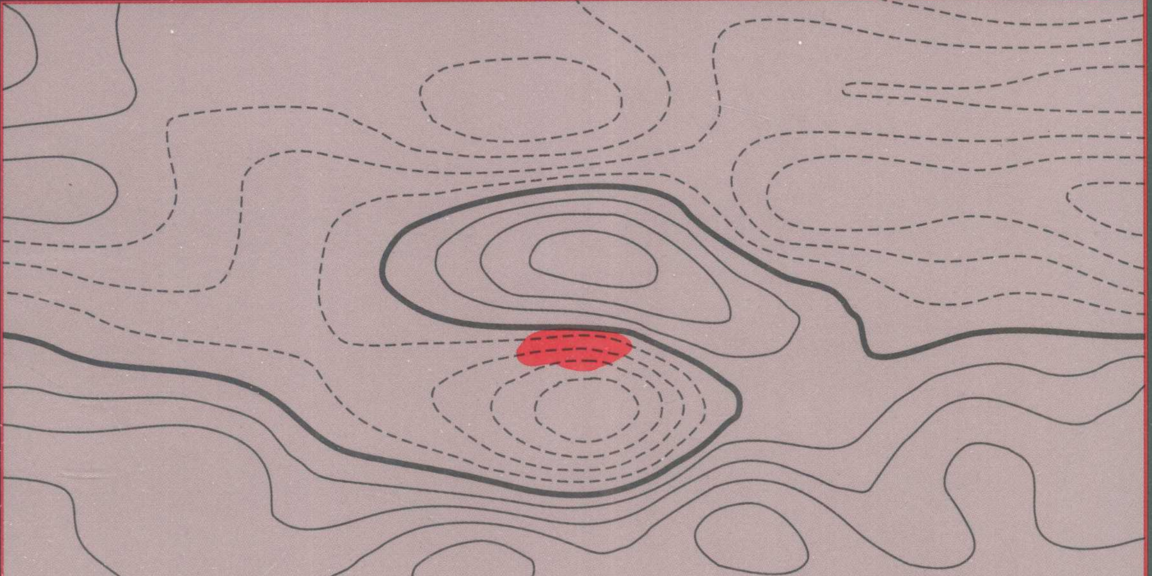
Numerical Simulations in the Environmental and Earth Sciences

Proceedings of the Second UNAM-CRAY Supercomputing Conference



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Increases in computer power and technology have rapidly advanced the applications of numerical modeling in the environmental and earth sciences. The progress of numerical modeling in atmospheric, oceanic, and geophysical sciences was the topic of an international conference held by the National Autonomous University of Mexico (UNAM).

The review articles and research papers in this volume constitute a wide-ranging and up-to-date account of modeling environmental and earth processes through a variety of numerical simulations. The book is split into four parts. The first part covers General Circulation Models and global change. This is followed, in the second part, by chapters on the application of atmospheric modeling for time and space scales from the mesoscale to the single-cloud scale. The third part looks at methods of geophysical data assimilation, and the final part reviews the mathematical and computational methods that have potential applications in geophysics.

This book forms an excellent introduction and overview for graduate students as well as a critical update for researchers.

Numerical Simulations in the Environmental and Earth Sciences

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Preface

Numerical modeling of atmospheric, oceanic and geophysical processes has always been a computationally demanding activity. The first supercomputers installed outside defense-oriented laboratories were devoted to numerical weather prediction and processing of geophysical data. Advances in the capability and performance of supercomputers have allowed researchers to tackle larger problems using fewer approximations, finer meshes and more realistic models. Newer, highly parallel computer architectures promise even larger performance gains, with a corresponding improvement in the physical insights and model accuracy to be gained.

The Second UNAM-CRAY Supercomputing Conference, **Numerical Simulations in the Environmental and Earth Sciences**, was held in the superb setting of *Universum*, a large science museum located in Ciudad Universitaria, the main campus of the National Autonomous University of Mexico (UNAM). The goal of this meeting was to bring together scientists working on a wide range of topics in the geosciences in order to exchange ideas and to stimulate new directions of research. A total of 59 participants from 10 different countries gathered together to discuss their most recent results, and the outcome of these fruitful three and a half days is reported in this book.

The meeting started with opening remarks by Dr. Gerardo Suárez-Reynoso, coordinator of scientific research at UNAM; Eric Pitcher, director of university marketing at Cray Research, Inc.; and Dr. José Sarukhán-Kermez, UNAM's rector. The conference consisted of a series of invited papers and submitted contributions; there was also a poster session. The presentations covered a wide range of topics that use supercomputers as a fundamental tool for research. Speakers organized their presentations as reviews of findings and discussion of challenges. Several papers described atmospheric and oceanic general circulation models, as well as coupled atmosphere–ocean models, and presented results of their investigations on El Niño/Southern Oscillation and climate change due to the increase in greenhouse gases. Other speakers addressed the advances and problems in the area of data assimilation for the atmosphere and the oceans. There was an invited presentation on mesoscale models of the atmosphere. Several speakers addressed the modeling of global and regional chemistry processes, with emphasis on air pollution. Advances in processing of satellite imagery were discussed. Another active area of research included in the program was seismology. A presentation focused on the importance for Latin America of modeling climate change. Submitted contributions complemented the invited presentations and extended consideration to other space and time scales. In the latter category, speakers discussed large eddy simulations, cloud models, atmospheric environmental management systems, and techniques to forecast marine productivity. Attention was also paid to computational methods used in large-scale problems. In the closing remarks of the Conference, Professor C. R. Mechoso (UCLA), representing the Conference's Scientific Committee, emphasized the importance to the Mexican as well as the international scientific community of the availability of supercomputer resources at UNAM. Those resources provide the support required by the development of successful research programs in areas of importance such as the environment. He also stated that continuing support was needed to maintain a state-of-the-art supercomputing facility at UNAM and encouraged earth and computer scientists to be prepared to work with the new computer architectures. The meeting motivated several discussions among participants on the establishment of future national and international collaborations.

These proceedings are organized in four parts, as follows: The first one includes presentations on the state of the art of both coupled and ocean and atmosphere General Circulation Models and some of their different applications to environmental problems.

In the second part a collection of papers is presented on applications of atmospheric modeling for a variety of time and space scales, from the mesoscale to the single-cloud scale. The third part covers specific methods applied to geophysical data assimilation, whereas the fourth part addresses general mathematical and computational methods with potential applications to a wide range of geophysical problems. The review papers provide a well-balanced overview of all these topics, and the peer-reviewed contributed papers illustrate current activities in each field. The final result is a comprehensive compendium of the most recent trends in environmental and geophysical simulations, with specific applications, which will allow the reader to have a general overview of these important and diverse topics of the geosciences.

We would like to acknowledge the members of the Scientific Committee, who reviewed and selected abstracts for inclusion in the program and refereed the full papers; Drs. John D. Farrara, Susana Gómez, Rong Lu, Chung-Chun Ma, Víctor Magaña and Everett Nickerson, who also helped review the full papers; and the other members of the Organizing Committee, for their excellent work in the design and organization of the meeting. We also thank our budget managers Ing. Enrique Pérez, of PUMA-UNAM, and Pedro Rocha, of DGSCA-UNAM, for sparing us the usual bookkeeping headaches with their very efficient financial organization, and to Toña Zimerman for her wonderful artwork and poster design. Very special thanks to Dr. Jorge Flores for graciously allowing us to use the wonderful auditorium at *Universum*, and to his staff, especially Arq. Serafín Pérez; to our talented executive secretaries Graciela González–de Hita and Luz del Carmen Pérez-Huerta, for maintaining the spirit of the meeting with their shining smiles and very efficient work, and to our enthusiastic crew Felipe Cruz, Ivonne Diéguez, Ian García, Juan Carlos de León-Violante, Lidia Maldonado, Héctor Perales-Valdivia, Rocío Reyes, Luis Felipe Rivera and Guadalupe Zárraga for keeping the meeting trouble-free.

Last, but certainly not least, we are very grateful for the generous grants provided by Cray Research, Inc., and Coordinación de la Investigación Científica (UNAM), and the financial support given by the Dirección General de Servicios y Cómputo Académico (UNAM).

Fernando García-García, Gerardo Cisneros,
Agustín Fernández-Eguiarte, Román Álvarez
México D. F., México, 1997

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PART I
General Circulation Models and Global Change

A General Circulation Model of the Atmosphere–Ocean System

By Carlos R. Mechoso

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This paper examines the methodology used in studies with general circulation models (GCMs) of the atmosphere and oceans, the sensitivity of these models' performances to the representation of physical processes, and the computational challenges encountered in running their large codes. Our discussion of the atmosphere–ocean coupled GCM focuses on the difficulties in modeling the atmosphere–ocean system due to the complex interactions and feedbacks between its components. We present an example that underscores the sensitivity of the system to relatively modest changes in radiation. We show that enhanced stratus clouds off the coast of Peru result in significant local and remote cooling of the ocean surface and argue that those impacts are primarily due to different mechanisms. We discuss the relationships between surface heat fluxes and sea surface temperatures. The paper also includes a presentation of computational issues that arise in running the coupled GCM codes in a heterogeneous, distributed computer environment.

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1. Introduction

To understand, and eventually predict, variations in climate is a particularly challenging task because of the complex interactions and feedbacks between different components of the system. General circulation models (GCMs) are computer codes that solve discretized expressions of the equations governing fluid motion, including parameterizations of physical processes at subgrid scales (e.g., cumulus convection, turbulence). Atmospheric and oceanic GCMs (AGCMs and OGCMs, respectively) have been extensively used in support of studies on the dynamics of the atmosphere and oceans. Running each of these models requires the specification of boundary conditions: (1) sea surface temperature (SST) and sea-ice cover for the AGCM and (2) surface fluxes of heat, water, and momentum for the OGCM. A coupled atmosphere–ocean GCM (coupled GCM) consists of an AGCM providing the surface fluxes of heat, water, and momentum to an OGCM, which returns the SST. (The sea-ice cover can be either prescribed or provided by a sea-ice module interacting with the other model components.) Coupled GCMs, therefore, can be used to study interactions and feedbacks of different components of the atmospheric and oceanic circulations.

This paper examines the methodology used in studies with GCMs, the sensitivity of these models' performance to the representation of physical processes, and the computational challenges found in running their large codes. Examples of outstanding problems that may be addressed with coupled GCMs are given in other papers of this volume. S. G. Philander focuses on the El Niño–Southern Oscillation (ENSO) events, which have dramatic impacts on the global climate (see, e.g., Ropelewski and Halpert [1987]; Pisciottano *et al.* [1994]). The ability to simulate and eventually predict ENSO with a coupled GCM is rightly considered a significant success of the model. G. A. Meehl and W. W. Washington show that a warming of the tropical Pacific Ocean (due to increased carbon dioxide and associated greenhouse effect, for example) would result in a stronger warming in the east than in the west, resembling ENSO conditions. M. Pontaud, L. Terray,