A study of the ionospheric source current systems of Equinoctial (E-) season over the 120^0-150^0E longitude region.

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Abstract

Geomagnetic Solar quiet (Sq) daily variations data recorded over the western Pacific region along the 120^0 - 150^0 E longitude margin have been utilized to determine the ionospheric source current systems. The spatial characteristics of the estimated current systems match well those obtained for the East Asian sector and other global regions. A careful observation of the derived season-wise current patterns showed a significant inter-hemispherical exchange of currents flowing across the equator from north to south during Equinoctial (E-) and summer (J-) seasons, although such a flow of currents was not observed during winter (D-) season. There also exists a west-ward shift of the Sq focus over the Pacific ocean region by about 25 mins., compared to its relative position in the southern hemisphere. We try to explore the reasons for such interesting behaviour of the external current systems, in the light of the spherical harmonic terms used in the estimation of current systems.

Introduction

The geomagnetic solar quiet-daily (Sq) variations as recorded at the Earth's surface can be expressed as a vector sum of both external and internal parts. The external part that arises due to the interaction of the solar wind with the Earth's magnetic field represents the surface manifestation of the current systems flowing in the E-region of the ionosphere at a height of about 110 km above the Earth's surface The internal part arises due to the induction of these external currents within the Earth and provides information on the electrical conductivity distribution beneath the Earth. The ratio of internal to external parts measures the *electromagnetic induction response* of the Earth. Thus it is always important to ensure *a priori*, a clear definition of the spatial characteristics of the external source field for successful determination of the Earth's electrical conductivity structure. Spherical harmonic analysis (SHA) could be used to isolate the observed Sq field variations into external and internal parts. The separated external and internal parts can best be used to study the spatial characteristics of the respective current patterns

Price and stone (1964) briefed about the penetration of the northern currents into the southern hemisphere during the Equinoctial (E-) and summer (J-) seasons,. Chandrasekhar et al. (2003) have substantiated this observation and further showed that such a penetration extends well up to 15^0S Lat during J-season and up to about 10^0S Lat during E-season although such a feature was not observed during winter (D-) season.

In Oceanic regions, the presence of Oceans greatly affects the internal current systems although their influence on the external current system is shown to be negligible (Chandrasekhar et al., 2003). However, there exist some notable differences between the external current systems derived for land and ocean regions in northern hemisphere. Malin and Gupta (1977) have reported a west ward shift of the position of Sq focus by about 105 minutes over the land (African) region and by about 40 mins. over the mid-Pacific, relative to their respective locations in southern hemisphere. Chandrasekhar et al (2003) have observed such a west-ward shift of the Sq focus over the Pacific to be about 20-25 mins. relative to its positions in the southern hemisphere.

In this paper, we aim to study the possible reasons (i) for the north-south asymmetry in the position of the Sq foci in both the hemispheres and also (ii) for inter-hemispherical current flow, by understanding the role of the various *n & m* combinations of spherical harmonic terms used in the calculation of the external current functions.

Determination of the Equivalent ionospheric Source Current Systems

For the present study, we have used the geomagnetic solar quiet daily variations corresponding to the solar quiet year, 1996, recorded at a chain of both temporary and permanent magnetic observatories, situated along the 120^0 -150^0 E longitude region, which spans the whole of western Pacific region. The geographic and geomagnetic coordinates of the stations used in this study are given in Table 1. We have selected quiet days, having Ap $\leq$ 6. We also have used some more quiet days (defined as Q* days) obtained in a statistical sense following the approach of Schmucker, 1999). We next have used the combined quiet and Q* days for subsequent season-wise analysis. We have Fourier analyzed the data for each season after following the usual initial data processing procedures. Fully processed data corresponding to E-season are shown in Figure 1. Full details of the data analysis procedures are detailed in Chandrasekhar et al. (2003).

We have applied the Spherical Harmonic Analysis technique to separate the observed field variations into external and internal parts. We have used the estimated Gauss external coefficients to determine equivalent ionospheric source current systems.

The general expression for equivalent current function, $J(\phi)$, in amperes (A) is given as (Campbell, 1989)

$$J(\phi) = \sum_{m=1}^{4} \sum_{n=m}^{12} [U_n^m \cos(m\phi) + V_n^m \sin(m\phi)] P_n^m \quad (1)$$

where, U_n^m and V_n^m are the current coefficients, P_n^m denotes the Schmidt normalized associated Legendre function of degree n and order m. For external current representation, U_n^m and V_n^m are defined as

$$U_n^m = -k[(2n+1)/(n+1)](aex)_n^m \text{ and}$$

$$V_n^m = -k[(2n+1)/(n+1)](bex)_n^m$$

where, $k = (R/400\pi)$ and R is the radius of the Earth in meters. aex and bex respectively denote the spherical harmonic gauss external cosine and sine coefficients. Substituting U_n^m and V_n^m in (1), the respective equivalent external current functions can be obtained for each hour $(\phi/15^0)$.

Table 1: Station name, geographic and geomagnetic coordinates of the stations along 120^0 -150^0E longitude region, whose data were used in the present study.

Station Name	Station code	Geographic Lat.	Geographic Long	Geomagnetic Lat	Geomagnetic Long
		(Degrees)		(Degrees)	
Zyryanka	ZYK	65.75	150.78	59.62	216.72
Magadan	MGD	59.97	150.86	53.56	218.66
Onagawa	ONW	38.43	141.47	31.65	212.51
Kagoshima	KAG	31.48	130.72	25.13	202.24
Ewa Beach	EWA	21.32	202.00	22.67	269.36
Chichijima	CBI	27.15	142.30	20.59	213.00
Lunping	LNP	25.00	121.17	13.80	189.50
Guam	GAM	13.58	144.87	04.57	214.76
Muntinlupa	MUT	14.37	121.02	03.58	191.57
Biak	BIK	-1.08	136.05	-12.18	207.30
Wepia	WEP	-3.55	141.88	-22.99	214.34
Darwin	DRW	-12.4	130.90	-23.13	202.68
Learmonth	LEM	-22.2	114.10	-34.15	185.02
Dalby	DLB	-27.2	151.20	-37.09	226.80
Canberra	CAN	-35.3	149.00	-45.98	226.14
Adelaide	ADL	-34.7	138.65	-46.46	213.66
Katanning	KAT	-33.7	117.62	-46.63	188.24

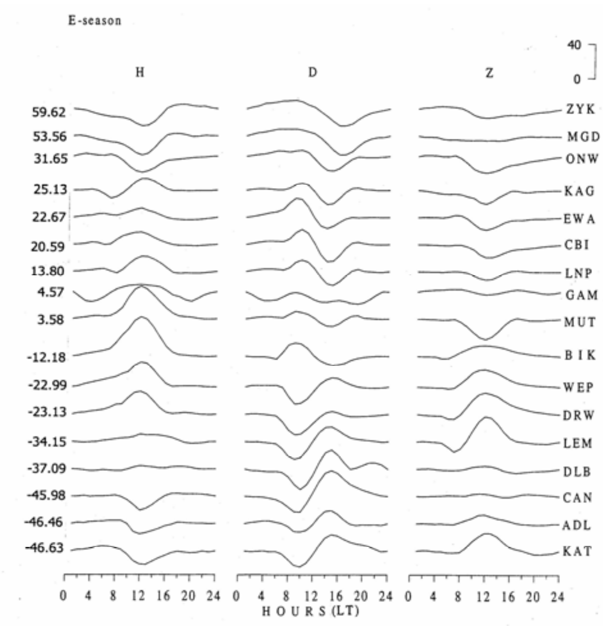

Figure 1–Processed data of averaged geomagnetic quiet-day variations of H, D and Z variations (in nT) of all the stations used in the present study.

Results and Discussion

Fig 2 represents the equivalent ionospheric source current systems, responsible for the generation Sq variations, drawn using all the P_n^m terms for E-season using equation (1). Fig.2a clearly shows the penetration of northern hemisphere currents into the southern hemisphere. This penetration extends up to 10^0S Lat., although this extends further south, say up to 15^0S Lat. during summer (J-) season (not shown here). Such an interesting observation of the inter-hemispherical current exchange was reported earlier by Price and Stone (1964). To understand the reasons for this phenomenon, we have observed the role of various combinations of P_n^m terms that contribute to the estimation of equivalent currents. Fig. 2b depicts the current systems same as that of Fig.2a, but drawn using only the odd $n - m$ tesseral harmonics.

The behaviour of odd $n - m$ tesseral harmonics is such that, it drives oppositely directed current vortices in both the hemispheres, resulting in the potential function that can be best represented by only these harmonics. Accordingly the current patterns generated using these harmonics (Fig. 2b) clearly show such an anti-symmetric behaviour. It is also pertinent to note here that, when only these harmonics are used, there is no penetration of the currents from northern hemisphere into the southern hemisphere (c.f. Fig. 2b).

This explains the fact, that reason for the so called inter-hemispherical exchange of current seen in E-season (Fig. 2a) could be attributed to the presence of even $n - m$ tesseral harmonics (which are symmetric about the equator) used in the estimation of the current systems. It can further be understood that it is these even harmonics and all other harmonic terms “other” than the odd $n - m$ tesseral harmonic terms, that contribute to the equatorial currents besides facilitating the drag of the northern currents into southern hemisphere.

West-ward shift of Sq focus: A close observation of Fig. 2a reveals that there exists a slight west-ward shift of the position of the Sq focus by about 25 mins. from noon, in northern hemisphere, relative its position in southern hemisphere. By analyzing IGY data of 1964-65, Malin and Gupta (1977) reported a west-ward lag for northern focus over the Pacific to be about 40 mins. which is small compared to such a shift seen over African region, which is about 105 mins. In an attempt to understand the reasons for such a west-ward lag of Sq focus, we have examined the current patterns generated by various n & m combination of spherical harmonic terms.

The dipole P_1^0 field moving with a P_n^1 velocity potential, interacts with the conducting ionosphere, to produce a P_{n+1}^1 magnetic variation potential. Therefore, accordingly, to produce Sq field, which chiefly describes the P_2^1 characteristics, the dipole field must interact with the ionosphere with a P_1^1 velocity function. Therefore, we have examined the current patterns obtained by the combined P_1^1 and P_2^1 potentials. Fig.3a represents the current patterns generated by using only the P_2^1 terms and Fig. 3b shows the currents generated by the combined P_1^1 and P_2^1 terms. The west ward shift of the position of the Sq focus is clearly seen in Fig.3b, emphasizing the role of P_1^1 terms in driving the Sq focus west-ward.

As regards the reason for different locations of the position of Sq focus over the land and ocean regions, it is believed that the differential frictional forcers offered by land and ocean, with the former offering more frictional resistance than the latter to the ionospheric thermo tidal winds as explained by Malin Gupta (1977).

Conclusions

The derived ionospheric source current systems for Sq match well with those reported for East Asian sector (Campbell, 1989). The current patterns show that the northern currents penetrate into the southern hemisphere during E-season. We believe that it is the even $n - m$ tesseral harmonics that contribute largely to such a penetration of inter hemispherical penetration of currents The pull of the northern currents into southern hemisphere also depends on the strength of the external currents, because, such a behaviour is not seen in winter (D-) season when the current strength is relatively weak (see Fig. 5a of Chandrasekhar et al., 2003). Besides, the even $n - m$ harmonic terms together with all other harmonic terms, other than odd $n - m$ terms, contribute to the equatorial currents.

The velocity winds of P_1^1 mode drives the main dipole P_1^0 field to produce the west-ward shift in the P_2^1 magnetic variation potential, which largely represents the Sq field. It is believed that the differential frictional forces offered by land and ocean, with the former offering a large frictional resistance than the latter to the ionospheric thermo tidal winds could be cause for west-ward shift of the Sq focus to be more over the land regions than over the oceans.

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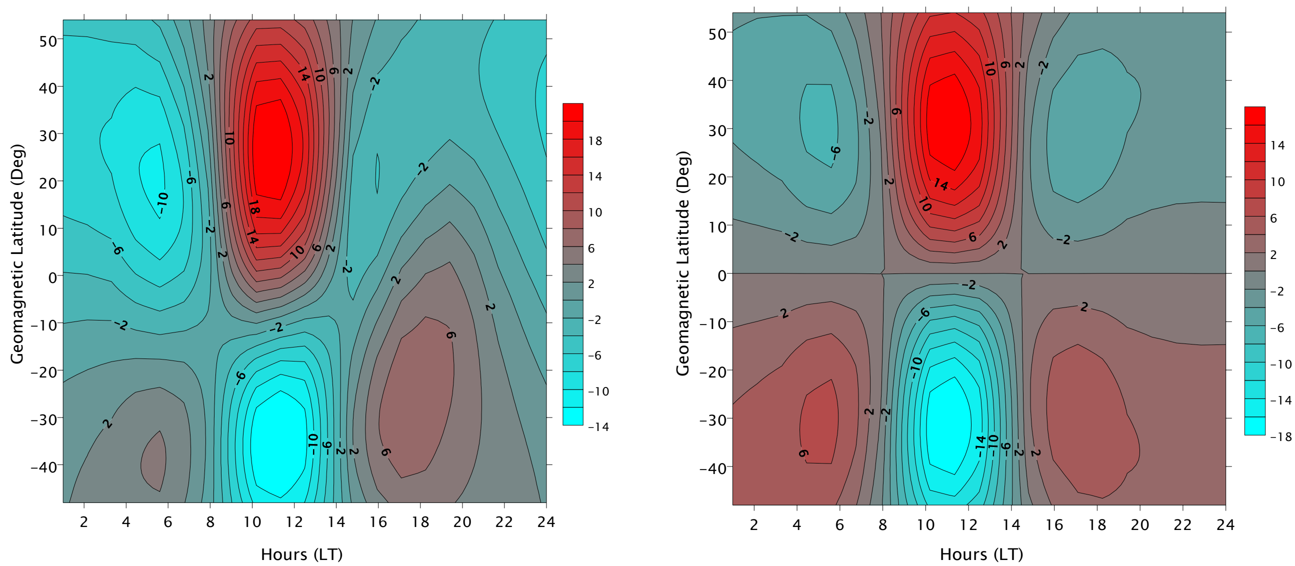
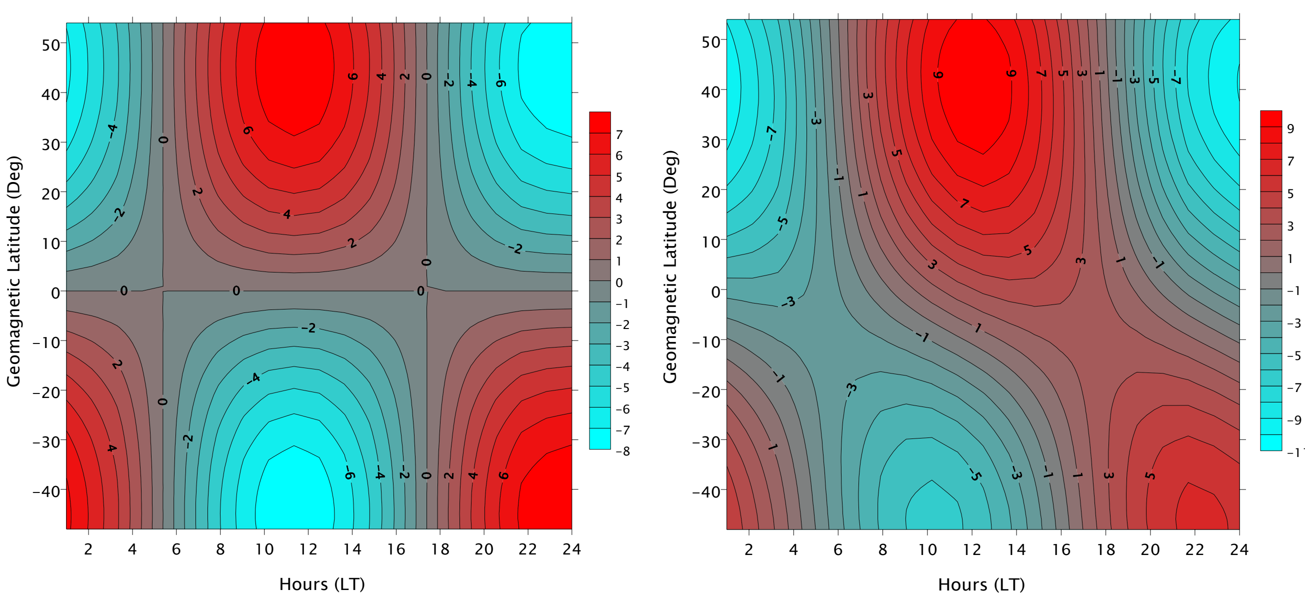


a **b**

Figure 2: Equivalent ionospheric source current systems of Sq for E-season over the 120^0-150^0 E longitude region, (a) when all the harmonic terms are used and (b) when only the odd *n*-*m* tersseral harmonic terms are used. The current between the adjacent contours is 20 kA.



a **b**

Figure 3: Same as in Fig. 2, but (a) when only P_2^1 harmonic terms are used and (b) when the combined harmonic P_1^1 and P_2^1 terms are used.