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BOOK REVIEW

Fundamentals of Geophysical Fluid Dynamics. By J. C. McWilliams. Cambridge University Press, 2006. 266 pp. ISBN 0521 85637X. £40.00.

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Although geophysical fluid dynamics (GFD) is ‘a mature subject’, as the author of this book reminds us in his preface, there were, until recently, only a few books devoted to the subject. Fewer still are accessible to graduate students with only basic knowledge of physics, mechanics and applied mathematics. James McWilliams’s clear and concise text, which aims precisely at this readership, is therefore a welcome addition to the literature. It will serve as a useful primer for graduate students entering the subject and may be used as a basis for graduate courses; it should also prove a valuable reference for more advanced researchers.

GFD can be described as that part of physics which examines the dynamics of the atmosphere and oceans from a fluid-mechanical standpoint. Its focus is not on description but on deduction: observations are explained from first principles through the study of simple models that capture the main mechanisms at work. McWilliams succeeds in conveying the philosophy of this approach by concentrating on some important aspects, mostly of large-scale mid-latitude dynamics (with a certain bias in favour of the ocean – perhaps predictably, given his own expertise). Thus some key phenomena including radiative transfers, humidity and salinity effects, internal waves, and tropical dynamics are consciously ignored. The selection of topics may be debated, of course, but it is well-judged and makes for a short and accessible introductory book.

The fluid dynamics involved in GFD is rather intricate, with numerous effects playing a part: rotation, density stratification, boundaries, curved geometry, etc. Depending on the spatial and temporal scales of the phenomena studied, some of these effects can be neglected; as a result, researchers rely on a collection of approximate models whose diversity can bewilder the newcomer in the field. McWilliams derives several of these models informally, using convincing scaling arguments rather than the machinery of asymptotics. This provides a gentle introduction to the standard approximations used in GFD (Boussinesq, hydrostatic, quasi-geostrophic, etc.). The more mathematically minded readers will prefer the approach of either Pedlosky (1992) or Salmon (1998), but McWilliams’s emphasis on the physical aspects will be appealing to many.

Turbulence plays a key role in GFD. In itself, it is only touched upon in this book. There is, for instance, only a brief discussion of the inverse energy and forward enstrophy cascades in two-dimensional turbulence. The Kolmogorov prediction for the energy spectrum of three-dimensional turbulence, and the Batchelor–Leith–Kraichnan analogues for two-dimensional turbulence are not introduced. What is central to the book, however, is the manner in which turbulent fluctuations organize themselves to influence and even control large-scale circulations. This theme presents a difficulty that is inherent to many turbulent phenomena: it is rarely possible to make *a priori* theoretical predictions, and much of the current understanding relies heavily on numerical simulations. McWilliams tackles this difficulty by presenting in detail the results of two sets of simulations. The first demonstrates the interaction between mean-flow and turbulent fluctuations in a statistically steady, baroclinically unstable jet; the second describes the influence of eddies on western boundary currents. The discussion illustrates well the nature of much of modern GFD research, in which computers are used as numerical laboratories, and the theoretical effort is mainly devoted to the development of diagnostic tools used for the interpretation of the results. The reliance on a few well-chosen numerical examples distinguishes McWilliams's book from earlier textbooks of a similar level such as Cushman-Roisin (1994) and Gill (1982), and makes it a fairer reflection of what GFD is now about.

The core of the book starts in Chapter 2 with a swift presentation of the equations of motion and of some of the standard approximations used for either the ocean or the atmosphere. The idea of geostrophic balance, motivated by a scale analysis, is introduced there. The next chapter is devoted to two-dimensional barotropic dynamics, including topics such as point vortices, barotropic and centrifugal instabilities, a first look at eddy–mean-flow interactions introducing Reynolds stresses and eddy viscosity, and the brief discussion of two-dimensional turbulence mentioned above. Chapter 4 considers the dynamics of the rotating shallow-water model; it examines the propagation of inertia–gravity and Kelvin waves and contains a satisfyingly detailed discussion of geostrophic adjustment. This contrasts with the treatment of shocks that follows immediately: this is probably too terse to enlighten the reader who has not previously studied the subject. The rest of the chapter derives the quasi-geostrophic approximation which is used directly to examine Rossby-wave propagation and emission.

Up to that point, the material covered is fairly conventional, and it is in the rest of the book that McWilliams's emphasis on the analysis of numerical simulations becomes clear. Chapter 5 considers baroclinic flows using multilayer quasi-geostrophic models: a standard treatment of Phillips's two-layer model of baroclinic instability is followed by the detailed description of the statistical equilibration of a baroclinic jet in numerical simulations of a three-layer model (based on McWilliams & Chow 1981). As mentioned above, this example illustrates how the eddies and mean flow interact and how this can be diagnosed from the numerics. It also allows the author to touch upon important concepts such as potential-vorticity homogenization, bolus velocity, and Eliassen–Palm flux.

The final chapter discusses boundary layers. Top and bottom Ekman boundary layers are examined first, with turbulent fluxes parameterized by an eddy viscosity; the limitation of this type of parameterization is emphasized by a comparison with the results of a direct numerical simulation of a bottom boundary layer due to Coleman (1999). Finally, the formation of the western boundary layer in a wind-forced ocean is discussed. Again, standard analytical results (derived by matched asymptotics for a single-layer ocean) are contrasted with the more realistic turbulent behaviour of a multilayer numerical model.

The book contains a series of 60 or so exercises, useful for those who will employ it as a graduate-course text. They range from straightforward computations to rather involved, open-type questions which could serve as a basis of student projects. The absence of a substantial reference list is unfortunate, however: the target readership, which needs guidance through the vast GFD literature, will have to find it elsewhere. This is a minor defect, however, in a book that has many strong points. With its emphasis on the interpretation of numerical simulations, it usefully complements earlier textbooks and provides an excellent free-standing introduction to modern GFD.

REFERENCES

COLEMAN, G. N. 1999 Similarity statistics from a direct simulation of the neutrally stratified planetary boundary layer. *J. Atmos. Sci.* **56**, 891–900.

CUSHMAN-ROISIN, B. 1994 *Introduction to Geophysical Fluid Dynamics*. Prentice Hall.

GILL, A. E. 1982 *Atmosphere-Ocean Dynamics*. Academic.

MCWILLIAMS, J. C. & CHOW, J. H. S. 1981 Equilibrium geostrophic turbulence: I. A reference solution in a β-channel. *J. Phys. Oceanogr.* **11**, 921–949.

PEDLOSKY, J. 1992 *Geophysical Fluid Dynamics*. Springer.

SALMON, R. 1998 *Lectures on Geophysical Fluid Dynamics*. Oxford University Press.

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