SCEC Community Models (CXM): A Tour

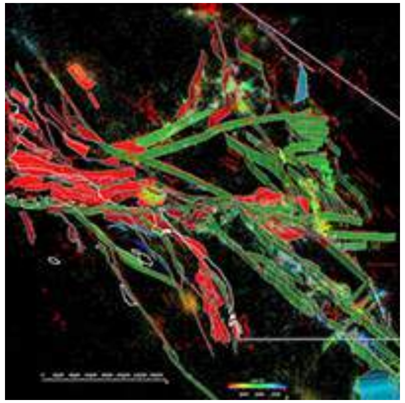
Elizabeth Hearn

CXM co-leader with Scott Marshall (Appalachian State)

https://www.scec.org/research/cxm

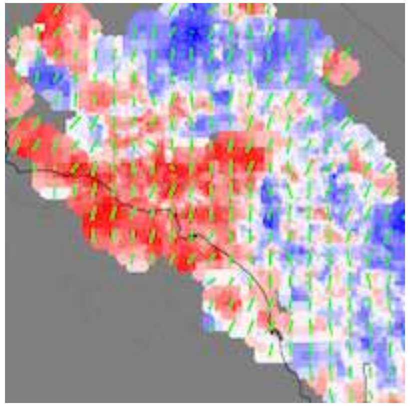
The Community Models and Their Representatives

Community Fault Model
(Scott Marshall)



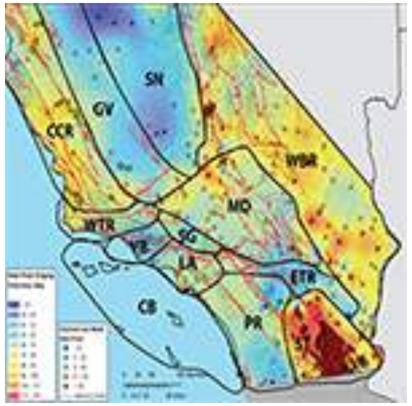
CFM

Community Stress Model
(Jeanne Hardebeck)



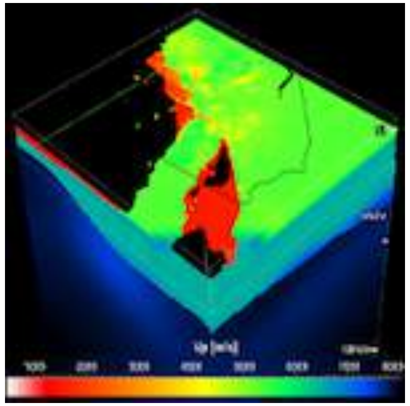
CSM

Community Thermal Model
(Wayne Thatcher)



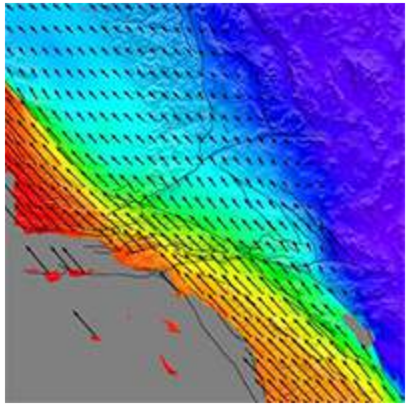
CTM

Community Velocity Model
(Andreas Plesch)



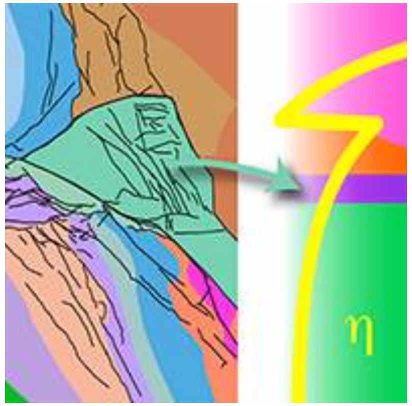
CVM

Community Geodetic Model
(David Sandwell)



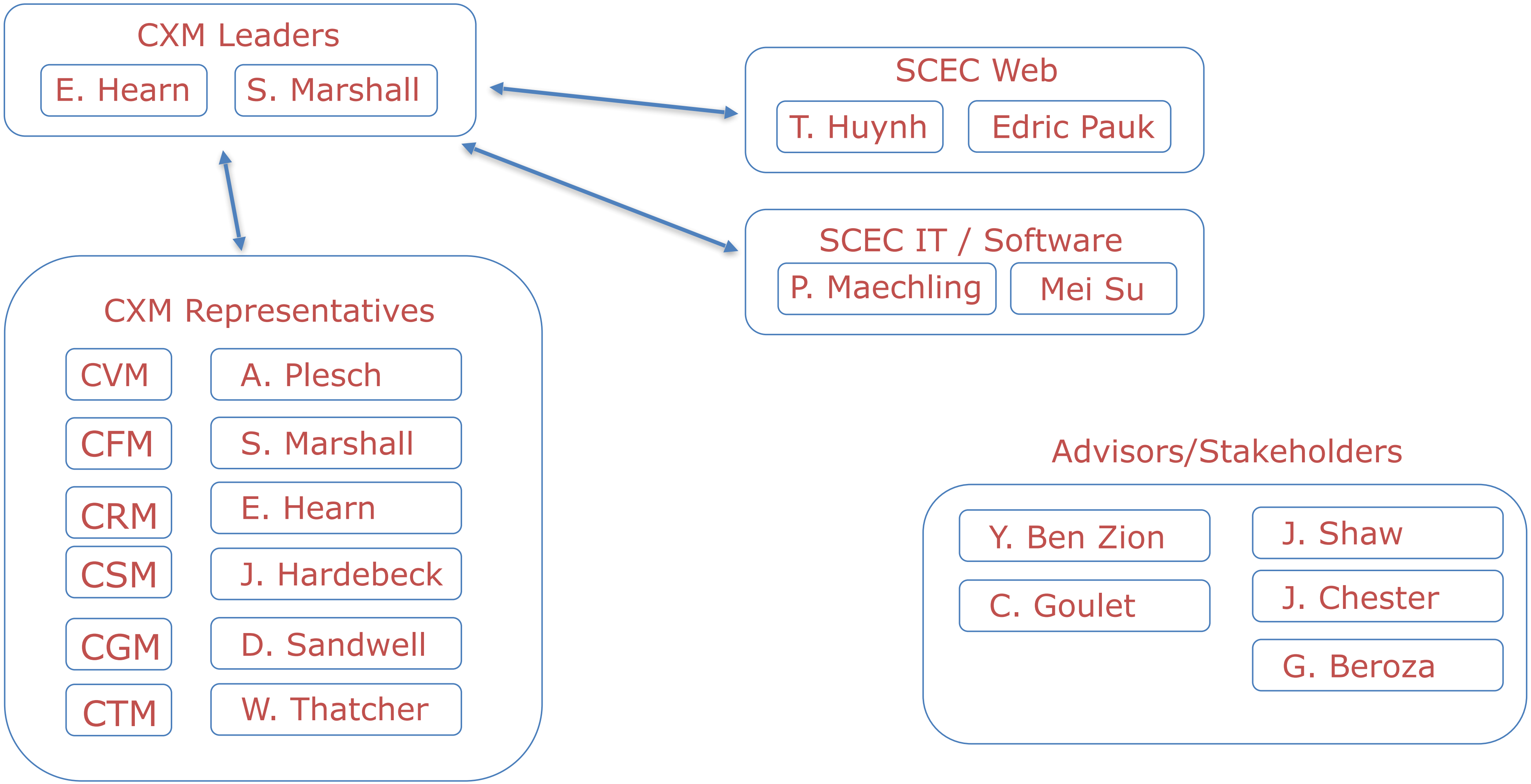
CGM

Community Rheology Model
(Elizabeth Hearn)

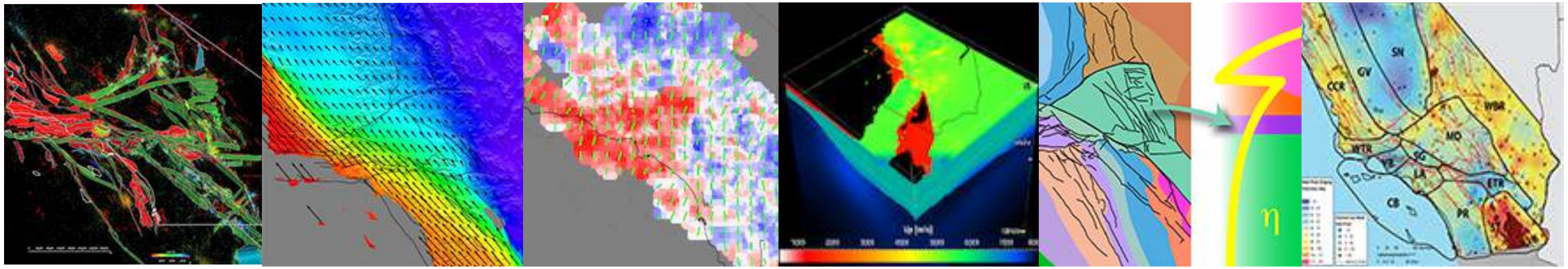


CRM

CXM Working Group Organization



CXM Activities - September 2018 to present



- CXM portal website setup (Sept 2018): access to all CXM’s
- coordinate setup of standardized SCEC-hosted websites for each community model. Priority: CFM, CSM and CGM.
- working with SCEC IT and CFM model representative to develop software tools to display, query and download CFM

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SCEC Community Models (CXM)

Introduction

The SCEC Community Models (CXM) working group develops, refines and integrates community models describing a wide range of features of the southern California lithosphere and asthenosphere. These features include: elastic and attenuation properties (Community Velocity Model, CVM), temperature (Community Thermal Model, CTM), rheology (Community Rheology Model, CRM), stress and stressing rate (Community Stress Model, CSM), deformation rate (Community Geodetic Model, CGM), and fault geometry (Community Fault Model, CFM). The ultimate long-term goal of the CXM working group is to provide an internally consistent suite of models that can be used together to simulate seismic phenomena in southern California.

Research Priorities

The SCEC research goals involve continued refinement of existing community models (CFM, CVM, CSM, CGM), development of new community models (CTM and CRM), and integration of the models into a self-consistent suite. Objectives also include quantification of uncertainties and development of techniques for propagating uncertainties from observations through community model development to simulation predictions.

Community Fault Model (CFM)

The CFM is an object-oriented three-dimensional geometric representation of more than 820 fault objects in southern California and adjacent offshore basins for which Quaternary

CXM WORKING GROUP

Leaders
Liz Hearn
Scott Marshall

CXM Coordinating Committee
CFM: Scott Marshall
CGM: David Sandwell
CRM: Liz Hearn
CSM: Jeanne Hardebeck
CTM: Wayne Thatcher
CVM: Andreas Plesch

SCEC Software Team
Mei-Hui Su
Phil Maechling
Edric Pauk
Tran Huynh

TECHNICAL SUPPORT

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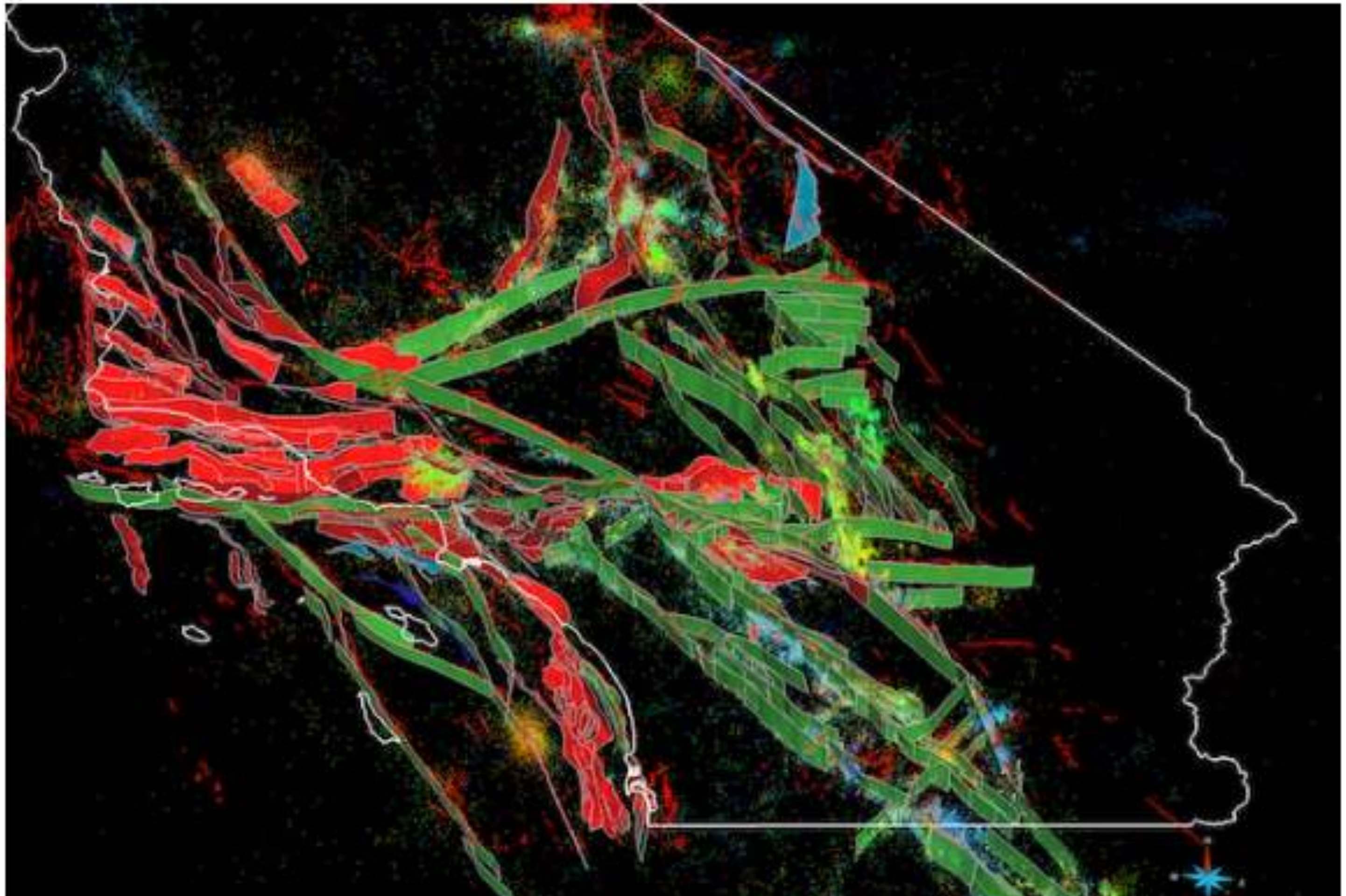
The SCEC Community Fault Model (CFM)



CFM WORKING GROUP

CXM Representative
Scott Marshall

CFM Developers
Andreas Plesch
Craig Nicholson
John Shaw

SCEC Software Team
Mei-Hui Su
Phil Maechling

DOWNLOADS

Current Model

CFM5.2 (2017)

Previous Models

CFM4 (2014)
CFM3 (2006)

SOFTWARE SUPPORT

Contact Us

Community Fault Model

Data files containing 3D geometry of active California faults, as well as a searchable hierarchical database, 3D viewer files, traces and tiplines, metadata and instructions

Based on surface traces, seismicity, seismic reflection profiles, well logs and geologic cross sections; developed in SKUA-GOCAD

Historically hosted at Harvard and maintained by John Shaw and Andreas Plesch. New SCEC-hosted website: www.scec.org/research/cfm

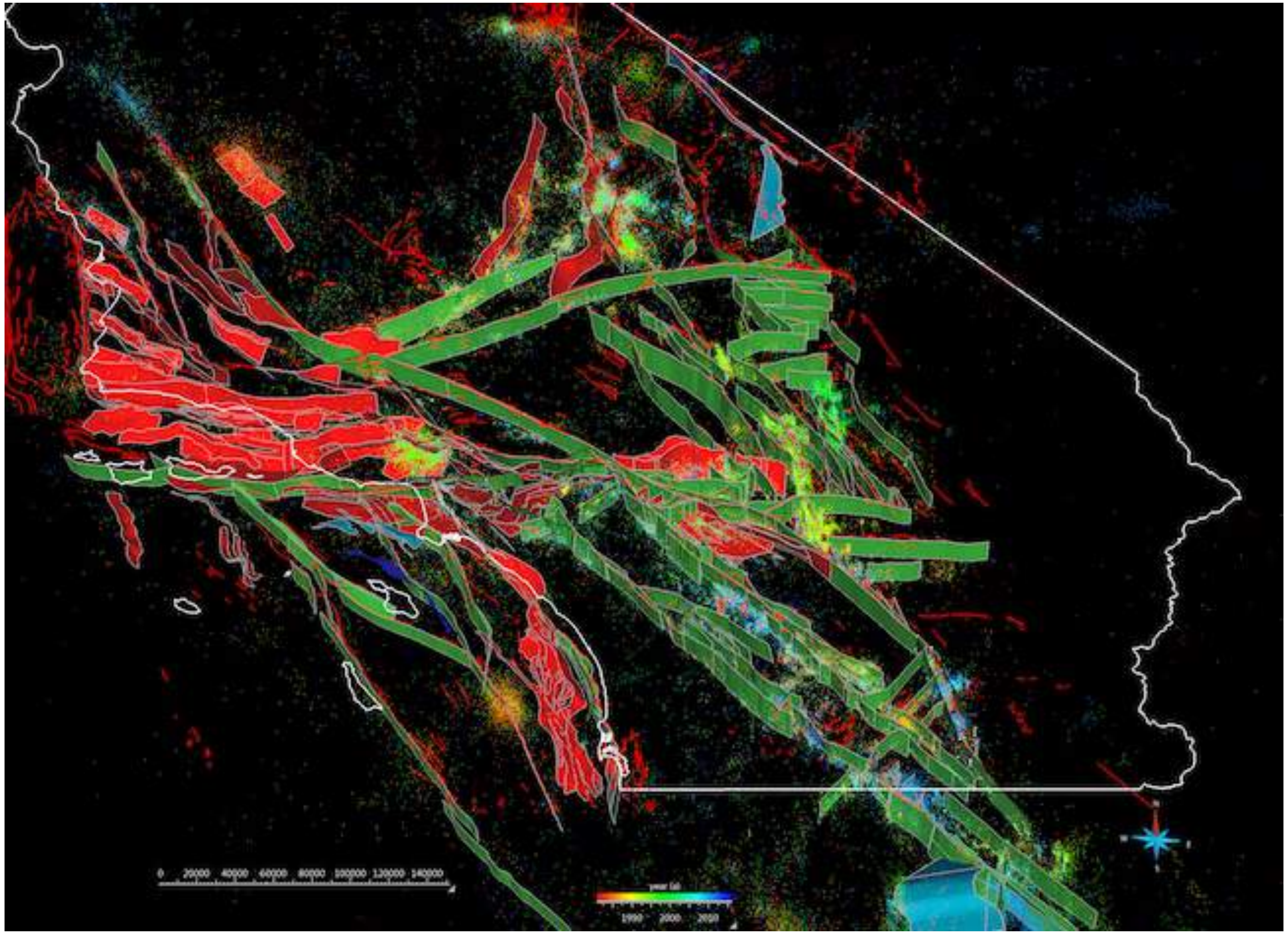
Versions now available for download: CFM3 (2006), CFM4 (2014) and CFM5.2 (2017)

Formats include GOCAD tsurf triangulated surfaces, mve files for use with MoVE viewing software,

- Preferred fault model: tsurfs, traces in 6 formats, mve files for 3D display
- Additional alternative fault representations: tsurfs

Main use *so far*: rupture propagation and boundary element deformation models.

Community Fault Model



New for Version 5.2

- added faults (105 systems, 820 objects)
- for *each* object: tsurf, mve, trace, metadata
- alternative representations
- improved, expanded database
- ~uniformly gridded surfaces, 500 m and 100 m spacing

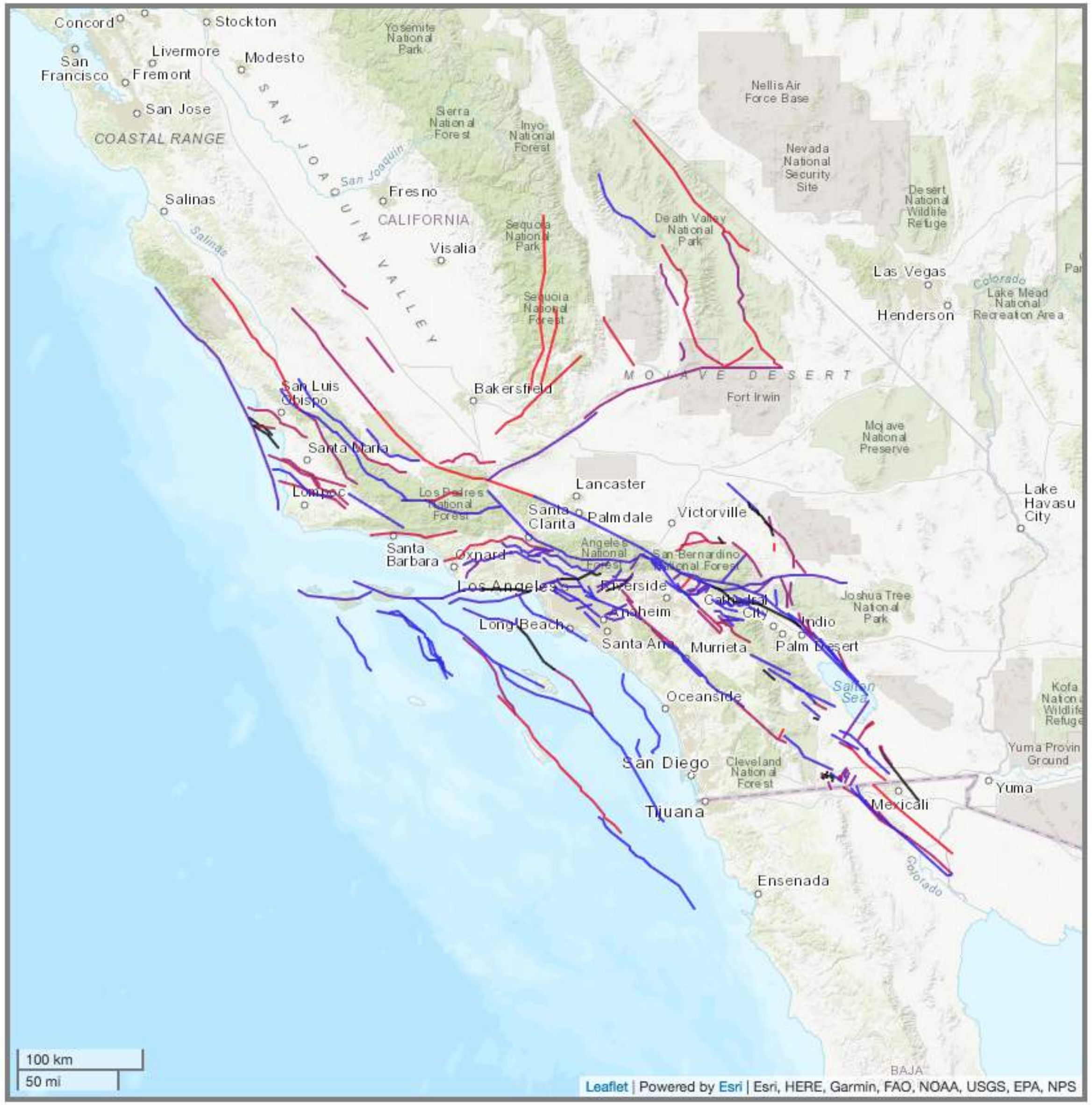
In Progress

- peer evaluation (2019)
- web-based visualization and query tools (now)

System | Region | Section | Name | Keyword | Latlon | Strike | Dip

CFM5.2 Fault Objects

✔	👁	WTRA-USAV-WLNC-Walnut_Creek_fault-CFM5
✔	👁	WTRA-USAV-UPLD-Upland_fault-dipslip-CFM1
✔	👁	WTRA-USAV-SNJH-San_Jose_fault-CFM5
✔	👁	WTRA-USAV-INDH-Indian_Hill_fault-CFM5
✔	👁	WTRA-SSRZ-OXNP-Bailey_fault-steep-CFM5
✔	👁	WTRA-SSRZ-MULT-Simi-Santa_Rosa_fault-listric-CFM5
✔	👁	WTRA-SSFZ-MULT-Santa_Susana_fault-CFM1
✔	👁	WTRA-SMFZ-SMDE-Sierra_Madre_fault-low-dip-CFM4
✔	👁	WTRA-SMFZ-MULT-Sierra_Madre_fault-west-CFM4
✔	👁	WTRA-SMFZ-CSPC-Clamshell_Sawpit_Canyon_fault-CFM4
✔	👁	WTRA-SGFZ-PLMS-Northern_San_Gabriel_fault-CFM4
✔	👁	WTRA-SGFZ-MULT-Southern_San_Gabriel_fault-CFM4
✔	👁	WTRA-SFNS-VRDM-Verdugo_fault-steep-CFM5
✔	👁	WTRA-SFNS-VRDM-Eagle_Rock_fault-steep-CFM5
✔	👁	WTRA-SFNS-SFNV-San_Fernando_fault-CFM4
✔	👁	WTRA-SFFS-SMMT-Malibu_Coast_fault-east-steep-alt2-CFM5
✔	👁	WTRA-SFFS-SGVS-Raymond_fault-extended-CFM5
✔	👁	WTRA-SFFS-LABS-North_Salt_Lake_blind_fault-CFM3



CFM querying tools under development by SCEC IT   http://asperity.scec.org/CFM/web/cfm_view.html

Community Velocity Model

Seismic velocities (Vp and Vs), and rock density, for 3D grids covering southern California lithosphere.

Two versions. Historically, CVM-H hosted by Harvard and CVM-S hosted by SCEC.

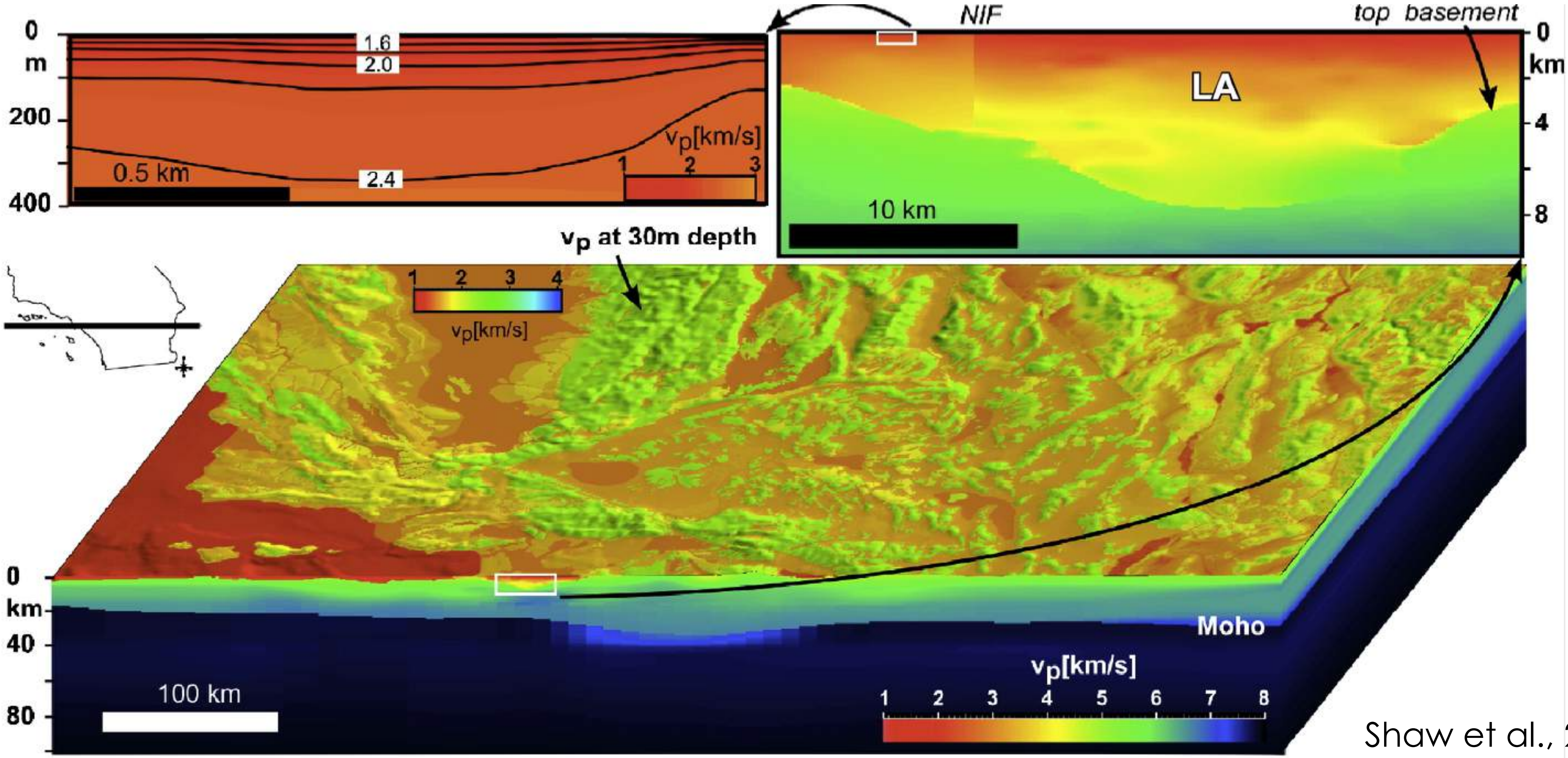
CVM-H (15.1.0, released in 2015) includes basin structures embedded in a 3D waveform inversion model (Tape et al., 2009), an explicit representation of the Moho, and an optional Vs30-derived 'geotechnical layer' for the top 350m. It is integrated with the CFM to form the "SCEC USR".

CVM-S (4.26, 2014) is based on fully 3D seismic tomography (Lee et al., 2014). Apparently "works better" with Cybershake, does not have sedimentary basins yet.

Access: Open-source SCEC software (UCVM, via GitHub). Typically, modelers contact Phil Maechling at SCEC to populate their model grids. CVM-H linked to SCEC CXM website.

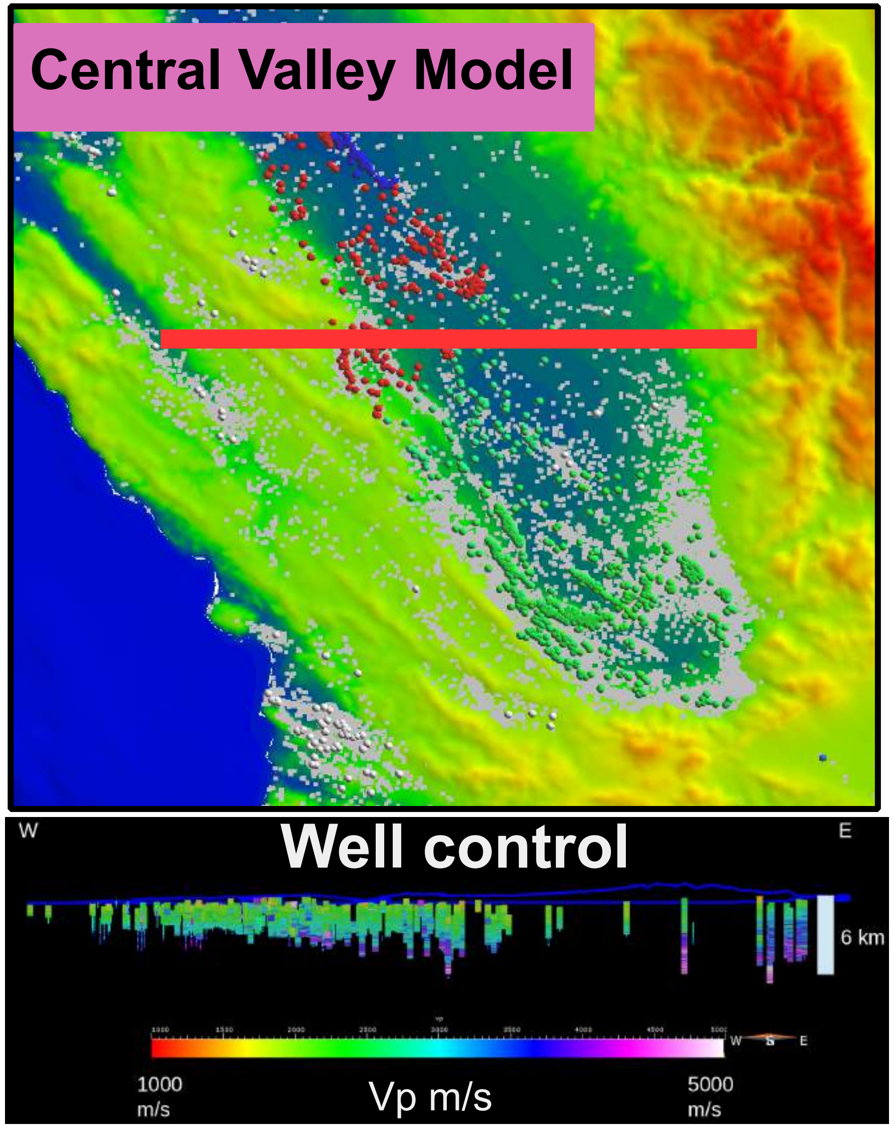
Main use *so far*: strong motion simulations (e.g. Cybershake).

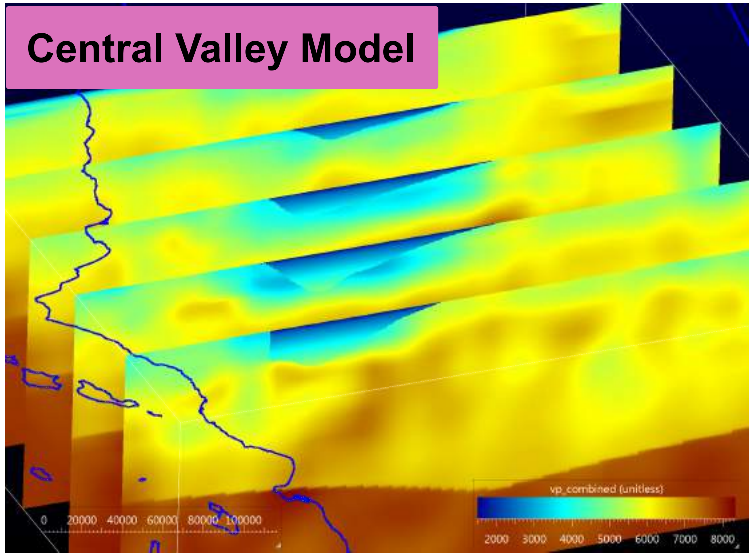
CVM-H 15.1

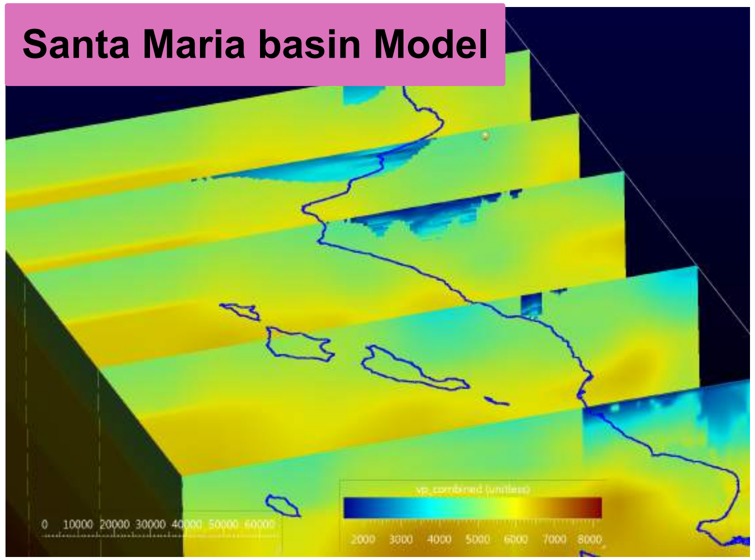


Shaw et al., 2015

Community Velocity Model CVM-H: Improved Basin Representation







New basin models

- Extensive new well log datasets
- Incorporate latest CFM 5.2 faults (USR)
- Embedded in Central California velocity model, 6th iteration (Chen et al., 2015)
- Next up: put these in CVM-H

Plesch and Shaw (2018)

Community Geodetic Model

GPS horizontal velocity field; gridded 2D surface velocities and strain rates (10 contributed versions, avg, mean and standard deviation); InSAR LOS displacement rates.

Format is ASCII text. Data and PDF figures showing the velocities and strains (contributed and averaged) can be viewed and downloaded from Scripps-hosted website https://topex.ucsd.edu/CGM/CGM_html/

Intermediate-maturity SCEC community model, started with SCEC4, v. 1.0 in 2018.

Users: deformation modelers, modelers inverting geodetic data for fault slip rates

Community Geodetic Model

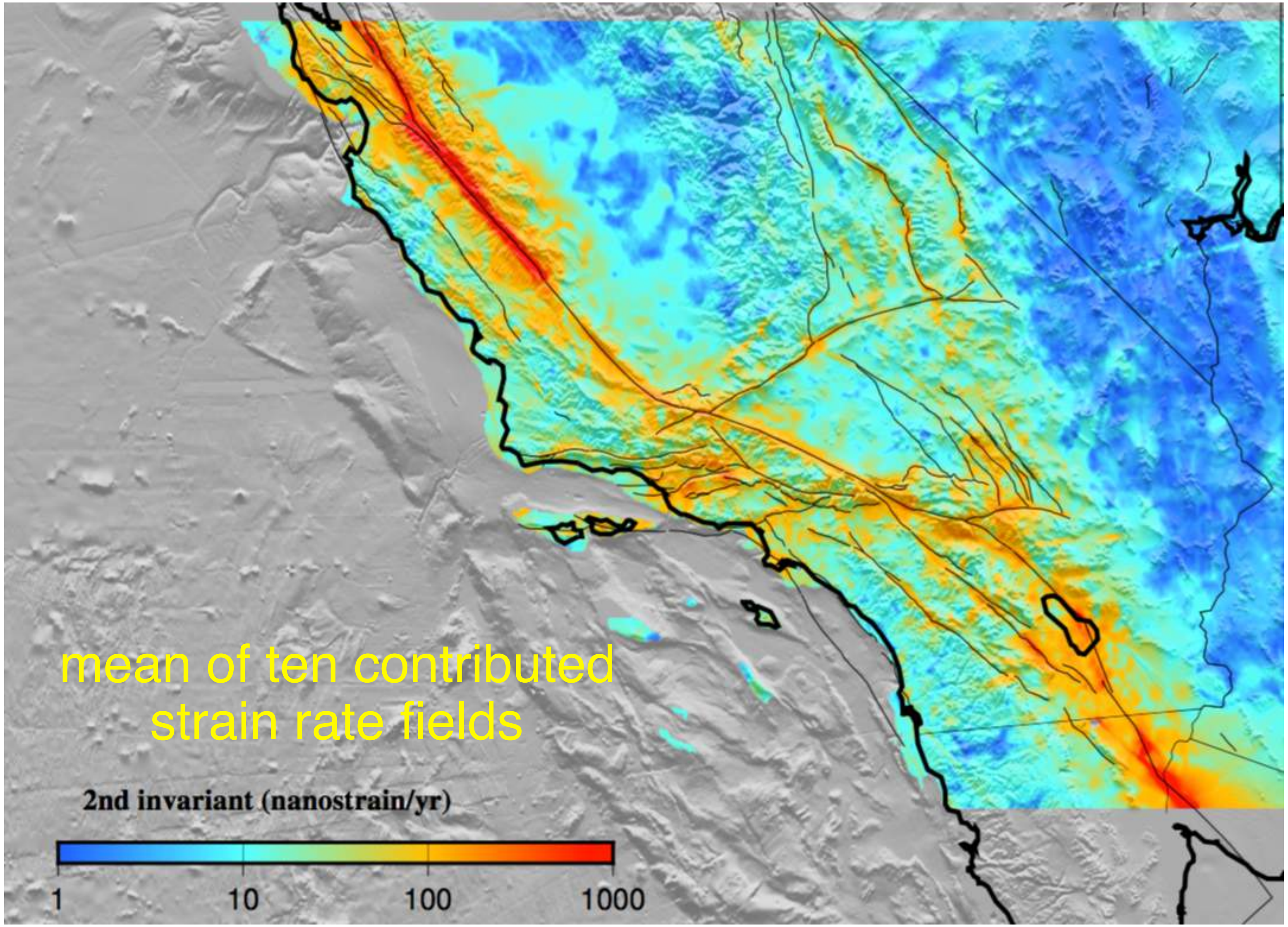


image from CGM website

Future Plans (as of Sept 2018)

Combination of GPS and InSAR time series

- InSAR scientists would like vector GPS time series with all tectonic and hydrological signals included but equipment signals removed.
- The groups will explore several integration methods to minimize tropospheric artifacts in the InSAR time series.

Cyberinfrastructure issues for the CGM

- web page needs to be updated, converted to SCEC format, moved to SCEC server
- add time series products to existing velocity and strain products

Community Stress Model

Intermediate-maturity SCEC community model, started with SCEC4.

Stress and stressing rate tensor components and derived quantities (e.g. SHMax alpha_phi) from seismicity inversions and models. ASCII format, gridded.

Website had data for download, tools to compare contributed stress and stressing rate models, figures, metadata, and more

Website currently being resurrected by Edric Pauk, Jeanne Hardebeck and others

Users: deformation modelers, CRM group (CRM, CSM and CGM are linked)

Next slides: *Website, Interrupted*

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Community Stress Model

Crustal stress is a fundamental quantity that is relevant to many aspects of the earthquake problem. SCEC has committed to the development of the Community Stress Model (CSM) to provide better constraints on the stress field, and a means to formally test physical connections between observations and stress models. The intended CSM end-products are a small suite of models for the 4D stress and stressing-rate tensor in the California lithosphere. There is a range of potential uses for the CSM, including seismic hazard estimates, crustal seismicity studies, dynamic earthquake rupture models and earthquake simulators. This web page presents and compares CSM submissions and candidate release models.

The SCEC CSM is a community effort informally steered by representatives from different user groups, including B. Aagaard (USGS), T.W. Becker (USC), J. Hardebeck (USGS), D. Sandwell (UCSD), B. Shaw (LDEO), and J. Shaw (Harvard). For questions about this web page, please contact twb@usc.edu.

If you're interested in participating in the CSM, you can request to be added to our e-mail list.

Project Menu

Community Stress Model

Navigation

- About
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  - Formats
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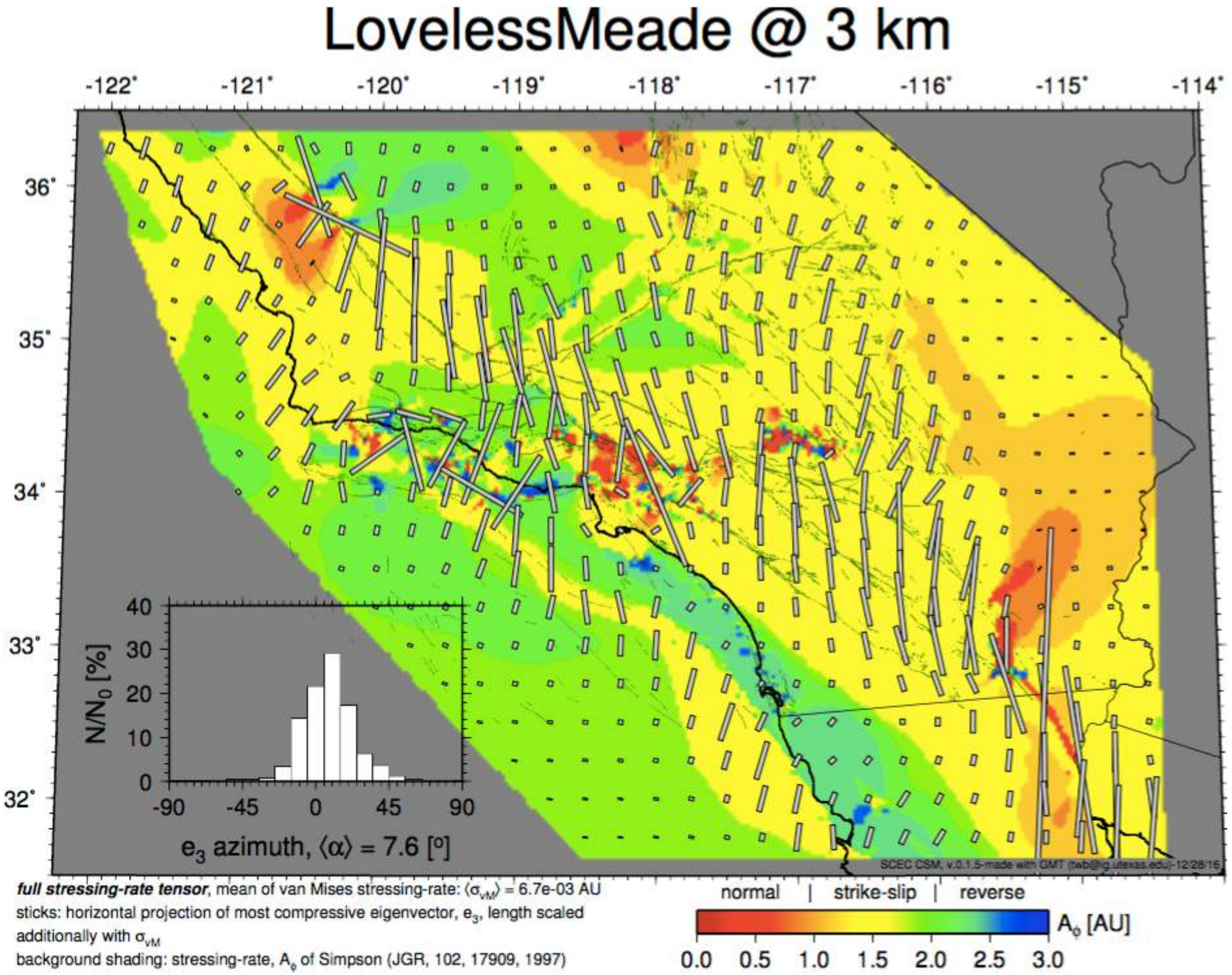
- Current candidate CSM releases
- Model Comparisons
  - Stress
  - Stressing Rate
- Background material
  - 2014 Workshop Summary and presentations
  - 2013 Workshop Summary and presentations
  - 2012 Workshop Summary and

http://stress2.scec.org/projects/CSM (still private)



Current Contributors and Model Downloads link

I chose Loveless and Meade stressing rate model

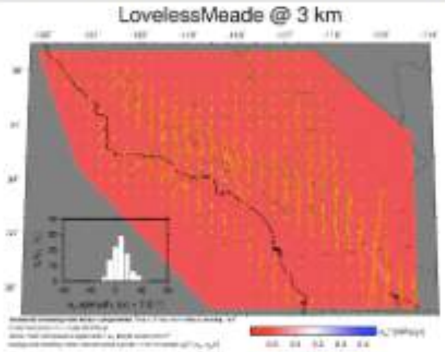
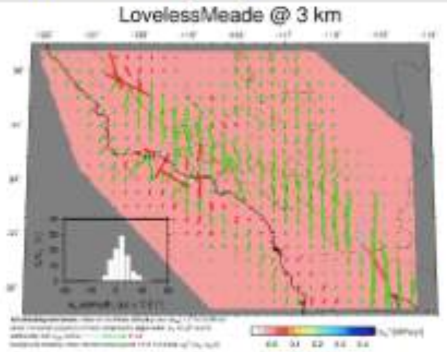
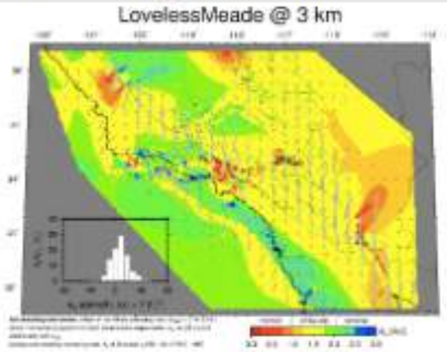
All have download links and PDF's

Model Description

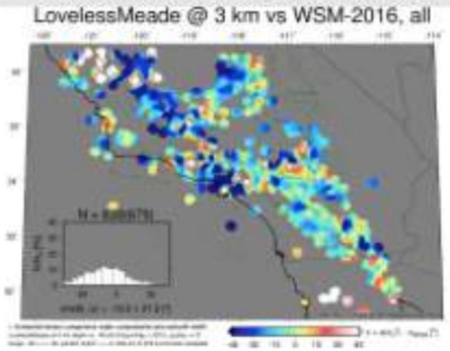
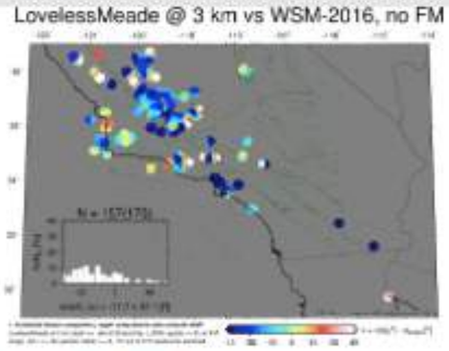
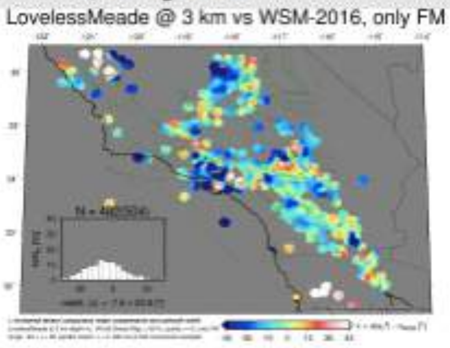
Select another model | go

LovelessMeade

Model properties

Horizontal stress tensor only	Horizontal projection	Stress Regime Ratio
		
PDF Format	PDF Format	PDF Format

Model validation

WSM all	WSM, no FM	WSM, only FM
		
PDF Format	PDF Format	PDF Format

Model meta data (if public)

Various parameters displayed, also comparisons with world stress map

We’ve got yer metadata right here

Model meta data information sheet

Name of model:	Harvard Crustal Dynamics Group stress rate model
Preferred acronym:	HCD
Type of model (stress, stressing-rate, other (specify)):	Stressing rate
Short description of methodology:	We calculate interseismic stress rate tensor components analytically using algorithms (Okada, 1992; Meade, 2007) giving strain due to slip on dislocations embedded in a homogeneous elastic half-space (mu = lambda = 3e10 Pa/m^2). Slip rates were calculated using a geodetically constrained elastic block model detailed in Loveless and Meade (2011). The fault geometry used in the block model is based on the SCEC CFM-R and the constraining GPS velocity field is compiled from several publications (McClusky et al., 2001; Shen et al., 2003; Hammond and Thatcher, 2005; McCaffrey, 2005; Williams et al., 2006; Plate Boundary Observatory network velocity field, 2008). The spatial resolution of the stress rate model is technically infinite, as the stress rate due to slip on all dislocations can be calculated analytically anywhere. The GPS velocity fields used to constrain interseismic deformation in the block model span 1993--2008, though some fields were "cleaned" to reduce postseismic signals.
Contact:	Jack Loveless
Contact email:	jloveles@smith.edu
Date of model completion:	9/26/2012
Version number:	1
Description of changes from previous version (if applicable)	
Reference:	Loveless, J.P. and B.J. Meade (2011), Stress modulation on the San Andreas fault due to interseismic fault system interactions, Geology, 39(11), 1035.1038, doi:10.1130/G32215.1.
Link to PDF of reference:	LovelessAndMeadeSocalStress.pdf
Type of data used (provide	GPS

(continued)

Type of data used (provide reference to datasets, if possible):	GPS
Spatial resolution [km]:	2
Polygon of areal coverage (provide lon-lat pairs [deg]):	-122.0783, 31.618 to -114.4187, 36.3491
Depth range:	1-100 km
OK to make model available to SCEC researchers:	Yes
OK to make model available to public:	Yes
Other references:	Hammond, W. C., and W. Thatcher (2005), Northwest Basin and Range tectonic deformation observed with the Global Positioning System, 1999.2003, Journal of Geophysical Research, 110, B10405, doi:10.1029/2005JB003678.
	McCaffrey, R. (2005), Block kinematics of the Pacific-North America plate boundary in the southwestern United States from inversion of GPS, seismological, and geologic data, Journal of Geophysical Research, 110(B7), B07401, doi:10.1029/2004JB003307.
	McClusky, S. C., S. C. Bjornstad, B. H. Hager, R. W. King, B. J. Meade, M. M. Miller, F. C. Monastero, and B. J. Souter (2001), Present day kinematics of the Eastern California Shear Zone from a geodetically constrained block model, Geophysical Research Letters, 28(17), 3369.3372.
	Loveless, J.P. and B.J. Meade (2011), Stress modulation on the San Andreas fault due to interseismic fault system interactions, Geology, 39(11), 1035.1038, doi:10.1130/G32215.1.
	Meade, B. J. (2007), Algorithms for the calculation of exact displacements, strains, and stresses for triangular dislocation elements in a uniform elastic half space, Computers and Geosciences, 33, 1064.1075, doi:10.1016/j.cageo.2006.12.003.
	Okada, Y. (1992), Internal deformation due to shear and tensile faults in a half-space, Bulletin of the Seismological Society of America, 82(2), 1018.1040.
	Plate Boundary Observatory network velocity field (2008), http://pboweb.unavco.org/.
	Shen, Z., D. Agnew, R. King, D. Dong, T. Herring, M. Wang, H.

"Current Candidate CSM Releases" link

Community Stress Model

Stress models (*)

A: focal mechanism inversion based: YHSM-2013

B: interpolation of stress indicator based: N/A

stressing-rate models (*)

A: Kostrov summation of co-seismic strain-release based: N/A

B: interpolation of geodetic velocity based strain-rates: N/A

C: geodesy plus fault structure based: N/A

(*) Notes:

- The state of stress and how to infer it are research questions. As such these models should not be considered as definitive answers to the problems but as useful steps along the way toward a better understanding of lithospheric deformation.
- Not all components of the stress tensor may be meaningful. For example, focal mechanism inversions do not constrain the absolute magnitude of stress, nor the isotropic component.
- There is some disagreement as to the interpretation of observables as to being indicative of stress, stressing-rate, or strain-rate, and sometimes models convert from one (e.g. strain-rate from GPS velocities) to the other (stressing-rate) simply by multiplying with a material parameter.

Hmmm. Just one annointed model

Community Thermal Model

Temperatures from the surface to 100 km depth, at 1-km depth intervals

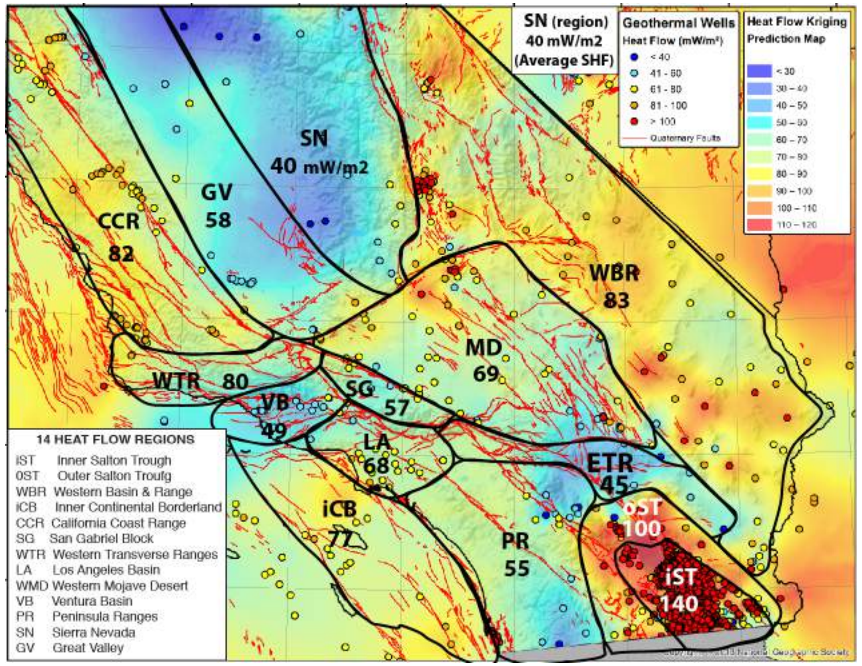
Geotherms are constrained by the surface heat flow, bounds on upper crustal radiogenic heat production, seismically estimated lithosphere asthenosphere boundary (LAB) depth, the dry and saturated asthenosphere solidi, and lava and xenolith P/T constraints

Version 1 will have geotherms for each of 13 heat flow regions (HFR's), HFR boundaries, and metadata (avg LAB depth, avg sfc heat flow for each HFR, avg properties (A and k vs depth) for each HFR, other guidance and description)

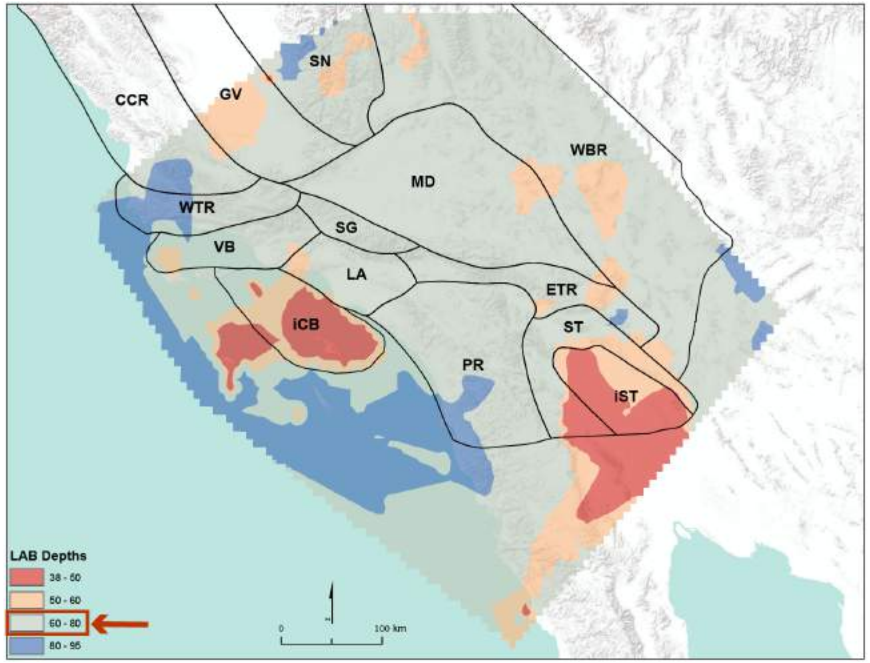
Steady-state conductive heat flow calculations are insufficient, non-steady heat flow modeling underway (next slide).

Anticipated Main Users: deformation modelers, CRM group

Wide Range in Surface Heat Flow



Shallow LAB Depth (70 km) Almost Everywhere



IMPLIES

- Cannot fit most of SoCal with steady-state 1D thermal conduction models
- Transient thermal processes required (e.g. slab-free asthenosphere window, slab rollback or detachment, lithospheric thinning)
- Contrary to expectations from surface heat flow, warm lower crust and upper mantle under most of SoCal

Community Rheology Model

(1) 3D geological map ("geologic framework") with specified lithologies, for host rock and shear zone material and **(2)** Flow laws (rheologies) for each rock type

Metadata, guidance, tools for computing effective viscosity and/or stress profiles (e.g. guidance and links to RHEOL, L. Montesi code)

Format: Undecided. Best guess below.
First: Depth intervals and rock types for each GF province, and flow laws, simple geographic query tool for GF.
Later: integrate flow laws and CTM directly into RHEOL. Use UCVM to query 3D GF lithology. Explore integration with other modeling frameworks.

GF workshop planned for April, CRM workshop planned for May. Draft CRM by September 2019 SCEC meeting.

Ductile rheology. Future versions will include brittle/plastic rheology, more realistic 3D geologic framework, and more detailed shear zone representation.

Anticipated main users: deformation modelers, CSM group

Geologic Framework

rocks!

rocks!

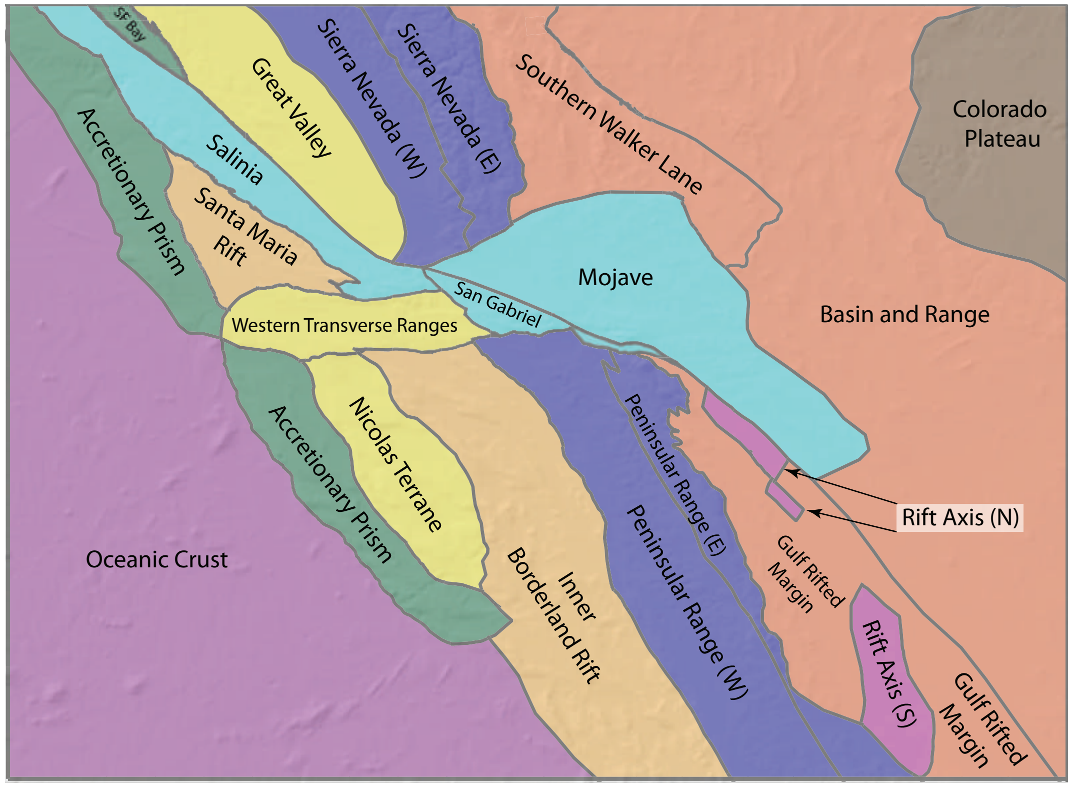
rocks!

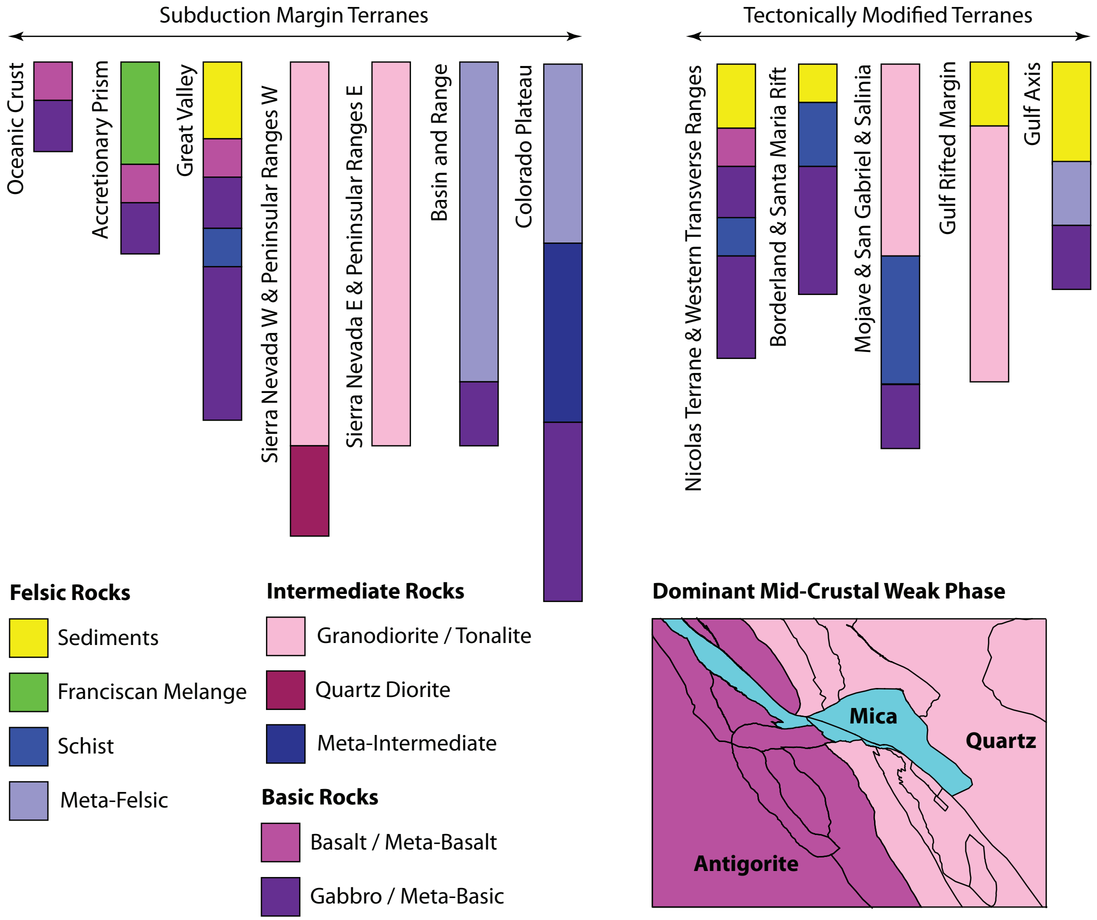
Preliminary Geologic Framework

12 distinct lithotectonic provinces with similar history and composition

Province boundaries are registered to SCEC USR features, have lat lon and shape files

1D lithological profiles are defined for all provinces





Images from Mike Oskin

Preliminary CRM Rheologies

Whole rock rheology for rocks from the exhumed southern Sierra Nevada crustal section

- modal mineralogy from point count data
- use mixing laws (e.g. Huet et al.) to estimate whole rock rheologies
- applicable to some other GF provinces

Most rocks: expert consensus on suitable flow laws to best represent lithologies.

$$\dot{\epsilon} = A\sigma^n e^{\frac{PV-Q}{RT}} f_{H_2O}{}^r$$

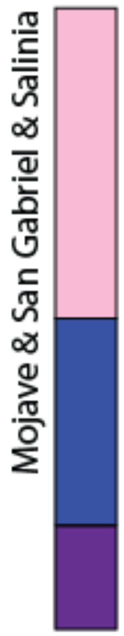
$$\eta_e = \frac{\sigma}{\dot{\epsilon}}$$

- T from Community Thermal Model
- P from density*g*depth
- assume stress or strain rate
- other parameters from flow laws

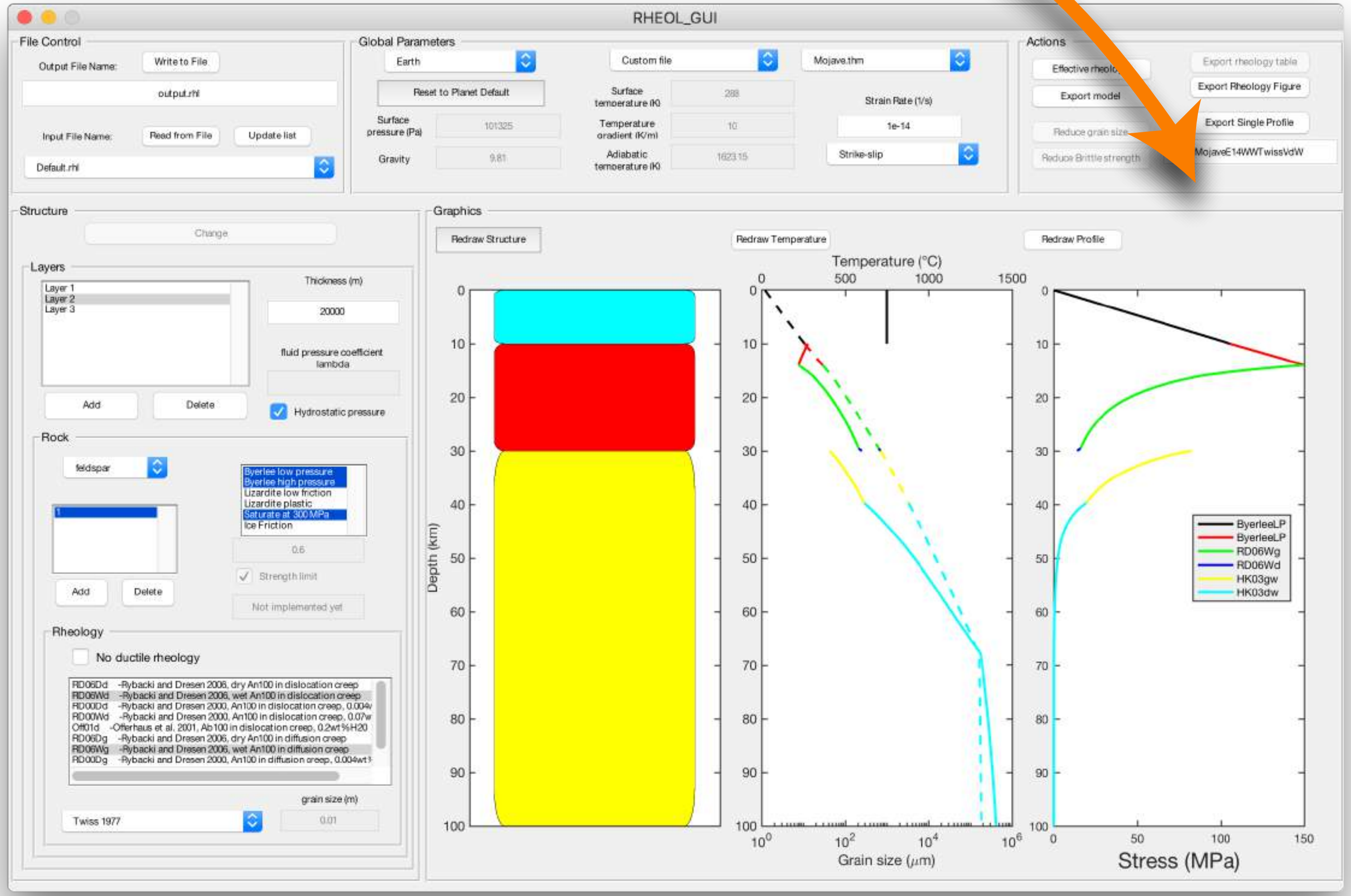
Alternative: infer modal mineralogy from CVM data

Shear zone rheology: dislocation creep of the weakest phase

Flow Law + **CTM temperatures**



“granodiorite/
tonalite”



RHEOL (Laurent Montesi)

Flow Law + CTM temperatures

“granodiorite/ tonalite”

CXM Areas of Concern / Potential Growth

- Making the community models easier to use
- Are the community models consistent with each other?
- Versioning
- Uncertainties and heterogeneity, alternate representations