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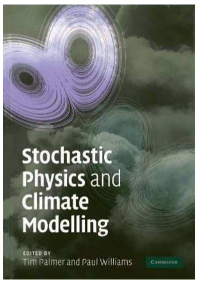
BOOK REVIEWS

STOCHASTIC PHYSICS AND CLIMATE MODELLING

Tim Palmer and Paul Williams, Eds., 2010, 480 pp., $150.00, hardbound, Cambridge University Press, ISBN 978-0-521-76105-5

This book, edited by Tim Palmer and Paul Williams, is a collection of topical articles written by some leading experts about the use of stochastic (i.e., random) processes to understand, model, and predict climate variability. Here "climate" is primarily meant to consist of atmosphere and ocean (including sea ice). This does not mean that the cryosphere, lithosphere, and biosphere are not major contributors to (long-term) climate variability, but that stochastic methods in climate research are nowadays predominantly (yet not exclusively) employed within the traditional realms of the atmospheric and oceanic sciences. Eleven articles in this volume were originally published in 2008 as a special issue of the Philosophical Transactions of the *Royal Society A: Mathematical, Physical and Engineering Sciences* (Volume 366; Issue 1875). Some of the original articles have been updated, and seven new articles were additionally solicited.

Because a book review in *BAMS* should be potentially of interest to a large and diverse audience of meteorologists, physical oceanographers, and related professionals, it might be useful to answer a very basic question first: What is meant by "stochastic physics" and why should we care? The basic idea of stochastic physics is commonly introduced by using the Brownian motion problem. In 1827, the Scottish botanist Robert Brown observed the jittery motion of tiny pollen grains immersed in a fluid. By repeating the experiment with other types of small particles, such as dust, Brown could rule out that the motion was due to pollen grains being "alive," although he was not able to account for the actual origin of the motion. It took almost 80 years before Einstein gave a brilliant and influential theoretical explanation of the phenomenon in one of his *Annus Mirabilis* papers. The irregular motion of a pollen grain (the Brownian particle) is due to numerous collisions (i.e., momentum transfers) between the large and heavy Brownian particle and the much smaller and lighter randomly fluctuating fluid molecules. Within the mathematical framework developed by Einstein, the effect of the numerous fluctuating fluid molecules is modeled by a stochastic force, uncorrelated in time, acting on the pollen grain. The key point is that because we are only interested in the expected net effect on the Brownian particle and not in the actual details of the momentum transfer, that it is sufficient to know the statistics, such as mean and variance, of the large and inert particle's path. That is, while all phenomena governed by classical mechanics are in principle deterministic, it is not necessary (and perhaps impossible) to solve the deterministic equations of motion for the myriad fluid molecules interacting with each other and the Brownian particle. Later it became clear that the theoretical concept of Brownian motion could be applied to many other phenomena, including situations where the particles are not real



particles at all, but instead some macroscopic property of the specific system under consideration. For example, in the terminology of a modern climate modeler, the stochastic treatment of Brownian motion is a subgrid-scale parameterization of the net effect the irregular motion of small, fast, and numerous fluid molecules (the unresolved subgrid scale) has on the larger Brownian particles (the resolved grid scale). Perhaps the best known stochastic climate model is the direct Brownian motion analogue introduced by Hasselmann in 1976, which explains the ubiquitous red spectrum of many climate time series.

In a nutshell, while the equations of motions we are dealing with as climate modelers are mostly deterministic, stochasticity is an important concept to model the plethora of processes we cannot incorporate into our models. The volume under consideration aims to review recent advances made in the physical and mathematical aspects of stochastic climate modeling, ranging from theoretical considerations to practical applications. The practical applications range from large-scale atmospheric oceanic dynamics, over mesoscale quasigeostrophic turbulence, to small-scale phenomena like convection and cloud physics. The related time scales cover a broad range, from daily to seasonal, decadal, and centennial.

Because I felt it might be a bit tedious for the reader of this review to be given a list and discussion on every one of the 18 articles in detail, I decided to loosely group and briefly introduce them around several overarching themes. That way, the overall content of the book should become clear, without being lost in bothersome (for nonexperts) details. There is some overlap, though, and the grouping of the articles into categories might be influenced by my personal view of the topics.

- The book starts with a general discussion of mechanisms that most likely are responsible for climate variability on yearly-to-decadal time scales (Vallis). The bottom line is, as already discussed above, that all mechanisms are in principle deterministic, but we do not always care about the details of the processes that give rise to climate variability. This sets the stage for more specific topics to come.
- Three articles focus on rather general aspects of climate variability and stochastic methods to study it (Kravtsov et al.; Wilks; Kleeman). Kravtsov et al. discuss the prevailing modeling hierarchy in climate research in general, and empirical methods to extract stochastic models from data in particular. Wilks stresses the importance of conceptual stochastic models to study climate variability. I also considered the Kleeman article on ENSO as falling under general aspects. The article reviews some observational and theoretical aspects of ENSO, highlighting the effect of stochastic atmospheric forcing on ENSO irregularity.
- A group of four articles deals with more mathematical aspects of stochastic climate modeling (Majda et al.; Duan; Penland and Ewald; Chu). Majda et al. present a systematic framework for how to account for the effect of the fast modes on the slow modes directly from the equations of motion. Duan discusses some properties of random dynamical systems in order to explore the predictability in stochastically forced nonlinear systems. Penland and Ewald explore the use of Lévy processes (instead of Gaussian white noise) as the stochastic forcing in stochastic differential equations. Chu discusses and uses the first passage time to analyze climate data.
- Two articles cover quasigeostrophic turbulence in the atmosphere and ocean (DelSole; Nadiga). DelSole reviews stochastic modeling of quasigeostrophic turbulence, including a thorough discussion of remaining challenges. He also introduces a new turbulence closure for specifying the parameters in stochastic models of inhomogeneous turbulence. Nadiga explores stochastic-versus-deterministic backscatter (the forcing of resolved scales by unresolved scales) of potential enstrophy in geostrophic turbulence.
- Three articles deal with stochastic aspects of the meridional overturning circulation (MOC) (Monahan et al.; Frankcombe et al.; Prange et al.). Monahan et al. contribute a review and discussion of stochastic MOC models with multiple steady states. Frankcombe et al. treat the Atlantic Multidecadal Oscillation as a stochastically forced dynamical system going through a Hopf bifurcation. In Prange et al., climate variability during the Holocene (about 12,000 years ago) is discussed, and it is suggested that the observed bimodal distribution of the Atlantic MOC might be due to stochastic resonance.
- Three articles look into the representation of small-scale phenomena such as cloud–radiation interactions and moist convection in the atmosphere (Tompkins and Di Giuseppe; Neelin et al.; Ball and Plant). Tompkins and Di Giuseppe discuss the physics and impact of clouds in the climate system. The focus is on how clouds interact with radiation and atmospheric dynamics and portray the current

state of the art in cloud–radiation interactions as represented in climate. Neelin et al. present novel observational constraints for stochastic convective schemes in climate models. Ball and Plant discuss the use of single-column models as a test bed for different stochastic parametrization approaches.

- The remaining two articles examine the implementation and impact of stochastic parameterizations in realistic models (Berner et al.; Allen et al.). Berner et al. are concerned with the impact of a quasistochastic cellular automaton backscatter scheme on the systematic error and seasonal prediction skill of a global climate model. Allen et al. propose and test stochastic parametrization schemes of multiscale processes using techniques from computer-game physics.

From this tour of the book, it is obvious that the articles cover a lot of ground in very different and important areas of climate research. Climate scientists should take notice of the many important contributions coming out of a relatively small and diverse community dealing with stochastic processes. Thus, this book serves a very useful purpose in providing a broad and current review of stochastic methods used in climate research.

The first thing a reader may notice after looking into the book's table of contents is that while the articles appear in approximately (but not exactly) the same order I used above, there are no thematic chapters organizing them. Thus, the reader has to conceive the organization of the articles into overarching topics himself. That is, of course, not a problem for someone already well-versed in stochastic climate modeling, but it might be difficult for a nonexpert looking for a general introduction into that field. Overall, for most of the articles included in the book the reader should have a solid background in meteorology, physical oceanography, and climate dynamics in general, and stochastic processes in particular. Therefore, it is not suited as an introductory text, nor as an advanced textbook.

That brings me to the intended audience of this volume. It is aimed at (advanced) graduate students and researchers in the atmospheric and oceanic sciences, including applied mathematicians, interested in a comprehensive, up-to-date review of stochastic dynamics and methods presently employed in climate research and related fields. Having that audience in mind, the book does a very good job of reviewing the state of the art of stochastic physics in climate modeling, and can be wholeheartedly recommended to any researcher seriously interested in that line of research.

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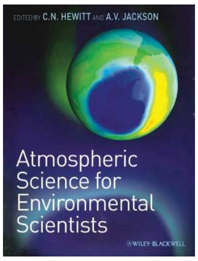
ATMOSPHERIC SCIENCE FOR ENVIRONMENTAL SCIENTISTS

C. N. Hewitt and A. V. Jackson, Eds., 2009, 300 pp., $85.00, paperbound, Wiley/Blackwell, ISBN 978-1-4051-5690-5

This book presents a wide spectrum of themes in atmospheric science, with a focus on topics related to climate change and air quality. It examines the climate, evolution, physical and chemical properties, and processes of the atmosphere, as well as urban air pollution and climate change. Edited by C. N. Hewitt and A. V. Jackson, the collection of 11 chapters in this book is a contribution mostly from active European researchers with expertise in respective aspects of atmospheric sciences. Each chapter in the book emphasizes a specific subject in atmospheric sciences, and collectively the chapters provide a good overview of our understanding of the state of the Earth's atmosphere and how it is changing.



As revealed in the title, the book aims at general readers in the field of environmental science. It is presented at a level of technical complexity that requires two years' college education. The material is delivered to the readers with a number of mathematical equations and chemical reactions. In addition, intuitive tables and graphs are employed to help readers to understand the scientific content. For those who are keen on a specific topic, references and an extended reading list are provided at the end of each chapter for further reading. Example problems and questions in each chapter help the readers to grasp crucial knowledge. This book serves well as an introduction for environmental professionals and for undergraduate and graduate students majoring in environmental sciences. Since it is practically impossible to encompass all the details of such broad disciplines in one book,