Exploring Pragmatic to Esoteric Applications of PBO High-rate Geodetic Data for Constraining Fault Slip

(told by a seismologist)

J. Gomberg, D. Schmidt, S. Minson, E. Roeloffs, J. Murray, J. Langbein, B. Crowell & I. Zaliapin

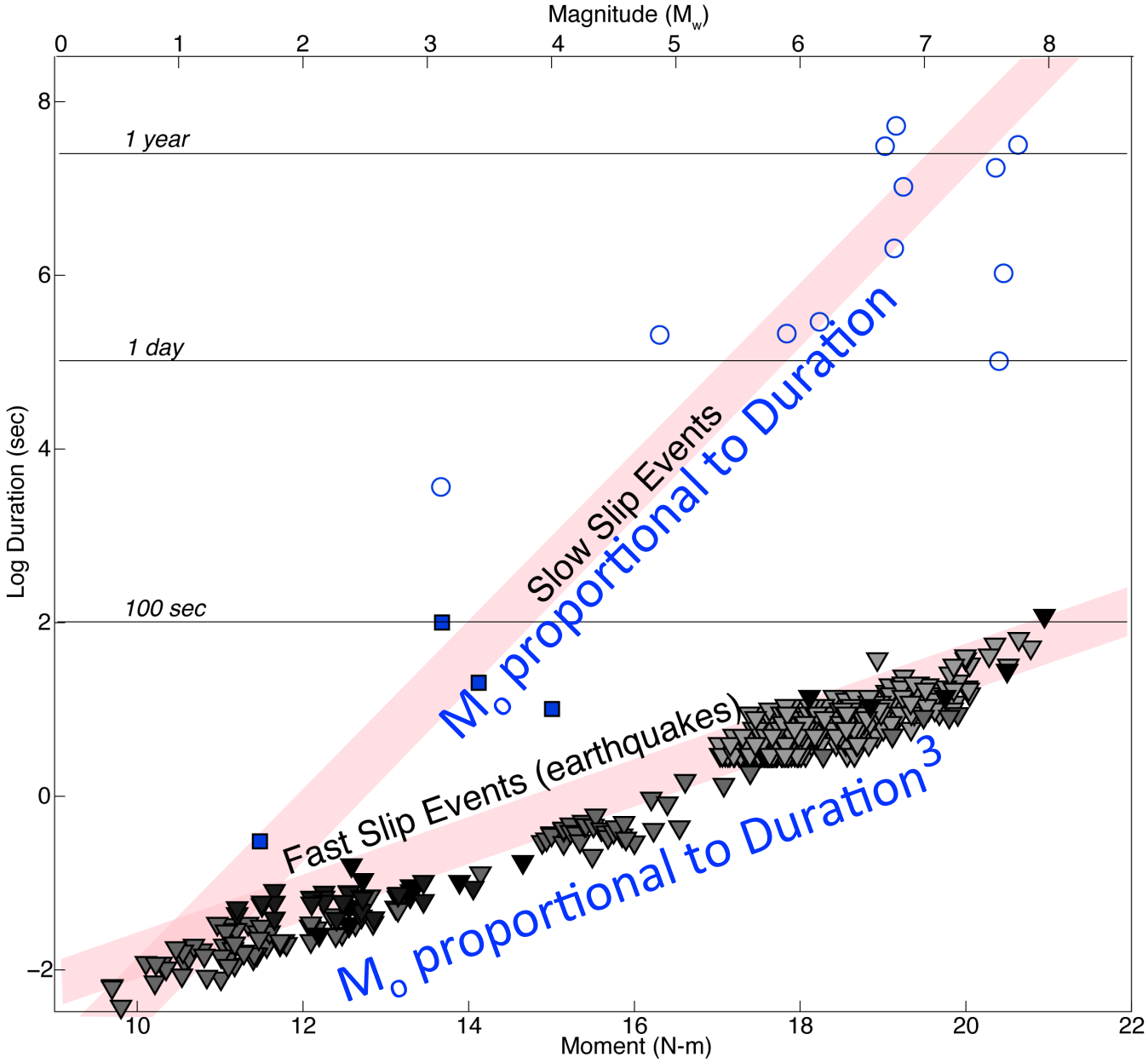
Talk Topics

Assessing what we can observe. Exploring the esoteric (scientific) question of duration vs moment scaling reveals significant gaps high-rate data may fill.

Exploring how well might high-rate data fill observations these gaps.

High-rate data also may fill gaps in the pragmatic task of monitoring fault slip, illustrated by applications to earthquake early warning.

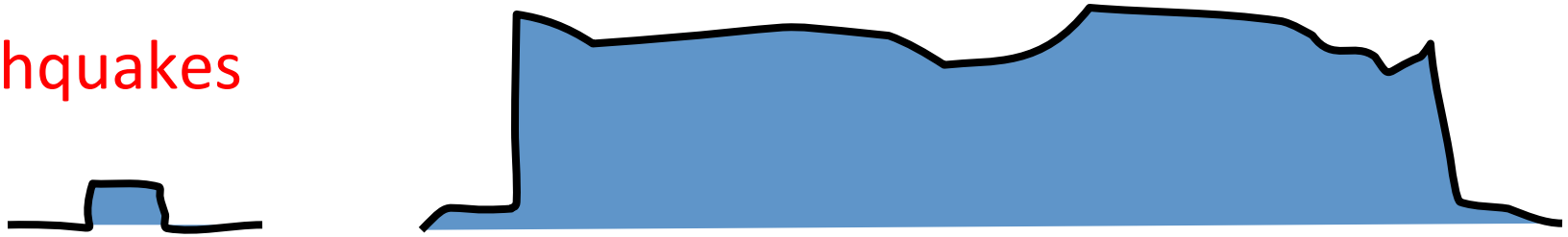
Assessing what we can observe. Exploring duration *vs* moment scaling reveals gaps high-rate data may fill.



Ide et al., 2007

Moment/duration scaling – key constraint on rupture physics

Earthquakes



Moment M_o= *rigidity* x *Slip* x Length^2

Stress drop $\Delta\sigma$ ~ *rigidity* x *Slip* /Length

Length = Rupture Velocity V_r x *Duration*

$M_o=\Delta\sigma \times L^3 = \Delta\sigma \times V_r^3 \times \text{Duration}^3$

Earthquake data show

$M_o=C \times \text{Duration}^3$

implying

$C=\Delta\sigma \times V_r^3$

V_r & $\Delta\sigma$ independent of rupture dimension, L

Moment/duration scaling – key constraint on rupture physics

Slow Slip Events

Moment M_o = *rigidity* x *Slip* x Length^2

Stress drop $\Delta\sigma$ ~ *rigidity* x *Slip* /Length

Length = Rupture Velocity V_r x Duration

$M_o = \Delta\sigma \times L^3 = \Delta\sigma \times V_r^3 \times \text{Duration}^3$

If M_o is ~proportional to Duration, or

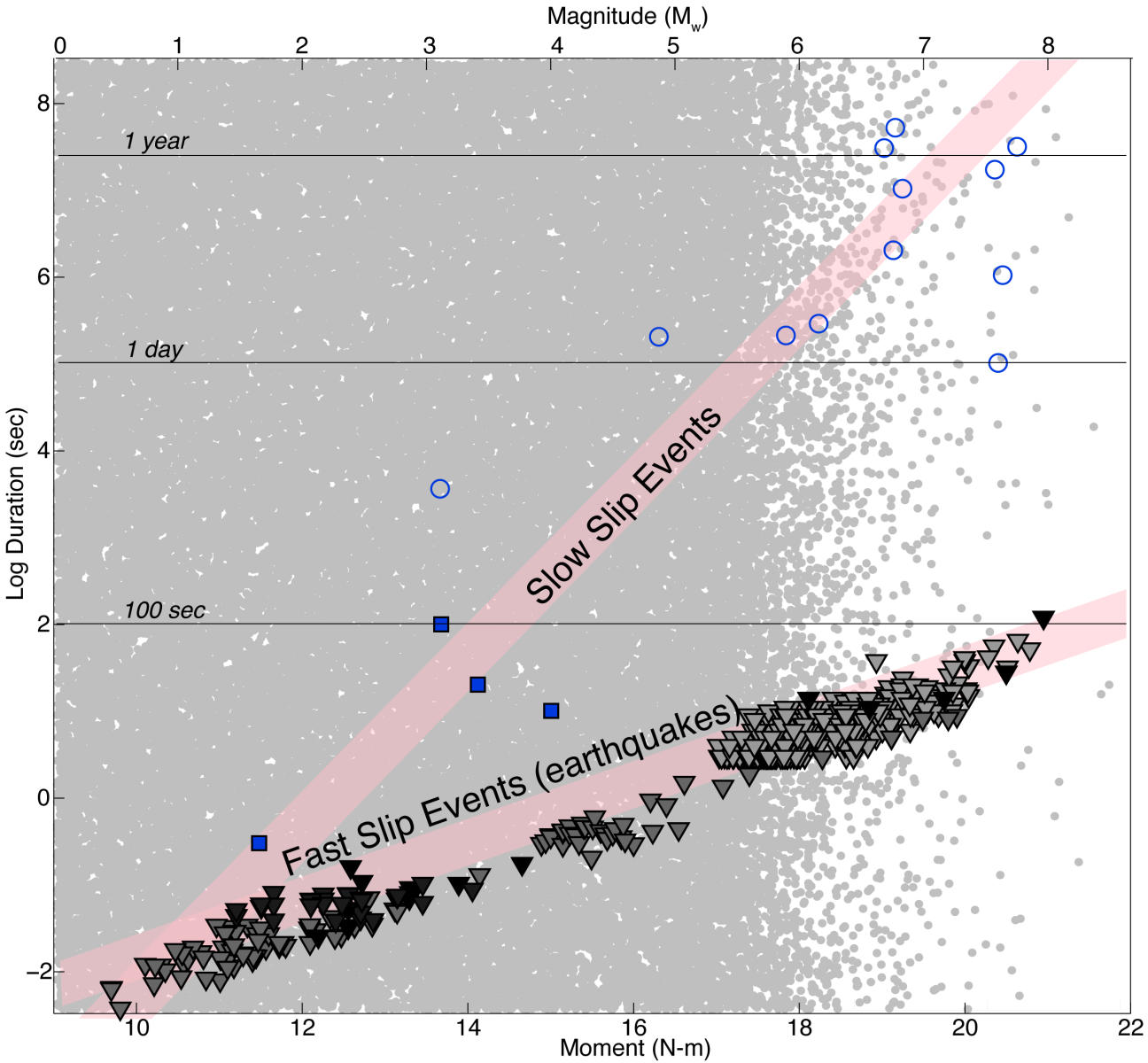
$M_o = C \times \text{Duration}$

implying

$C = \Delta\sigma V_r L^2$

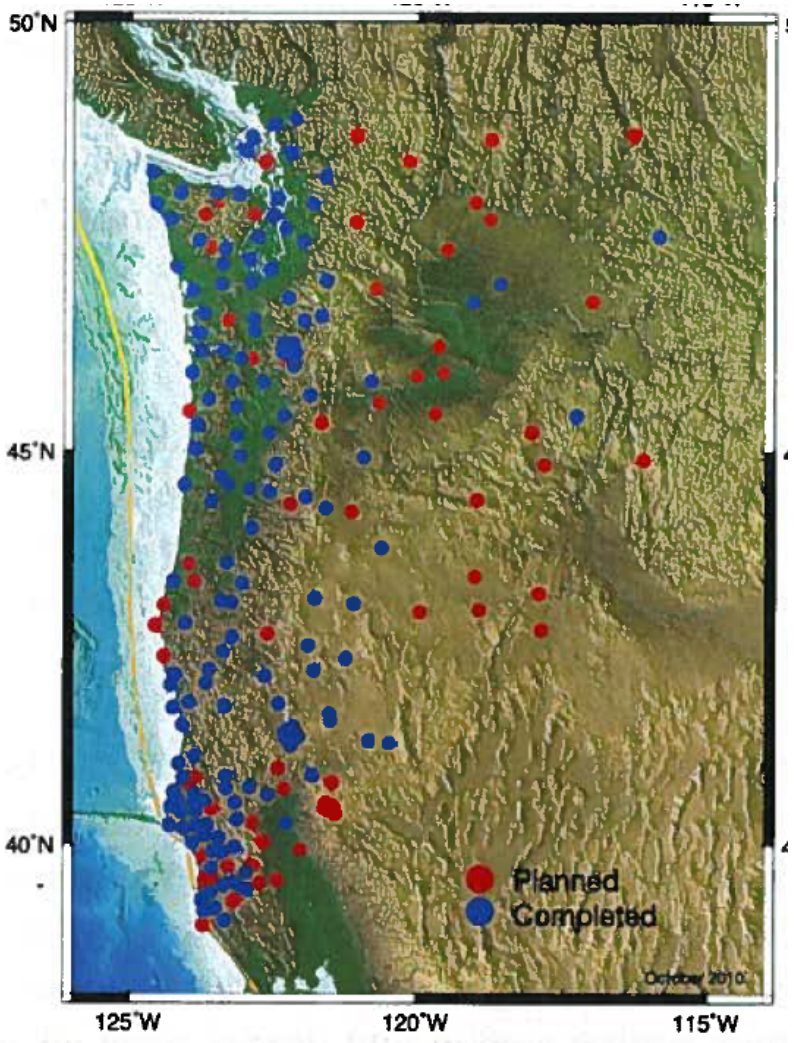
V_r & $\Delta\sigma$ decrease as rupture dimension, L, grows

Assessing what we can observe: Natural recurrence rates affect apparent scaling.

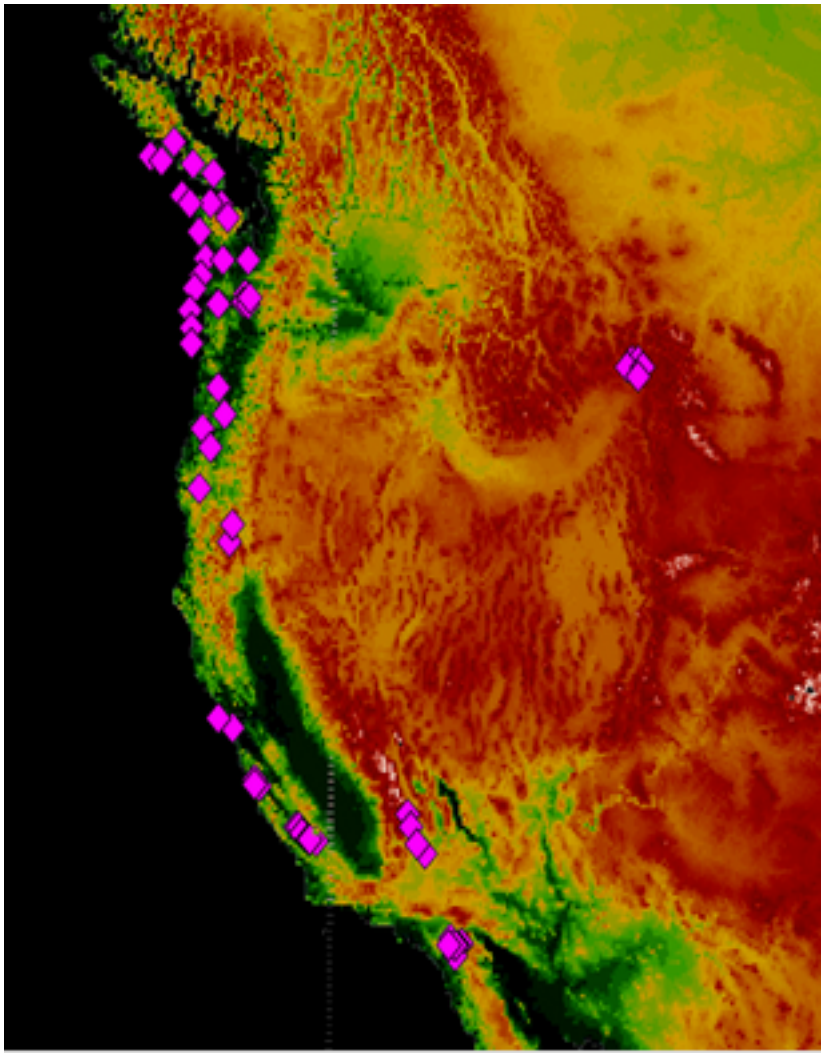


High-rate GPS & strainmeter data available only recently.

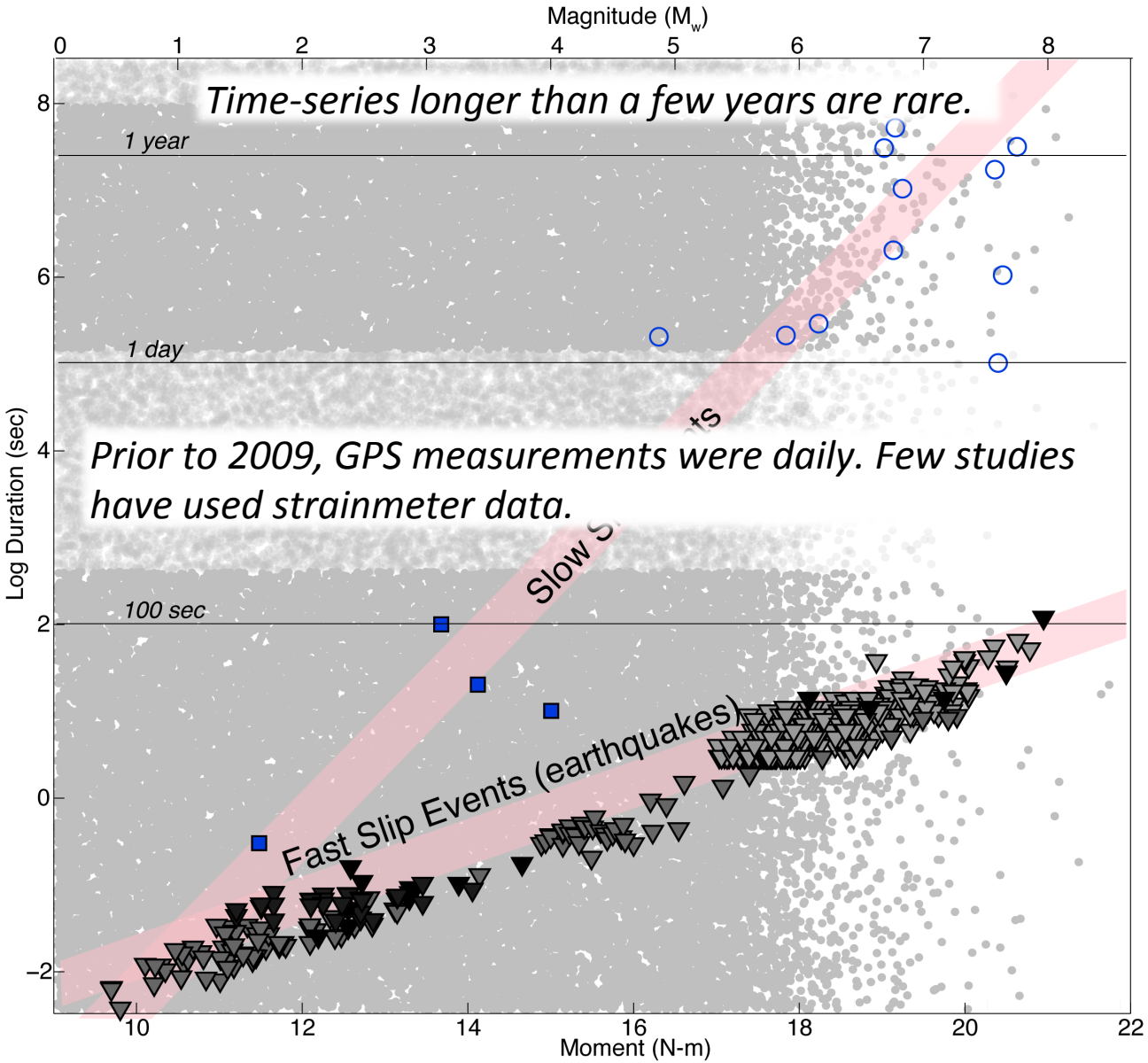
High-Rate GPS Network – 2009



PBO Borehole Strainmeter Network – 2005



Sampling rate & longevity of measurements affect apparent scaling.



Consider measurement detection thresholds

Agnew (UNAVCO Course, 2014)

Displacement, $u(t)$, at a distance, r, from a moment-tensor source, $M_0(t)$

$$u(t) = u_N + u_F = \frac{G_N(\theta,\phi)}{4\pi\rho c^2}\frac{1}{r^2}M_0(t - r/c) + \frac{G_F(\theta,\phi)}{4\pi\rho c^3}\frac{1}{r}\frac{dM_0(t - r/c)}{dt}$$

near-field term, r^{-2} decay — far-field term, r^{-1} decay

If $u(t)$ has time constant t_s,

$$u(t) \sim \frac{G(\theta,\phi)}{4\pi\rho c^2}\frac{1}{r^2}\left[M_0 + \frac{r\,M_0}{c\,ts}\right]$$

distance dependence

$u(t)$ has Fourier amplitude spectrum $U(f)$ & noise power spectrum $N(f)$.

The signal-to-noise ratio is

$$\text{SNR} = \left[\int^{\infty} \frac{|U(f)|^2}{N(f)}\,df\right]^{\frac{1}{2}} \sim \frac{u_{RMS}}{B(t_S)}$$

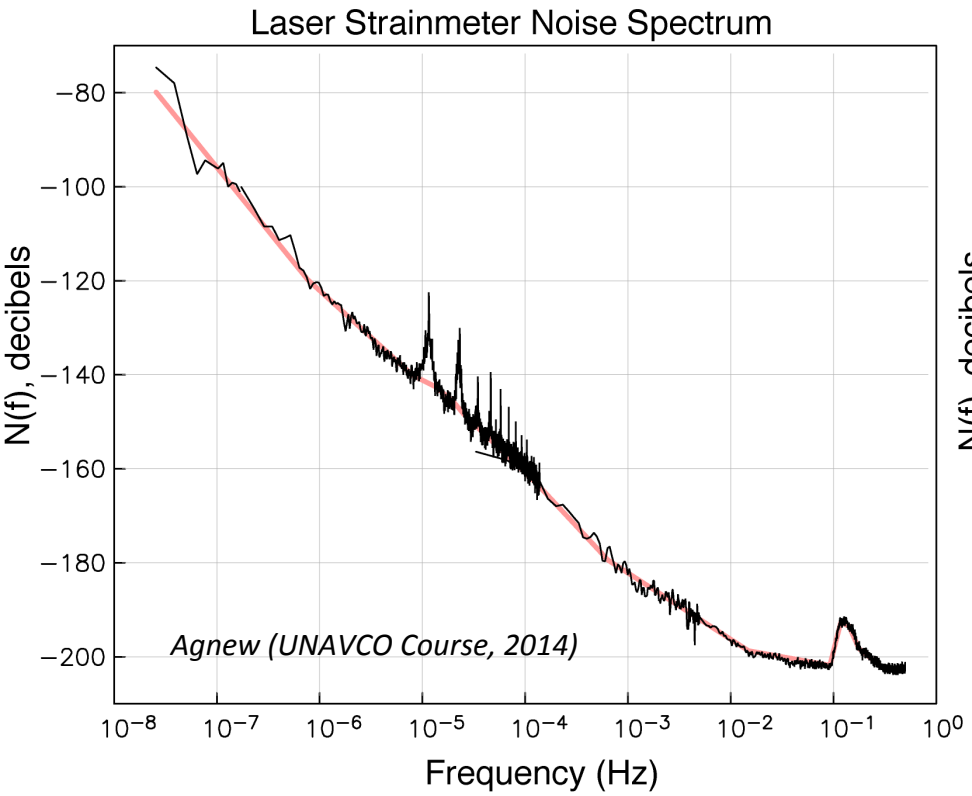
$B(t_S)$ is the RMS noise over a one-octave band,

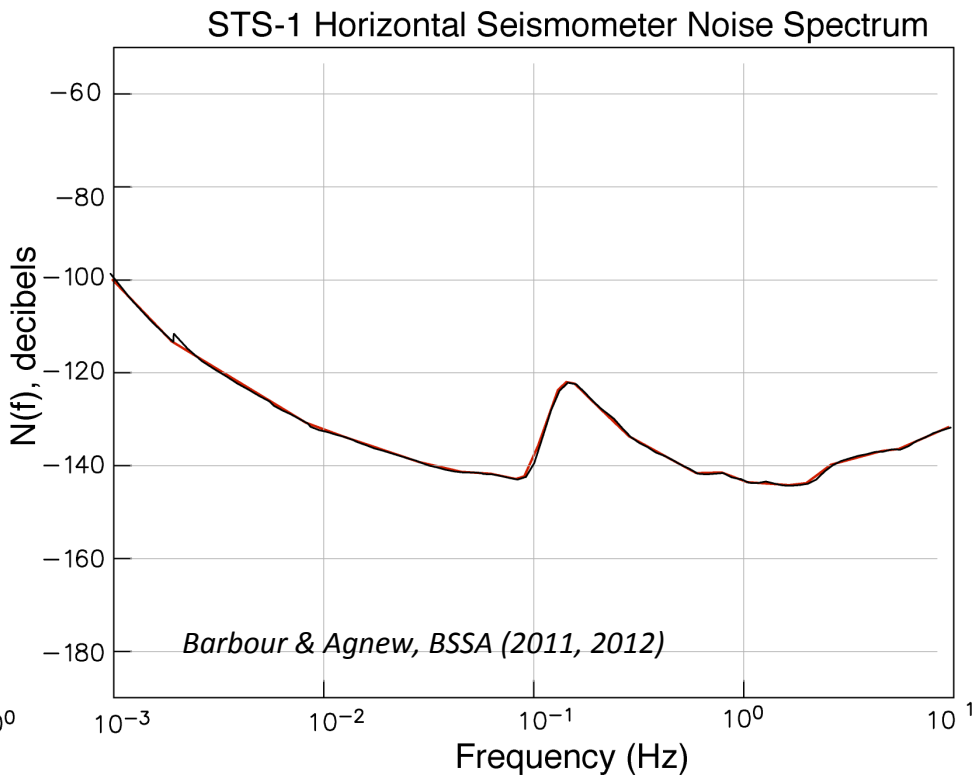
$$B(t_S) = \left[\int_{\frac{1}{\sqrt{2}t_S}}^{\frac{\sqrt{2}}{t_S}} N(f)\,df\right]^{\frac{1}{2}}$$

Detection requires SNR > 1 or $U_{RMS} > B(t_s)$. Detection threshold, M_0, for a value of t_s is

$$B(t_s) \sim \frac{G}{4\pi\rho c^2}\frac{1}{r^2}\left[1 + \frac{r}{ct_s}\right]M_0$$

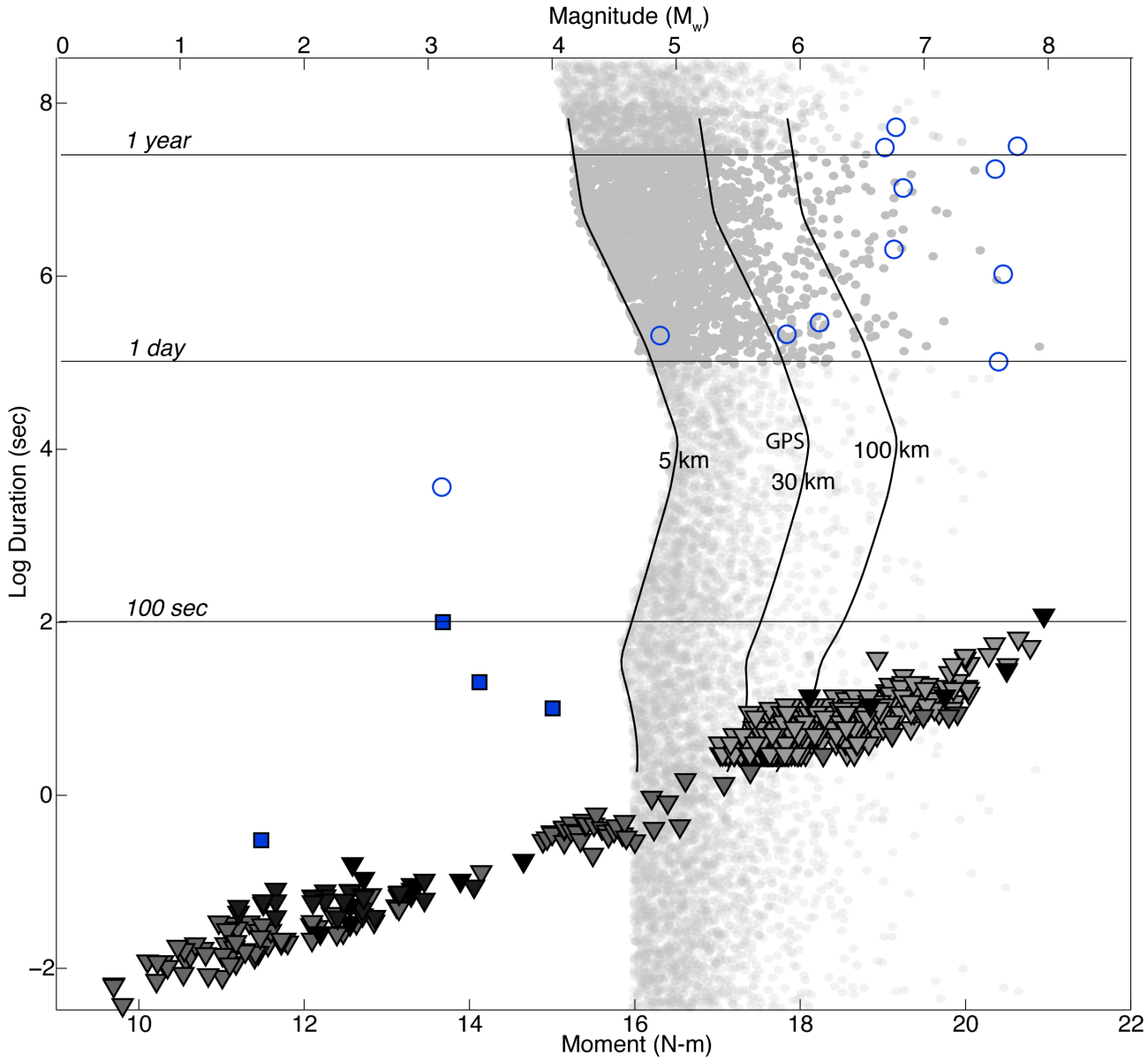
Measurement detection thresholds.



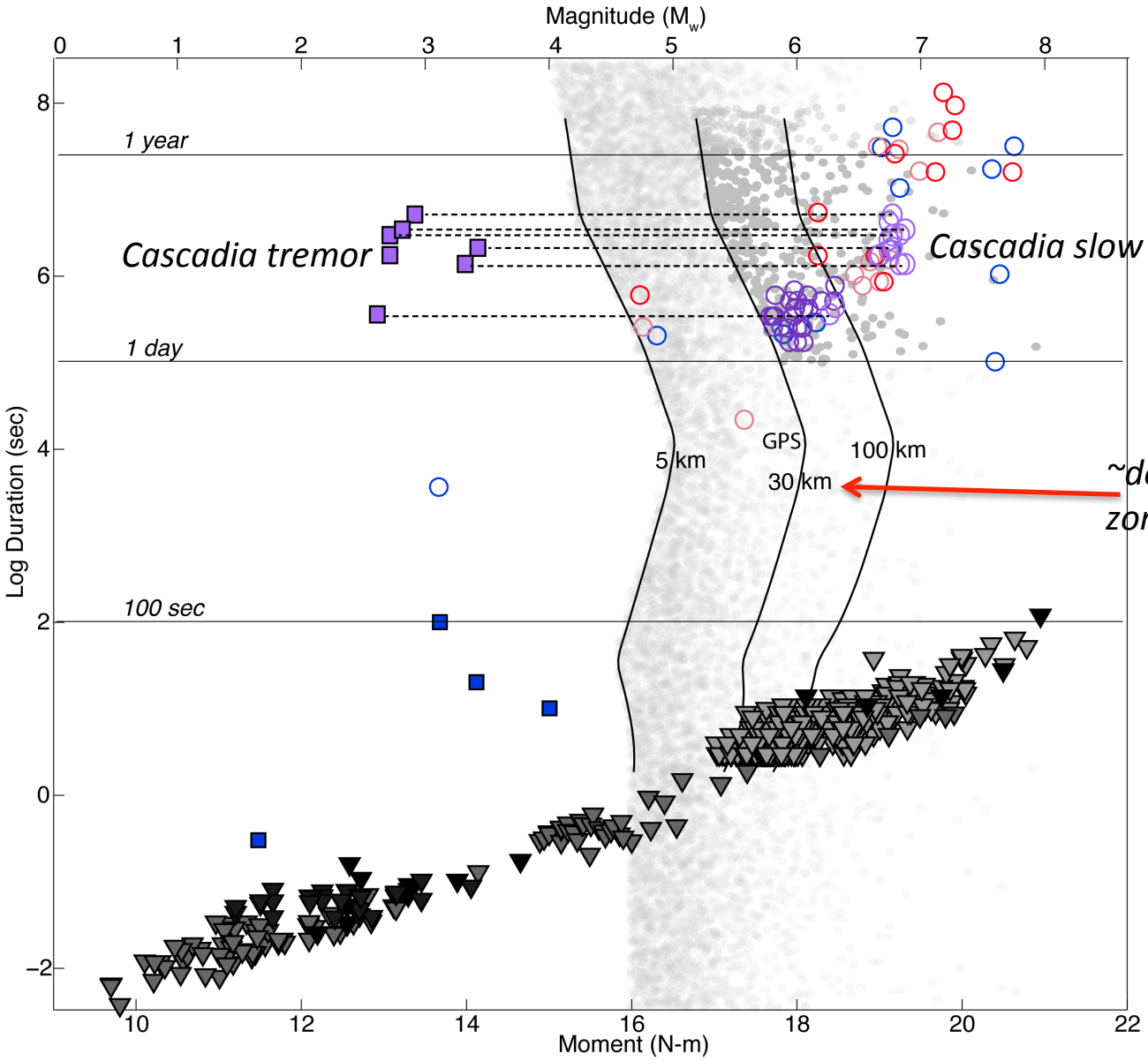


Compute $B(t_S) = \left[\int_{\frac{1}{\sqrt{2}t_S}}^{\frac{\sqrt{2}}{t_S}} N(f)\, df \right]^{\frac{1}{2}}$

GPS detection thresholds

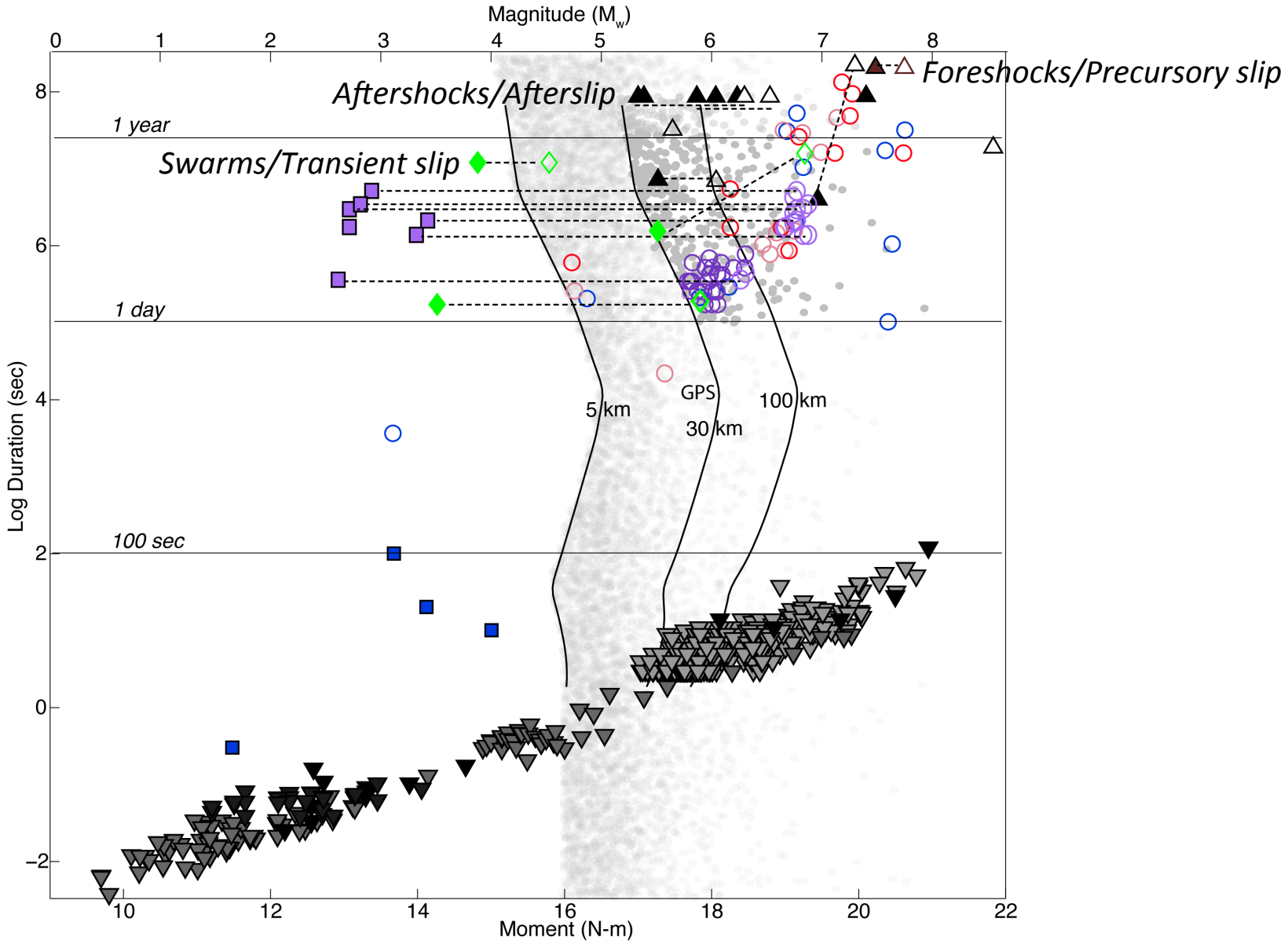


More GPS measurements of spontaneous slip events. The Earth also imposes sampling limitations.

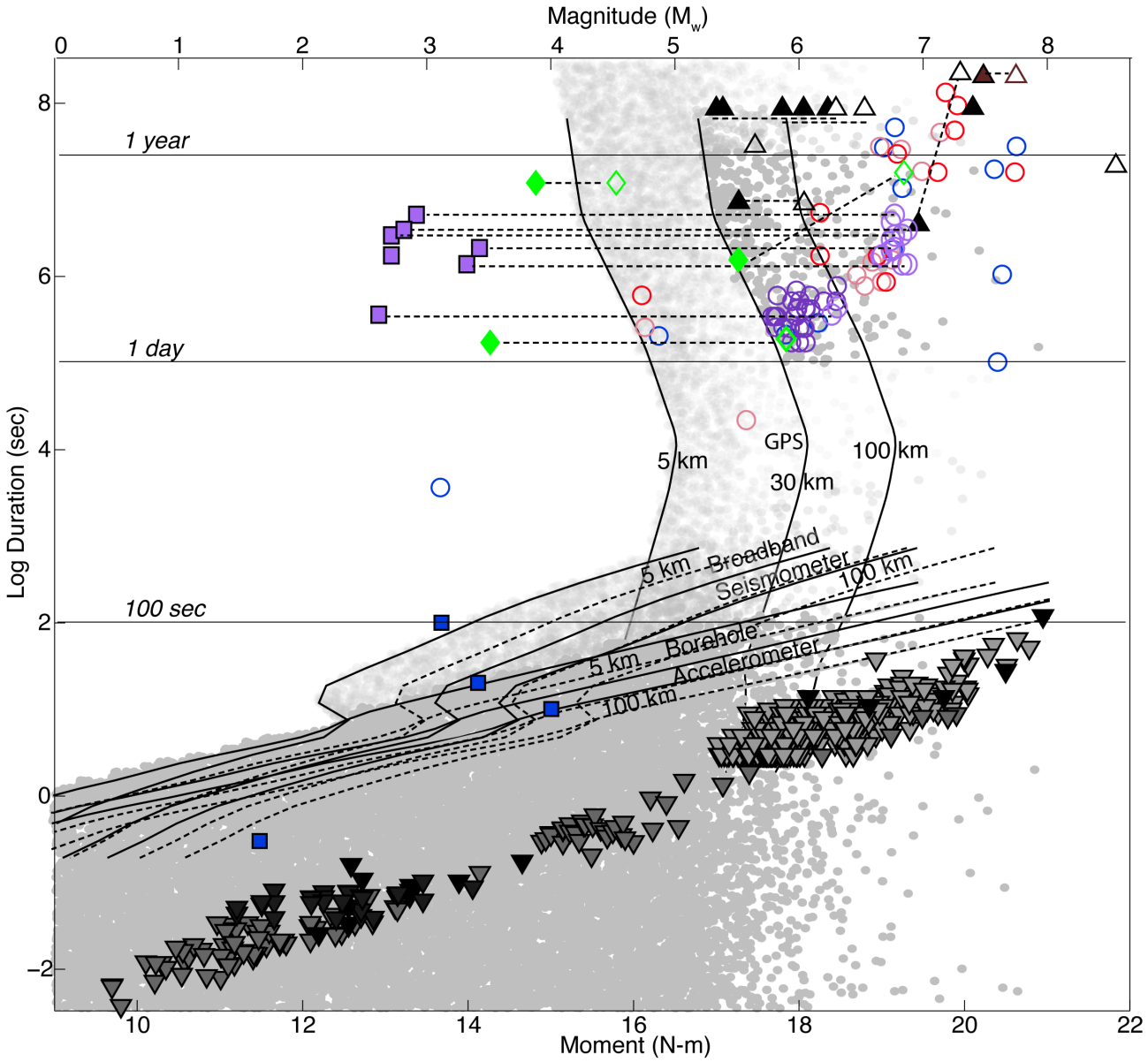


~depth to subduction zone aseismic slip

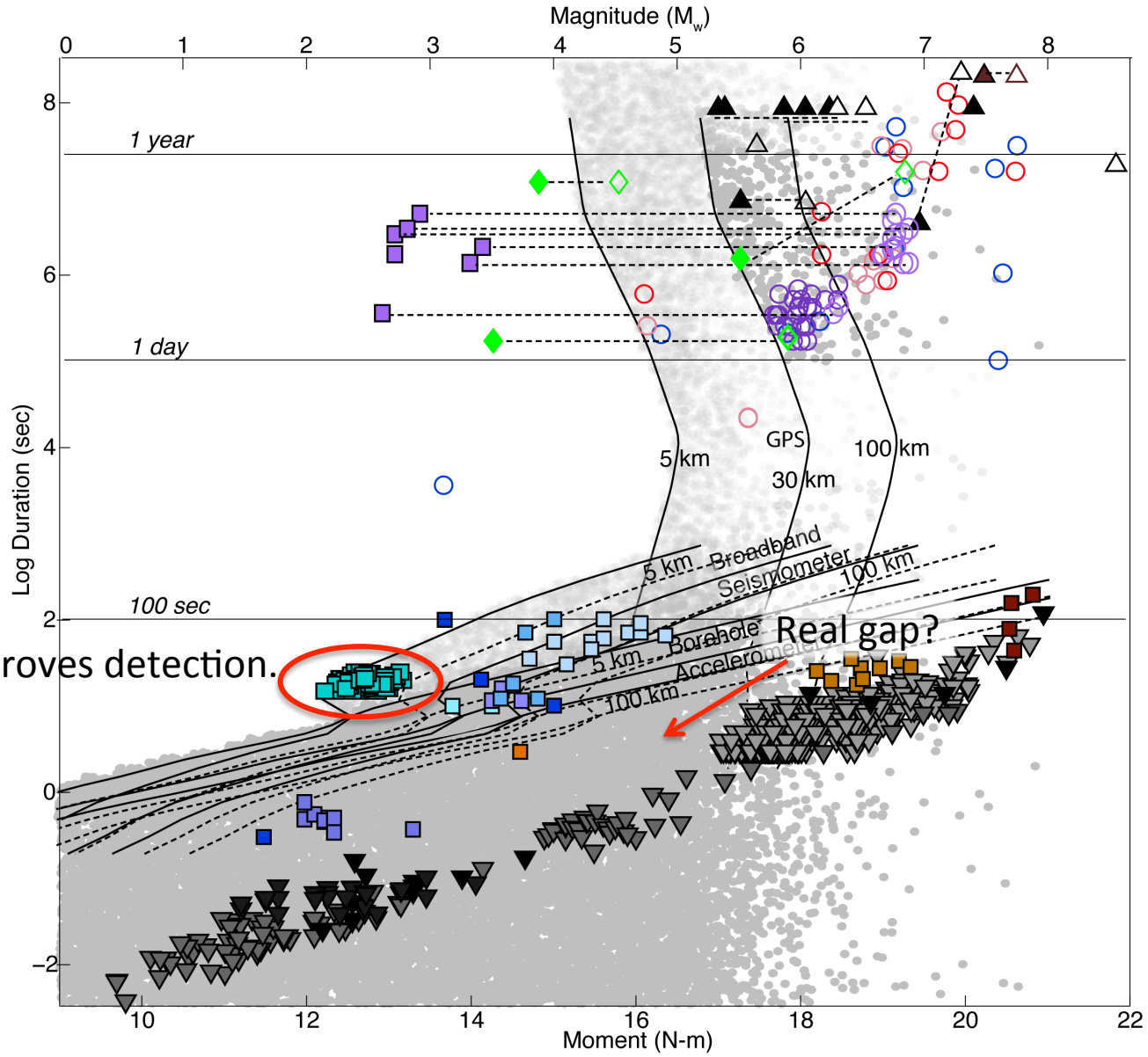
Coupled seismic & aseismic slip event measurements. We begin to fill the GPS detectable region.



Seismic Detection Thresholds.

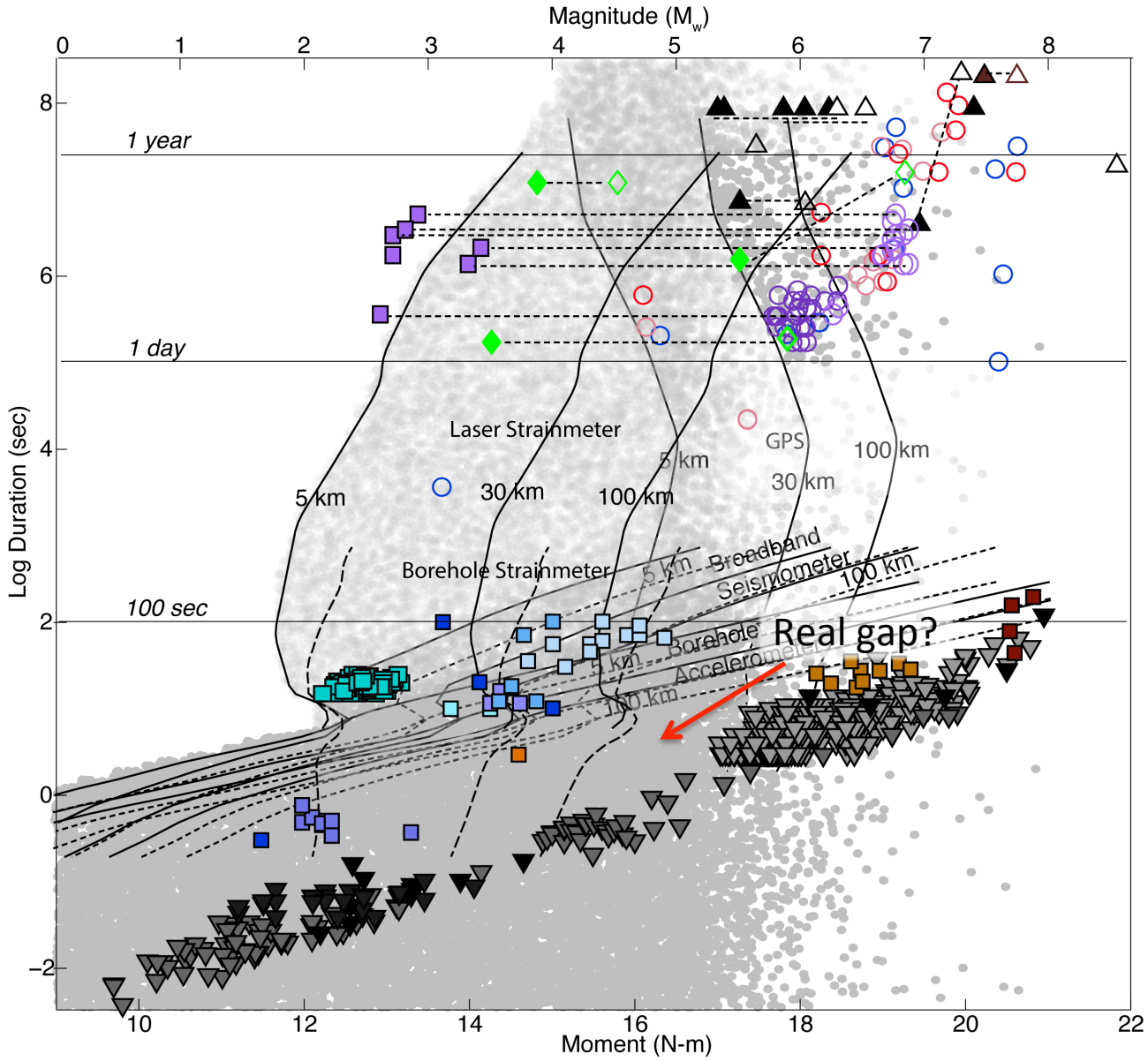


Seismic Detection Thresholds.

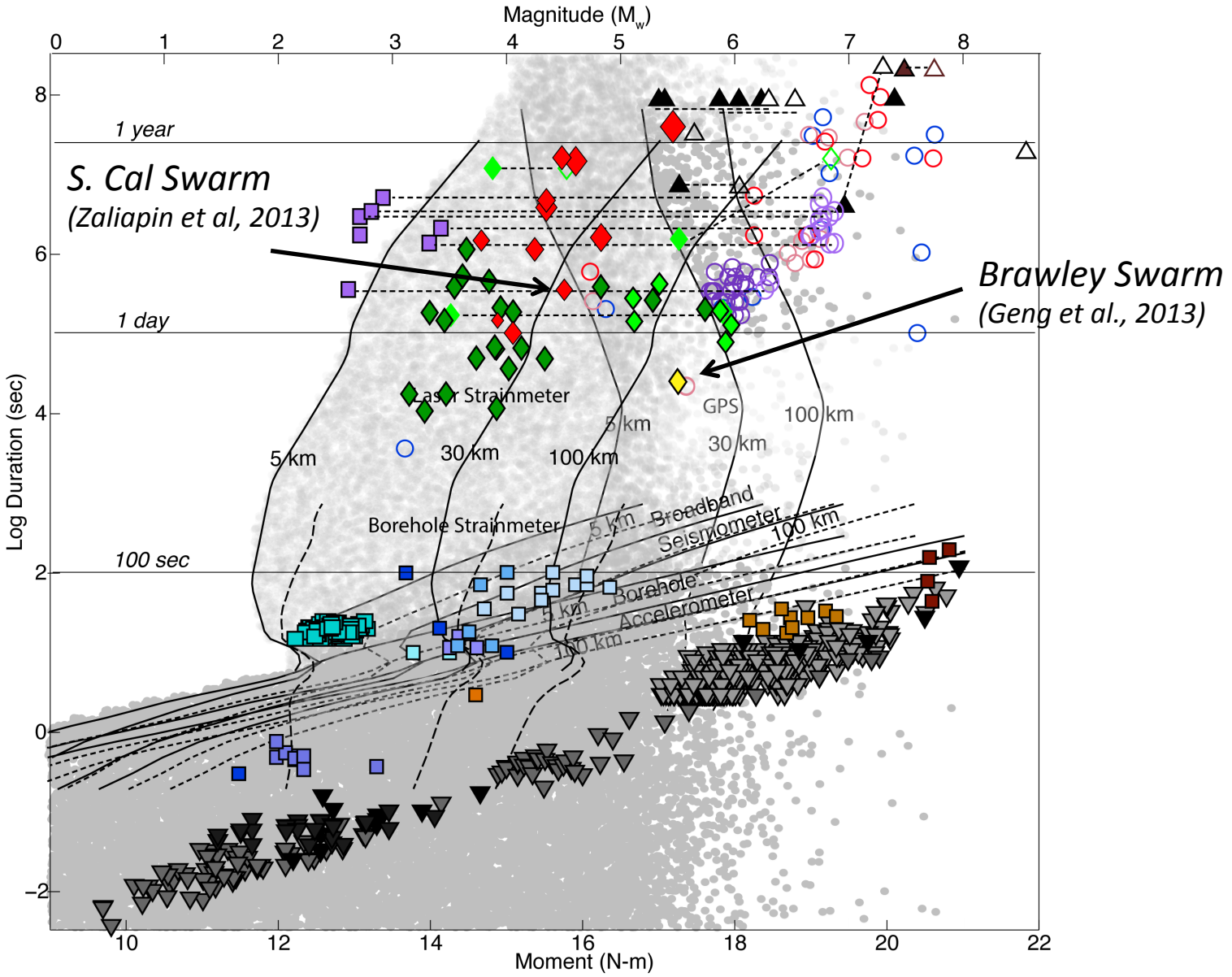


Stacking improves detection.

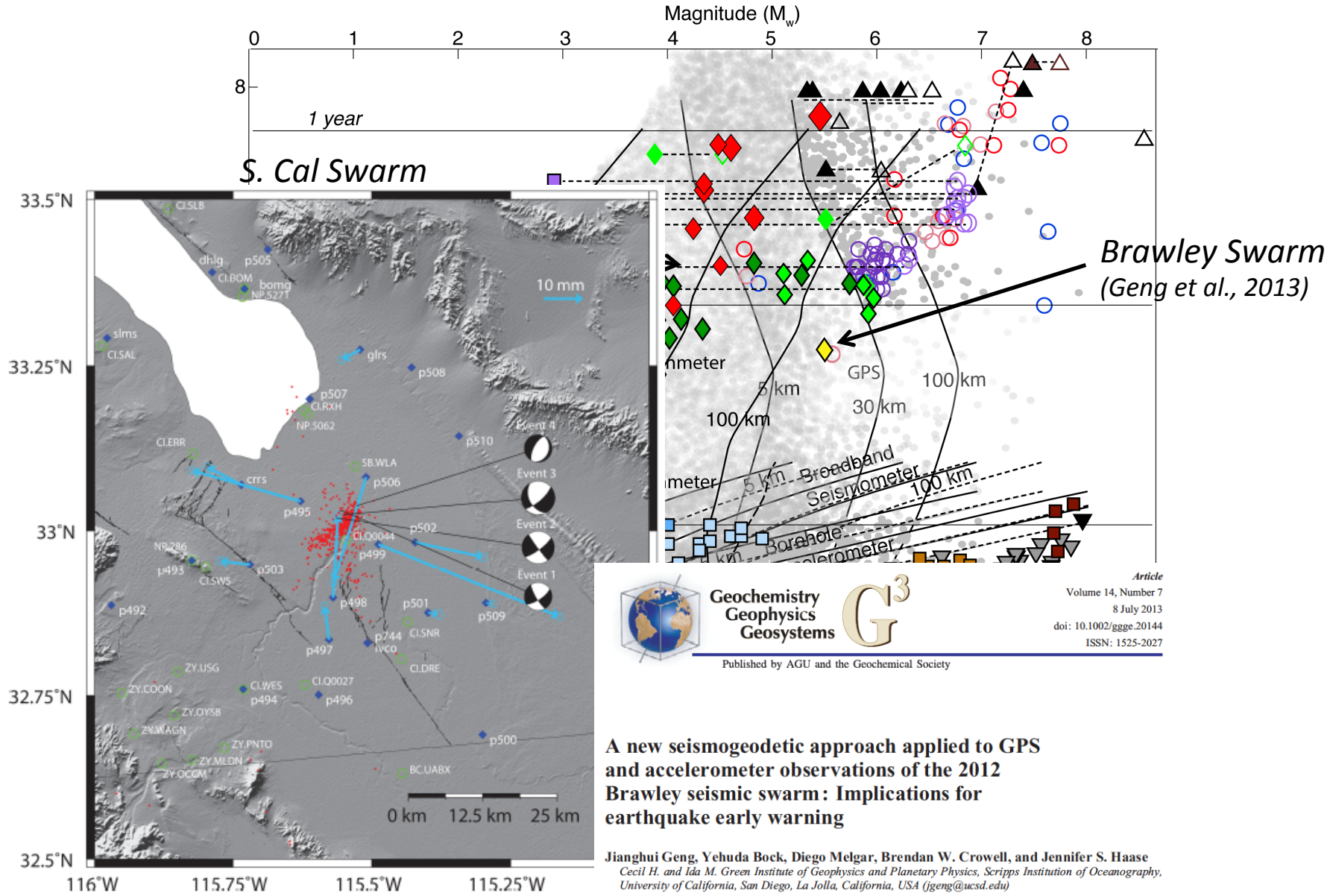
PBO strainmeter data promising gap fillers?



Exploration of high-rate data potential most likely fruitful for swarms (proxies for shallow slow slip).



Exploring high-rate GPS: the Brawley swarm.



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A new seismogeodetic approach applied to GPS and accelerometer observations of the 2012 Brawley seismic swarm: Implications for earthquake early warning

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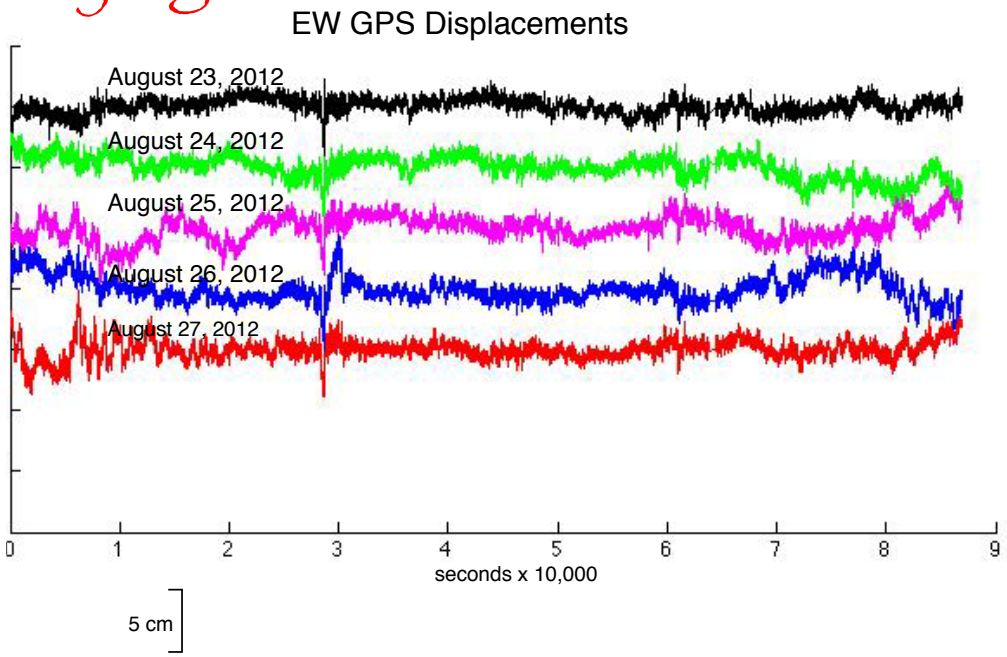
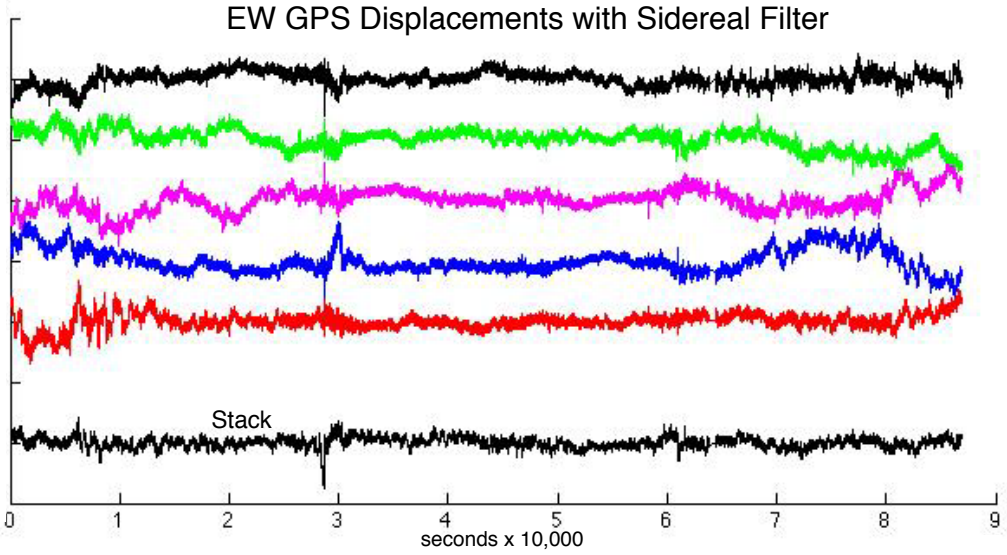
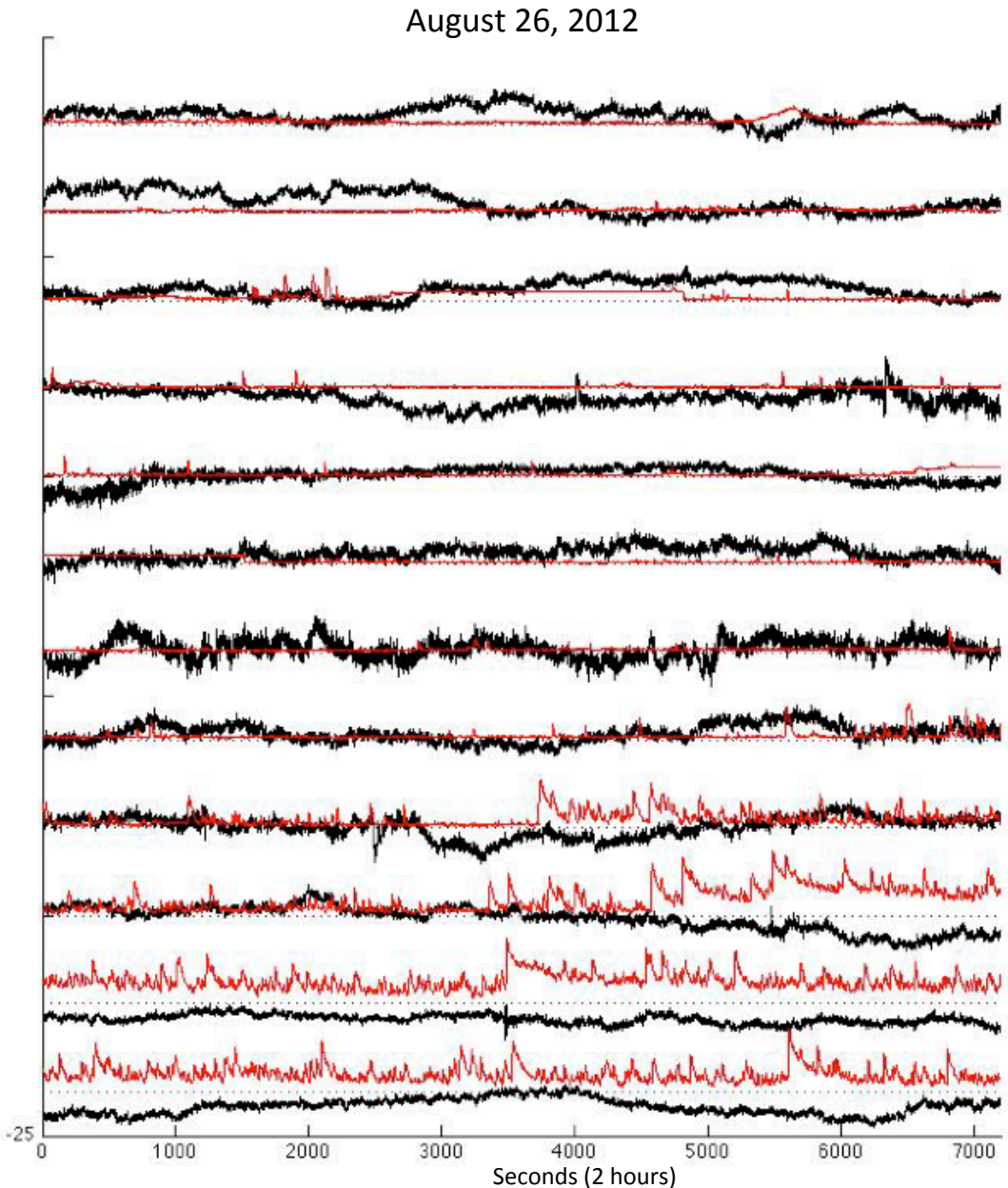
The best available 1-Hz GPS data (station P506) reveal no unambiguous Earthly signals…



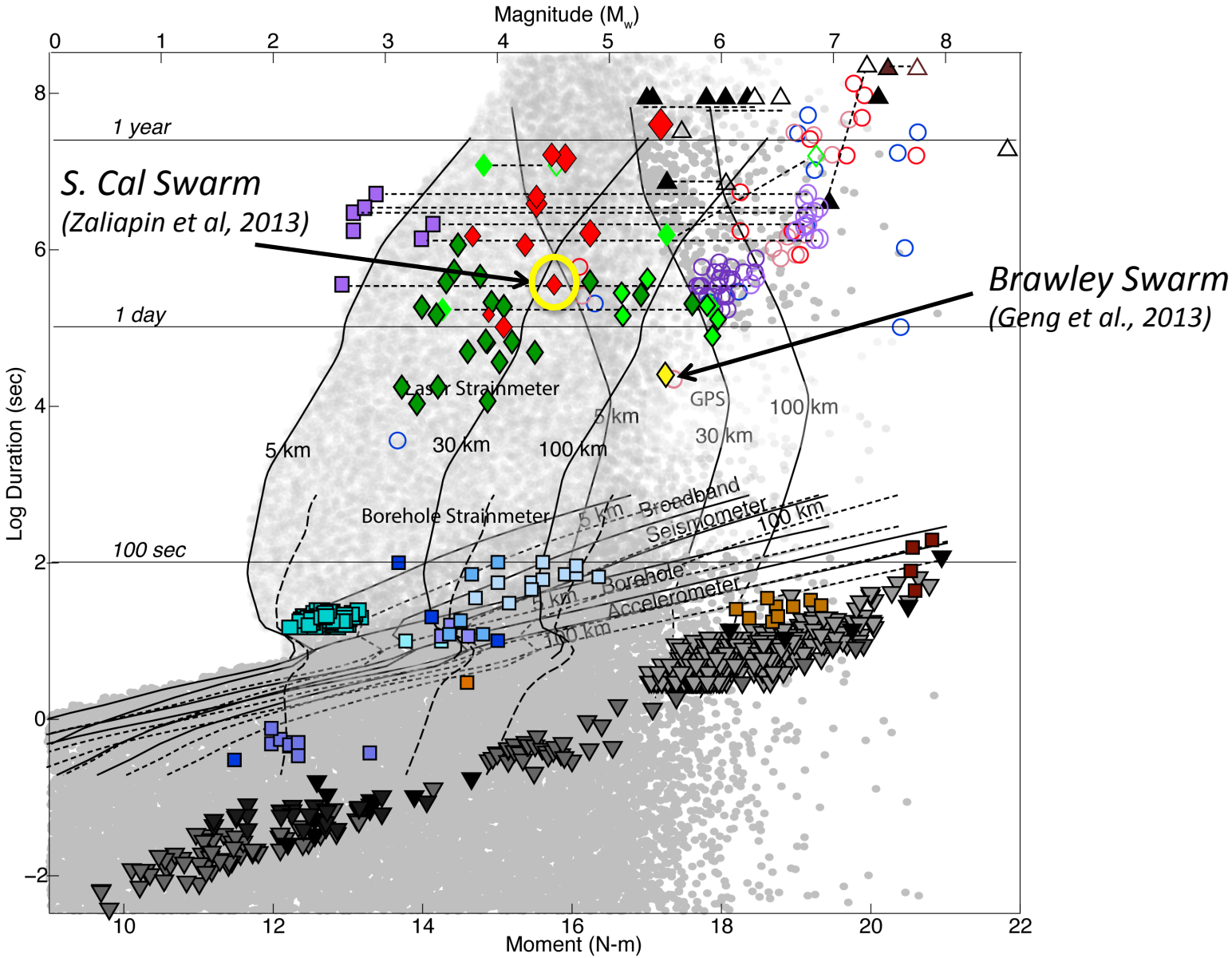


Change in high-passed accelerometer envelopes has no correlative in 1-Hz GPS displacements

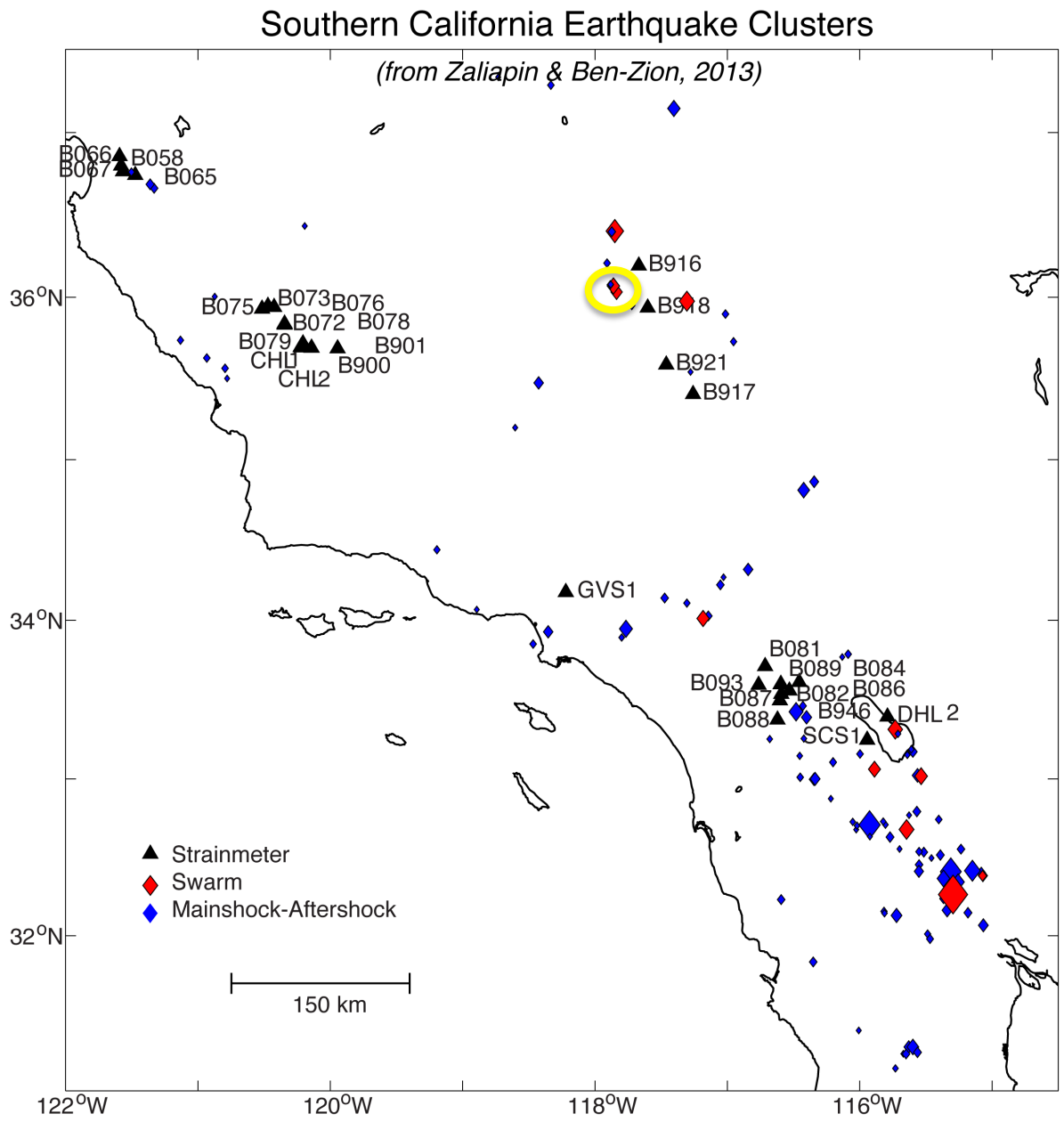


It takes a network…

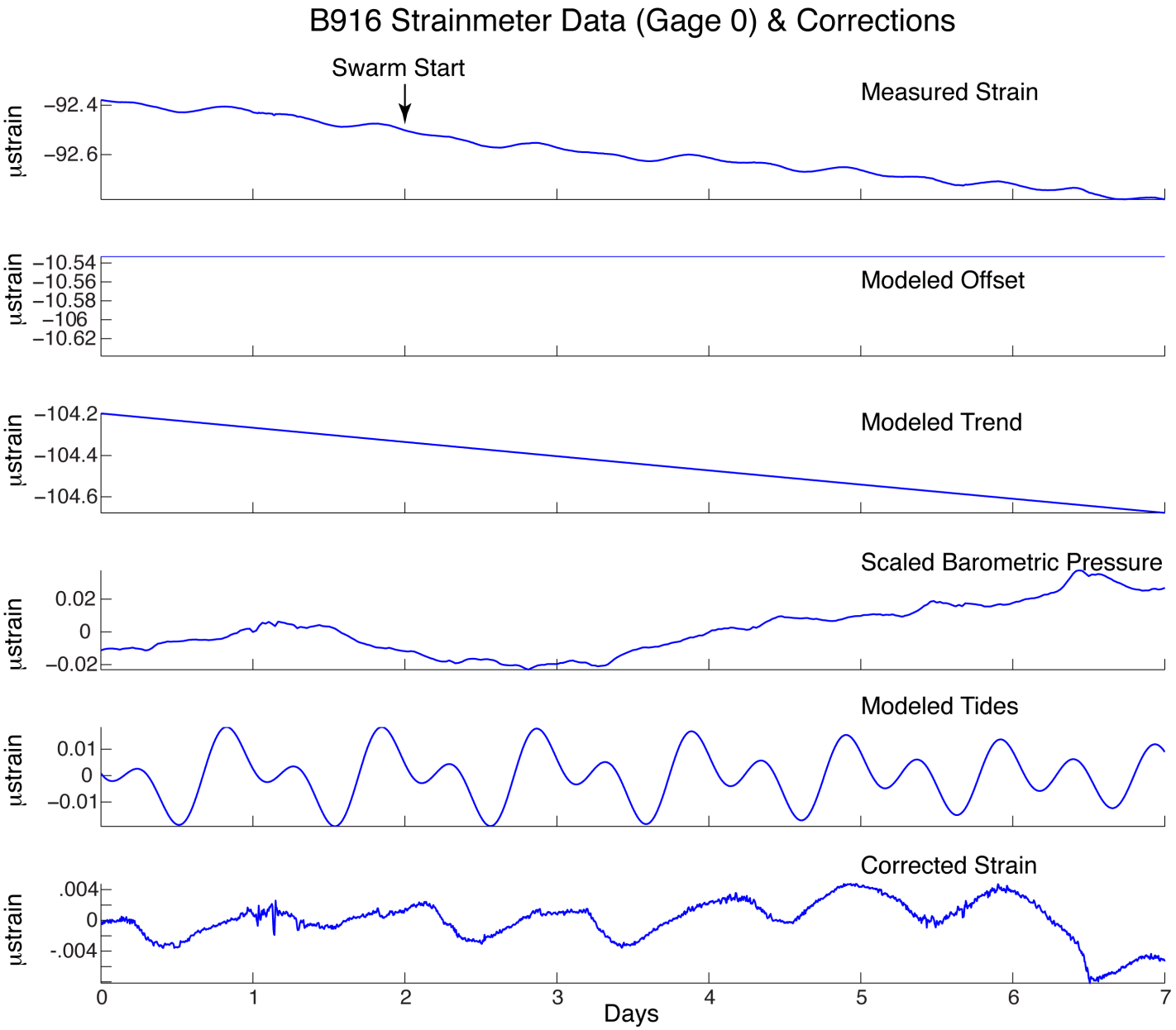
Exploring 20-Hz strainmeter data: Southern California swarms.



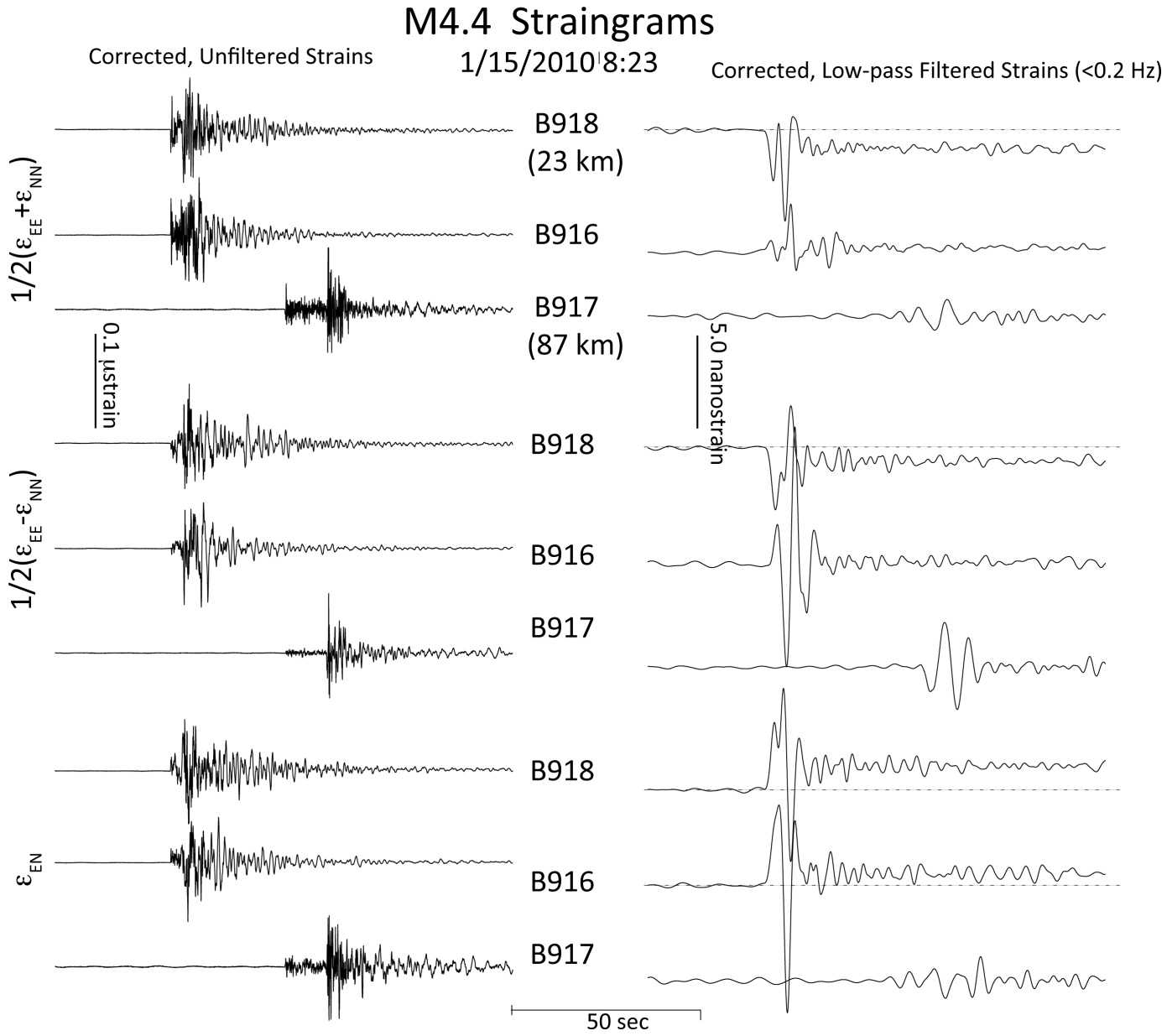
Clustered strainmeters help discriminate Earthly signals?



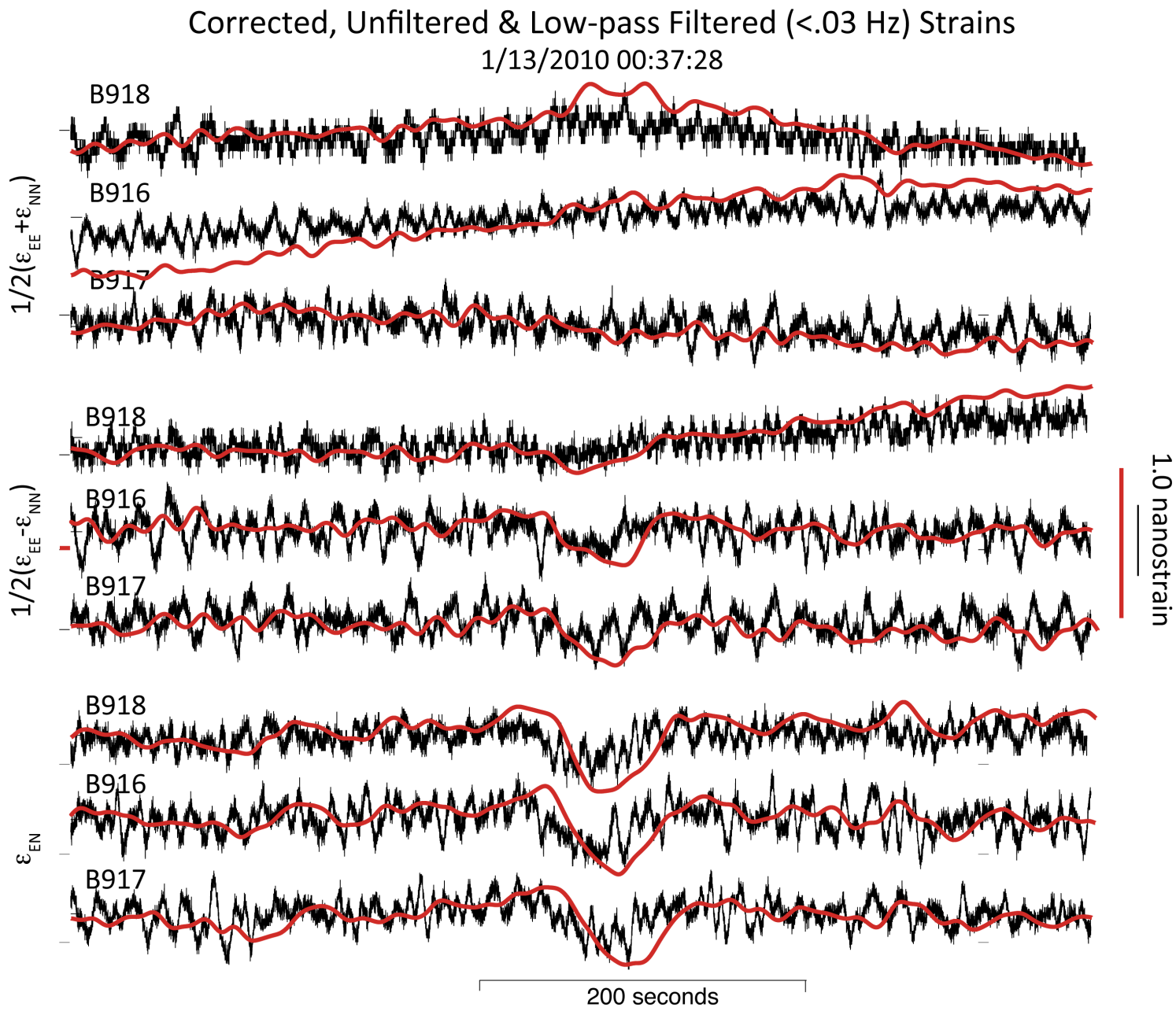
Low detection threshold = high deterministic noise levels (5 min data)



The complete earthquake deformation field for small earthquakes (20 Hz data)!



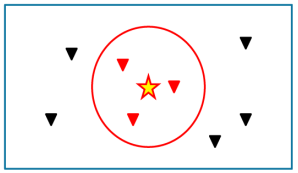
Short duration, aseismic transient deformations?



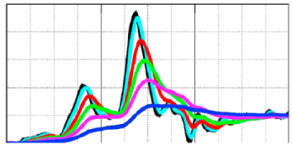
Exploring use of high-rate data for earthquake monitoring; application of near real-time, 1 Hz GPS data to early warning.

Hypocenter
Origin time

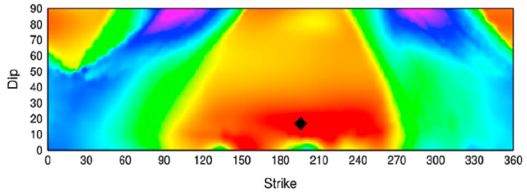
Select stations in P-wave range



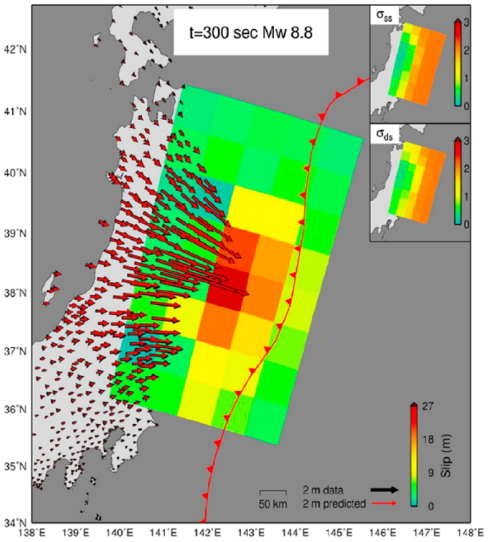
Estimate quasi-static offsets



Search over strike and dip



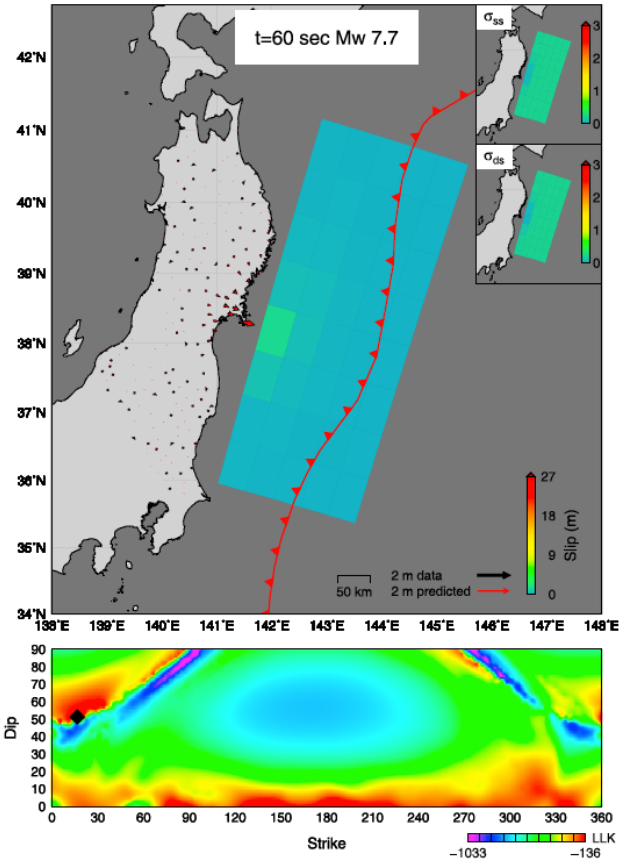
Report Mw and slip with uncertainties



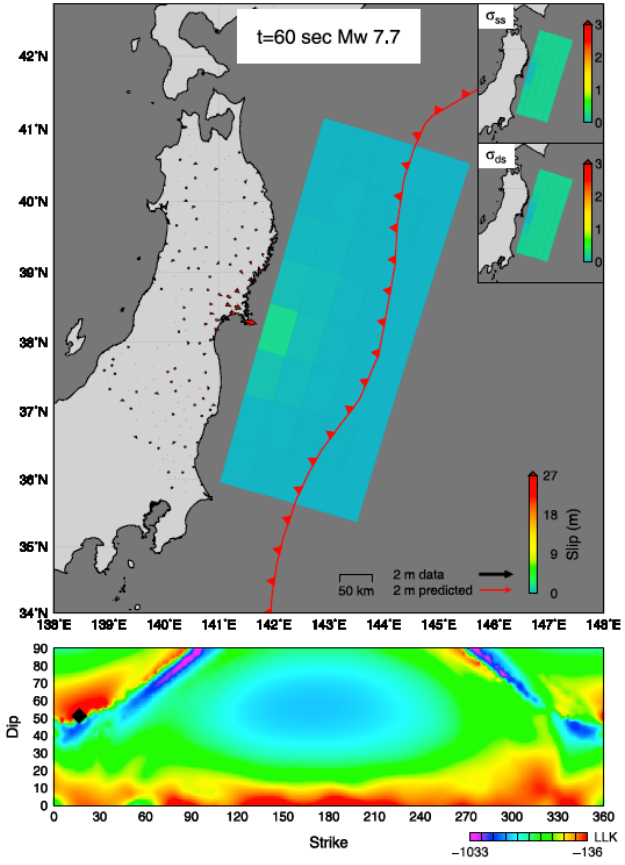
Repeat at next second

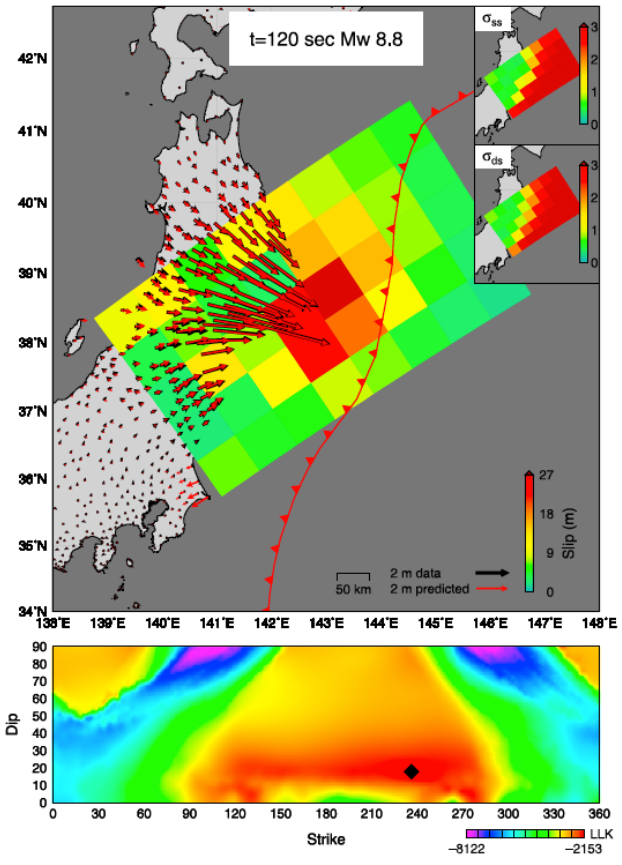
Minson et al., 2014

Tohoku example: after 60 sec fault geometry poorly resolved & rupture (moment) is still growing.

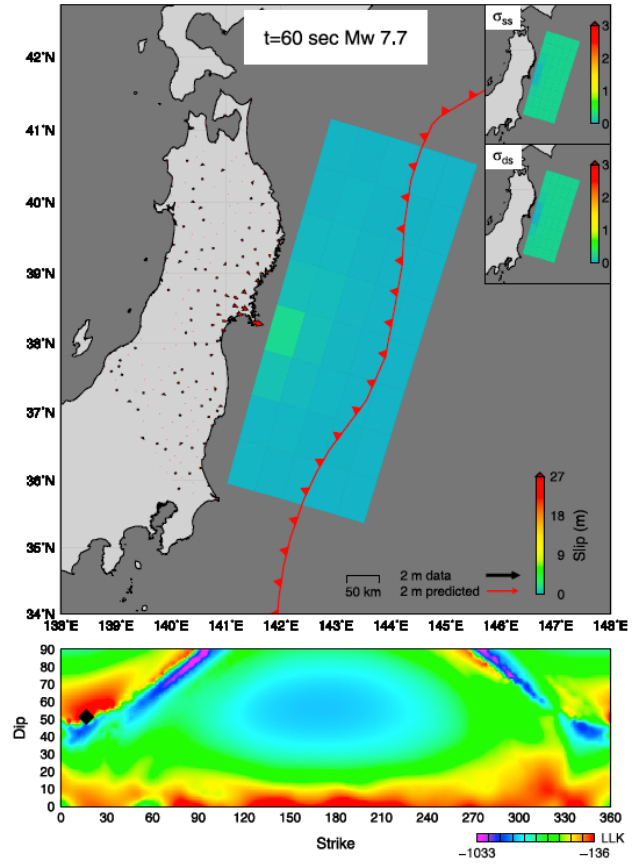


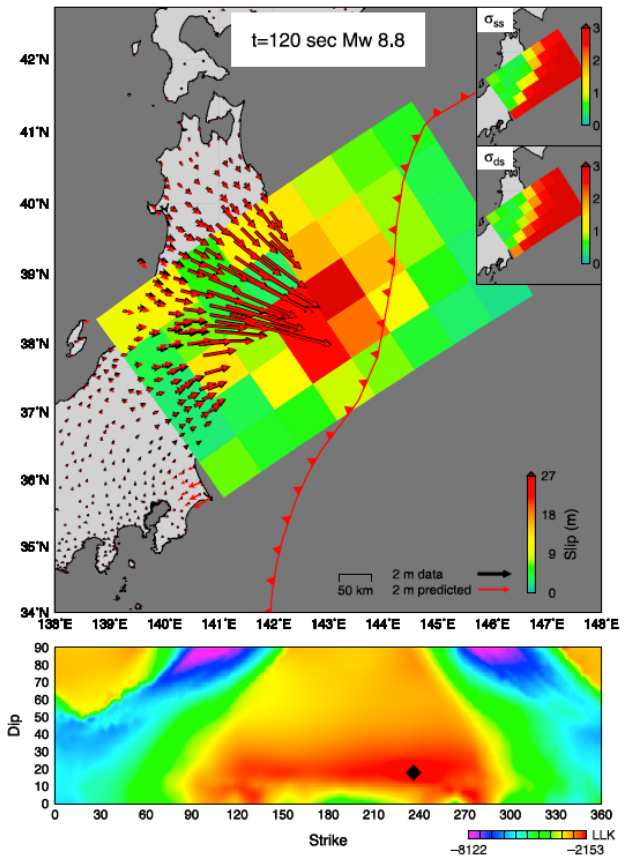
Tohoku example: after 120 sec fault geometry & slip still varying, but magnitude robust.

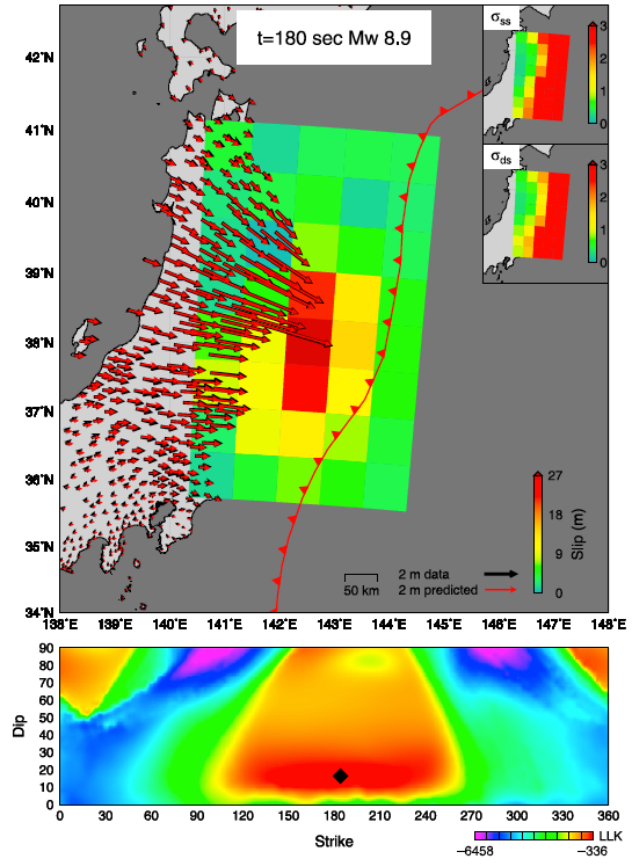




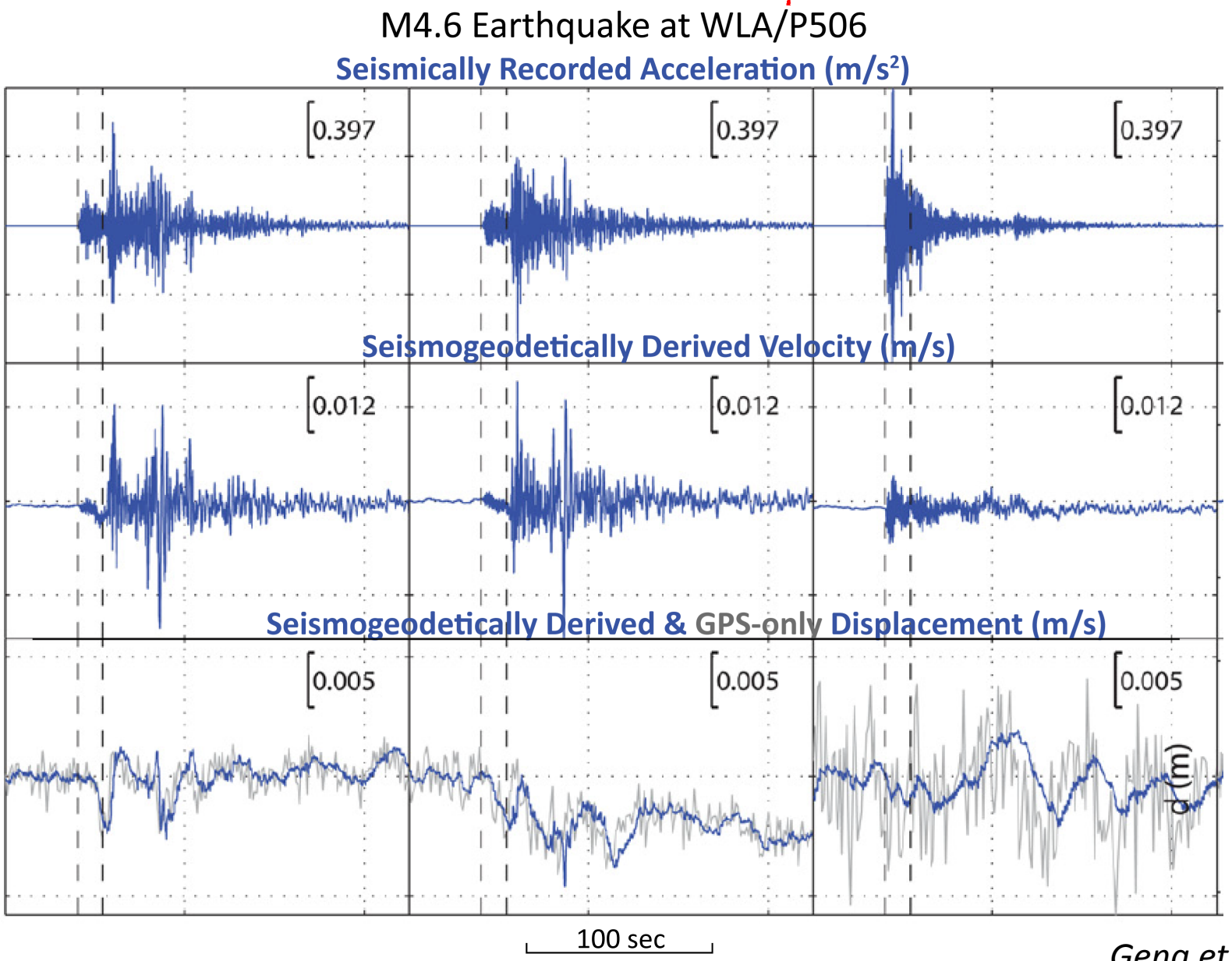
Tohoku example: after 180 sec fault geometry, slip, & magnitude are robust.







'Seismogeodetic' velocities & displacements derived from near real-time accelerometer & GPS data preserves best of both.



Geng et al., 2013

Conclusions

Continued exploration of the high-rate geodetic frontier will surely lead to exciting discoveries.

The benefits of making seismic data easy to access and use has been one of the great lessons from IRIS; this lesson should be applied to geodetic data too.

Thank you!