ROLE OF DAYTIME IONOSPHERE IN THE MODIFICATION OF COMPRESSIONAL WAVES

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ABSTRACT

Identification of compressional waves in 10 to 100 mHz frequency range, making up the Pc3-4 and Pi2 pulsations, is mainly from the amplitude and phase relations between satellite and surface measurements. Present study examines the ionospheric modulation of compressible hydromagnetic waves using the scalar magnetic field data obtained from Oersted satellite and ground magnetic data from the Japanese sector. It is shown that the dayside ionosphere introduces significant phase delays for higher frequencies. The phase delay increases with frequency and with increase in the conductivity of the ionosphere. There is also an increase in the amplitude of the wave above equatorial dayside ionosphere. The uniformly excellent coherence between the satellite and ground oscillations and systematically good correlation between the filtered time series at the two levels suggests that the compressional hydromagnetic waves are phase coherent over a wide range of latitudes.

INTRODUCTION

Geomagnetic pulsations, in the frequency range of 1 to 1000 mHz are manifestations of hydromagnetic waves generated through a combination of mechanical and electromagnetic forces. They originate mainly in the magnetosphere but are observed both on the surface of the earth and at satellite altitudes at various radial distances. The study of compressional waves in the 10 to 100 mHz frequency range making up the Pc3-4 and Pi2 pulsation using satellite and surface measurements [1,2] can be used to identify cavity waves. An estimate of the modifications introduced by the ionosphere is essential in any such exercise. Present paper examines the amplitude and phase changes introduced by the ionosphere on compressional hydromagnetic waves passing through it by means of ground based geomagnetic data from the low latitude Japanese sector and Oersted satellite data.
The polar orbiting Oersted satellite at an altitude of about 700 km, can allow us to study the latitudinal variation associated with the hydromagnetic wave. The absolute accuracy of the on board satellite scalar measurements is better than 0.3 nT. An orbital period of approximately 100 minutes implies that temporal variations with periods well in excess of one minute cannot be unambiguously identified because the spatial variations associated with quiet day ionospheric currents, including the equatorial electrojet, can masquerade as temporal variations in the satellite data. The study has, therefore, been restricted to frequencies in excess of 10 mHz. Ground based support is provided by the data from the Japanese stations (listed in Table 1). The component data from these stations have sampling rates of 1 sec. and a resolution of 0.01 nT. The present study examines specific periods that are characterized by the presence of oscillations both in satellite and in ground data during daytime and nighttime conditions.

Table 1. Ground stations in Japanese sectors

Station	Geographic		Geomagnetic	
	Latitude	Longitude	Latitude	Longitude
Kanoya (KAN)	31.4° N	130.9° E	21.4° N	200.3° E
Kakioka (KAK)	36.2° N	140.2° E	26.9° N	208.3° E
Memambetsu (MEM)	43.9° N	144.2° E	34.9° N	210.8° E

Table 2. LT and Geomagnetic latitude ranges of satellite passes.

Date	LT (hr:min)	Geomag. Lat. (°N)
14 Mar 99	26:25 - 25:53	+24.47 to –39.18
5 Apr 99(a)	26:05-25:34	+23.18 to –39.6
3 Apr 99	14:03-13:33	-31.96 to +26.14
5 Apr 99(b)	14:01-13:31	-32.49 to +26.03
1 May 99	13:41 - 13:10	-37.35 to +23.04
2 Nov 99	10:52-10:22	-35.27 to +22.54
11 Nov 99(a)	10:32 - 09:52	-10.97 to +46.86
11 Nov 99(b)	10:50-10:20	-46.14 to +12.23

DATA SELECTION AND TREATMENT

The analysis is restricted to satellite passes in the geographic longitude zone between *125° E* and *155° E* to minimize any complexities that may arise in the data interpretation because of large differences between satellite and ground station longitudes. The special reference field model, IGRF, based on the Oersted data [3] is used to subtract out the background field at each satellite position to get residual scalar magnetic field *(ΔF*) data that forms the basic time series in our analysis. The model includes internal main field coefficients to the order 13, secular changes to the order 8 and corrections for external fields derived from Dst values. Plots of the residual satellite field and the corresponding ground station values were generated. The plots showed clear signature of oscillations in both the satellite and ground data. A total of around 60 days of satellite data were similarly examined out of which around 25% of passes exhibited oscillations in the selected longitude zone. In order to study the role played by the ionosphere in modification of the oscillations, the present study includes nighttime and daytime passes listed Table 2.

BROAD SPECTRAL CHARACTERISTICS:

To remove long period trends and high frequency noise, the time series of the satellite and the three ground stations was passed through a band pass filter that allowed only 10 to 100 mHz oscillations. The filter was first tested with simulated time series to ensure that no detectable amplitude or phase distortions were introduced by it. The filtered time series for the satellite and three ground stations consisting of 1024 points for each pass are used for further analysis. The power spectra for satellite and surface stations (upper two panels of fig.1) reveal similar spectral structures on almost all events. This is important since the compressive modes should manifest themselves on ground with similar time structures at all the stations. However, not all the oscillations on the ground fall in this category. Peaks are sometimes absent at one or even two of these stations, which could be associated with special modes of generation/propagation and are therefore excluded from the present analysis of individual mode. Moreover, it is observed that multiple peaks in ground spectra appear as broad peak in the satellite spectrum. In other words, two closely spaced frequency peaks on the ground data tends to merge into a single peak in the satellite data. This spreading of the peak could be due to the satellite motion. It is also seen that the power spectral density (PSD) is higher at the satellite during daytime, whereas nighttime amplitudes are almost same at satellite altitude and on ground, which suggests that the E-region of daytime ionosphere modifies the amplitude of the magneto-acoustic wave as it passes through it.

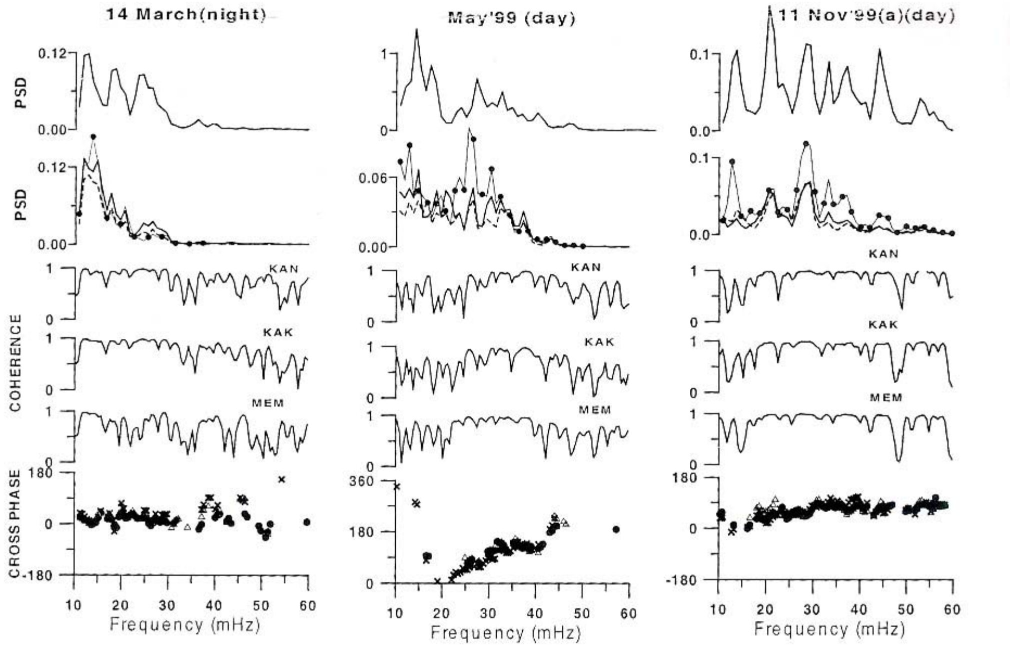

Fig. 1. Power spectral density (PSD) for satellite, Kanoya (—), Kakioka (- -), Memambetsu (–•–) and coherence with satellite oscillations for each of the ground stations. Cross phases for Kanoya (•), Kakioka (Δ) and Memambetsu (×) are depicted when coherence with satellite oscillations is greater than 0.85.

COHERENCE AND CROSS PHASE

To obtain the coherence and the phase relations between the satellite and each of the ground station, the time series of 1024 points is subjected to cross-spectral analysis [4]. Fig.1 displays results for one nighttime event and two daytime events representing different local time conditions. The left panel corresponds to nighttime, the middle panel to afternoon (LT 13-14 hrs) and the right panel to forenoon (LT 10-11 hrs) conditions. The ionospheric conductivity, which depends on the solar zenith angle, is greatest in the afternoon sector. The relationship between the spectra is brought out by the coherence between the signals at the satellite and the ground stations depicted in the middle panel. The coherence at the well defined common peaks is better than 0.9. The lower panel shows the cross-phase or the phase difference between the satellite and ground signals at the three stations. The phases are represented by discrete symbols characteristic for each station when coherence exceeds 0.85 for that particular frequency. The crossphase information is very revealing. It clearly shows that the satellite and ground oscillations are in phase during the night conditions. The phase lag is close to zero even in the daytime at lower frequencies but the phase lag increases with frequency. The rise is much steeper in the afternoon than in the forenoon hours. The phase lag thus increases with frequency as well as with the conductivity of the ionospheric medium it is passing through. This feature is consistently brought out by the cross-phases at all the three ground stations.

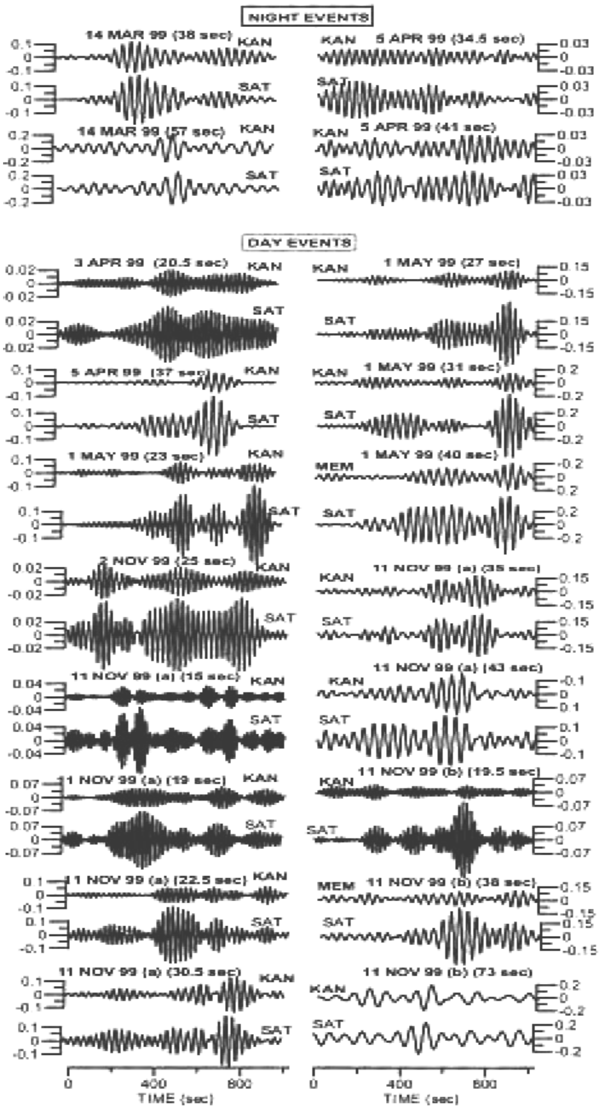

Fig. 2 Filtered Time series

Table 3: Attenuation of ground amplitude relative to satellite. Keys for attenuation are as follows:
$0.6 < NA \leq 1.5$; $1.5 < A \leq 2$; $2 < B \leq 3$; $C > 3$

Date	Peak Freq (mHz)	$\theta < -20$	$-20 \leq \theta \leq -5$	$-5 < \theta \leq 5$	$5 < \theta \leq 20$	$20 < \theta$
Nighttime						
14 Mar 99	26.3	NA	NA	A	NA	-
	17.5	NA	NA	NA	NA	-
5 Apr 99	29	NA	NA	NA	A	-
	24.4	NA	NA	NA	NA	-
Daytime						
3 Apr 99	48.8	B	A	B	B	-
5 Apr 99	27	NA	C	C	C	-
1 May 99	43.5	NA	C	A	C	-
	37	NA	NA	A	B	-
	32.3	NA	B	NA	B	-
	25	NA	C	B	B	-
2 Nov 99	40	NA	A	A	A	-
11 Nov 99(a)	66.6	-	A	C	B	NA
	52.6	-	A	A	B	NA
	44.4	-	A	C	C	NA
	32.8	-	A	A	C	NA
	28.6	-	NA	A	A	NA
	23.3	-	NA	NA	A	NA
11 Nov 99(b)	51.3	NA	B	B	B	-
	26.3	NA	C	C	A	-
	13.7	NA	NA	NA	NA	-

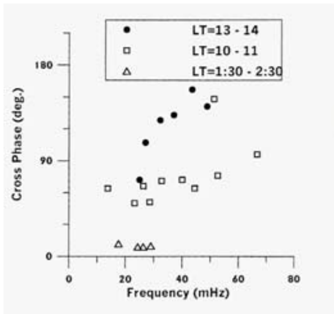

Fig. 3 Phase lags as a function of frequency.

TIME AND LATITUDINAL STRUCTURE

To get time and latitudinal structure associated with each of the peaks, the time series for each of the passes are subjected to narrow band pass filtering centered at each of the peaks. Fig.2 gives the resultant time variations at satellite and ground. The figure shows that hydromagnetic oscillations occur in bursts that are almost simultaneous at ground and satellite heights. In the nighttime events, the pulses at the satellite and ground have about the same amplitude but during daytime, the amplitude of pulses at the satellite heights are significantly larger especially at the lower latitudes.
For the systematic examination of the modulation of the amplitude of the incoming hydromagnetic wave by the

ionosphere, Table 3 shows attenuation of the ground amplitude relative to satellite. The attenuation is classified into four levels viz. NA, A, B and C, that represent the factor by which the satellite amplitudes are reduced when observed on ground (see the Table caption). The levels are arranged in five columns, according to geomagnetic latitude of the satellite observation, extending from latitudes lower than -20° to latitudes higher than +20°. Nighttime events clearly indicate no significant attenuation at all latitude sectors, whereas daytime events often show considerable attenuation. The satellite amplitude is enhanced within ±20° of the dip equator while outside this region the satellite and ground amplitudes are nearly same. This enhancement could be a result of partial screening of the wave due to the enhanced conductivity associated with the equatorial electrojet region. Screening generates a weak image current that reduces the field below the ionosphere but in the process enhances the field above. Unfortunately no suitable ground station was available in the electrojet region to verify this. However, the latitudinal dependence of ground-to-satellite ratio is weak and the expected maximum at the dip equator is not apparent.

CROSS CORRELATION ANALYSIS

While it is obvious from the fig.2 that the same source of oscillations are seen at the two heights, it is possible to get a quantitative confirmation by taking the correlation between the satellite and ground time series at various time lags. There are standard test for testing the significance for the level of peak correlation obtained in each event [*5*]. This is better than 99.9% in all the cases. In the majority of cases the peak correlation is in the region of 0.8 to 0.9. The time lag required for the maximum cross correlation gives another estimate of the phase delay because it indicates how much the filtered ground data has to be shifted backward in time to get the best correlation with the corresponding satellite data. The values obtained by the two methods are always very close in all the cases examined. This increases the confidence in present results. Fig. 3 shows the phase delays at Kanoya as a function of frequency, for all passes analyzed. The plot reaffirms the conclusions depicted in fig.1. The nighttime (Δ) ionosphere does not introduce any phase delay while during the day (•, □), a phase delay is produced by the ionosphere. This phase delay increases with frequency and also with the conductivity of the ionosphere.

RESULTS AND DISCUSSION

High degree of coherence between the satellite and fixed ground oscillation is found, despite the fact that the satellite covered a significant latitudinal distance. Even the time structures show a high degree of correlation over the large orbital distance. This suggests that the incident hydromagnetic waves are phase coherent over a large range of latitudes. The ionosphere introduces a phase delay that increases with increase in frequency of the oscillation as well as the electrical conductivity of the ionosphere. The frequency dependence is consistent with the results of [2]. Theoretical models for computing shielding and phase delays introduced by the high latitude ionosphere [6,*7*] are not valid in the latitude range of interest here. Reference [1] computed the phase delay based on the model of [6] and found that the phase shifts predicted are too small. Our values are in fair agreement with the observed phase delays of [1] which are around 50° to 60° at the period of 20 mHz.

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REFERENCES

[1] Kim, K.H. and K. Takahashi, "Statistical analysis of compressional Pc3-4 pulsations observed by AMPTE CCE at L=2-3 in the dayside magnetosphere", *J. Geophys. Res., 104,* 45394558, 1999.

[2] Kim, K.H., K. Takahashi and B. J. Anderson, "Ground-satellite coherence analysis of Pc3 pulsations", *J. Geophys. Res., 103,*11755-11769, 1998.

[3] Olson, N., Sabaka T. J. and L. Toffner-Clausen, "Determination of the IGRF2000 model", *Earth Planet and Space,* 52, 1175-1182, 2000.

[4] Robinson, E. A. *Multichannel time series analysis with digital computer programs,* 179 pp., Goose Pond press, Houston, Texas, 1983.

[5] Fisher, R I. *Statistical methods for research workers,* 189 pp., Macmillan Publishing Co. ,New York, 1970.

[6] Nishida, A. *Geomagnetic Diagnosis of the Magnetosphere,* Springer-Verlag, New York, 1978.

[7] Hughes, W. J., and D. J. Southwood, "The screening of micropulsation signals by atmosphere or ionosphere", *J. Geophys. Res.,*81, 3234-3240, 1976.