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Computational Earthquake Science
Part I

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1. Introduction

During the last decade earthquake science has benefited from new observations, improved computational technologies, and improved modeling capabilities. Combining approaches in computational science, data assimilation, and information technology are improving our understanding of earthquake physics and dynamics. The scientific method relies on development of a theoretical framework or simulation model describing nature. While no such model exists for the complete earthquake generation process, conceptual developments in understanding earthquake physics, numerical simulation methodology and advances in advanced computing offer the possibility to develop such models. Development of simulation models represents a grand scientific challenge due to of the complexity of phenomena and range of scales involved from microscopic to global. Such models are providing powerful new tools for studying earthquake precursory phenomena and the earthquake cycle. They will have direct application to earthquake hazard studies and earthquake engineering, and the potential to yield spin-offs in sectors such as mining, geophysical exploration, high performance computing, material science, and geotechnical engineering.

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To understand a nonlinear earthquake fault system necessarily implies that predictions about the future behavior and dynamics of the system can be made whose accuracy can be tested by future observations. This procedure is the true essence of the scientific method. Predictive models and simulations that capture the essential physics and dynamics of the system covered by earthquake observations can be tested by future observations. The construction of models is necessary, since earthquake observations can only be taken at the boundary (surface) of the earth, or at most in a small number of selected internal locations. Moreover, most of the significant nonlinear dynamical processes within earthquake fault systems operate over a vast range of spatial and temporal scales, from scales much smaller than human experience (tiny fractions of seconds and meters), to scales far larger (thousands of kilometers and many millions of years). Linkage of the processes over these scales means that understanding the physics at one set of scales cannot, in principle, be achieved without consideration of many other scales. Since our ability to make observations will always be limited by practical considerations, simulations are needed to interpolate between, and extrapolate beyond, the scales of resolution at which we can observe.

Modern developments in computational science and information technology have fundamentally altered the means by which knowledge is acquired, stored, manipulated, represented, and used during the modeling process. Specifically, the advent of the World Wide Web and the development of computational grids enabled by object definitions, middleware, and multi-tiered information architectures allow data and models to be manipulated by symbolic, and far more intuitive procedures. Thus new modes of scientific collaboration, discovery, and advance emerge as the people, databases and web pages, simulations and their results, sensors and their filtered data interact.

During the week of May 5–10, 2002 the United States hosted the Third International Workshop of the ACES (APEC Cooperation for Earthquake Simulations) in Maui, Hawaii. The workshop consisted of five days of technical discussions with no parallel sessions. The sessions focused on microscopic simulations, scaling physics, macro-scale simulations on earthquake generation and cycles and on dynamic rupture and wave propagation, computational environment and algorithms, data assimilation and understanding, and model applications.

The inaugural Workshop of ACES was held in 1999 in Brisbane and Noosa, Australia, during which time five topical working groups were formed and initial working group goals were identified. At a subsequent Working Group Meeting held in Tokyo in January 2000, two new working groups were added. This two-part volume represents articles from the seven working groups. Approximately 70 people attended the inaugural meeting in Brisbane, Australia in 1999, 130 people attended the meeting in Hakone, Japan in 2000, and 150 people attended the third meeting in Maui in 2002.

ACES aims to develop realistic supercomputer simulation models for the complete earthquake generation process, thus providing a "virtual laboratory" to probe earthquake behavior. This capability will provide a powerful means to study the earthquake cycle, and hence, offers a new opportunity to gain an understanding of the earthquake nucleation process and precursory phenomena. The project represents a grand scientific challenge due to of the complexity of phenomena and range of scales from microscopic to global involved in the earthquake generation process. It is a coordinated international effort linking complementary nationally based programs, centers, and research teams.

This issue is divided into two parts. The first part incorporates microscopic simulations, scaling physics, and earthquake generation and cycles. The second part encompasses dynamic rupture and wave propagation, computational environment and algorithms, data assimilation and understanding, and model applications.

Articles in Part I address constitutive properties of faults, scaling properties, and statistical properties of fault behavior. It also focuses on plate processes and earthquake generation from a macroscopic standpoint.

Part II addresses dynamic properties of earthquakes and the applications of models to earthquakes. It also contains articles on the computational approaches and challenges of constructing earthquake models. Data assimilation is critical to improving our understanding of earthquake processes, and papers addressing it are found in Part II.

We thank all of the participants of the 3rd ACES workshop and the contributors to these special issues. We particularly thank the Secretary General, John McRaney, for all of his undertakings working with the sponsors and implementing the workshop. We are grateful to Teresa Baker who served as the assistant editor for this volume, and to Ziping Fang who oversaw the web pages, and submittals and revisions of the papers. Without the efforts of these three people the workshop and publication of this volume would not have been possible. We also thank our sponsors including NASA[1], NSF[2], the USGS[3], DEST[4], ARC[5], QUAKES[6], UQ[7], RIST[8], NSFC[9], MOST[10], and CSB[11]. Portions of this work were carried out at the Jet Propulsion Laboratory, California Institute of Technology under contract with NASA.

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[1] National Aeronautics and Space Administration

[2] National Science Foundation

[3] United States Geological Survey

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