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PC 3,4 MAGNETIC PULSATIONS OBSERVED SIMULTANEOUSLY IN THE MAGNETOSPHERE AND AT MULTIPLE GROUND STATIONS

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Abstract. Periods of magnetic conjugacy between ISEE and the magnetometer array of the Institute for Geological Sciences have been examined to search for the simultaneous occurrence of Pc 3,4 magnetic pulsations. When compressional waves are seen in space, waves are also observed on the ground at the same frequency and with similar waveforms. The wave amplitude on the ground at midlatitudes is similar to that in space at ISEE but at high latitudes the amplitudes are larger than in space. The one occurrence of a purely transverse signal at ISEE was not observed on the ground. These results confirm that Pc 3,4 wave energy is most readily transported through the magnetosphere by compressional fluctuations.

Introduction

A variety of processes can excite nearly pure tones on magnetospheric field lines. These range from internal processes such as bounce and drift resonances to external ones such as upstream waves and instabilities on the magnetopause. One class of pulsations, dayside Pc 3,4 pulsations, has long been thought to be associated with upstream waves. The period of these waves is strongly correlated with the strength of the interplanetary magnetic field (IMF) [Troitskaya et al., 1972]. Their occurrence rate depends on the orientation of the IMF [Bolshakova and Troitskaya, 1968] occurring more frequently when the IMF is along the solar wind flow direction [Gul'yel'mi, 1974]. (See also the review by Odera [1986]). If Pc 3,4 pulsations are generated at or outside the magnetopause, they must propagate across magnetic fields to reach the low latitude stations at which they are frequently observed [cf. Russell et al., 1983]. Thus we would expect that the Pc 3,4 waves responsible for these low latitude signals would appear as compressional waves in the near equatorial regions of the Earth's magnetosphere. On the other hand not all dayside Pc 3,4 waves are correlated with the solar wind (e.g. Slawincski et al. 1988).

Several studies of synchronous orbit magnetometer data have attempted to test this expectation. Arthur and McPherron (1977) compared the frequencies of fluctuations at ATS-1 with simultaneous interplanetary magnetic field (IMF) magnitudes and found no correlation. Nevertheless, they did find a correlation between the amplitude of pulsations and the angle between the IMF and the solar wind flow (cone angle) as the IMF and the solar wind flow (cone angle) as has been confirmed by later authors [Engebretson et al. 1987]. Yumoto and Saito [1983] and Yumoto et al. [1985] used GOES 2 observations and compared the properties of Pc 3,4 waves at synchronous orbit with those seen on the ground at 4 widely based stations (in Japan, Hawaii, California and Alaska) and also with measured IMF properties. These two papers clearly showed that it was the compressional fluctuations at synchronous orbit that were associated with low latitude Pc 3,4 pulsations. The present study complements those of Yumoto and colleagues by using a larger, more closely spaced array with good latitudinal coverage from L values of 2.5 to 6.3 combined with ISEE satellite data on radial passes through the magnetosphere. The emphasis in this paper will be on the behavior of pulsations at midlatitudes rather than at equatorial and auroral latitudes where much previous work has been done.

The Present Study

The ground stations used by Yumoto et al. were spread over almost 100° in longitude and were essentially either at low latitudes or high. Thus it is possible that localized signals seen in space might be missed by this 4 station ground array. During the IMS several large ground magnetometer arrays were established. One of these was operated by the Geomagnetism Unit of the Institute of Geological Sciences (IGS) now the British Geological Survey (BGS) [Stuart 1971; 1982]. This network provided a closely-spaced 14 (and sometimes more) station network with close north-south spacing that reduced the possibility that localized signals could be missed. Figure 1 shows a map of northwestern Europe and north Atlantic, with the stations occupied by the IGS magnetometers during the IMS. On the map are drawn L-values computed at 120 km altitude for epoch 1977.5 from the main field model of Barraclough et al. [1975].

The instrument at each ground station was a three axis rubidium vapor magnetometer, with an essentially flat frequency response and a noise level typically ≤ 0.1 nT, recording magnetic variations in three orthogonal directions (magnetic NE, NW and Z). These can easily be converted into the conventional H, D, Z components. The magnetic variations were sampled every 2.5 seconds.

The satellite data were obtained from the ISEE 1 and 2 spacecraft. The magnetometer on board the 2 ISEE spacecraft is described in detail by Russell (1978). The data for this study were sampled at a rate of 4 times per second and averaged to the same resolution as the ground data in 5-second intervals overlapped by 2.5 seconds. Both satellite and ground data were examined, during the period of magnetic "conjugacy", i.e. when the foot point of the field line traversed by the ISEE satellites was close to the IGS chain of

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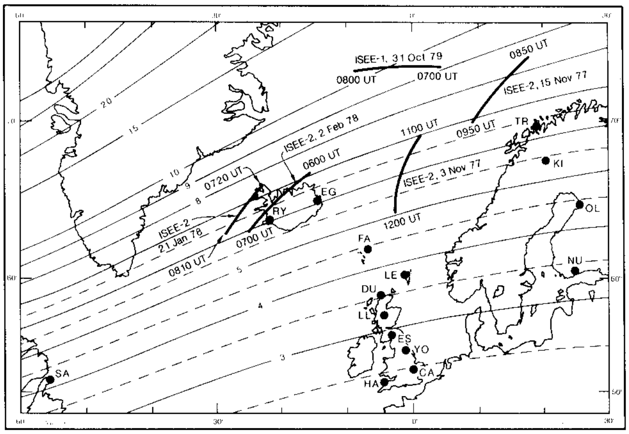

Figure 1. Map of northwestern Europe showing the location of the IGS magnetometer stations and L-value contours and the path of the ISEE spacecraft mapped along field lines, for each of the 5 events studied.

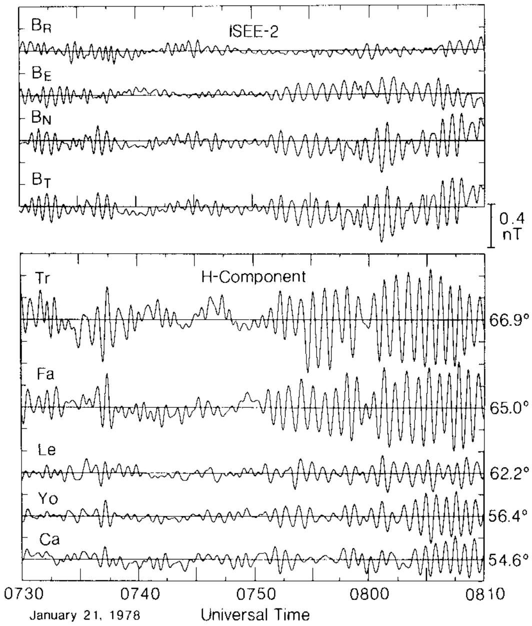

Figure 2. The waveforms of Pc 3,4 pulsation observed simultaneously, both in the magnetosphere (ISEE-2 spacecraft) and on the ground (IGS stations) on January 21, 1978. ISEE-1 measurements are of the radial, east and north components. The ground based records are the X-components. The D-components have similar magnitudes.

magnetometers. Below we refer to the points magnetically conjugate to ISEE simply as the spacecraft footprint.

Observations

We examined all intervals in 1977, 78 and 79 when the footprint of the ISEE spacecraft lay near the IGS chain. During daytime hours there were 75 such conjugate events. Sustained wave events were seen at ISEE in only 5 of these instances. By sustained we mean that were more than 10 cycles of the wave in a 40 minute period. The times of these events are given in Table 1 and the locations of the ISEE footprints for each of these times are shown in Figure 1. Four of these events had a significant compressional component and only one had no significant compressional components (Nov. 3, 1977, Event 1). During 4 of the events the ISEE spacecraft were within 5^0 of the equator. During event (October 31, 1979) the spacecraft were at a 40^0 magnetic latitude.

Figure 2 shows the x-component measured at 5 selected stations of the 14 available for a typical event, that on January 21, 1978. These data have been bandpass filtered in the frequency range 12-40 mHz. Geomagnetic activity was extremely low at this time. Kp was 0 and had been 0 for 12 hours. These records are typical of those throughout the chain. The top panel shows the simultaneous measurements obtained by the ISEE-2 magnetometer. The amplitudes in space are nearly identical to those at low latitude stations. The ISEE spacecraft was inbound, 2°north of the equator at this time, and close to the dawn terminator. The coordinate system of the ISEE data is oriented radially outward (B_R), magnetically eastward (B_E) and in the plane of the dipole magnetic field lines northward perpendicular to the radius vector (B_N). This latter direction is along the magnetic field at the equator. The significant B_N component identifies this as a compressional mode.

Figure 3 shows examples of power spectra for both satellite and ground data. The spectra were calculated using Fast Fourier Transform (FFT) method, over a segment of 18 minutes of data, during the enhancement of the wave activity, i.e. from 07:52 to 08:10 UT. Before the power spectra were calculated, the data were detrended; no filter was applied in this exercise. The upper left-hand panel shows the power spectra for each of the three components of the magnetic field at the ISEE-2 spacecraft. The spectra are plotted on the same horizontal and vertical scale. The

Table 1. Pc 3,4 waves observed at ISEE 1,2.

No.	Date	Time Interval	Power Ratio$^+$	Amplitude	Frequency	Period	Type	Kp
1.	Nov. 3,1977	1100-1140 UT	15.	0.7 nT	17.6 mHz	56.8s	Pc 4	1^-
2.	*Nov.15,1977	0840-0920	1.8	1.23	35.2	28.5	Pc 3	4^-
				[1.43]	[14.3]	[70.0]	[Pc 4]	
3.	Jan.21,1978	0730-0810	0.6	0.33	18.6	53.7	Pc 4	0
4.	Feb. 2,1978	0610-0650	1.8	0.19	35.3	28.3	Pc 3	3^-
5.	*Oct.31,1979	0700-0740	2.5	0.12	26.5	37.7	Pc 3	1^+
			[4.7]	[0.17]	[13.3]	[75.2]	[Pc 4]	

+ Ratio of transverse power to compressional power over bandwidth of wave.
* Two spectral peaks with the values corresponding to the longer period in square brackets.

spectral peaks for all the components are sharp and are at a weighted frequency of 18.6 mHz. The right-hand panels are a series of six spectra arranged in a column, each panel showing the power in the H-component of the ground data at the respective stations, arranged in the order of decreasing latitude. All the panels, both for the satellite and ground data, are plotted on the same frequency and power scales. The horizontal line drawn across each panel marks the zero-log power level (1 nT^2/Hz); the vertical dashed line marks the position of the weighted frequency, calculated from the power spectral matrix at the ISEE-2 spacecraft.

Three main points are illustrated by Figure 3. There is similarity between the frequency at the ISEE-2 satellite and that at all ground stations. The power level in the pulsation band at the ground stations decreases in general with decreasing latitude, and the compressional power is dominant over both radial and azimuthal powers at the ISEE-2.

The second point is further illustrated in Figure 4, which shows the scatter plot for the variation between amplitude and latitude of the ground stations. The horizontal axis is marked in degrees of magnetic latitude, rather than L-value, in order to spread the points more evenly from high latitude to low. The points on the graph are obtained by integrating under the spectral peak at each ground station; the power level in space is also shown. The different symbols correspond to the different sub-chains of the IGS network of magnetometers i.e., Scandinavia, UK and Newfoundland. Figure 4 again demonstrates that the amplitude decreases with decreasing magnetic latitude. The straight line is a least squares fit to the data and is significant at the 99.9% confidence level with a coefficient of correlation 0.7. The frequency of the waves at all stations was calculated as a weighted average over the spectral peak and was identical at each station within experimental error to that at the spacecraft.

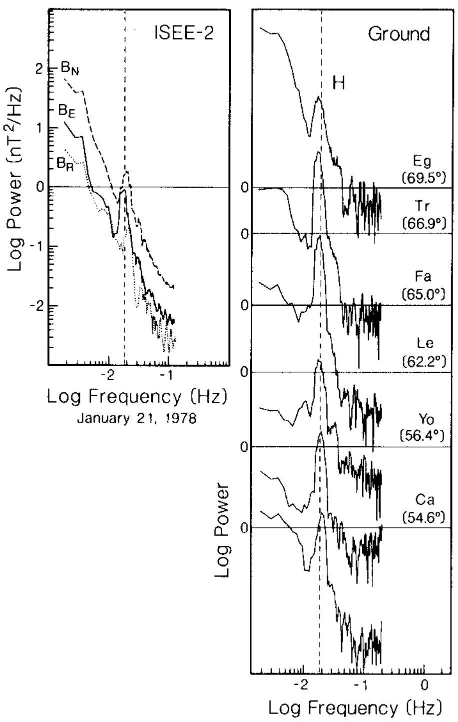

Figure 3. Power spectra of the Pc 3,4 wave event on January 21, 1978 both in the magnetosphere and on the ground. The trace of the spectral matrix is shown for both.

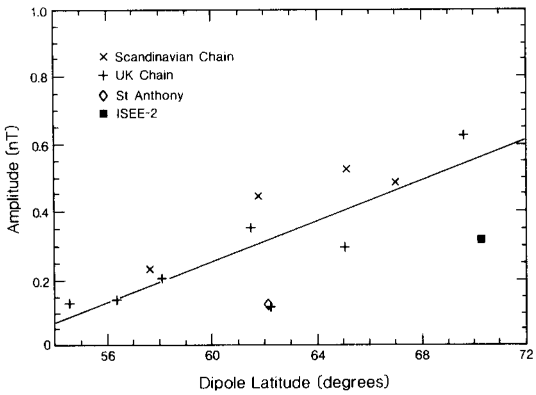

Figure 4. The relation between the amplitude of the Pc 3,4 pulsations on the ground and the geomagnetic latitude. Amplitudes are obtained by integrating under the peaks of the spectra shown in Figure 3.

The Transverse Event

Each of the 4 compressional events behaved in a similar manner to that shown in the previous 3 figures. However, the transverse event on Nov. 3, 1977 did not. Figure 5 shows the time series for the transverse event. The wave is seen very clearly at ISEE-1 which was located only 1° north of the equator, just past local noon, with its conjugate footprint right in the center of the IGS network as illustrated in Figure 1. At ISEE there is a strong transverse Pc 4 with period 57s. There is no compressional (B_N) component. While the data have been filtered to help identify any even weak ground signals, this filtering did not much affect the spectral purity of the space measurements. The waves at this time were very monochromatic.

On the ground there is no signal at these frequencies identifiable by eye in the time series. Nothing is seen at Reykjavik or Tromso, 20° to either side and at the same L-value. (However, the Tromso record is very noisy at this time). Nothing is seen at Faroe about 1 L-value further equatorward or at any other station. Clearly if there is a ground signature of this pulsation even the IGS network was too widely separated to observe it.

Discussion and Conclusions

The difference between the ground-satellite correlation for the compressional waves and the transverse waves is striking. The compressional waves appear at all latitudes on the ground. The amplitudes show only gradual variation with latitude and exhibit no obvious resonance effects. The amplitude at mid latitudes is almost identical to that in space. The temporal variation of their waveforms even look the same. In contrast the transverse wave event observed at ISEE looked very similar to these compressional events in period

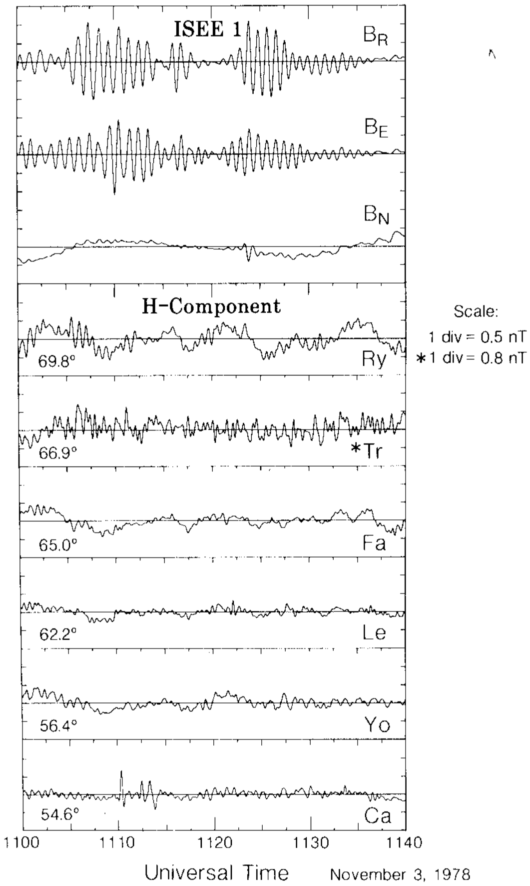

Figure 5. The waveforms of the transverse Pc 3,4 pulsation observed at ISEE on November 3, 1977 together with the waveforms at selected stations of the IGS network.

and amplitude but its ground signature, if any, must have been very limited in extent. It was not seen 20° to either side of the satellite track nor directly south of the satellite path along the backbone of the IGS chain.

Our results thus confirm the conclusions of Yumoto et al. [1985] concerning the importance of compressional waves in transporting Pc 3,4 wave energy through the magnetosphere. The coherent appearance of these waves over a wide range of latitudes on the ground simultaneous with their appearance in space indicates that the energy of these compressional waves is readily transported through the magnetosphere. The rather gradual change in amplitude with latitude at subauroral stations suggests that these compressional waves are little attenuated in the inner magnetosphere. In contrast, the one transverse event we detected appeared to be localized.

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