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 mag-
netic 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 re-
fect the temporal variation of the Hermean magnetic
field. We report first models computed with the TD-
ESD method using only Mercury’s sidereal days sep-
arately. We discuss the time-evolution of the mod-
eled 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 exter-
nal fields are reduced. The mean magnetic equator at
200 km altitude is found at 10° 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 objec-
tives 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 por-
tion of its orbit, and data with a good internal to ex-
ternal 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 arbi-
trariness. 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 com-
mon 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 mag-
netization [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 measure-
ments predicted on regular grids at 300, 400 and 500
km altitudes (ideal case) and along MESSENGER or-
bits (realistic case), with a synthetic geomagnetic field
model scaled to the size of Mercury. In both cases
the field is successfully recovered at measurement al-
titude.

To further quantify this method we also tested dif-
ferent 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 real-
istic 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 sepa-
rately, each one corresponding to one Mercury sidereal
day. Modeled magnetic field maps at body-fixed co-
dinates are obtained at 200 km altitude, for each
coverage. In these maps we find small scale mag-
netic field features rotating around the planetary rota-
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 sidereal 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.

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References