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MODELS OF THE GEOMAGNETIC FIELD AND MAGNETOMETER MEASUREMENTS OF CLUSTER FGM IN THE MAGNETOSPHERIC TAIL

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Abstract. The Electron Drift Instrument (EDI) on board Cluster measured the plasma drift vector within the magnetosphere. The EDI drift data were then mapped along the magnetic field lines into the upper ionosphere (~400 km) by use of the Tsyganenko-2002 (T01) geomagnetic field model. They provided the basis for statistical ionospheric convection pattern at high latitudes for various orientations of the interplanetary magnetic field (IMF) and constituted in this way a magnetospheric convection model. For estimating the correctness of the model assumptions, the T01, the Tsyganenko-1996 (T96) and the Paraboloid Magnetic Field (PM, *Alexeev et al*, 1996) model values of the geomagnetic field were compared with the flux gate magnetometer (FGM) measurements on board Cluster. The Cluster FGM data are not part of the T01 and T96 data bases and can therefore be used for an independent verification of these models. A comparison of Cluster FGM data with T01 model values was performed by *Woodfield et al.* [2007] from perigee up to a geocentric distance of 8 Re. Here, we show a corresponding comparison between observed (Cluster) and modelled (T01, T96, and PM) magnetic field values for the magnetospheric tail region between 8 Re and 15 Re. The results of the drift vector mapping by use of the T01 and T96 models were compared with analogous mappings using the PM geomagnetic field model.

Introduction

Four identical spacecraft, Cluster C1-C4, were launched in summer 2000 into a high-inclination polar elliptical orbit with perigee at around 4 Re and apogee near 19 Re geocentric distance, and an orbital period of about 57 hours. The Electron Drift Instrument (EDI) on board Cluster measured the 2D plasma drift in the plane perpendicular to the local geomagnetic field, while the Fluxgate Magnetometer (FGM) probe recorded the components of the full geomagnetic field vector. The EDI data were sorted with respect to the orientation of the interplanetary magnetic field (IMF) near the magnetopause into 8 distinct sectors. The spatially distributed EDI measurements were then mapped along the geomagnetic field lines to a common reference level at 400 km altitude into the high-latitude ionosphere using the Tsyganenko T01 magnetic field model [*Tsyganenko*, 2002]. The EDI data treatment and the procedure to relate the remote ACE observations of the solar wind and IMF to actual values at the magnetopause are described in the companion papers of *Haaland et al.* [2007] and *Förster et al.* [2007] as well as in *Förster et al.* [2008]. *Förster et al.* [2009] describe a methodology to derive four basic convection pattens (BCPs) for various orientations of the IMF, which constitutes an ionospheric convection model for any IMF value.
Possible sources of incorrect sampling for the EDI Cluster convection model might be caused by the magnetic field model, which is used for the projection of the EDI drift vectors into the ionosphere. To estimate possible induced errors, we compare subsequently the magnetic field magnitude measured by the Cluster satellite with magnetic field model values of the T96 [*Tsyganenko*, 1996], the T01 [*Tsyganenko*, 2002] and PM model [*Alexeev et al.*, 1996; *Feldstein et al*., 2005] along the same trajectories. The Cluster FGM data are not part of the T01 and T96 data base and can therefore be used for an independent verification of the model. For the calculation of the internal geomagnetic field contribution, the IGRF-2005 model was used.

Modelling of the magnetic field in the magnetospheric tail

The FGM instrument on board of Cluster consists of two triaxial fluxgate magnetic field sensors on one of the two radial booms of 5 m length of each spacecraft [*Balogh et al*, 2001]. There are four operative ranges of the FGM instrument, which covers magnetic field values within ±4000 nT with a precision of ± 0.1 nT.
Figure 1 shows the comparison of Cluster-3 FGM observations with the three (T01, T96, and PM) geomagnetic field models along the orbital trace from the far tail at the night side with ~20 Re geocentric distance to ~7 Re during geomagnetically quiet conditions on 10-11 August 2007 (left panels) and a similar orbit on 19-20 August 2006 during disturbed conditions (right panels). The time resolution of the data points presented here is 10 min. The characteristics of the interplanetary medium near the magnetopause during these two orbits are presented in Figure 2. The difference between the magnetic field magnitude measured by Cluster FGM and the PM model values, B(Cl)-B(PM), is generally positive during different activity levels (dotted lines in bottom panels of Figure 1).

These magnitude differences are generally smaller for the T96 and T01 models. In the case of the quiet geomagnetic conditions (left panels), the observed and modelled values practically coincide for the most part of the orbit.
While approaching the perigee during the geomagnetically quiet orbit, all three models predict smaller field values with respect to the measured ones up to ΔB ~15 nT. In the case of disturbed conditions (right panels), the differences between observed and modelled values are larger and the variations ΔB become more irregular. Near perigee at the end of the disturbance orbit example, all three models show a sharp increase with differences up to ΔB~40÷60 nT or almost 15% of the observed absolute values B(Cl). Here, ΔB for T01 and T96 reverses sign, but for PM it keeps negative. The differences in the nature of variations might be caused by an insufficient treatment of the ring current field in the models.
The root mean square values of the differences between the observed and modelled magnetic field magnitudes are shown in the lower panels of Figure1. During the quiet day they reached ~4.2 nT for T01 and up to ~9.5 nT for PM, while the T96 was in between with ~5.6 nT. The corresponding values gained ~10.9 nT (T01), 16.0 nT (T96) and 18.8 nT (PM) during the geomagnetically disturbed day. The T01 model appears to be therefore the most reliable.

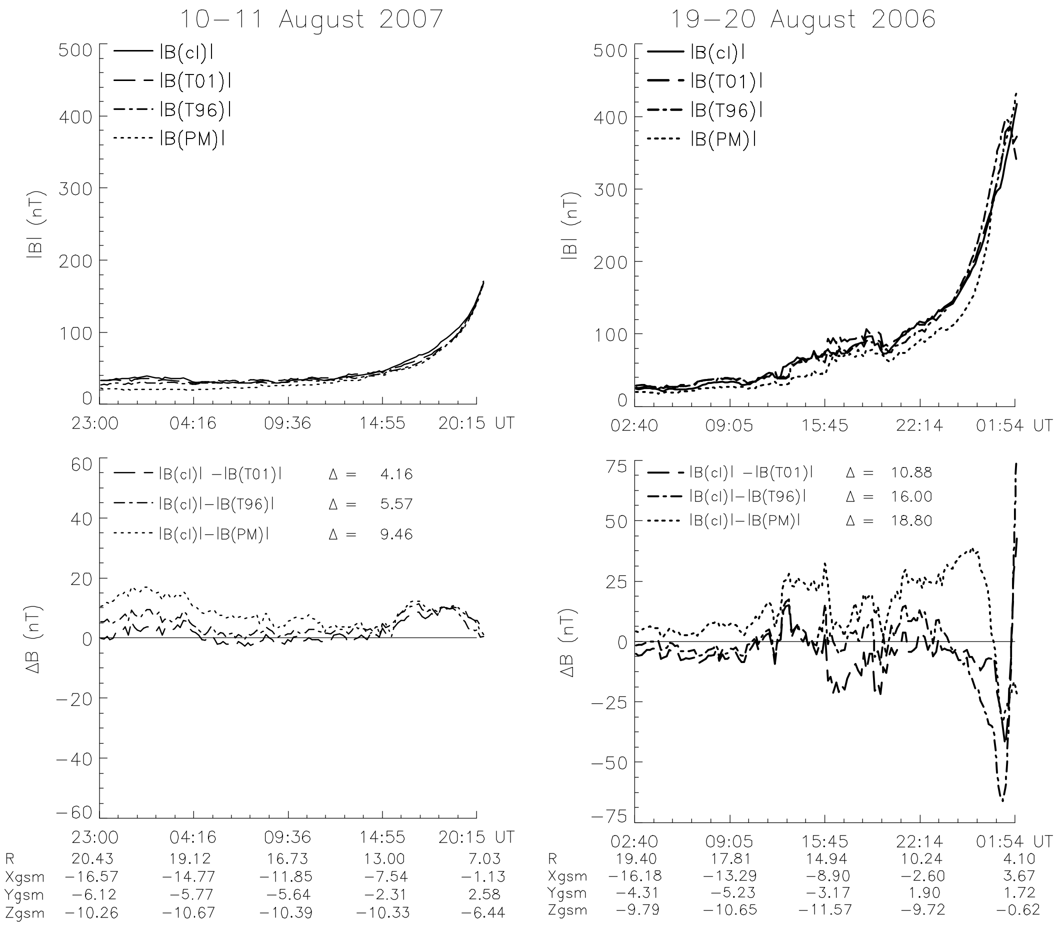

Figure 1: Variation of the FGM measurements along the Cluster C3 orbit, compared with the corresponding 1-min model values of T01, T96 and PM for the time interval August 10, 23 UT, till August 11, 2007, 20 UT (left) and August 19, 02 UT, till August 20, 2007, 02 UT (right). Top panels show the geomagnetic field magnitude | B |, and the bottom panels show the difference ΔB between the measured and model field magnitudes. The Δ numbers listed in the lower panels indicate the root mean square values of the differences ΔB.

The COmposition and DIstribution Function analyser (CODIF) [*Reme et al*, 1997] on board Cluster measured the main magnetospheric ions (H+, He+, O+) along the orbit within the energy range from ~0 keV to ~40 keV per charge with an angular resolution of 22.5°. This allowed to confirm that the spacecraft position on the night side magnetosphere was outside the plasma sheet along its orbital traces from 23 UT of August 10 to 20 UT of August 11, 2007 and from 02 UT of August 19 to 02 UT of August 20, 2007.

We performed a study of the differences ΔB = B(Cl)-B(model) for 10 Cluster orbits of the years 2002÷2008 with randomly selected data points along the satellite orbits at radial distances between 7.5 Re and 19 Re. T01, T96 and PM model values were analysed. In the Table, we list the GSM coordinates of the satellite, its radial distance R from the Earth's center, the magnetic field values of the FGM measurements on board Cluster together with the three

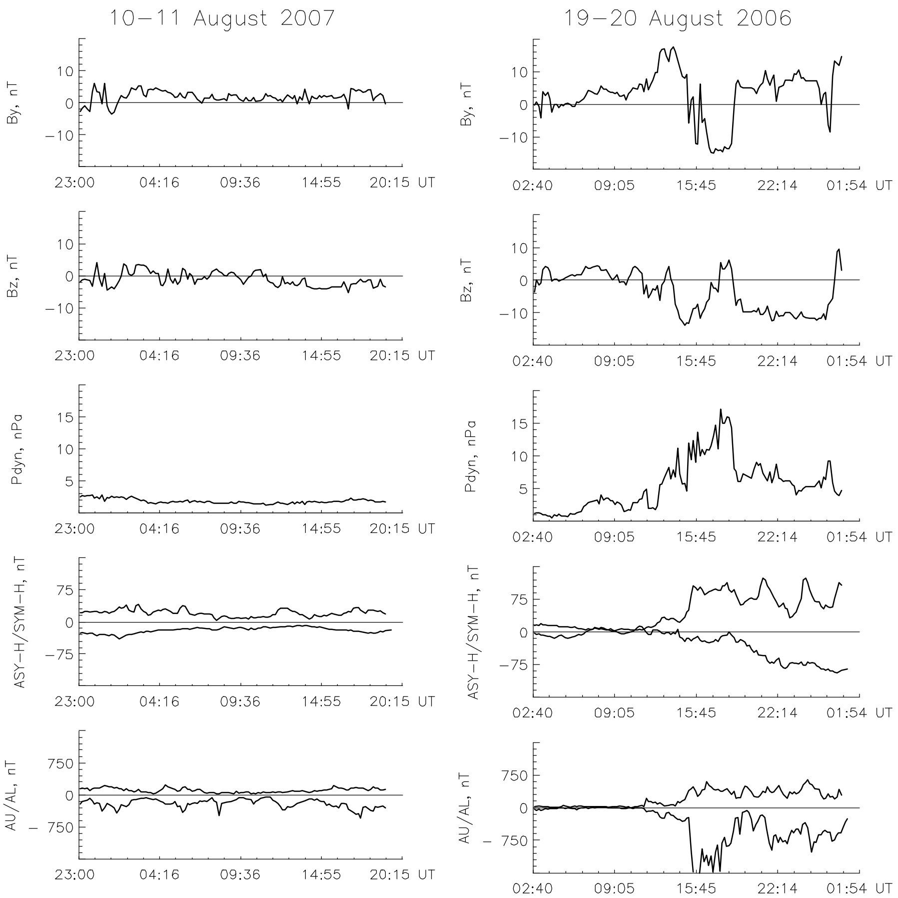

Figure 2. Variations of the IMF By and Bz components, the dynamic pressure Pdyn of the solar wind, and of the geomagnetic activity indices ASY-H, Sym-H, AU and AL for the interval of 10-11 August 2007 (left) and 19-20 August 2006 (right).

model magnetic field vectors and the geographic coordinates of the mapping along geomagnetic field lines from the satellite positions to an ionospheric level of 400 km.

On average, the ΔB (T01) value amounts to about 5.6 nT, ΔB (T96) to about 4.6 nT, while ΔB (PM) is near ~14.8 nT and almost everywhere in the positive range. The number of cases where ΔB is smaller for B (T01) than for B (T96) is 3 versus 7 with the inverted ratio. The average difference of the mapped geographic latitude positions using T01 and T96 is 0.72° and its longitudinal spread is 2.46°. The corresponding values for a comparison between the T01 and PM models are 2.46° in latitude and 14.3° in longitude, respectively. For some particular cases during geomagnetically disturbed conditions, the latitudinal difference of the mapped footpoints attains 3 °÷ 5°.

Conclusions

The compilation of magnetic field data, measured by FGM on board the Cluster satellites compared with T01, T96, and PM model values, mapped from the tail side magnetosphere into the ionosphere, shows the following:

1. The smallest deviations on average from the measured magnetic field in the magnetospheric tail is obtained by the T01 model. During the geomagnetically quiet example day it reaches ~4.2 nT, while it gains ~5.6 nT and ~9.5 nT for T96 and PM, respectively. The corresponding values for the disturbance day are ~10.9 nT (T01), ~16.0 nT (T96), and ~18.8 nT (ПМ). The best coincidence between measured and modelled tail magnetic field magnitude values is therefore obtained with the T01 model.
2. During disturbance intervals all three models concur in the fact, that the difference between observed and modelled magnetic field values is of the order of ~20 nT, but closer to perigee it grows to ~40 nT.
3 The mapping of satellite values from the magnetosphere into the ionosphere by use of the T01 and the T96 model differs on average by 0.72° in latitude and 2.46° in longitude. Comparing T01 and PM, the corresponding average values are 2.46° in latitude and 14.3° in longitude, increasing to 3°- 5° in latitude during disturbance intervals.
4. It would be very useful to have independent criteria, which allow to estimate the precision of the mapping along magnetic field lines from the magnetosphere into the ionosphere.

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Table. Magnetospheric magnetic field values as measured by Cluster C3 and obtained from the T01, T96, and PM models together with the results of the mapping along the magnetic field lines into the ionosphere at 400 km height.

Date	UT	Xgsm Re	Ygsm Re	Zgsm Re	R Re	BXgsm nT	BYgsm nT	BZgsm nT	|B|, nT	Geo Lat	Geo Long	
11.08.07	04:42	-14.58	-5.78	-10.66	18.96	-28.77	-3.68	-6.47	29.72			CL
						-30.47	-4.26	-4.53	31.09	-81.30°	85.96°	T01
						-27.91	-6.30	-5.21	29.08	-82.54°	88.00°	T96
						-22.52	-4.52	-4.74	23.46	-82.52°	43.55°	PM
19.08.06	12:19	-10.44	-4.32	-11.32	15.99	-60.48	-2.24	-14.36	62.20			CL
						-53.41	-2.88	-10.06	54.42	-81.61°	138.79°	T01
						-53.78	-9.06	-16.21	56.90	-81.06°	137.13°	T96
						-35.47	-5.83	-10.40	37.42	-84.01°	134.20°	PM
25.08.07	17:39	-10.31	-0.76	-11.93	15.79	-46.89	-1.90	-12.86	48.66			CL
						-41.58	-3.45	-10.91	43.12	-75.14°	127.32°	T01
						-37.76	-2.74	-14.04	40.37	-74.48°	126.37°	T96
						-31.72	-1.90	-10.33	33.41	-78.75°	110.22°	PM
02.09.06	20:50	-8.00	1.75	-12.47	14.92	-40.84	6.42	-20.35	46.08			CL
						-42.68	4.68	-17.45	46.34	-76.99°	128.45°	T01
						-37.48	5.10	-18.56	42.13	-76.59°	122.23°	T96
						-33.32	3.92	-14.81	36.67	-80.98°	97.51°	PM
01.11.05	00:14	-9.96	10.74	0.60	14.64	29.62	-20.10	5.56	36.22			CL
						17.41	-17.43	4.03	24.96	58.46°	294.86°	T01
						5.26	-15.20	13.52	21.01	59.62°	296.48°	T96
						20.60	-10.53	6.09	23.92	61.15°	290.74°	PM
11.09.02	00:56	-12.02	0.33	6.87	13.85	50.78	-5.43	-3.91	51.22			CL
						54.94	-0.84	-4.80	55.16	69.61°	318.84°	T01
						50.38	-0.85	-5.13	50.64	69.01°	320.31°	T96
						37.70	-0.60	-2.21	37.76	67.93°	320.79°	PM
21.08.05	10:39	-8.18	-1.93	7.52	11.27	57.10	7.39	-14.32	59.33			CL
						53.54	6.72	-9.02	54.71	69.48°	240.80°	T01
						54.24	7.18	-12.18	56.05	68.91°	239.84°	T96
						48.67	7.03	-7.18	49.70	69.69°	245.09°	PM
10.09.06	18:56	-9.27	-1.33	4.46	10.38	60.10	6.50	-2.38	60.50			CL
						57.88	2.67	3.72	58.06	74.11°	79.56°	T01
						59.76	4.10	-1.91	59.93	72.75°	79.20°	T96
						51.72	5.13	7.1	52.45	79.07°	61.28°	PM
31.10.05	16:56	-5.96	4.61	4.76	8.91	98.55	-54.52	-25.01	115.37			CL
						101.36	-53.49	-24.63	117.22	75.86°	37.79°	T01
						95.53	-61.39	-23.84	116.03	75.37°	45.97°	T96
						73.49	-51.64	-15.30	91.11	76.78°	21.35°	PM
05.10.03	23:35	-3.42	0.39	6.70	7.53	131.02	-10.50	-118.50	176.98			CL
						112.35	-14.95	-112.43	159.65	78.84°	309.36°	T01
						119.02	-15.51	-119.60	169.44	79.01°	308.24°	T06
						105.48	-11.78	-109.52	152.51	76.02°	312.23°	PM

References

Alexeev, I.I., E. S. Belenkaya, V.V. Kalegaev, Y.I. Feldstein, A. Grafe, Magnetic storms and magnetotail currents, *J. Geophys. Res*., 101, 7737 - 7747, 1996.

Balogh A., et al., The Cluster magnetic field investigations: overview of in-flight performance and initial results, *Ann.Geophys*., 19, 1207-1217, 2001.

Feldstein Y. I., A. E. Levitin, J. U. Kozyra, B. T. Tsurutani, A. Prigancova, L. Alperovich, W. D. Gonzalez, U. Mall, I. I. Alexeev, L. I. Gromova, L. A. Dremukhina, Self-consistent modeling of the large-scale distortions in the geomagnetic field during the 24–27 September 1998 major magnetic storm, *J. Geophys. Res.,* 110, A11214, doi:10.1029/2004JA010584, 2005.

Förster M., G. Paschmann, S. E. Haaland et al., High-latitude plasma convection from Cluster EDI: Variances and solar wind correlations, *Ann. Geophys*., 25, 1691, 2007.

Förster M., S. E. Haaland, Paschmann G. et al., High-latitude plasma convection during northward IMF as derived from in-situ magnetospheric Cluster EDI measurements, *Ann. Geophys*., 26, 2685, 2008.

Förster M., Y. I. Feldstein, S. E. Haaland, L. A. Dremukhina, L. I. Gromova, A. E. Levitin, Magnetospheric convection from Cluster EDI measurements compared with the ground-based ionospheric convection model IZMEM, *Ann. Geophys*., 27, 3077 - 3087, 2009.

Haaland S.E., G. Paschmann, M. Förster et al., High-latitude plasma convection from Cluster EDI measurements: method and IMF-dependence, *Ann. Geophys*., 25, 239, 2007.

Reme H., J. M. Bosqued, J. A. Sauvaud et al., The Cluster ion spectrometry (CIS) experiment, *Space Science Reviews*, 79, 303 – 350, 1997.

Tsyganenko N. A., Effects of the solar wind conditions on the global magnetospheric configuration as deduced from data-based field models, ESA SP-389, 181-185, 1996.

Tsyganenko N. A., A model of the near magnetosphere with a dawn-dusk asymmetry. 2. Parameterization and fitting to observations, *J. Geophys. Res.*, 107, 1176, doi: 1029/2001JA000220, 2002.

Woodfield E. E., M. W. Dunlop, R. Holme, J. A. Davies, M. A. Hapgood, A comparison of Cluster magnetic data with the Tsyganenko 2001 model, *J. Geophys. Res.*, 112, A06248, doi: 10.1029/2006JA012217, 2007.