An investigation of the form of the magnetospheric field from the Tsyganenko magnetic field models

GEOSPACE

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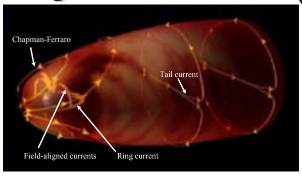
1 Abstract

The Tsyganenko models are empirically based models of the magnetic field generated by currents in the magnetosphere. The major current systems in this region have their own mathematical descriptions: Chapman-Ferraro (magnetopause), ring current, cross-tail current sheet and the large-scale field-aligned (Birkeland) currents. The last magnetic contribution included comes from the partial penetration of the interplanetary magnetic field inside the model magnetopause; this part is a potential magnetic field. The magnetic field strength from the other current systems is not assumed to be curl-free.

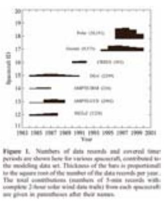
Comparisons of these models with data from the Cluster spacecraft show an overall favourable similarity between the model magnetic field and that observed by the four spacecrafts (Cluster data were not included in the data fitting process for the models and are therefore an independent measure of their success). Given these models are reasonably successful in modelling reality, we have investigated properties of the magnetospheric magnetic field using the models. 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.

2 Tsyganenko magnetic field

The Tsyganenko 2001 model [Tsyganenko, 2002a;b] estimates the magnetospheric magnetic field in a modular fashion from the main current systems (see right).

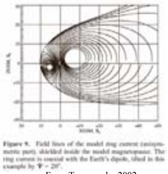


Many satellites have contributed to the data set used to fit the parameters in this model. The figure to the left (taken from Tsyganenko, 2002b) shows the temporal coverage of the data. Coverage is limited to $X_{GSM} > -15\ R_E$.



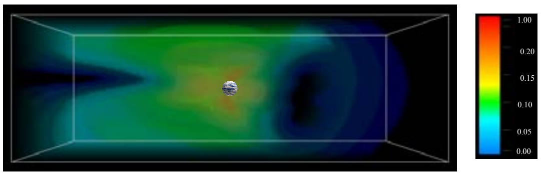
From Tsyganenko, 2002b

The figure on the right (taken from Tsyganenko, 2002a) shows the model ring current for a dipole tilt angle of 20°.



From Tsyganenko 2002a

Below is a representation of normalised magnetic field magnitude of the Tsyganenko 2001 model for quiet to moderate conditions viewing the X-Z (geocentric solar magnetic) plane.



The merit function used to optimize the 2001 model is the rms deviation of the full vectors of the external field.. This is in contrast to the 1996 version of the model which used a directional merit function.

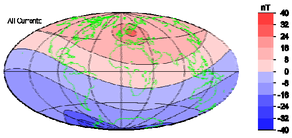
The input parameters used in the 2001 model are Solar wind speed, dynamic pressure (derived from Solar wind speed and density), Dst, interplanetary B_Y and B_Z. A time history is also included using two parameters G_1 and G_2 which are derived from the inputs already mentioned.

3 Method

- Assemble a regular grid of synthetic data from the Tsyganenko 2001 model for given steady interplanetary conditions at an altitude of 0 km.
- Use this data to generate a set of Schmidt normalised Gauss coefficients up to degree 14.
- Plot the results in terms of the radial magnetic field component.

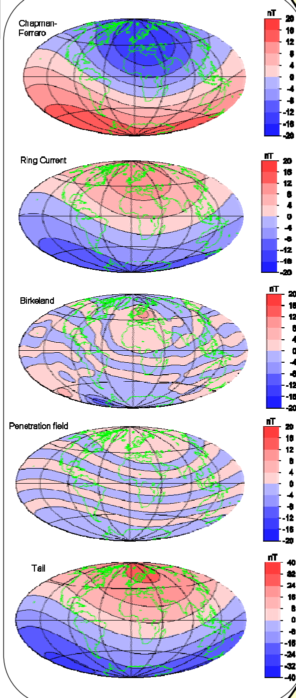
4 Quiet times

- Solar wind speed = 300 kms^{-1}
- Solar wind density = 5.0 cm^{-3}
- Interplanetary B_Y = 0.0 nT
- Interplanetary B_Z = -2.0 nT
- Dst = -2.0 nT



The plot to the left shows the radial magnetic field from the complete Tsyganenko 2001 model. This includes all magnetospheric sources and their shielding terms. It does not include an internal field, or any ionospheric terms.

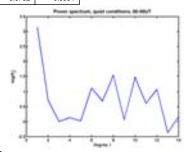
On the right are the various parts of Tsyganenko 2001. The individual terms include their own shielding term. So for example, the ring current part includes a shielding term as well as the contribution direct from the ring current. As a consequence, the plot at top left is not a simple sum of those on the right.



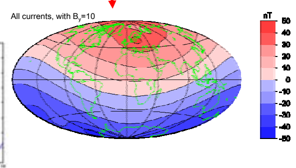
Degree	Order	g	h
0	0	-0.0008	
1	0	16.0294	
1	1	6.2208	3.5456
2	0	1.7728	
2	1	0.3553	-0.3859
2	2	-0.3859	-0.1055
3	0	-0.0703	
3	1	-0.1350	-0.1192
3	2	-0.1192	0.1084
3	3	0.1084	0.0071
4	0	0.0053	
4	1	0.0594	0.0586
4	2	0.0586	0.0254
4	3	0.0254	0.0364
4	4	0.0364	0.0292
5	0	0.0234	
5	1	-0.3927	-0.0013
5	2	-0.0013	-0.1549
5	3	-0.1549	0.2687
5	4	0.2687	0.0732
5	5	0.0732	0.0954

The table on the left contains the first 5 degrees of the spherical harmonic fit. (These are Schmidt normalised.) The degree 0 term is reassuringly small.

Below the table, on the left, is a plot of the power spectrum.

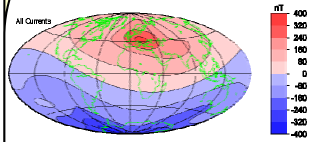


If an interplanetary east-west magnetic field component is added to the above conditions (+10nT), the total Tsyganenko output changes slightly.

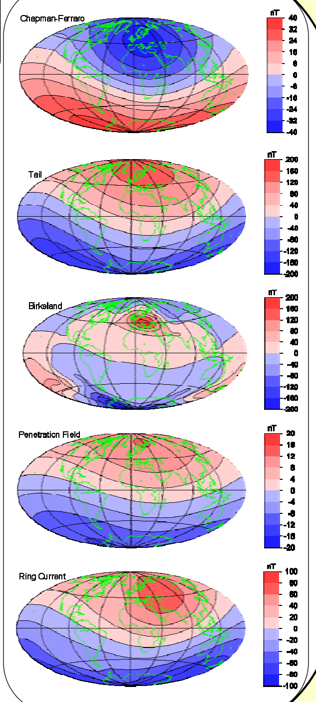


5 Active times

- Solar wind speed = 700 kms^{-1}
- Solar wind density = 5.0 cm^{-3}
- Interplanetary B_Y = 0.0 nT
- Interplanetary B_Z = -20.0 nT
- Dst = -150.0 nT



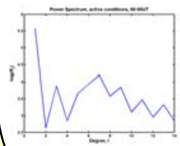
The plots to the left and right are as in section 4 but for active conditions.



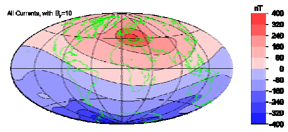
Degree	Order	g	h
0	0	0.0048	
1	0	179.6146	
1	1	76.4130	40.4880
2	0	20.2440	
2	1	-14.7107	11.4224
2	2	11.4224	6.5172
3	0	4.3448	
3	1	2.9092	4.8445
3	2	4.8445	-0.3361
3	3	-0.3361	7.1485
4	0	5.3614	
4	1	-0.6842	-3.8097
4	2	-3.8097	0.0059
4	3	0.0059	-2.6361
4	4	-2.6361	-1.7840
5	0	-1.4272	
5	1	-9.1921	-0.7395
5	2	-0.7395	-2.4663
5	3	-2.4663	4.4595
5	4	4.4595	3.0186
5	5	3.0186	1.7887

The table on the left contains the first 5 degrees of the spherical harmonic fit for the active conditions. Again, the degree 0 term is small.

Below the table on the left is a plot of the power spectrum.



If an interplanetary east-west magnetic field component is added to the above conditions (so now B_Y=10 nT), the total Tsyganenko output changes slightly as for the quiet conditions. Note that the interplanetary magnetic field clock angle does not change as much as for the quiet case with the same B_Y , since B_Z is so much larger now. (Clock angle is clockwise from positive B_Z axis in the geocentric solar magnetospheric coordinate system).



6 Discussion

As expected, the primary shape of the magnetospheric magnetic field is dipolar. 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 to be 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. The larger change in clock angle in the quiet case shows up in the pole location as one might expect.

The field-aligned current contribution is the only magnetic field that shows up as being particularly non-dipolar, although the ring current of course becomes asymmetric under storm conditions.

References

N.A. Tsyganenko, A model of the near magnetosphere with a dawn-dusk asymmetry: 1. Mathematical structure, J. Geophys. Res., 107, 10.1029/2001JA000219, 2002a.

N.A. Tsyganenko, A model of the near magnetosphere with a dawn-dusk asymmetry: 2. Parameterization and fitting to observations, J. Geophys. Res., 107, 10.1029/2001JA000220, 2002b.

Acknowledgements

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