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Hermean magnetic field models based on MESSENGER measurements

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Abstract

We model the magnetic field of Mercury as measured by the MESSENGER spacecraft during the first six Hermean years using a modified method based on the Equivalent Source Dipole (ESD) approach [1]. We analyze models using different data sets. First we analyze models using eighteen sidereal days separately. Because a periodic signal is observed each 3 sidereal days, we also analyze models of each solar day, corresponding to three consecutive sidereal days. Finally we analyze a model that contains all eighteen sidereal-day measurements together, termed the 6-solar-day model. At the timescale of 1 and 6 solar days, no coherent non-axisymmetric feature is recovered by our method, which was designed to recover an arbitrary internal field. We conclude that this provides strong evidence for the large-scale and close-to-axisymmetry structure of the internal magnetic field of Mercury.

1. Introduction

The internal magnetic field of Mercury is much weaker than that expected from a magnetostrophic force balance. Explaining this feature as well as unraveling the field morphology are among the objectives of the MESSENGER spacecraft which has been in orbit around Mercury since 2011. MESSENGER flies on a very eccentric, 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 high internal to external field ratio are available only above the northern hemisphere. Global methods such as the spherical harmonics are therefore not directly applicable without using regularizations that would introduce some arbitrariness. We apply a modified ESD method in order to model the Hermean magnetic field above the northern hemisphere.

The ESD method was developed to reduce to a common altitude static fields of lithospheric origin, induced by magnetized sources at shallow depths [2]. 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 [3, 4].

2. Method

We apply the ESD method with a deeper localization of the sources (inside the core of Mercury), in order to model and describe Mercury's core magnetic field at the altitude of MESSENGER [1]. This new approach has been validated for measurements predicted on regular grids and along MESSENGER orbits, with a synthetic geomagnetic field model scaled to the geometry and intensity of Mercury. In both cases the field is successfully recovered at measurement altitude. We also tested the altitude range to upward or downward continue the modeled magnetic field. For synthetic measurements along MESSENGER orbits this altitude range is 10 to 970 km with an error lower than 8% with respect to the initial scaled model.

3. MESSENGER data and models

Our method is applied to the first eighteen Hermean sidereal days separately, where each sidereal day corresponds to a complete longitudinal coverage of the northern hemisphere. Modeled magnetic field maps at body-fixed coordinates are obtained at 200 km altitude for each sidereal day, as well the corresponding residual maps. In these models and residual maps we find small scale features rotating around the planetary rotation axis from one sidereal day to the other, and repeating each 3 sidereal days. This observation together with the 3:2 spin-orbit resonance suggest that these small-scale rotating features have an external origin.

We then model complete solar days (three consecutive sidereal days) separately and obtain solar-day models. Those solar-day maps show reduced small-scales compared to the sidereal-day models, with a ratio of non-zonal radial field rms to total radial field rms lower than 12%, revealing that the field is dominantly axisymmetric.

Finally, we apply our method to all eighteen sidereal days together (or all 6 solar days). This 6-solar-day model, which is our most robust model, shows a dominantly axial dipolar field and contains a ratio of non-zonal radial field rms to total radial field rms comparable to the previous solar-day models. Converting this model into a spherical harmonic expansion, we obtain a stronger quadrupole-to-dipole ratio of 0.48 ± 0.03 and a weaker octupole-to-dipole ratio of 0.07 ± 0.01 compared to those obtained by [5]. A very small tilt of $0.92°$ is also obtained from the converted 6-solar-day model, slightly larger than the upper bound found by [5].

4. Discussion and Conclusions

We apply a modified ESD method to the global magnetic field of Mercury. When applying our method to MESSENGER data for each sidereal day, small scale features of the modeled magnetic field are rotating around the planetary rotation axis between each sidereal day, repeating each 3 sidereal days. These small scale features diminish when we model complete solar days of Mercury, suggesting that these features likely result from external sources. Temporal variations from one consecutive solar day to another are axisymmetric and vary substantially with time, but the rms difference remains lower than 80 nT. This suggests that some large-scale external fields are modeled together with the internal magnetic field. Our results call for a future development of a method to jointly model the internal and external fields. However, we emphasize that the lack of any coherent non-axisymmetric feature recovered by our method provides strong evidence for the large-scale and close-to-axisymmetry structure of the internal magnetic field of Mercury.

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