AN INVESTIGATION OF THE FORM OF THE MAGNETOSPHERIC FIELD FROM THE TSYGANENKO 2001 MAGNETIC FIELD MODEL

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ABSTRACT

The Tsyganenko 2001 model is an empirically based model of the magnetic field generated by currents in the magnetosphere. Comparison of this model with data from the Cluster spacecraft shows an overall favourable similarity between the model magnetic field and that observed by the four spacecraft. Given this model is successful in general, we have performed a simple, initial investigation of the properties of the magnetospheric magnetic field using the model. We have looked at both quiet and active times to assess the impact on the removal of magnetospheric signals from satellite data and also the input to induction studies.

1. INTRODUCTION

The Tsyganenko 2001 model (T01) [1,2] estimates the magnetospheric magnetic field in a modular fashion from the main current systems. The major current systems have their own mathematical descriptions: Chapman-Ferraro (magnetopause), ring current, cross-tail current sheet and the large-scale field-aligned (Birkeland) currents. The final magnetic contribution included comes from the partial penetration of the interplanetary magnetic field (IMF) inside the model magnetopause; this is a potential magnetic field. The magnetic field strength from the other current systems is not assumed to be curl-free.

Many satellites have contributed to the data set used to fit the parameters in this model. Coverage is limited to the inner magnetosphere, $X_{GSM} > -15\ R_E$ (GSM, Geocentric Solar Magnetospheric coordinates). The merit function used to optimize the 2001 model is the root mean square deviation of the full vectors of the external field. This is in contrast to the 1996 version of the model [3] which used a directional merit function. For a full description of the data and fitting procedures see [2].

T01 is driven by five input parameters: Solar wind dynamic pressure, Solar wind speed, disturbance storm time index (Dst - or its high time resolution counterpart SYM-H [4]) and IMF components in the Y_{GSM} and Z_{GSM} directions. These inputs feed into various coefficients within the model – notably two parameters which keep track of the history of external inputs to the magnetosphere, this provides a time-history component to the driver.

2. METHOD

To assess the impact of this physical approach to modelling the current systems and the resultant magnetic field we have conducted a spherical harmonic analysis of the T01 model. A regular grid of synthetic data from T01 for steady interplanetary conditions was calculated at an altitude of 0 km. We have not included any internal or ionospheric magnetic field components since we are solely concerned with the magnetospheric contributions to the overall field. This was used to generate a set of Schmidt normalised Gauss coefficients [e.g. 5] up to degree 14 using a least squares technique. No damping has been used in this simple analysis (this will be applied in a future study).

3. RESULTS

All the following plots show the radial magnetic field component, B_r, calculated at 00:00 UT.

3.1. Quiet interplanetary conditions

Fig. 1 depicts B_r from the complete T01 model during quiet conditions (see Tab. 1). This includes all magnetospheric sources and their shielding terms (the shielding keeps the magnetic field generated by the individual currents within the magnetopause).

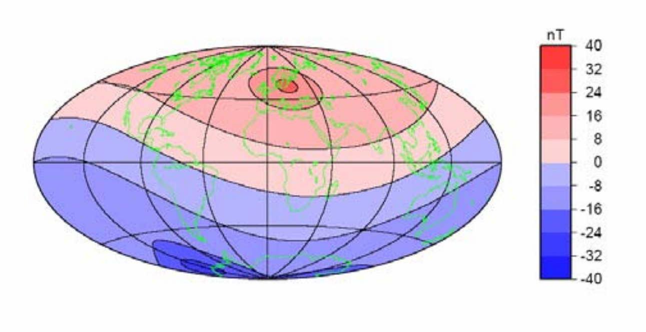

Figure 1. B_r from complete T01 during steady, quiet conditions.

	Quiet	Active
Solar wind speed, km s^{-1}	300.0	700.0
Solar wind density, cm^{-3}	5.0	5.0
IMF B_Y (GSM), nT	0.0	0.0
IMF B_Z (GSM), nT	-2.0	-20.0
Dst, nT	-2.0	-150.0

Table 1. Input parameters for T01.

The degree 0 term was included in the expansion and its value is reassuringly small (of the order of 10^5 times smaller than the degree 1, order 0 coefficient). The power spectrum, R_l, (Eq. 1) of the Gauss coefficients is shown in Fig. 2. Note that the power spectrum has a factor of l rather then $(l+1)$ because this is for the external magnetic field.

$$R_l = l\sum_{m=0}^{l}[(q_l^m)^2 + (s_l^m)^2]^{\frac{1}{2}} \qquad (1)$$

This spectrum is clearly noisy from degree 4 onward, it is unclear whether this extends back to degree 3. (Note that the power spectra given here are corrected versions of those shown in the poster). If we assume degrees 1 and 2 to be valid then there is a small contribution to the field structure from the quadrupolar term.

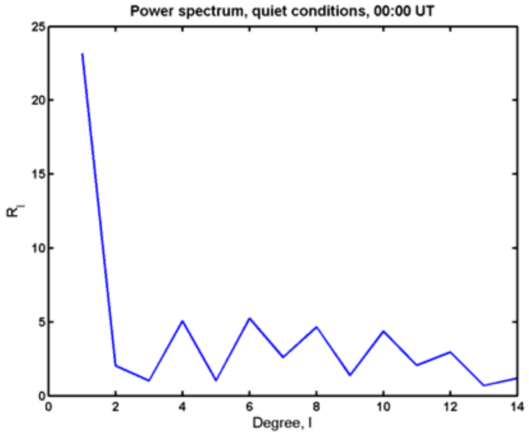

Figure 2. Power spectrum from the Gauss coefficients for quiet conditions

It is possible to split up the various contributing current systems of T01 and assess their individual impact (Fig. 3). Each module also contains its shielding term (for more details about how the shielding is achieved see [1]). So for example, the ring current part includes a shielding term as well as the contribution direct from the ring current. As a consequence, Fig. 1 is not a simple sum of the values in the plots of Fig. 3.

The striping in Fig. 3(c) and (e) is a processing artefact, the result of either very small values for B_r or possibly the result of not using any damping with the least squares fit. For example, the minimum and maximum for the IMF penetration case (Fig. 3(e)) are -1.15 and +1.15 nT respectively. This does not affect the total magnetospheric input to the magnetic field as shown in Fig. 1 since the magnitude of the contributions when combined is sufficiently large. The general non-dipole nature of the field-aligned current contribution does appear to be genuinely present in T01 (see section 3.2).

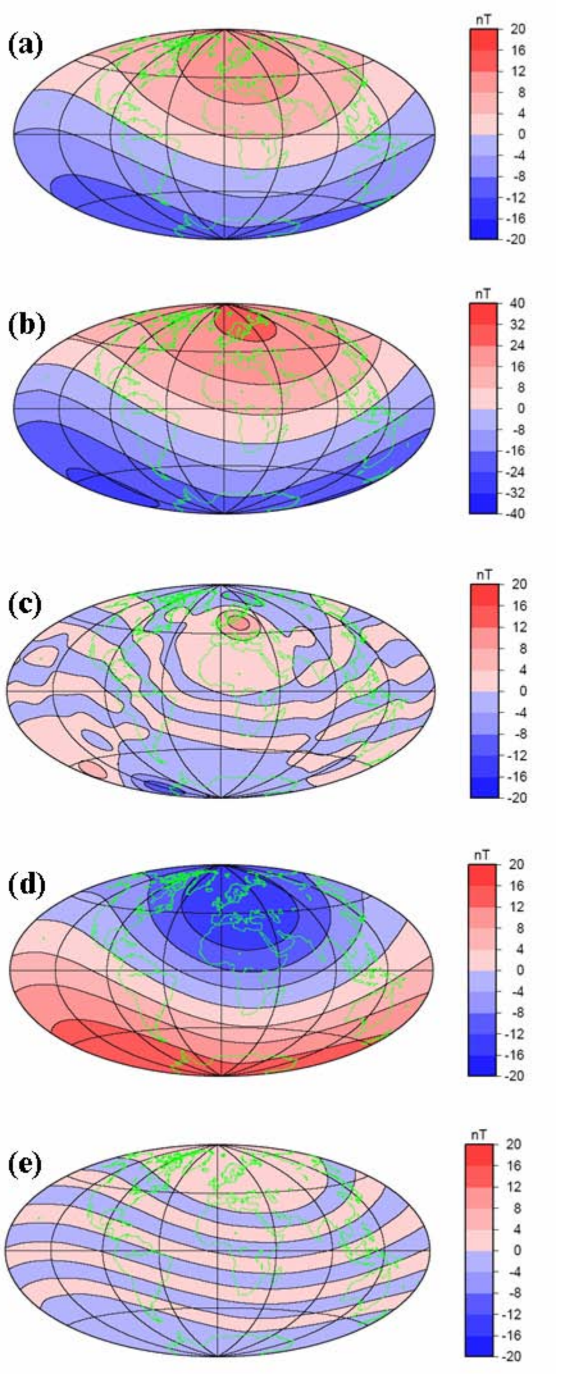

Figure 3. B_r during quiet conditions from: (a) ring current, (b) tail current, (c) field-aligned currents, (d) magnetopause current and (e)IMF penetration.

If an interplanetary east-west magnetic field component (B_Y=10 nT) is added to the quiet conditions, the total Tsyganenko output changes to that shown in Fig. 4. The clock angle in this case is 101° (clock angle is measured clockwise from positive B_Z in the GSM coordinate system), previously it was 180° with the purely southward IMF. There is undoubtedly a change in the structure of the magnetospheric field due to the change in clock angle although the effects are small. The most likely candidate for the changes is the field-aligned currents since they are strongly influenced by the IMF clock angle. This will be investigated at a later date.

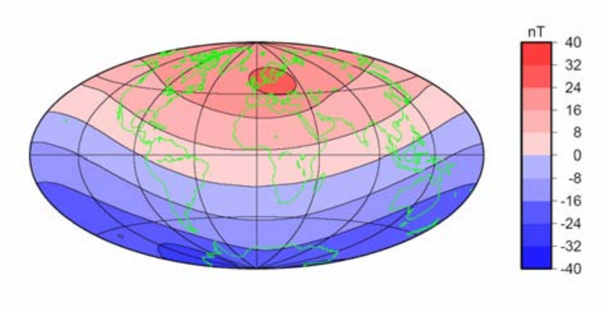

Figure 4. B_r from complete T01 during steady, quiet conditions with additional B_Y=10 nT.

3.2. Active interplanetary conditions

A similar analysis has been applied to active interplanetary conditions; Fig. 5 shows the results of applying steady active conditions (see Tab. 1). Note the values on the colour scale for B_r have increased by a factor of ten from Fig. 1.

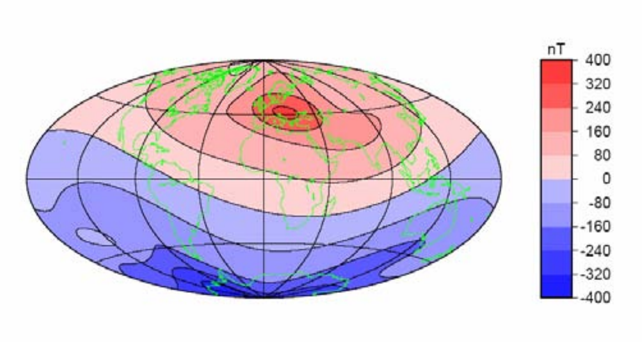

Figure 5. B_r from complete T01 during steady, active conditions.

The corresponding power spectrum is given in Fig. 6. As before, the degree 0 term is very small compared to the degree 1, order 0 coefficient (a factor of 10^5 smaller). The shape of the active power spectrum is distinctly different from the quiet case in the previous section. The active magnetosphere model has significantly more non-dipole power as we might expect. It is difficult to say at which degree the spectrum becomes dominated by noise rather than signal, but it appears that the generally larger signal due to the increased activity prevails over the noise beyond degree 2, possibly as far as degree 6.

The breakdown of the active conditions into the various components works much better at this higher activity level (Fig. 7) – all contributions except the FAC are mostly dipolar. There is a noticeable asymmetry in the ring current field, a result of the now more powerful partial ring current.

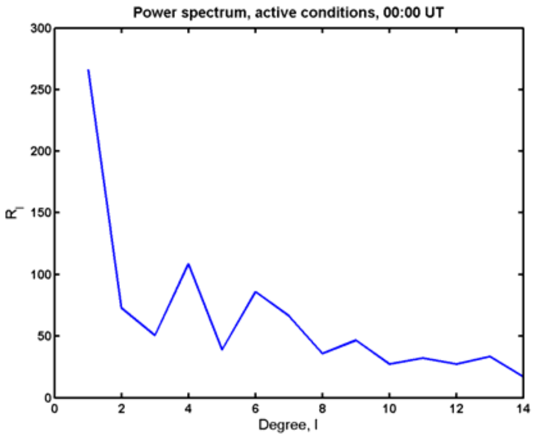

Figure 6. Power spectrum from the Gauss coefficients for active conditions.

If an interplanetary east-west magnetic field component is added to the above conditions (B_Y=10nT), the total T01 output changes as it did for quiet conditions (Fig. 8). Note that the IMF clock angle does not change as much as for the quiet case since B_Z is larger (clock angle now 153°). The asymmetry has nevertheless been further increased by the change in B_Y.

4. DISCUSSION

The form of T01 clearly produces an asymmetry in the magnetospheric magnetic field during active times as expected. There is also a small shift in the overall magnetospheric field at quiet times when there is an east-west component to the IMF.

An estimate of the location of the dipole axis (dipole centred at origin) for the 00:00 UT active case gives the northern pole at geographic latitude 64.3°N and longitude 27.9°E; for the quiet case, 65.9°N , 29.7°E. These two results seem remarkably similar. With the additional B_Y=10 nT, the active case gives a dipole location at 64.8°N, 24.3°E; quiet at 67.5°N, 4.8°E. It appears that the larger change in the clock angle in the quiet case has a significant effect on the pole longitude.

The partial ring current is clearly a major influence on the symmetry of the system at active times. At this stage in our investigations it is unclear precisely which other components contribute to the increased asymmetry, particularly when the IMF B_Y is non-zero. It seems likely that the field-aligned currents are partly responsible since they are influenced by the IMF clock angle. With this in mind we will be conducting a more detailed analysis of the effect of clock angle on the various components as well as the complete output of T01.

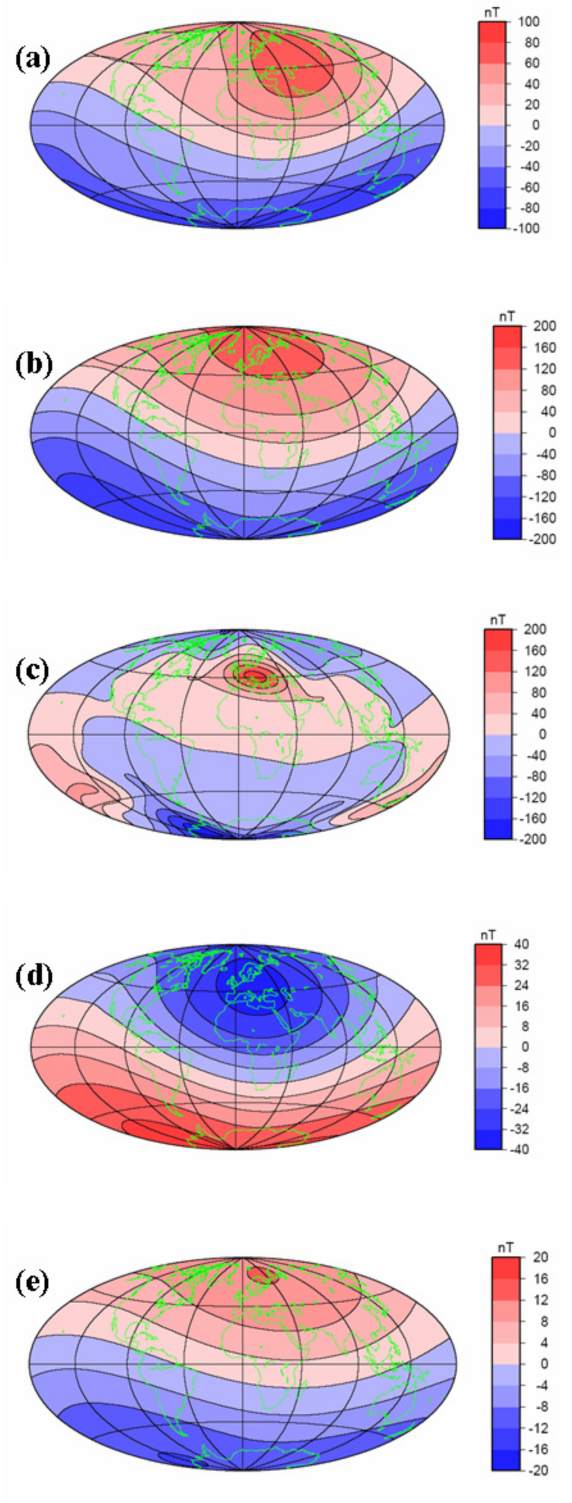

Figure 7. B_r during active conditions from: (a) ring current, (b) tail current, (c) field-aligned currents, (d) magnetopause current and (e)IMF penetration .

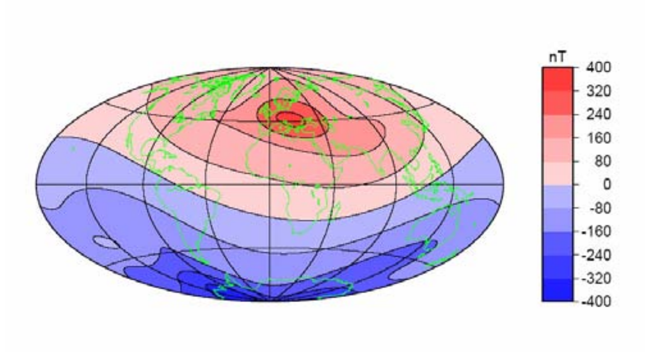

Figure 8. B_r from complete T01 during steady,acive conditions with additional B_Y=10 nT.

The T01 treatment of field-aligned currents is necessarily complex, but there is one simplification that may affect the results presented here. The closure of the currents is assumed to occur at the centre of the Earth, not in the ionosphere as in reality. Tests performed in [1] on the validity of this approach showed that this is a reasonable approximation; however, our use of T01 at 0 km altitude may be introducing unwanted effects. A future study will compare the application of T01 at a greater altitude and then applying downward continuation to the current results.

5. CONCLUSIONS

As expected, the primary shape of the magnetospheric magnetic field is dipolar. The field-aligned current contribution is the only field that shows up as being particularly non-dipolar under all conditions; the ring current becomes asymmetric under active conditions. Even under quiet conditions there is a small quadrupolar input to the magnetic field structure.

We plan to introduce a damping parameter to the least-squares fitting to lessen the influence of noise on the results. Then we will undertake a more full investigation of the effect of clock angle and a wider range of activity levels.

6. REFERENCES

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7. ACKNOWLEDGEMENTS

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