Multi-Method Systematic Search for Tectonic Tremor in the San Jacinto Fault, California & Applications of Coulomb Stress Modeling

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Introduction

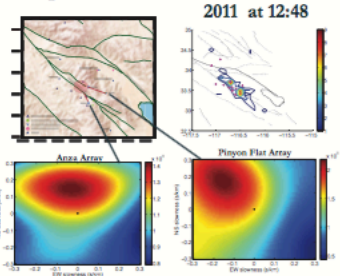
- With the application of visual inspection of seismic data, multibeam backprojection (MBBP) (Ghosh *et al.*, 2009), and envelope cross correlation (Wech & Creager, 2008), a thorough inspection of tremor activity near the San Jacinto Fault (SJF) was conducted for June, 2011

- After manually cross-referencing the ANSS earthquake catalog with envelope cross correlation findings, we detected an average of 27 time windows (with 300s durations) that contained tremor per day with two discrete source locations; to the northwest and the southeast of the Anza Gap, an aseismic section of the Anza segment of the SJF

- Events were selected at random for multi-beam backprojection where using the MAOTECRA high-density arrays, we were able to determine a relative source location based on azimuthal convergence; low slowness values also indicate a deep source helping to preclude the potential of a surficial noise source (i.e. trains, windmills, etc.); locations in ECC match the results of MBBP for the selected events thus far

- Using the slow earthquake scaling law (Ide *et al.*, 2007), we use a combined duration of tremor events to estimate their magnitudes and thus other variables required in Coulomb calculations (rupture area and

Example #1: Tectonic Tremor northwest of Anza Gap: June 1, 2011 at 12:48



- ECC results indicated that the tremor event that takes place at 12:48 on June 1, 2011 occurs at (-116.92, 33. 82)

- The approximate location identified through MBBP through beam convergence of the Pinyon Flat and Anza arrays from the MAOTECRA network is shaded in red (upper left) and contains the source locations identified through ECC

- The upper right hand figure gives a contoured plot of the number of events that occur within each contour, where the pink stations indicate the location of the stations used

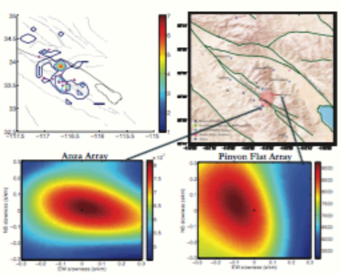
Example #2: Tectonic Tremor southeast of Anza Gap: June 8, 2011 at 4:49:48

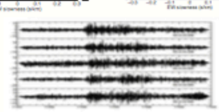
- ECC results indicate that the tremor event that takes place on June 8, 2011 occurs at (-116.7, 33.48)

- The approximate location identified through MBBP through beam convergence of the Pinyon Flat and Anza arrays from the MAOTECRA network is shaded in red (upper right) and includes the ECC location

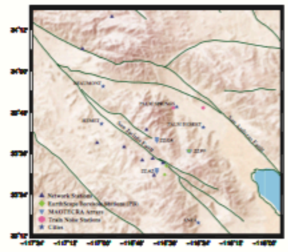
-- The upper left hand figure gives a contoured plot of the number of events that occur within each contour, where the pink stations indicate the location of the stations used -- here it is interesting to note that many events also occurred on this day near the San Gorgonio Pass. In the month-long histogram, June has more than 2x as much tremor as any other day

- The bottom right shows a seismogram from 1-4 Hz with only network stations (PB.B087, PB.B946, AZ.KNW, AZ.RDM, AZCRY). The emergent signal has a duration of ~ 100s and is depleted of energy in lowers frequency bands.





Study Location and Data



Study Area

- No rupture known since at LEAST 1890 (Sykes and Nishenko, 1984)
- Anza thought to remain aseismic because of high normal stresses from Buck Ridge and Coyote Creek segments of SJF that converge on that area; an oblique orientation of maximum normal stresses (Sanders & Kanamoori, 1984)
-Thatcher et al., (1975) forecasted a M6.5+ for this region

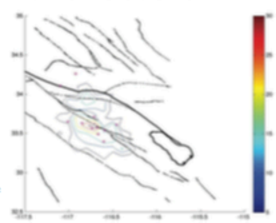
Data

-The MAOTECRA network consisted of three high density arrays near the Anza Gap that collected data from March - July, 2011 and were used for MBBP
-For ECC, 10 network stations were used from the Anza Network, the CalTech Netowrk, including three EarthScope borehole stations-
- All analyses were performed between 6-8 Hz to avoid characteristic train noise between 3-5 Hz (Cristea-Planton, 2013), and was observed in multiple frequency bands to eliminate uncataloged earthquakes

Spatial & Temporal Distribution of Tremor in June, 2011

RIGHT) Spatial Distribution of Tremor
The spatial distribution of 300s time-windows tremor in June 2011, after cross referencing the earthquake catalog, (right) shows there is a high concentration of events to the southeast of the Anza Gap, followed by two-thirds as many tremor events to the northwest of the seismic gap. The pink stars represent the network stations (including three borehole stations) used in ECC. There is also a cluster of the events near the San Gorgonio Pass

- All analyses were conducted between 6-8 Hz, the time window duration was 300s, and the time overlap was 150s. The minimum cross-correlation coefficient was 0.65, and a minimum of 4 stations were required to determine a hit.



LEFT) Temporal distribution of tremor in June, 2011

- This histogram indicates the number of 300s time windows per day that contain non-volanic tremor (though it hasn't been account for if they overlap)

- There is an average of ~23 time windows that contain tremor per day

-These events only reprent *clustered* events and are represented within the contour lines in the figure above

Summary of Main Points & Future Work

Summary

- Tremor was detected on a daily basis to the southeast and northwest of the aseismic Anza Gap in the SJF

- ECC, MBBP, and visual inspection were all used to confirm the findings and thus far are corroborative

- All analyses were conducted in frequency bands 6-8 Hz (ECC, MBBP) and 1-4 Hz (visual inspection) to avoid known sources of regional noise (train); some candidates were tested in alternative frequency bands to eliminate earthquakes not included in the earthquake catalog

- Coulomb models show that stress from combined tremor events is adding to stress up-dip of the rupture patches, and also on either side, adjacent to the rupture patches -- thus the Anza Gap has an increase in stress from both sides

Future Work

- Build a larger duration catalog (1+ year), incorporating array data where available to confirm ECC fingings with MBBP; explore spatiotemporal behavior in greater deapth; seek to determine tremor migration and decay patterns here

- Identify and characterize potential spatial and temporal relationships between tremor and regular local/regional earthquakes, or teleseismic events

- Model possible deep creep, or transient deformation in the Anza Gap and compare it to results of Coulomb models

Applications of Coulomb Stress Modeling to Tremor in the San Jacinto Fault

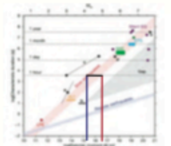
- We apply the slow earthquake scaling law (Ide et al., 2007) to determine seismic moment for a hypothetical event representing the combined duration of many tremor events (see red line for maximum seismic moment of 1 hr duration; blue line for minimum seismic moment of 1 hour of combined tremor activity)

- With seismic moment, we can then determine Mw, rupture area, and slip amount.

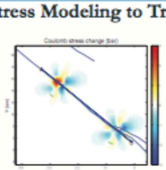
- We use a coefficient value of 0.4 since it is below Byerlee's crustal value for friction

- The reciever fault is oriented in the same way as the Anza Gap; our source is 15km deep

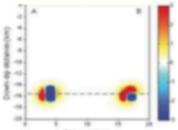
- **Each magnitude of event tested showed similar features, where stress is transferred from the rupture patch. up-dip to the locked zone, and also towards either side of it**

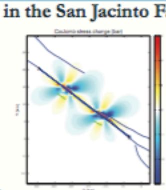


Slow earthquake scaling law (Ide *et al.*, 2007)

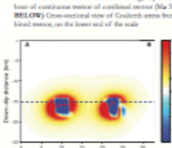


ABOVE) Aerial View of Coulomb stress change due to tremor after for what would be the minimum amount of energy expected to be produced in hour of continuous tremor of combined tremor (Mw 4.3)
BELOW) Cross-sectional view of Coulomb stress from one hour of combined tremor, on the lower end of the scale





ABOVE) Aerial View of Coulomb stress change due to tremor after for what would be the minimum amount of energy expected to be produced in hour of continuous tremor of combined tremor (Mw 5.0)
BELOW) Cross-sectional view of Coulomb stress from one hour of combined tremor, on the lower end of the scale



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