

The Crustal Activity Modelling Program: Progress toward Scientific Forecast of Earthquake Generation

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Introduction

The solid earth is a large-scale, very complex system, consisting of the crust, mantle and core which are different, both physically and chemically, from each other. For realistic simulation of solid earth dynamics, we need a very large, high-speed computer system. In Japan, fortunately, a joint project of earth science and computer science, called the Earth Simulator project, has started in 1998 as a national project promoted by the Science and Technology Agency of Japan. This project consists of two main parts; the development of a high performance, massively parallel processing computer system with 10 TB memory and 40 TFlops peak speed and the development of a multi-scale, multi-physics parallel computing software system for numerical simulation of ocean-atmosphere dynamics and solid earth dynamics. The mission of our group is to develop a solid earth simulation software system, named the Solid Earth Simulator, in collaboration with a computational science group. The Solid Earth Simulator is designed as a composite of three sub-systems, corresponding to long-term, global scale simulation of core-mantle dynamics, intermediate-term, regional scale simulation of crustal activity due to relative plate motion, and short-term, local scale simulation of earthquake rupture and strong ground motion. These three sub-systems with different simulation algorithms will be connected with each other through a solid earth simulation platform to be developed by the computational science group.

Crustal Activity Modelling Program

The Crustal Activity Modelling Program (CAMP) is one of the three main programs composing the Solid Earth Simulator project, which focuses on intermediate-term, regional scale crustal activity. The aim of CAMP is to develop a realistic numerical simulation model for the entire process of earthquake generation cycles in and around Japan in a very complex tectonic setting. In general, the earthquake generation cycle consists of tectonic loading due to relative plate motion, quasi-static rupture nucleation, dynamic rupture propagation and stop, and fault lithification and healing. The fundamental elements needed for modelling the earthquake generation cycle are; 3-D geometry of plate interfaces, elastic and viscoelastic slip-response functions that relate fault slip with stress changes in surrounding media, and fault constitutive laws that prescribe the evolution of frictional properties of faults with slip and time.

In Fig. 1 we show the conceptual design of the earthquake generation cycle model. The total system is divided into three components: the crust-mantle structure model, the tectonic loading model and the dynamic rupture model. First, to construct a structure model, we determine 3-D geometry of plate interfaces and characterize frictional properties of the interfaces by specifying abrasion and adhesion rates. Second, we develop a quasi-static tectonic loading model by combining the viscoelastic slip-response function and the slip- and time-dependent fault constitutive law on the structure model. The driving force of this quasi-static model is relative plate motion. Third, we develop a dynamic rupture model by combining the elastic slip-response function and a slip-dependent type of fault constitutive relation. The quasi-static loading model and the dynamic rupture model must share the same structure model. The initial stress distribution and the fault

constitutive relation used in the dynamic rupture simulation are given by the output of the quasi-static loading simulation at a critical state. In short, the quasi-static loading model and the dynamic rupture model are strongly coupled with each other, and this coupled system enables us to simulate the complete earthquake generation cycle.

Toward Scientific Forecast of Earthquake Generation

In the first stage of the Solid Earth Simulator project our CAMP group have completed the individual development of the three component models: the crust-mantle structure model, the tectonic loading model and the dynamic rupture model. The current outcomes concerning CAMP will be found in the 1-st ACES Workshop Proceedings, the forthcoming PAGEOPH Special Volumes, and also the Abstract Volume of this workshop [1-7]. In the next stage we will combine the three component models to construct a unified realistic simulation system for earthquake generation cycles in and around Japan. Outputs of this simulation system are the surface deformation, internal stress change and seismic wave radiation associated with the progress of seismic and/or aseismic slip on the plate interface. From comparison of these computed data and observed data, we can extract useful information to estimate the past slip history and the present stress state on the plate interface by using a technique of inversion analysis. The data assimilation software enables us to incorporate the information extracted from observed data into the computer simulation to forecast the next step of the earthquake generation cycle.

From the standpoint of earthquake prediction, our target is limited to large earthquakes. The essential difference between large and smaller events is in their stress accumulation and release processes. The large events that break down the entire seismogenic zone may be regarded as the process of tectonic stress release, while the smaller events that break down only a part of the seismogenic zone should be regarded as the redistribution process of local stress. Therefore, monitoring the past slip history and the present stress state through comparison of simulation output and observations is crucial for long-term prediction of interplate large earthquakes.

International and Interdisciplinary Collaboration

The Crustal Activity Modelling Program shares the ultimate goal in earthquake physics with the Australian Solid Earth Simulator project, the General Earthquake Models project in USA, and the Earthquake Prediction project in China. For further development in earthquake physics, both interdisciplinary collaboration with computational science and international collaboration with different national groups should be strengthened through activities of APEC Cooperation for Earthquake Simulation (ACES). The Japan-Australia collaborative research "Microscopic and macroscopic simulation study on earthquake generation and fault evolution" has been initiated successfully in 2000 under the support of the ACES visitors program funded jointly by JSPS and IREX, that is a good example of international and interdisciplinary collaboration.

Related Presentations in this Workshop

- [1] M. Ohnaka, A constitutive scaling law that unifies the shear rupture from small scale in the laboratory to large scale in the Earth as an earthquake source.
- [2] C. Hashimoto and M. Matsu'ura , Physical modelling of earthquake generation cycles at transcurrent plate boundaries.
- [3] K. Nakajima, C. Hashimoto and M. Matsu'ura , Parallel performance of the tectonic loading process model at transcurrent plate boundaries.

- [4] K. Fukui, T. Sato and T. Iwasaki, Modeling 3-D configuration of plate boundaries in and around Japanese Islands.
- [5] H. Aochi and E. Fukuyama, Scrutiny of the 3-D non-planer fault model of the 1992 Landers earthquake.
- [6] E. Fukuyama, C. Hashimoto, and M. Matsu'ura, Simulation of earthquake transition from quasi-static growth to dynamic propagation.
- [7] T.Sagiya, T. Sato, C. Hashimoto, I. Minami, and M. Matsu'ura, Viscoelastic inversion of crustal deformation data.

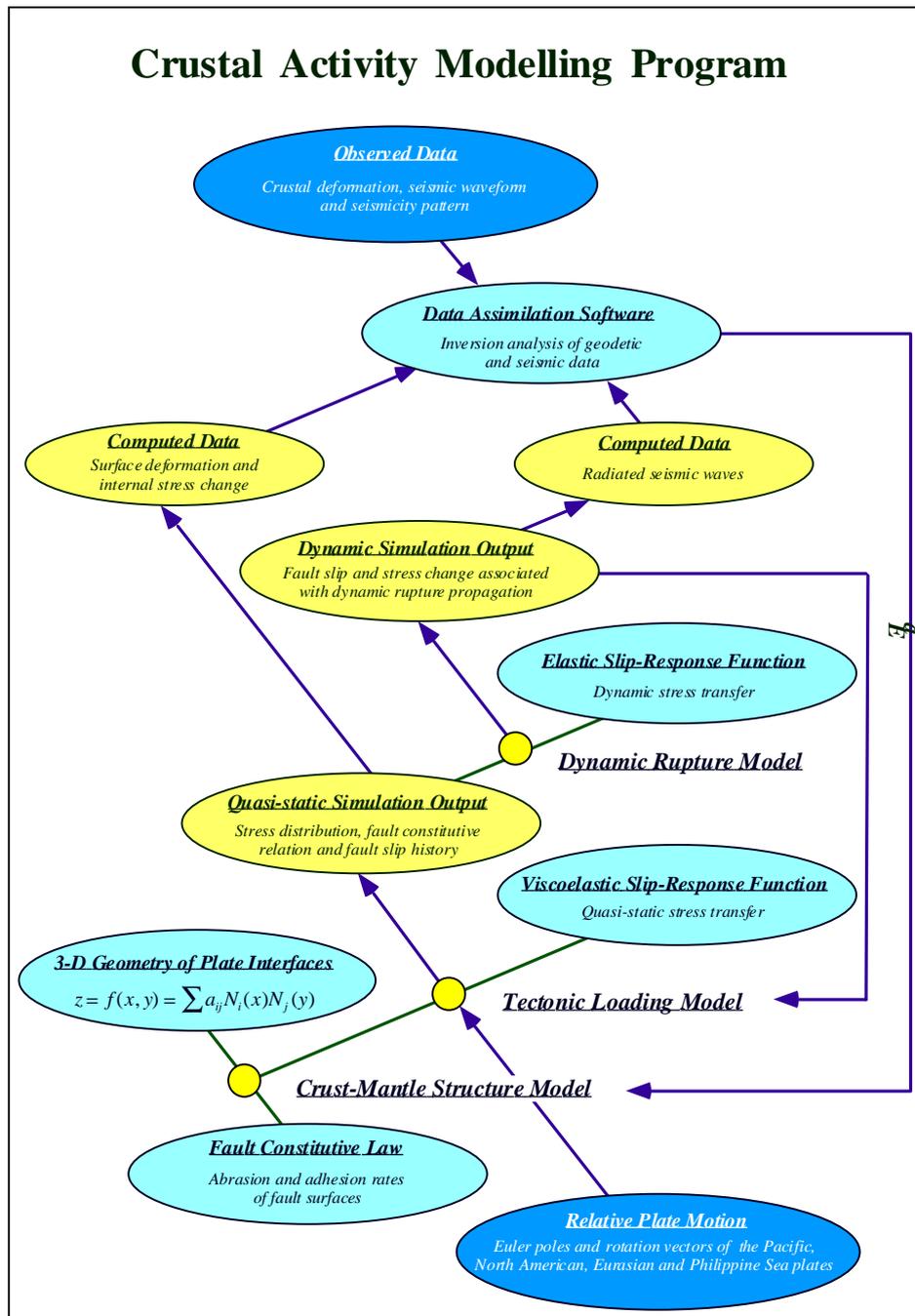


Figure 1: A diagram showing the hierarchic structure of the earthquake generation cycle model