Comparisons of eight years magnetic field data from Cluster with Tsyganenko models

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Abstract: An investigation comparing eight years of magnetic field data from the 4-spacecraft Cluster array with Tsyganenko 1989 (T89), 1996 (T96), and 2001 (T01) field models, while Cluster passes through, or adjacent to, the equatorial ring current, has been carried out, which extends that of Woodfield et al. (2007). The orbits sample the region slightly differently as a result of the changing dipole orientations through each perigee pass. There are therefore some differences in the comparisons of the data between the different models and between different spacecraft, and as a result of the changing magnetospheric location; also due to the progressive southward dropping of the Cluster orbit. The residual field values therefore have characteristic patterns during the period of the dataset. The study shows that the deviations between the data and the model take two forms: a sharp, bipolar signature and well-defined trends over a larger spatial region, where these residuals can reach ~20 nT near perigee. These deviations are much weaker during the later years, which might be because of the approach to the solar minimum. The well defined trends are interpreted as the main ring current signatures and during the ring current crossings (through perigee, at 4-5 Re), while the T01 and T89 models sometimes underestimate the ring current, the T96 always overestimates it. The sharp bipolar signatures are suggested to be Cluster crossings of the region 2 field-aligned currents (FACs) or low-altitude cusp FACs, depending on dayside or nightside orientation. Only the T96 and T01 models include forms for the region 2 FACs and T01 appears to model these better. Overall, the deviations for T01 are much weaker than for the other models, for all of field components, indicating that this model achieves the best fit to the data. The 4-spacecraft observe nearly the same signatures at the small separations achieved during the early years of the mission, but do sample different signatures at the large separations achieved during the later years. This allows spatial comparisons to be made during similar external conditions.

1. Introduction

We are carrying out an detailed comparison of eight years Cluster II data with the Tsyganenko magnetic field modes by extending the investigation of Woodfield et al. (2007) with the aim of improving external geomagnetic field modeling as part of the UK GEOSPACE consortium.

The scientific aims of GEOSPACE are to unravel and model the various sources contributing to the measured magnetic field and its time variation to a much higher degree of accuracy than previously achieved.

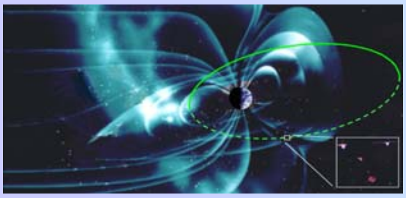
In this poster, we show the results of the extending analysis of comparison eight years magnetic field data from Cluster 4 spacecraft with Tsyganenko 1989 (T89), 1996 (T96), and 2001 (T01) field models.

2. Cluster II

The ESA Cluster mission is composed of an array of four spacecraft carrying identical payloads. The spacecraft were launched in pairs in July and August 2000 into elliptical, polar orbits with a perigee of 4 RE, an apogee of 19.6 RE and identical orbital periods of 57 hrs.

The separations of the spacecraft vary from a few hundred to several thousand km, so that the spatial scale was over 1500km after 2005 and about 300 km in 2003 & 2004.

Data with 4 sec resolution from the fluxgate magnetometer (FGM) onboard each Cluster spacecraft are used in this study.



3. Tsyganenko Magnetic Field Models

The Tsyganenko models are semi-empirical models of the magnetic field generated by external current sources in magnetoshere and therefore are useful tools for this study. Here, we consider 3 main versions:

-1989 (T89) –Field contributions from the tail current, ring current, return current, Chapman-Ferraro currents, field-aligned currents, are returned for input of tilt angle and Kp.

-1996 (T96) – In addition includes better optimisation and explicitly defined realistic magnetopause, large-scale Region 1 and 2 Birkeland current systems, and IMF penetration across the boundary. Input Parameters: tilt angle, Dst, Psw, IMFy, IMFz

-2001 (T01) – Current systems: are improved over the T96 model. Also includes a solar wind time history for the input parameters: tilt angle, Dst, Psw, IMFy, IMFz, G1, G2

Although a storm time version of T01 is available, most of the data set is not during a storm time in this study. We have used the International Geomagnetic Reference Field (IGRF) version 10 as our model of the Earth's internal magnetic field and Geocentric Solar Magnetic (GSM) coordinates are used throughout. In the following plots the residuals are $\mathbf{B}_{observed}$ - $\mathbf{B}_{model}$, and therefore a positive residual is an underestimate of the data.

Quasi-static (T89, Kp in 3 hours resolution) versus dynamic (T96 & T01, SYMH, solar wind and IMF in 1 min resolution) inputs are used for these comparisons.

4. Comparisons between different T models

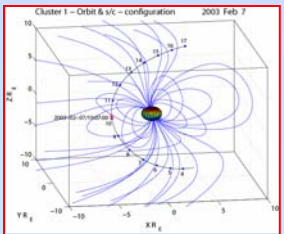


Fig.1 Orbit plot in GSM coordinates for orbit 402/403. Model geomagnetic field lines are drawn from the T01 model with the average inputting parameters: Pdyn= 1.25 nPa, IMF B_Y= -4.54 nT, IMF B_Z= -2.89 nT and DST= -36 nT.

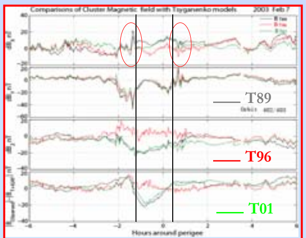


Fig.2 Residuals of T89 (black), T96 (red) and T01 (green) models on 7 Feb 2003. From top to bottom panels are for the X_{GSM}, Y_{GSM}, Z_{GSM} and the magnitude of the field. The red circle highlight the bipolar signatures thought as FACs and the black vertical lines show the ring current region crossing.

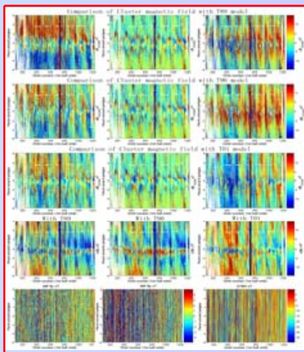


Fig. 3 Plots of the residuals for the whole eight years data. Each vertical strip is a section of an orbit – the x-axis is the orbit number, y-axis is time relative to perigee and the color scale is the value of dB_{XGSM}, dB_{YGSM}, dB_{ZGSM} (each row), for the nine panels of first three rows from T89, T96 and T01 respectively, the d|B| for the fourth row, the IMF B_Z, B_Y and SYMH.

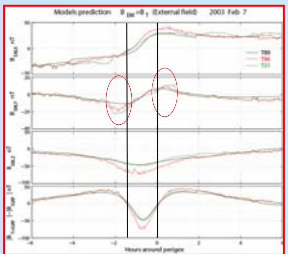


Fig. 4 External magnetic field predicted by T89 (black), T96 (red) and T01 (green) models on 7 Feb 2003. From top to bottom panels are for the X_{GSM}, Y_{GSM}, Z_{GSM} and the magnitude of the field. The red circle highlight the bipolar signatures thought as FACs and the black vertical lines show the ring current region crossing.

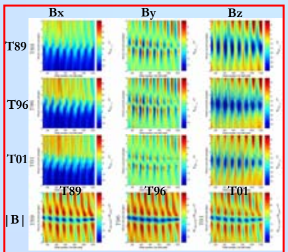


Fig.5 Plots of external magnetic field predicted by T89, T96 and T01at the Cluster S/C 1 positions for the whole eight years data. Each vertical strip is a section of an orbit – the x-axis is the orbit number, y-axis is time relative to perigee and the color scale is the value of dB_{XGSM}, dB_{YGSM}, dB_{ZGSM} (each row), for the nine panels of first three rows from T89, T96 and T01 respectively, and the |B| for the fouth row.

The two routes used for the comparisons: result in plots of the residuals (Figure 2 &3)and modeled (Figure 4& 5) external current contributions.

The models predicted the ring current shown as the trough in B_Z and |B| of the residuals around perigee (Figure 5), however, the residuals (Figure 3) show the T89 & T01 underestimate the ring current in earlier 4 or 5 years, while the T96 overestimate it for whole 8 years.

For T89, the dB_X component deviates much more than for the other models, whereas the dB_Y component is similar. The dB_x is overestimated in the pre-perigee crossing and underestimates in the post-perigee crossing (this affect is weaker for T96 and T01). The dB_Z behaviour is much more complicated, but is progressively underestimated during the later years, similar to T01.

For T01, all of the components of the deviations are much weaker than from the other models, indicating that this model achieves the best fit to the data. However, the residual trends have less meaning since the time varying input parameters return a time varying model field. T96 & T01 include Region 2 FACs; T96 overestimate the ring current.

There show clear ring current and FACs from the measured external current contributions, $\mathbf{B}_{observed}$-$\mathbf{B}_{IGRF}$ (Figure 6).

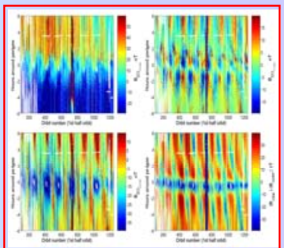


Fig.6 Plots of the residuals between observations and IGRF predictions at the Cluster S/C 1 positions for the whole eight years data.

5. Comparisons between 4-spacecraft

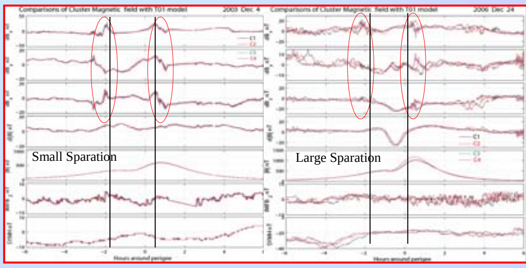


Fig. 7 Results from two orbits with different separations of Cluster 4 S/C on 4 Dec 2003 (small separation) and on 24 Dec 2006 (large separation). The x-axis is time relative to the perigee for each orbit. Top four panels are residuals (data-model) of magnetic field in GSM coordinates. Fifth panel shows the magnetic field magnitude from Cluster 4-S/C for the two orbits. Bottom two panels show the IMF B_Z and SYMH index for each case.

Small separation: 4 S/C almost observed same signatures at the same time; Large separation: 4 S/C observed same signatures one by one, and sometime observed different signatures. Local extent of FACs will be investigated in some detail by using the 4-spacecraft with a large separations in the later years (see Figure 8).

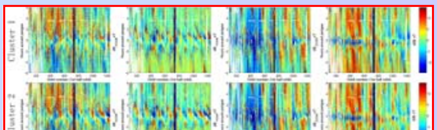


Fig. 8 Plots of the residuals between 4 S/C observations and T01 predictions at the Cluster positions for the whole eight years data.

6. Discussion:

The key results are listed in the abstract above. The measured residuals in Figure 3 show the T89 & T01 underestimate the ring current in earlier 4 or 5 years, while the T96 overestimate it for the whole 8 years. The deviations for T01 are much weaker than from the other models for all of field components, indicating that this model achieves the best fit to the data. Figure 5 shows that the modeled external magnetic field was stronger in B_X component and weaker in B_Y and B_Z components and |B| for T01 model. However, the time variation in input conditions causes similar deviations in B to those observed so that the detailed trends in the T01 residuals are sometimes less clear. Figure 6 attempts to show the absolute measured external field contributions relative to the IGRF only. We are developing a methodology to optimise the residuals relative to a quasi-static modeled field. The 4 S/C observe nearly the same signatures at the small separations during the early years of the mission, but do sample different signatures at the large separations during the later years. This will allow investigations of the local extent of FACs during similar external conditions.

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