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THE INFLUENCE OF THE MOON AND THE INNER PLANETS ON THE GEOMAGNETIC ACTIVITY

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ABSTRACT

The geomagnetic activity in Sodankylä during some 30 years shows a fairly systematic double-waved variation in a period corresponding to the synodic revolution of the Moon, the chief activity minimum occurring during the new moon. A decrease in the activity also appears at the times of the inferior conjunctions of the planets Mercury and Venus. This fact suggests that all these celestial bodies are surrounded by a magnetic field.

1. *Introduction*

According to current theory, the geomagnetic activity is caused by corpuscular streams emitted from the Sun. When the Earth happens to plunge into such a stream, the Earth's magnetic field obviously absorbs a part of its charged particles, thus producing the supposed ring current flowing around the Earth. Evidently the solar stream continues on its course past the Earth, but its subsequent energy must have been reduced by the amount taken from it by the geomagnetic field.

This fact, the reduction of the energy of the charged solar stream on passing a magnetic celestial body, can be used for testing whether the Moon or the inner planets Mercury or Venus are magnetic or not. The Moon is situated roughly between the Sun and the Earth and thus in the path of the solar stream at every new moon, and so are the inner planets in their inferior conjunctions with the Sun. Hence at these times a decrease in the observed geomagnetic activity must appear if these celestial bodies are surrounded by a magnetic field.

The examination of whether such a weakening of the magnetic activity really occurs on the occasions in question is the purpose of this paper.

In an earlier publication [4, p. 59—61] I have in passing touched upon this problem, with reference to the magnetic records from Sodankylä during 20 years. Here I will deal with the same question in greater detail.

2. *Method*

The examination is based on the daily means of the activity figures AZ [5, 6], derived from hourly ranges in the vertical component of the geomagnetic field at Sodankylä [4, p. 9—11], for the years 1914—1944, and, in the case of the Moon, in part also upon the activity indices »Absolute Storminess» in the vertical intensity, AS, from Tromsö, the Geomagnetic planetary three-hour range indices Kp, and the International magnetic character figures C.

It is well known that the geomagnetic activity varies from day to day within very broad limits (and this is to some extent also the case regarding the monthly activity means). Therefore, and because there is no other means of testing the power of a separate solar corpuscular outburst than through its influence on the geomagnetic field, the study of any individual case in which a celestial body is situated between the Sun and the Earth cannot give a reliable result. The effect sought can, for the present, be detected only by the aid of a statistical examination of reliable data on the geomagnetic activity for a sufficiently long succession of years. The activity figures AZ from Sodankylä afford suitable material for this investigation but unfortunately the time interval for which they are available is scarcely sufficiently long for the purpose in view.

Another difficulty in making this investigation consists in finding a suitable reference level with which the degree of magnetic activity on the individual days can be reliably compared. In order to secure as great a homogeneity as is feasible in the results obtained during the whole period under investigation, and to render the results from quiet and disturbed periods comparable with each other, I have here used the mean activity value for each individual month as reference level.

In those cases when, for instance, an intended moon phase occurs at most 4 hours before or after midnight, the mean of the activities on both days has been employed as the best estimate of the activity value. Similarly, when the day in question lies 4 or fewer days from the beginning or end of a month, the mean of the average activity figures for both successive months has been employed as reference value.

The ratio of the activity on the day to be examined to the reference activity level is expressed in the following tables as a percentage, the figure 100, of course, signifying the mean geomagnetic activity. Besides the selected days (the 4 principal moon phases and the days of the inferior conjunctions of the inner planets) the preceeding and the following days have also been included.

Concerning the results obtained some general remarks seem to be necessary.

In the first place, the uncertainty caused by the choice of the reference level may be pointed out. Very often the selected day happens to fall in the only disturbed period in an otherwise quiet month (The Moon or an inner planet by no means completly screens the Earth from a solar effect but only slightly reduces it, as will be seen later.) or, on the contrary, in an undisturbed interval in a month whose mean activity is high. Such cases affect the final result considerably. However, the employment of reference levels derived, for instance, from shorter periods of days in the vicinity of the day whose activity is to be compared, would undoubtedly entail arbitrariness in selection for which there could be no check, and for this reason I have preferred the systematic method described above.

As a result of the employment of this method and, in addition, of the very great fluctuations and capriciousness of the daily activity figures characteristic of data of this kind, the standard errors of the results become fairly high. In most of the cases these errors are great enough to mask the effect sought for. From a purely theoretical point of view the results communicated here can thus hardly be considered reliable.

However, in an investigation of this kind and taking into account all that has been said above, it does not seem essential to accord too great a significance to the size of the standard errors. I have taken as a criterion the circumstance of whether or not the effect obtained appears in a systematic manner. To ascertain this, the period investigated has been divided into three decades whose properties haye been examined separately. The results obtained reveal that there are distinct and systematic lunar and planetary effects on the geomagnetic activity, and that these effects must obviously be regarded as real, in spite of the large standard errors obtained for the results.

3. *The Moon's influence on the geomagnetic activity*

The period of over 30 years investigated contains 375 complete synodic revolutions of the Moon.

The results of the examination of the AZ activity values performed in the manner described above are summarized in Table 1. They show the following systematic features:

Table 1. The geomagnetic activity during the 4 drincipal moon phases and also during the preceeding and following duys, expressed as percentage of the mean activity.

Season	Moon phase / Decade	●			☽			○			☾		
Winter	1914—1923	103	94	87	93	99	97	82	88	102	84	96	112
	1924—1933	94	96	101	92	78	76	76	93	114	92	116	148
	1934—1944	111	112	106	78	72	68	90	92	139	116	98	86
	1914—1944	103	101	98	88	83	80	83	91	118	97	103	115
Equinox	1914—1923	78	79	73	138	140	98	122	129	132	85	86	68
	1924—1933	80	66	89	116	120	117	118	92	96	109	116	122
	1934—1944	84	87	110	112	106	99	96	81	90	105	121	112
	1914—1944	81	77	91	122	122.	105	112	101	106	100	108	101
Summer	1914—1923	96	95	101	88	117	127	93	88	66	96	94	118
	1924—1933	86	67	72	107	124	114	74	78	82	96	94	123
	1934—1944	102	94	86	112	110	112	100	94	86	74	79	87
	1914—1944	95	85	86	102	117	118	89	87	78	89	89	109
Year	1914—1923	92	89	87	106	119	107	99	102	100	88	92	99
	1924—1933	87	76	87	105	107	102	89	88	97	99	109	131
	1934—1944	99	98	101	101	96	93	95	89	105	98	99	95
	1914—1944	93	88	92	104	107	101	94	93	101	95	100	108

1) In the activity a distinct decrease, averaging −12%, occurs during the new moon, and another less marked decrease (of −7%) appears during the full moon. Correspondingly, the activity is higher than average during the first quarter (+7%). Thus the activity changes in a double-waved curve coinciding with the synodic revolution of the Moon, the first wave being dominant, with an amplitude some threefold that of the second wave.

2) This periodicity displays a marked annual variation. It appears at its greatest amplitude during the equinoctial months, when the average deviation of the activity from the general level is −23% during the new moon and +22% during the first quarter. In the summer the amplitude is also much more pronounced than the average for the whole year. But in the winter the course of this curve is of a different character: The dominating first wave is reversed in direction, showing during the new moon no effect at all, but a distinct minimum during the first quarter. It would be very interesting to know how the activity behaves at the same time in the vicinity of the southern Auroral zone, i.e. does the solar effect alternately impinge on the northern and on the southern polar region.

3) Comparing the results from the different decades, it is seen that the effects mentioned appear most clearly during the middle period,

Table 2. The magnetic activity during the 4 principal moon phases and the neighbouring days in the 5 moust disturbed and the 5 quitest years, as percentage of the mean activity.

Moon phase:	●			☽			○			☾		
The 5 most disturbed years: 1930, 1938, 1939, 1941, 1943:												
Winter	111	99	89	89	56	63	111	88	116	122	80	79
Equinox	107	80	102	120	98	95	104	85	83	116	112	114
Summer	84	77	82	100	133	123	115	118	95	72	52	59
Year	101	85	91	103	96	94	110	97	98	103	81	84
The 5 quietest years: 1914, 1923, 1924, 1925, 1934:												
Winter	87	90	80	59	55	97	60	95	121	85	140	201
Equinox	88	52	44	180	162	135	112	95	112	86	106	58
Summer	98	71	61	95	158	110	93	75	66	84	93	101
Year	91	71	62	111	125	114	88	88	100	85	113	120

1924—1933, and are least distinct during the last decade 1934—1944. The first decade mentioned is the calmest, the last the most disturbed one during the period under investigation. In order to obtain some insight into the influence of increased activity upon the results, the 5 calmest and the 5 most disturbed years were examined separately. The result is given in Table 2.

It shows that in the quiet years the double-waved rhythm in the change of the magnetic activity, established above, becomes still more pronounced than appears from Table 1, and especially during the equinox, where the decrease of the activity at the times of the new moon amounts to 48, and the increase during the first quarter to 62 per cent of the mean activity, the amplitude of the principal wave thus attaining 110 per cent! (These numerical figures must, of course, be considered with a certain degree of reservation.) In these calm years, too, the two waves of the activity change are inversed during the winter months. But in the most disturbed years the result is somewhat indefinite, and the wave-shaped cycle of activity is manifested very weakly, if at all.

Especially regarding a highly disturbed period, it must be considered that 5 years form a fairly short interval, within which fortuitous occurrences are able to affect the final result to a considerable extent. On the other hand, the possibility must also be allowed for that the influence of the Moon's magnetic field is perhaps more effective on those of the corpuscular radiations from the Sun which cause the moderate magnetic activity on the Earth, than on the radiations (of another kind or approaching the Earth in another manner?) which bring about magnetic storms.

In this connection there is cause to point out a fact that seems to be in conflict with that established above: The double-waved cycle of the activity, observed from the results in Table 1, appears to be most pronounced during the equinoctial months, but normally these are the most disturbed period of the year. Perhaps at the equinoctial seasons the Earth is in the most sensitive position for receiving the effect coming from the Sun and its fluctuations. On the other hand the winter is normally a fairly calm season [4], and for this reason the absence or the reversal of the wave-shaped cycle, common during the other seasons, must be due to causes other than the amount of activity.

As Tables 1 and 2 show, the effect noticed is also more or less obvious in the days preceeding and following the days of the principal moon phases. Since the Moon moves about 12^0 in a day, this seems to indicate that the screening effect of the Moon extends over a fairly broad area.

In order to gain additional information concerning the manner in which the Moon affects the geomagnetic activity, a distribution table of the mean daily activities during the principal moon phases (Table 3) was worked out. The figures denote the percentage of days.

Table 3. The percentage of days in the principle moon phaces with the activities fallig within the different classes of the mean daily activity.

AZ	Moon phase / Season	●			☽			○			☾		
< 50	Winter	27	27	28	29	33	35	33	33	27	29	28	34
	Equinox	26	26	23	21	21	27	21	26	22	19	20	28
	Summer	35	37	33	32	30	23	38	36	40	39	39	33
	Year	29	30	28	27	28	28	31	32	30	29	29	32
< 150	Winter	60	56	57	68	72	76	70	65	63	67	65	63
	Equinox	60	68	62	51	56	53	55	55	55	58	51	56
	Summer	70	74	75	66	65	60	73	76	74	74	75	70
	Year	63	66	65	62	64	63	66	65	64	66	64	63
> 500	Winter	6	2	2	6	6	3	5	5	8	6	6	9
	Equinox	7	7	11	13	13	10	10	10	10	8	12	13
	Summer	3	3	4	5	5	4	6	3	4	2	2	3
	Year	5	4	6	8	8	6	7	6	7	5	7	8
> 1000	Year	0	0	0	0	1	1	0	0	0	1	1	0
> 1000, cases	Year	0	0	1	1	4	3	1	2	1	3	3	0

The result of this examination is somewhat inconclusive, and only with the support of the result already obtained can some weak tendency in the same direction be detected. Thus it may be observed that the greatest disturbances are lacking during the new moon, and also that medium-sized disturbances are commoner during the quarters than at the times of the new or full moon. The result, expressed in Table 3, seems to indicate that the lunar magnetic field is not able to extinguish the solar effect producing magnetic disturbances on the Earth, but only somewhat to weaken it at the times of the new, and to a minor degree also of the full moon.

One shortcoming of this investigation arises from the fact that the period from which the AZ-activity indices are available is rather short. In order to get a considerably longer series I also examined by the same method the International character figures C, which are available for a period of 70 years, 1884—1953 [1, 2, 3, 8]. The result (Table 4), comprising the days of the new and the full moon for the period in question,

Table 4. The mean magnetic activity, obtained from the international C figures, at the new full moon.

Decade	●		○	
	%	years < 100	%	years < 100
1884 — 1893	113	2	105	3
1894 — 1903	100	4	102	4
1904 — 1913	93	8	92	7
1914 — 1923	102	6	100	5
1924 — 1933	89	7	93	5
1934 — 1943	106	7	95	6
1944 — 1953	89	9	111	2
1884 — 1953	99	6	100	5

divided into decades, do not indicate any effect of the kind obtained from the AZ figures, even in the three decades which coincide with the AZ examination. Because, according to the investigation based upon the latter, a distinct lunar effect really does exist, the failure of the C figures to give evidence of it must depend either upon the insensitivity of these activity indices, or upon the mode in which the effect of the solar corpuscular emission is distributed over the globe: If the effect is mainly concentrated within the Auroral zones, it is readily understandable that the C figures do not display this effect in any distinct way.

With a view to obtaining information relating to this question, if possible, I further investigated the Moon's effect on the magnetic activity during the years from which other contemporaneous activity indices are available. Besides the AZ and C figures there are the indices for the »Absolute Storminess», AS, from Tromsö [7] and the Planetary three-hour-range indices Kp [3]. Unfortunately, they are only all contemporaneous during the epoch 1937—1943 (the year 1944 is incomplete for Sodankylä), and, what is still worse, this period happens to be one of the most agitated of the whole period investigated: Out of these 7 years, 4 belong to the five most disturbed years of the period 1914—1943, the last year being the most strongly disturbed of this group. This circumstance, of course, makes the establishing of a lunar effect inconclusive. All the activity indices mentioned were examined according to the same method employed throughout this investigation. The result is seen from Table 5.

Table 5. The magnetic activity during the new moon aed the first quarter, according to different dctivity indices, as dercentage of the mean activity, and correlations

Year	Year								Equinox							
	●				☽				●				☽			
	AZ	AS	Kp	C	AZ	AS	Kp	C	AZ	AS	Kp	C	AZ	AS	Kp	C
1937	95	100	98	92	87	77	89	89	119	131	93	95	74	79	89	88
1938	71	89	95	98	113	111	97	103	44	50	69	66	92	95	90	81
1939	82	87	90	88	127	128	100	99	77	67	85	74	186	190	124	126
1940	107	95	116	120	105	78	100	87	68	58	93	103	180	77	126	110
1941	82	86	101	99	49	63	77	74	59	87	87	87	51	60	82	69
1942	83	94	99	94	127	110	111	123	24	37	56	33	118	77	115	123
1943	128	124	119	118	68	79	83	71	180	182	140	146	25	40	45	19
1937—1943	93	96	103	101	97	92	94	92	82	87	89	86	104	88	96	88
1937—1942	87	92	100	98	101	94	96	96	65	72	80	76	117	96	104	100
Correlations with the AZ-numbers:																
1937—1943	100 × r=	89 ±5	88 ±6	78 ±10	100 × r=	[illegible]7 ±6	96 ±2	90 ±5	100 × r=	96 ±2	95 ±2	90 ±5	100 × r=	72 ±12	94 ±3	86 ±7

Nevertheless, the result, particularly if the most strongly disturbed year 1943 is omitted, shows the more or less pronounced influence of the lunar effect on every kind of activity index. In the equinoctial months the effect appears more obvious than during these 7 years on average. Thus the correlation coefficients between the ratios obtained by means of the AZ and the other activity indices are fairly high. The mean values for these coefficients are:

$$\text{AZ and AS, } r = 0.86 \pm 0.03,$$
$$\text{AZ and Kp, } r = 0.93 \pm 0.02, \text{ and}$$
$$\text{AZ and C, } r = 0.86 \pm 0.03.$$

One would have supposed that the correlation between the AZ and the AS results, the latter indices coming from an observatory which lies still closer to the Auroral zone than Sodankylä, would have been still higher. It seems that this depends partly upon the method of producing these indices, partly on the fact that the AS series, particularly in the years 1940 and 1942, are rather incomplete.

This small comparison also provides evidence in favour of the hypothesis that the effect of the Moon on the geomagnetic activity, established in this examination, is greater in the polar regions than for the Earth in general. Thus a separate international compilation of activity figures concerning the polar regions would perhaps prove useful and instructive for future investigations.

4. *The influence of the inner planets on the activity*

The period under investigation contains 95 inferior conjunctions of the planet Mercury, and 19 inferior conjunctions of the planet Venus with the Sun.

The influence of the inner planets on the geomagnetic activity was examined, employing the AZ activity figures from Sodankylä and calculating in the same way as in the case of the Moon. Concerning Mercury, the summarized result of this investigation is given in Table 6, where n denotes the day of the inferior conjunction.

Table 6. The geomagnetic activity at the inferior conjunktion of Mercury and on the preceeding and following day, as a percentage of the mean activity.

Years	$n-1$	n	$n+1$
1914—1923	88	112	134
1924—1933	74	74	90
1934—1944	88	80	92
1914—1944	83	88	104

The screening effect, observed in the case of the Moon, also emerges here fairly distinctly, the diminution of the magnetic activity amounting to — 12 % of the mean activity during the inferior conjunctions.

Out of these 95 conjunctions, 5 happen to fall into highly disturbed periods in otherwise fairly calm months. If in these 5 cases instead of the mean monthly activity the mean of the disturbed period could be accepted as reference level, the percentage figures for the years 1914—1944 would drop to 78, 77 and 95, the effect on the day of the conjunctions thus amounting to −23% of the mean activity.

In consequence of the rotation of the Sun, the screening effect of Mercury on the solar corpuscular emission must probably be greatest slightly before the time of the inferior conjunction. In Table 6 the preceeding day really seems to be more affected than the other two, but this may well be due to chance.

Regarding Venus, a distinct screening effect likewise occurs during the inferior conjunctions of this planet with the Sun. The percentage figures for the day of the conjunction *n* and for the preceeding and the following day are:

$n-1$	n	$n+1$
104	81	72

In the case of Venus there are two conjunctions which fell in a very disturbed period. If in these cases likewise the same procedure is adopted as for Mercury, the percentage figures fall to 80, 62 and 66, the screening effect thus amounting to −38% of the mean activity.

5. *Conclusions*

The present investigation leads to the following conclusions:

1) The fact stated above, that the Moon or the planet Mercury or Venus entering the space between the Sun and the Earth causes a fairly well-pronounced reduction of the geomagnetic activity, indicates that these celestial bodies are able to screen the Earth from the solar corpuscular flow producing the disturbances; this implies that the Moon, Mercury and Venus are surrounded by a magnetic field of considerable strength. At the times of the moon quarters (particularly during the first) the Earth seems to receive the maximum possible solar corpuscular effect.

2) The — admittedly slight — reduction of the activity appearing during the full moon is harder to explain. The existence of this second minimum seems in any case to indicate that even in a position on the opposite side of the Earth from the Sun, the Moon is able to seize a part of the solar corpuscular flow that would otherwise have exerted its effect more entirely on the Earth.

3) This reduction in the activity is, as stated, most pronounced in the equinoctial months, but hardly, if at all noticeable during the northern winter. If (in the future) it should be established that this effect is well pronounced in the vicinity of the southern Auroral zone in November-February, this fact will indicate that the solar corpuscular flow does not affect the entire Earth (except during the equinoxes), but is limited chiefly to that (polar) region which is inclined towards the Sun.

4) It appeared that the reduction of the activity during the new moon etc. is much more pronounced in slightly or moderately disturbed magnetic conditions than during strong disturbances or magnetic storms. This seems to indicate the existence of solar corpuscular streams of (two) different kinds, of which one (the »softer» or slower) is much more affected by the lunar magnetic field than the other.

5) A comparison of the results obtained by the use of different activity indices has shown that the correlations between them are certainly pretty high, but also that the reduction of the activity during the new moon etc. appears more pronounced when using the AZ figures from Sodankylä than when employing activity indices relating to the entire Earth. This seems to show that the solar effect is directed mainly towards the Auroral zones. An indication in this direction was already implicit in conclusion 3) above.

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