Dakota, and Wisconsin, where the damage of the early period was quite insignificant compared with that of the later period.

The canvass of the country by the Climatological Service is continuing. The synopsis for 1924 has not yet (May, 1925) been prepared, but enough is already known to make sure that the year will include a greater property loss from tornadoes than that of any one year covered by Table 2, that is, the figure in dollars will be a larger one; it will probably be the highest figure for a year in the country's history. Furthermore, 1925 has already witnessed (March 18) the most serious single tornado ever known, and so the 1925 death toll is expected to exceed that of any previous year, save perhaps 1884, and its figure for damage will very likely surpass that of 1924.

In handling the reports of tornadoes the writer has at times noticed how narrowly a violent storm escaped being entirely unreported. It is thought that a few tornadoes, though probably not many, still occur in sparsely settled parts of the country without any news of them reaching the Weather Bureau.

In closing, the writer wishes gratefully to acknowledge the advice and assistance given by many Weather Bureau colleagues, particularly by Prof. A. J. Henry and Mr. P. C. Day; also by Dr. Charles F. Brooks.

THE 11-YEAR PERIOD OF TEMPERATURE IN THE NORTHERN HEMISPHERE IN RELATION TO THE 11-YEAR SUN-SPOT CYCLE

By Dr. FRANZ BAUR

[Wetter- und Sonnenwarte, St. Blasien, Germany, October, 1923]

The analytical method for investigating the periods in the course of the weather is essentially superior to the graphical method which has hitherto been almost exclusively adopted. Its application to the annual mean temperature for the period 1876–1919 of a number of European and North American meteorological stations shows that the maximum of the 11-year temperature period on the whole earth in no way coincides with regard to time even approximately with the minimum of solar activity as has been assumed up to now. In large areas of the Temperate Zone of the Northern Hemisphere the maximum of the 11-year temperature period occurs between the minimum and maximum of the sun-spot cycle; in some continental European regions it even coincides with the maximum itself. The shifting of the phases of the two periods seems to be determined by the latitude and climatic position of the place of observation. It is very probably a physical reality and due to the difference between the diathermancy of polar and tropical atmospheres. The greatest amplitudes are shown by the 11-year temeperature period in those regions in which its maximum falls about on the minimum of the sun-spot cycle. In the other regions, it has but little importance with regard to the annual mean temperature and falls far into the background compared with other periods.

The widespread opinion that the maximum of the 11-year temperature period coincides approximately on the whole earth with the minimum of the 11-year sun-spot cycle is based in the first place on the work of Köppen [1] and Mielke,[2] who, in deducing their results, adopted the graphical method of representing the course of temperature. A work on the sun-spot terrestrial temperature relations in the United States [3] which has recently appeared is also based on this method. The graphical method is, however, little suited to the investigation of periodic phenomena, for with it are necessarily connected smoothing processes in order to eliminate from the graph lesser periods than the required one, or the one under investigation. These smoothing processes tend both to obscure some really existing period and to make apparent a nonexistent one. But more important is the fact that these smoothings of the graph change in most cases the phase of the required period considerably. Therefore, the relation between the phases of the 11-year temperature period and those of the sun-spot cycle as set forth by Köppen and Mielke, can not be accepted, being insufficiently proved. Such a relation can only be established by a strictly mathematical method.

One of the best mathematical methods of investigating periodicities is the representation of the given function by a Fourier series. There is, in general, no real difficulty in resolving any empiric numerical function into a Fourier progression since the convergence of the progressions, which are of the general form

$$f(t)=\tfrac{1}{2}a_0+a_1\sin t+a_2\sin 2t+\ldots\ldots$$
$$+b_1\cos t+b_2\cos 2t+\ldots\ldots$$

is determined in large measure by mathematical theory. In meteorology, however, the problem becomes difficult, since it is a matter of compound functions of the form

$$f(t)=\tfrac{1}{2}r_0+r_1\sin(T_1t+\phi_1)+r_2\sin(T_2t+\phi_2)+\ldots\ldots$$

whose terms are not of definite number but, in general, of any number of incommensurable periods. Even if, as in the given example, it is only a matter of calculating a single period, the amplitude and phase resulting from Fourier's analysis for this one period may yet be falsified by the coexistence of other incommensurable periods. For each ordinate of the unsmoothed course of a phenomenon subject to periodic oscillations is the sum of several ordinates belonging to different periods. In order to eliminate the influence of other periods in determining the amplitude and phase of a period by means of Fourier's analysis, it is necessary either to examine a very large series of observations such as hardly yet exists in most cases for meterological purposes, or else a period of time must be made the basis of the calculation which is, at least approximately, a multiple of each of the existing periods.

Since in previous works [4] I have come to the conclusion that very probably there are contained in the fluctuations of temperature both a 2.4 and a 7.2 year period, I chose, for the determination of the phase shiftings of the 11-year temperature period, a period of 44 years, for this is approximately a multiple of 2.4, 7.2, and 11 years. The choice of a still longer period of time would not have been feasible, for the reason that the period is not exactly 11 years, but 11.1–11.4, so that in dividing the whole period of observation into intervals of 11 years

[1] Köppen W., Ueber mehrjährige Perioden der Witterung, insbesondere über die 11-jährige Periode der Temperatur. Zeitschr. der Oesterr. Gesellschaft für Meteorol. VIII, 1873, XV, 1880, XVI, 1881; Meteorol. Zeitschr. VIII, 1891, XXXI, 1914.

[2] Mielke Johannes, Die Temperaturschwankungen 1870–1910 in ihrem Verhältnis zu der 11-jährigen Sonnenfleckenperiode. Archiv der Deutschen Seewarte, XXXVI, No. 3, 1913.

[3] Henry A. J., Sun spots and Terrestrial Temperature in the United States. Mo. Weather Review, May 1923, vol. 51, pp. 243–249.

[4] e. g., F. Baur, Die Veränderlichkeit der Temperatur aufeinanderfolgender Monate und die periodischen Schwankungen der Jahrestemperatur in Deutschland, Abstract in Mo. Weather Review, April, 1922.

each, the phase of the oscillation in the fifth interval compared with that in the first would already be shifted by about a year. The 44 yearly averages were arranged according to the following scheme in 4 rows of 11 terms each, and of the 4 values in each column the average (M_1 M_2, etc.) was obtained. From the 11 mean values thus obtained are then calculated the amplitude and phase of the first term of Fourier's series by the known method.

y_1	y_2	y_3 -	y_{11}
y_{12}	y_{13}	y_{14} -	y_{22}
y_{23}	y_{24}	y_{25} -	y_{33}
y_{34}	y_{35}	y_{36} -	y_{44}
S_1	S_2	S_3 -	S_{11}
M_1	M_2	M_3 -	M_{11}

Besides the annual mean temperatures given in Table 1, there were also analyzed the annual temperature deviations for 10 districts of the United States, given in Table 4 of the above-mentioned work by Alfred J. Henry.[5] The position of the respective districts is shown in Figure 1. The deviations for the tenth district were not used, since in the table published by Henry, they are, apparently in consequence of a mistake, absolutely identical with those of the fourth district.

The results of the calculations have been arranged in Table 2. The phases in brackets (southern Italy, Ponta Delgada and Batavia) were obtained from a different period from all the others. The amplitudes were all changed into degrees Centigrade. The study of the table teaches first that the temperature maximum coincides with the sun-spot minimum by no means in all regions of the Northern Hemisphere, but that—at least in the period 1876–1919—in the northern and continental parts of Europe, both maxima approximately coincide. A close study of Table 2 gives for the period 1876–1919 the following relations between the 11-year temperature period and the sun-spot period of the same duration.

(1) The temperature maximum coincides approximately with the sun-spot minimum only in the Tropics

TABLE 1.—*Annual means of temperature*

Year	A	B	C	D	E	F	G	H	J	K	L	M	N	O	P	Q	R	S	T	U
	° C.	° C.	° C.	° C.	° C.	° F.	° C.	° C.	° C.	° C.	° C.	° C.	° C.	° C.	° C.	° F.	° F.	° F.	° F.	° C.
1874	16.3	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------
1875	16.6	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------
1876	17.4	9.80	8.3	10.6	8.47	50.00	6.9	5.8	2.8	2.25	20.4	−8.9	−1.4	3.1	------	43.9	50.5	55.4	77.0	25.89
1877	17.0	10.08	8.6	10.4	8.75	49.46	7.2	5.25	3.0	1.5	24.2	−8.1	−1.6	2.5	------	45.8	52.6	56.4	77.0	26.28
1878	17.0	9.16	8.7	10.0	9.00	49.41	8.1	6.65	4.9	2.8	22.1	−7.4	−0.3	2.2	------	48.5	52.9	57.0	77.1	26.64
1879	16.4	8.21	7.3	8.2	7.14	46.23	6.5	5.6	3.9	2.55	21.7	−8.0	−1.6	2.6	------	46.1	51.3	56.2	77.1	25.85
1880	16.9	9.91	8.85	10.6	8.83	49.17	7.6	6.65	3.7	1.95	21.4	−8.4	−1.9	3.7	16.9	46.7	52.2	56.9	78.7	25.65
1881	17.1	9.65	7.7	9.8	7.69	48.13	6.2	5.15	2.3	1.05	21.8	−7.9	−1.2	1.0	17.1	46.4	52.2	57.9	78.1	26.13
1882	17.0	9.44	9.1	10.2	8.92	49.44	8.5	7.1	5.1	3.0	20.4	−10.0	−3.6	1.9	17.7	47.1	51.5	57.3	78.2	25.78
1883	15.9	9.24	8.3	9.9	8.38	48.93	7.2	6.65	4.2	4.15	21.0	−7.3	−3.6	3.9	17.1	43.4	50.6	55.8	78.4	[25.88
1884	15.9	10.09	8.95	10.5	8.98	50.09	8.0	7.05	4.1	3.25	20.6	−10.3	−4.7	3.8	16.9	43.9	51.6	56.3	77.6	25.80
1885	16.6	9.82	8.65	9.8	8.19	48.08	7.6	5.9	4.1	1.55	21.3	−8.3	−2.0	2.2	17.5	41.4	49.8	51.7	76.5	26.00
1886	16.7	9.92	8.65	10.3	8.43	48.24	7.4	6.05	4.5	3.0	20.9	−10.0	−2.7	2.2	17.5	44.0	51.0	53.0	75.9	26.09
1887	16.8	8.56	7.8	8.8	7.46	47.47	7.1	6.55	4.9	2.7	21.4	−11.3	−2.8	1.9	17.6	44.6	51.9	55.3	76.1	25.70
1888	16.4	8.76	7.75	9.0	7.25	47.34	6.2	5.45	2.3	1.4	21.3	−8.8	−1.2	1.8	17.4	42.8	51.5	53.8	76.5	26.20
1889	16.3	8.81	8.0	9.5	7.99	48.59	7.2	7.3	4.5	3.6	21.5	−10.0	−2.2	3.4	17.8	46.1	53.5	54.8	76.0	26.41
1890	16.0	8.55	8.15	9.3	8.05	48.33	7.7	6.85	5.2	3.85	21.2	−9.2	−2.5	4.0	18.0	46.4	53.8	56.4	76.6	25.78
1891	16.1	8.76	8.0	9.5	8.04	47.79	7.3	6.65	4.5	2.75	21.5	−10.3	−2.5	2.9	17.9	46.7	53.8	54.7	76.1	26.25
1892	16.7	9.57	8.45	10.2	8.05	47.31	7.4	5.65	3.0	1.15	21.3	−8.1	−0.9	1.0	17.3	44.6	51.9	53.3	75.7	26.00
1893	16.4	10.12	8.4	10.8	8.38	50.38	6.7	6.25	2.5	0.9	20.2	−7.8	−1.3	3.1	17.6	43.8	51.3	53.7	76.9	25.71
1894	16.5	9.72	8.85	10.4	9.00	49.24	7.6	7.35	5.4	3.7	20.7	−10.4	−3.3	4.2	16.8	47.6	53.7	56.1	76.7	25.88
1895	16.4	9.27	8.0	9.9	8.02	48.26	7.3	5.85	4.0	2.7	20.8	−7.2	−0.6	3.2	16.6	45.1	51.4	53.6	75.9	26.02
1896	16.1	8.75	8.15	9.8	8.28	48.69	7.7	7.0	5.1	3.1	20.8	−10.1	−2.9	3.6	17.7	47.2	51.2	55.6	76.4	26.38
1897	16.5	9.74	8.8	10.6	8.59	49.49	7.6	6.75	4.8	2.75	20.3	−9.3	−2.5	3.5	17.1	46.8	51.6	55.3	77.2	26.60
1898	17.1	9.97	9.6	10.7	9.20	50.43	8.0	6.8	4.7	2.9	20.4	−10.6	−4.2	3.3	17.6	47.3	52.9	55.9	76.6	26.11
1899	16.8	10.17	8.65	10.8	8.84	50.11	7.7	6.7	3.5	1.15	20.6	−8.5	−2.2	3.1	17.4	46.8	52.6	55.0	76.9	25.98
1900	17.1	10.18	9.3	11.1	9.11	49.64	7.9	6.15	3.4	1.05	21.2	−6.9	−1.2	3.5	17.8	47.9	54.3	56.0	75.9	26.37
1901	16.5	9.11	8.5	10.0	8.39	48.84	7.7	7.0	4.7	3.2	21.6	−8.0	−0.9	4.0	17.6	46.7	52.3	54.0	74.7	26.23
1902	16.7	9.30	8.05	9.9	7.81	48.54	6.0	5.6	2.4	1.45	21.0	−7.7	−1.5	2.6	17.1	47.2	52.6	54.7	76.4	26.37
1903	16.4	9.39	9.0	10.3	9.13	49.30	8.1	6.7	5.4	2.9	19.8	−7.9	−1.7	3.1	17.0	46.0	52.5	54.3	76.5	26.28
1904	16.7	10.13	9.25	10.4	8.99	48.97	7.0	6.4	3.6	2.15	19.8	−9.2	−2.3	3.9	16.9	44.7	49.9	53.2	76.1	25.85
1905	16.3	9.43	9.0	9.9	8.80	49.03	7.6	6.75	4.7	2.7	20.3	−7.6	−1.5	3.7	17.4	45.8	52.0	54.2	76.8	26.51
1906	16.0	9.68	8.95	10.5	9.13	49.60	8.0	7.2	5.3	2.3	20.4	−8.9	−2.8	2.9	17.4	48.0	53.5	55.4	76.4	26.47
1907	16.5	9.48	8.85	10.1	8.56	48.68	6.7	6.35	3.4	3.1	19.6	−9.4	−3.1	2.6	17.5	45.5	51.2	54.2	77.4	26.02
1908	16.2	9.21	8.3	9.8	8.18	49.36	6.8	7.05	4.0	2.6	19.6	−7.3	−1.6	4.2	16.8	47.8	53.5	56.6	76.8	25.86
1909	15.9	8.85	8.15	9.5	8.09	48.09	7.0	5.95	4.1	2.0	20.6	−7.9	−1.4	3.6	17.2	46.3	52.7	54.9	76.6	25.90
1910	16.1	9.52	9.1	10.3	9.28	49.21	8.5	7.25	5.8	2.85	19.9	−9.0	−2.4	3.4	17.5	47.1	53.1	54.4	75.2	26.22
1911	16.7	10.38	9.45	11.3	9.82	50.71	8.3	7.45	4.9	3.2	20.0	−8.5	−2.3	3.4	17.4	48.3	52.9	56.7	77.5	26.30
1912	16.3	9.28	8.25	10.5	8.54	49.59	7.0	6.75	4.1	1.75	19.9	−6.5	−1.0	3.8	17.1	44.8	51.8	53.7	77.4	26.37
1913	16.8	9.84	8.85	10.9	9.30	50.35	8.2	7.35	5.2	2.8	19.8	−8.5	−2.6	4.0	16.9	47.9	54.3	57.0	77.3	26.45
1914	16.3	9.41	8.5	10.5	9.27	50.39	8.3	7.70	5.3	3.1	20.1	−9.9	−3.3	3.5	17.3	47.0	51.3	55.4	76.4	------
1915	16.5	9.60	8.7	10.4	8.57	48.84	8.0	5.35	2.5	0.75	20.5	−7.9	−0.8	3.5	17.8	46.6	52.6	53.7	76.2	------
1916	17.3	9.54	9.7	10.4	9.18	49.13	8.5	6.75	4.2	2.65	20.8	−7.0	−0.1	3.7	17.7	46.0	51.3	53.5	76.7	------
1917	16.8	8.81	8.75	9.3	8.24	47.04	7.6	5.75	3.8	1.4	20.2	−8.0	−0.1	2.7	16.8	43.2	49.8	50.4	76.3	------
1918	------	9.72	9.3	10.5	9.25	49.68	8.0	6.9	4.6	3.2	20.6	−10.2	−2.9	3.0	17.2	46.7	52.2	53.6	77.4	------
1919	------	9.38	8.35	9.9	8.06	47.94	7.2	5.75	3.9	1.9	20.6	−8.1	−0.5	2.1	17.3	47.5	52.8	54.4	77.3	------

A = South Italy (averages of the 3 stations: Naples, Lecce, Palermo).
B = Geneva (Switzerland).
C = Austria (averages of the 2 stations: Vienna and Kremsmünster).
D = Paris (France).
E = Germany (averages of the 10 stations: Königsberg, Berlin, Hamburg, Breslau, Leipzig, Münster i. w., Bamberg, Frankfurt a. m., Munich, Karlsruhe).
F = England (averages of the 8 stations: York, Cheadle, Rothamsted, Oxford, London, Marlborough, Ventnor, Plymouth).
G = Warsaw (Poland).
H = South Norway (averages of the 2 stations: Christiania and Bergen).
J = Helsingfors (Finland).
K = North Norway (averages of the 2 stations: Bodö and Alten).
L = Abbassia (Egypt).
M = Upernivik (Greenland).
N = Godthaab (Greenland).
O = Bernfjord (Iceland).
P = Ponta Delgada (Azores).
Q = Milwaukee, Wis.
R = New York, N. Y.
S = Cincinnati, Ohio.
T = Charleston, S. C.
U = Batavia (Java).

The numbers which are taken as the basis for these calculations are arranged in Table 1. For most places the same period 1876–1919 could be taken as a basis. For southern Italy, according to the material available, the period 1874–1917 had to be taken; for Ponta Delgada (Azores) the period 1887–1919; and for Batavia 1876–1908 were chosen. For each of these periods the phase of the 11-year sun-spot period was also determined in the manner indicated above, so that in each case the difference between the phases of the temperature period and sun-spot period could be calculated for the same period.

[5] Monthly Weather Review, May, 1923, Vol. 51, p. 249.

(Batavia), and in the Subtropics (Abbassia, Ponta Delgada, Charleston); in the Tropics it falls rather before the minimum.

(2) In the Temperate Zone, except the western districts of the United States, the temperature maximum falls after the sun-spot minimum, and so, in general, the higher the latitude of the place, the later the temperature maximum. The increase in the phase shifting with the latitude is shown clearly in the following groups:

(*a*) Charleston, New York, Milwaukee;
(*b*) Godthaab, Upernivik;
(*c*) Abbassia, southern Italy, Germany;
(*d*) England, southern Norway, northern Norway.

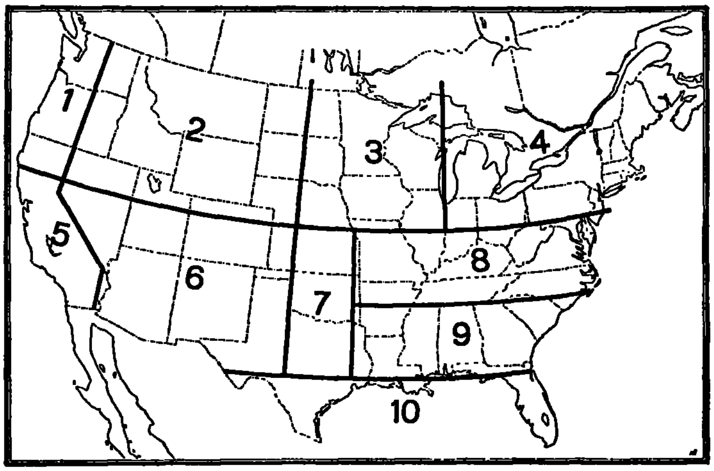

FIG. 1.—Subareas in the United States used in computation

TABLE 2.—*Phase differences of the 11-year temperature period*

District or station	Latitude	Amplitude in °C.	Phase	Difference: Phase of temperature period–phase of sun-spot cycle	Time of temperature maximum
A. *United States*			° ′	° ′	
1. District No. 1	40°–48°	0.205	40 44	−127 16	1⅗ years before sun-spot minimum.
2. District No. 2	40°–48°	0.231	12 11	−155 57	¾ year before sun-spot minimum.
3. District No. 3	40°–48°	0.428	341 11	+173 3	¼ year after sun-spot minimum.
4. District No. 4	40°–46°	0.384	347 57	+179 49	At time of sun-spot minimum.
5. District No. 5	32°–40°	0.157	72 6	−96 2	2½ years before sun-spot minimum.
6. District No. 6	30°–40°	0.222	16 5	−152 3	⅘ year before sun-spot minimum.
7. District No. 7	30°–40°	0.229	10 56	−157 12	¾ year before sun-spot minimum.
8. District No. 8	35°–40°	0.253	337 52	+169 44	⅖ year after sun-spot minimum.
9. District No. 9	30°–35°	0.065	16 50	−151 18	⅘ year before sun-spot minimum.
10. Milwaukee, Wis.	43° 2′	0.401	328 16	+160 8	⅗ year after sun-spot minimum.
11. New York, N. Y.	40° 43′	0.424	334 17	+166 9	⅖ year after sun-spot minimum.
12. Cincinnati, Ohio.	39° 6′	0.425	328 55	+160 47	⅗ year after sun-spot minimum.
13. Charleston, S. C.	32° 47′	0.087	341 48	+173 40	¼ year after sun-spot minimum.
B. *Atlantic Ocean*					
14. Upernivik	72° 47′	0.418	277 45	+109 37	3¼ years before sun-spot maximum.
15. Godthaab	64° 10′	0.319	314 22	+146 14	4½ years before sun-spot maximum.
16. Bernfjord	64° 40′	0.085	215 56	+47 48	1½ years before sun-spot maximum.
17. Ponta Delgada	37° 45′	0.191	(161 56)	−173 31	¼ year before sun-spot minimum.
C. *Europe*					
18. South Italy	38°–41°	0.099	(276 59)	+145 51	4⅗ years before sun-spot maximum.
19. Geneva	46°–12′	0.107	166 23	−1 45	At time of sun-spot maximum.
20. Austria	48°	0.189	161 11	−6 57	⅕ year after sun-spot maximum.
21. Paris	48°–50′	0.105	224 14	+56 6	1¾ years before sun-spot maximum.
22. Germany	48°–54°	0.112	196 39	+28 31	⅘ year before sun-spot maximum.
23. England	50°–54°	0.025	283 6	+114 58	3½ years before sun-spot maximum.
24. Warsaw	52°–13′	0.164	176 21	+8 13	¼ year before sun-spot maximum.
25. South Norway	59°–60′	0.091	255 15	+87 7	2⅗ years before sun-spot maximum.
26. Helsingfors	60°–10′	0.126	98 39	−69 29	2 years after sun-spot maximum.
27. North Norway	67°–70°	0.158	124 12	−43 56	1⅗ years after sun-spot maximum.
D. *Africa*					
28. Abbassia	30° 5′	0.407	347 32	+179 24	At time of sun-spot minimum.
E. *Tropics*					
29. Batavia	−6° 11′	0.082	(22 54)	−159 2	⅗ year before sun-spot minimum.

(3) The greatest amplitude is shown by the temperature period in those regions in which the maximum coincides approximately with the minimum of the sun-spot period (Abbassia, Cincinnati, New York, Milwaukee, western and eastern sea regions of the United States).

(4) Besides the latitude of the places, the degree of their continental or oceanic positions is of importance for the phase shifting. In the oceans and in the western coast regions it is less. On the continents the temperature maximum is delayed from west to east. This is clearly shown in the following groups:

(*a*) Districts No. 1, No. 2, No. 3 of the United States;
(*b*) Districts No. 5, No. 6, No. 7, No. 8 of the United States;
(*c*) Paris, Germany, Austria;
(*d*) England, Germany, Warsaw;
(*e*) Southern Norway, Finland.

(5) An important difference in the phase exists between North America and Europe. In the United States of America the maximum of the 11-year temperature period generally lies nearer the sun-spot minimum; in Europe, however, it falls for the most part nearer the maximum of the sun-spot cycle. This is, of course, due in the first place to the fact that a great part of the United States is situated in the Subtropics, while Europe belongs almost wholly to the Temperate Zone and polar regions. The difference mentioned is therefore in the first place only a further proof that the 11-year temperature maximum is delayed with increasing latitude. At the same time, even with places of the same latitude, the maximum (or minimum) of the 11-year temperature period in North America seems actually to precede that of Europe. Thus, for example, in New York the maximum occurs two-fifths of a year after the sun-spot minimum; in southern Italy, however, one and one-tenth of a year after.

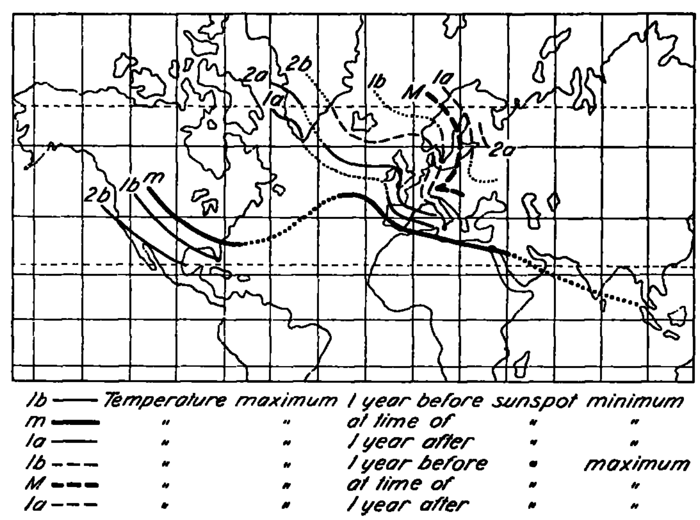

FIG. 2.—Lines of equal phase of the 11-year temperature period

The change of the 11-year temperature phase with the change of place is shown in Figure 2. From Russia and Asia, as well as from Canada, no long homogeneous series of temperatures could be obtained; unfortunately, therefore the survey is still somewhat incomplete.

There are two possible explanations of these phase shiftings. It may be that they are merely the result of mathematical calculation being influenced by still other periods, which influence the course of temperature—periods which are not the same in all places and which, as far as they are of like duration, are of different amplitudes and phases in different places. The second possibility is that a physical importance may be attached to the phase shifting. The fact that extensive terrestrial regions show quite opposed phases of the 11-year temperature period, makes it probable that phase shifting is no mere result of mathematical calculation, but has physical causes. If one assumes with Abbot that in the 11-year period increased solar radiation corresponds to increased sun-spot activity, and if one further makes the assumption, credible after recent investigations, that the transparency of the atmosphere to solar radiation is diminished by increased solar activity, then one can imagine that the temperature maximum in high latitudes coincides approximately with the sun-spot maximum, for the reason that, at that time, radiation is stronger and the diminished transparency of dry polar air is of minor importance. In lower latitudes, however, the diminution in transparency, in consequence of the greater humidity of the atmosphere, overweighs the increase in radiation, so that here the heat minimum corresponds to the maximum of sun spots and vice versa. The idea that the disagreement between the 11-year temperature period in higher and lower latitudes is caused by the different quality of the air, is supported by the result shown in Figure 2, according to which, in regions which come chiefly under oceanic influence, the phase is also in higher latitudes similar to that in the Subtropics.

If now, however, the quality of the air, especially its humidity, is of influence on the time relation between sun spots and the 11-year temperature period, the latter, even if one disregards the inequality of the time periods maximum-minimum and minimum-maximum, can not at all be a simple function,

$$y=\frac{1}{2}\,a_o+\sin\left(\frac{2\pi}{11}\cdot\ t+\varphi\right)$$

but there must result, at least in the Temperate Zone, a different relation between sun spots and temperature in winter from that in summer. In order to test the truth of this, I have examined separately the temperatures of Germany[6] and New York[7] in the period 1876–1919. The result is as follows:

Germany, winter temperatures: Amplitude $(a)=0.144°C$. phase $(\varphi)=147°\ 12'$ (maximum ⅔ years after sun-spot maximum). Summer temperatures: $a=0.060°C$. $\varphi=309°\ 34'$ (maximum 4⅓ years before sun-spot maximum).

New York, N. Y., winter temperatures: $a=0.720°C$. $\varphi=330°\ 38'$ (½ year after sun-spot minimum). Summer temperatures: $a=0.314°C$. $\varphi=12°\ 20'$ (¾ years before sun-spot minimum).

In Germany therefore, the 11-year temperature period has actually, in winter and summer temperatures, almost opposed phases; in winter, the phase corresponds to the type of higher latitudes, in summer, almost to the tropical or oceanic one. In New York also the maximum of temperature in winter occurs distinctly later than in summer, but the difference, corresponding with its more southerly and coast situation, is of course only slight. In Germany, as well as in New York, in consequence of the greater mean variability of winter temperatures, the amplitude of the 11-year period is greater in winter, so that the phase of the annual means is nearer to that of winter temperatures. To summarize, it can be stated that the different quality of the atmosphere in the Tropics, over the ocean, in the summer of the Temperate Zone on the one hand, and in the Polar Regions, over the continent, in the winter of the Temperate Zone on the other hand, seems to exercise a determining influence on the relation of the 11-year period of temperature to the sun-spot period.

TABLE 3.—*Mean amplitudes, r, in °C. for different periods*

Period (T)	Greenland [a]	Iceland [b]	Geneva [c]	Germany [d]	Abbassia [e]	United States, 9 [f]
36-year	0.41	*0.44*	*0.38*	*0.42*	*0.56*	0.06
18-year	0.21	*0.34*	*0.18*	*0.30*	0.20	0.15
12-year	0.43	0.06	0.01	0.07	0.21	0.16
11-year	0.37	0.19	0.06	0.16	0.21	0.20
10-year	0.34	0.15	0.10	0.19	0.21	0.22
9-year	0.34	0.06	0.11	0.10	0.15	0.19
8-year	0.40	0.23	0.11	9.11	0.14	0.13
7.2-year	0.43	0.14	0.13	*0.25*	0.12	0.15
6-year	0.18	0.27	*0.20*	0.19	0.07	0.13
5.1-year	0.25	*0.40*	0.07	0.17	*0.25*	0.11
4.5-year	0.08	*0.29*	*0.16*	0.09	0.20	0.15
4-year	*0.61*	0.24	0.14	0.16	0.07	0.13
3.6-year	0.11	*0.40*	0.11	0.17	0.15	0.10
3.3-year	*0.54*	0.20	0.11	0.19	0.15	0.12
3.0-year	0.16	0.13	0.09	0.09	0.10	0.14
2.8-year	0.17	0.06	0.07	0.11	0.07	0.11
2.6-year	0.29	0.02	0.08	0.12	0.02	0.16
2.4-year	*0.60*	*0.30*	0.07	*0.23*	0.14	0.16
2.25-year	0.44	0.10	*0.16*	0.15	0.10	0.14
2.1-year	0.12	0.15	0.05	0.14	0.09	0.11
$r^1=$	0.34	0.19	0.107	0.15	0.14	0.15

$$r^1=\left(\int_{2^1}^{1^2} r.dT\right):9.9$$

The italicized amplitudes are greater than 1.5 r^1.

[a] Upernivik and Godthaab, 1884–1919.
[b] Berufjord, 1884–1919.
[c] Switzerland, 1847–1918.
[d] 10 stations, 1884–1919.
[e] Egypt, 1884–1919.
[f] District No. 9 of United States, 1884–1919.

In conclusion, it may be pointed out that only on a small part of the earth's surface has the 11-year temperature period an amplitude worthy of mention. As already stated, it is greatest in the Subtropics, in the North American lake district and on the west coast of Greenland; but even in the Subtropics (e. g., Charleston, S. C.), it in places almost completely vanishes. The large amplitude on the west coast of Greenland is evidently connected with the fact that, in relation to the high latitude of Greenland, the phase shows here a strong approach to the tropical type. It is urgently necessary to express a warning against the overestimation of the 11-year period of temperature, or even, as has already unfortunately been done, to build up on this periodicity alone a forecast of the character of the temperature of coming years. In Table 3 the result of several investigations of different series of temperature observations which have been carried out according to the method of the periodogram-analysis[8] is shown. From this it can be seen that the 11-year period of temperature in relation to other periods falls considerably into the background everywhere.[9]

[6] Mitteilungen der Wetter- und Sonnenwarte, St. Blasien, Heft 2, p. 14.
[7] Compiled from "Annual Meteor. Summary, 1921, with comparative data of N. Y., p. 9.

[8] Cf. Mitteilungen der Wetter- und Sonnenwarte St. Blasien, Heft 2, p. 20.
[9] See also for a similar conclusion with respect to rainfall: Alter, Dinsmore, Application of Schuster's Periodogram to Long Rainfall Records, beginning 1748. Mo. Weather Rev., Oct., 1924, 52: 479–483.—B. M. V.