Is there a role for stress change modeling (fault interactions) to forecast aftershocks?

Answer: Yes, in hybrid mode with empirical methods (like ETAS).

Results from:

Parsons, T., Y. Ogata, J. Zhuang, and E. L. Geist (2012), Evaluation of static stress change forecasting with prospective and blind tests, Geophysical Journal International, v. 188, 1425–1440, doi: 10.1111/j.1365-246X.2011.05343.x.

Segou, M., T. Parsons, and W. Ellsworth (2012), Rate/state friction model implementation for earthquake forecasts in northern California, Seismological Research Letters, v. 82. (manuscript in preparation).

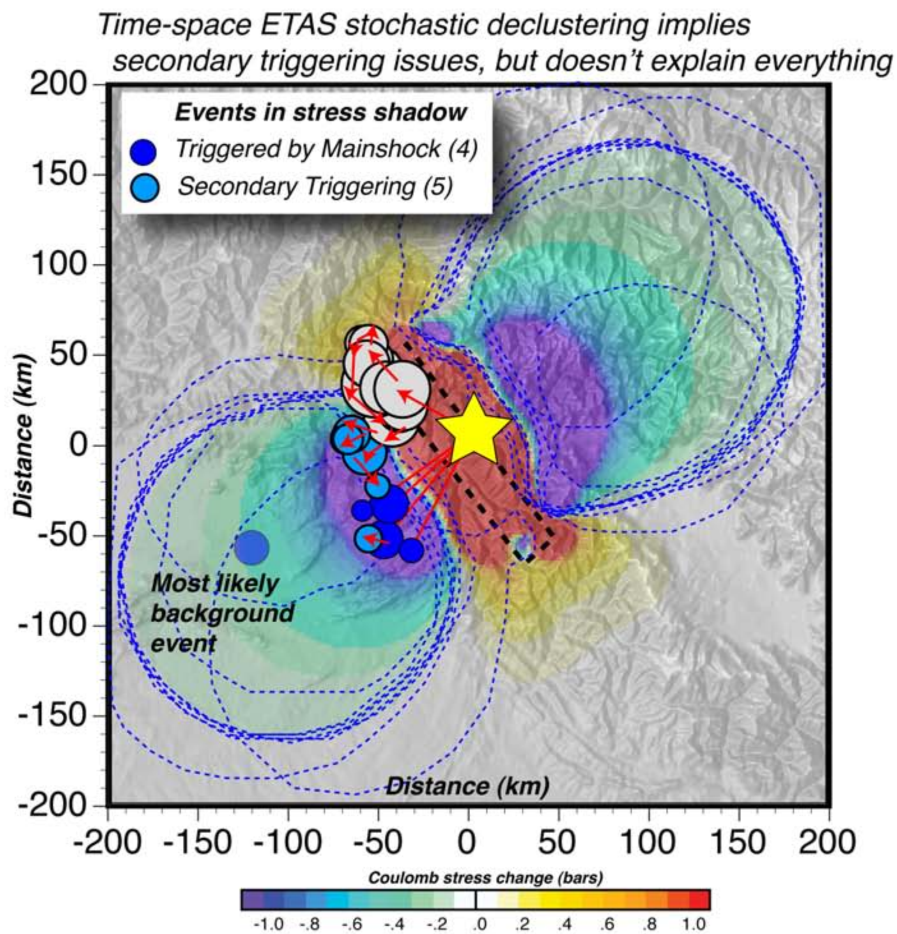
http://earthquake.usgs.gov/regional/nca/seminars/2012-05-23/

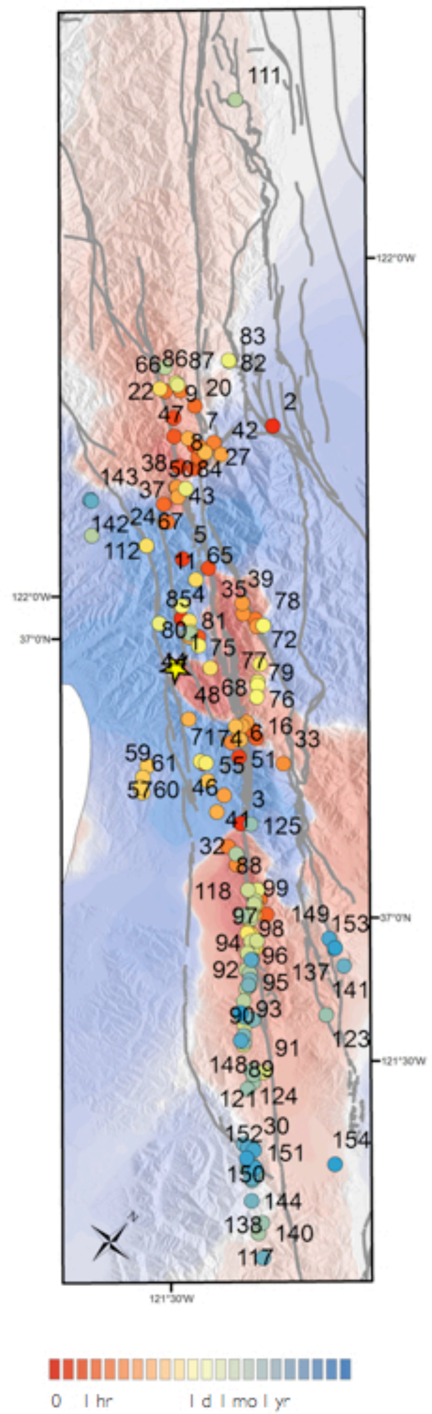
Or http://on.doi.gov/segou-seminar-2012

Or Google “USGS earthquake seminars”

Issue: Prospective testing of rapid Coulomb stress calculations routinely shows violations of calculated stress shadows (i.e., 8 October, 2005 M~7.6 Kashmir earthquake).

Causes include:
- **Rupture source complexity**
- **Unmodeled dynamic triggering**
- **Temporal stress evolution (secondary triggering)**





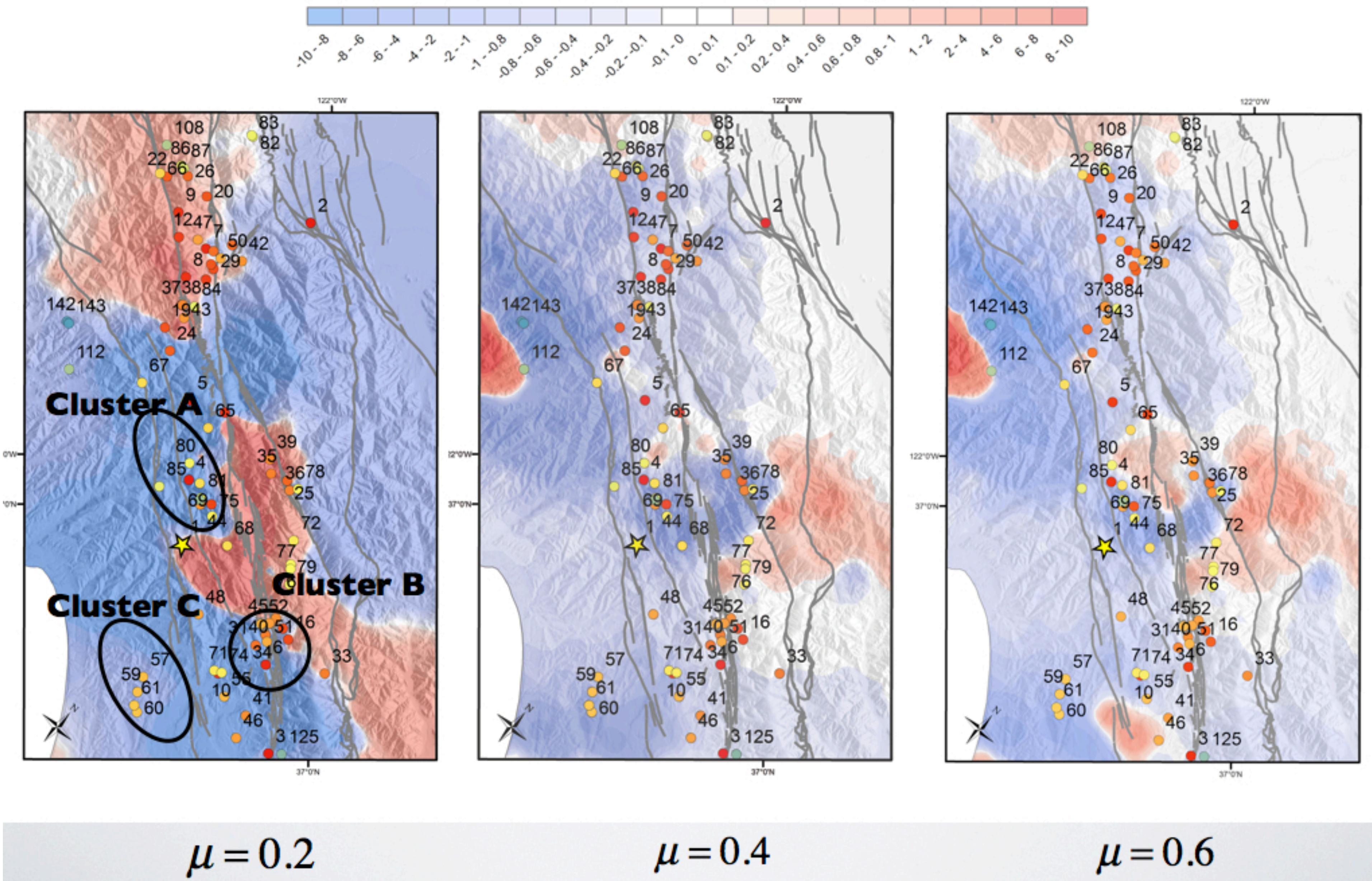
HOW IMPORTANT IS SECONDARY TRIGGERING FOR FORECASTING?

Motivation: Recent studies have supported that incorporation of secondary triggering is a critical aspect in operational forecasting [Parsons et al., 2012] and past studies refer to this as an possible source of uncertainty leading to poor performance of CRS with time [Toda et al., 2005].

Can we improve CRS-models by including stress perturbations of smaller events ?

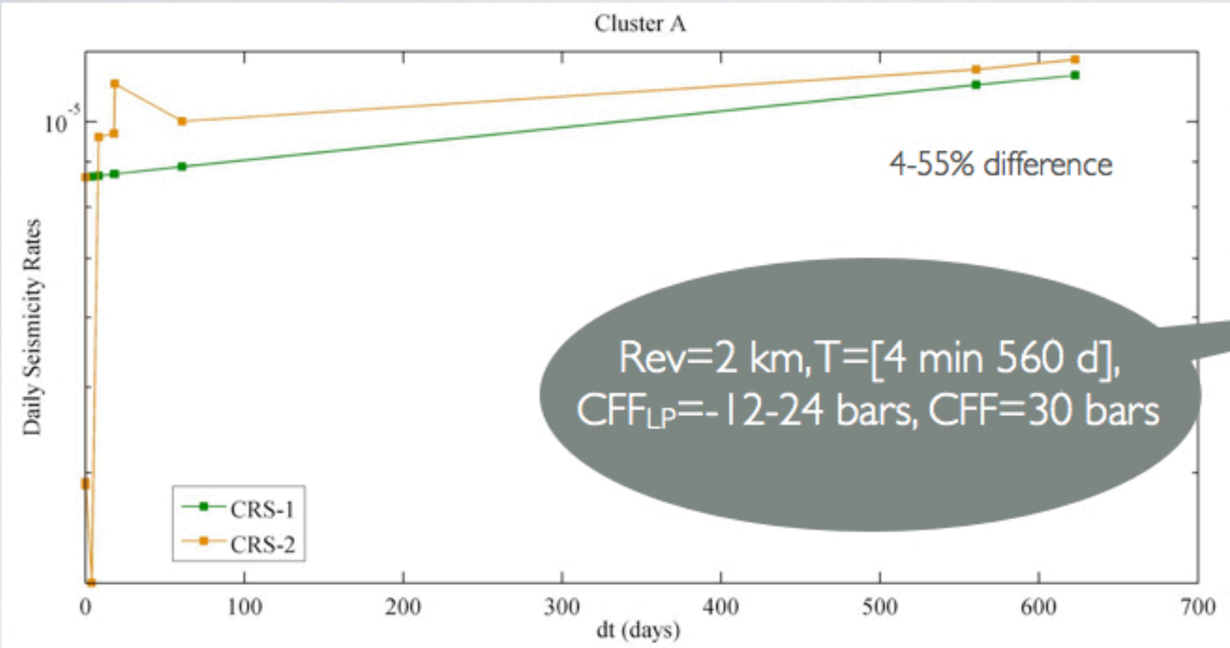
Designing the test: Loma Prieta aftershocks with M>3.5 lying in the stress shadow of the mainshock

Goal: Not to study how efficient CRS forecast models are, but that incorporating stress changes from 3.5<M<5.0 makes a difference

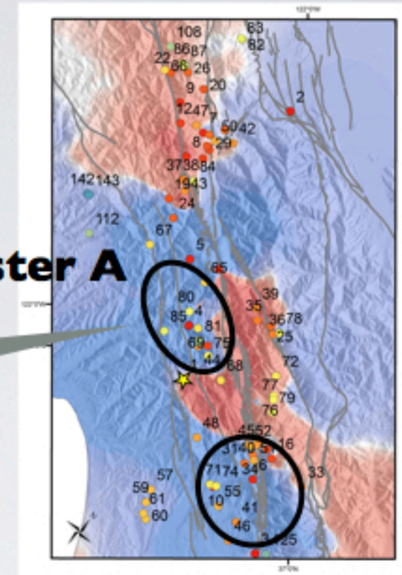


SENSITIVITY COULOMB STRESS CHANGE CALCULATION

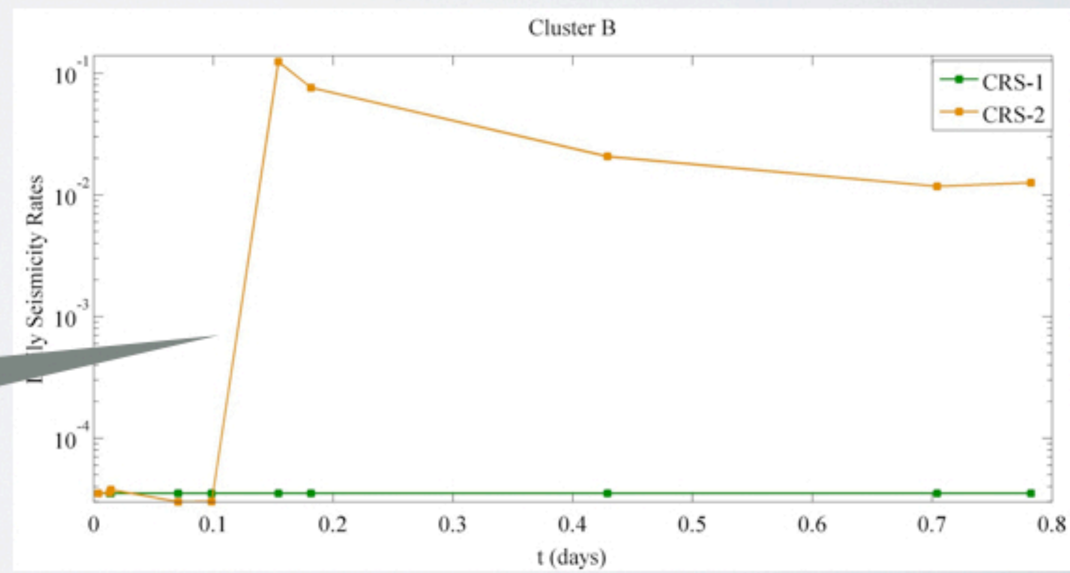
CRS-1 VS CRS-2



Rev=2 km, T=[4 min 560 d], CFF_{LP}=-12-24 bars, CFF=30 bars



CFF calculation grid 200m, depth 10 km



Rev=1.2 km, T=[1 d], CFF_{LP}=-30bars, CFF=30 bars

Tests are showing that ~50% of shadow violations can be explained by secondary static triggering

---

However, in many cases the initiation of the first shadow violator cannot be explained with simple Coulomb calculations, meaning that:

(1) Optimal fault orientation calculations are suspect, and that detailed geological fault assignments are needed

and/or

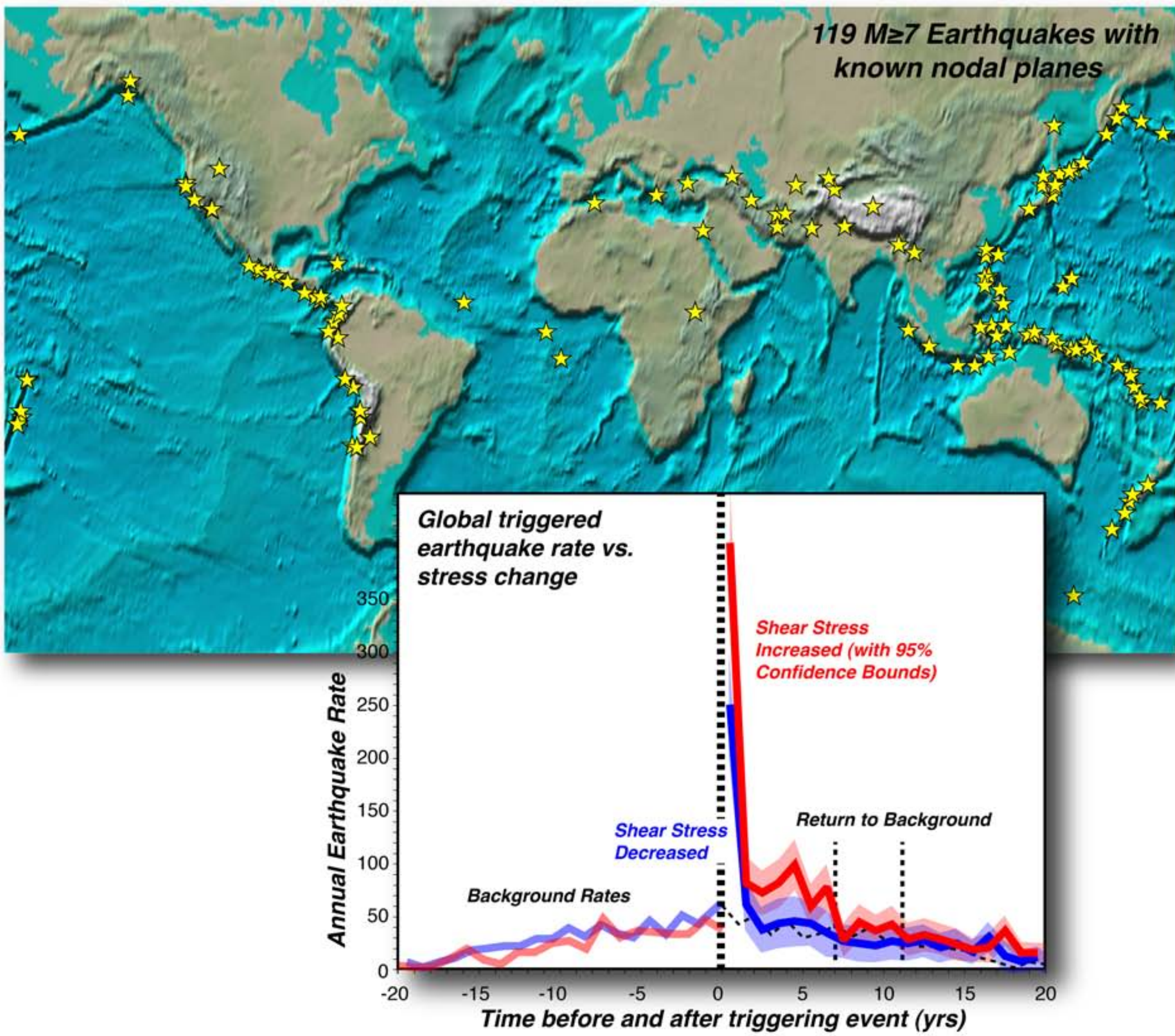
(2) True mainshock rupture complexity is not accounted for

and/or

(3) Near source dynamic triggering happens

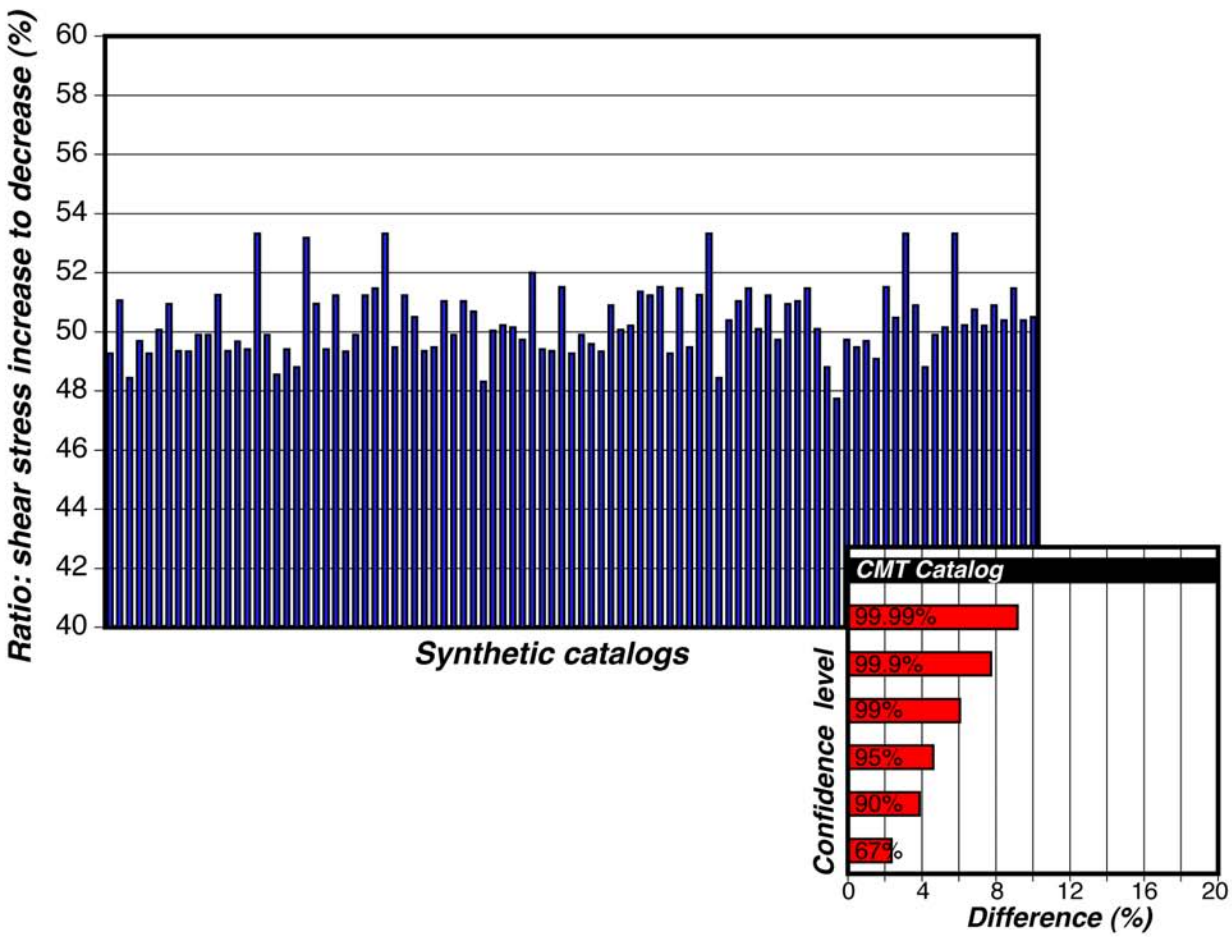
Revisiting global database of stress changes from centroid moment tensor planes of 119 M≥7 EQ's onto >1300 M≥4.5 planes:

Raw result: 61% of events within ~10-250 km range associated with increased shear stress over 20 yr



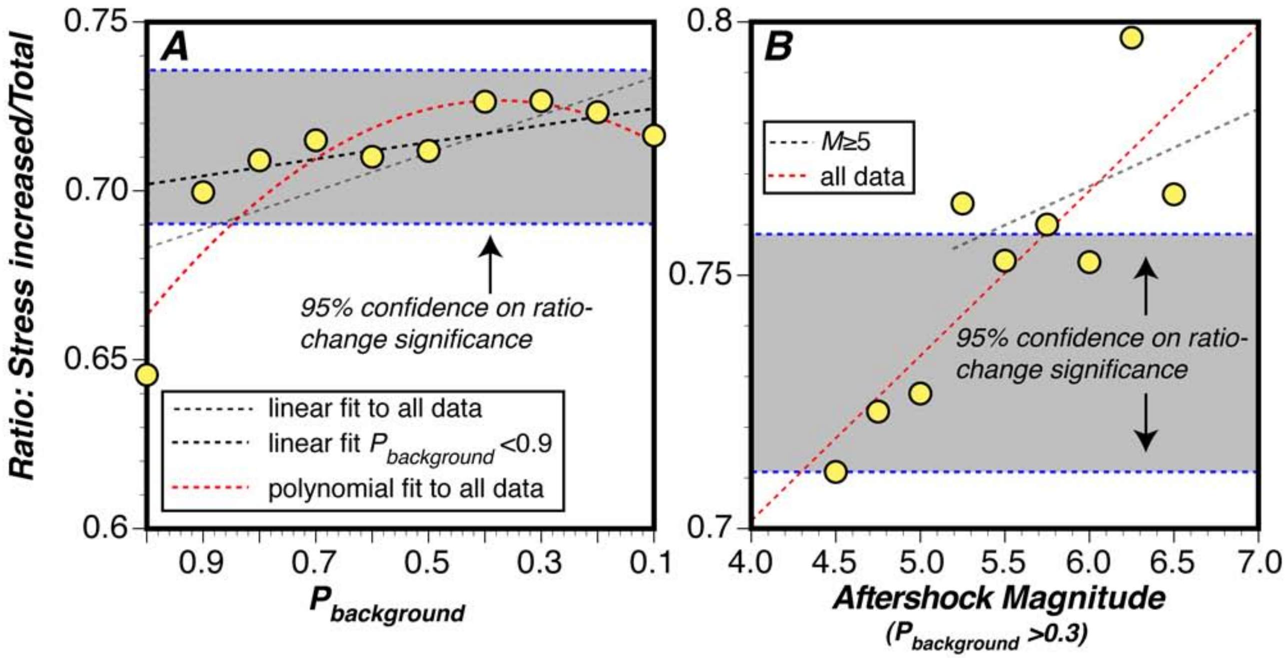
Revisiting global database of stress changes from centroid moment tensor planes of 119 M≥7 EQ's onto >1300 M≥4.5 planes:

Shear stress changes calculated using 100 synthetic catalogs show expected variability



Revisiting global database of stress changes from centroid moment tensor planes of 119 M≥7 EQ's onto >1300 M≥4.5 planes:

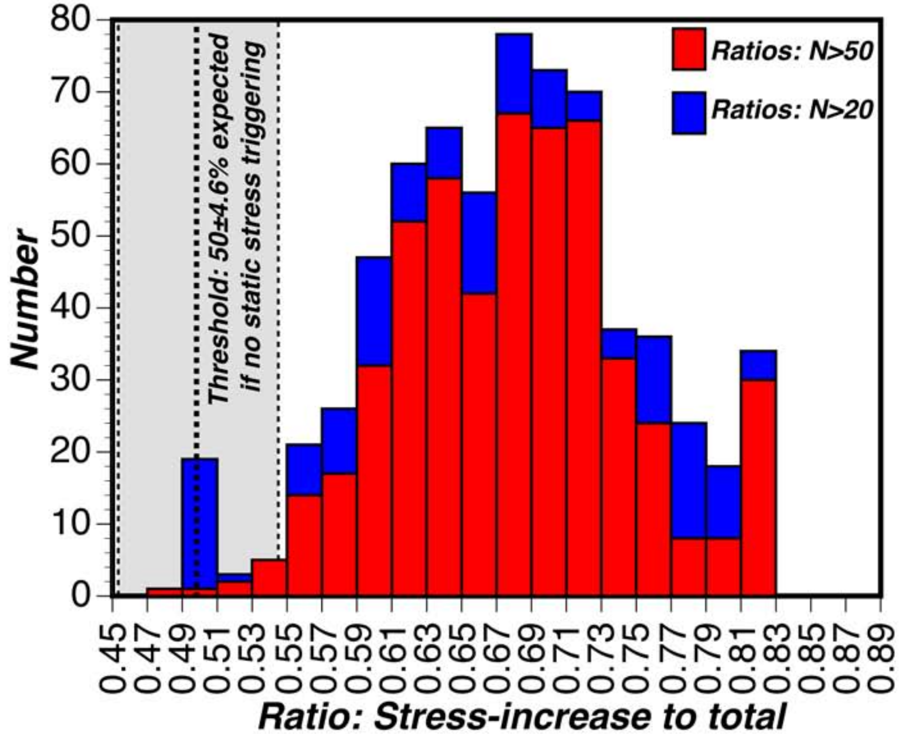
- *Stress-increased ratio grows with decreasing background probability*
- *Stress-increased ratio grows with increasing magnitude*



Revisiting global database of stress changes from centroid moment tensor planes of 119 M≥7 EQ's onto >1300 M≥4.5 planes:

Distribution of shear-stress-increase ratios as functions of:

- *Aftershock magnitude*
- *Mainshock magnitude*
- *Background proability*



Examining the the global catalog suggests that the largest aftershocks are most consistent with static stress calculations

We think this means that when the aftershock planes are well resolved, then the static stress change calculations are decent forecasters (consistent ~75-80% of the time above M=6).

Margarita Segou tests this idea with a retrospective forecast test in Northern California that compares a geologically-based Rate/State and an empirical ETAS forecast.

FORECASTING EARTHQUAKES IN NORTHERN CALIFORNIA USING PHYSICS-BASED AND STATISTICAL MODELS

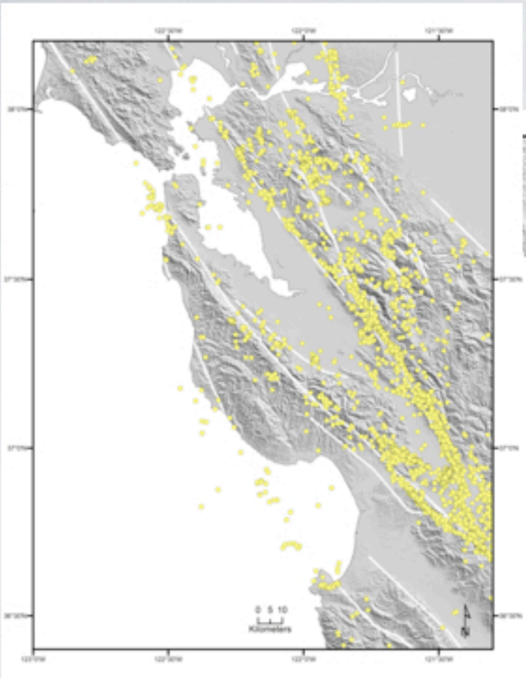
Margarita Segou

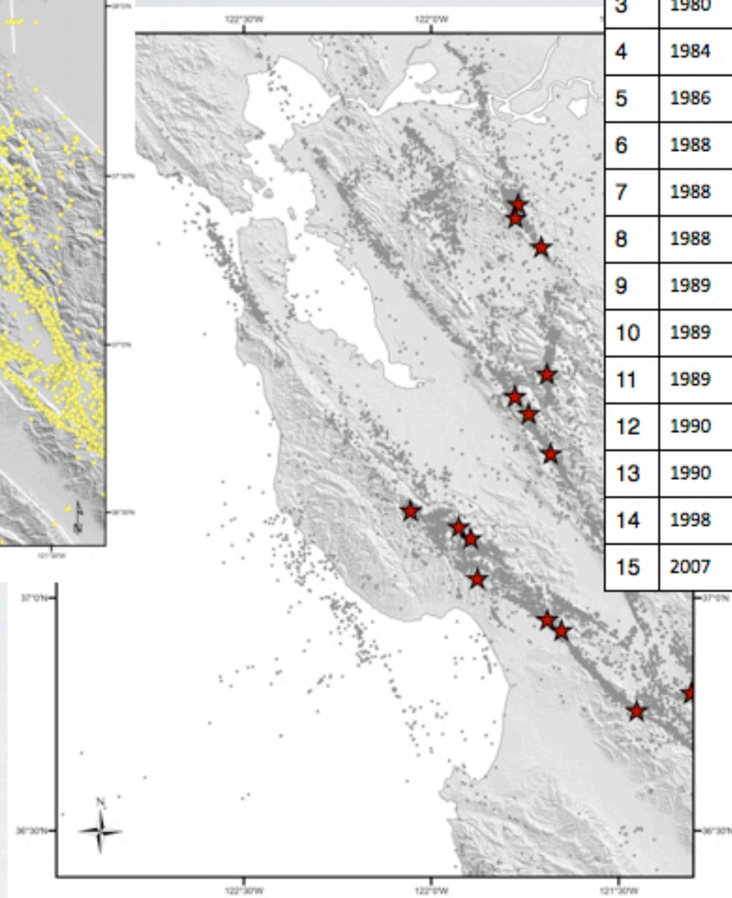
msegou@usgs.gov, msegou@gmail.com

Stanford Geophysics 5/22/12
USGS 5/23/12

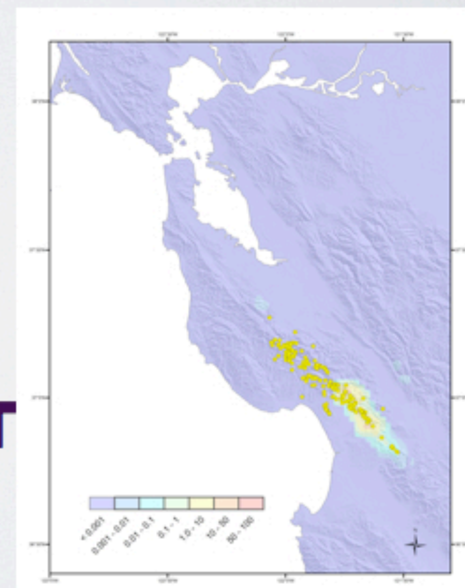
USGS science for a changing world

CRS components



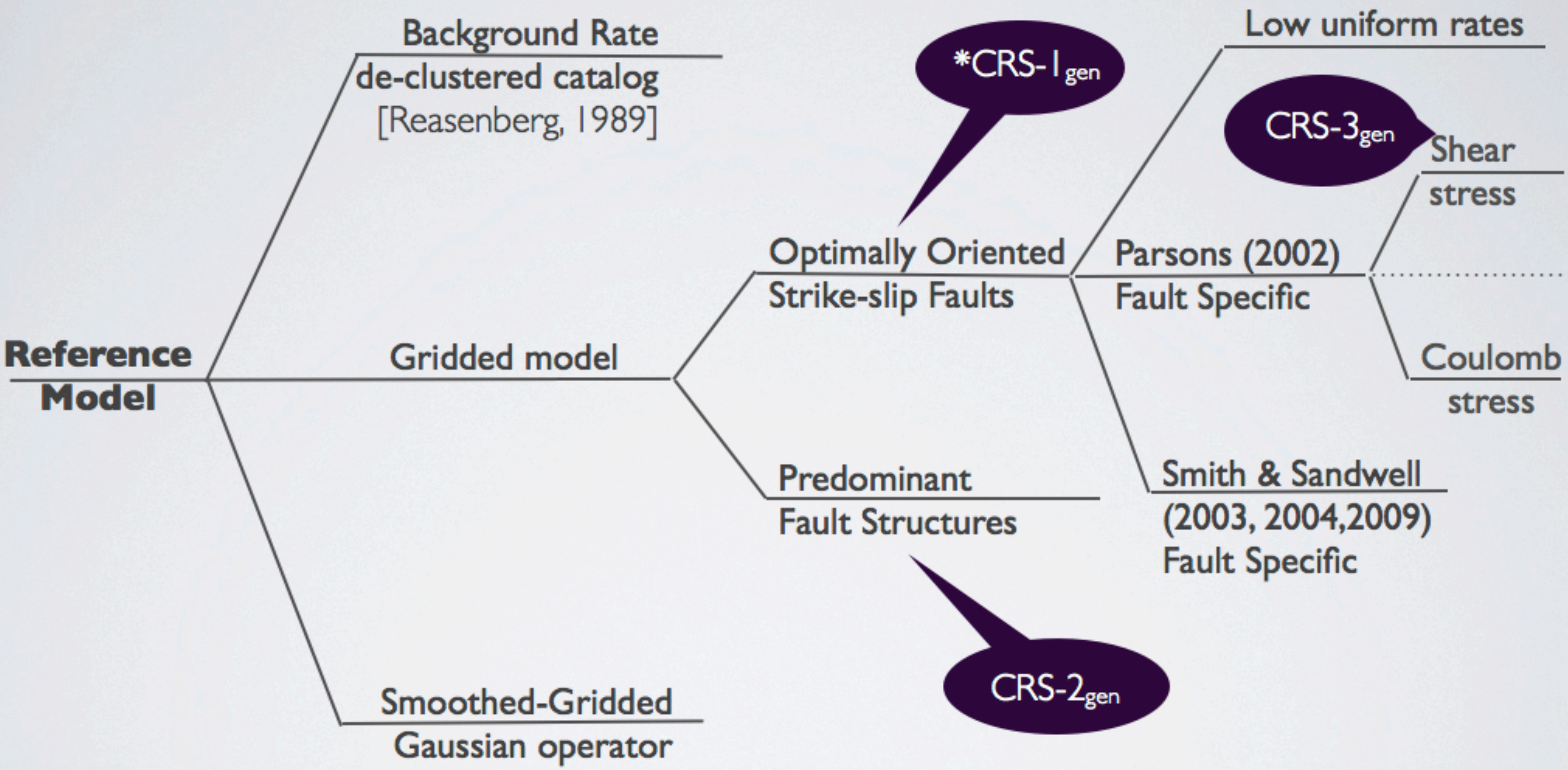


No	Y	mo	D	h	min	M	d	EQ name
1	1980	1	24	19	0	5.8	14.79	Livermore I
2	1980	1	24	19	1	5.1	6.9	LIvermore
3	1980	1	27	2	33	5.4	14.43	Livermore II
4	1984	4	24	21	15	6.2	7.968	Morgan Hill
5	1986	3	31	11	55	5.7	8.394	Mt. Lewis
6	1988	2	20	8	39	5.1	8.222	Alum Rock 1988
7	1988	6	13	1	45	5.3	8.869	Hollister
8	1988	6	27	18	43	5.3	11.54	Ellsman Lake I
9	1989	8	8	8	13	5.4	12.59	Ellsman Lake II
10	1989	10	18	0	4	7	16.41	Loma Prieta mainshock
11	1989	10	18	0	41	5.1	13.86	Loma Prieta aftershock-St Cruz Mts
12	1990	4	18	13	53	5.4	4.611	Watsonville I
13	1990	4	18	15	46	5.1	6.338	Watsonville II
14	1998	8	12	14	10	5.1	7.746	SJ Bautista
15	2007	10	31	3	4	5.4	7.486	Alum Rock 1988

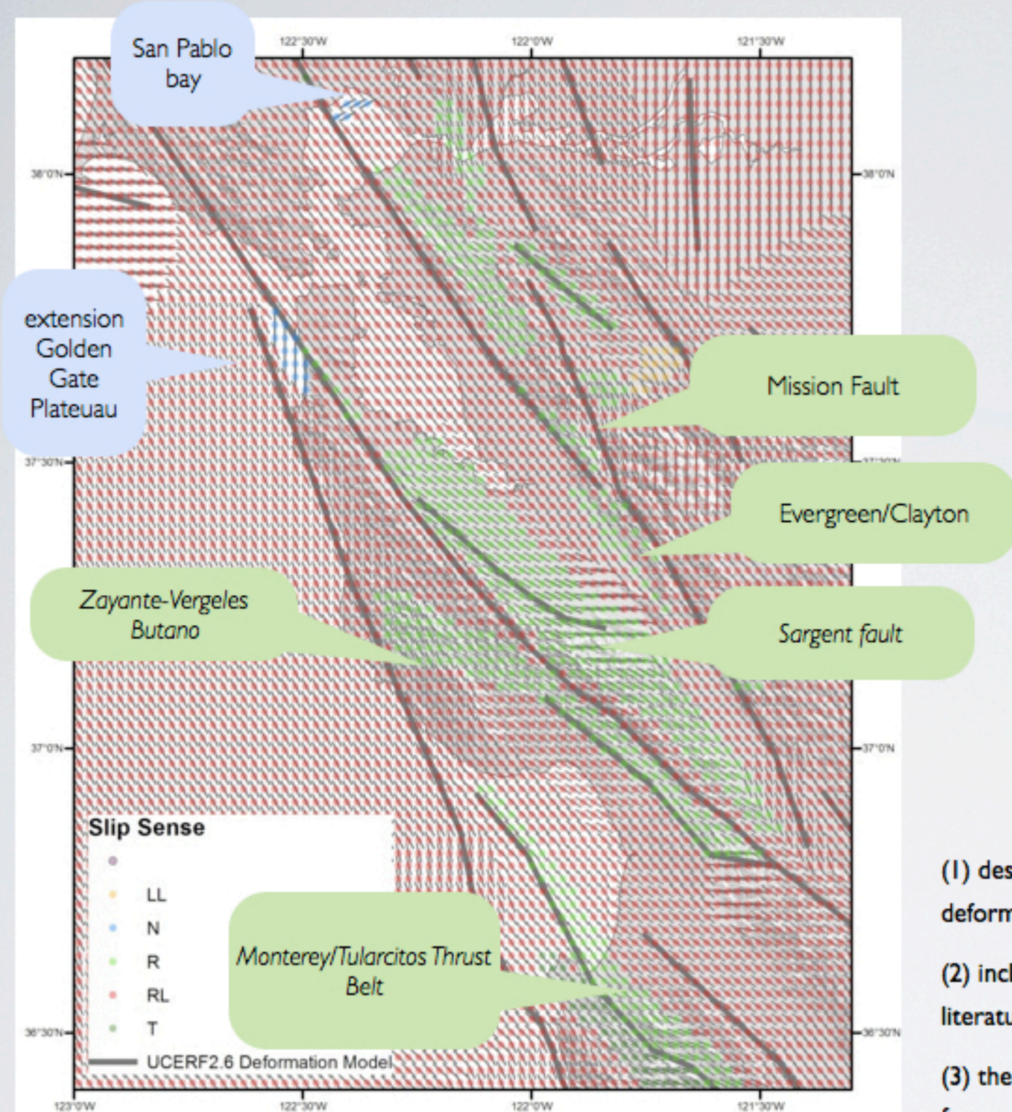


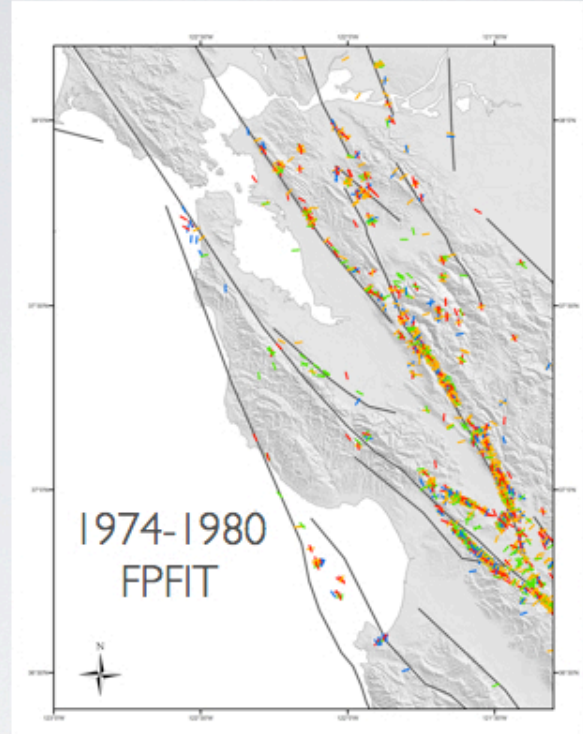
Reference Rate ANSS Mc3.0 **1974-1980** **+** **DCFF M>5.0 1980-2009** **=** **RETRO FORECAST** Mc3.0

Diagram for calculation sets for each CRS forecast model



* increases the number of free parameters &
refers to optimally oriented fault planes to the pre-mainshock stress field





Requirements

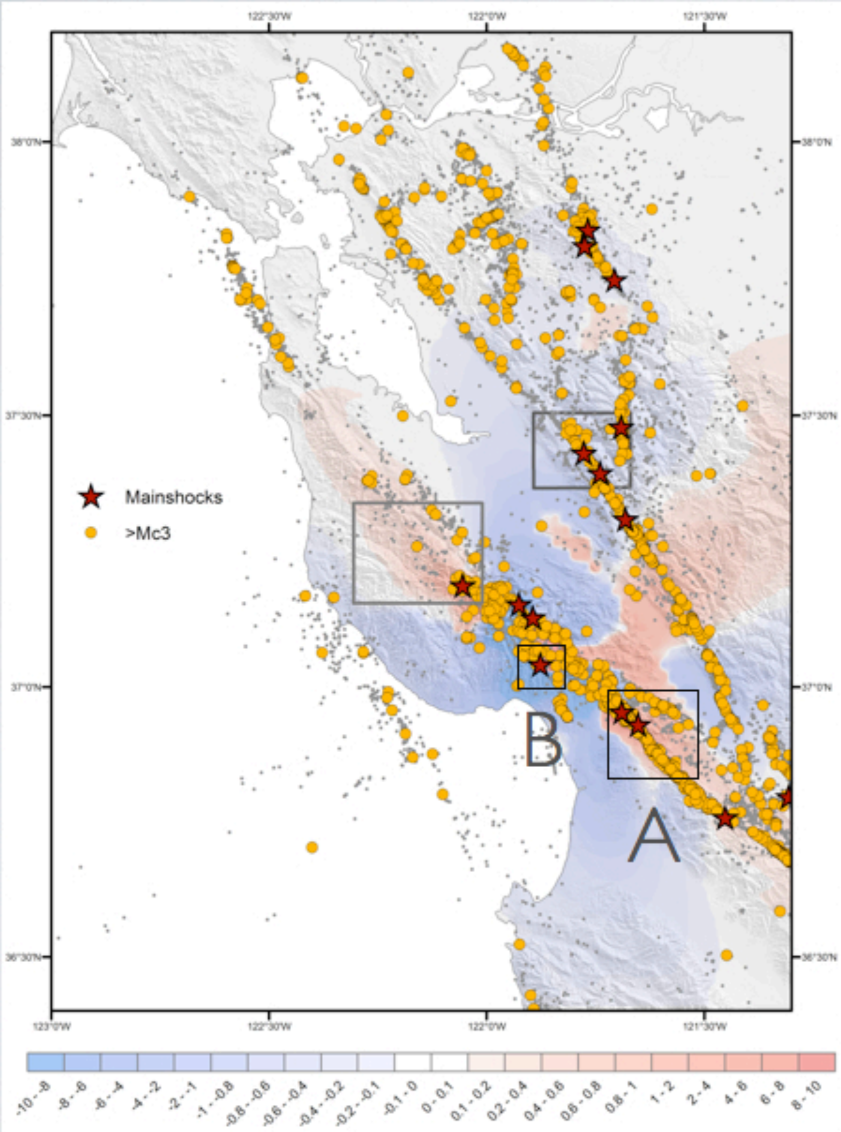
(1) describe main geological features which are involved in the long term deformation history of Northern California and

(2) include, whichever the scale, important structures for which we now from literature survey that there are spatio-temporal implications for their activity

(3) the use of seismological data should be constrained to data available inside the forecast's learning phase (1974-1980) to avoid conflicts arising from any prior knowledge, which would jeopardize our evaluation

3D-GRID DISCRETE FAULT PLANES

PREDOMINANT GEOLOGY



today we are focusing on areas A & B

Area A advantages

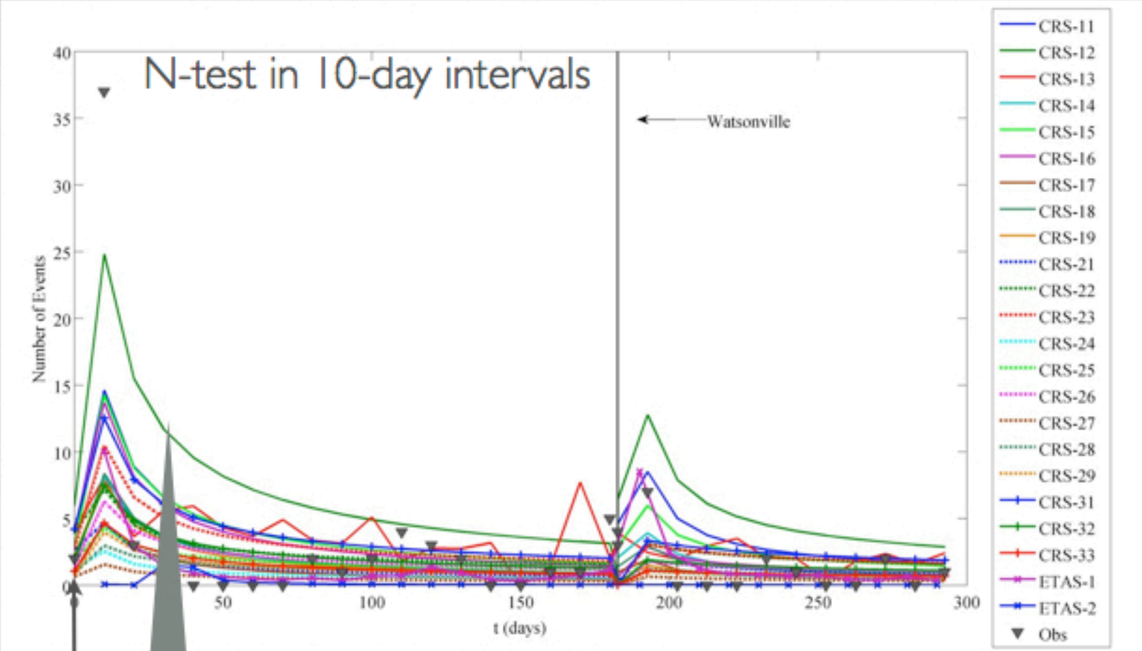
- study models' performance at the off-fault zones
- time-dependency of performance since Watsoville events occur some months after Loma Prieta

Area B advantages

- *which is the best choice for the near-source region? CRS or ETAS?*

Different Testing Areas? What we hope to find out?

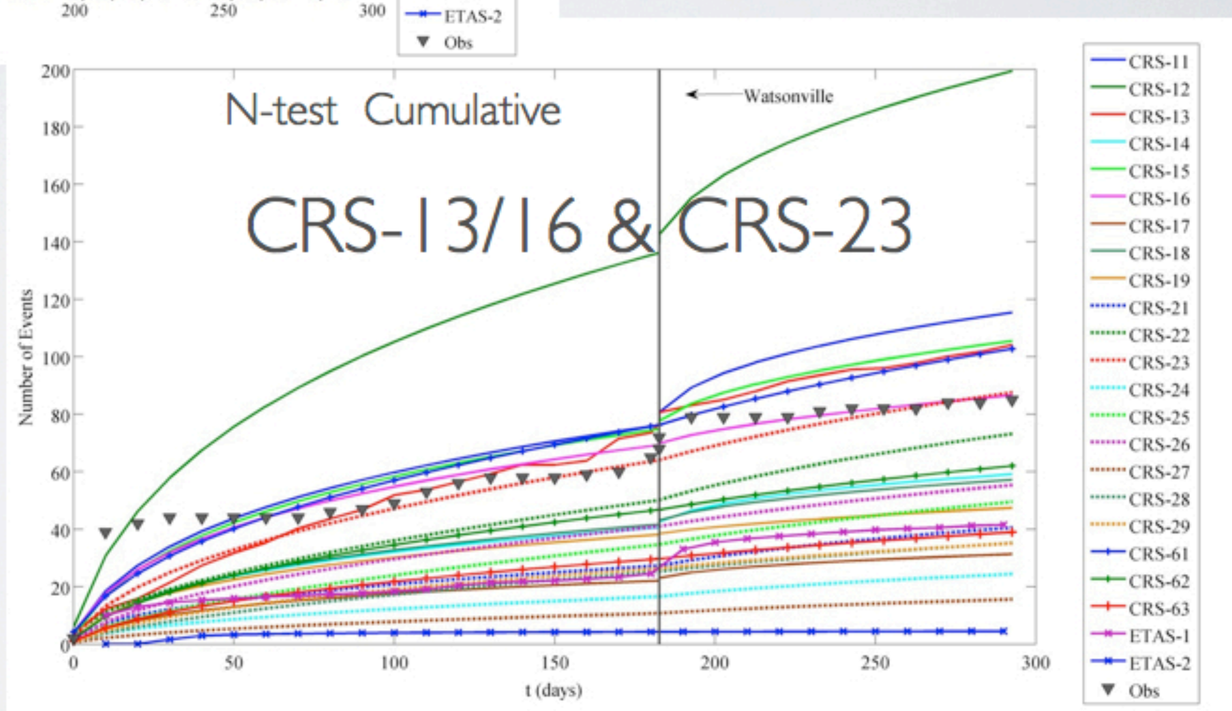
@off-fault



given sufficient time even the most slowly stressed 'faults' will return to reference state

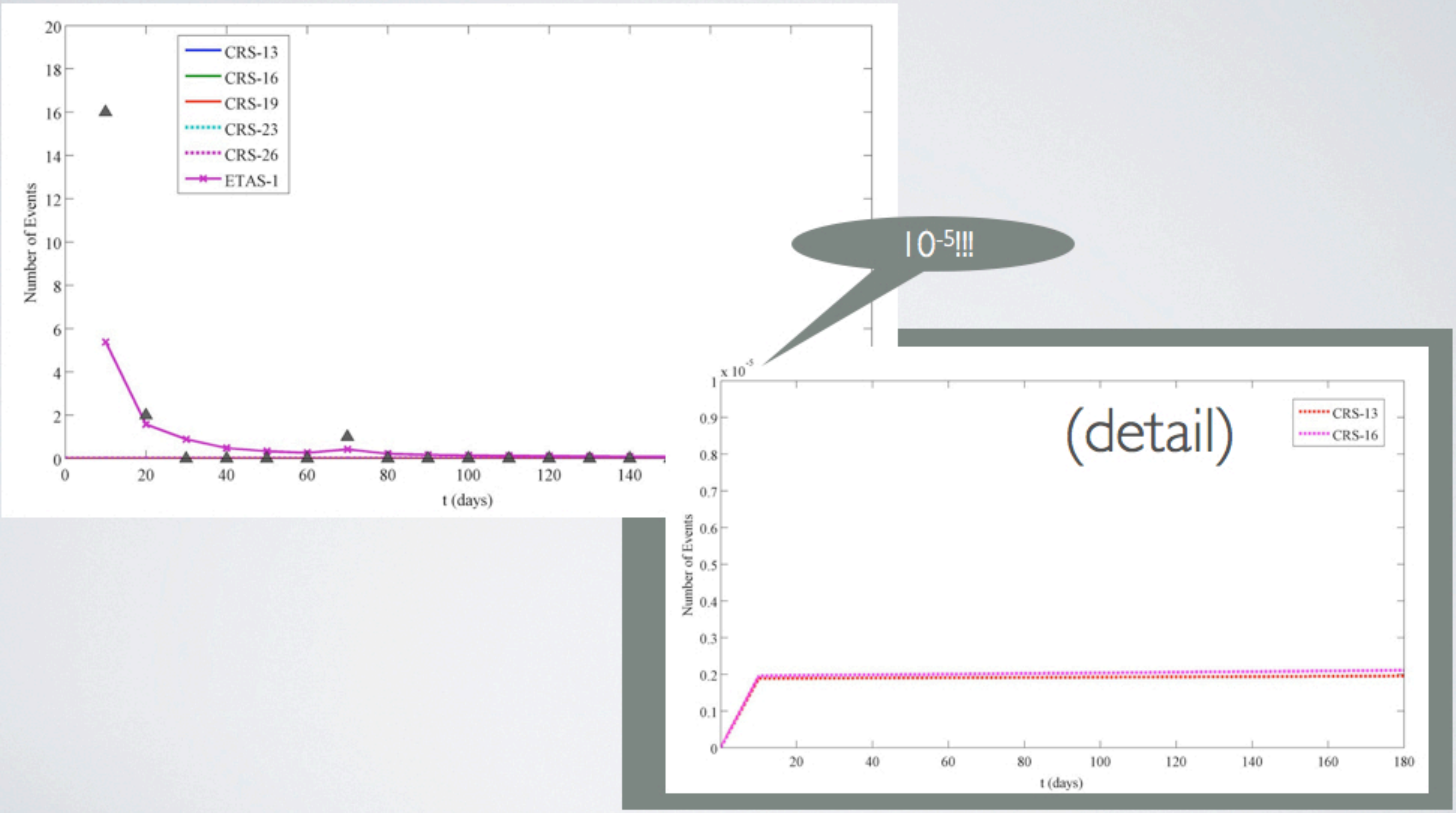
ETAS under-predicts in the beginning since a small number of ancestor events
CRS under-predicts due to low background rates

first 40 min



NUMBER OF EVENTS

@near source



10 km from Loma Prieta mainshock inside DCFF<0
crash test between the best performing forecast models

PERFORMANCE EVALUATION RESULTS

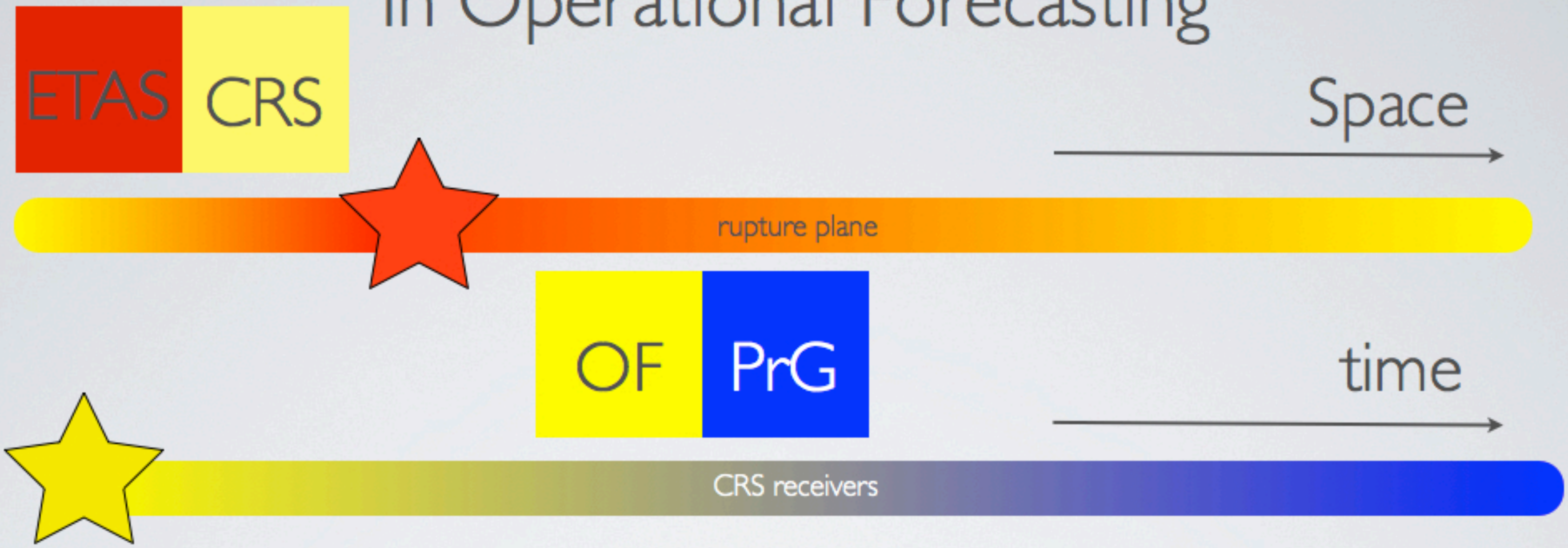
Physics-based models @short-term outperform ETAS @off-fault region. Formulations based on smoothed-gridded Coulomb-stress based on optimally-oriented with loading rates on SAF [0.067-0.3 bar/yr] & receivers based on predominant geology [0.3 bar/yr] result in better spatial consistency

CRS forecast models are represented @long-term @off-fault region by models resolved on predominant geology receivers

What happens @near-source region ? ETAS models outperform CRS models due to low reference rates & stress shadow zones

Critical to incorporate previous important ruptures

In Operational Forecasting



rely not on an optimum model but in a combination of best-performing models

we need pre-definition of best-performing CRS models & requires update of the state variable of the system

CRS models covers successfully the off-fault area where prediction is critical, no immediate need for variable slip distributions

introduction of stochasticity for simulations of early (1^{st} day) aftershocks, then revert to observed aftershocks as ETAS ancestor events, depending on network's detectability