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A high-resolution spherical harmonic model of the Martian lithospheric magnetic field

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Abstract

We present a spherical harmonic (SH) model of the Martian lithospheric magnetic field based on Mars Global Surveyor (MGS) data. We use several techniques in order to obtain a reliable and well-resolved model of the Martian lithospheric field. Static external fields were treated by a joint inversion of external and internal fields, whereas temporally variable external contributions were handled by regularizing the model using a L1-norm, which allows for a better representation of strong localized magnetic anomalies as compared to the conventional L2-norm. Further, a Huber-Norm was used to properly treat data outliers and the data was weighted based on an analysis of the data instead of taking the a-posteriori root mean square of the misfit.

1. Introduction

The sources of the Martian magnetic field are magnetized rocks in the Martian lithosphere (e.g. [1]), which likely acquired their magnetization from an ancient core dynamo, but the lifetime of this dynamo is still under debate (e.g. [2]).

Models of the lithospheric field can help to resolve this issue, as they allow to treat and remove external contributions in the data as well as to quantify the robustness of the observed anomalies.

Here, we present a new map of the Martian lithospheric magnetic field, based on the full MGS mapping phase orbit (MPO) nighttime and areobraking (AB/SPO) data set.

2. Data

We use the complete MGS vector magnetometer data set, acquired from 1999 to 2006, including the low-altitude AB as well as the high-altitude MPO data. For the MPO data, one data point every 20 km was selected on the satellite's surface track in order to reduce computational cost. Further, only nighttime data was selected to reduce the influence solar-wind induced magnetic fields. As AB nighttime data is very scarce, we decided to use all AB data below 200 km altitude. Although the contamination by external field contributions is more significant in this case, the lower altitude of the AB data is well-suited for resolving shorter wavelengths.

3. Model

Assuming that no magnetic sources are present at the satellite's orbit altitude, we describe the lithospheric magnetic field $\vec{\mathbf{B}}$ as the gradient of a scalar potential field V such that

$$\vec{\mathbf{B}} = -\vec{\nabla}\mathbf{V} \quad (1)$$

The scalar potential can then be expressed as a series of Schmidt-seminormalized spherical harmonic functions, given by

$$\begin{aligned} V(r,\theta,\phi) &= a\sum_{l=1}^{L_{int}} \left(\frac{r}{a}\right)^{l} g_l^m Y_l^m(\theta,\phi) \\ &+ a\sum_{l=1}^{L_{ext}} \left(\frac{a}{r}\right)^{l+1} h_l^m Y_l^m(\theta,\phi) \quad (2) \end{aligned}$$

where (r,θ,ϕ) are spherical coordinates, a is the reference radius of the model, and Y_l^m are the complex Schmidt-seminormalized spherical harmonics. L_{int}, L_{ext} are the maximal degree and g_l^m, h_l^m are the complex Gauss coefficients for internal and external fields, respectively.

The SH model was expanded up to $L_{int} = 110$, which we determined to be adequate to sufficiently resolve even the most intense anomalies in the AB data. External fields were modeled up to SH degree $L_{ext} = 10$.

4. Inversion

The quality of the expansion depends on the proper selection of data weights, which should optimally be weighted according to the underlying probability densitiy function (PDF). As the PDF is unknown a-priori, it is usually estimated a-posteriori. To estimate the a-priori data weights, we binned the data in areas of approximately equal size and calculated the respective standard deviation for each bin. The obtained standard deviations accounts for errors due to temporal variations in the data if the bin size is selected appropriately, and can be used as a-priori data weights.

Static non-lithospheric contributions to magnetic field data were found to be relevant at MGS orbit altitude [3] and we included an external field model upto degree 10. Further, large data outliers were treated by implementing a Huber-Norm [4].

As remaining non-lithospheric field contributions stemming from external fields generated below the MGS mapping altitude will leak into the lithospheric model, we additionally minimize the surface integral of the absolute value of the horizontal gradient of the radial magnetic field component, i.e.

$$\int_S \|\vec{\nabla}_{\mathbf{H}}\mathbf{B_r}\|_{\mathbf{1}}\mathbf{dA} \qquad (3)$$

This minimization is done using a L1-norm, allowing for strong, localized magnetic anomalies to be better represented as with the conventional L2-norm.

5. Results

The lithospheric field model is shown in Fig.1 for all three vector components of the magnetic field, which has been downward-continued to the surface altitude. The topographic dichotomy and the largest impact craters (Hellas, Isidis, Argyre, Utopia) are indicated by black solid and dashed lines, respectively. In agreement with previously published maps (e.g. [5]), it can be confirmed that the major impact craters appear to be demagnetized and the northern lowlands show generally lower magnetic fields than the southern highlands. In addition, many details are visible at high-field regions while showing a low noise level in low-field regions.

6. Summary and Conclusions

Here, we presented a spherical harmonic model of the Martian lithospheric magnetic field based on the entire MPO nightside and AB/SPO data set of the Mars Global Surveyor mission. The lithospheric field was modeled up to SH degree 110 and order and a static external field up to degree and order 10 was included. Several techniques have been applied to minimize leakage of non-lithospheric field contributions

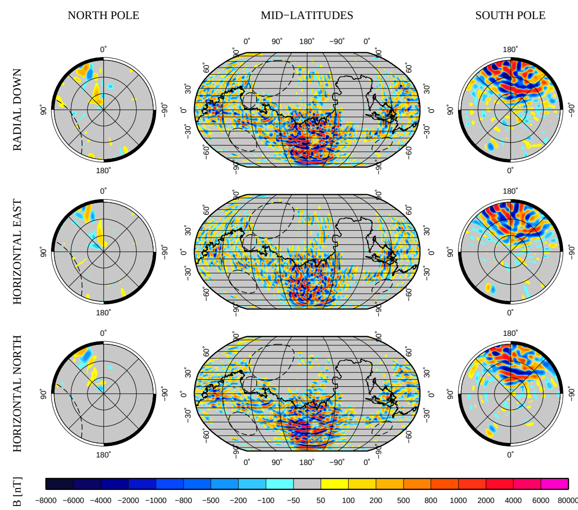

Figure 1: Map of the Martian magnetic field model evaluated at the average planetary radius of Mars (R=3393.5 km). The topographic dichotomy and major impact craters are indicated by the solid black and dashed lines, respectively.

to the model: a-priori data weights were determined from the data distribution within small spherical bins, a Huber-Norm was used to downweight data outliers and the model was regularized by minimizing the horizontal gradient of the absolute radial field component at the mean surface altitude. In this step, a L1-Norm was used to account for strong and localized magnetic anomalies.

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