A HIGH-RESOLUTION MODEL OF THE LITHOSPHERIC MAGNETIC FIELD OF MARS.

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Introduction: A spherical harmonic (SH) model of the Martian lithospheric magnetic field based on Mars Global Surveyor (MGS) data is presented. The model is stable when downward-continued to the surface and some examples of how this model can be used to investigate the Martian magnetic field history are given.

Data: We use the complete MGS vector magnetometer data set, acquired from 1999 to 2006. This data includes the low-altitude aerobraking and science phase orbit (AB/SPO) as well as the high-altitude mapping phase orbit (MPO) data [1]. In order to reduce the influence of solar-wind induced magnetic fields, we rejected all dayside MPO data. As nighttime data is scarce for low AB/SPO altitudes, all data below 200 km altitude was used. Although the contamination by external field contributions is more significant in this case, the lower altitude of the AB data provides valuable additional information on the shorter wavelengths of the field.

Model: We express the magnetic field in terms of a scalar potential field V, thus assuming that the data was collected in a source-free region. The vector magnetic field is then expressed as the gradient of this scalar potential V, which itself is expanded in terms of spherical harmonic (SH) functions.

The SH model includes a model for the lithospheric field itself and two models for the day- and nightside external fields, respectively. The internal lithospheric field model was expanded up to a maximum degree and order L_{int}=110, which was determined to be adequate to sufficiently resolve the intense anomalies in the AB data. The external field models were expanded up to maximum SH degrees and orders of L_{ext}=10 and L_{ext}=5 for the day- and nightside data, respectively.

Inversion: 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 an iteratively weighted least-squares algorithm (IRLS) to approach an L1-norm [2], which allows for a better representation of strong localized magnetic anomalies as compared to the conventional L2-norm. Further, a Huber-Norm [3] 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.

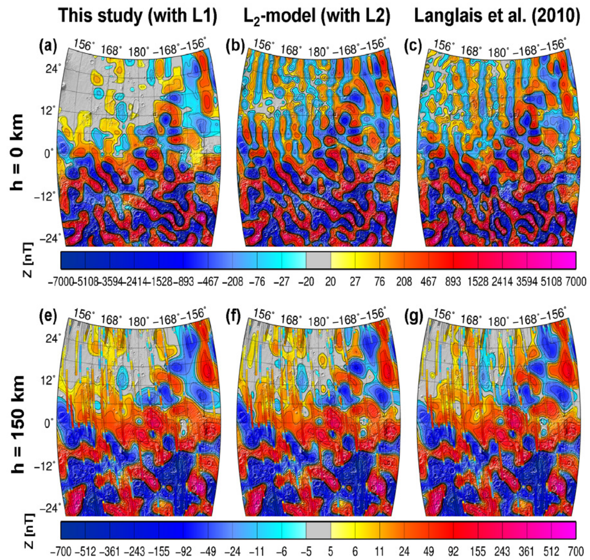

Figure 2: Map of the vertically down lithospheric magnetic field component for different models and altitudes of 150 km (lower row) and 0 km (upper row) above the surface altitude.

Results: In agreement with previously published maps (e.g. [4]), major impact basins appear to be demagnetized and the northern lowlands show generally lower magnetic field strengths than the southern highlands. In addition, many details are visible at high-field regions while showing a low level of noise in low-field regions.

We use an IRLS-algorithm to approach an L1-norm for regularizing our model. This allows the model to maintain strong field gradients while suppressing noise in the data. The effectiveness of this approach is illustrated in Fig. 2, where the vertically down magnetic field component Z is shown for the model using an L1-regularization (left column) at 0 (top row) and 150 km altitude (bottom row). For comparison, models with an L2-regularization (middle column) and the model of Langlais et al. (2010) [4] (right column) are also shown at both altitudes. At surface altitude, the L2-model and the model of Langlais et al. (2010) [4] show similar elongated anomalies in the north, which are aligned with the satellite orbit tracks. These kinds of anomalies are typical for the leakage of noise into the model, and are effectively suppressed in the L1-model. In the southern part, on the other hand, the L1-model is able to reproduce the strong fields.

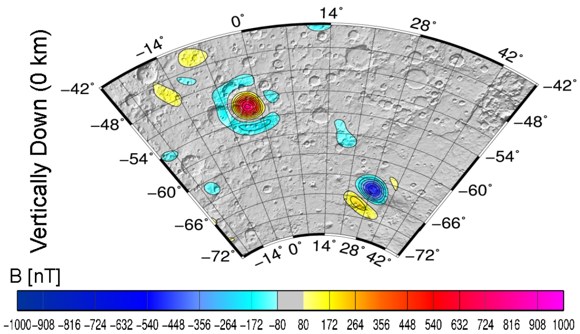

Figure 3: Vertically down component of the lithospheric field at surface altitude as predicted by the presented model. The shown area is located near the south pole and shows two isolated, relatively weak anomalies.

Discussion: Due to its high resolution and the ability to be downward-continued to the surface, the presented model can help to better understand the magnetic field history of Mars. For example, the magnetic signature of smaller craters or ancient volcanoes can be investigated and weak, isolated anomalies can be resolved.

The latter is particularly interesting for the determinamtion of paleopole orientations and the investigation of lithospheric magnetization. In Fig. 3, two weak isolated anomalies near the South Pole are shown, which exhibit a field signature corresponding to almost vertically oriented single dipoles. Each of these dipoles appears to be oriented in a different direction, which may hint to pole reversals of the ancient Martian dynamo. These anomalies may also be visible in other published model, but they are hard to detect at the MPO altitude, where many models have been interpreted. Also, these anomalies are relatively weak and can easily be masked by noise.

In Fig. 4a, the field intensity at surface altitude over three craters with diameters from 152 to 444 km is shown, and the circumferentially averaged intensity profiles over these craters are shown for different altitudes in Fig. 4b. For the unnamed crater (labelled 2), the field signature at 185 and 0 km altitude is similar, whereas the other two craters appear to be the more demagnetized the lower the altitude. This illustrates that the magnetic signature of impact craters can change in various ways with altitude, depending on crater size, surrounding magnetic field strengths and the coherence length of magnetization. The 3.92 Ga old [5] Schiaparelli crater (labelled 1) has previously been investigated using ER data at 185 km altitude [6] and statistical methods to investigate the crater's magnetization have been applied. They argued that Schiaparelli is most probably at least partially magnetized, which is in accordance with the profile at 185 km (Fig. 4a). However, at surface altitude, the crater appears to be almost completely demagnetized, which is in accordance with a dynamo shutdown at 4 Ga [6].

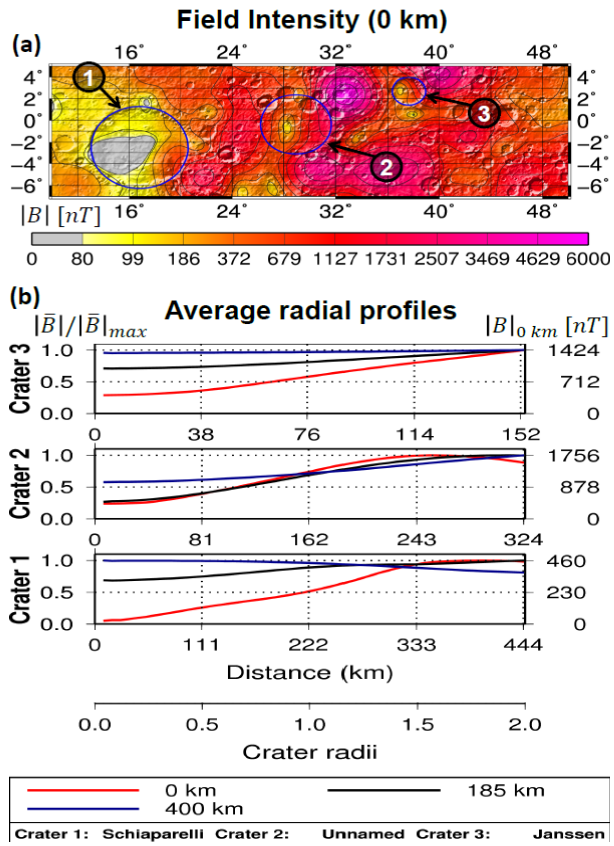

Figure 4: (a) Magnetic field intensity evaluated at the mean planetary radius over a region within the southern part of Arabia Terra. Impact craters with a diameter larger than 150 km are indicated by blue ellipses. These include Schiaparelli (labeled 1), an unnamed crater (labeled 2), and Janssen (labeled 3). (b) Circumferential average of the magnetic field intensity as a function of the radial distance from the crater's center and for altitudes of 400 km (blue solid line), 185 km (black line), and at the surface (red line).

Acknowledgements: This work has been supported by the German Research Foundation (DFG) within the Priority Program SPP1408 "Planetary Magnetism".

References: [1] Acuña M. H. et al. (2001) JGR, 106(E10), 23403-23417. [2] Farquharson C. G. and Oldenburg D. W. (1998) Geophys. J. Int., 134,213-227. [3] Huber P. J. (1964) Ann. Math. Stat., A6, 813-827. [4] Langlais B. et al. (2010) EPSC, Abstract# EPSC2010-393. [5] Werner S. C. et al. (2008) Icarus, 195, 45-60. [6] Lillis R. J. et al. (2013) JGR, 118, 1045-1062.