SCEC Statewide California Earthquake Center

U.S. National Science Foundation | USGS science for a changing world | U.S. Department of Energy | NASA | FEMA | Cal OES Governor's Office of Emergency Services | PG&E | USC

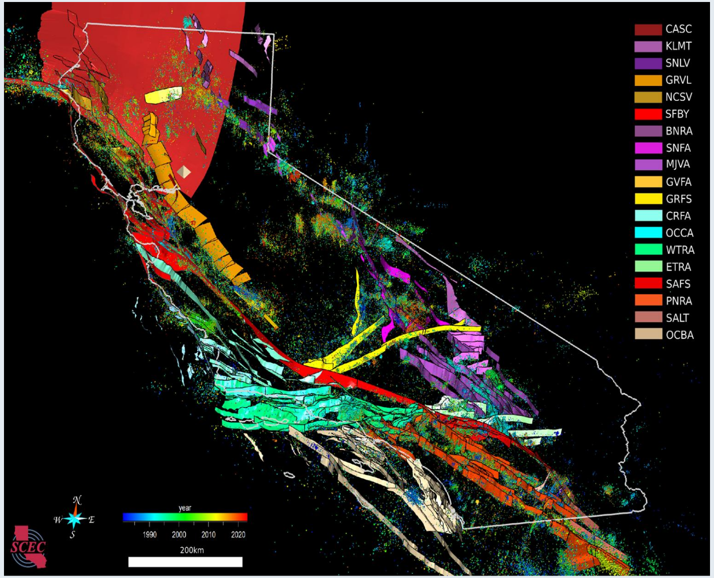
The SCEC Community Fault Model v7.0

...and Other SCEC Community Models

Scott Marshall
Appalachian State University

Andreas Plesch
Harvard University

John H. Shaw
Harvard University

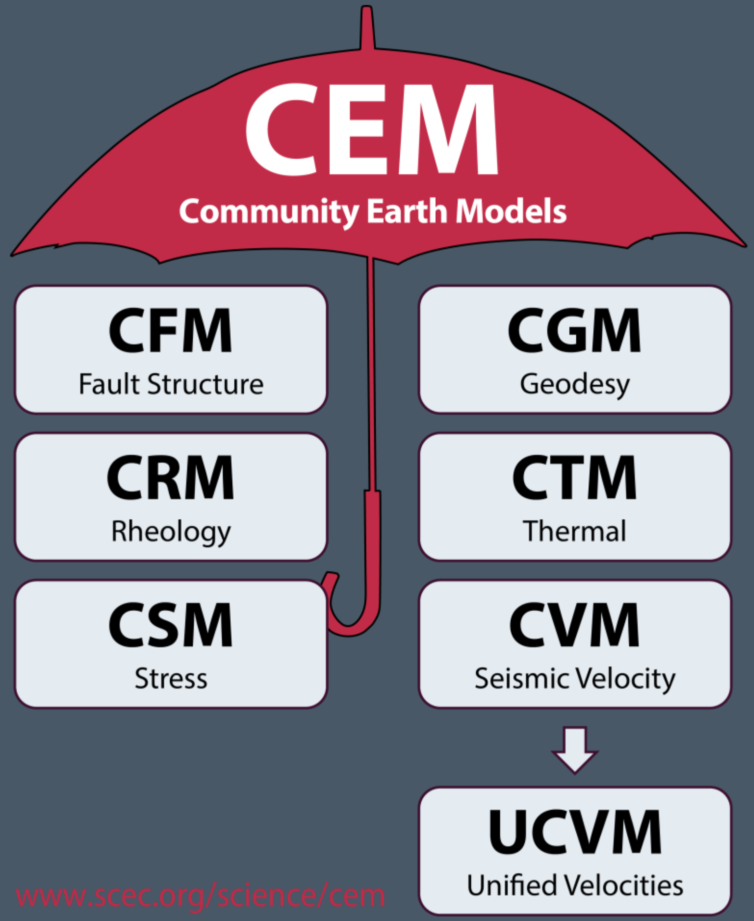


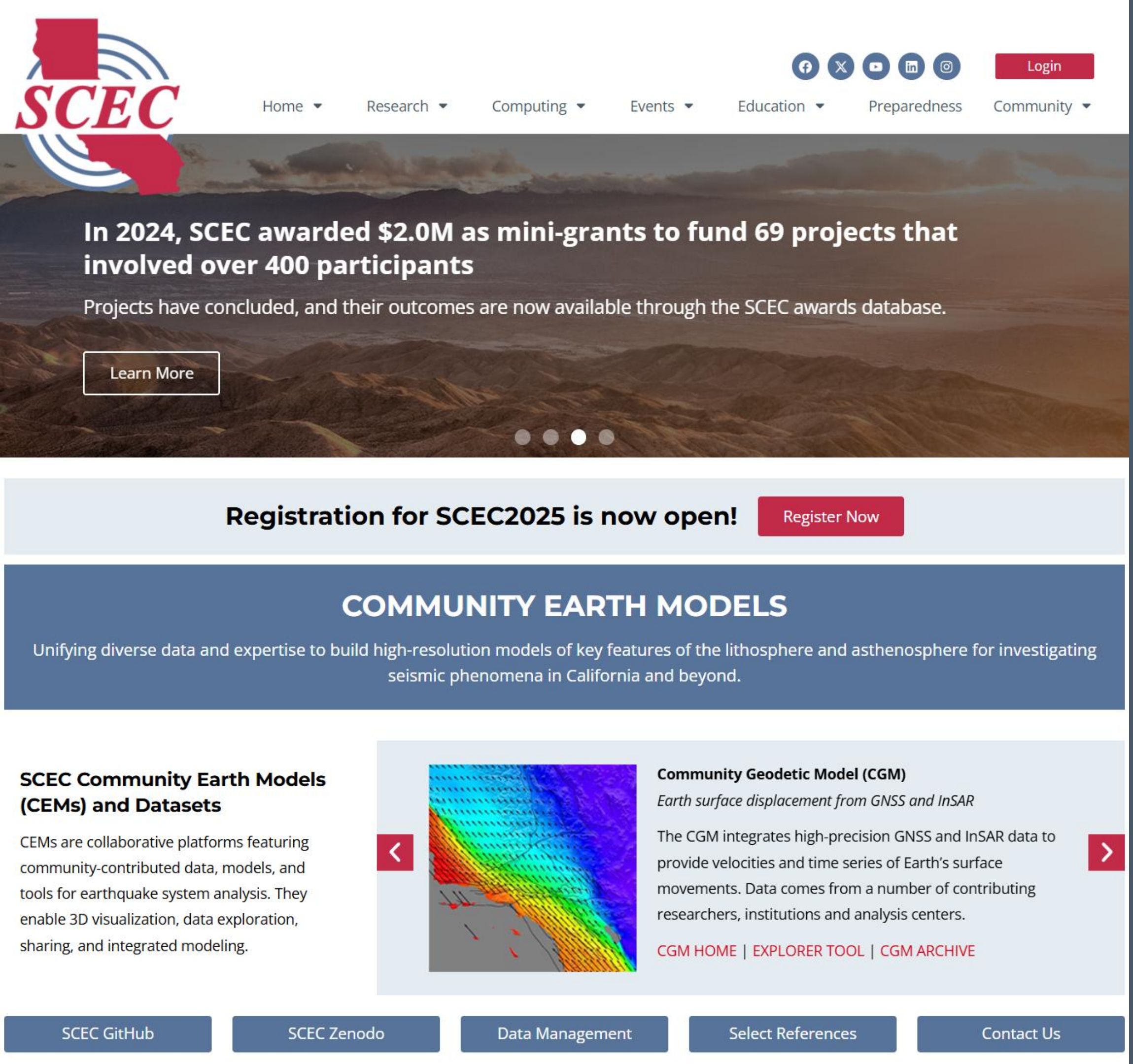
August 15, 2025
CRM Workshop, UC Davis

Community Earth Models

Current Inventory

- **CFM** : Community Fault Model
- **CGM** : Community Geodetic Model
- **CRM** : Community Rheology Model
- **CSM** : Community Stress Model
- **CTM** : Community Thermal Model
- **CVM** : Community Velocity Model
- **UCVM** : Unified Community Velocity Model Framework





SCEC IT/Web Team

CEMs: A collaboration between scientists, IT professionals, and the community

Tran Huynh

Associate Director for Science Operations
USC/SCEC

Philip J. Maechling

Associate Director for Information Technology
USC/SCEC

Edric Pauk

Software Engineer / Web Developer
USC/SCEC

Mei-Hui Su

CXM Software Engineer
USC/SCEC

CEMs and FAIR Principles

Recent efforts have focused on expanding CEMs statewide and meeting **FAIR** software standards

Findable

Can I find CEMs?

Accessible

Can I download and interact with CEMs?

Interoperable

Are CEMs in a data format I can use in my workflows?

Reusable

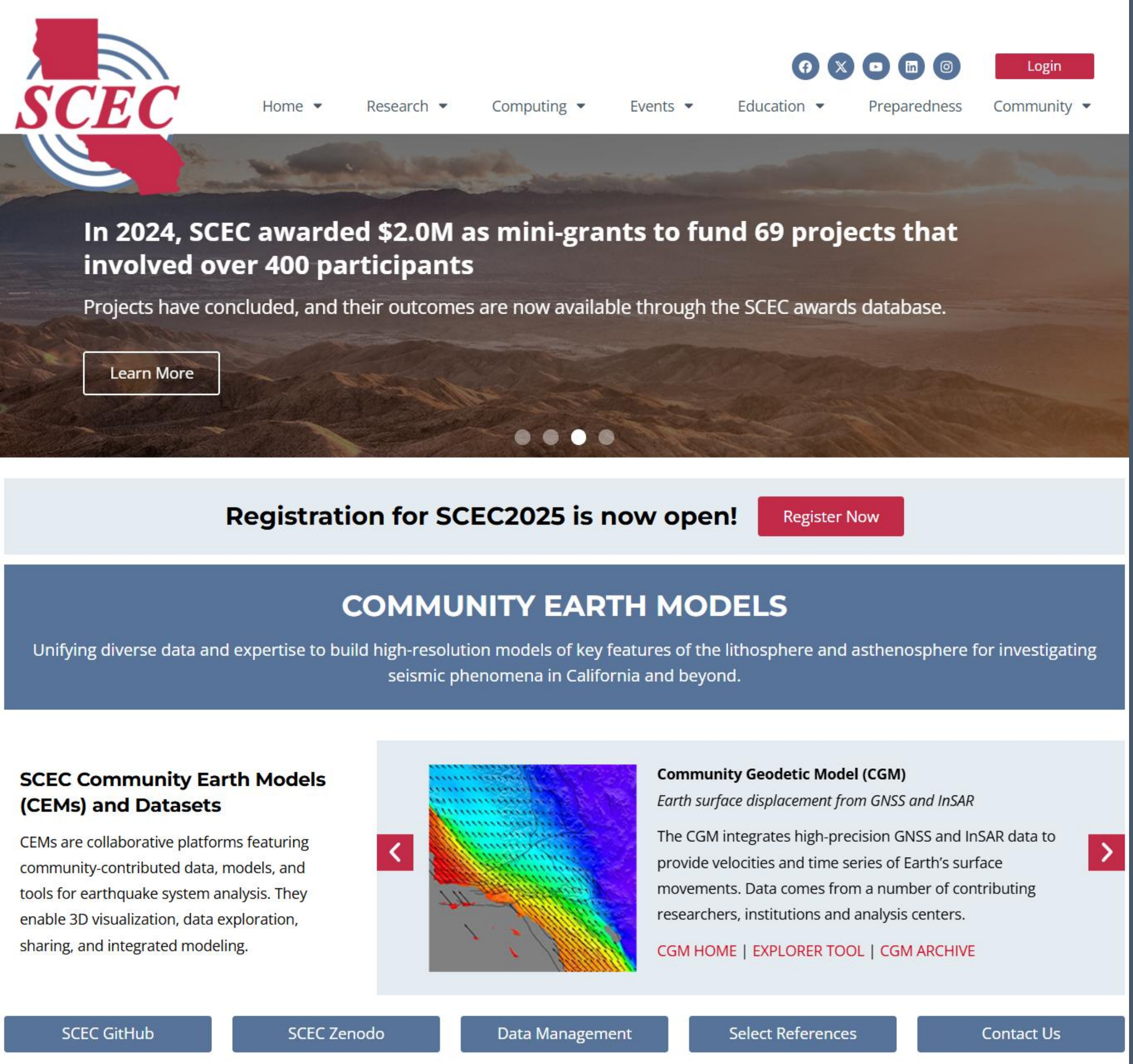
Are CEMs sufficiently documented so they can be used in a variety of ways?

Image from NIH

Findable

Accessible

CEM homepage is linked twice on SCEC homepage

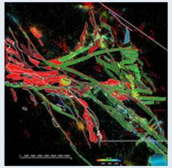


Findable

Accessible

CEMs are easily findable and accessible via the CEM homepage

The CEM widget automatically scrolls through the available CEMs



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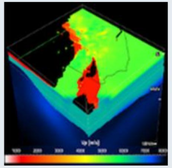
3D geometric representations of faults in California

CFM is an object-oriented, 3D representation of active faults in California, including geometries, depths, and slip potential. Explore and download data for use in fault system modeling, seismic hazard analyses, and many other applications.

CFM HOME | EXPLORER TOOL | CFM ARCHIVE

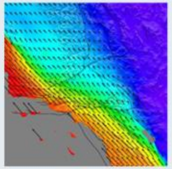


Unified Community Velocity Model (UCVM)

software for accessing seismic velocity models

A standard interface to multiple seismic velocity models that can be used to create velocity meshes for 3D wavefield simulations. UCVM is used by researchers working with Earth material properties on regional or local scales.

UCVM HOME | CVM HOME | EXPLORER TOOL

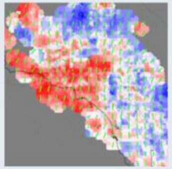


Community Geodetic Model (CGM)

Earth surface displacement from GNSS and InSAR

The CGM integrates high-precision GNSS and InSAR data to provide velocities and time series of Earth's surface movements. Data comes from a number of contributing researchers, institutions and analysis centers.

CGM HOME | EXPLORER TOOL | CGM ARCHIVE

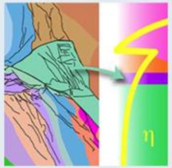


Community Stress Model (CSM)

suite of stress and stressing rate models

The CSM provides estimates of stress and stressing rates for various regions of California. The suite of models, derived using a variety of methods and datasets, are presented on a consistent grid.

CSM HOME | EXPLORER TOOL | CSM ARCHIVE

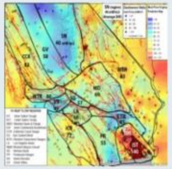


Community Rheology Model (CRM)

3D ductile rheology of lithosphere in California

The CRM provides a detailed, physics-based 3D model of ductile rheology (rock flow) for Southern California's lithosphere. The explorer provides an interface to query temperature, pressure, and rheology data.

CRM HOME | EXPLORER TOOL | CRM ARCHIVE



Community Thermal Model (CTM)

estimates of temperature and thermal properties

The CTM provides estimates of temperatures and thermal properties of the southern California lithosphere and asthenosphere. Currently, the CTM includes two models, each based on different methods.

CTM HOME | EXPLORER TOOL | CTM ARCHIVE

Geologic Slip Rate Database (GSRD)

geologic slip rates for CA, NV, and northern Mexico

SCEC's GSRD centralizes field-derived geologic slip rates crucial for seismic hazard estimates (e.g., NSHM), linked to relevant source publications. As a living archive, it welcomes updates via a user submission form.

GSRD HOME | EXPLORER TOOL

Precariously Balanced Rock (PBR) Database

field-derived data for PBRs in California

The database contains photographs, locations, and metadata for PBRs, valuable for constraining seismic hazard estimates and validating ground motion predictions. An interactive map viewer facilitates data exploration and querying.

PBR HOME

8 Total CEMs and other datasets available in the CEM widget

Findable

Accessible

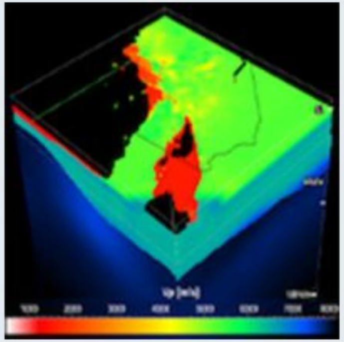
Scroll through the CEM widget

- Links to homepages, model explorers, DOIs

Other datasets also linked

- Geologic Slip Rate Database
- Precariously Balanced Rocks Database

The UCVM Widget



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A standard interface to multiple seismic velocity models that can be used to create velocity meshes for 3D wavefield simulations. UCVM is used by researchers working with Earth material properties on regional or local scales.

UCVM HOME | CVM HOME | EXPLORER TOOL

Link to UCVM software documentation

Link to CVM homepage

NEW!

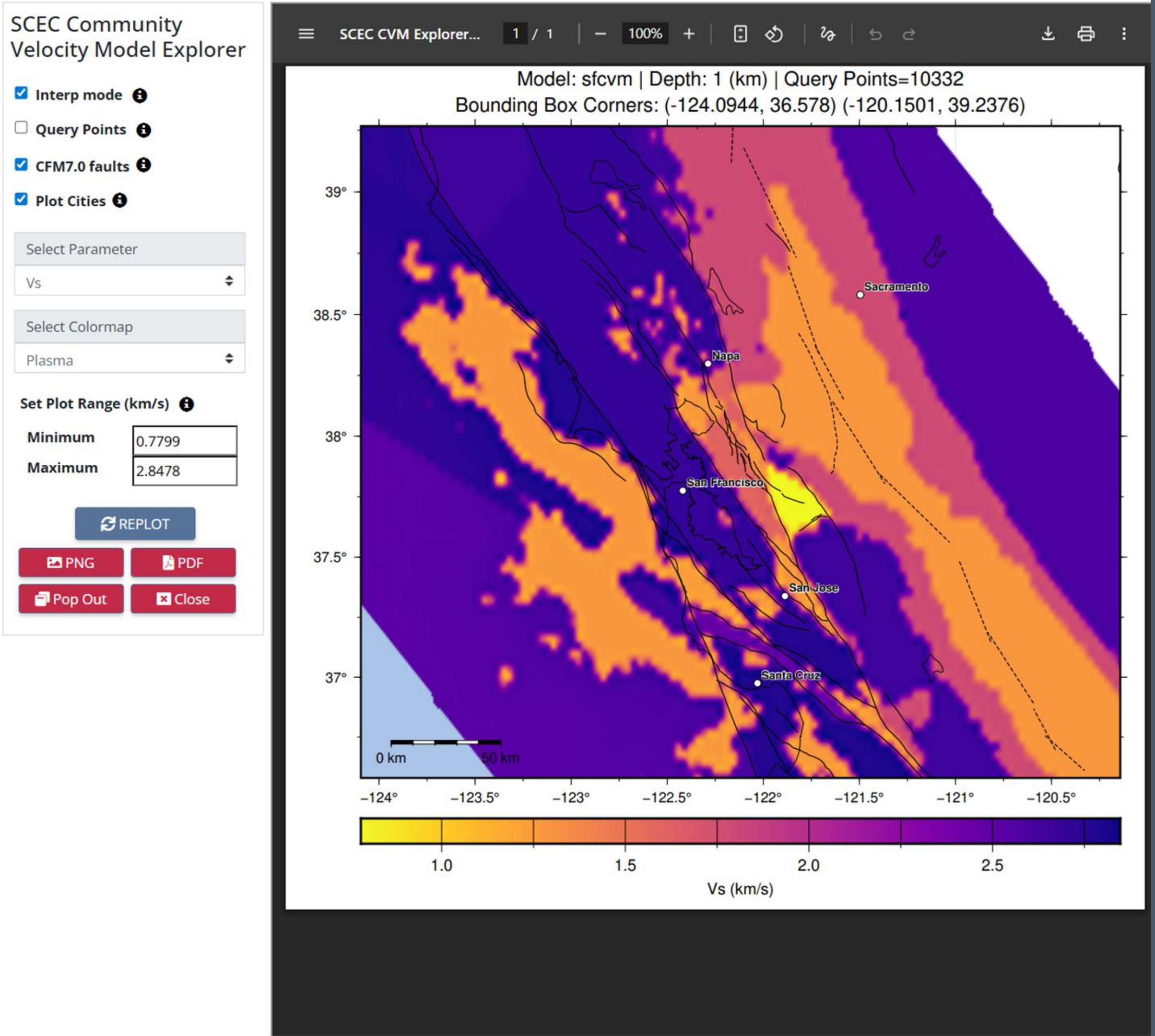
Link to web-based tool "CVM Explorer"

Findable

Accessible

Interoperable

Reusable



NEW!

CVM Explorer

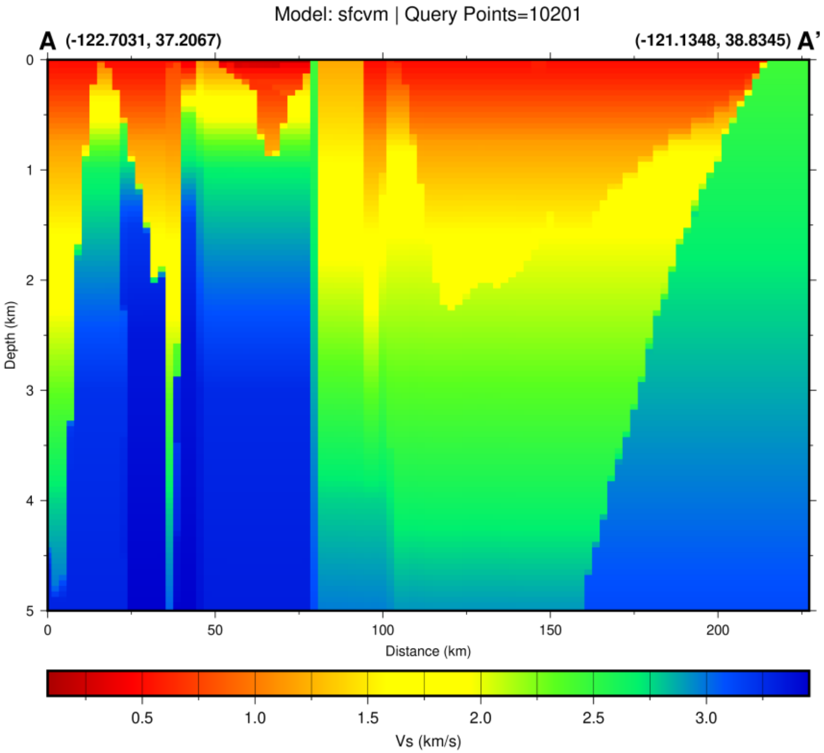
Web-based tools for Community Velocity Models

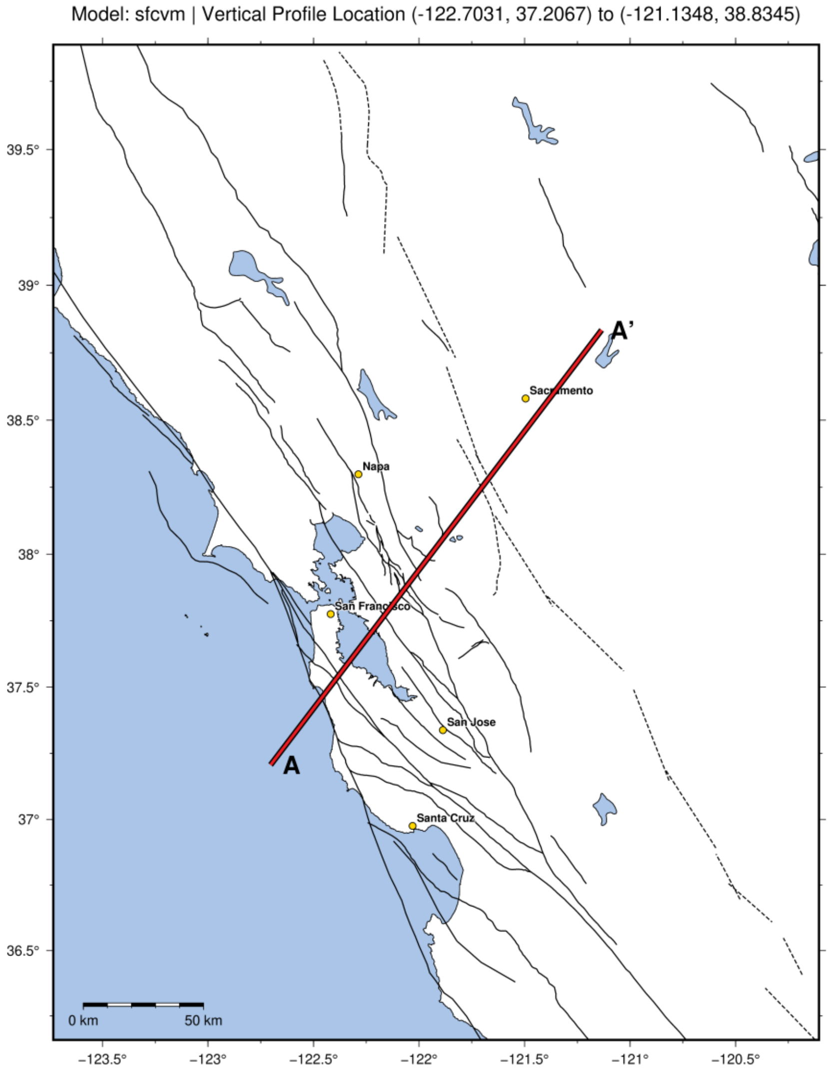
What does the Explorer do?

- Search/Query/Download
  - 24 CVMs; 6 tiled models
  - Extract data in .csv format
- Intuitive Plotting Interface
  - 2D horizontal slices
  - 2D cross sections
  - 1D profiles
  - 0D point extraction
- Plots saved in pdf/png formats
- No specialized software needed

CVM Explorer Plots

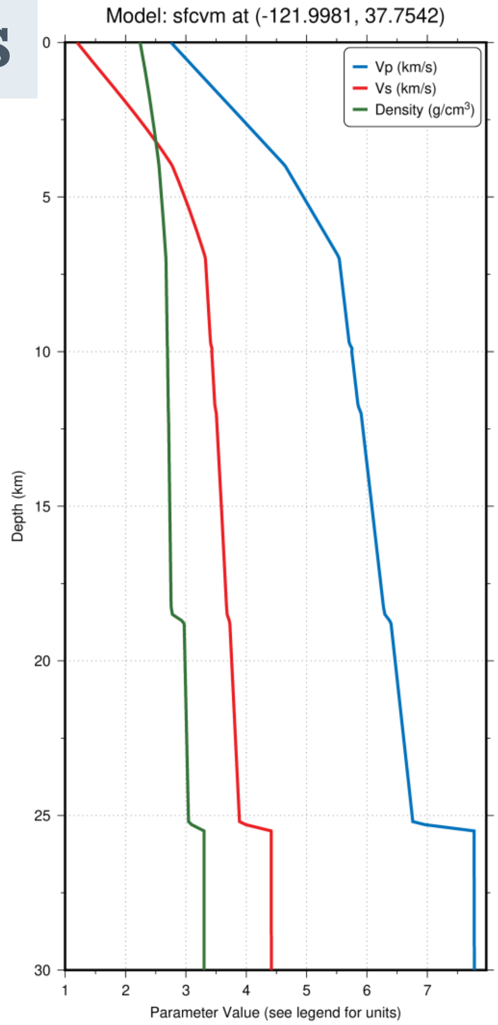
Vertical Cross Section Plots

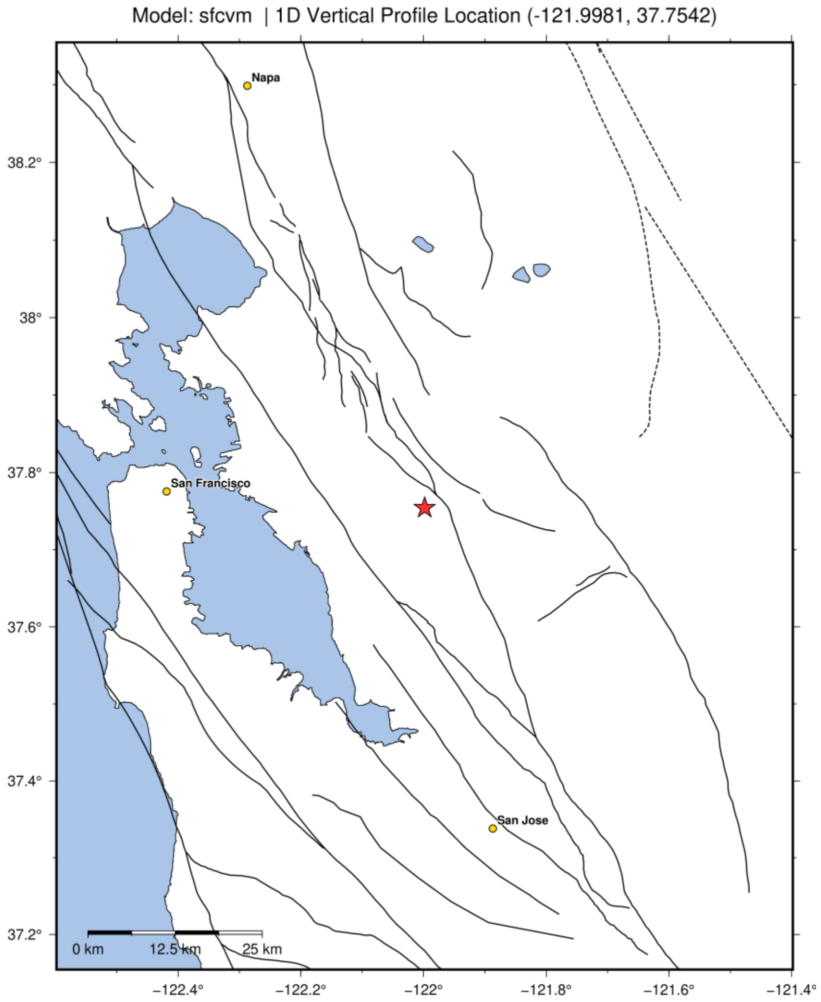




More Plots

1D Vertical Profiles





What is the CFM?

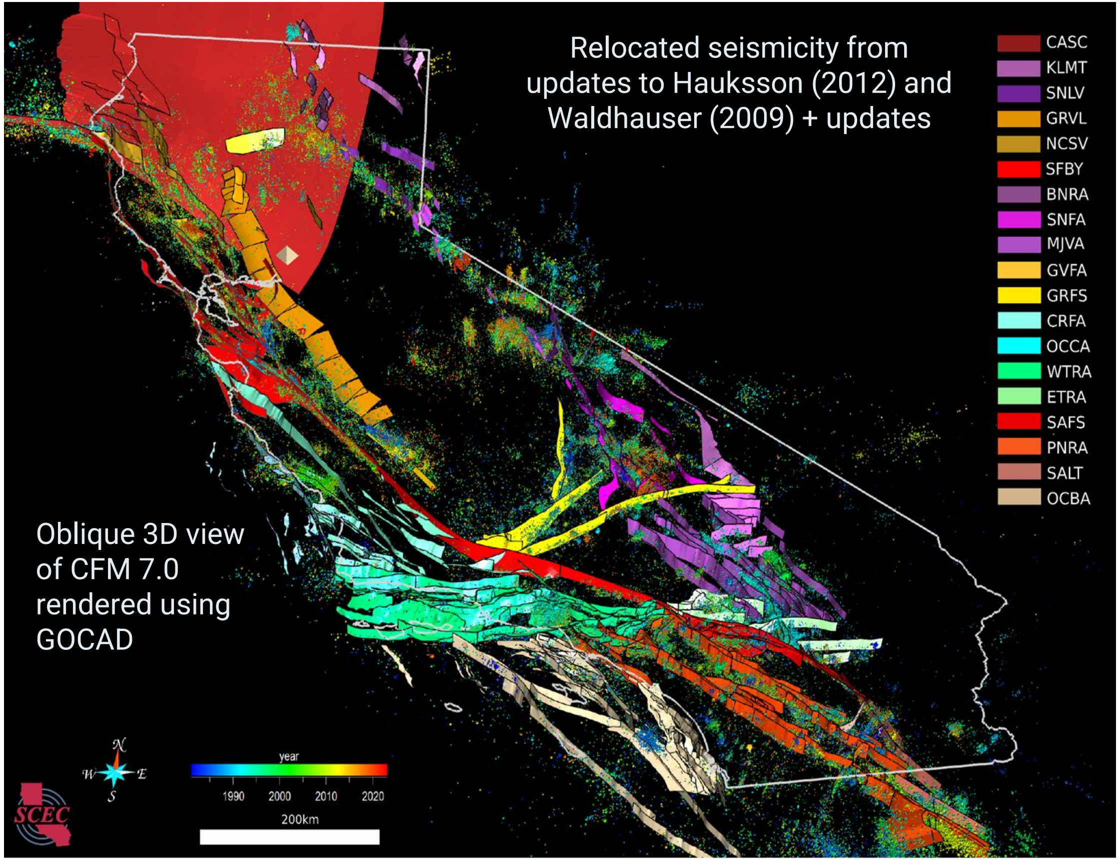
The CFM is an object-oriented, **fully 3D** geometric representation of active faults in California, adjacent offshore basins, and beyond

Who develops the CFM?

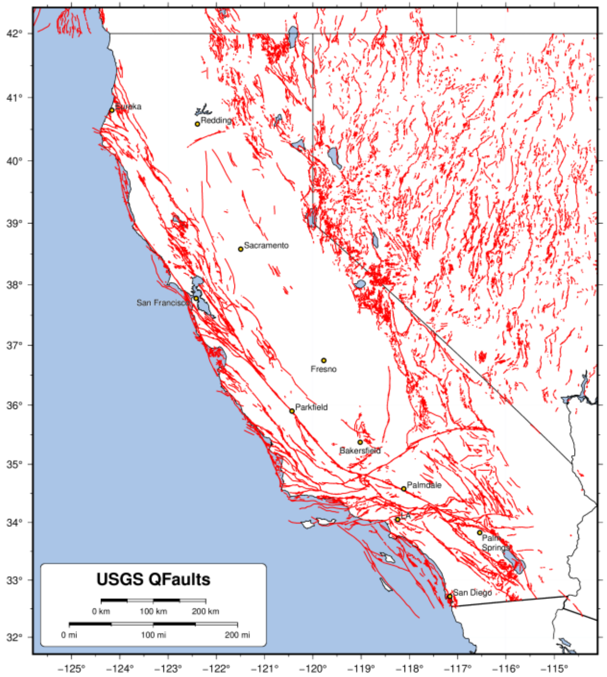


Andreas Plesch
John Shaw
Harvard University

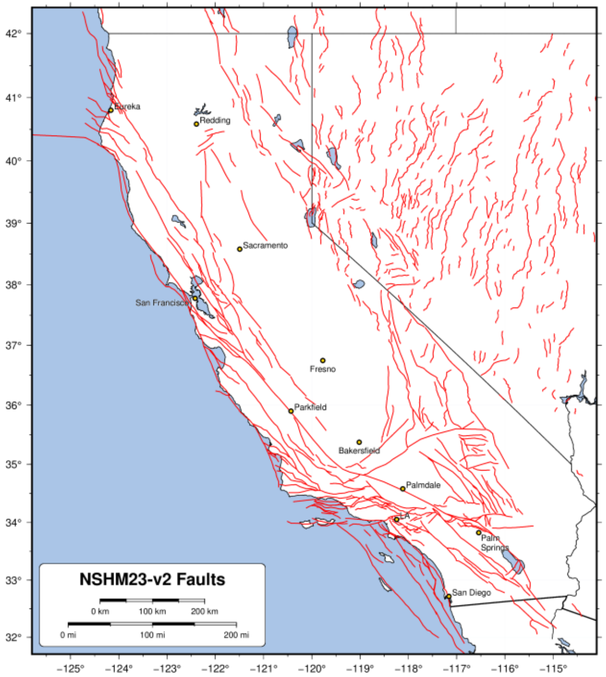
Scott Marshall
Appalachian State University



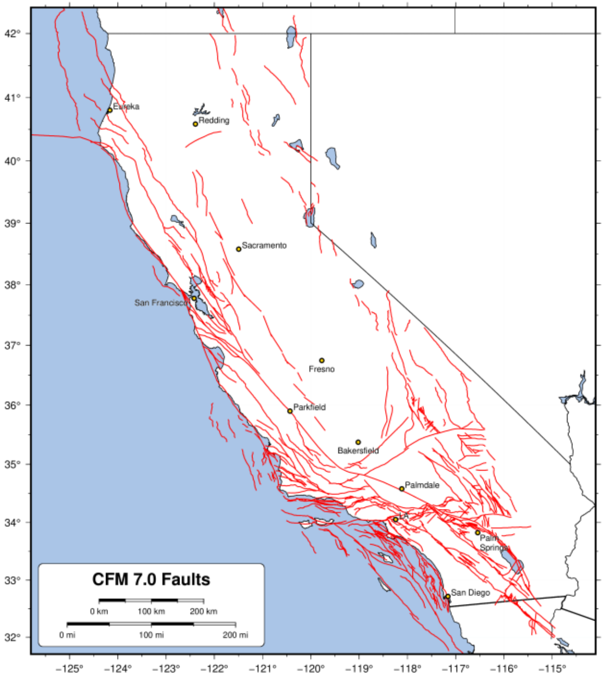
Fault Models Comparison



- 2D Model (traces)
- Geometrically complex
  - Defined mainly by mapping
- Identifies activity of faulting

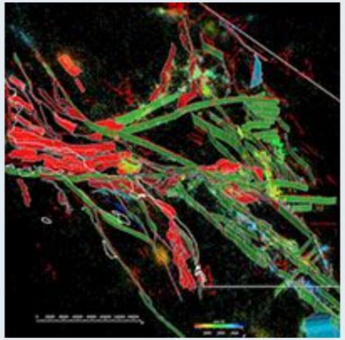


- 2.5D Model
  - Builds on UCERF3/CFM
- Geometrically smooth
- Developed for hazard analyses



- Full 3D Model
- Geometrically complex
  - Defined by source data
- Serves a variety of SCEC initiatives

The CFM Widget



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CFM HOME | EXPLORER TOOL | CFM ARCHIVE

Link to model homepage

Link to web-based tool "CFM Explorer"

Link to citable Zenodo archive

Findable

Accessible

Interoperable

Reusable

HOME | ABOUT SCEC | RESEARCH | LEARN & PREPARE

Search SCEC.org GO

SC/EC AN NSF+USGS CENTER

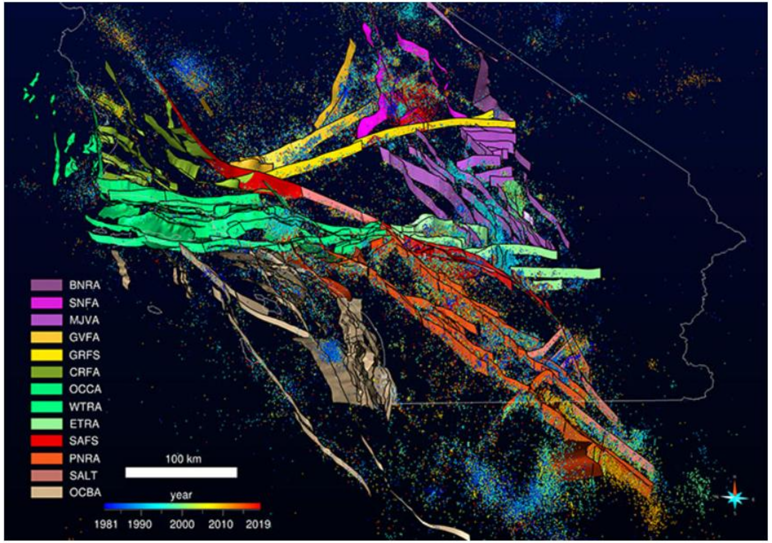
Southern California Earthquake Center

Studying earthquakes and their effects in California and beyond

SCEC became the **Statewide** California Earthquake Center in 2024. This is the archived website of the Southern California Earthquake Center with information about the Center through 2023. Visit www.scec.org for more information about the Center's new statewide activities.

Home / SCEC Community Research / The SCEC Community Fault Model (CFM)

The SCEC Community Fault Model (CFM)



Perspective view of the CFM6.0 with fault surfaces colored by the fault system. Relocated seismicity is colored by time (calendar year). (Hauksson et al., 2012, and 2019 updates)

Introduction

The SCEC Community Fault Model (CFM) is an object-oriented, three-dimensional representation of active faults in ...

The SCEC Community Fault Model: ... 2021 SCEC CFM Talk ...

CFM WORKING GROUP

CFM Developers

Andreas Plesch
Scott Marshall
John Shaw

SCEC Software Team

Mei-Hui Su
Phil Maechling

CFM Contributors

We could not make the CFM without support from the community of CFM contributors.

Do you have new data or interpretations that constrain the 3D geometry of CFM faults? Find out how to contribute to the CFM!

CFM Evaluators

We would like to thank those that volunteered their time and expertise to the rigorous evaluation of the CFM during the devlopment of version 6.1.

DOWNLOADS

DOI 10.5281/zenodo.4651667

Previous Models

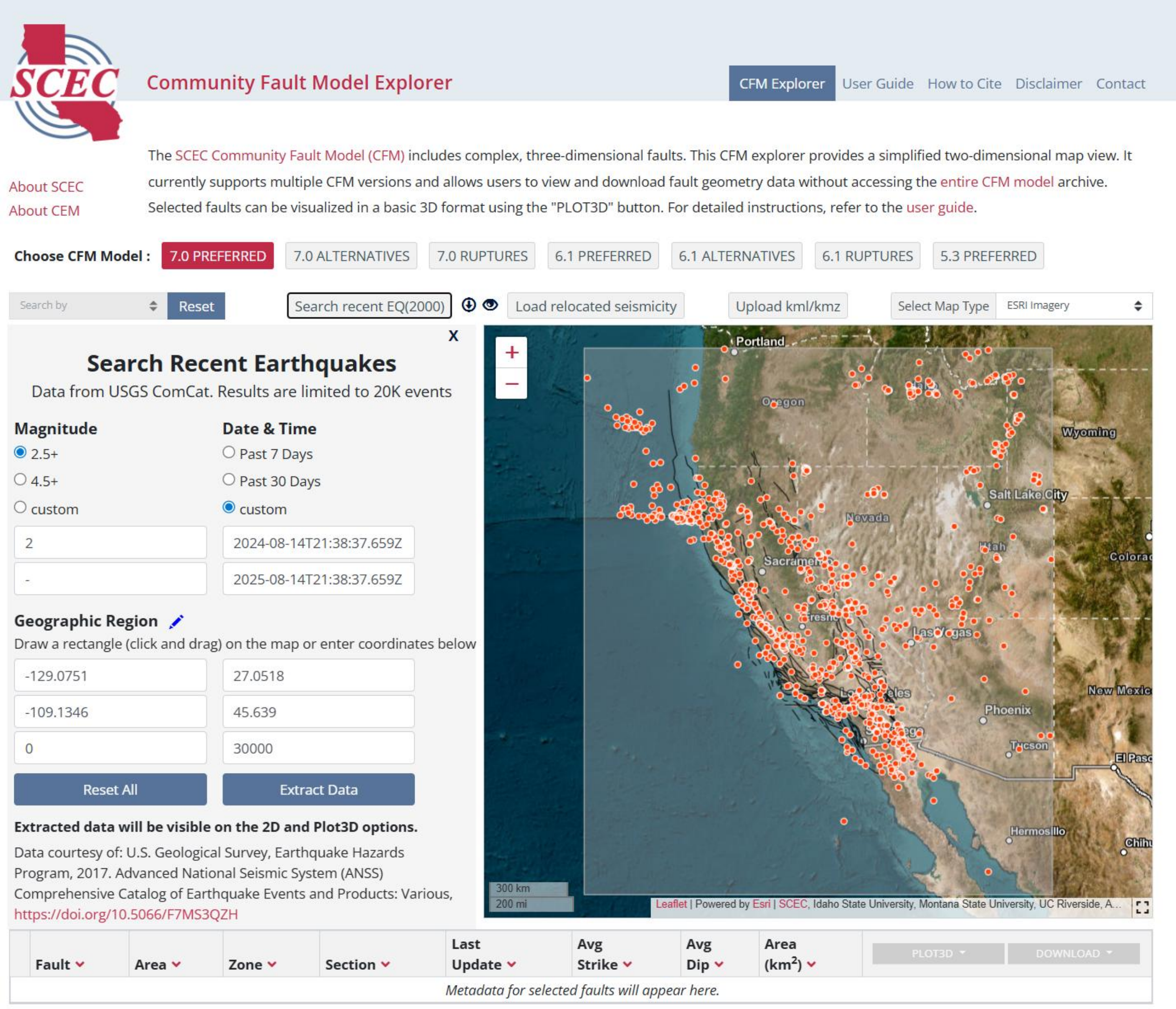
CFM5.3 (2022)

CFM Homepage

southern.scec.org/research/cfm

Any **southern.scec.org** site is an archived snapshot of where we were at the end of SCEC5

We are working to update the CEM homepages



CFM Explorer

Web-based tools for the Community Fault Model

What does the Explorer do?

- Search/Query/Download
  - CFM 7.0, 6.1, and 5.3
- Several basemaps
- Search recent USGS EQs! NEW!
- Display relocated EQs
  - Red circles: >M6 since 1900
  - Hauksson et al. (2012+updates)
  - Waldhauser (2009+updates)
- Upload/Display kml files
- View faults in 3D!!
  - Includes relocated seismicity in 3D

How is the CFM Built?

The CFM is not an algorithm

- A diverse array of data is used to define fault surfaces in 3D within seismogenic depths
- Most faults: generated manually by a person
  - Usually, Andreas Plesch or Harvard students
  - Error bars are not practical to generate
  - Covariance between neighboring elements
- We have a semi-automated algorithm for generating faults
  - Requires significant seismicity, focal mechanisms, surface trace/ruptures
  - Used for Ridgecrest and some new NorCal faults

Detailed 3D Fault Representations for the 2019 Ridgecrest, California, Earthquake Sequence

Andreas Plesch*[1], John H. Shaw[1], Zachary E. Ross[2], and Egill Hauksson[2]

ABSTRACT

We present new 3D source fault representations for the 2019 M 6.4 and M 7.1 Ridgecrest earthquake sequence. These representations are based on relocated hypocenter catalogs expanded by template matching and focal mechanisms for M 4 and larger events. Following the approach of Riesner *et al.* (2017), we generate reproducible 3D fault geometries by integrating hypocenter, nodal plane, and surface rupture trace constraints. We used the southwest–northeast-striking nodal plane of the 4 July 2019 M 6.4 event to constrain the initial representation of the southern Little Lake fault (SLLF), both in terms of location and orientation. The eastern Little Lake fault (ELLF) was constrained by the 5 July 2019 M 7.1 hypocenter and nodal planes of M 4 and larger aftershocks aligned with the main trend of the fault. The approach follows a defined workflow that assigns weights to a variety of geometric constraints. These main constraints have a high weight relative to that of individual hypocenters, ensuring that small aftershocks are applied as weaker constraints. The resulting fault planes can be considered averages of the hypocentral locations respecting nodal plane orientations. For the final representation we added detailed, field-mapped rupture traces as strong constraints. The resulting fault representations are generally smooth but nonplanar and dip steeply. The SLLF and ELLF intersect at nearly right angles and cross on another. The ELLF representation is truncated at the Airport Lake fault to the north and the Garlock fault to the south, consistent with the aftershock pattern. The terminations of the SLLF representation are controlled by aftershock distribution. These new 3D fault representations are available as triangulated surface representations, and are being added to a Community Fault Model (CFM; Plesch *et al.*, 2007, 2019; Nicholson *et al.*, 2019) for wider use and to derived products such as a CFM trace map and viewer (Su *et al.*, 2019).

KEY POINTS

- We present a 3D model of the source faults for the 2019 Ridgecrest, CA earthquake sequence.
- We employ an objective method of defining faults using hypocenter, focal mechanism, and geologic constraints.
- Source faults consist of two main segments, the Southern and Eastern Little Lake faults, and six large splays.

Supplemental Material

INTRODUCTION

Many of the fundamental aspects of earthquake science, including event nucleation, dynamic rupture and wave propagation, stress triggering, and other phenomena, are impacted by the properties of fault zones, including its location and geometry. Moreover, earthquake hazards assessments are largely based on inferences about the location and magnitudes of past and future earthquakes, which often involves defining the activity and slip rates on faults using geologic, seismologic, or geodetic observations. Among the most influential properties impacting earthquake phenomena and their associated hazards are source fault location and geometry. As a result, there have been many comprehensive efforts to map active fault zones in earthquake-prone regions. In California, these efforts began with the mapping of individual fault zones such as the San Andreas (e.g., Lawson *et al.*, 1908; Allen, 1957; Dibblee, 1973). These efforts expanded to comprehensive mapping and classification of active fault traces with regional and national fault trace databases maintained by the California and U.S. Geological Surveys, respectively (Jennings and Bryant, 2010; see Data and Resources). In recent decades, these maps have been extended to develop 3D digital representations of

1. Department of Earth & Planetary Sciences, Harvard University, Cambridge, Massachusetts, U.S.A.; 2. Seismological Laboratory, California Institute of Technology, Pasadena, California, U.S.A.

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Cite this article as Plesch, A., J. H. Shaw, Z. E. Ross, and E. Hauksson (2020). Detailed 3D Fault Representations for the 2019 Ridgecrest, California, Earthquake Sequence, *Bull. Seismol. Soc. Am.* **110**, 1818–1831, doi: 10.1785/0120200053

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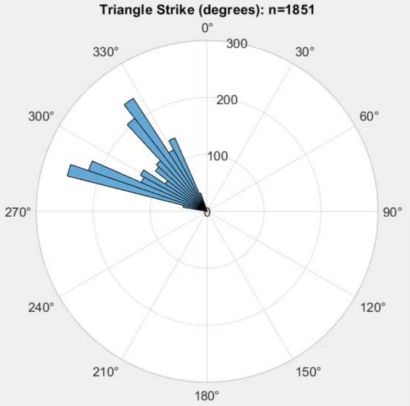
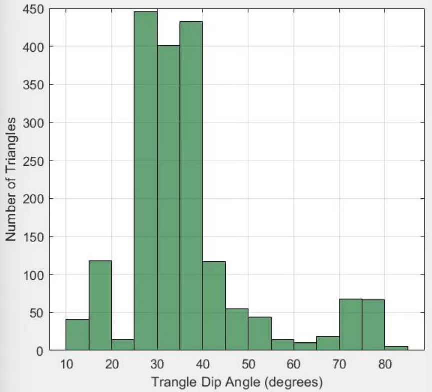
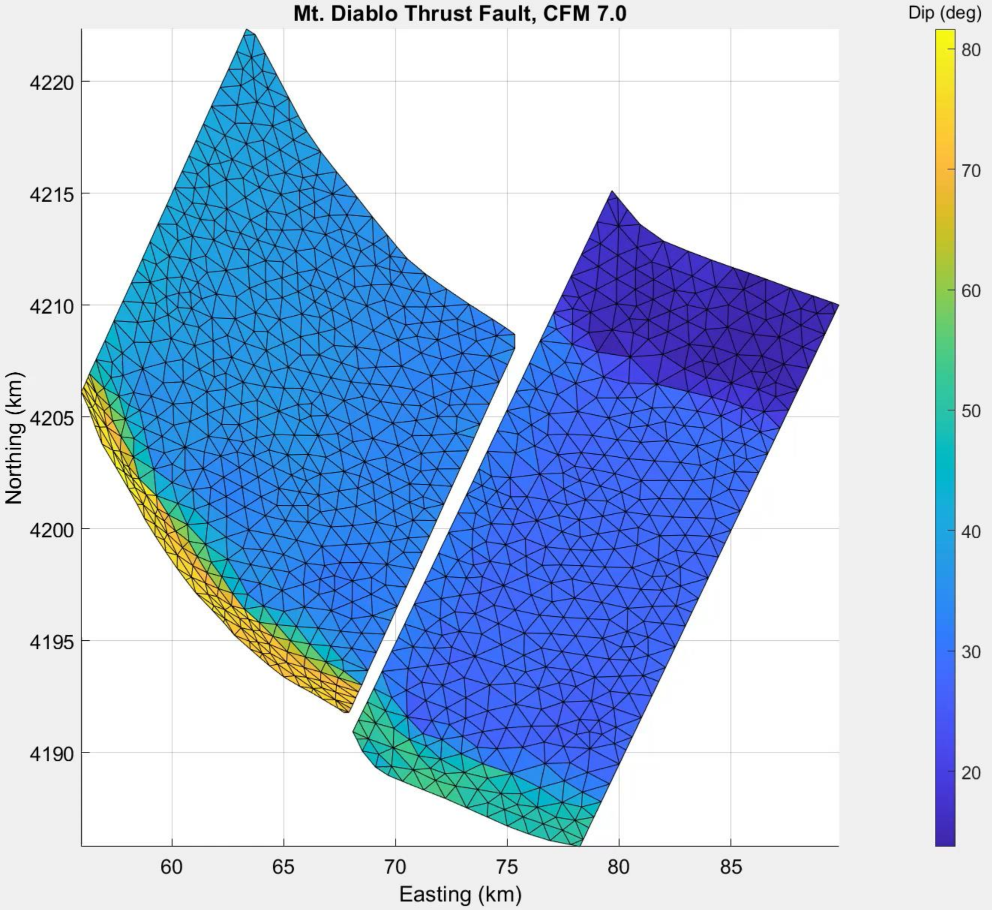
3D CFM Fault Example





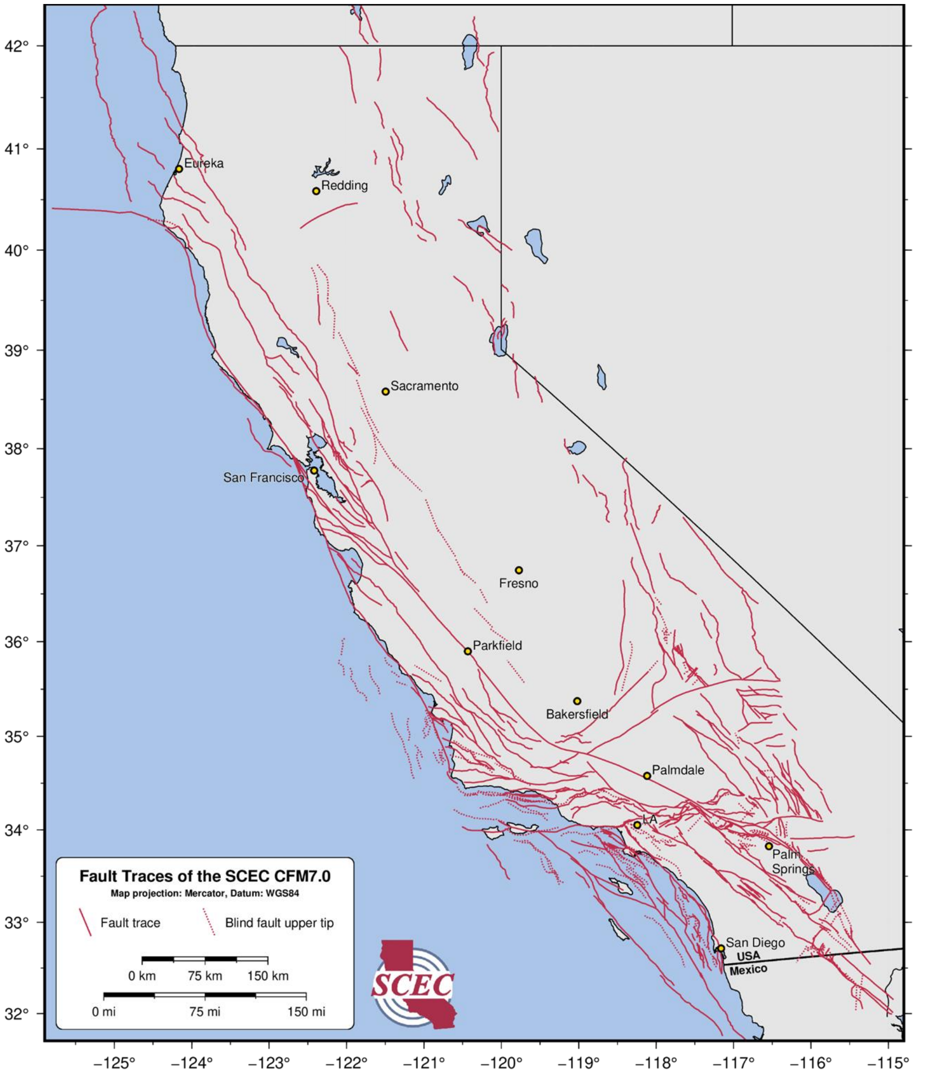


The CFM Version 7.0

CFM 7.0 is released!

- Now statewide (and beyond)
- SoCal faults: no change from v6.1
- N. California faults are preliminary
  - Were peer-reviewed this year
- Updated web-based "CFM Explorer"
- 3D Faults use open-source GOCAD .ts files
- 2D kml file has metadata as attributes

- **CFM 7.0 Submodels:**
  - **Preferred: 556 faults (113 new)**
  - **Ruptures: 13 faults**
  - **Alternatives: 39 faults**



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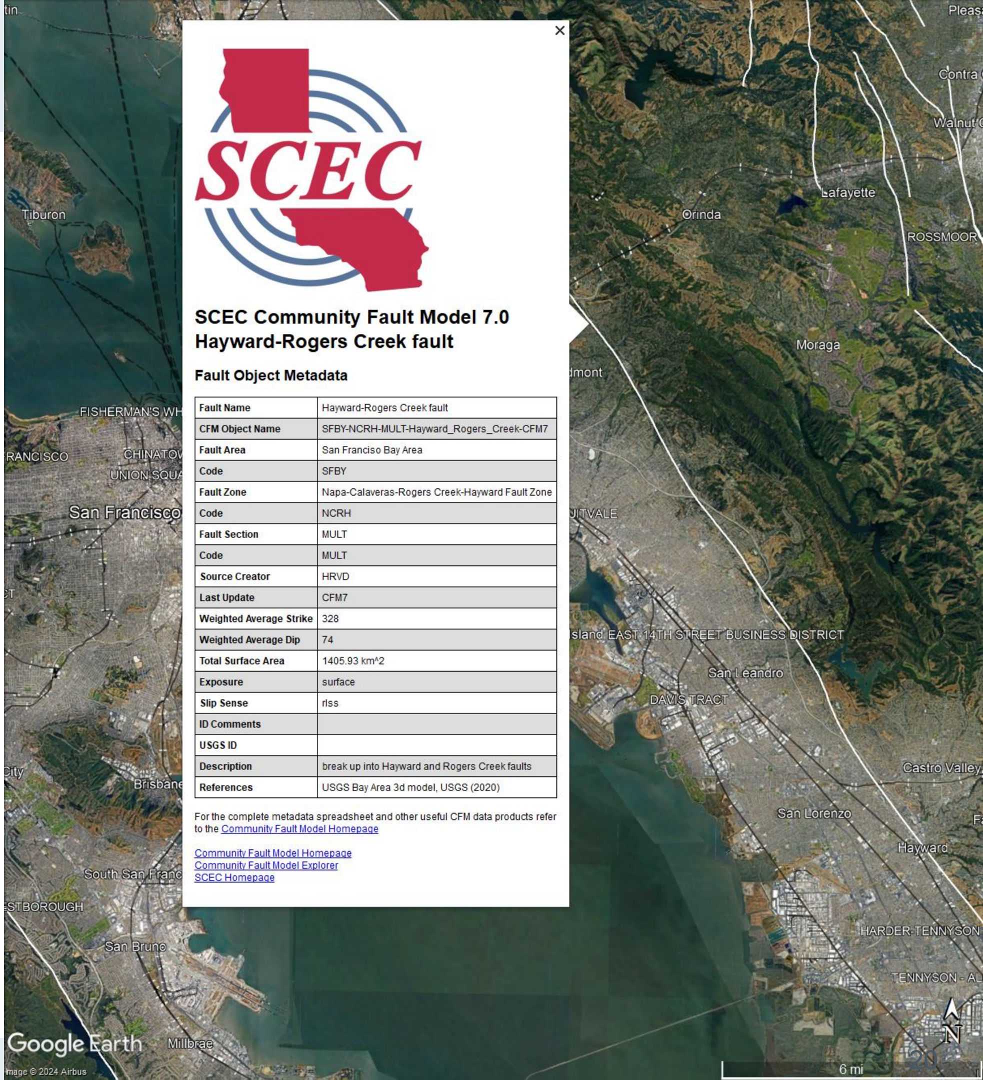

Fault Name	Hayward-Rogers Creek fault
CFM Object Name	SFBY-NCRH-MULT-Hayward_Rogers_Creek-CFM7
Fault Area	San Francisco Bay Area
Code	SFBY
Fault Zone	Napa-Calaveras-Rogers Creek-Hayward Fault Zone
Code	NCRH
Fault Section	MULT
Code	MULT
Source Creator	HRVD
Last Update	CFM7
Weighted Average Strike	328
Weighted Average Dip	74
Total Surface Area	1405.93 km^2
Exposure	surface
Slip Sense	rlss
ID Comments	
USGS ID	
Description	break up into Hayward and Rogers Creek faults
References	USGS Bay Area 3d model, USGS (2020)

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Statewide California Earthquake Center (SCEC)

Published September 4, 2024 | Version 7.0

Dataset | Open

SCEC Community Fault Model (CFM)

Plesch, Andreas[1] ; Marshall, Scott[2] ; Shaw, John[1]

Show affiliations

Introduction

The Statewide California Earthquake Center (SCEC) Community Fault Model (CFM) is an object-oriented, fully three-dimensional geometric representation of active faults in California and adjacent offshore basins. For each fault object, the CFM provides triangulated surface representations (t-surfs) in several resolutions, fault traces in several different file formats (shape files, GMT plain text, and GoogleEarth kml), and complete metadata including references used to constrain the surfaces. The CFM faults are defined based on available data including surface traces, seismicity, seismic reflection profiles, well data, geologic cross sections, and various other types of data and models. The CFM serves SCEC as a unified resource for physics-based fault systems modeling, strong ground-motion prediction, probabilistic seismic hazards assessment (e.g., the USGS National Seismic Hazard Model), and many other uses. Together with the Community Velocity Model (CVM-H 15.1.0), the CFM comprises SCEC's Unified Structural Representation of the Southern California crust and upper mantle (Shaw et al., 2015).

Current Model Version: CFM 7.0

The current version of the SCEC CFM is version 7.0 (CFM 7.0), which builds on the previous CFM releases and serves as the latest update to Plesch et al. (2007). CFM 7.0 is a significant update as this is the first CFM to cover the entire state of California, spanning the Pacific-North American plate boundary from northern Mexico to the southern Cascadia subduction zone. This latest version has no changes to the southern California portion of the model, but now includes 113 new fault representations in central and northern California in the preferred model. These new central and northern California fault representations will undergo a community evaluation in 2024-2025, therefore, the central and northern California faults should be considered preliminary representations.

CFM 7.0 contains three fully-documented sub models: preferred, ruptures, and alternatives. In total, CFM 7.0 comprises the following components:

1. **CFM 7.0 Preferred**: A set of 556 fault objects that constitute the preferred set of active faults. These faults have attained preferred status based on past community evaluations or are new representations.
2. **CFM 7.0 Ruptures**: A set of 13 fault objects assembled from the CFM 7.0 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. **CFM 7.0 Alternatives**: A set of 39 alternative representations where structural differences have been proposed that could

4K VIEWS | 575 DOWNLOADS

Show more details

Versions

Version 7.0 10.5281/zenodo.13685611	Sep 4, 2024
Version 6.1 10.5281/zenodo.8327463	Sep 7, 2023
Version 6.0 10.5281/zenodo.7809330	Apr 1, 2023
Version 5.3.2 10.5281/zenodo.5899364	Jan 24, 2022
Version 5.3.1 10.5281/zenodo.4660239	Apr 2, 2021

View all 6 versions

Cite all versions? You can cite all versions by using the DOI 10.5281/zenodo.4651667. This DOI represents all versions, and will always resolve to the latest one. Read more.

External resources

Indexed in

The CFM Archive

Available at Zenodo

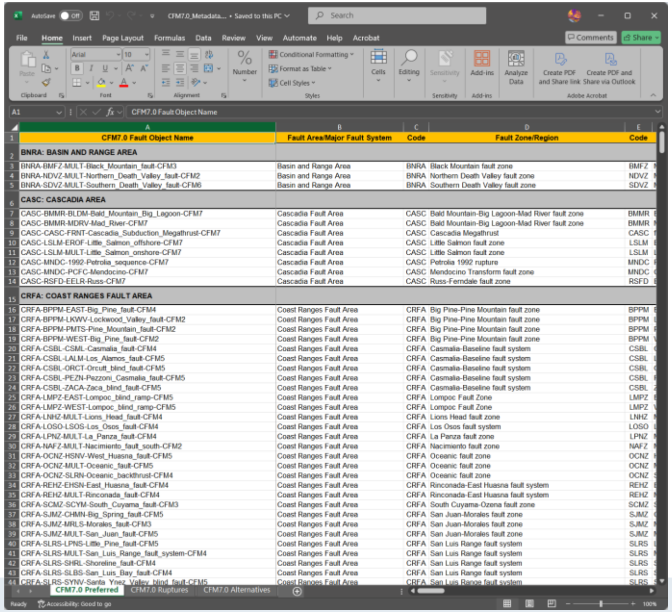
Complete CFM Archive

- .zip archives of CFM versions back to v5.3
- Contains data not available in the CFM Explorer
- What is in the archive?

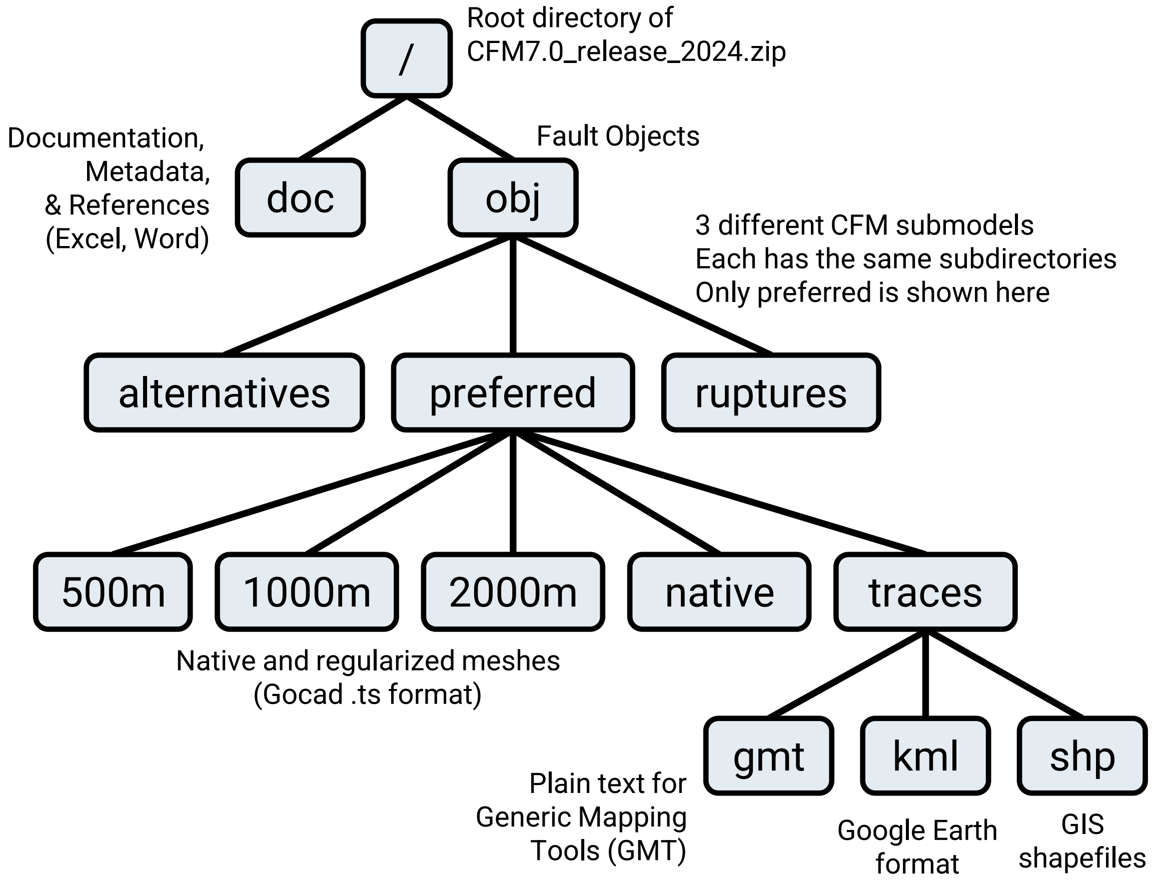
CFM Directory Structure

The Zenodo archive has data not available in the web tools

Screenshot of CFM Metadata spreadsheet



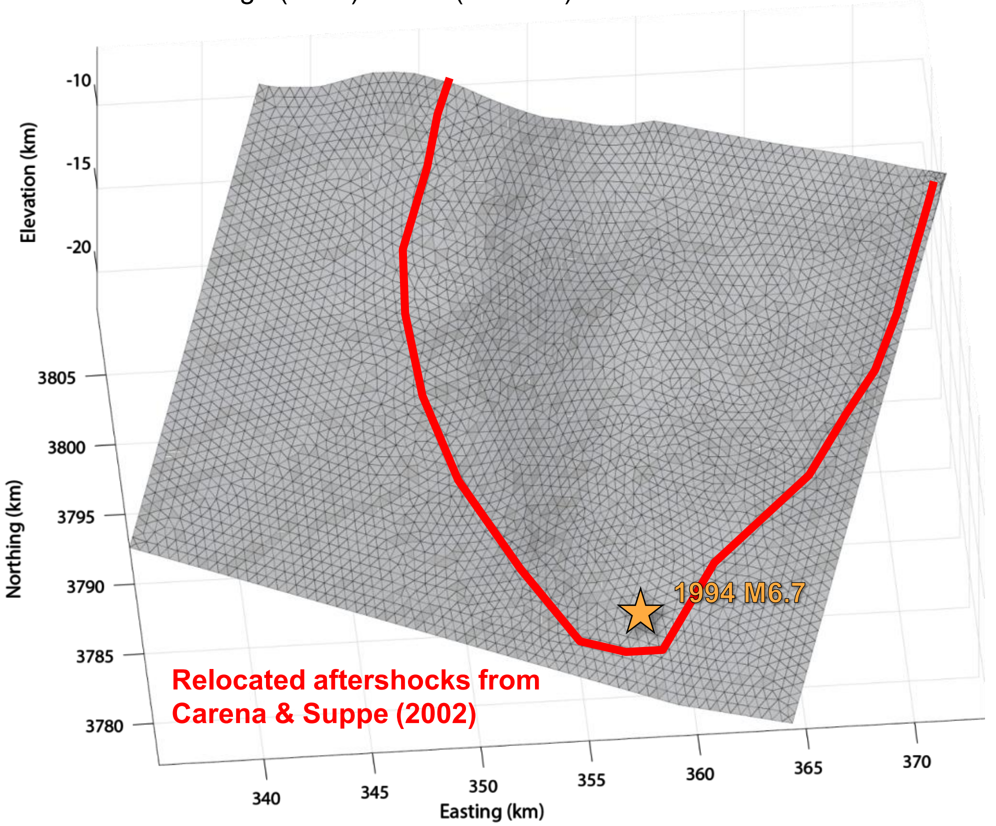
CFM7.0 Fault Object Name	Fault Area/Major Fault System	Code	Fault Zone/Region	Code
BNRA: BASIN AND RANGE AREA				
BNRA-BMFZ-MULT-Black_Mountain_fault-CFM3	Basin and Range Area	BNRA	Black Mountain fault zone	BMFZ
BNRA-NDVZ-MULT-Northern_Death_Valley_fault-CFM2	Basin and Range Area	BNRA	Northern Death Valley fault zone	NDVZ
BNRA-SDVZ-MULT-Southern_Death_Valley_fault-CFM6	Basin and Range Area	BNRA	Southern Death Valley fault zone	SDVZ
CASC: CASCADIA AREA				
CASC-BMMR-BLDM-Bald_Mountain_Big_Lagoon-CFM7	Cascadia Fault Area	CASC	Bald Mountain-Big Lagoon-Mad River fault zone	BMMR
CASC-BMMR-MDRV-Mad_River-CFM7	Cascadia Fault Area	CASC	Bald Mountain-Big Lagoon-Mad River fault zone	BMMR
CASC-CASC-FRNT-Cascadia_Subduction_Megathrust-CFM7	Cascadia Fault Area	CASC	Cascadia Megathrust	CASC
CASC-LSLM-EROF-Little_Salmon_offshore-CFM7	Cascadia Fault Area	CASC	Little Salmon fault zone	LSLM
CASC-LSLM-MULT-Little_Salmon_onshore-CFM7	Cascadia Fault Area	CASC	Little Salmon fault zone	LSLM
CASC-MNDC-1992-Petrolia_sequence-CFM7	Cascadia Fault Area	CASC	Petrolia 1992 rupture	MNDC
CASC-MNDC-PCFC-Mendocino-CFM7	Cascadia Fault Area	CASC	Mendocino Transform fault zone	MNDC
CASC-RSFD-EELR-Russ-CFM7	Cascadia Fault Area	CASC	Russ-Ferndale fault zone	RSFD
CRFA: COAST RANGES FAULT AREA				
CRFA-BPPM-EAST-Big_Pine_fault-CFM4	Coast Ranges Fault Area	CRFA	Big Pine-Pine Mountain fault zone	BPPM
CRFA-BPPM-LKWV-Lockwood_Valley_fault-CFM2	Coast Ranges Fault Area	CRFA	Big Pine-Pine Mountain fault zone	BPPM
CRFA-BPPM-PMTS-Pine_Mountain_fault-CFM2	Coast Ranges Fault Area	CRFA	Big Pine-Pine Mountain fault zone	BPPM
CRFA-BPPM-WEST-Big_Pine_fault-CFM2	Coast Ranges Fault Area	CRFA	Big Pine-Pine Mountain fault zone	BPPM
CRFA-CSBL-CSML-Casmalia_fault-CFM4	Coast Ranges Fault Area	CRFA	Casmalia-Baseline fault system	CSBL
CRFA-CSBL-LALM-Los_Alamos_fault-CFM5	Coast Ranges Fault Area	CRFA	Casmalia-Baseline fault system	CSBL
CRFA-CSBL-ORCT-Orcutt_blind_fault-CFM5	Coast Ranges Fault Area	CRFA	Casmalia-Baseline fault system	CSBL
CRFA-CSBL-PEZN-Pezzoni_Casmalia_fault-CFM5	Coast Ranges Fault Area	CRFA	Casmalia-Baseline fault system	CSBL
CRFA-CSBL-ZACA-Zaca_blind_fault-CFM5	Coast Ranges Fault Area	CRFA	Casmalia-Baseline fault system	CSBL
CRFA-LMPZ-EAST-Lompoc_blind_ramp-CFM5	Coast Ranges Fault Area	CRFA	Lompoc Fault Zone	LMPZ
CRFA-LMPZ-WEST-Lompoc_blind_ramp-CFM5	Coast Ranges Fault Area	CRFA	Lompoc Fault Zone	LMPZ
CRFA-LNHZ-MULT-Lions_Head_fault-CFM4	Coast Ranges Fault Area	CRFA	Lions Head fault zone	LNHZ
CRFA-LOSO-LSOS-Los_Osos_fault-CFM4	Coast Ranges Fault Area	CRFA	Los Osos fault system	LOSO
CRFA-LPNZ-MULT-La_Panza_fault-CFM4	Coast Ranges Fault Area	CRFA	La Panza fault zone	LPNZ
CRFA-NAFZ-MULT-Nacimiento_fault_south-CFM2	Coast Ranges Fault Area	CRFA	Nacimiento fault zone	NAFZ
CRFA-OCNZ-HSNV-West_Huasna_fault-CFM5	Coast Ranges Fault Area	CRFA	Oceanic fault zone	OCNZ
CRFA-OCNZ-MULT-Oceanic_fault-CFM5	Coast Ranges Fault Area	CRFA	Oceanic fault zone	OCNZ
CRFA-OCNZ-SLRN-Oceanic_backthrust-CFM4	Coast Ranges Fault Area	CRFA	Oceanic fault zone	OCNZ
CRFA-REHZ-EHSN-East_Huasna_fault-CFM4	Coast Ranges Fault Area	CRFA	Rinconada-East Huasna fault system	REHZ
CRFA-REHZ-MULT-Rinconada_fault-CFM4	Coast Ranges Fault Area	CRFA	Rinconada-East Huasna fault system	REHZ
CRFA-SCMZ-SCYM-South_Cuyama_fault-CFM3	Coast Ranges Fault Area	CRFA	South Cuyama-Ozena fault zone	SCMZ
CRFA-SJMZ-CHMN-Big_Spring_fault-CFM5	Coast Ranges Fault Area	CRFA	San Juan-Morales fault zone	SJMZ
CRFA-SJMZ-MRLS-Morales_fault-CFM3	Coast Ranges Fault Area	CRFA	San Juan-Morales fault zone	SJMZ
CRFA-SJMZ-MULT-San_Juan_fault-CFM5	Coast Ranges Fault Area	CRFA	San Juan-Morales fault zone	SJMZ
CRFA-SLRS-LPNS-Little_Pine_fault-CFM5	Coast Ranges Fault Area	CRFA	San Luis Range fault system	SLRS
CRFA-SLRS-MULT-San_Luis_Range_fault_system-CFM4	Coast Ranges Fault Area	CRFA	San Luis Range fault system	SLRS
CRFA-SLRS-SHRL-Shoreline_fault-CFM4	Coast Ranges Fault Area	CRFA	San Luis Range fault system	SLRS
CRFA-SLRS-SLBS-San_Luis_Bay_fault-CFM4	Coast Ranges Fault Area	CRFA	San Luis Range fault system	SLRS
CRFA-SLRS-SYNV-Santa_Ynez_Valley_blind_fault-CFM5	Coast Ranges Fault Area	CRFA	San Luis Range fault system	SLRS



CFM Metadata and File Management

- The CFM contains a variety of data in different formats for all 608 fault objects
- Metadata spreadsheet: 19 columns
  - Hierarchical Object Name
  - Fault Name
  - Avg Strike/Dip
  - Surface Area
  - References, etc…
- Gocad t-surfs in three resolutions
  - Native, 500m, 1000m, 2000m
- Fault traces (UTM and lon/lat)
  - GMT (plain text), and GIS shapefiles, GoogleEarth kml
- Complete references document

The Northridge (Frew) Thrust (CFM7.0)

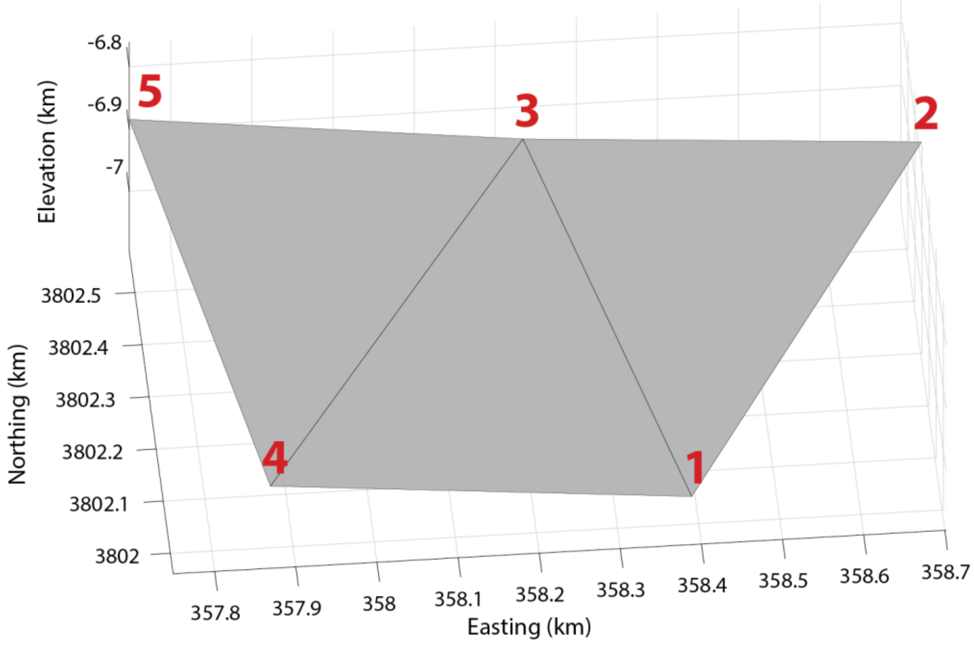


Gocad T-Surf Files are Open Source

```
GOCAD TSurf 1
HEADER {
name:WTRA-ORFZ-SFNV-Northridge_Frew_fault-CFM2_500m
*visible:true
*solid*color:0.082353 0.121569 0.858824 1
}
GOCAD_ORIGINAL_COORDINATE_SYSTEM
NAME Default
AXIS_NAME "X" "Y" "Z"
AXIS_UNIT "m" "m" "m"
ZPOSITIVE Elevation
END_ORIGINAL_COORDINATE_SYSTEM
TFACE
VRTX 1  358388.04688000 3801961.01562000 -7017.96484000
VRTX 2  358701.60938000 3802306.12500000 -6761.31885000
VRTX 3  358220.79688000 3802429.00000000 -6824.27686000
VRTX 4  357882.39062000 3802117.23438000 -7095.05664000
VRTX 5  357748.76562000 3802580.10938000 -6884.66162000
TRGL 1 2 3
TRGL 4 1 3
TRGL 4 3 5
END
```

Corresponding Gocad file contents.

There is a t-surf tutorial on CFM homepage.



3 randomly-selected elements from the Northridge (Frew) Thrust. Vertex numbers in red.

The SCEC Geologic Slip Rate Database (*not the CFM)

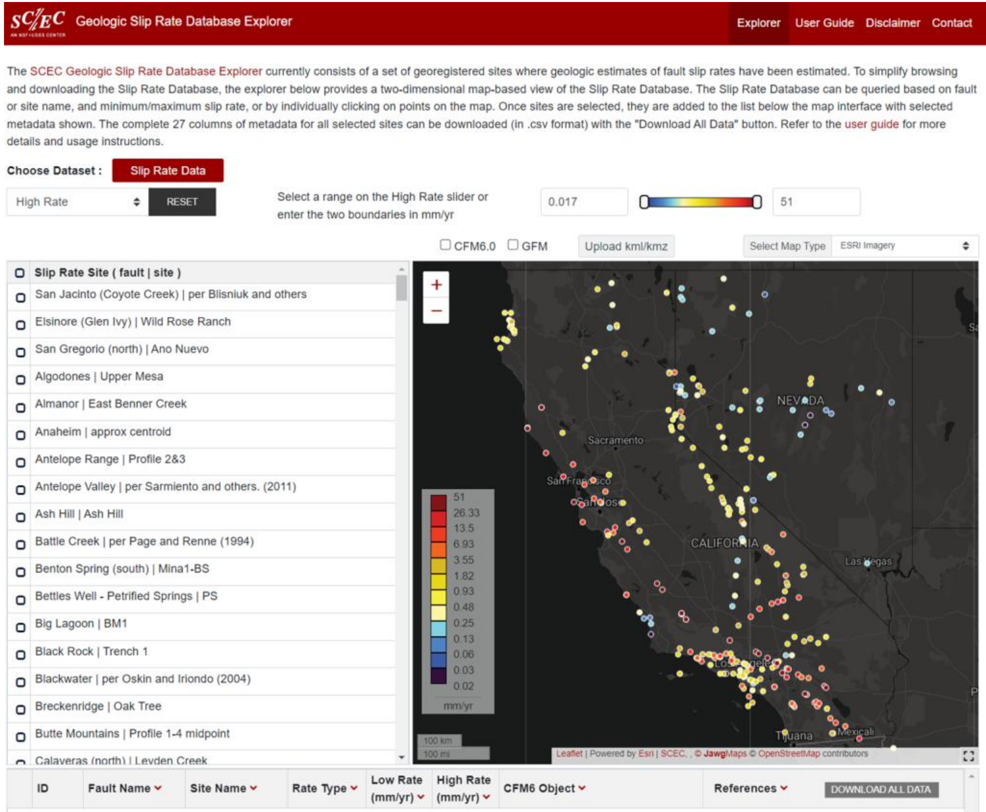
The SCEC CFM is a **geometric model** and provides no information about slip rates.

SCEC Geologic Slip Rate Database
https://www.scec.org/research/gsrd

- Geologic field-based estimates of fault slip rates
  - A subset of the USGS NSHM23 database and UCERF3
  - Direct hyperlinked references (where available)

- A subset of the NSHM23 geology inputs

  https://www.sciencebase.gov/catalog/item/6127b5d4d34e40dd9c050975



The Geologic Slip Rate Database Explorer showing slip rate sites colored by max slip rate (Marshall, Hatem, and Akçiz, 2023)

SCEC

Slip Rates From CFM-Based Deformation Models

The CFM provides the necessary geometry for use with deformation modeling.

Devine et al. (2022, SRL)
https://doi.org/10.1785/0220220182

Estimated slip rates and full 3D distributions of slip for 83 faults in southern California

- Fit 47/63 (75%) UCERF3 avg. slip rates
  - RMSE of 0.40 mm/yr.
- Fit 39/69 (60%) point based rates
  - RMSE of 0.79 mm/yr.

Focus Section: Deformation Models of Fault Slip for the 2023 Update

Mechanical Models of Fault-Slip Rates in the Transverse and Peninsular Ranges, California

Savannah Devine[1], Hugh Harper[2], and Scott T. Marshall[*1]

Abstract

The Transverse and Peninsular Ranges of Southern California host a geometrically complex network of seismically active faults with a range of slip senses. Here, we present 3D mechanical models of this region that are driven by the total Pacific-North American plate motion and slip on the San Andreas, San Jacinto, and Garlock faults. Based on these boundary conditions, we solve for the full 3D distribution of slip rates on 83 faults and compare model slip-rate predictions to long-term slip-rate data from Uniform California Earthquake Rupture Forecast version 3 (UCERF3) as well as individual geologic point-based estimates of long-term slip. About 46/68 (68%) model-predicted average fault-slip rates are within the UCERF3 slip-rate ranges with a root mean squared error (RMSE) of 1.03 mm/yr to the nearest (upper or lower) UCERF3 limit. The largest slip-rate discrepancies occur on the San Gabriel, Pine Mountain, and Big Pine faults, which may be presently inactive. We find that removing these three faults (i.e., assuming they are inactive) results in an improvement in all goodness-of-fit metrics with 47/63 (75%) UCERF3 slip rates fit with an RMSE of 0.40 mm/yr. We also compare this same model to existing point-based long-term slip-rate estimates and fit 39/69 (60%) with an RMSE of 0.79 mm/yr. The ability for the model to fit independent slip-rate data implies that strike slip along the "Big Bend" of the San Andreas fault (in conjunction with slip on the Garlock and San Jacinto faults) along with total plate motion is sufficient to reproduce both reverse-slip rates throughout the Transverse ranges and strike-slip rates in the Peninsular Ranges regions without additional driving forces needed. Overall, the models provide slip rates and distributions for 83 faults, including faults that currently do not have geologic slip-rate estimates and/or may not produce interseismic deformation.

Cite this article as Devine, S., H. Harper, and S. T. Marshall (2022). Mechanical Models of Fault-Slip Rates in the Transverse and Peninsular Ranges, California, *Seismol. Res. Lett.* **93**, 3135–3150, doi: 10.1785/0220220182.

Supplemental Material

Introduction

The Transverse and Peninsular Ranges of Southern California host a complex network of faults that accommodate both strike-slip and reverse motion (Wright, 1991). The Transverse Ranges region is situated just southwest of the "Big Bend," a major to the west (Donnellan, Hager, and King, 1993; Donnellan, Hager, King, and Herring, 1993; Hager *et al.*, 1999; Marshall *et al.*, 2013). Situated south of the Transverse Ranges, the Peninsular Ranges contain a series of active right-lateral strike-slip faults that generally parallel the San Andreas and

EQ to Fault Association

How can we evaluate CFM Completeness?

- Use method of Evans et al. (2020, BSSA)
- M3+ Combined Catalog (n=12,863)
  - Hypocenters: Hauksson et al. (2012+updates)
  - Focal Mech: Yang et al. (2012+updates)

How many relocated events (1981-2023) can be associated with a CFM 6.1 fault object?

A Statistical Method for Associating Earthquakes with Their Source Faults in Southern California

Walker S. Evans[1], Andreas Plesch[*1], John H. Shaw[1], Natesh L. Pillai[2], Ellen Yu[3], Men-Andrin Meier[3], and Egill Hauksson[3]

ABSTRACT

We present a new statistical method for associating earthquakes with their source faults in the Southern California Earthquake Center's 3D Community Fault Models (CFMs; Plesch et al., 2007) in near-real time and for historical earthquakes. The method uses the hypocenter location, focal mechanism orientation, and earthquake sequencing to produce the probabilities of association between a given earthquake and each fault in the CFM as well as the probability that the event occurred on a fault not represented in the CFM. We used a set of known likely associations (the Known Likely Sets) as training or testing data and demonstrated that our models perform effectively on these examples and should be expected to perform well on other earthquakes with similar characteristics including the full catalog of southern California earthquakes (Hauksson et al., 2012). To produce near-real-time associations for future earthquakes, the models have been implemented as an R script and connected to the Southern California Seismic Network data processing system operated by the California Institute of Technology and the U.S. Geological Survey to automatically produce fault associations for earthquakes of $M \geq 3.0$ as they occur. To produce historical associations, we apply the method to the most recent CFM version (v.5.2), yielding modeled historical associations for all events of $M \geq 3.0$ in the catalog of southern California earthquakes from 1981 to 2016. More than 80% of these events and 99% of moment within the geography covered by the CFM had a primary association with a CFM fault. The models can help identify clusters of small earthquakes that indicate the onset of activity associated with major faults. The method will also assist in communicating objective information about the faults that source earthquakes to the scientific community and general public. In the event of a damaging southern California earthquake, the near-real-time association will provide valuable information regarding the similarity of the current event to forecast scenarios, potentially aiding in earthquake response.

KEY POINTS

- Identifying source faults is difficult, time consuming, and subjective but critical for earthquake response.
- We develop and implement an automated method for associating earthquakes with known faults.
- The method can improve operational response, hazard assessments, and fault model completeness assessments.

INTRODUCTION

Determining source faults for earthquakes is often a difficult and time-consuming task. This is due to a number of challenges providing several options for the earthquake source. Finally, our knowledge of the fault structure is generally incomplete, and thus earthquakes may occur on faults that have not been previously recognized or do meet criteria (e.g., fault size) that warrant their inclusion in regional fault maps or models.

Today, source fault determinations are typically produced by expert examination of earthquake and fault-related data to manually identify source faults using information such as distance from earthquake hypocenters to fault surfaces, focal mechanisms, and foreshock and aftershock sequences. These subjective methods have proven ambiguous over time, with

1. Department of Earth and Planetary Sciences, Harvard University, Cambridge, Massachusetts U.S.A.; 2. Department of Statistics, Harvard University, Cambridge,

See Evans et al. (2020, BSSA) for the method details

EQ to Fault Association

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  - Hypocenters: Hauksson et al. (2012+updates)
  - Focal Mech: Yang et al. (2012+updates)

How many relocated events (1981-2023) can be associated with a CFM 6.1 fault object?

Caltech/USGS SCSN Event Information

Magnitude:	3.9
Time (PT -||- UTC):	2024/09/07 10:34:20 ---||--- 2024/09/07 17:34:20
Coordinates (lat,lon):	34.03, -117.586
Location:	4.6 km (2.9 mi) ESE from Ontario, CA
Depth (km/miles):	4.9/3.0
USGS ComCat URL:	ci40727543

CFM Fault Association Probability

Most Likely

Fontana Seismicity lineament (87%)

Alternates

Not associated with a CFM modeled fault (12%)

Other CFM faults (1%)

Probability Summary

CFM #	Fault Name	Distance (km)	Probability (%)
138	Fontana Seismicity lineament	2.27	87
329	not in CFM	NA: Not in CFM	12
151	Chino fault; Central Ave segment	11.88	0
152	Chino fault; main segment	13.57	0
323	San Jose fault	14.85	0

Background Information

Earthquakes can occur both near or on major known faults, and in places where no clear fault zones are known. Using the statistical method of

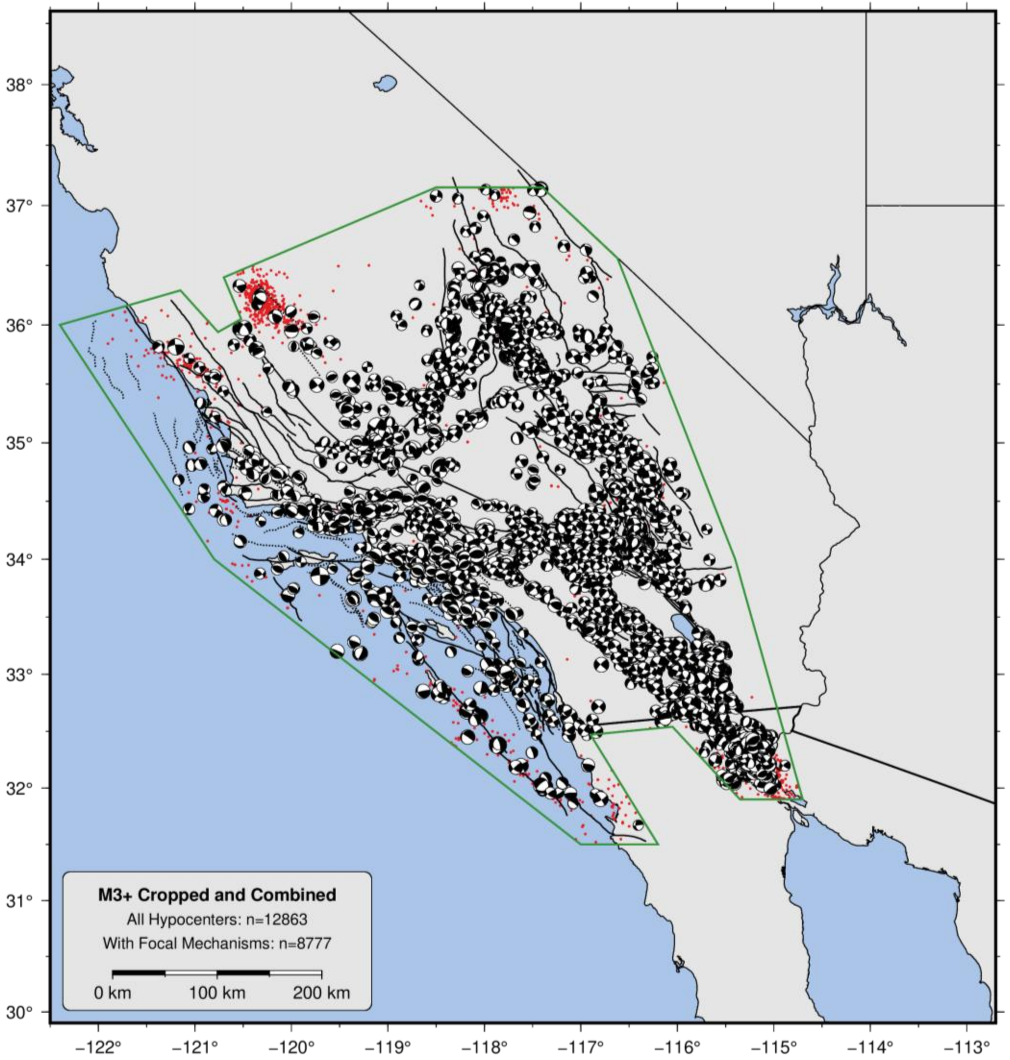
See Evans et al. (2020, BSSA) for the method details

EQ to Fault Association

How can we evaluate CFM Completeness?

- Use method of Evans et al. (2020)
- M3+ Combined Catalog (n=12,863)
  - Hypocenters: Hauksson et al. (2012)
  - Focal Mech: Yang et al. (2012)

How many relocated events (1981-2023) can be associated with a CFM 6.1 fault object?



EQ to Fault Association

How can we evaluate CFM Completeness?

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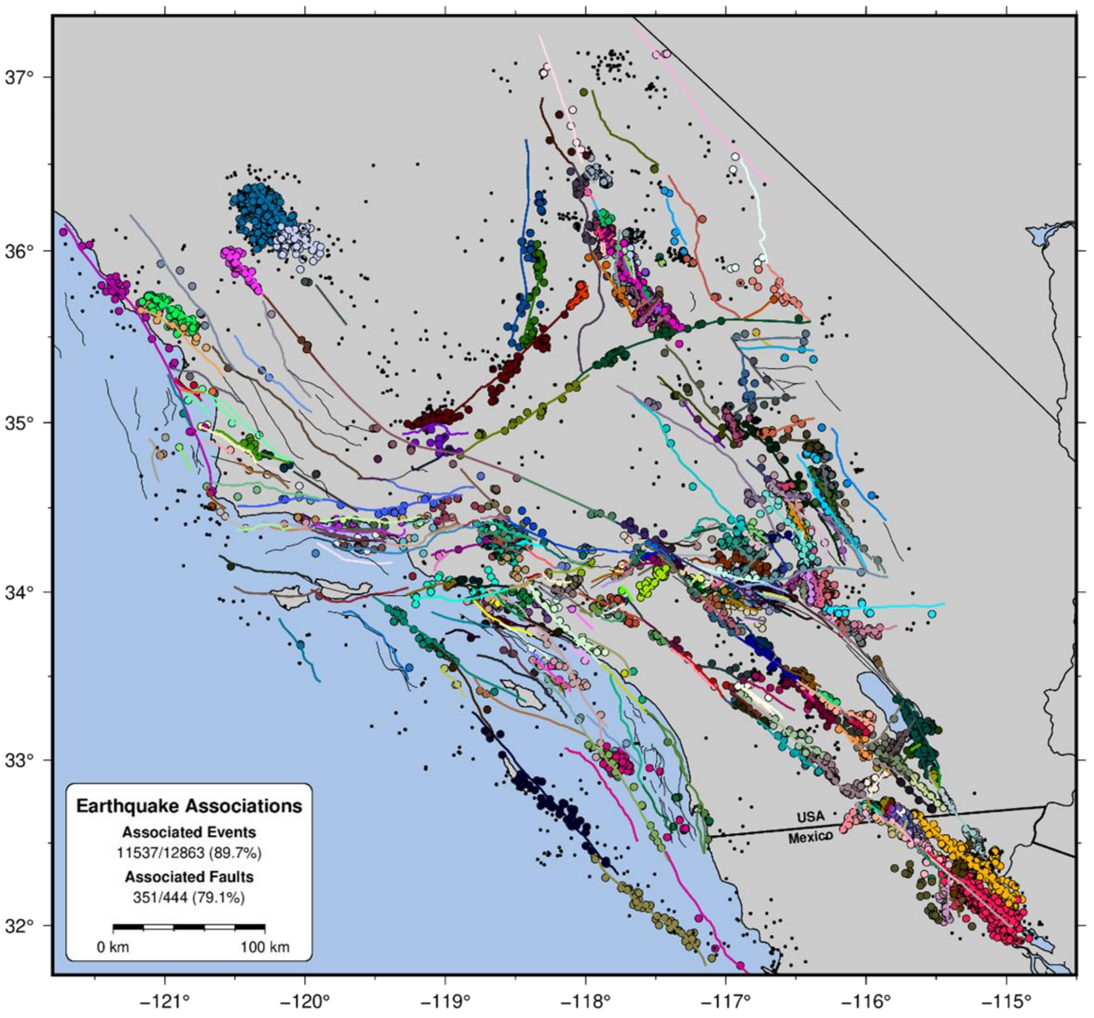
  - Hypocenters: Hauksson et al. (2012)
  - Focal Mech: Yang et al. (2012)

How many relocated events (1981-2023) can be associated with a CFM 6.1 fault object?

- **89.7%   M3+ events**
- **100%   M6+ events**



See Evans et al. (2020, BSSA) for the method details

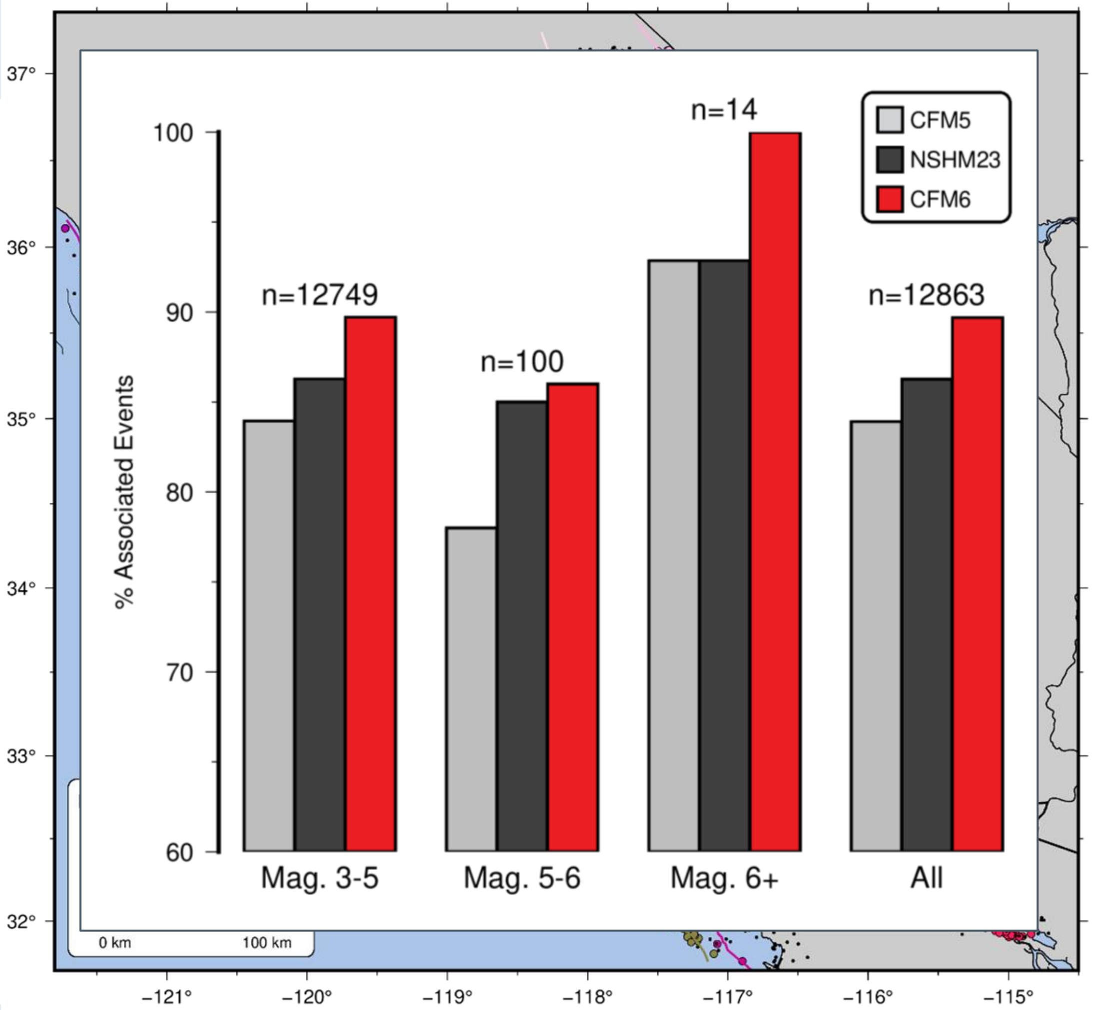
EQ to Fault Association

How can we evaluate CFM Completeness?

- M3+ Combined Catalog (n=12,863)
  - Hypocenters: Hauksson et al. (2012)
  - Focal Mech: Yang et al. (2012)
- Used method of Evans et al. (2020)

How many events (1981-2023) can be associated with a CFM 7.0 fault object?

- **89.7% M3+ events**
- **100% M6+ events**



CFM 7.0 Evaluation

The northern California CFM evaluation just finished in June

Significant feedback, will take time to review and address

Thank-you NorCal CFM Group Leaders!

Mark Hemphill-Haley (Cal Poly Humboldt)
Christie Rowe (UNR)
Alex Hatem (USGS)
Travis Alonghi (USGS)
Keith Knudsen (USGS)
Ben Melosh (USGS)
Jay Patton (CGS)
Sarah Minson (USGS)

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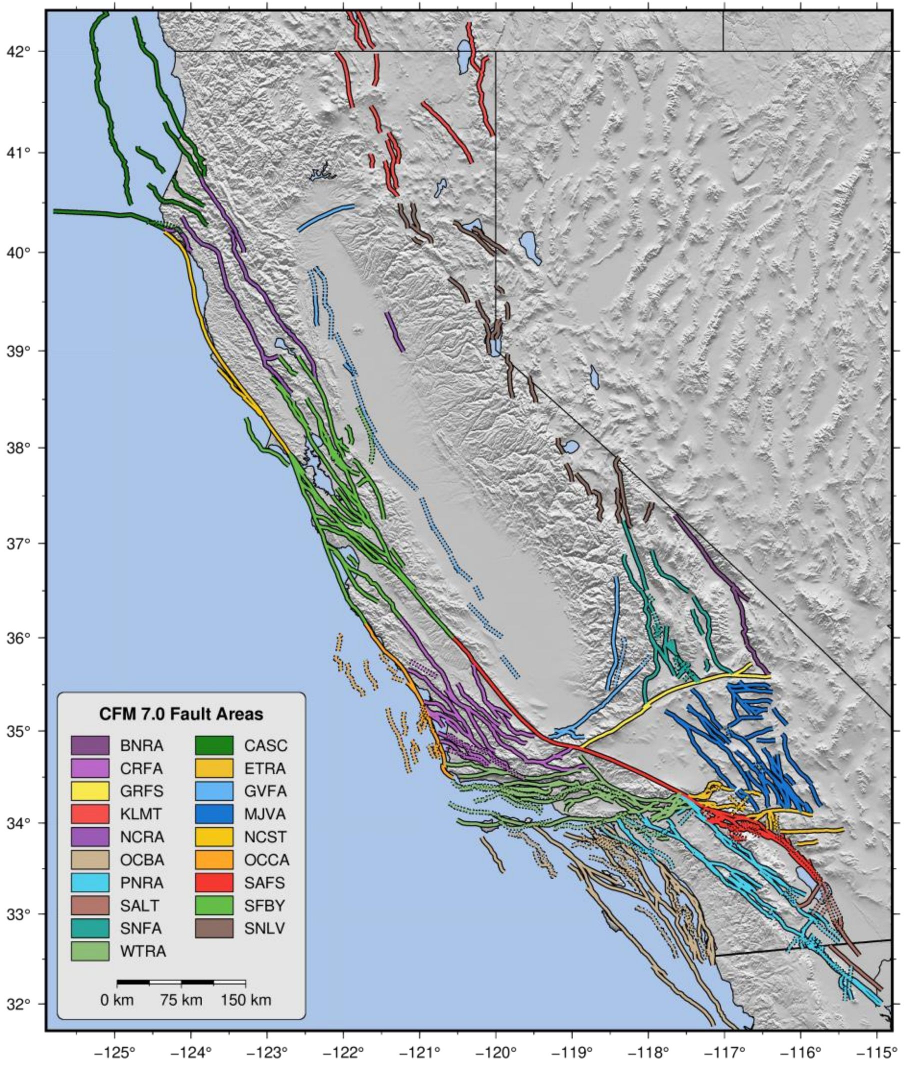

CFM Contact | marshallst@appstate.edu