

SCEC Community Stress Model (CSM) Workshop Report

Conveners: Jeanne Hardebeck, Thorsten Becker, Karen Luttrell, Patricia Persaud, and Joann Stock

Dates: January 15-16, 2019

Location: Kellogg West Conference Center, Pomona, California

SCEC Award: [18132](#)

Website: <https://www.scec.org/workshops/2019/csm>

Overview

At this workshop, we planned a coordinated research approach to further the development of the SCEC Community Stress Model (CSM). The CSM has made considerable progress in compiling stress orientation models and stressing rate models for the upper crust in the past, and we discussed how to build on these efforts going forward. We focused on five research themes that are key for future progress: (1) physics-based models of stress in the lithosphere, (2) borehole stress indicators, (3) absolute stress, (4) stress heterogeneity, and (5) user needs, model validation, and uncertainty. Workshop participants discussed the current status of research on each theme, and identified what is needed to make progress with respect to the CSM. A small number of invited talks on each theme were followed by group discussions to identify needs and opportunities.

Session 1: Physics-Based Models of Stress in the Lithosphere

We heard from workshop participants about Neogene stress evolution of the Pacific-North America plate boundary, methods of constraining depth integrated crustal strength, and investigations on the role of local fault geometry and fault interactions in regulating on-fault stress state. In general, building these types of models continues to be an area of active research, and groups are gradually developing products that could be contributed to the CSM. Participants expressed keen interest in the compilation of data/observations of stress state, and in working closely with the developing CTM and CRM efforts. Several participants highlighted depth dependence as a priority need, both in observations/data and in modeling results that can be interpreted and incorporated by users. Because some of the models for stressing rate depend on assumptions about fault slip rates, this effort needs to be updated in tandem with the latest slip rate results from the CFM.

Session 2: Borehole Stress Indicators

Workshop participants summarized different ways of using borehole data to constrain stress orientations and magnitudes, and how stress directions are estimated from geological indicators in the field and core from slip vector data. Participants discussed how geological indicators, when merged with constraints available for timing history can provide orientation changes over time. Available borehole datasets and ongoing research in southern California were presented. Participants showed that the spatial scale of stress variation is not uniform. Stress orientations are relatively uniform in the Alberta basin, Canada, but variable in southern California near active faults. Participants discussed how to integrate variability in stress directions and regime into models and several participants noted that averaging separate results together may not be meaningful. Rather, the users need two scales of information; i.e., different quantities are useful at different spatial scales to satisfy different data needs. Time dependence of the observations will be important to consider in future studies.

Session 3: Absolute Stress

Workshop participants discussed that the three stress magnitude models submitted to the CSM in 2012 disagree on stress magnitudes and also the magnitude of variations, and a newer model developed in 2017 assumes topography is not the dominant source of stress and provides a minimum in situ magnitude estimate. Participants noted that borehole breakouts sometimes agree with focal mechanism results, but sometimes they do not and whether this is related to length, depth or temporal scales. Participants discussed a potential relationship between absolute stress and b-values and whether b-value variations are a measure of absolute stress, and that pre-stress conditions for loading and history of previous slip events may influence long-term behavior of seismicity.

Session 4: Stress Heterogeneity

We discussed that the initial stress (pre-stress) in dynamic rupture models is one of three essential ingredients and is probably the least well constrained, and mechanical analyses show that heterogeneous stress fields exist in regions with fault complexities. Participants questioned how to determine the initial stress and explored stress heterogeneity from local and global borehole stress indicators, noting variability in stress orientations at length scales that are smaller than those observed in a regional-scale focal mechanism study. Participants also heard about variations in stress orientations with depth and laterally abrupt changes in stress ratios based on local focal mechanism inversions.

Session 5: User Needs, Model Validation, and Uncertainty

We discussed the fact that stress is affected by aseismic creep at depths below the frictional faults, and therefore the stress is expected to change during the interseismic cycle. Models of dynamic rupture need to take into account the geometric complexity and absolute values of the initial stress field which means they need as many observations as possible. Dynamic rupture modeling can help to test whether certain stress observations are consistent with certain rupture observations, but this requires a database of real stress orientations for real faults, and ideally information on how stress in the region might have changed due to previous earthquakes. Models need to constrain differences between on-fault and off-fault characteristics. We learned that models incorporating frictional and/or viscous shear heating along fault zones yield a suite of possible values for the depth to the brittle-ductile transition, with different implications for repeat times of major earthquakes and the lower depth limit of seismicity. The predicted values of stress based on these models can be compared to stress observations, and earthquake history, with the potential for better constraints on the rheology of the crust in Southern California (i.e. by making sure that the CSM and the CRM are internally consistent). The model results also depend on the geothermal gradient and the pore pressure, so we need more constraints on geographic variations in these parameters.

Session 6: Recommendations and Next Steps

During the meeting, we solicited feedback from workshop participants via a webform with 4 questions:

- What information and/or products would help advance your group's research? (Your Wish List)
- What information and/or products could your research group provide to advance the CSM effort? (Your Have List: just brainstorming, no obligation implied)
- What should be considered and/or included in the Minimum Viable Product for the CSM by the end of SCEC5? (i.e., what should/could be accomplished in the next 2.5 years for CSM?)
- What future avenues of research and development should the SCEC community pursue? (Thinking beyond SCEC5 and Pie-in-the-sky goals)

Individual responses were discussed and synthesized during Session 6, and resulted in the following recommendations/action items for the remainder of SCEC5:

- The CSM website must be restored to functionality and made available to the SCEC community, so that existing model and data contributions are accessible and can be easily queried by interested researchers.
- Contributions of data and models to the CSM should be citable for formal acknowledgement by users. SCEC staff are considering avenues for making resources citable in cases where contributions are not accompanied by a specific peer-reviewed journal article.
- Existing datasets pertaining to stress and stressing rate orientation and magnitude should be collected into a catalog and made available via the CSM website. Sources of data may include borehole observations, b-value analysis, geologic striations, observations of seismic anisotropy, localized and/or depth dependent analysis of earthquake focal mechanisms. We recommend the SCEC RFP continue to invite the creation, compilation, and submission of such datasets.
- As modelers continue their research, encourage them to contribute new models/update existing models as they become available. These may be full 3D tensor estimates of stress or stressing rate, or they may be constraints on stress state, such as total vertically-integrated strength. We recommend the SCEC RFP continue to invite the creation, synthesis, and submission of such model results.
- Workshop participants recognized the potential value in a stressing rate model derived from and consistent with the SCEC Community Geodetic Model products. Participants also recognized the effort involved in creating such a model. Soliciting researchers to create versions of this product should be explicitly added to future SCEC RFPs.

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SUMMARY: At this workshop, we will plan a coordinated research approach to further the development of the SCEC Community Stress Model (CSM). The CSM has made considerable progress in compiling stress orientation models and stressing rate models for the upper crust, and we will plan how to build on these efforts going forward. We will focus on five research themes that are key for future progress: (1) physics-based models of stress in the lithosphere, (2) borehole stress indicators, (3) absolute stress, (4) stress heterogeneity, and (5) user needs, model validation, and uncertainty. Workshop participants will discuss the current status of research on each theme, and identify what is needed to make progress with respect to the CSM. A small number of invited talks on each theme will be followed by group discussions to identify needs and opportunities.

JANUARY 15, 2019		
07:30 – 08:30	Breakfast in Dining Hall	
09:00 - 09:30	Workshop Check-In	
09:30 - 10:00	Welcome and Overview of Workshop Objectives	<i>Conveners</i>
10:00 – 12:00	Session 1: Physics-based Models of Stress in the Lithosphere <i>Moderator Patricia Persaud and Reporter Karen Luttrell</i>	
10:00 – 10:20	Dynamics of the Plate Boundary Zone in Western North America: Oligocene to the present	<i>Bill Holt</i>
10:20 – 10:40	Impact of lithospheric strength distribution on India-Eurasia deformation from 2-D and 3-D geodynamic models	<i>Lucy Flesch</i>
10:40 – 11:00	Considering fault interaction in estimates of stress in the San Geronio Pass region, southern California	<i>Jenn Hatch</i>
11:00 - 11:20	Break	
11:20 – 12:00	Discussion: needs and opportunities	<i>All</i>
12:00 - 13:00	Lunch	
13:00 - 14:40	Session 2: Borehole Stress Indicators <i>Moderator Karen Luttrell and Reporter Joann Stock</i>	
13:00 – 13:20	Techniques for Stress Field Constraints from Boreholes	<i>Joann Stock</i>
13:20 – 13:40	Implications of Borehole-Derived Stress Constraints for Fault Slip and Stress Heterogeneity beneath the Santa Barbara Channel	<i>Patricia Persaud</i>
13:40 – 14:00	Stress estimates from geologic indicators; examples (and limitations) from Southern California examples	<i>Jim Evans</i>
14:00 – 14:40	Discussion: needs and opportunities	<i>All</i>
14:40 – 15:00	Break	
15:00 – 16:40	Session 3: Absolute Stress <i>Moderator Joann Stock and Reporter Patricia Persaud</i>	
15:00 – 15:20	Using local topography to constrain absolute stress	<i>Karen Luttrell</i>
15:20 – 15:40	What allows seismic events to grow big? Insights from b-value and stress variations during laboratory experiments and tectonic earthquake sequences	<i>Thomas Goebel</i>
15:40 – 16:00	Modeling the low-heat, low-stress operation of mature faults	<i>Valere Lambert</i>
16:00 – 16:40	Discussion: needs and opportunities	<i>All</i>

16:40 – 17:00	Wrap-up for the day	
18:30 – 20:30	Dinner in Dining Hall	
JANUARY 16, 2019		
07:30 – 08:30	Breakfast in Dining Hall	
09:30 - 10:00	Update on larger CXM effort	<i>Liz Hearn</i>
10:00 – 12:00	Session 4: Stress Heterogeneity <i>Moderator Joann Stock and Reporter Patricia Persaud</i>	
10:00 – 10:20	Quantifying the heterogeneity of the stress field derived from local and global borehole data	<i>Martin Schoenball</i>
10:20 – 10:40	Stress Patterns in the San Jacinto Fault Zone and South Central Transverse Ranges	<i>Niloufar Abolfathian</i>
10:40 – 11:00	Stress heterogeneity and dynamic rupture along geometrically complex faults	<i>Benchun Duan</i>
11:00 - 11:20	Break	
11:20 – 12:00	Discussion: needs and opportunities	<i>All</i>
12:00 - 13:00	Lunch	
13:00 - 14:40	Session 5: User Needs, Model Validation, and Uncertainty <i>Moderator Karen Luttrell and Reporter Joann Stock</i>	
13:00 – 13:20	Stress setup for dynamic rupture modeling: Effects and needs/wants	<i>Julian Lozos</i>
13:20 – 13:40	Predictions of the brittle-ductile transition and lithospheric stress from viscoelastic earthquake cycle simulations	<i>Kali Allison</i>
14:00 – 14:40	Discussion: needs and opportunities	<i>All</i>
14:40 – 15:00	Break	
15:00 – 16:30	Session 6: Next Steps <i>Moderator Patricia Persaud and Reporter Karen Luttrell</i>	
15:00 – 16:30	Discussion: CSM Research Plan	<i>All</i>
16:30	Workshop Adjourns	

ATTENDEES

Niloufar Abolfathian (USC)

*Kali Allison (U Maryland)

*Alireza Bahadori (SUNY Stony Brook)

*Thorsten Becker (UT Austin)

Peter Bird (UCLA)

*Michele Cooke (UMass)

*Benchun Duan (Texas A&M)

Jim Evans (Utah State)

*Lucy Flesch (Purdue)

*Thomas Goebel (UC Santa Cruz)

*Jenn Hatch (UMass)

Liz Hearn (Capstone)

Bill Holt (SUNY Stony Brook)

Tran Huynh (USC)

Valere Lambert (Caltech)

Zefeng Li (Caltech)

*Dunyu Liu (Texas A&M)

Julian Lozos (Northridge)

Jens-Erik Lund Snee (Stanford)

Karen Luttrell (LSU)

*Edric Pauk (USC)

Patricia Persaud (LSU)

Daisuke Sato (DPRI, Kyoto)

Martin Schoenball (LBNL)

Joann Stock (Caltech)

*Ylona Van Dinther (ETH Zurich)