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Global seismic waveform modeling in the whole Mars - a preliminary study -

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Abstract

We construct a numerical scheme (spherical 2.5-D FDM) to calculate probable global seismic wave propagation for the whole Mars models. Using our modeling sheme, we have done preliminary study of Martian seismic waveform modeling in the whole Mars with probable 3-D Martian interior structure.

1. Introduction

Knowledge of interior structure of the planet is important and essential for studying their origin and evolution. However, for Mars, we did not have enough knowledge of their interior structure. In last decade, numerous Martian explorations were conducted, however, they concentrated for searching water and sings of life. So, they mainly did geological exploration of sedimentary rocks using rovers but did not done geophysical observations such as seismic observations. Current Martian interior models are therefore based on only indirect geophysical information such as static Martian gravity field, topography, tidal effect on an orbiter, and precession of the spin axis derived from tracking data of orbiters and landers. In addition, geochemical constraints based on analysis of SNC meteorites and / or chondrite meteorites are also incorporated [e.g., 1].

The Japanese community of planetary explorations is now planning a future Martian exploration called MELOS (Mars Exploration with Lander Orbiter Synergy). It is complex missions with landers and orbiters to answer the question 'why mars is red?' In this framework, we plan to install broadband seismometers and other geophysical instruments for studying internal structure of the Mars.

Looking back on investigation history of the Earth's interior, our knowledge has been enhanced by mutual progress of observation and numerical methods. Increased enthusiasm for Mars exploration in recent years strongly requires developing a method for numerical modeling of global seismic wave propagation based on our current knowledge of Martian interior.

2. Spherical 2.5-D FDM scheme

We have been developing numerical schemes using the finite-difference method (FDM) for accurate and efficient modeling of global seismic wave propagation through realistic Earth models with lateral heterogeneity. In spite of the ongoing increase of computational performance, full 3-D simulation of global seismic wavefields is still a challenge and far from being a routine tool for investigating the Earth's inner structure using, for example, the waveform inversion. Therefore, in the field of global seismology, a traditional method called axisymmetric modeling has often been employed, which solves the 3-D elastodynamic equation in spherical coordinates on a 2-D cross section of the Earth including a seismic source and receivers under assumption that the structural model is axisymmetric with respect to the axis through the source. It can perform the global waveform modeling with a similar computation time and memory as for 2-D modeling with consideration of full 3-D geometrical spreading although serious drawbacks are involved: structures are restricted to be axisymmetric due to the assumption. We have succeeded in extending the conventional axisymmetric modeling to treat realistic asymmetric structures and moment-tensor point sources keeping its efficiency [2, 3]. For more realistic simulations, we then enhanced the computation accuracy adopting the so-called effective grid parameters which enables us to accurately consider position of material discontinuity inside the FD grid cell [4], introduced inelastic attenuation [5], and solved problems related to the center of the Earth which is a singularity of wave equations in spherical coordinates [6]. The resulting scheme can provide accurate computations of global seismic wavefields excited from an asymmetric source and propagate through arbitrary heterogeneous, attenuative structures over the Earth's center, with a small computation requirement comparable to the 2-D modeling. This time we applied our scheme to Martian structure models. Since the radius of Mars is nearly half of the Earth's radius, modeling of Martian global seismic wave propagation requires less computational resources than for the Earth with the same frequency band.

3. Examples of numerical modeling

As a preparatory stage, we calculate synthetic seismograms for the model A and model B proposed by Sohl and Spohn [1]. Referring to the PREM [7], simple inelastic attenuation is imposed onto these two models with Q for the bulk modulus $Q\kappa=60000$ at all depths, and Q for the shear modulus $Q\mu=\infty$ for the liquid core and $Q\mu=600$ for other regions. We put a 30 km-depth seismic source of a simple dip-slip mechanism with non-zero momenttensor components of $M13=M31=M0$ since the most likely seismic events on Mars are considered to be analogous to intraplate oceanic earthquakes due to lithospheric cooling [8]. This time we employ a source time function as a phaseless bell-shaped pulse with width of 60 sec., which is sufficient for current target frequency range of observation by the MELOS. Figure 1 indicates snapshots of global seismic wave propagation at 3500 s after excitation for models A and B. Large differences between the two Mars models are crust thickness and depth of the core mantle boundary (CMB): the Model B has thicker crust and shallower CMB. At around the opposite side of the source position, we can clearly see that the model differences strongly affected on rows of

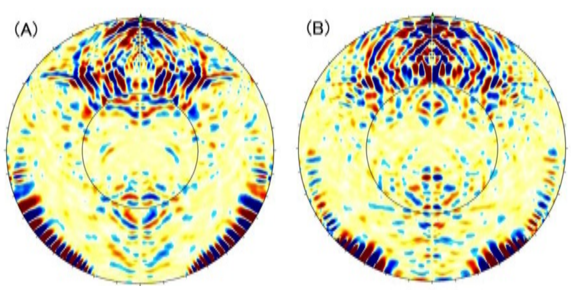

Figure 1 Snapshots of the global seismic wave propagation for the model A (top), and model B (bottom) at 3500 s after excitation. Red and blue denote relatively large positive and negative values of radial component of the particle velocity. The borders of the models are the free surface and the CMB. The source location is indicated by green star.

surface waves which have already passed through the antipodal point and are traveling toward the epicenter. The surface wave for the model A contains longer coda waves due to the shallower crust. Our scheme can easily treat lateral heterogeneities. In the presentation, we will show other numerical examples using probable laterally heterogeneous Mars structure models.

4. Summary

We develop a method for numerical modeling of global seismic wave propagation for the Mars. Our numerical scheme is calculates the 3-D equations of seismic waves in spherical coordinates only on a 2-D cross section of the whole Mars including a seismic source and receivers (spherical 2.5-D FDM), which enables global waveform modeling with the similar computation time and memory as for 2-D modeling with consideration of full 3-D geometrical spreading. Preliminary results based on current Martian interior models (Model-A and –B of Sohl and Spohn [1]) indicate clear difference of surface wave.

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