EPSC Abstracts
Vol. 9, EPSC2014-540-1, 2014
European Planetary Science Congress 2014

Modeling the internal magnetic field of Mercury with the Time Dependent Equivalent Source Dipole method

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Abstract

We model the internal magnetic field of Mercury as measured by the MESSENGER probe during its first year. We introduce a new modeling technique, the Time-Dependent Equivalent Source Dipole approach (TD-ESD). At a given location, the measured magnetic field is assumed to result from the sum of the contributions of individual dipoles located deep inside Mercury's interior which may vary with time to reflect the temporal variation of the Hermean magnetic field. We report first models computed with the TD-ESD method using only Mercury's sideral days separately. We discuss the time-evolution of the modeled field and compare it to the time-evolution of the residuals. There is a strong correlation between these two quantities, which confirms that external magnetic fields are somehow affecting the modeled, supposedly internal, field. We also compute a mean model using a complete solar day and find that most of the external fields are reduced. The mean magnetic equator at 200 km altitude is found at 10°N latitude on average, corresponding to a g_2^0/g_1^0 ratio of 0.28.

1. Introduction

The internal magnetic field of Mercury is much weaker than the value expected from a magnetostrophic force balance. Explaining this feature is one of the objectives of the MESSENGER spacecraft which has been in orbit around Mercury since 2011. It flies on a very elliptical, near-polar orbit, with a periapsis at 200 km altitude in the northern hemisphere. Because of the weak internal magnetic field, MESSENGER is inside the Hermean magnetosphere only during a short portion of its orbit, and data with a good internal to external field ratio are available only above the northern hemisphere.

Global methods such as the spherical harmonics analysis are therefore not directly applicable without using regularizations that would introduce some arbitrariness. We apply a new method, the TD-ESD, in order to model the Hermean internal magnetic field above the northern hemisphere.

2. Method

The ESD method was developed to reduce to a common altitude shallow, static and induced magnetic fields of lithospheric origin [1]. It has been adapted to the case of remanent magnetic fields on Mars, where all three components of the measured magnetic field are used to constrain the three components of the magnetization [2, 3]. Here we add two new features, a deeper localization of the sources (inside the core of Mercury), and a time-varying magnetization, to model and describe Mercury's internal magnetic field.

This new approach has been validated for measurements predicted on regular grids at 300, 400 and 500 km altitudes (ideal case) and along MESSENGER orbits (realistic case), with a synthetic geomagnetic field model scaled to the size of Mercury. In both cases the field is successfully recovered at measurement altitude.

To further quantify this method we also tested different altitudes at which we can upward or downward continue the modeled magnetic field. For the ideal case the magnetic field can be predicted between -300 and 1400 km altitudes with an error lower than 8% with respect to the initial scaled model. For the realistic case this range is reduced to -50 to 1000 km with the same error level.

3. Application to MESSENGER data

TD-ESD is applied to the first four coverages separately, each one corresponding to one Mercury sideral day. Modeled magnetic field maps at body-fixed coordinates are obtained at 200 km altitude, for each coverage. In these maps we find small scale magnetic field features rotating around the planetary rota-

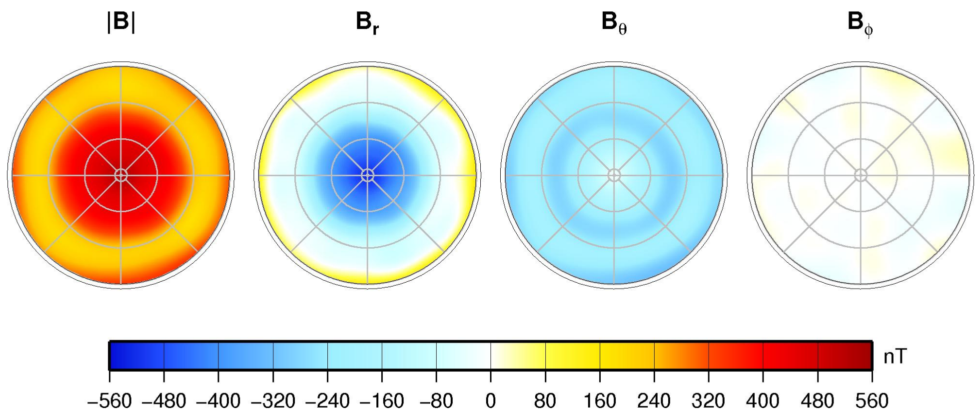

Figure 1: Stereographic north polar view maps of the predicted magnetic field from first solar day MESSENGER measurements. Maps are obtained at 200 km altitude, in Mercury body fixed coordinates. Grid lines are every 45° for longitude and every 30° for latitude. From left to right: Intensity, radial, co-latitudinal and longitudinal field components.

tion axis from one sideral day to the other. The amplitude and distribution of these small scale features are similar for the first and fourth sideral days. This and the 3:2 spin-orbit resonance suggest that these features have an external origin.

We then time-average one complete solar day coverage (or three successive sideral days) and obtain the modeled field maps shown in figure 1. The ratio of non-zonal radial field rms to total modeled radial field rms is 6.5%, demonstrating that the field is dominantly axisymmetric. We find that the magnetic equator is located on average at 10°N latitude at 200 km altitude, which corresponds to an axial quadrupole to axial dipole ratio of 0.28, substantially different from the 0.39 value obtained by [4] [5].

4. Discussion and Conclusions

The TD-ESD method is validated for both the ideal case where data are distributed on grids, and the realistic case where data are at spacecraft positions. For both cases this method allows for a downward and upward continuation with low errors.

When applying the TD-ESD method to MESSENGER data for each sideral day, small scale features of the modeled magnetic field are rotating around the planetary rotation axis between each coverage. These small scale features vanish when we time-average one complete solar day of Mercury, hinting that these features likely result from external sources. For the time-average model a very axisymmetric field is observed. The magnetic equator position is found at 10°N latitude on average, corresponding to an axial quadrupole to axial dipole ratio of 0.28.

Acknowledgements

This work is partly funded through the ANR project MARMITE (ANR-13-BS05-0012) and PNP/INSU/CNRS program.

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