There appears to be little doubt that the use of the mercurial fruit thermometers by the fruit growers is entirely practicable. When this has been thoroughly demonstrated, other types of thermometers may be substituted in the experimental work, in order to make the work less tedious.

It is not to be expected that all orange growers will immediately adopt the fruit thermometer for regulating the time of lighting their orchard heaters; indeed such a sudden, radical change is not to be recommended. In all cases the fruit grower should continue to use accurate, sheltered thermometers to obtain the temperature of the air in the orchard, and when the use of the fruit thermometer is first begun it should be only to supplement the information obtained from the sheltered thermometer. The average fruit grower is likely to meet with minor difficulties in obtaining fruit temperatures at first, and he should not depend on such readings until he is sure he thoroughly understands how to use them.

Probably some growers will prefer to continue to use the old methods of obtaining the temperature, if they feel that the men charged with reading the thermometers are not thoroughly trustworthy. On the other hand, the use of the fruit thermometers will not be difficult in any way after the orchard heating crew has become familiar with them, and it is believed that eventually most orange growers will consider them almost indispensable in handling orchard heating.

During the winter of 1923–24 a large number of records was secured showing the temperature inside lemons on the trees during frosty nights, in the same manner as that in which the orange temperatures were secured. The results of these observations will be published later.

OSCILLATIONS OF THE ATMOSPHERIC CIRCULATION OVER THE NORTH ATLANTIC OCEAN IN THE 25-YEAR PERIOD, 1881-1905 [4]

551.513 (261.1)

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[Translated from the German by W. W. Reed; abstracted and condensed by B. M. Varney]

In the paper: "Die Verteilung des Luftdruckes uber dem Nordatlantischen Ozean, etc.,"[5] were given for each month of the year new charts of mean air-pressure distribution for the whole region covered by the daily synoptic weather charts issued by the Deutsche Seewarte and the Danish meteorological service. Each chart is the mean of the 25 charts of a given month for the period 1881–1905. By the basis of them we may obtain the air-pressure anomalies for that period in the region under consideration. This extensive material furnishes an excellent basis for investigations of nonperiodic changes in the distribution of air pressure as well as of oscillations of the atmospheric circulation over the North Atlantic Ocean and adjacent lands. In the following pages will be set forth some of the most important results of investigations carried out on the basis of these charts. They constitute only a partial elaboration of the material from certain points of view, in order that the investigation should not be too voluminous.

1. *Air-pressure anomalies over the North Atlantic Ocean.*—If we compare anomalies with mean pressures at the intersections of parallels (5° apart) with meridians (10° apart), it appears that in the majority of cases the distribution of the anomaly belongs to a definite system which is a unit in itself. Hence it appeared desirable to confine the investigations to anomalies of pressure over the ocean, leaving out of consideration the extensive adjoining region of the European Continent. The North Atlantic was considered to include the region between 60° and 10° west longitude and from 75° to 10° north latitude. In all there are included 84 intersection points, so that the distribution of anomalies was given by 84 values.

The fact that on the whole the anomaly in the direction of each parallel had the same sign and the same magnitude makes it appear permissible to form mean values in the direction of the parallels for the entire region. Thus we obtain for each month a mean distribution of air-pressure anomaly in a north-south direction between 75° and 10° north latitude. Each value is the mean of the six values between 60° and 10° west longitude. These monthly values give at once a satisfactory view of the kind and magnitude of the departure of air pressure in the month considered, while in their succession they afford a history of air-pressure shiftings over the Atlantic Ocean. This is the first time that a summarized representation of air-pressure departures from normal for a period of 300 months has been compiled for such an extended region of the earth.

In this meridional distribution of air-pressure anomalies over the Atlantic one may very clearly discern the appearance and recurrence of certain characteristic types of anomaly. It is possible, without making too liberal an interpretation of the material, to arrange the 300 successive cases under four types, to which can be assigned indices of intensity of the departures occurring in them.

In type A there lies over the North Atlantic a region of positive pressure anomaly. It extends from the far north to about latitude 50° north, and on an average its center lies near 65° north in the vicinity of Iceland. South of this extends a region of negative anomaly, centered near latitude 40° north, which, gradually diminishing, extends to the thermal equator (10° north latitude). North and south have therefore opposite anomalies, atmospheric pressure in the north being relatively too high and in the south relatively too low. Of the 300 cases, 113, or nearly 38 per cent, fall under this type.

Type B shows the opposite distribution; the negative anomaly reaches from the far north to latitude 50°, with its center at 65°. The positive anomaly extends to latitude 10° north, with its center near 40°. Type B is thus exactly opposed to type A. One hundred and thirty-seven months show the type B distribution, or 46 per cent of all cases. Under A and B occur in the aggregate 83 per cent of all cases. The remaining 17 per cent excepting four cases in which it was difficult to make determination, belong to two other types, which again are opposed to each other.

Type C is related to type A; the positive anomaly usually extends from the far north to 35° north latitude and is centered between 55° and 50° north. The negative anomaly includes the whole southern portion. Twenty-five cases fall under type C. The exactly opposed type D, which is related to type B, appears in 21 cases.

If we combine types A and C, which show a pressure relatively too high in the north and too low in the south, they together include 138 months, or 46 per cent. Under

[4] Geografiska Annaler, 1924, H. 1, pp. 13–41.
[5] Denkschr. der Wiener Akad., Band 93, 1916.

B and D, in which the anomalies are reversed, occur 158 cases, or 53 per cent. The division into these two opposite types is thus nearly equal. A yearly march in the predominance of one or the other could not be determined; their distribution over the individual months is likewise practically uniform. The nature and interrelations of the four types are shown in Figure 1.

From this figure, and from maps not here reproduced, it is seen that these types represent primarily oscillations in the intensity, and to a lesser degree in the position, of the two centers of action in the North Atlantic Ocean, namely, the Iceland LOW and the Azores HIGH. In type A the Iceland LOW is considerably weakened and the Azores HIGH is subnormal; the south-north gradient, which is a measure of the rate of atmospheric circulation in the region, is thereby diminished. Type B, with opposite distribution of anomalies, shows an intensification of the pressure gradient between south and north and thus an increase in the intensity of the atmospheric circulation.

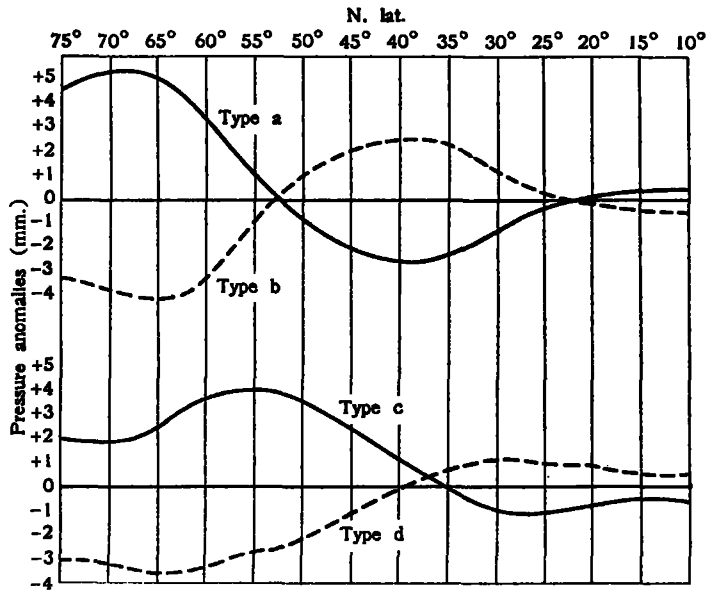

FIG. 1.—Types of pressure anomaly over the North Atlantic Ocean

In connection with the more important types A and B, the question was studied as to what extent positive and negative anomalies compensate each other, or, in other words, whether the deficiency of air mass in the region of negative anomaly probably corresponds to excess in the region of positive anomaly. If this were the case, it would not be too hazardous to assume that these types are produced mainly by the shifting of air masses in a meridional direction. On the basis of a mathematical discussion of the data, it can be said that there is almost complete compensation between north and south. Not only in the yearly means is this the case, but also in the several seasons, though in the latter case not with the same completeness. For the formation of type A, air masses must be shifted from south to north, and for type B from north to south. It is clear that from these strongly characteristic changes of pressure we may draw conclusions as to the intensity of the atmospheric circulation. In the first case the meridional pressure gradients become less steep and the atmospheric machine works with less force, while in the second case the gradients are steepened and the machine works with more force.

2. *The succession of the different types: Oscillations in atmospheric circulation in the years 1881–1905.*—In Table 1 (Table 4 in the original) the monthly values of air pressure anomalies are set forth according to the four types for the 25 years. The attached indices give the intensity of the formation of the type on a scale 0–3, in which there was taken into consideration mainly the amount of the departures;[6] only in a few cases of unusually great anomaly was the index 4 used. The table shows that in certain years the types A and C predominate, indicating intensification of the atmospheric circulation; in others the types B and D, which connote a weakening of the circulation. Because of their close relationship and for the sake of simplicity the types A and C on the one hand and B and D on the other will be combined in the following discussion.

If from Table 1 we combine the frequency of the types into A + C and B + D, it becomes evident that the frequency maxima of the type A + C correspond to the frequency minima of the type B + D, since in each year the two values must amount to 12. Moreover, the march of frequency of both types makes it clear that the pressure anomlies do not follow each other arbitrarily, but that through a rather long series of years first the one and then the other predominates, each oscillation having a period of several years.

TABLE 1.—*Anomalies of atmospheric pressure over the North Atlantic Ocean, 1881–1905*

Year	D[1]	J	F	M	A	M	J	J	A	S	O	N
1881	a_3	a_3	a_1	a_1	b_1	b_1	b_0	d_1	b_0	a_1	b_1	b_2
1882	b_1	b_1	b_0	b_2	a_1	a_0	c_0	b_1	b_0	b_1	b_1	b_2
1883	a_2	d_2	b_1	a_2	b_0	b_0	a_1	a_1	b_1	b_0	b_1	b_1
1884	c_2	b_0	b_1	b_1	a_1	a_1	b_1	a_1	b_1	d_1	b_1	c_2
1885	b_1	d_2	a_3	a_0	a_0	a_1	b_1	a_1	a_3	b_1	c_3	a_2
1886	a_3	c_1	c_1	a_1	a_0	a_1	b_1	b_1	b_1	a_1	b_1	a_0
1887	c_0	b_2	b_1	a_1	a_1	b_1	a_0	b_1	a_0	c_1	a_1	a_1
1888	a_0	a_0	c_1	a_1	c_0	a_0	d_1	a_0	a_0	a_1	a_3	b_2
1889	d_1	a_0/b_0	c_1/b_0	a_0	b_1	b_1	b_2	a_1	b_1	a_1	b_0	b_1
1890	b_0	b_3	b_0	b_1	b_1	a_1	b_0	b_1	b_1	c_0	a_1	b_2
1891	a_0/d_0	c_2	b_0	a_1	a_1	a_0	a_1	b_0	b_1	b_1	b_3	a_1
1892	b_1	c_2	a_2	a_1	a_1	a_1	a_1	b_0	a_0	b_1	a_2	a_1
1893	a_1	a_2	b_2	a_0	------	a_0	a_1	c_0	a_1	a_0	a_1	a_2
1894	b_1	b_1	b_3	b_1	d_1	a_1	b_2	b_1	b_1	a_2	a_1	b_2
1895	c_1	a_2	a_3	b_1	·b_0	b_1	a_1	b_1	a_1	d_1	a_1	b_1
1896	c_0	c_2	b_3	b_1	b_1	b_3	a_1	b_1	c_1	------	a_2	a_0
1897	d_1	a_3	b_0	b_2	b_2	b_1	a_2	b_1	d_1	c_1	d_1	c_1
1898	b_1	b_2	a_0	c_1	b_2	b_0	b_0	b_1	b_1	d_1	b_1	b_1
1899	b_1	b_2	b_2	a_1	a_1	a_1	b_1	b_1	a_1	b_1	a_0	d_2
1900	c_0	b_0	a_2	a_3	b_0	b_1	a_1	a_0	d_1	b_1	b_1	b_1
1901	b_1	d_2	a_2	a_1	b_1	a_1	b_1	b_1	b_0	b_2	b_1	a_2
1902	c_1	c_0	a_2	c_1	a_1	b_1	a_2	a_1	a_1	a_1	b_1	d_1
1903	d_0	d_1	b_2	b_2	a_1	b_1	a_2	a_1	a_1	a_1	a_1	a_1
1904	b_0	b_1	b_1	b_1	b_2	b_2	d_1	d_0	a_0	b_1	b_2	a_1
1905	a_0/b_0	b_0	a_0	b_3	a_1	b_2	b_2	d_0	b_0	b_0	a_1	b_0

[1] The year runs from December to November, inclusive, thus keeping the winter months, spring months, etc., together. Hence December, 1885, for example, falls in the year 1886.

In order better to express the intensity and extent of the anomalies for the purposes of Table 2 and Figure 2, each case with index 0 (Table 1) has been given the weight of 1, each case with index 1 the weight 2, etc., and for each year the sum of all cases was obtained by adding the index number to the frequency number. Since the type B + D showed opposite distribution to the type A + C, if a negative sign be applied to the B + D type, the sum (A + C) − (B + D) becomes an expression of the mean anomaly for a given year and of the intensity of the atmospheric circulation in the region. These are given in the "difference" column of Table 2, (Table 5 in the original), the smoothed values being given in the last column, where a positive number indicates a predominance of the A + C type and thus a weakening of the circulation, and a negative number a predominance of the type B + D and an intensification of the circulation.

[6] No exact statement of the criteria on which the indices were based is given by the author.—*Ed.*

TABLE 2.—*Frequency of the types A+C and B+D, with respect to their strength and development*

Year	Type A+C		Type B+D		Difference	Smoothed values
1881	5_8	13	7_6	13	0	−4.7
1882	3_1	4	9_9	18	−14	−8.8
1883	4_6	10	8_9	17	−7	−7.2
1884	5_7	12	7_6	13	−1	+0.2
1885	8_{11}	19	4_5	9	+10	+6.8
1886	8_8	16	4_4	8	+8	+7.5
1887	8_5	13	4_5	9	+4	+6.5
1888	10_5	15	2_3	5	+10	+3.8
1889	4_2	6	8_7	15	−9	−5.2
1890	3_2	5	9_9	18	−13	−8.2
1891	6_6	12	6_4	10	+2	+1.5
1892	9_{11}	20	3_2	5	+15	+12.0
1893	11_8	19	1_2	3	+16	+8.0
1894	3_4	7	9_{13}	22	−15	−2.5
1895	6_9	15	6_5	11	+4	−1.8
1896	7_6	13	5_8	13	0	−0.5
1897	4_7	11	8_9	17	−6	−7.2
1898	2_1	3	10_{10}	20	−17	−12.0
1899	5_4	9	7_{10}	17	−8	−8.5
1900	5_6	11	7_5	12	−1	−4.2
1901	4_6	10	8_9	17	−7	−0.5
1902	9_{10}	19	3_3	6	+13	+5.8
1903	7_8	15	5_6	11	+4	+0.8
1904	2_1	3	10_{11}	21	−18	−10.8
1905	3_2	5	9_7	16	−11	−13.3

We find as periods of weakened atmospheric circulation the years

1885–1888, especially 1885 and 1888;
1891–1893, especially 1892 and 1893;
1902–1903, especially 1902;

and as periods of intensified circulation the years

1882–1884, especially 1882;
1889–1890, especially 1890;
1894;
1897–1901, especially 1894 and 1898:
1904–1905, especially 1904.

Hence, if one considers only the more significant extremes, the smoothed values show a very uniform march and a mean interval from maximum to maximum or from minimum to minimum of about eight years.

3. *Oscillations of the meridional pressure gradient between latitudes 30° and 65° north.*—Another expression for the intensity of the atmospheric circulation over the North Atlantic Ocean and a comparison with the results already given has been obtained from a study of the oscillations of the meridional pressure gradient. By deriving the monthly anomalies of meridional pressure gradient between any two parallels, and letting a positive sign indicate increase in gradient and a negative sign a diminution, we express the departures of the mean meridional pressure gradient from the normal.

From a table of these departures [not here reproduced] it is evident that extremely marked deviations occur in the several months. The extreme values are −18.9 mm. in January, 1881, and 13.2 mm. in February, 1903. The positive and negative values do not follow each other in an irregular manner, but maintain the same sign for several months and then give place to departures of opposite sign.

There appears to be no simple relation in the sequence of these periods.

In the case of the annual means of the anomalies, the alternation of type agrees exactly with the alternation of the types A + C and B + D. These annual means are expressed for the purposes of figure 2 in percentages of the normal gradient, and are shown in the second curve.

4. *West-east gradient in the far north and the meridional pressure gradient over the North Atlantic.*—Inspection of monthly anomaly charts prepared in connection with this study and of tables showing the monthly and annual anomalies of pressure gradient between the North Atlantic and Europe revealed a striking parallelism between the meridional pressure gradients and the gradient between the North Atlantic and Europe. Anomaly values were found for the east-west gradient in the region from 0° to 40° west longitude and 60° to 75° north latitude, and the graphic representation of them is presented as number 4 in Figure 2, a positive sign there indicating an increase and a negative sign a decrease in the pressure gradient.

Comparison of the curve of frequency of the type (A + C) − (B + D), or even of the meridional pressure gradient with the curve of east-west gradient, shows a

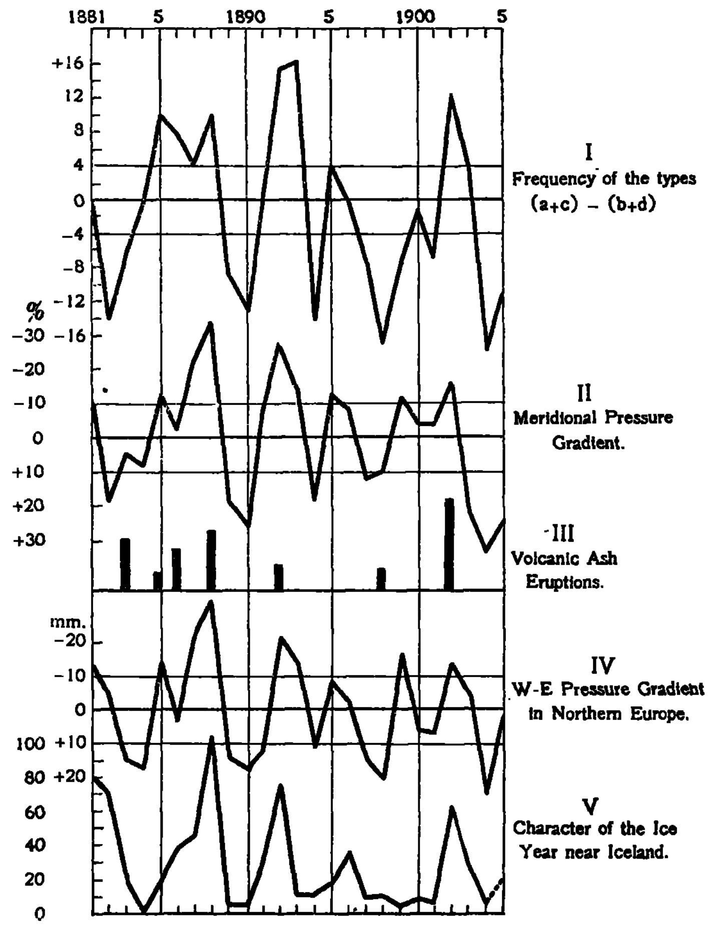

FIG. 2.—Variations in atmospheric circulation over the North Atlantic Ocean, and related phenomena

complete parallelism. Not only in the yearly means is this connection so well defined, but also when we compare the several seasons we find the same agreement. This fact can best be demonstrated by giving the correlation factors between meridional pressure gradient and the west-east gradient:

Winter	+0.76	±0.06
Spring	+0.85	±0.04
Summer	+0.59	±0.09
Autumn	+0.80	±0.05
Year	+0.762	±0.003

The connection seems to be least plainly shown in summer; in the other seasons the correlation reaches the high value of 0.8 with a probable error of 1/16 of r. The value for the yearly mean is calculated on the basis of 300 successive values, the probable error is 1/250 part of r, and the relation is thus extremely close.

Since in the formation of both the meridional and the west-east gradient there is one point in common, the close connection indicates that the anomalies are produced primarily by oscillations in pressure at the common point. This point coincides in general with the central position of the Icelandic depression. Thus it can be said that at times of weakening of this center of action there is conveyed thither for the production of the positive pressure anomaly air both from the Azores high and from northern Europe. With deepening of the depression, air masses are shifted chiefly to the south and west.

A similar shifting of air masses on the occasion of changes in the pressure gradient between central Europe and the North Atlantic Ocean was to be expected, but investigation showed that such is not the case. It appears that pressure oscillations over the Mediterranean Sea are significant in diminishing the influence of the pressure distribution to the northwest—that is, over central Europe.

5. *Relation of pressure gradient to oceanic circulation in the northern part of the Atlantic Ocean.*—Oscillations of atmospheric circulation over the North Atlantic must produce and be accompanied by corresponding oscillations in the water circulation. With strong atmospheric circulation the Gulf Stream flow must be strengthened and thereby its influence extended farther to the north; especially in this case does the Irminger Current [7] gain considerably in extent and volume toward Iceland. The polar front between the warm Gulf Stream Drift and the cold Polar Current thus lies farther north than normally. In contrast to this, in years with weak atmospheric circulation the cold, ice-bearing Polar Current gains in force and extent and drives toward the south the weakened branches of the Gulf Stream, especially the western and eastern divisions of the Irminger Current. The polar front then lies south of its normal position and Iceland is encircled by the branches of the Polar Current. It is therefore to be expected that a year with weak atmospheric circulation will be a year with abundant and long continued ice near Iceland, while with stronger circulation the quantity of ice will be less and the ice season shorter.

On the basis of studies [8] by W. Meinardus on the oscillations of the ice drift near Iceland, this line of reasoning was carried out in detail. The results are shown in the curve at the bottom of Figure 2. This curve is based on figures showing the character of the ice year as given by Meinardus, each month in which the ice was especially thick being assigned a double weight. It is clear that years with abundant ice always coincide with years having weak atmospheric circulation, and that years having little ice are years with strong circulation. The correlation factor between the meridional pressure gradient over the North Atlantic and the character of the ice year near Iceland is:

$$r \text{ equals} -0.59 \pm 0.09$$

and between the west-east gradient over northern Europe and the character of the ice year near Iceland:

$$r \text{ equals} +0.71 \pm 0.06,$$

indicating that the two phenomena are very closely related.

6. *Relation between oscillations in the strength of the North Atlantic northeast trade and the atmospheric circulation in the temperate latitudes.*—The pressure gradient from latitude 30° southward gives a measure of the force of the trade wind, which must show oscillation corresponding to those of the gradient. The monthly anomalies of pressure gradient in the region of the northeast having been determined with reference to the normal gradient for each month, it appears that in magnitude the oscillations of the gradient are considerably smaller than those of the gradients from the Azorean maximum northward, but they are just as changeable. This indicates a considerable inconstancy in the strenght of the northeast trade, and a close relation between the two sets of values. To a diminished meridional pressure gradient in the middle latitudes there corresponds in the majority of cases a diminished gradient toward the Equator in the lower latitudes. Likewise when the gradient from the Azores high northward increases, the gradient southward from it also increases. This would signify that the oscillations in the strength of the northeast trade go hand in hand with similar oscillations in the atmospheric circulation in the temperate latitudes of the North Atlantic. The closeness of this relation is shown by the correlation factors for the values of each month, as follows:

Correlation between the force of the northeast trade wind and that of the atmospheric circulation in the temperate latitudes of the North Atlantic Ocean.

December	+0. 776	June	+0. 506
January	+ . 846	July	+ . 582
February	+ . 885	August	+ . 662
March	+ . 851	September	+ . 622
April	+ . 755	October	+ . 696
May	+ . 457	November	+ . 651

Year, +0. 777±0. 105

The magnitude of the correlation factor shows a decided yearly march, being greatest in winter and least in summer, but the relation is always very well defined. The mean correlation factor, based on 300 successive monthly values with a probable error of 1/50 of the factor, indicates that the relation may be regarded as established.

Without entering upon an attempt at explanation of this striking relationship, it may merely be pointed out that it has already been implied by the fact that in the great majority of cases the pressure anomalies over the North Atlantic Ocean may be designated under the two types A and B. Stronger northeast trade wind originates especially through intensification of the Azores high, and an intensification of the Azores high in turn goes hand in hand with a deepening of the Iceland low. Thus the closed circulation of the lower latitudes is intimately connected with the circulation in the Temperate Zone.

Shaw in 1906 pointed out [9] a similar connection when, in a communication entitled "The pulse of the atmospheric circulation," he sought to bring into relation the oscillations in the intensity of the southeast trade winds in the South Atlantic with oscillations of the rainfall in southern England. The courses of the two phenomena, data on which were available for only the relatively short period 1892–1903, were surprisingly parallel. In a review of this paper, J. Hann points out [10] that perhaps the force of the northeast trade might be a more convenient guide to "feeling the pulse" of the atmosphere. Lack of suitable observational data prevented him from developing this idea further. The above results show definitely that the strength of the northeast trade is indeed such an index, and thereby probably also an index of the oceanic circulation.

[7] The Irminger Current constitutes the recurve on the northwest side of the Gulf Stream Drift south and southwest of Iceland.—*Ed.*

[8] Annalen der Hydrographie und Marit. Meteorologie, Jahrg. 1906.

[9] Shaw, W. N., The pulse of the atmospheric circulation. Nature, 21, Dec., 1905.

[10] Hann, J., Der Pulsschlag der Atmosphäre. Meteor. Zeitschr., 1906, p. 82.

In order to see further how the relation, pointed out by Shaw, between the circulation in lower and higher latitudes, appears in the now more extended data, there was calculated the correlation factor for the precipitation in England and the annual mean pressure gradient over the southern part of the North Atlantic Ocean (latitudes 30° north to 10° north). For the amount of rain over England there was taken the mean of the yearly totals in percentages of 50-year means at the five stations of Greenwich, Stonyhurst, Seathwaite, Edinburgh, and Rothesay.[11] The correlation factor resulting was r equals 0.42. It is thus relatively small, but on closer inspection of the months [table, not here reproduced] and of the individual stations it is very noticeable that in both series the extreme values fall in the same year, a fact which increases the impression of a direct relation. The combination of all the values reduced the correlation factor to the small one given, but nevertheless there appears to be a relation in the sense meant by Shaw.

7. *On the causes of oscillations in the atmospheric circulation.*—Study of the monthly pressure anomalies over the North Atlantic Ocean have shown that over these parts of the earth's surface rather significant oscillations in the atmospheric circulation take place, which, if all extremes are considered, appear to succeed each other irregularly in a period of some three to five years. A definite system in the succession does not appear to exist, while the shortness and variability of the period did not warrant the expectation that there is a relation to the rather regular changes in sunspot numbers. In the individual months, of course, there appeared to be some indication of such a relation, but on the whole a definite connection can not be affirmed. The period investigated is too short to admit of drawing a conclusion in the matter, as it includes only two sunspot periods. In this epoch the sunspot maxima occurred in the years 1884, 1894, and 1905 and the minima in 1889 and 1901.

In an exhaustive work [12] W. J. Humphreys has dealt with the question of an influence on temperature, and thereby on the general conditions of the circulation in our atmosphere, exerted by gigantic volcanic eruptions. He came to the conclusion that many, if not all, of the climatic changes on the earth have been caused by the eruption of ashes from volcanoes. Even if he seems to have gone somewhat too far in his line of reasoning—as W. Köppen has demonstrated in his paper, "Lufttemperaturen, Sonnenflecke und Vulkansausbrüche" still it appears that he was entirely correct in his belief that major eruptions of loose materials from volcanoes are a factor which is able to exert a profound influence upon the climatic conditions of our earth.

In an earlier paper [13] the writer sought to show how three factors are concerned in the determination of climatic changes, namely, solar radiation, earth radiation, and the circulation of the atmosphere. The last factor primarily takes the rôle of a regulator of meridional temperature distribution, and, due to that fact, it enters extremely intimately into the mechanics of climatic changes. Variations in the first two factors, however, are to be considered above everything else as primary causes of climatic change. If one wishes to regard oscillations of the solar constant as too small to be of climatic significance (which may not be the case, our knowledge on this point being still too limited), we have remaining as phenomena capable of affecting the temperature equilibrium of the earth's surface and of the lower layers of the atmosphere, only disturbances in the optical qualities of the earth's atmosphere. Enormous eruptions of loose material from volcanoes appear, as the most recent occurrences have forcefully shown us, to be sufficiently powerful to produce perturbations in the general circulation of the atmosphere. In such a case, as Humphreys has found, the envelope of volcanic turbidity must be 30 times as effective in obstructing solar radiation as in the repression of earth radiation. The fine, long-continuing dust veil of a volcanic ash eruption must therefore have a reversed hothouse effect, and with long continuance the resulting temperature of equilibrium of the earth would be lower than if there were no veil. The effect might be compared to that of a small diminution of the solar constant. These considerations make it appear as not improbable that in the oscillations of atmospheric circulation over the North Atlantic Ocean which we have recognized for the period 1881–1905, there are indications which support the above line of reasoning, reflecting in particular, that is to say, an influence due to the great eruptions of volcanic ash during this period.

In the study of this question, only the greater ash eruptions were considered, since only these, and not the eruptions with lava flows, are determining factors. Furthermore, the great number of small outbreaks, in which the masses of ashes and fine dust are too small and are carried to too slight a height (lower part of the troposhere), can exert no lasting influence. In the compilation of these greater eruptions, use was made of K. Sapper's "Beiträge zur Geographie der tätigen Vulkane,"[14] in which he classifies the great ash eruptions according to their intensity and to the mass of material ejected.

Tabulating the eruptions during the period 1881–1905 and assigning to eruptions of the first order the weight of 4, to those of the second order a weight of 2, and so on, we find the years 1883, 1886, 1888, and 1902 especially noteworthy. In Figure 2, below the curve for the meridional pressure gradient over the North Atlantic, these years with the greater eruptions of ashes are marked by vertical rectangles according to their weights. We observe at once that in the vicinity of those years, but especially soon after them, marked disturbances occur in the atmospheric circulation. This holds especially for the eruption years 1886 and 1888, 1892 and 1902. The fact that there is missing the year 1883, in which by the Krakatoa eruption enormous amounts of volcanic dust got into the atmosphere, is not of great significance, since in this giant eruption the dust masses were hurled far into the stratosphere, with the result that, in line with Humphreys's view, the chief effect on the atmosphere must have been shifted one or probably even two years. Indeed, we see that from 1883 to 1888 there is a continual decrease in the intensity of the atmospheric circulation, which agrees directly with the marked volcanic activity between those years. Also the years 1892 and 1902 show a diminution in atmospheric circulation. Hence it certainly does not appear to be too hazardous to assert that the major ash eruptions are accompanied by a decrease in atmospheric circulation.

Comparison of the two graphs shows us still another striking phenomenon. In the first or second years after those in which eruptions occurred and diminution in

[11] See Hellman, G., Untersuchungen über die Schwankungen der Niederschläge. Abhandl. des preuss. meteor. Instituts, Bd. III, no. 1, 1909.

[12] Humphreys, W. J., Volcanic dust and other factors in the production of climatic changes and their possible relation to ice ages. Bulletin of Mount Weather Observatory, 6, part 1, 1903. See also Physics of the air, Part IV, chapters 3 and 4.

[13] Defant, A. Die Zirkulation der Atmosphäre in den gemässigten Breiten der Erde. Geografiska Annaler, 1921, H. 3.

[14] Zeitschr. fur Vulkanologie. 1917, Band III.

atmospheric circulation appeared, there takes place an abrupt increase in the strength of the circulation. We see this at the end of each eruption period—in the years 1889–1890 following 1888, in 1894 following 1892, and in 1903–1904 following 1902. Inspection of the individual cases showed that the conditions appeared to be not independent of the magnitude of the eruption. Before the eruption the disturbances in the general circulation are in general small, pressure gradients departing less than 2 per cent from the normal on the average. Which is to say that in general the disturbances compensate each other, since there often occur lesser decreases and increases, which are probably the remains of earlier disturbances. But in the years of eruption the circulation is greatly disturbed, and there is found first a weakening of it which even in the average of all cases is very great, since the reduction of the normal pressure gradient amounts to 10 per cent, whereas in the more marked cases it reaches, even on the average, almost 20 per cent. But the circulation soon returns to the normal intensity, and indeed we find in the year after the eruption even an intensification of it. This increase in intensity continues and in the second year reaches 7 per cent and in the more marked cases 17 per cent. Thereafter the circulation again approaches normal conditions.

Disturbances in the equilibrium of the atmosphere due to great volcanic eruptions are thus extremely characteristic. First the atmospheric turbidity caused by the eruption induces a weakening of the general circulation. This soon ceases, however, and gives place to an increase in its intensity, which, after approximately two years, varying according to the strength of the volcanic outbreak, reaches a maximum, only to decline again. It appears as if the atmospheric circulation, when thrown out of equilibrium by the disturbance resulting from volcanic eruptions, proceeds to oscillate about the position of equilibrium. The amplitudes and the periods of these oscillations depend both on the intensity of the volcanic upheaval and on the duration of the optical disturbances. After a marked weakening in circulation and after the cessation of turbidity there follows an increase in intensity, and so on.

We may develop these conditions somewhat in detail, using the consideration which are found in the earlier investigation by the author, in order to reveal the causes of the pendulum swings of the atmosphere about its position of equilibrium, swings which may appropriately be designated as "pulsations of the atmosphere." The atmospheric circulation is a current system which, with normal temperature gradient between low and high latitudes, with normal outward radiation and normal interchange of air between high and low latitudes should remain in a certain condition of equilibrium. If any one of these factors is altered, the condition of equilibrium is disturbed and the circulation now executes oscillations about its position of equilibrium, as does every other system when so disturbed. The chief cause of these pulsations is to be sought in the inertia of current conditions, since both the more constant tropical circulation and the exchange of air between lower and higher latitudes of the Temperate Zone will not suddenly adjust themselves to the modified conditions of an altered temperature gradient or to changed conditions of insolation and earth radiation, but will always lag behind these. Hence the circulation once thrown out of equilibrium varies from it now in one direction, now in another. It will be now stronger, now weaker, and these "beats" will gradually diminish in force. The damped oscillations about the position of rest must follow a period which is determined by the structure of the atmospheric circulation and the dimensions of the earth. In other words, we have here to deal with a phenomenon which is similar to the free oscillation of a system, and these pulsations of definite period can be designated as such.

Let us consider one such case more closely. The atmosphere and its circulation are at first in normal condition. By a great volcanic eruption the temperature in the lower latitudes is considerably lowered. Thereby the meridional temperature gradient is automatically decreased, with the result that the closed circulation in the Tropics and subtropics and the exchange of air in higher latitudes undergoes a weakening. This weakening will proceed of itself at first as the result of movement once initiated. Later, due to lessened exchange between lower and higher latitudes, it will cause an increase in meridional temperature gradient, extending farther and farther because of the gradual fading of the turbidity, and causing an intensification of the circulation. After this again a weakening in the temperature gradient takes place and correspondingly a weakening in the strength of the circulation. So, after a given interval subsequent to an original weakening of the circulation, there follows an intensification and after this a weakening, and so on.

The period of these damped and subsiding pulsations should be obtainable in a purely theoretical manner, the equations from which one must proceed being given in the author's paper cited above. The mathematical difficulties which beset the solution of this problem may of course be considerable. It appears, however, that this fundamental period may be obtained from observations. The years 1883–1888 were characterized by great eruptions, but in this interval the period can not well reach complete development, since one turbidity in part overlaps another and there is disturbance in the evolution of the resulting phenomena. But after this time until 1902 very marked eruptions took place only in 1892 and 1898, and the phenomena resulting from the great eruption period 1883–1888 could develop almost undisturbed. The second curve of Figure 2 shows that in this period maximum follows minimum almost regularly, so that the mean period calculated from both maxima and minima amounts to 3.5 years, which is, therefore, probably the natural period of the pulsations of the atmospheric circulation. The circulation when once thrown out of equilibrium swings back and forth and thereby causes long-period climatic changes. The pulsations become gradually extinguished, however, as the case after 1888 shows, since the amplitude of the oscillations becomes smaller from swing to swing.

Only when a new disturbance, a new and mighty eruption, takes place, do the pulsations attain a greater amplitude. It is then a matter as to the point of time at which, in the fading pulsations of an earlier disturbance, the new one takes place whether the vibrations are now to proceed reinforced in the same phase, or, on the contrary, with a shift in phase. In the year 1892 the eruption takes place in a year of weakened circulation and the new disturbance is in the same phase as the earlier pulsations. In 1898, on the other hand, the eruption, only a weak one, to be sure, appears not to have been in the same phase, hence the period of marked disturbance, in 1902 is the first to bring a revival of the pulsations with suddenly increasing amplitudes.

It is extraordinarily striking that the same period of 3.5 years, which we have here designated as the natural period of the atmospheric circulation when its equilibrium is disturbed, has, it would seem, a very general character. This has been demonstrated unequivocally in the work of the Solar Physics Committee, "Mean monthly values of barometric pressure," by N. Lockyer.[15] C. Braak has investigated [16] this in detail for the Dutch East Indies and has shown that it is reflected in both the temperature and the pressure conditions as well as in precipitation, and that the periodic changes in the north-south gradients between Australia and the East Indies are the "faithful companions" of these pulsations.

It is not improbable that in this approximate 3.5 year period in the pulsations of the atmospheric circulation we are dealing with a phenomenon of extreme importance in the weather sequences of the longer periods of time.

[15] Lockyer, N., Solar Physics Laboratory, South Kensington, 1908.
[16] Braak, C., Periodische Klimaschwankungen, Meteor, Zeitschr., 1910, pp. 121–124. Die 3.5-jährige Barometerperiode, Meteor. Zeitschr., 1912, pp. 1–7.

551.515 (744)

TORNADO NEAR FITCHBURG, MASS., JULY 17, 1924[17]

By CHARLES F. BROOKS

(Clark University, Worcester, Mass., July 19, 1924)

About noon, July 17, 1924, with the arrival of the thundersquall on a marked wind-shift line, a tornado hit here and there along a path about 18 miles long from near Templeton, through Gardner, Westminster, southern Fitchburg, and Whalom, Mass. This course, averaging from west by south, when projected toward the east-northeast, passes near Lowell, Lawrence, Haverhill, and Newburyport, where torrential rain occurred shortly after. Here and there along the path there were groves of trees destroyed, factories nearly demolished, roofs and upper stories blown off, and chimneys generally blown down. So localized was the damage, however, that little was to be observed, for example, from the main thoroughfare from Leominster to Fitchburg across the storm path. Two were killed, and damage estimated at $500,000 to $1,000,000 was done, according to the Worcester Telegram.

While the local severity of the damage and the generally narrow and direct path in which destruction occurred, would lead one to suspect the action of a tornado, eye observation of the funnel cloud by Leroy Moreland and others at and near Whalom, and the criss-cross fall of forest trees there leave no doubt as to the whirling nature of the wind. With a geological compass I climbed over the fallen trees at Whalom, and obtained their direction of fall. Most were blown down from a west southwesterly direction, but near the northern edge of the zone of destruction, where the funnel cloud had been seen the trees were blown down from south and north as well as from west. A barn that was hit, blew down northwards, the north wall being blown out lower end first, and boards being carried a few tens of feet clear of the general wreckage.

A few details will be appropriate. After blowing down or partly wrecking some factories and tenements in the southern part of Fitchburg, the storm for the next 2 miles before reaching Whalom broke off or uprooted many large trees, blew down chimneys and damaged some roofs. A ball park fence was partly blown down, a tent carnival blown away, and a small grove of pines demolished, the trees generally being broken off half way up. Approaching Whalom, a large elm, well rooted, but exposed on a hill, was blown down from the southwest. The tree was about 3½ feet in diameter, and was said to have been growing there for at least 168 years. The upturned roots reached to a height of nearly 20 feet. A number of other trees were uprooted or blown down in this vicinity. A local resident said that another member of the family had seen a funnel cloud. At Whalom Park about half the trees (mostly pines 1 to 1½ feet in diameter) were blown down by uprooting or breaking. They lay mostly from southwest by west (compass bearing W.20–30° S.), though a few lay on top from about west northwest (compass W. 30° N.). This was one-half to three-quarters mile south of the path of the funnel center. Across the road from Whalom Park, in a grove one-quarter to one-half mile from the path, about two-thirds of the trees were blown down. These were larger than those in Whalom Park, ranging up to 2 feet in diameter. About as many were broken off as uprooted. They were blown down from the same directions as those in Whalom Park, though there were more from the west northwest, perhaps a quarter of the total, as compared with only a few in Whalom Park.

A little farther north, at Sunnyside Farm, I came upon the region within the path of the funnel cloud. In describing the storm, Mr. Leroy Moreland, who with his father manages the farm, said he was between the two barns that were not blown down (the more southerly of three) when he saw what he thought at first was the smoke from a bad fire in the woods westnorthwest of him. There was a ragged cloud mass, whirling violently, coming straight towards him. It appeared white. It seemed to be bouncing up and down somewhat as it approached. Suddenly it turned at about a right angle just in time to avoid all but one of the barns. He had never before seen a cloud anything like that. The noise was terrific. Unfortunately for further observation of the storm, Mr. Moreland had to take shelter. He said the tornado struck at 12:20 or 12:25 p. m. (At Fitchburg, 2⅓ miles away the time of the storm was reported as 12:15.) Another man at the same farm said he saw a whirling cloud approaching, and that it had become extraordinarily dark. Others, at Whalom Park, had not seen the tornado cloud. Anyway, trees would have prevented their viewing it. One man with whom I talked said he had seen a small funnel cloud at Manchester, N. H., at about the time of the storm here.

The mixed forest through which Mr. Moreland had seen the funnel cloud come was about half destroyed, an open gap being cut about 50 feet wide from the west-northwest where the center passed. South of this gap some individual trees and clumps were blown down from the southsoutheast (compass bearing S. 5° E.), and a few from the southwest, but the great majority lay from between west by south and westnorthwest (compass W. to W. 30° N.). North of the gap about half the large and small oaks, maples, birches, etc., were down, mostly from the westnorthwest (compass W. 30° N.). There were several, however, from the northnorthwest (compass bearing N. 10° W.) under those from more westerly directions. From 250 to 300 yards beyond this was the barn that was blown down at about the place where the funnel cloud turned. About 50 yards south of this barn a silo had gone down and the corner of a barn roof had been blown off, while a few yards farther all seven chimneys of the well-built farmhouse had been blown

[17] This is but a brief account. Clippings from the local press of important places affected, or nearby cities, and also a few photographs are on file at the U. S. Weather Bureau office, Boston, Mass. This published report is based on a brief tour of observation through the region of greatest damage near Fitchburg, and on some of the newspaper accounts for other portions of the path of the heavy storm.