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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part I

I-1-P2. Morphology of Magnetic Storms

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The average morphology of magnetic storms with sudden commencement is well studied by Sugiura and Chapman in their recent work, especially for the disturbance observed in moderate and low latitudes. In the present paper some important features of the magnetic disturbance field on the earth are pointed out especially for the part of the disturbance field, which has its origin in the electric current in the ionospheric region caused by the impinging of energetic particles into the auroral zone ionosphere from outside. The main points described are: the reversal of the direction of electric current across the polar cap in a short time during the sudden commencement; equatorial anomaly of the disturbance field in the early part of magnetic storms; characteristics of the polar elementary storm as the fundamental element of the polar disturbance field; small local disturbances taking place very often in high latitudes and their remarkable seasonal dependence of occurrence tendency; and the presence of persistent polar-cap disturbance of considerable magnitude caused by the persistent solar wind.

§ 1. Introduction

Geomagnetic variations observed on the earth's surface will conventionally be divided into two kinds, extraterrestrial and terrestrial parts, according to whether the location of the origin of the disturbance is far outside or very near the earth's surface. Here this classification is applied only for the magnetic field variation with its origin in the external space of the earth, and the electric current induced in the earth's interior by the varying external magnetic field is not dealt with. The disturbances originated far outside the earth's surface are such as those caused by the interaction of the solar corpuscular stream with the earth's permanent magnetic field in the magnetosphere, and the equatorial ring current. They are mainly responsible for the world-wide geomagnetic change called *Dst*-field. On the other hand, the longitudinal inequality component called *DS*-field (or *SD*-field for the average storm) of the disturbance should have its origin in the immediate vicinity of the earth, say in the ionospheric region.

Most of the magnetic variations recorded on ordinary magnetograms with paper speed of 15 or 20 mm/hr are now studied conventionally by means of the equivalent overhead electric currents in the ionosphere. This method is especially useful for the *DS*-field, in which the intense electric current along the auroral zone plays the most important and fundamental rôle. Shorter period disturbances are not easily analysed by means of ordinary magnetograms, and rapid-run recording is made for getting the satisfactory records. The morphology of geomagnetic pulsations of various kinds is not yet fully understood from the standpoint of electric current in the ionosphere. Instead, the idea of the propagation of disturbance by some hydromagnetic wave from the magnetosphere to the earth's surface is favoured for the physical interpretation of some of geomagnetic pulsations.

In this paper some important features are pointed out for the geomagnetic disturbance, which is considered to be originated mainly in the electric current flowing in the ionospheric region. Therefore, some of irregular variations including geomagnetic pulsations are not dealt with here, although they are also very important to understand the morphology of magnetic storms. The problems discussed in this paper should be carefully examined when theories of magnetic storms are studied.

§ 2. Revised Morphology of the Average Magnetic Storm in Middle and Low Latitudes.

M. Sugiura and S. Chapman have recently published the results of very comprehensive study of the average morphology of magnetic storms with sudden commencement[1]. They examined 346 (classified to 136 weak, 136 moderate and 74 great) storms during 1902–45 observed at 26 stations ranging from 80°N to 48°S, and many important features in middle and low latitudes are presented. Special effort is made for the analysis of the development of *Dst*-field and that for *DS*- or *SD*-field, and their mutual relationship. The problems not dealt with in their paper are average morphology in high latitudes, sudden commencements including *SC**, and geomagnetic variation immediately after the sudden commencement.

§ 3. Sudden Commencement of Magnetic Storm (*SC*)

It is generally said that a magnetic storm begins simultaneously all over the world. We have not yet final analytical conclusions about the propagation time of the sudden commencement on the earth's surface, although some suggestive results have been presented[2)-4)].

An important fact for the storm sudden commencement is that it is almost always accompanied by a small reverse kick immediately before the world-wide increase of the horizontal component *H* of geomagnetic field, when it is observed especially in middle latitudes in the early afternoon. An example[5)] of the equivalent overhead electric current-system at the time of *SC** is shown in Fig. 1.

After about 1 minute from the moment of

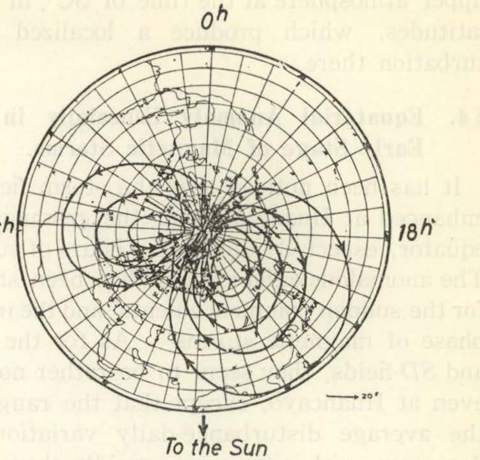

Fig. 1. Distribution of the equivalent current-arrows and current-system for the preliminary reverse impulse of *SC** at 06h 25m UT on May 29, 1933. (After Nagata and Abe).

*SC** the world-wide increase in *H* is observed. An overhead current-system for the developed stage of the main part of *SC* is shown by Fig. 2. The current-system for *SC*, simply denoted here by *D*(*SC*), is conventionally divided into two parts: *Dst*(*SC*) and *DS*(*SC*) just as in the ordinary way of separation into the zonal and logitudinal inequality parts[6)]. The electric current of *DS*(*SC*) in the polar cap flows just in the opposite direction to the current for *SC**.

It is one of the fundamental requirements for theories of magnetic storms to explain these observational facts of *SC** and *SC*. It is evident that some particles or hydromagnetic waves should reach the earth's

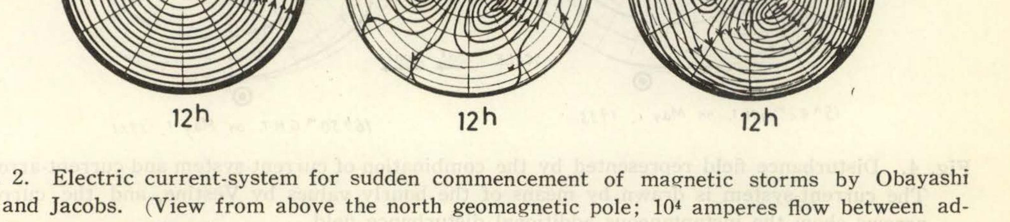

Fig. 2. Electric current-system for sudden commencement of magnetic storms by Obayashi and Jacobs. (View from above the north geomagnetic pole; 10^4 amperes flow between adjacent stream lines.)

upper atmosphere at the time of SC^* in high latitudes, which produce a localized perturbation there.

§ 4. Equatorial Anomaly Especially in the Early Stage of Magnetic Storms.

It has been noticed that the storm field is enhanced at Huancayo near the geomagnetic equator, especially during the hours of sunlit. The anomalous enhancement has been shown for the sudden commencements[7] and the initial phase of magnetic storms[8]. As for the *Dst*- and *SD*-fields, they seem to be rather normal even at Huancayo, except that the range of the average disturbance-daily variation *SD* decreases with time more rapidly than elsewhere, especially in the case of weak magnetic storms[1]. One might have the impression as if *Sq* were enhanced during storm days. This point requires further careful examination.

§ 5. Polar Elementary Storm or *DP* Substorm as a Fundamental Element of the Polar Disturbance Field.

Although the instantaneous disturbance field over the world is usually complicated in general, rather simple form of the disturbance sometimes appears. This simple pattern is called here the "polar elementary storm" according to Birkeland's classification[9]. Chapman and Akasofu propose to use the name *DP* substorm[10]. An example of

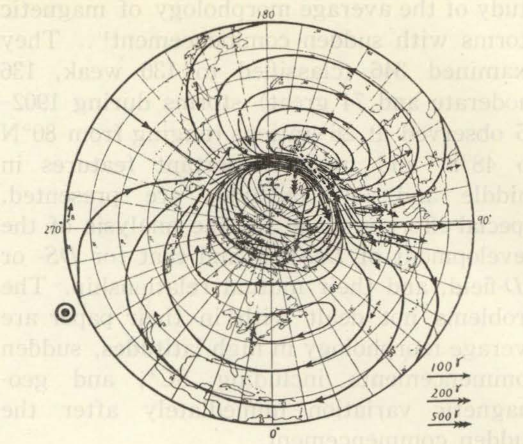

Fig. 3. Appearance of the polar elementary storm of dipole type at 21h 15m GMT on April 30, 1933.

the appearance of the polar elementary storm is shown in Fig. 3, where one sees an intense longitudinal current flow in some segment of the auroral zone, and the electric current in other regions seems to be the return current of this intense partial auroral zone current. Such a current-system appears in every stage of magnetic storms[11]. Sometimes it appears as an additional disturbance to the well-developed disturbance with intense westward and eastward auroral zone currents, as shown by examples in Fig. 4. The simplest pattern of the polar elementary storm will be illustrated by (A) or (B) of the

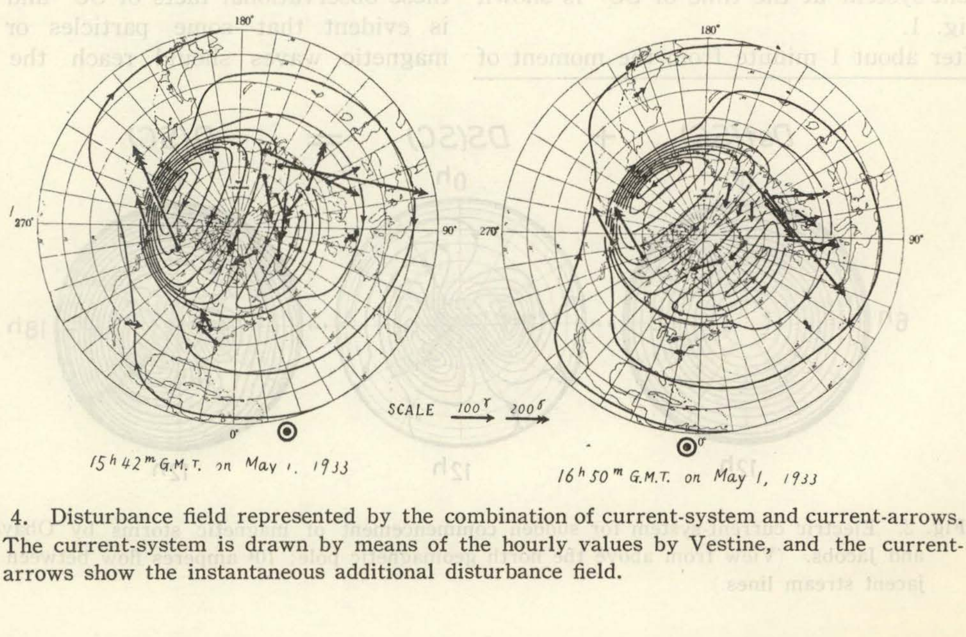

Fig. 4. Disturbance field represented by the combination of current-system and current-arrows. The current-system is drawn by means of the hourly values by Vestine, and the current-arrows show the instantaneous additional disturbance field.

lower part of Fig. 5, which is the electric current distribution on a conducting spherical surface when an electric dipole is placed at a point at the auroral zone latitude.

The appearance of the polar elementary storm is related to the production of a small activated area in the ionospheric region of the auroral zone due to the impinging of energetic particles. If the activated area is produced only at one small area in the auroral zone such as cases (A) and (B) of the upper part of Fig. 5, we may expect to have the corresponding electric current-system shown in the lower part of Fig. 5. On the other hand, when the whole auroral zone is activated, the resultant electric current-system will become very similar to the standard *SD* current-system, as illustrated by case (C) in Fig. 5.

Theories of magnetic storms should explain not only the mechanism for the average *SD*-field like case (C) in Fig. 5, but also the production of current-systems like cases (A) and (B), because the polar elementary storm is the fundamental disturbance, and this is not considered to be the result of some deviation from or fluctuation of the *SD*-field. On the contrary, the *SD*-field is the space and time average of a number of the instantaneous disturbance fields, many of which will be of the form of the polar elementary storm.

As for the mean duration of the polar elementary storm, it is from several minutes to a few hours. This is simply recognized from the inspection of magnetograms at high-latitude stations. A quantitative study is made by means of the quarter-hourly *Q*-indices[13] at some high-latitude stations for the disturbed period of Sept. 2–6, 1957. The auto-correlation value is calculated for the time series of *Q*-indices in order to see the persistency of the disturbance field at each station. As shown in Fig. 6, the auto-correlation value drops very rapidly with time especially in the auroral zone and inside the polar cap. It is evident from this result that each disturbance has rather short duration. The dependence of the decrease of the auto-correlation value on geomagnetic latitude may be interpreted by the electromagnetic induction effect in the ionospheric region.

It is generally thought or sometimes assumed that the geomagnetic disturbance takes place simultaneously and symmetrically with respect to the geomagnetic equator in the northern and southern hemispheres. The average *SD*-field in high latitudes shows really such a symmetric distribution[14]. On the other hand, individual disturbances do not alway show such a symmetrical tendency, although the correlation of simultaneous

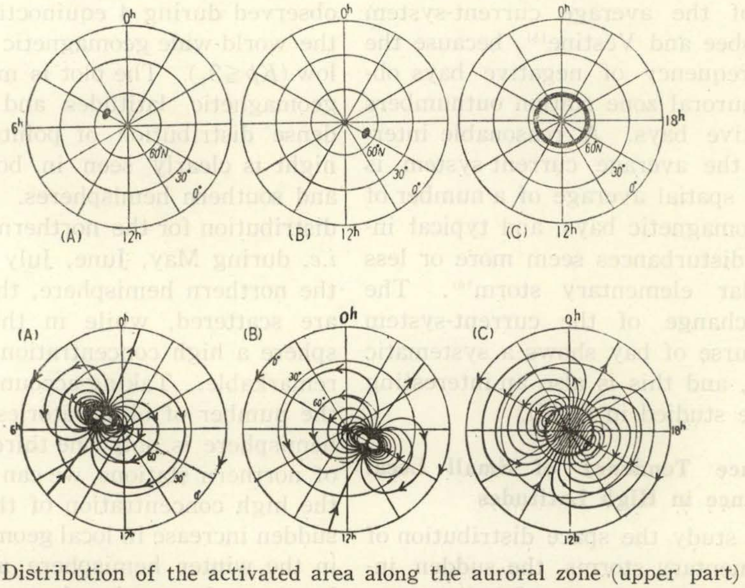

Fig. 5. Distribution of the activated area along the auroral zone (upper part) and the resulting electric current flow in the ionospheric region over the world (lower part).

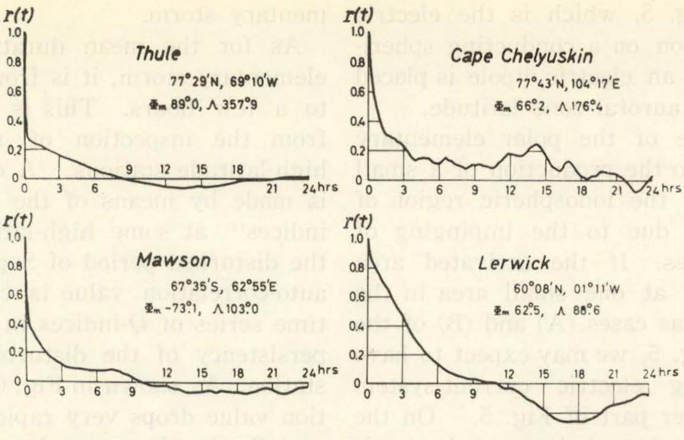

Fig. 6. Auto-correlation value $r(t)$ of the geomagnetic Q-indices for the disturbed period of September 2–6, 1957 (Ap=102, 135, 145, 112, 36).

disturbances at geomagnetically conjugate points is rather good[14]. With regard to this problem, the analysis of occurrence tendency of small local disturbances discussed in §7 and the persistent agitation in the polar cap of the sunlit hemisphere described in §8 should be taken into account.

§6. Remark on the Average Current-System for Geomagnetic Bays

Typical geomagnetic bays are considered to be nothing else but the appearance of polar elementary storm or *DP* substorm. But one may not consider that the typical geomagnetic bays are caused by the development and decay of the average current-system shown by Silsbee and Vestine[15], because the occurrence frequency of negative bays observed at an auroral zone station outnumbers that of positive bays. A reasonable interpretation for the average current-system is that it is the spatial average of a number of individual geomagnetic bays, and typical individual bay disturbances seem more or less like the polar elementary storm[16]. The progressive change of the current-system during the course of bay shows a systematic character[11,16], and this is also an interesting problem to be studied in detail.

§7. Occurrence Tendency of Small Local Disturbance in High Latitudes

In order to study the space distribution of the polar elementary storms, the sudden increase of the quarter-hourly Q-indices was examined. There are many cases of the sudden simultaneous increase of Q-indices at many stations, but there are also a number of cases when the sudden increase is observed only at one station. The latter case is considered to be the occurrence of small local geomagnetic activity. About 2500 examples of the sudden increase in Q-index (by 3 in 15 minutes or by 4 within an hour) are found during IGY by means of the reports at 16 stations, 12 in the northern hemisphere and 4 in the southern hemisphere. It is rather surprising that about 80% of the examples are the cases of sudden increase in Q-index at a single station. Fig. 7 shows the plot of the positions, where such local activity is observed during 4 equinoctial months, when the world-wide geomagnetic activity is rather low ($Kp \leqq 3_+$). The plot is made on a map of geomagnetic latitudes and local time. A dense distribution of points near local midnight is clearly seen in both the northern and southern hemispheres. Fig. 8 shows the distribution for the northern summer season, *i.e.* during May, June, July and August. In the northern hemisphere, the plotted points are scattered, while in the southern hemisphere a high concentration near midnight is remarkable. Taking account of the fact that the number of observatories in the southern hemisphere is only one-third of the number of northern stations, we can clearly recognize the high concentration of the appearance of sudden increase in local geomagnetic agitation in the winter hemisphere around midnight. In the polar region in summer season, the sudden local magnetic disturbance takes place

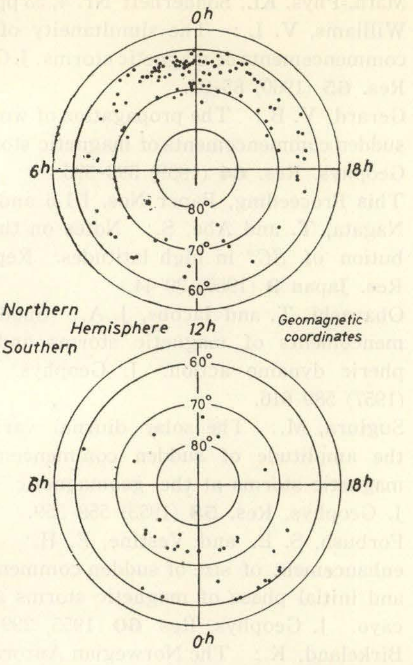

Fig. 7. Occurrence tendency of sudden increase in geomagnetic Q-index at single station when $Kp \leq 3_+$ in the equinoctial months.

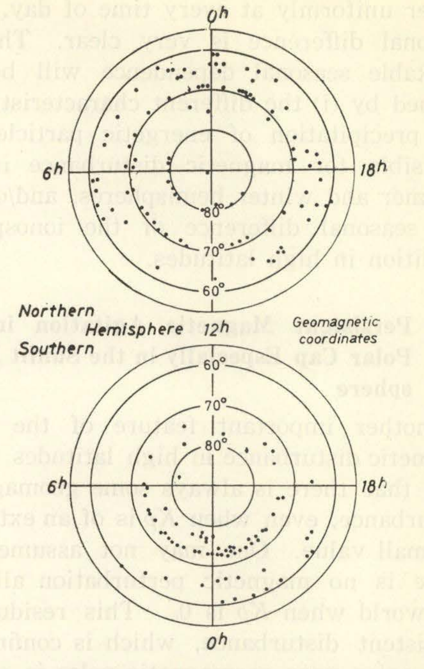

Fig. 8. Occurrence tendency of sudden increase in geomagnetic Q-index at single station when $Kp \leq 3_+$ in the northern summer months.

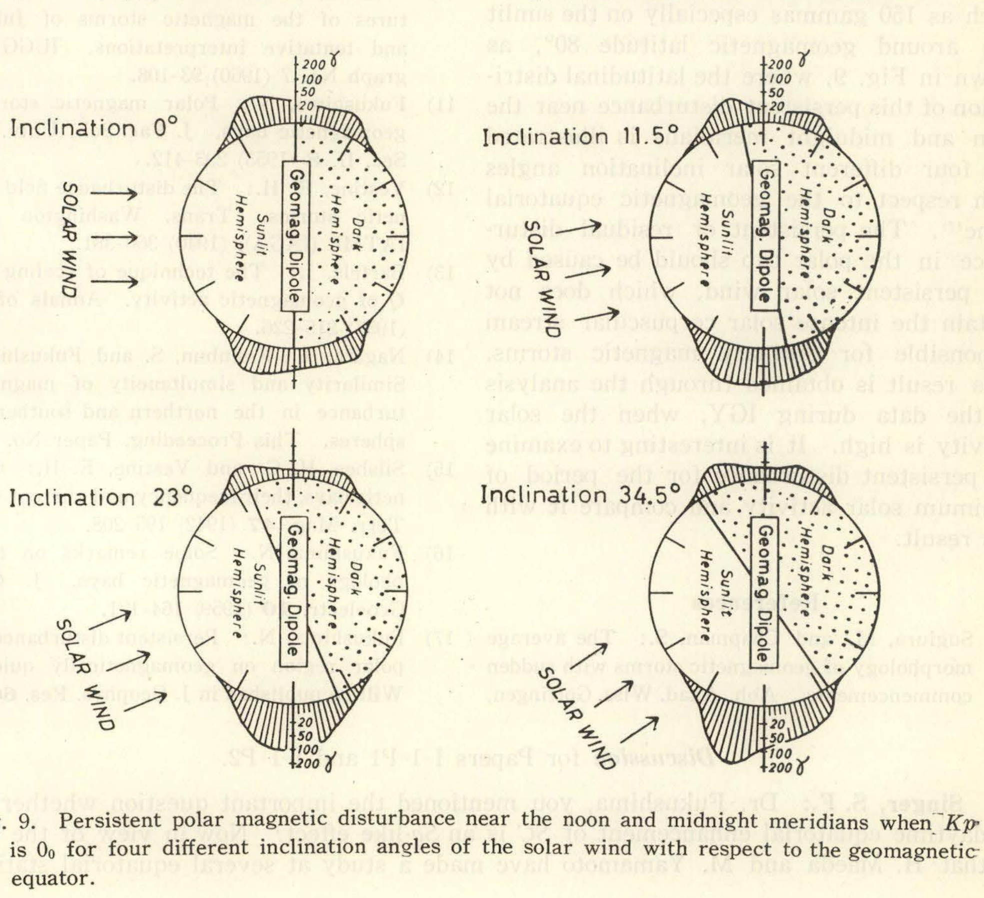

Fig. 9. Persistent polar magnetic disturbance near the noon and midnight meridians when Kp is 0_0 for four different inclination angles of the solar wind with respect to the geomagnetic equator.

rather uniformly at every time of day. This seasonal difference is very clear. The remarkable seasonal dependence will be explained by (i) the different characteristics of the precipitation of energetic particles responsible for magnetic disturbance in the summer and winter hemispheres, and/or (ii) the seasonal difference of the ionospheric condition in high latitudes.

§ 8. Persistent Magnetic Agitation in the Polar Cap Especially in the Sunlit Hemisphere

Another important feature of the small magnetic disturbance in high latitudes is the fact that there is always some geomagnetic disturbance, even when *Kp* is of an extremely small value. One may not assume that there is no magnetic perturbation all over the world when *Kp* is 0_0. This residual or persistent disturbance, which is confined to the region near geomagnetic poles is of the order of several tens of gammas in general, but in the summer season it amounts to as much as 150 gammas especially on the sunlit side around geomagnetic latitude 80°, as shown in Fig. 9, where the latitudinal distribution of this persistent disturbance near the noon and midnight meridians is illustrated for four different solar inclination angles with respect to the geomagnetic equatorial plane[17]. The persistent or residual disturbance in the polar cap should be caused by the persistent solar wind, which does not contain the intense solar corpuscular stream responsible for ordinary magnetic storms. This result is obtained through the analysis of the data during IGY, when the solar activity is high. It is interesting to examine the persistent disturbance for the period of minimum solar activity and compare it with this result.

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Discussion for Papers I-1-P1 and I-1-P2.

Singer, S. F.: Dr. Fukushima, you mentioned the important question whether the daytime equatorial enhancement of *SC* is an *Sq*-like effect? Now in view of the fact that H. Maeda and M. Yamamoto have made a study at several equatorial stations, don't you think that their results show this *Sq*-effect, presumably linked to ionospheric conductivity?

Fukushima, N.: I should have referred to their new work. I hope that the equatorial enhancement of *SC* and the initial stage of magnetic storms is clarified very soon all along the equator, in order to examine an *Sq*-like current produced at the time of magnetic storms.

Alfvén, H.: I have two questions to put to the speakers, and also to our chairman.

1. Since the time of Birkeland and Störmer it has been obvious that a considerable part of the storm field is produced by a ring current at large distance from the earth. The ring current is included in one form or other in all existing theories of magnetic storms. Under these conditions, why have you devoted so much work to construct two dimensional diagrams under the assumption that the current flows in the upper atmosphere?
2. By space probes the magnetic field in the exosphere is now explored, and it is obvious that there exists a complicated three-dimensional current-system. With this in mind, do you think that the same type of two-dimensional diagrams should be constructed also in the future?

Chapman, S.: I should like to say on Dr. Alfvén's first question. It is worthwhile to construct conventional diagrams. I have said, it is worthwhile in the first place making the convenient synthesis of the magnetic data to enable one to understand by a scale diagram the distribution of the field of the magnetic storm over the surface of the earth. Further, when the diagram was first constructed we could not really say where the current was. It was at that stage to be certainly useful. It is still a synthesis of the magnetic data of the surface of the earth. As regards whether it is still useful to construct such diagrams, it would be better if we could separate a perturbed field which comes from current in the space around the earth. But these current systems as constructed are always strongest in the polar region, and there they do represent well current in the atmosphere. However, they lose some reality in the middle belt of the earth.

Alfvén: Everybody agrees that the equatorial electrojet and the auroral jets flow in the ionosphere. One of the most important theoretical points is how these currents are closed. I think there are good agreements for the view that the electrojets in the auroral zones are closed by currents along the magnetic field line. For a discussion of these phenomena the diagrams you have shown are misleading.

Hines, C. O.: I would agree with Prof. Alfvén, that three-dimensional currents play an essential part in geomagnetic storms. However, I believe that these are completed through the ionosphere largely by means of Pedersen currents — almost certainly for the idealized *DS* system at least—and that these currents must have associated with them very much stronger Hall currents. The latter would be confined essentially to the ionospheric shell. If and when these Hall currents are indeed dominant, the representation which Prof. Alfvén has criticized would give a reasonable approximation to the actual current-system. For theoretical purposes, of course, the full three-dimensional system must be kept in mind, as Prof. Alfvén has said. The continued inclusion of ring-current effects in the analysis that represents ionospheric-level currents is indeed unfortunate, but the unambiguous removal of these effects is probably as yet impossible.

Nagata, T.: From viewpoint of physics, Prof. Alfvén's comments seem to be quite right. We have a certain certification for that these currents are situated not far from the earth's surface (lower than several hundred km in height) as proved by potential theory. But to discuss this sort of problem from not only geomagnetism but also from results of auroral and ionospheric observation is the main purpose of this Conference. I hope, in the end of this Conference, a number of evidence will be shown for distinguishing what part of currents is really originated in the ionospheric level and what part is not by joining results of studies on relevant phenomena.

Martyn, D.F.: I think that the existence of the electrojets, equatorial and auroral, proves that at least a substantial part of the disturbance current-system flows in the ionosphere.

Smith, E.J.: In view of satellite data obtained by magnetometers on Vanguard III and Explorer VI, wouldn't you agree that there is one possible source of the primary storm field responsible for the main phase which can be eliminated from further consideration, *i.e.*, a current in or near the ionosphere?

Vestine, E. H.: In the auroral regions, electrojets flowing in the low ionosphere appear, and estimates made indicate that closure of current flow may occur in conducting layers more or less transverse to the geomagnetic field. The satellite measurements indicate ring-current sources as well. It seems therefore natural to regard these as often appearing together, but it is not clear than one should be regarded as primary and the other secondary.

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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part I

I-1-P3. On Auroral Isochasms and the Orientation of Auroral Arcs

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Published observational data concerning the configuration and location of the northern and southern aurorol zones are reviewed and are compared with circles projected from the geomagnetic equatorial plane, outside the earth, on to the earth's surface along the geomagnetic field lines (in an approximation which includes the five first terms of the spherical harmonic development). Other auroral distance parameters are also compared with these circle projections.

Very good agreement has been found for the northern hemisphere. More accurate data are still needed for those parts of the southern auroral zone which lie over the ocean at a great distance from the Antarctic continent. In the author's opinion it is highly probable that the northern and southern auroral zones are geomagnetically conjugated curves and that they correspond to projections of circles in the geomagnetic equatorial plane on to the earth's surface along the real geomagnetic field lines.

Regularities in the average direction of arcs and bands at a given time are discussed. The results of an investigation of the diurnal variation in the direction of quiet auroral arcs at Kiruna are presented, and the observational results are compared with Alfvén's theory.

It has been found that near the auroral zones the diurnal variation curve is similar to the theoretical curve of Alfvén. Of special interest is a "discontinuity" observed in the mornings at Kiruna.

§1. Introduction

There are good reasons for postulating circular symmetry, in the geomagnetic equatorial plane outside the earth's surface, of distance parameters representing statistical averages for corresponding variables of those processes, in and near the equatorial plane, which are associated with the occur-