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Current Flow in Auroral Forms Responsible for Ps 6 Magnetic Disturbances

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Abstract. In this paper we use magnetometer and riometer data from an east-west station array to evaluate the location of energetic (keV) electron precipitation with respect to the region of equatorward ionospheric current flow responsible, in part, for Ps 6 magnetic disturbances. Using cross-correlation techniques we show that, for clear cut cases, the region of maximum energetic electron precipitation is colocated with the region of equatorward ionospheric current flow responsible for the positive *D*-component perturbation characteristic of the Ps 6 disturbance. This observation is consistent with the model of Kawasaki and Rostoker (1979) for Ps 6 disturbances which attributes the magnetic perturbation to a longitudinally localized three-dimensional current system involving anti-parallel Birkeland current sheets linked by an equatorward ionospheric current.

Key words: Aurora – Ps 6 magnetic disturbance – Auroral electrojet – Three-dimensional current system

Introduction

Ps 6 disturbances are normally seen as quasi-periodic pulses in the auroral zone magnetic field which occur at times of intense auroral electrojet activity. The disturbances have their maximum occurrence frequency at approximately local magnetic dawn (Rostoker and Barichello 1980) and tend to be detectable more often in the summer months than the winter months. Their quasi-periodic nature has caused some researchers to class them as magnetic pulsations (Saito 1978), however a Ps 6 disturbance may occur as an isolated spike so that it may be more correct to regard them as impulsive localized perturbations of the westward auroral electrojet.

Figure 1 shows a typical example of a sequence of Ps 6 disturbances recorded on 27 October 1977 over the Alberta sector. The geomagnetic coordinates and code names of the stations are listed in Table 1. There are three episodes of Ps 6 activity over this day. The first involves an interval from 1100–1215 UT during which severall events occurred in a quasi-periodic fashion. The second

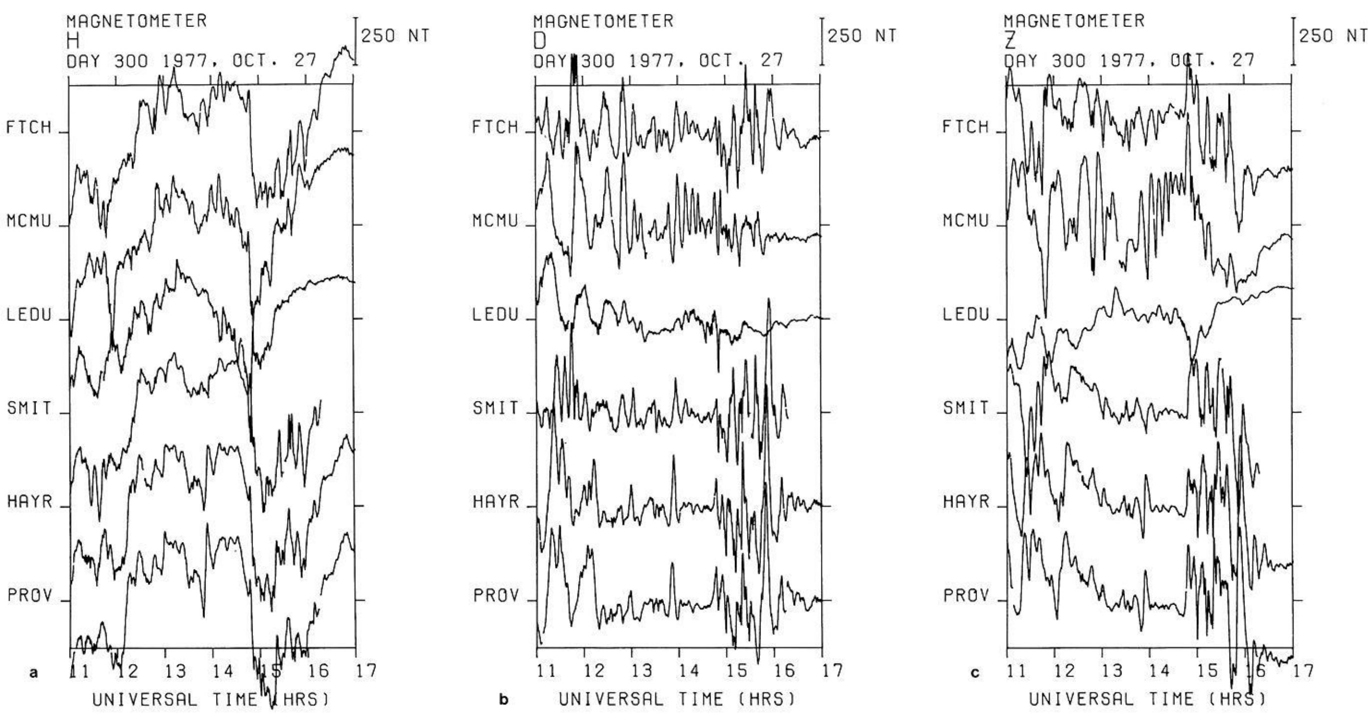

Fig. 1a–c. Magnetograms for 27 October 1977 recorded at stations in the Alberta array. Station coordinates and code names are shown in Table 1. **a** *H*-component; **b** *D*-component; **c** *Z*-component

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Table 1. Geomagnetic coordinates and code names of stations in the Alberta array

Station	Code name	Geomagnetic	
		Latitude (°N)	Longitude (°E)
Fort Providence	PROV	67.5	292.0
Hay River	HAYR	67.3	294.3
Fort Smith	SMIT	67.3	300.0
Uranium City	URAN	67.4	304.3
Fort Chipewyan	FTCH	66.3	302.1
Fort McMurray	MCMU	64.2	303.5
Leduc	LEDU	60.6	302.9

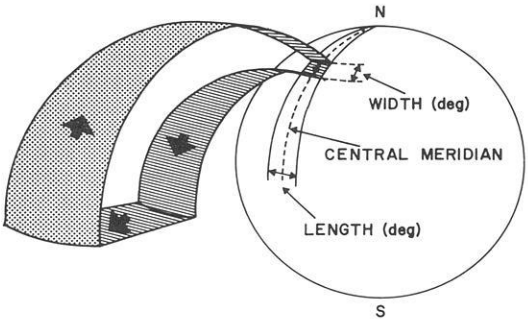

Fig. 2. Three dimensional model current system proposed by Kawasaki and Rostoker (1979) to explain Ps 6 disturbances (after Kisabeth and Rostoker 1977)

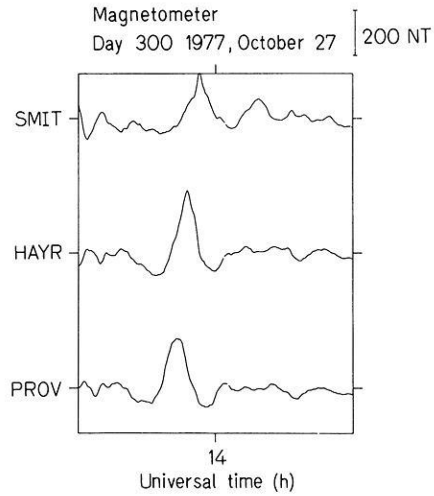

Fig. 3. *D*-component records from the east-west arm of the Alberta array for an expanded time scale of 1 h centered on 1400. The Ps 6 is clearly evident just prior to 1400 with the delay in response from *PROV* to *SMIT* of 4.9 min pointing to an eastward propagation velocity of ~1.2 km/s

episode involves a single isolated Ps 6 event occurring near 1400, while the third episode involves another sequence of quasi-periodic variations from 1440–1620. In keeping with the characteristic behavior of Ps 6 disturbances, most of the perturbation is in the *D*- and *Z*-components with relatively little in the *H*-component. Nonetheless, the negative *H*-perturbation prevailing during the Ps 6 events indicates the presence of significant westward electrojet current flow over the stations of PROV, HAYR and SMIT.

Both Kawasaki and Rostoker (1979) and Baumjohann (1979) have associated Ps 6 disturbances with auroral Ω-bands in which there is a strong equatorward ionospheric current flow. Kawasaki and Rostoker (1979) have estimated the east-west scale size of the current carrying region to be of the order of 5°–10° at 67.5° N, with the location of the equatorward current flow drifting eastward at ~ 0.8–$2.0\ \mathrm{km\ s^{-1}}$. The actual best model of the current system responsible for these perturbations has recently been the topic of some controversy. Kawasaki and Rostoker (1979), based on a limited amount of riometer data, concluded that energetic electron precipitation was maximal in the region of maximal equatorward ionospheric current flow, which led them to a model current system of the type shown in Figure 2. In this model it is suggested that either; (i) A patch of precipitating energetic electrons drifts eastward through a region of southeastward directed electric field under the combined influence of gradient and $\mathbf{E}\times\mathbf{B}$ effects; (ii) The electric field which is normally southward is perturbed toward the southeast over a time scale of a few minutes, after which it returns to its southward configuration. The region in which the perturbation takes place has a high background ionospheric conductivity; (iii) The arrival of a patch of precipitating energetic particles coincides with a southeastward perturbation of the electric field.

The key point to which this model addressed itself was the fact that Ps 6 disturbances do not significantly influence the *H*-component of the field. This strongly suggested that the perturbation is due primarily to equatorward current flow.

More recently Gustafsson et al. (1981) have suggested that Ps 6 disturbances are due solely to ionospheric Hall currents, based on the contention that the energetic electron precipitation coincides with a region to the east of the equatorward ionospheric current flow. They claim that the Ps 6 disturbance is caused by the development of an eastward electric field component which drives an equatorward Hall current that closes through the ionosphere in the region of enhanced conductivity due to precipitating electrons. The purpose of this paper is to study, in detail, several Ps 6 disturbances using both ground magnetometer and riometer data to investigate the location of the precipitating energetic electrons with respect to the region of equatorward ionospheric current flow.

Presentation of Data

We shall present data from two separate days which contain four distinct intervals of Ps 6 activity. For each event we shall present detailed plots comparing the positive *D*-component perturbation and the riometer perturbation associated with that event. We shall then present the cross-correlation between the riometer and *D*-component magnetometer, from which quantitative estimates of the displacement of the *D*-component peak and the maximum riometer deflection will be derived.

The first event we shall present is an isolated Ps 6 event which occurred just prior to 1400 UT on 27 October 1977. The normal magnetograms for the Alberta array stations are shown in Fig. 1. The event is clearly visible in the *D*-component at PROV, HAYR, and SMIT. However the degree to which these disturbances can be spatially localized is clearly evident in comparing the perturbation patterns at PROV, HAYR, and SMIT with those at the stations of FTCH and MCMU just to the south. It is interesting to note the extremely large amplitude Pc 5 oscillation at MCMU which is barely detectable along the east-west line (PROV, HAYR,

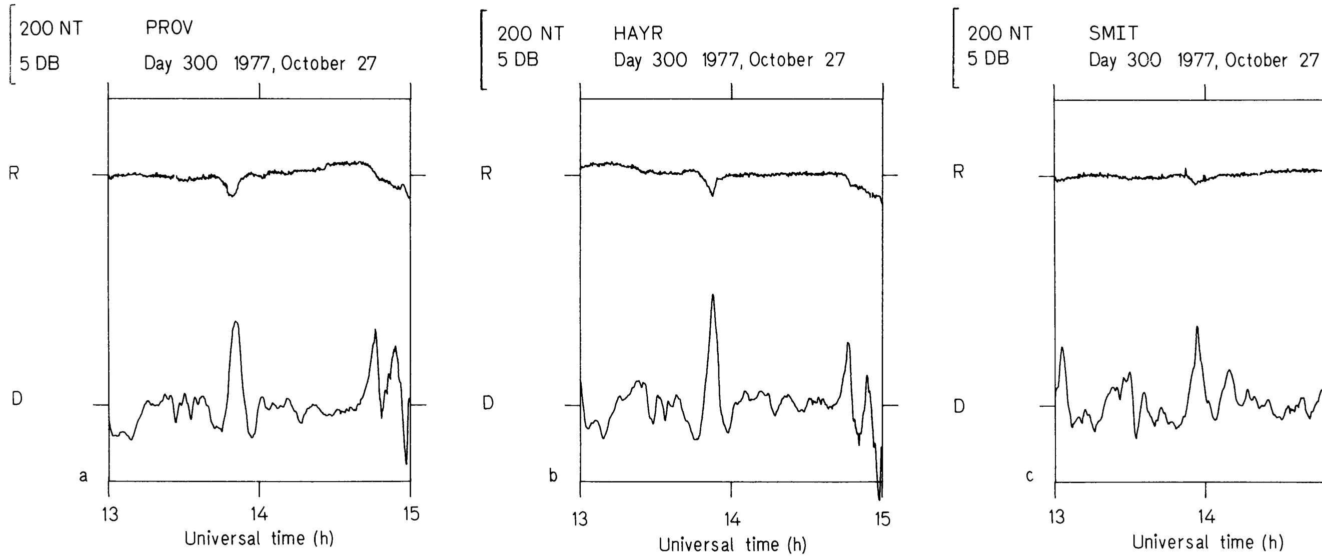

Fig. 4a–c. Riometer and *D*-component perturbations recorded on 27 October 1977. **a** at PROV; **b** at HAYR; **c** at SMIT

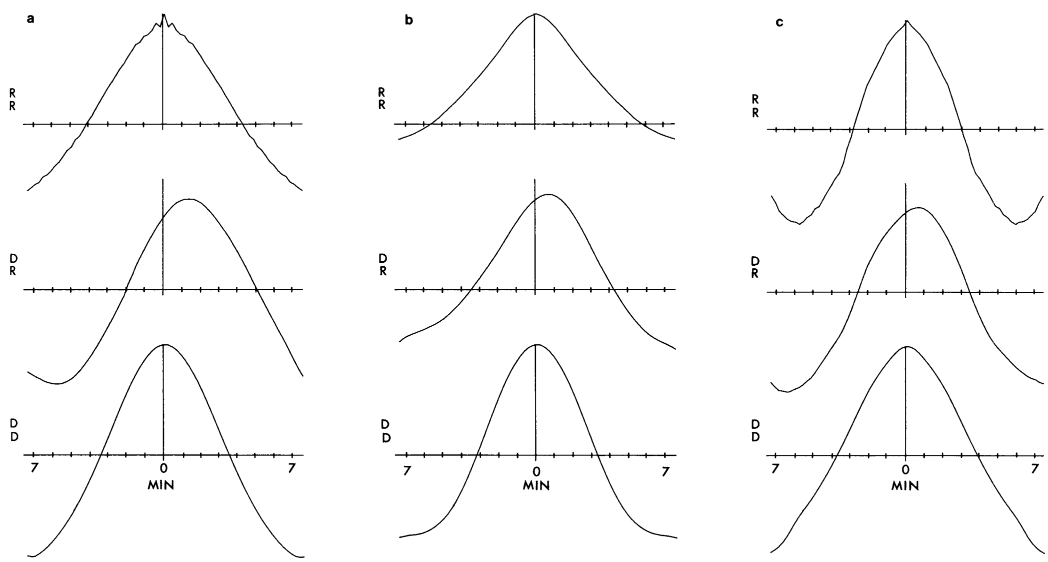

Fig. 5a–c. Cross-correlation function and autocorrelation functions for the riometer and *D*-component disturbances over the interval 1345–1400 on 27 October 1977. The number 35 refers to the number of data points used, the sample interval being 12.8 s. Any ramps in the original data have been removed during the course of the analysis. **a** at PROV; **b** at HAYR; **c** at SMIT and over the interval 1348–1403. The interval is changed slightly to take into account the propagation of the disturbance

SMIT). It is quite possible that the same occurrence which triggered the Ps 6 was responsible for providing the energy for the resonant oscillation near MCMU. Figure 2 shows the east-west line *D*-component data for the hour centered on 1400. The delay times for the appearance of the *D*-component peaks clearly indicate propagation from west to east, in accordance with the results of Kawasaki and Rostoker (1979). Figure 4 shows a detailed comparison between the *D*-component and riometer traces at PROV, HAYR, and SMIT. It is clear that there are well defined riometer responses associated with each *D*-component pulse and that the event maintains its structure over the 8° between PROV and SMIT. Finally we show in Fig. 5 the cross correlations between the *D*-component and riometer time series for PROV, HAYR and SMIT as well as the autocorrelations (which serve to demonstrate the degree of noisiness of the data). It can be seen that, for all three stations, the riometer leads the *D*-component of the magnetometer. This would imply that the precipitation starts slightly in advance of the buildup in equatorward current. However the actual delay times are 1.3 min for PROV, 0.6 min for HAYR and 0.6 min for SMIT. In light of the fact that the *D*-component has positive values above 50% of its maximum achieved value for a period of $\sim 4\,^1/_2$ min, it is apparent that the delay between the *D*-component peak and riometer maxima is rather small. On the basis of this event, we would suggest that the *D*-component peak (and therefore the region of equatorward flowing ionospheric current) is approximately coincident with the region of energetic electron precipitation.

We now consider a second event which consists of a series

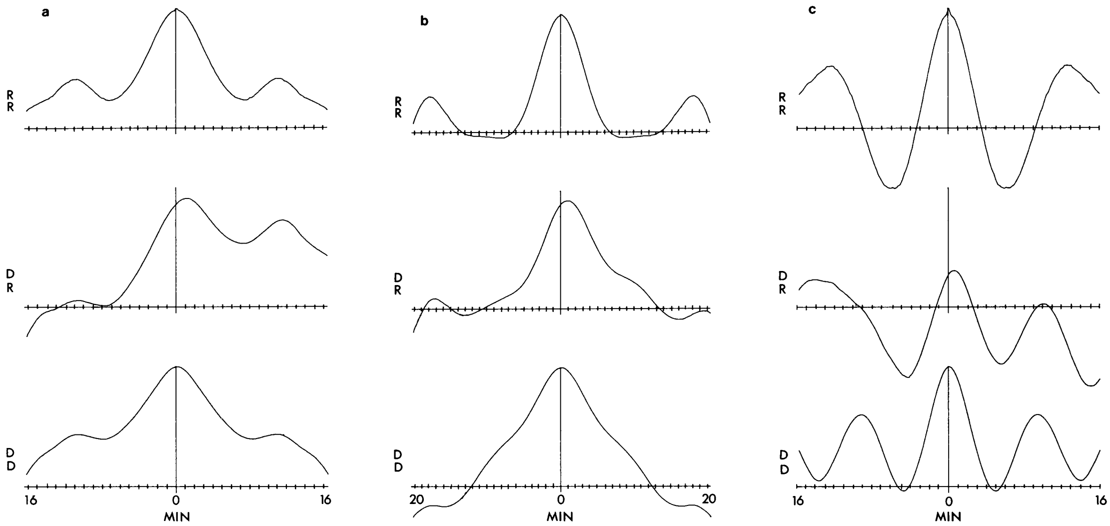

Fig. 6a–c. As Fig. 5 but for different time interval. **a** at PROV, 1109–1142; **b** at HAYR, 1105–1146; **c** at SMIT, 1116–1148

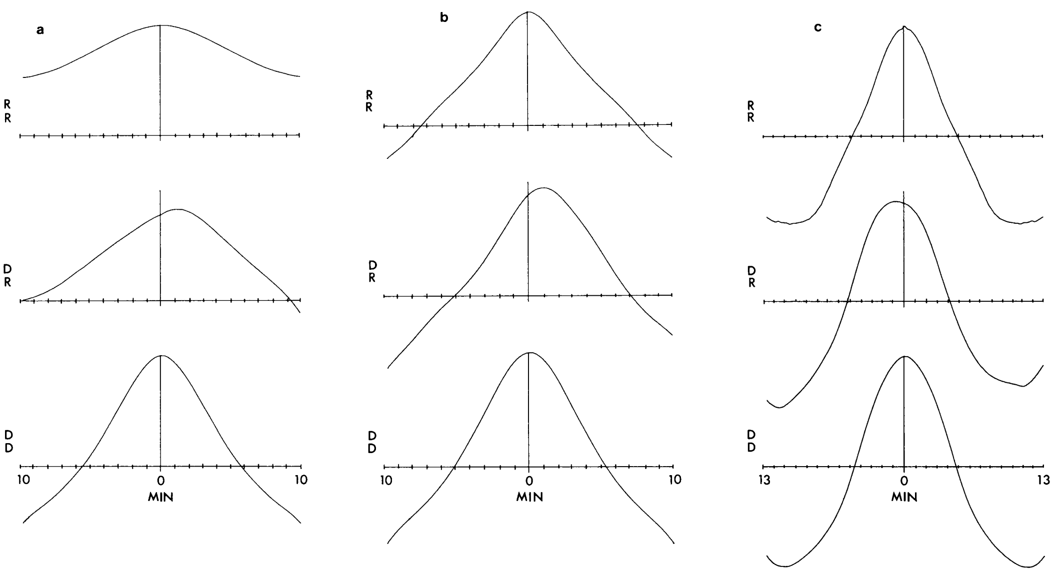

Fig. 7a–c. As Fig. 5 but for different time interval. **a** at PROV, 1540–1600; **b** at HAYR, 1540–1600; **c** at SMIT, 1540–1606

of Ps 6 disturbances which occur over the interval 1100–1215 on 27 October 1977. Figure 6 shows the cross-correlation and autocorrelation functions for the *D*-component and riometer time series for the stations of PROV, HAYR, and SMIT For this case there is more than one peak in the autocorrelation function, indicating that more than one Ps 6 spike occurred in the interval over which the cross-correlation funds are computed. The form of the cross-correlation function changes from station to station in this case, indicative of the fact that the perturbation pattern changes significantly over the east-west extent of the array. However the central peak is well defined in all cases, and indicates that the riometer leads the *D*-component magnetometer trace by 1.1 min at PROV, 0.9 min at HAYR and 0.7 min at SMIT Once again we would contend that the *D*-component positive peak and the riometer maximum are effectively coincident.

Our third event consists of a series of Ps 6 disturbances which occur over the interval 1440–1620 on 22 October 1977. Figure 7 shows the cross-correlation and autocorrelation functions for the *D*-component and riometer time series for the stations of PROV, HAYR, and SMIT The location of the peak in the cross-correlation function varies around the zero-lag marker. The riometer leads the *D*-magnetometer disturbance by 1.1 min at PROV and by 1.1 min at HAYR while it lags the *D*-disturbance by 0.7 min at SMIT Again we would claim that the *D*-component positive peak and the riometer maximum are coincident. We point out that the coincidence between the positive *D*-component peak and the riometer maximum is observed both early in the morning sector ($\sim$1100) as well as later ($\sim$1600).

To conclude this section on the observations, we present data from 30 January 1977 to demonstrate the variability of Ps 6 signatures over an east-west extent of $\sim 12°$ at auroral zone latitudes ($\sim 67.5°$ N). Figure 8 shows the magnetograms over the morning hours in the Alberta sector. While we shall analyse the event visible at PROV shortly after 1,400 (and at SMIT and URAN at slightly later times due to the propagation effect), it is useful at least to mention the fact that some disturbances do not maintain their structure across the array. For example, there is a clear sequence of three Ps 6 pulses at URAN between 1345 and 1415

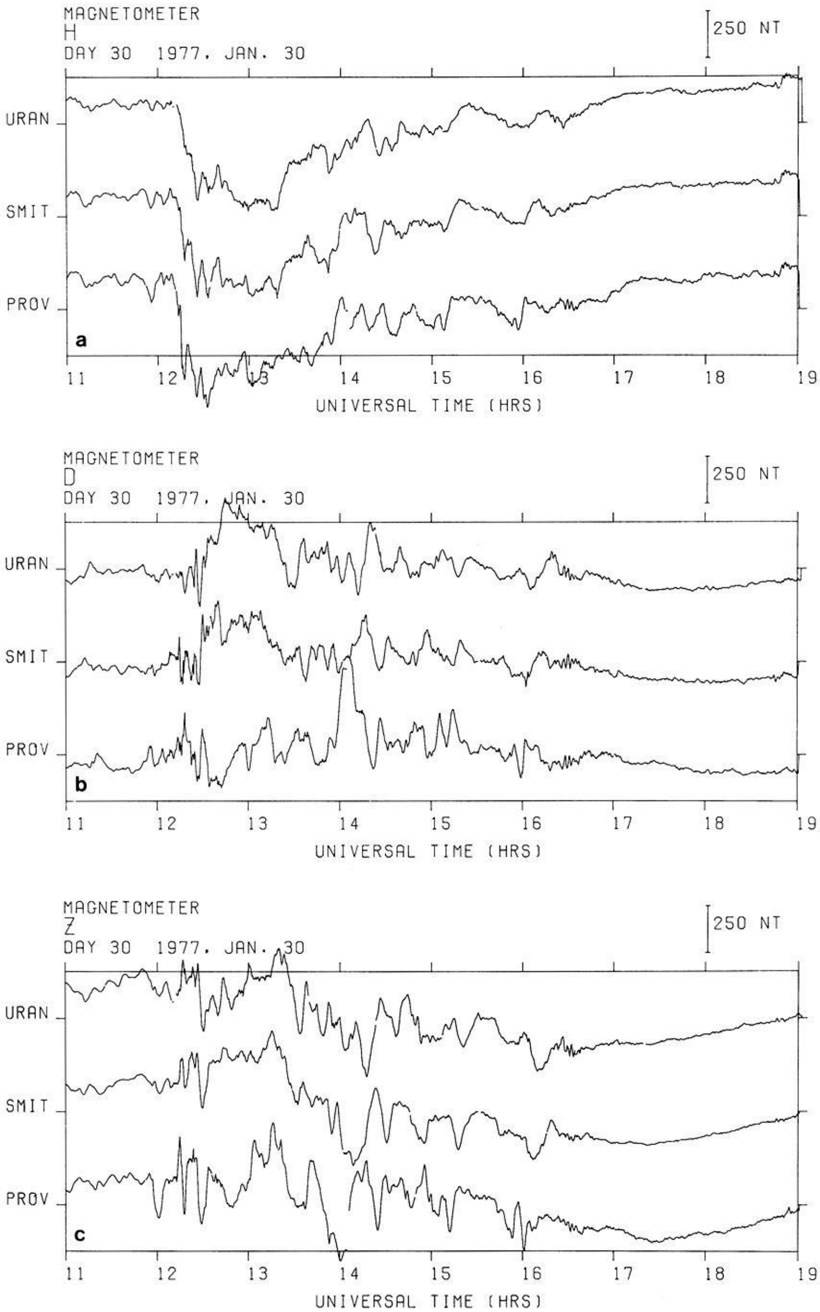

Fig. 8a–c. Magnetograms for 30 January 1977 recorded at stations along the east-west arm of the Alberta array. Station coordinates and code names are given in Table 1. **a** *H-component;* **b** *D*-component; **c** *Z*-component

with a corresponding structure being identifiable at SMIT. However, at PROV at least one of the three pulses is absent. Another example of such longitudinal localization can be seen by examining the two Ps 6 pulses observable at PROV shortly after 1,500. At least one of these pulses has vanished by the time the disturbance reaches SMIT. We can therefore see that the observation of a Ps 6 at a given longitude does not guarantee the continued existence of the structure as little as 5° of longitude away.

Continuing with the analysis of this day, we show in Fig. 9 the *D*-component disturbance and the riometer response on an expanded scale over the two hour interval centered on 1400. Clearly the magnitude of the *D*-component perturbation drops by a factor of ~ 2 from PROV to SMIT and the clear riometer response at PROV is complemented by a barely visible response at SMIT. The cross-correlation and autocorrelation functions for the *D*-component and riometer time series are shown in Fig. 10. While the PROV cross-correlation function peaks at zero lag (indicating that the peak *D*-component perturbation occurs at the time of maximal riometer response), the response at SMIT is rather different with the riometer appearing to lag the *D*-component by 3.4 min. This indicates that the energetic electron precipitation does not always correspond clearly to the region of maximum equatorward ionospheric current flow. In this particular case we note that the riometer response at SMIT is barely (if at all) identifiable. It is indeed possible that the cross-correlation function is dominated by the general cosmic noise absorption background in this case, rather than by a burst of electron precipitation associated with the Ps 6 disturbance. Nonetheless, this event points to the fact that caution must be exercised in comparing riometer and magnetometer data even when array data are available.

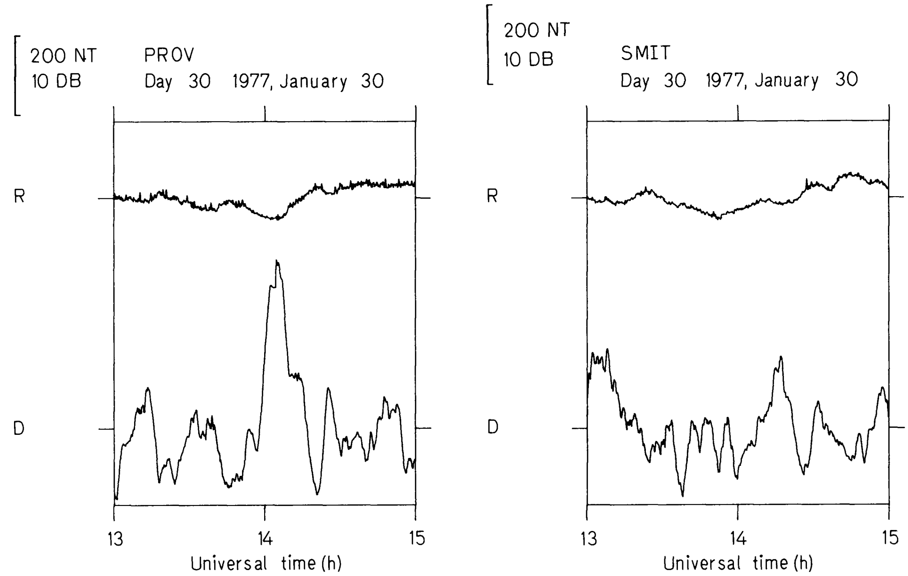

Fig. 9a, b. Riometer and *D*-component perturbations recorded on January 30, 1977. **a** at PROV; **b** at SMIT

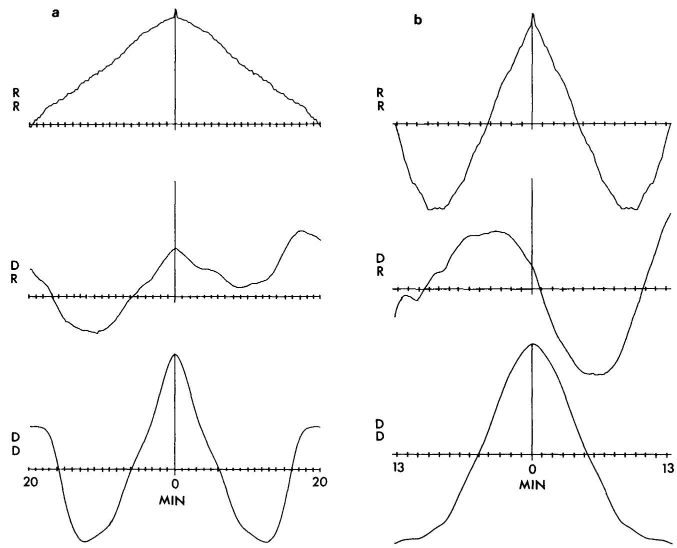

Fig. 10a, b. As Fig. 5a but for 30 January 1977. **a** at PROV; **b** at SMIT

Discussion and Conclusions

In this paper we have shown that the region of maximum equatorward ionospheric current flow in a Ps 6 disturbance occurs, in most cases, in the same region of space where the energetic electron precipitation maximizes. This is not in agreement with the observations of Gustafsson et al. (1981) but is in accord with the earlier contentions of Kawasaki and Rostoker (1979). We should like to note however, that we are still not in a position to distinguish uniquely between the real current systems proposed by Gustafsson et al. and Kawasaki and Rostoker. The results of Gustafsson et al. pointed to maximal electron precipitation in the region adjacent to the region of maximum equatorward current flow, and therefore they concluded that the southward ionopheric current was part of an ionospheric Hall current cell with poleward Hall current flowing both to the east and west of the equatorward current flow. Our results disagree with the observations of Gustafsson et al. but cannot disprove their model. It is possible, for example, that less energetic electron fluxes precipitate to the east and west of the region of equatorward current flow. Large fluxes of electrons having energies of a few keV can strongly influence E-region conductivity while barely penetrating to the D-region (which has the most influence on cosmic noise absorption). In fact, the only difference between the two models in question lies in the behaviour of the ionospheric equatorward current as it approaches the equatorward boundary of the auroral oval. In the model of Kawasaki and Rostoker, the ionospheric current would diverge up the field lines into the magnetosphere while in the model of Gustafsson et al. the current would be deflected to the east and to the west, eventually forming closed Hall current cells in the ionosphere. It is important to note that the model current systems in question produce effectively the same horizontal magnetic perturbation pattern at the earth's surface. Only the vertical component of the perturbation field could distinguish between the models, with the model involving ionospheric closure currents being expected to show weak *Z*-component edge effects associated with the northward Hall currents on either side of the heart of the Ps 6 disturbance region. Such edge effects would be extremely difficult to identify in a disturbed auroral oval, typical of the conditions in which Ps 6 disturbances occur.

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