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RELATIONSHIPS BETWEEN SC- AND SI-ASSOCIATED ULF WAVES AND IONOSPHERIC HF DOPPLER OSCILLATIONS DURING THE GREAT GEOMAGNETIC STORM OF FEBRUARY 1986

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Abstract

The sc- and si-associated ionospheric Doppler velocity oscillations and geomagnetic pulsations during the great geomagnetic storm of February 1986 are interpreted by considering the "dynamo-motor" mechanism of ionospheric $\vec{E}$ field and the global compressional oscillations of the magnetosphere and the ionosphere, respectively.

1. Introduction

A number of researchers have studied correlations between frequency oscillations of ionospherically reflected HF radio waves and geomagnetic oscillations [see references in Watermann, 1987 and Poole et al., 1988]. Most of the previous researchers have attempted to frame their observations in terms of the $\vec{E} \times \vec{B}$ drift mechanism by the oscillating $\vec{E}$ field in the F region [Rishbeth and Gariott, 1964]. However, all observed characteristics could not be accounted for. Recently, Poole et al. [1988] theoretically demonstrated that the major factor contributing to the oscillations in the phase delay of the radio waves is compressions and rarefactions of the ionospheric plasma associated with the field aligned component of the pulsation magnetic field. The second important cause of Doppler velocity oscillations is variations in the phase path brought about by the vertical bulk motion of the ionosphere in association with the east-west component of the pulsating electric field.

The Doppler frequency shift Δf of the ionospherically reflected radio wave is expressed by

$$\Delta f = 2 f_R V^* \cos\theta / c \tag{1}$$

where f_R, V^*, θ, c are the probing radio frequency, the Doppler velocity, the incident angle of radio wave into the ionosphere, and the speed of light, respectively. The dominant Doppler shift caused by compression and rarefaction of ionospheric plasma is approximately given by [see Poole et al., 1988]

$$V_c^* \sim \int_0^{z_R} [-i\omega(\partial\mu/\partial N)(N/B_o)b_p]dz \tag{2}$$

where z_R, ω, μ, N, B_o, and b_p are the real height of reflection, the ULF wave frequency, the real part of the refractive index in a collisionless ionosphere given by the Appleton–Hartree formula [Budden, 1961], the electron concentration, the ambient magnetic field, and the compressional ULF field, respectively. Another dominant mechanism of Doppler shift is the so-called "motor" part of the "dynamo-motor" theory [Rishbeth and Garriott, 1964];

$$V_E^* \simeq \int_0^{z_R} [(d\mu/dz)(\vec{E} \times \vec{B}_o)/B_o^2]dz, \tag{3}$$

viewing as an average of $v_z = -E_y \cos I / B_o$ with the dip angle "I" through the ionosphere, weighted by the function $(-d\mu/dz)$; where v_z is the vertical component of drift motion of the electron gas under the influence of an eastward directed electric field E_y. Poole et al. [1988] numerically solved above-mentioned equations, and obtained the following relations: (1) The V_c^* shows anti-phase relation with the ULF wave fields, while the V_E^* shows $-90°$ phase relation. (2) The V_c^* is directly proportional to the pulsation frequency ω, while the V_E^* does not depend on ω.

In the present report, we will show relationships between ionospheric HF Doppler velocity oscillations and sc– and si–associated ULF pulsations during the great geomagnetic storm of February 1986. Then, we will apply the theoretical model to find a causal relationship between the oscillative phenomena in the ionosphere. Detailed results of the HF Doppler measurements will be represented in this issue by Ogawa et al. [1989].

2. Observations

One of the largest geomagnetic storms in recent decades began with a sudden commencement at ~1312 UT on February 6, 1986. It developed slowly over the next two days, and, with a rapid intensification late on February 8, reached a minimum Dst of $-312nT$ during the first hour of February 9 [cf. Hamilton et al., 1988]. The magnetosphere was greatly compressed several times during the storm, and then the geostationary satellites, GOES–5 and –6, were in the magnetosheath at ~1635 UT and ~2127 UT on February 7, at ~1442 UT and ~2017 UT on February 8, and at ~1750 UT on February 9, 1986. These solar wind compressions of the magnetosphere excited sc/si–associated ULF magnetospheric and ionospheric HF Doppler velocity oscillations.

Sc–associated 2012 UT event on February 8

Figure 1 shows simultaneous amplitude-time variations in B_z (north-south) and B_T (total) components of the interplanetary magnetic field (IMF) at IMP-J in the solar wind, H (parallel to the ambient field), V (outward), D (eastward), and B_T (total) components of geomagnetic field at the geostationary GOES-5 satellite ($\Lambda = 74°W$), in the magnetosphere, H–component normal-run magnetogram at Kakioka (KAK: $\Phi = 25.64°, \Lambda = 210.95°$), and H-component induction magnetogram at Onagawa (ONW). The H– and V–components variations at GOES–5 show the dipolarizations associated with magnetospheric substorms at ~0500 UT, ~0735 UT, and ~0955 UT on February 8. The magnetosphere was greatly compressed at ~1442 UT and ~2017 UT, when the GOES–5 satellite was outside the magnetosphere, where negative H component was observed. The maximum phase of the geomagnetic storm occurred a few hours after a major increase in the solar wind speed and a southward turning of the IMF. The solar wind speed is believed to have reached a very high level on February 8, probably faster than 1200 km/s. It is suggested that the solar wind compressions stimulated si– and sc–associated magnetospheric and ionospheric oscillations.

Figure 2 shows a correlation diagram of ionospheric Doppler velocity oscillations observed at Kokubunji (KOK: $\Phi = 25.5°, \Lambda = 205.8°$) and Akita (AKI: $29.5°, 205.9°$), and induction magnetograms obtained at Onagawa during the major sudden commencement at ~2012 UT on February 8. The phase induction magnetograms in the lower panel have $-90°$ phase relation with normal-run magnetograms. Because of a superposition of dominant two magnetic waves with $\geq$ 2–min and $\leq$ 1–min periods, it is not easy to examine the phase relation between the ionospheric Doppler velocity oscillations and the induction magnetic fields. However, one can see anti-phase and in-phase relations between dH/dt pulsation with 2-min period at ONW and longer-period V^* oscillations at KOK and at AKI, respectively, i.e., $\mp 90°$ relations between the ionospheric Doppler velocity and the ordinary geomagnetic field oscillations, indicating that the sc–associated geomagnetic oscillations observed on the ground are caused by the circular current driven by the ionospheric $\vec{E}$ field around KOK and AKI.

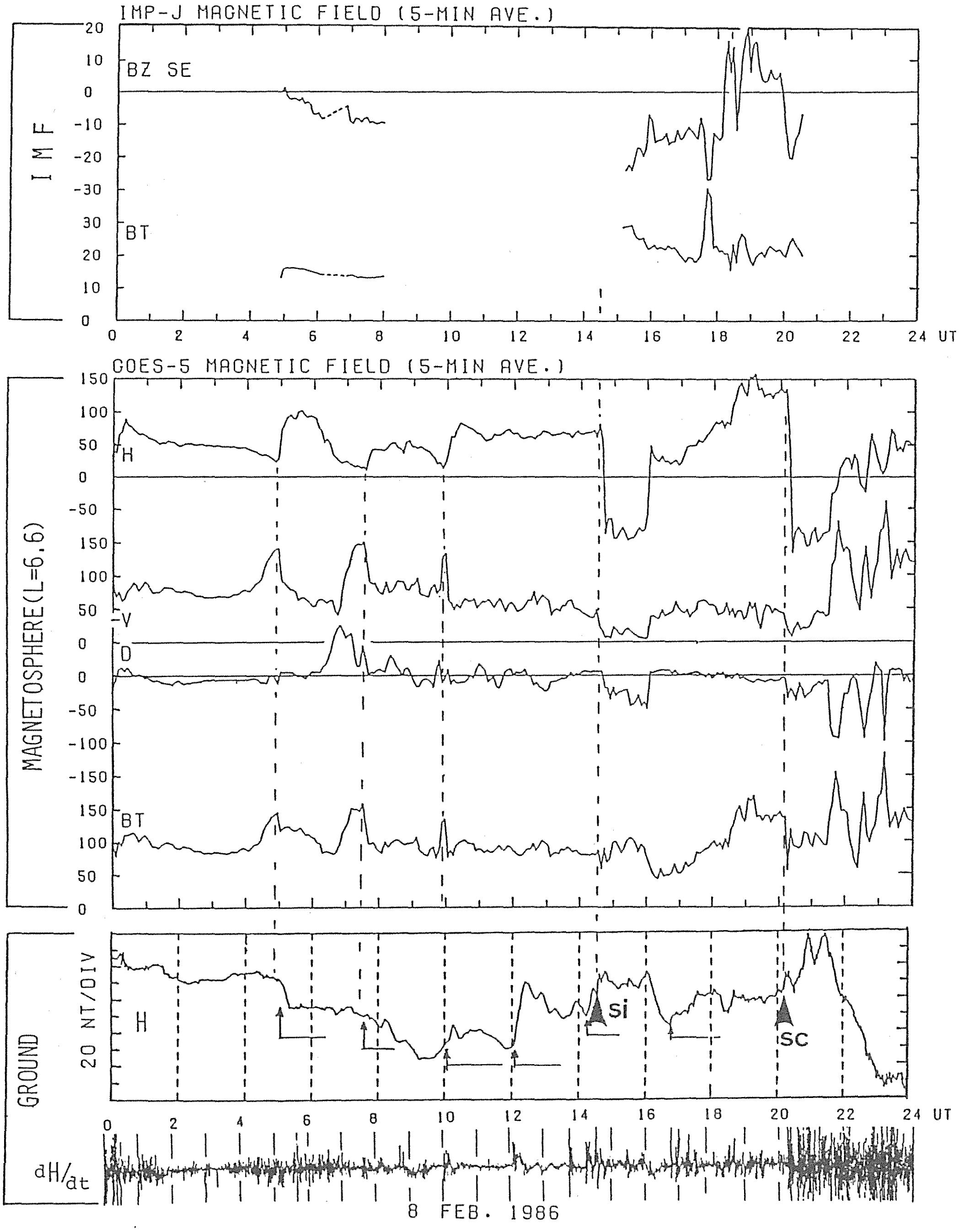

Fig. 1. The IMF variation at IMP–J in the upstream solar wind, magnetic fields at the geostationary GOES–5 satellite (L = 6.6, MLT ≃ UT + 19.0 hr), H-component normal-run magnetogram on the ground at Kakioka (L = 1.23, MLT ≃ UT + 9.0 hr), and H-component induction magnetogram at Onagawa (L = 1.3) during February 8, 1986.

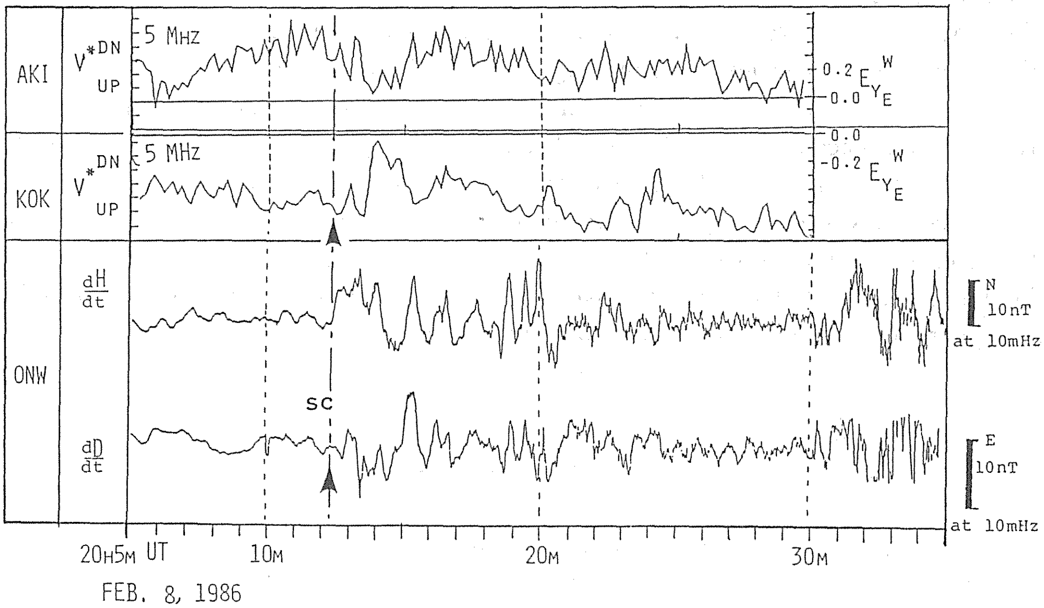

Fig. 2. The sc–associated ionospheric and geomagnetic oscillation event at 2012 UT on February 8, 1986. (Upper panel) Ionospheric HF Doppler velocity variations at Akita ($\Phi = 29.5°, \Lambda = 205.9°$) and Kokubunji ($25.5°, 205.8°$). (Lower panel) Induction magnetogram at Onagawa.

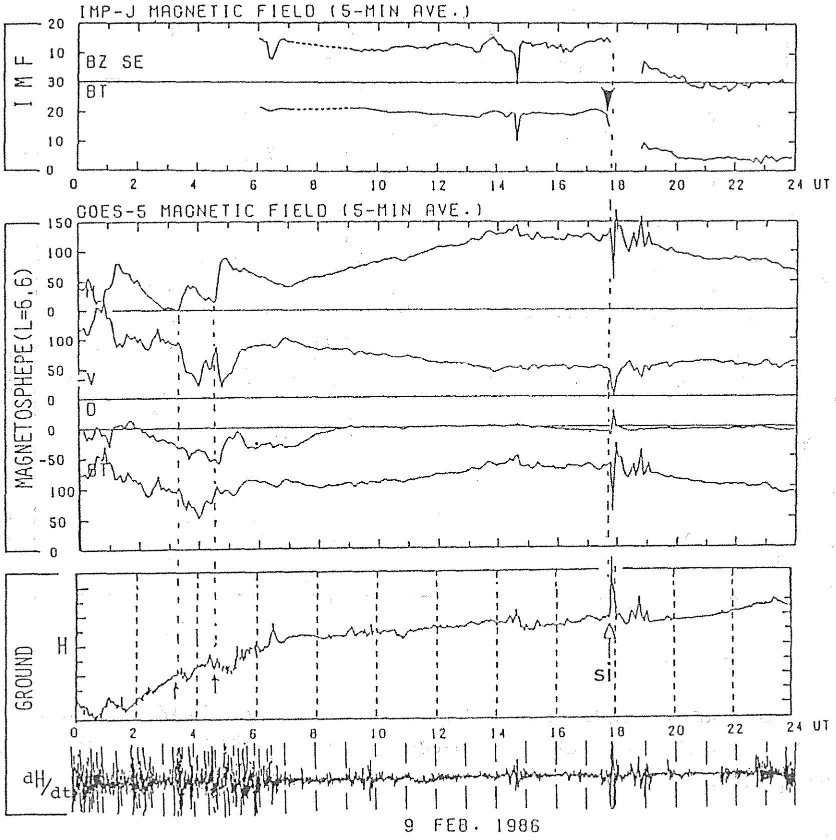

Fig. 3. Same as in Figure 1, except the si–associated event on February 9, 1986

Si-associated 1748 UT event on February 9

The rapid Dst recovery in this storm occurred ~10 hours after the minimum Dst at ~01 UT as shown on the normal-run magnetogram (lower panel) in Fig. 3, which may be related with the positive B_z component of the IMF (top panel). The final, impulsive compression took place at ~1748 UT on February 9 during the recovery phase of the storm. The 1-min averaged magnetic field data from GOES-5 and -6 (not shown here) indicate that the spacecrafts were in the magnetosheath for a few minutes. At that time the associated magnetic impulse of about 80 nT was also observed on the ground at low latitude (KAK). The si-associated pulsations with ~ 2.5– min period were excited globally in the magnetosphere and the ionosphere as shown in Fig. 4. The top panel shows H (parallel to

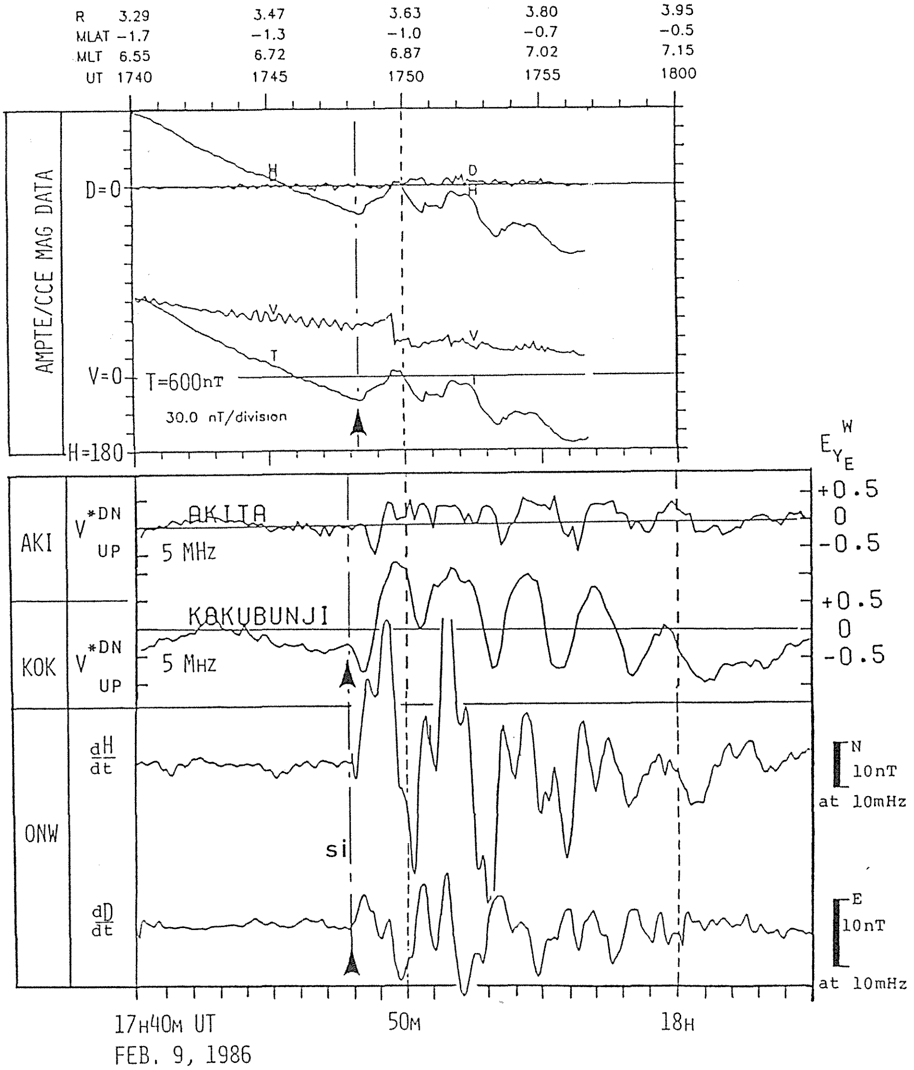

Fig. 4. Same as in Figure 2, except the si-associated 1748 UT event on February 9, 1986 and the magnetic variations at the AMPTE/CCE spacecraft in the magnetosphere.

the ambient field), V (outward), and T (total) components of magnetic fields observed by the AMPTE/CCE satellite, which was located at a radial distance of $\sim 3.6R_E$ in the morning sector (MLT ~6.8 hr) during the impulive compression. The middle and the bottom panels show ionospheric Doppler velocity oscillations at KOK and AKI [cf. Ogawa et al., 1989], and induction magnetic fields at ONW, respectively. The 6.2–s averaged magnetic field data from GOES–6 at $L = 6.6$ and 1020MLT also show multiple magnetopause crossings in concurrence with the magnetospheric compressions and rarefactions.

It is noteworthy that simultaneous globally compressional oscillations with ~2.5–min and ~1.25–min periods were excited in space and on the ground. In consideration of the -90^0 phase delay of the induction magnetogram at ONW, we find in-phase relation of the 1748 UT, si–associated event among the total field variation at AMPTE/CCE, the ionospheric Doppler velocity oscillation (V^*) at KOK and AKI, and H–component normal-run magnetic field at ONW. The observations suggest that the si–associated ionospheric Doppler velocity oscillations and geomagnetic pulsations on the ground were caused by magnetospheric compressions and rarefactions, as theoretically predicted by Poole et al. [1988].

3. Conclusion

The sc– and si–associated ionospheric Doppler velocity oscillations and geomagnetic pulsations at ~2012 UT on February 8 and ~1748 UT on February 9 during the great geomagnetic storm of February 1986 are interpreted by considering the "dynamo-motor" mechanism of ionospheric $\vec{E}$ field and the global compressional oscillations in the magnetosphere and the ionosphere, respectively. It is also found that the sc– and si–associated ionospheric and geomagnetic oscillations were excited during the periods of negative and positive B_z components of the IMF, respectively.

Further theoretical and observational studies on the magnetospheric response with respect to various kinds of impulsive solar wind compressions and rarefactions are needed to investigate how the two type ionospheric and geomagnetic oscillations can be stimulated in the magnetosphere.

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