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# Longitudinal dependence of eastward and westward magnetic variations at mid-latitudes

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***Abstract:*** The magnetic local time (MLT) dependence of magnetic variations on the ground at mid-latitudes caused by field-aligned currents is estimated for two cases where the distribution of the field-aligned currents is defined at the magnetosphere and at the polar ionosphere. The results show that the MLT distribution of the magnetic variations shifts eastward or westward by a few hours in the latter case because the terrestrial magnetic field declines from the geographic meridian. Whether the distribution shifts eastward or westward depends on the longitude of the observatory. This fact suggests that whether the distribution of a phenomenon propagating along the terrestrial magnetic field is mainly determined in the magnetosphere or in the ionosphere may be determined by comparing the MLT distribution of the phenomenon's magnetic effect at observatories located at various longitudes.

## 1. Introduction

The MLT (magnetic local time) is often used to analyze the magnetic variations caused by phenomena propagating along the terrestrial magnetic field, such as field-aligned currents or geomagnetic pulsations. When the MLT distribution of such phenomena is analyzed, the sources of the phenomena are assumed to be located in the magnetosphere. If these sources are in the polar ionosphere or if the distributions of the phenomena are controlled by polar ionospheric conditions, however, analyzing their MLT dependence may not be appropriate.

In this paper, the MLT profiles of magnetic variations at mid-latitudes caused by field-aligned currents are estimated using a numerical calculation for two cases where the distribution of the field-aligned currents is given at the magnetosphere and at the polar ionosphere. The results of the calculations are then compared. Based on these results, we suggest a method for determining whether the distribution of the field-aligned current is controlled in the magnetosphere or in the ionosphere. The results of our data analysis are described and compared with our estimations as an example application of this method.

## 2. Estimation

The MLT profiles of eastward and westward magnetic effects produced by field-aligned currents at mid-latitudes were numerically estimated for two cases. In Case 1,

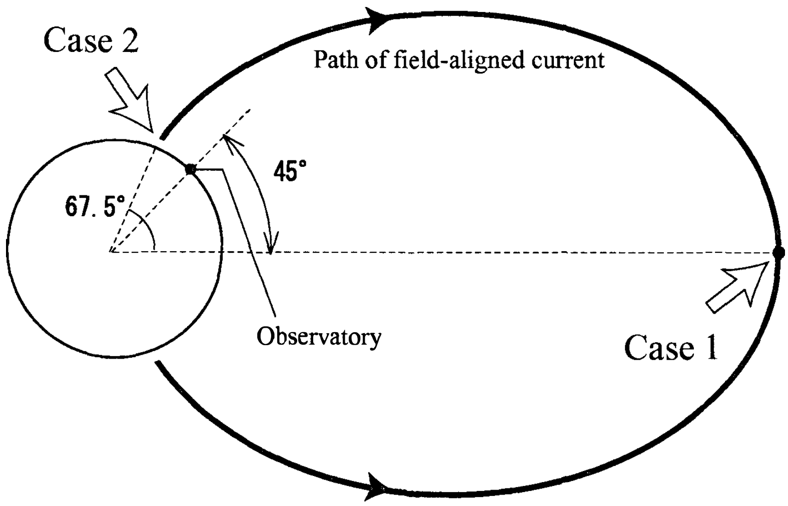


*Fig. 1. Distribution of field-aligned currents described by the theoretical calculations. In Case 1, the field-aligned currents are distributed at the apex along the magnetic field line, which is similar to the magnetic local time in the equinox. In Case 2, the field-aligned currents are distributed at the altitude of the ionosphere.*

the longitudinal distribution of the field-aligned currents ($j$) was given as

$$j=j_0 \cos (LT_m \times \pi/12), \quad (j_0=1 \text{ A/m}) \tag{1}$$

where $LT_m$ is the local time of each field line at the apex along the magnetic field line, which is similar to the magnetic local time in the equinox. Thus, the distribution of the field-aligned currents was defined at the magnetospheric equator in Case 1. In Case 2, the distribution of the field-aligned currents ($j$) was

$$j=j_0 \cos(LT_t \times \pi/12), \quad (j_0=1 \text{ A/m}) \tag{2}$$

where $LT_t$ is the local time at the footprint of the field-aligned currents at the altitude of the ionosphere in the equinox. Thus, the distribution of the field-aligned currents is defined at the ionosphere in Case 2 (see Fig. 1). In both cases, a symmetric distribution of the field-aligned currents between the northern and southern hemispheres is assumed. In this calculation, the field-aligned current is assumed to flow from an apex latitude of 67.5° at an altitude of 100 km to the apex of the terrestrial magnetic field line calculated using the IGRF 95 model (IAGA WG, International Geomagnetic Reference Field, 1995 Revision, 1995). The field-aligned currents are assumed to close via the azimuthal currents flowing along the contour line at the apex latitude of 67.5°. The current system considered in this calculation is shown in Fig. 2. We calculated the field-aligned current effects on the ground for three locations at a geomagnetic dipole latitude of 45°N and a dipole longitude of 90°E, 220°E, and 320°E. These locations correspond to a European station, an Eastern Siberian station, and a Northern American station, respectively.

Figure 3 shows the results of our calculations for the three locations in Case 1 (upper panel) and Case 2 (lower panel). In Case 1, the pattern of the field-aligned current effects on the MLT shifts slightly westward at a geomagnetic longitude of 90°

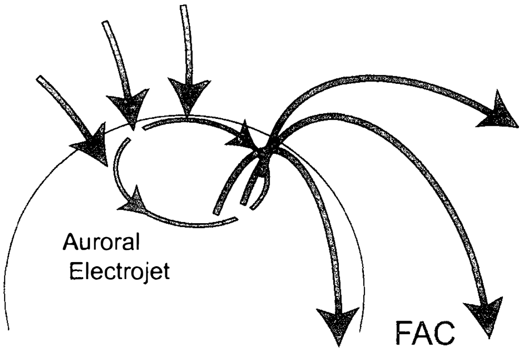


*Fig. 2. Schematic drawing of the current system considered in our calculations. The downward field-aligned currents flow into the ionosphere on the dayside and feed the anti-sunward currents along the auroral oval. These currents feed the upward field-aligned currents on the nightside.*

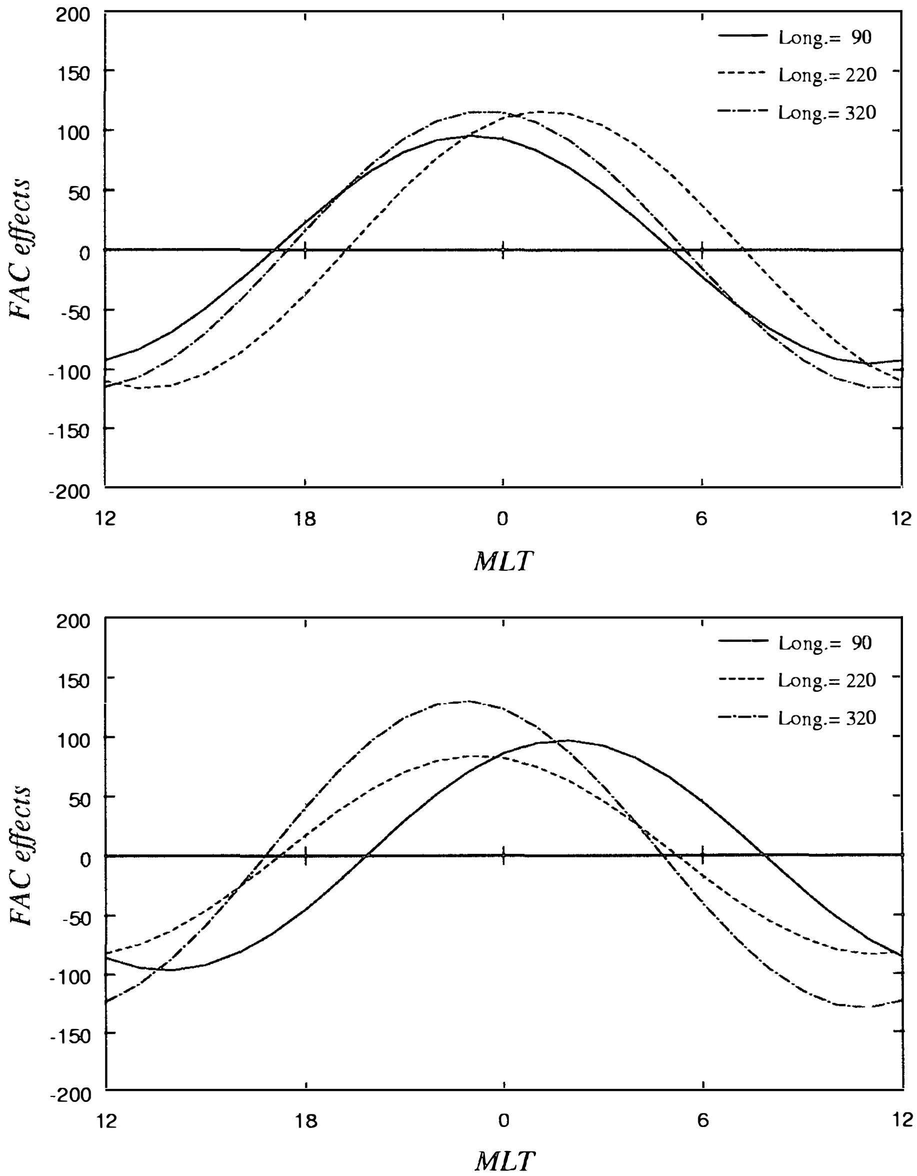


*Fig. 3. Estimated MLT distributions of field-aligned current effects in $\Delta D$ In the upper panel, the distribution of the field-aligned currents is defined by the MLT (Case 1). In the lower panel, the distribution is defined by the local time at the footprint of the field-aligned currents at the equinox (Case 2).*

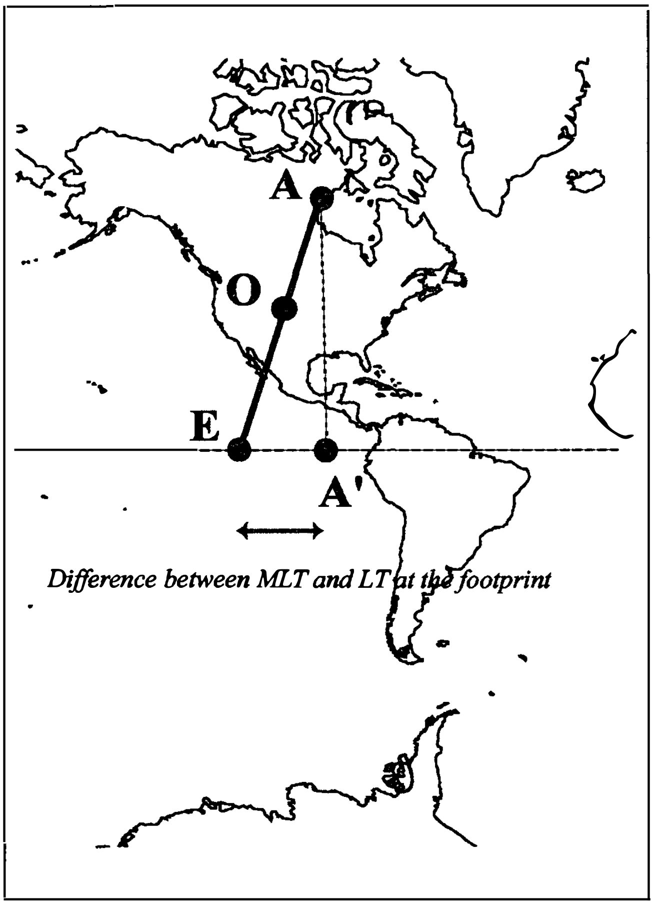


*Fig. 4.* *Schematic illustration of the difference between the MLT and the local time at the ionospheric footprint of the field-aligned current in Northern America, where the terrestrial magnetic field declines eastward.* ***A, O,*** *and* ***E*** *are the footprint of the field-aligned current, the observation point, and the location of the footprint on the equatorial plane in the magnetosphere, respectively.*

and 320° and shifts eastward at a geomagnetic longitude of 220°. In Case 2, however, the pattern of the field-aligned current effects undergoes a large shift eastward at a geomagnetic longitude of 90° and shifts westward at a geomagnetic longitude of 320°.

The shifts in Case 2 can be explained by the declination of the terrestrial magnetic main field. Figure 4 schematically shows the difference between the MLT and the geographic local time at the footprint of the field-aligned current flowing over a Northern American station (denoted by the point **O**) as an example. Since the terrestrial field declines eastward by a considerable amount around this observatory, the MLT, which is the local time at point **E**, is a few hours later than the geographic local time at the footprint of the field-aligned current flowing over the observatory (point **A**). Thus, when the field-aligned currents are distributed within the polar ionosphere and fixed by the geographic local time at the ionospheric footprint, the distribution of the field-aligned current effects on the MLT is shifted to a later MLT by a few hours.

## 3. Discussion

In this paper, we examined the MLT distribution of eastward and westward magnetic variations generated by field-aligned currents at mid-latitude for two cases where the distribution of the field-aligned currents was defined at the magnetosphere and at the polar ionosphere. The results show that the MLT distribution for the latter case shifts eastward or westward by a few hours because the terrestrial magnetic field declines from the geographic meridian. Since the declination of the terrestrial field depends on the longitude, whether the distribution shifts eastward or westward also depends on the longitude of the observatory.

As shown in Fig. 3, longitudinal dependence should be observed with respect to the MLT distribution for magnetic effects originating in the polar ionosphere. Therefore, the longitudinal difference in the MLT distribution should enable one to determine whether the distribution of the phenomenon is determined in the magnetosphere or in the ionosphere.

Shifts in the MLT distribution are sometimes observed. This occurs, for example, in the MLT dependence of eastward or westward magnetic variations at mid-latitudes that appear during the development of auroral electrojets. The eastward or westward magnetic variations at mid-latitudes are expected to be mainly caused by the net field-aligned currents, which are the integral of the downward and upward field-aligned currents along a meridian (*e.g.,* Sun *et al.,* 1984). The regression line is expressed as

$$\Delta D = \alpha \times AE' + \beta, \tag{3}$$

and is fitted to the hourly values of the east-west component, $\Delta D$, of 1990 using the least squares method for each MLT. The constant term, $\beta$, corresponds to the $S_q$ variation. $AE'$ denotes the normalized $AE$, which corresponds to the auroral electrojet intensity. In fitting the regression line of eq. (3), we must take into account the fact that the $AE$ index is dependent on the universal time and that this dependence can affect the $\alpha$ in eq. (3). Thus, each $AE$ value is normalized into $AE'$ by dividing by the average $AE$ at each MLT. The slope of the regression line $\alpha$ corresponds to the average of the ratio of the east-west magnetic disturbances and the $AE$ index for each observatory. A positive $\alpha$ indicates an eastward magnetic disturbance as the $AE$ index increases.

Figure 5 shows the $\alpha$ at each MLT hour for the three mid-latitude observatories shown in Table 1. The $\alpha$ is positive over the entire nightside sector and negative over the entire dayside sector; $\Delta D$ tends to be eastward on the nightside and westward on the dayside when the $AE$ develops. This indicates that the average net field-aligned current is upward on the nightside and downward on the dayside when the eastward magnetic variations are caused by a field-aligned current flowing to the north of the observatory. By comparing these results with data observed at the three observatories, we found that the $\alpha$ pattern shifts westward by a few hours at BOU compared to that at CLF. Such a shift was also seen in data obtained in 1991 and 1992 (data not included). This fact is consistent with Case 2 in Fig. 3 except for PET, where the terrestrial field undergoes a significant decline from the dipole field because of the Siberian anomaly (see Table 1). From these results, we predict that the distribution of the field-aligned currents associated with the auroral electrojets is mainly determined in the ionosphere. To confirm this hypothesis, however, data from other observatories needs to be analyzed in future studies.

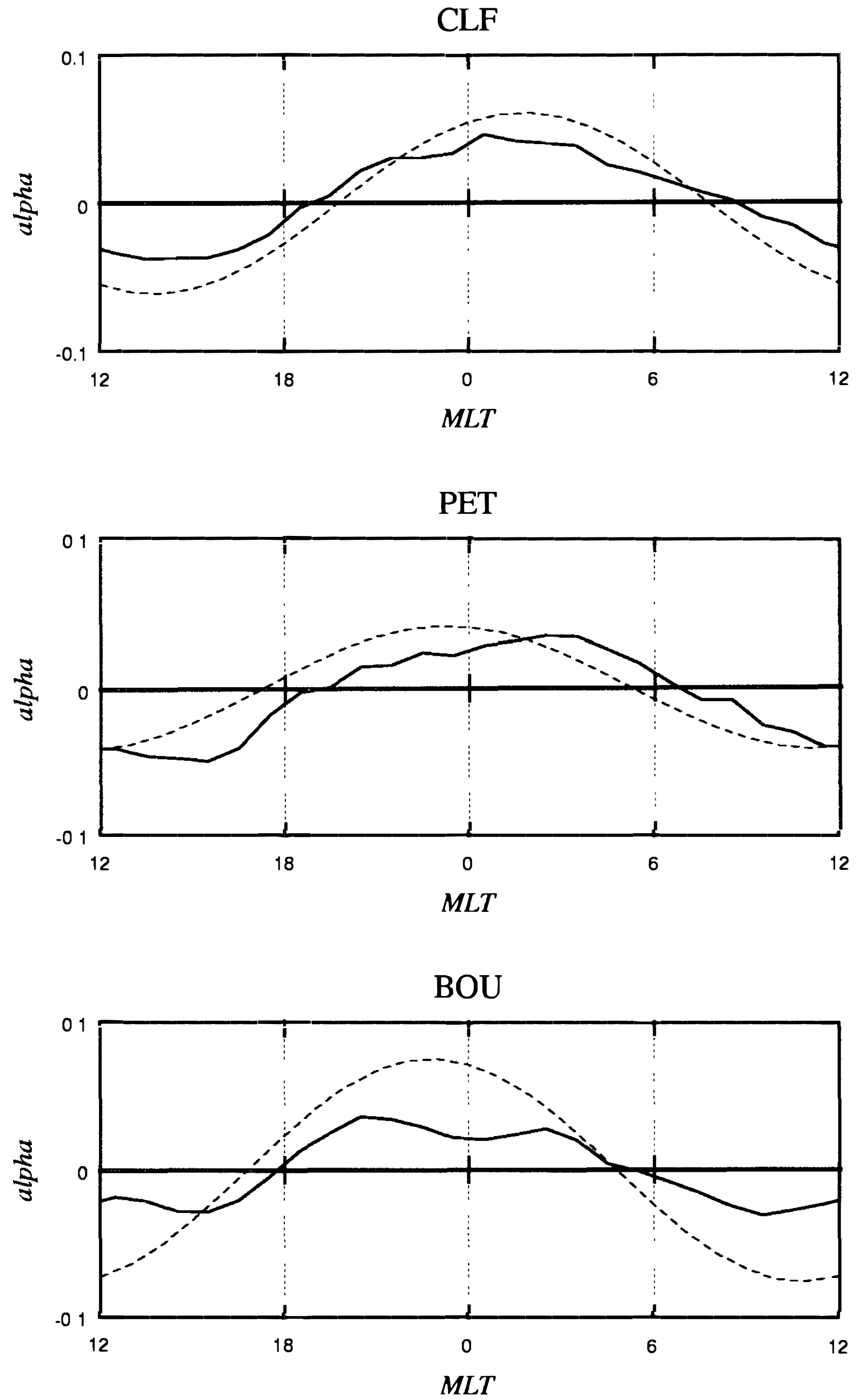


*Fig. 5.* *MLT dependence of $\alpha$ (i.e., the variation in $\Delta D$ versus the corresponding AE index). A positive $\alpha$ indicates an eastward variation, and a negative $\alpha$ indicates a westward variation. The MLT dependence of the field-aligned current effects in $\Delta D$ for a case where the distribution of the field-aligned currents is given by the local time at the footprint of the field-aligned currents at the equinox is superposed for reference.*

*Table 1. List of geomagnetic observatories used in this paper. Their geographic coordinates, dipole latitudes, corrected geomagnetic (CGM) latitudes, declinations of the dipole pole direction from the geographic north, and declinations of the main field are shown.*

| | Dipole | | CGM | Dipole | Decli. |
|---|---|---|---|---|---|
| | Lat. (N) | Long. (E) | Lat. (N) | Decli. | |
| Chambon-La-Foret (CLF) | 50.31 | 85.07 | 43.58 | −16.08 | −2.19 |
| Petropavlovsk (PET) | 44.81 | 219.26 | 46.25 | 11.37 | −5.94 |
| Boulder (BOU) | 49.04 | 317.40 | 49.23 | 9.01 | 10.97 |

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### Reference

Sun, W., Ahn, B.-H., Akasofu, S.-I. and Kamide, Y. (1984): A comparison of the observed mid-latitude magnetic disturbance fields with those reproduced from the high-latitude modeling current system. J. Geophys. Res., **89**, 10881–10889.

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