Workshop Report: Crustal Deformation Modeling

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Introduction

The 2012 Crustal Deformation Modeling workshop was held June 18-22 on the campus of Colorado School of Mines in Golden, CO. The agenda, presentation materials, and list of participants are available at `http://www.geodynamics.org/cig/community/workinggroups/short/workshops/CDM2012`. This meeting continued an ongoing series of workshops held over the past 10 years. The focus of these workshops is physically based models of the distribution of lithospheric stress in space and time via simulation of the strain accumulation, dynamic rupture propagation, and postseismic relaxation over multiple earthquake cycles.

In 2011 we switched holding workshops on an annual basis to holding them on a biannual workshops in even years and holding virtual online tutorials in odd years. The most recent previous workshop was held in June 2010, and we plan to hold our next workshop in June 2014.

Participants

The workshop included participation from 62 scientists. As in previous workshops in this series, nearly two-thirds of the participants were graduate students and postdocs. In this workshop 44% of the participants were graduate students, 21% were postdocs, 18% were faculty, and 18% were researchers. About 80% of the attendees participated in both the tutorials on the first two days of the workshop (Monday and Tuesday) and the science talks and discussions over the following two and one-half days (Wednesday, Thursday, and Friday).

Invited Presentations

The 11 science talks covered a range of topics associated with modeling earthquake deformation. Peter Bird and Wayne Thatcher discussed the role of geodetic modeling in UCERF3. Jack Loveless expanded upon this discussion with presentation of elastic block modeling for Japan, California, and Tibet. Sarah Minson presented an application of Bayesian methods for inverting for coseismic slip to the Tohoku-oki earthquake. David Schmidt and Jessica Hawthorne outlined conceptual models for slow slip at the down dip extent of the seismogenic zone. Rowena Lohman outlined the need for SCEC benchmarks related to geodetic source inversions. Margaret Boettcher and Jolante van Wijk discussed the rheology of the lower crust and constraints from crust-mantle interactions on seismic behavior. Nadya Cubas presented results from a critical taper analysis of the 2010 Maule earthquake and insights from earthquake cycle modeling. Greg McLaskey discussed multi-scale analysis of laboratory rock friction experiments involving foreshocks and slow-slip leading to rupture nucleation.

Discussions

The workshop included two discussion sessions with focused topics. The first discussion centered on whether the crustal deformation modeling community should develop a community inversion code. Advocates argued that such an effort would make leverage efforts of individual scientists across the community, facilitate verification of inversion codes, and make earthquake source inversions more transparent to fellow scientists. The desired features require a highly modular implementation in order to permit various data sources (GPS, InDAR, creepmeters, etc), complex physics for fault slip and bulk rheologies, and both classical optimization and Bayesian methods. The general consensus was that the principal obstacle would be finding a scientist to lead/champion the effort, and it would be helpful to start simple with a subset

of the most important components. Additionally, SCEC community benchmarks could be used to drive development.

The second discussion provided an opportunity for the community to give feedback on prioritizing new features to add to PyLith. The PyLith developers outlined the two main features planned for addition: earthquake cycle modeling and multiphysics (coupling elasticity with heat and/or fluid flow). Many more participants expressed support for adding multi-physics capabilities compared to earthquake cycle modeling capabilities. The PyLith developers listed a number of features slated for inclusion in the coming months in support of more complex simulations, such as finite-element integrations on GPUs, adaptive time stepping based on strain rate, and higher order basis functions. Participants also suggested adding time-dependent Green's functions, integration with open-source meshing tools, and implementation of fault slip using equivalent body forces.

Tutorials

The first two days of the workshop were dedicated to tutorials for Relax, a Fourier-based new open-source code developed by Sylvain Barbot for elastic and viscoelastic deformation in a homogeneous half-space, and PyLith, an open-source finite-element code developed by Brad Aagaard, Charles Williams, and Matthew Knepley for elastic, viscoelastic, and elastoplastic deformation. The Relax tutorials provided an overview of the code and several in-depth examples. The PyLith tutorials covered intermediate and advanced topics (beginning topics were covered prior to the workshop via online material), including modeling of the earthquake cycle on a 2-D subduction zone with a nonplanar fault surface and prescribed slip models, fault friction on a vertical strike-slip fault in 3-D, creating finite-element meshes with nonplanar geometry for geophysical models, strategies for selecting of PETSc solver options in PyLith, dynamic spontaneous rupture, and using the new user-friendly interface in for computing static Green's functions and application to simple kinematic source inversions.

Workshop Outcomes

Consistent with previous workshops, participants voiced strong support for future workshops on crustal deformation modeling. The format of two days of tutorials followed by two and a half days of science talks that include some informal time for additional informal tutorials worked very well.

- Community kinematic inversion code
  The participants expressed strong support for a community kinematic inversion code using a highly modular approach. Such a code would target the geodetic modeling community but might support seismic data as well. The main obstacle is finding the appropriate scientist to lead/champion the code development effort.

- PyLith development priorities
  Based on the discussion, the PyLith developers revised the priorities of new features to add to PyLith.

  1. New C implementation of Sieve (underway)
  2. Finite-element integrations on GPU (planned)
  3. Integration with open-source meshing tools (if no modifications are required to provide the information PyLith needs)
  4. Body forces approximation for fault slip
  5. Coupling dynamic+quasi-static with same mesh

6. Adaptive time stepping based on strain rate and slip rate
7. Incompressibile elasticity via pressure field
8. Elasticity + fluid flow
9. Elasticity + heat flow
10. Time-dependent Green's functions
11. Higher order basis functions
12. Coupling dynamic+quasi-static with separate meshes

- Future workshops
  Participants voiced strong support for continuing the series of workshops on a biannual basis with the same location and time of year.