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Global Pc5 geomagnetic pulsations of March 24, 1991, as observed along the American sector

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Abstract. Analysis of the globally coherent Pc5 geomagnetic pulsation event of March 24, 1991, from a chain of stations extending from the auroral oval to the equatorial region along the American sector, has shown unequivocal evidence on the enhancement of pulsation amplitude in the narrow equatorial band centered at the dip equator. The fine spatial structure of this equatorial enhancement, documented observationally for the first time, emphasizes the importance of an ionospheric component associated with enhanced Cowling conductivity. The presence of an ionospheric component is also indicated at mid-latitudes by the sharp increase in the amplitude of pulsations, more dominantly in the Y than in the X component, on the sunward side of the dawn terminator. The sunrise effect also causes a reversal of the sense of rotation of the wave polarization across the dawn terminator. Propagation of the magnetospheric inducted polar electric field to low and equatorial latitudes through the ionosphere is invoked to account for the equatorial enhancement and the sunrise effect seen in these Pc5 pulsations.

Introduction

ULF waves in the frequency range 1 mHz to 10 mHz, corresponding to the Pc5 class, are commonly observed at ground stations near auroral regions, often after an interval of geomagnetic disturbance. Several theories invoking field line resonance driven by Kelvin-Helmholtz instability, large-scale cavity oscillations, drift mirror waves, etc. have been advanced for the generation of Pc5 pulsations, all suggesting high latitudes as the source region [see *Hughes*, 1994 for overview]. In recent years, there has been increasing evidence on the appearance of Pc5 pulsations at mid- and low-latitudes [*Ziesolleck and Chamalaun*, 1993; *Bloom and Singer*, 1995], and even at equatorial latitudes [*Reddy et al.*, 1994]. However, not only do we still lack an accurate statistical picture of wave properties at these latitudes but also our understanding on how the energy from the outer magnetosphere is coupled or propagates down to low latitudes, and especially near the magnetic equator, remains rudimentary.

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This paper reports an analysis of a large global Pc5 event from a network of magnetic observatories extending right from auroral latitudes to the magnetic equator, along the American sector. The event took place on March 24, 1991 and its occurrence was reported at worldwide observatories [*Fujitani et al.*, 1994; *Reddy et al.*, 1994]. Data for the present study were obtained from a temporary magnetometer array in the Brazilian equatorial region and a permanent USGS network. Figure 1 shows the locations of the 17 stations whose data are analyzed here.

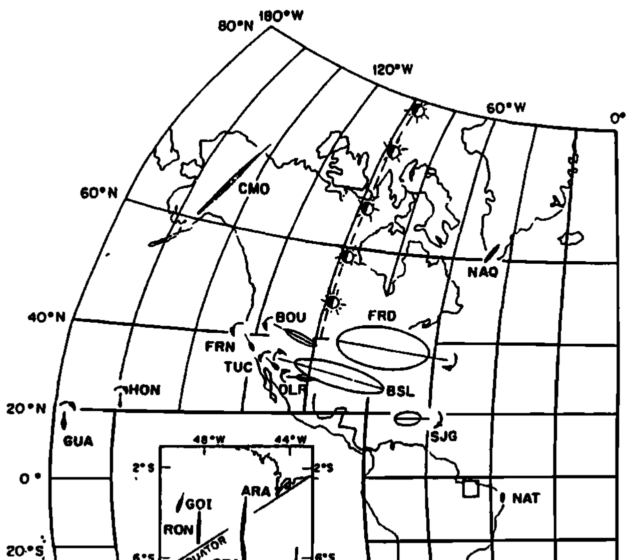

Figure 1. Mercator map of the American sector showing locations of magnetic stations used in this study. Station GUA (13.6°N, 215.1°W) is shown at a displaced position. Inset gives the position of magnetometer sites in the equatorial belt of Brazil. The sunrise longitudes corresponding to the central time (1230 UT) of the Pc5 event is also shown. Also superimposed are the polarization ellipses and their azimuthes and sense of polarization. Note that ellipse scales for stations GUA through FRD are increased by a factor of 10.

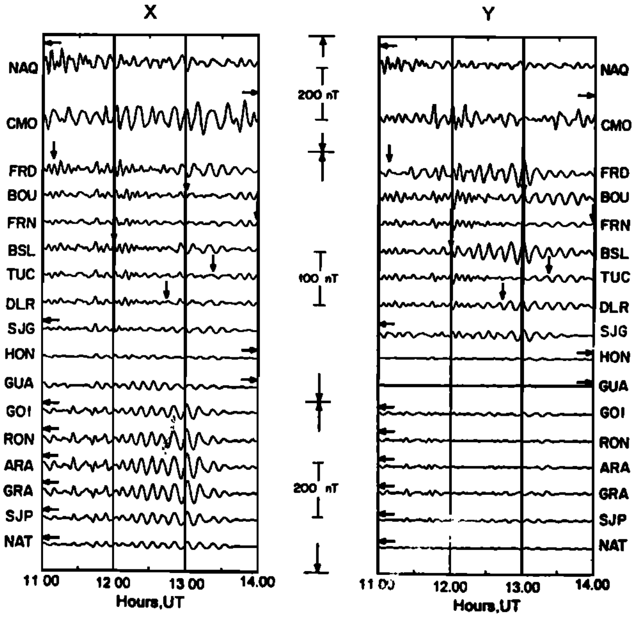

Figure 2. Stacked plots of the filtered geomagnetic field variations in X and Y components for the time interval of 1100-1400 UT on March, 24, 1991. Plots are stacked upwards in order of increasing dip angle. The vertical arrows mark the time of local sunrise and arrows on the side point to the direction of local dawn terminator. Note the different scales for mid-latitude stations from GUA to FRD.

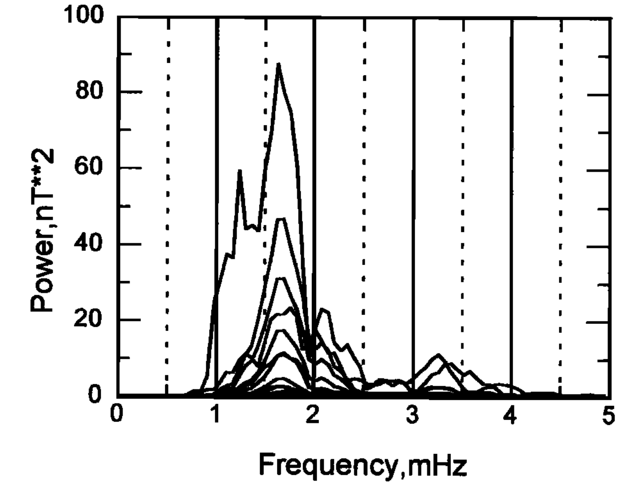

Figure 3. Stacked plots of polarized spectra power for all stations under study.

Data Treatment

The Pc5 event occurred on March 24, 1991 when a severe magnetic storm, following a sudden commencement at 0342 UT, was in progress. One-min values of geomagnetic components were filtered using a zero-phase shift Butterworth function with unit response in the period range of 3-15 min. Figure 2 shows the stacked plot of filtered data in X and Y components for the interval of 1100-1400 UT, when the pulsation train was well developed.

The signals were subjected to a FFT analysis with a frequency resolution of 0.065 mHz. Figure 3 shows stacked plots of the total power spectra of the polarized signal. Except for a couple of stations situated close to the auroral region, other stations show very similar spectral composition with a single peak centered at 1.69 mHz (period 590 s). This period is in close agreement to those reported by *Fujitani et al.* [1994] along the 210° Meridian Chain, European SAMNET and EISCAT magnetometer arrays, and by *Reddy et al.* [1994] at the Indian station Trivandrum, situated close to magnetic equator, all ranging between 560 and 720 s.

The spectral estimates confined to the narrow frequency band of 1.30 to 1.89 mHz, with 9 degrees of freedom, were used to estimate the wave polarization parameters using computational procedures described in *Kanasewich* [1981]. The parameters computed are polarized spectral power (PSP), degree of polarization (DEGP), azimuth (AZI), and ellipticity (ELP) of the plasma wave. The positive (clockwise) and negative (counterclockwise) sign of ELP corresponds to the left-handed and right-handed polarization respectively, when viewed in the direction of the main field in the northern hemisphere. The estimated values of these parameters are given in Table 1 and the resulting polarization ellipses in the horizontal plane are superimposed on the station location map in Figure 1.

Results and Discussion

A noteworthy feature of Figure 2 is that the amplitude of pulsations in the X component shows a marked enhancement at the stations close to the dip equator. The PSP versus latitude plot in Figure 4 shows that spatial behaviour of the equatorial enhancement is similar to the ground magnetic signatures of the intense band of the equatorial electrojet (EEJ) currents associated with enhanced Cowling conductivity. GUA, another equatorial station located in the night sector during the interval of the event, also shows clear pulsations in X, however with smaller amplitudes due to the weakening or absence of the EEJ currents. Pulsations in the Y component at all equatorial stations are negligibly small. As a consequence the polarization ellipses

Table 1. Polarization Parameters at the Study Stations for the Pc5 Event of March 24, 1991 (1100-1400 UT)

Station	Dip	L-Value	PSP	DEGP	AZI	ELP
NAQ	77.0	8.89	15.8	99	29	-0.04
CMO	77.1	5.69	58.7	84	22	0.01
FRD	67.6	2.32	6.3	69	89	0.45
BOU	67.3	2.30	2.6	81	-74	-0.12
FRN	61.7	1.92	0.3	43	-29	-0.39
BSL	61.0	1.73	6.3	84	-82	0.21
TUC	59.0	1.72	0.4	39	-67	-0.40
DLR	56.1	1.63	1.3	66	-89	0.19
SJG	47.0	1.30	1.7	80	83	0.57
HON	38.9	1.16	0.1	52	-14	0.37
GUA	11.3	1.01	0.8	95	1	0.19
GOI	4.2	1.01	10.8	96	14	-0.02
RON	1.2	1.01	20.0	97	0	-0.04
ARA	-0.3	1.01	29.8	98	3	-0.02
GRA	-2.6	1.01	23.5	97	-5	-0.04
SJP	-6.6	1.00	10.1	97	-3	0.19
NAT	-15.6	1.00	4.0	97	3	0.15

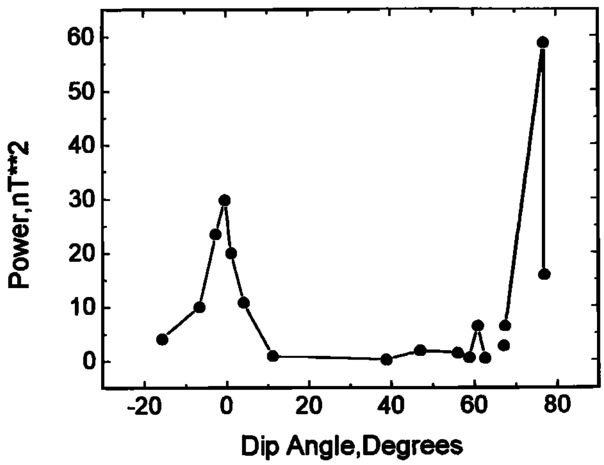

Figure 4. Variation of polarized spectral power as a function of dip angle.

in the equatorial belt are dominantly oriented in the north-south direction.

At low- and mid-latitude stations, HON through FRD in Figure 2, pulsation waveforms both in X and Y are generally well formed but amplitudes vary greatly between stations. Also the ellipticity and azimuth switches between large negative and positive values (Table 1, also see Figure 1). An examination of the magnetic variations of Figure 2 with respect to the local sunrise reveals that the pulsation behaviour changed between groups of stations located in the pre- and post-dawn sectors (e.g. see differences between FRN and FRD, TUC and BSL, or HON and SJG). The sharp changes due to sunrise are also evident at TUC and DLR across the dawn terminator. The effect of local sunrise on the ULF waves has been reported earlier [e.g., *Sutcliffe and Rostoker,* 1979; *Saka et al.,* 1982]. The proportionally larger enhancement of pulsations in the Y component compared to the X component (see Figure 2) would bring rotation of azimuth and depending upon the relative phase changes would even alter the polarization. At some stations, the DEGP is below the critical threshold of 70%, perhaps affecting reliability of the computed ELP and AZI [*Ziesolleck and Chamalaun,* 1993]. Ignoring such stations, the observed rapid changes in the azimuth and polarization at other mid-latitude stations reflect changes associated with the increased ionospheric conductivity at the sunward side of the dawn terminator. It is noteworthy that both ellipticity and azimuth at stations on the sunlit side of the dawn terminator (FRD, BSL and SJG) are comparable to those reported by *Ziesolleck and Chamalaun* [1993] for stations at comparable latitudes in the southern hemisphere, such that both hemispheric stations show left-handed polarization when viewed in the direction of the ambient magnetic field in respective hemispheres.

Further north, in the auroral zone, pulsations again show large amplitudes with clear dominance in the X component. The observed latitudinal changes in the sense of polarization and amplitude (PSP) broadly conform to the typical behaviour of Pc5 pulsations summarized in *Samson* [1991] and *Hughes* [1994]. The reduction of ellipticity from a relatively large value at FRD to near linear polarization at CMO, where amplitude is largest, suggests the proximity of CMO to the line of maximum amplitude across which polarization changes from left-handed to right-handed polarization. The rapid drop of polarized power at NAQ in comparison to CMO, with ellipticity again close to zero, marks the approach of the line of amplitude minimum, north of which a polarization switch is expected again [*Samson,* 1991]. These latitudinal changes in the sense of polarization are more clearly seen as reversals in the waveform of the X component, first between FRD and CMO and second between CMO and NAQ (Figure 2). However, *Samson* [1978] has shown that these large latitudinal phase changes in the X component bring in reversal, though not always, in the sense of wave polarization across the line of maximum (or minimum) amplitude.

Interpretation and Conclusions

The amplitude and polarization characteristics across the auroral oval described above are consistent with a field line resonance model driven by the Kelvin-Helmholtz instability [*Samson,* 1991; *Southwood,* 1974]. However, the global appearance of the event with a latitudinal and longitudinal invariant period supports global compressional or cavity wave oscillations [*Kivelson and Southwood,* 1986] as the likely source of energy which drives field line resonances to produce globally coherent Pc5 pulsations such as observed on March 24, 1991.

Due to the very strong damping in the F-region, the hydromagnetic waves associated with compressional mode or with cavity resonance are not likely to produce any significant perturbation in the ground magnetic records of the equatorial region [*Reddy et al.,* 1994]. In contrast, our results show the unequivocal presence of pulsations at the equatorial region with amplitudes almost 50 percent of the peak amplitude in the auroral oval. The marked enhancement of pulsation amplitude at the dip equator in comparison to low latitudes, clearly emphasizes the role of enhanced ionospheric conductivity at the dip equator during daytime. The direct measurements of ionospheric electric fields during periods of magnetic disturbances provides unambiguous evidence on the almost simultaneous penetration of the electric fields associated with magnetospheric convection to middle and equatorial latitudes through the polar region [*Gonzales et al.,* 1983; *Blanc,* 1983 and references therein]. The polarization characteristics observed here tend to corroborate the electric field pattern measured at mid- and equatorial latitudes, which suggests dominance of zonal (east-west) electric fields or currents at auroral and equatorial latitudes [*Gonzales et al.,* 1983] whereas at mid-latitudes meridional (north-south) currents or electric fields appear to be relatively stronger [*Blanc,* 1983]. The observations are also consistent with the theoretical model associated with geomagnetic sudden commencements (SC) which suggests near instantaneous transmission of the polar electric field to the equator [e.g., see *Kikuchi and Araki,* 1979]. Consistent with such theoretical models, it can be visualized that electric current impressed by the resonating field lines may enter the polar ionosphere as field aligned currents at the dusk side and flow out at the dawn side. The dawn-dusk electric field would set up twin vortex-type ionospheric currents with strong flow along the auroral arc. The dayside vortex may extend equatorward to produce equatorial enhancement of the pulsations. Such a propagation mode may explain the close phase correlation of the waveforms in the X component seen between the equatorial and auroral zones and may also account for the dominance of the pulsation in the Y component at mid-latitudes, associated with meridional current flow. Numerical simulation of the global distribution of the ionospheric currents produced by the electric field for the SC-type of fluctuations [*Tsunomura and Araki*, 1984] has indicated that the amplitude of the electric field decreases as it propagates towards the equator but it will still cause an enhancement of the ionospheric current with the aid of the enhanced Cowling conductivity. The spatial structure of the equatorial enhancement seen here for Pc5 pulsations is compatible to such a mechanism. Direct detection of electric field perturbation in-phase with the polar magnetic field for this Pc5 event at the Indian equatorial station Trivandrum further emphasizes the significance of low- and high- latitude electric field coupling at the pulsation period, as was invoked by *Reddy et al.* [1994]. The presence of such an ionospheric contribution coupled with nightside and dayside conductivities may be able to account for the sunrise effect seen here and also reported earlier. This ionospheric contribution, which dominates in the Y component at mid-latitudes, may possibly explain the anomalously large azimuthal angle of Pc5 pulsations in the morning sector, reported by *Ziesolleck and Chamalaun* [1993], and the results of *Bloom and Singer* [1995] that the diurnal variations in the power of the Pc4-5 band of pulsations peak differently in east-west and north-south magnetic field components.

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