park, and it was found that the average difference almost equalled that for September.

The following quotation is from an article "On the influence of the accumulations of snow on climate," by Alexander Woeikoff, Quarterly Journal of the Royal Meteorological Society, Vol. XI, 1885, p. 299.

A covering of snow on the ground acts, firstly, as a bad conductor, rendering the interchange of temperatures between the surface of the ground and the lower stratum of air much slower than when the snow is absent.

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We see that as a covering of snow protects the upper parts of the ground from radiation and makes the conduction of heat much slower than it would otherwise be, it thus tends to raise the temperature of the soil; but it must have a contrary influence on the lowest stratum of the air, as the snow protects it from the conduction of heat from the ground, an action which, as this is generally warmer in winter, must make the lowest stratum of the air colder. This it undoubtedly does; but in this respect another quality of the snow is even more important, namely, that it is a good radiator of heat.

The influence of smoke from the factories of the city upon the minimum temperature differences has also been studied. It was invariably noticed that on the day preceding a night with an unusually large minimum temperature difference, the wind which had been from the north, became calm. On the eastern horizon the smoke of the city appeared very dense and extended upward to an unusual height, while at the park the sky was very clear. On the following morning the wind changed to the south and gradually increased in velocity.

If two or more consecutive days showed a remarkable difference in the minimum temperatures at our two stations, as was the case in January, 1892, it was because the air remained calm and clear at the park, while the smoke appeared to be heaped up over the city. Invariably at such times the barometer indicated the presence of the crest of an area of high pressure, and its passage accounted for the change in the direction of the wind.

It thus appears that the principal cause of the difference in the minimum temperature readings at the Forest Park and the Weather Bureau observatories is the accumulation of smoke over the city, especially on nights when the sky is clear and the wind light. These conditions favor a rapid radiation of heat from the ground at the park, while the smoke over the city acts like a cloud covering and materially retards radiation.

It is well to notice here the advantages that arise from selecting the northwesterly sections of a city for residence purposes and southeasterly sections for manufacturing purposes.

## STUDIES ON THE STATICS AND KINEMATICS OF THE ATMOSPHERE IN THE UNITED STATES.

By Prof. FRANK H. BIGELOW.

### I. A NEW BAROMETRIC SYSTEM FOR THE UNITED STATES, CANADA, AND THE WEST INDIES.

On January 1, 1902, at the 8 a. m. observation, seventy-fifth meridian time, a new system for the reduction of the station barometric pressures to the sea-level plane, was put in operation for the United States, Canada, and the West Indies. The daily weather maps used in forecasting the intensity and the path of storms, and the other allied phenomena, are therefore constructed upon a basis differing from any hitherto used. Students who consult the published weather maps should remember that the series terminating with the above date is not comparable with the others following it, the difference at some stations on the Rocky Mountain Plateau for certain seasons of the year amounting to several tenths of an inch of pressure by the mercurial barometer. The problem of reducing the pressures observed at stations located on the Rocky Mountain Plateau to sea level has always been recognized as one of unusual scientific difficulty, and it has been under discussion in the Washington Office at intervals ever since the establishment of the Government service. So far as can be judged at the present writing the success of the new system is assured, and if this favorable opinion is confirmed by continued use, it will mark the termination of thirty years' effort to solve this question in a practical form. The other plateau districts of the world, Mexico, South America, especially Argentina, south Africa, Australia, and southern Asia, will doubtless profit by the experience of the United States Weather Bureau, on consulting the solution adopted for the United States, Canada, and the West Indies.

Prof. R. F. Stupart, Director of the Canadian Meteorological Office, has courteously cooperated by supplying the necessary data for the Canadian stations, since the common interests of both countries require the adoption of the same methods of barometric reductions. There is no task properly belonging to the Weather Bureau upon which more time and labor has been expended than upon this problem, and the present discussion is the sixth well defined attempt to reach a satisfactory conclusion. The importance of putting the barometric pressures on the elevated plateau, covering one third of the territory for which the official forecasts are made, on a satisfactory scientific basis, fully justifies this work, because it is of primary importance not to attribute to weather conditions any pressure changes that are in reality due to the method of reduction to the plane of reference.

#### PRELIMINARY REMARKS.

The eastern and central portions of the United States and Canada are generally at levels less than 1,000 feet above the sea, and also the Pacific coast is at low level, so that for these districts the barometric reduction offers no difficulty. Between these, throughout the Rocky Mountain region, there is a rough country where the stations are at different elevations up to 7,000 feet, where the surface temperature conditions range enormously, say from $-40°$ F. to $+60°$ F. on a single map in extreme cases, where the prevailing winds from the Pacific Ocean produce one type of weather on the western slopes of the mountains and another on the eastern, to say nothing of the effect of great arid districts between them, and where the configuration of the mountain valleys, in which many of the stations are located, relative to the neighboring ranges rising up to 12,000 or 14,000 feet in some cases, causes various local peculiarities in the behavior of the barometer.

A description of the construction of our new station pressure normals is properly a preliminary to the solution of the plateau problem. In the years between 1871–1880, while the barometric network was being extended over the plateau districts, many of the elevated stations were at the Army posts where no measurement of the altitude had been made, except by the barometer. We now know that several of these early elevations were seriously in error, say from 10 feet up to 200 feet, and as a change of 10 feet in altitude corresponds approximately to 0.010 inch pressure, the irregularities on the sea-level plane arising from this source alone were not inconsiderable. The gradual extension of the various surveys by the Government over the plateau, together with the railroad levels executed and revised by the different companies, have gradually built up a system of check levels at intersecting points, with accurate differential levels between them, so that now the absolute elevations of the several stations have been determined with much accuracy. An adjustment of these levels was made by Prof. Cleveland Abbe in 1871–72; the work was then taken up by the Geological Survey, and the latest results of these surveys are given in Gannett's Dictionary of Altitudes, edition of 1900. The Weather Bureau was supplied with the corrected altitudes before the publication of this report by the Geological Survey, so that we have had the advantage of this data from an early stage in our own work.

THE ADOPTED STANDARD ELEVATION FOR THE EPOCH, JANUARY 1, 1900.

Besides the incorrect actual elevations which, for one reason or another, have been adopted during thirty years, there have been numerous changes in the elevation of the local offices of the service at the same station, involving many small variations in the altitude above sea level. A very careful reexamination of the station records of the respective stations showed that it was practically impossible to assign correct absolute elevations for the several changes as referred to the sea level, but that it was possible to discover the differences by which the successive changes in height followed each other (that is, the height of the barometer in the new office above or below that in the old office), the series of variations giving a chain of steps up and down in the succession of changes. These were carefully determined, and they were then applied to the elevation occupied by the station at the epoch January 1, 1900, so that the actual heights were thus found for the respective intervals during which the barometer remained in one position, and they were referred in this way to our latest and best elevations as given by recent surveys. Having adopted the elevation for the station at the given epoch, all the recorded actual pressures were reduced to the elevation of 1900 by small differential pressure corrections, so that the entire pressure system becomes homogeneous for the station.

During the years following 1900 a similar plan is to be followed, and all pressures will be reduced back to the standard elevation, so that the series will be maintained strictly comparable throughout the life of the station itself. There is great advantage in this procedure, for two reasons. It was found that in the other attempts to construct pressure normals the earlier computations were readjusted to the latest elevations at the different dates, thus obscuring the record and consuming a great amount of labor without arriving at final results. Also, the reduction tables to sea level, provided for the use of the stations, had to be renewed with every removal, which also consumed much time. On the new plan, however, each year's observations is added directly to a homogeneous station system, and the same reduction table serves without modification in consequence of any local changes. Indeed it is absolutely essential to reach such a basis of operation in meteorology as this, if there is to be made possible a scientific study of the secular variations of the weather, that is, the large problem of why and how the seasons, the climate, and the crops, differ from year to year, this being the next great problem awaiting practical meteorology. Evidently all the cosmical questions involving variations in the radiations of the sun must be compared with as definite a pressure system as this, if scientific results are to be secured from the meteorological data. It may be stated in passing, that in recent years, since the Government has erected large buildings in the cities of the United States, the Weather Bureau offices have been more permanently located, and that the average series of unbroken observations is growing longer than it used to be 10 and 20 years ago. At the same time the elevations are a little higher, because the offices are usually placed in the upper rooms of the lofty federal buildings.

OTHER CORRECTIONS TO THE STATION PRESSURES.

Besides reducing the observed pressures to an adopted station elevation it was necessary to make several more corrections in order to obtain a homogeneous system of normals. (1) The records were thoroughly inspected for the several corrections which ought to be applied to the barometer readings, and we have now a complete list of the barometer numbers and their errors for capilarity, scales, etc. Besides eliminating a few mistakes, there were two important special corrections to be applied. During the interval 1873–1878 a correction of 0.013 inch had been added to the Signal Service standard barometer to reduce it to the supposed Kew standard, but a system of comparisons instituted in 1877–78 showed that this was probably an error, and I have, therefore, removed it from the new series. A policy prevailed in the office from 1888 to 1898 to the effect that small errors could properly be neglected in the barometer reductions, and in accordance with it all corrections for scale error and capillarity smaller than $\pm 0.007$ inch were discarded; these have now been all restored. (2) The correction to standard gravity, at sea level on the forty-fifth parallel of latitude, was applied during some years and omitted during others, so that there was irregularity in this respect. The gravity correction has now been systematically added by me since the beginning of 1873. (3) The hours of simultaneous observation have been changed several times since the opening of the service, but practically the observations can be grouped in two series of selected hours, 7 a. m., 3 p. m., 11 p. m., till June 30, 1888, and 8 a. m., 8 p. m. since that date. Referred to the mean of 24 hourly observations which is the natural standard to adopt for the world, these two systems present very different types of corrections for the North American Continent, and they must be reduced to some one system in order to be comparable. Accordingly auxiliary tables were prepared by which observations at a few selected hours could be reduced to the mean of 24 hourly observations, and the different series have been so corrected since January 1, 1873. These 24 hourly corrections will be applied in the future to all monthly and annual pressures published by the Weather Bureau, so that the fundamental system may remain intact in case other hours of observation should ever be adopted, differing from those now in use.

The application of the corrections for local elevation, scale error, capillarity, instrumental temperature, gravity, and diurnal variation, to the barometric readings, gives a smooth homogeneous system of values, from which the mean annual and the mean monthly station normals were derived and checked by cross addition; they are noted as $B$. From these the annual and the monthly variations from the general mean were obtained, and they have been thoroughly discussed in the Report of the Chief of Weather Bureau, 1900–1901, Vol. II. In order to determine our final station normals, $B_n$, it was further necessary to reduce all the short series to a standard fixed by the long 27-year series for a large number of stations sufficient to control the work. There are about two hundred and sixty-five stations, including the Canadians, to be dealt with, and of these about seventy-five had a long record of twenty-seven years. The run of the monthly residuals increases in irregularity as the number of years of observation decreases, but we have so managed the discussion that a short series normal can be reduced to the long series normal, and thus the station placed upon the standard basis. Whenever a new station is opened by the Weather Bureau a standard normal pressure can now be constructed by a brief computation, and the normal is more accurate than any that could be obtained by fifteen years direct observations, since these take up all the turbulent pressure fluctuations due to the general and local circulations, which it is impossble to eliminate, except by the use of the observations of many years. I may add that my experience with the barometric observations of the United States convinces me that they have always been of a high order of scientific excellence, and that the apparent residuals are not in fact due to accidental irregularities, but possess general and even cosmical significance when they are thoroughly discussed. It has been a mistake to assume that they are not worth the most exact treatment in the reductions; on the other hand there is every reason to believe that they will become of prime importance in the solution of several solar-terrestrial problems.

### THE SEA LEVEL, 3,500-FOOT AND THE 10,000-FOOT PLANES OF REFERENCE.

Having obtained these reliable station pressures throughout the United States and Canada, the plateau problem now comes before us for discussion, in order to reduce the pressures taken at different elevations to the adopted planes of reference, in our case to the sea-level plane, to the 3,500-foot plane and the 10,000-foot plane. All the forecasting problems have been heretofore studied solely on the sea-level plane. But it seems evident that our grasp upon the weather problem will be greatly strengthened if we can study at least three sections through the atmosphere daily instead of the one at the bottom of it. I selected the 3,500-foot plane because this is the average height of the Rocky Mountain stations, to which the least possible reduction is required; also, because it is the average altitude of the base of the cumulus cloud sheet over the eastern districts, upon which observations can be most favorably made with theodolites for gradients of pressure, temperature, and vapor tension. Besides this, it is the altitude at which the moving currents of air are sufficiently distant from the ground to take on their natural configuration when freed from the surface turbulent friction. The 10,000-foot plane was chosen because it is already in use by the MONTHLY WEATHER REVIEW to show the monthly mean isobars at a considerable altitude. Furthermore, it is just in the midst of the most rapid-moving horizontal local currents, which build up the cyclones and anticyclones of the middle latitudes and upon which the intensity of storms depends. We know that the isobars on these three planes differ considerably from one another, the closed curves on the lower plane tending to open out into long sweeps on the upper plane, and it is probable that an intercomparison of these varying isobars from map to map will be valuable.

### THE NEW REDUCTION PRESSURE TABLES.

It is evidently necessary to possess reduction tables of a perfectly general and flexible kind in order to make the necessary reductions from the several stations to these three planes, and from one plane to the other, in either direction upward or downward. As there are no such tables in print, I have first computed logarithmic reduction tables in English measures, similar to those in metric measures, described in the International Cloud Report of 1898–99, the intervals being for every 100 feet up to 10,000, and for every 10° F. from —40° to + 100°. From these general tables the special station tables were made, giving the corrections to be applied to the station pressure at intervals of 0.20 inch to reduce it to the three planes, respectively. These individual tables contain a correction for the humidity term separated from the dry-air term, a correction for the plateau effect, a residual reduction for a few stations, and two temperature arguments—first, the mean temperature of the air column, and second, the corresponding surface temperature, which is the mean value of two successive 8 o'clock observations, the last always including that hour for which the reduction is made. In order to simplify matters as much as possible for the observers on the stations, the individual station tables are constructed by combining all these corrections and applying them at short intervals of the station pressure, namely, for every tenth of an inch, and for such close intervals of the temperature argument that there shall be no interpolation necessary in this direction in order to obtain the hundredth of an inch of reduced pressure. The result is contained in three tables, one for each plane, with the surface temperature and station pressure as the arguments, and the reduced pressure to the three planes, respectively, in the body of the table, instead of the correction to the observed pressure. There is thus no computation to be done at the station to reduce the observation, and the time consumed in preparing this portion of the cipher code message is very short. The special tables for the stations for use in reduction to the 3,500-foot and the 10,000-foot planes are now being made up, the first and the second forms leading up to them being completed and checked. The tables for reduction to sea level are already in operation, and, so far as known, there is no occasion to modify the reductions at any of the stations. When one considers the large amount of painstaking and careful labor required to produce such a result as this in so complex a problem, it is a pleasure to commend the faithful work of Mr. Heiskell and Miss Hawkins, who have been my assistants in this computation. We hope to be able to make a trial of the working of the pressures on the higher planes before very long.

### PREVIOUS DISCUSSIONS OF THE PLATEAU PROBLEM.

After all these preliminary matters have been concluded we may proceed to the really difficult portions of the work. They group themselves around three points, (1) the proper relation between the observed surface temperature, $t$, and the mean temperature of the air column, $\theta$, corresponding to and substituted for the plateau at the regular intervals for which the general logarithmic reductions were computed; (2) the effect of the plateau itself upon the free air pressure; (3) the residual local effects which can not be classified with the other reductions. These will become clearer to the reader by briefly mentioning the previous methods which have been employed in reducing the plateau pressures to the sea-level plane. (1) From 1871 to June, 1881, the old Guyot tables were used in reducing low-level stations, with the surface temperature and pressure at the time of observation as the argument. Certain annual constants were employed in the cases of high stations. The effect was to cause the isobars to swing widely between the morning and evening hours, and generally the maps were very unsteady. (2) July, 1881, to June, 1886, monthly constants were used for each station, as recommended by the first board on barometer reductions; a single constant answered for each month; these are sometimes known as the Abbe–Upton constants. (3) July, 1886, to June, 1887, the entirely new system of tables by Professor Ferrel was used, thus introducing several valuable principles. Thus, the mean temperature of the preceding twenty-four hours was used instead of that belonging to the respective hours of observation; this was reduced by a vertical temperature gradient, 0.165 per 100 feet, to the approximate mean of the column; the pressure and temperature arguments $(B, t)$ were both employed in entering the table; a special correction for the plateau effect was made in the form $C, \Delta\theta, H$, where $C = 0.00105$, $\Delta\theta$ is the variation of the temperature from the annual mean, and $H$ is the altitude in units of a thousand feet. The application of the correction for the plateau effect removes the wide range in pressure which occurs on the plateau between summer and winter and reduces it to about the same value on the plateau and in the low level eastern districts. For example, if the mean annual temperature is 50°, that for January 25°, and for July 80°, at a station 5,000 feet above the sea level, we have $0.00105 \times (-25) \times 5 = -0.131$ inch for January, and $0.00105 \times (+30) \times 5 = +0.158$ inch for July. The annual range for high stations on the plateau is about 0.400 inch, and on the low levels it is only 0.150, the difference being simply the plateau effect. Professor Ferrel's tables were not used very long. (4) July, 1887, to December, 1890, a mixture of Ferrel's and Hazen's tables; 1891–1901, Hazen's tables. Professor Hazen constructed a general empirical formula with the object of simplifying the form of the station table. For this purpose he assumed that Mount Washington is the type for the plateau reductions, which is in fact erroneous, since that isolated mountain acts like a free air point, except for the modified value of $\theta$; he assumed that the sea-level pressure should always be exactly 30.00 inches, and at the same time abandoned the pressure argument entirely, with all depending upon it, and computed the correction under these conditions; he rejected the plateau effect correction, and at the same time the change of surface temperature to the mean temperature, $\theta$, was neglected. On applying this system to the daily map it was necessary to make certain arbitrary changes in the computed reductions in order to produce smooth isobars. The great simplicity in the use of this table, having only the surface temperature as argument, seems to have been considered sufficient ground for substituting these tables for Ferrel's, so that from 1891 till 1901, inclusive, they have been employed in making the daily weather maps, although well known to be unscientific and inaccurate. However, it should be said that although the plateau correction was omitted, the practical working of the Hazen method was such as to make the sea-level reductions conform much more closely to the Ferrel system than to the pure Laplacean system, which is correct for free air reductions only. On this account the Ferrel and the Hazen systems work in the same direction for wide departures of the temperature from the annual mean, and to some extent relieve the plateau exaggeration, so that we conclude that the weather maps have served fairly well for the practical purposes of forecasting. (5) 1895–1896, Professor Morrill, in connection with a second board on barometry, rediscussed the problem and computed a set of tables which have not been published, though they have been used for some office work, especially the construction of the sea level and the 10,000-foot plane maps for the MONTHLY WEATHER REVIEW during 1896–1901. The Laplacean free air reduction was computed by special tables for the pressure and the temperature arguments, the value of $\theta$ being found by certain adopted average vertical gradients varying for the different seasons of the year; the humidity term was made so as to modify the logarithmic argument; the plateau term was entirely omitted; the tables were in the form of a logarithmic argument, which was not very convenient for rapid work. It was suggested at the same time that a system of constants, daily rather than monthly, be resumed for making the necessary forecasting isobars.

### BIGELOW'S SYSTEM OF BAROMETRY, 1902.

We now come to the sixth attack upon the problem, and shall here merely enumerate the steps in the discussion, while the report itself will be found in Volume II, Annual Report, Chief of Weather Bureau, 1900–1901. In substance the principles laid down by Ferrel have been adopted, but the work has been carried far beyond the degree of perfection possible to him nearly twenty years ago, in consequence of the numerous observations at our disposal, whereas Professor Ferrel contented himself with only four years of observation at the plateau stations preceding the time of his studies.

### THE SEA-LEVEL TEMPERATURES.

The object to be obtained is to separate the temperature argument from the plateau effect, and to arrive at smooth isobars in correct relations to the winds and the weather throughout the Rocky Mountain region. Having prepared the monthly station pressure normals, as described above, the corresponding station temperature and vapor tension normals were extracted from the office records. The plateau is therefore to be considered as dotted over with 60 or 70 stations where the monthly values of the elements ($B$, $t$, $e$) are known. Assuming an average vertical temperature gradient of 0.30° per 100 feet, the temperatures were first reduced from those given at the station elevation, to corresponding values at selected heights, 500, 1,500, ...... 6,500 feet, through short distances; for example, all between 0 and 1,000 feet were corrected to 500 feet, and so on. This concentrates the reductions on a few planes. Then a preliminary set of temperature gradients in latitude and longitude was computed from the temperatures on these few planes, throughout the region west of the Mississippi Valley. Certain *centers of reduction* were taken, namely, where the one hundred and twentieth meridian crosses the fiftieth, forty-fifth, fortieth, and thirty-fifth parallels of latitude, and the one hundred and tenth, one hundredth, and ninetieth meridians cross the same parallels, and the temperatures were reduced by the two horizontal gradients to these centers, so that a series of temperatures varying with the altitude are now known in vertical directions, at about 18 geographical points. These temperatures were plotted on a diagram whose abscissas are temperature values and whose ordinates are altitudes, one chart for each month and one for the year; average curves were drawn through the plotted temperatures and prolonged by best judgment to the sea level. In the majority of cases it was easy to do this, as the curvature was distinctly developed on the diagrams. In this way sea-level temperatures were found at several evenly distributed points beneath the plateau, and they were transferred to monthly charts on the sea-level plane, which were completed for the Pacific low level districts and for the central and eastern portions of the United States and Canada. A system of well graded isotherms was drawn through them for the entire country. Small adjustments of the temperatures on the centers of reduction were required to make the temperatures of the vertical system and of the horizontal system interlock harmoniously and agree together on the sea-level plane. Furthermore, new and more accurate temperature gradients in latitude and longitude could now be obtained, and the work was therefore repeated from the beginning to the end with the improved values. The adopted temperature system is the result of two or three such approximating computations, so that it has at last sufficient reliability to become the substantial basis for further reductions. The sea-level temperatures at the several stations can easily be scaled from these charts to the tenth of a degree, and such values are called $t_o$. The use of centers of reduction commends itself by the fact that the stations can be grouped in several ways, since the same station can be reduced to different centers, and the local inaccuracies will thus check themselves out; also by the fact that the entire amount of computation is much smaller and its accuracy can be controlled by the algebraic differences for uniform spaces. The most important result of this discussion is the development of well defined temperature inversions during the winter on the northern Rocky Mountain slope, and in the summer in the southern California districts. The former are due to the dynamic heating of the air blowing eastward over the Rocky Mountain divide, and the latter to the excessive surface heating of the arid region relatively to the temperature of the Pacific Ocean. The introduction of these inversion gradients relieves the congestion of the isothermal lines heretofore drawn in these districts.

### THE FIRST PRESSURE REDUCTION TO SEA LEVEL.

Finally, the relative humidities were assumed to be the same for the surface and the sea-level plane throughout the plateau, and from the values of $t_o$ just found the corresponding sea-level vapor tensions, $e_o$, were computed. We have thus obtained all the elements required for a reduction of the surface pressure, $B$, to the sea-level pressure, $B_o$, by taking as a first approximation $\theta = \frac{t + t_o}{2}$ and the ratio $\frac{e_o}{B_o}$, where $B_o$ is nearly 30.00 inches for all monthly means. Using our new logarithmic tables, the monthly and annual pressure at each station in the United States and Canada was reduced to sea level, and the results were transferred to charts. Isobars were drawn through these sea-level pressures as accurately as the data permitted, though the values of $B_0$ were quite discordant in many places, and the lines somewhat in doubt. Of course the plateau correction was included in the sea-level reduction, as stated above.

TO FIND $t-\theta$.

For practical working by the tables, it was first necessary to determine the relations of $t$ and $\theta$ for the entire range of temperatures throughout the year, and this was a task of no little perplexity. It was, however, finally accomplished by two processes. It will be remembered that in the Abbe-Upton system of monthly constants and in the Hazen empirical tables this modification of the surface temperature argument was omitted; that Ferrel used a constant vertical gradient of 0.165° per 100 feet for the year to pass from $t$ to $\theta$, and that Morrill modified this gradient by taking per 100 feet, 0.150° in winter, 0.200° in spring and autumn, and 0.250° in summer. My vertical temperature gradient came out about 0.195° for each month in the year, as the average for the entire plateau, but it was distinctly shown that the several portions of the plateau have very different gradients in the same month, and that for the same locality they change greatly from month to month. Hence it was improper to attempt to deal with the plateau as a whole by using the same temperature gradient; so that, in fact, each station must be considered not only by itself, but also in its relations to the neighboring stations. Finally, special curves have been constructed for temperatures between $-40°$ F. and $+100°$ F., showing the variable difference between $t$, the surface temperature for twenty-four hours, and the corresponding $\theta$, or the mean air temperature of an air column substituted for the plateau itself. The $\theta$ can not be considered as the arithmetical mean temperature between the surface and the sea-level temperatures, because the connecting line is a curve and is not straight, so that it is essential to arrive at an integral mean temperature instead of an arithmetical mean. In a graphical construction the values of $\theta$ may be taken as the abscissæ and the differences, $t-\theta$, as the ordinates of a curve, which we seek to construct. The first approximation is evidently equal to $t-\theta = t - \frac{1}{2}(t+t_0) = \frac{1}{2}(t-t_0)$, but the true value may differ from this by several degrees at many of the high stations.

THE FIRST PROCESS.

We proceeded to discuss this point by two distinct methods, the first covering the low temperatures from $-40°$ to $+30°$, and the second covering the temperatures from about 10° to 90°, so that there shall occur a small overlapping of the two systems in the middle temperatures, and thus allow the two to be joined together. About fifty maps were selected for the winter season, when high pressures and low temperatures prevailed in the Rocky Mountain districts. The pressures for the plateau stations were next reduced to the 3,500-foot plane, because this requires the least average run for the corrections, and hence there is little error arising from selecting the wrong temperature arguments. This configuration of isobars was drawn in red lines; then the low stations near the Pacific Ocean and those in the Mississippi Valley were reduced to sea level; also some of the stations on the mountain slope at moderate elevations were reduced to the 3,500-foot plane as well as to sea level. A set of isobars was drawn on the sea level in blue lines. It was now assumed that the configuration on the 3,500-foot plane is substantially correct for that elevation. and is what the forecaster really wants at sea level for practical work. It was therefore joined with the sea-level system by simply making the red and blue lines flow together and uniting them smoothly; in other words, the upper configuration was depressed to sea level by simply renumbering the isobars in inches as determined by the true sea-level lines, so that a single system of well-balanced isobars covered the country. Next the question was, what is the value of $\theta$ that will be required to transform the observed station pressure into the sea-level pressure thus constructed? This was computed from the data in a reverse direction, and the differences, $t-\theta$, found; these were collected by groups for each station on the plateau above 1,000 feet in elevation; the means were taken and plotted as ordinates on the abscissa axis of $\theta$. The result was very instructive, and it at once separated the plateau into groups corresponding to the geographical and climatic location, and showed that all the attempts to use one value of the vertical gradient for a given time is very erroneous. It should be remarked that the value of $t-\theta$ thus found was much too large, because it included within itself the real plateau effect, and this ought first to have been separated; but it gave true relative variations of $t-\theta$ with the range of temperature from $-40°$ to $+30°$, so that it was only necessary to discover the reduction factor to make the scale of values correct.

THE SECOND PROCESS.

For the warmer temperatures of the year, from $+30°$ to $+90°$, I took the mean monthly values of $t$ and $t_0$, surface and sea-level temperature, respectively, and found $t-\theta = \frac{1}{2}(t-t_0)$ and $\theta = \frac{1}{2}(t+t_0)$. These were plotted month by month in coordinate points through which it was easy to draw approximate mean curves. It is noted that during the winter months the ordinates average a little larger for the same values of $\theta$ than during the summer months, but as we are limited to constructing a set of tables representing mean conditions, this mean line is the best that can be taken. The variation on the mean line does not often exceed $\pm 1°$, and this small change in the resulting argument has really but little influence upon the sea-level reductions which are required. Finally the slope of the second system of curves at the temperatures from $+10$ to $+30°$ indicated the slope that should be assigned to those found by the first method, that is, they gave us the scale factor for reducing the slope first obtained. The resulting curves are published in the full report, but they can hardly be described without diagrams. Generally speaking, on the north and east of the plateau the $(t-\theta)$ curves have a short ordinate from 10° to 40°, and a considerable increase toward either end; on the central portions of the plateau the curves are nearly flat, the length of the ordinates being about proportional to the altitude; on the western side of the plateau the curves have ordinates which are longest in the central parts and shortest at the ends, that is to say, they are about reversed in shape from those on the eastern plateau. These differing results are largely due to the climatic effects of prevailing winds from the Pacific Ocean, which blow upon the mountain ranges and precipitate their moisture on the western side; the clear skies and cold waves prevail on the eastern side; also there are seen to be certain dynamic heating effects. This subject is, however, too large to expand in this connection.

THE SECOND PRESSURE REDUCTION TO SEA LEVEL.

Equipped with these first approximate values of $\theta$ for each month as derived from the surface $t$, the reductions to sea level were made for the mean monthly normal station pressures, $B_0$, as already mentioned, and the corresponding isobars were drawn. The sea-level pressures, as shown by the resulting map itself, apart from the reduced values, are really more nearly well balanced and correct than those derived from the individual reductions, because the isobars depend upon the mean result of many neighboring stations, whose mutual claims must be simultaneously satisfied in drawing the pressure lines. The pressures were, therefore, scaled from the maps, giving $B_m$, and the differences taken between them and the original values as reduced by the computation for $B_0$-$B_m$. The outcome was exceedingly valuable and suggestive. For some stations the differences between the map and reduced values were such as to indicate only minor irregularities of a few thousandths of an inch, and these are to be referred to imperfections in the station normals; for others the difference was nearly constant, suggesting an error in the assumed elevation, especially for the old stations at military posts where the elevation had been derived from barometer readings; for others there was a very marked annual period in the differences, which could only be due to an error in the assigned value of the mean temperature, $\theta$, since the differences disappeared at certain points, the signs being reversed between the low and the high temperatures. To be brief, all these sources of difference were removed, the entire work was recomputed a second time, a new system of isobars was drawn, and generally the entire subject was worked over in every available way. The practical effect was a readjustment of some elevations, and of the values of $\theta$, so that the final differences between the map and the reduced sea-level pressures became small, usually less than one hundredth of an inch (0.010 inch), for the long record stations. In a few cases it was found that the constant error, called $\Delta A$, was due to the fact that the initial temperature from which the plateau correction was computed, namely, $C \Delta \theta H$, was not accurately chosen. Usually this was taken as a mean annual temperature, but for some stations, especially on the southwestern edge of the plateau, Santa Fe, Flagstaff, Modena, Independence, etc., it should have been somewhat different. The variation can not be due to elevation, because this has been carefully determined by the surveys, but it must be caused by the local influence of the great desert in connection with the adjacent lofty mountain ranges. There are other stations of low elevation, lying in the eastern or in the Pacific coast districts, where no important error can arise from the reduction data, at which there is a small constant correction required to make the station harmonize with the others, as, for example, Lynchburg, Va., and Portland, Me. These stations have been known, at the Central Office, to act out of perfect harmony with their surroundings, and it is still difficult to understand the causes of these discrepancies. It has been found, furthermore, that the low stations on the north Atlantic and south New England coast and also on the north Pacific coast, are not so perfectly in accord as might be expected, and this may be due to the effect of some land and sea action which is operating in these localities. On the whole the reductions as completed are very reliable when all corrections are applied, that is to about 0.010 inch, under all possible circumstances. We note further that the differences outstanding between the finally adjusted reductions to sea level from the station normal pressures and the map pressures derived from the balanced system of isobars, can be properly considered as corrections to the station normals which will reduce them to the homogeneous or balanced normals. This is distinctly true for stations of short record, e. g., two or three years, where the monthly variations are really considerable, so that by applying these residuals as corrections the station normals are brought to agree with the more correct system which would be derived from a long record of observations. In short, since the long record stations really control the map construction, the short records can be at once improved by applying these small final residuals. Such residual corrections have, therefore, been added to all station normals, and the entire system is thus reduced to a long range homogeneous system and it is called $B_n$, normal pressure at the station, and $B_m$, normal pressure at the sea level. These values become our standard normals for further developements and have been so used in the remainder of the work. It is also evident that whenever a new station is opened, we can easily compute a more correct station normal pressure, by starting with the values of $B_m$ as interpolated from the map, than could be found by less than fifteen or twenty years of observations.

PRESSURES COMPUTED ON THE 3,500-FOOT AND THE 10,000-FOOT PLANES.

We have now obtained the following quantities: At the stations, $B_n$, $t$, $e$, $R. H.$, normal pressure, temperature, vapor tension, and relative humidity; on the sea-level plane, $B_m$, $t_0$, $e_0$; also the ratio $\frac{e}{B}$ was computed for use in the reductions. It is next proposed to compute $B_1$, $t_1$, $e_1$, on the 3,500-foot plane, and $B_2$, $t_2$, $e_2$, on the 10,000-foot plane. For this purpose the temperature gradients in the free air must first be determined. There are three sources of information available, namely, the European balloon ascensions, the American kite ascensions, and the Washington gradients derived from computation on the cloud formations observed with the theodolites in 1896–97. These were all thoroughly discussed and they agree together sufficiently well to permit the assignment of average gradients from the surface to the two upper planes in the free air. The temperatures were computed on these planes for enough stations to permit drawing systems of isotherms with accuracy. As regards the 3,500-foot plane, the temperatures were found from the free air gradients for stations outside the plateau and of lower elevation than 3,500 feet; for points within the plateau the temperatures on that plane were taken from the diagrams of vertical temperatures, previously constructed; these two systems agree well together, and the isotherms are continuous. The isotherms on the 10,000-foot plane are simple curves joining the Atlantic and Pacific districts and present no trouble in crossing the plateau. There is one result of interest, however, at the surface of the plateau, which I call "gradient refraction." Within the plateau the vertical temperature gradient averages about 0.195° per 100 feet, and in the free air for the eastern districts about 0.300° up to 10,000 feet. Now it is evident that this plane is high enough above the plateau to escape the influence of the surface conditions, and that it is in the midst of the rapidly drifting current of air whose direction is eastward, so that quite uniform temperature must prevail along the same parallel of latitude. Hence, it follows that by using the smaller gradient 0.195° to the surface of the plateau, larger values than 0.300° must be employed from the surface to 10,000 feet, if the average gradient is to be about 0.300°, such as it would be if the plateau were removed. Therefore at the surface of the plateau there is something like an abrupt change in the gradients which is similar to refraction. Finally, by means of the temperatures thus found and the relative humidities, assumed to be the same as for the surface stations, the vapor tension on the 3,500-foot plane was computed. For the 10,000-foot plane it was assumed that the relative humidity is 50 per cent of the surface amount at all places; this may be subject to criticism, but it is near the truth and the effect on the vapor tension of even considerable changes in the relative humidity would be unimportant at the low temperatures prevailing at that altitude.

THE FIRST COMPUTATION OF $B_1$ $B_2$.

Instead of computing the values of $t_1$, $e_1$, and $t_2$, $e_2$, for the several stations at the outset, the work was much shortened by interpolating the values of all this data on selected points of the charts, namely, centers of reduction; that is, where the meridians 5° apart, 125°, 120° ...... 65°, cross the parallels 5° apart, 55°, 50° ...... 30°. On these centers of reduction the sea level $B_m$, $t_0$, $e_0$ were also drawn from the charts, so that the data is complete for reducing the sea-level pressures to the higher planes. There are two objects gained by this method of discussion; (1) the work of computation is shortened very much; and also (2) the result affords an admirable check on the entire system of reductions, as will be seen by what follows. The pressures $B_1$ and $B_2$ on the 3,500-foot plane and the 10,000-foot plane, respectively, were computed by the logarithmic tables from the data thus obtained on the centers of reduction, and the corresponding systems of isobars were drawn. There now exists the same general harmony in these isobars as on the sea-level plane, and no further corrections are required. It is to be especially noted that in the plateau region the reductions from sea level to the upper planes were made by the same principles as if it had been a free air column, so that all plateau questions are laid aside.

THE SECOND COMPUTATION OF $B_1$, $B_2$.

From the $B_1$ and $B_2$ charts the pressures belonging to all the stations were interpolated, so that the values of $B_1$, $B_2$, to be derived by a direct computation from the station data could be compared as a check. Meanwhile the several station reduction tables to the three planes had been completed, and as a final check the three values, $B_0$, $B_1$, $B_2$, were computed and compared with the values derived from the charts, as explained in the first process. The differences between the two sets of values for $B_0$, $B_1$, $B_2$ were about the same on the three planes; they average about 0.010 inch, the majority being 0.000 or 0.010 inch, a few 0.020 inch, with occasional larger variations due to errors of computation readily detected, or to a local peculiarity, involving a slight readjustment of the corrections in the station tables. These checks, therefore, involved the three distinct parts of the entire discussion, since the process has been arranged practically in a circuit so as to pass from the station $B_n$ to $B_1$ and $B_2$ by two separate routes, as described. Hence, (1) the processes of eliminating the plateau effect, and of computing the temperature arguments $t$ and $\theta$ were successful; (2) the logarithmic tables and the numerical station tables are in agreement; (3) the charts are accurately drawn, and represent the observations with precision.

As the result of this discussion we have prepared charts for the United States and Canada, giving the monthly and annual normals of pressure, temperature, and vapor tension on the sea-level plane, the 3,500-foot plane, and the 10,000-foot plane, also the relative humidity on the sea-level plane, i. e., 130 charts for these data. There are also charts of gradients of temperature in latitude, in longitude, and in altitude; and charts of pressure variations for a few selected hours referred to the mean of 24 hourly observations. Furthermore, the corresponding numerical values are entered in a summary table for all stations on the sea-level plane, about 265 in number; also for all the stations which were in use by the Weather Bureau, either in the United States, Canada, and the West Indies, at the beginning of the year 1900, or which have been opened for service since that date, making about 175 on the upper planes.

It has not been found necessary to revise any of the reductions to sea level since the tables were put in operation on January 1, 1902, showing that they bear the test of practical work at the hands of many observers. The station tables for the upper planes will soon be tried, and an estimate made as to their value in increasing the accuracy of the forecast system of the Weather Bureau.

We conclude with the remark that the pressure observations and computations of the United States have been at last placed upon a strictly scientific basis, and that all the corrections required by theory will be systematically applied in the future, and the entire series from 1873 onwards will be kept strictly homogeneous. We shall, therefore, for the first time be ready to take up the problems of seasonal variation of the weather, the changes of the climate and crop from year to year, and also the true cosmical problems involved in the radiation effects of the sun upon the earth's atmosphere. Even if we do not ourselves succeed in resolving these questions, we shall have left this portion of the data in form for others to make reliable discussions.

## THE TERM INDIAN SUMMER.[1]

By ALBERT MATTHEWS, Boston, Mass., dated December 15, 1901.

However much we Americans may abuse our ever changing climate,[2] there is at least one portion of the year upon which we unite in lavishing praise. It need scarcely be said that I allude to that highly indefinite but always delightful period known as the Indian summer. Connected as this season is, both by name and in popular belief, with the aborigines, it would seem as if the name itself must be of some antiquity; yet, so far as my observation goes, it is not until the year 1794 that the expression Indian summer occurs at all, and not until the nineteenth century that it became well established. If the term is, in fact, barely more than a century old, it would again seem as if we ought to be able to trace out its origin with some certainty. Yet such is far from being the case.

It is proper to define the scope of this paper. In a little more than a century there has grown up, as will soon be abundantly proved, a popular belief that there occurs in our autumn a spell of peculiar weather, and to this has been given the name Indian summer. It has been stated that this spell appears in September; that it comes in October; that it occurs in November or not at all; that it takes place in January; that it lasts for three or five days only; that it extends over a period of more than four weeks; that it is peculiar to New England; that it does not occur in New England at all; that it is now more marked than was formerly the case; that in former years it was more pronounced than it is now; that it has at present ceased to occur anywhere. Amid these various and conflicting assertions, it is not easy to arrive at any definite conclusion; but, eliminating the points in regard to which there is divergence of opinion, it is tolerably clear that this supposed spell of peculiar weather is characterized by three special features—by a warmth greater than that of the few days or weeks immediately preceding, by smokiness, and by haziness. It is true that some scientific writers have denied the existence of the increased warmth and have declared that the alleged smokiness is an optical illusion.[3] But the popular belief—and it is

[1] During the past ninety years much has been written about this term, but until now no attempt has been made to give its history in detail or to collect and examine critically the explanations that have been advanced as to its origin. The term is not found in Webster's Compendious Dictionary (1806), nor in his American Dictionary (1828), nor in his Letter to the Hon. J. Pickering on the Subject of his Vocabulary (1817); nor in J. Pickering's Vocabulary or Collection of Words and Phrases, which are supposed to be peculiar to the United States (1816); but it was recognized in the 1841 edition of Webster. Its history was first indicated in the Oxford Dictionary (1900), and some of the extracts there quoted are also given in this paper. Lest it be thought that I have taken these without acknowledgement, I may be permitted to add that of the nine extracts previous to 1883 quoted by Dr. Murray all but one (from De Quincey, dated 1830) were furnished by me.

My attention has been directed to the term for more than twelve years, and this paper is based on material collected during that period. I am, however, indebted to Prof. Cleveland Abbe for turning over to me the extracts and correspondence in his possession; to the editors of the Dial, the Journal of American Folk-Lore, the Nation, and the New England Historical and Genealogical Register for inserting queries in their journals; and to various correspondents for replying to appeals for information. Wherever this has been obtained and used, due acknowledgment is made in the notes.

[2] In 1789 Dr. Rush said: "Perhaps there is but one steady trait in the character of our climate, and that is, it is uniformly variable." (American Museum, 1790, vii, 334.)

Rush was speaking of Pennsylvania, but his remark is equally applicable to the country at large. The sudden and violent changes which occur in our temperature have for three centuries been a favorite subject of comment.

[3] In 1833 a Baltimorean wrote: "Again this redness of the air together with the mechanical irritation produced by the denseness of the aerial vapor, excites a painful affection of the eyes—this sensation, connected with the smoky appearance of the sky, induces great numbers of the inhabitants of this country to believe that the Indian summer consists of a smoky state of the air produced by burning the vegetable decidua which are collected together in the fall season for this purpose, or as