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BOOK REVIEWS

The Ocean Circulation Inverse Problem. By C. WUNSCH. Cambridge University Press, 1996. 442 pp. $54.95

This is a personal book, setting out the author's unique views on the culture, challenges, and teaching of physical oceanography. Wunsch ties together a set of problems and solutions to which he has devoted much attention throughout his career, and which have been influential in shaping modern physical oceanography. It is much more than a collected set of papers and offers an accessible introduction to modern methods of combining data with models, but it is by no means a review of all ocean circulation inverse problems. The book covers the interface between the physics of ocean circulation and statistical analysis and inverse methods, and it assumes a solid grounding in both. The emphasis is on results, and the exposition is accordingly terse, so that, as the author notes, supplemental texts would be necessary for students.

The preface and the first chapter are entertaining reading, outlining a personal analysis of the past and future culture of physical oceanography. The portrait of oceanography in the past fits the pattern of a 'postmodern science': since proofs have been impossible, consensus has determined what is 'truth'. The book is intended as part of a transition in oceanography away from unquestioned assumptions ('myths') and sparsely supported scenarios ('story-telling') towards quantitative hypothesis testing using realistic numerical models and global datasets. Although Wunsch mentions that this is a step down in romance, from exploration to Hamiltonian mechanics of information, it represents the maturing of the science.

The author concentrates on discrete methods, arguing that finite-dimensional vector spaces are frequently more accessible than infinite-dimensional ones. This makes the book complementary to a related work by Bennett (1992), which covers a few similar problems and methods, but for continuous systems. The first chapter suggests that the book is meant to be accessible to 'first- and second-year graduate students with only the beginnings of a knowledge of ocean dynamics'. In retrospect, this is true for most of the chapters, but not for Chapter 3, which is a compressed summary of all the linear algebra and statistical tools needed for the inverse problems covered later, including the most advanced data assimilation.

The first chapter includes a clear exposition of the fundamentals of inverse problems using examples which should already be familiar to a graduate student with a background in physics and applied mathematics, showing how these familiar problems turn out to be special cases of a broad theory. The basic terminology ('forward problem', 'inverse problem', 'inverse methods', etc.) is introduced using these examples, and the author's fundamental philosophy of inverse methods is introduced. One main theme is that all problems with noisy data are underdetermined, because the amount of noise contaminating each datum is an unknown, so there are always at least as many unknowns as data. A second theme is that error analysis is paramount, since many solutions are possible, and the uncertainty of the output estimate reflects the often subtle trade-off between solution detail and stability. One might add that these uncertainty calculations depend unfortunately often on sketchy statistical assumptions, and can sometimes be shaded to confirm prejudices.

Wunsch is forthright in noting at the end of the first chapter that the book is neither a monograph on the general circulation nor a basic text on linear algebra and statistics.

It is important to keep this qualification in mind if using it as a graduate text, making sure that students have sufficient background in both dynamics and estimation methods, and keeping other texts near at hand to supplement the concentrated summaries given here.

Chapter 2 discusses theories and observations of the general circulation, introducing the theories first, to be compared and contrasted with the observations in the latter part of the chapter. The treatment covers all necessary results: geostrophy, water masses, Ekman theory, and buoyancy forcing and upwelling. The comparisons of these theories with data are made more interesting by including historical discussions to illustrate how ideas evolved. Of particular note is the history of the original application of these circulation inverse methods: a geostrophically balanced North Atlantic circulation which conserves tracers. Inevitably, some of the data comparisons have been superseded; for example, the most recent, and satisfying, comparisons of Ekman theory with observations are not included.

Chapter 3 covers the 'basic machinery', which includes nearly everything necessary to solve and understand the various inverse problems to be covered, including variational principles and 'adjoint equations'. The emphasis is on least-squares, from parameter estimation through mapping of continuous fields. The author brings together many useful techniques which would otherwise be scattered across several texts. The chapter takes up almost one-third of the book, and distills at least one semester's worth of material from the author's lectures at MIT. Students without a strong background in linear algebra and estimation theory will probably need some guidance to profit fully from the discussion. Much pedagogical care went into the chapter, but (as noted in the introduction) the large amount of information contrasts with the abbreviated treatment in the other chapters, and the ordering of the discussion may be difficult for beginners to follow.

Chapter 3 also covers singular vector analysis, for examining the construction of solutions in detail, and illustrating concepts of rank and null space. The chapter ends by combining observations with a steady-state numerical model, deriving both the Pontryagin and Green's-function approach. Gauss–Markov theory is introduced for producing continuous fields from discrete data (objective mapping), with an excellent discussion of estimation of a spatial mean field.

Chapter 4 brings these methods into action, estimating steady ocean circulation from data and dynamical constraints. This chapter starts with simple examples, gradually adding complications and extra constraints, such as local transport measurements. The discussion is primarily focused on methods and results of the author's, but includes, for example, the work of Fiadeiro and Veronis on reference level choices. There is a section on heat-flux calculations, including a detailed discussion of Bryden & Hall (1980) and Hall & Bryden (1982), showing the link to the inverse approach, and providing perspective on the application of their methods to other sections. The chapter finishes with discussions of the inverse method applied to real datasets, including an inverse solution for the North Atlantic and the beta spiral. This brings out several important practical issues, including averaging choices in climatologies, and assumptions of mixing terms.

Chapter 5 ('Additional Useful Methods') supplements Chapter 4, introducing methods outside the linear least-squares techniques: inequality constraints and non-negative least-squares, linear programming, water mass analysis using EOFs, Kriging, and nonlinear problems. The discussions are much more accessible than the original literature, and provide a clear introduction to methods that sometimes seem magical. The chapter is meant only to make the reader aware that these methods are available, and what they may be good for, but the interested reader will need to look at the suggested supplemental texts.

Chapter 6 anticipates the future of the inverse method in physical oceanography, bringing the data together with sophisticated numerical models and making the most of the information content of both. Most of the mathematical tools come from Chapter 3, and the main novelty is the introduction of time dependence. The chapter covers, in order: the Kalman filter and smoother, the terminal control problem (which gives rise to the equations used in the 'adjoint method' in the physical oceanography literature), error estimates (controllability and observability), and nonlinear models. The discussion is again personalized in that it does not cover (for example) the iterative solution of the 'adjoint method' as it is often implemented, or the discrete analogue of the 'representor method' derived by Bennett (1992) for continuous systems. Assuming that the reader by now has a mastery of linear algebra, the discrete approach makes the results simple extensions of the earlier treatment of steady problems.

In summary, Wunsch provides an introduction both to the philosophy and methods of inverse problems in general, and to the ocean circulation inverse problem in particular, at a level usually accessible to students. He also provides a sourcebook of results and explanations for practitioners. The key is first to read the instructions in the first chapter and then, for those who find the subsequent exposition too terse, to consult supplemental works for the basic geophysical fluid dynamics and estimation theory. Although the author means to supply the tools for a future in which objective methods have supplanted storytelling, he also shows how much information is required for these methods, and how hard it is to obtain reliable estimates of the statistics of interior ocean variability. Even with modern global datasets, the oceans are sufficiently complicated that it will probably be some time before the accountants dominate the raconteurs.

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Gravity Currents in the Environment and the Laboratory (2nd Edn). By J. E. Simpson. Cambridge University Press, 1997. 244 pp. ISBN: 0521 56109 4. £50.

I had the pleasure of writing a foreword to the first edition of this book. Being therefore clearly identifiable as a supporter and admirer of the book I was consequently in two minds about accepting the Editor's invitation to review the second edition. I assume the request was directed as a keen challenge to my objectivity. Since, however, my foreword was written some ten years ago and deals more with the author than with the content of the first edition, and because I have no involvement at all in the preparation of the second, I decided to accept. The reader will however recognize that my review will not be totally objective since, if only to prove my impartiality, it is almost imperative that I should say something of the weakness of the book as well as of its evident strengths. (I guess the Editor knew all this would pass through my mind.)

The strength and attraction of this book is that it illustrates both pictorially and verbally the use of quite simple laboratory experiments to explain the extraordinarily wide range of phenomena which involve gravity or density currents. Perhaps following J. S. Turner's experience in DAMTP, '… I learned very early … not to compete with the awesomely well-trained mathematicians on their own ground' (Turner 1997), Simpson, also in DAMTP, avoids the use of mathematics, using physical arguments wherever possible. Students of the sciences of the natural environment, such as meteorology, oceanography, hydrology, glaciology and geology, will find much of great interest and relevance, and (sadly) many will prefer the avoidance of mathematical argument. Simpson draws attention to the many different environmental phenomena with similar, if not identical, physics. Comparison across this broad range, some phenomena familiar, some less so, helps to give insight into how fundamental processes really work.

There are 18 chapters in the second edition. Ten describe the phenomena, which include thunderstorm outflows and seabreeze fronts, oil slicks and turbidity currents, avalanches and glaciers, lava and mud flows, the spread of gases in mines, and even ventilation of houses and termite mounds. The use of satellite imagery (e.g. of rope clouds) mentioned in the first edition is strengthened, and hydrothermal plumes are now included. Seven of the remaining eight chapters deal mainly with laboratory experiments. These include gravity currents in two-fluid flows, meeting obstacles, colliding, flowing into stratified fluid or over porous media, in two dimensions and in radial collapse, and the effects of viscosity and rotation. There is finally a brief chapter on numerical models. It is a very comprehensive coverage. The book provides a very useful base of reference to the subject.

The format of the second edition is different from the first, published by Ellis Horwood in 1987. For example, the illustrations, all in black and white, are slightly smaller but most have greater sharpness and clarity. Some are, however, less than clear, and in particular the satellite images of an oceanic internal bore and tidal mixing fronts are hardly the best presently available. It must have been tempting to include figures in colour; the dramatic avalanche and the laboratory gravity current on the dust jacket illustrate how much more detail and impact are conveyed by its use. Simpson has taken the opportunity to rearrange some of the chapters which helps the logic of the order of presentation, but has made no serious attempts to revise or clarify the text. This is a pity. In some places it could be improved. The example, undular bores have (p. 7): '… waves, each of which carries energy as it moves away from the front …' (of the bore), whilst (p. 188): '… the undulations … travel upstream at the bore speed'! The text fails to explain that energy may not be carried at the phase speed of the waves. A clear definition of an undular bore is needed. Greater distinction is also required between intrusions and intrusive gravity currents; it is perhaps unlikely that the temperature section across an axial valley vent system, illustrated in figure 10.11, shows an actively advancing current as in the laboratory shadowgraph of figure 13.7. Again (p. 101): 'The satellite photograph … shows interfacial features associated with the internal flow glinting in the sun', is ambiguous. It should be made clear that it is the modulation of surface gravity waves by the near-surface flow field, and the consequent change of light reflection, which makes the pattern of the internal waves apparent. In the same paragraph: 'Since in the Mediterranean, the effect of evaporation exceeds that of river discharge, the water is more saline than that of the Atlantic', should also make some reference to the relatively low precipitation over the sea. The text, although easy to read, is not as sharp, or the definitions as precise, as might be desirable for undergraduate teaching. Moreover, few of the graphs showing measured values have error estimates ascribed, and I should have liked to have seen more detail (e.g.

parameter ranges) given in the figure captions, particularly of laboratory experiments where space was often available, to emphasize the precision available and relevance to natural phenomena with comparable parameters.

But in comparison with the overall achievement, these are minor quibbles. In the final analysis, and in the spirit of the times, one has to be impressed by the evident cost effectiveness of the investment in the science and laboratory experiments which Simpson so graphically describes. The applications are far broader than the fairly small number of scientists involved could have perceived in advance, and they are of demonstrable value, for example to pollution and fire control and domestic ventilation. It is a growing field of research; there are already other important types of gravity flow being recognized and investigated by laboratory studies (e.g. Poulliguen, Delour & Savage 1997). I look forward to reading about them in a third edition.

My abiding impression is of a book which conveys the joy of scientific enquiry into the workings of the environment. It expresses the author's desire to inform and excite the reader. I recall especially the door of a warm house held open for a few seconds on a cold day (p. 2). 'This open door experiment is recommended to the reader, who may care to use soap bubbles… to detect the sudden onset of the gravity current after the door has been opened.' Try it!

I, likewise, recommend this book to the reader. It is an improvement on the first edition. But would whoever has borrowed and *forgotten to return* my copy of the first edition please return it?

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