ON THE RELATION BETWEEN THE ROTATION OF THE SUN AND VARIATIONS IN ATMOSPHERIC TEMPERATURE

BY

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Introduction.

It is a well known fact, that the variation of magnetic and meteorological elements can sometimes be resolved into a series of more or less periodic oscillations. The most prominent of these oscillations have periods of about 13 and 27 days respectively. Already in a previous paper[1]) I have shown that a period of about 28 days is represented by the variations in atmospheric temperature recorded in Oslo for the year 1904. The period was calculated to be 28.5 days and the mean amplitude was 3°.2 C. For the temperature of Stockholm *Wallén,*[2] for the years 1908—1912, found the corresponding oscillation to have a mean period of 28.5 days, and a mean amplitude of 4°.5 C.

Some authors place the two mentioned periodicities in connection with the moon, but it seems to be much more reasonable to connect these occurrences with the rotation of the sun, considering the well-known tendency of sunspots to concentrate along opposite meridians. If we study sunspot data, we see that the said tendency is not always developed to an equal degree. Wolfer wrote to me as follows: «Ein frappantes Beispiel dafür habe ich in Band I unserer «Publikationen» für die 3 Jahre 1887—89 behandelt, wo jene Beständigkeit und Diametralstellung mit besonderer Deutlichkeit hervortritt, ein anderes aus neuerer Zeit stammt aus dem Jahre 1916 und ist in No. CIX der Astr. Mitt. besprochen, die Kurve der täglichen Relativzahlen hat dort einen Verlauf von solcher Regelmässigkeit, wie er nur bei regulären veränderlichen Sternen vorkommt. Die Anhäufung der Fleckengruppen um einen bestimmten Meridian herum ist dort so ausgesprochen und von so langer Dauer, wie in keinem andere mir bekannten Jahre».

Material used for the Investigations.

Intending to discuss the question regarding the relation between the variations in the temperature and the rotation of the sun, it is thus natural to base our studies on records for precisely the year mentioned by Professor Wolfer, viz 1916. Before we

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[1]) K. F. Wasserfall: On Periodic Variations in Terrestrial Magnetism, Geofysiske Publikasjoner Vol. V, No. 3 — Sur les variation périodiques du Magnétisme terrestre, Bulletin de l'Observatoire de Lyon, Tome X, No. 4 — «Naturen», Bergen, 1928.

[2]) Axel Wallén: Flerårige variationer hos vattenståndet i Mälaren, nederbörden i Upsala och lufttemperaturen i Stockholm, Meddelanden från hydrografiska byrån 4, Stockholm.

begin to deal with the temperature records, we will give a short account of the sunspot data for the year in question. The mean value for the frequency of sunspots in the year 1916 is stated by Wolfer to be: R = 57.1. Compared with the preceding year the value has increased by 9.7 units. In 1915 there were 12 spotless days, while in 1916 there were only four. The highest value of frequency of sunspots during the 11-year period in question was reached in 1917. To obtain a general view of the longitudinal distribution of the sunspots during the year I have given in Fig. 1 a copy of Wolfer's graph in Astronomische Mitteilungen for 1916.

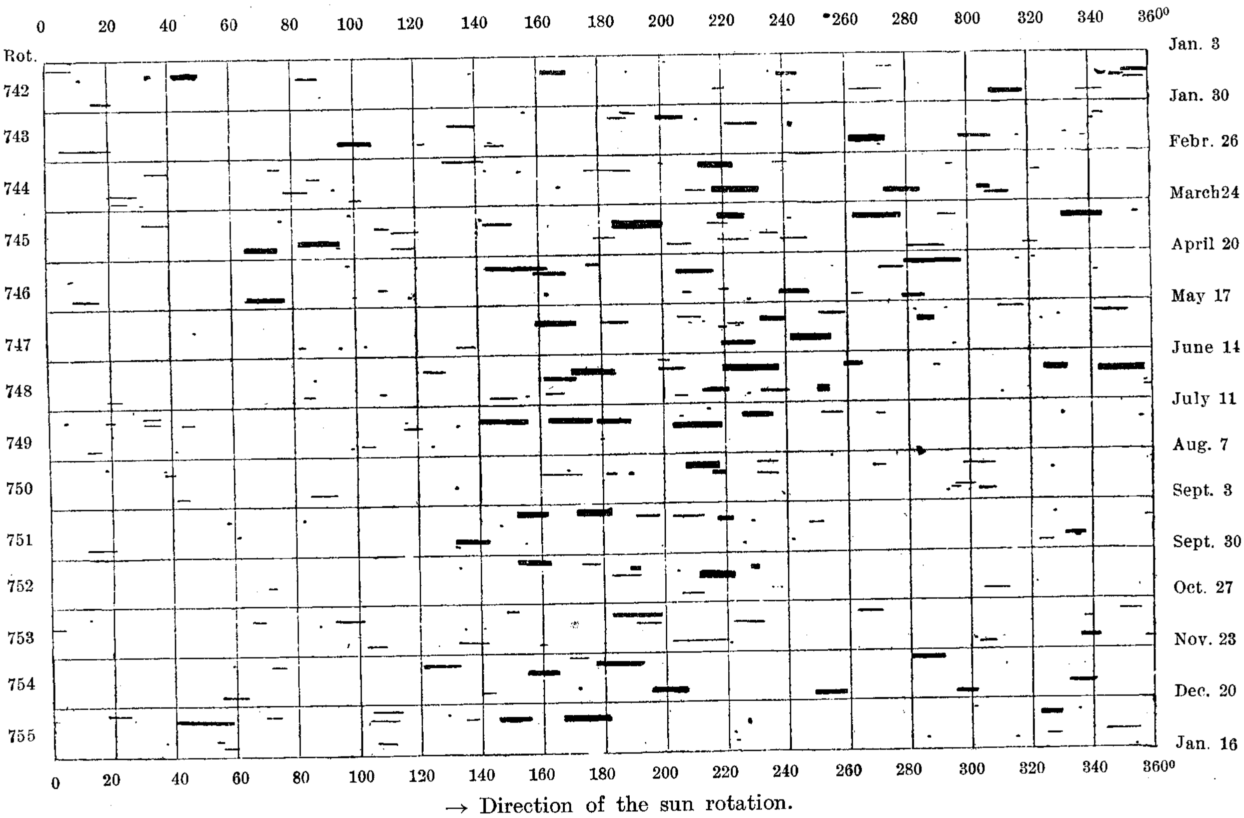

Fig. 1. Reproduction of Wolfer's graph of the sunspots during the year 1916.

The figures for heliographic longitude will be seen above and below, and the rotation of the sun corresponds with increasing figures. The figures to the left refer to Wolfer's numbers of the continuous rotation of the sun, while the dates to the right refer to the day when the zero meridian coincides with the centre of the apparent sun disc. The spot groups are marked by small horizontal lines, the length of which refers directly to the size of the spots in this direction, while the thickness more or less represents the number of individual spots — thus covering to a certain degree Wolfer's figure R, obtained by the aid of the Wolf-formula:

$$R = k. \ (10.g + f)$$

where g refers to the number of visible groups and f to the total number of individual spots, whereby the weight 10 has been applied to g, because the appearance of a new area of activity must be considered to be of essential importance — k is a constant depending on the instrument used for the observation.

A glance at the graph shows that nearly all the more important sunspots are concentrated in the middle, the area being limited by the 120th and the 320th meridian. We see that the spots gradually move from right to left during the year, so that the mean meridian of the groups may be put at 245° for the 743th rotation, while for the 755th rotation the mean meridian may be put at 145°. This means that the sunspot groups, in reference to the longitudinal lines of the sun, have gradually moved about 100° from right to left during 12 synodic periods, corresponding to 8°.3 for one rotation, and to 0°.3 per day. Regarding this gradual movement of the spots during the year, Wolfer states as follows: «Dies entspricht ziemlich nahe dem Unterschied zwischen dem bei Berechnung der heliographischen Längen angewanten Rotationswinkel 14°.27 und demjenigen, der nach dem Rotationsgesetz der mittleren heliographischen Breite — absolute genommen — der Flecken des Jahres 1916 zukommt».

As to the above mentioned secondary area of activity, which is usually found to be situated at a distance of 180° from the main area, it was not well developed in 1916. However, during the rotation periods 743—746 there certainly is a secondary area of activity, more or less limited by the 140th and the 60th meridian. But after the 746th rotation the activity of this area becomes very slight. During the rotation periods 753—755 a considerable activity has developed between the 360th and the 250th meridian, and this area is so situated, that its mean meridian has nearly the same distance from the mean meridian of the main area as the above mentioned area of activity at the beginning of the year.

Accepting for the secondary area of activity the same displacement during the year — from right to left — as that of the main area, Wolfer suggests that the two mentioned secondary groupings may be considered as belonging to one and the same area of activity, being comparatively large at the beginning of the year up to the middle of May, when the activity slackens down during the summer, and starts again in the middle of October, from which date there is comparatively strong activity until the close of the year.

As space does not allow us to go further into details, we now turn to the temperature records. As material for this element I have chosen the data observed at the Astronomical Observatory in Oslo, published in the annual report of the Meteorological Institute in Oslo.[1]) To obtain a general view of the variation, I have in Fig. 2 made a graphic illustration of daily means of the temperature (the curve above). The values refer to the scale to the left of the figure.

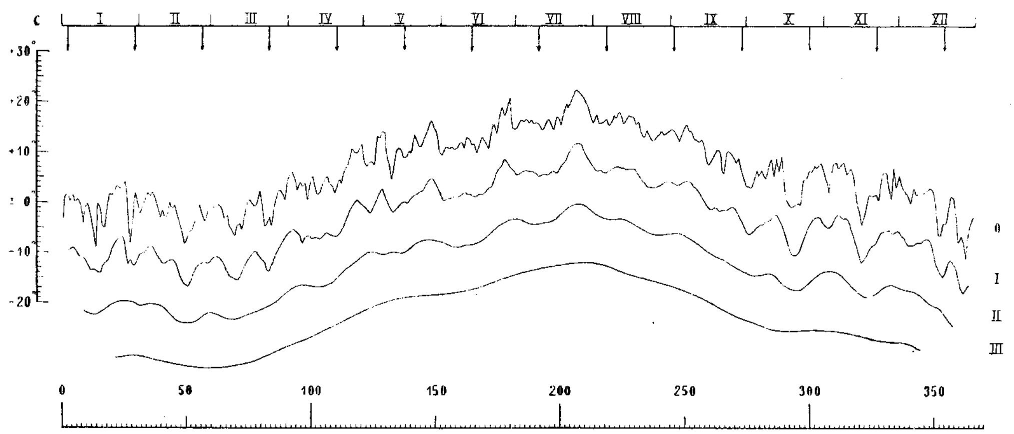

Fig. 2. Variations in atmospheric temperature in Oslo during the year 1916. The curve above, marked O, represents actually observed daily means. The curves I—III have been smoothed according to *Cock-Blanford's Method.*

[1]) Jahrbuch des Norwegischen Meteorologischen Instituts für 1916. p.p. 8—13.

For further details of the sunspots I have also to some extent made use of the Greenwich Publication,[1]) containing data for measurements of photographic records of the sunspots for the year in question. Finally Abbot's data[2]) for the solar constant for the interval June—September, 1916, have been used for comparison with a short periodic oscillation in the temperature records.

Method of Work.

As we intend to study the variation in the temperature in detail, we shall have to separate each wave from the rest, and this separation has been obtained by the aid of *Cock-Blanford's Method.*[3] This method has been explained in the above mentioned paper — Geofysiske Publikasjoner, Vol. V, No. 3 — and I shall not repeat it here, but only remark that a certain period may be eliminated by using the same number of figures in the successive means, as the period itself indicates. The first period we wish to study is, as mentioned above, the one having a wave length of about 13 days, and to obtain a clearer picture of this variation, I have smoothed the original figures with 5, whereby the disturbing effect of a smaller, more or less periodic oscillation, with a wave length of between 3 and 4 days, has been eliminated. The curve smoothed with 5 figures is in Fig. 2 marked with I, and by the next curve, marked II, the 13-day period has been eliminated through a new smoothing with 13 figures, whereby the 27-day period will be seen to stand out comparatively clearly. If finally the 27-day period is also eliminated by a third smoothing with 27 figures in the successive means, we get the curve marked III, which more or less shows the annual wave of the temperature as an effect of the Earth's motion around the sun. Regarding the three smoothed curves, they will be understood to have been drawn in correspondance to scales identical with the one belonging to the curve marked 0 — on each occasion displaced a distance corresponding to 10 units of the scale mentioned.

If we smooth a curve by aid of the mentioned method, the amplitude of the wave will be diminished. This error of amplitude, however, can be more or less corrected by introducing a factor of reduction. The theoretical side of this question has been discussed[4]) by *Schreiber* and according to him we have the following formula:[5])

$$\mu = \frac{1}{n} \times \frac{\sin \frac{n . 180^\circ}{l}}{\sin \frac{180^\circ}{l}} \qquad \text{(I)}$$

where n is the number of figures used for the smoothing, and l the length of the period. Calculating by formula (I) we find how many per cent of the true value are represented in the smoothed curve, and finally we get the multiplicator ε by putting:

$$\varepsilon = \frac{1}{\mu} \qquad \text{(II)}$$

If now we multiply the ordinate of the smoothed curve by ε, we obtain the true value.

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[1]) Results of Measures made at the Royal Observatory, Greenwich, under the direction of Sir Frank Dyson, in the year 1916.

[2]) Anales of the Astrophysical Observatory of the Smithsonian Institution, Vol. IV, by C. G. Abbot (page 373).

[3]) G. Hellmann: Die Niederschläge in den Norddeutschen Stromgebieten. Vol. I, page 38.

[4]) Schreiber, Paul: Vier Abhandlungen über Periodizität des Niederschläges, theoretische Meteorologie und Gewitterregen. Abhandl. des Kgl. Sächs. Meteorol. Inst. Heft I, Leipzig 1896.

[5]) Das Klima des Königreiches Sachsen. Heft VII, page 30.

Preliminary Discussion of the 13-day and 27-day Period.

Looking at the curve in Fig. 2, marked 0, giving daily mean values of the temperature in agreement with the data published by the Meteorological Institute, we can already see here the intimate connection between the variation of the curve and the most characteristic features of the sun's surface in the way illustrated in Wolfer's graph, copied in Fig. 1. We see the unbroken series of partly well-defined, fairly regular oscillations, the mean wave length of which may be put at 27.3 days, which agrees very well with the synodic time of rotation for those girdles of the sun where the spots usually appear. Comparing, for instance, the maxima of these waves during the middle of the year with the short vertical arrows below the time division, which refer to the dates when the zero meridian coincides with the centre of the apparent sun disc, we see the agreement very clearly both in the first curve, and still better in the second, where the disturbing effect of the above mentioned small oscillation of between 3 and 4 days has been eliminated.

The fact that the 27-day wave is so well developed during the interval — the middle of May to the beginning of October — even in the original curve, is scarcely accidental — the reason is in fact plainly to be seen from Fig. 1. During this interval the area of activity of the sun will be seen to have been singularly stationary. Excepting the activity during the 748th rotation, when a secondary area of activity appears between the 320th and the 360th meridian, almost all the sunspots are concentrated within the comparatively limited area between the 140th and the 280th meridian.

In order to obtain a still better picture of the two periodicities in question, I have prepared the two curves given in Fig. 3. The curve above represents the 13-day period of the temperature in Oslo for the year 1916, obtained by subtracting curve II from

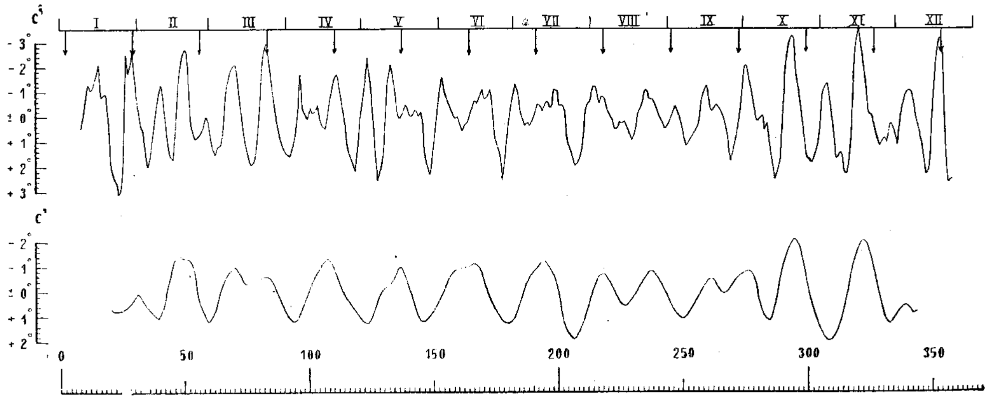

Fig. 3. The 13-day and the 27-day period of the temperature in Oslo for the year 1916. Type (I ÷ II) and Type (II—III).

curve I in Fig. 2, while the second curve represents the 27-day period, obtained by subtracting curve III from curve II. As the beginning of the two curves seem to lie negatively in relation to the dates, when the active part of the sun turns towards our globe, the curves in Fig. 3 have been put up-side-down, and thus the scale will be seen to have the negative signs above and the positive signs below.

In Table I are given the data for the mean wave length and the mean amplitude of the curves. The mean periods, given in the first column, have been put equal to 13.6 and 27.3 days respectively. Under the heading «Amplitude» — the difference between maximum and minimum of the oscillations — are given mean data for the summer half year (s), the winter half year (w) and for the mean. The figures in the first three columns refer to direct measurements of the curves in Fig. 3, while in the next three columns these data have been multiplied by the figures given under the heading ε. As mentioned on page 6, the amplitudes of the oscillations in the smoothed curves are diminished, and calculation with formula (I) shows, that the smoothing with 5 and 13 figures has diminished the amplitudes of the 13-day period so that 75 per cent of the true value is represented, and by the 27-day period, where there has been smoothed twice, 94 and 66 per cent of the true value is represented respectively by the first and second smoothing. In consequence of what has been said, the directly measured amplitudes of the two curves in Fig. 3 will have to be multiplied by the figures given under the heading ε in Table I.

Table I.

Duration	Amplitude						ε
	Direct			Corrected			
	s	w	mean	s	w	mean	
	°	°	°	°	°	°	
13.6 days	3.0	4.0	3.5	4.0	5.3	4.7	1.33
27.3 »	2.3	2.5	2.4	3.8	4.0	3.9	1.61

We see that the oscillations are of considerable size; they are slightly larger during the winter half year than during the summer half year. For the temperature in Stockholm Wallén found as the mean value for the amplitude of a 28-day period, for the five years 1908—1912, 4°.5 C, which is a somewhat larger value than ours for 1916 — 3°.9 C. Wallén also found a larger amplitude during the winter and a smaller one during the summer. The mean value of the amplitude of the 28-day period of the temperature in Oslo for the year 1904 came out 3°.2 C, (cp. Geofysiske Publikasjoner, Vol. V, No. 3, page 15), but the period was by no means as regular as that of 1916. The 13-day period in 1904 was very indistinct, and in neither period was there any decided difference in the size of the amplitude during the summer and during the winter.

Synthetical Reconstruction of the Variation.

Looking at the curve marked I in Fig. 2, we see that the variation is of such a nature, that it should be comparatively easy to construct a theoretical curve, showing more or less the same features as the said curve, if as elements for such a curve we chose an expression for:

A. the annual period of the temperature — the effect of the Earth's annual motion around the sun,
B. the 27-day period — the effect of the sun's rotation in combination with the main area of activity,
C. the 13½-day period — the effect of the sun's rotation in combination with both the main and the secondary area of activity.

Before we decide upon the form of the above-mentioned elementary curves, we shall have to discuss some further details regarding the wave length, the amplitudes of the oscillations and the transformation of phase, besides the maximum effect of the solar activity.

According to Table I, the mean wave length of the two curves in Fig. 3 has been put equal to 13.6 and 27.3 days respectively. For 1904 the mean wave length of the temperature curve of Oslo was found to be 28.5 days, which is the same figure found

Table II.

Min.		Max.		Min.	Max.	Ampl.
Day	△	Day	△	δ	δ	
	°		°			°
15	÷ 2.1	24	+ 3.1			5.2
				14	11	
29	÷ 2.6	35	+ 2.0			4.6
				12	10	
41	÷ 1.3	45	+ 1.7			3.0
				10	17	
51	÷ 2.7	62	+ 1.5			4.2
				20	15	
71	÷ 2.1	77	+ 1.9			4.0
				12	15	
83	÷ 2.9	92	+ 1.6			4.5
				13	14	
96	÷ 1.7	106	+ 0.5			2.2
				15	13	
111	÷ 1.7	119	+ 2.2			3.9
				12	8	
123	÷ 2.4	127	+ 2.6			5.0
				10	9	
133	÷ 2.1	136	+ 0.1			2.2
				6	12	
139	÷ 0.5	148	+ 2.3			2.8
				14	13	
153	÷ 1.6	161	+ 0.6			2.2
				16	17	
169	÷ 1.1	178	+ 2.6			3.7
				14	9	
183	÷ 1.3	187	+ 0.4			1.7
				15	20	
198	÷ 1.1	207	+ 2.0			3.1
				16	22	
214	÷ 1.2	229	+ 1.0			2.2
				21	14	
235	÷ 1.0	243	+ 0.5			1.5
				12	8	
247	÷ 0.4	251	+ 1.2			1.6
				12	18	
259	÷ 1.2	269	+ 1.8			3.0
				16	18	
275	÷ 2.0	287	+ 2.5			4.5
				18	14	
293	÷ 3.2	301	+ 1.9			5.1
				14	14	
307	÷ 1.3	315	+ 2.3			3.6
				14	14	
321	÷ 3.6	329	+ 1.2			4.8
				19	18	
340	÷ 1.0	347	+ 2.3			3.3
				13	9	
353	÷ 3.1	356	+ 2.6			5.7
—	—	—	—	14.1	13.8	3.5

by Wallén for the temperature of Stockholm for the years 1908—1912, as mean for those five years (see footnote page 3). Looking at Wallén's results for each of the five years, we see that the figures vary considerably. Thus for 1910 he obtained 31.4 days, and for 1911: 26.4 days, which gives a difference of 5 days. It has already been remarked that the figure 27.3 agrees well with the synodic time of rotation for those girdles of the sun where the spots usually appear, but geophysical elements are mostly found to have a larger period. The reason why, for 1916, we found agreement in the wave length of the curve in Fig. 3 and the synodic time of rotation of the sun is no doubt due to the exceptionally high degree of stationarity of the active area of the sun during that year.

It has been mentioned that the 13-day and the 27-day period of the temperature both in Stockholm and in Oslo showed a slightly higher figure for the amplitude during the winter than during the summer. Now, it is a well-known fact, that the majority of geophysical elements show effects due to the Earth's annual motion around the sun both directly — the measurements themselves, and indirectly — the distribution of the size of the amplitudes. However, when there is a question of the sun rotation period of geophysical elements, there is reason to believe that the size of the amplitudes is principally dependent on the distribution of the solar activity during the year. Looking at the matter from this point of view, we might therefore measure the amplitudes of the 13-day period during the time when the activity of the secondary area of the sun is strong, and when this activity is weak. The result of this measurement will, in detail, be found in Table II. The days of the year are, as will be seen, numbered with figures from 1 to 365, and the columns headed «Day». Here is stated the day, on which a maximum or minimum occur. Under the heading $\triangle$, I have given the oscillation on each side of zero, (directly measured from the above curve in Fig. 3), which together gives the «double» amplitude of the wave in question, entered under the heading «Ampl.». Finally, under the heading δ, the number of days between two on each other following maxima (minima) are added. Below are given the mean values of the three last columns.

The table will be seen to be divided into three parts, of which the part in the middle belongs to the period where nearly all the activity of the sun is concentrated about the main area, while during the time intervals before and after there is a considerable activity also in the secondary area (cf. Fig. 1). The mean duration of the 13-day period is in Table II seen to come out as 14.0 days, while in Table I the mean duration has been put equal to 13.6. Regarding this disagreement, it may be remarked that figure 13.6 is simply the half of 27.3, got by the lowest curve in Fig. 3, and consequently the most reasonable value. The mean figures for the last column «Ampl.» — for each of the three parts in which the table is divided — will be found in Table III. Multiplied by

Table III.

Duration	Jan.—Apr. 134 days	May—Aug. 128 days	Sep.—Dec. 103 days
Area of activity	Main and Secondary	Only Main	Main and Secondary
Amplitude ...	4°.1	2°.3	4°.3

1.33, we obtain as corrected mean amplitude for the period during which nearly all the activity of the sun is concentrated about the main area: 3°.1 C., and for the rest of the year: 5°.6 C. This gives a difference equal to: 2°.5 C., but in this connection it must be remembered that every second oscillation of the $13\frac{1}{2}$-day period is due to the activity of the main area, the consequence of which is that a constant amplitude of 3°.1 C. does not give a wholly satisfactory expression of what we see in Fig. 3.

Studying the relation between the rotation of the sun and the variation of curve I in Fig. 2, we see that — within the interval 15th of May to 10th of December — the maximum (high temperature) of the 27-day waves falls about 12 days after the small arrows below the scale division marking the dates when the zero meridian coincides with the centre of the apparent sun disc. Looking at Fig. 1, we see that this position of the maximum corresponds almost exactly with the dates when the main area of activity turns towards the Earth. If for the above mentioned interval, we put the 200th degree as mean meridian of the main area of activity, we have: $(360° \div 200°) = 160°$, and as one day corresponds to 13°.3, we see that the maximum effect ought to occur 12 days after the passage of the zero meridian. During the rest of the year there is a negative relation between the 27-day period and the activity of the sun, but with the exception of the small interval from the beginning of the year up to the 22nd of January. The relation of the 13-day period will be seen to be negative from the beginning of the year up to the 15th of May, where both curves thus show transformation of phase. From this date the relation is positive up to the 16th of October, when again the relation becomes negative till the close of the year.

Under due consideration of what has been said above, we may now draw the two elementary curves B and C. For the size of the amplitude of curve B we use 3°.9 C. for the whole year — thus in agreement with the corrected mean figure of Table I. For curve C, we use the amplitude size 5°.6 C. during the intervals, for which the relation is negative while during the interval between we take 3°.1 C. (see further investigation p.p. 12—14). As a satisfactory expression for the effect of the Earth's annual motion around the sun, curve A, I have chosen 60-yearly monthly means of the temperature in Oslo, calculated for the interval, 1861—1920, by B. J. Birkeland.[1]) These 60-yearly monthly means are given in Table IV under the headings I to XII, the geographical coordinates of the station being added under the headings α and λ, beside height above sea level under the heading h — expressed in meters.

Table IV.

α	λ	h	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Jear
59° 55′	10° 43′	m 25	—4°.2	—3°.6	—0°.8	4°.7	10°.5	15°.6	17°.3	15°.5	11°.3	5°.7	0.°5	—0°.1	5°.8

The three curves A, B and C will be seen drawn at the top of Fig. 4, where curve A refers to the scale on the left, and the curves B and C refer to the two scales on the right. There has been used for the two curves respectively a constant wave length of 27.0 and 13.6 days, whereby the size of the amplitudes and the transformation of phase is made in accordance with what has been said above — positive relation between temperature

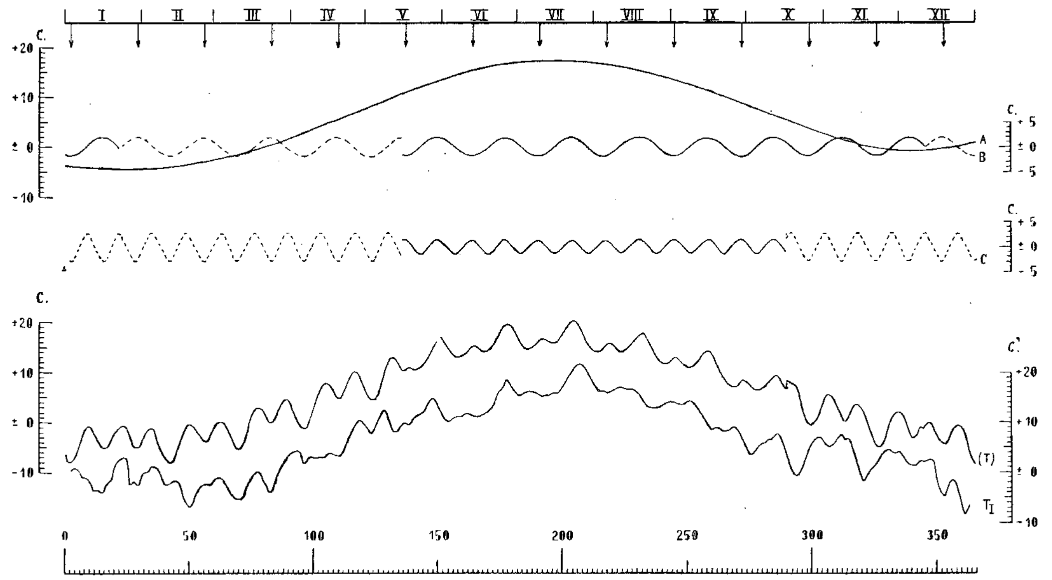

Fig. 4. The three curves A, B and C are elements of which the curve (T) is composed. The curve T_I has been copied from Fig. 2, where it corresponds to the one marked I.

and solar activity has been indicated by full, and negative relation by a dotted lines. If now we combine the three curves A, B and C, we obtain the curve (T),

[1]) B. J. Birkeland: Temperaturmidler 1861—1920, 60 År, «Norsk Geografisk Tidsskrift», Hefte 1, 1928.

referring to the scale to the left. I have copied below the curve in Fig. 2, marked I, here marked T_I, which refers to the scale to the right.

Even if we doubted the relation between the variation in certain terrestrial elements and that of the activity of the sun, we cannot get away from the fact, that through the curves drawn in Fig. 4, we have obtained a striking illustration of this relation merely by comparing the curve T_I, which, though slightly smoothed, gives the actually observed data for the temperature of Oslo, and the curve (T), representing a synthetical reconstruction, where besides the supposed effect of the rotation of the sun, only the effect of the Earth's annual motion around the sun has been considered.

Further Details of the Activity of the Sun.

Before we draw a final conclusion from the results of our studies, we will try to explain the reason for the mentioned transformation of phase. Let us begin with the critical point in the middle of May, where both the two curves B and C turn. Looking at Wolfer's illustration in Fig. 1, we see that just about the said date, the 15th of May, the activity of the secondary area fades away. If really this fading away of the secondary area of activity of the sun gives rise to transformation of phase in the effect of the sun-rotation influence in the variation of the temperature of Oslo, this is of so great interest that we shall have to go a little more into detail, than Wolfer's illustration allows. The following data, given in Table V, have been extracted from the well-known Greenwich Publication.[1]) The data given are measurements taken from photographs of the sun, and the complete list of data, for the month of May, has been copied in the said table, where the first column contains the current number of the spots, the second column the duration of each group in days, the third and fourth the dates for the appearance, and disappearance of the spot (group). In the fifth and the sixth column there is given the mean area of umbra and whole spot, corrected for foreshortning, expressed in millionths of the sun's visible hemisphere, and finally in the seventh and eight column there are entered the mean heliographic longitude and latitude of the spot (group). The zero meridian has been taken according to Carrington,[2]) and agrees, as far I as can see, with that used by Wolfer.

Looking at the longitudinal distribution of the spots during May, we see that most of the activity during the interval April the 25th and May the 15th — the current numbers 7704 to 7721 — belong to the secondary area. From the 16th of May — No. 7722 — the chief activity of the sun concentrates about the main area, and in Wolfer's illustration, Fig. 1, we see that this situation is practically in keeping up to the last days of October, where the new-building in high degree of longitude, between the 360th and 250th meridian, sets in, as mentioned on page 5. According to what has been said on page 11 regarding the transformation of phase of curve C, we accepted the 16th of October as the date for the change from positive to negative relation between the activity of the sun and its effect on our temperature curve. According to the Greenwich publication, the activity in high degree of longitude sets in exactly on the 16th of October — current number 7858. The mean area of umbra and whole spot is here respectively measured to be 16 and 96 units, and the mean heliographic longitude and latitude was 332° and ÷ 11° respectively. As we see, we have again obtained agreement in the longitudinal variation of the activity of the sun and the transformation of phase in our temperature curve. Finally, the curve B has been turned the 22nd of January and the 10th

[1]) Results of Measures made at the Royal Observatory, Greenwich, under the direction of Sir Frank Dyson, in the year 1916.

[2]) Carrington, R. C.: Observations of Solar Spots made at Redhill.

Table V.

No.	Dur. in days	from	to	Mean area		Mean	
				Umbra	Whole	Long.	Lat.
						°	°
7701	12	Apr. 20	May 1	32	172	228	+ 22
7702	13	» 20	» 2	45	298	244	÷ 27
7703	5	» 22	Apr. 26	2	9	201	÷ 19
7704	5	» 25	» 29	5	18	210	+ 19
7705	1	» 25	May 4	17	65	174	÷ 16
7706	4	» 27	Apr. 30	2	10	121	+ 10
7707	8	» 29	May 6	14	71	133	+ 12
7708	13	» 29	» 11	50	299	83	+ 10
7709	13	» 29	» 11	41	244	87	÷ 14
7710	5	» 30	» 4	3	15	149	÷ 16
7711	13	» 30	» 12	75	452	76	+ 13
7712	3	May 1	» 3	0	4	130	+ 22
7713	4	» 3	» 6	3	15	135	÷ 16
7714	4	» 3	» 6	3	13	50	÷ 18
7715	3	» 4	» 6	21	69	128	+ 24
7716	9	» 6	» 14	14	73	15	÷ 20
7717	11	» 8	» 18	4	27	17	÷ 22
7718	2/3	» 10	» 12	3	13	27	÷ 11
7719	1/2	» 10	» 14	0	8	29	÷ 18
7720	11	» 11	» 21	11	47	309	÷ 19
7721	12	» 13	» 24	18	67	304	+ 25
7722	3	» 16	» 18	5	14	235	+ 8
7723	4	» 17	» 20	11	30	277	+ 26
7724	3	» 18	» 20	2	8	260	÷ 26
7725	1	» 20	» 28	13	54	210	+ 14
7726	11	» 21	» 31	18	59	198	+ 20
7727	12	» 21	Jun. 1	237	1109	167	÷ 12
7728	12	» 21	» 1	18	91	156	+ 13
7729	12	» 22	» 2	26	136	153	÷ 16
7730	1	» 23	May 28	8	20	130	+ 6
7731	6	» 25	» 30	14	58	168	÷ 21
7732	4	» 24	» 27	2	10	123	+ 11
7733	13	» 26	Jun. 7	34	181	80	+ 10
7734	5	» 27	May 31	5	25	147	+ 14

of December. As to the first of these changes I may refer to Wolfer. Speaking of a graph plotted with daily values for frequency of sunspots,[1]) he says: «Hohe, in der Mehrzahl scharf ausgeprägte Maxima wechseln mit tiefen, aber etwas flacher und unregelmässiger gestaltenten Minima in zeitlich ganz rythmischer Folge, alle Maxima fallen nahe auf dieselbe Phase, nämlich nahe auf die Mitte der einzelnen Rotationsperioden, und ebenso legen sich die Minima, wenn auch wegen des flacheren und weniger einfachen Verlaufes mit etwas grösseren Abweichungen, in die Nähe des Anfanges jeder Rotation. *Eine Ausmahme macht Rot 742, wo Maximum und Minimum auf eine etwas frühere Phase der Periode verschoben erscheinen.* Aus der Figur allein schon geht also klar hervor, dass diese sekundären Wellen der allgemeinen Fleckenkurve die blosse Folge der Sonne

[1]) Astronomische Mitteilungen No. CIX, 1916, by Prof. A. Wolfer.

und einer in diesem Jahre besonders stark hervortretenden einseitingen Verteilung der Fleckenbildungen in der Richtung jener Rotation sind». A corresponding irregularity in the variation of the daily data for R cannot be seen during the last rotation of the year, but looking at Fig. 1 we see a comparatively large activity between the 40th and 60th meridian during the 755th rotation, which occurrence may be responsible for the said transformation of phase.

Not to go too far into details, I shall only call attention to the following two peculiarities — the large regular oscillations during the interval from the middle of April to the first days of May, and the displacement of about 4 days of the dates for maximum (minimum) during the interval 16th of October to the close of the year — in both cases to be seen in the upper curve of Fig. 3. Regarding the first of these occurences, I may refer to Fig. 1, where we see the large sunspot during the 746th rotation, between the 60th and 80th degree of longitude. It is not inprobable that these two occurences have something to do with each other. As to the mentioned displacement, this is a well known peculiarity, which no doubt is due to the interplay between activity at different parts of the sun.

In any case we should have obtained a still better agreement between (T) and T_I (Fig. 4), if, in the first place, we had used the smaller amplitude value for C already from the beginning of April, however, with the larger one during the above mentioned interval, instead of taking the change from large to small amplitude only once in the middle of May. And in the same way better agreement would have been obtained, if we had considered a displacement of about 4 days to the left in curve C for the mentioned interval 16th of October to the close of the year.

Some Supplementary Remarks on the Transformation of Phase.

The discussion in the preceding pages has been based on direct comparison between the sunspot data and the temperature records, but we have of course no right to take it for granted that direct influence is the case — in fact, there is every reason to believe, that the «*road*» between «*effect on the temperature*» and the «*origin*» is long and perhaps inpassable. However, even if the road between two places is of the nature that it cannot be traversed, it might be possible to pass the distance by aeroplan, so that we might get glimpses of what would otherwise have been hidden. This is more or less what we have done when we have compared the sunspot data directly with our temperature records.

There seems to be reason to believe that the changes in solar activity affect the distribution of the pressure of the air before the effect passes to the temperature recorded at the place in question, and by the aid of this hypothesis we may also be able to explain the fact that the relation between solar activity and the temperature of the air is sometimes positive and sometimes negative, just as we have seen in our case. Discussing the results of temperature measurements of the Atlantic Ocean, Helland-Hansen and Nansen formulated the following rule:[1]) «At places where the prevailing wind carries a comparatively high temperature, high solar activity must produce rising temperature on account of increasing wind, while at places where the prevailing wind carries a low temperature, the contrary effect must take place».

Accepting the theory of a rather complicated indirect connection between solar activity and temperature, this does not alter the conclusion we have drawn in the pre-

[1]) B. Helland-Hansen and F. Nansen: Temperaturschwankungen des Nordatlantischen Oceans und in der Atmosphäre. Videnskapsselskapets Skrifter, Mat.-Naturv. Klasse I, 1916, No. 9 — Temperature Variations in the North Atlantic Ocean and in the Atmosphere. Smithsonian Miscell. Collections, Vol. 70, No. 4, Washington, 1920. — «Naturen», Bergen, 1920.

ceding pages. Regarding the fact that sometimes we find contrary correlation to solar activity for the 27-day and the 13-day period for the temperature, it might be remarked that the author has had this experience before, and that also other investigators have stated an analogous opposition between two periodic undulations in meteorological elements (cp. «On Periodic Variations in Terrestrial Magnetism», page 15).

As far as I know, no attempt has been made to explain this peculiarity, but it seems that the result of our discussion p.p. 12—14 may give us a hint concerning a possible reason. It has here been shown that there seems to be coicindence between transformation of phase in the oscillations of the temperature records and the longitudinal variation of the activity of the sun — the activity is at times largest in the main area, at others in the secondary area. In one case both the 27-day and the 13-day oscillation turns, in the other cases the two periods turns at different dates, but in each case we are able to point out a change in the nature of the activity in the manner this makes itself known through the sunspot data. It may, however, be remembered in this connection, that the sunspots only represent one of various phenomena caused by the activity of the sun.

Some Remarks on the Short Period of between 3 and 4 Days.

It has already been mentioned (page 6) that in order to obtain a clearer picture of the 13-day period, we smoothed the original figures of the temperature data, recorded in Oslo, with 5 figures. Taking the difference between the figures of the outcoming table and corresponding data for the temperature actually observed, we obtain the curve drawn in Fig. 5. This curve shows a somewhat irregular character, which to a

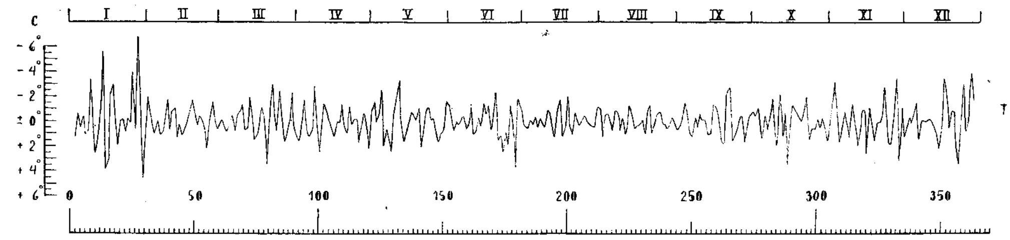

Fig. 5. The period of between 3 and 4 days in the temperature of Oslo for the year 1916. Type (0—I).

certain degree is due to the fact that it is not smoothed. All the same there seems to be no doubt about a more or less periodic undulation of some few days. By counting up the tops of the undulation, above and below, I have obtained an average duration of the oscillations of something like 4 days. However, it is possible that a further consideration of «missing waves»[1]) may reduce the wave length to a somewhat lower figure — for instance 3.5. The amplitude of the oscillations will be seen to be largest during the middle of the winter, smalest during the two intervals February—March and August—September, while the size of the undulations during the interval March—August lies between those of the winter and those of the two mentioned intervals. The average value of the amplitude (measured from maximum to minimum) may be put as equal to 3°.3 C.

Such short oscillations in the temperature records have been shown by Wallén (see footnote page 3). His examination of the temperature records for Stockholm for the years 1908—1912 shows the existence of an almost continuous fluctuation of between 6 and 7 days. The average length of the waves changes from year to year between 6.0

[1]) cf. Geofysiske Publikasjoner, Vol. V, No. 3, page 9.

to 7.0 days, and this change in value is also found in the amplitude, where the average has been put to 4°.0 C. In the above mentioned investigation the author of this paper made with the temperature records of Oslo for 1904, he found an average wave length of 4.8 days, and an amplitude, for the summer half year and the winter half year respectively, and for mean: 4°.2, 2°.6 and 3°.4 C.

Comparison with Data for the Solar Constant.

In connection with this short period in the temperature, it might be of interest to say some words regarding Abbot's measurements of solar radiation. On studying his material, he found repeated signs of various periodic oscillations in the data for the solar constant. For instance, for the year 1915 he found a well-defined periodicity of about 27 days. In his report[1]) he says: «. . . . . Both curves show a periodicity of about 27 days, no doubt associated with the solar rotation. There was evidently during this

Table VI.

Date	June			July			August			September		
	C	C'	△	C	C'	△	C	C'	△	C	C'	△
1	—	—	—	1.953	1.958	÷ 5	—	1.937	—	1.929	1.931	÷ 2
2	—	—	—	1.929	1.952	÷ 23	—	1.934	—	1.913	1.932	÷ 19
3	—	—	—	1.947	1.944	+ 3	—	1.932	—	1.911	1.934	÷ 23
4	—	—	—	1.954	1.940	+ 14	—	1.931	—	1.970	1.937	+ 33
5	—	—	—	1.945	1.937	+ 8	—	1.931	—	1.936	1.940	÷ 4
6	—	—	—	1.951	1.934	+ 17	—	1.932	—	1.921	1.944	÷ 23
7	—	—	—	1.942	1.932	+ 10	—	1.934	—	1.940	1.952	÷ 12
8	—	—	—	1.942	1.931	+ 11	—	1.937	—	1.957	1.958	÷ 1
9	—	—	—	1.958	1.931	+ 27	—	1.940	—	1.906	1.964	÷ 58
10	—	—	—	1.876	1.932	÷ 56	2.010	1.944	+ 66	1.899	1.970	÷ 71
11	—	—	—	1.914	1.932	÷ 20	1.942	1.952	÷ 10	1.955	1.974	÷ 19
12	—	—	—	1.925	1.937	÷ 12	1.879	1.958	÷ 79	1.937	1.978	÷ 41
13	—	—	—	—	1.940	—	1.962	1.964	÷ 2	1.964	1.980	÷ 57
14	—	—	—	—	1.944	—	1.987	1.970	+ 17	1.923	1.980	÷ 57
15	—	—	—	1.913	1.952	÷ 39	1.942	1.974	÷ 32	2.025	1.980	+ 45
16	—	—	—	2.016	1.958	+ 58	1.935	1.978	÷ 43	1.968	1.978	÷ 10
17	1.941	1.944	÷ 3	1.940	1.964	÷ 24	2.011	1.980	+ 31	1.934	1.974	÷ 40
18	—	1.952	—	1.931	1.970	÷ 39	1.920	1.980	÷ 60	2.033	1.970	+ 63
19	1.940	1.958	÷ 18	1.964	1.974	÷ 10	1.931	1.980	÷ 49	—	—	—
20	1.949	1.964	÷ 15	—	1.978	—	1.955	1.978	÷ 23	—	—	—
21	—	1.970	—	—	1.980	—	1.976	1.974	+ 2	—	—	—
22	1.947	1.974	+ 27	1.952	1.980	÷ 28	1.944	1.970	÷ 26	—	—	—
23	1.989	1.978	+ 11	1.992	1.980	+ 12	—	1.964	—	—	—	—
24	1.966	1.980	÷ 14	2.011	1.978	+ 33	—	1.956	—	—	—	—
25	1.938	1.980	÷ 42	1.944	1.974	÷ 30	1.940	1.952	÷ 12	—	—	—
26	1.948	1.980	÷ 32	—	1.970	—	—	1.944	—	—	—	—
27	—	1.978	—	—	1.964	—	1.936	1.940	÷ 4	—	—	—
28	—	1.974	—	1.945	1.958	÷ 13	2.011	1.937	+ 74	—	—	—
29	—	1.970	—	1.932	1.952	÷ 20	1.911	1.934	÷ 23	—	—	—
30	1.914	1.964	÷ 50	1.953	1.944	+ 9	1.937	1.932	+ 5	—	—	—
31				1.940	1.940	± 0	1.948	1.931	+ 17			

[1]) Anales of the Astrophysical Observatory of the Smithsonian Institution, Vol. IV, by C. G. Abbot. (page 373).

season a tendency towards a hot and a cold side of the sun, which persisted during several rotations but diminished at the latter end of the season».

Already in the above mentioned earlier work the author pointed out that just in the year 1916 Abbot found a well defined periodicity of 3.5 days. As this periodicity evidently lies close up to the fluctuations seen in Fig. 5, a comparison may be of interest. In Table VI I have therefore copied Abbot's data for the solar constant for the year 1916, covering the interval from the middle of June to the middle of September. The said data are to be found in our table under the heading C. Regarding the 27-days period, Abbot says that it does not seem to be present in that year, but «$11^1/_3$ full periods, as regular as the time intervals of 24 hours between observations permit, occur in 40 days». This series evidently refers to the data during the interval August the 10th and September the 18th.

After having plotted the whole series of data for the solar constant given in Table VI, I came to the result that also for this season there is a 27-day period. The undulation cannot be said to be, absolutely definned, but as to a certain degree, it seems to disturb the picture of the shorter period, I have found it best to try to get it eliminated. As mentioned above the whole series of data for the solar constant was plotted. The mean course of the supposed 27-day undulation was then marked with a lead pencil, whereon a rhythmically oscillating curve — having the mean amplitude and mean wave length of the curve mentioned — was constructed. This last curve, expressed in figures, will be seen given under the heading C' The wave length is 27 days and it oscillates between the two limits 1.980 and 1.931.

The difference between C and C' has been put under the heading △, expressed in a unit corresponding to the third decimal place of the figures under C and C', and finally in Fig. 6 I have plotted the data given under △, and below added the corresponding part of the curve given in Fig. 5. Several circumstances make it doubtful to draw any conclusion from a direct comparison between the two curves, but we see, that the general character is more or less the same in both curves, and taking the average length for the whole series, under due consideration of missing data in Abbot's series, I obtain for both curves 4.0 days, while for the interval August—September of the solar constant, I obtain 3.5, in agreement with Abbot. In the lower curve, the parts corresponding to the curve above have been drawn in full lines, while the rest of the curve has been dotted.

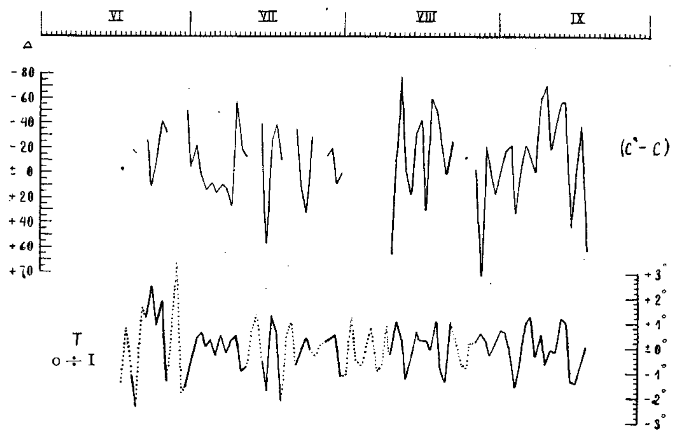

Fig. 6. The 4-day period of the solar constant (above). The corresponding period in the temperature of Oslo (below). Both curves refer to 1916.

Summary.

1. It is a well-known fact that sunspots have a certain tendency to concentrate about one meridian, forming a main area and another acting as a secondary area of activity. During the year 1916 the area of activity of the sun was singularly stationary, and we might therefore expect to find a well defined 27-day period in all geophysical elements, which might be supposed, directly or indirectly, to be influenced by the activity of the sun.

2. As the temperature records of Oslo for the year 1916, show well-defined oscillations with a mean wave length of 27,3 days and an average amplitude of 3°.9 C., this is a good test for the existence of the relation between the variation in temperature and the activity of the sun, and this test is supported by the fact that the amplitude of the 13-day period of the temperature becomes smaller when the activity of the secondary area slackens down during the summer.

3. The transformation of phase in the above mentioned undulations of the temperature curve of Oslo seems to take place simultaneously with certain variations in the longitudinal distribution of the activity of the sun.

4. The character of the meridional concentration and the stationarity of the activity of the sun seems to govern the degree of rhythmicality of the oscillations of geophysical elements, as well as the size of the amplitude of the undulations.

5. A short period of about 4.0 days, with an average amplitude of 3°.3 C. is found in the temperature records of Oslo for the year 1916, and Abbot states that the data for the solar constant of that year show a similar periodicity.

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