The Climate Demon

Climate predictions – and the computer models behind them – play a key role in shaping public opinion and our response to the climate crisis. Some people interpret these predictions as "prophecies of doom," and some others dismiss them as mere speculation, but the vast majority are only vaguely aware of the science behind them. This book provides an overview of the strengths and limitations of climate modeling. It covers historical developments, current challenges, and future trends in the field. The accessible discussion of climate modeling requires only a basic knowledge of science. Uncertainties in climate predictions and their implications for assessing climate risk are analyzed, as are the computational challenges faced by future models. The book concludes by highlighting the dangers of climate "doomism," while also making clear the value of predictive models, and the severe and very real risks posed by anthropogenic climate change.

R. SARAVANAN is Head of the Department of Atmospheric Sciences at Texas A&M University. He is a climate scientist with a background in physics and fluid dynamics and has been a lead researcher using computer models of the climate for more than thirty years. He built an open-source simplified climate model from scratch and has worked with complex models that use the world's most powerful supercomputers. He received his Ph.D. in Atmospheric and Oceanic Sciences from Princeton University and his M.Sc. in Physics from the Indian Institute of Technology, Kanpur. He carried out postdoctoral research at the University of Cambridge and subsequently worked at the National Center for Atmospheric Research in Boulder, Colorado. Saravanan has served on national and international committees on climate science, including the National Research Council (NRC) Committee on the Assessment of Intraseasonal to Interannual Climate Prediction and Predictability, and the Science Steering Committee of the Prediction and Research Moored Array in the Atlantic (PIRATA). He recently helped create the TED-Ed animated short "Is the Weather Actually Becoming More Extreme?"

"If you wish to correctly interpret climate modeling results, read *The Climate Demon*. Saravanan's brilliant and humorous book helps both scientists and the general public objectively understand strengths and limitations of climate predictions."

Samuel Shen, Distinguished Professor, San Diego State University

"A wide-ranging guided tour of the modern science of climate prediction, told by a leading expert without jargon or mathematics, and illuminated by history, philosophy, technology and even literature."

Richard C.J. Somerville, Scripps Institution of Oceanography, University of California, San Diego

"Output from climate models completely underpins our policies on cutting emissions and making society more resilient to future climate – issues that will be affecting everyone on the planet in years to come. I thoroughly recommend this book if you want to understand the science behind these all-important [climate] models."

Tim Palmer, University of Oxford

"R. Saravanan is probably the most knowledgeable person in the world to write this book. This is a book that is accessible to the average college graduate and even many with less formal education. The pace of the reading is smooth, with many metaphors and analogies taken from a wide variety of sources … all whimsical but hitting his points perfectly. Readers will enjoy these features. This is a first rate, well-researched summary and analysis of how predictions in climate science work hand-in-hand with high-tech empirical data and detailed climate simulation models along with their enabler: the modern supercomputer. All this without a single equation and only a handful of figures used for clarification or sometimes just to draw a smile. This is a must read for natural and social scientists from all walks of life, as well as policymakers and managers in all sectors who have any interest in climate science and its inferences. The book makes the point that comprehensive climate models are our only means of making serious forecasts into the future. It is stressed that the most likely method of mitigating serious climate change is to curb our production of carbon dioxide. The book considers these necessities while at the same time giving a sober analysis of the limitations of climate model forecasts. The book is not a 'Doomsday' book, nor does it advocate doing nothing, but rather following a rational course, using our best tools, given to us by ever-improving computers and climate models."

Gerald R. North, Texas A&M University

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Past, Present, and Future of Climate Prediction

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To my parents,
Ramalingam and Kamala

Contents

Figures

Preface

I was originally trained as a physicist. Thirty years ago, for my Ph.D., I switched fields to climate science, which is a natural application of physical principles. I remain conflicted between the very different philosophies of physics and climate science, especially with regard to the use of models for prediction. F. Scott Fitzgerald observed that intelligence is perhaps the "ability to hold two opposed ideas in mind at the same time and still retain the ability to function." This book aspires to intelligence in that sense: It celebrates climate modeling even as it critiques it.

To determine the value of a fundamental physics constant, physicists do not form a committee to aggregate differing estimates of the constant and come up with an officially sanctioned value. Rather, if one group of physicists measures a fundamental constant and comes up with a number, it is expected that all other groups of physicists measuring the constant will come up with almost the same number, once the field has matured. The replication of measurements is a cornerstone of the scientific method; it ensures objectivity, and it is what distinguishes science from more subjective disciplines of study.

But in the world of climate science, it is not uncommon to survey models (or even experts), statistically aggregate the numbers they provide (which may vary by a factor of two or more), and only then estimate a climate parameter and its uncertainty. A different analysis technique or model may yield a different estimate for the parameter. While most scientists (and models) are in general agreement on the causes of and the future of climate change, it is hard for us to obtain very precise numbers for measures of climate change.

Why can't climate science be more precisely replicable? The short answer is that climate scientists are trying to solve a complex and urgent problem, to which it is impossible to apply the standard techniques of basic physics, such as experimenting repeatedly with the planet's climate (this is also true of branches of physics like cosmology[1]). Climate change is a messy problem, but we can't just ignore it and move on to a cleaner problem, unless we are prepared to move to a different planet (which, at the time of writing, is not a viable option). Exact replication of predictions is hard in climate science, and, in some ways – as I explain in this book – exact replication is not even desirable in the short term.

We can also ask a related question: How accurate does our knowledge of climate parameters have to be before we can take action to mitigate climate change? We need to know the gravitational constant very accurately to plan interplanetary space travel. But it may be sufficient to know a climate parameter (for example, how much the Earth is likely to have warmed by the year 2100) within a factor of two. If we know that the climate impacts of increased carbon dioxide are going to be seriously bad, we must act quickly, even if we are not sure whether the impacts will be terrible or two times as terrible.

It is worth explaining the intricacies of climate prediction to the general public. There are some who appear to be making life-changing decisions based on the belief that climate predictions are prophecies of doom. But the making of climate predictions is not unlike the making of sausage – the product may be nicely packaged, but the process underlying the product is quite messy. I hope that acquainting readers with the many uncertainties inherent in climate predictions will lead them to treat these predictions less as a cause for despair and more as a call for stronger action to tackle global warming.

As a climate scientist, I have built simple models to understand climate phenomena, and I have worked with complex models to make climate predictions. In November 2016, I was attending a workshop at Princeton University on the topic of modeling hierarchies when I happened to purchase a copy of the *Old Farmer's Almanac* at Labyrinth Books, across from the campus. The folksy predictions in the $7.95 almanac were a stark contrast to the multimillion-dollar predictions discussed at the workshop. I started to think about the philosophical basis for model predictions; two years later, in October 2018, I gave a talk titled "On the Complications of Simplified Models" at the retirement symposium, also at Princeton University, for my Ph.D. adviser, Isaac Held. Several chapters in this book grew out of that talk. The discussion of model tuning (Section 10.1) is directly motivated by a question posed during the symposium – a younger member of the audience asked something to the effect of, "Why should tuning be considered a bad thing in climate models, since it is definitely a good thing in music?" This question made me realize that a philosophical analysis of climate modeling would be useful to scientists as well as the general public.

This book is about places I have been in and people I have met. At the time, I had little awareness of the historical significance of these places or the scientific achievements of these people; only many years later did I begin to appreciate their significance. For example, I took classes for two years in Princeton University's Jones Hall, with little knowledge of its past role in the history of computing! I have been fortunate to interact with some of the pioneers of climate modeling mentioned in the book. Suki Manabe, Kirk Bryan, Akira Kasahara, and Warren Washington were teachers and colleagues. I have also been in the physical presence of several others mentioned in the book, such as Freeman Dyson, Joe Farman, Ed Lorenz, Joe Smagorinsky, and Phil Thompson. But, as a junior scientist, I never really spoke to them beyond the occasional exchange of pleasantries.

I apologize in advance for this book being US-centric and, in particular, Princeton-centric, for narrative reasons and also due to my own familiarity with people and places. Many important people and scientific developments in the history of climate prediction, especially outside the United States, are not covered. This book is not meant to be a comprehensive or authoritative history of either climate change or climate prediction. There are other books that serve that purpose.

I apologize also to philosophers of science. I am not a philosopher – just a scientist who thinks about how science is done. I aim to apply some elementary philosophical concepts to climate science. I have restricted myself to limited philosophical terminology whose interpretation is generally self-evident from the normal English meaning of the words. For readability, I have, in most cases, dropped the technical qualifiers used in philosophy; I use "deductivism" instead of hypothetico-deductivism, and "determinism" instead of causal determinism.

This book is not about the narrow topics of my own scientific research. It is about my broad philosophical understanding of climate modeling, shaped by more than three decades of working with climate models, both simple and complex. While this book is about both philosophy and climate prediction, it is neither an academic treatise on philosophy nor a scientific textbook on climate prediction. Also, it is not a comprehensive book about climate change, although many aspects of climate change are discussed in the context of climate prediction.

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There are several people whose expression of specific ideas (in parentheses) over the years influenced this book, although they are not explicitly mentioned or cited in the text: Jeff Anderson (compensating errors), Joe Barsugli (modeling philosophy), Byron Boville (constraining power), Ken Bowman (Manabe koan), Kevin Hamilton (sunspots), Boris Hanin (machine learning), Rol Madden (p-hacking), Michael McIntyre (conservation principles), Cécile Penland (statistical modeling), Prashant Sardeshmukh (model errors), and Mark Taylor (supercomputing).

The writing of this book has benefited greatly from transcripts of oral interviews recorded and made publicly available by Spencer R. Weart, author of *The Discovery of Global Warming*, and Paul N. Edwards, author of *A Vast Machine*: *Computer Models, Climate Data, and the Politics of Global Warming*. Both are excellent books that cover the topics of global warming and computer modeling much more comprehensively than this one.

The Oral History Project of the American Meteorological Society, archived at the National Center for Atmospheric Research, was the source of transcribed interviews with Susan Solomon and Warren Washington. The Oral History Project of the American Institute of Physics, archived at the National Center for Atmospheric Research, was the source of transcribed interviews with Akira Kasahara and Syukuro Manabe.

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