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# Frequency dependence of equatorial electrojet effect on geomagnetic micropulsations

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The micropulsation data (Pc3–Pc4 range) from off-equatorial and equatorial stations Alibag (ABG) and Tirunelvelli (TIR) in the Indian zone during 1991 are analysed for delineating the electrojet effect. The ratios of the spectral amplitudes at significant frequency bands the horizontal component of the magnetic field at TIR to that at ABG are worked out as a function of frequency. The results show that the lower frequencies undergo larger equatorial amplification. However, above a certain frequency the pulsation signal is found to attenuate rather than exhibit the general enhancement. The ratio becomes minimum around the period, 18 to 24 sec. At further higher frequencies, there is again the normal electrojet amplification. The explanation of such a behaviour of the electrojet on the pulsation amplitude is rather difficult at the present stage and to some extent becomes controversial even if it is offered.

## 1. Introduction

One of the interesting geophysical phenomena associated with the equatorial ionosphere is the enhancement of geomagnetic variations on the ground at the equatorial stations when compared to those at off-equatorial latitudes. This phenomenon known as "equatorial electrojet" (EEJ) is observed on a variety of periodicities in the geomagnetic field. The general explanation of this effect is that the two dimensional current system in the sun lit part of the $E$-region of the ionosphere has a narrow band of enhanced current density almost parallel to the dip equator approximately in the west-east direction. If one assumes that the vertical currents are zero then the anisotropic Cowling conductivity in the equatorial region becomes large thereby producing a strong but narrow current band known as equatorial electrojet. Therefore any geomagnetic variation which is due to the currents in the $E$-region is expected to show EEJ enhancement.

The question, then, arises whether the short period geomagnetic variations, known as micropulsations, would also experience EEJ effect as the source of these hydromagnetic waves is generally at the outer space much above the ionosphere. The results of Matsuoka *et al.* (1997) with the help of 210° Magnetic Meridian data have shown that the Pc 3 amplitudes during day time are larger at the dip-equator when compared to those at off-equatorial stations. On the other hand the Pi 2 pulsations (which have similar frequency ranges as those of Pc 3 s) at night side (Osaki *et al.*, 1996) from the same chain of stations do not show any equatorial magnification. The analysis of Pi 2 pulsation by Shinohara *et al.* (1997) also shows the same equatorial magnification at day time but not during night hours. Comparing the signals of micropulsations from an equatorial station to that from an off-equatorial observatory at the Indian region Sarma and Sastry (1995) have shown that the EEJ effect is indeed manifested in the short period variations. All these above observational studies confirm that the process of electrojet magnification is indeed operative even for short period geomagnetic signals like micropulsations. However, for periods less than about 30 sec., the equatorial signals have been reported to suffer attenuation rather than amplification (Sarma and Sastry, 1995). The reason for this opposite electrojet effect, if one has to state, is not clear as yet. One may argue that the pulsation signal incident on the top of the ionosphere will get attenuated (Hughes and Southwood, 1976; Newton *et al.*, 1978) as it penetrates the ionosphere and higher frequencies are expected to undergo more attenuation. Here we are concerned about the relative strengths of the signals below an electrojet station and a station off-electrojet not very far away. The ground signals basically are the effects of the ionospheric current system generated by the incident hydromagnetic wave energy. Therefore, the fields have to exhibit the familiar electrojet effect irrespective of the frequency (Sastry *et al.*, 1979). There is no evidence, however, as to exactly how and why the electrojet effect has to depend on the frequency of the micropulsation signal.

All these past studies were concerned with the average amplitude of a Pc 3 signal in a rather wide band of frequencies. Therefore, it has been decided to investigate in this communication the frequency dependence of the pulsation signals from 100 sec. to less than 10 sec. period and closely examine the electrojet effect. We try to explore the possible physical mechanisms responsible for such behaviour.

## 2. Data

The micropulsation signals from induction coil magnetometers at two Indian stations are analysed. These stations are Tirunelveli (TIR): dip latitude 0°10′N, and Alibag (ABG): dip latitude 12.96°N. Simultaneous acquisition of two component data ($X$- the geomagnetic north-south and $Y$- the east-west) from the sensors of induction coil from these stations are recorded on floppy discs. The sampling rate is 2 sec. The data are subjected to specially designed filters to register unattenuated signals between periods of 10 sec. to 100 sec. Software and hardware details of the system are given in Udare (1992). After chosing suitable events during the day time, the relevant hour is divided into intervals of 8 min. 32 sec. duration, overlapping each other by 50 percent of data points. Tapering by a 50 percent cosine bell is applied to each of the data sets prior to transformation by Fast Fourier Transform routine. Each frequency component is suitably weighted and averaged by the two nearest neighbouring components on either side. The coherency at each of the frequencies between TIR and ABG filtered time series is calculated. We have chosen those peaks of the spectra for which both TIR (Tirunelveli) and ABG (Alibag) have appreciable and statistically significant power. Moreover, at those peaks there exists coherency of seventy percent or more between the two stations. This is done so as to ensure that the signal is a simultaneous event both at TIR and at ABG. However, the seventy percent criterion is rather arbitrary, but can be argued to be a satisfactory one considering the numerical uncertainty associated with FFT method of spectral analysis.

## 3. Results and Discussion

Two typical spectra in $H$ are shown in Figs. 1(a) and 1(b), the duration of each data set being 8 min. 32 sec. at the two stations on 17th March and 4th April, 1991 respectively. Some of the peaks in the power spectra are common in both the stations. However it does not exclude the possibility of some peaks to be selectively present only in one or the other station.

The $X$-component is basically $\Delta H$ parallel to the local geomagnetic north-south direction. The ratio of the amplitude of a frequency from TIR spectrum to the corresponding ABG spectrum indicates the degree of EEJ amplification. From the above figures, it is apparent that for lower frequencies there is the expected electrojet magnification and for higher frequencies an unexpected attenuation. At further higher frequencies the usual electrojet magnification is again restored. These features are present in both the Figs. 1(a) and 1(b). It is, thus, evident now that both the low and very high frequencies of the spectra show electrojet amplification whereas for the intermediate frequencies the ABG amplitudes are more than those at TIR.

In order to estimate the EEJ effect more clearly, we have chosen those spectral components where the peaks at TIR and at ABG are within each other's half width. The average frequency of these two peaks is considered as the common frequency at the two stations. The square root of the ratio of the powers at TIR to that at ABG is defined as the electrojet effect. In spite of being an arbitrary definition, this is a reasonable parameter to indicate a qualitative measure of the effect. If this ratio is greater (less) than one we term the phenomenon as electrojet magnification (attenuation).

In Figs. 2(a) to 2(d) this parameter $\Delta H_T/\Delta H_A$ is shown as a function of frequency for March 17, 1991 event. The numbers above the data points are the coherence factor (percentage coherency) between TIR and ABG corresponding to that particular frequency. EJ index, the measure of the strength of the equatorial electrojet at that hour, which should be generally estimated from the difference of hourly geomagnetic variations in $H$ at Tirunelveli over Alibag on the particular day is substituted by another equatorial station Kodaikanal, as the hourly data from Tirunelvelli are not available. Since EJ is just qualitative measure, this shift of station will not very much vitiate the discussions.

One can infer from the results in Figs. 2(a) to 2(d) that the EEJ amplification generally decreases with increasing frequency. As the frequency increases the electrojet effect even becomes an attenuation rather than amplification. For further higher frequencies this quantity again becomes greater than one. The implication is that the EEJ attenuation reaches a minimum at a certain frequency, say, $f_0$ and the attenuation is limitted to a narrow band of frequencies around $f_0$. In Fig. 2(a), the Electrojet Index (EJ) is considerable in magnitude and it is noticed that the attenuation of the signal at TIR is rather very weak. However, the frequency versus electrojet magnification curve passes through a minimum. In Fig. 2(b) the electrojet index is slightly less and the attenuation is more clear. In Figs. 2(c) and 2(d) the attenuation is not only further pronounced but also the ratio $\Delta H_T/\Delta H_A$ is less than one over a wider range of frequencies when compared to the higher EJ magnitudes.

Similarly in Figs. 3(a) to 3(c) the same ratio as in Fig. 2 have been shown for April 4, 1991 event. In this case also the same result is obtained. During strong electrojet interval the attenuation is found to be weak and confined to a narrower band of frequencies when compared to weak electrojet conditions.

The detailed analysis of 210° Magnetic Meridian data by Matsuoka *et al.* (1997) has also shown the equatorial magnification in the average power in the Pc 3 range of pulsations. The detailed spectral analysis result of their work was confined only to mid and high latitudes. They have not worked out the relative strengths at a particular frequency between an equatorial and a very low latitude stations. As their spectra were averaged over five raw spectral estimates the frequency dependence observed here may have been averaged out in their analysis. Similarly, the work of Sinohara *et al.* (1997) also looked at the field averaged over periods between 40 sec. to 150 sec. As such both these studies have not noticed magnification, attenuation and subsequent magnification effects.

The present observation of electrojet attenuation actually implies that the pulsation signals at certain frequencies in the ionosphere at ABG is rather stronger than those at TIR so that the conventional electrojet magnification effect is actually nullified and therefore the attenuation. This is, however, confined to a band of frequency around $f_0$ and at further higher frequencies again the conventional electrojet magnification is observed.

It is not clear why this attenuation is confined to a rather narrow band of frequencies around $f_0$. The question arises whether this preferential response at ABG can be termed as the conventional field line resonance mechanism. The work of Yomoto *et al.* (1995a) implies that low latitude field lines are not capable of undergoing the conventional field line resonance mechanism because of mass loading effect

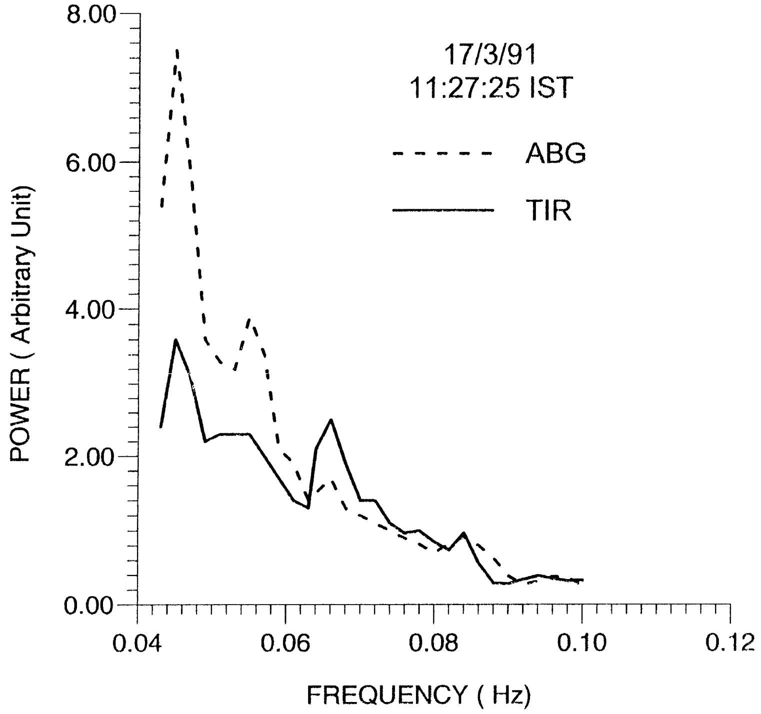


Fig. 1(a). A typical power spectra of the micropulsation signals at TIR and ABG on 17/3/91 at 11 hr. 27 min. 25 sec.

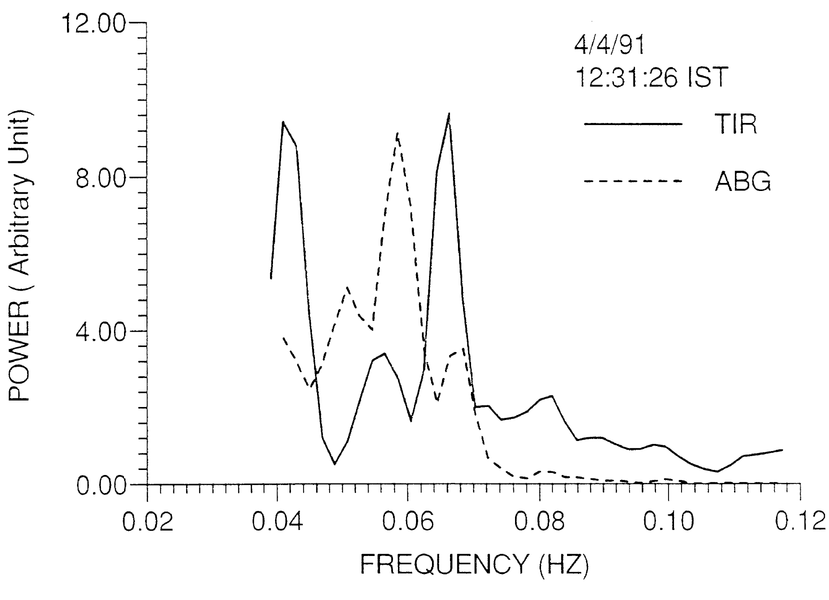


Fig. 1(b). The high frequency part of a spectrum at TIR and ABG for 4/4/91 at 12 hr. 31 min. 26 sec.

at these latitudes. According to the calculations of Yumoto *et al.* (1994), damping factor at very low latitude is very large for a realistic ionosphere. Moreover, the half width of the calculated resonance response at low latitude is also quite large. It is true that the field line corresponding to ABG is mostly embedded inside the ionosphere. Therefore its response towards its eigen period will be sluggish and rather spread over a wider radial distance in the equatorial plane of the field line. However, one must realise that large damping factor means that a resonator, once excited, will decay very fast. Therefore, an impulse induced pulsation event will not be able to excite a field line with large damping factor. If, on the other hand, the source of the pulsation is continuous pumping of energy into the inner magnetosphere from the solar wind (Saito *et al.*, 1981; Vellante *et al.*, 1989) it is conceivable that rate of excitation may overcome, albeit weakly, the damping rate.

The eigen periods of the toroidal mode of the standing

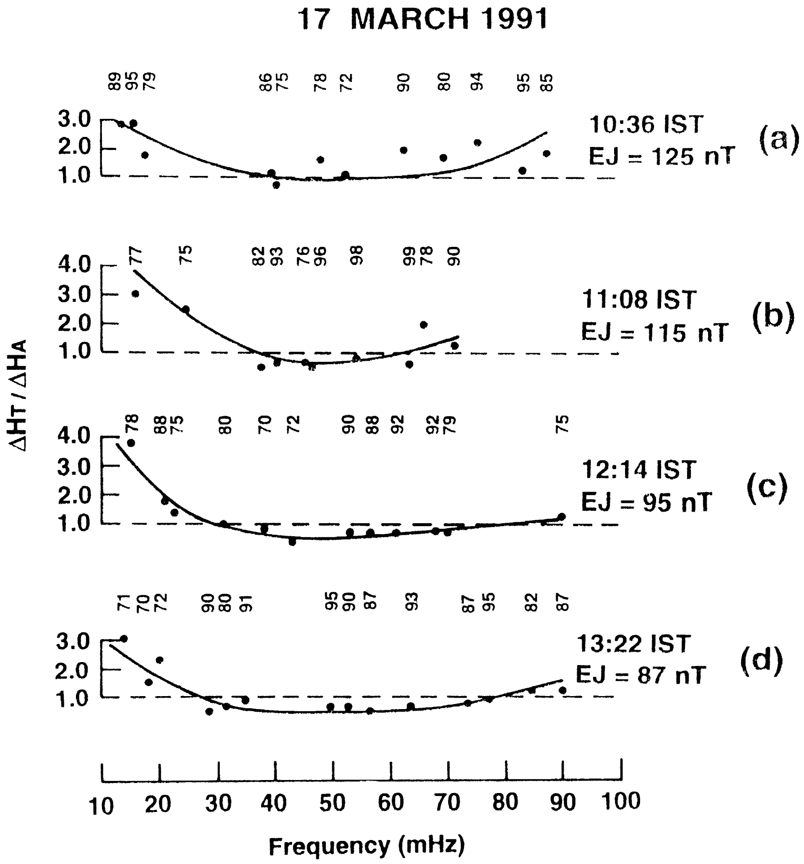


Fig. 2. The ratios of $\Delta H_T/\Delta H_A$ as a function of frequency for different local times having different electrojet strengths.

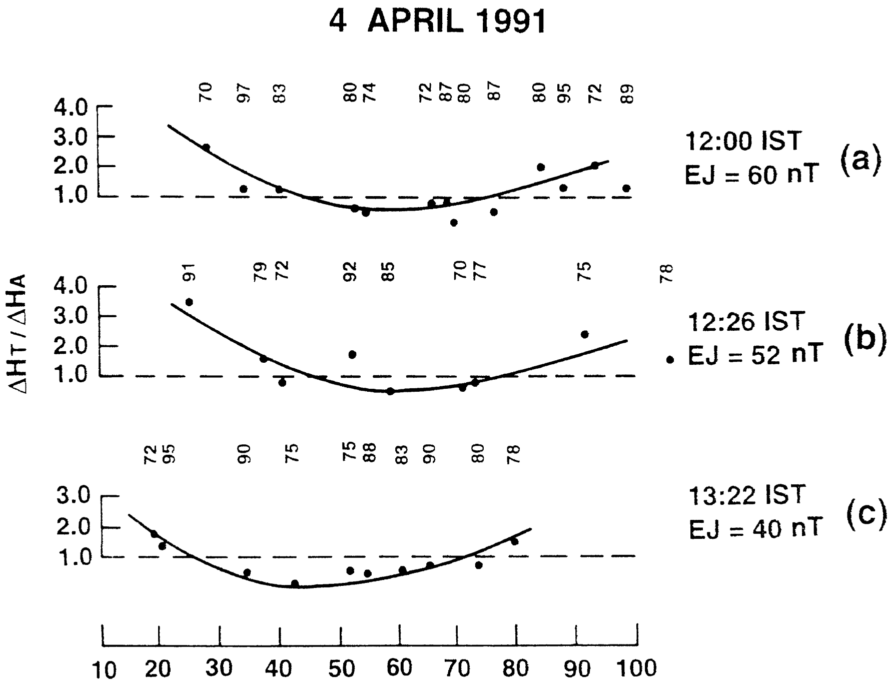


Fig. 3. The same as Fig. 2 but for April 4, 1991 event.

waves along a field line have been calculated by many researchers (e.g. Orr and Mathew, 1971; Singer *et al.*, 1981; Poulter *et al.*, 1984, etc.) primarily for high and mid latitude stations. For lower latitudes one may refer to the works of Saito *et al.* (1981), Hattingh and Sutcliffe (1987), Vellante *et al.* (1989) and Green and Worthington (1993) to name a few. But the near equatorial latitudes have not attracted much attention probably because of the mass loading effect as mentioned earlier which excludes the existence of FLR at ultra low latitudes.

Theoretically at least, it is possible to calculate the field line resonance (FLR) frequency of very low latitude stations even where the field lines are mostly embedded inside the ionosphere. Earlier, Poulter *et al.* (1988) calculated the FLR periods from 60° latitude to the equator. Figure 5 of their paper indicates that the toroidal mode period at around 10° latitude (Alibag station's latitude is 9.74°) is some where between 15 sec. to 25 sec. depending on the local time.

The more recent calculations of Yumoto *et al.* (1994) also show that the FLR frequency at latitudes of about 10° may be estimated to be (if one extrapolates figure 2 of their paper) some where between 20 sec. to 30 sec. The observations of Yumoto *et al.* (1995b) have measured the frequency only up to 20° latitude which has a period of the order of 25 sec. and figure 9 of their paper indicates the tendency of slightly increased period towards further lower latitudes. On the other hand the theoretical calculation of Poulter *et al.* (1988) give the FLR period to be somewhat less than 20 sec. at ABG latitude. Our results from Figs. 2 and 3 show the minima of the curves occur at the frequency $f_0$ which is between 45 to 60 mHz (22 to 16 sec.), rather slightly higher frequency than the observations of Yumoto *et al.* (1995b).

The present study definitely shows that the equatorial and off-equatorial stations do indeed respond differently towards different frequencies even though the application of FLR may be questionable at these latitudes. It is, thus, all the more important to undertake further theoretical as well as observational investigations in these regions.

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