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POLAR CAP PATCHES AND AURORAL BLOBS OBSERVED WITH ANTARCTIC HF RADARS: PRELIMINARY RESULTS

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Abstract: We present preliminary results of the Antarctic HF radar observations of decameter-scale irregularities associated with polar cap patches and auroral blobs in the southern high latitude ionosphere. Somewhat surprisingly, patches appear even under northward interplanetary magnetic field (IMF) conditions. These patches seem to have been transported from the dayside cusp into the polar cap, although we need more data analysis to confirm this conclusion. The blobs, clearly detected with the Halley radar, in the evening auroral zone seem to be well explained by previous simulations that calculated the time evolution of a patch initially located in the polar cap.

1. Introduction

Isolated electron density enhancements, appearing in the high latitude *F* region ionosphere, with horizontal scale sizes of 100–1000 km are called "polar cap patches" (hereafter referred to as patches) when they are observed inside the polar cap or "auroral blobs" (hereafter referred to as blobs) when they are observed outside the polar cap, that is, at auroral latitudes. It is now believed that most patches are transported from the dayside solar-illuminated ionosphere through the cusp region into the polar cap under the influence of high-latitude plasma convection, and that most blobs result from the distortion and fragmentation of patches due to the nightside convection pattern (CROWLEY, 1996).

Patches have been observed by various different techniques including ionosonde, 630 nm airglow imager, coherent and incoherent scatter radars, and others. RODGER *et al.* (1994a) summarize the main characteristics of patches as follows: (1) patches of scale sizes of 200–1000 km drift antisunward across the polar cap with speeds of 300–1000 m/s, (2) they are observed under negative IMF Bz conditions, (3) they are observed in both summer and winter at sunspot maximum and minimum, (4) they are associated with intermediate-scale electron density irregularities, (5) they may form simultaneously in geomagnetically conjugate regions, and (6) the electron temperature of a patch is low and unstructured, indicating that energetic particle precipitation is unimportant when the patch is within the polar cap. Patches are usually transported over very long distance across the polar cap and then within the auroral zone. To understand how patches are distorted and fragmented during the course of this transportation, modeling and simulation have extensively been made (ROBINSON *et al.*, 1985; SOJKA *et al.*, 1994; VALLADARES *et al.*, 1996; BOWLINE *et al.*, 1996; ANDERSON *et al.*, 1996).

Patches and blobs usually accompany decameter-scale irregularities produced through some plasma instabilities (TSUNODA, 1988). Since these irregularities are responsible for coherent back scatter of HF radio waves, we can study the formation and dynamics of patches and blobs by using HF radars. Until now HF radar observations of patches have been focused on their formation (PINNOCK *et al.*, 1993; RODGER *et al.*, 1994a) and their transportation within the polar cap (ROSENBERG *et al.*, 1993; RODGER *et al.*, 1994b). This paper briefly reports the HF radar echoes associated with the patches and blobs that were detected from 0000 to 2400 UT on July 14, 1995 with two Antarctic SuperDARN HF radars at Syowa Station and Halley. Geomagnetic condition on that day was weakly disturbed ($Kp=1-, 0+, 1-, 1+, 1, 2+, 3-, 2+$).

2. Observations and Discussion

2.1. Some features

Figure 1 shows fields of view (FOV) of the Syowa Station and Halley HF radars in magnetic coordinates. Each FOV is covered with sixteen narrow beams (NISHITANI *et al.*, 1997). As can be seen, both radars can detect *F* region decameter-scale irregularities in the polar cap and auroral latitudes. Note that magnetic local time (MLT)

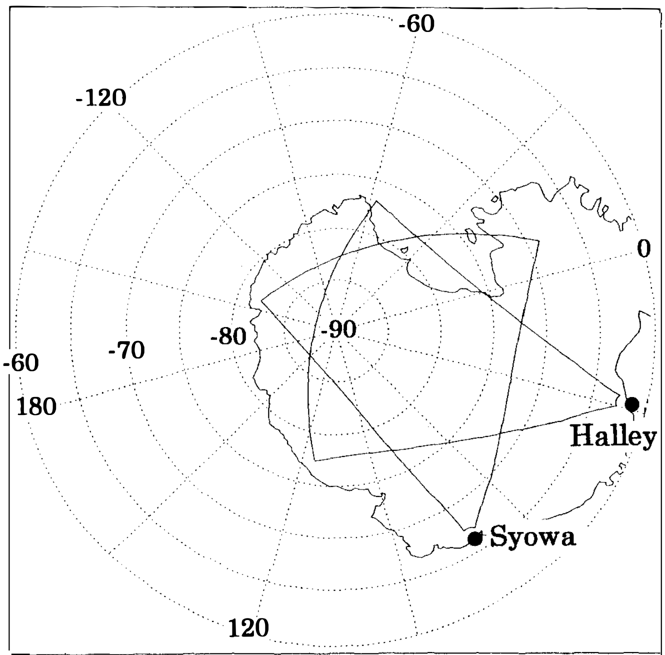

Fig. 1. Fields of view (FOV) of Syowa Station and Halley HF radars in magnetic coordinates. Each FOV is covered with sixteen beams.

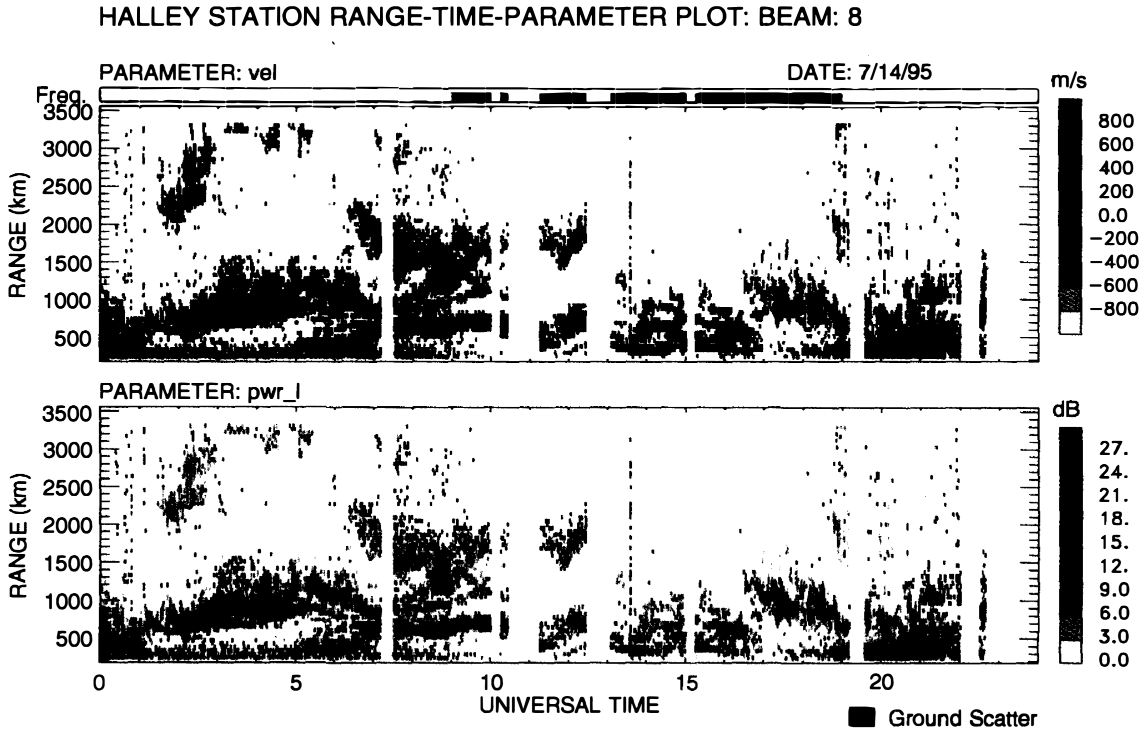

Fig. 2. One-day plots of Doppler velocity (upper) and echo power (lower) on beam number 8, observed with the Syowa Station radar on July 14, 1995, as a function of UT and radar range from Syowa Station. Beam 8 looks in the area near the center of FOV in Fig. 1. The ground-scatter echoes are indicated by green color in the upper panel. The radar frequency is also shown by color code (yellow: 9 MHz; purple: 19 MHz). Data are not plotted for the periods of no radar operation.

$\simeq$UT at Syowa Station and MLT$\simeq$UT–2.8 hours at Halley.

Figure 2 displays one-day plots of Doppler velocity and echo power on beam number 8, observed with the Syowa Station radar on July 14, 1995, as a function of UT and radar range from Syowa. Beam 8 looks in the area near the center of FOV. Nominal *E* and *F* region echoes from the auroral ionosphere appear below the 500 km range and between 500 and 1500 km, respectively. These echoes are, more or less, regularly observed with the Syowa radar (NISHITANI *et al.*, 1997). Relatively weak *F* region echoes also appear intermittently from 2000 up to 3300 km (limit of data acquisition) or more between 0130 and 0520 UT and again from 1500 up to 3300 km between 1830 and 2200 UT: these echoes return from the patches in the polar cap.

Figure 3 displays data from the Halley radar (beam number 8). In contrast to the Syowa echoes in Fig. 2, the Halley *F* region echoes are limited below 1700 km and show no signature of patch-related echoes at farther ranges. Interesting echo features can be seen after 1700 UT: a series of echo bands (blobs), mainly flowing toward sunward direction, approach successively to Halley. Note that weak signatures of such behavior of the echoes are also discernible at Syowa after 1730 UT. Approaching-velocities (of the order of 70–140 m/s) of the echo bands are much faster than those (≤50 m/s) expected from the HEPPNER and MAYNARD (1987) convection model.

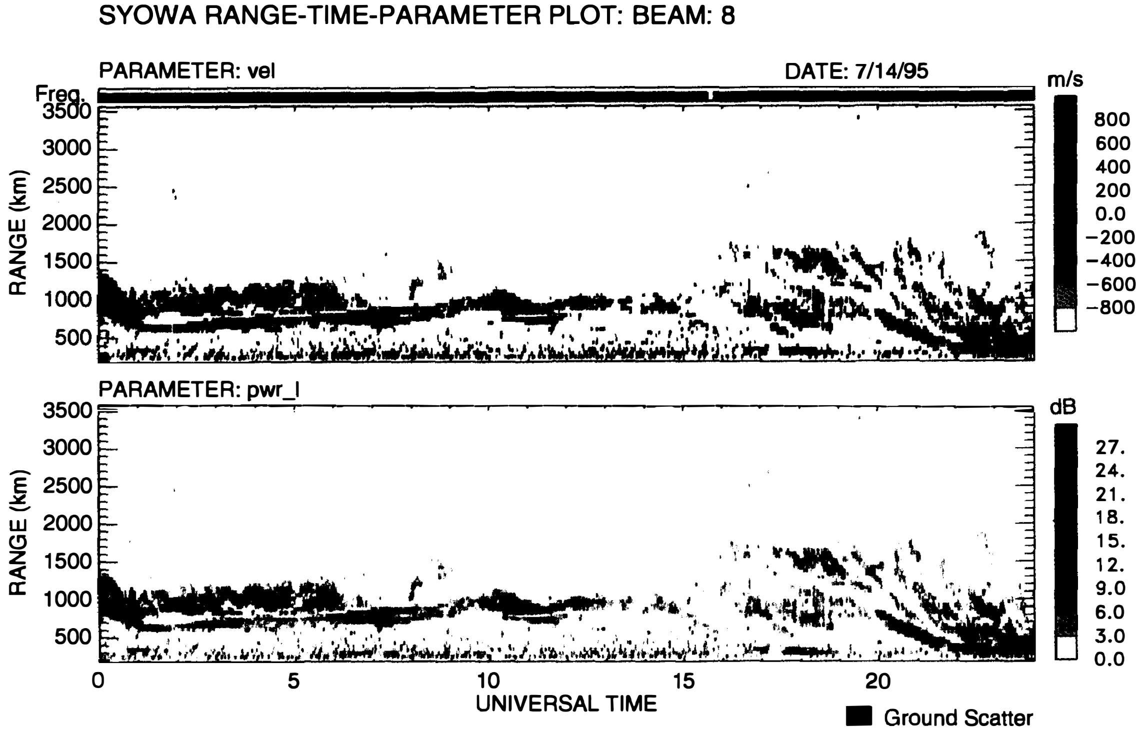

Fig. 3. Same as Fig. 2 but for the Halley radar.

ROBINSON *et al.* (1985) calculated the time evolution and distortion of an ionization enhancement (a patch), that was initially located in the polar cap, to find that the patch drifts to the equatorward edge of the evening auroral oval and then elongates along the boundary as a blob. The elongation results from the different convection times associated with various streamlines on which the patch and blob are located. Moreover their calculation indicates that the elongation along the auroral zone boundary has a tilt with respect to the streamlines: higher latitudes at earlier MLTs and lower latitudes at later MLTs. When the Halley radar moves toward later MLTs, this tilt combined with the sunward blob motion produce the echo band approaching Halley. ROBINSON *et al.* (1985) further noted that if during the few hours that the first blob is stretched out along the boundary a second patch crosses the polar cap, a second boundary feature will appear extremely close to the previous one but never overlapping. This scenario is applicable to our observations at Halley. In fact, the Syowa radar detected many polar patch events after 1730 UT. These patches can be related to a series of the blobs detected at Halley. We believe that our observations are the first ones to support the model of ROBINSON *et al.* (1985).

2.2. Comparison of radar results with model convection

Figure 4 shows a two-dimensional map of the Doppler velocities observed for the period 0158:04–0159:59 UT with the Syowa and Halley radars. For this time period, IMF By and Bz components observed by the Geotail satellite that was located just outside the dayside magnetopause were around $+1$ nT. Thick curves in Fig. 4 represent the streamlines of the plasma convection model (BC model for weakly positive IMF

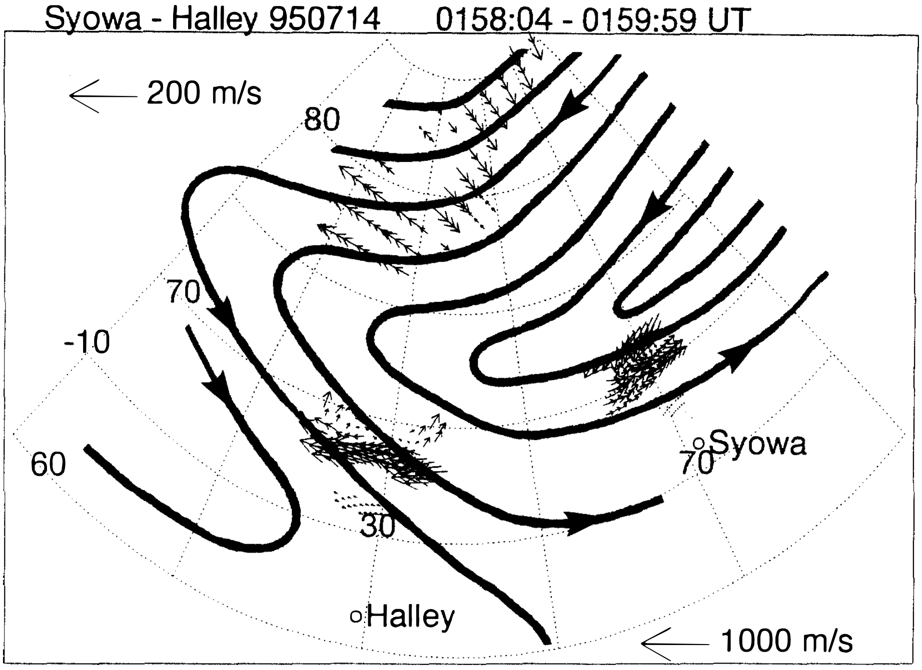

Fig. 4. Map (in magnetic coordinates) of Doppler velocities observed for the period 0158:04–0159:59 UT with the Syowa and Halley radars. A velocity scale of 200 m/s is applicable to the data at latitudes higher than 75° while that of 1000 m/s is applicable for latitudes lower than 75°. Thick curves represent streamlines of the BC plasma convection model of HEPPNER *and* MAYNARD *(1987). Magnetic local time (MLT) at Syowa ≃ UT and MLT at Halley ≃ UT–2.8 hours.*

Bz conditions) given by HEPPNER and MAYNARD (1987). In Fig. 4, radial Doppler velocity components are plotted for the latitudes higher than 75° while two-dimensional velocity vectors, calculated by using the method of RUOHONIEMI *et al.* (1989), are plotted for the lower latitudes: at the higher latitudes it was impossible to calculate two-dimensional vectors because the data points along a constant *L*-shell were smaller than the points (≥5) required by RUOHONIEMI *et al* (1989). The patch-associated irregularities at the higher latitudes have radial velocities less than 50 m/s and velocity signs consistent with the model convection. At the lower latitudes, the Syowa velocity vectors (≤400 m/s) are partly consistent with the model showing an eastward plasma flow, whereas the Halley velocity vectors showing a westward flow are opposite to the model.

The patch size as observed with the Syowa radar is 700 km along the radar beams and more than 1500 km perpendicular to them. A size detected by an HF radar, however, may not necessarily be equal to a patch size as observed with ionosonde or 630 nm airglow imager capable of detecting electron density itself. An HF radar is likely to see only the *irregularities* generated around the edge of a patch through the gradeint-drift instability (*e.g.*, TSUNODA, 1988), and moreover HF radio wave propagation does not guarantee that the radar can detect all irregularities within FOV. In the future, simultaneous HF radar and ionosonde/optical observations of a patch are necessary to clarify a spatial relationship between irregularities and electron density enhancement.

It is believed that polar cap patches are observed under negative *Bz* conditions. *Bz* on July 14, however, was weakly positive (0~+2.5 nT) between 0000 and 0600 UT except for weakly negative (−0.5~0 nT) between 0450 and 0520 UT, corresponding to low *Kp* values (0+, 1−): *By* during this period was between +1 and +6 nT. When *Bz* is positive, particle precipitation into the polar cap *F* region is expected to produce sun-aligned polar cap arcs (*e.g.*, OBARA *et al.*, 1996) and electron density enhancement resulting in the generation of decameter-scale irregularities. A quick survey of DMSP satellite particle data suggests that the low energy (≤500 eV) electron fluxes into the polar cap were less than 1×10^8/cm^2·s·sr, being too small to produce sun-aligned arcs and enhanced electron density (OBARA *et al.*, 1996). We have calculated an angle θ (=arctan (*Bz*/*By*)) to examine a hodogram of the IMF in the Y–Z (GSM) plane between 0000 and 0600 UT. The θ's were below +20° for the periods 0000–0035 UT, 0240–0435 UT, and 0450–0600 UT. This result means that during these periods a standard two cell convection pattern was possible (FREEMAN *et al.*, 1993) to transport a patch from the dayside cusp into the polar cap.

Figure 5 displays a two-dimensional map for the period 1847:56–1849:55 UT. Thick curves represent the streamlines of the plasma convection model (DE model for negative *Bz* and positive *By* conditions; HEPPNER and MAYNARD, 1987). For this time period, the Geotail satellite detected relatively stable *By* of +7 nT and very variable *Bz* between −4 and +4 nT. The patch-associated irregularities have antisunward velocities of the order of 200 m/s, being faster than the patch velocities (≤50 m/s) in

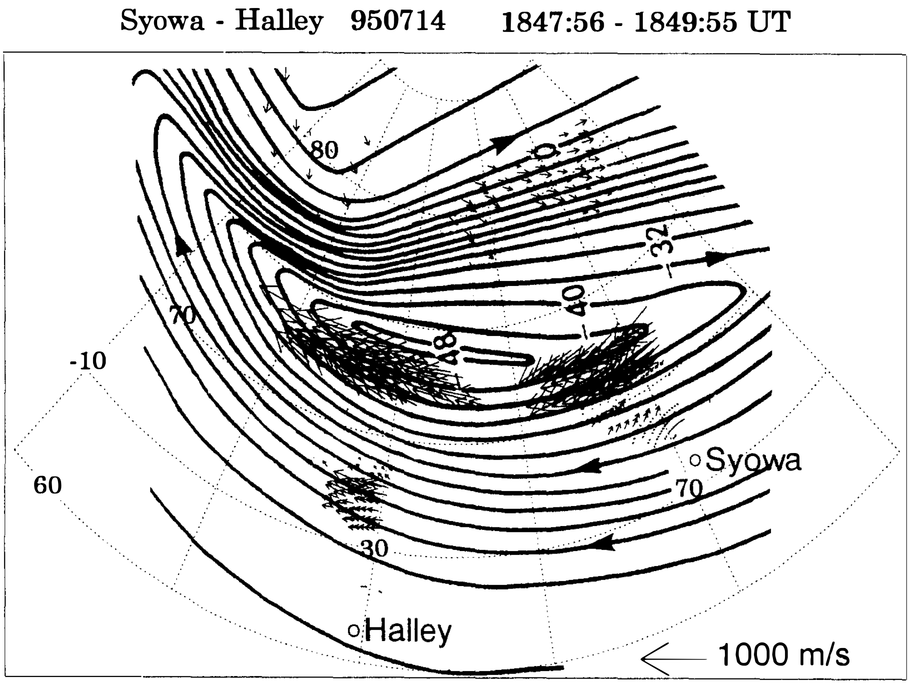

Fig. 5. Map (in magnetic coordinates) of Doppler velocities observed for the period 1847:56-1849:55 UT with the Syowa and Halley radars. Thick curves represent streamlines of the DE plasma convection model of HEPPNER and MAYNARD (1987). Magnetic local time (MLT) at Syowa ≃ UT and MLT at Halley ≃ UT–2.8 hours.

Fig. 4. This difference is due to the different *Bz* conditions. At the lower latitudes between 70° and 75°, the Syowa and Halley vectors have velocities 300–800 m/s, again being faster (≤400 m/s) than those in Fig. 4. The overall flow directions observed are very consistent with the model convection (antisunward flow in the polar cap and sunward flow in the auroral zone). We believe that patches such as shown in Fig. 5 have been observed and studied by other techniques such as ionosonde and optical imagers (*e.g.*, CROWLEY, 1996).

3. Conclusion

The important points that we have found in this paper are: (1) the striated echo patterns (due to a series of the blobs) clearly observed between 1700 and 2400 UT at Halley are well explained by the simulation made by ROBINSON *et al.* (1985) who calculated the time evolution and transportation of a patch initially located in the polar cap, and (2) patches appear even under northward IMF conditions. As far as the authors are aware, our observations are the first ones supporting ROBINSON *et al*'s simulation. As for item 2, we have suggested a possibility of patch transportation from the dayside cusp into the polar cap when the IMF *By-Bz* clock angles (θ) are smaller than +20°.

Acknowledgments

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