Overview of the SCEC Community Stress Model

Brad Aagaard and Jeanne Hardebeck

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From the SCEC4 proposal

Six Fundamental Problems in Earthquake Physics:

- Stress transfer from plate motion to crustal faults: long-term fault slip rates
- Stress-mediated fault interactions and earthquake clustering: evaluation of mechanisms
  - Development of a Community Stress Model (CSM) for southern California, based on merging information from borehole measurements, focal mechanisms, paleo-slip indicators, observations of damage, topographic loading, geodynamic and earthquake cycle modeling, and induced seismicity.

Community Stress Model Users

Internal and external users with different needs

- **External users:** Rupture dynamics, geodynamics, seismic hazard, stress triggering, others?
  - **Use:** One or more reference stress and stressing rate models accessible through an interface developed jointly with the user communities
  - **Needs:** Tell CSM organizers (Jeanne Hardebeck, Brad Aagaard, Thorsten Becker, Bruce Shaw, and John Shaw)
- **Internal users:** Researchers working on problems directly related to stress.
  - **Use:** 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.
  - **Needs:** Access to existing data and models, easier ways to integrate and compare models and observations.

CSM Workshop # 1: Sep 2011

See workshop report for details

- 1/2 day workshop following SCEC annual meeting
- Presentation from potential contributors and users
- Much wide-ranging discussion
- 1st step: compile all existing relevant data and models and put them in common formats
- Hold smaller workshop in 2012 focused on comparing existing stress models

CSM Workshop # 2: Oct 2012

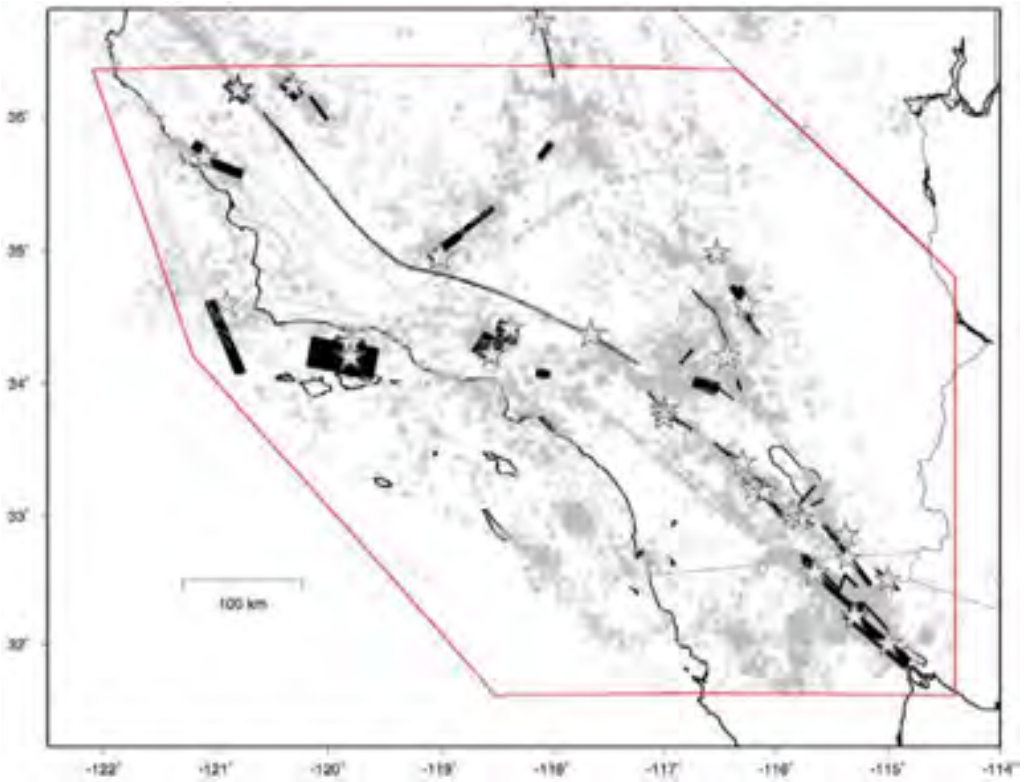
See workshop report for details

- 8+ stress or stressing rate models
  - Peter Bird (interpolated WSM and thin shell models)
  - Michele Cooke and Scott Marshall (BEM model)
  - Attreyee Ghosh and Thorsten Becker (shear wave splitting)
  - Jeanne Hardebeck (WSM and focal mechanisms)
  - Karen Luttrell, Bridget Konter, and David Sandwell (3-D dislocation model)
  - Brendan Meade and Jack Loveless (block model)
  - Ann Strader and Dave Jackson (static Coulomb stress model)
  - Wenzheng Yang and Egill Hauksson (focal mechanisms)
- Day 1: Discussion and comparison of models
- Day 2: Discussion of how to move forward

Model Format

Standardize format for stress and stressing rate models

- All models sampled on common grid (oversample models)
- Resolution: 2km for $<$25km depth; 5km for $>$25km depth
- Modelers responsible for interpolating their models



Model Format

Desire tensor representation of stress field

- Stress or stressing rate
- Representation options
  - Stress tensor
  - SHmax direction, SHmax, Shmin, SV
- Comments
  - Almost all models are represented as tensors, but not all have meaningful isotropic and/or deviatoric stress amplitudes
  - Almost no submitted models include uncertainty

Stress Model Format

Simple ASCII text files on a variable resolution grid

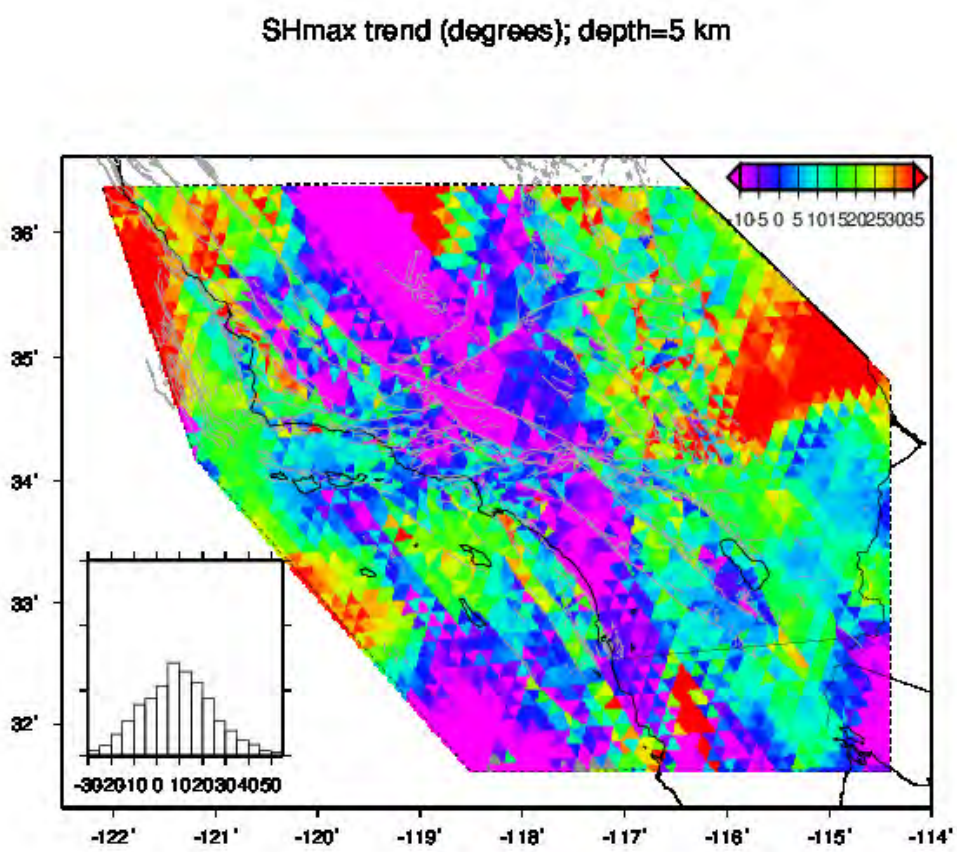
- Values at a grid of points
  - Prescribed set of points intended to oversample models
  - Lon/Lat in WGS84, depth in km
  - Stress in MPa (MPa/yr for rate), positive is tension
  - Undefined values set to NaN
- Metadata as comments
  author, contact info, date, description, resolution, etc

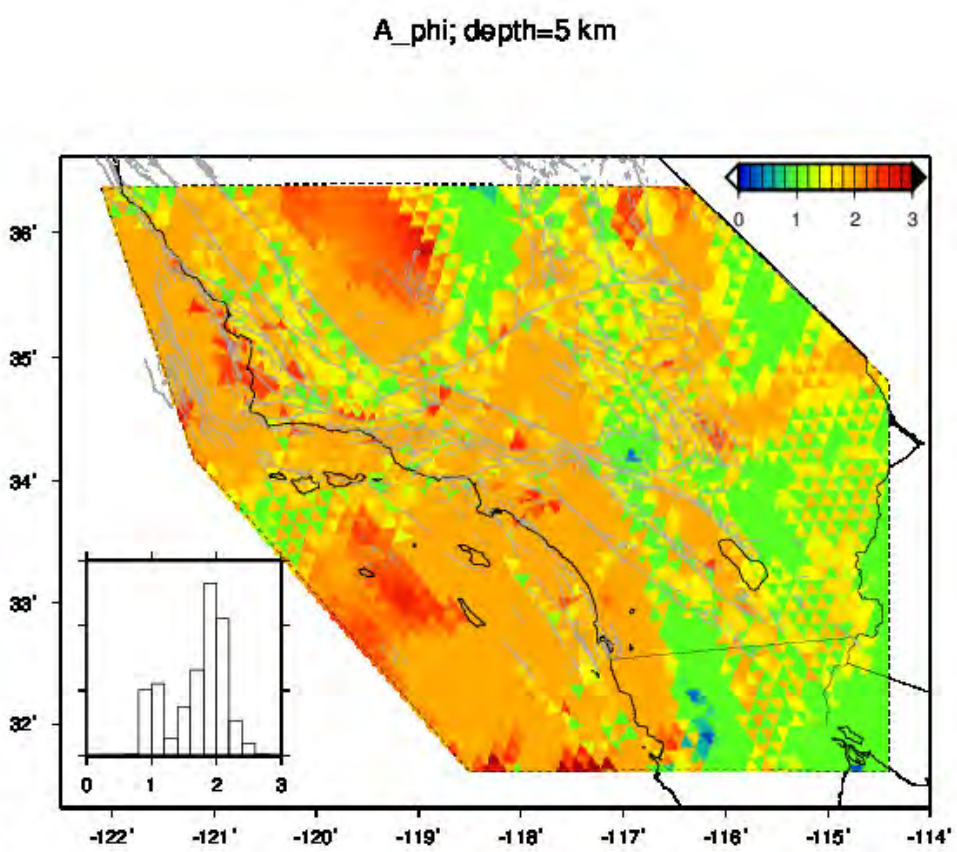
```
# metadata in free format header
LON LAT DEP 1 SHmax_trend SHmax_mag SHmin_mag SV_mag  See Sen Seu Snn Snu Suu RATIO DEV  ISO
LON LAT DEP 2 1-sigma 1-sigma 1-sigma 1-sigma DOT dot-1sig ANG s1-1sig s2-1sig s3-1sig 1sig 1sig 1sig
```

Comparison of SHmax trend and Aphi

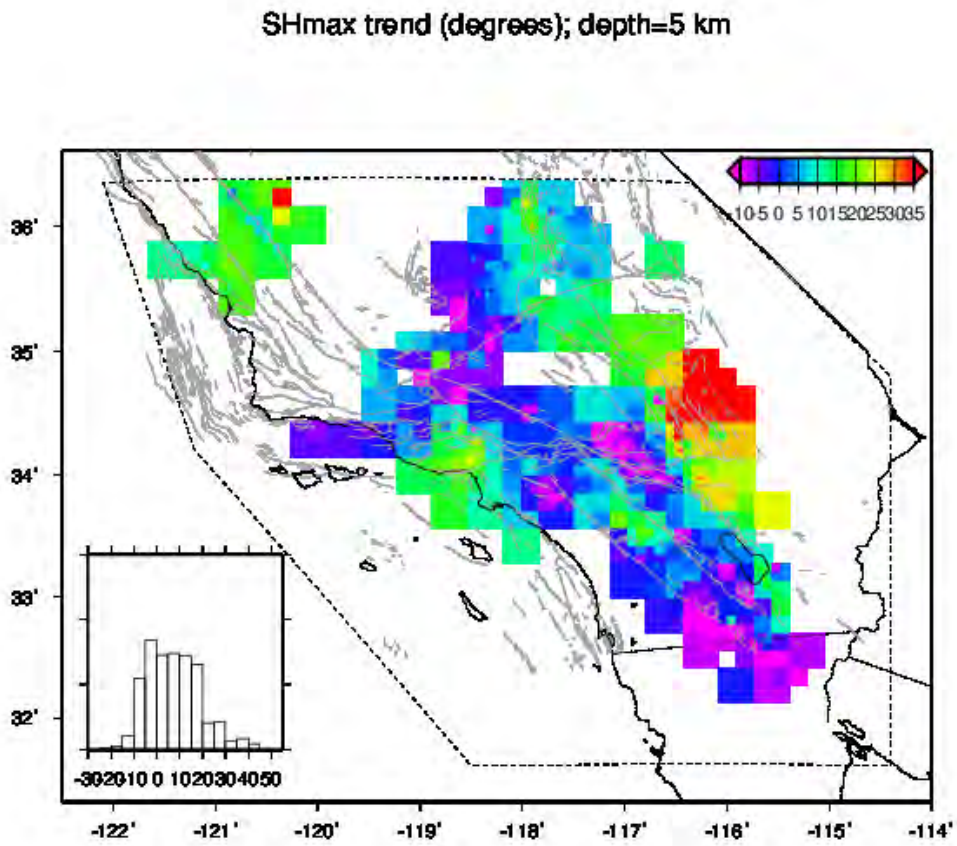
- PRELIMINARY Models from workshop #2
- Horizontal slice at 5km depth
- SHmax trend: orientation of maximum horizontal compressive stress direction
- Aphi, phi = $\frac{\sigma_2 - \sigma_3}{\sigma_1 - \sigma_3}$
  - Aphi = phi (0–1: normal faulting)
  - Aphi = 2-phi (1–2: strike-slip faulting)
  - Aphi = 2+phi (2–3: reverse faulting)

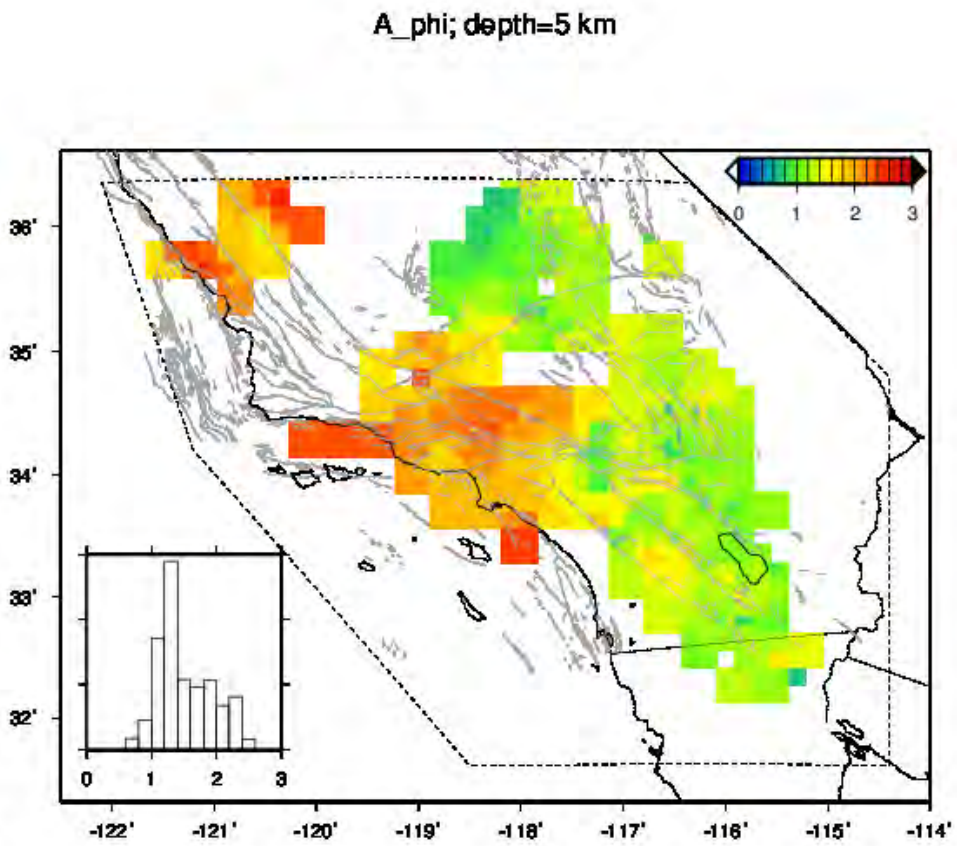
Stress: Bird SHELLS



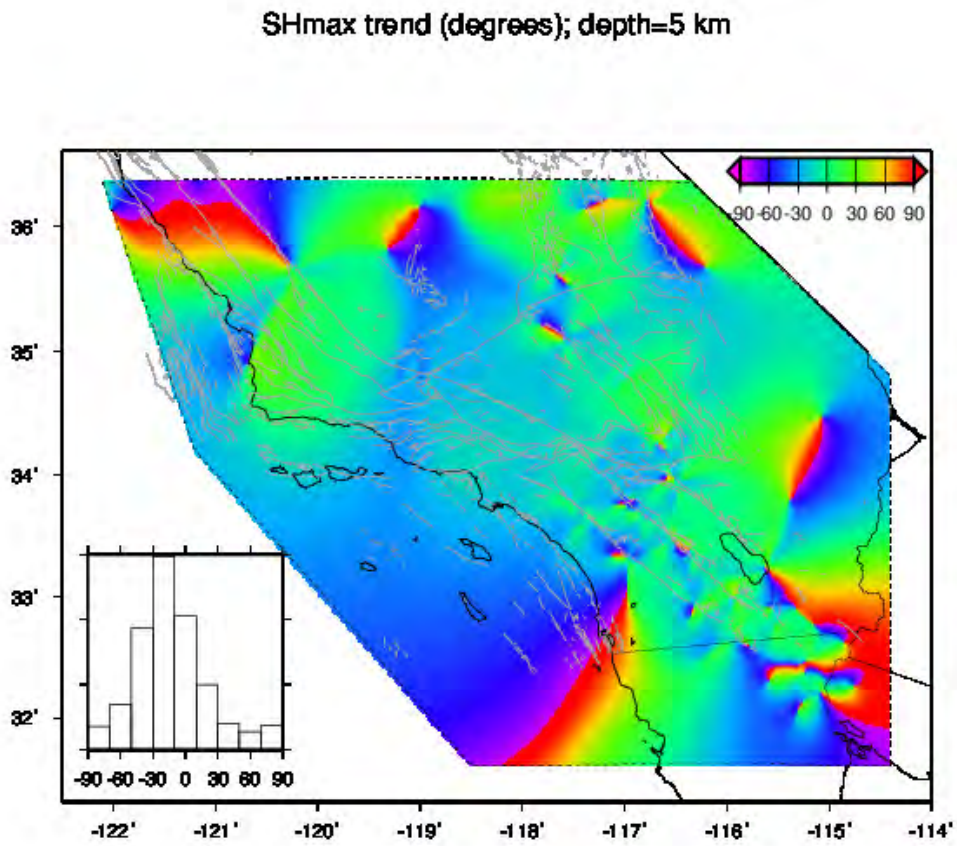


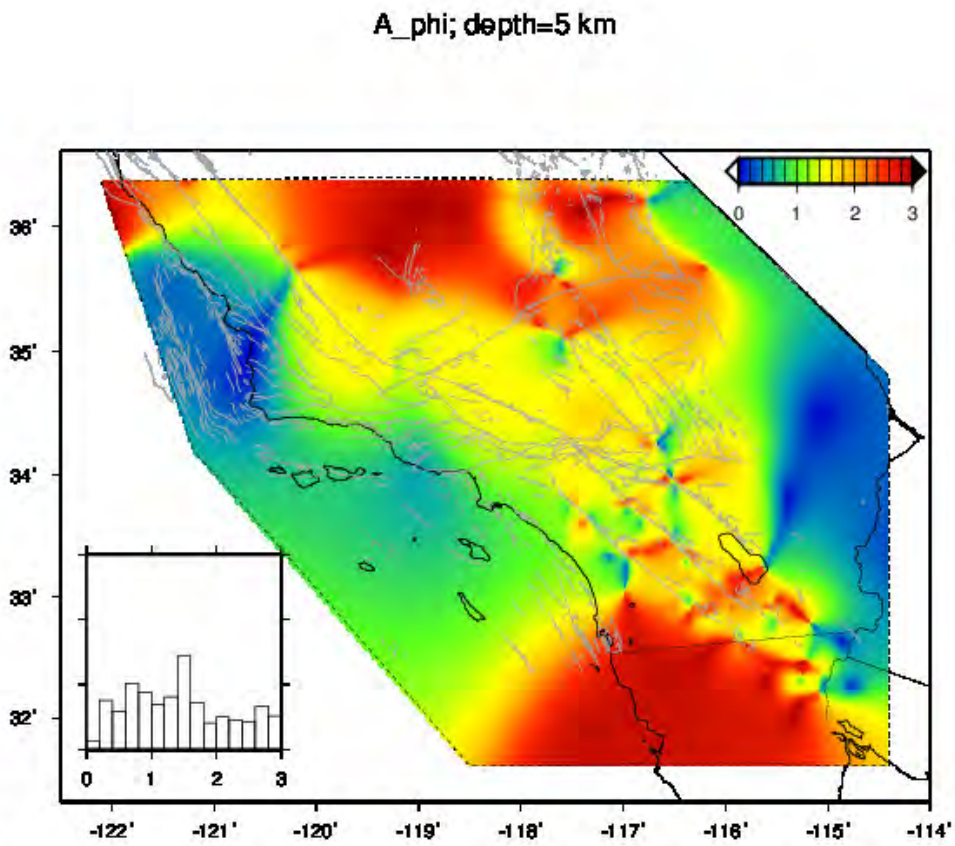
Stress: Hardebeck Focal Mechanisms





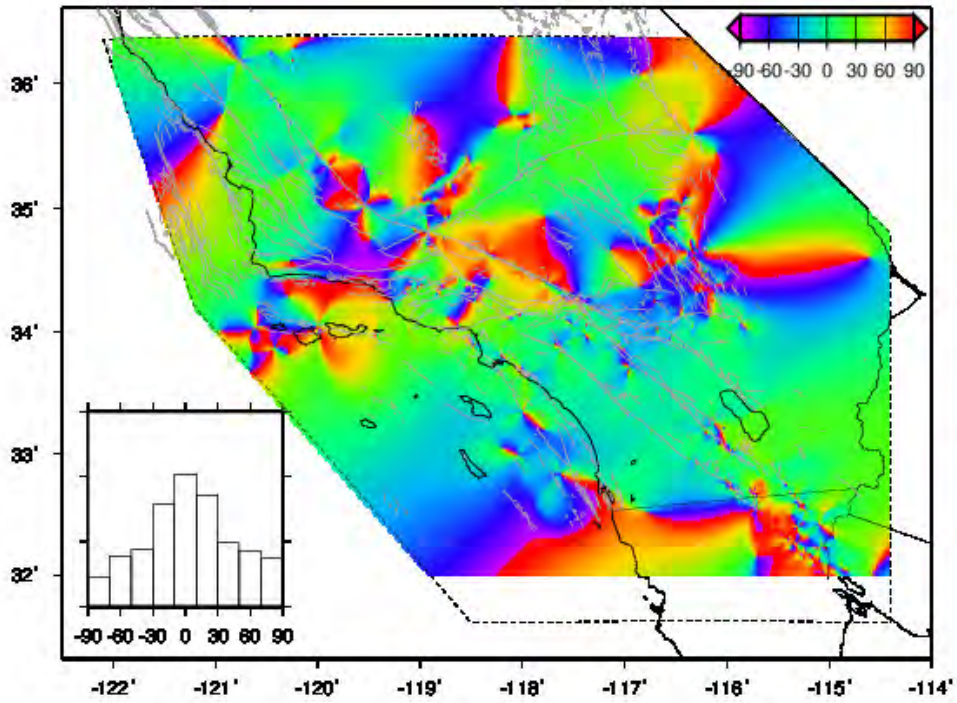
Stress: Smith-Konter & Sandwell



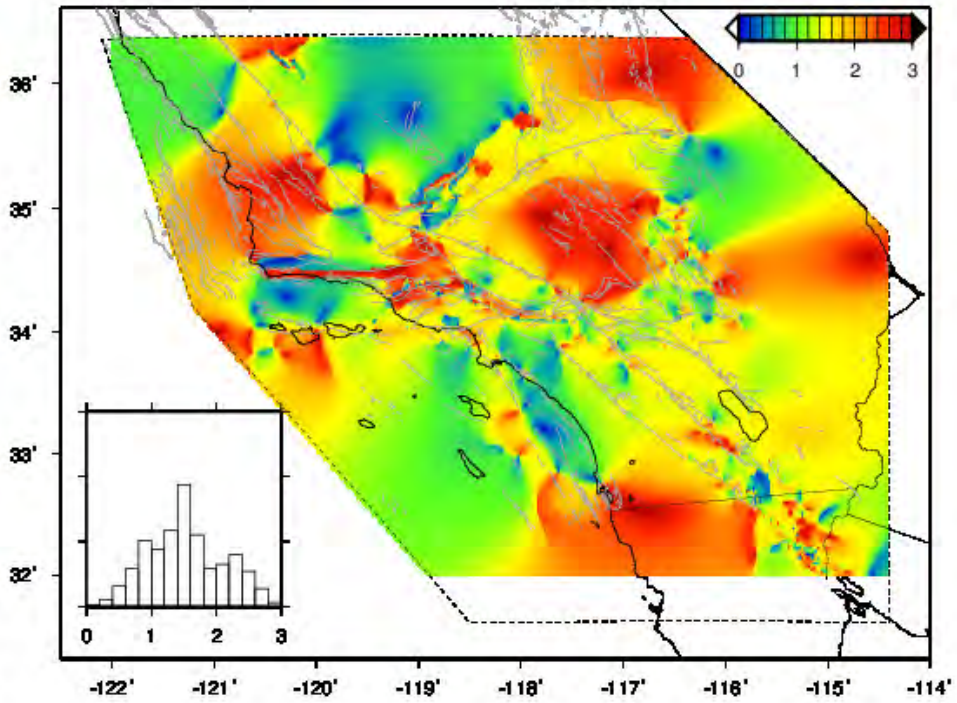


Stress: Strader & Jackson

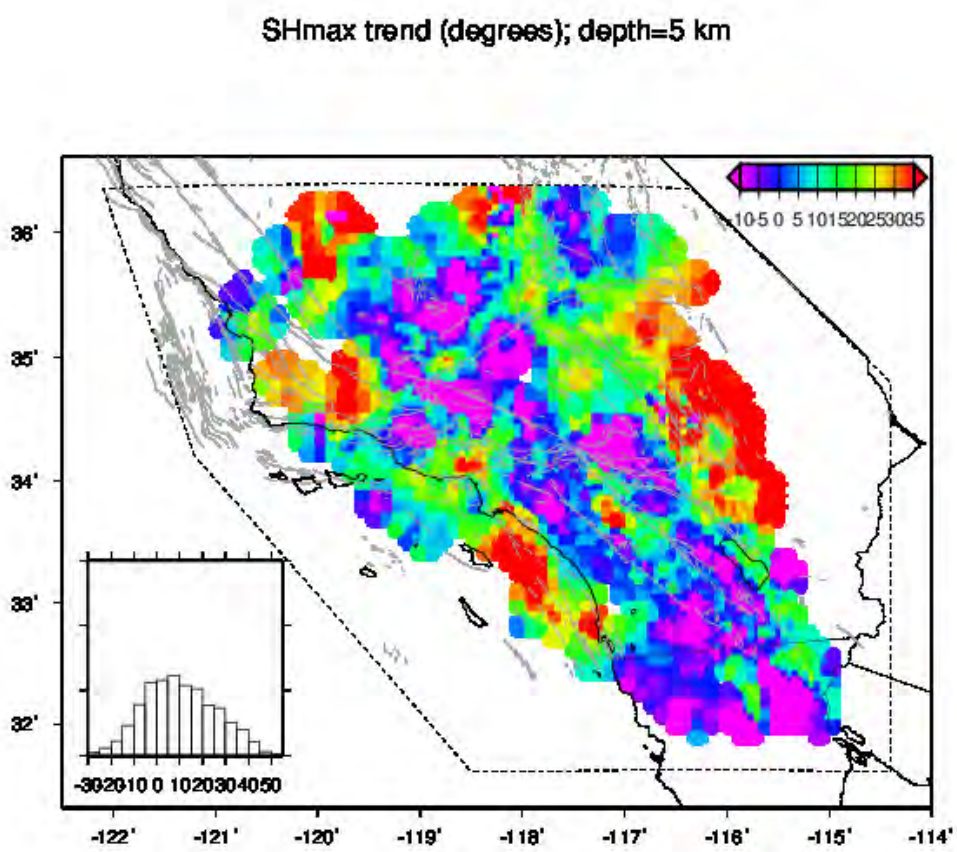
SHmax trend (degrees); depth=5 km

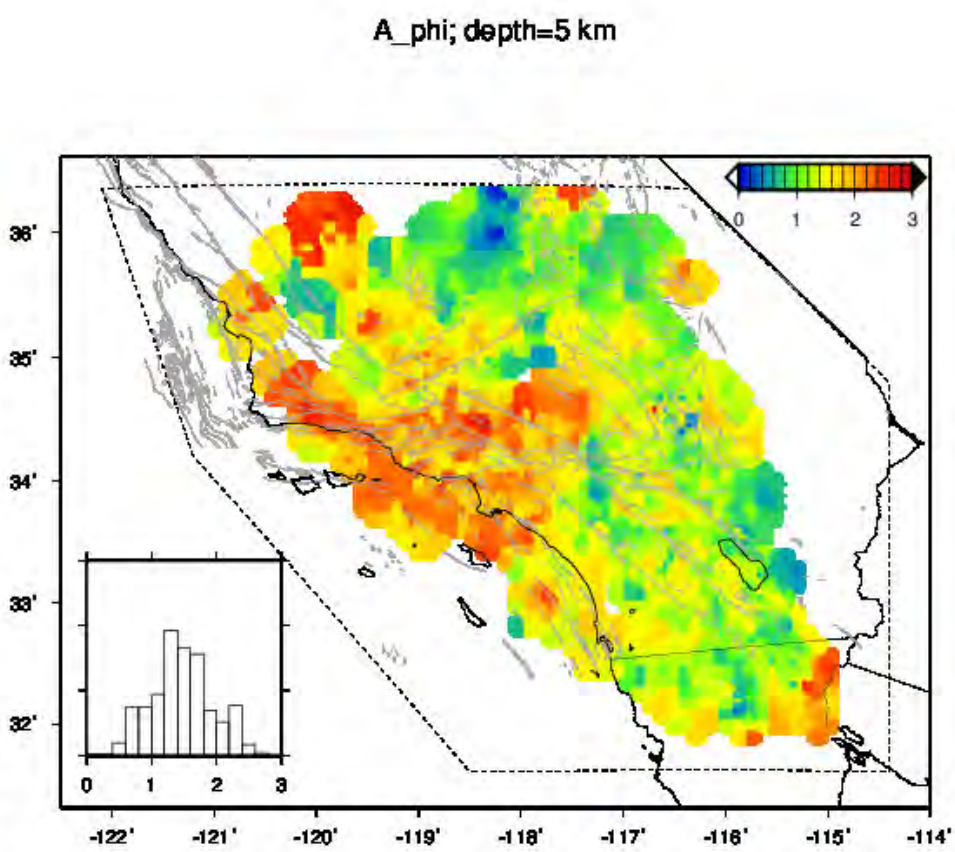


A_phi; depth=5 km

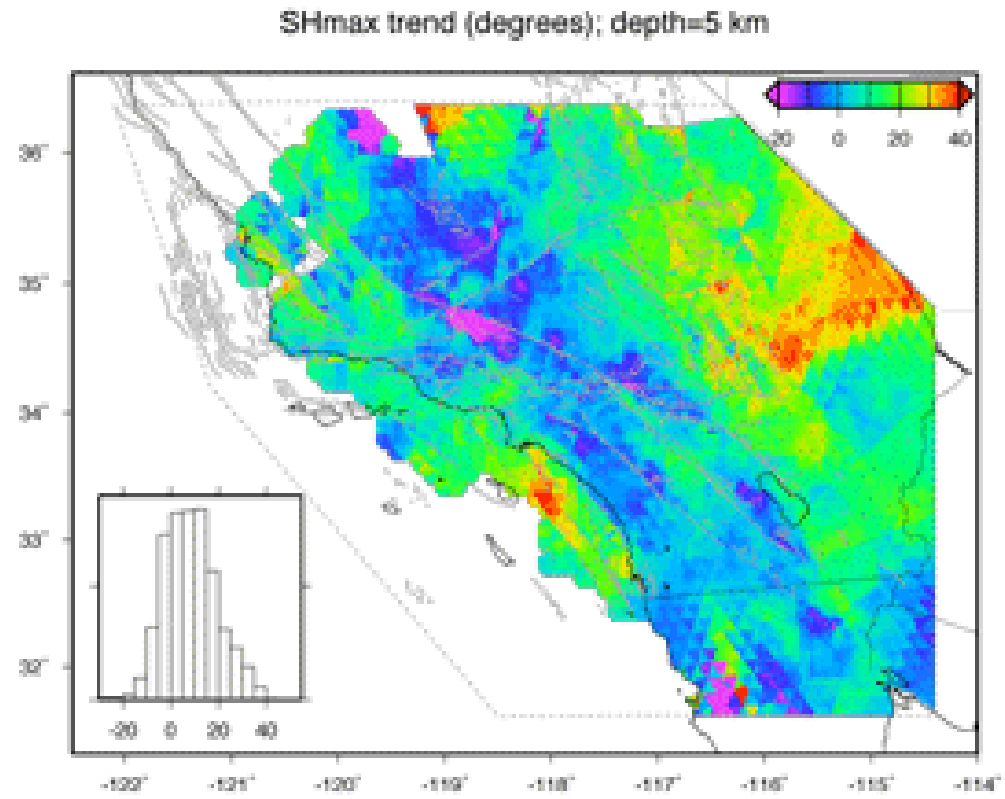


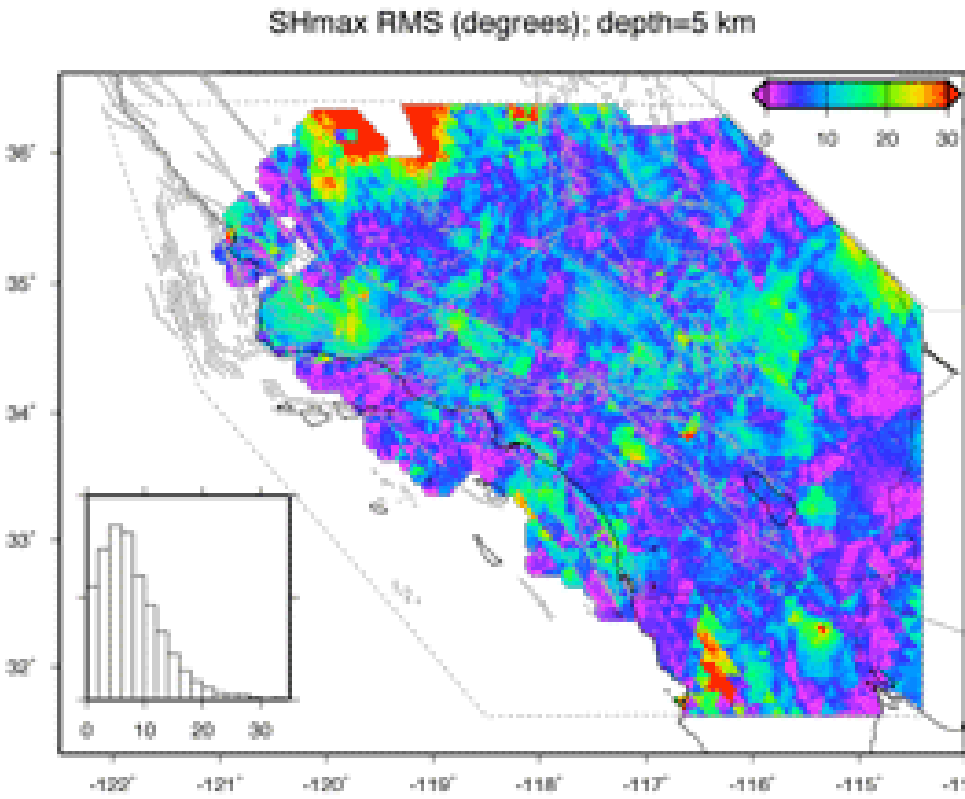
Stress: Yang & Hauksson





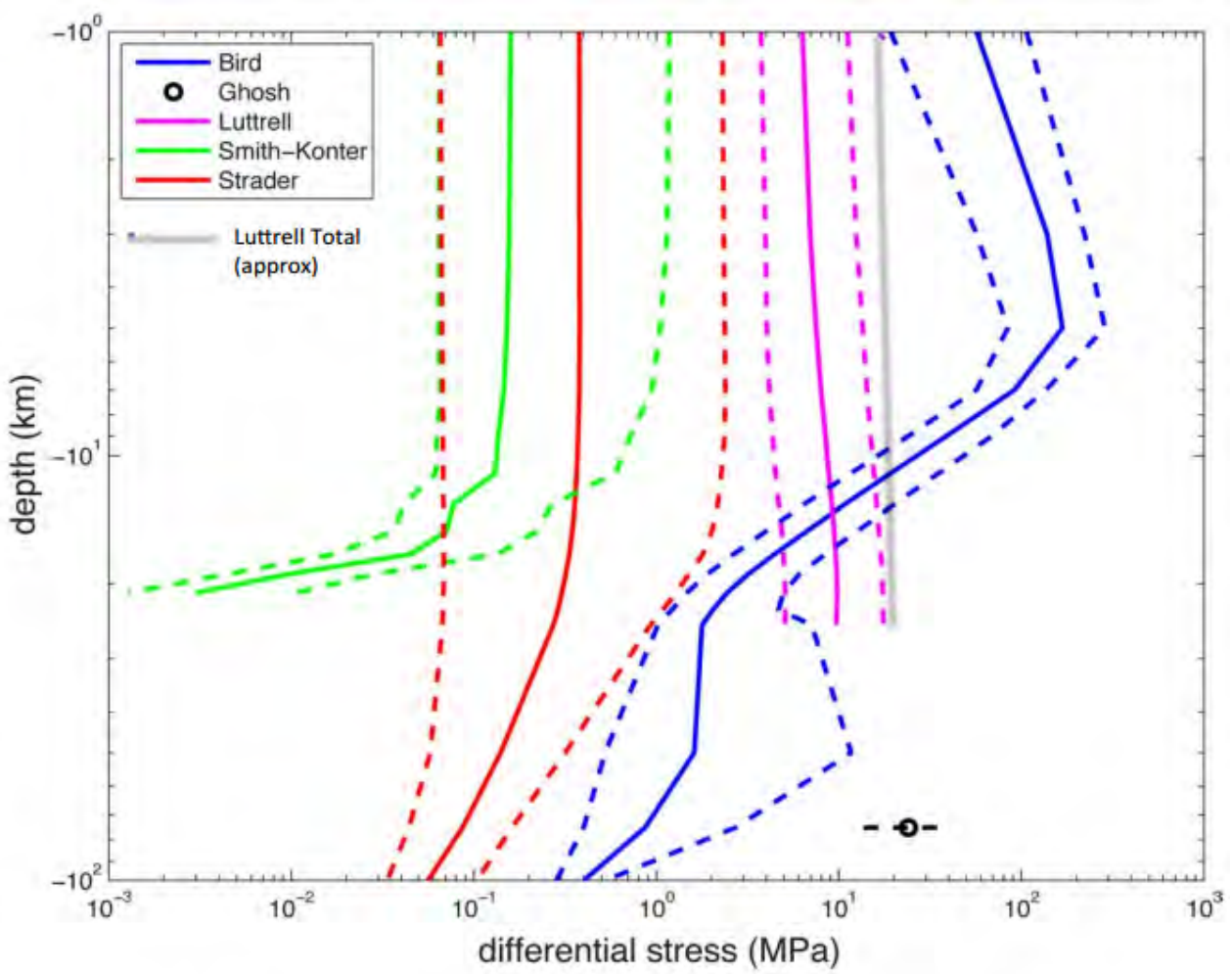
Stress: Model Average





Comparison of Differential Stress

Very poor agreement in differential stress ($\sigma_1 - \sigma_3$) versus depth



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

Comparison of SHmax trend and Aphi

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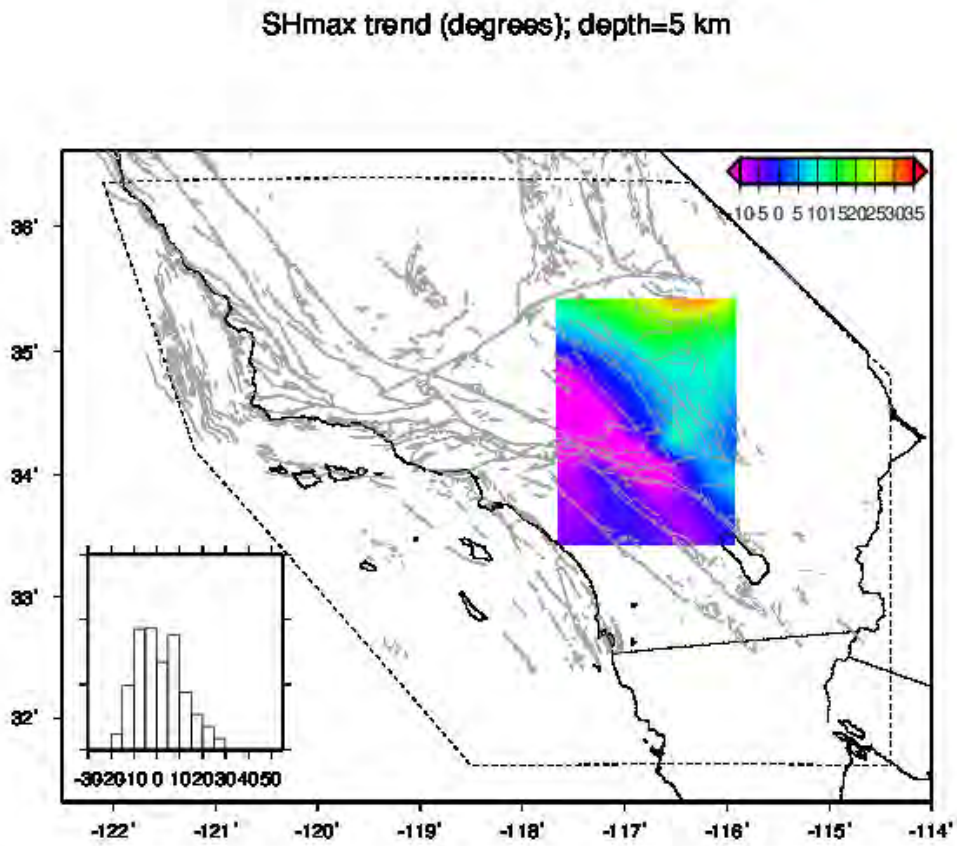
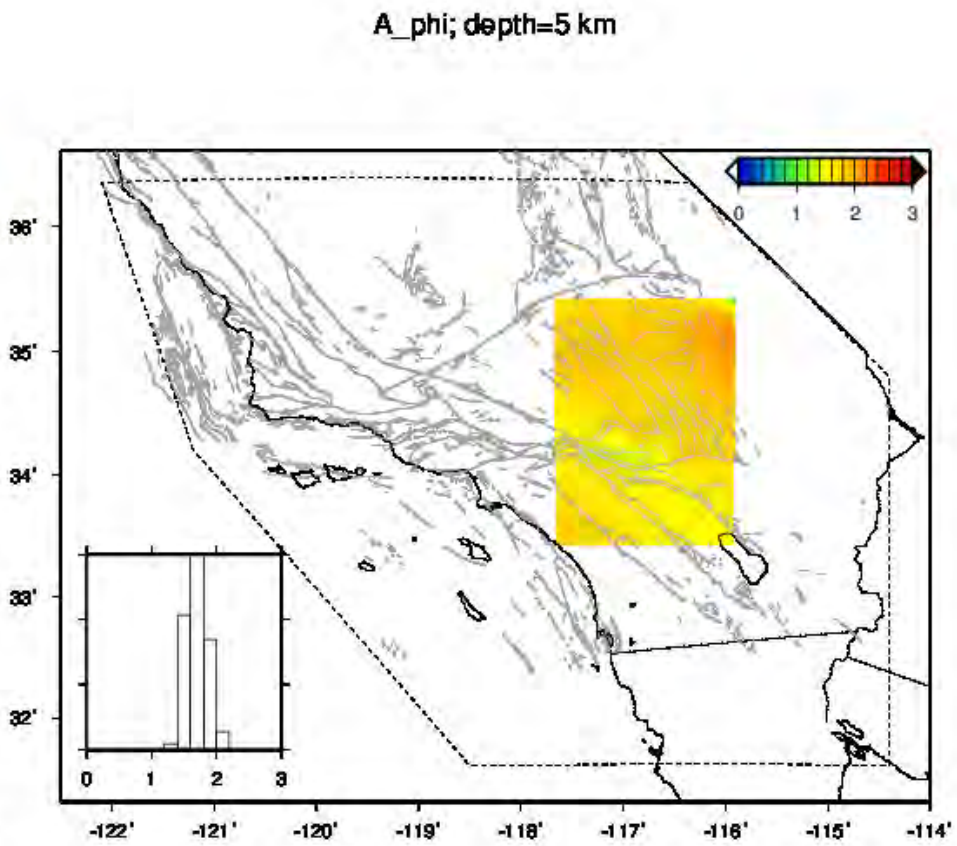
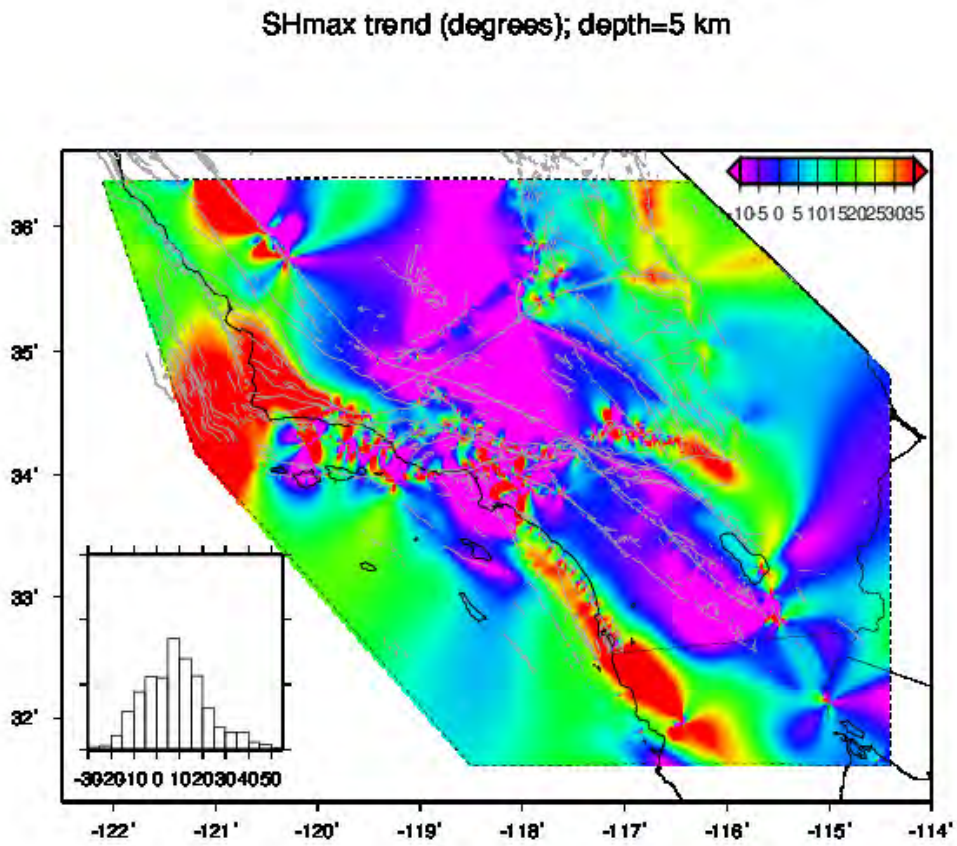
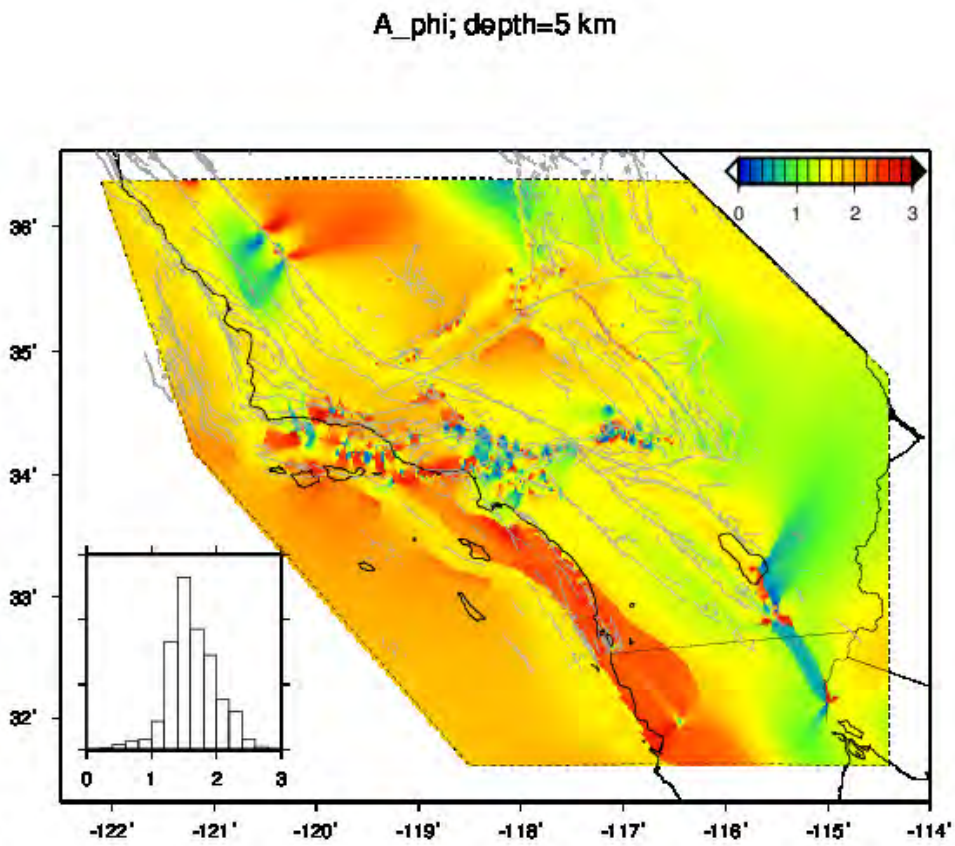
Stressing Rate: Cooke



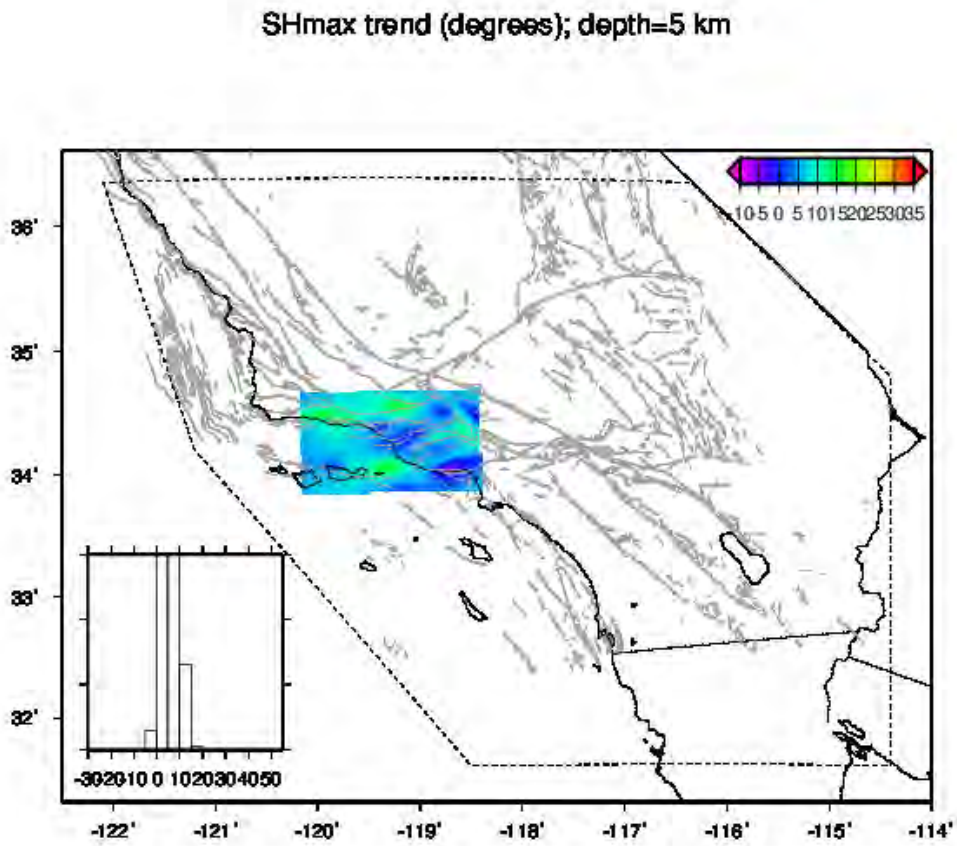


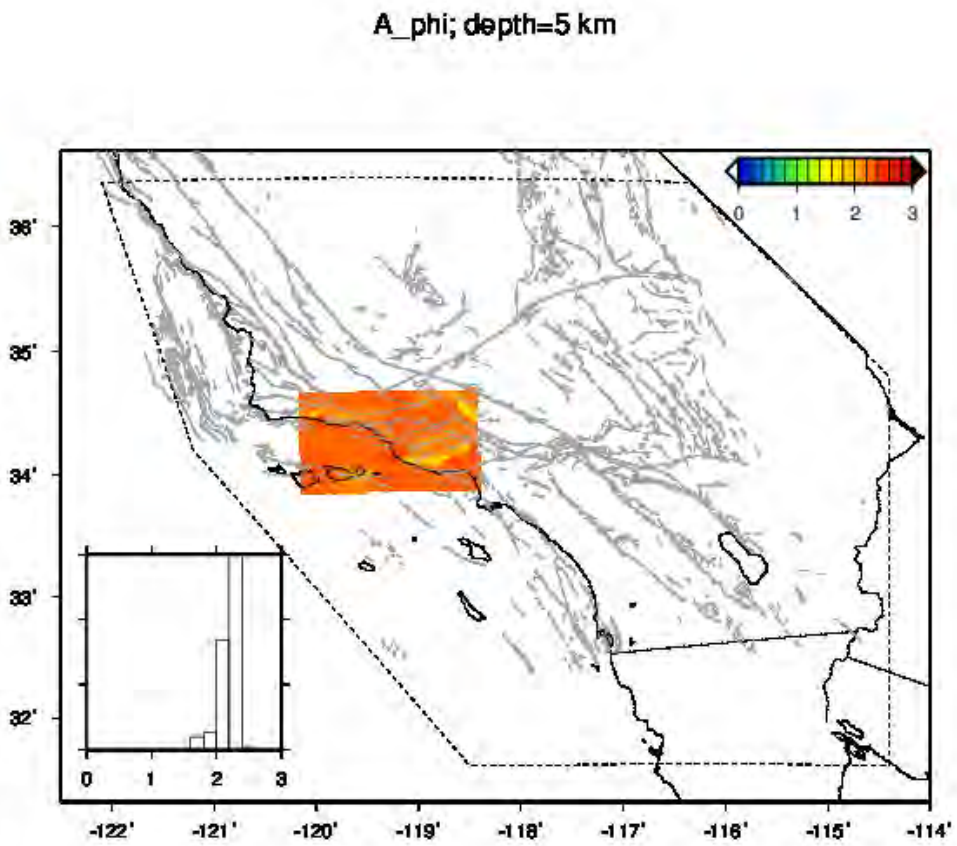
Stressing Rate: Loveless & Meade



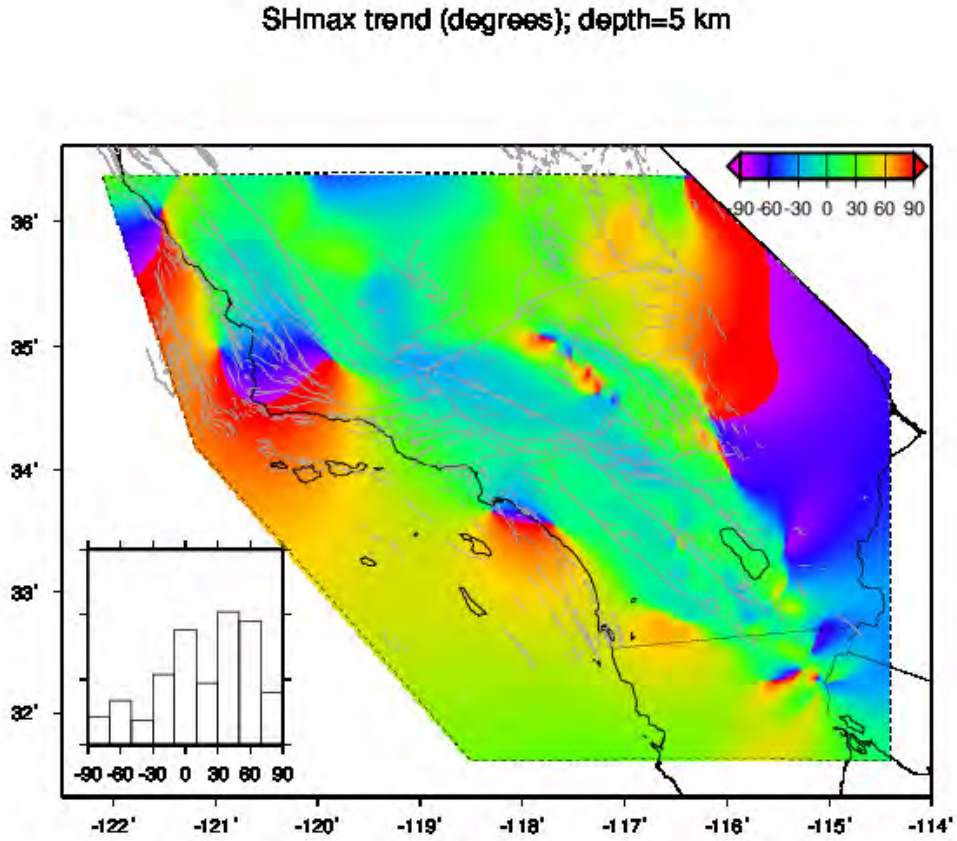


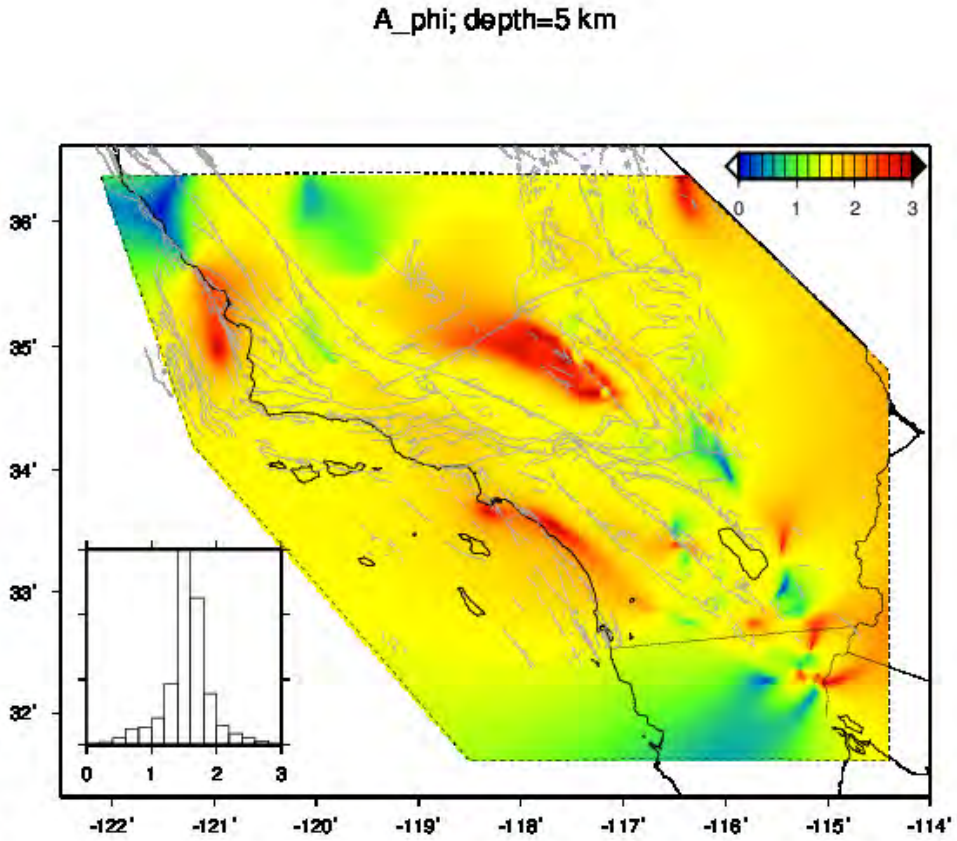
Stressing Rate: Marshall



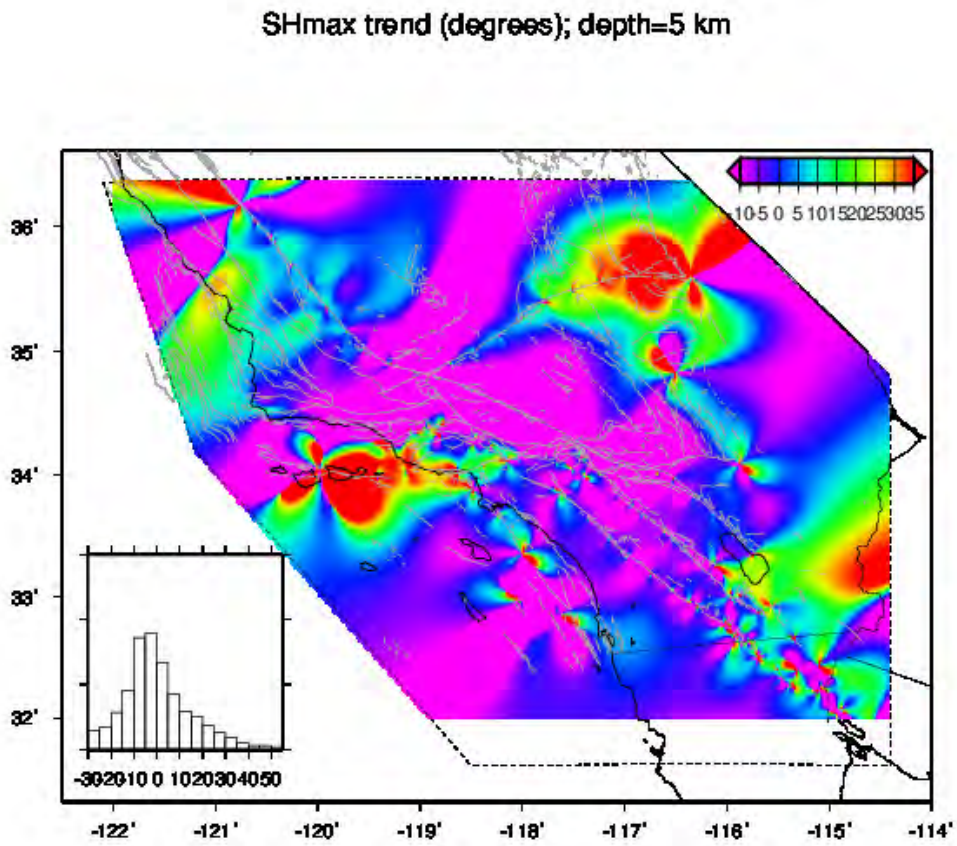


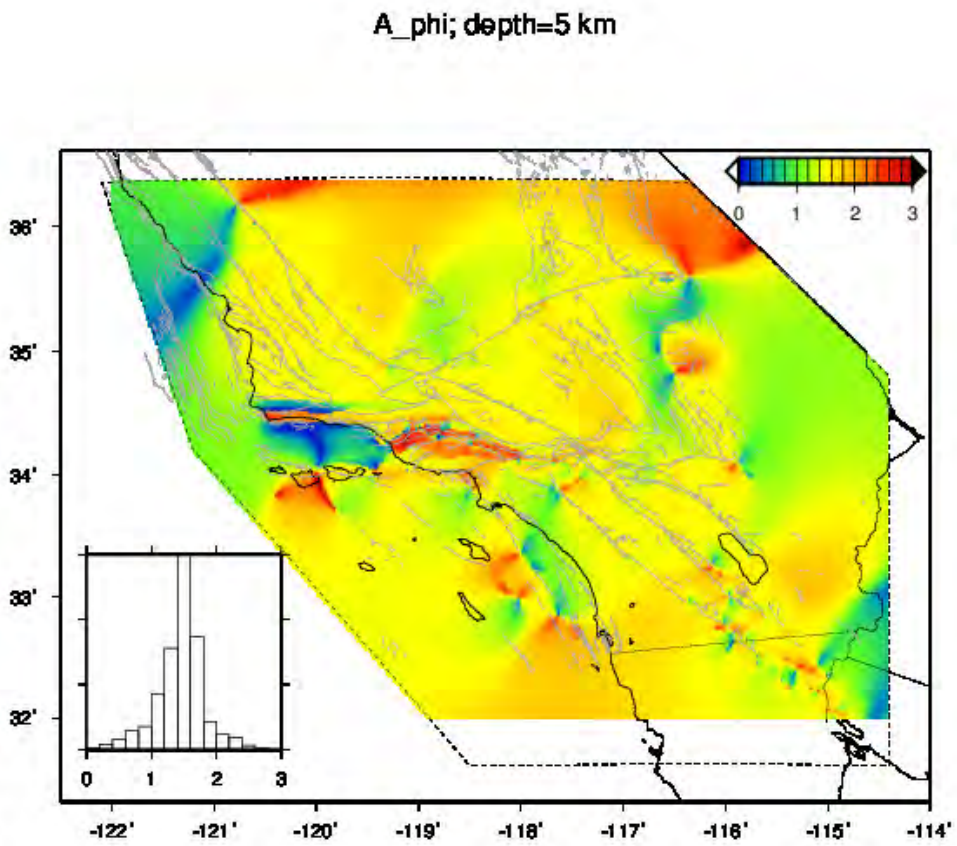
Stressing Rate: Smith-Konter & Sandwell





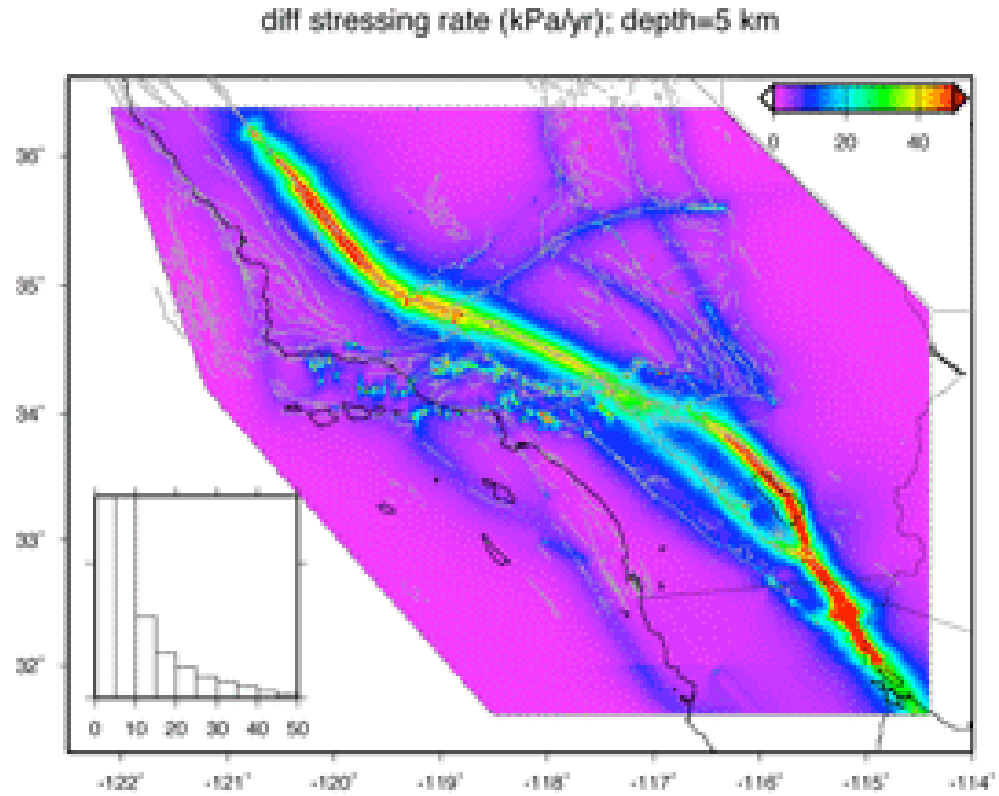
Stressing Rate: Strader & Jackson

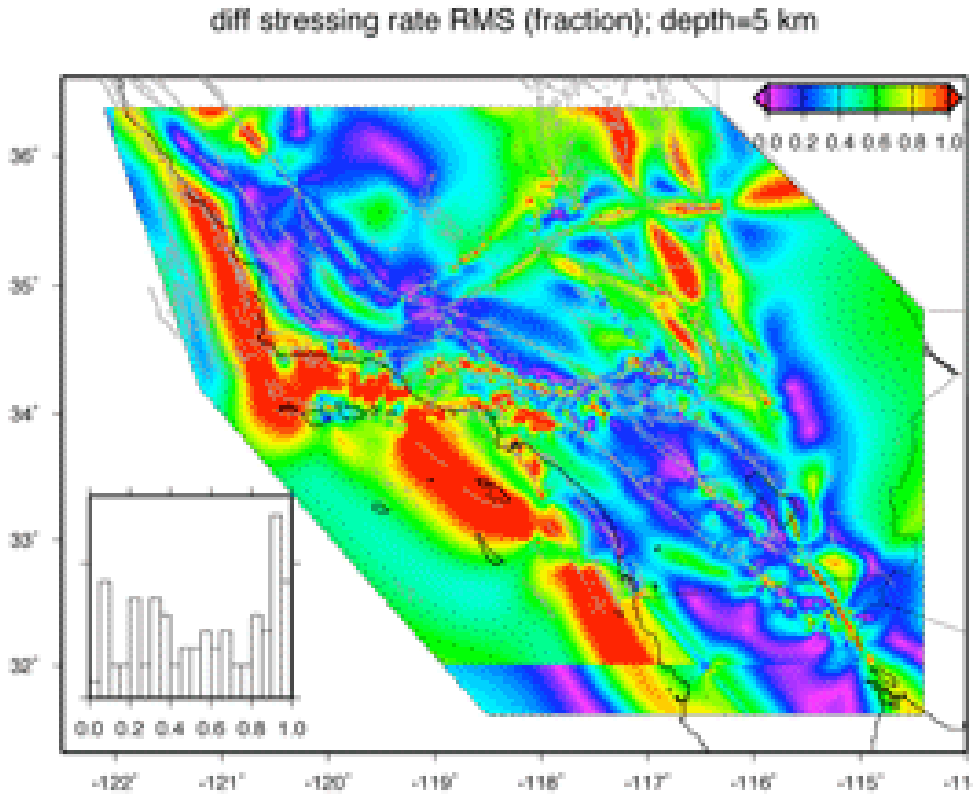




Stressing Rate: Model Average

Good agreement along the major fault traces





Summary of Model Comparisons

- Better agreement among models in central portion
- Most models limited to stress orientation
- Bird SHELLS only model with significant amplitude depth dependence
- Infrastructure needed
  - Compare/merge models
  - Smoothing/interpolation filter
  - L1 norm for differences

Classes of Models

Goal: Merge models into smaller subset of reference models

- Data
  - Focal mechanisms
  - World Stress Map
  - Crustal splitting
  - Well/borehole logs
- Physics-based stress
- Physics-based stress rate

Next Steps

- Orientation of stress field
  Likely cause of faulting style disagreement identified and modelers are reconciling differences.
- Deviatoric stress
  Encourage further research to place bounds on the magnitude of the deviatoric stress at depth.
- Stressing rate
  Translate deformation models produced from UCERF3 to stressing rate and incorporate into the CSM.
- Validation
  Solicit more relevant data. Develop metrics for validating models and apply metrics to submitted models.
- Uncertainty
  Add Monte Carlo uncertainty estimates. Range of the models also gives a measure of the uncertainty.

CSM Workshop # 3: May 2013

- Back-to-back with Community Geodetic Model workshop
  Strongly encourage stressing rate model contributions from UCERF3 efforts
- Stressing rate models
  Understand and reconcile differences among models
- Validation
  Develop and apply metrics to validate stress and stressing rate models against a variety of data