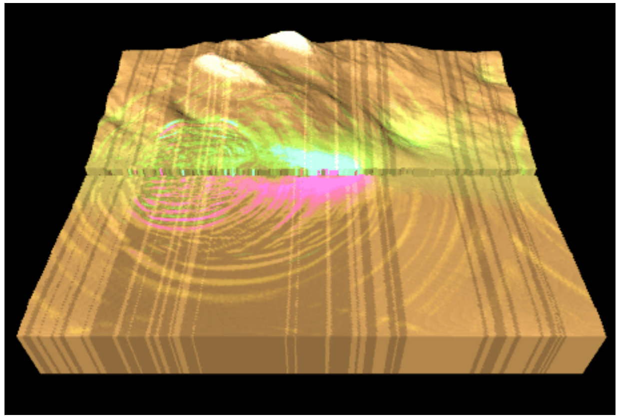
APEC Cooperation for Earthquake Simulation

A collaboration between leading research groups in Australia, China, Japan, and the USA dedicated to the development of simulation models for the entire earthquake process.

Innovations in High Performance Computing, parallel computational methods, and earth systems science.

Background

Earthquakes are amongst the most costly and deadly of all natural phenomena. An overwhelming majority of the world's earthquakes strike APEC member economies located around the Pacific Rim. Much remains unknown about the earthquake generation process, hampering earthquake mitigation and forecasting efforts. However, recent developments in earthquake physics, numerical simulations, and High Performance Computing offer the possibility of modelling the entire earthquake generation process. Such a general earthquake model is the goal of the APEC Cooperation for Earthquake Simulation (ACES). To achieve this goal, ACES intends to capitalize upon the complementary strengths of earthquake research programs in Australia, China, Japan, and the USA.



An earthquake simulated using a 2D particle−based Lattice Solid Model. Colours represent ground−velocity due to slip along a fault which bisects the model.

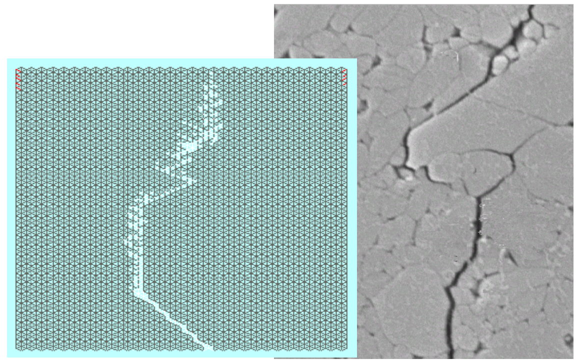
Earthquake simulations

Earthquake generation is controlled by a vast range of physical processes occuring over many orders of magnitude of scale in space and time. At the smallest scales, these processes include microscopic frictional interactions within fault zones and rock fracture. Motions of tectonic plates and mantle convection are important at the largest scales. At present, no simulation model exists for the entire range of scales involved. However, a number of research groups in ACES are making advances in simulating some of the processes responsible for earthquakes.

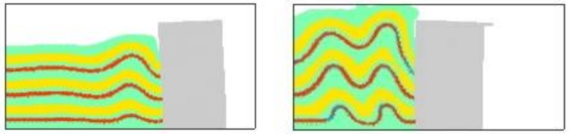
Microscopic simulations

The microscopic physics of earthquakes may be simulated using particle−based numerical models. Such models rely upon the fact that rocks ultimately consist of atoms held together in a crystalline lattice by interatomic forces. The Queensland University Advanced Centre for Earthquake Studies (QUAKES) is an ACES member institution developing a particle−based model known as the Lattice Solid Model. Complex fault zones may be specified, consisting of rough surfaces separated by a layer of broken rock called fault gouge The Lattice Solid Model has been highly successful, providing insight into earthquake nucleation, frictional heat generation, the localization of slip into narrow bands within a complex fault zone, and the earthquake cycle.

Researchers at the Laboratory for Nonlinear Mechanics (LNM) in China have developed statistical meso−damage mechanics and numerical models to simulate the dynamic failure of brittle materials. Simulated rock is damaged by breaking bonds between nearby particles. The LNM has found that damage tends to localise along cracks which progressively grow and join up to form a large fracture. The Centre for Analysis and Prediction (CAP) in China is developing theoretical and observational techniques for forecasting the occurrence of macroscopic failure. CAP seeks to identify precursors to macroscopic failure which might be used as warning signs. It is hoped that this research will result in forecasting techniques which identify an impending earthquake days to months prior to the event.



Dynamic failure of a brittle material using a model by the Laboratory of Nonlinear Mechanics. Crack patterns in the model are very similar to cracks in natural rocks.



Folding of sedimentary layers due to continental collision is simulated using a particle in cell finite element method. Patterns similar to those above are common geologic features.

Macroscopic simulations

Particle−based models are ideal for simulations of small−scale physics due to their geometrical versatility. However, extremely large models would be required to simulate large−scale phenomena such as seismic wave propagation and plate tectonics. Another method applicable to macroscopic simulations is known as the Finite Element Method. A model region is specified by defining a mesh of small, finite elements. Each element represents a large volume of rock.

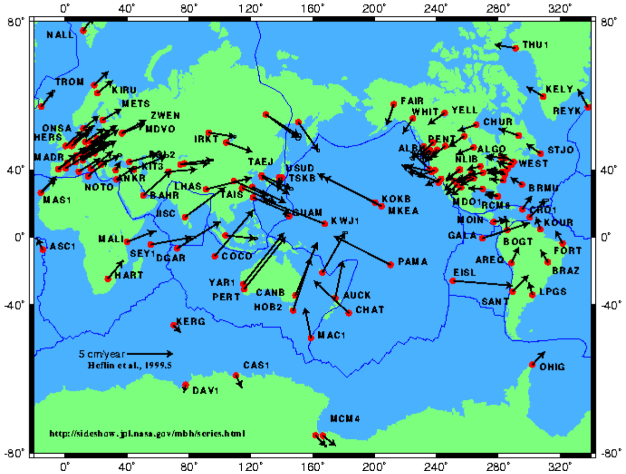
A simulation of crustal material subducting into a viscous medium representing the upper mantle, or asthenosphere. The simulation was performed using the particle in cell finite element method of the Solid Mechanics Research Group.

Researchers at the Solid Mechanics Research Group of CSIRO and the University of Western Australia have developed a hybrid model which combines the geometrical versatility of particle−based models with the robustness and speed of the finite element method. The result is the particle in cell finite element method. This method has been used to simulate mantle convection, continental dynamics, and large−scale crustal deformation such as folding and faulting.

Data assimilation and model validation

Regardless of the numerical method employed, simulation models are only approximations of the real, physical processes they represent. The validity of a particular numerical model may be tested by comparing the results of simulations with relevant physical observations. This is known as data assimilation. Laboratory experiments involving frictional sliding or fracture of natural rock samples provide physical contraints for microscopic simulations.

Large−scale crustal deformation and tectonic motions are detectable using the Global Positioning System (GPS). The Southern California Earthquake Center (SCEC) is a multi−institutional, multi−disciplinary group which maintains a considerable volume of earthquake−related data. Participants in SCEC include field seismologists, experimentalists, and theoreticians. The NASA Jet Propulsion Laboratory affiliated with SCEC, performs studies of global and regional crustal motions using a network of GPS stations distributed world−wide. The General Earthquake Models (GEM) group in the USA is a collaboration developing a set of tools to simulate earthquake processes with a strong emphasis upon data assimilation in order to both validate and constrain the physics of earthquake models.



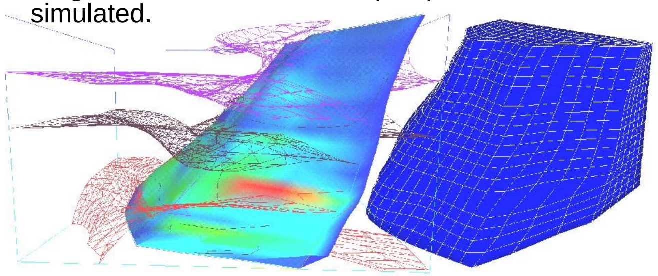
Global tectonic plate motions obtained via GPS by the Jet Propulsion Laboratory of NASA, a member of SCEC.

Towards a *virtual* Earth

The Science and Technology Agency of Japan has initiated an *Earth Simulator* project. The aim of this project is to develop the infrastructure necessary to implement a *virtual Earth* using a massively vector−parallel supercomputer called the Earth Simulator or GS40. In 2002, this supercomputer will have a peak performance of 40 Tflops and 10 TBytes of memory. Under intensive collaboration between geophysical and computational researchers, four groups in Japan are developing the *Solid Earth Simulator* which is large−scale parallel software for the GS40.

A core/mantle dynamics group, a crustal activity modelling group, and a dynamic rupture and strong motion modelling group are developing modules for a pluggable software platform developed by a computational science group called GeoFEM.

In Australia, a new thematic national HPC facility, the Australian Solid Earth Simulator (ASES), is being established. Its aim is to provide infrastructure for the simulation of solid earth processes by Aust. ACES groups and ACES visitors. QUAKES is developing new microscopic simulation code known as LSMearth. This modular application will be highly adaptable allowing a vast range of different microscopic processes to be simulated.



A sample analysis of the faults around the Japanese islands showing the normal contact forces and equivalent stresses. The analysis was performed using an early version of the GeoFEM Finite Element software.

Models applications

The research performed by ACES will directly lead to advancements in understanding earthquake physics, improvements to earthquake hazard mitigation techniques, and forecasting of potentially destructive earthquakes. Because the simulation of earthquakes involves modelling many physical processes such as fracture, friction, and material failure, the ACES initiative also offers an opportunity for innovative spinoff applications in industrial domains including materials engineering, minerals and geophysical exploration, mining, and infrastructure.

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