Temporal Changes of Seismicity in Salton Sea Geothermal Field with Waveform-matched Catalog

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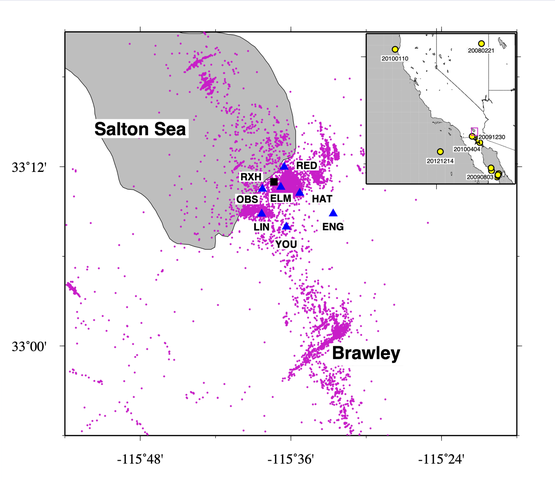
Introduction

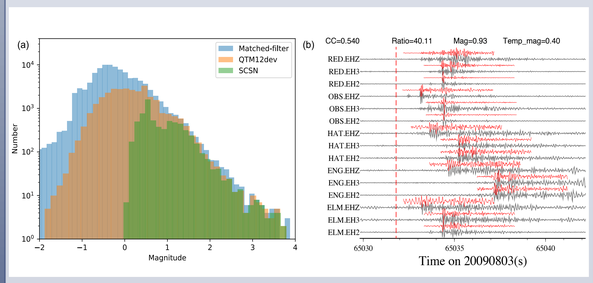
The Salton Sea Geothermal Field (SSGF) is one of the most seismically active and geothermally productive fields in California. Geothermal fields are sensitive to stress changes caused by distant and regional large earthquakes. In this study we analyze the temporal and spatial changes in seismicity in the SSGF during 2007-2014, with a newly detected catalog from template matching using seismic data recorded by the borehole seismic network (EN).

Study Region



Salton Sea Geothermal Field and EN stations, the violet dots are relocated template events from 2007/12/31 to 2014/01/11 [Hauksson et al., 2013]. Blue triangles are EN stations and RXH is a broadband station in CI. Inset shows location of SSGF, the yellow dots are regional target events for investigation of triggering.

Matched-Filter Detection



(a) Magnitude distribution for three catalogs. Three catalogs are: matched-filter detected (MFD) catalog in this study, the QTM catalog from Ross et al. (2019) and the relocated SCSN catalog from Hauksson et al. (2013). The MFD catalog in this study is 3 times and 15 times more than the QTM and SCSN catalogs respectively. (b) Example of a detected event on 08/03/2009 with cross-correlation coefficient 0.54.

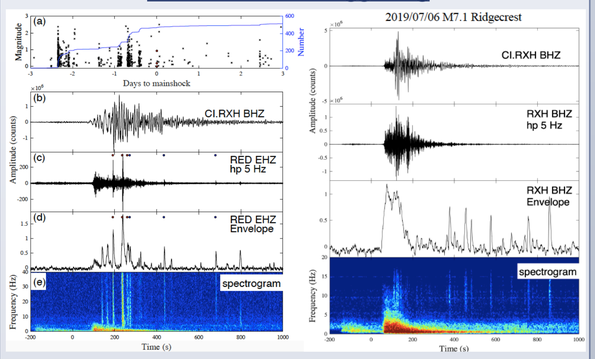
Searching for Triggered Seismicity Change

We search for triggered seismicity following 42 M>5.5 earthquakes with distance larger than 50 km from SSGF, and compare the seismicity around the mainshocks with the matched-filter catalog, by computing β-value in different triggering windows: during surface wave window with velocity of 2-5km/s, 1 day, and 30 days after the mainshocks.

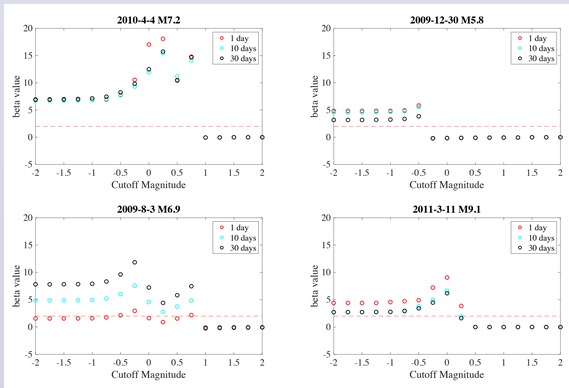
$$\beta = \frac{N_a - N(T_a/T)}{\sqrt{N(T_a/T)(1-(T_a/T))}}$$

Ta: triggering window
Na: number of events in Ta
N(Ta/T): expected number of Na
T: total time window before and after the mainshock

Instantaneous Triggering

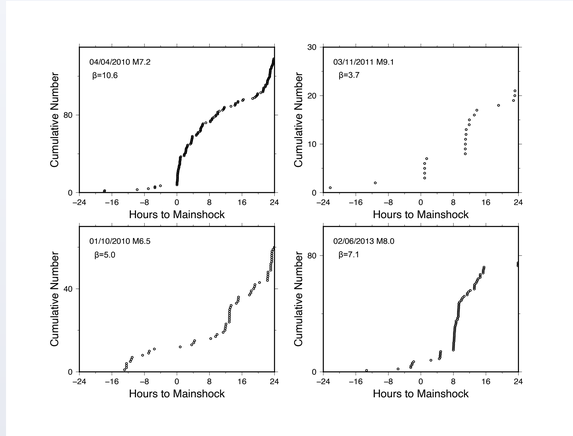


Left: (a) Detected events 3 days before/after the 08/03/2009 M6.9 Baja California Earthquake, red circles are events within 600s of the mainshock with M>=0, blue circles are events with M<0. (b) Waveform in broadband station RXH. (c) High-pass 5 Hz waveform on station RED, (d) envelope of (c), (e) spectrogram of (c). Right: Waveforms and high-pass 5 Hz filtered envelope of station RXH following the 2019/07/06 M7.1 Ridgecrest earthquake.



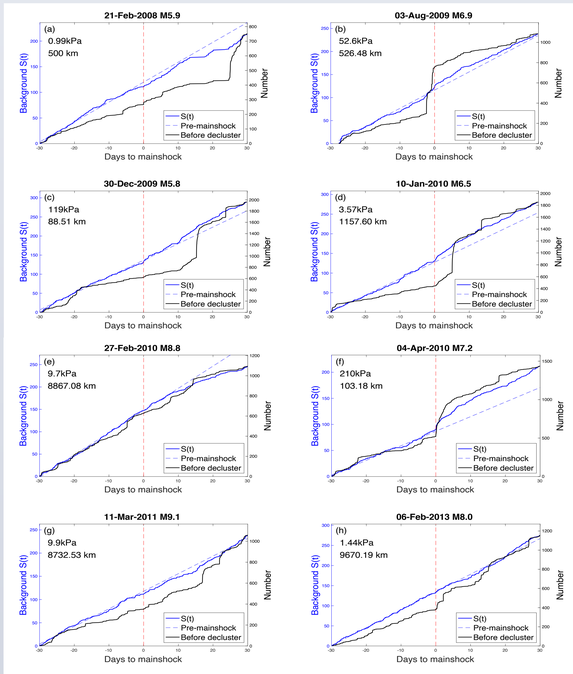
Example of β-value with different cutoff magnitude for the MFD catalog, different colors are 1 day, 10 days and 30 days pre-mainshock window used to compute the β-value. Red dashed lines denote the 95% confidence of significant triggering (β=2).

Delayed Triggering



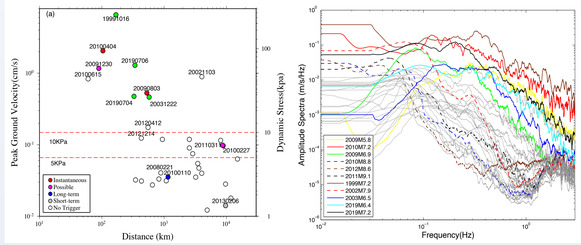
Cumulative number of earthquakes of M>0 in SSGF after four earthquakes, the 04/04/2010 M7.2 El Mayor-Cucapah Earthquake triggered seismicity increase immediately after the mainshock, others trigger with hours of time delay.

Background Seismicity Change

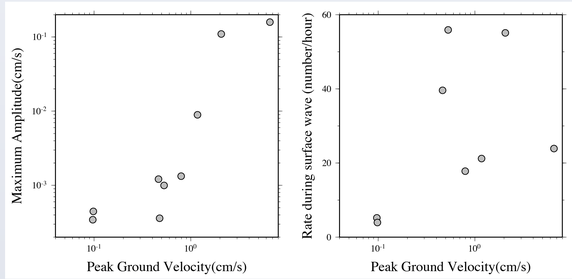


To remove the effect of local aftershock triggering, we apply a stochastic declustering method based on space-time Epidemic-Type Aftershock Sequence (ETAS) model to the catalog (Ogata 1998; Zhuang et al, 2004). Then we calculate the cumulative background seismicity $S(t)$ in the catalog based on the background probability of each event. This figure shows that the 2009/08/03 M6.9, 2010/04/04 M7.2 and 2010/01/10 M6.5 earthquakes triggered seismicity increase 30 days afterwards.

Dynamic Triggering Patterns

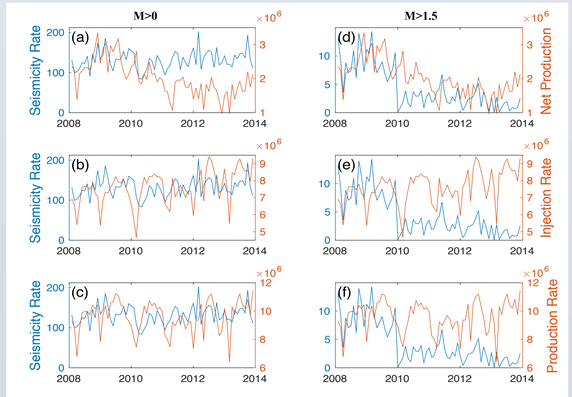


(a) Peak ground velocity in station CI.RXH and estimated dynamic stress change versus distance from SSGF. (b) Amplitude spectra for all events, the waveform between surface wave velocity of 2km/s and 5km/s are used. No clear threshold for PGV.



Relationship between maximum amplitude of triggered events, seismicity rate during surface wave and PGV for all the positive triggering earthquakes. The maximum amplitude is correlated with PGV.

Long-term Seismicity Change



Monthly cumulative background seismicity of events with M>0 in Salton Sea compared with (a) net production rate, (b) injection rate and (c) production rate. (d) (e) (f) Same for events with M>1.5. The M>1.5 events are likely correlated with net production rates.

Summary

- With a 6-year matched-filter detected catalog in SSGF, we find more evidences of triggered seismicity.
- The M5-7 events within 500 km are more likely to trigger long-term seismicity in SSGF than teleseismic M>8.0 earthquakes, likely because they produce larger dynamic stresses at shorter periods.
- The maximum amplitude (magnitude) of triggered events in SSGF are likely correlated with peak dynamic stress changes.