The ACES international cooperation: advances and challenges

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Abstract

Sponsored by Australia, China, Japan and USA under the Asia Pacific Economic Cooperation (APEC), ACES activities commenced in 1999 at an Inaugural Workshop held in Queensland, Australia. Since then, two subsequent major workshops and two Working Group meetings have been held in each of Japan and USA with growing participation levels. Advances made by ACES groups include development of new and enhanced microscopic and macroscopic simulation models for study of the earthquake generation process, linkage of microscopic simulation models with laboratory observations, development of prototype interfaces between simulation software systems developed in different countries, improved data assimilation methodologies, and advances in understanding the physics of earthquakes. ACES has both stimulated international collaboration and helped to foster development of new national programs and infrastructure. While the ACES Cooperation has gained in momentum, the greatest challenges lie ahead in its ultimate goal of fostering development of simulation models for the complete earthquake generation process.

Aims and activities

The APEC Cooperation for Earthquake Simulation (ACES)[1] aims to

• develop realistic numerical simulation models for the physics of the complete earthquake generation process and to assimilate observations into such models,
• foster collaboration between the relevant complementary programs of participating member economies, and
foster development of the required research infrastructure and research programs.

Activities commenced in 1999 at the ACES inaugural workshop held in Australia with around 60 international scientists participating, followed by two workshops and two working group meetings in each of Japan and USA (see [1], Events and Workshop Proceedings). The 3rd workshop held in Maui, USA, had participation of 100 scientists from Australia, China, Japan, USA, Europe and Mexico. Two workshop proceedings volumes[1] and two special issues of an international journal [5,6] have been published and the 3-rd Proceedings and Special Issue for the Maui Workshop are being prepared. The number of researchers participating in ACES has grown to over 120 spanning some 50 institutions and research centers worldwide. An active visitors program was initiated in 2000 between Australia, China, Japan and USA sponsored by the Australian Research Council, JSPS, China NSF, USGS and other organizations in USA leading to around 20 joint publications so far.

ACES cooperative activities are achieved through workshops, collaborative research projects, working group activities and meetings, visitors programs, and via new national research infrastructure and initiatives.

**Advances**

Numerical models and a parallel software system (Solid Earth Simulator/GeoFEM) for simulation of the dynamics of the solid earth and subducting slab under the Japan Islands is being developed in Japan within the $US400M Earth Simulator national project (Fig. 1).

![Figure 1: Finite-element discretisation of the solid earth (upper) and the subducting slab under southwest Japan (lower) using the GeoFEM software system[7] – courtesy of Hiroshi Okuda, co-leader GeoFEM group.](image)

This large-scale macroscopic simulation software system is being coupled to a microphysical based numerical model and software system being developed in Australia (LSMearth) to allow fault zone and nucleation processes to be simulated (Figure 2).
Research to study earthquake generation and interacting fault system dynamics has commenced using these models and is providing evidence for a mechanism for intermediate-term earthquake forecasting (e.g. Figure 3).

In USA, projects under the GEM group have been initiated to simulate the San Andreas interacting fault system and to develop advanced techniques to analyze observations and help reveal the complex system dynamics of this fault system (Figure 4).

Simulations of earthquake dynamics are providing new insights into earthquake physics and scaling relations. Working group activities involving NASA and GSI of Japan have commenced with the goal of making use of GPS data to drive and constrain large-scale regional simulation models. Spaceborne observations in USA by NASA JPL are providing
new abilities to map the evolution of the Earth’s surface deformation field (Figure 5). Assimilation of these data into earthquake simulation models will provide a basis to develop earthquake forecasting methodologies analogous to those applied in the atmospheric sciences.

Figure 5: Mapping of surface deformation evolution using C-Band InSAR difference fringes. The difference fringes are small (upper left: red=positive and blue=negative regions), and are concentrated along the portions of the San Andreas that are about to initiate sliding, either in the main shock or the pre-and post-shocks (upper right). Courtesy of Andrea Donnellan & John Rundle.

Joint research projects involving Australia, China and USA have been initiated to study fault system dynamics using refined cellular automata models to probe classes of fault system behaviour. These are providing insights into the general conditions when earthquake forecasting may be possible and are motivating numerical experiments with more realistic and CPU intensive models aiming to better link the CA models to real fault systems. Collaborative research on the “Load-Unload Response Ratio” (LURR) involving China and Australia has suggested a new scaling relation between earthquake magnitude and critical region size and has reproduced LURR signals in simulations (Figure 6). The results have provided encouragement for earthquake forecasting and for probing the underlying physical mechanism with simulation, and have motivated further simulation and observational research in Australia, China and USA. Numerous other collaborative research activities are being undertaken within the seven ACES working groups involving computational scientists, seismologists, physicists and engineers.

Figure 6: Left: LURR critical region size scaling with earthquake magnitude – courtesy of Xiang-chu Yin and Keyin Peng. Right: Simulation of rock failure (upper) and resultant LURR signal – courtesy of Mora, Wang, Place and Yin.
Infrastructure and national program developments

New research infrastructure – both software and hardware – has been and is being developed. This includes Japan’s 40 TFlops Earth Simulator parallel machine (Figure 7) and its software system which will enable large scale simulations of the ocean, atmosphere and solid earth, with the solid earth component being largely focused on crust and mantle dynamics for simulation of Japan’s great earthquakes.

Figure 7: The Earth Simulator superparallel supercomputer facility in Japan[2]: peak performance = 40 Tflops, main memory 10 Tbytes.

In Australia, a new major national research facility initiative called the Australian Computational Earth Systems Simulator (ACcESS) is about to commence which aims to construct a simulator (numerical models and software plus establish hardware capacity ~ 2 TFlops) for earth processes ranging from mantle and crustal evolution to crustal dynamics and mineralisation (Figure 8).

Figure 8: Logo for the Australian Computational Earth Systems Simulator Major National Research Facility in Australia[3]. Image design and realisation by David Place. Contributors, Place, Mora, Mülhaus, Moresi, Coutel, Zhang and Yuen.

In China, a key national project is being conducted to study evolution theory and failure prediction involving computational, laboratory and observational research. In USA, the General Earthquake Model Group has been established aiming to develop general earthquake simulation models and to simulate the dynamics of the San Andreas fault system. The new Southern California Earthquake Center (SCEC II) has placed its focus on the physics of earthquakes and numerical simulation. NASA JPL is reviewing its Solid Earth Program[4] and its satellite infrastructure plan which aims to enable surface deformation evolution to be mapped in near real time to provide input into earthquake simulation systems.
ACES is fostering collaboration between the different national initiatives in Australia, Japan, China and USA, and in some instances, has helped foster establishment of new initiatives.

Challenges

The ACES goal of simulation models for the complete physics of earthquakes across multiple tectonic settings involves many scientific challenges due to the vast range of scales involved, the complexity of the physics, and the sheer magnitude of the computational problem. However, the complementary nature of national programs in ACES coupled with progress so far in constructing the necessary research infrastructure – numerical models, software and parallel supercomputer hardware – suggest this goal will ultimately be achieved. The advances made using the preliminary models provide encouragement for the prospects of developing greatly improved understanding of the physics of crustal fault systems and for the possibility of earthquake forecasting.

For continued success, the ACES initiative must also continue to meet the challenge of operating within a world where policies on international linkages are highly heterogeneous.

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References


¹ Department of Industry, Science and Resources
² Australian Research Council
³ Research Organisation for Information Science and Technology
⁴ Ministry of Sciences and Technology
⁵ China Seismological Bureau
⁶ Chinese Academy of Sciences
⁷ National Science Foundation of China