Foreword

Ocean models embody a wide range of oceanic knowledge. There are issues concerned with the numerical representation of processes and of conservation equations on different finite spatial grids. There is the need to respect the smallness of diapycnal mixing and particularly not to allow horizontal diffusion to cause false diapycnal density fluxes. Do the model variables represent the Eulerian mean quantities, or are they the result of some other type of averaging process? Is the Boussinesq approximation really made in a model or is this simply a matter of interpretation? Should the diffusion tensor be symmetric, and if not, what is the physical justification for the skew component of diffusion? Where this book really shines is that rather than simply presenting workable recipes to each of these issues (and many more), the underlying physics is expertly described, usually first in differential equations and then in the discrete representation on the numerical grid. Because of this clarity and attention to detail, the book will appeal not only to ocean modellers but to a much broader spectrum of oceanographers.

As a branch of fluid dynamics, distinguishing features of the ocean are its rather strong stratification and the smallness of its diapycnal mixing processes. For climate purposes the seemingly small diapycnal mixing processes are very important yet their faithful representation in models has been a formidable obstacle. While we have known the importance of diapycnal processes in controlling the thermohaline ocean circulation for some decades, it is only in the past decade that we have learned how to control the amount of diapycnal mixing in z-coordinate ocean models, and then only at coarse resolution. This goal has been achieved by clear thinking about the conservation of properties in ocean models, particularly the way in which diffusion is imposed. With this book we now have the relevant averaged model equations derived carefully from first principles, and the subtleties associated with interpreting averaged quantities should no longer need to be glossed over.

The present book can be described as providing comprehensive treatment of the following subjects (i) deriving the ocean's conservation equations from first principles, (ii) carefully considering the issues that arise when these equations are averaged, (iii) describing the many numerical procedures that are used to integrate the averaged equations forward in time, and (iv) providing the tensorial underpinning so that the equations can be transformed consistently onto different grids on the spherical earth. This book clearly fills a void in the oceanographic literature. The usual development skips the first two topics and treats the averaged equations as given (which begs the question of what the model variables might represent), while the subject of tensor analysis is familiar to too few oceanographers, especially given the range of grids that are now in common use in ocean models.

Two key advances in ocean modelling over the past decade are the rotation of the (symmetric) diffusion tensor to be aligned with respect to the local neutrally buoyant directions, and the discovery and implementation of the so-called Gent-McWilliams mixing scheme for mesoscale eddies. These two topics are expertly described in this book and together they occupy one third of its pages. This is entirely appropriate since both these advances have been crucial for controlling the false diapycnal mixing that otherwise occurs across sloping density surfaces in low-resolution z-coordinate models. Both advances have been hard-won by oceanographers. The solution of the first involved the subtle thermobaric nature of the equation of state of seawater, while the second relies on the action of mesoscale eddies to release potential energy, with the mixing scheme being best viewed as either an extra quasi-Stokes advection or alternatively as an additional amount of diffusion which happens to be skew diffusion. These issues are subtle and are not covered in existing oceanographic texts, and yet they have been at the root of the biggest improvements in ocean climate modelling in more than twenty years.

This book truly lives up to its title. By delving into the physical basis for the choices made in present ocean models, the book does indeed establish the fundamental basis of ocean models. Where the issues are not yet agreed on by the oceanographic community, the book takes on the character of a review of these research issues. The book will prove invaluable to ocean modellers and to those concerned with how fundamental ocean physics is represented in ocean models.

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