

Analysis of S_q^p current systems by using corrected geomagnetic coordinates

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Abstract The S_q^p equivalent current system of the quiet day geomagnetic variation in the polar region is very complicated. It is composed of several currents, such as the ionospheric dynamo current and the auroral electrojet caused by the field-aligned current. S_q^p is unsymmetrical in both polar regions. In this paper, the S_q^p current systems are analyzed in the corrected geomagnetic coordinates (CGM) instead of the conventional geomagnetic coordinates (GM), and the symmetries of the S_q^p current in different systems are compared. Then the causes of S_q^p asymmetry in the GM coordinates are discussed; the effects of each component in S_q^p are determined.

Key words S_q^p equivalent current systems, corrected geomagnetic coordinates, solar quiet day variation.

1 Introduction

The polar cusp is a hotspot in the geo-space study because it has open geomagnetic field lines. In terms of geomagnetics, there are very complicated current systems causing the variations in geomagnetic field. These currents are the ionospheric dynamo current (IDC), the field-aligned current (FAC), the auroral electrojet and the polar cap current (PCC), etc.. Although the FAC do not flow in the ionosphere, it completes the current loops with the auroral electrojet and the PCC. The solar quiet day geomagnetic variation in the polar region, S_q^p , provides a useful means to study the basic structure of these currents.

Many S_q^p researches show the asymmetry of S_q^p in both polar regions (e. g. Xu 1994). The S_q^p equivalent current systems are directly related to the ionospheric wind systems and the main geomagnetic field. The difference of the main field in both polar regions may be one of the factors that cause the asymmetry of S_q^p (Xu *et al.* 1998). In order to investigate the contribution of the main field to the asymmetrical characteristic of S_q^p , we try to use the corrected geomagnetic coordinates (CGM) instead of the conventional geomagnetic coordinates (GM). The CGM coordinate system, as a useful magnetic coordinates system, is based on the International Geomagnetic Reference Field (IGRF) instead of the dipole geomagnetic field in the GM coordinates system (Gustafsson *et al.* 1992). The CGM system takes into account of the local distorts of magnetic field lines. In the GM system, a point on the Earth's surface can project to a certain point on the ge-

omagnetic equatorial plane by mapping it along the dipole field line. One can use the projecting point on the equatorial plane to represent the point on the surface by this projecting relation. The coordinates of the point on the surface, $(\lambda, \varphi_{\text{GM}})$, can be transferred to (ϕ, L) , where λ and φ are the longitude and the latitude of the point on the surface, ϕ and L are the azimuth and the central distance of the projecting point on the equatorial plane. In the GM system ϕ is equal to λ , and the relation between $(\lambda, \varphi_{\text{GM}})$ and (ϕ, L) is setup by the dipole field line. The CGM coordinates system adjusts this projecting relation with the IGRF line instead of the dipole field line. To calculate the CGM coordinates of a point on the Earth's surface, two steps are required:

- (1) Calculate the IGRF line from the geographic coordinates of the point, $(\lambda, \varphi_{\text{G}})$, and tracing it to the geomagnetic equatorial plane to get (ϕ, L) ;
- (2) Calculate the CGM coordinates of the point by the relation between $(\lambda, \varphi_{\text{GM}})$ and (ϕ, L) , and take $(\lambda, \varphi_{\text{GM}})$ here as $(\lambda, \varphi_{\text{CGM}})$.

In this paper the data are all in 1994, so we have to use the interpolation of the IGRF-1990 and the IGRF-1995. Since the higher order of IGRF field depresses much with distance from the Earth, we take the order depressed as

$$N = \text{round}(1 + 9R_{\text{E}}/r) \quad (1)$$

where R_{E} is the radius of the Earth, r is the distance to the center of the Earth, and round is the integral function with less 0.5 abandoned.

2 Data processing

The data used are from geomagnetic quiet days of 1994, which mainly come from INTERMAGNET, addition with the data from Zhongshan Station (ZHS), Antarctica, and Beijing Ming-Tomb Station (BMT), China. There are all together 65 stations shown in Fig. 1. Among them 25 stations have latitudes higher than 60° . There are 54 stations with minute value data, and 9 stations with hourly value data. Because the number of stations in the southern hemisphere are less than in the northern hemisphere, there are big gaps in latitude distribution in the south, we add two stations, Macquarie Island (MCQ) and Vostok (VOS), with data of 1993 and 1995 into our data set.

All data are divided into three sections. January, February, November and December are noted as D months; March, April, September and October are as E months; and from May to August are as J months. E months is equinox season; D months is winter for the northern hemisphere and summer for the southern hemisphere; J months is summer for the northern hemisphere and winter for the southern hemisphere. 5 geomagnetic quiet days are selected in each month.

Since the S_{q}^{p} is analyzed in the CGM system, we have to transfer the position of each station to the CGM latitude and longitude. The local time will be different when we use different coordinate systems. The magnetic local time for a station in the CGM system can be obtained from the longitude difference between the subsolar point and the station in the CGM system. Because the S_{q}^{p} currents are assumed in the ionospheric E layer, the height of the subsolar point is assumed as 110 km. Just as many authors did, e. g. Matsushita and Maeda (1965), the method applied in the present study is spherical harmonic analysis. We choose the highest order $M = 8$, and highest degree $N = m + 60$ because the current systems in the polar region are very complicated.

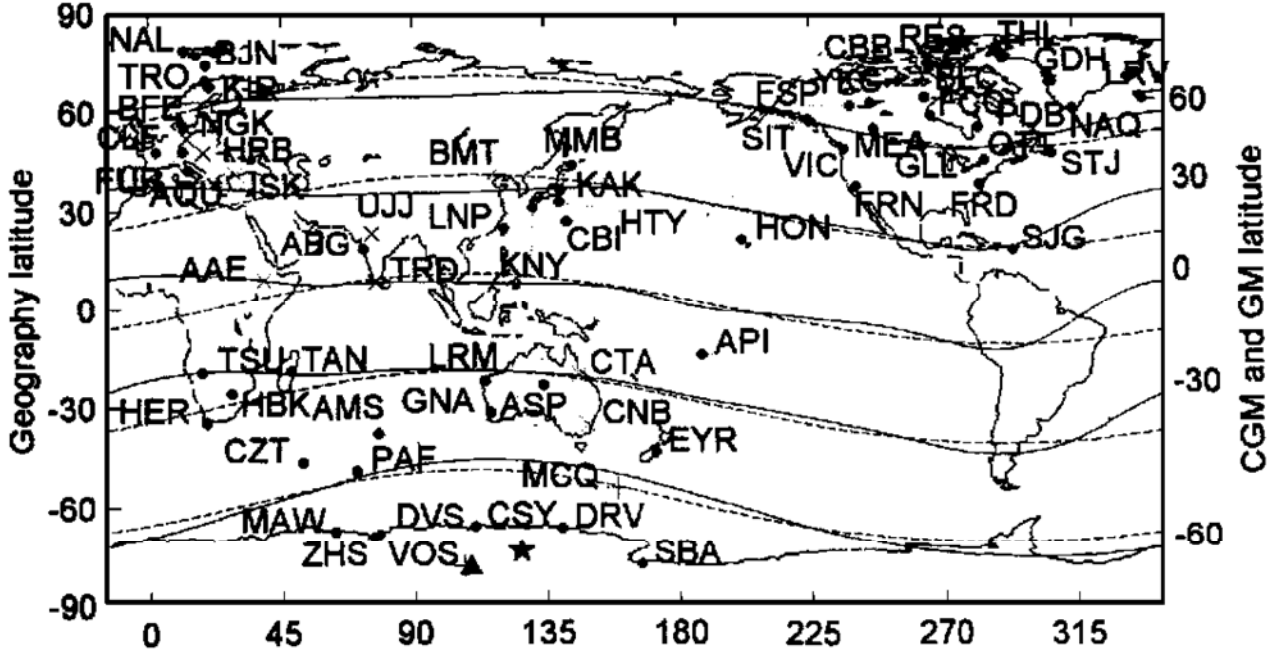


Fig. 1. The distribution of the stations. $-$: corrected geomagnetic latitude; $-$: geomagnetic latitude; \star : corrected geomagnetic pole; \blacktriangle : geomagnetic pole; \bullet : stations with minute value data; \times : stations with hour value data; $+$: stations with data of 1993 and 1995.

The datum line of the S_q has to be carefully chosen. The electronic density in the ionospheric E layer at night has been observed only about one-fiftieth of the noon value (Bourdeau 1963 referenced in Matsushita and Maeda 1965). This result is typical for middle latitudes. On the other hand, the S_q variation in high latitudes is not only due to IDC, but also due to the loop of FAC, which is typical in the dawn and dusk. For simplification, we set datum line as the average value of the whole night from 1800 MLT in the dusk to 0600 MLT in the morning, so that it can be simply adapted to both middle and high latitudes.

We use the Fourier translation to get the time spectrum of each station, then use the least square method to fit the spectra with the co-latitude based function. Since the distribution of stations is not uniform and the measurement may have errors, it is difficult to fit the spectrum directly. Each spectrum is smoothed before fitted. The smooth method is so-called the cubic smoothing spline. If y_i is the measured data on the coordinate x_i , the smoothing function $f(x)$ must make follow equation minimum:

$$u = (1 - P) \sum_i [y_i - f(x_i)]^2 + P \int [S(x) - f(x)]^2 dx \quad (2)$$

where $S(x)$ is the cubic spline function determined by the data series (x_i, y_i) ; P is a parameter to eliminate the 'noise'. If $P = 0$, the smoothing function $f(x)$ is least square fitted function; if $P = 1$, it is spline function. $P = 0.75$ was chosen in our analysis.

3 Result

In Fig. 2, the S_q^p equivalent current systems of 1994 are shown in both the GM (Fig. 2a) and the CGM (Fig. 2b) coordinates. Fig. 2a shows that in the GM coordinates the S_q^p current systems in the northern and southern polar regions are obviously asymmetrical. In the northern polar region, there is a clear vortex in the dusk, but in the south-

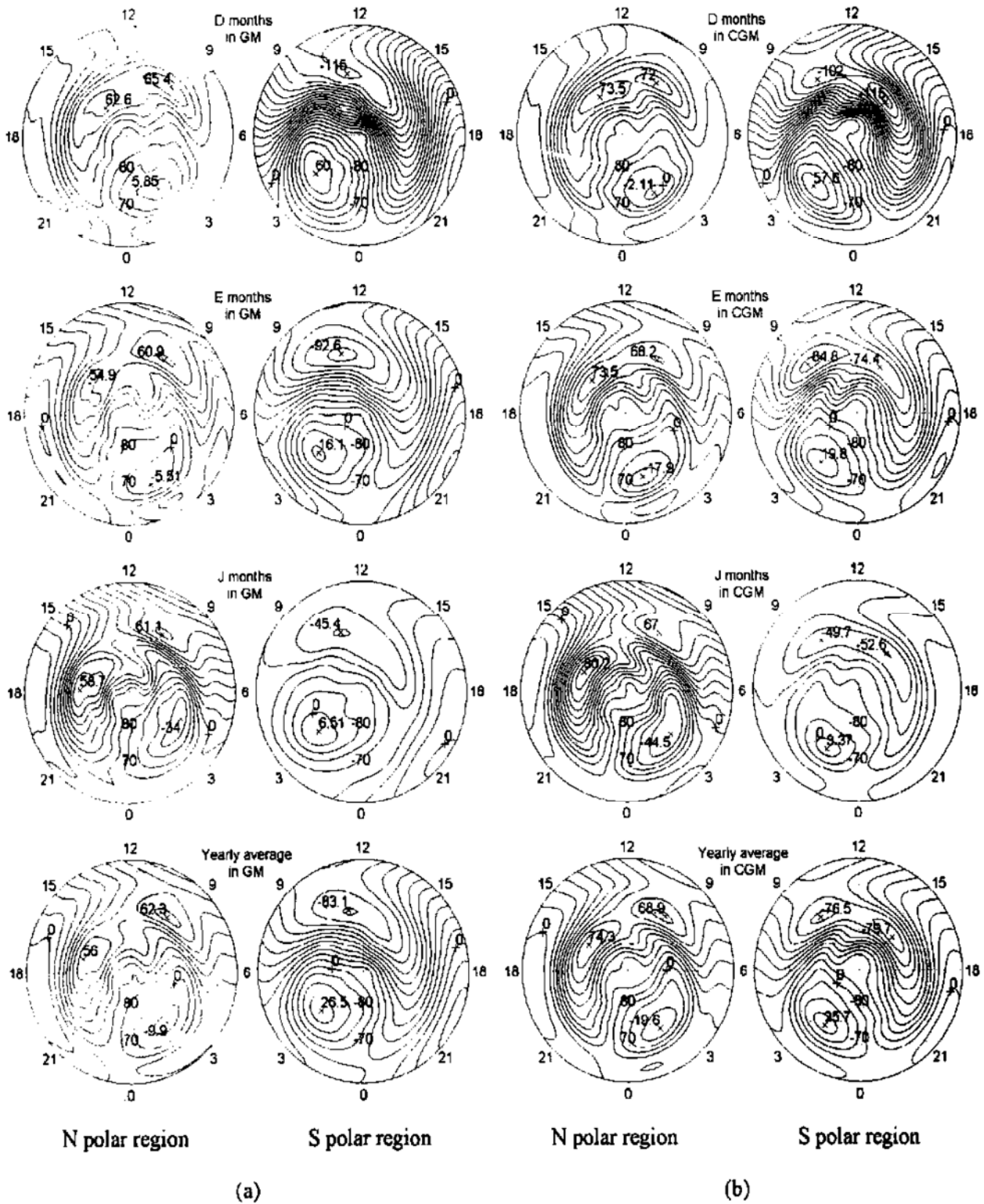


Fig. 2. The external S_q^p equivalent current systems of 1994. The contour interval is 7.5 kA. (a) In the GM coordinates; (b) In the CGM coordinates.

ern hemisphere, the dusk vortex disappears. On the other hand, the S_q^p equivalent current systems in the CGM coordinates are much more symmetrical in both polar regions as Fig. 2b shows. In the northern polar region, the S_q^p current systems do not change too much when comparing the results in the GM coordinates with those in the CGM coordinates. Fig. 3 gives a summary of the three current centers in the CGM coordinates.

Kamide *et al.* (1996), investigating the substorm-time current patterns over the entire polar region, obtained that the current patterns consist of two components: the two-

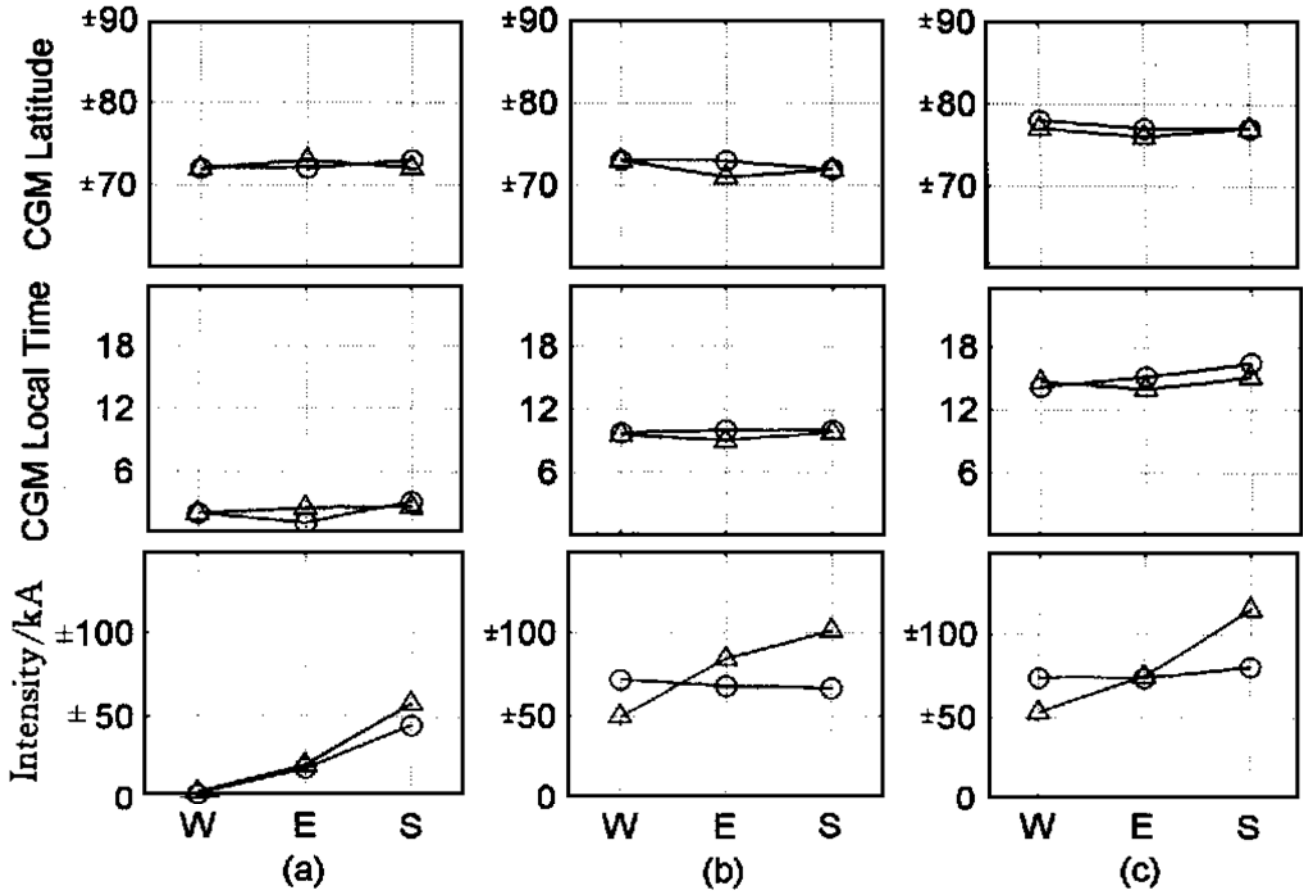


Fig. 3. The comparison of S_q^p current vortices in both polar regions in the CGM coordinates. The first row is the comparison of the latitude of vortex centers; the second row is the comparison of the local time; the third row is the comparison of current values. Mark \odot and \triangle are for the northern and southern hemispheres respectively. The values of both sides are reversed except the local time. W, E and S at the horizontal axis represent the winter (D months for the northern hemisphere and J months for the southern hemisphere), the equinox and the summer (J months for the northern hemisphere and D months for the southern hemisphere) respectively. (a) The dawn vortex; (b) The daytime maximum; (c) The dusk vortex.

cell convection pattern and the westward electrojet in the dark sector. The total current in our result is around 100 kA. This value is between the quiet-time value (75 kA) and growth phase value (158 kA) in the paper of Kamide *et al.* (1996). During the quiet-time and growth phase period, the current pattern is dominated by the two-cell convection pattern according to the Fig. 3 of that paper, with the dawn vortex center at about 0200 MLT and the dusk vortex center at about 1500 MLT. Our result is very similar to those of Kamide *et al.*

Fig. 2 shows, the S_q^p equivalent current systems are composed of two vortices, so called the two-cell pattern. As Fig. 3 shows, the positions of vortices are not changed with seasons. One is in the dawn (after midnight, around 0200 MLT, latitude $\pm 72^\circ$). The other is in the dusk (1500 MLT, latitude $\pm 77^\circ$). The dusk vortex tends to elongate to whole daytime, and form a second maximum in the morning (about 0900 MLT, latitude $\pm 72^\circ$).

The polar cap current, shown in Fig. 4, changes with seasons. It is because that the density of charged particles in the ionosphere is different with seasons. Different season means different solar radiation.

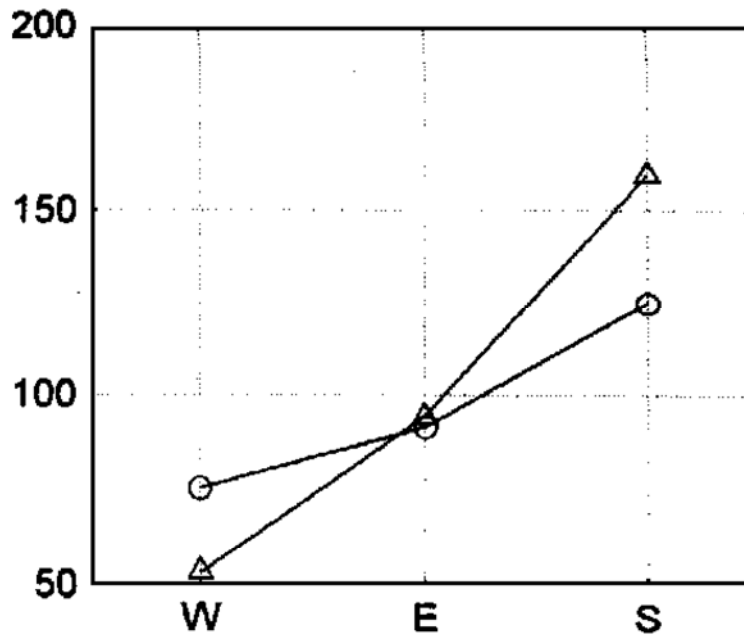


Fig. 4. The polar cap current. Mark \odot and \triangle are for the northern and southern hemispheres. W', E' and S' are the winter (D months for the northern hemisphere and J months for the southern hemisphere), the equinox and the summer (J months for the northern hemisphere and D months for the southern hemisphere) respectively.

4 Discussion

It raises a question from our result: why the current pattern symmetry is improved in the CGM coordinates. The principal factors affecting the structure of the S_q^p current systems include the distribution of the conductivity in the ionosphere, ionospheric wind systems and the geomagnetic main field. Let's check the distribution of the main field in both the GM and the CGM coordinates firstly.

Fig. 5 shows the distribution of the field magnitude, the dip angle and the apex of the field lines (projects of constant latitudes on the equatorial plane) of IGRF of year 1994 in the GM coordinates (Fig. 5a) and in the CGM coordinates (Fig. 5b). From Fig. 5, we can see that the field magnitude and the dip angle of the geomagnetic main field are not very different in both coordinates, but the project of constant latitudes on the equatorial plane in the CGM is much more symmetrical than in the GM coordinates. When $L > 14$, Tsyganenko model (Tsyganenko 1989) should be used instead of IGRF model. The Tsyganenko model counts in the effect of the tail current sheet, which does not affect the symmetrical distribution in both hemispheres. So, it is reasonable to conclude that the improvement of symmetry of S_q^p current systems in the northern and southern polar regions in the CGM coordinates is due to the symmetrical relation of the CGM coordinates to its projecting point at the equatorial plane. It suggests that the abnormality of the main field take a great part in the ionosphere-magnetosphere coupling because the CGM coordinates takes into account of the distorts of magnetic field lines.

The S_q^p current systems can be divided into two kinds of origination: the IDC current is the ionospheric origination; the FAC and its closed currents in the ionosphere (the auroral electrojet and the polar cap current) are the magnetospheric origination that closely related with the field line projecting. The symmetry of the S_q^p current systems in the

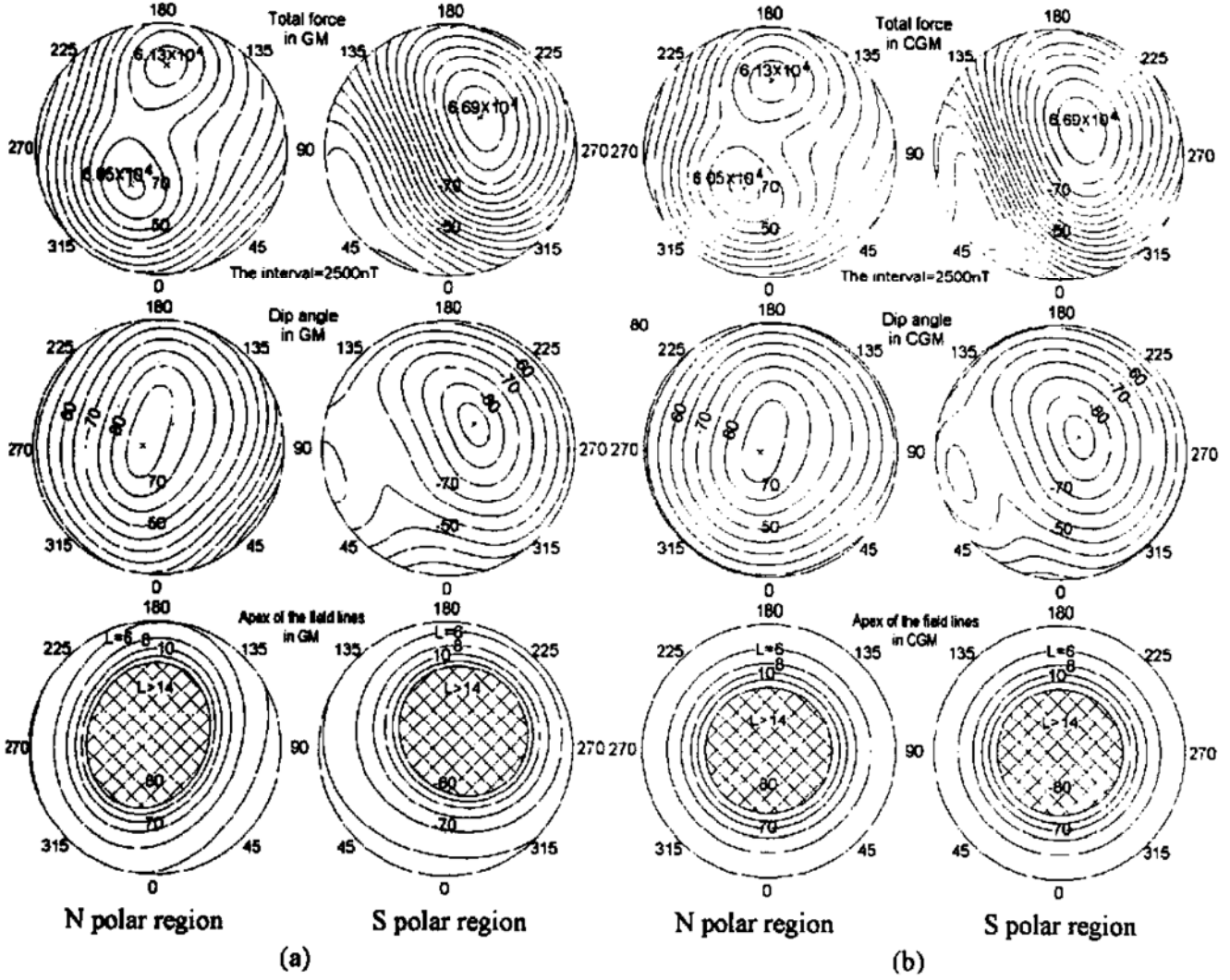


Fig. 5. The distributions of the IGRF field magnitude, the dip angles and the apex of field lines (projects of constant latitudes on the equatorial plane). (a) In the GM coordinates; (b) In the CGM coordinates.

CGM coordinates suggests that the main part of the S_q^p current systems is the magnetospheric origination. From Fig. 3, we can see that the positions of the vortices do not change with seasons. This is one of the characteristics of FAC and its closed currents in the ionosphere. They are changed with different activity level according to Kamide *et al.* (1996).

From Fig. 3b and 3c, we can see that the values of the current intensity in the day-time do not change symmetrically with seasons. The CGM coordinates improve the symmetry of field line projecting, but break out the symmetry of solar position in both hemispheres. In the quiet time, when the particle precipitation is much less, the ion density of the ionosphere in daytime depends on the solar radiation, so the conductivity distribution in the ionosphere is not symmetrical in the CGM coordinates. On the other hand, the conductivity distribution dominates the IDC pattern; it may not be symmetrical in both the northern and southern polar region in the CGM coordinates.

5 Conclusion

By analysis of geomagnetic data of 1994 in the CGM coordinates, the S_q^p equivalent current systems are composed of two vortices called two-cell pattern. The current pattern

does not change with seasons, but the values of the current intensity do. The shape of the current pattern and the structure of the S_q^p current systems are symmetrical in both hemispheres; it dominated by the FAC and its closed currents in the ionosphere: the auroral electrojet and PCC. Since the CGM coordinates break the symmetrical pattern of the conductivity distribution in the daytime, the seasonal variation of the S_q^p current in daytime is not equal in both the northern and southern hemispheres.

The CGM coordinates improve the symmetry of the field line projecting in both the northern and southern polar regions. It suggests that the abnormality of the main field take a great part in the ionosphere-magnetosphere coupling.

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