Surface-Atmosphere Exchange within Ecosystems

Authors: Russell Monson and Dennis Baldocchi,

Preface

This book is about *interactions* – those that occur between the earth's surface and the atmosphere. Understanding surface-atmosphere interactions is a core activity within the intellectual discipline known as *earth system sciences*. Many of the most pressing environmental issues that face human societies (e.g., climate warming, pollution by various oxidants, and stratospheric ozone depletion) can be traced to the flux of mass and energy between the earth's surface and the atmosphere. Surface-atmosphere exchange within ecosystems lies at the foundation of both the remedies and causes of many of these issues. For example, photosynthetic processes within ecosystems are responsible for the 2-3 billion tons of CO_2 that are removed from the atmosphere each year, slowing the inevitable rise in atmospheric CO_2 concentration that accompanies anthropogenic CO_2 emissions. Respiratory processes, however, mitigate the potential for ecosystems to sequester atmospheric CO_2, and this mitigation is highly sensitive to climate changes, especially climate warming, which has been linked to anthropogenic CO_2 emissions. Traditionally, we have studied the processes that control ecosystem surface-atmosphere exchanges within a broad range of traditional disciplines, including biochemistry, physiology, micrometeorology, climatology and atmospheric physics.

As we undertook the challenge to write this book, we recognized that a new framework for studying surface-atmosphere has emerged over the past two decades. Biologists have been attending traditional meetings and workshops associated with meteorology and geochemistry and conversely meteorologists and geochemists have been in attendance more frequently at biology meetings. As a result new sub-disciplines have appeared in the topics of biometeorology, bioclimatology, ecohydrology, and biogeochemistry. Thus, the time seemed right to formulate a new textbook aimed at students inhabiting these emergent disciplines; a textbook that takes the integration of biological and micrometeorological processes to greater depths. We have written this book as two colleagues who have migrated from different ends of the biology-micrometeorology spectrum – one from a history of formal training in the biological sciences and one from the micrometeorological sciences – but whom also have struggled to re-invent themselves to accommodate the interfaces between these disciplines. In many ways this book is biographical; it reflects past lessons that we learned during the re-invention process. Looking forward, the book represents an effort to intellectually integrate our divergent histories and begin building a common language so that students of the next generation, while recognizing distinctions between the atmosphere and biosphere, will also be able to blur those distinctions and move these traditionally divergent perspectives, particularly as they seek quantitative description.

This book is intended to be used as both a text and reference book. As a text it is intended to support courses for advanced undergraduate students or beginning graduate students on topics incorporating biosphere-atmosphere interactions. As a reference book it is intended to provide detailed mathematical derivations of some of the most commonly-used relations in biosphere-atmosphere interactions. In order to address both aims, we have structured the chapters such that the main text can be isolated from the detailed derivations and advanced topics and used as the focus of course readings. The detailed mathematical derivations and advanced topics are presented as isolated Appendices or as topical Boxes, respectively, at the end of the main text in each chapter. These latter sections may be most useful as reference material as students come back to these topics during their careers, or they may be used simultaneously with the course readings for those more advanced students.

One of the greatest challenges to writing a book like this is to develop a strategy for presenting the topics in a way that illustrates their connections and stimulates intellectual integration. As we began to organize the book we faced a fundamental decision: should we organize it around chapters that individually describe the various environmental factors that interact with plant processes (e.g., a chapter on water, a chapter on light, a chapter on temperature, and so on), or should we organize it around chapters that build in scale, from consideration of smaller scales toward larger scales of both space and time (e.g., a chapter on cells and metabolism, a chapter on leaves and diffusion, a chapter on canopies and turbulent transport, and so on). Traditional treatments have tended to follow the former model, and they have done so with good success. After much discussion and deliberation, we decided to follow the second model, though with a bit of allowance for hybridization between the two models. Thus, the chapters in the book tend to build in scale, beginning with processes and models at the subcellular scales and progressing to the planetary boundary layer scale. We feel that our focus on scaling, rather than independent treatment of environmental factors, is better suited to teaching students about the integration of processes and to placing the focus on the processes themselves, rather than the nature of physical factors. As an example of the difficult deliberations we faced on this issue, we struggled with how to bring the ever increasing use of stable isotope analyses into the discussion of ecosystem processes and surface-atmosphere interactions. Should we present this as a separate chapter, such that the focus is on the isotopic approach itself, or should we introduce the topic in pieces as we consider plant processes at different scales, thus emphasizing its utility as a supporting tool? Similarly, we put considerable thought into the best way to present the topic of surface-atmosphere water exchange. Should we present it in a single chapter that crosses scales, thus emphasizing the continuity of water transport from the soil to the lower atmosphere, or should we introduce the concept of leaf control over water transport at the same time that we introduce the concept of leaf control over carbon transport, and concordantly the topic of canopy dynamics in water transport at the same time we introduce canopy dynamics in momentum and heat transport? In both of these examples, we concluded that it would be best to organize the topics around scales of space and time, rather than constituent identity. One additional reason for settling on the chapter organization which we have adopted is that it naturally follows many of the hierarchichal strategies that have been used to construct surface-atmosphere exchange models during the past few decades. Models are often constructed such that the resolution of logic at smaller scales feeds the initiation of logic at higher scales. Our hope is to establish congruency between mechanisms and hierarchichal modeling that can be carried forward by students as they think of new ways to represent natural processes in mathematical frameworks.

Within the scope of these caveats, one might ask why it's necessary to delve as deeply as biochemistry to understand ecosystem function; and similarly, why stop with processes at the planetary boundary layer, rather than proceed to topics involving global circulation and global surface-atmosphere exchange. We make the case early in the book that the modern effort to explain ecosystem dynamics, and to design quantitative models to describe those dynamics, often extends to biochemical processes. The carboxylation potential of the enzyme Rubisco, for example, lies at the foundation of many surface-atmosphere models that predict CO_2 exchange at the scale of leaves, ecosystems, and the entire biosphere. In teaching our own classes on the topic of surface-atmosphere interactions we have found it necessary to begin our discussions within the context of these biochemical processes. Thus, this is the lowest scale at which we decided to begin the book. We decided to end the treatment at the scale of the planetary boundary layer because we wanted to keep the focus on ecosystem processes. Global scale circulation and biogeochemistry seems to fit within a scope all to itself, and requires consideration of an entirely new set of processes involved with ocean circulation, cloud physics and continental air flow patterns. We decided not to venture into this broader arena. Our expertise is best represented at the local-to-regional scales.

The overall emphasis of the book is on understanding the processes that control flux. Less emphasis is provided to descriptions of specific chemical pools, reservoirs, and descriptions of biogeochemical cycles. We also pay less attention to the instrumentation involved in making measurements, and specific experimental or measurement protocols. In some cases, it is unavoidable to move the discussion into measurement strategy, particularly when flux theory begins to merge with flux observation; e.g., use of the eddy covariance approach to measuring turbulent fluxes. In those cases, we try to take on a combined discussion of theoretical and measurement topics. In all chapters we have focused on the mathematical descriptions of mass and energy flux. Most of the examples we draw upon are related to CO_2 and H_2O fluxes, although we also take up the topic of other trace gases in briefer format. Finally, we note that our treatment focuses exclusively on terrestrial ecosystems. Our decision not to venture into marine ecosystems was principally determined by recognition of our strengths and weaknesses as scientists and authors not lack of recognition of the importance of these systems to global processes.

We appreciative of many discussions with colleagues and the generosity of virtually everyone we called upon to provide insight and fill in gaps in our understanding. Reviews of several of the chapters in early form were provided by Dave Bowling, Tom Sharkey, John Finnigan, Rowan Sage, Ray Leuning, Laura Scott, and Keith Mott. While these colleagues provided many useful insights and suggestions, responsibility of the final form of the chapters belongs with us…