**Introduction to Earth System Modeling**

**Preface of the paper collections**

In 1945, shortly after von Newmann wrote the famous architecture of modern computers, he submitted a proposal with a team of scientists in Princeton and MIT to the Navy Office of Research and Invention (ORI) to do weather research. The US military immediately funded his proposal. This was the time of the nuclear bomb, and with the advent of computers, human control on weather was seriously envisioned as a possible means of war.

Sixty some years later, the profound impact of computers on human life is beyond anyone’s imagination at that time. What is also profound is the capability of the human activities in modifying Earth environment that we live in. The inventors of computers perhaps had not imagined that their initial intended use of computers in weather control is being answered in an unexpected way, due to the inadvertent control of human activities on climate. During this period, the concentration of carbon dioxide in the atmosphere has increased from about 315 ppmv to 395 ppmv on a global scale.

Global change of the Earth environment, as most significantly manifested by global warming as a result of increasing greenhouse gases in the atmospheric, poses one of the most significant scientific, societal, and political challenges of our time. Given the complexity of the interactive processes within the earth system, and the multiple scales, ranging from micrometer to global scale, from millisecond to millennium, the only feasible approach to understand and project future changes is through numerical modeling by using Earth System Models (ESM) that run on supercomputers.

By necessity, ESMs need to describe the main circulation systems in the atmosphere and oceans, the energy and water cycles within the land-ocean-atmosphere-ice systems, and the associated physical, chemical, biogeochemical, hydrological and ecological processes. In addition, the ESMs need to accurately describe the human drivers of climate change, including emissions of greenhouses gases and aerosols and land use changes. The application of the ESMs further calls for these models to provide information about the potential impact of global change on the natural environment and socioeconomic structures.

The challenges are daunting, and the feasibility of using ESM to address global change problems remains to be proven. But history can provide some hint to the future development of ESMs. From 1946 to 1950, Charney, Fjortoft and von Neumann successfully produced the first weather calculation of the 500 hPa geopotential height with 24 hour lead time, for which they simulated the atmosphere with only one level and 19×16 grid points. Although their calculation did not have any practical value at the time, it set a landmark of numerical weather prediction and immediately prompted the establishment of the Joint Numerical Weather Prediction Unit of (JNWPU) of the US military the Weather Bureau– which was the predecessor of the present National Center for Environmental Prediction (NCEP). Today, numerical weather prediction is benefiting all countries in the world in people’s everyday life. In 1955, Norman Phillips demonstrated the first successful but crude simulation of the general circulation of the atmosphere, using 16×17 grids and two layers to represent the atmosphere. Again, it was of academic research in nature, but it laid a milestone for the development of atmospheric general circulation models and immediately prompted the establishment of the General Circulation Research Section in Washington, DC, now the Geophysical Fluid Dynamics Laboratory (GFDL) in Princeton. Today’s extended range weather forecasts and seasonal predictions are primarily based on the development of these models. In the last twenty five years, these models have played another essential role is assessing climate changes as used by the Inter-governmental Panel for Climate Change (IPCC).

While ESMs are still at their initial stage, societal demands on them are high. Countries need to negotiate agreements to curb undesirable climate change. The urgency and mitigation methods depend on how global change will manifest in different centuries in the coming decades. The specifics of global change on regional scales can potentially touch every aspect of human society. Choices need to be made collectively and individually before it might be too late to combat climate change. These requirements will surely make ESMs an indispensable tool of science and technology for every country in the future.

In view of these interests, in 2010, the Center of Earth System Sciences (CESS) of Tsinghua University organized a summer colloquium on ESM. Prominent speakers are invited from various countries and from Chinese institutions to lecture on different aspects of ESMs. This book is a collection of translated papers by the invited foreign lecturers on topics related to what they presented at the colloquium. Lectures and papers by domestic speakers are not included since these can be found elsewhere in Chinese.

The papers are organized around five topics, as were the lectures at the colloquium. The first is overviews of ESMs. We selected two models in the US and one in Japan to introduce to the reader some of the commonalities and differences among the models. These models represent the state-of-the art models as of 2012; their simulations will be used for the next IPCC Assessment Reports (AR5). The second topic describes one of the drivers of climate change -- the surface emission of gases and aerosols, both for the past and for the future to be used in IPCC AR5. The third topic describes the second driver of climate change -- land use and land cover change, also both for the past and for the future. The fourth topic is on ESM software architecture and engineering. The last topic touches upon the numerical aspect of ESM, including the emerging practice of multiscale modeling and the perpetual modeling theme of numerical accuracy, consistency, and efficiency. We wish to emphasize that the overview articles, by necessity, can only describe a skeleton of the ESMs presented, especially about the physical processes within the models. Papers on some of the topics can only represent a small sample of a vast amount of available research. These papers are only intended to give a glimpse of the large picture of current status of ESMs and outstanding issues. More in-depth materials can be found in the references cited by the papers.

It is our desire that this book can be helpful for students in many disciplines to learn about ESMs, for researchers to track the latest progress in the related fields, and to stimulate ESM research in China.

We wish to thank the authors, translators and the proofreaders of the collected articles for their diligent work. We also thank Tsinghua University and the Beijing Normal University for their sponsorship of 2010 ESM Colloquium that resulted in this book. We apologize in advance for possible errors in the book and will appreciate any comments or suggestions from the readers.

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