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Periodic Variations in the Equatorial Electrojet Strength Associated with Planetary Wave

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Assuming that the diurnal range of the equatorial field represents the strength of the electrojet current, quasistationary periodicities in the intervals of 12 to 16 days and 5 to 7 days are inferred from the spectra of five sets of time series of the electrojet strength chosen from the period 1975-77. Many of these cyclic variations are also noticed in the spectra of electrojet field at individual hours around local noon as well as in the corresponding series of noontime critical frequencies of F2 and Es from Kodaikanal, a station under the electrojet in South India. The periodicities in the interval of 5 to 7 days appear to arise from the modulation of ionospheric zonal wind by mixed Rossby-gravity waves. The longer period variations seem to be associated with either the lunar semi-monthly tide or a harmonic of the solar synodic rotation period. A signal of 4-day period is conspicuous by its persistence.

1. Introduction

Detection of cyclic oscillations in the strength of the electrojet field is of immense help in planning special observations using rockets for studies of the upper atmosphere. Kane[1] derived an index, SDI, which is the difference between the horizontal component of the field observed at a station close to the centre of the equatorial electrojet and corresponding field at a station outside the influence of electrojet, with the S_q at low latitude added. Using field signatures of the electrojet strength in the Indian region, obtained by a different procedure detailed below, a search is made to detect the cyclic variations of periods in excess of two days in the electrojet strength.

2. Analysis

The difference of the field, for each hour, between a pair of stations in the same longitude zone so located that one is close to the centre of the electrojet (Trivandrum; dip, 1°S) and other outside it (Alibag ; dip, 24°N) is a good measure of the strength of the electrojet not augmented by planetary Sq. The procedure to isolate the electrojet field and the merit over the earlier methods were discussed by Bhargava *et al.*,[2] Rangarajan and Arora[3] and Rangarajan.[4] The daily range of purely electrojet field thus computed is defined here as the difference between the maximum hourly value of the field (generally around local noon) and the minimum value computed in the above manner in a day. A cursory examination of these daily ranges indicated a suspected 6-day quasi-stationary periodicity in the years 1975 and 1976. To identify with certainty these quasi-stationary periodicities in the electrojet ranges sophisticated spectral analysis technique, using the concept of entropy called the maximum entropy method (MEM),[5-7] has been employed. Though the MEM is data adaptive and has many advantages over the conventional spectral approaches, a major drawback of this method is in determining the optimal length (L) of the prediction error filter (PEF). It is usually recommended that the spectrum is to be computed for several values of L and a suitable choice is then made which could lead to a spectrum consistent with known characteristics of the time series under consideration. Courtillot *et al.*[8] have shown that a choice of 20-50% of the length of the data sample would be adequate in most cases. Daily electrojet ranges for the period 1 Apr. 1975 - 30 Sep. 1977 are divided into 5 sets of time series of six monthly duration. The MEM spectra are obtained for each of the sets of about 180 data series with $L = 20$ and maximum lag of 120. The choice of the smaller L value results in a smoothed spectrum obviating the resolution advantage of MEM and at the same time avoiding any instability that is likely to be caused by line splitting. The amplitude spectra of periods

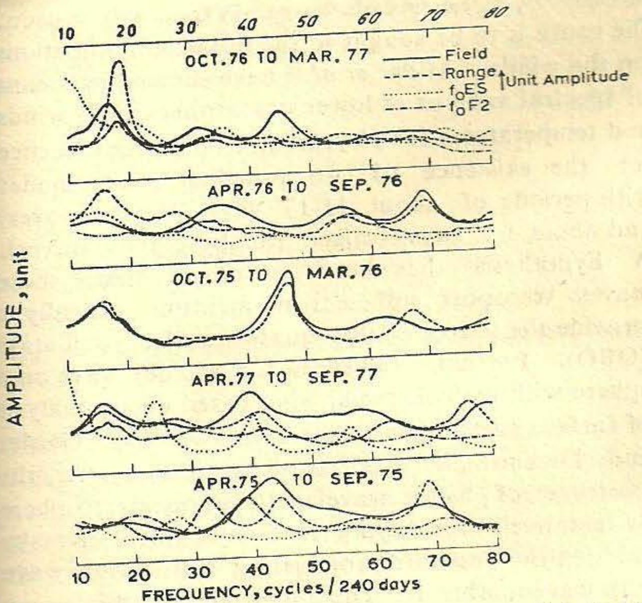

Fig. 1—Plots showing the amplitude spectra of electrojet field, electrojet range, f_0 Es and f_0 F2 at Kodaikanal from 24- to 3-day period

from 24 to 3 days are shown in Fig. 1 for all the five sets. Periodicities identified from the spectra in Fig. 1 are given in Table 1.

3. Results and Discussion

Quasi-stationary periodicities in the interval of 12 to 16 days and 5 to 7 days are noticed in the amplitude spectra of all the sets (Table 1). The amplitudes are obtained as the product of the square *root of the power density and the bandwidth of the* estimate. It is known that the amplitudes could be biased by a large factor,[9,10] but the relative amplitudes at different frequencies are reliable. The main advantage in the MEM method of spectral analysis is its ability to isolate significant periodicities without undue frequency shift. The stability of the spectral estimates is checked by varying the length of the Akaike PEFs. The significance of the periodicities is also checked by subjecting series of other physical parameters to the same technique of MEM analysis and comparing the common wavelengths. For this, time series of the electrojet field

Table 1—Periodicities Identified in the Electrojet Field and Ranges as well as in the Ionospheric and Other Parameters

Interval	Periodicities (in days) at					Other parameters (period in days)					
	1000 hrs LT	1100 hrs LT	1200 hrs LT	1300 hrs LT	Range	R_T	R_A	f_0F2	f_0Es	D_{st}	A_p
1 Apr. 1975 to 30 Sep. 1975	13·33 5·33 3·43 — —	8·89 5·85 3·43 — —	13·33 6·00 3·48 — —	12·00 6·15 4·53 3·75 —	15·00 7·50 5·45 4·14 3·48	14·12 7·06 4·62 3·58 —	14·12 8·28 5·22 4·21 —	12·00 6·15 4·29 — 3·33	8·89 — 4·44 — 3·24	17·14 — 4·44 — —	13·33 8·28 5·22 4.07 —
1 Oct. 1975 to 31 Mar. 1976	16·00 5·22 — 3·48 —	16·00 5·22 — 3·58 —	16·00 5·22 — 3·81 —	16·00 5·22 — 3·87 3·12	15·00 5·22 — 3·53 —	10·00 6·15 — 3·75 —	9·23 6·86 4·14 3·53 —	— — — — —	— — — — —	21·82 9·60 6·67 3·81 —	21·82 9·23 4·53 3·53 —
1 Apr. 1976 to 30 Sep. 1976	14·12 — 6·49 3·48 —	14·12 — 6·86 3·48 —	17·14 — 6·86 4·36 3·48	17·14 — 6·49 4·44 3·53	15·00 — 4·29 3·48 —	14·12 8·89 5·33 3·48 —	24·00 5·00 3·75 3·08 —	12·63 — 7·27 4·21 —	— — 5·58 4·21 3·08	12·63 4·29 3.43 — —	30·00 10·00 6·49 4·62 —
1 Oct. 1976 to 31 Mar. 1977	13·33 7·06 5.45 — 3·24	12·63 7·06 5·33 — 3·29	14·12 7·50 5·33 — 3·58	15·00 7·74 — 5·33 3·64	12·63 7·06 3·58 — —	14·12 7·27 5·33 4·07 3·29	14·12 6·32 4·21 3·16 —	*13·33* 7·27 3·64 — —	— 6·86 4·90 4·00 3·33	*13·63* 7·50 4·44 3·58 —	*13·33* 7·27 5·00 3·33 —
1 Apr. 1977 to 30 Sep. 1977	10·00 6·32 3·81 3·12 — —	16·00 *9·23* 6·15 3·08 — —	15·00 *6·00* 4·07 3·04 — —	14·12 *6·00* 4·36 3·04 — —	16·00 *8·89* 5·85 3·81 3·16 —	17·14 *8·89* 5·71 3·93 3·20 —	21·82 9·60 6·67 4·44 3·69 3·20	15·00 8·00 5·71 3·58 — —	10·00 6·00 *4·29* 3·33 — —	12·63 4·29 *3·33* — — —	12·63 7·06 *4·36* 3·20 — —

around local noon hours (from 1000 to 1300 hrs LT) are formed and subjected to identical MEM spectral analysis. Periodicities from these amplitude spectra are included in Table 1. Several of the periodicities observed earlier in the daily range series are also seen in the elecrojet field at various hours, which indicate that the observed quasi-stationary oscillations, predominantly in the intervals of 12 to 1 6days and 5 to 7 days, are real. The wavelengths computed, using the individual time series of daily ranges at Trivandrum and Alibag, are also included in Table 1 under the columns R_T and R_A respectively. Only Trivandum series exhibits periodicities close to those obtained corresponding to the electrojet field at various hours and its daily range. Similar time series of f_0 F2 and f_0Es, the critical frequencies of F2 and Es layers, respectively, for Kodaikanal, a station under the influence of equatorial electrojet (dip 3·1°N) at noonmtie (75°E meridian time), have been chosen for the same intervals and subjected to identical MEM analysis to examine if they exhibit any periodic variations in common with the electrojet strength. Time series could not, however, be formed for one set, viz. 1 Oct. 1975 to 31 Mar. 1976, due to the loss of data and is excluded from the analysis. These amplitude spectra also are shown in Fig. 1 and periodicities identified are given in Table 1. A few of the periodicities, especially in the samples of f_0F2, correspond to those observed in the electrojet field at various hours and electrojet range.

It is well-known that there is a strong lunar modulation of the electrojet current. Some of the periodic variations in the interval of 12 to 16 days may either be associated with the modulation of the lunar semi-monthly tide or the first harmonic of solar synodic rotation period, the latter being primarily of disturbance origin. The disturbance effect is, however, considerably eliminated in the process of evaluating the electrojet field defined here. In fact, Rangarajan[4] has shown that the phase progression in local time of the lunar semi-monthly tide is consistent with the theoretical consideration of Stening.[11] Thus, the signals close to 14·9 day observed in the range of equatorial electrojet field may be associated with the lunar semi-monthly tide.

The origin of the lines in the interval of 5 to 7 days is, however, not clear. The observed periodicities result from modulations either of the ionospheric conductivity in the electrojet region or on the prevailing winds in the upper atmosphere. There seems to be no physical mechanism that can bring about a cyclic modulation of the ionospheric conductivity in the period-range 5-7 days and as such, the cause is to be sought in the possible modulations on the winds. Miller *et al.*[12] have shown, by means of spectral analysis of lower stratospheric daily winds and temperatures for 11 years in tropics, the evidence for the existence of two principal wave modes with periods of about 11-17 days (Kelvin waves) and about 4-5 days (mixed Rossby-gravity waves). A hypothesis has been proposed that these waves transport sufficient momentum vertically to provide the source of the quasi-biennial oscillation (QBO). Further, evidence for a 5-day wave on a sphere with realistic zonal wind based on an analysis of surface pressure data, has been given by Geisler and Dickinson.[13] Roders[14] has also shown the existence of 5-day wave in the upper stratosphere by tentatively identifying a 5-day global Rossby mode in the westward propagating temperature wave with wavenumber 1. The amplitude of this wave was typically 0·5 K and its period varied between 4·5 and 6·2 days. It, therefore, appears that the 5- to 7- day periodicity observed in the electrojet field is associated with the modulation of the mixed Rossby-gravity wave. It is known that the Rossby wave is a stationary longer periodic wave whose rate of movement could be from 2-4° to 10-20° longitude per day.[15] Perhaps the observed shift in the periodicities from 5 to 7 days in various samples may be the result of the change in the wavelength of the Rossby wave.

While discussing the origin of geomagnetic fluctuations of ultra long periods (several days) Kitamura[16] has attributed a clear 7-day period, occasionally shown by the S_q focus location, to the westward zonal currents accompanied by MDP1 and MDP2. (The DP2 type of geomagnetic flucutations have a time scale of about one hour and appear coherently all over the world. It differs from the polar substorms, DP1, in that it is not caused by the activation of the auroral electrojet. Types MDP1 and MDP2 are the modifications on the DP1 and DP2 current systems responsible for field fluctuations). As this periodic geomagnetic fluctuation results from a worldwide current system similar to the well known DP1 and DP2, he concludes that this current system may not be of the planetary wave origin but must be of magnetospheric origin. For a confirmation of our conclusion, periodicities are worked out by MEM spectral analysis detailed earlier in the time series corresponding to daily A_p and the equatorial D_{st} indices at 0600 hrs UT (1100-1200 hrs LT) for identical intervals. These periodicities are given in

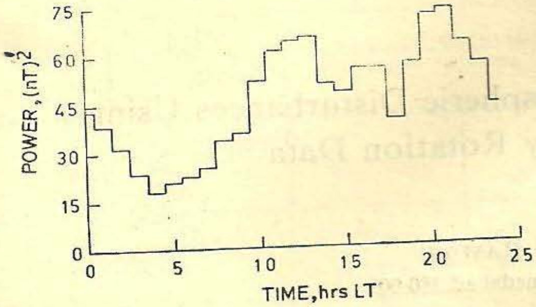

Fig. 2—Variation of power density of H at Alibag with local time.

Table 1. It is noticed from the results that 5- to 7-day period is observed in many of the samples of A_p series but not in the D_{st} series except for the set 1 Oct. 1975 - 31 Mar. 1976. It, thus, appears that the 5- to 7-day line is not entirely of magnetospheric origin.

Apart from the above periodicity, there exists a line in all the time-sets, for most of the parameters, corresponding to 4-day period. The presence of such a signal is examined in a spectrum of hourly values of the horizontal component at Alibag for the year 1959. For this, 24 spectra are computed by Blackman and Tuckey[17] approach for each of the UT hrs separately after subjecting the series to numerical filtration to eliminate longer period variations in excess of 7·2 days. All the hourly spectra uniformly show a peak corresponding to 4·5 days. The power density, P, related to the amplitude by $(2\sqrt{P})$ is shown as a function of local time in Fig. 2. The variation of power densities at different hours will be discussed elsewhere. The presence of a line at 4·5 days in the geomagnetic field at all the hours and nearly 4-day periodic variations in several of the parameters in Table 1 in different intervals of time for the years 1975 and 1977 confirms the reality of the existence of the signal. The origin of this signal, whether it is due to planetary wave or magnetospheric modulation, can be ascertained with certainty only by an analysis of ionospheric zonal wind data simultaneous with the geomagnetic and other parameters on a global scale.

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