JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN Vol. 17, SUPPLEMENT A-I, 1962
INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part I

I-3-7. On the Geographical Distribution of the Areas of the Solar Corpuscular Impingements in the Arctic*

A. P. NIKOLSKY
Arctic and Antarctic Research Institute, Leningrad, U.S.S.R.

During the development of the questions of the theory of magnetic storms one usually proceeds from the following facts. Magnetic storms, as well as accompanying them aurorae are more frequent and intensive at the night side of the Earth in certain belts of geomagnetic latitudes (63°~66°N and S). It is considered evident that it is in these areas of the Earth that the most intensive impingements of solar corpuscular streams occur, being the initial cause of magnetic—ionospheric storms and aurorae. However, there are many obscure sides in the question by which way the solar corpuscles arrive at the Earth. For example, the Störmer theory[1] suggests that the corpuscular streams penetrating into the upper layers of the Earth's atmosphere might arrive here directly from the Sun. Martyn[2] believes that the solar corpuscular streams firstly form an equatorial current ring. Then the corpuscles might run out of the equatorial ring and follow along the magnetic lines of force toward the polar areas of the Earth into the ring zones where they would cause magnetic storms and polar aurorae. In the most recent years in connection with the discovery of the two radiation belts around the Earth with the help of rockets and satellites some suggestions were made that the corpuscles producing magnetic storms and polar aurorae might "pour out" of the outer belt during the periods of an increased solar activity into the upper layers of the Earth's atmosphere.

However, the above mentioned conceptions on the space-time distribution of magnetic disturbances and polar aurorae prove to be approximate and do not correspond enough to the facts.

Thus, as early as 1935, Stagg[3] showed that there were two maxima in the diurnal variation of magnetic activity in high latitudes both in the day time and in the night time. Later, on the basis of the analysis of the hourly characteristics of magnetic activity ($r_H\gamma$) it has been shown by us[4] that in the Arctic the most typical variation of magnetic activity is a curve with three maxima in the morning, evening and night hours of the day. The relative intensity of these maxima and the time of their appearance are in a complicated dependence upon the geographical position of the station. Further it was confirmed by O. A. Burdo[5] for the diurnal variation of the horizontal component of the magnetic disturbance vector.

From the analysis of magnetic disturbances, in the Arctic, it has been suggested by us[4],[6] that there exists in the circumpolar area the second zone with an increased intensity for the morning magnetic disturbances, and it has been given its approximate position. Later, it has been well confirmed by the observational data of the drifting stations in the Central Arctic. Lassen[7] on the basis of the analysis of visual observations of polar aurorae in Greenland during 1952–1956, independently from us, arrived at a conclusion on the existence of an inner zone for the morning polar aurorae. The position of the inner zone of polar aurorae over Greenland according to Lassen exactly coincided with the position, which was supposed by us from magnetic data.

It has been shown by us[4],[6] and then by many other scientists that the geographical distribution of the maximal phase of some phenomena, caused by the impingements of solar corpuscles in the Arctic and Antarctic has a spiral-shaped form. With this, for magnetic disturbances as Burdo[5] has shown, there are three such spirals in the Arctic, one of them unrolling clockwise and two others unrolling counter-clockwise. A similar result was received by E. I. Dolgova[8] for a certain type ef sporadic ionization in the *E*-layer. On the basis of the analysis of hourly synoptic maps of magnetic disturbances for

---

* This paper was read by A. I. Lebedinsky.

the Arctic sector from 33° to 190°E. A. I. Ohl[9] has shown that the magnetic disturbance distribution in general agrees with the system of spirals of Burdo-Nikolsky.

At present it is difficult to imagine, if it is possible to explain these facts, proceeding from the Martyn's theory representations or from the supposition that the corpuscles, which are responsible for the occurence of magnetic storms and polar aurorae, arrive in the upper layers of the Earth's atmosphere from radiation belts. If we examine the most part of the mentioned facts, it seems that some possibilities for their explanation, being only qualitative, so far, will appear on the basis of the Störmer's theory conclusions.

The possibility of existence of the inner auroral zone was shown by Alfvén[10] and Hultqvist[11] who proceeded from another theoretical considerations. The possibility of the spiral distribution, in particular, proceeds also from theoretical premises of Chamberlain, Kern and Vestine[12]. It is also true that a number of other mentioned facts they do not explain.

The task of the present investigation is an attempt to find out in detail the space-time distribution of the areas of the solar corpuscular impingements in the Arctic. It is suggested that the area with the highest amplitude of the hourly variation of the horizontal component of the magnetic field r_H^γ is, in the first approximation, the area of the most intensive corpuscular impingements.

In order to carry out such investigations we could use only the data of six stationary magnetic observatories: Heiss (Tikhaya), Murmansk, Chelyuskin, Dixon Is., Tixie Bay and Cape Wellen and of two drifting stations in the Central Arctic: NP-6 and NP-7. Stationary observatories were situated in the Arctic sector from 30° to 190°E and from 66° to 80°N.

The drifting stations covered the circumpolar region, the station NP-7 drifting partly even in the Western Hemisphere. The location of the observatories and drifting stations is shown in Fig. 1.

From the Dixon Observatory data for 1957, 1958 and 1959 the days at the intervals from 0 to 24 hours U.T. were selected, when the mean diurnal value of r_H^γ was more than 125, that correspond to disturbed days. Then, for each of the selected days a table according to the Universal Time with hourly values of r_H^γ for each of the above mentioned eight stations was prepared. Further, in each hour of the universal days the station with the highest value of r_H^γ was selected. Even the preliminary examination of data has shown at once that maximum values of r_H^γ one meets by no means permanently in the zone of the maximum frequency and intensity of magnetic disturbances and polar aurorae.

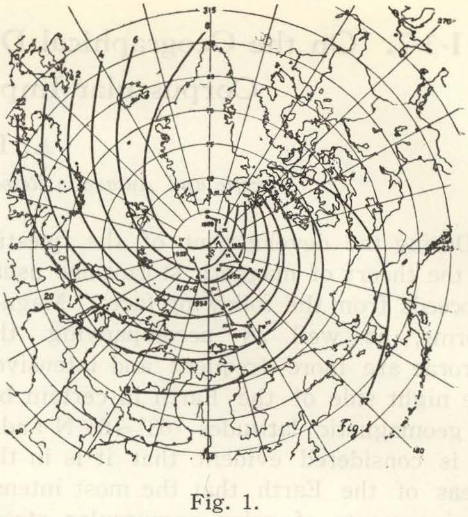

Fig. 1.

The hours were found when the most intensive magnetic disturbance occurred in the area of the geographical pole at the geomagnetic latitudes 78–82°, while in the auroral zone at that time it was more quiet.

As a result of statistical processing of data for 1957, 1958 and 1959 for each of eight stations it was obtained the diurnal distribution of cases when at the given station the values of r_H^γ reached the maximum value comparing to the other 7 stations. The results obtained were shown in Fig. 2.

First of all, at all the eight stations, without exeption, the morning maximum is seen very well. The time of its appearance is in a very good agreement with the system of isochrone-spirals (Fig. 1) which was prepared by us earlier on the basis of the mean diurnal variation of magnetic activity of a great number of stations. There is a tendency at all the stations toward the appearance of the morning maximum a little bit later than it

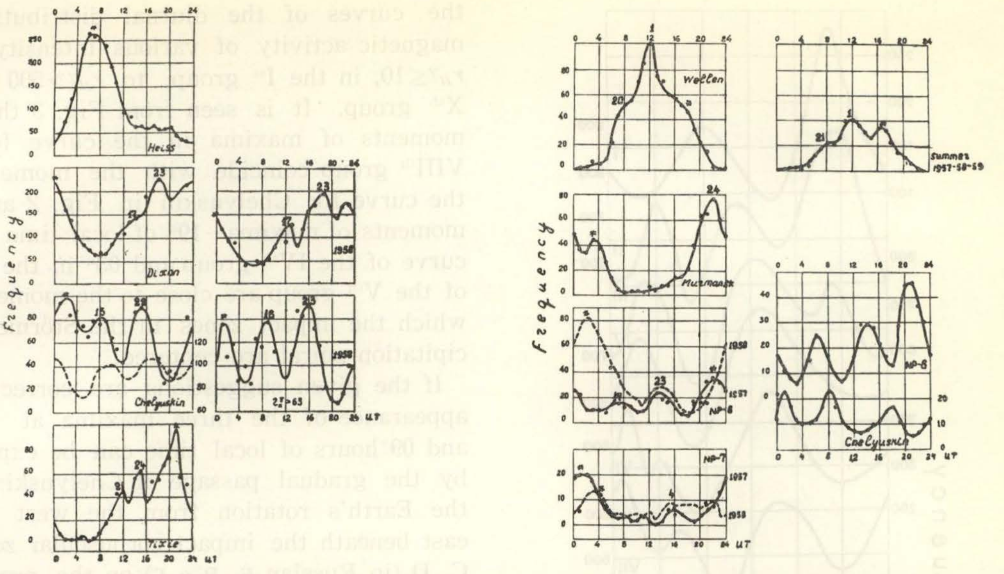

Fig. 2. Diurnal distribution of cases, when there was the most intensive magnetic disturbance at a given station; ---- mean many years diurnal variation at Chelyuskin for summer; * morning maximum.

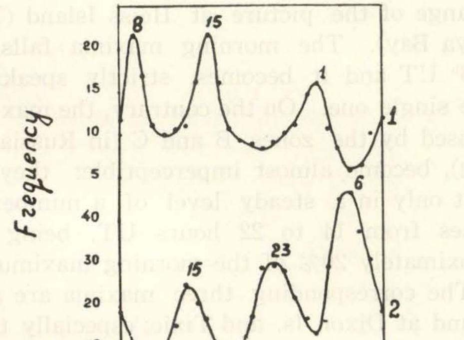

Fig. 2a. Diurnal changes of magnetic disturbance at: 1-Chelyuskin, 2-NP6, 3-NP7; numbers at maxima mean hours of geomagnetic time.

follows from the isochrone map. It is connected with the fact that here we consider disturbed days, while isochrones are plotted for all days.

It was shown by us[13] that with the increase of the solar corpuscular velocity (which takes place with the increase of the magnetic storm intensity) the precipitation spiral can move away from the pole, and as a consequence, the morning maximum will be slightly shifted to the later hours of local time.

The most surprizing picture has been observed at Chelyuskin, where three maxima in the diurnal distribution of the cases, when the most intensive corpuscular impingements occured in the area of this station, were especially well pronounced. These maxima were centered at 02, 08–09 and 15–16 hours of universal time (09, 15–16 and 22–23 hours of universal geomagnetic time). These three maxima can be considered as a result of the existence of the primary corpuscular impact zones on the Störmer precipitation spiral[4),14)].

These impact zones, beginning from the farthest from the pole end of the precipitation spiral, fall on 14–16, 20–22, 02–04 and 08–10 hours of local geomagnetic time and were named by us the zones of A, B, C, D (in Russian letters А, Б, В, Г), respectively.

Moreover, it was shown by us[13] that with the increase of the disturbance intensity the evening and night maxima can be markedly shifted to the earlier hours of local time. This is well seen for instance, in the data of Chelyuskin (Fig. 3). The Fig. 3 shows

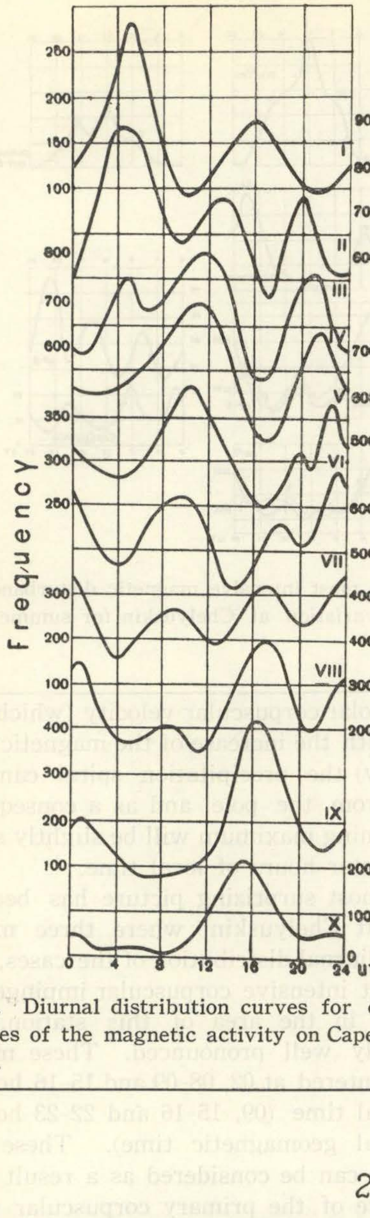

Fig. 3. Diurnal distribution curves for different grades of the magnetic activity on Cape Cheliuskin.

the curves of the diurnal distribution of magnetic activity of various intensity from $r_H^\gamma \leq 10$, in the Ist group, to $r_H^\gamma > 500$ in the Xth group. It is seen from Fig. 3 that the moments of maxima in the curve for the VIIIth group coincide with the moments in the curve for Chelyuskin in Fig. 2 and the moments of maxima—19^h of local time in the curve of the IVth group and 03^h in the curve of the Vth group are close to the moments to which the impact zones in the Störmer precipitation spiral are centered.

If the given suggestions are correct, the appearance of the three maxima at 15, 22 and 09 hours of local time can be explained by the gradual passage of Chelyuskin with the Earth's rotation from the west to the east beneath the impact corpuscular zone B, C, D (in Russian Б, В и Г) on the precipitation spiral.

We shall use these supposition for the interpretation of the distribution curves (Fig. 2) for other stations also. There is a sharp change of the picture at Heiss Island (Tikhaya Bay). The morning maxima falls on 6–8^h UT and it becomes, strictly speaking, the single one. On the contrary, the maxima caused by the zones B and C (in Russian Б и В), become almost imperceptible: they affect only in a steady level of a number of cases from 14 to 22 hours UT, being approximately 20% of the morning maximum.

The corresponding three maxima are also found at Dixon Is. and Tixie; especially they are perceptible at the first station. In Wellen

Table I.

20 Jule 1958

Tabl. 1

Station.	1	2	3	4	5	6	7	8	9.	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	UT
Drift. ST „NP-6"	272	162	90	119	124	99	107	116	138	126	280	143	146	44	96	72	55	88	110	132	94	94	118	138	
Drift. ST „NP-7"	555	165	128	499	158	142	172	75	165	105	105	525	135	142	142	188	165	90	68	52	45	75	218	180	
Bay Tikhaya (Heiss)	250	123	135	181	200	408	168	270	216	153	208	114	139	177	146	293	270	114	73	84	62	62	146	97	
Chelyuskin	260	290	330	362	99	180	153	324	190	160	170	108	178	111	190	350	390	82	69	58	50	59	189	71	
Dixon	340	198	264	409	79	103	125	99	158	145	310	145	185	158	475	541	433	119	119	87	59	265	231	125	
Tixie	57	84	62	120	53	57	82	100	191	65	112	54	52	162	277	492	372	71	61	57	57	69	42	42	
Wellen	75	70	85	164	138	183	95	75	121	38	77	191	85	54	130	252	239	57	33	27	38	27	34	20	
Murmansk	216	471	245	528	82	105	73	41	66	48	175	160	116	91	151	184	75	58	29	44	103	104	119	50	

2 June 1958

Wellen	48	111	136	103	111	82	191	299	54	33	63	333	184	239	164	110	241	299	171	34	29	35	14	18	

two of three maxima are expressed only as a slow rising and lowering of the curve, but their existence is out of doubt, because in summer these three maxima are distinguished already more distinctly. Even certain days can be selected, when their presence will be still more distinctly pronounced. For example, on June 2, 1958 (Table I) there were three intervals of time, when at this station there were the highest values of r_H^{γ}, in comparison with other seven stations. These intervals fall on 20, 01 and 06–07 hours of local time. It is interesting that the latter interval falls on 17–18 hours UT and exactly corresponds to the isochrone of the morning maximum, as it was obtained by us earlier.

In Murmansk the predominant maximum falls on 24^h of local time and it is associated with the impact zone C (in Russian B) on the precipitation spiral. The influence of the B-zone in Murmansk is not revealed distinctly. The presence of the slight morning maximum at 3^h of local time is out of doubt also.

The data of the drifting stations NP-6 and NP-7 are given separately for 1957 and 1958 in connection with the great change of their geographical position. The number of cases of morning disturbances, when values of r_H^{γ} at these stations were maximum ones, in comparison with Heiss decreases.

This effect increases as the drifting station of approch to the pole.

The moments and the intensity of the morning maximum well correspond to the system of isochrones and to the existence of the second zone with enhanced intensity of the morning magnetic disturbance between Heiss and the Geographical Pole. When the drifting station NP-6 was in the southernmost part of the drift (in 1957), the influence of the impact zones B and C was perceptible especially in summer; in 1958 when the station NP-6 was carried farther to the north, the influence of impingements, associated with the zones B and C, decreased very much and only morning impingements in the impact zone, associated with the crossing of the precipitation spiral were left. It should be stressed that the three maxima at the station NP-6 for 1957 (Fig. 2) were as well expressed as at Chelyuskin.

This should be expected because it was in this year that the geomagnetic latitudes of these two stations were nearest of all; the difference in their longitude was 60°.

The number of cases, when at the station NP-7 there was the highest value of r_H^{γ}, is small, less than at any other station. The morning maximum, the time of occurence of which in the range of $\pm 1^h$ coincides with isochrones (Fig. 1), is distinctly seen in the curves of the diurnal distribution, both for 1957 and 1958. In the rest hours of the day the curve changes little and only in 1957 as a tendency the increase about 03–04 hours of local time begins to show. The drift of the station NP-7 was in a very interesting area and the materials of observations take additional investigations.

The review of the tables prepared made it possible to reveal some more interesting facts. For each selected day the number of hours for 24 hours in which r_H^{γ} were maximum ones at a given station, was calculated. In the distribution of such hours among eight stations a very great variability from one day to another was revealed. Farther,

Table II.

Stations	High latitude type		Mean for both type	Low latitude type	
	Mean	1st July 1958		Mean	1st January 1958
NP-7	3	1	1		
NP-6	6	9	4	1	
Heiss	5	8	5	2	
Chelyuskin	4	3	3	2	2
Dixon Is.	4	2	6	6	7
Tixie	1	1	2	4	5
Wellen	—		1	5	6
Murmansk	1		2	4	4

an average distribution among stations was calculated, which is given in Table II.

The review of the material made it possible to reveal many such days when the areas with maximum r_H^γ were in comparison with an average picture far away to the north at Heiss Is., NP-6 and NP-7; and on the contrary, there were days when the areas of maximum r_H^γ were far away to the south at the latitudes of the stations Tixie, Wellen and Murmansk. Some idea about this one can make from Table II, in which it is shown the mean (according to several dozens of cases) distribution of hours with maximum r_H^γ for the days with the high latitude and low latitude types of magnetic storm distributions. These two types of the latitudinal distribution were especially well pronounced, for instance, on the 1st of January 1958 (low latitude type) and on the 1st of July 1958 (high latitude type), see Table II.

It should be also marked an extraordinary variability in the space and time distribution of the areas with the maximum values of r_H^γ from hour to hour. Table I for July 20, 1958 is given as an example.

Among the selected days there were days when in the interval of 22–02 hours UT the values r_H^γ and consequently the intensities of corpuscular impingements were the highest in comparison with other stations, at the NP-6 and at Murmansk.

There were 19 days of such a well pronounced type from January to March, 1957 and 27 days were found from April to December, 1958 (Table III, Column 1). There were days when the maximum value of r_H^γ was at the NP-6 (Table III, Column 2) and the one in Murmansk; in other days it was *vice versa* (Table III, Column 3) and the corresponding mean values of r_H^γ are given in Table III.

There occurred the days when highest values of r_H^γ were at the NP-7 and in Murmansk.

Such a peculiarity in the distribution of the areas with the maximum r_H^γ, the areas of the most intensive impingements of corpuscles in a given hour becomes understandable, if one sees Fig. 1. It is seen from this figure, that the belt between isochrones of 22–02 hours UT in its southern part passes close to Murmansk and its northern part is close to the area of the drift of the stations NP-6 and NP-7. Taking into account that the width of the precipitation spiral and its curvature do not stay unchangeable; the results shown in Table III can be explained as follows: The morning maximum at the NP-6 is an ordinary maximum, associated with the direct passage of the station beneath the northern part of the spiral (close to the impact zone D (in Russian Г)). Maximum in Murmansk arises as a result that this station occurs under the influence of corpuscular impingements in the impact zone C (in Russian В) that is timed to 22–04 hours of local time and it is situated just in the precipitation spiral which passes at these hours of UT in the area of the stations NP-6 and NP-7. All the rest 5 stations are under such a position of the precipitation spiral either outside of it (Heiss, Tixie, Wellen) or somewhere between the impact zones C and D (in Russian В and Г), Chelyuskin, Dixon Is.

In spite of the fact that the station NP-7 drifted in the area of Central Arctic which is the most distant from the auroral zone, at $\Phi \sim 78$–$82°$, there occured certain hours

Table III.

Stations	1	2	3
NP-7	78	54	74
NP-6	246	260	211
Heiss	100	51	70
Chelyuskin	129	96	95
Dixon	142	102	155
Tixie	117	76	140
Wellen	81	32	54
Murmansk	248	142	315

Table IV.

Stations	1957	1958
NP-7	660	317
NP-6	100	193
Heiss	160	160
Chelyuskin	150	111
Dixon	150	95
Tixie	70	60
Wellen	50	64
Murmansk	100	78

when the maximum values of r_H^γ were at this station. The mean distribution of r_H^γ for several such cases is given in Table IV.

The total number of such cases was not great: for 8 months of 1957 it amounted to 126 and in 1958 it was 220 which amounted from the total number of hours in selected days to 4.5% and 5.5%, respectively.

The location of the stations NP-6, NP-7, Heiss, Chelyuskin and Dixon is such that if magnetic disturbances occur at these stations in the interval from 00 to 06 hours, UT, then they must appear in their predominant part as a result of the passage of these stations beneath the northern part of the precipitation spiral (under the impact zone D (in Russian Г)).

At the stations Tixie and Wellen at this time the hours are most quiet. The cases were found when the highest value of r_H^γ was observed at one of the mentioned northern stations; at all other stations r_H^γ was less and decreased depending on the distance from the station, where r_H^γ was highest. For each of these stations several days were found from which the mean value was computed.

In Fig. 4, the values proportional to r_H^γ depending on the distance from the selected station with the highest value of r_H^γ are given. It is interesting that when NP-6, NP-7 and Heiss were taken for the base stations, the dependence upon the distance proved to be very well pronounced. If we take the stations Tixie and Wellen as base stations the dependence upon the distance is not revealed and such stations as Chelyuskin, Dixon and Murmansk fall out of it. It seems that in the first case the corpuscular impingements occur only in high latitudes and are limited in longitude, while in the latter case the impingement occupies wider areas in longitude. This speaks well, to a certain extent, for the fact that the locality of impingements in the circumpolar area is more expressed than in the auroral zone.

If we eliminate some minor details, then the above-mentioned facts enable us to make the following conclusions which define more exactly the results obtained earlier. The solar corpuscular streams, arriving at the Earth from the Sun for 1.5–2.5 days are focused by the Earth's magnetic field during impingement into the upper atmosphere not less than into two spirals, lying in high latitudes of the Arctic and Antarctic.

These spirals come out of the poles of the homogenous magnetization, occupy a wide belt and round nearly the entire Earth.

As a result of the continuing operation of the focusing mechanism as the stream approaches to the Earth, the thickening of the

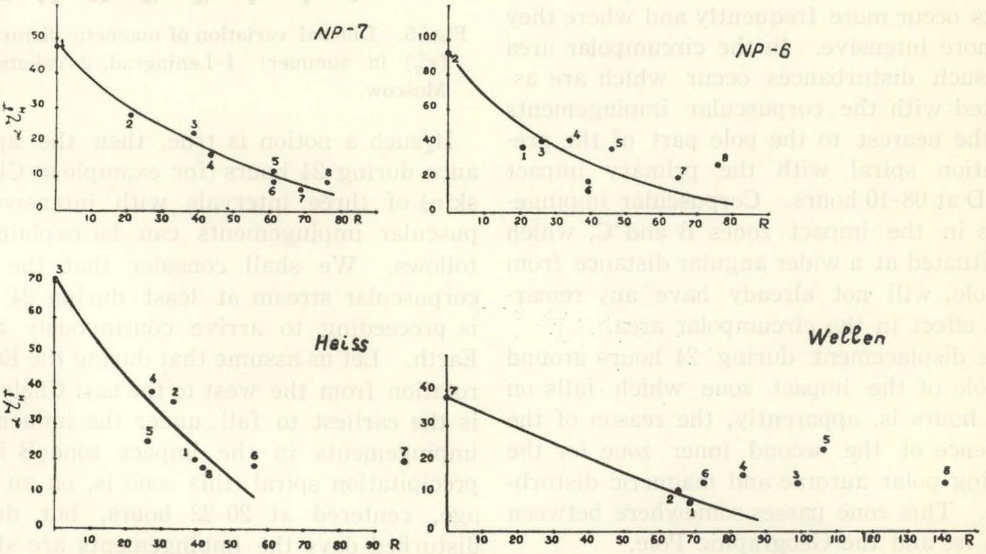

Fig. 4. Changes of amplitudes for the horizontal component in dependence on the distance (R) to the station with the greatest dr_H^γ: 1–NP-7, 2–NP-6, 3–Heiss, 4–Chelyuskin, 5–Dixon, 6–Tixie, 7–Wellen, 8–Murmansk.

trajectories of particles—the zone of primary impact is formed on the precipitation spiral.

These impact zones in the first approximation are centered at 20–22, 02–04 and 08–10 hours of local time (areas of B, C and D, respectively). These three impact zones can be shifted to earlier and later hours and become sometimes wider, sometimes narrower.

With the increase of the disturbance intensity—that is with the increase of corpuscular velocity—the precipitation spiral deviates from the pole and as a result, the morning disturbances associated with the passage of the station beneath the northernmost parts of the precipitation spiral (under the zone D) are shifted to the later hours of local time. The corpuscles with higher velocities precipitate farther from the pole, as a result, the evening disturbances (the impact zone B) and the night disturbances (the impact zone C) are shifted to some more early hours of local time.

The precipitation spiral of solar corpuscles, on an average, is situated so that the primary impact zones lying on it and giving two most intensive maxima of magnetic disturbances about 17–22 and 23–02 hours are situated in Soviet Arctic at latitudes $\Phi \sim 63$–66°. Displacement of the precipitation spiral position from hour to hour determines by itself the average position of the zone of magnetic disturbances and polar aurorae where these events occur more frequently and where they are more intensive. In the circumpolar area only such disturbances occur which are associated with the corpuscular impingements into the nearest to the pole part of the precipitation spiral with the primary impact zone D at 08–10 hours. Corpuscular impingements in the impact zones B and C, which are situated at a wider angular distance from the pole, will not already have any remarkable effect in the circumpolar area.

The displacement during 24 hours around the pole of the impact zone which falls on 08–10 hours is, apparently, the reason of the occurence of the second inner zone for the morning polar aurorae and magnetic disturbances. This zone passes somewhere between Heiss Is. and the Geographic Pole.

More to the South into subpolar and middle latitude the precipitation spiral sinks apparently too seldom and the direct corpuscular impingements here become less and less probable. It is necessary only to point out that at many subpolar stations (Yakutsk, Moscow, Leningrad) there is a maximum of magnetic activity in summer which falls on 15–16 hours of local time (Fig. 5) which can, apparently, be associated with the fourth impact zone—the zone A—in the precipitation spiral.

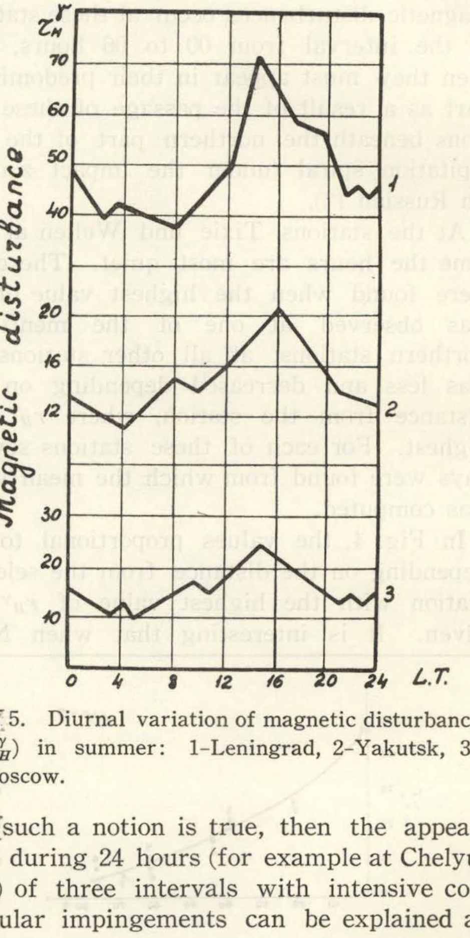

Fig. 5. Diurnal variation of magnetic disturbance (r_H^γ) in summer: 1-Leningrad, 2-Yakutsk, 3-Moscow.

If such a notion is true, then the appearance during 24 hours (for example at Chelyuskin) of three intervals with intensive corpuscular impingements can be explained as follows. We shall consider that the solar corpuscular stream at least during 24 hours is proceeding to arrive continuously at the Earth. Let us assume that during the Earth's rotation from the west to the east Chelyuskin is the earliest to fall under the influence of impingements in the impact zone B in the precipitation spiral (this zone is, on an average, centered at 20–22 hours, but due to disturbed days the impingements are shifted to earlier hours) the first maximum appears at 15–16 hours. Farther, as the Earth rotates, Chelyuskin falls under the influence of impingements in the impact zone C—and the second maximum appears about 22–23 hours. During the further Earth's rotation Chelyuskin has obligatory to cross the northern part of the precipitation spiral where the corpuscular impact zone D is situated; as a consequence the morning magnetic dirturbances appear about 8–9 hours a.m.

If the arriving of solar corpuscles at the Earth will continue, then in 7–8 hours the impact zone B will come to Chelyuskin again and magnetic disturbances will occur again with a maximum about 15–16 hours *etc.* Similar explanation can be used for the station NP-6 (1957).

As it was mentioned before, O. A. Burdo and some other authors showed that with increasing of latitude the time of evening and night maxima of magnetic and ionospheric disturbances shifted to earlier hours. Consideration of this dependence in polar coordinates exposes two spirals, evening and night ones, except of the morning one.

Because of insufficiency of time this problem is not considered here. Still, one may suppose that its explanation can be based on Störmer's theory.

During recent years many scientists have shown that the geographical distribution of events, associated with solar corpuscular impingements in a number of case has a spiral-shaped form. In connection with this a number of authors and we have paid attention to the Störmer theory again, which made it possible, even if it be qualitatively, to understand some of the facts recently revealed. There is another point of view. Agy[15] in his recent paper has made a number of comments, the main point of which is that the found spiral distributions have bearing neither on the theoretical precipitation spiral obtained by Störmer, nor on the experimental spiral obtained by Birkeland.

However, the results of the present investigation, from their qualitative side, best of all correspond to the Störmer's conclusion on the focusing of the solar corpuscular stream into spiral, on which there are primary impact zones falling on to the certain hours of the day. In connection with this it is interesting to note that the impact zones of cosmic rays on the Earth associated with solar flares fall on the same hours of the day. This fact is considered as an evidence that the störmer theory is applicable for the cosmic rays ejected from the Sun.

Recently K. Sakurai[16] in his paper "Motion of Low-Energy Solar Cosmic Ray Particles in the Earth's Magnetic Field" has theoretically showed that the precipitation of such particles in circumpolar region of the Earth occurs along the spiral curves and that it is confirmed by the observational results.

Therefore it seems to be extremely necessary to try once more to eliminate those theoretical difficulties which arise with the attempts to use the Störmer's theory conclusions for qualitative explanations of magnetic disturbances in high latitudes.

The conducting of a similar investigation with the use of data of the entire polar cap, undoubtedly, made it possible to receive some new conclusions which would play an important part for understanding of the nature of magnetic disturbances and related phenomena in high latitudes of the Arctic and the Antarctic.

References

1) C.Störmer: "The Polar Aurora" Oxford, (1955).
2) D. F. Martyn: Nature, **167**, No. 4238, (1951).
3) T. Stagg: Proc. Roy. Soc., A., **149** (1935).
4) A. P. Nikolsky: Trudy AANII, **83** (1956).
5) O. A. Burdo: Trudy AANII, **223** (1960).
6) A. P. Nikolsky: DAN SSSR, **109**, No. 5, (1956).
7) K. Lassen: Publ. fra det Danske Meteor. Inst., N 23, (1958).
8) E. I. Dolgova: Problemy Arktiki, No. 7, (1961).
9) A. I. Ohl: Sbornik MGG, Magnetic disturbances, N 3, (1961).
10) H. Alfvén: Tellus, **7**, No. 1, (1955).
11) B. Hultqvist: Nature, **183**, No. 4673, (1959).
12) J. Chamberlain, J. Kern and R. Vestin: J. Geophys Res., **65**, No. 8 (1960).
13) A. P. Nikolsky: DAN, SSSR, **127**, No. 1 (1959).
14) A. P. Nikolsky: Trudy AANII, **223** (1960).
15) V. Agy: Journ. Atmos Terr. Phys. **19**, No. 2, (1960).
16) K. Sakurai: J. Geomag. Geoel., **12**, No. 2, (1961) 59–61.