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Combining large-scale numerical simulations of thermal evolution and seismic wave propagation to model the interior of Mars

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The InSight mission (Interior exploration using Seismic Investigations, Geodesy and Heat Transport) will perform seismic and heat flow measurements in the Elysium Planitia region on Mars [2] to constrain the present-day interior structure and heat budget of the planet, and in turn its thermal and chemical evolution.
We combine global scale planetary evolution and propagation of seismic waves in a 3D geometry to provide a framework that can be used to select interior models compatible with the InSight measurements and will help to interpret the mission data in a global context.
We use the mantle convection code Gaia [3] to compute the thermal evolution of Mars. All our thermal evolution models use crustal thickness models derived from gravity and topography data [e.g., 4] and vary parameters such as crustal enrichment in heat producing elements (HPE), crustal thermal conductivity, mantle viscosity, thermal expansivity, and core size [5].
The seismic velocities are computed from the 3D temperature field calculated for the present-day. We use the BurnMan code [6] with the Stixrude & Lithgow-Bertelloni 2011 [7] mineral database to compute the 3D seismic velocity structure, density, and shear and bulk modulus. The latter are used to calculate the attenuation in the mantle by employing the Andrade pseudoperiod model [8].
The seismic velocities and the attenuation values are further used as input for the 3D global seismic wave propagation solver SPECFEM3D_GLOBE [9] to model seismic-wave propagation by using a spatially variable seismic velocity distribution. To input the data into SPECFEM3D_GLOBE we use a spherical harmonic expansion. The SPECFEM3D_GLOBE package has been previously used to compute seismic wave propagation on Mars with a 1D mantle model combined with 3D crustal thickness and topography variations [10]. Attenuation, ellipticity, gravity and rotation are also included in simulations.
Our models suggest a difference between maximum and minimum P-wave velocity of up to 5% in the uppermost 300 – 400 km that correlates with the crustal thickness dichotomy. These variations, located in the lithosphere, are the combined effect of the insulating crust, its enrichment in HPE and the convection pattern in the mantle. Hence, in addition to constraining the crustal thickness by using the seismic velocity difference between the mantle and crust, the detection of a seismic velocity dichotomy in the Martian lithosphere could be used to constrain the crustal enrichment in HPE.
Synthetic seismograms, which will be computed for such thermal evolution models, can be directly compared to the InSight data. This comparison will help to select thermal evolution models compatible with InSight measurements and in turn to better understand the thermochemical history of Mars.

References:
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