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BOOK REVIEW

Ocean Modelling and Parameterization. By E. P. CHASSIGNET & J. VERRON. NATO Science Series C, Vol. 516, Kluwer, 1998. 500 pp. ISBN 0-7923-5228-9. NLG 400, $216, £136.

A French ski resort seems an unlikely place for an oceanographic meeting, but this one was evidently successful. The volume is the proceedings of a NATO Advanced Study Institute held in Les Houches in January 1998, with the first plaudits going to the editors, authors and publishers for bringing out the volume later in the same year.

The theme of the volume is the need for numerical models of ocean circulation, required for practical reasons including those associated with climate change, to represent the effects of processes which cannot be resolved explicitly. The magnitude of the problem is pointed out by James McWilliams in an excellent, comprehensive, opening article which sets the stage for later more detailed chapters; oceanic motions occur all the way down to time and space scales of the order of a second and a millimetre respectively, while ocean models used for climate research must be integrable for about ten thousand years in ocean basins many thousands of kilometres across and several kilometres deep. Dealing numerically with the more than 10^{40} degrees of freedom is inconceivable.

The range of physical processes needing to be parameterized is large, including air–sea interaction which forces the ocean, turbulent processes in the upper boundary layer of the ocean and in boundary layers on the sea floor, and mixing processes in the stratified ocean interior driven by internal waves or the differential diffusion of heat and salt. Even resolving some intense currents and energetic 'mesoscale' eddies on the scale of tens of kilometres can only be achieved in models of single ocean basins integrated for decades. At present (though this will change with an increase in computer power by a factor of about a thousand) global models integrated for thousands of years must parameterize these eddies as well, a topic addressed in several chapters.

The volume is based on lectures given to graduate students and young scientists attending the ASI. It will appeal to these and to a wider audience of oceanographers seeking up-to-date reviews of the different topics. Maybe it will even attract into the field other fluid dynamicists and physicists seeking intellectual challenge combined with social relevance! While a few articles are by authors who have recently written for *Annual Review of Fluid Mechanics*, the overlap is not substantial.

Following the opening article by McWilliams, Bernard Barnier describes what we know about fluxes of momentum, heat and water across the air–sea interface and the types of boundary conditions used to drive ocean models or to connect models of the ocean and atmosphere; specifying the heat flux may drive the surface temperature of an inaccurate model ocean to wrong values, whereas relaxing to a chosen temperature may imply erroneous fluxes. Historically, semi-empirical formulae determine the fluxes from routine observations by merchant ships of variables such as wind speed and sea surface temperature. Improved global coverage is now coming from observations from satellites and from 'reanalyses' of the output of numerical weather forecasting models. The difficulties and inaccuracies of all these approaches are emphasized by integrating over the globe and finding, for example, significant non-zero average heat input to the oceans.

It is this uncertainty in surface fluxes which leads William Large, in his wide-ranging chapter on the important and often turbulent surface boundary layer of the ocean, to suggest that the simple models required for incorporation into global ocean models are best tested against large-eddy simulations (LES) rather than against oceanic observations. This approach is indeed useful in showing the inadequacies of some common turbulence closure schemes, but is dangerous if both the simple models and the LES omit important physical processes such as Langmuir circulation (helical circulation cells in the surface layer) or the effect of internal waves at the base of the mixing layer.

The following article by James Price on the vertical structure of horizontal velocity in the mixing region of the upper ocean emphasizes the importance of the diurnal cycle in stratification (perhaps a warning for large-scale models with larger time steps than a few hours). In a thoughtful concluding section, Price adds *falsifiability* to the attributes of accuracy, consistency, simplicity, scope and fruitfulness required of a model or parameterization. In another nice article, with Jiayan Yang, Price discusses how marginal sea overflows of dense water may be represented by sidewall boundary conditions. Their scheme relies on hydraulic control of the exchange followed by entrainment into a sinking density current. Focusing on the Mediterranean overflow, they show how it has a major impact in a simple model of the Atlantic Ocean. They also show how the plausible entrainment scheme they use implies that an increase of evaporation minus precipitation in the Mediterranean will lead to an increase in the transport of the density current when it settles out in the Atlantic, but not its density.

A descending density current on a slope could, of course, be included explicitly in an ocean circulation model, but, as discussed by Aike Beckman, this introduces numerical as well as fluid dynamical problems. For a start, a rectangular coordinate grid will represent the slope as a staircase, with unrealistic flows resulting. Beckman discusses different approaches, and reviews other aspects of bottom boundary layer dynamics. These include the asymmetry between upwelling and downwelling Ekman layers beneath an along-slope current, various ways in which oscillatory forcing can lead to rectified flows, and the profound influence of canyons. He illustrates these effects with useful idealized numerical models, with references to papers which discuss the basic physics in more detail. One of the major difficulties in dealing with the effects of complex bottom topography in the ocean is its inhomogeneity; any particular location chosen for field studies is almost bound to be atypical.

Moving to the ocean interior, John Toole focuses on diapycnal (across mean density surfaces) mixing of scalars such as temperature, salinity and tracers. The overturning circulation of the oceans, driven by different surface buoyancy fluxes in tropical and polar regions, is known to be sensitive to the diapycnal mixing rate, so that even concern with changing climate on the global scale leads to an emphasis on studying phenomena at the scale of millimetres. Remarkable progress in the last few decades has produced a framework which ties together inferences from observed large-scale density patterns, direct and technically impressive measurements of turbulence (with a typical value of ϵ being 10^{-9} W kg^{-1}, equivalent to “one hairdryer per cubic kilometre”!), fascinating results of tracer release experiments, and theoretical expectations from internal wave theory. Much of the ocean seems to be only weakly mixed, with flow over rough topography being implicated in regions that do display enhanced internal wave energy and mixing. It appears that this flow can be either eddies, as beneath the Antarctic Circumpolar Current, or barotropic tides, as in the deep Brazil Basin. The latter possibility, illustrating the role of the Moon in the Earth's climate, is particularly intriguing.

Raymond Schmitt presents the case for the role of double-diffusive processes in ocean mixing. Some regions of the ocean display staircase profiles of temperature and salinity. These are clearly related to salt fingers in the tropical ocean (with warm, salty water above colder, fresher water) and to the diffusive regime (with cold, fresher water above warmer, saltier water) in some polar regions. A wonderful recent study by Schmitt and Louis St. Laurent, only briefly cited here, has shown convincing evidence for the importance of intermittent salt fingering even in a region of the North Atlantic without staircases. Schmitt also discusses the role of double-diffusive intrusions in lateral mixing, and, in another article, Kelvin Richards argues for the dynamical importance of interleaving features to the equatorial currents, and hence to large-scale phenomena such as El Niño.

Convection sometimes occurs to great depth (2 km or more) in the ocean and is then influenced by the Earth's rotation. The rich multi-scale fluid dynamics that then occurs, and its parameterization, are reviewed in a concise article by Uwe Send and Rolf Käse, with a balanced discussion of the physics, observations, numerical simulation and consequences.

Several chapters discuss the parameterization of mesoscale eddies, as might be generated by baroclinic instability of large-scale currents. Even deciding on the correct kinematic description is a challenge, as shown by Trevor McDougall's careful analysis of the subtleties arising from the differences in averaging in height or density coordinates. He shows that the framework that has come to be used for the adiabatic flattening of mean density surfaces (or smoothing of potential vorticity) is appropriate if correctly matched to boundaries. The details of the parameterization are discussed in more detail by Peter Killworth. His passing, and critically important, remark on the need to avoid feeding momentum into the system could usefully have been amplified as reminder to would-be parameterizers to heed basic constraints.

An alternative approach to parameterizing the effects of mesoscale eddies using profound ideas of statistical mechanics is reviewed by Joël Sommeria and by Alberto Alvarez and Joaquin Tintoré, though it seems that, in the presence of forcing and dissipation, it is not easy to decide how quickly the ocean might relax to some statistical equilibrium even if such a state is a useful idea. It does not really seem possible, to this reviewer anyway, to bypass completely a more reductionist approach to the precise physics of, say, eddy interaction with a frictional and bumpy sloping lateral boundary, even if clues are provided by statistical tendencies.

It is interesting, in fact, that, while most of the articles on the parameterization of small-scale processes are firmly based on detailed observations of the processes themselves, other parameterizations rely for their acceptability on circumstantial evidence for their success, i.e. that model output is rendered more acceptable. As Eric Kunze has pointed out, this is reminiscent of the success of Ptolemy's epicycles in pre-Copernican accounts of planetary orbits, and is at the very least risky if we aspire to predictive capability for a changing ocean. We must derive reliable and practical parameterization formulae (not just present values) for unresolved processes, and these must be checked against adequate observations of the processes themselves. Such an approach may, of course, be aided by high-resolution numerical models, as discussed earlier, with LES playing a particularly valuable role. This technique, and some geophysical applications, are nicely reviewed in this volume by Oliver Métais.

Other chapters towards the end of this wide-ranging book include a review by Geir Evensen *et al.* of the mathematical foundations of parameter estimation in dynamical models and an introduction by Thierry Fichefet *et al.* to the rich physics of sea ice and its importance for the global as well as local ocean. Both topics could justify more attention, or even books of their own.

The complexity of ocean modelling does not arise solely from the difficulties of parameterizing unresolved processes, but also has significant technical challenges in the devising of suitable numerical schemes. These are discussed in McWilliams' opening chapter, while Rainer Bleck comments on the limited 'gene pool' of mostly fixed-grid numerical models in his chapter on the Miami model which uses density as a coordinate. He gives a useful account of the difficulties, as well as advantages, of this approach, and presents some results for a near-global domain.

While some readers might find some areas of ocean modelling and parameterization, such as inverse modelling, to be inadequately represented, the coverage is excellent for a single volume and the general standard of the articles is unusually high, with comprehensive and up-to-date references to other literature. It is highly recommended, though a new student or an outsider (and insiders too) might be bewildered by the richness and complexity of the field, with its intertwining of so many phenomena with scales from millimetres to megametres. A newcomer might seek a discussion of the sensitivity of the global models to the parameterizations of different processes, that might help us focus on key processes and reduce our efforts on those that do not seem critical. Maybe the answer is still that we do not know; models which are realistic enough to provide good guidance are generally too time-consuming computationally to allow numerous runs for sensitivity tests. All of the physical processes discussed in the book need more attention, so take your pick!

The publishers have produced a fine volume in an established and worthwhile series and probably deserve any profit they make out of the high price of the book. It does seem a pity, though, that, as with many scientific journals, such profits are going to faceless shareholders rather than to our professional scientific societies.

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