Award #06HQGR0035

Title: Detection of slow-slip events associated with the Cascadia subduction zone using the InSAR persistent scatterer method

Author: Rowena Lohman
previously at:
Woods Hole Oceanographic Institution
221 Oyster Pond Road
Woods Hole, MA 02543

Now at:
Cornell University
Ithaca, NY 14850
Phone: 607 255 6929, email: rbl62@cornell.edu

Abstract:
Within subduction zones around the Pacific, observations of slow or silent earthquakes releasing strain equivalent in moment to M6-7 earthquakes has prompted studies that attempt to better understand the spatial and temporal distribution of these events. In the Cascadia subduction zone, slow slip events are detected by the local continuous GPS array and detections of contemporaneous seismic tremor at fairly regular intervals (~ every 14 months). The exact updip and downdip limits of the zones that deform in each event are still open questions. Our ability to determine the process governing slow slip events depends in part on whether we can correlate the regions of their occurrence with known variations in rock properties, zones of dehydration, etc., so the exact locations are of key importance to researchers studying the region.

In this project, we proposed to apply the persistent scatterer method to Synthetic Aperture Radar (SAR) data acquired over the Cascadia subduction zone since 1992. The horizontal motions recorded by the GPS array have magnitudes of up to 6 mm, which should correspond to 5-10 mm of deformation in the nearly vertical satellite line-of-sight (LOS). Reported detection limits for the persistent scatterer method are ~ 1mm, so the expected signal is reasonably large. The vegetation and high rainfall have proved problematic for traditional Interferometric Synthetic Aperture Radar (InSAR) in the Pacific northwest, but the persistent scatterer method may be able to take advantage of the roads, clearcut areas within the forest and buildings that dot the region.

The nearly vertical component of deformation observed by InSAR is complementary to the mainly horizontal constraints provided by GPS. The dense spatial coverage of InSAR may also detect regions of anthropogenic subsidence that may bias some of the GPS stations, or strain gradients that are missed in regions where the GPS station coverage is sparse.

This project was funded at the level of a proof-of-concept-scale study in order to prove that the InSAR time series methods would be able to resolve the target strain field within the Cascadia subduction zone. Therefore, we focused on identifying whether sufficient areas remained coherent over long enough time intervals to perform the InSAR time series analysis at a future date.

Main body of report:

The seed money allocated to this project was used in order to perform preliminary analysis of InSAR data covering the Cascade region in order to determine whether coherence was likely to be high enough to detect the slow slip events using the persistent scatterer (PS) method. At the same time, a parallel project was performed in cooperation with Noah Finnegan and Matthew Pritchard at Cornell in order to determine whether the various time series methods available to us could resolve crustal fault and anthropogenic motions with the urban Seattle metropolitan area. Since the urban areas have much higher coherence than the surrounding regions, the likelihood of success for time series methods was deemed to be much higher.

Below are comments on the following topics: 1: Success of PS method within urban regions, along with the resultant error bounds, 2: Interferometric coherence of radar data within Cascadia as a whole and prospects for future work

1: PS-method success in urban regions
While this work was performed using funding from a different USGS NEHRP proposal, the error analysis results have bearing on the prospects for detecting slow slip events within Cascadia as well, so I will briefly review the work. Noah Finnegan examined SAR imagery from two overlapping ERS tracks and one Radarsat track spanning overlapping time periods from 1992 to 2007. They found strong coherence within the Seattle metropolitan areas over time periods up several years, and compared the time series results within the spatial area covered by all three SAR tracks (Figure 1).

Finnegan quantified the precision of the time series estimates in two ways – by comparing the deformation rates from the InSAR time series to nearby continuous GPS observations projected into the satellite line-of-sight (LOS), and by examining the InSAR time series from separate satellite tracks. In both cases, the results were consistent with precisions on the order of 0.5 mm/yr. The agreement between observations from independent datasets covering different satellite tracks suggests that in this area, much of the short-wavelength deformation signal is vertical, since the local line-of-sight vectors differ between the tracks at any given point.

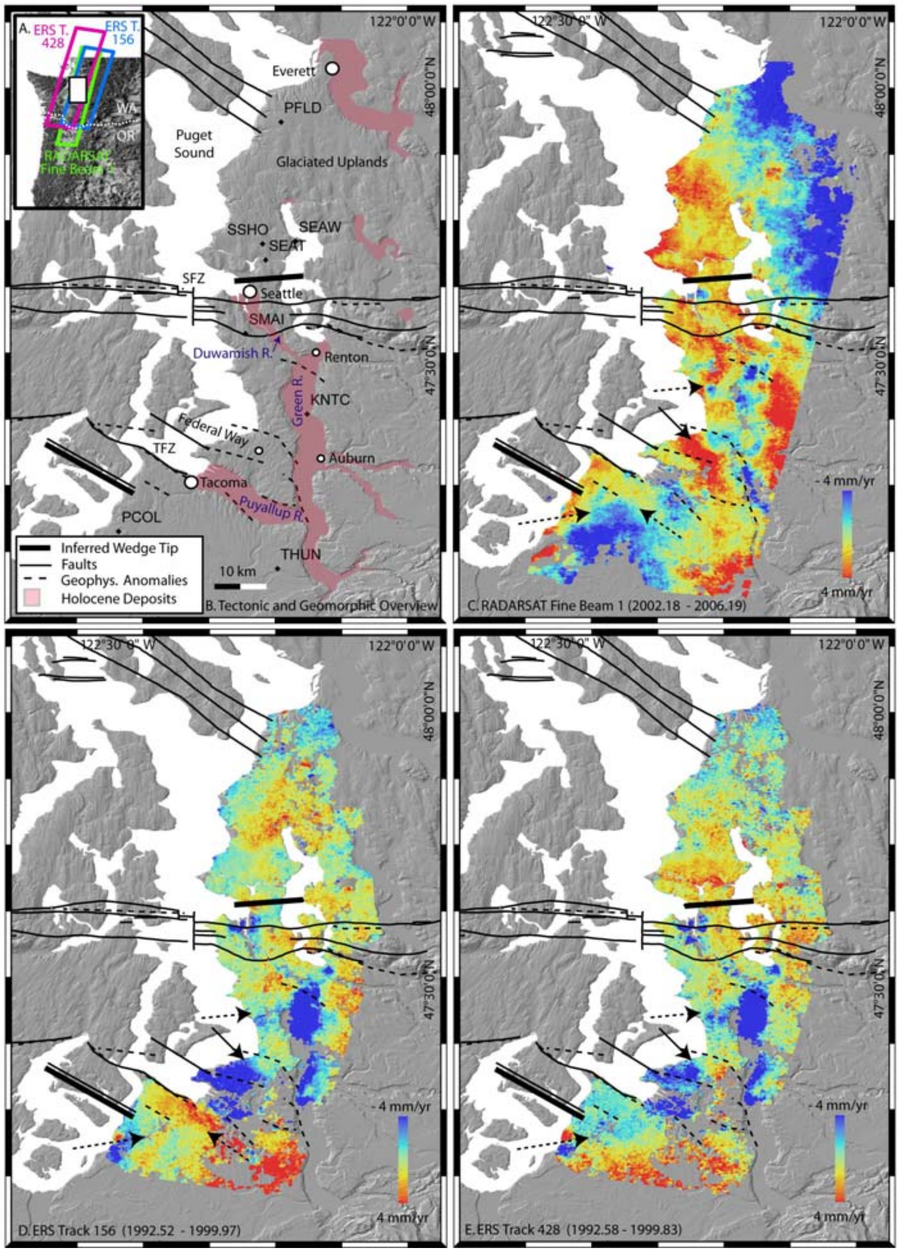

Figure 1: Previous results from Finnegan et al., 2008. (a) Fault locations (black lines, U.S. Geological Survey (2006) and Johnson et al., 1999; 2004), geophysical anomaly data (dashed black lines, Brocher et al. 2001; 2004), and GPS stations (black dots, *www.geodesy.cwu.edu/*). SFZ = Seattle Fault Zone, TFZ = Tacoma Fault Zone. (b-d) Patterns and magnitudes of mean radar LOS surface velocity over a region covered by three independent SAR tracks, calculated from (b) 38 RADARSAT Fine Beam 1 interferograms spanning the period 2002-2006, (c) 24 ERS track 156 interferograms spanning the period 1992-1999, and (d) 31 ERS track 428 interferograms spanning the period 1992-1999.

Cascadia-wide coherence:
While the results from Finnegan's work allowed examination of the behavior of specific crustal faults within the Seattle metropolitan area, our studies of slow slip events will require coherent InSAR studies over a larger spatial aperture. Our examination of individual interferograms outside the area shown in Figure lead us to the following conclusions;

1: Radarsat fine-beam data tends to have very good coherence, almost comparable to the high coherence of ALOS imagery across all but the steepest regions and except for during winter months.

2: Conduits of high coherence in most interferograms exist along the northern coast of the Olympics, as well as wide regions along the west coast south of the Olympic Mountains. E-W swaths of high coherence also exist along river valleys south of and within the Olympic Mountains. These are favorably oriented for studies of slow-slip events since they are approximately perpendicular to the subduction zone. While individual valleys would be difficult to interpret given the strong atmospheric signals within the area, the group as a whole might be potentially more useful since they span a wide range of elevations.

3: South of the Olympic Mountains, there are fairly regularly scattered spots of strong coherence within small towns, fields, and clearcut regions. As a whole, these are dense enough that they can be unwrapped with a high degree of confidence, even for interferograms spanning up to a year.

4: There are numerous gravel pits and small reservoirs that have strong signals associated with them, probably due either to subsidence, soil moisture variations or other non-tectonic factors. Since they are often associated with barren landscapes, they often have a very strong, coherent signal. These will need to be accounted for and/or removed during attempts to interpret slow slip events.

5: In regions with agricultural fields, such as the area north of Seattle, there are often very strong phase changes between the fields and intervening roads, similar to what has been observed in other agricultural areas such as Southern California. These phase jumps tend have magnitudes of up to a quarter cycle or so, and also will require some treatment since they are probably a sign of changes in soil moisture and have nothing to do with tectonic processes. We have had success using land-use maps in Louisiana to mask out the “double-bounce” effect that occurs in marshes – perhaps a similar treatment could be used here.

Future work: The slow-slip signal associated with the Cascadia subduction zone is definitely a high-risk target for the use of InSAR data, but the progression of time and acquisition of more and denser data sets will certainly reduce the error bounds and make the detection of this signal more likely. We expect that the best results will come from focusing on conduits of high coherence that stretch across the Olympic peninsula, which could at the very least be compared with forward model from slip inversions based on the existing continuous GPS data.