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Density in the Tharsis Province from Mars Express Data

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1. Introduction

The probe Mars Express (MEX) has been in orbit around Mars since 25 December 2003 and is still operating seven years later. The onboard Mars Express Radio Science Experiment (MaRS) has performed a series of 'gravity on target' experiments, which consist in measuring radio signal Doppler shifts as the spacecraft flies at low altitude (270-330 km) above targets of geophysical interest. These Doppler shifts can be converted into variations of the spacecraft velocity along the line-of-sight between the spacecraft and the Earth, which are attributed to anomalies in the gravitational field of Mars. Since anomalies of small wavelength are mainly due to variations in the density of the crust, the experiment provides constraints on the density of the crust at the target.

2. Data

ESA and DSN ground stations measure Doppler shifts at least 20 mn before and after the pericenter, at which points the altitude is higher than 1330 km. We use the software GINS to transform the observed Doppler shifts into LOS velocity residuals with respect to MEX orbit ephemeris (up to degree and order 50) provided by the European Space Operation Center. Since the gravity perturbation ($\ell > 50$) is already negligible at an altitude of 500 km, we define the pericenter pass by a maximum altitude of 500 km. Emphasis was put during the mission on targets that had the best signal-to-noise ratio, namely Olympus Mons and the Tharsis Montes, though some observations were also done at Valles Marineris. The number of observations was 25 in 2004, 28 in 2005, 19 in 2006, 11 in 2007, 4 in 2008 and 4 in 2009, resulting in 17, 15 and 8 observations at Olympus Mons, Ascraeus Mons and Valles Marineris, respectively.

3. Analysis

We analyze each pericenter pass with the method of [1]. First, the velocity residuals are filtered, differentiated and resampled with a uniform spacing along the groundtrack. Second, we compute in the spectral domain the coherence and the gain factor between the observed acceleration residuals and the acceleration due to the uncompensated topography. Our aim is to obtain a quantity depending on the geophysical properties of the targeted area but independent of the particular geometry of the pericenter pass. Third, we compare the 'observed' gain factor with the same quantity as predicted by a geophysical model of the targeted area (see Fig. 1). The parameters of the model are the surface (load) density, the elastic thickness of the lithosphere and the possible presence of subsurface (bottom) loading. For each set of parameters, we compute the misfit between the observed and predicted gain factor, from which we can estimate (as done in [2]) the probability distribution of each parameter (see Fig. 2). Finally, we obtain the mean value of the model parameter and the $1\,\sigma$ uncertainties by fitting a Gaussian to the probability distribution. For comparison, we do the same analysis on the acceleration residuals associated with the latest version of the observed global gravity field of Mars, called MRO110B [3].

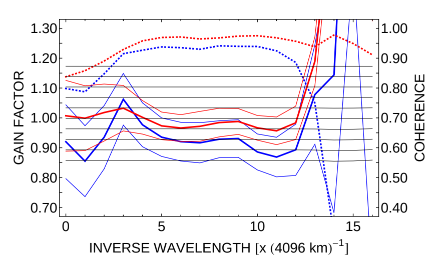

Figure 1: Pericenter pass 1140 above Ascraeus Mons: observed gain factor (thick colored curves), $\pm 1\sigma$ errors (thin colored curves), coherence (dotted curves). MEX results are shown in blue while equivalent results from the global gravity field are shown in red. Horizontal lines are the predictions for the gain factor, with $\rho_l = 2500 - 3400\,\mathrm{kg/m^3}$ (bottom to top), the increment being $100\,\mathrm{kg/m^3}$.

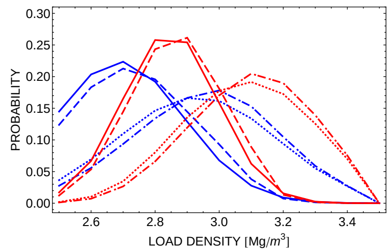

Figure 2: Probability for the load density (pericenter pass 1140 above Ascraeus Mons) from MEX data (blue) and with the global gravity field (red). Four cases are shown: $f = 0$ and $T_e = 80\,\mathrm{km}$ (continuous curves), $f = 0$ (dashed curves), $T_e = 80\,\mathrm{km}$ (dotted curves), f and T_e free (dash dotted curves).

4. Results

By repeating the procedure described above for all pericenter passes above Olympus Mons, Ascraeus Mons and Valles Marineris, we compute estimates of the load density and associated error bars (see Fig. 3) for models without ($f = 0$) or with ($f \neq 0$) bottom loading (the elastic thickness is left free in both cases). For each target, each model and each data set (MEX or global gravity field), the weighed average and its associated uncertainties are given in Table 1.

Target	no bottom loading		with bottom loading	
	ρ_{MEX}	ρ_{MRO}	ρ_{MEX}	ρ_{MRO}
Olympus	3110 ± 50	3190 ± 30	3190 ± 50	3270 ± 30
Ascraeus	2870 ± 60	3030 ± 30	3100 ± 60	3240 ± 40
Valles M.	2570 ± 80	2530 ± 40	2920 ± 130	2970 ± 120

Table 1: Weighed average of the load density estimates (in $\mathrm{kg/m^3}$) at each target (see Fig. 3) for the two models without or with bottom loading. *MRO* denotes the global gravity field.

If there is no bottom loading, the most likely values of the load density are high (3100-3200 $\mathrm{kg/m^3}$) at Olympus Mons, medium (2900-3000 $\mathrm{kg/m^3}$) at Ascraeus Mons and low (2500-2600 $\mathrm{kg/m^3}$) at Valles Marineris. The introduction of bottom loading favors higher density estimates: the shift is 80 $\mathrm{kg/m^3}$ for Olympus, more than 200 $\mathrm{kg/m^3}$ for Ascraeus and of the order of 400 $\mathrm{kg/m^3}$ for Valles Marineris. However, bottom loading does not improve much the goodness-of-fit. For the volcanoes, the MEX data set yields a lower mean density estimate than the global gravity data set: 80 $\mathrm{kg/m^3}$ smaller for Olympus and about 150 $\mathrm{kg/m^3}$ smaller for Ascraeus; for Valles Marineris, the estimates are comparable. The uncertainties with the MEX data set are about twice the uncertainties associated with the global gravity data set. Nevertheless, the goodness-of-fit (not shown) between the observed gain factor and the predictions is not better with the global gravity field.

In comparison with the analysis done in [3] and [4] with a gravity field at lower resolution, our findings confirm that the surface density is high at Olympus Mons, but MEX data yield a lower estimate for the density at Ascraeus Mons. In agreement with [4], our models yield medium or low estimates of the density at Valles Marineris depending on whether bottom loading is present or not.

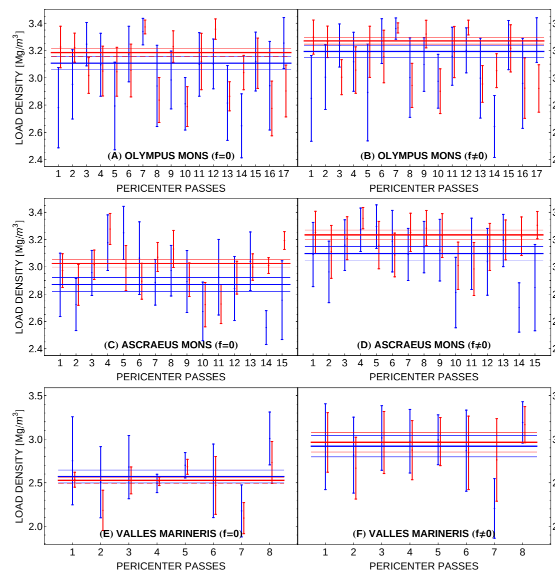

Figure 3: Estimates of the load density from individual profiles at Olympus Mons, Ascraeus Mons and Valles Marineris from MEX data (blue) and with the global gravity field (red). Error bars correspond to the $\pm 1\,\sigma$ interval of the normal distribution fitted to the discrete probability distribution. The weighed average and its $1\,\sigma$ uncertainties are shown as horizontal lines Left (resp. right) panels show results without (resp. with) bottom loading.

Acknowledgements

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