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LOCAL TIME DEPENDENCE OF IONOSPHERIC CURRENT CORRELATIONS IN LOW LATITUDES

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ABSTRACT

The study of the correlation of the daily ranges ΔH at all local time hours, at 7 stations close to the same longitude, has given more information on the correlation of ionospheric current intensities and their changes than is obtainable from daily ranges only. At night-time, the correlation coefficients of all pairs of stations are positive, very high and independent of the distance between the two correlating stations. They are attributed to magnetospheric sources. The correlation coefficients of two stations in the equatorial electrojet (EEJ) zone or two stations in the worldwide part of the Solar Quiet daily variation Sq (WSq) zone outside the influence of the EEJ are positive, very high and remain fairly steady for all hours of the day. In contrast, the correlation coefficient of a station in EEJ zone with a station in WSq zone is very high and steady at night-time but in daytime, it decreases drastically to low and ,mostly insignificant values. All the correlation coefficients between Jaipur and stations equatorward of it are unduly low. These results have been discussed and explained in terms of the following current systems: the EEJ current system occasionally modulated by the counter equatorial electrojet (CEJ) current system, and the WSq current system occasionally modulated by the single vortex current (SVC) system. The correlations involving Jaipur are unduly low because the ΔH from the SVC responsible for the low values is effective only in the region of about 12°–35° latitude.

Key words: **ionospheric currents, correlation coefficients, local time dependence.**

1 INTRODUCTION

There have been several studies of the correlations of ionospheric currents and their associated parameters. These have covered the equatorial, low, middle and high latitudes in many sectors of the earth. The studies include: Chapman and Stag (1929, 1931), Forbush and Casaverde (1961), Osborne (1964, 1966, 1968). Ogbuehi et al. (1967), Onwumechili and Ogbuehi (1967), Schlapp (1968), Greener and Schlapp (1979), Mac Dougall (1969), Burrows (1970), Kane (1971a). Hibberd (1981, 1985), Briggs (1984), Schlapp and Mann (1983), Brown and Butcher (1981), Butcher and Brown (1980, 1981), Mann and Schlapp, (1985, 1987, 1988), Hibberd and Davidson (1988), Schlapp, Mann and Butcher (1988), Phillips and Briggs (1991), and Butcher (1982a,b). These papers have been reviewed in Onwumechili (1997) sections 8.5, 8.6 and 8.12.

Practically all these studies are based on geomagnetic daily ranges or parameters derived from them. But the daily range gives only the picture around local noon period of about 1100 to 1300 L.T and is not necessarily consistent for the same hour everyday. Information on the correlations for other hours of the day is therefore missing.None of the above is the correlation of current intensity for several hours of the day.On the other hand, the study of fluctuations of current intensity by Onwumechili and Ogbuehi (1962) suggests that the correlations of ionospheric current intensities could possibly depend on local time. For full information, it has become necessary to study the correlations for all hours of the day. Consequently, the objective of this paper is to report the study of the local time dependence of the correlations of ionospheric current intensity at low latitudes.

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2 PRESENTATION OF DATA AND RESULTS

Studies of ionospheric currents are normally based on the observational data of their magnetic fields or on parameters derived from the fields. Here we use the horizontal component H of the geomagnetic solar quiet daily variation Sq. Sampath and Sastry (1979) have demonstrated that Sq(H) is linearly related to ionospheric current intensity measured directly *in situ* with rockets.

Our Sq (H) data were recorded at the 8 observatories whose coordinates are given in Table 1 where δ is the actual latitudinal distance measured from the magnetic dip equator. All the 124 quiet days of 1986 with $Ap \leq 6$ whose H data were available at 6 of the stations were used in the study. The data were corrected for storm time variation (Dst) using Sugiura and Kamei (1991). Each day was also corrected for non-cylic change (Onwumechili 1997, p. 256).

Table 1. Coordinates of the observatories.

Code	Observatory	Geographic		Dip Latitude		Geomagnetic	
		Latitude DegreeN	Longitude DegreeE	δ DegreeN	$L=\tan^{-1}Z/2H$ DegreeN	Latitude DegreeN	Longitude DegreeE
	Dip Equator	8.09	76.82	0.00	0.00	-1.5	147.5
1.	Trivandrum	8.29	76.57	0.20	0.20	-1.2	146.4
2.	Kodaikanal	10.23	77.47	2.14	2.15	0.6	147.1
3.	Annamalainagar	11.36	79.68	3.28	3.44	1.4	149.4
4.	Hyderabad	17.42	78.55	9.33	11.22	7.8	148.9
5.	Alibag	18.63	72.87	10.54	13.26	9.5	143.6
6.	Ujjain	23.18	75.78	15.09	18.55	13.5	147.0
7.	Jaipur	26.92	75.80	18.83	22.81	17.3	147.4
8.	Sabhawala	30.37	77.80	22.28	27.26	28.8	149.8

Thereafter, the mean of the first and last hourly values was subtracted from every hourly value for the day. Consequently, the first and the last hourly values of the out come for the day were reduced to virtually zero. In effect, the resulting sequence of 24 hourly departures ΔH_t for $t = 1$ to 24, were based on the midnight average values of virtually zero. If as a result of rounding up the value for $t = 1$ and 24 hr is up to 0.1 nT, that value is again subtracted from all the 24 values to make the final values for $t = 1$ and 24hr equal to zero.

The final sequence of 24 values of ΔH_t for $t = 1$ to 24 (with $\Delta H_1 = 0 = \Delta H_{24}$.) for each of the 124 days are then correlated for two chosen stations, covering all the combinations of the 6 stations. The station codes are: 1 Trivandrum (TRI), 2 Kodaikanal (KOD), 3 Annamalainagar (ANA), 4 Hyderabad (HYD), 5 Alibag (ALI), 6 Ujjain (UJA), 7 Jaipur (JAP) and 8 Sabhawala (SAB). For convenience, we refer to the stations: TRI, KOD and ANA in equatorial electrojet (EEJ) zone as E stations; and refer to the low latitude stations: HYD, ALI, UJA, JAP and SAB in the worldwide part of Sq (WSq) zone as L stations. Our L stations are taken to be in low latitudes but outside the influence of the equatorial electrojet.

To limit the effect of abnormal phase quiet days (APQDs) that spreads from midlatitudes towards the equator, (Onwumechili 1997 p. 540) Sabhawala station was not included in the correlations. Ujjain was not fully used because of unavailable data. The remaining 15 full correlation coefficients for all the 124 days are given in Table 2 for $t = 2$ to 23 hr. The hours $t = 1$ and 24 are omitted because ΔH_1 and ΔH_{24} are identically zero. The ordinal codes of the stations in the preceding paragraph are used in Table 2 such that R27 refers to the correlation coefficient between the data of Kodaikanal and Jaipur. For convenience, the correlation coefficients Rmn in the Table 2 are multiplied by 100. N. M. = night-time mean, S. D. = sample standard deviation and D.M. = daytime mean. To provide three correlation coefficients between Alibag and L stations, the correlation coefficient [illegible] is included inTable 2 even though its count is limited to 78 because of some unavailable data at Ujjain station. The count is 124 for all other Rmn

Some selected correlation coefficients are shown in Figs. 1 and 2. Fig. 1 shows basically the correlation coefficients among the three E stations of Trivandrum, Kodaikanal and Annamalainagar together with the correlation coefficients of Trivandrum with the three L stations of Hyderabad, Alibag and Jaipur outside the influence of the EEJ. Fig. 2 shows simply the correlation of the L station of Alibag with the three E stations of Trivandrum, Kodaikanal and Anamalainagar, and with three L stations of Hyderabad, Ujjain and Jaipur.

The remarkable features of the results are as follows. The correlation coefficients between any two E stations or between any two L stations are positive, very high and highly significant in both daytime and night-time. But when an E station is correlated with an L station: (a) the correlation coefficients are positive, very high and highly significant in night-time; but (b) on the contrary the correlation coefficients are unusually low and mostly not significant at daytime. Indeed, a few of the correlation coefficients become slightly negative in daytime. Consequently, the diurnal variation of the correlation coefficient between an E and an L station exhibits a drastic fall from a steady high in night-time to a deep trough in daytime. The above results are supported by those correlation coefficients in Table 2 which are not plotted in figs. 1 and 2.

Table 2. Hourly correlation coefficients Rmn between station m and station n. See text.

Hour	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	R12	R13	R14	R15	R17	R23	R24	R25	R27	R34	R35	R37	R45	R47	R56
1															
2	89	88	86	79	74	89	87	83	77	93	82	80	81	80	82
3	95	93	91	94	90	95	92	96	94	94	96	94	95	94	88
4	95	93	91	93	84	96	94	96	87	95	97	89	96	90	91
5	94	92	92	94	81	94	94	95	84	93	95	85	97	86	90
6	79	86	75	89	80	79	71	81	76	79	91	83	84	83	80
7	81	80	57	65	51	81	61	67	58	77	81	62	83	81	79
8	85	70	37	38	10	73	45	45	15	58	53	25	89	70	81
9	90	77	27	20	-22	85	37	26	-17	56	42	-5	89	50	77
10	94	87	39	28	-16	91	50	36	-12	65	51	0.1	89	44	80
11	94	86	37	30	9	91	46	36	11	63	53	26	89	59	91
12	94	81	33	22	18	87	43	32	23	65	56	36	90	66	93
13	93	78	26	15	10	85	37	27	14	60	51	25	88	64	89
14	92	80	29	17	6	86	39	25	10	59	50	23	89	66	89
15	94	81	38	24	11	89	47	34	19	60	53	30	81	67	87
16	93	80	42	30	11	88	54	43	20	70	62	38	91	74	88
17	91	82	55	44	33	87	67	58	43	81	74	57	92	75	86
18	87	87	75	72	66	87	77	76	72	89	87	82	94	89	86
19	86	90	84	88	76	86	82	85	73	91	93	81	94	80	89
20	90	89	82	87	73	91	87	89	74	91	94	79	90	75	90
21	93	92	86	92	74	94	90	94	76	90	95	76	94	74	95
22	89	88	82	89	70	90	87	91	73	90	94	77	93	74	95
23	85	80	72	85	58	83	76	86	65	82	88	64	86	62	85
24															
N.M.	89	89	83	87	75	89	85	88	77	90	92	81	91	81	88
S.D.	5	4	7	7	9	5	8	7	8	5	5	8	5	9	5
D.M.	92	80	34	25	4	86	44	34	9	62	52	22	88	62	86
S.D.	3	5	6	7	14	5	6	7	14	4	5	15	3	10	5

3. DISCUSSION OF THE RESULTS

3.1 Comparison of Daytime with Night-time Correlation Coefficients

All the rocket flights up to March 1973 failed to detect any ionospheric currents earlier than 0800 and later than 1600 L.T. (Onwumechili 1997 section 2.5). The experience of the POGO satellites was very similar (Cain and Sweeney 1972). For the purpose of ionospheric currents, we have therefore adopted 0800-1600 L.T. as daytime and 1800-0600 L.T. as night-time, leaving out 0700 and 1700 L.T. as transition hours.

For the comparison of daytime and night-time correlation coefficients, Fig.3 shows the average and sample standard deviations in the two periods for the correlation coefficients plotted and in the order they are plotted in Figs. 1 and 2. It is seen that: (i) For the correlation of the E stations among themselves (R12, R13 and R23), and of the L station of Alibag with three other L stations (R45, R56 and R57), there is no significant difference between the daytime and night-time correlation coefficients. (ii) For the correlation of an E station with an L station (R14, R15, R17, R25 and R35), the differences between daytime and night-time correlation coefficients are very significant. We attempt to explain this result in section 3.4.

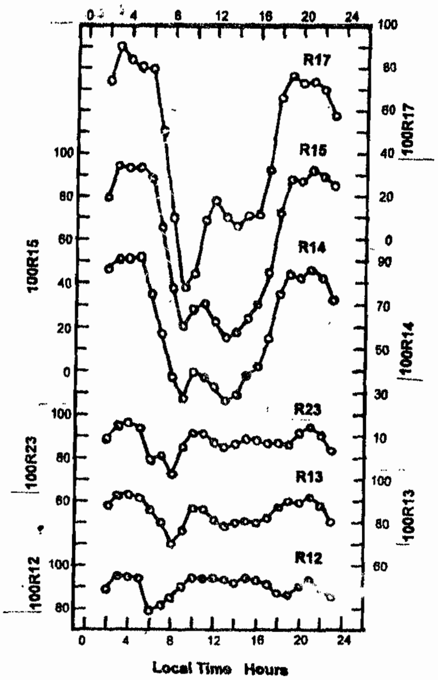

Fig. 1

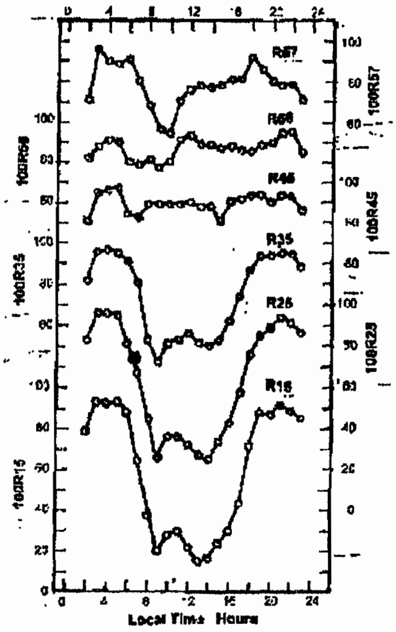

Fig. 2

Fig.1. The diurnal variation of selected correlation coefficients Rmn between station m and station n. The stations: 1 Trivandrum, 2 Kodaikanal, 3 Annamalainagar, 4 Hyderabad, 5 Alibag, 6 Ujjain and 7 Jaipur are combined two at a time. The correlation coefficients are multiplied by 100.

Fig.2. The diurnal variation of the correlation coefficients between Alibag and 6 other stations. The Correlation coefficients Rmn between station m and station n refer to the stations: 1 Trivandrum, 2 Kodaikanal, 3 Annamalainagar, 4 Hyderabad, 5 Alibag, 6 Ujjain and 7 Jaipur. The correlation coefficients are multiplied by 100.

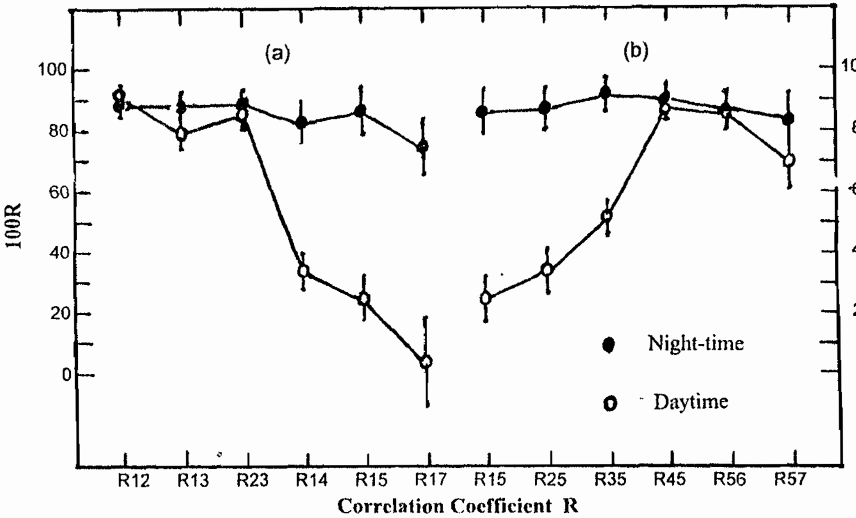

Fig.3. Comparison of the average correlation coefficients in daytime (0800 to 1600 L.T.) with the average correlation coefficients in night-time (1800 to 0600 L.T.) for the correlation coefficients plotted (a) in fig. 1 and (b) in Fig.2; and in the order they are plotted in the two figures.

3.2 Dependence of Correlation Coefficients on Distance Between Two Correlating Stations

It is not surprising that Chapman and Stagg (1929, 1931) found that the correlation coefficients decreased as the distance between the two stations increased. This was clearly demonstrated later by Schlapp (1968) who further found that the decrease was anisotropic, being faster in latitude than in longitude. He states that the correlation coefficient decreases to 0.5 for separation of about 15° in latitude and about 40° in longitude. Here the largest separation is 18.63° in latitude between Trivandrum and Jaipur and 6.81° in longitude between Annamalainagar and Alibag. We are therefore mainly concerned with the effect of separation in latitude of our correlation coefficients.

For night-time, the effect of separation on correlation coefficients among E stations may be judged from:
R12:R23:R13 = 89:89:89 on the average but
R12:R23:R13 = 95:96:93 at 0400 L.T. and
R12:R23:R13 = 90:91:89 at 2000 L.T.

While for night-time the separation effect on correlation coefficients among L stations may be judged from:
R45:R46:R47 = 91:83:81 on the average but
R45:R46:R47 = 96:89:90 at 0400 L.T. and
R45:R46:R47 = 90:85:75 at 2000 L.T.

It is seen that at night the separation effect on correlations among E stations and among L stations is negligible even for R47 which involves a separation of 9.5° in latitude and 2.75° in longitude between Hyderabad and Jaipur.

We now compare the above with the separation effects in daytime.
For E stations: R12:R23:R13 = 92:86:80 on the average but
R12:R23:R13 = 94:91:87 at 1000 L.T. and
R12:R23:R13 = 92:86:80 at 1400 L.T
For L stations: R45:R46:R47 = 88:79:62 on the average but
R45:R46:R47 = 89:[illegible]6:41 at 1000 L.T. and
R45:R46:R47 = 89:83:66 at 1400 L.T.

The effect from E stations is negligible probably because their separations are small. The largest separation for R13 is 3.08° in latitude and 3.11° in longitude between Trivandrum and Annamalainagar. On the other hand the effect on L stations is considerable and is comparable to the effect found by Schlapp (1968).

We now turn to the correlation of an E station with an L station. Here the effect of separation at night may be judged from
R14:R15:R16:R17 = 83:87:85:75 on the average but
R14:R15:R16:R17 = 91:93:92:84 at 0400 L.T. and
R14:R15:R16:R17 = 82:87:86:73 at 2000 L.T.

Again, this effect is negligible at night. But because the distance between Ujjain and Jaipur is only 3.74° in latitude and 0.02° in longitude, we note on comparing R16 with R17 that R17, involving Jaipur is much lower than expected from the rest. But even the value of R17 implies a much smaller decrease than about 0.5 expected from Schlapp (1968) because the distance from Trivandrum to Jaipur is 18.63° in latitude and 0.77° in longitude. Therefore the assertion of a negligible decrease rate at night stands.

We now study the correlation of E-L pairs of stations in daytime from
R14:R15:R16:R17 = 34:25:24:4 on the average but
R14:R15:R16:R17 = 39:28:10:-16 at 1000 L.T. and
R14:R15:R16:R17 = 29:17:22:6 at 1400 L.T.

This represents a drastic collapse from the night-time values and not a mere decrease. The latitudinal separations for R14,R15,R16 and R17 are 9.13°, 10.34°, 14.89° and 18.63° respectively. None of the separations can account for the extent of the low correlation coefficients. A more powerful second factor than the distance separating the two stations is in operation. Again, considering the sequence of these low values, the R17 involving Jaipur is lower than would be expected from the sequence.

We may summarize section 3.2 as follows. Irrespective of whether the correlation is between E-E pair, L-L pair or E-L pair of stations, the effect of the distance separating them is negligible at night-time. In daytime, the effect of the distance separating the L-L correlating pair of stations is to reduce their correlation coefficient to an extent comparable with the result of Schlapp (1968). But here, the effect of the distance separating E-E pair of stations in daytime is negligible probably because of the small distances separating them in our cases. For E-L pairs of stations, there is evidence that an entirely different local factor makes the correlations involving Jaipur to be lower than expected even after taking the separation and other factors into account.

In daytime, in general, a second factor probably stronger than the effect of the distance separating E-L pairs of stations, drastically reduces their correlation well below the expectation from their separation. In addition to the evidences already adduced, we note that Kodaikanal and Jaipur are at about the same distance from Alibag. From Alibag to Kodaikanal is 8.4° in latitude and 4.6° in longitude while Alibag to Jaipur is 8.3° in latitude and 2.9° in longitude. But their correlation coefficients R25 and R57 respectively with Alibag give:

R25: R57 = 34:70 on the average but
R25:R57 = 36:54 at 1000 L.T. and
R25:R57 = 25:72 at 1400 L.T.

Thus even though the Jaipur local factor makes R57 lower than it would have been, the stronger second factor has reduced R25 to about half of R57 in spite of their distances of separation being equal.

3.3 The local Factor at Jaipur Observatory

A comparison of the diurnal profile of Sq(H) at Jaipur with that at the other stations reveals the effect of the Jaipur local factor. On most of the days, the diurnal profile at Jaipur is regular and compares favourably with the other stations. But sometimes the Jaipur profile is modulated by depression for several hours. Usually, the noticeable depressions occasionally occur: (a) at about 0800 to 1000 L.T. pushing the daily maximum to the afternoon, (b) at about 1100 to 1300 L.T. pushing the diurnal maximum to early morning or evening and (c) at about 1300 to 1500 L.T. pushing the daily maximum to the forenoon. From time to time the period of the depression extends to more hours.

It is these depressions which are out of tune with the stations equatorward of Jaipur that cause the unduly low correlation coefficients when Jaipur is correlated with these other stations. However, these depressions invariably also occur and are even larger at Sabhawala, poleward of Jaipur. When the depression is large at Jaipur it may also extend to Ujjain but usually to a lesser degree. Some permanent imperfection at Jaipur observatory may be considered as the cause of the depressions. But it cannot be anomalous electrical conductivity of the earth because the effect is not permanent but occasional and it affects certain local time hours more than others. Can't it be the effect of imperfect temperature compensation of the recording equipment at Jaipur? This suggestion must be rejected because the effect is also observed simultaneously at the next poleward station of Sabhawala and sometimes also at the next equatorward station of Ujjain.

Fig. 4 illustrates the depression on the international quiet day of 30 April 1986, Ap = 5. On this day, Sq (H) at Jaipur and Sabhawala is depressed below zero for most hours of the day. But the particular depression is from about 0800 to about 1100 L.T., and the daily maximum is pushed to 1400 L.T. Such modulations of the Sq(H) profile at a station near the Sq focus can be caused by movements of the focus. As the Sq focus moves northwards and southwards, the Sq(H) profile at a station near the focus is variously modulated from day to day.

Butcher and Brown (1980, 1981) and Butcher (1982 b, c) found that the movement of Sq focus is caused by the supperposed magnetic field (SPMF). When an abnormal phase Sq(H) occurs at a midlatitude station in the northern hemisphere such as Hartland, it arises from a superposed northward magnetic field (SPNMF). In the northern hemisphere this reduces the amplitude of the Sq(H) poleward of the Sq focus and increases it equatorward of the Sq focus. Consequently, the northern Sq focus moves northwards. In the southern hemisphere at the same time, the Sq(H) amplitude is reduced equatorward of the southern Sq focus and is increased poleward of that focus. Consequently the southern Sq focus also moves northward. When a superposed southward magnetic field (SPSMF) occurs over the southern hemisphere, it causes an abnormal phase quiet day (APQD) at a southern midlatitude station like Hermanus. The changes above are all reversed. Depending on the season, the SPMF is maximum between 35° - 55° latitude and tends to zero at about less than 12° latitude and greater than 65° latitude.

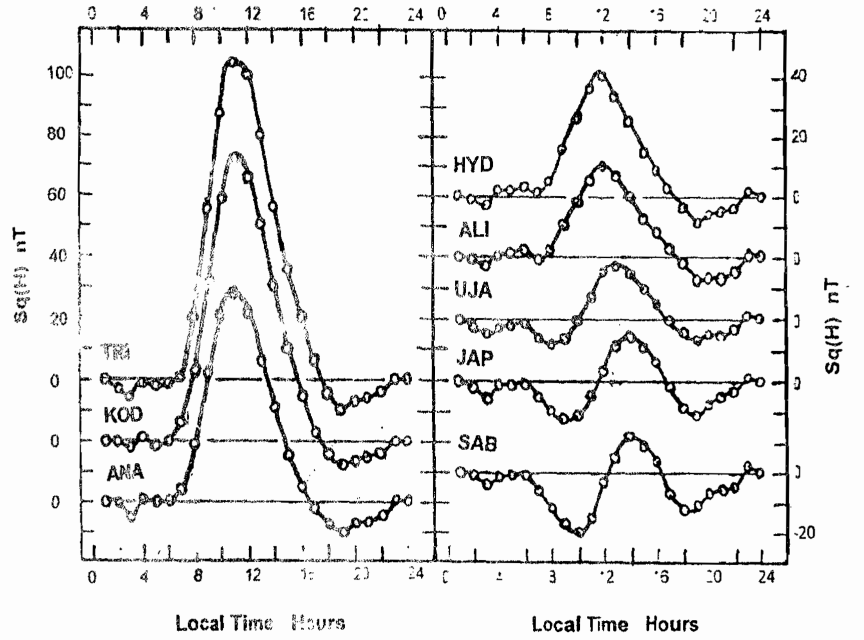

Fig.4.: The diurnal variations of Sq(H) at Trivandrum (TRI), Kodailanal (KOD), Annamalainagar (ANA), Hyderabad (HYD), Alibag (ALI), Ujjain (UJA), Jaipur (JAP) and Sabhawala (SAB) on the international quiet day of 30 April 1986, Ap = 5.

Butcher (1982a, 1987) and Schlapp et al. (1988) have discussed the single vortex current (SVC) system believed to produce the SPMF. Fig 5 shows the SVC with its single focus at the equator. Its east-west component is effective only in the range of about 14° - 60° latitude. It is the SPMF produced by the SVC that modulates the diurnal profile of Sq(H) at Jaipur and Sabhawala and impairs the correlation with Jaipur on quiet days that may be APQDs at northern or southern midlatitude stations. As seen in Fig.4 and in first paragraph of section 3.3, such days are also most likely to be APQDs at Jaipur and Sabhawala.

We recall that representation of Sq as a function of latitude is difficult because none of geographic, geomagnetic or dip latitude is ideal (Onwumechili 1964). Therefore, we cannot place a definite limit on which of our stations here can be affected by SPMF and SVC. However, our results here raise doubts as to whether Jaipur and Sabhawala are sufficiently low latitude stations to merit the label of L station for the purpose of the current study. We observe that in this sector, the lower latitudinal limit of SPMF and SVC accord better with geomagnetic and dip (δ) latitudes than with mean and geographic latitudes.

3.4 Explanations of the Major Features of the Results.

The special local factor that makes the correlation of Jaipur with some other stations equatorward of it unduly low has already been explained in section 3.3. We now attempt the explanations of: (a) the night-time correlation coefficients of all pairs of stations; (b) the decrease of the daytime correlation coefficients of any pair of stations as the distance of their separation increases; (c) the drastic fall of daytime correlation coefficients between E-L pairs of stations and (d) the lack of significant difference between the daytime and night-time correlation coefficients of any E-E pair or L-L pair of stations.

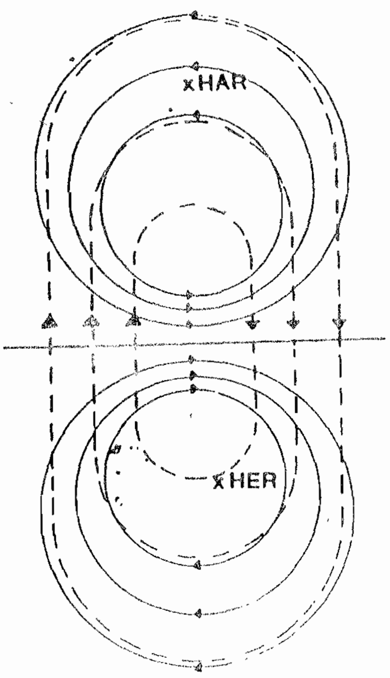

Fig 5.

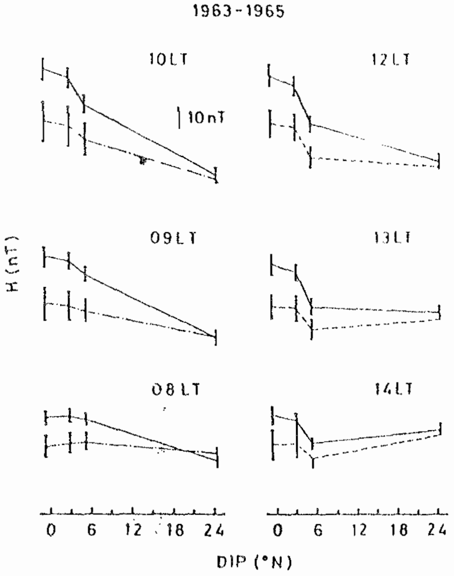

Fig 6.

Fig.5. Relation of the single vortex current system (broken curves) to the normal Sq double vortex current system (solid curves). The approximate positions of the staions Hartland and Hermanus are also shown. (After Schlapp et.al. 1988).

Fig.6. Mean latitudinal profiles of the H field in Indian equatorial region at selected local times against the magnetic dip angle of the stations on international quiet days when the daily maximum of H at Trivandrum occurred in the intervals: 0930-1030 (------), 1030-1130 (———), and 1130-1230 LT (-.-.-.-) during the years (1963-1965) of low solar activity. The difference between the solid and the broken profiles is the magnetic field (SPMF) superposed of the normal phase quiet days when the maximum is at 1030-1130 to create the abnormal phase quiet days of the broken profiles. The vertical bars represent 99 percent confidence intervals of the mean values. (After Sastri 1982).

3.4.1 Night-time correlation coefficients of all pairs of stations.

Olsen (1970a,b, 1974) suggested that magnetospheric currents contribute significantly day and night to the regular geomagnetic variations on the earths surface. He estimated this at 20% of the contributions of ionspheric currents to Sq. Using exceptionally quiet days, Mayaud (1976) studied nigh-time variations. He could not detect the regular variations of Olsen (1970b) but he found irregular variations which he ascribed to solar wind variations. Compared with daytime, variations at night are slow but their level changes from day to day. These field levels have been studied by Campbell (1973), who attributed them to magnetospheric currents. Later, Campbell (1979) found that the night-time slow variations and changes in their level from magnetospheric sources persist even on specially selected 37 quietest days of the solar activity minimum year of 1965. Some other field changes at night have also been attributed to magnetospheric causes by: Sarabhai and Nair (1969), Hutton (1970), Kane (1971 b,c,) Matsushita (1971) and Onwumechili and Ezema (1977).

On the other hand, Takeda and Araki (1985) calculate that ionospheric currents flow at night, most likely in F-region, and could contribute 10% of Sq at solar activity maximum period. However, other calculations suggest that this is doubtful. Rishbeth (1971) estimates that the F-region dynamo currents, both by day and by night, produce a ground-level magnetic fields of about 1 nT, which is negligible. In a comprehensive study of the night-time variations of H at Trivandrum, Annamalainagar, Alibag, Tatuoca, Addis Ababa, Dallas, Fuquene, Fredricksburg. Honolulu, Paramaribo, Huancayo, Pilar, Sitka, San Juan, Tucson, Trelew and Victoria, Stening and Winch (1987) clearly depicted the general decrease and slow variations of H at night. But their calculations with an upper limit on the possible night-time electron density gives ionospheric current intensity from E-region only about 1/40 of the typical Sq daytime solar activity minimum values and from F-region only about 1/400 of that typical Sq daytime value. These being so small, they discussed the night-time variations in terms of magnetospheric sources.

Finally, we mention important observations suggesting that the cause of night-time geomagnetic variations is magnetospheric and not ionospheric currents. Rockets and POGO statellites failed to detect unambiguous evidence of ionospheric currents from 1700 to 0700 L.T. Secondly, the ATS 1 satellite at the height of 6 earth radii observed the nigh-time general decrease and variations of H (Sarabhai and Nair 1969). The field of ionospheric currents should not be detectable at such a distance.

Thus, the geomagnetic variations at night correlated here are widely believed to arise from magnetospheric sources even on quiet days. Consequently, all the stations are affected similarly at the same time. That explains why the night-time correlation coefficients of all the pairs of stations are positive, very high and independent of the distance separating the correlating stations.

3.4.2 Dependence of daytime correlation coefficient on the distance between two stations.

It is easy to explain the dependence of the daytime correlation coefficients on the distance separating the two stations. In daytime, ionospheric currents flow and generate the daytime geomagnetic variations being correlated. The intensity of the ionospheric currents depends on electric field and electrical conductivity in the ionosphere. It therefore depends on the wind velocity $\underline{W}$, the ambient magnetic field B, the dip angle I, the plasma density N, the gyrofrequency ω, the collision frequency ν, the temperature T and the height h. These parameters are location specific. The greater the distance separating two stations, the more the parameters are likely to be different at the two stations. Consequently, the current intensity and the magnetic variations differ at the two stations. This accounts for the decrease of the daytime correlation coefficients between two stations as the distance separating them increases.

3.4.3 Drastic fall of daytime correlation coefficients between E- L pairs of stations

It is logical to next explain the drastic fall of the daytime correlation coefficients between E-L pairs of stations. For this purpose, it is best to first recall the various current systems at play in the region of our interest. The comprehensive study of rocket measurements of ionospheric currents (Onwumechili 1992a, b, c, d, e) show that the rockets found one ionospheric current layer at latitudes far from the dip equator. But they found mostly two current layers near the dip equator, the upper layer being the continuation of the single layer far from the dip equator. Because of its global spread, the upper current layer is called the worldwide part of the Sq (WSq) current systems. The lower current layer near the dip equator fits the characteristics of the equatorial electrojet and is therefore called the equatorial electrojet (EEJ) part of the Sq current systems.

Section 3.3 has discussed how the SVC (current) system produces SPMF and modulates the WSq on abnormal phase quiet days (APQDs). But the horizontal component of the SPMF is limited to about 12° ÷ 65° latitude. We shall call this latitude range the subtropical and midlatitude zones. On the other hand, Sastri (1982) finds that a current system with the same characteristics as the counter equatorial electrojet (CEJ) produces SPMF and modulates the EEJ on APQDs in that region. When the modulating current system and its SPMF are sufficiently strong the entire EEJ is reversed and we have a full CEJ. Here, we shall refer to the general modulating current system in this region as the counter electrojet (CEJ) current system. But the horizontal component of the SPMF from the CEJ current system is limited to about 0° ÷ 11° dip latitude δ (Sastri 1982). We shall call this latitude range the equatorial and low latitude zones.

In fig.6, Sastri (1982) demonstrates this latitude limitation. In that fig.6 the difference between the solid and broken curves is the SPMF. It is important to note that an APQD in the equatorial and low latitude zones is not an APQD in the sub-tropical and midlatitude zones and conversely.

We may now attempt the explanation. In daytime, the L stations of Hyderabad, Alibag and Jaipur are always under the influence of the WSq current system. Occasionally, Jaipur is in addition under the influence of the SVC system when an APQD occurs in the sub-tropical and midlatitude zones. On the other hand, in daytime, the E stations of Trivandrum, Kodaikanal and Annamalainagar are always under the influences of the WSq (upper) current layer and the EEJ (lower) current layer. Occasionally, they are in addition under the influence of the CEJ current system when an APQD occurs in the equatorial and low latitude zones.

For a start let us consider only the regular current systems of EEJ and WSq and ignore the modulating systems of CEJ and SVC. Because the EEJ and WSq flow at different heights, the parameters W, B, I, N, ω, v, T and h controlling their intensities are different. Consequently, their intensities and changes of their intensities do not often correlate. But the correlation coefficient of E-L pair of stations is not necessarily zero because the E station is also under the influence of the WSq currents. Accordingly, the correlation coefficient between E-L pair of stations falls drastically below the night-time value. See R14 in fig. 3a between TRI and HYD and R35 in Fig.3b between ANA and ALI.

As the distance between the two stations increases, substantial differences develop between the parameters and intensities of the WSq above the L station and the WSq above the E station and the correlation coefficient falls further. An example is R15 in Fig.3a and also R25 and R15 in fig.3b. If the SVC modulates the WSq above the L station, like Jaipur, the correlation coefficient decreases even further because the SVC does not extend to the WSq above the E station. R17 in fig.3a between TRI and Jaipur exemplifies such a case. If the CEJ modulates the EEJ above an E station, like Trivandrum, the effect will be similar because the CEJ current does not extend to Jaipur.

3.4.4 Daytime and nigh-time E-E and L- L correlation coefficients.

We first consider R12, R23 and R13 in Fig.3a for E-E pairs of stations. In daytime the stations are under the same EEJ plus the WSq current systems. Therefore, the correlation coefficients are positive and very high. The distance of 3.08° of latitude and 3.11° of longitude between TRI and ANA for R13 is the greatest among the three pairs. Accordingly the greatest difference between daytime and night-time correlation coefficients is for R13, but the distance is too small to make a significant difference. Therefore, none of R12, R23 and R13 shows a significant difference between daytime and night-time.

Similarly, the L-L pairs of stations for R45, R56 and R57 are all under the same WSq current system in daytime. The distances between the station pairs are 1.21° of latitude and 5.68° of longitude for R45, 4.55° of latitude and 2.91° of longitude for R56 and 8.29° of latitude and 2.93° of longitude for R57. It is seen from Table 2 and Fig.3a that their differences between daytime and night-time correlation coefficients are consistent with their distances apart. In particular the greatest distance apart for R57 accords with the greatest difference, but even this difference is not statistically significant. Therefore, none of R45, R56 and R57 shows significant difference between daytime and night-time. From this section it becomes clear that the decrease of daytime correlation coefficient caused by the distance apart of E-E and L-L station pairs is not as important as the decrease caused by EEJ in cases of E-L pairs of stations.

4. CONCLUSIONS

The investigation of the correlation of ΔH for all local time hours of the day has given more information on the correlation of ionospheric current intensities and their changes than is obtained from daily ranges. The ionospheric current systems: the equatorial electrojet (EEJ) current system and the counter equatorial electrojet (CEJ) current system that occasionally modulates it, together with the worldwide part of Sq (WSq) current system and the single vortex current (SVC) system that occasionally modulates it, have been used to discuss the local time variations of the correlation coefficients found in this study.

The correlation coefficients of ΔH: at two stations in the EEJ zone (called E stations) and at two stations in low latitudes outside the influence of the EEJ (called L stations) are positive, very high and highly significant, and remain fairly steady for all hours of the day. But the diurnal profile of the correlation coefficients of ΔH at an E station with ΔH at an L station is characterized by very high and steady values at night-time and a drastic decrease to low and often insignificant values at daytime.

It is explained that the correlation coefficients of all pairs of stations in night-time are positive, very high and independent of the distance separating the two stations because the small-amplitude variations at night being correlated arise from magnetospheric sources even on very quiet days.

In daytime, the effect of the distance separating L-L pair of stations is to reduce their correlation coefficient to an extent comparable with the result of Schlapp (1968). This is attributed to differences in the wind W, the magnetic field B, the dip angle I, the plasma density N, the gyrofrequency ω, the collision frequency v, the temperature T and the height of the current h in the ionosphere above the two stations. These determine the ionospheric current intensity and its changes at the two stations.

The unduly low correlation coefficients observed when Jaipur station is involved is attributed to the occasional modulations of Sq(H) diurnal profile at stations in the region of about 12° - 65° latitude. The distortion is caused by superposed magnetic field (SPMF) generated by the SVC system on abnormal phase quiet days (APQDs) in the region.

The drastic collapse of the correlation coefficients of E-L pairs of stations from very high values at night-time to very low values at daytime is most importantly caused by the differences between the EEJ (lower) current layer and the WSq (upper) current layer. The distance between the E-L stations and the modulating current systems of CEJ and SVC make their smaller contributions. At the E station the difference between EEJ and WSq mainly arises from the different heights at which they flow where W, B, I, N, ω, v, T and h are normally different. At the L station, there is no EEJ, and the intensity of the WSq there may be different from that of the WSq at the E station because of the distance between the stations.

The difference between the night-time and the daytime correlation coefficients for E-E and L-L pairs of stations is not statistically significant. The distance between the two stations and the modulating current systems of CEJ and SVC make their contributions but these are not sufficiently strong to make the differences significant. The relative ineffectiveness is because the two correlating stations are under the same current systems.This confirms that the dominating cause of the drastic daytime fall of the correlation coefficients of E-L pairs of stations is the difference between EEJ and WSq current systems.

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