
Earth’s climate system has all the characteristics of a complex system. It has many components (atmosphere, oceans, cryosphere, biosphere, lithosphere), all components interact in complicated nonlinear ways, and there are many feedback loops that can be positive (reinforcing) or negative (inhibiting) depending on the state of the system. It is self-organizing and shows more emergent phenomena than we can handle. Unfortunately, controlled experiments are impossible: there is no Planet B. Since the beginning of the industrial revolution we have been engaged in an uncontrolled experiment, and the results don’t look good. Climate change is a fact, and we had better gather our intellectual resources to see what might happen if we change our habits or if we do nothing.

Fortunately, climate models enable us to explore “what-if” scenarios through large-scale numerical simulations. In fact, the computer has become the laboratory of the climate scientist and so-called community climate models (CCMs) are the in-silico tools of the trade. The Intergovernmental Panel on Climate Change (IPCC) assesses the state of our knowledge of the climate system every four years or so on the basis of results obtained with a collection of “sanctioned” CCMs.

Climate models are process models that incorporate many of the processes which determine the dynamics of our climate system. But they cannot incorporate all the processes, either because we don’t know enough about them or because they play out on scales that cannot be captured. As a consequence, projections generated by CCMs for the future are always subject to uncertainty. This makes climate modeling an interesting topic of research for the SIAM community.

CCMs are essentially algorithmic implementations of the laws of nature. These laws determine how the system evolves in time and are commonly formulated as (ordinary or partial) differential equations. The equations are discretized according to any of a number of approximation procedures and implemented in numerical algorithms designed for the particular computer architecture on which the simulations are to be performed. All this is the bread and butter of computational science.

The book under review was written from the perspective of a particular climate model, namely, the Community Climate System Model (CCSM), which was (and is still being) developed by a research community sponsored by the U.S. Department of Energy. The book gives an overview of what goes into the CCSM and how the algorithms are formulated and implemented. The focus is on the atmosphere and ocean, the two primary components of the climate system.

The book opens with a chapter on climate data and the basic circulation patterns of Earth’s atmosphere and oceans. Chapter 2 is devoted to the formulation of the basic equations, the conservation equations of mass, momentum, and energy for a fluid on the surface of a rotating sphere. The Coriolis effect plays an important role and, depending on the scale of interest, various simplifications are possible (geostrophic wind approximation, hydrostatic approximation, shallow water approximation, etc.). The chapter ends with two examples: the hydrostatic baroclinic equations used in the atmospheric component of the Community Atmosphere Model and the continuity, momentum, and hydrostatic equations for the Parallel Ocean Program.

Chapter 3 is devoted to the discretization of the basic equations, in both the spatial domain and the time domain. The author describes in detail the control-volume method, the semi-Lagrangian transport method, and Galerkin spectral methods. In the course of the discussion, the reader learns about various solution methods (factorization, conjugate gradient, GMRES), concepts (consistency, stability, convergence, computer architectures), and special functions (spherical harmonics).

The short Chapter 4 presents two case studies: a paper by Barron and Washing-
ton [1] that looks into the distant past and analyzes climate conditions warmer than the present-day conditions, and a paper by Lawrence and Chase [2] that concerns the climate impact of global land-cover change. For each case, the author explains the methodology, highlights the conclusions, and raises some critical issues that are inherent in the use of climate models.

The final Chapter 5 addresses climate analysis. As the author notes, a significant problem is that the observational network is sparse, especially over the Earth’s oceans. The author discusses several methods to approximate functions on a sphere, including spectral methods and empirical orthogonal functions, as well as statistical and data assimilation techniques.

A chapter called “Conclusion” summarizes likely future developments in climate modeling. The book ends with a bibliography and index. Supplementary material is available on the web at www.siam.org/books/mm19.

The book is a useful introduction to computational climate science and makes for a good topic course in computational science. The style is somewhat informal and exercises are sprinkled throughout the text. Of course, the book does not give the whole story. Our climate system consists of more than atmosphere and oceans. To be useful, a CCM must also account for snow and ice, forests, land cover, atmospheric chemistry, and a host of other processes. Some of these topics are discussed in the supplementary material.

The actual text could have benefited from some careful editing. Style, grammar, and punctuation are not always what they should be, and this reviewer spotted several errors (for example, “Gibb’s phenomena” on p. 96; “Li’s Principle Sums” on p. 91, taken from unpublished work [114], should most likely have been “Li’s Principal Sums”; “Delaney triangulation” on p. 102; “Lorentz grid” on p. 108). Some additional figures would have made it easier for the reader to follow the arguments (for example, in the discussion of coordinates in section 2.2).

The image on the cover, though colorful, is identified only as “Visualization of time dependent fields of the CCSM.” It would have been nice to learn a few more details. Also, this reviewer noted several errors and missed items in the index.

Despite these few criticisms, this reviewer enjoyed reading the book and appreciates the author’s efforts to make this information available to the computational science community. The book is a welcome complement to the textbook [3].

REFERENCES


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