The SCEC Community Stress Model (CSM) Project

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Community Stress Model (CSM):

• New project starting in SCEC4.

• Long-term goal: a model or set of models of stress and stressing rate in the southern California lithosphere.

• The CSM will probably not be a single model, but a (hopefully small) set of models.

• Any branches in the CSM will be based on clearly-defined differences in data or assumptions.
Who are the users of the CSM and what do they need?

**External users:** Rupture dynamics, geodynamics, seismic hazard, stress triggering, others?

**Needs:** You tell us! (Invite representatives of external user communities to all workshops.)

**Provide:** One or more reference stress and stressing rate models, accessible through an interface developed jointly with the user communities.

**Internal users:** Researchers working on problems directly related to stress.

**Needs:** Access to existing data and models, easier ways to integrate and compare models and observations.

**Provide:** A modeling environment with tools that will enable researchers to develop and test candidate models against suites of data and/or quantitatively compare their models with other models.
Progress:

• First workshop, September 2011, at SCEC Annual Meeting. Large wide-ranging group discussion.

• Second workshop, October 2012: compiled and compared existing stress and stressing rate models from the SCEC community.
  • All models in common format on pre-defined 3D grid.
  • Most models were submitted as full 6-component stress or stressing rate tensors.

• Third workshop planned for May 29-30 2013: focus on reconciling stressing rate models, and validating models with data.
Contributed Models:

Stress:

1) Inversion of focal mechanisms for stress orientation. – *Wenzheng Yang and Egill Hauksson (Caltech)*.

2) Finite element model including topography, depth-dependent rheology, frictional faults, and long-term deformation model. – *Peter Bird (UCLA)*.

3) Inversion for stress field that fits topography, fault loading from dislocation model, tectonic loading, and focal mechanisms. – *Karen Luttrell (USGS), Bridget Smith-Konter (Texas), and David Sandwell (UC San Diego)*.

4) Global model from density-driven mantle flow, plus lithosphere gravitational potential energy, fit to geoid and global plate motions. – *Attreyee Ghosh and Thorsten Becker (USC)*.
Average Stress Model: average normalized deviatoric stress tensor.

* Average of Bird; Luttrell, Smith-Konter & Sandwell; and Yang & Hauksson models, everywhere at least two of these models are defined.
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\[
\phi = \frac{\sigma_2 - \sigma_3}{\sigma_1 - \sigma_3}
\]

\[A\phi = \phi \quad 0-1: \text{normal faulting (}\sigma_1 \text{ most vertical})\]

\[A\phi = 2 - \phi \quad 1-2: \text{strike-slip faulting (}\sigma_2 \text{ most vertical})\]

\[A\phi = 2 + \phi \quad 2-3: \text{reverse faulting (}\sigma_3 \text{ most vertical})\]
Average Stress Model: average normalized deviatoric stress tensor.

\[ \phi = \frac{\sigma_2 - \sigma_3}{\sigma_1 - \sigma_3} \]

\[ A_{\phi_i} = \phi \]

- 0-1: normal faulting (\( \sigma_1 \) most vertical)
- 1-2: strike-slip faulting (\( \sigma_2 \) most vertical)
- 2-3: reverse faulting (\( \sigma_3 \) most vertical)
Stress Models: differential stress ($\sigma_1 - \sigma_3$) versus depth.

Solid line/symbol: median. Dashed line: middle 68%.
Contributed Models:

Stressing Rate:

1) Block model fit to geodetic data. – *Jack Loveless (Smith) and Brendan Meade (Harvard).*

2) Fault loading from dislocation model using geologic and geodetic slip rates. – *Bridget Smith-Konter (Texas), and David Sandwell (UC San Diego).*

3) Fault loading from dislocation model plus static stress changes from earthquakes. – *Anne Strader and David Jackson (UCLA).*

4) Local boundary element model fit to slip rates. – *Michele Cooke (UMass) and Scott Marshall (Appalachain State).*
Average Stress Rate Model: average differential stressing rate: $\delta(\sigma_1-\sigma_3)/\delta t$. 

diff stressing rate (kPa/yr); depth=5 km

diff stressing rate RMS (fraction); depth=5 km
Average Stress Rate Model: average differential stressing rate: $\delta(\sigma_1-\sigma_3) / \delta t$. 

diff stressing rate (kPa/yr); depth=17 km

diff stressing rate RMS (fraction); depth=17 km
Average Stress Rate Model: average normalized deviatoric stress tensor – orientation only.

SHmax trend (degrees); depth=5 km

SHmax RMS (degrees); depth=5 km
Average Stress Rate Model: average normalized deviatoric stress tensor – orientation only.
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\[ \phi = \frac{\sigma_2 - \sigma_3}{\sigma_1 - \sigma_3} \]

\[ \Delta \phi = \phi \]

\[ \Delta \phi = 2 - \phi \]

\[ \Delta \phi = 2 + \phi \]

\[ \phi = 0 - 1 : \text{normal faulting (}\sigma_1\text{ most vertical}) \]
\[ \phi = 1 - 2 : \text{strike-slip faulting (}\sigma_2\text{ most vertical}) \]
\[ \phi = 2 - 3 : \text{reverse faulting (}\sigma_3\text{ most vertical}) \]
Average Stress Rate Model: average normalized deviatoric stress tensor – orientation only.

\[ \phi = \left( \sigma_2 - \sigma_3 \right) / \left( \sigma_1 - \sigma_3 \right) \]

- \( \phi \approx 0 - 1 \): normal faulting (\( \sigma_1 \) most vertical)
- \( \phi \approx 2 - \): strike-slip faulting (\( \sigma_2 \) most vertical)
- \( \phi \approx 2 + \phi \): reverse faulting (\( \sigma_3 \) most vertical)
How can the CSM benefit from a better understanding of ductile rheology?

- Physics-based stress and stressing rate models rely on assumptions about rheology.

- Stress and stressing rate models are generally in good agreement in the upper crust where elastic and brittle deformation dominate.

- Models become more different near the base of the seismogenic zone. Much of this disagreement is due to differences in assumed fault locking depth – better understanding of the brittle-ductile transition could reduce this source of uncertainty.

- Very poor agreement of models below seismogenic depths. Therefore, the depths where we are in most need better constraints are the depths where ductile rheology is important.

- If you have a physics-based model of stress and/or stressing rate in the lithosphere, please consider contributing it to the CSM project.