Workshop Report: Numerical Modeling of Crustal Deformation

Andrew Freed (PI), Purdue University
Brad Aagaard (co-PI), United States Geological Survey
Carl Gable (co-PI), Los Alamos National Laboratory
Mark Simons (co-PI), California Institute of Technology
Thorsten Becker (co-PI), University of Southern California

Introduction and Motivation

Over the past several years, the SCEC Crustal Deformation Modeling (CDM) group has implemented a coordinated community effort to (1) build and validate 3-D quasi-static, finite-element codes for modeling crustal deformation; (2) construct deformation models of Southern California consistent with observed topography, fault geometries, rheological properties, geologic slip rates, geodetic motions, and earthquake histories; and (3) use these models to infer fault slip, rheologic structure, and fault interactions through stress transfer. We have helped catalyze the development of a suite of tools for studying crustal deformation in Southern California, including PyLith, an open-source, portable, parallel finite-element code for modeling quasi-static and dynamic crustal deformation; and a suite of benchmarks for comparison and verification of numerical codes for modeling pre- and post-seismic deformation. An ultimate goal of our modeling community is to derive 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. Recent earthquake cycles provide rich observational constraints, whereas hundreds of earthquake cycles provide stable statistics for clustering and seismicity.

The SCEC CDM community has developed into a cohesive group with the following Mission Statement: (1) build tools to aid in the understanding of slip characteristics and rupture propagation using seismological and geodetic constraints; (2) build tools to aid in the understanding of rheological structure based on geodetically constrained postseismic deformation; and (3) simulate interactions among fault systems through the earthquake cycle in order to understand the evolution of regional strain rates, stresses, topography, and earthquake hazards.

History of the Workshops

The first CDM workshop at Caltech (June, 2002) focused on assessing the accuracy, speed, and ability to modify software in use by members of the community. The community concluded that much of the software in use at that time was not capable of handling realistic geologic models. The second workshop (August, 2003) was expanded in both length and participation. The workshop was hosted by Los Alamos National Laboratory, enabling SCEC scientists to benefit from attendance by Lab experts, particularly those with expertise in meshing. By leveraging SCEC, NASA, and LANL support, we were able to increase the number of students and senior researchers attending, as well as meet for five days instead of two. A highlight of the workshop was intense discussion of computational frameworks and how they might be used to construct a state-of-the-art modular numerical code for crustal deformation modeling. Because members of the NASA-sponsored SERVO QuakeSim group participated in the workshop, there was significant exchange of ideas and software.

The third and fourth annual workshops (August, 2004 and July, 2005) were also at LANL. Based on the success of previous workshops, the funding base was expanded to include NSF EarthScope, as well as SCEC, LANL IGPP, and NASA. The participation grew from 30 scientists from 12 universities, the USGS, JPL, Los Alamos National Laboratory, and Sandia National Laboratory in 2004 to 42 scientists in 2005. This workshop had a "hands-on" emphasis. The goals of the workshops were (1) to leave the workshop knowing how to do more with basic tools than before the workshop; (2) to use Southern California and the benchmark suite as convenient and important examples for developing the next generation of crustal deformation modeling tools; (3) to focus on constructing meshes with realistic geologic structures; and (4) to learn to use GeoFEST and Lithomop (aka TECTON) - what it takes to get these up and running, what they can do, and how they can be modified. The 2005 workshop also focused on defining the tools necessary for end-to-end modeling from conceptualizing and constructing a geologic model, discretizing the model using a mesh generator, running a simulation, to finally, visualizing the results. Because modest support

from SCEC has enabled our community to organize and articulate its priorities and plans, we have been able to take advantage of the NSF-IT CIG initiative from its conception. At this workshop, we spent significant time defining our community's priorities and needs with respect to CIG activities.

The four most recent workshops were held in June of 2006, 2007, 2008, and 2009 on the campus of the Colorado School of Mines in Golden, Colorado. For details of the workshops, please see `http://www.geodynamics.org/cig/workinggroups/short/workshops/`. The format of the workshop changed with a much stronger emphasis on science application presentations and discussions. A notable change occurred in 2008 with many more participants applying the meshing tools and simulation software to problems of research interest rather than simply running toy example problems. Starting in 2006, we began reaching out to the Fault And Rupture Mechanics (FARM) community with talks on laboratory friction models, dynamic slip modeling, and simulation of seismicity catalogs. This represents a concerted effort by the community to implement modeling codes that can handle time scales of seconds to thousands of years, truly a daunting task, but an important one if we want to make progress in understanding the evolution and impact of 3-D variations in crustal stress.

Our Most Recent Workshop

Our ninth workshop in June 2010 was also held in Golden, Colorado at the Colorado School of Mines. This workshop was attended by 68 participants (our largest workshop so far with 28 graduate students, 9 postdocs, and 31 faculty and research scientists). Several of the faculty attended previous CDM workshops as graduate students. The first two days were dedicated to training in the use of state-of-the-art finite-element codes for modeling crustal deformation with the remaining three days filled with science talks and discussions. See `http://www.geodynamics.org/cig/workinggroups/short/workshops/cdm-10/agenda` for the complete agenda and slides for all of the presentations. This year's workshop included several presentations on the recent Haiti, Chile, and El Mayor-Cucapah earthquakes along with talks on fault and bulk rheologies with a focus on the base of the seismogenic zone. The workshop continued our successful efforts to build a community of researchers focused on crustal deformation modeling, to discuss the latest observations and modeling results associated with coseismic, postseismic, and interseismic deformation, and to train researchers in the use of modern modeling software.

A discussion at the end of the workshop indicated overwhelming support for continuing the series of annual workshops. Graduate students and postdocs as well as faculty and researchers appreciate the opportunity to become engaged in the community and learn how to use state-of-the-art tools. In early 2011 the organizing committee decided that in order to keep the scientific agenda fresh and increase interest among leading researchers, we will switch to biannual meetings and skip holding a workshop in 2011. Instead we will hold a virtual (online) workshop in 2011 focused solely on training users in the use of PyLith and related codes for modeling crustal deformation. This experiment with online training should enable us to determine if this approach is effective and how to distribute our efforts in the future between in-person training at workshops versus online training. Our 2012 workshop will likely focus on modeling coseismic and postseismic deformation from the recent Haiti, Chile, El Mayor-Cucapah, Darfield, and Tohoku earthquakes.