EPSC Abstracts
Vol. 11, EPSC2017-535, 2017
European Planetary Science Congress 2017

A time-averaged regional model of the Hermean magnetic field

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Abstract

This paper presents the first regional magnetic field model of Mercury developed with mathematical continuous functions. The model is derived to the spatial resolution of about 830 km without a priori information about the geometry of the internal and external fields or regularization. It relies on an extensive dataset of the MESSENGER's measurements selected over its entire orbital lifetime between 2011 and 2015. A first order separation between the internal and the external fields over the Northern hemisphere is achieved under the assumption that the magnetic field measurements are acquired in a source free region within the magnetospheric cavity. When downward continued to the core-mantle boundary, the model confirms the general structures already observed in previous studies such as the dominance of zonal field, the location of the North magnetic pole, and the global absence of significant small scale structures. The transformation of the regional model into a global spherical harmonic one provides an estimate for the axial quadrupole to axial dipole ratio of about g20/g10=0.27. This is much lower than previous estimates of about 0.40. We however note that it is possible to obtain a similar ratio provided that more weight is put on the location of the magnetic equator and less elsewhere.

1. Introduction

One of the objectives of the MESSENGER spacecraft was to better describe the magnetic fields surrounding the planet Mercury and to better understand their origin. The magnetic measurements are acquired by MESSENGER along a near polar but very elliptical orbit and are useful for internal magnetic field studies mostly above the northern hemisphere. This orbital configuration challenges our ability to separate the measured magnetic fields into their internal and external contributions and to model them globally to high spatial resolution using classical mathematical techniques such as the spherical harmonics ([1], [2]).

In the recent years, attempts have been made to circumvent this difficulty using dedicated regional or local techniques. Such techniques could rely on an equivalent representation of sources (e.g. [3]) using hypotheses about the location of the magnetic field sources. However, other techniques inherited from Earth's studies based on regional mathematical functions could equally be applied without the need for a priori information about the sources. In this paper, we apply the Revised Spherical Cap Harmonic Analysis ([4]) to derive a magnetic field model from the magnetic field measurements of the MESSENGER spacecraft.

2. Model and results

We use the latest MESSENGER calibrated magnetic field measurements (MESSENGER Data Release 15, version V08) acquired during more than 8 Mercury solar days from 23 March 2011 until 30 April 2015. We apply a proxy defined by [3] to identify and select for each orbit the measurements within the magnetospheric cavity and below 1000 km altitude. This maximum altitude aims at excluding data too close to the day side magnetopause that may have large spatio-temporal variability. The selected orbit portions correspond to reduced external field perturbations. The selected data are confined within a cone of 85° half-aperture. The cone is aligned onto Mercury's axis of rotation and covers almost the entire Northern hemisphere. A full azimuthal coverage in the Mercury Body Fixed (MBF) coordinate system is completed every sidereal day on Mercury (about 56 Earth's days). The geographical coverage within the cone in the MBF reference frame is therefore very dense. Due to the spin orbit 3:2 resonance on Mercury, all MLT are surveyed after 3 days or 2 years, which corresponds to 1 solar day. The coverage in MLT is sufficient to average out (in principle) the external field contributions which are more or less static in the Mercury-centric Solar Orbital (MSO) reference frame. The median and mean altitudes of the measurements are 500 and 530 km, respectively. The radial distribution is dense, but the low latitude measurements are at higher altitudes, with a median altitude equal to 700 and 450 km south and north of 45. This data selection protocol generates a dataset of 1,675,748 data triplet (5,141,166 vector field components).

The magnetic field is strongly axisymmetric. The North dip pole is located at 87N;94W. The most striking feature in the maps is the absence of small scale structures at the CMB. This observation is not novel but relied so far on SH models truncated to very low degrees and orders. The magnetic equator is found around latitude 14.9°N at 200 km altitude and at about 11.5N at 1000 km altitude. This latter estimation is consistent with the average location of the solar wind standoff distance at Mercury estimated to be at 1.41 Mercury's radius [2]. We finally transform the regional model into a truncated global SH model. We estimate only the low degree coefficients that are the least correlated over the northern hemisphere and compare the coefficients to those published by [1].

Table 1: Comparison between the SH model coefficients obtained in this paper and the model of [1]

Coefficients	This paper	Model of [1]
g_1^0	-213.6	-190.0
g_1^1	0.9	n/a
h_1^1	1.5	n/a
g_2^0	-57.7	-74.6
g_3^0	-35.8	-22.0
g_5^0	2.1	n/a

3. Summary and Conclusions

Our results illustrate that if the co-estimation of the zonal internal quadrupole and the external dipole terms are important to preserve the most robust features detected by the MESSENGER's measurements, an alternative picture of Mercury's magnetic field can be obtained in SH by relaxing this constrain. In such a case, the axial quadrupole to axial dipole ratio is significantly reduced from 0.4 to 0.27. This result could broaden the class of acceptable dynamo regimes for Mercury by perhaps alleviating the need for heterogeneous heat flux at the CMB. The model of Anderson et al. [1] is therefore probably a suitable model to estimate the location of the magnetic dip pole at altitudes larger than 800 km with few SH parameters but seems not optimal for representing the magnetic field in the lower altitude range, particularly at the CMB. However, even if the SH model presented in this paper is by construction currently uncertain, the regional model downward continued to the CMB could represent an attractive alternative to constrain dynamo simulations.

Acknowledgements

This work is partly funded through the ANR project MARMITE (ANR-13-BS05-0012)

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