

## Book reviews

**Climate System Modeling** edited by K.E. Trenberth (Cambridge University Press, 1992) ISBN 0 521 43231 6. Hardcover, 788 pp., \$120.00.

This comprehensive book is intended to form a basis for advancing our ability to model the earth's climatic system. To achieve this ambitious goal two things have to be done. First, the most important aspects of the system need to be described to 'provide background so that more specialized texts can be digested, to place in a clear perspective the role of [the atmosphere, ocean, cryosphere, terrestrial ecosystem and other land surface processes] in the overall system'. Second, there needs to be a discussion of the main 'sources of uncertainty, the assumptions [and simplifications made in the modelling approach, and a presentation of] the mathematical, physical and biological basis of the models employed'. The authors and editor have attained these goals for the space and time-scales relevant to global warming. The book consequently represents a milestone in global climate system modelling.

It is divided into six parts (1. Introduction, 2. The Science: Subsystems and Processes, 3. Modeling and Parameterization, 4. Couplings and Interactions, 5. Sensitivity Experiments and Applications, 6. Future Prospects). Part One consists of two chapters. The first introduces many of the issues raised in the subsequent chapters. For example: the need to quantify human impacts on climate; the principal human activities which influence climate; the importance of feedbacks within a given component and between components and the uncertainty associated with them; the large uncertainty due to evolving modes of human behaviour; the rationale behind the use of a hierarchy of models; subgrid-scale parametrisation and the corresponding uncertainty; predictability; model verification; and salient features of the climate system (e.g., the Earth's radiation budget and the greenhouse effect).

Chapter 2 deals with the coupling between human activity and physical processes related to climate change: the socio-economic factors which contribute to climate-related environmental change; the interaction between political pressure and policy formulation; the history of CO<sub>2</sub> increase; basic statistics on the contribution made by the main greenhouse gases to radiative forcing; the relative roles of fossil fuel burning and deforestation in increasing CO<sub>2</sub> levels; the concept of 'environmental colonialism'; sources of N<sub>2</sub>O, CH<sub>4</sub> and CFCs and the uncertainty associated with future projections of their emission; deserti-

fication; nuclear power as an alternative energy source; and the Montreal Protocol. The chapter concludes with a plea for the integration of the human component into climate system models.

Part 2 contains discussion of many of the fundamental properties of the atmosphere, ocean, sea and land-ice, biophysical and biogeochemical processes and chemical transport in the atmosphere. For example: the composition, structure and basic physics of the atmosphere; radiative transfer in the atmosphere; the general circulation of the atmosphere and ocean; the role of vegetation in modifying surface fluxes; possible feedbacks from terrestrial ecosystems; chemical paths involving O<sub>3</sub>, CH<sub>4</sub>, N<sub>2</sub>O and CFCs; the primary importance of H<sub>2</sub>O as a greenhouse gas; the subtle interplay between CO<sub>2</sub> and the chemically active constituents of the atmosphere; the importance of the ocean in the carbon cycle; the organic matter pump; and the possible importance of iron in ocean productivity.

Part 3 deals with the 'nuts and bolts' of the science — the models and the computers on which they run. There is an interesting history of the development of atmospheric general circulation models (AGCMs) from an American perspective, and an introduction to a number of basic concepts in numerical modelling (e.g., spectral and finite difference methods). The difference in priorities between numerical weather prediction and climate modelling is described (e.g., accuracy versus conservation), as is the extraordinary progress made in numerical weather prediction performance and computer hardware, and the fact that improved performance in speed can only be maintained in the future if code is designed to suit the evolving hardware. There is an excellent discussion of the hierarchy of atmospheric models from 1-D globally averaged energy balance models to GCMs. Other issues discussed include linear feedback analysis and the parametrisation of cumulus processes, the planetary boundary layer and gravity wave drag; and cloud prediction schemes.

In the discussion of model verification there is no mention of the surface fluxes of heat, freshwater or momentum. In the context of coupled modelling the atmospheric and oceanic components have not really been verified unless these additional fields are also considered. It is only recently that reasonable observational estimates of these fields have become available, and so these fields were allowed to roam parameter space far more freely than the more traditional and better observed verification fields (e.g., sea-level pressure, 500 hPa geopotential height). This has, in part, led to the many surprises encountered when these models were first coupled together.

The ocean modelling chapter covers a wide range of issues including the parametrisation of the surface mixed layer; the boundary conditions used to force and constrain ocean models;  $z$ ,  $\sigma$  and isopycnal coordinates; the general inadequacy of the discretisation of the advective equations; the hierarchy of ocean models from box models of the thermohaline circulation through to ocean GCMs (OGCMs); the existence of multiple equilibria in these models and the apparent sensitivity of them to high latitude freshening. The equilibria are described as phenomena internal to the ocean. In fact they are equilibria of very crude coupled models, so we should regard them as suggestive, in the absence of any supporting geological evidence. Other topics discussed include the widely used but simplistic parametrisation of convective overturning; the uncertainty associated with the bulk formulae for wind stress; the dependence of meridional heat transport upon the (crude) parametrisation of vertical diffusion; and the fact that the inclusion of a global eddy resolving model (considered to be 1/8 by 1/8 degrees) into a coupled climate model is years away.

Chapter 12 describes how sea-ice substantially modifies albedo and air-sea fluxes and the important coupling between the dynamics and thermodynamics of sea-ice in determining its distribution. The powerful assumption that sea-ice can be modelled as a 2-D continuum is also presented. Both viscous plastic and the simpler cavitating fluid models of sea-ice are described.

The next chapter describes how land-ice evolves on time-scales much longer than those usually associated with greenhouse warming scenarios. As a result, land-ice modelling is not regarded as crucial in the greenhouse context (but essential in models of glacial and interglacial periods and the transitions between them). One exception to this lies in the instability of the West Antarctic Ice Sheet, which the author regards sceptically but nevertheless treats as an open question.

The problem of modelling land surface processes is broken down into three sub-fields: biophysics, biogeochemistry and ecosystem dynamics. The greatest obstacles to a comprehensive model of these processes are regarded as their incompatible time and space-scales. The importance of land surface processes in modifying albedo and surface fluxes of heat, momentum and water are described. Appropriate models of stomatal and soil resistance in latent heat flux formulations are emphasised. Other issues discussed include radiative transfer involving vegetation canopies and soil and our incomplete understanding of the mechanisms underlying stomatal resistance. The chapter conveys the staggering complexity of the processes involved and an appreciation of the ingenious modelling strategies employed.

The next chapter describes the numerical difficulties encountered in chemical transport modelling when dealing with a system that has disparate time-scales. The primary importance of good advection schemes, and the advantages and disadvantages of semi-Lagrangian methods (principally accuracy and efficiency vs. conservation) are also discussed.

The last chapter in Part 3 describes the biological, chemical and physical processes which determine the distribution of  $\text{CO}_2$  in the ocean and which might lead to changes in atmospheric  $\text{CO}_2$  on time-scales longer than a few hundred years but less than a few thousand years. Many issues are discussed including the recent controversy over the magnitude of the oceanic uptake of  $\text{CO}_2$ ; and an outstanding need to determine if iron input from wind-blown dust is the major factor in limiting the biological uptake of nutrients. The latter is important because it might then make the difficult task of including complex food web interactions (which can also limit uptake) into biogeochemical models less urgent.

Two classes of coupled models are described in Part 4: global coupled models and tropical Pacific El Niño — Southern Oscillation (ENSO) models. The surface heat fluxes diagnosed from decoupled global OGCM and AGCM integrations are presented and compared with observational estimates, with the OGCM fluxes by far the worst. As a result, the lion's share of the systematic error underlying the climate drift exhibited by the coupled model described is attributed to the OGCM (Chapters 17 and 20).

It should be noted that this conclusion is resolution dependent: the surface heat fluxes diagnosed from an OGCM with increased resolution are in better agreement with observational estimates than are the fluxes derived from AGCMs with the same horizontal (R21) and vertical resolution (L9). This should not be interpreted as a statement that OGCMs are somehow superior to AGCMs. On the contrary, we know that there are gross deficiencies in other aspects of the OGCMs used in global coupled models and that the range of physical processes modelled by a typical AGCM is much greater than for a typical OGCM. The point is, however, that systematic bias should be high on the agenda for modellers of *all* components. Many other interesting issues are discussed, including the advantages and disadvantages of adjusting surface fluxes which are used to alleviate climate drift during coupled integration.

Chapter 18 provides an excellent review of ENSO and ENSO modelling and the interplay between observational and modelling work. Issues covered include the role of equatorial waves, horizontal advection, equatorial upwelling thermocline displacement and the delay action oscillator in ENSO dynamics; the encouraging hindcast and

predictive skill of intermediate tropical models (e.g., anomaly models which encapsulate what is believed to be the essential physics of the problem), and their significant role in increasing our understanding of ENSO over the last two decades; the relative skill of AGCM and tropical OGCMs (a view is presented which is consistent with the discussion in the previous paragraph); and the fact that increased model sophistication is required to obtain information about remote teleconnections to tropical variability, but does not necessarily guarantee improved performance in terms of hindcast and predictive capability.

A few important points are not made. First, by definition anomaly models presume the existence of a realistic background state, whereas models consisting of coupled GCMs do not — it too must be modelled. Thus improved modelling of processes which are not considered essential for anomaly model performance may in fact play a crucial role in coupled GCM performance if those improvements lead to a better background state. As a result the conditions needed by anomaly models to obtain reasonable hindcast skill provide only a sub-set of the necessary conditions required by coupled GCMs. This is one of the main reasons why the intermediate models have been so successful compared with the early coupled GCMs: many essential features which are difficult to model are presumed *a priori*.

The second point relates to the author's view that it is a more difficult task to test global models used in enhanced CO<sub>2</sub> studies because the evolution has no precedent, and so the hindcasting approach to model verification employed in ENSO studies cannot be applied. This is true, but the fact that we can (and do) verify the basic state against observations — something that obviously cannot be done with an anomaly model — is overlooked.

The third and final point is that the intermediate models have limited applicability. For example, it is difficult to employ them to test hypotheses regarding interactions between the variability and an evolving background state. This is because they have, by necessity, parametrised important processes in terms of current climatic conditions, which may not be applicable in the coming decades. Furthermore, only global models can provide self-consistent scenarios for how the mean state might evolve. It seems certain, therefore, that our understanding of ENSO and how it might interact with a changing climate will continue to benefit from studies using a wide range of modelling approaches, and that coupled GCMs will almost certainly be of more use than the picture painted in this particular chapter.

In Part 5 various sensitivity experiments and applications of some of the models discussed in the earlier chapters are described. Sensitivity to various perturbations are considered. Model re-

sults which illustrate the fundamental importance of the water vapour feedback in amplifying the direct radiative surface warming provided by enhanced CO<sub>2</sub> levels are described, as is the importance of other feedbacks involving clouds, snow, sea-ice and the ocean in modifying the sensitivity. The fact that the crude representation of these feedbacks is the major source of error in the assessment of sensitivity is illustrated using the results of international model intercomparisons. A discussion of future work includes the need to incorporate individual greenhouse gases rather than an *effective* CO<sub>2</sub>.

Chapter 21 provides a summary of issues relating to modelling past climatic changes including the utility of AGCMs in this context, the need to incorporate more realistic representations of the ocean, and the fact that models developed to investigate possible future climatic conditions can also play a role in helping to solve fascinating puzzles about the Earth's past.

The climatic significance of deforestation, desertification and shifting biomes is discussed in the last chapter of Part 5. This is an excellent chapter which highlights many of the broader issues related to climate modelling. Projections of future land cover are strongly linked to unpredictable human decisions. An interesting example (also discussed in Chapter 14) is given of how even the most compelling hypothesis can be contradicted by results from sensitivity experiments if important feedbacks at work in the model are overlooked in the formulation of the hypothesis. Conversely, it should be added that behaviour evident in models which are reliant upon crudely parametrised feedbacks should be regarded as merely suggestive. (Indeed subsequent research has shown that the sensitivity of the ocean models discussed in Part 2 is crucially dependent upon the simplistic air-sea coupling used in these models and so it too remains an open question.) The chapter concludes with the statement that land surface processes have not yet advanced to the point where they will reliably predict consequences of hypothetical changes of the land surface.

Part 6 consists of only one chapter which summarises many of the issues raised in the previous chapters and a few that are not. Most of the discussion centres on how the atmospheric model can be improved. Limitations of the parametrisation of subgrid-scale atmospheric processes are suggested as the principal reason for the cold bias exhibited by most, if not all AGCMs. The incorporation of major ice sheets and the biosphere for CO<sub>2</sub> studies is regarded as less urgent than for any of the other components. Most of the recurrent themes not picked up on here are briefly discussed in the preface to the book.

A few recurrent themes probably should have been discussed further, and one or two additional points could have been made. For example, many

of the authors emphasised the great benefits that have been achieved by a hierarchy of modelling approaches and the great physical insight that the simpler models have provided. These simpler models will continue to play an important role, primarily as tools for developing reasonable hypotheses that can be tested using more sophisticated models. Other themes include: the fundamental importance of interactions between the various components in determining the response to a given perturbation; the difficulty of modelling processes involving disparate time and space scales; the continuing need for a more extensive observational base (and the verification of models against this expanding base); the need to identify additional important feedbacks and to quantify them; and the need to improve many of the parametrisation schemes in the various models by making them more physically based and by reducing excessive 'tunability' where it occurs.

The inherent uncertainty involved in climate system modelling due to the human element in the system would have been worth reiterating in this final chapter. Nowhere in the book is there an explanation of *how* the human element can be integrated into the system. In my opinion the integration can best be achieved by generalising the scenario approach to effective CO<sub>2</sub> release currently employed, rather than attempting to include the element as if it were yet another physical component (as was recently proposed at an international conference on climate modelling). This will then yield a range of possible outcomes with corresponding estimates of the probabilities associated with them. It is important to realise that on the regional and decadal scales this range will be quite large given the demonstrable sensitivity of the coupled climate models to seemingly minor changes to the initial conditions.

It would also have been worth mentioning that studies which focus on the impact of climate change on these scales should probably consider scenarios outside the limits set by the current generation of models for two main reasons. First, the great expense of each transient experiment prohibits an exhaustive study of the possible outcomes. Second, we know that the models share common problems and so it is likely that they also exhibit generic biases in their response to a given perturbation.

The book is well written, with very few lapses into jargon that has not been previously defined. Some of the chapters are an absolute joy to read — with complicated and involved subjects described in an almost story book fashion. They are easy to follow for anyone with a mathematical — physical sciences background. Most of the chapters (though not all) include a helpful summary section, many include fascinating accounts of the historical development of our understanding in

these fields. The chapters are linked together very well with repetition kept to a minimum and the cross-referencing between chapters helpful rather than intrusive. The diagrams are excellent: clear, concise yet very informative. There is an extensive reference list (although one or two of the chapters have a limited number of citations — their saving grace being that in all other respects they are among the especially well-written chapters). There is a useful list of acronyms, a summary of basic notation and commonly used physical constants, some quite striking colour plates and a comprehensive index. It provides an excellent reference for researchers and graduate students in the field and would provide a sound basis for a graduate course on Earth System Modelling. There is also plenty to interest the general reader provided they are not put off by skipping some of the more technical sections. The book costs \$120 and is worth every cent.

**Scott Power**

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**Climate, Earth Processes and Earth History** by Richard John Huggett (Springer-Verlag, 1991) ISBN 3 540 53419 9. Hardcover, xiv + 281 pp., DM128.

The International Geosphere-Biosphere Programme and the 1992 Rio de Janeiro Earth Summit's Agenda 21 are among the strong catalysts stimulating many of the scientific community to become more environmentally literate and more climatically aware. Hence the growing need for good, clear, authoritative texts dealing with climate change as well as the related issue of interactions between land, sea and air, now and in the past. The present volume deals with both of these topics, is well served with a comprehensive and up-to-date bibliography of some 1200 references, together with a glossary of 576 items. There is no index, which is a pity, since a thoughtfully compiled index is an invaluable research tool.

Huggett begins with a short discussion of climatic change at different scales in time and space. A long chapter on the global climate systems covers solar, orbital and geophysical forcing, including the historical context to present day ideas. He deals at length with climatic cycles,

although the even-handed approach occasionally lapses into blandness. The next three chapters discuss ice and water, sediments (erosion, deposition, palaeosols), and landforms and soils. The discussion of laterites is one of the best I have read. My only quibble here lies in discussing soil processes after a review of the palaeoclimatic significance of palaeosols, which lacks logic and leads to repetition.

Two interesting and long chapters on plant and animal diversity and on biogeography conclude with an account of mass extinctions and climate — a useful background against which to view current biodiversity losses. The final chapter, labelled synthesis, includes a simple mathematical model describing links within the biosphere and between other components of our global environmental systems, and concludes with a succinct account of cyclic changes in the biosphere.

Overall, this book will be of interest to anyone wishing to enlarge their appreciation of how climate interacts (and has interacted) with the biosphere in particular, and of how climatic variability is influenced by a complex array of forcing factors, both internal and external to our planet.

**M. Williams**

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**The Atmospheric Boundary Layer** by J.R. Garratt (Cambridge University Press, 1992) ISBN 0 521 38052 9. xviii + 316 pp., \$175.00.

Over the past three decades, a wealth of information on the structure and dynamics of the atmospheric boundary layer (ABL) has accumulated. Advances in electronics and instrumentation have led to ability to perform sophisticated field and laboratory measurements, and the explosion in computing power has made more complex and more realistic ABL models possible. *The Atmospheric Boundary Layer* by John Garratt is one of several recent books that summarise the state of knowledge in this area (also see, for example, S.P. Arya, *Introduction to Micrometeorology*; Z. Sorbjan, *Structure of the Atmospheric Boundary Layer*; R.B. Stull, *Introduction to Boundary Layer Meteorology*). It is published as part of the Cambridge Atmospheric and Space Science Series.

Many readers of this journal will already be familiar with Garratt's work through his extensive research in boundary layer and mesoscale meteorology. His book on the ABL is a moderately advanced text, attempting to fill the needs of both postgraduate students and research workers. In it he describes the fundamental mathematical and physical ideas governing ABL processes with an eye to applying them to numerical modelling of climate. A major strength of his book is his emphasis on observations as well as modelling results and on physical interpretation as well as mathematical description.

The book is divided into nine chapters. Chapters 1 to 3 introduce the topic and lay the groundwork of fundamental equations and definitions. Scaling laws for mean and turbulent quantities, such as mean profiles, standard deviations and spectra, are then developed and compared with observations. Chapters 4 and 5 deal with surface properties. Much of Chapter 4 is devoted to a discussion of surface roughnesses for momentum, heat and moisture, the role of the vegetative canopy and interfacial sublayer relations, but attention is also paid to the properties of the internal boundary layer. Chapter 5 examines the surface energy balance. It includes a detailed discussion of the individual components: the net radiative flux, the soil heat flux and the heat and moisture fluxes from a bare soil surface and from a vegetated surface. There is also a brief discussion of condensation processes.

The next part of the book, Chapters 6 and 7, describes the structure of the convective and stably stratified ABL. While most of the observations have been taken over land in horizontally homogeneous conditions, in Chapter 6 Garratt also has sections on the ABL in coastal and marine environments and mesoscale flow and growth of the internal boundary layer. The material in Chapter 7 concentrates on observations and modelling of the cloud-topped boundary layer.

The final two chapters are devoted to parametrisation of soil and canopy processes, surface fluxes and schemes for closing the turbulence equations. The parametrisation schemes are described in Chapter 8 and applications to climate models, including a discussion of the sensitivity of climate to the ABL and land surface, are given in Chapter 9. Garratt concludes by outlining several ABL research priorities for climate applications: area-averaging techniques for flow over heterogeneous terrain, ABL theory over complex terrain, canopy and surface hydrology parametrisation and ABL clouds.

Garratt has chosen to emphasise fairly simple conceptual models to illustrate the physical principles governing ABL behaviour (e.g. force-restore method for calculating surface temperature and moisture, jump models of the convective boundary layer and cloud-topped boundary layer,

Nieuwstadt's model of the stable boundary layer, Thorpe and Guymer's model of the low-level jet). Results of detailed numerical ABL models receive relatively less treatment. As with any book, choices had to be made about what material to omit. Topics such as diffusion applications, instrumentation and laboratory modelling of the ABL are not included.

I found only a few minor blemishes. In Chapter 1 terms such as 'turbulent closure problem', 'stationary' and 'homogeneous' are used before they are defined. Equation 1.2 is really an approximation. On p. 99 the footnotes actually belong to Table 5.1 on p. 134. In Fig. 4.12

the theoretical predictions of Panofsky and Townsend have been omitted.

Overall this is a book that students and researchers will want to use and to refer to and I highly recommend it. It is a pity that the publisher has set the price so high that only a few individuals will be able to afford it. Make sure that your library has a copy.

**Dale Hess**

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