Implementation and Testing of the CVM-H (Harvard) in Large-Scale Ground Motion Simulations

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Overview

One of the most successful and widely used SCEC products is the Community Velocity Model (CVM). This model provides a 3D representation of the seismic wave velocity and crustal structure throughout southern California, and forms the basis for the generation of large-scale computational models used in the numerical simulation of earthquake ground motions. Currently, there are 2 forms of the model available: CVM-S (S=SCEC) is the rule-based model developed by Kohler et al (2003), and CVM-H (H=Harvard) is the model developed by Suess and Shaw (2003). The CVM-S has been used in many past SCEC activities related to the simulation and prediction of ground motion effects in southern California (e.g., Day et al, 2005; Graves and Somerville, 2005; Olsen et al, 2006; Graves et al, 2008). However, further development of the CVM-S beyond the currently available version 4.0 (CVM-S_4.0) is not planned; rather the USR group has decided to concentrate its efforts on refinement of the CVM-H.

The main objectives of the current project are to **1)** design and implement a practical and efficient method for generating large-scale 3D computational velocity models using the CVM-H, and **2)** analyze the performance of this model in matching recorded waveforms for past EQs and compare these results with simulations computed using CVM-S_4.0. To date, significant progress has been made on the first objective and we are now starting to set-up the simulations to address the second objective.

Implementation Issues

The most current version of the CVM-H is version 5.7 (CVM-H_5.7, http://structure.harvard.edu/cvm-h). The model is defined on a rasterized grid having 3 regions of differing resolution. In the highest resolution portion of the model, which includes the greater Los Angeles basin region, the current representation of the CVM-H has a sampling of 250 m horizontally and 100 m vertically. The vertical spacing is defined as elevation with respect to sea level, thus surface topography and bathymetry are implicitly included in the model. In order to implement CVM-H in a manner consistent with previous applications of CVM-S, the following primary issues have been identified:

- Removing topography
- Grid-based resolution limit
- Geotechnical Layer
- Efficient model generation

Addressing theses issues is an ongoing process and involves a broader group of SCEC researchers, including members of the CME group (in particular Patrick Small). Below, I briefly provide the status of work on these issues.

Removing Topography

Most previous simulations using the CVM-S are based on codes that are restricted to a flat free-surface. In addition, the rule-based formulas of the CVM-S are constructed in terms of depth below the free-surface, which is implicitly consistent with the assumption of a planar free-surface boundary. This type of representation is referred to as “squashing” in that all surface topographic features are pushed down to a common elevation (as opposed to “bulldozing”, which simply scrapes off all material above a common elevation). In order to perform the same types of simulations with CVM-H, we need to develop an implementation that allows the squashing of topography.

Each voxel (or node) in the CVM-H has various data associated with it including the elevation of the ground surface. The current approach to “squash” topography is to first query the model at a particular location (lon,lat) and determine the surface elevation (Z_0). Then, the model is queried again at the same location at elevations of Z_0, Z_0-h, Z_0-2h, …, where h is the vertical grid spacing of the target model. Unfortunately, the elevation of Z_0 does not always have defined media values. In this situation, the model is drilled down to an elevation where valid media are found, and then the remainder of the depth profile is constructed. This process is described in more detail at http://earth.usc.edu/~patrices/run1.html.

Grid-based Resolution Limit

Another concern with the CVM-H representation is the inherent (or limiting resolution) of the underlying model. In the highest resolution portion of the model, the current CVM-H is on a rasterized grid having a resolution of 250 m horizontally and 100 m vertically. The grid based simulation models are already using node spacings on the order of 100 m or less, so it is clear that the resolution of the CVM-H needs to be increased, at least in the upper 1-2 km of the model. The two approaches being considered to address this issue are 1) build an “on-the-fly” interpolation module to calculate the media value at a specified location based on an interpolation of its neighbors, or 2) generate a refined CVM-H representation using a higher resolution grid. Approach 1) has the advantage of utilizing the existing model database, but will require additional computations to generate each model value. Approach 2) would require no additional computations when the model is queried; however, the size of the underlying model database would be increased significantly. We plan to work with the USR group to determine an appropriate grid resolution that will balance the needs of the simulation models, the level of knowledge of subsurface structure, and practicality of model storage/representation.

Geotechnical Layer

The topmost portion of the CVM-S is represented using the Geotechnical Layer (GTL), which tapers the velocity structure in the upper 300 m to values typically found in the near surface. The profiles used for this tapering are constructed from a library of shallow borehole velocity profiles. The CVM-H has applied a similar approach to incorporate the shallow structure by overlying the GTL onto the topmost 300 m of the model. While this approach reproduces the GTL velocities at the grid locations (e.g., every 100 m in depth for the high resolution portion of the model), it cannot provide information at a higher resolution and thus potentially aliases the underlying GTL. This may create problems when the desired model sampling is less than the voxel sampling, and the GTL profile is incorrectly represented as a coarse model with artificial discrete layering.

Efficient Model Generation

One of the issues faced by many of the ground motion simulation groups within SCEC is the need for efficient generation of large-scale 3D velocity models (on the order of 10^9 grid points). For the CVM-S_4.0, this issue has been addressed either through the development of parallelized model query software (e.g., Ely / Graves), or through the use of rasterized representations of the model for a specific volume (e.g. ETREE representation developed by the CMU group). Software distributed with the CVM-H can perform simple queries of the model to retrieve media parameters at arbitrary *(x,y,z)* locations. Patrick Small of the SCEC CME group has developed a parallelized implementation of this code, which has reduced the model generation procedure to a manageable level (16 hours for 10^{10} points). We plan to test the performance of this software for various model regions (e.g. ShakeOut, Northridge) and to compare/contrast these models with similar ones generated for the CVM-S.

Point Profile Comparison with CVM-S_4.0

Figure 1 shows the locations of 8 sites in Southern California where we compare 1D velocity profiles extracted from CVM-S_4.0 and CVM-H_5.7. These sites are all in basins regions: Imperial Valley (DRE, MGE), San Bernardino (CFS), Los Angeles (RUS, DLA, SMS), and San Fernando (NOT, FLL). Figure 2 plots the extracted Vp, Vs and density profiles at these sites for the 2 models. In general, the profiles show many similarities; however, all sites exhibit some level of difference. From this limited sampling, it is hard to determine if the differences follow any systematic pattern. For example, CFS and MGE appear to have a shallow basement depth for the CVM-H_5.7 model compared to CVM-S_4.0. Other sites have somewhat different velocity gradients (DRE, FLL, NOT) for the 2 models. And some sites (DLA, NOT, RUS, SMS) have structural features (e.g., high- or low-velocity zones) that are present in one model but not the other.

Currently, Patrick Small of the CME group is generating slices through each of the 2 models in order to get a more comprehensive view of the similarities and differences between them. Additionally, several of the waveform simulation groups are preparing EQ calculations for the CVM-H_5.7 that can be directly compared with existing results previously generated using CVM-S_4.0. These results should be available for presentation at the SCEC Annual Meeting.

References

Day, S. J. Bielak, D. Dreger, R. Graves, S. Larsen, K. Olsen, A. Pitarka, and L. Rameriz (2005). Numerical simulation of basin effects on long period ground motion, *Proc 8th Nat. Conf. Earthquake Eng.*, San Francisco, CA.

Graves, R. and P. Somerville (2008). Broadband simulations for scenario earthquakes on the Puente Hills fault, *Proc 8th Nat. Conf. Earthquake Eng.*, San Francisco, CA.

Graves, R., B. Aagaard, K. Hudnut, L. Star and J. Stewart (2008). Broadband ground motion simulations for a M_w 7.8 southern San Andreas Earthquake, *submitted to Geophys. Res. Lett.*

Kohler, M., H. Magistrale and R. Clayton (2003). Mantle heterogeneities and the SCEC reference three-dimensional seismic velocity model version 3, *Bull. Seism. Soc. Am.*, **93**, 757-774.

Olsen, K., Day, S., Minster, J., Cui, Y., Chourasia, A., Faerman, M., Moore, R., Maechlin, P., and Jordan, T., 2006, Strong shaking in Los Angeles expected from a southern San Andreas earthquake, *Geophys. Res. Lett.*, **33**, L07305.

Suess, M. P., and J. H. Shaw (2003). P-wave seismic velocity structure derived from sonic logs and industry reflection data in the Los Angeles basin, California, *J. Geophys. Res.* **108** B3 ESE13,1 -18.

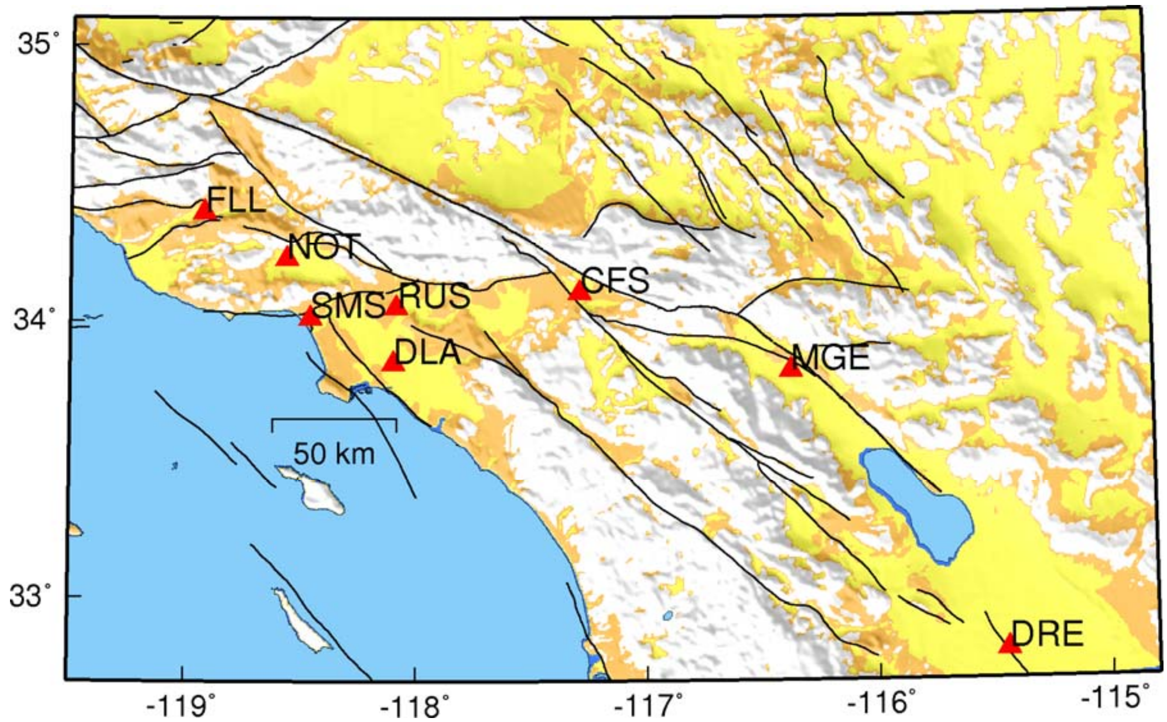

Figure 1: Locations of 1D velocity model comparisons for CVM-S_4.0 and CVM-H_5.7.

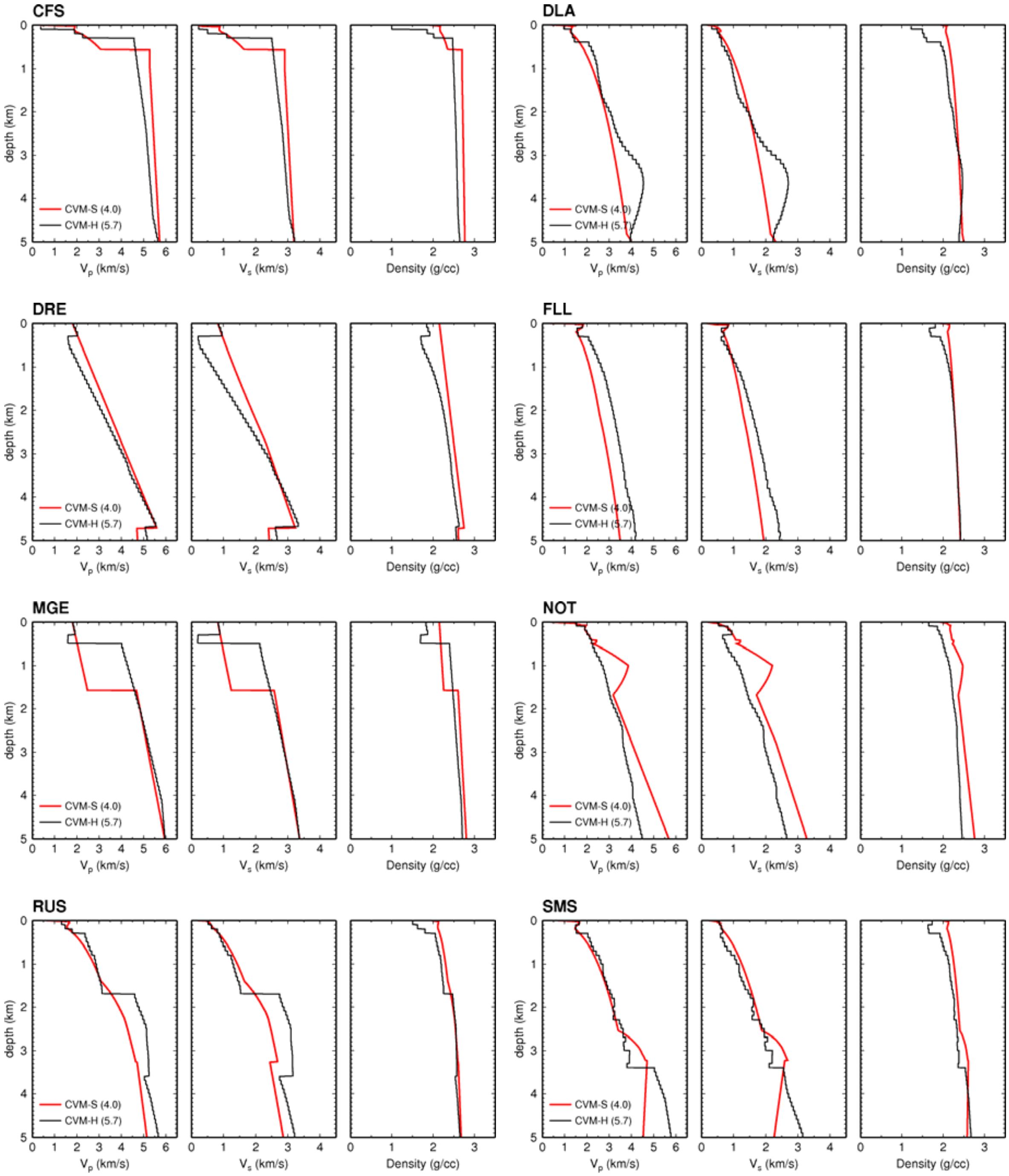

Figure 2: Comparison of 1D P-wave velocity (left panel), S-wave velocity (middle panel) and density (right panel) profiles from the CVM-S_4.0 (red) and CVM-H_5.7 (black) at 8 sites indicated in Figure 1.