Properties of Low-Frequency Earthquakes Triggered by Large Earthquakes in Southern Taiwan

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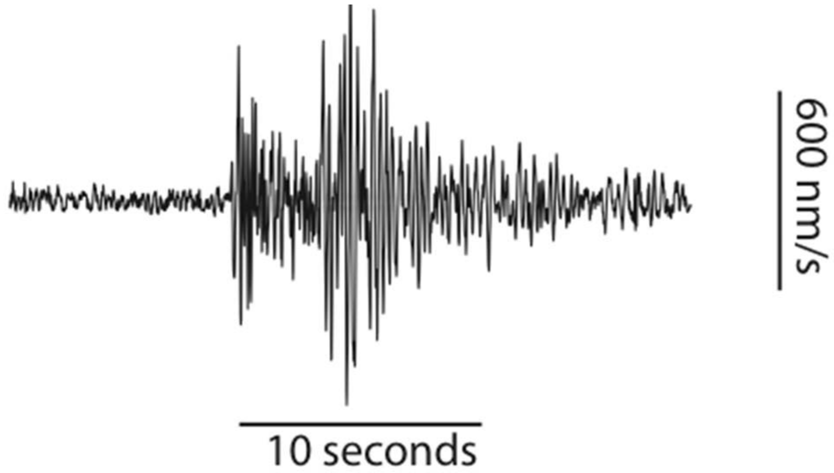
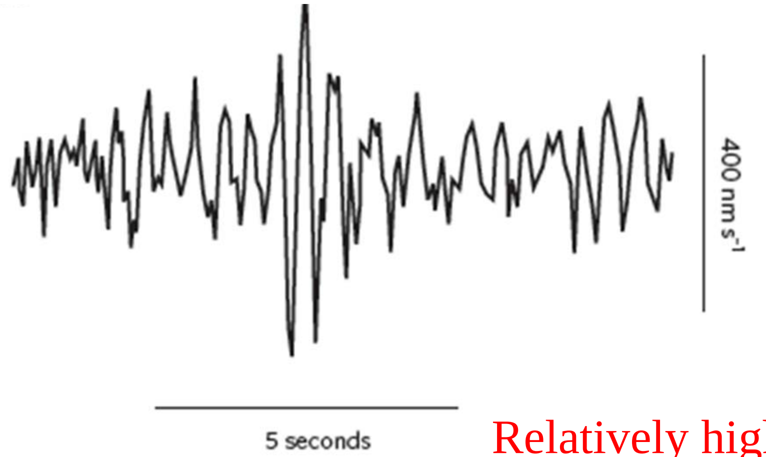
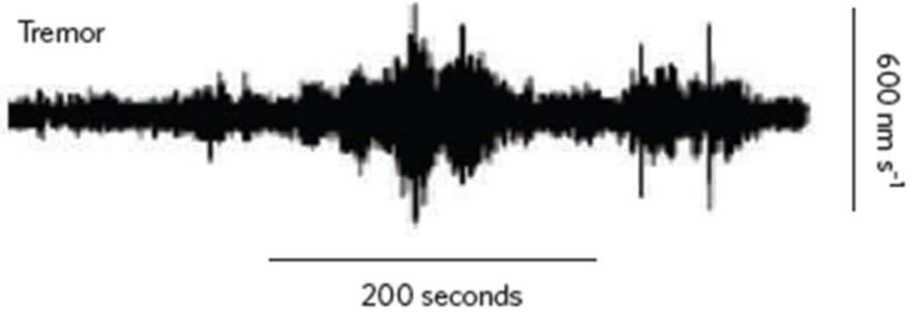
Low-frequency earthquakes (LFEs)

Earthquake

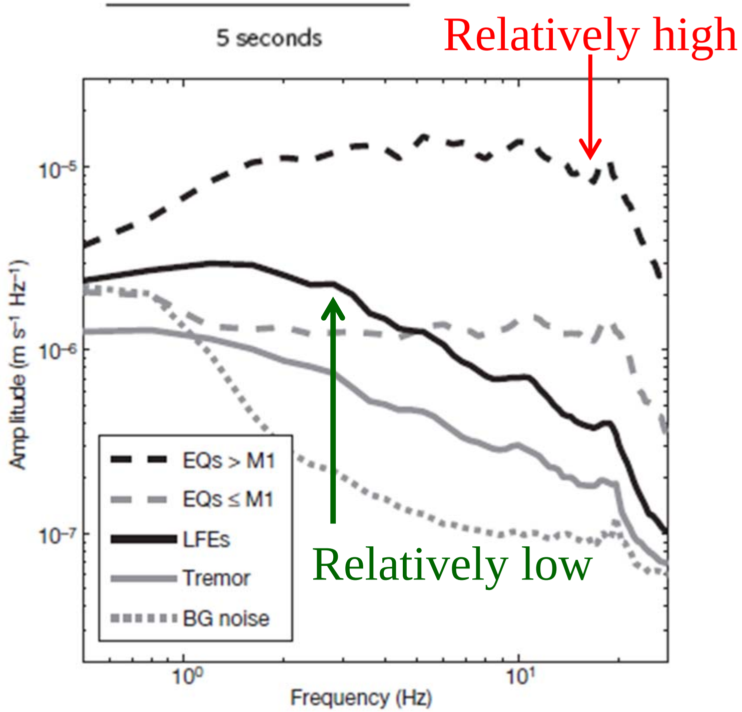


Low-frequency Earthquake (LFE)



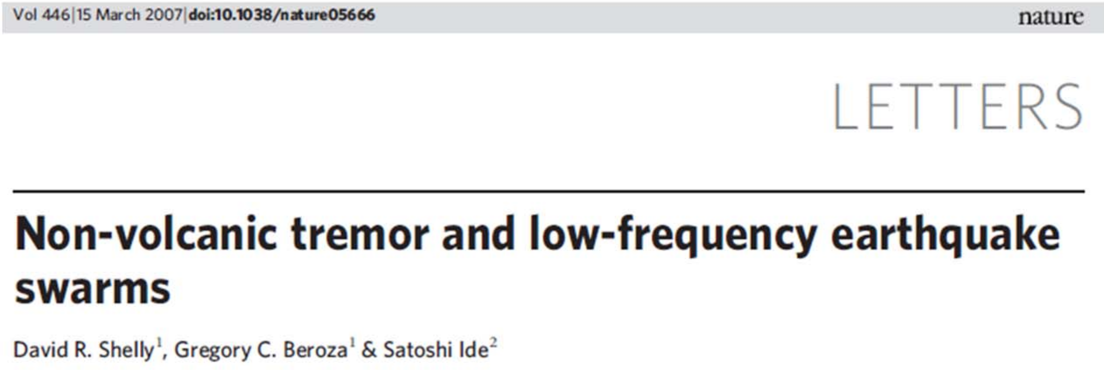


(Peng and Gomberg, 2010, Nature Geoscience)



(Shelly et al., 2007, Nature)

LFEs and Tremor



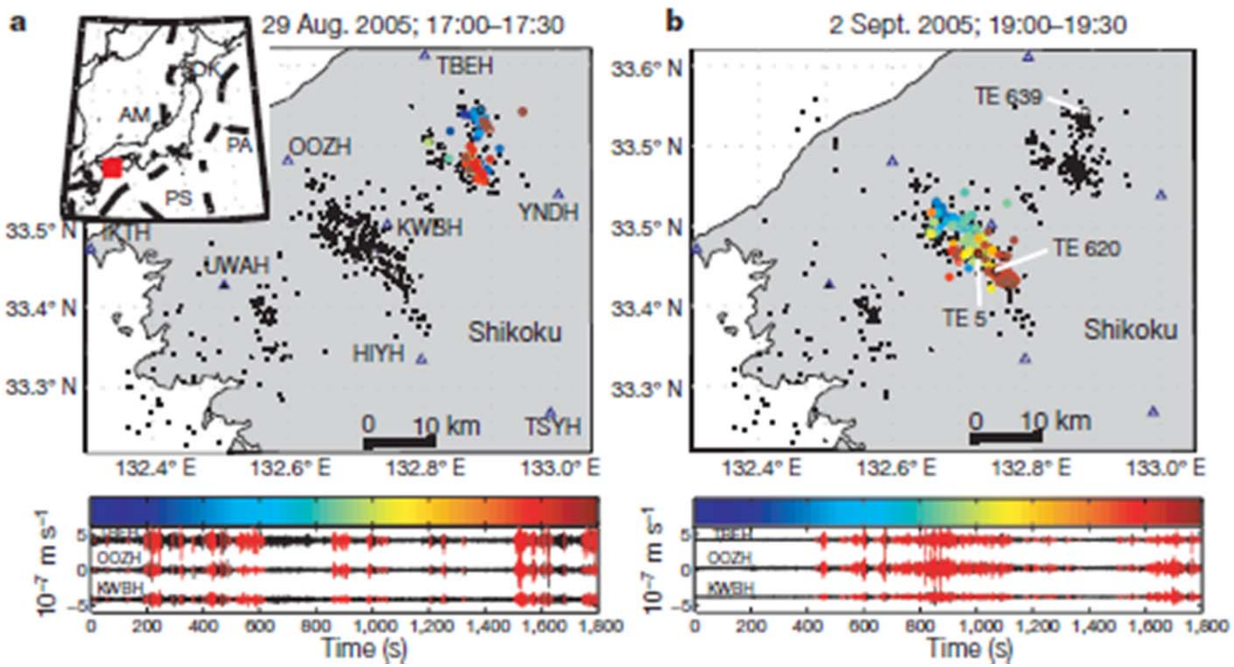
Vol 446|15 March 2007|doi:10.1038/nature05666

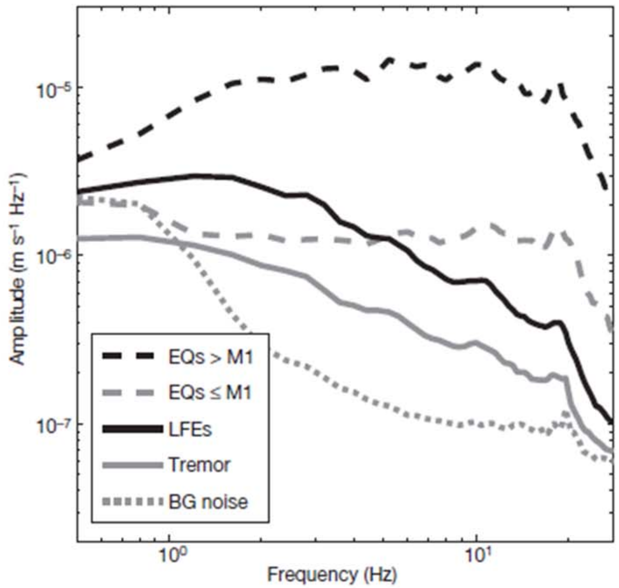
nature

LETTERS

Non-volcanic tremor and low-frequency earthquake swarms

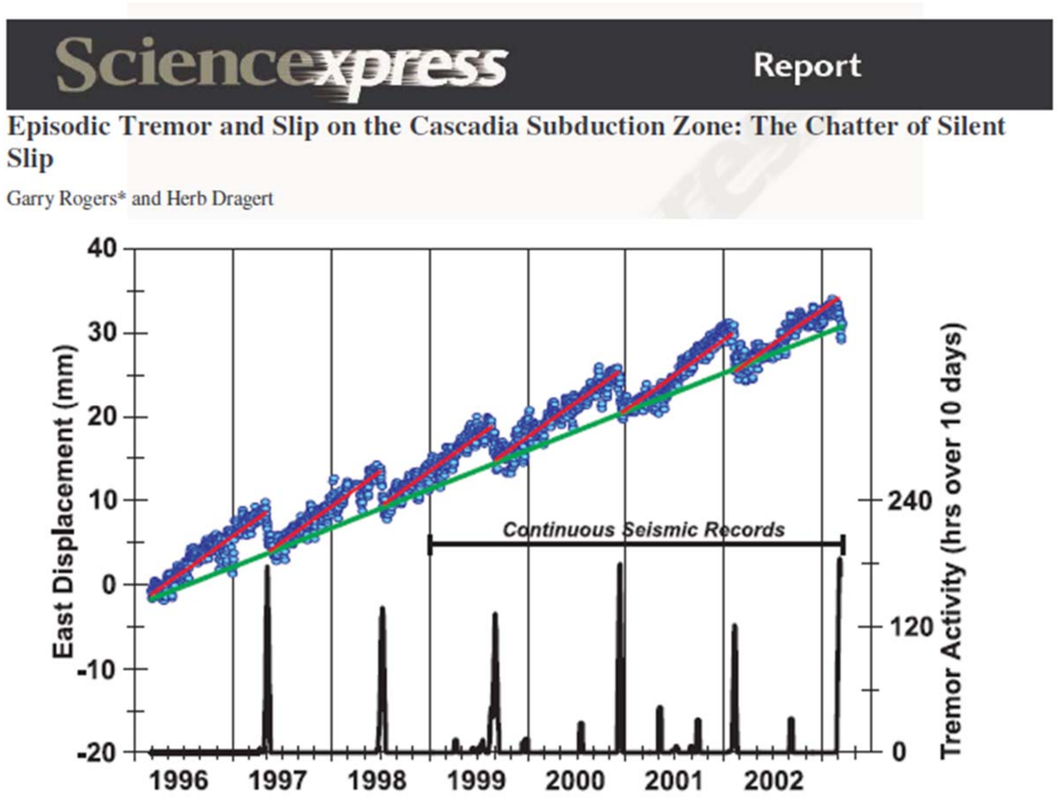
David R. Shelly[1], Gregory C. Beroza[1] & Satoshi Ide[2]

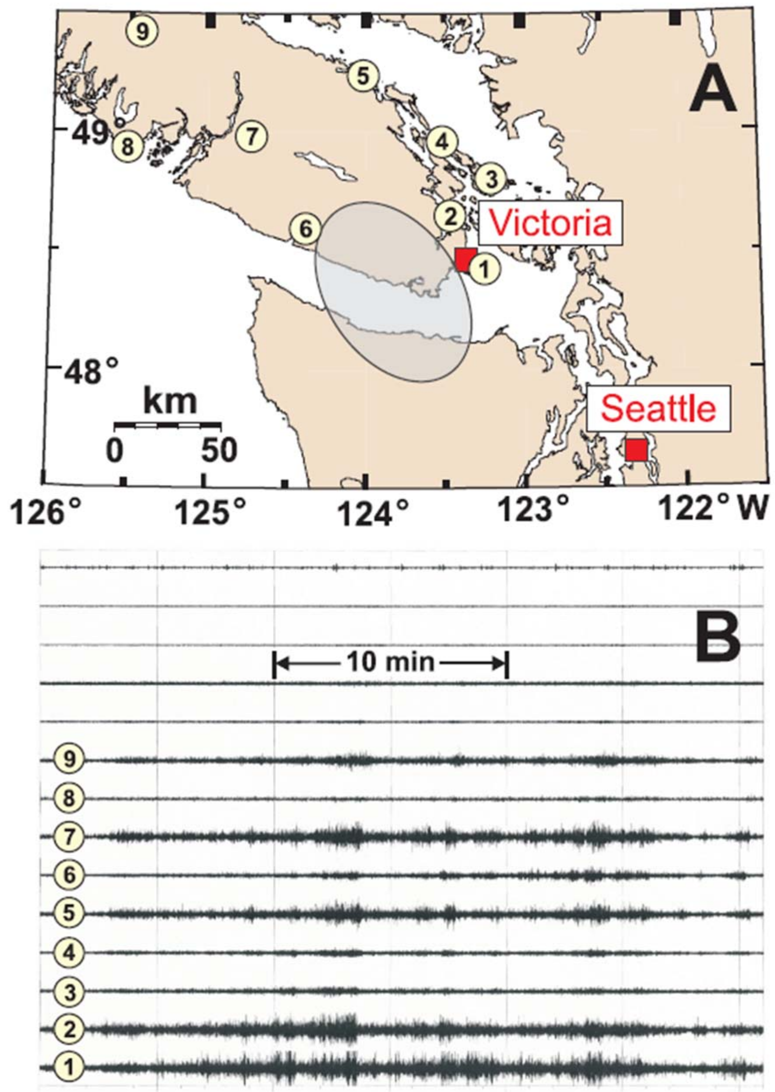




*Ambient tremors mainly compose of LFE swarms.

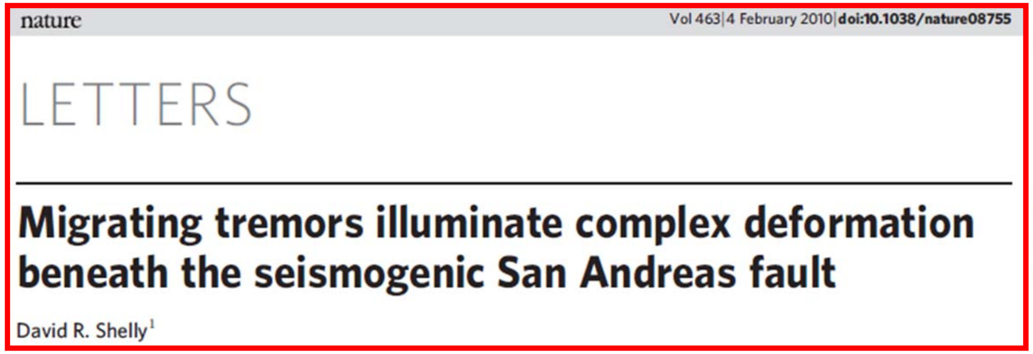
Why do we study LFEs?





*Tremor activity well corresponded to slip derived from GPS observation.

Why do we study LFEs?

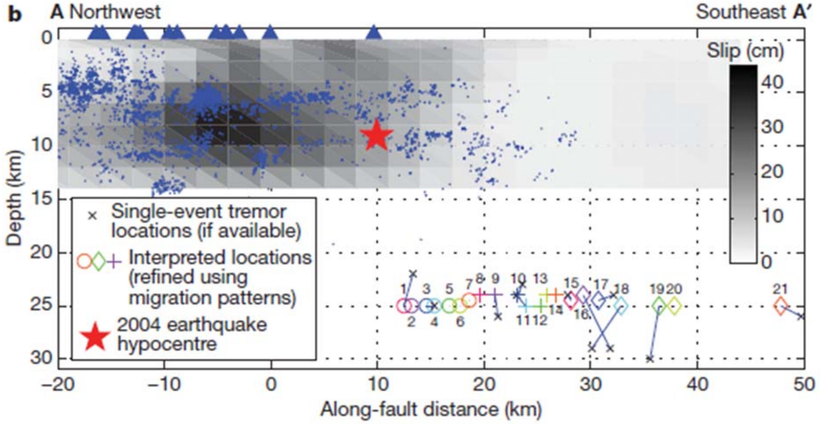

nature Vol 463|4 February 2010|doi:10.1038/nature08755

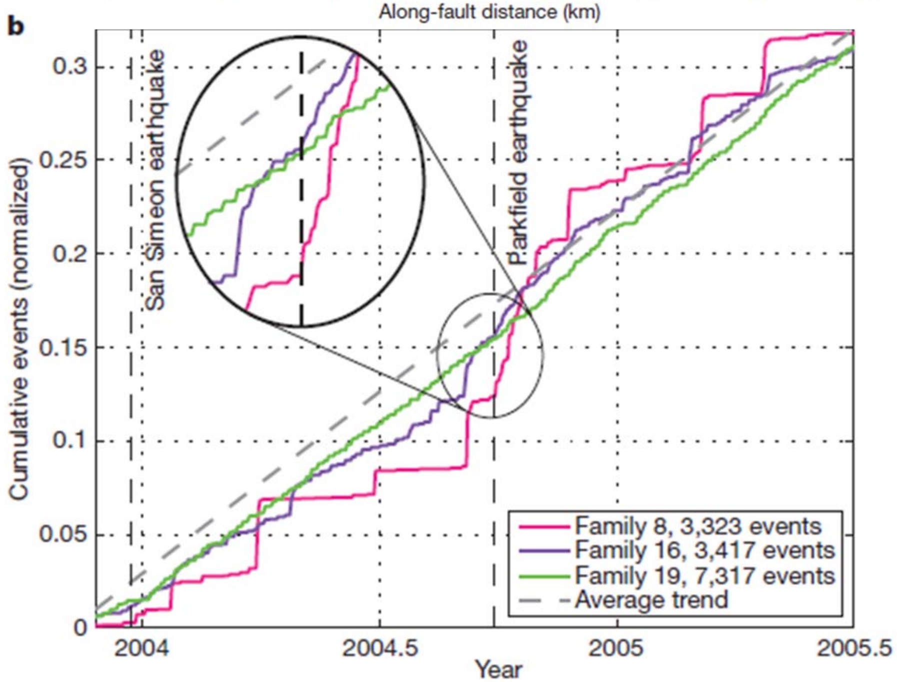
LETTERS

Migrating tremors illuminate complex deformation beneath the seismogenic San Andreas fault

David R. Shelly[1]

Ambient Tremor





(Shelly, 2010, Nature)

*Locations of tremor might reflect fault properties and static and dynamic stresses decaying away from the rupture.

*Tremor and LFEs are extremely stress sensitive and hence could act as a **natural 'stress meter'** to monitor time-dependent changes around deep faults, especially before large earthquakes.

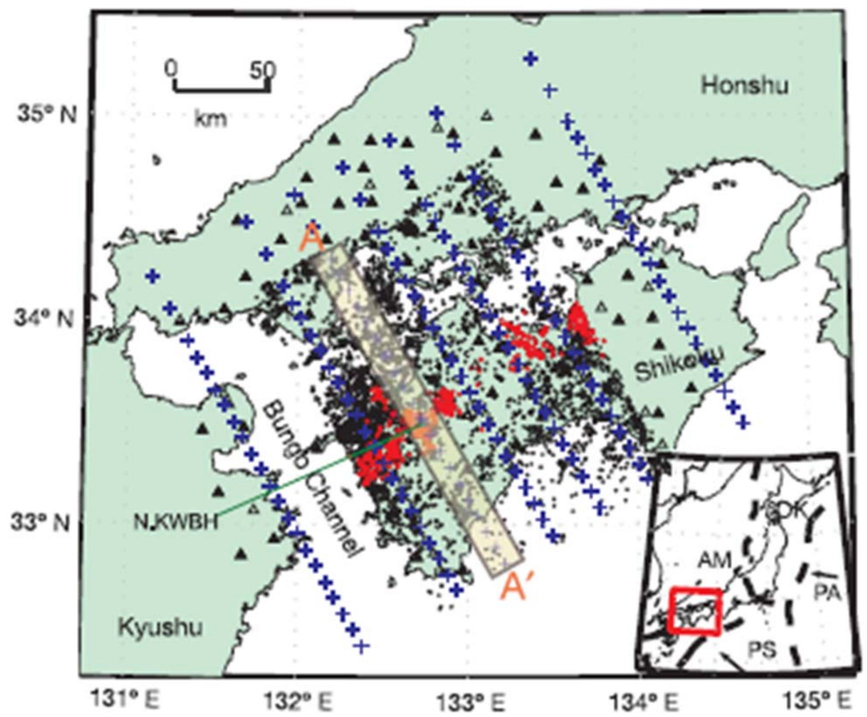
Ambient LFEs in Japan

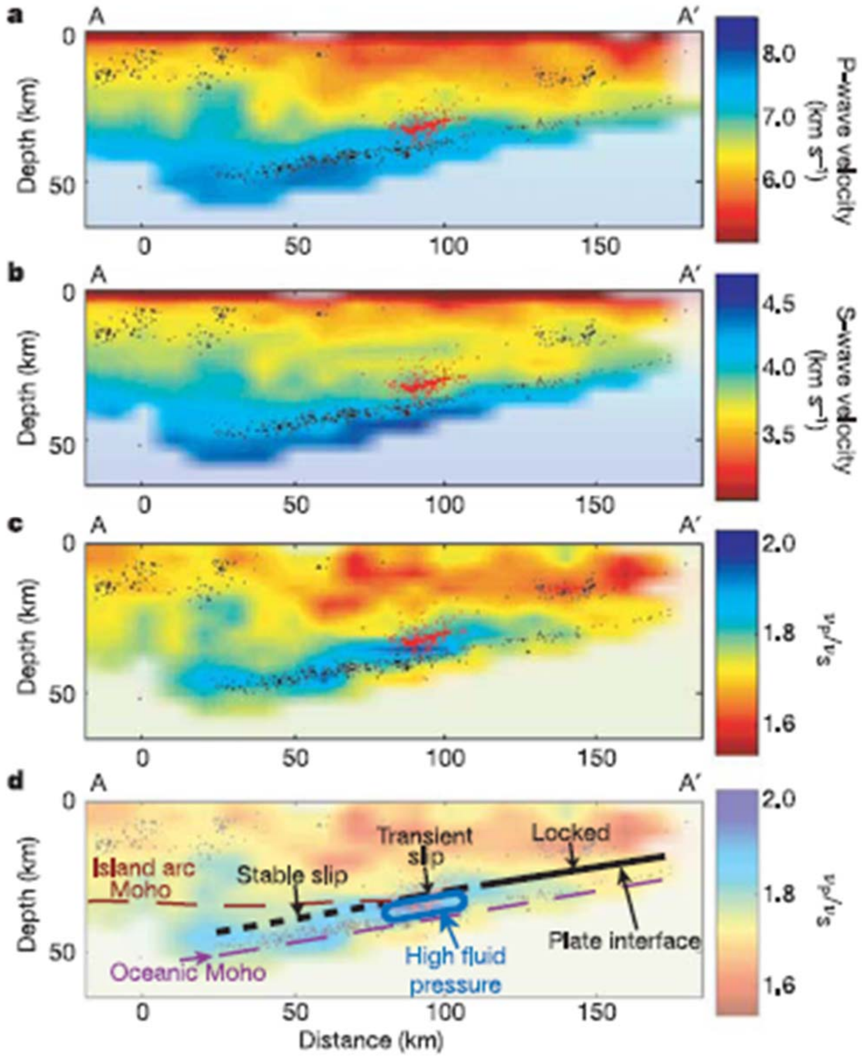
nature Vol 442|13 July 2006|doi:10.1038/nature04931

LETTERS

Low-frequency earthquakes in Shikoku, Japan, and their relationship to episodic tremor and slip

David R. Shelly[1], Gregory C. Beroza[1], Satoshi Ide[2] & Sho Nakamula[3]



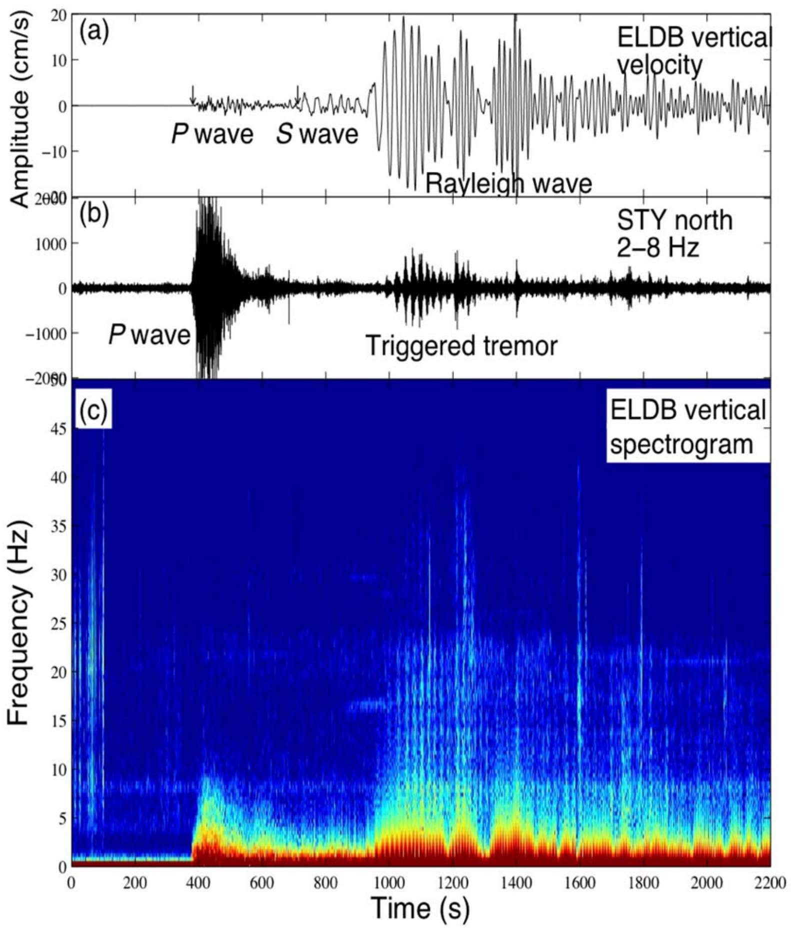


Large distant earthquakes with triggering potential

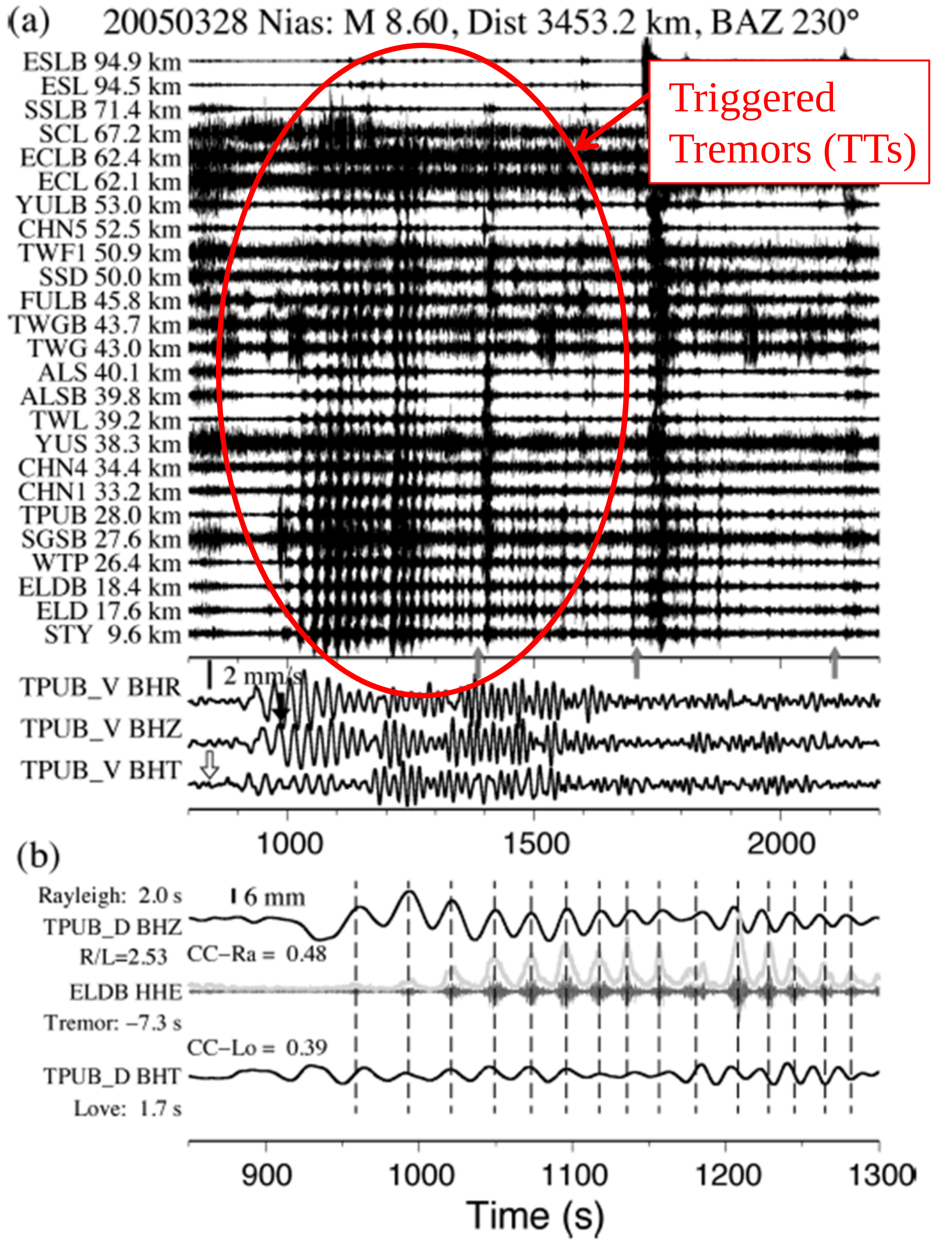
FUNDAMENTAL QUESTIONS:

1. **Locations of LFE/Tremor in Taiwan**
2. **LFE-generated mechanism**

2005 M_w8.6 Nias Earthquake



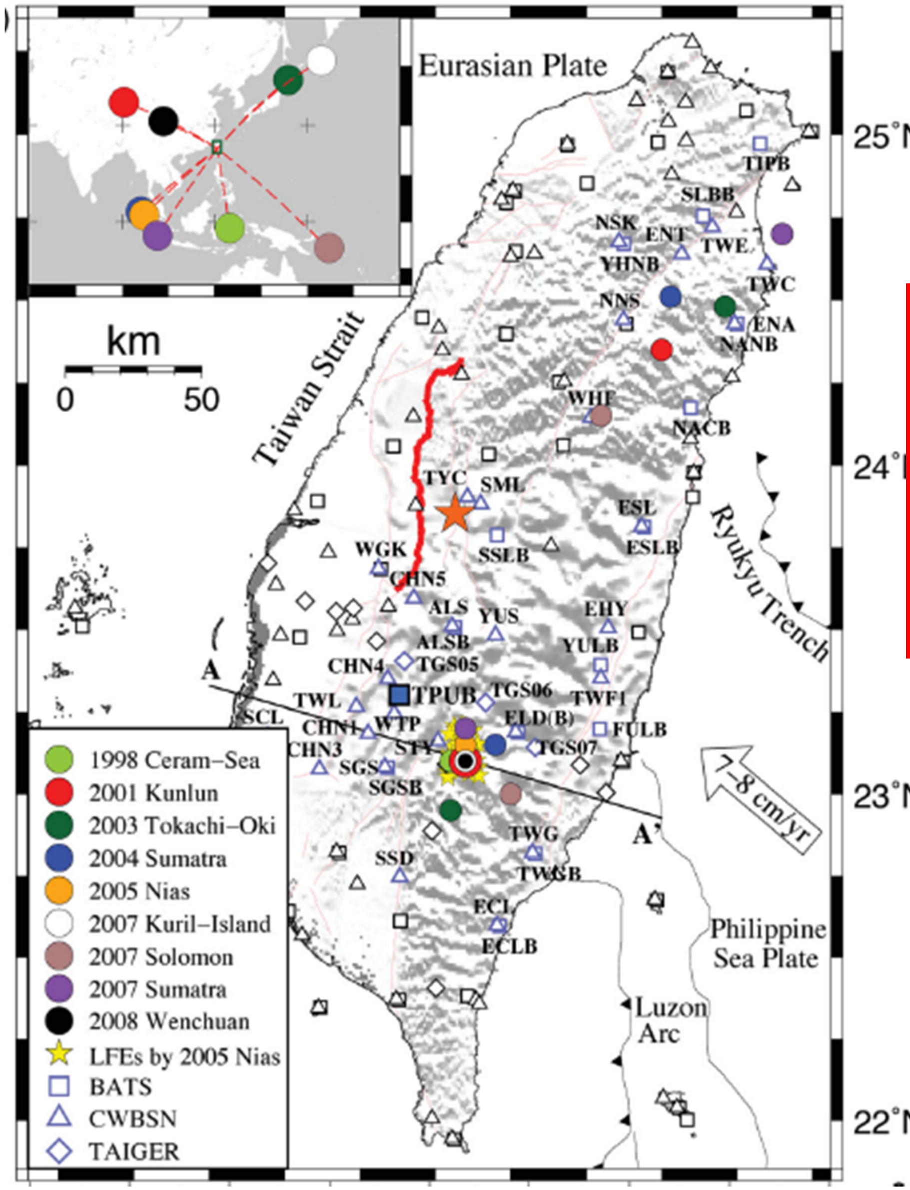
(Chao et al., 2012, GJI)



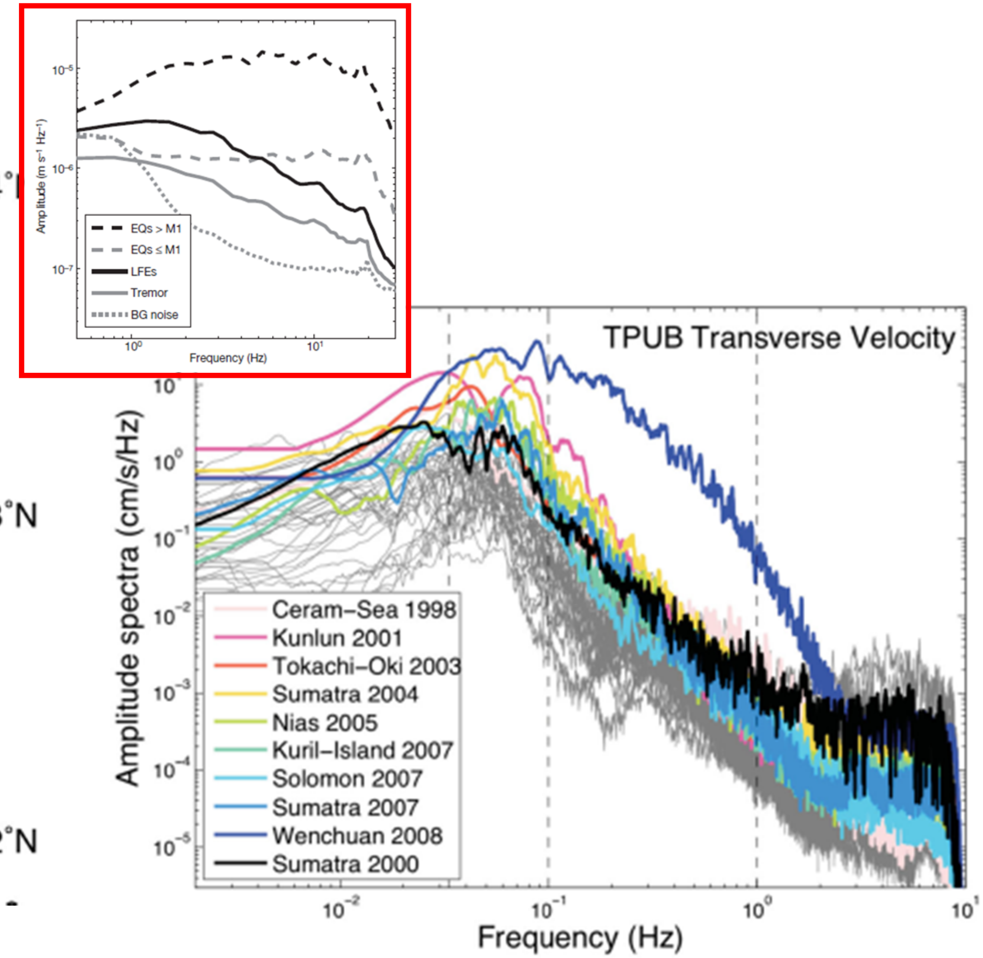
Large distant earthquakes with triggering potential

- **Survey of triggered tremor were performed for 45 teleseismic earthquakes from 1998 to 2009 with M ≥ 7.5 and epicentral distance ≥ 1000 km.**

- **9 earthquakes could trigger tremors.**



(Chao et al., 2012, GJI)

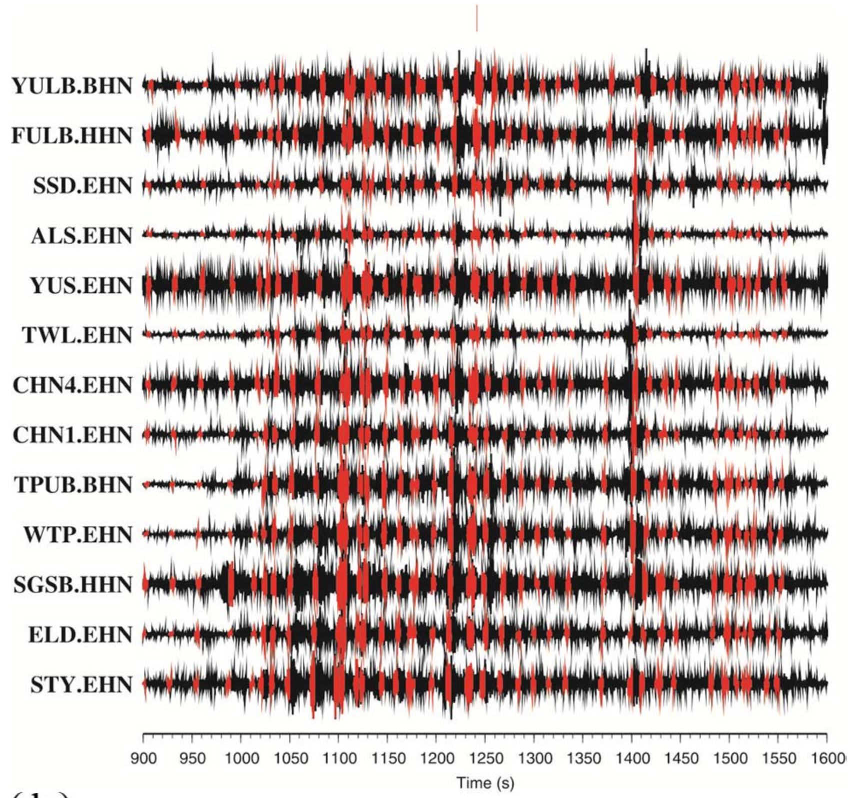


Detecting LFEs in tremors
-- Match filter technique

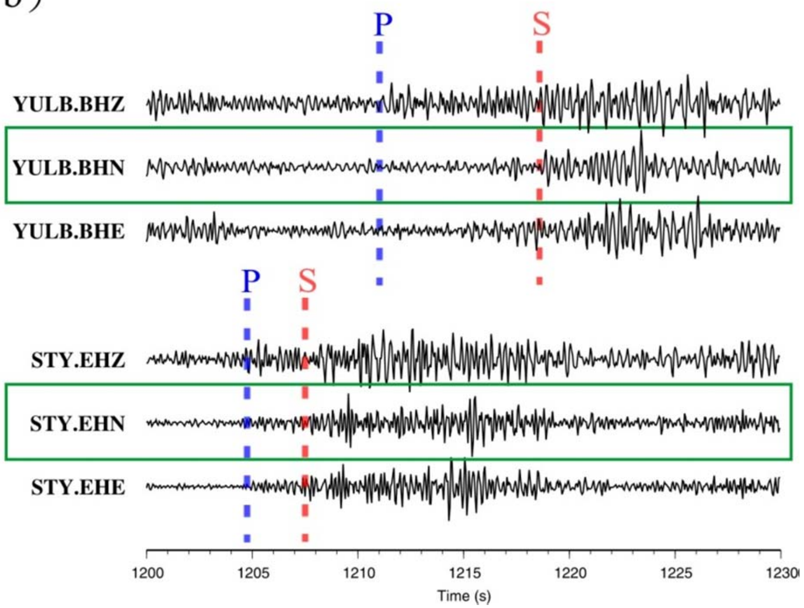
An example of waveform detection

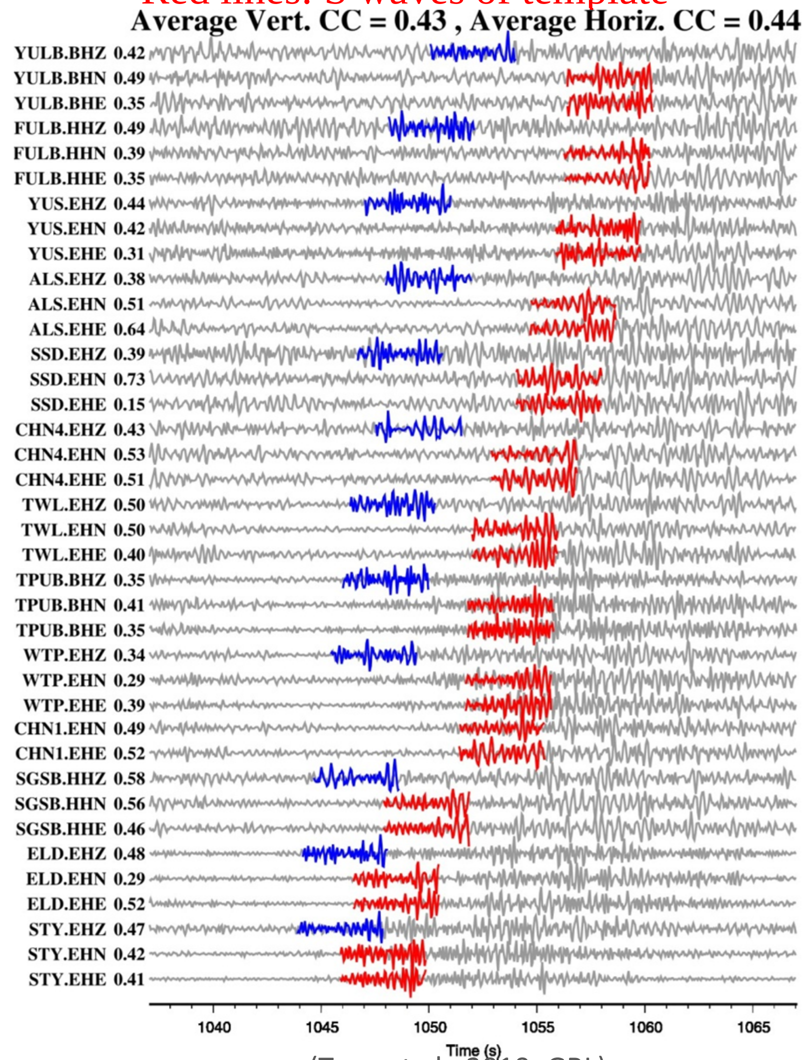
Blue lines: P waves of template

Red lines: S waves of template



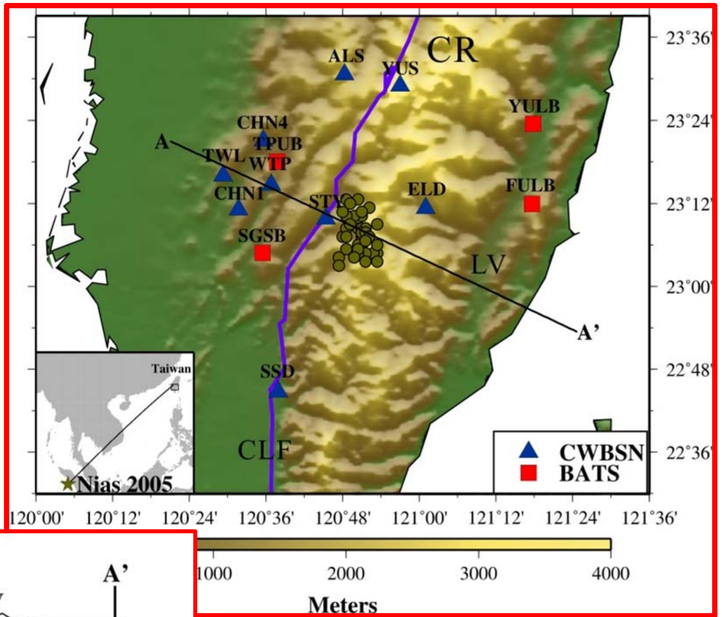
(b)



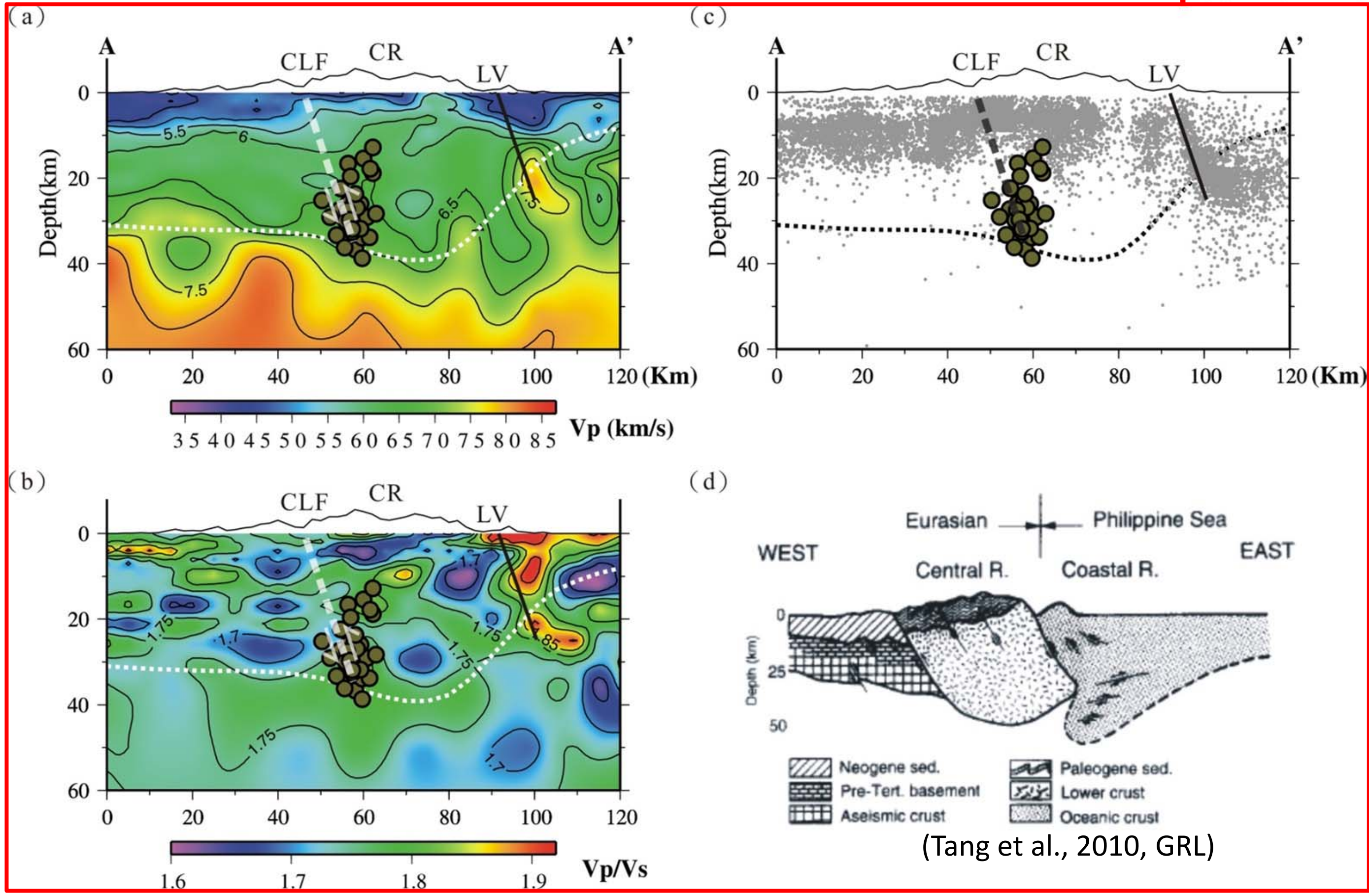


(Tang et al., 2010, GRL)

Detecting LFEs in tremors



***The locations of LFEs are near a region with relatively high Vp/Vs ratios, suggesting that triggered tremor and LFEs reflect possible deep fault slip at the lower crust facilitated by dynamic stresses and elevated fluid pressures.**



(Tang et al., 2010, GRL)

Significance of detected LFEs

***To examine the statistical significance of detected LFEs during large-amplitude surface waves, we computed a β-statistic value (Aron and Hardebeck, 2009).**

$$\beta = \frac{Na - NTa/T}{\sqrt{N(Ta/T)(1 - Ta/T)}}$$

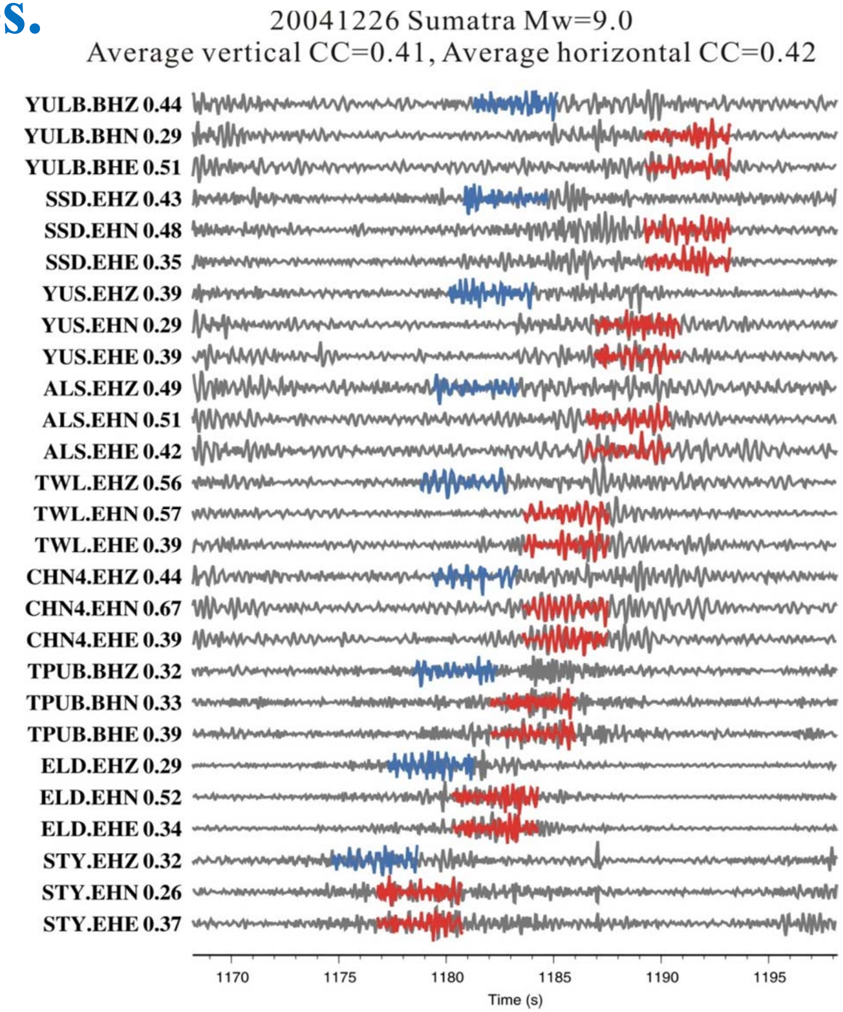
, where Na and N are the number of events in the interested period and total number of events, respectively. Ta and T are the time length of interest and the whole time period.

***For absolute values of $\beta \geq 1.64$, the difference in seismicity rate between the two time periods is significant at 90% confidence level, and for $\beta \geq 2.57$, it is significant at 99% confidence level.**

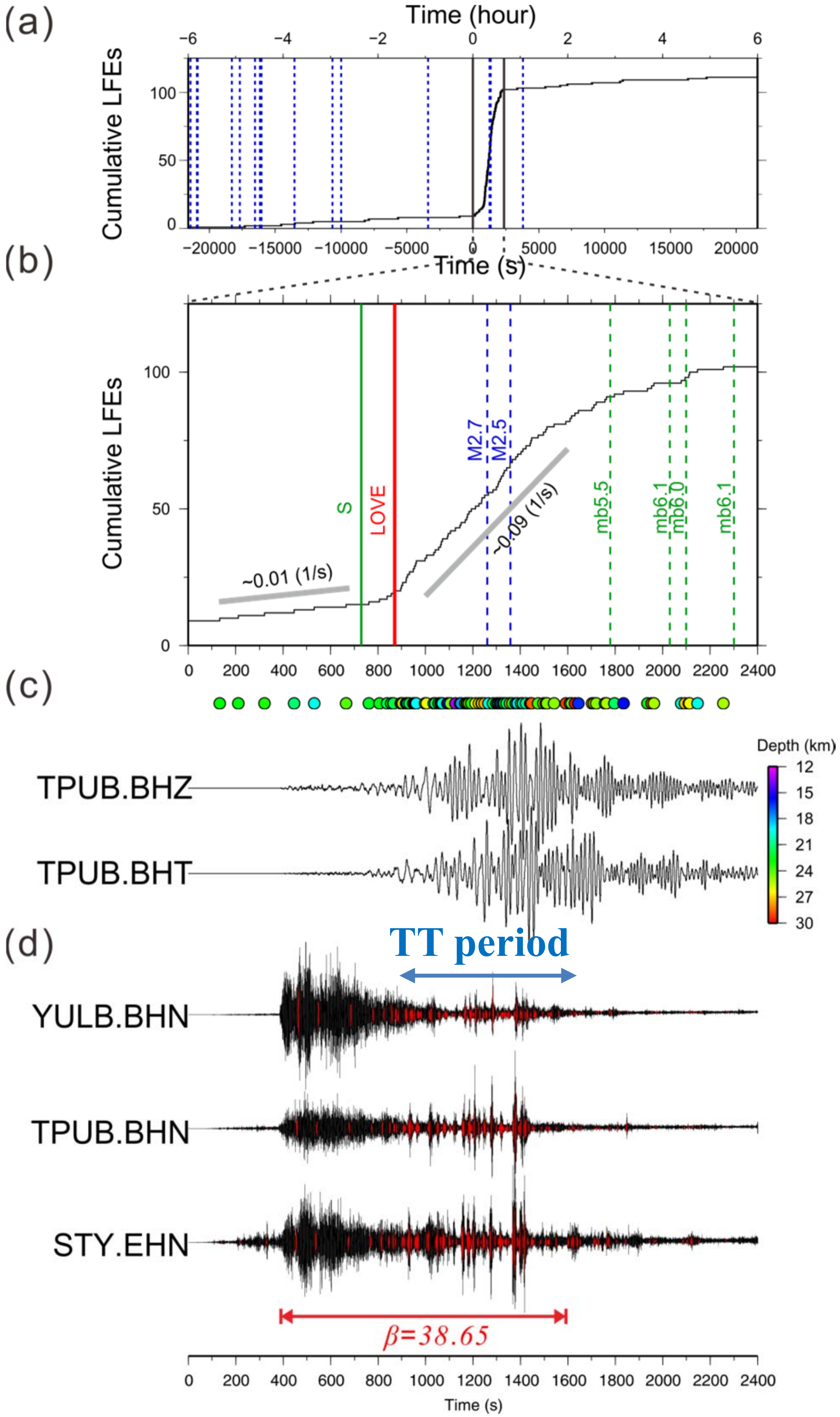
Reoccurring LFEs

***Is LFE able to be re-triggered by large teleseismic events?**

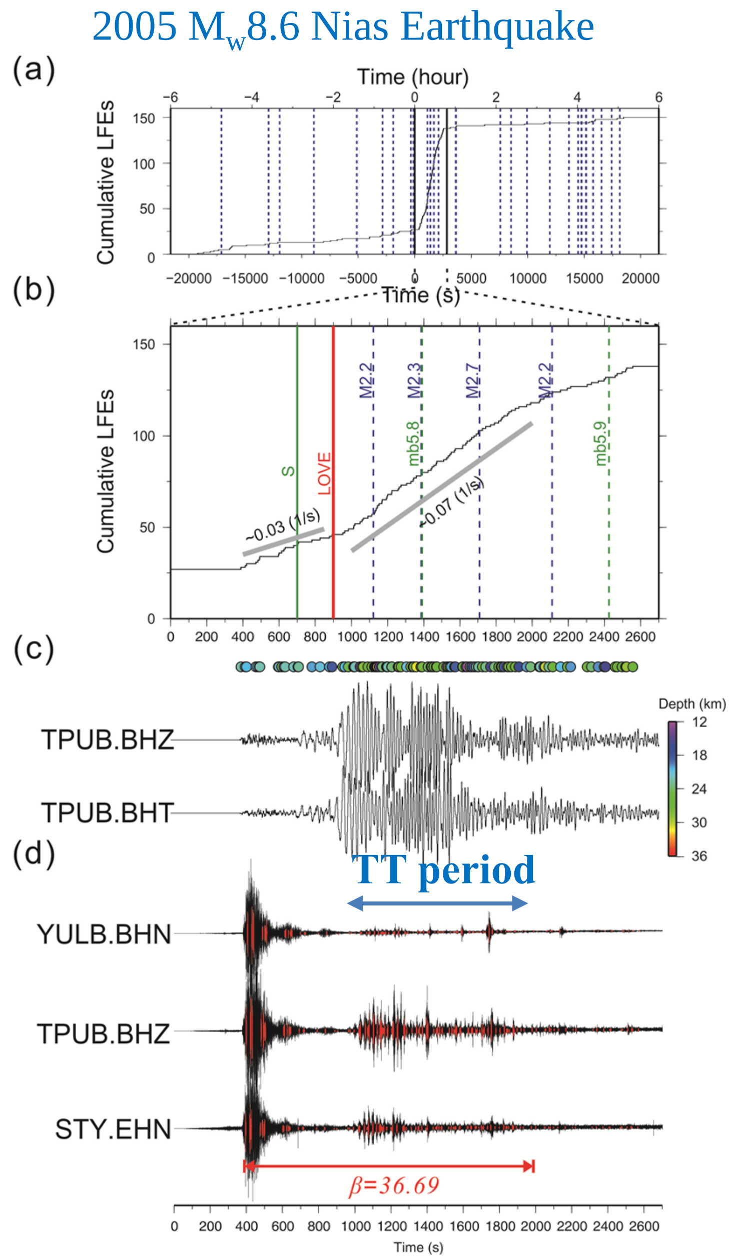
Yes.

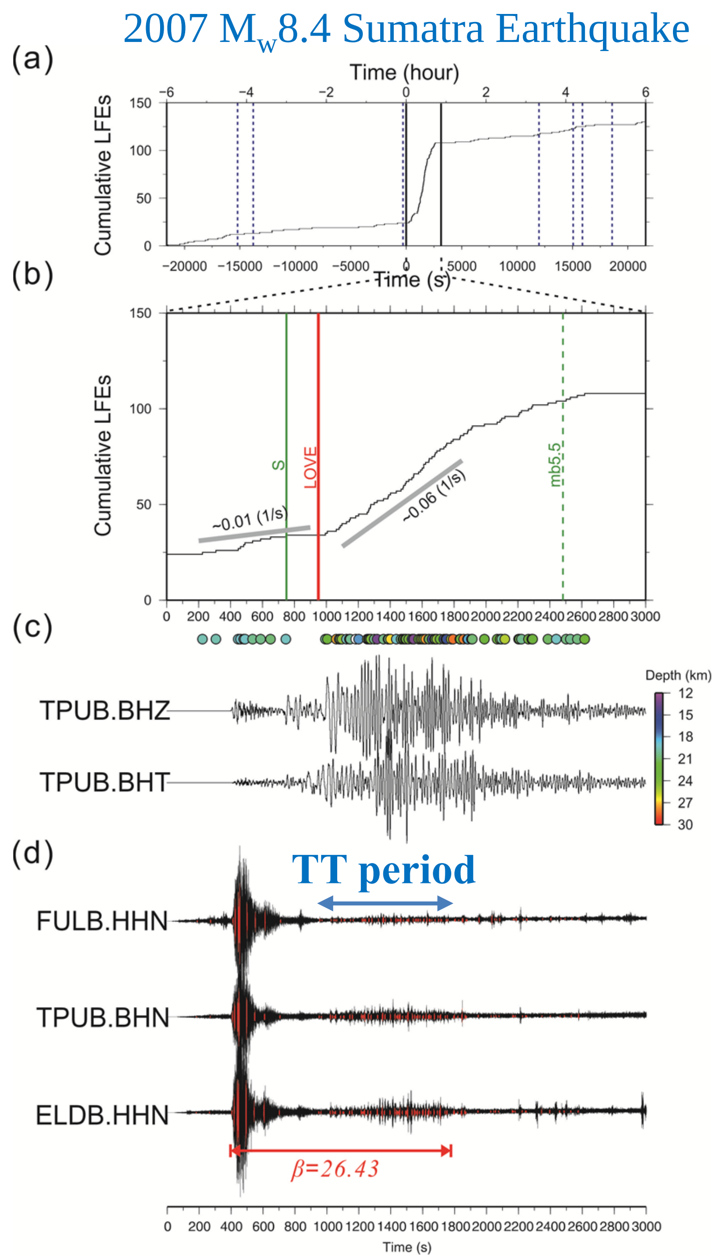


(Tang et al., 2013, EPSL, *in press*)



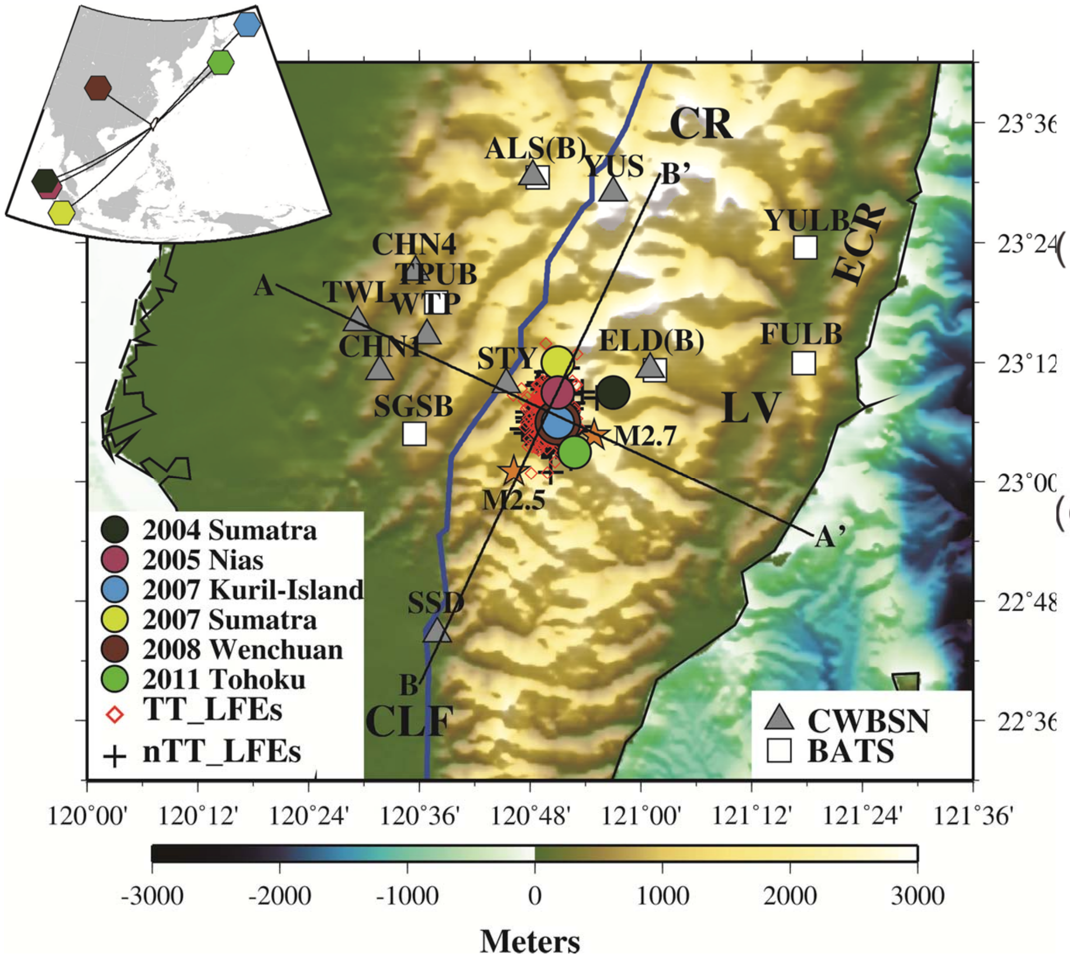
Reoccurring LFEs

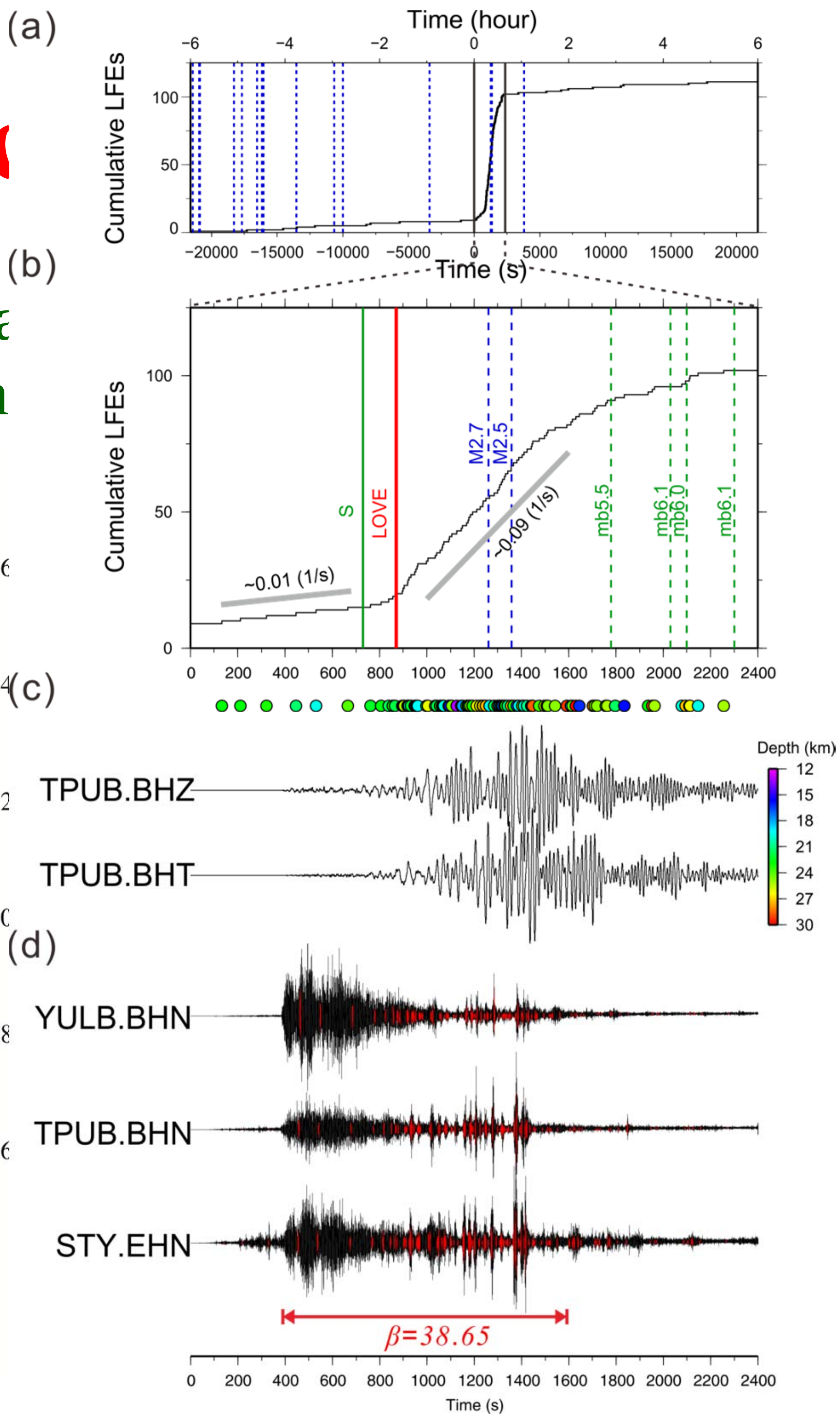




Locations of reoc

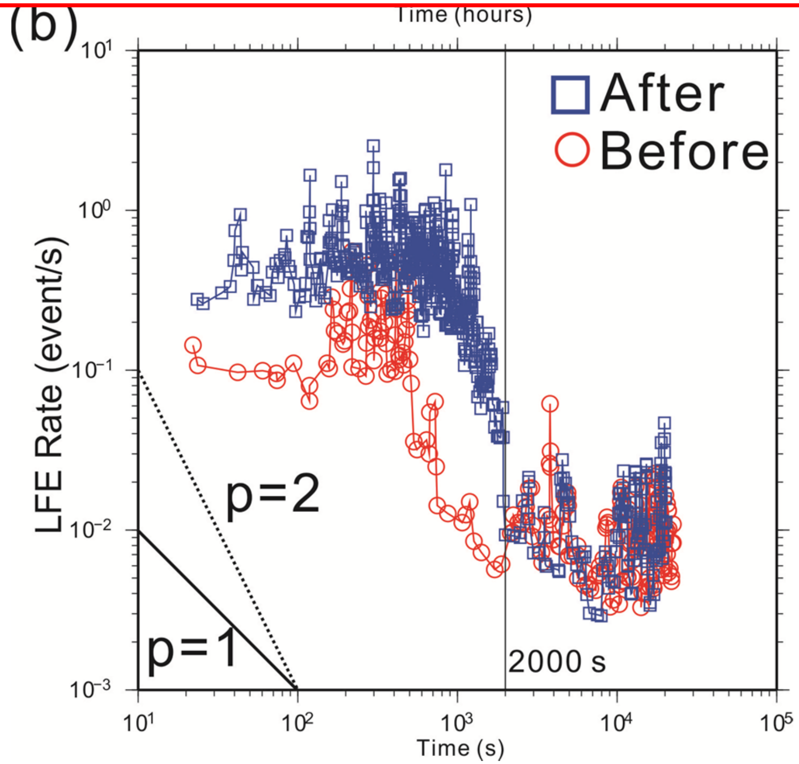
- The LFEs were mainly located in a
  12 and 36 km in depth near the Ch



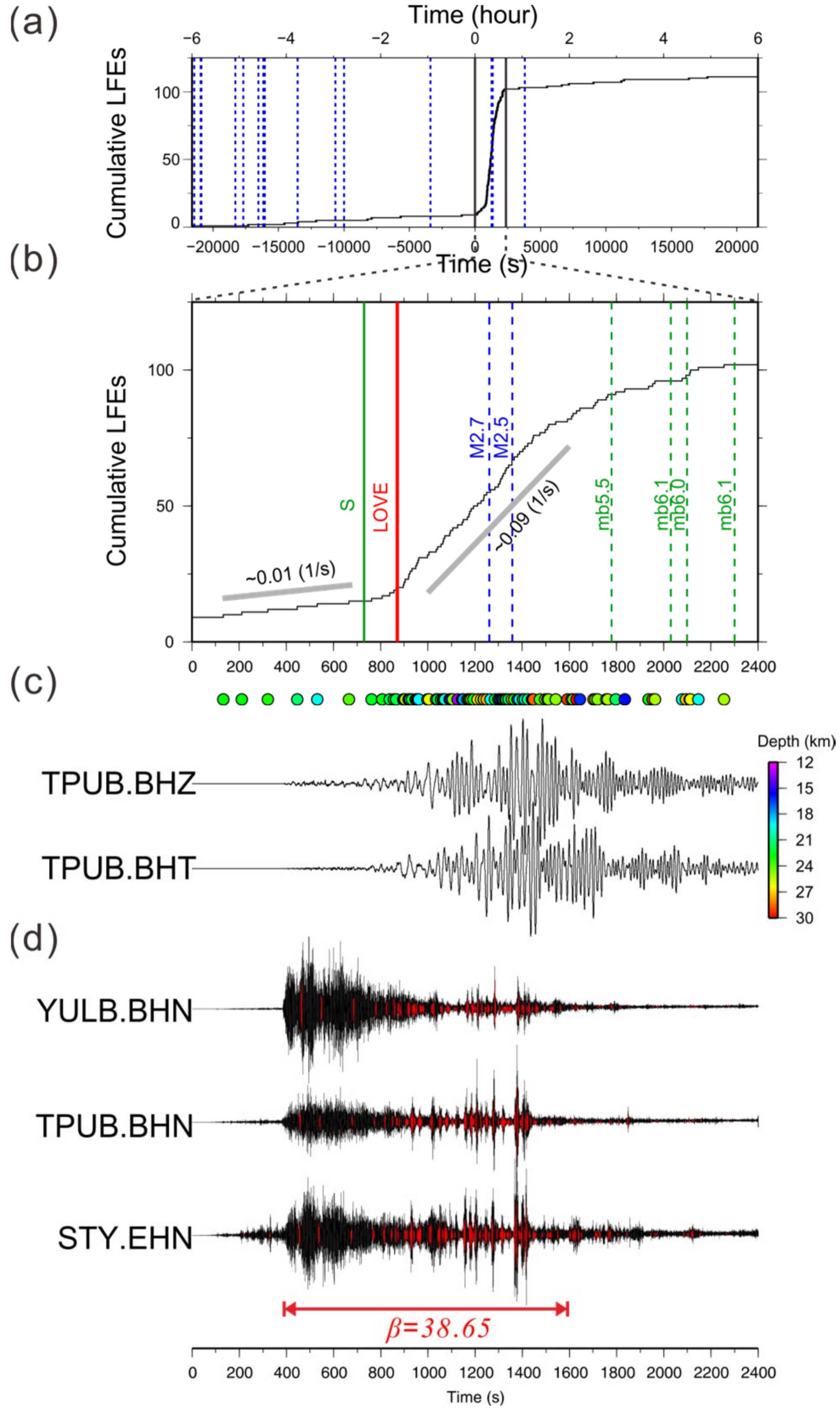


Statistical Properties of LFEs

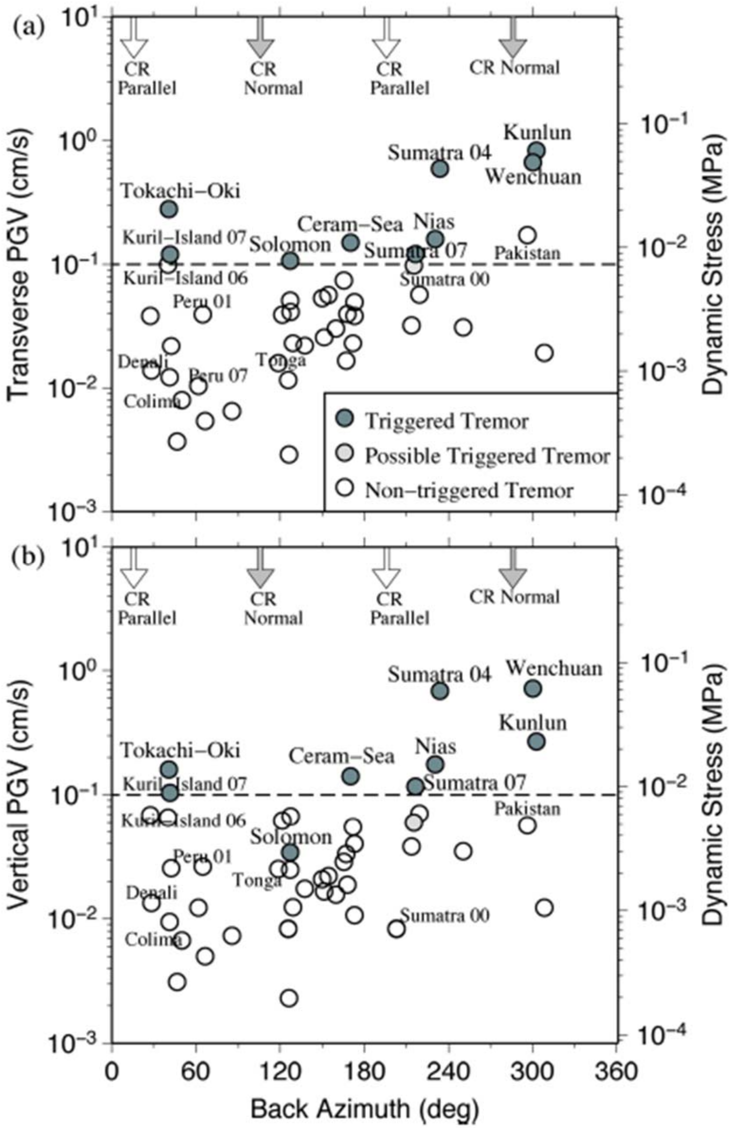
*The LFE rates do not follow an Omori's type decay, but rather abruptly return to the background rate immediately after the surface-wave passage.



(Tang et al., 2013, EPSL, *in press*)



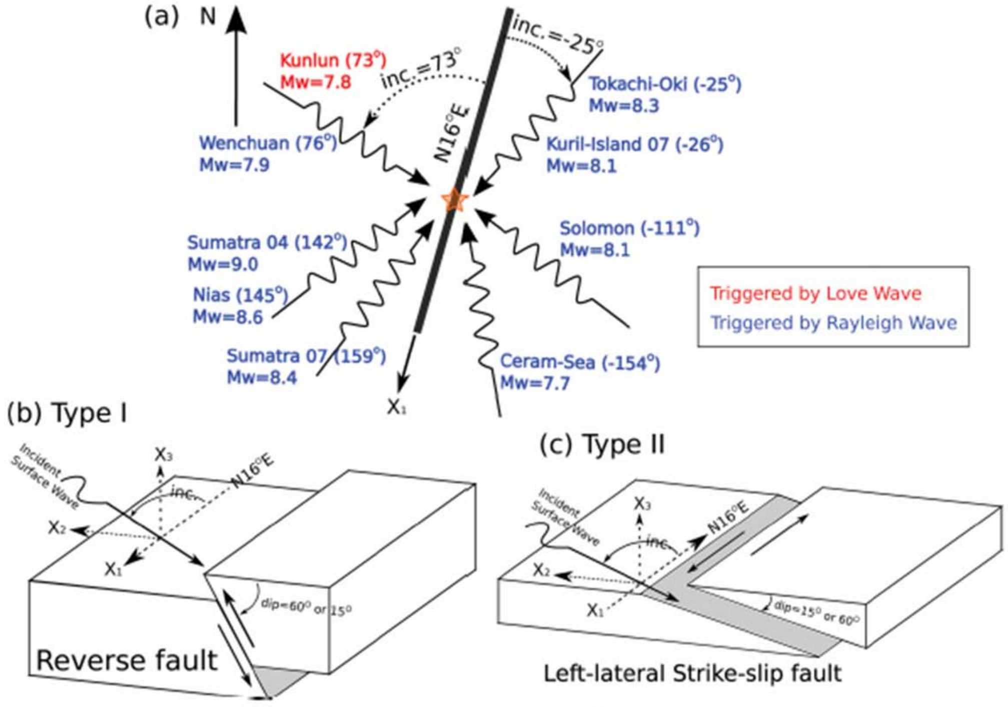
Triggering potential – Amplitude/Peak ground velocity (PGV)



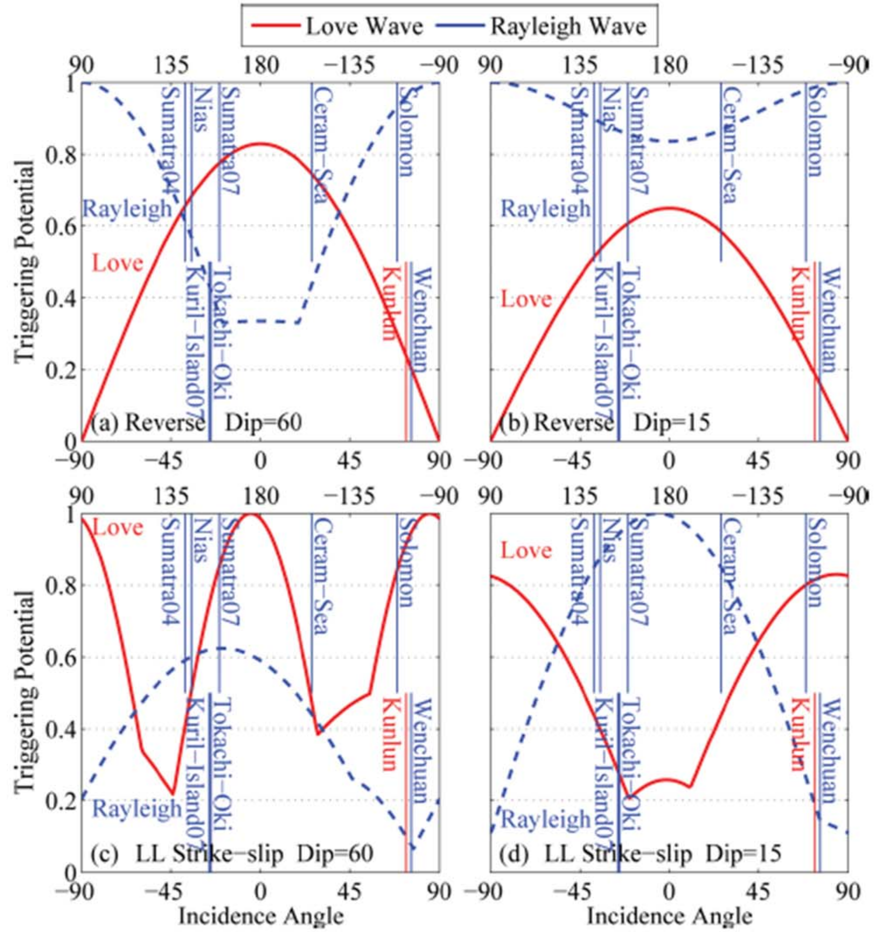
(Chao et al., 2012, GJI)

- For all nine triggering earthquakes, the measured transverse PGV ranges from 0.10 cm/s to 0.835 cm/s, which corresponds to the peak dynamic stress of 7.8–61.1 Kpa.
- The PGV of 0.1 cm/s appears to separate most of triggering and non-triggering earthquakes in both transverse and vertical components, which corresponds to an apparent tremor-triggering threshold 7-8 Kpa.

Triggering potential – Incidence angle

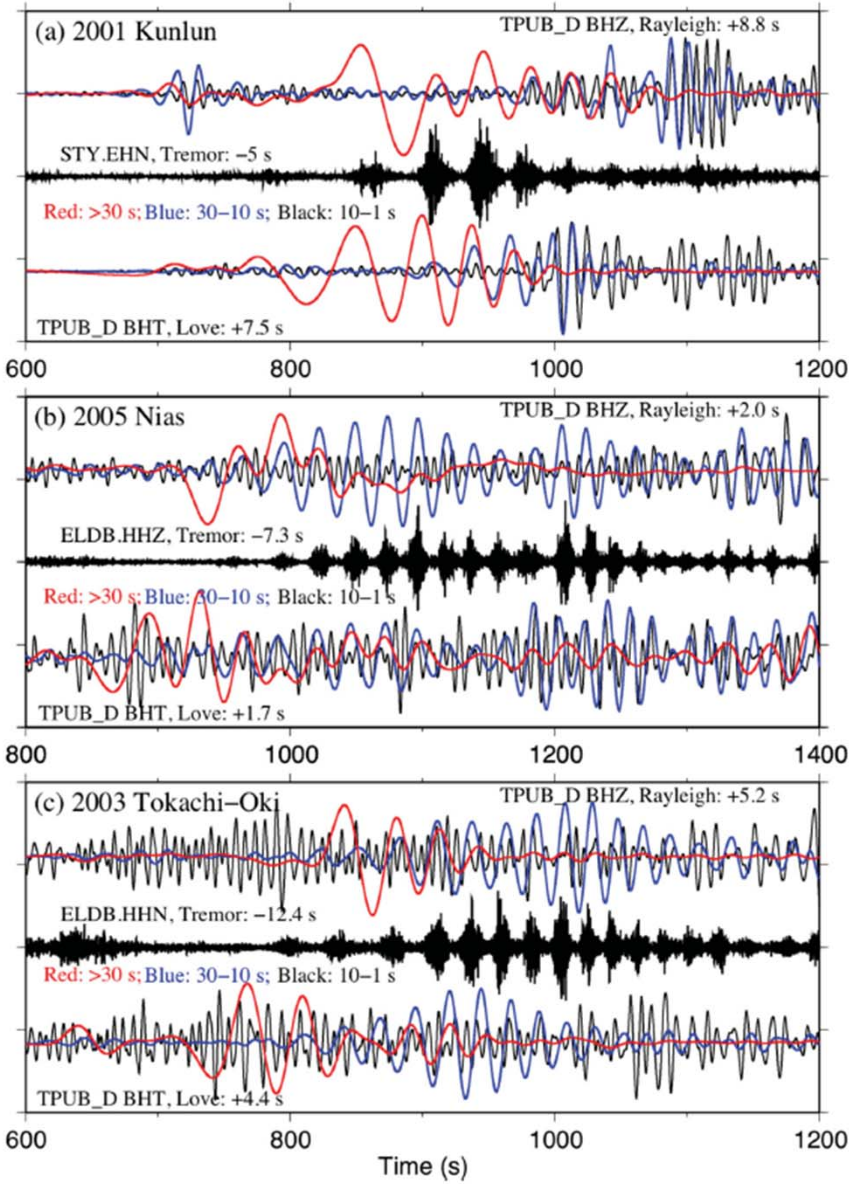


(Chao et al., 2012, GJI)



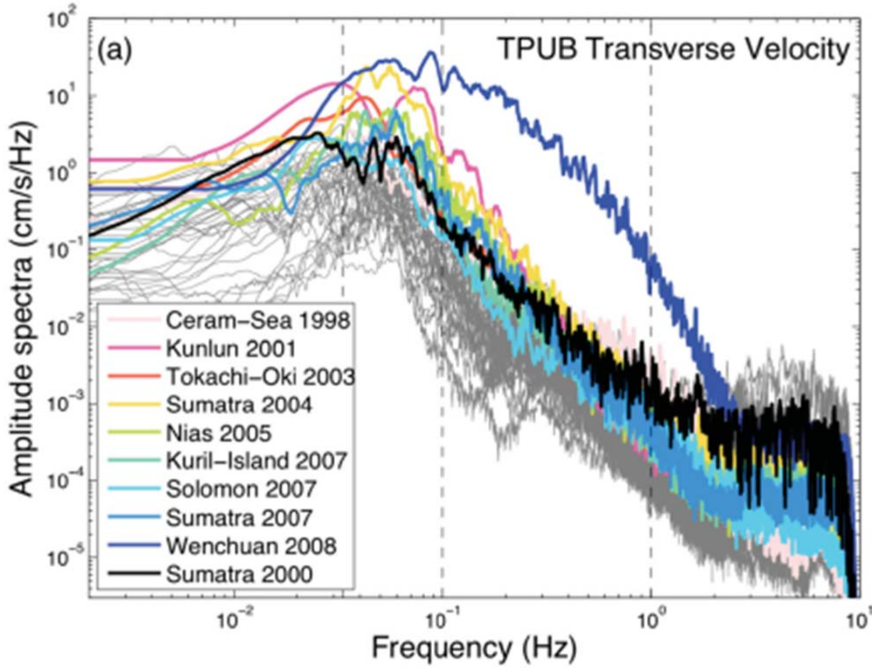
- **There is no model which is consistent with all observations.**
- **Low-to-median dipping angle of left-lateral strike-slip fault model could better explains the observations.**

Triggering potential – Frequency



(Chao et al., 2012, GJI)

- **Intermediate-period (30-10 s) surface waves could trigger/modulate tremor/LFE and long-period signals are not always needed.**
- **The apparent associations between the triggered tremor and intermediate-period surface waves could also be explained by the amplitude difference in different frequency bands.**



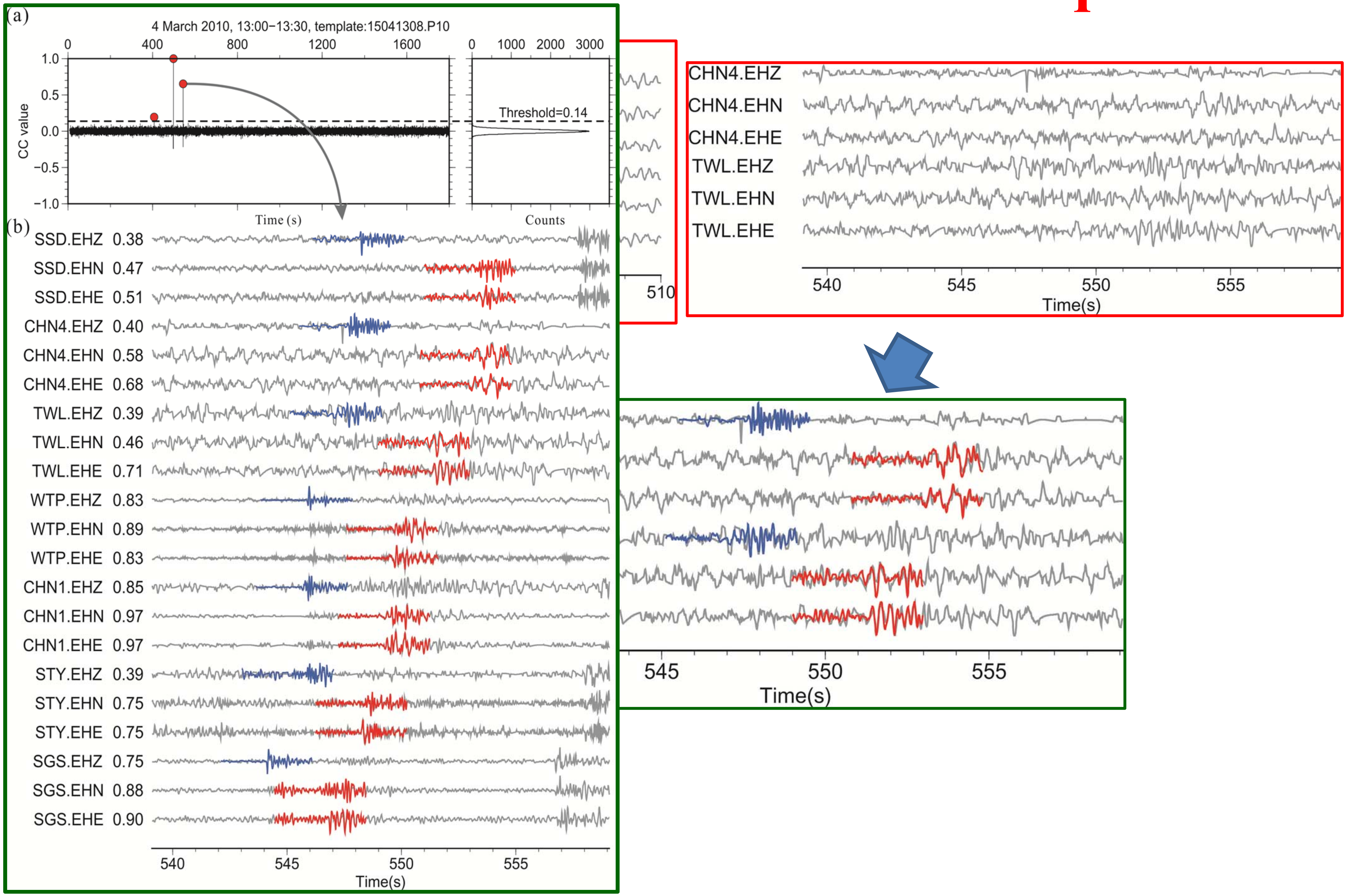
Conclusions

- Triggered tremor consist of many LFEs.
- LFEs could be re-triggered by large distant earthquakes.
- The LFEs were mainly located in a compact region between 12 and 36 km in depth near the Chaochou-Lishan Fault.
- The LFE rates do not follow an Omori's type decay, but rather abruptly return to the background rate immediately after the surface-wave passage.

Conclusions

- The locations of LFEs are close to a region with relatively high Vp/Vs ratios.
- Apparent triggering threshold of LFE/tremor are ~0.1 cm/s, or 7–8 Kpa.
- Low-to-median dipping angle of left-lateral strike-slip fault is a better explanation for triggering.
- Intermediate-period (30-10 s) surface waves could trigger/modulate tremor/LFE and long-period signals are not always needed.

What else can the match filter technique do?



Thank you for coming.