TS07D Magnetic Field Model Data Products Users Guide

Table of Contents

Overview 1

TS07D Model 2

TS07D Geomagnetic Field Model Data Products 3

TS07D Coefficients 3

File Format 3

Naming Convention 4

Availability 4

Use 4

TS07D Magnetic Field Potential Cubes 6

File Format 6

Cube sizes 7

Naming Convention 8

Availability 8

Use 8

TS07D Magnetic Ephemeris Files 8

File Format 8

Naming Convention 9

Availability 9

# Overview

Magnetospheric and radiation belt sciences can often benefit from having accurate and dynamic magnetic field models and the associated magnetic vector potentials. Additional, the third adiabatic invariant is an important quantity to define the dynamics of stably trapped particles in a slowly changing magnetic field. Often times, realistic and time-varying models will be exceptionally computationally expensive when compared to simple dipole approximations. Additionally, realistic magnetic field models are complex, demanding the magnetic vector potential and the third invariant to be computed numerically, while the dipole approximation has simple analytic values. This results in many studies to simply ignore such models.

A potential solution to this challenge, is to precompute the field vectors on time varying cubes. The evaluation of the model is now comprised of an interpolation of the identified vectors within the cubes.

Here we present a variety of magnetic field derived data products using the TS07D empirical magnetic field model. The products are available on the Van Allen Probes Science Gateway [webpage](http://rbspgway.jhuapl.edu/analysis_models).

## TS07D Model Description

The Tsyganenko and Sitnov magnetic field model (Tsyganenko and Sitnov, 2007), hereinafter called TS07D, is dynamical and high-resolution model of the external magnetic field of the Earth’s magnetosphere caused by electric currents external to the Earth. This model contrasts from the classical Tsyganenko models by replacing the predefined equatorial electric current systems (symmetric ring, partial ring, and tail currents) with a single current system described using a Basis-function expansion. This allows the model to reconstruct potential asymmetries and other morphological features that were missing from the hand-made description of these current systems. The Figure below demonstrates the difference in the reconstructed equatorial currents between the TS05 model and the TS07D model.



Each term in the equatorial expansion is accompanied by a scalar coefficient. In the classical models, each of these coefficients would be made a function of some combination of solar wind inputs. Owing to the large number of coefficients in the expansion, this is no longer practical, so a different dynamic binning technique is applied based on ‘Nearest Neighbors’ (<https://en.wikipedia.org/wiki/Nearest_neighbor_search>). The global state of the magnetosphere’s magnetic field configuration is assumed to be a function of a limited set of solar wind and global parameters. This set of parameters then forms the basis for an n-dimensional parameter space, where every moment in time represents a point in this space. Within an n-dimensional sphere of this point, will be other moments in time when the magnetosphere’s magnetic field configuration was most similar to the instant we are attempting to model. In the TS07D model, the parameter space is chosen to capture the dynamics of magnetosphere on geomagnetic storm time scales. The parameter space is defined by the solar wind electric field (*vBz*), the storm strength as measured by the *SymH* index, and the storm phase as measured as the time derivative of the *SymH* index. This follows the Burton-McPherson-Russell formulism [Burton et al., 19??], which relates these three parameters. These parameters are smoothed, in order to minimize the impact of higher frequency features such as substorms, and are then normalized. The source of these is the OMNI database (<https://omniweb.gsfc.nasa.gov>), which is derived from ACE, WIND, and the IMP-8 spacecraft and has been time delayed to the bowshock nose.

Additionally, the dynamic pressure of the solar wind (also derived from the OMNI database) and the dipole tilt angle, defined as the angle between the *+Z* axis of the Geocentric Solar Magnetic (herein GSM) coordinate system and the dipole magnetic axis, are explicit built in parameters to the model and must also be supplied as inputs to the model.



# TS07D Geomagnetic Field Model Data Products

## TS07D Coefficients

As described above, the model has several necessary inputs including a set of coefficients dynamic coefficients that are fit for each moment of time in the model. The cadence for these files was chosen to match the five minutes of the OMNI data files from which the ‘Nearest Neighbor’ parameter space was constructed.

A note on terminology, the use of the term parameter and coefficient are often ambiguous. Sometimes coefficient is used to represent the scalar multiplier in a linear combination and often comes up in linear regression. However, the term parameter is often used to describe unknown quantities within an analytic model, and thus more often associated with nonlinear regression. Other times, parameter is used to denote that a scalar value is unknown or unspecified while in contrast a coefficient is a known or previously solved for value. Given that the TS07D model contains both linear and non-linear elements and we may be discussing the model parameters or their solved values, historically the terms have been used interchangeable. For clarity in this document, we will stick to the term coefficient for all the solved scalar values (both linear and nonlinear) that are in the model.

### File Format

The coefficients are written out as text files, using the .par extension. Each line contains one coefficient for the model and can be read using the FORTRAN/IDL format statement ‘G15.6’. Following the value is a brief description of the coefficient. Following the coefficients, the end of the file contains six line of additional information, where Q is a modified form of and is a representation of the goodness of fit. B\_rms represents the root mean square of the magnetic field values used in the fit. These two values are only available on hourly files. M represents the number of azimuthal expansions and N represents the number of radial expansions used in the portion of the model describing the equatorial current systems. The final two lines of the file contain the two global parameters that are explicitly built into to the model structure, and must be supplied when constructing the model, that is the Pdyn or the dynamic pressure of the solar wind and tilt representing the tilt angle between SM and GSM coordinate system.

1.00000 # dipole shielding field amp.

-12.8487 # n-1 eq. amp.

. . .

. . .

5.21083 # m-4 n-5 even \* sqrt(pdyn) eq. amp.

0.424873 # reg-1 M-1 asym. amp.

0.108123 # reg-1 M-2 asym. amp.

-0.138204 # reg-2 M-1 asym. amp.

0.0711830 # reg-2 M-1 sym. amp.

2.78264 # current sheet thickness

8.48790 # hinge distance

27.4807 # warping parameter

1.08288 # reg-1 scaling

1.62288 # reg-2 scaling

-0.000118300 # twist factor \* 10

Q= -9999.99

B\_rms= -9999.99

M= 4

N= 5

Pdyn= 1.06000

tilt= -0.182722

### Naming Convention

The following naming convention is used:

**year\_doy\_hh\_mm.par**

And a day worth of files are compressed into tarballs, which use the following:

**year\_doy.gzip**

### Availability

The coefficients are available on the Van Allen Probes science gateway at the following link: <http://rbspgway.jhuapl.edu/new_coeffs_mag_models>, for the years 2012 through the present given the availability of the OMNI database.

Because there are a large number of files (~100,000 per year) the coefficient files have been compressed as tarballs (.tgz) on daily, yearly, and a file containing all the coefficients.

### Use

A sample FORTRAN program is included on the Van Allen Probes Science gateway at the following link:

<http://rbspgway.jhuapl.edu/sites/default/files/SpaceWeather/SAMPLE_MODEL_CODE.for>.

Firstly, the static shielding coefficients are read using the supplied files and the values are stored in arrays. This set of coefficients only needs to be loaded once and is a constant for all moments. The program then reads the variable coefficients and stores these values in an array. The dynamic pressure is then provided and the dipole tilt is computed using the Geopack library. Alternatively, these two inputs have been appended to the end of the TS07D

## TS07D Magnetic Field Cubes

The TS07D model is computationally expensive, particularly in computations where the model may need to be evaluated millions of times, such as particle tracing and numerical computation of magnetic field derived quantities like Euler potentials and L\*. Precomputing these field values and writing the vectors to a cube file provides a significant increase in evaluation speed. The computation is then a simple lookup into the cube and an interpolation of the values on the adjacent cube vertices to the location of interest. The TS07D model magnetic field output has been computed using the aforedescribed coefficients and written out to files containing the cubed data using the VTK image data format.

### File Format

The magnetic field and magnetic vector potential cubes are written out to VTK image data files (.vti). It is a commonly used format for several visualization tools, including the *Visualization Toolkit*, *Paraview*, and *VisIt*.

The top of these files contains XML lines that define the metadata and layout of the files. Following this is the keyword “AppendedData” which contains a block of binary data consisting of the single precision components of the magnetic field vectors.

Please see the VTK file format [PDF](http://www.vtk.org/wp-content/uploads/2015/04/file-formats.pdf.) for more details.

### Cube Description

<?xml version="1.0"?>

<VTKFile type="ImageData" version="0.1" byte\_order="LittleEndian">

<ImageData WholeExtent="-80 60 -80 80 -40 40" Origin="0 0 0" Spacing="0.20 0.20 0.20">

<Piece Extent="-80 60 -80 80 -40 40">

<PointData Vectors="B">

<DataArray type="Float32" Name="Bext" NumberOfComponents="3" format="appended" offset="0"/>

</PointData>

</Piece>

</ImageData>

<AppendedData encoding="raw">

\_...data…

</AppendedData>

The dimensions of the cubes in physical coordinates are +12 to -16 Earth Radii in the x-GSM direction, +16 to -16 RE in the y-GSM direction, and +8 to -8 RE in the z-GSM direction. The grid spacing in all three dimensions is 0.20 RE. This results in a cube that is large enough to perform line traces for the vast majority of the Van Allen Probes spacecraft locations, but small enough to allow the cubes to be manageable. Also, to limit the size of the cubes, the vector values are stored in single precision (4-byte real). This yields a cube that is approximately, 22 MB in size.

dx=dy=dz = 0.2 RE

+16

+16

Y-GSM

X-GSM

Z-GSM

-16

+12

-8

+8

### Naming Convention

The following naming convention will be used for the magnetic field cube files:

**ts07d\_bfield\_cube\_year\_doy\_hh\_mm.vti**

### Availability

The coefficients are available on the Van Allen Probes science gateway at the following link: <http://rbspgway.jhuapl.edu/bfield>.

Because of the size (~22 MB) and number of the files (~100,000 per year) the coefficient files you must click through yearly and day-of-year links.

### Use

The magnetic field cubes can immediately be read using a variety of visualization software that supports the VTK format, such as ParaView and VisIt. Additionally, a sample FORTRAN program is included on the Van Allen Probes Science gateway at the following link:

<http://rbspgway.jhuapl.edu/sites/default/files/SpaceWeather/bfieldCube.for>.

The sample program shows how the file can be read and the values of the cube stored in a four dimensional array (three for the cube dimensions and one for the vector values), and then how the values in this array can be interpolated to yield the external magnetic field vectors.

## TS07D Magnetic Ephemeris Files

The magnetic ephemeris files include important magnetic field derived quantities that are defined along the trajectory of the Van Allen probes spacecraft, including the second and third invariant. Additionally, these files include the Geophysical coordinates.

### File Format

|  |  |  |  |
| --- | --- | --- | --- |
| Column #’s | Title | Units | Description |
| 1 | Time | N/A | The UT time |
| 2 | TiltAng | deg | The dipole tilt angle |
| 3 | DipoleL | RE | The dipole L-shell |
| 4-6 | Xgeo, Ygeo, Zgeo | RE | The spacecraft position in GEO coordinates |
| 7-9 | GeodLat, GeodLon, GeodHeight | deg, deg, RE | SC pos. in Geodetic |
| 10-12 | Xgsm, Ygsm, Zgsm | RE | SC pos. in GSM coordinates |
| 13-15 | Xsm, Ysm, Zsm | RE | SC pos. in SM coordinates |
| 16-18 | Xgei, Ygei, Zgei | RE | SC pos. in GEI coordinates |
| 19-21 | Xgse, Ygse, Zgse | RE | SC pos. in GSE coordinates |
| 21-24 | CD\_MLAT, CD\_MLON, CD\_MLT, CD\_R | deg, deg, deg, RE | SC pos. in centered dipole coordinates |
| 25-27 | BTotXgsm, BTotYgsm, BTotZgsm | nanoTesla | The modeled total magnetic field at the SC pos. in GSM coordinates |
| 28-36 | L\*10.00, L\*20.00, …, L\*90.00 | RE | The second invariant for a given pitch angle |
| 37-45 | I\*10.00, I\*20.00, …, I\*90.00 | RE | The third invariant for a given pitch angle |
| 46 | FTVolume | RE/nT | The flux tube volume |

### Naming Convention

The following naming convention will be used for the magnetic field cube files:

**ts07d\_rbspa\_magephem\_year\_doy\_hh\_mm.vti**

**ts07d\_rbspb\_magephem\_year\_doy\_hh\_mm.vti**

### Availability

The TS07D magnetic ephemeris files are available on the Van Allen Probes science gateway at the following link: <http://rbspgway.jhuapl.edu/SGMagEphem>.