High-resolution tremor imaging in Cascadia using multiple seismic arrays

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Cascadia subduction zone under Washington experiences large slow quakes every 14.5 months or so. Each such event is characterized by geodetically observed slow slip and deep seismic tremor. This remarkably periodic coupled phenomenon is known as episodic tremor and slip (ETS). We installed 8 small aperture seismic arrays in northern Washington to capture the intimate details of tremor activity in Cascadia. The Array of Arrays focuses on the tremor-active megathrust in this region, including the area we previously imaged with a solo seismic array in 2008 [Ghosh et al., 2009]. Each array consists of 10 to 20 three-component sensors recording in continuous mode. Since it became operational in June 2009, the Array of Arrays recorded several tremor episodes, including the recent episodic tremor and slip (ETS) event in August 2010. During the ETS, each array was augmented by 10 additional single-channel, vertical-component sensors.

We have developed a Multi-Beam Backprojection (MBBP) technique to image tremor in high resolution using data from multiple seismic arrays. We apply a beamforming technique at each array to stack the seismic energy at every 0.2 Hz from 2 to 20 Hz using 1-minute sliding time window. During tremor episodes, the arrays show stable slowness, and azimuth over the tremor frequency band (generally 3-8 Hz). We get the best slownesses from all the available arrays, and backproject to find the tremor source location in 3-D space. While P-wave energy stacks coherently up to 10 Hz and higher, S-wave extends only up to 6 Hz or so.

The MBBP algorithm is applied to 15.5 months of continuous seismic data from multiple seismic arrays to detect and locate tremor. We observe tremor streaks, bands, and patches confirming the observations made in our previous studies [Ghosh et al., 2010a, 2010b; Ghosh et al., 2009]. Moreover, MBBP algorithm has reasonable depth resolution. We found that majority of the tremor in the vicinity of the arrays is located near the plate interface, aligns parallel to the dip of the interface, and form a layer above the ordinary earthquakes (Figure 1). This algorithm is able image the details of rupture propagation of slow earthquakes not only during the ETS 2010, but also smaller events during inter-ETS time period. Generally, slow quakes show complex rupture pattern. Particularly interesting is the change of propagation velocity from 8 km/day to 18 km/day during the August 2010 ETS in this area. Tremor locations appear to illuminate a discontinuity in the oceanic crust separating highly tremor-active north from the feebly active south, possibly indicating variation in frictional properties across the discontinuity. These intriguing observations are providing new insights into the physics of slow earthquakes and tremor.

References:
Figure 1: Top panel shows tremor location (red circles) using MBBP method for the entire 15.5 months. Black boxes marks the arrays. Gray rectangle covers the area tremor and earthquake locations are taken from to make the cross-section below. Gray dash lines are the contours showing the plate interface (Audet et al., 2009). Bottom panel shows the cross-section along a E-W line going right through the middle of the gray rectangle in the top panel. Red circles are tremor location. Black circles are ordinary earthquakes scaled by their magnitude. Two lines represent two models of the plate interface; shallow one is by Audet et al., 2009; deep one is by McCrory et al., 2006. For tremor location in depth, only well-constrained locations every 30-minutes are plotted in the cross-section.