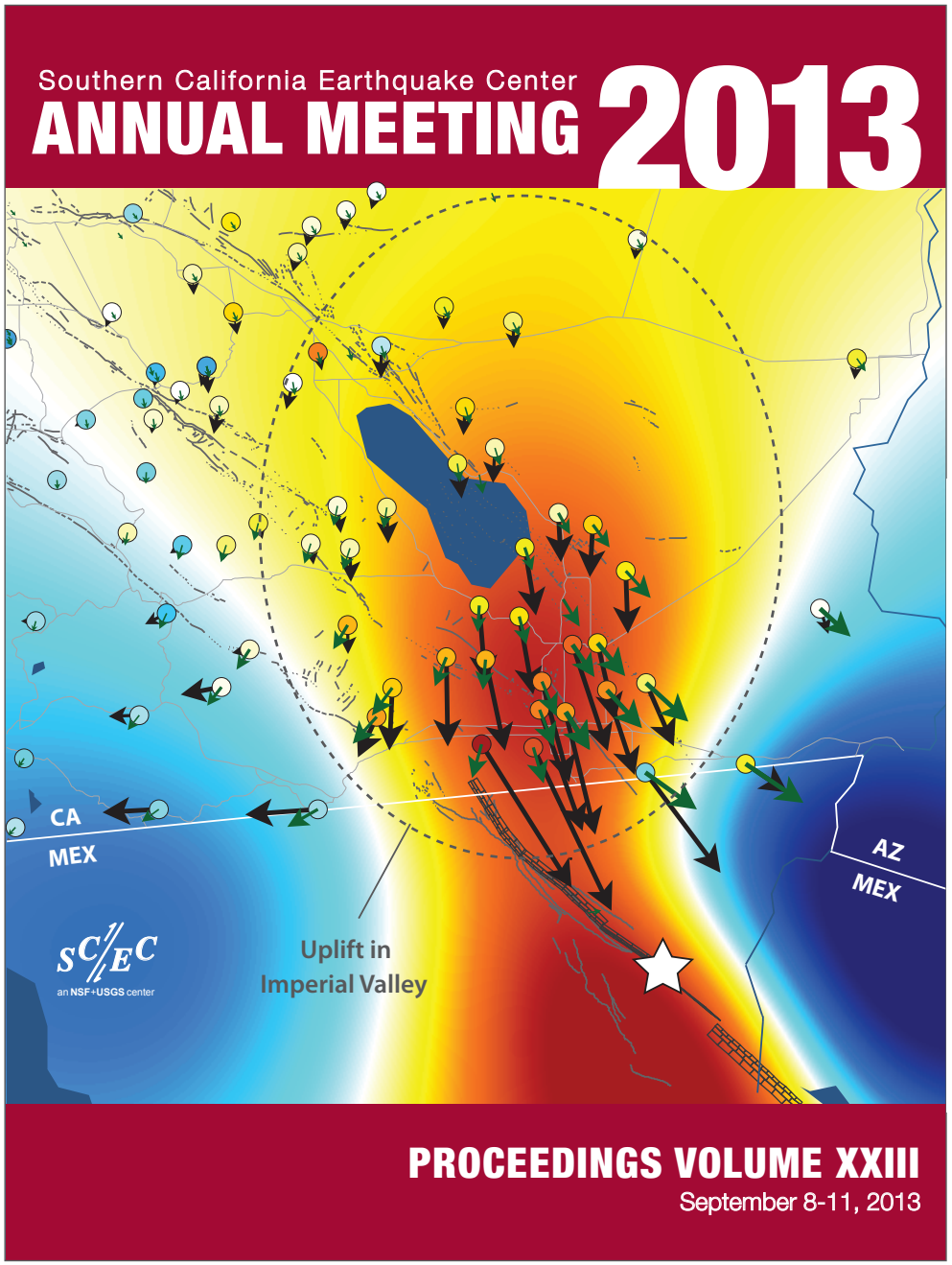
SCEC4 Science – Year 2

Greg Beroza (Deputy Director)

SCEC

an NSF + USGS center



AVAILABLE FOR DOWLOAD

www.scec.org/meetings/2013am/SCEC2013Proceedings.pdf

Table of Contents

Goals of the Meeting

Assess the state of SCEC research

- **Overview Talks** (Monday am)
- **Plenary talks** (each day)
- **Poster Sessions** (dedicated time)

Consider what course corrections are required and amend the collaboration plan accordingly

- **Plenary discussions**
- **Collaboration Plan session** (Wednesday am)
- **Forge collaborations throughout**
- **Planning Committee meeting** (Wednesday pm)

Milestones

YEAR 1 (2012-2013)

Improved Observations

Transient Geodetic Signals

Community Modeling Environment

Community Geodetic Model

Community Stress Model

Special Fault Study Areas

Ground Motion Simulation Validation

Source Modeling

Time-Dependent Earthquake Forecasting

Progress on SCEC4 Problems

Milestones: Improved Observations

YEAR 1 (2012-2013)

Archive and make available at the SCEDC waveforms, refined catalogs of earthquake locations and focal mechanisms for the period 1981-2011.

Begin cataloging validation earthquakes and associated source descriptions and strong ground motion observations for California for use in ground motion simulation validation.

Implement automated access to EarthScope GPS data for transient detections.

Initiate planning with IRIS and UNAVCO to improve the scientific response capabilities to California earthquakes. [I-VI]

Milestones: CME

YEAR 1 (2012-2013)

Implement, refine, and release software tools for accessing the SCEC CVMs. Define reference calculations and evaluation criteria for 3D velocity models.

Conduct comparative evaluations among different CFMs and CVMs.

Deliver statewide versions of CFMs for use by WGCEP in UCERF3.

Develop dynamic rupture verification exercises that incorporate effects of large-scale branching fault geometry on dynamic rupture and ground motions. [II, III, IV, VI]

Milestones: SFSAs

YEAR 1 (2012-2013)

Identify requirements for SFSA Science Plans. Solicit SFSA Science Plan(s) from SCEC community to be ratified by PC and then included into 2013 RFP.

Coordinate interdisciplinary activities, including workshops, to prototype at least one SFSA. [I-VI]

Plenary Science Sessions

(Organized Around Six Fundamental Problems of ESP)

Mon 11:30-13:00 Stress transfer from plate motion to crustal faults: long-term fault slip rates. (Moderator: Kaj Johnson)

- Kate Scharer (USGS)
  New paleoseismic data from SoSAFE: time dependency and rupture patterns on the San Andreas and San Jacinto Faults
- Bill Ellsworth (USGS)
  Beyond the Time-Independent Uniform California Earthquake Rupture Forecast: Where Should SCEC Go From Here?

Mon 14:30-16:00 Stress-mediated fault interactions and earthquake clustering: evaluation of mechanisms. (Moderator: Morgan Page)

- Katie Keranen (Cornell)
  Variable seismic response to fluid injection in central Oklahoma
- Max Werner (Princeton) Recent Results from the Collaboratory for the Study of Earthquake Predictability (CSEP)

Plenary Science Sessions

Tue 08:00-09:30 Evolution of fault resistance during seismic slip: scale-appropriate laws for rupture modeling. (Moderator: Eric Dunham)

- Fred Chester (TAMU)
  Insights into subduction thrust structure and mechanics from drilling the rupture zone of the 2011 Tohoku-oki earthquake
- Shuo Ma (SDSU)
  Uncovering the Mysteries of Tsunami Generation and Anomalous Seismic Radiation in the Shallow Subduction Zone

Tue 09:30-11:00 Structure and evolution of fault zones and systems: relation to earthquake physics. (Moderator: Emily Brodsky)

- Yuri Fialko (Scripps)
  Back to the roots: Ductile shear zones below major faults, and stresses at the bottom of the seismogenic crust
- Heather Savage (LDEO)
  Biomarkers heat up during earthquakes: new evidence of seismic slip in the rock record

Plenary Science Sessions

Tue 11:30-13:00 Causes and effects of transient deformations: slow slip events and tectonic tremor. (Moderator: Rowena Lohman)

- Manoochehr Shirzaei (ASU)
  4D maps of fault aseismic slip obtained through multitemporal InSAR and time-dependent modeling
- Bill Holt (SUNY Stonybrook)
  Toward a Continuous Monitoring of the Horizontal Displacement Gradient Tensor Field using cGPS Observations from PBO

Tue 14:30-16:00 Seismic wave generation and scattering: prediction of strong ground motions. (Moderator: Pablo Ampuero)

- Steve Day (SDSU) High-frequency rupture dynamics and ground motion prediction
- Victor Tsai (Caltech)
  Using Ambient Noise Correlations for Studying Site Response

Plenary Science Sessions

Wed 08:00-09:30 Earthquake Early Warning and Risk Communication (Moderator: Lucy Jones)

- Richard Allen (UCB)

Earthquake early warning: Now, or after the next big quake?

- Ann Bostrom (UW)

Setting the stage for early earthquake alerts and warnings

SCEC4 Planning Committee

Disciplinary Groups:

- Seismology
- Earthquake Geology
- Tectonic Geodesy
- Computational Science

SCEC

an NSF + USGS center

Interdisciplinary Focus Groups

- Unified Structural Representation
- Fault and Rupture Mechanics (FARM)
- Southern San Andreas Fault Evaluaion (SoSAFE)
- Stress and Deformation Over Time (SDOT)
- Earthquake Forecasting and Predictability
- Ground Motion Prediction
- Earthquake Engineering Implementation Interface

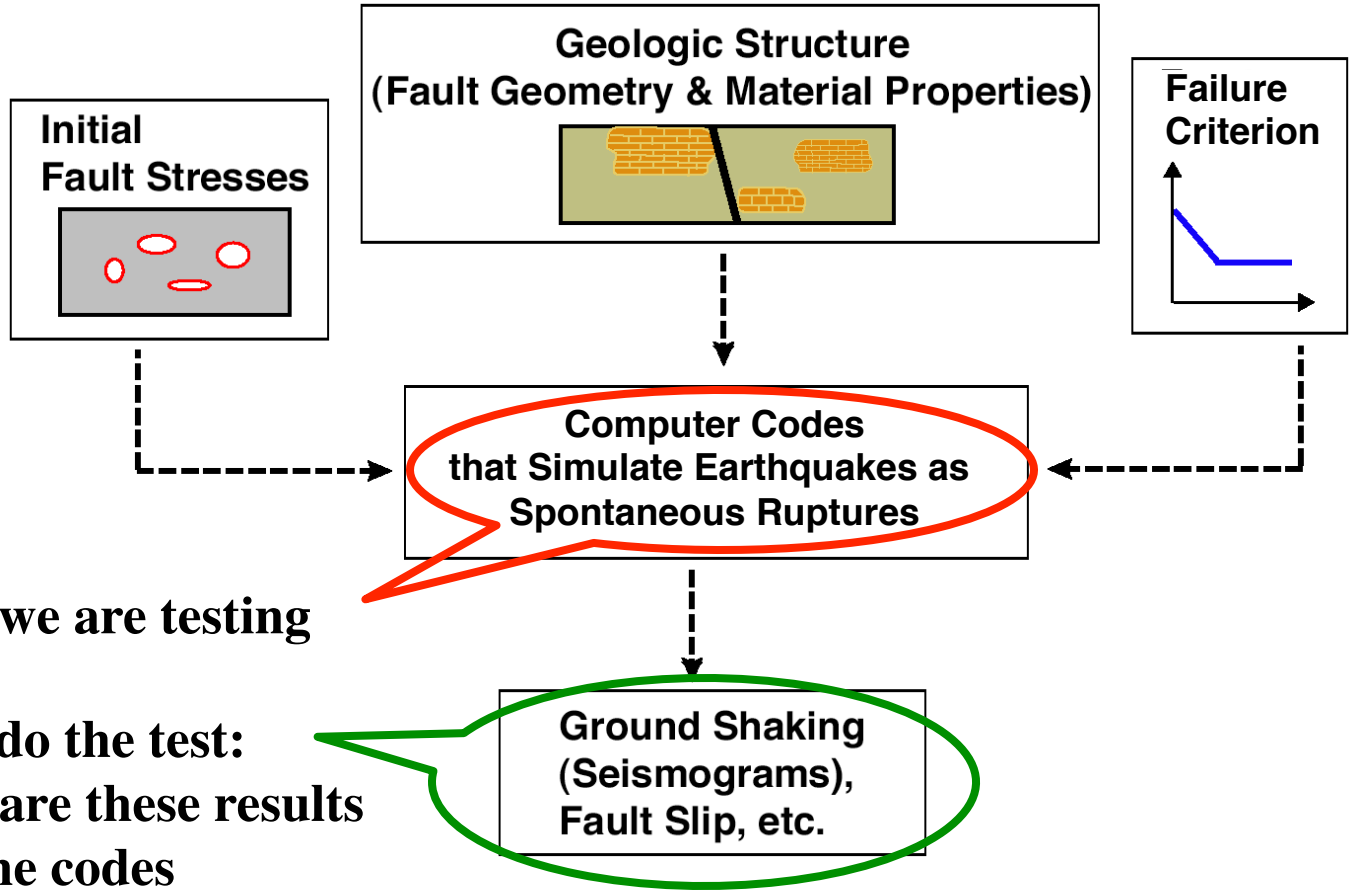
Technical Activity Groups (TAGs)

Develop and test critical methods for solving specific forward and inverse problems. TAGs typically involve:

(1) posing well-defined "standard problems"
(2) solving them by different researchers with different approaches
(3) virtual/in person meetings to compare solutions, discuss discrepancies, and work on improvements

Dynamic Rupture Code Verification
Aseismic Transient Detection
Source Inversion Validation
Earthquake Simulators
Ground Motion Simulation Validation

Dynamic Rupture Code Comparison TAG



What we are testing

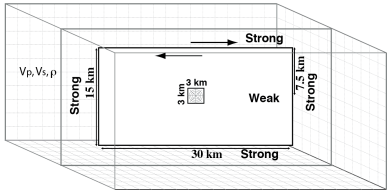
How we do the test:
we compare these results
among the codes

Please see the website http://scecdata.usc.edu/cvws

Harris- Sept. 2013

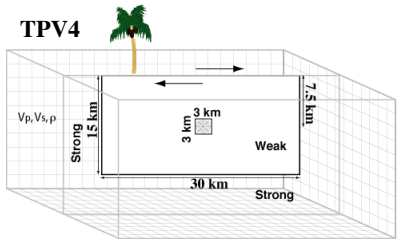
Code Comparison Benchmarks – Incrementally add complexity

TPV3

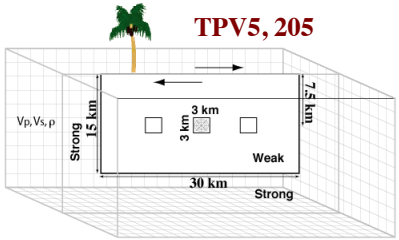


Slip-weakening friction

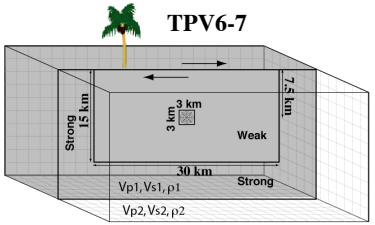
TPV4



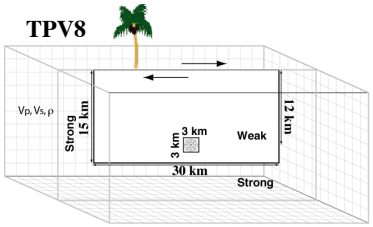
TPV5, 205



TPV6-7

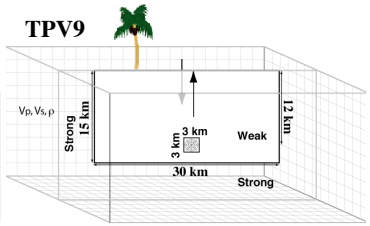


TPV8

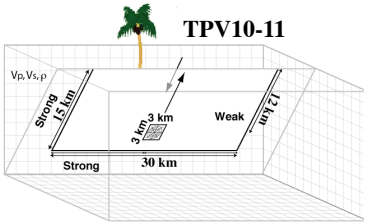


Slip-weakening friction

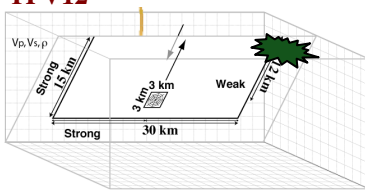
TPV9



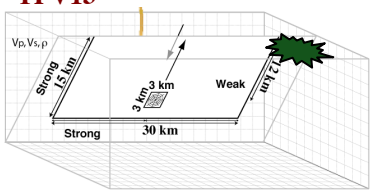
TPV10-11



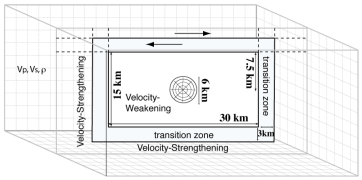
TPV12



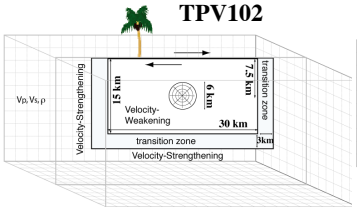
TPV13



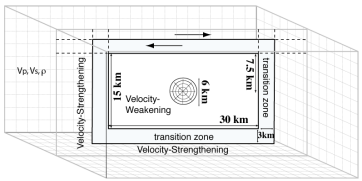
TPV101



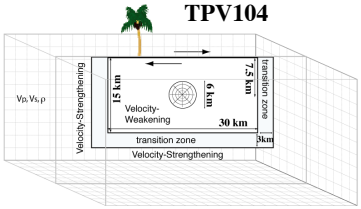
TPV102



TPV103



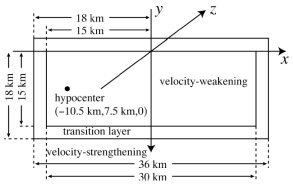
TPV104



Rate-state friction using an aging law

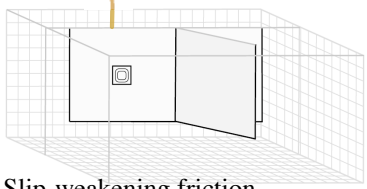
Rate-state friction using a slip law with strong rate-weakening

TPV105-2D



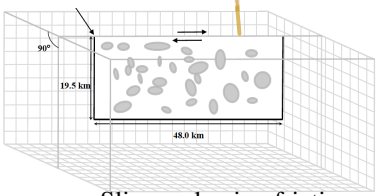
Thermal pressurization, rate-state friction, slip-law, strong rate-weakening

TPV14-15, 18-21



Slip-weakening friction

TPV16-17



Slip-weakening friction

Harris- Sept. 2013

Next Steps for the TAG

(end of Summer 2013-Winter 2014)

Planar Vertical Fault set in a Plastic Medium

Simple Rough Fault

Comparison Metrics

Harris- Sept. 2013

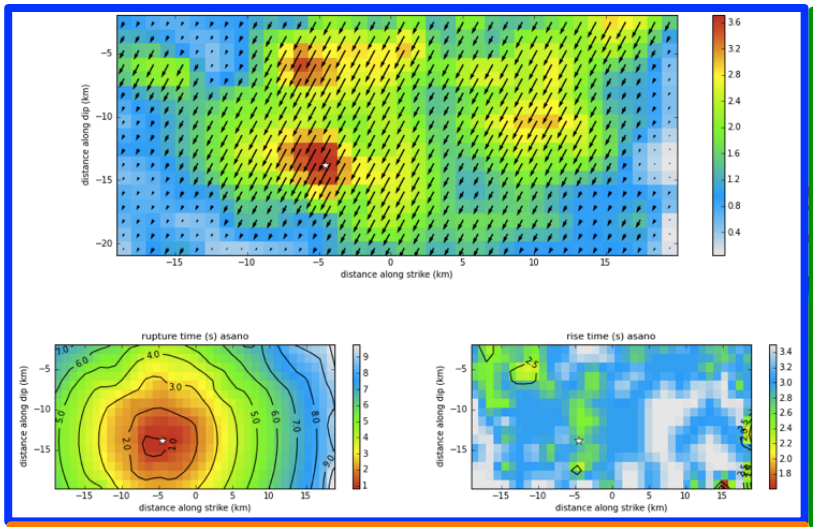
SIV: Source Inversion Validation TAG
Status Report

- **SIV-workshop main discussion points**
  - **Reconciling back-projection imaging and teleseismic source inversion**
  - **Accounting for uncertainty in Earth structure**
- **Forward-modeling tests carried out by a few more groups**
  - **Results are encouraging, but still differences in solutions to exactly specified forward problems**
    - ***Approach: provide input parameter files for computing the reference solution for some commonly used codes***
- **Current inversion benchmark conducted by four teams**
  - **Three of the four solutions reasonably well reproduce target (detailed statistics not yet done; all four solutions match data)**

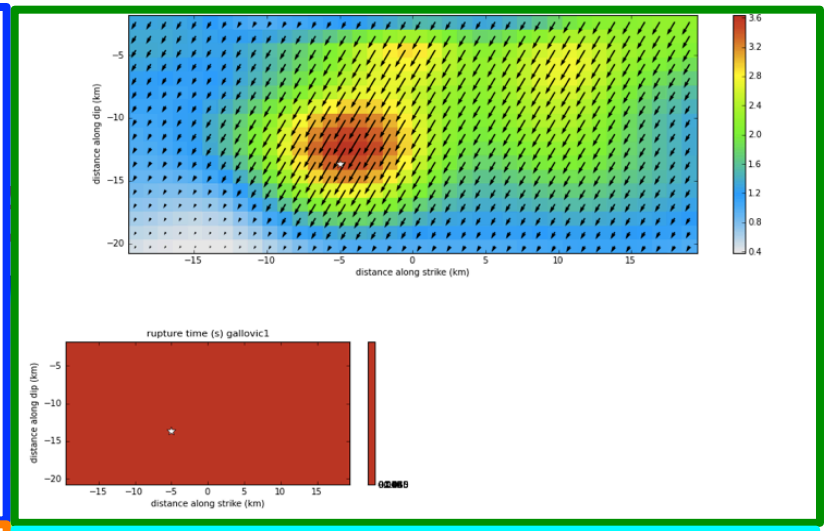
Current SIV benchmark inv 2a

M 7 kinematic normal-faulting EQ; uncertainty in some meta-data

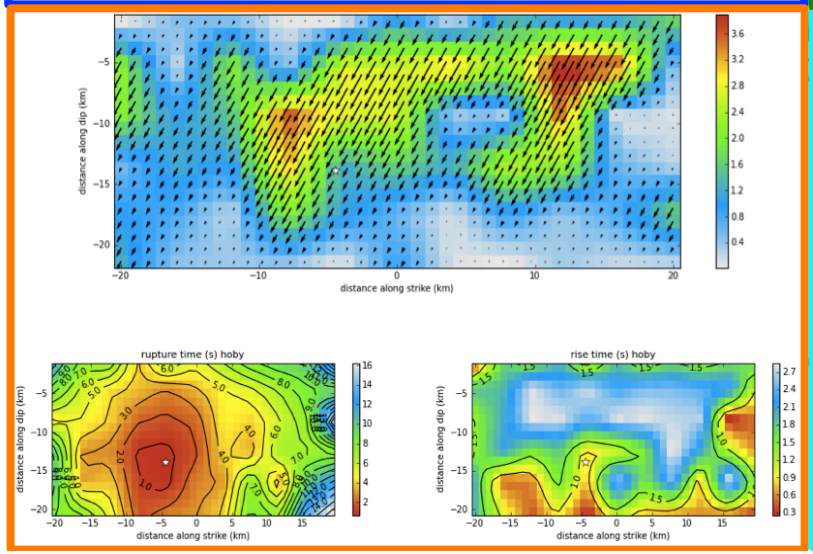
Team A



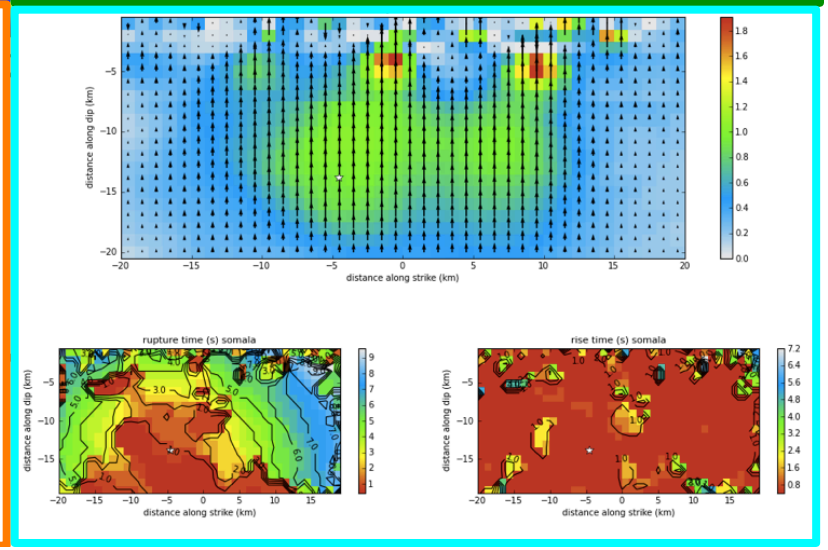
Team B



Team D



Team C

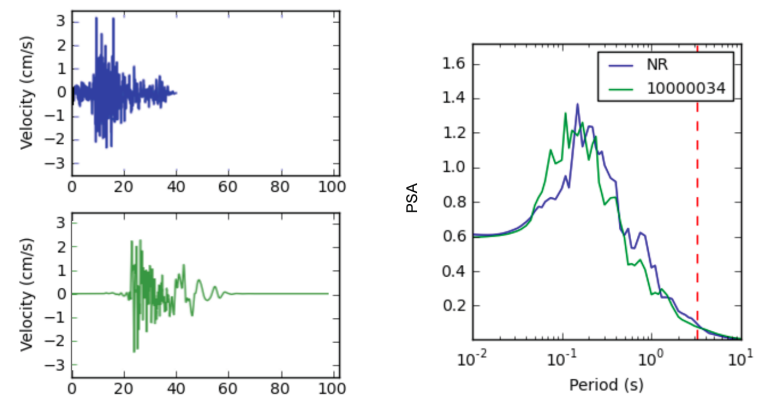


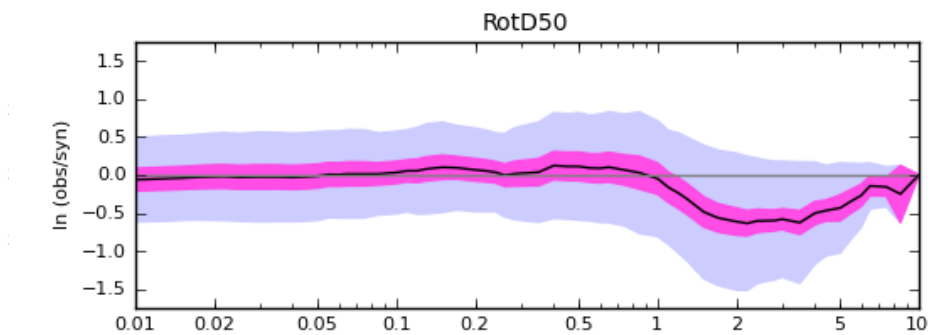
Next Steps

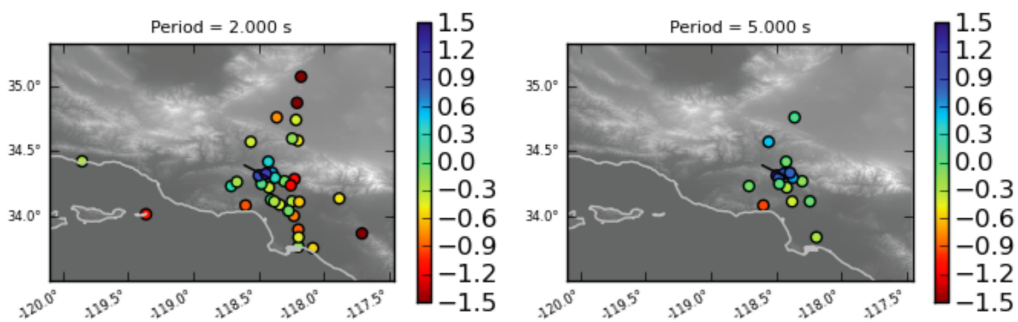
- Construct benchmark exercises as test cases for earthquakes in Southern California
- Design benchmark exercise for both teleseismic inversion and back-projection imaging
- Design benchmark exercise on regional/local scale for rupture embedded in 3D geological structure
  - Approach: Partially leverage previously constructed rupture models (perhaps even synthetic data)
- Dedicated SIV-workshop (2-3 days) in Spring 2014 (active SIV participants only) to work on the benchmarks mentioned above

BroadBand Platform Validation for Ground Motion Projects

- Focus: pseudo-spectral acceleration (0.01 to 10 sec)
- Validation of median from multiple source realizations against:
  - 23 earthquake events, ~40 stations each
  - Ground Motion Prediction Equations for ~M6.5, R20-50km
- First round of evaluation complete: 3 out of 5 methods deemed usable for forward simulations

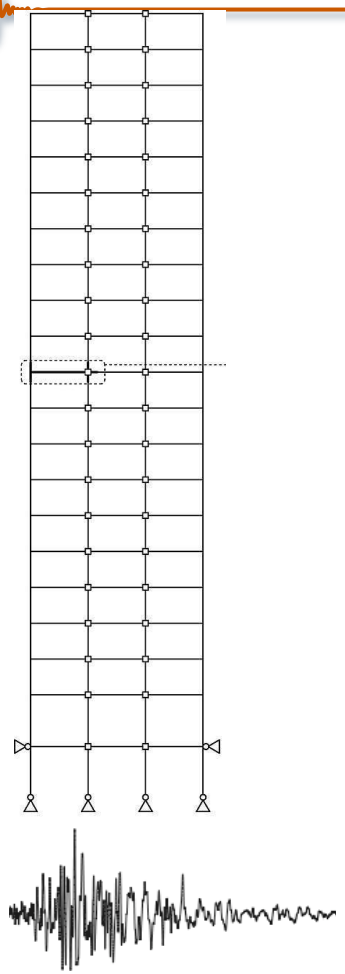




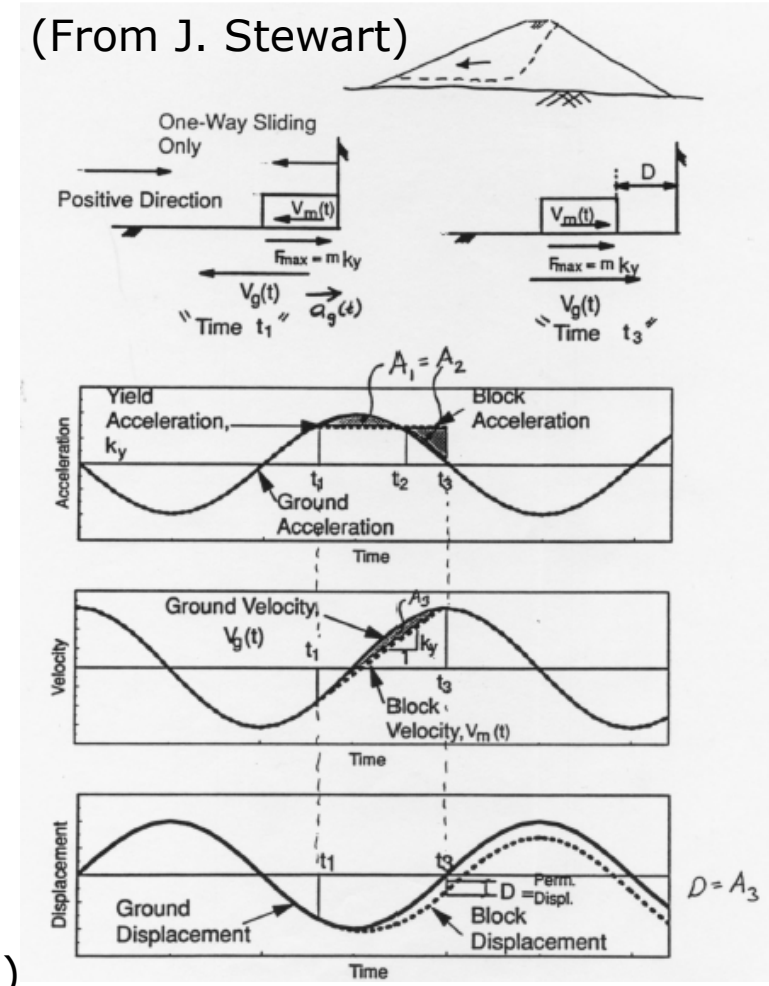


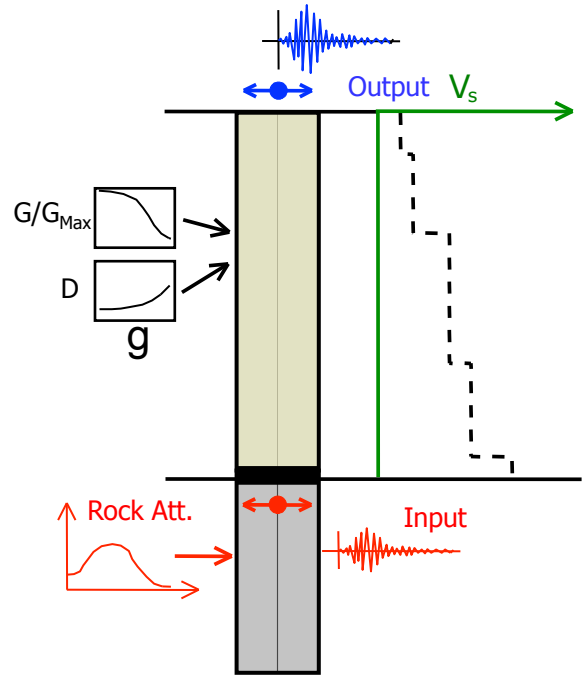
- See posters 203-210!!

Ground Motion Simulation Validation TAG



(From F. Zareian)





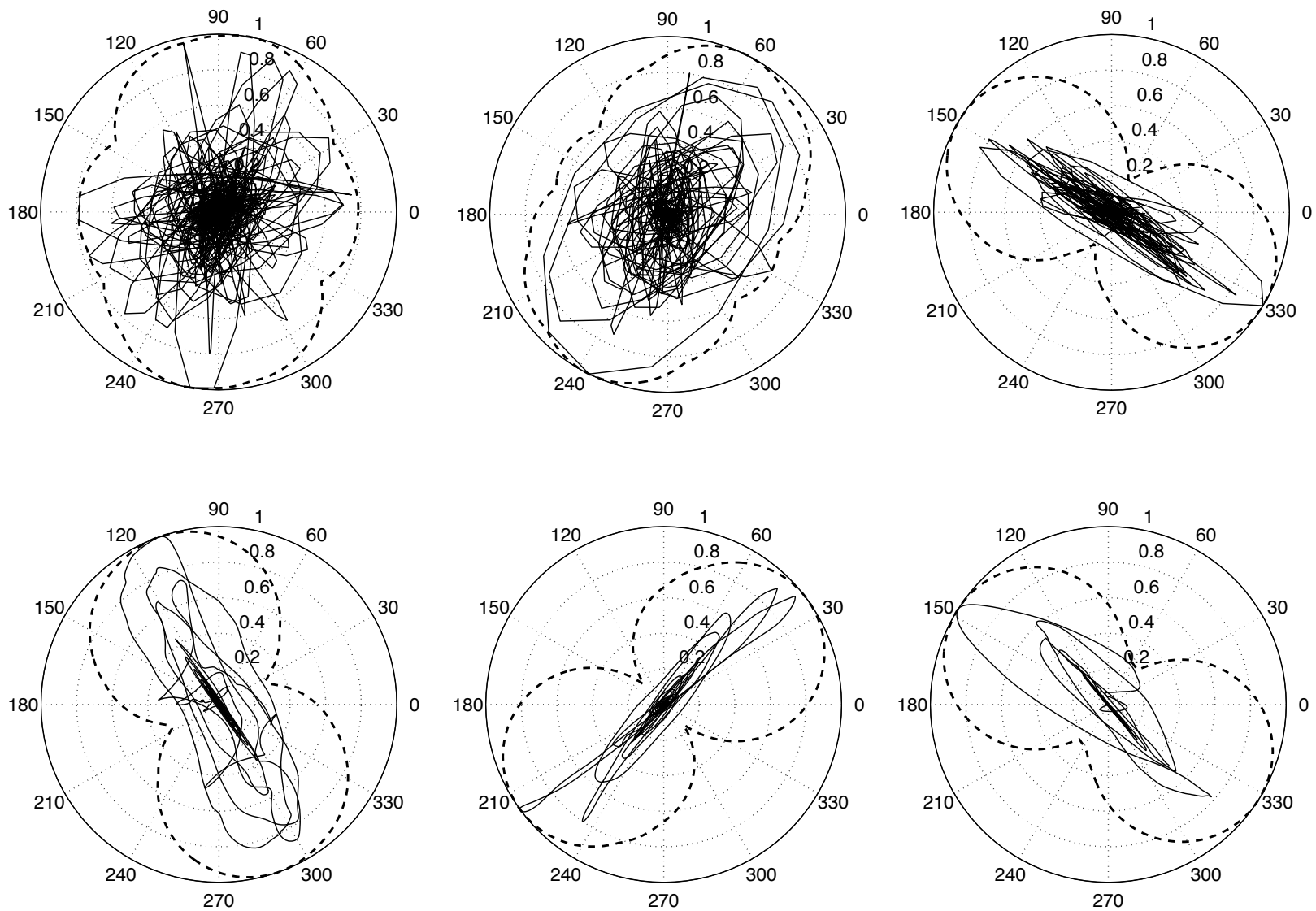
(From C. Goulet)

Ratio of $Sa_{RotD100}$ to Sa_{RotD50}

Loma Prieta records | GP simulations | CSM simulations

T = 0.2s

T = 3s



PEER

Community Models

Develop and Evolve Models that are used by the broader earthquake science community

Community Fault Model (longstanding)

Community Velocity Model (longstanding)

Community Geodetic Model (new)

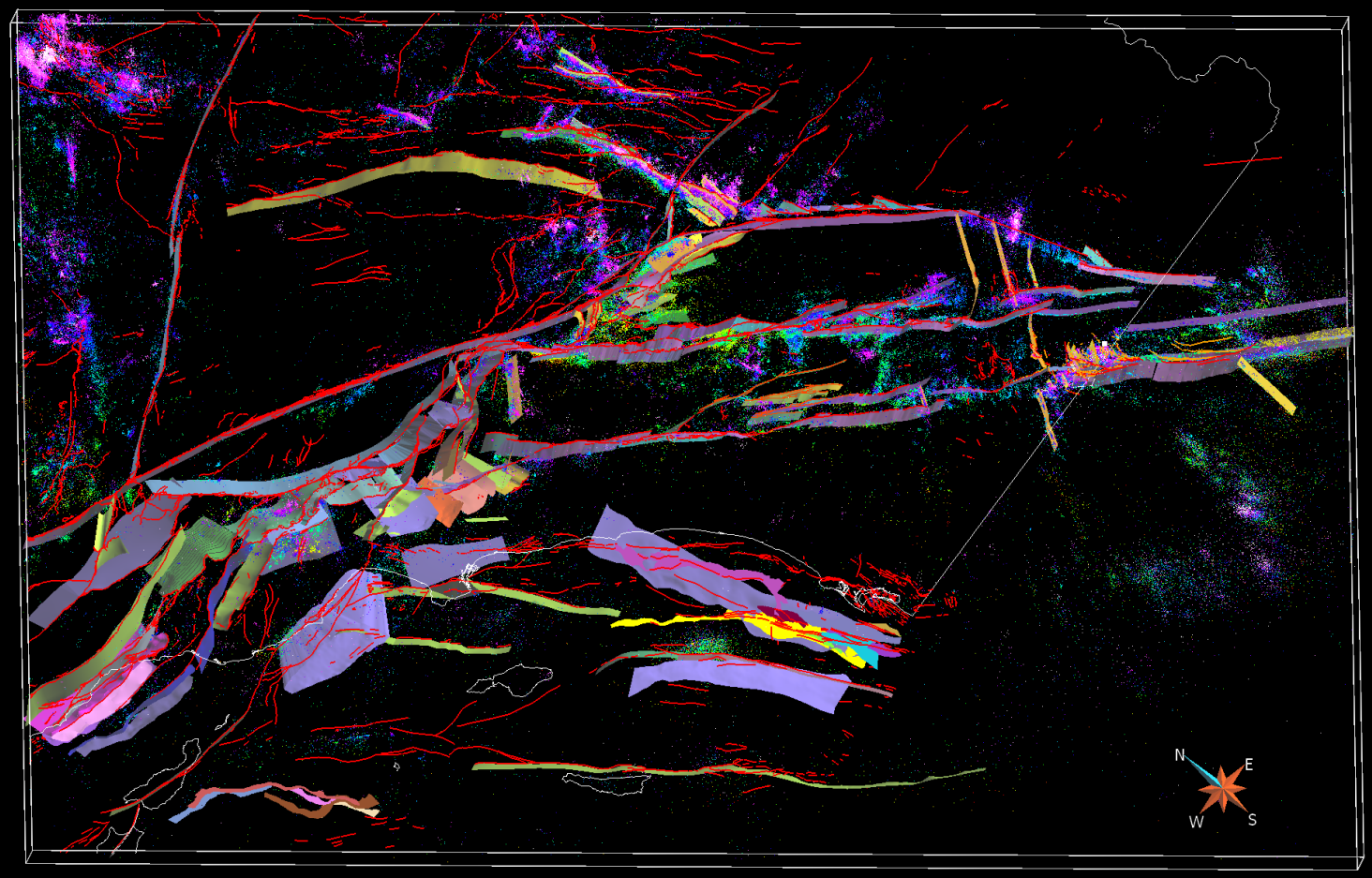
Community Stress Model (new)

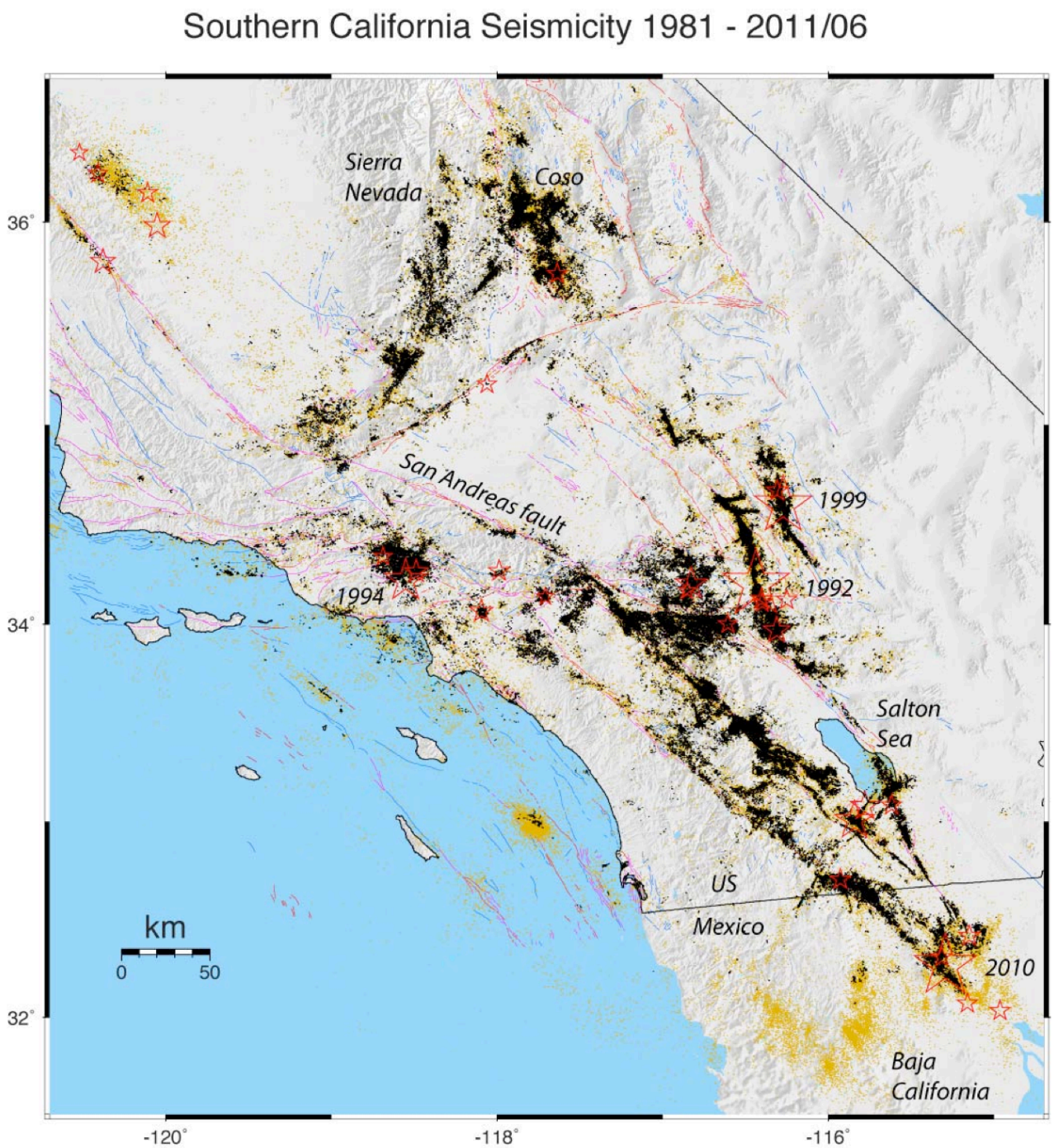
SCEC Community Fault Model (CFM)

(Nicholson et al., 2013)

CFM 4.0 has been substantially enhanced, including development of:

- new fault representations in the Peninsular and Transverse Ranges that are compatible with the USGS Qfault traces
- new fault nomenclature that is compatible with the US Qfault database
- detailed 2010 El Mayor – Cucapah earthquake rupture

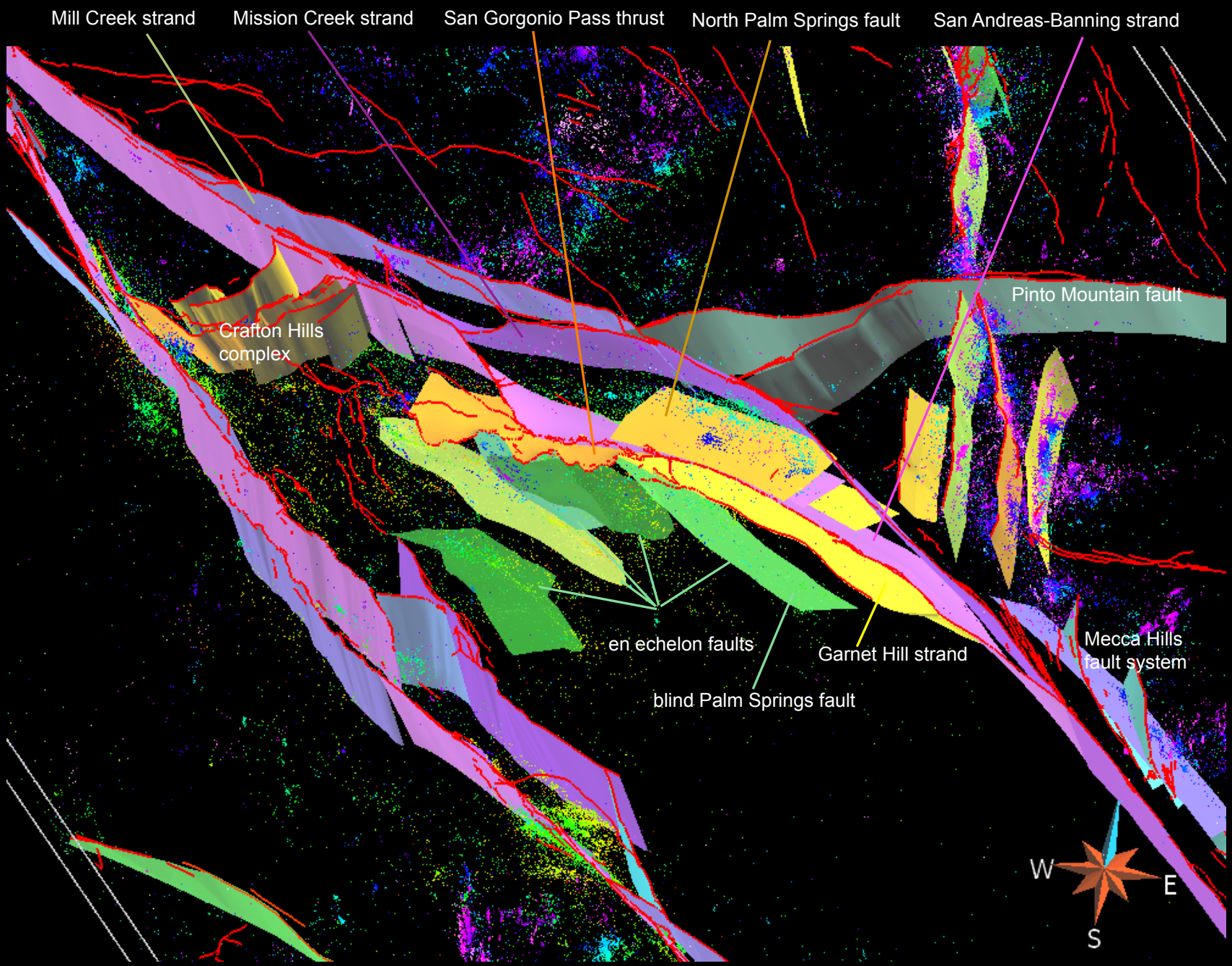




HYS Catalog

Shearer and Hauksson report

Updated and Revised CFM 3D Fault Representations for the San Gorgonio Pass Region



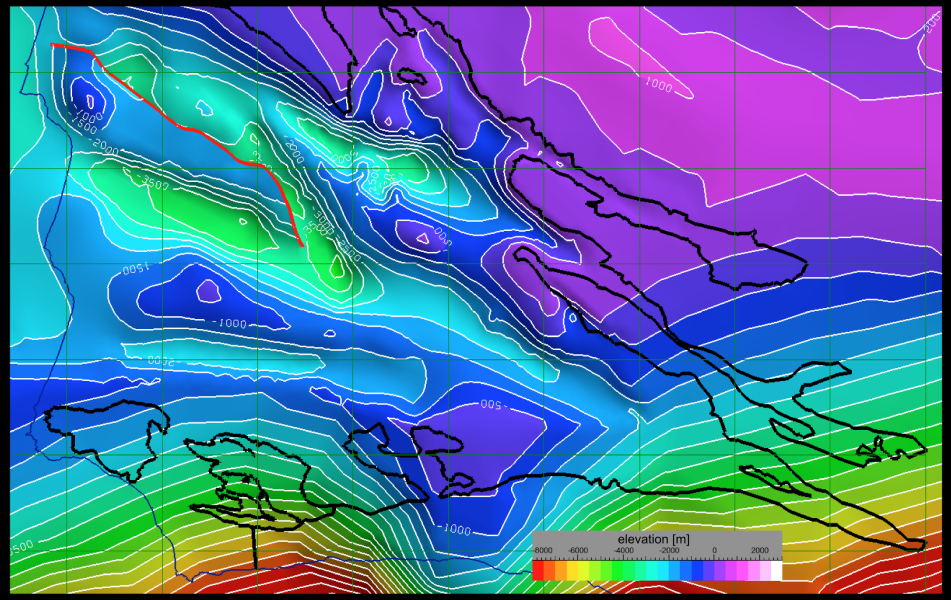
SCEC Community Velocity Models

The SCEC CVM's (CVM-S and CVM-H) are being evaluated and enhanced using 3D tomographic waveform methods (Chen et al., Tape et al.)

Models are being assessed using goodness-of-fit measures.

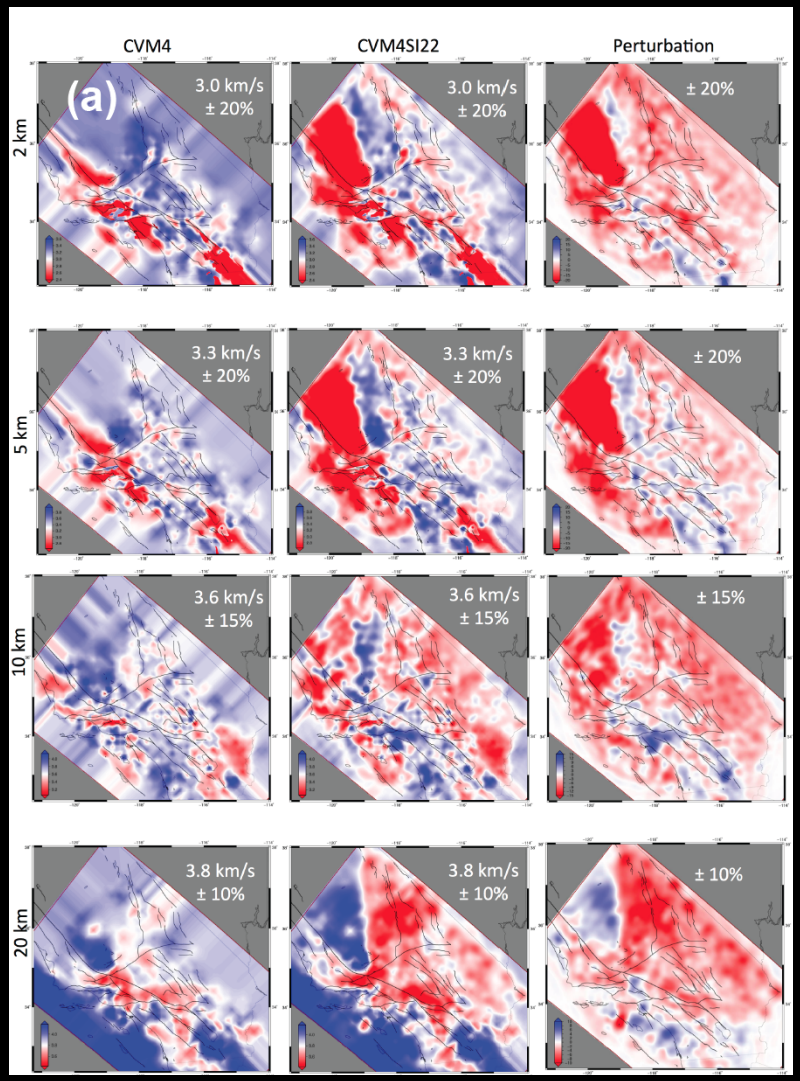
CVM-H has been enhanced to include new representation of the Santa Maria basin structures that is compatible with faults in CFM.

Santa Maria basin in CVM-H



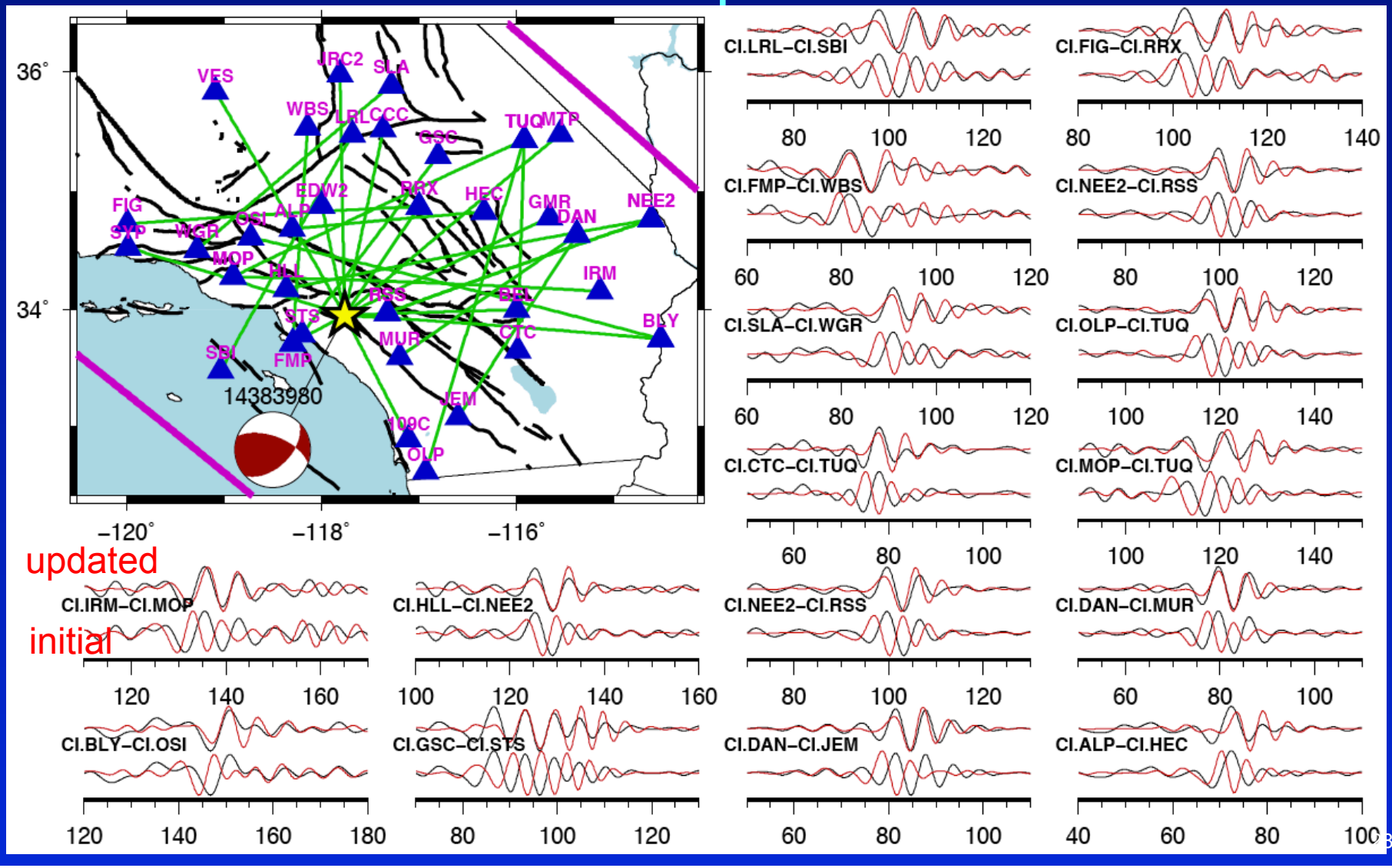
Depth contours on top basement in new Santa Maria basin model. (Plesch et al.)

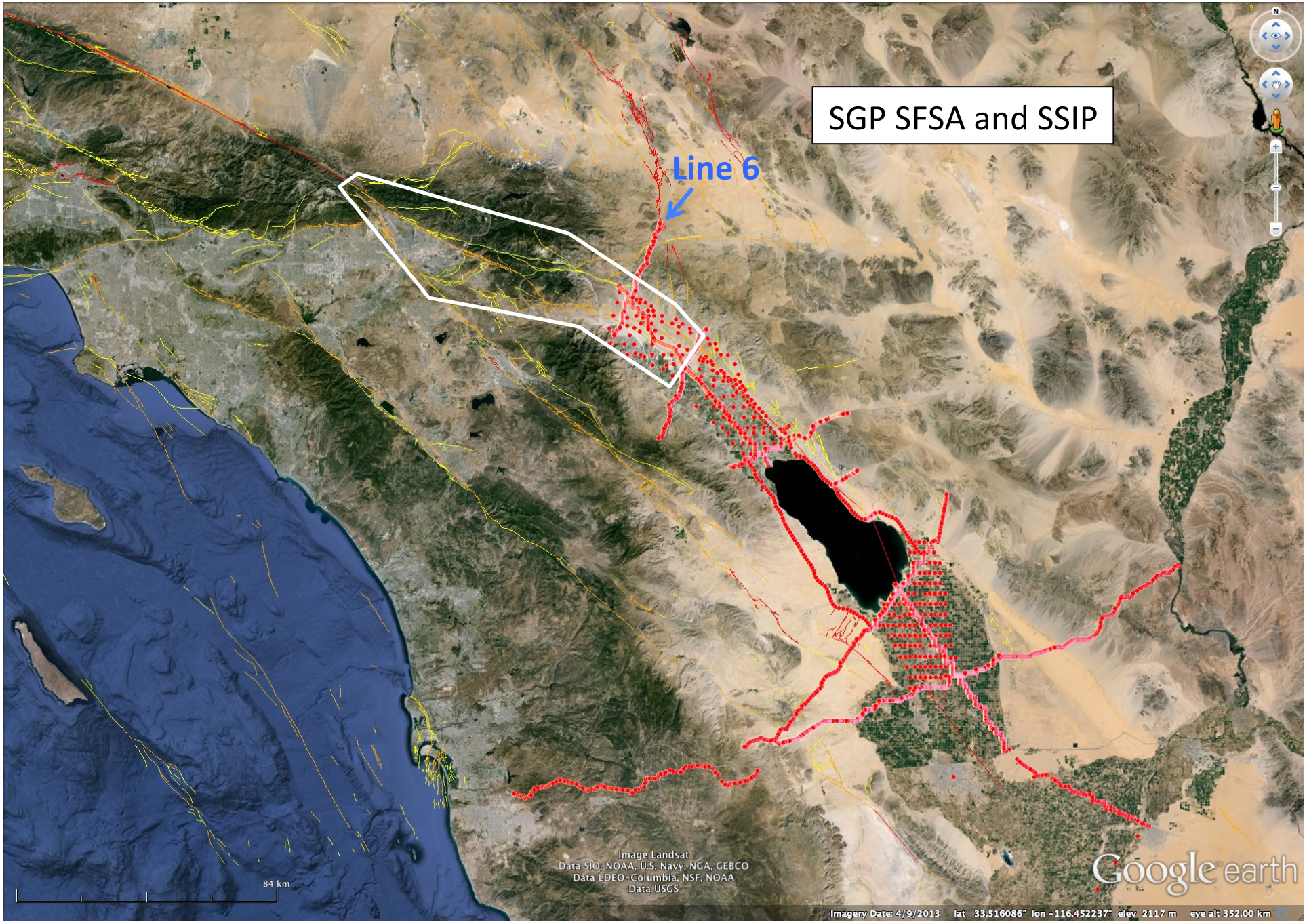
CVM-S 3D inversion



CVM-S4 (left) iterated using 3D waveform inversion (center). (Chen et al., 2013).

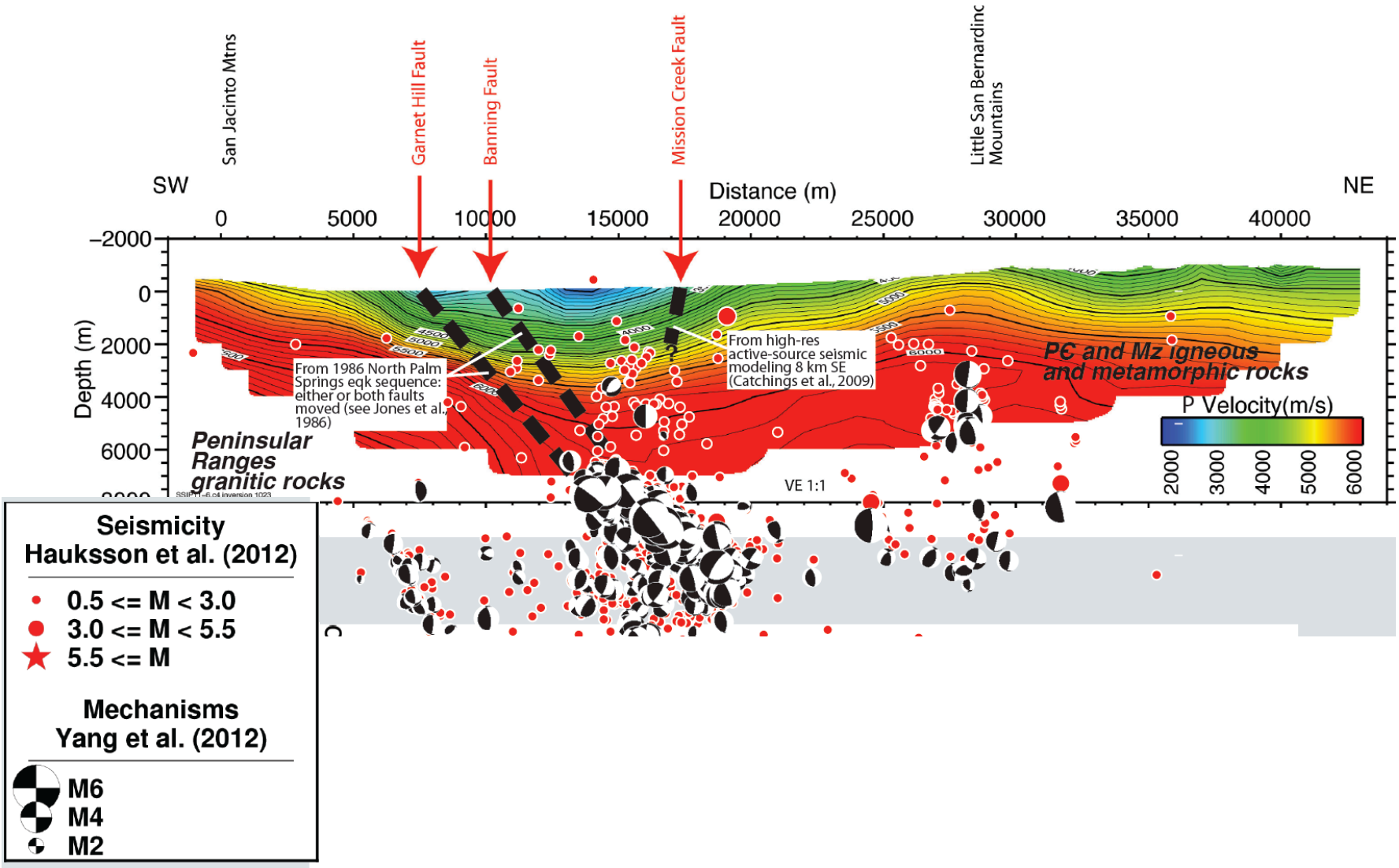
Tomography-based CVM updates produce waveform improvements





Courtesy of Joann Stock

Refraction Model (preliminary) from Line 6, SSIP



Fuis et al., 2012 http://earthquake.usgs.gov/research/structure/salton/SSIP-poster-2012-12.pdf

Stochastic Descriptions of Basin Velocity Structure from Analyses of Sonic Logs and the SCEC Community Velocity Model (CVM-H)

A. Plesch, J. H. Shaw & T. Jordan

Results:

- expansion to LA basin wide scale shows a 6.5% overall variability relative to CVM-H for the small (7m) length scale, and that the variability distribution is not Gaussian.

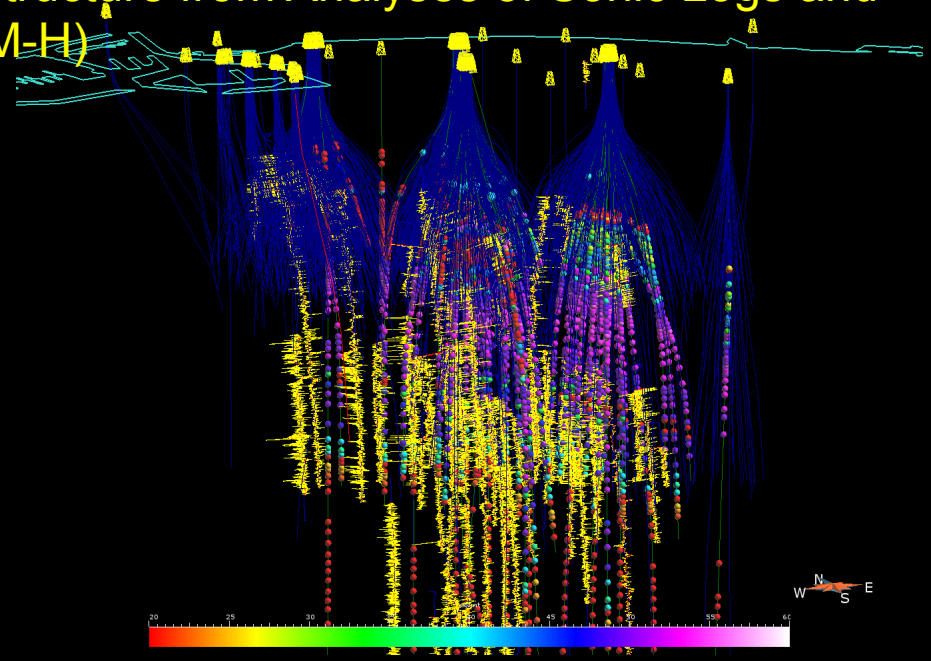
- variogram analyses reveals a (maximum) vertical correlation distance of 80-100m

- both are consistent with pilot study

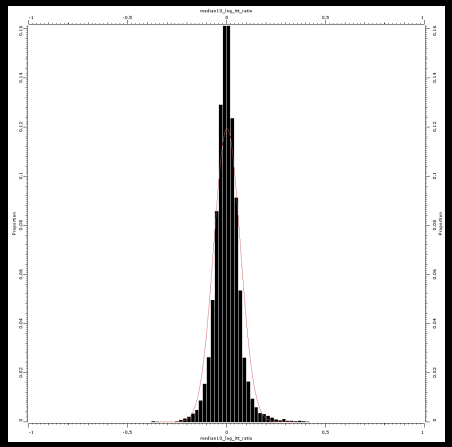
- analyses of Wilmington field data shows good potential for determination of horizontal correlation distances

- well mapped fold structure also allows for studying lateral velocity structure within thin (10-100m) layers.

- first results show horizontal corr. distance of 500m and larger layer parallel distances (see poster).



Wilmington field: 70 well paths on 7km x 2.5km with data, >1.1 million samples of interval travel times by logging tools; logs in yellow and tops as spheres

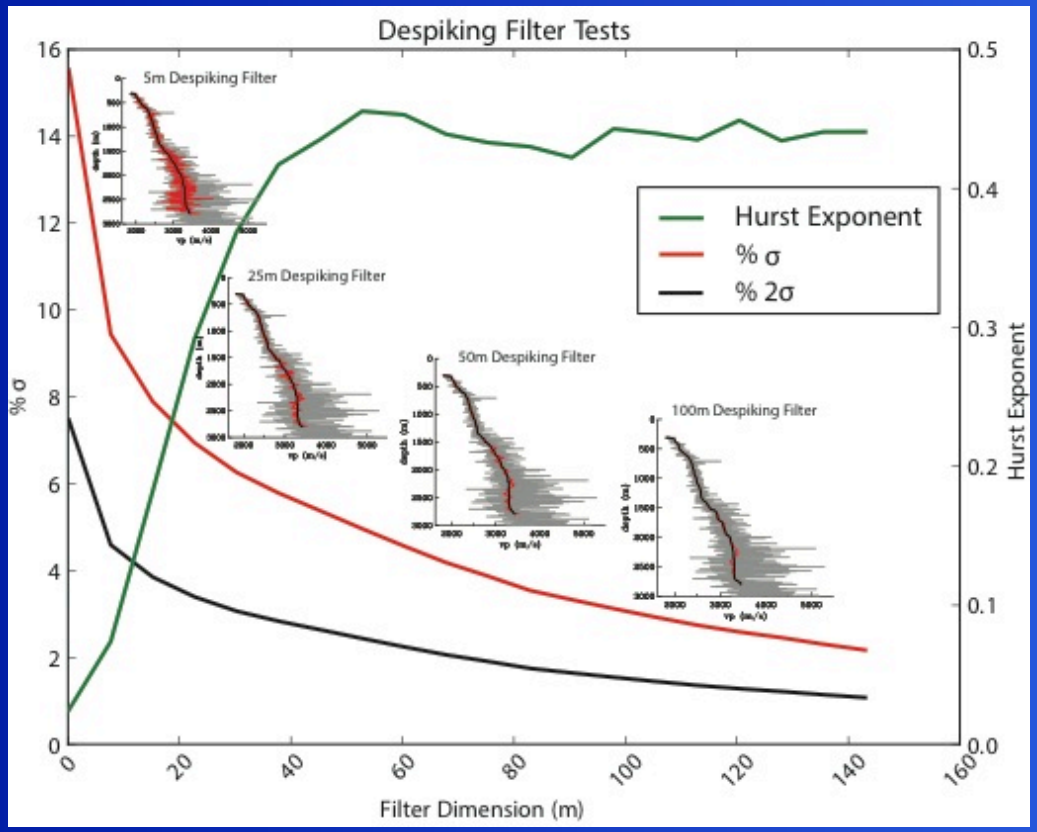


Logarithmic histogram of despiked velocities relative to CVM-H

standard deviation is 0.063 →
$e^{0.063} = 1.065$
+/- 6.5 % overall variability

Effects of Small-scale Heterogeneities on Ground Motions

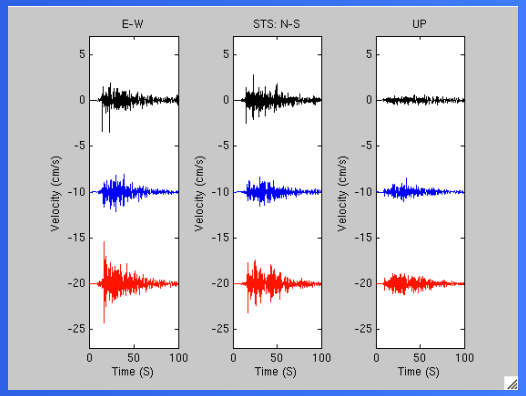
Savran, Olsen, Jacobsen (2013)

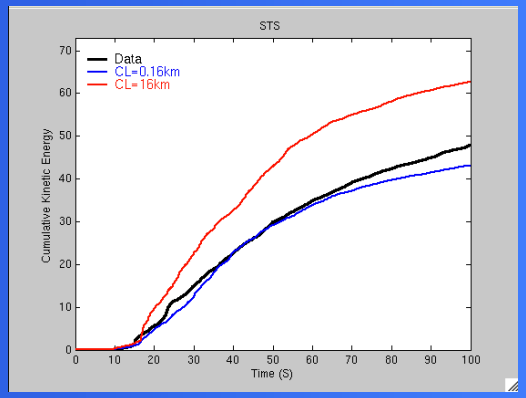


Analysis of 38 LA basin sonic logs:

Vertical Correlation Length	25-100m
Hurst Exponent	0-0.1
σ	5-10%

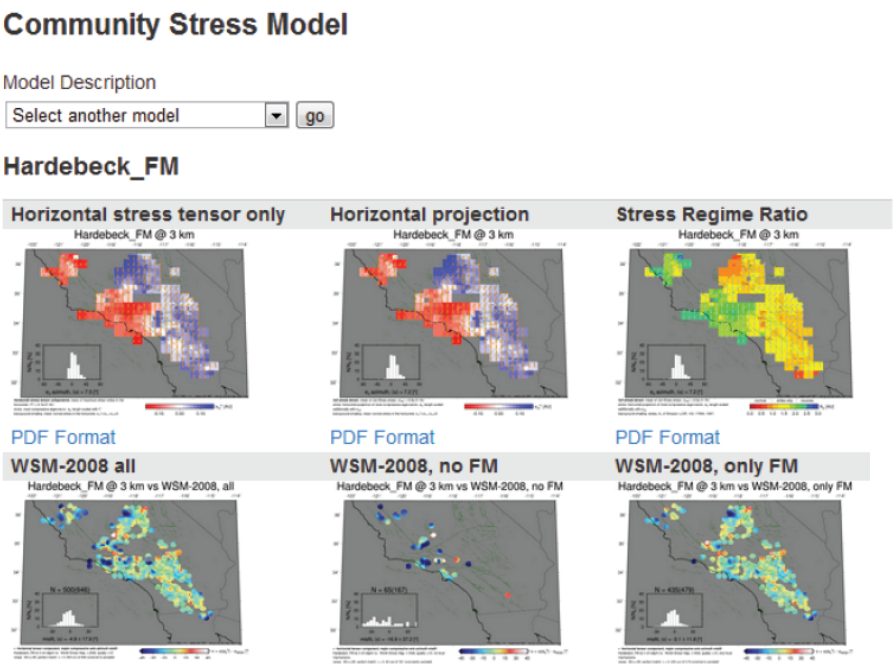
Chino Hills Test Case – (short) correlation length from data provides better fit

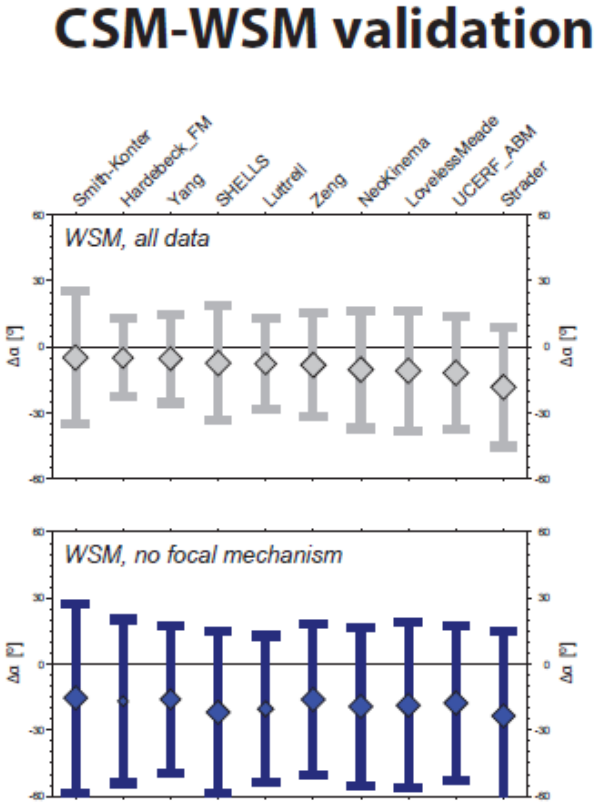


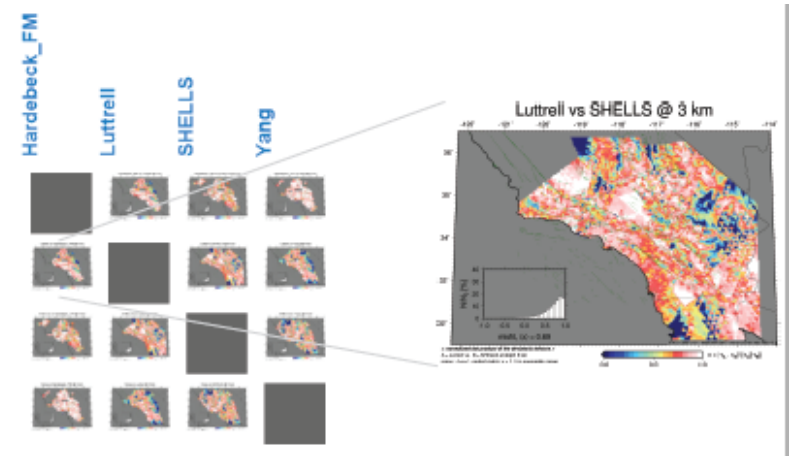


SCEC Community Stress Model (CSM)

- Workshop in Menlo Park (May 2013)
- CSM web site now online with
  - 4 stress, 6 stressing rate models
  - “validation” of models with WSM
  - All data, scripts, workshop presentation downloadable







The Community Geodetic Model

Motivation:

Spatially and temporally dense time series of ongoing deformation utilizing the complimentary features of GPS and InSAR data are expected to be central to several SCEC4 core initiatives and science targets.

The continued expansion of GPS coverage, pending launch of new SAR satellites, recent advances in InSAR time series analysis, and ongoing advances in noise assessment and mitigation can be leveraged in order to develop methodology for generating a combined GPS/InSAR time series product.

Some target applications for the CGM:

- Quantifying slip rates and strain rates and their spatial variations in the complexly faulted southern California region, including off-fault strain
- Assessing non-tectonic time-varying signals without aliasing
- Detecting transient deformation and tracking its space/time evolution at sufficient precision to relate it to other processes such as seismicity
- Constraining lithospheric rheology and evaluating its role in earthquake cycle deformation
- Characterizing postseismic deformation and the underlying physical processes
- Providing input to develop or refine stress and stressing rate models and/ or to validate candidate stressing rate models for the Community Stress Model

Different applications require different spatial and temporal data coverage and resolution; GPS and InSAR can complement each other.

Available Data: GPS and EDM

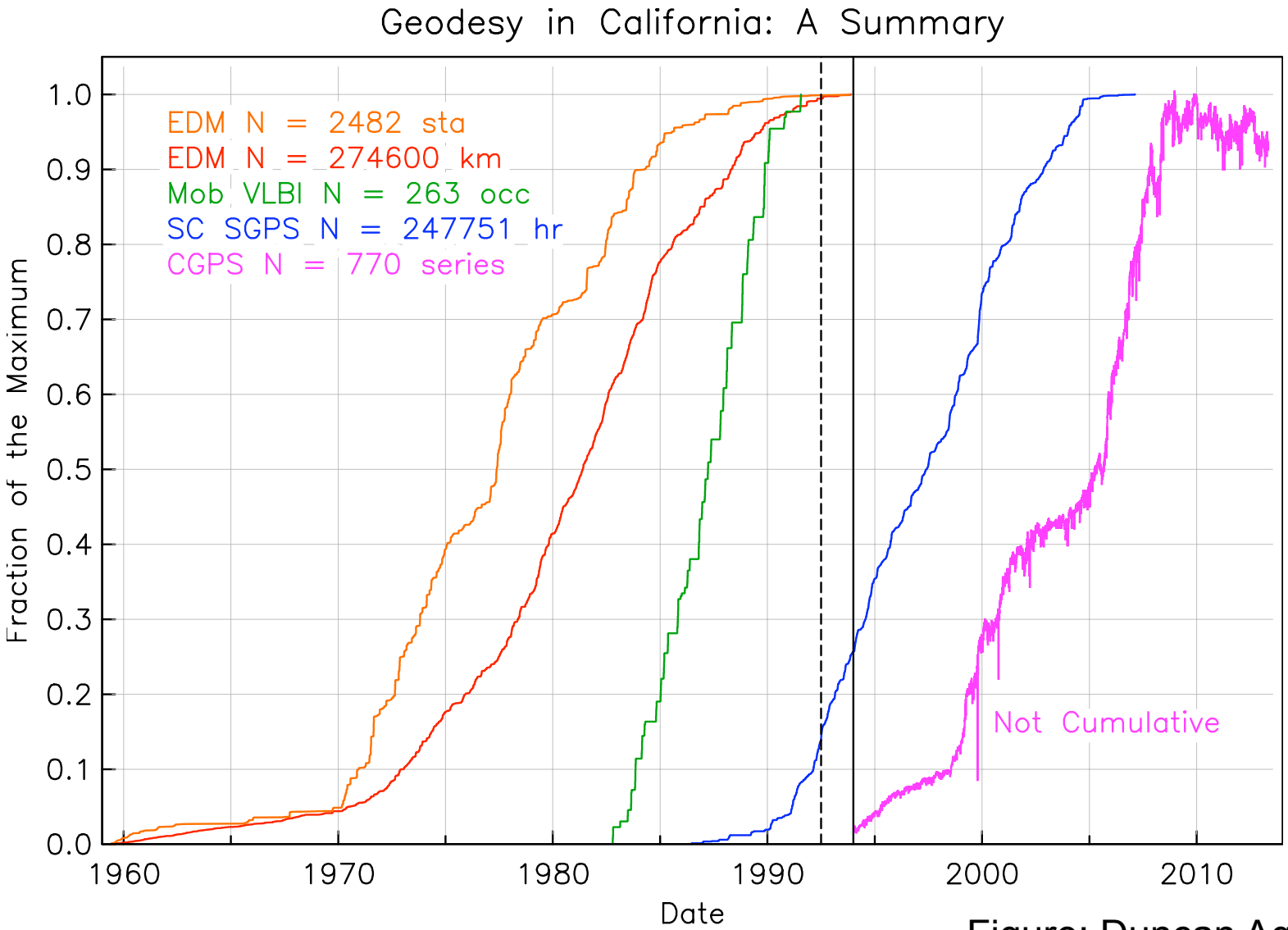
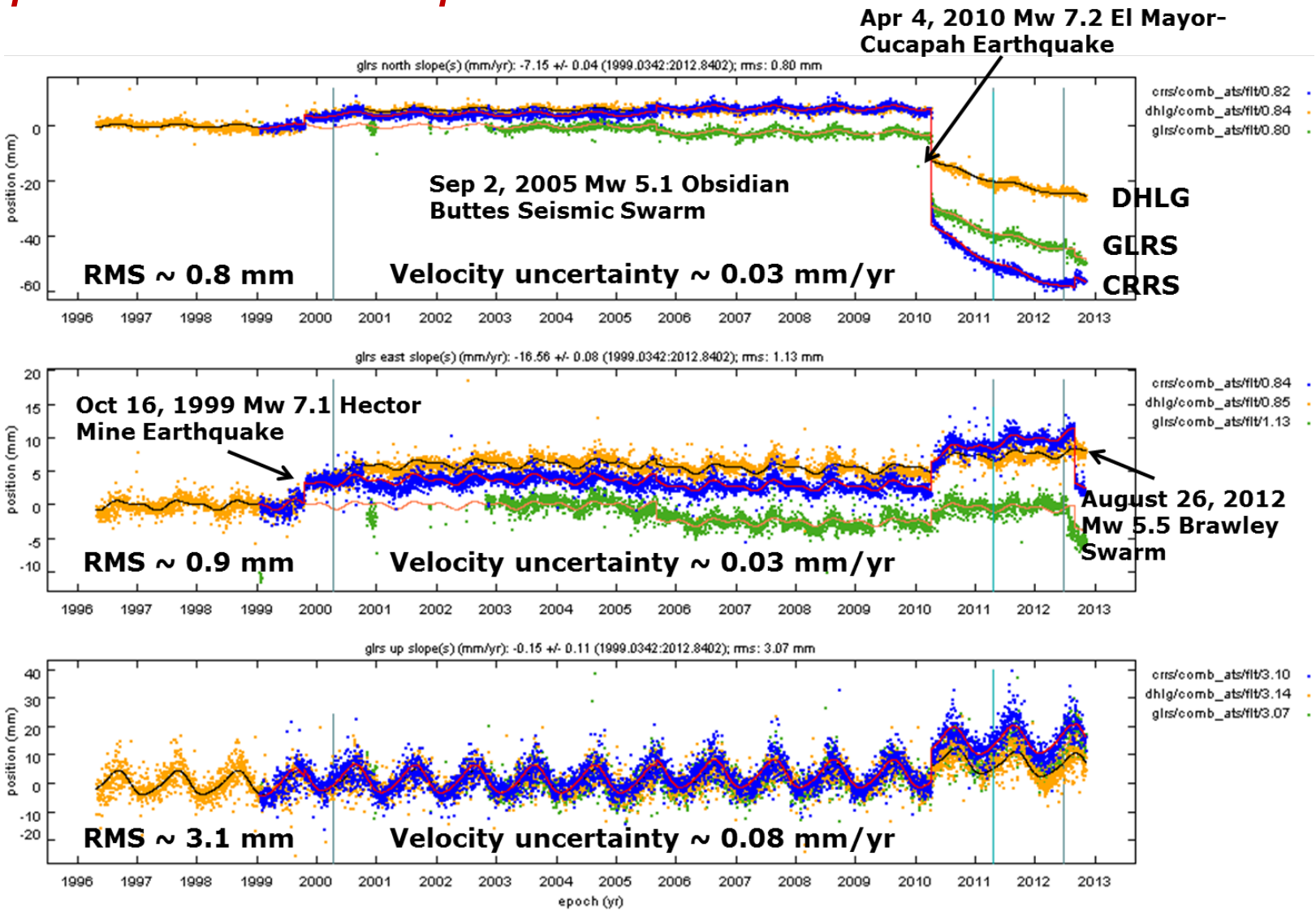


Figure: Duncan Agnew

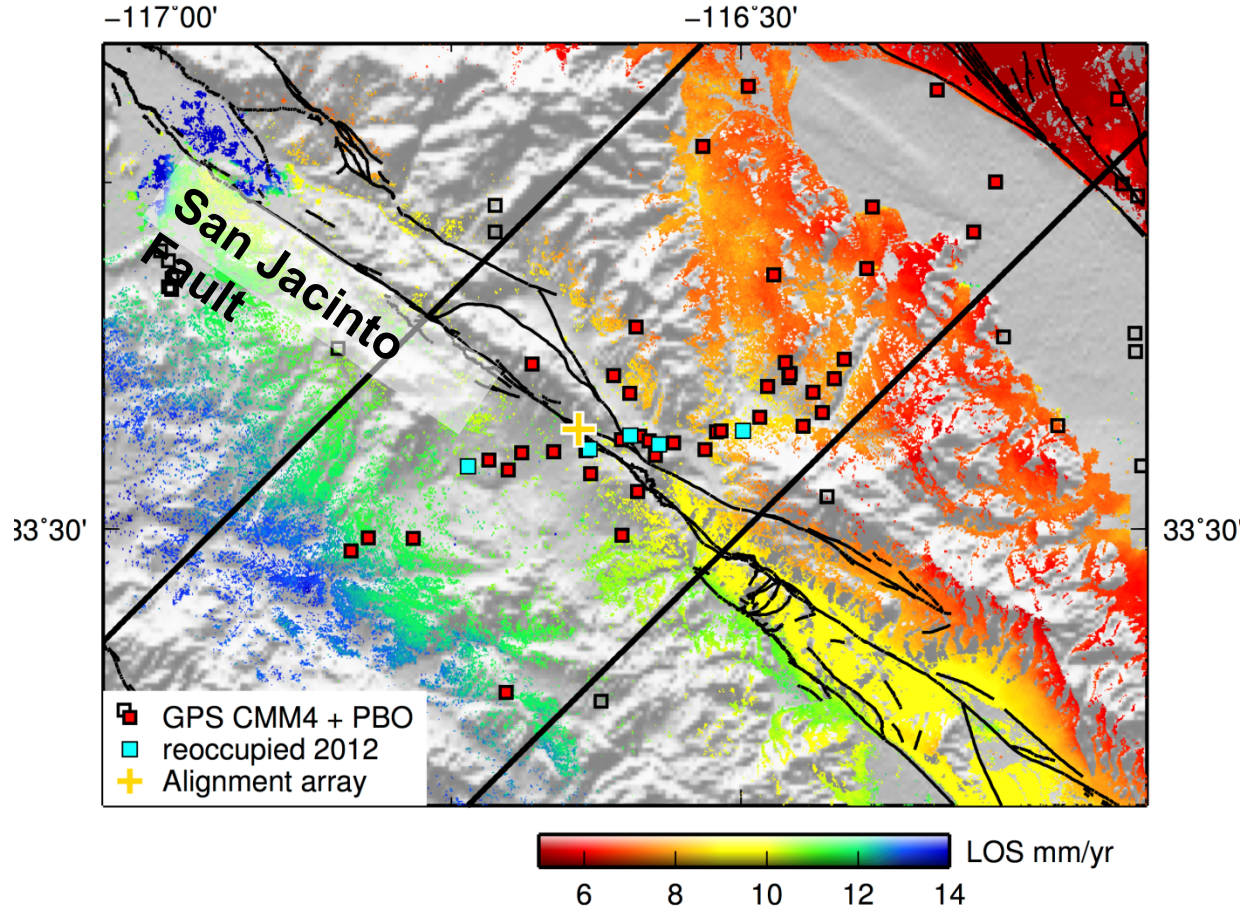
GPS can provide high temporal resolution and three displacement components

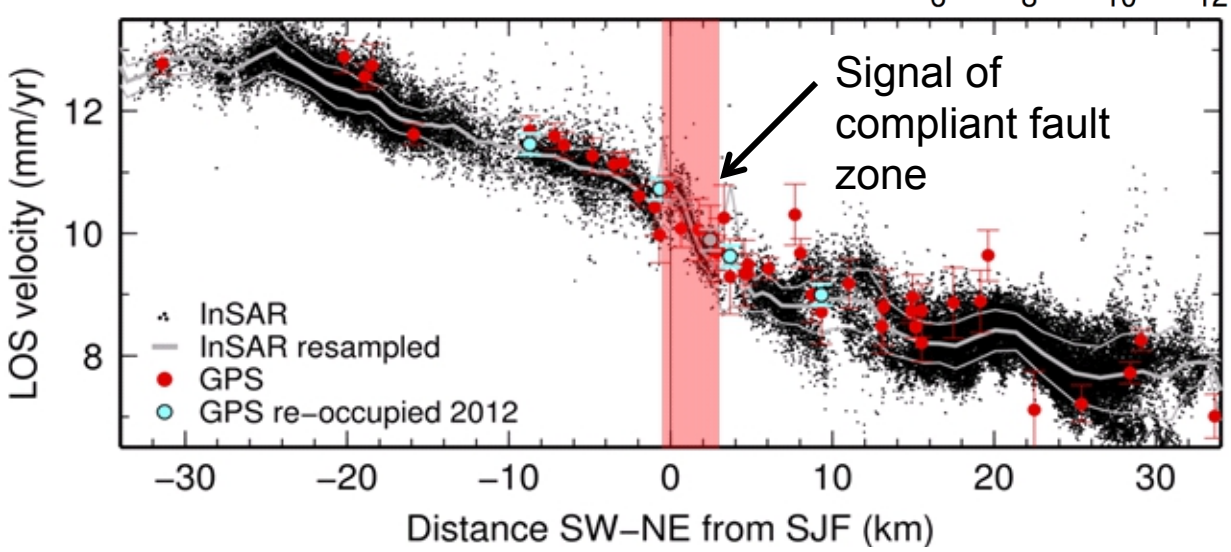


JPL/SOPAC Combined Time Series, figure courtesy Sue Owen

InSAR data reveal fine-scale features

Here, increased shear strain rate near SJF may indicate a compliant fault zone with implications for inferred locking depth and stress state.





Figures courtesy Yuri Fialko

CGM Workshop: May 30 – 31, 2013, Menlo Park

- 29 participants including experts in GPS and InSAR as well as representatives of the CSM, Ductile Rheology, Transient Detection, and UCERF3 efforts
- Established what CGM will comprise:
  - Will include campaign and continuous GPS, any available InSAR data
  - Three basic categories: GPS-only, InSAR-only, combined product
  - Raw time series: GPS 3D, InSAR LOS
  - Derived quantities: secular rates, offsets, outliers, postseismic decay terms, seasonal models, noise parameters, common mode filter parameters, InSAR coseismic displacement fields
  - Combined product will not be interpolated to a uniform grid; will be more dense near faults (in part driven by availability of GPS sites which are used to constraint InSAR)

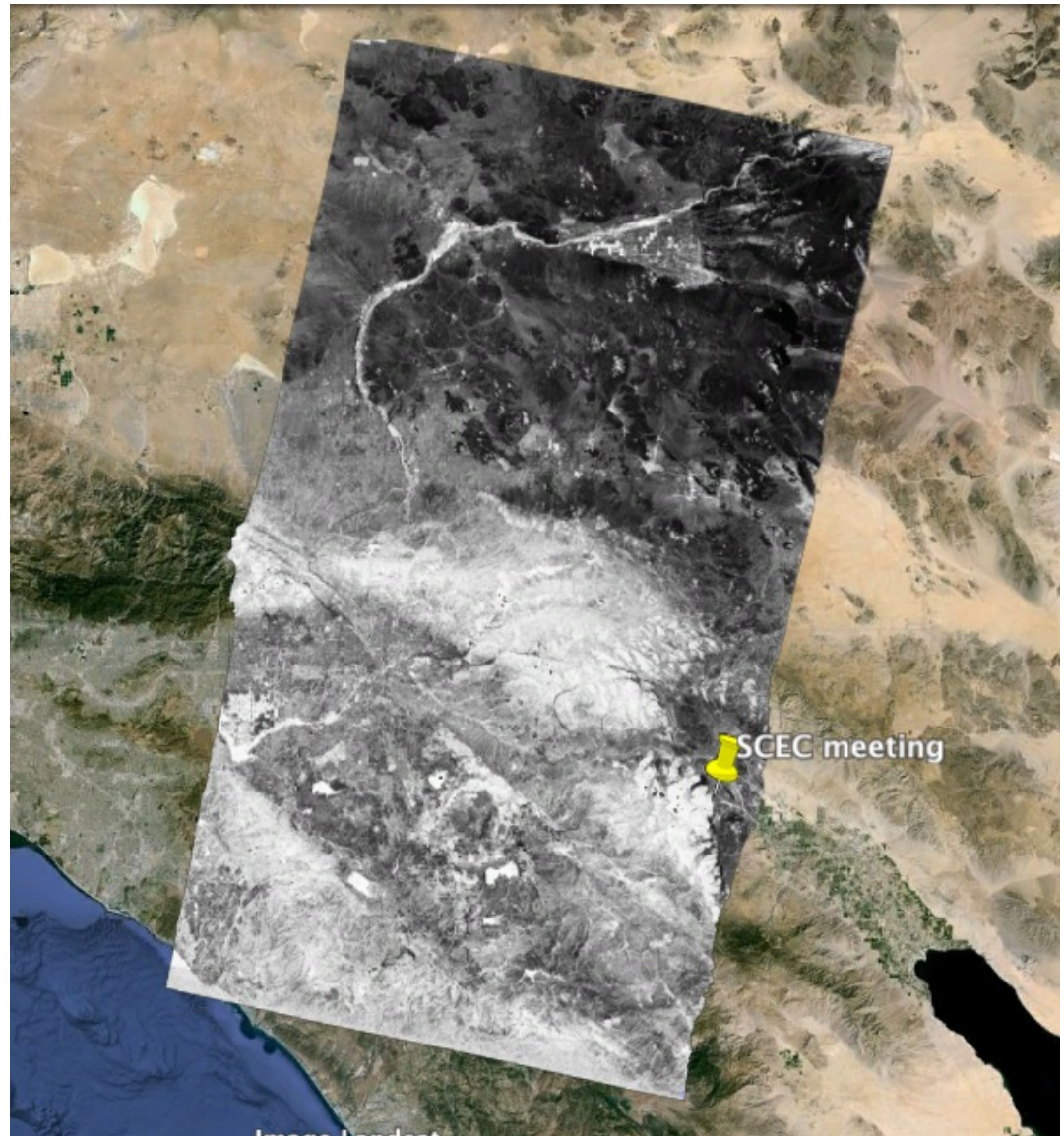
Next Steps

- **Additional data gathering, comparisons, and method development are needed for both the GPS and InSAR components before we can begin merging them**
- **This will be done within two working groups, GPS and InSAR**
- **GPS action items:**
  - Gather all SGPS data and metadata
  - Compare results from different groups' GPS processing
  - Merge campaign and CGPS processed results (reprocess if needed)
  - Perhaps collect more campaign data (low-hanging fruit)
  - Decide best strategy for modeling noise, postseismic, seasonal and apply
- **InSAR action items:**
  - InSAR time series analysis test exercise to establish best practices
  - Reach out to broader InSAR community, including international, as appropriate
- **Both:**
  - Determine what computational infrastructure is needed for working group activities (e.g., for SGPS metadata compilation and validation, comparison of solutions, blind tests of different approaches)
  - Follow-on: Noise modeling; approaches for obtaining covariance of joint data product

Crustal Geodetic Model

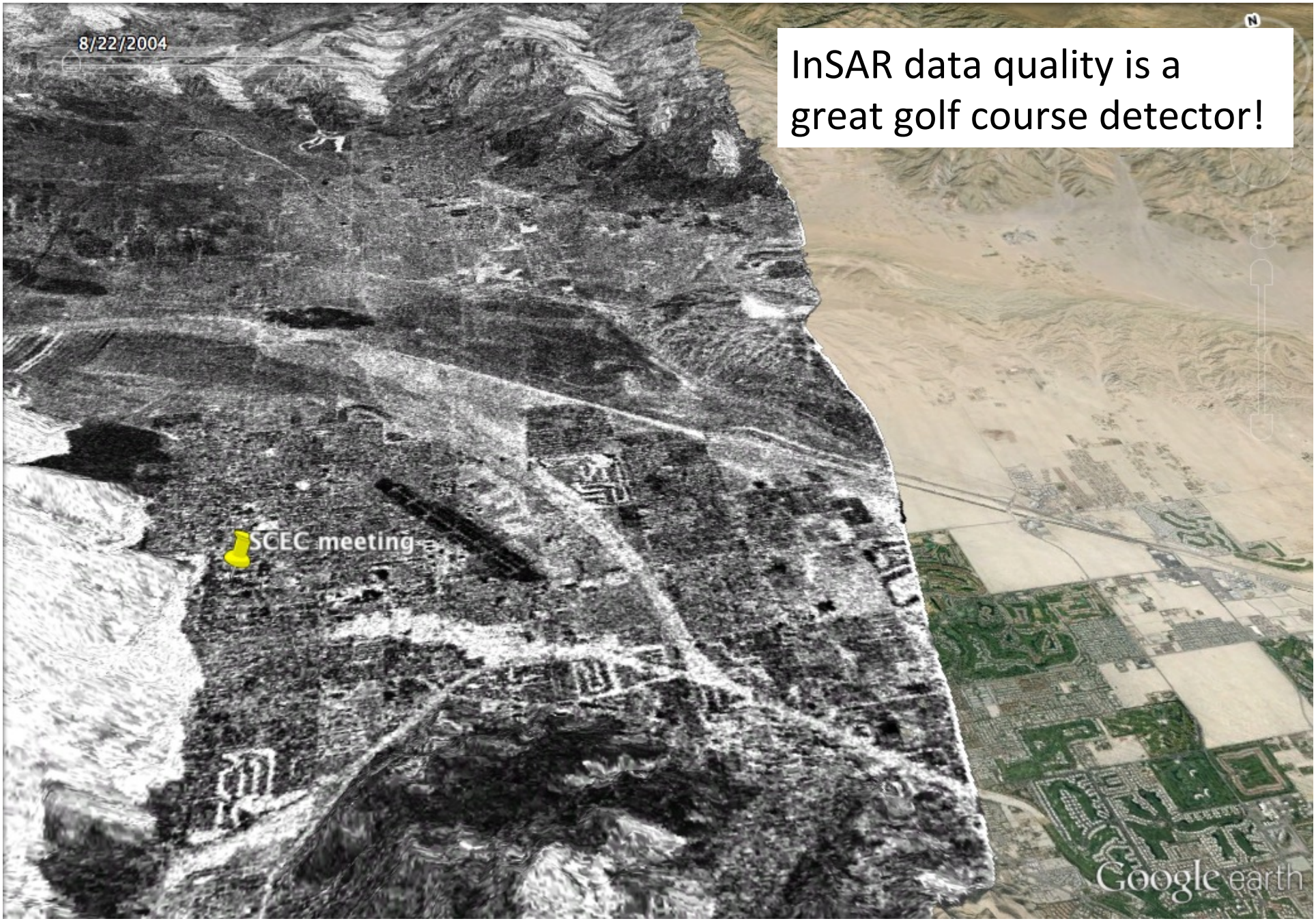
InSAR time series comparison exercise:

- Explore InSAR-only signal
- Compare against individual GPS sites
- T399 (ERS+Envisat)
- Any time series approach welcomed!



Average interferogram quality over test area
Dark = high, light = low


SCEC meeting
Google earth



InSAR data quality is a great golf course detector!

For more information

Breakout session: **Monday 4:00 – 5:00 PM in Oasis II**

Workshop webpage: http://www.scec.org/workshops/2013/cgm/index.html

Workshop report:

Murray, J., R. Lohman and D. Sandwell (2013), Combining GPS and Remotely Sensed Data to Characterize Time-Varying Crustal Motion, *Eos Trans. AGU, 94*(35), 309.

Wiki: http://collaborate.scec.org/cgm

Mailing lists:

http://mailman.scec.org/mailman/listinfo/cgm **(general postings)**

http://mailman.scec.org/mailman/listinfo/cgm-g **(for GPS focus-group)**

http://mailman.scec.org/mailman/listinfo/cgm-i **(for InSAR focus-group)**

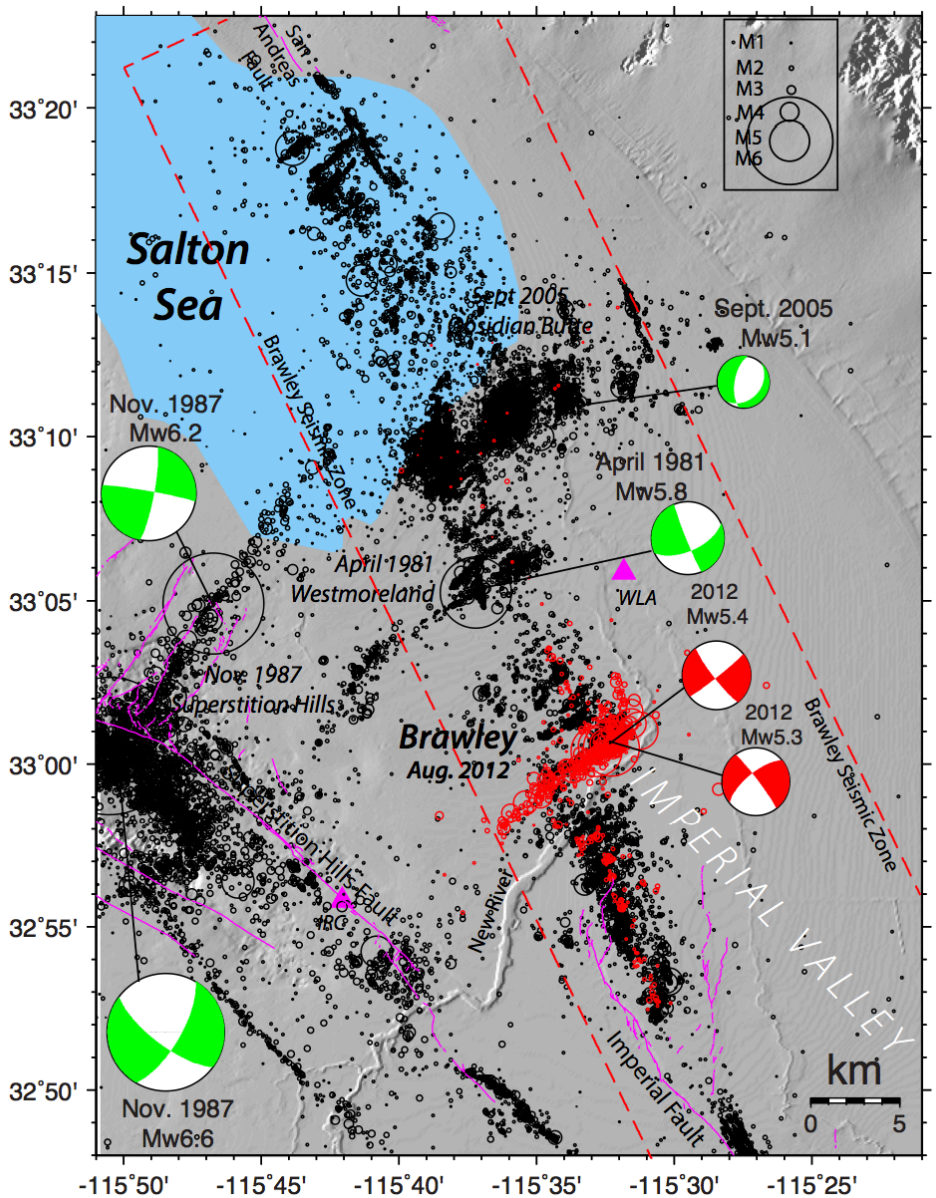
Contact information:

Jessica Murray (jrmurray@usgs.gov)

Rowena Lohman (rolohman@gmail.com)

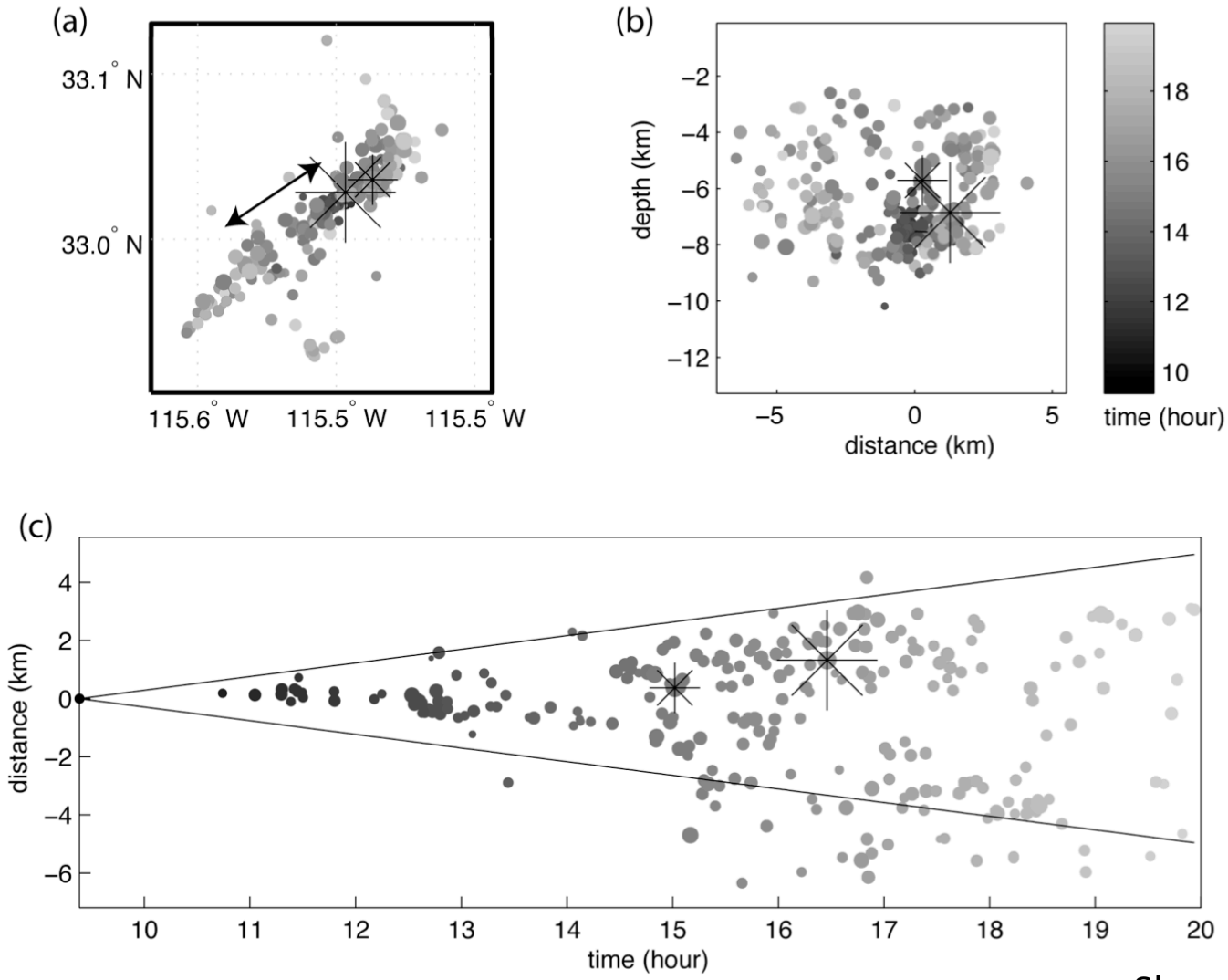
David Sandwell (dsandwell@ucsd.edu)

Ready to Respond to Events: Brawley Seismic Swarm



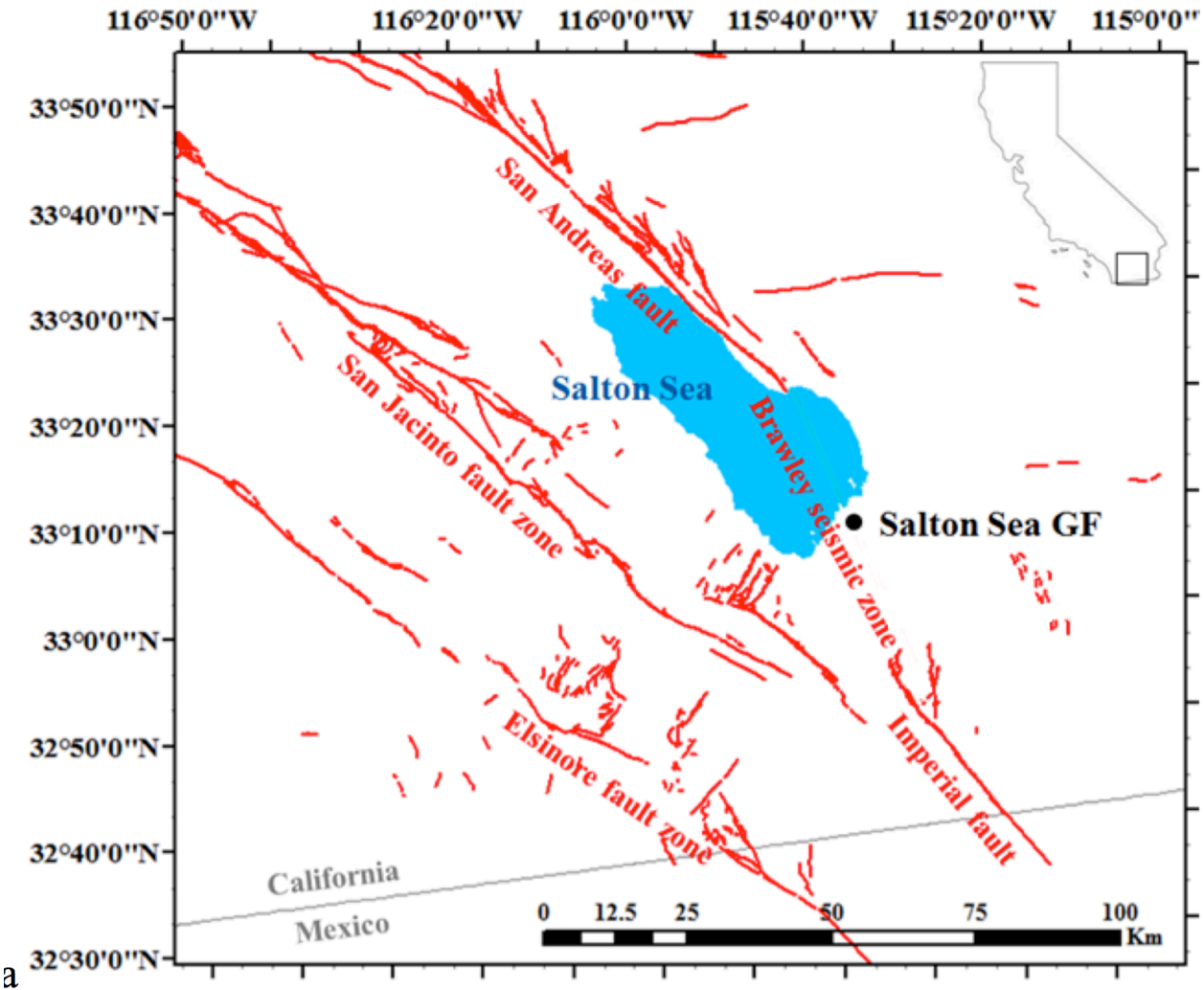
Shearer and Hauksson report

Brawley Seismic Swarm



Shearer and Hauksson report

Connecting Induced Seismicity Rates to Operations at The Salton Sea Geothermal Field



Poster #258 a

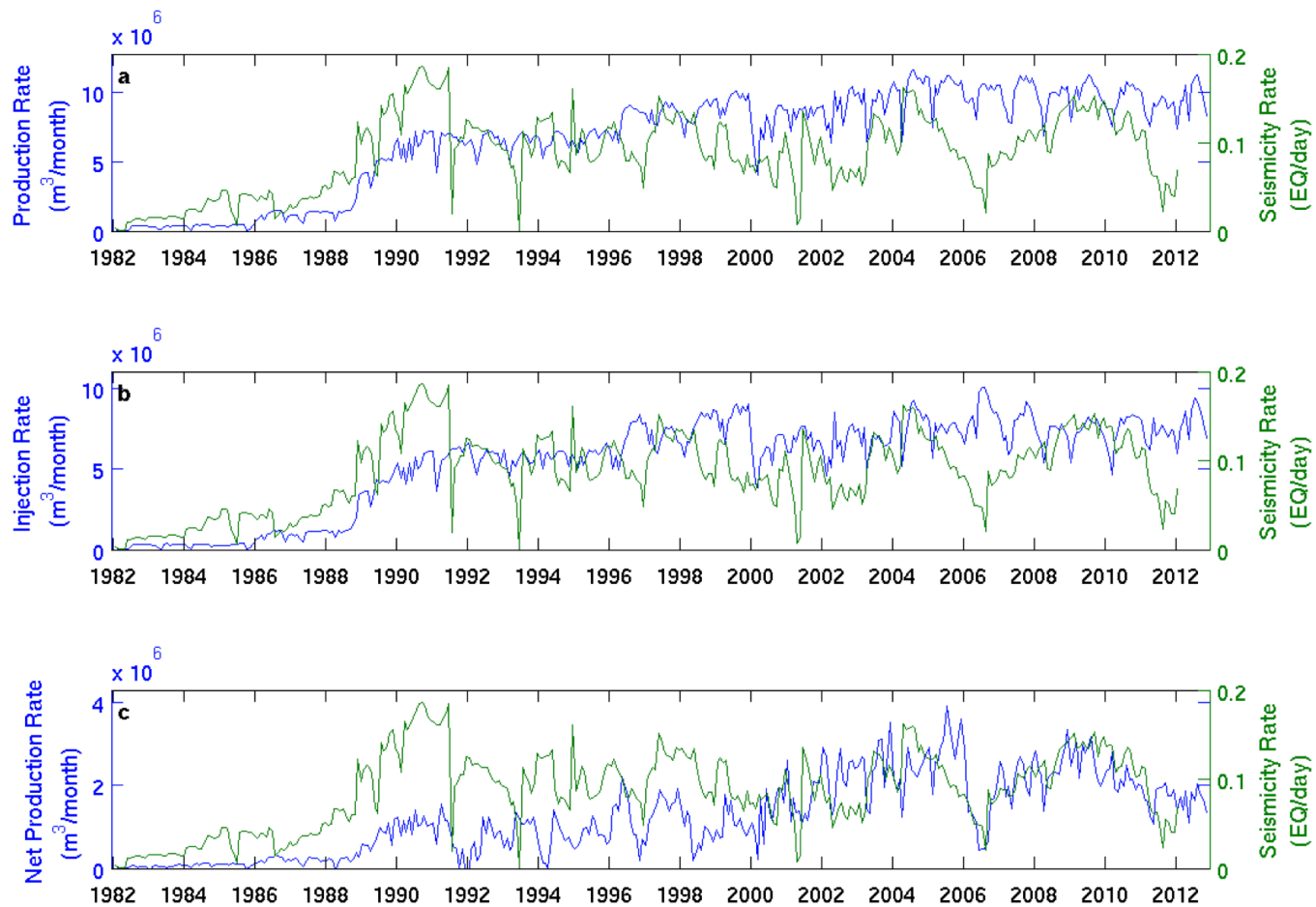
Brodsky and Lajoie, 2013

Connecting Induced Seismicity Rates to Operations at The Salton Sea Geothermal Field

Production

Injection

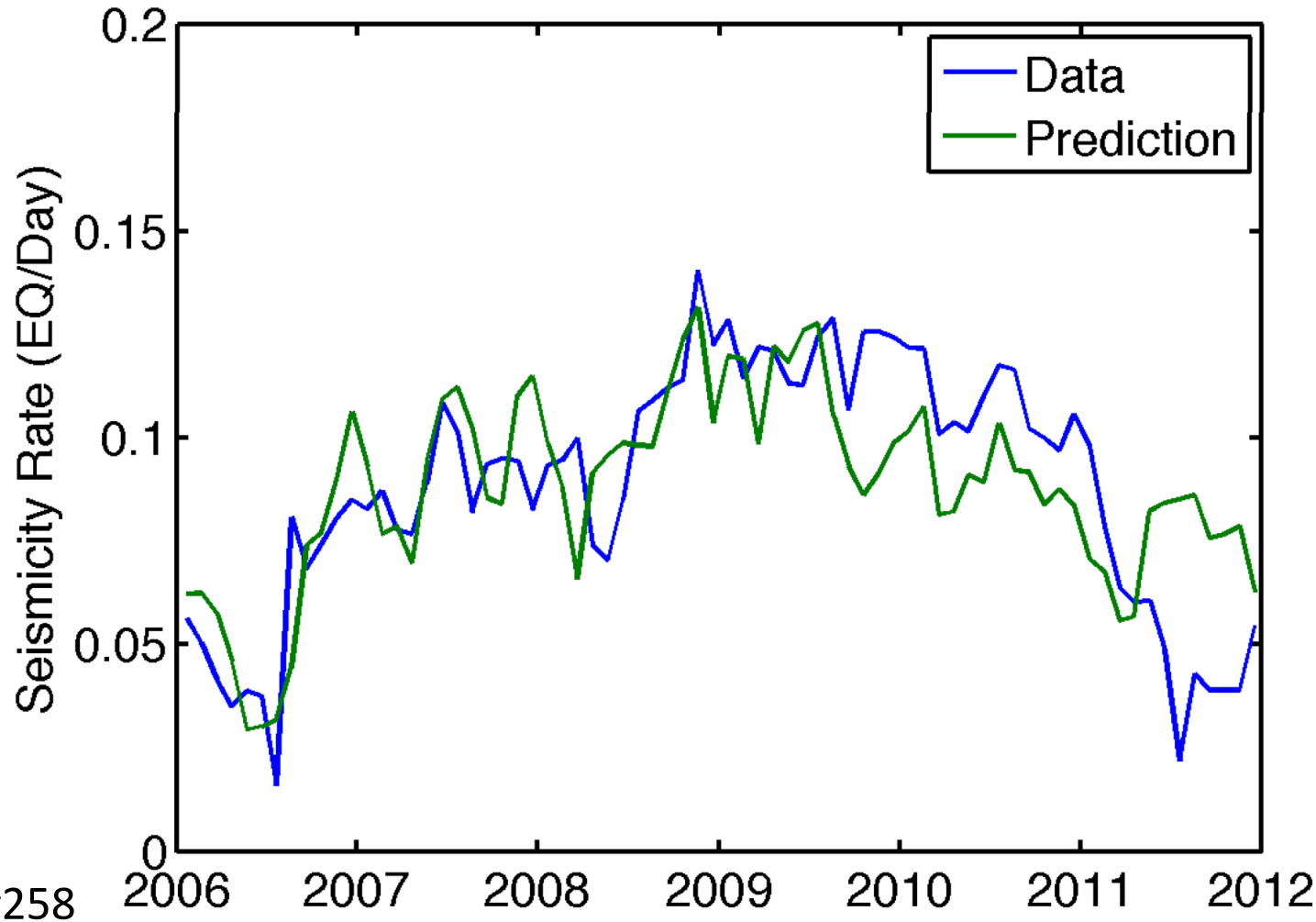
Net



Poster #258

Brodsky and Lajoie, 2013

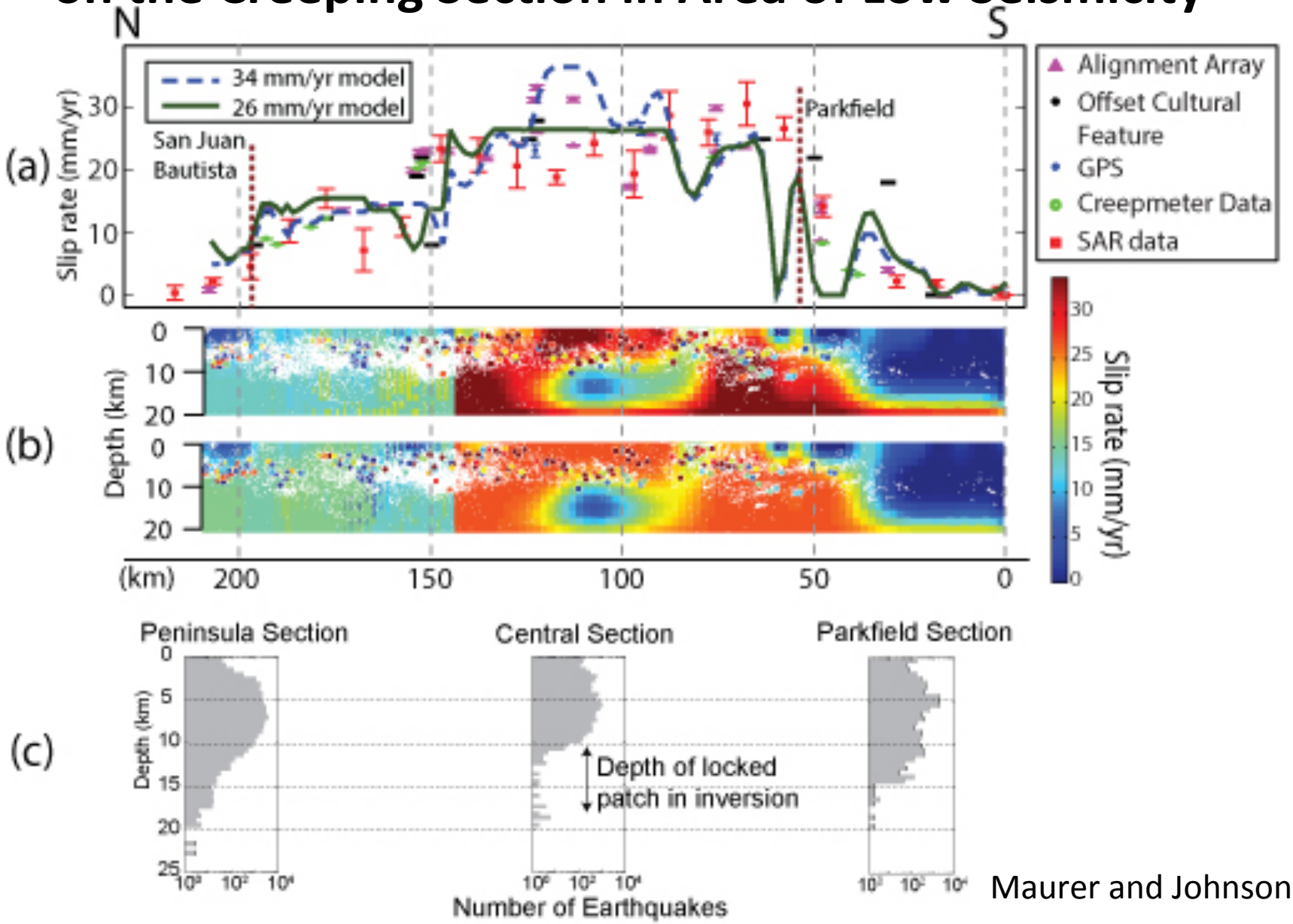
Connecting Induced Seismicity Rates to Operations at The Salton Sea Geothermal Field



Poster #258

Brodsky and Lajoie, 2013

GPS + InSar Show Possible Locked Patch on the Creeping Section in Area of Low Seismicity



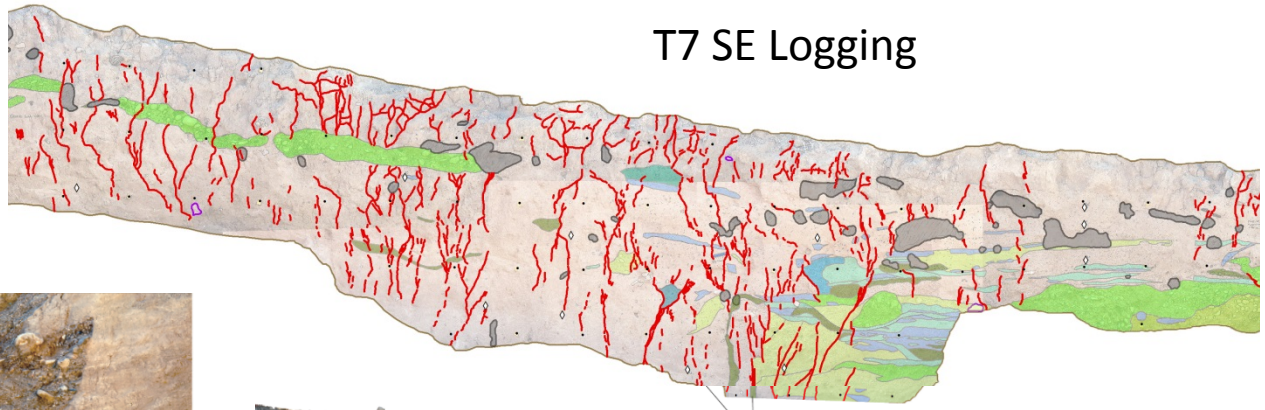
Maurer and Johnson

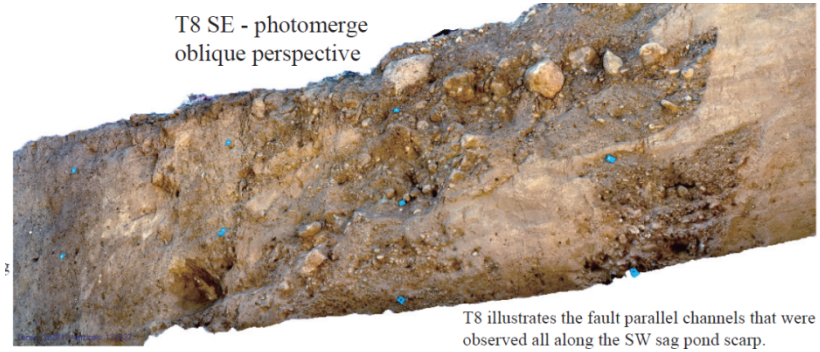
Dry Lake Valley Site *(Creeping Section)*
9 Trenches, > 1300 Years of Stratigraphy,
No Large Ground Ruptures, but Plenty of Creep

(maybe evidence of accelerated creep due to moderate magnitude or nearby quakes)

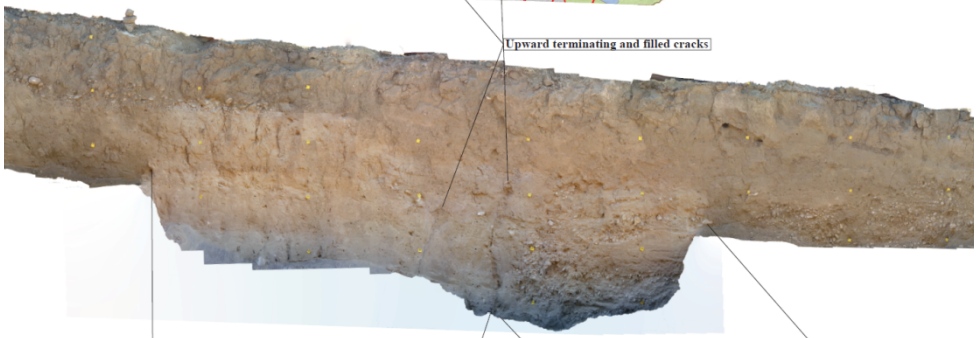
Agisoft Photoscan 3D mosiacs
A Great Tool for Photologging!

T7 SE Logging

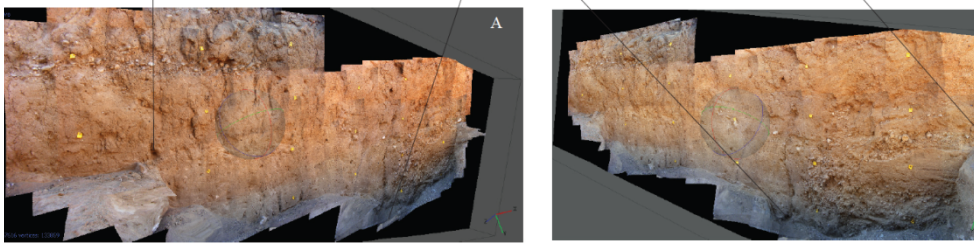




T8 illustrates the fault parallel channels that were observed all along the SW sag pond scarp.



T7 SE - perspective views facing west (A) and east (B) from AgiSoft Photoscan



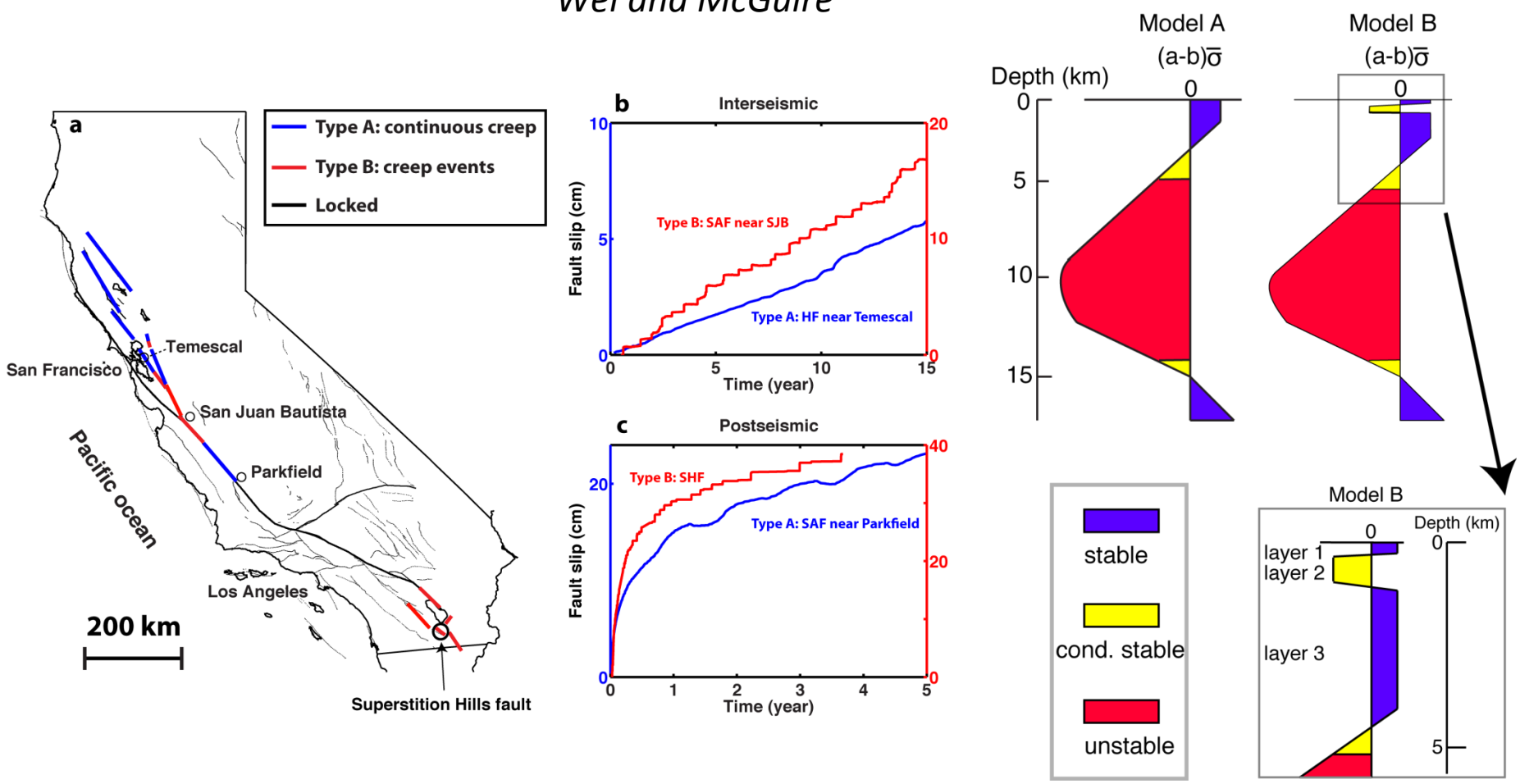
UTAH VALLEY UVU UNIVERSITY Department of EARTH SCIENCE

ASU SCHOOL OF EARTH & SPACE EXPLORATION ARIZONA STATE UNIVERSITY

Nathan Toké, J. Barrett Salisbury, J Ramón Arrowsmith
Ephram Matheson, Lawrence Kellum, Kade Carlson,
and Danny Horns
Tsurue Sato, Nicole Abueg, Jim Anderson, and Jeff Selck

Investigation of causes and effects of transient deformation on the Superstition Hills Fault with physics based model

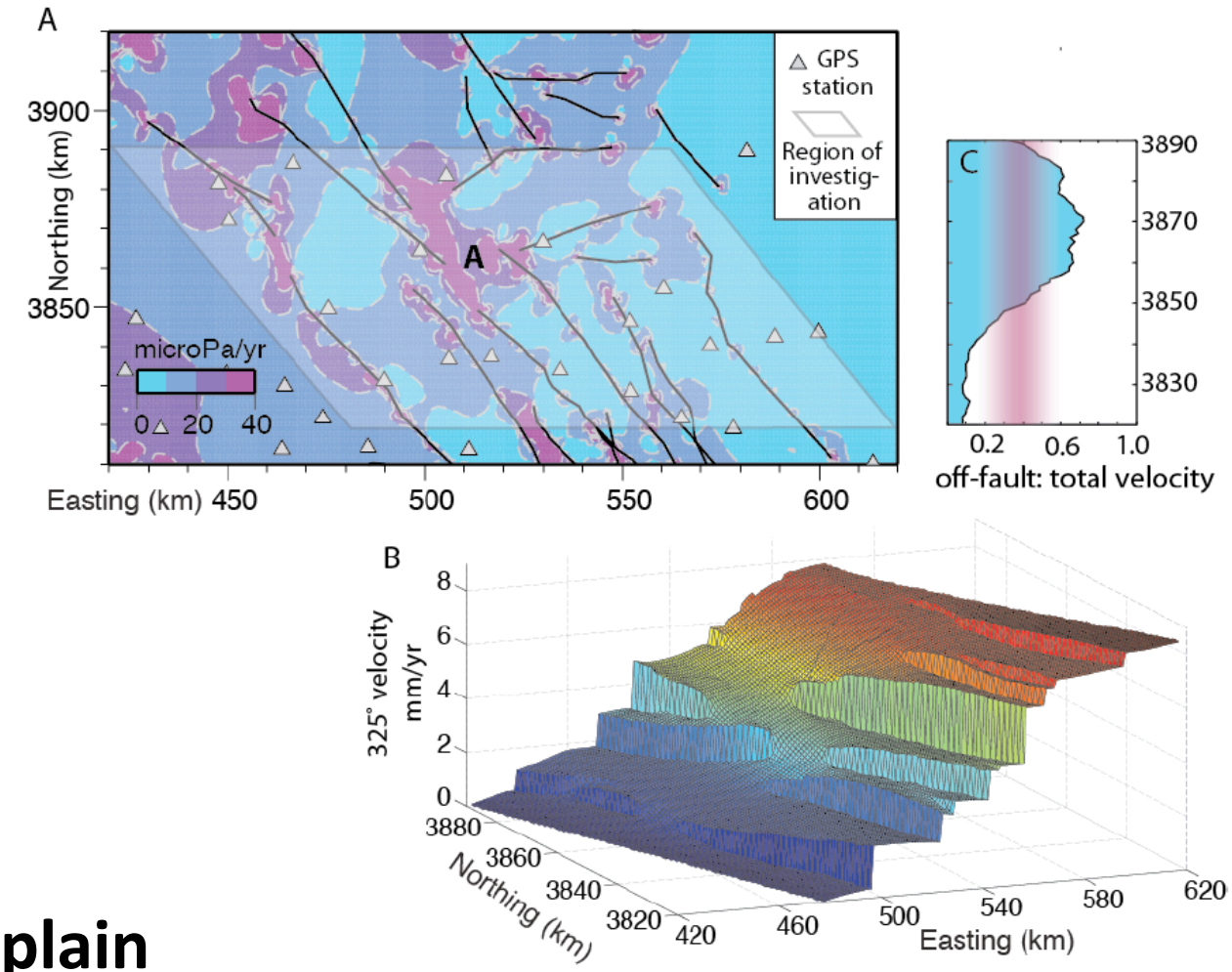
Wei and McGuire



Shallow frictional heterogeneity (Model B) is required to explain the observation on the Superstition Hills Fault

Wei et al., Nature Geoscience, 2013

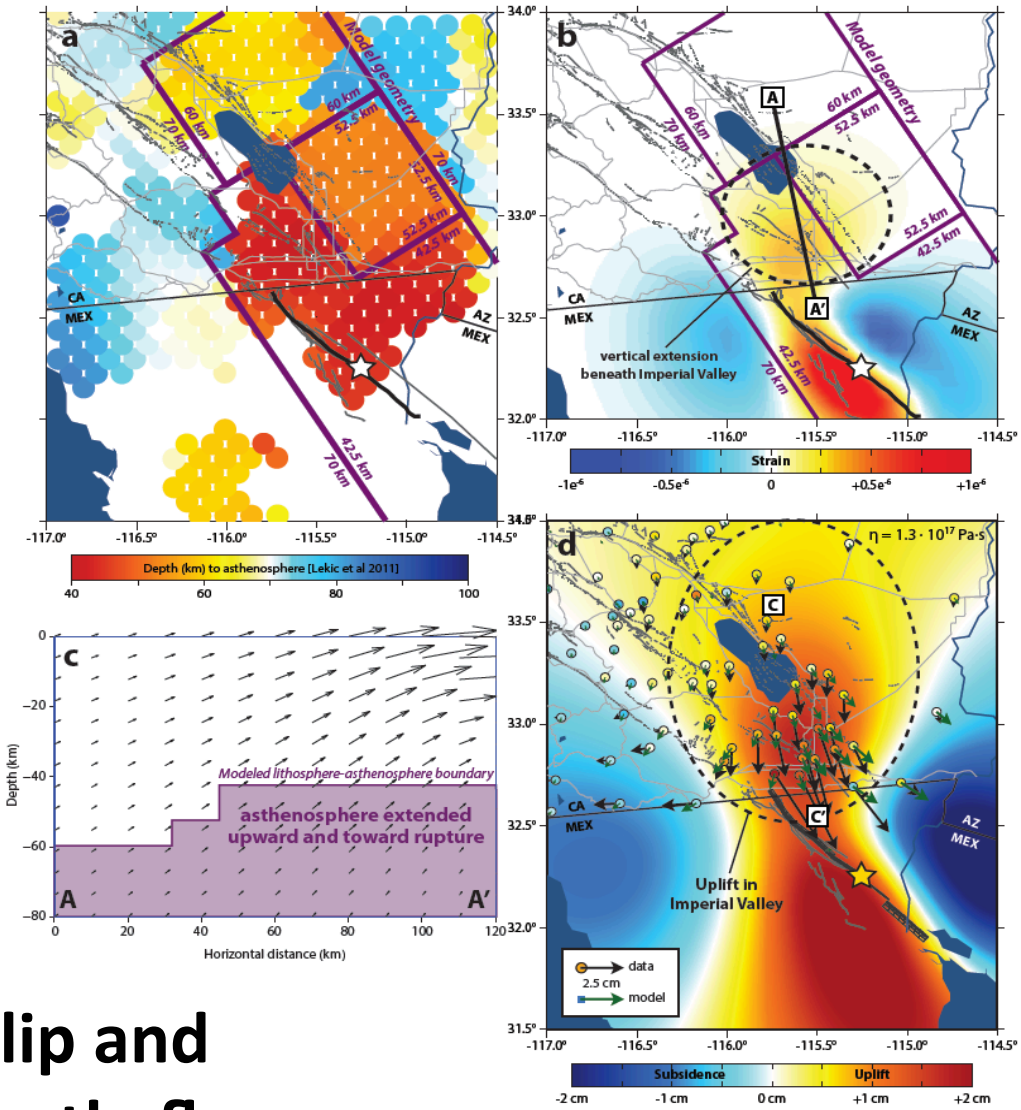
Slip on Discontinuous Faults in the ECSZ



Could explain discrepancy between geology and geodesy

Cooke and Oskin
Poster #126

El Mayor-Cucapah Postseismic Deformation



Both afterslip and induced mantle flow required to fit the data.

Rollins *et al.*

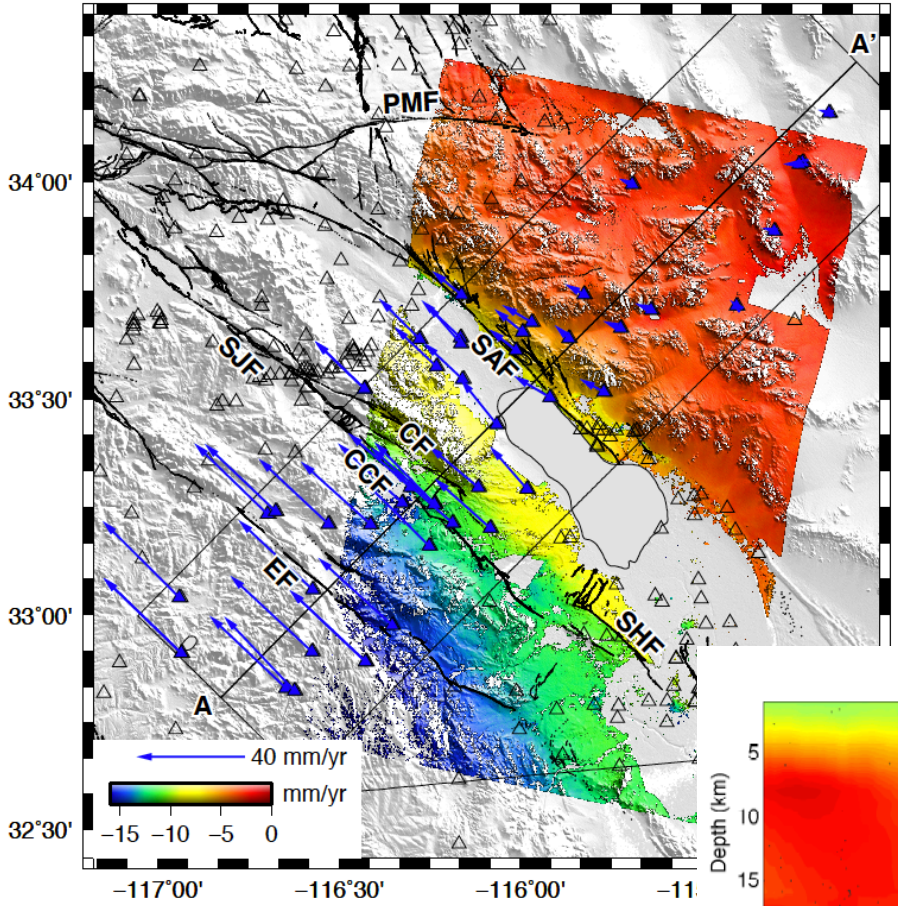


Figure 1: Map of the study region showing horizontal GPS velocities in tl (NAFD) frame and InSAR data from ERS-1/2 track 356, in addition to US faults (cite) and shaded topography. Data used in the inversion were sele profile from A - A'. Faults considered in the model are the Elsinore fa fault (CCF), Clark fault(CF), and San Andreas fault (SAF). Also shown a (SHF), Imperial (IF), northern San Jacinto (SJF), and Pinto Mountain fa

Elastic variations have a small effect, but fault geometry has a large effect, on estimated slip rates.

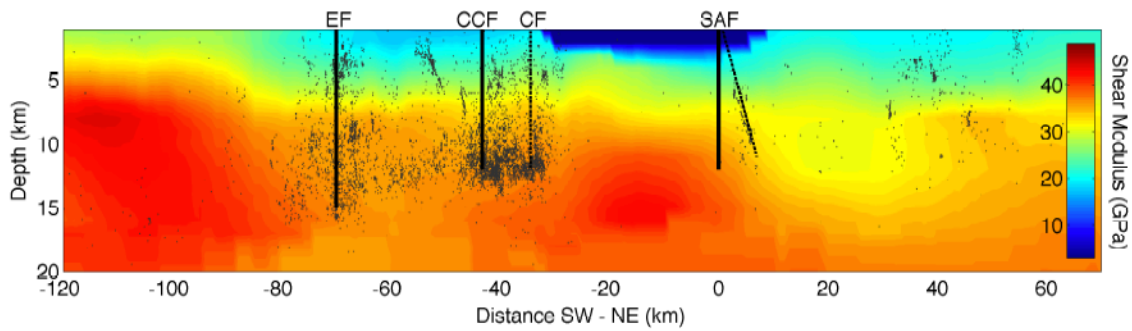
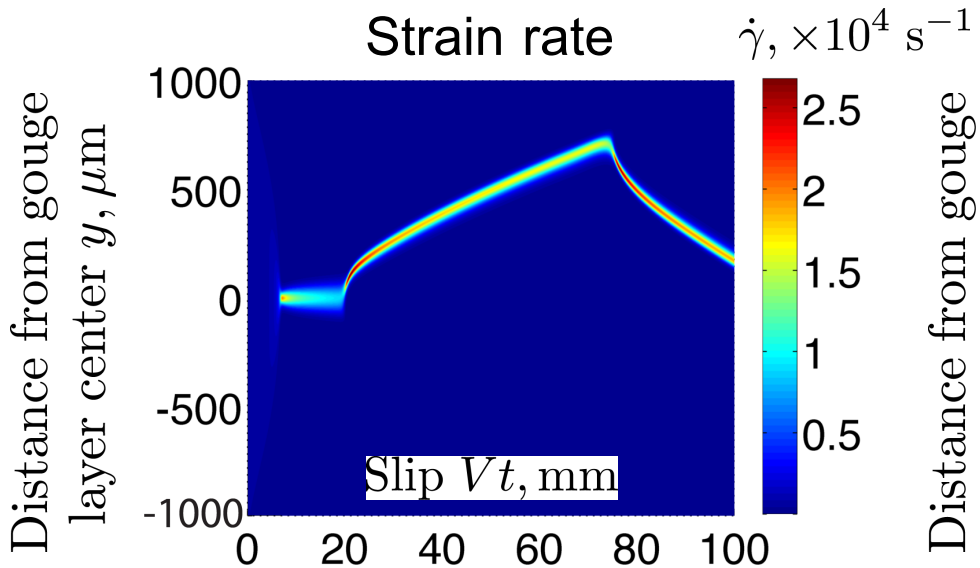
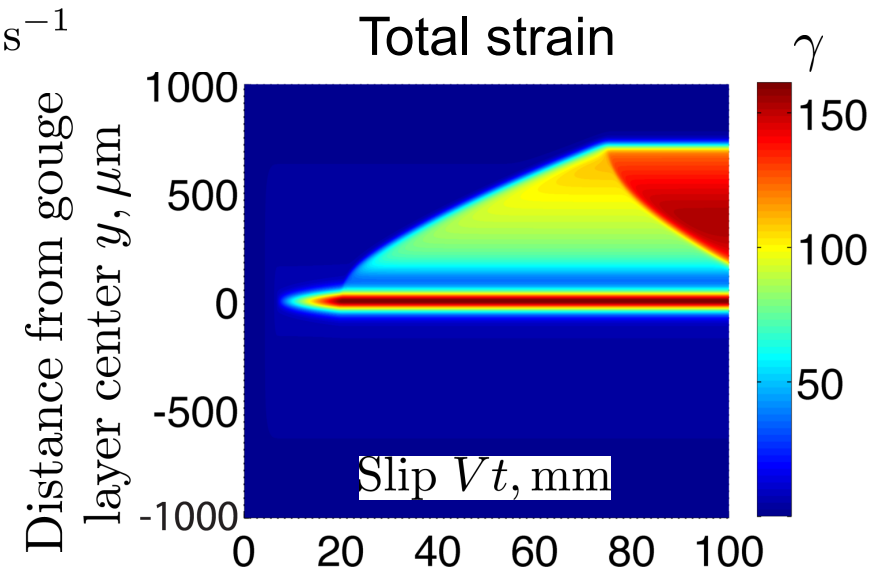


Figure 2: Shear modulus computed from the SCEC regional velocity model CVM-H 6.3 (*Plesch et al.*, 2009; *Suess and Shaw*, 2003), along with relocated seismicity (*Lin et al.*, 2007) and location of locked faults along the profile A-A'. Proposed alternate fault geometry is shown in dashed lines.

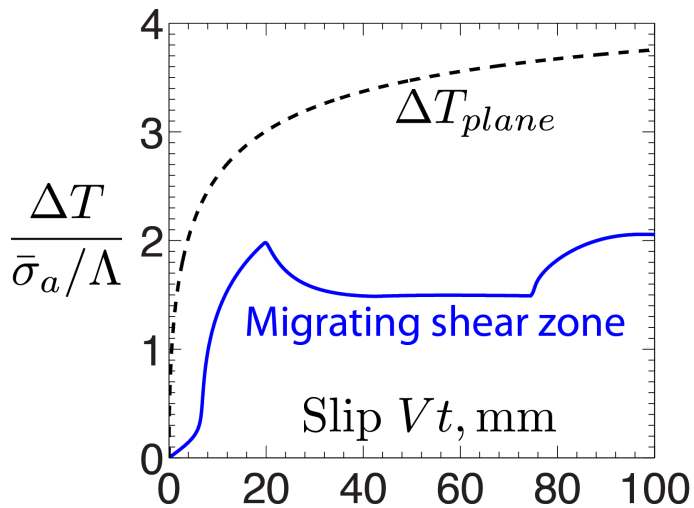
Lindsey and Fialko



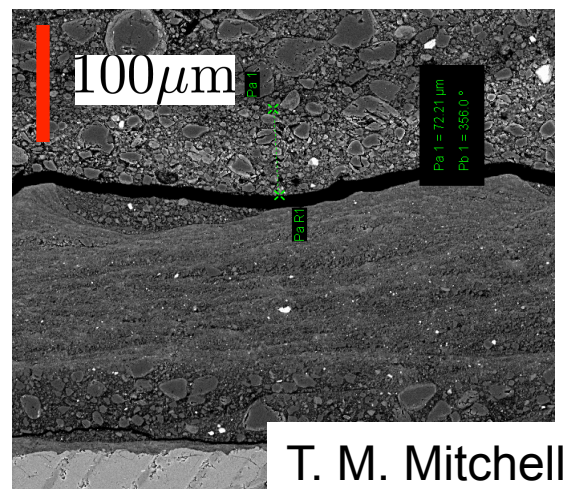
Straining is highly localized and migrates across the gouge layer.



Shear zone migration leads to complex final strain profiles.



Migration distributes frictional heating, leading to a lower temperature rise than for slip on a fixed plane.



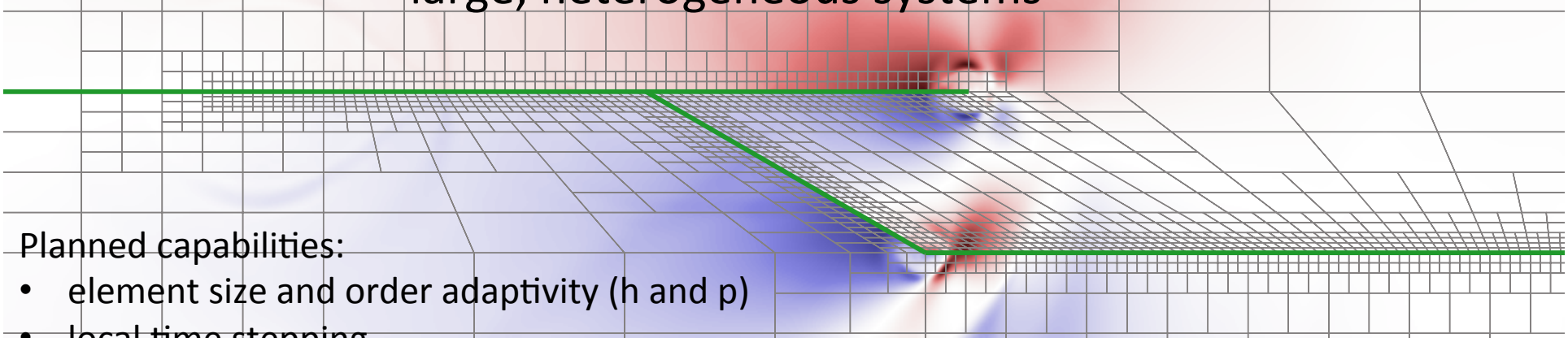
Consistent with observations from rotary shear experiments.

Platt, J. D., and J. R. Rice, Poster 138

Scalable and Adaptive Rupture Dynamics

Jeremy Kozdon and Lucas Wilcox
Naval Postgraduate School

We are building a new rupture dynamics and computational seismology framework for multiscale, complex geometry simulations capable of running on large, heterogeneous systems



Planned capabilities:

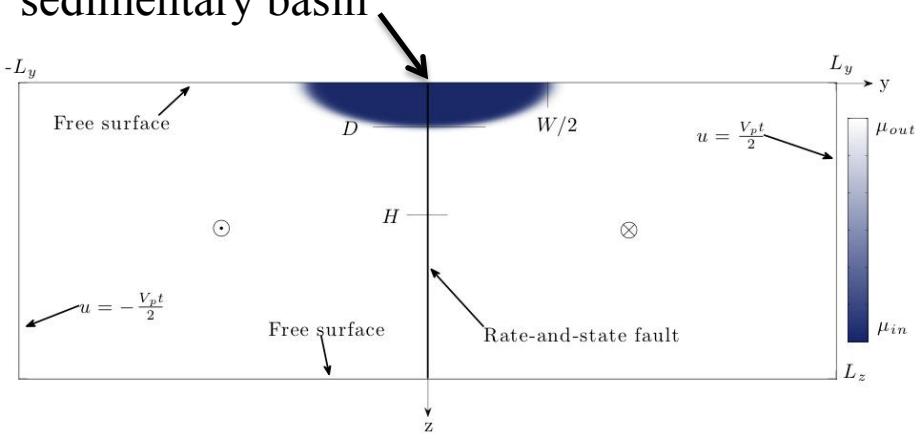
- element size and order adaptivity (h and p)
- local time stepping
- bullet-proof stability
- CPU, GPU, and Xeon Phi kernels
- perfectly matched layer
- coupled structured-unstructured grids
- high-order finite difference and discontinuous Galerkin Finite Element methods

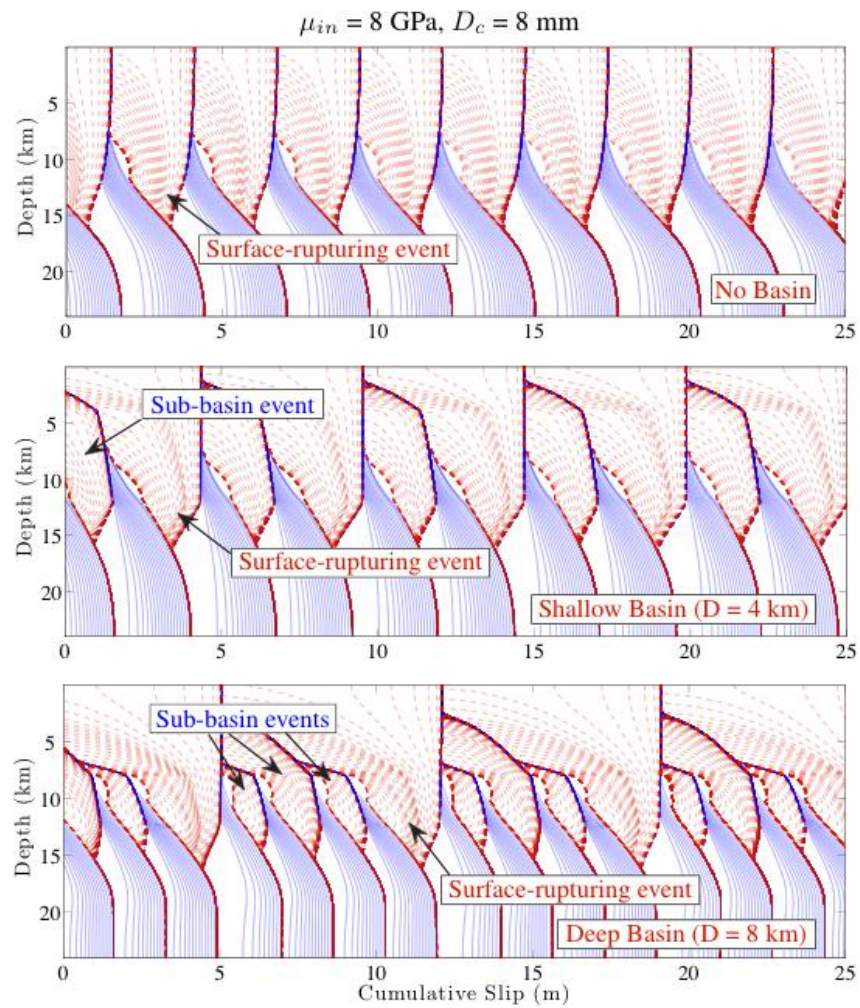
Poster #151

Follow the development at
http://bfam.in

A Finite Difference Method for Earthquake Cycles in Heterogeneous Media:
Alternating Buried and Surface-rupturing Events Crossing a Sedimentary Basin

Quasi-dynamic cycle simulations for strike-slip fault extending into a compliant sedimentary basin





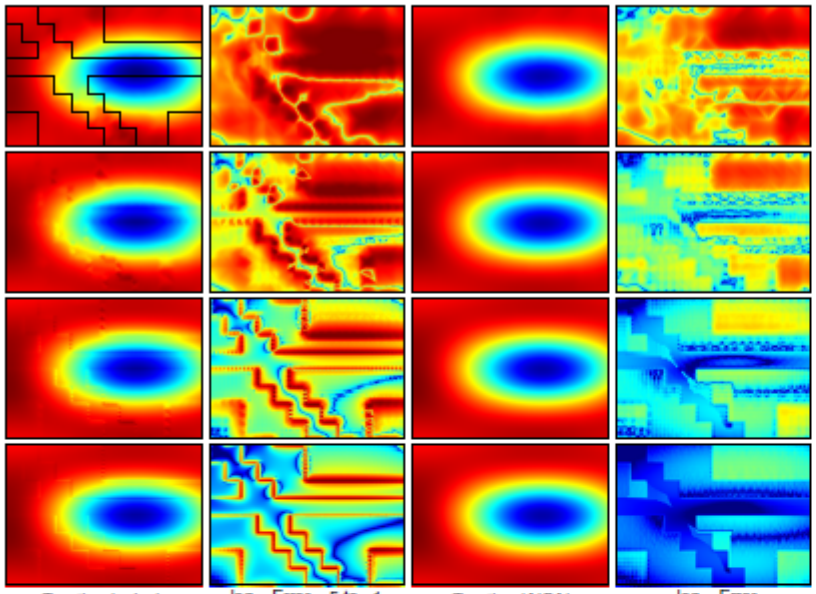
Deep, compliant basins promote the emergence of sub-basin ruptures which alternate with surface-rupturing events

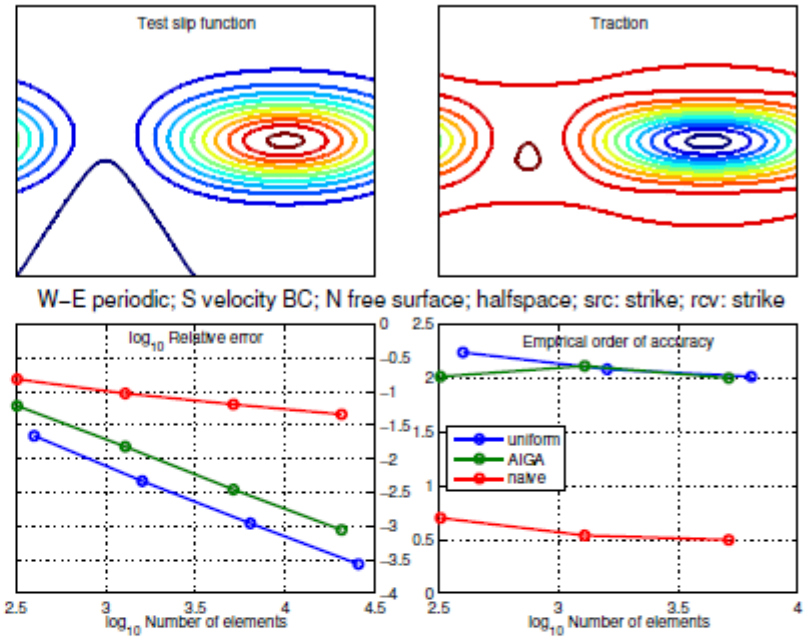
[Erickson and Dunham, submitted to JGR, 2013]; Poster 069

Efficient Quasi-static Earthquake Simulations

Bradley and Segall

dc3dm: SOFTWARE FOR EFFICIENT QUASISTATIC DISLOCATION-TRACTION OPERATORS ON NONUNIFORMLY DISCRETIZED RECTANGULAR FAULTS



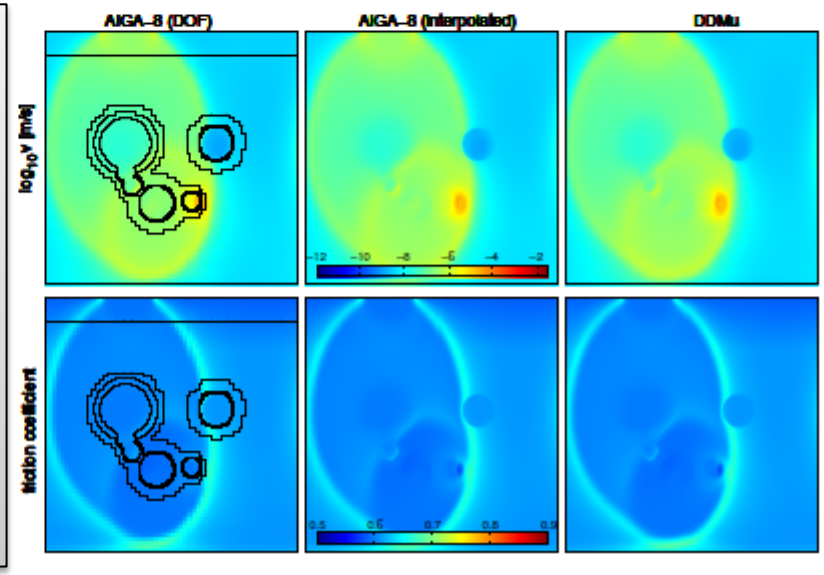


dc3dm:

Effort scales linearly rather than quadratically with number of elements

Uniform/Non-uniform meshes

Free and Open Source



10Hz SORD Dynamic Rupture and Wave Propagation with and without small scale Heterogeneities

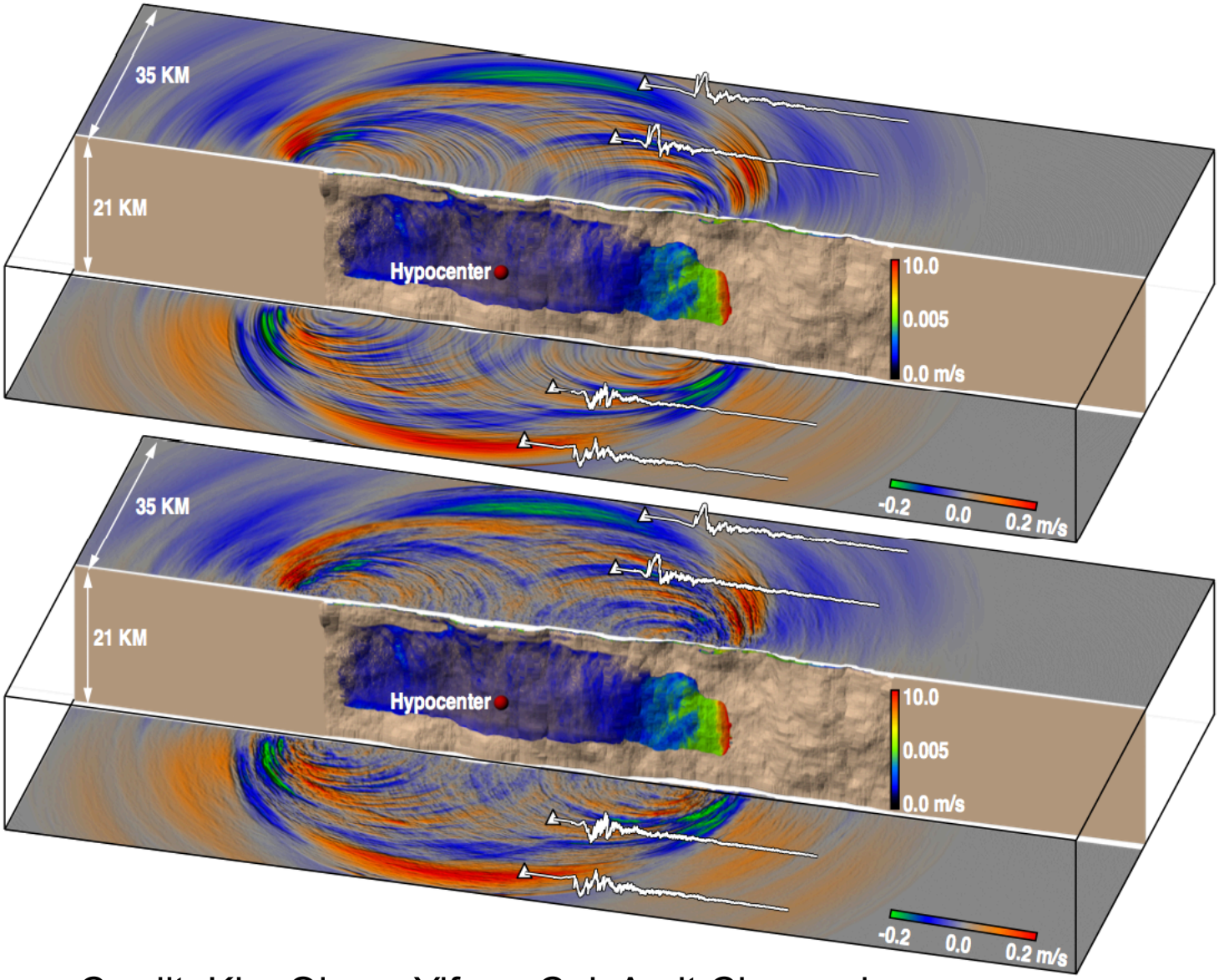
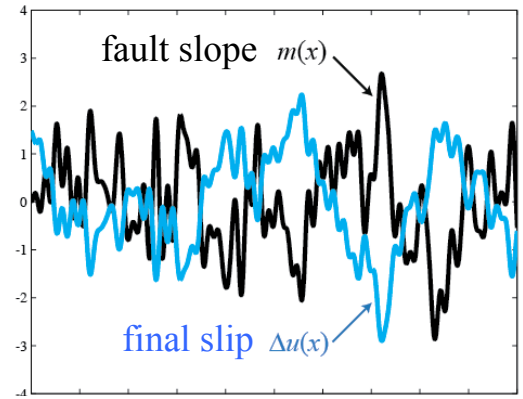


Image Credit: Kim Olsen, Yifeng Cui, Amit Chourasia

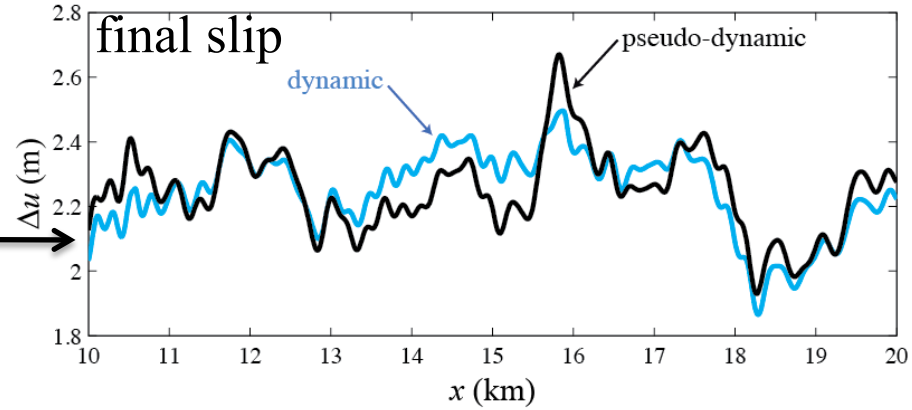
A 2D Pseudo-dynamic Rupture Generator for Earthquakes on Geometrically Complex Faults

Daniel T. Trugman and Eric M. Dunham

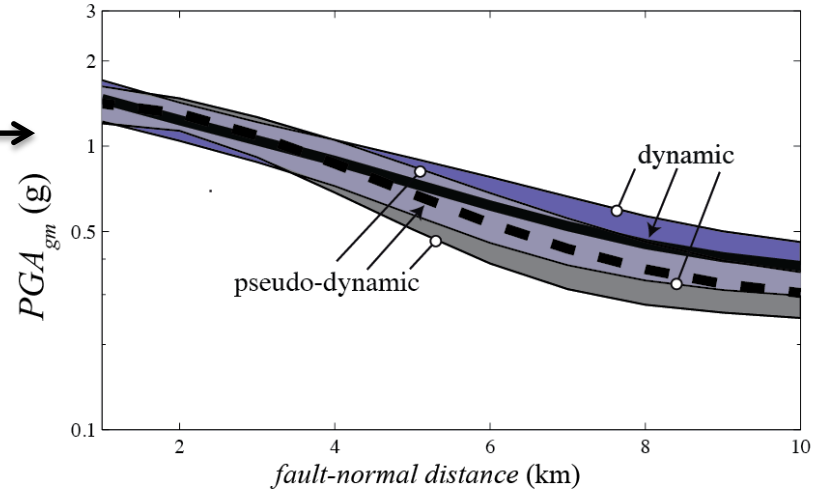
Objective: *Kinematic rupture generator that mimics dynamic ruptures on rough faults*



1. Quantify correlations between fault slope and kinematic source parameters (slip, rupture velocity, peak slip rate) from hundreds of 2D dynamic ruptures
2. Starting with realization of random fractal fault, generate kinematic rupture history
3. Generate synthetic seismograms from kinematic rupture



Ensemble simulations quantify mean and standard deviation of engineering intensity measures

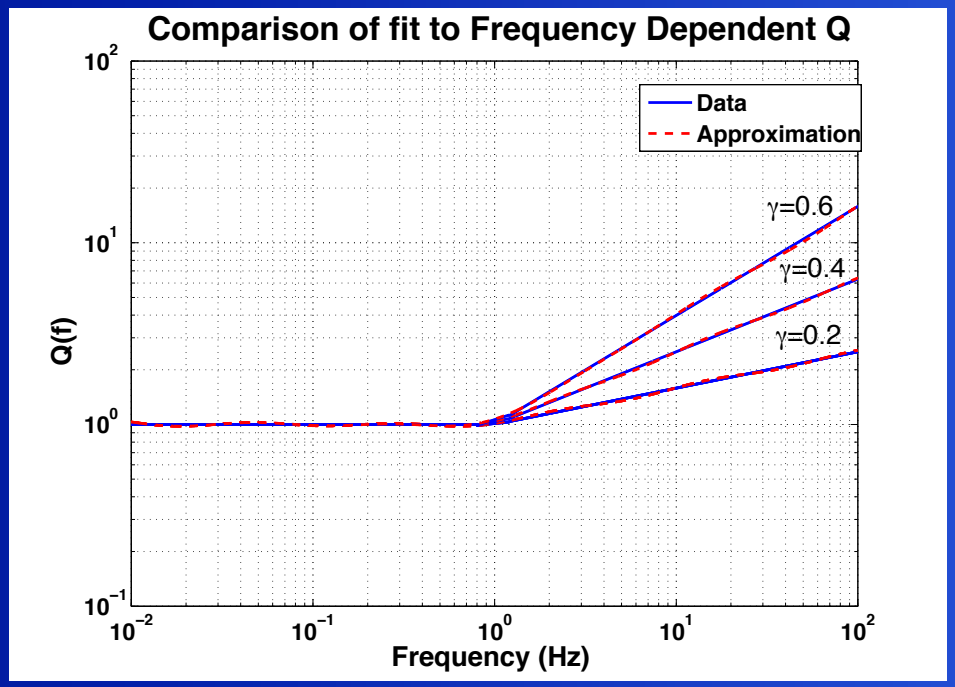


Awarded the David M. Kennedy Prize

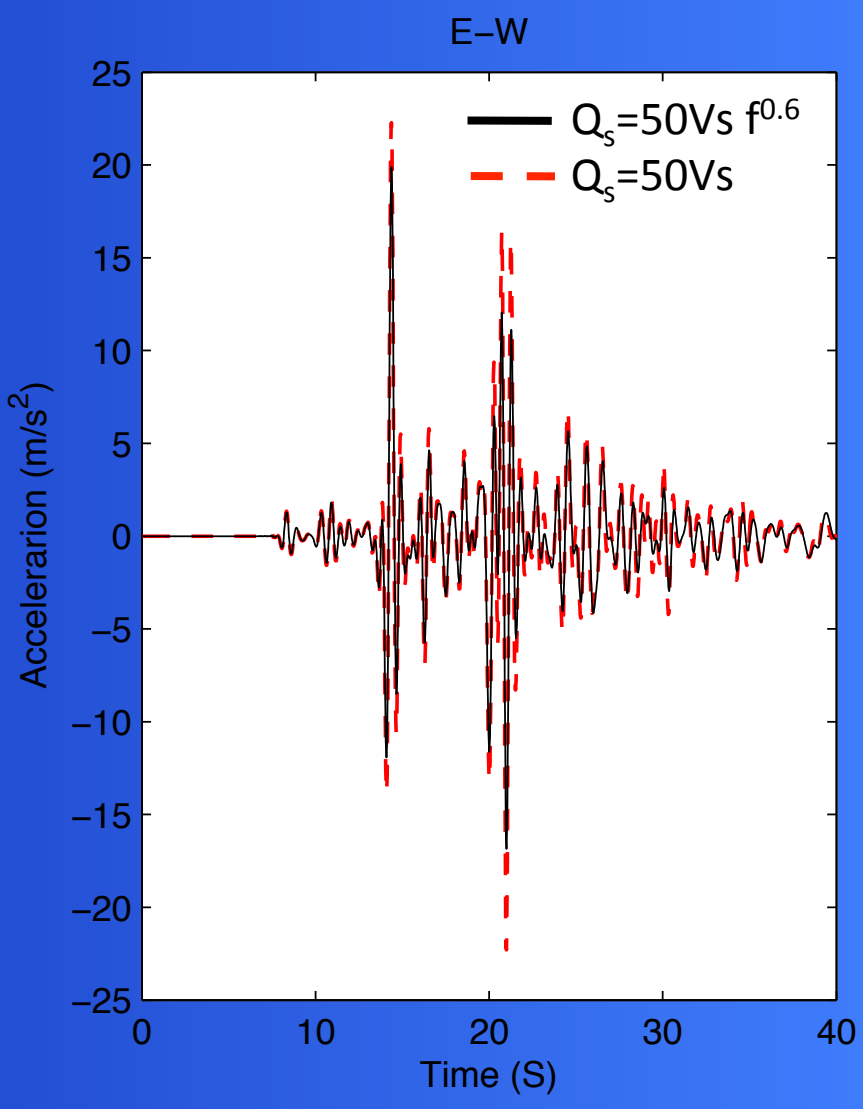
Implementation of Q(f)

Withers, Olsen, Day (2013)

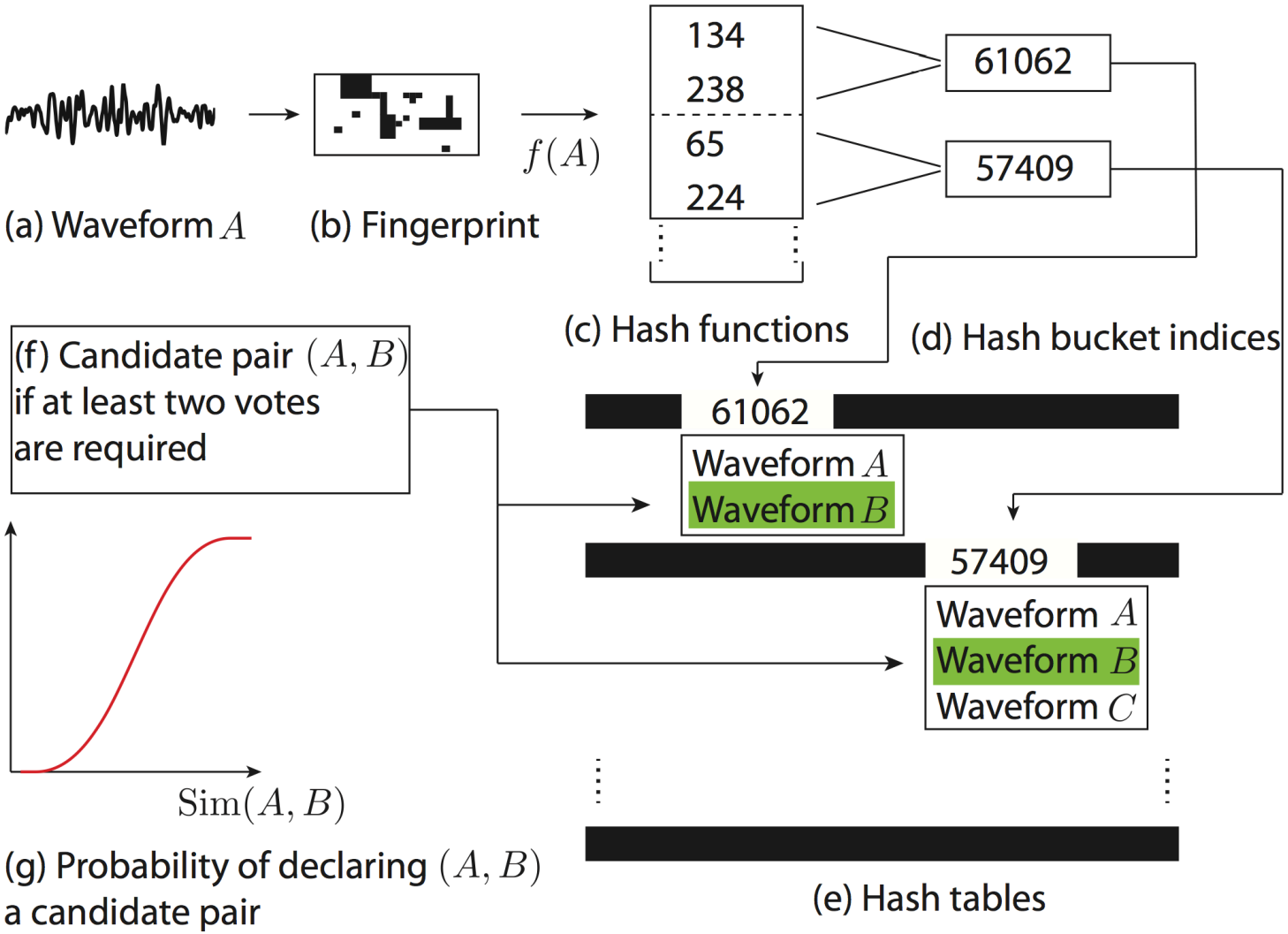
As frequencies increase (>~1Hz), frequency-dependent anelastic attenuation becomes increasingly important. We have achieved a preliminary power law implementation of Q_s frequency dependency $Q_s(f) = Q_o f^n$ in AWP-ODC.



Deep basin site DLA for 0-2.5 Hz
Chino Hills – comparison of contant Q and frequency-dependent Q.



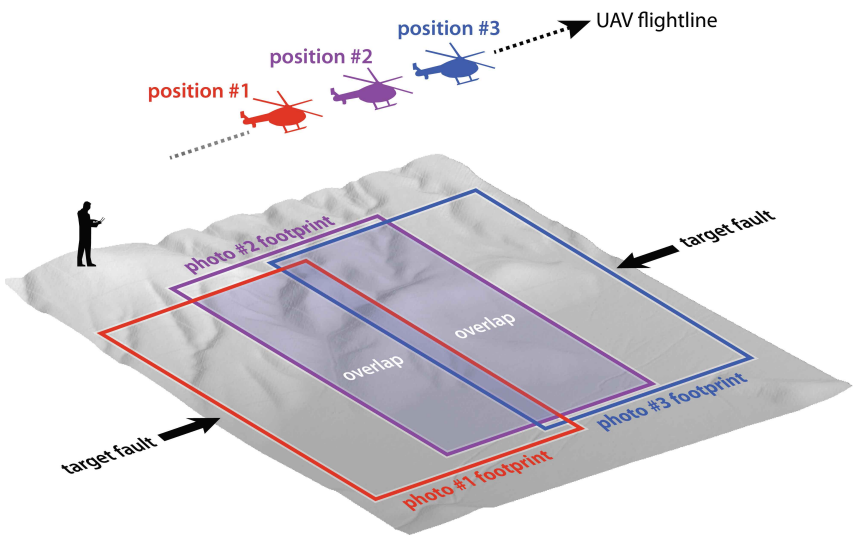
Waveform Similarity Search



O'Reilly et al. #107

Decimeter resolution fault zone topography with Structure from Motion

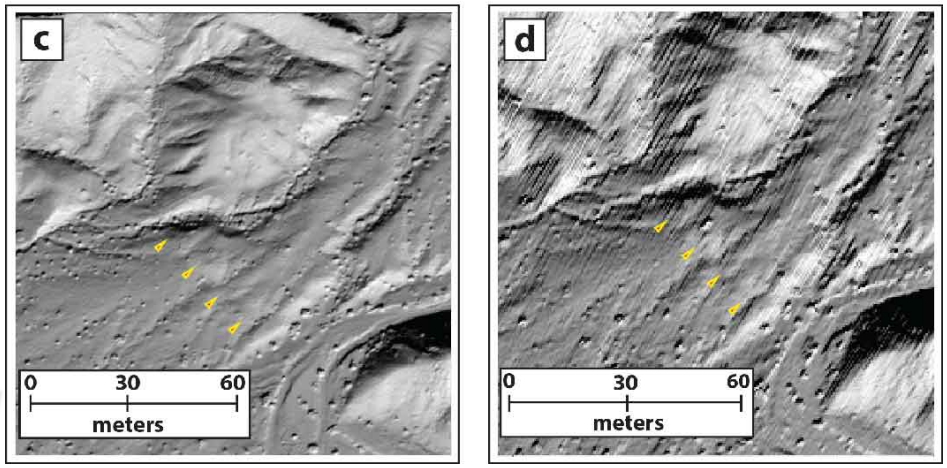
Lead P.I.s Ed Nissen (Colorado School of Mines), Ramon Arrowsmith, Sri Saripalli (Arizona State)



Cheap, off-the-shelf UAVs and helium balloons used as camera platforms

An affordable and easy-to-deploy alternative to airborne Lidar with numerous applications:

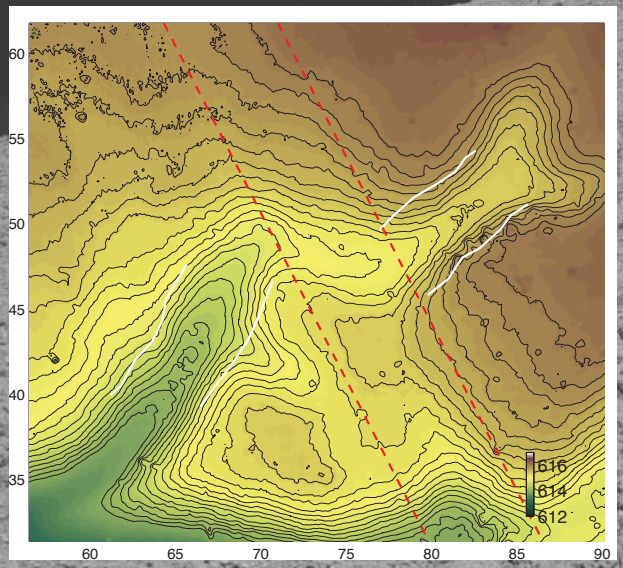
- *reveal subtle geomorphic offsets generated in last event(s)*
- *scarp characterization and degradation modeling*
- *rapid response topographic mapping tool*



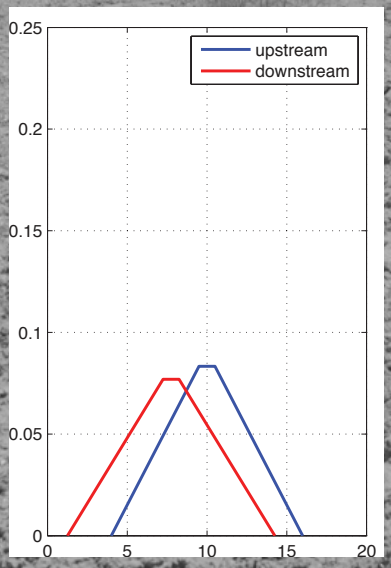
Comparison of dm-resolution SfM topography (left) and meter-resolution Lidar data (right) showing stream offset on SAF

Alternate approach for measuring offset stream channels using new mobile laser scanning data from the Carrizo Section, SAF

Ben Brooks, Ken Hudnut, Sinan Akciz , Kate Scharer, Jaime Delano, Craig Glennie, Darren Hauser, Carol Prentice, and Steve DeLong



distance (m)



offset (m)

USGS
science for a changing world

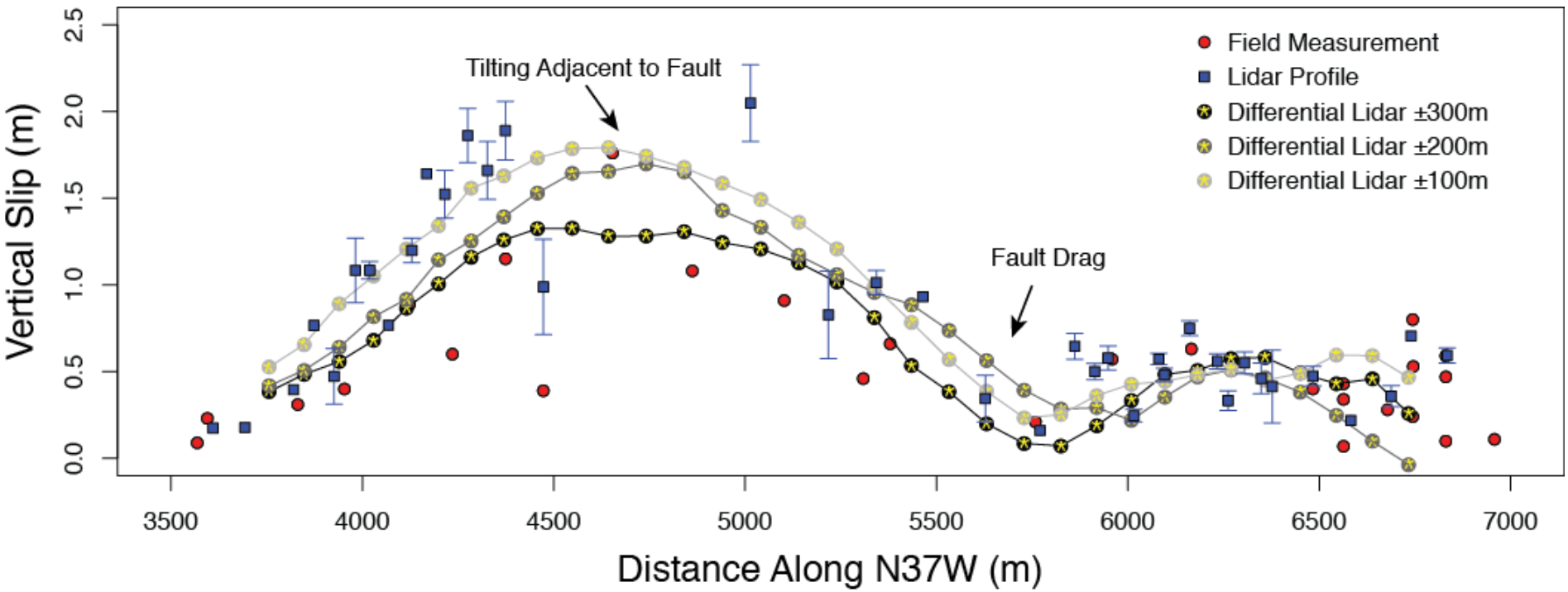
NCALI
The National Center for Airborne Laser M
University of Houston • University of California, Ber

Origins of Variability in Fault-Rupture Slip Measurements: Comparison of Field Observations to Airborne & Differential LiDAR

Jaime Delano, Divya Banesh, & Mike Oskin

(See related poster (#18) by Oskin et al.)

Paso Inferior Normal Fault Vertical Slip Distribution

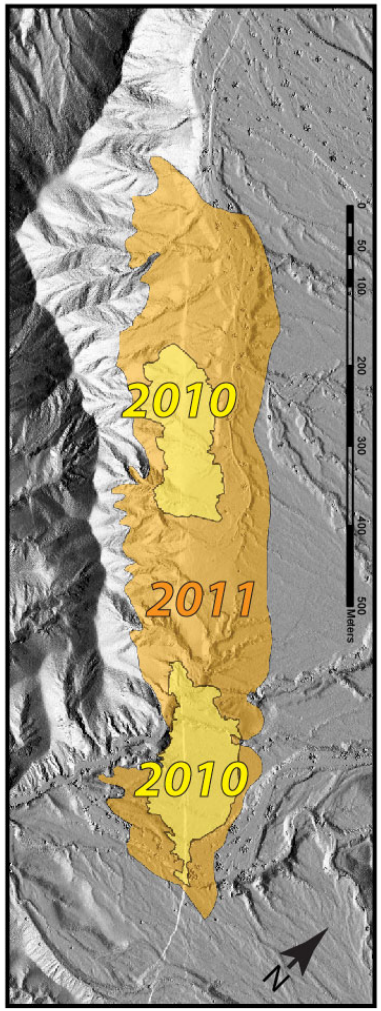


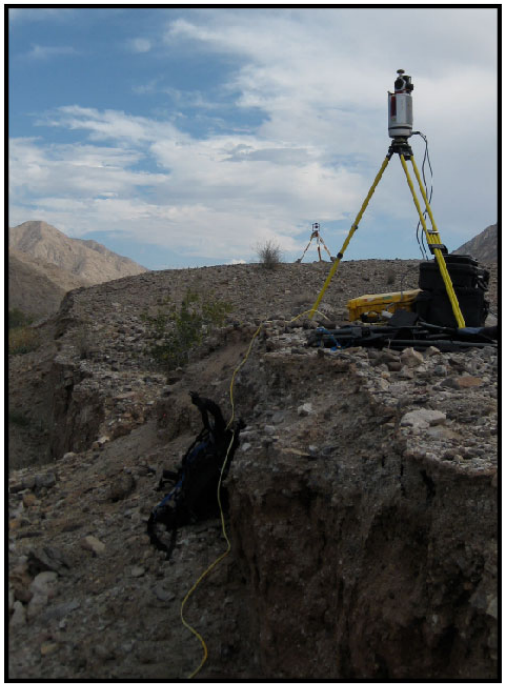
1. Field measurements under-estimate slip on normal fault.
2. Post-earthquake airborne LiDAR profiles reveal near-fault distributed deformation.
3. Differential LiDAR yields smoother deformation than either set of measurements.

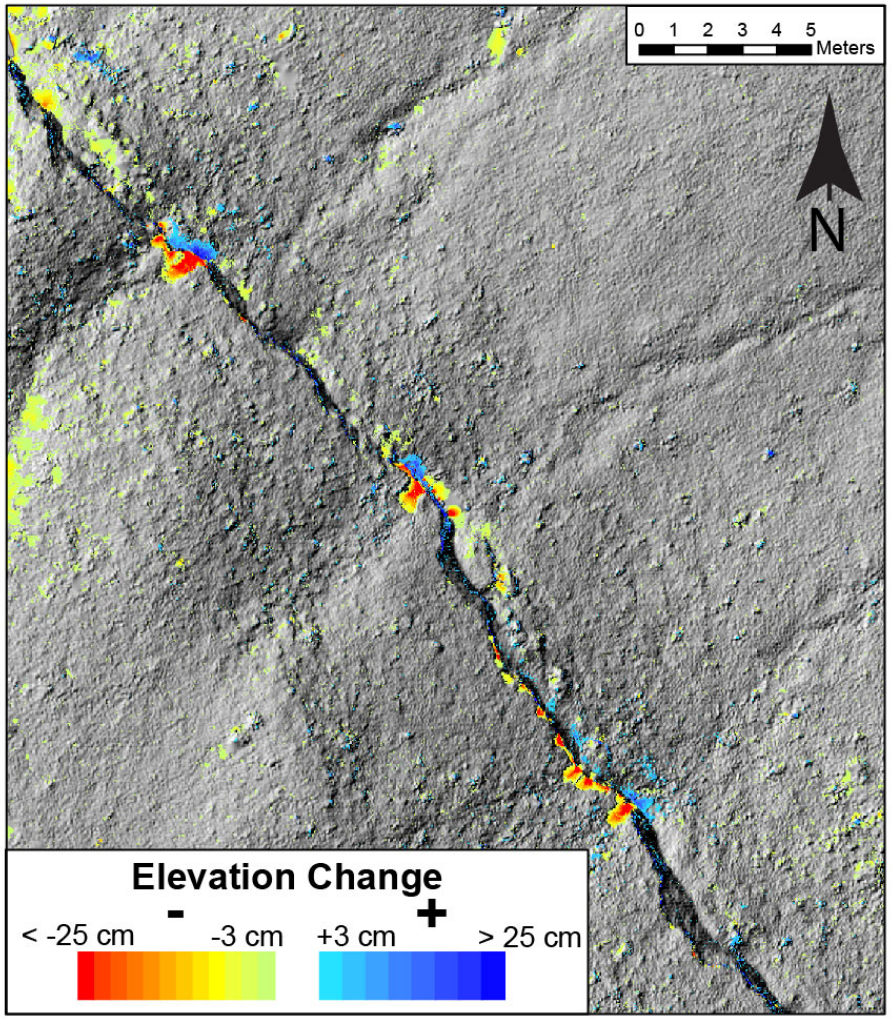
LiDAR time-series of EMC post-earthquake change

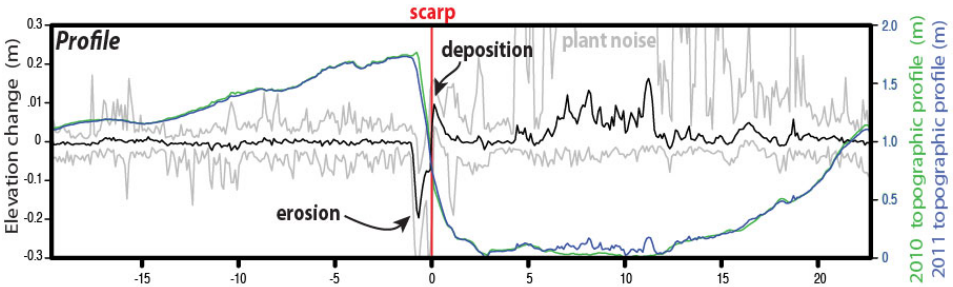
Austin Elliott et al. – collaboration of UC Davis, U. Kansas, & CICESE

- -No detectable afterslip
- -Erosion widens offset piercing lines
- -Fissures filled within 1 year of surface rupture



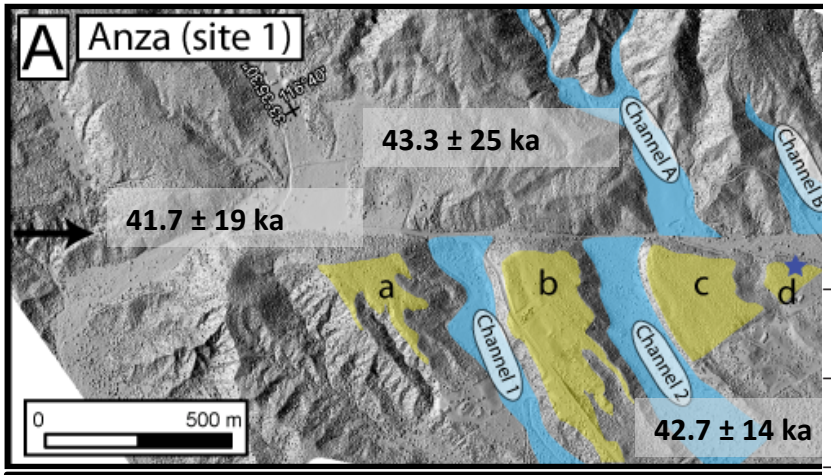


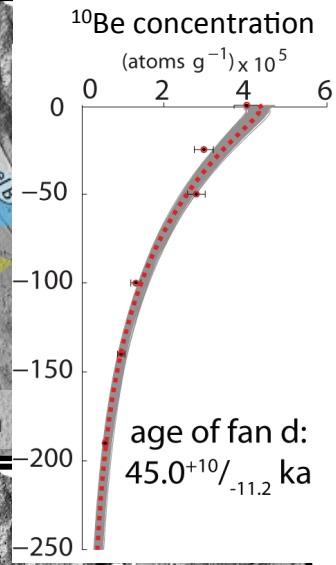


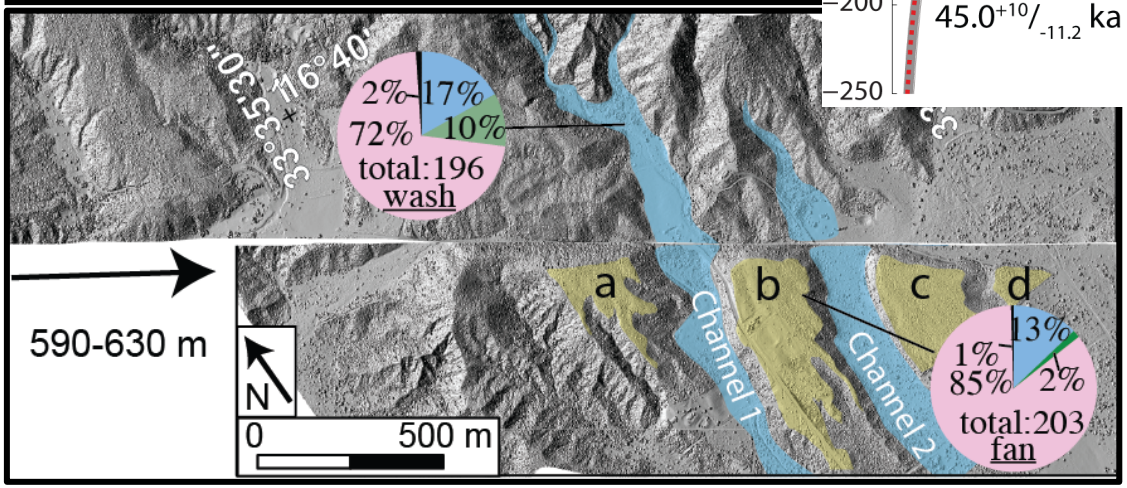


San Jacinto fault: Anza

11-15 mm/yr since ~5 ka, 45 ka and 700 ka (Blisniuk et al., 2013)





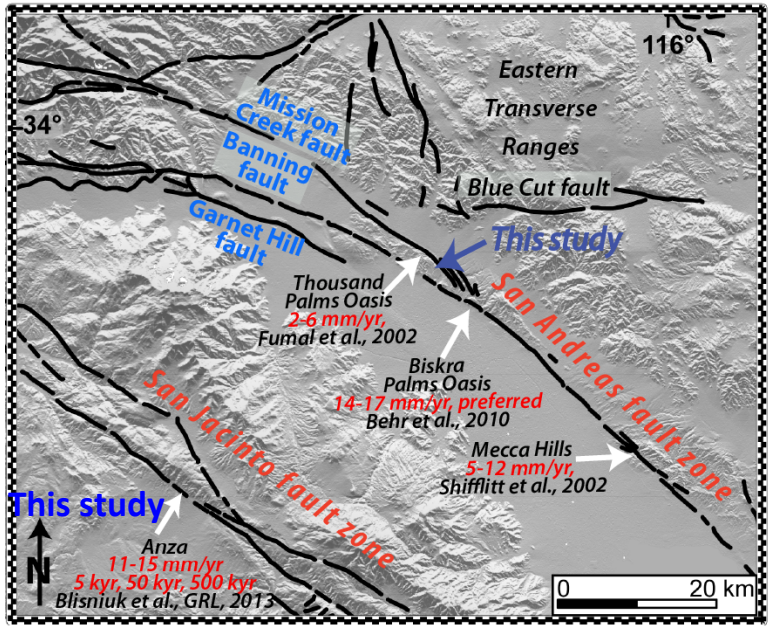


2 Channels incised into late Pleistocene alluvial fan complex

(Rockwell et al., 1996, Blisniuk et al., GRL, 2013)

KEY

- Q2c fan deposit
- channel
- modelled ^{10}Be concentration
- depth profile location

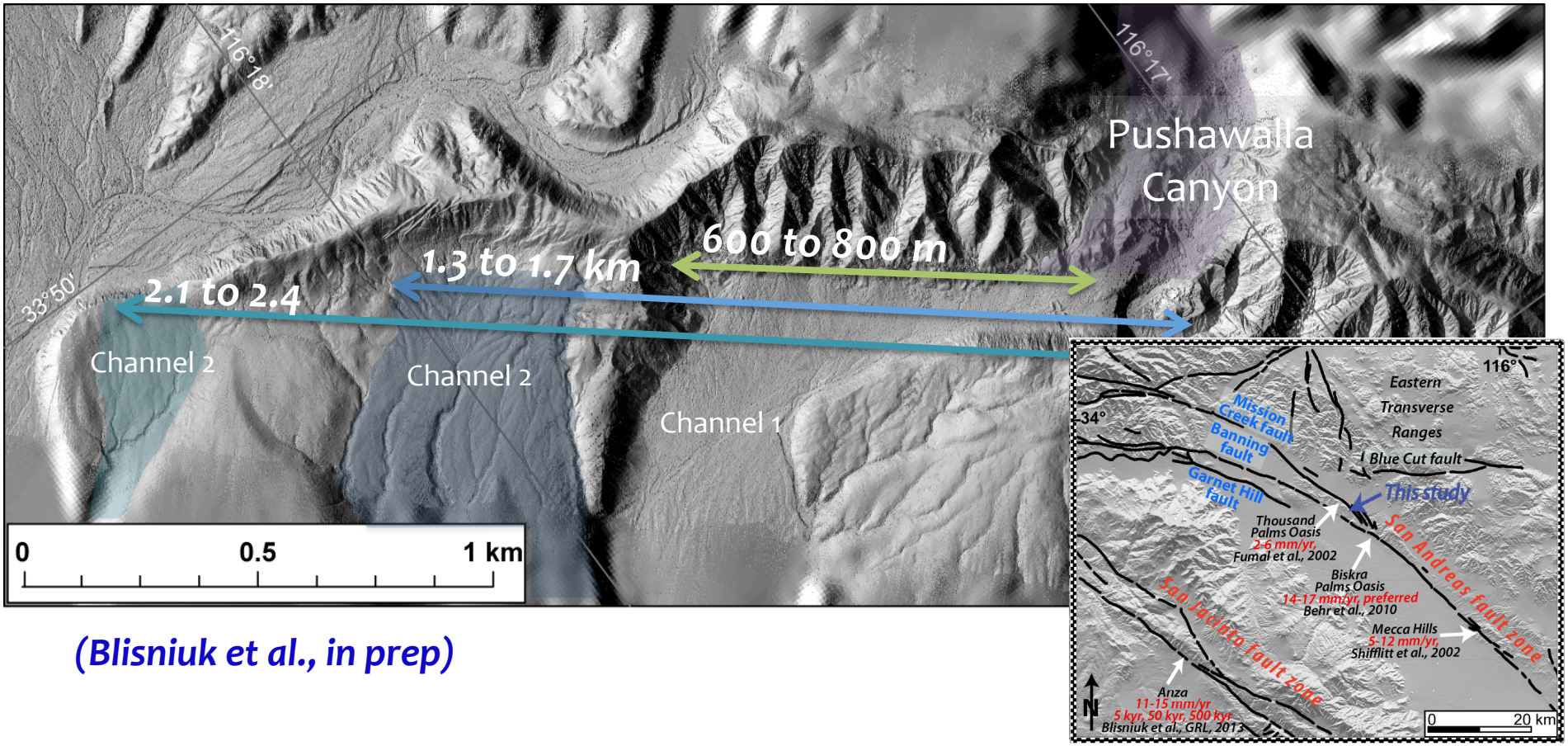


Mission Creek fault: Coachella Valley

1300 to 1700 m offset since ~69.2 $^{+1.4}/_{-1.4}$ ka → 21 $^{+3.5}/_{-3.5}$ mm/yr

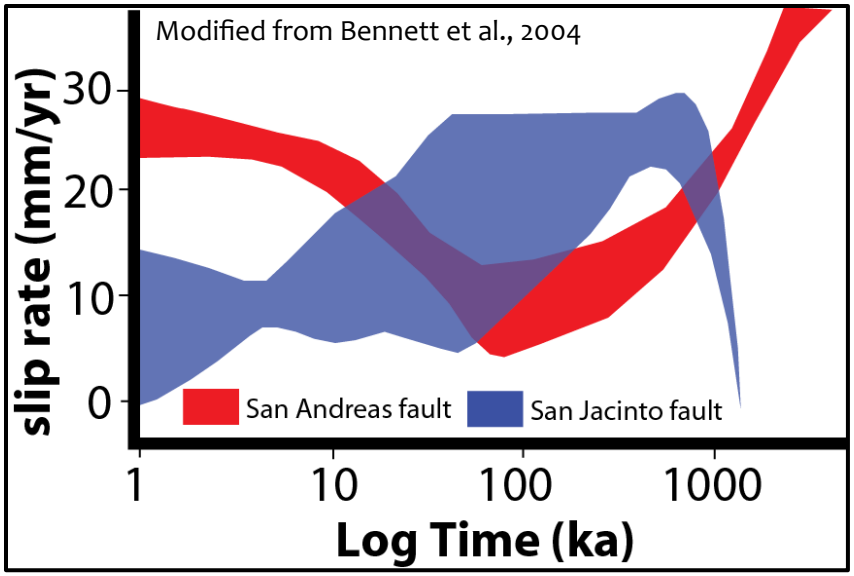
Geometry of offset channels:

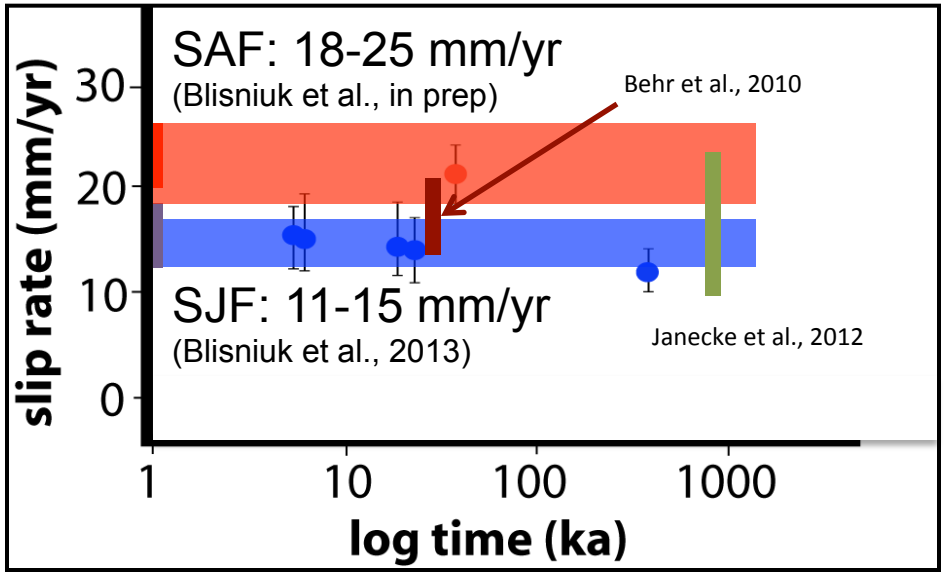
(1) 3 channels completely beheaded along the Mission Creek fault
(2) 3 old surfaces that grade into Pushawalla Canyon, the only plausible source



(Blisniuk et al., in prep)

How do the San Jacinto fault zone and San Andreas fault zone share Pacific-North America plate boundary deformation?





Observation for the SAFZ and SJFZ at this latitude:

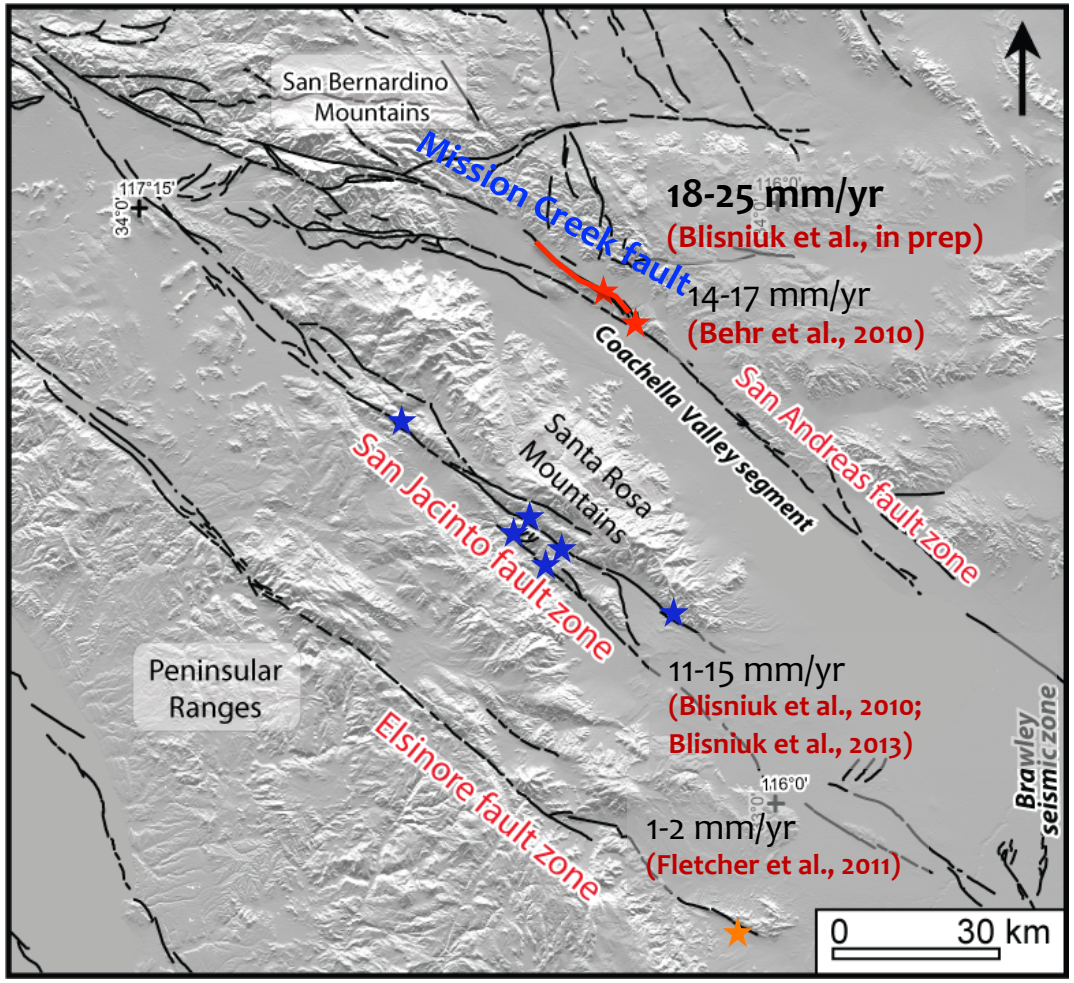
(1) No temporal slip rate variation

(2) Trade-off in slip rate is not supported by the available data

(3) Time-constant slip rates on both the San Jacinto and San Andreas fault zones

(4) San Andreas fault is the dominant structure, specifically the Mission Creek fault strand.

Conclusion:



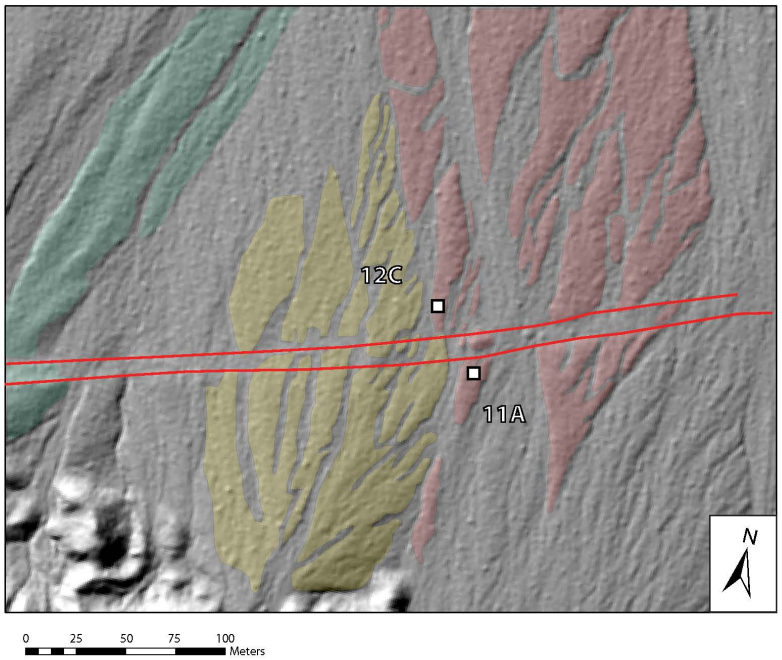
(1) Rapid minimum slip rate of **~18-25 mm/yr** for the SAFZ since ~70 ka.

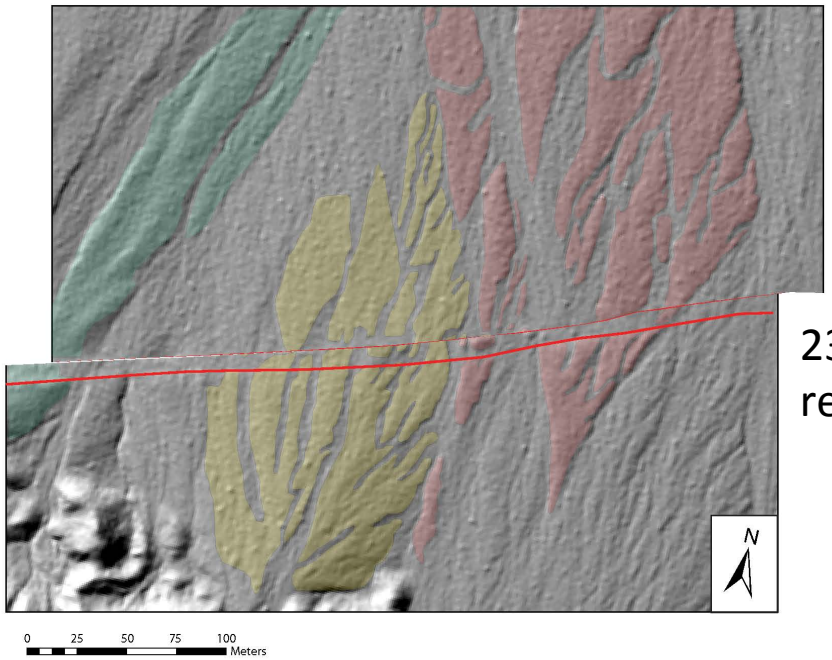
(2) San Andreas fault zone is dominant, specifically the Mission Creek fault, accordingly slip does not appear to be transferred to the Banning fault north of Biskra Palms, as previously suggested.

(3) Support a slip deficit of **5.0- 7.5** m accumulated over the past 300 years is likely to be relieved in a large-magnitude earthquake.

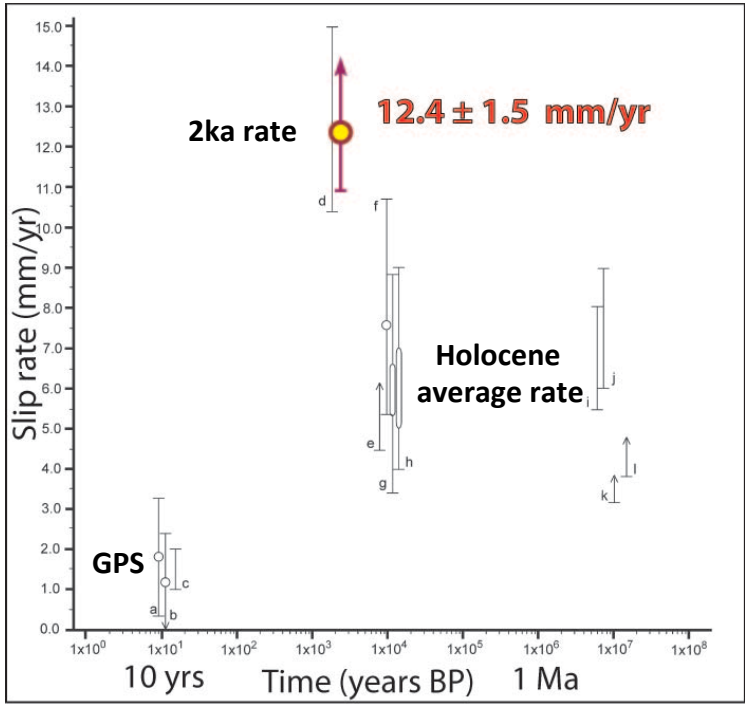
(4) Cumulative slip rate of **31-41 mm/yr** across the PA-NA plate boundary appears to be accommodated on the faults at this latitude.

Site 1 (Target 1A)





23 m restored



In contrast: Highly variable Holocene slip rate on central Garlock fault

- Holocene (8-10ka) average rate = 5-7 mm/yr
- Late Holocene (2ka) rate = > 12 mm/yr
- Rapid late Holocene rate corresponds to 4-event EQ cluster (Dawson et al. 2003)
- Garlock fault exhibits 2 slip-rate modes: millenial-scale fast rates interspersed with millenial-scale 0mm/yr periods

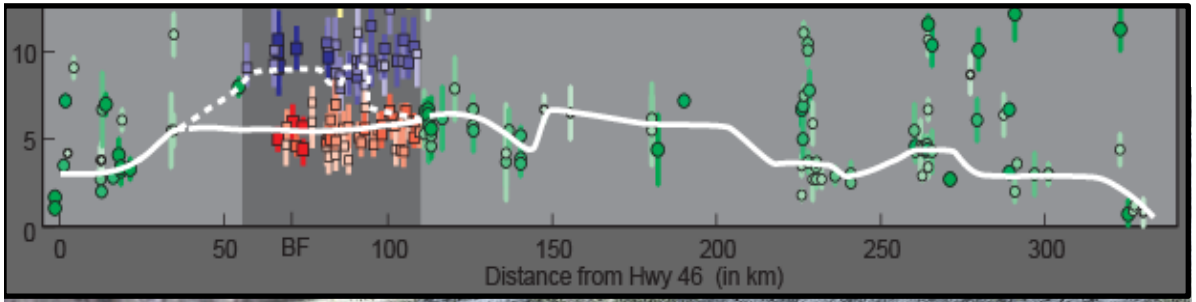
McAuliffe et al. in prep

Preliminary Report on Paleoseismic Investigation of Offset Channel Sieh31 in the Carrizo Plain, California

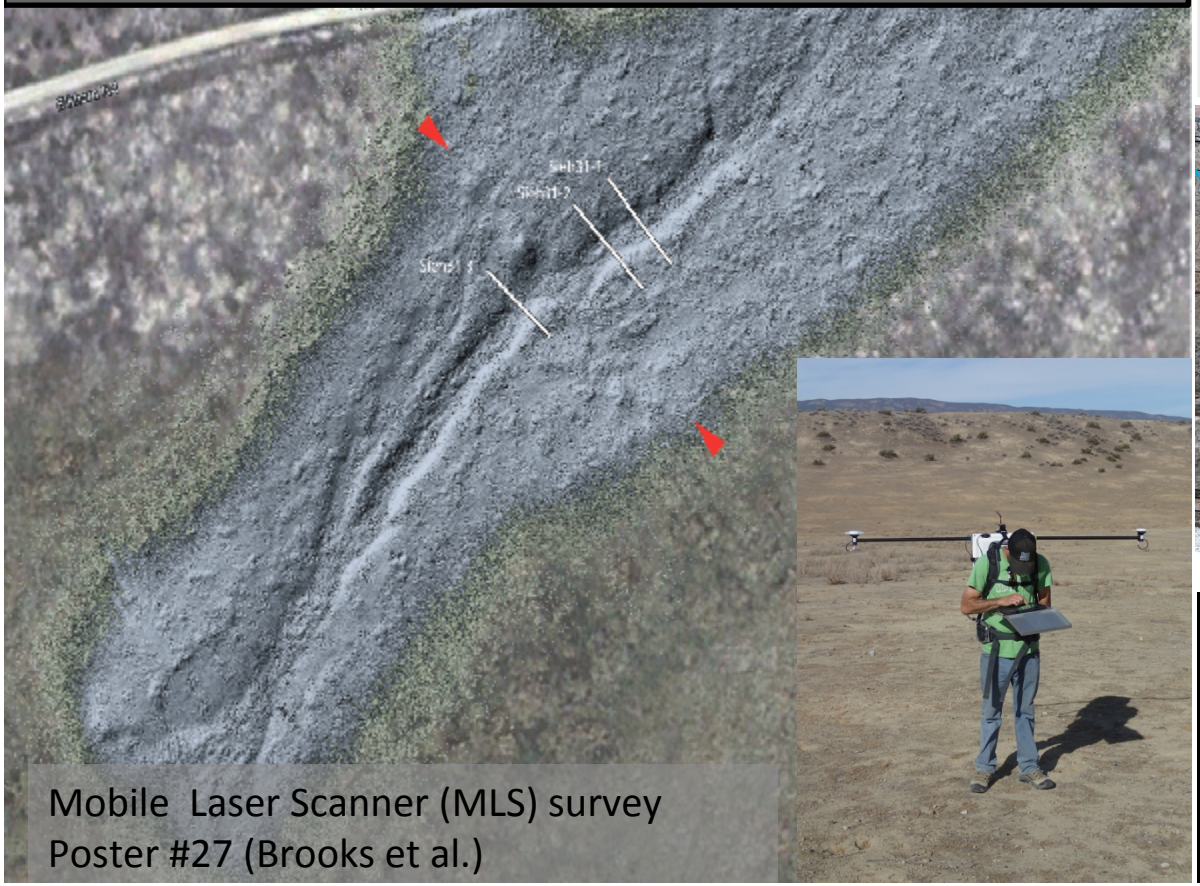
Halford.D., Akciz, S., Grant Ludwig, L., Salisbury, J. B., Kleber, E. J., Arrowsmith, J R., Marliyani, G. I.

9 m or 5 m? That is the question…

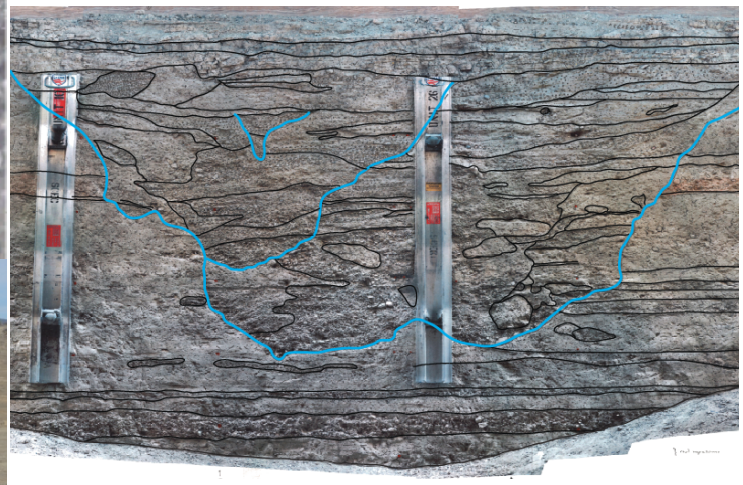
Poster 244



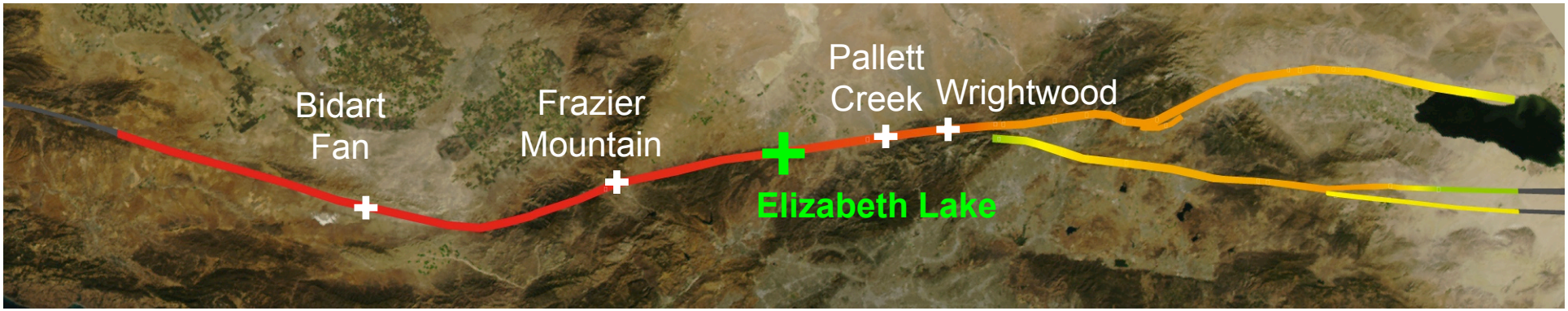
Location	Sieh31
Sieh 1978 interpretation & quality rating	9.1 ± 1 m; excellent
Zielke et al., 2010 interpretation & quality rating	6 ± 1 m; high



Mobile Laser Scanner (MLS) survey
Poster #27 (Brooks et al.)



- Channel thalweg is ~2 m deep
- Multiple cut/fill sequences
- Buried thalweg does not coincide with the median of the channel margins, nor the present day thalweg.
- Stay tuned for 3D excavation results

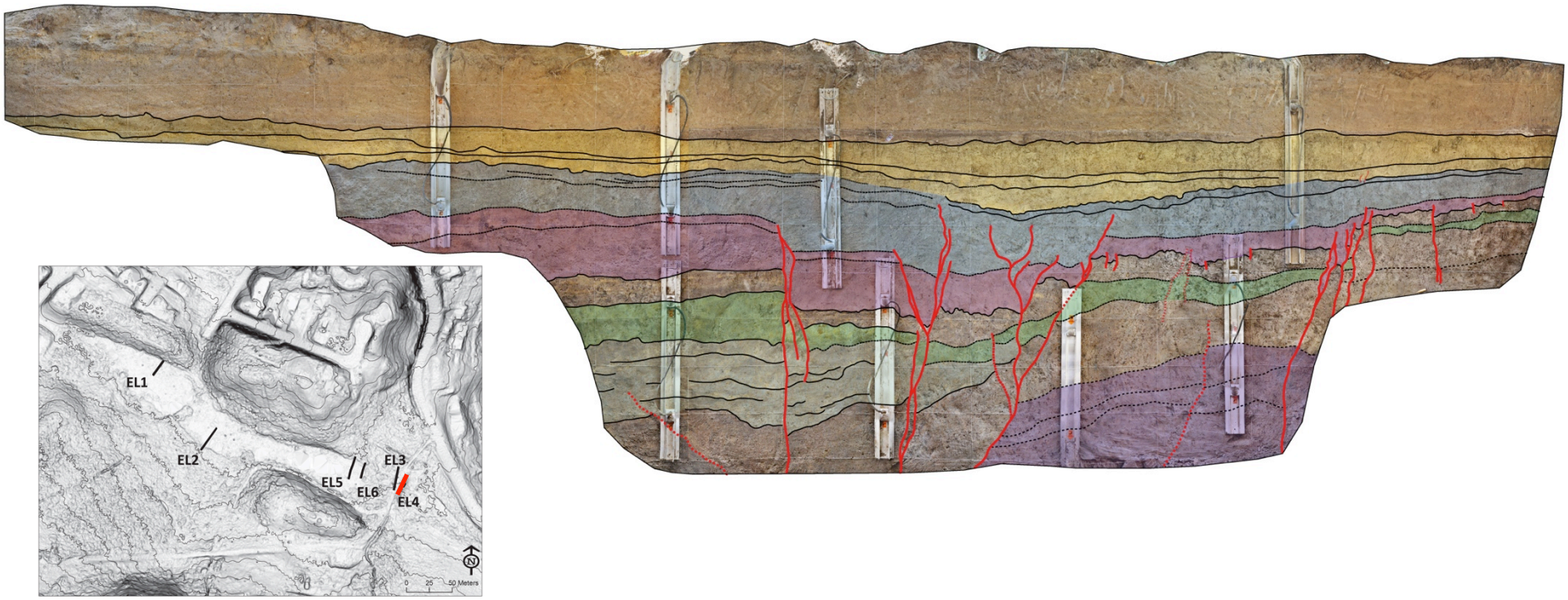


How often do 1857-size ruptures occur on the southern San Andreas Fault?

Elizabeth Lake Paleoseismic Site

Trenches from July 2013

Sean Bemis, Kate Scharer, James Dolan

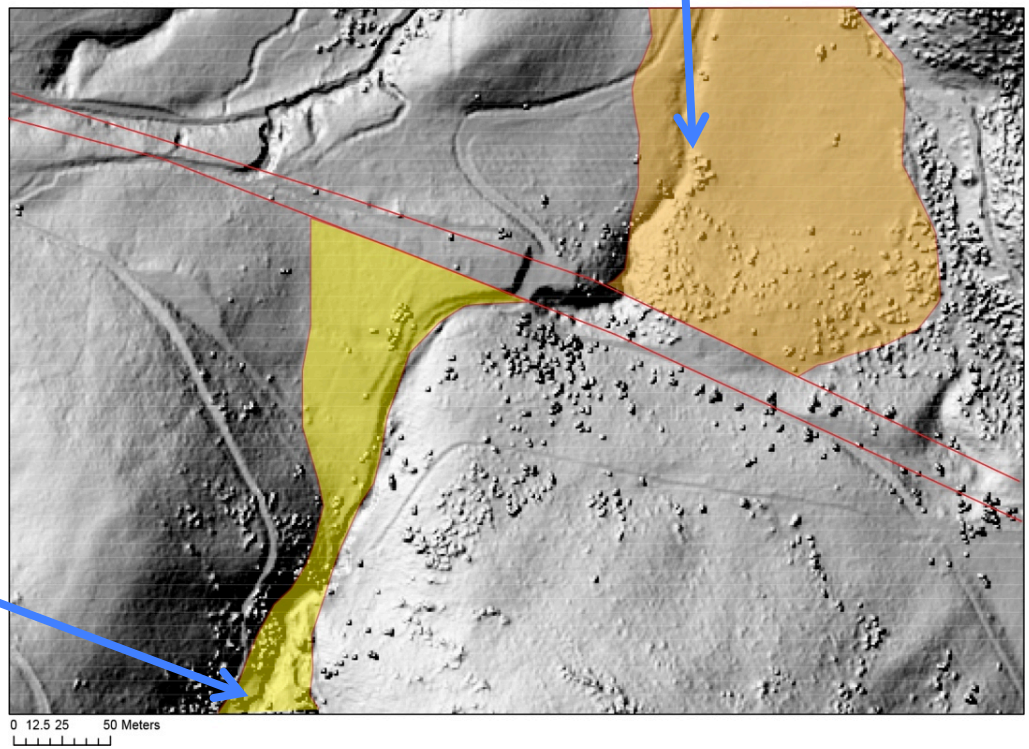


New fieldwork:

Late Holocene slip rate on the Mojave section of the SAF

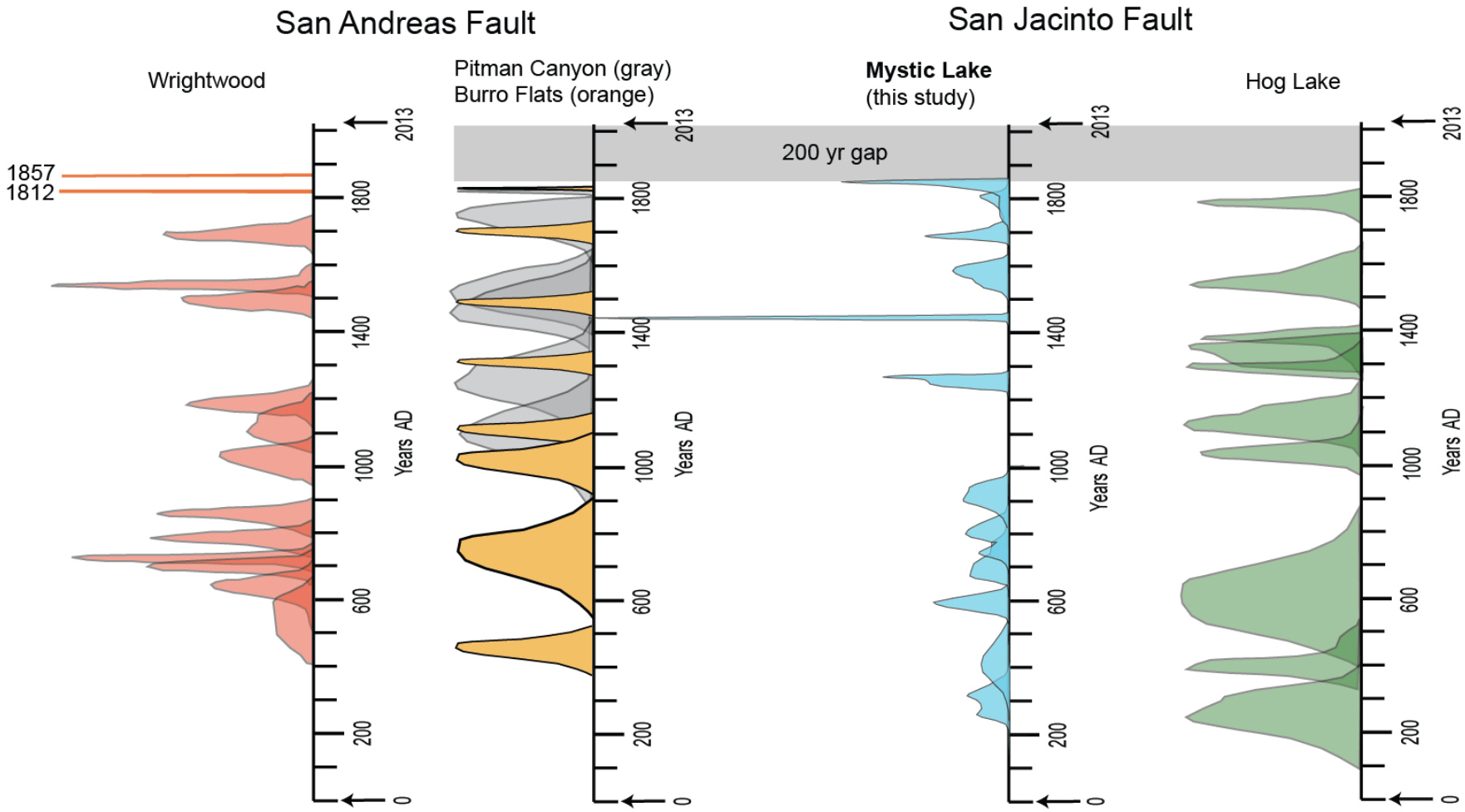
August, 2013

Eric Cowgill, Mary Barr, Kate Scharer



Paleoseismology of the northern San Jacinto fault from the Mystic Lake site

N. Onderdonk, S. McGill, T. Rockwell, and numerous SCEC interns and CSU students

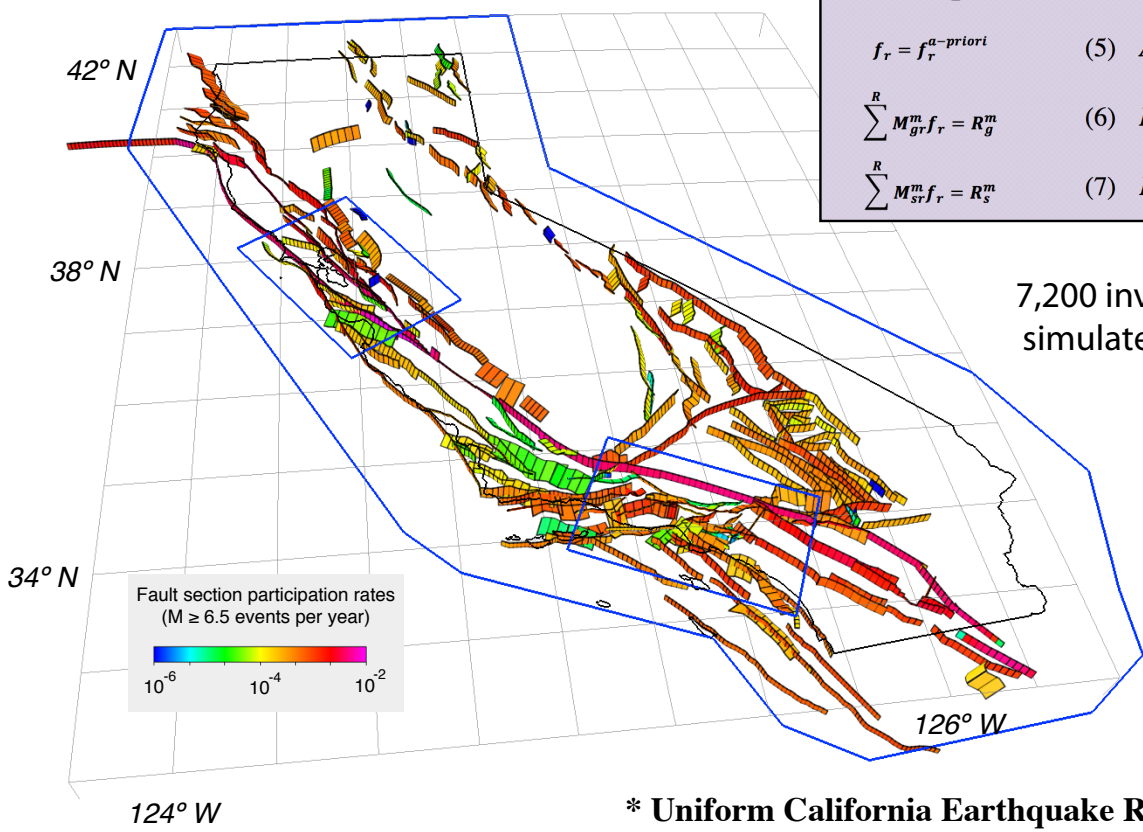


A comparison of paleoseismic data from sites in the San Bernardino area from the San Andreas and San Jacinto faults

*UCERF3**

Solving for the frequency of California's damaging earthquakes

to be used in USGS National Seismic Hazard Maps and to set building codes and insurance rates



Inverting a System of Equations

$\sum^{R} D_{sr} f_r = v_s$	(1)	***Fault Slip-Rates***
$\sum^{R} G_{sr} P_r^{paleo} f_r = f_s^{paleo}$	(2)	***Paleoseismic Event-Rates***
$R_s^m = \frac{R_{s-1}^m + R_{s+1}^m}{2}$	(3)	***Fault-Section Smoothness***
$f_r = f_r^{a-priori}$	(5)	***A Priori Constraints***
$\sum^{R} M_{gr}^m f_r = R_g^m$	(6)	***Regional MFD Constraints***
$\sum^{R} M_{sr}^m f_r = R_s^m$	(7)	***Fault Section MFD Constraint***

7,200 inversions using threaded simulated annealing algorithm

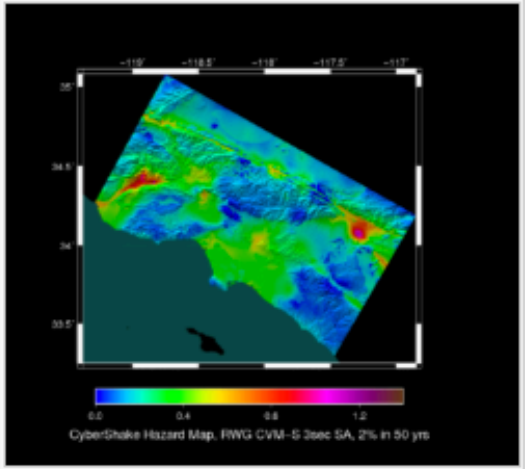
3 Inversions per Stampede compute node: 200,000 SUs

Wall clock time: 10 hrs

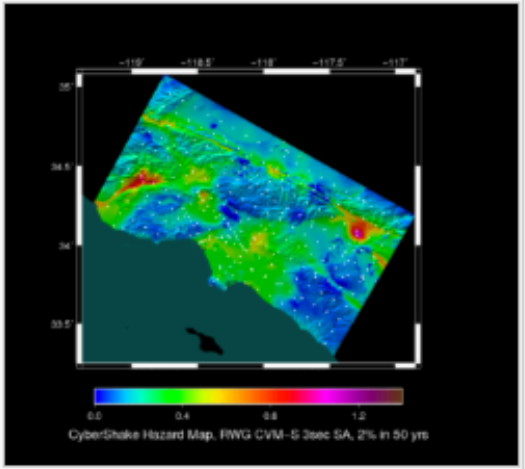
*** Uniform California Earthquake Rupture Forecast, Version 3**

Basic Hazard Maps (3s)

RWG, CVM-S

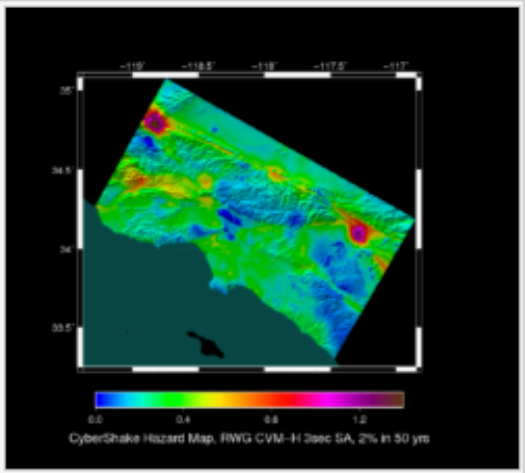


CyberShake Study 13.4 Hazard Map (300 ppi, ps file)

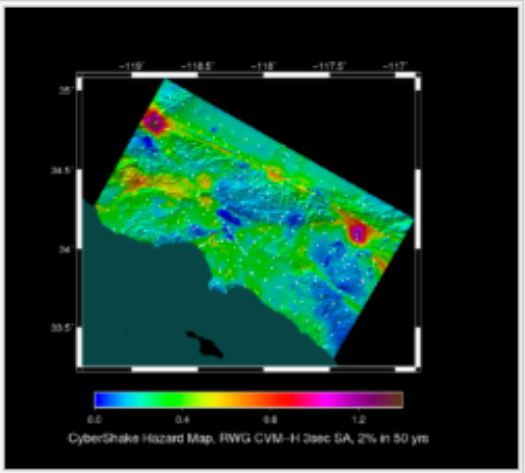


CyberShake Study 13.4 Hazard Map, sites marked (300 ppi, ps file)

RWG, CVM-H



CyberShake Study 13.4 Hazard Map (300 ppi, ps file)

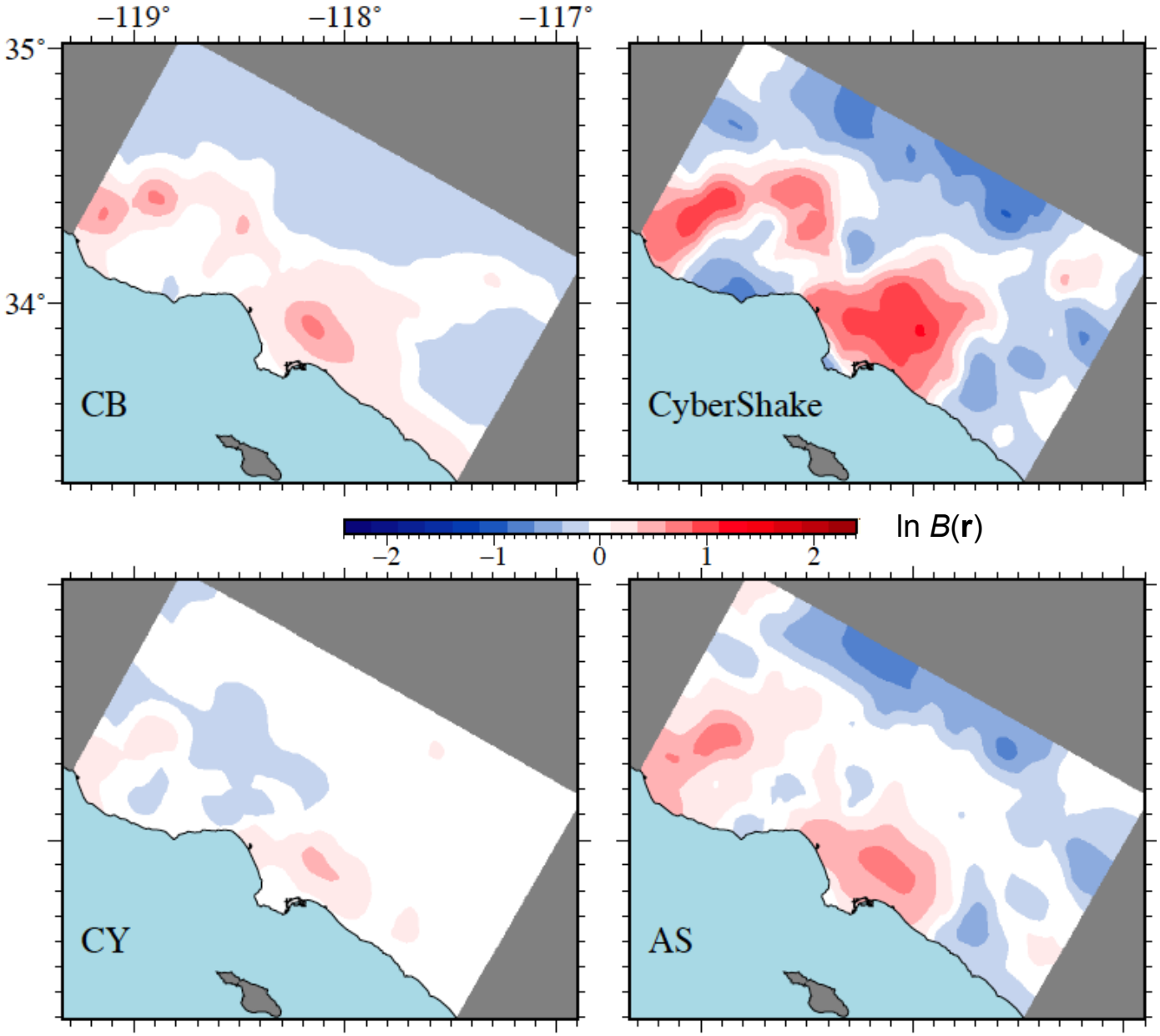


CyberShake Study 13.4 Hazard Map, sites marked (300 ppi, ps file)

CyberShake Hazard Maps from CyberShake 13.4 Study

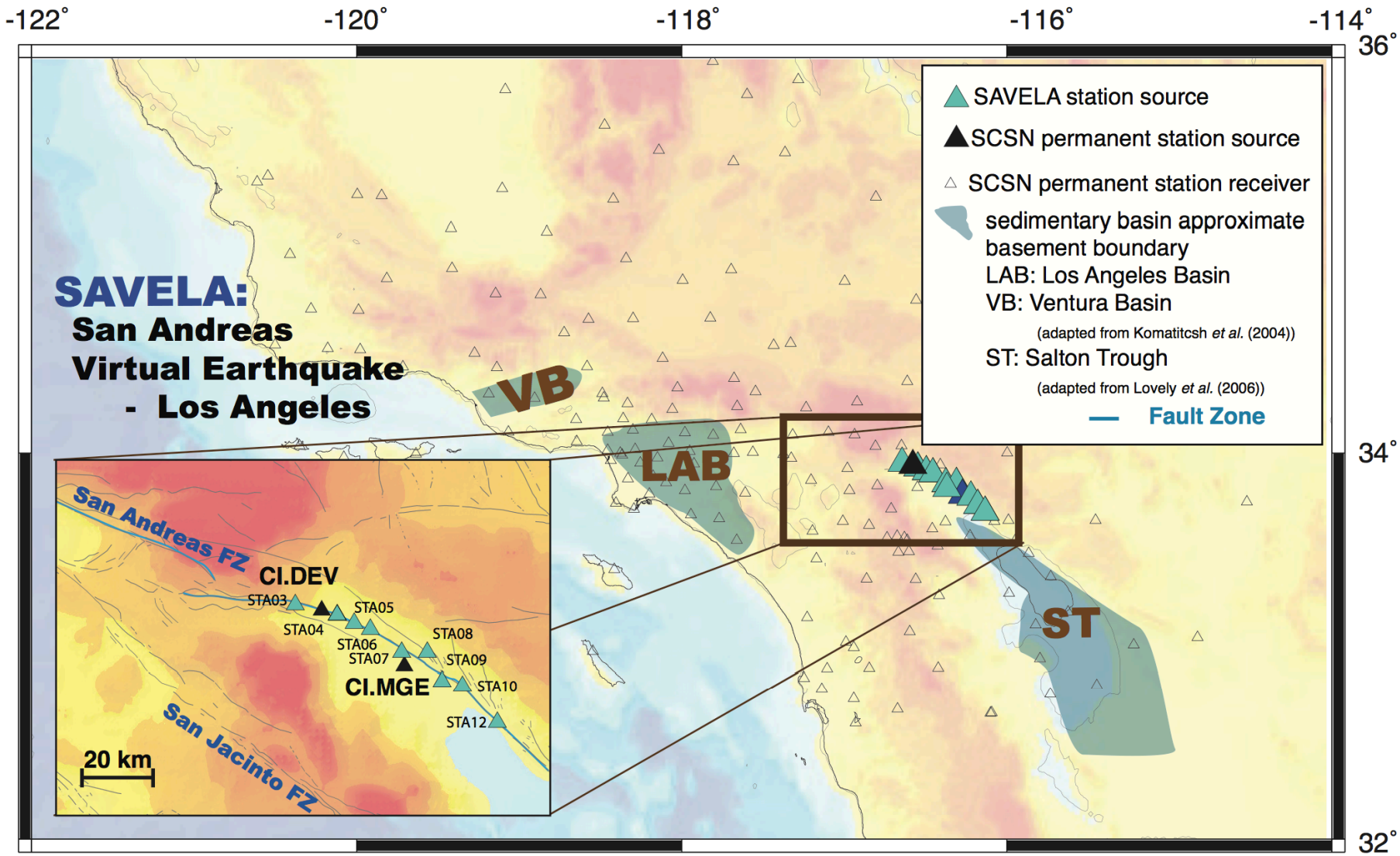
ABF Basin Amplification Maps

(SA-3s corrected for V_S30)



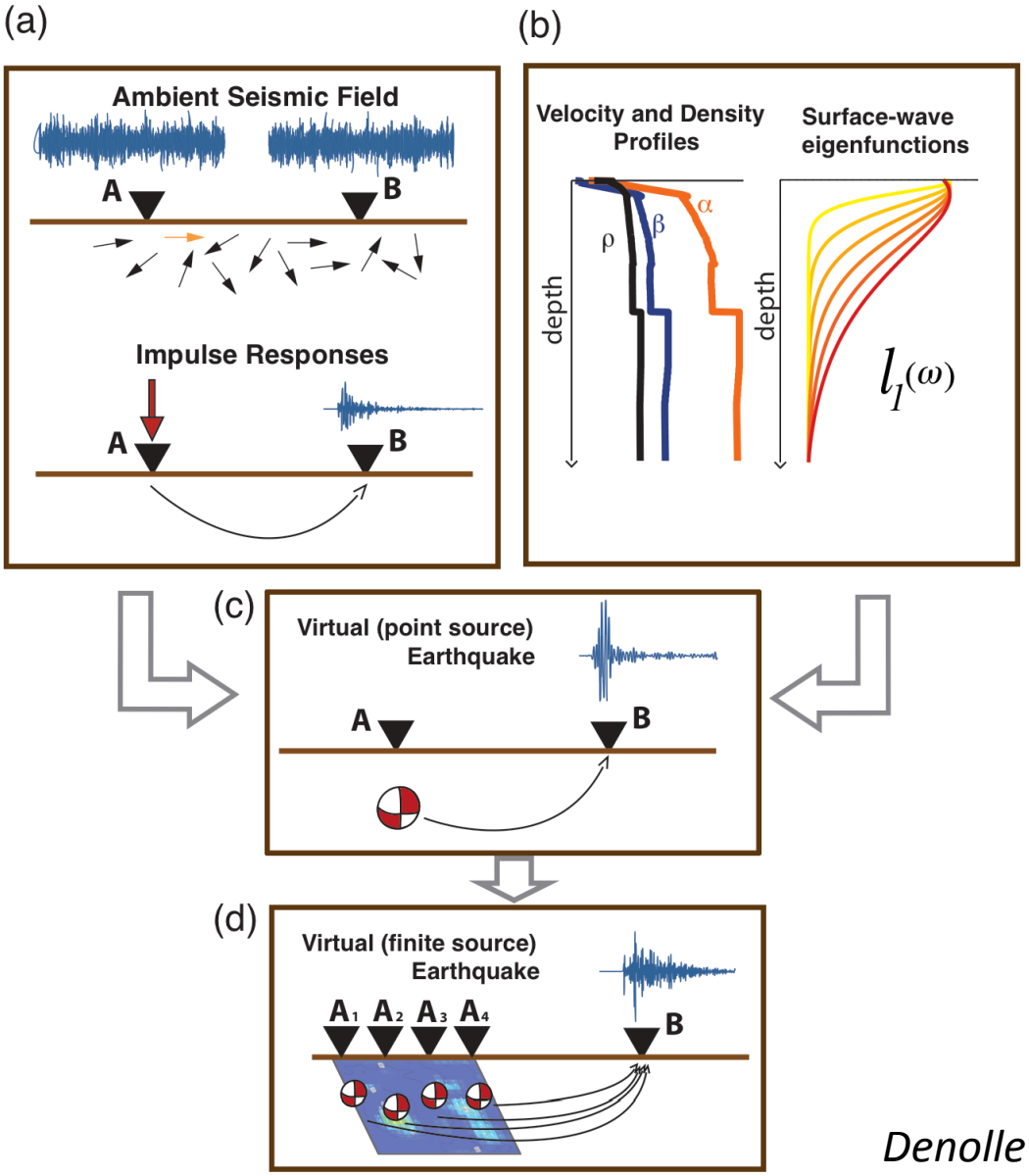
Wang & Jordan
(2013)

Ambient-Field Green's Functions for GMP



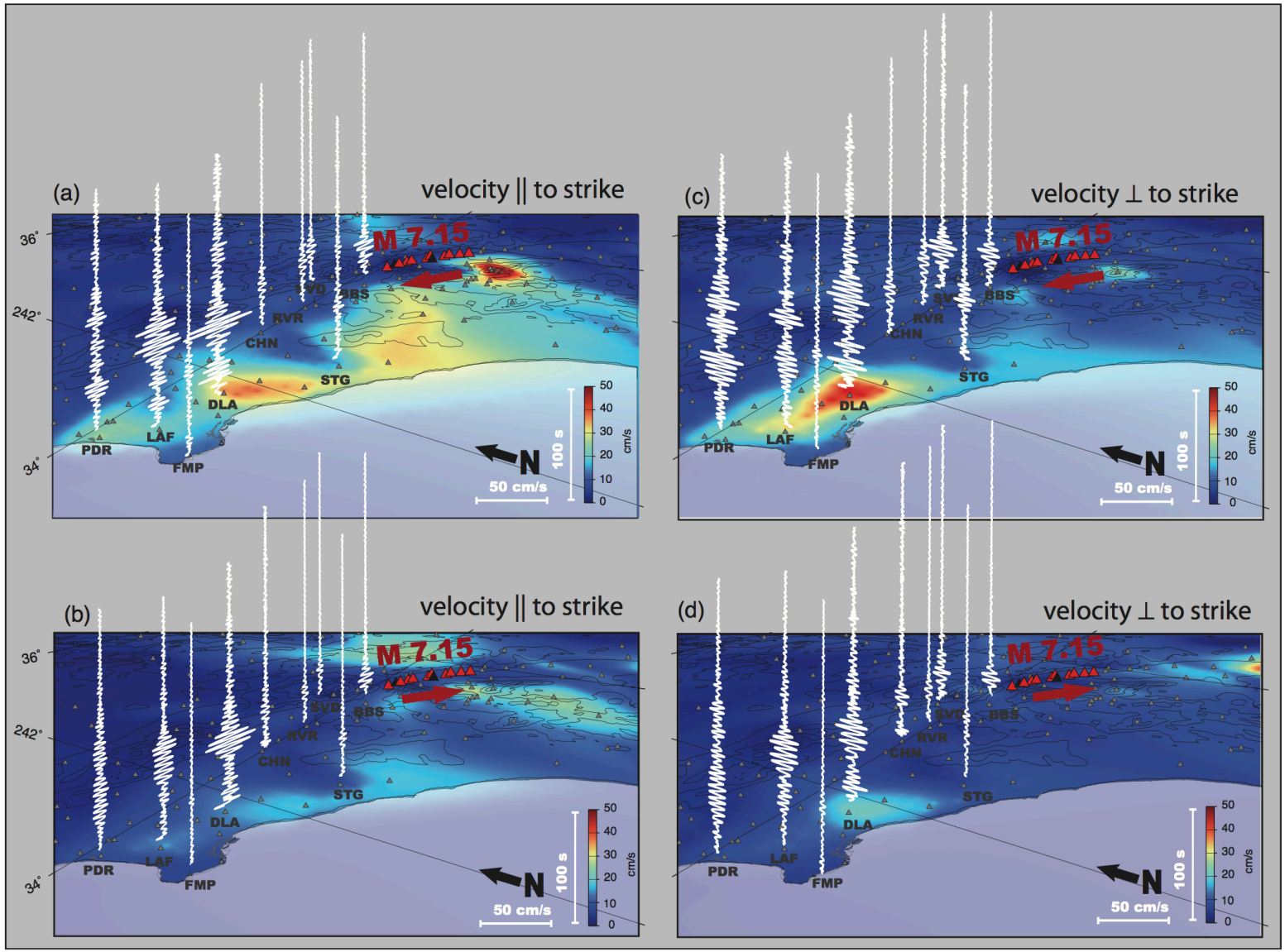
Denolle et al., 2013

Ambient-Field Green's Functions ➔ Virtual Earthquakes



Denolle et al., 2013

Basin Amplification Similar to Independent Simulations

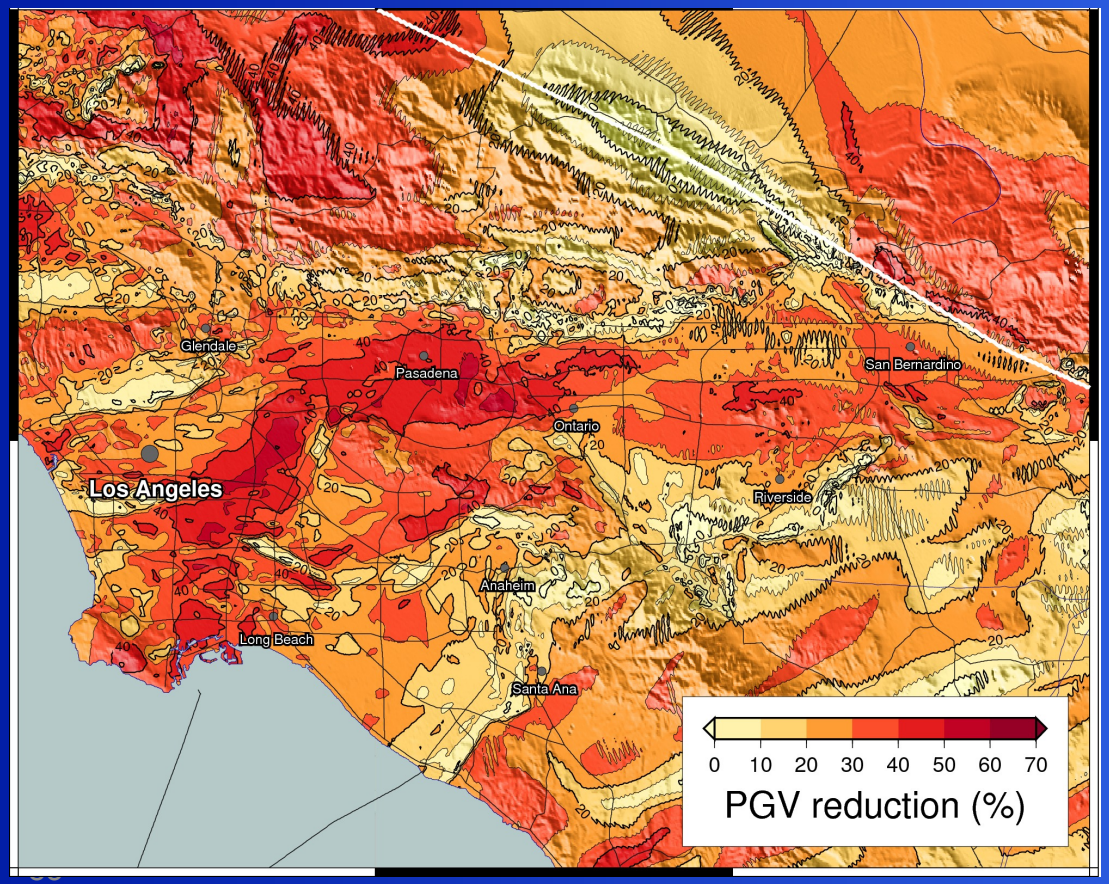


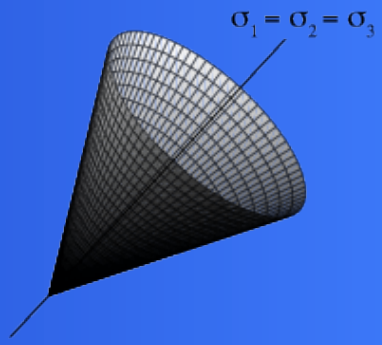
Denolle et al., 2013

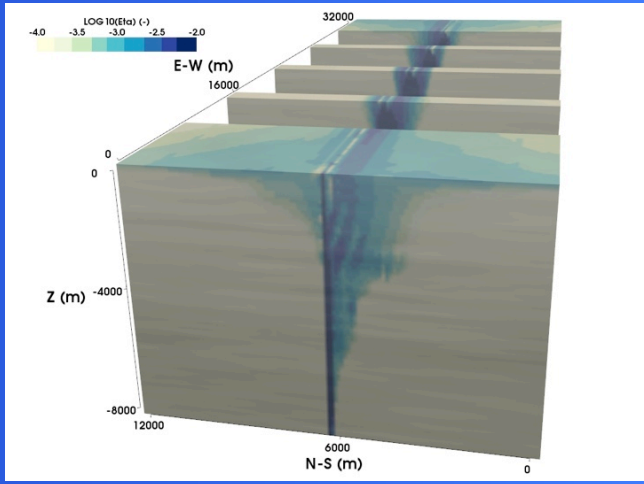
Up to 50% Reduction in ShakeOut Amplitudes From Plastic Yielding

Implementation of Drucker-Prager Plastic Yielding in AWP-ODC

Roten, Olsen, Day, Fäh (2013)







Rupture propagation in fracture damaged media
Sammis

Candy-glass: Kc = 0.04 Mpa $m^{1/2}$

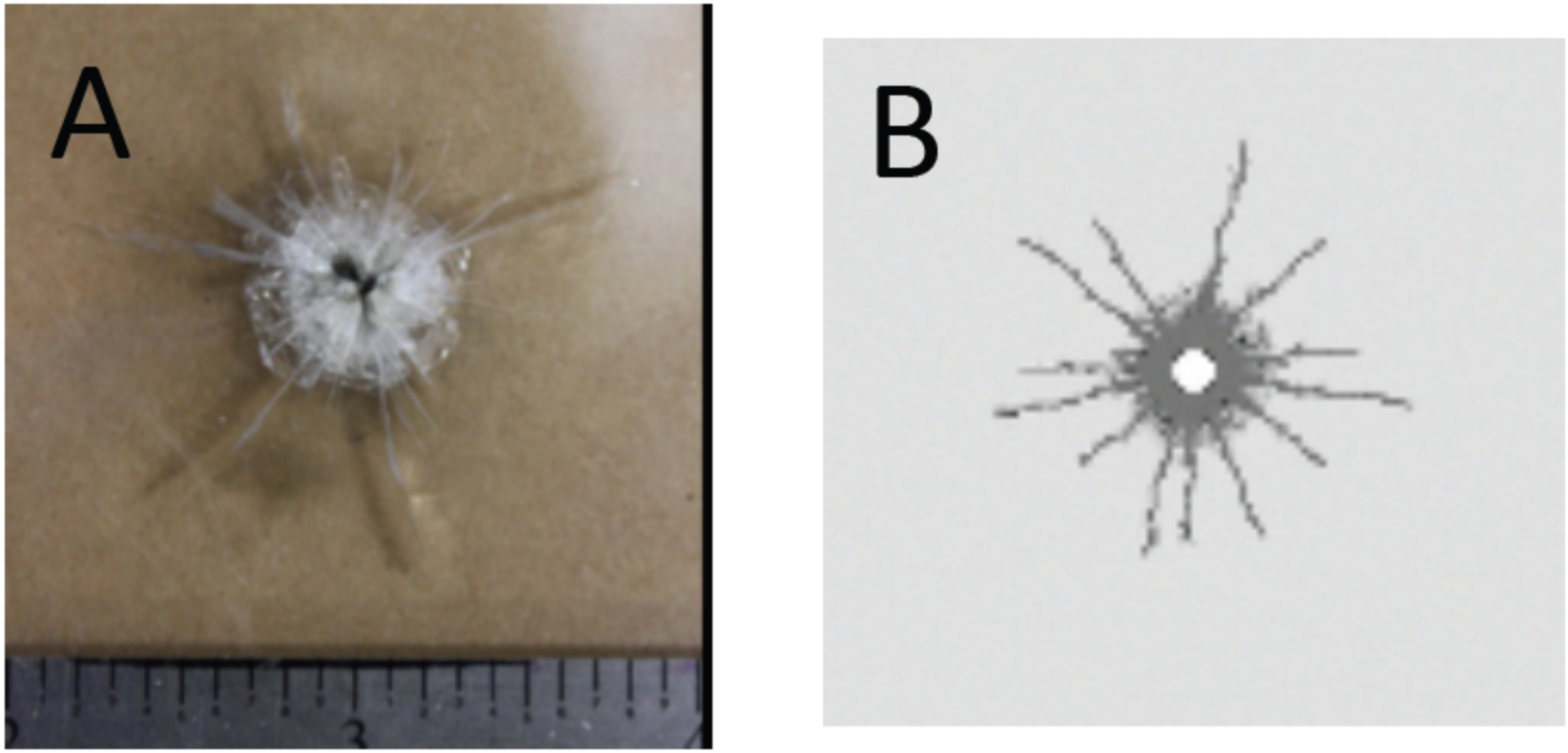
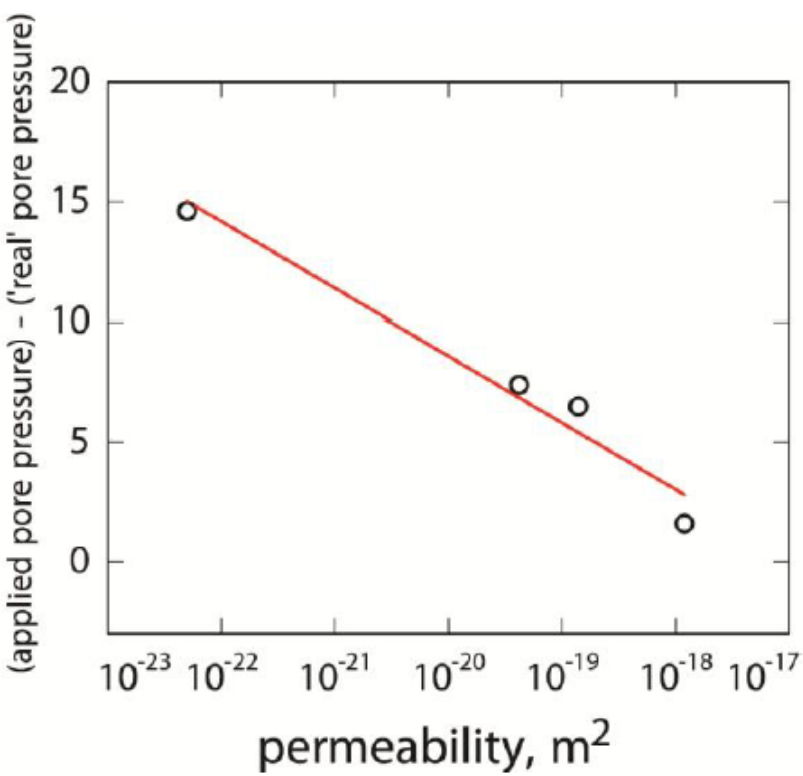


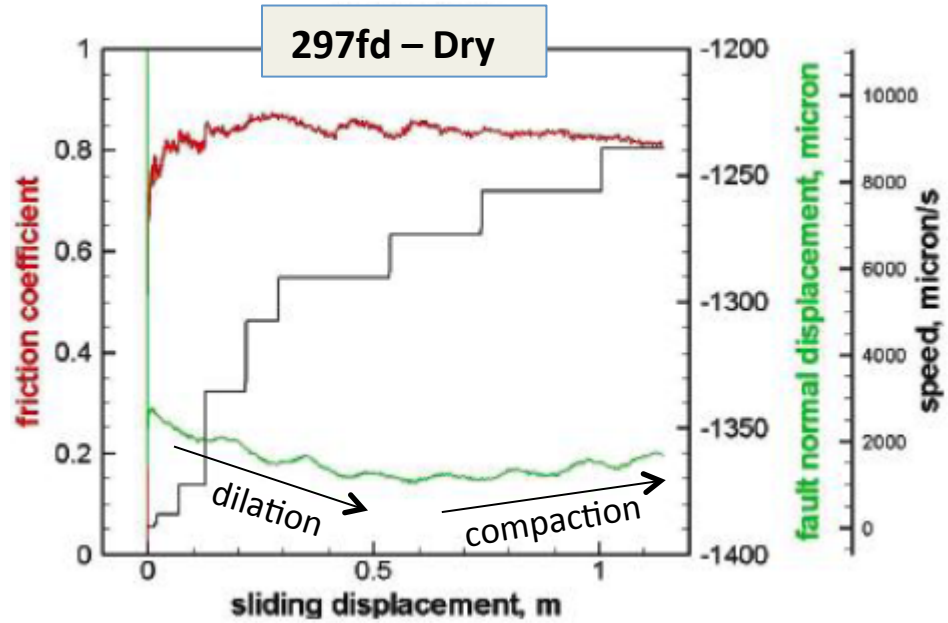
Figure 1. Panel A shows the damage resulting from an exploding wire. Panel B shows an ABAQUS simulation using the dynamic damage mechanics.

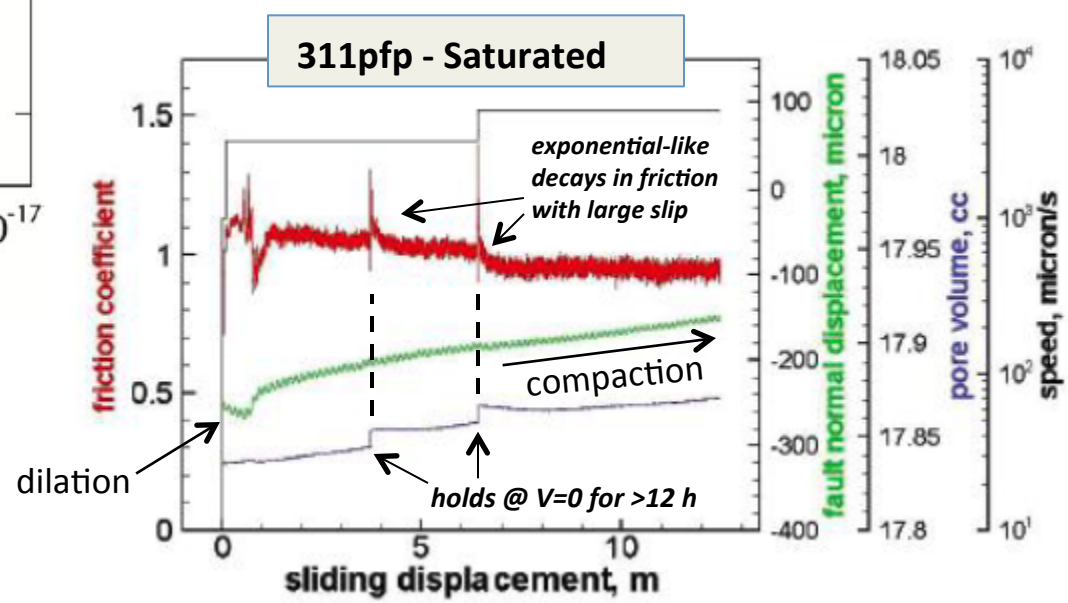
"Laboratory Experiments on Fault Shear Resistance Relevant to Coseismic Earthquake Slip"

Goldsby and Tullis

Thermal pore fluid pressurization

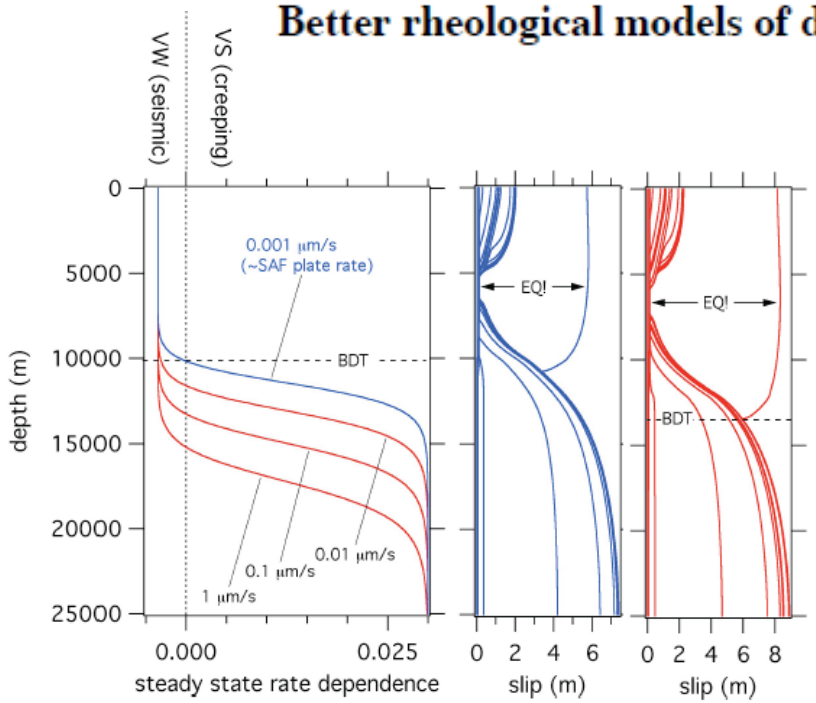






Better rheological models of deep coseismic slip, aseismic slip and shear localization

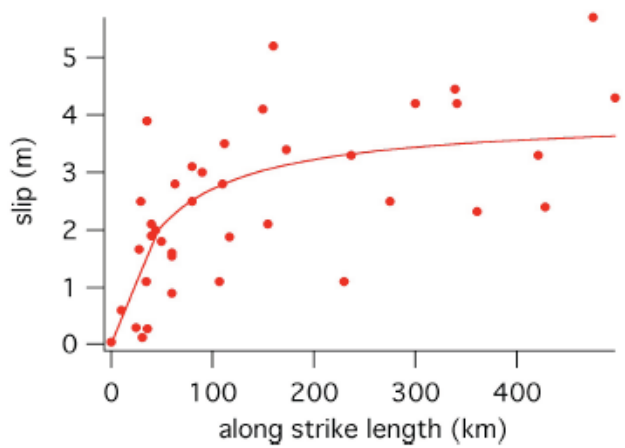
(Tullis, Hirth , Beeler)

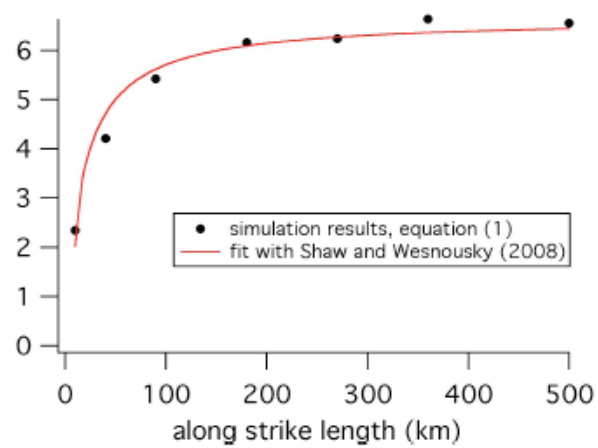


Rate-and-state with velocity cut-off in direct effect → rate-dependent deepening of the seismic-aseismic transition

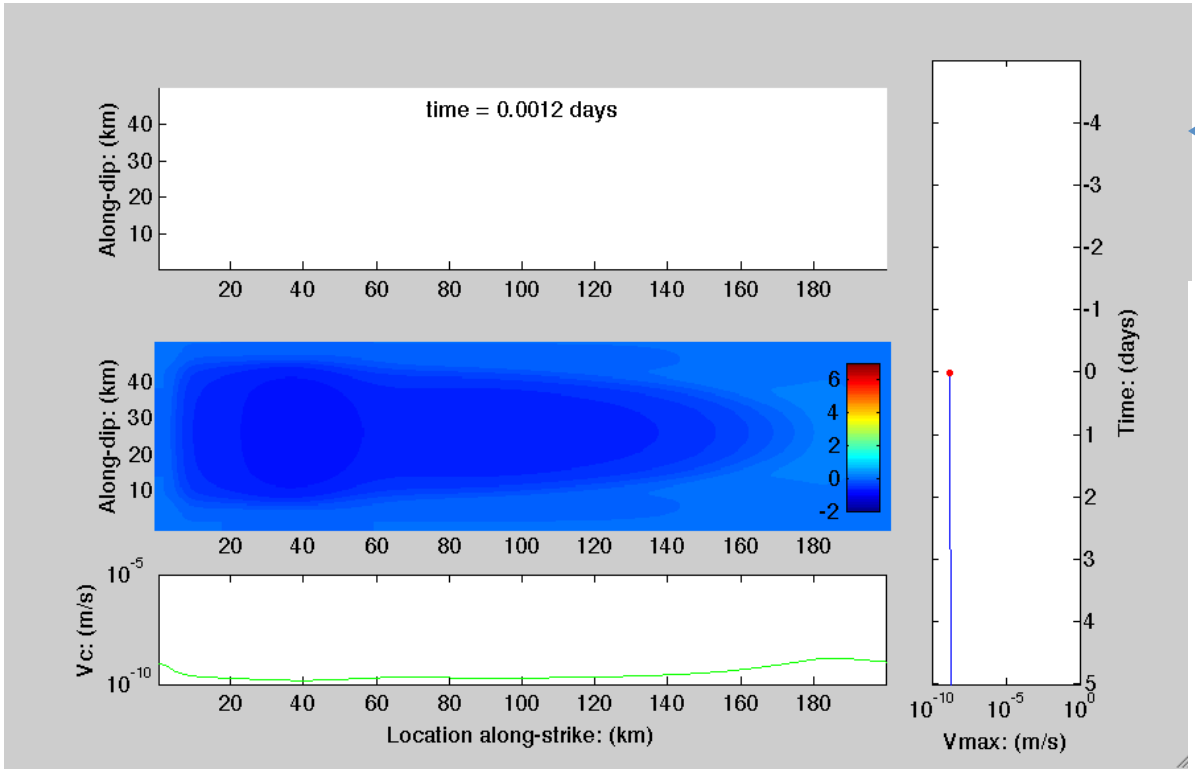
Coseismic rupture penetrates into the deep velocity-strengthening regions

Implications for slip-length scaling laws

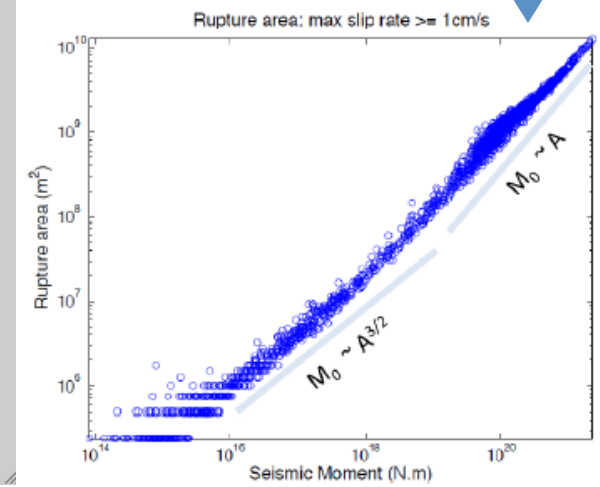


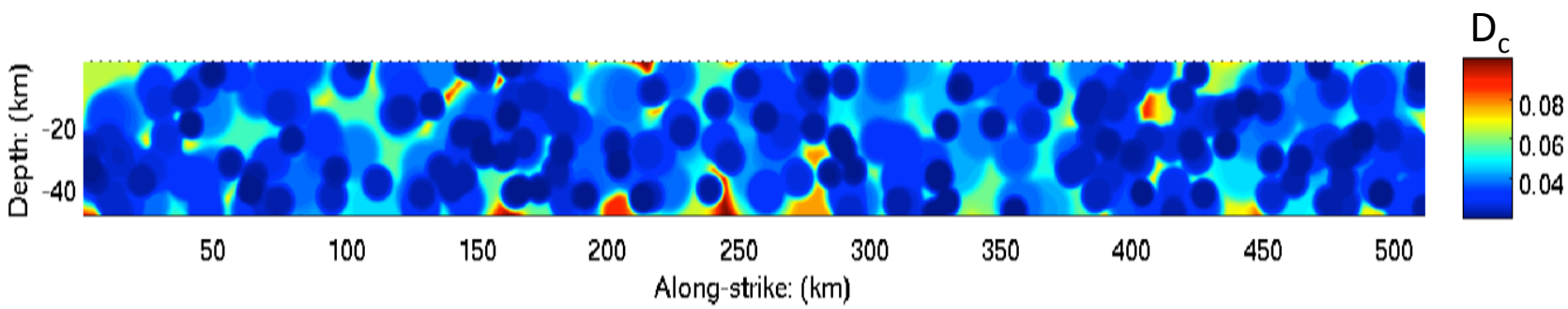


Spatio-temporal Patterns of Tectonic Tremor Activity (Ampuero)



Dynamics of heterogeneous faults:
slow slip & tremor
earthquake cycle & scaling

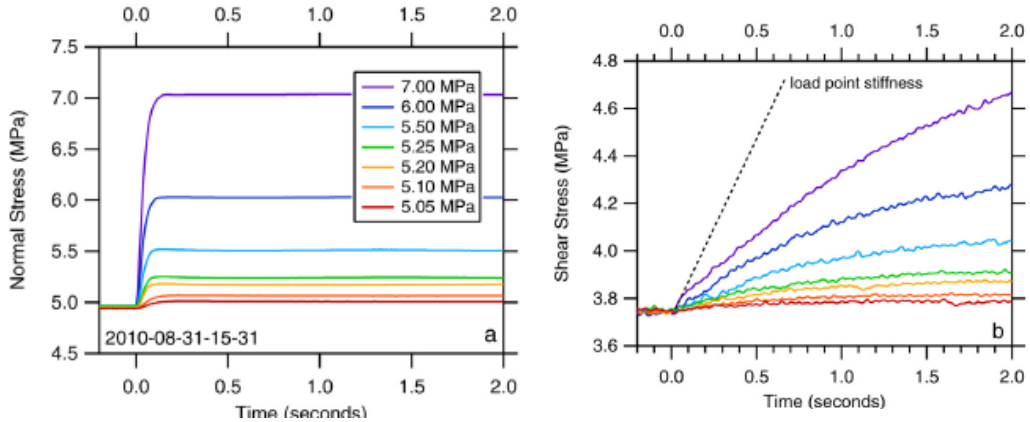


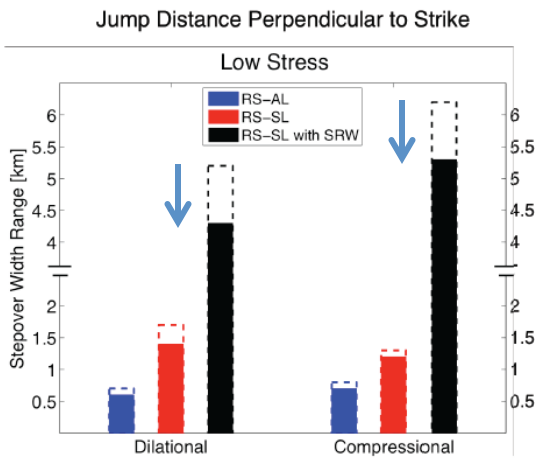


Dynamic rupture models incorporating a new laboratory-based normal stress-dependent constitutive friction law

(Oglesby, Beeler)

Lab: delayed fault response to normal stress (Kilgore et al 2012)

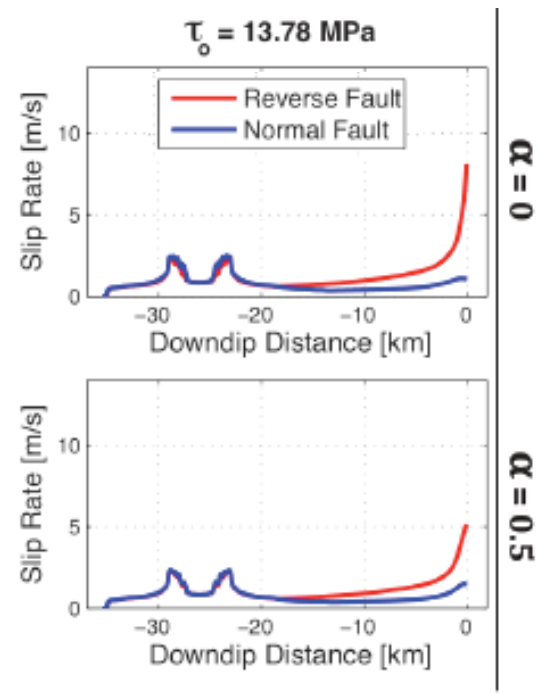




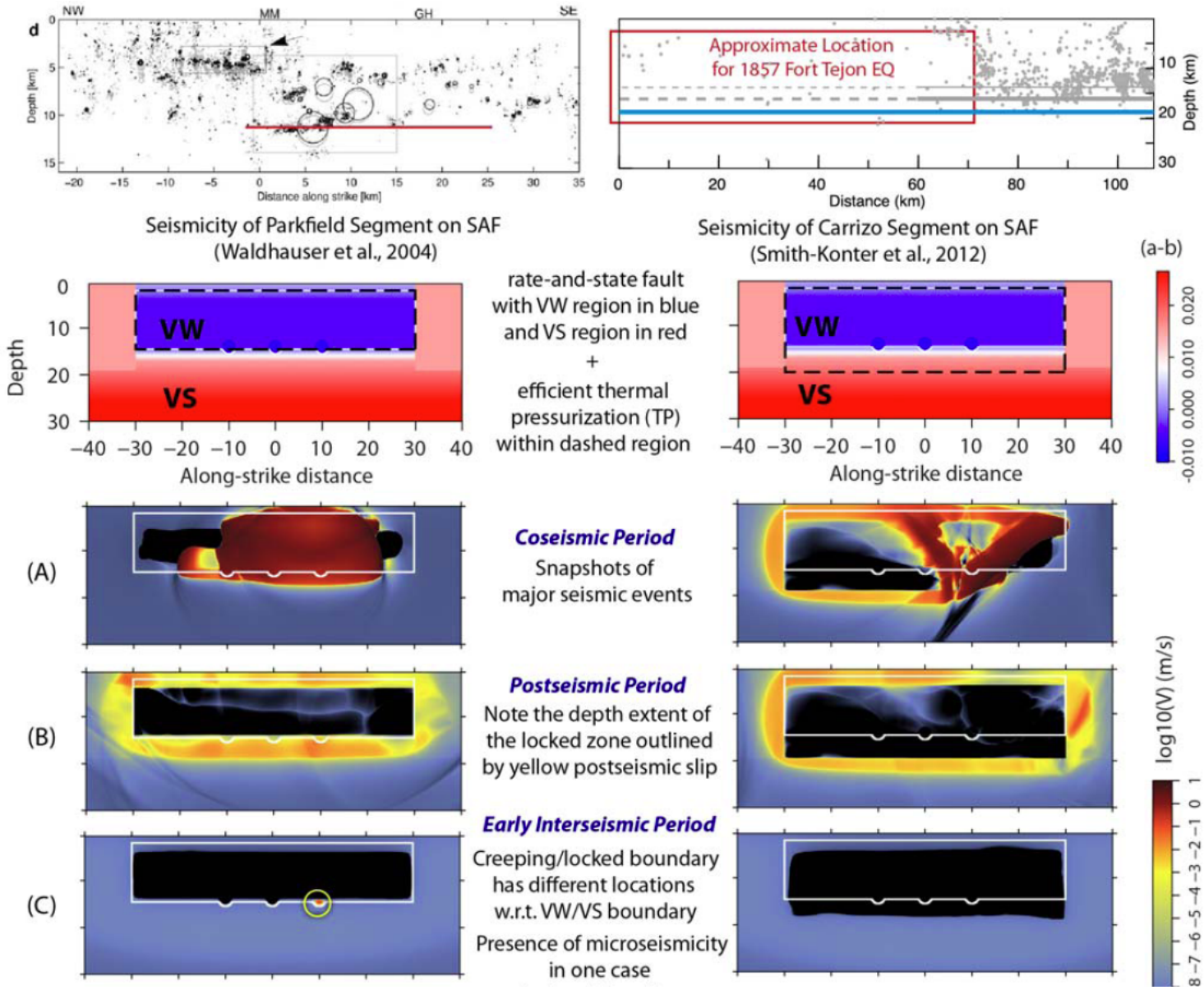
Implications developed through dynamic rupture simulation:

Reduced maximum stepover jump distance

Reduced difference between thrust and normal faulting

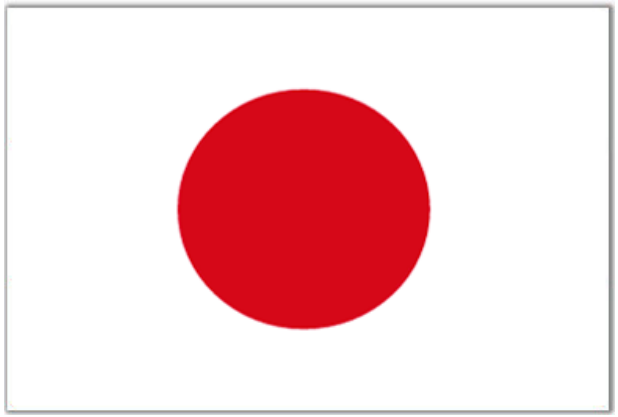


Lack of microseismicity concentration may point to deep penetration of large events (Lapusta and Jiang, poster)



NSF Science Across Virtual Institutes (SAVI)

Virtual Institute for the Study of Earthquake Systems (VISES)



Science Coordinated through the regular PC process.

Japan Side Coordinated through ERI/DPRI/+Others

Virtual Institute for the Study of Earthquake Systems (VISES)

- **<u>Premise</u>: research on fault systems in different tectonic regions can be synthesized into a physics-based understanding of earthquake phenomena**
- **<u>Program</u>: fundamental research to address basic questions of earthquake system science**
- **<u>Research goal</u>: improve seismic hazard analysis**
- **<u>Educational goal</u>: involve a new generation of earthquake scientists in interdisciplinary, multi-institutional research**

Virtual Institute for the Study of Earthquake Systems (VISES)

Funding

- NSF/SAVI will supplement to SCEC4 proposal by $200K/yr
- SCEC will allocated $100K/yr from its base program to VISES activities
- Total NSF funding will be $300K/yr for all years of SCEC4

Management

- VISES Executive Committee will comprise the SCEC Director and Deputy Director and representatives appointed by the ERI and DPRI directors
  - ERI: Hitoshi Kawakatsu (Deputy Director) and Katzushige Obara (PC Chair)
  - DPRI: Jim Mori
- SCEC resources will be management through the Planning Committee annual recruitment process
  - VISES will be built into the SCEC Science Plan
  - Funding for workshops, exchanges, and joint projects will be recommended by the PC in January and approved by the BoD in February

Virtual Institute for the Study of Earthquake Systems (VISES)

Types of joint activities

- **Workshops**
  - ERI-SCEC workshop held in Matsushima at the end of October, 2012
  - CORSSA Workshop at Tokyo in December, 2013
  - DPRI international forum in March, 2013
- **Scientific exchanges, with emphasis on students and early-career scientists**
  - Summer School on Diversity of Earthquakes at Hakone in September, 2013
  - High Resolution Topography in Earthquake Studies Workshop at Tsukuba in September, 2013
- **Research projects**
- **Cyberinfrastructure for virtual collaborations, data exchange, and modeling**

VISES SCEC workshop on high resolution topography applied to earthquake studies (GSJ, Tsukuba, Sept. 16-20, 2013)

Goals:

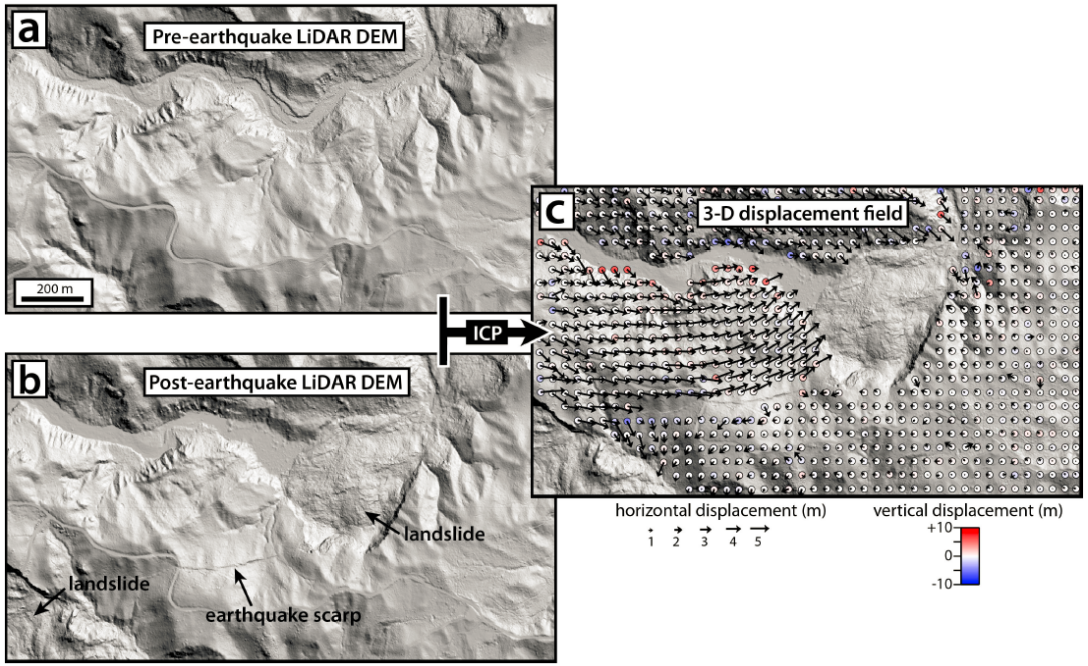
1) Review the scientific opportunities and recent results coming from the analysis of high resolution topography (<1 m/pixel; past earthquake reconstruction, tectonic geomorphology, and especially lidar differencing, etc.).

2) Training of students and other young scientists on the technologies associated with gathering, processing, and analyzing high resolution topography for earthquake applications.

3) Planning of future collaborative research.

Planning team:

Ramon Arrowsmith (Arizona State University)
Chris Crosby (UNAVCO)
Tadashi Maruyama (MEXT)
Edwin Nissen (Colorado School of Mines)
Koji Okumura (Hiroshima University)
Mike Oskin (UC Davis)
Srikanth Saripalli (Arizona State University)
Shinji Toda (Tohoku University)



Example science activity: We obtained these small patches of pre- and post-event LiDAR DEMs covering part of the epicentral region of the 13 June 2008 Iwate-Miyagi earthquake (Mw 6.9). Iterative Closest Point results are shown on the right, with horizontal displacements marked with black arrows and vertical displacements with colored circles. (Nissen, et al., in preparation)

International Summer School on Earthquake Science "Diversity of Earthquakes (Hakone, Japan, Sept. 23-27, 2013)

Topics:

Huge Earthquakes

Transient Phenomena

Fault Zones

15 keynote lectures (1 hour each)

8-10 shorter presentations from young scientists (1/2 hour each)

Poster session with 2 minute explanation for all additional participants (~30 early career scientists)

2013-2014 VISES Projects

Asimaki	Nonlinear Site Response
Becker	Summer School
Beroza	Basin Amplification
Bielak	Ground Motion Simulation
Tanimoto	High Frequency Modeling
Arrowsmith	Topography Workshop
Werner	Earthquake Predictability

Milestones

YEAR 2 (2013-2014) and Year 3 (2014-2015)

Improved Observations

Transient Geodetic Signals

Community Modeling Environment

Community Geodetic Model

Community Stress Model

Special Fault Study Areas

Ground Motion Simulation Validation

Source Modeling

Time-Dependent Earthquake Forecasting

Progress on SCEC4 Problems

Milestones: Improved Observations

YEAR 2 (2013-2014)

Begin cataloging SCEC-supported geochronology analyses available for Southern California.

Complete cataloging validation earthquakes and associated source descriptions and strong ground motion observations for California for use in ground motion simulation validation.

Start comparing InSAR and GPS data to flag any suspect data as a first step to integrated use of GPS and InSAR in the CGM.

Start developing plans for enhanced seismic instrument deployments in the SFSAs and elsewhere in Southern California.

Update coordination of earthquake response capabilities of the SCEC community with partner organizations, including USGS, IRIS, and UNAVCO. **[I-VI]**

Milestones: Improved Observations

YEAR 3 (2014-2015)

Archive and make available at the SCEDC waveforms, refined catalogs of earthquake locations and focal mechanisms for the period 1981-2013.

Continue cataloging SCEC-supported geochronology analyses available for Southern California.

Submit a proposal to NSF/Earthscope that focuses on high-resolution imaging of SFSAs and elsewhere in Southern California.

Begin developing catalogs of prehistoric surface rupturing events along major faults in the system. **[I-VI]**

Milestones: Transient Geodetic Signals

YEAR 2 (2013-2014)

Increase the number of geodetic transient detection algorithms automated within CSEP that continuously operate on authoritative GPS data streams.

Assess and refine detection thresholds through the use of synthetic data for a range of earthquake sizes for all operating detectors. **[V]**

Milestones: Transient Geodetic Signals

YEAR 3 (2014-2015)

Using the first two years of results from Southern California, assess the capability and consistency of the geodetic transient detection procedures.

Develop ensemble-based detection procedures that combine the output of multiple detection algorithms. **[II, V]**

Milestones: CME

YEAR 2 (2013-2014)

Improve CVMs by applying full-3D waveform tomography to data from hundreds of earthquakes.

Perform reference calculations and apply goodness-of-fit measures to evaluate CVMs against earthquake waveform data.

Improve stochastic kinematic rupture models that incorporate source complexity observed in dynamic rupture simulations, including supershear rupture.

Provide access to the UCERF3 statewide hazard model via the OpenSHA software platform. Develop methodology for calculating an extended ERFs based on UCERF3. **[II, III, IV, VI]**

Milestones: CME

YEAR 3 (2014-2015)

Incorporate results from the Salton Seismic Imaging Project into the CVMs.

Incorporate stochastic descriptions of small-scale heterogeneities into the upper layers of the CVMs and evaluate the importance of these heterogeneities in ground motion models.

Integrate and evaluate a statewide unified CVM suitable for 3D ground motion modeling. Incorporate new information on fault complexity from SFSA projects into the CFM. **[II, III, IV, VI]**

Milestones: CGM

YEAR 2 (2013-2014)

Start generating a unified GPS time series dataset for secular and transient deformation and compiling LOS velocity maps from available SAR catalogs.

Establish strategy for estimating secular rate as well as temporally variable signals (e.g., seasonal, postseismic). Assess the feasibility and the potential benefits of incorporating additional datasets (e.g., strainmeter, LiDAR) into CGM.

Specify the CGM output needed for input to the CSM and transient detection and begin providing preliminary datasets as available. **[I, II, V]**

Milestones: CGM

YEAR 3 (2014-2015)

Integrate InSAR and GPS in order to formulate a uniform resolution model for secular surface velocities and associated uncertainties and covariances.

Revise or refine the technical specifications of the CGM based on results obtained in years 1 and 2 and input from the CSM and the Geodetic Transient Detection TAG.

Define the framework and infrastructure for maintaining CGM. Identify and test algorithms for time-dependent InSAR analysis. [I, V]

Milestones: Source Modeling

YEAR 2 (2013-2014)

Develop numerical methods that simultaneously resolve fault zone processes and large-scale rupture, including fault interaction, complex geometries, heterogeneites and multiple fault physics.

Assess data available to distinguish source from path/site effects at high frequencies.

Develop a methodology for uncertainty quantification in finite-fault source inversion and back-projection source imaging, tested on standardized data sets. **[III, VI]**

Milestones: Source Modeling

YEAR 3 (2014-2015)

Verify numerical methods and assess physical formulations of fault geometries.

Develop and calibrate parameterization of resistance mechanisms that are suitable for large scale models of dynamic ruptures, including interaction with fault roughness and damage-zone properties.

Develop improved source inversion approaches with enhanced information extraction from high frequencies, including by integration with back-projection imaging. **[III, VI]**

Milestones: Time-Dependent EF

YEAR 2 (2013-2014)

Assess the capabilities of UCERF3 for time-dependent forecasting through comparisons with earthquake catalogs or synthetic catalogs from earthquake models.

Through CSEP and in collaboration with the USGS and CGS, test the suitability of deploying UCERF3 as an operational earthquake forecast.

Couple UCERF3 to the Cybershake simulation suite for the Los Angeles region to prototype a time-dependent urban seismic hazard model. **[II, VI]**

Milestones: Time-Dependent EF

YEAR 3 (2014-2015)

Develop approaches for using physics-based earthquake models in forecasting.

Employ these models for studying the predictability of large events and constraining seismic cycle parameters (maximum magnitude, inter-event time, etc.).

Conduct prospective forecasting experiments in CSEP that test the key hypotheses that underlie time-dependent forecasting methods. **[II]**

Milestones: Progress on SCEC4 Problems

YEAR 2 (2013-2014)

Report to the SCEC4 community and Advisory Council on the progress made so far in formulating and testing hypotheses that address the six fundamental problem areas of earthquake physics.

YEAR 3 (2014-2015)

Report to the SCEC4 Community and Advisory Council on the progress made so far in formulating and testing hypotheses that address the six fundamental problem areas of earthquake physics and report to SCEC4 community.

Questions/Comments/Discussion?

Status of Special Fault Study Areas (SFSAs)

Integrated, multi-disciplinary projects focused on areas of complex fault behavior.

Require coordinated teams of researchers with diverse expertise.

There are currently two SFSAs

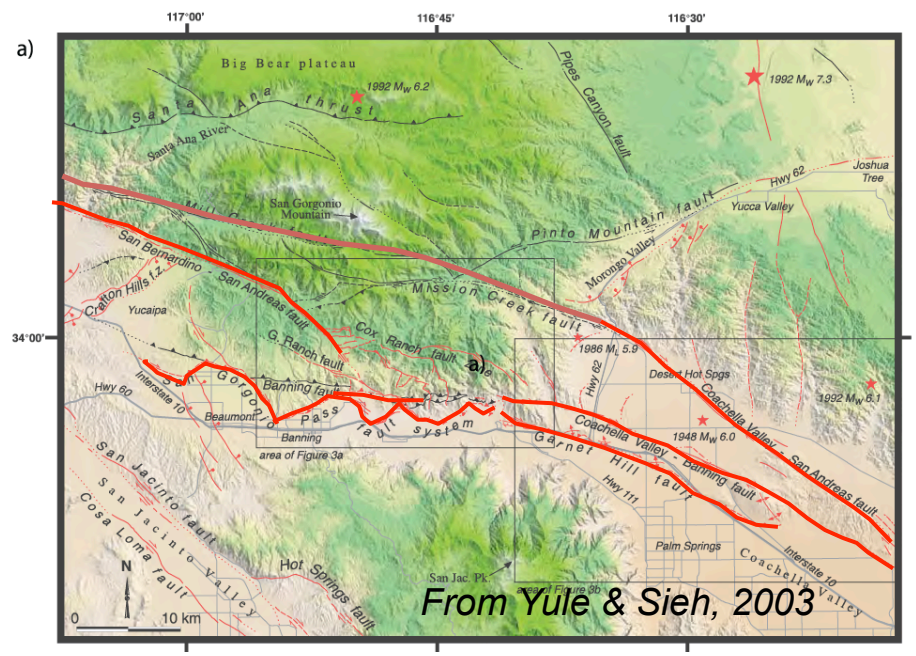
- **San Gorgonio Pass**
- **Ventura Area**

Not planning to initiate new SFSAs in SCEC4

San Gorgonio Pass

Special Fault Study Area

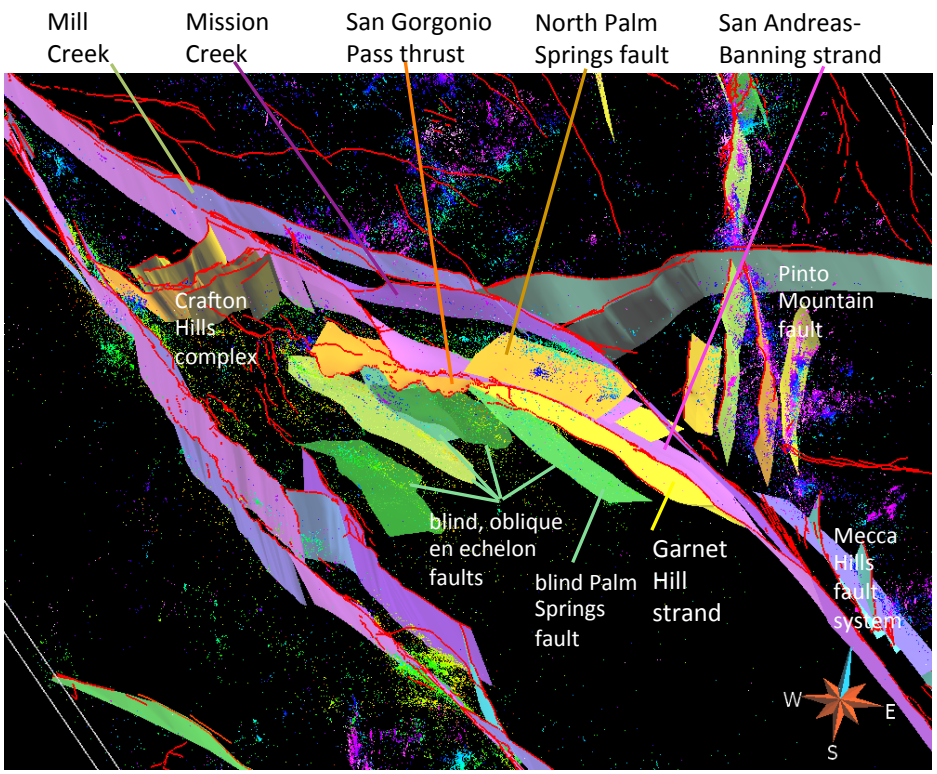
- Q1: *How do we reconcile deep and shallow structure? What is the active 3D structure*
- *Q2: What is the current pattern of deformation in SGP and how may this relate to earthquake potential?*
- *Q3: Can rupture pass through the SGP?*



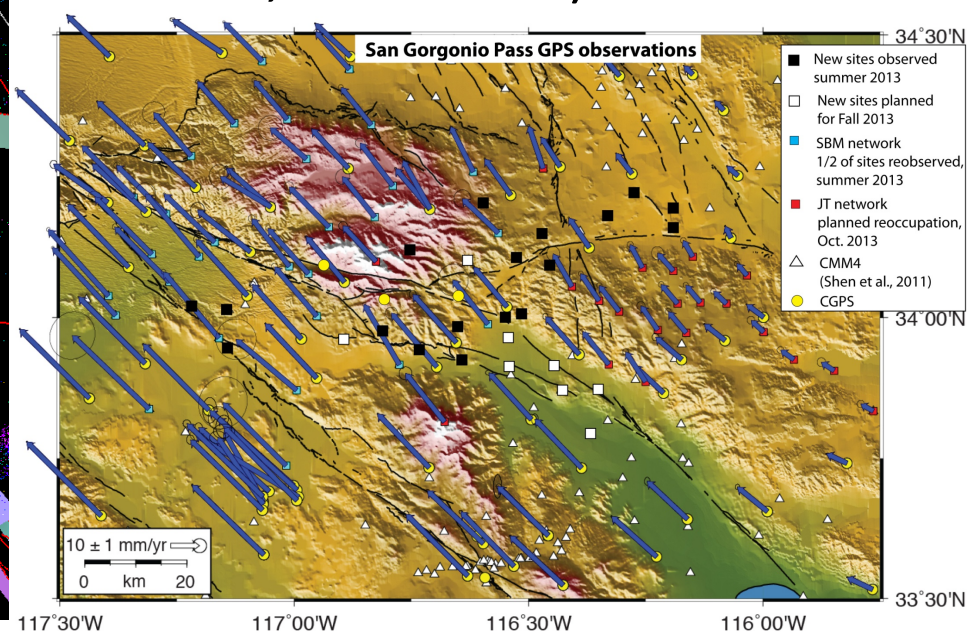
From Yule & Sieh, 2003

Q1: *How do we reconcile deep and shallow structure? What is the active 3D structure*

- Microseismicity guides updates to the Community Fault Model (*Nicholson et al. #123*)

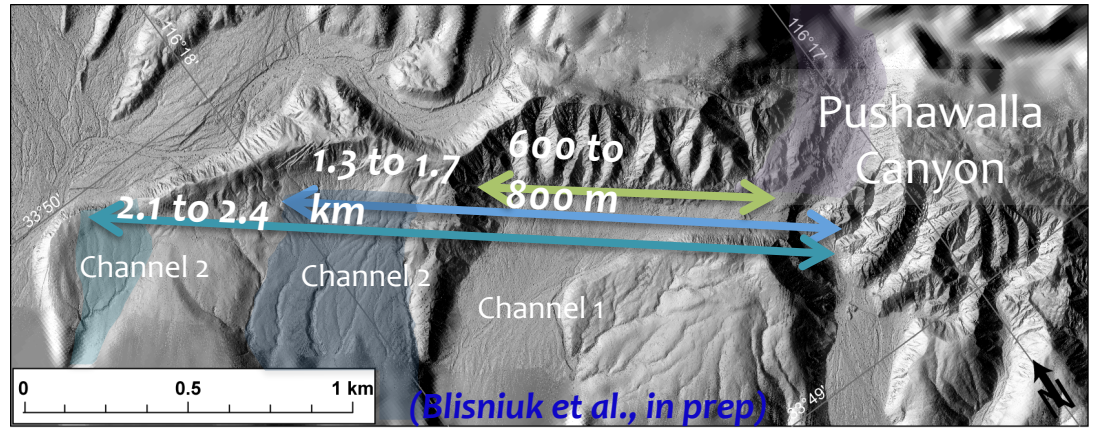


- GPS velocities including 25 new stations reveal surface expression of deeper deformation *(McGill, Spinler et al., #39 & #40*)



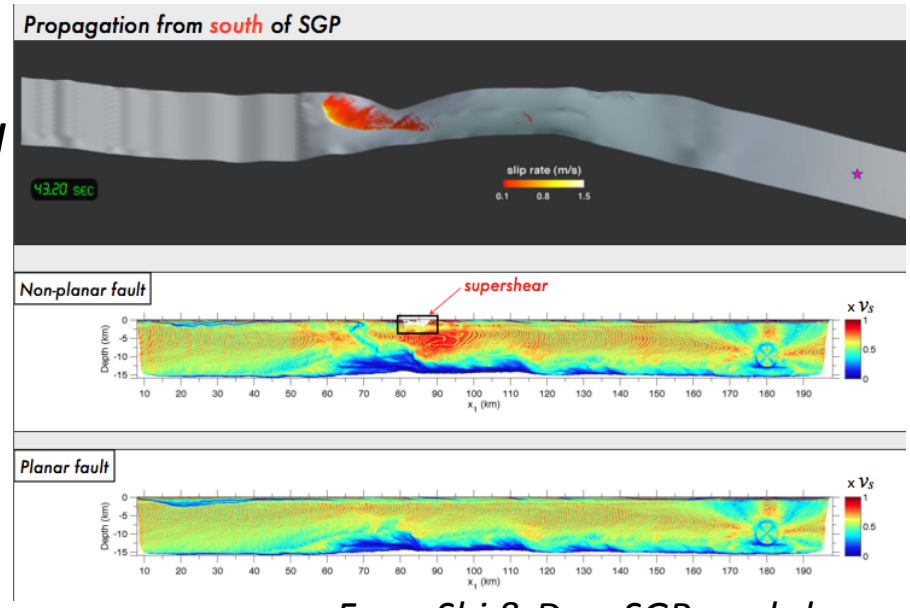
Q2: What is the current pattern of deformation in SGP and how may this relate to earthquake potential?

- Ongoing GPS *(McGill, Spinler et al., #39 & #40*)
- New slip rate estimates within data gap along the Mission Creek fault *(Blisniuk et al, #32)*
- Mega trench to extract 6000 year rupture history *(Scharer et al., Wolff et al., #29, #30 and Scharer plenary talk)*
- Garnet Hill Fault study *(Cardona #31)*



Q3: Can rupture pass through the SGP?

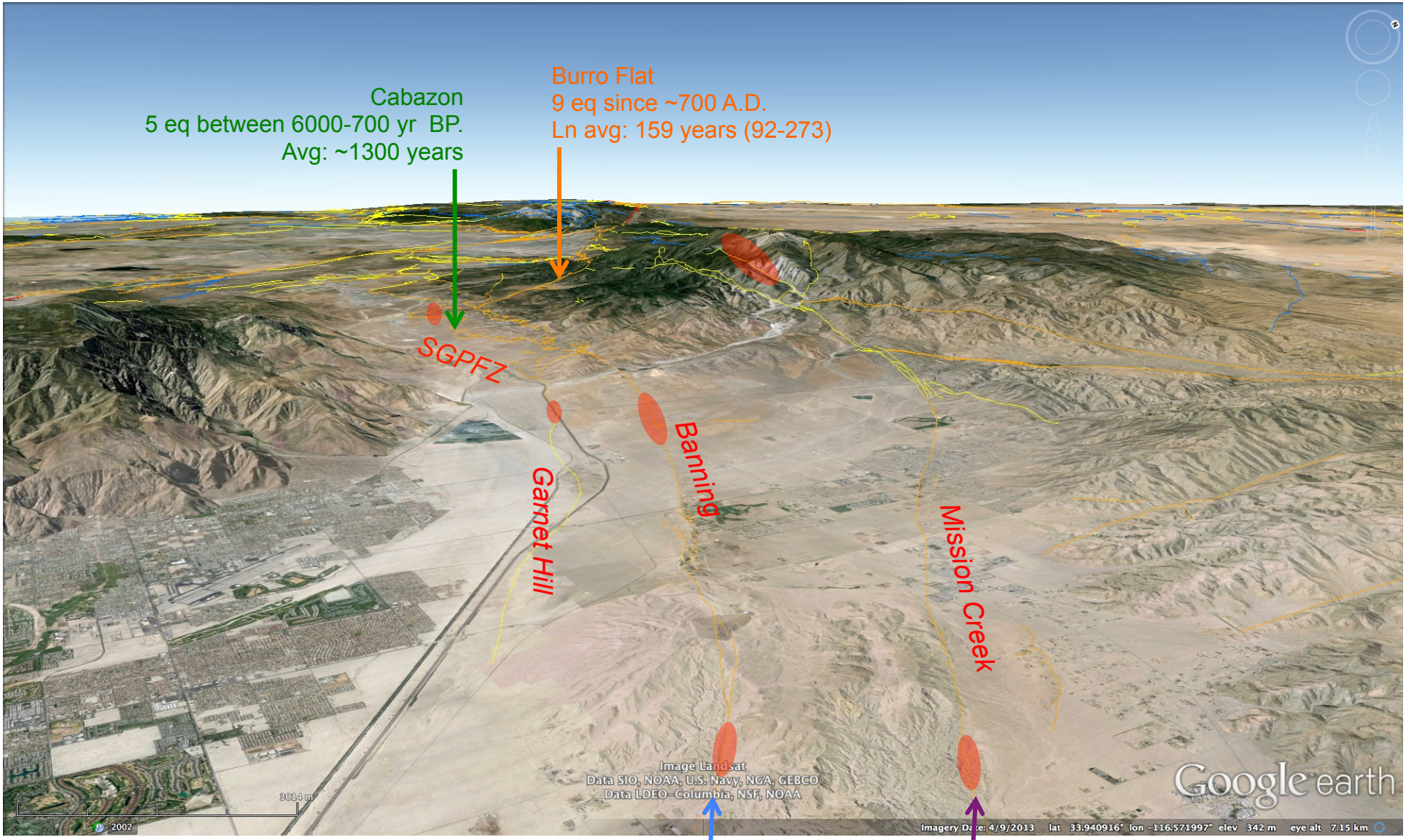
- Megatrench paleoseismology *(Scharer, Yule et al., #29, #30 and Scharer plenary talk)*
- Earthquake simulations using complex fault geometry reveal sensitivity to both geometry and stress conditions.



From Shi & Day, SGP workshop

In the coming year(s)…

- More slip rates and paleoseismology to fill data gaps
- Crustal deformation models that can resolve interpreted deep and shallow fault geometry
- More subsurface constraints on geometry
- Revise earthquake rupture models based on input from other studies; include fault intersections
- Lots more

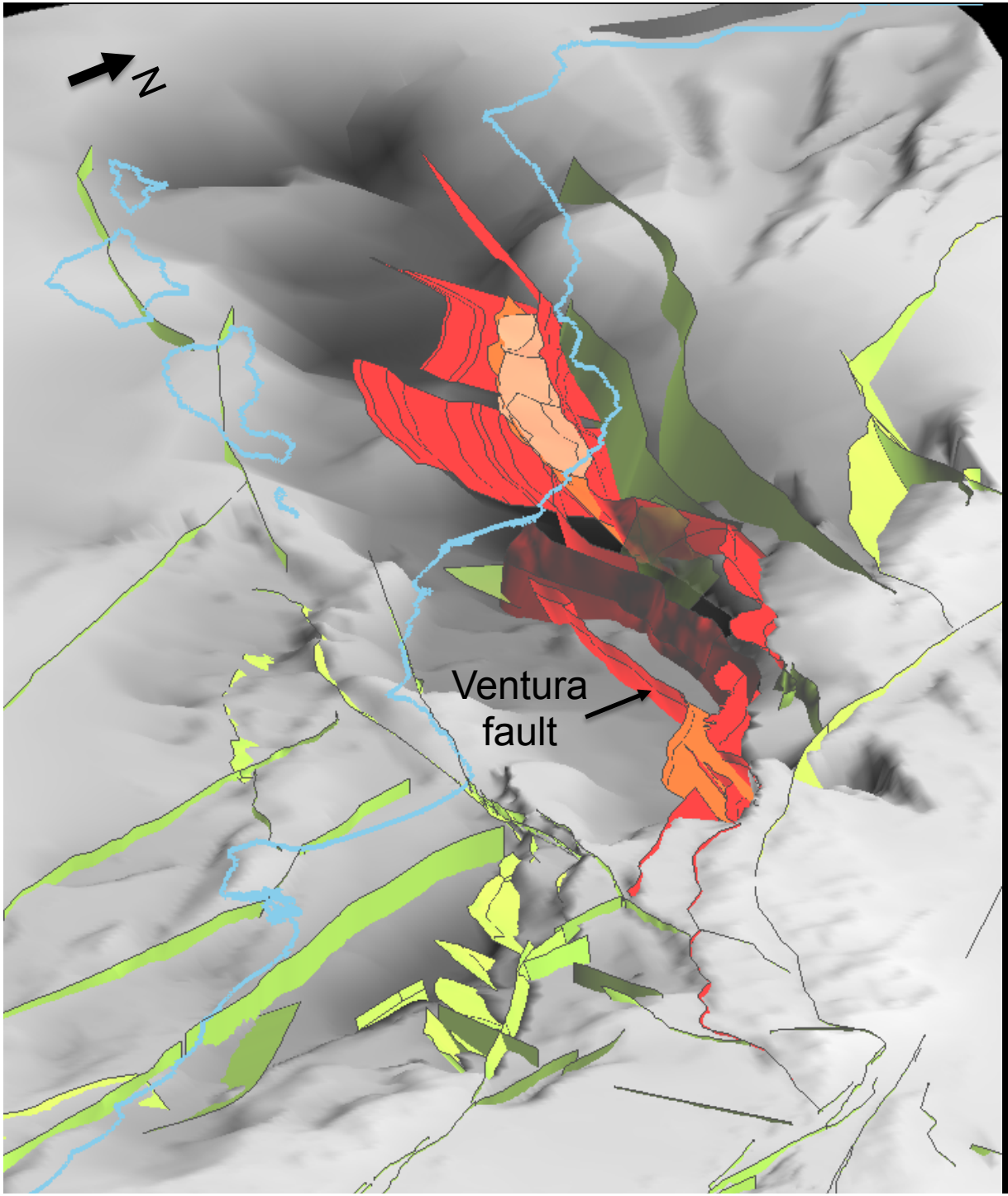


On-going slip rate and paleoseismic studies
PIs Behr, Blisniuk, Heermance, Kendrick, Scharer, Yule

Coachella (B + MC)
7 eq since ~950 A.D.
Ln avg: 131 years (73-236)

Thousand Palms (MC only)
5 eq since ~840 A.D.
Ln avg: 231 years (147-364)

Yule, 2000; Fumal et al., BSSA, 2002; Philibosian et al., BSSA, 2011; Biasi, UCERF3, 2013



SCEC Ventura Special Fault Study Area (SFSA)

Evaluating the prospects for large, multi-segment thrust fault earthquakes in southern California

Assessing the hazards posed by such events

A multi-disciplinary SCEC effort

- paleoseismology
- structural analysis
- reflection seismology
- earthquake seismology
- tectonic geodesy
- dynamic rupture modeling
- strong ground motion simulations
- tsunami hazards
- …

Inaugural Ventura SFSA Workshop Field Trip (8/15-16)

Goals for the Ventura SFSA

Test and refine the record of large multi-segment ruptures on the Ventura fault system along strike, and extend the record back in time.

Determine how slip and deformation are distributed in these large, multi-segment ruptures, and how might this vary over multiple earthquake cycles.

Characterize the interseismic strain accumulation along the Ventura thrusts system.

Define a viable set of multi-segment rupture scenarios with dynamic rupture modeling, and evaluate these using the paleoearthquake record.

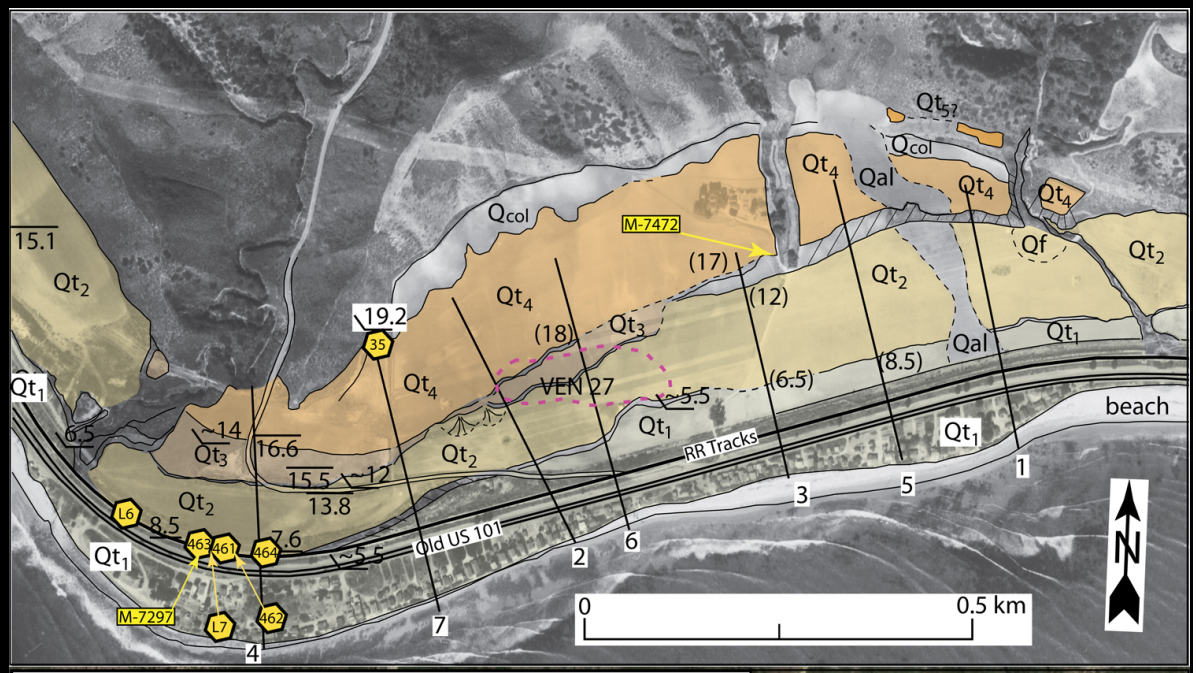
Define the intensity, duration, and distribution of strong ground shaking and tsunami runup we should anticipate for these events.

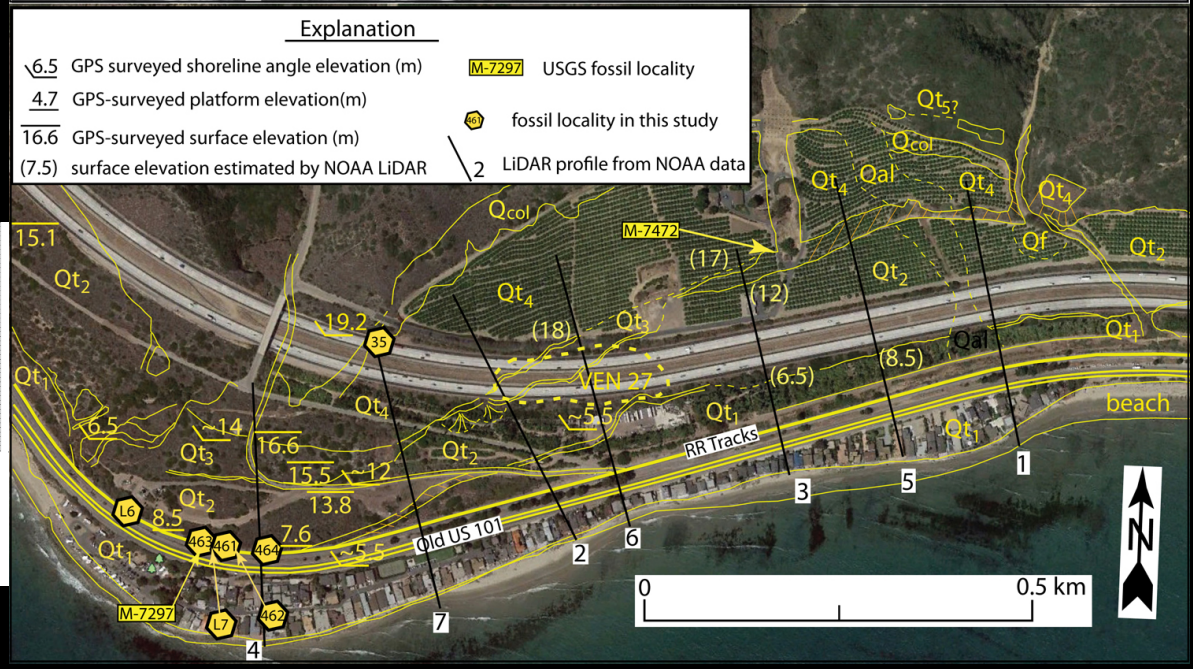
Establish if there is a tsunami record associated with these events, and assess these hazards.

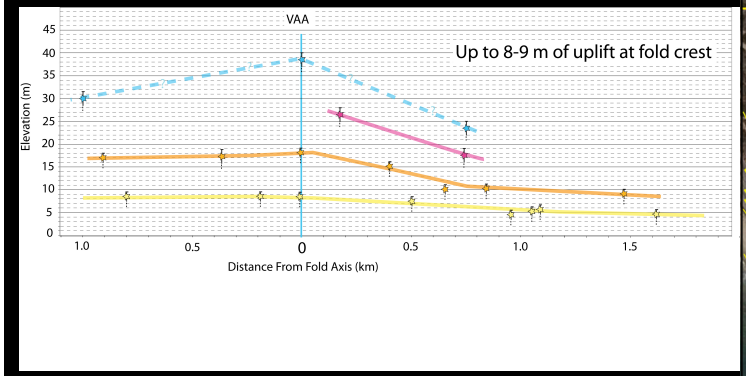
Current efforts - Pitas Point Holocene Emergent Terraces

Deformed marine terraces suggests the occurrence of four large Holocene earthquakes on the Ventura fault with up to 9 meters of uplift at the fold crest.

Such events seem to require multi-segment fault ruptures involving others thrust faults in the Transverse Ranges

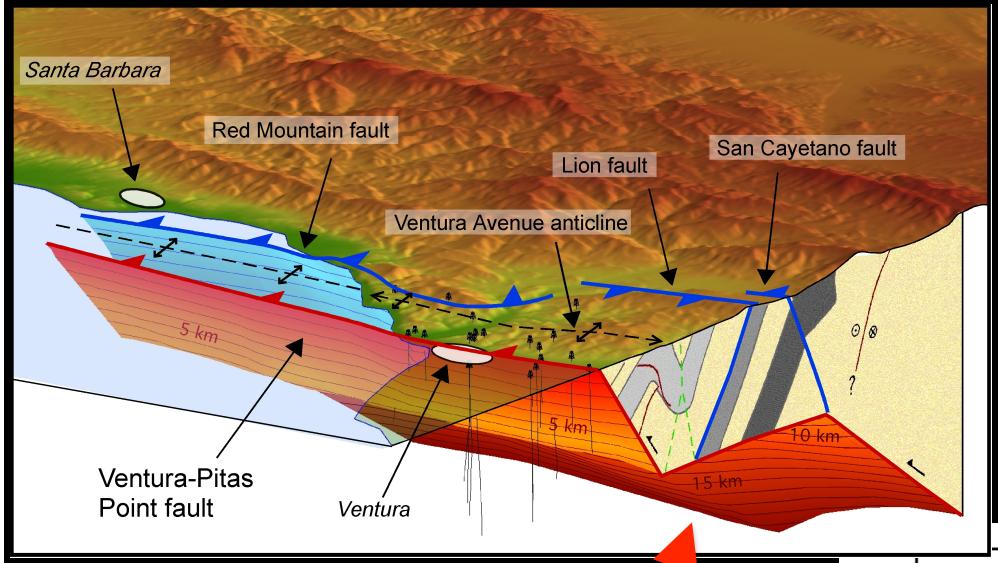






Rockwell et al., (in prep)

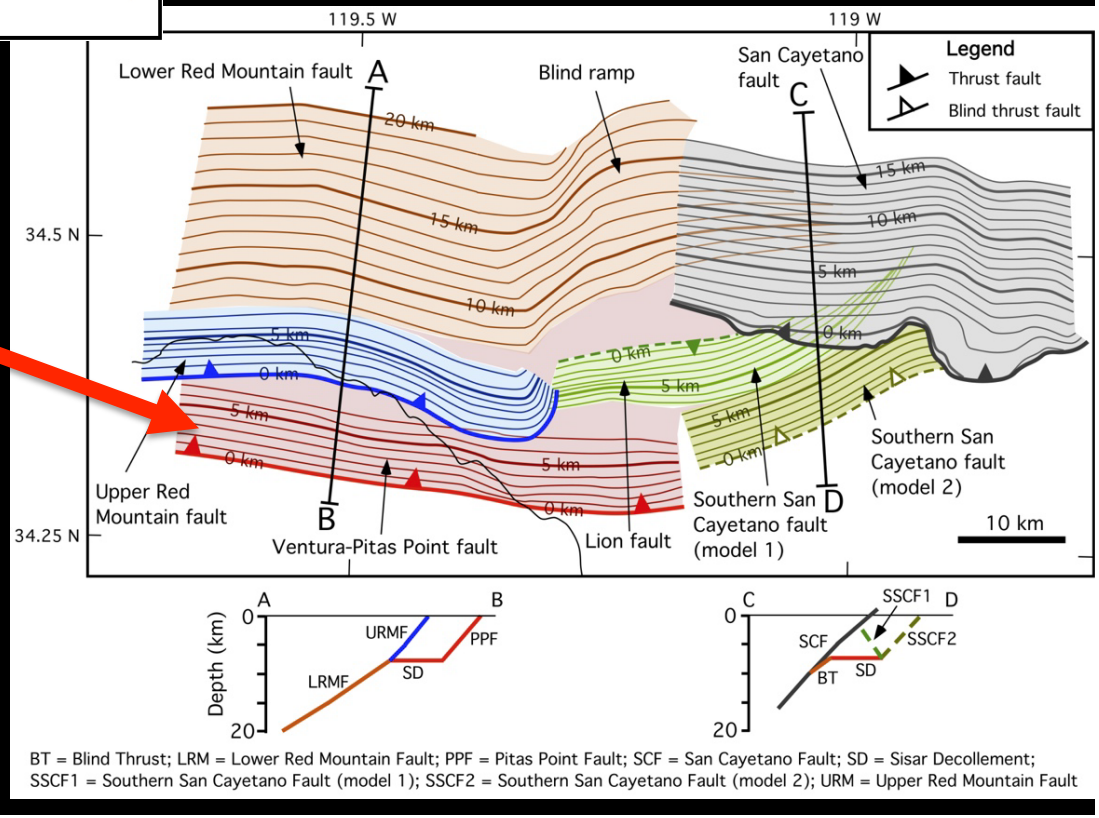
Current Efforts - Subsurface Structural Characterization



Subsurface structural analysis suggests that the Ventura fault represents a direct linkage between some of the largest, highest slip rate thrust faults in the Transverse Ranges, including the Pitas Point fault (left) and San Cayentano fault (below).

This may enable the large, multi-segment ruptures implied by the terrace records.

Ventura Fault



Hubbard et al., (in press)

Current efforts - Paleoseismology

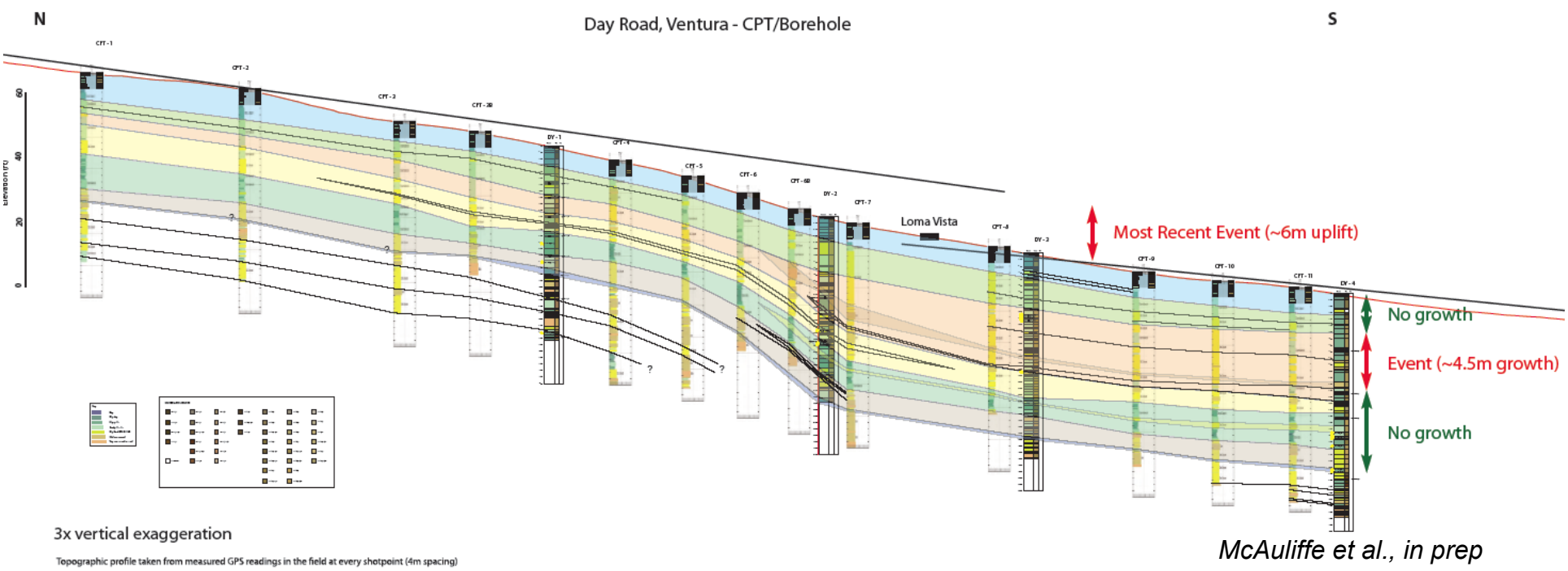
Borehole/CPT locations along Day Road

Seismic profile acquired in 2010

Borehole (yellow)/CPT (green) locations

McAuliffe et al., (in prep)

Current efforts - Paleoseismology

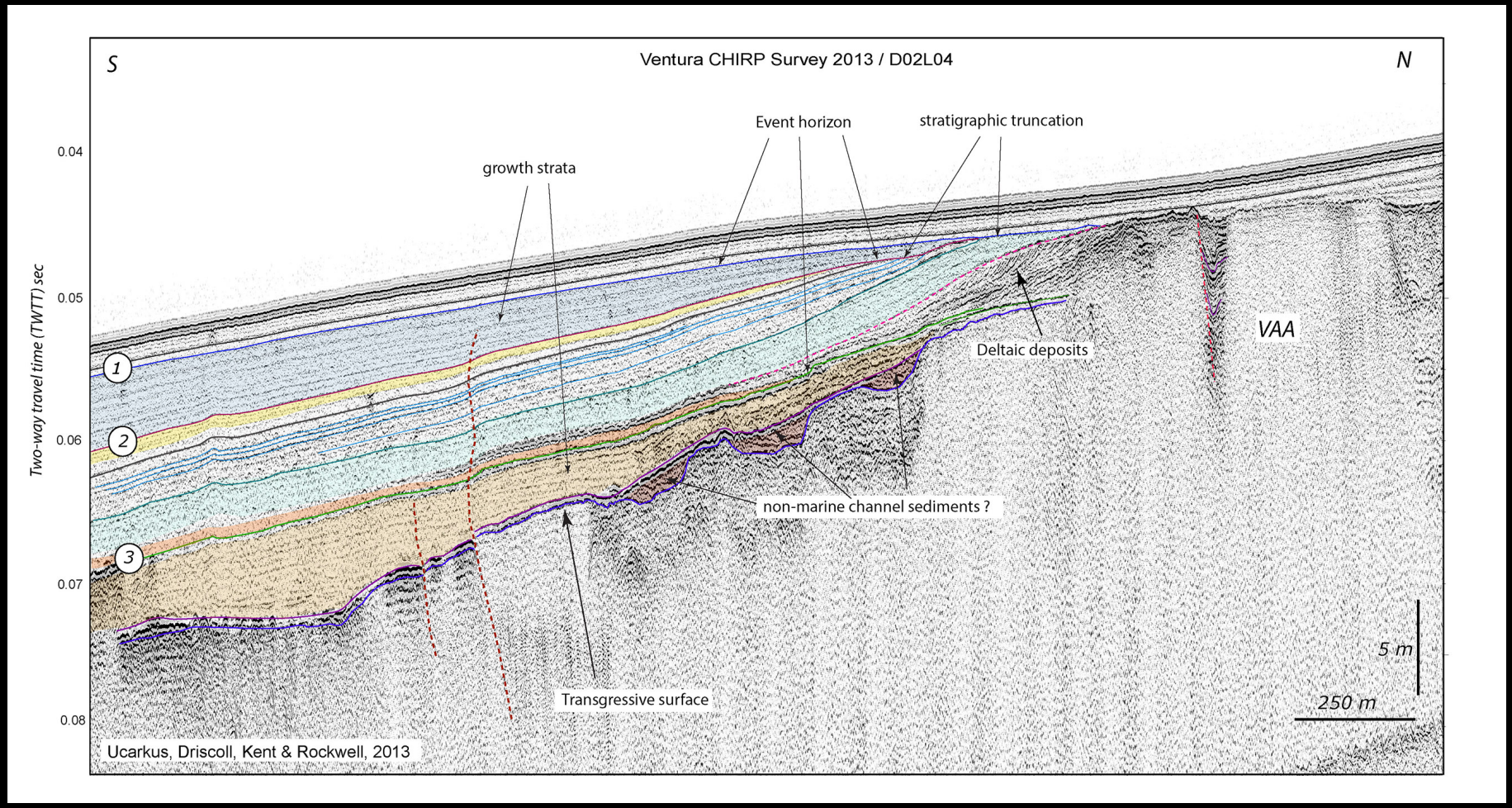


McAuliffe et al., in prep

Excavations across the Ventura fold/fault scarp show evidence of two large Holocene uplift events.

These appear to correlate with terrace uplift events, and record large multi-segment thrust fault earthquakes.

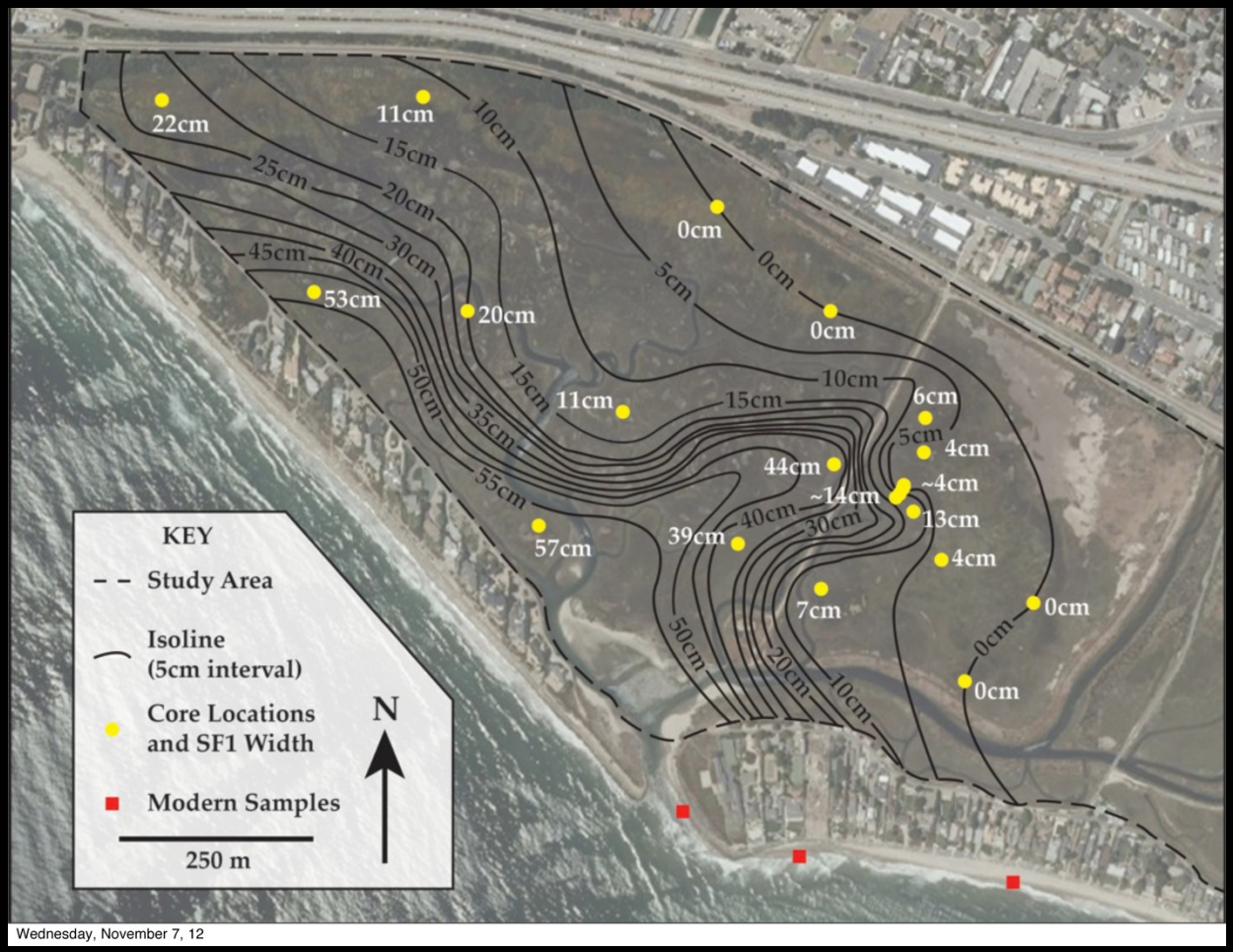
Current efforts – Offshore geophysics

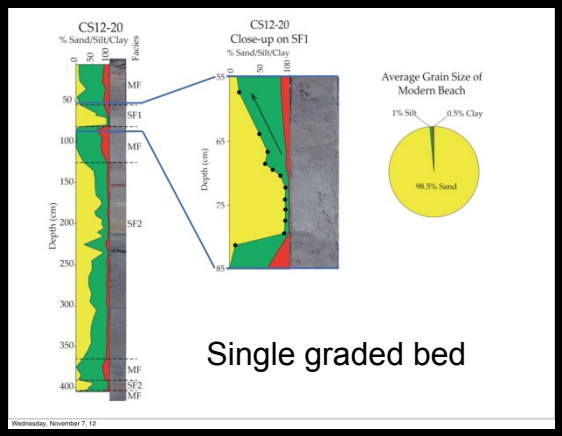


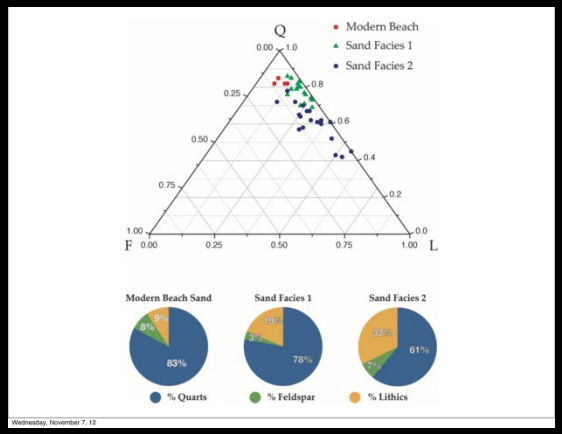
Offshore high-resolution seismic profiles acquired across the Ventura fold reveal deformed growth strata that can be used to refine the event chronology.

This line shows evidence for at least 3 major fold growth events in the middle to late Holocene, consistent with the onshore terrace work.

Potential Paleo-Tsunamis of the Santa Barbara Channel







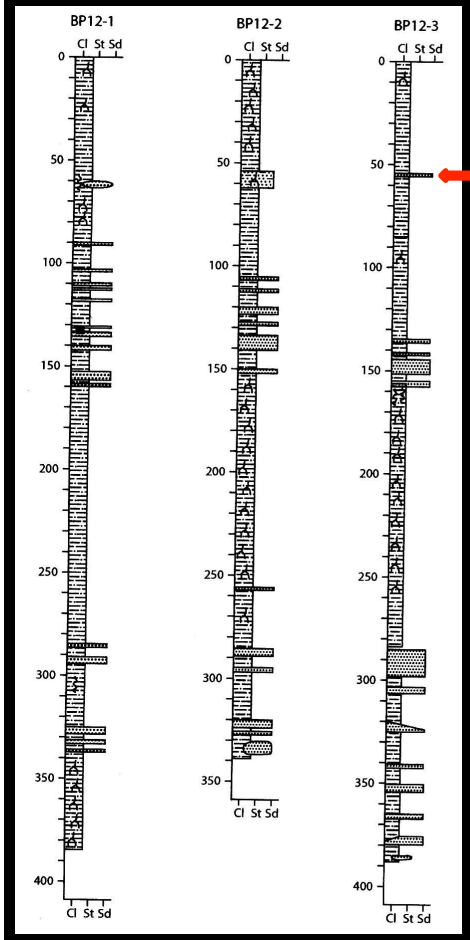
Similar mineralogy as beach sand

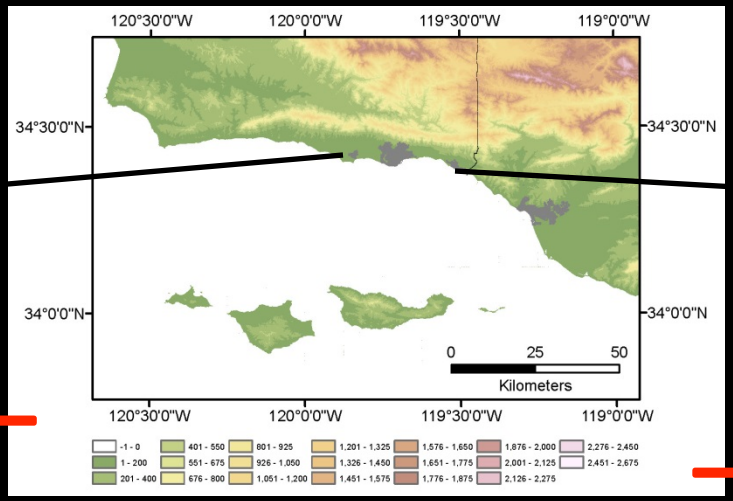
Simms et al., in prep

One sand bed identified within most of Carpinteria Slough that dates to between ~1780 and ~1870 and thought to represent a tsunami in 1812.

Not unique in time or space

Dune Pond





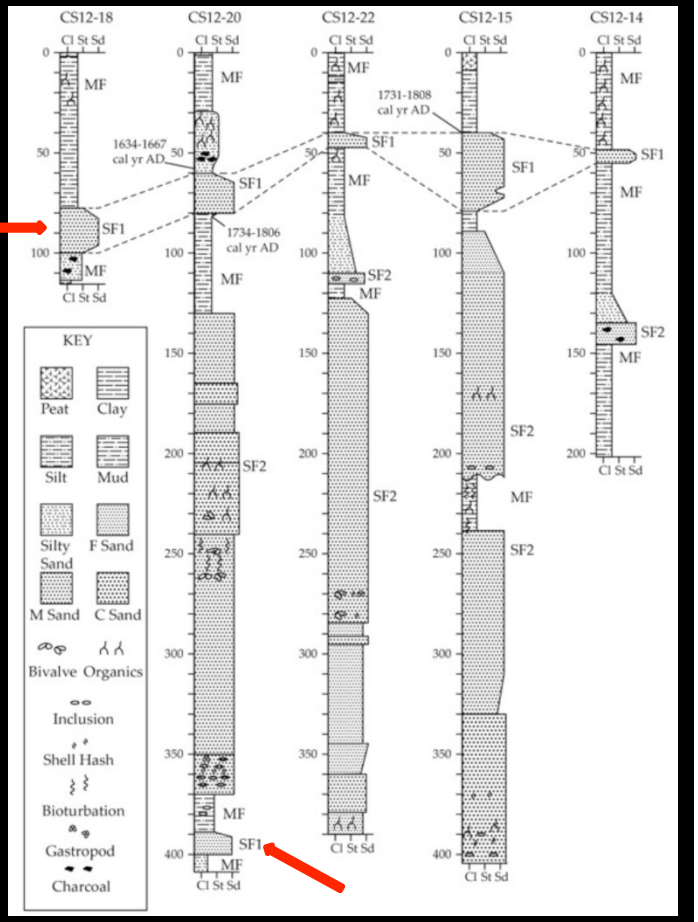
Other potential tsunami deposits found:

1.) ~4 m depth in Carpinteria Slough

2.) ~8 m depth in Carpinteria Slough

3.) Same depth/time as SF1 in Dune Pond

Carpinteria Slough

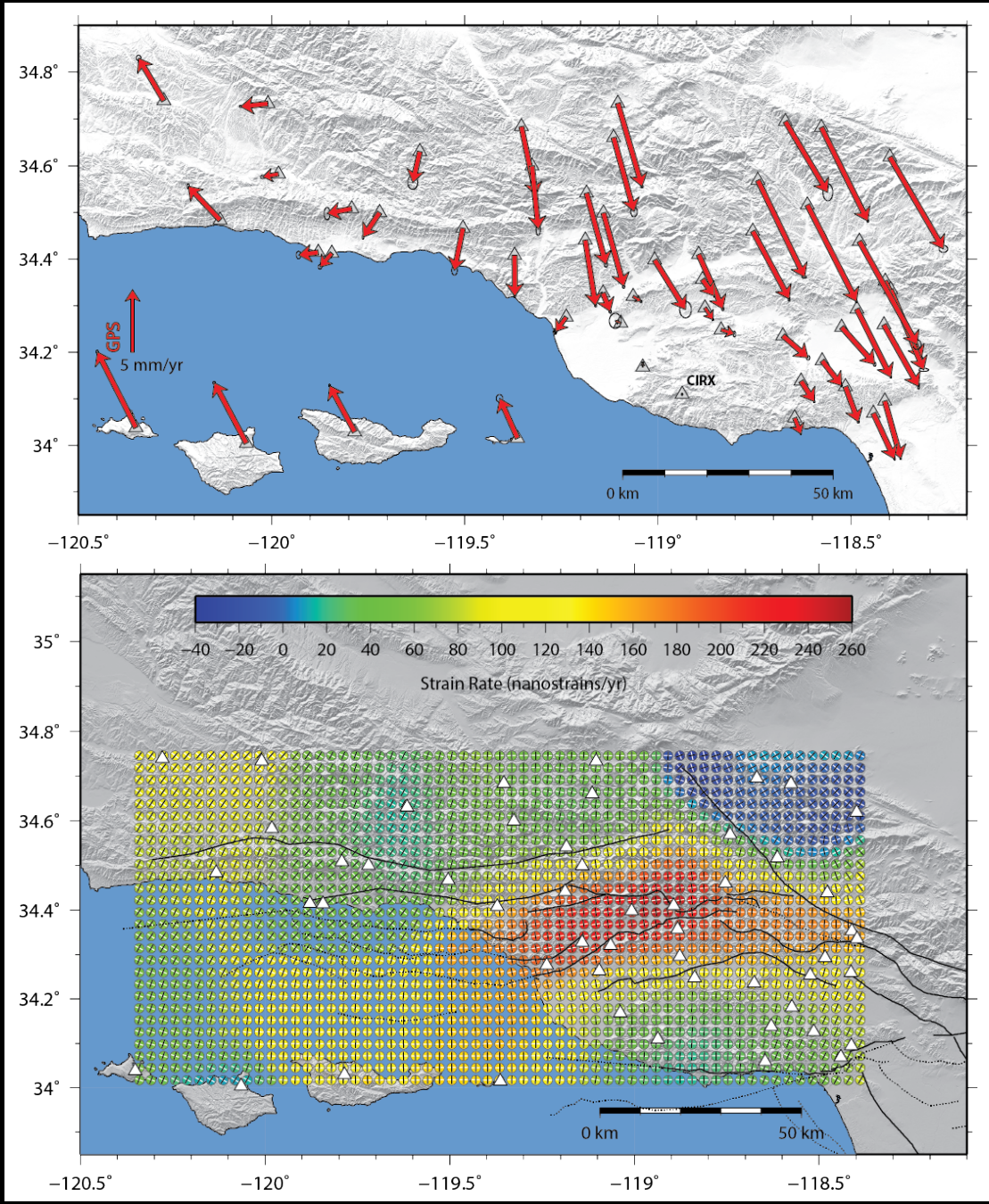


Simms et al., in prep

Continuous GPS

- Top: GPS relative to CIRX after removal of SAF interseismic effects
  - Clockwise regional rotation rate ~ 2.3° / Myr
  - Shortening decreases in the offshore Santa Barbara Channel

- Bottom: Principal contraction rates inverted from GPS
  - Fast localized contraction near Ventura basin
  - Everywhere else: little to no strain accumulation

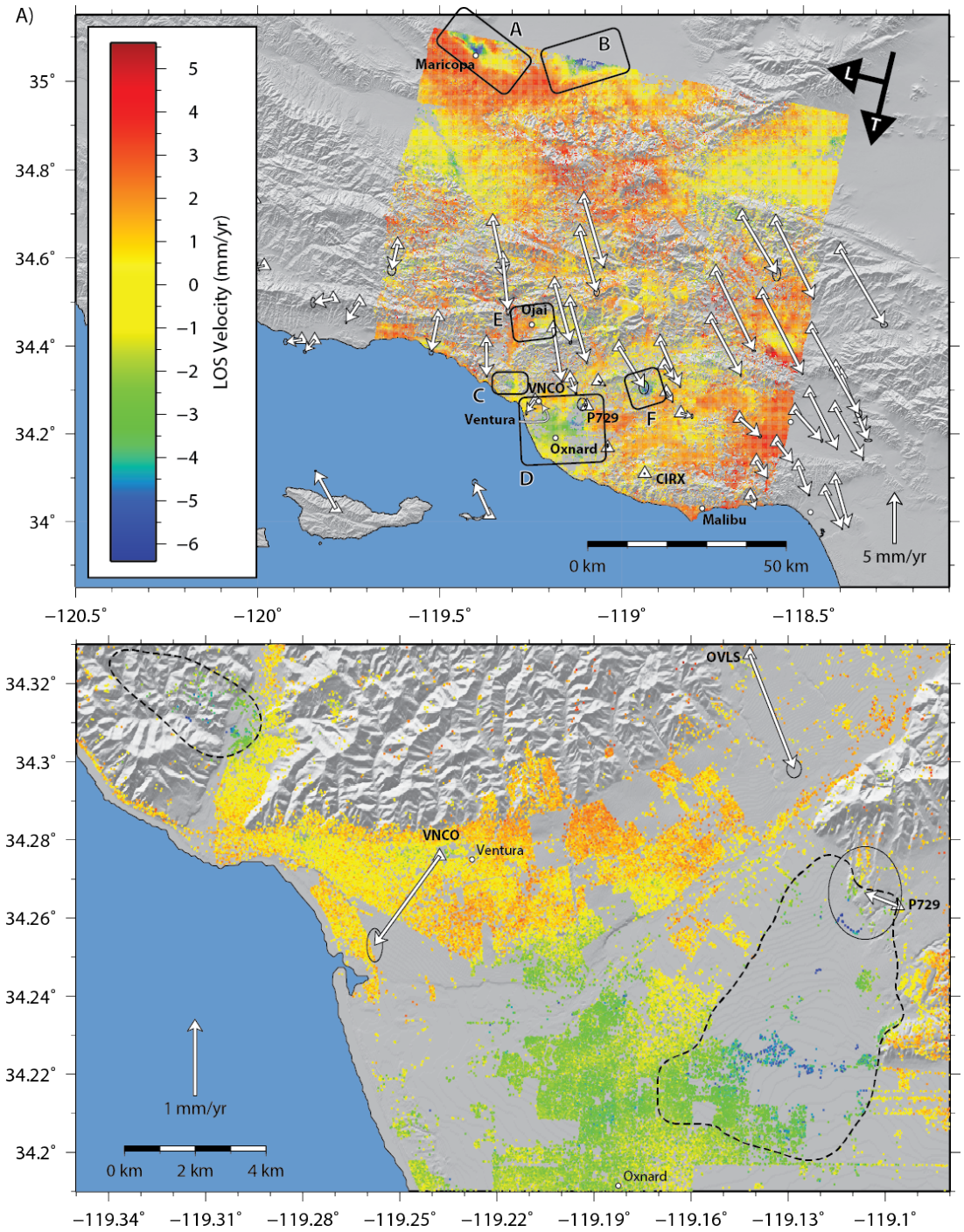


From: Marshall et al. 2013 (JGR)

Persistent Scatterer InSAR

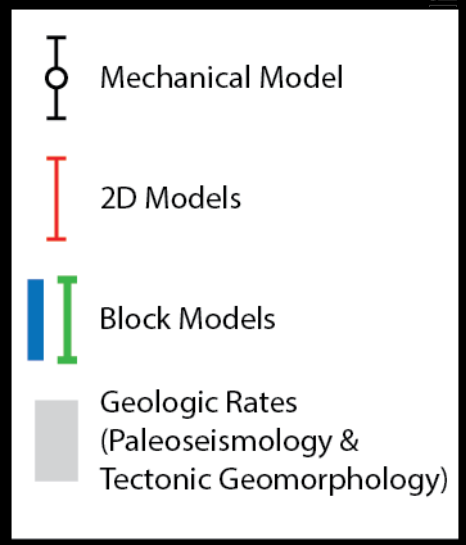
- Top: Persistent Scatterer InSAR velocities
  - Zones of anthropogenic motion are detected (A-F)
  - Do not affect most GPS sites
- Bottom: Focus on Ventura Area
  - Oil extraction along the Ventura Ave anticline produces only localized deformation
  - P729 is not reliable
  - Rest of GPS should be OK

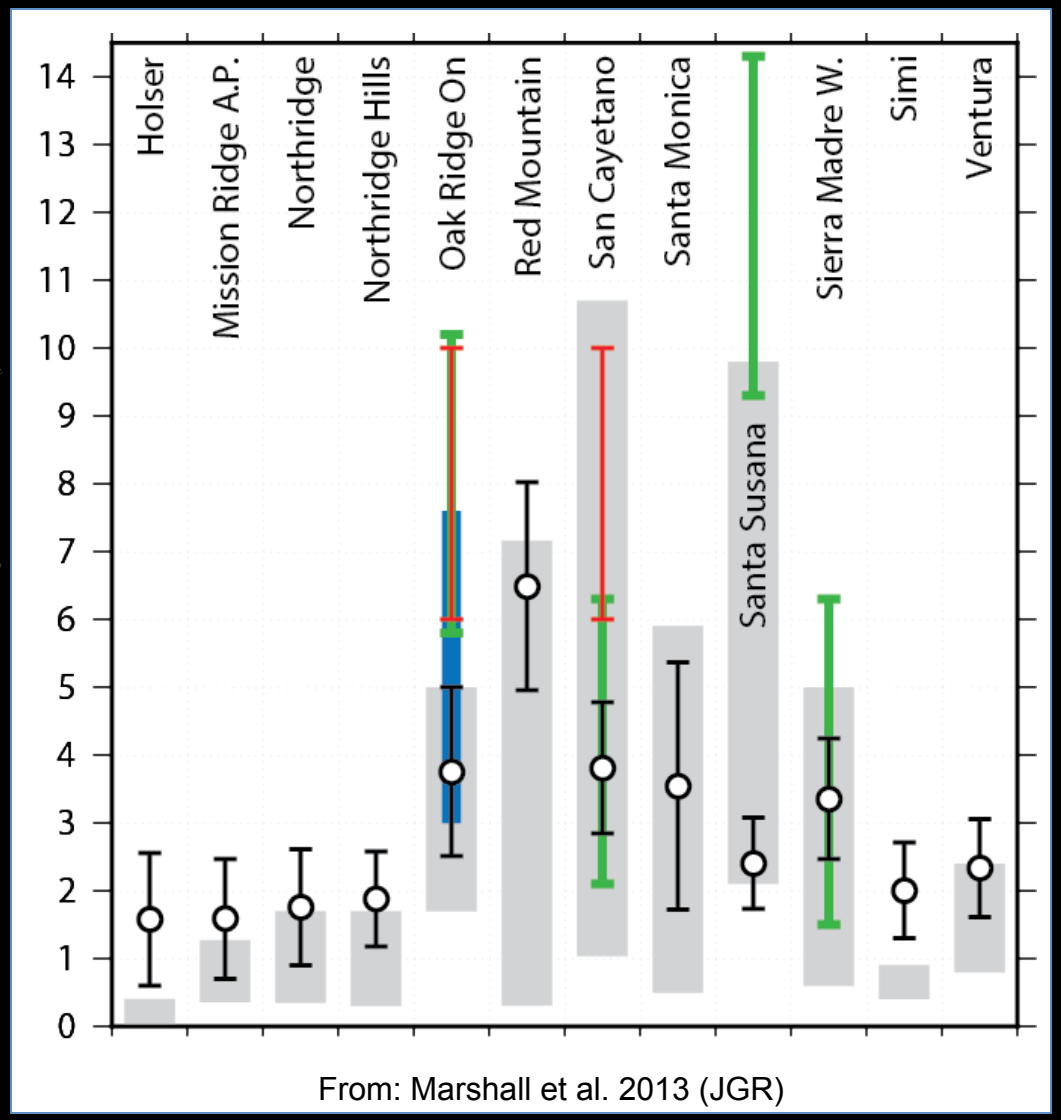
From: Marshall et al. 2013 (JGR)



Current Efforts - Mechanical Models of Fault Slip Rates

- Uses the CFM geometry
- Driven by geodetic strain rates
- Long and short term slip rates are generally compatible

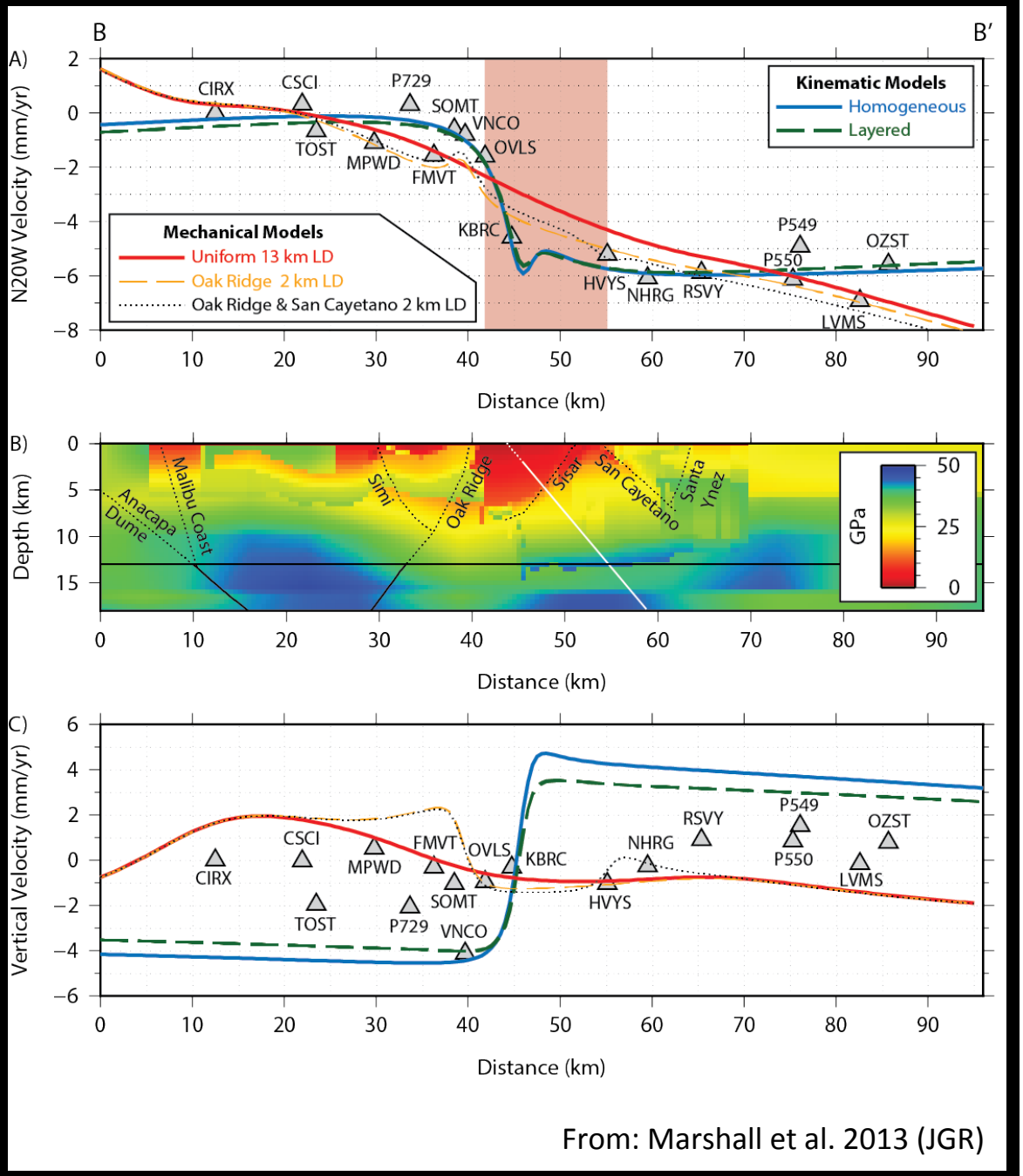




From: Marshall et al. 2013 (JGR)

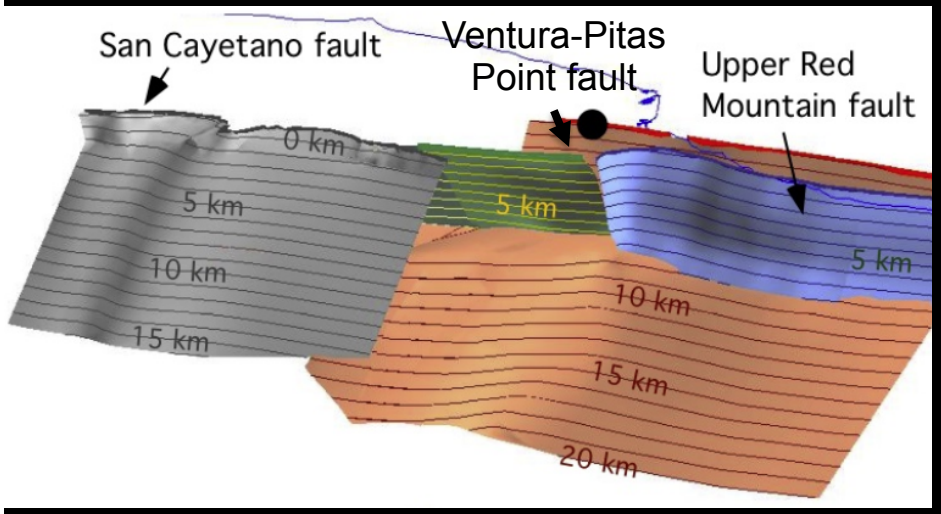
Current Efforts – Modeling GPS Velocities

- Top: Horizontal Velocities (perpendicular to basin)
  - CFM does not produce localized contraction
  - Fast contraction corresponds to basin sediments
- Middle: Shear modulus values from SCEC CVM
- Bottom: Vertical Velocities
  - GPS shows no vertical gradient across basin
  - Models that match horizontal rates, produce large vertical signals not seen in GPS



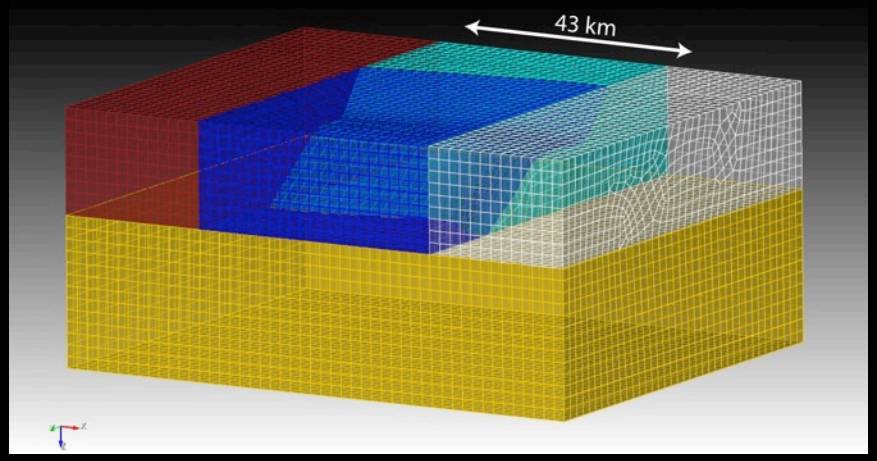
From: Marshall et al. 2013 (JGR)

Current Efforts – Fault Dynamics



Hubbard, 2011

We are building 3D meshes of potential fault geometry in this region for dynamic rupture modeling. The output of these simulations may be used in hydrodynamic modeling of tsunami generation, propagation, and runup.

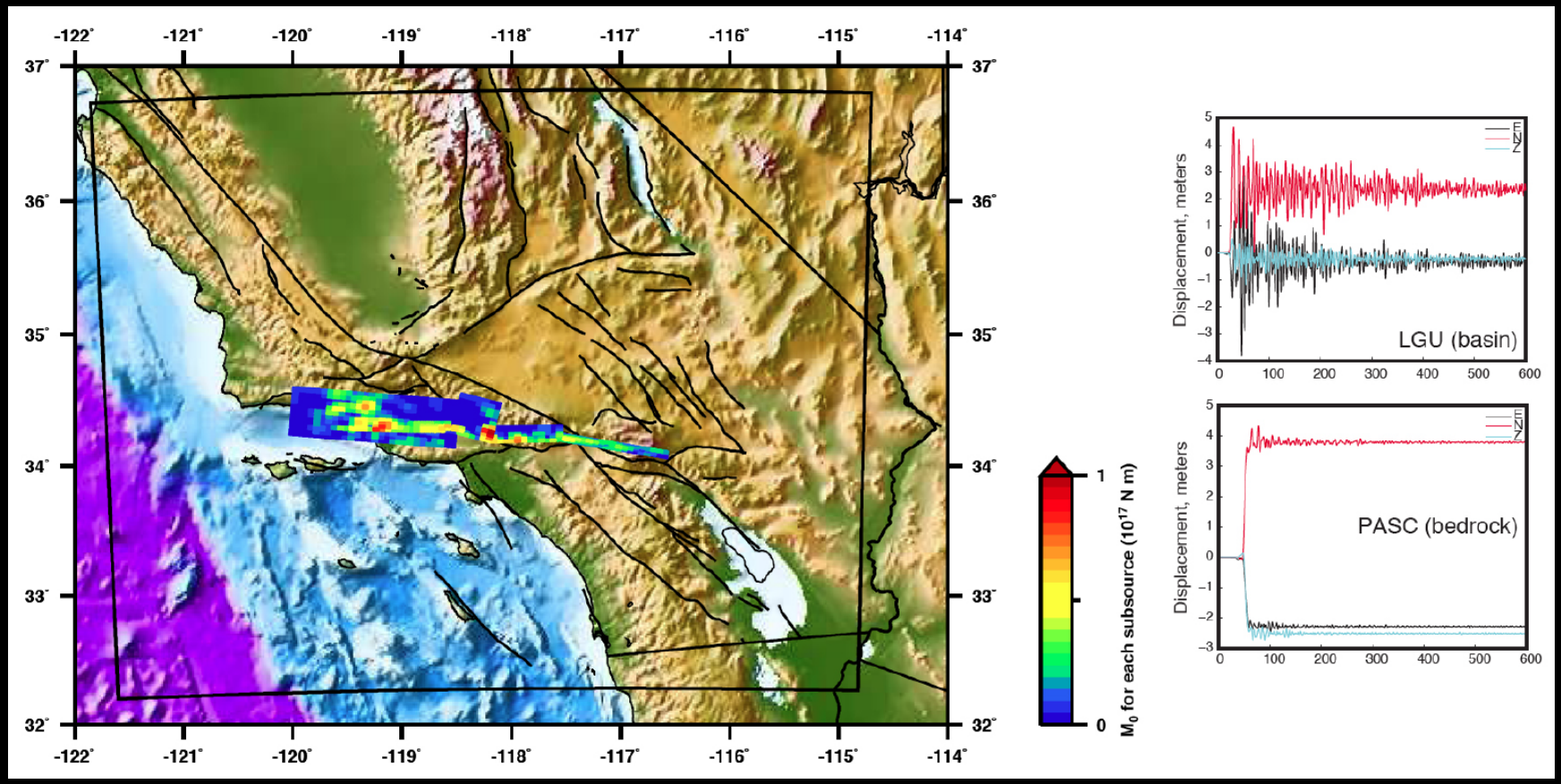


Oglesby et al., 2013

Current efforts - Kinematic rupture simulations

Source model

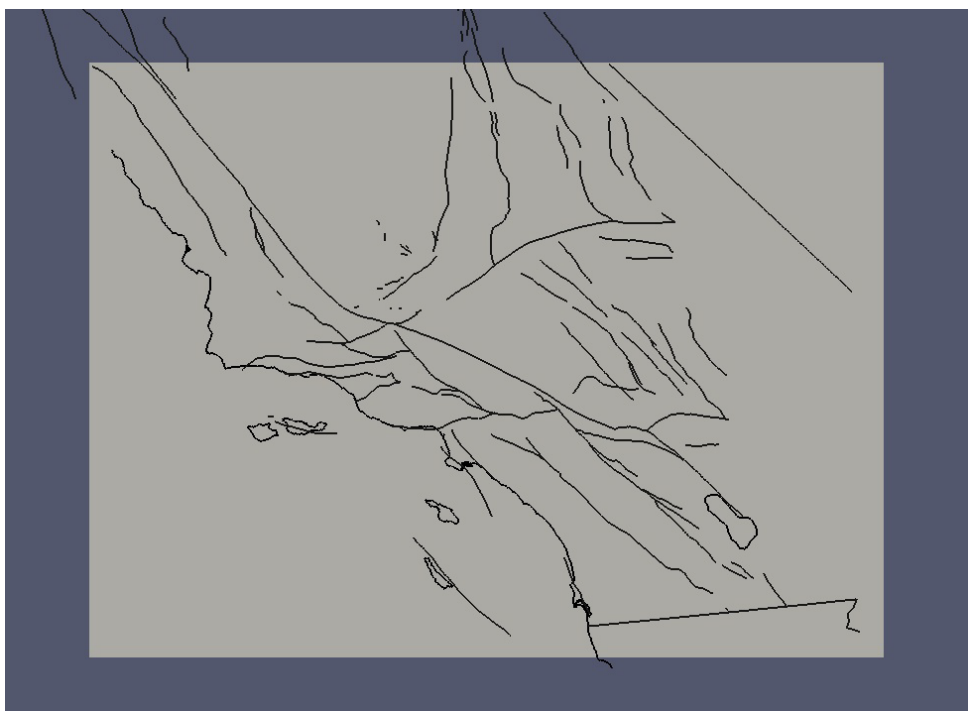
- Mw 7.9 Wenchuan earthquake (Chen Ji)
- 70,587 subsources, each characterized by hypocenter, origin time, rise time, and moment tensor (double couple assumed)
- Simulations also record the static offsets



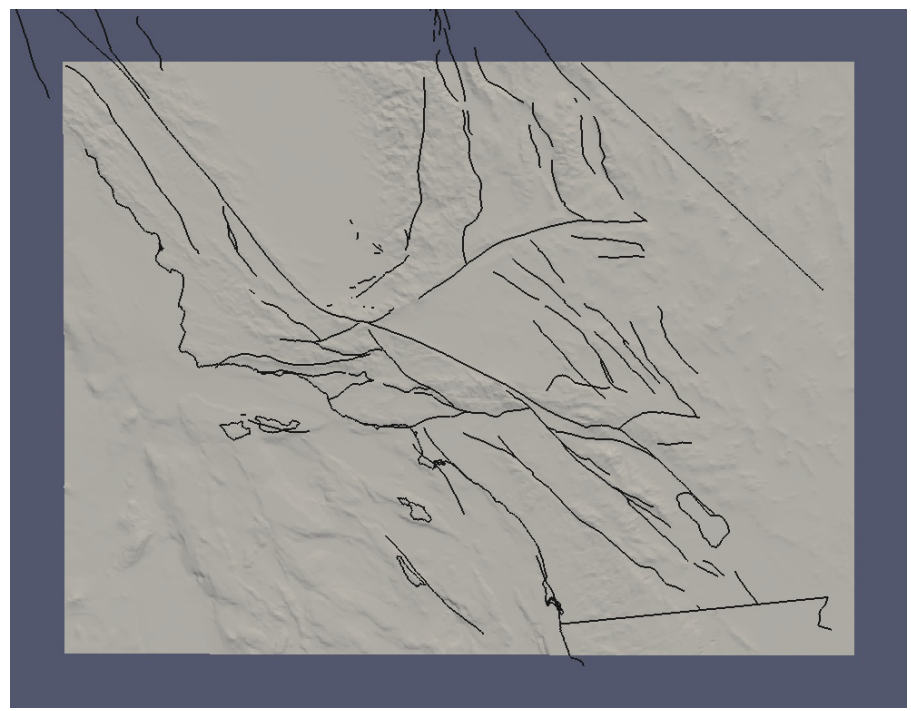
Tape et al., (in prep)

- Structure model: SoCal 1D (left) versus CVM-H 11.9 (right)
- Source model: Mw 7.9 Wenchuan earthquake (Chen Ji) mapped to the Ventura fault system in southern California
- Simulation: SPECFEM3D
- 1000 s of seismograms requires >100,000 time steps (DT = 0.009 s)
- The 3D simulation is performed on meshes with two resolutions in order to demonstrate numerical accuracy.
- Static displacements up to 5 m

Socal 1D model



CVM-H 11.9 3D model



Short term objectives

Extend the paleoearthquake record in space and time – confirm if terrace, borehole excavation, and offshore seismic event records are consistent.

Develop and test sets of alternative 3D fault representations for the possible linkages between the Ventura-Pitas Point and other thrust systems in the WTR. Make these available to the SCEC Community for use in dynamic rupture modeling, fault system studies, and strong ground motion simulations.

Expand the current geodetic data set to include more GPS stations, and InSAR scenes. Use more advanced noise models to get realistic error bars.

Expand upon kinematic rupture simulations using more detailed finite source representations and alternative slip models; explore the implications for strong ground motion forecasts.

Perform preliminary, simplified dynamic models of one or two scenario earthquakes for use as reference models for later, more precise work. Use these models to predict tsunami characteristics (e.g. inundation, impact on coastal infrastructure).

More work characterizing (e.g. vertical and lateral trends in grain size, more chronology, XRF, diatoms, etc.) the hypothesized 1812 tsunami bed in Carpinteria Slough and use it as an analogue for identifying older tsunami beds in longer cores. Repeat the experiment in other locations (e.g. Goleta Slough (Santa Barbara).

Tsunami Simulations

Steve Ward (2013)

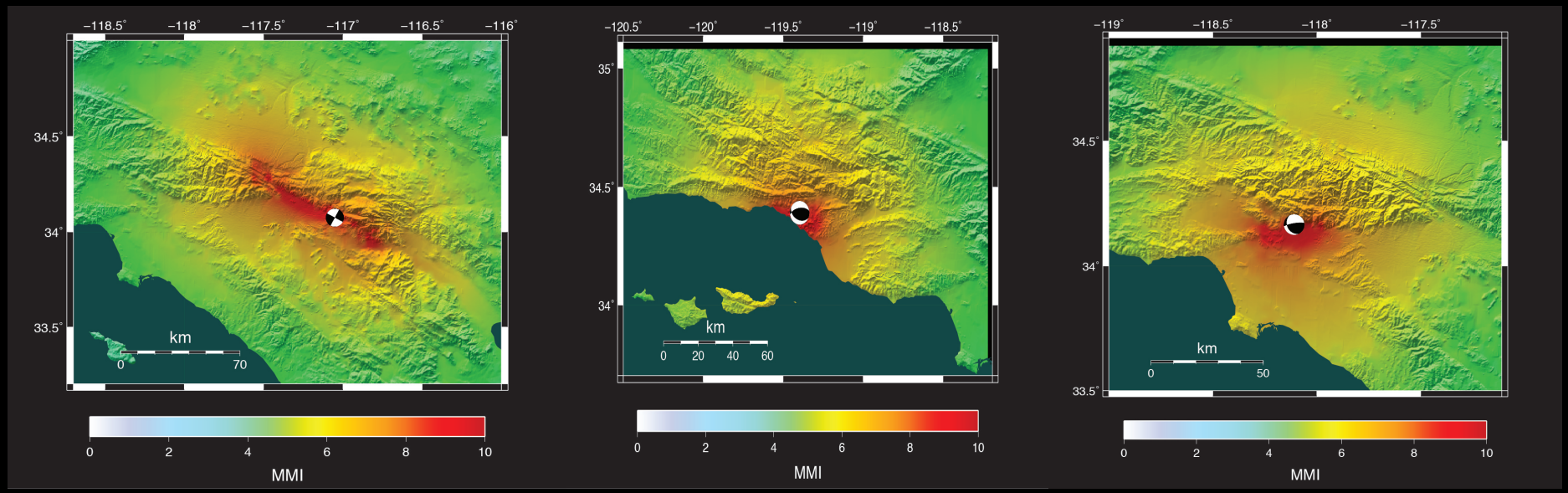
SCEC Annual Meeting
SCEC UseIT Interns'
'Northridge Near You' Scenarios

How can SCEC interns' products influence our scientific creative process at this year's SCEC Annual Meeting?

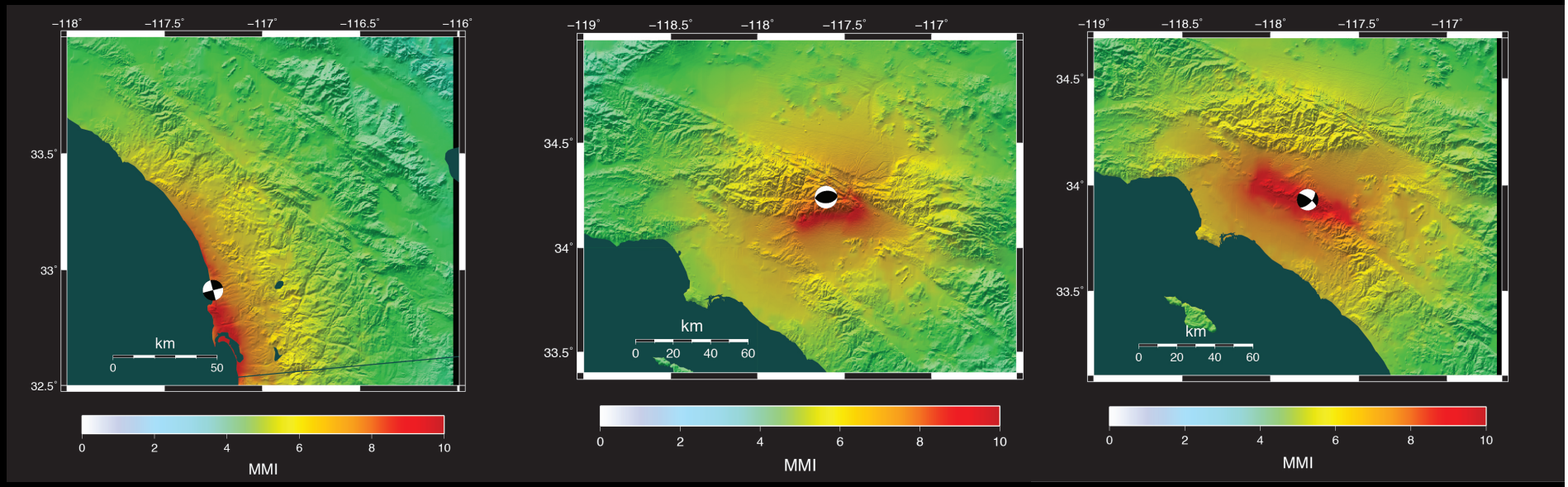
Make use of scenarios as a series of thought exercises, building on the 'Northridge Near You' theme, and considering ways to ensure that thoughtful & necessary observations will be made after future earthquakes in southern California

SCEC earthquake science exercise

- **Thought-provoking scenario exercise uses**
  - **How would the scientific community respond?**
  - **In what ways can advanced (and rapid) planning result in improved scientific data acquisition?**
  - **What key observations are needed to answer remaining big questions in earthquake science?**
  - **For each scenario, think it over and interact with the interns and your colleagues in lobby**



2013 SCEC Annual Meeting - Scientific Response Scenario Activity



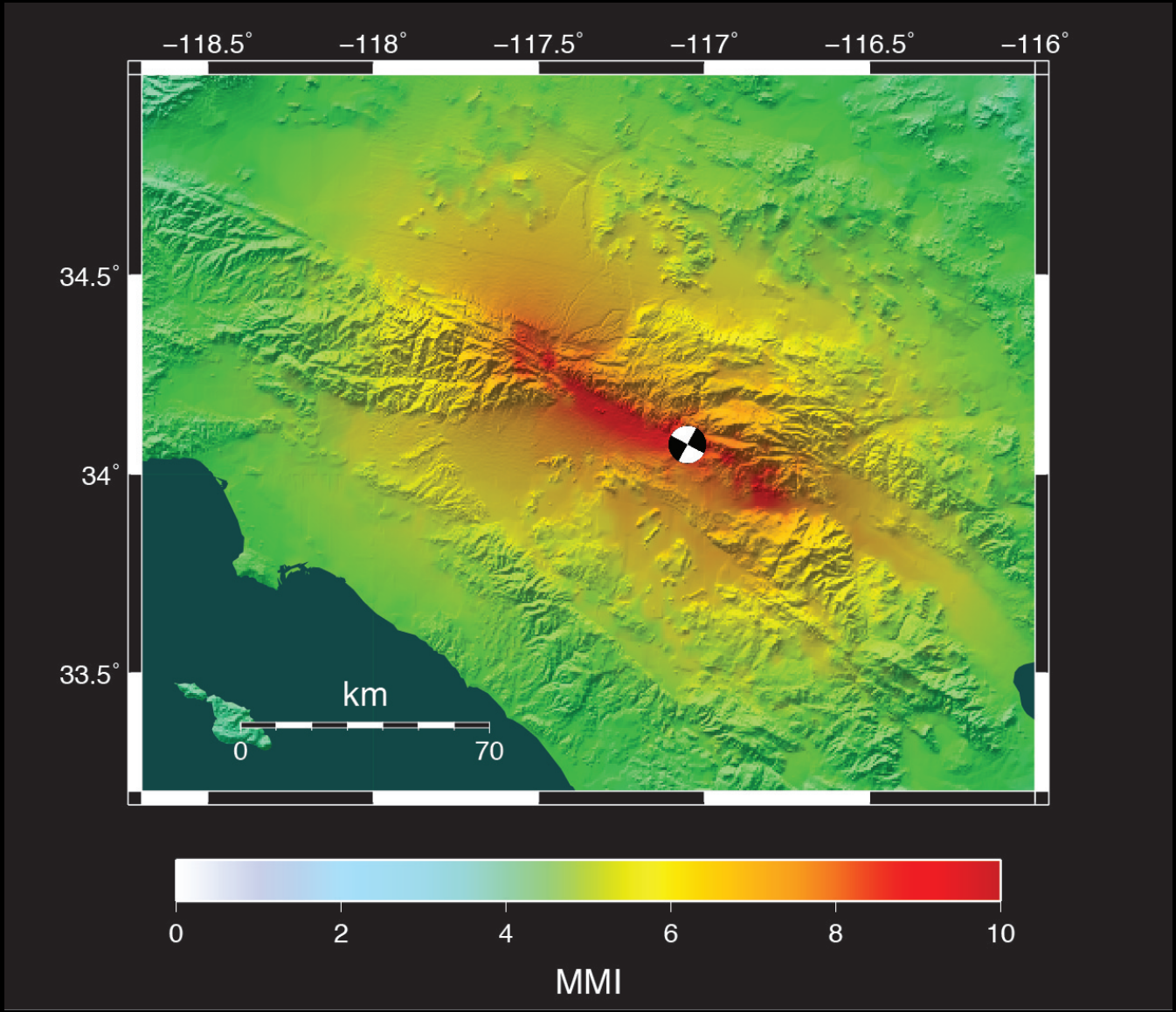
Classic Post-Eq Science

- **How can immediate post-earthquake data acquisition influence our science?**
  - **Obtain synoptic overview of main rupture, and significant secondary effects**
  - **Capture evanescent data such as surface faulting, landslide, liquefaction, etc.**
  - **Observe aftershock patterns and characterize statistics of their occurrence**
  - **Capture deformation transients (retrieve high-rate continuous data, augment continuous GPS station coverage with survey-mode GPS, establish new continuous GPS stations)**

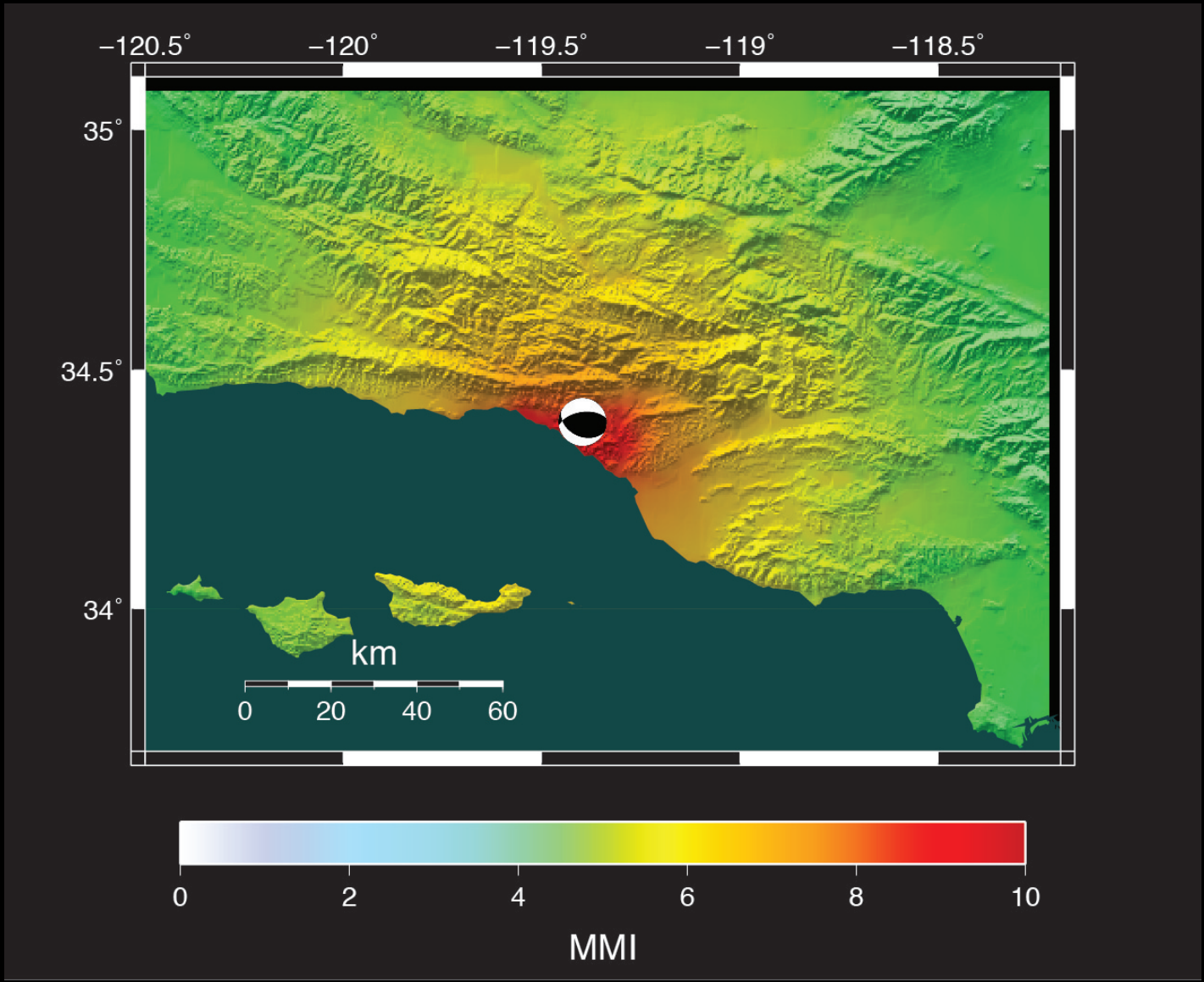
Novel Post-Eq Science

- **In what *new ways* can immediate post-earthquake data acquisition *revolutionize* our science? What can we only know from a well-designed post-earthquake experiment?**
  - **Heat from fault by drilling, frictional properties? (as was recently done for Tohoku, resulting from pre-earthquake scientific workshop & coordination)**
  - **Correlate fault geometry or damage zones with radiated energy? (deploy array?)**
  - **Predict aspects of aftershock sequence statistics or migration with respect to co-seismic fault; will a second large event happen off the end of the first rupture?**
  - **Predict secondary fault ruptures, e. g. Coulomb stress changes on nearby faults**
  - **Employ new technologies (e.g., new seismic array configurations, or repeat-pass airborne image differencing methods) to help examine slip variation along-strike and other aspects of the rupture process**

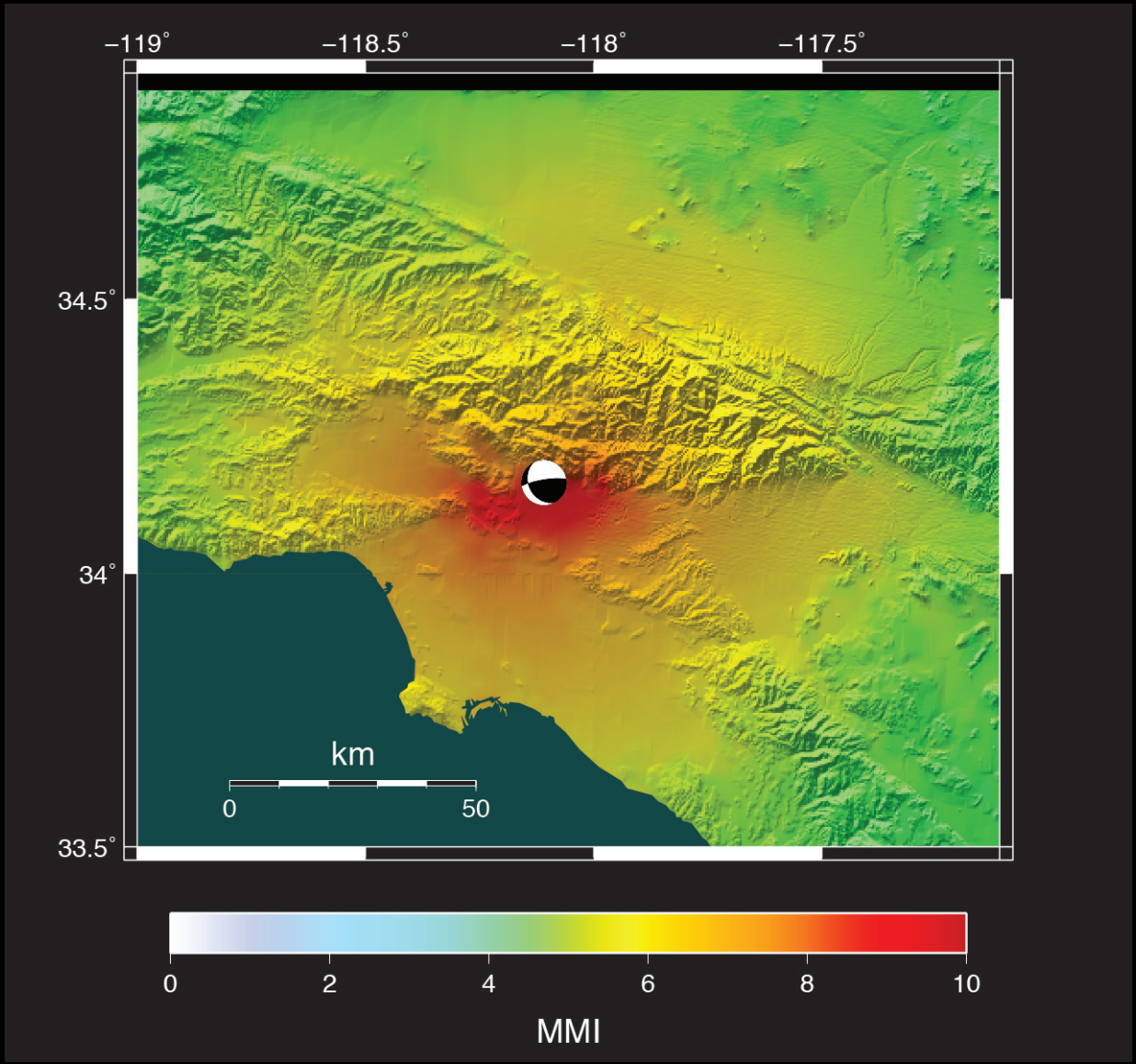
1) San Bernardino – San Andreas; M 6.85, right-lateral strike slip (local thrusting)
34.116, -117.112, depth = 7 km



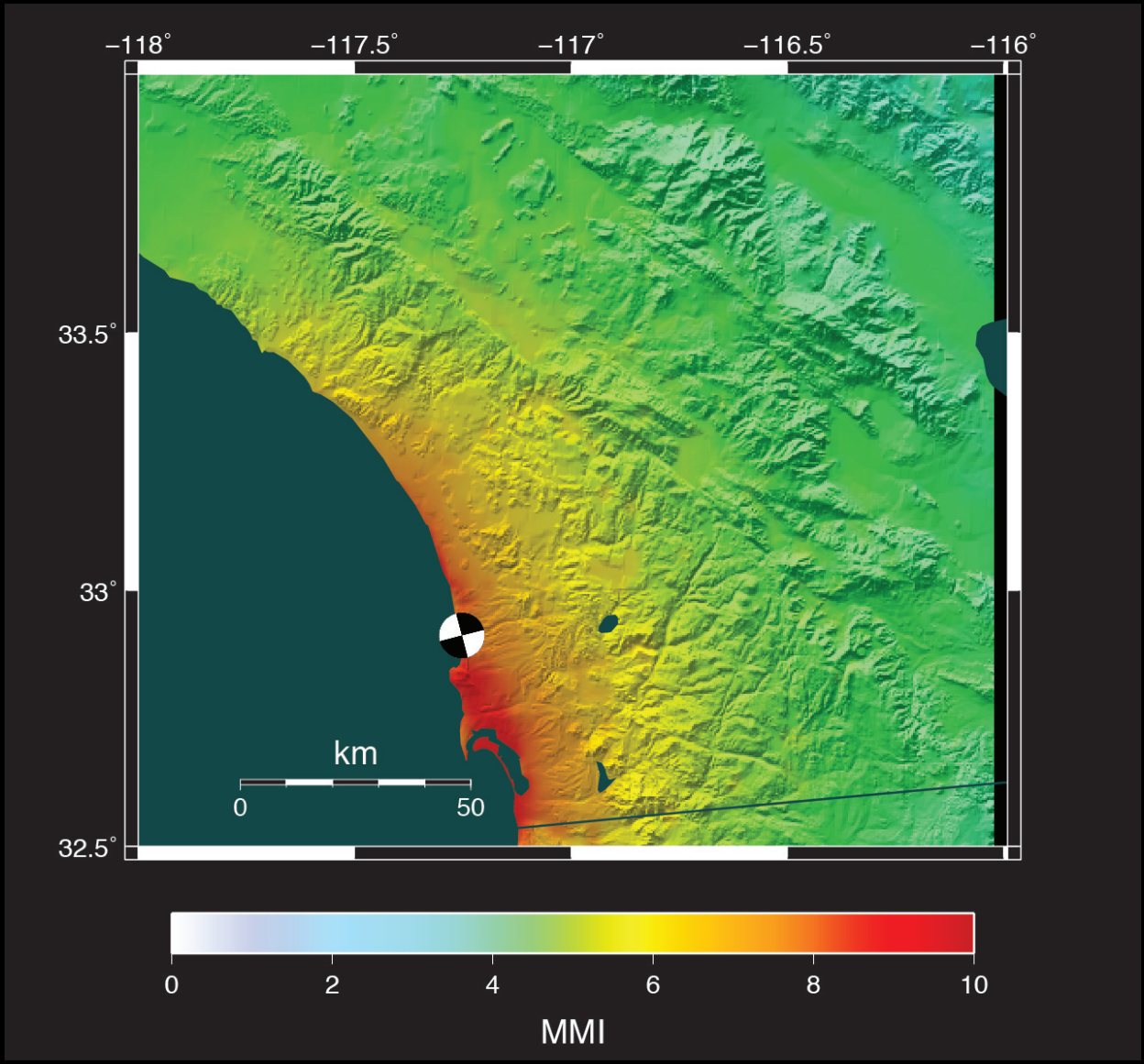
2) Santa Barbara - Red Mountain (Ventura); M 6.55, thrust
34.401, -119.235, depth = 12 km



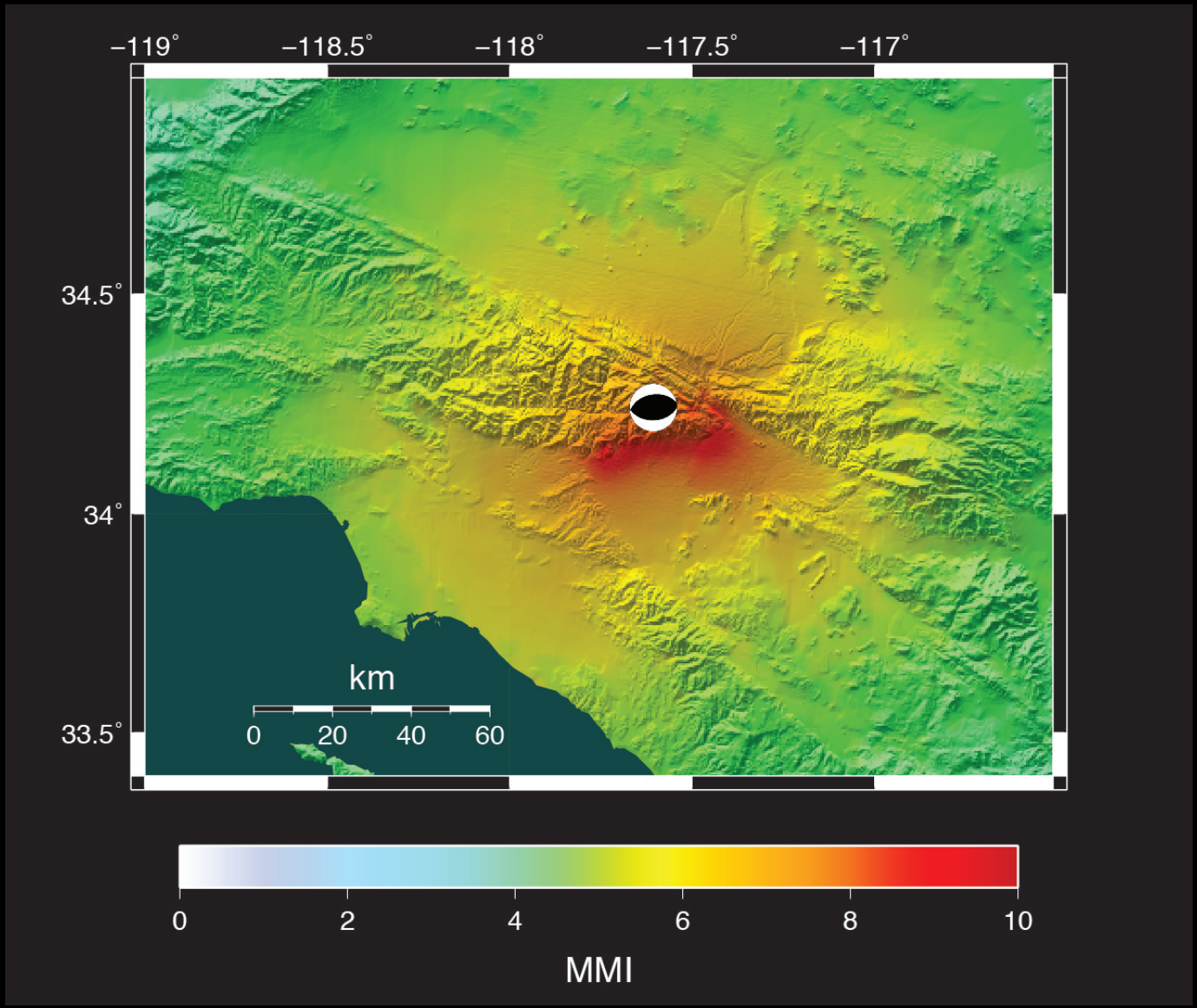
3) Pasadena - Raymond (Downtown LA); M 6.65, oblique, thrust & left-lateral
34.179, -118.137, depth = 9 km



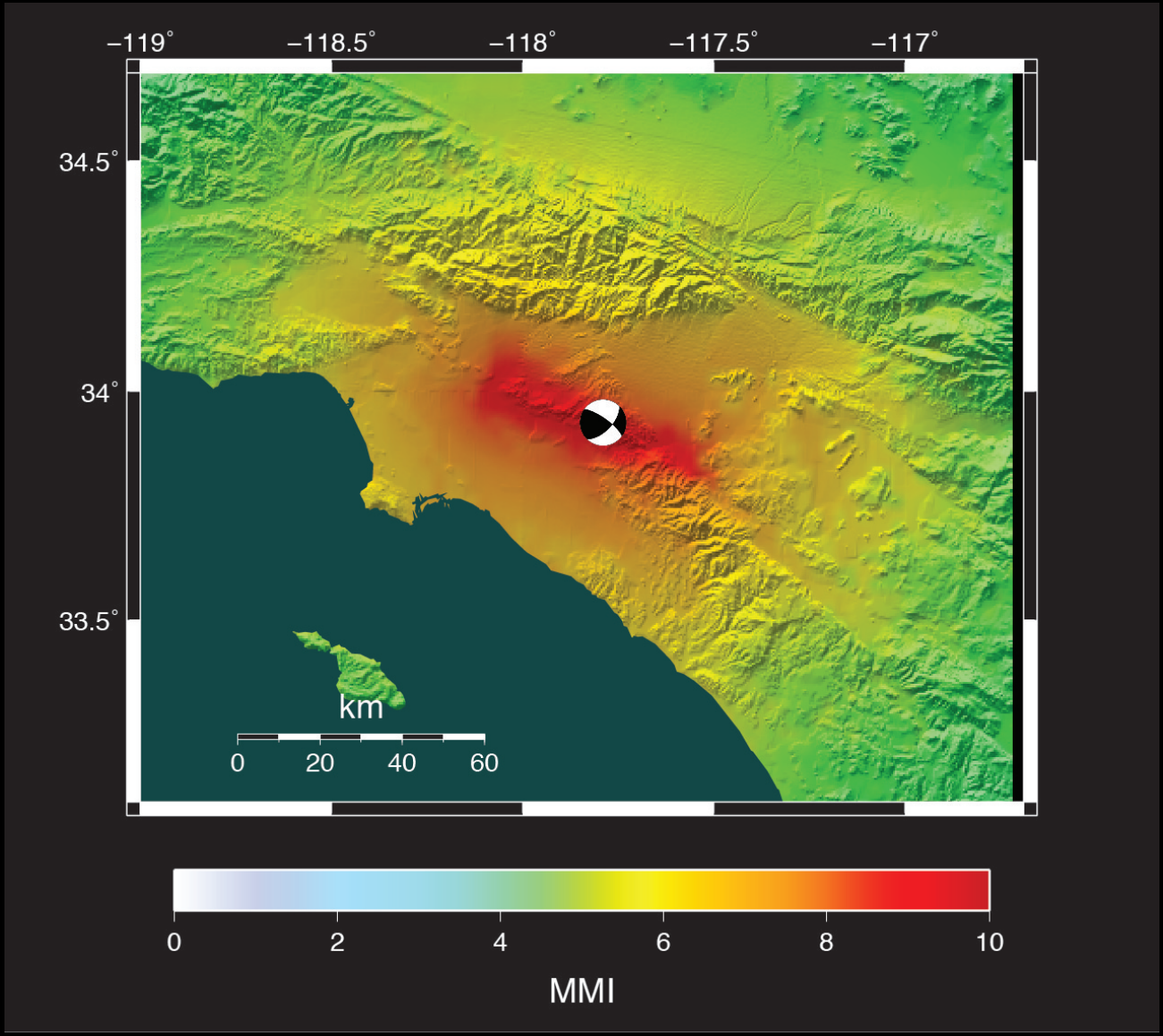
4) Mission Valley – Rose Canyon (San Diego); M 6.75, right-lateral strike slip
32.898, -117.259, depth = 6 km



5) Ontario – Cucamonga (Rialto); M 6.55, thrust
34.240, -117.517, depth = 7 km



6) Santa Ana – Elsinore (Whittier); M 6.85, oblique, thrust & right-lateral
33.944, -117.811, depth = 7 km



Milestones: Community Stress Model

YEAR 1 (2012-2013)

Develop a strategy for archiving and curating observational and model-based constraints on the tectonic stress field in Southern California.

Based on this strategy, begin developing components of the database that will underlie the CSM.

Organize a SCEC collaboration to contribute existing observational and model-based constraints to this database. [I, II]

Milestones: Community Geodetic Model

YEAR 1 (2012-2013)

Obtain input from the SCEC community via a workshop in order to define the conceptual and geographic scope of the CGM, including the time-independent and time-dependent model components, the data to be assimilated into the model, and the type and spatial distribution of model output. [I, V]

Milestones: Community Geodetic Model

YEAR 1 (2012-2013)

Obtain input from the SCEC community via a workshop in order to define the conceptual and geographic scope of the CGM, including the time-independent and time-dependent model components, the data to be assimilated into the model, and the type and spatial distribution of model output. [I, V]

Milestones: Transient Geodetic Signals

YEAR 1 (2012-2013)

Develop data-processing algorithms that can automatically detect geodetic transients localized within Southern California using continuously recorded GPS data.

Provide access to authoritative GPS data streams through CSEP.

Implement at least two detection algorithms as continuously operating procedures within CSEP. [V]

Milestones: Ground Motion Simulation

YEAR 1 (2012-2013)

Develop a set of validation procedures suitable for the application of ground motion simulations in seismic hazard analysis and earthquake engineering.

Identify a set of ground motions recorded in large California earthquakes to use for validation.

Use codes available in the CME to simulate the ground motions. Compare these simulations with the observed recordings and other empirical models where they are well-constrained. [VI]

Milestones: Source Modeling

YEAR 1 (2012-2013)

Assess field evidence for the importance of specific resistance mechanisms during fault rupture, and plan fieldwork to collect new diagnostic data.

Develop laboratory experiments that explore novel weakening mechanisms.

Standardize observations from key earthquakes for the testing of different methods of finite-fault source inversion, and set up standardized inverse problems as cross-validation exercises. [III, VI]

Milestones: Time-Dependent Forecasting

YEAR 1 (2012-2013)

Support WGCEP in the development and release of UCERF3.

Reduce the updating interval of the short-term forecasting models being tested in CSEP.

Improve methods for detecting, classifying, and analyzing various types of seismic clustering. [II, V]