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AVERAGED PATTERN OF IONOSPHERIC ECHO REGION AND CONVECTION: INITIAL RESULTS FROM THE SYOWA STATION HF RADAR

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Abstract: We present initial results of the HF radar observations at Syowa Station, which started its operation in April 1995, as one of the SuperDARN radars. We give results for 30 days in September 1995, when the radar took the data under good operational conditions. In the analysis we use the SMR (summary) data which was obtained on a beam aligned in the geomagnetic north-south direction. During quiet periods, the echo regions show a pattern similar to a quiet auroral oval, indicating that most of ionospheric irregularities are caused by an auroral particle precipitation and/or strong electric fields. As the geomagnetic activity increases, the echo regions expand to lower latitudes and the velocity amplitudes increase. In general, the Doppler velocity pattern clearly shows a two-cell convection.

1. Introduction

An observation of ionospheric plasma drift patterns is very important for the study of a magnetosphere-ionosphere coupling. There are a number of studies in the statistical convection patterns derived from electric field data, such as from the polar-orbiting satellite DE-2 (*e.g.*, HEPPNER and MAYNARD, 1987) and from the incoherent scatter radar (*e.g.*, SENIOR *et al.*, 1990). One important point is that the ionospheric and magnetospheric dynamics are highly sensitive to changes of the solar wind that is always variable. Therefore, it is crucial to observe a two-dimensional distribution of the ionospheric plasma drifts in order to study spatial and temporal changes of the convection. The shortcoming of the above observation is that those give very limited information on the separation of spatial-temporal changes.

Recently HF-radars have been regarded as a powerful tool for investigating ionospheric plasma drift patterns (GREENWALD *et al.*, 1995). Its main advantage over other methods is that HF radars can explore the ionosphere over a very wide area within a relatively short scanning time. The SuperDARN project has recently started and several radar facilities have been operating in both the northern and southern hemispheres.

The Syowa Station radar, which is the second HF radar in Antarctica, was proposed by OGAWA *et al.* (1989, 1990) and started in late April 1995 to acquire data. In this paper we report some initial results from this radar. Particularly, we want to know the spatial and temporal distributions of the echo region and of the Doppler velocity as well as their dependence on geomagnetic activity. HANUISE *et al.* (1991) made a statistical analysis of the high-latitude *E*-region Doppler spectra obtained with the SHERPA HF radar data. However, there have been very few statistical studies on the *F*-region Doppler spectra based on HF radars. In this study we will focus on the echo characteristics from the *F*-region ionosphere.

2. Data

Because of the limited capability of the data transmission link between Syowa Station and the National Institute of Polar Research, Tokyo, most of the data that we have is so-called 'summary data', that is, specific one-beam data as a function of time and range. The summary data were obtained on Beam No. 15 which is

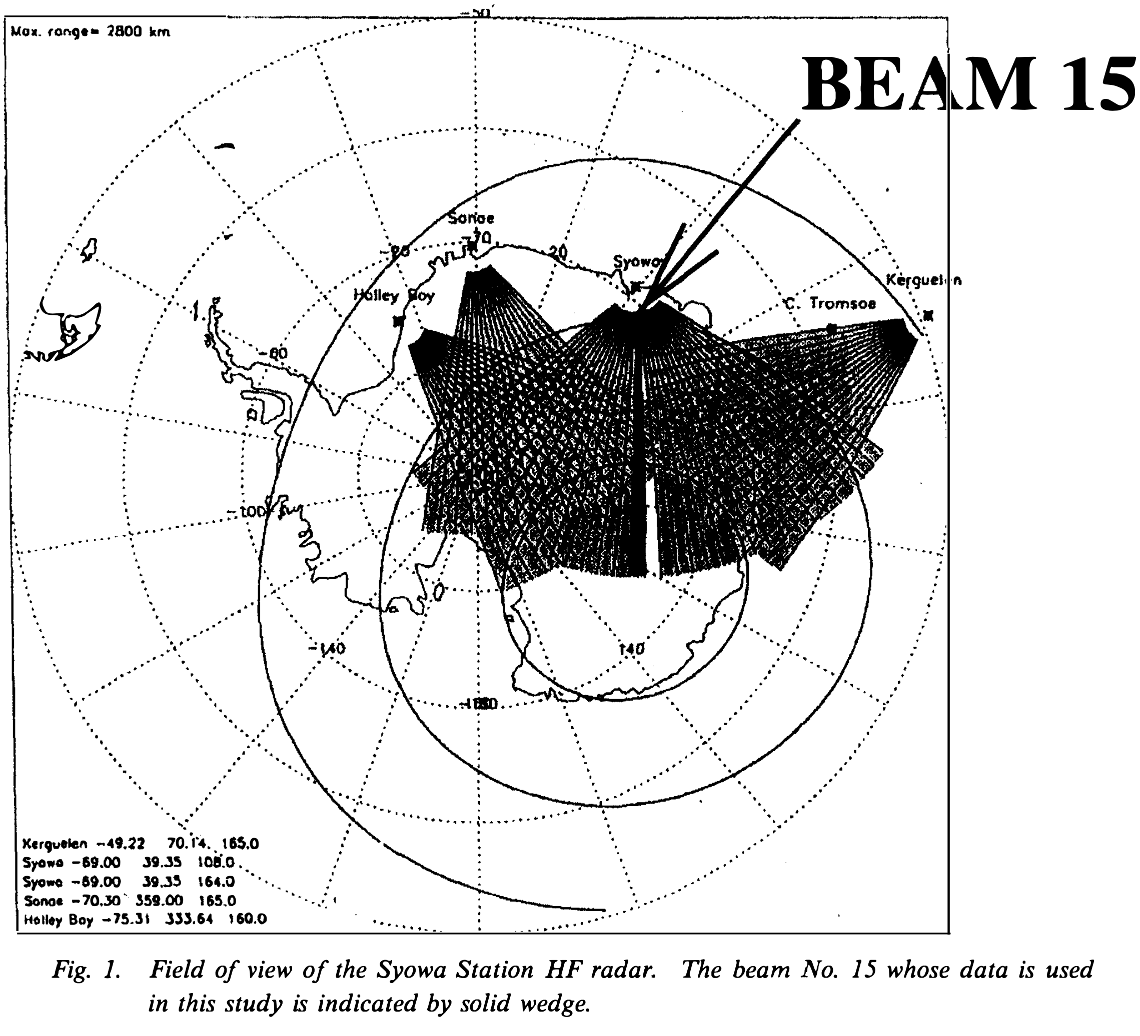

Fig. 1. Field of view of the Syowa Station HF radar. The beam No. 15 whose data is used in this study is indicated by solid wedge.

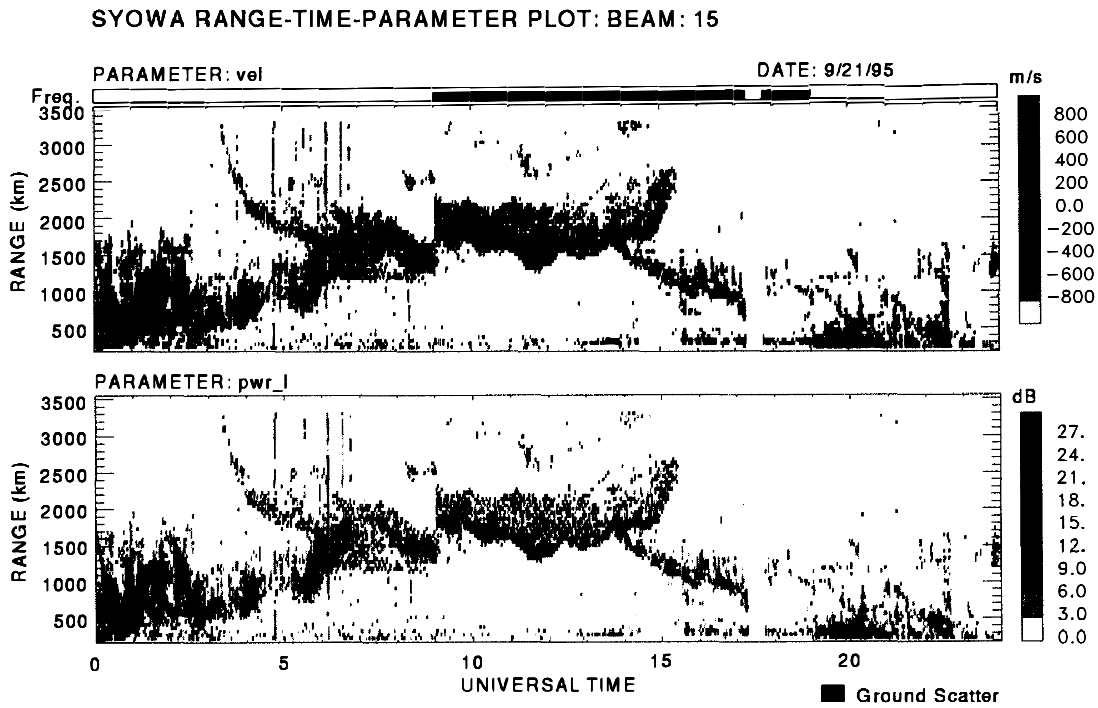

Fig. 2. One-day profile of the SMR (summary) data. The upper and lower panels show line-of-sight Doppler velocity and echo power, respectively, as a function of universal time and range from the radar site. The ground-scatter echoes are indicated by green color. The radar wave frequency is also illustrated by the color code (yellow: 9 MHz; purple: 19 MHz).

approximately aligned in the geomagnetic north-south direction. Figure 1 shows the orientation of Beam No. 15 together with other beams at Syowa Station and field-of-views of other HF radars. At present we have summary data from late April to late September 1995 for Beam 15. In order to present an averaged echo pattern without dipole-tilt (seasonal) effects, we use the data only for the period of September when the dipole tilt is close to zero.

Figure 2 shows one example of the summary data plots. The velocity and echo power are plotted as a function of universal time and range (distance from the radar site along the ray path). Magnetic local time at Syowa Station is approximately the same as universal time. It is noticeable in the velocity profile data that there is a green region termed 'ground scatter' which is a scatter reflected from the ground and does not necessarily show true ionospheric Doppler velocity. We distinguish the ground scatter echoes from other echoes on the basis of the criterion that the absolute value of the Doppler velocity is less than 20 m/s with echo spectral width less than 20 m/s. (We should mention here that these are rather empirical values and not all the ground scatter echoes can be separated from ionospheric echoes with this method.) In the following plots, we exclude these ground scatterings from the analysis in order to see only the scatter directly coming from the ionosphere.

3. Averaged Pattern

Figure 3 shows profiles of the velocity and echo power for the Beam 15 during very quiet periods: K indices at Syowa range from 0 to 1. The data are averaged over the whole period for each range (45 km) bin and time (2 min) bin. It can be clearly seen that the echo regions are located at higher latitudes in the noon sector and at lower latitudes in the midnight sector. They are nearly aligned with an empirical location of the auroral oval proposed by STARKOV (1969): the solid curve in each figure shows the equatorward auroral oval boundary in a quiet-time period in his model, $Q=1$ (refer to MAYAUD, 1980 for Q index). This fact clearly demonstrates that the radar echoes mainly come from the auroral oval where many irregularities, probably caused by strong electric fields and/or particle precipitation, are expected to exist. ,Note that there is, however, a considerable discrepancy between the equatorward boundary of the auroral oval based on the model and that of the radar echo regions. One candidate for this discrepancy is that the radar range is measured from a round trip time of the radar wave and does not represent the distance between the radar site and a sub-ionospheric point of interest.

The Doppler velocity in the north-south direction is basically poleward (southward) in the dayside and equatorward (northward) in the nightside. These senses of velocity are consistent with the two-cell convection pattern (HEPPNER and MAYNARD, 1987).

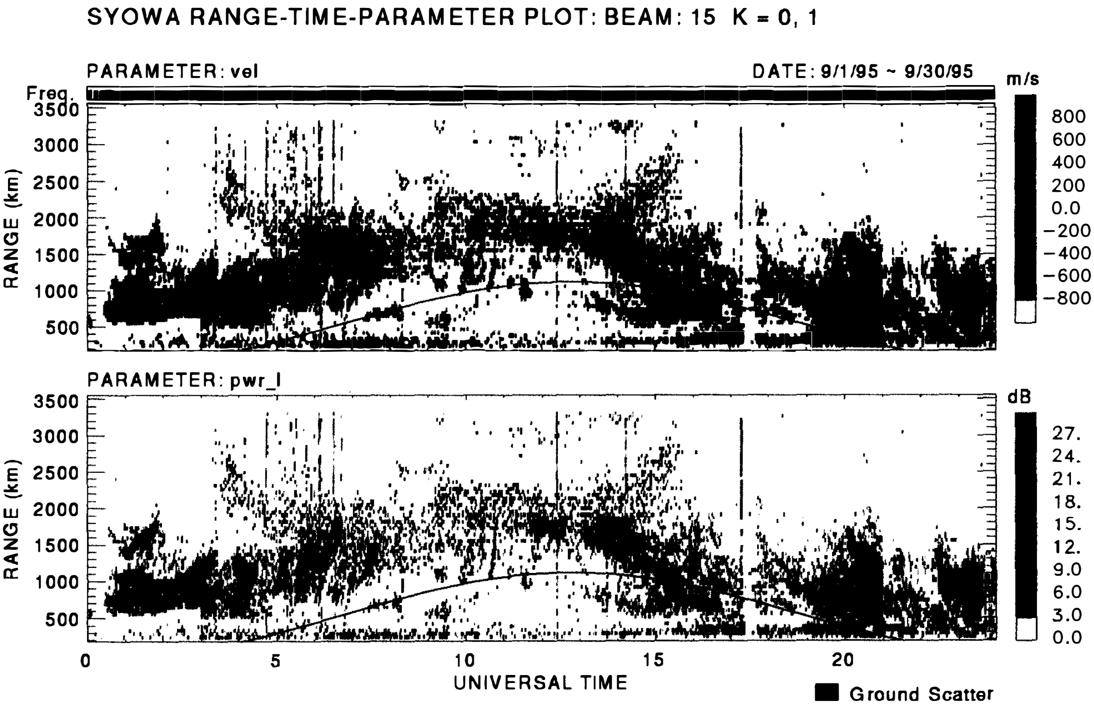

Fig. 3. Averaged Doppler velocity and echo power patterns for quiet periods (K =0, 1). Solid line is the equatorward boundary of the auroral oval based on Starkov's model (1969) for Q index=1.

4. Dependence on Geomagnetic Activity

Figure 4 shows the profile for higher K indices (2 to 3), using the same format as Fig. 3. It can be seen that the echo regions expand to lower latitudes both in the dayside and in the nightside. This coincides with the equatorward shift of the auroral oval region with increasing geomagnetic activity as reported by many authors (*e.g.*, FELDSTEIN and STARKOV, 1967). As K index becomes higher, the echo region expands further to lower latitudes as shown in Fig. 5. (In Figs. 4 and 5, equatorward edges of the auroral oval based on Starkov's model are drawn for $Q=$ 4 and 6 respectively. Q index has twelve levels of ranges while K index has ten.)

It may be noticeable in Figs. 3, 4, and 5 that the echo characteristics at closer ranges (smaller than 500 km) are slightly different from those at further ranges (larger than 500 km). This is due to the fact that the radar echoes come from the E region at closer ranges and from the F region at further ranges (*e.g.*, OGAWA *et al.*, 1990). In order to examine the characteristics of the F-layer convection pattern, we must consider only the data at ranges longer than 500 km.

Another important point is that the averaged velocity increases with increasing geomagnetic activity. Such a characteristic is more clearly demonstrated in Fig. 6 which shows scattered plots of the Doppler velocities for three activity levels. In this figure, only the echoes at ranges longer than 500 km are considered. Because of the relatively short span of the investigation, there is a lack of the data around the noon

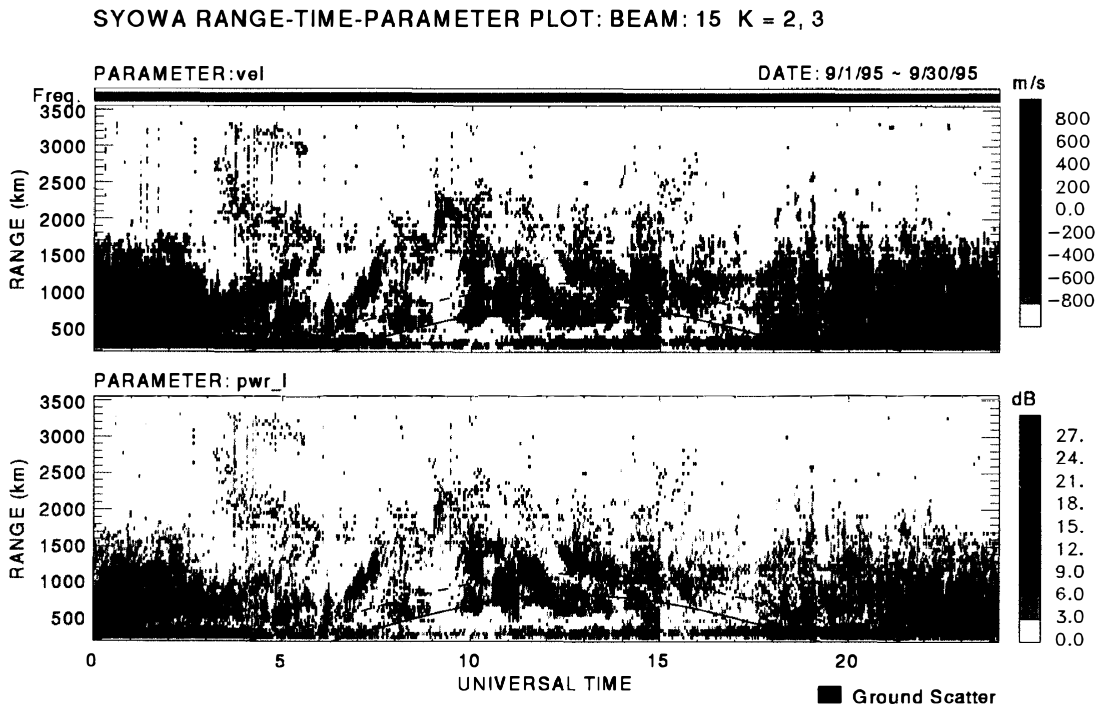

Fig. 4. Averaged Doppler velocity and echo power patterns for moderately disturbed periods ($K=2$, 3). Dashed line is the equatorward boundary of Starkov's auroral oval during quiet periods ($Q=1$) while solid line is during moderately disturbed periods ($Q=4$).

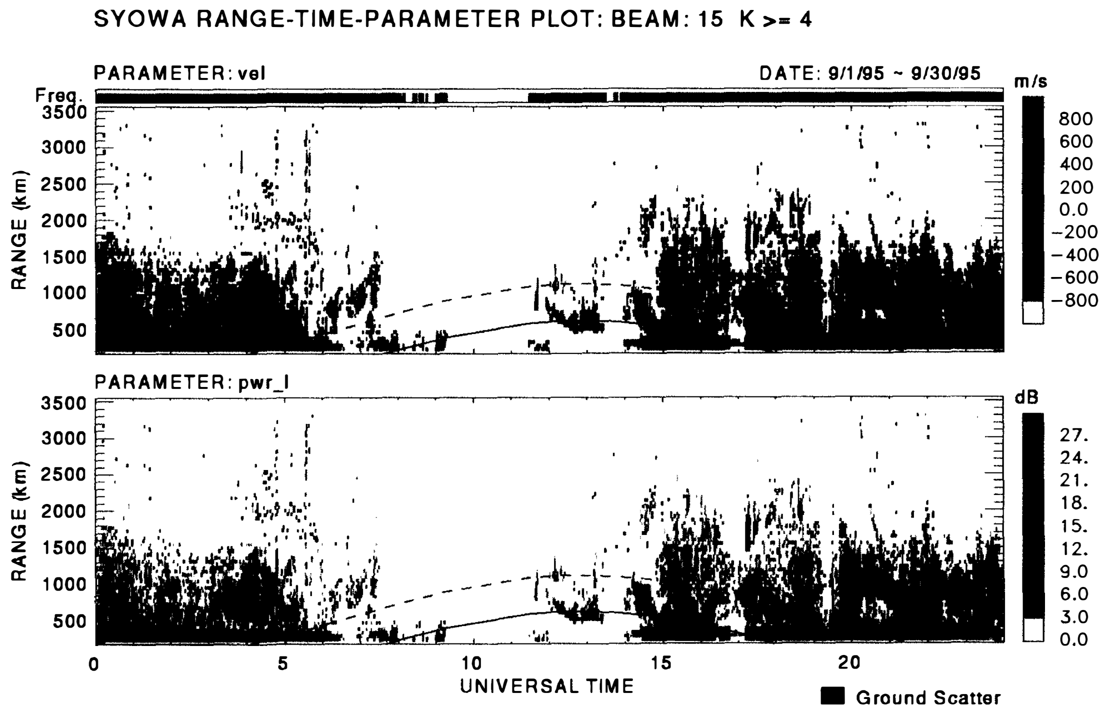

Fig. 5. Averaged Doppler velocity and echo power patterns for very disturbed periods ($K \geqq 4$). Dashed line is the equatorward boundary of Starkov's auroral oval during quiet periods ($Q=1$) while solid line is during disturbed periods ($Q=6$).

sector for $K \geqq 4$, but still we can find a tendency of strong poleward velocity in the dayside sector and equatorward velocity in the nightside sector.

5. Discussion

The Syowa Station radar did not take the data for the whole period of September 1995 but for 57% of the period. Nevertheless, the result of this paper demonstrates the usefulness of the Syowa Station radar data for studying the dynamics of the ionosphere-magnetosphere coupling. The one-beam radar data show a clear convection pattern and its dependence on the geomagnetic activity.

The averaged velocity pattern observed by the radar is basically consistent with the two-cell convection pattern. On the other hand, when the IMF (Interplanetary Magnetic Field) is northward, which is expected to be the case for half of the total period, the four-cell convection pattern should be observed with equatorward velocities in the high-latitude noon sector (*e.g.*, HEELIS *et al.*, 1986). Such a signature is scarcely seen in Fig. 6. One possibility of this apparent discrepancy is that during the northward IMF, the ionosphere is less irregular due to the less precipitation of particles, so that the echo is weaker. Another candidate for this is that the echo regions are located at lower latitudes when the IMF is southward than when it is northward. So, the regions are easily detected. Since these are based on assumptions, we need further study regarding this topic by using the IMF data.

The radar data show a strong poleward flow in the dawn sector (6–8 MLT) as

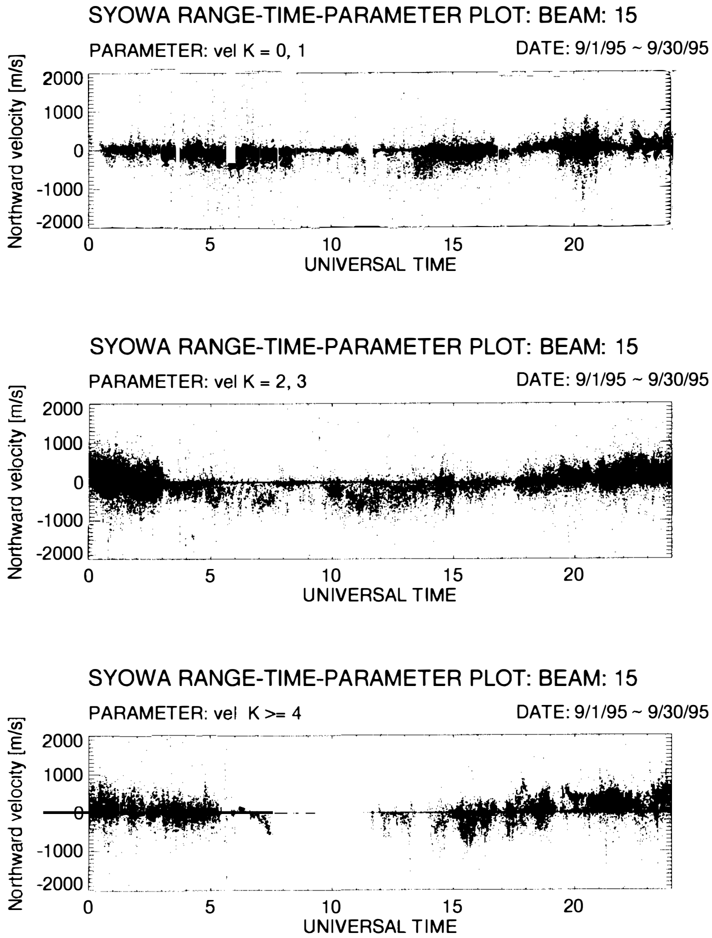

Fig. 6. Scatter plots of Doppler velocities at ranges larger than 500 km for three levels of geomagnetic activity.

indicated in the middle panel in Fig. 6. More detailed analysis of the data reveals that this signature comes from one-day data on September 25. Further study is necessary to explain the cause for this strong flow.

The echo regions show the latitudinal distribution similar to the auroral oval expanding with increasing geomagnetic activity. This fact is consistent with the results by MÖLLER (1974). Meanwhile, MÖLLER found two peaks of the echo occurrence in the latitude: one is near the poleward edge of the auroral oval and the other is near the plasmapause. In this study we observed only one peak. This is because the radar site is located in the auroral region and the radar cannot observe the near-plasmapause latitude region.

In this paper we showed initial results from the Syowa Station HF radar and its usefulness. We need more detailed studies in the future by using the original multi-beam data. In addition, we are expecting to get new results from the combined observations with the Halley Bay and Sanae radars; the latter radar is expected to start its operation in the beginning of 1997.

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