ON SEPARATING MANTLE AND CRUSTAL CONTRIBUTIONS TO MARS GRAVITY AND TOPOGRAPHY. S. D. King, Department of Geosciences, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061 e-mail: sdk@vt.edu

Introduction: The global topography data from Mars Orbiter Laser Altimeter (MOLA) [1] and gravity data from Doppler tracking residuals [2] from the Mars Global Surveyor (MGS) spacecraft are powerful observations that provide information on the internal structure of Mars. The internal structure has profound implications for the thermal history and evolution of the planet. Zuber et al. [3] interpreted the global Bouguer gravity field in terms of a crustal thickness model with an average crustal density of 2900 kg/m^3 and average thickness of 50 km. In this model, the crust was up to 90 km thick under the southern hemisphere and significantly thinner under the northern hemisphere.

Any density field derived from a gravity model is non-unique and, while it is likely that the shorter wavelength features of the Bouguer gravity field represent crustal structure, it is impossible to rule out contributions from the mantle at longer wavelengths. Unfortunately, for many of the questions surrounding the thermal evolution of Mars, such as the origin of the crustal dichotomy or Tharsis rise, understanding how much of these long wavelengths contain a contribution from mantle density anomalies is critical.

Without additional observations or theory constraining the crustal structure, mantle density anomalies will be mapped into the crustal structure model. In terrestrial crust and upper mantle studies, often seismic structure and gravity are used jointly to solve for crustal structure and, obviously this is not an option for the Mars. I use spherical calculations of mantle convection to estimate the probable wavelengths of convection in the Martian mantle.

Approach: Some of the parameters that are used in convection calculations have large uncertainties (e.g., the viscosity of the mantle) and there is always the possibility that the pattern of the solution is controlled by the initial conditions. Therefore, I use an ensemble average of a number of model results to produce estimates of the probability of mantle structure at each wavelength, similar to the approach used in global climate modeling and operational weather forecasting. This enables me an estimate of the likelihood that a wavelength of the gravity or topography data contains a significant component of mantle structure. While the probabilistic nature of the ensemble averaging approach seems well suited for a Bayesian inversion formalism, I begin with a somewhat more conventional damped least-squares inversion where I vary the uncertainty of each wavelength in the inversion. I invert for crustal structure only, assigning a large uncertainty to the harmonics that have significant component of mantle structure from the ensemble averaging.

Preliminary Work: I have a number of 3D spherical convection calculations in a Mars-geometry spherical shell using the CitcomS finite element program [4,5] from the Computational Infrastructure for Geodynamics (CIG) initiative. (www.geodynamics.org) I use a temperature-dependent olivine-like rheology [6], internal heating, and a Rayleigh number in the range of 10^5-10^7. I have performed calculations with and without an endothermic phase transformation from wadsleyite to perovskite plus ferropericlase, which occurs on average at 1910 km on Mars [7] and may or may not be present depending on the size of the core. I have implemented a cooling core boundary condition, following the approach outlined by Steinbach and Yuen [8] that is consistent with the thermal evolution models presented by Hauck and Philips [9].

An isosurface of the temperature field (T=0.85) from one of the 3D convection calculations can be seen in Figure 1. In this particular calculation, the Rayleigh number is 6.7 x 10^6, the internal heat generation rate is 20 mW/m^3. This calculation does not have a cooling core boundary condition or a perovskite phase at the base of the mantle. The temperature structure shown in this figure is dominated by a spherical harmonic degrees 2 and 3, also the dominant pattern of the geoid and dynamic topography from the solution.

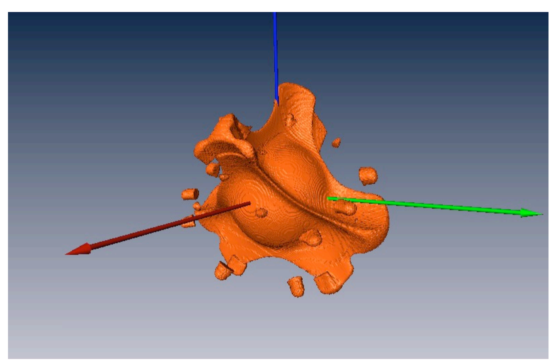

Figure 1: A hot isosurface from a 3D convection calculation in a Mars-like geometry with temperature-dependent Newtonian viscosity. The temperature structure is dominated by a spherical harmonic degrees 2 and 3.

Assuming, for the sake of illustration, that this calculation is representative of the ensemble average of a series of whole mantle convection models. I then form an inversion for the crustal structure that allows an *a priori* large uncertainty to the crustal structure for degree 2 and 3 terms and compare the resulting crustal structure from this inversion with a standard inversion with no *a priori* assumption regarding the uncertainty of the terms. In this case, 'uncertainty' comes not from the uncertainty associated with the data, which is practically zero for the longest wavelengths of the geoid and topographic data, but in the unmodelled mantle density component that would otherwise be projected into the crustal structure model. The goal of increasing the uncertainty in the harmonics that have strong components of mantle structure from the ensemble averaging is to allow the inversion to fit as much of the data at this harmonic as possible, given the constraints of the other harmonics, but not have the inversion dominated by data at wavelengths that are likely to have a strong mantle contribution. By comparing the two inversions, I have an indication of how much the mantle density anomalies are impacting the crustal structure.

Following on with this example, if I invert for crustal structure allowing the degree 2 and 3 terms to float, I get a crustal thickness of approximately 80 km and a crustal density of 3200 kg/m^3. If I compare this with the case where I force a fit to the degree 2 and 3 terms, I get 140 km thick crust and a crustal density of 3200 kg/m^3. (These crustal thicknesses are almost certainly too large and this example was to serve as an illustration only.) The real power of this method is that I have the ability to test different mantle scenarios (e.g., whole mantle vs. layered mantle, presence or absence of a perovskite layer at the base of the mantle) because these will produce significantly different mantle density patterns.

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