Art. LIX.—*Prediction of Cold-waves from Signal Service Weather Maps;* by T. Russell.

[Read before the American Association for the Advancement of Science, at Indianapolis, August 25, 1890, by T. Russell, Assistant Professor, Signal Service.]

In addition to the regular fall of temperature that takes place from day to night, there are irregular falls occurring from time to time. The extent of country covered by these falls is various at different times. When the fall of temperature in twenty-four hours is twenty degrees or more and covers an area of at least fifty thousand square miles and the temperature in any part of the area goes as low as 36° it is called a cold-wave. Answering to this definition, there have been in the United States in the past ten years, 1880 to 1890, six hundred and twenty-one cold-waves, as shown by the 7 A. M. weather-maps of the Signal Service.

In Table I, is given the number of cold-waves, of various extents, according to the area enclosed by the twenty-degree temperature-fall line, that have occurred in ten years, in the months of October, November, December, January, February and March.

Table I.

Number of cold-waves, 1880 *to* 1890, *according to extent of twenty-degree temperature-fall areas.*

Ten Months.	50,000 to 100,000.	100,000 to 200,000.	200,000 to 300,000.	300,000 to 400,000.	400,000 to 500,000.	500,000 to 600,000.	600,000 to 700,000.	700,000 to 800,000.	800,000 to 900,000.	900,000 to 1,000,000.	1,000,000 to 1,100,000.	1,100,000 to 1,200,000.
January	13	27	25	29	16	13	9	4	3	1	1	2
February	23	26	19	24	13	10	6	5	2	2	2	1
March	30	24	13	11	12	1	2	1	1	--	--	--
October	21	13	2	1	1	--	--	--	--	--	--	--
November	32	14	12	10	8	5	1	--	1	2	--	--
December	31	30	21	16	14	5	1	3	5	1	--	--
Sums	150	134	92	91	64	34	19	13	12	6	3	3

The greatest cold-wave was that of January 17, 1882. The twenty-degree fall line included an area of 1,101,000 square miles, and the ten-degree fall line an area of 2,929,000 square miles. There have been in ten years six cold-waves with the area of the twenty-degree fall greater than one million square miles. The magnitude of maximum temperature-fall in cold-waves varies greatly at different times. The different curves of temperature-fall lie one within the other, the twenty-degree within the ten-degree, the thirty within the twenty and so on. There is a gradual increase of temperature-fall from the border of a cold-wave area to the center which is the place of maximum-fall. There have been two cases in ten years where the maximum fall was over sixty degrees, the greatest being sixty-three. There were sixteen cases where the maximum fall was between fifty and sixty degrees; seventy-seven cases with the maximum fall between forty and fifty degrees; two hundred and sixty-two cases between thirty and forty degrees; and two hundred and sixty-four between twenty and thirty.

The Signal Service weather-maps show that these cold-waves always occur over the country covered on the preceding day by an area of low barometric pressure, or over the country covered by an area of high pressure. Where both occur, the cold-waves attain their greatest extent. The cold-waves occur from the center of the areas of low pressure towards the west. There are a few cases where low pressure areas have not been followed by a fall in temperature at their centers. There are twelve of these in ten years where there have been rises in temperature instead of falls around the centers of low pressure. On the other hand, no cold-waves ever occur without the presence of an area of high or low pressure. Why there are exceptions is not known.

The Signal Service observations made at 8 A. M. (at 7 A. M., previous to July 1, 1888) are given on the weather-maps issued daily. The barometric pressure at the various stations reduced to sea-level are generalized by the isobars. The temperatures are shown by the isotherms drawn through places having the same temperature.

A typical case of weather-map preceding a cold-wave is that of February 9, 1885. The map shows a characteristic feature of the isotherms preceding a cold-wave. They run from southwest to northeast in the country covered by the low pressure, and after passing the center bend towards the southeast and east. To the west of the region of high pressure the isotherms bend to the northwest. The general appearance of the isotherms would seem to indicate that the air in the low pressure has progressed from the south, and that in the high from the north, carrying with it the isothermal lines peculiar to those regions. The temperature-falls on February 10, 1885, shown on a map by lines joining the points of equal fall, give areas which are quite regular, having usually the appearance of ellipses one within the other. The total temperature-fall on a map has graphically the semblance of a cone. The temperature-fall lines are sections of planes with the cone. The maximum or greatest fall of temperature in the center is the altitude of the cone, and the area enclosed by the lines of no change is its base.

An examination of the maps preceding cold-waves shows that the extent of cold-wave is dependent on the extent of the area of low pressure and the area of high pressure on the day preceding it. The extent of cold-wave depends very greatly on the density or sparseness of the isothermal lines in the region of the low area and to the west of it. When they are numerous and close together, the falls will be very great and will cover a wide extent of country. The maps preceding cold-waves vary very much as regards isotherms. There is always some diminution of temperature to the northwest of a low area. Sometimes it is not more than twenty degrees in a distance of 500 miles from the center, and sometimes eighty degrees in the same distance.

To show to what extent the amount of temperature-fall and the area of fall depend on the variation of barometric pressure and contrast of temperature, the means in a number of selected cases are shown in Table II.

TABLE II.

Summary of Pressure and Temperature Gradients, and Mean Temperature Falls.

Mean Temperature Falls.		Mean Temp. Grad'nt per 500 miles.	Mean Pres. Grad'nt per 500 miles. Inches.	Mean extent of cold-wave.
53°·6	16 cases	55°	0·66	26·1
43°·3	60 cases	47°	0·56	15·1
33°·5	"	44°	0·59	10·0
24°·0	"	34°	0·46	3·7
14°·3	"	23°	0·40	

In forming the means in Table II, sixty cases each of falls between thirty and forty, twenty and thirty, and ten to twenty were selected, one from each month, October to March, during the ten years. The changes less than twenty degrees do not class as cold-waves, but are given, to show the dependence in magnitude of the temperature-fall on the pressure and temperature gradients in the case of small changes. The last column of Table II, contains the extent of cold-wave, the unit being a fall of twenty degrees over an area of 50,000 square miles, or ten degrees over an area of 100,000. The extent of fall in cold-waves, including all the fall greater than ten degrees, but not including any less than ten degrees, varies in different cases from 5 to 60 on this basis. The temperature-fall is computed as the contents of a rough cone. The areas of the falls are measured with a planimeter and the altitude expressed in units of ten degrees of the greatest fall in temperature.

The shapes and relative positions of high and low areas of pressure preceding cold-waves are very various. The principal types most frequently recurring are as follows:

1. A low pressure without any accompanying high pressure. Cold-waves with this type are not apt to be important or extensive, unless the area is continental in extent. With a central pressure as low as 29·3 inches, and a distance across the thirty-inch isobar of 1,600 miles, the cold-wave is apt to be considerable.

2. A low pressure area with a high to the northwest of it. This is the most frequently occurring type. The cold-waves

accompanying it may be of any extent from the smallest to the largest.

3. A great area of high pressure, with a slight or very ill-defined low pressure, irregular in shape to the southeast of it, or very far to the east. The cold-waves are not apt to be great in this case. The area of temperature-fall is a long narrow strip extending from southwest to northeast, and never reaching more than 300 miles from the southeastern edge of the high area.

4. An area of low pressure with an area of high southwest of it. The temperature-fall area is a long narrow strip in this case. This type is usually a sequence of type 2 and always follows after a severe cold-wave has prevailed the day before in country farther to the west and north.

5. A double V-shaped area of low pressure, one in the region of the Great Lakes open to the northeast, the other in Louisiana or Texas and open to the southwest, a great area of high pressure in between the two, to the northwest. The cold-waves of greatest extent have occurred with this type.

6. A double low, one in the Lake Region and the other on the Atlantic coast. The cold-waves with this type are always extensive, but keep well towards the north.

These varieties may be still further subdivided according to the shape and position of the isobars in the area of low pressure. The low may have closed isobars, or it may be open in any direction. The closed isobars may be circular or elliptical. When elliptical, the long axis may be from northeast to southwest, from north to south, east to west, or northwest to southeast. The latter variety is very unusual. The cold-waves following each of these varieties have distinctive features. These various types have distinctive features in the areas of twenty-degree fall following them. The longer axis of the area of temperature fall extends in the direction in which the isobars are open, etc.

The method given here for the prediction of cold-waves, does not give a correct result at all times. It represents very fairly the average of cases that occur; though in a few cases, it gives largely erroneous results. It is purely empirical. What follows certain combinations of isobars and isotherms is seen from past weather-maps, and it becomes a question how to formulate the conditions and use them, for judging what may occur in any special case in the future.

From an examination of the charts of temperature-fall in connection with the weather-map twenty-four hours preceding, it will appear that the extent of the cold wave depends on the extent and depth of the area of low pressure. It likewise depends on the extent and height of the area of high pressure.

When both a low and high pressure occur together, the cold wave is apt to be very great. The surest indication of a coming great fall of temperature, both deep and extensive, is a crowded condition of the isothermal lines to the northwest of an area of low pressure. This condition is usually the result of a great fall of temperature in the preceding twenty-four hours, in a district to the west and north. Sometimes, however, this crowded condition of the isotherms is the result of a slow cooling over a wide area of country, lasting several days. Then a low area of pressure putting in an appearance to the southeast of it, the next day there follows a great and extensive fall of temperature, without any very great fall the day preceding. At times, there is a regular progression of the areas of fall from west to east, or southeast. Areas of low pressure appearing in the vicinity of Lake Superior, with a high area to the west, have temperature-falls on the next day at places east of the Missouri River and skirting along as far south as the Ohio River.

One of the most important types of map is that of a low area of pressure in Texas and a great high to the north. Areas of great temperature-fall always follow this type, with the long axis extending north to south. The greatest falls occur in the southwest. The areas of fall on the next day are farther to the east, and later, falls follow to the north, in Maryland, Pennsylvania, New Jersey and New York. This is a type for which it is possible, when the high and low areas are large, to make successful predictions of cold-waves for the eastern States two days in advance.

Inasmuch as the extent and depth of temperature-fall depend on the extent of the areas of high and low pressure, it was decided to ascertain how far this was true, and to determine if possible the numerical relation between them. The areas enclosed by the temperature-fall lines of ten, twenty, thirty, forty degrees, etc., in the various cold-waves were measured by means of a planimeter on maps of the United States on a scale of $\frac{1}{10,000,000}$. The areas between the isobars of high and low areas of pressure on the maps preceding cold-waves were measured in the same way. The areas between the isothermal lines in the region covered by the areas of high and low pressure were also measured.

The method proposed for the prediction of cold-wave, is as follows:

1. From the measured extent of the high and low area of pressure always preceding cold-waves to determine what the total extent of the fall in the cold-wave will be.

2. To determine the maximum fall of temperature that is to take place in a cold-wave.

3. The extent of cold-wave being known, which is the contents of a cone, and the altitude being known, which is the maximum fall of temperature expressed in units of ten degrees, then from suitably prepared tables, the areas included by the ten and twenty degree temperature-fall lines to be taken, these lines being the sections of planes with the cone.

4. The various shapes that the twenty degree temperature-fall areas take with different types of high and low pressure will be determined. The shape of the areas will be taken as exactly elliptical, with varying ratio of axes in different cases. This is not strictly the shape of temperature-fall areas in actual cold-waves, but it is sufficiently near for practical purposes, and the best that can be adopted. In more than 90 per cent of the cases, a regular ellipse will represent actual temperature-falls with errors not greater than six degrees.

5. The location of point of greatest temperature-fall will be determined, and the position of the longer axis of the twenty-degree fall area.

6. A previously prepared piece of card-board of the size and shape of the twenty-degree fall area will be placed on a map in its proper position and a line drawn around it. The thirty degree, forty degree, etc., temperature-fall lines will be drawn in with regard to this twenty degree fall line, and the point of maximum fall.

7. From these curves the falls at various stations in the region covered can be estimated, and the isothermal lines drawn for the day on which the cold-wave is to prevail. The isothermal lines in a region where a cold-wave prevails, always have a certain smoothness and definiteness of sweep. If the predicted isothermal lines are crooked and irregular, some slight adjustment can be made, and new isotherms put in, so as to represent the average position of the ones first drawn.

Extent of Cold-Wave.

The extent of a cold-wave has been taken, as proportional to the extent of the area of low pressure multiplied by an unknown factor, plus the extent of the high area multiplied by another unknown factor, plus another term, composed of the product of an unknown factor by the extent of low area of pressure, and a number expressing the density of the isothermal lines throughout the region of the high and low areas. The unit of deficiency of pressure in the low area, below a pressure of 30 inches and excess in the high, is taken as one inch over an area of 100,000 square miles. In different cases the number expressing this excess or deficiency of pressure varies from a small fraction of a unit to as much as ten units. Observation equations were formed on this plan, of the form,

$Hh+Ll+Ll_{,}F-E=0$. h, l and $l_{,}$, are the unknown quantities and, E, the extent of cold-wave; H and L, are the measured extents of high and low pressure. As regards F, the number expressive of the density of the isothermal lines, it was derived in the following way.

Consider two contiguous areas, between three successive isotherms. The tendency is for the wind to blow from the high area towards the low, and carry the air from places of low temperature to those where it is high. The mean temperature of a strip between two isotherms as compared with a strip adjoining it is ten degrees different, the one to the west and north being the lower. If the area of higher temperature is of less extent than the lower one, there is a possibility of all the air from the lower one overflowing the higher, and that the fall in temperature will be equal in extent to the area of the higher multiplied by one, their difference of temperature being ten degrees. If the area of lower temperature is less than the higher one, it is not likely that it will change the temperature any more than the area of the lower multiplied by the difference of temperature unless there is cold air coming from above. Consider a third area with respect to the one of highest temperature. The fall of temperature produced by it may be taken in extent, as equal to the area of the smaller one of the two areas multiplied by two, the difference of their mean temperatures being twenty degrees, but somewhat less than this on account of the two areas being farther apart than in the case of the first two considered. Part of the low temperature is expended in lowering the temperature of the intervening area. It is not known what the law is, according to which this effect diminishes with distance of the areas apart. There is some reason, however, for believing that it is inversely as their distance apart. The effects of the areas, in causing extent of fall, have been taken as inversely proportional to their distances apart expressed in units of one hundred miles. Considering all the other areas with respect to the area of highest temperature, in a similar manner a series of numbers will be obtained, expressive of the possible extent of temperature-fall. The next area of temperature below the one of highest temperature, will in like manner give a similar series of numbers, and likewise a third area considered with respect to all those below it will give a series, and so on, until the last two areas are taken into account which give a single number. The sum of all these numbers gives a total number expressive of the possibility of temperature-fall, provided there is sufficient of a low area to induce such a circulation of the air, that the air from places of low temperature will reach places where it is high. The more extensive and deep the area of low pressure, the more this will be accomplished. Accordingly, a term is included in the equation which gives the temperature-fall, which is proportional to this number multiplied by the extent of the low area and an unknown quantity. This number expressive of density or sparseness of isotherms in the case of different weather-maps preceding cold-waves varies from 5 to 95.

To establish the numerical relation between the extent of cold-wave and the extent of high and low areas of pressure, 127 cases of cold-wave were selected from those that have occurred in ten years. They were so chosen as to include the greatest possible variety in extent of cold-wave from the smallest to the largest, the greatest and least areas of high and low pressure concerned in their production, cases in which the "high" was in different positions with respect to the "low," and cases of the greatest diversity of the isothermal lines passing through the low area.

Normal equations were formed, and from them the values of the unknown quantities derived:

$$h = 2{\cdot}75,\ l = 3{\cdot}15,\ l_{\prime} = 0{\cdot}0547$$

From the residuals obtained by substituting the values of the unknown quantities in the observation-equations, the probable error in the extent of a cold-wave derived by this method was found to be $\pm$ 5. The average extent of cold-wave in the 127 cases was 20. The extent of different cold-waves varied from 5 to 60.

Several different forms of equation were tried. The one described, gave more satisfactory values of the residuals than any of the others. From a consideration of the residuals in the various methods tried, it was inferred that the fall of temperature in a cold-wave must be composed of two parts. One part depends on the presence of a high or low area of pressure, and the other on the transmission of air from places in the northwest, where it is cold, to places where the temperature is high, in the vicinity of the low area. The first part probably results from the intermixture of air near the ground with that from a great altitude, this intermixture resulting from a great diminution of temperature upward in the air. In Winter, on account of the greater lengths of the nights, there is excessive cooling of the upper layers of air. The determining factor of a convective interchange, is the upward diminution of temperature. The air over a wide area of country being in unstable equilibrium, a circumstance, such as a slight excess of heating at the ground may be the cause of an intermixture of the strata throughout a great height. Intermixture would cause the air to become nearly uniform in temperature, which would cause a fall at the surface of the earth, and a rise in temperature high up in the air. This latter, however, would not be maintained long on account of the greater radiation in the upper air, which would cause the temperature to diminish rapidly to the normal peculiar to the altitude and the time of the year. A mixture of the air throughout a height of five miles, computation shows, would cause a fall in temperature of forty degrees, if the temperature at the surface of the earth is 60°.

The change of temperature upward in the air is very slight in a region covered by an area of high pressure. This is the region where a cold-wave is prevailing and intermixture has taken place. In fact, there is sometimes in such a region an increase of temperature upward, which is, however, mostly due to local causes, a ridge or peak radiating strongly into space during the night, and the thin layer of air cooled by contact with it, flowing down over the lower portions of the land into valleys, and giving rise to an abnormal contrast of temperature at slightly differing altitudes.

The fact that most of the severe cold-waves in the northwest start in the afternoon, just after the occurrence of the maximum temperature, tends to strengthen this view. The higher up in the air, the less the diurnal range of temperature. At the time of maximum temperature at the surface of the earth the rate of upward diminution of temperature must be greatest, and consequently at that time the greatest tendency to an interchange of the air above and below. The fact that the same density of isotherms with same extent of high and low in different cold-waves, do not always produce the same extent of temperature-fall proves conclusively that the fall is not due entirely to progress of cold air from the northwest, or dependent solely on temperature conditions at the surface of the ground, but that part of it must come from above.

Cases can be shown on the Signal Service weather-maps, where the fall of temperature certainly cannot be due to progress of air from places of low temperature to those of high unless it comes down from the upper air, because there is no lower temperature to the northwest to be carried by the winds.

In the high area, the main part of the cold-wave is due to the convective action in high and low strata. The high is to some extent merely the result of low temperature. The equation will not admit of a term consisting of the extent of high area multiplied by the factor dependent on the density of the isotherms. There are a few cases, however, where a slight term of this kind would improve the residuals. An area of high barometer no greater than 30·4 inches has very little power to transmit or produce a cold-wave to the east or southeast of it. Up to that limit, the high pressure is mainly the result of the low temperature over the area, and there is no appreciable cold-wave without a very considerable low to the east. In the low area, the fall of temperature is due both to the intermixture of upper and lower air and the presence of cold air brought from the northwest by the action of the typical winds around it.

The greatest fall of temperature.

An examination of the weather-maps in 217 cases preceding cold-waves shows, that the greatest falls in 134 cases occurred inside of the lowest isobar of the low area of pressure or within 100 miles of the center of the low. In 62 cases, it was south of the center of the low 200 miles or more. In 8 cases it was north of the center; in 4, west of it; in 3, east of it; and in 6 cases so remote from the center as to have no apparent relation to it. In at least 80 per cent of all the cases of cold-waves, the place of greatest temperature-fall can be located twenty-four hours beforehand somewhere on the map within a radius of one hundred miles of its true place by taking it at the place of highest temperature within 100 miles of the center of the low.

The magnitude of greatest temperature-fall is conspicuously dependent upon the temperature gradient on the weather-map preceding it. The values of maximum temperature-fall, pressure and temperature gradients given in Table II. might be used for deriving the greatest fall. Taking the fall as proportional to the product of the temperature gradient by the pressure gradients in five hundred miles, the mean greatest falls of 53·6, 43·3, 33·5, 24·0 and 14·3 degrees, give values for the factor respectively of 1·49, 1·66, 1·29, 1·54, 1·55, the mean of which is 1·48. This factor multiplied by the product of the 500 mile pressure and temperature gradient in any case, will give an approximate value of the maximum fall in a coming cold-wave. The value found in this way would be good if the areas between the isotherms were more regular than is usually the case.

A better method was found to be the following:

On a line drawn from the point of greatest prospective temperature-fall, and perpendicular to the isotherms, about where they are closest together on the map, measure the distances between the isotherms. The temperature at the place of greatest fall after the cold-wave has prevailed, will be the weighted mean of the mean temperatures of the various sections of the line between the isotherms, the weights being taken directly as the lengths of the various sections, and inversely as the distances of their centers from the point of greatest prospective fall. The mean of the temperature from the point of greatest fall to the first isotherm to the northwest of it, or for at least a distance of 200 miles from the point of greatest fall when there is more than one isotherm in the distance, is taken with a weight of one. The mean temperature of a section is the mean of its bounding isotherms. When the decrease of temperature towards the northwest in a distance of 500 miles is not more than thirty degrees, the greatest fall may be taken as not greater than five-sixths of the change in 500 miles.

The probable error of greatest temperature-fall by this rule as derived from 201 cases of cold-waves is about ±2·5 degrees for falls of twenty degrees and ±6·5 degrees for falls of fifty degrees. Table III shows the distribution of errors.

TABLE III.

Errors in Computed Temperature Falls.

Cases.	Error in degrees.	Cases.	Error in degrees.
14	0°	5	±10°
36	±1	4	±11
24	±2	3	±12
22	±3	7	±13
14	±4	3	±14
19	±5	1	±15
19	±6	4	±16
10	±7	1	±17
15	±8	2	±18
8	±9		

The computed fall is less than the observed. On the average it is less by one degree for falls of twenty degrees; by two degrees for falls of thirty; by half a degree for falls of forty; and by five degrees for falls of fifty degrees. The average of all cases gives the computed fall two degrees less than the observed.

This method of deriving the maximum fall can only be used where the pressure gradient is at least 0·4 of an inch in 500 miles. It is worthy of note that the mean temperature throughout the areas of high and low pressure, as derived from the planimeter measurements of areas between isotherms, agrees in most cases within a few degrees with the temperature at the place of greatest fall after the fall has occurred as computed by this rule. Where the computed falls differ greatly from the observed, probably correspond to times of widely differing diminution of temperature upward in the air.

With the computed maximum fall derived in this way, and the computed extent of temperature-fall, the areas of ten and twenty-degree temperature-falls can be taken from suitably prepared tables. The agreement of the computed and observed areas is on the whole tolerably satisfactory. It is difficult to estimate the accuracy of the method without a map for each special case. There are two cases where the method fails badly, those of Dec. 5, 1885, and Dec. 20, 1887, when there were twenty-degree fall areas of 863,000 and 723,000 square miles and the method gives no twenty-degree fall. There are twenty-four cases where the observed area being 300,000 square miles or more, the computed is less than half the observed and may be classed as not good. There are four cases of over 300,000 square miles where the computed area is more than twice as great as the observed area. In the other cases the agreement is tolerably good.

Shape and Position of Twenty-Degree Temperature-Fall Area.

In the case of areas of twenty-degree fall greater than 200,000 square miles when the "high" is to the northwest of the low area, the ratio of the axes of the area in the average of cases is 2·5 to 1·0 For the case of the high southwest of the low, the ratio is 4·0 to 1·0. In double V-shaped lows and exceptionally long areas of low pressure, the ratio is about 5·0 to 1·0. Lows accompanied by highs no greater than 30·3 inches in pressure have the fall areas of same general shape as the isobars of the low area.

Where the isothermal lines are close together, which is always the case in a great cold-wave, the long axis is pretty certain to be at least two and a half times the length of the short one.

The position of the long axis is usually from southwest to northeast. It is parallel to the long axis of the area of low pressure or parallel to the general direction of the isotherms. It is always sure to extend in the direction of the open end of the low area of pressure. The shape of the ten-degree temperature-fall area pretty generally conforms to the shape of the twenty-degree fall area. The ten-degree falls very generally overlap on successive days. The twenty-degree fall areas rarely overlap and when they do, only slightly, not more than throughout a strip fifty miles in width in the case of the very greatest cold-waves. The larger the twenty-degree fall areas are, the more likely they are to be just tangent to each other or slightly overlap. When a well-defined area of twenty-degree fall has already occurred, a consideration of its distance from the center of low pressure, or point of prospective greatest temperature-fall, is of service in determining what the length of one axis of the twenty-degree fall may be the next day.

At the southern limit of a cold-wave, when there is doubt about the position of the lower boundary of a temperature-fall area, the wind direction is useful in locating its position. In the lower Mississippi valley, when the winds having been northwest, and there have been falls of temperature to the north, and the winds turn to the northeast, no farther falls in the vicinity need be anticipated.

Tables and charts have been prepared showing the lowest and highest 7 A. M. temperatures that have occurred in the months of November, December, January, February and March. These are of use in locating the areas of fall and in estimating by differences the low temperatures that may occur to the east, by comparison with what has already occurred where a cold-wave is prevailing.

There is very little time for extensive or elaborate computations in the work of predicting cold-waves. This fact has been borne in mind in devising the method. It will not require more than half an hour to apply it in any particular case. Planimeter measurements of the extent of high and low areas of pressure were resorted to in the special cases used in determining the constants of the formula. But this is not necessary in determining the extent of an area of low pressure in the prediction of cold-waves. The area computed from the measured lengths of the greatest and least axis of the outside isobar of the area will be sufficient. Considering this area as the base of a cone, and the altitude as the difference between the outside isobar and the lowest barometer reading, its contents can be computed with sufficient accuracy for the purpose required.

The predictions of cold-waves according to this method will be better than those of the past in that part of the country south of the States of Missouri and Kansas and south of the Ohio River. Not much improvement can be expected in the far northwest, where there is no opportunity to measure the extent of the "high," where it is apt to be over a country not covered by observation. Neither can the method give much improvement in the New England States, where the "low" is often out over the ocean and the "high" to the north of the Dominion of Canada. The use of the rule for computing maximum fall will, however, make some improvement in the predictions for these regions. Though only adapted for giving the temperature at the place of greatest fall, it can nevertheless be used for other places, and will give a value for the fall that will certainly not be exceeded.

Fuller details for the use of this method in prediction of cold-waves will be found in the annual report of the Chief Signal Officer for the year 1890.