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Rising and Decay Rates of Solar Quiet Daily Variation and Electrojet at Equatorial Region

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Abstract: The rates of rising and decay of solar quiet daily variation, Sq and equatorial electrojet, EEJ, strength at equatorial zone have been quantified and examined over a long term (1980-2000). A quantitative measurement of the rising and decay rates are proposed and used in the study. Estimated rates and their ratios are subjected to morphological and statistical analysis. The rising and decay rates exhibit day-to-day variability and traditional geomagnetic equinoctial maximum. The daily rates are solar controlled with Sq showing greater response to solar activity than EEJ. The rising rate is greater than decay rate for both current systems. Electromagnetic induction effect is expected to be greater during the rising of the currents. While EEJ builds faster than Sq, they both exhibit insignificant different decay rates. The cumulative mean values of (rising; decay) rates for the entire period are (10.49; 7.02) nT h^{-1} and (8.54; 7.09) nT h^{-1} for EEJ strength and Sq respectively. The diurnal rates demonstrate positive correlation with the ionospheric and existing Sq current /EEJ model parameters. The ratio of the rising rate to decay rate has an average value of 1.57±0.51nT h^{-1} for EEJ and 1.22±0.26 nT h^{-1} for WSq. The results indicate that the effect of local wind activity on the ionospheric dynamo process is more pronounced in the EEJ field than Sq.

Key words: Equatorial electrojet, ionospheric current, geomagnetic variations

INTRODUCTION

The existence of the ionosphere was first postulated as a means of explaining the observed geomagnetic field variations (Charmers, 1962). The study of the ionosphere has continued to attract significant attention due to its increasing application in communication technology. Geomagnetic observation has remained a veritable tool in understanding the state of the ionosphere. There have been tremendous advances in geomagnetic field studies since its inception. From mere object of investigation, geomagnetism has grown to become a proxy for space weather prediction.

Low latitude solar quiet daily variation, Sq and equatorial electrojet, EEJ have long been observed to exhibit diurnal variation which describes a steady rise in the morning to a maximum around local noon and then fall towards a night minimum (e.g., Gouin, 1962; Onwumechili, 1967). This variation has been ascribed to the augmentation of the field H in daytime in consistency with the atmospheric dynamo theory of the geomagnetic daily variations (Onwumechili and Ezema, 1977). The peak is not always centered on the local noon as the hour of maximum vary from one day to another (Brown and Williams, 1969; Arora, 1972 and Rigoti *et al*., 1999). The asymmetry in the diurnal pattern have been observed by several authors (Gouin, 1962 and Rigoti *et al*., 1999). Gouin (1962) attributed the asymmetry to lunar modulation. Onwumechili (1967) defined a quantitative measure of the asymmetry, A_s, of the diurnal variation of H and discovered that in a network of eight equatorial stations, the predominant type of quiet diurnal variation is the positive asymmetry.

It has equally been observed by Rigoti *et al.* (1999) that the rate of morning increase in the field amplitude is always greater than the rate of decay in the afternoon. However, there has not been a quantitative estimation of the rising rate and decay rate of Sq and equatorial electrojet. This work is a response to this gap.

Geomagnetic field variations at Abnormal Quiet Days (AQD) have been defined and studied by Brown and Williams (1969), Brown (1987) and Butcher (1987) among others. Arora *et al.* (1982) constructed EJ and CEJ indices for Indian region and evaluated the spectral characteristics of the associated geomagnetic field in the region. Alex *et al.* (1998) designated days characterised by small electrojet strength, $\leq$ 10 nT, as Abnormal Electrojet days (AEJ). Okeke *et al.* (1998) reviewed several aspects of the variabilities of geomagnetic field amplitudes at low latitudes that have

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been studied and employed a measure of day-to-day variability proposed by Onwumechili (1992) to study the variability of Sq at a fixed local time hour from one day to the next.

With increasing interest in modeling the geomagnetic observations (Richmond *et al.*, 1992; Onwumechili, 1997; Rigoti *et al.*, 1999; Doumouya *et al.*, 2003) it becomes necessary to examine every aspect of the variation field for accurate formulation and evaluation of model parameters. Richmond (1995) identified the need for further exploitation of observed geomagnetic phenomena to study possible long-term changes associated with a changing atmospheric state. In this study, we present for the first time the long-term quantitative analysis of the rising and decay rates of Sq and electrojet strength at equatorial zone, as well as their ratios. Then we attempt to study their variabilities and relationship with solar activity and ionospheric current parameters.

RESULTS

The data set consists of hourly values of H field for the years 1980 to 2000, obtained at two low latitude stations Ettaiyapuram ETT (dip lat. 2.1°N, geog. Lat. 9.2°N, long. 78.0°E) and Hyderabad HYB (dip lat. 9.3°N, geog. Lat. 17.4 °N, long. 78.6°E). With dip latitude 2.1 ETT is obviously an EEJ station and so a combination of WSq and EEJ field. HYB represents WSq station. The EEJ field is obtained by subtracting HYB hourly values from ETT values, that is H (ETT-HYB).

The solar indices were obtained via the website of National Geophysical Data Center (NGDC) http://www.ngdc.noaa.gov. The sunspot number R_Z and solar radio flux index F10.7 are well known traditional indices for atmospheric modeling. Only quiet condition was considered, we utilised the international quiet days for convenience.

The mean midnight level was removed from the hourly H values to obtain the hourly departures which were further corrected for non-cyclic variation effect after Matsushita (1967) to give the hourly profile of Sq(H). We define the rates of rising and decay of the diurnal amplitudes of the Sq and EEJ strengths as follows:

Rising rate $Rr = (A_{max} - A_{06}) / (LT_{max} - 06)$

Decay rate $Dr = (A_{max} - A_{18}) / (18 - LT_{max})$

Ratio ? = R_r / D_r

Where A_{max} is the maximum hourly value of Sq or EEJ; A_{06} is the value of Sq or EEJ at 0600 h LT; LT_{max} is the local time of occurrence of the maximum; A_{18} is the value of Sq or EEJ at 1800 h LT. 0600 h LT and 1800 h LT are taken as the sunrise and sunset hours at the neighborhood of observation. The ratio ? is a measure of the normalisation of the rates.

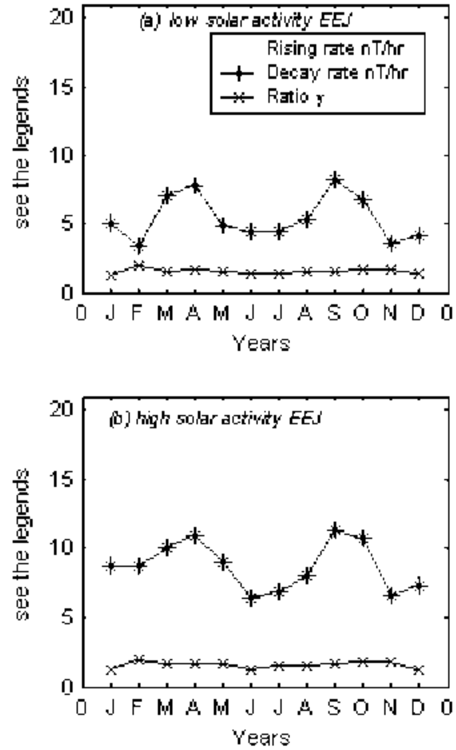


Fig. 1: Month to month variation of the diurnal rates of EEJ Strength and their ratios

Considering sunspot as the measure of solar activity, the years with sunspot number R≥90 have been classified as years of "high" solar activity, while those with R<90 are regarded as "low" solar activity period. Hence in this work high solar activity refers to the years 1980, 1981, 1982, 1988, 1989, 1990, 1991, 1992, 1999 and 2000 (R = 126.4±24.9, F10.7 =178.8±31.2), while low solar activity period includes 1983, 1984, 1985, 1986, 1987, 1993, 1994, 1995,1996,1997 and 1998 (R=33.6±20.8, F10.7 = 90.7±18.1).

Time scale variability of Rr, Dr and ?: Most of the daily profiles exhibit positive asymmetry. The rates of rising and decay are observed to vary in magnitudes from one quiet day to another. The month-to-month variations of mean R_r, D_r and ratio ? are presented in Fig. 1 and 2 for EEJ strength and WSq, respectively.
The data are grouped into three Llyod's seasons:

- Equinox (E-season): March, April, September and October.
- December solstice (winter or D-season): November, December, January and February.
- June solstice (summer or J-season): May, June, July and August.

Figure 3 presents the seasonal variation of Rr, Dr, ? in EEJ and WSq zones, respectively. Table 1 and 2 present the seasonal values of the rates Rr, Dr and ? under the two solar activity groups for EEJ and WSq

Table 1: Mean seasonal values of Rr, Dr and their ratios for EEJ

		Low solar activity			High solar activity		
		E	J	D	E	J	D
Rr	Mean	11.93	6.64	5.91	17.91	10.48	10.76
	St. dev	1.87	0.94	1.48	4.47	4.25	4.09
Dr	Mean	7.47	4.79	4.07	10.76	7.60	7.87
	St. dev	0.92	0.73	0.86	3.17	3.66	3.55
G	Mean	1.62	1.47	1.59	1.70	1.46	1.53
	St. dev	0.22	0.14	0.22	0.20	0.25	0.50

Table 2: Mean seasonal values of Rr, Dr and their ratios for WSq

		Low solar activity			High solar activity		
		E	J	D	E	J	D
Rr	Mean	7.58	7.10	5.12	11.97	11.15	8.90
	St. dev	0.82	0.69	0.51	1.95	1.64	1.32
Dr	Mean	6.41	6.39	4.74	9.01	9.45	6.92
	St. dev	0.71	0.81	0.68	0.86	1.24	1.13
G	Mean	1.19	1.12	1.09	1.35	1.21	1.33
	St. dev	0.10	0.08	0.08	0.12	0.17	0.13

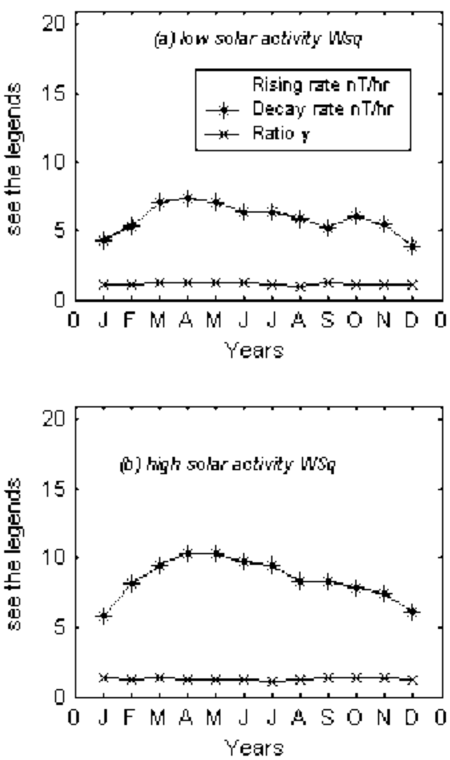


Fig. 2: Month to month variation of the diurnal rates of WSq and their ratios

respectively. During low solar activity both the rising and decay rates of EEJ strength as well as WSq exhibit equinoctial maximum and winter minimum. However, the ratio γ, which is a normalisation of the rates, has maximum in E-season and minimum in J season for EEJ; while the ratio γ of WSq has similar variation pattern with the rates.

Table 3: Mean values of Rr, Dr and their ratios for the entire period

	EEJ	WSq
Mean Rr	10.49	8.54
St.dev	5.66	3.12
Mean Dr	7.02	7.09
St. dev	3.70	2.35
Mean ?	1.56	1.21
St. dev	0.50	0.25

At high solar activity, the Rr, Dr and ratio ? of EEJ strength have equinoctial maximum and exhibit insignificant difference between their values for summer and winter. The rising rate Rr and ratio ? of WSq follows the same pattern of EEJ strength that is equinoctial maximum, while its decay rate reaches maximum in June solstice (summer). An obvious result is that the duo of the rising rate and the ratio ? demonstrate equinoctial maxima across the seasons throughout the epoch.

Table 3 shows the overall means of the parameters. The mean rising rate of EEJ strength (10.49 nT h^{-1}) is greater than that of WSq (8.54 nT h^{-1}). While the decay rate Dr of EEJ strength (7.02 nT h^{-1}) is insignificantly different from that of WSq (7.09 nT h^{-1}). This is quite expected as the additional electric field in the EEJ strip generates enhanced current in the region, which is responsible for the stronger intensity of EEJ. The electrojet strength builds faster, attains maximum values at earlier hours on most days, than the Sq and decays at a slower rate. This explains why the EEJ leads in Indian sector as rightly observed by Patil *et al.* (1990a) using harmonic representation.

Solar activity effects: The annual mean rates of rising and decay of Sq and EEJ strengths as well as their ratio γ along with the corresponding annual sunspot number

Table 4: Correlation coefficients between the rates, their ratios and solar indices

	EEJ			Wsq		
	Rr	*Dr*	γ	Rr	*Dr*	γ
Sunspot number R	0.767	0.684	0.158	0.967	0.974	0.691
F10.7 cm flux	0.746	0.642	0.250	0.964	0.967	0.693

Table 5: 1986 correlation coefficients between the rates, their ratios and current parameters I_F and J_o (at 12 h LT)

	EEJ			Wsq		
	Rr	*Dr*	γ	Rr	*Dr*	γ
I_F	0.601	0.710	-0.211	0.572	0.750	-0.177
J_o	0.586	0.770	-0.283	0.590	0.717	-0.140

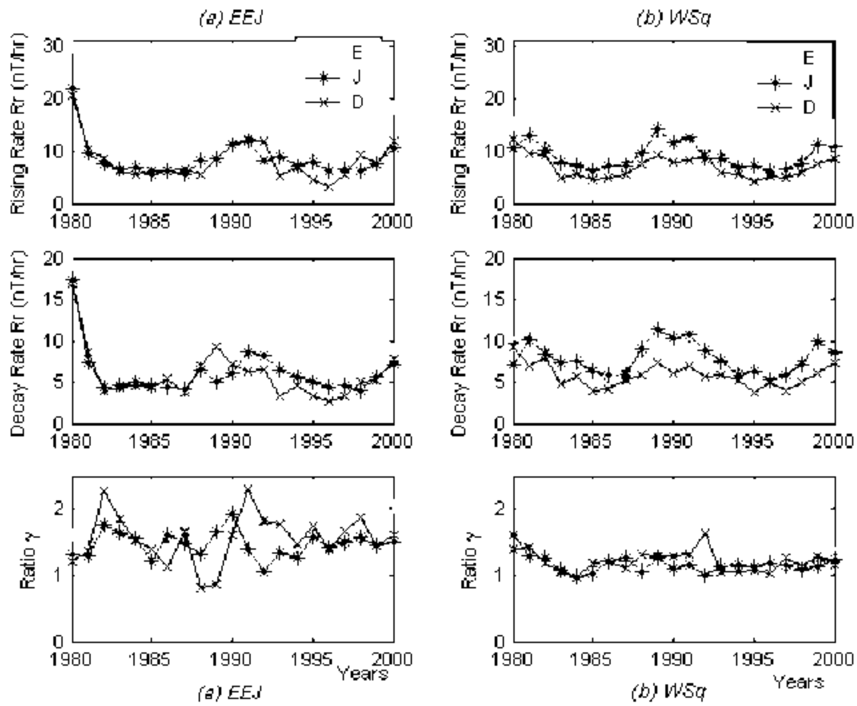
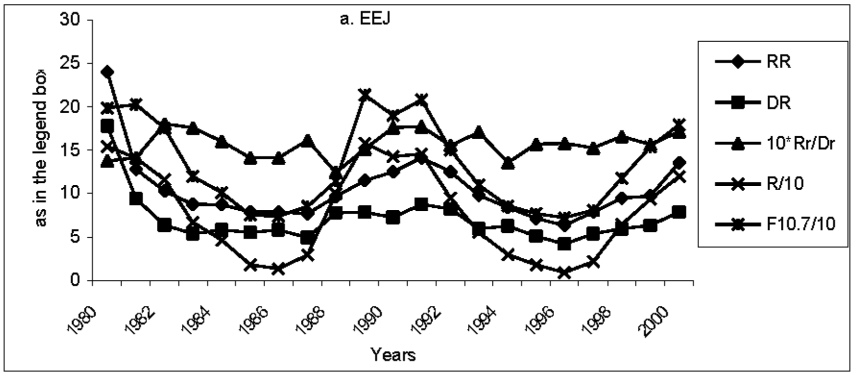


Fig. 3: Seasonal variation of Rr, Dr and γ of the (a) EEJ strength and (b) WSq

(R_z) and solar radio flux index (F10.7) are presented in Fig. 4. The correlation coefficients between the rates, their ratio, γ, sunspot number R_z and F10.7 are shown in Table 4. Positive and strong correlations exist between the rates and the pairs of solar indices Rz and F10.7 used. The rising rate of EEJ has stronger correlation with both solar indices, 0.767 with Rz and 0.746 with F10.7, while the decay rate has lower correlation coefficients of 0.685 and 0.643 with R_z and F10.7, respectively. Both the rising and decay rates of WSq exhibit strong correlation with solar indices. The rising rate of WSq is well correlated with the sunspot number (0.967) and solar radio flux F10.7 (0.947), while the decay rate has correlation coefficients of (0.974) and (0.967) with the sunspot number and solar F10.7 flux, respectively.

Ionospheric current effects: In a quest to ascertain the significance of the ratio ?, we proceed to consider the probability of relationship between the ionospheric current parameters and the ratio along with the rates of rising and decay. We chose the relevant data estimated from the Onwumechil (1966) continuous current distribution model and plotted as the forward current intensity I_F and current density J_o in Fig. 4 of Onwumechili *et al.* (1996) and Fig 4 of Oko *et al.* (1996) for WSq and EEJ, respectively. The values have been validated to be within the appropriate limits for Indian Sector (Onwumechili, 1997; Jadhav *et al.*, 2002a). The values of I_F and J_o obtained from these figures were correlated against the 1986 monthly means of R_r, D_r and γ (Table 5). We used 1986 data as the estimated parameters were for the year 1986.



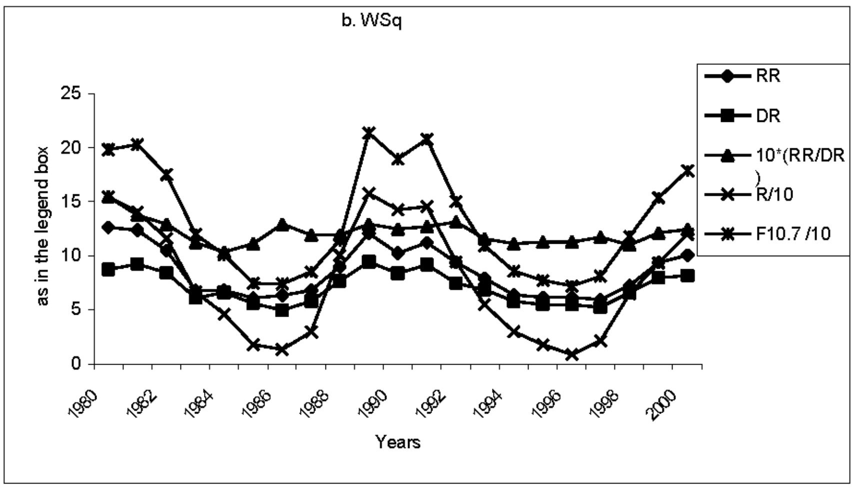


Fig. 4: Year to year variability of the rates and their ratio with solar indices

RESULTS AND DISCUSSION

The fact that the magnitudes of the rising rates of both the EEJ and the Sq are always greater than the decay rates implies that the ionospheric currents changes more rapidly at the rising period. It is obvious that the electromagnetic induction effect is expected to be greater during the rising of the currents. The rates of rising and decay of Sq and electrojet in equatorial zone show consistent seasonal variation and significant response to solar activity. It is a known fact that the variability in Sq and electrojet strength arises from the corresponding variability of the ionospheric currents responsible for them. Richmond (1995) gave a comprehensive review of the ionospheric wind dynamo and the effects of its coupling with different atmospheric regions.

Seasonal effects: The rising and decay rates of EEJ demonstrate equinoctial maximum, a hallmark of geomagnetic variation. Several authors have found strongest electrojet in equinoctial season (for example Onwumechili, 1997). Patil *et al.* (1990a,b) observed the equinoctial maxima at both low and high solar activity period in American and Indian sectors. Generally, the equinoctial maxima of geomagnetic phenomenon have been attributed to one or more of three models known respectively as axial, equinoctial and Russell-McPherron mechanisms (Russel and McPherron, 1973; Crooker and Siscoe, 1986; Clua de Gonzalez *et al.*, 1993; Orlando *et al.*, 1993; Chaman-Lal, 2000 and Clua de Gonzalez *et al.*, 2001).

Solar activity effects: As expected, throughout the epoch considered, the rates of rising and decay for both WSq and EEJ strength at high solar activity are greater than their corresponding values at low solar activity (Table 1 and 2). Patil *et al.* (1990a,b) have noticed that, in Indian sector, the magnitude of the peak in diurnal variations of both equatorial and non-equatorial stations is greater during high solar activity when compared with low solar activity. Patil *et al.* (1990b) estimated the ratios of the EEJ strength at high solar activity to low solar activity at Indian and American sectors and found a discrepancy between the values at the two sectors. They attributed the observed ratios at a

Table 6: Ratios of high to low solar activity values of EEJ rates of rising and decay compared with those of diurnal peak obtained by Patil *et al.*(1990b)

	Patil *et al.* (1990b) Ratio of peak diurnal value (1958-59)/(1964-65)	Rr high/low	Dr high/low
D	1.9	1.82	1.93
E	1.4	1.50	1.44
J	1.5	1.57	1.58
Total period	1.5	1.59	1.60

- Particular sector to the variation of wind system at different phases of solar activity and the magnitude of the induced currents especially those associated with additional equatorial electrojet. We compared the Patil *et al.*(1990b) ratio of EEJ strength for Indian sector with our own ratios of the diurnal rates at high to those at low solar activity, (Table 6). It is obvious that the ratios compared well with theirs and exhibits similar seasonal order with theirs; we therefore, favour their probable explanation for this observation.

Both the rising and decay rates of EEJ exhibits different response to solar activities when compare with corresponding rates in WSq field. It is interesting to note that despite the fact that the rising rate of WSq exhibits stronger correlation with solar activity than EEJ strength, the EEJ still rise faster and peaks ahead of Sq (Table 1-3). The correlation results on Table 4 gives a good picture of the differential response of WSq and EEJ field to different phases of solar activity.

The diurnal rates of the Sq and EEJ exhibit strong correlation with the solar activity as measured with the sunspot number and F10.7 indices. It is well known by now that the solar activity has strong influence on the ionospheric dynamo action through variations in both winds and electrical conductivity in the ionosphere. The fact that the correlation with solar indices of the diurnal rates of EEJ strength are less than those of WSq further suggests the presence of some other local causes peculiar to the strip.

Significance of ratio γ: The normalisation ratio γ for EEJ strength shows an obvious random low correlation with solar activity (Table 4). Combining this result with the poor negative correlation obtained between the ratio ? and the EEJ current parameters for Indian sector, it becomes obvious that the ionospheric current cannot account for the variability of this ratio and thus manifest its significance. Really the variability of this ratio is an evidence of the variability of strong local effect of regional winds in the equatorial zone. The wind contribution seems to be of more important in the EEJ region.

The control of the diurnal rates Rr and Dr by the diurnal variation of conductivity have been tested as follows. The daily magnitudes of Rr and Dr are solar controlled as evident in their strong correlation with solar indices on Table 4 and Fig. 4. For each day the magnitude of Rr is divided by the corresponding Dr, the factor of ionospheric current intensity cancels out. This ratio minimizes the effect of conductivity. The total electric field E' that drives Sq is given by E' = E + W x B. Where B is the ambient magnetic field, W is the wind velocity and WxB is the locally induced electric field. Okeke *et al.* (1998) argued that when the diurnal effects of the magnitudes of conductivity s and E are suppressed, the observed field variation must have arisen from WxB. The variabilities of the ratio with months and seasons are illustrated by Fig. 3 and 4 and Table 1 and 2. The ratio is supposed to be independent of ionospheric current and this is justified by its very poor correlation with the current parameters of both Sq and EEJ in Table 5. The obvious inference here is that the dominant cause of the variability of the ratio across the time scale is likely to be local and regional winds. The larger value and dispersion observed at EEJ section simply imply that this local factor has greater/prominent influence at EEJ zone more that WSq field. Okeke *et al.* (1998) interpreted the variability in the ratio of sequential variability to Sq at low latitude, which constitute a normalization that minimizes the solar control trends of the ionospheric conductivity and of the global Sq dynamo polarization electric field E, as a pointer to the presence of local and regional winds in the region. Jadhav *et al.* (2002a) suggested that besides conductivity, atmospheric tidal modes play important role in defining the zonal variability of the EEJ current system. The reduction in the solar control of the rising and decay rates of EEJ may be due to the greater impact of the random variations of these local and regional winds.

Macdougal (1979) had reported a local variability of dynamo region wind fields near the equator. Onwumechili (1985) has suggested the possibility of regional prevailing winds at electrojet altitudes. Hagan *et al.* (1997) observed non-migratory tides in the mesosphere and lower thermosphere which traverse dynamo region. More recently Jadhav *et al.* (2002) using Oersted satellite data suggested the presence of variable background winds or “non-migratory tides” at electrojet altitudes.

CONCLUSION

The results presented here show that:

* The rising rate of EEJ is of greater magnitude than that of WSq
* Electromagnetic induction effect is expected to be greater during the rising of the currents
* The rising rate of Sq and EEJ strength exhibits equinoctial maximum in any given epoch of solar activity.
* Sq and EEJ demonstrate differential response to solar activity. The rising rate of Sq and EEJ follows solar activity with stronger correlation existing in WSq.

There is an indication of the effect of wind activity on the ionospheric dynamo process being more pronounced at the EEJ field than Sq. Throughout the period considered the daily rising rate of Sq and EEJ strengths are greater than their corresponding decay rates by mean cumulative ratios of 1.22±0.26 and 1.57±0.50, respectively.

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