2015 SCEC Report

Development of a Unified Structural Representation for Central California

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Summary
This past year, we developed an initial Unified Structural Representation (USR) for Central California in support of the newly established Central California Seismic Project (CCSP). This project was a natural extension of the current SCEC USR in southern California, and is designed to help facilitate more comprehensive assessment of earthquake sources and physics-based waveform modeling to define path effects in the region.

Specifically, we:
1) Enhanced the SCEC Community Fault Model (CFM) to include more detailed representations in the study region, making use of relocated earthquake hypocenter and focal mechanism catalogs;
2) Developed and refined 3D models of basin structures (e.g., Santa Maria, San Joaquin), including top basement surfaces and sediment velocity parameterizations based on tens of thousands of direct measurements from boreholes and seismic reflection/refraction datasets.
3) Presented these results at a workshop with the USGS Menlo Park to facilitate coordinating collaborative fault and wavespeed modeling efforts.

This proposal represents a new effort to develop community-based fault and velocity models in support of the CCSP Project by the lead developers of the SCEC CFM and CVMH models. We used these models to populate computational grids and meshes that will be used for 3D seismic waveform tomography to developed improved velocity models in the region. These, in turn, will be used to assess ground motion hazards through numerical simulation of rupture and wave propagation.

USR Framework
The concept of a Unified Structural Representation (USR) has been pioneered by the SCEC Community to support a wide range of earthquake science and hazard assessment efforts. The SCEC USR for southern California is a three-dimensional description of crust and upper mantle structure consisting of interrelated Community Fault (CFM) and Velocity (CVM) models. The developed of these models has been inspired by recent advances in numerical methods and parallel computing technology that have enabled large-scale 3D simulations of seismic wavefields in realistic earth models [e.g., Olsen et al., 1995; Komatitsch & Tromp, 1999; Komatitsch et al., 2004; Bielak et al., 2010]. These simulations are able to capture the effects of basin amplification, resonance, wave focusing, and dynamic rupture propagation. Thus, they offer a physics-based alternative to attenuation relationships for forecasting the distribution of hazardous ground shaking during large earthquakes (e.g., Zhao et al., 2000; Tromp et al., 2005; Tromp et al., 2005; Tarantola, 1984; Chen et al., 2007). These methods also provide an objective, quantitative means of using seismic observations to improve the USR. These revised models, in turn, better define path and site effects and thus help make strong ground motion forecasts more accurate.

Central California USR
The CCSP study area extends from the Transverse Ranges in southern California north to the Santa Cruz Mountains in the Pacific Coast Ranges, and from the Pacific plate east across the Great Valley and Sierra Nevada Ranges (Figure 1). This area effectively lies north of the current SCEC USR for southern California, which includes only limited representations of Coast Ranges structures and none for the Central Valley and Sierra Nevada region. Below we describe the various USR components that were developed for the CCSP study area.

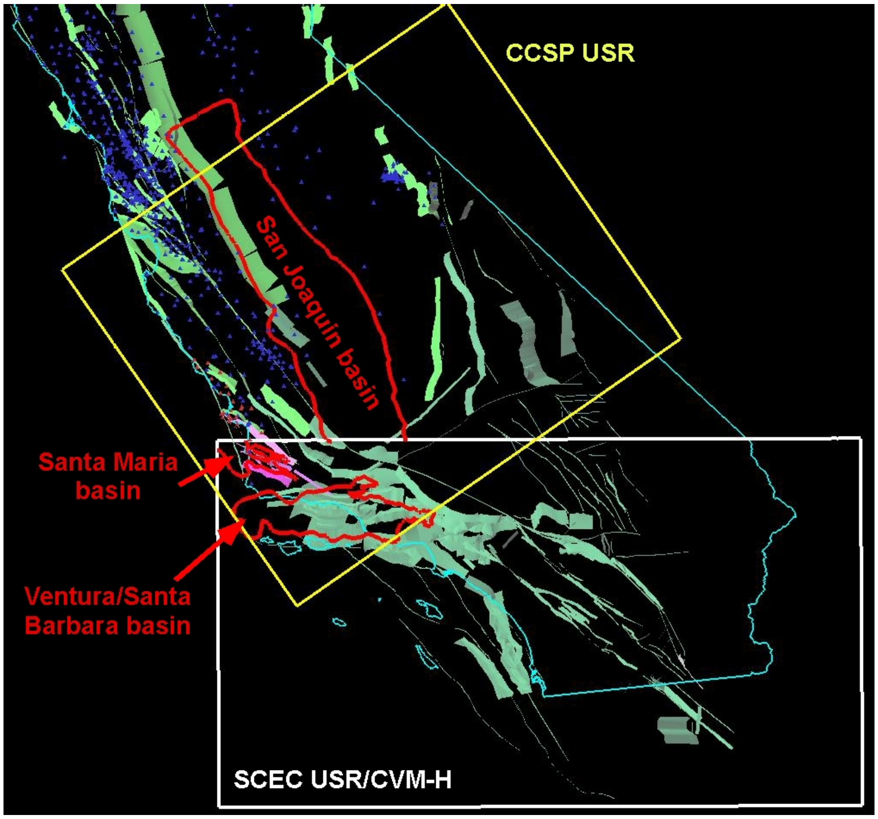

Figure 1: Map of California showing regions of the Central California Seismic Project (CCSP) (yellow) and the existing SCEC Unified Structural Representation (USR) (white). We developed a USR in the CCSP area, refining the SCEC Statewide Community Fault Model (SCFM) (current faults are shown) and basin velocity structures (Santa Maria and San Joaquin).

Extending Community Fault Models

The USR for Central California includes compatible descriptions of 3D fault and velocity structures. Following the approach used in southern California (Plesch et al., 2007), fault representations are generated using a range of different datasets, including detailed fault traces, earthquake hypocenters, focal mechanisms, seismic reflection and refraction surveys, and well logs. These data are integrated into a 3D, object-oriented modeling environment, and used initially to generate representations of fault patches that are well constrained by these datasets ("interpolated fault segments"). These fault segments are then extrapolated to generate full, 3D representations of the fault surfaces. These fault surfaces are represented as triangulated surfaces (tsurfs), and archived in a database that employs a hierarchical naming structure along with additional information, including a quality factor that is used to assemble preferred model versions.

To develop the new central California USR, we needed to improve the representations of faults in the study area using detailed fault traces from the USGS Fault & Fold Database (QFaults) and precisely relocated earthquake hypocenter and focal mechanism catalogs (Lin et al., 2007; Yang et al., 2012; Hauksson et al., 2012; Waldhauser & Schaff, 2008). Most prior fault representations in the CCSP region (particularly in the Coast Ranges) were based on the surface traces of Jennings (1994), with simple extrapolations to depth based on average fault dips. Thus, we refined fault locations and segmentation using the more detailed Qfault traces, and the down dip geometry of the faults using the relocated hypocenter and focal mechanism catalogs. The improved fault representations that we develop as part of this study (Figure 2) will be used as source representations and constraints on 3D velocity structure as described below.

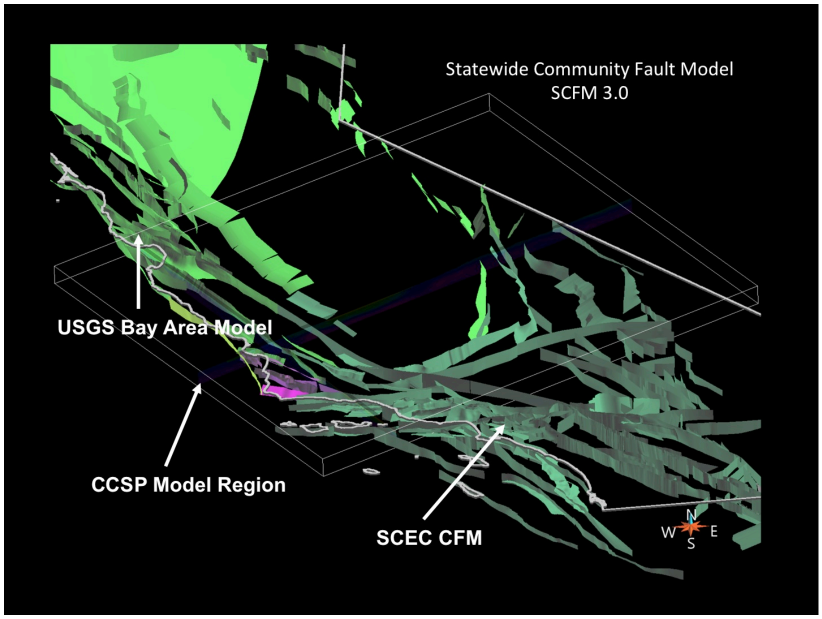

Figure 2: Perspective view of revised CFM used to develop central California USR.

Developing basin representations

One of the primary goals of the CCSP study is to facilitate 3D waveform tomographic inversions that will help to improve our understanding of regional velocity structure and reduce uncertainties due to path effects in calculated strong ground motions. We support this aspect of the CCSP by refining and implementing sedimentary basin structures in the starting models that are used for these inversions. Deep sedimentary basins in California represent the primary velocity structures in the crust. These basins are generally filled with thick (up to 10 km) sequences of relatively low velocity and density sediments that have been shown to amplify seismic waves and localize hazardous ground shaking during large earthquakes (e.g., Bonamassa and Vidale, 1991; Frankel and Vidale, 1992; Bouchon and Barker, 1996; Olsen, 2000; Graves et al., 1998; Bielak et al., 1999; Aagaard et al., 2001; Komatitisch et al., 2004; Minster et al., 2004; Graves et al., 2011). In the CCSP study area, we used high quality datasets (e.g., well logs, seismic reflection and refraction surveys) that enable us to define the geometry and wave speed structure of these sedimentary basins. Basins in the southern part of the CCSP study area, including the Ventura and Santa Barbara basins, are already included in the latest iteration of the SCEC southern California Velocity Model (CVMH). Thus, this past year we focused on developing representations of the Santa Maria and San Joaquin basins (Figure 3).

The southern part of the Santa Maria basin is represented in the current SCEC southern California Velocity Model (CVMH). We refined this basin structure by incorporating the locations and displacements of major faults and extending the basin structure offshore and to the north. The northern and offshore extents of the Santa Maria basin are of particular importance for characterizing path effects in the region of the PG&E Diablo Canyon nuclear generating station, which lies along the coast and about 10km northwest of the onshore basin edge.

In addition, we developed a new representation of the San Joaquin basin for the CCSP. Prior to this effort, there was no representation of the San Joaquin basin in the current southern California USR/CVMH. The San Joaquin basin forms the southern part of the Central Valley in California, and is bounded on the east by the Sierra Nevada mountain range and to the west by the Coast

Ranges. The basin contains up to 10 km of upper Jurassic to Holocene strata, and forms a broad asymmetric syncline. On the east side of the basin, strata dip gently to the west and onlap metavolcanic and plutonic basement that rises to the Sierra Nevada Mountains. In contrast, sediments on the west side of the basin dip more steeply to the east, and are folded and faulted in a series of structures that form the eastern margin of the Coast Ranges. Representing these basin structures in the new USR started with defining geological horizons that describe basin shape and depth. Of these geologic horizons, the base of the Jurassic forearc section, corresponding locally to the top of the Mesozoic accretionary and plutonic complex, is one of the most important boundaries (Wentworth et al., 2005). Sonic logs show that this “acoustic” basement horizon represent an abrupt change in compressional and shear wave velocities, as well as density. Moreover, other major geologic horizons within the sedimentary section represent important velocity interfaces (Brocher, 2005), and thus can provide constraints on our model. For the initial model version, we choose to use the basement and base Quaternary surfaces, as these showed the most consistent velocity contrasts. As was the case for the Santa Maria basin, we ensured that geologic horizons were compatible with the locations and displacements of major faults.

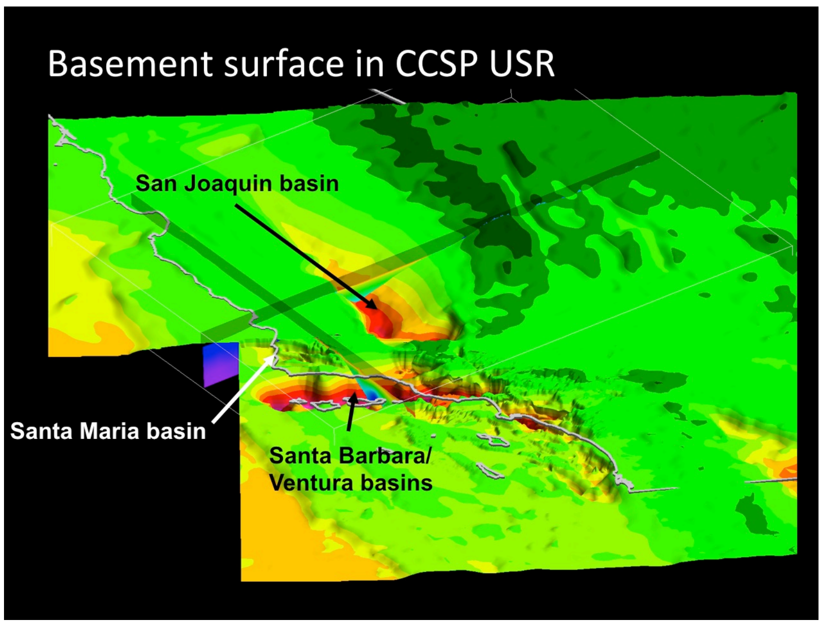

Figure 3: Perspective view of the top basement surface used to develop central California USR.

Within the enveloping topographic and geologic surfaces, we will develop topologically regular grids in order to interpolate the velocity structure. We constrained the seismic velocities in the San Joaquin basin using a database of more than 100 sonic logs and thousands of stacking velocity measurements from industry reflection profiles (Figure 4). These formerly proprietary data offer extremely precise and accurate measures of P wave velocities. The different observational methods sample velocities at different scales, between audible and ultrasonic (10 versus 104 Hz) frequencies, and were compared and calibrated prior to their integration in a common velocity model using the approach of Süss and Shaw (2003). Our calibrated data set includes several tens of thousands of interpolated and 25-ms-averaged velocities derived from seismic stacking measurements and ten meter averaged sonic velocity measurements. Preliminary analysis suggests that both sonic log and processed stacking velocities show similar mean values and ranges for interval velocities (Vp) that increase systematically with depth and time, from about 1500 m/s near the surface to more than 5000 m/s at depth.

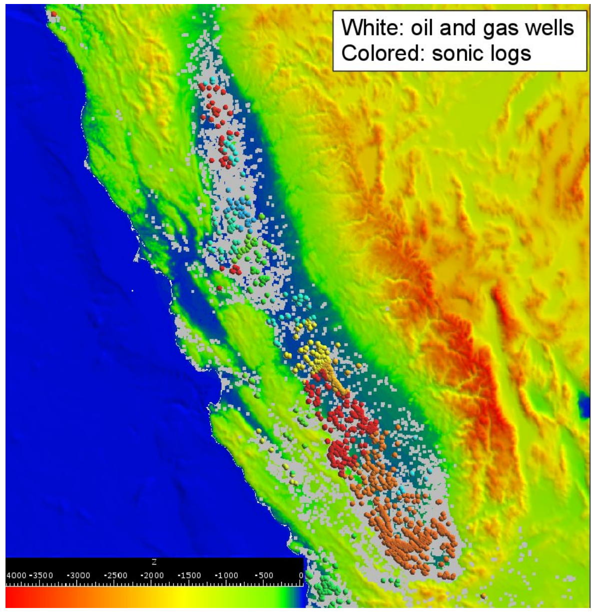

Figure 4: Map showing the Central Valley of California, the southern portion of which consists of the San Joaquin basin. Dots show the locations of oil and gas wells, many of which have sonic and other log types that will help to constrain the velocity structure in our model.

We develop the initial central California USR by integrating these components, and parameterizing Vp, density, and Vs using simple depth dependent functions based on the well control (Figure 5). The resultant model was embedded in the regional tomographic model of Chen et al., (2015, in progress), and shows abrupt velocity contrasts associated with basin and fault structures. In future work, we plan to refine the parameterization of the basin velocity structures using geostatistical interpolation methods. In parallel, the model will be used for further iterations of 3D waveform tomography to evaluate and improve velocity representations.

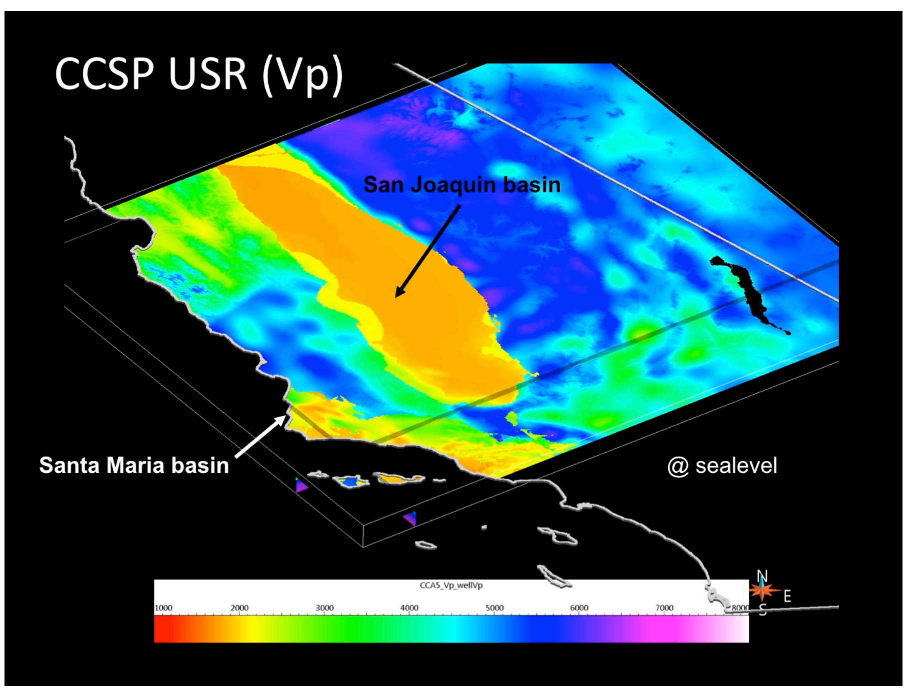

Figure 5: Perspective view of CCSP USR at sea level showing Vp structure.

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