Preface

The goal of this book is to provide a brief introduction to the role of ecosystems in the climate system, and in the changing Earth System. The climate we experience on the surface of planet Earth results from interactions between *spheres* with different compositions and behaviors. Earth derives the bulk of its energy from the sun, and so *solar–terrestrial* interactions control the amount of energy for life. The atmosphere continuously exchanges water and energy with the oceans, and so *ocean–atmosphere* interactions govern many climate phenomena, as well as life in the oceans. Additionally, scientists have recently discovered ways in which organisms affect the climate, through myriad pathways. These *atmosphere–ecosystem* interactions are the focus of this book.

This book covers the effect of climate on the behavior and physiology of organisms, on the geography of organisms, and on the distribution of species of plants and animals over the planet. The text discusses how organisms influence the exchange of matter and energy at the land surface, and how terrestrial and marine organisms affect the composition of the atmosphere and hence its energy balance. By considering how interactions ecosystems affect the atmosphere, we can analyze how ecosystems cause changes that will affect the future climate.

This book is a broad overview of climate–ecosystem interactions. It covers terrestrial and marine ecosystems and addresses the organismal and physical/chemical aspects of ecosystems. Many excellent reviews of specific aspects of ecosystem–climate interactions are available (see references) for readers who need more detail on particular problems. Climate change is a major theme of the book. It provides a foundation for understanding how ecosystems interact with climate change ultimately caused by fossil fuel burning and describes mechanisms through which ecosystems change in response to climate change.

Climate and Ecosystems complements the other books in the Princeton Primers in Climate series that cover the physics of the Earth System. The responses and effects of the biosphere are intimately tied to the physics and chemistry of the climate system, and although this volume stands on its own, the reader will find greater depth on many phenomena in the other Primers in Climate volumes that will further illuminate issues covered in this book: the whole of the series of primers is more than the sum of the separate volumes.

Climate and Ecosystems is organized as follows:

Chapter 2 covers the basics of climate and energy balance from an organism's-eye view and provides critical physical concepts that underpin the rest of the book.

Chapter 3 addresses the effects of climate on ecosystems, including geographic patterns and the physiological and behavioral responses of organisms.

- Chapter 4 focuses on ecosystem effects on climate through control of atmospheric chemistry, the carbon cycle, and the surface energy balance.
- Chapter 5 discusses challenges and progress in modeling the future of ecosystems as the climate changes, and the interactions between ecosystem change and the climate.
- Chapter 6 is a concluding discussion of climate change and some of the scientific frontier issues that form a basis for informing society about risk and opportunity.

This book is a product of my own curious path. I began my graduate career interested in the role of herbivores in ecosystems, particularly in their role in biogeochemical cycles. Through studies of nutrient loss to the atmosphere from urine and feces (really) I gained experience in trace gas flux measurements and modeling. When the much broader role of biogenic gases in climate and ozone depletion emerged (chapter 4), my trace gas skills became relevant to a new class of problems that coupled ecology and atmospheric chemistry. I gained a new world of colleagues in atmospheric chemistry and climate science and eventually moved to the National Center for Atmospheric Research to pursue studies of nitrous oxide and other nitrogen gases in the atmosphere. This work led to a great collaboration with Andi (Meinrat) Andreae and one of the first books on atmosphere–ecosystem interactions.

My involvement with climate studies began in a random way. In the mid-1980s my friend and colleague Bill

Parton and I did some consulting work for Budweiser Breweries. The company was building a brewery in Fort Collins, Colorado, and wanted to dispose of beer waste by spraying it on farmland. We were engaged to evaluate the impacts of that process on soil nitrogen. Our colleague John Altenhofen persuaded us to use our earnings to buy an integrating light sensor (a LiCOR ceptometer), an instrument that could be used to estimate light interception by plant canopies. He thought this was an emerging approach for estimating productivity (see chapter 3).

Soon after, Bill and I read a NASA call for proposals for a large climate and ecosystems field campaign that emphasized light interception and the emerging LUE paradigm (see chapter 3). We had never focused on this aspect of production ecology, having worked mainly on nitrogen limitation, but, hey, we had a ceptometer, so we could measure canopy light use. We were successful, and as a result of that project, the First International Land Surface Climatology Project Field Experiment (FIFE), I began working directly with climate scientists and other researchers like Piers Sellers who were pioneering coupling the land surface with climate models. FIFE led to many more projects and a lifelong involvement with climate science, remote sensing, and biophysics. I have often reflected on the consequences of that ceptometer purchase and my debt to the Fort Collins Budweiser Brewery.

In the mid-1990s I was asked to lead the first Intergovernmental Panel on Climate Change assessment of the carbon cycle, which recognized that ecosystems are at the heart of many of its unknowns, and I began a rapid learning process that eventually engaged me deeply in understanding the entire carbon cycle and not just its terrestrial components. The emerging techniques of inverse modeling and data assimilation for understanding land and ocean fluxes were exciting and related well to my long-term interest in modeling techniques. Using the atmosphere as an integrator, as is discussed in chapter 4, allows understanding the global carbon cycle but is limited in its resolution of specific processes and regions because atmospheric mixing blurs many of the details.

In the same period, rapid advances were occurring in the science of remote sensing of the biosphere using satellite-borne sensors. These new measurements complement atmospheric measurements by providing a global view, but one that is resolved in time and space. I became extremely interested, again, because of the work that began with the ceptometer, along with many colleagues, in using satellite-based techniques to understand where and why carbon exchange was changing. This period, while NASA's Earth Observing System (EOS) was being planned and launched, was a time of amazing discoveries, hard-fought scientific controversy, and great technical achievement, and laid the foundation for the extraordinary developments occurring today. It was a time of all-night meetings, early-morning conferences, huge decisions, and adrenaline-charged science, different from the pace and scale of most ecology.

In the first decade of this century, the pace of climate change, with its impacts on ecosystems, has been far faster than I or most colleagues expected. The investment during the 1990s in observing systems resulted in the detection of changes to growth patterns, phenology, species ranges, and the carbon cycle that hadn't been expected until perhaps midcentury. For a variety of reasons, most scientists underestimated how rapidly ecosystems might change. Models, it turned out, consistently underestimated the physical and biological sensitivity of the Earth System. I wrote this book with a growing sense of urgency about the need to understand—but even more important, to begin to manage—the climate and its impacts on the biosphere and humanity before irreversible and damaging change is inevitable.

The authorship of a book like this never does justice to all the people who contributed. This book is for my wife and best field companion, Susan Bonfield, who inspires me and has taught me to care about and focus on organisms and not just abstract systems. I'd like to thank my mentors, Jerry Melillo, Bob Woodmansee, Bill Parton, Vern Cole, Berrien Moore III, Inez Fung, and Francis Bretherton, and my many friends and partners in learning about the Earth System, but especially Rob Braswell and Scott Doney, to both of whom this book owes a great deal.

I have benefited from the best of colleagues, Arvin Mosier, a great trace gas and isotope scientist; biogeochemist Andi Andreae; biogeochemist Pam Matson; Dennis Ojima, companion on many a scientific venture; Piers Sellers, astronaut and biophysicist par excellence; Russ Monson, plant physiologist and global ecologist, tropical

ecologist, and NEON partner; Michael Keller; Steve Running, cowboy global tree physiologist; Tony Janetos and Peter Backlund, colleagues in assessing and communicating climate change impacts; soil oceanographer Sue Trumbore; and Chris Field, global ecologist and skiing companion. This list doesn't begin to acknowledge all the scientific debts I owe to students, postdocs, collaborators, and colleagues, and I thank them all.

The view of science as a pyramid—of standing on the shoulders of giants—suggests a linear and hierarchical process. To me, research seems more like standing in a crowd, drinks in hand, passing ideas passed throughout the room. If you are lucky, when you wake up the next morning, one of those ideas takes hold and you can run with it. The next time you're with colleagues again, you toss out your morning idea and see what happens.