2019 SCEC PROGRESS REPORT

Assimilating SSIP data into a Full 3D Tomography (F3DT) model of the Salton Trough

SCEC Award No. **19014**

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Proposal Categories:
A: Data Gathering and Products

SCEC Science Priorities:
P4.a, P3.a, and P2.b

Interdisciplinary Working Groups:
Ground Motions (GM)
San Andreas Fault System (SAFS)
SCEC Community Models (CXM)

ABSTRACT

To improve earthquake hazard assessments in the Salton Trough, we must accurately forecast strong ground motions through realistic 3D earth models. Recently, we have utilized active-source data from reflection and refraction seismic experiments in the Salton Trough such as the 2011 Salton Seismic Imaging Project to produce 3D travel time velocity models for Coachella and Imperial valleys (Ajala et al., 2019; Persaud et al., 2016). Comparisons of our models with two popular community velocity models reveal significant differences in basin geometry and crustal heterogeneity. To investigate the accuracy of the models in ground motion prediction, we registered our velocity models into the SCEC Unified Community Velocity Model software framework. This facilitates the construction of hybrid velocity models and mesh generation.

Using the SPECFEM3D Cartesian package[1], we have simulated ground motions for a M5.2 earthquake in four velocity models with geotechnical layers in the top: (1) our travel time velocity models embedded in CVM-H15.1, (2) our travel time velocity models embedded in CVM-S4.26, (3) CVM-H15.1 only, and (4) CVM-S4.26 only. Preliminary results show significant improvement in waveform misfit, especially in the sedimentary basins when our travel time velocity models are embedded into CVM-H15.1, compared to CVM-H15.1 alone. This highlights the importance of active-source data in developing accurate crustal models. Ongoing work involves reducing waveform misfit due to inaccuracy from the model and mesh construction. The best model will subsequently be improved by incorporating existing active-source data in a full-waveform inversion to develop an improved crustal model for the Salton Trough.

EARTHQUAKE SIMULATION

We simulated a 2016 M5.2 event (red circle in Figure 1). that was not used in the development of any of the models currently being assessed. The event occurred at a depth of 12.7 km. The zeroth-order moment tensor was determined from the strike, rake, and dip using formulas in Aki and Richards (2009, p. 112). The source half-duration is computed from the scalar moment using the empirical relation in Ekstrom et al. (2012). The SPECFEM3D cartesian package (Komatitsch & Tromp, 2002a, 2002b and many more), which implements the spectral-element solution to the 3D wave equation for hexahedral meshes was used for the simulation. The preliminary mesh (Figure 2) covers the same areal extent shown in Figure 1 and is 220 km by 252 km, with the vertical axis extending from the free surface to 50 km below sea level. The mesh is constructed to contain mostly cube-like elements and includes refinement layers at 10 km depth and at the Moho. Each hybrid velocity model used in the simulation is constructed using SCEC UCVM (Small et al., 2017). Each model is described in terms of elastic wave speeds (*P* and *S* wave speeds), density, and attenuation. While registering our *P* wave velocity models (Ajala et al., 2019; Persaud et al., 2016), empirical relationships from Brocher et al. (2005) were used to determine *S* wave speeds and density. In all the models, attenuation is determined using empirical relationships between *S* wave speeds and Q from Olsen et al. (2003). Anisotropy has not been incorporated in the models. Simulation time for each model is 200 s. Analysis of the mesh and velocities in the model indicate that the simulation is capable of resolving ground motions with periods as low ~2 s. Synthetic seismograms from the simulations and recorded seismograms filtered between 6 s and 30 s are shown in Figure 3. Videos showing wavefield simulations are available at https://www.geol.lsu.edu/persaud/Data.html.

[1] https://geodynamics.org/cig/software/specfem3d/

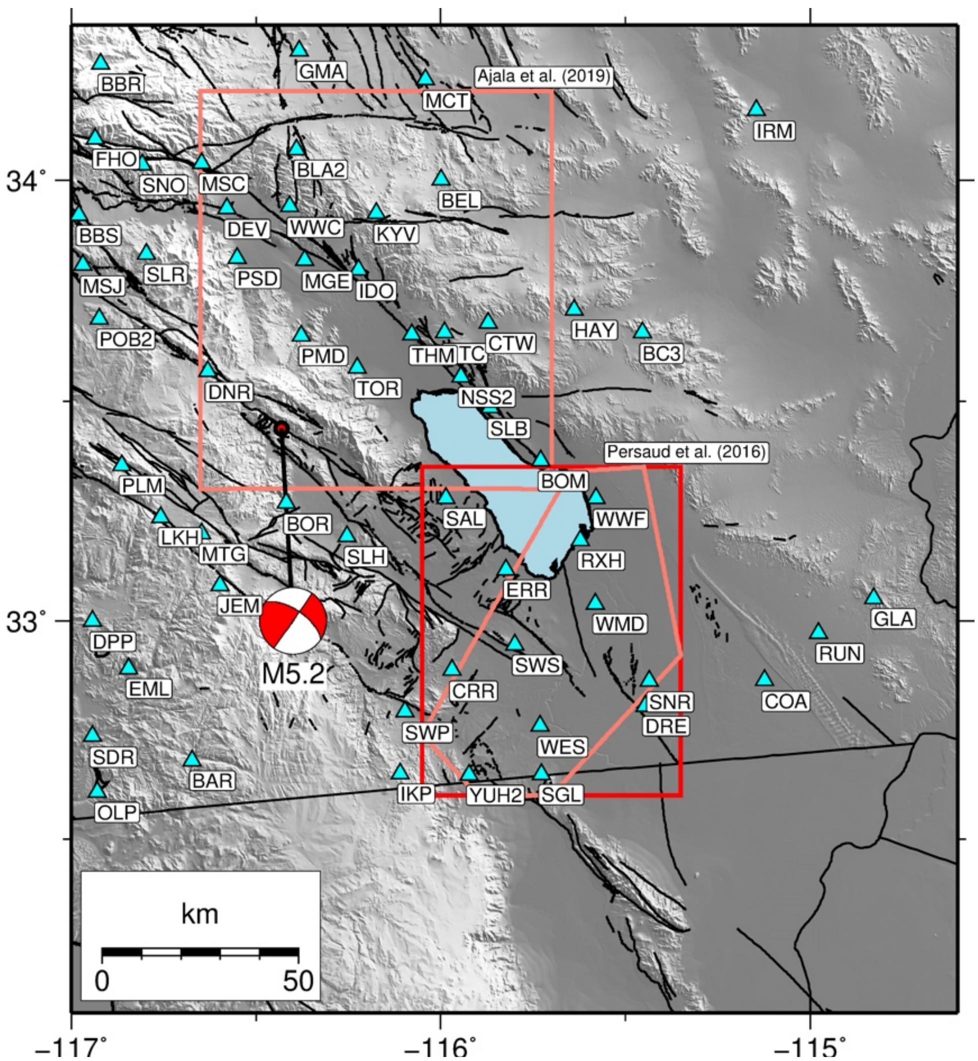

***Figure 1**: Map showing the extent of our earthquake simulation domain in the Salton Trough. Red circle indicates the location of the earthquake used in the simulation from the Southern California Earthquake Data Center (Yang et al., 2012). Blue triangles are SCSN broadband stations that recorded the event. Pink polygons show areas in Coachella and Imperial valleys where we have developed 3D travel time P wave velocity models (Ajala et al., 2019; Persaud et al., 2016) that were embedded in SCEC Unified Community Velocity Model (UCVM). Red polygon in Imperial Valley shows the extent of the model which we have currently registered in UCVM but will be refined to the pink irregular polygon where data coverage in the model is good.*

Wavefield snapshots for our **ely** + **cv** + **iv** + **cvmh** model (available online at https://www.geol.lsu.edu/persaud/Data.html) show artifacts resulting from disagreement in velocities between the interpolated **iv** model and **cvmh**. This indicates some of the improvements we are currently working on. To address this issue, we will refine the iv model to its actual areal extent shown in Figure 1, where the model is well determined. Also, a restrictive boundary mollification for our travel time velocity models needs to be implemented to reduce edge effects.

All of these changes are currently being implemented to UCVM and will be made available to the SCEC community via GitHub upon completion. After these changes have been made, a relative waveform assessment for the full-length seismograms will be carried out to quantitatively assess the hybrid models. However, by visual inspection alone, CVM-H 15.1 appears to overestimate ground motions in some areas in the Salton Trough compared to the rest of the models (Figure 3). A good example of where this occurs in Coachella Valley is station TOR (sixth station from the top in Figure 3), whereby embedding our travel time velocity models significantly improves the waveform misfit.

INTELLECTUAL MERIT

Our model has practical significance for improving the accuracy of earthquake hazard studies by providing a more accurate seismic velocity model for the region surrounding the southern San Andreas fault system. The accuracy of ground motion estimates strongly depends on the seismic velocity structure, especially the basin structure which is key in determining shaking intensity (Lee et al., 2014). Fault geometry and earth models with realistic material properties are key ingredients of dynamic rupture simulations of the earthquake process (Barall and Harris, 2015).

Data from the 2011 Salton Seismic Imaging Project offers a new opportunity to improve the existing CVMs with active source data that lack the standard source location and origin time uncertainties of earthquake-only data sets and densely sample the upper crust where earthquakes are sparse. For example, using SSIP data, Persaud et al. (2016) identify concealed faults in Imperial Valley that are not associated with mapped surface faults and currently do not exist in the CFM but are aligned with well-defined seismicity lineaments. Similarly, Ajala et al. (2019) show an irregular basement structure in Coachella Valley that will result in different ground shaking estimates than for a symmetric basin and regular basement structure in current regional community velocity models used in seismic hazard analysis for Southern California. Incorporating SSIP data into the existing large-scale CVMs is thus a crucial next step in creating the next generation of CVMs that can then be improved through full waveform inversion**.**

BROADER IMPACTS

This award has supported a PhD student and the research program of an early-career tenure-track faculty. A manuscript was published with the 3-D velocity model for the Coachella Valley (Ajala et al., 2019). Preliminary project results showing the hybrid model and wave simulations were presented at the 2019 SCEC Annual Meeting.

We have made our wavefield simulations publicly available at our LSU research webpage (https://www.geol.lsu.edu/persaud/Data.html). We have provided our 3-D velocity model as well as the derived basement and estimated $Z_{2.5}$ surfaces important for seismic hazard assessment to the organizers of the SCEC CVM for incorporation into the Community Modeling Environment. These files are also publicly available for download at our LSU research webpage.

All final models will be made available to SCEC community in UCVM.

PEER-REVIEWED PUBLICATIONS RESULTING FROM THIS AWARD

Ajala, R., Persaud, P., Stock, J. M., Fuis, G. S., Hole, J. A., Goldman, M., & Scheirer, D. (2019). Three-dimensional basin and fault structure from a detailed seismic velocity model of Coachella Valley, Southern California. *Journal of Geophysical Research: Solid Earth, 124*, 4728-4750. https://doi.org/10.1029/2018JB016260

PRESENTATIONS RELATED TO THIS PROJECT

Ajala, R., Persaud, P., Juarez, A., & Ayeni, G. (2019)., Evaluating seismic velocity models in the Salton Trough using spectral-element wave simulation of validation events, *Poster presentation at the 2019 SCEC Annual Meeting*.

Persaud, P. (2019)., Contributions from 3-D seismic velocity models to improving seismic hazard estimates within the southern San Andreas fault system, *Oral presentation at Utah State*

University.

Ajala, R., Persaud, P., Stock, J., Fuis, G., Hole, J., Goldman, M., & Scheirer, D. (2019)., Crustal imaging for improved seismic hazard assessment in the Salton Trough, Southern California, Oral *presentation at Louisiana State University symposium*.

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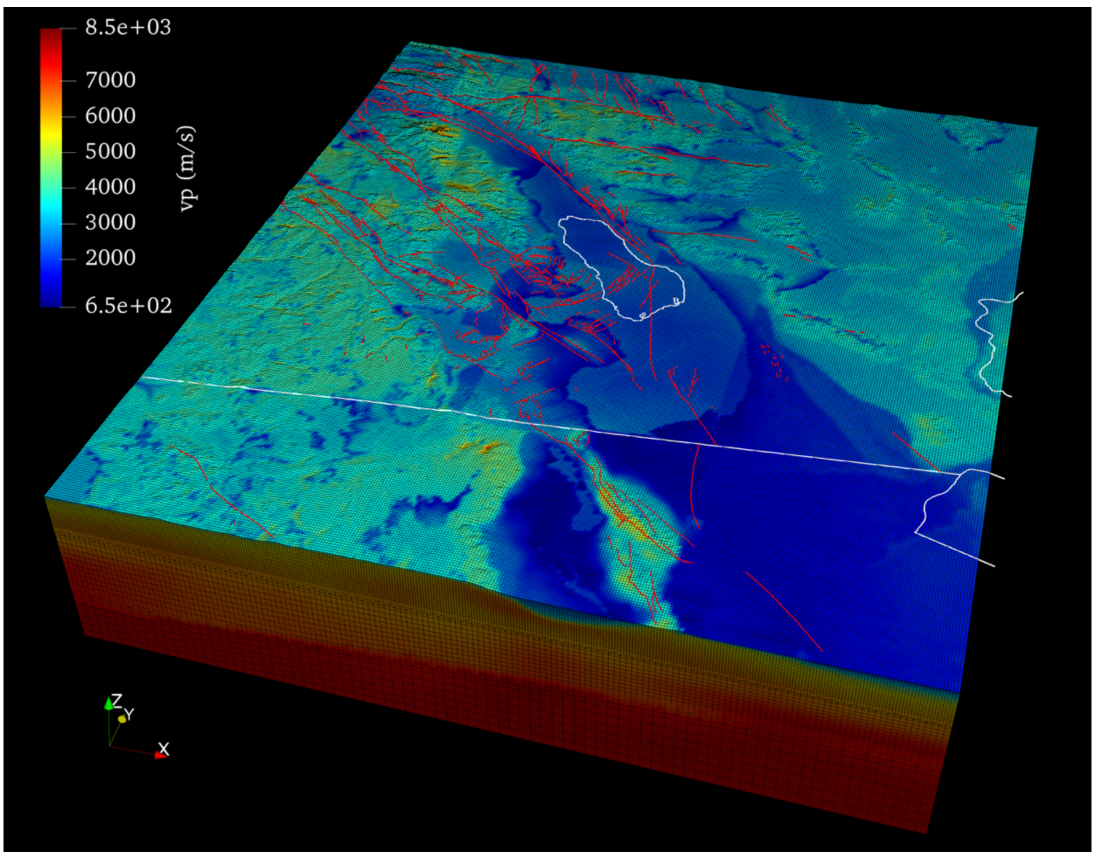

Figure 2*: Preliminary unstructured hexahedral mesh of the Salton Trough region showing P wave velocities constructed from a combination of our travel time velocity models and CVM-S4.26. The mesh is developed using the internal meshing program of the SPECFEM3D Cartesian package and includes topography and Moho interfaces, and two refinement layers at 10 km below sea level and the Moho. The mesh contains a total of 1,958,400 elements, with the smallest and largest element size being 532 m and 5300 m, respectively. Each element is sampled with five grid points along each dimension, i.e., 125 grid points in each element. Red lines are surface traces of mapped faults in the region.*

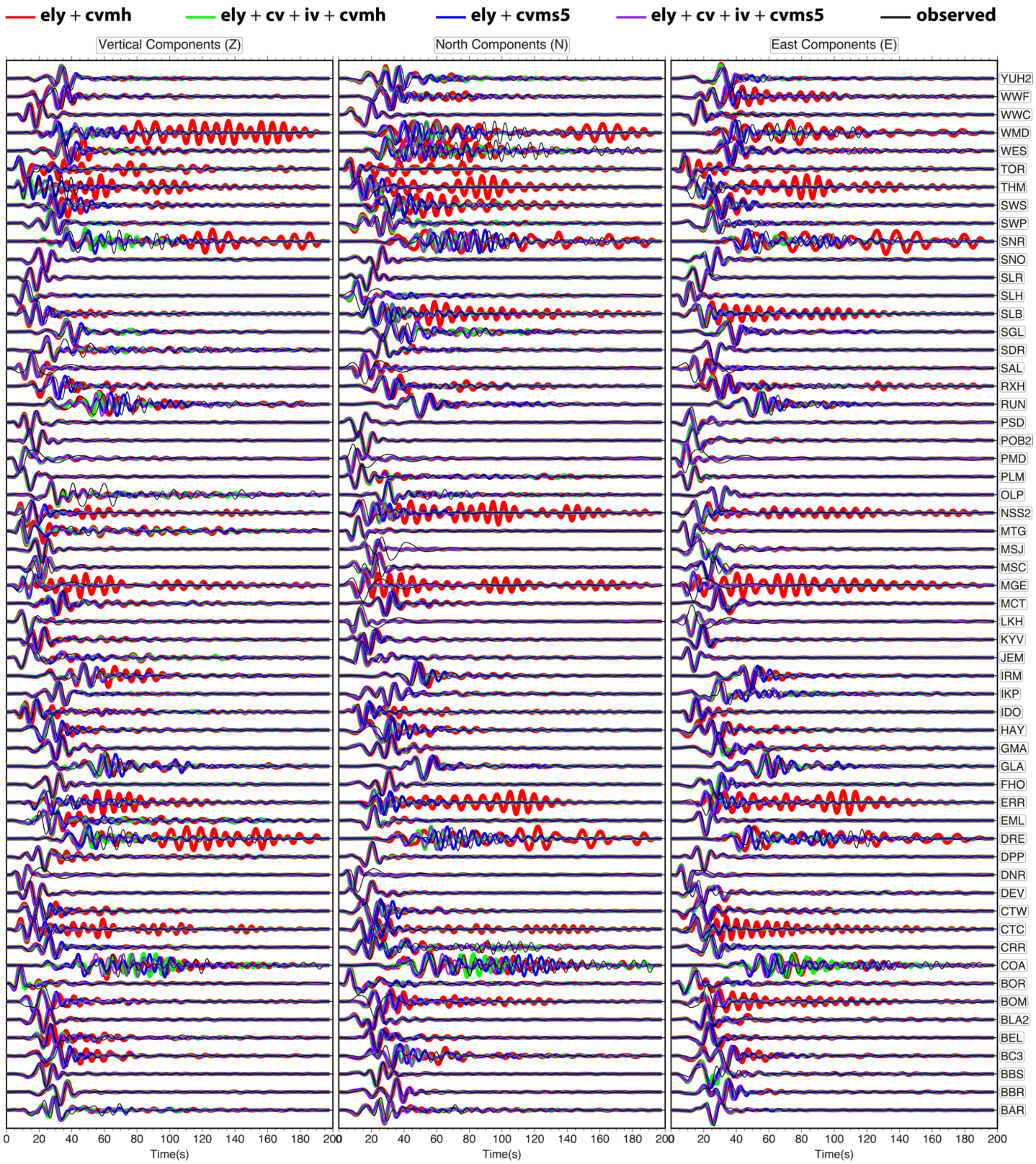

Figure 3: *Comparisons of ground displacement records between synthetic seismograms generated from the simulation using the velocity models and observed seismograms (black) of the earthquake. Seismograms are filtered between 6 s and 30 s. Color code of seismograms for each model is shown at the top of the figure. Station labels are shown to the right of the plot. Velocity model abbreviations as embedded in UCVM:* ***cv*** *– Ajala et al. (2019) travel time velocity model;* ***cvmh*** *– Tape et al. (2009, 2010) F3DT model (CVMH-15.1);* ***cvms5*** *– Lee et al. (2014) F3DT model (CVM-S4.26);* ***ely*** *– Ely et al. (2010) geotechnical model;* ***iv*** *– Persaud et al. (2016) travel time velocity model (Note: while constructing the velocity models in UCVM, in areas where* ***cv*** *and* ***iv*** *overlap,* ***cv*** *is preferentially queried.)*

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