ON PERIODIC VARIATIONS IN TERRESTRIAL MAGNETISM

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Material and Method of Working.

The studies for this paper are principally based upon daily means of the horizontal intensity, registered at the Polar station *Gjøahavn.* As is known, Roald Amundsen occupied this station from the 1st of November 1903 until the 1st of June 1905. The report of the scientific results of the Gjøa Expedition has not yet been published, but the editing of the observations was completed in 1922. During the last 7 years the author of this paper partook in the reduction of the magnetic observations, and thus had an opportunity of studying the material in detail. During my work I noticed that the characteristic features, often observed in the variation of magnetic elements, in this particular case stood out exceptionally clearly, and hoping by special studies to be able to throw some new light on the nature of this complicated variation, I have in the following pages taken up for close examination the form of variation which is usually called periodic.

"The Editing Comittee for the Scientific Results of the Gjøa-Expedition" have kindly permitted me to make use of the magnetic and meteorological material in question, and I have, as said, based my studies on daily means of the horizontal intensity, which element in the following pages will be referred to as H. A satisfactory reduction — based on register readings and absolute measurements taken by Amundsen — had already been worked out, and I had thus only to tabulate the daily means for the interval of time I intended to use, viz 1904.

The geographical coordinates of the station are:

$$\varphi = 68^\circ\ 37'\ \mathrm{N} \text{ and } \lambda = 95^\circ\ 55'\ \mathrm{W}$$

The station is situated near the magnetic pole and the horizontal component is accordingly very small. The mean value for the year 1904 is computed to be:

$$760\ \gamma = 0{,}00760 \text{ C. G. S.}$$

Fig. 1 gives a graph showing the variation of H during the time Amundsen kept his register at Gjøahavn.

As the comparison between the magnetic and meteorological elements has special interest in this connection, the temperature records for Gjøahavn, and later on also for Oslo have been examined. These elements will be referred to as T. Furthermore, the variation of the two elements H and T is compared with solar activity, and for this comparison Wolfer's relative figures for the sunspots for the year in question have been used. This element is referred to as R. For special purposes there is also made use of the hourly means of H and T for the month of June 1904.

When finally the Gjøa observations were examined, it was found necessary to extend the studies beyond the time limited by records from Gjøahavn, and as material for these studies I chose the monthly means of H recorded at *Potsdam* Observatory.

A glance at the curve in Fig. 1 shows that the variation from day to day is very large and irregular. This makes a possible existence of regular waves almost invisible. That, however, this variation is really represented will be shown in the following pages. The annual wave is easy to see, and a closer examination shows that there is a more or less periodical movement of about 28 days. Even an indication of an undulation of half this length may be detected, but judging from Fig. 1 nothing decided can be said.

For the study of a variation which is so complicated, it is of great importance to be able to separate each wave from the rest, and according to Hann[1], the most convenient treatment is to make use of the Cock-Blankford method[2]. This method is so well known that I do not consider it necessary to give any detailed explanation, but will shortly mention the system according to which I have worked.

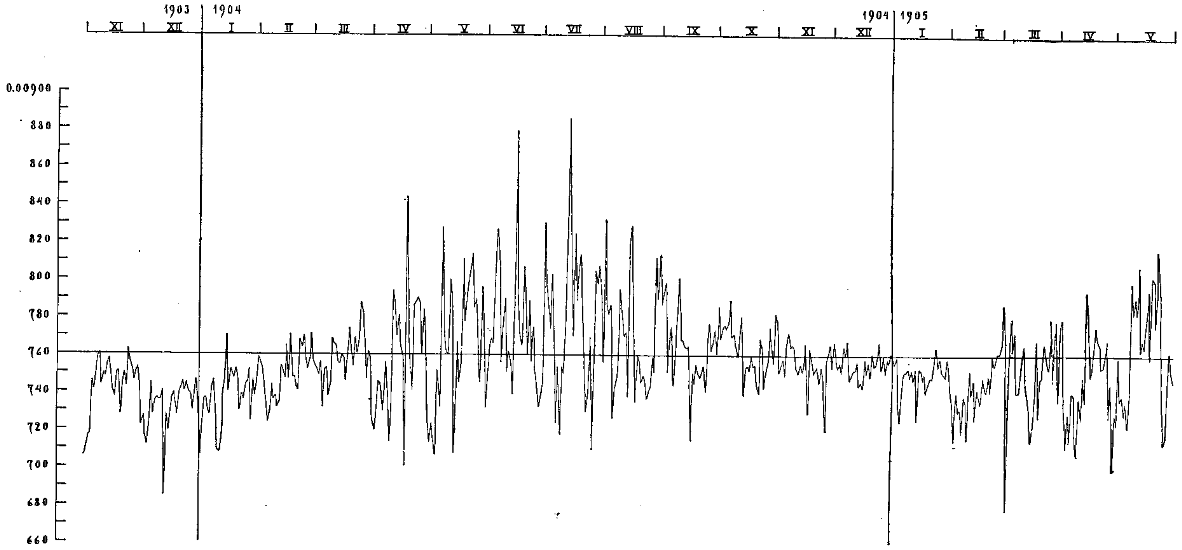

Fig. 1. Variation of the daily means of the horizontal intensity at Gjøahavn from 1st of November 1903 till 1st of June 1905, O.

Let the figures of a table be represented by: $a_1, a_2, a_3, \dots a_n$ .. and the new series of figures, constructed through a successive formation of means, by: $b_1, b_2, b_3, \dots b_n$ .., where n is the number of figures forming the wave in question. The relation between the a- and b-figures is then:

$$\text{(I)} \quad b_1 = \frac{a_1 + a_2 + a_3 + \dots a_n}{n}$$

$$b_2 = \frac{a_2 + a_3 + a_4 + \dots a_{n+1}}{n}$$

A certain period may, as we know, be eliminated by using the same number of figures in the successive means, as the period itself indicates. Supposing that we have a wave, the length of which is 5 days, we put $n=5$ and b_1 in the smoothed series will then correspond to a_3 in the original, b_2 to a_4 etc. In the b-curve, the said wave of 5 days has now been eliminated, and if we take the difference between corresponding figures in the two series, we get the separated 5-day wave, while in the b-curve it will

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[1] J. Hann: Lehrbuch der Meteorologie, Leipzig 1903.

[2] G. Hellmann: Die Niederschläge in den Norddeutschen Stromgebieten I, pag. 38.

be more easy to detect an eventual wave with a longer period. Supposing that this wave has a duration of 14 days, we smooth with 14-day means and get the series: c_1, c_2, c_3, ... c_{14}, .., whereupon we calculate the differences between corresponding figures in the b- and c-series to have the 14-day wave separated. As, however, 14 is an even number, none of the c-terms correspond directly in time with the b-terms, but we may establish a correspondence by forming the means of two successive values, e. g.:

$$c_1' = \left(\frac{b_1 + b_2 + \ldots . b_{14}}{14} + \frac{b_2 + b_3 + \ldots . b_{15}}{14}\right) : 2 \qquad \text{(II)}$$

$$c_1' \text{ then corresponding in time to } \frac{c_1 + c_2}{2}, \text{ or to } b_8$$

In many cases the error will not be large by letting c_1 correspond either to b_7 or to b_8, and I have for my purpose found it sufficiently exact to use for instance b_7, by which we get a displacement of half a day to the left. The right point of time is, however, restored again, if, by the next subtraction of an eventual d-series — where also n happens to be an even number — we let d_1 correspond to the last of the two figures in question. To avoid all difficulty I have sometimes used the odd number next to the one I should have used. The error by this procedure is mainly of no consequence.

It is not convenient to indicate the various tables by a, b, c, ..., and I have therefore called the original table 0, the first smoothed 1, the second 2, and so on. The curves, constructed by aid of these data, are indicated by 0, I, II, etc., and finally the curves of the separated waves (0—I), (I—II) .... etc.

If the original curve, 0, is smoothed with 5, the I-curve will still show the 14-day wave, if this wave exists, and the periodicity, as said before, will probably stand out clearer in the I-curve than it did in the 0-curve. The amplitude of the wave has, however, in the smoothed curve become smaller than it is in reality. This error of the amplitude can be more or less corrected by introducing a "factor of reduction". The theoretical side of this question has been intimately discussed by Schreiber[1] and his conclusion is as follows:

If we suppose that the observations can be represented by a series of sinterms, we may put:

$$\eta = \mu\, a \sin\left(\frac{180^\circ}{l} + b\right) \qquad \text{(III)}$$

Where l is the length of the period, a half the amplitude and μ the factor of reduction, the value of which we get by putting:

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

where n is the number of figures used for the smoothing. Calculating by formula (IV) we find how much of the true value is represented in the smoothed curve, and finally we get the multiplicator ε by putting:

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

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

If now we multiply the ordinates of the curves of differences by ε, we get true values and may thus construct the curves, so that such values can be directly measured. As, however, the curves of this paper have not been drawn according to this system, we must — to obtain true values — multiply a directly measured value by the multiplicator ε, the value of which has always been stated. However, to make direct measurement on the curve possible also in our case, the drawings have been provided with an extra scaling by the aid of which true values can be obtained. For the mean amplitude, measured on the curve, a corrected value is always added.

The various Periods of the "Waves" studied.

The Fluctuations of 3 and 5 Days.

When I begun the studies of the periodicities of the Gjøahavn records for H, I was not aware of any shorter "wave" than the above-mentioned one of about 14 days. To make this undulation stand out clearer there was smoothed at random with 5 figures. During this work I was struck by repeated indications of a periodicity of between 3 and 4 days. As I had never seen discussed a wave of this length, I made out the curve of differences $(0—I)_{\mathrm{H}}$. Thus we get the second curve from above in Fig. 2. As this curve is not smoothed at all, it has a rather irregular character, but there is no doubt about a more or less periodical undulation of some few days. By counting the lower and upper tops of the undulations, I obtained an average duration of the periods of 3.3 days. It will be seen that the amplitudes are of considerable size, especially during the summer. Measurements gave the values shown in Table A, where Summer is indicated by *s* and Winter by *w*.

When later on the temperature records for Gjøahavn and for Oslo were taken up for examination, I tried if a corresponding period could be traced. This was not the case, but, as will be seen in Fig. 2, I found a short undulation also here, and for this period we get a mean duration of 4.8 days with the amplitudes stated in Table A.

As the curves of Fig. 2 are of the type (0—I), the directly measured values for the amplitude are true values.

Table A.

Station	Element	Duration	Amplitude		
			w	s	Mean
Zürick . . .	R	3.3 days	-	-	16
Gjøahavn	H	3.3 »	21 γ	59 γ	40 γ
Gjøahavn	T	4.8 »	9°.2	2°.4	5°.8
Oslo.	T	4.8 »	4°.2	2°.6	3°.4

The existence of similiar short undulations in the temperature has been shown by Wallén[1]. He examined the temperature records for Stockholm for the years 1908—1912, and found almost constantly a periodic movement of between 6 and 7 days. Wallén for the development of his curves made use of the Cock-Blanford method, and worked according to more or less the same system as has been used in this paper. The mean length of the periods and the mean amplitude will be found in Table B. The mean amplitude, as will be seen, is 3°.1, but as Wallén has smoothed his curve, this is not the true value, which he states to be 4°.0 C. Wallén suggests that this short "wave" may have something to do with the movement of the moon.

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

Table B.

Year...........	1908	1909	1910	1911	1912	Mean
Duration in days	6.4	6.0	6.6	6.7	7.0	6.5
Amplitude in C'°	3.6	2.8	3.0	3.4	2.8	3.1

As I found it possible that the variation in our T-curves might correspond to the period found by Wallén, the original temperature records for Gjøahavn were smoothed with 7 days, instead of using 5 days, as with H. The resulting curves $(O-I)_T$ however showed, that in our records for T no 7-day period can be traced — but as mentioned a 5-day period was stated. A consequence of this is that the best figure for smoothing is 5 for the T-records, just as by H we should have used 3 instead of 5. As the curve calculated with 7 might come out less correctly than the one smoothed with 5, I have, to be on the safe side, recalculated T for Gjøahavn — using 5 for the smoothing. In Fig. 2 the curves $(O-I)_T$ — for Gjøahavn and for Oslo will be found as the third and fourth.

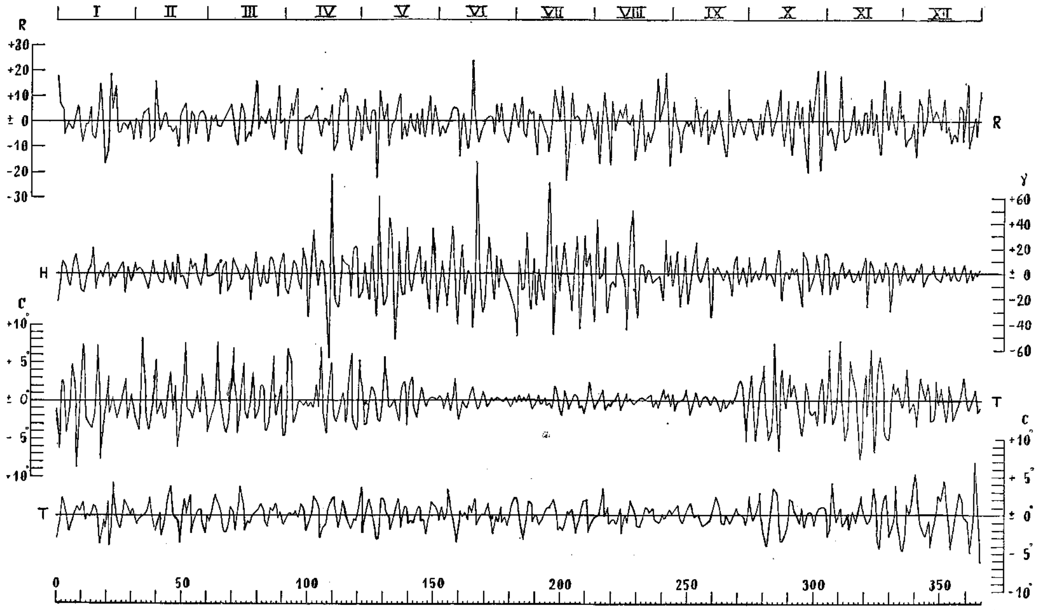

Fig. 2. The 3-day period of R and H and the 5-day period of T for Gjøahavn and Oslo for the year 1904. (0--I).

The sunspots, as mentioned, will be discussed later on, and as also by this element a periodicity of 3.3 days was found, the curve $(O-I)_R$ has been put above $(O-I)_H$ in Fig. 2.

Looking at Wallén's results, Table B, we see, that for the different years he found a different duration. Thus he found for 1912, 7.0 days but for 1909 only 6.0 days. It would have been very interesting if Wallén had gone back as far as to 1904, but as he did not, we do not know how long the corresponding period was for that year. As to the question how much the duration of a period found for a series of years can be supposed to differ it is of course impossible to answer, but if Wallén's supposition that the variation has something to do with the moon is correct, there is perhaps reason to believe that the limit of the variation in the mean length of the period is represented by Table B. If, however, the variation is in one way or another connected with certain solar phenomena, the duration of the period may from year to year vary so much, that the 5-day period, found for T, has the same universal origin as Wallén's curves.

Before we leave the curves of Fig. 2, I may point out the way in which the size of the amplitudes exhibits the Earth's annual motion around the sun. The two Gjøahavn curves show a remarkable opposition — the 3-day wave of H has small amplitude during the winter and large during the summer, while the 5-day wave of T shows just the contrary picture. Wallén also found a larger amplitude during the winter and a smaller one during the summer, but the difference is not so marked as that found for Gjøahavn, but it is larger than that found for Oslo.

Indications of a Period of between 10 and 11 Days and its possible Relation to a similar Period in the Solar Activity.

Further examination of the smoothed tables for H and T for Gjøahavn showed that beside the 3-day and 5-day periods respectively, there were signs of another undulation having a length which lies between the said period and the 14-day one. As this undulation seemed to show a somewhat variable duration of between 8 and 12 days, there was smoothed with 10 figures. The curves of differences $(\mathrm{I}-\mathrm{II})_H$ and $(\mathrm{I}-\mathrm{II})_T$ are to be seen in Fig. 3.

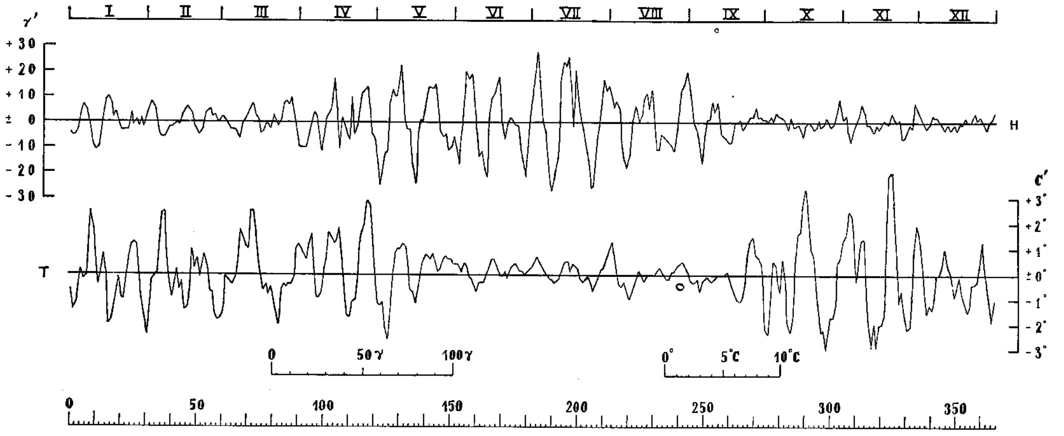

Fig. 3. The 10-day period of H and T for Gjøahavn for the year 1904. (I—II).

A periodical movement of about 11 days for the temperature has been suggested by Clayton, but for the magnetic elements I have never seen it discussed beyond what Bauer says in the article mentioned below. I may however remark that, according to a verbal communication, the astronomer Einbu found, from magnetic registrations at Dombaas, that a 10-day fluctuation in the variation of H occurs rather frequently. Of very much interest in this connection is Abbot's results concerning the variability of the solar constant, for he believed he had found a periodicity of about 10 days in the variation of the solar radiation. According to Abbot[1], his observations from Mount Wilson in 1903 indicated "that the sun is a variable star of irregular periodicity and range". Later on the existence of the said periodicity of the solar constant was tested on various occasions, which always confirmed the first result. The most valuable test was obtained in 1911, when Abbot had an opportunity of gathering a long series of simultaneous observations at Mount Wilson and Bassour, Algeria. Concerning these results Abbot states:

"These duplicate series of observations confirm the supposed variability of the sun. When high solar constant values are obtained at Bassour, high values are found at Mount Wilson, and vice versa". As to the magnitude of the variation of the solar constant Abbot states 10 per cent.

The good results Abbot obtained in 1911 — also confirmed by later series of simultaneous observations — have induced several investigators to use his material for com-

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[1] Annales of the Astronomical Observatory of the Smithsonian Institution. 1913, Vol. III, by C. G. Abbot.

parison. Thus Bauer in the above mentioned article, in "Terrestrial Magnetism" for December 1915, page 11, indicated a correlation between the variation of solar radiation and certain fluctations of terrestrial magnetism. Clayton found a positive correlation between the temperature of the air and solar radiation[1]. As material for his investigations Clayton used temperature records for Buenos Aires and he points out that there seems to be a period of $2 \times 11 = 22$ days.

In spite of what Abbot states, the variability of the sun has been doubted — his fine results are said to be due to the variation in atmospheric conditions.

An examination of the curves in Fig. 3 shows that there are repeated signs of a fluctuation of about 10 days, especially T shows some fine oscillations of the said duration, though in general the length of the periods may be said to have a somewhat irregular character. This irregularity, however, may partly be due to the fact, that in this special case, we have to deal with two sets of undulations of respectively 10 and 14 days, which we have tried to separate — an operation which is very difficult.

Table C.

Horiz. Intens.				Air. Temperat.			
Max.		Min.		Max.		Min.	
Day	δ	Day	δ	Day	δ	Day	δ
		2		-			
6			9			*2*	
	10	11		9			*14*
16			11			*16*	
		22		-			*15*
-						*31*	
		-		26			
33					12	-	
	14	*37*		38			
47			*15*		11	*46*	
	9	*52*		49			*13*
56						*59*	
		-		-			
-						-	
		68		72			
73			*8*			-	
	14	*76*		-			
87			*16*			*83*	
	10	92		96			*16*
97			8		11	99	
	8	100		107			12
105					11	111	
	12	-		118			
117						-	
		123		-			
-						126	
		-		132			11
131					10	137	
	13	*137*		142			9
144			*17*			146	
	14	154		-			15
158			11			161	
	11	165		167			11
169					9	172	
		-		176			8
-					9	180	
		180		185			12
185			10		11	192	
	11	190		196			
196						-	
		-		-			
-						*207*	
		206		214			
212			*14*		10	-	
	13	*220*		224			
227					9	221	
		-		233			6
-					9	227	
		-		242			9
244						236	
	9	250		-			13
255			11			249	
		261		260			15
-					10	264	
		-		270			12
-					8	276	
		-		278			8
-					13	284	
		-		291			
-						-	
		-		-			
304						*299*	
	9	308		308			
313			10			-	
	12	318		-			
325			11			*317*	
	9	329		325			*14*
334			10		10	331	
		339		335			9
-					11	340	
		-		346			15
358					*15*	355	
		363		*361*			10
-						365	
(Mean)	*11.1*		*11.5*		*10.5*		*11.8*
Mean	10.0		10.1		10.2		10.9

To demonstrate the character of the variation in figures, I have worked out Table C, which shows the day on which a maximum or minimum occurs. The days of the year are, as will be seen, numbered with figures from 1 to 365 and the columns headed "Day". Under the heading δ, the number of days between two on each other following maxima (minima) is added. Arranging Table C, it is natural to put the figures under the heading "Day" so that corresponding extremes for H and T are placed in the same horizontal line. It will than often occur that one element shows a decided extreme, while the corresponding extreme for the other element cannot be pointed out. Studying periodicities of this nature, we often find that not all the "waves" are defined — here and there a "wave" may be missing. I interpret this so, that the influence has in this case been too weak, and the amplitude may be said to be ± 0. In such cases the open space in the column, headed "Day", is indicated by a short horizontal line. There is, as mentioned, reason to believe that some of the undulations of the curve of Fig. 3 belong to the 14-day period — not having been duly excluded. Acting on this suspision, the extremes, which may be supposed to belong to the 14-day period, have been printed in italics. The figures under the heading δ are not filled in, if a "missing wave" occurs between two figures in column "Day". If one or both — on each following figures — in this column are printed in italics, the corresponding figure in column δ is also printed in italics.

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[1] Smithsonian Miscellaneous, 1917. Vol. 68, nr. 3.

Table D.

Max.		Min.	
H	T	H	T
		2	2
73	72		
97	96		
105	107		
117	118		
131	132		
		137	137
144	142		
169	167		
		180	180
185	185		
		190	192
196	196		
		206	207
212	214		
		220	221
244	242		
		250	249
		318	*317*
325	325		
		329	331
334	335		
		339	340
		363	365

As mean figures under column δ are those printed in italics, the average of all the figures of the column, while in the calculation of the other mean figures, the italics of the column are excluded. However, to obtain the most exact expression for the duration of the period — especially in such a case as this — we should rather use the column "Day" and select two defined maxima (minima) — belonging to the same series of "waves" — and divide the inter-distance by a reasonable number of undulations. For $H_{\max}$ we have thus, that the first and last extreme — belonging to the variation in question — occurs the 6th and 334th day. Counting "missing waves", there should have been 33 oscillations on these 328 days and we obtain a mean duration of the "wave" in question of 10.0 days. Calculating in the same way for the other columns, we have also for $H_{\min}$ 10.0 days while the corresponding figures for T are 10.0 and 10.4.

Table D contains a list of days, when maximum (minimum) occurs more or less simultaneously in the two elements, while Table E shows the few cases, where the maximum of H corresponds to the minimum of T. The last table, Table F, contains a list for the values of the amplitudes, in all cases where measurement is possible. Each element has two columns, containing the values of the amplitudes of the "waves" during the summer-half-year (*s*) and the winter-half-year (*w*). We must, however, remember, that the curves have been smoothed with 5 and 7 days respectively for H and T, whereby the figures of Table F, are not true values. Putting $n = 5$ ($n = 7$) and $l = 11$ in formula (IV) we get for H, $\mu = 0.70$ and for T, $\mu = 0.46$, which means, that only 70 % and 46 %, respectively for H and T, are represented in the amplitude, measured from Fig. 3. We must therefore multiply by 1.4 and 2.2 respectively and obtain for H, 40.6 γ for the summer and 16.8 γ for the winter. The corrected figures for T are 3°.7 C. and 8°.8 C.

As a conclusion of what has been stated above, we might say, that the existence of a continuous undulation of about 10 days has not been proved. On the other hand a glance at Table C shows, that the data for both H and T have a sporadic tendency to rise and fall in harmony with a continuous wave of the said duration. In addition, Abbot has stated a similar periodicity in the variation of the solar constant.

Table E.

H		T	
Max.	Min.	Max.	Min.
	11	9	
16			*16*
33			*31*
	37	38	
47			*46*
97			99
144			146
	165	167	
227			227
	261	260	
	308	308	
	363	*361*	

Table F.

Number	·	1	2	3	4	5	6	7	8	9	10	11	12	Mean
Horizontal Intensity in γ...	s	14	28	21	38	37	40	9	50	53	24	24	9	29
	w	12	21	10	12	10	14	14	15	8	14	7	—	12
Temperature in C'°	s	2.8	4.6	3.8	2.0	0.6	1.3	0.6	0.7	0.9	1.2	0.8	0.8	1.7
	w	3.9	4.9	1.9	3.6	3.5	2.6	2.9	5.7	5.5	6.9	4.2	2.5	4.0

The 28-day Period and Comparison with Spörers Epochs of the Rotation of the Sun.

We will now turn to the above-mentioned undulation of 14 and 28 days. In order to get these "waves" separated, we shall have to smooth again. Having done this, the two tables of differences were worked out and the figures reproduced graphically — the curves (III—IV) and (IV—V) for H and T are respectively to be found in Fig. 6

and Fig. 4. The two periods of about 14 and 28 days, found in magnetic and metorological elements, are usually supposed, in some way or other, to be connected with the rotation of the sun. Since the chief effect of the rotation is represented in the 28-day period, we may first discuss this varation.

Table G.

Rot.	from—till	from—till
580	— 22	Dec. 25—Jan. 22
581	22— 49	Jan. 22—Feb. 18
582	49— 76	Feb. 18—March 16
583	76—103	March 16—April 12
584	103—130	April 12—May 9
585	130—157	May 9—June 5
586	157—184	June 5—July 2
587	184—211	July 2—July 29
588	211—238	July 29—Aug. 25
589	238—265	Aug. 25—Sep. 21
590	265—293	Sep. 21—Oct. 19
591	293—320	Oct. 19—Nov. 15
592	320—347	Nov. 15—Dec. 12
593	347—	Dec. 12—Jan. 8

It will be known, that comparisons made between sunspot frequency and terrestrial elements show that high figures for frequency correspond generally to low figures for magnetic force, and that the temperature sometimes shows high, sometimes low figures. As regards T, this apparently confusing relation will be discussed later, but I may already here remark, that investigations seem to have proved, that the higher the activity on the sun, the more disturbances there are, both in meteorological and magnetic elements. As to H, we shall see, that also in our case the relation is generally negative between this element and solar activity. The negative relation between H and R is explained by the fact, that the effect of magnetic disturbance is in general found to diminish the mean absolute value of the horizontal intensity. I may, however, in this connection remark that this rule seems apparently to stand in strong opposition to what the curve of Fig. 1 shows. In this curve we see that the maximum of the yearly wave corresponds to the strongest oscillations of the daily means. This fact has a special reason which will be discussed later, and I shall therefore only remark, that we should make a mistake, if we founded the relation between H and solar activity on the variation of H in Fig. 1. Fig. 4 may, however, give us means to come to a more or less reliable conclusion regarding the relation between H and R. To judge this relation we can build on the following arguments:

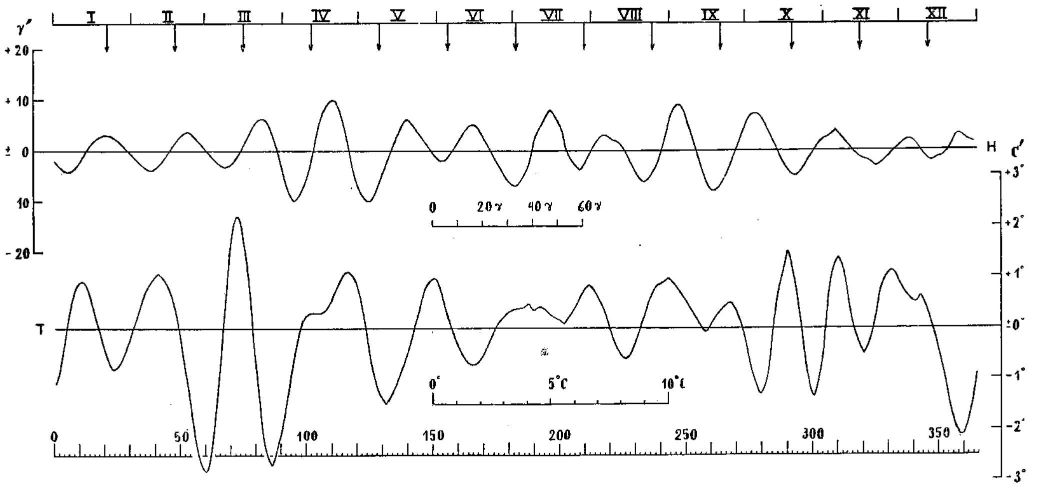

Fig. 4. The 28-day period of H and T for Gjøahavn for the year 1904. (III—IV).

Solar activity seems to concentrate around certain parts of the sun — more or less those parts where we observe the sunspots. We may further expect the largest terrestrial effect, when the meridian about which the spots gather, coincides with the centre of the apparent sun disc. Now referring to page 25—26, where the distribution of the spots with reference to heliographic longitude during the year in question has been

Table H.

Horizontal Intensity							Temperature of the Air							Lag	
Max.		Min.		Max.	Min.	Amp.	Max.		Min.		Max.	Min.	Amp.	I	II
Day	Δ	Day	Δ	δ	δ		Day	Δ	Day	Δ	δ	δ			
	γ		γ			γ		°		°			°		
		6*	— 4				12*	+0.9							+ 6
22*	+ 3				33	7			24*	—0.8	30		1.7	+ 2	
		39	— 4	31			42	+1.1				37			+ 3
53	+ 4				30	8			61	—2.8	32		3.9	+ 8	
		69	— 3	30			74	+2.2				26			+ 5
83	+ 6				27	9			87	—2.7	—		4.9	+ 4	
		96	—10	28			—					—			—
111	+10					20			—	—				—	
							117	+1.1							
					29										
		125	—10	30											—
141	+ 6				29	16			132	—1.5	35		2.6	(— 9)	
		154	— 2	31			152	+1.0				35			— 2
172	+ 5				29	7			167	—0.7	37		1.7	— 5	
		183	— 7	25			189	+0.5				36			+ 6
197	+ 8				26	15			203	+0.1	23		0.4	+ 6	
		209	— 4	22			212	+0.8				24			+ 3
219	+ 3				25	7			227	—0.6	32		1.4	+ 8	
		234	— 6	29			244	+1.0				32			(+10)
248	+ 9				28	15			259	—0.1	22		1.1	(+11)	
		262	— 8	30			268	+0.5				21			+ 6
278	+ 7				32	15			280	—1.3	23		1.8	+ 2	
		294	— 5				291*	+1.5				21			— 3
									301	—1.3	20		2.8	—	
				32											
310	+ 4				32	9									
		326	— 3	30			311	+1.4				20			
340	+ 2					5			321	—0.5	21		1.9		
							332	+1.1							—
					22	5								—	
		348*	— 2	20			—					38			—
360*	+ 3								359*	—2.1			3.1	— 1	
28.2	+5.3	28.5	—5.2	28.2	28.5	11	27.9	+1.1	27.9	—1.2	27.5	29.0	2.3	3.0	3.2

The figures in brackets are not considered.

discussed, we see that the chief part of the sunspots is more or less concentrated along the zero meridian (cp. Fig. 11 and Fig. 12). If now we combine the data for the rotation of the sun (Table G) with the location of the oscillations of *H* and *T* in Fig. 4, I have come to the result that: High solar activity — sunspots passing the middle of the suns disc — are followed by low magnetic intensity and high temperature.

In Table G — according to Wolfer — are given the data in question for the rotation of the sun. The figures in the first column refer to Wolfer's counting for the continuous rotations, the third column gives the interval during which dates a rotation lasted, while in the second column these intervals are put according to the counting used in this paper. The duration of each rotation will be seen indicated in Fig. 4 by the short vertical arrows. These arrows refer to the dates when the zero meridian — chosen by Spörer[1] — coincides with the centre of the apparent sun disc.

With reference to the nature of the phenomena dealt with, we must not be surprised to find that the "waves", even in this case, do not show the same duration. The active parts of the sun may keep constant even through an interval of several rotations, but it also happens that suddenly a new active area is developed far from the first place, while this first area of action gradually dies out. The terrestrial effect of this is that we get a series of waves which cannot be directly combined, but within each series there may be a decided periodicity. We must also remember, that as the general development of the sunspot phenomena increases or decreases, when passing the middle of the sun's disc, the moment for maximum effect on our globe may be respectively forwarded or delayed. Beside these irregularities we have, especially by *T*, the often occuring transformation of phase.

Passing to Table H, we see that for the maximum and minimum of the two elements *H* and *T* (Fig. 4), there are two columns headed "Day" and *Δ*. As to the first heading I may refer to what has been said on page 9, while under the heading *Δ* I have given the

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[1] Astronomische Mitteilungen by Prof. A. Wolfer. Nr. LXXXVIII, 1896.

oscillation on each side of the line of zero, which together give the "double" amplitude of the wave in question, entered under the heading "Amp". Besides this the duration of the periods, counted from maximum to maximum (minimum to minimum), has been entered under the heading δ. The last column, headed "Lag", concerns the amount of disparity between the corresponding oscillations for H and T.

Concerning the calculation of the mean duration of the period in question we may simply take the mean by the column δ. We may, however, also in this case use the column "Day". The mean duration of the periods is seen in Table H to have been calculated according to both methods and under column "Day" the two extremes, to which we have referred, are marked by a *. The H-curve does not seem to show any irregularity of consequence for the calculation of the duration — though the last figures in the columns δmax and δmin are probably abnormal — the result is therefore in either case the same. With T, however, there seems to be a more serious irregularity in March and during the last part of the year — thus I may point out the great difference between the two mean values under δmax and δmin — 27.5 and 29.0. For this reason I have in the first column for T put the star by the maximum occuring the day 291. The mean duration of the oscillations for H and T in Fig. 4 may respectively be put to 28.3 and 28.0 days. The lag, counted from Hmax to Tmin, has been entered in the column headed I, where the mean value is seen to be 3.0 days. The counting between Hmin and Tmax gives a mean value of 3.2 days — column II. As the lag between the data for the solar radiation and its effect on magnetic elements seems to be practically equal to zero, we may conclude that change in the radiation makes itself felt in the temperature at Gjøahavn about 3 days later. Clayton found between the changes in the solar radiation and those of the temperature a lag of between 1 and 5 days. The mean amplitude for H will, according to the columns headed "Amp" be seen to be 11 γ' and for T — 2°.2 C'. It may perhaps be more correct to refer the figure for mean amplitude to the difference between the mean maximum and mean minimum, but the result in our case will be the same as stated above. These values are, however, uncorrected. The curves will be seen to have been smoothed 3 times — with 5 (7), 10 and 14 figures. Calculation shows that the smoothing has diminished the amplitudes to 95 % (90 %), 81 % and 64 % respectively in each case. The factor ε with which the figures in Table H must be multiplied is for H — 2.02 and for T — 2.15, giving an amplitude of 22.5 γ and 4°.7 C respectively. As the sunspots are more or less stationary — at times even through several rotations of the sun — we can, by observing the movement of spots over the sun's disc, calculate the time the sun uses to rotate about its axis. Such calculations have been made several times, whereby also the movement of the sun facula has been considered. These measurements lead to the astonishing result that the different parts of the sun rotate with a different angular volocity. Thus, the period becomes larger as we approach the poles from the equator. For comparison with the values for the duration of the "waves" stated in Table H, I give in Table I the synodic time for the girdles of the sun, where respectively, according to Warrinton and Stratonoff, the spots and faculae usually appear. As the mean latitude (south and north) for the spots during the year 1904 may be placed at ± 17°, we may expect the period in our curves to be about 27.3 days. We have, however, found a mean duration of about 28.0 days. That a larger value is found for the duration of the periods, owing to the effect of the rotating sun, has been noticed so often that it is scarcely due to incorrectnes in the results obtained, whatever the explanation may be. From Table K we see that Wallén, for the temperature

Table I.

Helio-graphic latitude	Sun-faculae	Sun-spots
0°—10°	26.4 days	27.0 days
10°—20°	27.2 »	27.4 »
20°—30°	27.4 »	28.2 »
30°—40°	28.5 »	29.0 »

records of Stockholm, has stated 28.5 days as the mean duration, while **Krogness** for the temperature of several parts of Norway has found 27.3 days, or exactly the figure we should have according to Table I.

Looking at the figures in column δ in Table *H*, there seem to be signs of an annual variation. An annual variation of the duration of these undulations is, however, in close harmony with **Størmer's** theory concerning the North Light phenomena. According to him the terrestrial effect of the rays from the sun depends upon the mutual relation between the active part of the sun, the ecliptic and the axis of the earth.

The Sun Rotation Period of *T* for Oslo.

There have been made various attempts to find a reasonable system in the variation of the temperature registered in Oslo. The variation is always found to be singularly irregular. For Stockholm, however, Wallén found a fairly well developed system, and in Table K I have given his values for the duration of the period owing to the rotation of the sun. It will be seen that the values for the various years differ considerably — thus for 1910 he found 31.4, but for 1911 only 26.4. His mean figure for the five years 1908—1912 is as mentioned 28.5 days.

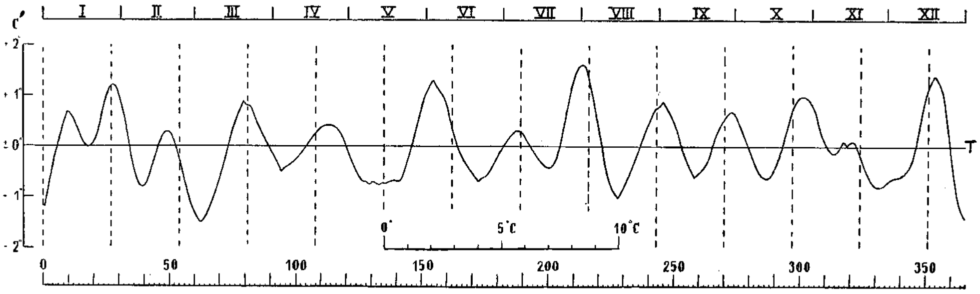

Fig. 5. The 28-day period of T for Oslo for the year 1904. (III—IV).

In the examination of the temperature records for Oslo[1] I have treated the data exactly as those for Gjøahavn, and one of the results will be seen in Fig. 5, another is to be found in Fig. 2. The 10-day and the 14-day periods have not been reproduced, as the variation came out so irregularly that the curves had no interest for this paper. The "wave" produced by the rotation of the sun may, however, be said to be fairly well defined and will be seen in Fig. 5. Comparing this curve with the *T*-curve for Gjøahavn (Fig. 4)., one must take into consideration the peculiarity that the Oslo curve seems to have a tendency to transformation of phase. Thus we see that the undulations are more or less parallel during the summer, but opposite to each other during the winter. It may be that precisely this tendency to transformation of phase explains the above mentioned irregularity in the 10-day and 14-day periods, for I have found several typical species of oscillations belonging to the said variation, which may show that the periodicity is represented, but hidden.

Table K.

Year	1908	1909	1910	1911	1912	Mean
Duration in days Amplitude in C'°	29.4 2.4	27.5 2.2	31.4 2.3	26.4 2.7	27.6 2.2	28.5 2.4

Calculating the mean length of the period of the curve in Fig. 5, I have taken into consideration the irregularities, and founded the mean duration of the "wave" on

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[1] Jahrbuch des Norwegischen Meteorologischen Institutes, Kristiania 1904, by H. Mohn.

the two intervals — 28 to 114 and 155 to 354. These intervals give the two values 28.7 and 28.4 — or put together 28.5 days. Wallén found, as mentioned above, 28.5 days and Krogness 27.3 days. The mean amplitude of T measured in Oslo is 1°.5 — corrected value 3°.2 C. The corrected amplitude for T in Stockholm is stated to be 4°.5 C.

The 14-day Period of *H* and *T* for Gjøahavn, where *T* shows a typical Transformation of Phase from Winter to Summer.

In Fig. 6 the two Gjøahavn curves $(\mathrm{II}—\mathrm{III})_H$ and $(\mathrm{II}—\mathrm{III})_T$ are reproduced and for the study of the variation the two tables L and M have been prepared.

From Table L we gather that the T-curve shows transformation of phase, a factor which to a certain degree is also the case in the T-curve of Fig. 3. During the summer high intensity corresponds to high temperature, while during the winter high intensity corresponds to low temperature. If we suppose that high solar activity corresponds to low intensity, we see that the relation between solar activity and temperature is in this case "negative" for the summer and "positive" for the winter. For the 28-day period we found "positive" correlation for the whole year, and consequently the summer at Gjøahavn shows a contrary correlation to solar activity for the 28-day and the 14-day period for T. This peculiarity has also been stated by Bigelow[1], who found an analogous opposition between two periodic undulations in meteorological elements, registered in certain parts of United States. To mark out the transformation of phase in the T-curve I have in Table L divided it into three parts, whereby corresponding figures for H and T in column "Day" have been printed in italics. The relation between H and T during the latter part of the year, October—December, is very difficult to determine on account of the irregularities shown by this part of the H-curve. — Which of the various small tops is the maximum, belonging to the 14-day period, is more or less a matter of conjecture.

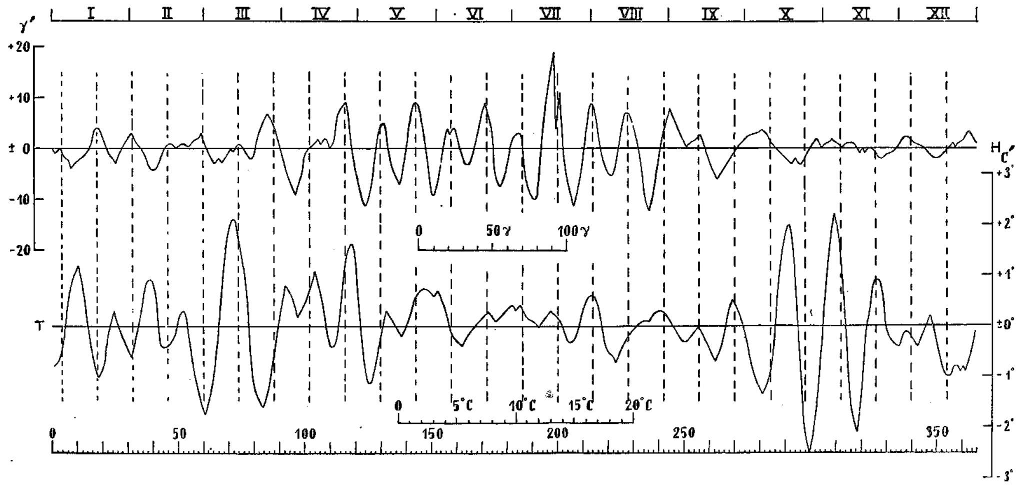

Fig. 6. The 14-day period for H and T for Gjøahavn for the year 1904. (II—III).

Another peculiarity of the curves in Fig. 6 is that apparently corresponding extremes for H and T are suspiciously close to each other in point of time. Often the extremes of T is seen to fall even earlier than by H. — The same thing will be noticed also in Fig. 3. — As this is contrary to experience, I should be inclined to think that the

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[1] Bigelow, F. H.: The relation between the metereological elements of the United States and the solar radiation. American Journal of Science (4), XXV, 1908.

Table L.

Horizontal Intensity							Temperature of the Air						
Max.		Min.		Max.	Min.	Amp.	Max.		Min.		Max.	Min.	Amp.
Day	Δ	Day	Δ	δ	δ		Day	Δ	Day	Δ	δ	δ	
	γ		γ			γ		°		°			°
4	*± 0*	8	— 4	15	18	8	11	+1.2	—	—	14	13	1.3
19	*+ 4*	26	— 3	13	15	6	25	+0.3	*19*	*—1.0*	14	13	1.5
32	*+ 3*	41	— 4	15	—	5	39	+0.9	*32*	*—0.6*	13	16	0.7
47	*+ 1*	—	—	13	—	—	52	+0.3	*45*	*—0.4*	21	—	3.8
60	*+ 3*	69	— 3	15	11	4	73	+2.1	*61*	*—1.7*		—	
75	*+ 1*	80	— 2	11		9	—		—	—			
86	*+ 7*								*84*	*—1.6*			
—	—	97	— 9	—	14	11	*93*	*+0.8*	98	+0.2	12	13	0.9
106	*+ 2*	111	± 0	11	13	9	*105*	*+1.1*	111	—0.4	14	13	2.0
117	*+ 9*	124	—11	14	14	16	*119*	*+1.6*	126	—1.1	14	13	1.4
131	*+ 5*	138	— 7	13	13	16	*133*	*+0.3*	159	—0.2	10	—	0.9
144	*+ 9*	151	— 9	13	13	13	*143*	*+0.7*	—	—	10	—	—
157	*+ 4*	164	— 3	15	14	12	*153*	*+0.7*	163	—0.4	20	13	0.7
172	*+ 9*	178	— 7	13	14	10	*173*	*+0.3*	176	+0.2	12	17	0.2
185	*+ 3*	192	—10	14	15	29	*185*	*+0.4*	193	±0.0	12	13	0.3
199	*+19*	207	—11	15	15	30	*197*	*+0.3*	206	—0.4	17	18	1.0
214	*+19*	222	— 5	14	15	12	*214*	*+0.6*	224	—0.7	—	—	—
228	*+ 7*	237	—12	17	14	20	—	—	—	—	—	—	—
245	*+ 8*	251	∓ 0	11	13	3	*241*	*+0.3*	251	—0.3	15	12	0.3
256	*+ 3*	264	— 6	—		—	*256*	*±0.0*	263	—0.7	14		1.2
—	—						*270*	*+0.5*					
281	*+ 4*	293	— 3	22	—	5	292	+2.0	*282*	*—1.3*	18	18	3.3
303	*+ 2*	—	—	14	—	—	310	+2.2	*300*	*—2.5*	17	19	4.7
317	*+ 2*	—	—	—	—	—	327	+0.9	*319*	*—2.2*	12	12	3.1
—	—	—	—	—	—	—	339	—0.1	*331*	*—0.4*	9	—	0.3
338	*+ 2*	350	— 2	—	—	—	348	+0.2	—	—		—	—
—	—	—	—	—	—	—	—	—	—	—		—	—
—	—	—	—	—	—	—	—	—	—	—		—	—
363	*+ 3*				—				*362*	*—0.9*			
Mean				14.1	14.1	12					14.1	14.5	1.5

figures printed in italics only apparently correspond, and that the maximum for *H* in reality corresponds to the extreme of *T*, printed in ordinary type. The consequence would, however, be a lag of about 7 days, which seems to be a somewhat large figure, remembering that in Fig. 4 we found only about 3 days.

Table M.

Element . .	H			T		
	s	w	Mean	s	w	Mean
Direct . . .	14.1	4.3	9.2	1.0	2.0	1.5
Corrected .	47.9	14.6	31.2	4.3	8.6	6.4

Calculating the mean length of the period in the same way as before, we obtain for *H* and *T* respectively 14.3 and 14.1 days. The inter-distance between the dotted lines in the figures is 14 days. The amplitude for *H* has been reduced to 81 % by the first and to 36 % by the second smoothing — giving $\varepsilon = 3.4$. For *T* we have 64 % and 36 % respectively — giving $\varepsilon = 4.3$. The mean amplitude has been calculated for the summer half-year (*s*) and for the winter half-year (*w*), and is given in Table M as directly measured and corrected means.

As to the temperature curve of Fig. 6, I may call attention to the strong oscillations during March and October. This peculiarity may perhaps have something to do with the supposed periodicity of 7 2/3 month — a period Wolf found traces of in the data for the sunspots[1].

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[1] Astronomische Mitteilungen XX, 1866, by Dr. R. Wolf.

The probable origin of the 14-day wave has already been aluded to on page 11, where we called attention to a peculiarity in the distribution of the spots in reference to heliographic longitude. Wolfer has repeatedly pointed out the fact, that the sunspots have a tendency to concentrate about one main area and a secondary one, situated with an interdistance of about 180°. I may in this connection remind you of professor Kr. Birkeland's remarkable experiments[1] with his so-called magnetic "terella", where he lets the magnetic globe represent the sun, and causes it to emit cathodic rays. When the charge was sufficiently strong, the rays had a marked tendency to concentrate about two spots at diametrical opposition to each other. The photographs taken during the experiment show a striking likeness to the phenomena actually taking place on the sun.

The Periods in *H* of 41 and 70 Days. The supposed Origin of these Undulations.

We have now arrived at a table in which the "waves" of 28 days have been eliminated. It was to be expected that the curve plotted with these figures would show a more or less clean annual wave. This was, however, not the case and by studying the variation one could fix a fairly regular undulation of about 41 days. Besides this I could see signs of another oscillation which seeemed to be about 70 days. In consequence of what had been done before we should now smooth with 41 figures. As, however, the variation was very little from day to day, I prefered to convert the table, with data for every day, into a new one, in which five and five figures were put together in means.

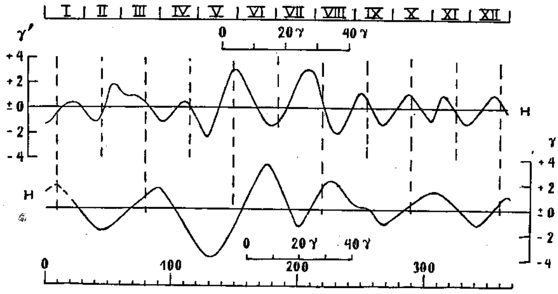

Fig. 7. The 41-day and the 70-day period of *H* for Gjøahavn for the year 1904. (IV—V) and (V—VI).

With this table of pentades I smothed with 7 figures — corresponding to 35 days. In Fig. 7 the curve $(IV—V)_H$ is placed above. The wave-length is, as mentioned, about 41 days and as the factor $\varepsilon = 4.0$, the true amplitude will be equal to 12 γ. To obtain the next "wave" there was smoothed with 14 figures (70 days), the table of differences was worked out and the second curve of Fig. 7, $(V—VI)_H$, was plotted. The period is about 70 days and as $\varepsilon = 4.8$, we get as true amplitude 17 γ.

Concerning the origin of these curious periods, I have arrived at the conclusion that they are scarcely caused by direct exterior influence, but merely an effect of a rhythmical coincidence of maxima (minima) of two shorter waves. Thus the 41-day oscillation may be built by the 10-day and the 14-day periods — we see that a coincidence of the extremes will more or less occur after 4 and 3 oscillations respectively for each wave, and by the 70-day period after 7 and 5 oscillations. The interdistance of the vertical lines of Fig. 7 is 35 (70) days. The temperature was also examined, and various signs of a similar variation were found, but the results were not so good that we need to produce the curves. The study of the 70-day period of *H* by the aid of the Gjøahavn records is not satisfactory, and I have therefore made further investigations. Concerning these studies the reader is referred to page 31.

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[1] Birkeland, Kr.: The Norwegian Aurora Polaris Expedition 1902—1903. Part. II, Chapter VI.

On the Question: High Solar Activity corresponding — now to high and now to low Temperature. Helland-Hansen and Nansen's rule.

Comparisons between the sunspot data and those of magnetic and meteorological elements have, as mentioned, often lead to the most confusing results, and a probable reason has therefore been much discussed. Concerning the temperature of the air I may remark, that meteorologists now seem to be inclined to put an apparently contradictory effect of solar activity in connection with the movement of certain large minima centra, but they had not formed a clear theory. Discussing the results of temperature measurements of the Atlantic Ocean, Helland-Hansen and Nansen took up this question of the changes in solar activity and its effect on temperature[1]. Through a series of striking illustrations these investigators tried to show, that in the first place the changes in solar activity affect the distrubution of pressure, which again affects the temperature of the air. As a result of these studies, they have formulated the following rule:

"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."

Table N.

Month	N	NE	E	SE	S	SW	W	NW	C
I	26	7	6	2	14	3	7	17	18
II	18	3	1	0	15	12	16	10	25
III	23	2	4	0	13	8	8	26	16
IV	27	9	8	11	10	7	7	11	10
V	22	14	8	7	5	11	10	19	4
VI	24	13	2	4	11	11	12	17	6
VII	22	16	6	8	14	8	1	14	11
VIII	28	29	10	2	6	2	4	16	3
IX	47	5	16	2	5	5	6	10	4
X	24	5	10	7	12	10	9	12	11
XI	31	2	7	2	17	5	7	18	11
XII	42	8	1	0	3	9	7	18	12
Year	28	9	6	4	11	7	8	16	11

Now, it may of course be a question if this rule can be supposed to be aplicable when data have been collected from one single station, but it might nevertheless be of interest to glance at some meteorological data from Gjøahavn. Table N contains a summary, worked out by Graarud, who has reduced the meteorological observations of the Gjøa Expedition. Under the heading — N, NE, E etc. the frequency of wind is stated for each month of the year. In the last horizontal line the mean frequency for the year is given for each wind direction and when calm — C. As to the effect of the different winds Graarud states:

a. Warm winds are SE, NE, E, which means winds coming from the North Atlantic ocean.

b. Cold winds are W, NW, N, which means winds blowing from the shors.

c. There is a comparatively high pressure during the winter and spring, whilst there is a comparatively low pressure during the summer and autumn.

Table N shows that the most frequent wind is N, followed by NW — and these winds may thus be said to be the prevailing winds, which according to the rule should demand a "negative" relation between solar activity and temperature. According to researches, however, "positive" relation seems mostly to be found for the parts of the globe in question. (cp. Helland-Hansen and Nansen — the English edition page 278). Now we really found positive correlation between solar activity and temperature, where the 28-day period was concerned, however, for the 14-day period we found that T showed transformation of phase, so that a positive correlation was found only during the winter and spring, whilst during the summer and autumn negative correlation was found. This corresponds with Graaruds statement *c* — comparatively low pressure during the summer

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[1] B. Helland-Hansen and F. Nansen: Temperaturschwankungen des Nordatlantischen Ozeans 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.

half-year and comparatively high pressure during the winter half-year. We see from Table N that the wind coming from NE is the only one which may be said to show a decided annual wave with a maximum frequency during the summer. This wind has its origin in the North Atlantic Ocean, and carries according to Graarud "high" temperature. We should thus expect positive relation during the summer, which, however, again is contrary to what seems to be gathered from Fig. 6.

From what has been said above, we see that the meteorological conditions at Gjøahavn are so complicated, that Helland-Hansen and Nansen's rule cannot be expected to give any decided result.

The Diurnal Variation and Examination of the Hourly Means of *H* and *T*. Discovery of a short Undulation of about 80 Hours duration and a similiar Undulation found by Abbot in the Data for the Solar Radiation.

When observing the sunspots, we are soon aware of the comparatively rapid changes in the activity of the sun. The sunspot groups appear and die out one after the other, within each group we may often see great changes from day to day. This coming and going of the spots and these changes within each group seem to be a quite aperiodic phenomenon — of course allowing for the well known 11-year period — but may not after all more or less periodic occurrences develop? In any case, it would be interesting to see if the data for Gjøahavn give signs of such a comparatively short undulation and if we could not trace a "wave" development.

Acting upon the said supposition I took up for examination a series of hourly values — namely hourly means for the month of June 1904. After having copied out hourly means for *H* and *T* for the said month, I let the data pass the usual repeated smoothing process with 6 and 12 figures, and from these tables two sets of mean hourly values were calculated. The smoothing with 6 and 12 was made, because the diurnal variation seems to be composed of a 24-hour wave in combination with two smaller oscillations. We will not here enter upon this variation as, in the first place this would require a special study which would be beyond the scope of this paper, and secondly because the diurnal wave is so strongly bound to the geographical location of the station, that study by the aid of a single station would have little interest. In Fig. 8 I have, however, given the curves marked *O* — beside the corresponding smoothed curves I and II plotted by aid of mean hourly values. Above we have the *H*-set and below the *T*-set. For a better comparison between *H* and *T*, I have drawn the *T*-curves up-side-down.

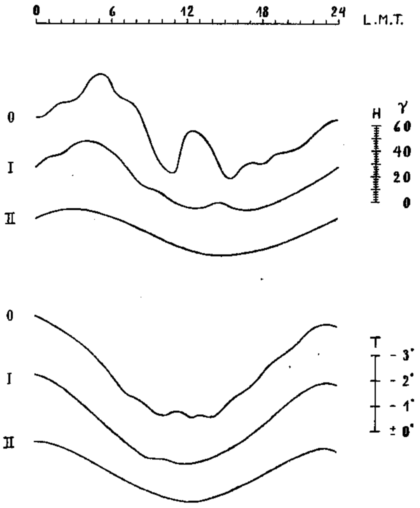

Fig. 8. Mean hourly variation of *H* and *T* for Gjøahavn for the month of June 1904.

As to the vertical scale to the right of the curves, it is of course understood that measurement by the aid of the same give true values only when used for the curve marked *O*. The data for the amplitudes, given in the table, are, however, corrected values. In Table *O*, I have given some data regarding the hour for the maximum and minimum, beside the values of the amplitudes.

Having stated these data we may proceed with the table in which the 24-hour wave has been eliminated. Plotted graphically these figures in fact showed the suspected short

Table O.

Element	Extremes	Hour	Differences corrected
		h m	
H_O	Chief maximum	5 15	....82 γ
»	» minimum	15 20	
»	Secondary maximum .	12 30	....32 γ
»	» minimum .	10 55	
H_{II}	Maximum	3 00	....65 γ
»	Minimum	15 00	
T_{II}	Maximum	12 30	....3°.6 C
»	Minimum	23 00	

undulation, which proved to be a more or less regular period, the mean length of which might be put to about 80 hours. In the customary way the table of differences was worked out and the figures ploted. In Fig. 9 the curves *(III—IV)*$_H$ and III—IV)$_T$ are reproduced. We see that at least some of the periods are well defined, both in *H* and *T*, and we get, with $\varepsilon = 1.16$, a corrected mean amplitude for *H* and *T* respectively equal to 48 γ and 2.°4 C. As 80 hours are equal to 3.3 days, the undulation found in Fig. 9 is identical with the variation found for both sunspots and horizontal intensity in Fig. 2.

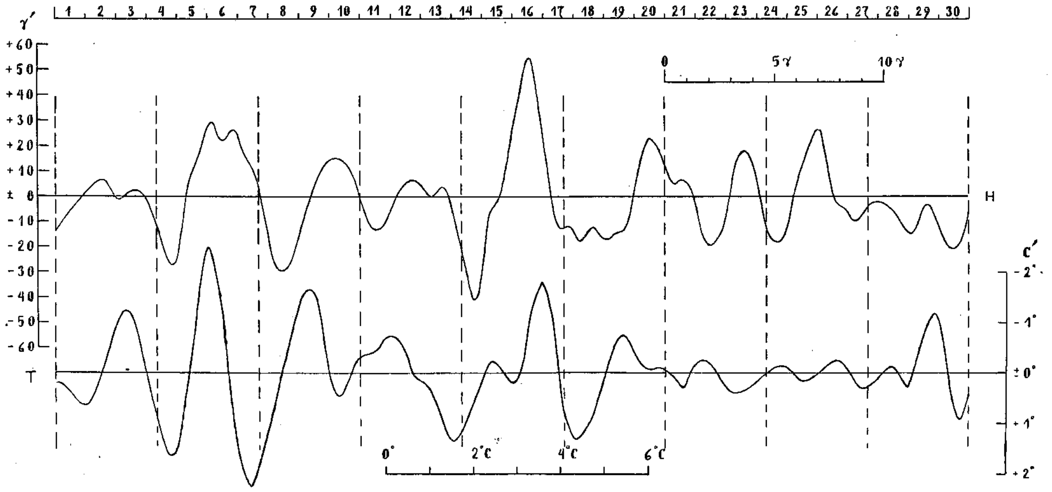

Fig. 9. The 80-hour period of *H* and *T* for Gjøhavn for the month of June 1904. (III—IV).

I may, however, here remark, that when the examination of hourly means was made, I was not aware of the fact that even daily means indicated the existence of this short periodicity. At the time when these studies were worked out, 1920, I do not think any periodicity of this length had been discovered, but I now see that Abbot found a similar short period in the data for solar radiation for 1916[1]. This is very interesting, and I will shortly mention, what Abbot states:

". . . . . . Not less extraordinary is the result for 1916 . . . . 11 full periods, as regular as the time intervals of 24 hours between observations permit, occur in 40 days. This periodicity is then approximately 3.5 days. It is unique among the whole series of years. If the range of the correlation factor was smaller I would regard it as surely due to error. But the range averages more than 50 per. cent from crest to trough in correlation factor whose probable error is only about 8 per. cent. It is really a most extraordinary result."

From what Abbot states, we may conclude that this short periodicity is not a permanent one. It seems, however, that the variation of the solar radiation may actually now and then take the shape of a short regular undulation. If now we suppose that this development has taken place in the year 1904, we may perhaps expect a similar varia-

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[1] Annales of the Astionomical Observatory of the Smithsonian institution by C. G. Abbot. 1922, Vol. IV, page 374.

tion in certain terrestrial phenomena. That the data for sunspots really show a period of 3.3 days has already been shown in Fig. 2.

The period of the curves of Fig. 9 may, as said, be placed at 80 hours — 3.3 days, or the same length which was found for *H* and *T* in Fig. 2. The period of Abbots "wave" in the radiation of the sun is stated to be 3.5 days.

Summary and General Remarks on the Relation between Solar Activity and the Variation of Terrestrial Elements.

In Table P, I have summed up the results concerning the system of the variation of the Gjøahavn records for *H* and *T*. The table gives the period of the "waves" as they have been estimated to in each special case. The total amplitude is given for the summer half-year (*s*), winterhalf-year (*w*) and Mean. Beside the 24-hour "wave" we have thus found the 7 more or less regular undulations, represented in Table P. Furthermore we shall later on discuss a half-yearly period and the annual period.

Since Abbot first put forward his theory about the variability of the sun, many important investigations have been made (C. G. Abbot, F. E. Fowle, L. B. Aldrich, L. A. Bauer, H. Helm Clayton, B. Helland-Hansen and F. Nansen etc.). By way of drawing a conclusion I may quote from the postscript to Helland-Hansen and Nansen's English edition (cp. footnote page 25):

"It is now established beyond doubt that on the one side the radiation of the heat from the sun varies not only from year to year more or less periodically in a similar way as the sun spots, but there are also very great fluctations in the radiation within short intervals of a few days, and on the other side it is shown that correlation exists between these fluctations in the solar radiation and meteorological and magnetic changes on the earth".

Table P.

Duration		Corrected Amplitude					
		H			T		
H	T	s	w	Mean	s	w	Mean
		γ	γ	γ	°	°	°
1.0 days	1.0 days	65*	—	—	3.6*	—	—
3.3 »	3.3* »	59	21	40	2.4*	—	—
—	4.8 »	—	—	—	2.4	9.2	5.8
10.0 »	10.2 »	41	17	29	3.7	8.8	6.2
14.3 »	14.1 »	48	15	32	4.3	8.6	6.4
28.3 »	28.0 »	—	—	22	—	—	4.7
ca. 41 »	—	—	—	12	—	—	—
ca. 70 »	—	—	—	17	—	—	—

* refer only to June 1904.

It is probable that the magnetic data from within the zone of the Northern Lights are especially well adapted for the study of corresponding variation in the solar activity and of terrestrial elements, and we have in the preceding pages seen that the variation of the observed data seems to be composed of a series of more or less periodic oscillations, some of which are of considerable magnitude — taking for instance the 28-day "wave", we have seen, that the mean amplitude of the undulations is 22 γ and $4^{\circ}.7$ C respectively for *H* and *T*. Beside this well known "wave" we have found other fluctation some of which seem to be more or less permanent, while others may be characterised as passing appearances, analogous to what Abbot has stated for the variation of the solar constant. In view of these facts it might be of considerable interest to make a more detailed study of the solar activity for the year in question with a special view to the distribution of the more active parts of the sun.

When we desire to investigate the relation between solar activity and terrestrial phenomena, the difficulty occurs, as to which of the various data for the solar activity we should prefer for comparison. We have the sunspots, recorded at Zürich, the faculae, recorded at Greenwich, the prominences, recorded at Rome and finally, since 1919, the solar constant, recorded at Mount Wilson. However, we do not yet know which of these data best represents the form of solar activity having the greatest influence on the variation of our terrestrial phenomena. In this connection I may mention that the question concerning the relation between solar activity and sunspots — as well as the relation between these phenomena and the magnetic elements, has quite recently been discussed by Bauer and Duvall[1]. Their conclusion regarding a comparison between sunspots and magnetic elements may be thus stated:

"There is in general a high correlation between solar activity and magnetic variation, but we may rather say that solar as well as earth magnetic disturbance are effects of an as yet undisclosed cause."

Especially where *T* is concerned it would have been interesting to compare with the data for the solar radiation, but no such data exist for 1904. Abbot has, however, stated that the solar constant varies in more or less the same way as the figures for the frequency of sunspots, though reversal of the agreement between the two curves may in some cases occur.

The Sunspots.

The Variation of the Sunspot Phenomena during the Year 1904.

For a comparison in our case the sunspots have been chosen, and I will give below some details. In Fig. 10 we find a graph of the sunspots, plotted with the data Wolfer stated in his annual report[2]. Wolfer gives for 1904, $R = 42.0$ and discussing the records of the year he says:

"The indications that we are near the maximum of the present epoch are represented — the character is more or less as during 1884 and 1894 — the monthly means do not, however, show the generally observed large variation, which characterise the approaching maximum. The difference between the highest and lowest monthly mean is not more than 40 units The curve rises — interrupted by the characteristic secondary undulations — slowly up to the largest maximum in the last days of August. This rise is chiefly owing to a very complex stream of spots, which appeared the 22nd of August and vanished again the 2nd of September."

From Table Q we see that this group corresponds to the Greenwich number 5296. The components of this group underwent constant changes. In our curves — *H* in Fig. 1. and Fig. 3 — we see this wave well represented, but a direct comparison between the sunspot curve and our terrestrial curves do not seem to show any general similarity, except the curve for *H* in Fig. 3, where in some parts we can find a tolerable parallelism. The interval of the *H*-curve of Fig. 3, from 16th of February to 29th of March, seems to correspond more or less with the curve of Fig. 10 from 13th of February to 26th of March. To demonstrate this parallelism I have drawn it above the sunspot curve of Fig. 10 with three days displacement to the left. Also other parts of Fig. 3 show some similarity to Fig. 10 — again with the mentioned displacement. Besides this we must remember that for the smoothed curves for *H* and *R* we have found a periodic movement of 3.3 days. (Fig. 2.)

Going back to the general march of the sunspots in Fig. 10, we see that the well known characteristic dipression takes place in the first days after the mentioned maximum but afterwards the curve again begin to rise, with a series of smaller undulations, until in

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[1] Terrestrial Magnetism and Atmospheric Electricity for December 1925, by L. A. Bauer.

[2] Astronomische Mitteilungen. No. XCV, Zürich 1904. by A. Wolfer.

Table Q.

Number		Duration		Date for max. devel.	Long.	Lat.	Max. area		Remarks
Rot.	Group	from	to				Umbra	Whole	
					°	°			
580	5142	29/12	9/1	1/1	172	—15	34	212	a stream of spots.
»	5146	4/1	16/1	7/1	84	+18	38	179	a large regular spot.
»	5151	13/1	24/1	17/1	330	+20	52	293	a large composite spot.
»	5152	16/1	25/1	23/1	314	+22	31	183	a stream of spots.
581	5154a	20/1	28/1	26/1	298	—14	57	504	a group which rapidly increases in size.
»	5154b			27/1	257	—14	60	271	
»	5164a	4/2	16/2	9/2	38	+12	54	476	a fine stream of spots.
»	5164b			11/2	37	+13	33	221	
582	5171	19/2	2/3	26/2	209	—12	56	348	a number of spots.
»	5174a	2/3	6/3	3/3	127	—13	35	137	a pair of small spots.
»	5174b				122	—14	35	143	
»	5182	9/3	21/3	10/3	312	—17	28	188	a large regular spot.
583	5183	15/3	26/3	19/3	236	+ 9	35	150	a large regular spot.
»	5186	19/3	26/3	20/3	185	+10	63	287	a number of spots in an increasing stream.
584	5202a	8/4	21/4	17/4	280	—15	86	514	a fine irregular stream of spots.
»	5202b			15/4	273	—17	60	511	
»	5206	14/4	26/4	17/4	198	+18	31	155	a large regular spot.
»	5209	21/4	3/5	25/4	105	—13	147	642	a very large regular spot.
»	5210	21/4	3/5	25/4	111	+13	60	381	a fine irregular stream of spots.
586	5253	13/6	25/6	17/6	121	+13	37	328	a large composite spot.
587	5264a	8/7	20/7	10/7	149	+13	26	158	a fine stream of spots.
»	5264b				139	+14	33	218	
»	5269	15/7	27/7	22/7	69	—19	69	395	a number of spots.
588	5281	28/7	4/8	31/7	295	—17	27	344	a group, rapidly increasing in size.
»	5283	2/8	13/8	6/8	182	+26	33	120	a large regular spot.
»	5285	4/8	15/8	6/8	156	+13	55	300	a large composite spot.
»	5296	22/8	2/9	28/8	285	—18	41	331	a very fine and complex stream of spots.
»	5300	26/8	3/9	26/8	230	—19	55	524	a fine regular stream of spots.
590	5313	18/9	25/9	23/9	344	—21	30	243	a group developing into a stream of spots.
»	5317	22/9	26/9	26/9	328	—23	44	284	a fine stream of spots appearing suddenly.
»	5321	5/10	11/10	7/10	133	+17	37	228	a group in front of 5320.
»	5322	6/10	16/10	10/10	55	—17	50	265	a fine stream of spots.
»	5325	9/10	20/10	10/10	22	+13	67	375	a large regular spot.
591	5339	24/10	1/11	30/10	216	+12	125	776	a continually changing group.
»	5343	27/10	7/11	29/10	124	—16	38	303	a fine regular stream of spots.
»	5356	10/11	21/11	12/11	300	—22	44	259	a large regular spot.
592	5360	16/11	27/11	16/11	218	+11	35	140	a large regular spot.
»	5366	22/11	27/11	25/11	240	+28	131	1066	spot — rapidly developing.
»	5373	28/11	1/12	1/12	176	+12	33	421	a fine irregular stream of spots.
»	5381	4/12	15/12	6/12	353	+21	37	189	a large regular spot.
»	5383	5/12	16/12	7/12	336	+17	69	300	a fine stream of spots.
»	5387a	7/12	14/12	8/12	353	+ 9	38	186	a fine irregular stream of spots.
»	5387b				347	+10	38	195	
»	5389	8/12	19/12	11/12	290	+13	62	260	a large regular spot.
»	5390	9/12	22/12	11/12	270	+17	71	329	a fine irregular stream of spots.
593	5396	12/12	20/12	13/12	240	+29	65	489	a large composite spot.
»	5413a	25/12	6/1	31/12	76	—15	40	300	gradually developing into a large regular spot.
»	5413b				71	—16	35	217	

the middle of December it shows a new maximum of nearly the same size as that in August. This maximum is owing to a series of spot groups — No. 5381 to 5396 in Table Q — some of which are fine large spots. The direct effect of this activity does not seem to be represented iu our curves. Only in Fig. 5 — *T* for Oslo — we see a somewhat higher wave.

In order to be able to study the sunspots in detail I have made out an extract from the Greenwich publication[1] — to be seen in Table Q. In the first column the number of the rotation is given according to Wolfer's counting. The second column gives, according to the Greenwich counting, the number of the group and the letter of the spot a, b, . . . meaning individual spots of a group. The third and the fourth column state the dates for the appearance and disappearance of the groups, and in the fifth column I have added the date on which the spot in question reaches its greatest development (size). The sixth and seventh columns give the heliographic longitude and latitude of the spots, and finally the maximal area of the "Umbra" and "Whole Spot" is given in the two last columns — in both cases referring to the date in the fifth column. The measurements are taken from photographs, and reduced so that the size is expressed in millionths of the sun's visible hemisphere — allowing for foreshortening. In the table only the large spots have been selected to a number of 48. The Greenwich publication shows that 273 groups have been recorded during the year 1904. Allowing for the double spots, we see that only 18 % of the groups are represented in Table Q. On the other hand, however, the *area* is represented by 95 % and 77 % respectively for "umbra" and "whole spot".

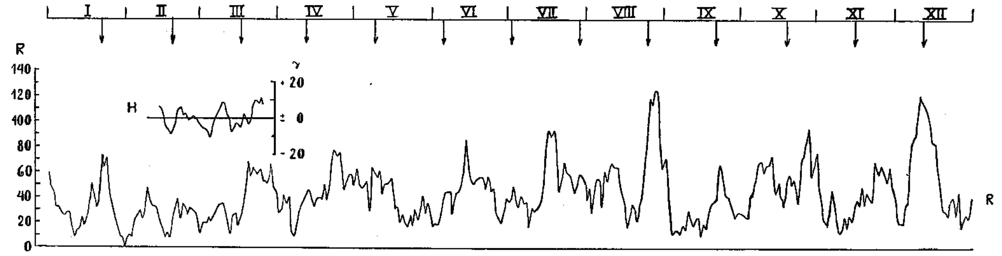

Fig. 10. The variation of the frequency of sunspots during the year 1904 according to Wolfer's data — O. Above a part of the curve *H* of Fig. 3., displaced three days to the left.

Table R.

Rot.	South		North		Mean max. area	
	n.	Lat.	n.	Lat.	Umbra	Whole
		°		°		
580	1	15	3	20	39	217
581	2	14	2	12	51	368
582	4	15	0	—	38	204
583	0	—	2	10	49	218
584	3	15	2	15	77	441
585	0	—	0	—	0	0
586	0	—	1	13	37	328
587	1	19	2	14	43	257
588	3	18	2	20	42	324
589	0	—	0	—	0	0
590	3	19	2	15	46	279
591	2	19	1	12	69	446
592	0	—	9	16	57	343
593	2	16	1	29	45	335
Mean		17		16	42	269

Examination of the Distribution of Sunspots during the Year 1904.

Table R is an extract of Table Q, and gives for each rotation the mean maximum area for the "umbra" and the "whole spot". The two columns headed South and North give the number of spots (*n*) and their latitude (Lat.) for each hemisphere. As to the distribution south and north the figures will be seen to come out 21 and 27 respectively. Counting directly from the Greenwich publication, south and north, however, are equally represented. The mean

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[1] Results of Measurements made at the Royal Observatory, Greenwich, under the direction of Sir W. H. M. Christie. 1904.

latitude will be seen to be 17 and 16 respectively south and north. The mean figures below "Mean max. area" come out 42 and 269.

To show the longitudinal distribution, I have in Fig. 11 copied the very interesting graph Wolfer gives in his annual report. The numbers of the rotations are put to the left, while the dates to the right refer to the day when the zero meridian coincides with the centre of the apparent sun disc. Above are the figures for the heliographic longitude given, and the rotation of the sun corresponds with increasing figures. The latitude is added to each spot. The spot groups are marked by small horizontal lines, the length of which refer directly to the relative size of the spots in this direction, while the thickness more or less represents the number of individual spots.

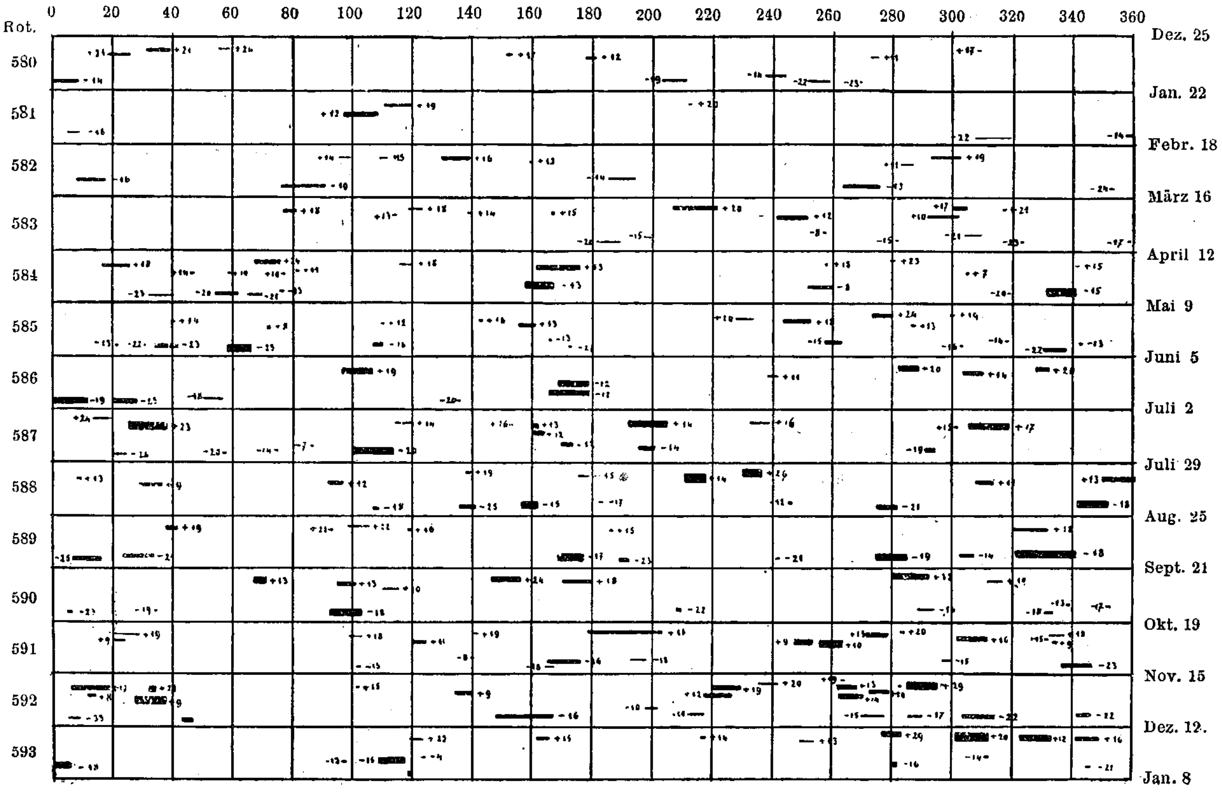

Fig. 11. Reproduction of Wolfer's graph of the sun spots during the year 1904 — taken from Astronomische Mitteilungen No. XCV.

Thus while the Greenwich publication gives the area of the spots — expressed in millionths of the suns visible hemisphere — Wolfer gives the frequency — expressed by the relative figure R, depending upon calculation by means of Wolf's well known formula:

$$R = k \times (10\,g + f),$$

where g refers to the number of the visible groups and f to the total number of individual spots. Wolf considered the appearance of a new area of activity to be of essential importance, and he therefore put the weight 10 to g. Finally k is a reduction coefficient, by the aid of which observations, taken with any other instrument than Wolf's standard telescope, can be reduced.

Wolfer, as mentioned before, has frequently pointed out the peculiarity of the longitudinal distribution of the spots — namely that they have a strong tendency to concentrate along two meridians which have an interdistance of about 180°. This distribution was, as will be seen in Fig. 11 and Fig. 12, fairly well developed in 1904. As this peculiarity seems to be the most important point for the discussion of the curves from Gjøahavn, I have, in order to give the clearest possible picture of this interesting phenomena, drawn Fig. 12. By the aid of tracing paper I have lined in the parts of the sun disc, where few or no spots appear. These parts are left white, while the rest of the disc has been painted black. We see that the principal black field can roughly be said to be outlined by the 60th and 260th meridian, the mean of which is 340°. The middle meridian of the secondary black field may be said to be about 160°, by which we obtain an interdistance of 180° between the two fields, as pointed out by Wolfer. The combined effect of this distribution of the spots and the rotation of the sun will

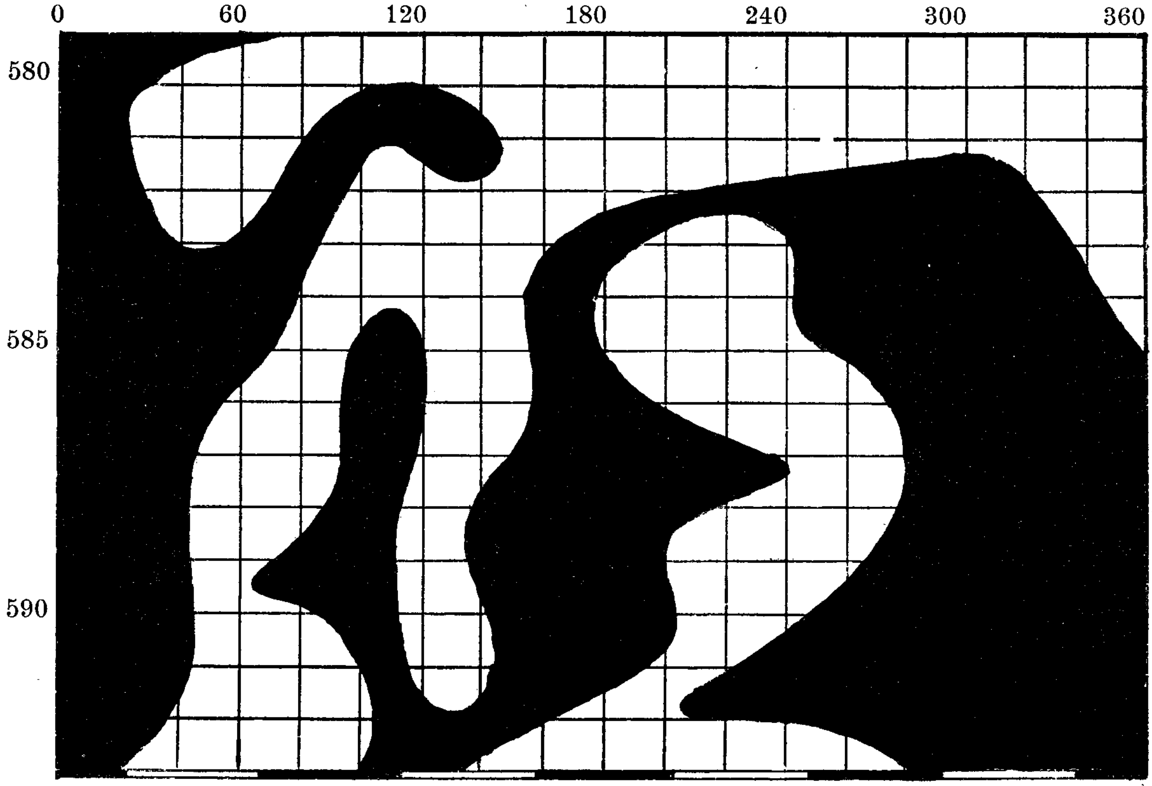

Fig. 12. Illustration of the longitudinal distribution of the sun spots during the year 1904.

then cause the well known 28- and 14-day variation in terrestrial elements, as we have seen them in the curves of Fig. 4, Fig. 5 and Fig. 6.

For 1904 the 14-day and the 28-day periods are only tolerably developed in the sun spot curve, but came out nicely in 1903. Wolfer says: "In detail the march of the curve is less regular than during the last year (1903), where especially the periodic appearance of secular maxima, depending on the rotation of the sun, appears to be very distinct."

Looking more closely at the distribution of the black and white fields of Fig. 12, we see that we may even go more into detail than Wolfer has done. If for instance, we divide 360° into 8 parts, in the manner indicated by the horizontal black-and-white line at the bottom of the drawing, we see that alternately we pass corresponding black and white fields in the figure above — with the exception that the principal black field occupies $^2/_8$th of the disc. When the sun rotates, these active and inactive sectors shall pass our globe, and may thus cause a more or less periodic variation in the data of magnetic and meteorological elements. As the rotation takes about 27 days, we see that these sectors of the sun — $^{360}/_{8}$ equal to 45° — might cause a periodic variation in our curves of 6.8 days. This period corresponds very well with the undulation Wallén found (see Table B, Page 7), but does not agree with the one we have found in the data for T for Gjøahavn and Oslo. The period found for H and R, as we remember, has the length of 3.3 days, which nearly corresponds to $6.8 : 2 = 3.4$ days.

Finally I may draw attention to an eventual consequence of the distribution in question, namely that it indicates how a "missing wave" might be caused. As said, the principal black field covers about $^{2}/_{8}$ of 360°, and if therefore the distribution of active and inactive sectors of the sun really causes periodic variation in terrestrial data, we shall, for each rotation of the sun, have one "missing wave".

The distribution of the spots on each side of the sun's equator has already been mentioned, namely, that the spots were nearly equally divided about the mean latitudes ± 17°. I may add that spots observed at a high latitude occurred the 7th and 24th of September, respectively at 30° south and at 31° north. On the 28th of November a spot was observed at 40° north, and finally on the 12th of December at 33° south. There does not seem to be any special effect on our curves.

Prognosis.

The System of Periods in the Records of the Temperature discussed in View of the Possibility of thereby forecasting the Distribution of Temperature during the Season.

Before I conclude this part of the paper, based on the Gjøahavn records, I will give the following set of curves for the temperature for Gjøahavn during the winter seasons 1903—1904 and 1904—1905. It seems to me that these curves give a good picture of the system of the variation actually taking place. The curves also illustrate the possible use we might make of accepting the existence of such a system of "waves". The first curve to the right and left, marked *O* (Fig. 13), will be understood to be a graph of the actually observed daily means at Gjøahavn, while the following curves *I* to *VI* represent the curves by which the 5, 10, 14, 28, 41 and 70 day "waves" have been eliminated. If we study the curves, we shall see that especially the 28-day period is more or less decisive for the character of the distribution of the temperature during the season. We notice, for instance, the remarkable difference between the two sets — the comparatively cold period during the last days of February and the beginning of March 1904, and the two minima for temperature during the last part of December 1904 and in the middle of February 1905. This distribution is no doubt due to the relation between the variation of the temperature and the rotation of the sun — a relation which to a certain degree can be precalculated. I am told that Krogness — the director of the Geophysical Institute at Tromsø — actually used the rotation period of the sun for prognosis of the temperature of the air as well as for other meteorological elements, and to study the validity of this theory I have tried to work out prognosis for the two winter seasons in question.

Table S.

Season	XII	I	II	III
	°	°	°	°
1903—1904	—31.7	—36.5	—39.5	—37.1
1904—1905	—34.4	—34.9	—36.9	—31.3
Mean	—33.0	—35.7	—38.2	—34.2
»Normal« . .	—31.9	—36.5	—37.8	—34.9

Starting these studies, the first difficulty was to procure the most probable "Normal". We have only two years' observations for the mentioned season, and between the two results there is a considerable difference. According to Graarud we have the above given monthly means (Table S).

The four figures of the horizontal line marked "Mean" were plotted graphically, and a curved line — equal to the curve marked A in Fig. 14 and Fig. 15 — was drawn free-hand. This curve conforms the data in the last horizontal line of Table S, and for want of safer data this "Normal" has been accepted. For the amplitude of the B-curve of Fig. 14 — the 27-day wave — I have chosen $3.2 \times 2.15 = 6^\circ.9$, where 3.2 is the directly measured amplitude for the two seasons and 2.15 is the value of the factor ε. It is difficult to say upon what we should build by dating the extremes of the B-curve, but we might perhaps reason as follows:

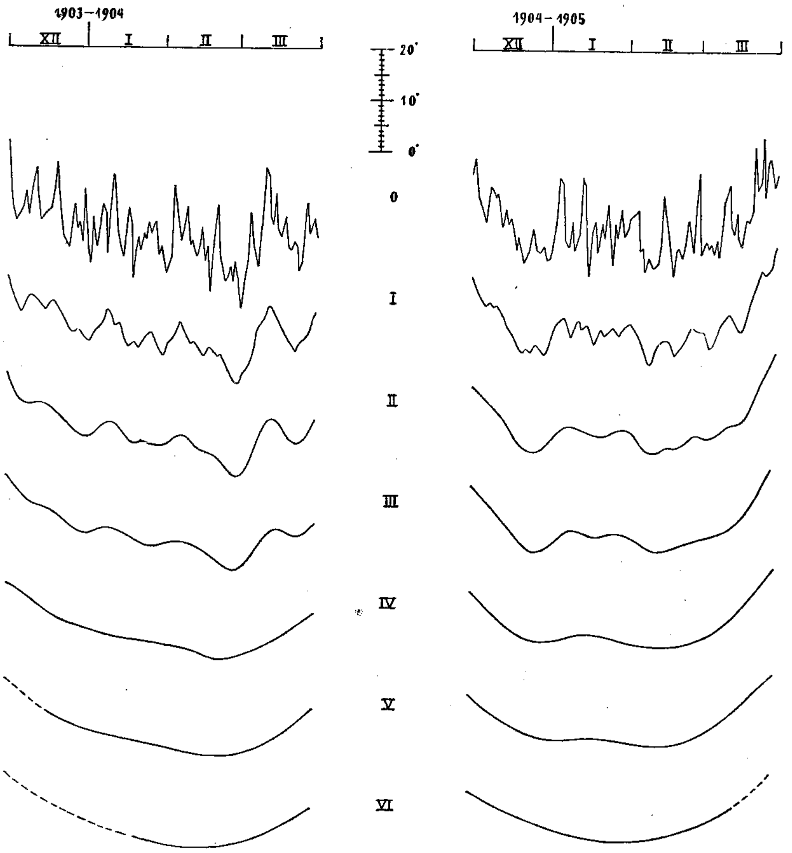

Fig. 13. Variation of the temperature of the air at Gjøahavn during the two winter seasons 1903—1904 and 1904—1905.

Studying the curves of Fig. 4 we came to the result that H was negative and T positive in relation to the arrows, marking the coincidence of the zero meridian with the centre of the sun's disc. Furthermore we see from Fig. 12 that the middle meridian of the principal black area lies about 20° to the left of the zero meridian, the consequence of which is, that the middle of the black sector passes the centre of the sun's disc about two days later than the zero meridian. From Table H we see that the extremes of the T-curve falls about 3 days later than those of H. Supposing, as before, the effect in the magnetic elements to be more or less simultaneous with the passage of the mentioned meridian 340°, we should place the first maximum of the B-curve 5 days later than the by Wolfer in Table G given data for coincidence. The first of these coincidences will be seen to be the 25th of December and we have thus:

$$\text{Date} = 25 + 2 + 3 = 30.$$

The maximum of the first wave of the B-curve should thus be placed on the 30th of December. This date will, however, be seen to fit the first winter season — 1903—1904 — very badly. If, on the other hand, we inverted the B-curve, we could more or less accept the above date. A glance at Fig. 4 shows that a transformation of phase may very well have taken place in H as in T — probably in the middle of March 1904. Already when we discussed the 28-day period — see Fig. 4 and Table H — we were aware of some irregularity about that time of the year. Thus we have allowed for a "missing wave" between $T_{\max}$ occuring the 74th and the 117th day ($T_{\min}$ occuring the 87th and 132nd day). We see now, that this "missing wave" is due to a transformation of phase. However this may be, I have dated the first — or rather the second — minimum of the B-curve so that it occurs the 30th of December 1903. The relation between the B-curve and the arrows once fixed has been kept for the next winter season — which, however, does not seem to be correct, as will be seen below.

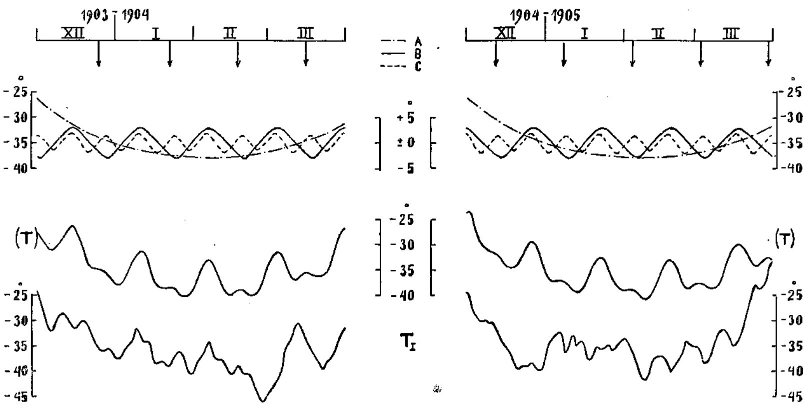

Fig. 14. Prognosis for the temperature of the air at Gjøahavn for the two winter seasons 1903—1904 and 1904—1905. A, B and C are elements, (T) the combined curve and T_I the in Gjøahavn actually observed variation.

The next question regards the duration of the waves. Ought we to use 28 days, the wave length found in Fig. 4, or should we use the rotation period of the sun's equator — 27 days. This last period has been chosen, but there can be said both for and against. As to the C-curve, the dating of the maxima is more or less bound to the already fixed B-curve, but there may also here be an uncertain moment — the transformation of phase in March and October. Regarding the amplitude, I have considered the principal and secondary area of action by making every second wave somewhat higher — using 4°.0 C., and 3°.0 C respectively, whilst in the B-curve I used 6°.9 C.

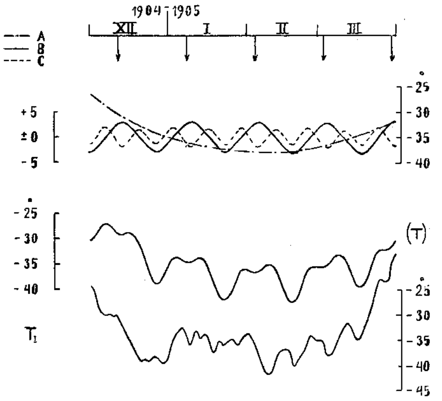

Fig. 15. Prognosis for the winter season 1904—1905. The elementary curves B and C have here been inverted.

If now we combine the elements A, B and C, the result will be the curve marked (T) and below this curve I have, for comparison, copied the curve marked I in Fig. 12. This curve is not plotted by the aid of the actually observed data — it is, as we remember, smoothed with 7 — but it is a better object for comparison just because it has been smoothed. As to the variation itself, it gives a sufficiently true picture of the situations.

Now to the result of the prognosis. It must for the first winter season, 1903—1904, be admitted to be fairly satisfactory, and it shows the dominating effect of the rotation of the sun. The result for the next winter season, 1904—1905, on the other hand is not very satisfactory. It is, however, easy to see that the bad result is to a great extent due to a wrong dating of the extremes of the *B*- curve. This is in fact a further proof of the existence of the supposed transformation of phase and this transformation took place in March 1904. As we remember some irregularity was also pointed out in the last days of October (see Table H), but whatever this irregularity was, there can evidently not have been a transformation of phase, as by using a positive relation — also found for the summer 1904 — we obtain much better result for the prognosis (see Fig. 15). However this may be I have for the final prognosis for the second winter season simply inverted the *B*- and *C*-curves of Fig. 14. Comparing the two curves (T) and T_{I} in Fig. 15, we see that the result is not so bad after all. There is, however, for this season much more abnormality in the variation of T than in the first season.

If we may draw any conclusion regarding forecasting on this basis, we may say, that the result may be fairly satisfactory, if we forecast for — let us say — three month in advance, provided safe dating of the extremes of the *B*- and *C*-curve can be obtained from known data during the preceding months. We must, however, remember that an eventual transformation of phase may occur, and this event will of course spoil our forecast. This side of the question requires further study, but it is not beyond probability, that there exists a *system* also for these occurences.

Examination of the Potsdam Data for *H* for the Years 1905—1917.

Further Proof of the Existence of a 70-day Period.

The scope of this paper is, as mentioned, to try to detect and discuss the system of periodical variations of magnetic elements, within the limit of one year. Working out

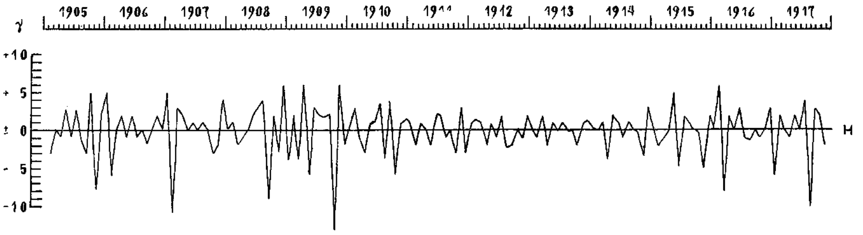

Fig. 16. The 70-day period for *H* for the years 1905—1917 for Potsdam. (0—I).

the Gjøahavn observations, we have seen, that there were signs of an undulation of about 70 days. As the Gjøa-material does not cover more than one year and a half, we have not sufficient data for the study of this comparatively large undulation — besides the fact that we may even expect to find an oscillation of half a year, not to speak of the annual wave. I have therefore taken refuge in data from a known European station, namely the magnetic observatory at Potsdam.

As, according to experience, we must expect contrary oscillations of the annual wave on both sides of equator, I had originally worked out corresponding data for a magnetic station, situated suitably for this purpose — namely the Argentine observatory Pilar. Circumstances have, however, forced me not to publish my results from this last station, and having failed to get data from any other station, conveniently situated south of equator, I shall only have to give the results based on monthly means for *H*, for the years 1905—1917, recorded at Potsdam Observatory[1]. The geographical coordinates of this station are:

$$\varphi = 52^\circ 23' \text{ N and } \lambda = 13^\circ 04' \text{ E.}$$

The original data for H are here, as before, indicated by 0, and these data have been treated in the usual way by Cock-Blanford's method. Successively we get the "working tables" 1, 2 and 3 — using respectively 3, 5 and 11 figures for the formation of means, whereon the tables of differences were worked out. In Fig. 16 we see the curve $(0—I)_H$.

Looking at the curve of Fig. 16 it will be seen that the interdistance between the extremes is somewhat irregular — the curve shows an extreme value every two or three months. The mean length of the oscillations may be put to $2^1/_3$ months — allowing for "missing waves". We have, as mentioned, used monthly means and cannot therefore expect a clearer picture. This might have been obtained if we had used decadic means instead of monthly. The curve, however, strengthens what already the curve of Fig. 7 seemed to indicate — namely the existence of a variation of about 70 days, and even that this variation may be more general than might be expected. The amplitude may be put at 5 γ, and as the curve is not smoothed, this is the true value. For Gjøahavn we found 17 γ.

In this connection I may mention that Unterweger[2], in the data for sun spots, claims to have found a periodicity of 69.4 days. The existence of a "wave" of this length — beside other undulations — has partly been confirmed by Köppen[3]. I have tried to find traces of such a "wave" in the data for the sun spots for 1904, but have not succeeded. I may therefore, at least for that year, keep to the theory, given on page 17, as the most probable explanation.

The half-yearly Period and that of about 8 Months.

The curve $(I—II)_H$ was now plotted, and it showd a rather regular half-yearly wave — Fig. 17. This period has, as we shall see, been mentioned by Bauer and Duvall, and has in Norway been drawn attention to by Krogness in some before mentioned interesting articles, where he discusses his results of direct comparisons between meteorological and magnetic elements.[4] Krogness has as magnetic data made use of observations taken in Oslo and at Haldde Observatory. As a standard for the variation of the magnetic element he has adopted a quantity, which he calles "storminess", originally introduced by Kr. Birkeland.

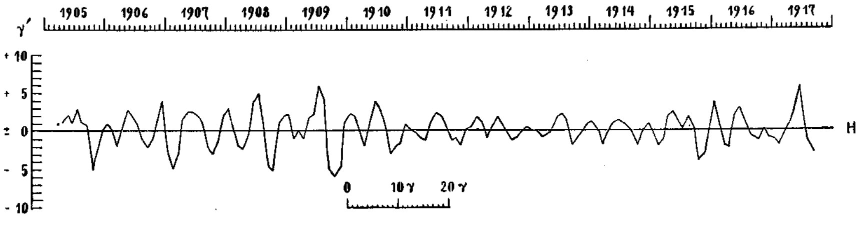

Fig 17. The half-yearly period of H for the years 1905—1917 for Potsdam. (I—II).

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[1] Ergebnisse der magnetischen Beobachtungen in Potsdam, von Ad Schmidt.

[2] Unterweger, J.: Über die kleinen Perioden der Sonnenflecken und ihre Beziehung zu einigen periodischen Erscheinungen der Erde. Wien 1891.

[3] Meteorologische Zeitschrift VIII, 1891

[4] The Norwegian Magazine "Naturen". 1917.

The curve in Fig. 17 shows a high intensity in June and December, and Krogness found a minimum for "storminess" just in the same months. Now "storminess" is more or less the same as daily amplitude, a quantity, which generally varies contrary to the absolute value of *H*, and his results are thus i harmony with our curves. The amplitude of our curve is represented by 67 % of the true value, which gives a corrected mean of 7.5 γ.

I have already on page 16 referred to a possible variation in the sunspots, the length of which should be about 7 ⅔ months. This variation is sometimes supposed to be accounted for by the conjunction of Jupiter and Venus, occuring every 236th days. Both Krogness and Helland-Hansen and Nansen have examined their material with the intention of establishing more proof of the existence of this interesting undulation, and they seem to have suceeded in showing, in the first place that Wolf's assumption was well founded and beside this they have procured proofs of the existence of a similar variation in terrestrial elements. In Fig. 18 I give another example of the said periodicity.

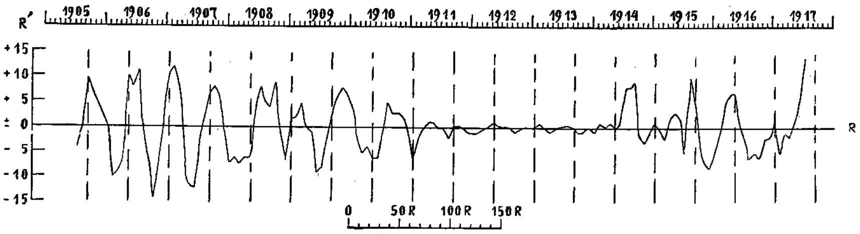

Fig. 18. The 8-monthly period in the sunspots for the interval 1905—1917. (I—II).

The amplitude is seen to be comparatively large during the intervals 1905—1911 and 1914—1917, while the interval between shows rather small oscilotions. This peculiarity seems to be connected with the 11-year periodicity, so that at the time of a minimum of sunspots the amplitudes of the 8-monthly wave is small. Judging the amplitude by Fig. 18, we must, however, consider the smoothing. To eliminate the half-yearly period we have smoothed with 5 — a figure which, in comparison to 8 is so large, that only 20% of the size is represented in the oscillations. A direct measurement of the mentioned intervals gives a mean value of 17.3 for the high "waves" and 2.0 for the small. As $\varepsilon = 5.0$, we get as a true mean amplitude for the oscillations near the sunspot maximum 86.5 units and for the rest of the epoch 10.0 units. If these oscillations are really caused by the said conjunction of Jupiter and Venus, the effect is very large. I have also tried to trace this variation in the Potsdam records for *H*, but the result was negative. It thus seems that this period does not exist in the month to month varration of *H*, but may perhaps be found in the data for range, which is in fact more or less the same as that represented by "storminess", for which element Krogness found a well-defined periodic variation of 8 months. His series covered the years 1875—1910. He has also added data for temperature of the air and temperature of the sea, with the same good result.

The Annual Wave of Magnetic Elements and a very curious Variation in the Data for Sunspots.

We will now pass on to the last curve, plotted in Fig. 19 — above. The intensity will be seen to be high in summer and low in winter. The mean amplitude is measured directly 6.6 and as $\varepsilon = 1{,}63$ we get a corrected mean value of 10.8 γ. The mean amplitude of the annual wave for *H* at Gjøahavn was 39 γ. The result I obtained from the data for the observatory Pilar (Argentine) cannot be stated here (cp. page 30), but I may remark that this (II—III)-curve for *H* shows the same variation and the same magnitude as the curve in Fig. 19, only with the interesting difference, that the curve is inverted. Concerning the annual wave I may, by way of comment, quote some remarks from the above mentioned article by Bauer and Duwall. (see footnote page 22):

"In attempting any comparisen, month by month, or day by day, between measures of solar activity and geophysical activity, the great difficulty is adequately to eliminate from the geophysical measures the effects due to the Earth's annual motion around the sun. Every geophysical measure has an annual periodicity of its own, which is not necessarily reflected in whatever measure of solar activity we may use. Take, for example, the well known double periodicity during the year of magnetic disturbances. The mean daily frequency and the mean daily magnitude of terrestrial magnetic disturbances, in the Northern and Southern hemisphere, pass through maxima values near the equinoctial month, and minima values near the solstitial month. This characteristic terrestrial periodicity has not yet been quantitatively explained in a satisfactory manner, by "Earth" periodicities of solar measures, or by the changing efficiency of a given sunspot area in producing a terrestrial magnetic disturbance as the heliographic latitude of the Earth varies during the year. Sunspot numbers apparently show the earth periodicity, just described, during periods of low activity[1], but the magnitude of this "Earth-effect" in sun spottedness is not sufficient to account for the terrestrial magnetic periodicity, and furthermore the question arises whether any observed Earth effect in solar activity may not have a purely terrestrial origin."

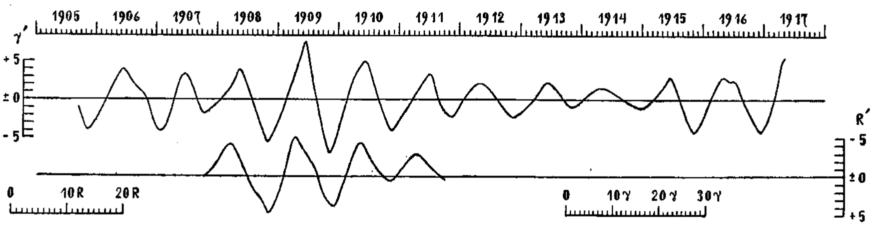

Fig. 19. The annual wave of *H* for Potsdam for the years 1905—1917 and a similar variation in the sunspot frequency. (II—III).

In the Potsdam records we have seen the double periodicity, mentioned, by Bauer and Duvall, nicely developed in Fig. 17 and I have also mentioned that the Pilar records showed the inverted wave of *H* in Fig. 19. Besides this, I have already earlier drawn attention to the annual periodicity of the amplitudes in the curves of Fig. 1, Fig. 2, and Fig. 6. Also an example of the curious "Earth effect" of the sunspots is to be found in Fig. 19, where *R* will be seen to be inverted in order to obtain parallelism. This "Earth effect" was long ago noticed by Wolf — I may thus refer to Astronomische Mitteilungen No. X, for 1858 — and has also been pointed out by Helland Hansen and Nansen. The magnitude of the large oscillations is sometimes seen to pass 16 units — in Fig. 19 is *R* smoothed with 5, so that 74 $^0/_0$ is represented and as $\varepsilon=1,35$, the amplitude of the highest wave — in 1909 — is 14 units.

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[1] cf. Bauer, Luis A. Note regarding the "Earth-effect" on Solar Activity and Relation with Terrestrial Magnetism. Terr. Mag. Vol. 26, 1921. p. p. 113—115.