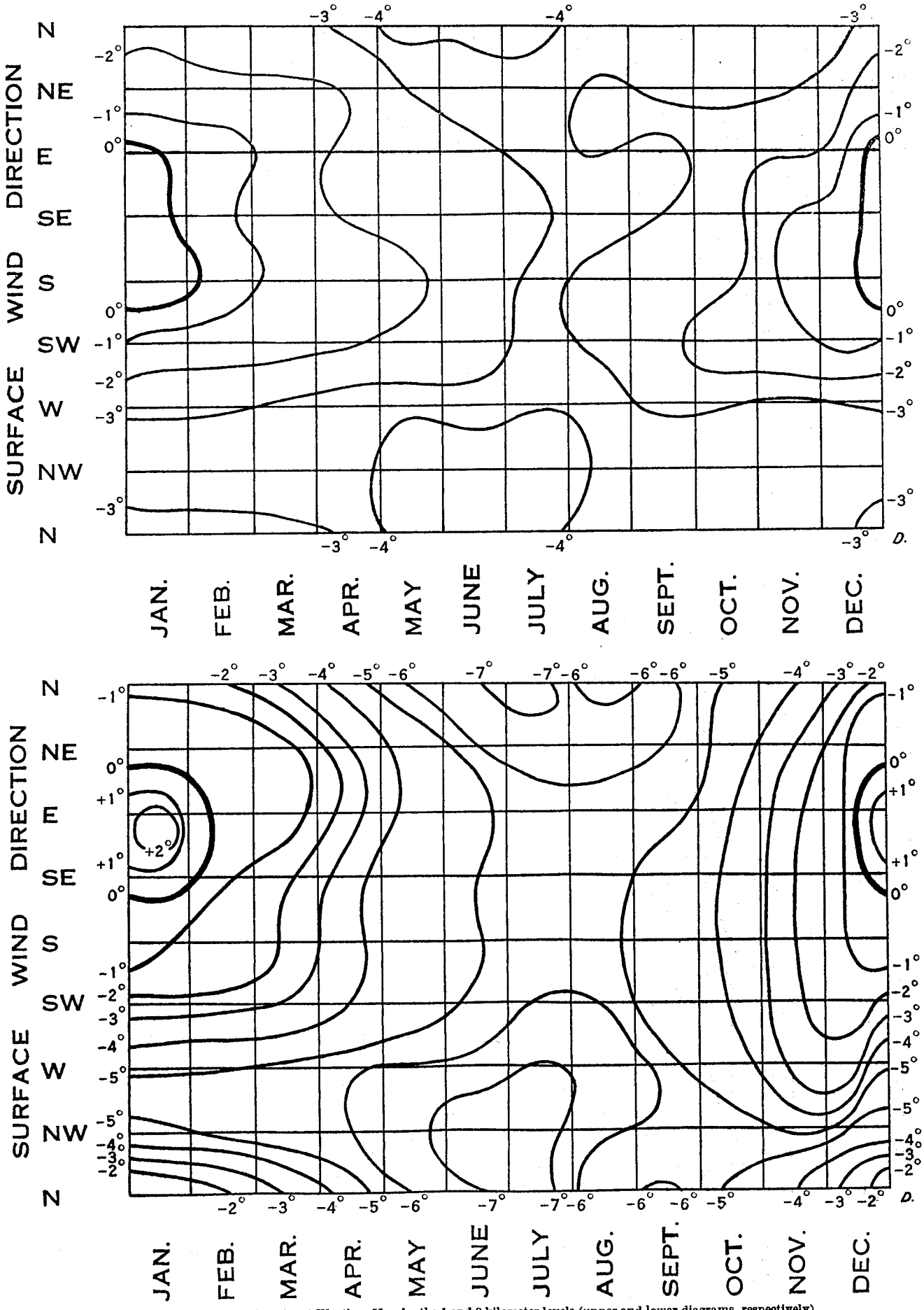


FIGS. 9-10.—Isopleths for Groesbeck, Tex., for the 1 and 2 kilometer levels (upper and lower diagrams, respectively).

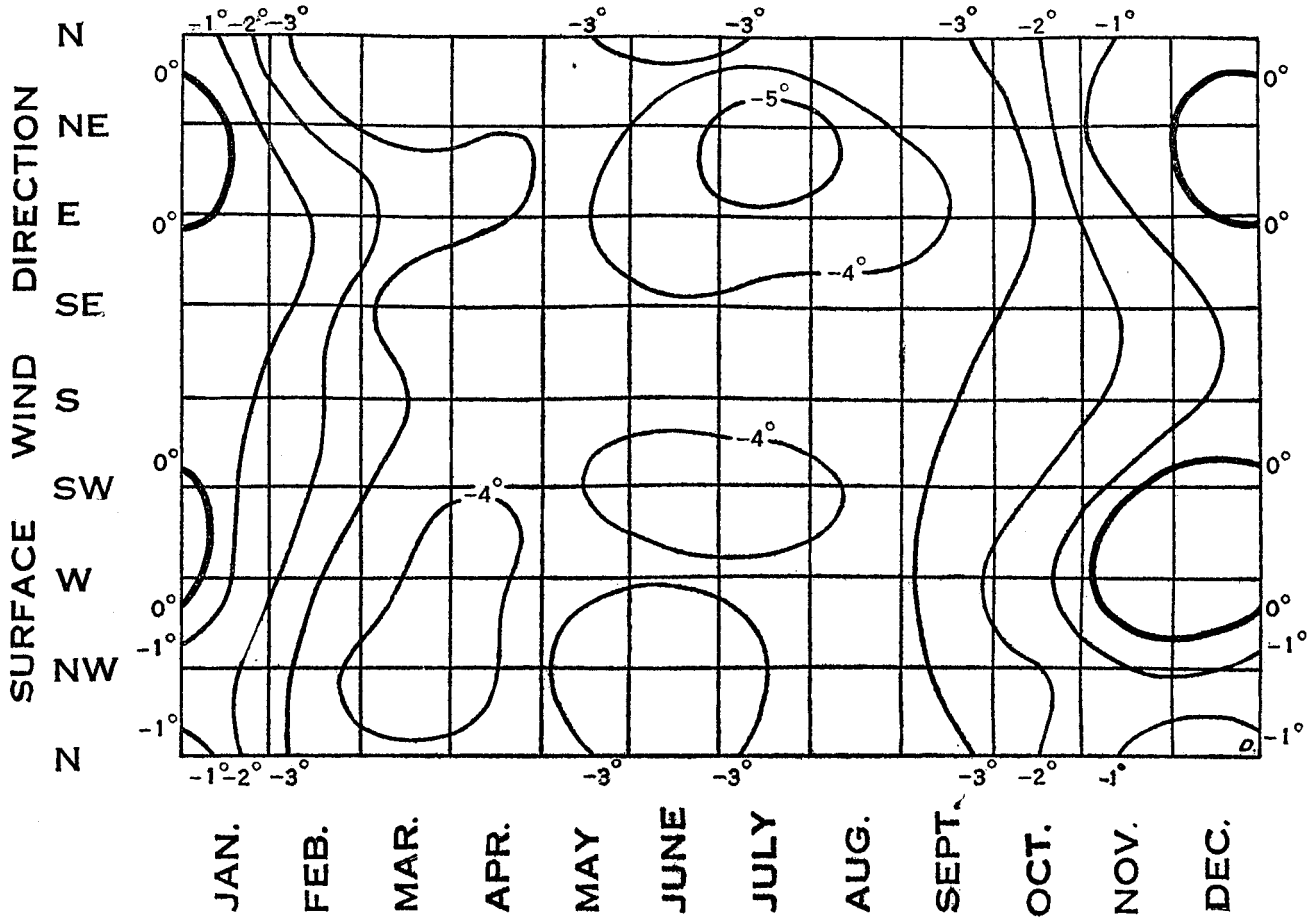


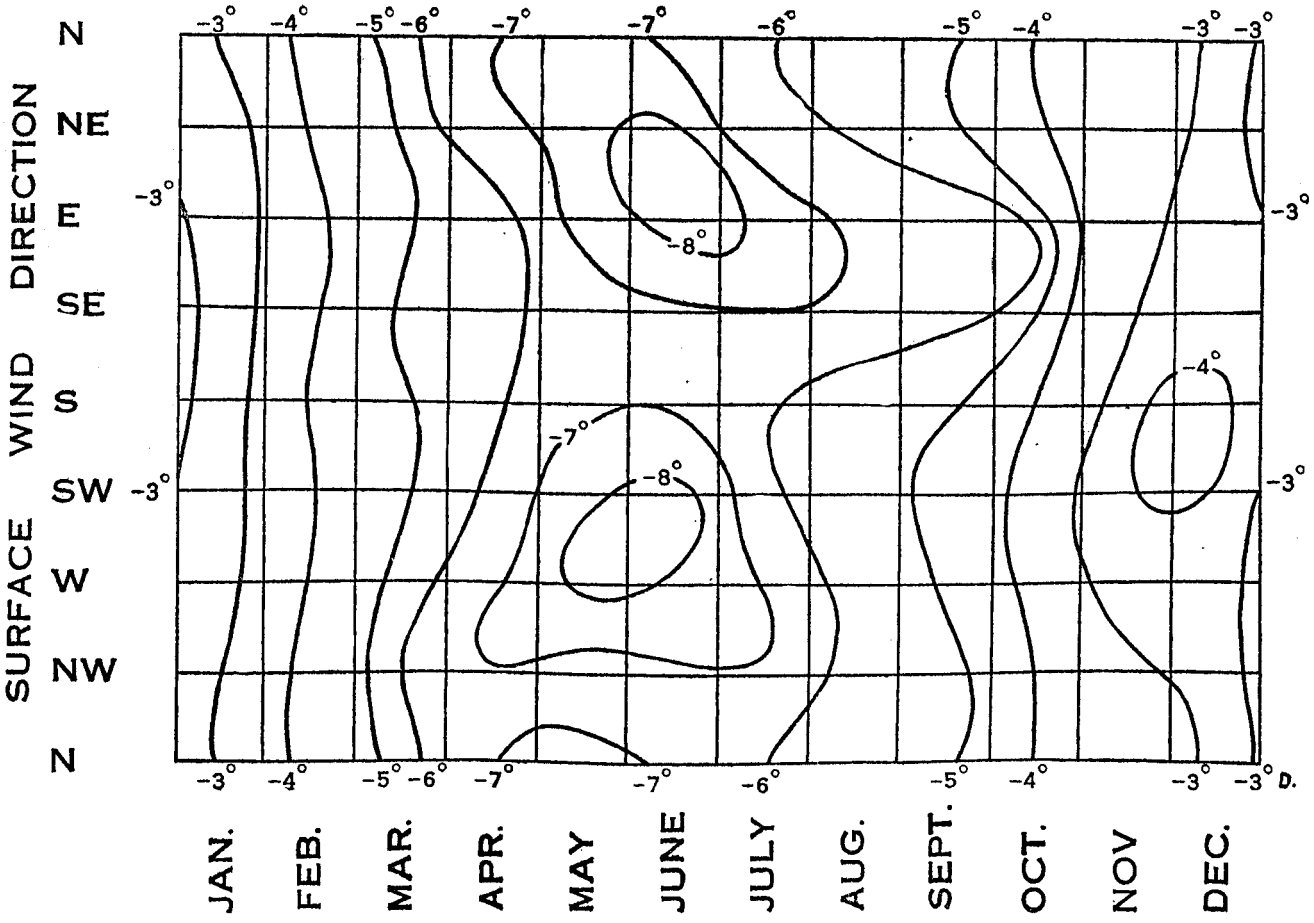


FIGS. 11-12.—Isopleths for Royal Center, Ind., for the 1 and 2 kilometer levels (upper and lower diagrams, respectively).



FIGS. 13-14.—Isopleths for Mount Weather, Va., for the 1 and 2 kilometer levels (upper and lower diagrams, respectively).





FIGS. 15-16.—Isopleths for Leesburg, Ga., for the 1 and 2 kilometer levels (upper and lower diagrams, respectively).

wind at Leesburg (1 km.) the surface wind direction is such that the source of air influential in the free-air temperature must lie to the south. This implies, for practically all stations, a Gulf source, although, in the case of Mount Weather, the Atlantic with its warm Gulf Stream is undoubtedly also a contributor of warm air.

The Leesburg anomaly noted above is only an apparent disagreement because one or two local factors must be considered with respect to this station. In the first place, the Leesburg isopleth is relatively "flat," and the fact that a maximum occurs with a northeast wind is not so significant when it is noted that this maximum is no more marked than is the maximum at the same season with southerly winds. The southerly location of the station and its situation with respect to large water areas to the south and east would lead one to expect less marked differences with different winds.

In the second place, the winds at Leesburg in the lower levels are usually light so that the effect of radiational surface cooling may be operative (especially when the total lack of snow cover is considered), tending to produce a slight morning inversion. If importation *is* concerned when light winds prevail, it will be remembered that Leesburg is so situated that air within the lowest kilometer might have had its origin along the Atlantic coast or even over the Gulf Stream. Above the 1-kilometer level, the normal turning is counterclockwise and the source would thus be thrown toward the north, whence lower temperatures should come, as indicated. Reference to the 2-kilometer isopleth for Leesburg will show that the highest mean temperature of the air column up to that level occurs when the source of the air is south of the station, hence, over the Gulf.

(3) The occurrence of the highest values of Δ in the winter months is the natural consequence of the seasonal variation of temperatures at the surface and aloft, the effect of introduction of air aloft from warmer regions, and inversions. Seasonal variations of free-air temperatures are not only of smaller amplitude than surface variations, but also exhibit a certain lag. This, combined with the frequent occurrence of strong surface radiation induces temperature inversions, sometimes of astonishing magnitude.

(4) The same arguments offered in (2) concerning the effect of a southerly component apply in an opposite sense to the effect of a northerly component as a cooling agent. Average turning with altitude of northerly surface winds is far less than with southerly. Drexel and Ellendale show the lowest temperature differences with easterly and northeasterly winds. This means that cool air from the Lake region and possibly even from the James Bay region of Canada is introduced. Broken Arrow and Groesbeck, Royal Center, and Mount Weather indicate northerly or westerly sources of relatively cool air, while Leesburg, again because of its coastal situation gets its cool air in summer from the marine sources to the east and south.

(5) The failure of the lowest values of Δ to occur in the middle of the summer rather than in late spring and early summer is, no doubt, to be ascribed to the combined effects of rapid seasonal increase of temperature at the surface and the lag of winter cold aloft. This, so long as the air has been subject to the large-amplitude seasonal fluctuations of continental temperatures would explain the tendency to greater coldness aloft at that season, with winds from such continental sources.

At stations where water influences are characteristic the season of greatest negative values of Δ should occur later, for it is the surface temperature rather than the free-air temperature that undergoes the greatest change. Hence the greatest contrast is to be expected when the surface temperature is at its maximum in midsummer or later, and that is what one finds.

(6) The slight lag of Δ when the 2-kilometer level is considered relative to the corresponding value for the 1-kilometer level is probably the result of the effect mentioned in (3). It is believed, however, that this interpretation should not be too strongly stressed both because of the lack of convincing evidence of its presence in the isopleths and because of the small magnitude of the effect as shown by temperatures below 2 kilometers.

These remarks, it is believed, cover the essential characteristics of the isopleths and afford confirmatory evidence of the conspicuous part played by wind direction below 2 kilometers in the control of free-air temperatures.

The water-vapor effect.—In accordance with the remarks contained in the discussion of the hypsometric formula in Part 2, there have been added to the various values of Δ obtained from the isopleths certain small values of temperature which are equivalent to the effect upon the pressure at the 1 and 2 kilometer levels of the mean monthly vapor pressure at the several aerological stations.

The equation by means of which this transformation was accomplished is given in Part 2. The technique of deducing the actual values is very simple and is that employed in the Aerological Division of the Weather Bureau. For the various stations have been tabulated the mean monthly vapor pressures in millibars for each of the several levels. In order to find the temperature equivalent of the mean vapor pressure of a given air column, a table entitled "Humidity correction (add to mean temperature)" has been prepared by the Aerological Division. An example of its use follows:

To find the temperature equivalent of the mean vapor pressure of an air column from the surface to 1 kilometer above sea level, at Ellendale in January, it is found that the mean vapor pressure at the surface is 2.41 mb. and at the 1-kilometer level is 2.16 mb. The mean surface pressure is 964 mb., and the mean pressure at 1 kilometer

is 897 mb. The barometric pressure is the vertical argument of the "humidity correction" table, and the vapor pressure is the horizontal argument. Hence, for the surface, we find 0.1 °C., and for the 1-kilometer level, also 0.1 °C., for the temperature values corresponding. Each of these quantities represents one-half of the equivalent temperature effect *at its level.* Thus when one-half the effect at each of two different levels are added together the result is the total effect of the mean vapor pressure of the intervening air column.[6] In this way we may add 0.1° to 0.1°, obtaining 0.2° C. as the quantity which should be added to the mean temperature of the air column in order to introduce the water-vapor effect into the calculation.

Table 5 has been prepared in this manner and gives for the seven stations the humidity effect for each month. It is true that the humidity is different with various winds, but this difference has not been taken into account here because its small magnitude would introduce a refinement incommensurable with the probable accuracy of the final values. At no station does this effect exceed 2.5° C. Hence it is clear that the classification of humidity by wind direction would be unnecessary.

[6] Cf. description of Table 61, pp. xlvi-xlvii, *Smithsonian Meteorological Tables*, 4th rev. ed., Washington, 1918.

TABLE 5.—*Vapor pressure effect in terms of temperature at various stations throughout the year (° C.).*

Station.	Ellendale.		Drexel.		Broken Arrow.		Groesbeck.		Royal Center.		Mount Weather.		Leesburg.	
Level (km.)	1	2	1	2	1	2	1	2	1	2	1	2	1	2
January	0.2	0.2	0.4	0.3	0.5	0.5	0.7	0.6	0.4	0.3	0.5	0.4	1.0	0.9
February	0.2	0.2	0.4	0.3	0.5	0.5	0.8	0.7	0.4	0.3	0.5	0.4	0.9	0.8
March	0.4	0.3	0.5	0.4	0.8	0.8	1.0	0.9	0.5	0.5	0.7	0.7	1.0	0.9
April	0.5	0.5	0.7	0.7	1.1	0.9	1.3	1.1	0.7	0.6	0.9	0.8	1.4	1.1
May	0.9	0.8	1.1	1.0	1.8	1.5	1.7	1.5	1.0	0.9	1.2	1.0	1.7	1.6
June	1.6	1.3	1.7	1.5	2.1	1.8	1.9	1.7	1.7	1.4	1.8	1.6	1.7	1.5
July	1.7	1.4	1.9	1.7	2.3	2.1	2.5	2.1	1.8	1.5	2.0	1.8	1.9	1.8
August	1.5	1.3	1.7	1.6	2.1	1.8	2.1	2.0	1.7	1.6	1.9	1.8	2.5	2.2
September	1.0	0.9	1.4	1.3	1.8	1.5	2.0	1.8	1.4	1.2	1.6	1.4	1.9	1.5
October	0.7	0.7	0.8	0.7	1.5	1.1	1.9	1.5	1.2	1.0	1.4	1.2	2.0	1.8
November	0.4	0.3	0.6	0.5	0.7	0.7	1.1	0.9	0.6	0.5	0.9	0.8	1.2	0.9
December	0.4	0.3	0.4	0.3	0.6	0.5	0.8	0.7	0.4	0.3	0.6	0.4	0.8	0.8

Final values of Δ *including vapor pressure effect.*—Having taken from the isopleths the smoothed values of Δ and added to each value the proper increment of temperature depending upon the vapor pressure, it is now possible to present tables of these values. Appendix A (pp. 64–66) gives in tables, for all stations throughout the year and for each of the eight wind directions, the value of Δ, which, when added algebraically to the surface temperature, will give a value of θ, by means of which the pressure at the chosen levels may be computed. How these values are treated in order to study their geographic distribution is the discussion allotted to Part 5.

Part 5.—THE GEOGRAPHICAL DISTRIBUTION OF Δ.

Harmonic analysis of Δ with opposing winds.—A general inspection of the isopleths indicates that southeast and northwest winds at practically all stations represent the extremes throughout the year. All other directions, with but few exceptions, yield values of Δ lying between these extremes. Hence, it will be instructive to subject the annual march of Δ with these two wind directions to harmonic analysis, not for the purpose of attempting to associate physical processes with the several harmonics, but to bring these curves into a mathematical form for a more convenient examination of their characteristics.

In performing these analyses, the simple method used and described by Turner [1] has been employed and the first three harmonics computed. The general form of the equation is, as applied to the present problem:

$$\Delta = M + A_1 \sin \alpha + B_1 \cos \alpha + A_2 \sin 2\alpha + B_2 \cos 2\alpha + A_3 \sin 3\alpha + B_3 \cos 3\alpha,$$

in which A_1 and B_1, A_2 and B_2, A_3 and B_3 are, respectively, the amplitudes of the sine and cosine components of the first three harmonics, M is the annual mean of Δ and α is the angle represented by the time interval between the epoch of the first value of the annual series and subsequent values.

Δ may be more conveniently expressed in the usual way as a function of cosine terms through the relations:

$$A = B \tan \alpha$$

and

$$a = B/\cos \varphi$$

in which φ is the angle representing the time interval between the epoch of the first value of Δ and the first maximum of the curve. Whence,

$$\Delta = M + a_1 \cos(\alpha_1 - \varphi_1) + a_2 \cos 2(\alpha_2 - \varphi_2) + a_3 \cos 3(\alpha_3 - \varphi_3),$$

in which a_1, a_2, and a_3 refer to the particular harmonics and represent their several amplitudes computed according to the equation for a above.

Instead of presenting the individual equations for the several stations, the values of a_1, a_2, and a_3, are given in tabular form below, and the several curves, together with the original values from which they were computed, appear in Figure 17.

TABLE 6.—*Coefficients of first three harmonics of Δ (2 km.)*

Station.	a_1		a_2		a_3	
	NW.	SE.	NW.	SE.	NW.	SE.
Ellendale	2.9	4.8	0.5	0.1	0.2	0.4
Drexel	2.0	3.8	0.7	1.0	0.4	.....
Broken Arrow	1.4	3.0	1.4	0.2	0.8	0.5
Groesbeck	1.8	1.6	0.4	0.5	0.6	.....
Royal Center	1.4	4.0	0.3	0.7	0.4	0.6
Mount Weather	0.8	2.0	0.4	0.8	.....	0.1
Leesburg	1.9	1.5	0.4	0.4	0.2	0.1

[1] Turner, H. H.: The facility of harmonic analysis. *Journal of the British Astronomical Associations*, Vol. XVIII, No. 6, pp. 250-254.

It is obvious from the table that the second and third harmonics have little significance, owing to their small amplitudes. If the values of a_1 for each of the wind directions are examined, it will be seen that there is an unmistakable geographical relation between them. But a_2 and a_3 have no systematic geographical distribution. It may be said, therefore, that the second and third harmonics are merely the result of fortuitous variations in the observed data, probably due to the relatively short period of observation. The geographical distribution of a_1 is quite to be expected, as was shown in the previous section, and the physical reality of the first harmonic is unquestioned, for it follows directly the annual march of insolation and radiation, which are periodic in character.

Several features of the curves in Figure 17 are worth noting:

(1) The more northerly the station, the greater the difference between values of Δ with northwest and southeast winds. In winter, at northern stations, the southeast surface wind implies a southerly wind aloft, which, coming from warm regions, makes greater contrast with the surface temperature than the northwesterly wind. In summer at southerly stations, the southeast wind as well as the northwest are cool, the former because of the marine source, and the latter because of its source in higher latitudes.

(2) At northerly stations the southeast wind gives higher temperatures aloft in comparison to the surface than northwest winds throughout the year. At southerly stations the southwest wind tends to give lower relative temperatures aloft than northwesterly winds in the autumn. The effect at the northerly stations is explained by the fact that even in summer the southeasterly wind, owing to the great distance from the coast, is likely to be warmed above that coming from higher latitudes. The autumnal effect at southerly stations is clear, for the marine source gives cool air at a time when the maximum temperature of northwesterly air is reached aloft.

(3) Free-air temperatures at southerly stations tend to be lower than the surface temperature through a greater portion of the year, while at northerly stations it is only in summer that temperatures in these lower kilometers are lower than the surface. This is because the inland stations, as previously explained, show temperature inversions in the morning hours, owing chiefly to the markedly greater amplitude of diurnal change at the surface than in the free air.

The comparison of the data, indicated by dots and crosses with the curves drawn from the data harmonically analyzed, shows at once that for the purposes of this study the difference between isopleth values and the points on the harmonically smoothed curve will not be of sufficient magnitude to influence subsequent work.

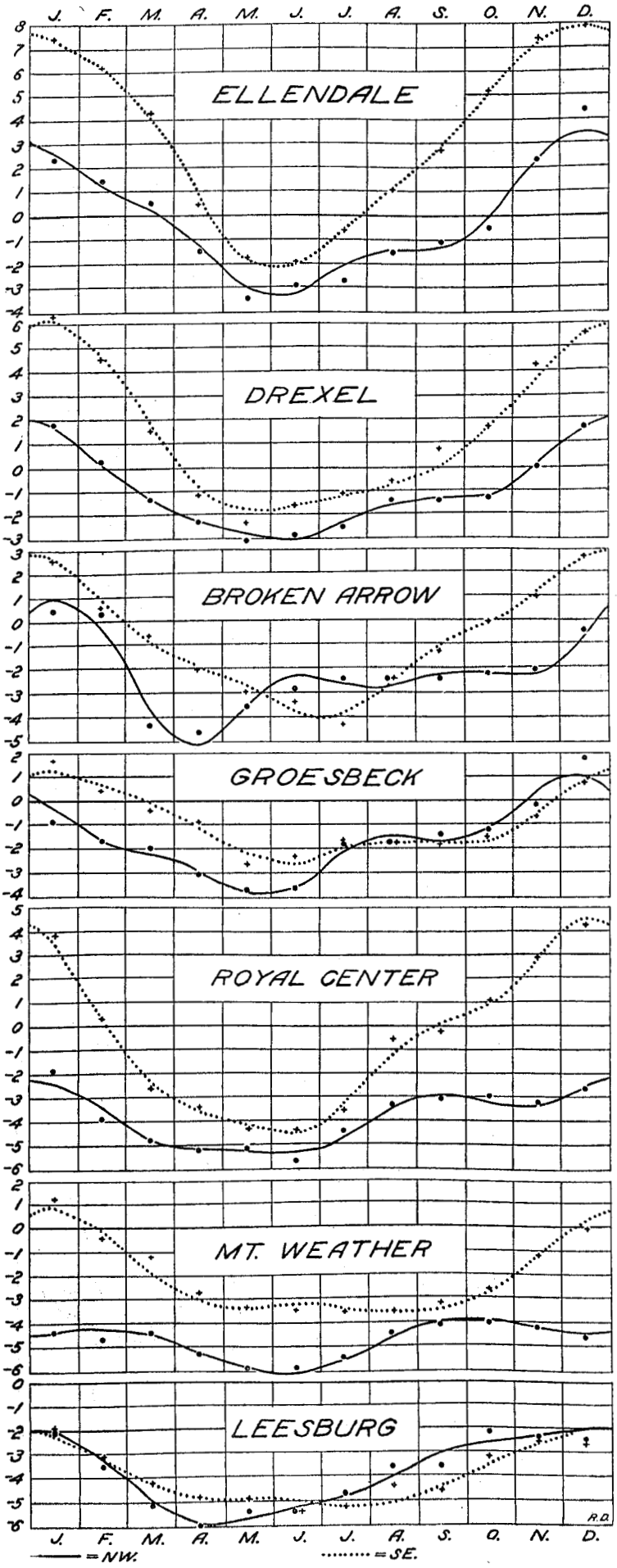


FIG. 17—Annual march of Δ for northwest and southeast winds at the kite stations.

Hence it seems hardly worth while to engage in the labor, slight as it might be for a few cases, of analyzing all the eight wind directions for the seven stations and two levels. The next step therefore is to construct maps for each of the eight wind directions for each month at each of the stations.

Maps of the distribution of Δ.—From the tables in Appendix A (pp. 64–66) were secured the data for making maps of the distribution of Δ in the eastern United States. Thus, taking a given wind direction and a certain level, 12 maps were drawn, one for each month, the proper value of Δ being plotted at the location of the station. The same was done for each of the other wind directions and the other level for the 1st and 15th of each month, making, in all, 384 maps. There may be those who would criticize this attempt to study the geographical distribution upon the basis of so few widely separated stations. But the facts that the topographic irregularities in the eastern half of the country are relatively slight and the transition from coast to interior quite regular seem to defend the procedure.

No one should object to additional aerological stations in this network. Indeed, the plotting of these values on the maps showed how useful would be an additional station in central Tennessee and one in the extreme northern part of the Michigan Peninsula. These would form, with Royal Center, a very interesting meridional profile comparable with the Ellendale-Groesbeck group. This aerological *réseau* could profitably be extended indefinitely, but for the present, at least, this extension must lie in the realm of lethargic phantasy. One must make the most of available resources.

If these values when geographically plotted seemed to be wholly unrelated to their position and of random distribution, there would be little object to the process. The fact is, however, that there is a splendid and smooth distribution of values, as is shown by the accompanying figures. Figures 18 and 19 are maps showing this distribution of Δ for each of the four directions—northeast, southeast, southwest, and northwest. These four wind directions are believed to be sufficiently representative and are therefore chosen in place of the four cardinal points. This also obviates the necessity of presenting the complete series of diagrams. Figure 18 gives these maps with reference to the 1-kilometer level, while Figure 19 shows the distribution with reference to the 2-kilometer level.

The true significance of these maps must not be missed. They do not picture a *real* condition existing at any given time, but show what the distribution of values is when a given wind is blowing at *all* the stations. Of course there never is a time when all stations have the same wind direction simultaneously, and because of this fact the chief value of these maps lies in their importance as basic material for the interpolated tables in Appendix B. It is true that certain interesting features are to be found in Figures 18 and 19, more especially in the latter, because it is farther removed from surface influence. There is, for example, a certain interest in the development of the circular formation of the isograms in practically all of the midsummer maps. The isograms show the greatest

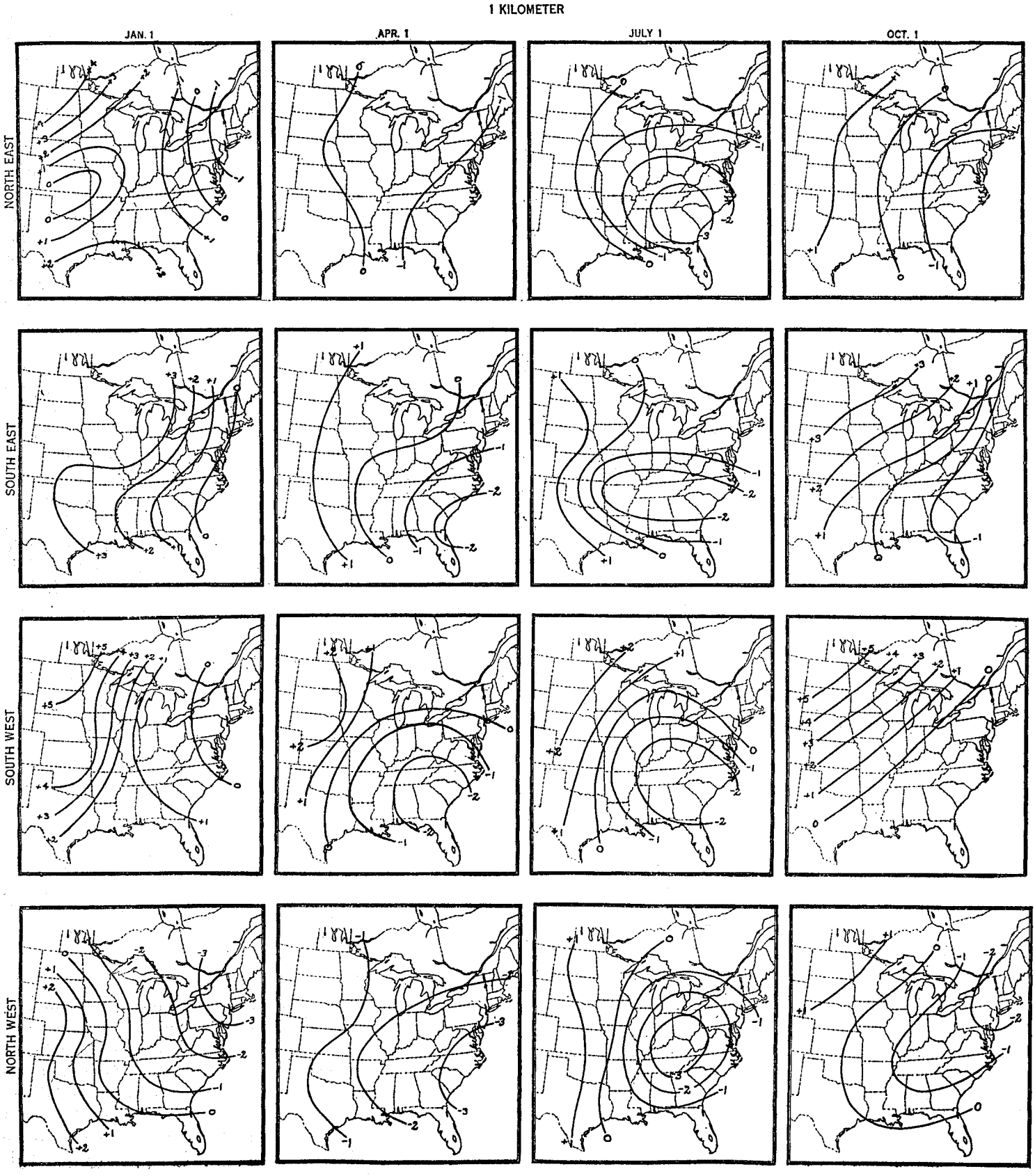


FIG. 18.—Specimen charts of the distribution of Δ at 1 kilometer.

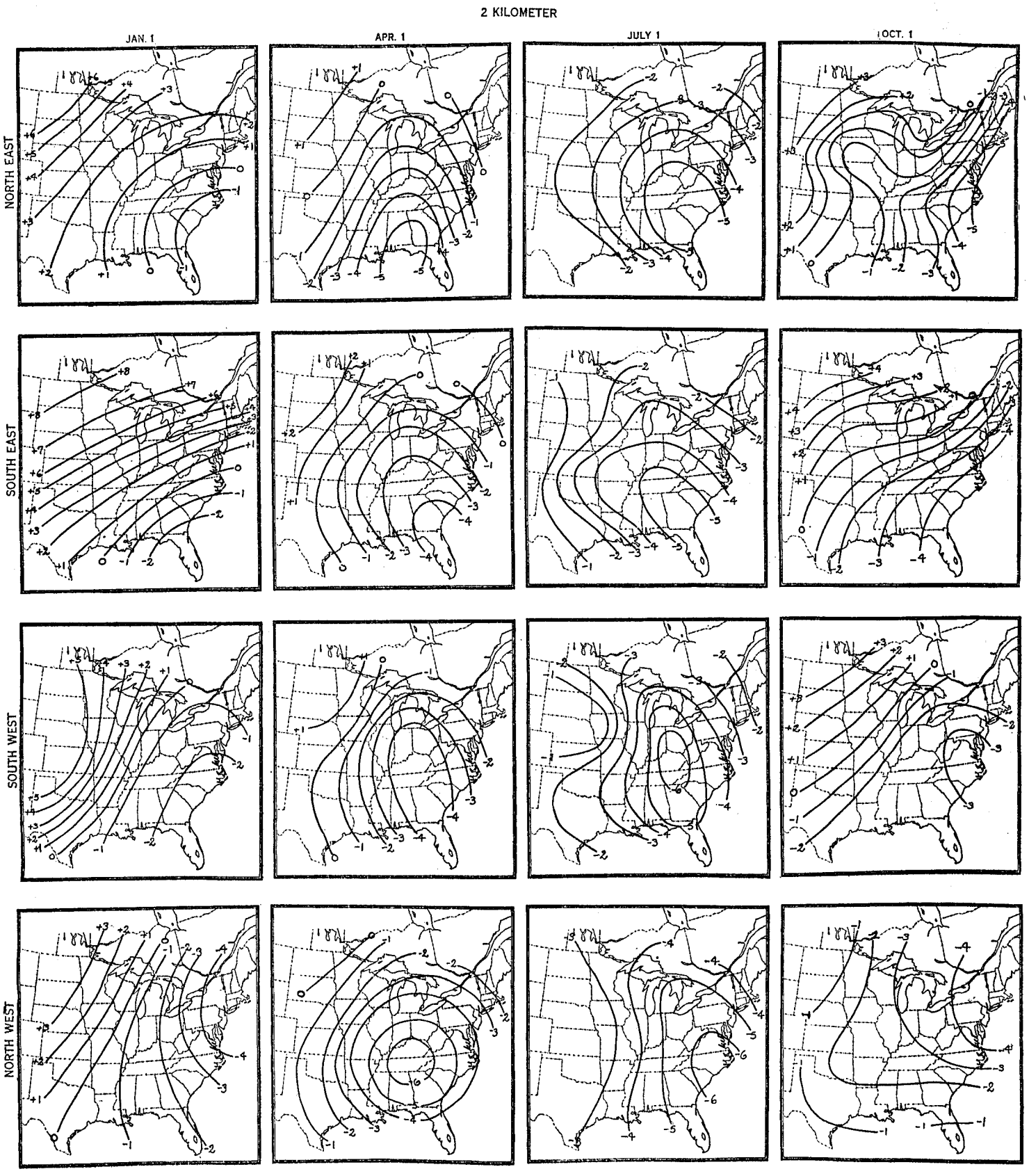


FIG. 19.—Specimen charts of the distribution of Δ at 2 kilometers.

tendency toward straightness in winter, while spring and autumn appear to be transitional.

The selection of stations.—An attempt was made to select about 30 regular Weather Bureau stations having good anemoscope exposures. It must be confessed that this was difficult. The location of wind vanes on high buildings in large cities where they are affected by eddies caused by surrounding buildings or architectural features not infrequently renders the recorded wind direction at variance with the direction at surrounding stations and the general flow indicated by the isobars. Again, certain anemoscope exposures are not comparable with those at surrounding stations because of topographic irregularities, valleys, slopes, etc., which deflect the vane from the direction the pressure gradient requires. Perhaps there have been included in this list some that are not the best from this standpoint.

Another qualification, however, is that they shall be rather evenly spaced about the country within the limits deemed safe for interpolation. The following table gives a list of the 32 stations selected, their altitudes above sea level, and the length of the air column to the two reduction levels:

TABLE 7.—*The stations, their altitudes and distances from the two reduction levels (meters).*

Station.	Altitude above m. s. l.	Length of air column to—	
		1 km. above m. s. l.	2 km. above m. s. l.
Albany N. Y.	30	970	1,970
New York, N. Y.	96	904	1,904
Washington, D. C.	34	966	1,966
Norfolk, Va.	28	972	1,972
Wilmington, N. C.	24	976	1,976
Columbia, S. C.	107	893	1,893
Jacksonville, Fla.	13	987	1,987
Atlanta, Ga.	358	642	1,642
Thomasville, Ga.	83	917	1,917
Pensacola, Fla.	17	983	1,983
Anniston, Ala.	226	774	1,774
Vicksburg, Miss.	75	925	1,925
New Orleans, La.	16	984	1,984
Houston, Tex.	42	958	1,958
Little Rock, Ark.	109	891	1,891
Memphis, Tenn.	121	879	1,879
Nashville, Tenn.	166	834	1,834
Lexington, Ky.	301	699	1,699
Indianapolis, Ind.	250	750	1,750
Columbus, Ohio.	250	750	1,750
Pittsburgh, Pa.	257	743	1,743
Buffalo, N. Y.	231	769	1,769
Port Huron, Mich.	194	806	1,806
Duluth, Minn.	345	655	1,655
Moorhead, Minn.	286	714	1,714
Madison, Wis.	297	703	1,703
Des Moines, Iowa.	262	738	1,738
St. Louis, Mo.	173	827	1,827
Yankton, S. Dak.	376	624	1,624
Concordia, Kans.	424	576	1,576
Oklahoma City, Okla.	370	630	1,630
Abilene, Tex.	530	470	1,470

It is possible that experience will dictate certain modifications in this list. Administrative exigencies may, in event of the establishment of this system for a practical trial, demand that certain of these be omitted and others substituted. Possibly more stations should be included, although not so many stations are required for free-air study as are necessary for the treatment of surface data, but it is imperative that these few be the best possible for the purpose. Figure 20 shows the distribution of these stations.

Figure 21 is interesting in that it shows the distribution of Δ at two of the interpolated stations. The upper curves give the annual march of Δ without respect to wind direction (i. e., the mean of all wind directions) at Moorhead, Minn., and Anniston, Ala., two stations representative of geographical extremes. The values for both levels are shown. The tendency for the temperature inversion throughout most of the year at the northern station is apparent, while the southern station shows a positive lapse rate except for the 1-kilometer level in winter.

On the radial coordinates are shown the annual mean values of Δ for the eight wind directions. The dotted circle indicates the locus of the zero of the diagram. Values falling outside the circle are positive and indicate a negative lapse rate or inversion of temperature. The contrast between the two stations is striking: At Moorhead the 1-kilometer curve shows positive values for all directions, and the 2-kilometer curve lies only slightly within the zero circle for west and southwest winds. At Anniston, both curves lie completely within. The Moorhead values show considerable contrast between northerly and southerly winds, thus making the curves elliptical, while the Anniston curves are more nearly circular.

The station tables in Appendix B (pp. 67–76) were constructed from the complete series of maps of the distribution of Δ, and values of Δ were tabulated for the beginning and middle of the month, for the eight wind directions throughout the year. The procedure, then, in determining the most probable mean value of the air temperature above one of these stations at 8 a. m., 75th meridian time, is simply to note the wind direction and temperature (° C.) at that time, look up in Appendix B the value of Δ corresponding to that date and wind direction, and add it algebraically to the current temperature. With this value of θ and the *surface* pressure, it is possible to compute the pressure at the chosen free-air level.

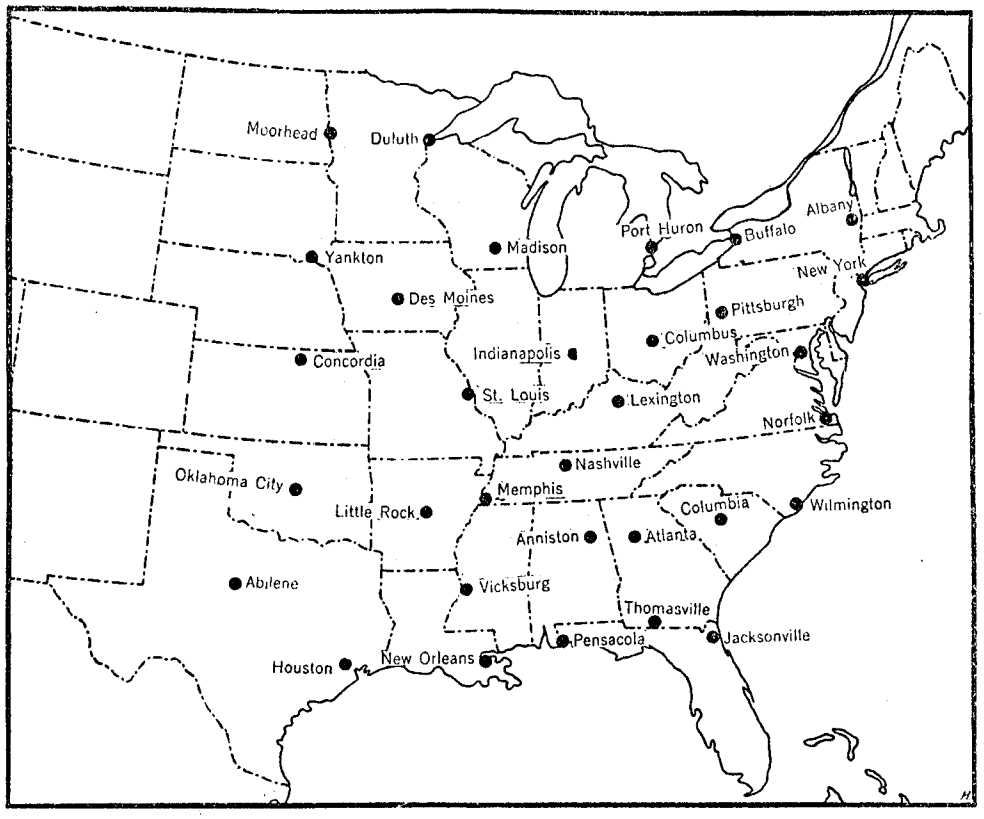


FIG. 20.—Reduction stations employed in the study.

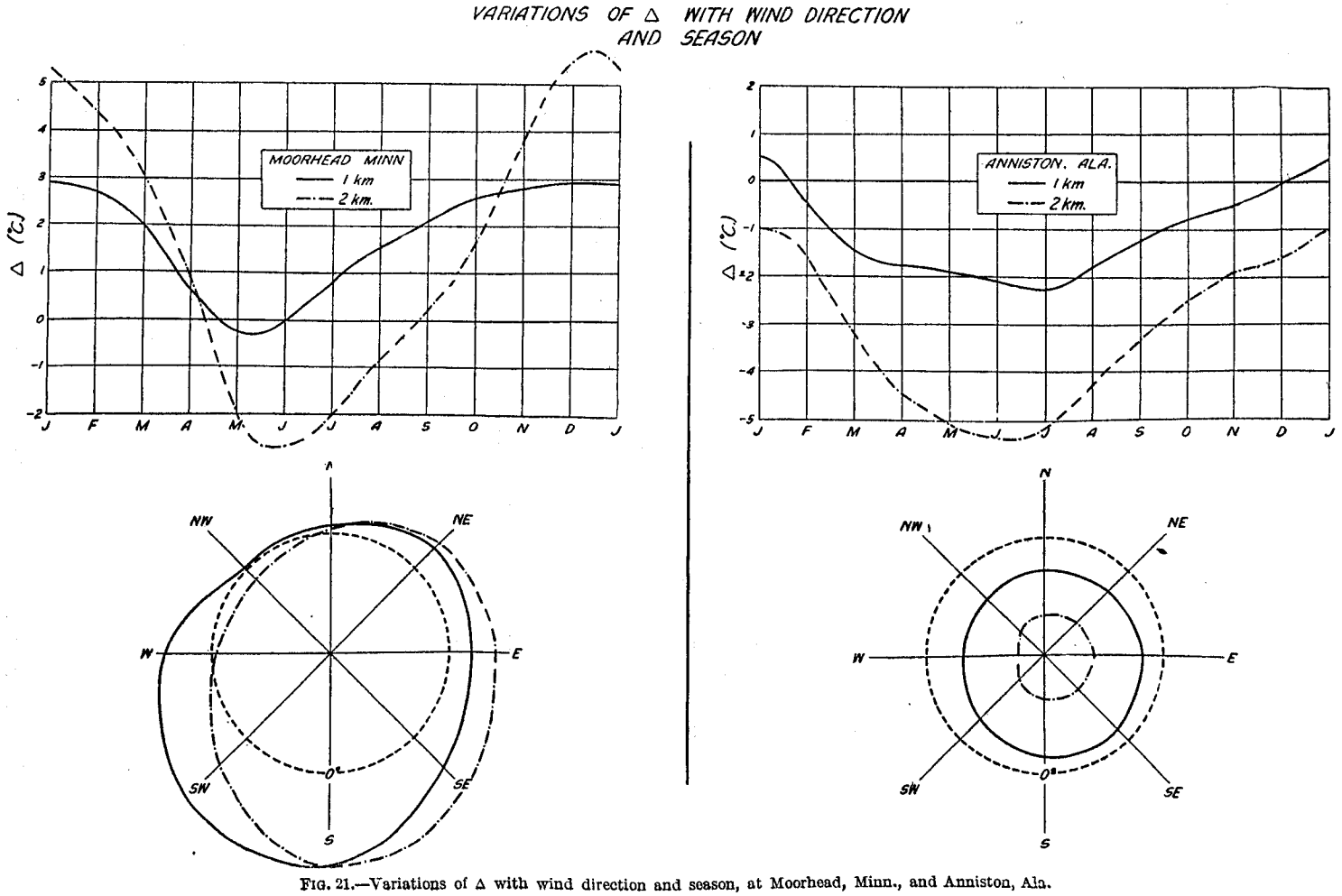


FIG. 21.—Variations of Δ with wind direction and season, at Moorhead, Minn., and Anniston, Ala.

Part 6.—TESTING THE METHOD.

INTRODUCTION.

The nature of the tests.—Before proceeding with the values of Δ deduced in the foregoing pages to the actual making of upper maps, it is desirable to subject the scheme to as many tests as possible. It is practically impossible at the present time to know the absolute synchronous pressure distribution at free-air levels; hence comparisons of pressures computed by this method with those actually existing are difficult. But three methods of approaching such tests suggest themselves, the first being direct while the second and third are indirect but dependent upon well-known and theoretically sound physical relations. These methods are:

(1) The comparison of computed pressures with those actually measured with kites. The Due West, S. C., station was inaugurated so recently that it was impossible to include in the data of this paper observations from that station. Such values of Δ as may be applied to Due West must be interpolated from the maps of the previous chapter and are in no way influenced by actual observations at that point. If, then, such interpolated values of Δ yield temperature arguments giving computed pressures in good agreement with those observed, the method may be regarded as satisfactory.

(2) Having made maps based upon observed free-air wind velocities and gradient wind relations, it is now possible to make comparison maps computed from surface data. If the two maps agree, confidence in both will be increased.

(3) On certain days when widespread pilot-balloon observations were made up to 2 kilometers it was possible to prepare computed maps for the 1 and 2 kilometer levels and, upon the basis of the gradient wind relations, to compare the observed direction and speed of the wind with the trend and spacing of the isobars.

COMPARISON OF OBSERVED AND COMPUTED PRESSURES.

Computations for Due West, S. C.—Considering the first plan, the procedure for comparing computed with observed pressure values as obtained by the meteorograph at Due West was as follows:

(1) The aerological records of 42 kite flights made at about 8 a. m. and reaching the 2-kilometer level were selected at random except that a general seasonal distribution was sought. These 42 flights were made between March 6, 1921, and January 11, 1922.

(2) The surface data at the beginning of the flights were the bases for the computations and consisted of wind direction, pressure, and temperature. These were tabulated, together with the observed pressures, at the 1 and 2 kilometer levels.

(3) Values of Δ interpolated from the maps of Part 5 were applied to the surface temperature and the pressure at the upper level computed by the hypsometric formula.

These comparisons are shown in Table 8. Inspection of the "Difference" columns for the two levels show values gratifyingly small. For the 1-kilometer level the average difference is −0.5 mb. and for the 2-kilometer level it is −1.4 mb.

TABLE 8.—*Comparison of observed and computed pressures at Due West, S. C. (mb.).*

Date.	1-kilometer level.				2-kilometer level.			
	Pressure.		Difference.	Adjusted difference.	Pressure.		Difference.	Adjusted difference.
	Computed.	Observed.			Computed.	Observed.		
1921.								
Mar. 6	907.4	908.5	−1.1	−0.8	803.3	805.8	−2.5	−2.3
8	909.1	910.3	−1.2	−0.8	805.6	808.0	−2.4	−2.1
21	915.6	916.3	−0.7	−0.7	812.6	815.0	−2.4	−2.4
Apr. 5	911.2	912.0	−0.8	−0.4	806.7	808.9	−2.2	−1.9
7	909.3	909.5	−0.2	−0.2	805.9	808.0	−2.1	−2.1
16	904.5	905.0	−0.5	−0.5	802.4	804.0	−1.6	−1.8
22	903.2	902.8	+0.4	−0.2	800.8	800.4	+0.4	−0.7
May 4	896.0	896.2	−0.2	−0.2	792.3	792.0	+0.3	+0.3
19	907.6	907.8	−0.2	0.0	804.5	805.4	−0.9	−0.7
31	902.2	902.3	−0.1	−0.1	801.3	800.6	+0.7	+0.7
July 19	908.9	909.2	−0.3	−0.3	807.8	809.2	−1.4	−1.4
20	905.9	907.0	−1.1	−1.1	805.6	807.2	−1.6	−1.6
22	905.1	906.0	−0.9	−0.3	803.7	805.4	−1.7	−0.8
Aug. 3	909.3	909.0	+0.3	+0.3	809.5	810.6	−1.1	−1.1
9	908.0	908.4	−0.4	−0.4	806.9	808.0	−1.1	−0.8
14	909.3	909.6	−0.3	−0.3	808.7	809.8	−1.1	−1.1
17	906.8	907.1	−0.3	−0.3	806.1	808.6	−2.5	−2.3
18	906.1	906.0	+0.1	+0.4	806.7	807.2	−0.5	−0.3
Sept. 13	909.9	910.4	−0.5	+0.4	810.0	810.0	0.0	+0.8
18	909.3	910.6	−1.3	−1.3	808.9	811.5	−2.6	−2.6
23	909.7	909.8	−0.1	+0.2	809.5	811.0	−1.5	−0.9
30	904.5	904.5	0.0	−0.4	804.3	804.2	+0.1	+0.1
Oct. 7	905.3	906.0	−0.7	−0.3	802.6	804.0	−1.4	−0.8
8	900.5	900.0	+0.5	+1.0	797.6	796.0	+1.6	+3.0
10	902.6	903.8	−1.2	−0.9	800.0	803.2	−3.2	+3.0
14	915.2	915.5	−0.3	0.0	808.7	810.5	−1.8	−1.6
15	912.0	913.0	−1.0	−0.6	807.6	808.0	−0.4	−0.4
Nov. 1	890.0	890.0	0.0	−0.3	788.1	786.2	+1.9	−1.4
7	909.9	909.8	+0.1	+0.5	803.7	808.2	−4.5	−4.5
12	900.9	900.3	+0.6	+1.2	794.9	794.4	+0.5	+1.5
19	908.4	908.3	+0.1	+0.1	807.2	807.0	+0.2	+0.2
28	892.5	891.8	+0.7	+1.0	788.3	787.2	+1.1	+1.7
Dec. 11	897.6	900.2	−2.6	−3.0	791.8	795.3	−3.5	−3.8
12	890.2	890.4	−0.2	+0.4	786.0	789.0	−3.0	−1.9
16	916.2	917.4	−1.2	−0.9	808.5	810.7	−2.2	−2.0
22	908.4	908.6	−0.2	+0.4	802.8	805.6	−2.8	−1.7
23	906.6	908.4	−1.8	−1.8	799.8	805.4	−5.6	−5.3
1922.								
Jan. 1	898.3	897.8	+0.5	+0.5	792.7	790.8	+1.9	+2.1
3	909.1	909.8	−0.7	−0.7	800.4	805.3	−4.9	−4.6
4	905.9	907.8	−1.9	−2.2	799.8	804.4	−4.6	−4.6
5	905.5	905.8	−0.3	+0.1	802.6	804.2	−1.6	−0.7
11	879.8	880.6	−0.8	−0.5	777.5	777.2	+0.3	+1.1
Mean	.....	.....	−0.5	−0.3	.....	.....	−1.4	−1.1
Mean temperature correction	.....	.....	.....	+0.1	.....	.....	.....	+0.2
Final mean error	.....	.....	.....	−0.2	.....	.....	.....	−0.9

The average difference, it will be noted, is negative for both levels, indicating that the computed pressure is, on the average, too low. The following effects may account for such a tendency:

(1) Change of pressure at the upper levels between the time of kite launching, i. e., the epoch of the computation, 8 a. m., and the time the kite reaches a given level. This may result in three ways. First, the increase of the mean temperature of the air column through insolation. On the average, in the flights enumerated, there was an interval of an hour between the launching time and the time of attaining the 1-kilometer level, and an interval of about two hours between launching and arrival at the 2-kilometer level. Within this time, especially in the middle of the morning, it is possible for the temperature of the air column to increase appreciably owing to warming in the very lowest layers. Second, the approach or recession of cyclonic disturbances. In this case, the change would be slightly less at the upper levels than at the surface, but in the same direction. Third, the diurnal variation of pressure. This would probably be involved in the mean of many flights.

(2) An inherent tendency for too low values of Δ in this region as the result of interpolation. Such an error must be expected and it is interesting to discover its magnitude, for upon this point hinges a great deal of the value of the method.

The effect of approach or recession of cyclonic areas and the diurnal variation of pressure.—A change in surface pressure appears at the upper levels also, as a change in the same direction but of slightly smaller magnitude, if change of temperature is left out of consideration. Hence, by noting the changes of surface pressure which occurred during the intervals under consideration in the various flights, one can estimate the amount of pressure change at the upper levels at the same time. This change of pressure includes both the diurnal change and the aperiodic variations due to cyclonic approach and recession. In the column of "Adjusted difference" these corrections have been made, regarding the pressure change at 1 and 2 kilometers as, respectively, 9/10 and 8/10 of the change at the surface. The means of these two columns show that the inclusion of this effect reduces the average error by 0.2 mb. and 0.3 mb., respectively.

At first thought, it would seem that in the long run, the aperiodic variations would not affect the mean because they are sometimes negative and sometimes positive. It is possible to get some idea of the magnitude of the diurnal change, and from the difference between it and the effect observed, to learn whether this conclusion is warranted.

The diurnal pressure wave comes to a maximum about 10 a. m. According to Bennett,[1] the annual mean pressure variations between 8 and 9 a. m. and between 8 and 10 a. m. at Washington are 0.0051 inch and 0.0065 inch, or 0.18 mb. and 0.22 mb. If we consider that the diurnal effect amounts to about 0.2 mb. at the levels under consideration and we found above that the mean of 42 cases was decreased by 0.2 mb. and 0.3 mb., respectively, we may justly conclude that the irregular variations are only slightly operative and that the diurnal change is the controlling factor in the adjustment of these observations.

The effect of temperature change.—The average change of temperature between times of kite launching and arrival at the 1-kilometer level was 0.7° C.; between the time of launching and attaining the 2-kilometer level was 1.7° C. The annual mean hourly change of temperature at the various levels at Drexel, Nebr., indicates that at about 350 meters above the surface the effect of surface warming between 8 and 10 a. m. is imperceptible.

Hence, assuming a linear lapse rate from the surface to 560 meters above sea level at Due West (station elevation plus 350 meters, approximately) and no change above that height, it is possible to ascertain the approximate effect of this warming in the levels nearest the surface upon the mean temperature of the air column. This would have the effect of raising the mean temperature of the air column by about 0.2° C. for each of the levels, an effect which, converted into terms of pressure at the two levels, amounts to approximately 0.1 mb. and 0.2 mb., respectively. That is to say that, on the average (only these 42 flights considered), the computed pressure would be too small by the above amounts. Hence if the means of the adjusted differences are corrected for this temperature effect to the time of kite launching the outstanding error will be, as shown at the foot of the table, -0.2 mb. for the 1-kilometer level and -0.9 mb. for the 2-kilometer level.

Errors of interpolation.—The residual negative tendency is small enough to exert but little effect upon the whole map when it is considered that the isobars will be drawn for intervals of 2.5 mb., horizontal difference of pressure. Moreover, such tendencies will probably not be localized at certain stations but will, in general, be operative over considerable areas, with the result that the horizontal gradients of pressure will be but little affected. It is the gradient rather than the absolute pressure that is of chief concern.

The scatter of the data.—To decrease the negative tendency by the application of the probable thermal effect to the mean of the column of adjusted differences does not alter the scatter of the residuals. It merely transfers them *en masse* from axes represented by -0.3 mb. and -1.1 mb. to -0.2 mb. and -0.9 mb., respectively. In other words, the computed pressure is adjusted so as to conform as nearly as possible with observations made at 9 a. m. and 10 a. m. at the two levels, except for the probable slight underestimation of Δ by interpolation.

If the probable variation of the individuals in the adjusted difference columns from the means of those

[1] Bennett, Walter J.: Hourly pressures for Washington, D. C., 1891-1904. Mo. WEATHER REV., July, 1915, p. 317.

columns are computed from the customary formula

$$E = \pm 0.6745\sqrt{\Sigma v^2/n},$$

in which Σv^2 is the sum of the squares of the residuals and n is the number of cases, they are found to be ± 0.54 mb. and ± 1.21 mb., respectively. This computation is justified by the fact that earlier statistical studies of the variations of Δ revealed the distribution of residuals to be that required by the Gaussian normal-error curve; hence that their occurrence is fortuitous. Here are pressure residuals which are a direct result of the accidental variation of Δ, and they may therefore be subjected to a similar statistical treatment. It is interesting to note that the probable variation as derived in the earlier paper from temperature data only was ± 0.55 mb. for 1 kilometer and ± 1.29 mb. for 2 kilometers, *almost identical with that just found at Due West.*

When it is considered that Due West is an interpolated station and not one from which original data were taken, it is apparent that the computation of upper pressures by the method here proposed is entirely feasible. The persistent negative tendency of Δ is not an argument against the reliability of wind direction as an index to upper temperatures but an argument for more aerological stations in order to obviate the necessity of interpolating over great geographical distances. It may be remarked further that interpolation for Due West is about as difficult an interpolation as has to be performed in the entire eastern United States, both because of the great distance between Mount Weather and Leesburg and the lack of a third station to the eastward to consult in the interpolation. Other combinations of stations are not so difficult. The Leesburg-Royal Center interpolation, the longest, is more reliable because of the presence of the western group on the one hand and Mount Weather on the other. The Leesburg-Groesbeck interpolation is safer because of the decided geographical similarity and the smaller amplitude of variation of Δ at the southern stations. All this supports the proposal for interpolating between these stations even at great distances. The establishment of additional stations, as was said before, would certainly be desirable, since they would add more of the fundamental data to the final working tables.

A cursory examination of the adjusted differences shown in Table 8 with special reference to seasonal variation of reliability will be of interest. If the 42 cases are grouped by seasons (December, January, and February constituting winter, and so on) we have too small a number of examples to treat statistically, yet their means may be significant. Table 9 shows these seasonal mean residuals:

TABLE 9.—*Mean adjusted difference between observed and computed pressures at Due West, S. C., in different seasons (mb.).*

Season.	1 kilometer.	2 kilometers.
Spring	−0.4	−1.3
Summer	−0.2	−1.2
Autumn	0.0	−0.1
Winter	−0.8	−2.1

This indicates for both levels a smaller reliability in winter than in any other season. These facts are pointed out for whatever value they may have, but attention is invited to the fact that the preliminary study of a very much larger body of temperature data indicated no appreciable difference from season to season.

Table 8 shows, further, that the large value of the probable variation at the 2-kilometer level is due mainly to a few large discrepancies. In fact, if the five flights giving an adjusted difference greater than 3 mb. were eliminated the probable variation for this level would be ± 1.07 mb. instead of ± 1.21 mb. and, what is more striking, the mean of the 37 observations would be -0.6 mb. instead of -1.1 mb. Investigation of each of these cases of large residuals showed that inversions of temperature occurred during the flights—unusual phenomena for the particular surface winds with which they were associated. The only attitude that can be assumed with regard to these occasional large differences is that they *will* occur and that their occurrence will be according to the law of chance. We must expect them, but we know that they will not occur frequently. The critic may justly say that it is the *current* value of pressure that counts and not the average. This is true, but the answer has been given before, that we are chiefly concerned with the gradient rather than the absolute pressure. Therefore, so long as abnormal tendencies distribute themselves over a considerable region and do not localize at individual stations (as they do at present in the plateau region in reducing to sea level) the horizontal gradient will not be seriously affected.

Similar comparisons at other stations.—In the MONTHLY WEATHER REVIEW for April, 1921,[2] there was given, in this connection, a table showing 20 comparisons of observed and computed pressures at the remaining kite stations. These stations were used in the original derivation of Δ, but the dates for comparison were all later than the period included by the original data. This table is reproduced here with certain modifications to render it comparable with Table 8; i. e., the signs of the residuals have been reversed and the mean recomputed. These flights were all made in the wintertime, hence are not useful in discussing seasonal variations of reliability.

[2] Pp. 238–239.

However, they are comparable with the winter average in Table 9.

TABLE 10.—*Comparison of observed and computed pressures at upper levels at various aerological stations (mb.).*

Station.	Date.	1-kilometer pressure.			2-kilometer pressure.		
		Computed.	Observed.	Difference.	Computed.	Observed.	Difference.
	1921						
Ellendale, N. Dak.	Jan. 8	902.8	901.8	+1.0	794.1	792.1	+2.0
	Jan. 24	909.7	909.6	+0.1	799.4	800.5	−1.1
	Feb. 8	890.0	891.0	−1.0	780.2	784.9	−4.7
	Feb. 27	891.4	893.0	−1.6	786.4	789.6	−3.2
Drexel, Nebr.	Jan. 2	891.9	892.2	−0.3	787.2	787.4	−0.2
	Jan. 7	898.4	898.4	0.0	793.7	792.1	+1.6
	Feb. 7	902.7	904.1	−1.4	792.3	794.2	−1.9
	Feb. 14	903.1	904.4	−1.3	802.1	802.1	0.0
Broken Arrow, Okla.	Jan. 1	896.2	896.5	−0.3	791.9	792.5	−0.6
	Jan. 27	908.9	907.7	+1.2	801.2	803.9	−2.7
	Feb. 10	895.7	896.0	−0.3	791.9	791.7	+0.2
	Feb. 21	898.9	899.1	−0.2	792.1	793.1	−1.0
Groesbeck, Tex.	Jan. 13	899.0	898.9	+0.1	792.7	794.1	−1.4
	Jan. 21	911.3	910.4	+0.9	810.1	808.3	+1.8
	Feb. 10	899.5	899.6	−0.1	795.1	795.4	−0.3
	Feb. 18	904.6	905.1	−0.5	800.1	800.9	−0.8
Royal Center, Ind.	Jan. 5	898.7	898.0	+0.7	792.5	792.0	+0.5
	Jan. 6	906.5	906.6	−0.1	800.8	802.3	+1.5
	Feb. 2	899.5	899.3	+0.2	792.1	790.0	+2.1
	Feb. 14	903.5	904.1	−0.6	799.1	800.2	−1.1
Mean				−0.2			−0.5

Here it is seen that the mean difference is slightly negative, but when the mean difference is adjusted in a manner similar to that in Table 8, we have 0.1 mb. and 0.0 mb. as the respective mean differences for the two levels. This appears to be a very satisfactory agreement. Owing to the small number of observations no attempt will be made to apply statistical methods.

Accuracy of kite observations.—It should be remembered that the *observed* pressures do not necessarily represent absolute accuracy, owing to instrumental errors, errors of estimation, or accidental errors of computation in working from the original meteorograph sheet. The very careful scrutiny and numerous checks to which aerological data are subjected practically eliminate computational errors; there may be occasional accidental errors, however, in reading from the meteorograph traces, especially when the record shows considerable vibration of the pens. While no study of the errors of these meteorograph pressure values has been made, it is estimated that it probably does not exceed ±1 mb. A determination of the probable error of observed pressures and other aerological elements would be of value.

PRESSURE MAPS BY TWO INDEPENDENT METHODS.

Pressure maps from observed wind velocities.—The theory underlying the gradient wind is well known, and, except for levels within approximately 500 meters of the surface, the equations may be assumed to hold with sufficient accuracy when the distribution of pressure at the upper level is known. A rough approximation of the gradient wind just above this level may be made from the sea-level distribution of pressure providing the station altitude is not great. But, at best, this is a hazardous procedure, and in computing the gradient speed and direction the best results are obtained by using pressure gradients *at the level in question.*

The region lying roughly within the first 500 meters of the surface can not be accurately estimated by the ordinary gradient-wind equations because of the retarding effect upon wind velocity exerted by the earth's surface and the lower layers of air in which turbulence prevails. The introduction of this element into the gradient-wind equations at once renders it a problem of considerable mathematical complexity. The question has been thoroughly studied by Taylor, Richardson, Whipple, and others. All of the stations that will be considered in this study are so far from the 1-kilometer level that the influence of this retarding factor will be inappreciable; hence it will be quite unnecessary to consider it in the computations.

The equations for the gradient velocity above, say, 500 meters above the surface, are for cyclones, straight isobars, and anticyclones, respectively:

$$V=\sqrt{rdp/\rho dn+(r\omega \sin \varphi)^2}-r\omega \sin \varphi;$$

$$V=(dp/dn)/2\omega\rho \sin \varphi;$$

and

$$V=r\omega \sin \varphi-\sqrt{(r\omega \sin \varphi)^2-rdp/\rho dn},$$

in which V is the velocity, r is the radius of the small circle upon which the air is moving, dp/dn is the horizontal pressure gradient, ω is the angular velocity of the earth's rotation, ρ is the density of the air, and φ is the latitude of the place.[3]

From these equations it is possible to compute the velocity if the various terms in the right-hand members are known. Conversly, if the gradient dp/dn is unknown, but the speed of the wind is observed by kite or pilot balloons, it is possible to solve the equations for dp/dn and thus determine the gradient. If this is done for a number of stations, the distance between isobars can be computed and the distribution of pressure at the upper level determined, the trend of the isobars being indicated by the observed wind directions. A few kite flights reaching the required levels enable one to assign actual values to the isobars, thus completing the map.

In 1920, as a matter of interest, this was done.[4] Figures 22, 23, and 24 show, respectively, the barometric situation at 8 a. m., March 27, 1920, at sea level, 1 kilometer, and 2 kilometers above sea level. These maps are reprinted from that article. The wind arrows show the directions from which the trend of the isobars was determined. At that time it was impracticable to compute the pressure at the upper levels in any other way; with the completion of the tables of Δ, however, it is now possible to compute a map for the same date and time based only upon surface conditions. The similarity of the two sets of maps thus independently arrived at

[3] Cf. Humphreys, W. J.: *Physics of the air*, pp. 138–144.

[4] Meisinger, C. Le Roy: The making of upper-air pressure maps from observed wind velocities. MO. WEATHER REV., Dec., 1920, pp. 697–701.

indicates not only that both are substantially correct but also that the Δ-method of computing pressures is reliable.

The reader is therefore invited to compare Figures 23 and 24 with Figures 25 and 26. It is needless to say that the agreement is striking.

Only one feature need be remarked upon, and that not because of its importance but because of its suggestiveness. As we shall see shortly, there are conditions when the wind does not agree in direction with the trend of the isobars. Hence, in drawing isobars such as those in Figures 23 and 24, one must draw boldly, attempting to make the general air movement over a given area agree with the isobaric trend. Consequently, little thought was given the matter when the wind arrow at West Point, Ky., was found to be somewhat discordant with the isobaric trend based upon adjacent stations. But the computed map, Figure 26, shows an irregularity in the 795 mb. isobar, which exactly accords with the observation. The author has no desire to stress this point as being remarkably significant, but wishes to suggest that the coincidence is probably more than accidental.

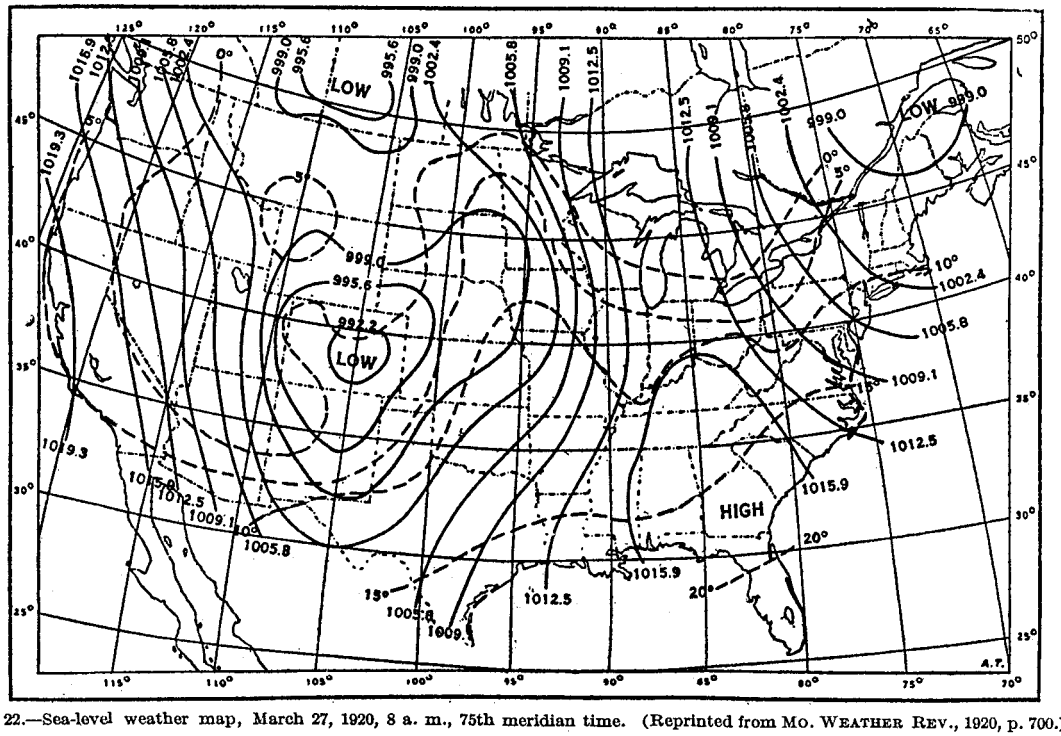


FIG. 22.—Sea-level weather map, March 27, 1920, 8 a. m., 75th meridian time. (Reprinted from MO. WEATHER REV., 1920, p. 700.)

FURTHER COMPARISONS OF OBSERVATION AND THEORY.

Computed maps and observed winds.—In line with the above idea is that of drawing free-air pressure maps by computation alone, and then comparing them with free-air wind observations at as many stations as possible. This is substantially the same idea as that employed above, except that no map is drawn from the observed wind velocities.

The Aerological Division, from an inspection of its records, supplied a list of dates when widespread pilot-balloon observations were made at the several stations of the Weather Bureau, the Signal Corps, and the Navy. Pressure maps, based entirely upon surface data, were computed. The observed winds were then compared with the maps. It must be remembered that the wind arrows were entered upon the maps *after* they were drawn, and were in no way influential in determining the distribution of the isobars. Figures 27 to 30 show the result.

Gradient wind in theory and practice.—Before proceeding to consider the relations between the trend of the *computed* isobars and *observed* winds, there are several considerations concerning the theory of the gradient wind that are worth presenting, because they are helpful in determining what is to be expected of the winds in a given isobaric situation. In the preceding pages, isobars were drawn upon the basis of wind arrows. In general, however, it imposes too much upon nature, especially when meteorological phenomena are involved, to expect perfect concordance with theory, or, to state it more modestly, it is expecting too much of theory to anticipate an accounting for *all* the phenomena of nature expressed in the weather complex.

But even the theory of the gradient wind does not assert that the winds should parallel the isobars unless (1) the pressure formation is stationary, and (2) a steady state of adjustment between wind and gradient has been attained.

Concerning the former qualification, Col. E. Gold [5] says "the curvature of the isobars is not the same as the curvature of the path of moving air unless the pressure

[5] Barometric gradient and wind force. *Meteorological Office Publication No. 190*, London, 1908, pp. 42-43.

system remains for some time unchanged. This, in general, is not the case * * *."

Sir Napier Shaw [6] shows that at any time in a moving cyclone the wind is blowing around a center which he calls the "kinematic" center, while the isobars are concentric about the "dynamic" center, the latter being on a line perpendicular to the direction of travel of the cyclone and at a distance from the kinematic center equal to $V/(2\omega \sin \varphi + \zeta)$, where V is the velocity of translation of the system and ζ the angular velocity of rotation. It is clear, therefore, that the faster the pressure system moves the greater will be the angle between the isobars and the wind direction at any instant.

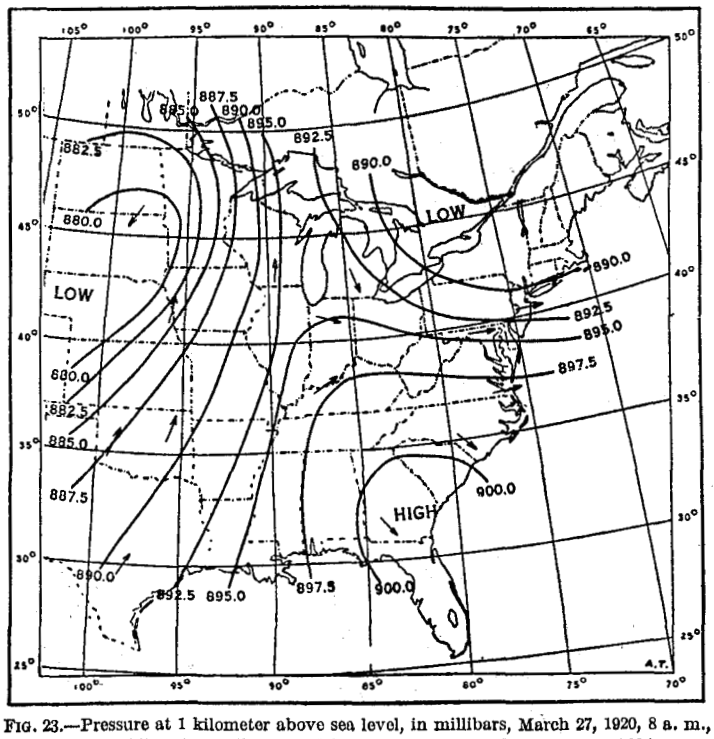


FIG. 23.—Pressure at 1 kilometer above sea level, in millibars, March 27, 1920, 8 a. m., 75th meridian time. (Reprinted from Mo. WEATHER REV., 1920, p. 700.)

Moreover, if there is a rapid change in the intensity of the pressure there will be some lag in the adjustment of the wind to the gradient; in fact, when the pressure is continually changing; i. e., when the gradient itself is undergoing change, as it nearly always is, the process of adjustment is constantly going on. This adjustment would therefore be most nearly perfect with a slow-moving or stationary formation of unchanging intensity. Colonel Gold [7] has computed the length of time required for such a steady state to be attained under conditions of (1) a particle starting from rest and moving in response to a constant force in a constant direction, and (2) a particle starting from the center (polar coordinates) and moving in response to a force of constant magnitude but directed from a fixed point. In the first case the acceleration in the direction of motion vanished after about 4 hours and the velocity in that direction ceases after about 8 hours; in the second case the acceleration along the radius vector vanishes after 5 hours and the velocity in that direction vanishes after about 16 hours. These figures imply rather long intervals for the adjustment to take place, but in nature the initially perfectly stagnant condition is seldom, if ever, attained and the adjusting process is always operative.

Jeffreys,[8] after giving the approximate equation for geostrophic winds, remarks that this relation is "often assumed to be correct even when the pressure distribution is changing with time; but this involves the assumption that the air is not accelerated along its path, which

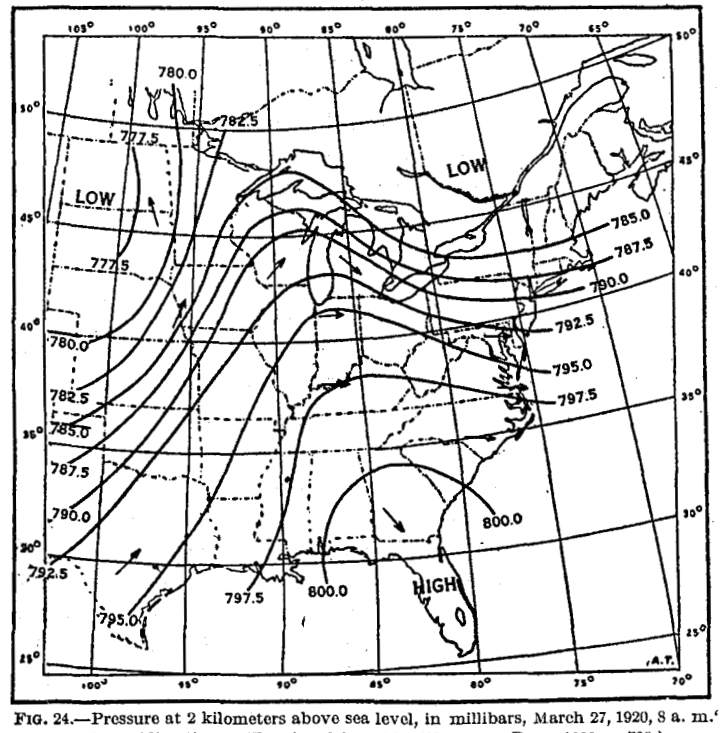


FIG. 24.—Pressure at 2 kilometers above sea level, in millibars, March 27, 1920, 8 a. m., 75th meridian time. (Reprinted from Mo. WEATHER REV., 1920, p. 700.)

means that dV/dt is neglected while $\partial p/\partial t$ is retained. This is a very uncertain hypothesis, for in general these two quantities would be expected to be of the same order of magnitude."

Thus it is seen how with a very rapid change of pressure there might be some tendency, in addition to the phenomena of translation, for the winds to fail to agree with the isobars. Shaw,[9] however, says in this regard:

> From the results of our work it seems possible that as a general rule in the free atmosphere in ordinary circumstances the disturbances of the balance are not large enough to interfere with the conclusions to be drawn from it, but there may be in special localities singular points or lines, points or lines of convergence or divergence, and therefore of convection, to which we can not apply the assumption of a balance between the field of pressure and the field of velocity.

It appears therefore that of the effects mentioned the first, dealing with the rotation of winds about the "kinematic" center, is the more important in causing observed

[6] Manual of Meteorology, Part IV. *The relation of wind to the distribution of barometric pressure.*

[7] Loc. cit., pp. 13-15.

[8] On traveling atmospheric disturbances. *Philosophical Magazine*, January, 1916, p. 3.

[9] Loc. cit., p. 133.

winds in the free air to disagree with the trend of the isobars.

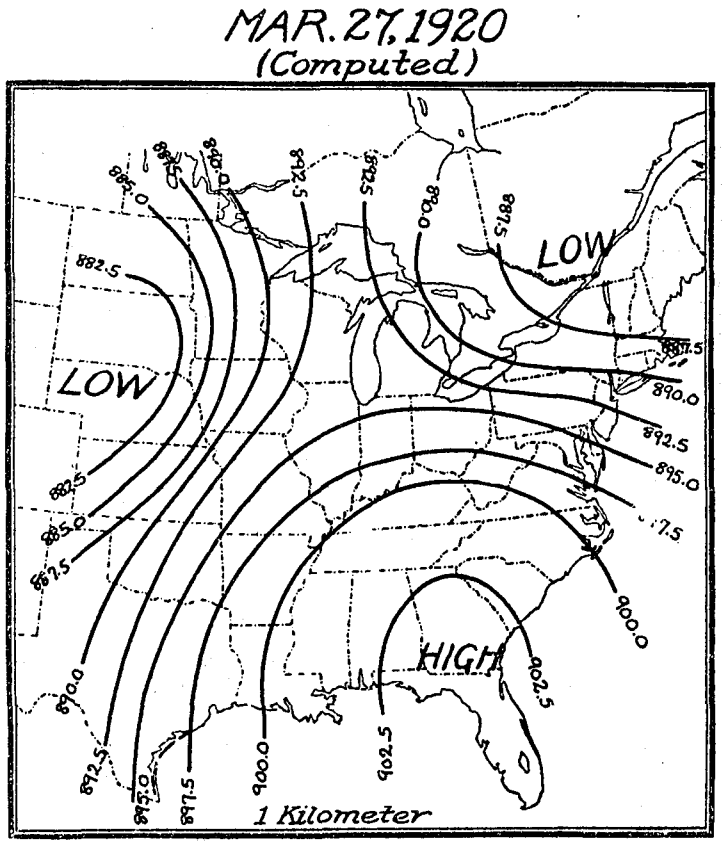
In the *Manual of Meteorology*, Shaw rather vigorously defends the method of comparing the isobars with the winds in the free air against the criticism of Bjerknes [10] that "the accordance of these curves (the isobars) with the direction of the arrows (representing the stream lines) is never complete and should be complete only in exceptional cases."

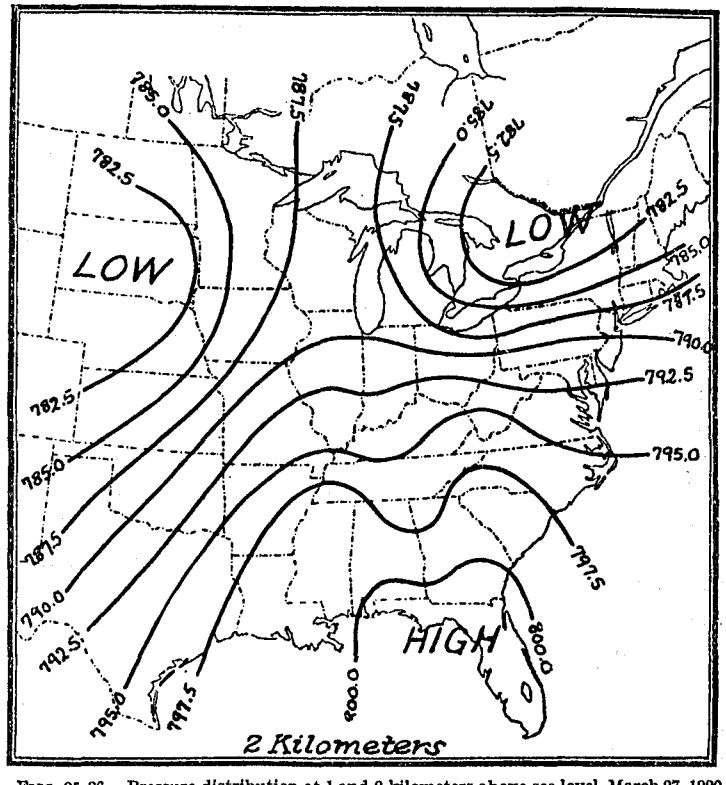
There are other reasons why the observed wind might not agree with the isobars, assuming the latter to be correct. First, the recorded wind may actually be in error either because of accidental error in reading the theodolite, in plotting, or in copying; second, owing to stagnant conditions, the direction taken without regard to speed may give an erroneous impression. This is the case usually when there is a lack of latitudinal temperature contrast at the surface and a consequent decrease of the horizontal pressure gradient in the free air.[11]

Third, owing to convective irregularities [12] and minor irregularities in pressure [13] the difference in direction recorded at the same level after a short time may be considerable.

Enough has been said to show that a failure of "perfect" agreement between computed isobars and observed winds is not to be wholly attributed to inaccuracies in the isobars, although it is not the purpose here to shield the computed isobars in any way behind a barrage of criticism of the results of pilot-balloon observations. The previous agreement of fact and theory in this connection indicates quite clearly that no such defense is necessary. These remarks are adduced rather to explain if possible those inevitable cases in which it is difficult to know what the winds *should* do under given isobaric distributions.

Comparison maps at 1 and 2 kilometers.—In general, the maps (figs. 27, 28, 29, and 30) speak for themselves, and, when studied with respect to the various considerations presented earlier in this section and in connection with the table of observed wind speeds at the two levels (Table 11), the agreement in nearly all cases is strikingly satisfactory. In fact, only one map, that of August 23, shows wind arrows that are not in good agreement with the isobars. Table 11, however, shows that, with very few exceptions, the wind speeds over the entire country were low; in fact, the air was generally stagnant. There were only two observations where the wind exceeded 10 meters per second, namely, at the 1-kilometer level at Broken Arrow, Okla., and at the 2-kilometer level at Lee Hall, Va. In the vicinity of these stations, however, the winds were light, and, since the pilot-balloon speed is really the result of only a momentary observation it is





FIGS. 25-26.—Pressure distribution at 1 and 2 kilometers above sea level, March 27, 1920, 8 a. m., 75th meridian time, computed from surface data.

[10] Dynamic meteorology and hydrography. *Carnegie Institution of Washington Publication No. 88*, Part II, p. 62.

[11] Gregg, W. R.: Temperatures versus pressures as determinants of winds aloft. MO. WEATHER REV., May, 1920, p. 263.

[12] Tannehill, I. R.: Some observed irregular vertical movements of pilot balloons. MO. WEATHER REV., April, 1919, pp. 223-225.

Ibid.: Note on pilot-balloon flights in a thunderstorm formation. MO. WEATHER REV., October, 1919, pp. 725-727.

Warren, Leslie A.: Wind stratification near a large thunderstorm. MO. WEATHER REV., June, 1919, pp. 395-396.

[13] Dobson, G. M.: Forecasting the winds from the pressure gradient. *Quarterl Journal of the Royal Meteorological Society*, October, 1921, pp. 261-269

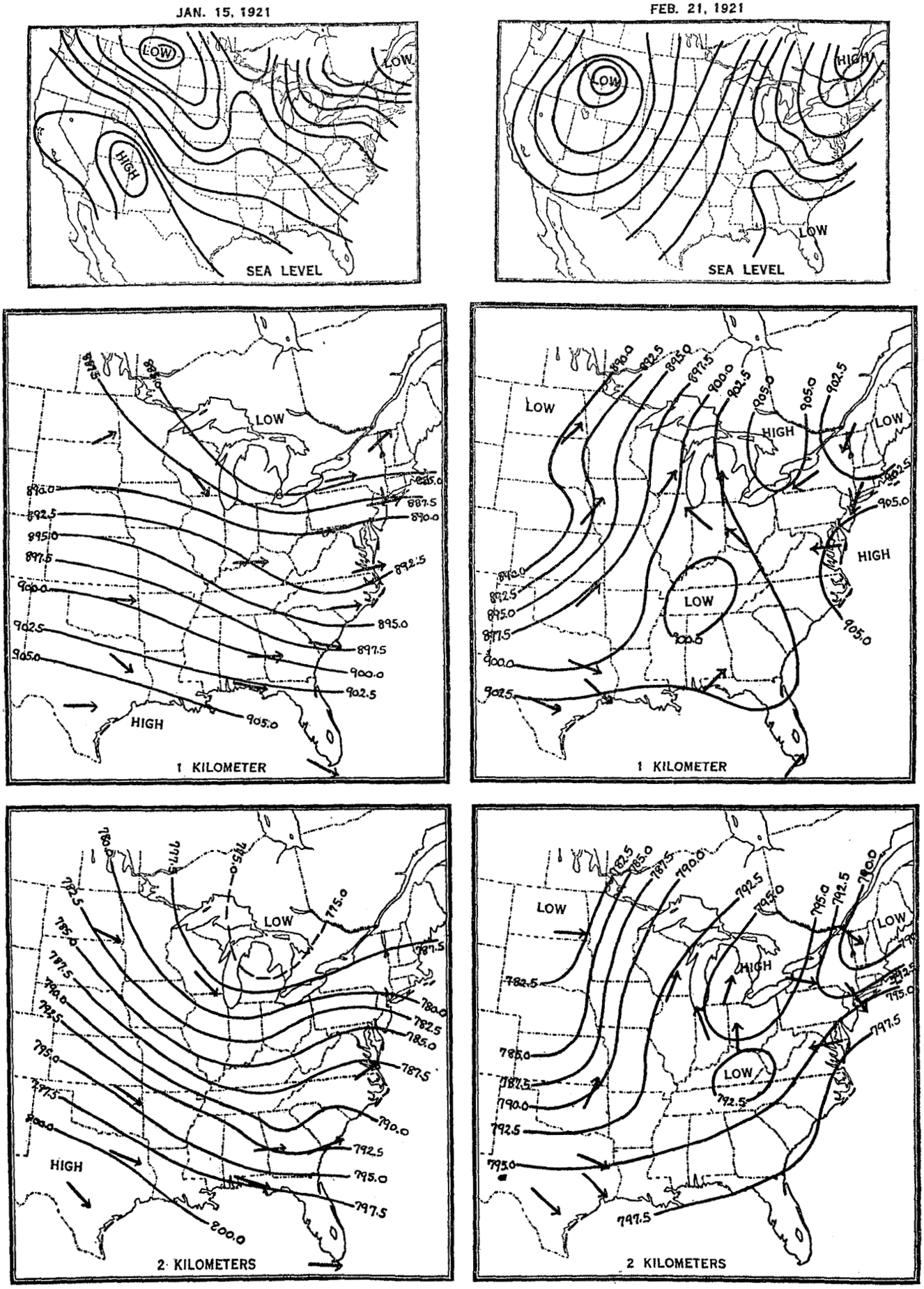
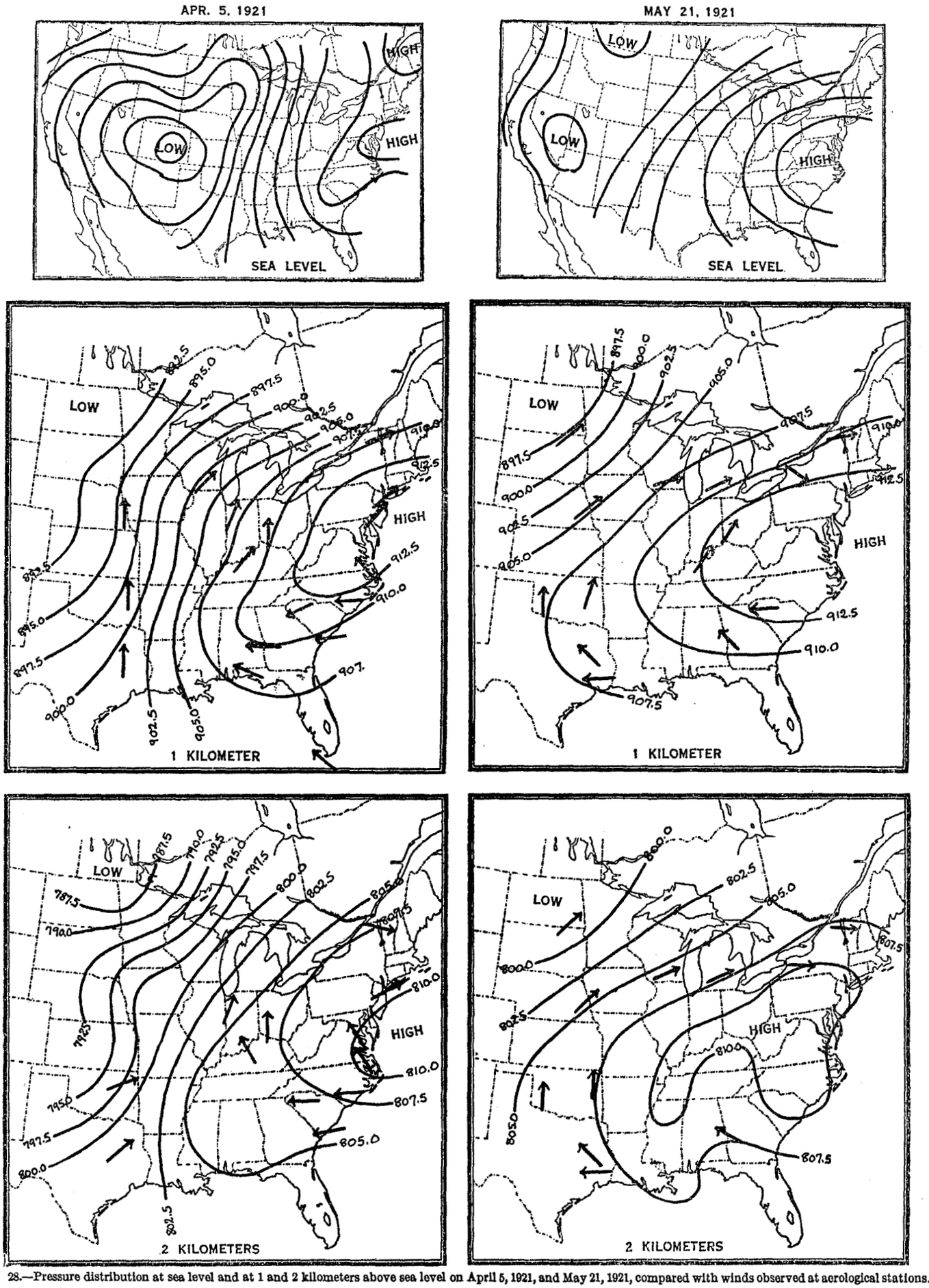


FIG. 27.—Pressure distribution at sea level and at 1 and 2 kilometers above sea level on January 15, 1921, and February 21, 1921, compared with winds observed at aerological stations.



28.—Pressure distribution at sea level and at 1 and 2 kilometers above sea level on April 5, 1921, and May 21, 1921, compared with winds observed at aerological stations.

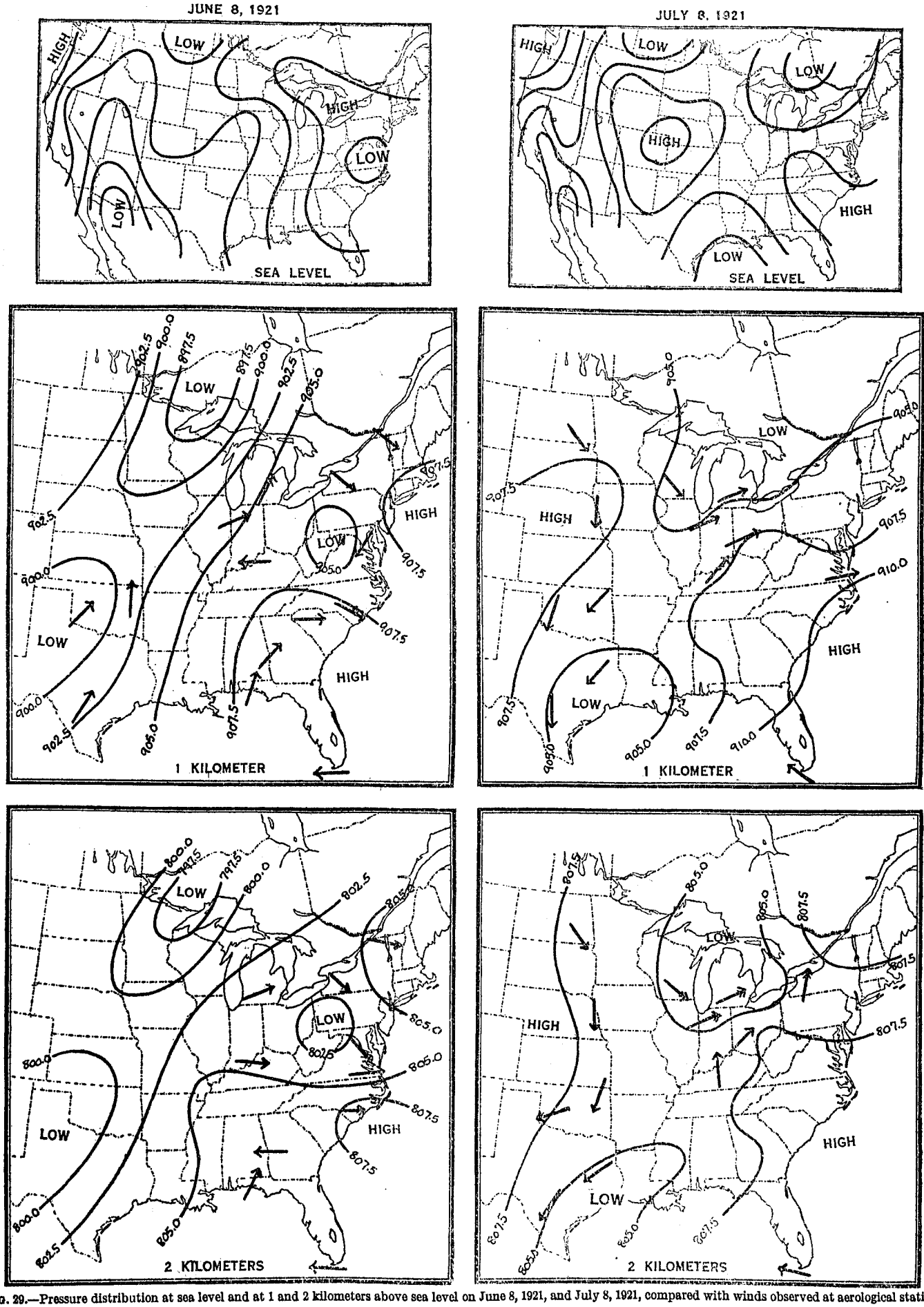


FIG. 29.—Pressure distribution at sea level and at 1 and 2 kilometers above sea level on June 8, 1921, and July 8, 1921, compared with winds observed at aerological stations.

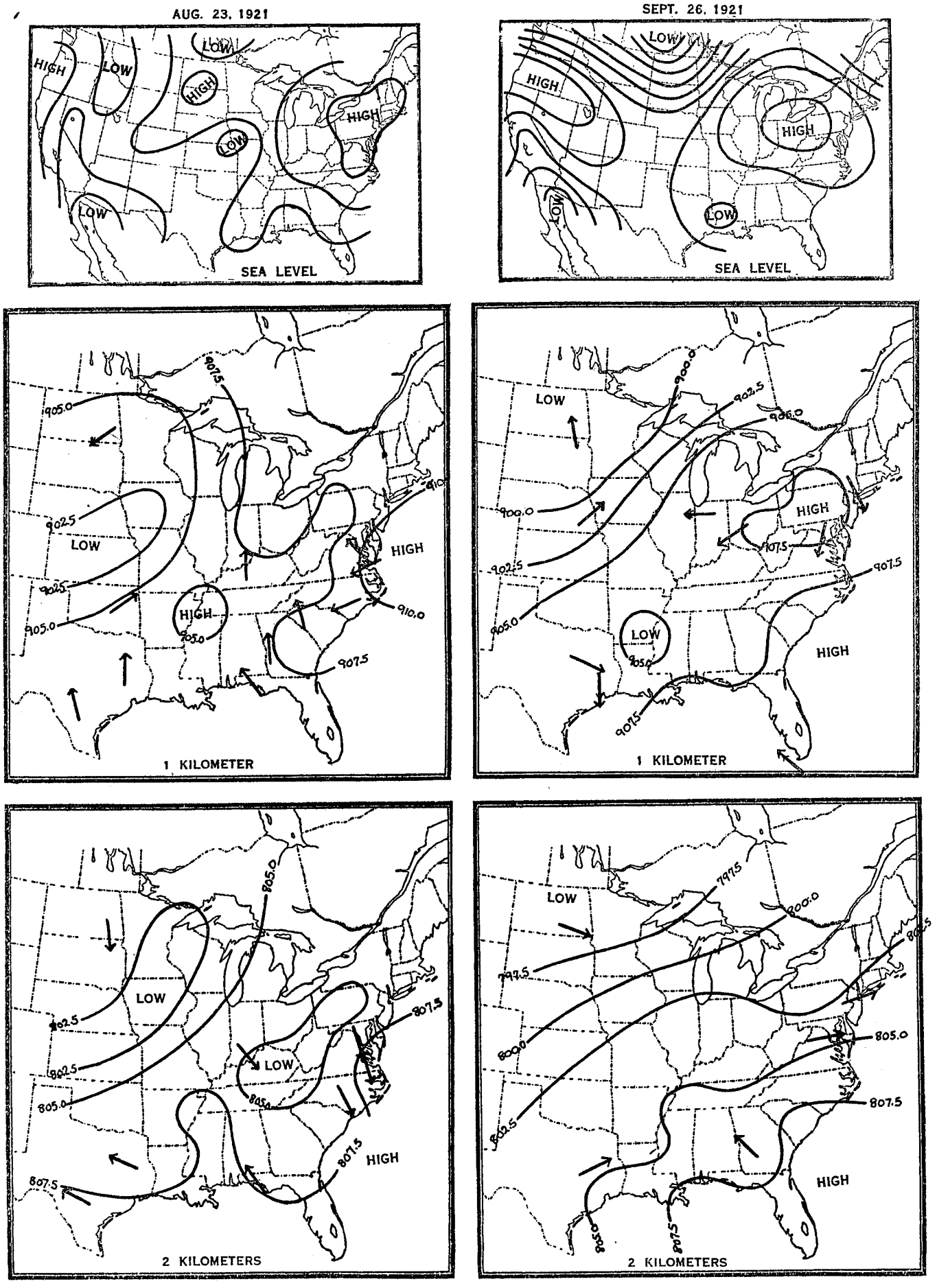


FIG. 30.—Pressure distribution at sea level and at 1 and 2 kilometers above sea level on August 23, 1921, and September 26, 1921, compared with winds observed at aerological stations.

altogether possible that the balloon was under the influence of local convection, which might give rise to a momentary lurch or turbulent gust.

Kite flights were made at the same time at Ellendale, Drexel, Broken Arrow, and Royal Center. At all places, the direction given pilot balloons and kites is in substantial agreement, and the same can be said of the speed, except at Royal Center, at the 1-kilometer level, where the pilot-balloon speed was 4 m. p. s. as opposed to 10 m. p. s. registered by the kite.

It should be noted that the horizontal temperature gradient between Duluth and Key West was only about 12° C., and the θ gradient from which the free-air pressures were computed were only 6.7° C. at the 1-kilometer level and 8.6° C. at the 2-kilometer level, between Duluth and Jacksonville. This is in accord with the point which has often been made, that, under conditions of a weak latitudinal temperature gradient at the surface, the upper winds may be expected to be light and variable; with a steep temperature gradient, the sea-level pressure formations change rapidly with altitude and the isobars tend to lie from west to east at relatively low elevations.

It is easily seen, therefore, from these maps, that when the pressure formations are relatively well defined, the agreement of observed winds with computed isobars is best; when the map is "flat" and the pressure formations vague and irregular, the agreement is not so dependable. This, however, does not militate against the accuracy of the computed isobars, for it is a well-known fact that light and variable winds always accompany such pressure formations when the horizontal temperature gradient is weak. These maps have their particular application to aviation, but, under conditions of light winds, the problem of aerial navigation is correspondingly simplified. On such stagnant summer days, the aviator is more concerned with the vertical component of the air than the horizontal. On August 28, 1921, there was probably not a single section east of the Mississippi and Ohio Rivers where the wind speeds were of sufficient magnitude to be a factor in the navigation of either lighter-than-air or heavier-than-air craft.[14] West of these regions, where the observed winds were stronger, the pressure formation was more definite and the agreement in direction better. Attention is called to the fact that the tongue of low pressure protruding from the Southwest into the Missouri Valley was more pronounced at the upper levels than at sea level, and its reality is confirmed strongly by the Ellendale, Drexel, and Broken Arrow observations.

[14] Meisinger, C. LeRoy: The weather factor in aeronautics. Mo. Weather Rev., December, 1920, pp. 701-708.

TABLE 11.—*Velocities of observed winds at pilot-balloon stations (m. p. s.).*

Station.	km.	Jan. 15.	Feb. 21.	Apr. 5.	May 21.	June 8.	July 8.	Aug. 23.	Sept. 26.
Burlington, Vt.	1	9	7	9	13	5	3		
	2		8	11	12	7	3		
Ithaca, N. Y.	1	12	6	3	8	17	3		
	2		4		8	21	5		
Mitchell Field	1	12	9	11				3	11
	2		10	7				5	16
Lakehurst, N. J.	1			8					
	2			2					
Washington, D. C.	1		10	4	1	5	2	5	9
	2		7	5	2	10	2	7	12
Lee Hall, Va.	1	13		5	1	6	4	9	2
	2			10	1	10	1	13	
Camp Bragg, N. C.	1	6		8	4	7	3	7	
	2			8		5	2	7	
Due West, S. C.	1			12	5	10	2	5	3
	2			8		2	3	4	2
Parris Island, S. C.	1	16	10	10					
	2	20		6					
Key West, Fla.	1	14	3	7		5	10	2	5
	2	29		1		5	8	4	4
Pensacola, Fla.	1	18	8	9		9	7	7	4
	2	25				5		9	3
Camp Benning, Ga.	1	17		12	8	5		8	4
	2	23		2		5		2	5
Camp Knox, Ky.	1	11		7	8	8	15	5	
	2			7	4	11	10	5	
McCook Field, Ohio.	1		8	5	5		10	1	5
	2		8	5	3		8	3	4
Royal Center, Ind.	1		4	12	3	7	9	[1] 4–10	8
	2		6	14	2	3	10	6	2
Lansing, Mich.	1		5		5	8	7		
	2		6		7	4	14		
Madison, Wis.	1	7	9	18	13	4	10		
	2	14	11		7	3	8		
Ellendale, N. Dak.	1	13	3		9		8	[1] 6– 7	14
	2	18	8		8		8	[1] 9–10	14
Fort Omaha, Nebr.	1		9	15	20		7	[2] 5	14
	2				12		12	[2] 1	
Broken Arrow, Okla.	1	13	8	19	12	15	5	[1] 16–15	
	2	20	11	15	5		10	[1] 2– 5	
Groesbeck, Tex.	1	8	8	13	8		10	5	7
	2	17	14	17	9		8	5	8
Fort Sill, Okla.	1				13	11	4		
	2				11		11		
Ellington Field, Tex.	1		10		12				5
	2		21		12				3
Kelly Field, Tex.	1	8	9			6	4	5	3
	2	8	17				6	9	2

[1] Kite observation.
[2] Kite observation at Drexel, Nebr., about 20 miles west of Fort Omaha.

These tests could be continued indefinitely, but it is believed that sufficient evidence has been brought forward to justify the conviction that these free-air maps are accurate. Are we not, therefore, justified in carrying on? If the answer is in the affirmative, we are obliged to give the maps the most thorough study possible in order to ascertain their value for day-to-day forecasting. Their value in relation to aviation is unquestioned, and, if the example of the Japanese meteorologists is to carry any weight with us, we can not escape the belief that these daily charts of free-air conditions will be useful in general forecasting.

Part 7.—SPECIMEN MAPS.

REDUCTION TECHNIQUE.

Introduction.—The point has now been reached when it is possible to carry out the actual reduction of pressure. For a single worker to perform all the reductions for a series of synoptic maps, even when as few as 32 stations are employed is a laborious process. It was seen at the outset that such an undertaking necessitated the use of a graphical reduction device instead of the more precise but time-consuming method of calculation directly from the formula. About the time that various plans were being considered for carrying out the reductions in the most expeditious manner, the problem was solved by the appearance of a nomogram for pressure reduction in *Meteorologische Zeitschrift.*[1] With certain modifications required to adapt it to the special needs of this problem, this chart was constructed and has been used in all the maps that follow. A brief description of this chart is given here, but extended explanation and tables may be found elsewhere.[2]

The reduction nomogram.—In its simplest form, this chart consists of three scales, which are parallel and horizontal. The topmost scale, designated the θ-scale, is graduated to show the mean temperature of the air column; the lowest of the three scales is designated the B-scale and shows sea-level pressure; the intermediate scale, designated the b-scale, shows the pressure at some intermediate level. Any number of intermediate scales may be drawn according to the intended use of the chart. The equations used in the calculation of points on these scales follow and are so arranged that they give greater spacing between intermediate scales corresponding to the lower levels of the atmosphere than do those of Schwerdt and Loebe:

$$x_1 = -533.333/(1+\alpha\theta) \qquad y_1 = 0$$
$$x_2 = 8(1000 \log B - 3070) \qquad y_2 = -400$$
$$x_3 = -20\, y_3(\log b - 3.07) \qquad y_3 = -400/(1+0.0008145\, h)$$

It is clearly seen that the θ-scale and the B-scale are fixed by the arbitrarily chosen distance between them, but y^3, the ordinate of the b-scale. is a function of the altitude above sea level, h. Hence, if one wishes to deal with station pressures and their reduction to sea level, it is necessary to construct an intermediate scale corresponding to the altitude of the station above sea level. Similarly, if one wishes to reduce pressure from sea level or any station level to levels in the free air, it is necessary to draw as many intermediate scales as there are levels of interest. Having these scales, it is only necessary to connect two known elements, such as station pressure and mean temperature of the air column, with a straight line, and the third, or unknown element— say pressure at some free-air level—will be given at the intersection of the appropriate scale and the line. The chart employed in these reductions had intermediate scales ruled for each of the 32 stations and for the 1 and 2 kilometer levels.

Errors of the chart.—Theoretically, the nomogram is perfectly accurate, and if it were only possible to draw an "ideal" chart, the graphical reduction method (save for the errors of estimating tenths between units) would be quite as accurate as the computations performed on a calculating machine. But the chart can not be perfect; it is inevitable that errors of graduation will creep in, and that a certain amount of distortion will result from changes of humidity if the chart is made of cardboard. The great saving in time, however, makes it really worth while to determine carefully the errors of the chart and then apply a correction to the final readings. For each of the stations, three test readings were made at various well-separated points, and the reductions compared with computed values. In most cases, the correction was slight, amounting to only two or three tenths of a millibar, while the largest correction amounted to 2.8 mb. It appeared that, in this latter case, the station scale was slightly displaced from its correct position, for the three points gave identical corrections.

The actual corrections are not given here because they are characteristic of this particular chart and would differ for every other, hence they are not of general interest. It suffices to say, therefore, that all the data plotted in the following free-air maps were corrected for the errors of the nomogram.

VARIATIONS OF PRESSURE WITH ALTITUDE.

The thermal effect in pressure formations.—When one approaches the question of thermal effects in and about pressure formations, it is quite necessary, owing to the multiplicity of opinions concerning the origin and maintenance of cyclones, to define clearly one's viewpoint. This is not a discussion of the dynamics of the atmosphere, but a presentation of certain free-air pressure maps representative of the barometric distribution in the lowest 2 kilometers of the atmosphere on given dates. It is desired, first of all, to make it clear that there is no intention of becoming involved in the question of the origin of storms, for that is obviously outside the field of this

[1] Schwerdt, H. G., and Loebe, W. W.: Eine nomographische Tafel zur Luftdruck reduktion. *Meteorologische Zeitschrift*, May, 1921, pp. 139-142.

[2] Meisinger, C. Le Roy: Concerning a graphical device for pressure reduction. Mo. WEATHER REV., July, 1921, pp. 396-399.

paper. Therefore, two considerations are paramount: (1) The cyclone, in this paper, is regarded as an atmospheric disturbance which sweeps into the field of observation, displays its phenomena, and passes on; its place and mode of formation are at present of no concern; (2) the temperature distribution below the 2-kilometer level is regarded as a consequence of the presence of the particular distribution of pressure. These two premises are not intended to conceal dynamic phenomena, but rather to define the viewpoint in the following discussion.

The latitudinal temperature gradient at the surface.—Let us consider for a moment the significance of a strong surface latitudinal temperature gradient, leaving initial pressure differences at the surface out of consideration. Suppose the surface pressure equal between two points on a meridian. This is equivalent to saying that an equal weight of atmosphere is pressing upon the two stations. But, on the surface, the temperature gradient is very steep from cold in the north to warm in the south. It follows clearly that the air above the warm station will be expanded to a greater extent than above the cold station, hence a given free-air isobaric surface will lie higher above the warm station than above the cold. This will create a pressure slope downward toward the north along which the air begins to flow in response to gravity; but the rotation of the earth quickly causes this air, initially directed toward the north, to become a west wind flowing parallel to the surface isotherms. Upon some level of equal gravity potential above the warm station there will be higher pressure than above the cold.

Similarly, if the thermal contrast at the surface is longitudinal—that is, if two stations, one warm and one cold, lie in the same latitude—the air will obey gravity in attempting to flow from above the warm to above the cool station. If the warm one is the more easterly, the air starts westward but becomes a southerly wind, owing to deflection by the rotating earth. At a given time, then, there is high pressure over the warm station and low pressure over the cold, while the station pressures may be exactly the same, assuming, of course, equal station altitudes and vertical gradients of temperature. In other words, the temperature term in the hypsometric equation has a reciprocal effect and the greater the value of this term, the smaller will be the difference between surface and free-air pressure.

The thermal effect of a pressure gradient.—Let a pressure formation, a cyclone, for instance, be superposed upon the system of parallel surface isotherms. The circulation will be counterclockwise, and, as soon as the depression has had time to make its influence felt, it will tend to disturb the hitherto parallel distribution of the surface isotherms and they will be shifted in accordance with the thermal characteristics of the air which is being imported. Since simple initial thermal conditions have been assumed, the isotherms will be shifted to the north in the front of the cyclone and to the south in the rear (Northern Hemisphere). When this occurs, the pressure center in the free air ceases to be directly above the surface center, but is shifted toward the region of coldest low-level air, for the reasons shown above. The direction of this shift, would, under such conditions, be toward the northwest. Moreover, if the region to the south and southeast is relatively cool and that to the northwest relatively warm, the shifting of the center will be toward the east in the free air. This may occur on the Pacific coast in winter, although aerological observations to prove it are wanting. Since the sense of rotation of an anticyclone is opposite to that of a cyclone, the center will be shifted in a similar manner to that of the cyclone with increase of altitude. Naturally, the amount of this shifting will be a function of the intensity of the temperature contrast between the front and rear of the formation.

Simultaneous operation of both effects.—If, now, both processes are placed in simultaneous operation, the resulting conditions will be those actually found in practice. In the eastern United States, the tendency is for the eastern half of the cyclone to be warm and the western cold; while on the North Pacific coast, in winter, the rear of the storm is usually warmer than the front in the lowest levels. These are obviously effects of importation. Figure 31 illustrates schematically a cyclone in eastern United States with a strong temperature contrast between the southeast and northwest quadrants. The solid lines are isobars (sea level) and the dotted lines are surface isotherms. The lower portion of the diagram shows various cross sections of the cyclone taken on the four lines passing through the center of the storm. The vertical dimensions are, of course, greatly exaggerated. The solid lines in the lower diagrams are the intersections of isobaric surfaces with the section plane. A free-air level is shown passing through both. The upper right-hand diagram shows the isobaric distribution at the free-air level, drawn from the projection of points of intersection in the lower sections.

The conclusions to which considerations of the mutual relation between surface temperature gradients and pressure gradients in the eastern United States lead are:

(1) In winter, when latitudinal temperature gradients are strongest, the sea-level pressure distribution is less influential in determining the movement of air at free-air levels; in other words, at this season, the free-air movement tends to become westerly at relatively low elevations.

(2) In summer, when latitudinal temperature gradients are weakest, the sea-level pressure distribution is more influential in determining the movement of air at free-air levels; in other words, in summer, the free-air movement agrees fairly well with that at sea level even to great heights.

(3) The shifting of the center with altitude occurs most frequently in winter since the strongest temperature contrasts between front and rear occur during the cold season.

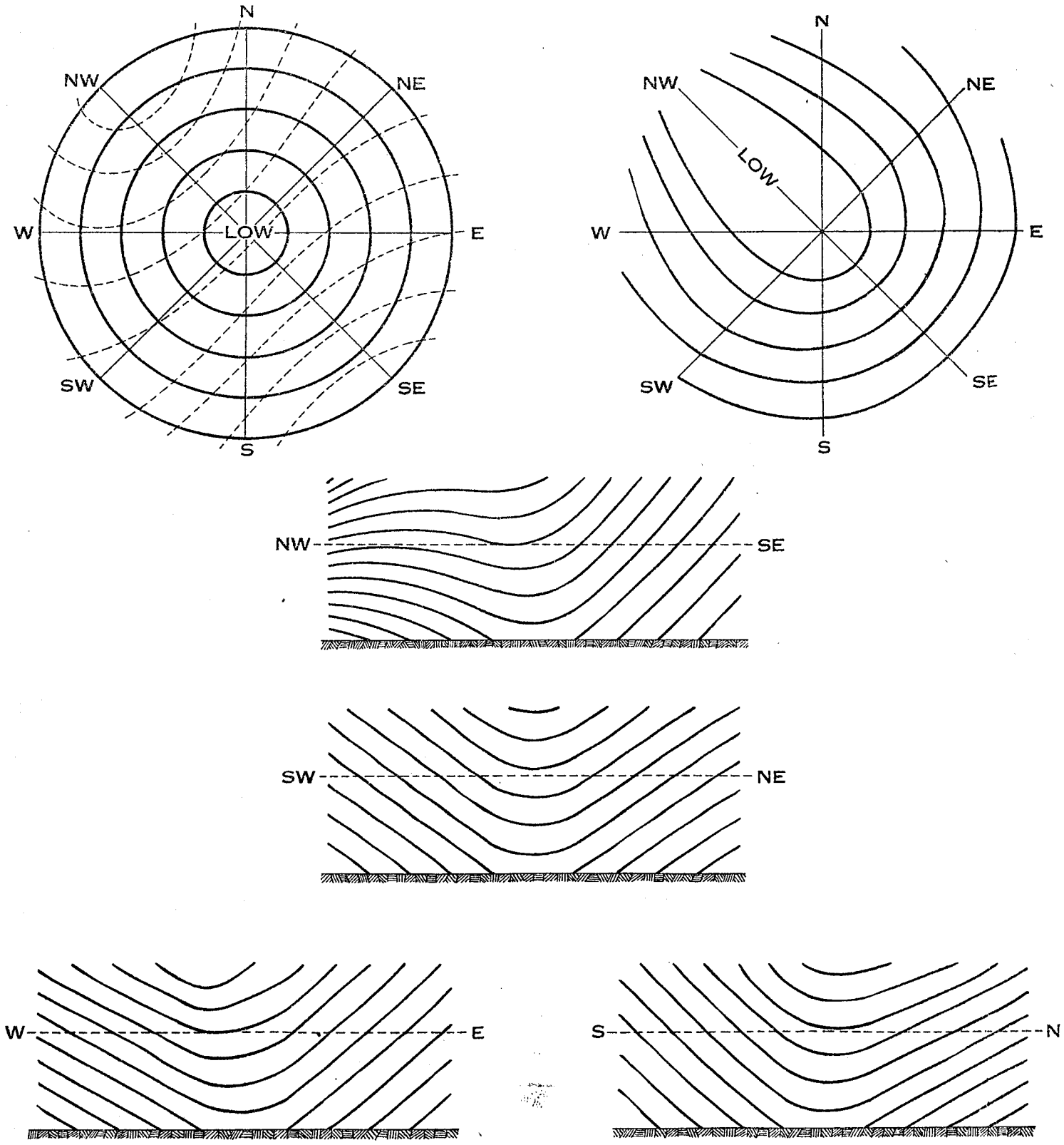


FIG. 31.—Schematic representation of the effect of a strong horizontal temperature gradient upon the distribution of isobaric surfaces in the free air.

These conclusions are in accord with cloud, pilot-balloon, and kite observations.[3]

It appears that these facts should have considerable bearing upon problems in practical forecasting. The occurrence of high westerly winds quite near the surface when there is little or nothing in the sea-level distribution of pressure to indicate their presence, the occurrence of precipitation after the wind has shifted to west and northwest at the surface, the vertical depth of anticyclones as compared with cyclones, are all considerations intimately related to conditions in the free air. These are not new thoughts, for the forecaster is familiar with many indications apparent to him in the current weather or on the sea-level map which herald the approach of unusual weather. But if the free-air maps show the reason with sufficient directness it will be possible to eliminate from the forecaster's mode of thinking one step of an empirical character, and thus bring his art so much nearer the physical cause of the phenomena.

JAPANESE EXPERIENCE IN FORECASTING FROM FREE-AIR MAPS.

As has been stated before, practical experience will be required to demonstrate the value of free-air pressure maps. We, in the United States, do not yet possess this experience. In Japan, however, daily maps of the 3-kilometer level have been drawn for several years and have been of great service to Japanese forecasters. Dr. S. Fujiwhara, who recently visited the Central Office of the United States Weather Bureau in Washington, told of the simple principle employed in their construction, and this has been discussed on page 17.

It remained for Dr. R. Sekiguchi, who has had experience in forecasting from these maps, to prepare a statement concerning their actual use in Japan. This note has appeared in the MONTHLY WEATHER REVIEW.[4]

Sekiguchi's principles for forecasting from free-air charts.—(1) The movement of cyclonic centers in the Far East shows, in most cases, better agreement with the general trend of the isobars on the 3-kilometer maps than with that at sea level.[5]

(2) A cyclone in the vicinity of a region where sea-level and 3-kilometer isobars are parallel will not move toward that region but will move toward unmistakable "crossing" of the isobars of the two levels. Parallel isobars indicate continued fair weather.

(3) Two classes of "crosses" are distinguished:

(*a*) That in which the turning from sea level upward is clockwise and approximately at right angles—for example, turning from southeasterly at the surface to southwesterly at the upper level. This is the "cyclone-attracting" class which gives the most pronounced effects when the upper drift is of warm origin. It is sometimes used to foretell the formation of a storm at some distance.

(*b*) That in which the turning from sea level upward is counterclockwise and approximately at right angles—for example, turning from northeasterly at the surface to northwesterly in the free air. This is indicative of clearing weather.

(4) Moving anticyclones tend to progress with greater speed if the "crosses" in the rear of them are conspicuous.

(5) A very deep[6] anticyclone persists longer than a shallow one.

(6) In colder seasons, as long as the upper isobars over the East China Sea lie from northwest to southeast, weather in Japan remains fair; the gradual change from this direction to southwest-northeast indicates the approach of a continental cyclone to the east coast of China, with bad weather for Japan. The close attention of the forecaster is given to the waver of the isobars and he is thus enabled to take advantage of the first sign of cyclonic approach.

(7) Nearly opposite direction of upper and lower winds during the winter-monsoon season in the East China Sea should be taken into account in the explanation of the phenomenon hitherto regarded as strictly of orographic origin.

(8) With upper and lower isobars parallel on the front, right and left of the path of the cyclone, the storm generally remains stationary. Nor does the storm move if wedges of high pressure appear from each side of the path. The space between the wedges is called the "gate of the cyclone" because typhoons show a tendency to move toward the "gate" but do not make much headway until the "gate" is opened.

(9) Many cases of rain are explained by the introduction in the upper strata of cold air over southerly surface wind, thus producing instability with consequent convection.[7]

These are the chief features of the use of free-air maps in Japan as outlined by Doctor Sekiguchi. While it is true that they apply particularly to the problems of the Japanese forecasters, they constitute interesting precepts for the discussion and study of similar charts in our own country. It should be remarked that Bigelow,[8] in 1904, gave precepts for forecasting that contain some ideas in common with those of Sekiguchi. The precepts of Bigelow, however, appear to involve themselves in details which, we believe, implied a greater accuracy than his charts possessed.

[3] Cf. Clayton, H. H.: The distribution of the meteorological elements around cyclones and anticyclones up to 3 kilometers at Blue Hill. *Annals of the Astronomical Observatory of Harvard College*, Vol. LXVIII, Pt. I, 1909, pp. 85–90.

[4] May, 1922, pp. 242–243.

[5] Mr. C. L. Mitchell has found similar interesting relations for the movement of anticyclones in the United States. See Relation between rate of movement of anticyclones and the direction and velocity of winds aloft (west and southwest of highest pressure). MO. WEATHER REV., May, 1922, pp. 241–242.

[6] Evidently this has reference to the vertical extent of the formation.

[7] A significant case of this type of isobars has been noted by Vincent E. Jakl, at Drexel, Nebr., when, on Mar. 28, 1920, a stratum of air of temperature as low as that of the midwinter mean for that altitude (4,250 meters) was found overrunning surface winds from south and southwest. Thirteen tornadoes occurred with the passage of this storm. See MO. WEATHER REV., April, 1920, pp. 198–200.

[8] The circulation in cyclones and anticyclones, with precepts for forecasting by auxiliary charts on the 3,500-foot and the 10,000-foot planes. MO. WEATHER REV., May, 1904, p. 216.

It is well to avoid the pronouncement of precepts of too great refinement until those broader relations which are believed to exist are demonstrated.

THE MAPS.

The selection of dates for map drawing.—It is manifestly impossible to cover in a limited number of maps, the myriad interesting cases in which capricious nature checkmated the forecaster. Instead of selecting dates at random, however, it was believed that greater interest would attach to those in which the unexpected occurred. C. L. Mitchell, forecaster at the Central Office of the Weather Bureau, kindly selected a long list of dates of this character from which all the maps that follow, the first excepted, were drawn. These seem to offer much suggestive material.

The viewpoint.—The following groups of maps represent the culmination of effort in this paper. No attempt will be made to draw sweeping conclusions; there is no intention to force beyond the point of justification the significance of these charts. In other words, they must speak for themselves, and their value must be demonstrated by consistent day-to-day study and interpretation. It is desired only to present such running comment as seems pertinent and suggestive.

The charts.—For each date there are three maps; the first is a copy, so far as isobars and isotherms are concerned, of the weather maps except that the units have been converted. The black lines are sea-level pressure, the red, surface temperature, and the black shaded areas show regions in which precipitation occurred in the 24 hours *following the time of the map.* This last feature is not the same as that shaded area on the daily weather map, but corresponds to the shaded area on the map of the following day. This is for use in connection with the possible prognostic value of the free-air charts for precipitation. The two smaller maps show the pressure distribution, in black, at the respective levels. The red lines on these smaller maps are not isotherms in the usual sense, but are lines of equal value of θ or lines of equal temperature argument. In general, this conforms to the distribution of surface temperature and is somewhat representative of the distribution of free-air isotherms, but care should be taken not to interpret them as isotherms corresponding to the level of the isobars. They may be considered as approximate temperatures at some intermediate level.

CHART I.

December 17, 1919.—The especial features which rendered this date remarkable have been discussed by Mr. W. R. Gregg.[9] The highest velocity ever observed in the free air below 10 km. in the United States, 83 meters per second, was observed at an altitude of 7,200 meters on this date at Lansing, Mich. This observation was corroborated by numerous observations of extremely high velocities at the levels reached and a very rapid increase of speed with altitude at other stations, although no other observations reached so great an altitude. It was of interest, therefore, to draw the upper isobars for this date in order to see to what extent the computed isobars bore out the testimony of the observations. The result is striking.

Perhaps the first feature that will appear to the student is the complete obliteration of the sea-level pressure configuration below 1 kilometer. At 2 kilometers, the isobars are parallel over the eastern United States and the gradient steeper than at 1 kilometer. In other words, what appeared to be a "ridge" of high pressure at sea level has disappeared except for a suggestion of it in the bend of the isobars over Arkansas and Missouri at 1 kilometer. Even the southern development of the cyclone on the Atlantic coast is overrun at 1 kilometer by northwest winds.

The reason for this sudden change within a small limit of altitude is not hard to find. It lies in the marked gradient of surface temperature which is accentuated and somewhat smoothed in the 1-kilometer distribution of θ. It is clear that the temperature distribution and not the surface pressure was the dominating influence on this day. The wind, in attempting to flow from above the warm region to the cold region was deflected by the earth's rotation with the result that it flowed nearly parallel to the isotherms.

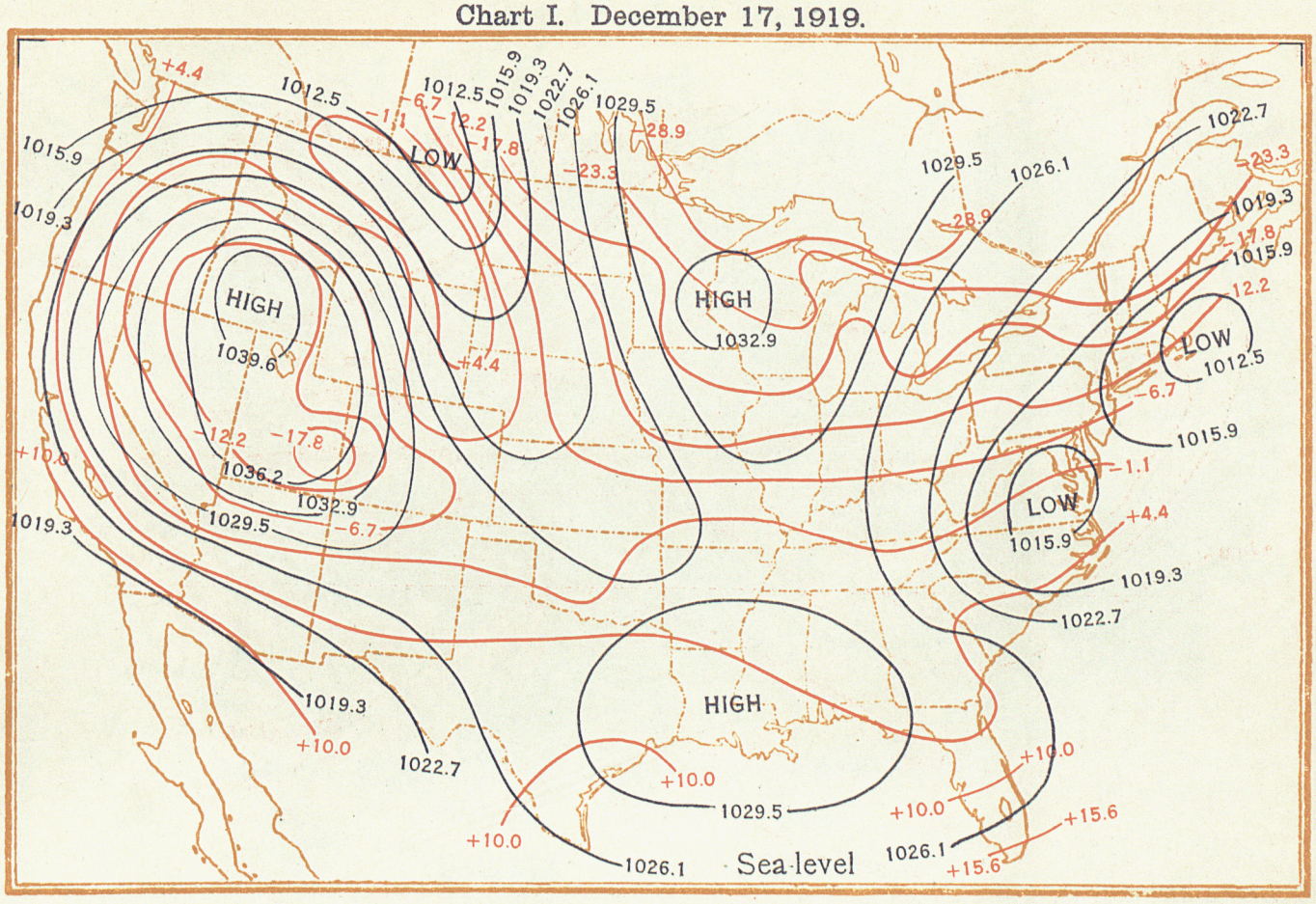
The forecaster doubtless would have forecast westerly winds at a quite low elevation, but it is a question whether he would have anticipated that opposing winds at ordinary flying levels between New York and Chicago would have a force approximately equal to half the air speed of a commercial airplane. Or that a high-powered commercial dirigible flying the same route would have had its speed reduced to less than that of an express train. Or that the same craft flying from Chicago to New York would have been able to arrive at the destination several hours sooner than usual. These are facts of the greatest importance in the dispatching of mail and will be of greater importance as the activities of commercial aviation multiply. Free-air maps disclose the facts without surmise or guess.

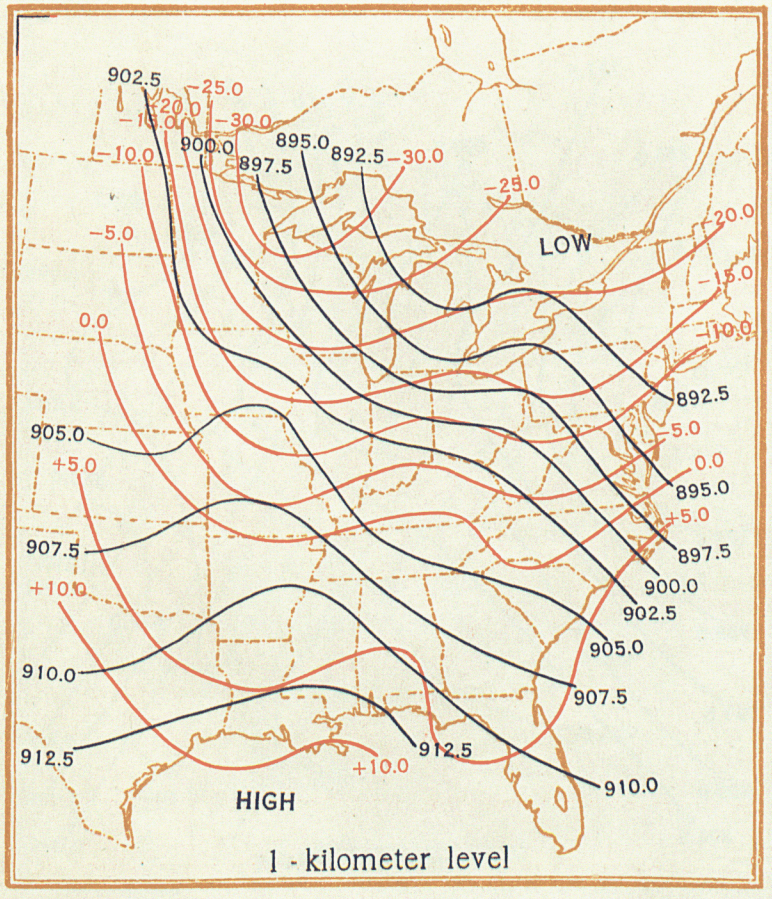
CHARTS II–IV.

March 14–16, 1919.—Preceding the first day of this period, a low pressure area had traveled along a curved path from the middle of the Oregon coast to the point in the northern part of Colorado, where it is seen on the sea-level map (Chart II). A well-marked high-pressure area is found over Ontario, and between the high and low centers lie evenly spaced isobars representing a difference of pressure of about 54 mb. The direction of movement of the low center is of chief interest in this series. Judging from the forecasts of colder in the west portions of Nebraska and South Dakota for the following day, it was

[9] Note on high free-air wind velocities observed Dec. 16–17, 1919. Mo. Weather Rev., December, 1919, pp. 853–854.

Chart I. December 17, 1919.





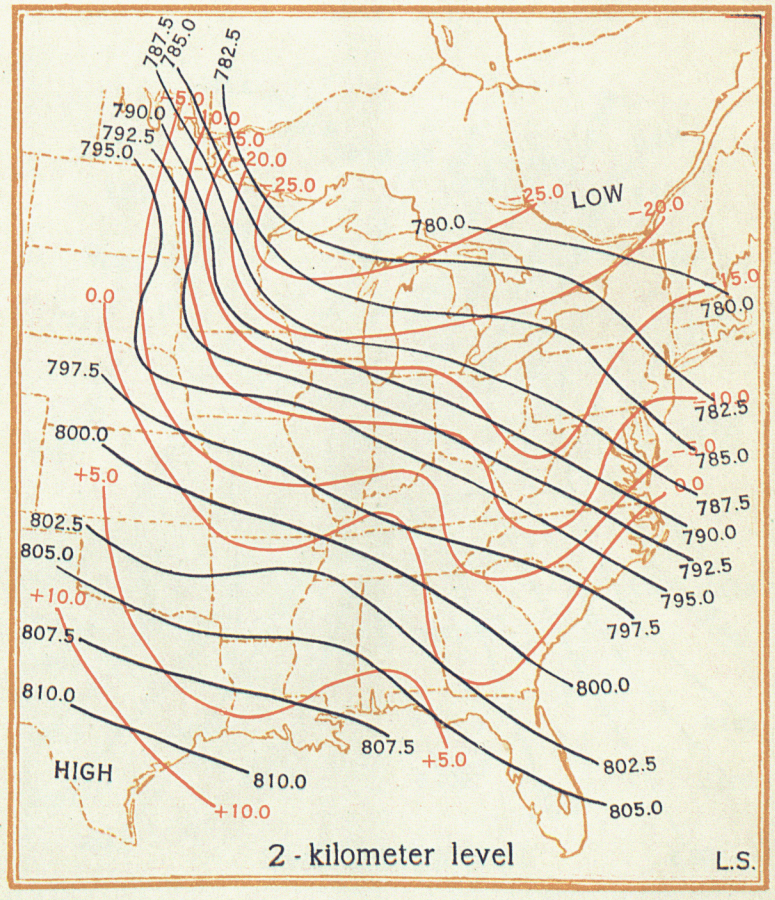
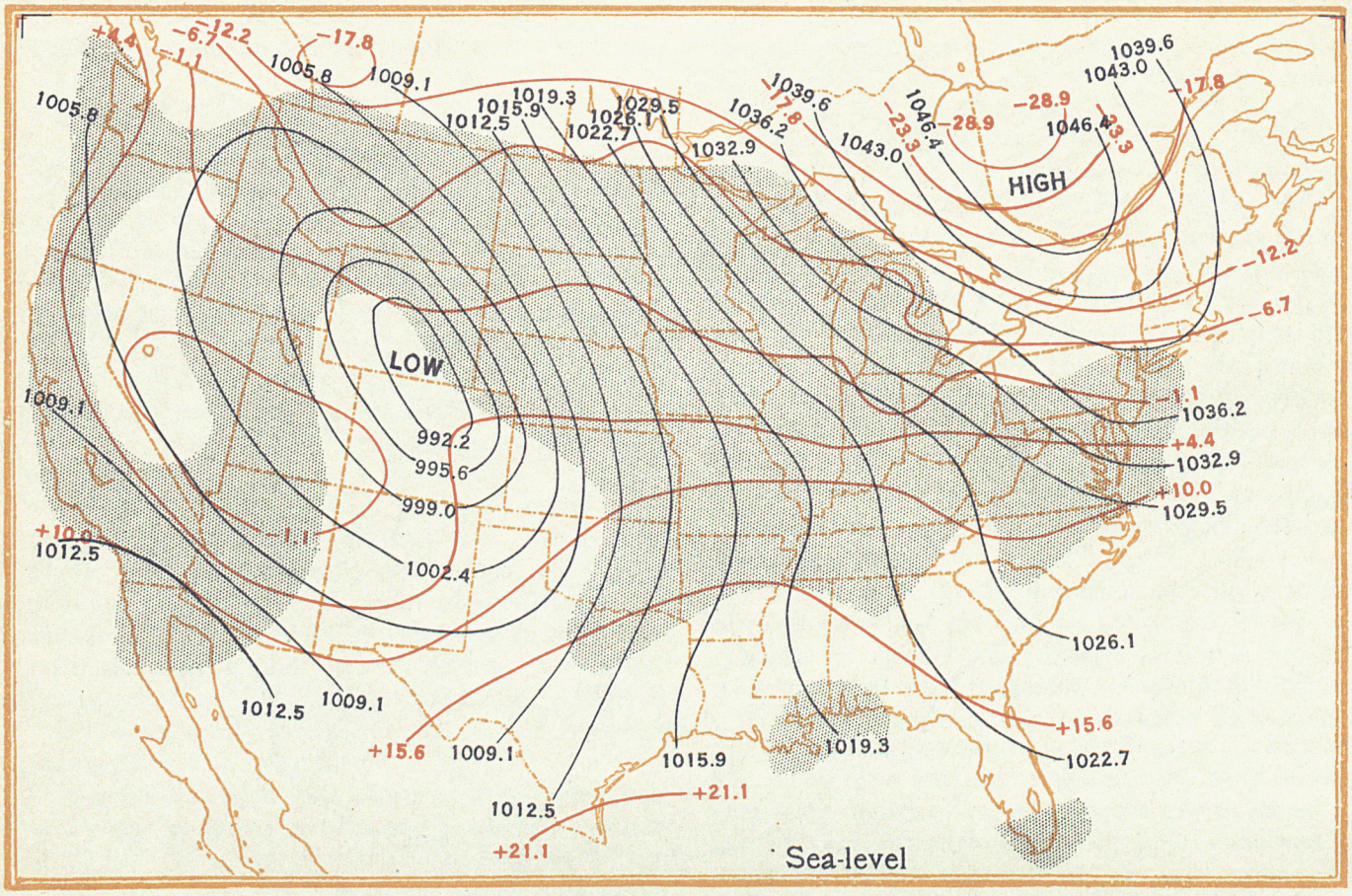
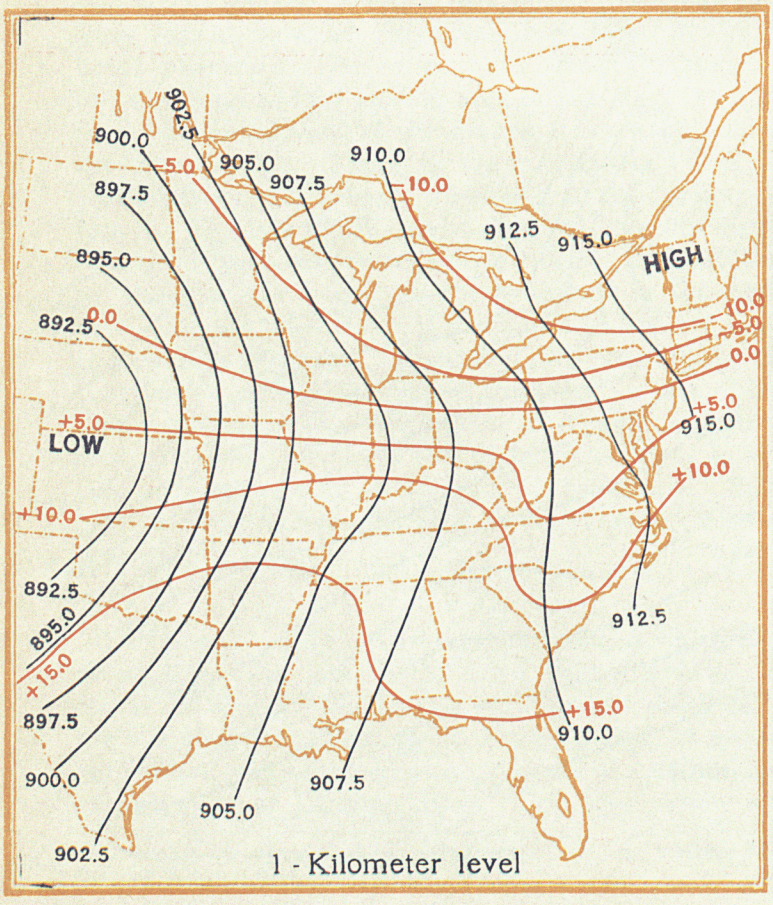


Chart II. March 14, 1919.





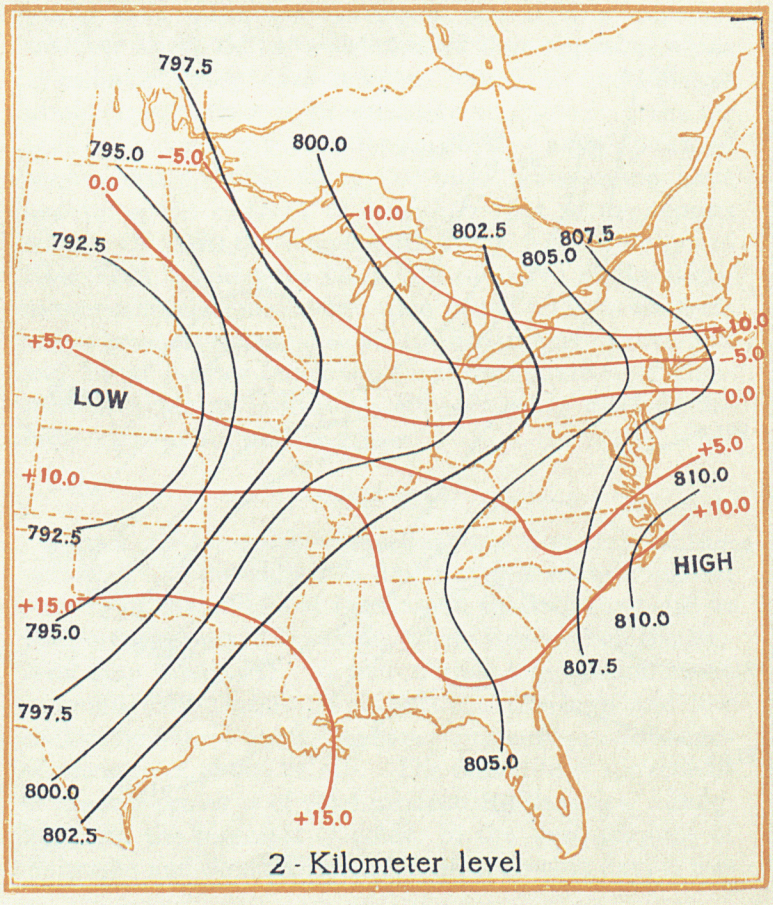
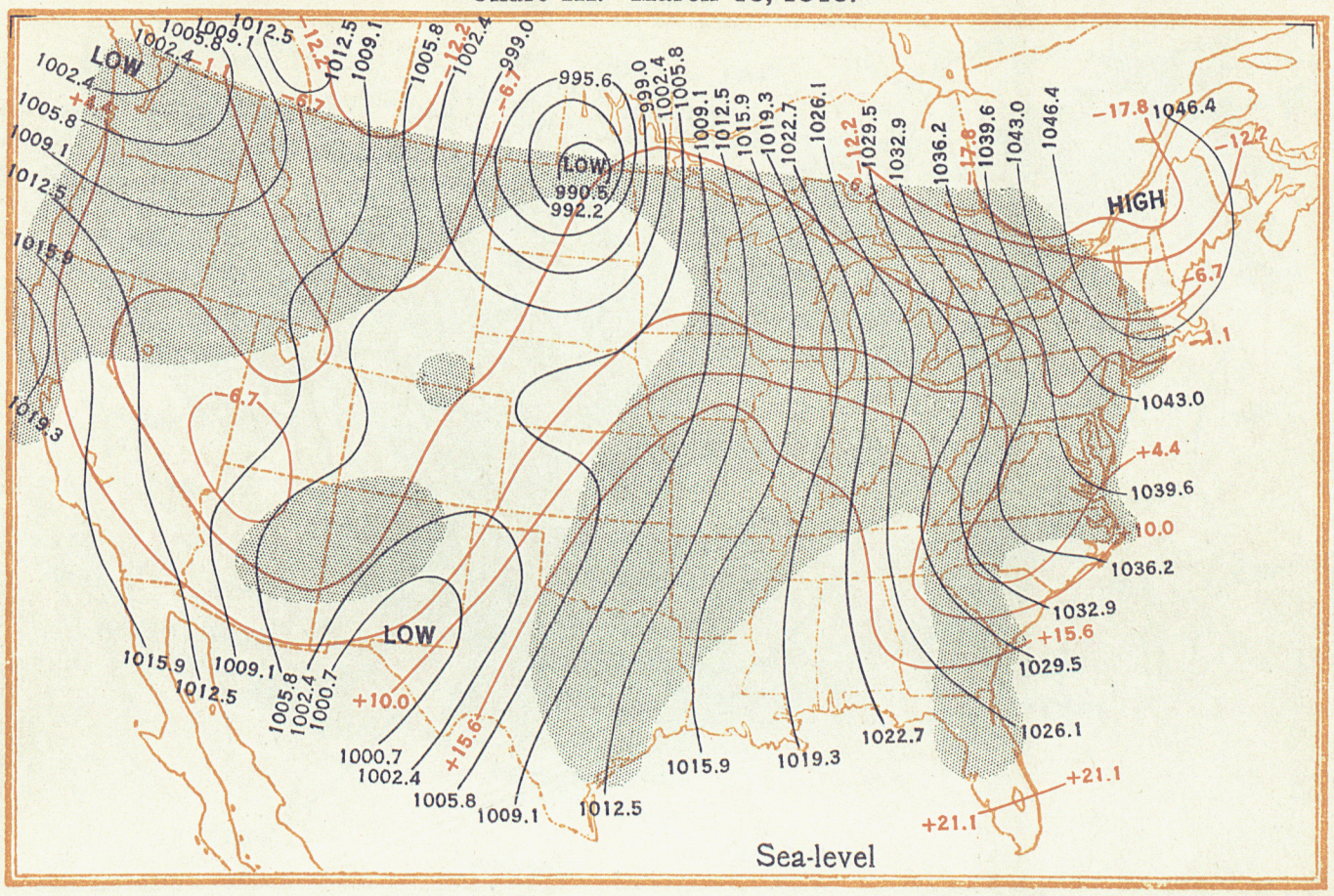
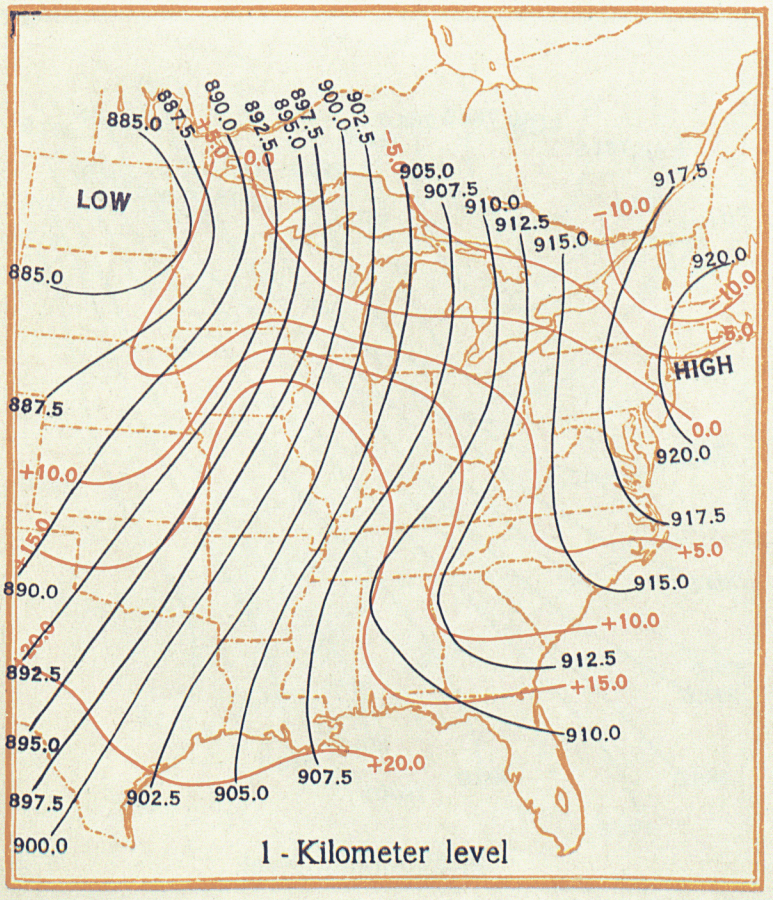


Chart III. March 15, 1919.





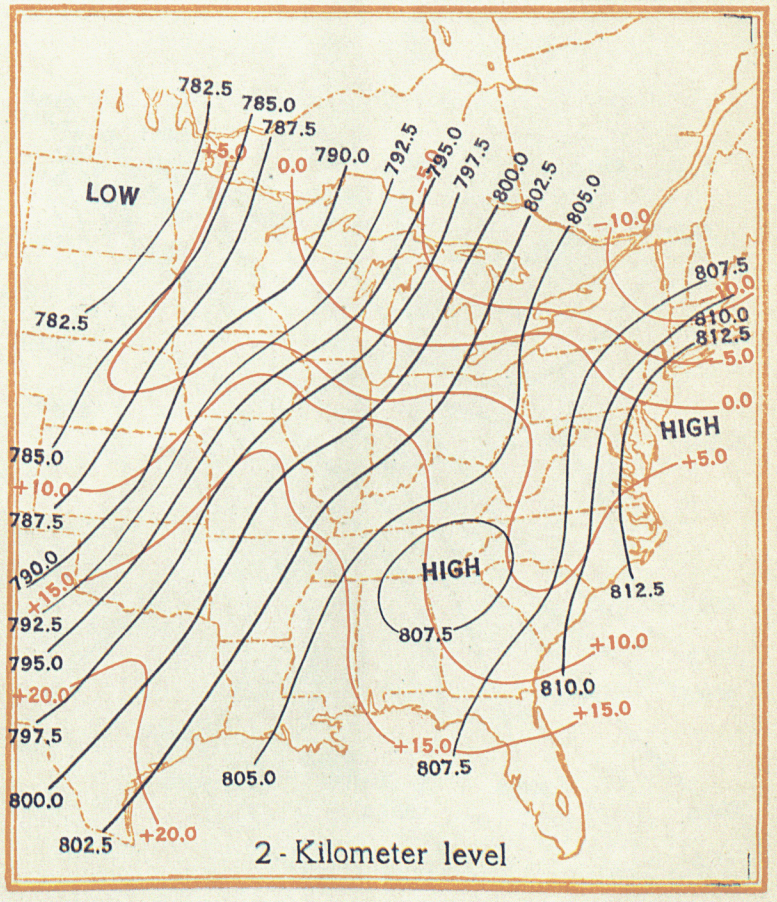
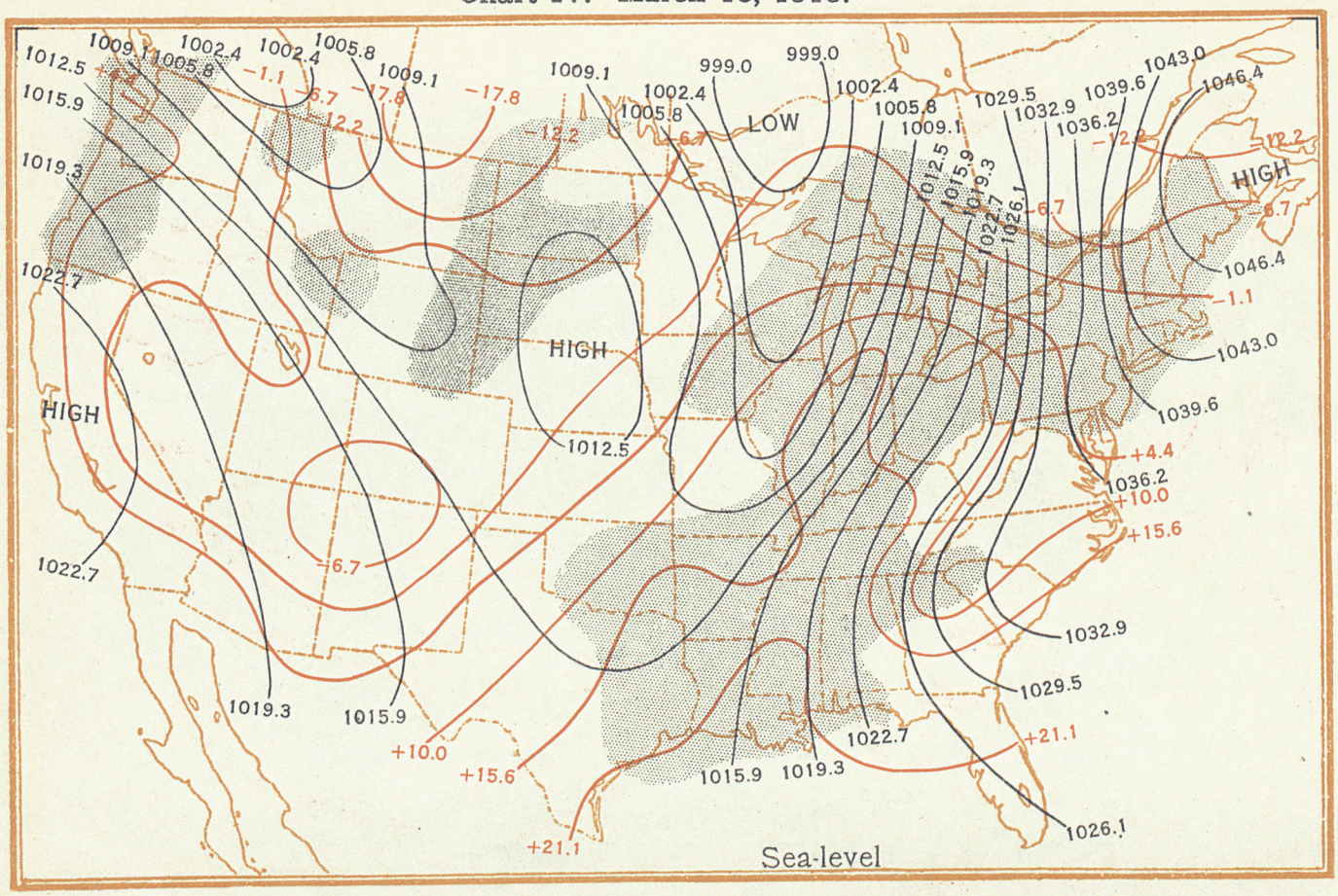
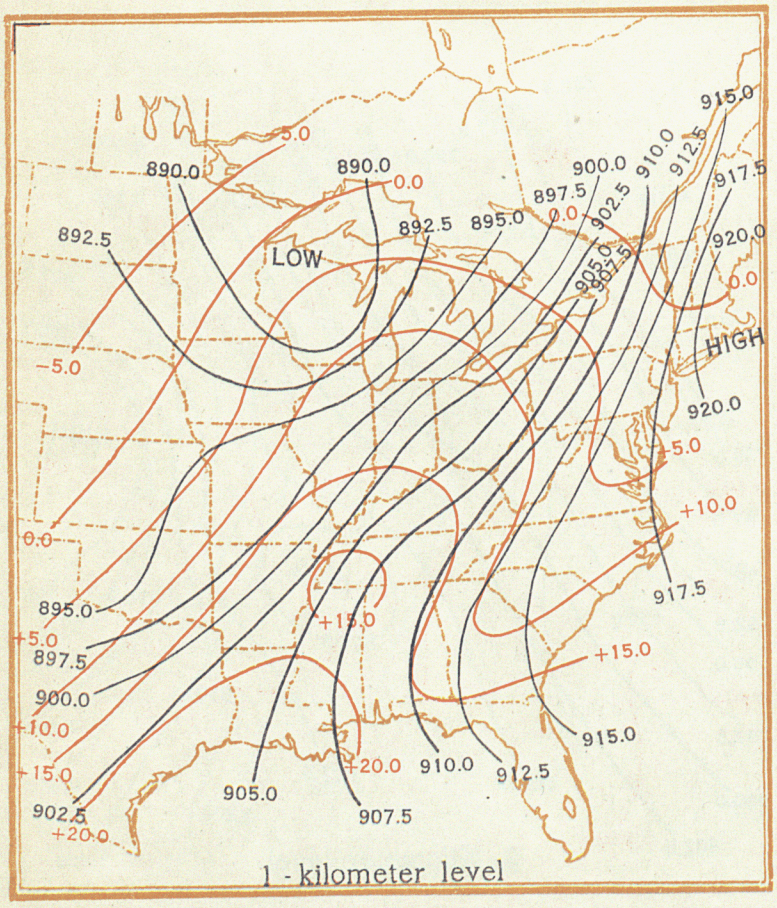


Chart IV. March 16, 1919.





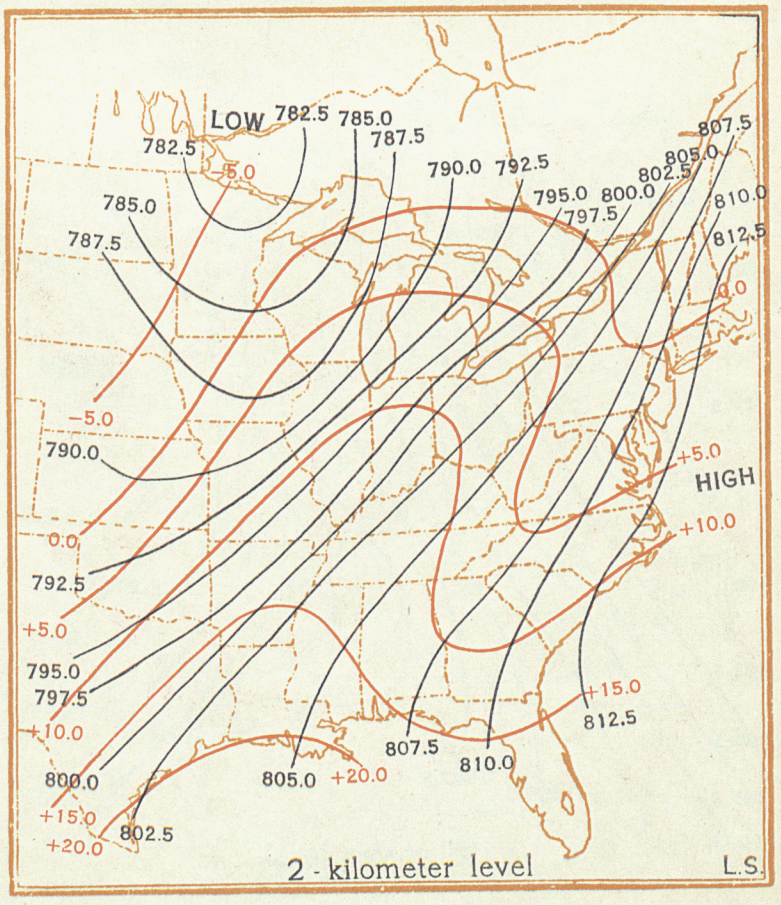
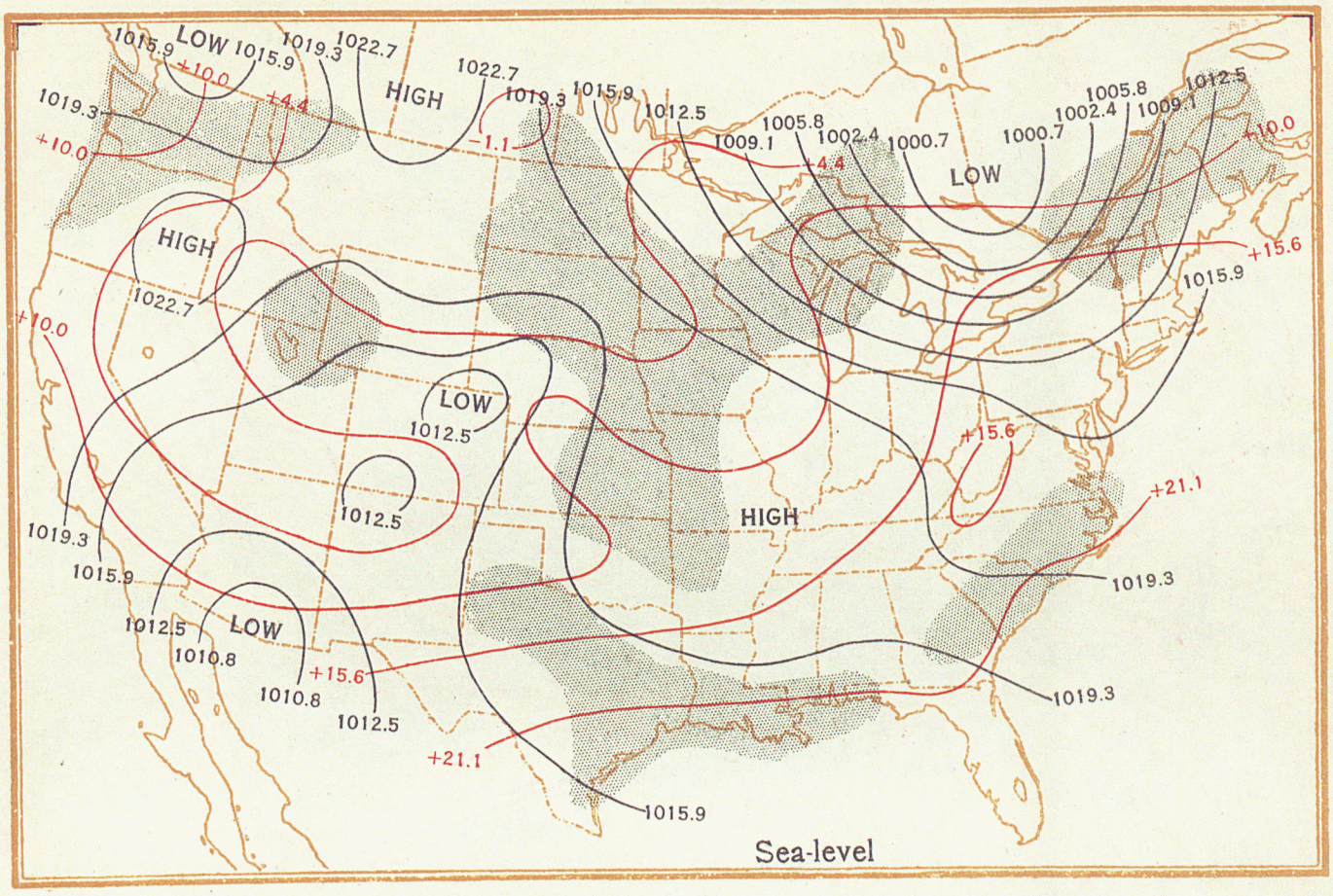
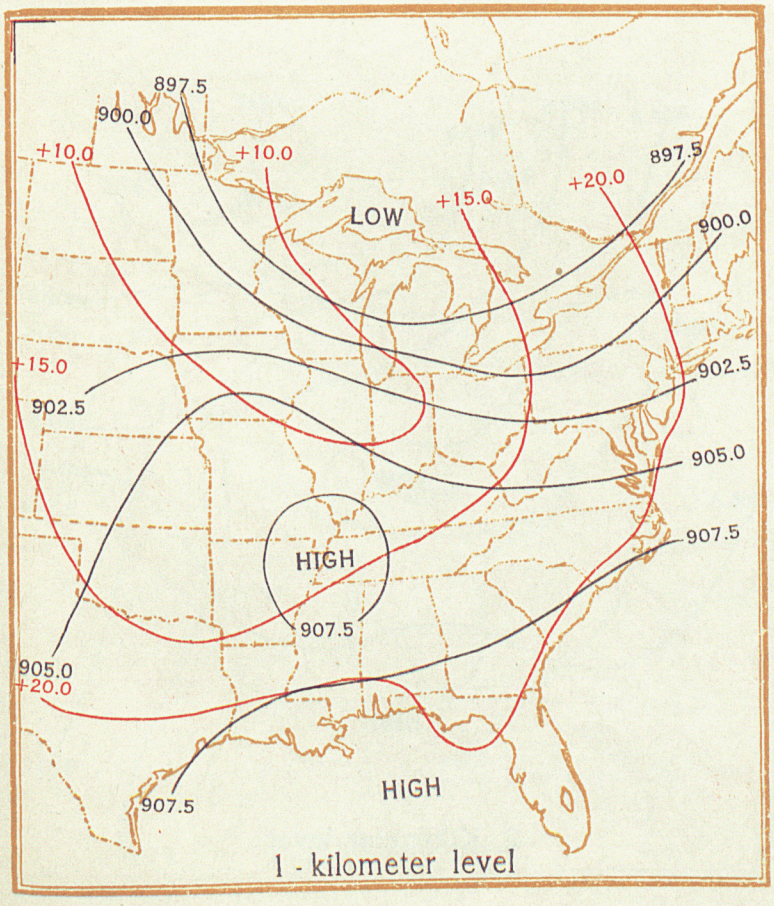


Chart V. October 11, 1914.





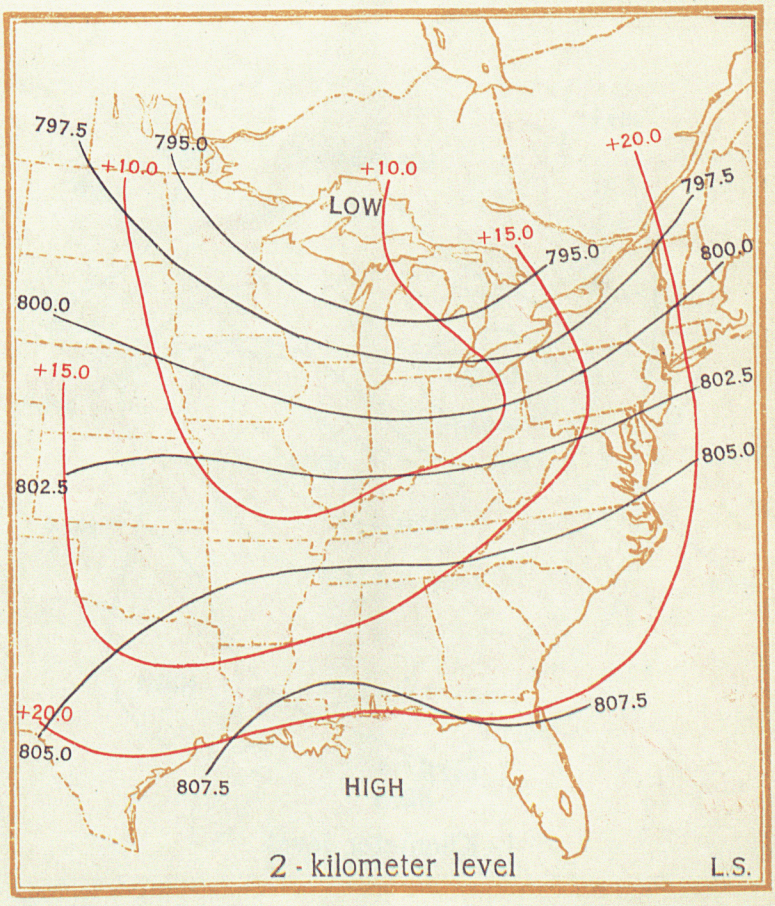
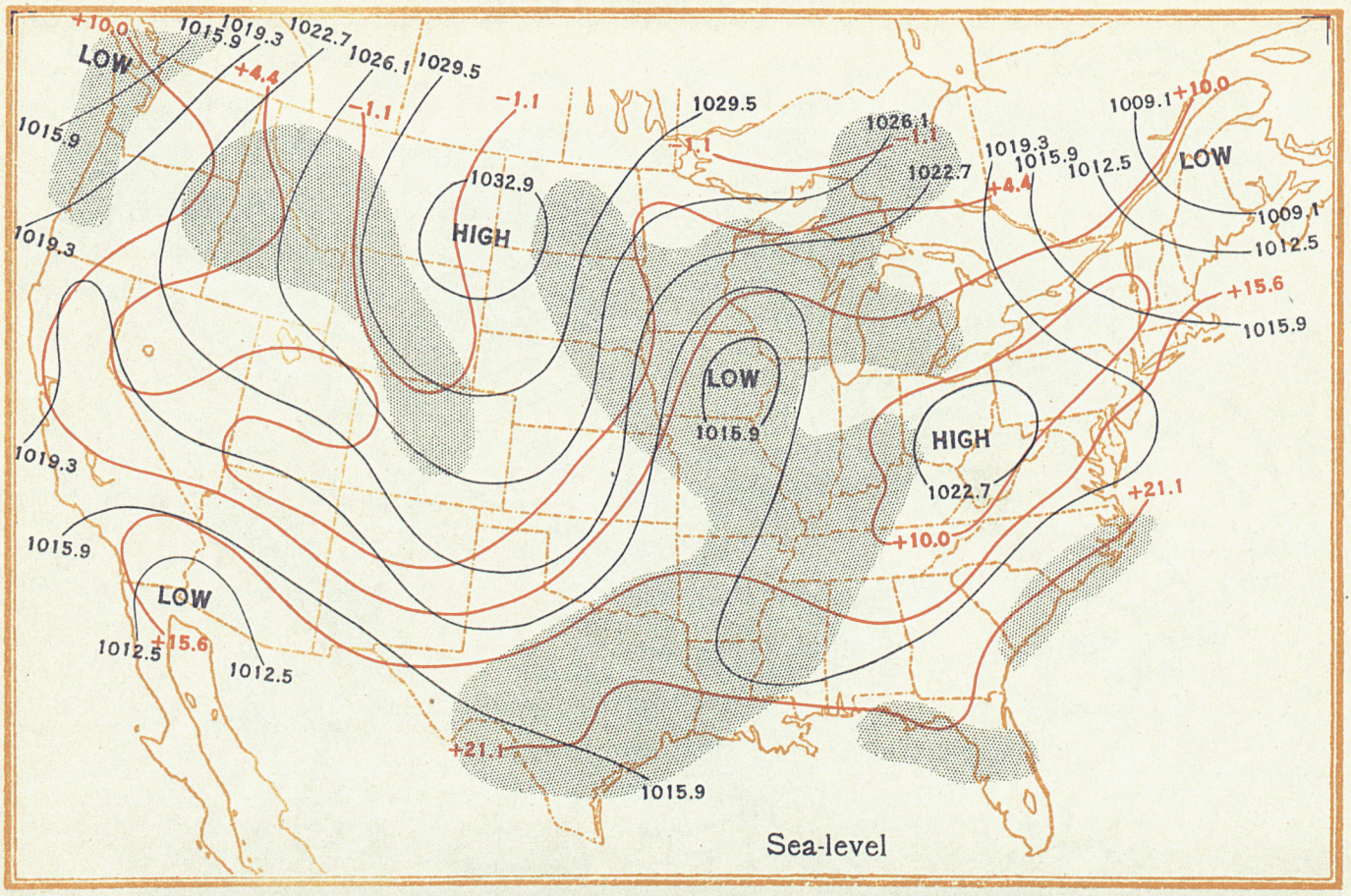
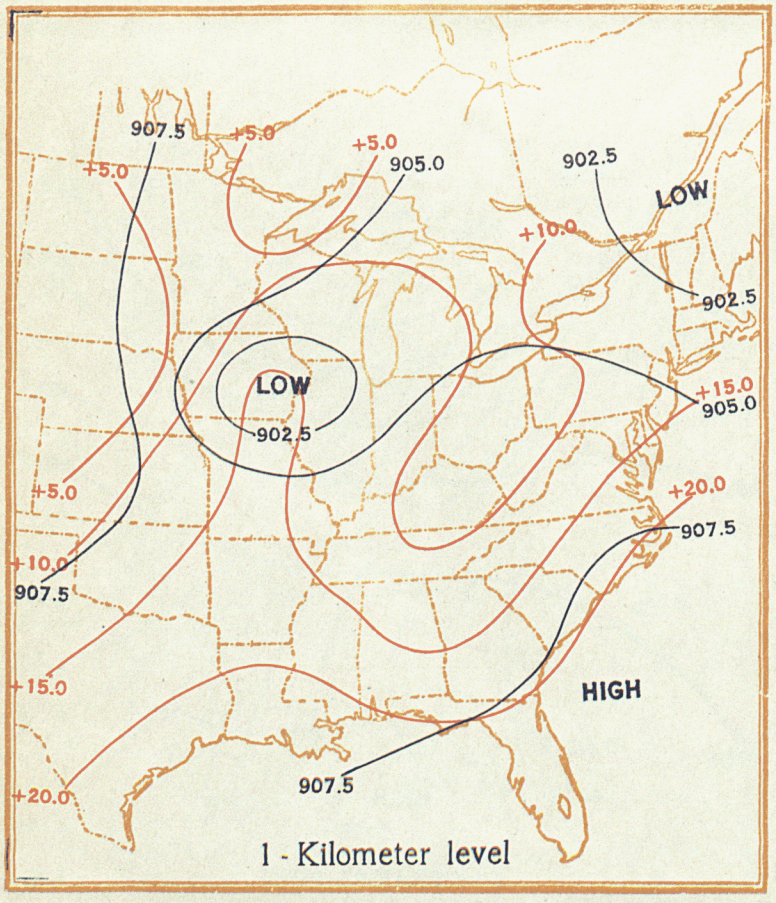


Chart VI. October 12, 1914.





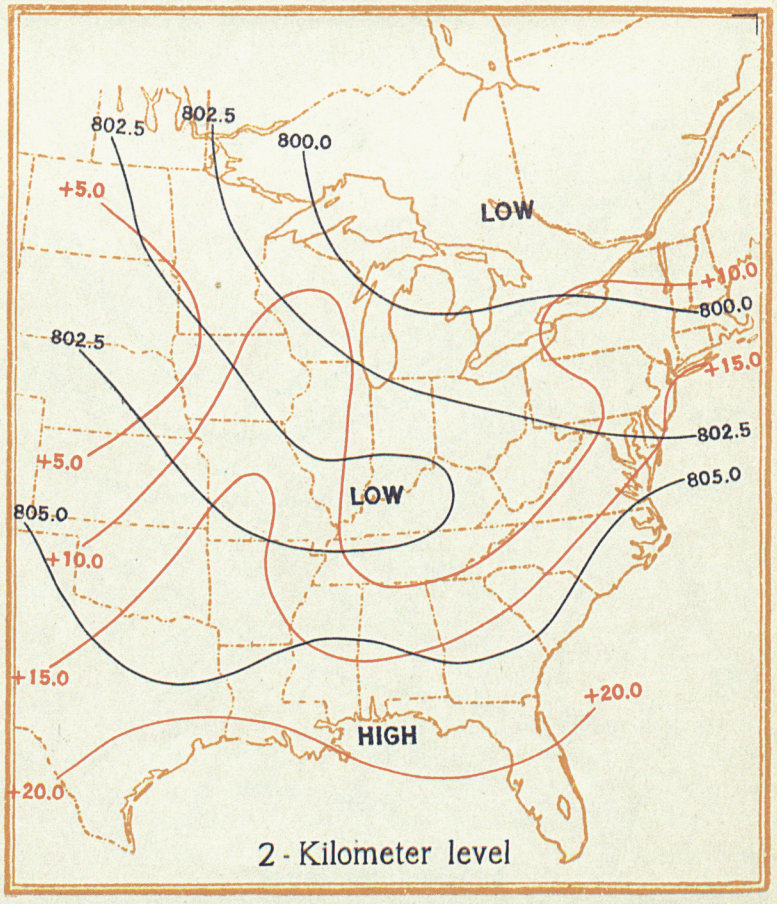
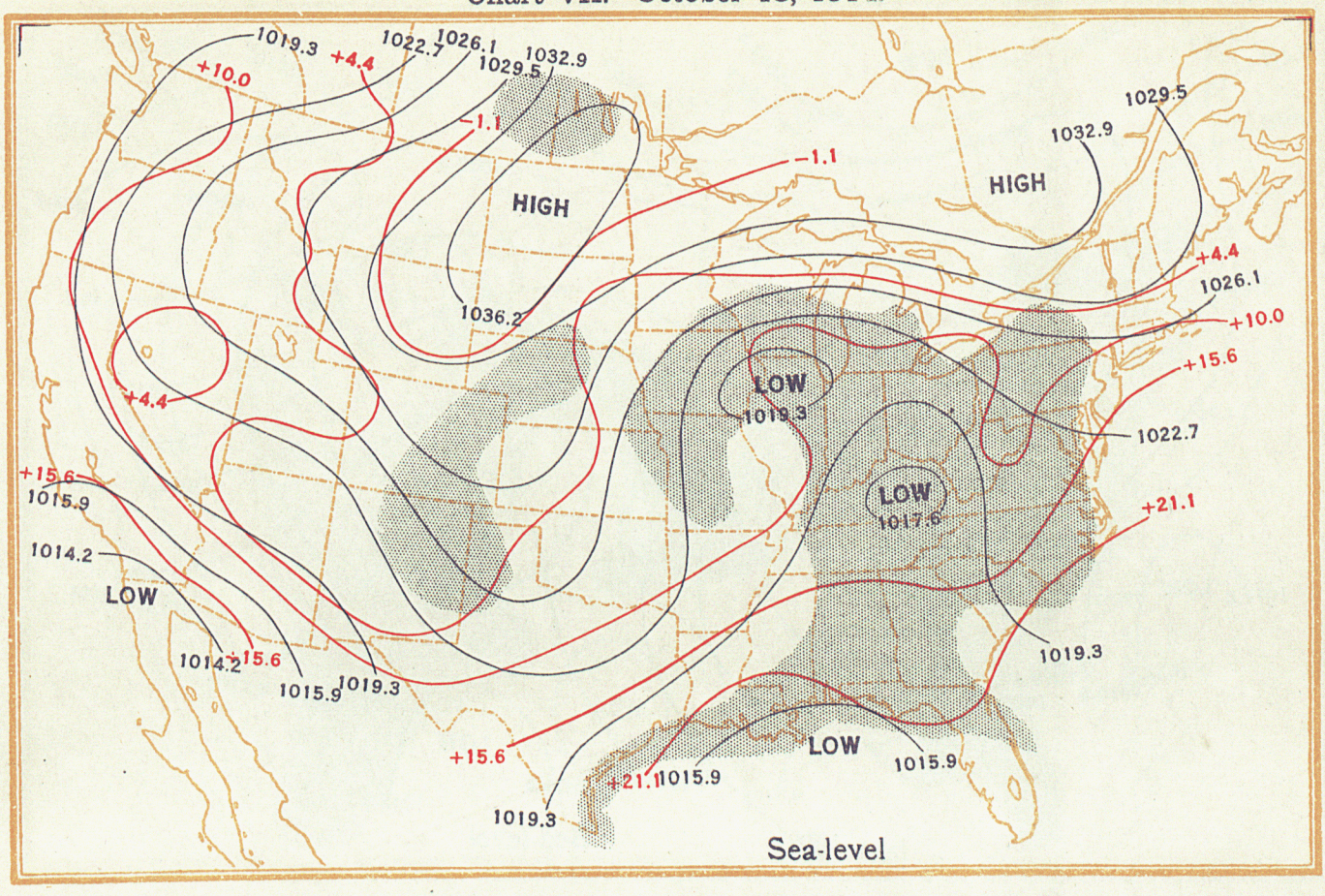
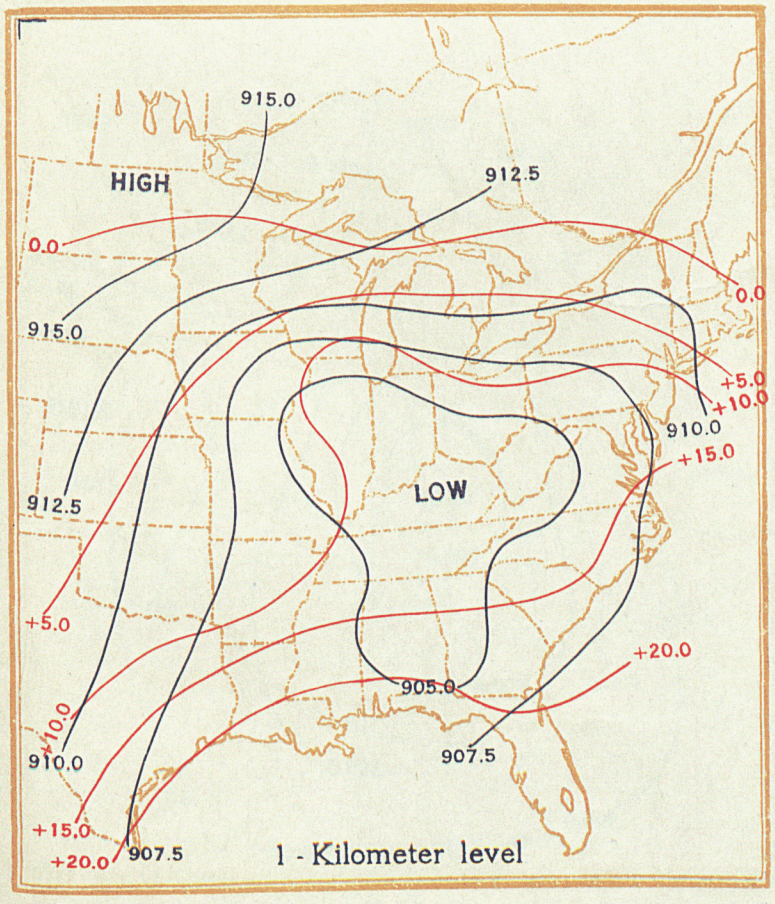


Chart VII. October 13, 1914.





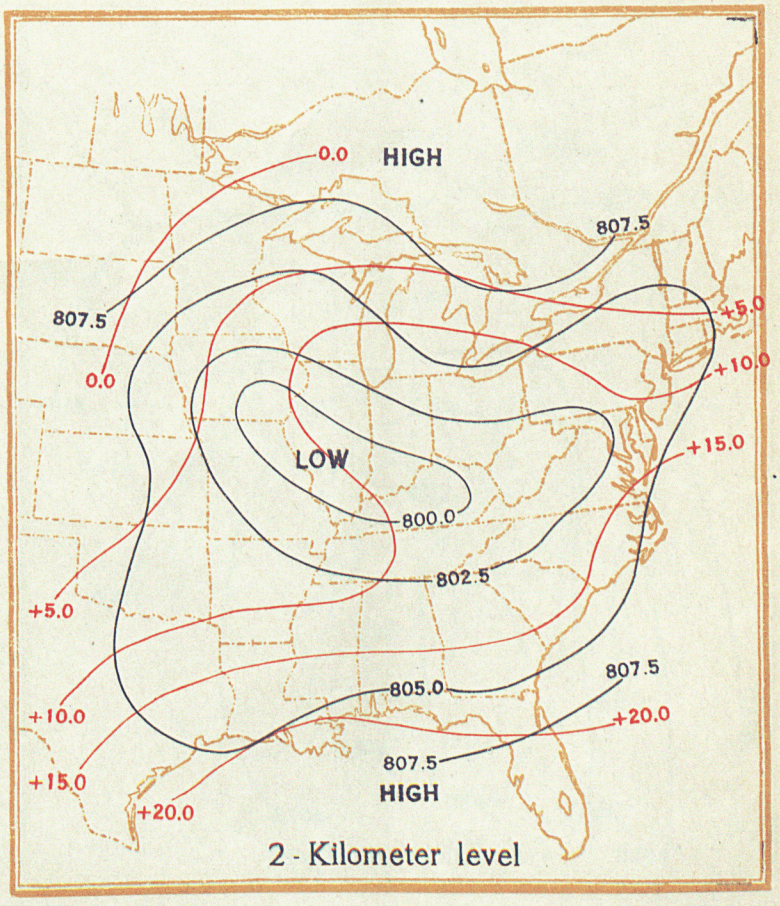
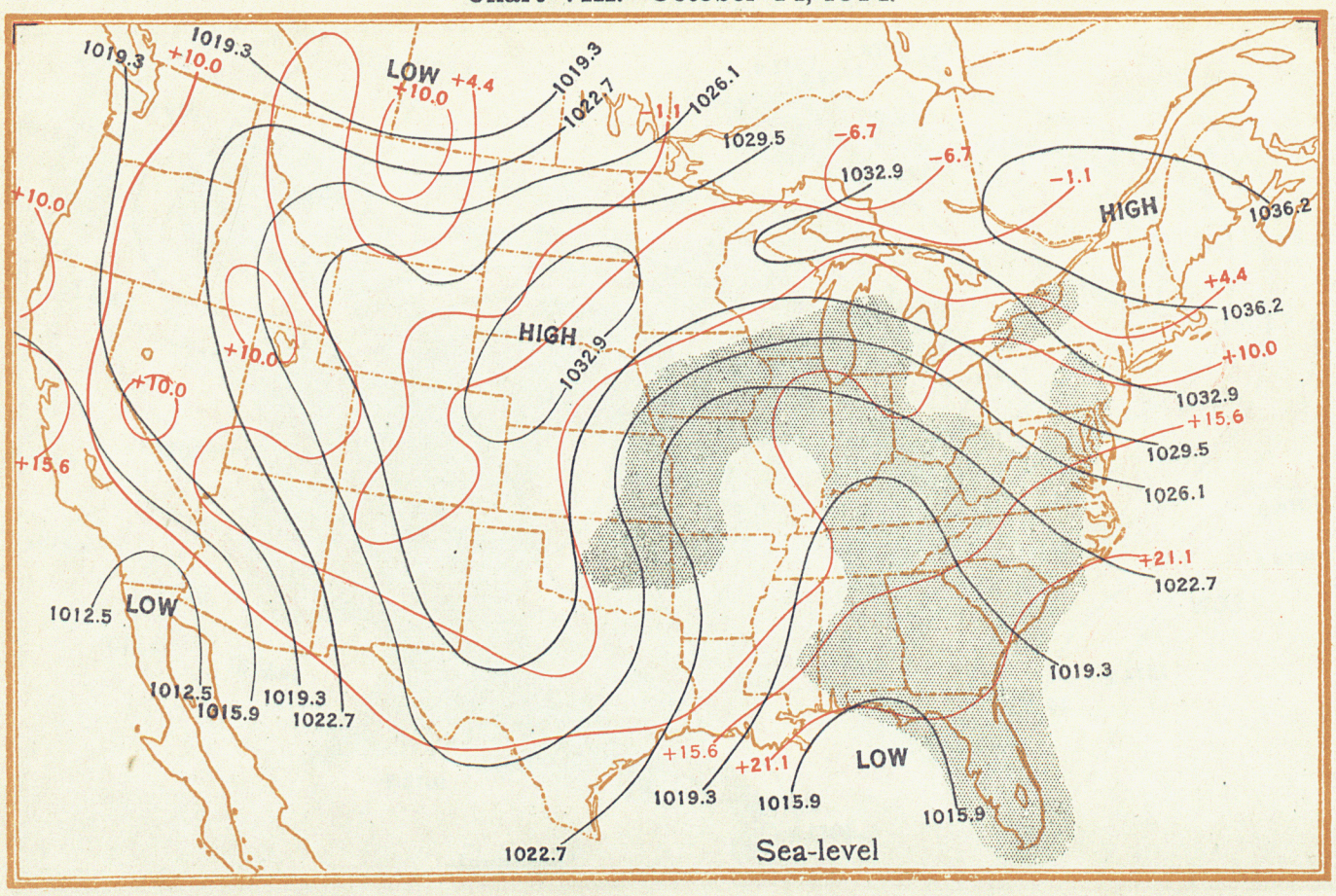
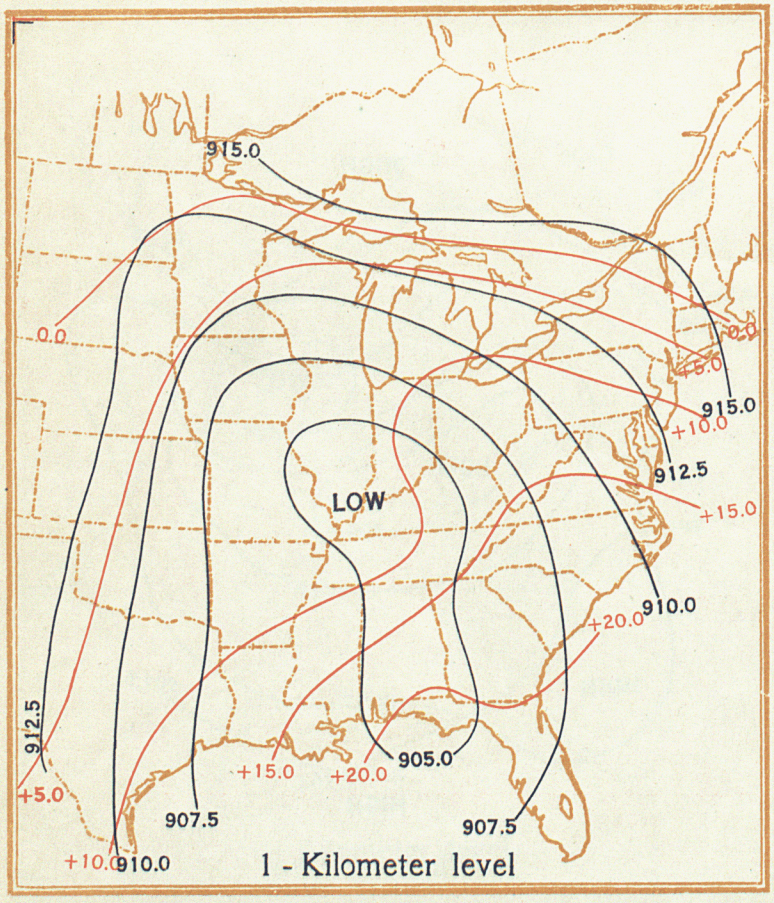


Chart VIII. October 14, 1914.





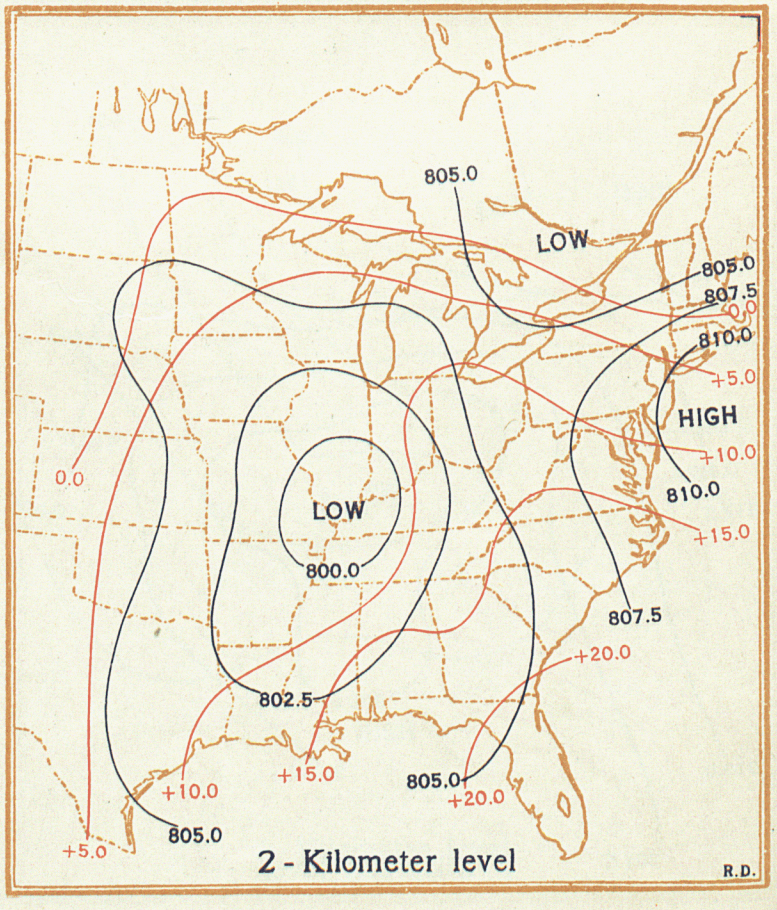
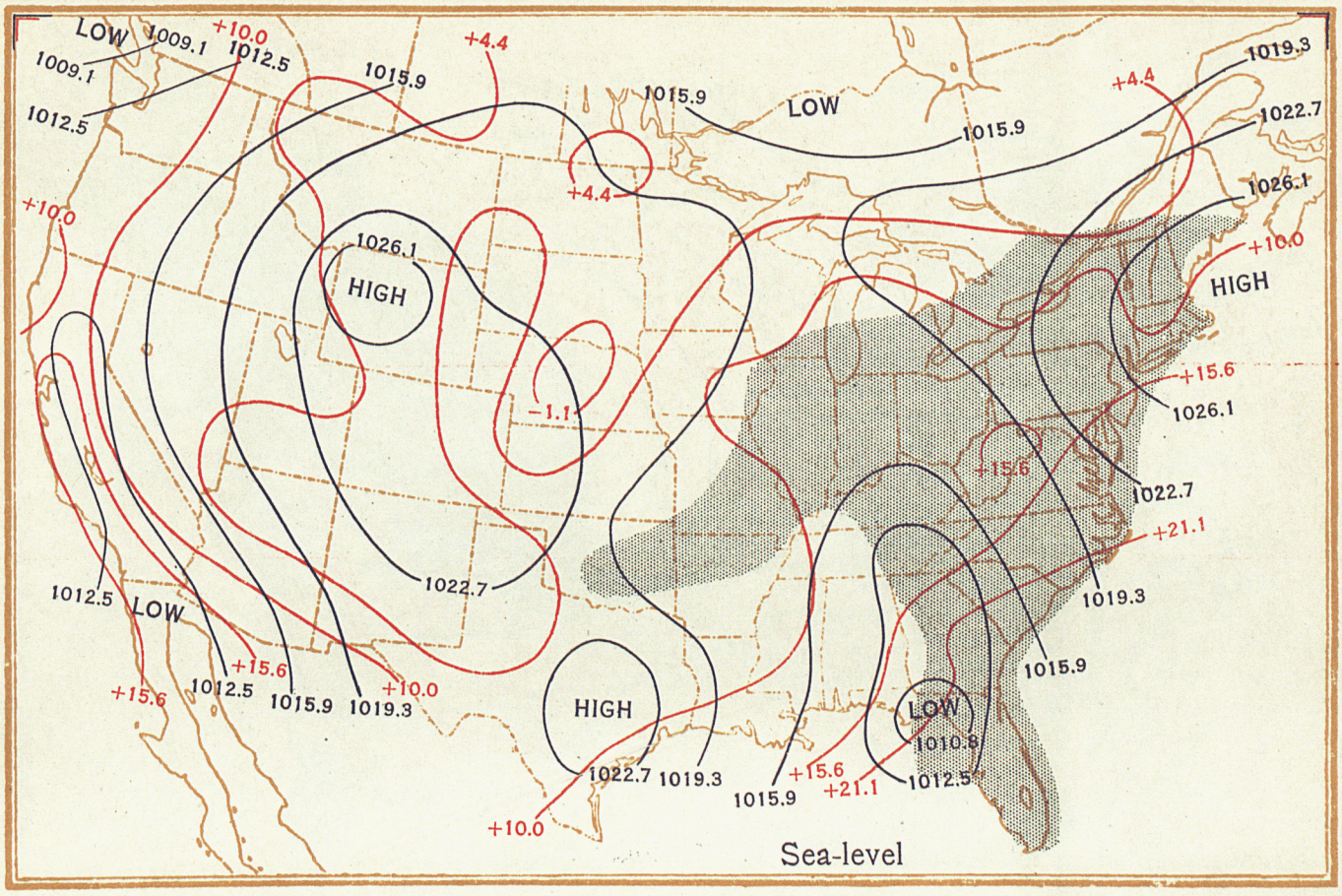
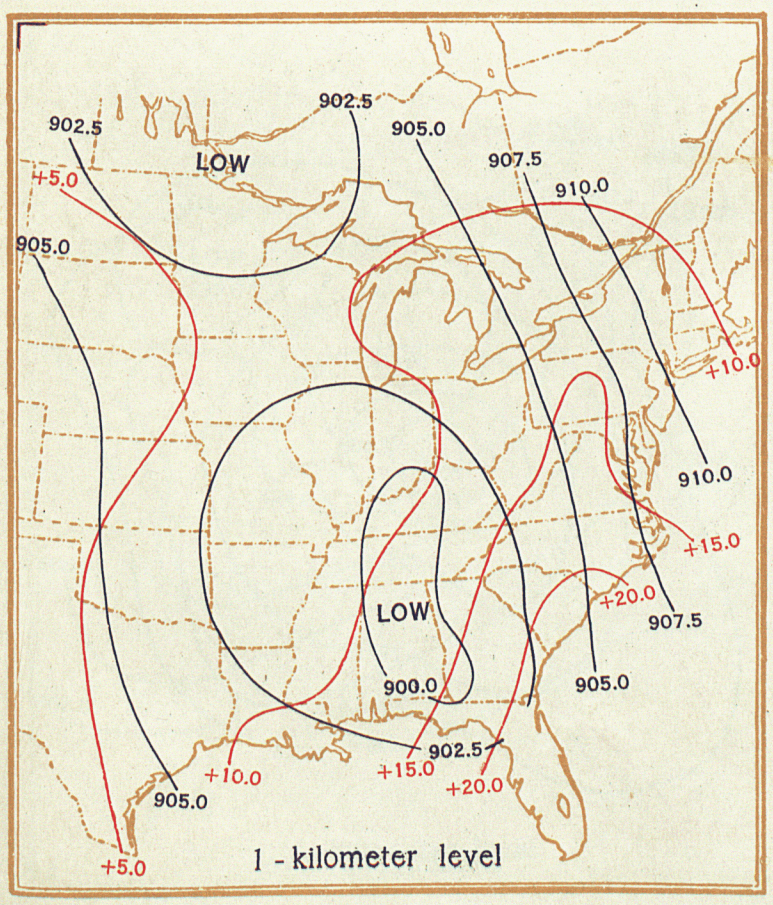


Chart IX. October 15, 1914.





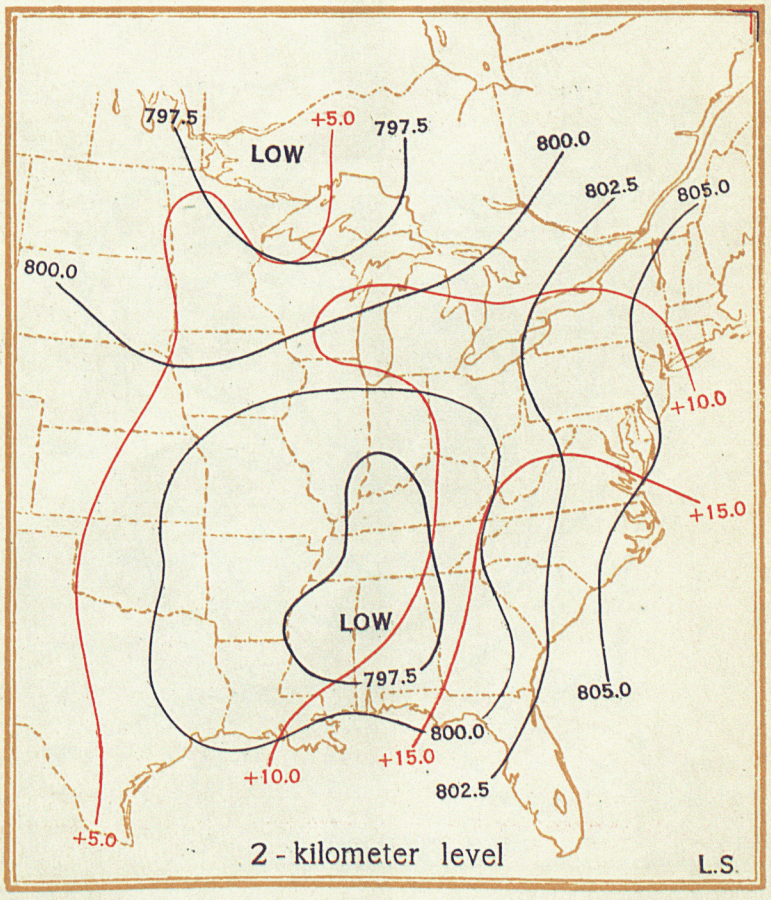
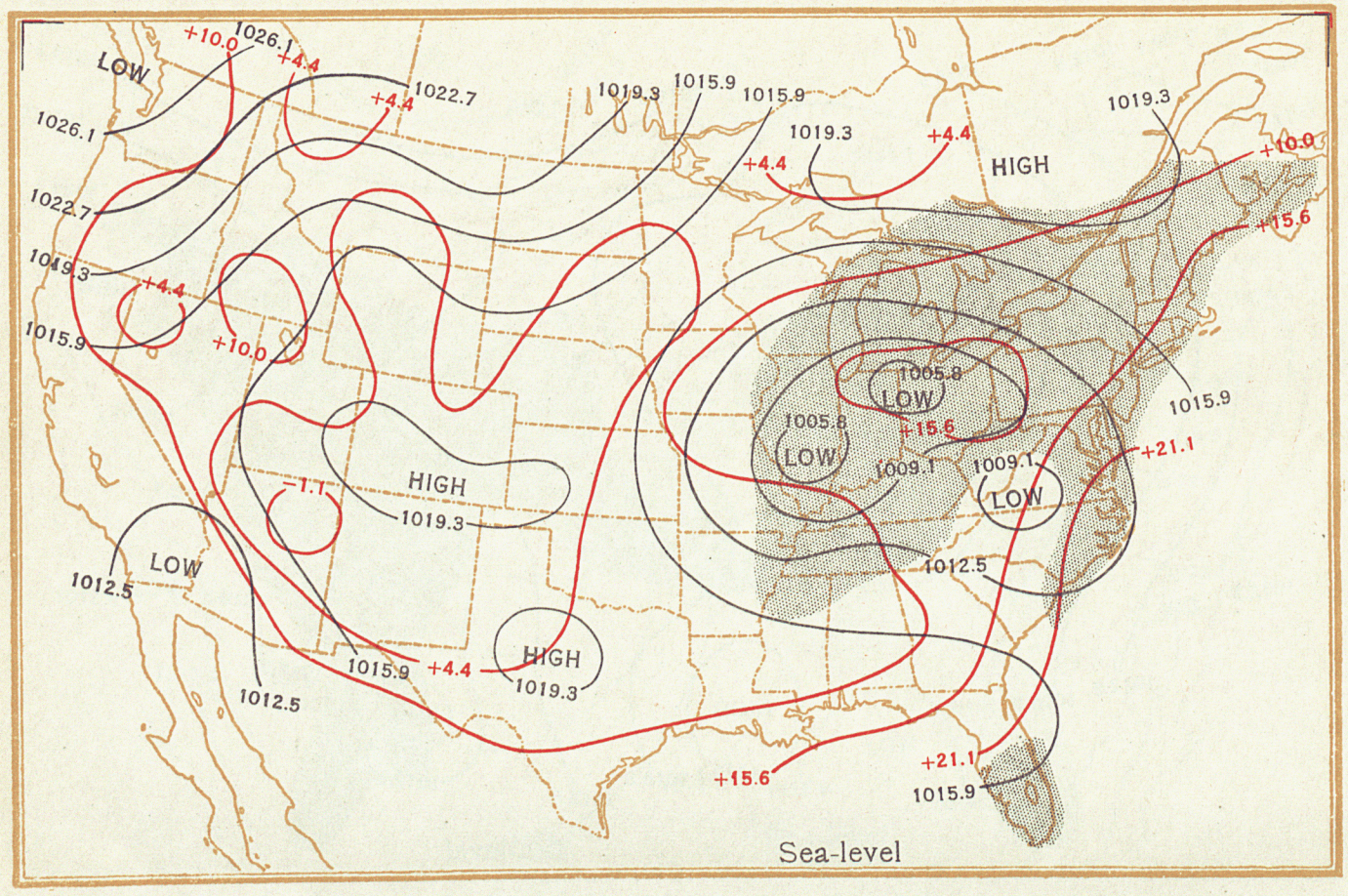
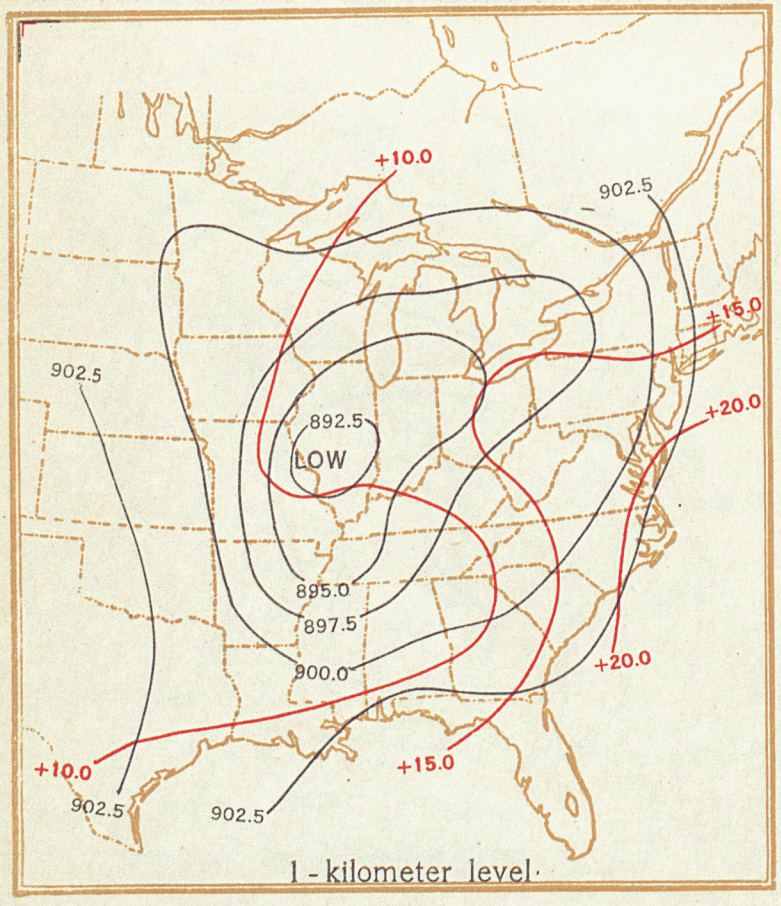


Chart X. October 16, 1914.





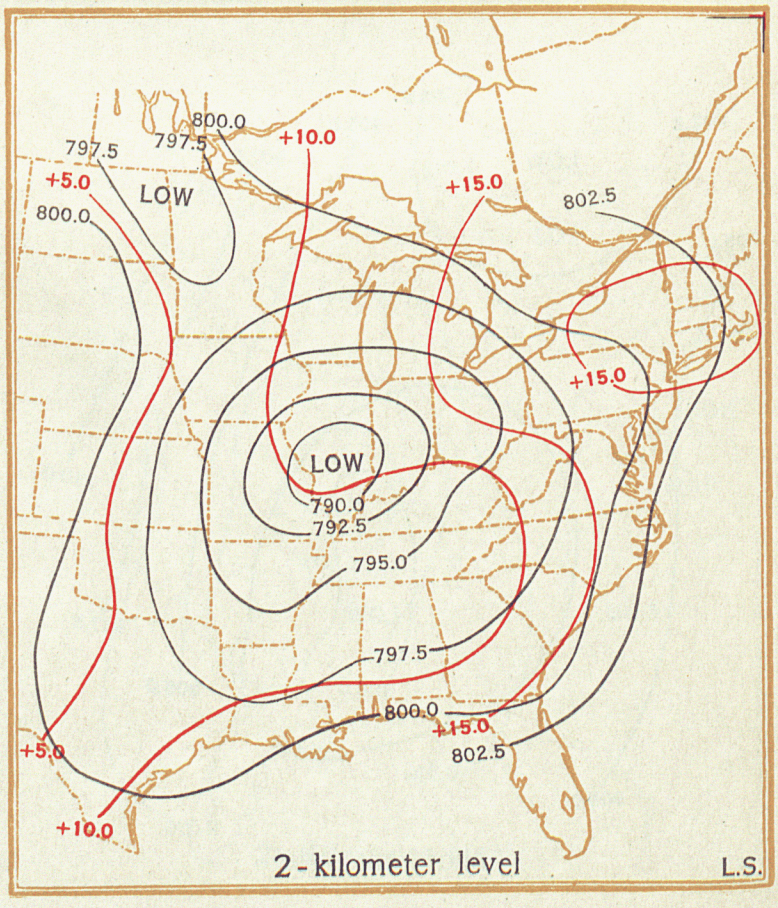
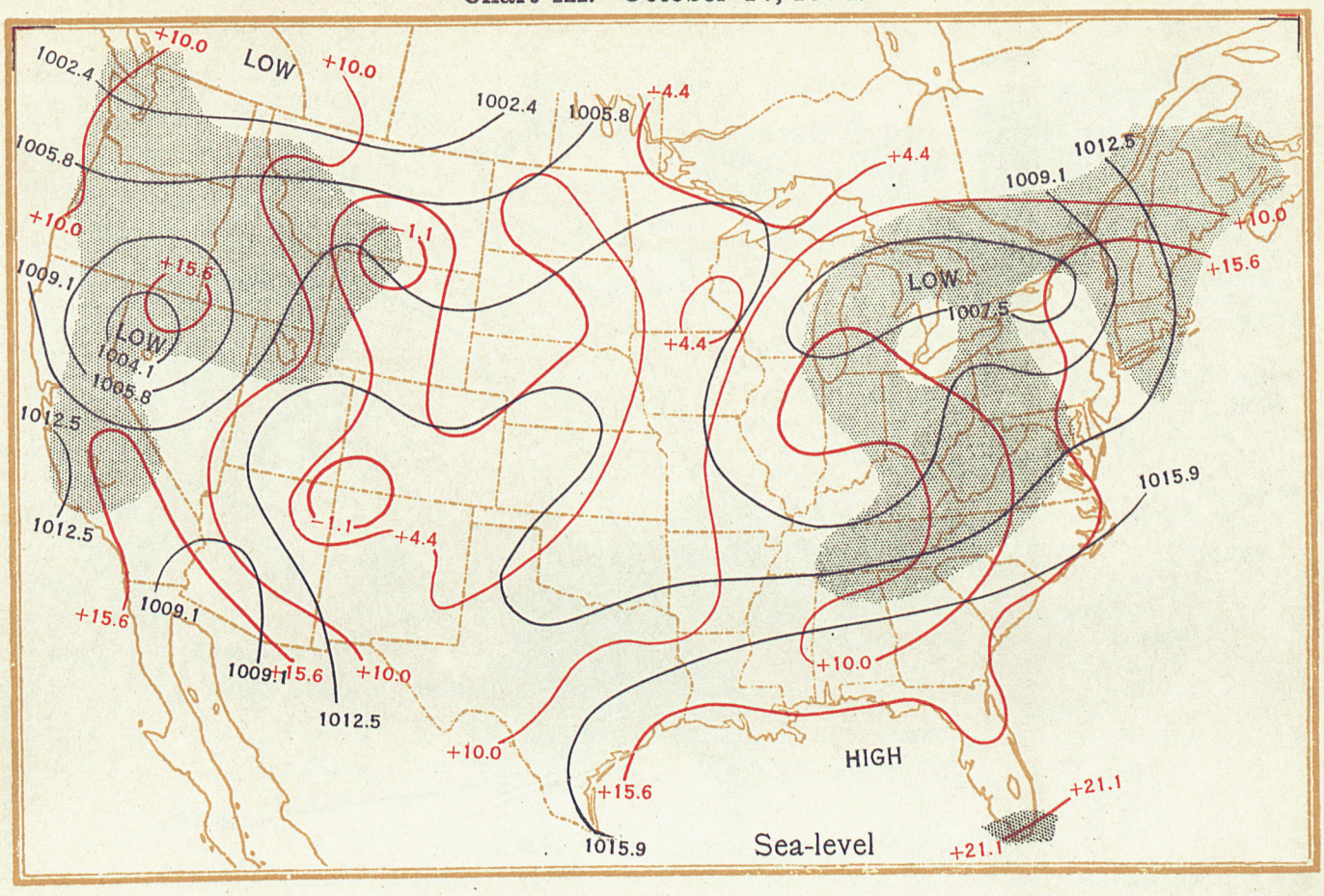
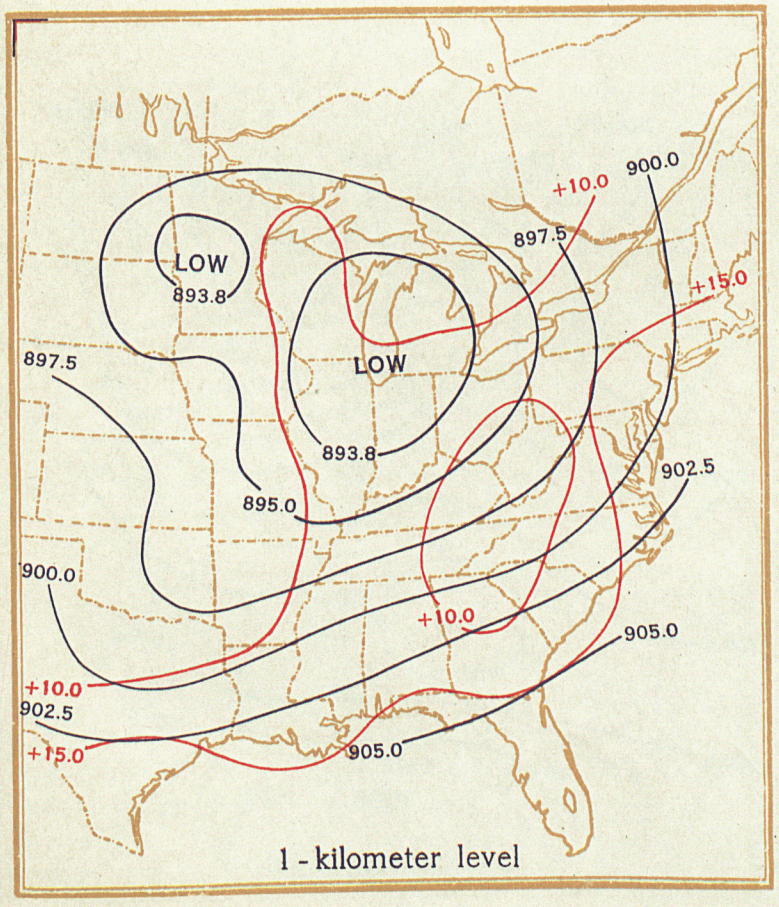


Chart XI. October 17, 1914.





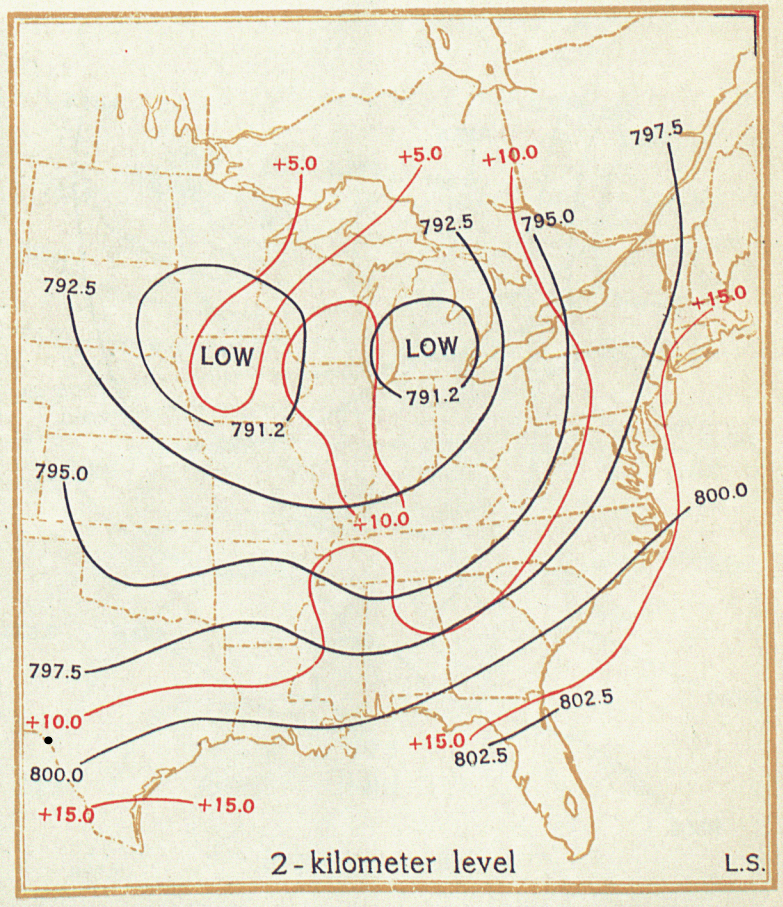
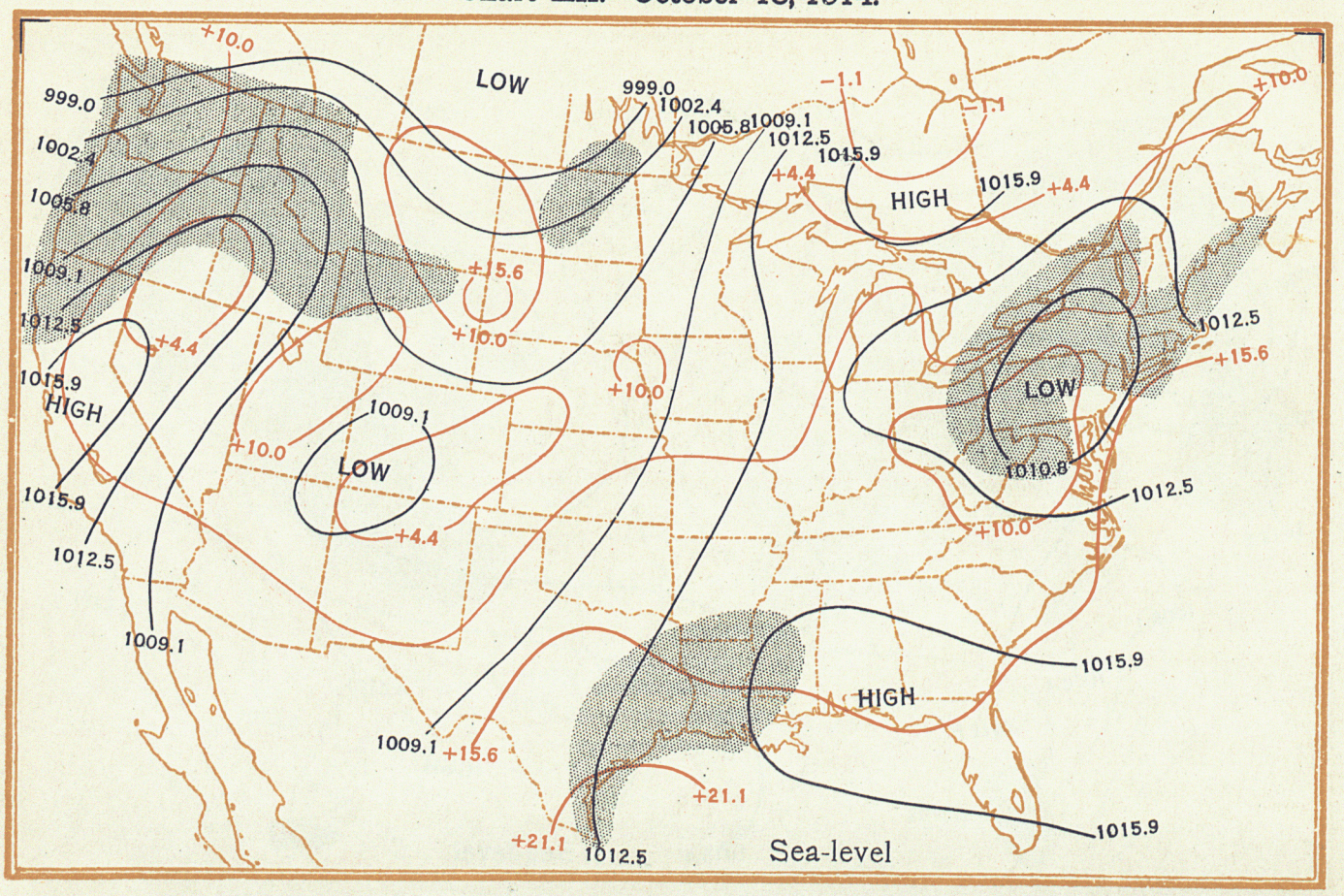
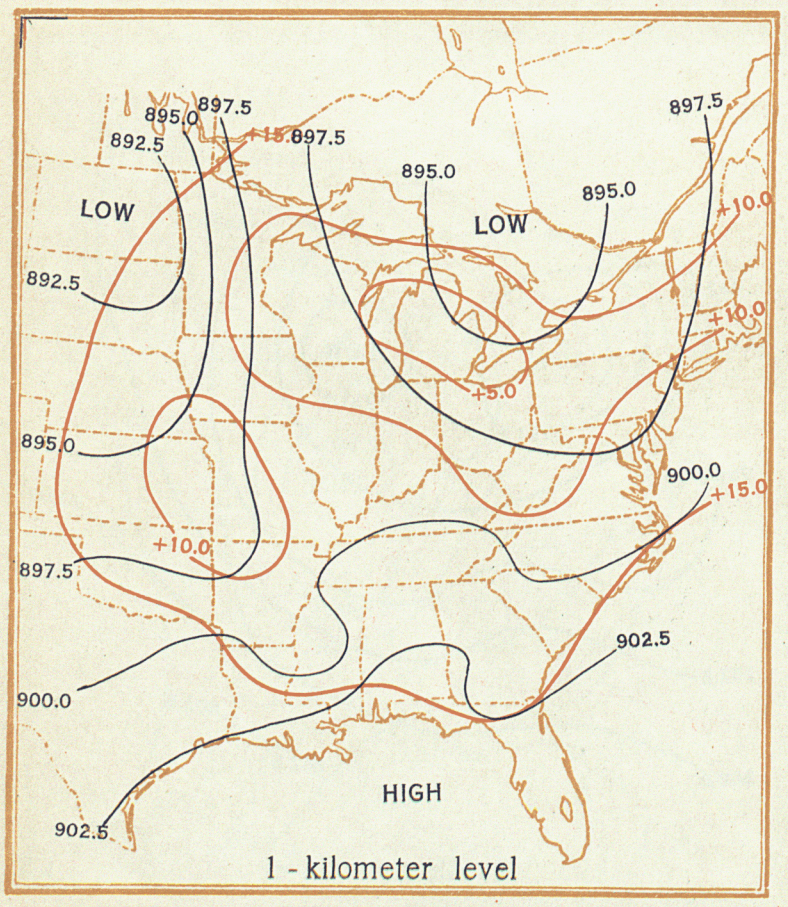


Chart XII. October 18, 1914.





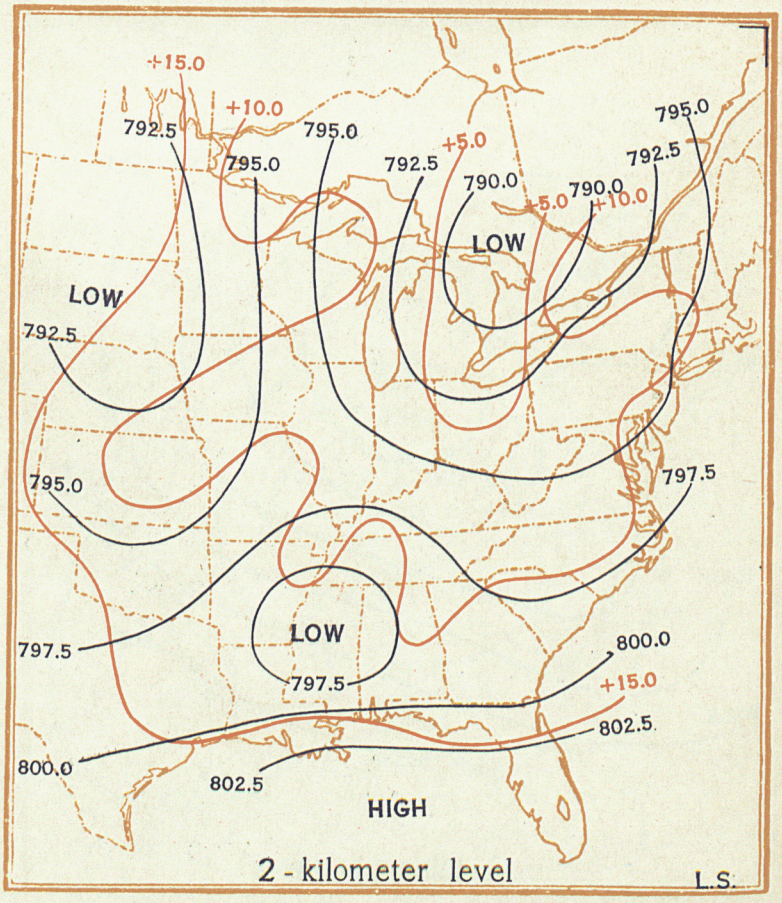
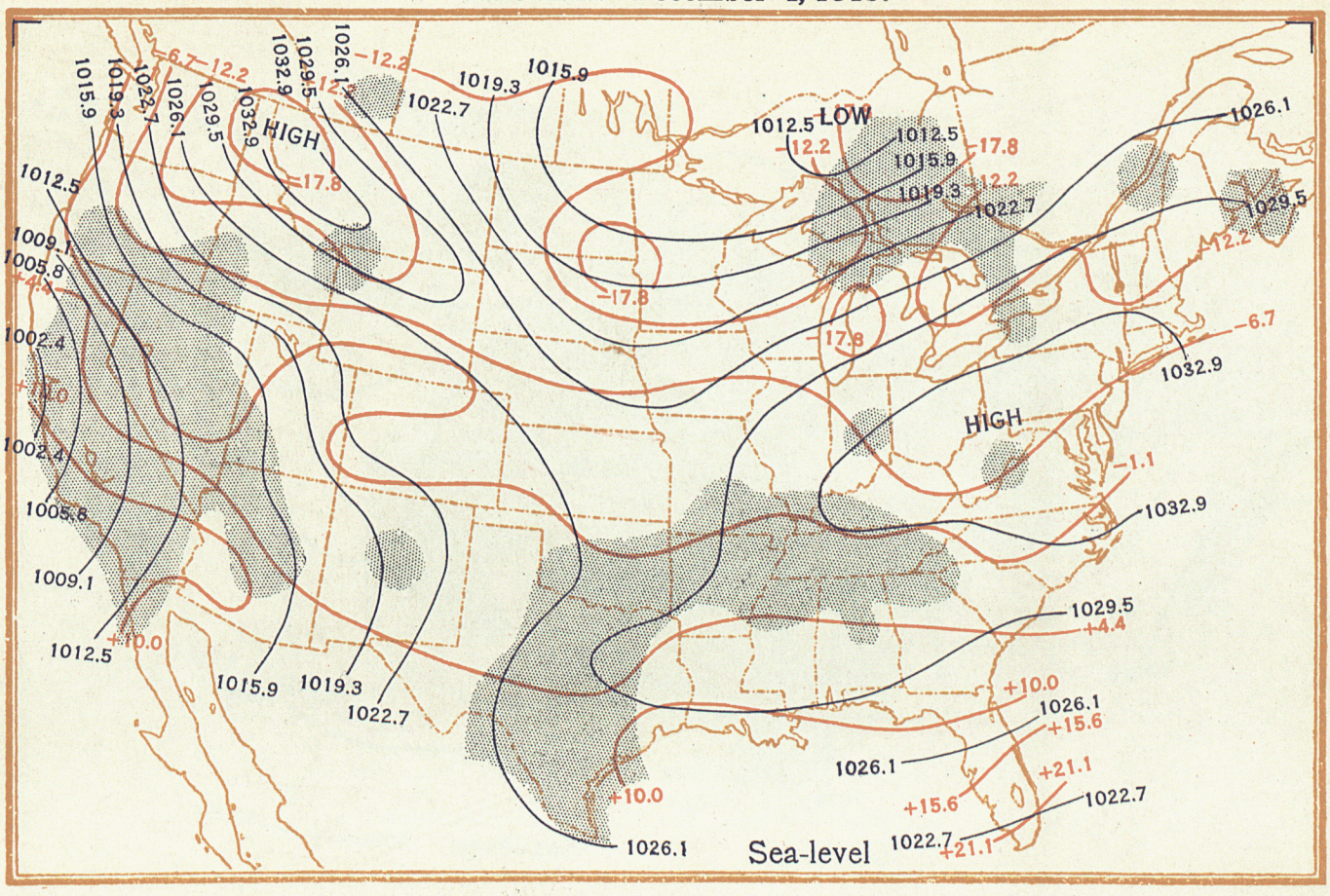
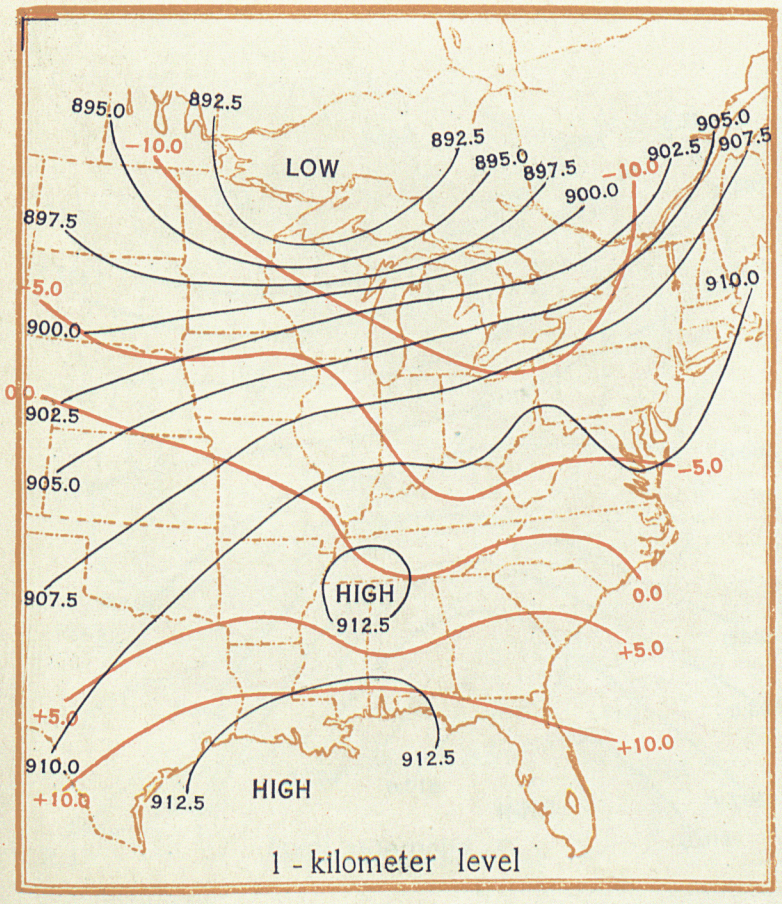


Chart XIII. December 4, 1919.





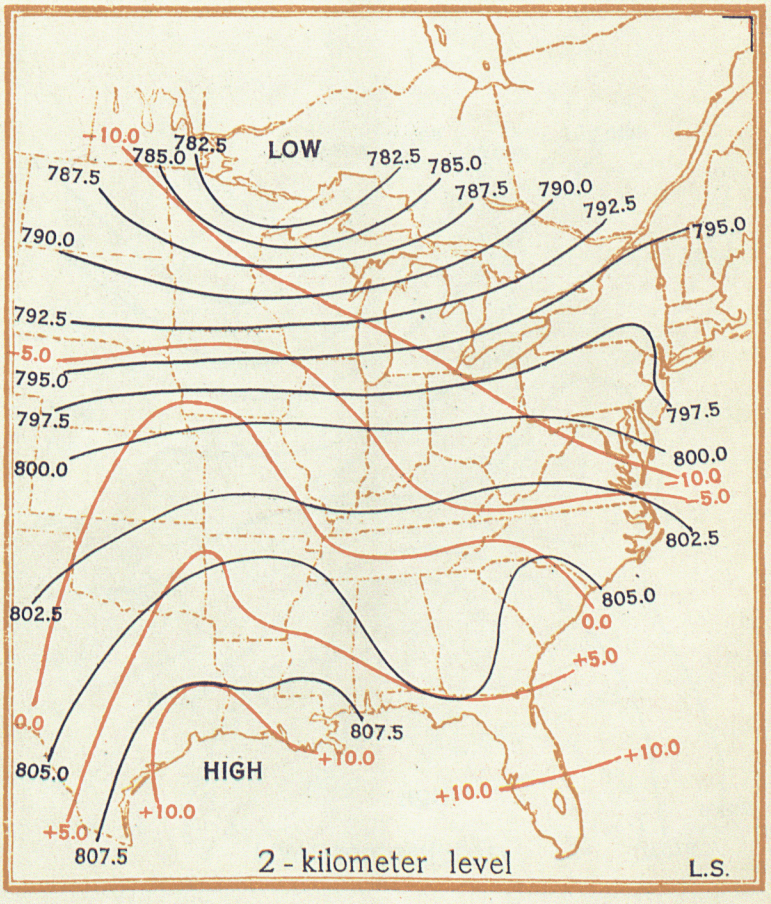
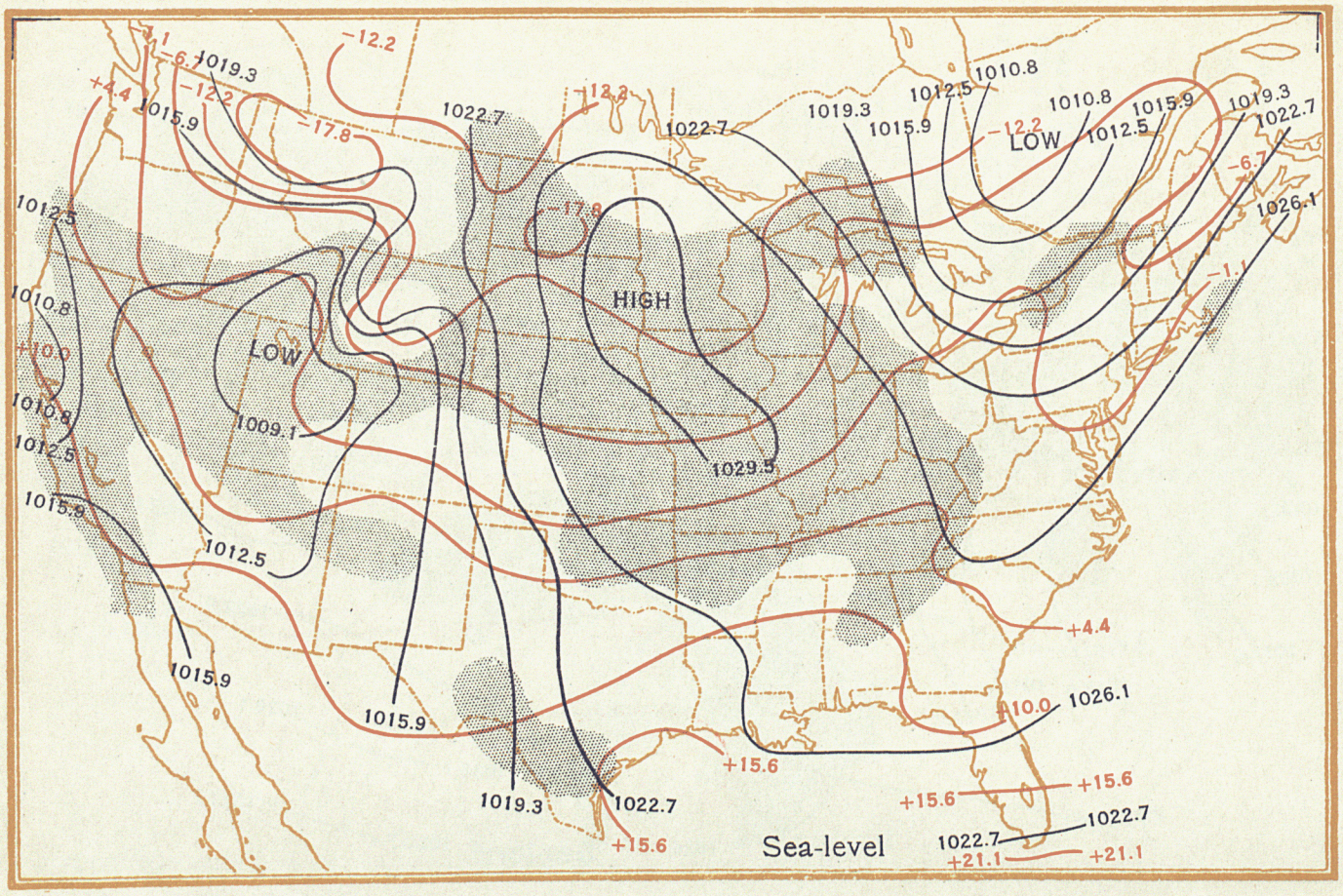
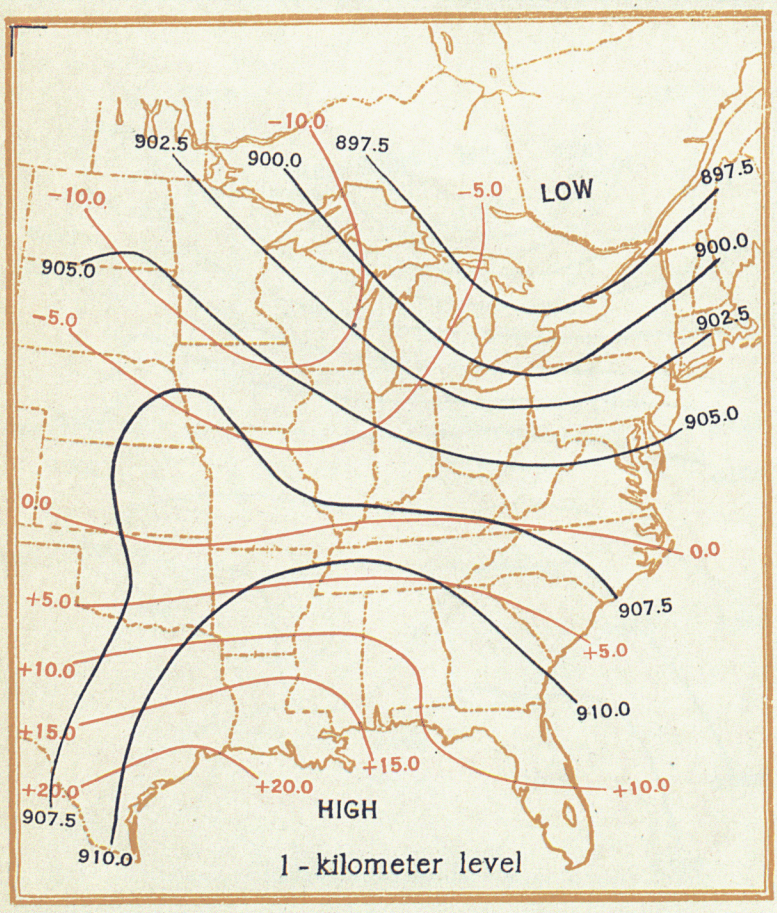


Chart XIV. December 5, 1919.





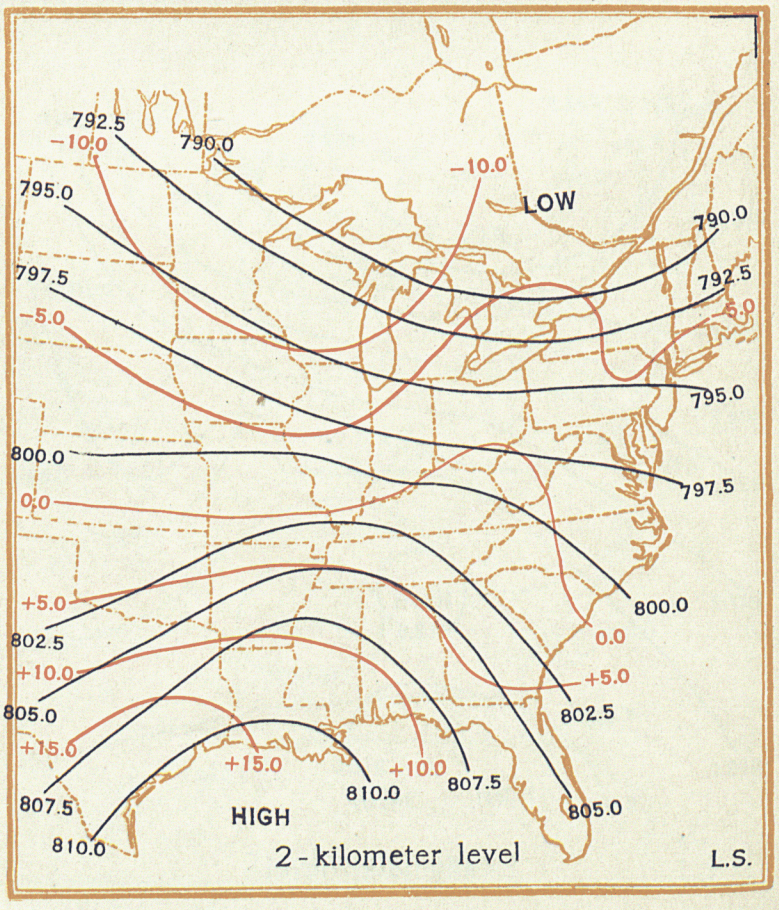
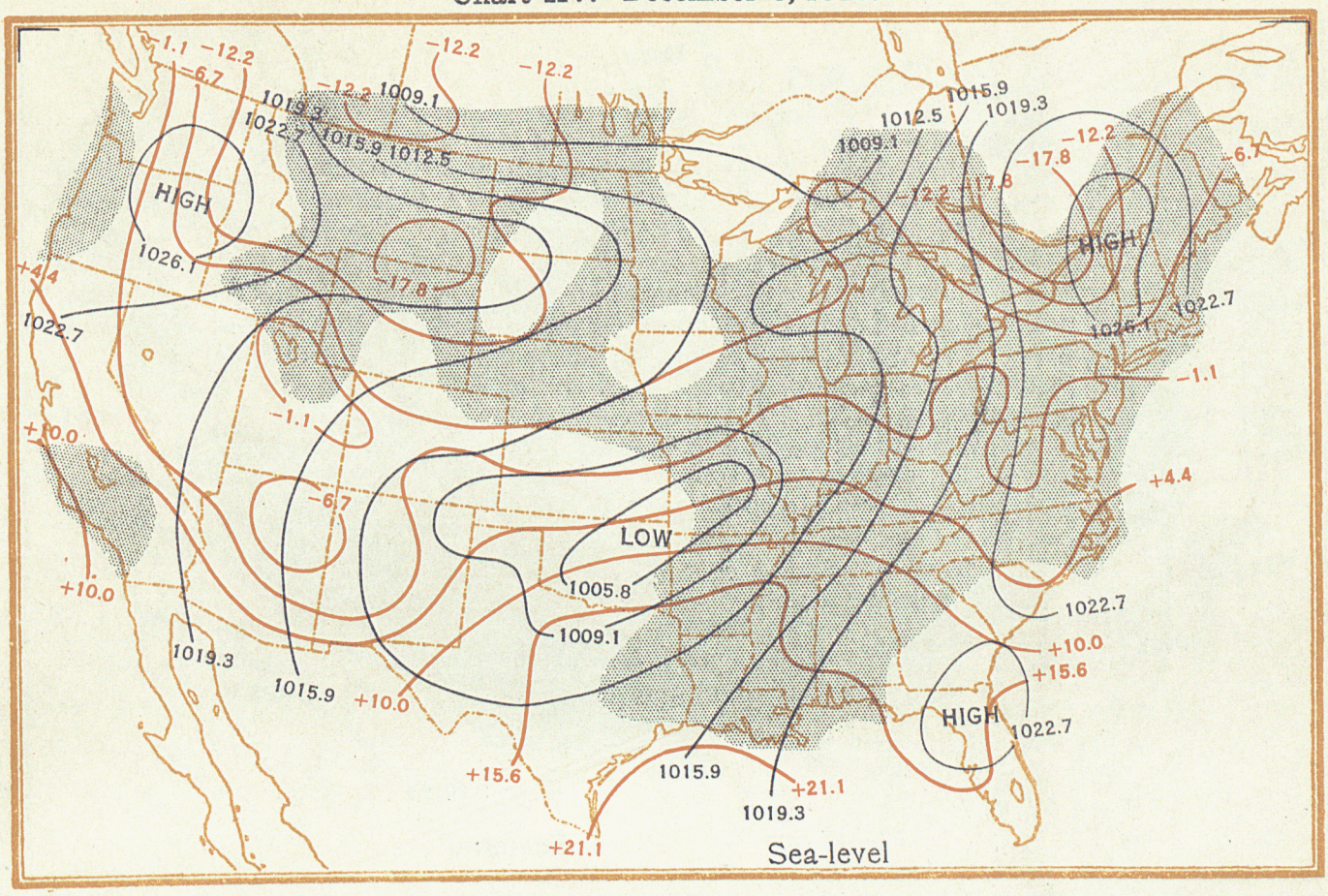
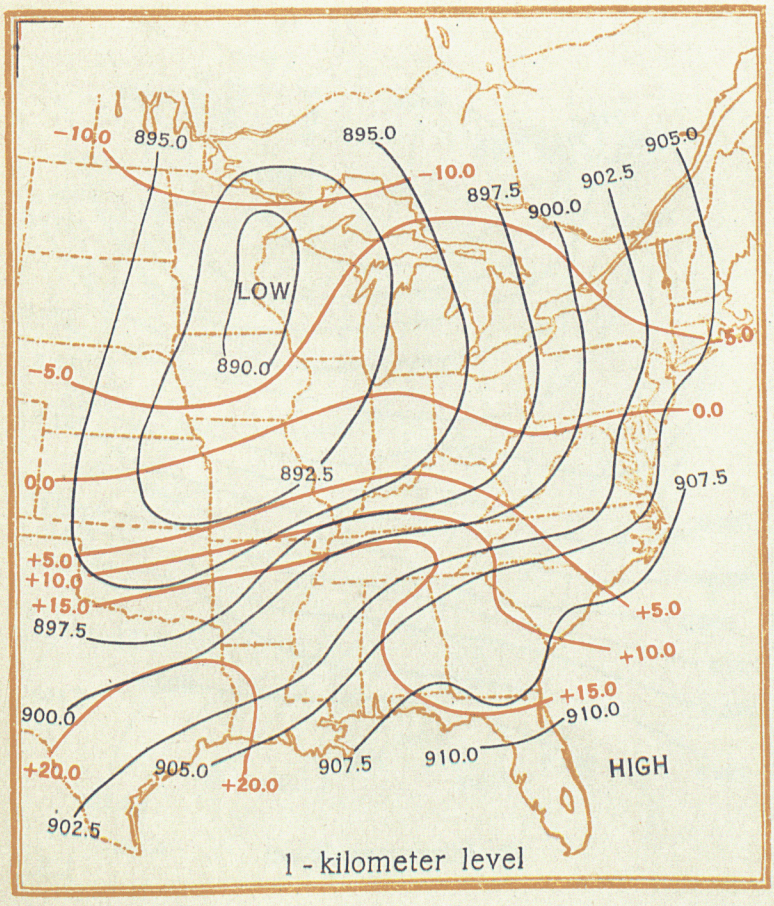


Chart XV. December 6, 1919.





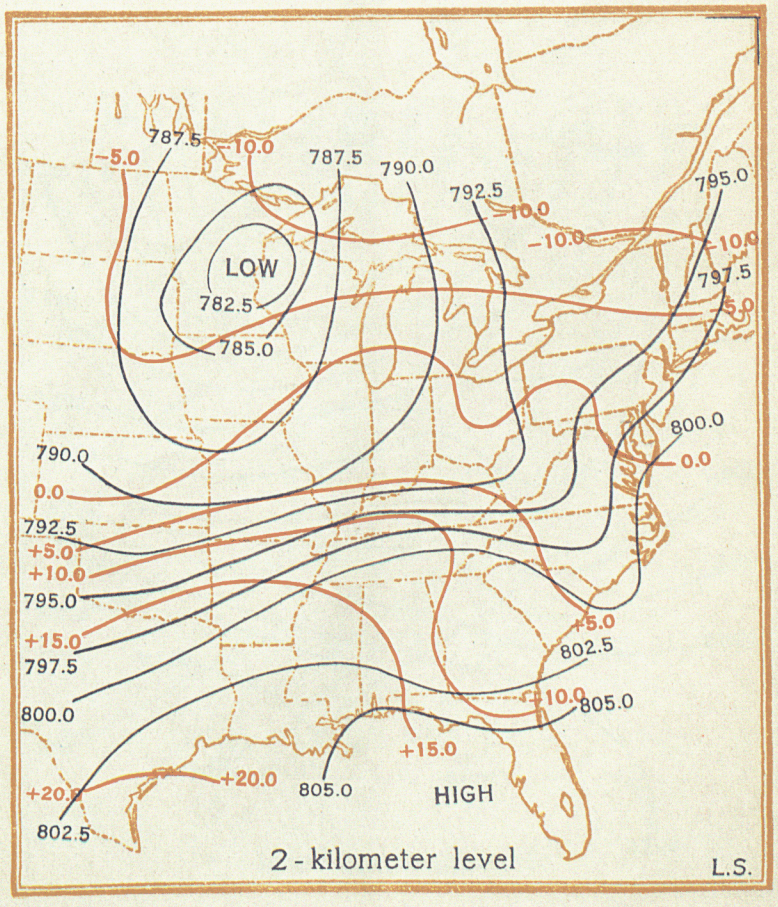
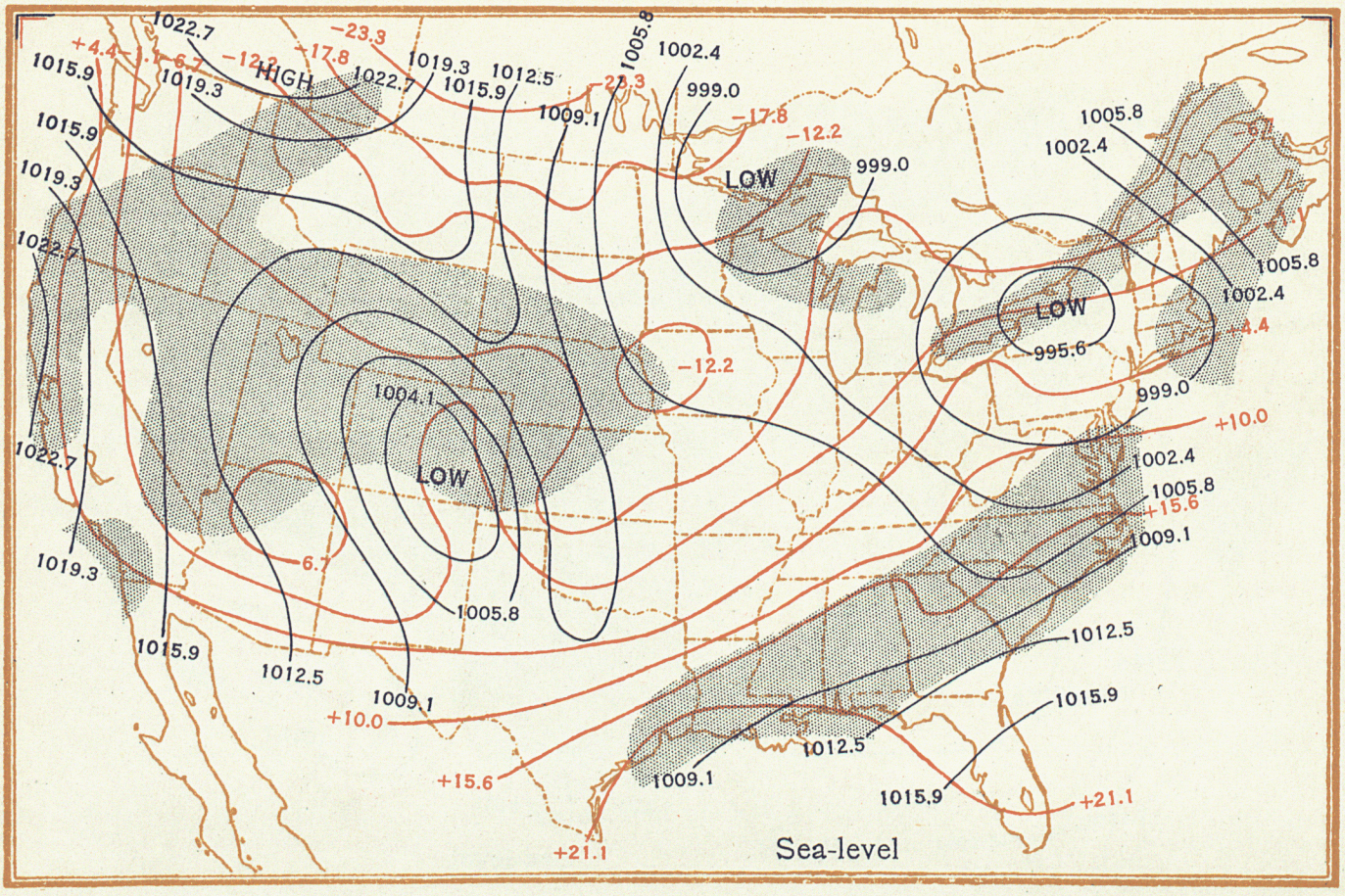
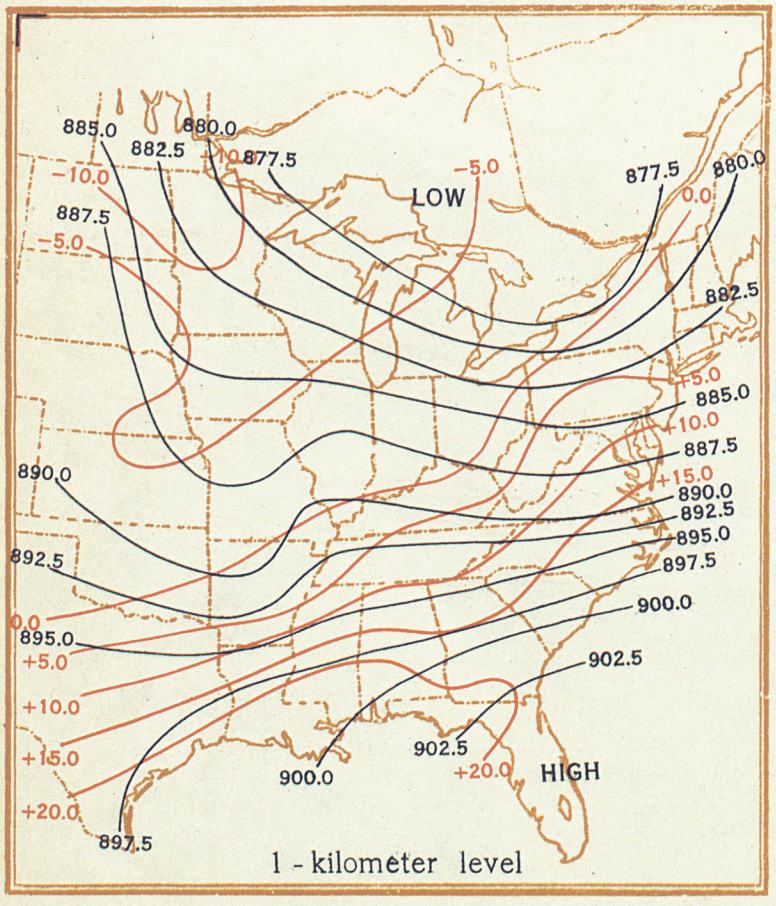


Chart XVI. December 7, 1919.





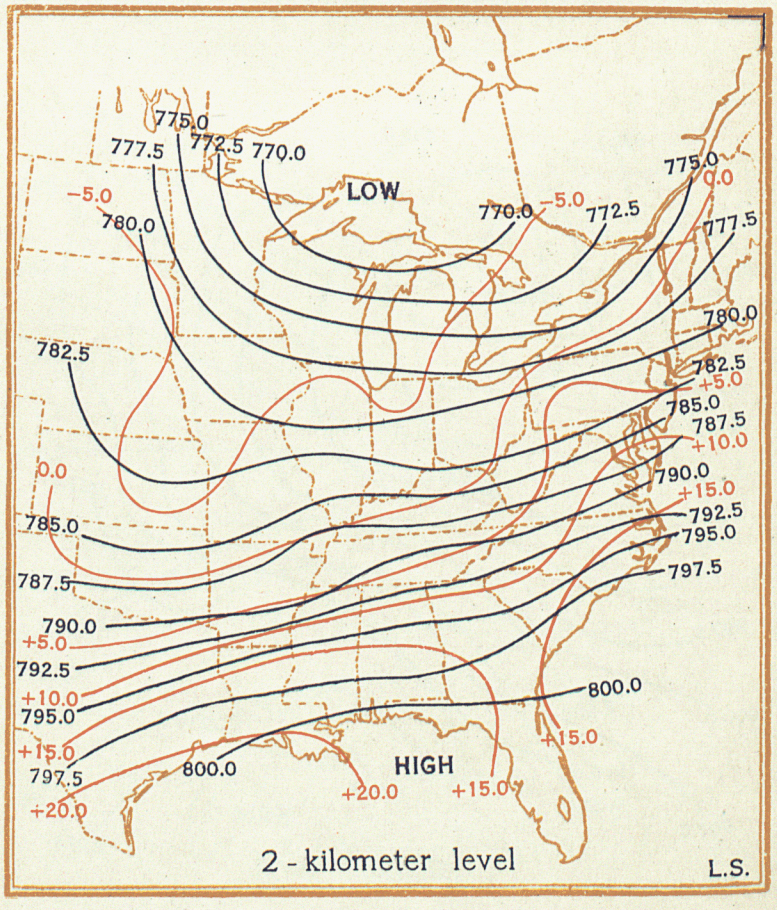
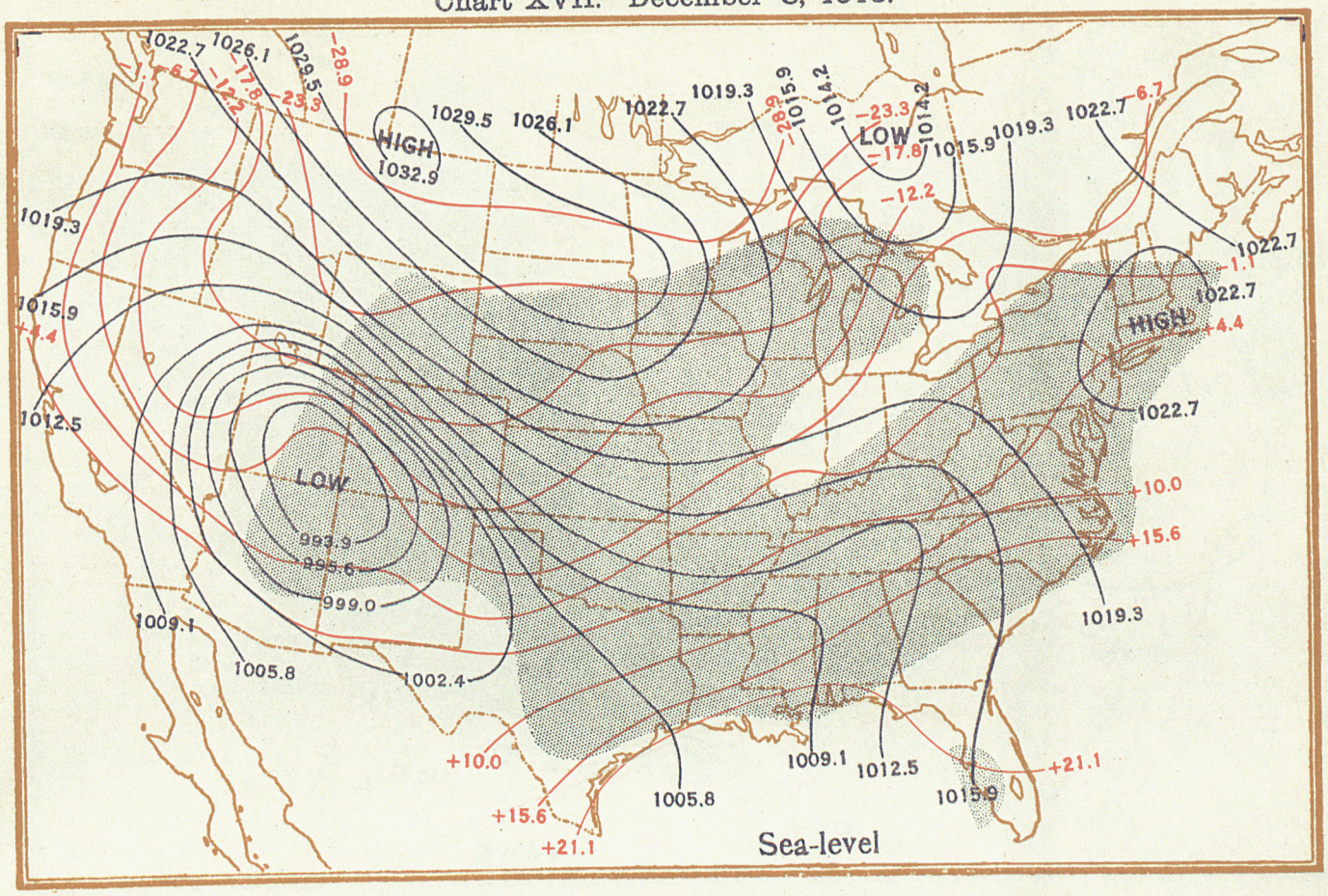
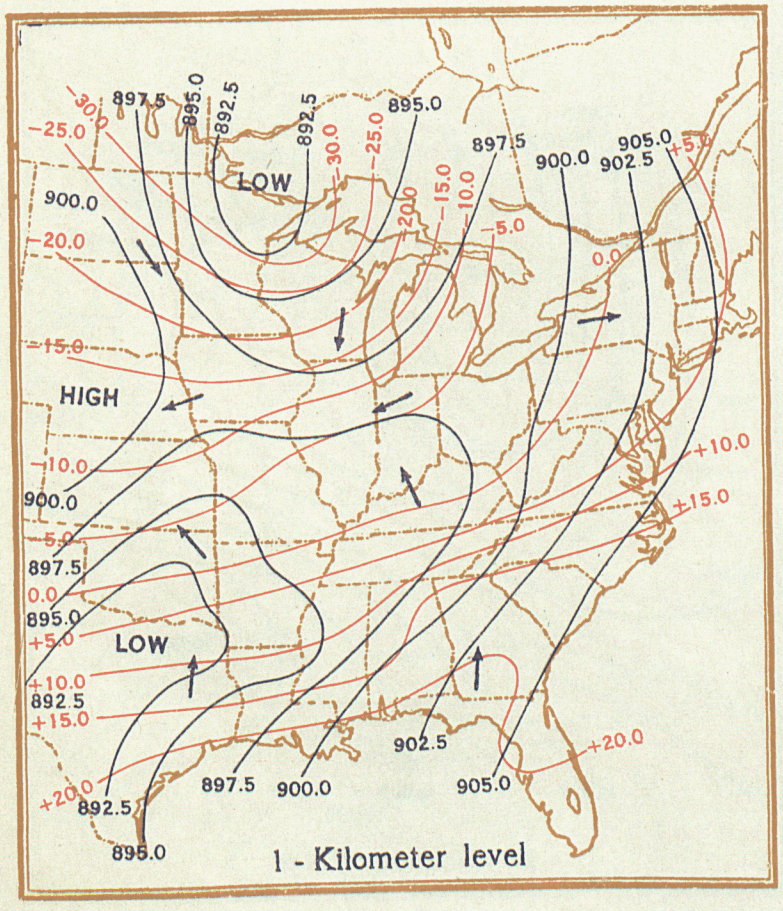


Chart XVII. December 8, 1919.





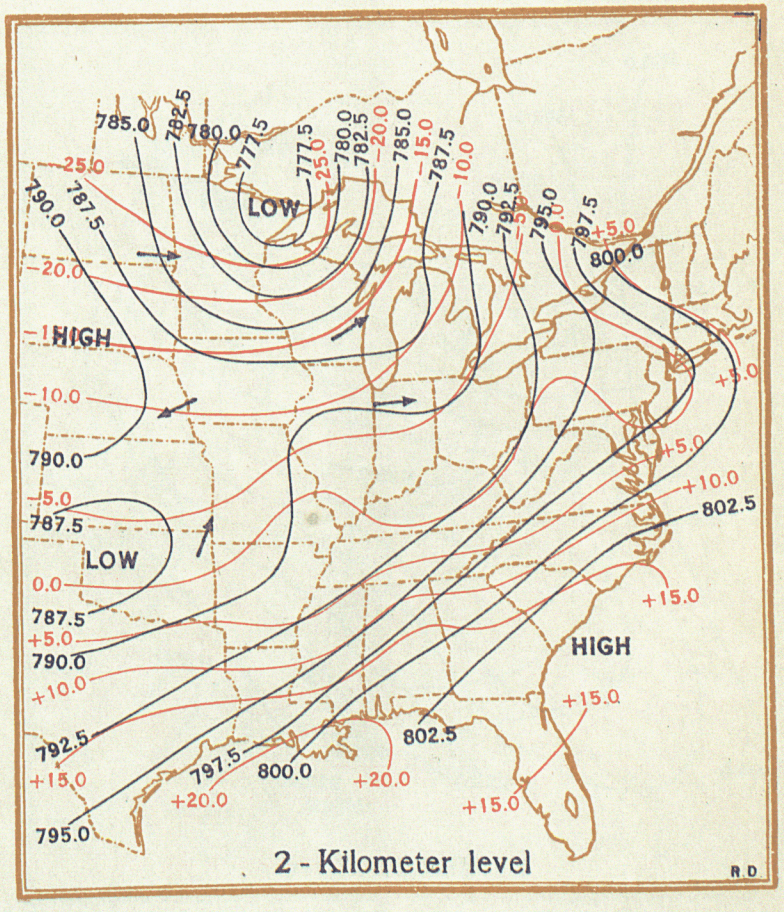
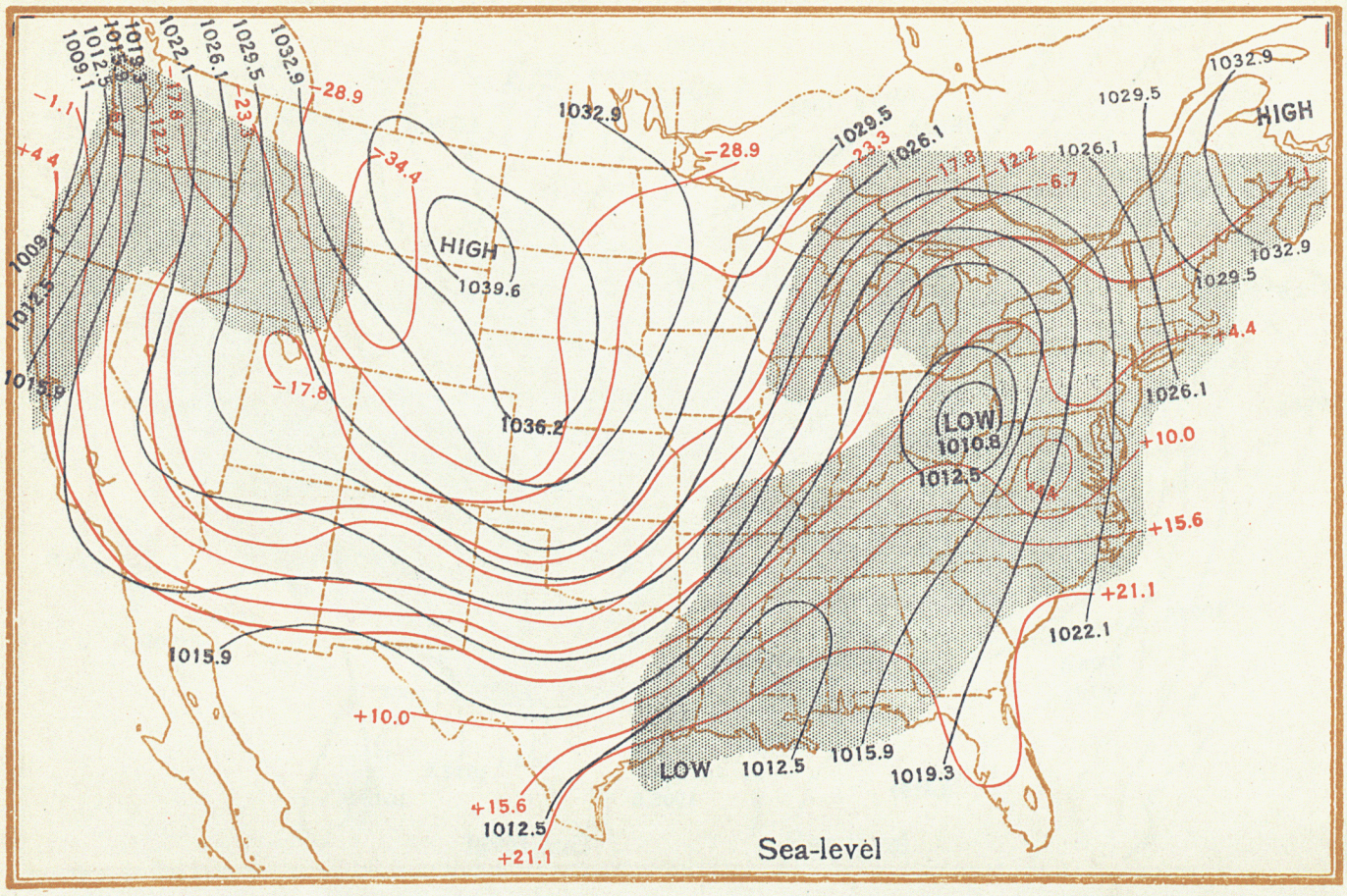
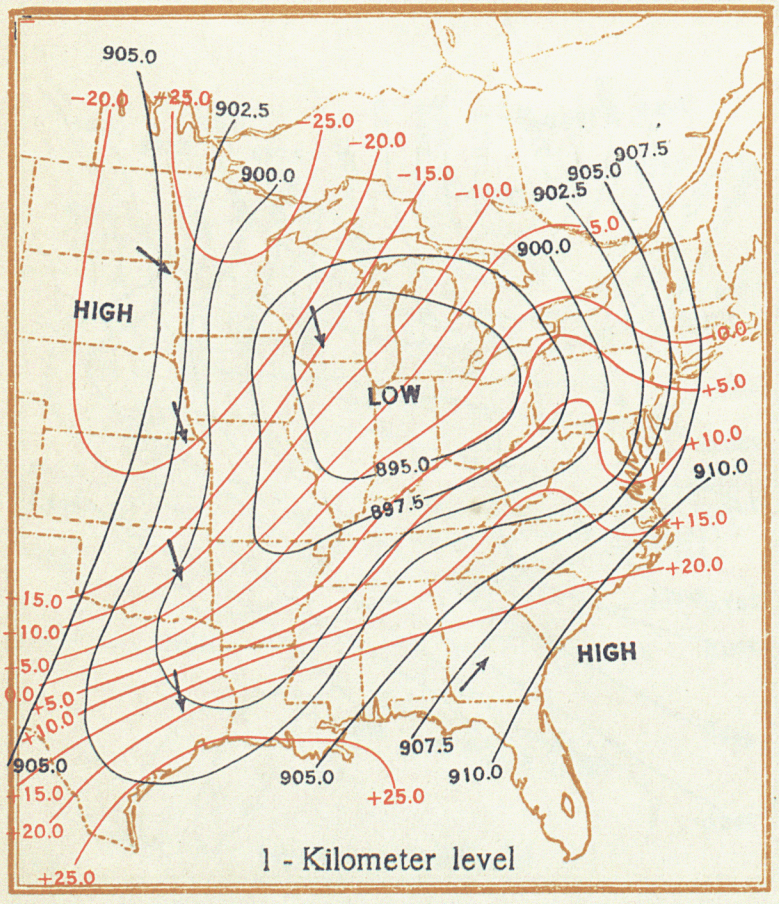


Chart XVIII. December 9, 1919.





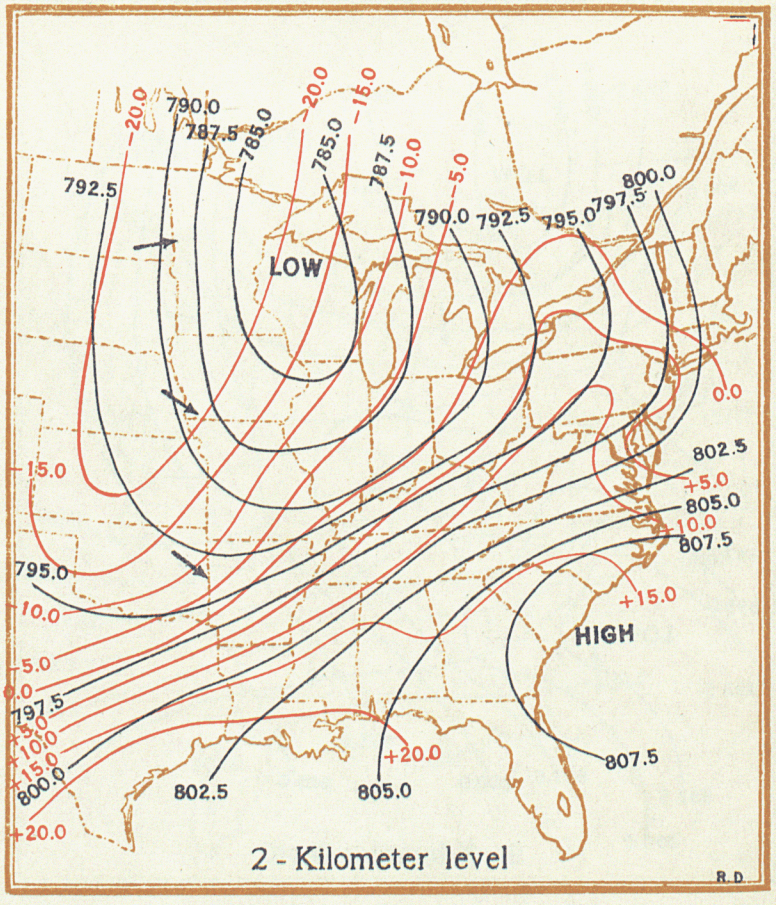
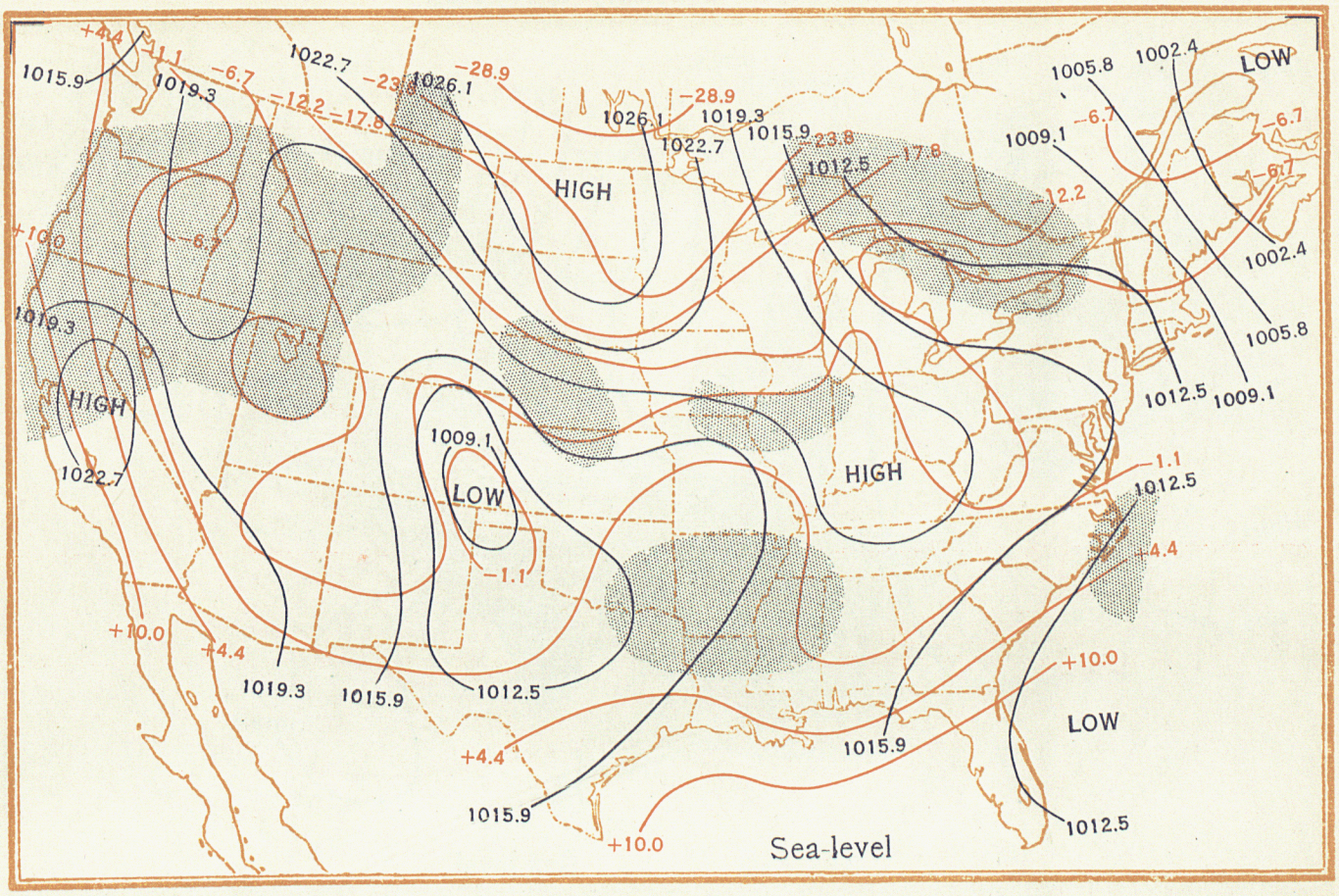
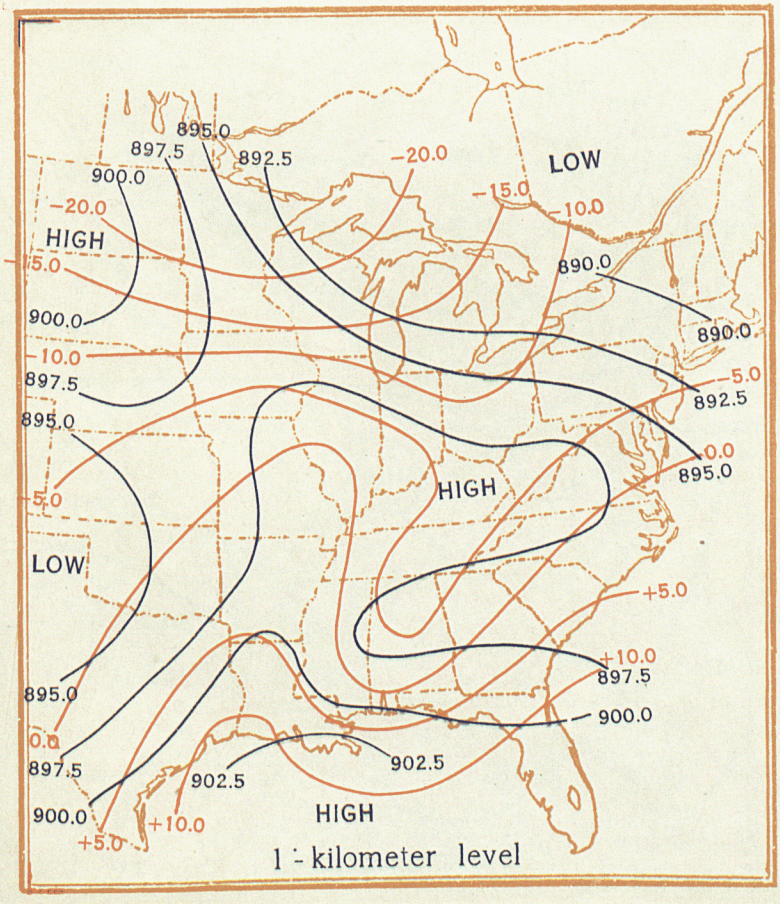


Chart XIX. February 6, 1919.





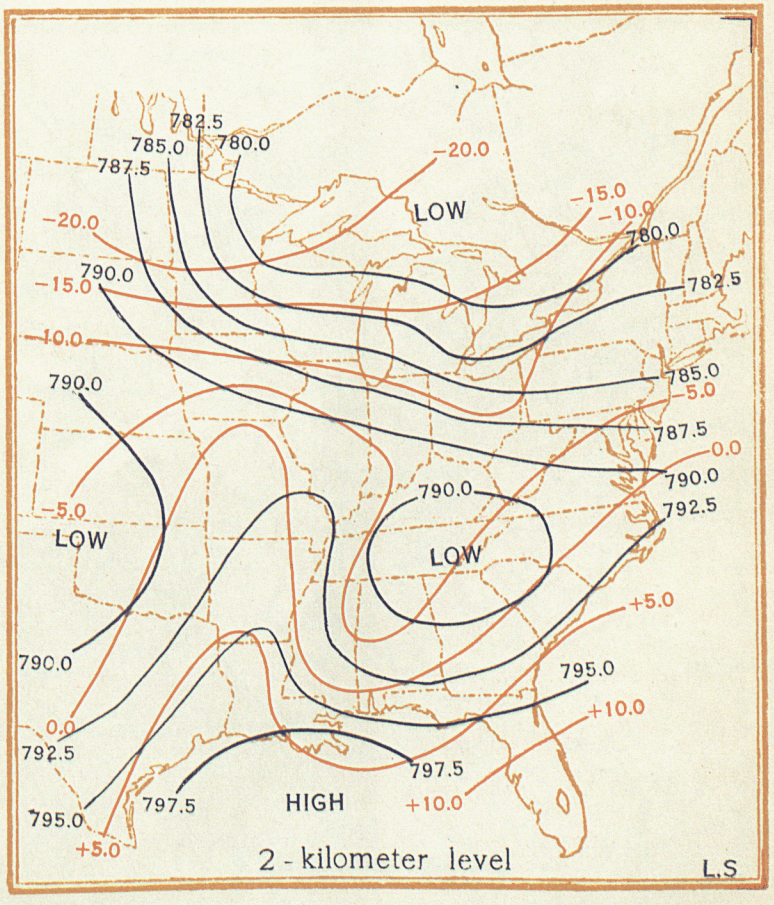
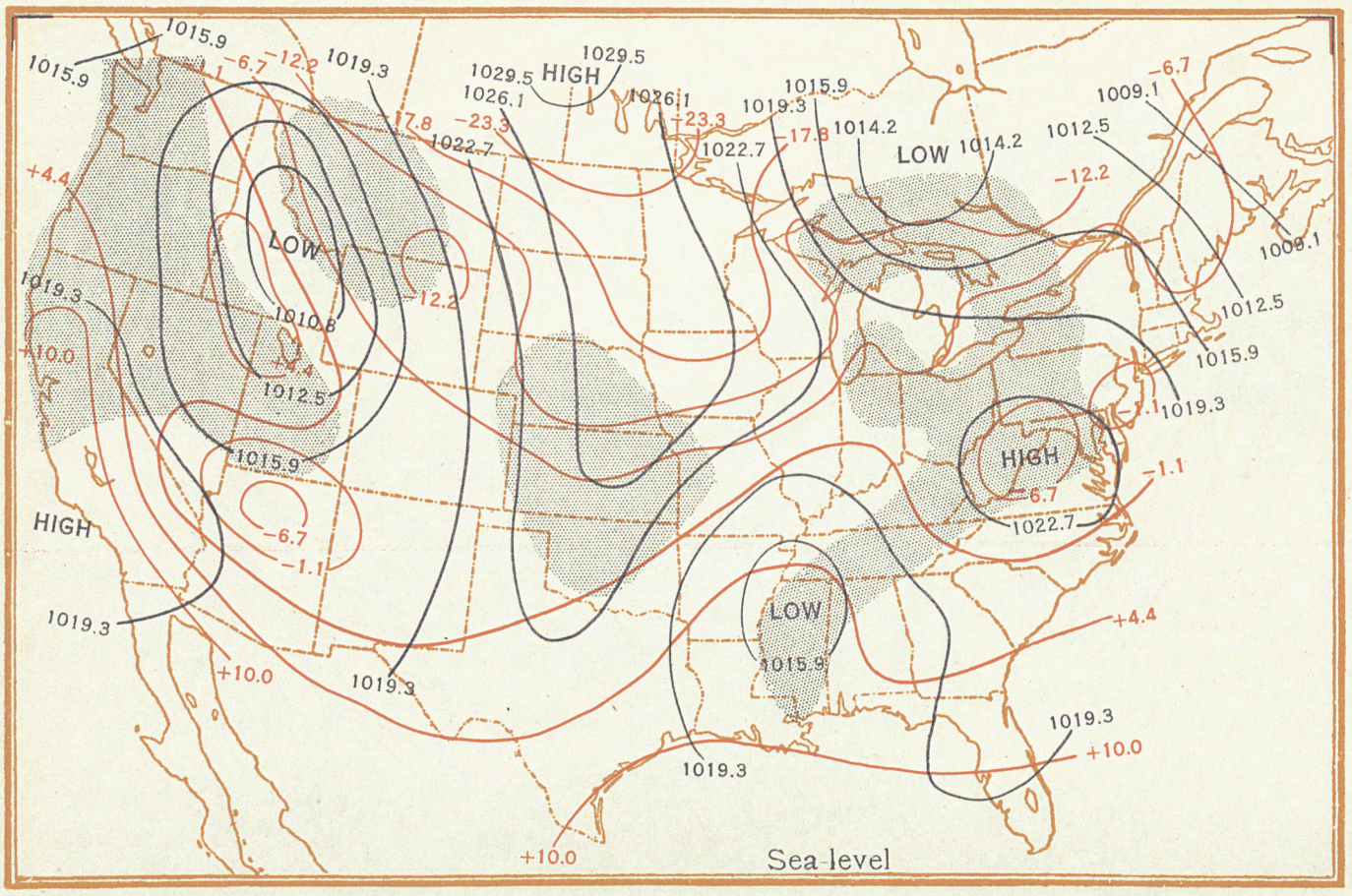
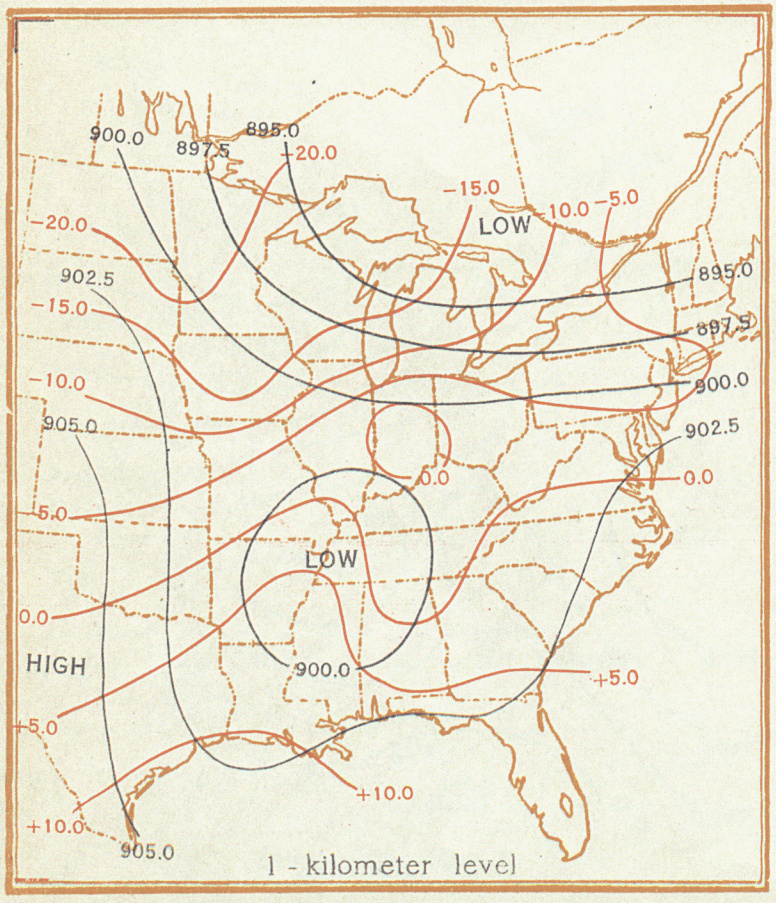


Chart XX. February 7, 1919.





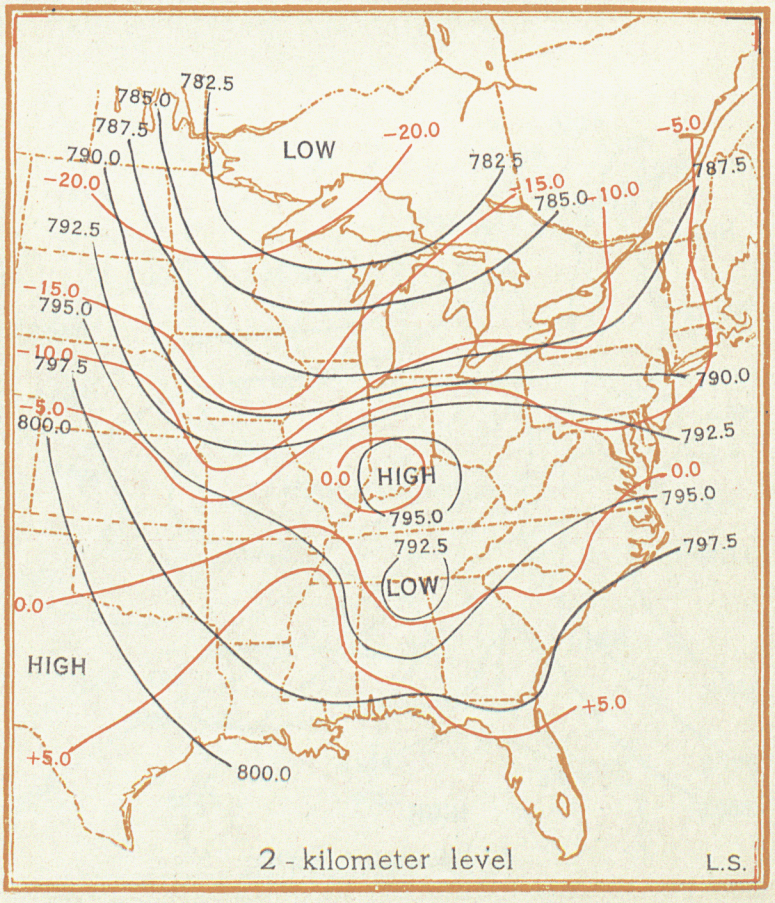
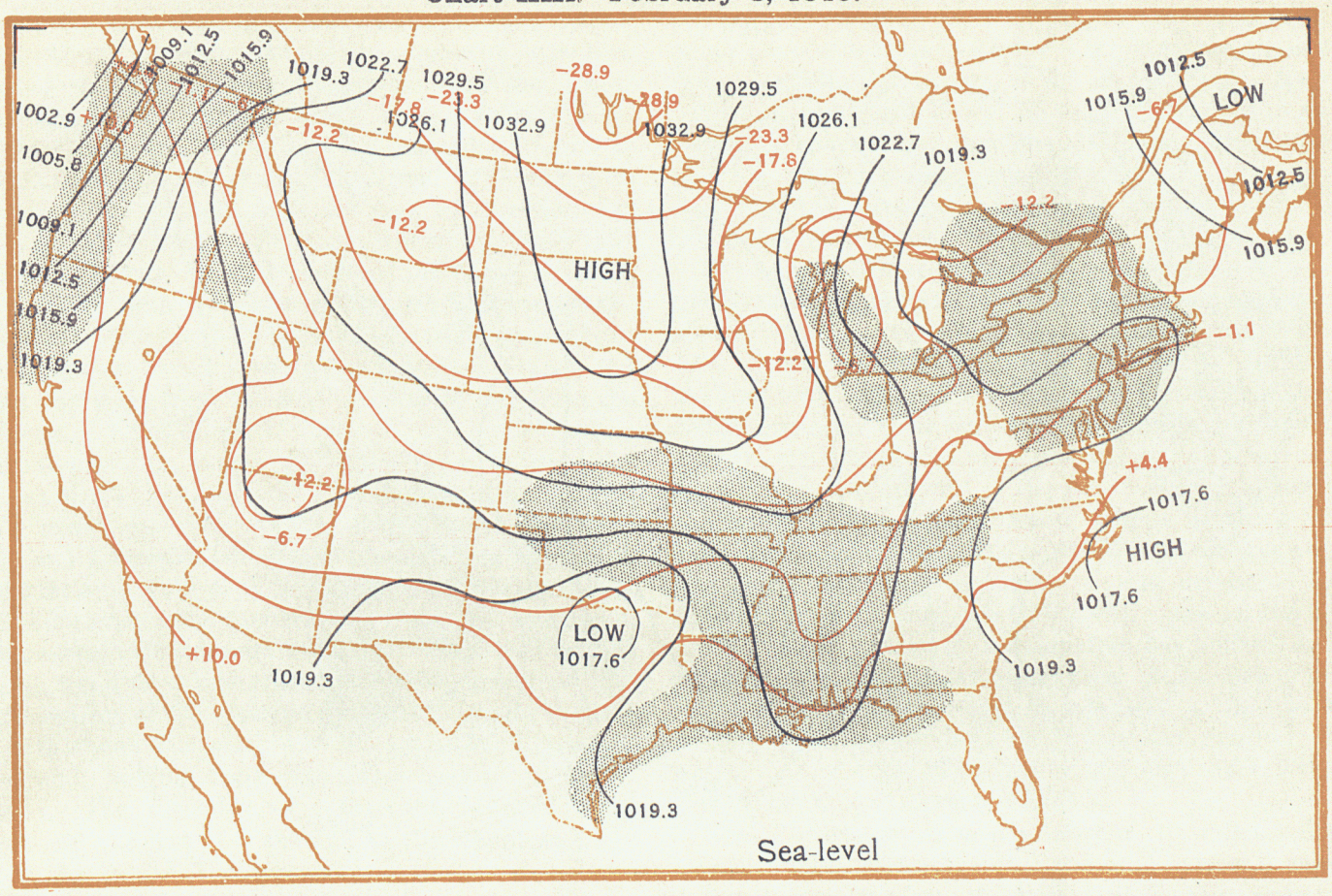
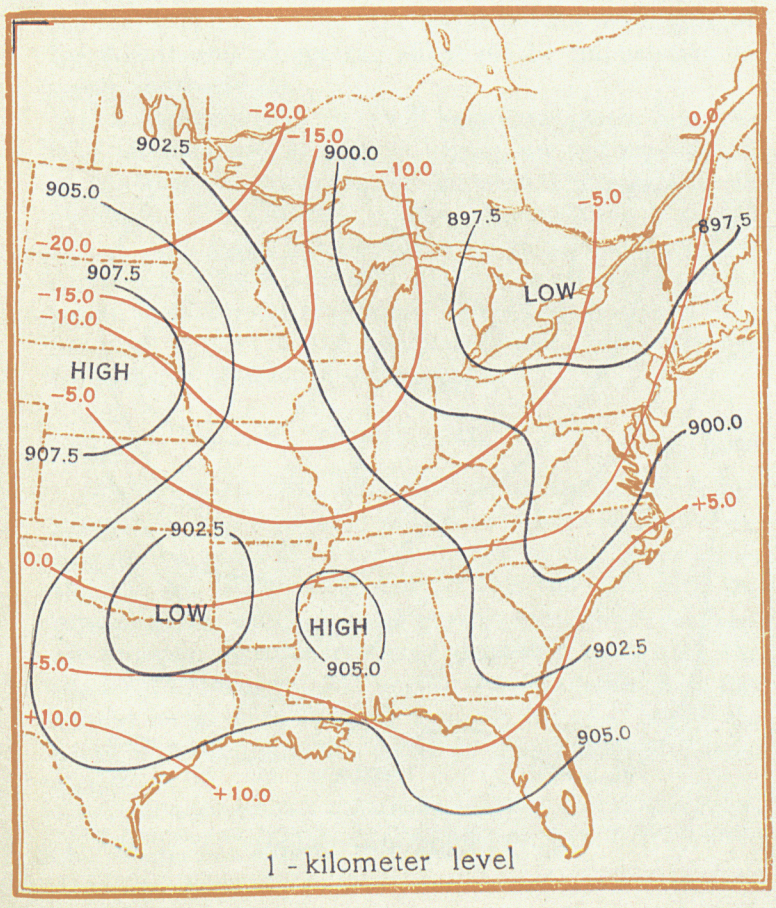


Chart XXI. February 8, 1919.





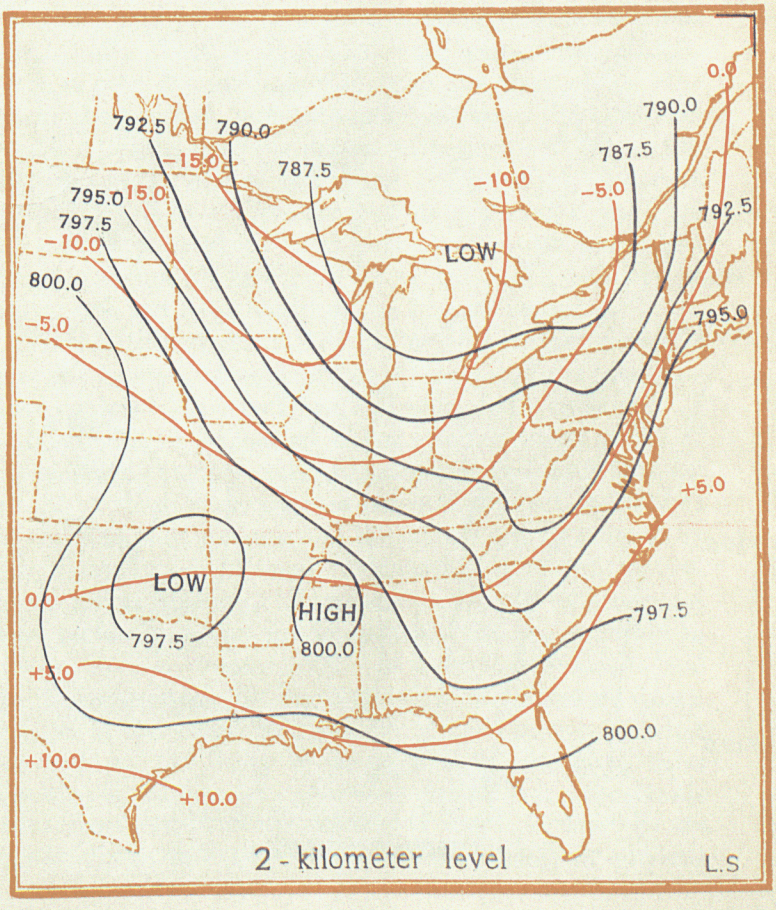
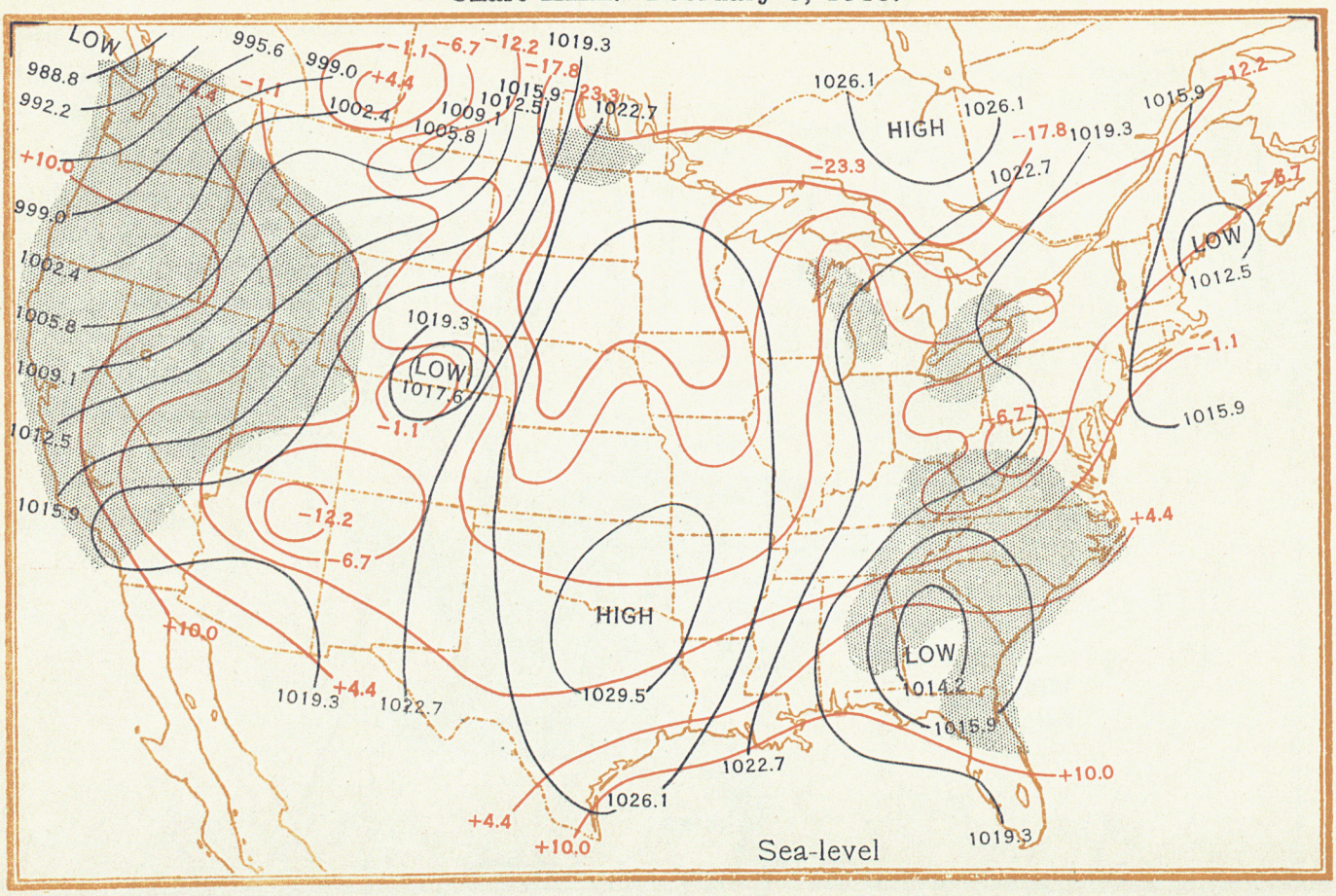
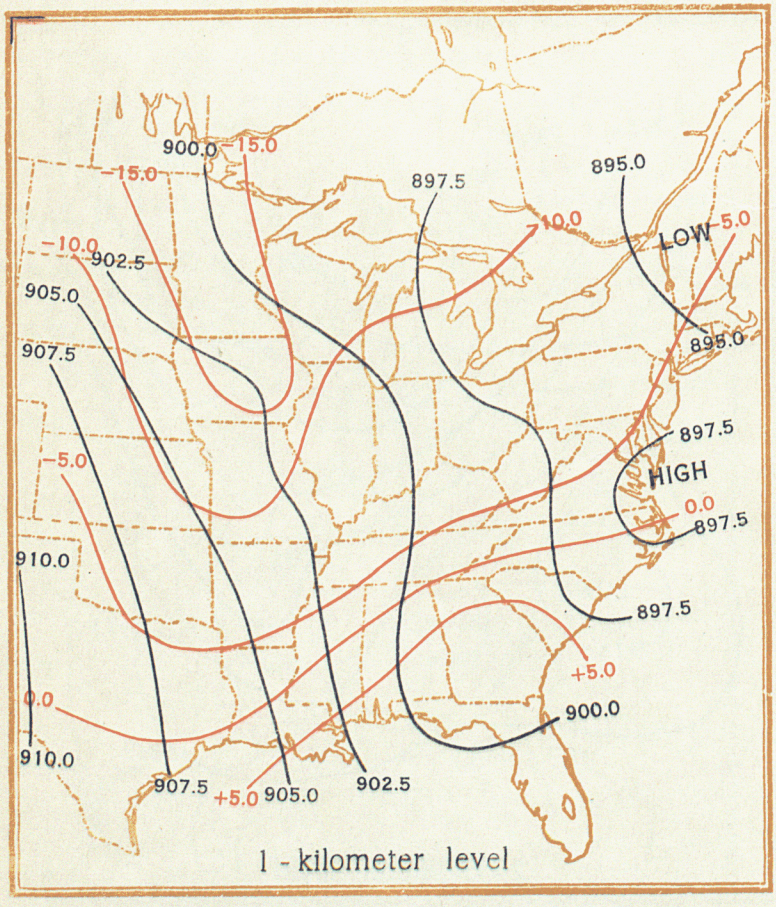
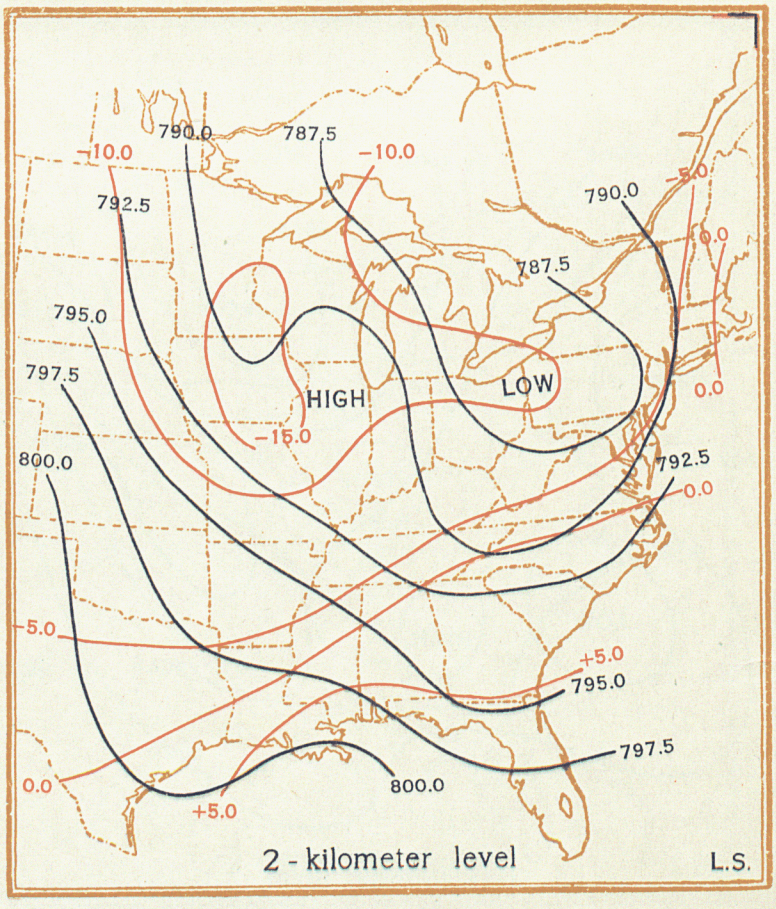


Chart XXII. February 9, 1919.







apparently anticipated that the cyclone would move more to the east than it actually did. In fact, as the map for the 15th shows, the north component of motion exceeded that of the east component and the center appeared in north central North Dakota (Chart III). The third day, the 16th (Chart IV), the disturbance is found in Canada north of Lake Superior. The map does not extend far enough north for one to ascertain the location of the lowest pressure, but it is not unlikely that it lies in a general line with the direction of the previous day. This motion was from a little south of southwest. The sea-level isobars the first day had a trend from southeast to northwest over the eastern United States, the second day more from the south, the third day from the southwest. What do we find aloft?

On the first day, instead of high pressure so far to the north as pictured at sea level, it appears more as a general high pressure region east of the United States producing winds at 1 kilometer below latitude 40° from the south-southwest and north of that latitude from the southeast. At 2 kilometers, the isobars are from the southwest. With general high pressure to the east and a well-defined isobaric trend at 2 kilometers, it is quite apparent that the movement of the cyclonic center is definitely related. The 15th shows this southwest current still better established and, judging from the closer isobars, of higher velocity. The direction of movement of this center throughout the period is parallel to these isobars. The developing "wall" of high pressure in the free air extends parallel to the Atlantic coast,—a fact not discernible on the sea-level map. The progressive northward bulging of the θ-isotherms shows the effect of the importation of warm, southerly air.

It is apparent here, as it will be in later maps, that sea-level anticyclones, at least in winter, are not reproduced in the free air with the positiveness characteristic of cyclones. The Colorado cyclone, for instance, is apparent at each level, but the eastern high pressure does not conform to that at sea level, and the small high-pressure region in Nebraska and South Dakota on the 16th does not even appear on the 1-kilometer map, being overrun by westerly or northwesterly winds.

CHARTS V–XII.

October 11–18, 1914.—In this series are to be found many effects of a peculiar nature, which, in spite of their singularity, seem to be much simpler at the upper levels than at sea level. Especially is this the case with the precipitation, which seemed to correspond with the free-air pressure distribution more definitely than with the sea-level indications. It is entirely reasonable that this should be so since it is air at some distance above the earth that produces rain as result of mechanical convection.[10]

[10] Cf. Bjerknes, J., and Solberg, H.: Meteorological conditions for the formation of rain. *Geofysiske Publikationer*, Vol. II, No. 3, Kristiania, 1921.

The first feature worth noting is the small high-pressure area at 1 kilometer. At sea level, this is a considerable bulge in the isobars with its center in northeastern Arkansas; at 2 kilometers, it has disappeared. Doctor Sekiguchi remarked, it will be recalled, that deep anticyclones persist longer than shallow ones. The sea-level map for the 12th shows a small high pressure region over West Virginia, but there is no vestige of it in the free air. On the 13th it has disappeared from the sea-level map.

The next feature is the low pressure centered in northern Colorado on the 11th. The 2-kilometer map shows a general west-to-east isobaric trend, and the map for the 12th shows the disturbance directly east of its former position now centered in Iowa. At 1 kilometer, the low center coincides with sea level, but at 2 kilometers the appearance is that of a tongue of low pressure intruding from the west-northwest. The sea-level map now gives the impression of a low-pressure tongue inserting itself from the Gulf, but this does not appear in the free air on the 13th. The only response to this persistent low-pressure activity along the Gulf coast comes on the 15th when the low center at 2 kilometers has shifted as far south as southern Alabama. Over Lake Superior is found another storm equal in intensity to that in the South; the following day (16th) there has occurred what appears as a merger of the two with a very much intensified center in west central Illinois.

This disturbance is nearly circular, its importational power is most perfectly developed, and low temperature is found intruding from the west until the temperature of the south half of the formation is lower than that of the north half. This is significant with respect to rainfall. Here is cold dry air imported from the west and northwest; the warmer, moisture-laden air from the Gulf and South Atlantic coasts is drawn with pinwheel symmetry into the north half of the storm. This effect, apparent at both levels in the free air, but complicated at sea level by the tri-centered low area in the east, seems to explain the occurrence of precipitation in the north half of the storm and but little south of the free-air center.

The shifting of the center to the west in the free air is also the result of the marked development of the temperature contrast between front and rear of the cyclone.

Having actually curled about itself streams of air of considerable temperature difference, it is found that on the 17th there is an isolated mass of cold air cast adrift in the southeast quadrant (1 kilometer) and a symmetrically located mass of warm air detached north of the previous storm center (2 kilometers). This latter warm air was certainly influential in splitting the low pressure in two at the 2-kilometer level. In general, this might lead to the suggestion that the anomalous temperature distribution is the cause of the rapid disintegration of what seemed on the 16th to be a well-developed circular cyclone in the free air. In other words, it is conceivable that the storm literally destroyed itself, at least in the lower layers, through its own vigor in mixing air currents

of markedly differing temperature and humidity.[11] On the succeeding dates, the barometric situation changed rapidly, and a new régime was begun which would introduce a whole new series of charts.

Attention is again invited to the importance of these maps in aviation. Here we have had a wide expanse of country largely cloud covered. Had aerological stations been functioning in 1914, they could have afforded little assistance in the matter of free-air movements. The circulation aloft was well defined, but it was not so apparent at the surface; the gradients aloft were quite steep and it is likely that high winds prevailed. Would these maps have aided the aviator?

CHARTS XIII–XVIII.

December 4–9, 1919.—This series illustrates several interesting features, some already mentioned and others not apparent in previous examples. The period begins with westerly winds of moderate intensity in the free air. The tendency is then for the Utah low-pressure area (Chart XIV) to move toward the east. The "storm-attracting crosses" mentioned by Doctor Sekiguchi are suggested by the isobaric turning in the general region of Arkansas and Oklahoma, where, indeed, the sea-level center did appear on the 6th. Similarly, "crosses" are indicated for the following day in the Lake region where, again, the storm *did* appear. It may be remarked, however, that in a region so large as the eastern United States this criterion of crossed isobars will have to be used with considerable care. The area is so great that several groups of "crosses" may appear on the same map, and, having greater or less significance, might complicate an attempted interpretation. This criterion, nevertheless, should not be discarded because it may, in company with other criteria—especially that of the general trend of air at the 2-kilometer level—prove of considerable value.

On the 5th and the following days the low pressure center in the free air was north of the sea-level center; in fact, when the sea-level cyclone was centered in eastern Oklahoma the upper center was in Minnesota. Such shifting was undoubtedly the result of the low temperatures prevailing in the north. With the establishment of a strong southwesterly drift, the temperature contrast was accentuated so that the isobars followed the trend of the isotherms very closely.

The low center in the Lake region, being circular and slow moving, developed considerable intensity and introduced extremely cold air, farther and farther to the south in the Mississippi Valley, while the front was being fed with a steady stream from the southwest. The meeting place of these two drifts of differing temperature occurred along a band from northeast Texas to Indiana, where the surface temperature gradient gave a simultaneous temperature difference of 20° C., between the north and south ends of Illinois on the 9th.

The map for the 9th gives a splendid example of the shift of the low-pressure center toward the west and northwest when there is strong temperature contrast between front and rear. In this case the sea-level center is in West Virginia, the 1-kilometer center is in northern Indiana, and the 2-kilometer center is in west central Wisconsin. How significant, then, must be the effects of importation of air from different sources—air of different moisture content and temperature—about depressions having the same core, but with this core sloping at a considerable angle from the vertical. The regions of rainfall in this series, especially in those maps near the end of the period, show this significance strikingly. It is interesting to observe how closely the rainfall region agrees with the sweeping streams of southerly air drawn forward by the pressure disturbance.

For the benefit of those who are desirous of observations to substantiate the rather startling shifting of the low-pressure center revealed in this series, Table 12 is offered. Pilot-balloon observations were limited in altitude practically universally to 1 kilometer or less, but at several of the kite stations the altitudes attained were somewhat greater.

TABLE 12.—*Free-air winds at aerological stations, December 8–9, 1922.*

[Speed in meters per second.]

I. OBSERVATIONS WITH KITES.

Station.		Dec. 8.		Dec. 9.	
		1 km.	2 km.	1 km.	2 km.
Royal Center, Ind.	Direction	ENE.	[1] W.	.....	.....
	Velocity	.....	8.9	.....	.....
Ellendale, N. Dak.	Direction	NW.	W.	WNW.	WSW.
	Velocity	10.7	12.3	7.9	7.4
Drexel, Nebr.	Direction	ENE.	[2] ENE.	NNW.	WNW.
	Velocity	12.7	2.4	13.4	12.3
Broken Arrow, Okla.	Direction	SE.	SSW.	NNW.	[3] WNW.
	Velocity	12.5	16.7	16.2	17.6
Groesbeck, Tex.	Direction	S.	.....	[4] NNW.	.....
	Velocity	7.2	.....	17.3	.....

II. OBSERVATIONS WITH PILOT BALLOONS.

Ithaca, N. Y.	Direction	W.	.....	.....	.....
	Velocity	2	.....	.....	.....
Lansing, Mich.	Direction	NNE.	.....	.....	.....
	Velocity	1	.....	.....	.....
West Point, Ky.	Direction	SSE.	.....	.....	.....
	Velocity	13	.....	.....	.....
Madison, Wis.	Direction	N.	SW.	NNW.	.....
	Velocity	3	12	10	.....

[1] 1 p. m. observation. [2] 1,815 meters. [3] 1,842 meters. [4] 658 meters.

CHARTS XIX–XXII.

February 6–9, 1919.—This group of maps may be appropriately regarded as a study in secondaries, for the entire period seems to be concerned with certain formations apparently subordinated to larger and more definite members to the north and south. The sea-level map of the 6th shows a sweep of high pressure extending

[11] Since sending the manuscript to press, a new paper by J. Bjerknes and H. Solberg, entitled, "Life cycle of cyclones and the polar front theory of atmospheric circulation" (*Geofysiske Publikationer*, Vol. III, No. 1, Kristiania, 1922) has appeared. In this paper it is shown how, through the process of "occlusion," masses of warm air are cut off from the source and the dissolution of the cyclone follows.

from the Canadian border of North Dakota to the Gulf coast by way of Illinois, Indiana, and Kentucky. At 1 kilometer, the high pressure in the Ohio Valley is apparent, the low pressure over New England, and the high area over the Gulf are more pronounced; while at 2 kilometers, the Ohio Valley high pressure is supplanted by a secondary low area, fostered, without doubt, by the tongue of low temperature invading the Gulf States from the upper Ohio Valley. The 2-kilometer map is thus very different from that at sea level, and it at once calls up the picture, so graphically given by the Japanese workers, of the cyclone facing the closed "gate." They say that when the "gate" is closed—that is, when straight isobars lie on one side of the center while those on the other three sides are parallel—the storm can not advance. Here is a secondary depression at 2 kilometers; at the same level, there is a much deeper depression over the Lake region; and there is high pressure to the south. To the west, there is another branch of low pressure of equal intensity to that over Tennessee which is probably related to the sea-level depression in southeastern Colorado.

East-to-west isobaric trend indicates that the western depression should move east and the closed gate indicates that the secondary should not move at all, hence a merger of the two is reasonable. The next day, the sea-level anticyclone passed to the east (upper drift from west to east); at 1 kilometer, it had disappeared while a weak secondary depression still confronting the closed gate was centered over western Tennessee. The pressure had risen generally in this region, and now, except for the presence of this secondary, the circulation seemed to be dominated by the northern low-pressure area. At 2 kilometers, a slight high pressure effect is seen in southern Indiana, probably engendered by the small region of slightly higher temperature found in that vicinity.

The 8th (Chart XXI) shows the low center moved westward from northern Louisiana to north-central Texas; the upper maps show the small secondary formations apparently jostled about and pushed aside by the advancing winds from the northwest. The "gate" is still closed, and the secondary depression is like a chip along the river's edge, bobbing about until admitted to the main drift of the current.

The next map shows a large high pressure region at sea level, where on the 8th there was a small depression, the latter having now moved to central Georgia. In the free air, the large northern depression is still dominant, the high sea-level pressure seems influential only in accentuating the north-south trend of the isobars. The Georgia depression does not show in the free air except as a hook in the 1-kilometer isobars. This sea-level disturbance is apparently the last vestige of the vacillating secondary, which, during the preceding 24 hours, had become involved in the general stream and had moved forward.

Summary.—This cursory study has indicated that the fundamental considerations regarding the interaction of surface temperature and sea-level (surface) pressure in influencing free-air pressure are justified. Meteorological phenomena, influenced, as they are, by a multiplicity of factors, are often difficult to study, and these maps are not exceptional. Nevertheless, it is believed that the results of the interplay of these factors are much more clearly discernible in the free air than at the surface, because they are not subjected to the modifying influences of surface friction and turbulence.

The evidence of the dissipation of an area of low pressure in the lowest levels as a result of its own activity in importing air of strongly contrasting temperature, seems highly suggestive. The displacing of free-air centers through strong temperature contrasts, the conduct of free-air secondaries and their influence on surface conditions, the relation of these effects to the distribution of precipitation, are all subjects rich in importance to general forecasting.

The importance to aviation interests has already been emphasized. The perusal of these charts shows clearly that a correct surmise of what the winds are doing aloft is often impossible from the sea-level chart. This knowledge is, however, absolutely essential to the safe and efficient conduct of aerial traffic.

Part 8.—SUMMARY AND CONCLUSIONS.

History.—The history of barometric reduction in the United States is the record of its development from a very simple and crude system to one which, for stations of no great elevation above sea level, is quite satisfactory for reducing to that level. The work of Bigelow, the way to which was prepared by the efforts and experience of Abbe, Ferrel, and Hazen, is the most important contribution that has ever been made to American barometry. The chief weakness of Bigelow's method lies in the treatment of the temperature argument in the plateau region of the West, where, owing to the exceedingly long fictitious air column, large errors may occur on the sea-level map.

Aerological data, now accumulated in considerable abundance in the eastern United States, indicate that improvement might be made by applying them to the derivation of new temperature arguments for reductions in the West. Again, the fact that the weather phenomena which we experience are the consequence of the pressure distribution at and above the surface of the earth and *not at some level from one to two thousand meters below the surface* demands that some thought be given the contention that maps of pressure at some representative level, approximately that of the plateau itself, would be useful in forecasting for that region.

History, then, points the way to improvement. Improvement in barometry must go hand in hand with aerological observations, and these we do not now have in the plateau. The gleam of hope for which we have sought is found, it is believed, in the aerological data of the eastern United States applied in conjunction with free-air reduction levels to the western plateau. This paper has dealt with the eastern United States only, and its immediate value lies in its application to aviation and to possible general forecasting in that region. But in the background, there has been the confident expectation that the experience and results thus obtained will be useful in the study of the more difficult western problem.

Fundamental assumption.—The fundamental assumption of the paper is that surface wind direction is a reliable index to the mean temperature of the air column at least as high as 2 kilometers above sea level in the eastern United States. This implies that the importation of air from different sources is the controlling factor in the determination of temperature conditions in these lowest 2 kilometers. The data, as has been shown, justify this assumption.

Method.—The organization of the data consisted in the tabulation of the difference between surface temperature and the mean temperature of the air column at 8 a. m., 75th meridian time, and the subsequent classification of these differences by months and surface wind directions. Means thus obtained were studied with respect to both vertical and horizontal distributions and, in all cases, the results seemed smooth and consistent. Believing this classification to be as detailed as the quantity of data would permit, no cognizance has been given the possible variation with surface wind speed. Experience, as subsequent study, may make such further classification desirable. The final values of this difference, Δ, were so arranged that by adding them, algebraically, to the surface temperature the resulting number gives the mean temperature of the air column, the effect of mean vapor pressure having been already included.

Accuracy of the maps.—Tests of the accuracy of these free-air reductions consisted of (1) comparison of reductions at Due West, S. C., and other stations with kite observations; (2) comparison of free-air winds as observed by means of kites and pilot balloons with the trend of isobars computed by this independent method. The latter comparisons were made on the basis of the known relation between pressure gradient and wind velocity, and account was taken of the several factors which might cause the observed winds to disagree with the true isobars. All of these tests indicated a reasonable degree of accuracy, the first showing such discrepancies as were indicated by a more extensive statistical study of temperature data and the second showing a satisfactory agreement between observed winds and computed isobars.

On the basis of these tests it is believed that the computed maps are accurate with respect to the gradients at the upper levels and are also quite accurate with respect to the actual values of the pressure. This means that the maps are reliable aids in determining the trend of the streams of free-air winds from surface data alone; hence, that they would be a valuable and important adjunct to the forecaster's equipment.

Advantages.—The method is both practicable and practical. There is no unsurmountable obstacle to the accomplishment of its objects and it can be turned at once into useful channels. It will assist in the most economical manner with the visualization of the third dimension of the weather. The labor of reduction can be performed with no more experience than is required for reduction to sea level, the basic material for the reduction embraces no observation not already required for the daily reports, and no more of the station observer's time will be required than is devoted at present to sea-level reduction.

The maps would give additional knowledge of the free-air winds. From the examples given in this paper it is obvious that many cases occur when the free-air conditions can not be accurately judged from sea-level data. These often occur at times of stormy weather when pilot-balloon observations are not available. Such times are likewise trying to the aviator, and it is then that he wants the most reliable advice.

It is believed that these maps will eventually have significance for general forecasting because of the close relation between free-air conditions and certain phases of surface weather, precipitation, cloudiness, and temperature. If these maps are found useful in the eastern United States and those tentative plans which have been suggested above for attacking the pleateau are found fruitful, there is the encouraging possibility that we may realize an ambition to blanket our country from coast to coast with a weather map of three dimensions. This may not be a universal panacea for all the ills of forecasting, but it will at least afford a glimpse of the physical processes at work and lift us from the annoying disappointments of empiricism a little nearer to that ultimate goal toward which all students of weather forecasting are striving.

APPENDIX A.

SMOOTHED VALUES OF △ INCLUDING VAPOR PRESSURE.

[See Part 4 for explanation of this table.]

JANUARY.

1 kilometer.

	N.		NE.		E.		SE.		S.		SW.		W.		NW.	
	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15
Ellendale	1.5	1.5	3.9	4.4	2.2	1.3	3.4	2.3	5.6	5.9	5.2	5.3	2.8	2.8	0.2	0.2
Drexel	0.1	0.1	0.3	0.7	3.5	3.5	3.5	3.2	3.4	3.3	4.3	4.2	3.4	2.9	1.2	1.1
Broken Arrow	−1.0	−1.3	−0.3	−0.6	0.8	0.5	2.3	1.3	4.0	3.7	4.7	4.8	1.4	2.2	0.2	0.3
Groesbeck	1.2	1.0	1.6	1.5	2.9	2.6	2.8	2.5	1.8	1.5	1.4	1.0	1.1	1.1	1.2	0.8
Royal Center	−1.6	−0.9	1.4	1.7	2.7	2.8	3.5	3.7	2.3	2.4	0.3	0.2	−0.8	−0.6	−1.7	−1.5
Mount Weather	−1.7	−1.7	−0.9	−0.9	0.5	0.5	0.8	0.6	0.7	0.7	−0.5	−0.7	−2.3	−2.3	−2.8	−2.8
Leesburg	0.3	0.0	1.3	1.0	1.1	0.9	0.7	0.7	0.7	0.9	1.1	0.3	1.2	0.1	−0.1	−0.8

2 kilometers.

Ellendale	4.7	4.1	5.9	5.8	7.1	6.4	7.8	7.4	8.5	8.4	5.1	3.5	3.1	2.4	3.2	2.3
Drexel	1.8	1.6	3.4	3.3	5.2	5.3	6.4	6.3	6.3	6.2	5.1	5.1	3.3	3.1	2.1	1.8
Broken Arrow	1.1	1.5	1.8	1.5	2.2	1.9	3.1	2.6	4.8	3.5	4.6	3.0	1.3	1.4	0.4	0.5
Groesbeck	0.5	0.1	1.3	1.2	1.9	1.8	1.6	1.6	1.1	0.9	0.6	0.3	−0.1	−0.5	−0.4	−0.9
Royal Center	−1.0	−0.8	1.5	2.5	4.6	4.6	4.3	3.8	1.1	1.0	−0.7	−0.5	−1.7	−1.7	−1.8	−1.8
Mount Weather	−0.9	−0.9	0.1	0.1	2.0	2.4	1.1	1.2	−0.3	−0.4	−1.8	−1.8	−4.4	−4.5	−4.1	−4.3
Leesburg	−2.0	−2.2	−0.9	−2.0	−2.1	−2.0	−2.3	−1.9	−2.3	−2.0	−2.1	−2.1	−1.9	−2.0	−1.9	−2.1

FEBRUARY.

1 kilometer.

Ellendale	1.2	1.0	3.9	2.8	1.0	0.6	1.1	0.6	6.4	7.2	5.7	5.7	2.7	2.6	0.2	0.2
Drexel	−0.1	−0.4	1.4	0.9	3.0	2.2	2.6	2.2	3.4	3.3	4.7	4.4	2.7	2.4	0.4	0.2
Broken Arrow	−1.5	−1.7	−0.6	−0.4	0.5	0.6	1.3	0.8	3.5	1.5	4.0	1.5	1.3	0.5	−0.5	−1.2
Groesbeck	0.9	0.5	1.4	0.9	2.0	1.3	1.9	0.8	1.0	0.5	0.6	0.1	0.2	−0.4	0.4	−0.4
Royal Center	−0.6	−1.4	1.4	0.4	2.4	1.6	3.4	1.9	1.4	0.4	0.1	−0.3	−0.6	−0.8	−1.6	−1.8
Mount Weather	−1.7	−1.7	−1.1	−1.2	0.1	−0.2	0.3	−0.3	0.6	0.1	−0.8	−1.0	−2.3	−2.4	−2.8	−2.8
Leesburg	−1.7	−2.2	−0.5	−1.3	0.1	−0.3	0.0	−0.7	−0.4	−1.1	−0.6	−1.2	−1.1	−2.1	−1.8	−2.5

2 kilometers.

Ellendale	3.5	3.1	5.4	5.2	5.2	3.9	6.2	6.2	9.1	9.2	3.0	3.0	1.9	1.5	1.9	1.4
Drexel	1.3	0.6	3.0	2.4	4.9	4.2	5.3	4.5	5.6	4.8	5.3	4.4	2.3	1.0	1.0	0.3
Broken Arrow	1.3	0.3	1.1	0.7	1.3	0.7	1.7	0.6	1.5	0.5	1.2	0.2	0.8	0.5	1.5	0.3
Groesbeck	−0.3	−1.3	0.7	−0.3	1.5	0.2	1.2	0.4	0.7	0.1	−0.1	−0.5	−0.8	−1.1	−1.3	−1.6
Royal Center	−1.5	−2.5	2.3	1.3	4.4	2.3	2.3	0.3	0.3	−1.7	−1.2	−2.3	−2.7	−3.8	−3.0	−3.8
Mount Weather	−1.1	−1.5	0.1	0.0	1.2	0.2	0.5	−0.4	−0.8	−1.0	−1.9	−2.2	−4.5	−4.6	−4.6	−4.6
Leesburg	−2.9	−3.5	−2.5	−3.3	−2.3	−3.1	−2.4	−3.1	−2.5	−3.2	−2.5	−3.2	−2.6	−3.2	−2.8	−3.5

MARCH.

1 kilometer.

Ellendale	0.9	0.6	2.2	1.6	0.4	−0.1	0.4	0.6	6.4	4.6	5.2	4.2	2.2	1.5	0.3	−0.1
Drexel	−0.6	−0.9	0.4	−0.1	1.3	0.4	1.7	−0.3	2.7	2.0	3.5	3.0	2.3	2.0	0.0	−0.3
Broken Arrow	−1.2	−1.2	0.0	0.0	0.7	0.4	0.6	0.3	−0.2	−0.4	−0.5	−0.8	−1.2	−2.0	−1.0	−1.7
Groesbeck	0.0	−0.5	0.7	0.4	0.8	0.6	0.7	0.5	0.5	0.2	0.0	−0.3	−0.8	−1.2	−1.0	−1.5
Royal Center	−1.7	−2.2	0.1	−0.2	0.6	0.2	1.2	0.4	0.3	−0.2	−0.5	−0.9	−1.0	−1.3	−1.9	−2.1
Mount Weather	−1.8	−2.0	−1.1	−1.1	−0.3	−0.6	−0.5	−0.7	−0.2	−0.5	−0.9	−1.0	−2.3	−2.3	−2.6	−2.6
Leesburg	−2.1	−2.1	−2.0	−2.1	−0.8	−1.3	−1.6	−2.3	−1.5	−2.0	−1.9	−2.4	−2.5	−3.0	−3.1	−3.3

2 kilometers.

Ellendale	2.5	1.5	4.3	2.8	3.2	2.4	5.8	4.3	7.6	5.3	3.3	3.0	1.0	0.6	1.0	0.5
Drexel	−0.4	−1.4	1.9	1.2	3.6	2.3	3.8	1.6	1.9	1.4	3.4	1.5	0.2	−0.2	−0.5	−1.3
Broken Arrow	−0.5	−1.4	0.5	−0.2	0.5	−0.3	0.2	−0.6	−0.3	−0.6	−0.5	−0.8	0.3	−2.0	−2.2	−4.2
Groesbeck	−1.6	−2.2	−1.1	−1.9	−0.1	−0.6	−0.1	−0.4	−0.2	−0.5	−0.4	−0.8	−1.2	−1.4	−1.6	−1.9
Royal Center	−3.0	−3.7	−0.3	−1.5	1.2	−0.5	−1.3	−2.5	−2.4	−3.0	−3.0	−3.8	−4.3	−4.6	−4.2	−4.7
Mount Weather	−1.7	−2.3	0.0	−0.2	0.2	−0.1	−0.5	−1.2	−1.0	−1.4	−2.2	−2.4	−4.3	−4.4	−4.4	−4.4
Leesburg	−3.9	−4.9	−3.7	−4.2	−3.4	−4.0	−3.5	−4.2	−3.6	−4.0	−3.5	−4.0	−3.7	−4.2	−3.9	−5.1

APRIL.

1 kilometer.

Ellendale	−0.2	−0.5	0.6	−0.5	−0.5	−1.0	1.0	0.6	3.5	1.7	2.7	1.6	1.0	0.4	−0.7	−1.5
Drexel	−1.0	−1.5	−0.3	−0.8	0.0	−0.5	0.7	0.0	1.5	1.2	2.7	2.2	1.7	1.0	−0.3	0.2
Broken Arrow	−0.9	−1.0	0.3	0.1	0.4	0.2	0.1	−0.1	−0.4	−0.6	−1.0	−1.4	−1.9	−2.1	−1.9	−1.9
Groesbeck	−0.7	−0.7	0.5	0.2	0.5	0.3	0.4	0.1	0.2	0.0	−0.3	−1.6	−1.2	−1.6	−1.7	−1.7
Royal Center	−2.3	−2.7	−0.3	−1.4	0.1	−0.3	0.2	−0.2	−0.4	−0.8	−1.1	−1.7	−1.4	−2.2	−2.2	−2.8
Mount Weather	−2.0	−2.4	−1.0	−1.1	−0.9	−1.4	−0.8	−1.2	−0.5	−0.6	−0.9	−1.1	−2.3	−2.3	−2.8	−2.9
Leesburg	−2.1	−2.0	−1.7	−1.6	−1.3	−1.6	−1.8	−1.8	−1.7	−1.8	−2.4	−2.4	−2.9	−2.8	−2.8	−2.6

APRIL—Continued.

2 kilometers.

	N.		NE.		E.		SE.		S.		SW.		W.		NW.	
	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15
Ellendale	1.0	−1.0	1.0	−1.3	1.3	−0.5	2.9	0.5	3.5	0.5	1.5	0.1	−0.1	−1.5	0.1	−1.5
Drexel	−2.3	−2.8	0.2	−1.1	1.6	−0.5	0.7	−1.1	0.5	−0.3	0.7	0.2	−0.3	−0.6	−1.3	−2.3
Broken Arrow	−2.1	−2.1	−0.7	−1.4	−1.1	−2.0	−1.2	−2.0	−1.0	−1.6	−1.1	−0.9	−3.1	−3.2	−4.3	−4.5
Groesbeck	−2.9	−3.0	−2.3	−3.0	−0.9	−1.7	−0.6	−0.9	−0.6	−0.9	−0.8	−1.1	−1.5	−1.9	−2.3	−3.0
Royal Center	−3.8	−4.3	−2.2	−2.7	−1.4	−2.3	−2.8	−3.3	−3.4	−4.2	−4.4	−4.8	−4.9	−5.4	−4.8	−5.1
Mount Weather	−3.0	−3.7	−1.0	−2.2	−0.5	−1.7	−1.8	−2.7	−2.2	−2.9	−2.7	−3.2	−4.5	−5.2	−4.7	−5.2
Leesburg	−5.2	−5.8	−5.0	−5.4	−4.2	−4.7	−4.3	−4.7	−4.3	−4.8	−4.4	−5.0	−5.1	−5.8	−5.4	−5.9

MAY.

1 kilometer.

Ellendale	−0.2	−0.2	−0.5	−0.9	−1.2	−1.3	0.4	−0.4	1.4	0.7	1.3	0.7	−0.2	−0.4	−1.4	−1.2
Drexel	−1.1	−1.2	−1.1	−2.1	−0.7	−1.3	−0.2	−0.7	1.1	0.3	2.2	1.8	1.5	1.2	−0.6	−0.5
Broken Arrow	−0.6	−0.8	0.0	0.3	0.6	0.3	0.4	0.2	−0.1	−0.7	−1.0	−1.7	−1.6	−1.7	−1.0	−0.9
Groesbeck	−0.3	−0.2	−0.2	0.2	−0.2	−0.2	0.4	0.1	−0.1	−0.3	−0.3	−0.5	−1.3	−1.4	−1.3	−1.0
Royal Center	−2.8	−3.2	−2.0	−2.5	−1.0	−1.5	−1.0	−1.5	−1.3	−2.0	−2.2	−2.3	−2.7	−3.3	−3.3	−4.0
Mount Weather	−2.8	−2.9	−1.4	−1.9	−1.2	−1.4	−1.1	−1.2	−0.6	−0.7	−0.8	−1.0	−2.3	−2.3	−2.9	−3.0
Leesburg	−1.7	−1.3	−1.4	−1.9	−1.5	−2.3	−1.9	−2.0	−1.9	−1.9	−2.1	−2.3	−2.0	−1.7	−1.5	−1.1

2 kilometers.

Ellendale	−2.3	−2.4	−2.7	−3.2	−2.2	−3.4	−0.2	−1.7	0.0	−1.2	−1.2	−2.2	−2.7	−3.4	−3.3	−3.4
Drexel	−2.7	−3.1	−2.0	−2.5	−1.4	−2.1	−1.5	−2.2	−0.7	−1.0	0.2	−0.3	−0.5	−0.8	−2.4	−3.0
Broken Arrow	−1.5	−2.0	−1.3	−2.3	−2.1	−2.6	−2.3	−2.9	−1.5	−2.3	−2.0	−2.7	−3.2	−3.1	−3.7	−3.5
Groesbeck	−2.8	−2.8	−2.8	−2.8	−2.0	−2.6	−1.5	−2.6	−1.2	−2.3	−1.3	−2.4	−2.5	−3.0	−3.3	−3.7
Royal Center	−4.1	−4.2	−3.1	−3.8	−3.1	−3.9	−3.7	−4.3	−4.4	−4.7	−4.9	−5.6	−6.1	−7.1	−4.9	−5.1
Mount Weather	−4.2	−5.0	−2.9	−3.5	−2.5	−3.3	−3.1	−3.3	−3.2	−3.3	−3.3	−3.4	−5.0	−5.0	−5.4	−5.8
Leesburg	−5.5	−5.6	−5.4	−5.9	−4.9	−5.6	−4.6	−4.9	−4.8	−5.1	−5.4	−6.1	−6.0	−6.5	−5.4	−5.4

JUNE.

1 kilometer.

Ellendale	0.2	0.2	−0.1	0.0	−0.8	−0.6	0.0	0.1	1.2	1.7	1.6	1.7	0.6	1.5	−0.1	0.4
Drexel	−0.7	−0.5	−1.4	−1.0	−0.8	−0.2	−0.2	0.2	0.6	0.5	2.1	1.7	1.5	0.9	0.1	0.1
Broken Arrow	−0.7	−0.8	−1.0	−1.1	0.2	−0.4	0.2	−0.7	−1.0	−2.1	−1.6	−1.9	−1.1	−1.0	−0.1	0.3
Groesbeck	0.6	0.6	0.5	0.5	0.3	0.3	0.0	−0.3	−0.2	−0.3	−0.6	−0.6	−1.2	−1.2	−0.4	−0.3
Royal Center	−2.5	−2.6	−2.1	−2.3	−1.1	−1.1	−1.1	−1.1	−1.6	−1.5	−2.0	−2.1	−3.1	−3.3	−3.6	−3.5
Mount Weather	−2.4	−2.4	−1.4	−1.5	−1.0	−1.1	−0.6	−0.8	−0.4	−0.7	−0.7	−0.9	−1.7	−1.7	−2.5	−2.5
Leesburg	−1.3	−1.4	−2.3	−2.8	−2.6	−2.9	−2.2	−2.2	−2.1	−2.1	−2.6	−2.7	−1.4	−1.4	−1.7	−1.8

2 kilometers.

Ellendale	−2.5	−2.5	−2.8	−2.6	−3.1	−3.0	−1.9	−1.9	−1.1	−0.8	−1.9	−1.7	−3.0	−3.0	−2.9	−2.9
Drexel	−2.8	−3.3	−2.2	−2.4	−1.8	−1.7	−1.8	−1.5	−1.2	−1.5	0.0	−0.3	−0.7	−1.5	−2.7	−2.8
Broken Arrow	−1.9	−2.3	−2.3	−2.8	−2.6	−3.0	−2.9	−3.3	−3.0	−3.6	−2.7	−3.1	−3.0	−2.9	−2.8	−2.8
Groesbeck	−2.6	−2.5	−2.5	−2.4	−2.8	−2.4	−2.6	−2.3	−2.4	−2.6	−2.5	−2.5	−3.2	−3.4	−3.8	−3.6
Royal Center	−4.1	−4.4	−4.1	−4.8	−3.9	−4.5	−4.0	−4.4	−4.6	−4.8	−5.6	−5.8	−6.9	−7.0	−5.4	−5.6
Mount Weather	−4.8	−5.3	−3.3	−4.4	−3.0	−3.3	−3.1	−3.4	−3.1	−3.3	−3.2	−3.6	−4.5	−4.8	−5.6	−5.8
Leesburg	−5.7	−5.4	−6.7	−6.5	−6.4	−6.7	−5.4	−5.5	−5.5	−5.4	−6.6	−6.6	−6.6	−6.4	−5.4	−5.4

JULY.

1 kilometer.

Ellendale	0.4	0.4	0.5	0.7	0.7	1.7	0.7	1.7	1.9	2.2	2.1	2.5	1.9	2.3	0.6	0.7
Drexel	−0.1	0;1	−0.2	0.2	0.5	0.9	1.0	1.1	0.8	1.0	1.7	1.6	0.8	0.8	0.4	0.4
Broken Arrow	−0.7	−0.7	−1.1	−1.2	−1.0	−1.4	−2.0	−1.6	−0.7	−0.2	−0.7	0.0	−0.7	0.3	0.6	0.5
Groesbeck	0.7	0.6	0.9	0.9	0.7	0.7	0.4	0.4	0.2	0.2	−0.2	−0.2	−0.6	−0.6	−0.1	−0.3
Royal Center	−2.4	−2.3	−2.0	−1.5	−0.8	−0.2	−0.5	0.0	−1.4	−1.1	−1.8	−1.5	−2.8	−2.0	−3.0	−2.2
Mount Weather	−2.2	−2.1	−1.7	−1.6	−1.0	−1.2	−0.8	−0.9	−0.9	−1.2	−1.0	−1.4	−1.7	−1.9	−2.3	−2.3
Leesburg	−0.9	−1.2	−3.2	−3.3	−2.9	−3.0	−1.9	−1.9	−1.9	−1.9	−2.4	−2.4	−1.6	−1.5	−0.9	−1.1

2 kilometers.

Ellendale	−1.8	−1.8	−1.6	−0.6	−2.6	−0.9	−1.6	−0.6	0.0	0.7	−1.2	−0.7	−2.7	−2.6	−2.8	−2.7
Drexel	−3.4	−3.4	−2.2	−2.1	−1.3	−1.1	−1.1	−1.0	−1.4	−1.3	−0.3	−0.7	−1.4	−1.3	−2.6	−2.4
Broken Arrow	−2.1	−2.2	−2.9	−3.0	−3.0	−3.5	−4.0	−4.2	−3.7	−3.8	−2.8	−2.7	−2.2	−2.1	−2.5	−2.4
Groesbeck	−1.8	−1.6	−1.7	−1.4	−1.7	−1.5	−1.7	−1.6	−2.1	−2.1	−2.5	−2.5	−2.8	−2.6	−2.6	−1.8
Royal Center	−4.4	−3.5	−4.8	−4.5	−4.5	−3.5	−3.9	−3.6	−4.6	−5.2	−5.7	−5.4	−6.7	−5.7	−4.8	−4.4
Mount Weather	−5.4	−5.4	−4.4	−4.5	−3.4	−3.5	−3.4	−3.5	−3.4	−3.5	−4.0	−4.2	−5.0	−5.2	−5.7	−5.4
Leesburg	−4.7	−4.3	−5.2	−4.7	−6.4	−5.9	−5.2	−5.2	−4.9	−4.3	−5.5	−4.5	−5.6	−5.2	−5.1	−4.7

AUGUST.

1 kilometer.

Ellendale	0.4	0.6	1.1	1.6	1.7	1.9	1.8	2.2	2.4	2.9	2.5	3.2	2.3	2.7	1.1	1.5
Drexel	−0.1	−0.1	0.5	0.8	0.9	1.2	1.4	1.6	1.7	2.1	1.5	1.7	0.7	1.5	0.3	0.5
Broken Arrow	−0.7	−0.5	−1.1	−0.9	−1.2	0.1	−0.3	0.4	0.0	0.4	0.1	0.1	0.3	0.2	0.3	0.3
Groesbeck	0.1	0.0	0.3	0.3	0.2	0.2	−0.1	−0.1	−0.4	−0.4	−0.6	−0.7	−1.1	−1.1	−0.9	−0.9
Royal Center	−2.3	−2.3	−1.3	−0.8	0.0	0.3	0.3	0.7	−0.6	0.0	−1.2	−0.8	−1.2	−0.8	−1.2	−0.9
Mount Weather	−2.1	−1.9	−1.3	−1.1	−1.3	−1.1	−1.2	−1.3	−1.1	−0.9	−1.1	−0.9	−1.9	−1.5	−2.3	−2.0
Leesburg	−1.2	−1.1	−2.6	−2.0	−2.3	−2.0	−1.4	−1.4	−1.4	−1.4	−1.6	−1.4	−1.3	−0.9	−0.7	−0.8

AUGUST—Continued.

2 kilometers.

	N.		NE.		E.		SE.		S.		SW.		W.		NW.	
	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15
Ellendale	−1.9	−1.8	−0.4	−0.1	−0.5	−0.2	0.3	1.1	1.1	1.5	−0.7	0.1	−2.1	−1.5	−2.5	−1.5
Drexel	−3.2	−2.3	−1.4	−1.2	−1.0	−0.8	−0.8	−0.5	−0.2	0.8	−0.4	0.6	−0.9	−0.5	−2.4	−1.4
Broken Arrow	−2.4	−2.3	−3.1	−2.2	−2.6	−1.7	−3.6	−2.4	−3.4	−2.4	−2.2	−1.2	−2.3	−2.0	−2.5	−2.4
Groesbeck	−1.2	−0.9	−1.0	−0.8	−1.3	−1.1	−1.7	−1.7	−2.1	−2.1	−2.6	−2.5	−2.1	−1.0	−1.8	−1.7
Royal Center	−3.0	−2.6	−2.5	−1.4	−1.4	−0.1	−1.9	−0.6	−3.4	−2.4	−4.4	−3.5	−4.9	−4.1	−3.5	−3.3
Mount Weather	−4.5	−4.2	−4.5	−4.5	−4.0	−3.8	−3.7	−3.5	−3.6	−3.3	−4.3	−4.2	−5.1	−4.7	−4.9	−4.4
Leesburg	−3.6	−3.5	−4.0	−3.6	−5.0	−4.6	−4.8	−4.4	−3.7	−3.5	−3.7	−3.4	−4.0	−3.6	−4.0	−3.6

SEPTEMBER.

1 kilometer.

Ellendale	0.5	0.7	1.3	1.4	1.8	2.0	2.0	3.0	3.4	4.3	3.4	4.2	2.8	3.1	1.3	1.6
Drexel	−0.5	−0.5	0.7	1.1	1.1	1.4	1.7	2.3	2.2	2.8	2.0	2.7	1.7	2.5	0.3	0.4
Broken Arrow	−0.4	−0.1	−0.2	0.8	0.5	1.0	0.6	1.0	0.5	0.8	1.0	1.3	−0.2	−0.2	−0.2	−0.2
Groesbeck	0.0	0.2	0.1	0.2	0.1	0.3	−0.1	−0.1	−0.4	−0.3	−0.8	−0.7	−1.2	−1.0	−1.0	−0.6
Royal Center	−1.6	−2.1	−0.6	−0.5	0.4	0.7	0.9	1.6	0.4	0.7	−0.5	0.0	−0.6	−0.3	−0.9	−0.8
Mount Weather	−2.2	−2.1	−1.4	−1.5	−1.4	−1.5	−1.5	−1.4	−1.1	−0.9	−0.9	−0.6	−1.4	−1.2	−2.1	−2.1
Leesburg	−1.4	−1.2	−2.1	−1.7	−2.4	−2.1	−2.0	−1.7	−1.9	−1.2	−1.4	−0.8	−1.2	−0.7	−1.3	−0.8

2 kilometers.

Ellendale	−2.1	−0.9	0.1	1.4	−0.2	1.4	1.3	2.7	1.9	3.0	0.4	1.9	−1.4	−0.8	−1.5	−1.1
Drexel	−1.9	−1.5	−1.2	−1.0	−0.8	0.3	0.3	0.8	0.9	1.4	0.7	1.1	−0.4	0.1	−1.7	−1.4
Broken Arrow	−2.5	−1.5	−1.5	−0.3	−0.5	0.5	−2.0	−1.3	−2.3	−1.7	−1.0	−0.5	−1.7	−1.5	−2.6	−2.4
Groesbeck	−0.9	−0.5	−0.8	−0.5	−1.2	−0.8	−1.8	−1.8	−2.3	−2.3	−2.3	−2.3	−2.0	−1.8	−1.5	−1.4
Royal Center	−2.6	−2.2	−0.6	−0.3	−0.1	0.3	−0.6	−0.3	−2.2	−1.6	−3.4	−2.8	−3.8	−3.5	−3.3	−3.1
Mount Weather	−4.6	−4.6	−4.7	−4.6	−4.1	−3.8	−3.6	−3.2	−3.5	−3.2	−3.6	−3.2	−4.7	−3.7	−4.6	−4.1
Leesburg	−3.8	−3.6	−4.0	−3.6	−5.1	−4.8	−4.9	−4.6	−3.9	−3.6	−3.6	−3.2	−3.8	−3.4	−4.0	−3.6

OCTOBER.

1 kilometer.

Ellendale	0.7	0.7	1.4	1.5	2.1	2.4	3.7	3.6	5.2	6.5	4.9	5.5	3.4	3.7	1.5	1.4
Drexel	−1.2	−1.2	0.8	1.0	1.8	3.0	2.6	3.4	2.8	3.3	2.8	3.4	2.5	3.1	0.3	0.8
Broken Arrow	0.1	0.2	0.8	1.4	1.1	1.4	1.1	1.4	1.0	1.5	0.5	1.0	−0.7	−0.7	−0.3	−0.5
Groesbeck	0.7	0.9	0.7	1.0	0.5	0.8	−0.1	0.4	−0.3	−0.2	−0.5	−0.3	−0.8	−0.1	−0.1	0.4
Royal Center	−2.8	−2.8	−0.8	−1.4	0.6	0.6	1.5	1.9	0.9	1.1	0.2	0.4	−0.3	−0.3	−1.0	−1.1
Mount Weather	−2.1	−2.1	−1.7	−1.7	−1.5	−1.1	−1.3	−0.9	−0.9	−0.7	−0.5	−0.3	−1.4	−1.6	−2.0	−2.0
Leesburg	−0.7	0.0	−1.3	−0.1	−1.4	−1.0	−1.0	−0.6	−0.8	−0.5	−0.4	0.0	0.0	0.8	−0.3	0.0

2 kilometers.

Ellendale	−0.3	1.7	2.9	3.7	3.3	4.7	3.7	5.2	4.2	5.6	3.0	4.7	−0.5	0.2	−0.8	−0.5
Drexel	−1.8	−1.5	−1.3	−0.1	0.4	1.5	0.9	1.7	1.1	1.6	1.1	1.5	−0.1	0.6	−1.7	−1.3
Broken Arrow	−0.9	−0.2	0.7	1.3	1.1	1.3	−0.9	−0.1	−1.2	−0.1	−0.2	0.5	−1.2	−0.6	−2.5	−2.2
Groesbeck	−0.6	−0.2	−0.6	−0.3	−1.0	−0.6	−1.9	−1.5	−2.6	−2.4	−2.5	−1.0	−1.9	−1.6	−1.6	−1.2
Royal Center	−2.0	−1.9	−0.1	0.0	1.1	1.8	0.0	1.0	−1.2	−0.6	−2.3	−1.7	−3.2	−3.0	−3.1	−3.0
Mount Weather	−4.3	−3.7	−4.1	−3.4	−3.7	−2.8	−3.1	−2.6	−3.0	−2.5	−3.1	−2.8	−3.6	−3.2	−4.1	−4.0
Leesburg	−2.8	−2.2	−2.8	−2.3	−4.3	−3.3	−4.2	−3.2	−2.8	−2.2	−2.4	−1.8	−2.5	−2.0	−1.5	−2.2

NOVEMBER.

1 kilometer.

Ellendale	0.4	0.4	1.3	1.6	2.4	2.4	4.7	4.7	7.1	7.4	5.7	5.9	3.5	3.4	0.9	0.4
Drexel	−1.4	−1.4	0.6	−0.9	3.9	4.7	3.9	4.6	3.6	4.6	4.1	5.6	3.7	4.3	0.8	1.1
Broken Arrow	−0.8	−0.8	0.9	0.7	1.3	1.9	1.1	1.9	1.3	2.0	0.7	1.5	−1.3	−1.1	−1.6	−1.4
Groesbeck	0.3	0.9	0.7	1.1	0.6	1.1	0.1	1.1	−0.6	0.3	−0.9	0.1	−0.4	0.4	0.1	0.5
Royal Center	−3.3	−2.9	−2.4	−2.4	0.1	0.5	1.6	2.1	0.6	1.0	−0.2	0.0	−0.8	−0.8	−1.8	−1.9
Mount Weather	−2.4	−2.3	−2.2	−2.1	−1.3	−1.2	−0.9	−0.2	−0.8	0.1	−0.7	−0.4	−2.1	−2.1	−2.4	−2.4
Leesburg	−0.2	0.3	0.2	0.7	−0.8	0.0	−1.1	−0.6	−1.0	−0.5	−0.1	0.7	1.0	1.4	−0.2	0.2

2 kilometers.

Ellendale	2.5	3.6	4.5	5.5	6.3	6.7	6.3	7.3	7.1	8.4	6.0	6.4	2.3	3.3	0.1	2.3
Drexel	−1.5	−0.5	0.5	1.5	2.5	3.5	2.5	4.3	2.5	4.5	2.5	4.7	1.1	2.3	−0.7	0.0
Broken Arrow	0.5	0.3	1.0	1.2	0.9	1.2	0.1	0.9	0.8	1.8	1.1	2.5	−0.3	0.5	−2.5	−2.1
Groesbeck	−0.5	−0.1	−0.4	0.1	−0.8	−0.3	−1.4	−0.7	−2.1	−0.9	−2.0	−1.0	−1.6	−0.8	−1.0	−0.2
Royal Center	−2.2	−2.0	−0.7	−1.0	1.9	2.5	1.5	2.8	−0.7	−0.5	−1.9	−1.8	−3.4	−3.2	−3.4	−3.2
Mount Weather	−3.7	−3.3	−3.2	−2.2	−2.5	−1.5	−2.3	−1.3	−2.3	−1.3	−2.4	−1.5	−3.0	−2.1	−4.2	−4.2
Leesburg	−2.9	−2.6	−2.9	−2.6	−3.1	−2.6	−2.9	−2.4	−2.3	−2.6	−2.1	−2.9	−2.3	−2.9	−2.7	−2.4

DECEMBER.

1 kilometer.

Ellendale	0.4	1.7	2.7	3.7	2.4	2.5	4.6	4.3	7.1	6.4	5.8	5.5	3.4	3.1	0.4	0.4
Drexel	−1.1	−0.4	−0.4	0.1	5.6	4.9	5.6	5.1	5.3	5.1	6.1	5.6	4.4	4.0	1.1	1.2
Broken Arrow	−0.7	−0.8	0.3	−0.1	1.8	1.5	2.5	2.6	2.7	3.6	2.1	3.2	0.7	0.3	−1.3	−0.4
Groesbeck	0.9	1.3	1.5	1.8	2.1	2.8	2.2	2.9	1.4	2.0	0.8	1.3	0.8	1.3	0.8	1.2
Royal Center	−2.5	−2.0	−2.0	−0.6	1.0	1.9	2.3	2.9	1.2	1.9	0.0	0.1	−1.1	−1.0	−2.1	−2.0
Mount Weather	−2.5	−2.4	−2.2	−1.5	−1.4	−0.4	−0.2	0.4	0.1	0.5	−0.4	−0.2	−2.4	−2.4	−2.7	−2.7
Leesburg	0.2	0.3	0.8	1.1	0.3	0.8	−0.5	0.9	−0.5	1.0	1.0	1.0	1.1	1.1	−0.1	−0.2

2 kilometers.

Ellendale	4.5	4.7	6.0	6.1	7.3	7.3	7.6	7.8	9.3	9.3	6.6	5.8	4.1	4.3	3.1	4.3
Drexel	0.3	1.3	2.3	3.3	4.3	4.8	5.0	5.5	6.1	7.3	6.3	6.8	3.3	3.3	1.0	1.6
Broken Arrow	0.1	0.5	1.3	1.7	1.5	1.9	2.0	2.6	3.5	4.5	3.5	4.6	0.6	1.5	−1.3	−0.5
Groesbeck	0.3	0.8	0.4	0.9	0.5	0.9	−0.3	0.7	−0.5	0.5	−0.3	0.7	0.2	1.0	0.5	1.7
Royal Center	−1.9	−1.8	−1.0	0.0	2.8	3.8	3.6	4.1	−0.2	0.4	−1.8	−1.2	−3.0	−2.6	−3.0	−2.6
Mount Weather	−2.9	−1.7	−1.6	−0.5	−1.1	−0.1	−1.0	−0.1	−1.0	−0.4	−1.0	−1.4	−2.0	−2.6	−4.6	−4.6
Leesburg	−2.5	−2.2	−2.3	−2.2	−2.2	−2.5	−2.5	−2.6	−3.3	−3.2	−3.3	−3.2	−3.0	−2.7	−2.2	−2.4

APPENDIX B.

TABLES OF Δ FOR SELECTED STATIONS.

[See Part 5 for explanation of this table.]

ALBANY, N. Y.

1-kilometer level.

Surface wind direction.	Jan.		Feb.		Mar.		Apr.		May.		June.		July.		Aug.		Sept.		Oct.		Nov.		Dec.		Annual mean.	Extremes.		Range.
	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15		Max.	Min.	
N	−1.6	−1.5	−1.4	−1.4	−1.4	−1.5	−1.7	−1.9	−2.0	−2.1	−2.1	−2.0	−1.9	−1.9	−1.9	−2.0	−2.0	−1.8	−1.8	−1.8	−1.7	−1.7	−1.6	−1.6	−1.8	−1.4	−2.1	0.7
NE	−0.8	−0.7	−0.6	−0.5	−0.5	−0.6	−0.8	−0.9	−0.9	−0.9	−0.9	−0.9	−0.9	−0.9	−0.9	−0.9	−1.0	−1.2	−1.4	−1.6	−1.5	−1.5	−1.2	−1.1	−1.0	−0.5	−1.6	1.1
E	−0.3	−0.3	−0.4	−0.4	−0.5	−0.7	−0.8	−1.0	−1.0	−1.0	−0.9	−0.7	−0.5	−0.4	−0.7	−1.0	−1.2	−1.4	−1.5	−1.5	−1.5	−1.4	−1.0	−0.6	−0.9	−0.3	−1.5	1.2
SE	0.2	0.1	0.0	−0.2	−0.4	−0.6	−0.6	−0.8	−0.8	−0.8	−0.7	−0.5	−0.3	−0.3	−0.5	−0.8	−1.0	−1.0	−0.9	−0.7	−0.5	−0.2	−0.1	0.0	−0.5	0.2	−1.0	1.2
S	0.8	0.7	0.6	0.4	0.3	0.2	0.2	0.2	0.1	0.0	0.0	−0.1	−0.2	−0.3	−0.4	−0.4	−0.5	−0.6	−0.6	−0.7	−0.4	0.0	0.4	0.6	0.0	0.8	−0.7	1.5
SW	−0.5	−0.6	−0.6	−0.5	−0.5	−0.4	−0.3	−0.3	−0.2	−0.2	−0.1	−0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	−0.1	−0.1	−0.2	−0.2	−0.3	−0.2	0.0	−0.6	0.6
W	−2.3	−2.4	−2.3	−2.2	−2.0	−1.8	−1.8	−1.7	−1.6	−1.4	−1.2	−1.1	−1.0	−0.8	−0.8	−0.7	−0.6	−0.7	−0.9	−1.3	−1.8	−2.0	−2.2	−2.3	−1.5	−0.6	−2.4	1.8
NW	−3.0	−3.0	−3.0	−3.0	−2.9	−2.8	−2.7	−2.6	−2.5	−2.4	−2.3	−2.1	−2.0	−1.8	−1.8	−1.8	−1.8	−1.8	−1.9	−2.1	−2.3	−2.5	−2.7	−2.1	−2.4	−1.8	−3.0	1.2
Mean	−0.9	−1.0	−1.0	−1.0	−1.0	−1.0	−1.1	−1.1	−1.1	−1.1	−1.0	−0.9	−0.8	−0.8	−0.9	−0.9	−1.0	−1.1	−1.1	−1.2	−1.2	−1.2	−1.1	−0.9	−1.0	−0.8	−1.2	0.4

2-kilometer level.

N	0.7	0.6	0.5	0.2	−0.4	−1.1	−1.8	−2.5	−3.0	−3.6	−4.0	−4.2	−4.3	−4.4	−4.4	−4.4	−4.4	−4.4	−4.3	−4.1	−3.8	−3.1	−2.0	−0.2	−2.6	0.7	−4.4	5.1
NE	1.2	1.7	1.8	1.5	0.8	0.2	−0.5	−1.1	−1.7	−2.3	−2.9	−3.2	−3.4	−3.5	−3.6	−3.6	−3.6	−3.5	−3.4	−3.0	−2.6	−2.0	−1.1	−0.1	−1.6	1.8	−3.6	5.4
E	3.6	3.4	2.7	1.9	1.1	0.4	−0.2	−0.8	−1.3	−1.8	−2.2	−2.4	−2.6	−2.8	−3.0	−3.0	−3.0	−2.9	−2.7	−2.2	−1.7	−0.9	0.3	1.7	−0.8	3.6	−3.0	6.6
SE	2.5	2.1	1.4	0.6	−0.1	−0.8	−1.2	−1.6	−1.9	−2.2	−2.4	−2.5	−2.6	−2.7	−2.8	−2.7	−2.6	−2.4	−2.2	−1.7	−0.9	0.0	1.0	2.0	−1.0	2.5	−2.8	5.3
S	0.6	0.6	0.5	0.3	0.0	−0.4	−0.8	−1.2	−1.6	−1.9	−2.2	−2.3	−2.4	−2.4	−2.4	−2.4	−2.3	−2.2	−2.2	−2.0	−1.7	−1.2	−0.7	−0.1	−1.3	0.6	−2.4	3.0
SW	−0.8	−0.9	−1.0	−1.1	−1.3	−1.5	−1.7	−1.9	−2.2	−2.4	−2.7	−3.0	−3.3	−3.5	−3.6	−3.6	−3.5	−3.2	−2.8	−2.2	−1.5	−0.6	0.1	0.3	−2.0	0.3	−3.6	3.9
W	−3.6	−4.0	−4.3	−4.2	−4.0	−3.7	−3.6	−3.6	−3.6	−3.7	−3.9	−4.0	−4.2	−4.2	−4.3	−4.3	−4.2	−4.2	−4.0	−3.3	−2.4	−1.4	−1.0	−1.5	−3.6	−1.0	−4.3	3.3
NW	−4.0	−3.7	−3.5	−3.4	−3.4	−3.5	−3.6	−4.0	−4.3	−4.6	−4.9	−5.0	−5.0	−4.9	−4.6	−4.4	−4.2	−4.1	−4.0	−4.1	−4.2	−4.4	−4.4	−4.3	−4.2	−3.4	−5.0	1.6
Mean	0.0	0.0	−0.2	−0.5	−0.9	−1.3	−1.7	−2.1	−2.4	−2.8	−3.1	−3.3	−3.5	−3.6	−3.6	−3.6	−3.5	−3.4	−3.2	−2.8	−2.4	−1.7	−1.0	−0.3	−2.1	0.0	−3.6	3.6

NEW YORK CITY, N. Y.

1-kilometer level.

N	−2.0	−1.8	−1.6	−1.5	−1.5	−1.6	−1.7	−1.8	−2.0	−2.1	−2.1	−2.0	−2.0	−2.0	−2.0	−2.0	−1.9	−1.9	−1.8	−1.8	−1.8	−1.9	−2.0	−2.0	−1.9	−1.5	−2.1	0.6
NE	−1.0	−0.7	−0.6	−0.7	−0.8	−0.9	−1.0	−1.0	−1.0	−1.0	−0.9	−0.9	−1.0	−1.0	−1.0	−1.2	−1.3	−1.5	−1.6	−1.7	−1.7	−1.7	−1.6	−1.5	−1.1	−0.6	−1.7	1.1
E	−0.1	−0.1	−0.2	−0.2	−0.4	−0.5	−0.7	−0.8	−1.0	−1.1	−1.2	−1.3	−1.3	−1.4	−1.4	−1.4	−1.4	−1.4	−1.4	−1.3	−1.2	−1.0	−0.8	−0.5	−0.9	−0.1	−1.4	1.3
SE	0.1	0.2	0.0	−0.2	−0.5	−0.7	−0.8	−0.9	−1.0	−1.0	−0.8	−0.6	−0.4	−0.4	−0.6	−0.9	−1.1	−1.2	−1.1	−1.0	−0.8	−0.6	−0.4	−0.1	−0.6	0.2	−1.2	1.4
S	0.6	0.6	0.5	0.4	0.2	0.0	−0.1	−0.2	−0.2	−0.3	−0.2	−0.2	−0.3	−0.4	−0.5	−0.7	−0.8	−1.0	−1.0	−0.8	−0.6	−0.4	−0.1	0.2	−0.2	0.6	−1.0	1.6
SW	−0.5	−0.8	−1.0	−0.8	−0.6	−0.5	−0.4	−0.3	−0.2	−0.2	−0.2	−0.2	−0.1	−0.1	0.0	0.0	−0.1	−0.2	−0.2	−0.2	−0.1	0.0	−0.1	−0.3	−0.3	0.0	−1.0	1.0
W	−2.4	−2.3	−2.2	−2.2	−2.0	−2.0	−1.8	−1.7	−1.6	−1.5	−1.4	−1.2	−1.1	−0.9	−0.8	−0.8	−0.7	−0.8	−1.0	−1.5	−1.8	−2.1	−2.2	−2.2	−1.6	−0.7	−2.4	1.7
NW	−3.2	−3.0	−2.9	−2.8	−2.6	−2.6	−2.5	−2.4	−2.3	−2.2	−2.2	−2.1	−2.0	−2.0	−1.9	−1.8	−1.8	−1.8	−1.9	−2.0	−2.2	−2.4	−2.6	−2.8	−2.3	−1.8	−3.2	1.4
Mean	−1.1	−1.0	−1.0	−1.0	−1.0	−1.1	−1.1	−1.1	−1.2	−1.2	−1.1	−1.1	−1.0	−1.0	−1.0	−1.1	−1.1	−1.2	−1.2	−1.3	−1.3	−1.3	−1.2	−1.2	−1.1	−1.0	−1.3	0.3

2-kilometer level.

N	0.3	0.2	0.0	−0.3	−0.8	−1.4	−2.1	−3.0	−3.6	−4.0	−4.4	−4.6	−4.8	−4.9	−5.0	−4.9	−4.8	−4.8	−4.6	−4.4	−3.9	−3.2	−2.2	−0.6	−3.0	0.3	−.05	5.3
NE	0.0	0.3	0.4	0.3	0.1	−0.2	−0.6	−1.2	−1.8	−2.5	−3.0	−3.5	−3.8	−4.0	−4.1	−4.2	−4.2	−4.2	−4.0	−3.5	−2.8	−2.0	−1.2	−0.4	−2.1	0.4	−4.2	4.6
E	2.8	2.9	2.5	1.6	0.8	0.1	−0.6	−1.2	−1.6	−2.1	−2.5	−2.9	−3.2	−3.6	−3.8	−4.0	−4.0	−3.9	−3.6	−3.2	−2.6	−1.8	−0.8	0.8	−1.4	2.9	−4.0	6.9
SE	1.4	1.2	0.8	0.4	−0.1	−0.6	−1.1	−1.6	−2.1	−2.5	−2.7	−2.9	−3.0	−3.1	−3.0	−3.0	−3.0	−2.9	−2.7	−2.3	−1.8	−1.1	−0.2	0.8	−1.5	1.4	−3.1	4.5
S	0.3	0.3	0.2	0.0	−0.4	−0.6	−1.0	−1.4	−1.8	−2.0	−2.3	−2.5	−2.6	−2.8	−3.0	−3.1	−3.1	−3.0	−2.8	−2.5	−2.1	−1.6	−1.0	−0.2	−1.6	0.3	−3.1	3.4
SW	−0.6	−1.1	−1.4	−1.6	−1.9	−2.0	−2.1	−2.2	−2.4	−2.5	−2.7	−2.9	−3.2	−3.4	−3.6	−3.6	−3.6	−3.4	−3.0	−2.4	−1.6	−0.6	−0.2	−0.3	−2.2	−0.2	−3.6	3.4
W	−3.8	−4.2	−4.3	−4.3	−4.2	−4.2	−4.2	−4.1	−4.0	−4.0	−3.9	−3.9	−4.0	−4.0	−4.0	−4.0	−4.0	−3.9	−3.6	−3.2	−2.5	−1.6	−1.4	−2.2	−3.6	−1.4	−4.3	2.9
NW	−4.6	−4.5	−4.3	−4.0	−3.6	−3.4	−3.6	−4.0	−4.4	−4.8	−5.0	−5.1	−5.2	−5.1	−5.0	−4.8	−4.6	−4.4	−4.3	−4.3	−4.4	−4.5	−4.6	−4.8	−4.5	−3.4	−5.2	1.8
Mean	−0.6	−0.6	−0.7	−1.0	−1.3	−1.5	−1.9	−2.3	−2.7	−3.0	−3.3	−3.5	−3.7	−3.9	−3.9	−3.9	−3.9	−3.8	−3.6	−3.2	−2.7	−2.0	−1.4	−0.9	−2.5	−0.6	−3.9	3.3

WASHINGTON, D. C.

1-kilometer level.

N	−1.6	−1.6	−1.6	−1.7	−1.8	−1.9	−2.2	−1.5	−1.8	−1.8	−1.4	−1.3	−2.2	−2.1	−2.0	−2.0	−2.0	−2.0	−2.1	−2.2	−2.4	−2.4	−2.5	−2.4	−1.9	−1.3	−2.5	1.2
NE	−1.0	−1.0	−1.0	−1.0	−1.0	−1.0	−1.0	−1.3	−1.6	−1.6	−1.4	−1.5	−1.7	−1.6	−1.3	−1.2	−1.2	−1.3	−1.5	−1.7	−2.0	−2.1	−2.0	−1.5	−1.4	−1.0	−2.1	1.1
E	0.5	0.4	0.2	0.0	−0.4	−0.6	−0.9	−1.1	−1.2	−1.2	−1.2	−1.2	−1.2	−1.3	−1.4	−1.5	−1.6	−1.6	−1.4	−1.3	−1.3	−1.4	−1.1	−0.4	−0.9	0.5	−1.6	2.1
SE	1.8	1.7	1.4	0.8	0.5	0.4	0.2	−0.1	−0.2	0.0	0.2	0.2	0.2	0.1	−0.1	−0.4	−0.6	−0.6	−0.3	0.0	0.4	0.9	1.2	1.6	0.4	1.8	−0.6	2.4
S	0.7	0.7	0.5	0.1	−0.2	−0.5	−0.6	−0.6	−0.6	−0.7	−0.9	−0.8	−1.0	−1.2	−1.1	−1.0	−1.0	−1.0	−0.9	−0.8	−0.6	−0.1	0.2	0.5	−0.4	0.7	−1.2	1.9
SW	−0.5	−0.7	−0.8	−1.0	−1.0	−0.9	−0.9	−1.0	−1.0	−0.8	−0.8	−0.8	−1.0	−1.2	−1.2	−1.0	−0.8	−0.6	−0.5	−0.5	−0.6	−0.5	−0.4	−0.2	−0.8	−0.2	−1.2	1.0
W	−2.3	−2.3	−2.3	−2.3	−2.3	−2.3	−2.3	−2.3	−2.3	−2.2	−1.8	−1.7	−1.7	−1.8	−1.8	−1.5	−1.3	−1.2	−1.4	−1.7	−2.0	−2.2	−2.3	−2.4	−2.0	−1.2	−2.4	1.2
NW	−2.8	−2.8	−2.8	−2.8	−2.6	−2.6	−2.8	−2.8	−2.8	−3.0	−2.6	−2.5	−2.3	−2.2	−2.4	−2.4	−2.2	−2.1	−2.0	−2.0	−2.2	−2.4	−2.6	−2.7	−2.5	−2.0	−3.0	1.0
Mean	−0.6	−0.7	−0.8	−1.0	−1.1	−1.2	−1.3	−1.3	−1.4	−1.4	−1.2	−1.2	−1.3	−1.4	−1.4	−1.4	−1.3	−1.3	−1.3	−1.3	−1.3	−1.3	−1.2	−0.9	−1.2	−0.6	−1.4	0.8

2-kilometer level.

N	−0.9	−0.9	−1.1	−1.4	−1.8	−2.4	−3.1	−3.8	−4.3	−4.8	−5.0	−5.2	−5.4	−5.2	−4.7	−4.4	−4.5	−4.5	−4.4	−4.0	−3.6	−3.1	−2.4	−1.6	−3.3	−0.9	−5.4	4.5
NE	0.1	0.2	0.2	0.2	0.0	−0.4	−1.2	−2.0	−2.7	−3.4	−4.0	−4.3	−4.4	−4.4	−4.4	−4.5	−4.7	−4.6	−4.1	−3.5	−2.9	−2.2	−1.4	−1.6	−2.5	0.2	−4.7	4.9
E	2.3	2.0	1.4	0.9	0.3	−0.3	−1.0	−1.7	−2.5	−3.2	−3.2	−3.2	−3.4	−3.6	−3.9	−4.0	−4.1	−4.0	−3.6	−3.0	−2.4	−1.6	−0.9	0.2	−1.8	2.3	−4.1	6.4
SE	1.1	1.1	0.6	0.0	−0.7	−1.4	−2.0	−2.6	−2.9	−3.1	−3.3	−3.4	−3.4	−3.6	−3.7	−3.6	−3.5	−3.4	−3.0	−2.6	−2.0	−1.5	−0.8	0.0	−2.0	1.1	−3.7	4.8
S	−0.3	−0.4	−0.5	−0.8	−1.0	−1.5	−2.2	−2.8	−3.2	−3.2	−3.2	−3.3	−3.4	−3.5	−3.6	−3.5	−3.4	−3.3	−3.0	−2.6	−2.0	−1.4	−0.8	−0.4	−2.2	−0.3	−3.6	3.3
SW	−1.8	−1.8	−1.9	−2.0	−2.2	−2.4	−2.8	−3.2	−3.3	−3.3	−3.4	−3.6	−3.9	−4.2	−4.3	−4.2	−3.6	−3.3	−3.0	−2.7	−2.4	−1.5	−1.0	−1.4	−2.8	−1.0	−4.3	3.3
W	−4.4	−4.5	−4.5	−4.5	−4.0	−4.0	−4.6	−5.0	−5.0	−4.8	−4.6	−4.8	−5.0	−5.1	−5.1	−4.9	−4.5	−3.9	−3.6	−3.2	−2.7	−2.1	−2.0	−4.3	−4.5	−2.0	−5.1	3.1
NW	−4.2	−4.4	−4.6	−4.6	−4.4	−4.4	−4.6	−5.2	−5.5	−5.7	−5.8	−5.8	−5.7	−5.4	−4.9	−4.5	−4.3	−4.2	−4.1	−4.1	−4.2	−4.3	−4.5	−4.6	−4.8	−4.1	−5.8	1.7
Mean	−1.0	−1.1	−1.3	−1.5	−1.7	−2.1	−2.7	−3.3	−3.7	−3.9	−4.0	−4.2	−4.3	−4.4	−4.3	−4.2	−4.1	−3.9	−3.6	−3.2	−2.8	−2.2	−1.7	−1.7	−3.0	−1.0	−4.4	3.4

NORFOLK, VA.

1-kilometer level.

Surface wind direction.	Jan.		Feb.		Mar.		Apr.		May.		June.		July.		Aug.		Sept.		Oct.		Nov.		Dec.		Annual mean.	Extremes.		Range.
	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15		Max.	Min.	
N	−1.3	−1.5	−1.8	−2.0	−2.1	−2.3	−2.4	−2.4	−2.5	−2.4	−2.4	−2.1	−2.0	−1.9	−1.9	−1.9	−2.0	−2.0	−2.2	−2.2	−2.2	−2.0	−1.7	−1.4	−2.0	−1.3	−2.5	1.2
NE	−0.9	−1.0	−1.3	−1.6	−1.8	−1.9	−1.8	−1.6	−1.6	−1.6	−1.6	−1.8	−1.8	−1.8	−1.8	−1.9	−1.9	−1.9	−1.9	−1.8	−1.8	−1.6	−1.4	−1.0	−1.6	−0.9	−1.9	1.0
E	0.2	0.0	−0.2	−0.4	−0.7	−1.0	−1.1	−1.3	−1.5	−1.6	−1.8	−1.8	−2.0	−2.0	−2.1	−2.2	−2.1	−2.0	−1.7	−1.4	−1.4	−1.2	−1.0	−0.3	−1.3	0.2	−2.2	2.4
SE	0.2	0.1	−0.2	−0.6	−1.1	−1.4	−1.6	−1.7	−1.7	−1.6	−1.4	−1.2	−1.3	−1.6	−1.6	−1.8	−1.8	−1.8	−1.5	−1.2	−0.8	−0.6	−0.3	−0.1	−1.1	0.2	−1.8	2.0
S	0.3	0.2	0.0	−0.4	−0.7	−0.9	−1.0	−1.0	−1.0	−0.9	−0.9	−1.0	−1.2	−1.5	−1.5	−1.6	−1.5	−1.4	−1.2	−1.0	−0.7	−0.4	0.0	0.2	−0.8	0.3	−1.6	1.9
SW	−0.3	−0.7	−0.9	−1.2	−1.3	−1.4	−1.4	−1.2	−1.1	−1.0	−0.9	−0.8	−0.9	−1.1	−1.2	−1.1	−1.0	−0.7	−0.6	−0.4	−0.2	0.0	0.0	0.0	−0.8	0.0	−1.4	1.4
W	−2.2	−2.2	−2.3	−2.7	−2.8	−3.0	−3.0	−2.7	−2.4	−2.0	−1.6	−1.4	−1.5	−1.8	−1.9	−1.8	−1.4	−1.0	−0.8	−0.6	−0.6	−0.8	−1.2	−1.7	−1.8	−0.6	−3.0	2.4
NW	−2.1	−2.5	−2.8	−3.0	−3.1	−3.0	−3.0	−2.9	−2.8	−2.7	−2.6	−2.5	−2.4	−2.2	−2.0	−1.9	−1.8	−1.6	−1.4	−1.3	−1.3	−1.4	−1.6	−1.8	−2.2	−1.3	−3.1	1.8
Mean	−0.8	−0.9	−1.2	−1.6	−1.7	−1.9	−1.9	−1.9	−1.8	−1.7	−1.6	−1.6	−1.6	−1.7	−1.7	−1.8	−1.7	−1.6	−1.4	−1.2	−1.1	−1.0	−0.9	−0.8	−1.4	−0.8	−1.9	1.1

2-kilometer level.

N	−1.2	−0.9	−1.0	−1.4	−2.0	−2.8	−3.4	−4.1	−4.7	−5.1	−5.3	−5.4	−5.4	−5.4	−5.3	−5.1	−4.7	−4.4	−4.0	−3.8	−3.5	−3.4	−3.0	−2.2	−3.6	−0.9	−5.4	4.5
NE	−0.9	−0.5	−0.2	0.0	−0.2	−0.5	−1.3	−2.2	−3.0	−3.6	−4.0	−4.5	−4.8	−5.0	−5.1	−5.0	−5.0	−4.8	−4.4	−3.8	−3.3	−2.7	−2.1	−1.5	−3.0	0.0	−5.1	5.1
E	−0.2	0.1	−0.2	−0.6	−1.0	−1.4	−1.8	−2.3	−2.8	−3.2	−3.5	−3.8	−4.2	−4.4	−4.6	−4.8	−4.7	−4.4	−4.2	−3.8	−3.2	−2.5	−1.8	−1.0	−2.7	0.1	−4.8	4.9
SE	−0.2	−0.2	−0.4	−0.6	−1.2	−1.8	−2.3	−2.8	−3.2	−3.5	−3.8	−4.1	−4.3	−4.4	−4.5	−4.5	−4.4	−4.2	−3.8	−3.4	−2.9	−2.2	−1.6	−0.7	−2.7	−0.2	−4.5	4.3
S	−1.2	−1.2	−1.2	−1.3	−1.6	−1.9	−2.3	−2.8	−3.0	−3.2	−3.4	−3.7	−3.7	−3.8	−3.8	−3.8	−3.8	−3.6	−3.2	−2.7	−2.4	−2.0	−1.6	−1.4	−2.6	−1.2	−3.8	2.6
SW	−2.1	−2.1	−2.1	−2.2	−2.4	−2.6	−2.9	−3.2	−3.4	−3.6	−3.8	−3.9	−4.0	−4.0	−4.0	−4.0	−3.9	−3.7	−3.4	−3.0	−2.4	−2.0	−1.8	−2.0	−3.0	−1.8	−4.0	2.2
W	−4.4	−4.6	−4.5	−4.3	−4.3	−4.5	−4.8	−5.0	−5.0	−4.8	−4.8	−4.8	−5.0	−5.0	−5.1	−5.0	−4.6	−4.2	−3.8	−3.3	−2.8	−2.4	−2.3	−3.0	−4.3	−2.3	−5.1	2.8
NW	−4.0	−4.0	−4.0	−4.0	−4.2	−4.4	−4.6	−5.0	−5.5	−5.7	−5.9	−5.9	−5.8	−5.5	−5.2	−4.8	−4.6	−4.3	−4.2	−4.1	−4.0	−4.0	−4.0	−4.0	−4.6	−4.0	−5.9	1.9
Mean	−1.8	−1.7	−1.7	−1.8	−2.1	−2.5	−2.9	−3.4	−3.8	−4.1	−4.3	−4.5	−4.6	−4.7	−4.7	−4.6	−4.5	−4.2	−3.9	−3.5	−3.1	−2.6	−2.3	−2.0	−3.3	−1.7	−4.7	3.0

WILMINGTON, N. C.

1-kilometer level.

N	−0.6	−1.0	−1.8	−2.2	−2.4	−2.4	−2.5	−2.5	−2.5	−2.4	−2.2	−2.1	−2.0	−1.9	−1.8	−1.7	−1.7	−1.8	−1.8	−1.7	−1.3	−0.6	−0.4	−0.4	−1.7	−0.4	−2.5	2.1
NE	0.2	−0.2	−0.8	−1.5	−2.0	−2.1	−1.9	−1.8	−1.8	−1.9	−2.1	−2.2	−2.2	−2.3	−2.3	−2.4	−2.3	−2.2	−1.8	−1.4	−1.0	−0.8	−0.4	0.0	−1.5	0.2	−2.4	2.6
E	0.3	0.2	0.0	−0.4	−0.7	−1.0	−1.3	−1.6	−2.0	−2.2	−2.5	−2.7	−2.8	−2.9	−2.8	−2.6	−2.4	−2.1	−1.8	−1.6	−1.3	−0.8	−0.3	0.0	−1.5	0.3	−2.9	3.2
SE	0.1	−0.2	−0.5	−0.9	−1.2	−1.5	−1.7	−1.8	−1.9	−2.0	−2.0	−2.0	−2.1	−2.1	−2.1	−2.0	−2.0	−1.9	−1.8	−1.4	−1.1	−0.7	−0.4	0.0	−1.4	0.1	−2.1	2.2
S	−0.1	0.0	−0.4	−0.9	−1.5	−1.8	−1.8	−1.7	−1.4	−1.2	−1.2	−1.3	−1.4	−1.6	−1.6	−1.6	−1.6	−1.4	−1.2	−1.0	−0.8	−0.5	−0.2	0.0	−1.1	0.0	−1.8	1.8
SW	0.2	−0.3	−0.8	−1.5	−2.0	−2.3	−2.2	−2.0	−1.8	−1.7	−1.6	−1.8	−2.0	−1.9	−1.6	−1.3	−1.0	−0.7	−0.4	−0.2	0.0	0.4	0.6	0.6	−1.1	0.6	−2.3	2.9
W	−1.2	−1.8	−2.2	−2.7	−2.9	−3.0	−2.9	−2.8	−2.4	−2.0	−1.5	−1.4	−1.5	−1.6	−1.6	−1.6	−1.2	−0.8	−0.3	0.0	0.3	0.5	0.5	0.2	−1.4	0.5	−3.0	3.5
NW	−1.4	−2.0	−2.6	−3.0	−3.3	−3.4	−3.2	−3.0	−2.7	−2.5	−2.2	−2.0	−1.8	−1.6	−1.5	−1.4	−1.5	−1.4	−1.2	−0.8	−0.7	−0.6	−0.8	−1.1	−1.9	−0.6	−3.4	2.8
Mean	−0.3	−0.7	−1.1	−1.6	−2.0	−2.2	−2.2	−2.1	−2.1	−2.0	−1.9	−1.9	−2.0	−2.0	−1.9	−1.8	−1.7	−1.5	−1.3	−1.0	−0.7	−0.4	−0.2	−0.1	−1.5	−0.1	−2.2	2.1

2-kilometer level.

N	−2.0	−1.8	−1.9	−2.2	−2.7	−3.4	−4.0	−4.7	−5.1	−5.4	−5.4	−5.4	−5.4	−5.2	−5.0	−4.8	−4.4	−4.0	−3.7	−3.4	−3.2	−3.1	−2.9	−2.4	−3.8	−1.8	−5.4	3.6
NE	−1.5	−1.2	−1.0	−1.0	−1.2	−1.6	−2.0	−2.7	−3.4	−4.1	−4.7	−5.0	−5.2	−5.4	−5.3	−5.2	−4.8	−4.5	−4.1	−3.8	−3.4	−3.0	−2.4	−2.0	−3.3	−1.0	−5.4	4.4
E	−1.3	−1.3	−1.5	−1.8	−2.0	−2.3	−2.6	−2.9	−3.3	−3.6	−4.0	−4.4	−4.8	−5.0	−5.2	−5.3	−5.2	−5.0	−4.5	−4.0	−3.4	−2.8	−2.3	−1.8	−3.3	−1.3	−5.3	4.0
SE	−1.1	−1.2	−1.4	−1.9	−2.4	−2.9	−3.2	−3.5	−3.8	−4.1	−4.4	−4.5	−4.2	−4.2	−4.2	−4.2	−4.2	−3.8	−3.2	−2.8	−2.5	−2.6	−2.6	−2.4	−3.1	−1.1	−4.5	3.4
S	−2.0	−2.0	−2.0	−2.0	−2.2	−2.6	−3.0	−3.4	−3.6	−3.8	−4.0	−4.1	−4.2	−4.2	−4.3	−4.3	−4.2	−3.8	−3.2	−2.8	−2.5	−2.6	−2.6	−2.4	−3.1	−2.0	−4.2	2.3
SW	−2.4	−2.4	−2.4	−2.6	−2.8	−3.0	−3.4	−3.8	−4.1	−4.4	−4.5	−4.6	−4.6	−4.6	−4.5	−4.3	−4.0	−3.6	−3.2	−2.8	−2.6	−2.4	−2.4	−2.4	−3.4	−2.4	−4.6	2.2
W	−3.4	−3.8	−4.0	−4.1	−4.3	−4.6	−5.0	−5.2	−5.2	−5.3	−5.2	−5.2	−5.2	−5.1	−4.9	−4.6	−4.2	−3.8	−3.3	−3.0	−2.7	−2.7	−2.8	−3.0	−4.2	−2.7	−5.3	2.6
NW	−3.3	−3.5	−3.7	−4.0	−4.4	−4.6	−5.0	−5.3	−5.6	−5.7	−5.8	−5.8	−5.7	−5.6	−5.2	−4.8	−4.3	−3.8	−3.5	−3.2	−3.2	−3.1	−3.1	−3.1	−4.4	−3.1	−5.8	2.7
Mean	−2.1	−2.1	−2.2	−2.4	−2.7	−3.1	−3.5	−3.9	−4.3	−4.5	−4.7	−4.9	−4.9	−4.9	−4.8	−4.7	−4.4	−4.0	−3.6	−3.2	−2.9	−2.8	−2.6	−2.4	−3.6	−2.1	−4.9	2.8

COLUMBIA, S. C.

1-kilometer level.

N	−0.5	−0.9	−1.7	−2.3	−2.4	−2.3	−2.3	−2.3	−2.3	−2.2	−2.0	−1.9	−1.8	−1.7	−1.7	−1.6	−1.6	−1.5	−1.4	−1.4	−1.2	−1.0	−0.6	−0.4	−1.6	−0.4	−2.3	1.9
NE	0.4	0.2	−0.8	−1.5	−2.2	−2.2	−1.8	−1.6	−1.8	−2.2	−2.6	−2.9	−3.1	−3.0	−2.8	−2.6	−2.3	−1.9	−1.5	−1.2	−0.8	−0.4	0.0	0.3	−1.5	0.4	−3.1	3.5
E	0.4	0.2	0.0	−0.3	−0.6	−0.9	−1.2	−1.4	−1.7	−1.9	−2.2	−2.8	−3.0	−2.9	−2.6	−2.4	−2.2	−1.8	−1.5	−1.2	−1.0	−0.6	−0.3	0.0	−1.3	0.4	−3.0	3.4
SE	0.4	0.4	0.0	−0.6	−1.1	−1.4	−1.6	−1.8	−2.0	−2.1	−2.1	−2.1	−2.1	−2.0	−2.0	−1.8	−1.6	−1.4	−1.2	−1.0	−0.8	−0.5	−0.2	0.0	−1.2	0.4	−2.1	2.5
S	0.7	0.4	−0.3	−0.8	−1.4	−1.8	−2.0	−2.0	−1.9	−2.0	−2.0	−2.0	−2.0	−2.0	−1.9	−1.8	−1.5	−1.2	−1.0	−0.8	−0.5	−0.2	0.2	0.4	−1.1	0.7	−2.0	2.7
SW	0.5	0.1	−0.5	−1.2	−1.7	−2.1	−2.3	−2.4	−2.4	−2.5	−2.4	−2.4	−2.4	−2.2	−2.0	−1.7	−1.5	−1.2	−1.0	−0.6	−0.4	−0.1	0.1	0.4	−1.3	0.5	−2.5	3.0
W	−0.1	−1.0	−1.7	−2.2	−2.7	−3.0	−2.0	−2.9	−2.7	−2.4	−2.1	−2.0	−1.9	−1.8	−1.7	−1.6	−1.2	−0.8	−0.4	0.0	0.2	0.3	0.4	0.2	−1.4	0.4	−3.0	3.4
NW	−1.2	−1.6	−2.2	−2.8	−3.1	−3.3	−3.2	−3.0	−2.7	−2.4	−2.2	−2.1	−1.9	−1.8	−1.6	−1.5	−1.4	−1.2	−1.1	−0.8	−0.7	−0.7	−0.8	−1.0	−1.8	−0.7	−3.3	2.6
Mean	0.1	−0.2	−0.9	−1.5	−1.9	−2.1	−2.2	−2.2	−2.2	−2.2	−2.2	−2.3	−2.3	−2.2	−2.0	−1.9	−1.7	−1.4	−1.1	−1.0	−0.6	−0.4	0.0	0.0	−1.4	0.1	−2.3	2.4

2-kilometer level.

N	−2.2	−2.1	−2.4	−3.0	−3.5	−4.2	−4.7	−5.1	−5.4	−5.5	−5.4	−5.2	−5.2	−5.1	−4.9	−4.8	−4.6	−4.4	−4.2	−3.8	−3.4	−3.1	−2.8	−2.5	−4.1	−2.1	−5.5	3.4
NE	−1.4	−1.5	−1.8	−2.1	−2.4	−3.0	−3.6	−4.3	−5.0	−5.6	−5.9	−6.0	−5.8	−5.6	−5.2	−4.8	−4.6	−4.0	−3.6	−3.2	−2.8	−2.4	−2.0	−1.6	−3.7	−1.4	−6.0	4.6
E	−1.0	−1.2	−1.5	−1.9	−2.3	−2.6	−3.0	−3.6	−4.2	−4.7	−5.2	−5.5	−5.6	−5.5	−5.4	−5.1	−4.8	−4.5	−4.0	−3.6	−3.1	−2.6	−2.2	−1.6	−3.5	−1.0	−5.6	4.6
SE	−1.2	−1.2	−1.7	−2.4	−3.0	−3.5	−3.9	−4.2	−4.4	−4.6	−4.8	−5.0	−5.2	−5.2	−5.2	−5.0	−4.7	−4.4	−3.9	−3.4	−3.0	−2.5	−2.0	−1.6	−3.6	−1.2	−5.2	4.0
S	−2.0	−2.0	−2.2	−2.5	−3.0	−3.4	−3.9	−4.3	−4.6	−4.8	−4.9	−5.0	−4.8	−4.6	−4.3	−4.0	−3.7	−3.4	−3.2	−2.9	−2.7	−2.6	−2.4	−2.1	−3.5	−2.0	−5.0	3.0
SW	−2.1	−2.2	−2.5	−2.9	−3.4	−3.8	−4.3	−4.8	−5.2	−5.4	−5.7	−5.7	−5.6	−5.2	−4.6	−4.1	−3.6	−3.2	−2.8	−2.6	−2.6	−2.7	−2.8	−2.6	−3.8	−2.1	−5.7	3.6
W	−3.0	−3.2	−3.4	−3.8	−4.3	−4.8	−5.4	−5.9	−6.2	−6.3	−6.4	−6.2	−5.9	−5.5	−5.0	−4.7	−4.2	−3.8	−3.3	−3.0	−2.8	−2.6	−2.6	−2.8	−4.4	−2.6	−6.4	3.8
NW	−2.7	−2.8	−3.2	−3.6	−4.1	−4.7	−5.3	−5.6	−5.8	−5.8	−5.8	−5.6	−5.6	−5.3	−4.9	−4.5	−4.2	−3.8	−3.4	−3.2	−2.9	−2.7	−2.7	−2.7	−4.2	−2.7	−5.8	3.1
Mean	−1.9	−2.0	−2.3	−2.8	−3.2	−3.8	−4.3	−4.7	−5.1	−5.3	−5.5	−5.5	−5.5	−5.3	−5.0	−4.6	−4.3	−3.9	−3.5	−3.2	−2.8	−2.6	−2.4	−2.2	−3.9	−1.9	−5.5	3.6

JACKSONVILLE, FLA.

1-kilometer level.

N	0.4	−0.1	−1.6	−2.0	−2.2	−2.1	−2.0	−1.8	−1.7	−1.7	−1.3	−1.2	−1.0	−0.9	−0.8	−0.8	−0.8	−0.7	−0.5	−0.2	0.2	0.3	0.4	0.5	−0.9	0.5	−2.2	2.7
NE	1.4	0.7	−0.6	−1.2	−1.6	−1.6	−1.6	−1.7	−1.8	−2.0	−2.2	−2.4	−2.6	−2.6	−2.5	−2.3	−2.1	−1.6	−1.0	−0.3	0.4	0.9	1.2	1.4	−1.1	1.4	−2.6	4.0
E	1.2	0.7	0.4	−0.2	−0.6	−1.1	−1.4	−1.7	−2.0	−2.2	−2.3	−2.4	−2.4	−2.5	−2.5	−2.4	−2.2	−2.0	−1.6	−1.1	−0.5	0.1	0.7	1.0	−1.1	1.2	−2.5	3.7
SE	0.2	0.0	−0.4	−0.8	−1.0	−1.2	−1.3	−1.4	−1.4	−1.5	−1.5	−1.6	−1.6	−1.6	−1.6	−1.6	−1.5	−1.4	−1.2	−1.0	−0.8	−0.6	−0.2	0.2	−1.0	0.2	−1.6	1.8
S	0.4	0.0	−0.3	−0.8	−1.0	−1.3	−1.4	−1.5	−1.6	−1.6	−1.6	−1.6	−1.7	−1.7	−1.8	−1.8	−1.8	−1.6	−1.4	−1.2	−0.9	−0.6	−0.1	0.3	−1.1	0.4	−1.8	2.2
SW	0.8	0.1	−0.6	−1.2	−1.6	−1.8	−2.0	−2.0	−2.0	−2.0	−2.0	−2.0	−2.0	−2.0	−1.8	−1.6	−1.2	−0.7	−0.3	0.1	0.4	0.9	1.2	1.3	−0.9	1.3	−2.0	3.3
W	1.0	0.1	−1.0	−1.8	−2.3	−2.6	−2.5	−2.3	−1.9	−1.5	−1.3	−1.2	−1.2	−1.2	−1.2	−1.0	−0.8	−0.2	0.4	0.9	1.3	1.5	1.6	1.5	−0.6	1.6	−2.6	4.2
NW	0.0	−0.5	−1.2	−2.2	−2.8	−3.0	−2.8	−2.2	−1.8	−1.4	−1.2	−1.0	−0.9	−0.8	−0.8	−0.8	−0.8	−0.6	−0.2	−0.1	0.1	0.2	0.2	0.1	−1.0	0.2	−3.0	3.2
Mean	0.7	0.1	−0.7	−1.3	−1.6	−1.8	−1.9	−1.8	−1.8	−1.7	−1.7	−1.7	−1.7	−1.7	−1.6	−1.5	−1.4	−1.1	−0.7	−0.4	0.0	0.3	0.6	0.8	−1.0	0.8	−1.9	2.7

JACKSONVILLE, FLA.—Continued.

2-kilometer level.

Surface wind direction.	Jan.		Feb.		Mar.		Apr.		May.		June.		July.		Aug.		Sept.		Oct.		Nov.		Dec.		Annual mean.	Extremes.		Range.
	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15		Max.	Min.	
N	−2.0	−2.1	−2.4	−3.0	−3.8	−4.6	−5.2	−5.4	−5.4	−5.4	−5.3	−5.0	−4.8	−4.4	−4.0	−3.7	−3.4	−3.1	−2.9	−2.7	−2.5	−2.4	−2.3	−2.2	−3.7	−2.0	−5.4	3.4
NE	−1.8	−2.1	−3.5	−3.0	−3.6	−4.1	−4.7	−5.3	−5.8	−6.2	−6.4	−6.3	−5.4	−4.6	−4.1	−3.7	−3.4	−3.2	−3.0	−2.8	−2.6	−2.5	−2.2	−1.8	−3.8	−1.8	−6.4	4.6
E	−2.2	−2.3	−2.5	−3.0	−3.5	−4.1	−4.5	−4.7	−5.0	−5.5	−6.1	−6.4	−6.2	−5.6	−5.2	−5.0	−5.0	−4.9	−4.3	−2.8	−3.5	−3.1	−2.7	−2.4	−4.2	−2.2	−6.4	4.2
SE	−2.4	−2.1	−2.5	−3.0	−3.5	−4.0	−4.2	−4.4	−4.6	−4.8	−5.0	−5.0	−5.0	−4.9	−4.8	−4.7	−4.6	−4.4	−4.1	−3.7	−3.2	−2.7	−2.6	−2.8	−3.9	−2.1	−5.0	2.9
S	−2.4	−2.3	−2.6	−3.2	−3.6	−4.1	−4.4	−4.6	−4.9	−5.2	−5.2	−4.9	−4.5	−4.0	−3.5	−3.5	−3.9	−3.9	−3.0	−2.4	−2.5	−3.0	−3.4	−3.2	−3.7	−2.3	−5.2	2.9
SW	−2.5	−2.4	−2.6	−3.0	−3.5	−4.0	−4.4	−4.8	−5.4	−6.0	−6.3	−6.2	−5.2	−4.3	−3.5	−3.5	−3.8	−3.3	−2.7	−2.2	−2.4	−3.0	−3.4	−3.3	−3.8	−2.2	−6.3	4.1
W	−2.4	−2.5	−2.7	−3.1	−3.6	−4.4	−5.1	−5.4	−5.6	−6.4	−6.4	−6.2	−5.6	−4.8	−3.9	−3.5	−3.8	−3.4	−2.6	−2.1	−2.1	−2.5	−3.0	−2.6	−3.9	−2.1	−6.4	4.3
NW	−2.0	−2.1	−2.5	−3.1	−4.0	−4.8	−5.3	−5.4	−5.3	−5.2	−5.2	−5.2	−5.1	−4.6	−4.1	−3.5	−3.8	−3.5	−2.8	−2.3	−2.0	−1.8	−1.9	−2.3	−3.7	−1.8	−5.4	3.6
Mean	−2.2	−2.2	−2.5	−3.0	−3.6	−4.3	−4.7	−5.0	−5.2	−5.6	−5.7	−5.6	−5.2	−4.6	−4.1	−3.9	−3.9	−3.7	−3.2	−2.6	−2.6	−2.6	−2.7	−2.6	−3.8	−2.2	−5.7	3.5

ATLANTA, GA.

1-kilometer level.

N	−0.2	−1.0	−1.7	−2.2	−2.3	−2.3	−2.2	−2.1	−2.0	−1.9	−1.8	−1.8	−1.8	−1.7	−1.6	−1.5	−1.4	−1.3	−1.2	−1.1	0.1	0.2	0.4	0.6	−1.3	0.6	−2.3	2.9
NE	0.8	0.0	−0.9	−1.6	−2.1	−2.1	−1.7	−1.6	−1.9	−2.3	−2.7	−3.1	−3.3	−3.2	−2.8	−2.4	−2.0	−1.6	−1.1	−0.7	−0.3	0.0	0.4	0.6	−1.5	0.8	−3.3	4.1
E	0.7	0.4	0.0	−0.3	−0.7	−0.9	−1.0	−1.0	−1.3	−1.9	−2.6	−3.0	−3.2	−3.0	−2.5	−2.1	−1.7	−1.4	−1.0	−0.8	−0.4	−0.1	0.2	0.4	−1.1	0.7	−3.2	3.9
SE	1.0	0.8	0.4	−0.3	−0.8	−1.2	−1.3	−1.3	−1.4	−1.9	−2.3	−2.4	−2.4	−2.2	−1.6	−1.3	−1.2	−1.1	−1.1	−1.0	−0.2	−0.4	0.2	0.8	−1.0	1.0	−2.4	3.4
S	1.0	0.7	0.1	−0.6	−1.4	−2.0	−1.7	−1.6	−1.9	−2.0	−2.2	−2.2	−2.2	−2.0	−1.5	−1.2	−1.0	−0.9	−0.8	−0.8	−0.7	−0.4	0.2	0.8	−1.0	1.0	−2.2	3.2
SW	0.6	0.4	−0.3	−1.2	−1.9	−2.3	−2.5	−2.4	−2.4	−2.4	−2.6	−2.7	−2.6	−2.2	−1.8	−1.6	−1.3	−1.0	−0.7	−0.6	−0.4	0.0	0.3	0.6	−1.3	0.6	−2.7	3.0
W	−0.6	−0.9	−1.4	−2.0	−2.6	−2.9	−3.0	−2.8	−2.5	−2.4	−2.3	−2.1	−2.0	−1.8	−1.7	−1.6	−1.4	−1.1	−0.8	−0.5	−0.3	−0.1	0.0	−0.1	−1.5	0.0	−3.0	3.4
NW	−1.2	−1.4	−1.6	−2.2	−2.8	−3.2	−3.2	−2.8	−2.4	−2.1	−2.0	−2.0	−1.8	−1.4	−1.2	−1.2	−1.2	−1.1	−0.9	−0.8	−0.8	−0.8	−0.9	−1.0	−1.7	−0.8	−3.2	2.3
Mean	0.3	−0.1	−0.7	−1.3	−1.8	−2.1	−2.1	−1.9	−2.0	−2.1	−2.3	−2.5	−2.4	−2.2	−1.8	−1.6	−1.4	−1.2	−1.0	−0.8	−0.5	−0.2	0.1	0.3	−1.3	0.3	−2.5	2.8

2-kilometer level.

N	−2.0	−2.1	−2.5	−3.2	−4.0	−4.7	−5.0	−5.3	−5.4	−5.5	−5.4	−5.2	−4.9	−4.4	−4.0	−3.6	−3.3	−2.9	−2.7	−2.5	−2.4	−2.4	−2.4	−2.2	−3.6	−2.0	−5.5	3.5
NE	−1.0	−1.2	−1.8	−2.6	−3.5	−4.2	−4.6	−5.1	−5.4	−5.6	−5.6	−5.6	−5.4	−5.1	−4.7	−4.3	−3.8	−3.3	−2.8	−2.5	−2.0	−1.8	−1.4	−1.2	−3.5	−1.0	−5.6	4.6
E	−0.3	−0.6	−1.1	−1.8	−2.5	−3.2	−3.8	−4.4	−4.8	−5.4	−5.9	−6.0	−6.0	−5.6	−5.2	−4.8	−4.2	−3.8	−3.2	−2.7	−2.2	−1.6	−1.2	−0.8	−3.4	−0.3	−6.0	5.7
SE	−0.2	−0.4	−0.8	−1.9	−2.8	−3.5	−4.2	−4.7	−5.2	−5.5	−5.6	−5.6	−5.4	−5.3	−5.0	−4.8	−4.4	−4.0	−3.4	−3.0	−2.5	−1.9	−1.5	−1.0	−3.4	−0.2	−5.6	5.4
S	−1.2	−1.3	−1.8	−2.5	−3.4	−4.1	−4.7	−5.1	−5.2	−5.4	−5.4	−5.4	−5.2	−5.0	−4.5	−4.0	−3.6	−3.0	−2.6	−2.2	−1.8	−1.6	−1.9	−1.5	−3.4	−1.2	−5.4	4.2
SW	−2.0	−1.7	−2.0	−2.8	−3.5	−4.2	−4.8	−5.4	−5.9	−6.3	−6.6	−6.5	−6.0	−5.4	−4.8	−4.1	−3.4	−2.8	−2.2	−1.8	−1.8	−2.7	−3.0	−2.6	−3.8	−1.7	−6.6	4.9
W	−2.4	−2.9	−3.0	−3.2	−3.9	−4.8	−5.5	−6.2	−6.6	−6.8	−6.9	−6.8	−6.3	−5.6	−4.9	−4.2	−3.7	−3.3	−2.8	−2.5	−2.6	−3.2	−3.2	−2.9	−4.5	−2.4	−6.9	4.5
NW	−2.2	−2.3	−2.7	−3.7	−4.6	−5.4	−5.7	−6.0	−6.0	−5.9	−5.8	−5.6	−5.2	−4.8	−4.1	−3.5	−3.0	−2.8	−2.6	−2.6	−3.0	−3.0	−2.8	−2.4	−4.0	−2.2	−6.0	3.8
Mean	−1.4	−1.6	−2.0	−2.7	−3.5	−4.3	−4.8	−5.3	−5.6	−5.8	−5.9	−5.8	−5.5	−5.1	−4.6	−4.2	−3.7	−3.2	−2.8	−2.5	−2.3	−2.3	−2.2	−1.8	−3.7	−1.4	−5.9	4.4

THOMASVILLE, GA.

1-kilometer level.

N	0.4	−0.2	−1.7	−2.1	−2.1	−2.1	−2.0	−1.8	−1.6	−1.4	−1.2	−1.0	−0.9	−0.9	−1.0	−1.1	−1.2	−1.2	−0.6	−0.1	0.2	0.3	0.4	0.4	−1.0	0.4	−2.1	2.5
NE	1.3	0.9	−0.2	−1.2	−1.8	−2.0	−1.7	−1.3	−1.4	−1.9	−2.3	−2.8	−3.2	−3.1	−2.6	−2.0	−2.0	−1.8	−1.2	−0.3	0.3	0.7	1.0	1.2	−1.1	1.3	−3.2	4.5
E	1.1	0.8	0.3	−0.2	−0.8	−1.3	−1.3	−1.4	−1.6	−2.2	−2.6	−3.0	−3.0	−2.8	−2.3	−2.0	−2.3	−2.1	−1.4	−1.0	−0.8	−0.1	0.4	0.8	−1.2	1.1	−3.0	4.1
SE	0.7	0.6	0.2	−0.5	−1.3	−2.0	−1.8	−1.5	−1.8	−2.0	−2.2	−2.2	−2.0	−1.8	−1.4	−1.4	−1.9	−1.7	−1.0	−0.6	−1.0	−0.7	0.0	0.6	−1.1	0.7	−2.2	2.9
S	0.8	0.4	−0.3	−1.0	−1.6	−1.9	−1.6	−1.4	−1.9	−1.9	−2.0	−2.0	−2.0	−1.8	−1.5	−1.5	−1.9	−1.4	−0.8	−0.6	−0.9	−0.6	0.0	0.7	−1.1	0.8	−2.0	2.8
SW	1.1	0.3	−0.6	−1.3	−1.9	−2.4	−2.5	−2.3	−2.2	−2.3	−2.6	−2.6	−2.5	−2.2	−1.8	−1.5	−1.4	−0.8	−0.4	−0.1	0.0	0.6	1.0	1.1	−1.1	1.1	−2.6	3.7
W	0.0	−0.5	−1.2	−2.0	−2.5	−2.9	−2.9	−2.5	−2.0	−1.6	−1.5	−1.5	−1.6	−1.5	−1.2	−0.9	−1.2	−0.8	0.0	0.6	1.2	1.4	1.4	1.0	−0.9	1.4	−2.9	4.3
NW	−0.1	−0.8	−1.7	−2.4	−3.0	−3.2	−3.0	−2.3	−1.5	−1.3	−1.6	−1.6	−1.1	−0.8	−0.8	−0.9	−1.2	−0.9	−0.4	−0.2	0.0	0.1	0.1	0.1	−1.2	0.1	−3.2	3.3
Mean	0.6	0.2	−0.6	−1.3	−1.9	−2.2	−2.1	−1.8	−1.8	−1.8	−2.0	−2.1	−2.0	−1.9	−1.6	−1.4	−1.6	−1.3	−0.7	−0.3	−0.1	0.2	0.5	0.7	−1.1	0.7	−2.2	2.9

2-kilometer level.

N	−2.0	−2.2	−2.7	−3.3	−4.0	−4.8	−5.4	−5.6	−5.5	−5.4	−5.3	−5.2	−4.7	−4.0	−3.7	−3.6	−3.8	−3.6	−2.8	−2.6	−2.6	−2.6	−2.4	−2.1	−3.8	−2.1	−5.6	3.5
NE	−1.7	−2.0	−2.5	−3.1	−3.7	−4.2	−4.8	−5.3	−5.8	−6.3	−6.8	−6.4	−5.6	−4.7	−3.8	−3.4	−3.8	−3.5	−2.8	−2.6	−2.8	−2.5	−2.1	−1.8	−3.9	−1.7	−6.8	5.1
E	−2.0	−2.1	−2.4	−2.9	−3.4	−3.9	−4.3	−4.6	−5.0	−5.8	−6.4	−6.7	−6.4	−5.9	−5.1	−4.8	−5.0	−4.8	−4.3	−3.6	−3.0	−2.6	−2.4	−2.2	−4.1	−2.0	−6.7	4.7
SE	−2.3	−2.0	−2.4	−3.0	−3.6	−4.0	−4.4	−4.7	−4.8	−5.0	−5.4	−5.4	−5.3	−5.2	−5.0	−4.8	−4.7	−4.5	−4.0	−3.5	−3.0	−2.6	−2.5	−2.5	−4.0	−2.0	−5.4	3.4
S	−2.2	−2.1	−2.5	−3.1	−3.6	−4.0	−4.4	−4.8	−5.0	−5.2	−5.4	−5.3	−4.9	−4.3	−3.8	−3.6	−3.8	−3.6	−2.8	−2.2	−2.3	−2.7	−3.3	−3.1	−3.7	−2.1	−5.4	3.3
SW	−2.1	−2.2	−2.6	−3.0	−3.5	−4.0	−4.5	−5.0	−5.6	−6.2	−6.6	−6.5	−5.5	−4.5	−3.7	−3.4	−3.5	−3.2	−2.4	−1.9	−2.1	−2.8	−3.2	−3.2	−3.8	−2.1	−6.6	4.5
W	−1.9	−2.1	−2.5	−3.0	−3.6	−4.3	−5.0	−5.7	−6.2	−6.5	−6.6	−6.3	−5.8	−5.0	−4.1	−3.7	−3.7	−3.2	−2.5	−2.1	−2.3	−2.9	−3.0	−2.7	−3.9	−1.9	−6.6	4.7
NW	−1.9	−2.0	−2.4	−3.2	−4.1	−5.0	−5.5	−5.8	−5.7	−5.6	−5.6	−5.5	−5.2	−4.7	−4.2	−3.6	−3.2	−2.6	−2.3	−2.4	−2.6	−2.4	−2.2	−2.0	−3.8	−1.9	−5.7	3.8
Mean	−2.0	−2.1	−2.5	−3.1	−3.7	−4.3	−4.8	−5.2	−5.4	−5.7	−6.0	−5.9	−5.4	−4.8	−4.2	−3.9	−3.9	−3.6	−3.0	−2.6	−2.6	−2.6	−2.6	−2.4	−3.9	−2.0	−6.0	4.0

PENSACOLA, FLA.

1-kilometer level.

N	0.8	0.1	−1.0	−1.4	−1.5	−1.6	−1.6	−1.5	−1.3	−1.1	−0.9	−0.8	−0.8	−0.9	−1.0	−0.9	−0.8	−0.6	−0.4	−0.2	0.2	0.3	0.5	0.6	−0.6	0.8	−1.6	2.4
NE	1.8	1.6	0.2	−0.7	−1.0	−1.2	−1.1	−1.0	−1.0	−1.1	−1.5	−1.9	−2.0	−2.0	−1.8	−1.6	−1.3	−1.0	−0.5	0.0	0.5	0.9	1.2	1.6	−0.5	1.8	−2.0	3.8
E	1.8	1.1	0.6	0.2	−0.2	−0.5	−0.8	−1.1	−1.3	−1.4	−1.5	−1.7	−1.8	−1.6	−1.4	−1.4	−1.7	−1.5	−1.0	−0.6	−0.2	0.4	1.0	1.5	−0.5	1.8	−1.8	3.6
SE	1.6	1.5	0.9	0.0	−0.9	−1.5	−1.4	−1.1	−1.0	−1.2	−1.4	−1.4	−1.4	−1.3	−1.2	−1.2	−1.2	−1.0	−0.7	−0.5	−0.4	0.0	0.6	1.2	−0.5	1.6	−1.5	3.1
S	1.1	0.8	0.3	−0.4	−0.8	−1.0	−1.0	−1.0	−1.0	−1.2	−1.4	−1.6	−1.2	−1.1	−1.1	−1.1	−1.1	−1.0	−0.6	−0.3	−0.3	−0.2	0.3	0.8	−0.6	1.1	−1.6	2.7
SW	1.3	0.4	−0.3	−0.9	−1.3	−1.6	−1.8	−1.9	−2.0	−2.0	−2.0	−2.0	−1.9	−1.8	−1.6	−1.3	−1.0	−0.7	−0.4	−0.2	0.2	0.6	0.8	1.0	−0.8	1.3	−2.0	3.3
W	0.2	−0.2	−0.5	−1.0	−1.5	−1.9	−2.2	−2.2	−2.0	−1.7	−1.5	−1.3	−1.2	−1.2	−1.1	−1.1	−1.1	−1.0	−0.6	0.0	0.5	1.0	1.3	1.2	−0.8	1.3	−2.2	3.5
NW	0.3	−0.4	−1.0	−1.7	−2.2	−2.6	−2.6	−2.2	−1.7	−1.4	−1.3	−1.2	−1.0	−0.9	−0.8	−1.0	−1.0	−0.7	−0.3	0.0	0.1	0.3	0.4	0.5	−0.9	0.5	−2.6	3.1
Mean	1.1	0.6	−0.1	−0.7	−1.2	−1.5	−1.6	−1.5	−1.4	−1.4	−1.4	−1.5	−1.4	−1.4	−1.3	−1.2	−1.2	−0.9	−0.6	−0.2	0.1	0.4	0.8	1.1	−0.5	1.1	−1.6	2.7

2-kilometer level.

N	−1.7	−1.9	−2.4	−2.9	−3.5	−4.0	−4.5	−4.8	−5.0	−5.0	−4.8	−4.4	−4.0	−3.6	−3.2	−2.8	−2.5	−2.2	−2.0	−1.9	−1.8	−1.6	−1.5	−1.6	−3.1	−1.5	−5.0	3.5
NE	−0.4	−0.9	−1.8	−2.8	−3.6	−4.4	−5.0	−5.3	−5.3	−5.2	−5.0	−4.8	−4.4	−3.9	−3.4	−3.1	−2.9	−2.7	−2.4	−2.2	−1.9	−1.6	−1.2	−0.6	−3.1	−0.4	−5.3	4.9
E	−0.8	−1.0	−1.3	−2.0	−2.8	−3.1	−3.2	−3.4	−4.2	−4.9	−5.3	−5.4	−5.0	−4.3	−4.0	−3.9	−4.0	−4.1	−3.8	−3.2	−2.5	−1.8	−1.4	−1.1	−3.2	−0.8	−5.4	4.6
SE	−1.4	−1.0	−1.4	−2.2	−3.0	−3.4	−3.2	−3.2	−3.6	−4.2	−4.9	−5.0	−4.6	−4.0	−3.8	−3.6	−3.6	−3.6	−3.4	−3.1	−2.4	−2.0	−1.9	−1.8	−3.1	−1.0	−5.0	4.0
S	−2.0	−1.5	−1.7	−2.3	−2.8	−3.3	−3.7	−4.0	−4.3	−4.4	−4.4	−4.4	−4.3	−4.1	−3.6	−3.3	−3.2	−3.2	−2.8	−2.4	−2.2	−2.3	−2.5	−2.6	−3.1	−1.5	−4.4	2.9
SW	−2.0	−1.8	−2.0	−2.4	−2.8	−3.3	−3.8	−4.2	−4.6	−5.0	−5.2	−5.1	−4.6	−4.0	−3.6	−3.3	−3.2	−3.0	−2.5	−2.2	−2.2	−2.4	−2.8	−2.6	−3.3	−1.8	−5.2	3.4
W	−1.5	−1.7	−2.0	−2.5	−3.0	−3.6	−4.2	−4.7	−5.2	−5.6	−5.8	−5.7	−5.2	−4.5	−3.8	−3.3	−2.9	−2.6	−2.3	−2.1	−2.0	−2.1	−2.1	−1.9	−3.3	−1.5	−5.8	4.3
NW	−1.4	−1.6	−2.1	−2.7	−3.2	−3.9	−4.4	−4.9	−5.2	−5.4	−5.2	−5.0	−4.6	−4.0	−3.6	−3.2	−3.1	−3.1	−3.1	−3.0	−2.5	−1.9	−1.4	−1.3	−3.3	−1.3	−5.4	4.1
Mean	−1.4	−1.4	−1.8	−2.5	−3.1	−3.6	−4.0	−4.3	−4.7	−5.0	−5.1	−5.0	−4.6	−4.1	−3.6	−3.3	−3.2	−3.1	−2.8	−2.5	−2.2	−2.0	−1.8	−1.6	−3.2	−1.4	−5.1	3.7

ANNISTON, ALA.

1-kilometer level.

Surface wind direction.	Jan.		Feb.		Mar.		Apr.		May.		June.		July.		Aug.		Sept.		Oct.		Nov.		Dec.		Annual mean.	Extremes.		Range.
	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15		Max.	Min.	
N	−0.1	−1.0	−1.7	−2.1	−2.2	−2.2	−2.1	−2.0	−1.8	−1.7	−1.6	−1.5	−1.6	−1.7	−1.7	−1.5	−1.3	−1.1	−0.9	−0.9	−1.1	−0.9	−0.6	−0.4	−1.4	−0.1	−2.2	2.1
NE	0.4	0.0	−0.8	−1.3	−1.6	−1.5	−1.4	−1.3	−1.5	−1.8	−2.3	−2.8	−3.1	−3.1	−2.6	−2.0	−1.5	−1.0	−0.6	−0.3	−0.1	0.0	0.0	0.2	−1.2	0.4	−3.1	3.5
E	0.7	0.4	0.2	0.0	−0.2	−0.4	−0.6	−0.8	−1.1	−1.4	−1.9	−2.3	−2.8	−2.8	−2.4	−1.5	−1.1	−0.8	−0.5	−0.4	−0.2	0.0	0.2	0.6	−0.8	0.7	−2.8	3.5
SE	1.5	1.4	1.0	0.1	−0.6	−0.9	−1.1	−1.2	−1.4	−1.7	−1.9	−2.1	−2.2	−2.0	−1.6	−1.4	−1.0	−0.8	−0.6	−0.4	−0.2	0.1	0.5	0.9	−0.6	1.5	−2.2	3.7
S	1.4	1.3	0.7	−0.1	−0.7	−1.0	−1.2	−1.4	−1.6	−2.0	−2.2	−2.3	−2.2	−1.8	−1.4	−1.0	−0.9	−0.8	−0.6	−0.5	−0.4	−0.1	0.5	1.0	−0.7	1.4	−2.3	3.7
SW	0.8	0.6	−0.2	−1.0	−1.7	−2.2	−2.3	−2.4	−2.4	−2.5	−2.8	−2.8	−2.7	−2.3	−1.8	−1.5	−1.2	−1.0	−0.8	−0.5	−0.2	0.1	0.4	0.7	−1.2	0.8	−2.8	3.6
W	0.0	−0.4	−1.0	−1.8	−2.2	−2.6	−2.8	−2.8	−2.8	−2.7	−2.6	−2.4	−2.1	−1.9	−1.8	−1.8	−1.8	−1.5	−1.2	−0.9	−0.7	−0.4	−0.3	−0.2	−1.6	0.0	−2.8	2.8
NW	−0.8	−1.0	−1.5	−1.9	−2.2	−2.5	−2.8	−2.8	−2.5	−2.1	−1.9	−1.6	−1.5	−1.4	−1.3	−1.2	−1.2	−1.1	−1.1	−1.0	−1.0	−1.0	−1.0	−0.9	−1.6	−0.8	−2.8	2.0
Mean	0.5	0.2	−0.4	−1.0	−1.4	−1.7	−1.8	−1.8	−1.9	−2.0	−2.1	−2.2	−2.3	−2.1	−1.8	−1.5	−1.2	−1.0	−0.8	−0.6	−0.5	−0.3	0.0	0.2	−1.1	0.5	−2.3	2.8

2-kilometer level.

N	−1.6	−1.9	−2.4	−3.1	−3.8	−4.3	−4.6	−4.7	−4.9	−4.9	−4.8	−4.6	−4.3	−4.0	−3.8	−3.6	−3.2	−2.8	−2.4	−2.0	−1.8	−1.6	−1.6	−1.5	−3.3	−1.5	−4.9	3.4
NE	−0.4	−0.6	−1.2	−2.1	−3.1	−4.1	−4.8	−5.0	−4.9	−4.8	−5.0	−5.2	−5.2	−4.8	−4.4	−3.8	−3.3	−2.7	−2.2	−1.9	−1.8	−1.6	−1.2	−0.8	−3.1	−0.4	−5.2	4.8
E	−0.2	−0.3	−0.7	−1.4	−2.1	−3.0	−3.6	−4.1	−4.4	−4.6	−5.1	−5.6	−5.8	−5.4	−4.6	−4.0	−3.5	−3.1	−2.7	−2.2	−1.6	−1.0	−0.6	−0.2	−2.9	−0.2	−5.8	5.6
SE	0.1	0.2	−0.3	−1.7	−2.8	−3.3	−3.8	−4.1	−4.4	−4.8	−5.1	−5.2	−5.2	−5.0	−4.8	−4.2	−3.8	−3.4	−3.0	−2.5	−1.9	−1.5	−1.0	−0.4	−3.0	0.2	−5.2	5.4
S	−0.8	−1.0	−1.5	−2.4	−3.0	−3.7	−4.3	−4.7	−4.9	−5.2	−5.2	−5.2	−5.0	−4.8	−4.3	−3.8	−3.3	−2.8	−2.3	−2.0	−1.6	−1.4	−1.3	−1.2	−3.1	−0.8	−5.2	4.4
SW	−1.4	−1.6	−2.0	−2.6	−3.4	−4.0	−4.4	−5.0	−5.4	−5.8	−6.0	−6.0	−5.7	−5.1	−4.4	−3.8	−3.3	−2.9	−2.3	−1.8	−1.4	−1.6	−1.9	−1.8	−3.5	−1.4	−6.0	4.6
W	−1.8	−2.0	−2.4	−3.0	−3.5	−4.1	−4.9	−5.6	−6.2	−6.5	−6.6	−6.3	−5.8	−5.2	−4.6	−4.0	−3.5	−3.0	−2.5	−2.4	−2.4	−2.9	−3.0	−2.4	−3.9	−1.8	−6.6	4.8
NW	−1.8	−1.6	−2.0	−3.0	−4.0	−5.0	−5.4	−5.6	−5.8	−5.7	−5.5	−5.2	−4.8	−4.3	−3.8	−3.4	−3.1	−2.8	−2.6	−2.6	−2.6	−2.5	−2.3	−2.0	−3.6	−1.8	−5.8	4.0
Mean	−1.0	−1.1	−1.6	−2.4	−3.2	−3.9	−4.5	−4.8	−5.1	−5.3	−5.4	−5.4	−5.2	−4.8	−4.3	−3.8	−3.4	−2.9	−2.5	−2.2	−1.9	−1.8	−1.6	−1.3	−3.3	−1.0	−5.4	4.4

VICKSBURG, MISS.

1-kilometer level.

N	0.5	0.0	−0.9	−1.2	−1.4	−1.4	−1.3	−1.2	−1.0	−0.8	−0.6	−0.5	−0.4	−0.6	−0.8	−0.8	−0.7	−0.2	0.2	0.3	0.1	0.0	0.2	0.4	−0.5	0.5	−1.4	0.9
NE	1.4	1.0	0.2	−0.3	−0.5	−0.5	−0.5	−0.5	−0.6	−0.7	−0.9	−1.2	−1.4	−1.6	−1.6	−1.2	−0.7	−0.3	0.1	0.4	0.5	0.7	1.0	1.2	−0.3	1.4	−1.6	3.0
E	1.3	1.0	0.8	0.5	0.2	0.0	−0.2	−0.4	−0.6	−0.8	−1.0	−1.3	−1.4	−1.4	−1.2	−0.8	−0.5	−0.2	0.0	0.2	0.4	0.7	0.9	1.2	−0.1	1.3	−1.4	2.7
SE	2.0	1.9	1.5	1.0	0.4	−0.1	−0.4	−0.6	−0.8	−0.9	−1.0	−1.1	−1.1	−1.1	−1.0	−0.9	−0.7	−0.5	−0.3	0.2	0.5	0.9	1.3	1.6	0.0	2.0	−1.1	3.1
S	1.7	1.3	0.5	0.0	−0.3	−0.6	−0.8	−1.0	−1.0	−1.1	−1.1	−1.0	−0.9	−0.8	−0.7	−0.6	−0.6	−0.5	−0.4	−0.3	−0.1	0.3	0.9	1.4	−0.2	1.7	−1.1	2.8
SW	1.0	0.8	0.4	−0.3	−0.8	−1.2	−1.5	−1.7	−1.8	−1.8	−1.7	−1.6	−1.4	−1.1	−1.0	−0.8	−0.7	−0.6	−0.4	−0.2	0.0	0.2	0.5	0.8	−0.6	1.0	−1.8	2.8
W	0.6	0.4	−0.4	−1.0	−1.6	−1.8	−2.0	−2.1	−2.0	−1.9	−1.8	−1.6	−1.4	−1.4	−1.4	−1.4	−1.4	−1.2	−1.1	−0.8	−0.4	0.0	0.3	0.5	−1.0	0.6	−2.1	2.7
NW	0.1	−0.2	−0.5	−1.2	−1.7	−2.0	−2.2	−2.1	−1.8	−1.4	−1.2	−1.0	−0.8	−0.7	−0.8	−1.0	−1.1	−0.8	−0.5	−0.3	−1.1	0.0	0.1	0.1	−0.9	0.1	−2.2	2.3
Mean	1.1	0.8	0.2	−0.3	−0.7	−0.9	−1.1	−1.2	−1.2	−1.2	−1.1	−1.1	−1.1	−1.1	−1.1	−0.9	−0.8	−0.5	−0.3	−0.1	0.0	0.3	0.6	0.9	−0.4	1.1	−1.2	2.3

2-kilometer level.

N	−0.4	−0.8	−1.3	−1.8	−2.4	−3.1	−3.5	−3.7	−3.8	−3.8	−3.6	−3.3	−3.0	−2.8	−2.5	−2.2	−2.0	−1.7	−1.4	−1.2	−1.0	−0.8	−0.7	−0.5	−2.1	−0.4	−3.8	3.4
NW	0.7	0.4	−0.2	−1.3	−2.4	−3.2	−3.6	−3.8	−3.8	−3.7	−3.6	−3.4	−3.3	−3.0	−2.8	−2.4	−2.1	−1.7	−1.4	−1.0	−0.7	−0.3	0.0	0.3	−1.9	0.7	−3.8	4.5
E	0.4	0.2	0.0	−0.5	−1.0	−1.6	−2.1	−2.7	−3.1	−3.4	−3.8	−3.8	−3.8	−3.6	−3.4	−3.1	−2.8	−2.5	−2.1	−1.7	−1.2	−0.8	−0.4	0.0	−1.9	0.4	−3.8	4.2
SE	0.6	0.6	0.0	−0.6	−1.4	−1.9	−2.4	−2.8	−3.3	−3.6	−3.9	−4.0	−3.9	−3.8	−3.6	−3.3	−3.1	−2.8	−2.5	−2.1	−1.6	−1.1	−0.6	0.0	−2.1	0.6	−4.0	4.6
S	−0.1	−0.2	−0.5	−1.0	−1.4	−1.9	−2.3	−2.7	−3.0	−3.4	−3.6	−3.8	−3.8	−3.8	−3.6	−3.4	−3.1	−2.8	−2.4	−2.0	−1.7	−1.3	−1.0	−0.5	−2.2	−0.1	−3.8	3.7
SW	−0.8	−0.8	−0.9	−1.3	−1.7	−2.2	−2.6	−3.0	−3.3	−3.6	−3.9	−4.0	−4.0	−3.8	−3.5	−3.2	−2.8	−2.4	−2.2	−2.0	−1.8	−1.6	−1.4	−1.1	−2.4	−0.8	−4.0	3.2
W	−0.9	−1.1	−1.4	−1.8	−2.2	−2.6	−3.1	−3.8	−4.2	−4.7	−5.0	−5.0	−4.6	−3.8	−3.2	−2.8	−2.5	−2.2	−2.0	−1.8	−1.6	−1.3	−1.0	−0.9	−2.6	−0.9	−5.0	4.1
NW	−0.8	−1.2	−1.6	−2.2	−2.9	−3.4	−3.9	−4.3	−4.6	−4.8	−4.7	−4.3	−3.8	−3.2	−2.8	−2.6	−2.4	−2.2	−2.1	−2.0	−1.9	−1.7	−1.2	−1.0	−2.7	−0.8	−4.8	4.0
Mean	−0.2	−0.4	−0.7	−1.3	−1.9	−2.5	−2.9	−3.3	−3.6	−3.9	−4.0	−3.9	−3.8	−3.5	−3.2	−2.9	−2.6	−2.3	−2.0	−1.7	−1.4	−1.1	−0.8	−0.3	−2.3	−0.2	−4.0	3.8

NEW ORLEANS, LA.

1-kilometer level.

N	1.0	0.5	−0.5	−0.9	−1.1	−1.2	−1.3	−1.2	−1.0	−0.7	−0.2	0.0	0.0	−0.1	−0.3	−0.4	−0.4	−0.1	0.2	0.3	0.4	0.5	0.7	0.9	−0.2	1.0	−1.3	2.3
NE	1.8	1.6	0.9	0.3	−0.1	−0.4	−0.7	−0.8	−0.8	−0.8	−0.8	−0.9	−0.9	−0.9	−0.8	−0.7	−0.6	−0.4	−0.1	0.2	0.5	1.0	1.3	1.6	−0.1	1.8	−0.9	2.7
E	2.2	2.0	1.5	0.9	0.3	0.0	−0.4	−0.8	−1.0	−1.0	−0.8	−0.7	−0.6	−0.6	−0.7	−0.9	−1.0	−1.0	−0.7	−0.3	0.1	0.6	1.1	1.8	0.0	2.2	−1.0	3.2
SE	2.0	2.0	1.4	0.5	0.0	−0.5	−0.7	−0.8	−0.9	−0.9	−1.0	−1.0	−0.8	−0.7	−0.8	−0.9	−0.9	−0.8	−0.6	−0.4	−0.2	0.4	1.0	1.7	−0.1	2.0	−1.0	3.0
S	1.2	1.0	0.6	0.2	0.0	−0.4	−0.6	−0.7	−0.9	−1.0	−1.0	−0.9	−0.6	−0.6	−0.8	−0.9	−1.0	−0.8	−0.6	−0.4	−0.2	0.2	0.7	1.2	−0.8	1.2	−1.0	2.2
SW	1.2	0.6	0.0	−0.4	−0.7	−1.0	−1.2	−1.2	−1.2	−1.2	−1.1	−1.1	−1.1	−1.1	−1.1	−1.0	−1.0	−0.8	−0.6	−0.3	0.2	0.6	0.9	1.1	−0.5	1.2	−1.2	2.4
W	0.6	0.1	−0.4	−0.8	−1.2	−1.6	−1.8	−1.8	−1.8	−1.6	−1.4	−1.3	−1.2	−1.2	−1.1	−1.1	−1.0	−0.8	−0.4	0.0	0.5	1.0	1.2	1.1	−0.7	1.2	−1.8	3.0
NW	0.6	0.3	−0.4	−1.1	−1.8	−2.0	−2.0	−1.8	−1.6	−1.2	−1.0	−0.8	−0.8	−0.7	−0.8	−0.8	−0.8	−0.6	−0.3	0.0	0.2	0.4	0.6	0.6	−0.7	0.6	−2.0	2.6
Mean	1.3	1.0	0.4	−0.2	−0.6	−0.9	−1.1	−1.1	−1.2	−1.1	−0.9	−0.8	−0.7	−0.7	−0.8	−0.8	−0.8	−0.7	−0.4	−0.1	0.2	0.6	0.9	1.2	−0.3	1.3	−1.2	2.5

2-kilometer level.

N	−0.4	−0.7	−1.4	−2.4	−3.2	−3.6	−4.0	−4.2	−4.2	−4.1	−3.9	−3.5	−3.0	−2.6	−2.3	−2.0	−1.7	−1.5	−1.4	−1.3	−1.3	−1.2	−0.8	−0.4	−2.3	−0.4	−4.2	3.8
NE	0.5	−0.1	−1.1	−2.2	−3.0	−3.7	−4.3	−4.5	−4.5	−4.3	−4.0	−4.7	−3.2	−2.8	−2.3	−2.0	−1.8	−1.7	−1.6	−1.5	−1.3	−0.9	−0.6	−0.2	−2.3	0.5	−4.7	5.2
E	−0.3	−0.1	−0.2	−0.8	−1.3	−1.9	−2.4	−3.0	−3.5	−3.8	−3.7	−3.4	−3.1	−3.0	−2.9	−3.0	−3.2	−3.3	−3.1	−2.6	−2.0	−1.5	−1.0	−0.6	−2.2	−0.1	−3.8	3.7
SE	−0.2	−0.1	−0.4	−1.0	−1.6	−2.2	−2.6	−3.0	−3.4	−3.6	−3.8	−3.7	−3.4	−2.8	−2.5	−2.4	−2.6	−2.9	−3.1	−2.7	−2.1	−1.6	−1.0	−0.6	−2.2	−0.1	−3.8	3.7
S	−1.0	−1.0	−1.2	−1.5	−1.7	−2.0	−2.2	−2.6	−2.9	−3.2	−3.3	−3.4	−3.3	−3.2	−3.2	−3.0	−2.9	−2.8	−2.6	−2.4	−2.3	−2.1	−1.8	−1.5	−2.4	−1.0	−3.4	2.4
SW	−1.2	−1.4	−1.4	−1.8	−2.0	−2.2	−2.4	−2.8	−3.2	−3.5	−3.8	−3.8	−3.7	−3.6	−3.6	−3.6	−3.3	−2.9	−2.6	−2.3	−2.1	−1.8	−1.7	−1.5	−2.6	−1.2	−3.8	2.6
W	−1.3	−1.5	−1.8	−2.2	−2.4	−2.7	−3.0	−3.4	−4.0	−4.7	−5.0	−4.8	−4.5	−3.9	−3.1	−2.8	−2.6	−2.4	−2.0	−1.8	−1.7	−1.6	−1.3	−1.1	−2.7	−1.1	−5.0	3.9
NW	−1.0	−1.2	−1.6	−2.0	−2.5	−3.1	−3.6	−4.0	−4.4	−4.6	−4.6	−4.4	−4.0	−3.2	−2.7	−2.4	−2.2	−2.1	−1.9	−1.8	−1.5	−1.1	−0.7	−0.6	−2.5	−0.6	−4.0	3.4
Mean	−0.6	−0.8	−1.2	−1.7	−2.2	−2.7	−3.1	−3.4	−3.8	−4.0	−4.0	−4.0	−3.5	−3.1	−2.8	−2.6	−2.5	−2.5	−2.3	−2.0	−1.8	−1.5	−1.1	−0.8	−2.4	−0.6	−4.0	3.4

HOUSTON, TEX.

1-kilometer level.

N	1.4	1.3	1.0	0.6	0.1	−0.2	−0.6	−0.6	−0.3	0.1	0.4	0.6	0.7	0.6	0.4	0.2	0.2	0.4	0.7	0.8	1.0	1.0	1.1	1.2	0.5	1.4	−0.6	2.0
NE	2.0	1.9	1.5	1.0	0.8	0.5	0.4	0.1	−0.2	−0.1	0.2	0.5	0.7	0.7	0.6	0.5	0.3	0.4	0.6	0.9	1.2	1.6	1.9	2.1	0.8	2.1	−0.2	2.3
E	3.1	2.7	2.2	1.4	0.9	0.5	0.2	0.0	−0.2	−0.2	0.0	0.4	0.6	0.7	0.6	0.4	0.1	0.1	0.2	0.4	0.6	1.2	2.2	3.0	0.9	3.1	−0.2	3.3
SE	2.9	2.7	1.8	0.8	0.3	0.3	0.4	0.3	0.2	0.1	0.0	−0.1	0.0	0.1	0.0	−0.3	−0.4	−0.3	−0.1	0.1	0.4	1.0	2.0	2.7	0.6	2.9	−0.4	3.3
S	1.8	1.6	1.4	1.0	0.8	0.5	0.3	0.1	−0.1	−0.2	−0.1	0.0	0.2	0.1	−0.2	−0.5	−0.5	−0.6	−0.5	−0.3	0.0	0.5	1.0	1.5	0.3	1.8	−0.6	2.4
SW	1.6	1.0	0.6	0.2	0.0	−0.2	−0.4	−0.5	−0.5	−0.4	−0.3	−0.2	−0.1	−0.2	−0.4	−0.5	−0.5	−0.4	−0.4	−0.4	−0.2	0.4	1.0	1.4	0.1	1.6	−0.5	2.1
W	1.2	0.5	0.1	−0.3	−0.6	−0.8	−1.0	−1.2	−1.2	−1.2	−1.2	−0.8	−0.4	−0.5	−0.9	−1.1	−1.1	−0.9	−0.6	−0.2	0.4	1.0	1.6	1.8	−0.3	1.8	−1.2	3.0
NW	1.2	0.9	0.4	−0.1	−0.8	−1.2	−1.4	−1.3	−1.0	−0.8	−0.4	−0.2	−0.1	−0.1	−0.3	−0.7	−0.7	−0.4	0.0	0.3	0.6	1.0	1.2	1.2	−0.1	1.2	−1.4	2.6
Mean	1.9	1.6	1.1	0.6	0.2	−0.1	−0.3	−0.4	−0.4	−0.3	−0.2	0.0	0.2	0.2	0.0	−0.2	−0.3	−0.2	0.0	0.2	0.5	0.9	1.5	1.9	0.3	1.9	−0.4	2.3

HOUSTON; TEX.—Continued.

2-kilometer level.

Surface wind direction.	Jan.		Feb.		Mar.		Apr.		May.		June.		July.		Aug.		Sept.		Oct.		Nov.		Dec.		Annual mean.	Extremes.		Range.
	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15		Max.	Min.	
N	0.6	0.0	−0.7	−1.4	−2.0	−2.5	−2.8	−3.0	−3.1	−3.1	−2.9	−2.5	−2.0	−1.4	−1.1	−0.9	−0.8	−0.6	−0.7	−0.8	−0.8	−0.4	0.6	1.0	−1.3	1.0	−3.1	4.1
NE	1.0	0.6	0.0	−0.9	−1.8	−2.5	−3.0	−3.3	−3.3	−3.1	−2.8	−2.3	−1.7	−1.3	−0.9	−0.7	−0.6	−0.6	−0.8	−0.9	−0.8	−0.4	0.2	0.7	−1.2	1.0	−3.3	4.3
E	1.0	1.2	1.2	1.0	0.4	−0.2	−0.9	−1.5	−2.3	−2.9	−3.0	−2.4	−1.7	−1.4	−1.4	−1.5	−1.8	−1.9	−1.8	−1.7	−1.4	−0.9	−0.3	0.4	−1.0	1.2	−3.0	4.2
SE	0.6	0.8	0.8	0.4	−0.8	−0.9	−0.6	−0.6	−1.2	−2.2	−2.6	−2.2	−1.6	−1.1	−1.0	−1.3	−1.6	−1.9	−2.0	−2.0	−1.6	−1.1	−0.6	0.1	−1.0	0.8	−2.6	3.4
S	0.1	0.5	0.1	−0.3	−0.6	−0.5	−0.4	−0.8	−1.4	−1.9	−2.3	−2.3	−2.2	−2.2	−2.1	−2.2	−2.2	−2.4	−2.5	−2.4	−2.1	−1.5	−0.9	−0.3	−1.3	0.5	−2.5	3.0
SW	0.0	−0.2	−0.5	−0.7	−0.8	−0.9	−1.2	−1.6	−2.0	−2.3	−2.4	−2.5	−2.5	−2.6	−2.6	−2.6	−2.5	−2.4	−2.2	−2.0	−1.8	−1.4	−0.8	−0.3	−1.6	0.0	−2.6	2.6
W	−0.3	−0.9	−1.2	−1.3	−1.4	−1.4	−1.4	−1.7	−2.2	−3.0	−3.5	−3.8	−3.5	−2.9	−2.3	−2.0	−1.8	−1.7	−1.6	−1.4	−1.3	−1.0	−0.1	0.1	−1.8	0.1	−3.8	3.9
NW	−0.4	−0.9	−1.1	−1.2	−1.5	−1.6	−2.0	−2.7	−3.4	−3.9	−3.8	−3.4	−2.8	−2.2	−1.8	−1.7	−1.8	−1.8	−1.6	−1.2	−0.7	0.0	0.5	0.5	−1.8	0.5	−3.9	4.4
Mean	0.3	0.2	−0.2	−0.5	−1.1	−1.3	−1.5	−1.9	−2.4	−2.8	−2.9	−2.7	−2.2	−1.9	−1.6	−1.6	−1.6	−1.7	−1.6	−1.5	−1.3	−0.8	−0.2	0.3	−1.3	0.3	−2.9	3.2

LITTLE ROCK, ARK.

1-kilometer level.

N	−0.8	−1.1	−1.3	−1.4	−1.4	−1.4	−1.4	−1.3	−1.2	−1.0	−0.9	−0.8	−0.8	−0.8	−0.8	−0.8	−0.8	−0.7	−0.6	−0.6	−0.7	−0.8	−0.8	−0.8	−1.0	−0.6	−1.4	0.8
NE	0.4	0.2	0.0	−0.2	−0.5	−0.6	−0.8	−1.0	−1.1	−1.2	−1.2	−1.3	−1.3	−1.2	−1.1	−0.9	−0.6	−0.3	0.0	0.2	0.4	0.5	0.6	0.5	−0.4	0.6	−1.3	1.9
E	1.0	0.9	0.8	0.7	0.6	0.5	0.3	0.1	−0.1	−0.4	−0.7	−1.0	−1.2	−1.4	−1.3	−0.8	−0.2	0.2	0.5	0.7	0.8	0.9	1.0	1.0	0.1	1.0	−1.4	2.4
SE	2.0	2.0	1.8	1.4	0.9	0.4	0.1	−0.3	−0.6	−0.8	−1.1	−1.2	−1.0	−0.8	−0.5	−0.2	0.1	0.3	0.6	0.9	1.2	1.5	1.7	2.0	0.4	2.0	−1.2	3.2
S	2.2	2.0	1.5	1.0	0.5	0.0	−0.5	−0.9	−1.1	−1.2	−1.3	−1.2	−1.1	−0.9	−0.7	−0.5	−0.3	−0.2	0.0	0.2	0.5	1.0	1.5	1.9	0.2	2.2	−1.3	3.5
SW	1.5	1.2	0.8	0.2	−0.2	−0.7	−1.0	−1.3	−1.5	−1.6	−1.6	−1.5	−1.3	−1.0	−0.8	−0.7	−0.6	−0.5	−0.4	−0.3	−0.2	0.2	0.8	1.4	−0.4	1.5	−1.6	3.1
W	1.0	0.8	0.1	−0.8	−1.4	−1.7	−2.0	−2.1	−2.2	−2.2	−2.2	−2.0	−1.7	−1.5	−1.3	−1.2	−1.2	−1.1	−1.1	−1.2	−1.2	−1.1	−0.7	0.0	−1.2	1.0	−2.2	3.2
NW	−0.2	−0.3	−0.8	−1.2	−1.6	−1.8	−1.9	−2.0	−1.8	−1.6	−1.3	−1.0	−0.8	−0.7	−0.7	−0.8	−0.8	−0.8	−0.7	−0.7	−0.8	−1.0	−1.0	−0.9	−1.1	−0.2	−2.0	1.8
Mean	0.9	0.7	0.4	0.0	−0.4	−0.7	−0.9	−1.1	−1.2	−1.3	−1.3	−1.3	−1.1	−1.0	−0.9	−0.7	−0.5	−0.4	−0.2	−0.1	0.0	0.1	0.4	0.6	−0.4	0.9	−1.3	2.2

2-kilometer level.

N	0.2	−0.1	−0.5	−1.2	−1.8	−2.5	−3.0	−3.2	−3.2	−3.2	−3.2	−3.2	−3.2	−3.1	−3.0	−2.8	−2.4	−2.0	−1.6	−1.1	−0.8	−0.5	−0.3	−0.1	−1.9	0.2	−3.2	3.4
NE	1.1	0.8	0.4	−0.4	−1.2	−1.8	−2.4	−2.8	−3.1	−3.3	−3.5	−3.6	−3.6	−3.6	−3.3	−2.6	−2.1	−1.6	−1.1	−0.7	−0.2	0.2	0.5	1.0	−1.5	1.1	−3.6	4.7
E	1.4	1.2	0.7	0.3	−0.4	−1.0	−1.7	−2.4	−2.8	−3.1	−3.3	−3.4	−3.4	−3.3	−3.0	−2.6	−2.0	−1.4	−1.0	−0.6	−0.1	0.5	0.9	1.2	−1.3	1.4	−3.4	4.8
SE	2.0	1.7	1.1	0.3	−0.5	−1.3	−2.0	−2.5	−3.0	−3.4	−3.7	−4.0	−4.1	−4.1	−3.8	−3.3	−2.7	−2.3	−1.8	−1.3	−0.6	0.0	0.6	1.3	−1.6	2.0	−4.1	6.1
S	1.0	1.0	0.6	0.0	−0.6	−1.2	−1.7	−2.3	−2.8	−3.2	−3.6	−3.9	−3.9	−3.8	−3.5	−3.2	−2.7	−2.4	−2.0	−1.5	−1.0	−0.5	0.0	0.5	−1.7	1.0	−3.9	4.9
SW	0.3	0.0	−0.4	−0.9	−1.4	−1.7	−2.2	−2.6	−3.0	−3.3	−3.5	−3.7	−3.6	−3.3	−3.0	−2.7	−2.3	−2.0	−1.6	−1.2	−0.8	−0.5	−0.3	0.0	−1.8	0.3	−3.7	4.0
W	−0.3	−0.5	−0.8	−1.2	−1.8	−2.5	−3.2	−3.7	−4.0	−4.2	−4.2	−4.0	−3.6	−3.3	−3.0	−2.6	−2.3	−2.0	−1.6	−1.3	−1.0	−0.7	−0.5	−0.3	−2.2	−0.3	−4.2	3.9
NW	−0.4	−0.4	−0.7	−1.5	−2.7	−3.7	−4.1	−4.0	−3.8	−3.4	−2.9	−2.6	−2.2	−2.0	−1.8	−1.7	−1.6	−1.5	−1.4	−1.4	−1.4	−1.4	−1.2	−1.0	−2.0	−0.4	−3.5	3.1
Mean	0.7	0.5	0.0	−0.6	−1.3	−2.0	−2.5	−2.9	−3.2	−3.4	−3.5	−3.5	−3.5	−2.8	−3.0	−2.7	−2.3	−1.9	−1.5	−1.1	−0.7	−0.4	0.0	0.3	−1.8	0.7	−3.5	4.2

MEMPHIS, TENN.

1-kilometer level.

N	−1.0	−1.3	−1.6	−1.7	−1.8	−1.8	−1.7	−1.6	−1.5	−1.4	−1.3	−1.2	−1.3	−1.4	−1.4	−1.3	−1.2	−1.0	−0.8	−1.0	−1.2	−1.1	−1.0	−1.0	−1.3	−0.8	−1.8	1.0
NE	0.2	−0.1	−0.7	−0.8	−1.0	−1.1	−1.0	−0.9	−1.0	−1.2	−1.6	−2.0	−2.3	−2.3	−2.1	−1.5	−1.0	−0.4	0.0	0.2	0.2	0.0	−0.2	−0.2	−0.8	0.2	−2.3	2.5
E	0.6	0.5	0.4	0.4	0.4	0.3	0.2	−0.1	−0.4	−0.8	−1.0	−1.4	−2.0	−2.4	−2.2	−1.0	−0.3	0.1	0.2	0.3	0.4	0.5	0.6	0.6	−0.2	0.6	−2.4	3.0
SE	2.0	1.9	1.6	1.1	0.6	0.1	−0.3	−0.8	−0.8	−0.5	−0.8	−1.7	−2.1	−2.0	−1.2	−0.5	0.0	−0.4	−0.6	−0.2	1.1	1.4	1.6	1.8	−0.2	2.0	−2.1	4.1
S	2.0	1.6	1.0	0.2	−0.5	−1.0	−1.0	−1.0	−1.1	−1.7	−2.0	−2.0	−1.8	−1.3	−0.8	−0.5	−0.3	−0.2	−0.2	−0.2	0.1	0.4	1.1	−1.7	−0.3	2.0	−2.0	4.0
SW	1.5	1.4	1.7	−0.2	−1.1	−1.8	−1.9	−1.9	−2.0	−2.2	−2.4	−2.5	−2.2	−1.7	−1.2	−0.9	−0.7	−0.6	−0.6	−0.5	−0.3	0.0	0.4	1.0	−0.8	1.7	−2.5	4.2
W	0.6	0.4	−0.3	−1.2	−1.8	−2.2	−2.4	−2.6	−2.6	−2.7	−2.7	−2.5	−1.8	−1.4	−1.3	−1.2	−1.2	−1.2	−1.2	−1.3	−1.2	−1.2	−1.1	−0.6	−1.4	0.6	−2.7	3.3
NW	−0.7	−0.8	−1.1	−1.6	−2.1	−2.4	−2.6	−2.6	−2.3	−2.0	−1.8	−1.8	−1.6	−1.1	−1.0	−1.1	−1.2	−1.1	−1.0	−1.0	−1.1	−1.3	−1.2	−1.0	−1.5	−0.7	−2.6	1.9
Mean	0.6	0.4	0.1	−0.5	−0.9	−1.2	−1.3	−1.4	−1.5	−1.6	−1.7	−1.9	−1.9	−1.7	−1.4	−1.0	−0.7	−0.5	−0.4	−0.3	−0.3	−0.2	0.0	0.3	−0.8	0.6	−1.9	2.5

2-kilometer level.

N	−0.8	−1.0	−1.3	−2.1	−2.7	−3.2	−3.6	−3.8	−3.8	−3.8	−3.8	−3.8	−3.6	−3.5	−3.4	−3.1	−2.6	−2.1	−1.7	−1.4	−1.2	−1.1	−1.0	−1.0	−2.5	−0.8	−3.8	3.0
NE	0.8	0.6	−0.2	−1.2	−2.0	−2.6	−3.0	−3.3	−3.6	−3.8	−4.0	−4.1	−4.2	−4.1	−3.6	−3.1	−2.5	−2.0	−1.5	−1.2	−0.8	−0.5	−0.2	0.2	−2.1	0.8	−4.2	5.0
E	1.1	1.0	0.7	0.1	−0.8	−1.7	−2.5	−3.0	−3.2	−3.4	−3.8	−4.3	−4.5	−4.4	−3.9	−3.1	−2.4	−2.0	−1.7	−1.2	−0.6	0.0	0.6	1.0	−1.7	1.1	−4.5	5.6
SE	1.5	1.6	1.0	0.0	−1.0	−2.0	−2.7	−3.2	−3.6	−4.0	−4.4	−4.6	−4.8	−4.8	−4.2	−3.5	−2.8	−2.4	−2.1	−1.7	−1.1	−0.6	0.2	1.0	−2.0	1.6	−4.8	6.4
S	1.3	1.5	0.9	−0.1	−1.2	−2.0	−2.7	−3.2	−3.6	−4.0	−4.3	−4.6	−4.9	−4.8	−4.1	−3.3	−2.7	−2.2	−1.7	−1.2	−1.0	−0.8	−0.5	0.2	−2.0	1.5	−4.9	6.4
SW	−0.8	−0.6	−0.8	−1.2	−1.8	−2.4	−2.9	−3.4	−3.9	−4.3	−4.5	−4.6	−4.6	−4.2	−3.7	−3.1	−2.7	−2.3	−1.8	−1.4	−1.3	−1.6	−1.6	−1.2	−2.5	−0.6	−4.6	4.0
W	−1.0	−1.1	−1.4	−1.9	−2.5	−3.4	−4.1	−4.8	−5.2	−5.2	−5.3	−5.1	−4.6	−4.0	−3.6	−3.1	−2.8	−2.5	−2.2	−2.0	−1.8	−1.7	−1.5	−1.2	−3.0	−1.0	−5.3	4.3
NW	−1.1	−1.2	−1.5	−2.3	−3.6	−4.7	−5.2	−5.4	−5.2	−4.9	−4.6	−4.2	−3.8	−3.4	−3.1	−2.9	−2.8	−2.7	−2.6	−2.7	−2.8	−2.6	−2.2	−1.7	−3.2	−1.1	−5.4	4.3
Mean	0.1	0.1	−0.4	−1.1	−1.9	−2.7	−3.3	−3.7	−4.0	−4.2	−4.3	−4.4	−4.4	−4.1	−3.7	−3.1	−2.7	−2.3	−1.9	−1.6	−1.3	−1.1	−0.8	−0.3	−2.4	0.1	−4.4	4.5

NASHVILLE, TENN.

1-kilometer level.

N	−1.2	−1.4	−1.7	−2.0	−2.1	−2.2	−2.2	−2.2	−2.2	−2.1	−2.1	−2.0	−2.0	−2.0	−2.0	−1.8	−1.5	−1.5	−1.6	−2.0	−2.4	−2.0	−1.6	−1.4	−1.9	−1.2	−2.4	1.2
NE	0.0	−0.3	−0.9	−1.2	−1.4	−1.5	−1.5	−1.7	−2.0	−2.3	−2.7	−3.0	−3.2	−3.0	−2.5	−1.9	−1.4	−1.1	−0.9	−0.8	−0.9	−1.0	−1.0	−0.4	−1.5	0.0	−3.2	3.2
E	0.5	0.4	0.4	0.3	0.2	0.0	−0.2	−0.6	−1.0	−1.5	−2.0	−2.3	−2.6	−2.6	−2.1	−1.7	−1.5	−1.2	−1.1	−1.1	−1.0	−1.0	−0.9	−0.7	−1.0	0.5	−2.6	3.1
SE	1.5	1.4	1.1	0.8	0.3	−0.2	−0.6	−1.1	−1.5	−1.7	−1.9	−2.0	−2.2	−2.1	−1.7	−1.2	−0.7	−0.2	0.1	0.4	0.6	0.8	1.0	1.3	−0.3	1.5	−2.2	3.7
S	1.8	1.5	0.9	0.3	−0.4	−0.8	−1.1	−1.4	−1.7	−2.2	−2.3	−2.4	−2.3	−2.0	−1.3	−0.8	−0.4	−0.2	−0.1	−0.1	−0.1	0.2	0.8	1.4	−0.5	1.8	−2.4	4.2
SW	0.4	0.4	0.0	−0.5	−1.1	−1.7	−2.1	−2.4	−2.5	−2.6	−2.6	−2.5	−2.4	−2.0	−1.6	−1.2	−1.0	−0.7	−0.6	−0.5	−0.4	−0.3	−0.2	0.2	−1.1	0.4	−2.6	3.0
W	−0.4	−0.5	−1.0	−1.6	−2.1	−2.5	−2.9	−3.1	−3.2	−3.2	−3.2	−2.9	−2.5	−2.1	−1.9	−1.6	−1.5	−1.4	−1.3	−1.2	−1.3	−1.5	−1.4	−1.2	−1.9	−0.4	−3.2	2.8
NW	−1.1	−1.3	−1.7	−2.0	−2.4	−2.6	−2.8	−2.9	−2.7	−2.5	−2.6	−2.8	−2.6	−2.0	−1.6	−1.4	−1.2	−1.2	−1.2	−1.2	−1.2	−1.2	−1.3	−1.3	−1.9	−1.1	−2.9	1.8
Mean	0.2	0.0	−0.4	−0.7	−1.1	−1.4	−1.7	−1.9	−2.1	−2.3	−2.8	−2.5	−2.5	−2.2	−2.0	−1.5	−1.1	−0.9	−0.8	−0.8	−0.8	−0.7	−0.6	−0.3	−1.3	0.2	−2.8	3.0

NASHVILLE, TENN.—Continued.

2-kilometer level.

Surface wind direction.	Jan.		Feb.		Mar.		Apr.		May.		June.		July.		Aug.		Sept.		Oct.		Nov.		Dec.		Annual mean.	Extremes.		Range.
	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15		Max.	Min.	
N	−1.1	−1.4	−2.2	−3.0	−3.8	−4.2	−4.4	−4.2	−4.2	−4.4	−4.6	−4.7	−4.5	−4.3	−4.0	−3.7	−3.2	−2.7	−2.3	−2.1	−1.9	−1.8	−1.7	−1.4	−3.1	−1.1	−4.7	3.6
NE	0.1	0.2	−0.4	−1.5	−2.6	−3.3	−3.7	−4.1	−4.4	−4.6	−4.8	−4.9	−4.9	−4.8	−4.5	−4.2	−3.9	−3.5	−3.1	−2.8	−2.5	−2.0	−1.6	−1.2	−3.0	0.2	−4.9	5.1
E	1.3	1.2	0.8	0.1	−0.9	−2.1	−3.0	−3.7	−4.2	−4.6	−5.0	−5.1	−5.0	−4.8	−4.3	−3.4	−2.8	−2.3	−1.8	−1.2	−0.6	0.0	0.6	1.1	−2.1	1.3	−5.1	6.4
SE	1.4	1.4	0.6	−1.3	−2.3	−2.9	−3.4	−3.9	−4.5	−4.9	−5.2	−5.3	−5.2	−5.1	−4.7	−4.3	−3.7	−3.1	−2.4	−1.8	−1.2	−0.5	0.2	0.8	−2.6	1.4	−5.3	6.7
S	0.0	−0.1	−0.7	−1.9	−2.8	−3.5	−4.0	−4.5	−4.9	−5.1	−5.2	−5.3	−5.3	−5.0	−4.4	−3.7	−3.1	−2.4	−1.8	−1.4	−1.0	−0.8	−0.5	−0.2	−2.8	0.0	−5.3	5.3
SW	−1.2	−1.0	−1.4	−2.3	−3.4	−4.0	−4.5	−4.9	−5.2	−5.5	−5.7	−5.8	−5.8	−5.5	−4.9	−4.2	−3.4	−2.8	−2.2	−1.8	−1.6	−1.9	−2.1	−1.9	−3.5	−1.0	−5.8	4.8
W	−1.8	−2.0	−2.5	−3.2	−4.0	−4.7	−5.3	−6.0	−6.3	−6.6	−6.6	−6.5	−6.3	−5.6	−4.5	−3.7	−3.3	−3.0	−2.9	−2.8	−2.8	−2.9	−2.9	−2.4	−4.1	−1.8	−6.6	4.8
NW	−1.4	−1.7	−2.2	−3.1	−4.1	−5.1	−5.9	−6.0	−5.6	−5.5	−5.8	−5.5	−5.0	−4.4	−4.0	−3.6	−3.3	−3.0	−2.9	−2.9	−2.9	−2.8	−2.5	−2.1	−2.8	−1.4	−6.0	4.6
Mean	−0.3	−0.4	−1.0	−2.0	−3.0	−3.7	−4.3	−4.6	−4.9	−5.1	−5.4	−5.4	−5.2	−5.0	−4.4	−3.9	−3.3	−2.9	−2.4	−2.1	−1.8	−1.6	−1.3	−0.9	−3.1	−0.3	−5.4	5.1

LEXINGTON, KY.

1-kilometer level.

Surface wind direction.	Jan. 1	Jan. 15	Feb. 1	Feb. 15	Mar. 1	Mar. 15	Apr. 1	Apr. 15	May. 1	May. 15	June. 1	June. 15	July. 1	July. 15	Aug. 1	Aug. 15	Sept. 1	Sept. 15	Oct. 1	Oct. 15	Nov. 1	Nov. 15	Dec. 1	Dec. 15	Annual mean.	Extremes. Max.	Extremes. Min.	Range.
N	−1.5	−1.5	−1.6	−1.8	−2.0	−2.2	−2.5	−2.7	−2.7	−2.6	−2.5	−2.5	−2.4	−2.4	−2.4	−2.0	−1.8	−1.9	−2.2	−2.8	−3.2	−3.0	−2.3	−1.8	−2.3	−1.5	−2.7	1.2
NE	0.6	0.0	−0.6	−1.0	−1.3	−1.3	−1.4	−1.8	−2.2	−2.5	−2.7	−2.8	−2.7	−2.4	−2.0	−1.5	−1.2	−1.0	−1.0	−1.2	−1.9	−2.0	−1.9	−0.9	−1.5	0.6	−2.8	3.4
E	1.0	1.1	1.0	0.6	0.3	−0.1	−0.4	−0.8	−1.2	−1.5	−1.8	−2.0	−1.9	−1.7	−1.4	−1.0	−0.7	−0.5	−0.4	−0.2	−0.2	−0.2	−0.2	0.7	−0.5	1.1	−2.0	3.1
SE	1.9	1.9	1.5	1.0	0.6	0.0	−0.4	−0.9	−1.4	−1.6	−1.8	−1.9	−1.8	−1.6	−1.3	−0.9	−0.6	−0.2	0.1	0.4	0.7	1.0	1.3	1.5	−0.1	1.9	−1.9	3.8
S	1.5	1.4	1.0	0.5	0.0	−0.6	−1.2	−1.6	−1.8	−2.0	−2.1	−2.1	−2.1	−1.8	−1.2	−0.8	−0.4	−0.2	−0.1	−0.1	−0.1	0.2	0.6	1.2	−0.5	1.5	−2.1	3.6
SW	0.5	0.3	−0.1	−0.6	−1.1	−1.6	−2.0	−2.3	−2.5	−2.6	−2.7	−2.8	−2.5	−2.0	−1.6	−1.2	−0.9	−0.6	−0.5	−0.4	−0.2	−0.1	0.0	0.1	−1.1	0.5	−2.8	3.3
W	−1.2	−0.9	−1.0	−1.6	−2.0	−2.5	−2.8	−3.0	−3.2	−3.4	−3.4	−3.3	−2.9	−2.4	−2.1	−1.7	−1.6	−1.5	−1.5	−1.6	−1.8	−2.0	−1.9	−1.6	−2.1	−0.9	−3.4	2.5
NW	−1.6	−1.7	−1.8	−2.2	−2.6	−2.8	−3.0	−3.1	−3.2	−3.0	−2.8	−3.0	−3.0	−2.6	−2.0	−1.6	−1.5	−1.4	−1.5	−1.6	−1.7	−2.0	−2.0	−1.9	−2.2	−1.6	−3.1	1.5
Mean	0.1	0.1	−0.2	−0.6	−1.0	−1.4	−1.7	−2.0	−2.3	−2.4	−2.5	−2.5	−2.4	−2.1	−1.7	−1.3	−1.1	−0.9	−0.9	−0.9	−1.0	−1.0	−0.8	−0.3	−1.3	0.1	−2.5	2.6

2-kilometer level.

Surface wind direction.	Jan. 1	Jan. 15	Feb. 1	Feb. 15	Mar. 1	Mar. 15	Apr. 1	Apr. 15	May. 1	May. 15	June. 1	June. 15	July. 1	July. 15	Aug. 1	Aug. 15	Sept. 1	Sept. 15	Oct. 1	Oct. 15	Nov. 1	Nov. 15	Dec. 1	Dec. 15	Annual mean.	Extremes. Max.	Extremes. Min.	Range.
N	−1.6	−1.6	−2.2	−3.2	−3.8	−4.3	−4.6	−4.8	−4.9	−5.0	−5.0	−4.9	−4.6	−4.3	−4.0	−3.7	−3.4	−3.0	−2.8	−2.6	−2.4	−2.4	−2.2	−2.0	−3.5	−1.6	−5.0	3.4
NE	0.2	0.4	−0.2	−1.0	−2.0	−2.8	−3.4	−3.8	−4.1	−4.6	−5.0	−5.4	−5.4	−5.1	−4.4	−3.6	−3.0	−2.5	−2.1	−1.8	−1.7	−1.6	−1.4	−0.7	−2.7	0.4	−5.4	5.8
E	1.9	2.0	1.7	1.0	0.0	−1.4	−2.6	−3.4	−4.1	−4.5	−4.8	−5.0	−5.0	−4.4	−3.7	−3.0	−2.4	−2.0	−1.5	−1.1	−0.5	0.1	0.6	1.1	−1.7	2.0	−5.0	7.0
SE	1.8	1.5	0.8	−0.9	−2.3	−3.2	−3.8	−4.4	−4.8	−5.0	−5.0	−5.0	−4.8	−4.5	−4.1	−3.6	−3.1	−2.5	−2.0	−1.5	−0.8	−0.2	0.5	1.1	−2.3	1.8	−5.0	6.8
S	0.0	−0.1	−0.8	−1.8	−2.7	−3.5	−4.1	−4.7	−5.0	−5.2	−5.3	−5.3	−5.2	−4.7	−4.2	−3.6	−3.0	−2.4	−1.8	−1.3	−1.0	−0.7	−0.4	−0.2	−2.8	0.0	−5.3	5.3
SW	−1.4	−1.3	−1.9	−2.8	−3.6	−4.2	−4.7	−5.2	−5.6	−6.0	−6.2	−6.2	−6.1	−5.4	−4.8	−4.0	−3.3	−2.8	−2.4	−2.0	−1.8	−2.2	−2.2	−2.0	−3.7	−1.3	−6.2	4.9
W	−2.2	−2.5	−2.9	−3.6	−4.2	−4.8	−5.4	−6.0	−6.4	−6.8	−7.2	−7.2	−6.8	−6.0	−5.1	−4.4	−4.0	−3.6	−3.3	−3.2	−3.1	−3.2	−3.2	−2.8	−4.5	−2.2	−7.2	5.0
NW	−2.0	−2.3	−2.8	−3.6	−4.5	−5.3	−5.9	−6.1	−6.1	−6.2	−6.2	−5.9	−5.2	−4.6	−4.0	−3.7	−3.5	−3.3	−3.2	−3.3	−3.4	−3.4	−3.2	−2.6	−4.2	−2.0	−6.2	4.2
Mean	−0.4	−0.5	−1.0	−2.0	−2.9	−3.7	−4.3	−4.8	−5.1	−5.4	−5.6	−5.6	−5.4	−4.9	−4.3	−3.7	−3.2	−2.8	−2.4	−2.1	−1.8	−1.7	−1.4	−1.0	−3.2	−0.4	−5.6	5.2

INDIANAPOLIS, IND.

1-kilometer level.

Surface wind direction.	Jan. 1	Jan. 15	Feb. 1	Feb. 15	Mar. 1	Mar. 15	Apr. 1	Apr. 15	May. 1	May. 15	June. 1	June. 15	July. 1	July. 15	Aug. 1	Aug. 15	Sept. 1	Sept. 15	Oct. 1	Oct. 15	Nov. 1	Nov. 15	Dec. 1	Dec. 15	Annual mean.	Extremes. Max.	Extremes. Min.	Range.
N	−1.7	−1.1	−1.0	−1.3	−1.8	−2.1	−2.4	−2.7	−2.8	−2.8	−2.7	−2.6	−2.4	−2.3	−2.2	−2.0	−2.0	−2.1	−2.5	−3.0	−3.2	−2.9	−2.5	−2.0	−2.3	−1.0	−3.2	2.2
NE	0.8	1.0	0.4	−0.1	−0.5	−0.8	−1.2	−1.6	−2.1	−2.6	−2.7	−2.6	−2.3	−2.0	−1.5	−1.0	−0.7	−0.6	−0.7	−1.1	−2.0	−2.7	−2.0	−0.7	−1.2	1.0	−2.7	3.7
E	2.0	2.1	1.9	1.3	0.4	0.2	0.0	−0.3	−0.9	−1.5	−1.6	−1.5	−1.3	−1.0	−0.6	−0.2	0.0	0.2	0.2	0.2	0.2	0.3	0.6	1.5	0.1	2.1	−1.6	3.7
SE	3.0	2.9	2.4	1.5	0.9	0.4	−0.1	−0.5	−0.9	−1.2	−1.4	−1.3	−1.2	−0.9	−0.4	0.0	0.4	0.8	1.0	1.2	1.4	1.7	2.0	2.4	0.6	3.0	−1.4	4.4
S	2.2	2.1	1.5	0.9	0.4	−0.1	−0.6	−1.0	−1.5	−1.8	−1.9	−1.8	−1.7	−1.2	−0.7	−0.3	0.1	0.4	0.6	0.6	0.6	0.7	1.3	1.8	0.0	2.2	−1.9	4.1
SW	0.8	0.6	0.3	−0.2	−0.6	−1.0	−1.4	−1.8	−2.2	−2.4	−2.4	−2.3	−2.1	−1.7	−1.4	−1.0	−0.6	−0.2	0.1	0.2	0.2	0.0	0.0	0.1	−0.8	0.8	−2.4	3.2
W	−0.5	−0.3	−0.4	−0.9	−1.4	−1.8	−2.2	−2.6	−3.0	−3.2	−3.3	−3.3	−2.9	−2.2	−1.6	−1.1	−0.9	−0.8	−0.9	−0.9	−1.0	−1.1	−1.2	−1.0	−1.6	−0.3	−3.3	3.0
NW	−1.6	−1.5	−1.6	−1.8	−2.0	−2.4	−2.7	−3.0	−3.3	−3.4	−3.5	−3.4	−3.0	−2.1	−1.3	−1.0	−1.0	−1.0	−1.1	−1.4	−1.6	−1.9	−2.0	−2.0	−2.1	−1.0	−3.5	2.5
Mean	0.6	0.7	0.4	−0.1	−0.6	−0.9	−1.3	−1.7	−2.1	−2.4	−2.4	−2.4	−2.1	−1.7	−1.2	−0.8	−0.6	−0.4	−0.4	−0.5	−0.7	−0.7	−0.5	0.0	−0.9	0.7	−2.4	3.1

2-kilometer level.

Surface wind direction.	Jan. 1	Jan. 15	Feb. 1	Feb. 15	Mar. 1	Mar. 15	Apr. 1	Apr. 15	May. 1	May. 15	June. 1	June. 15	July. 1	July. 15	Aug. 1	Aug. 15	Sept. 1	Sept. 15	Oct. 1	Oct. 15	Nov. 1	Nov. 15	Dec. 1	Dec. 15	Annual mean.	Extremes. Max.	Extremes. Min.	Range.
N	−1.2	−1.1	−1.6	−2.5	−3.4	−3.9	−4.1	−4.3	−4.4	−4.5	−4.5	−4.5	−4.4	−4.1	−3.7	−3.2	−2.9	−2.6	−2.4	−2.2	−2.2	−2.1	−2.0	−1.8	−3.1	−1.1	−4.5	3.4
NE	1.0	1.8	1.5	0.2	−1.1	−2.0	−2.8	−3.2	−3.6	−4.0	−4.4	−4.8	−4.9	−4.5	−3.7	−2.2	−1.4	−1.0	−0.8	−0.8	−1.0	−1.0	−1.0	−0.2	−1.8	1.8	−4.9	6.7
E	3.0	3.4	3.0	2.0	0.4	−1.0	−2.0	−2.8	−3.5	−4.0	−4.4	−4.6	−4.6	−3.9	−2.5	−1.4	−0.9	−0.3	0.2	0.6	1.0	1.5	2.0	2.5	−0.7	3.4	−4.6	8.0
SE	3.0	2.9	1.9	0.0	−1.5	−2.7	−3.5	−3.9	−4.2	−4.4	−4.4	−4.4	−4.4	−4.0	−3.3	−2.6	−2.0	−1.3	−0.7	−0.1	0.5	1.3	2.0	2.7	−1.4	3.0	−4.4	7.4
S	0.9	0.8	0.3	−1.2	−2.4	−3.2	−3.8	−4.2	−4.6	−4.8	−5.0	−5.1	−5.1	−4.7	−4.2	−3.5	−2.8	−2.2	−1.5	−1.0	−0.5	0.0	0.3	0.6	−2.3	0.9	−5.1	6.0
SW	−0.9	−0.8	−1.3	−2.4	−3.2	−3.9	−4.5	−5.0	−5.3	−5.6	−5.9	−6.0	−5.8	−5.3	−4.6	−4.0	−3.2	−2.6	−2.1	−1.8	−1.8	−2.0	−1.9	−1.5	−3.4	−0.8	−6.0	5.2
W	−1.8	−2.0	−2.6	−3.2	−3.9	−4.6	−5.3	−5.8	−6.5	−7.0	−7.1	−7.0	−6.6	−5.7	−5.0	−4.3	−3.7	−3.3	−3.1	−3.0	−3.0	−3.0	−2.9	−2.4	−4.3	−1.8	−7.1	5.3
NW	−1.8	−2.2	−2.9	−3.7	−4.3	−4.9	−5.3	−5.6	−5.7	−5.7	−5.6	−5.4	−4.8	−4.2	−3.8	−3.6	−3.4	−3.2	−3.1	−3.2	−3.2	−3.1	−2.9	−2.2	−3.9	−1.8	−5.7	3.9
Mean	0.3	0.3	−0.2	−1.3	−2.4	−3.3	−3.9	−4.4	−4.7	−5.0	−5.2	−5.2	−5.1	−4.5	−3.8	−2.7	−2.5	−2.1	−1.7	−1.4	−1.3	−1.1	−0.8	−0.3	−2.6	0.3	−5.2	5.5

COLUMBUS, OHIO.

1-kilometer level.

Surface wind direction.	Jan. 1	Jan. 15	Feb. 1	Feb. 15	Mar. 1	Mar. 15	Apr. 1	Apr. 15	May. 1	May. 15	June. 1	June. 15	July. 1	July. 15	Aug. 1	Aug. 15	Sept. 1	Sept. 15	Oct. 1	Oct. 15	Nov. 1	Nov. 15	Dec. 1	Dec. 15	Annual mean.	Extremes. Max.	Extremes. Min.	Range.
N	−1.8	−1.3	−1.1	−1.4	−1.8	−2.2	−2.4	−2.6	−2.8	−2.9	−2.7	−2.5	−2.3	−2.2	−2.2	−2.2	−2.2	−2.4	−2.7	−3.2	−3.4	−3.1	−2.6	−2.2	−2.3	−1.1	−3.4	2.3
NE	0.8	0.4	0.0	−0.4	−0.7	−0.8	−1.0	−1.4	−2.0	−2.4	−2.6	−2.6	−2.4	−2.0	−1.5	−1.2	−1.0	−1.0	−1.1	−1.5	−2.2	−2.6	−2.3	−1.1	−1.3	0.8	−2.6	3.4
E	1.4	1.5	1.2	0.8	0.4	0.0	−0.4	−0.8	−1.2	−1.6	−1.8	−1.7	−1.4	−1.0	−0.6	−0.4	−0.3	−0.3	−0.2	−0.3	−0.4	−0.5	−0.4	0.6	−0.3	1.5	−1.8	3.3
SE	2.0	2.5	2.3	1.1	0.3	−0.2	−0.6	−1.0	−1.2	−1.4	−1.4	−1.3	−1.2	−1.0	−0.8	−0.5	−0.2	0.1	0.4	0.7	0.9	1.0	1.0	1.4	0.1	2.5	−1.4	3.9
S	1.6	1.5	1.1	0.6	0.0	−0.4	−0.6	−1.0	−1.5	−2.0	−2.0	−1.8	−1.6	−1.2	−0.8	−0.5	−0.2	−0.1	0.0	0.1	0.2	0.4	0.8	1.2	−0.3	1.6	−2.0	3.6
SW	0.4	0.1	−0.2	−0 5	−0.8	−1.2	−1.5	−1.8	−2.1	−2.3	−2.4	−2.4	−2.2	−1.8	−1.4	−1.1	−0.8	−0.5	−0.2	−0.1	−0.1	−0.2	−0.2	−0.1	−1.0	0.4	−2.4	2.8
W	−1.4	−1.0	−1.1	−1.4	−1.8	−2.1	−2.5	−2.8	−3.1	−3.2	−3.1	−2.8	−2.4	−2.1	−1.8	−1.4	−1.1	−0.9	−0.8	−1.0	−1.4	−1.9	−2.1	−1.9	−1.9	−0.8	−3.2	2.4
NW	−2.0	−2.1	−2.1	−2.2	−2.3	−2.4	−2.6	−3.0	−3.4	−3.6	−3.6	−3.6	−3.2	−2.6	−2.0	−1.6	−1.4	−1.4	−1.5	−1.8	−2.1	−2.3	−2.4	−2.4	−2.4	−1.4	−3.6	2.2
Mean	0.1	0.2	0.0	−0.4	−0.8	−1.2	−1.4	−1.8	−2.2	−2.4	−2.5	−2.3	−2.1	−1.7	−1.4	−1.1	−0.9	−0.8	−0.8	−0.9	−1.1	−1.1	−1.0	−0.6	−1.2	0.2	−2.5	2.7

2-kilometer level.

Surface wind direction.	Jan. 1	Jan. 15	Feb. 1	Feb. 15	Mar. 1	Mar. 15	Apr. 1	Apr. 15	May. 1	May. 15	June. 1	June. 15	July. 1	July. 15	Aug. 1	Aug. 15	Sept. 1	Sept. 15	Oct. 1	Oct. 15	Nov. 1	Nov. 15	Dec. 1	Dec. 15	Annual mean.	Extremes. Max.	Extremes. Min.	Range.
N	−1.5	−1.4	−2.0	−2.7	−3.4	−3.9	−4.2	−4.4	−4.7	−4.9	−5.0	−4.9	−4 6	−4.2	−3.8	−3.5	−3.4	−3.3	−3.0	−2.8	−2 7	−2 6	−2 3	−2.0	−3.4	−1.4	−5.0	3.6
NE	0.5	1.0	0.8	0.0	−1 0	−1.9	−2.6	−3.1	−3.4	−4.2	−3.8	−5.0	−5.0	−4.7	−4.2	−3.6	−3.0	−2.2	−1.7	−1.5	−1 5	−1.5	−1.2	−0.6	−2.2	1.0	−5.0	6.0
E	3.0	3.0	2.6	1.6	0.3	−0.9	−1.9	−2.7	−3.5	−4.1	−4.6	−4.8	−4.7	−4.1	−3.0	−2.0	−1.4	−0.9	−0.5	−0.2	0.2	0.5	1.0	1.9	−1.0	3.0	−4.8	7.8
SE	2.4	2.2	1.3	0.0	−1 2	−2.4	−3.2	−3.7	−4.1	−4.4	−4.6	−4.4	−4.2	−3.9	−3.4	−3.0	−2.5	−2.0	−1.3	−0.8	−0.2	0.6	1.4	2.0	−1.6	2.4	−4.6	7.0
S	0.4	0.0	−0.7	−1.6	−2.4	−3.2	−3.8	−4.4	−4.6	−4.8	−5.0	−4.9	−4.8	−4.5	−4.0	−3.5	−2.9	−2.4	−1.8	−1.5	−1.0	−0.7	−0.3	0.0	−2.6	0.4	−5.0	5.4
SW	−1.4	−1.1	−1.5	−2.3	−3.0	−3.7	−4.4	−4.9	−5.3	−5.6	−5.8	−5.9	−5.8	−5.6	−5.0	−4.2	−3.4	−2.9	−2.5	−2.2	−2.0	−2.0	−2.0	−1.7	−3.5	−1.1	−5.9	4.8
W	−2.6	−2.8	−3.3	−3.8	−4.4	−5.0	−5.5	−6.0	−6.5	−6.8	−7.0	−6.8	−6.5	−6.0	−5.4	−4.8	−4.2	−3.7	−3.4	−3.2	−3.1	−3.0	−3.0	−2.8	−4.6	−2.6	−7.0	4.4
NW	−2.5	−2.5	−3.0	−3.7	−4.4	−5.0	−5.4	−5.7	−5.9	−6.0	−6.0	−5.9	−5.4	−4.8	−4.2	−3.8	−3.6	−3.6	−3.5	−3.5	−3.5	−3.5	−3.4	−3.2	−4.3	−2.5	−6.5	4.0
Mean	−0.2	−0.2	−0.7	−1.6	−2.4	−3.2	−3.9	−4.4	−4.7	−5.1	−5.2	−5.3	−5.1	−4.7	−4.1	−3.5	−3.0	−2.6	−2.2	−2.0	−1.7	−1.5	−1.2	−0.8	−2.9	−0.2	−5.2	5.0

PITTSBURGH, PA.

1-kilometer level.

Surface wind direction.	Jan.		Feb.		Mar.		Apr.		May.		June.		July.		Aug.		Sept.		Oct.		Nov.		Dec.		Annual mean.	Extremes.		Range.
	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15		Max.	Min.	
N	−2.0	−1.5	−1.3	−1.4	−1.7	−2.0	−2.3	−2.5	−2.6	−2.6	−2.6	−2.4	−2.4	−2.3	−2.2	−2.2	−2.2	−2.3	−2.4	−2.6	−2.8	−2.7	−2.7	−2.4	−2.3	−1.3	−2.8	1.5
NE	0.0	0.2	0.0	−0.4	−0.6	−0.9	−1.1	−1.3	−1.6	−1.8	−1.9	−2.0	−1.8	−1.6	−1.5	−1.3	−1.2	−1.2	−1.4	−1.8	−2.2	−2.4	−2.3	−1.6	−1.3	0.2	−2.4	2.6
E	0.8	0.8	0.5	0.2	−0.1	−0.4	−0.8	−1.1	−1.3	−1.4	−1.5	−1.4	−1.2	−1.0	−0.9	−0.8	−0.8	−0.9	−0.8	−0.8	−0.9	−1.0	−0.8	0.0	−0.7	0.8	−1.5	2.3
SE	1.5	1.8	1.6	0.8	0.2	−0.4	−0.8	−1.0	−1.2	−1.2	−1.1	−1.0	−0.8	−0.8	−0.8	−0.7	−0.6	−0.4	−0.2	0.1	0.3	0.5	0.8	1.2	−0.1	1.8	−1.2	3.0
S	1.0	1.3	0.9	0.4	0.0	−0.4	−0.6	−0.8	−1.0	−1.1	−1.1	−1.1	−1.1	−1.0	−0.9	−0.8	−0.7	−0.6	−0.4	−0.3	−0.2	0.0	0.3	0.6	−0.3	1.3	−1.1	2.4
SW	−0.2	−0.3	−0.5	−0.6	−0.8	−0.9	−1.0	−1.1	−1.3	−1.4	−1.5	−1.5	−1.5	−1.4	−1.1	−0.8	−0.7	−0.6	−0.6	−0.5	−0.4	−0.4	−0.4	−0.3	−0.8	−0.2	−1.5	1.3
W	−1.8	−1.8	−1.8	−1.8	−1.9	−2.0	−2.2	−2.4	−2.6	−2.6	−2.4	−2.0	−2.0	−2.0	−1.8	−1.4	−1.2	−1.1	−1.2	−1.5	−1.8	−2.1	−2.2	−2.1	−1.9	−1.1	−2.6	1.5
NW	−2.5	−2.5	−2.5	−2.5	−2.5	−2.6	−2.6	−2.8	−3.1	−3.2	−3.0	−2.8	−2.6	−2.4	−2.3	−2.1	−2.0	−1.9	−1.9	−2.1	−2.2	−2.4	−2.6	−2.7	−2.5	−1.9	−3.2	1.3
Mean	−0.4	−0.3	−0.4	−0.7	−0.9	−1.2	−1.4	−1.6	−1.8	−1.9	−1.9	−1.8	−1.7	−1.6	−1.4	−1.3	−1.2	−1.1	−1.1	−1.2	−1.3	−1.3	−1.2	−0.9	−1.2	−0.3	−1.9	1.6

2-kilometer level.

N	−1.1	−1.2	−1.6	−2.0	−2.5	−2.9	−3.5	−3.9	−4.4	−4.8	−5.0	−5.1	−4.9	−4.5	−4.2	−4.0	−4.0	−3.9	−2.5	−3.2	−3.0	−2.9	−2.4	−1.7	−3.3	−1.1	−5.1	4.0
NE	0.5	0.9	0.7	−0.2	−0.8	−1.4	−1.9	−2.3	−2.8	−3.3	−4.0	−4.5	−4.6	−4.4	−3.5	−3.0	−2.6	−2.4	−2.3	−2.2	−2.1	−1.9	−1.5	−0.5	−2.1	0.9	−4.6	5.5
E	2.8	2.8	2.2	1.3	0.3	−0.7	−1.5	−2.2	−2.9	−3.9	−3.8	−4.0	−4.0	−3.6	−3.1	−2.6	−2.2	−1.7	−1.4	−1.1	−1.0	−0.6	0.1	1.4	−1.2	2.8	−4.0	6.8
SE	2.2	2.0	1.0	0.0	−0.9	−1.7	−2.4	−2.9	−3.4	−3.9	−4.0	−3.8	−3.6	−3.3	−3.0	−2.8	−2.6	−2.2	−2.0	−1.5	−1.0	−0.3	0.6	1.5	−1.6	2.2	−4.0	6.2
S	0.2	0.0	−0.5	−1.2	−1.8	−2.3	−2.7	−3.1	−3.4	−3.7	−3.8	−4.0	−4.0	−3.9	−3.7	−3.4	−3.1	−2.7	−2.3	−1.8	−1.4	−1.0	−0.6	−0.1	−2.3	0.2	−4.0	4.2
SW	−1.5	−1.6	−2.0	−2.3	−2.8	−3.2	−3.7	−4.1	−4.4	−4.7	−4.8	−4.9	−5.0	−4.8	−4.6	−4.2	−3.6	−3.2	−2.6	−2.2	−1.8	−1.6	−1.6	−1.5	−3.2	−1.5	−5.0	3.5
W	−3.4	−3.5	−3.7	−4.0	−4.3	−4.6	−4.9	−5.3	−5.6	−5.8	−5.8	−5.9	−6.0	−5.7	−5.4	−4.9	−4.4	−4.0	−3.7	−3.4	−3.2	−2.8	−2.6	−2.8	−4.4	−2.6	−6.0	3.4
NW	−3.4	−3.4	−3.7	−4.0	−4.4	−4.8	−5.2	−5.5	−5.8	−5.9	−5.9	−5.8	−5.5	−5.2	−4.8	−4.4	−4.0	−3.9	−3.8	−3.8	−3.8	−3.9	−3.9	−3.8	−4.5	−3.4	−5.9	2.5
Mean	−0.5	−0.5	−0.9	−1.5	−2.1	−2.7	−3.2	−3.6	−4.1	−4.4	−4.6	−4.7	−4.7	−4.4	−4.0	−3.6	−3.3	−3.0	−2.7	−2.4	−2.2	−1.9	−1.5	−0.9	−2.8	−0.5	−4.7	4.2

BUFFALO, N. Y.

1-kilometer level.

N	−1.6	−1.4	−1.4	−1.4	−1.5	−1.7	−1.9	−2.2	−2.3	−2.4	−2.4	−2.2	−2.0	−2.0	−2.0	−2.0	−2.1	−2.1	−2.1	−2.1	−2.1	−2.1	−2.1	−2.0	−2.0	−1.4	−2.1	0.7
NE	0.0	0.9	0.9	0.2	−0.2	−0.6	−0.8	−1.0	−1.0	−1.1	−1.2	−1.2	−1.1	−1.0	−0.9	−0.8	−0.8	−1.0	−1.2	−1.4	−1.6	−1.7	−1.5	−0.8	−0.8	0.9	−1.7	2.6
E	0.4	0.3	0.2	0.1	0.0	−0.2	−0.6	−1.0	−1.3	−1.4	−1.2	−0.8	−0.5	0.0	0.0	−0.1	−0.5	−0.6	−0.5	−0.5	−0.8	−0.9	−0.8	−0.1	−0.4	0.4	−1.4	1.8
SE	2.1	2.2	1.4	0.5	0.0	−0.2	−0.4	−0.6	−0.7	−0.7	−0.6	−0.4	−0.2	−0.1	0.0	0.0	0.2	0.3	0.4	0.4	0.6	0.8	1.0	1.2	0.3	2.2	−0.7	2.9
S	1.3	1.7	1.4	0.8	0.5	0.2	0.0	−0.2	−0.3	−0.4	−0.5	−0.5	−0.4	−0.4	−0.2	−0.1	−0.1	−0.1	0.0	0.2	0.4	0.6	0.8	1.0	0.2	1.7	−0.5	2.2
SW	−0.2	−0.3	−0.3	−0.4	−0.4	−0.4	−0.4	−0.5	−0.6	−0.6	−0.6	−0.6	−0.5	−0.4	−0.3	−0.2	−0.1	0.0	0.0	0.0	0.0	−0.1	−0.2	−0.2	−0.7	0.0	−0.6	0.6
W	−1.6	−1.6	−1.6	−1.6	−1.5	−1.4	−1.6	−1.9	−2.0	−2.0	−1.7	−1.5	−1.4	−1.3	−1.1	−0.9	−0.6	−0.4	−0.4	−0.6	−1.0	−1.4	−1.6	−1.7	−1.3	−0.4	−2.0	1.6
NW	−2.8	−2.6	−2.3	−2.2	−2.1	−2.1	−2.3	−2.7	−3.1	−3.3	−3.0	−2.4	−2.1	−1.9	−1.8	−1.8	−1.8	−1.8	−1.8	−1.8	−2.0	−2.2	−2.5	−2.8	−2.3	−1.8	−3.3	1.5
Mean	−0.3	−0.1	−0.2	−0.5	−0.6	−0.8	−1.0	−1.3	−1.4	−1.5	−1.4	−1.2	−1.0	−0.9	−0.8	−0.7	−0.7	−0.7	−0.7	−0.7	−0.8	−0.9	−0.9	−0.7	−0.9	−0.1	−1.5	1.4

2-kilometer level.

N	0.0	0.0	−0.5	−1.1	−1.6	−2.1	−2.7	−3.1	−3.6	−4.1	−4.5	−4.5	−4.3	−4.0	−3.8	−3.8	−3.9	−3.9	−3.8	−3.5	−3.0	−2.2	−1.6	−0.8	−2.8	0.0	−4.5	4.5
NE	1.2	2.0	1.8	1.0	0.3	−0.5	−1.4	−1.9	−2.6	−3.0	−3.6	−3.9	−3.9	−3.8	−2.8	−2.0	−1.4	−1.0	−0.8	−1.0	−1.3	−1.4	−1.1	−0.1	−1.3	2.0	−3.9	5.9
E	4.4	4.3	3.5	2.1	0.8	−0.2	−1.0	−1.8	−2.5	−3.0	−3.2	−3.4	−3.2	−2.9	−2.4	−1.8	−0.9	−0.2	0.4	0.7	1.0	1.6	2.6	3.6	−0.1	4.4	−3.4	7.8
SE	3.9	2.9	1.7	0.7	−0.1	−0.8	−1.5	−2.2	−2.8	−3.2	−3.3	−3.2	−3.0	−2.6	−2.2	−1.6	−1.2	−0.6	0.0	0.6	1.4	2.3	3.2	3.8	−0.3	3.9	−3.3	7.2
S	0.8	0.7	0.1	−0.6	−1.1	−1.5	−2.0	−2.3	−2.7	−2.9	−3.1	−3.2	−3.2	−3.1	−2.9	−2.6	−2.4	−2.0	−1.8	−1.4	−1.0	−0.7	−0.3	0.3	−1.6	0.8	−3.2	4.0
SW	−0.7	−0.9	−1.3	−1.7	−2.1	−2.4	−2.8	−3.1	−3.3	−3.6	−3.8	−4.0	−4.2	−4.3	−4.2	−3.9	−3.5	−3.1	−2.5	−2.0	−1.5	−1.1	−0.8	−0.7	−2.6	−0.7	−4.3	3.6
W	−2.6	−3.1	−3.6	−4.0	−4.2	−4.4	−5.7	−4.9	−5.0	−5.1	−5.1	−5.1	−5.1	−5.0	−4.9	−4.6	−4.3	−4.0	−3.7	−3.3	−2.8	−2.2	−2.0	−2.2	−4.0	−2.0	−5.1	3.1
NW	−3.2	−3.2	−3.4	−3.6	−3.8	−4.1	−4.4	−4.7	−5.0	−5.4	−5.6	−5.4	−5.0	−4.6	−4.3	−4.0	−3.8	−3.6	−3.6	−3.6	−3.7	−3.8	−3.9	−3.6	−4.1	−3.2	−5.6	2.4
Mean	0.5	0.3	−0.2	−0.9	−1.5	−2.0	−2.6	−3.0	−3.4	−3.8	−4.0	−4.1	−4.0	−3.8	−3.4	−3.0	−2.7	−2.3	−2.0	−1.7	−1.4	−0.9	−0.5	0.0	−2.1	0.5	−4.1	4.6

PORT HURON, MICH.

1-kilometer level.

N	−1.8	−1.0	−0.9	−1.0	−1.4	−1.9	−2.2	−2.4	−2.6	−2.6	−2.6	−2.5	−2.4	−2.3	−2.2	−2.1	−2.1	−2.2	−2.4	−2.5	−2.6	−2.6	−2.5	−2.2	−2.1	−0.9	−2.6	1.5
NE	0.8	1.2	1.0	0.7	0.2	−0.3	−0.8	−1.2	−1.6	−1.8	−2.0	−1.8	−1.6	−1.4	−1.1	−0.8	−0.7	−0.7	−0.9	−1.5	−2.0	−2.0	−1.6	−0.6	−0.8	1.2	−2.0	3 2
E	1.2	1.0	0.7	0.4	0.1	−0.3	−0.6	−1.0	−1.3	−1.4	−1.4	−1.1	−0.6	−0.1	0.1	0.2	0.1	0.0	−0.1	−0.2	−0.3	−0.2	0.0	0.8	−0.2	1.2	−1.4	2.6
SE	3.0	3.2	2.8	0.5	0.1	0.1	0.0	−0.3	−0.9	−1.3	−1.2	−1.0	−0.4	0.0	0.2	0.4	0.5	1.0	1.3	1.4	1.4	1.5	1.7	2.1	−0.7	3.2	−1.3	4 5
S	2.0	1.9	1.4	1.0	0.5	0.1	−0.2	−0.5	−0.8	−1.0	−1.1	−1.1	−0.9	−0.6	−0.3	0.0	0.3	0.4	0.5	0.6	0.7	0.9	1.1	1.5	0.3	2.0	−1.1	3.1
SW	0.1	0.0	−0.2	−0.2	−0.2	−0.2	−0.4	−0.8	−1.4	−1.8	−1.8	−1.6	−1.1	−0.9	−0.7	−0.5	−0.2	0.0	0.2	0.2	0.1	−0.1	−0.2	−0.1	−0.5	0.1	−1.8	1.9
W	−1.1	−1.0	−0.9	−0.9	−1.0	−1.1	−1.4	−1.8	−2.3	−2.4	−2.2	−2.0	−2.0	−1.8	−1.4	−0.9	−0.6	−0.5	−0.5	−0.6	−0.8	−1.0	−1.3	−1.4	−1.3	−0.5	−2.4	1.9
NW	−2.1	−2.0	−1.9	−1.9	−1.9	−2.1	−2.4	−2.8	−3.6	−3.8	−3.4	−2.8	−2.4	−2.0	−1.6	−1.3	−1.0	−1.0	−1.1	−1.4	−1.8	−2.2	−2.4	−2.4	−2.1	−1.0	−3.8	2.8
Mean	0.3	0.4	0.3	−0.2	−0.4	−0.7	−1.0	−1.3	−1.8	−2.0	−2.0	−1.7	−1.4	−1.1	−0.9	−0.6	−0.5	−0.4	−0.4	−0.6	−0.6	−0.7	−0.6	−0.3	−0.8	0.4	−2.0	2.4

2-kilometer level.

N	−0.4	−0.5	−0.8	−1.7	−2 4	−3.0	−3.5	−3.8	−4.2	−4.4	−4.7	−4.7	−4 6	−3.8	−3.2	−3.1	−3.4	−3.3	−3.0	−2.8	−2.7	−2.5	−1.9	−1.2	−2.9	−0.4	−4.7	4.3
NE	1.4	2.2	2.0	0.8	−0 3	−1.2	−1 9	−2.5	−3 0	−3.6	−4.1	−4.5	−4 8	−4 8	−3.5	−1.7	−0 7	−0.1	0.1	−0.2	−0.6	−1.0	−0.9	−0.2	−1.4	2.2	−4.8	7.0
E	5.0	4.2	3.0	1.8	0.7	−0 3	−1 3	−2.2	−3.0	−3.5	−4 0	−4 2	−4 0	−2 9	−1.7	−0.8	0 0	0.6	1.2	1.6	2.0	2.4	2.8	3.7	0.0	5.0	−4.2	9.2
SE	4.5	3.6	2.1	0.8	−0 2	−1 0	−1 9	−2 7	−3 3	−3.8	−4.0	−3 8	−3 4	−2.7	−1 9	−1 2	−0 6	0.1	0.8	1.5	2.2	3.0	3.7	4.4	−0.1	4.5	−4.0	8.5
S	1.0	0.7	0.0	−0.7	−1 5	−2 1	−2 7	−3 1	−3 5	−3.8	−4 0	−4.0	−3 9	−3 7	−3 2	−2 6	−2 0	−1.6	−1.3	−1.0	−0.8	−0.5	−0.1	0.4	−1.8	1.0	−4.0	5.0
SW	−0.7	−0.8	−1 2	−1.6	−2 1	−2 6	−3 2	−3.8	−4 3	−4.7	−5 0	−5.1	−5 2	−5 0	−4.6	−4.0	−3 4	−2.7	−2.4	−2.1	−1.8	−1.6	−1.3	−1.1	−3.0	−0.7	−5.2	4.5
W	−2.1	−2 6	−3 0	−3 5	−4 0	−4 5	−5 0	−5 4	−5 8	−6 0	−6 2	−6 2	−6 0	−5 8	−5.3	−4.7	−4 2	−3.7	−3.2	−2.9	−2.6	−2.4	−2.2	−2.1	−4.1	−2.1	−6.2	4.1
NW	−2.2	−2 6	−3.1	−3 6	−3.9	−4 1	−4.4	−4.8	−5.1	−5.5	−5.8	−5.7	−5.4	−4.9	−4.4	−4.0	−3.8	−3.6	−3.4	−3.3	−3.3	−3.3	−3.2	−3.0	−4.0	−2.2	−5.8	3.6
Mean	0.8	0.5	−0.1	−1.0	−1.7	−2 4	−3.0	−3.5	−4.0	−4.4	−4.7	−4.8	−4.7	−4.2	−3.5	−2.8	−2.3	−1.8	−1.4	−1.1	−0.9	−0.7	−0.4	0.1	−2.2	0.8	−4.8	5.6

DULUTH, MINN.

1-kilometer level.

Surface wind direction.	Jan.		Feb.		Mar.		Apr.		May.		June.		July.		Aug.		Sept.		Oct.		Nov.		Dec.		Annual mean.	Extremes.		Range.
	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15		Max.	Min.	
N	0.4	0.5	0.3	0.0	−0.2	−0.5	−0.8	−1.0	−1.2	−1.2	−1.1	−1.0	−0.6	−0.3	−0.3	−0.4	−0.4	−0.4	−0.5	−0.6	−0.7	−0.6	−0.4	−0.1	−0.5	0.5	−1.2	1.7
NE	2.1	2.8	2.6	1.9	1.2	0.5	−0.1	−0.5	−0.8	−1.0	−1.0	−0.9	−0.5	0.0	0.3	0.6	0.9	1.0	0.8	0.2	0.0	0.3	0.8	1.5	0.5	2.8	−1.0	3.8
E	1.4	1.1	0.7	0.3	−0.1	−0.5	−0.8	−1.0	−1.2	−1.2	−0.9	−0.3	0.4	0.9	1.1	1.2	1.2	1.2	1.3	1.2	1.2	1.2	1.5	1.6	0.5	1.6	−1.2	2.8
SE	3.3	3.2	2.1	0.0	0.2	0.4	0.5	0.3	−0.1	−0.8	−0.5	−0.1	0.4	1.0	1.5	2.0	2.4	2.7	2.8	2.8	2.9	3.0	3.2	3.3	1.5	3.3	−0.8	4.1
S	4.5	4.6	4.5	4.3	3.8	2.8	1.7	1.0	0.6	0.4	0.4	0.5	0.8	1.1	1.5	1.9	2.3	2.8	3.2	3.7	4.2	4.6	4.8	4.8	2.7	4.8	0.4	4.4
SW	3.6	3.9	4.2	4.1	3.5	2.8	1.6	0.9	0.4	0.0	0.1	0.4	0.9	1.4	1.7	2.0	2.5	3 0	3.4	3.6	3.4	3 3	3 3	3.4	2.4	4.2	0 0	4.2
W	1.5	1.3	1.4	1.6	1.4	0.7	0.0	−0.5	−0.8	−0.8	−0.4	0.2	0.6	1.1	1.5	1.8	2.1	2.3	2.4	2.4	2.4	2.2	2.0	1.8	1.2	2.4	−0.8	3.2
NW	−1.2	−1.0	−0.8	−0.7	−0.8	−1.0	−1.4	−1.9	−2.3	−2.5	−2.2	−1.3	−0.5	0.0	0.3	0.6	0.8	0.9	0.8	0.6	0.1	−0.5	−1.0	−1.2	−0.7	0.9	−2.5	3.4
Mean	1.9	2.0	1.9	1.4	1.1	0.7	0.1	−0.3	−0.7	−0.9	−0.7	−0.3	0.2	0.6	0.9	1.2	1.5	1.7	1.8	1.7	1.7	1.7	1.8	1.9	1.0	2.0	−0.9	2.8

2-kilometer level.

Surface wind direction.	Jan. 1	Jan. 15	Feb. 1	Feb. 15	Mar. 1	Mar. 15	Apr. 1	Apr. 15	May 1	May 15	June 1	June 15	July 1	July 15	Aug. 1	Aug. 15	Sept. 1	Sept. 15	Oct. 1	Oct. 15	Nov. 1	Nov. 15	Dec. 1	Dec. 15	Annual mean.	Extremes. Max.	Extremes. Min.	Range.
N	2.3	2.1	1.6	1.0	0.0	−1.0	−2.0	−2.9	−3.1	−3.2	−3.3	−3.2	−3.0	−2.8	−2.4	−2.0	−1.6	−1.1	−0.6	0.0	0.5	1.1	1.7	2.1	−0.8	2.3	−3.3	5.6
NE	4.6	4.2	3.6	2.8	2.0	1.0	−0.2	−1.8	−2.9	−3.3	−3.3	−3.0	−2.4	−1.7	−1.0	−0.4	0.4	1.0	1.6	2.1	2.6	3.1	3.6	4.0	0.7	4.6	−3.3	7.9
E	6.6	6.1	4.9	5	2.1	0.9	−0.2	−1.3	−2.5	−3.4	−3.8	−3.6	−3.0	−2.2	−1.2	−0.2	0.8	2.0	3.0	4.0	5.0	5.4	6.1	6.5	1.5	6.6	−3.8	10.4
SE	7.3	7.0	5.9	4.4	3.0	1.7	0.5	−0.5	−1.5	−2.2	−2.6	−2.6	−2.0	−1.2	−0.5	0.4	1.3	2.2	3.3	4.4	5.3	6.2	6.8	7.2	2.2	7.3	−2.6	9.9
S	5.9	6.2	6.0	5.0	4.5	2.0	0.8	−0.2	−1.0	−1.6	−1.8	−1.6	−1.2	−0.7	−0.2	0.4	1.0	1.6	2.2	2.9	3.6	4.4	5.0	5.6	2.0	6.2	−1.8	8.0
SW	3.4	2.1	1.6	1.6	1.5	1.0	0.1	−1.0	−2.1	−2.8	−3.2	−3.1	−3.0	−2.6	−2.1	−1.4	−0.5	0.4	1.3	2.0	2.8	3.3	3.7	3.8	0.3	3.8	−3.2	7.0
W	1.9	1.3	0.6	0.1	−0.4	−1.0	−1.8	−2.7	−3.6	−4.2	−4.7	−4.6	−4.3	−3.8	−3.0	−2.5	−2.2	−2.0	−1.6	−1.0	−0.1	1.3	2.2	2.5	−1.3	2.5	−4.7	7.2
NW	1.8	1.3	0.3	−0.7	−1.1	−1.2	−1.6	−2.5	−3.6	−4.0	−4.2	−4.1	−3.8	−3.3	−2.8	−2.4	−2.2	−2.0	−1.8	−1.4	−0.6	0.4	1.2	1.8	−1.5	4.2	−3.4	7.6
Mean	4.2	3.8	3.1	2.2	1.4	0.4	−0.5	−1.6	−2.5	−3.1	−3.4	−3.2	−2.8	−2.3	−1.6	−1.0	−0.4	0.3	0.9	1.6	2.4	3.1	3.8	4.2	1.1	4.2	−3.4	7.6

MOORHEAD, MINN.

1-kilometer level.

Surface wind direction.	Jan. 1	Jan. 15	Feb. 1	Feb. 15	Mar. 1	Mar. 15	Apr. 1	Apr. 15	May 1	May 15	June 1	June 15	July 1	July 15	Aug. 1	Aug. 15	Sept. 1	Sept. 15	Oct. 1	Oct. 15	Nov. 1	Nov. 15	Dec. 1	Dec. 15	Annual mean.	Extremes. Max.	Extremes. Min.	Range.
N	1.2	1.1	0.9	0.7	0.4	0.0	−0.3	−0.4	−0.5	−0.4	−0.2	0.0	0.2	0.3	0.4	0.4	0.4	0.3	0.2	0.2	0.2	0.2	0.3	0.8	0.3	1.2	−0.5	1.7
NE	3.5	3.8	3.4	2.8	2.1	1.2	0.4	−0.3	−0.7	−0.8	−0.6	−0.2	0.0	0.5	0.9	1.1	1.2	1.4	1.3	1.2	1.0	1.1	1.8	2.7	1.2	3.8	−0.8	4.6
E	2.0	1.4	0.9	0.5	0.2	−0.1	−0.5	−1.1	−1.3	−1.2	−0.9	−0.1	0.6	1.3	1.6	1.8	1.8	1.8	1.9	1.9	2.0	2.2	2.3	2.3	0.9	2.3	−1.3	3.6
SE	3.4	2.8	1.8	0.7	0.3	0.5	0.8	0.7	0.0	−0.4	−0.2	0.2	0.7	1.2	1.6	2.0	2.4	2.9	3.4	3.8	4.0	4.2	4.2	3.9	1.7	4.2	−0.4	4.6
S	5.4	5.3	6.2	6.6	5.8	4.0	2.8	1.8	1.3	1.0	1.0	1.2	1.6	2.0	2.3	2.8	3.3	4.0	4.7	5.5	6.2	6.5	6.5	6.2	3.9	6.6	1.0	5.6
SW	5.2	5.3	5.5	5.5	5.0	3.6	2.2	1.5	1.2	1.0	1.1	1.4	1.7	2.2	2.6	3.0	3.5	4.0	4.6	4.8	5.0	5.1	5.2	5.2	3.6	5.5	1.0	4.5
W	2.5	2.5	2.6	2.6	2.5	1.6	0.7	0.0	−0.4	−0.3	0.3	1.0	1.5	1.8	2.1	2.4	2.7	3.1	3.4	3.5	3.4	3.1	2.9	2.6	2.0	3.5	−0.4	3.9
NW	0.0	0.0	0.0	0.1	0.1	−0.2	−0.9	−1.4	−1.6	−1.2	−0.6	0.0	0.4	0.8	1.0	1.2	1.3	1.3	1.3	1.0	0.7	0.4	0.2	0.0	0.1	1.3	−1.6	2.9
Mean	2.9	2.8	2.7	2.4	2.0	1.3	0.6	0.1	−0.3	−0.3	0.0	0.4	0.8	1.3	1.6	1.8	2.1	2.4	2.6	2.7	2.8	2.9	2.9	3.0	1.8	3.0	−0.3	3.3

2-kilometer level.

Surface wind direction.	Jan. 1	Jan. 15	Feb. 1	Feb. 15	Mar. 1	Mar. 15	Apr. 1	Apr. 15	May 1	May 15	June 1	June 15	July 1	July 15	Aug. 1	Aug. 15	Sept. 1	Sept. 15	Oct. 1	Oct. 15	Nov. 1	Nov. 15	Dec. 1	Dec. 15	Annual mean.	Extremes. Max.	Extremes. Min.	Range.
N	3.9	3.5	3.0	2.5	1.8	1.0	0.0	−1.1	−2.3	−2.9	−2.9	−2.6	−2.2	−1.8	−1.6	−1.7	−1.6	−1.3	−0.5	0.6	1.8	2.8	2.5	4.0	0.2	4.0	−2.9	6.9
NE	5.4	5.3	5.1	4.6	3.5	2.3	0.6	−1.3	−2.8	−3.2	−3.1	−2.7	−1.8	−1.0	−0.5	0.0	0.5	1.2	2.1	3.0	4.0	4.9	5.3	5.6	1.5	5.6	−3.2	8.8
E	6.8	6.3	5.3	4.3	3.2	2.0	0.8	−0.6	−2.2	−3.4	−3.5	−3.2	−2.5	−1.2	−0.6	0.0	0.7	1.7	3.0	4.4	5.6	6.5	7.0	7.1	2.0	7.1	−3.5	10.6
SE	7.6	7.3	6.7	5.9	4.6	3.3	2.0	0.6	−0.6	−1.8	−2.1	−1.9	−1.4	−0.8	0.0	1.0	2.0	3.0	4.0	5.0	5.9	6.6	7.2	7.6	3.0	7.6	−2.1	9.7
S	8.0	7.8	8.5	8.7	7.4	5.0	3.0	1.1	−0.4	−1.4	−1.4	−1.0	−0.4	0.4	1.0	1.6	2.1	2.8	4.0	5.4	6.4	7.3	8.2	8.5	3.9	8.5	−1.4	9.9
SW	4.5	3.4	3.0	2.8	2.8	2.4	1.4	0.0	−1.4	−2.0	−2.2	−2.0	−1.7	−1.3	−0.8	−0.2	0.5	1.4	2.6	3.9	5.2	6.0	6.1	5.5	1.6	6.0	−2.2	8.3
W	3.3	2.4	1.8	1.3	0.8	0.4	−0.3	−1.6	−2.9	−3.4	−3.4	−3.3	−3.1	−2.8	−2.3	−1.7	−1.4	−1.0	−0.5	0.4	1.9	3.2	4.0	4.1	−0.2	4.1	−3.4	7.5
NW	2.7	2.3	1.6	1.0	0.4	0.0	−0.6	−1.7	−3.0	−3.4	−3.4	−3.3	−3.1	−2.8	−2.4	−2.0	−1.6	−1.2	−0.7	−0.1	0.6	1.6	2.6	3.2	−0.6	3.2	−3.4	6.6
Mean	5.3	4.8	4.4	3.9	3.1	2.0	1.0	−0.6	−2.0	−2.7	−2.7	−2.5	−2.0	−1.4	−0.9	−0.4	0.2	0.8	1.7	2.8	3.9	4.9	5.5	5.7	1.5	5.7	−2.7	8.4

MADISON, WIS.

1-kilometer level.

Surface wind direction.	Jan. 1	Jan. 15	Feb. 1	Feb. 15	Mar. 1	Mar. 15	Apr. 1	Apr. 15	May 1	May 15	June 1	June 15	July 1	July 15	Aug. 1	Aug. 15	Sept. 1	Sept. 15	Oct. 1	Oct. 15	Nov. 1	Nov. 15	Dec. 1	Dec. 15	Annual mean.	Extremes. Max.	Extremes. Min.	Range.
N	−1.0	−0.3	−0.5	−0.9	−1.3	−1.7	−2.0	−2.1	−2.0	−2.0	−1.9	−1.8	−1.6	−1.5	−1.5	−1.4	−1.5	−1.6	−1.8	−2.0	−2.2	−2.1	−1.9	−1.6	−1.6	−0.3	−2.2	1.8
NE	1.4	2.0	1.6	1.2	0.6	0.0	−0.4	−1.0	−1.5	−1.8	−2.0	−1.7	−1.4	−0.9	−0.6	−0.1	0.2	0.3	0.0	−0.7	−1.5	−1.8	−1.2	−0.1	−0.4	2.0	−2.0	4.0
E	2.4	2.2	1.8	1.2	0.6	0.1	−0.4	−0.9	−1.3	−1.4	−1.1	−0.6	−0.2	0.2	0.5	0.7	0.8	0.9	0.9	0.8	0.8	1.1	1.8	2.2	0.5	2.4	−1.4	3.8
SE	3.5	3.3	2.6	1.8	1.2	0.6	0.0	−0.5	−0.9	−1.2	−1.0	−0.7	−0.2	0.4	0.8	1.2	1.5	1.8	1.9	1.9	2.0	2.3	2.9	3.3	1.2	3.5	−1.2	4.7
S	3.0	2.9	2.7	2.4	1.8	1.2	0.6	0.0	−0.4	−0.8	−0.9	−0.8	−0.5	0.0	0.4	0.9	1.3	1.6	1.9	2.2	2.5	2.8	2.9	3.0	1.3	3.0	−0.9	3.9
SW	2.4	2.2	1.9	1.6	1.3	0.9	0.4	−0.3	−0.8	−1.0	−1.0	−1.0	−0.7	−0.3	0.1	0.6	1.0	1.5	1.9	2.0	1.6	1.8	2.4	2.6	0.9	2.6	−1.0	3.6
W	0.8	0.8	0.6	0.4	0.0	−0.4	−0.8	−1.2	−1.4	−1.5	−1.4	−1.2	−0.9	−0.5	−0.2	0.2	0.5	0.8	1.1	1.4	1.4	0.8	0.4	1.0	0.0	1.4	−1.5	2.9
NW	−1.0	−0.8	−0.8	−0.9	−1.2	−1.4	−1.8	−2.2	−2.6	−3.0	−2.9	−2.2	−1.5	−1.0	−0.6	−0.4	−0.3	−0.2	−0.3	−0.6	−1.0	−1.3	−1.4	−1.0	−1.3	−0.2	−3.0	2.8
Mean	1.4	1.5	1.2	0.8	0.4	−0.1	−0.5	−1.0	−1.4	−1.6	−1.5	−1.2	−0.9	−0.4	−0.1	0.2	0.4	0.6	0.7	0.6	0.4	0.4	0.7	1.2	0.1	1.5	−1.6	3.1

2-kilometer level.

Surface wind direction.	Jan. 1	Jan. 15	Feb. 1	Feb. 15	Mar. 1	Mar. 15	Apr. 1	Apr. 15	May 1	May 15	June 1	June 15	July 1	July 15	Aug. 1	Aug. 15	Sept. 1	Sept. 15	Oct. 1	Oct. 15	Nov. 1	Nov. 15	Dec. 1	Dec. 15	Annual mean.	Extremes. Max.	Extremes. Min.	Range.
N	0.5	0.4	0.2	−0.4	−1.3	−2.4	−3.2	−3.6	−3.8	−3.9	−3.9	−3.8	−3.6	−3.2	−3.0	−2.6	−2.2	−2.0	−1.7	−1.4	−1.2	−1.0	−0.6	0.0	−2.0	0.5	−3.0	4.4
NE	2.5	3.1	2.9	1.8	0.5	−0.5	−1.2	−2.4	−3.2	−3.8	−4.0	−4.0	−3.7	−3.0	−2.2	−1.2	−0.3	0.0	0.0	0.1	0.4	0.6	1.2	1.9	−1.8	3.1	−4.0	7.1
E	5.2	5.1	4.3	3.0	1.6	0.3	−1.0	−2.2	−3.1	−3.7	−4.0	−3.8	−3.4	−2.7	−2.0	−1.0	0.0	0.7	1.5	2.2	2.9	3.6	4.2	4.7	0.5	5.2	−4.0	9.2
SE	5.6	5.0	3.8	2.4	1.0	−0.4	−1.5	−2.3	−2.9	−3.3	−3.4	−3.4	−2.8	−2.1	−1.3	−0.5	0.2	0.3	0.6	1.9	3.0	4.2	5.1	5.6	0.6	5.6	−3.4	9.0
S	3.8	3.7	2.5	1.3	0.2	−0.8	−1.5	−2.5	−3.0	−3.4	−3.4	−3.4	−3.2	−2.8	−2.4	−1.8	−1.1	−0.4	0.3	0.8	1.0	1.2	2.0	3.0	−0.4	3.8	−3.4	7.2
SW	1.7	1.4	0.9	0.2	−0.6	−1.3	−2.0	−2.7	−3.3	−3.8	−4.1	−4.3	−4.2	−3.8	−3.0	−2.4	−1.6	−0.8	−0.3	0.2	0.6	0.9	1.2	1.4	−1.2	1.7	−4.3	6.0
W	0.0	−0.4	−0.9	−1.4	−2.0	−2.7	−3.3	−4.0	−4.8	−5.4	−5.6	−5.6	−5.0	−4.3	−3.8	−3.2	−2.8	−2.5	−2.3	−2.2	−2.0	−1.0	0.0	0.3	−2.7	0.3	−5.6	5.9
NW	0.0	−0.3	−1.0	−2.1	−2.8	−3.2	−3.6	−4.0	−4.3	−4.5	−4.5	−4.3	−4.0	−3.6	−3.2	−3.0	−2.9	−2.9	−2.8	−2.5	−2.0	−1.5	−0.9	−0.4	−2.7	0.0	−4.5	4.5
Mean	2.4	2.2	1.6	0.6	−0.4	−1.4	−2.2	−3.0	−3.5	−4.0	−4.1	−4.1	−3.7	−3.2	−2.6	−2.0	−1.3	−1.0	−0.6	−0.1	0.3	0.9	1.6	2.1	−1.1	2.4	−4.1	6.5

DES MOINES, IOWA.

1-kilometer level.

Surface wind direction.	Jan.		Feb.		Mar.		Apr.		May.		June.		July.		Aug.		Sept.		Oct.		Nov.		Dec.		Annual mean.	Extremes.		Range.
	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15		Max.	Min.	
N	−0.8	−0.5	−0.6	−0.8	−1.0	−1.4	−1.6	−1.7	−1.8	−1.6	−1.4	−1.1	−1.0	−0.9	−0.8	−0.8	−1.0	−1.2	−1.6	−1.8	−1.8	−1.8	−1.7	−1.3	−1.2	−0.5	−1.8	1.3
NE	0.5	1.0	1.0	0.8	0.4	−0.2	−0.8	−1.2	−1.6	−1.8	−1.7	−1.3	−1.0	−0.6	−0.2	0.1	0.3	0.4	0.4	0.2	−0.3	−0.8	−0.8	−0.4	−0.3	1.0	−1.8	2.8
E	3.4	3.3	2.6	1.8	1.2	0.5	−0.1	−0.6	−1.0	−1.0	−0.9	−0.6	−0.2	0.1	0.4	0.7	0.9	1.0	1.2	1.6	2.0	2.5	3.0	3.2	1.0	3.4	−1.0	4.4
SE	3.4	3.2	2.8	2.2	1.6	0.9	0.3	−0.3	−0.7	−0.8	−0.7	−0.5	−0.1	0.3	0.7	1.0	1.4	1.8	2.1	2.3	2.6	3.1	3.6	4.0	1.4	4.0	−0.8	4.8
S	3.2	3.0	3.0	2.6	2.0	1.2	0.6	0.2	−0.2	−0.4	−0.4	−0.4	−0.1	0.2	0.6	1.0	1.4	1.8	2.2	2.7	3.2	3.7	4.0	4.0	1.7	4.0	−0.4	4.4
SW	3.6	3.5	3.3	2.9	2.4	1.8	1.2	0.6	0.2	0.0	−0.2	−0.2	0.0	0.2	0.5	1.0	1.4	1.8	2.0	2.3	2.5	3.0	3.6	3.9	1.8	3.9	−0.2	4.1
W	2.2	2.0	1.7	1.2	0.8	0.3	−0.1	−0.2	−0.4	−0.4	−0.4	−0.3	−0.2	0.0	0.2	0.4	0.8	1.2	1.6	2.2	2.6	2.5	2.2	2.2	0.9	2.6	−0.4	3.0
NW	0.2	0.1	−0.3	−0.7	−1.0	−1.2	−1.3	−1.3	−1.4	−1.3	−1.1	−0.8	−0.4	−0.1	0.0	0.0	0.0	0.0	−0.2	−0.3	−0.4	−0.4	−0.1	0.1	−0.5	0.2	−1.4	1.6
Mean	2.0	1.9	1.7	1.2	0.8	0.2	−0.2	−0.6	−0.9	−0.9	−0.8	−0.7	−0.4	−0.1	0.2	0.4	0.6	0.8	1.0	1.1	1.3	1.5	1.7	2.1	0.6	2.1	−0.9	3.0

2-kilometer level.

N	1.0	1.2	1.0	0.4	−0.5	−1.9	−2.7	−3.2	−3.5	−3.6	−3.5	−3.6	−3.5	−3.4	−3.2	−2.8	−2.2	−1.8	−1.3	−0.9	−0.6	−0.2	0.3	0.7	−1.6	1.2	−3.6	4.8
NE	2.8	3.1	2.9	2.0	1.1	0.1	−0.9	−1.8	−2.5	−2.9	−3.1	−3.2	−3.1	−3.0	−2.5	−1.7	−1.7	−1.3	−1.0	−0.3	1.4	1.2	1.9	2.5	−0.5	3.1	−3.2	6.3
E	4.5	5.0	4.5	3.6	2.5	1.4	0.1	−1.1	−2.1	−2.7	−2.9	−2.9	−2.7	−2.4	−1.9	−1.3	−0.6	0.1	1.0	1.6	2.4	3.1	3.8	4.2	0.7	5.0	−2.9	7.9
SE	5.9	5.3	4.2	2.8	1.3	0.0	−1.1	−2.0	−2.5	−2.7	−2.8	−2.6	−2.4	−2.0	−1.6	−1.1	−0.4	0.3	1.0	1.7	2.6	3.5	4.5	5.3	0.7	5.9	−2.8	8.7
S	5.1	4.7	3.6	2.2	1.0	0.0	−0.7	−1.3	−1.8	−2.3	−2.5	−2.7	−2.8	−2.6	−2.0	−1.4	−0.8	0.0	0.6	1.2	2.0	2.9	3.7	4.6	0.4	5.1	−2.8	7.9
SW	4.1	3.4	2.6	2.0	1.0	0.1	−0.5	−1.1	−1.6	−2.0	−2.3	−2.3	−2.2	−1.9	−1.4	−0.9	−0.3	0.2	0.6	1.3	2.1	3.3	4.2	4.6	0.5	4.6	−2.3	6.9
W	1.5	1.3	0.9	0.0	−0.7	−1.4	−2.0	−2.4	−2.7	−2.9	−3.0	−3.0	−2.8	−2.6	−2.4	−2.1	−1.7	−1.4	−1.0	−0.4	0.2	0.9	1.2	1.5	−1.0	1.5	−3.0	4.5
NW	0.8	0.6	0.0	−0.9	−1.7	−2.5	−3.0	−3.4	−3.6	−3.5	−3.4	−3.3	−3.2	−3.0	−2.8	−2.5	−2.3	−2.2	−2.2	−2.0	−1.6	−1.2	−0.5	0.1	−2.0	0.8	−3.6	4.4
Mean	3.2	3.1	2.5	1.5	0.5	−0.5	−1.4	−2.0	−2.5	−2.8	−3.3	−3.3	−2.8	−2.6	−2.2	−1.8	−1.3	−0.8	−0.3	0.3	0.9	1.7	2.4	2.9	−0.3	3.2	−3.3	6.5

ST. LOUIS, MO.

1-kilometer level.

N	−1.4	−1.1	−1.1	−1.3	−1.6	−1.9	−2.0	−2.1	−2.0	−2.0	−1.9	−1.9	−1.8	−1.7	−1.6	−1.6	−1.6	−1.7	−1.8	−2.3	−2.6	−2.4	−2.0	−1.6	−1.8	−1.1	−2.6	1.5
NE	0.4	0.2	0.0	−0.2	−0.5	−0.8	−1.1	−1.4	−1.8	−2.0	−2.3	−2.4	−2.4	−2.0	−1.4	−1.0	−0.5	−0.2	0.0	−0.2	−0.5	−0.6	−0.4	0.0	−0.9	0.4	−2.4	2.8
E	2.0	2.0	1.6	1.2	0.8	0.4	0.0	−0.3	−0.6	−1.0	−1.1	−1.2	−1.3	−1.2	−0.8	−0.4	0.1	0.5	0.8	0.9	0.8	0.8	1.0	1.4	0.3	2.0	−1.3	3.3
SE	2.8	2.7	2.3	1.7	1.0	0.4	−0.1	−0.6	−1.0	−1.2	−1.4	−1.4	−1.3	−1.0	−0.5	0.0	0.4	0.8	1.1	1.2	1.4	1.8	2.2	2.6	0.6	2.8	−1.4	4.2
S	2.6	2.4	1.9	1.3	0.7	0.0	−0.4	−0.9	−1.2	−1.5	−1.6	−1.7	−1.5	−1.0	−0.6	−0.2	0.2	0.5	0.6	0.8	1.0	1.5	2.0	2.3	0.3	2.6	−1.7	4.3
SW	2.0	1.7	1.2	0.4	−0.2	−0.7	−1.3	−1.6	−1.8	−2.0	−2.0	−1.9	−1.8	−1.4	−1.1	−0.7	−0.4	0.0	0.4	0.6	0.9	1.2	1.4	1.7	−0.2	2.0	−2.0	4.0
W	1.2	0.7	0.0	−0.6	−1.2	−1.6	−1.9	−2.2	−2.4	−2.4	−2.4	−2.3	−2.0	−1.6	−1.3	−1.0	−0.9	−0.8	−0.7	−0.6	−0.6	−0.6	−0.4	0.2	−1.1	1.2	−2.4	3.6
NW	−0.8	−0.8	−1.0	−1.3	−1.6	−2.0	−2.2	−2.4	−2.4	−2.4	−2.2	−2.0	−1.7	−1.3	−1.0	−0.8	−0.8	−0.8	−0.8	−1.0	−1.4	−1.6	−1.7	−1.4	−1.5	−0.8	2.4	3.2
Mean	1.1	1.0	0.6	0.1	−0.3	−0.8	−1.1	−1.4	−1.6	−1.8	−1.9	−1.9	−1.7	−1.4	−1.0	−0.7	−0.4	−0.2	−0.1	−0.1	−0.1	0.0	0.3	0.6	−0.5	1.1	−1.9	3.0

2-kilometer level.

N	−0.4	−0.8	−1.2	−1.8	−2.4	−2.9	−3.3	−3.6	−3.8	−3.9	−4.0	−3.9	−3.8	−3.7	−3.5	−3.2	−2.8	−2.3	−1.9	−1.5	−1.2	−1.0	−0.8	−0.5	−2.4	−0.4	−4.0	3.6
NE	1.4	1.3	0.6	−0.3	−1.0	−1.8	−2.4	−2.8	−3.2	−3.5	−3.8	−4.0	−4.1	−4.0	−3.6	−3.2	−2.6	−2.0	−1.5	−0.9	−0.4	0.1	0.6	1.0	−1.7	1.4	−4.1	5.5
E	3.0	3.0	2.7	2.0	0.9	−0.5	−1.5	−2.3	−3.0	−3.3	−3.6	−3.7	−3.6	−3.3	−2.8	−2.0	−1.2	−0.6	0.0	0.7	1.2	1.8	2.2	2.5	−0.5	3.0	−3.7	6.7
SE	3.2	2.7	2.0	0.9	−0.2	−1.4	−2.3	−3.0	−3.4	−3.7	−4.0	−4.1	−4.0	−3.7	−3.2	−2.8	−2.1	−1.5	−0.8	−0.1	0.7	1.6	2.4	3.3	−1.0	3.3	−4.1	7.4
S	2.9	2.8	1.0	−0.3	−1.4	−2.0	−2.7	−3.2	−3.6	−4.0	−4.2	−4.3	−4.4	−4.1	−3.6	−3.0	−2.3	−1.7	−1.1	−0.6	−0.2	0.2	0.7	1.2	−1.6	2.9	−4.4	7.3
SW	0.6	0.6	0.4	−0.4	−1.8	−2.6	−3.2	−3.6	−4.0	−4.4	−4.5	−4.5	−4.3	−4.1	−3.7	−3.2	−2.8	−2.3	−1.8	−1.3	−0.9	−0.5	−0.1	0.2	−2.2	0.6	−4.5	5.1
W	−0.6	−0.6	−1.1	−1.7	−2.5	−3.3	−4.0	−4.5	−4.8	−4.9	−4.8	−4.6	−4.3	−3.9	−3.4	−2.8	−2.4	−2.1	−1.8	−1.4	−1.1	−0.9	−0.8	−0.7	−2.6	−0.6	−4.9	4.3
NW	−1.0	−0.4	−0.7	−2.3	−3.5	−4.5	−4.9	−5.0	−4.8	−4.6	−4.3	−4.0	−3.8	−3.6	−3.4	−3.2	−3.1	−3.0	−2.9	−2.8	−2.8	−2.6	−2.2	−1.7	−3.1	−0.4	−5.0	4.6
Mean	1.1	1.1	0.5	−0.5	−1.5	−2.4	−3.0	−3.8	−3.8	−4.0	−4.1	−4.1	−4.0	−3.8	−3.4	−2.9	−2.8	−2.0	−1.5	−1.2	−0.6	−0.2	0.2	0.7	1.9	1.1	−4.1	5.2

YANKTON, S. DAK.

1-kilometer level.

N	1.6	1.4	1.2	0.0	−0.2	−0.5	−0.7	−0.9	−0.9	−0.8	−0.6	−0.3	0.0	0.2	0.2	0.0	−0.2	−0.5	−0.7	−0.9	−1.0	−0.9	−0.7	−0.1	−0.2	1.6	−1.0	2.6
NE	1.5	1.9	1.9	1.5	1.0	0.2	−0.2	−0.8	−1.2	−1.4	−1.2	−0.8	−0.2	0.3	0.7	0.9	1.0	1.1	1.0	0.8	0.4	0.2	0.4	1.0	0.4	1.9	−1.4	3.3
E	3.4	3.0	2.6	1.9	1.0	0.2	−0.3	−0.7	−0.9	−0.9	−0.7	−0.2	0.5	1.0	1.4	1.5	1.3	1.4	1.9	2.6	3.2	3.6	3.9	3.9	1.4	3.9	−0.9	4.8
SE	4.0	3.2	2.4	1.8	1.0	0.6	0.2	−0.2	−0.4	−0.4	−0.2	0.2	0.7	1.2	1.5	1.6	1.6	2.2	2.8	3.4	4.0	4.5	5.0	4.9	1.8	5.0	−0.4	5.4
S	4.2	4.0	4.3	4.5	3.6	2.6	1.9	1.4	1.0	0.6	0.5	0.7	1.0	1.3	1.8	2.3	2.6	3.1	3.6	4.0	4.6	5.1	5.4	5.3	2.8	5.4	0.5	4.9
SW	4.5	4.6	4.9	4.5	4.0	3.2	2.7	2.0	1.6	1.3	1.1	1.2	1.3	1.5	1.8	2.2	2.5	3.0	3.5	4.0	4.7	5.4	5.8	5.6	3.2	5.8	1.1	4.7
W	3.3	2.9	2.5	2.2	1.8	1.5	1.2	1.0	0.8	0.8	0.8	0.8	0.9	1.1	1.3	1.6	2.0	2.4	2.8	3.2	3.6	4.0	4.0	3.8	2.1	4.0	0.8	3.2
NW	1.0	0.8	0.4	0.1	−0.2	−0.3	−0.5	−0.6	−0.6	−0.4	0.0	0.3	0.5	0.6	0.7	0.8	0.8	0.8	0.8	0.8	0.9	0.9	1.0	1.0	0.4	1.0	−0.6	1.6
Mean	2.9	2.7	2.5	2.1	1.5	0.9	0.5	0.1	−0.1	−0.1	0.0	0.2	0.6	0.9	1.2	1.4	1.4	1.7	1.9	2.2	2.5	2.8	3.1	3.2	1.5	3.2	−0.1	3.3

2-kilometer level.

N	2.4	2.2	1.8	1.3	0.4	−0.9	−1.7	−2.3	−2.7	−3.0	−3.0	−3.0	−3.0	−2.8	−2.6	−2.3	−1.8	−1.5	−1.2	−0.7	−0.2	0.5	1.3	2.0	−0.8	2.4	−3.0	5.4
NE	4.0	4.0	3.0	2.2	1.3	0.2	−1.1	−2.2	−2.8	−2.7	−2.6	−2.2	−2.2	−1.8	−1.4	−1.1	−1.0	−0.5	0.0	0.8	1.6	2.4	3.4	3.9	0.2	4.0	−2.8	6.8
E	5.5	5.4	5.0	4.2	3.3	2.2	1.0	−0.4	−1.6	−2.1	−2.2	−2.1	−1.8	−1.4	−1.0	−0.6	0.0	0.6	1.5	2.4	3.5	4.4	5.0	5.3	1.5	5.5	−2.2	7.7
SE	6.9	6.5	5.7	4.6	3.3	2.0	0.7	−0.5	−1.4	−2.0	−2.1	−1.9	−1.5	−1.0	−0.6	0.0	0.6	1.4	2.0	2.9	3.8	4.9	5.7	6.4	2.0	6.9	−2.1	9.0
S	6.9	6.8	6.4	5.5	4.1	2.7	1.3	0.0	−0.7	−1.2	−1.4	−1.4	−1.2	−0.8	−0.3	0.4	1.0	1.6	2.4	3.2	4.0	5.2	6.3	7.0	2.4	7.0	−1.4	8.4
SW	5.2	4.9	4.5	4.0	3.0	2.0	1.0	0.3	−0.3	−0.7	−0.9	−1.0	−0.9	−0.7	−0.4	0.0	0.5	1.0	1.8	2.6	3.9	5.0	5.9	5.9	1.9	5.9	−1.0	6.9
W	3.2	2.8	2.0	1.3	0.6	0.0	−0.6	−0.9	−1.2	−1.5	−1.7	−1.9	−2.0	−1.8	−1.4	−1.0	−0.8	−0.5	−0.2	0.4	1.2	2.2	3.1	3.5	0.2	3.5	−2.0	5.5
NW	2.2	1.8	1.1	0.5	−0.2	−0.9	−1.5	−2.2	−2.7	−2.8	−2.9	−2.8	−2.7	−2.6	−2.2	−1.8	−1.6	−1.5	−1.4	−1.0	−0.4	0.5	1.4	2.0	−0.8	2.2	−2.9	5.1
Mean	4.5	4.3	3.7	2.9	2.0	0.9	−0.1	−1.0	−1.7	−2.0	−2.1	−2.0	−1.9	−1.6	−1.2	−0.8	−0.4	0.1	0.6	1.3	2.2	3.1	4.0	4.5	−0.8	4.5	−2.1	6.6

CONCORDIA, KANS.

1-kilometer level.

Surface wind direction.	Jan. 1	Jan. 15	Feb. 1	Feb. 15	Mar. 1	Mar. 15	Apr. 1	Apr. 15	May. 1	May. 15	June. 1	June. 15	July. 1	July. 15	Aug. 1	Aug. 15	Sept. 1	Sept. 15	Oct. 1	Oct. 15	Nov. 1	Nov. 15	Dec. 1	Dec. 15	Annual mean.	Extremes. Max.	Extremes. Min.	Range.
N	0.0	0.0	−0.2	−0.4	−0.6	−0.9	−1.0	−1.0	−1.0	−0.8	−0.5	−0.2	−0.1	0.0	0.0	−0.1	−0.2	−0.5	−0.8	−1.0	−1.0	−1.1	−1.0	−0.5	−0.5	0.0	−1.1	1.1
NE	0.0	0.5	0.8	0.6	0.4	0.0	−0.4	−0.8	−1.2	−1.2	−1.2	−0.8	−0.5	−0.1	0.2	0.6	0.8	1.0	1.1	1.0	0.6	0.2	0.0	0.0	−0.1	1.1	−1.2	2.3
E	3.6	3.0	2.6	2.0	1.3	0.6	0.2	−0.1	−0.4	−0.6	−0.5	−0.3	−0.1	0.2	0.5	0.8	1.0	1.4	2.0	2.6	3.1	3.8	4.3	4.3	1.5	4.3	−0.6	4.9
SE	3.9	3.2	2.4	1.7	1.1	0.6	0.2	0.0	−0.1	−0.1	0.0	0.3	0.6	1.0	1.2	1.3	1.5	1.8	2.2	2.8	3.4	4.2	4.9	4.8	1.8	4.9	−0.1	5.0
S	4.2	3.7	3.1	−0.5	−1.9	−1.4	1.0	0.7	0.5	0.3	0.0	0.0	0.4	0.7	1.1	1.5	1.8	2.1	2.4	2.8	3.2	4.0	4.8	4.8	2.0	4.8	0.0	4.8
SW	4.7	4.5	4.2	3.7	3.1	2.7	2.2	1.8	1.6	1.4	1.2	1.1	1.0	1.0	1.1	1.3	1.7	2.1	2.6	3.1	3.9	5.0	5.4	5.3	2.7	5.4	1.0	4.4
W	3.2	2.7	2.2	2.0	1.7	1.4	1.2	1.0	0.8	0.6	0.6	0.5	0.5	0.6	0.8	1.1	1.5	1.8	2.3	2.8	3.4	3.9	4.0	3.6	1.9	4.0	0.5	3.5
NW	1.3	1.1	0.7	0.2	−0.2	−0.5	−0.6	−0.6	−0.6	−0.4	0.0	0.3	0.4	0.4	0.4	0.4	0.3	0.2	0.2	0.3	0.5	0.8	1.0	1.2	0.2	1.3	−0.6	1.9
Mean	2.6	2.3	2.0	1.5	1.1	0.7	0.4	0.1	−0.1	−0.1	0.0	0.1	0.3	0.5	0.7	0.9	1.0	1.2	1.5	1.8	2.1	2.6	2.9	2.9	1.2	2.9	−0.1	3.0

2-kilometer level.

Surface wind direction.	Jan. 1	Jan. 15	Feb. 1	Feb. 15	Mar. 1	Mar. 15	Apr. 1	Apr. 15	May. 1	May. 15	June. 1	June. 15	July. 1	July. 15	Aug. 1	Aug. 15	Sept. 1	Sept. 15	Oct. 1	Oct. 15	Nov. 1	Nov. 15	Dec. 1	Dec. 15	Annual mean.	Extremes. Max.	Extremes. Min.	Range.
N	1.9	1.8	1.4	0.6	−0.2	−1.1	−1.8	−2.2	−2.6	−2.8	−3.0	−3.0	−3.0	−3.0	−2.8	−2.4	−1.8	−1.4	−0.9	−0.4	0.1	0.5	1.1	1.6	−1.0	1.9	−3.0	4.9
NE	3.0	2.9	2.6	2.1	1.5	0.7	−0.2	−1.0	−1.7	−2.2	−2.4	−2.4	−2.4	−2.3	−2.0	−1.6	−1.3	−0.9	−0.4	0.1	0.8	1.6	2.3	2.7	0.0	3.0	−2.4	5.4
E	4.6	4.6	4.3	3.7	3.0	2.0	0.9	−0.4	−1.4	−1.9	−2.0	−2.0	−1.9	−1.7	−1.4	−1.1	−0.5	−0.2	−0.9	1.6	2.4	3.1	3.7	4.2	1.0	4.6	−2.0	6.6
SE	5.6	5.4	4.8	3.8	2.4	1.0	0.0	−0.9	−1.6	−2.0	−2.1	−2.1	−2.0	−1.8	−1.4	−0.9	−0.4	0.2	0.9	1.7	2.5	3.5	4.5	5.2	1.1	5.6	−2.1	7.7
S	6.2	5.6	4.9	4.0	2.8	1.4	0.5	−0.3	−0.9	−1.4	−1.7	−1.9	−1.9	−1.6	−1.0	−0.4	0.2	0.7	1.2	1.8	2.5	3.7	5.6	6.4	1.5	6.4	−1.9	8.3
SW	5.6	5.2	4.6	3.7	2.7	1.7	0.8	0.2	−0.2	−0.5	−0.8	−0.8	−0.9	−0.8	−0.6	0.0	0.6	1.0	1.2	1.7	2.7	4.3	5.4	5.8	1.8	5.8	−0.9	6.7
W	3.2	2.8	1.9	1.2	0.6	0.0	−0.5	−0.8	−0.9	−1.1	−1.2	−1.3	−1.3	−1.2	−1.2	−1.0	−0.8	−0.5	−0.1	0.4	1.1	1.9	2.6	3.0	0.3	3.2	−1.3	4.5
NW	1.8	1.6	1.1	0.4	−0.5	−1.4	−2.2	−2.7	−2.8	−2.9	−2.8	−2.8	−2.7	−2.5	−2.3	−2.0	−1.8	−1.8	−1.8	−1.6	−1.2	−0.6	0.3	1.2	−1.2	1.8	−2.9	4.7
Mean	4.0	3.7	3.2	2.4	1.5	0.5	−0.3	−1.0	−1.5	−1.9	−2.0	−2.0	−2.0	−1.9	−1.6	−1.2	−0.7	−0.3	0.1	0.7	1.4	2.3	3.2	3.8	0.4	4.0	−2.0	6.0

OKLAHOMA CITY, OKLA.

1-kilometer level.

Surface wind direction.	Jan. 1	Jan. 15	Feb. 1	Feb. 15	Mar. 1	Mar. 15	Apr. 1	Apr. 15	May. 1	May. 15	June. 1	June. 15	July. 1	July. 15	Aug. 1	Aug. 15	Sept. 1	Sept. 15	Oct. 1	Oct. 15	Nov. 1	Nov. 15	Dec. 1	Dec. 15	Annual mean.	Extremes. Max.	Extremes. Min.	Range.
N	0.0	0.0	−0.1	−0.3	−0.7	−0.8	−0.8	−0.7	−0.5	−0.3	−0.2	0.0	0.0	0.0	−0.2	−0.2	−0.1	0.1	0.3	0.2	0.0	−0.2	−0.1	0.0	−0.2	0.3	−0.8	1.1
NE	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.2	0.0	−0.2	−0.2	−0.2	−0.2	0.0	0.2	0.7	1.1	1.2	1.2	1.0	0.8	0.6	0.4	1.2	−0.2	1.4
E	1.4	1.2	0.9	0.7	0.5	0.4	0.4	0.5	0.5	0.4	0.2	0.0	−0.2	−0.2	0.0	0.3	0.7	1.0	1.2	1.6	1.9	2.2	2.3	2.0	0.8	2.3	−0.2	2.5
SE	3.0	2.2	1.5	1.1	0.8	0.5	0.4	0.3	0.2	0.0	0.0	0.0	0.0	0.1	0.3	0.5	0.6	0.9	1.2	1.5	1.9	2.3	2.8	3.2	1.1	3.2	0.0	3.2
S	3.8	3.5	2.8	1.6	0.7	0.2	−0.2	−0.3	−0.4	−0.5	−0.5	−0.4	−0.3	0.0	0.2	0.5	0.7	0.8	1.0	1.2	1.3	1.6	2.5	3.4	1.0	3.8	−0.5	4.3
SW	4.5	4.4	3.7	1.5	0.6	0.1	−0.4	−0.7	−1.0	−1.2	−1.2	−0.9	−0.3	0.2	0.4	0.5	0.6	0.6	0.8	1.0	1.4	2.0	2.6	3.4	0.9	4.5	−1.2	5.7
W	1.8	1.7	1.0	0.0	−0.5	−0.8	−1.0	−1.0	−1.1	−1.0	−0.7	−0.3	0.0	0.2	0.2	0.2	0.1	0.0	−0.1	−0.2	−0.2	−0.1	0.5	1.0	0.0	1.8	−1.1	2.9
NW	0.8	0.5	0.0	−0.4	−0.8	−1.2	−1.2	−1.2	−0.9	−0.5	0.0	0.4	0.7	0.6	0.3	−0.1	−0.2	−0.3	−0.3	−0.3	−0.2	0.0	0.2	0.6	−0.1	0.8	−1.2	2.0
Mean	2.0	1.7	1.3	0.6	0.1	−0.1	−0.3	−0.4	−0.4	−0.4	−0.3	−0.2	0.0	0.1	0.1	0.2	0.3	0.5	0.6	0.8	0.9	1.1	1.4	1.8	0.5	2.0	−0.4	2.4

2-kilometer level.

Surface wind direction.	Jan. 1	Jan. 15	Feb. 1	Feb. 15	Mar. 1	Mar. 15	Apr. 1	Apr. 15	May. 1	May. 15	June. 1	June. 15	July. 1	July. 15	Aug. 1	Aug. 15	Sept. 1	Sept. 15	Oct. 1	Oct. 15	Nov. 1	Nov. 15	Dec. 1	Dec. 15	Annual mean.	Extremes. Max.	Extremes. Min.	Range.
N	1.6	1.4	0.8	0.1	−0.8	−1.5	−2.0	−2.0	−2.1	−2.2	−2.2	−2.2	−2.1	−2.1	−2.0	−1.9	−1.6	−1.2	−0.8	−0.3	0.2	0.5	0.7	0.7	−0.9	1.6	−2.2	3.8
NE	1.8	1.6	1.2	0.7	0.2	−0.4	−1.0	−1.6	−1.8	−2.0	−2.3	−2.4	−2.4	−2.3	−2.1	−1.7	−1.1	−0.3	0.6	1.1	1.2	1.1	1.3	1.6	−0.4	1.8	−2.4	4.2
E	2.3	2.1	1.7	1.0	0.4	−0.3	−1.0	−1.5	−2.0	−2.5	−2.6	−2.6	−2.5	−2.3	−1.8	−1.2	−0.6	0.0	0.4	0.7	0.8	1.2	1.8	2.1	−0.2	2.3	−2.6	4.9
SE	2.5	2.1	1.6	1.1	0.5	0.0	−0.7	−1.3	−1.9	−2.3	−2.6	−2.7	−2.7	−2.6	−2.2	−1.8	−1.5	−1.1	−0.6	−0.2	0.4	1.0	1.9	2.4	−0.4	2.5	−2.7	5.2
S	4.4	3.4	2.2	1.5	0.8	0.1	−0.6	−1.1	−1.6	−2.1	−2.4	−2.6	−2.7	−2.6	−2.5	−2.2	−1.9	−1.5	−1.0	−0.4	0.6	2.0	3.5	4.3	−0.1	4.4	−2.7	7.1
SW	3.8	2.8	2.0	1.1	0.4	−0.3	−0.8	−1.3	−1.8	−2.0	−2.2	−2.4	−2.4	−2.3	−2.1	−1.7	−1.2	−0.7	0.0	0.7	1.4	2.5	3.5	4.1	0.0	4.1	−2.4	6.5
W	1.5	1.4	1.0	0.5	0.0	−0.8	−1.4	−2.1	−2.7	−3.0	−3.0	−2.8	−2.5	−2.3	−2.0	−1.7	−1.5	−1.3	−1.0	−0.5	0.0	0.4	1.0	1.5	−0.9	1.5	−3.0	4.5
NW	0.8	0.9	0.6	0.0	−1.0	−2.0	−2.9	−3.6	−3.6	−3.3	−3.0	−2.6	−2.2	−2.1	−2.1	−2.0	−2.0	−2.0	−2.0	−1.8	−1.4	−1.0	−0.3	0.4	−1.6	0.8	−3.6	4.4
Mean	2.3	2.0	1.4	0.8	0.1	−0.6	−1.3	−1.8	−2.2	−2.3	−2.5	−2.5	−2.4	−2.3	−2.1	−1.8	−1.4	−1.0	−0.5	−0.1	0.4	1.0	1.7	2.1	−0.1	2.3	−2.5	4.8

ABILENE, TEX.

1-kilometer level.

Surface wind direction.	Jan. 1	Jan. 15	Feb. 1	Feb. 15	Mar. 1	Mar. 15	Apr. 1	Apr. 15	May. 1	May. 15	June. 1	June. 15	July. 1	July. 15	Aug. 1	Aug. 15	Sept. 1	Sept. 15	Oct. 1	Oct. 15	Nov. 1	Nov. 15	Dec. 1	Dec. 15	Annual mean.	Extremes. Max.	Extremes. Min.	Range.
N	1.5	1.4	1.3	1.0	0.7	0.2	0.0	−0.2	−0.1	0.2	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.7	0.8	1.0	1.3	0.6	1.5	−0.2	1.7
NE	2.2	2.0	1.7	1.4	1.1	0.9	0.7	0.5	0.3	0.2	0.2	0.4	0.7	0.9	1.0	0.9	0.9	1.0	1.3	1.4	1.4	1.8	2.1	2.2	1.1	2.2	0.2	2.0
E	3.0	2.9	2.4	1.6	0.9	0.2	0.2	0.5	0.5	0.0	0.4	0.7	0.9	1.0	1.0	1.0	0.9	1.0	1.0	1.2	1.6	2.0	2.5	2.9	1.3	3.0	0.0	3.0
SE	3.2	2.7	1.6	1.0	0.9	0.7	0.7	0.6	0.5	0.5	0.6	0.6	0.8	0.9	0.9	0.9	0.9	0.9	1.0	1.4	1.8	2.3	2.8	3.1	1.9	3.2	0.5	2.7
S	2.8	2.4	1.6	1.1	0.9	0.8	0.8	1.0	0.9	0.8	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.8	0.8	0.9	1.1	1.5	2.1	2.6	1.1	2.6	0.6	2.0
SW	3.0	3.2	2.8	2.2	1.6	1.0	0.6	0.2	−0.1	−0.3	−0.4	−0.2	0.2	0.5	0.6	0.6	0.6	0.6	0.6	0.7	1.1	1.8	2.2	2.7	1.1	3.0	−0.4	3.4
W	1.8	1.5	1.1	0.7	0.3	0.0	−0.3	−0.6	−0.7	−0.8	−0.5	0.0	0.2	0.2	0.1	0.1	0.1	0.2	0.3	0.4	0.8	1.2	1.7	1.9	0.4	1.9	−0.8	2.7
NW	1.6	1.1	0.6	0.2	−0.3	−0.7	−0.9	−1.0	−0.9	−0.4	0.2	0.6	0.8	0.7	0.4	0.0	−0.1	0.0	0.2	0.4	0.6	1.0	1.3	1.5	0.3	1.6	−1.0	2.6
Mean	2.4	2.2	1.6	1.1	0.8	0.4	0.2	0.1	0.0	0.0	0.2	0.4	0.6	0.7	0.6	0.6	0.6	0.6	0.7	0.9	1.1	1.5	2.0	2.3	0.9	2.4	0.0	2.4

2-kilometer level.

Surface wind direction.	Jan. 1	Jan. 15	Feb. 1	Feb. 15	Mar. 1	Mar. 15	Apr. 1	Apr. 15	May. 1	May. 15	June. 1	June. 15	July. 1	July. 15	Aug. 1	Aug. 15	Sept. 1	Sept. 15	Oct. 1	Oct. 15	Nov. 1	Nov. 15	Dec. 1	Dec. 15	Annual mean.	Extremes. Max.	Extremes. Min.	Range.
N	1.8	1.5	1.0	0.4	−0.2	−0.8	−1.3	−1.8	−2.0	−2.1	−2.0	−1.9	−1.6	−1.2	−0.9	−0.6	−0.4	−0.2	−0.2	−0.1	0.1	0.4	0.7	1.1	−0.4	1.8	−2.1	3.9
NE	2.0	1.5	1.0	0.5	−0.1	−0.6	−1.0	−1.4	−1.7	−1.9	−2.0	−1.9	−1.6	−1.2	−0.8	−0.5	−0.2	−0.2	0.6	0.9	1.2	1.4	1.6	1.6	−0.1	2.0	−2.0	4.0
E	2.2	2.4	1.8	1.0	0.3	−0.3	−0.7	−1.1	−1.6	−1.9	−2.1	−2.0	−1.7	−1.5	−1.2	−0.9	−0.6	−0.3	0.0	0.2	0.4	0.6	1.0	1.4	−0.2	2.4	−2.1	4.5
SE	2.5	2.4	2.1	1.6	1.0	0.4	0.0	−0.4	−1.2	−1.8	−1.9	−1.7	−1.3	−1.1	−0.9	−0.8	−0.8	−0.7	−0.7	−0.6	−0.5	0.1	0.8	1.6	−0.1	2.5	−1.9	4.4
S	3.2	2.6	2.0	1.6	1.2	0.8	0.5	0.0	−0.6	−1.2	−1.7	−2.0	−2.1	−1.8	−1.5	−1.3	−1.2	−1.4	−1.6	−1.5	−1.0	0.8	2.5	3.4	0.0	3.4	−2.1	5.5
SW	3.2	2.6	1.8	1.2	0.7	0.1	−0.4	−0.8	−1.4	−1.6	−1.9	−2.0	−2.0	−2.0	−2.0	−1.8	−1.7	−1.4	−0.8	0.0	0.9	1.6	2.5	3.3	−0.1	3.3	−2.0	5.3
W	1.5	1.1	0.8	0.5	0.1	−0.3	−0.8	−1.3	−1.8	−2.2	−2.5	−2.5	−2.4	−2.2	−2.0	−1.8	−1.6	−1.2	−0.9	−0.7	−0.4	0.2	0.8	1.2	−0.8	1.5	−2.5	4.0
NW	1.2	0.9	0.4	−0.6	−1.3	−1.8	−2.4	−0.8	−1.0	−1.0	−0.8	−0.5	−2.5	−2.2	−2.0	−1.6	−1.4	−1.2	−1.1	−1.1	−0.8	0.1	1.0	1.2	−0.8	1.2	−2.5	3.7
Mean	2.2	1.9	1.4	0.8	0.2	−0.3	−0.8	−0.9	−1.4	−1.7	−1.9	−1.8	−1.9	−1.6	−1.4	−1.2	−1.0	−0.8	−0.6	−0.4	0.0	0.6	1.4	1.9	−0.3	2.2	−1.9	4.1

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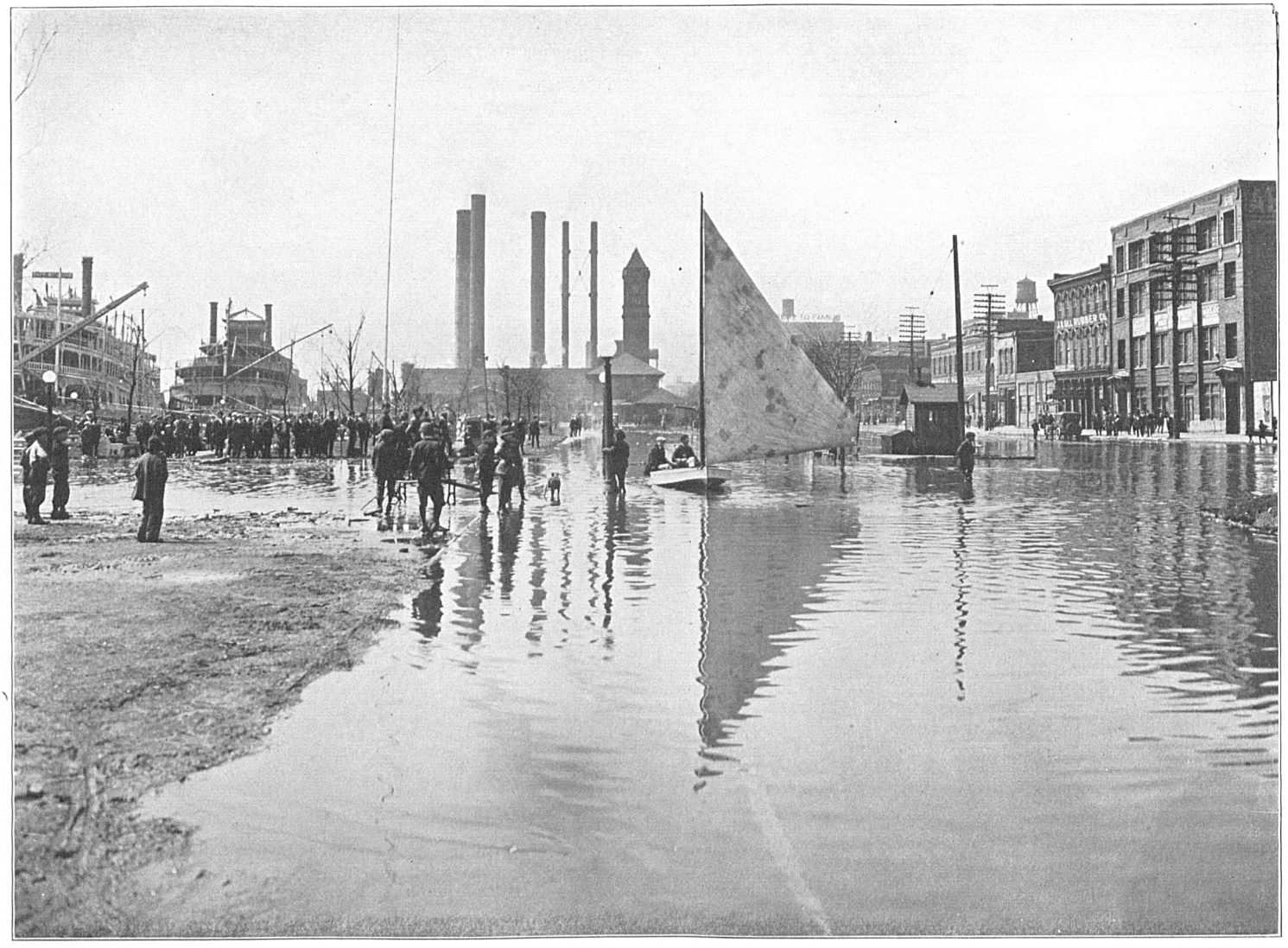

FIG. 1.—Looking southwestward down Water Street, Peoria, Ill. Sailboat at intersection of Main and Water Streets. Clock tower on Chicago, Rock Island & Pacific Railway Station.