2021 SCEC Report

Enhancements to the Community Fault Model (CFM) and its IT infrastructure to support SCEC science

SCEC Award 21018

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1. Summary

This report documents the continued primary effort to develop and enhance SCEC's Community Fault Model (CFM), a widely used resource (Plesch et al., 2007; Nicholson et al., 2021; Plesch et al., 2021) with many science and seismic hazards assessment applications. The CFM also directly contributes to other community modeling efforts, such as the Geological Framework (GFM), Community Rheologic (CRM), and Community Velocity (CVM-H) Models.

The SCEC Community Fault Model version 5.3.2 (CFM5.3) is the latest in a series of continued, incremental improvements to our understanding of fault structure in Southern California. The model comprises 442 fault objects (in the preferred model) that are deemed capable of generating damaging earthquakes. Fault objects are organized in a self-consistent manner with a system-level hierarchy that is reflected in fault names. During the past year, our collaboration has produced a revised model version (5.3.2) and improved the web-based tools that host, visualize, and deliver the CFM to a wide audience. As the most established SCEC CXM effort, many of these web-based resources are being directly used to support other community models. In parallel, we initiated an online peer-evaluation of the current CFM5.3.2. Progress on these topics as well as plans for the future are described in the sections below.

2. Improvements to CFM Fault Representations

The latest additions to the CFM were based on SCEC-sponsored fault studies that included relocated earthquake catalogs, machine-learning enabled catalogs, focal mechanism, and surface geology (e.g., Nicholson et al., 2021; Hauksson et al., 2020; Ross et al., 2019; Plesch et al., 2020). New contributions include major updates to faults in the 2019 Ridgecrest epicentral zone, the Salton Sea region, Santa Monica Bay, and the Santa Barbara Channel (Figure 1). Several of these fault representations were developed using a new objective, constraint-based interpolation method (Riesner et al., 2017). Specifically, hypocenter alignments in the Ridgecrest sequence allowed representing a system of faults in the China Lake area, in the Coso Junction and Rose Valley areas, as well as in the southern extension of the Owens Valley fault. In the Santa Monica Bay, interpretation of an extensive grid of seismic reflection profiles led to a reassessment of the Palos Verdes fault and associated faults in a complete set of alternative representations (Wolfe et al., 2021). In another major improvement, the offshore Pitas Point thrust fault and splays in the Santa Barbara Channel were updated using a large database of 2- and 3-D seismic reflection data by incorporating additional alternative representations into the CFM, as well as adding a new Mid-Channel thrust fault and detachment connecting to the south of the Ventura-Pitas Point fault (Don et al., 2021).

3. Improvements to CFM Web-based Tools

In collaboration with SCEC IT, we also made a series of enhancements to the web-based tools that help support the CFM. This included implementing the capability to visualize earthquake catalogs in both 2D and 3D, and to display these events colored by different attributes (e.g., depth, magnitude, or time) (Figure 2). This allows users to directly compare and evaluate CFM fault representations relative to earthquakes that were used to constrain them or that occurred after model releases. Currently, the earthquake catalogs available in the system include the Hauksson et al. (2012) waveform cross correlation and the Ross et al. (2019) Quake Template Matching (QTM) seismicity catalog, as well as historical events 1900-present with > M6.0

(shown with red circles in the map interface). The 3D interface also now has the ability to save direct links so users can link and share specific 3D views with colleagues.

4. Peer Evaluation of CFM5.3

We have initiated a formal peer-review of the CFM to establish the preferred fault representations that will comprise the next model release, CFM version 6.0. The CFM5.3 evaluation will formally begin on April 7th with an online workshop that provides information about the web-based evaluation tools and how to best evaluate the model.

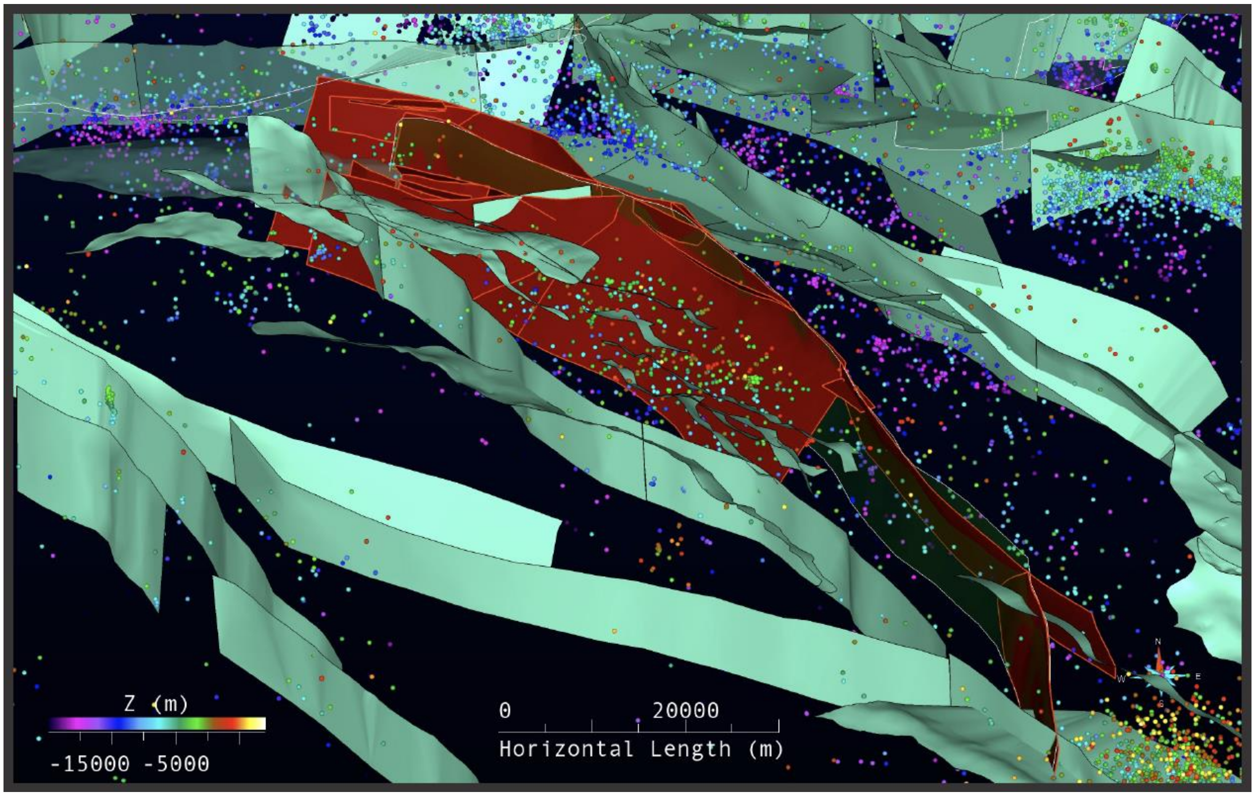

Figure 1: Perspective view of a new, comprehensive fault model of the Palos Verdes fault zone in the Los Angeles basin shown as red surfaces (Wolfe et al., 2021). This new representation builds on work of several previous SCEC investigations, and has been embedded in a self-consistent way with the surrounding faults (green surfaces) in the CFM. This and other alternative representations are being peer reviewed.

The SCEC CFM currently contains a series of alternative representations (~1,000 fault objects) for many of the faults in southern California. Some alternatives often reflect a different degree of detail within the fault representations, based on the quality of the seismologic constraints and/or degree of details in surface fault traces used to construct the 3D fault surfaces. Other alternative fault representations are more significant and describe fundamental differences in interpretation, including the length, dip, and dip direction of these structures. Contrasts between the current preferred model and these significant alternatives can have a major influence on fault kinematics and hazard, as they yield different fault surface areas, depths, and degrees of connectivity with surrounding fault systems. Thus, a critical element of evaluating these alternatives and defined preferred fault representations has been the review of the CFM by a group of experts within the SCEC community. We are currently engaged in such a review of CFM 5.3, to develop fault rankings and a set of preferred representations that will constitute CFM 6.0. We have identified fifteen sets of alternative fault representation to address in this review. Each set contains one fault or fault system, for a total of about 35 alternative, individual fault representations. This focus on selected sets rather than the complete model (of more than 300 fault representations) as in previous peer evaluations makes the review more manageable for both evaluators and model developers.

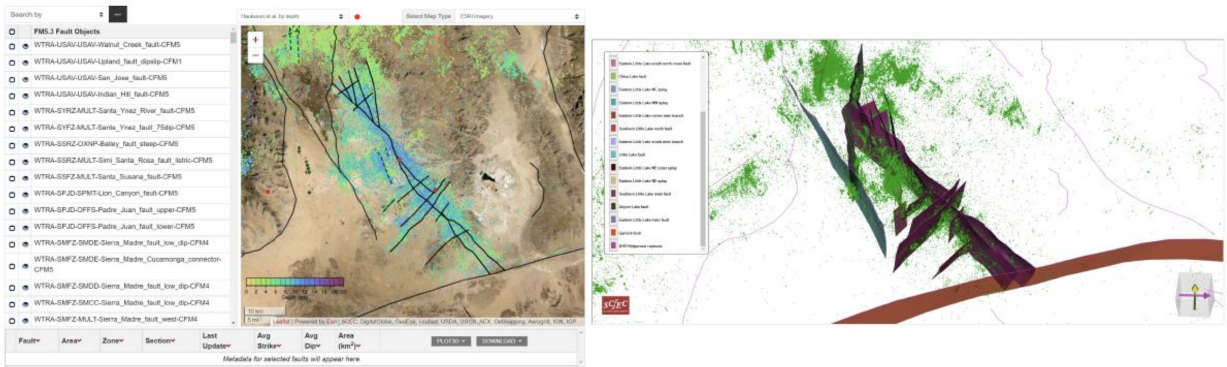

Figure 2: Map and perspective views of earthquake catalogs displayed in the CFM web-based tools. These faults and earthquakes are in the 2019 Ridgecrest epicentral zone. Earthquakes are from Hauksson et al., (2020) catalog and are color-coded by depth in the 2D map viewer. The red circles show the two 2019 mainshocks of M6.4 and M7.1, with the magnitude and year information popping up on mouseover.

To prepare for this review, we completed several tasks:

1) developed organized sets of alternative representations for each fault system (Figure 3).
2) ensured that the supporting metadata for these alternatives, including citations and datasets used to develop them, are complete, up to date, and accurate.
3) created narrative descriptions for each fault system and competing alternatives so that reviewers can understand what the representations are based on.
4) generated a clone of the CFM webtools that is used by reviewers to evaluate fault alternatives. Unlike the public CFM web viewer, this clone has the alternatives loaded.
5) created a web-based survey tool for reviewers to provide numerical fault rankings and other comments that might help to improve fault representations in future model versions.

The CFM peer-review process involves scientists visualizing major alternative fault representations using a specially developed survey tool. Each reviewed fault group has a unique survey page with images of the fault alternatives, a brief description of the basis for these representations, and links to the CFM 3D Viewer so users can interact with the faults in 3D and see how the surfaces are related to seismicity. Participants will rank the fault groups, and are encouraged to provide comments on ways that the model representations might be further improved. As reviewers complete the evaluation, the tool provides the information to the review team and collates responses. Several dozen SCEC researchers are engaged in the peer-review process, and we are currently encouraging others to join.

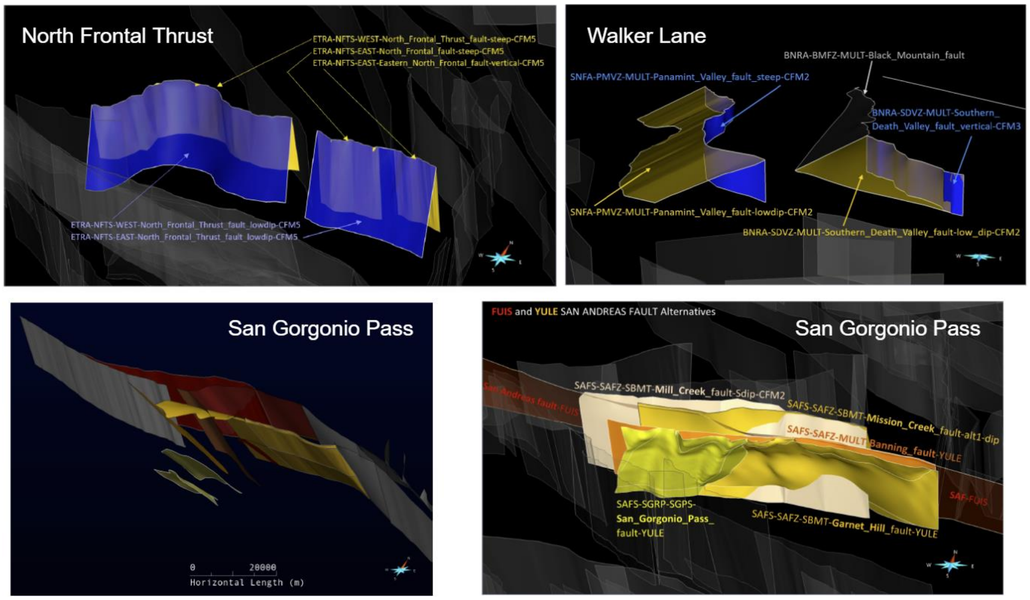

Figure 3: Examples of alternative faults that are being evaluated in the CFM5.3 peer review. Representations shown are from Carena et al., (2004), Fuis et al., (2012), Yule and Sieh (2003), Plesch et al., (2021); Nicholson et al., (2020) and others.

5. Compilation and Release of CFM6.0

We anticipate that we will spend most of the summer reviewing the evaluator responses and making the necessary changes to the CFM. The resultant updated model will comprise CFM6.0 and will be released through the web, and made available in our web-based tools. Establishing the inventory of faults will be a straightforward task after the peer-review is complete. However, substantial work is required to complete the associated metadata and develop associated products so that the new fault model can be made available through the CFM Viewer. Each fault object has numerous metadata components including information about the fault, its geometry, and references that were used as the basis for developing the representation. In addition, we prepare different 3D surface meshes (at different resolutions), each contained in a different file. We also create fault trace data (in several different file formats) that can be used in maps. This results in a volume of data that cannot be manually managed. Therefore, we have developed a set of semi-automated scripts that test various components of the model for accuracy and self-consistency including:

1) All CFM faults now have a listed reference that indicates what each surface is based on.
2) Hierarchical object names now conform to a consistent naming convention. This allows users to write code that can easily parse the fault names from the various files.
3) Hierarchical object names are now checked with the various metadata columns for self-consistency.
4) We provide direct automated calculations of fault surface area and average strike/dip. Average strike/dip calculations are weighted by element area, to represent a true average orientation of the fault surface regardless of mesh variations.
5) All fault objects are verified to exist with consistent names as t-surf files in the native, 500m, 1000m, and 2000m mesh resolutions. Similar checks are made for the fault trace data files.
6) All fault surfaces are provided as a single patch (in GOCAD files) instead of various grouped surfaces. The same is true for fault traces.

6. Publication

We will prepare and submit for publication in a peer reviewed journal a manuscript describing the CFM6.0 and how it was created. The last major peer reviewed publication for the CFM was associated with version 3.0 (Plesch et al., 2007), and the CFM is significantly different now to justify a new publication. In addition, we will follow our past practice of posting the model on Zenodo and obtaining a DOI for the latest model, similar to the approach we took for v. 5.3 (https://zenodo.org/record/4660239#.YYVVEy1h0sM).

7. Enhancements to the CFM webpage and viewer:

Our collaboration has produced CFM web tools that are now well-established and have facilitated other CXM development. For example, the same backend software is being used by the CGM and the geologic framework component of the CRM. A tool that we developed to display large numbers of point data (earthquake catalogs) on the CFM map interface has been adopted by the CGM to display InSAR data. The main enhancements planned for the CFM web tools are the addition of a Google Earth kml file uploader to the map interface. This plugin is freely-available on git hub and should be easily adaptable to our interface. This will allow users to upload their own kml files to the CFM map interface to compare their own data with the CFM model. We will also work with the SCEC web team to determine the best method to serve the alternative fault representations as these are not currently served by the web tools.

8. Facilitating Future Improvements to the CFM:

Currently, additions or modifications to faults in the CFM are driven largely by SCEC PI's whose research offers new constraints on fault activity and/or geometry. In addition, our development team has worked to systematically refine fault representations using newly available datasets, such as fault trace maps or relocated earthquake catalogs. However, given the maturity of the CFM and its growing number of contributors and users, it is important to formalize the process by which members of the SCEC community request/submit fault modifications. Thus, we will continue our efforts to develop a user-friendly web-based system for researchers to request additions or modifications to the CFM. This will include a mechanism to upload key datasets and references that will be used to constrain the new fault representations. Such a web service will provide universal access to all registered SCEC participants, and formally document and archive suggestions for new fault representations. The site will be periodically reviewed by the CXM leadership and CFM development team, which will decide how to allocate time and resources to prioritize and implement these suggestions. The new system will be accessible from the SCEC CFM website.

9. Application to SCEC5 Goals

This proposal represents a primary effort to address the following SCEC priority:

> P3.b. Refine the geometry of active faults across the full range of seismogenic depths, including structures that link and transfer deformation between faults.

Moreover, through the development and delivery of the CFM this project contributes to the CXM modeling effort and a range of other SCEC goals.

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