Report on Research Activities at ERI From July 16, 2014 to November 15, 2014
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What controlled the dynamic rupture propagation and seismic radiation in the 2011 Mw 9.0 Tohoku earthquake? Answers to this question are essential for learning from this unexpected megathrust earthquake and thus better assessing seismic hazard along the Japan Trench and other subduction zones worldwide. During my visit at ERI from July 16, 2014 to November 15, 2014, based on my previous work (Duan, JGR, 2012) that proposed a subducted seamount may have played a critical role in rupture propagation and seismic radiation of the event, I build more advanced dynamic rupture models of the event and perform large-scale simulations of these models on supercomputers.

Two major improvements to the previous model (TPM) are made during this visit. One is to incorporate 3D geometry of a subducted seamount just up-dip of the hypocenter of the 2011 event into the finite element method (FEM) mesh of dynamic rupture models, as TPM just parameterized the seamount by higher static friction, lower pore pressure, and higher initial shear stress relative to the surrounding areas on the subduction plane, without real seamount geometry in FEM mesh. This is nontrivial, as we also need to deal with the shallow dipping (e.g., ~10°) subduction plane in the FEM mesh and bad element shape in the mesh can cause severe problems in dynamic simulations. I successfully created 3D FEM mesh with the shallow dipping subduciton plane on which a subducted seamount just up-dip of the hypocenter is seated. A spontaneous rupture model with this 3D seamount geometry (similar base dimensions as in TPM ~70km by 23 km, and 3 km height), but without parameterization as in TPM, shows that just this 3D seamount geometry cannot reproduce rupture propagation features inferred from kinematic inversions. In particular, this 3D geometry only delays up-dip rupture about 15 seconds, not 45 seconds as kinematic inversions inferred, resulting in a much faster rupture propagation overall. In addition, slip becomes much smaller (e.g., maximum slip is ~20 m near the hypocenter) and slip near the trench is minor. These results suggest some parameterization of the seamount is needed to account for possible heterogeneities in pore pressure and initial shear stress (e.g., due to previous events that may be stopped by the seamount) associated with a subducted seamount.

The other major improvement is to incorporate 2D velocity structure of the subduction zone (e.g., Miura et al., 2005) into the FEM models, as TPM assumes 1D velocity structure for simplicity. This also takes lots of efforts to successfully build the FEM mesh that takes into account both 2D velocity structure and 3D seamount geometry. Thankfully, I succeed in this effort during this visit. A spontaneous rupture model with 2D velocity structure and seamount parameterization as in TPM (but no 3D seamount geometry) shows that 2D velocity structure has moderate effects on rupture propagation and slip distribution. Specifically, 2D velocity structure results in a little faster rupture along the dip direction (e.g., up-dip rupture is delayed ~35 seconds, rather than 45 seconds in TPM), while a little slower rupture along the strike direction. In addition, 2D velocity structure produces a little larger slip compared with TPM, particularly near the trench (> 30 m slip, compared with <25 m in TPM). The maximum slip up-dip the hypocenter is about 52 m, compared with ~49 m in TPM.

Although the focus of examination of my dynamic rupture models has been on rupture propagation and other quantities (including slip, stress drop, etc) on the subduction plane (i.e., the fault plane) so far, we do have seismic propagation in 3D models, and thus can compare our synthetics with real recordings, including near-field (e.g., on the Japan island) seismograms and GPS measurements, so that we may adjust our model parameters to better match observations. I have made some efforts on this aspect during the visit, in terms of finding more than 20 stations in creating my FEM mesh and preparing for use of some K-net and Kik-net stations' recordings, which may have relatively less site effects. This is only possible with help of Dr. Hiroe Miyake at ERI, who provides many advices on station selection and data usage.

In addition to above research activities, I attended two major meetings (and gave presentations) in Japan (but outside ERI), and gave two presentations at ERI. One meeting was AGOS 2014 in Sapporo in late July to early August, and my presentation is entitled "Exploring dynamic rupture processes of recent large earthquakes and predicting ground motions from future scenario earthquakes with high performance computing". The other meeting was the slow-earthquake workshop in Kyoto in early September, and my presentation is entitled "3D dynamic rupture simulations of a megathrust fault with a subducted seamount". One presentation I gave at ERI was on September 30 for seismological seminar at ERI, and it is entitled "Dynamics of geometrically complex faults, off-fault damage, and ground motion simulations". The other presentation I gave at ERI was on October 17 for the 931st Danwakai, and it is entitled "How may a subducted seamount have played a vital role in the 2011 M9 Tohoku earthquake?".

I have also enjoyed (and benefited from) interactions with many colleagues at ERI, including my host Dr. Nobuki Kame on source physics, Dr. Hiroe Miyake on ground motion, visiting researchers Dr. Xin Zhou on postseismic deformation of the 2011 Tohoku earthquake, Dr. Elmer Ruigrok on seismic interferometry, Dr. Chin-Wu Chen and Dr. Anne Sheehan on subsurface imaging.

My visit to ERI will be a memorable period in my career and life. Thank you all, my colleagues and friends at ERI and Tokyo!