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Digital Library for Computational Seismology

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Computational methodologies play an increasingly important role in Earth sciences. However, Earth science curricula in general often do not equip scientists with the necessary background in mathematical and computational aspects of the rapidly expanding field of simulation technology.

This lack of preparation applies in particular to the field of computational seismology. Despite the fact that the same numerical methodologies (e.g., finite differences, finite/spectral elements) are used in various domains (e.g., exploration seismics, volcanology, global seismology, earthquake physics), there often has been little interaction and exchange of experiences among researchers working in these different domains.

Since 2004, the European-funded Marie Curie Research Training Network has brought together 14 institutions (universities and research centers) and several associated partners (exploration industry, seismic data and computing centers, and non-European universities) in a project to carry out research in computational seismology. The Seismic Wave Propagation and Imaging in Complex Media: A European Network (SPICE) Consortium aims to integrate institutions with specializations in physical, mathematical, geological, and computational aspects of wave propagation. The goal is to develop, verify, and apply computational tools for wave propagation and imaging problems on all scales.

The project scope was reported by *Igel* [2004] and the SPICE Team. This brief report outlines recent achievements and describes tools and material available to the community.

One of the key deliverables of the project is an open, Internet-based digital library comprising a wide range of seismological codes (wave and rupture simulation, analytical solutions, processing, visualization, and so forth), training materials, and benchmarking exercises in the field of wave and rupture propagation modeling. The library could be of interest to scientists and students working in the field of numerical wave and rupture modeling. It can be accessed at the Web site: http://www.spice-rtn.org. Although the project draws to an end in December 2007, the library will remain in operation after that date.

Software and Training Materials

The software library was initiated in 2005, and several algorithms are now available to the scientific community. The library's goal is to provide codes and tools that may be useful for researchers who are starting out in the field or observational seismologists who are interested in using the simulation techniques. In addition to the library's sophisticated, parallelized, three-dimensional wave propagation algorithms based on finite differences, finite (spectral) elements, or the pseudospectral methods for local, regional, and global models, there are also simple training codes that can help with getting started with a particular method or that can be used in tutorials.

The library also contains "classical" techniques such as ray approaches, and the reflectivity and normal mode methods. Strong attention also is paid to the provision of analytical solutions (Lamb's problem, source at bimaterial interface, and so forth) that can be used to test numerical solutions and that are often difficult to obtain.

Each available code is supplemented by a manual and one or more examples. The codes are classified in many categories according to, for example, solution type (numerical, quasi-analytical, and analytical) and code level (production code, research, and training). The classification can in turn be used to filter the entries and therefore to provide quick orientation among the codes.

The library is an open platform so that anyone can participate and submit a code. For example, an author can submit a code to the software library under any license (e.g., GNU general public license). Then the author can benefit from other users who would be interested in that particular code, providing software bug reports, and/or helping with the code development. Regarding the latter, the library also can be used as a version control system because it keeps track of all previous versions.

The network has organized four open research and training workshops with lecture series and computer practicals. Most of the key presentations by invited lecturers are published in the library, including several audio-video lectures. The library also includes two books (with pdf versions available) developed in connection with the SPICE research and training workshops [*Brokesova*, 2006; *Moczo et al.*, 2004]. The library's training material covers a broad range of seismological topics, such as basics in wave propagation and rupture modeling, theory, applications of seismic inversions, and recent issues in volcano seismology.

Benchmarking Exercises

The library provides three benchmarks related to global tomography, wave-propagation code validation, and source imaging. In the global tomography benchmark [*Qin et al.*, 2006], a synthetic data set for testing global tomographic methods is provided. This global-scale benchmark data set comprises complete full-waveform seismograms synthesized with the spectral element method for a three-dimensional model of the mantle that is realistic and that contains complexities on various spatial scales and different types of heterogeneities in velocity, anisotropy, attenuation, and density.

In addition, the benchmark data set takes into account topography, ellipticity, Earth's rotation, self-gravity, and ocean thickness. Each participant can download the benchmarking synthetic seismograms and test the performance of his or her tomography code.

Within the wave-propagation code validation benchmark, an interactive Web interface has been developed, offering a simple way to compare numerical, analytical, and/

or semianalytical solutions. A set of testing examples is included, together with their thorough descriptions and reference solutions, allowing participants to fully replicate the model with their own code. Reference solutions can be downloaded for comparison purposes. Alternatively, the simulation result then can be uploaded to the server, which will calculate and display the time-frequency misfits between selected solutions (*Kristekova et al.* [2006]; see also the SPICE code library).

The source-imaging benchmark is a blind test on kinematic source inversion. A synthetic data set for a hypothetical source model (based on the 2000 Tottori earthquake in Japan) is provided for a set of receivers. Participants can download this data set, try to invert for the slip distribution, and compare the result with the correct one that was used to obtain the benchmarking database.

Outlook

We hope the library helps researchers get started in using computational tools in seismology. The next step is to develop a more sophisticated infrastructure that facilitates the implementation and execution of large simulations on a routine basis.

At a joint meeting of SPICE and CIG (Computational Infrastructure in Geodynamics, a U.S. project providing community codes for geodynamics; Web site: http://www.geodynamics.org) held 8–12 October 2007 in Jackson, N. H., participants discussed how to facilitate the use of computational methods in seismology, and they indicated the need to coordinate developments (e.g., benchmarking, on-demand computing, model and data exchange formats, and training) on an international scale. To meet this need, it was decided to initiate a new Internet platform (http://www.computational-seismology.org) and an associated mailing list, through which information on meetings, recent developments, publications, projects, and new software in the field of computational seismology can be disseminated.

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NEWS

In Brief

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High-school-age science assessments Students in Finland had the highest science scores in a 57-country survey of 15-year-olds. According to a 4 December report issued by the Organisation for Economic Co-operation and Development (OECD), other high-scoring countries included Canada, Japan, New Zealand, Hong Kong-China, Chinese Taipei, and Estonia. More than 400,000 students from 57 countries participated in the Programme for International Student Assessment (PISA), a triennial survey of the knowledge and skills of 15-year-olds. The study found that on average across OECD countries, 1.3% of 15-year-olds reached level 6, the highest proficiency level on the science scale. These students could consistently identify, explain, and apply scientific knowledge in many situations. The number of students at that level could not be reliably predicted from a country's overall performance. For instance, while Korea had an overall high score of 522 points (above the average 500) and the United States had a score of 489, both countries had similar percentages of students at level 6. For more information, visit the Web site: http://www.oecd.org.

U.S. regional impacts of climate change On 4 December, the Pew Center on Global Climate Change released a report that assesses climate vulnerabilities in four different areas of the United States. "Regional impacts of climate change: Four case studies in the United States" notes that midwestern cities are likely to experience more frequent, longer, and hotter heat waves; that wildfires are likely to increase in the U.S. West; that sustaining fragile Gulf Coast wetlands ecosystems will be increasingly difficult due to climate change; and that the Chesapeake Bay may respond to climate change with more frequent and larger hypoxia events. The report indicates that adaptation measures need to be a critical component of any long-term U.S. climate strategy. "The degree to which we can adapt to the consequences of climate change will be determined in large part by the policies and management practices we put in place today," said Pew Center president Eileen Claussen. For more information, visit the Web site: http://www.pewclimate.org.

—Randy Showstack, Staff Writer