EFFECTS OF THE INTERPLANETARY MAGNETIC FIELD ON THE CHARACTERISTICS OF Pc 3–4 PULSATIONS AT GLOBALLY COORDINATED STATIONS

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Abstract: Daytime Pc 3–4 pulsation activities observed at globally coordinated low-latitude stations [SGC ($L=1.8$, $\lambda=118.0$°W), EWA (1.15, 158.1°W), ONW (1.3, 141.5°E)] are evidently controlled by the cone angle θ_{XB} of the IMF observed at ISEE 3. Moreover, the Pc 3–4 frequencies (f) at the low latitudes and high latitude (COL; $L=5.6$ and $\lambda=147.9$°W) on the ground and that of compressional waves at geosynchronous orbit (GOES 2; $L=6.67$ and $\lambda=106.7$°W) are simultaneously correlated with the IMF magnitude (B_{IMF}). The correlation of f of the compressional Pc 3–4 waves at GOES 2 against B_{IMF} is higher than those of the Pc 3–4 pulsations at the globally coordinated ground stations, *i.e.*, $\gamma=0.70$ at GOES 2, and (0.36, 0.60, 0.66, 0.54) at (COL, SGC, EWA, ONW), respectively. The standard deviation ($\sigma_n=\pm\Delta f$ mHz) of the observed frequencies from the form $f(\text{mHz})=6.0\times B_{IMF}(\text{nT})$ is larger at the ground stations than at GOES 2, *i.e.*, $\Delta f=\pm6.6$ mHz at GOES 2, and $\pm$(13.9, 9.1, 10.7, 12.1) mHz at (COL, SGC, EWA, ONW), respectively. The correlations between the IMF magnitude B_{IMF} and Pc 3–4 frequencies at the low latitudes are higher than that at the high latitude on the ground, which can be interpreted as a "filtering action" of the magnetosphere for daytime Pc 3–4 magnetic pulsations. The scatter plots of pulsation frequencies observed in the magnetosphere *versus* the IMF magnitude show a remarkable distribution restricted within the forms of $f=4.5\times B_{IMF}$ and $f=7.5\times B_{IMF}$. The observed frequency range is theoretically confirmed to be consistent with the inferred frequency range ($\omega_{sc}/\Omega_i=0.3$–0.5) in the spacecraft frame of the magnetosonic upstream waves excited by the anomalous ion cyclotron resonance with reflected ion beams, which is observed to be $V_{/\!/}=650$–1150 km/s in the solar wind frame by the ISEE satellite in the earth's foreshock. It is concluded that the magnetosonic right-handed waves excited by the reflected ion beams in the earth's foreshock are convected through the magnetosheath to the magnetopause, being transmitted into the magnetosphere without significant changes in spectra, and then couple with various HM waves in the Pc 3–4 frequency range at various locations in the magnetosphere.

1. Introduction

The dominant frequency (f) of Pc 3–4 magnetic pulsations on the ground was demonstrated to be controlled by the strength of the interplanetary magnetic field

(IMF), B_{IMF}, *i.e.*, $f(\mathrm{mHz}) \sim 6.0 \times B_{IMF}(\mathrm{nT})$ (TROITSKAYA *et al.*, 1971; GUL'ELMI *et al.*, 1973; PLYASOVA-BAKOUNINA *et al.*, 1978; VERÖ and HOLLÓ, 1978; GREEN *et al.*, 1983). The empirical relationships have been used to define the Borok B index consisting of five levels which represent the IMF strength of <2.5, 2.5–4, 4–6, 6–8, and <8 nT (GUL'ELMI and BOL'SHAKOVA, 1973). The intensity of the IMF has been statistically estimated from the frequency of Pc 3–4 pulsations observed on the ground (*cf.* RUSSELL and FLEMING, 1976). RUSSELL and HOPPE (1981) and HOPPE and RUSSELL (1982) demonstrated a relationship between the Pc 3–4 band frequency of transverse upstream waves in the earth's foreshock and the strength of the IMF from ISEE 1 and 2 observation, which is expressed as $f = 5.81 \times B_{IMF}$. On the basis of the Pc 3 band observed at geosynchronous orbit, ARTHUR and MCPHERRON (1977) first reported that no relationship is found between the IMF magnitude and the frequency of both transverse and compressional magnetic pulsations, but there is a clear, although weak, relationship between the cone angle of the IMF and the amplitude of the pulsations. However, YUMOTO *et al.* (1984) recently demonstrated that compressional Pc 3 pulsations, identified by comparing with low-latitude Pc 3 pulsations at ground near the meridian through the GOES satellite, at the geostationary orbit have a high positive correlation between pulsation frequencies and the IMF magnitude. From the satellite observations in the earth's foreshock and the magnetosphere and from the earlier ground results, it is believed that the upstream waves were a possible source of daytime Pc 3–4 pulsations in the magnetosphere, being convected through the magnetosheath to the magnetopause and then transmitted into the magnetosphere.

The purpose of the present paper is to reexamine how the IMF magnitude controls the frequencies of Pc 3–4 pulsations simultaneously observed at globally distributed ground stations and at GOES 2 in space. We will also clarify the relation among the compressional Pc 3–4 waves at GOES 2, the magnetosonic upstream waves and the reflected ion beams observed by the ISEE satellites in the earth's foreshock. We will then discuss a probable excitation and propagation mechanism of daytime Pc 3–4 magnetic pulsations in the magnetosphere.

2. Relationships between the IMF and Pc 3–4 Magnetic Pulsations on the Ground

In order to clarify dependences of the activity and frequency of Pc 3–4 pulsations, observed at globally coordinated stations on the ground and in space, on the IMF direction and magnitude, respectively, we have analyzed three newly available data sets (see YUMOTO *et al.*, 1984). Figure 1 shows an example of correlation between the cone angle $\theta_{XB} = \cos^{-1}(B_x/B_{IMF})$ of the IMF and the digital dynamic spectrograms at three stations [San Gabriel Canyon; SGC ($\phi = 34.2°$N, $\lambda = 118.0°$W), Ewa Beach; EWA (21.4°N, 158.1°W), Onagawa; ONW (38.4°N, 141.5°E)]. SGC and ONW are separated by approximately 7 h in local time (LT). Each of the dynamic spectrograms at the three stations is shown after having been band-pass filtered in the Pc 3 period range, *i.e.*, 10–45 s. The IMF data are obtained by ISEE 3 at the Lagrange point ($\sim 256\ R_E$), thus the trace of the cone angle of the IMF is sifted about ~ 70 min backward. Switchings of the IMF direction occurred at ~ 19 h, ~ 21 h and ~ 24 h UT

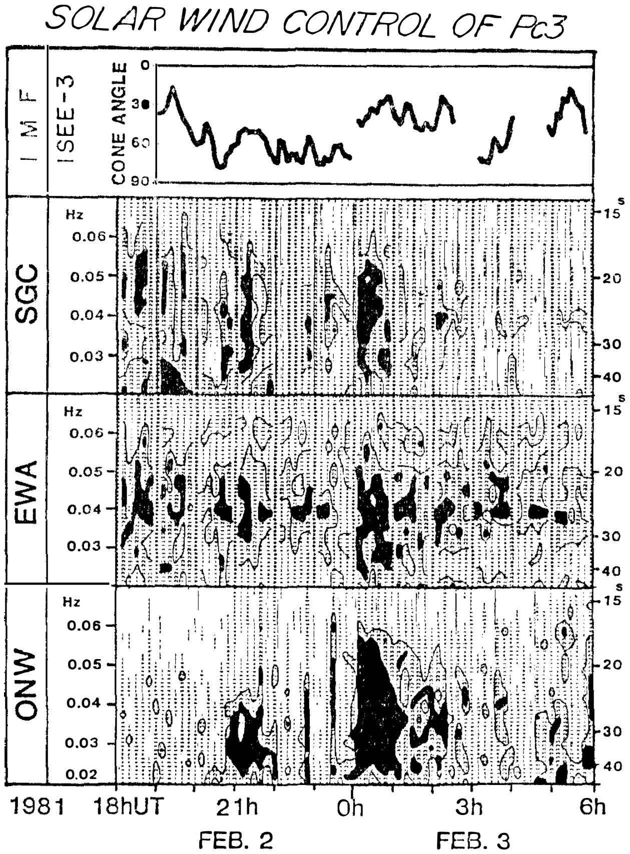

Fig. 1. An example of digital dynamic spectrograms of low-latitude Pc 3 pulsations observed at SGC ($L=1.8$, $\Lambda=305.0°$), EWA (1.15, 267.9°), ONW (1.3, 208.1°) against the cone angle θ_{XB} of the IMF observed by ISEE 3.

without increases in the magnitude of the IMF. We can identify the association between the IMF orientation and the pulsation activities at the three stations located in daytime, *i.e.*, the interval from 2000 to 0100 UT, 1200–1700 LT at SGC, 1000–1500 LT at EWA, and 0500–1000 LT at ONW during February 2–3, 1981. Because of a local time effect on the Pc 3 activity, there is no enhancement of Pc 3 activity at ONW until about 20 h UT. The changes of the cone angle are coincident with the microstructure of Pc 3 amplitudes during 1800–0600 UT, on February 2–3, 1981. Global enhancements and depressions in Pc 3 magnetic activity at the stations separated by ~7 h in local time are evidently controlled by the cone angle θ_{XB} of the IMF.

Relationships between pulsation frequencies observed at globally coordinated stations and the IMF magnitude are examined as shown in Fig. 2. The dominant frequencies of the *H*-components of daytime Pc 3–4 pulsations on the ground (COL, SGC, EWA and ONW) were compared with the strength of the IMF observed by ISEE 3. The details of the procedure used to determine the pulsation frequency of daytime Pc 3–5 magnetic pulsations are given by YUMOTO and SAITO (1983). The highest peak in the power spectrum performed on 20-min segments of data was defined as a dominant frequency of the Pc 3–4 events. For this study the IMF data from the ISEE satellite were averaged for 20-min segments shifted about 60 min backward to the Pc 3–4 event segments. The average values of total field strength of the IMF

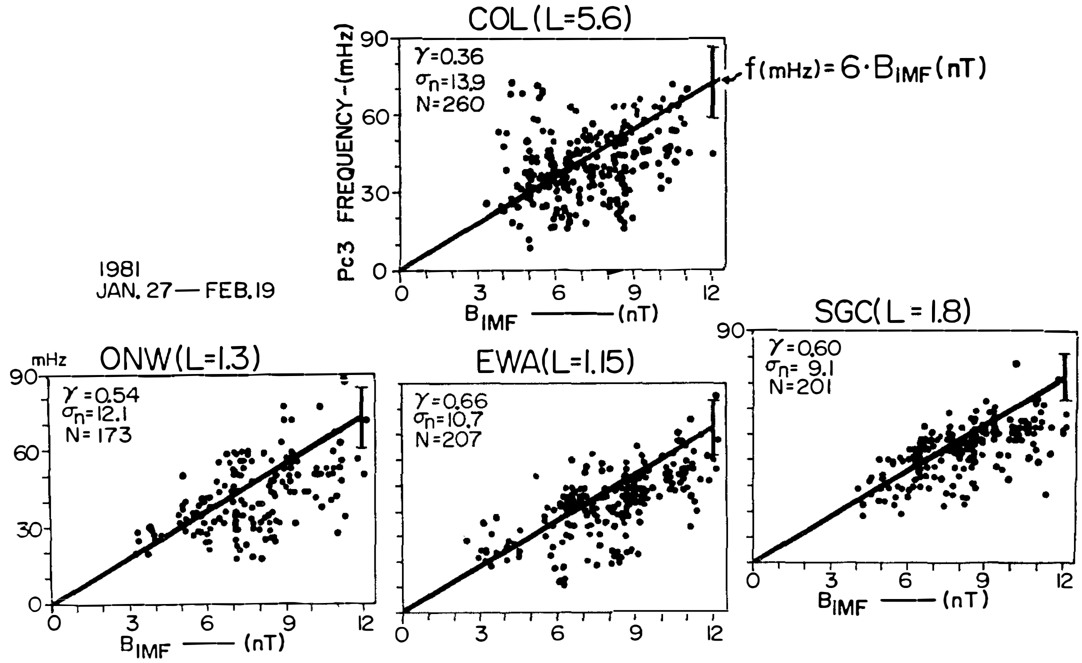

Fig. 2. Scatter plots of daytime Pc 3–4 frequencies observed at the globally coordinated four stations (COL; $L=5.6$, $\Lambda=258.0°$, SGC, EWA, ONW) against the IMF magnitude observed at ISEE 3 during January 27–February 19, 1981. Solid line indicates the form f(mHz) $=6.0\times B_{\mathrm{IMF}}$(nT). γ and σ_n are the linear correlation coefficient and the standard deviation ($\pm\Delta f$ mHz) of the observed frequency from $f=6.0\times B_{\mathrm{IMF}}$, respectively.

were compared with the dominant frequencies of the events. Scatter plots of pulsation frequencies (f) against the IMF magnitude (B_{IMF}) are represented for Pc 3–4 events at the four stations during the each station's local daytime (0600–1800 LT) from January 27 to February 19, 1981 in Fig. 2. The solid lines indicate f(mHz)$=$ $6.0\times B_{\mathrm{IMF}}$ (nT). The linear correlation coefficient (γ) and the standard deviation (σ_n) from $f=6\times B_{\mathrm{IMF}}$, are summarized in each panel of the figure. We find that the correlations between the IMF magnitude and the frequencies of low-latitude Pc 3–4 pulsations at SGC ($L=1.8$), ONW (1.3), and EWA (1.15) are higher than that of high-latitude Pc 3–4 pulsations at COL ($L=5.6$). The pulsations in the Pc 3–4 frequency range at high latitudes can be interpreted to consist of not only daytime Pc 3–4 pulsations associated with upstream waves in the earth's foreshock but also other localized pulsations, *e.g.*, Pic pulsation, *i.e.*, ionospheric current fluctuations associated with a post-midnight micropulsation storm in the auroral zone (see SAITO, 1969), and localized HM waves near the magnetopause (SOUTHWOOD, 1979; TAMAO, 1981; YUMOTO, 1984). Only a propagating compressional Pc 3–4 wave transmitted from outside the magnetosphere near the magnetopause can traverse the ambient magnetic field into the inner magnetosphere, while the localized and/or boundary waves in the outer magnetosphere cannot reach low latitudes on the ground (YUMOTO *et al.*, 1984). The higher correlation between f and B_{IMF} at the low latitudes than the high latitude can be interpreted as a "filtering action" of the magnetosphere for daytime Pc 3–4 magnetic pulsations.

The dominant frequencies of compressional and transverse modes of HM waves

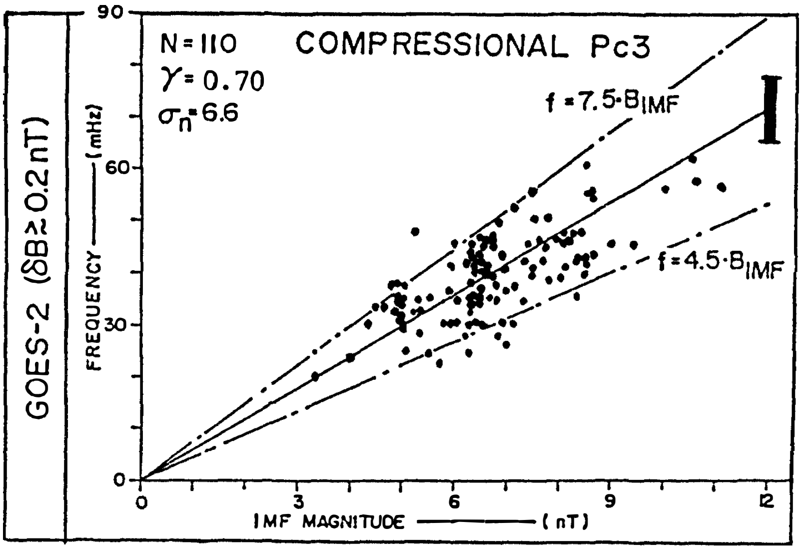

Fig. 3. Scatter plots of compressional Pc 3–4 frequencies at GOES 2 against the IMF magnitude. The compressional Pc 3–4 events with smaller amplitude ($\delta B=0.2\sim 1.0$ nT) were identified by comparing with the low-latitude Pc 3–4 observed by high-sensitive rulfmeter at SGC located $\sim 11°$ west of GOES 2's geographic longitude during the same interval of Fig. 2 (YUMOTO et al., 1984).

at synchronous orbit (GOES 2) were also compared with the strength of the IMF observed by ISEE 3. Compressional and transverse modes of magnetic pulsations in a wide frequency range exist simultaneously in the dayside outer magnetosphere (YUMOTO and SAITO, 1983). The amplitude of the compressional waves dominating in the Pc 3 frequency range is generally smaller than that of the transverse waves dominating in the Pc 4–5 frequency range. Because there is no or little relationship between the frequency of the transverse waves at GOES 2 and the IMF magnitude, the scatter plots of f against B_{IMF} for the transverse waves at synchronous orbit are not shown in Fig. 3. The scatter plots of the compressional waves observed at GOES 2 in daytime, *i.e.*, 0800–1700 LT during January 27–February 16, 1981, show a remarkable distribution restricted within the dashed lines of forms $f=4.5\times B_{IMF}$ and $f=7.5\times B_{IMF}$. We will discuss the remarkable frequency distribution with respect to the reflected ion distribution and the magnetosonic right-handed waves in the earth's foreshock in the next section. It is noteworthy that the linear correlation coefficient (γ) of f against B_{IMF} is higher at geosynchronous orbit in space than at the globally coordinated stations on the ground. The standard deviation ($\sigma_n=\pm\Delta f$ mHz) of the observed frequencies from the form of f (mHz)$=6.0\times B_{IMF}$ (nT) is larger at the ground stations than in the outer magnetosphere as shown in Figs. 2 and 3, *i.e.*, ($\gamma=0.70$, $\Delta f=\pm 6.6$ mHz) at GOES 2, (0.36, 13.9) at COL, (0.60, 9.1) at SGC, (0.66, 10.7) at EWA, and (0.54, 12.1) at ONW. The more scattered distributions of Pc 3–4 frequencies on the ground than in the magnetosphere as shown in Figs. 2 and 3 can be interpreted to be due to various resonant frequencies of HM oscillations (see YUMOTO and SAITO, 1983) coupled with the compressional Pc 3–4 waves with a finite frequency bandwidth in the magnetosphere. The frequencies of the resonant HM oscillations are believed to be dependent mainly on the local plasma parameters in the magnetosphere (YUMOTO and SAITO, 1983).

3. Relation between Upstream Waves in the Earth's Foreshock and the Compressional Pc 3–4 Waves at GOES 2

A major early discovery was the existence of large-amplitude low-frequency waves that fill most part of the upstream region that is connected to the bow shock by the IMF (GREENSTADT *et al.*, 1968; FAIRFIELD, 1969). The upstream waves are considered to be generated by reflected protons coming from the earth's foreshock (FAIRFIELD, 1969; BARNES, 1970; FREDRICKS, 1975; KOVNER *et al.*, 1976; GRAY *et al.*, 1981; LEE, 1982; WATANABE and TERASAWA, 1984). Using magnetic field data from the dual ISEE 1 and 2 spacecraft, HOPPE and RUSSELL (1983) have determined the plasma rest frame frequencies of the large-amplitude low-frequency upstream waves as shown in Fig. 4. The time delay between signals of the intermediate wave from the two spacecrafts is illustrated in the lower left panel of Fig. 4 where simultaneous traces from the two spacecrafts are superposed. Experimentally determined rest frame frequencies, normalized to the local proton cyclotron frequency (Ω_i) are plotted *versus* wave number

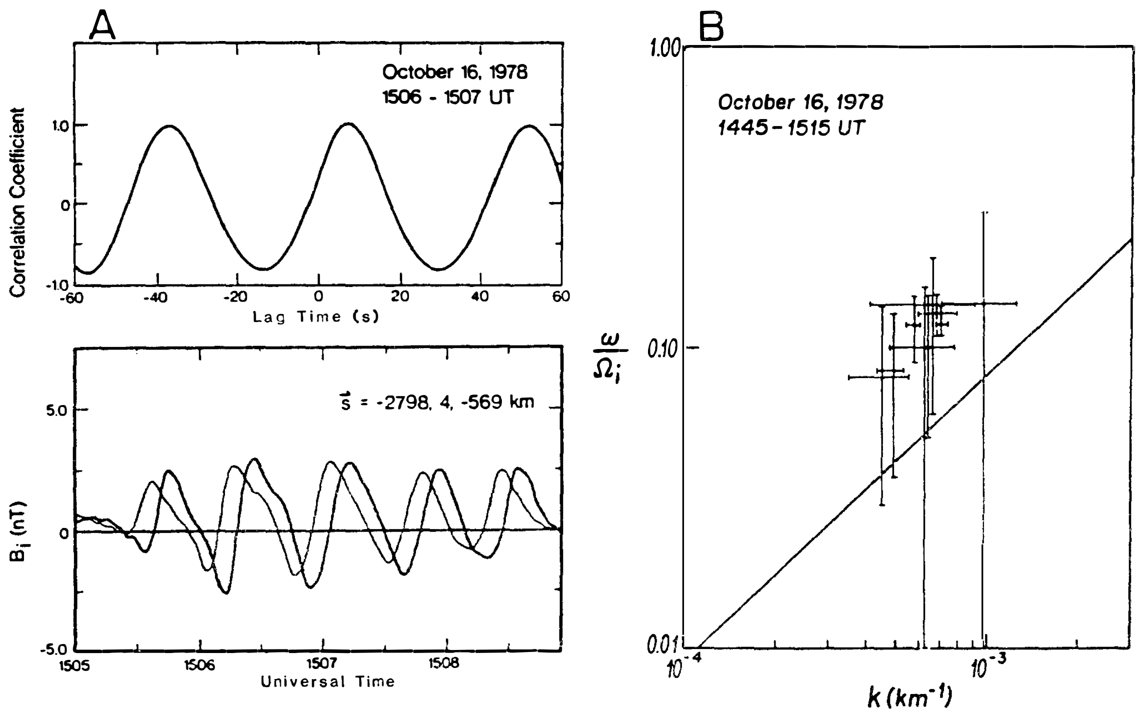

Fig. 4. Upstream wave identification by the dual ISEE satellite observations (after HOPPE and RUSSELL, 1983).

(a) Time delay studies for case of intermediate wave. In the lower panel the Z_{GSE} components of the signals from ISEE 1 (heavy trace) and ISEE 2 (lighter trace) are overlaid. In the upper panel the correlation coefficient between the signals is plotted as a function of time lag with positive Δt corresponding to signals seen first at the upstream spacecraft.

(b) Experimentally determined rest frame frequencies, normalized to the local proton gyrofrequency, plotted versus wave number for intervals of magnetosonic waves.

in the right panel of the figure. They identified these as magnetosonic right-handed mode signals on the basis of their rest frame polarizations. It is noteworthy that the rest frame frequency of the upstream waves is of the order 0.05–0.2 times Ω_i in the earth's foreshock. When the cone angle θ_{XB} of the IMF is small, the subsolar foreshock is occupied by the complex, compressional waves. Although the relationship between the IMF magnitude and the frequencies of the complex, compressional foreshock waves have not been published, we expect that characteristic frequencies of the complex, compressional upstream waves are mainly those of the magnetosonic right-handed waves excited by the well-known ion cyclotron-resonance mechanism with narrow ion beams.

On the other hand, GOSLING *et al.* (1978) had reported the presence of two distinct and mutually exclusive populations of low-energy ions ($\lesssim$40 keV) in the upstream solar wind, so-called 'reflected' and 'diffuse' components. PASCHMANN *et al.* (1981) indicated the distinction between three types of upstream ion populations on the basis of pronounced differences in their distribution functions, *i.e.*, 'reflected' ion beam, 'intermediate', and 'diffuse' ion distribution. Although the low-frequency magnetosonic

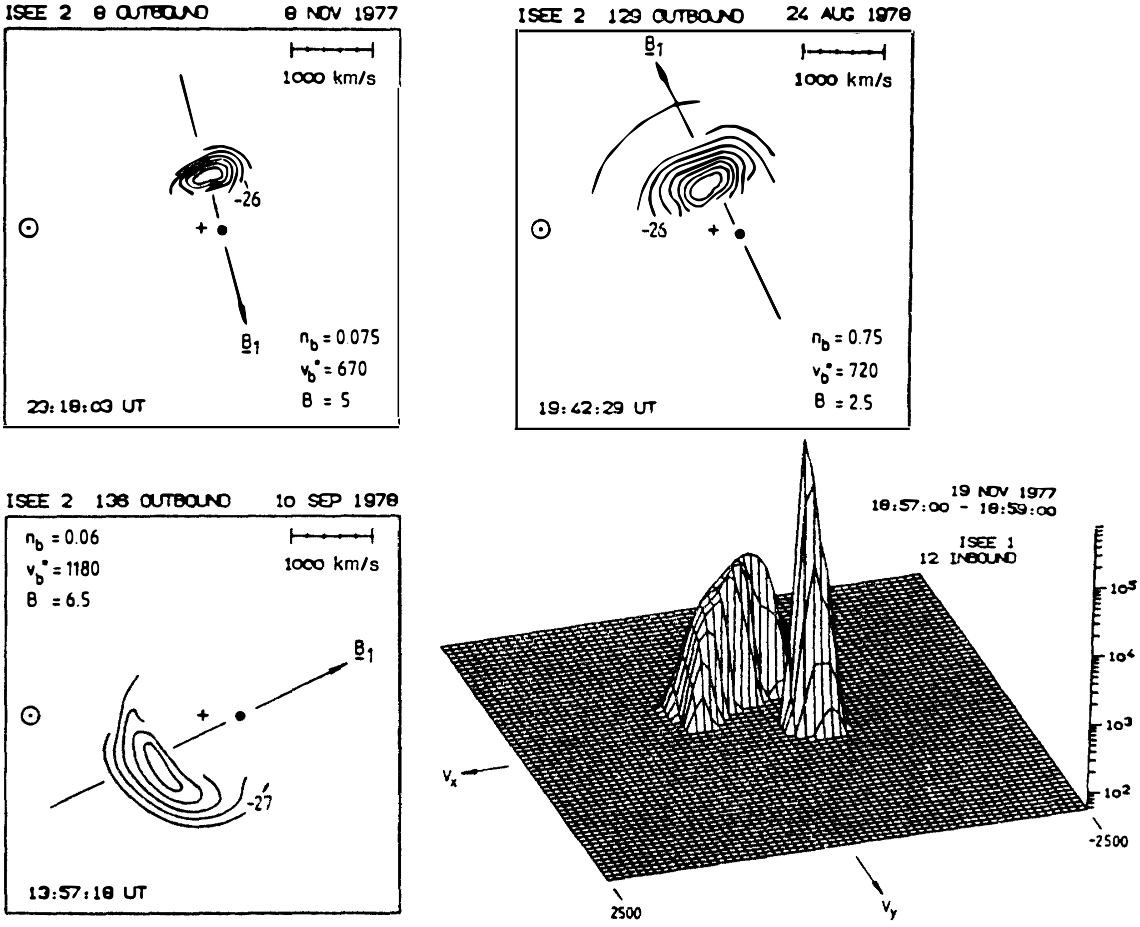

Fig. 5. Examples of contour plots and relief plot of reflected ions observed by ISEE 1 and 2 (after PASCHMANN et al., 1981). For each case, the velocity scale (upper right), the beam density n_b (in cm^{-3}), the beam speed v_b in the solar windframe (in km/s), and the magnetic field strength B (in nT) and direction are indicated.*

waves with larger amplitude were demonstrated to be associated mostly with the intermediate and diffuse ion distributions (PASCHMANN *et al.*, 1980, 1981; SENTMAN *et al.*, 1981; HOPPE *et al.*, 1981; TSURUTANI and RODRIGUEZ, 1981; RUSSELL and HOPPE, 1983), it is generally considered that instability of the reflected ion beams generates the waves; the waves pitch angle scatter the beams into intermediate and diffuse distributions, and then all are convected back toward the shock (GRAY *et al.*, 1981; BAVASSANO-CATTANEO *et al.*, 1983; HOPPE and RUSSELL, 1983). Figure 5 shows examples of contour plots of reflected ions observed by ISEE 1 and 2 (PASCHMANN *et al.*, 1981). The large variation from 650 to 1150 km/s in the observed beam speeds is indicated in the solar wind frame, *i.e.*, in the rest frame. If the low-frequency magnetosonic waves with $(\omega/\Omega_i)=0.05\sim0.2$ in the earth's foreshock as shown in Fig. 4 are assumed to be magnetosonic right-handed waves excited by the well-established

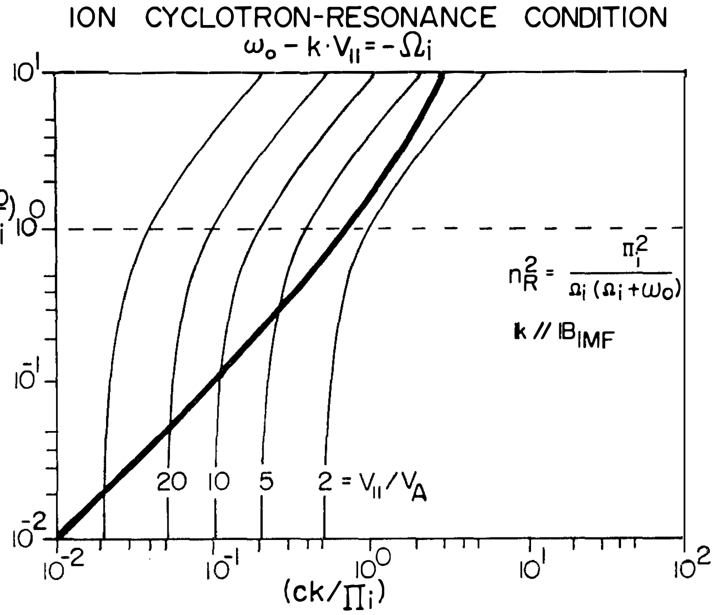

Fig. 6. (ω, k)-diagram of magnetosonic right-handed wave excited by the anomalous Doppler-shifted ion cyclotron resonance. Thick and thin lines indicate the dispersion relation of the R-H wave and the condition of the ion cyclotron-resonance, respectively (YUMOTO et al., 1984).

cyclotron resonance mechanism driven by narrowly reflected ion beams (STIX, 1962; KENNEL and PETSCHEK, 1966), the proton resonant velocity $(V_{/\!/})$ in the solar wind frame is expected to be $(V_{/\!/}/V_A)\sim 8$–20 by means of the resonance condition as illustrated in Fig. 6 (YUMOTO *et al.*, 1984). The thick line indicates the dispersion relation of the magnetosonic right-handed wave in the solar wind frame. The thin lines represent the condition of the anomalous Doppler-shifted ion cyclotron-resonance between the wave and the reflected ions with speed $(V_{/\!/})$ parallel to the IMF. The local Alfvén velocity (V_A) in the upstream region is typically 50 km/s. The proton resonant velocity $(V_{/\!/})$ exciting the magnetosonic right-handed waves with $(\omega/\Omega_i)=0.05\sim0.2$ in the rest frame as shown in Fig. 4 is inferred to be 400–1000 km/s; this result is also consistent with the range of the observed speeds of the reflected ion beams in the solar wind frame as shown in Fig. 5. The low-frequency magnetosonic waves with large amplitude in the earth's foreshock are believed to be the magnetosonic right-handed waves excited by the anomalous Doppler-shifted ion cyclotron-resonance with the narrowly reflected ion beams (see YUMOTO *et al.*, 1984).

4. Summary and Conclusions

In the present paper, we clarified relationships between the IMF magnitude observed by ISEE 3 and the pulsation frequencies simultaneously observed both at GOES 2 (L=6.67, λ=106.7°W) and at globally coordinated stations on the ground [COL (L=5.6, λ=147.9°W), SGC (1.8, 118.0°W), EWA (1.15, 158.1°W), and ONW (1.3, 141.5°E)]. The relation among the Pc 3–4 pulsations in the magnetosphere, the upstream waves and the reflected ion beams observed in the earth's foreshock was also examined. The analyzed results are summarized as follows:

(1) Daytime Pc 3–4 activities at the globally coordinated low-latitude stations (SGC, EWA, and ONW) separated by ~7 h in local time are clearly controlled by the cone angle θ_{XB} of the IMF as shown in Fig. 1.

(2) The correlations between the Pc 3–4 frequencies and the IMF magnitude at the low latitudes are higher than that at the high latitude (COL, *cf.* Fig. 2), which can be interpreted as a "filtering action" of the magnetosphere for daytime Pc 3–4 magnetic pulsations. High-latitude Pc 3–4 pulsations must be mixed with localized pulsations and/or HM waves penetrating from the magnetospheric boundary, etc., of which excitation mechanisms are not associated with the upstream waves in the earth's foreshock.

(3) Both frequencies of the daytime compressional Pc 3–4 pulsations at GOES 2 in space and the Pc 3–4 pulsations at the globally coordinated four stations on the ground are simultaneously correlated with the strength of the IMF. The linear correlation coefficient (γ) between the pulsation frequencies and the IMF magnitude is higher at GOES 2 in the outer magnetosphere than at the ground stations. The standard deviation ($\sigma_n = \pm\Delta f$ mHz) of the observed frequencies from the form f(mHz)= $6.0\times B_{IMF}$ (nT) is larger at the ground stations than at GOES 2 (Figs. 2 and 3).

(4) The scatter plots of the compressional Pc 3–4 waves at GOES 2 show a remarkable distribution restricted within the forms $f=4.5\times B_{IMF}$ and $f=7.5\times B_{IMF}$. The frequency distribution of the compressional Pc 3–4 waves against the IMF magnitude (Fig. 3) is excellently consistent with the inferred frequency range (ω_{sc}/Ω_i=0.3–0.5) in the spacecraft frame of the magnetosonic right-handed waves excited by the anomalous Doppler-shifted ion cyclotron-resonance with the reflected ion beams, which was demonstrated to be $V_{/\!/}$=650–1150 km/s in the solar wind frame by the ISEE satellite as shown in Fig. 5.

From these observational facts, we can construct a scenario of the excitation and propagation mechanism of daytime Pc 3–4 magnetic pulsations as follows; The magnetosonic upstream waves excited by the anomalous Doppler-shifted ion cyclotron-resonance with the narrowly reflected ion beams in the earth's foreshock can propagate across the magnetosheath and the magnetopause into the magnetosphere without significant changes in spectra, and can be observed as the compressional Pc 3–4 pulsa-

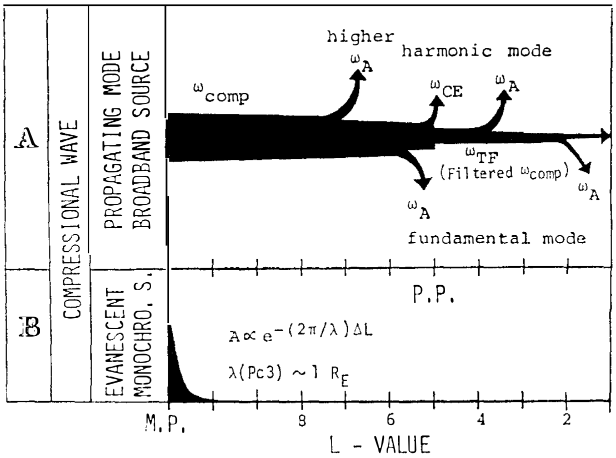

Fig. 7. Propagation mechanisms of Pc 3-type pulsations in the magnetosphere. (a) Propagating compressional waves with Pc 3 band frequency can couple with various HM waves at various locations in the magnetosphere, i.e., high-harmonic standing oscillation (ω_A) of a local field line in the outer magnetosphere, fundamental eigen-oscillation (ω_A) in the plasmatrough, high-harmonic surface waves (ω_{CE}) at the plasmapause, a trapped oscillation (ω_{TF}) of fast magnetosonic wave, and fundamental and high-harmonic standing oscillations (ω_A) in the plasmasphere. (b) Evanescent Pc 3 waves have a larger damping rate in the radial direction and hardly couple with the various HM waves in the deep magnetosphere.

tions in the outer magnetosphere. The transmitted compressional waves (ω_{comp}) with finite Pc 3–4 bandwidth from outside the magnetopause can excite high-harmonic standing oscillation (ω_A) of a local field line in the outer magnetosphere and a fundamental standing oscillation (ω_A) just outside the plasmapause, *i.e.*, in the plasmatrough as shown in Fig. 7a. The excited Alfvénic waves can be transferred only to the high-latitude ionosphere. High-harmonic collective eigen-oscillations (ω_{CE}), *i.e.*, surface waves at the plasmapause are also excited by the compressional Pc 3–4 waves. In the plasmasphere, the ω_{comp} from outside the plasmapause can propagate into low latitude and couple with any of a trapped oscillation (ω_{TF}) of fast magnetosonic wave in the trough between two peaks of Alfvén speed, a high-harmonic standing oscillation (ω_A) at mid-latitude, and a fundamental standing oscillation at very low latitudes (YUMOTO and SAITO, 1983).

The existence of Pc 3 pulsations, which are associated with the upstream waves in the earth's foreshock, at the very low latitudes (SGC; $L=1.8$, EWA; 1.15, and ONW; 1.3) is hardly explained by the externally excited surface waves at the magnetopause, because of the large damping rate of the evanescent waves in the Pc 3 frequency range in the radial direction as shown in Fig. 7b. For example, the damping rate $[A/A_0=\exp[-(2\pi/\lambda)\times\Delta L)]]$ is of the order 10^{-3} for $\lambda\sim(V_f/f)\sim 500\,\mathrm{kms}^{-1}/60\,\mathrm{mHz}\sim 1R_E$ at the penetrating distance of $\Delta L=1R_E$ from the magnetopause, where A, λ, V_f, and f indicate the amplitude, characteristic wavelength, phase velocity, and frequency of the evanescent Pc 3 waves, respectively. The boundary waves and localized waves near the magnetopause can be a probable source of only high-latitude pulsations, which has been theoretically discussed by TAMAO (1981) and YUMOTO (1984).

Observational relationships among Pc 3-type magnetic pulsations at various locations, *i.e.*, the solar wind, the bow shock, the magnetosheath, the mangetopause, the magnetosphere, the plasmapause, the plasmasphere, the ionosphere, and the earth's surface are not yet sufficiently clarified, however, the major steps forward would appear to come when data from different sources were combined, *e.g.*, chain stations, ground/satellite, and multi-satellite studies. Further coordinated observations with sufficient timing accuracy and high sensitivity of magnetometers at widely spaced stations are necessary to establish the excitation and propagation mechanisms of daytime Pc 3–4 magnetic pulsations.

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