Determining the Optimal Design of a Seafloor Geodetic Observatory on the Cascadia Subduction Zone: Final Report

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Introduction

In 2012, the *W. M. Keck Foundation* awarded funds to WHOI to build the instrumentation needed to create a state-of-the-art geodetic observatory offshore of Vancouver Island at the updip end of the Cascadia Subuction Zone. Note that while the main field program was funded by Keck and NSF; the DOEI funded a modeling study that we did ahead of time to help design the experiment.

The goal of this observatory is to study the deformation and fluid flow transients associated with the subduction zone megathrust that repeatedly ruptures in magnitude 9 earthquakes. This award funded the design and instrumentation for measuring deformation at three temporal and two spatial scales. At the shortest temporal and spatial scales, geodetic-quality tiltmeters will be installed ~300 m below the seafloor in IODP Hole 1364A, which is located near the up-dip end of the subduction zone and only ~4 km above the thrust interface, and where these is an existing sub-seafloor hydrological observatory. The tiltmeter data, as well as the data from existing hydrological and proposed temperature sensors will be telemetered ashore in real-time via the cabled observatory run by Ocean Networks Canada. Borehole tilt is the most sensitive seafloor geodetic data for detecting deformation transients with time scales of a month or shorter.

The borehole installation will be combined with a wider spatial array of pressure gauges and geodetic benchmarks for monitoring transient fault motion and inter-seismic strain respectively. Eight autonomously-recording absolute pressure gauges (APG) units will catch any large transient signals with time scales from hours to months, similar to the Tohoku earthquake's after-slip signal. The primary goal of this proposal is to determine where to install these 8 seafloor geodetic benchmarks for monitoring long-term inter-seismic strain accumulation and to determine what magnitude of signals are likely to be recorded on the tiltmeter.

Results

In order to optimize the geometry of seafloor benchmarks, we evaluated the resolution of the up-dip limit of the locked zone that would be achievable under different mechanical and ROV scenarios. We calculated models of the expected deformation field using the finite element software PyLith for both inter-seismic locking and transient slow earthquakes (Figure 1). We included spatially variable material properties (Figure 2) and focused on inverting the synthetic datasets for locking distributions. In addition, we will also incorporate variables such as elastic plate thickness, which can be important in modeling inter-seismic deformation. The results have informed the expected magnitudes of signals we expect to measure in the geodetic network and have clarified the need to include 3-dimensional models of rock properties in any future inversion studies that will be done with the seafloor geodetic observatory.

This proposal contributed to the professional development of WHOI post-doctoral investigator Meng Wei. Meng is now an assistant professor at the University of Rhode Island. The results also contributed to a successful NSF proposal that is funding an upcoming (summer 2016) cruise to install the borehole observatory using WHOI's ROV Jason.

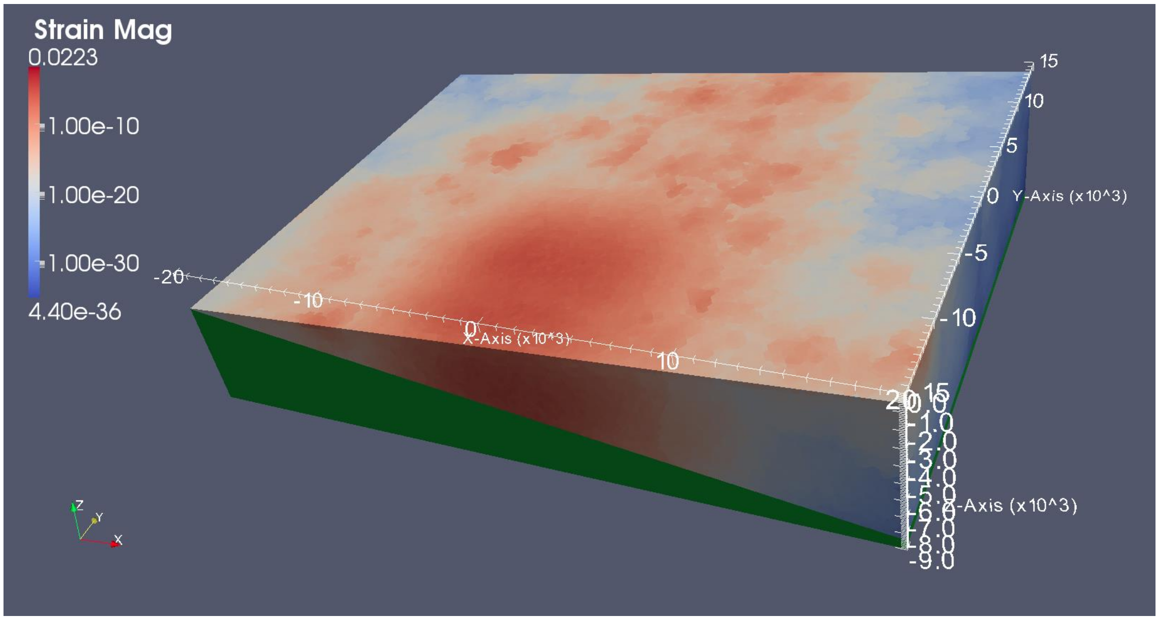

Figure 1. Example finite element calculation of the strain field (first invariant) that would result from a M5.5 slow earthquake on the up-dip end of the thrust interface. Colors in the upper volume represent strain in the accretionary wedge which has material properties derived from the study of *Willoughby et al*. [2000]. The green wedge denotes the subducting oceanic crust. Future studies will test spatially variable locking and material property distributions.

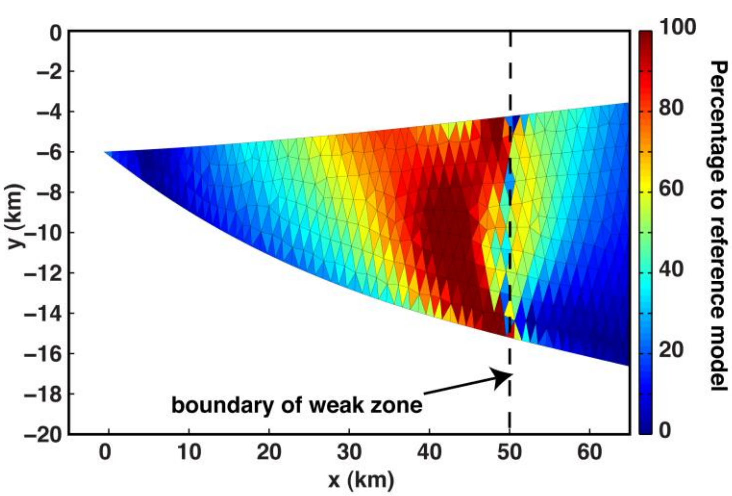

Figure 2. Example of a finite model that encorporates a transition in shear modulus in the outermost acretionary wedge which mimics that seen in some of our ocean bottom seismometer studies. The colors indicate the amount of interseismic strain that is accumulated relative to a model with homogeneous material properties. The inclusion of realistic material properties results in a 100% larger strain-rate in the region of our seafloor geodesy observatory.