

ISEE 1 AND 2 OBSERVATION OF THE SPATIAL STRUCTURE OF A COMPRESSIONAL Pc5 WAVE

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Abstract. A compressional Pc5 wave was observed on an ISEE 1 and 2 outbound path on September 28, 1981 at $L = 5.6-7.3$ near the magnetic equator at ~ 10 hr local time during the recovery phase of a geomagnetic storm. The wave propagated westward with a large azimuthal wave number of ~ 30 and exhibited in-phase oscillations of plasma density and magnetic field magnitude. During this event, component-dependent variations in phase and amplitude were observed for the magnetic field oscillations. The radial and compressional components had a constant phase and their amplitude was finite. In contrast, the azimuthal component changed its phase by 180° and its amplitude became zero during the middle of the wave event. We interpret this observation as indicating the spatial structure of the Pc5 wave. The polarization reversal is likely to be caused by a crossing of a node of a standing wave located 4° above the geomagnetic equator.

Introduction

Compressional Pc5 magnetic waves have been observed in the magnetosphere during the recovery phase of a geomagnetic storm [Nagano and Araki, 1983; Takahashi et al., 1985]. Since these observations were made only at the geosynchronous altitude, the spatial structure of compressional Pc5 waves is not well understood. In this paper we discuss the structure of a compressional Pc5 wave based on ISEE 1 and 2 magnetic field observations.

Observations

The event of interest was observed on September 28, 1981, during the recovery phase of a magnetic storm. Its overall feature is illustrated in Figure 1, using ISEE 1 magnetic field data

[Russell, 1978]. The data are presented in a coordinate system where \hat{H} (north) is antiparallel to the geomagnetic dipole, \hat{D} is eastward and $\hat{V} = \hat{D} \times \hat{H}$ is approximately radially outward. Note that only deviations from the Olson-Pfizer model field [Olson and Pfizer, 1977] are plotted. The total component (not plotted) is essentially the same as the H component.

The compressional Pc5 wave was present between 0400 and 0510 UT. During this interval, the L value, local time, and magnetic latitude of the satellite changed from (5.6, 0930, 8.2°) to (7.3, 1010, 1.9°). Throughout the wave event the V component oscillated without any phase variation and had a period of ~ 400 s. The electric field associated with this magnetic wave did not exhibit any 400 s oscillation above the measurement noise level [Cattell, personal communication, 1984].

In addition to the magnetic field data, data from the ISEE 1 and 2 plasma wave experiment [Gurnett et al., 1978] were examined for information on the plasma density. A sharp emission line at the upper hybrid resonance frequency prior to 0410 UT and the plasma frequency cutoff of trapped continuum radiation after 0410 UT were used to estimate the plasma density at ISEE 1 and the result is shown at the bottom of Figure 1. The density decreased from $\sim 11/\text{cm}^3$ at $L = 4.7$ (0330 UT) to $\sim 3/\text{cm}^3$ at $L = 7.1$ (0500 UT), which roughly follows the L^{-4} variation characteristic of the outer magnetosphere. From an examination of ISEE 2 plasma wave data, the plasmapause was found to be located at $L \sim 4.4$.

For a short interval from 0410 to 0426 UT, the cutoff of the continuum radiation was clear enough to be used for determining the phase relation between oscillations in the plasma density n and the magnetic field magnitude B_T . In Figure 2 we show the variations in n and B_T using a logarithmic scale. Clearly, B_T and n oscillated in phase for this interval. Such a phase relation was observed by Kivelson et al. [1984] for a compressional Pc5 magnetic pulsation, and they took it as evidence for a global (fast mode) compressional mode. This observation is against the drift mirror instability [Hasegawa, 1975], which would produce antiphase oscillations.

To discuss the properties of the wave in some detail we show detrended wave forms for the interval 0400 to 0510 UT in Figure 3. Magnetic field data from ISEE 2 [Russell, 1978] are also shown. During the wave event ISEE 1 was located

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ISEE 1, September 28, 1981

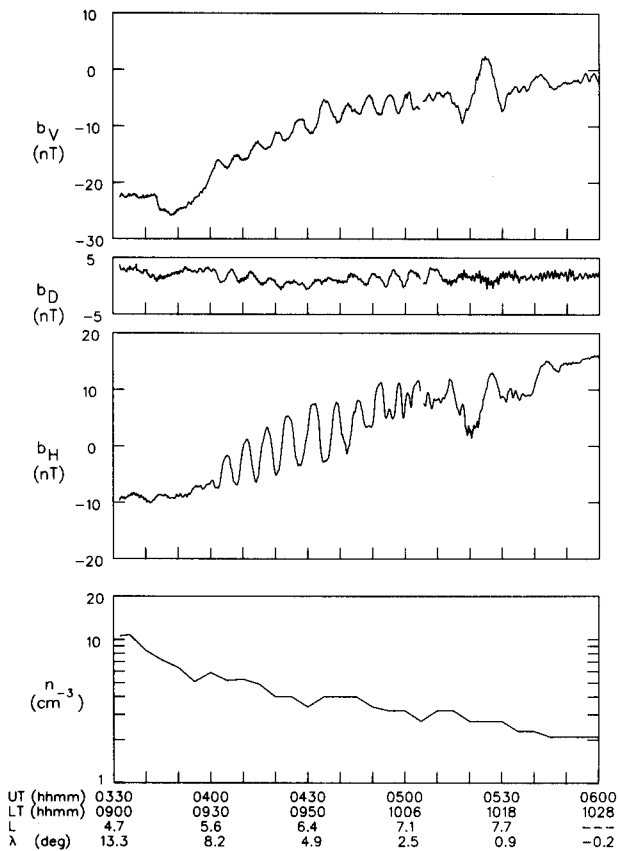


Fig. 1. ISEE 1 magnetic field and plasma density data during a compressional Pc5 wave event. Local time (LT), L value, and magnetic latitude (λ) of the satellite are shown at the bottom.

inside and westward of ISEE 2. Apparently, the wave propagated from ISEE 2 to ISEE 1. If we assume that the propagation is strictly azimuthal, this observation means that the wave propagated westward. The average lag of the wave form, determined with correlation lag analysis, is ~ 20 s for the interval of 0400 to 0430 UT and it is ~ 15 s for 0430 to 0500 UT. These lags correspond to a constant angular velocity of $0.027^\circ/\text{s}$, since the azimuthal separation $\Delta\phi$ of the spacecraft decreased from 0.53° at 0415 UT to 0.40° at 0445 UT. Using this angular velocity and the average period of 400 s for the wave, we obtain an azimuthal wave number of 34. This value, as well as the westward propagation, is consistent with the previous observations at synchronous orbit [Walker et al., 1982; Takahashi et al., 1985].

The amplitude and phase variation is component dependent. The V component has a relatively constant amplitude, but the H component has its amplitude maximum at ~ 0430 UT. These components oscillate out of phase. In contrast, the amplitude of the D component became essentially zero at ~ 0430 UT, and at this instance its oscillation phase changed by 180° . Before 0430 UT b_V lagged b_D by 90° and after 0430 UT b_V led b_D by 90° . Thus, before ~ 0430 UT, the polarization in the b_V - b_D plane was left-handed with respect to the ambient magnetic field direction, and it was right-handed afterward.

ISEE 1, September 28, 1981

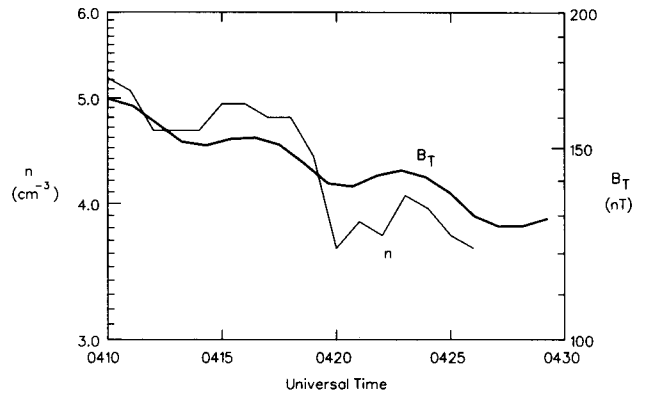


Fig. 2. Phase relation between oscillations in plasma density n and magnetic field magnitude B_T .

Discussion

Since compressional Pc5 waves observed during the recovery phase of a geomagnetic storm have a duration of several hours or longer [Nagano and Araki, 1983; Takahashi et al., 1985] and there was no great change in geomagnetic activity during the present wave event, we take the above observations as showing the spatial structure of the Pc5 wave.

There is a marked difference between the observed phase and amplitude variations of the Pc 5 wave and those described by the theory of field line resonance [Chen and Hasegawa, 1974; Southwood, 1974]. According to the theory, b_D should exhibit an amplitude maximum coincident with its phase shift. In our data, however, the amplitude of b_D became minimum at the point (~ 0430 UT) where the phase shift occurred.

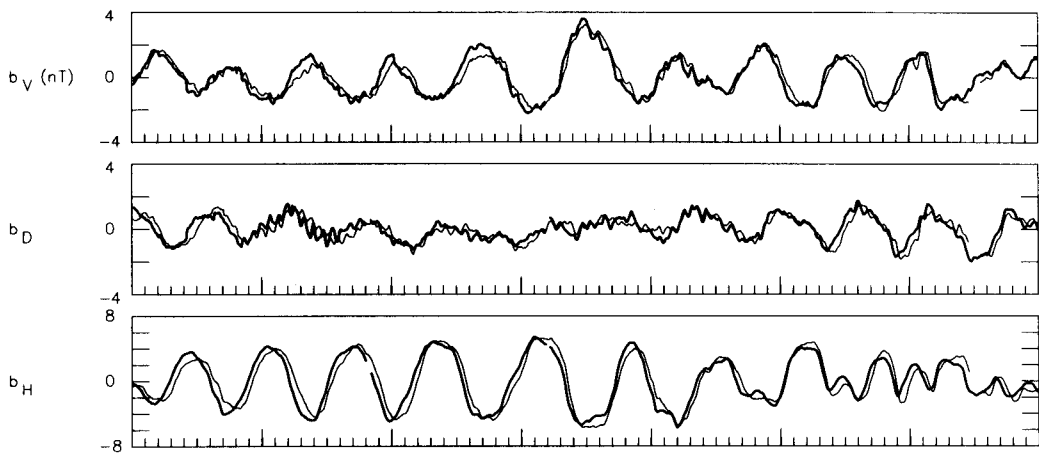
This discussion against a radial structure may not be valid if the propagation direction is radial rather than azimuthal. From our observations alone we cannot determine the propagation direction. However, based on previous results [Walker et al., 1982; Takahashi et al., 1985], we assume azimuthal propagation.

An alternative explanation for the amplitude variation and polarization reversal could be given in terms of a standing wave structure along the ambient magnetic field similar to the one originally proposed by Walker et al. [1983]. Our model, illustrated in Figure 4, differs from the Walker et al. model in that the oscillations between b_V and b_H are out of phase at the equator.

Figure 4 illustrates our model at five different time steps evenly spaced between $t = 0$ and T , where $t = 0$ is defined as the time of $b_V = 0$ at the equator and T is the period of the wave. In the model a fundamental mode (b_D and b_H) and a second harmonic mode (b_V) are assumed, but only the structure near the equator is essential for our discussion.

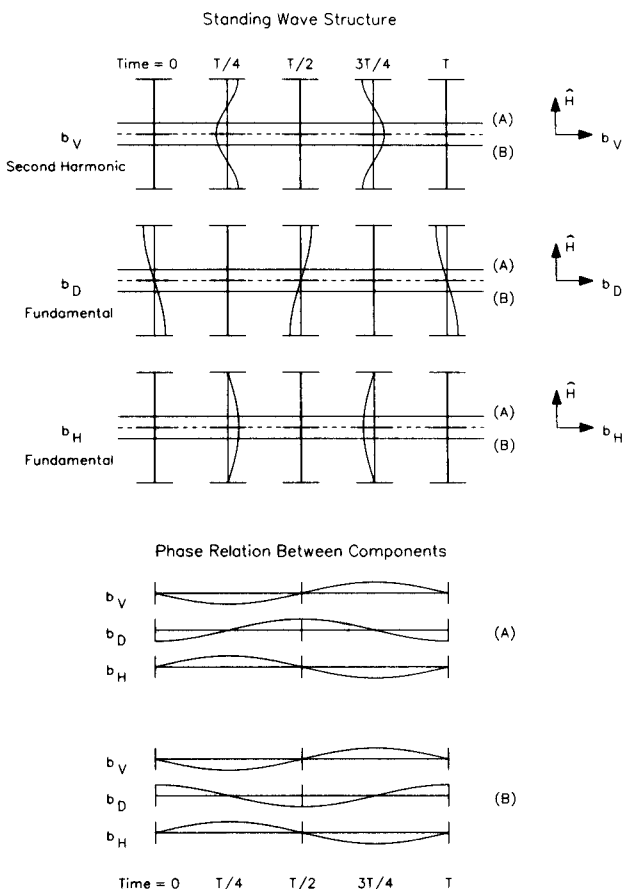
We could interpret our observation in terms of this model as the following. Initially, the satellite was at position (A), above the node of b_D , which is indicated by a horizontal broken line. Here b_V and b_H oscillated out-of-phase and b_D led b_V by 90° . In passing across the node as the satellite moved toward (B), the phase of b_D changed by 180° , whereas that of b_V and b_H remained unchanged.

Detrended Magnetic Field, September 28, 1981
 ISEE 1 (thin line) and ISEE 2 (thick line)



UT (hhmm)	0400	0410	0420	0430	0440	0450	0500	0510
LT1 (hhmm)	0930	0938	0944	0950	0956	1001	1006	1010
L1	5.59	5.88	6.15	6.41	6.66	6.90	7.12	7.32
$\lambda 1$ (deg)	8.2	6.9	5.8	4.9	4.0	3.2	2.5	1.9
ΔR (km)	711	687	666	646	628	611	595	579
$\Delta\phi$ (deg)	0.63	0.56	0.50	0.45	0.41	0.38	0.35	0.32

Fig. 3. Detrended magnetic field observed at both ISEE 1 and 2. The radial separation ΔR and azimuthal separation $\Delta\phi$ of the two spacecraft are shown at the bottom. LT1, L1, $\lambda 1$ are the local time, L value, and the magnetic latitude of ISEE 1.



Throughout the wave event, the satellites were above the nominal magnetic equator, and the phase shift of b_D occurred at $\sim 4^\circ$ above the equator. In order for the standing wave model to work, it is thus required that the node of b_D was located 4° above the nominal geomagnetic equator.

A node located near 4° can also explain observations of the phase relation between b_H and b_D made by Takahashi et al. [1985] with geostationary satellites. They found that at GOES 2 (magnetic latitude of 9°) b_H led b_D by 90° for all the cases they studied, whereas at GOES 3 (5°) b_D led b_H for five cases and b_H led b_D for two cases. Since the L values of the field lines threading GOES 2 and 3 are different only by ~ 0.1 , it seems difficult to explain the observation by Takahashi et al. [1985] by a polarization reversal taking place exactly between the L shells of GOES 2 and 3. Rather, the mixed phase relation at GOES 3 can be explained by a node of b_D located slightly above or below the GOES 3 latitude of 5° .

At present we do not know why the transverse components b_D and b_V can have different latitudinal structures. According to a numerical calculation by Cummings et al. [1969], purely transverse oscillations in the D direction and V direction have similar frequencies for the same harmonic mode. Therefore, we would expect b_V and

Fig. 4. Standing wave structure of compressional Pc5 waves, which is a modification of the one proposed by Walker et al. [1983]. Amplitude variation along the ambient magnetic field line is illustrated for the three components at the top.

b_D to oscillate in the same harmonic mode for transverse waves. For the case of compressional waves, this simple intuition does not seem to work.

As for the generation of the wave, a mechanism needs to be sought that takes into account the observed large azimuthal wave number, westward propagation, and fast mode-like oscillations in plasma density and field magnitude.

Acknowledgments. We would like to thank C. A. Cattell and J. Etcheto for providing us with plasma density and electric field data, although these data do not appear in the final manuscript. One of us (K. T.) would like to thank C. S. Lin for helpful discussions on compressional Pc5 waves and P. R. Higbie for reading the initial manuscript. Work at Los Alamos National Laboratory was done under the auspices of the U. S. Department of Energy. Work at University of California, Los Angeles was supported by the National Aeronautics and Space Administration under research contract NAS5-28448. Work at The University of Iowa was supported by the National Aeronautics and Space Administration under research contract NAS5-28701.

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(Received June 14, 1985;
accepted July 1, 1985.)