Southern California Earthquake Center (SCEC3) Final Report

Zhigang Peng (PI)
School of Earth and Atmospheric Sciences
Georgia Institute of Technology, Atlanta, GA, 30338
February 28, 2012

I. Highlight of major research findings in SCEC3

Funding from SCEC3 has supported several lines of research at Georgia Tech's earthquake seismology group over the past few years. The major research findings are summarized below, and some are further elaborated in the technical report submitted together in this report.

1. Dynamic triggering of deep tremor and shallow earthquakes in California

In this direction, we mostly focused on understanding the physical mechanisms and necessary conditions for dynamic triggering of deep tremor and shallow earthquakes in California. Peng et al. [2010] examined triggered earthquakes in the Coso geothermal regions and triggered tremor around Parkfield-Cholame following the 2010 Mw8.8 Chile earthquake. They found that both triggered earthquakes and tremor were consistent with frictional failure at different depths on critically-stressed faults under the Coulomb failure criteria. Peng et al. [2011a] found the first evidence of dynamic triggering of microearthquakes at Coso by multiple surface waves of the Chile earthquake. Aiken et al. [2011] systematically analyzed triggered microearthquakes in three geothermal regions (Long Valley, Coso and Geysers) in California and found different triggering behaviors. Such differences likely reflect different background seismicity levels or ambient physical conditions in these regions. Chao et al. [2012] found that tremor in the San Jacinto Fault in Southern California (SC) and the Calaveras Fault in Northern California (SC) was not easily triggered by teleseismic earthquakes, when compared with the Parkfield-Cholame section of the San Andreas Fault in Central California (CC). The lack of widespread triggered tremor in NC and SC is not simply a consequence of their different background noise levels from CC, but rather reflects different background tremor rates in these regions.

Peng et al. [2011b] found that artificial high-frequency signals could be generated from the analysis procedure when computing spectrograms. They recommended several ways to mitigate such problems. Peng et al. [2012] and Kilb et al. [2012] also converted seismic data into sounds and animations to help convey information about dynamic triggering of tremor and microearthquakes to general audience.

2. Temporal changes of site response and high-frequency bursts during strong motions

In this direction, we conducted a sequence of studies to understand temporal changes of site response induced by strong ground motions. Wu et al. [2010] used sliding window spectral ratio technique to track temporal changes of site response induced by weak to moderate strong ground motions recorded by the borehole seismic network KiK-Net in Japan. They found evidence of nonlinear site response with near instantaneous recovery with peak ground accelerations (PGA) as small as ~20-30 gal. When the PGA is larger than ~60 gal, they observed considerably stronger drops of the peak frequencies followed by logarithmic recovery with time. This may reflect the generation (and then recovery) of additional rock damage. Wu and Peng [2012] applied the same technique to the data recorded by the KiK-Net during the Mw9.1 Tohoku-Oki earthquake. They found evidence of up to 70% co-seismic temporal changes in site response, and followed by two stage of recovery process. The first stage is a rapid recovery within several hours, and the second stage is a slow recovery of more than five months.

A few years ago, we have examined high-frequency (>20 Hz) bursts during the 2004 Mw6.0 Parkfield earthquakes recorded by the dense UPSAR array [Fisher et al., 2008]. Because these bursts were not coherent among nearby stations, we suggested that they were caused by secondary sources immediately beneath each station. Together with Professor Assamaki in the CEE at Georgia Tech, we are in the process of understanding the physical mechanism the high-frequency bursts associated with the 3g acceleration at station MYG004 during the Tohoku-Oki mainshock [Wu et al. 2012].

3. Testing static vs. dynamic triggering of aftershocks in southern California

Understanding how earthquakes are triggered by static or dynamic stress changes remains to be one of the most debated topics in earthquake science. We took advantage of the dense seismic observations in SC following the 2010 Mw7.2 El Mayor-Cucapah earthquake, and apply a waveform-based template detection technique to identify missing earthquakes in the Salton Sea geothermal region after the mainshock. Using GPU parallel computing, we have successfully detected ~70 times more earthquakes than listed in the SCSN catalog around the mainshock [Meng et al., 2012]. These newly detected events suggest that dynamic triggering is mostly dominant immediately after the mainshock. However, static triggering became more important in the next few months after the mainshock. We are in the process of applying the same procedure to a larger space-time region in Southern California.

II. Technical Report of 2011 SCEC3 Funded Project
Dynamic triggering of shallow earthquakes and deep tremor in Southern California

Summary

A systematic analysis of triggered seismic activity in southern California not only provides important new information on the fault mechanics on the shallow and deep crustal faults but also may shed new light on the predictability of large earthquakes. Our past year's effort mainly focused on the following two directions: (1) systematic comparison of triggered tremor in Southern, Central, and Northern California; (2) systematic search of dynamic triggering in geothermal regions at Salton Sea, Coso, and the Geysers geothermal regions, and the Long Valley caldera. Our results suggest a difference in the triggerability of tremor and earthquakes in California, which are likely related to the background seismicity in these regions.

1. Introduction

Deep non-volcanic tremor is a newly observed seismic signal away from volcanic regions with non-impulsive arrival, low amplitude, and long duration [Peng and Gomberg 2010; Beroza and Ide 2011; and references therein]. Tremors generally occur near or below the seismogenic zone where regular earthquakes occur and sometimes accompany slow-slip events. Together they are termed "Episodic Tremor and Slip" (ETS) [Rogers and Dragert, 2003]. After the initial discovery of tremor in southwest Japan [Obara, 2002], tremors have been identified in many regions along major plate boundaries around the Pacific plate [Schwartz and Rokosky, 2007; Peng and Gomberg, 2010], and the San Andreas Fault (SAF) system in Central California [Nadeau and Guilhem, 2009; Shelly and Hardebeck, 2010].

Recent studies have shown that tremor can be instantaneously triggered by passing surface waves of regional and teleseismic earthquakes [Peng and Gomberg, 2010; and references therein]. Triggered tremors are mostly found at places where ambient tremors (i.e. not associated with teleseismic earthquakes) are identified, and their spectra shapes are similar [Rubinstein et al., 2007; Peng et al., 2008]. In addition, at least portions of triggered tremor consists of many low-frequency earthquakes (LFEs) [Peng et al., 2010; Shelly et al., 2011], suggesting that triggered and ambient tremors are generated by similar failure processes but with different loading condition [Gomberg, 2010].

Despite these recent tremor observations, many questions remain open. For example, what is the exact relationship between deep tremor and shallow earthquakes? What are the physical mechanisms and nessesary conditins for tremor generations. To answer these questions, we have conducted a systematic search and comparison of triggered tremor and microearthquakes in California, which are summarized below.

2. Systematic comparison of triggered tremor in California

Chao et al. [2012] conducted a visual inspection of deep tremor triggered by large teleseismic earthquakes in the following three regions in California: the Calaveras Fault (CF) in Northern California, the Parkfield section of the SAF in Central California, and the Anza section of the SJF in Southern California. Out of the 42 large ($M_w \geq 7.5$) teleseismic earthquakes between 2001 and 2010, only the 2002 Mw7.9 Denali Fault earthquake triggered observable tremor in the CF and the SJF (Figure 1). This is in marked contrast with the Parkfield section of the SAF, where 12 earthquakes have triggered tremor in that region. We have examined and rule out the possibility of the background noise levels, path/site effects, or instrumentations as the primary cause of lack of widespread triggered tremor in the CF and SJF. Instead, we suggested that background tremor rates could be the main control of the different triggerability in these regions.

This hypothesis is supported by abundant ambient tremor activity at Parkfield [Shelly and Hardebeck, 2010], lack of reliable ambient tremor report in the SJF [J.P. Ampuero, per. comm. 2011] and CF. It is also consistent with the 'clock-advance' model [Gomberg, 2010], which assumes that triggered tremor occurs on the same patch of ambient tremor and that their duration time is advanced by the passing surface waves. In that model, the perturbed seismicity rate r is proportional to the background rate r_0, and a function is used to describe how the failure time of a fault patch is advanced by the perturbing stress. Finally, we also found that the amplitude of the triggered tremor correlates with that of the triggering surface waves at Parkfield (Figure 1), again matching well with the prediction of the clock-advance model.

Shelly et al. [2011] investigated both short and long-term behaviors of triggered tremor at Parkfield identified from an LFE-template approach [Shelly and Hardebeck, 2010]. They found that triggered tremor migrated along the SAF strike during the passing surface waves, with a migration speed similar to those of ambient tremor [Shelly, 2010]. In addition, sometimes tremor activities continued a few days after the occurrence of teleseismic earthquakes. They suggested that triggered tremor was driven by a slow-slip event that was itself triggered by the distant event. Finally, it is worth noting that tremor was mostly triggered at Cholame, where most of Parkfield's background tremor activity occurs.

The exact reason for different triggering and ambient tremor rates in these regions is still not clear [Peng and Gomberg, 2010; Beroza and Ide, 2011]. Ellsworth [2008] suggested that triggered tremor in CC and NC might be associated with serpentinized fossil oceanic crust in these regions. However, such inference is rather speculative at this stage. Systematic searches for triggered and ambient tremor elsewhere, along with detailed analysis of the geophysical and material properties at tremor depth are needed to further identify essential factors for tremor generation.

Following the 2011 Mw9.0 Tohoku-Oki earthquake, we also conducted a systematic search of triggered tremor in California [Chao et al., 2011]. We identified clear tremor signals beginning around the long-period S-wave arrival and then further modulated by the Love and Rayleigh waves at the Parkfield section of the SAF [Hill et al., 2012]. In comparison, only weak tremor signals were observed during the large-amplitude surface waves around the SJF in southern California. The surface wave amplitudes and pre-event background noises in these two regions are similar, yet the triggered tremor amplitudes differ by nearly an order of magnitude (Figure 2). As was found in our previous studies [Chao et al., 2012], we suggest that such difference could be related to different ambient tremor rate or tremor triggering threshold in these regions.

3. Dynamic triggering of microearthquakes in geothermal regions in California

Previous studies have suggested that regions with active volcanism and/or geothermal fields are more susceptible to dynamic and delayed triggering of microearthquakes than other regions due to the circulation of fluids [Hill and Prejean, 2007; and references therein]. During the past few years we have conducted a systematic study of dynamic triggering in four geothermal regions in California: Long Valley Caldera, Coso Geothermal Field, the Geysers, and the Salton Sea [Aiken et al., 2011; Doran et al., 2011]. In each region, we applied a band-pass filter to examine high-frequency signals during and immediately after moderate to large regional and teleseismic earthquakes. We confirmed the statistical significance of triggering effects by computing the β- and *z*-statistical tests based on hand-picked events before and after the mainshock (e.g., Figure 3). Our current results suggest that the Geysers is the most susceptible to dynamic triggering of the three, as the region appears to require the least amount of dynamic stress (~1kPa) to trigger seismic activity. In contrast, Long Valley is the least sensitive to dynamic stress, even though Long Valley and Coso Geothermal Field share a common higher stress threshold (~5kPa) for triggering earthquakes. We hypothesize that the Geysers may be the most susceptible to triggering because of its high earthquake productivity, but this region's high surface heat flow rate may also be a factor. This finding is comparatively similar to the Salton Sea geothermal region in California. Doran et al. [2011] found that the Salton Sea region also has a low triggering threshold of (~1-2kPa), perhaps because this region is also characterized by a high surface heat flow rate and background seismicity rate like the Geysers. Meanwhile, Long Valley's relative unresponsiveness to regional and remote earthquakes suggests that other factors potentially play a role in the dynamic triggering process, i.e. the Long Valley region may currently be in a state of quiescence.

4. Student Support and Involvement.

This project provided partial support for the GT graduate student Kevin Chao, who has become an export in studying triggered tremor in Taiwan, California, and New Zealand. He is expected to defend his Ph.D. thesis in May and his work in California triggered tremor [Chao et al., 2012] will become a chapter of his thesis. In addition, it provides summer support to the second-year graduate student Chastity Aiken to work on comparison of triggered microearthquakes in geothermal regions in California. Chastity is expected to continue working on comparing triggered tremor in Central and Southern California if she successfully passes her comprehensive exam in April 2012.

References

Aiken, C., Z. Peng, and C. Wu (2011), Dynamic triggering of microearthquakes at three geothermal regions in California, *Seismo. Res. Lett.*, 82, 290.

Beroza, G. C. and S. Ide (2011), Slow earthquakes and Nonvolcanic Tremor, *Annu. Rev. Earth Planet. Sci., 39*, 271-296, doi:10.1146/annurev-earth-040809-152531.

Chao, K., Z. Peng, D. P. Hill, D. R. Shelly, B. Enescu, B. Fry, and C. Aiken (2011), Triggered non-volcanic tremor following the 2011 Tohoku-Oki Earthquake, abstract presented at the 2011 Annual SCEC meeting.

Chao, K., Z. Peng, A. Fabian, and L. Ojha (2012), Comparisons of triggered tremor in California, *Bull. Seismol. Soc. Am.*, 102(2), doi: 10.1785/0120110151.

Doran, A., X. Meng, Z. Peng, C. Wu and D. Kilb (2010), Dynamic triggering of earthquakes in the Salton Sea region of Southern California from large regional and teleseismic earthquakes, *Eos Trans. AGU*, *91*, Fall Meet. Suppl., Abstract S33B-2104.

Ellsworth, B. (2008), Nonvolcanic Tremor Beneath the San Andreas Fault: Why?, *the "Aseismic Slip, Non-Volcanic Tremor, and Earthquakes" Workshop in Sidney, British Columbia, Canada*, http://www.earthscope.org/es_doc/ETS/Talks/Ellsworth_ETS08_dunsmuir.pdf.

Gomberg, J. (2010), Lessons from (triggered) tremor, *J. Geophys. Res.*, *115*, B10302, doi:10.1029/2009JB007011.

Hill, D. P., and S. G. Prejean (2007), Dynamic triggering, in Treatise on Geophysics, 257–292, ed. Schubert, G., Vol. 4: Earthquake Seismology, ed. Kanamori, H., Elsevier, Amsterdam.

Hill, D. P., D. R. Shelly, Z. Peng, and C. Aiken (2012), Tectonic tremor beneath the Parkfield section of the San Andreas Fault triggered by shear and surface waves from the Mw 9.0 Tohoku-Oki, Japan, earthquake, *Bull. Seismol. Soc. Am.*, in prep.

Kilb, D., Z. Peng, D. Simpson, A. Michael, M. Fisher and D. Rohrlick (2012), Listen, watch, learn: SeisSound video products, *Seismol. Res. Lett.*, 83(2), 281-286, doi: 10.1785/gssrl.83.2.281.

Meng, X., X. Yu, Z. Peng and B. Hong (2012), Detecting earthquakes around Salton Sea following the 2010 M_w7.2 El Mayor-Cucapah earthquake using GPU parallel computing, *Procedia Computer Science*, submitted

Nadeau, R. M. and A. Guilhem (2009), Nonvolcanic Tremor Evolution and the San Simeon and Parkfield, California, Earthquakes, *Science*, *325*, 191-193.

Obara, K. (2002), Nonvolcanic deep tremor associated with subduction in southwest Japan, *Science*, *296*, 1679-1681, doi:10.1126/science.1070378.

Peng, Z. and J. Gomberg (2010), An integrated perspective of the continuum between earthquakes and slow-slip phenomena, *Nature Geosci.*, *3*, 599-607, doi: 10.1038/ngeo940.

Peng, Z., J. E. Vidale, K. C. Creager, J. L. Rubinstein, J. Gomberg, and P. Bodin (2008), Strong tremor near Parkfield, CA excited by the 2002 Denali Fault earthquake, *Geophys. Res. Lett.*, *35*, L23305, doi:10.1029/2008GL036080.

Peng, Z., D. P. Hill, D. R. Shelly, and C. Aiken (2010), Remotely triggered microearthquakes and tremor in Central California following the 2010 Mw8.8 Chile Earthquake, *Geophys. Res. Lett.*, *37*, L24312, doi:10.1029/2010GL045462.

Peng, Z., C. Wu, and C. Aiken (2011a), Delayed triggering of microearthquakes by multiple surface waves circling the Earth, *Geophys. Res. Lett.*, *38*, L04306, doi:10.1029/2010GL046373.

Peng, Z., L. T. Long, and P. Zhao (2011b), The relevance of high-frequency analysis artifacts to remote triggering, *Seismol. Res. Lett.*, 82(5), 654-660, doi: 10.1785/gssrl.82.5.654.

Peng, Z., C. Aiken, D. Kilb, D. Shelly, and B. Enescu (2012), Listening to the 2011 magnitude 9.0 Tohoku-Oki, Japan earthquake, *Seismol. Res. Lett.*, 83(2), 287-293, doi: 10.1785/gssrl.83.2.287.

Rogers, G. and H. Dragert (2003), Episodic Tremor and Slip on the Cascadia Subduction Zone: The Chatter of Silent Slip, *Science*, 300**,** 1942-1943, doi 10.1126/science.1084783.

Rubinstein, J. L., J. E. Vidale, J. Gomberg, P. Bodin, K. C. Creager, and S. D. Malone (2007), Non-volcanic tremor driven by large transient shear stresses, *Nature, 448***,** 579-582.

Schwartz, S. Y. and J. M. Rokosky (2007), Slow slip events and seismic tremor at circum-Pacific subduction zones, *Rev. Geophys., 45,* RG3004, doi:10.1029/2006RG000208.

Shelly, D. R. (2010), Migrating tremors illuminate complex deformation beneath the seismogenic San Andreas fault, Nature, *463*, 648-652, doi:10.1038/nature08755.
Shelly, D. R. and J. L. Hardebeck (2010), Precise tremor source locations and amplitude variations along the lower-crustal central San Andreas Fault, *Geophys. Res. Lett.*, *37*, L14301, doi:10.1029/2010GL043672.
Shelly, D. R., Z. Peng, D. P. Hill and C. Aiken (2011), Triggered creep as a possible mechanism for delayed dynamic triggering of tremor and earthquakes, *Nature Geosci. 4*, 384-388.
Wu, C., Z. Peng, and Y. Ben-Zion (2010), Refined thresholds for nonlinear ground motion and temporal changes of site response associated with medium size earthquakes, *Geophys. J. Int.*, 183, 1567-1576, doi: 10.1111/j.1365-246X.2010.04704.x.
Wu, C., and Z. Peng (2011), Temporal changes of site response during the M9.0 off the Pacific coast of Tohoku earthquake, *Earth Planets Space*, 63(7), 791-795, doi:10.5047/eps.2011.06.011.
Wu, C., and Z. Peng (2012), Long-term change of site response after the Mw9.0 Tohoku earthquake in Japan, *Earth Planets Space*, in revision.
Wu, C., Z. Peng and D. Assimaki (2012), Long-term change of site response and high-frequency radiations associated with the Mw9.0 Tohoku-Oki Earthquake in Japan, submitted to the Annual Seismological Society of America meeting, San Diego, April 2012.

III. Figures that highlight your research with captions

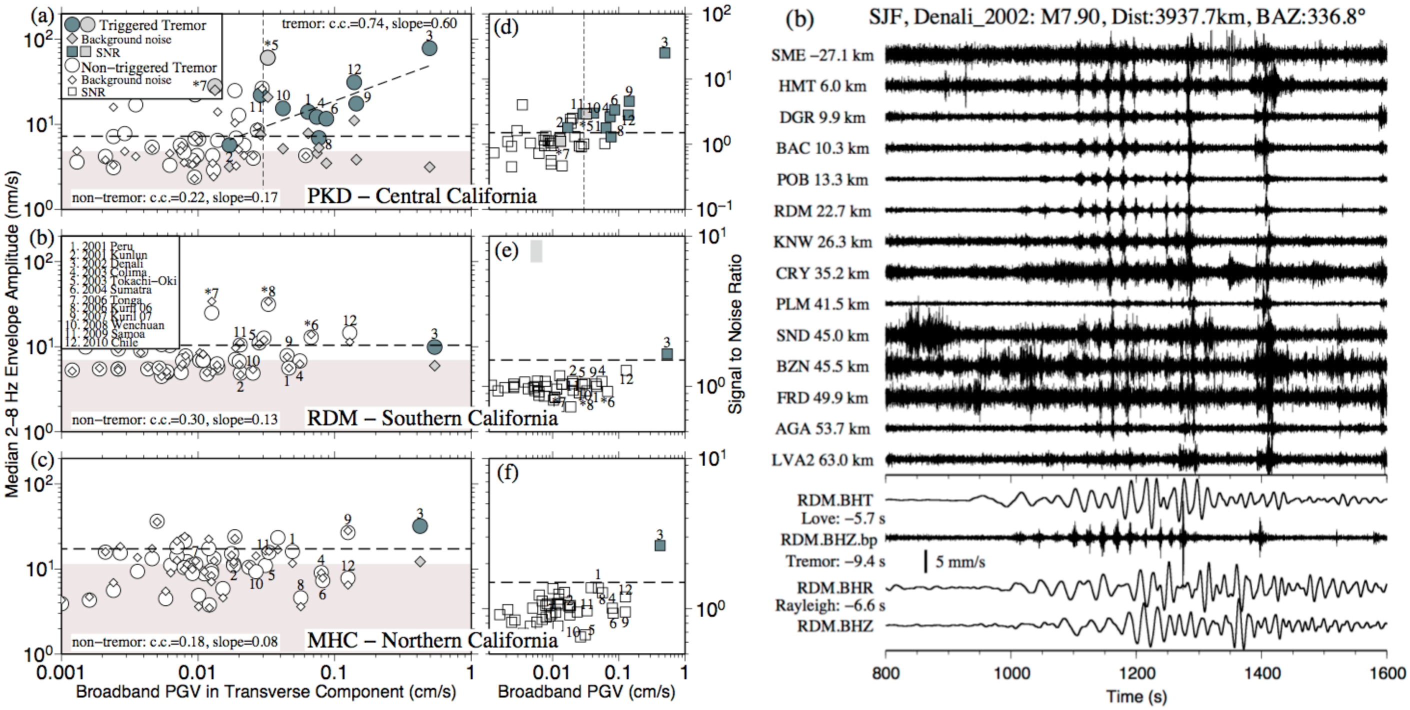


Figure 1. (**Left**) Maximum peak ground velocity (PGV) of surface wave (horizontal axis) in transverse component versus median amplitude of the 2-8 Hz 3-components band-pass-filtered envelope functions during the surface waves **(a-c)** and signal to noise ratio (SNR) (**d-f**) at broadband stations PKD, RDM, and MHC in Central California (CC), Southern California (SC), and Northern California (NC), respectively. (**Right**) Top: 2–8-Hz band-pass-filtered vertical seismograms showing the move-out of tremor triggered by the Denali fault earthquake along the San Jacinto fault (SJF) in southern California (SC). The seismograms are plotted along the SJF strike. Bottom: A comparison between the velocity and the 2–8 Hz band-pass-filtered seismograms recorded at the broadband station RDM. From Chao et al. [2012].

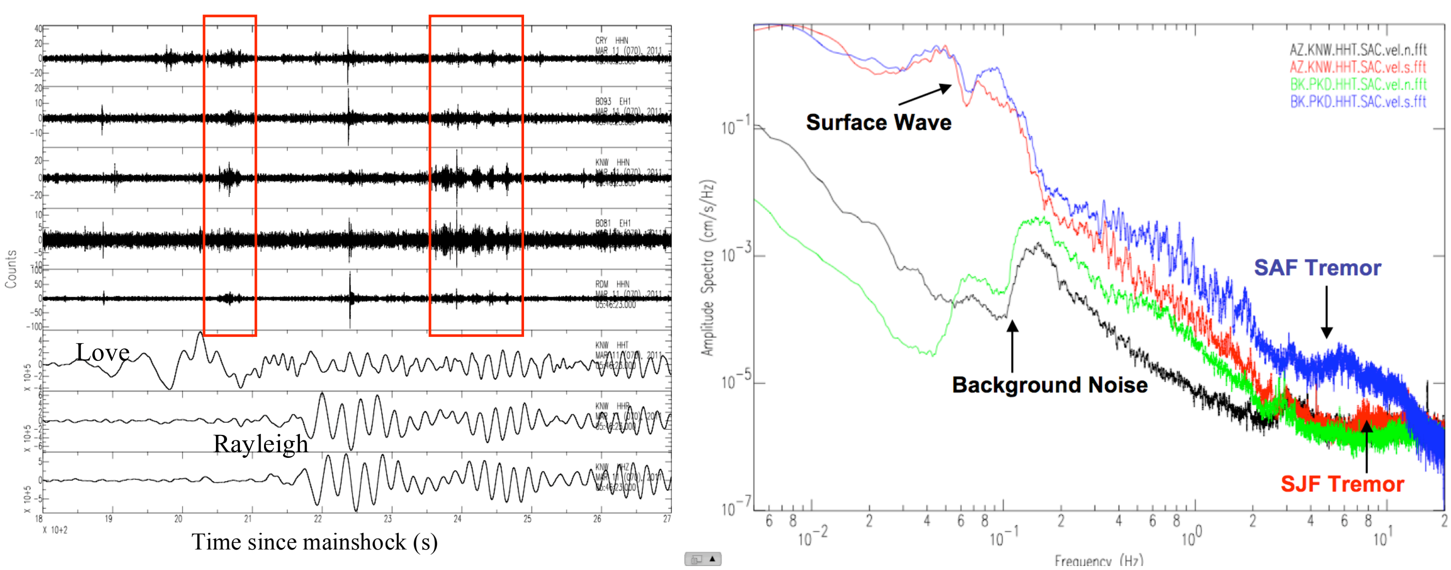
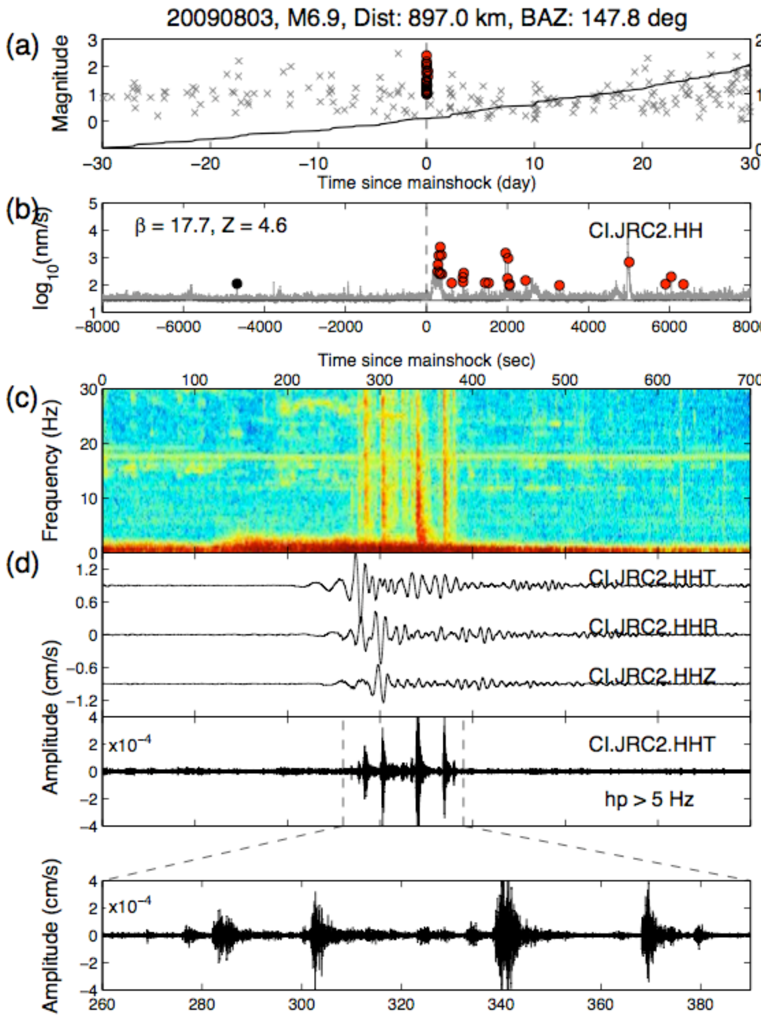


Figure 2. (**Left**) A comparison between 2-8 Hz band-pass filtered seismograms showing weak triggered tremor at the San Jacinto Fault and the broadband velocity seismograms at station KNW during by the Tohoku-Oki earthquake. (**Right**) A comparison of the amplitude spectra computed from the transverse component seismograms recorded at station PKD in Central California (blue) and station KNW in Southern California (red) during the large-amplitude surface waves of the Tohoku-Oki earthquake. The green and black lines denote the spectra before the mainshock for station PKD and KNW, respectively. Despite similar amplitudes for the long-period surface waves, the amplitudes in the tremor band of 2-10 Hz are quite different for these stations.



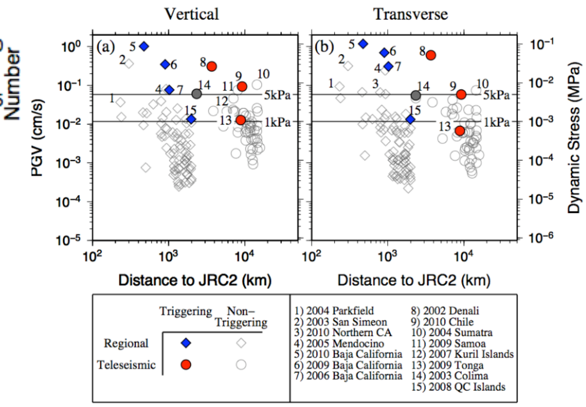


Figure 3. (**Left**) Earthquakes triggered in Coso by the 2009/08/03 M6.9 Baja California earthquake. (a) 30-day seismicity around the mainshock origin time with cumulative number of events. (b) Band-pass filtered (2-16 Hz) envelope function as recorded in Coso. (c) Spectrogram with high-frequency bursts representative of local earthquakes. (d) Broadband velocity seismogram with instrument response removed, band-pass filtered (2-16 Hz) seismogram showing triggered earthquakes, and zoom in of triggered earthquakes. (**Right**) Peak ground velocity (PGV) vs. epicentral distance to Coso. (a) Vertical PGV measured from the low-passed filtered 1 second Z component seismogram. (b) Transverse PGV measured from the low-passed filtered 1 second T (transverse) component seismogram.

IV. Information on outreach activity you have performed during SCEC3

The PI Peng has given multiple seminars and talks on the findings of non-volcanic tremor in Central and southern California at various institutions during SCEC3. These include the USGS Menlo Park (Summer, 2010), China Earthquake Administration in 2008 and 2011, and Caltech Seismolab in Spring 2009.

In addition, PI Peng has hosted a total of 5 SCEC summer interns during SCEC 3 (Summer Ohlendorf, Summer 2007; Amanda Fabian and Lujendra Ojha, Summer 2009; Adrian Doran and Meghan Fisher, summer, 2010). They have been working on various projects that are directly or partially funded by SCEC3. Their work has been presented at previous SCEC, AGU and SSA annual meetings, and some have resulted in peer-review publications [e.g., Chao et al., 2012; Kilb et al., 2012].

V. A bibliography of all publications supported by SCEC3 funds including papers in review (by calendar year)

Fischer, A., Z. Peng, and C. G. Sammis (2008), Dynamic triggering of high-frequency bursts by strong motions during the 2004 Parkfield earthquake sequence, *Geophys. Res. Lett.*, 35, L12305, doi:10.1029/2008GL033905.

Wu, C., Z. Peng and Y. Ben-Zion (2009a), Non-linearity and temporal changes of fault zone site response associated with strong ground motion, *Geophys. J. Int.*, 176, 265-278, doi: 10.1111/j.1365-246X.2008.04005.x.

Wu, C., Z. Peng, and D. Assimaki (2009b), Temporal changes in site response associated with strong ground motion of 2004 Mw6.6 Mid-Niigata earthquake sequences in Japan, *Bull. Seismol. Soc. Am.*, 99(6), 3487–3495, doi: 10.1785/0120090108.

Wu, C., Z. Peng, and Y. Ben-Zion (2010), Refined thresholds for nonlinear ground motion and temporal changes of site response associated with medium size earthquakes, *Geophys. J. Int.*, 183, 1567-1576, doi: 10.1111/j.1365-246X.2010.04704.x.

Peng, Z., D. P. Hill, D. R. Shelly and C. Aiken (2010), Remotely triggered microearthquakes and tremor in Central California following the 2010 Mw8.8 Chile Earthquake, *Geophys. Res. Lett.*, 37, L24312, doi:10.1029/2010GL045462.

Peng, Z., C. Wu, and C. Aiken (2011), Delayed triggering of microearthquakes by multiple surface waves circling the Earth, *Geophys. Res. Lett.*, 38, L04306, doi: 10.1029/2010GL046373.

Shelly, D. R., Z. Peng, D. P. Hill and C. Aiken (2011), Triggered creep as a possible mechanism for delayed dynamic triggering of tremor and earthquakes, *Nature Geosci.*, 4, 384–388, doi: 10.1038/ngeo1141.

Peng, Z., L. T. Long, and P. Zhao (2011), The relevance of high-frequency analysis artifacts to remote triggering, *Seismol. Res. Lett.*, 82(5), 654-660, doi: 10.1785/gssrl.82.5.654.

Wu, C., and Z. Peng (2011), Temporal changes of site response during the M9.0 off the Pacific coast of Tohoku earthquake, *Earth Planets Space*, 63(7), 791-795, doi:10.5047/eps.2011.06.011.

Chao, K., Z. Peng, A. Fabian, and L. Ojha (2012), Comparisons of triggered tremor in California, *Bull. Seismol. Soc. Am.*, 102(2), doi: 10.1785/0120110151.

Wu, C., and Z. Peng (2012), Long-term change of site response after the Mw9.0 Tohoku earthquake in Japan, *Earth Planets Space*, in revision.

Kilb, D., Z. Peng, D. Simpson, A. Michael, M. Fisher and D. Rohrlick (2012), Listen, watch, learn: SeisSound video products, *Seismol. Res. Lett.*, 83(2), 281-286, doi: 10.1785/gssrl.83.2.281.

Peng, Z., C. Aiken, D. Kilb, D. Shelly, B. Enescu (2012), Listening to the 2011 magnitude 9.0 Tohoku-Oki, Japan earthquake, *Seismol. Res. Lett.*, 83(2), 287-293, doi: 10.1785/gssrl.83.2.287.

Meng, X., X. Yu, Z. Peng and B. Hong (2012), Detecting earthquakes around Salton Sea following the 2010 M_w7.2 El Mayor-Cucapah earthquake using GPU parallel computing, *Procedia Computer Science*, submitted.