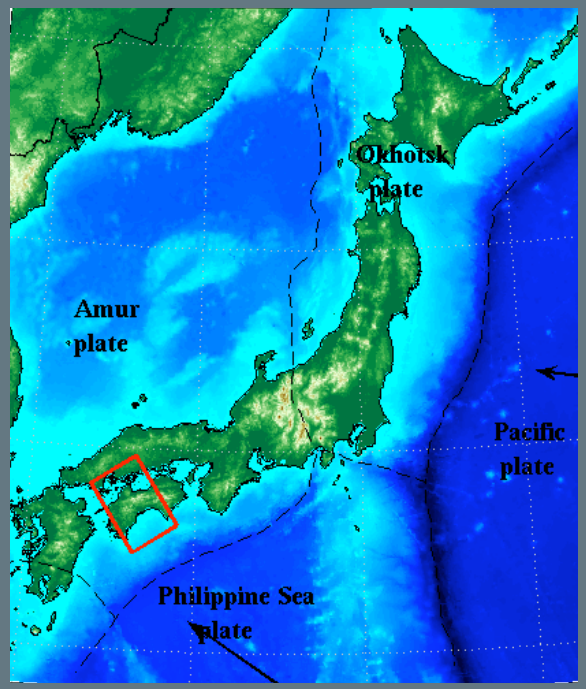
Low-Frequency Earthquake Swarms and Non-Volcanic Tremor Under Shikoku



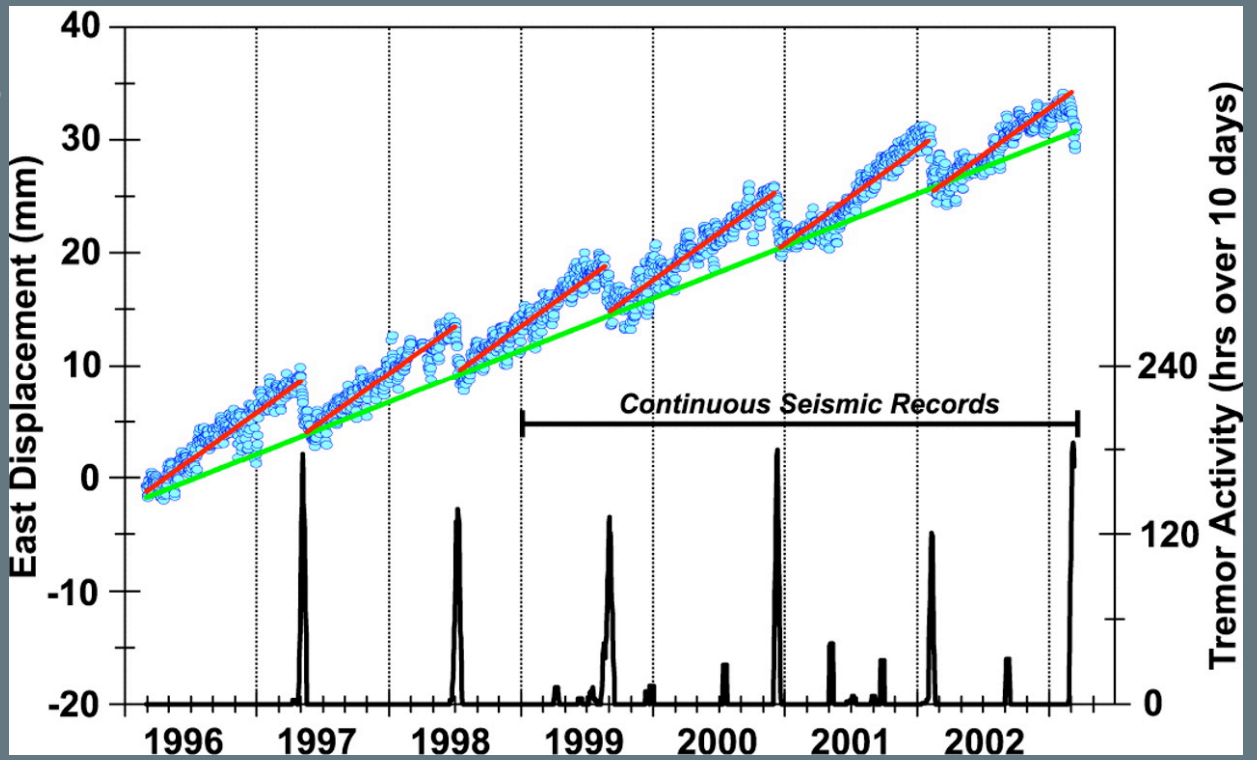
David R. Shelly
Stanford University

Collaborators:
Gregory C. Beroza *Stanford University*
Satoshi Ide *University of Tokyo*

Episodic Tremor and Slip

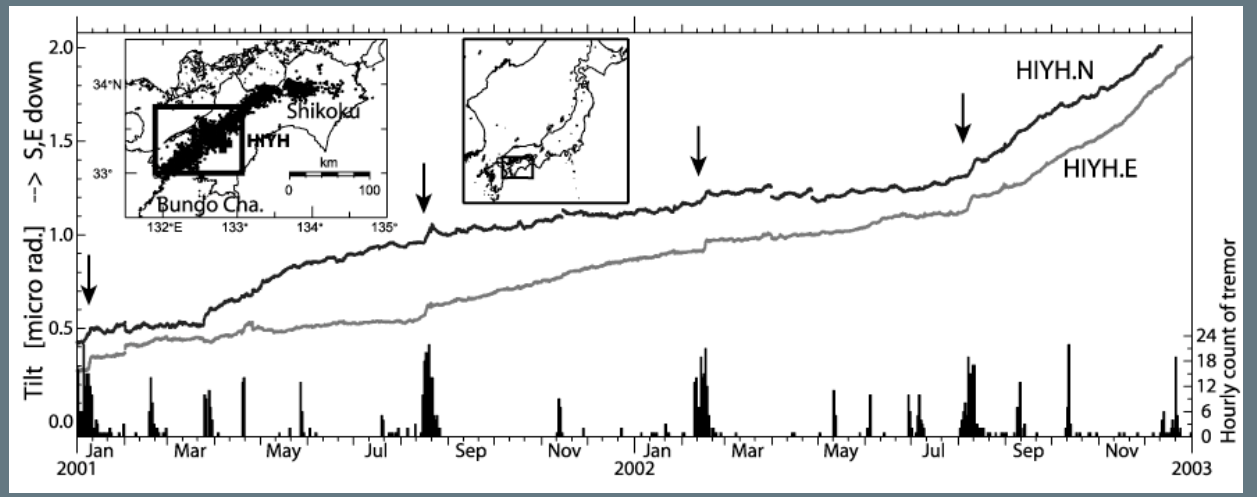
Rogers and Dragert, 2003

Cascadia



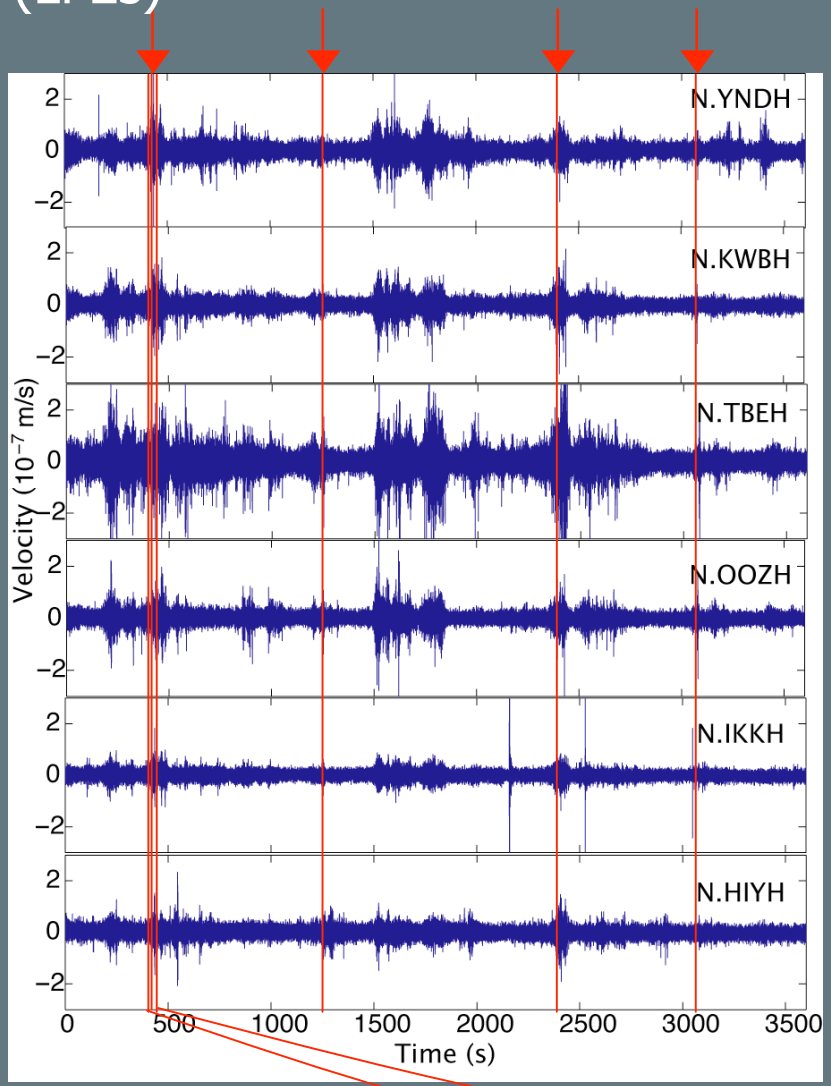
Southwest Japan

Obara *et al.*, 2004



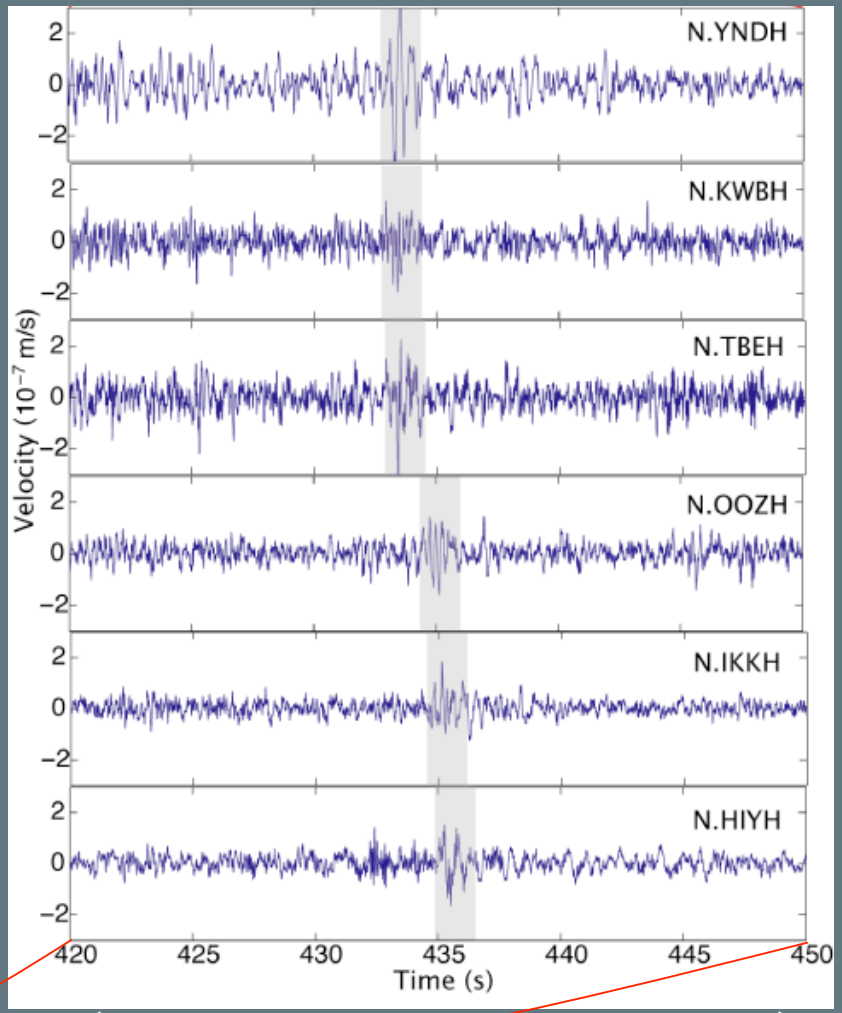
Tremor Waveforms

Low frequency earthquakes (LFEs)



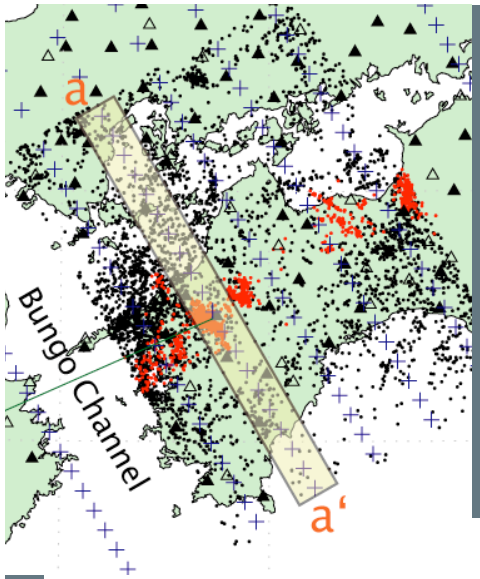
1 hour

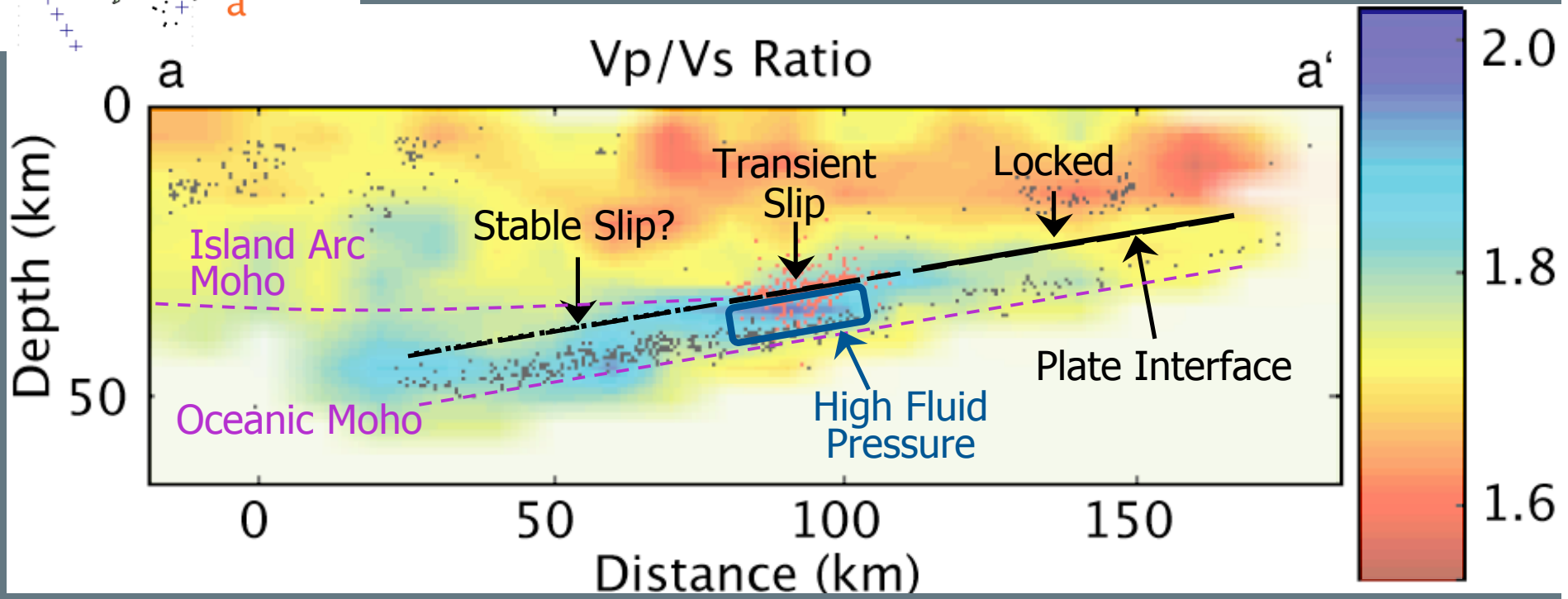
S-wave arrival



30 sec

Event Locations and Interpretation





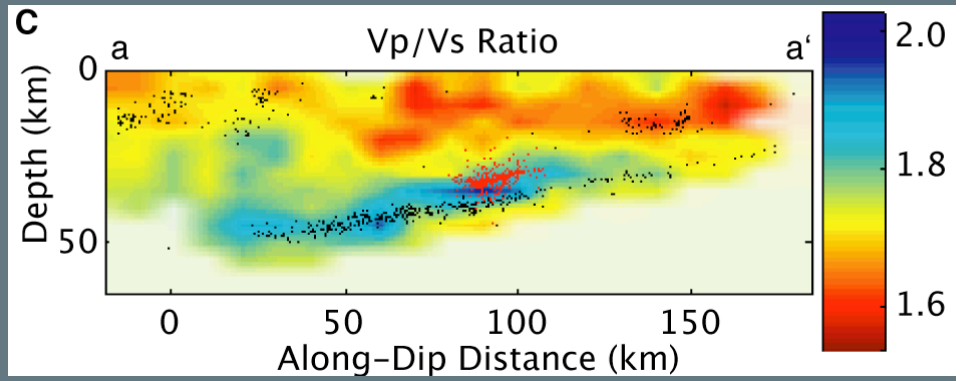
Shelly et al., *Nature*, 2006

Red=Low-Freq. EQs
Black=Regular EQs

LFEs Generated by Shear Slip

Evidence:

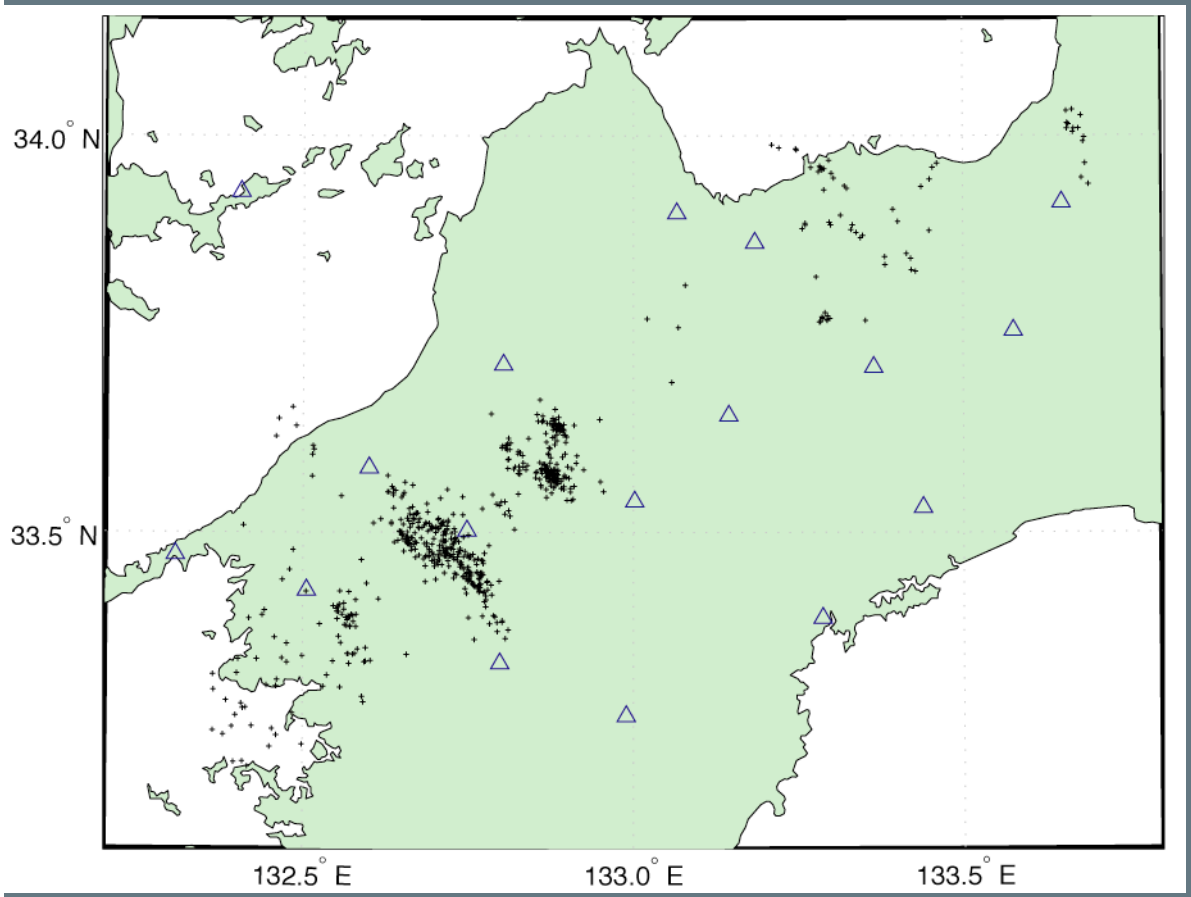
1. Location on plate interface
2. Temporal and spatial correspondence observed between LFEs/tremor and slow slip
3. P-wave first motions (Ide et al., 2006)



High fluid pressure may enable slip under low shear stresses

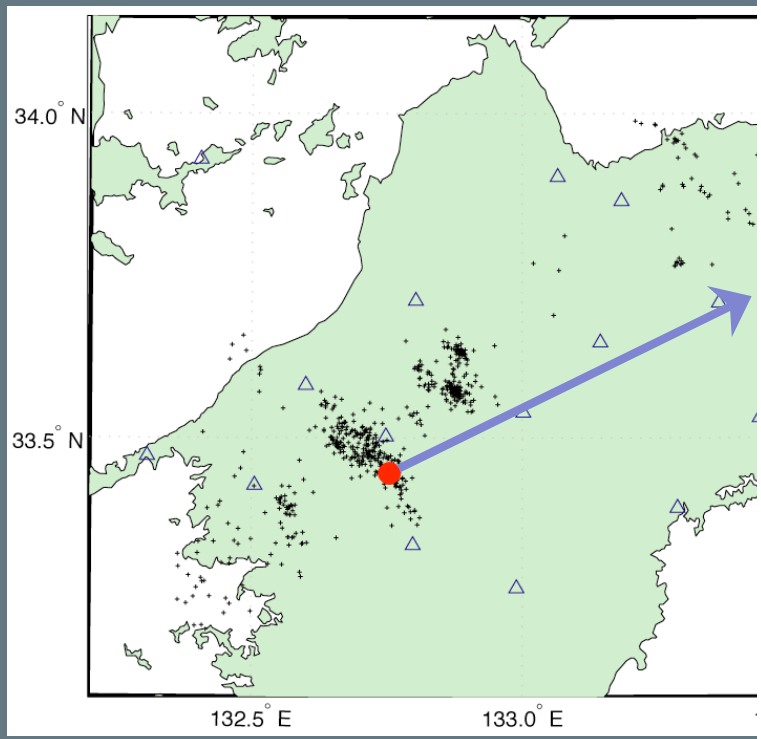
But, are LFEs are representative of tremor as a whole?

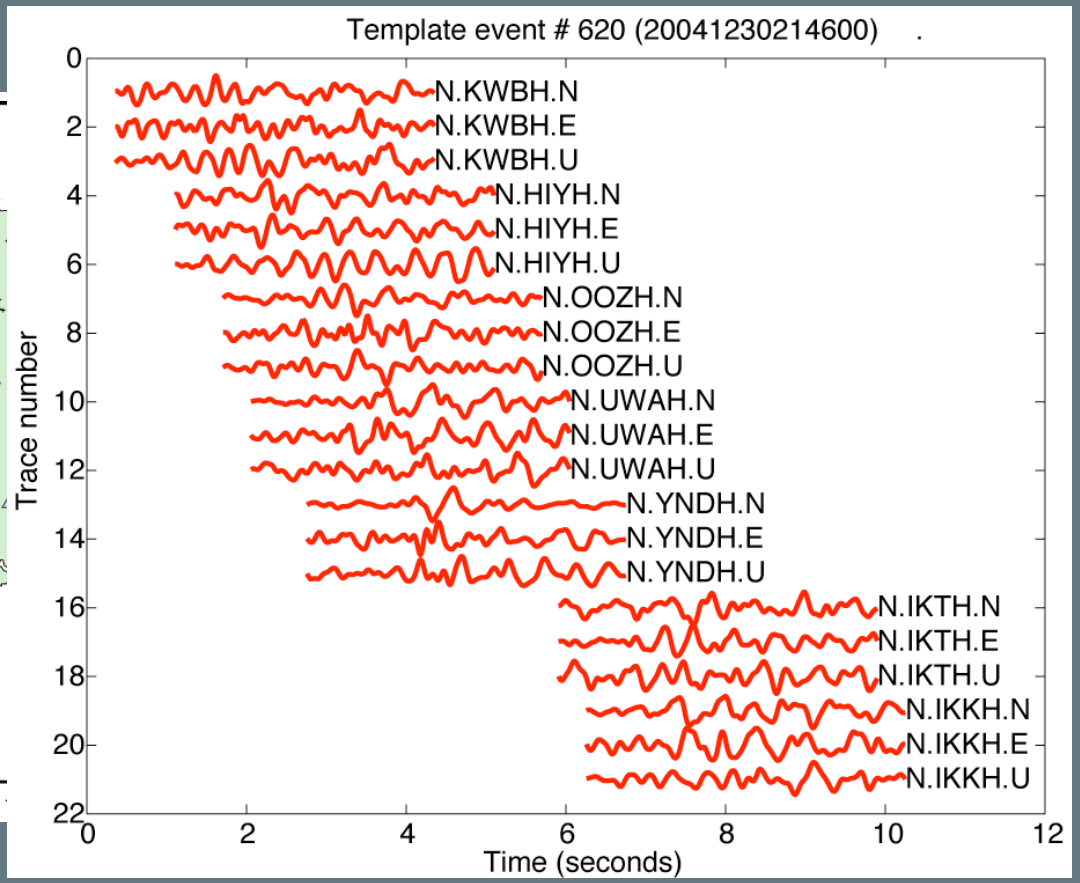
Template Events



- Best-recorded of located LFEs
- Each with
  - 6+ stations
  - 18+ channels
- 677 LFE template events

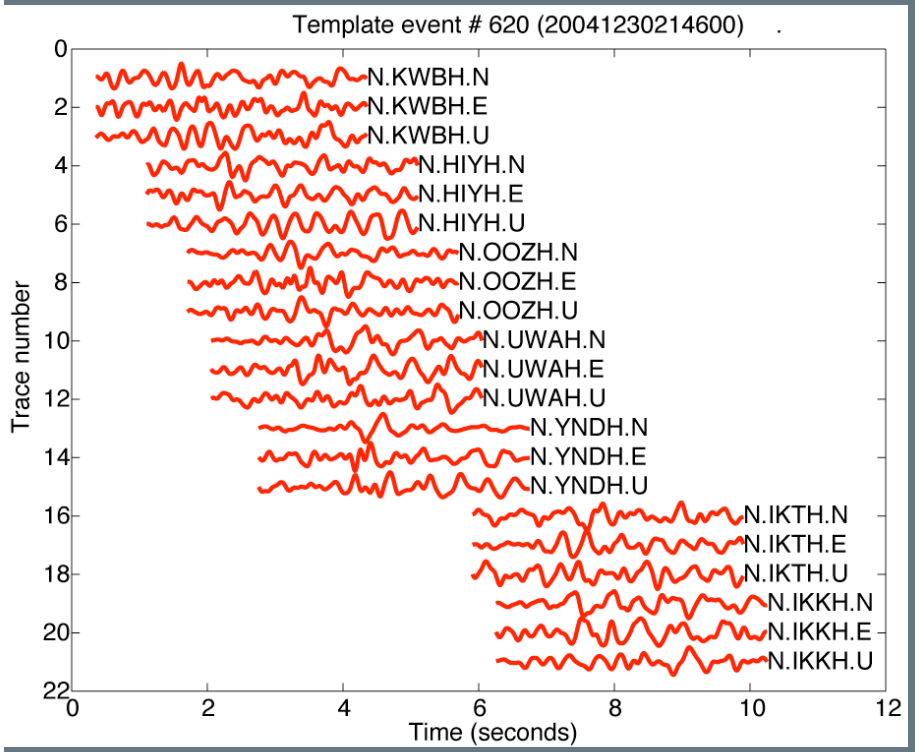
Template Event Waveforms



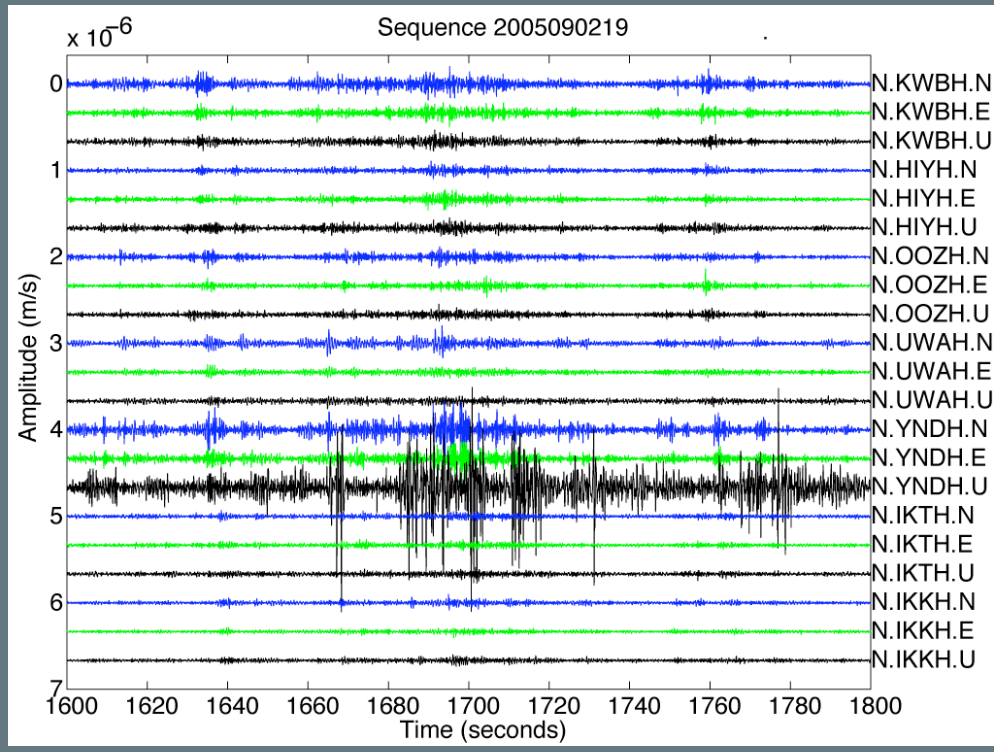


Template LFE Buried in Tremor?

Template LFE

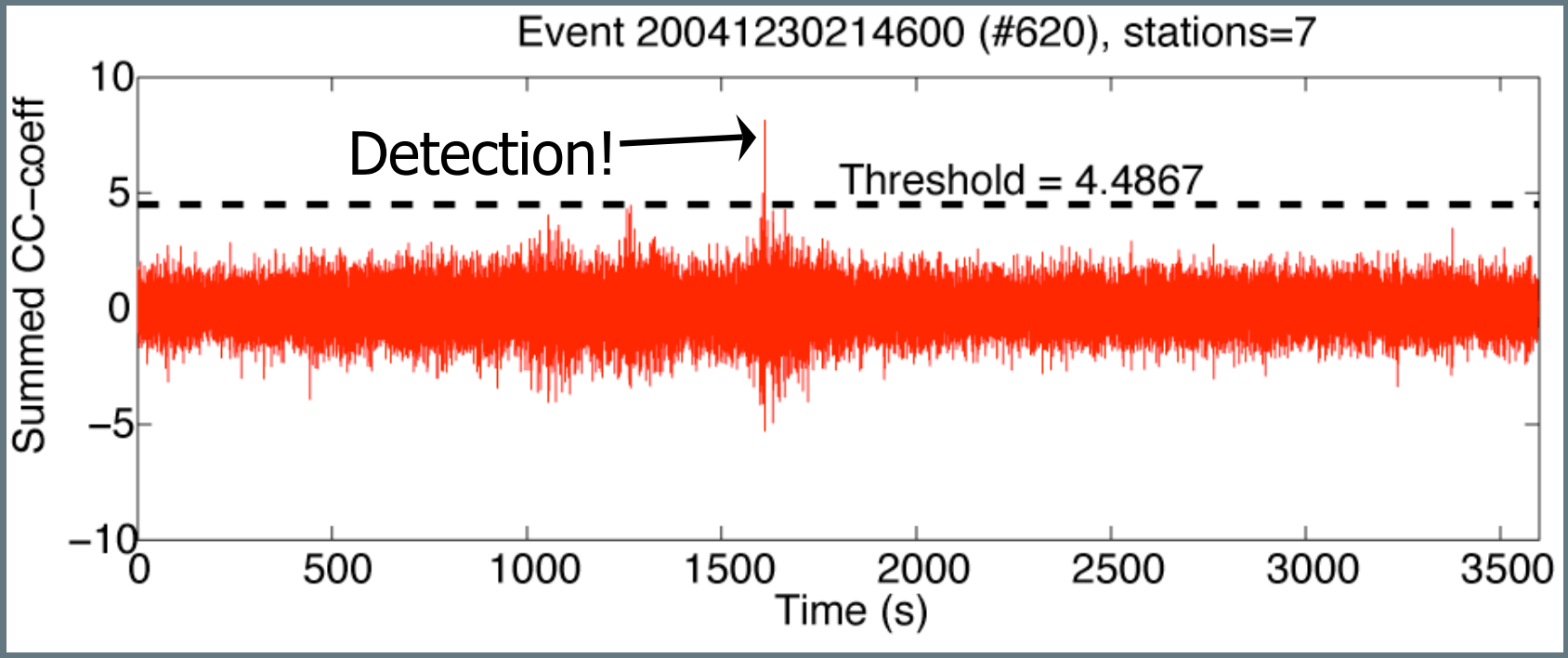


Continuous Tremor

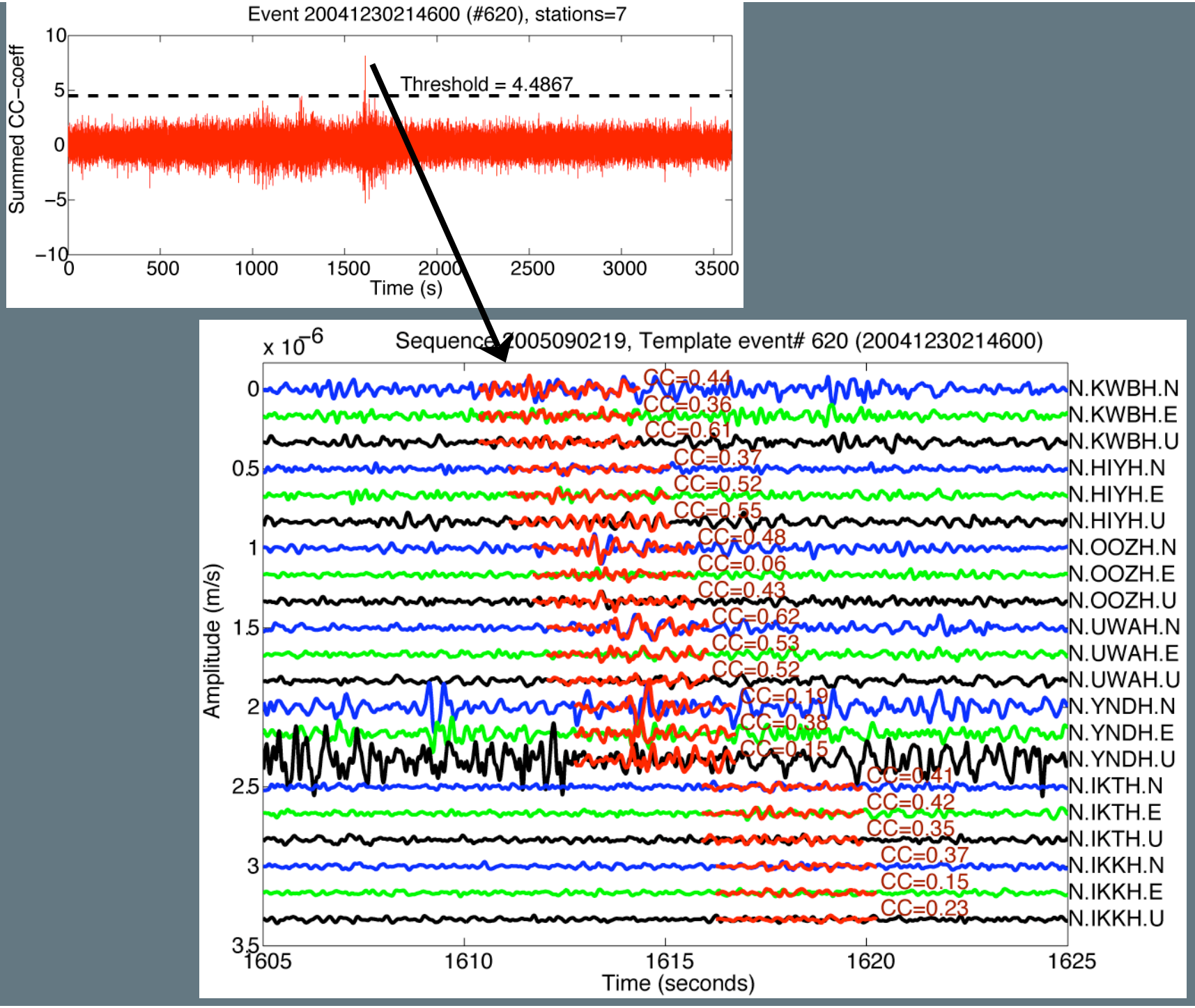


Is it in here somewhere???

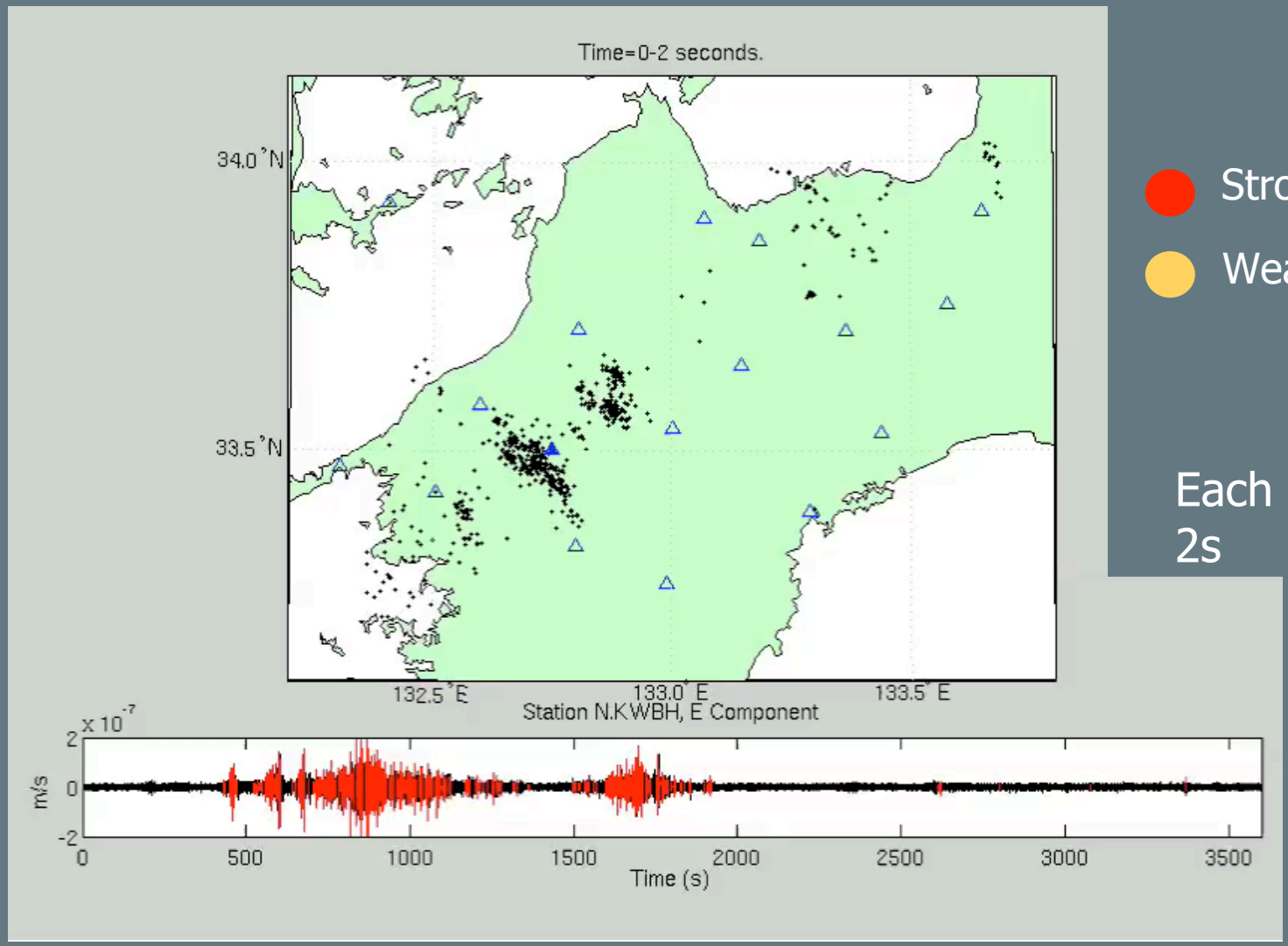
Summed correlation function



1 hour


Event 20041230214600 (#620), stations=7
Summed CC−coeff
Threshold = 4.4867
Time (s)
x 10^−6
Sequence 2005090219, Template event# 620 (20041230214600)
Amplitude (m/s)
CC=0.44
CC=0.36
CC=0.61
CC=0.37
CC=0.52
CC=0.55
CC=0.48
CC=0.06
CC=0.43
CC=0.62
CC=0.53
CC=0.52
CC=0.19
CC=0.38
CC=0.15
CC=0.41
CC=0.42
CC=0.35
CC=0.37
CC=0.15
CC=0.23
N.KWBH.N
N.KWBH.E
N.KWBH.U
N.HIYH.N
N.HIYH.E
N.HIYH.U
N.OOZH.N
N.OOZH.E
N.OOZH.U
N.UWAH.N
N.UWAH.E
N.UWAH.U
N.YNDH.N
N.YNDH.E
N.YNDH.U
N.IKTH.N
N.IKTH.E
N.IKTH.U
N.IKKH.N
N.IKKH.E
N.IKKH.U
Time (seconds)

Putting detections from all 677 template events together….



Strong Detection

Weaker Detection

Each frame = 2s

Conclusions

1. LFEs are probably generated by fluid-enabled shear slip at plate interface asperities

2. Continuous tremor appears to be a swarm-like sequence of LFEs, demonstrating tremor and slow slip are simply different manifestations of a single process!