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ON CERTAIN CHARACTERISTICS OF IRREGULAR MAGNETIC ACTIVITY OBSERVED AT CANADIAN MAGNETIC OBSERVATORIES DURING 1960

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On Certain Characteristics of Irregular Magnetic Activity Observed at Canadian Magnetic Observatories during 1960

E.-I. Loomer and K. Whitham

Abstract:—Hourly range data in three orthogonal components for the year 1960 are summarized for the Canadian magnetic observatories at Victoria, Meanook, Churchill, Baker Lake and Resolute Bay. The times of maxima of the two major patterns of high-latitude corpuscular precipitation are clearly defined for these locations with one year's data. However the third pattern of disturbance (the afternoon maximum of disturbance in the auroral zone) postulated by Russian workers is found to be very weak and scarcely identifiable in the average data for one year. It appears most clearly in the data for disturbed days but the records from one year are then insufficient to remove all the random peaks. This statistical weakness of the third peak is in agreement with the theory of Axford and Hines (1961).

The diurnal plots for different components are similar at high latitudes, whereas the latitudinal variation of the mean levels of activity for each component differ significantly. Part of this difference can be attributed to varying contributions from induction, and reasonable approximate estimates of the magnitude of the induced terms can be made assuming a random source model.

Résumé:—Les auteurs résument dans la présente étude les données relatives aux variations horaires de trois composantes orthogonales compilées pour l'année 1960 à partir de données obtenues des observatoires magnétiques de Victoria, Meanook, Churchill, Baker Lake et Resolute Bay. Les moments maximums des deux principaux schémas de bombardement corpusculaire à latitude élevée sont clairement définis pour chacun des endroits susmentionnés à l'aide des données pour une année. Toutefois, le troisième schéma de perturbations (maximum d'activité de l'après-midi au sein de la zone aurorale) postulé par des chercheurs russes semble très imprécis et difficile à reconnaître d'après les données moyennes annuelles. Ce troisième schéma apparaît plus distinct, compte tenu des données relatives aux jours perturbés, mais les chiffres pour une année ne peuvent servir à faire disparaître toutes les crêtes réparties au hasard. Cette déficience de la statistique en ce qui concerne le troisième schéma est d'ailleurs conforme à la théorie d'Axford et Hines (1961).

Les tracés diurnes pour diverses composantes se ressemblent aux latitudes élevées tandis que la variation suivant la latitude des niveaux moyens d'activité de chaque composante est bien différente. Cette différence peut être attribuée en partie aux variables de l'induction, mais l'on peut en arriver à des approximations raisonnables de la grandeur des termes induits en supposant un modèle de sources prises au hasard.

Introduction

Whitham, Loomer and Niblett (1960) have described some results of an investigation of irregular magnetic activity in Canada using four months of simultaneous records from the IGY network of magnetic observatories and variation stations. This network was sufficiently dense, except in the polar cap, to outline the main features of the latitudinal distribution, the seasonal variations and the diurnal variations. Two important matters discussed in the earlier paper have now been investigated further. In the first place the anomalous level of irregular magnetic activity discovered at Alert, Ellesmere Island, has been studied both experimentally and theoretically, and a tentative explanation has now been given by Whitham and Andersen (1962). This phenomenon will not be considered again here. Secondly it was concluded earlier, from the principal horizontal component range data available, that only two regimes of magnetic activity (night-time and day-time) could be identified with certainty, and that the diurnal variation curves for monthly data were too variable and indented to identify unambiguously a second class of day-time activity reported in Russian work (Burdo, 1957). This suggested that it must be a very weak phenomenon, a point not clear in the Russian papers available to us.

Since the article by Whitham et al. (1960), Hope (1961) has written an account of high-latitude geomagnetic agitation following, in general, the morphological features suggested by the Russian work. On the other hand Green (1961) has independently discussed magnetic activity between Saskatoon and Churchill with results and conclusions similar to those given by Whitham et al. (1960): Green's data also demonstrates the great difficulty in deciding which maxima in the diurnal variation curves are significant. It is generally agreed that there are two major patterns of corpuscular precipitation and that the polar cap disturbance has a summer maximum whereas an equinoctial maximum is found in the auroral zone and to its south. There is less agreement, however, about the third pattern—its existence and its importance—although it is widely recognized that overlapping of the phenomena makes this disagreement difficult to resolve. A theoretical prediction of the mean loci of irregular magnetic activity has now been made by Axford and Hines (1961).

Since, as pointed out by Whitham et al. (1960), there is no theoretical basis for smoothing the data, it appeared worthwhile to use a comparatively large amount of observatory data to investigate the afternoon maximum, and its seasonal variations. The Canadian observatories are particularly well placed for such a study: e.g. a significant afternoon effect should be clear at Meanook to the south of the auroral zone because the expected separation of the day-time peaks should be close to a maximum there, and at Baker Lake in the transitional region between the auroral zone and the polar cap. At the same time, it was decided to investigate at each observatory each of the three orthogonal magnetic field components separately in order to avoid the confusion and assumptions which are found in the literature.

The results follow from an examination of the records for one year using hourly ranges to specify irregular magnetic activity. A physical interpretation of the use of the hourly range to specify the r.m.s. magnetogram noise in the component under study has been given by Whitham et al. (1960), and confirmed by Green (1961).

The Diurnal Variation of the Mean Hourly Ranges

The hourly ranges in gammas for each of three orthogonal components of the geomagnetic field were measured for the magnetic observatories at Victoria, Meanook, Churchill, Baker Lake and Resolute Bay, for the year 1960. The geomagnetic latitude of each observatory and the orthogonal components recorded are listed in Table I. Figures 1 to 5 show the mean hourly ranges R for each component plotted against local time, for the three seasons of the year and for the five observatories, for all days (A), for the international disturbed days (D), and for the international quiet days (Q). Figure 6 presents a summary for the year 1960 for all the observations for all days (A) and for the international disturbed days (D).

TABLE I

Observatory	Geomagnetic Latitude	Components Recorded
Victoria	54.3° N	H, D, Z,
Meanook	61.9° N	H, D, Z
Churchill	68.8° N	X, Y, Z
Baker Lake	73.9° N	X, Y, Z
Resolute Bay	83.1° N	X, Y, Z

Figure 6 can be used directly to describe the diurnal variations since the A curves are sufficiently smooth for clear interpretations, with the exception of the data from Victoria. The D curves however still contain insufficient data to smooth out completely the random effects. It is clear that data from more than sixty disturbed days would be necessary to do this. It should also be obvious that contamination of the range index with longer period diurnal variations is appreciable at Victoria where the level of irregular magnetic activity is not so high. For this reason, at Victoria the D curves only are used in the following discussion: in these curves the index is a more reasonable representation of irregular magnetic activity only.

It is obvious that the R_X or R_H diurnal curves most clearly illustrate the different maxima. These different maxima are summarized in Table II for all components. The afternoon maximum at Meanook and Churchill observatories is very weak and is visible in the summer and equinoctial months only. At Baker Lake it is impossible to use the seasonal relationship in Figure 4 to identify definitely the association of the peaks, barely resolved near noon, with one or the other of the day-time precipitation patterns. The afternoon maximum at Resolute Bay is associated arbitrarily with the morning effect in the auroral zone and to the south because it represents in the second group of columns in Table II the dominant day-time class reported by Whitham et al. (1960). Since the seasonal characteristics in Figures 1 to 5 are obscure it is quite possible that the best association of the different day-time maxima might be the reverse of that indicated. Both day-time maxima appear to be summer-equinoctial.

In any case, a very weak but apparently significant summer-equinoctial afternoon maximum can be deduced from the data for one year. This maximum is probably associated with fluctuations in the eastward electrojets which are stronger in the summer than in the winter.

The "nose-effect" in the time of the night-time maximum is confirmed in Figure 6: combining the results with those of Green (1961), the maximum departure to the east is found to occur near the latitude of Meanook. The magnitude of the effect is less than that reported by Burdo (1957).

The practice of summarizing high latitude geomagnetic activity by showing the loci of precipitation on polar plots is misleading. With such plots the large part of the disturbance which does not vary diurnally is neglected at the expense of maxima which may be only a few per cent above the ambient level. Also the obvious inequality of the maxima is implicitly neglected in such curves. For this reason, three polar plots of irregular magnetic activity showing the mean hourly range in gammas in three orthogonal components X, Y, and Z,

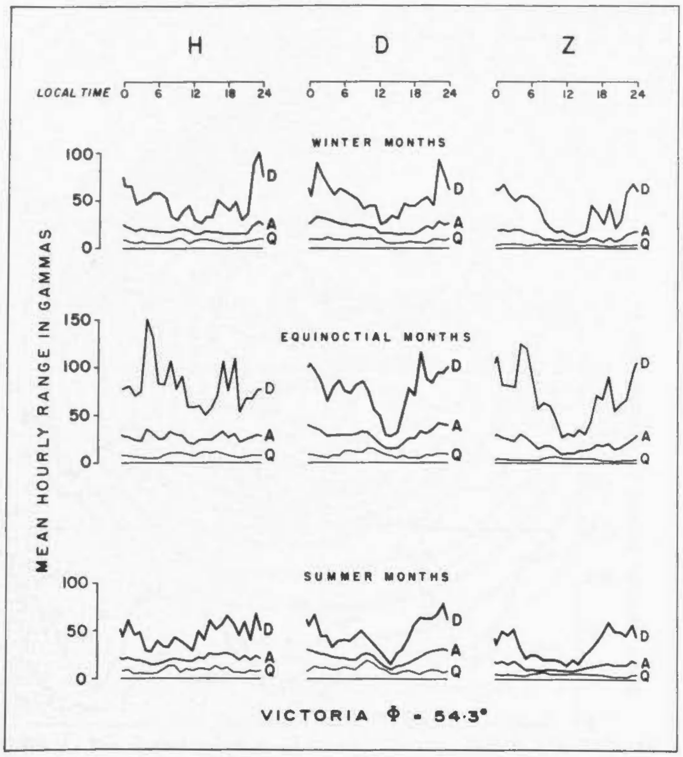

Figure 1. Irregular magnetic activity in three orthogonal components observed at Victoria magnetic observatory during 1960 for all seasons and three classes of days.

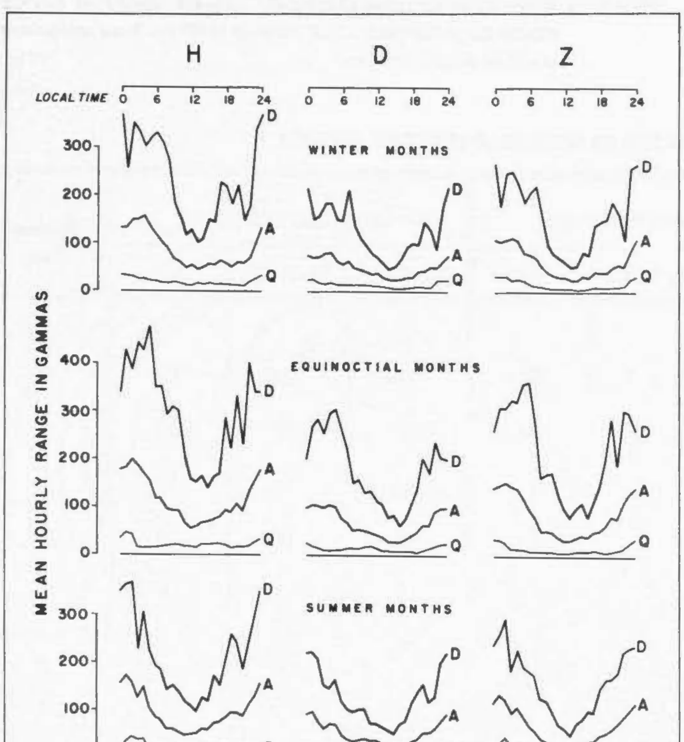

Figure 2. Irregular magnetic activity in three orthogonal components observed at Meanook magnetic observatory during 1960 for all seasons and three classes of days.

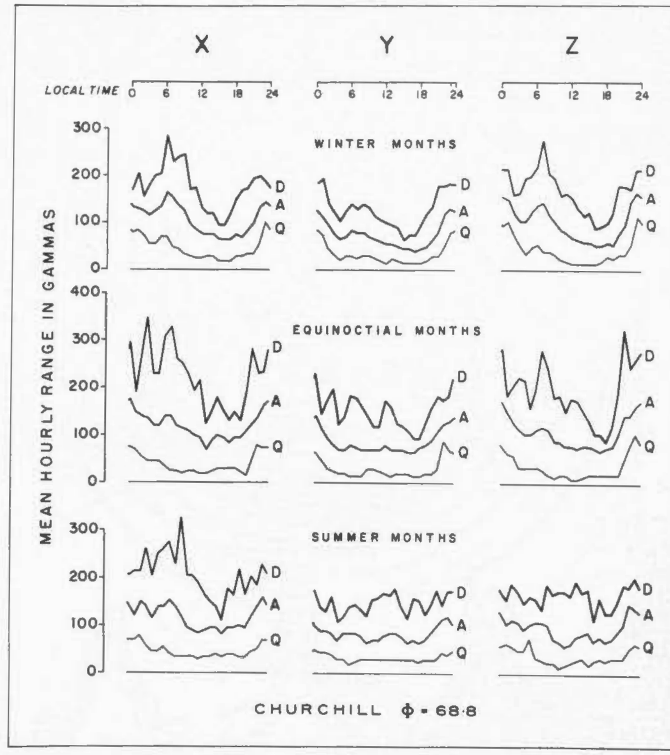

Figure 3. Irregular magnetic activity in three orthogonal components observed at Churchill magnetic observatory during 1960 for all seasons and three classes of days.

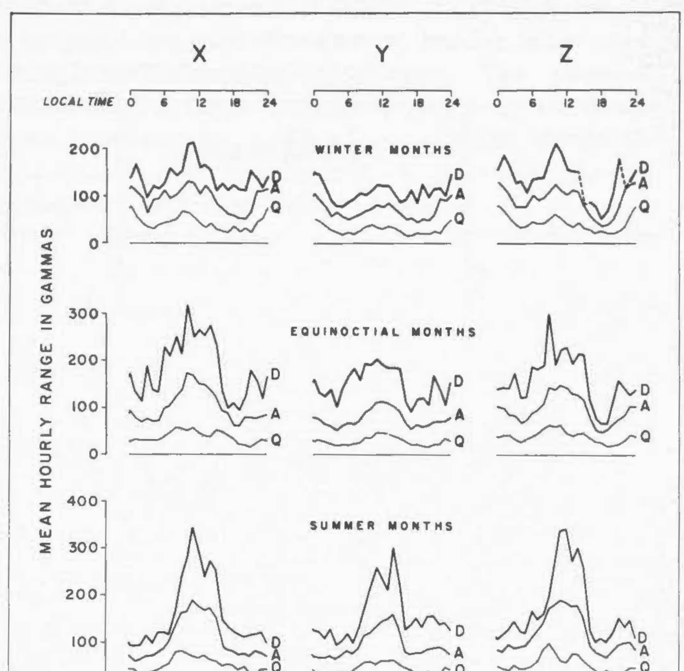

Figure 4. Irregular magnetic activity in three orthogonal components observed at Baker Lake magnetic observatory during 1960 for all seasons and three classes of days.

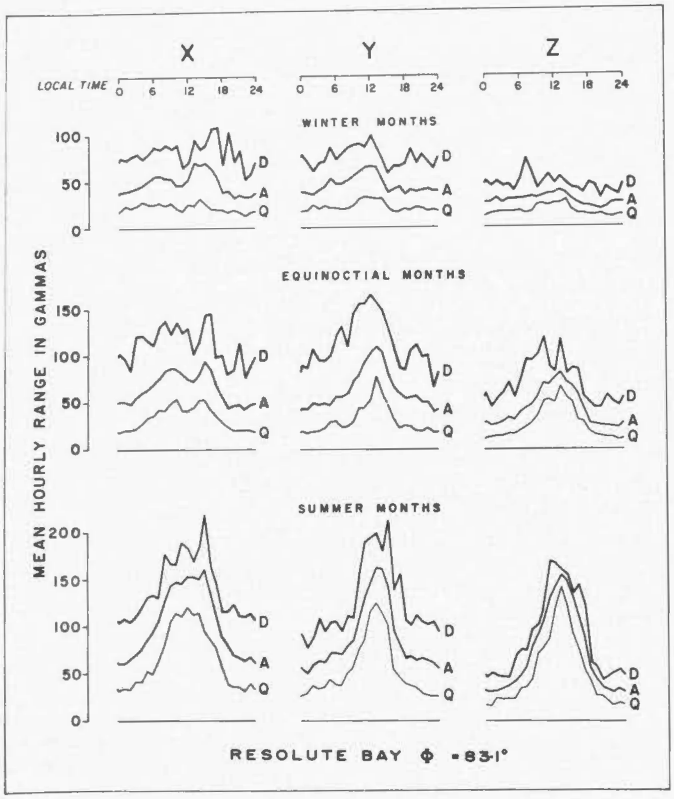

Figure 5. Irregular magnetic activity in three orthogonal components observed at Resolute Bay magnetic observatory during 1960 for all seasons and three classes of days.

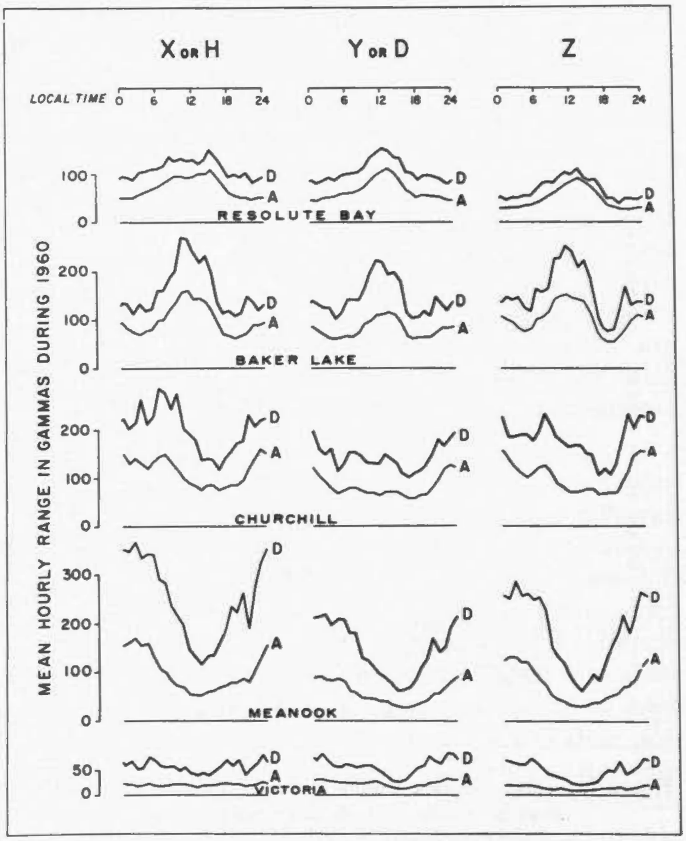

Figure 6. Summary diurnal plots of irregular magnetic activity at five Canadian magnetic observatories during 1960 for three components and two classes of days.

TABLE II—LOCAL TIMES OF SIGNIFICANT MAXIMA IN IRREGULAR MAGNETIC ACTIVITY

—	Night-time Maximum			Morning Maximum			Afternoon Maximum			Source Days
	R_X or R_H	R_Y or R_D	R_Z	R_X or R_H	R_Y or R_D	R_Z	R_X or R_H	R_Y or R_D	R_Z	
Victoria...........	23	23	23	04?	01?	04?	19?	19?	19?	D
Meanook..........	01-02	01	01	04	04	04	20	20	20	A
Churchill..........	23	23	23	07	07	07	15	14	15	A
Baker Lake........	24	24	23	11	u	11	13	13	u	A
Resolute Bay......				15	13	13	10	u	u	A

Symbol u stands for "unresolved in data".

are shown in Figures 7, 8, and 9. The contours show the mean activity for all days in 1960. It is realized that lack of detailed data leaves some details of the contour pattern ambiguous. The insignificance of the afternoon effect is obvious: the curve of corpuscular precipitation called the dominant day-time activity, outlined earlier by Whitham et al. (1960), merges with the night-time activity in the southern part of the auroral zone and is the outstanding feature of the three diagrams. These diagrams are in good general agreement with the theoretical predictions of the unifying theory of high latitude geophysical phenomena of Axford and Hines (1961).

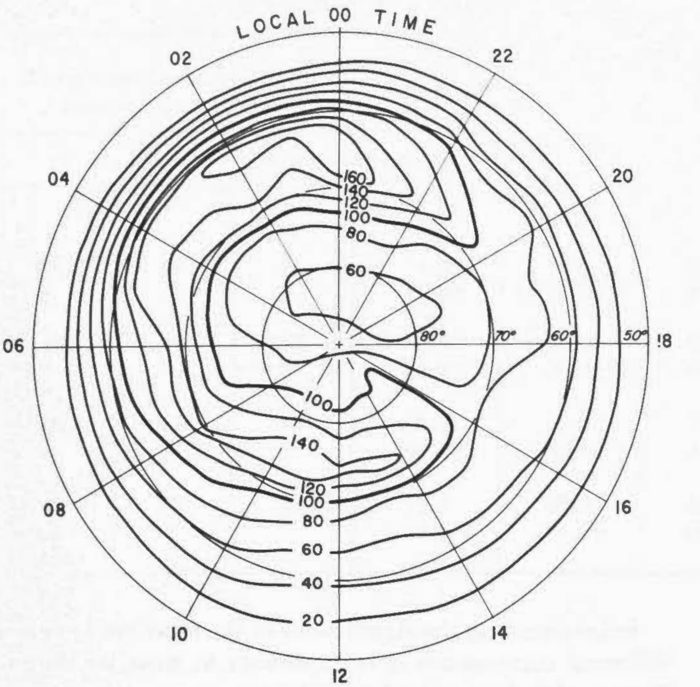

Figure 7. The diurnal variation of the mean hourly range in X (or H) for all days of 1960.

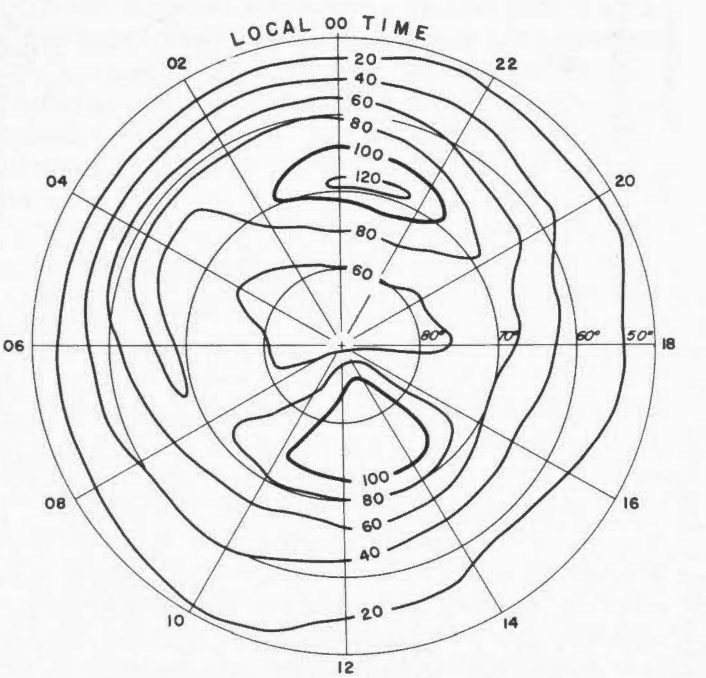

Figure 8. The diurnal variation of the mean hourly range in Y (or D) for all days of 1960.

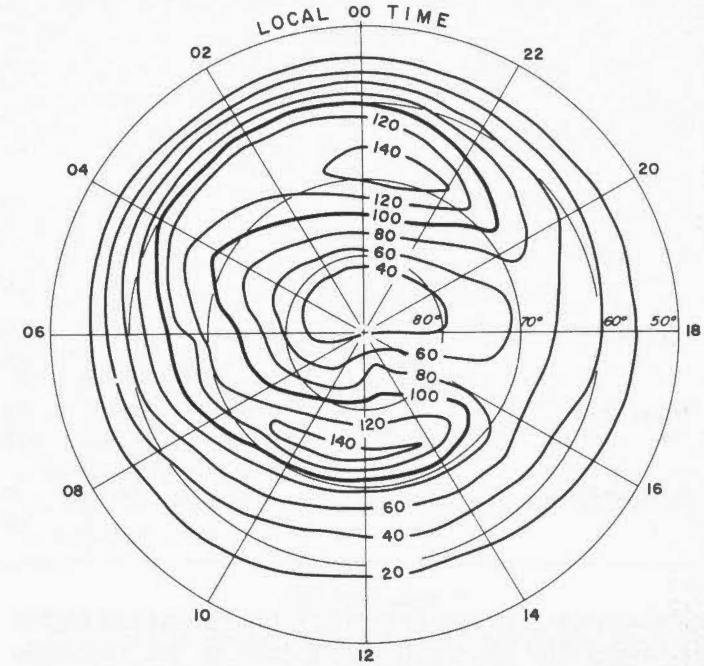

Figure 9. The diurnal variation of the mean hourly range in Z for all days of 1960.

Axford and Hines examined the patterns of convected turbulence mapped down the field lines to the ionosphere and showed that two particular regions can account for the night-time and dominant day-time patterns of irregular magnetic disturbance, besides other upper atmospheric disturbance phenomena. The afternoon patterns of Burdo, proved above to be very weak and almost non-existent on the all-day average, should not appear on the Axford and Hines model unless the convection in the magnetosphere is sufficiently strong in relation to rotation. This is exactly what is found in the magnetic data—only when convection is strong i.e. on disturbed days when the solar wind is strong, does the afternoon pattern appear. The seasonal associations remain as yet unexplained, but presumably follow from different geometrical considerations in the sun-earth environment in different seasons.

The Relations Between Different Components

Table III shows, for the auroral zone and polar cap stations, the mean hourly range for all days in 1960 for all three components, together with the standard deviation about the mean for the average diurnal variation of each component and the correlation between the diurnal variations of the mean hourly range for each pair of components.

The correlation between all pairs of components is high in these latitudes: the differences are barely significant statistically although the correlation between components with the greatest variance (usually X and Z) is

TABLE III—RELATION BETWEEN IRREGULAR MAGNETIC ACTIVITY IN DIFFERENT COMPONENTS

Observatory	Mean hourly ranges in gammas			Correlation coefficients			Standard deviations about daily mean in gammas		
	R_X or R_H	R_Y or R_D	R_Z	r_{XY} or r_{HD}	r_{XZ} or r_{HZ}	r_{YZ} or r_{DZ}	σ_X or σ_H	σ_Y or σ_D	σ_Z
Meanook	97	55	70	0.94 ±0.02	0.99 ±0.00	0.97 ±0.01	38	21	35
Churchill	113	80	100	0.73 ±0.10	0.92 ±0.03	0.91 ±0.03	27	19	29
Baker Lake	101	80	102	0.87 ±0.05	0.94 ±0.02	0.89 ±0.04	31	18	30
Resolute Bay	72	66	48	0.86 ±0.05	0.94 ±0.02	0.97 ±0.01	20	21	22

a maximum. The results prove that in auroral and higher latitudes the indefinite distinctions in the literature between different components are not important in the identification of significant diurnal maxima.

Maximum diurnal effects are found to the north and south of the centre of the auroral zone, as might be expected. Movement of the same current sources towards a station can cause an increase in activity, and consequently an increase in a vector range may not be a reliable indication of an increase in the number of sources near the auroral zone. Some attempts have been made to distinguish the two effects using plots of D day ranges minus expanded A day ranges, and attributing the differences to motion. Although the spatial resolution is poor, with Meanook, Churchill and Baker Lake only in or near the auroral zone, it appears that the centre of the increased activity does move significantly to the south: no clear northward movement is indicated by this method.

However, real differences do exist in the latitudinal distribution of the irregular magnetic activity in the different components. Figure 10, which shows these, confirms the pattern established by Whitham et al. (1960). The maximum agitation in the Y component is significantly smaller than that in the X component in the auroral zone, whereas near equality is suggested well inside the polar cap from the evidence of Whitham and Andersen (1962). In the auroral zone, the component results are consistent with the hypothesis that fluctuations in the magnitude of the SD current systems are more important than fluctations in direction.

Figure 11 shows the diurnal variation of the ratios of the mean range in different pairs of components. It is seen that when irregular magnetic disturbance is a minimum, Rx/Rz is a maximum i.e. the weak sources are more nearly uniformly distributed at all latitudes.

In interpreting the significance of the relations between different components it is important to consider the influence of induction in the conducting earth. It is impossible to determine the contribution from internal **and**

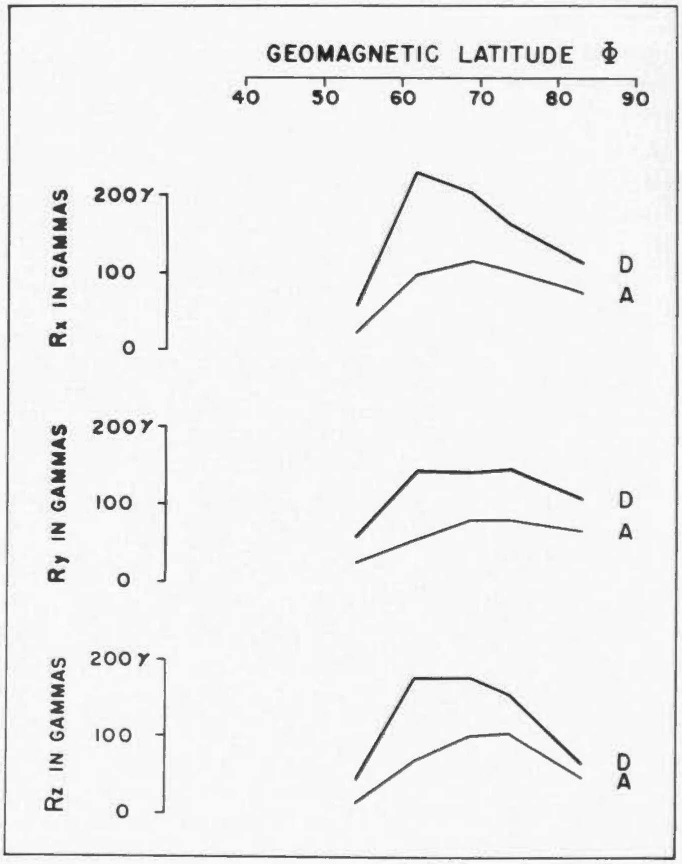

Figure 10. Summary plot of the latitudinal variation of irregular magnetic activity in 1960 deduced from five Canadian magnetic observatories for three components and two classes of days.

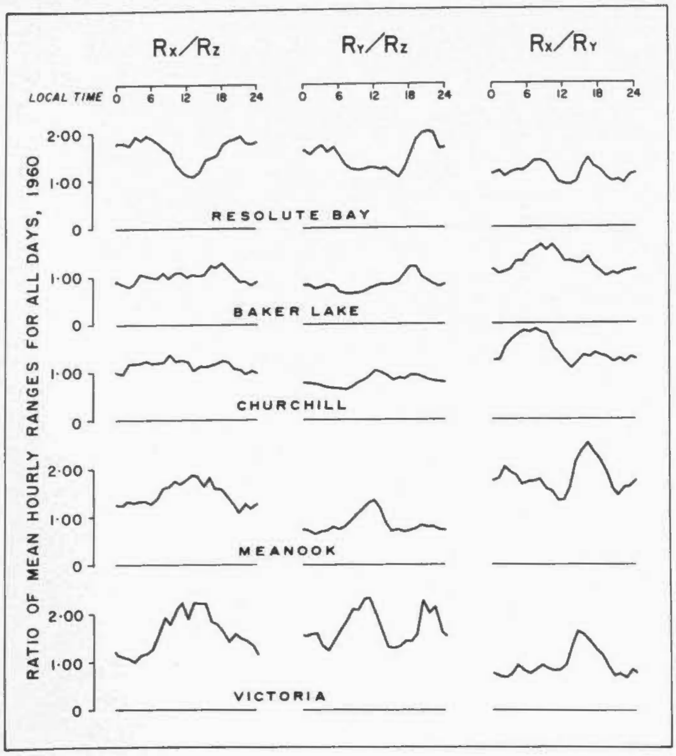

Figure 11. The diurnal variation of the ratios of the mean range for all days in 1960, for each pair of components at five Canadian magnetic observatories.

external sources by applying potential theory directly to the hourly ranges because sign is neglected in determining these. However, it appears possible to derive the approximate magnitude of the average induction corrections from the measured relationships between hourly ranges in different components. If random pole or dipole sources are assumed in the ionosphere, the ratio of the r.m.s. disturbance in the vertical field to that in either horizontal field component can be shown equal to $2^{\frac{1}{2}}$: 1. If the ratio of the induced to the inducing term is denoted by α and it is assumed that H observed = H external $(1+\alpha)$ and Z observed = Z external $(1-\alpha)$, then it is possible to determine the mean value of $1-\alpha/1+\alpha$, and hence the mean value of α. Using the range component ratios at times when R_X and R_Y are equal or most nearly equal, thus most nearly satisfying the source distribution assumed above, the mean value of α is about 0.4 to the south of the auroral zone, about 0.2 in the zone and about 0.3 inside the polar cap. Individual events may of course vary widely in the appropriate induced term because of their different frequency content. Although the magnitude of the correction deduced is reasonable it is not possible to assess the significance of the apparent change of mean α with latitude, since the average spectral content of longer period magnetic disturbance at high latitudes is not known. For the longer diurnal periods α is usually taken to be 0.3 to 0.4 in auroral latitudes and about 0.1 in the polar cap (Vestine et al. 1947). However, Akasofu and Chapman (1960) assumed $\alpha = 0.5$ in estimating individual D_p magnetic disturbance vectors between latitudes $\pm 50°$. None of these results is in basic disagreement with the values derived here using the above simplifying assumptions.

A more exact determination by statistical means is not possible since the interaction of the distribution of the primary sources field with the conductivity and its variation with depth and with the spectral content of the event must be considered separately for each event in any rigorous theory. Because of the large separation of the five observatories and the complicated source field distributions observed in the auroral zone, it is impossible to use these results to confirm or deny the existence of anomalous regions of conductivity at or near the five magnetic observatories. For this purpose the IGY network and analysis of individual events would be preferable.

Conclusions

1. Only two major patterns of high-latitude corpuscular precipitation can be clearly defined, in agreement with earlier work. One of these patterns is usually referred to as night-time activity and is dominant to the south of the auroral zone; the second pattern is a daytime activity whose local time of maximum occurrence increases with increasing latitude.

2. A third pattern of precipitation, postulated in Russian work, is found to be very weak, can scarcely be identified in the average for one year, and appears most clearly in the data for disturbed days. The statistical weakness of this third pattern is in agreement with the theory of Axford and Hines (1961).

3. The diurnal properties in different components are shown to be similar at Canadian latitudes.

4. Using the statistical properties of irregular magnetic activity in different components and a random source model, no clear evidence can be found for anomalous regions of conductivity at or near Victoria, Meanook, Churchill, Baker Lake, and Resolute Bay magnetic observatories. However, the method used requires the adoption of a number of simplifying assumptions, and is not capable of very great sensitivity.

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