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Book Review

Nonlinear physical oceanography: a dynamical systems approach to the large scale ocean circulation and El Niño, by Henk A. Dijkstra, 2nd edition, Springer, Dordrecht, The Netherlands, 2005, 532 pp., £54, $34.95, €73.80, (hardcover), ISBN: 978-1-4020-2262-3.

This book – the second, revised and enlarged edition of a book first published by Kluwer in 2000 – falls into the broad category of advanced graduate text *cum* research monograph. It does more than most books in this category to actually serve as a text, since this second edition, among many other changes and improvements, contains abundant sections of exercises at the end of each chapter.

The dynamical systems approach to problems in the atmospheric, oceanic and climate sciences goes back to the pioneering papers of E.N. Lorenz, H. Stommel and G. Veronis in the 1960s and, in book form, to Ghil and Childress (1987). As a matter of fact, the preface to this book's first edition clearly acknowledged its debt to a review paper, which finally appeared in 2005, the same year as this second edition (Dijkstra and Ghil 2005), but originally planned by its two co-authors over drinks at the General Assembly of the European Geophysical Society in The Hague in 1996! Having admitted to this obviously favourable bias, I'm now free to review the book at greater length.

Like its first edition, the book starts with a Chapter 1 on the phenomena to be explained: past and present climate variability, and the role of the ocean circulation therein; this chapter has been improved by adding recent estimates of mass and energy fluxes. Chapter 2 deals with the governing equations, vorticity generation and transport, and general stability issues. The classification and brief description of different hydrodynamic instability concepts is an attractive feature of this chapter.

The ideas and methods that form the backbone of the dynamical systems approach and of its applications to the problems at hand are presented in Chapters 3 and 4. Chapter 3 introduces the basic concepts of dynamical systems: mainly invariant sets, such as fixed points and limit cycles, and bifurcations. The latter include not only the classical saddle-node, pitchfork and Hopf bifurcations, but also more "esoteric" bifurcations with respect to two parameters, such as the Devil's staircase, used later in Chapter 7 on the El Niño/Southern Oscillation (ENSO). Greater attention has been given in this edition to homoclinic orbits; since the first edition, these orbits have been shown to play a significant role in the interannual variability of the wind-driven ocean circulation (Simonnet *et al.* 2005), which is treated in Chapter 5.

The author's major research contribution has been to bring to bear the numerical bifurcation methods presented in Chapter 4 to the problems of the ocean circulation and ENSO. All aspects of these methods are carefully and clearly covered, from the principle of pseudo-arclength continuation of Keller (1977) to the subtleties of branch switching and of solving the large linear systems arising from the Jacobians involved.

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The size N of the bifurcation problems that can be solved by this approach has increased from $N = 25$ in the first application of the method in the geosciences (Legras and Ghil 1985) through $N = 1500$ in the first oceanographic application a decade later (Speich *et al.* 1995) to $N = O(10^6)$ in the most recent applications by Dijkstra and co-authors.

Chapters 5–7 form the core of the book; these deal with the wind-driven circulation (WDC), the thermohaline circulation (THC), and ENSO, respectively. Each of these chapters starts with a description of the phenomena to be explained, proceeds through a hierarchy of models that attempt to produce such an explanation with an increasing degree of realism, and concludes with a synthesis of the results and their potential relevance to the phenomena of interest. The systematic approach to climate studies via a hierarchy of models goes back to Schneider and Dickinson (1974) and, more recently, to Ghil and Robertson (2000). Section 5.3.4 here, for instance, proposes a detailed notation for classifying WDC models, according to the governing equations, basin geometry, and number of vertical levels.

Chapter 5 concentrates on the best-known aspects of the WDC in the oceans' mid-latitude basins, the Gulf Stream in the North Atlantic and the Kuroshio in the North Pacific. Quasi-geostrophic (QG) and shallow-water (SW) models of increasing degrees of realism are introduced. While Pedlosky (1996) dealt with the so-called single-gyre problem associated with the larger, subtropical gyre of the WDC, this book, written a few crucial years later, concentrates on the double-gyre problem that encompasses both the subtropical and the smaller, but still significant, subpolar gyre. Unfortunately, the author does not draw the fullest advantage from this broader setting and there is no mention of the Labrador Current or the Oyashio in the otherwise quite helpful index. The chapter's synthesis deals with the issues of multiple paths of the major western boundary currents, as well as with the interannual variability of the near-surface, wind-driven currents.

The focus of Chapter 6 is the THC in the North Atlantic basin, although the introductory sections touch upon the potential role of wind-induced upwelling in other parts of the ocean. This second edition eliminates flux-corrected models and de-emphasizes zonally averaged models, while expanding the discussion of multiple equilibria and of multidecadal variability across a hierarchy of three-dimensional models. The synthesis here includes a good discussion of the various reasons for today's observed THC forming deep water in the subpolar North Atlantic. Arguments for observed multidecadal variability in the Atlantic being due to an oscillatory THC mode are formulated, based on the chapter's hierarchy-of-model results.

In Chapter 7, we move from mainly oceanic phenomena in the mid-latitudes to essentially coupled, ocean-atmosphere phenomena in the Tropical Pacific. The author acknowledges here the inspiration provided by the review papers of Neelin *et al.* (1994, 1998) but provides considerably more detail in derivations and results than possible in the more restrictive setting of journal papers. This is in many ways the most ambitious chapter in the book, as it attempts to answer a fairly large set of questions about both the climatology and variability of ENSO. The hierarchy of models used includes both hybrid and intermediate coupled models (HCMs and ICMs), in which the atmosphere is represented in a less detailed manner than the ocean, given the faster adjustment time of the former. The synthesis here discusses the role of stochastic processes, on time scales shorter than the ENSO modes of 2–3 and 4–5 years (Jiang *et al.* 1995), as well as of global warming and of multidecadal variability, on longer time scales.

The problem sets are quite ambitious and I would like very much to have as many graduate students as possible who can solve them without substantial hints; these are offered quite concisely in the form of further reading suggestions. The presentation of more technical material in the form of clearly identified ''technical boxes'' of 1–2 pages is an interesting way of dealing with such matters. Another nice feature of the book, for the musically inclined, is the presence of mottoes on the title page of each chapter, comprising several measures from works by Spanish and Latin American composers.

The presentation of the book is excellent and includes a nice selection of color plates at the end (reproduced in black and white at the proper location in the text). The number of typos and other minor ''misteaks'' is quite minimal. If there is one fault to find, it might be the lack of material on the predictability of the phenomena studied. While obviously connected to the book's dynamical systems approach, including such material would probably have pushed its length beyond the already quite ample 532 pages.

The book clearly belongs on the shelf or in the departmental library of any serious physical oceanographer and is highly recommended for applied and computational mathematicians becoming interested in the ever more popular climate problems of the day. As outlined in the Preface, it can serve in advanced graduate courses of various flavors, but is not for the faint of heart.

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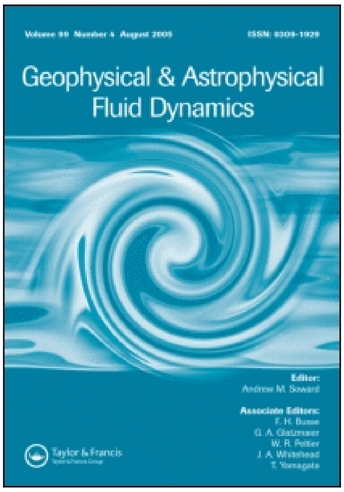

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