CIDER 3D Reference Earth Model Workshop

Attendees: Eric Debayle, Arwen Deuss, Adam Dziewonski, Göran Ekström, Ulrich Faul, Ana Ferreira, Steve Grand, Brent Grocholski, Saswata Hier-Majumder, Gabi Laske, Sergei Lebedev, Ved Lekic, Guy Masters, Raj Moulik, Mark Panning, Mike Pasyanos, Jeroen Ritsema[1], Barbara Romanowicz, Nicholas Schmerr, Peter Shearer, Dan Shim, Jeroen Tromp, Don Weidner.

Summary: The workshop took place on April 26th and 27th, 2013 at the University of Maryland and was funded as a "working group" by CIDER. Lekic presented a proposal for developing a 3D reference model (REM-3D) for the Earth, which was submitted to NSF Geophysics in Dec 2011 by Lekic, Romanowicz, Dziewonski, Masters and Ritsema. This initial proposal was declined, the panel recommended more community input, in the form of a workshop. Active discussion and brief presentations characterized the remainder of the workshop.

Consensus was achieved on the following conclusions:

1. The deep Earth community – global seismology, mineral physics, geochemistry, and geodynamics – would benefit from the development of a long wavelength reference 3D model, including its spherical average, as long as such a reference model is consistent with relevant conclusions and recommendations;

2. The reference 3D model has to be consistent with dispersion of long period surface waves, normal mode center frequencies and splitting functions, travel times of long period (20s) P and S waves, mass of the Earth and moment of inertia (making it the first such model since PREM);

3. Though shear wavespeed structure (Vs) is easiest to constrain, the utility of REM-3D for the broader deep Earth community would be enhanced if variations in compressional wavespeed (Vp) and density – or, if possible, bulk modulus and its depth derivative – were specified, even if at lower resolution;

4. For some important parameters (e.g. parameter η in radial anisotropy, attenuation), REM-3D will only be able to specify a depth-dependent spherical average (i.e. a 1D profile);

5. The uncertainties, resolution and trade-offs between parameters of REM-3D must be systematically investigated with model-space exploration techniques (when computationally feasible) and standard techniques (including the method of Backus and Gilbert) to estimate model covariance, resolution and uncertainty. These must be presented in an easy-to-understand way designed for scientists in related fields;

6. Development of REM-3D is justified by both excellent agreement among tomographic models at long wavelengths, and general consistency among available long period seismic datasets;

7. Accurate treatment of crustal structure is crucial for reliable estimation of lateral variations of radial anisotropy, and other less-well-constrained seismic parameters;

8. Development of broadly distributed set of reference seismic datasets – used in the construction and (in)validation of REM-3D – should be considered a major project deliverable;

9. Comparison of mineral physics observations/predictions against the 1D PREM or other 1D seismic models without associated uncertainties can be misleading given the amplitude of lateral variations in seismic velocities, and streamlined direct comparison against data would be preferable;

To guide model development, the following recommendations were issued:

1. Two families of REM-3D should be developed with different but complementary parameterizations that would meet needs of different research communities and offer complementary advantages:

---

[1] Via teleconference.

a. Regionalization – REM-3D that specifies reference profiles of Vs, Vp, density and anisotropic parameters appropriate for individual geographic regions, which themselves are defined by cluster analysis of tomography in the lower mantle (2 regions) and cluster analysis or surface tectonics in the uppermost 300 km (4-8 regions). Region-appropriate scalings between well- and poorly-resolved seismic parameters (e.g. attenuation) informed by mineral physics should be explored in this version of REM-3D. Since geographic extents of regions will be kept fixed, the number of parameters to be inferred should be small enough to allow systematic evaluation of uncertainty using Bayesian model space exploration techniques.
b. Smooth parameterization – Low order spherical harmonic expansion that would not have the strong a priori constraint imposed by regionalization and avoid waveform complexities possible with edges of regions. General sense of the participants was that Vs structure up to degree 12 in the uppermost mantle and degree 6 in the lower mantle may be sufficiently robust to warrant inclusion in REM-3D. Majority preferred a continuous parameterization in depth, though no consensus on this point was achieved. Though uncertainties on the spherically average model can be explored using Bayesian model space exploration techniques, the large number of parameters in the spherical harmonics expansion will require other methods for quantifying uncertainty, such as by estimating the posterior covariance matrix.

2. Three workgroups should be created to advise, oversee and evaluate the reference model development and compilation / reconciliation of reference datasets. To expedite progress and minimize expense, the scope of the workgroups should be limited to reconciliation of only those data incompatibilities that result in significant differences in REM-3D structure. The workgroups should be: 1. Surface wave dispersion, normal mode frequencies and splitting; 2. Body wave travel times, major discontinuity (410, 660) depths and Vp, Vs, density contrasts; 3. Physical parameterization informed by constraints from mineral physics, including, but not limited to determining optimal scaling factors for presently seismically unresolved parameters.

3. A well-documented and easy-to-use computational tool should be developed to quantify the compatibility of trial profiles of various physical parameters (Vs, Vp, density, pressure, etc.) with the reference seismic datasets compiled and reconciled as part of the REM-3D effort.

4. The 220 km discontinuity present in PREM should not be imposed a priori in REM-3D.

5. Core structure, including update on 1D outer core structure and inner core anisotropy, should be considered;

6. Crustal structure from CRUST 1.0, which remedies known inadequacies of CRUST 2.0, should serve as the basis for REM-3D, potentially modified by long-wavelength perturbations to crustal velocities (and/or Moho depth) necessary to reconcile lateral variations of mantle structure of REM-3D with the reference dataset;

7. Azimuthal anisotropy may not be resolved well enough to justify inclusion in REM-3D, but should be accounted for (corrected for) in the construction of the reference datasets and model;

8. Potential of the proposed long-period REM-3D for predicting the travel times of higher-frequency waves – such as the travel-time picks carried out by the International Seismological Centre – should be quantified, and a range of reasonable attenuation structures explored.

The following action items were proposed:

1. (Re)submission of NSF proposal to Geophysics (or, potentially cSEDI) to fund: 1. Model and reference dataset development by a postdoctoral researcher supervised by Lekic; 2. Expenses associated with the functioning of the workgroups; 3. Maintenance / development of web-based resources for data/model dissemination; 4. Future workshops to solicit input of broader deep Earth community and evaluate progress on REM-3D.

2. Call for contribution to the reference dataset effort of surface wave, free-oscillation, absolute and relative body-wave travel time datasets should be circulated to the broader community.

3. An avenue for publishing descriptions of and giving proper credit to individuals contributing datasets should be investigated.