# 50 MHz AURORAL DOPPLER RADAR OBSERVATIONS ASSOCIATED WITH Pc 5 GEOMAGNETIC PULSATIONS

Kiyoshi IGARASHI[1], Tadahiko OGAWA[1], Yasukazu KURATANI[1], Ryoichi FUJII[2] and Natsuo SATO[2]

[1]*Radio Research Laboratories, 2–1, Nukui-Kitamachi 4-chome, Koganei-shi, Tokyo 184*
[2]*National Institute of Polar Research, 9–10, Kaga 1-chome, Itabashi-ku, Tokyo 173*

***Abstract:*** Radio auroral echo oscillations associated with Pc 5 geomagnetic pulsations are investigated using the 50 MHz doppler radar installed in 1982 at Syowa Station, Antarctica. First, it is found that Pc 5 radar echo pulsations occur most frequently around dawn and dusk hours but do not appear around noon and midnight. Then, the doppler power spectrum of the Pc 5 pulsating radio aurora is presented which indicates that the irregularities causing echo pulsations might be produced by the gradient-drift plasma instability in the disturbed *E*-region. It is also demonstrated by using the mean doppler velocity of the Pc 5 pulsating radio aurora that during the pulsations the north-south components of electric fields are far larger than the east-west components, being consistent with the Kelvin-Helmholtz instability hypothesis as a cause of Pc 5 geomagnetic pulsations.

## 1. Introduction

Since doppler velocity of *E*-region irregularities observed by a VHF auroral radar is approximately equal to electron $E \times B$ drift velocity, electric fields under disturbed condition can be estimated through the doppler velocity measurement (*e.g.*, ECKLUND *et al.*, 1977). Relying on this fact, it has been confirmed that a doppler radar is a powerful tool for studying the auroral *E*-region dynamics (FEJER and KELLEY, 1980).

In recent years, the study of spatial structure and dynamical behavior of geomagnetic pulsations has largely advanced with the advent of the STARE (Scandinavian Twin Auroral Radar Experiment) radar in northern Europe (WALKER *et al.*, 1979; ALLAN and POULTER, 1984). This radar has a wide covering area (approximately 400 $\times$400 km) in the auroral *E*-region with a spatial resolution of 20 km, thereby being capable of exploring two-dimensional characteristics of geomagnetic pulsations.

The 50 MHz auroral doppler radar was installed at Syowa Station in February 1982 as part of the ground-based study program in Antarctica for the Middle Atmosphere Program (MAP, 1982–1985) (IGARASHI *et al.*, 1982). Preliminary results of the radar experiments have been presented by OGAWA *et al.* (1983, 1985). The intensity and doppler velocity of backscattered echoes were obtained using two radar operation modes, spectrum mode and double-pulse mode. The spectrum mode gives the doppler spectrum of echoes while the double-pulse mode gives the mean doppler velocities of the irregularities.

In this paper we report some observational results of pulsating radar echoes associated with Pc 5 (150–600 s) pulsations during the period February 1982–January 1983 which include the diurnal occurrence pattern of Pc 5 pulsation events, the plasma instability process generating these pulsating echoes, and the behaviors of east-west and north-south components of the doppler velocities associated with pulsating echoes.

## 2. Equipments

The 50 MHz radar was located at Syowa Station (geographic coordinates 69°00′S, 39°35′E; geomagnetic coordinates 70.0°S, 80.2°E) in Antarctica. As shown in Fig. 1, the radar has two beams directed toward both the magnetic south (GMS beam) and 32.8° west from the magnetic south (GGS beam). Each beam has a beam width of approximately 4° in the horizontal plane and is formed by using three 14-element coaxial collinear antennas. Also shown are the $L$ shells and the aspect angles ($\alpha$). Some parameters of the radar pertinent to the present radar are given in Table 1. See a paper of IGARASHI *et al.* (1982) for detailed descriptions of the radar and computer systems and of the data processing procedures.

The radar beam was alternately switched to obtain the two-dimensional structure of doppler velocities. In this experiment, the switching interval was 13 and 17 s for the spectrum mode and the double-pulse mode, respectively, and the integration time of radar echoes was 7.7 and 10.0 s for each mode.

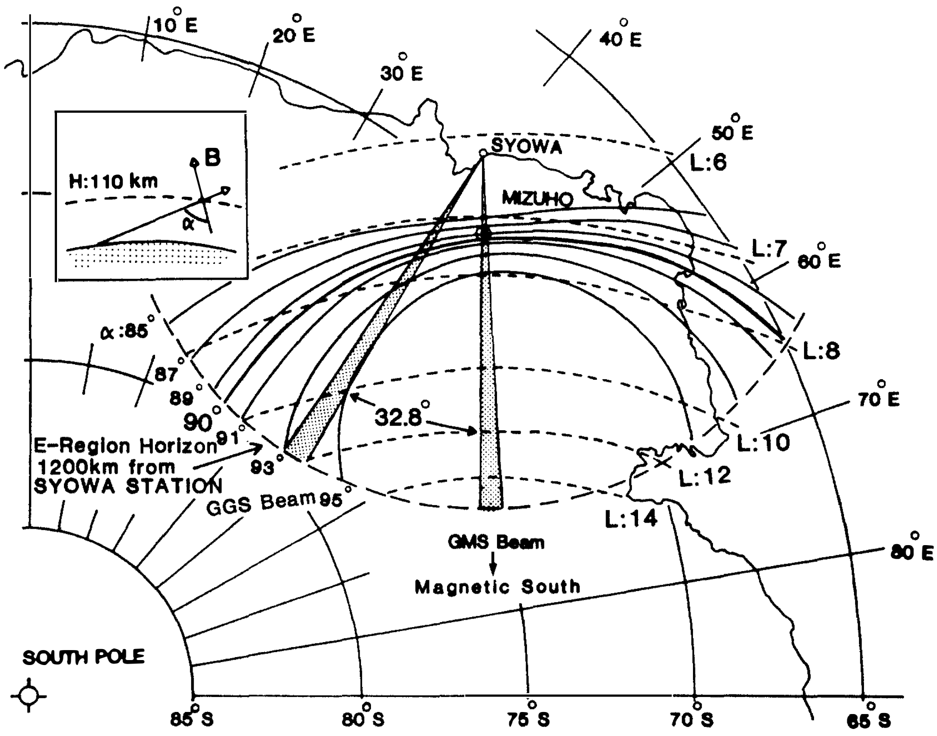


*Fig. 1. Plan view of radar antenna patterns together with contours of L value and aspect angle α for a height of 110 km. The azimuth angle measured from geographic north to east is 133.6° for the GMS beam and 166.4° for the GGS beam.*

*Table 1. Parameters of 50 MHz doppler radar pertinent to present study.*

| | |
|---|---|
| Site | Syowa Station, Antarctica (69°00'S, 39°35'E) |
| Type | Coherent pulse radar |
| Frequency | 50 MHz |
| Peak power | ~15 kW |
| Pulse width | 100 $\mu$s |
| PRF | 333 Hz |
| Double pulse separation | 1.5 ms |
| Antenna | Three 14-element coaxial collinear type (two way) |
| Antenna gain | 25 dB |
| Antenna beam width | ~4° (half power) in horizontal plane |
| Azimuthal resolution | 15–40 km (range-dependent) |
| Invariant latitude of coverage | $L=7$ to 8.5 (antenna-dependent) |
| Receiver noise figure | 4 dB |
| Receiver bandwidth | 10 kHz (matched to pulse width) |
| Data processing | On-line minicomputer (MELCOM 70/25) with array processor (MSP-2) for spectral analysis |
| Operation mode | 1. Spectrum mode<br>2. Double-pulse mode |

## 3. Results and Discussions

The observation periods and operation mode during February 1982–January 1983 are summarized in Fig. 2. The Pc 5 pulsating radio aurora events observed by the spectrum and double-pulse modes were selected for the following analyses.

### 3.1. *Diurnal variation of Pc 5 pulsating radio aurora occurrences*

Figure 3 shows the diurnal variation of the number of pulsating radio aurora

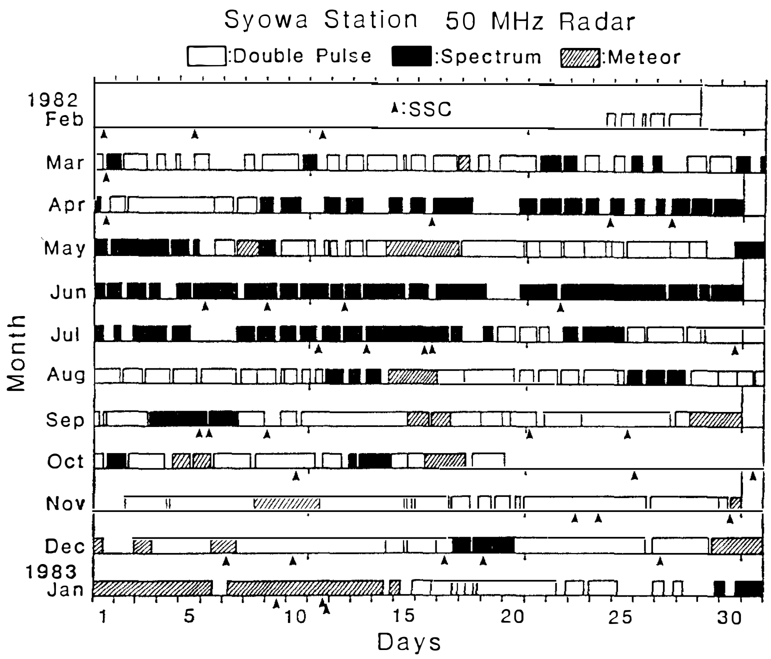


*Fig. 2. Summary diagram showing observation periods and mode of 50 MHz doppler radar. Solid triangle means ssc.*

occurrences associated with Pc 5 geomagnetic pulsations. The results obtained only by the double-pulse mode operation were used for these statistics. The criterion for determining pulsating radio auroras is that there should be at least three cycles of the echo amplitude oscillations in the range-time-intensity (RTI) record (see Fig. 8 for example) which was reproduced from digital magnetic tape records. This criterion was also adopted by WALKER and GREENWALD (1981) for the statistical study of Pc 5 pulsating radio aurora using the STARE radar.

It is evident in Fig. 3 that the maximum occurrence appears around 4–7 UT and 15–19 UT (UT=LT−3 h), *i.e.* roughly around dawn and dusk hours while no pulsation activity around noon and midnight. This diurnal variation suggests that

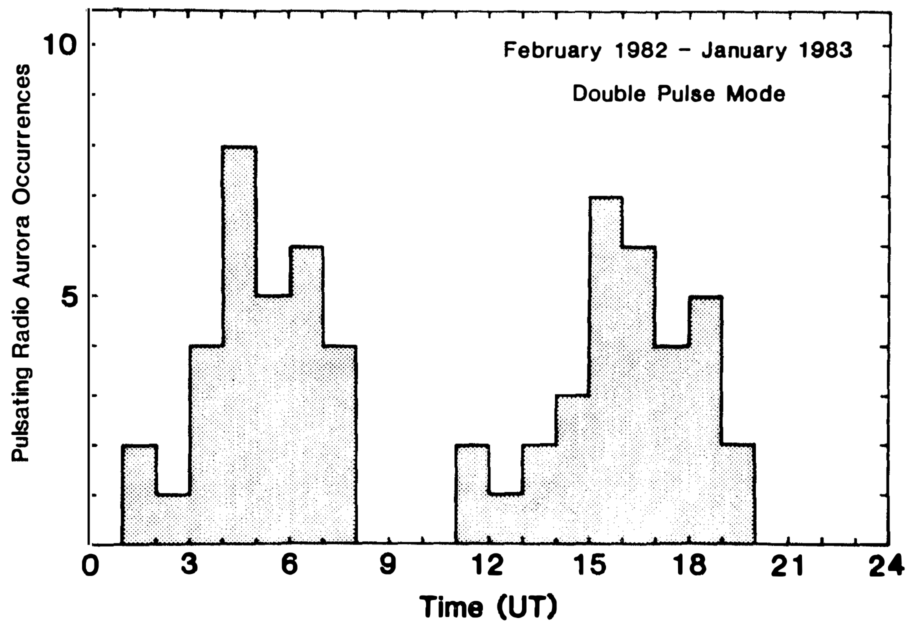


*Fig. 3. Diurnal variation of pulsating radio aurora occurrences associated with Pc 5 geomagnetic pulsations.*

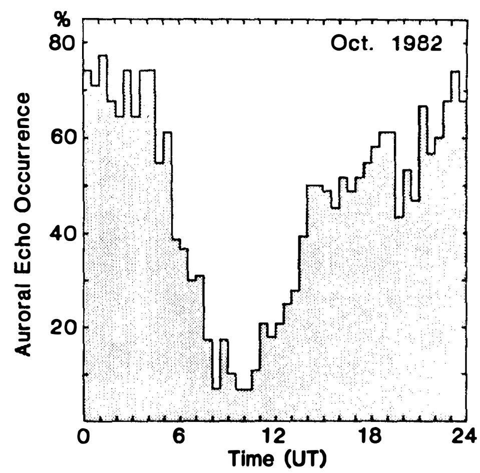


*Fig. 4. Diurnal variation of probability of auroral radar echo occurrences in October 1982.*

the hydromagnetic wave phenomena concerned here were caused by the solar wind driving the Kelvin-Helmholtz-Instability on the magnetopause (SOUTHWOOD, 1974; CHEN and HASEGAWA, 1974).

The diurnal variation of the radio aurora occurrences in October 1982 (see Fig. 2) is shown in Fig. 4. The maximum occurrence appears near midnight. It is clear that the diurnal variation of Pc 5 pulsating radio aurora events shown in Fig. 3 is largely different from that of the radio auroras.

### 3.2. *Pc 5 pulsating radio aurora features as seen by the doppler power spectrum*

An example showing two Pc 5 events observed by the spectrum mode is presented in Fig. 5. The first event began at about 0715 UT on December 19, 1982 and lasted until about 0805 UT. During this period, 8 cycles of oscillations (8 echoing bands) of echo amplitude having an average period of 357 s appeared on the RTI along the GGS and GMS beams. The second event beginning at about 0907 UT shows 2 cycles of oscillations having a period of 270 s.

For investigating the first event in more detail, Fig. 5 is partly enlarged in Fig. 6 where the band structure beginning at about 0715 UT is evident in both RTI displays and within each band, the poleward movement of echoing region with time is discernible, especially in the GMS display. Such features are common in Pc 5 radar pulsations (WALKER *et al.*, 1979). Also noted in Fig. 6 is that the time variation of the maxi-

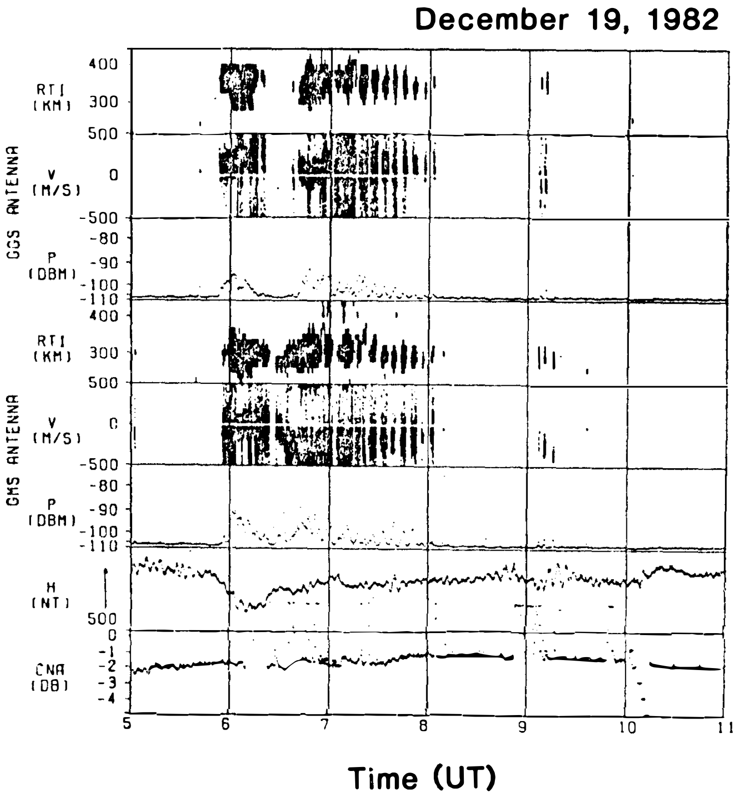


*Fig. 5. Summary plots of auroral radar echoes observed by spectrum mode operation on December 19, 1982. Time variations of RTI, half power width of doppler spectrum (V) and maximum echo intensity (P) obtained by GGS and GMS antenna beams and also of geomagnetic H-component and 30 MHz CNA at Syowa Station are shown from top to bottom.*

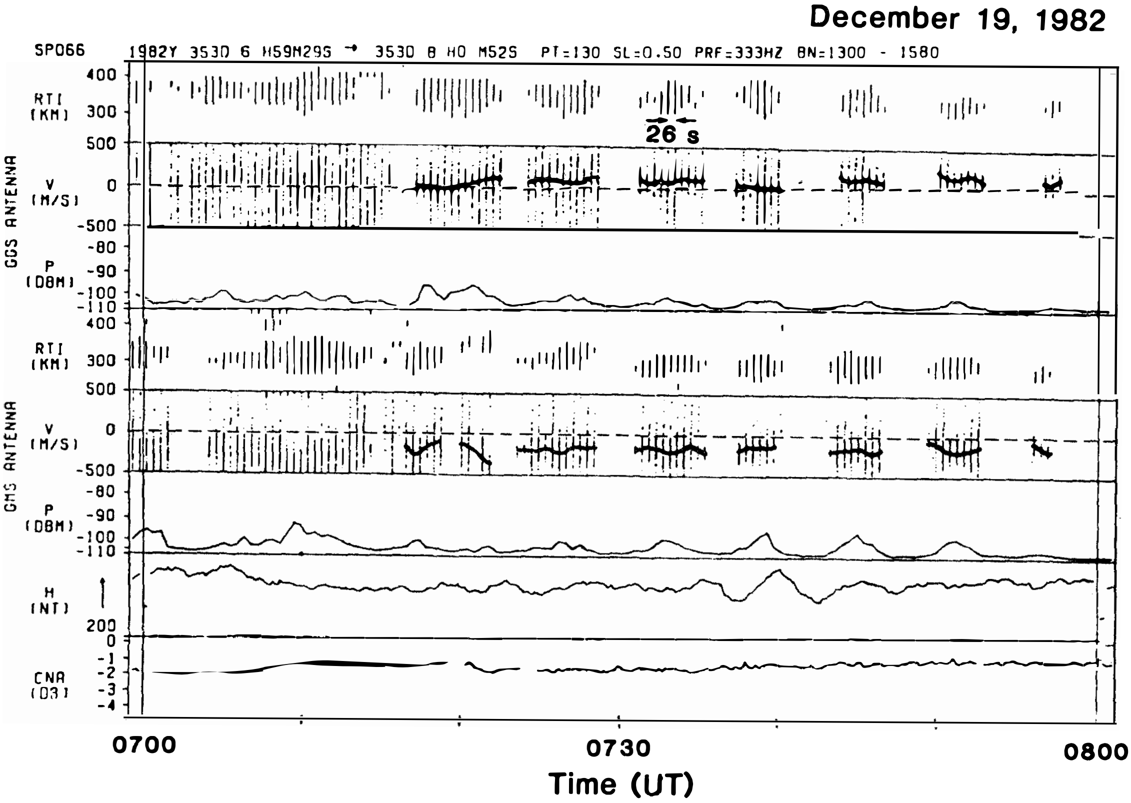


*Fig. 6. Same as Fig. 5 but for partial enlargement. Since antenna beam is alternately switched every 13 s, data of RTI, V and P for each beam are obtained every 26 s.*

mum echo intensity ($P$) is correlated well with that of the geomagnetic $H$-component at Syowa Station, though a phase difference between them exists because the echo regions over Mizuho Station are about 270 km away from Syowa Station.

Since it has been suggested that auroral radar echoes are caused by plasma instabilities in the $E$-region like the two-stream and gradient-drift (cross-field) instabilities (*e.g.*, OGAWA and IGARASHI, 1982), the band structure appearing in Fig. 5 indicates that the plasma instability must be periodically switched on and off depending on the time variations of electron density gradient and/or electric field associated with geomagnetic pulsations. Figure 7 shows the slant range profiles of echo power and doppler velocity spectrum at 0739: 12 UT (left panel) and 0739: 25 UT (right panel) when the instability occurred. All the spectra when the echoes appear do not exhibit narrow spectral features which may be caused by the two-stream instability operating under strong electric field ($\gtrsim$25 mV/m), but rather have broad half power widths which suggest the importance of the gradient-drift instability under the combined action of density gradient and relatively weak electric field ($\lesssim$25 mV/m) (GREENWALD, 1974). This suggestion is also confirmed from the mean doppler velocities (solid line connecting the centers of half power width in Fig. 6) which are always below 500 m/s since it is well known that mean doppler velocities of irregularities due to the gradient-drift instability are usually smaller than those due to the two-stream instability ($\gtrsim$500 m/s).

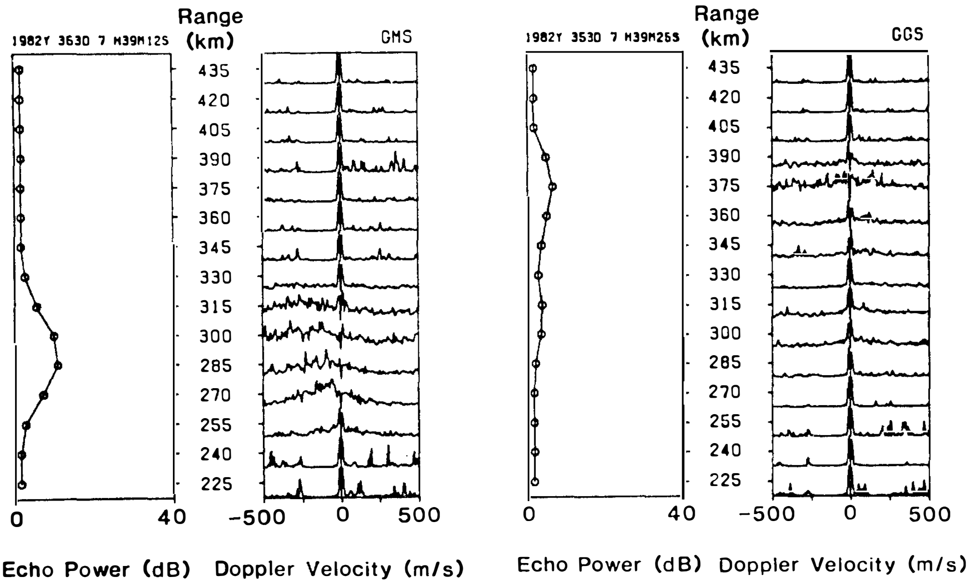


*Fig. 7. Normalized doppler power spectrum and echo power intensity along slant range for GMS beam (left panel) and GGS beam (right panel). Note that spectra having no echo intensity and narrow spikes appearing around 0 m/s are not real.*

### *3.3. Pc 5 pulsating radio aurora features as seen by the mean doppler velocity*

An example obtained from the double-pulse mode operation is shown in Fig. 8 where several Pc 5 events are marked by horizontal arrows. The event around 6 h UT is enlarged in Fig. 9. This event started at about 0540 UT on September 21 (264 days) and ended at about 0600 UT. The echo amplitude decayed with time while oscillating. The magnetic *H*-component and 30 MHz CNA at Syowa Station oscillate in phase. This phenomenon indicates that high energy particle precipitation is also modulated by ULF waves (POULTER and NIELSEN, 1982). The top panel in Fig. 9 shows the two-dimensional drift velocity vectors of the irregularities which were derived by combining the doppler velocity at the maximum echo intensity along the GGS beam (third panel) with that along the GMS beam (sixth panel). This figure indicates the geomagnetically eastward drift velocity (equatorward-directed electric field) of about 300 m/s (15 mV/m) at an initial phase of the pulsation around 0540 UT.

Under the assumption of a spatially uniform plasma flow, Fig. 10 shows the time variations of geomagnetic east-west component (top panel) and north-south component (second panel) of the two-dimensional doppler velocity vector (see the top panel in Fig. 9). During the pulsations after 0540 UT, the E–W components are usually larger than the N–S components which are nearly zero. The maximum E–W component is about 300 m/s, equivalent to the northward-(equatorward-)directed electric field of about 15 mV/m. This is consistent with the results obtained by the STARE radar that the toroidal velocities (north-south electric fields) are dominant compared with the poloidal ones (east-west electric fields) (POULTER, 1982). Figure 10 also indicates that during the pulsations the plasma instability giving rise to the radar echoes is shut off for drift velocities below, say, 100 m/s (electric fields below 5 mV/m).

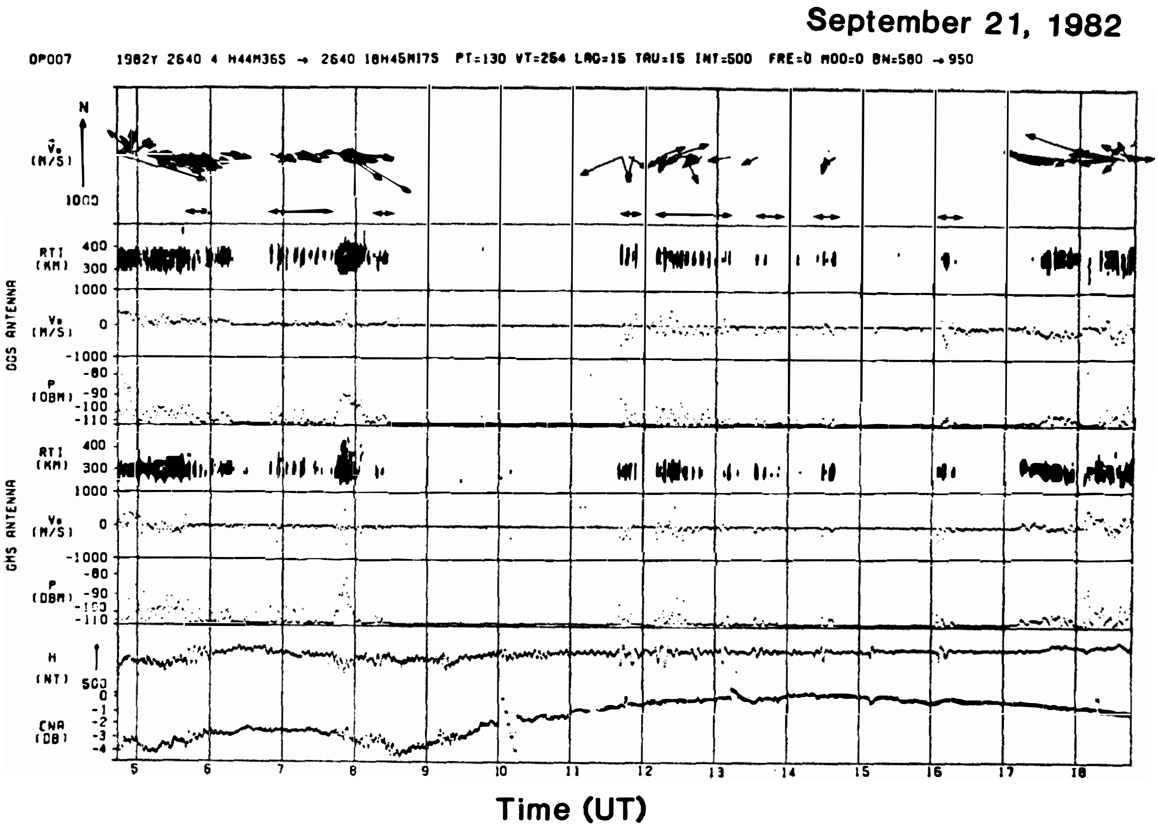


*Fig. 8. Summary plots of auroral radar echoes observed by double pulse mode operation on September 21, 1982. Time variations of RTI, mean doppler velocity (Ve) at range where echo intensity maximizes and maximum echo intensity (P) obtained by GGS and GMS antenna beams and also of geomagnetic H-component and 30 MHz CNA at Syowa Station are shown from second to bottom. Top panel displays velocity vector in geomagnetic coordinates constructed from two Ve's along both beams.*

## 4. Summary

Some characteristics of radio auroral echo associated with Pc 5 pulsations were investigated by using the 50 MHz auroral doppler radar at Syowa Station. The summary diagram (Fig. 1) showing the observation mode and its operation period during February 1982–January 1983 has been presented for the convenience of co-operative studies. Our results are summarized as follows:

(1) The maximum occurrence of diurnal variation of Pc 5 pulsating radio aurora appears around 4–7 h and 15–19 h UT, *i.e.* roughly around dawn and dusk hours and pulsations disappear around noon and midnight.

(2) The poleward movement of echoing area within each pulsation is discernible.

(3) The half power widths of doppler spectra of the pulsating echoes are broad and the mean doppler velocities are smaller than 500 m/s. It is speculated that the electron density irregularities causing these radar echoes were generated by the gradient-drift instability.

(4) One example (September 21, 1982) shows that the north-south component of the drift velocity is smaller than the east-west component, suggesting the Kelvin-

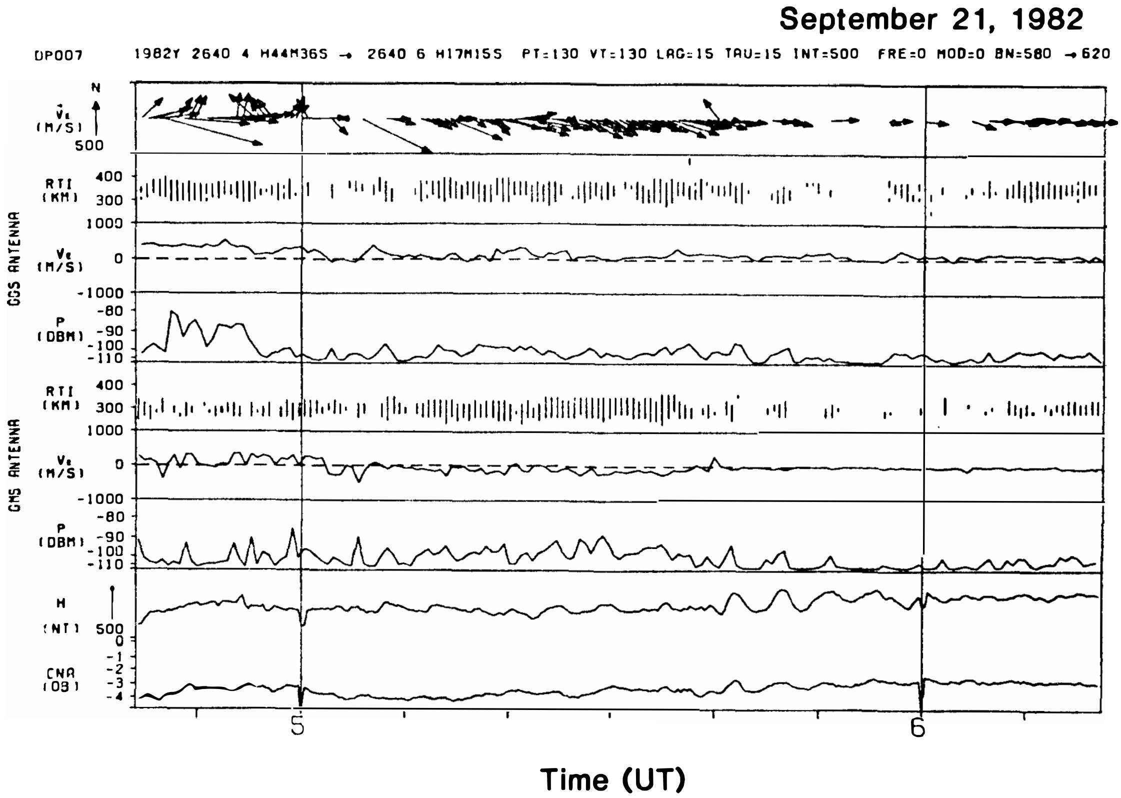


*Fig. 9. Same as Fig. 8 but for partial enlargement. Since antenna beam is alternately switched every 17 s, data of RTI, Ve and P for each beam are obtained every 34 s.*

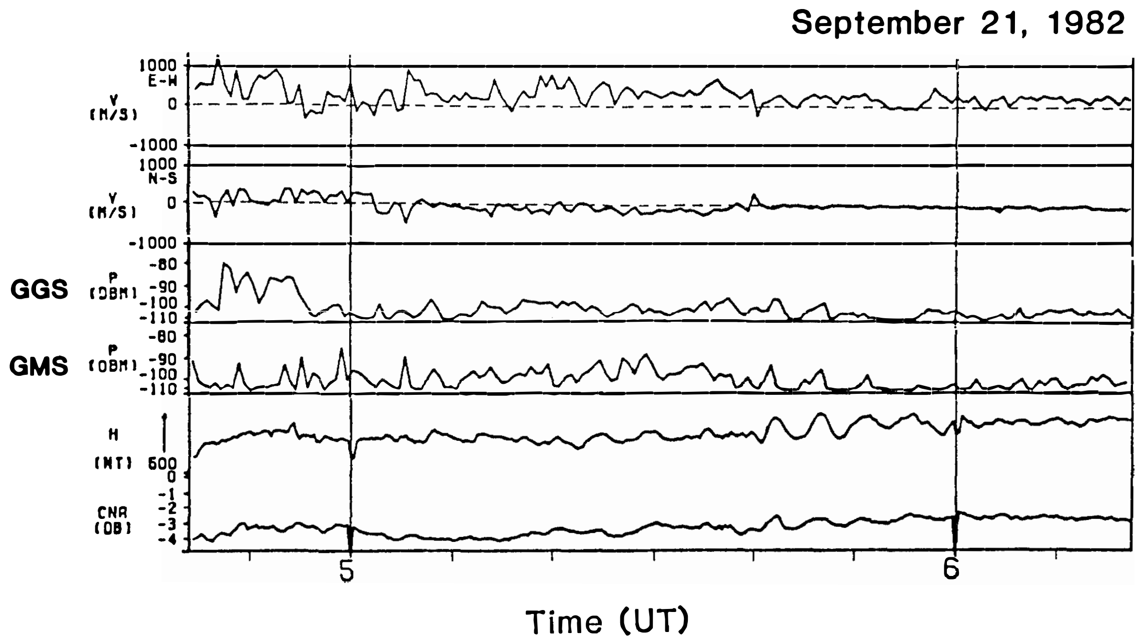


*Fig. 10. East-west and north-south components of doppler velocity vector are displayed in top and second panels, respectively. Time variations of maximum echo intensity (P) obtained by GGS and GMS antenna beams and also of geomagnetic H-component and 30 MHz CNA at Syowa Station are shown from third to bottom.*

Helmholtz instability as a cause of these pulsations.

(5) These results indicate that our radar system is a very useful diagnostic tool for the study of the auroral ionospheric dynamics.

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