SIMULTANEOUS OBSERVATIONS OF AURORA WITH A DOPPLER-RADAR AND SOUNDING ROCKETS

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Abstract: A 50 MHz auroral doppler-radar was operated at Syowa Station, Antarctica, in 1978 in cooperation with sounding rocket experiments during the International Magnetospheric Study. *E*-region irregularity-drift was measured by the radar while electric field, electron density fluctuation and other parameters were measured by the rockets. Electric field components perpendicular to the radar wave-vector, which were derived from the doppler shifts of echoes, are compared with *in situ* electric field measurement to find a qualitative agreement between both results. Sharp peaks due to the two-stream instability were found in echo spectra. The radar echo intensity seems to be dependent on the drift velocity of irregularities.

1. Introduction

Frequency spectrum of radar echo scattered from electron density irregularities in the auroral *E*-region is invaluable for understanding irregularity production and scattering mechanisms (*e.g.* BALSLEY and ECKLUND, 1972a). Recently it has been suggested that doppler shifts of echoes are also usable for determining ionospheric electric fields (ECKLUND *et al.*, 1977; CAHILL *et al.*, 1978). These indicate that the auroral radar having a function of doppler detection is capable of monitoring dynamical processes occurring in the auroral ionosphere (GREENWALD *et al.*, 1978; KEYS and JOHNSTON, 1979).

Auroral radar observations at 112 MHz started at Syowa Station (69°00′S, 39°35′E; geomagnetic lat. 69.6°S, long. 77.1°E) in 1966 and range- and azimuth-characteristics of radar echoes were investigated (HASEGAWA and SHIRO, 1970). Thereafter, occurrences of radio aurora at four frequencies (50, 65, 80 and 112 MHz) were studied during 1974–1979 (SHIRO and YAMAZAKI, 1976). This four-frequency radar was modified partly to detect doppler-shifts of 50 MHz echoes and its operation started in 1978. About sixty doppler measurements were made during active periods from March 25, 1978 to January 7, 1979. Four S-310JA type rockets were launched in the winter of 1978 from Syowa Station to measure auroral phenomena, and the doppler radar was simultaneously operated during these rocket flights.

The purpose of this preliminaly report is to describe that *E*-region irregularity drifts deduced from the auroral radar experiment agree reasonably with electric fields measured by the rockets.

2. Radar System and Antenna Pattern

The 50 MHz doppler radar used for this study was installed at Syowa Station. Table 1 gives the radar parameters, and Fig. 1 shows the block diagram. The radar was operated at four frequencies (50, 65, 80 and 112 MHz), out of which 50 MHz was used for the doppler measurement. The output from second IF (2 MHz) of the receiver is introduced to the doppler adapter. Then, this is mixed with 2 MHz from the local oscillator to get two outputs; one is in-phase with the second IF (In-phase channel) and the other is phase-shifted by 90° (Quadrature-phase channel). These outputs containing information of both phase and amplitude of the scattered signal are recorded directly on the analog magnetic tape, together with the timing of transmitting antenna beams. The antenna beams are in the direction of magnetic south with an elevation angle of 25°. An 8-element Yagi with a beamwidth of 40° in horizontal plane was mostly used and sometimes a collinear array (16-elements) with a beamwidth of about 10° located at about one wavelength height (~6 m) was used as a receiving antenna (BALSLEY and ECKLUND, 1972b).

Table 1. Parameters of the auroral doppler radar at Syowa Station, Antarctica.

Frequency	50, 65, 80, 112 MHz
Peak pulse power	3 kW (at PRF=700 Hz)
Pulse width	50, 100 μs
Pulse repetition frequency (PRF)	50~800 Hz (variable)
Antenna beamwidth in horizontal plane	~40° for 8-element Yagi antenna
	~10° for 16-element coaxial collinear antenna
Receiving bandwidth	25 kHz

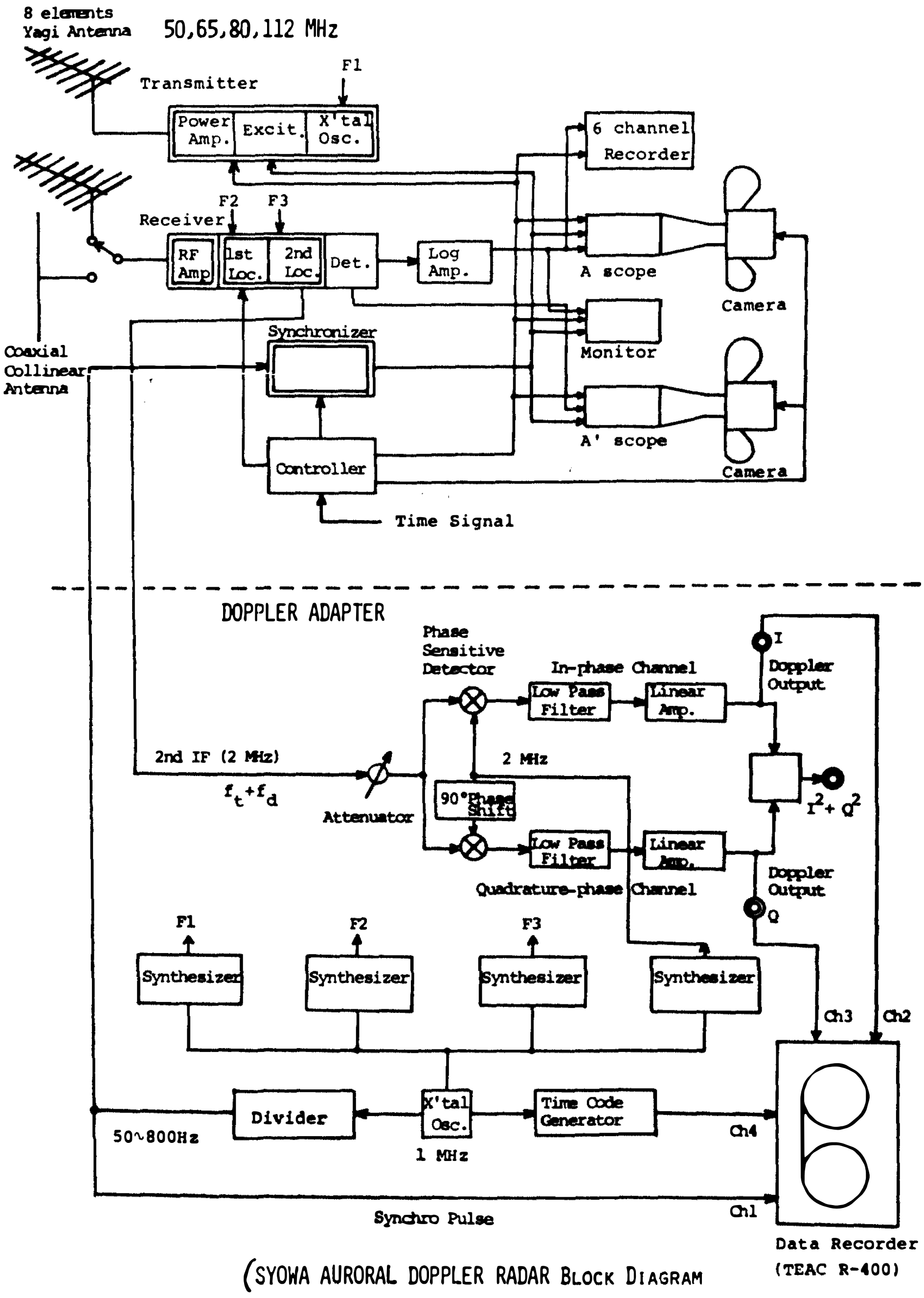

Fig. 1. System block diagram of the auroral doppler radar. Yagi antenna is used for the transmitting antenna. Yagi antenna is usually used for the receiving antenna, and a coaxial collinear antenna is occasionally used for the receiving antenna. Signal scattered from ionospheric irregularities is recorded on the analog data recorder.

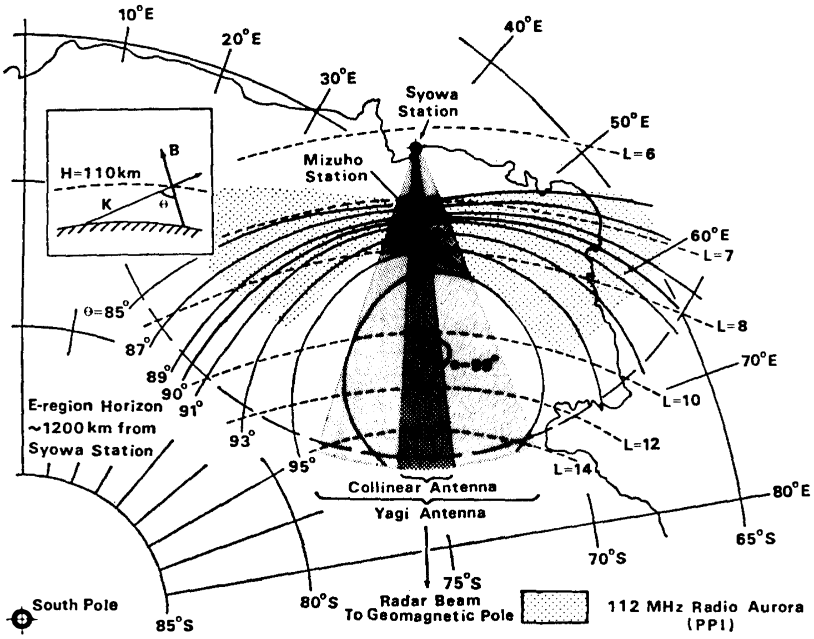

Fig. 2. Plan view of radar antenna patterns (Yagi and collinear antennas) together with contours of L value and aspect angle θ. The aspect contours are shown for a height of 110 km. The dotted-area represents the echo region of 112 MHz radio aurora.

The antenna patterns are schematically given in Fig. 2 which includes also the contour of the "aspect-angle" θ (the angle between the magnetic field vector $\boldsymbol{B}$ and the transmitted wave-vector $\boldsymbol{K}$) at the 110 km height. The dotted-area represents the echo region obtained by the 112 MHz PPI (Plan Position Indication) observation in 1966. Since electron density irregularities are generally field-aligned, scattering property is largely dependent on the aspect angle. Fig. 2 indicates that the 112 MHz echoes are limited within $\theta=90\pm5°$ or so. Since the antenna patterns for the present observations are directed geomagnetically southward as shown in Fig. 2, we can expect that most radar echoes return from the vicinity of Mizuho Station where $\theta\simeq 90°$.

Frequency power spectrum of radar echo at a particular range was obtained by applying a 128-point fast Fourier transformation after analog-to-digital conversion (sampling frequency = 10 kHz) of analog recording (GREENWALD, 1972). Twenty spectra were averaged over 6.4 s to get one averaged-spectrum when the pulse repetition frequency (PRF) was 400 Hz.

3. Simultaneous Observations with Radar and Rockets

3.1. S-310JA-4

The S-310JA-4 rocket aimed mainly at finding out what kinds of plasma insta-

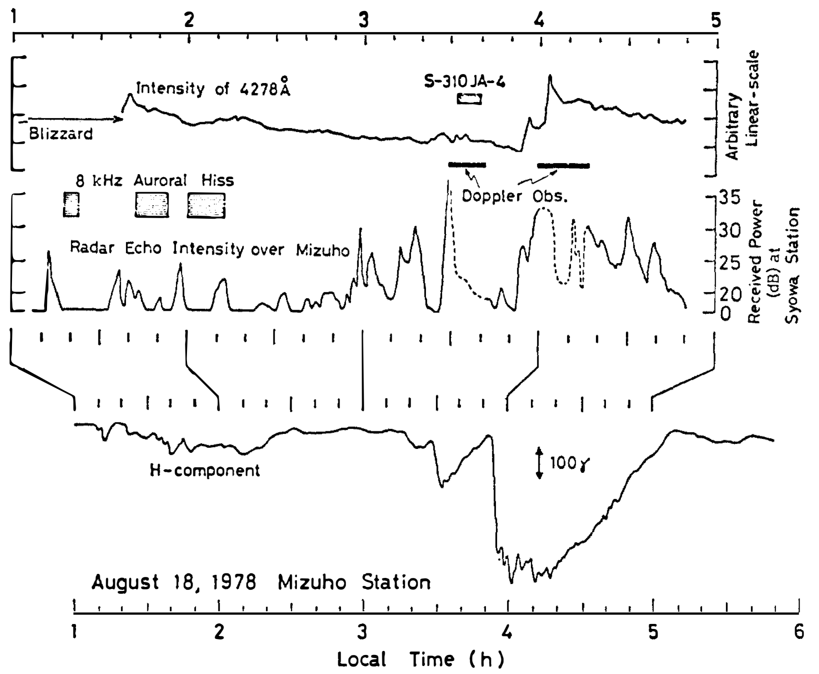

Fig. 3. Time profiles of 50 MHz radar echo intensity received at Syowa Station, optical aurora intensity (4278 Å) observed by the photometer and geomagnetic H-component at Mizuho Station. The doppler radar was operated during the time interval indicated by a thick line. The S-310JA-4 rocket was launched at 0332:43 LT on August 18, 1978.

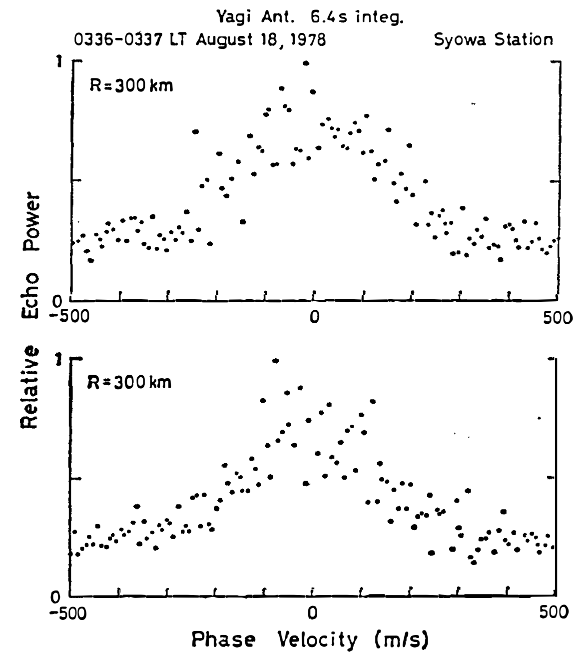

Fig. 4. Echo power spectra obtained during 0336–0337 LT on August 18, 1978. Power spectra were taken at 300 km range with PRF=330 Hz and Yagi receiving antenna. The upper figure precedes the lower figure in time.

bilities generate ionospheric irregularities within aurora. This rocket was launched at 0332:43 LT on August 18, 1978, in the direction of magnetic south with an elevation angle of 76°. The radar echo intensity, geomagnetic *H*-component and optical aurora intensity (4278 Å) observed at Mizuho Station are shown in Fig. 3. The echoes had been very strong at the launching time but became weak when the rocket came into the radar beam.

Two doppler spectra during 0336–0337 LT when the rocket was near the apogee are given in Fig. 4. Power spectrum analysis was made at an echo range of 300 km. Each spectrum is normalized in amplitude so that the maximum spectral power density is unity. The abscissa represents the drift velocity component parallel to the transmitting wave vector $\boldsymbol{K}$. The plus sign means the drift velocity going away from Syowa Station and *vice versa*.

It is known that the irregularities in the auroral *E*-region move almost together with the background plasma. Then, the drift velocity of the irregularities, V_d, is given by

$$V_d = \boldsymbol{E} \times \boldsymbol{B}/B^2 \tag{1}$$

where $\boldsymbol{E}$ is the electric field vector and $\boldsymbol{B}$ is the magnetic field. As can be seen in Fig. 4, dominant peak of V_d is near zero with half-power width of 150 m/s. It is inferred from eq. (1) that the east-west (E-W) component of the electric field must be relatively small. When the rocket was within the main lobe of the radar beam after 0337 LT, the echo intensities were within the main lobe of the radar beam after 0337 LT, the

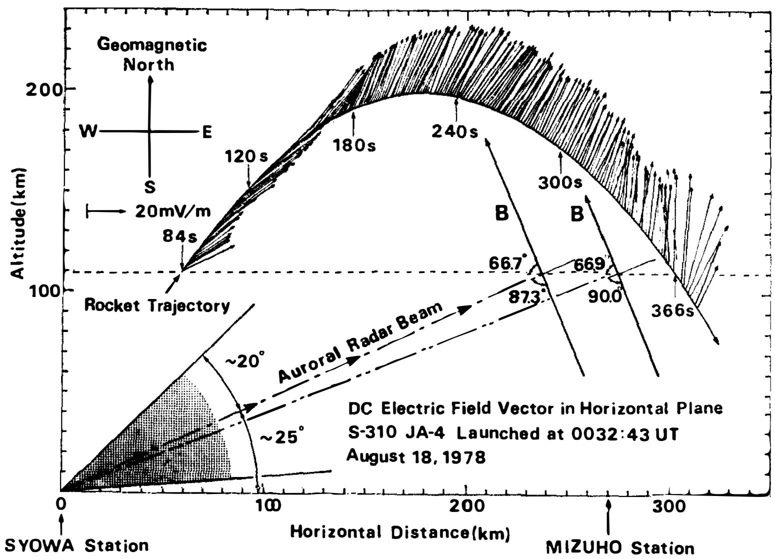

Fig. 5. Electric field vectors in the horizontal plane measured by S-310JA-4 which was launched at 0032:43 LT on August 18, 1978 and radar beam pattern in meridian plane.

echo intensities were very low (see Fig. 3) and therefore it is difficult to get a meaningful spectrum because of the insufficient signal-to-noise ratio.

Fig. 5 shows the result of the electric field measurement (YAMAGISHI *et al.*, 1981) and the configuration of the radar beam in the N-S meridian plane. The electric field vectors in the geomagnetic coordinates are shown along the rocket trajectory. *E*-region irregularities associated with aurora exist usually around 90–120 km (OGAWA *et al.*, 1976), and so the radar echoes also return from these heights. By taking 110 km as a typical echo height, the aspect angle θ and the dip angle of the magnetic field are estimated as shown in Fig. 5. The spectra shown in Fig. 4 must be compared directly with the *in situ* electric field measurement on the same magnetic field line if equi-potentiality along the field line is assumed. The rocket reached the apogee at about 0036:34 LT, after which the E-W component of the electric field became much smaller than the N-S component as shown in Fig. 5. Corresponding to this, the echo spectra shown in Fig. 4 have a broad peak around zero. Thus the electric field inferred from the echo spectra agrees qualitatively with the result of the rocket measurement.

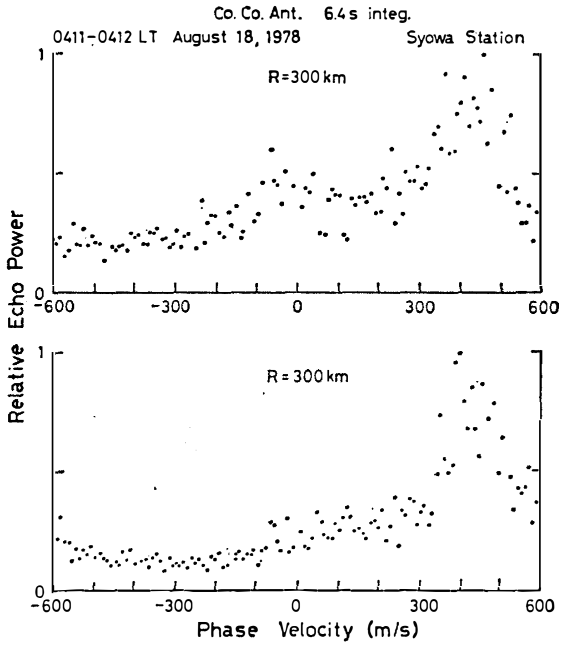

Fig. 6. Echo power spectra obtained during 0411–0412 LT on August 18, 1978. Power spectra were taken at 300 km range with PRF=330 Hz and coaxial collinear receiving antenna. The dominant doppler shift is seen approximately at 450 m/s corresponding to the electric field component of about 23 mV/m. The upper figure precedes the lower figure in time.

An intense substorm started at 0035 LT after launching of S-310JA-4 (see Fig. 3). Examples of the doppler spectrum during the substorm are shown in Fig. 6. The receiving antenna was a coaxial collinear array. The spectral peaks appear around 450 m/s, which indicates the electric field of 20–25 mV/m directed toward the magnetic east. The half-power widths are about ± 50 m/s which is narrower than those shown in Fig. 4. The two-stream-generated irregularities are excited when electron drift velocity (relative to ions) exceeds the ion-acoustic velocity (FARLEY, 1963). The ion-acoustic velocity is about 400 m/s at the height of 110 km in the auroral region, which is almost consistent with the doppler velocity of 400–500 m/s as shown in Fig. 6. From this and the narrow spectral width it is inferred that the irregularities are due to the two-stream instability (for details, see BALSLEY and ECKLUND, 1972a; HALDOUPIS and SOFKO, 1978).

3.2. *S-310JA-5 and S-310JA-6*

S-310JA-5 was launched geomagnetically northward at 0156:50 LT on June 11, 1978. The doppler-radar operation was executed during the rocket flight, but no echoes were detected.

S-310JA-6 was launched geomagnetically northward at 0056:00 LT on August 28, 1978. As the rocket was not launched toward south, the doppler-radar operation was not made. However, the 6-channel chart recording of radio aurora intensity, the 35 mm film recording of A-scope display and the range-time-intensity (RTI) were obtained in the routine observations (IGARASHI and TSUZURAHARA, 1980).

3.3. *S-310JA-7*

The purpose of S-310JA-7 was to measure wave phenomena, precipitating electrons, electric field, electron density and so on. This rocket was launched geomagnetically northward at 2215:50 LT on March 27, 1978. The data during the rocket flight are shown in Fig. 7, where the right top curve gives the 30 MHz cosmic

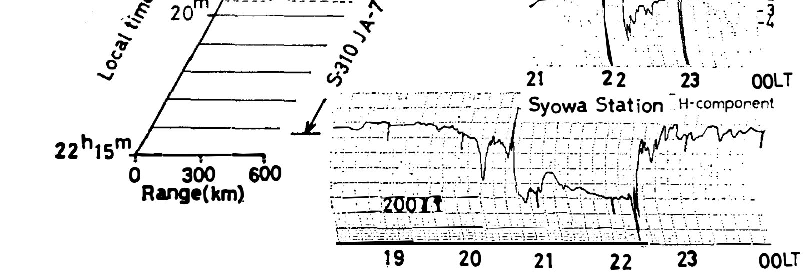

Fig. 7. Time variation of A-scope display of the 50 MHz radio aurora when S-310JA-7 was launched at 2215:50 LT on March 27, 1978. Geomagnetic H-component at Syowa Station, and 30 MHz cosmic noise absorption at Mizuho and Syowa Stations are shown on the right.

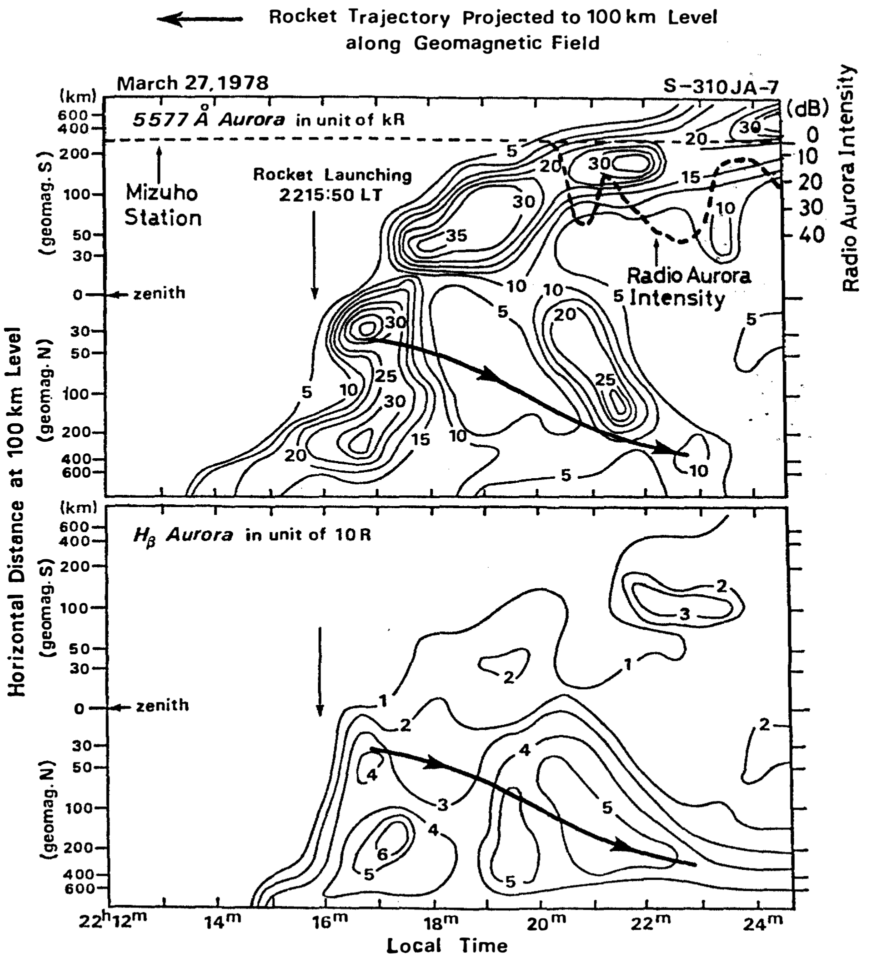

Fig. 8. Contours of 5577 Å aurora and H_β aurora measured by scanning photometer at Syowa Station. The S-310JA-7 rocket trajectory projected down to 100 km level along the geomagnetic field is also shown. Time variation of auroral radar echo intensity over Mizuho Station is represented by a thick broken curve.

noise absorption (CNA) obtained at Mizuho Station, and the middle and bottom curves show the 30 MHz CNA and the H component of the geomagnetic field recorded at Syowa Station, respectively. The left oblique figure shows the time profiles of relative backscattered power as a function of range from Syowa Station for 2215–2228 LT. Each profile was obtained from the 35 mm film record of radar A-scope. Fig. 8 shows contours of 5577 Å aurora and H_β aurora measured by the scanning photometer with the rocket trajectory projected to 100 km level along the geomagnetic field. The radar echo intensity at a range of 300 km is indicated in the top of this figure. After launching, an aurora arc moved toward magnetic south with an averaged-velocity of about 900 m/s. The radio aurora was not detected for some time after this launching. Strong discrete echoes began to appear at ranges between

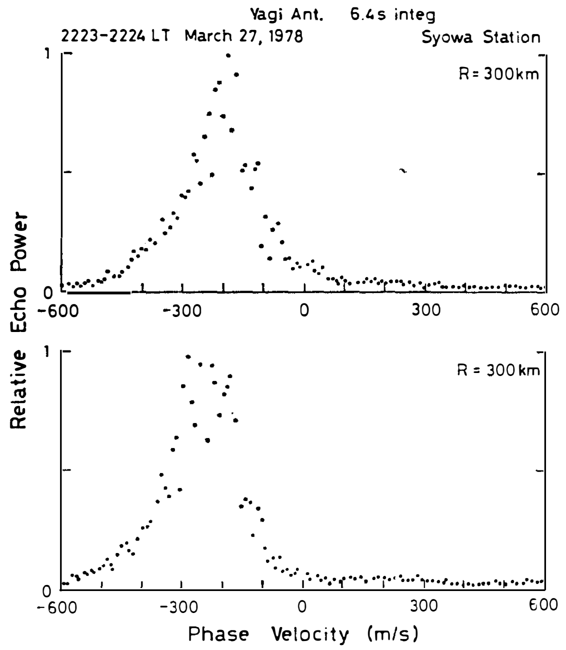

Fig. 9. Echo power spectra obtained during 2223–2224 LT on March 27, 1978. Power spectra were taken at 300 km range with PRF=400 Hz and Yagi receiving antenna. The dominant doppler shift is seen approximately at −250 m/s corresponding to the electric field component of about 13 mV/m. The upper figure precedes the lower figure in time.

240 and 294 km at about 2220:30 LT when the auroral arc reached over Mizuho Station. The 30 MHz cosmic noise absorption at Mizuho Station was about 2 dB.

Two power spectra from 2223 to 2224 LT at the 300 km range are shown in Fig. 9. The Yagi antenna was used for echo reception. The power peaks at the phase velocities between 200 and 250 m/s. This means from eq. (1) that the westward components of the electric fields were between 10 and 13 mV/m. The electric field observed by S-310JA-7 was about 50 mV/m and westward (OGAWA *et al.*, 1981). It is unreasonable to compare directly the strength of electric fields determined by radar experiment with those by the rocket measurement, because of the rocket launching toward magnetic north. However, both results seem to coincide qualitatively as to the direction of the electric field.

The spectral shapes seen in Fig. 9 are very similar to those presented in Fig. 6 except for the spectral peak positions. This may lead us to the speculation that the spectra shown in Fig. 9 are due to the two-stream instability. In the case of Fig. 9, however, the phase velocities (200∼250 m/s) at the spectral peaks are almost half the two-stream instability threshold (∼400 m/s). This contradiction may be resolved partly by considering that the radar can detect only the component of the $\boldsymbol{E}\times\boldsymbol{B}$ irregularity drift along the beam. In order to justify the above speculation, a two-dimensional determination of the drift velocity vector would be needed (GREENWALD, 1978).

4. Concluding Remarks

Preliminary comparisons between the auroral doppler-radar and S-310JA type rocket experiments indicate the following.

(1) Electric fields deduced from the doppler shifts are qualitatively consistent with those measured by the rockets.

(2) Simultaneous radar observation with S-310JA-4 shows that the doppler shift is small and the backscattered power is low when the electric field vectors are in the north-south direction.

(3) The two-stream spectra generated by strong electric fields were found during a substorm phase.

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