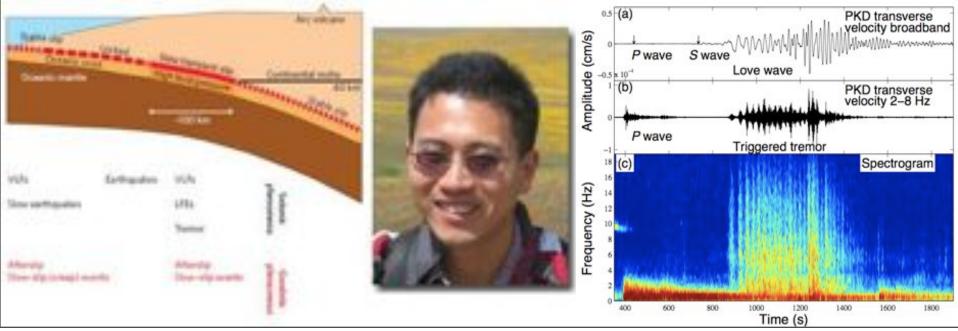
Tremor, Triggering and Slow-Slip Phenomena

Zhigang Peng School of Earth and Atmospheric Sciences

Georgia Institute of Technology



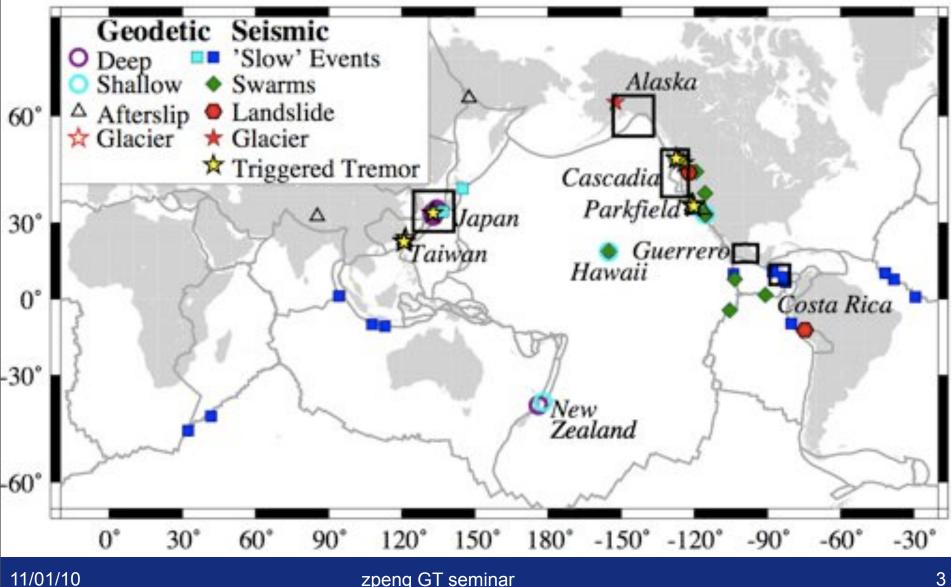
Outline

- Remote triggering of tremor around the San Andreas Fault (Peng et al., 2008, 2009, 2010; Shelly et al., 2010)
- Remote triggering of tremor beneath the central Range in Taiwan (Peng and Chao, 2008; Tang et al., 2010; Chao et al., submitted)

Acknowledgements

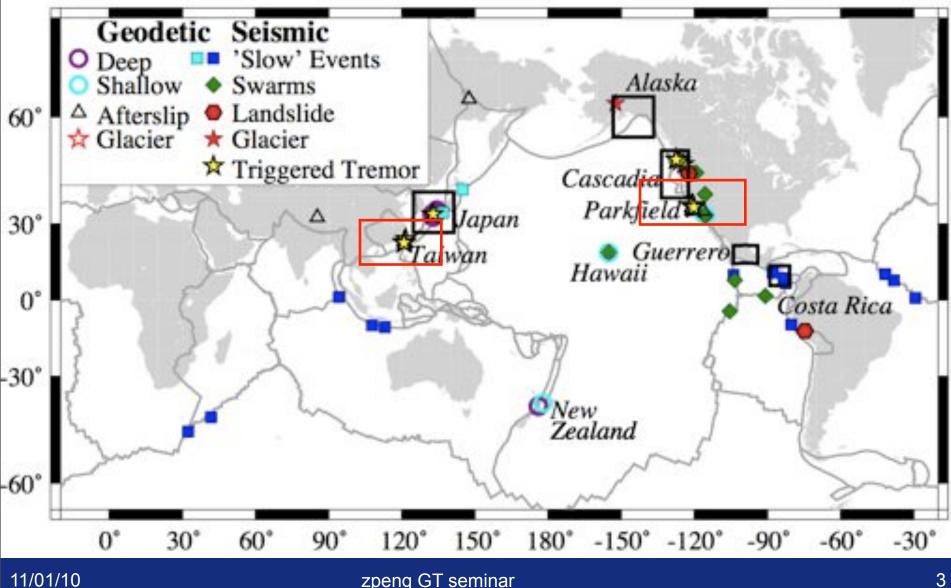
The work is supported by the NSF's Geophysics and CAREER programs.

Maps showing where tremor and slow-slip events have been observed (Peng and Gomberg, NGEO, 2010)



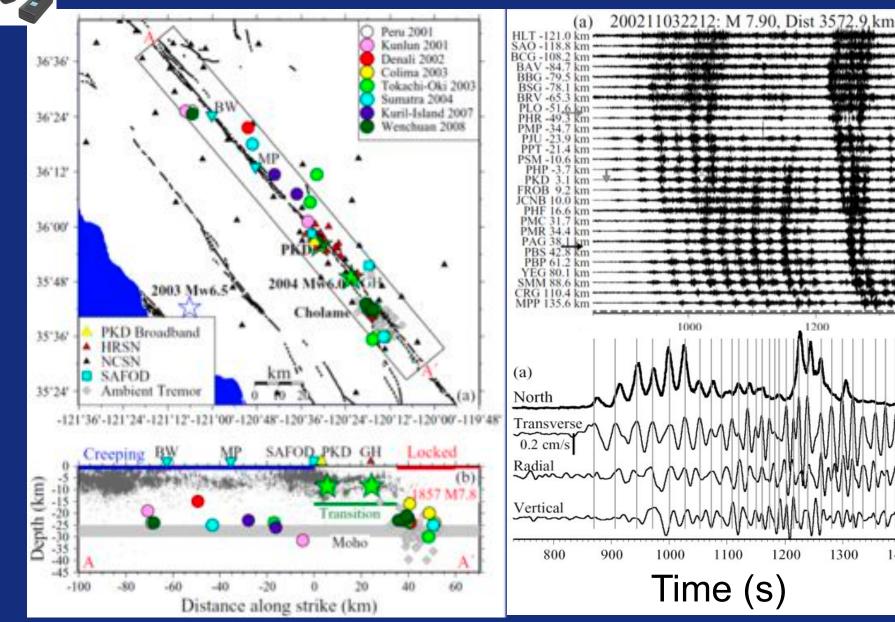
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Maps showing where tremor and slow-slip events have been observed (Peng and Gomberg, NGEO, 2010)



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What we already knew about triggered tremor



11/01/10 Peng et al. (JGR, 2009) zpeng GT seminar

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1400

1200

Peng et al. (GRL, 2008)

1300

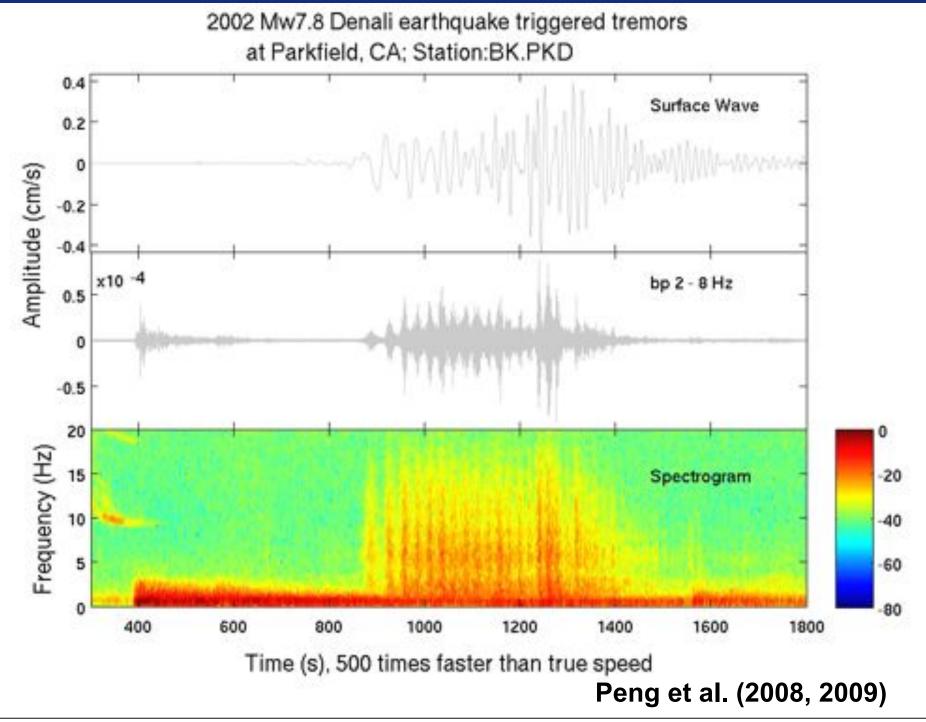
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Peng et al. (2008, 2009)



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What we don't know about triggered tremor

- Does triggered tremor consist of many low-frequency earthquakes (LFEs) like ambient tremor (Beroza and Ide, Science, 2009)?
- Does triggered tremor occur at the same places (depth) as the ambient tremor, with similar mechanism, except that the driving forces are different (Beroza and Ide, Science, 2009)?
- Can the triggered tremor be explained by the 'clockadvanced' model (Gomberg, JGR, 2010)?
- What are the relationship between 'triggered' tremor and slow-slip events (Smith and Gomberg, JGR, 2009)?



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Magnitude 8.8 OFFSHORE MAULE, CHILE Saturday, February 27, 2010 at 06:34:17 UTC February 27, 2010 Chile Earthquake (M=8.8) Global Displacement Wavefield N-Stime pure properted by Richard Arter, New Me 148 140 ON COCC 21.20 degr 1:66 ä Ï 2,44.8 t can of vertical ground displacement Segument Time from Earthquake (minutes

Global record section

The global surface wave displacements around the globe are shown. The closest shown station is in Argentina and the most distant one is in Mongolia. A 6.9 aftershock is visible for comparative scale near 90 minutes after the mainshock.

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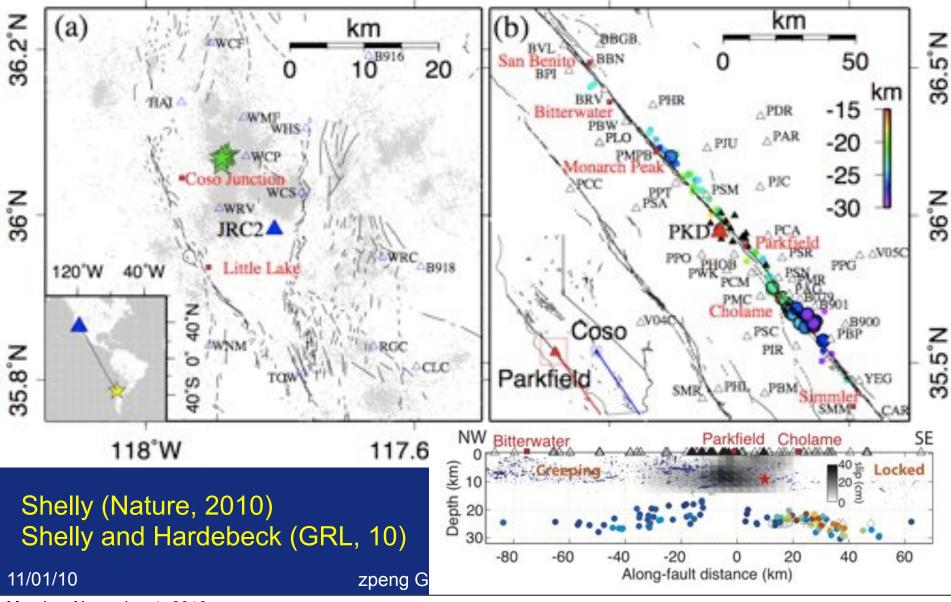
Global record section

The global surface wave displacements around the globe are shown. The closest shown station is in Argentina and the most distant one is in Mongolia. A 6.9 aftershock is visible for comparative scale near 90 minutes after the mainshock.

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Remotely triggered microearthquakes and tremor in Central California following the 2010 Mw8.8 Chile Earthquake (Peng/ Hill/Shelly/Aiken, GRL, in review)

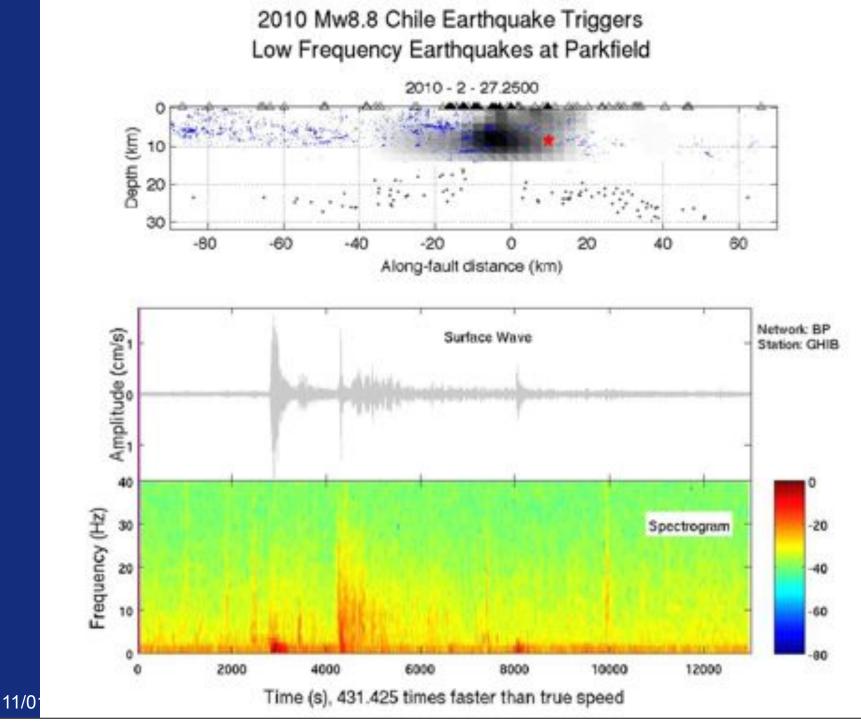


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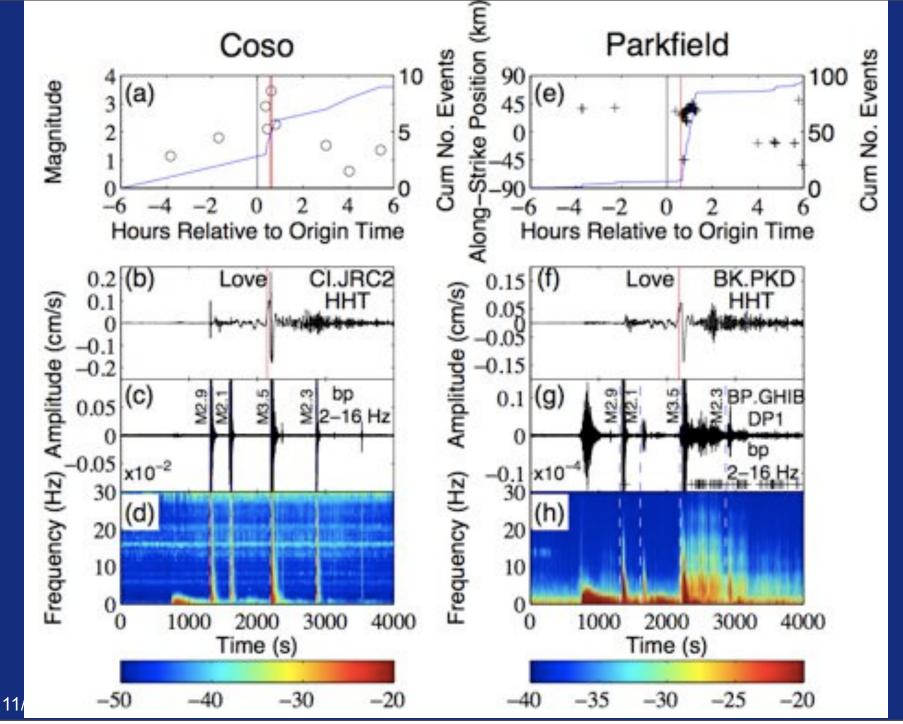
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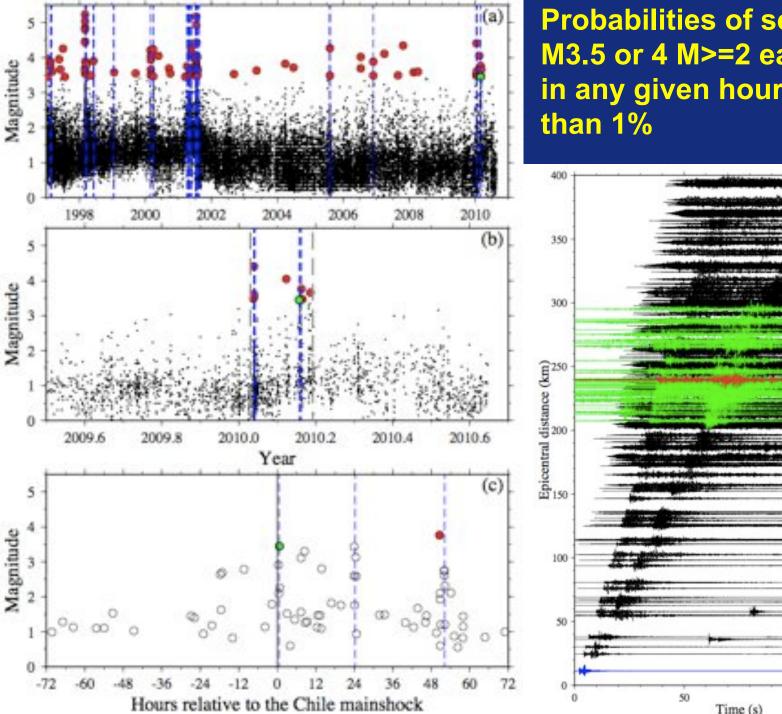
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Probabilities of seeing a M3.5 or 4 M>=2 earthquakes in any given hour is less

KD

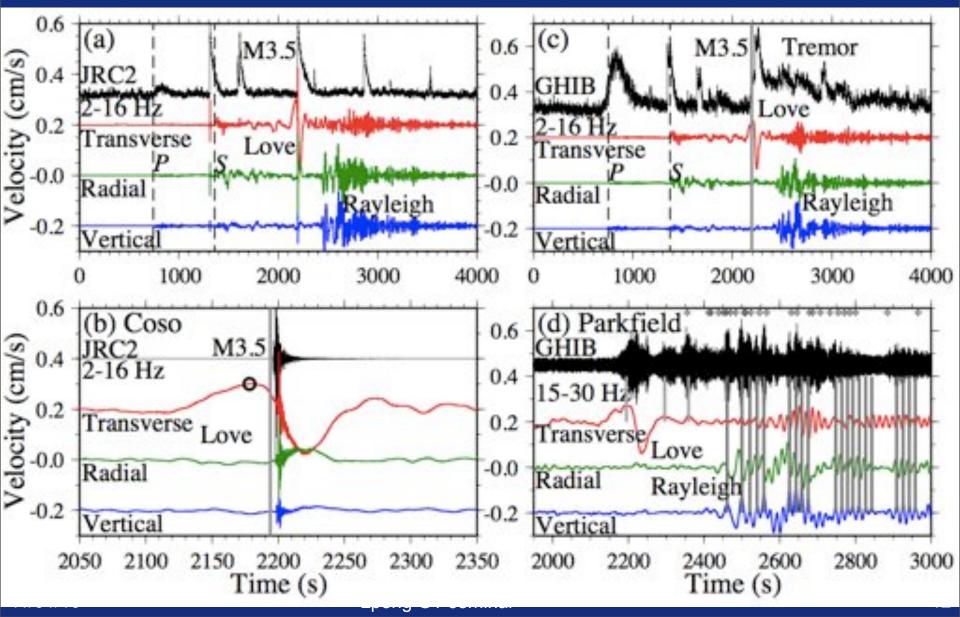
JRC2

150

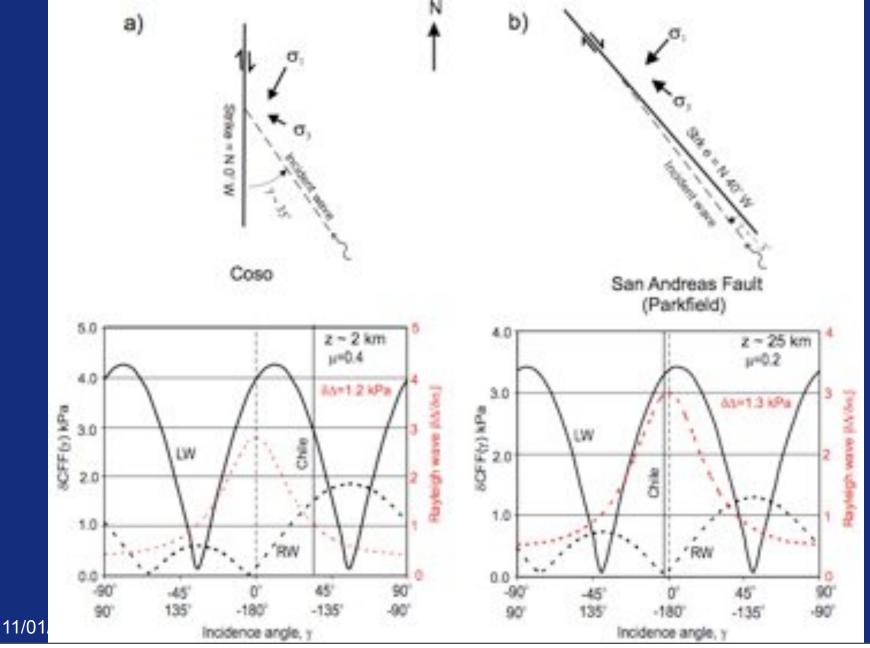
100

Time (s)

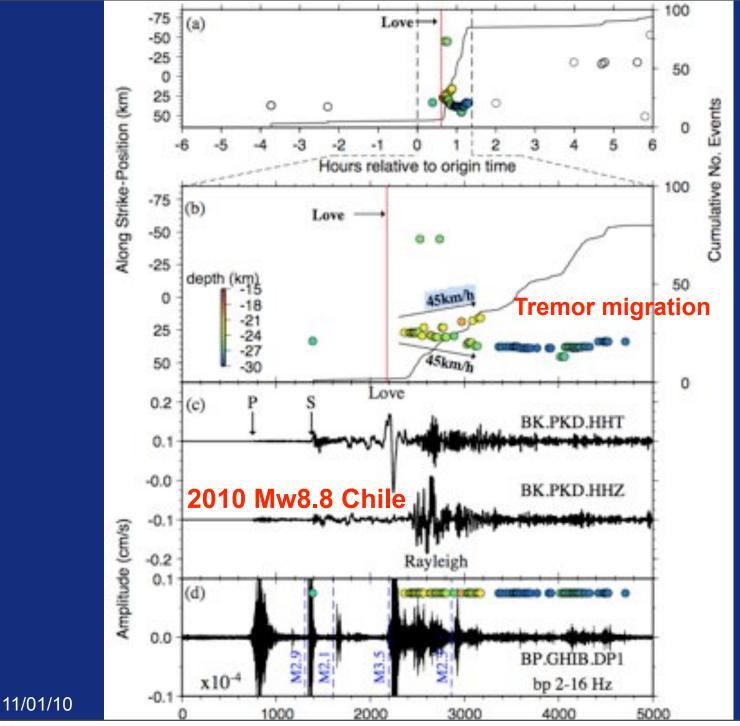
Comparisons between the surface waves and triggered activity



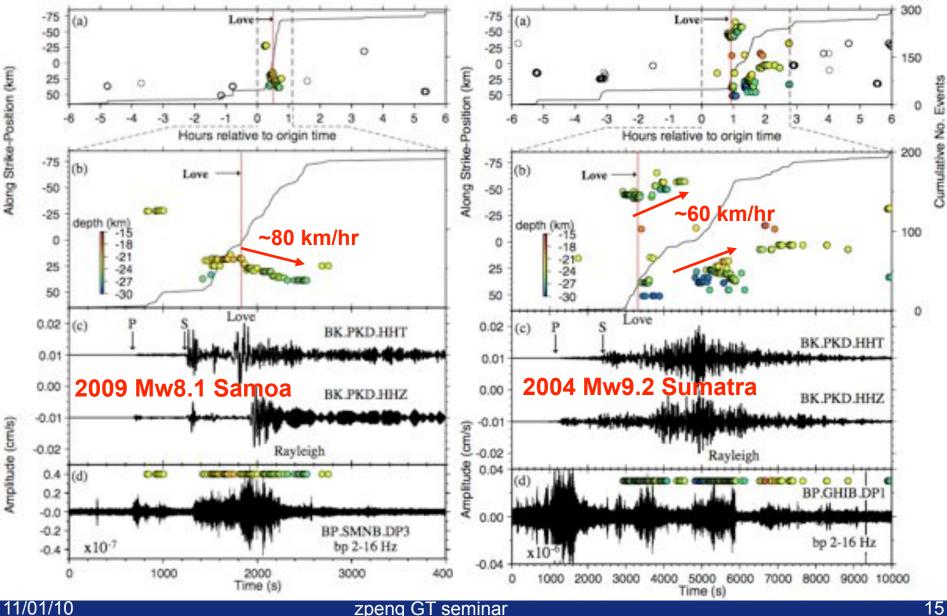
Triggering potential for Love and Rayleigh waves from Coulomb failure criterion (Hill, BSSA, 2008, 2010)



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Triggered tremor migration triggered by the 2009 Mw8.1 Samoa and 2004 Mw9.2 Sumatra EQs (Shelly et al., submitted)

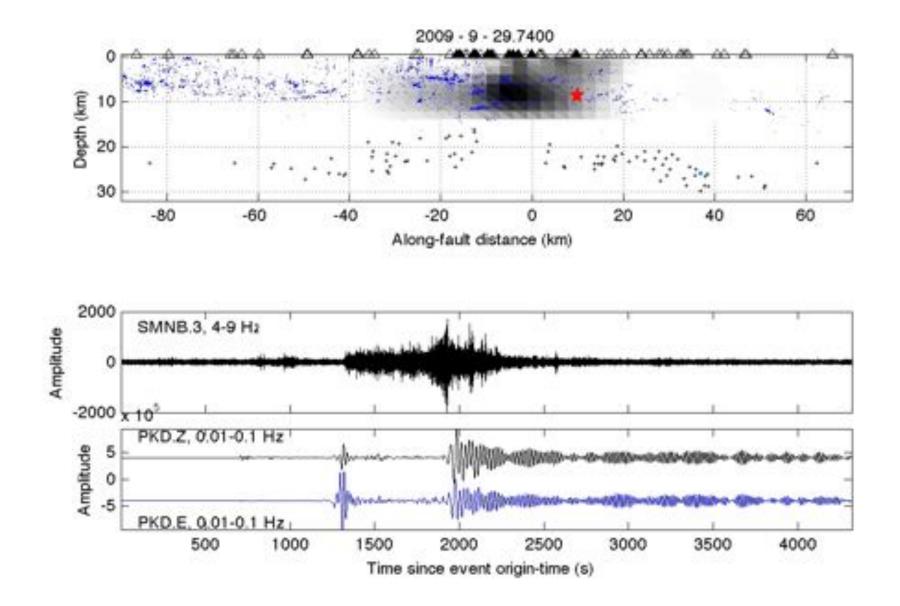


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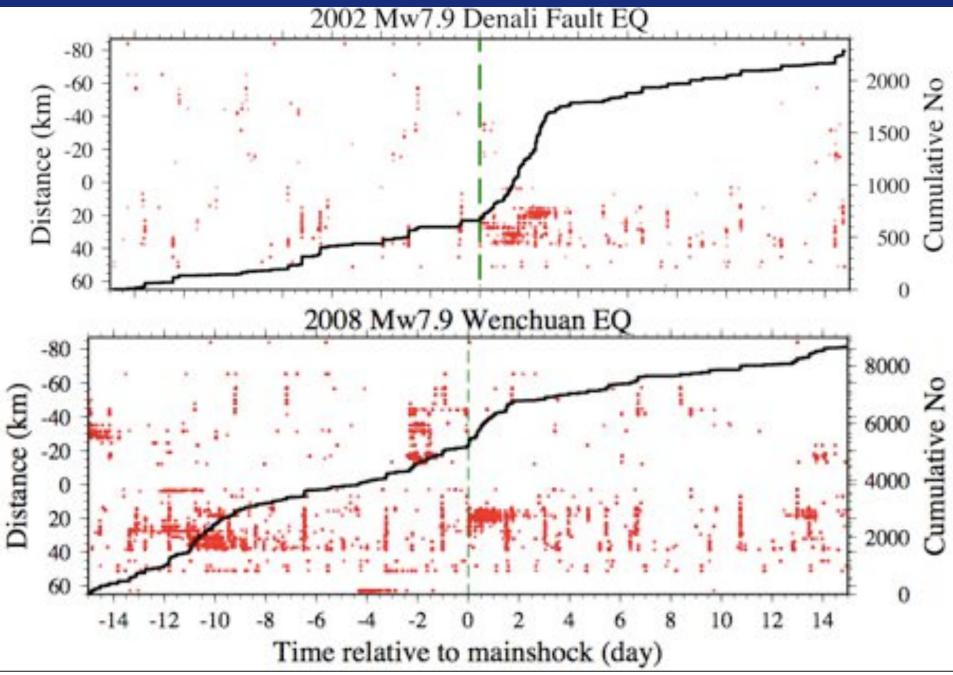
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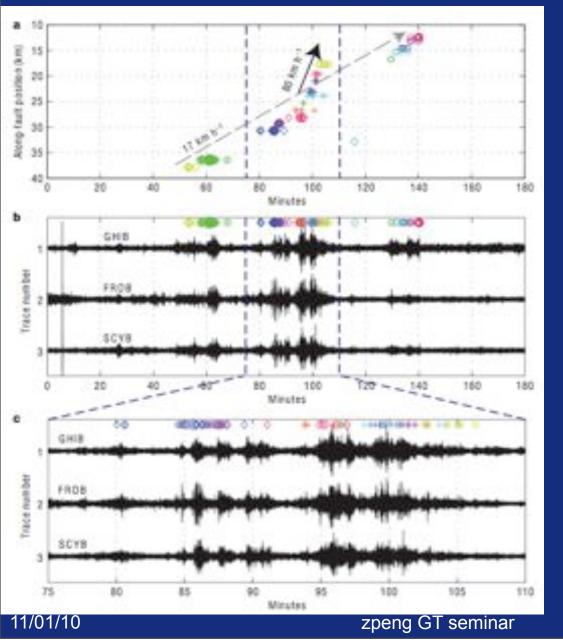
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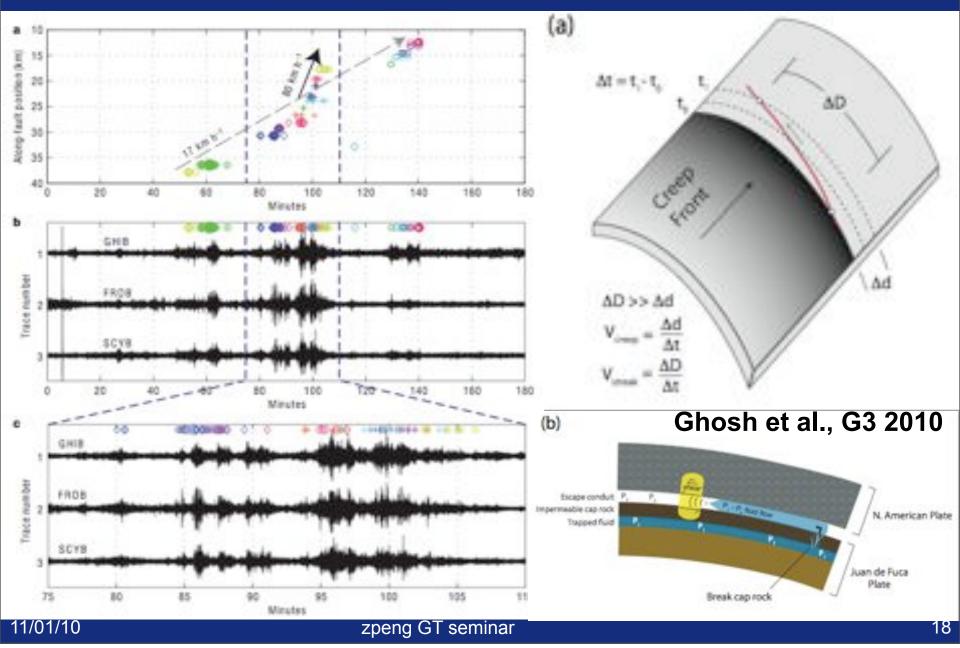
Delayed triggering of tremor after surface waves



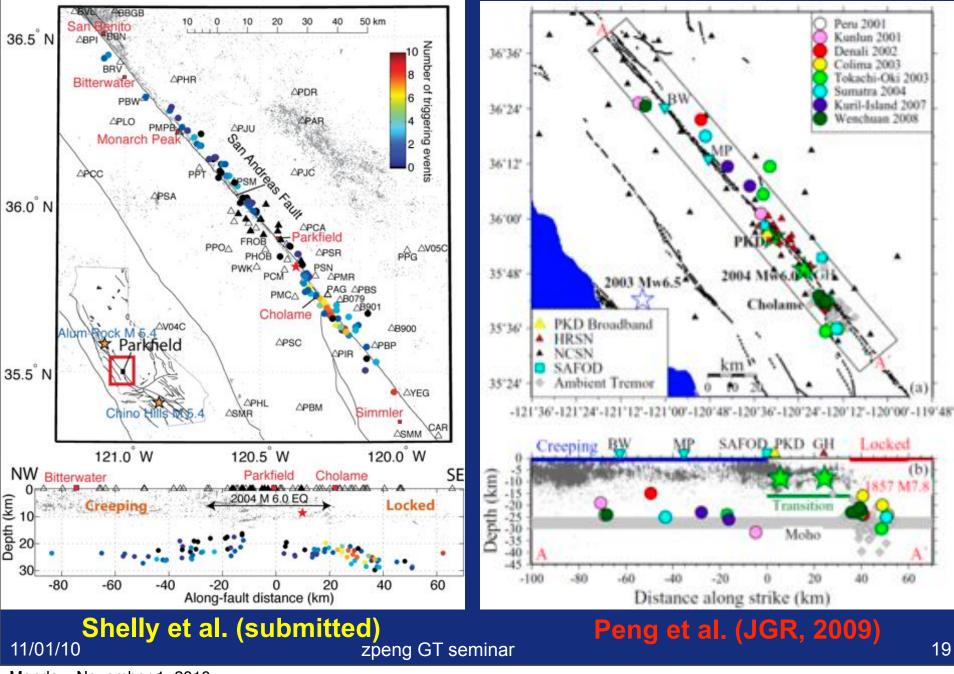
Ambient Tremor migration - deep slow-slip



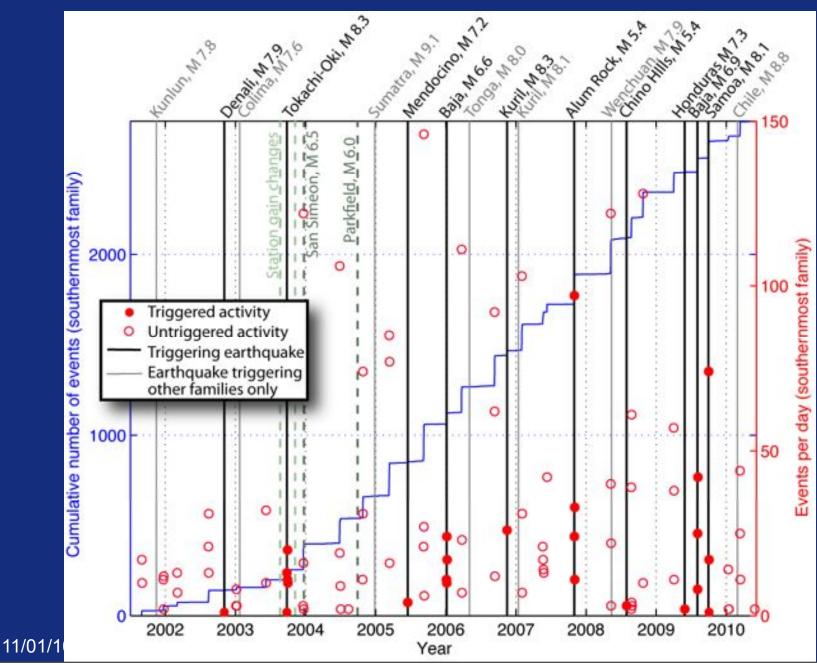
Ambient Tremor migration - deep slow-slip



Most triggered low-frequency eqs were at Cholame



Triggering activity in southernmost family





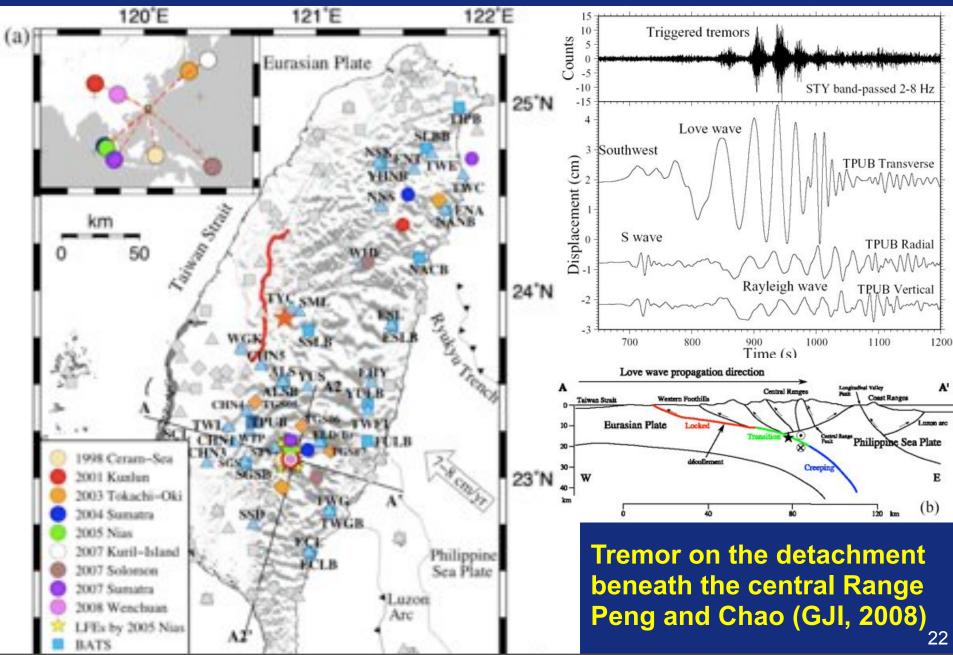




Summary I

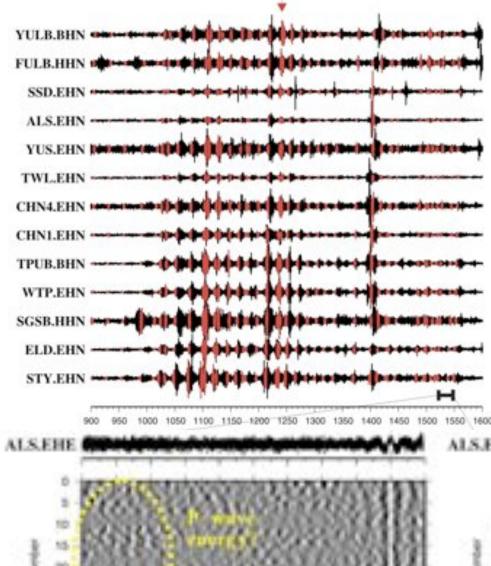
- Triggered and ambient tremor shares common sources (consisting of many low-frequency earthquakes) and a common physical mechanisms.
- Triggered earthquakes and tremor could be explained by the simple Coulomb failure criterion, although their timing with the surface waves are different.
- Some triggered tremor sequences show clear along-strike migrations, likely reflecting small triggered deep creep events.
- Some sequences have elevated tremor activities lasting a few days, similar to triggered earthquakes, perhaps
 ^{11/01/10} Indicating somewhat a grand langer duration) slow-slip²¹
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Triggered tremor in Taiwan

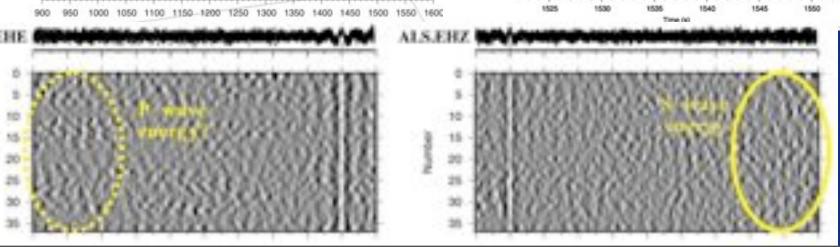


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Triggered LFEs (Tang et al., GRL, 2010)

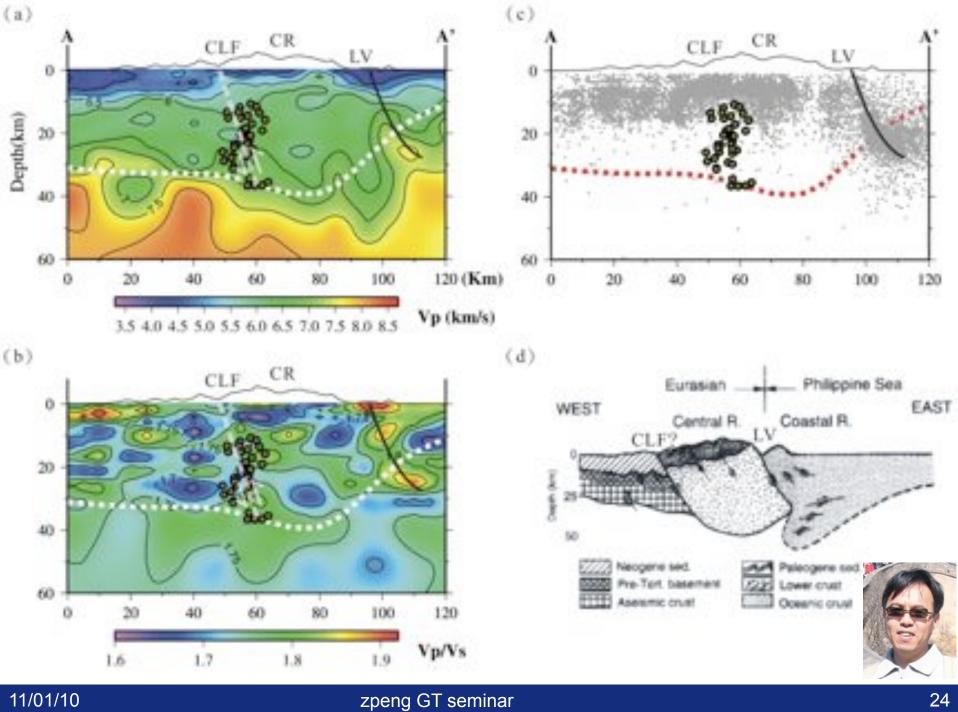


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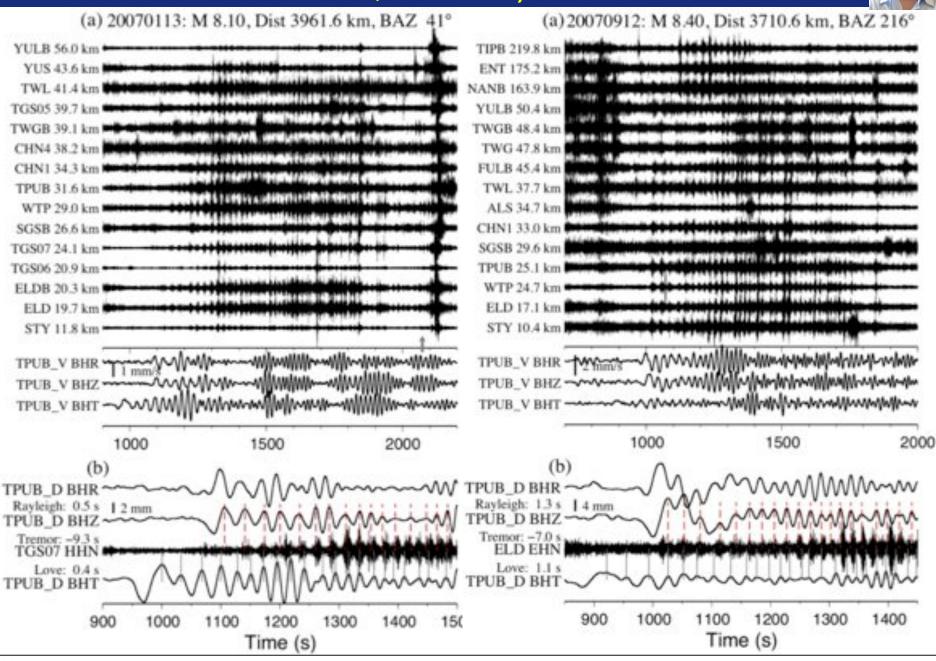


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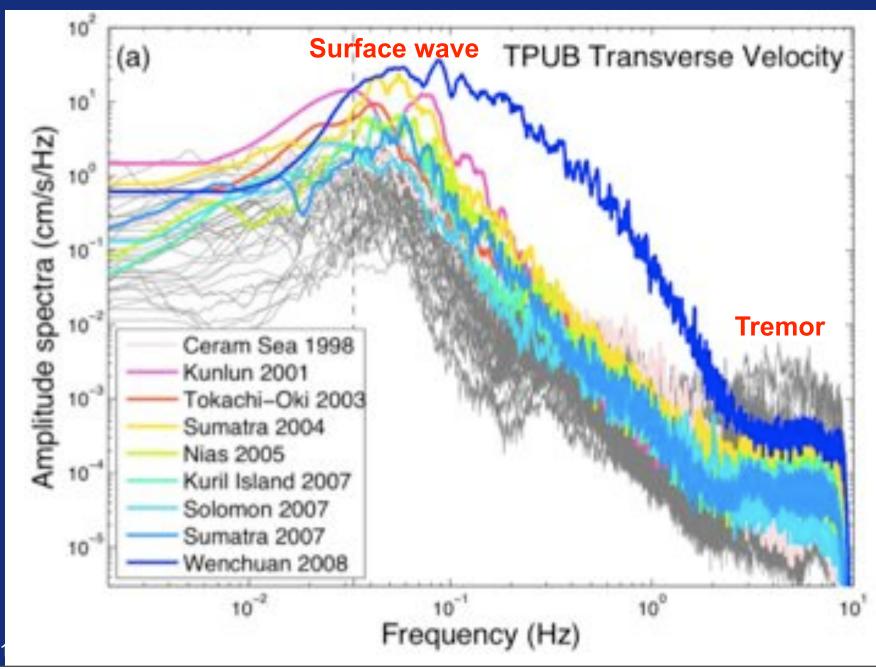
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More triggered tremor observations in Taiwan (Chao et al., GJI, submitted)

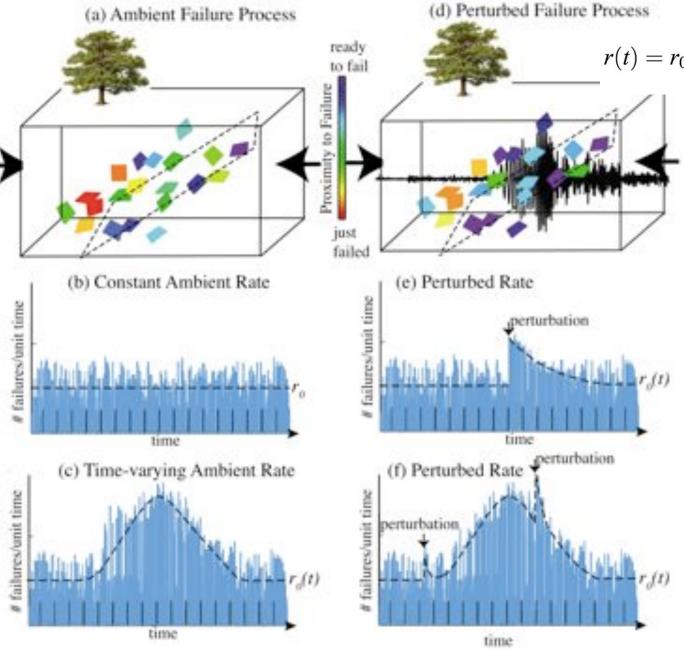


Frequency dependence of triggering potential



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Cartoon of tremor and the clock-advanced model (Gomberg, JGR, 2010)



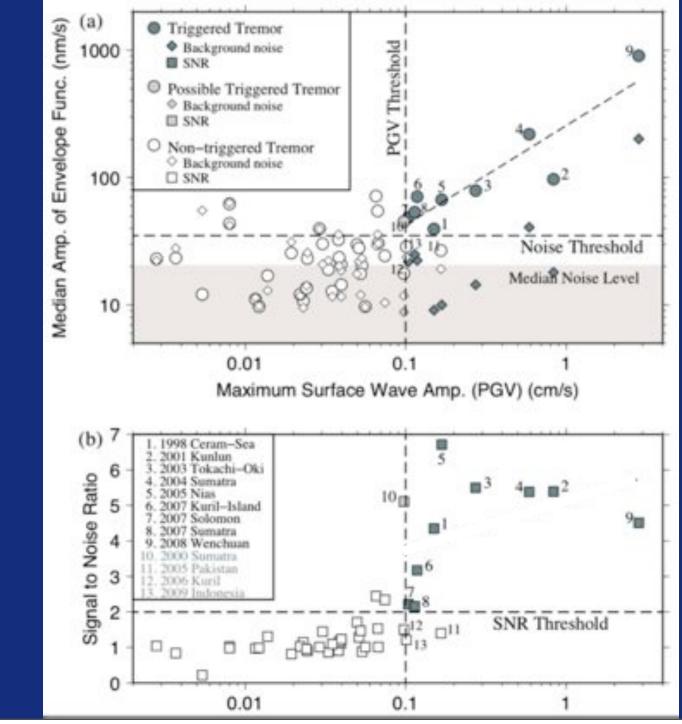
$$r = r_0(t - \Delta t) \times \left[1 - \frac{d\Delta t}{dT}(t)\right]^{-1}$$

A greater ambient rate would correspond to higher likelihood of triggering.

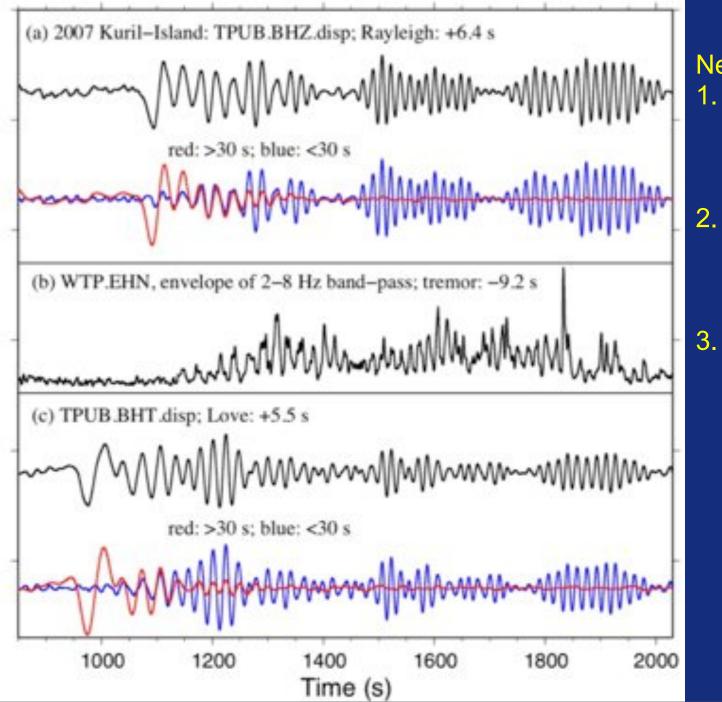
Larger triggering waves would result in larger triggered tremor signals.



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New observations:

- 1. Long-period Love waves did not trigger any tremor.
 - Tremor started 1-2 cycles after the Long-period Rayleigh waves. **Tremor continues** during the highfrequency (<30 s) surface waves, and the tremor amplitudes does not correlate well with the surface wave amplitudes.



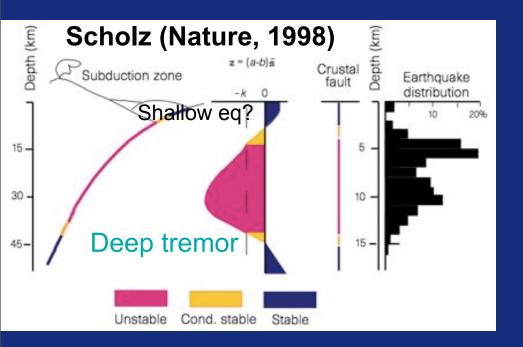
Summary II



Triggered tremor in Taiwan also appear to be consisted of many low-frequency earthquakes, and may occur on a more vertical dipping faults rather than the shallow detachment fault.

The triggering potential depends largely on the amplitude of the surface waves, and less on the incidence angle and the frequency content.

Surface waves with larger amplitudes appear 11/01/10 to trigger tremorgiwittle larger amplitude, 30 Monday, November 1, 2010



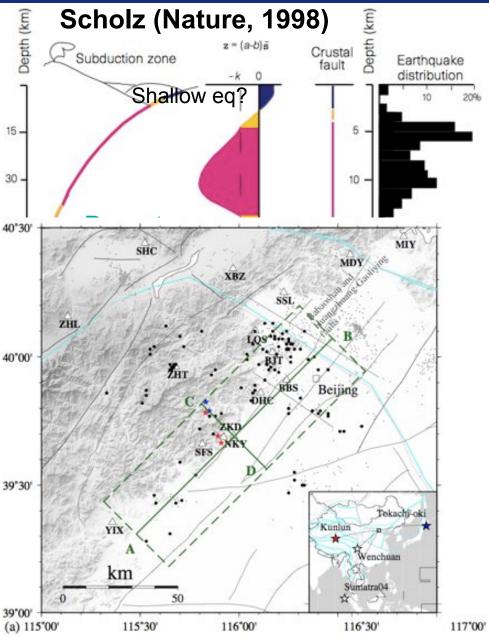
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Dynamic triggering of shallow earthquakes in Beijing (Wu et al., GJI, submitted)



Triggered seismicity are extremely shallow (<3 km) and do not correlate with background seismicity

Shallow creep observed at times

