READINGS

ESSAY

IS SCIENCE FICTION A GENRE FOR COMMUNICATING SCIENTIFIC RESEARCH?

A Case Study in Climate Prediction

By T. N. PALMER

Are there situations where science fiction is an effective genre for communicating—for example, to key policy- and decision makers—results from contemporary scientific research? Indeed, might sci-fi sometimes be a more effective genre for communication than conventional means? I want to discuss this question in the context of anthropogenic climate change.

Certainly there have been a number of sci-fi stories that deal with the climate change problem (e.g., by Kim Stanley Robinson and Michael Crichton), including one very memorable movie: *The Day After Tomorrow*. I am sure readers will have mixed feelings about the effectiveness of such works of fiction in promoting the science underlying climate change.

However, it is not the issue of climate change per se I want to discuss here. I will take it as given that we have now reached the stage where the threat of dangerous climate change is taken seriously by our decision- and policy makers. Rather, my concern is somewhat the opposite. How can we scientists more effectively communicate to these same decision- and policy makers the notion that they must not now be complacent that the science of climate change [e.g., as described in the recent highly influential and successful Fourth Intergovernmental Panel on Climate Change (IPCC) assessment] is largely “done and dusted?” My particular concern is that the science of climate prediction is far from done and dusted, and my reason for being concerned is that the current global models represent the equations of motion of climate rather poorly on the regional scale. As discussed below, this is of particular importance as we now start to plan how to adapt to future climate change.

As a child, I read many science fiction stories. I can still vividly recall Isaac Asimov’s *Nightfall*, fre-

quently described as the finest science fiction story of all time. *Nightfall* describes a civilization’s first encounter with darkness for thousands of years. The civilization inhabits the planet Lagash, which orbits one of six gravitationally-bound suns. *Nightfall* occurs during a total eclipse, when only one of the suns is above the horizon. Lagash’s solar system lies in the centre of a giant cluster of stars, and during the short period of darkness, tens of thousands of distant stars shine brightly in the night sky. None of the civilization’s astronomers had predicted this. The sudden unforeseen realization of the vastness of the universe, with consequent implications of Lagash’s utter insignificance in the cosmos, gives rise to widespread panic and feelings of desperation, leading to a rapid disintegration of civilization.

I recall quite vividly feeling dizzy trying to grasp the utter enormity of what it must have been like to see the night stars for the first time, having had no previous inkling of their existence. In thinking back at this reaction, I started to wonder whether such an overwhelming existential crisis, in experiencing for the first time some dramatic and totally unforeseen natural phenomena, could be brought to bear in communicating my concerns about current uncertainties in the science of climate prediction?

If we use the terminology of Edward Lorenz’s classic 1970 paper, then predicting the effects of anthropogenic climate change on the one hand and the effects of the annual cycle of insolation on the other can be both classed as “predictions of the second kind”: given a specified change in some prescribed forcing (atmospheric greenhouse gas concentration or insolation), calculate the corresponding change in the probability distribution of regional weather states. By

focusing on probability distributions, rather than specific individual weather patterns, predictions of the second kind are intrinsically predictable, even though the underlying climate system is chaotic. By contrast, “predictions of the first kind” are initial value problems and highly sensitive to uncertainties in the initial state, due to the chaotic nature of climate.

Although in this sense climate change is inherently predictable, we don’t know how reliable our predictions of climate change are in practice. But what about a prediction of the second kind that we can validate, the annual cycle—is that reliable using today’s climate models? In other words, can our global climate models simulate the effects of the annual cycle of insolation? Well, yes, to some extent—the models correctly predict the relative warmth in the summer hemisphere! But would you trust them completely? How about the simulation of precipitation distributions associated with the transition from winter to summer monsoons, or the annual cycle of sea surface temperature in the tropical oceans?

Thinking about this in conjunction with my recollections of *Nightfall* led me to the following thought: Suppose you lived in a world that had been in a perpetual winter state for many generations. However, due to some strange astronomical event, about which the civilization’s astronomers are fully aware, the climate is about to flip into a perpetual summer state. The people of this world therefore know that a

rather dramatic change in climate is imminent and want some advice on how to adapt. They call on you, their chief meteorologist, to guide them about infrastructure investment to adapt to this new climate. You have available to you output from models from the IPCC AR4 multimodel ensemble (www-pcmdi.llnl.gov/ipcc/about_ipcc.php), properly adapted for the topography and astronomical conditions of this world! [This is the idea developed in the short story “Sunrise” (doi: 10.1175/2010BAMS3187.2).]

I’m afraid your advice turns out to be disastrous! Please read the story for details.

The first message of the story is that reliable predictions of regional climate change are crucially important to guide decisions on infrastructure investment for societies to adapt to future climate change. For example, if our terrestrial models suggest a substantial increase in the frequency of drought for some particular region, then it may make sense (given geopolitical constraints) to invest in infrastructure to store more water, or to pump water from neighboring water-rich areas. Conversely, if models suggest an increase in the frequency of flood events, it may make sense to invest in better flood defenses, storm sewers, and so on. However, such investments will be useless and the corresponding finances squandered if the region predicted to get more drought actually suffers more flooding, and vice versa.

NEW PUBLICATIONS

EXTREME WEATHER & CLIMATE

C. D. Ahrens and P. Samson, 2011, 508 pp., \$121.95, paperbound, Brooks/Cole/Cengage Learning, ISBN 978-0-495-11857-2

Written in an accessible style, but with foundational coverage of the science of meteorology, this textbook introduces the causes and impacts of extreme weather events and conditions, and discusses the science of meteorology in the context of important and often familiar weather events such as Hurricane Katrina. The book has a companion Web site that includes numerous resources for both students and instructors, including animations, videos, quizzes, chapter summaries, answers to in-text questions, and a test bank.

THE MET OFFICE BOOK OF THE BRITISH WEATHER

The MET Office, 2010, 160 pp., £9.99, paperbound, David & Charles, ISBN 978-0-7153-3640-3

This reference work presents British weather data in a series of maps showing every aspect of national and local weather throughout the year. Based on Met Office statistics, it charts sunshine hours, rainfall, temperature, wind, and many other indicators. In addition to the statistics, it forecasts the likely weather for the British Isles over the next 30 years, and in so doing provides insight into how climate change is likely to affect Britain, based on the very latest data compiled by climate scientists.

GLOBAL PERSPECTIVES ON TROPICAL CYCLONES: FROM SCIENCE TO MITIGATION

J. C. L. Chan and J. D. Kepert, 2010, 436 pp., \$133.00, hardbound, World Scientific, ISBN 978-981-4293-47-1

Originally published in 1995, this is a completely rewritten, updated, and expanded new edition. It presents a comprehensive review of the state of science and forecasting of tropical cyclones together with the application of this science to disaster mitigation. Since the previous volume, enormous progress in understanding tropical cyclones has been achieved. New material in this edition includes discussion of the vast growth in observational capability, the effects of climate change on tropical cyclone activity, and seasonal prediction.

The second message of the story is that if current climate models can systematically misrepresent the regional effects of the annual cycle, they can also misrepresent the regional effects of climate change. Here I am using the notion that both are essentially predictions of the second kind, and hence inherently predictable, as discussed above.

The third message of the story is that climate prediction is a computationally demanding problem. Indeed, I would say there is no more computationally demanding problem in science. In my view, inaccuracies in the current generation of climate models arise less because of uncertainty in our understanding of the equations of motion themselves, and more because of the performance limitations of the computers on which the models are integrated. Because of such performance limitations, the underlying partial differential equations of climate have to be truncated at scales typically of hundreds of kilometers. As a result, processes associated with scales less than the truncation scale are represented in climate models by relatively simple, empirically derived parametrization formulae. It is possible to quantify the errors made by such a truncation/parametrization ansatz (e.g., by comparing parametrized temperature tendencies with those arising from coarse-grained budgets of cloud-resolving models where truncation scales are two orders of magnitude smaller). In general, the

Read Tim Palmer's sci-fi story about climate prediction, "Sunrise," in the BAMS Web archive at doi:10.1175/2010BAMS3187.2.

errors are substantial (e.g., as shown by Shutts and myself in 2007). Because of the inherent nonlinearity of climate, these truncation-scale errors can induce systematic deficiencies in the simulation of climate fields on scales significantly larger than the truncation scale. It is the inherent nonlinearity of climate and the fact that the state space of climate has such a large dimension that make climate prediction so computationally challenging.

One way to reduce these systematic deficiencies would be to simulate more of the climate system with the proper equations of motion—that is to say, increase the resolution of climate models (e.g., to 1 km so that organized deep convection can be resolved). But increasing resolution is computationally demanding—an increase in resolution by a factor of 2 may require an increase in computing speed by up to a factor of 16 (c.f. the four dimensional nature of space-time). Increasing climate-model resolution to the resolution of contemporary numerical weather prediction models will require dedicated multipetaflop machines. Increasing to 1-km resolu-

DUST STORMS: ELEMENTAL COMPOSITION, CAUSES AND ENVIRONMENTAL IMPACTS

S. Brstilo and Q. Madunic, 2010, 266 pp., \$145.00, hardbound, Nova Science Publishers, ISBN 978-1-60876-456-3

This book provides a short review on dust aerosol optical and physicochemical properties, the seasonal variability of dust outbreaks, the dust source regions, and the main results of similar studies. It also presents two dust-storm spring seasonal prediction models, gives analytical results for three different sample sets related to Asian dust-storm phenomena, examines the effectiveness and application of a meteorological descriptor quantifying the daily-dust storm probability, and addresses the dust-related climate in North China and its prediction.

CACHING THE CARBON: THE POLITICS AND POLICY OF CARBON CAPTURE AND STORAGE

J. Meadowcroft and O. Langhelle, Eds., 2010, 320 pp., \$135.00, hardbound, Edward Elgar, ISBN 978-1-84844-412-6

This book examines the way carbon capture and storage (CCS) has been brought into the political realm, the different interpretations of the significance of this emerging technology, and the policy challenges government and international institutions face with respect to its development, deployment, and regulation. The book includes case studies of engagement with CCS in a number of developed countries, as well as more thematically focused analysis.

WEATHER WHYS: FACTS, MYTHS, AND ODDITIES

P. Yeager, 2010, 224 pp., \$14.95, paperbound, Perigee/Penguin, ISBN 978-0-399-53570-3

This book looks at the facts, myths, and oddities in the world of weather. It takes readers on a journey through weather myths and misconceptions, weird phenomena, and ways in which weather has affected history. Among the questions it addresses are which city is actually the windiest, how the temperature affects tire pressure, why humidity makes hair go limp or frizzy, why a coming storm causes sore joints, why it's a good idea to water a garden after it rains, and much more.

tion may require exaflop machines. There are good scientific arguments for doing this (see the papers by Shukla et al. and Shapiro et al. in this issue), but how does one convincingly make the case to fund an ultrahigh-performance computing facility dedicated to climate?

This brings us to the fourth and final message of the story. Typical economic metrics to gauge whether some proposed new facility is worth funding involve cost/benefit ratios. What is the cost/benefit ratio of a dedicated multipetaflop or exaflop computing facility for climate? In the case of the civilization of Sunrise, if only your climate models could have been run at higher resolution, you would have been able to save the civilization from disaster! In this case, while the cost of the required computing facility would have been finite, the benefit would have been infinite—making a cost/benefit ratio of zero!

Can this analysis be applied to planet Earth? I don't know, but perhaps at least it is time for an analysis of the economic benefit of reliable climate prediction systems to be considered more carefully than has been done to date.

So is sci-fi an effective genre to put over these points? I leave you, the reader, to judge!

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FOR FURTHER READING

Asimov, I., 1995: *Nightfall. The Complete Stories of Isaac Asimov*. Volume 2. Collins. 432 pp.

Crichton, M., 2004: *State of Fear*. HarperCollins. 603 pp.

ELOQUENT ADVICE

In his new AMS book, *Eloquent Science: A Practical Guide to Becoming a Better Writer, Speaker & Atmospheric Scientist*, David Schultz reaches out to scientists who want to improve their communication skills. The following is one in a series of short tips excerpted from the book that will appear periodically in BAMS. To order a copy of *Eloquent Science*, visit the AMS online bookstore at <https://secure.ametsoc.org/amsbookstore/>; for more information about the book and the topic of communication in science, go to <http://eloquentscience.com/>.

LOSING YOUR WAY

As writing and editing proceeds on your manuscript, you may lose your path. You may know what you want to say, but the writing just somehow cannot represent it. Perhaps your writing looks like what Strunk and White (2000, p. 25) call a “succession of loose sentences,” sections of text devoid of organization. Such a situation typically arises when authors sit down and type directly into the computer without a well-structured outline. Furthermore, because manuscripts take more than one day to write, the internal coherence that might develop if it were written in a single day is lost. Or, seeing the forest through the trees may be difficult as the words become too familiar. Alternatively, some authors have difficulty producing a manuscript with a logical progression, and they need help in determining when their train of thought derailed. Whatever the reason, your text may contain great ideas and will contribute to a strong document eventually, but, in its present form, lacks structure and organization.

If you feel this way, let the work sit overnight or for several days. If the respite does not help, look at the big picture you are writing about. What is the logical progression of ideas? Are you first presenting model output,

then the supporting observations? Would it help to present the observations first to motivate the modeling simulations? Do you jump around between scales of motion, presenting mesoscale and microscale observations interspersed among the synoptic-scale discussion? . . .

One way to visualize how the text is organized is to go through the confusing section and label the topics of the text in the margins of the paper, grouping the topics into similar themes. Classify statements, then look for common themes to group together. The weaknesses in the organization of the text will likely become apparent, and you will see your way toward improving the text. If you need to, print out the text, cut out the different sections from the manuscript with scissors, and try possible arrangements of the strips of paper on a table.

The paragraph-level organization of the writing/editing funnel can be one of the most difficult stages of writing a scientific document. Once the paragraphs (clearly defined by their topic sentences) are in place, sentences and words follow much more easily.

- Lorenz, E. N., 1970: Climate change as a mathematical problem. *J. Appl. Meteor.*, **9**, 325–329.
- Nature*, 2008: The next big climate challenge. *Nature*, **453**, 257.
- Palmer, T. N., 2005: Global warming in a nonlinear climate: Can we be sure? *Europhys. News*, **36**, 42–46.
- Robinson, Kim Stanley, 2004: *Forty Signs of Rain*. Bantam Dell, 358 pp.
- Shapiro, M., and Coauthors, 2010: An Earth-system prediction initiative for the twenty-first century. *Bull. Amer. Meteor. Soc.*, **91**, 1377–1388.
- Shukla, J., T. N. Palmer, R. Hagedorn, B. Hoskins, J. Kinter, J. Marotzke, M. Miller, and J. Slingo, 2010: Toward a new generation of world climate research and computing facilities. *Bull. Amer. Meteor. Soc.*, **91**, 1407–1412.
- Shutts, G. J., and T. N. Palmer, 2007: Convective forcing fluctuations in a cloud-resolving model: Relevance to the stochastic parameterization problem. *J. Climate*, **20**, 187–202.
- Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Avery, M. Tignor, and H. L. Miller, Eds., 2007: *Climate Change 2007: The Physical Science Basis*. Cambridge University Press, 996 pp. [Available online at www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg1_report_the_physical_science_basis.htm.]

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.

—PHILIP SURA

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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,

the readers are advised to refer to more specialized books for in-depth descriptions.

The book starts with an introduction of the causes, history, and distributions of the Earth's climate (chapter 1), which is followed by a chapter that discusses the creation and chemical composition evolution of the atmosphere. Chapter 3 is concerned with the radiation balance of the Earth and the atmosphere, as well as the vertical structure of Earth's atmosphere. It would be more logical to place chapter 9 right after chapter 3, since chapter 9 covers the boundary layer meteorology and atmospheric dispersion. The first two chapters (1–2) mainly consist of descriptive reading materials with specialty terms, which may require the readers to go through the text several times before comprehending the material. The other two chapters (3, 9) contain most of the mathematical equations in the book, which generally turn out to be a bit challenging for environmental scientists. However, readers may overlook some of the equations without weakening their ability to understand the content.

Chapter 4 addresses the biogeochemical cycles of the elements, including carbon, nitrogen, sulfur, hydrogen, and halogens in the atmosphere. It starts with a simple source-sink box model to calculate the atmospheric concentration of chemical species, followed by examples of the most crucial compounds in global biogeochemical cycles. This chapter offers a clear idea of sources and sinks of selected atmospherically important species. One missing piece is the discussion of how chemical species are partitioned among the atmosphere, the water body, the biota, and the soil, which would bring forth the topic of biogeochemical cycles in a wider scope. Also not included are discussions of the biogeochemical cycles of persistent organic pollutants and the element mercury, both of which have considerable environmental importance.

The chemical processes in the atmosphere are discussed in chapters 5–8, including tropospheric chemistry, stratospheric chemistry, cloud chemistry, and aerosol physics and chemistry. As expected, extensive chemical reactions are involved in the four chapters. While most chemical equations are necessary and adequate, one issue is that some chemical formulas are presented in an unconventional fashion

and hence are inexplicable (such as $\text{CH}_3\text{CO}_2\text{O}_2\text{NO}_2$ for peroxyacetyl nitrate). The four chapters cover the majority of the important subjects in atmospheric chemistry, although not in great depth. In particular, chapter 7 ("Particulate Matter in the Atmosphere") could be strengthened to cover more topics that are of interest to readers in environmental science. For instance, the subject of formation and transformation of secondary organic aerosols—a frontier research area in atmospheric chemistry—is only casually discussed. Also, the working principle of the differential mobility analyzer, one of the most widely used aerosol instruments, is omitted in the aerosol measurement section.

This book ends with two of the most pressing issues facing us today: air quality and climate change. The two chapters are presented in a way that combines physical science, social science, and policy decision-making. This approach allows readers to comprehend the inherent complexity of our environmental challenges, but unfortunately undermines the readers' ability to understand the science behind the curtain. The integration between science and policy is not well-elaborated in this chapter. In addition, a fraction of the content in chapter 11 ("Global Warming and Climate Change Science") overlaps with the discussions of the biogeochemical cycles in chapter 4, although they focus on different aspects. Readers are advised to refer to chapter 4 while reading the last chapter. Another shortcoming of the book is the lack of a discussion of the highly publicized debate on geoengineering.

Overall, this book offers a comprehensive overview of many important subjects in atmospheric sciences that are interesting to environmental scientists. It makes a worthwhile addition to your shelf for a quick reference if you seek a general understanding of those topics.

—LIN WANG AND RENYI ZHANG

Lin Wang is an assistant research scientist in the Department of Atmospheric Sciences at Texas A&M University, and Renyi Zhang is a professor of atmospheric sciences and chemistry, director of the Center for Atmospheric Chemistry and the Environment, and holder of the Harold J. Haynes Chair in Geosciences at Texas A&M University.