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HF DOPPLER OSCILLATIONS DURING THE GEOMAGNETIC STORM OF FEBRUARY 6–9, 1986

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Abstract

Some results of HF Doppler (HFD) measurements using the Communications Research Laboratory HFD network during the large geomagnetic storm of February 6–9, 1986 are reported. In association with the storm sudden commencement at 1312 UT on February 6, HFD frequency deviations belonging to an SCF(+−) type, which is believed to be caused by westward and subsequent eastward electric fields, were observed. Wave parameters of large-scale traveling ionospheric disturbances (period = 80 − 100 minutes, phase velocity = 440 m/s and horizontal wavelength = 2100 − 2600 km) detected on the night of February 7 are almost completely consistent with those observed by the MU radar at Shigaraki. Very clear, sinusoidal HFD oscillations with a period of 2.5 minutes triggered by the sudden impulse at 1748 UT on February 9 were simultaneously accompanied with the geomagnetic pulsation. These HFD oscillations can be explained by the compressions and rarefactions of the ionospheric plasma due to the pulsation magnetic field.

1. Introduction

An HF Doppler method for measuring the frequency change of an ionospherically reflected HF standard radio wave has been long used to detect electron density variation and plasma motion in the ionosphere. Since the first development of an observation system by Ogawa (1958), this method has largely contributed to the understanding of ionospheric disturbances such as abnormal ionization due to solar flares (e.g., Chan and Villard, 1963), plasma motion associated with geomagnetic storms (e.g., Huang et al., 1973), and medium- and large-scale traveling ionospheric disturbances (TID's) (e.g., Georges, 1968).

Communications Research Laboratory (CRL; formerly, Radio Research Laboratory) started HF Doppler (HFD) measurements in 1981 and is now operating an HFD network comprised of seven observing stations distributed in Japan. This paper reports some observational results obtained from the CRL HFD network during the large geomagnetic storm of February 6–9, 1986. Special attention is paid to the periods of storm sudden commencement (SSC) and sudden impulse (SI), and also to the large-scale TID's (LSTID's). An HFD analysis similar to the present one was reported by Kikuchi et al. (1986), who used HFD data only at Kokubunji and Okinawa, for the events associated with the solar-terrestrial disturbances of June–September 1982.

2. Observation

As is well known, HF radio wave frequency reflected in the ionosphere changes according to temporal changes in the reflecting height and/or refractive index (Davies et al., 1962). The Doppler frequency due to the reflecting height change, Δf_1, is given by

$$\Delta f_1 = -\frac{2f}{c}\frac{dh}{dt}\cos(i) \tag{1}$$

where f is the probing frequency, h the height, i the incidence angle into the ionosphere, c the light velocity and t the time. On the other hand, the Doppler frequency due to the refractive index change, Δf_2, caused by an excess electron density in the non-deviating slab through which the probing wave propagates, is given by

$$\Delta f_2 = \frac{kd}{cf}\frac{dN}{dt}\sec(s) \tag{2}$$

where N is the electron density, d the slab thickness, s the incidence angle into the slab and $k = 8.06 \times 10^{-11}$. In deriving eq. (2), we neglected the effect of the geomagnetic field. Then, $\Delta f (= \Delta f_1 + \Delta f_2)$ is the Doppler frequency observed at a receiving station. It is difficult to separate observationally Δf into Δf_1 and Δf_2 components.

Figure 1 illustrates seven radio paths from the JJY station at Nazaki (NAZ; 36.18° N, 139.85° E) which transmits the 2.5, 5, 8, 10 and 15 MHz standard radio waves. Table 1 lists parameters pertinent to the receiving stations, Wakkanai, Akita, Hiraiso, Inubo, Kokubunji, Yamagawa and Okinawa, shown in Figure 1. Since the incidence angle, i (s) in

TABLE 1. Parameters of HFD Receiving Stations

Receiving Stations (Abbreviation)	Geographic Coordinates Lat.(°N)	Long.(°E)	Horizontal Distance from JJY (km)
Wakkanai (WAK)	45.39	141.69	1037
Akita (AKI)	39.73	140.14	396
Hiraiso (HIR)	36.37	140.63	73
Inubo (INB)	35.70	140.86	105
Kokubunji (KOK)	35.71	139.49	62
Yamagawa (YAM)	31.20	130.62	1018
Okinawa (OKN)	26.29	127.81	1587

in eq. (1) ((2)), is dependent on the radio path length, Δf_1 (Δf_2) becomess smaller (larger) at a more remote receiving station if other physical parameters are invariable. Moreover, the frequencies that can be received depend on the incidence angle, maximum electron density ($foF2$) and ionospheric absorption. Thus, it should be kept in mind that an HFD event detected at a certain station does not always have counterparts at other stations.

3. Results and Discussion

HFD activity during February 6–9

Figure 2 shows the geomagnetic H–component at Kakioka during February 5–11, 1986. We note SSC (1312 UT) on February 6 initiated the large geomagnetic storm, SC (1521 UT) on February 7, SI (1430 UT) and SC (2012 UT) on February 8, and strong SI (1748 UT) on February 9, of which here we have primary concerns with SSC on February 6 and SI on February 9.

Time variations of the 5 MHz HFD frequency at seven receiving stations and the Kakioka H–component during February 6–9 are plotted in Figs. 3a–d. It can be clearly seen from theses figures that the HFD activity was largely enhanced in association with the storm development, especially in the nighttime hours (8–23 h UT; LT=UT+9 hours) on February 7 and 8. The daytime (23–8 h UT) activity at farther stations (Wakkanai, Akita, Yamagawa and Okinawa) seems to be more suppressed, probably due to larger incidence angle [see eq. (1)] and/or stronger ionospheric absorption resulting in very small signal-to-noise ratio, and therefore may not necessarily reflect real ionospheric variations. Using enlarged HFD plots, we will discuss below in more detail the observed HFD characteristics.

HFD associated with SSC at 1312 UT on February 6

Time variations of the 5 MHz HFD frequency at Wakkanai, Kokubunji and Okinawa are enlarged in Figure 4. At all stations, the SSC at 1312 UT on February 6 was followed by the preliminary increase (0.1–0.2 Hz) in Doppler frequency with a duration of one minute and then by the large decrease (0.4–0.8 Hz) with a duration of about 8 minutes.

From a statistical study, Kikuchi et al. (1985) divided HFD frequency deviations associated with SSC's, shortly called SCF's, into two categories; one is the SCF (+−) appearing in the daytime and evning sectors (6–21 h LT) and the other the SCF (−+) appearing in the nighttime sector (21–6 h LT). Here, the combination of signs (+−) (or (−+)) means that the preliminary frequency deviation caused by westward (or eastward) ionospheric electric field is positive (+) (or (−)) and the subsequent, main deviation caused by eastward (or westward) electric field is negative (−) (or (+)). According to this categorization, our SCF belongs to the SCF (+−) type due to the westward electric field in the preliminary phase and the eastward electric field in the main phase, albeit the present SSC occurred at 1312 UT (2212 LT), which is a little later than the predicted demarcation hour (21 h LT).

Large-scale TID's

Large-scale TID's (LSTID's) have wavelengths longer than 1000 km, periods of 0.5–3 hours and phase velocities of 400–1000 m/s, and are believed to be triggered by Joule heating and/or Lorentz force during an auroral activity at high-latitudes (e.g., Hunsucker, 1982). Here, we exemplify two LSTID's events. LSTID's detected on the night of February 7, 1986 appear in Figure 5 where apparent phase progressions from north to south are indicated by the oblique lines. In this figure, LSTID's are manifested as the HFD oscillations with two cycles during 1130–1430 UT (2030–2330 LT). The signature of LSTID's is obscured a little at Okinawa, indicating their disappearance around Okinawa. From the geographical configuration shown in Figure 1 and an assumption that the waves propagated toward due south, we obtain a phase velocity of about 440 m/s. Frequency spectra of HFD data at Wakkanai and Okinawa are displayed in Figure 6 where the predominant periods of 80 minutes at Wakkanai and 90–100 minutes at Okinawa are clearly discernible. Therefore, we have a horizontal wavelength of 2100–2600 km.

The above-mentioned LSTID's were also detected by the Kyoto University MU radar located at Shigaraki (34.85° N, 136.10° E; see Figure 1) during 1000–1800 UT. Oliver et al., (1988) have reported the following wave parameters; wave period = 100 minutes, direction of travel = 19° west of south, wave speed = 410 m/s and horizontal wavelength = 2500 km. These parameters show excellent agreement with those derived from the present HFD observations.

LSTID's on the night of February 8 appear in Figure 7. The geomagnetic K_p indices this night were extremely high, thus suggesting a high probability of LSTID's occurrence; 8 (12–15 h UT), 8– (15–18 h UT) and 9 (18–21 h UT). An apparent phase progression represented by the oblique line indicates a phase velocity of about 500 m/s. Taking into account the frequency spectra at Akita and Okinawa in Figure 8, which show the predominant periods of 100–110 minutes, we have a horizontal wavelength of about 3000–3300 km.

At present, we have no direct evidences showing that the LSTID's reported here were produced by auroral activities at high-latitudes. However, the estimated wave parameters and the north-to-south propagation corroborate that these LSTID's came from auroral latitudes. In this issue, Kamide (1989) reports the superposed H–component records at high-latitudes from which we recognize that very intense substorms often occurred prior to and around the hours when LSTID's in Figs. 5 and 7 were observed.

HFD oscillations associated with SI on February 9

Sinusoidal-like HFD oscillations were detected in association with the occurrence of strong SI at 1748 UT on February 9. In Figure 9, we observe five very clear cycle oscillations, especially at Kokubunji with a fundamental period of 2.5 minutes. There seem to exist second harmonics of oscillation at Hiraiso, Inubo and Kokubunji. There were no clear oscillations at Yamagawa and Okinawa, perhaps due to very low signal-to-noise ratio.

Yumoto et al., (1989) report in this issue the geomagnetic pulsation with a period of 2.5 minutes in harmony with the present HFD oscillations. Relying on the theory proposed by Poole et al. (1988), Yumoto et al. (1989) explain the HFD oscillations as a result of the compressions and rarefactions of the ionospheric plasma due to the field-aligned component of the pulsation magnetic field.

4. Summary

The results from the CRL HFD network measurements during the large geomagnetic storm of February 6–9, 1986, can be summarized as follows:

1. HFD activity was strongly enhanced in the nighttime hours (8–23 h UT; 17–8 h LT), implying that the activity is closely related to the ionospheric disturbances during the storm.

2. SCF (+−) was observed in association with SSC at 1312 UT on February 6. According to the SCF categorization by Kikuchi et al. (1985), the positive and subsequent negative Doppler frequency deviations are caused by the westward and eastward electric fields, respectively.

3. LSTID's on the night of February 7 have a period of 80–100 minutes, phase velocity of 440 m/s and horizontal wavelength of 2100–2600 km, and are the same as those observed by the MU radar (Oliver et al., 1988). LSTID's having a longer period, higher phase velocity and larger wavelength were detected on the night of February 8. We infer that these LSTID'S were produced by auroral activities at high-latitudes. This relationship can be examined in detail by using high-latitude data (AE index, satellite auroral image and others).

4. Very clear, sinusoidal oscillations with a period of 2.5 minutes triggered by SI at 1748 UT on February 9 were simultaneously observed with the geomagnetic pulsation. These oscillations can be explained by the compressions and rarefactions of the ionospheric plasma due to the pulsation magnetic field (Yumoto et al., 1989).

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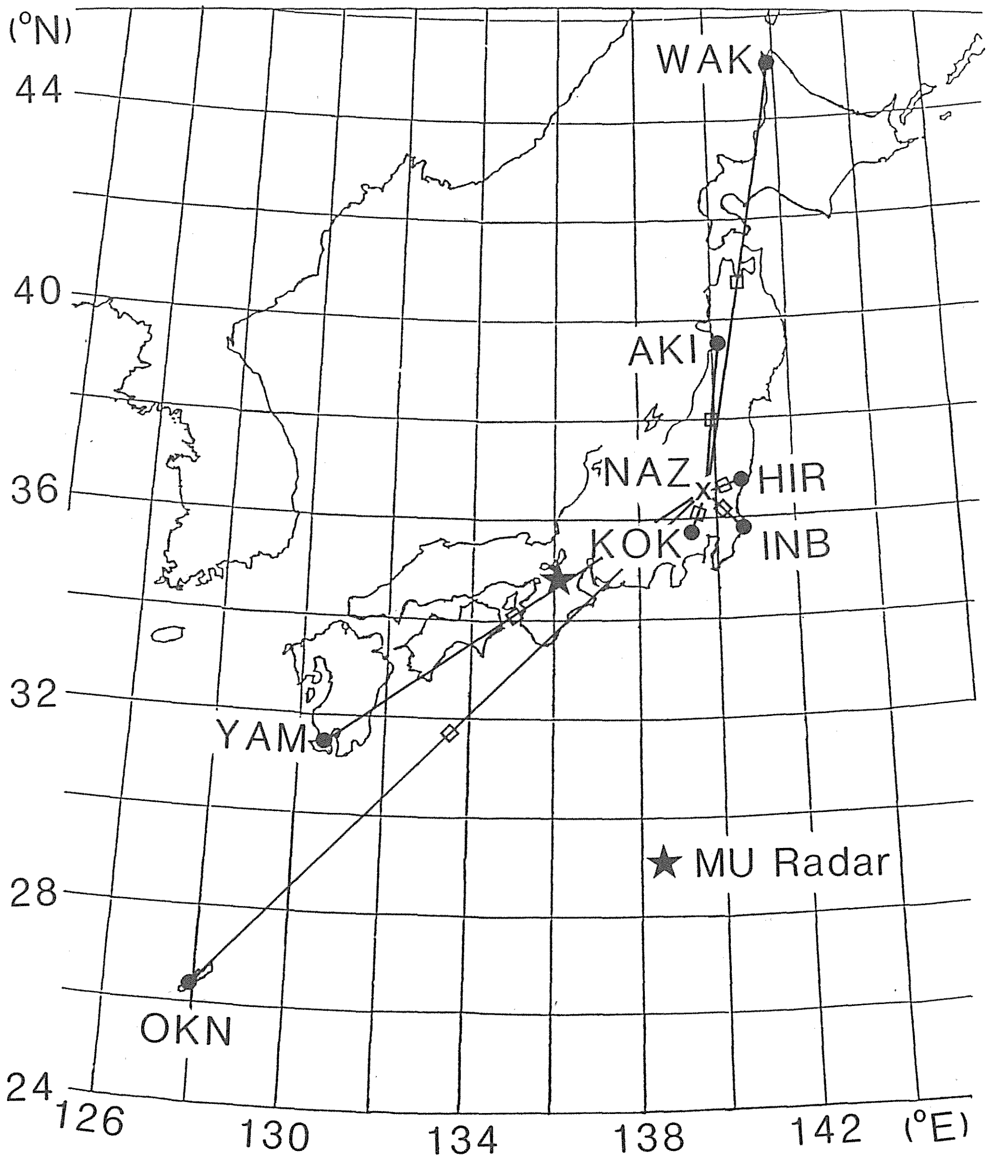


Fig. 1. Seven radio paths from JJY transmitting station at Nazaki (NAZ). White square on each path indicates midpoint on the path. Location of the MU radar is also shown.

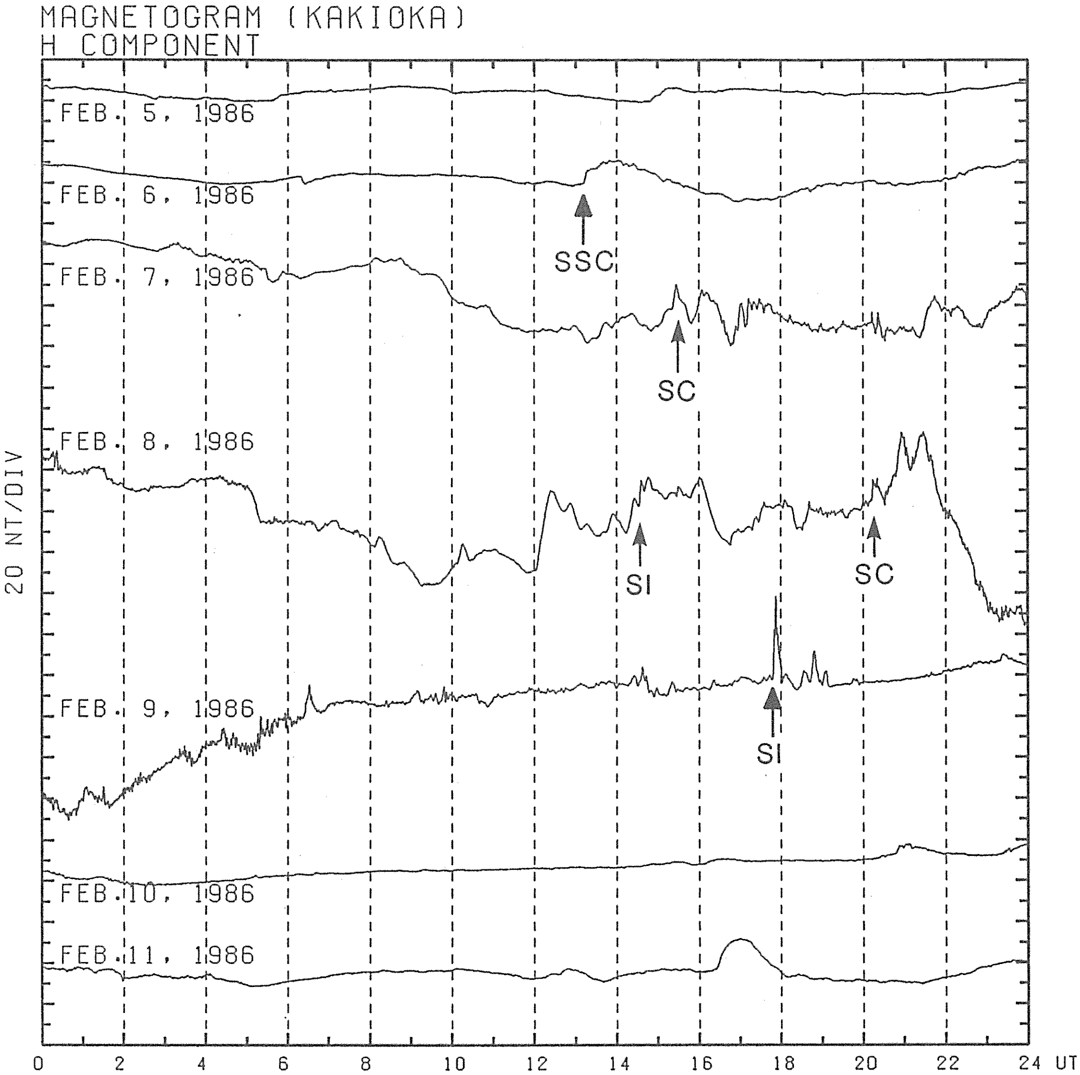
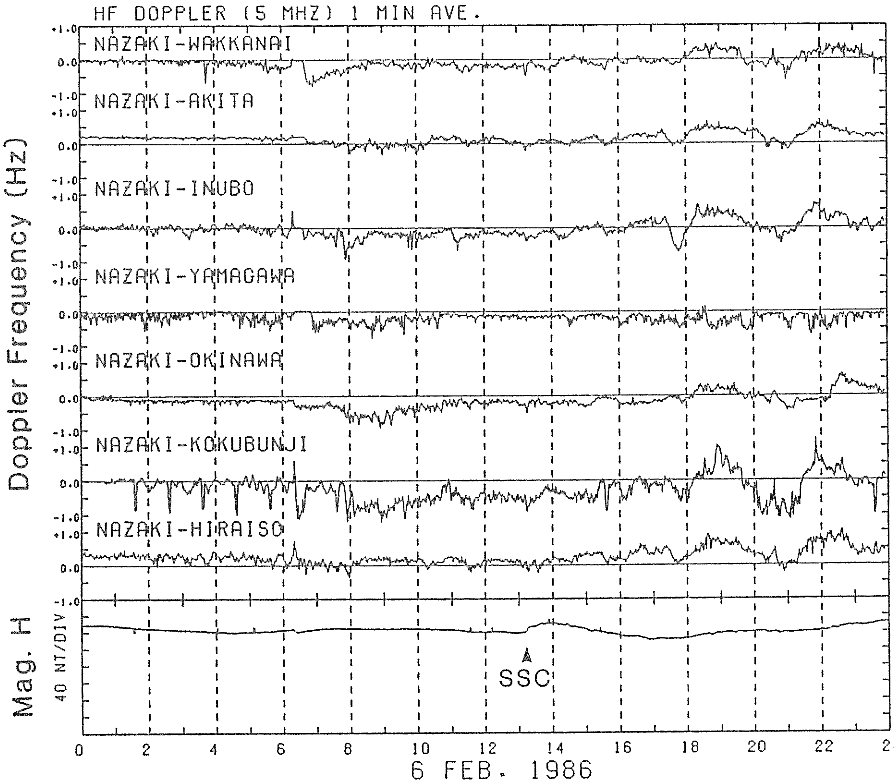


Fig. 2. Time variation of geomagnetic H–component at Kakioka during February 5–11, 1986.


HF DOPPLER (5 MHZ) 1 MIN AVE.
NAZAKI-WAKKANAI
NAZAKI-AKITA
NAZAKI-INUBO
NAZAKI-YAMAGAWA
NAZAKI-OKINAWA
NAZAKI-KOKUBUNJI
NAZAKI-HIRAISO
Doppler Frequency (Hz)
Mag. H
40 NT/DIV
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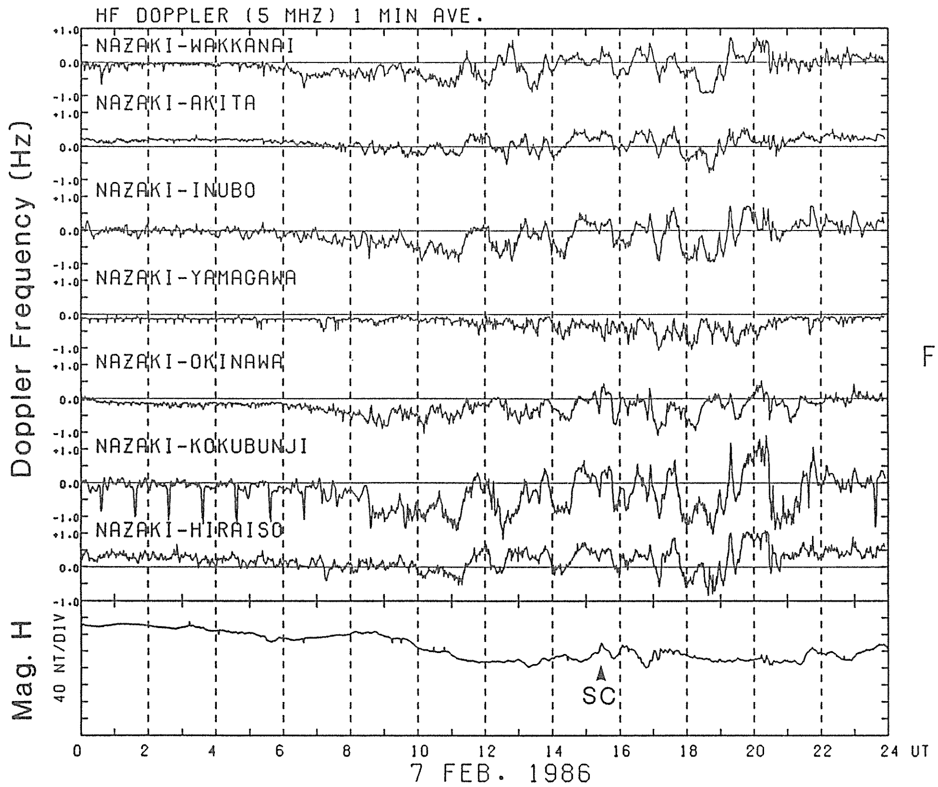
0 2 4 6 8 10 12 14 16 18 20 22 24 UT
6 FEB. 1986

Fig. 3a.


HF DOPPLER (5 MHZ) 1 MIN AVE.
NAZAKI-WAKKANAI
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NAZAKI-OKINAWA
NAZAKI-KOKUBUNJI
NAZAKI-HIRAISO
Doppler Frequency (Hz)
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0 2 4 6 8 10 12 14 16 18 20 22 24 UT
7 FEB. 1986

Fig. 3b.

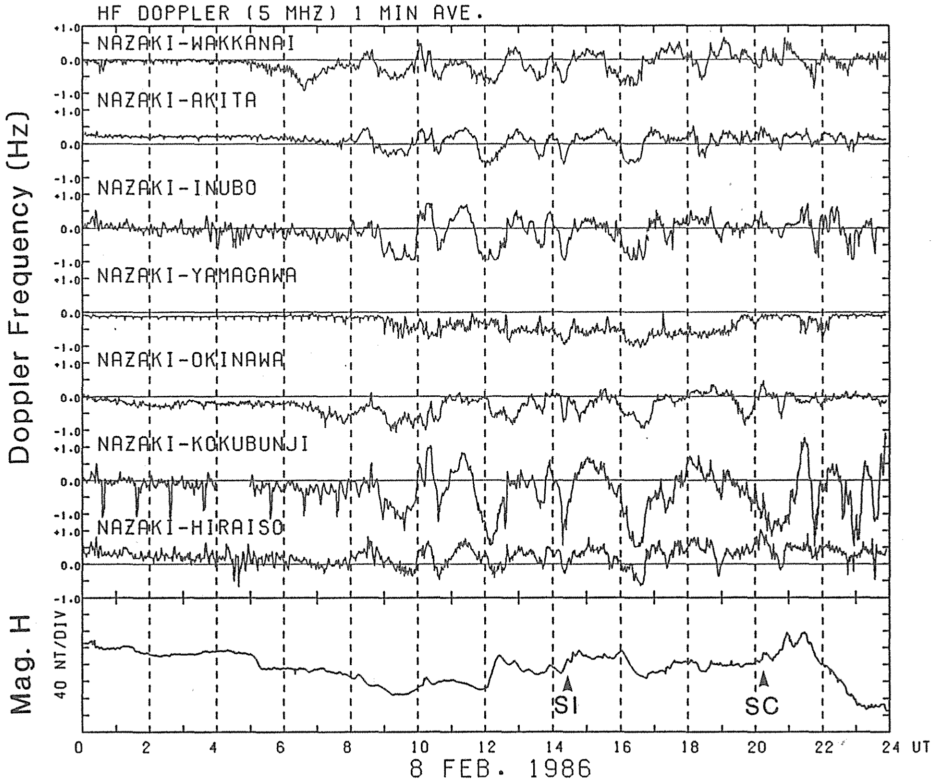


Fig. 3c.

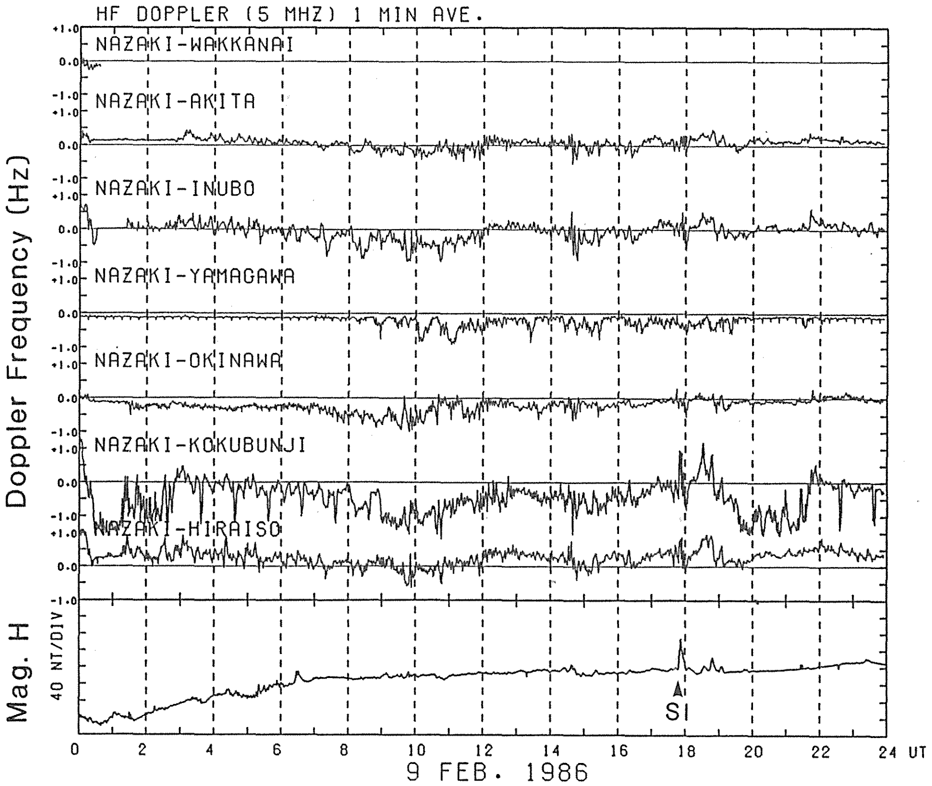


Fig. 3d.

Fig. 3. Time variations of 5 MHz HF Doppler frequency at seven receiving stations and geomagnetic H-component at Kakioka during February 6–9, 1986.

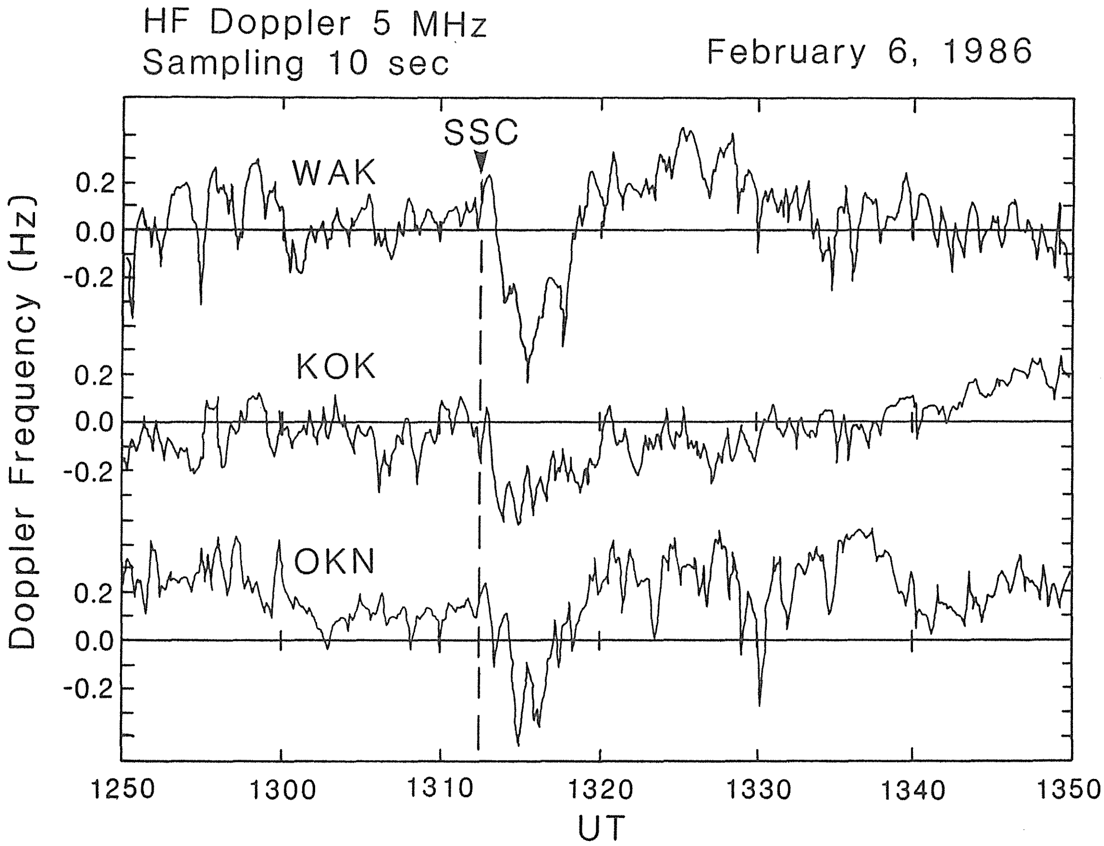


Fig. 4. Time variations of 5 MHz HF Doppler frequency at three receiving stations during 1250–1350 UT on February 6, 1986. Note SSC at 1312 UT.

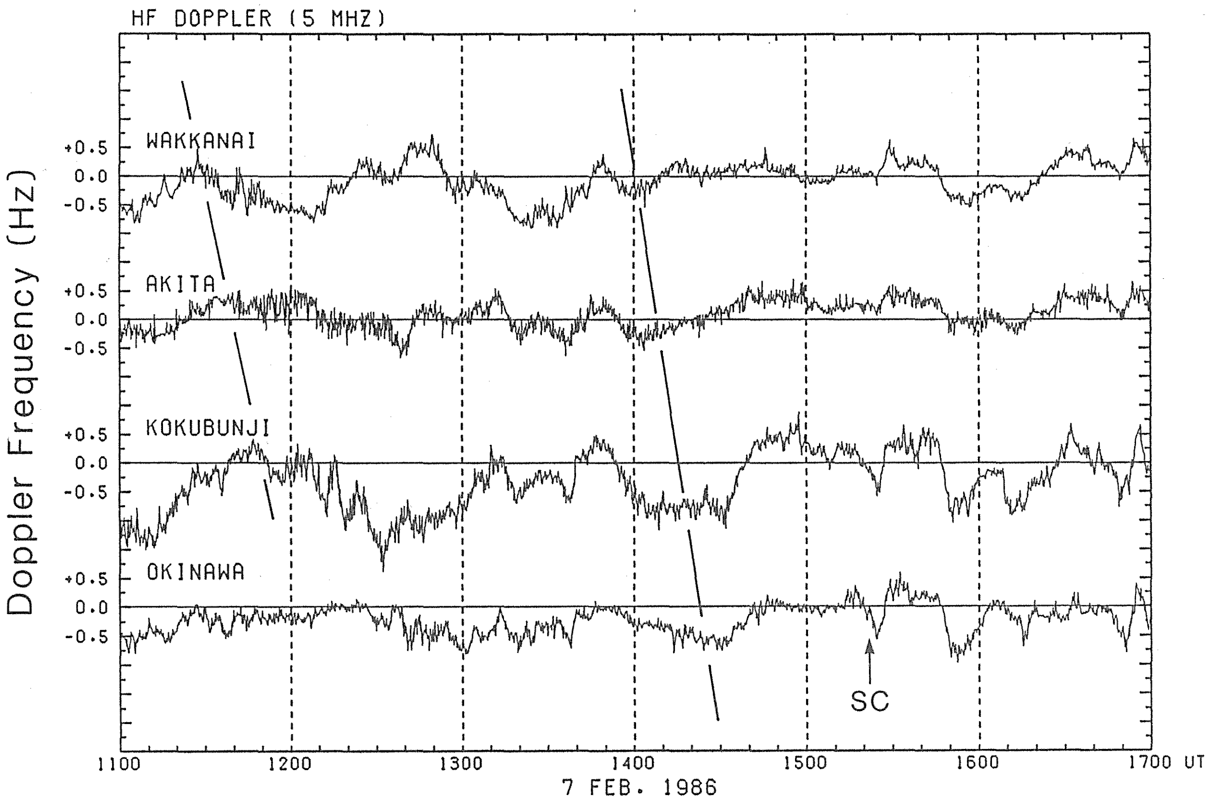
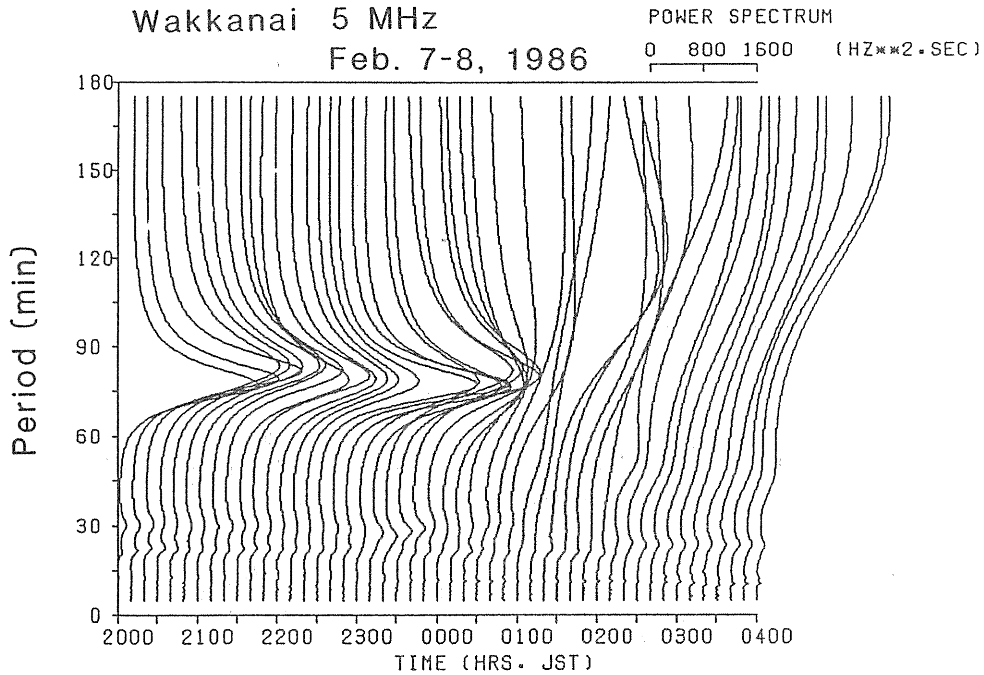


Fig. 5. Time variations of 5 MHz HF Doppler frequency at four receiving stations during 1100–1700 UT on February 7, 1986.



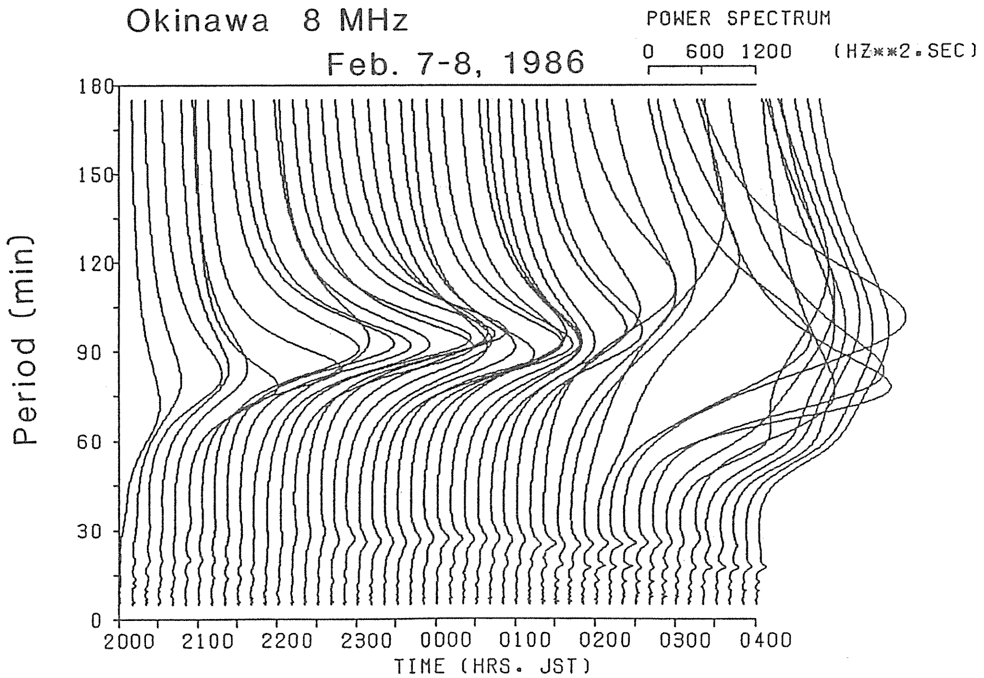


Fig. 6. Power spectra of HF Doppler frequency at Wakkanai (5 MHz; upper) and Okinawa (8 MHz; lower) between 2000 JST on February 7 and 0400 JST on February 8, 1986. Note that JST=UT+9 hours.

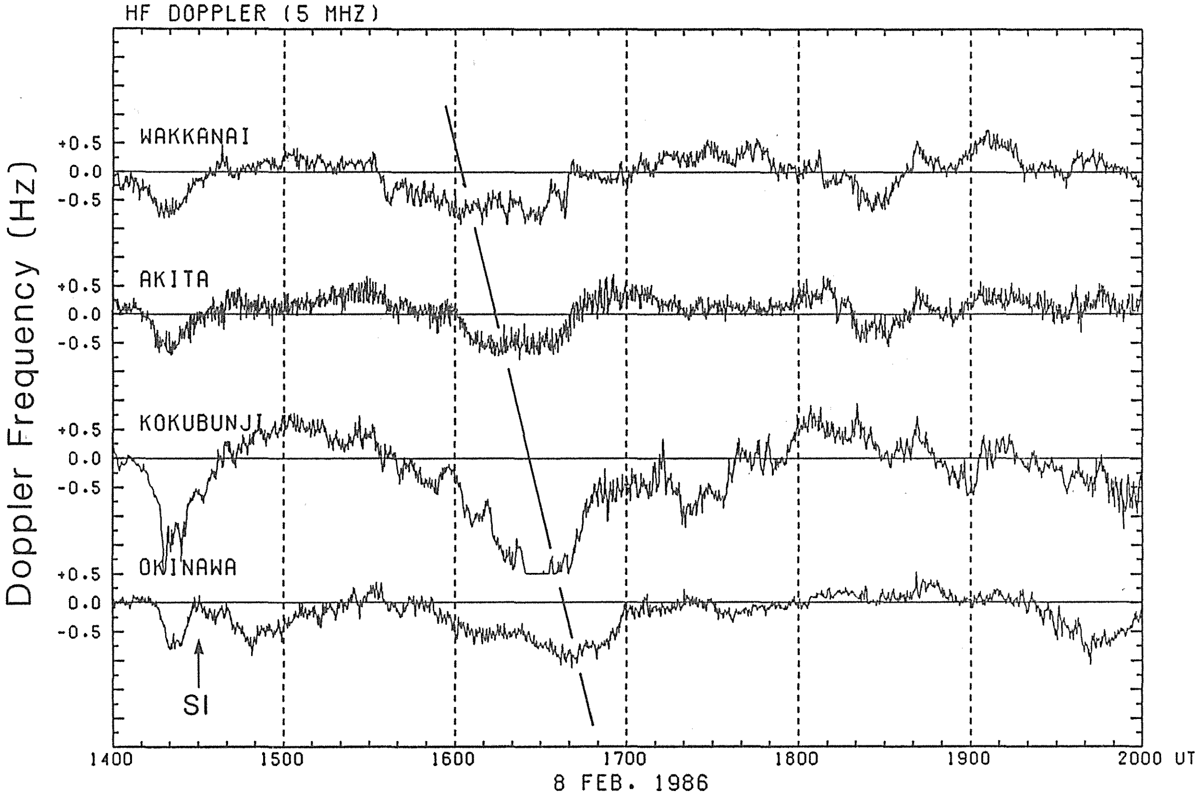
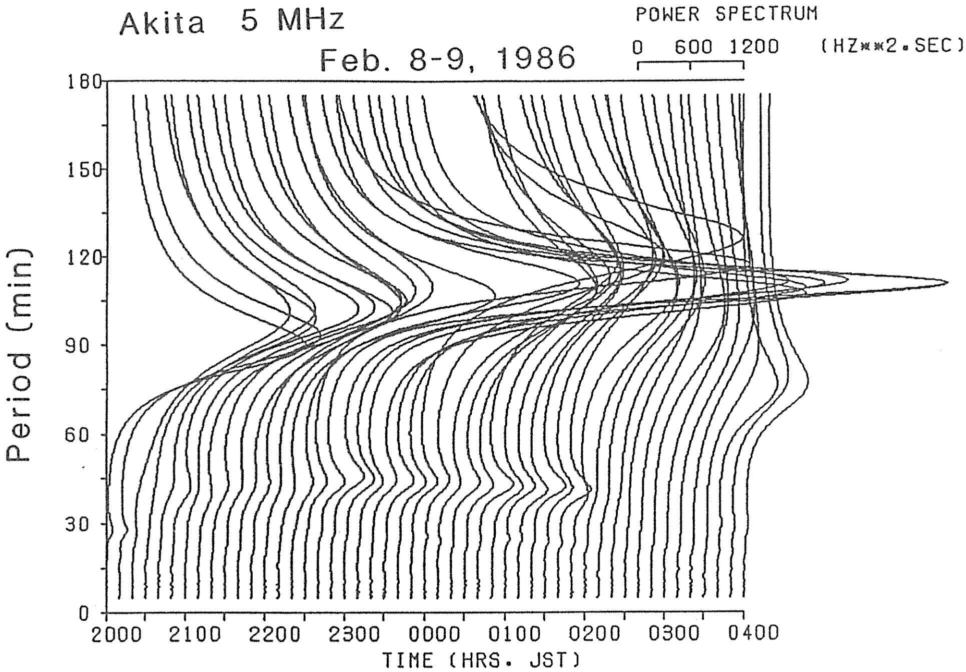


Fig. 7. Same as Fig. 5 but for 1400–2000 UT on February 8, 1986.



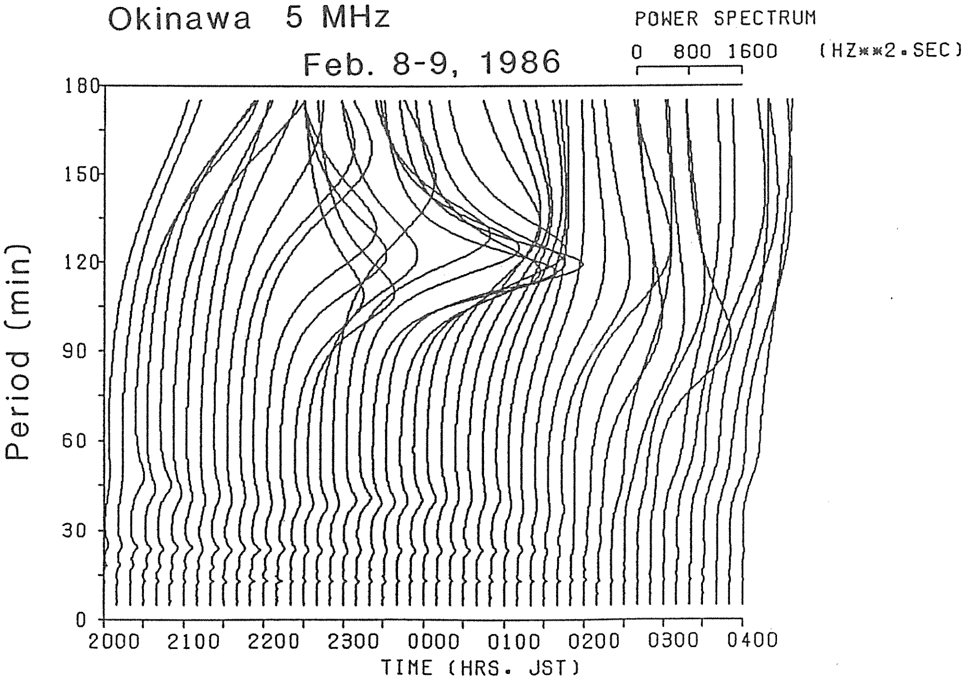


Fig. 8. Power spectra of 5 MHz HF Doppler frequency at Akita (upper) and Okinawa (lower) between 2000 JST on February 8 and 0400 JST on February 9, 1986. Note that JST=UT+9 hours.

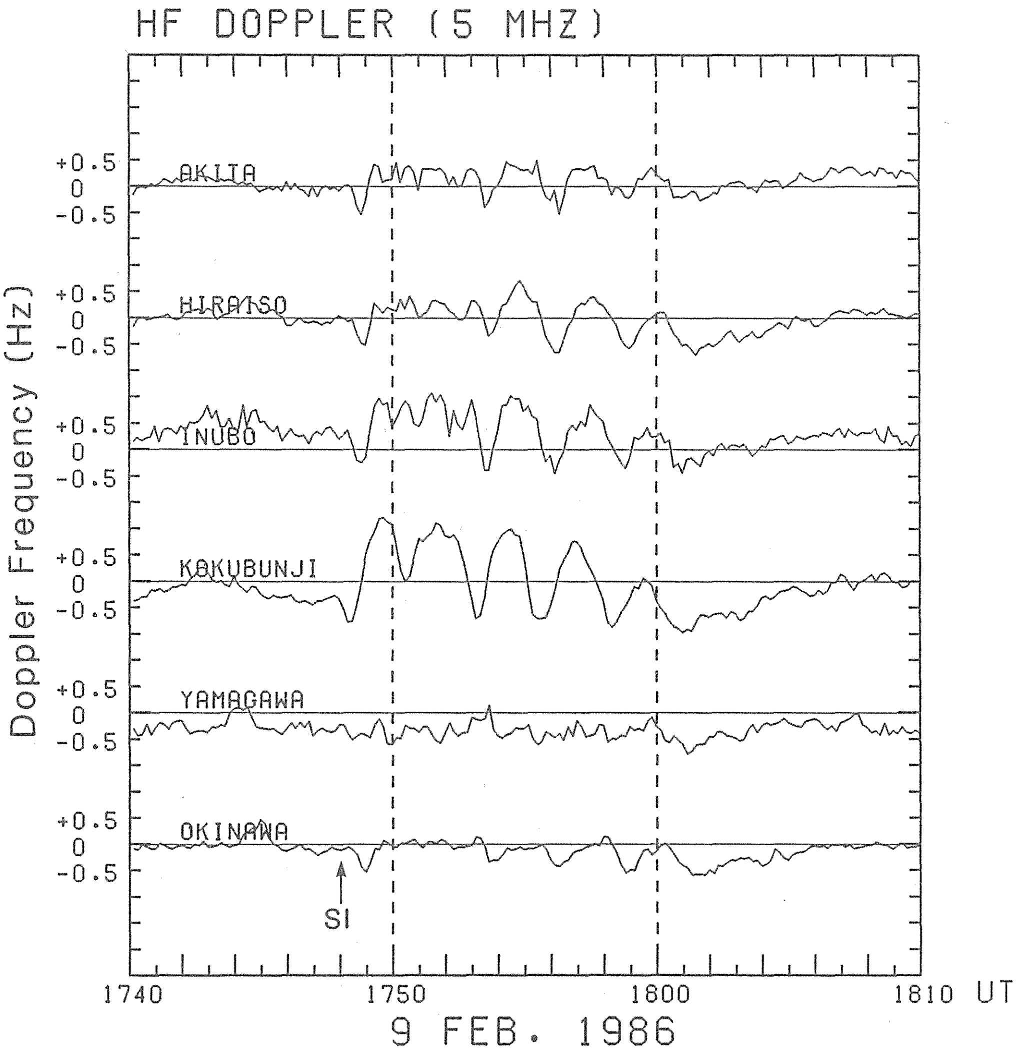


Fig. 9. Time variations of 5 MHz HF Doppler frequency at six receiving stations during 1740–1810 UT on February 9, 1986. Note SI at 1748 UT.