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SECTION II.—GENERAL METEOROLOGY.

ON STORM-FREQUENCY CHANGES IN THE UNITED STATES.

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While, with the assistance of Dobrowolski, Amundsen, and Lecointe, I was making hourly meteorological observations on board the *Belgica*, the ordinary cyclonic explanation of the subantarctic storms seemed most unsatisfactory to me.

I often thought that the barometric depressions of the circumpolar belt of low pressure were more or less regular waves, extended between the South Pacific and polar anticyclonic centers of action, and that these waves traveled eastward around Antarctica, sweeping on both sides the high pressure areas, and that, from the north as well as from the south, anticyclonic crests were wedged between this rotating system of furrows.

Such a wave-motion hypothesis was too old-fashioned (1)[1] and at the same time too radical to be discussed on the basis of one year's observations at an absolutely isolated station. Convinced, however, of the fact that our knowledge of atmospheric circulation could be greatly advanced by a systematic study of subantarctic weather conditions, I dared to propose at the British Association meeting at Dover in 1899, the organization for the years of the *Discovery* and *Gauss* expeditions, of meteorological stations installed on the islands between South America, Australia, and the Antarctic continent.

This project came to nothing, but sooner or later it should be realized. The publication of daily weather maps of the Southern Hemisphere, attempted by the Royal Society (2), as well as the elaborate discussions of Meinardus and Mecking (3), give still more weight to this desideratum, and now it appears perfectly clear that an extensive study of the meteorological conditions of the Southern Hemisphere belt of lows would very greatly advance our knowledge of the mode of formation and the orientation of displacement of storms. The interesting and most suggestive memoir of W. J. S. Lockyer (4) on the Southern Hemisphere surface-air circulation and Merecki's extensive researches on barometric waves (5) also point to the same conclusion.

In the Northern Hemisphere the distribution of atmospheric pressure is more complicated than it is about the Antarctic continent, therefore the lows are greatly deformed and follow different belts of prevalent storm tracks. In Europe, the superposition of all observed tracks of lows gives the impression of a most intricate network. The maps published by Gen. Rykatchew (6) may be cited as example.

In North America conditions are simpler. The charts of relative storm frequency published by Finley (7) in 1884 plainly show the predominance of the belt of lows along the Great Lakes. The chart of aggregate storm tracks traced by Dunwoody (8) from the International Simultaneous Observations taken at Noon, Greenwich time, during the years 1878 to 1887, shows that "the region of greatest storm frequency in the Northern Hemisphere is included in an area which extends from eastern Lake Superior to the Middle St. Lawrence Valley." It may be of interest to notice that the monthly charts by Dunwoody show that "for the spring months the average track of storms over the North American continent is farther south than during the winter season.

Later Bigelow (9) classified the different American types of storm tracks and studied their seasonal variations of frequency, but it is only recently that the relations between storm movements and the pressure distributions have been extensively investigated by Bowie (10).

> Of the centers of action that affect the weather conditions of the United States east of the Rocky Mountains, the subpermanent high over the middle latitudes of the North Atlantic Ocean is perhaps most influential. When this is well developed and stable temperatures above the seasonal average are to be expected over the great central valleys and the Eastern and Southern States, and areas of high and low pressure crossing the United States will move in high latitudes and pass on to the ocean by way of the St. Lawrence Valley (11).

As early as 1868 Mohn expressed the opinion that, in general, lows have a tendency to circulate around high-pressure areas, keeping the maximum to the right. In 1870 Prestel found that the lows go clockwise around the highs, and in 1876 Clement Ley pointed out that the center of a barometric depression moves generally at a right angle to the greatest barometric gradient (12).

Coming back, now, to the problem of sub-Antarctic storms, let us extend the experience gained from the study of the daily weather maps to average climatic conditions. We may venture to suppose that wherever there is a more or less permanent area of high pressure with strong temperature and moisture gradients conditions will favor the formation of storms and that these storms will have a tendency to travel around this high-pressure area.

This working hypothesis may be applied to abnormal climatic conditions, e. g., such as I have called the pleionian variations of climate. In the case of atmospheric pressure, in particular, I have shown that when we chart the departures of annual means from quasi-normal values we reveal extensive areas of hyper- and hypo-pressure having more or less resemblance to wave crests and troughs. In case of temperature the areas of positive departures have been called thermopleions. For sake of analogy in the nomenclature of these climatic anomalies we may call the areas of hyperpressure barapleions. In the United States the same barapleion may be observed for several years in succession, but on different areas and with a change of orientation of the crest of highest positive departures (13).

Coming back again to the purely imaginary conception of the sub-Antarctic storms—and remembering the general conclusions gained by Bowie from the study of the United States daily weather maps—we may suppose that a barapleion will have a tendency to act upon atmospheric circulation as the Antarctic Continent does. If so, the barapleions will be surrounded by a belt of waves, accentuated on the side of the steepest gradient of temperature.

[1] Black-faced numbers in curves refer to the list of references at end of the paper.

Leaving completely aside for the present this question of a possible correlation between observed changes in the distribution of storm tracks and barepleions, I will restrict myself in this essay to the study of the variations that occur in the frequency and geographical distribution of lows and shall endeavor to establish the fact that these variations are in harmony with the pleionian cycle.

ANNUAL VARIATION OF THE FREQUENCY OF LOWS.

Utilizing the maps published in the MONTHLY WEATHER REVIEW I counted month by month, for the years 1883–1913, the number of tracks of lows that crossed the 100th, the 90th, and the 80th meridians. If a given low, having a complicated course, crossed one of these meridians twice or three times, as it sometimes occurs, this low was counted for one and not for two or three.

The total numbers of lows that crossed the 100th, 90th, and 80th meridians during the 31 years considered, are 3,044, 2,843, and 2,875, respectively. The monthly totals, divided by 31 (number of years) and reduced to months of 30 days duration, give the following table of means:

TABLE 1.—*Mean frequency of lows crossing meridians 80, 90, and 100 within the United States.*

Meridian.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
100	9.27	9.00	9.08	8.03	7.74	6.51	7.05	6.84	7.61	7.77	8.68	9.21
90	9.61	9.59	9.18	7.42	6.49	5.45	5.99	5.96	6.23	6.58	8.55	9.43
80	9.43	9.49	9.42	7.00	6.62	5.61	6.18	6.34	6.74	7.02	8.23	9.40
Mean..	9.44	9.36	9.23	7.48	6.95	5.86	6.41	6.38	6.86	7.12	8.49	9.35

It is evident that these figures express the average annual variation more correctly than the tables of the number of storms as given by Waldo (**14**) or Bowie and Weightman (**15**). Table 1 shows that on the average the lows observed in the United States are most frequent in January and least frequent in June, and that the frequency in June is 38 per cent smaller than the total for January. Of course the figures of Table 1 give a greater frequency of lows than would result from counting the waves registered by a barograph at some station, and this for the simple reason that not all the lows crossing the meridian north or south of that station influence the area where the station is located. This fact does not greatly affect the amplitude of the annual variation as given above.

It is therefore of interest to compare these figures with the results obtained by counting the barometric waves recorded at given stations. In the case of the *Belgica* observations I obtained (**16**), counting the waves of a minimum amplitude of 5 mm., a mean duration of 83 hours for the months May–July and of 201 hours for November–January, or 8.9 and 3.7 waves per month, respectively. This gave for the southern summer months 41 per cent of the number of lows for the winter months. Table 1 gives for December–February in the United States a mean of 9.38 lows and for June–August 6.22 per month, which makes the number for the northern summer 88 per cent of that for the winter. The annual variation of the frequency of lows must, therefore, be very much more accentuated in the Antarctic regions than it is in the United States.

The interesting fact, however, is that the frequency variation of barometric waves is not everywhere characterized by a simple oscillation showing a well-pronounced minimum during the summer months. For example, in Warsaw the mean duration of the waves, expressed in days and fractions of a day, is, according to Merecki (**17**):

Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
5.7	5.7	5.5	5.7	5.8	5.8	5.6	5.7	5.5	5.8	5.7	5.7

This table shows a maximum frequency of waves in March and another maximum in October, a minimum during the winter and a more pronounced minimum in May and June.

Now, tracing from Table 1 the curve of the mean frequencies of lows observed in the States (*a* in fig. 1) we notice that the figure 9.23 for March, which seems too high, as well as the figure 5.86 for June, which seem too low, may have been influenced by the superposition of a double oscillation, similar to that observed in Warsaw, upon the simple normal oscillation.

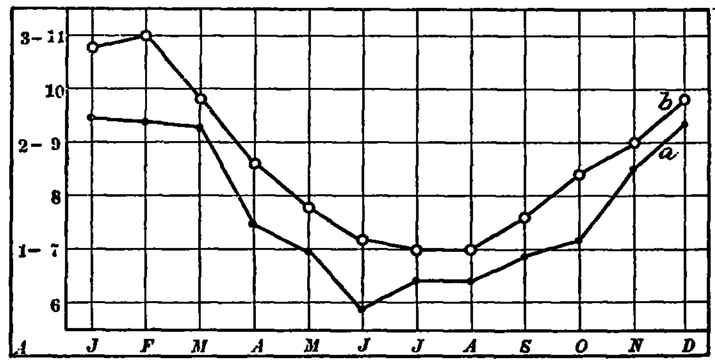

FIG. 1.—Curve of mean frequencies of lows in the United States. (Curve *a* and right-hand scale.)

Curve of mean meridional temperature gradient (°F) in the United States, based on *Bartholomew's Atlas of Meteorology*. (*Curve b and left-hand scale.*)

A further study of these slight anomalies, examined year by year, would certainly be of some interest. The second curve (*b* in fig. 1) proves it very well. This curve represents the monthly values of the mean temperature gradient (°F.) in the United States. The figures have been obtained from the monthly charts published in Bartholomew's Meteorological Atlas. The distribution of the isotherms crossing the 100th, 90th, and 80th meridian is very regular, so that it is sufficient to take the differences of the means for the 50th and the 30th parallel, and in the case of the 80th meridian, the differences between the crossing of Montreal River and the latitude of Cape Sable. The totals of these differences divided by 61 give the following figures for the mean meridional gradient per degree of latitude:

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
°F.	2.9	3.0	2.4	1.8	1.4	1.1	1.0	1.0	1.3	1.7	2.0	2.4

The great similarity between the curve (*b* in fig. 1) expressing these figures graphically and the frequency curve of lows (*a* in fig. 1) shows that a correlation between the gradient of temperature and the occurrence of storms may be admitted. It seems to be a question of gradient. It can not be that the storms are less frequent during the summer simply because temperature is higher. Merecki's figures for the annual variation of the barometric waves observed in Warsaw show indeed that there the lows must be less frequent [2] during the winter as well as during the summer. It must be the same [2] through all Russia and Siberia (**17b**). The table of "relative frequency of storms in various seas for different months of the year" compiled by W. Doberck (**18**) shows also great regional differences. It would therefore be of some interest to study the problem more in detail.

TABLE 2.—*Mean temperature observed on board the* Belgica *and mean duration of the barometric oscillations.*

Period.	Mean temperature.	Duration of oscillation.
	°C.	*Hours.*
February–April	− 7.28	138
May–July	−15.24	83
August–October	−12.58	129
November–January	− 3.45	201

In the case of the *Belgica* observations Table 2 shows that the agreement between temperature and the mean duration of barometric waves is perfect. This may be due to the fact that on the open sea north of the Antarctic circle the temperature is increasing very rapidly at the time when it is cold on the ice, whereas during the summer the temperature gradient is small.

LATITUDE DISTRIBUTION OF LOWS.

There is a great advantage in employing the numbers of barometric waves observed at individual stations, instead of the frequency of lows of the weather maps, both because of greater precision and also of the regional differences in the distribution of lows. We will see now what these differences are.

According to the latitude considered the annual variation in the frequency of lows may be very different from that of the mean values of a given meridian.

The maps accompanying the recently published report of Bowie & Weightman (**11**) demonstrate this fact very clearly. The statistics of Bowie & Weightman's memoir favor an investigation of the annual displacements of the zone of greatest frequency of lows, but as that report was published after my computations were finished I regret that I can not here discuss that problem more fully.

The figures for the 100th and 80th meridians, which I collected from the MONTHLY WEATHER REVIEW maps, may serve as an illustration of a method of research which seems especially suited to pedagogical purposes.

Taking the monthly totals of the numbers of lows that crossed the 100th meridian during the years 1883–1913 between the 55–50th, 50–45th, . . . 30–25th parallels, respectively, I plotted these figures in columns and drew into this table lines of equal frequency; the resulting diagram is shown in figure 2. A more accurate illustration of the annual variation could be obtained by equalizing the monthly values and expressing the numbers in per cent of the total number of lows; but for my present purpose this is not necessary. The inspection of figure 2 shows at once that along the 100th meridian three types of distribution of frequency of lows are distinguishable, viz, the July-September type, the November-January type, and the March-May type. The months of June, October, and February are transitional.

[2] The forecasters of the Weather Bureau feel some doubt of the correctness of this inference.—C. A. Jr.

In August there is a progressive decrease in the numbers of observed lows from the north toward the south. December shows a maximum in the north, another maximum on the 35th parallel, and a secondary minimum between the two maxima. In April the maximum is well pronounced and occurs north of the 35th parallel.

Along the 80th meridian the conditions, as figure 3 shows, are entirely different. This is partly because of the deflecting action of the Appalachian Mountains. October shows a slightly accentuated secondary maximum between 30°–35° latitude, but with this exception the greatest frequencies are observed north of the 45th parallel all the year through. The ascent is steepest in July, when immediately below the figure 125 we notice only 45 lows observed between 45°–40° latitude. During the winter and the spring, particularly in February and in March, the lows have a tendency to travel farther south than during the summer months.

The high figures for latitudes 20°–25° in August, September, and October confirm Poëy's statistics of cyclones observed at Havana (**19**). A. Poëy found that 67 per cent of the observed cyclones occurred during these months.

THE ANNUAL MAXIMUM AND MINIMUM OF FREQUENCY OF LOWS IN DIFFERENT LATITUDES.

There is a radical difference between the annual changes in the distribution of lows along the 100th and the 80th meridians, which fails to appear on the preceding diagrams. This difference concerns the latitude shift of the time of occurrence of the annual minimum and maximum of frequency of lows. In other words, the minimum and the maximum of the annual variation do not occur in the same months in different latitudes; they occur earlier or later in the year, according to latitude, and the character of this displacement along the 80th meridian is entirely different from what it is along the 100th.

In order to demonstrate this fact more plainly than would be possible with words I reproduce in figures 4 and 5 the monthly departures from the averages, as given in the first column of figures.

We see in figure 4 that along the 100th meridian the annual maximum of frequency of lows occurs in February near the 30th degree of north latitude, in March between 30° and 35°, in April between 35° and 40°, in July near the 45th parallel, in August between the 45th and 50th, finally, in October or December, between 55° and 50° or north of the 55th parallel. The minimum occurs in June between 25° and 30°, in July between 35° and 30°, in August between 40° and 35°, in December north of the 40th, in February between the 50th and 45th, and in April north of the 55th parallel. The maximum as well as the minimum are therefore displaced northward as the year advances. Along the 80th meridian (fig. 5) we notice also a well pronounced displacement, but it is directed southward. Here the phenomenon is, however, more complicated, since in latitudes 20°–30° the annual variation has two maxima and two minima.

Comparing these two diagrams with the charts giving the monthly distribution of atmospheric pressure (**20**), or, better, with the monthly departures from the annual means (**21**), one is tempted to admit that, in their annual variation, the storm tracks display a tendency to move clockwise around the shifting high pressure area.

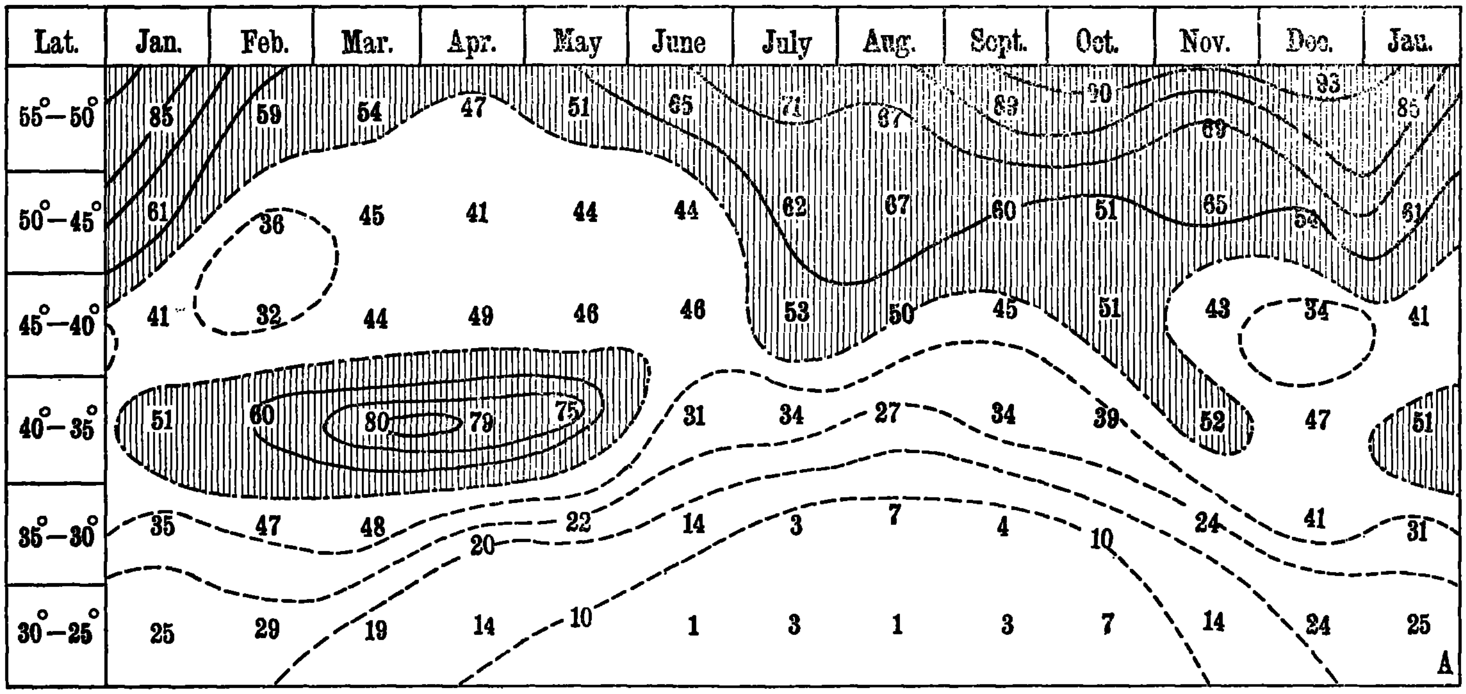

FIG. 2.—Isopleths of lows crossing the 100th meridian from 1883 to 1913, by latitudes and months.

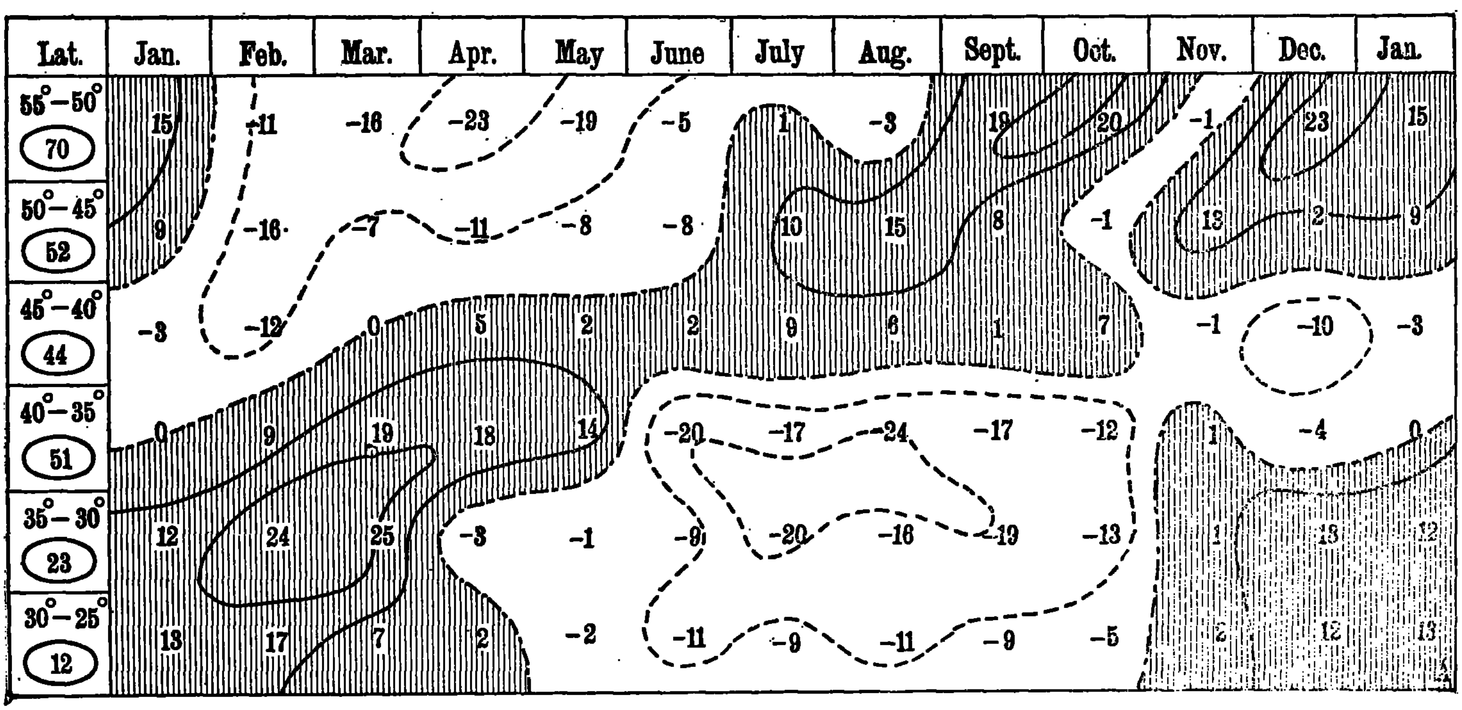

FIG. 4.—Isopleths of monthly departures from the average number of lows crossing the 100th meridian (1883–1913) at different latitudes in the United States. The average number of lows for each latitude zone is stated by the figure in oval at the left; shaded areas indicate seasons of positive departures.

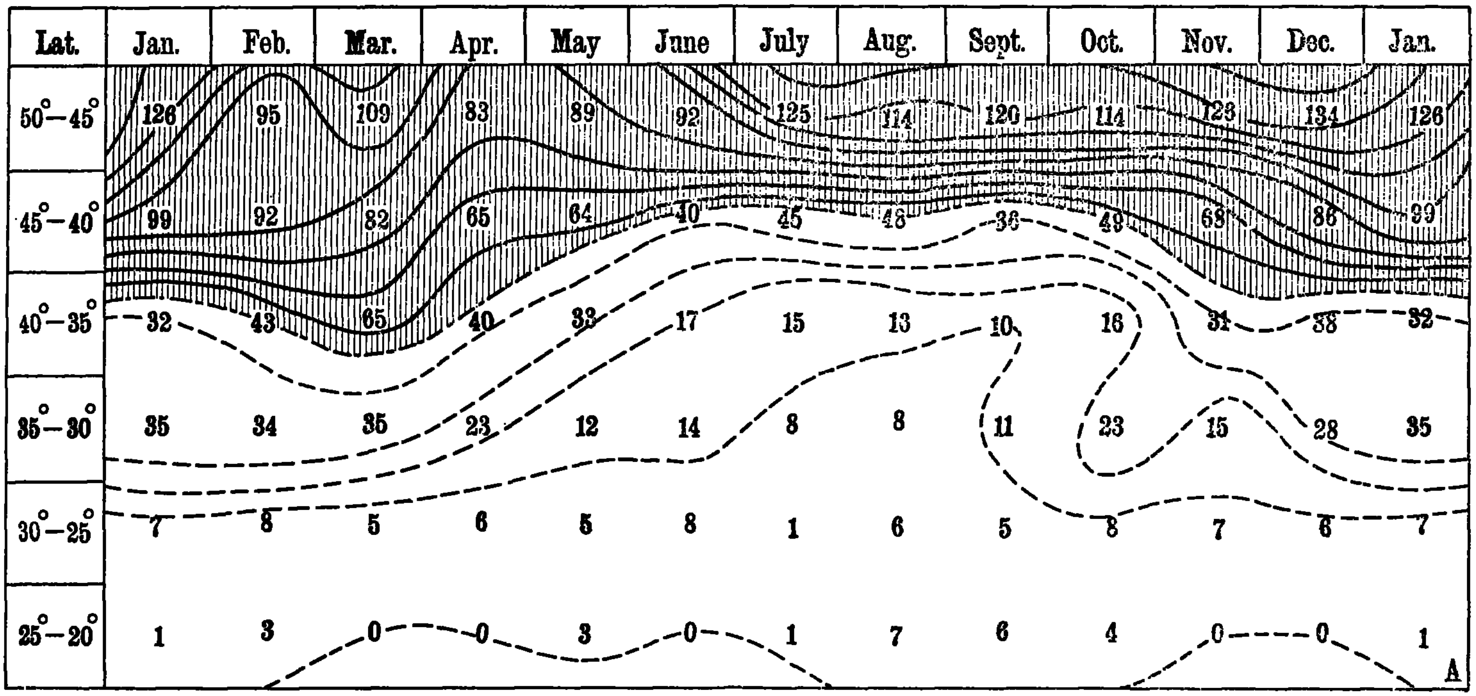

FIG. 3.—Isopleths of lows crossing the 80th meridian from 1883 to 1913, by latitudes and months.

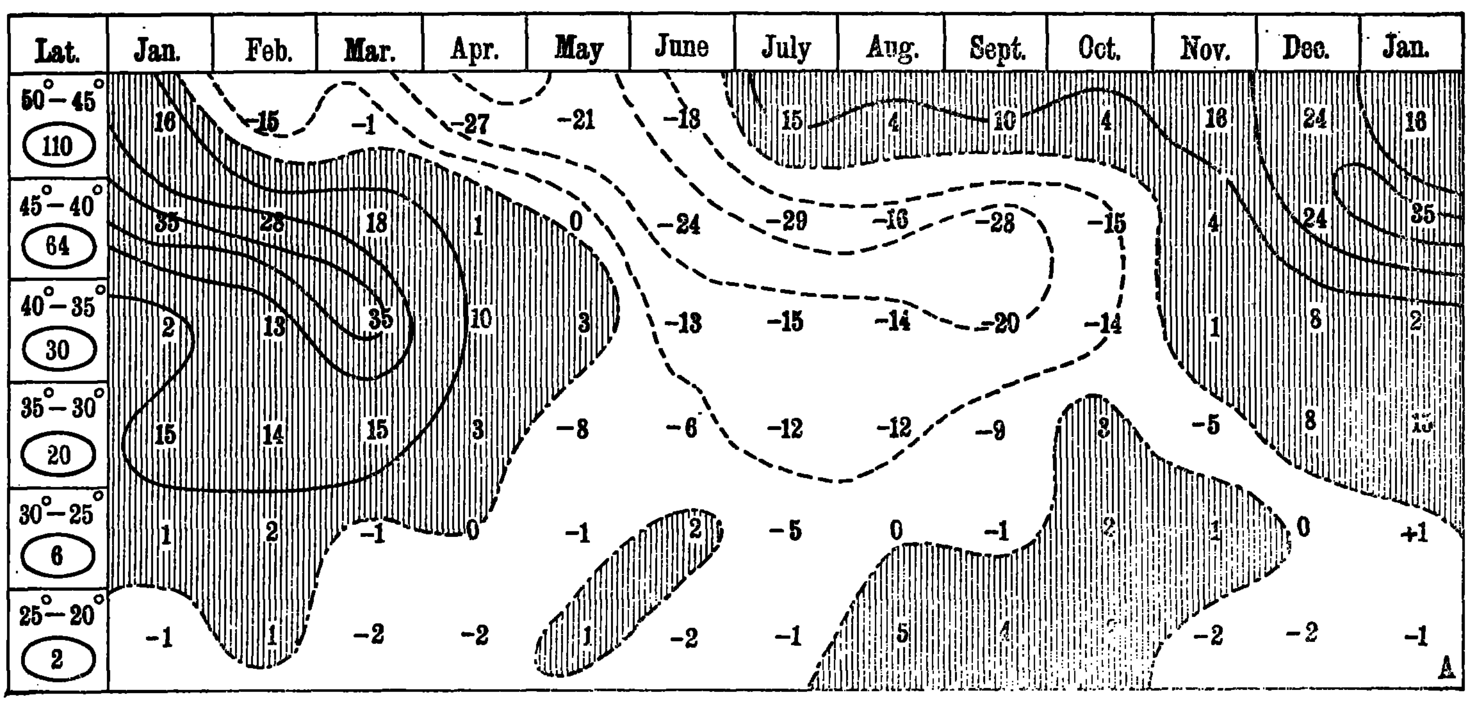

FIG. 5.—Isopleths of monthly departures from the average number of lows crossing the 80th meridian (1883–1913) at different latitudes in the United States. The average number of lows for each latitude zone is stated by the figure in oval at the left; shaded areas indicate seasons of positive departures.

YEARLY FREQUENCY OF LOWS.

In Table 3 I tabulate my counts of the number of lows that crossed the 80th and the 100th meridians during the years 1883–1913.

It is important to remember that the figures given in Table 3 do not represent the yearly or the average frequency of lows that crossed the North American Continent, but simply the tracks that were indicated on the maps published by the United States Weather Bureau. The Canadian lows, of course, are not all taken into consideration. The maps of the tracks of Canadian low areas for January, 1908, published in the MONTHLY WEATHER REVIEW for January, 1909, may be taken as an example serving to show how much information is lacking. The figures for the 55th to 50th parallels in the case of lows crossing the 100th meridian, and for the 50th to 45th parallels in the case of those crossing the 80th meridian must therefore be considered as slight underestimates, while those for higher latitudes, being completely wrong, are omitted.

has not influenced, one way or the other, the compilations made.[3]

Utilizing the data collected by Charles J. Kullmer, Ellsworth Huntington (22) discussed at length the distribution in latitude of the frequency of lows that passed across the zones of 5 to 5 degrees in longitude. Huntington compared the curves for the years of sun-spot maxima and sun-spot minima with those representing the average conditions and arrived at most interesting and far-reaching conclusions (23).

Since 5°-zones of latitude widen from north to south, the figures may be affected in favor of southern lows. This cause of error would perhaps have some influence on the discussion of the seasonal variation. But Huntington studied only annual data, and in this case a reduction to equal areas does not seem to be necessary. It is obvious, however, that there is an advantage in counting the lows that crossed a certain meridian instead of counting those that have been observed in a zone between two meridians.

TABLE 3.—*Number of lows that annually crossed the 100th and the 80th meridians between 1883 and 1913.*

LOWS CROSSING THE 100TH MERIDIAN.

Between latitudes.	1883	1884	1885	1886	1887	1888	1889	1890	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913
60-55 N.	...	...	...	...	...	...	1	3	...	...	1	3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
55-50	21	23	22	27	32	24	25	37	38	36	39	36	37	34	39	32	30	33	17	14	13	26	39	31	25	34	15	19	9	15	18
50-45	15	21	11	18	14	11	25	20	22	23	23	26	23	26	15	19	16	24	21	14	17	22	16	14	24	22	30	31	23	26	18
45-40	17	14	17	14	21	15	16	14	16	19	25	29	19	13	14	12	17	18	23	15	17	19	15	14	15	12	16	13	24	20	21
40-35	18	17	16	18	15	18	17	18	13	17	27	13	10	19	17	15	19	18	20	22	17	21	27	25	20	24	30	25	26	22	25
35-30	6	4	1	8	8	7	9	10	14	14	11	9	5	3	6	9	9	13	9	16	9	14	8	7	10	8	12	8	6	9	12
30-25	4	3	1	9	6	1	4	6	4	2	1	7	4	...	4	6	8	6	5	...	7	2	10	5	11	6	5	9	4	...	8
25-20	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...
Total	**81**	**82**	**68**	**94**	**96**	**76**	**97**	**108**	**107**	**111**	**127**	**123**	**98**	**95**	**95**	**93**	**99**	**112**	**95**	**81**	**80**	**104**	**115**	**96**	**106**	**106**	**108**	**105**	**92**	**92**	**102**

LOWS CROSSING THE 80TH MERIDIAN.

Between latitudes.	1883	1884	1885	1886	1887	1888	1889	1890	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913
55-50 N.	3	3	1	3	3	3	6	7	7	3	6	8	...	3	3	1	1	1	...	...	...	4	3	...	2	1	...	...	1	4	...
50-45	44	61	38	37	43	37	41	49	46	53	53	51	50	46	45	53	44	45	33	30	29	45	45	41	42	45	36	38	32	35	39
45-40	26	20	20	24	20	16	23	30	24	22	25	14	19	21	22	23	24	25	28	29	29	26	26	22	34	25	28	29	33	34	32
40-35	12	12	10	11	3	9	11	6	8	7	8	19	7	9	8	7	10	11	17	10	8	12	13	11	18	7	16	18	19	21	18
35-30	6	6	8	10	8	6	11	7	6	6	7	7	10	5	6	6	8	13	13	8	7	2	12	8	11	9	6	7	5	9	8
30-25	1	1	2	1	3	2	1	1	5	3	2	2	5	...	1	1	7	2	4	1	4	4	2	4	4	...	5	1	1	1	1
25-20	...	...	...	2	3	2	...	...	1	1	1	1	2	...	...	1	...	2	4	...	...	3	...	...	...	...	2	...	...	...	...
20-15	...	...	...	1	2	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Total	**92**	**103**	**79**	**89**	**85**	**75**	**94**	**100**	**97**	**95**	**102**	**102**	**93**	**84**	**85**	**92**	**94**	**99**	**99**	**78**	**77**	**96**	**101**	**86**	**111**	**87**	**93**	**93**	**91**	**104**	**98**

Therefore we do not know whether the total number of lows crossing the 100th meridian is highest between latitudes 55° N. and 50° N. The same is true of the lows crossing the 80th meridian between 50° N. and 45° N. It may be that in both cases the zone of maximum frequency lies farther north, and even if this is not so on the average there can be no doubt that it is actually true for particular years or groups of years. In any case the correct position of the northern belt of lows can not be ascertained from this table, although the discussions of maps for the Northern Hemisphere published by the Signal Service justify an assumption of the existence of such a belt.

On the other hand, one may properly doubt the validity of the assumption that the maps of tracks of lows published in the MONTHLY WEATHER REVIEW represent a perfectly homogeneous series of observations. It is certainly the best material at our disposal, but the personal factor of the meteorologist who compiles the daily weather maps in order to draw the tracks of lows has an unquestionable importance, and it is difficult to admit that this personal factor has not undergone some changes and

Now the advantage of taking into consideration the seasonal variation of the occurrence of lows is to change somewhat the discussion of the differences that may be observed between the data of individual years, such, for example, as the years of maximum and the years of minimum of sun spots.

Figure 6 gives the curves of mean distribution of frequency along the one hundredth meridian for the months of July, December, and April, which may be considered as representing the typical seasonal changes. The curve

[3] The Weather Bureau meteorologists are of the opinion that the personal equation of the meteorologist who draws the daily weather map does not constitute a very important factor influencing the face of the map. It is recognized, however, that personal factor is quite important when it comes to selecting highs and lows for tracing their paths during each month and also in the actual tracking of each.

As all students of our maps are more or less directly interested in this matter, the following list gives the approximate terms of service of different officials (designated by letters) in connection with the plotting of highs and lows on Charts II and III, respectively:

A, 1888–1901.
B, June, 1901–January, 1904.
C, February and March, 1904.
D, April, 1904–January, 1905.
E, February–December, 1905.
F, 1906–1910; March, 1914—date.
G, 1910–February, 1914.

Y, obtained from annual data, expresses the superposition of these three types of curves. The first maximum, *a*, affects the months June to February; the second maximum, *b*, the months of February or even January to May. If, therefore, during a given year the spring was particularly stormy, in all probability the frequency distribution of lows for the year will belong to the April type (IV). If, on the contrary, lows occurred predominantly during the summer and the autumn, the northern maximum will be more accentuated and the second maximum will be missing; the curve will belong to the July type (VII).

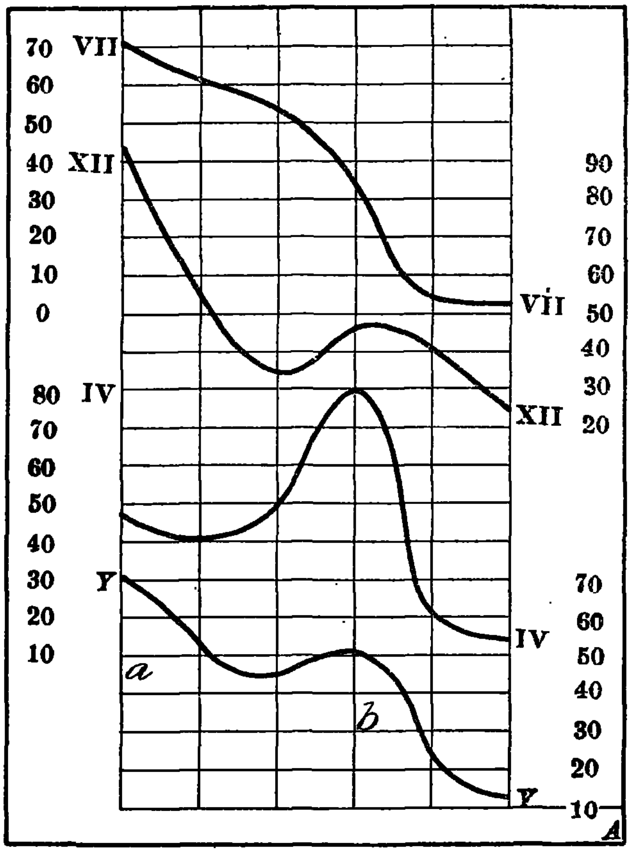

FIG. 6.—Curves expressing the mean distribution of frequency of lows along the 100th meridian in July (VII), December (XII), April (IV), and the Year (Y).

Let us see now if really important differences of the curves of yearly data are principally due to the season during which most of the lows occurred. Figure 7 presents the curves of storm distribution for those years having sunspot maxima and minima. We notice at once a radical difference, at least between the curves of 1893 and 1906 and those of 1901 and 1913. The two last-named curves are very peculiar, indeed; the curve for 1913 in particular, indicates apparently an unmistakable shifting of the northern storm-belt toward the south.

Tracing the curves for each year we notice that it is not accidental that the curves of the years of sunspot minima differ from the curves of the years of sunspot maxima; the curves for years before and after those of sunspot maxima or minima display a striking tendency to similarity. Table 3 enables one to thus trace the curves for the individual years and we need not enter into the details. Now, since the curves of the years 1883–1885, 1892–1894, 1905–1907, may be considered as being similar and as representing the conditions at the sunspot maxima [4] for three consecutive cycles, while the curves of the sunspot minima years 1888–1890, 1900–1902, 1911–1913, are also mutually similar but different from the other curves, the differences that exist between the averages of these two groups of years may serve to test the conclusion advanced by Kullmer and presented in form of a theory by Huntington.

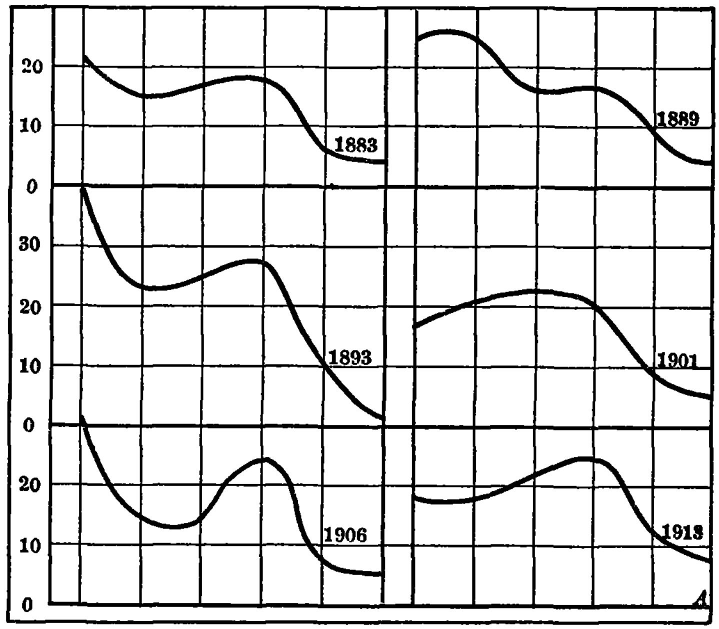

FIG. 7.—Curves of mean distribution of frequency of lows along the 100th meridian during years of sunspot maxima (1883, 1893, 1906) and sunspot minima (1889, 1901, 1913).

The monthly totals of observed lows are given in Table 4.

TABLE 4.—*Frequency of lows on the 100th meridian during the years of sunspot maxima and sunspot minima.*

YEARS OF SUNSPOT MAXIMA.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1883	10	5	6	7	7	5	9	3	6	4	6	13	.....
1884	10	8	7	6	8	2	5	7	11	10	6	2	.....
1885	7	5	7	6	6	4	7	4	6	5	4	7	.....
1892	10	8	9	6	11	7	12	7	10	10	12	9	.....
1893	14	9	12	9	10	11	8	6	9	15	12	12	.....
1894	11	11	13	10	4	9	6	10	13	11	14	11	.....
1905	7	10	9	15	10	7	8	7	8	9	14	11	.....
1906	11	10	10	7	14	4	4	7	6	7	6	10	.....
1907	9	6	14	11	9	8	9	8	7	7	10	8	.....
Total	**89**	**72**	**87**	**77**	**79**	**57**	**68**	**59**	**76**	**78**	**84**	**83**	**909**

YEARS OF SUNSPOT MINIMA.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1888	5	5	7	9	8	8	3	5	4	12	4	6	.....
1889	6	8	6	8	7	7	15	5	8	10	5	12	.....
1890	8	12	9	8	13	6	7	9	6	8	10	12	.....
1900	11	12	11	7	6	8	11	7	7	10	9	13	.....
1901	17	10	9	6	5	7	4	3	5	10	12	7	.....
1902	7	4	8	8	4	7	6	7	9	5	8	8	.....
1911	8	8	10	6	7	7	5	10	8	8	9	6	.....
1912	10	7	9	7	7	7	9	8	4	9	5	10	.....
1913	13	8	10	8	7	8	9	7	5	10	10	7	.....
Total	**85**	**74**	**79**	**67**	**64**	**65**	**69**	**61**	**56**	**82**	**72**	**81**	**855**
Difference	*−4*	*+2*	*−8*	*−10*	*−15*	*+8*	*+1*	*+2*	*−20*	*+4*	*−12*	*−2*	*−54*

[4] For years of sunspot maxima and minima, according to Wolf-Wolfer relative numbers, see this REVIEW, July, 1915, p. 313.

We may first consider the difference between the annual totals. This difference is 54, or 6 storms less per year during the years of sunspot minima than during the years of sunspot maxima. This is in complete accord with one of Kullmer's conclusions, viz, that years of greatest frequency of sunspots are more stormy than those corresponding to minima of the solar cycle. The same fact was stated long ago by Poëy (24), Meldrum (25), and Piddington (26) concerning the cyclones of the West Indies, the Indian Ocean, and the China Sea; in a more general way it was also stated by Joseph Baxendell, who, already in 1871, reached the conclusion that the forces which produce the movements of the atmosphere are more energetic in years of maximum than in years of minimum sunspot activity (27).

An increased agitation of the terrestrial atmosphere corresponding to increased disturbances of the solar atmosphere may therefore be considered as a fact just as well established as the atmospheric temperature correlation. In the case of temperature, however, the increase during the years of a sunspot minimum is very small and the correlation that exists is a most complicated phenomenon. The same may be said about storminess. First, the average of the 18 years gives only 6 lows more per year, and, since the yearly mean of the number of storms that crossed the 100th meridian is 98, it means only an increase of 6.1 per cent.

Again, if we look over the differences for the individual months we notice at once that, together with the decrease or increase of storminess, a radical difference of the annual variation appears to be a very much more important characteristic than the variation of storminess.

The decrease of frequency of lows specially affects the months March to May, September and November, whereas from June to August we notice an increase, as well as in February and October.

LATITUDE DISTRIBUTION OF LOWS FOR THE DIFFERENT MONTHS DURING YEARS OF SUNSPOT MAXIMA AND SUNSPOT MINIMA.

Tables of the monthly numbers of lows observed in different latitudes during the 9 sunspot-maxima years and during the 9 sunspot-minima years, when subtracted from one another give the diagram shown in figure 8. This diagram shows that, along the 100th meridian, the annual variation of the distribution of lows in latitude is very different during the years of sunspot maxima from that of the years of sunspot minima. As far as annual data are concerned, it confirms Kullmer's conclusion: "When sunspots are numerous the main storm belt shifts northward" (28). Huntington adds that "at such times the main storm belt tends to split. The major portion moves northward, while a smaller portion shifts southward and oceanward" (29). It may be, however, that this displacement is only an apparent one. Bowie and Weightman show indeed very clearly that different types of lows are distinguishable and that there is a pronounced annual variation in the geographical distribution of the occurrence of these types. Concerning the 100th meridian, the numbers indicate that years of sunspot minima are characterized by a more uniform latitude distribution throughout the year. During years of sunspot maxima, on the contrary, the latitude distribution is more unequal; and in these years both belts of lows are more accentuated, the northern belt during February, September, October, and particularly in November, and the southern belt during the months of February to May. The shifting of the storm belts in accordance with the changes shown by Wolfer's sunspot numbers is therefore questionable. The action of the increase of sunspots upon the storms seems to be primarily an action of coordination. Not only the annual frequency of storms

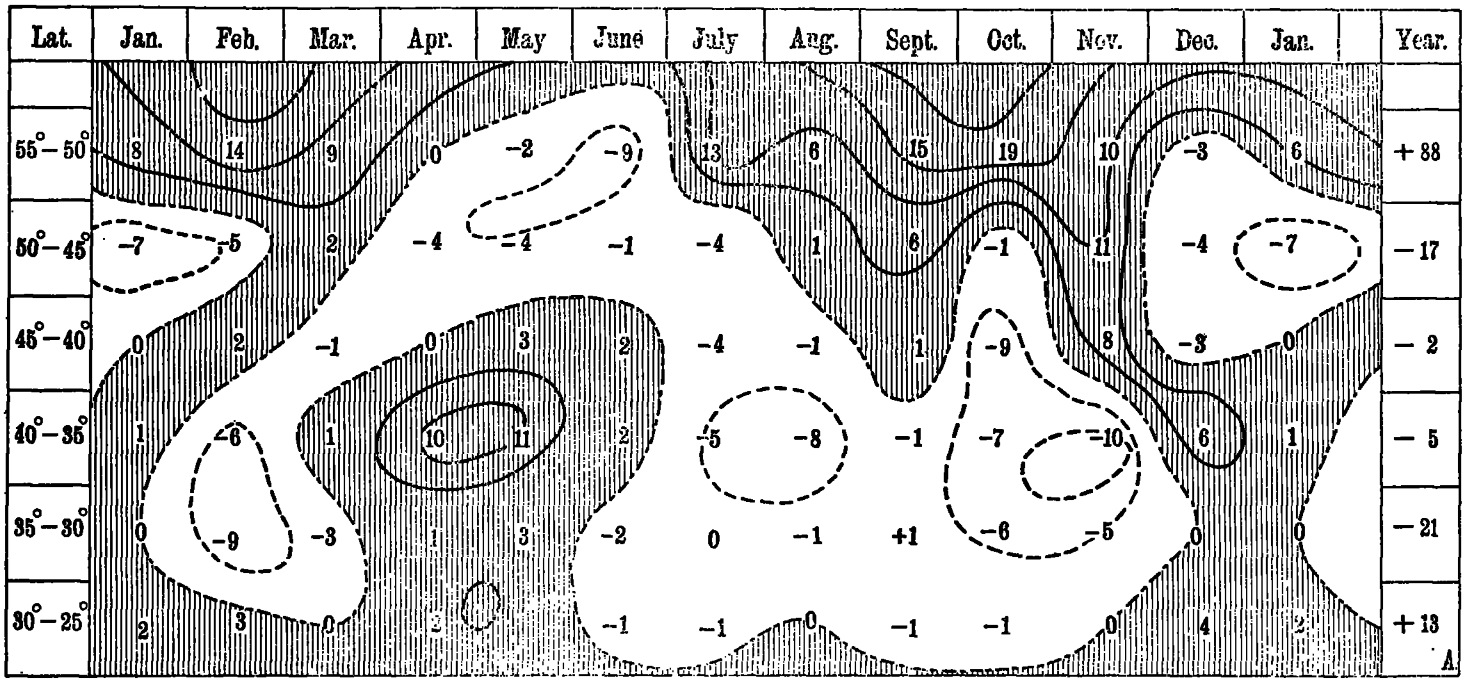

Fig. 8.—Contrast in latitude distribution of the frequency of lows crossing the 100th meridian during sunspot maxima and minima. Shaded areas indicate seasons and regions when the frequencies under sunspot maxima *exceed* those under sunspot minima.

is slightly increased, but also the paths that the storms follow are more definite and closely confined to the storm belts, in the southern belt from March to June, in the northern during the rest of the year.

The conclusion to be drawn from this coincidence is that the annual variation in the geographical distribution of atmospheric pressure must be essentially different in the years of sunspot maxima from that during years of sunspot minima. It seems probable that the gradients must be more pronounced or less pronounced in harmony with the coordination or lack of coordination of the tracks of barometric lows.

THE PLEIONIAN VARIATION OF THE FREQUENCY OF LOWS.

On the following diagram (fig. 9) the curves *A*, *B*, and *C* express graphically the overlapping totals of yearly frequencies of lows crossing the 100th, the 90th, and the 80th meridians, curve *S* gives the annual values of the relative numbers of sun spots and curve *E* represents the variation in frequency of lows observed on the 80th meridian between 45° and 40° of latitude. This last curve will simply serve for the purpose of demonstrating a striking disagreement with the sun-spot curve as well as some very pronounced disagreements with the curve giving the total number of lows for all parallels along the 80th meridian.

The disagreements between curves *C* and *E* show most plainly how important the shift of the main storm belt may be occasionally. I shall insist upon this fact later. Comparing the curves *A*, *B*, and *C* with *S*, we notice at once that the variations in frequency of storms correspond but vaguely with the sun-spot variation. Some degree of correlation is undeniable, but this correlation is certainly not the main factor affecting the variation of frequency of lows. We must admit that the maxima of frequency of sun spots show corresponding maxima of frequency of lows; but at sun-spot minima we observe also maxima of lows. Therefore the period of the variation of atmospheric storms—as far as the United States are concerned—must be at least one-half of the 11-year cycle.

In order to harmonize this fact with solar variations, we might imagine that the double period of terrestrial storminess corresponds to the known variations in the latitude distribution of the solar prominences, which are concentrated in two zones at both the times of maxima and of minima of sun spots, but lie in four zones during the intervening years (**30**). Again, one might imagine that this terrestrial double period is related to the secondary maximum of sun-spot frequency recognized by De la Rue and others (**31**). The curves of overlapping totals of lows display, however, secondary maxima between the so-far admitted maxima. If therefore we accept as real the correspondence between the solar curve and the frequency curves of storms, we must admit that upon the 11-year period is superposed a shorter period of about 2¾ years' duration and that this period is predominant

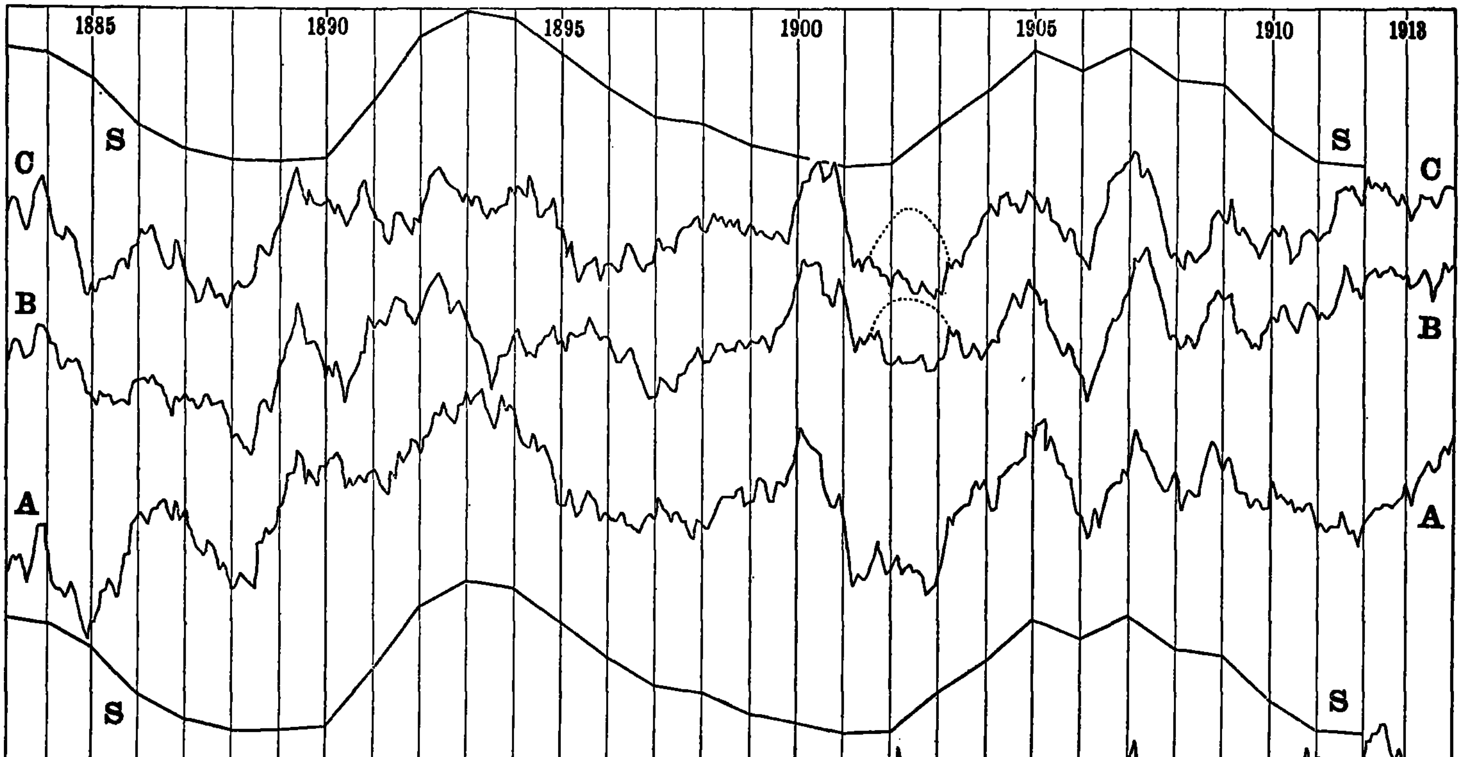

FIG. 9.—Yearly frequencies of lows compared with the curve of relative sunspot numbers (*S*). *A*, *B*, *C*, curves of overlapping totals of yearly frequencies of lows crossing 100° W., 90° W., and 80° W., respectively.

E, the yearly frequency of lows crossing 80° W. between 45° N. and 40° N.

in its effects upon atmospheric phenomena. A solar period of 1,004 days (or 2.75 years) has already been found by Bigelow (**32**), and the above inference from the inspection of curves *A*, *B*, and *C* of figure 9 harmonizes very well with Bigelow's short period (**33**).

However, it may be that the mean duration of this most characteristic variation is shorter than 2.7 years. In studying the consecutive means of atmospheric pressure, temperature, and sunshine for New York City I have found a mean of 25 months (**34**). A similar result was also obtained long ago by H. H. Clayton (**35**). Moreover, it is only as a first approximation that we may admit a correspondence of the maxima of curves *A*, *B*, and *C* with the principal maxima and minima of the sun-spot variation. In reality the phenomenon is more complicated. We notice indeed that the maximum of 1900 on curve *A* is retarded on curve *B* and very much more retarded on curve *C*. In the case of the maximum of 1905 the same phenomenon is again clearly demonstrated, but now curve *C* is in advance over *B* and *A*.

Together with the general appearance of the curves, this phenomenon of a progressive westward or eastward displacement of a maximum is precisely what characterizes the pleionian variations. But it is not a simple question of analogy. On the contrary, there is a strong argument in favor of the hypothesis that the crests of the storm-frequency curves are pleionian crests; in other words, that the changes of the amount of observed lows are determined by the same causes as those affecting temperature.

I have shown that the temperature variation at Arequipa, Peru, is typical and that the curve of overlapping yearly means observed at that station may be used as a standard for comparisons (**36**). The thermopleionian variations of many other stations correspond with the Arequipa variation. So do the crests of the frequency variations of lows in the United States. The crests of 1900, 1905, 1907, and 1912 correspond in a very satisfactory way with the thermopleionian crests of Arequipa. The crest of 1909, however, is missing on the Arequipa curve and a well-marked crest observed at Arequipa between 1902 and 1903 is missing on curves *B* and *C*. But the presence of a small crest on curve *A* and the two small crests on curve *B* show that we have to deal with an anomaly. The dotted lines at 1902.5 on *C* and *B* indicate the portion of the curves which may have been depressed.

Of course only a detailed study of all the meteorological phenomena could serve as a basis for a further discussion. Previous to 1900, we observe in tropical regions (**37**) thermopleionian crests in 1883-84, 1886, and 1889 corresponding perfectly with the crests of the frequency-curves of lows. For the years 1891 to 1899 I do not possess at present the necessary curves to make positive statements; besides, the curves *A*, *B*, and *C* disagree. The number of very satisfactory correspondences that have been noticed is sufficient, however, to draw the conclusion that the frequency-variation of barometric lows in the United States is related to the pleionian variation.

If this conclusion is correct—and remembering the important yearly variation of the distribution in latitude of the lows which must be due to the seasonal differences in the distribution of atmospheric pressure—we must admit that in a similar way the presence of a baropleion on one part of the continent will influence the average movement of the lows. It may be that the lows have a tendency to swing around the area of abnormally high pressure; if so, the shifting of the storm belt from year to year must be due to passing or pendulating baropleions.

Evidently a great amount of research work remains to be done in order to verify this hypothesis. First of all, the normal conditions of the circulation of lows are far from being well known. Four most important "centers of action" influence directly the atmospheric disturbances observed in North America. During the summer the North Pacific and the Icelandic centers of action practically join into one low pressure belt; the high-pressure areas of the Atlantic and Pacific Oceans are generally more or less connected from October to March, at least so far as average conditions are concerned. It seems to me that in the present state of our knowledge it would be difficult to decide whether it is variations at these centers of action that determine the observed pleionian variations in frequency of lows or, on the contrary, the lows that influence the changes in position and extent of the centers of action. Reasoning does not help. It is a discussion of the actual facts which is needed.

The same remark applies to the supposed influence of baropleions on the temporary anomalies in the distribution of lows. How important these anomalies may be is illustrated by a striking fact. Expressing the lows observed between latitudes 55° and 45° N. as percentages of the total number of lows observed crossing the 100th meridian, we have 63.1 per cent in 1896 and 34.5 per cent in 1902, a difference of 28.6 per cent. The per cent of lows crossing the 80th meridian between 50° and 45° N. was 58.7 in 1898 and 33.3 in 1901, a difference of 23.4 per cent. The distribution of the tracks of lows for these particular years must have been radically different; a strong concentration in one case, a lack of concentration in the other. Now, the degree of concentration considered in the same way, from year to year, displays a long-range variation of much longer periodicity than the sun-spot cycle. Since long-range variations in the distribution of atmospheric pressure must also be admitted, a possible correlation may be expected.

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A UNIFORM THERMOMETER EXPOSURE AT METEOROLOGICAL STATIONS FOR DETERMINING AIR TEMPERATURE AND ATMOSPHERIC HUMIDITY.

By VLADIMIR KÖPPEN.

[Sections translated from Met. Ztschr., 1913, 30: 485-488, 513-523.]

* * * All in all, we are at last in a position to state definitely the errors due to the customary thermometer exposures, to attack the problem of eliminating these errors, and to begin to work toward a uniform manner of exposing thermometers throughout the world. Although it is much to be regretted that we still have no such series of comparisons in tropical and subtropical regions as are available for central and northern Europe, nevertheless the already observed differences due to sun's altitude, cloudiness, and wind velocity enable us to draw quite approximate conclusions for the Tropics also.

The daily means of temperature, so far almost the sole element employed for making climatological comparisons, do not vary greatly even for quite divergent methods of exposure because their daytime and nighttime errors balance each other to a certain extent. The latter is least true for great massive shelters such as those of Wild and Neumayer, because in these the daily heating in the sunshine and the nocturnal damping due to the mass of wood upset the balance so that their records yield too high daily means. On the other side stands the English shelter, which, according to the Potsdam comparisons,[1] gives a prevailing too low daily mean. For the 24-hour means in the English shelter during the long-night months of November to February were 0.2° to 0.3°C. lower than those in the [metallic window] shelter, while from March to October both exposures gave means agreeing within ±0.1°C. Again the mean temperature from thrice daily observations within the English shelter departs from that of the surrounding air determined in the same manner by more than 0.1°C. (at Pavlovsk this holds for June and July only; at Potsdam for these same months and also in January only).

We must demand, however, that not only the daily means but also the individual term-observations shall be comparable, and this also both for our prevailingly cloudy climate and for climates of clear skies and strong radiation. In other words, the monthly means of the term-observations in such climates shall not show systematic errors, i. e., influences due to thermometer exposure, greater than 0.1° or 0.2° C. We must demand that the important climatic element of daily temperature range shall be susceptible of comparative study. At present, even under selected favorable exposures in Potsdam, this element is 20 per cent greater in June when measured in the English shelter than if determined in the Prussian window shelter and still greater if the French exposure is used.

Hellmann is right in the closing sentence of his report[2] when he says, "It is quite inappropriate to employ two fundamentally different methods of thermometer exposure, such as the window shelter and the ground shelter, in one and the same meteorological réseau, for we thereby greatly reduce the comparability of the observations and particularly of the individual term observations."

This statement, however, is to be extended to the whole globe. We must endeavor to establish a network of comparable observations embracing the whole globe, and must not be content with a Prussian, a French, a German-Colonial, and various other concepts of air temperatures. Naturally, it will require many years to actually attain this ideal; therefore the sooner we begin to strive toward it the better for all.

It will be impossible to adopt a window exposure, or any other such location in the shadow of a building, for our universal uniform exposure. To be sure, such an exposure most readily avoids disturbances due to radiation, and in our climate it yields quite good comparable means. But there are to be considered—

(1) The air in such a shadow is an exception, while the air over an open surface is the rule; hence the former may

[1] Hellmann *in* Bericht, Preuss. Meteorol. Instit., 1911, pp. 64-68.
[2] Hellmann *in* Bericht, Preuss. meteorol. Instit., 1911, p. 83.