Boundary-Layer Meteorol
DOI 10.1007/s10546-016-0204-3

BOOK REVIEW

Vilà-Guerau de Arellano et al.: Atmospheric Boundary Layer: Integrating Air Chemistry and Land Interactions

Cambridge University Press, New York, 2015, 265 pp

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Received: 11 August 2016 / Accepted: 18 August 2016

The book *Atmospheric Boundary Layer: Integrating Air Chemistry and Land Interactions* by Vilà-Guerau de Arellano et al. investigates the interplay between the atmospheric boundary layer, land-surface exchange processes, and free atmospheric conditions. The book differs from previous references on the topic of atmospheric boundary layer (Lumley and Panofsky 1964; Arya 1988; Stull 1988; Sorbjan 1989; Garratt 1992; Emanuel 1994; Kaimal and Finnigan 1994; Arya 1999; Oke 2002; Foken and Nappo 2008; Wyngaard 2010; Blackadar 2012; Csanady 2012) in content, style, and organizational structure. In addition, it complements introductory references such as Wallace and Hobbs (2006), the seminal text by Seinfeld and Pandis (1998) in atmospheric chemistry and air pollution, classical textbooks on land-atmosphere interactions (Eagleson 1970; Brutsaert 1982), environmental physics and plant physiology (Nobel 1999; Larcher 2003; Campbell and Norman 2012), climate science reviews (Peixóto and Oort 1984) and plant-water-climate interactions (Rodríguez-Iturbe and Porporato 2007). The primary aim of the book is to facilitate the flow of conceptual constructs of atmospheric and biospheric processes, theory, and the application of such concepts to case studies prominently featured in air pollution and climate sciences (Chameides et al. 1994; Feddema et al. 2005; Pielke 2005; Wang et al. 2009; Runyan et al. 2012; Shindell et al. 2012). Therefore, only limited literature surveys or recent developments on boundary-layer physics and air chemistry are presented.

Before proceeding further, a few words about the authors are in order. Jordi Vilà-Guerau de Arellano and Chiel van Heerwaarden bring expertise in boundary-layer meteorology, land-atmosphere interactions, and atmospheric turbulence simulations whereas Bart van Stratum's research thrust is on the interplay between the boundary layer and cloud formation, and Kees van den Dries's work supplies a key link between meteorology and air quality. While

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Vilà-Guerau de Arellano and den Dries are ‘seasoned’ scholars with more than a decade of research and teaching experience, Heerwaarden and Stratum bring a fresh look at this transdisciplinary topic reflected in the book’s organization to service research and instructional needs. Vilà-Guerau de Arellano’s research has the distinctive approach of distilling complex problems into their essential elements and applying insightful analyses to arrive at the key ingredients to solve them. This approach is adopted in virtually every chapter of the book.

The compass of the book is to bridge atmospheric dynamics, air chemistry and pollution, and biotic/abiotic and surface controls on land-surface exchanges of mass, energy, and momentum. What makes this book unique is the availability of an open source Chemistry Land-surface Atmosphere Soil Slab (labelled as CLASS) model that allows hands-on exercises to be conducted and what-if scenarios to be tested. Also, superb instructional and knowledge clips supplement the book and the usage of CLASS (links available from www.cambridge.org/vila).

The organization is logical and the progression of the material is linear. **Chapter 2** covers the fundamentals of the convective atmospheric boundary layer with a brief review of Reynolds averaging and Reynolds-averaged equations describing air turbulence. No attempt is made to offer a replacement to introductory books on this topic (Tennekes and Lumley 1972) but the selected material covered in this chapter judiciously makes the book reasonably stand-alone. One deficiency is the absence of discussions on the onset of (i) convection in fluids and its associated dimensionless number (e.g., the Rayleigh number), and (ii) turbulence (and the Reynolds number). While Chapter 6 briefly touches on these topics through its coverage of the turbulent kinetic energy (TKE) budget, an early description of these topics and associated dimensionless numbers would have been preferred. **Chapter 3** covers the key time scales of atmospheric constituents along with the relevant spatial scales, and a discussion on transport versus chemical transformations along with the emergence of the appropriate dimensionless numbers (e.g., the Damköhler number) representing their relative significance in mass balance equations. This chapter distills the seminal work conducted by Harm Jonker, Jordi Vilà-Guerau de Arellano, and Peter Duynkerke on variances and spectra (Jonker et al. 2004) and the failure of gradient-diffusion models (Arellano and Duynkerke 1992) for reactive compounds dispersed within the convective boundary layer. **Chapter 4** provides a brief thermodynamic review and elaborates on the potential temperature budget in the convective boundary layer. It is the first instance in the book where connections between the thermodynamic state of the boundary layer (i.e., its potential temperature), the entrainment and land-surface fluxes, and the evolving convective boundary layer is established. **Chapter 5** repeats Chapter 4 but for the specific moisture budget in the atmospheric boundary layer. It also features the crossing of the convective boundary-layer height and lifting condensation level as a necessary (but not sufficient) condition for cloud formation. **Chapter 6** explores the mean momentum and TKE budgets for the surface layer and the mixed layer, introduces the flux and gradient Richardson numbers along with the resulting stability classification of the atmosphere. The chapter concludes with the interplay between the Coriolis force, the shear stress at the ground (or friction), and the geostrophic flow and explains the internal variability in the wind vector as an inertial oscillator. **Chapter 7** repeats Chapter 5 but for scalars using carbon dioxide (CO_2) as a biologically active scalar. **Chapter 8** replicates Chapter 7 but for reactive scalars, where the chemical transformations are now introduced as sources and sinks above and beyond the flux-gradient term originating from turbulent flux differences at the surface and at the boundary-layer top. The nitric oxide–ozone–nitrogen dioxide (NO–O_3–NO_2) reactions are used as prototypical as they also allow for the addition of solar radiation variation to affect photochemical processes on time scales commensurate with the convective boundary-layer growth rate. One attribute is the simplified presentation and application of photochemical mechanisms developed to investigate the formation of O_3 and hydroxyl radical (OH) in the atmospheric boundary layer from the oxidation of plant emitted hydrocarbon compounds (e.g., isoprene and monoterpenes) as a function of nitrogen oxides.

Chapters 2−8 are reasonably ‘stand-alone’ in organization and material and the authors label them as the ‘Uncoupled System’. The common thread in Chapters 2−8 is the use of a zero-order mixed-layer slab model that has been shown to reasonably describe the diurnal evolution of the convective boundary-layer depth (Pino et al. 2006). The goal of these chapters neatly lays the foundations for the problem at hand in the book—‘the Coupled System’. In the coupled system, there are numerous non-linear feedback mechanisms between root-zone soil moisture content, heat and moisture exchange rates occurring between the land surface and the atmosphere, and the slowly evolving large-scale free atmospheric states above the convective boundary layer.

The role of biotic factors controlling the ecosystem fluxes of sensible and latent heat as they may be affected by the large-scale entrainment of heat and water vapour are addressed in Chapters 9−13. **Chapter 9** explores the coupled radiation and energy balances at the land surface (treated here as an interface) and covers the Penman–Monteith equation, the Jarvis formulation for stomatal conductance as a function of environmental variables, and reviews the so-called ‘force-restore’ approach now in use in several climate models to represent the dynamics of soil temperature and soil moisture. Here, the vegetation system is treated as a ‘big leaf’, and the soil/root system is treated as a single well-mixed non-linear reservoir when representing water extraction and water storage. Complex cases where rooting depth may be dynamic or where the water table fluctuates are outside the scope of this chapter. **Chapter 10** offers several case studies on the interaction between the soil-plant system and the atmosphere using the CLASS model. **Chapter 11** considers the lower boundary condition (i.e., the land surface) when formulating the budget equation for CO_2 and revises the Penman–Monteith equation covered in Chapter 9 by adding a realistic coupled photosynthesis-stomatal conductance model so as to distinguish between C3 and C4 photosynthetic pathways. It also introduces soil respiratory terms as a function of soil moisture and temperature. Hence, the coupled exchanges of heat, water, and CO_2 between the land and the atmosphere are completed on time scales where vegetation remains static (i.e., leaf area, root density, carbon stocks, and all the eco-physiological variables do not vary) but atmospheric and soil processes vary rapidly (on diurnal and daily time scales). A Crassulacean acid metabolism photosynthesis example, which has interesting dynamics between stomatal opening during nighttime and closure during daytime, would have completed the discussion on the role of the photosynthetic machinery on boundary-layer processes. Unfortunately, this example must await future editions.

Chapter 12 explores the effects of elevated air temperature and atmospheric CO_2, reduced rainfall, light dimming, and plant photosynthetic pathways on the dynamics of the atmospheric boundary layer and the evolution of the land-surface fluxes using the CLASS model. **Chapter 13** builds on Chapter 12 and considers more complex conditions where horizontal transport (e.g., advection) is relevant (such as the case with the sea breeze) over a wide range of time scales. Likewise, the effects of long droughts (i.e., where plants experience appreciable stress after being well watered) are also covered by the case studies. The case studies highlight the sensitivity of the coupled land-atmosphere system to vegetation cover (though as earlier noted, not the other way around). The chapter concludes with a pollution example in the CLASS model so that diurnal to multi-day time scales are treated and where the land surface also plays a role in O_3 removal (mainly by chemical transformations and physical surface deposition). Missing from this discussion is the fact that the soil moisture and soil temperature gradients as well as root density gradients can be large in the soil system and not amenable to a 'force-restore' representation. The root-zone soil moisture dynamics in the rhizosphere as well as the entire topic of plant hydraulics, both needed to describe water supply and transport to the photosynthesizing leaf tissues, are also omitted. Within-canopy turbulent and radiative transfer processes, needed in 'stitching' the canopy to the overlying atmosphere, are entirely ignored. Clearly, for such a broad subject, the number of topics missed by the book can be expanded *ad infinitum*. However, if revisions are to be suggested for future editions, it is worth ending each chapter with a section titled 'Study Limitations' paralleling the 'Supportive Literature' already included. Having these two aforementioned sections coordinated will be a definite plus.

Chapters 14 and **15** switch from the land surface (bottom boundary condition) to the top of the boundary layer, where cloud formation is now the subject of attention. The work here covers the macroscopic physical processes relevant to dry cloud formation and growth but bypasses all aspects of cloud microphysics. The focus of Chapter 14 is on the radiative component of stratocumulus clouds with minimal representation of the turbulent exchange processes but does cover land-surface controls on their initiation phase. Chapter 15 delves deeper into the radiative and turbulent transport processes as well as feedbacks in the cloud layer and the upper most level delineating the limit of convection. The focus here is on types of instabilities, concomitant cloud growth and the role of the land surface and free atmospheric states in setting them. These cloud-forming instabilities are then introduced into the slab model covered by CLASS, and several examples are featured to show how cloud thickness can elicit photo-dissociation of relevant molecules. **Chapter 16** is actually crafted as a 'user-manual' for the CLASS model illustrating how to initiate modules, import and export files, and how to use the graphical user interface. Some baseline cases are illustrated, where the parameters are documented in tables that cite the appropriate equations or parameters in the book. The appendices derive key equations not covered in the main text, which we found to be a plus because it keeps the main text readable and not loaded with intermediate equations or results. The appendices are reasonably crafted as stand-alone documents. For a book that has to 'juggle' so many symbols (and units) so as to adhere to different conventions in the literature, we found the transitions among chapters and topics reasonably smooth and Appendix G fills any unforeseen gaps on unit conversions.

In general, the writing is pellucid and equations are derived from first principles where possible. For the most part, the figures are readable and appropriate to augment the information included in the text. The book is ideal for undergraduates and graduates majoring in atmospheric science and a perfect text for courses dealing with the physics, chemistry, and ecology of land-atmosphere interactions. The CLASS model and the supplementary videos available from the website (http://classmodel.github.io/) make the book an appealing companion for a short intensive course or a workshop on the topic. The instructional clips are 'professional grade' in style and presentation. The first two clips introduce the book and the CLASS model. These are followed by ten mini-video clips, each lasting about 4–5 min, explaining variables, parameters, and switches to turn on or off for various modules in the CLASS model. Seven clips, labeled as knowledge clips, review the theory (many times supported with impressive graphics and occasionally featuring large-eddy simulation animations) in the CLASS model in relation to specific chapters and equations (or appendices) in the book. Unsurprisingly, many aspects of the book will be appreciated by meteorologists, hydrologists, ecologists, air pollution and climate scientists involved in courses dealing with the intersection between all these fields. Perhaps future editions will be fully interactive so as to allow the CLASS model and the video clips to be embedded in the document and called upon while reading the text or running a sample calculation.

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