—研究論文—
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Characteristics of Field-Aligned Currents Deduced from Preliminary Data Analysis of MAGSAT Observations

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MAGSAT 衛星で観測された沿磁力線電流の特性

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要旨: 地球磁場の精密な測定を目的とした MAGSAT 衛星が，米国宇宙航空局によって 1979 年 10 月 30 日に，低高度・準極軌道に打ち上げられた．これまでの POGO や TRIAD や ISIS 衛星の磁場測定と較べ，測定精度および時間分解能が良いこと，データが連続的で衛星軌道が常に朝-夕方子午面内にあるという特徴を活用し，初期データ (1979 年 11 月 2 日～4 日) を用いて特に高緯度地方の沿磁力線電流 (以下 FAC という) の特徴を調べた．これまでの結果に加え，(1) FAC の緯度方向の幅が，今までの結果より拡がっていることが判明した．特に高緯度側の領域 I の緯度方向の拡がりが約 2°～3° 位であるのに対し，低緯度側の領域 II は約 5° 位拡がっている．(2) 朝側および夕方側で連続して観測された FAC は，非対称性を持っており，さらに南北両半球でも非対称であることが判明した．

Abstract: Preliminary analyses of the MAGSAT magnetic field data have been carried out. In high latitudes the signatures of field-aligned currents are clearly recognized to have the following characteristics: (1) the persistent basic pattern of current flow (so-called Regions 1 and 2), with the dominate in intensity of Region 1 (pole-side) current over Region 2 (equator-side) current, and with greater variability of Region 2 current presumably depending on the substorm activity; (2) spatial latitudinal extent of field-aligned current being about 3° for Region 1 and about 5° for Region 2, wider than previously expected, and unusual reverse polarity of current flow direction; and (3) apparent dawn-dusk asymmetry in the field-aligned current intensity between the north and south polar regions.

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1. Introduction

Intended specifically to survey the geomagnetic field near the earth, the MAGSAT was launched on October 30, 1979, by the NASA into a low-altitude (initial apogee of 561.2 km and perigee of 352.3 km), near-polar orbit (an inclination of 97°), which is a sun-synchronous orbit keeping its orbital plane in the earth's dawn-dusk meridian plane, *i.e.* twilight local times (NASA/GSFC, 1979; LANGEL *et al.*, 1980). This satellite measured continuously the geomagnetic field with an accuracy of ± 1 nT (nanotesla) and a time interval of 8 per second for the scalar magnetic field and also with an accuracy of ± 3 nT and a time interval of 16 per second for the vector components. By substracting a reference magnetic field from the observed data, variations of the geomagnetic field vector components were deduced and the results in high latitude regions evidently suggest the currents flowing into and out of the ionosphere along the geomagnetic field lines.

It has been recognized that these field-aligned currents (hereinafter abbreviated to FAC) play an important role in the magnetosphere-ionosphere coupling in consequence of solar wind-magnetosphere interaction, and characteristics of FAC have been intensively studied by many investigators (see reviews by KAMIDE, 1979, POTEMRA, 1979, and references therein). Since the driving energy of FAC is inevitably an input from solar wind, it is important to investigate relationships between FAC and interplanetary conditions, *e.g.* interplanetary magnetic field (IMF) (FUJII and IIJIMA, 1979) which is likely to be one of key parameters that control FAC's intensity and make the spatial asymmetric distribution in the dawn and dusk sectors and/or in the northern and southern hemispheres. The MAGSAT with continuous data makes it possible to study the above-mentioned detailed structures and characteristics of FAC, whereas it is difficult by the previous satellites, *e.g.* the TRIAD which has no continuous observational data available.

The present paper gives a preliminary result of FAC obtained by analyses of the MAGSAT magnetic field data of November 2 to 4, 1979. Several characteristics of FAC are revealed in detail. Especially spatial distributions of FAC (so-called Region 1 and Region 2 currents) over both hemispheres and the unusually observed reverse polarity of current flow direction (MCDIARMID *et al.*, 1978) are examined, and comparisons of subsequent asymmetric FAC intensities in the dawn-dusk sectors and also in the northern and southern hemispheres, observed within the characteristic time of substorm, are carried out.

2. Data Analysis

The MAGSAT CHRONINT (intermediate attitude determination data) tapes provided by the World Data Center A, NASA/GSFC are used for this study. They contain satellite position data (including inertia coordinates, invariant latitude, magnetic local time, dip latitude, and observation time), scalar and vector data in separate records. The accuracy of the satellite attitude determination is about 20 arc-seconds rms, which is equivalent to a vector component accuracy of 5 nT in a 50000 nT field (LANGEL *et al.*, 1980). The CHRONINT tapes are converted to the EDITINT tapes which contain universal time, positions, scalar and vector data at every 0.5 s. Scalar and vector data are averaged values over 0.5 s. Positions in inertia coordinates are calculated from the data points at every minute and converted to geographical latitude, longitude, and altitude by programs INTORB and SATPOS provided by NASA, which give an accuracy of position determination less than 60 m radial and 300 m horizontal, sufficient for the present study.

The MAGSAT data of November 2 to 4, 1979 were utilized. The geomagnetic activities for the period were moderately disturbed ($2- \leq Kp \leq 4-$). At each observational data point (*i.e.* every 0.5 second), 3 components of the reference field MGST 6/80 model were computed and substracted from the components of measured magnetic field. The horizontal components in geographic coordinates are then converted

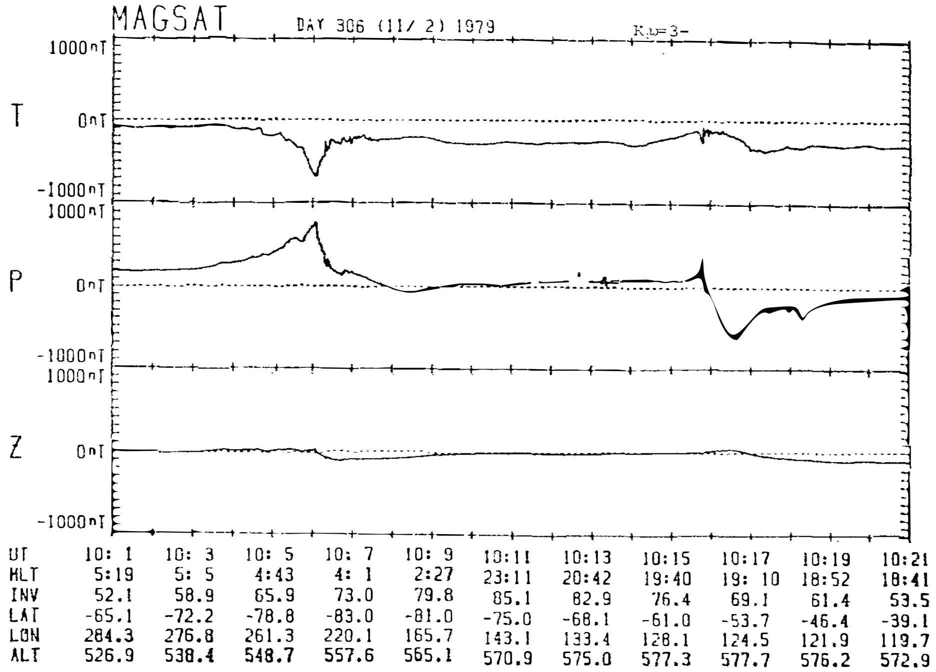
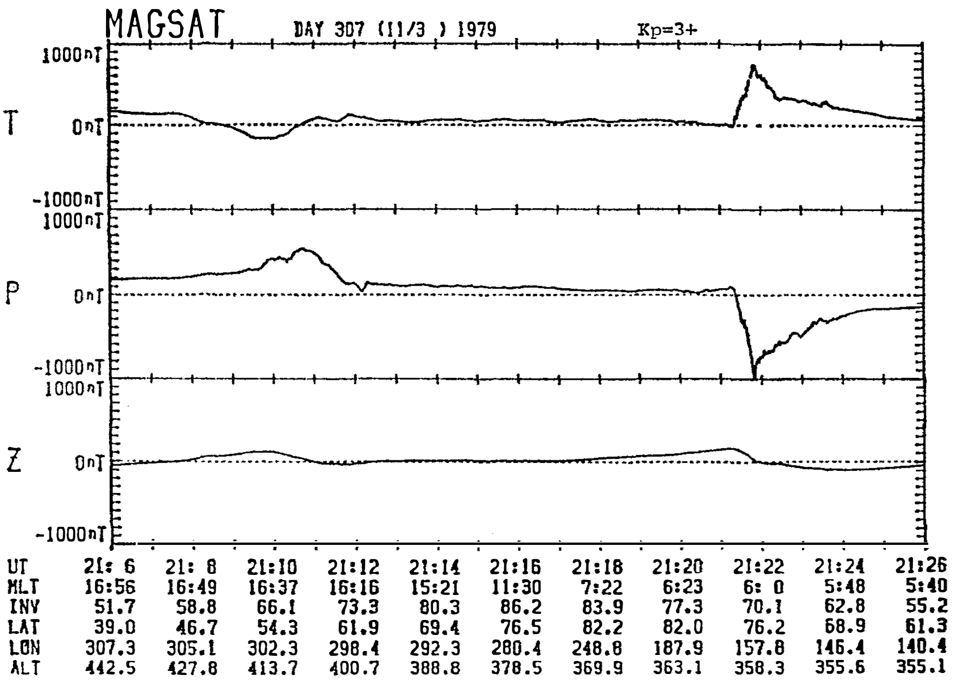


Fig. 1a.



b.

Fig. 1. Typical example of the MAGSAT magnetic field data in high latitudes: (a) southern hemisphere and (b) northern hemisphere. 3 components of residual magnetic field from the MGST 6/80 reference field are north [T], east [P] and down-ward [Z]. For other abbreviations see text.

to those in geomagnetic coordinates with the geomagnetic north pole, at latitude of 78.80° and longitude of 70.75°, derived from the MGST 6/80 model.

Figure 1 is a typical data display format, in which residuals of the vector geomagnetic field from the reference field in north [T], east [P] and down [Z] in geographic coordinates are plotted against universal time [UT], magnetic local time [MLT], invariant latitude [INV] in degree, geographical latitude [LAT] in degree, east longitude [LON] in degree and altitude [ALT] in km. The figure also shows the date of observations and the planetary magnetic three-hour-range indices Kp.

3. Results and Discussions

3.1. General characteristics of FAC

Figure 1 shows a typical example of magnetic field perturbations associated with FAC at the southern (a) and northern (b) high latitudes. Large variations of the north [T] and the east [P] components with much smaller perturbation of the vertical [Z] direction are observed around 10: 6 UT and 10: 17 UT in Fig. 1a and around 21: 11 UT and 21: 22 UT in Fig. 1b, and the characteristics suggest that these magnetic variations are caused by currents flowing along the magnetic field lines, *i.e.* FAC. High latitude sides are corresponding to so-called Region 1 and low latitude sides to Region 2. Current intensities in A/m are estimated to be 0.08 times the amplitude of magnetic field variation in 100 nT, *e.g.* 0.4 A/m to 0.8 A/m current intensities are observed in this case.

Since dawn and dusk FAC's are observed within a time interval of about 10 minutes, which is less than the characteristic time of substorm, these two FAC's are thought to be existing simultaneously. To compare the amplitudes of current intensity and spatial extents in latitude for Region 1 and Region 2, it is evident that the current intensity for Region 1 is greater than that for Region 2 as previously investigated (ZMUDA and ARMSTRONG, 1974; SUGIURA and POTEMRA, 1976; IIJIMA and POTEMRA, 1976), and that spatial extents in latitude are about 3 degrees for Region 1 and about 5 degrees for Region 2 which is much wider than that previously reported, *i.e.* about 1 to 2 degrees. The FAC boundary is defined in this paper to be an intersecting point of tangential lines of an apparent FAC magnetic field and the background geomagnetic field in the coordinate system illustrated in Fig. 1. Since an accuracy of attitude determination and correction for the MAGSAT is much better than that for the previous satellite such as the TRIAD or ISIS, the FAC width can be estimated more precisely than that observed previously.

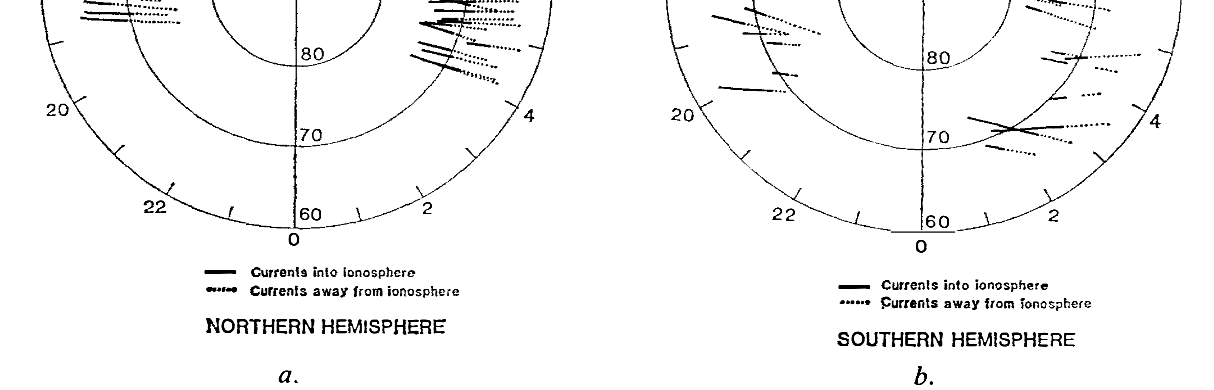


Fig. 2. Statistical results on the locations of FAC in the MLT-INV coordinate system: (a) northern hemisphere and (b) southern hemisphere.

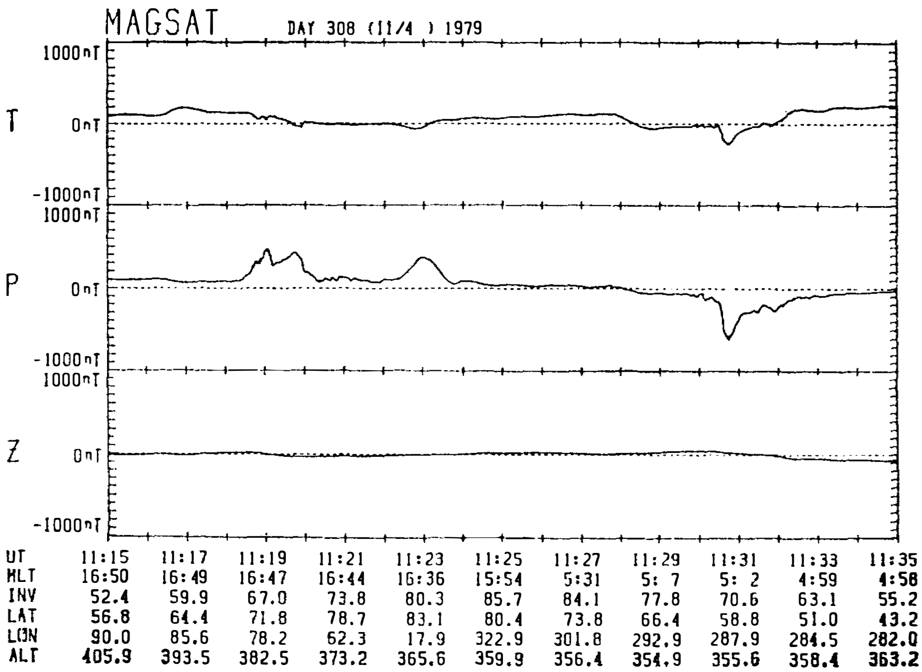


Fig. 3. MAGSAT data observed on November 4, 1979. Two sets of FAC's are clearly identified in the dusk. Format is the same as Fig. 1.

Another characteristic feature of the FAC revealed in this analysis is that small amplitude fluctuations are found to be superimposed on the Region 2 variations whereas not on the Region 1.

Fig. 2 shows statistical results on the locations of FAC observed along the orbits during the period of November 2 to 4, 1979; *Kp* being between 2— and 4—. General characteristics about the locations of Region 1 and Region 2 with their current flow directions and their spatial extents in latitude are found to be the same as discussed above. However, there are a few cases having characteristics different from general FAC's.

Fig. 3 depicts one example observed on the dawn-dusk region of northern high latitudes. In the dusk two sets of FAC's are clearly observed, one being around 11: 19 UT and another around 11: 23 UT, and their locations are 67° INV and 80° INV respectively at nearly the same geomagnetic local time, whereas no FAC phenomena could be found from 70° to 80° INV along this orbit. Therefore, these two are separate from each other. For each set of FAC's, the higher latitude side FAC is flowing out of the ionosphere and the lower latitude side FAC is into the ionosphere.

Another example is a reverse polarity of current flow direction, unusually observed in the dawn, that is, higher latitude side exhibits a current flowing away from the ionosphere and lower latitude side into the ionosphere.

3.2. North-south/dawn-dusk asymmetry of FAC

Since an orbital period of the MAGSAT is 93.7 minutes, the MAGSAT traverses from the dawn to the dusk within about 10 minutes and from the north to the south polar regions within about 45 minutes. Spatial characteristics of subsequent changes in observed FAC intensity along the orbit are studied as discussed below.

Figure 4 illustrates a case that the MAGSAT first traversed the south polar region around 6: 28 UT, December 17, 1979, and observed the FAC where FAC intensity

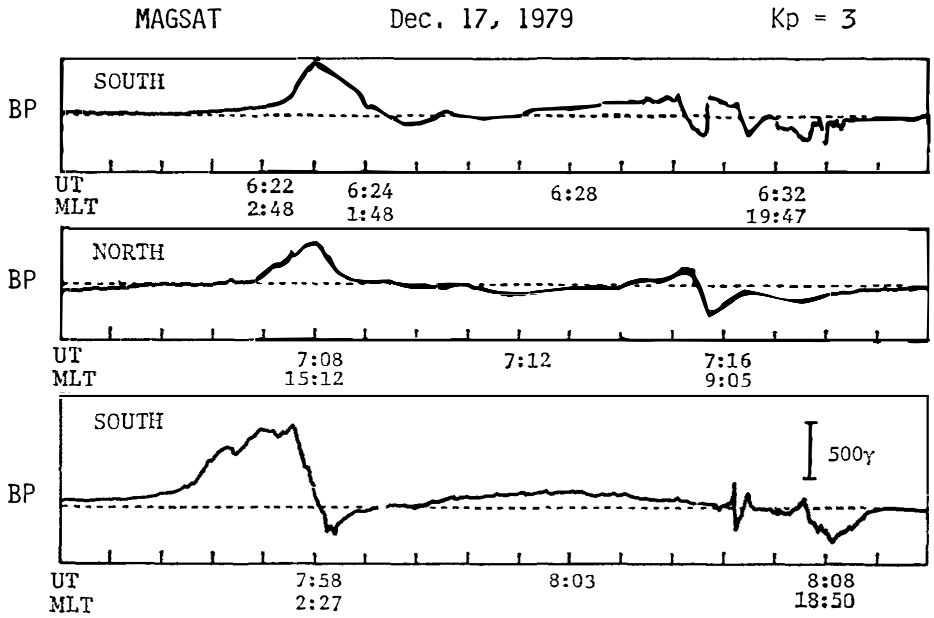


Fig. 4. Typical examples of north-south/dawn-dusk asymmetry of FAC's observed sequentially on December 17, 1979. BP is a longitudinal component of the residual magnetic field.

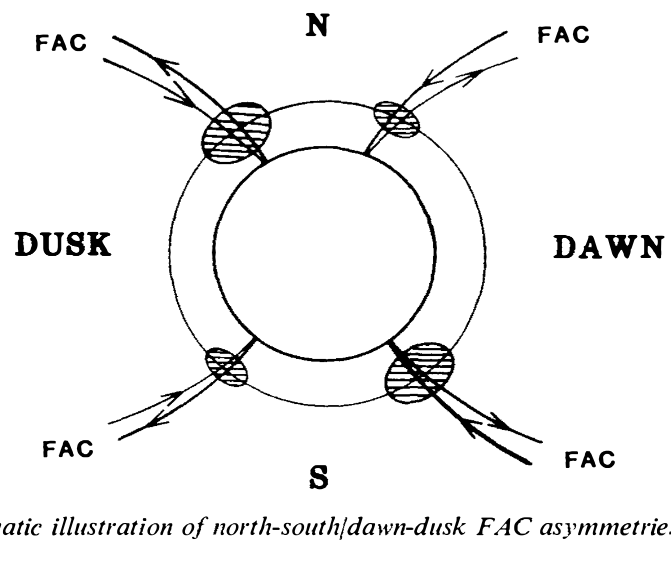


Fig. 5. Schematic illustration of north-south/dawn-dusk FAC asymmetries.

Table 1. Statistics of north-south/dawn-dusk asymmetry of the FAC. DAWN>DUSK means that the FAC intensity in the dawn is larger than that in the dusk, and so forth.

		North	South
2	A.M.		8 : 27 DAWN>DUSK
		9 : 13 DUSK>DAWN	10 : 01 DAWN>DUSK
		10 : 47 DUSK<DAWN	11 : 34 DAWN<DUSK
	P.M.	12 : 20 DUSK<DAWN	13 : 07 DAWN>DUSK
		13 : 54 DUSK<DAWN	14 : 39 DAWN>DUSK
		15 : 27 DUSK<DAWN	16 : 12 DAWN>DUSK
		17 : 01 DUSK<DAWN	17 : 45 DAWN<DUSK
3	A.M.		
	P.M.	16 : 28 DUSK<DAWN	17 : 12 DAWN>DUSK
		21 : 06 DUSK<DAWN	21 : 52 DAWN<DUSK
4	A.M.	1 : 50 DUSK<DAWN	
		11 : 05 DUSK<DAWN	
	P.M.		12 : 02 DAWN>DUSK
		12 : 48 DUSK>DAWN	13 : 34 DAWN>DUSK
		14 : 22 DUSK>DAWN	
		15 : 55 DUSK<DAWN	16 : 39 DAWN<DUSK
		17 : 28 DUSK<DAWN	18 : 12 DAWN<DUSK
		19 : 01 DUSK<DAWN	19 : 45 DAWN>DUSK

in the dawn was larger than that in the dusk. After about 44 minutes, *i.e.* 7: 12 UT, the MAGSAT moved from the south polar region to the north polar region, and observed the FAC whose intensity in the dusk was larger than that in the dawn. After another 51 minutes, *i.e.* about 8: 03 UT, when the MAGSAT came back to the south polar region again, the asymmetric state was almost the same as the previously observed FAC. These imply that the same situation had persisted during 90 minutes and that intensity of FAC in the dusk (dawn) north polar region was large (small) when that in the dusk (dawn) south polar region was small (large). Figure 5 depicts schematically the observed characteristics of combined north-south/dawn-dusk asymmetry of the FAC. The FAC intensity is considered to be controlled by the ionospheric conductivity and the magnetospheric source in a simplified ionosphere-magnetosphere coupling model. Dawn-dusk FAC asymmetry, observed at the positions symmetric with respect to the sun, suggests that this is mainly due to the asymmetry of the source. But the intensity reverse observed in another hemisphere can not be explained by this source asymmetry.

Table 1 summarizes statistics of the FAC asymmetry characteristics observed on November 2 to 4, 1979 by the MAGSAT. Intensities of FAC in the dawn are sometimes larger than those in the dusk, but this relation is sometimes reversed as shown in the table. This statistics shows the fact that this north-south/dawn-dusk asymmetry is not of rare occurrence but general features of the ionosphere-magnetosphere coupling.

Acknowledgments

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