



## COMPUTATIONAL INFRASTRUCTURE FOR GEODYNAMICS

## Research Highlight - SPEC3D

# Dynamic Earthquake Rupture and the 2011 M9 Tohoku Earthquake

An important goal of computational seismology is to simulate dynamic earthquake rupture and strong ground motion in realistic models that include crustal heterogeneities, non-linear rheologies, and complex fault geometries. Increasing computational power is allowing scientists to resolve the small-scale processes through the use of numerical models at high resolution and large scales. Towards this goal, Galvez et al. (2014) incorporate dynamic rupture modeling capabilities in a spectral element solver on unstructured meshes, the 3-D open source code SPEC3D, and employ state-of-the-art software (CUBIT) for the generation of unstructured meshes of hexahedral elements. These tools provide high flexibility in representing fault systems with complex geometries, including faults with branches and non-planar faults. The domain size is extended with progressive mesh coarsening to maintain an accurate resolution of the static field. The implementation of dynamic rupture boundary conditions does not affect the parallel scalability of the code, enabling high-performance execution for large-scale dynamic rupture calculations. The accuracy of the implementation is verified by comparing the results to those of two finite element codes on benchmark problems

including branched faults through the SCEC/USGS Dynamic Rupture Code Validation Project.

The tool is applied to develop a preliminary dynamic rupture model of the 2011 Mw 9.0 Tohoku earthquake that includes a non-planar plate interface with heterogeneous frictional properties and initial stresses. The final 3-D model consists of 2 km hexahedral mesh, 7,498,240 elements, with predetermined placements of asperities. The simulation used about 15,000 cpu hours at the Swiss National Supercomputer Center.

The rupture history produced by this model reproduces multiple rupture fronts. The up-dip front gradually accelerates and develops super-shear rupture speeds close to the trench, whereas the down-dip front propagates slowly below the hypocenter and migrates more rapidly towards the South. This model is in qualitative agreement with observation by other researches: high frequency radiation in the deep regions of the plate interface and low frequency radiation with large slip close to the trench.

The team is now developing a refined dynamic rupture model that matches quantitatively the seismological and geodetic observations of the Tohoku

VOLUME 4 ISSUE 1

# CIG

## NEWS

### ELEMENTS

## IN THIS ISSUE

## CONTENTS

|                   |    |
|-------------------|----|
| CODE CORNER       | 02 |
| GOVERNANCE        | 03 |
| EVENTS            | 04 |
| WEBINAR           | 04 |
| UPCOMING MEETINGS | 05 |

## ANNOUNCEMENTS

Next Webinar: Thursday, February 12

*Distribution of rupture velocity in a dynamic rupture model of the Tohoku earthquake. Supershear emerges at the rupture near the trench.*

Please send us your recent publications as well as research highlights so we may continue to keep the geosciences community informed of all the current research being conducted in geodynamics with CIG codes.

Submit publications at:  
<http://geodynamics.org/cig/news/publications/submit/>

earthquake. Overall, this tool offers a great potential to simulate more realistic earthquakes in complex faults systems.

Galvez, P. and Ampuero, J.- P. and Dalguer, L. A. and Somala, S. N. and Nissen-Meyer, T. (2014) "Dynamic earthquake rupture modelled with an unstructured 3-D spectral element method applied to the 2011 M9 Tohoku earthquake", *Geophysical Journal International* Volume 198 (2)  
 DOI: [10.1093/gji/ggu203](https://doi.org/10.1093/gji/ggu203)

# Code Corner

## NEW RELEASES

- deal.II 8.2 1.1 2015-01-01
- ASPECT 1.2 2015-01-26

## ALLOCATIONS

|             |                       |
|-------------|-----------------------|
| Stampede    | 1,666,207 / 1,886,789 |
| Yellowstone | 467,102 / 490,000     |

## User Meetings

ASPECT User Meetings are held once a month on Fridays from 2-3 pm.

[contact@geodynamics.org](mailto:contact@geodynamics.org).

Date, time, and connection information for all events can be found on the Event calendar: <http://geodynamics.org/cig/events/calendar/>

## Shijie Zhong Named 2014 AGU Fellow

Congratulations to Professor Shijie Zhong, who was recently elected a 2014 Fellow of the American Geophysical Union. Dr. Zhong was recognized, "for fundamental, profound, and unselfish contributions to advancing the understanding of the dynamics of the Earth, Moon, and the terrestrial planets."

Dr. Shijie Zhong's research is focused on understanding the dynamics of planetary interiors and its relation to observations at the planetary surfaces including gravity, magnetism, topography, volcanism, and tectonics. In his work, Dr. Zhong uses methods of fluid dynamics with both numerical and theoretical models.

For full article see:

<http://phys.colorado.edu/events/shijie-zhong-named-2014-agu-fellow>



## NEW RELEASE

### deal.II

Version 8.2 of deal.II, the object-oriented finite element library awarded the J. H. Wilkinson Prize for Numerical Software, has been released. It is available for free under an Open Source license from the deal.II homepage at:

<http://www.dealii.org/>

This version has a significant number of noteworthy new features:

- Comprehensive support for geometries described by arbitrary manifolds and meshes that respect this description not only on the boundary but also internally
- Support for geometries imported from CAD using the OpenCASCADE library
- Three new tutorial programs on complex geometries, CAD geometries, and time stepping methods
- Support for users wanting to use C++11 features
- Improvements to multithreading support
- Vectorization of many vector operations using OpenMP SIMD directives
- At least 140 features and bug fixes

For more information see:

<https://journals.ub.uni-heidelberg.de/index.php/ans/article/view/18031> (release paper)

[https://www.dealii.org/8.2.1/doxygen/deal.II/changes\\_between\\_8\\_1\\_and\\_8\\_2.html](https://www.dealii.org/8.2.1/doxygen/deal.II/changes_between_8_1_and_8_2.html) (changelog)

*Wolfgang Bangerth, Timo Heister, Guido Kanschat, Matthias Maier, and many other contributors.*

### ASPECT

We are pleased to announce the release of ASPECT 1.2. ASPECT is the Advanced Solver for Problems in Earth's ConvecTion. It uses modern numerical methods such as adaptive mesh refinement, multigrid, and a modular software design to provide a fast, flexible and extensible mantle convection solver. ASPECT is available from:

<http://geodynamics.org/cig/software/aspect>

This release includes the following changes:

- methods to have truly concentric shells without distorted cells
- linear solver improvements which give up to 2x speedup in some cases
- boundary names like "top" instead of numbers are now supported in input files
- new example: free surface computation with a crust as a stagnant lid

- new benchmarks: Davies et al. and Burstedde et al.
- new initial condition: S40RTS perturbation based on shear wave data
- fixes to minimum/maximum refinement plugins
- better error messages when linear solvers fail
- many other fixes and small improvements (direct solver, file output, checkpointing, etc.)

A complete list of changes can be found at:

[http://aspect.dealii.org/doc/doxygen/changes\\_between\\_1\\_81\\_and\\_1\\_82.html](http://aspect.dealii.org/doc/doxygen/changes_between_1_81_and_1_82.html)

*Wolfgang Bangerth, Timo Heister, and many other contributors.*

## Frontiers in Planetary and Stellar Magnetism Through High Performance Computing

Congratulations to the CIG Geodynamo Working Group for receiving 83 million core-hours on the IBM Blue Gene/Q "Mira" through the INCITE program at the Argonne Leadership Computing Facility (ALCF). Led by Jon Aurnou and Nick Featherstone, the team looks forward to working with the ALCF experts in running massive dynamo simulations using the CIG developed code *Rayleigh*. The 3 year project will push the frontiers of our understanding of the Earth's, Jupiter's and the Sun's dynamo. The massive datasets generated will be open to the community for analysis. For the latest information see the project's webpage: <http://geodynamics.org/cig/projects/dynamo-frontiers>



## CIG Codes and Science

CIG HQ is soliciting "One-Pagers" to include in our proposal for the next phase of CIG. Your "One-Pager" can be a scientific research area or education and outreach effort that CIG maintained software has enabled. The extended abstract of your research should include a picture exemplifying your research problem and code used. A template can be downloaded at:

<http://geodynamics.org/cig/events/calendar/one-pager-template>

# Governance

## Letter from Director

Dear Colleagues,

As we approach the 10<sup>th</sup> anniversary of the establishment of CIG, here at headquarters we are reflecting on what CIG has accomplished as a community and we are looking forward to CIG-III. I am excited about the future directions we are taking, some of them outlined in this newsletter. The CIG-III proposal writing committee met in January; keep an eye on (subscribe):

<https://geodynamicsblog.wordpress.com/>

for updated information on our progress. The writing committee will be asking for your input on a variety of matters; as a community-based, community-governed organization, CIG's effectiveness depends on your participation.

This month, we bid goodbye to long-time CIG staffer Dr. Eric Heien, who will be leaving CIG for an industry position. We appreciate Eric's many valuable and wide-ranging contributions to CIG and we wish him well on his new adventure.

Two CIG projects are ramping up. The geodynamo group holds its benchmark workshop this week, comparing accuracy and performance of codes from groups from around the world. The workshop sets the stage for the recently-approved INCITE project, which will run very large geodynamo models using the Rayleigh code on Mira, Argonne National Lab's fast and energy efficient computer. The geodynamo model outputs will be made available for scientists to study and interpret for years to come.

CIG's Software Attribution for Geoscience Applications (SAGA) project is a collaboration with library and social scientists to determine how best to give intellectual credit by enabling citation of software. The project is funded by an NSF EAGER project. The team conducted interviews with CIG scientists at the Fall AGU meeting, and is preparing a broader survey of the community. Stay tuned for additional developments.

Best wishes,

Louise



*Members of the CIG III Proposal writing committee hard at work.*

## WORKING GROUP UPDATES

Annual Working Group Plans are under development. Please contact Working Group Leads to contribute and for more information.

### Short Term Crustal Dynamics

The Short-Term Crustal Dynamics working group recently refreshed its members. Current members are: Brad Aagaard, Lead (U.S. Geological Survey), Eric Hetland (University of Michigan), Eric Lindsey (UC San Diego), Jeanne Sauber-Rosenberg (NASA Goddard), Charles Williams (GNS Science).

Most of the development effort has been fixing a few PyLith bugs and keeping in sync with PETSc improvements to DMPlex. We expect to release PyLith v2.1.0 in the next month.

*Brad Aagaard*

### Geodynamo

In 2015, the Geodynamo Working Group is carrying out two main tasks. First, we are running a community benchmarking workshop in Boulder, CO, in early February. Bringing together just over 30 planetary and solar dynamo specialists, we will compare accuracy and performance tests of spherical shell dynamo models and discuss how best to develop next generation models that can run on peta-scale devices. In addition to this, we will be carrying out a suite of massively parallelized geodynamo simulations using the Rayleigh Code developed by Nick Featherstone (CIG / CU Boulder). These simulations will be made using 83 million computing hours on the Mira supercomputer (Argonne National Lab).

*Jon Aurnou*

### Long Term Tectonics

Last year, the LTT working group organized a joint CIG/EarthScope Institute for Lithospheric Modeling (February 2014). Participants discussed and identified the primary science drivers, common numerical techniques, and the needs and challenges that the LTT community faces. A full report describing the outcomes of the meeting can be found on the CIG website. The meeting organizers submitted a short summary of the meeting that also included suggestions for future growth within the community to GSA Today. This article will be in the May 2015 edition.

For 2015, the LTT working group will be focusing its efforts on two activities: 1) building and conducting a survey to determine the computational needs of the community and how users and developers validate and verify their code, and 2) organizing a one day workshop before AGU to discuss the survey outcomes and LTT specific benchmarks.

*Katie Cooper*



### 2014 Elections

Congratulations to our new Executive Committee and Science Steering Committee members. On our EC, Scott King returns as Chair along with Bruce Buffet, Claire Currie, David Bercovici, and new member Omar Ghattas. On our SSC, Brad Aagaard returns as Chair along with Magali Billen, Jolante van Wijk, Tim Ahern, Jon Aurnou, re-elected members Jed Brown and Carl Tape, and new member David May.

Many thanks to outgoing EC member Wolfgang Bangerth and SSC Member Roger Buck; and to our Nominating Committee – Marc Spiegelman, Gary Glatzmaier and Rowena Lohman.



# Events

## CIG Webinars

CIG webinars draw from a pool of experts from mathematicians, to computer scientists, and to geoscientists, among others to bring together a cross-cutting community of faculty, students and researchers to both inform and disseminate knowledge on the tools and methodologies employed to further the study of problems in geodynamics.

The one hour webinars will be held the 2<sup>nd</sup> Thursday of each month October through May (no webinar in December due to AGU) at 2pm PT unless otherwise noted. Webinars will be recorded for later viewing. Reminders and details are sent through the cig-all mailing list.

This year's series features topics in software infrastructure and development that enables our science. Webinars focus on bridging communities, laying foundations for robust and usable software that address active areas of geodynamic research and HPC for big data.

## Webinar Schedule

**February 12** –Eric Heien & Hiro Matsui, *UC Davis*

**March 12** – Cedric Thieulot, *U. Utrecht*

**April 9** – Lucy Fleisch, *Purdue*

**May 14** - Arben Pitarka, Stanley Ruppert, & Douglas Dodge, *LLNL*

## Next Webinar

**Thursday, February 12, 2015 @ 2pm PT**  
Accuracy and Performance Benchmarks for Geodynamo Simulation

*Eric Heien and Hiro Matsui*  
*UC Davis*

Numerical simulations of planetary dynamos have revealed many scientific insights over the past several years. However, due to the limitations of computing power current models are unable to properly resolve turbulent dynamos or approach simulation of realistic liquid metal dynamos. In order to better understand the best path forward to a realistic dynamo simulation, we have performed accuracy and performance benchmarks using 17 codes which use different numerical methods (spectral, finite difference, finite element, hybrid methods) and different domain decompositions. We examine the convergence rates of different methods, parameters necessary to resolve different physical regimes, and scalability of

different schemes up to large numbers of processes. The goal of this work is to understand which methods work best in preparation for high resolution runs on  $O(10^5)$  cores.

For more details on this and all CIG webinars see:

<http://geodynamics.org/cig/events/webinars>

## CIDER

The 2015 CIDER summer program will be held at UC Berkeley from June 28th to July 31st, on the theme "Solid Earth and Climate".

The program includes a 4 week tutorial program for about 35 advanced graduate students and post-docs (July 5-31, 2015), while more senior scientists are also welcome at any point in the program.

A Carbon Observatory workshop will be held in conjunction with the CIDER program on July 1-3, 2015.

Support for students is available for both workshops.

More information at: <http://www.deep-earth.org/summer15.shtml>

Application deadline: February 1, 2015

## SIAM

The next **SIAM Conference on Mathematical and Computational Issues in the Geosciences** will be organized at Stanford University, June 29 – July 2, 2015. The themes are (at large) mathematical models and methods in the Geosciences. More details can be found in the attached flyer, and at:

<http://www.siam.org/meetings/gs15/>



2014 CIG Annual Business Meeting



The ASPECT Users Group enjoys a sunny San Francisco day at the 2014 Fall AGU Meeting

## POSTDOCTORAL FELLOWSHIP

### L'Oréal USA for Women in Science Program

Applications for the 2015 L'Oréal USA For Women in Science fellowship program are now open.

The L'Oréal For Women in Science program recognizes and rewards the contributions women make in STEM fields and identifies exceptional women researchers committed to serving as role models for younger generations. More than 2,000 women scientists in over 100 countries have been recognized since the program began in 1998.

The L'Oréal USA For Women In Science fellowship program will award five postdoctoral women scientists in the United States this year with grants of up to \$60,000 each. Applicants are welcome from a variety of fields, including the life and physical/material sciences, technology (including computer science), engineering, and mathematics.

<http://www.lorealusa.com/forwomeninscience>

## Upcoming Meetings

### February 5-6, 2015. Geodynamo Benchmarking Workshop, Boulder, Colorado

Workshop will focus on accuracy and performance benchmark results from participating research groups and examining the future direction of geodynamo codes.

### May 19-30, 2015 tentative. 2015 ASPECT Hackathon, location tbd

### June 1– July 31, 2015. CIDER 2015 Summer Program, Berkeley, California

Next summer's theme - Solid Earth Dynamics and Climate, [www.deep-earth.org/summer15.shtml](http://www.deep-earth.org/summer15.shtml)

### Multiple Dates. 2015 Crustal Deformation Modeling Tutorials, virtual

Beginner Workshops are tentatively scheduled for the week of June 22; Advance for the week of August 24.

### June 29-July 2, 2015. SIAM, Stanford, CA

Mathematical and Computational Issues in the Geosciences, <http://www.siam.org/meetings/g515/>

### August 31- September 5, 2015. XIV International Workshop on Modeling of Mantle and Lithospheric Dynamics, Olerons Island, France

Held every 2 years, this workshop combines lectures, poster sessions, student meeting with speakers and evening plenary discussions.

<https://sites.google.com/site/geodynamicsxiv>

For more information on CIG hosted events, please go to [geodynamics.org](http://geodynamics.org)

## Recently Published

A.T. Ringler and M.T. Hagerty and J. Holland and A. Gonzales and L.S. Gee and J.D. Edwards and D. Wilson and A.M. Baker (2014) "The data quality Analyzer: A quality control program for seismic data", *Computers & Geosciences* DOI: doi:10.1016/j.cageo.2014.12.006

de Wit, R.W.L. and Käufel, P.J. and Valentine, A.P. and Trampert, J. (2014) "Bayesian inversion of free oscillations for Earth's radial (an)elastic structure", *Physics Of The Earth And Planetary Interiors* DOI: 10.1016/j.pepi.2014.09.004

Galassi, Gaia and Spada, Giorgio (2014) "Sea-level rise in the Mediterranean Sea to 2050: Roles of terrestrial ice melt, steric effects and glacial isostatic adjustment", *Global And Planetary Change* DOI: 10.1016/j.gloplacha.2014.10.007

Kim, Yoon-Mi and Lee, Changyeol (2014) "Effect of time-evolving age and convergence rate of the subducting plate on the Cenozoic adakites and boninites", *Journal Of Asian Earth Sciences* DOI: 10.1016/j.jseaes.2014.06.029

Retailleau, L. and Shapiro, N. M. and Guilbert, J. and Campillo, M. and Roux, P. (2015) "Detecting and locating seismic events with using USArray as a large antenna", *Advances In Geosciences* Volume 40 DOI: 10.5194/adgeo-40-27-2015



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*The Computational Infrastructure for Geodynamics (CIG) is a community-driven organization that advances Earth science by developing and disseminating software for geophysics and related fields.*

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