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A Result on Pc 3-4 Waves in the Indian Equatorial Region

D. R. K. RAO

Indian Institute of Geomagnetism, Dr. Nanabhoy Moos Marg, Colaba, Bombay 400 005, India

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A few characteristics of Pc 3-4 geomagnetic pulsation recorded at a station close to the equatorial electrojet in the Indian region under varied ionospheric conditions are reported. The polarization characteristics of these pulsations during counter electrojet condition are found to change in their ellipticities and orientation axes. These are attributed to either height distortions of ionospheric electric fields during the counter electrojet time or to changes of gyrotropic MHD waves that might be endogenously generated by the turbulence of equatorial electrojet.

1. Introduction

It has been shown in the literature that regular geomagnetic pulsations encompassing the entire spectral range can be explained theoretically by resonance excitations in the magnetospheres (Fraser and Ansari, 1985 and references therein). Within the outer boundary of the magnetosphere and the lower limit of the ionosphere, characteristics of these pulsations are changing and are influenced by many factors which reflect immensely on the frequency of ULF waves. Some of the factors are the pressure of the solar wind which squeezes the magnetosphere and determines its dimension, the distribution of plasma within the magnetosphere, etc. Thus, even with one type of input disturbance of the system, variety of phenomena may be observed on the earth's surface due to changes in the transient characteristics. Mainly two sources of daytime Pc 3 and Pc 4 (period ranges: 10 to 45 and 45 to 150 sec. respectively) geomagnetic pulsations have been identified (Yumoto *et al.*, 1985). Boundary waves in the Pc 3-4 frequency range which may be generated near the magnetopause and penetrate into the magnetosphere, can be a source of high latitude pulsations. The other source could be upstream waves in the foreshock region that are transmitted across the magnetosheath and magnetopause propagating as compressional waves into the magnetosphere. Within the magnetosphere, part of these could couple to transverse waves observed on the ground as low latitude pulsations, exhibiting field line resonance behaviour (Kivelson and Southwood, 1985). Studies were undertaken extensively to understand the nature of Pc 3-4 pulsations on the ground at low latitudes, $L<3$ (e.g. Kuwashima *et al.*, 1979; Lanzerotti *et al.*, 1981; Fraser and Ansari, 1985; Ziesolleck *et al.*, 1986). All these studies are confined to observations of pulsations to the lowest latitude of $L = 1.3$. Rao (1992) reported Pc 3-4s that are observed at three stations (L in the range of 1.02 to 1.20) in the Indian longitudinal zone. In this communication after briefly describing the experimental set up, results of ULF wave observations during the counter electrojet and control times are presented and discussed.

2. Data Acquisition, Selection and Analysis Technique

Three sets of induction magnetometers, consisting of N-S and E-W sensors, suitable preamplifiers and digital data loggers, were kindly fabricated by the Physics Department of the University of New Castle, Australia for exclusive studied of low latitudes pulsations under a joint collaborative project. Hardware and software details of the system were given by Udare (1992). On ascertaining the identical gain factors and filter characteristics (having unattenuated signal response in the 10 to 100 sec. period ranges), the three systems were deployed at strategic locations at Tirunelveli (geographic lat. 8°41′ N,

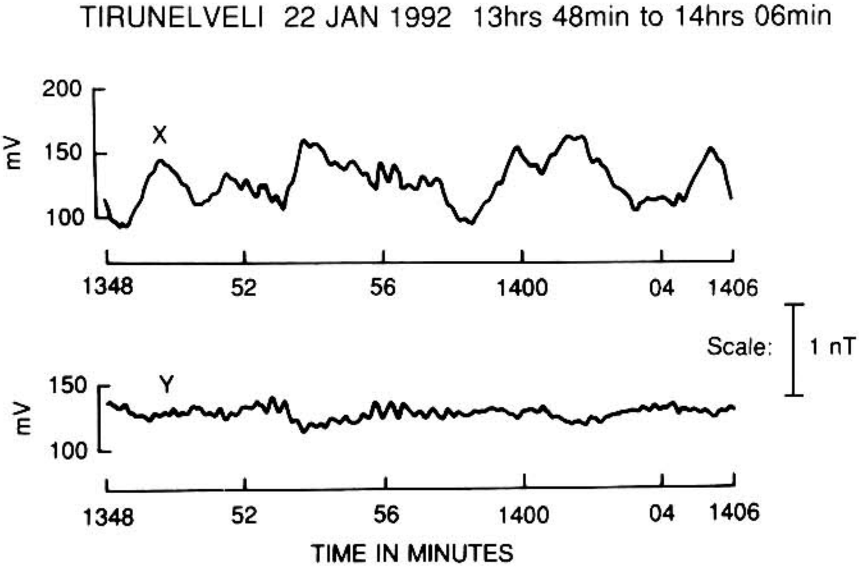

Fig. 1. Amplitude (mV/m) and time records of X (N-S component) and Y (E-W component) magnetic variations during counter electrojet interval.

geographic long. 77°46′ E; $L \simeq 1.02$), a station under the influence of the daytime equatorial electrojet and closer to its axis, at Alibag (geographic lat. 18°38′ N; geographic long. 72°52′ E; $L \simeq 1.05$), a station far from the electrojet influence and the *Sq* focal latitude and, at Sabhawala (Dehra Dun) (geographic lat. 30°22′ N; geographic long. 77°48′ E; $L \simeq 1.20$), closer to the northern *Sq* focal latitude. Sampling interval of data acquisition was maintained at 2 sec. uniformly and the scale factor of conversion to amplitude of the output was 1 nT for 80 mV of potential difference in the flat range of frequencies. A frequency-direction analysis technique, facilitating computer processing of amplitude-time recordings in two orthogonal directions was adopted for investigating a planar stationary-oscillatory events. The methodology, details of which are given by Rao (1992) and Rao and Asinkar (1994), is extremely useful to work out the fine structure of short-period geomagnetic pulsations. It enables to obtain quantitative information on the frequency components representing the pulsations, the distribution of overall energy in the spectrum of pulsation, the ellipticities, the orientation of the major axes of the ellipses and the senses of rotation of the disturbance vectors.

One of the draw backs of the observations at widely separated stations is a lack of control over the time accuracies. Though the times at individual stations are kept through manual correction of data logger clock, there is no absolute standard of precision in the recorded pulsation activity from among the three stations. The group velocities of train of pulsation towards estimating the direction of propagation are, therefore, worked out on statistical basis via MEM (Maximum Entropy Method) spectral technique.

For pulsations during the counter electrojet (CEJ) intervals, when the Cowling conductivity effect in the vicinity of the dip equator during daytime reverses on few occasions during morning and evening times, a special scrutiny for the data selection has to be carefully made. One of the IAGA resolutions identified the interval from Sept. '91 to March '93, initially, as International Equatorial Electrojet Year (IEEY). During this period, intensive compaigns-based observations of equatorial electrojets were conducted to understand the aeronomical phenomena associated with all aspects of the equatorial electrojet. This, in-turn, would be absorbed in the STEP-associated activity which has a wider scope. In India, four intensive and coordinated compaigns were conducted by encompassing ground based experiments and rocket launchings. The first compaign was during 7–22, January 1992 wherein a sequence of counter electrojet intervals (from 20th to 22nd Jan.) was registered from the ground

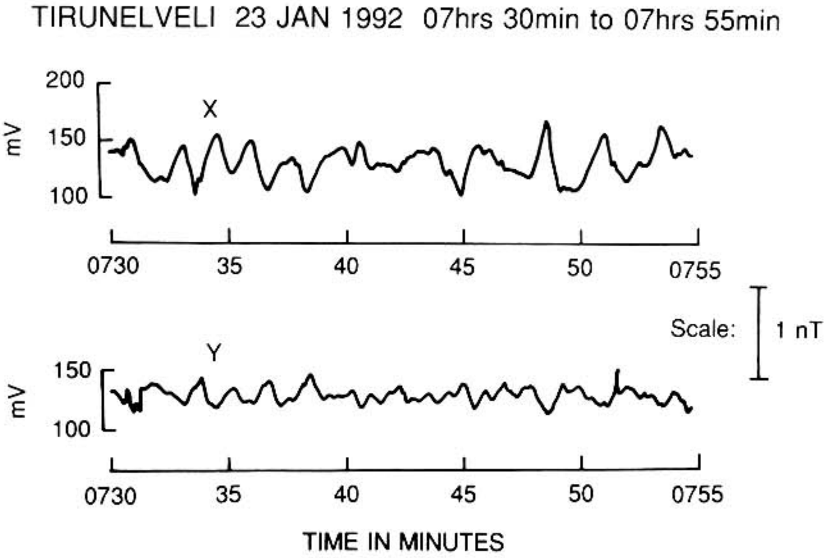

Fig. 2. Similar to Fig. 1 during the control interval.

magnetometer measurements. Pc 3-4 class of pulsations were recorded during the counter electrojet time on 22nd Jan. '92 in the post noon time at Tirunelveli. Similar class of pulsations were also recorded at the same station on 23rd Jan. between 07:00 and 08:00 IST (IST = UT + 5 hrs. 30 min.). The train of pulsations in both the occasions were recorded during relatively quiet geomagnetic conditions (*Ap* on 22nd and 23rd Jan. were 7 and 4 respectively) when counter electrojet conditions were present and absent. Both *X* (N-S) and *Y* (E-W) series of data in the time interval from 13:48 to 14:06 IST on 22nd Jan. '92 when three hourly planetary geomagnetic index, *Kp*, was 1°, are shown in Fig. 1. Similar data series in the control time interval (07:30 and 07:55 IST on 23rd Jan. '92) ($Kp = 1$) are shown in Fig. 2.

3. Results

X and *Y* component amplitude spectra as a function of wave period between 20 to 100 sec. during the interval of counter equatorial electrojet (CEJ) time are shown in Fig. 3 top and bottom respectively. Similar results from the control interval data are shown in Fig. 4. The scales of plots of the amplitude spectra are different between *X* and *Y* components. There are few common periodicities at all the spectra in the Pc 3-4 range both during CEJ and control intervals. The results from frequency-direction analysis, amplitudes of *X* and *Y*, the total power, direction of maximisation of the power (*Y* on the E-W direction reckoned zero degrees and *X* on N-S direction with 90°), the ellipticity and sense of rotation (R-clockwise with reference to the *X*-component N-S aligned sensor and L-counter clockwise of the disturbance vector) are summarized in Table 1.

Barring the polarization characteristic variations associated with the local time, the same class of pulsations with near identical periods show differences under varied ionospheric conditions. During the counter electrojet time interval when the *E*-layer conductivity behaves westerly directed as opposed to its normal easterly direction, there is perceptible change in the pulsation characteristics. The directions of the disturbance vectors at all periodicities change from N-W during the control interval to more northerly during the CEJ. Also, the magnitudes of the ellipticities are found to be higher uniformly during the CEJ time. However, the senses of rotation of the disturbance vectors associated with the pulsations remain more or less clockwise (R) in both the intervals except that at 24-sec. period during the control interval where it has shown L polarization.

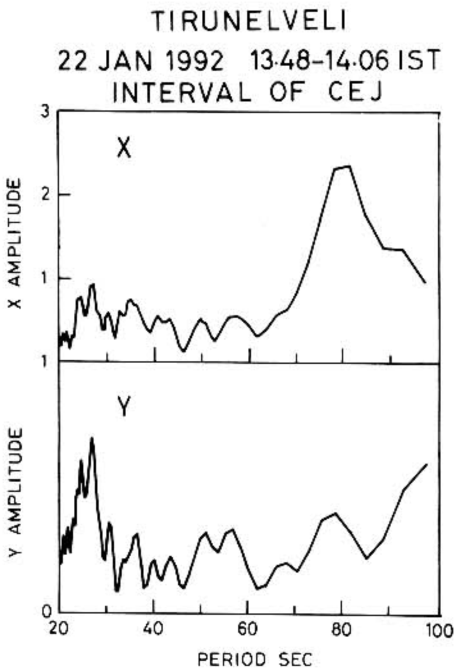

Fig. 3. Amplitude-period plots of (top) X-series (bottom) Y-series from the computed spectral results during the counter electrojet interval.

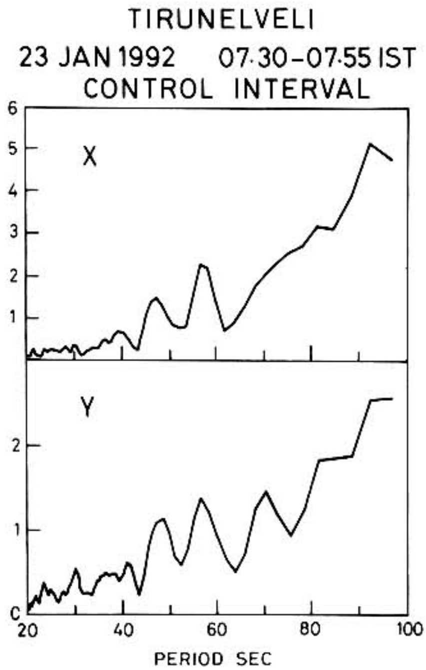

Fig. 4. Similar plots in Fig. 3 for the control interval.

Table 1. Results from frequency-direction analysis.

During counter electrojet CEJ

22nd Jan. 1992 between 1348 to 1406 LT						
Period sec.	*X*-amp.	*Y*-amp.	Total power	Direction deg.	Ellipticity	Sense of rotation
58	0.563	0.268	0.203	104	0.35	R
50	0.497	0.302	0.189	124	0.36	R
30	0.598	0.367	0.288	108	0.56	R
27	0.919	0.658	0.717	122	0.34	R
24	0.785	0.611	0.577	116	0.64	R

During control interval

23rd Jan. 1992 between 0730 to 0755 LT						
Period sec.	*X*-amp.	*Y*-amp.	Total power	Direction deg.	Ellipticity	Sense of rotation
57	2.300	1.380	5.230	120	0.23	R
48	1.490	1.100	1.780	132	0.03	R
30	0.300	0.543	0.278	156	0.25	R
24	0.178	0.259	0.111	142	0.08	L

4. Discussion

Several authors, through numerical simulation, attempted to identify the effective tidal modes which may reproduce CEJ events. Forbes and Lindzen (1976) showed that an appropriate combination of the (1,1), (1,–2), (2,–2) and (2,4) vital modes cannot account for the negative excursions of the equatorial magnetic fields. Stening (1977) demonstrated that CEJ is associated with the imposition of a current system generated by semi-diurnal modes. Hanuise *et al.* (1983) were successful in bringing out the CEJ-related perturbations in the magnetic fields at both equatorial and non-equatorial latitudes by a suitable combination of semi-diurnal (2,2) and (2,4) modes of tides. Employing antisymmetric tidal modes (2,3) and (2,5) for deriving the ionospheric current system, Stening (1989) argued that (2,3) tidal mode's role to be vital in explaining certain facts of CEJ with confidence than any other modes. Using the simultaneous observations of coherent VHF backscatter radar, magnetometer and digital ionosonde, Somayajulu *et al.* (1994) gave direct evidence for the theoretically predicted distortions in the equatorial electrojet associated with the local effects of shearing zonal neutral winds at the Indian longitudes.

Sometime ago, Kato (1973) showed that at the magnetic equator, local east-west winds with significant vertical shears can interact with the electrojet plasma and generate substantial wind induced polarization electric fields perpendicular to the geomagnetic field in the magnetic meridian plane. It is argued, here, that during the interval of counter electrojet, the propagation characteristics of the ULF waves can be modified by the wind induced polarization electric fields resulting in the changes of ellipticities and directions of orientation of the disturbance vectors. The effect of the polarisation electric field is to increase the zonal component of the magnetic vector in Pc 3-4 class of pulsations to make them more elliptically polarised than that of usual near linear polarisation (Ref: Table 1). However, the absolute magnitudes of *Y* are not found to show an increase during CEJ over the control interval but the phases of variations are optimal for more elliptically polarised vectors.

Also, during the last decade some theoretecians demonstrated the existence of specific modified

MHD waves in the lower ionosphere. These waves are due to anisotropy of the conductivity in the E-layer (Hall conductivity, $\sigma_H >>$ Pedersen conductivity, σp) and are called gyrotropic MHD waves (e.g. Surkov, 1990 and references therein). These propagate along the E-layer with velocity much less than Alfvén velocity. Further theoretical probe has revealed that these waves at mid-latitudes will be heavily attenuated due to the escape of wave energy into the magnetosphere along the field lines and due to the pedersen dissipation (Pilipenko, personal communication, 1994). However, theory allows the existence of these class of waves near the equator. The mechanism can be visualised as follows. Intense instabilities (shears) of the daytime equatorial electrojet may excite wide-band of MHD disturbances in the lower ionosphere. The part of these disturbances with frequencies corresponding to gyrotropic MHD modes (about 20–60 sec.) are trapped into the E-layer and propagate away from the equator with velocities 10–30 km/sec. The calculation by Surkov (1990) indicated that the dissipation of these waves is minimal near the periods at 60 sec. The damping coefficient at these frequencies is about 3.6×10^{-3} km^{-1}, hence the wave amplitude has to decrease e-times at a distance of 300 km, from the source. Endogenic sources for the equatorial pulsations have been discussed in the literature in the past (Saito, 1983). Also, it is shown from computing the stable phase angles at these three widely separated stations that the Pc 3 pulsations in the afternoon hours in the Indian longitudes propagate away from the equator (Udare *et al.*, 1993). Propagation direction and the sensitivity of the Pc 3-4 pulsations to the ionospheric conditions indicate that they may have been originated in the equatorial regions during times when electrojet is active. Unfortunately, the ground recordings at the other two stations on these two specially chosen occasions were missing as such direct comparison of the results at CEJ and at control interval derived for Tirunelveli cannot be carried out at the other two stations in order to ascertain CEJ associated polarisation changes.

Saka and Alperovich (1993), while studying the Pc 3-4 geomagnetic pulsations at an equatorial station, Huancayo in the American longitudinal sector, have shown that the oscillation were observed predominantly in the magnetic North-South (H) component. However, they observed the D (East-West) component signals in the same frequencies on occasions during few hours in the vicinity of sunrise timings. At these times, a tilt of the polarization angle in the H-D plane (NW-SE) without significant change in the ellipticity as opposed to the general NE-SE quadrant of the angle during the winter months was shown by them. This change was attributed to the dawn terminator at the dip equator for Pc 3-4 pulsations. The control interval on 23rd Jan. '92 in the present study was during the sunrise time at the Indian equatorial electrojet region and the observed change in the orientation angle may alternately be understood as the dawn terminator effect during the morning time. The polarization characteristics near the dip equator are, however, not fully clarified theoretically for any definite conclusion. From the observational point of view, it is very essential to delineate the dawn terminator effect and construct a good statistical base on the diurnal changes of the horizontal disturbance vector in Pc 3-4 pulsations to conclusively attribute the polarization changes entirely to the ionospheric conditions at counter electrojet occasion. In case the counter electrojet effect exists in the propagation of pulsation waves, it is possible that either changes in the polarisation electric fields or the nature of gyrotropic MHD waves may have to be looked into as the candidate sources.

Thus, the observed changes in the polarization characteristics at the two varied conditions of the equatorial ionospheric E-region may either be explained as due to changes of polarization electric field effects or to the changes in the nature of gyrotropic MHD waves. Detailed study employing several such examples of pulsations recorded simultaneously at all the three stations is contemplated in the near future.

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