# 2022 SCEC Report

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

**SCEC Award 22066**

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P3b; P1a; P1b

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## 1. Summary

The SCEC Community Fault Model (CFM) is one of the most established SCEC community models and serves as a widely used resource (Plesch et al., 2007; Nicholson et al., 2021; Plesch et al., 2021) in 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.

This past year, we developed a new, comprehensive update to the SCEC Community Fault Model (CFM 6.0) in southern California (Figure 1) along with enhancements to the web-based model viewer and database. This model version is designated with a major release number due to significant revisions from the previous CFM version, including an in-depth community evaluation process. The CFM 6.0 features 37 new or revised fault representations, including updates to the San Andreas system, faults in the Los Angeles and Ventura basins, offshore areas, and other regions. All additions and revisions come with a complete set of metadata that includes, among other information, naming based on fault system hierarchy, average strike/dip, source references, and the associated fault ID number in the USGS Quaternary fault and fold database.

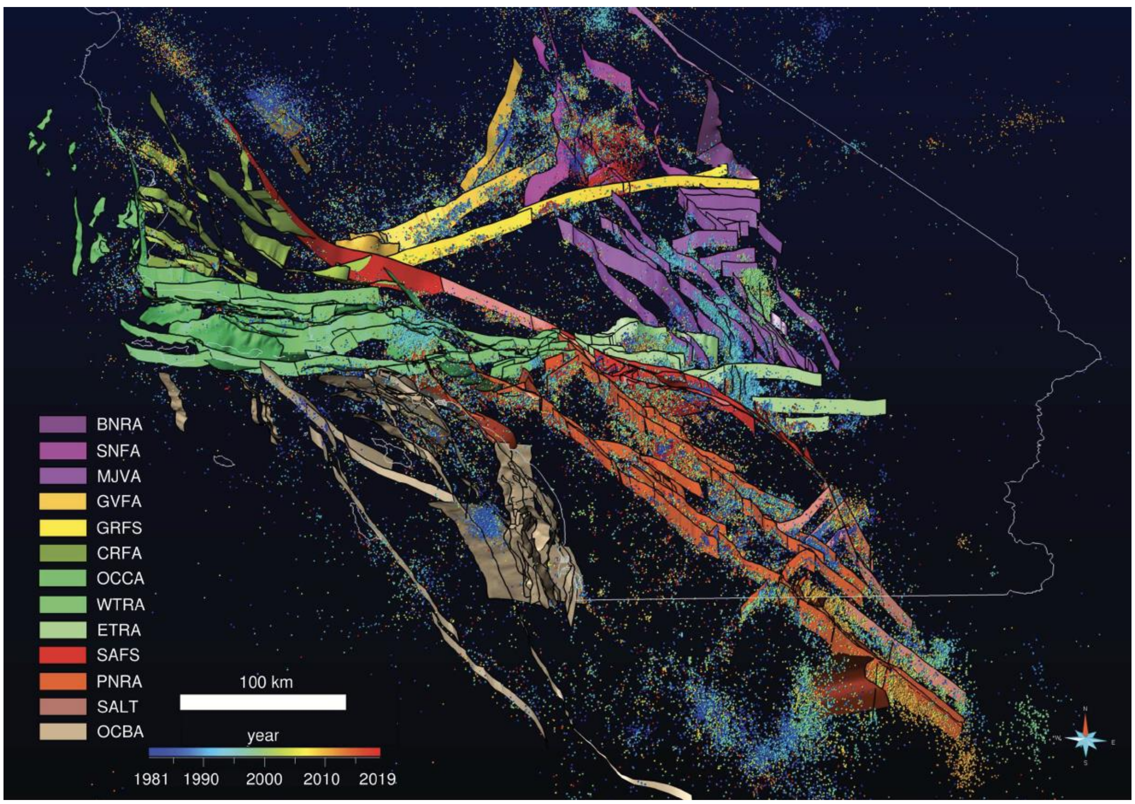


**Figure 1:** Perspective view of the CFM 6.0. Faults are bounded at depth by the local seismogenic thickness and appear as colored bands. Fault color is mapped to fault area, the top level in a hierarchical naming system. Small dots are relocated hypocenters (after Hauksson et al., 2012), which are colored by their time of occurrence. BNRA: Basin and range, SNFA: Sierra Nevada, MJVA; Mohave, GVFA: Great Valley, GRFS: Garlock Fault, CRFA: Coast ranges, OCC: Offshore Central California, WTRA: Western Transverse Ranges, ETRA: eastern Transverse Ranges, SAFS: San Andreas Fault, PNRA: Peninsular Ranges, SALT: Salton Sea, OCBA: Offshore Continental Borderland.

## 2. Updates to the CFM

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, the Los Angeles basin, the Ventura basin, and the Santa Barbara Channel. 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 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 updated 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). Finally, results from the 2022 CFM peer evaluation required fault compatibility adjustments in the San Gorgonio Pass area. We worked with the authors of the source data for these faults to produce new representations that were most compatible with the respective source data and interpretations. In the end, the connection of the San Bernardino section of the San Andreas fault with the Garnet Hill fault was updated to a non-intersecting splay configuration, and the eastern termination of the Garnet Hill fault was prepared to be extended farther east to connect to the Coachella Valley section of the Southern San Andreas fault.

## 3. Peer Evaluation

The updated CFM 6.0 model was developed through an open peer-review process involving 29 SCEC investigators, who evaluated and quantitatively ranked 23 current and alternative fault representations under consideration for CFM 6.0. To prepare for this review, we completed several tasks:

1) developed organized sets of alternative representations for each fault system.
2) ensured that the supporting metadata for these alternatives, including citations and datasets used to develop them, were complete, up to date, and accurate.
3) created narrative descriptions for each fault system and competing alternatives so that reviewers could understand what the representations are based on.
4) generated a clone of the CFM webtools that was used by reviewers to evaluate fault alternatives. Unlike the public CFM web viewer, this clone had 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 involved scientists visualizing major alternative fault representations using a specially developed survey tool which required no specialized software or downloads. Everything was web-based. Each reviewed fault group had 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 ranked the fault groups and were encouraged to provide comments on ways that the model representations might be further improved (we received ca. 14k words of written comments). Once the review period was complete, the evaluation tool provided reviewer response information to the development team in an organized format. The fault representations receiving the highest overall ranking by the reviewers were incorporated as "preferred representation" in CFM 6.0. As a result, 14 out the 23 faults evaluated were designated as new preferred version in CFM 6.0 (Figure 2).

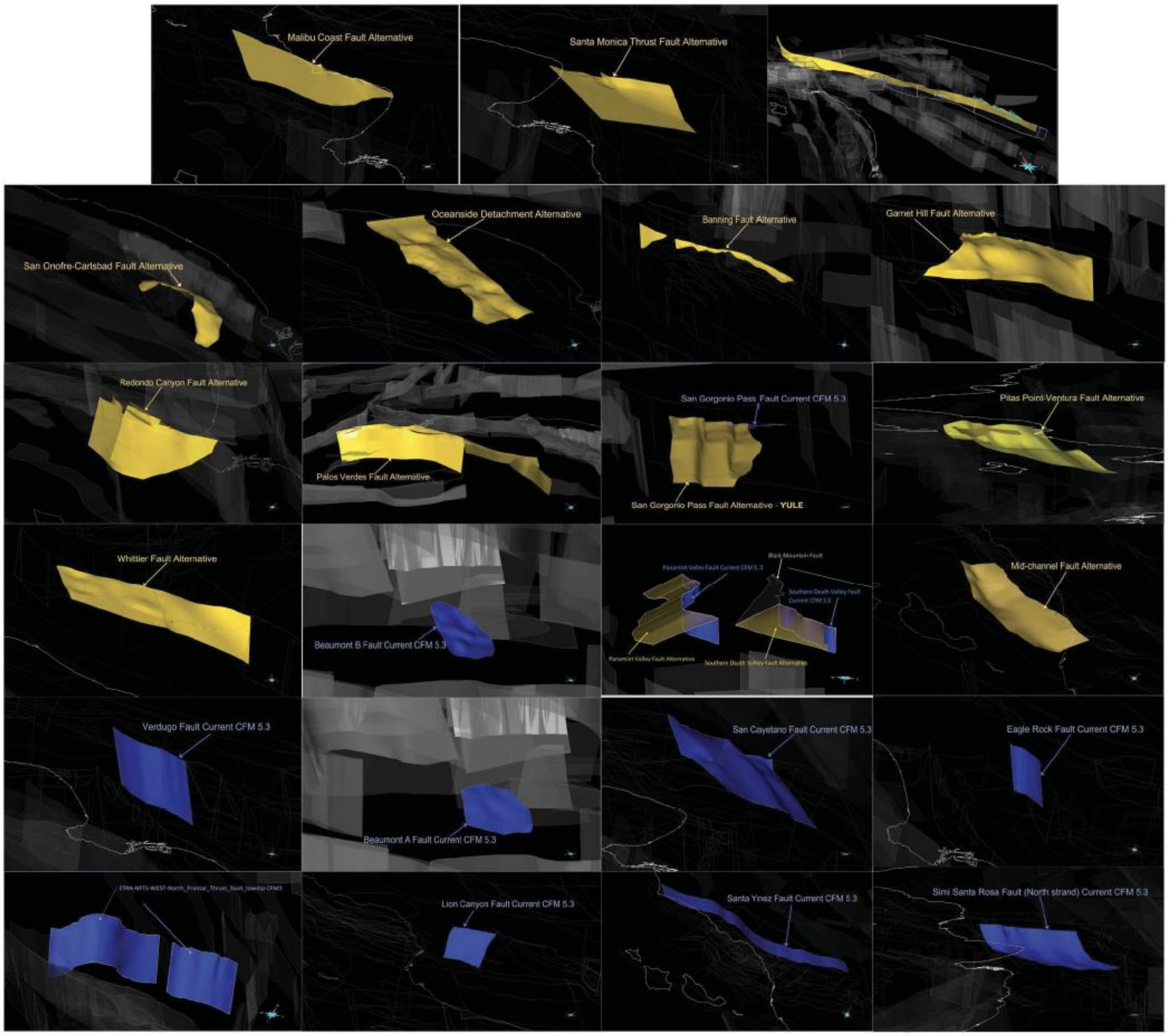


**Figure 2:** View of faults evaluated and designated as preferred representations for CFM 6.0. Yellow faults are new preferred faults (replacing versions in prior model releases). Blue faults were voted as preferred and remain unchanged from previous model versions.

## 4. Database and Web-Based Tool Updates

New to CFM6.0 are two additional separate and fully-documented sub models: the ruptures and alternatives models. In total, CFM6.0 comprises the following components:

1. The CFM6.0 Preferred Model: a set of 443 fault objects that constitute the preferred set of active faults in southern California.

2. The CFM6.0 Rupture Model: a set of 13 fault objects assembled from the CFM6.0 preferred model that ruptured during selected significant historic events. These are not earthquake source models but are representations of the entire fault surfaces where a significant historic rupture occurred. This model is intended to indicate which CFM fault objects were involved with selected significant historic ruptures.
3. The CFM6.0 Alternatives: a set of 36 alternative representations where structural differences have been proposed that could potentially significantly impact fault mechanics and associated seismic hazards. These alternative representations were selected based on community rankings following a comprehensive evaluation of the CFM that took place in May of 2022.

Including all sub models, the CFM6.0 incorporates 492 fully documented objects. The CFM web viewer developed by the CFM development team in coordination with the SCEC web team (https://www.scec.org/research/cfm-viewer/) was also updated to, for the first time, deliver the preferred, alternatives, and rupture model fault representations in map and 3D views. In the past, only the preferred model was served in the online system. Our ongoing meetings and discussions with colleagues at the USGS and CGS provided us with key information about how the alternatives may be used in future seismic hazard assessments. This feedback allowed us to revise the CFM alternatives and complete their metadata so they can also be served though the online tools.

The CFM web tools also now contain some feature updates including the option to upload georegistered images and other data in Google Earth (.kml/.kmz) format, and the ability to resize the map interface to three different sizes depending on the user's preference (Figure 3). Along with the CFM webtools updates, the CFM homepage (https://www.scec.org/research/cfm) has been updated with relevant information for CFM6.0, including links to a new web form where SCEC community members can request additions or modifications to the CFM as new papers are published. This form will allow the CFM development team to be notified when new information has been published and the web form clarifies what kind of information is needed by the CFM development team. All these enhancements together will further facilitate the use of the SCEC CFM in earthquake science and seismic hazard assessment applications and the development of other related community-based structural models.

## 5. Compilation and Release of CFM6.0

Fault ranked highest in the evaluation process were assembled to prepare CFM 6.0. To facilitate this, we have developed and updated 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) Based on user feedback, all fault surfaces are provided as a single patch (in GOCAD files) instead of various grouped surfaces. The same is true for fault traces.


**Figure 3:** View of the updated CFM web tools zoomed to the Los Angeles region with new features highlighted with red outlined text boxes. The view above shows two kml/kmz files loaded. The circles show locations of permanent GPS stations. The image overlay is a map from Dolan & Pratt (1997) of the Santa Monica Mountains regional geology. Allowing users to upload their own kml files allows for direct and easy comparison of user data to the CFM and should be useful for other SCEC community models in the future.

## 6. Publication of CFM 6.0

We presented the new CFM 6.0 model release at the 2022 SCEC Annual Meeting (Plesch et al., 2022) and will prepare and submit for publication in a peer reviewed journal a manuscript. 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 complete model archives on Zenodo and obtaining a DOI for the latest model, similar to the approach we took for v. 5.3 (https://doi.org/10.5281/zenodo.4651667).

## 7. 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.

## References


Carena, S., J. Suppe, and H. Kao (2004). Lack of continuity of the San Andreas fault in southern California: Three dimensional fault models and earthquake scenarios,J. Geophys. Res.109,B04313,doi 10.1029/2003JB002643.

Dolan, J. F., and T. L. Pratt (1997), High-resolution seismic reflection profiling of the Santa Monica fault zone, west Los Angeles, California, Geophys. Res. Lett., 24(16), 2051– 2054, doi:10.1029/97GL01940.

Don, J., Shaw, J. H., & Plesch, A. (2021). Comprehensive 3D model of the Ventura-Pitas Point fault system and associated structures in the Santa Barbara Channel and Ventura basin for the CFM. Poster Presentation at 2021 SCEC Annual Meeting.

Fuis G., Daniel S. Scheirer, Victoria E. Langenheim, Monica D. Kohler, 2012, A New Perspective on the Geometry of the San Andreas Fault in Southern California and Its Relationship to Lithospheric Structure. Bulletin of the Seismological Society of America 2012; 102 (1): 236–251. doi: https://doi.org/10.1785/0120110041

Hauksson, E., Yang, W., and Shearer, P. M., 2012, Waveform relocated Earthquake catalog for southern California (1981 to June 2011): Bulletin of the Seismological Society of America, v. 102, no. 5, p. 2239-2244.

Nicholson, C., Plesch, A., Sorlien, C., Shaw, J., Hauksson, E., 2020, Updates, Evaluation and Improvements to the Community Fault Model (CFM version 5.3), Poster Presentation at the SCEC Annual Meeting, Palm Springs, California, 14-17 September 2020.

Nicholson, C., Plesch, A., Shaw, J. H., & Hauksson, E., 2021. Updates and Additions to the Community Fault Model (CFM version 5.3): detachments, cross faults and en echelon fault sets. Poster Presentation at 2021 SCEC Annual Meeting.

Plesch, A., Shaw, J. H., Benson, C., Bryant, W. A., Carena, S., Cooke, M. L., Dolan, J. F., Fuis, G., Gath, E., Grant, L., Hauksson, E., Jordan, J. H., Kamerling, M. J., Legg, M., Lindvall, S. C., Magistrale, H., Nicholson, C., Niemi, N., Oskin, M., Perry, S., Planansky, G., Rockwell, T. K., Shearer, P., Sorlien, C., Süss, M. P., Suppe, J., Treiman, J., and Yeats, R., 2007, Community Fault Model (CFM) for Southern California: Bulletin of the Seismological Society of America, v. 97, p. 1793-1802.

Plesch, A., Marshall, S. T., Nicolae, A., Shaw, J. H., Maechling, P. J., & Su, M., 2021, Updates to the SCEC Community Fault Model (CFM), and to web-based tools, and plans for its peer review and version 6.0. Poster Presentation at 2021 SCEC Annual Meeting.

Plesch, A., Marshall, S. T., Nicolae, A., Shaw, J. H., Su, M., Maechling, P. J., Huynh, T. T., & Pauk, E. (2022). The SCEC Community Fault Model Version 6.0: additions and updates after community evaluation. Poster Presentation at 2022 SCEC Annual Meeting.

Riesner, M., Durand-Riard, P., Hubbard, J., Plesch, A., and Shaw, J. H., 2017, Building Objective 3D Fault Representations in Active Tectonic Settings: Seismological Research Letters, v. 88, no. 3, p. 831-839.

Ross, Z. E., Trugman, D. T., Hauksson, E., and Shearer, P. M., 2019, Searching for hidden earthquakes in Southern California: Science, v. 364, no. 6442, p. 767-771.

Wolfe, F. D., Shaw, J. H., & Plesch, A. (2021). Kinematic evolution of the Palos Verdes restraining bend and 3-D architecture of the fault, Southern California. Poster Presentation at 2021 SCEC Annual Meeting.

Yule, D., and K. Sieh (2003). Complexities of the San Andreas fault near San Gorgonio Pass: Implications for large earthquakes, J. Geophys. Res.108,2548, doi 10.1029/2001JB000451