

Preface

This book is directed primarily to beginning graduate students in physical oceanography and to working scientists in allied fields seeking some understanding of what the science teaches us about the behavior of the fluid ocean. My main motivation has been to provide an introduction conveying what the observational revolution of the past thirty years has taught us—a revolution that is primarily about the ocean as a time-varying system. The field does have a number of good textbooks outlining—primarily—the essential theoretical side of the subject and having varying breadth and depth (Gill, 1982; Pedlosky, 1996; Vallis 2006; Huang, 2010; Olbers, Willebrand, and Eden, 2012). For a graduate student, or a scientist trying to understand oceanic biology or chemistry or their role in climate, however, no adequate introduction exists depicting the qualitative behavior of the fluid as now perceived—beyond the exhortation to read hundreds of sometimes difficult and contradictory papers. Continued dependence on an outmoded description of the fluid ocean has become an obstacle to progress.

The attraction of writing a book that is primarily about the theory is plain: the author can write something like: “Assume the motions have periods between a and b , and length scales between c and d . Let the dynamics be linear, hydrostatic, and have a flat bottom, etc. The governing equations are then” A complete, sometimes, elegant deductive product then follows. In contrast, understanding observations involves all of that theory, and a great deal more: Do the observed motions actually lie between a , b and c , d ? Is the seafloor sufficiently simple that the real topography can be ignored? Are the motions demonstrably linear and hydrostatic? How much noise is there in the data (some always is)? Is it negligible or dominant? Most likely the beautiful theory explains some, but not all, of what is observed. How does one distinguish them? What about the unexplained part?

What I have tried to do here is to sketch the major elements of modern physical oceanography, with an emphasis on observations and what they seem to say. Physical oceanography is a subdiscipline of fluid dynamics, and its history shows the need for a strong and continuous coupling between theory and observation (experiment). The equations of fluid motion are so rich in possible solutions that theory without observations tends to diverge from realism; conversely observations are uninterpretable without a strong theoretical framework for their analysis. Observing the ocean is remarkably difficult: it is corrosive, opaque to electromagnetic radiation, produces biological fouling of instruments, imposes pressures over 600 atmospheres, is extremely large and time varying, and near the surface imposes rapid and

strong mechanical cycling (wave forces). Existing understanding and depiction of the fluid ocean and its climate implications are perceived through the distorting lens of a very specific set of practical observations. A long list of important oceanic phenomena are known that previously existing theory could have predicted but didn't¹ and for which a theory was put in place only after the observations became available. Nonetheless, the narrative is simpler with a theoretical framework for context.

One of the more troubling developments in physical oceanography over the last thirty years has been the ever-greater separation of scientists from the data they are scrutinizing. Years ago, there was the silly mantra that “real oceanographers make their own observations,” and it was used to both separate the club of seagoing scientists from their more theoretically inclined colleagues and disparage meteorologists who, as they were faced with a global system, had come to rely heavily on government-operated weather-observing systems. Of course, oceanography encountered climate and became global, and the science became much more sophisticated. The result has been that proportionally ever-fewer oceanographers still make their own observations and the subject has come to much more closely resemble the situation in meteorology. This development has two consequences: we know enormously more about the ocean than the individual scientists of thirty years ago could even dream of, and we have a new generation of scientists with little understanding of how complex observations can be and the consequent possibilities for misinterpretation.

With the rise of computers, the maturing of dynamical systems theory, and other powerful theoretical tools, it is easy to forget that physical oceanography and climate remain fundamentally observational subjects. Modelers spend much time comparing their results but sometimes lose sight of the idea that comparison to observations is the test of a model's skill—not whether it reproduces the same results as all the other models.

In recent years new elements have arisen to complicate the problem of distinguishing scientific fact from mere hypothesis or rationalization or description of untested model results. Much ocean physics, as it influences the climate system, is “slow,” spanning decades and centuries. Direct observations over long time periods are extremely rare. With rising interest in climate change and the consequent growth of a tabloid science (epitomized by *Nature*, *Science*, their would-be competitors, and media-camp followers), much speculative storytelling, far outstripping the observational record, has come to dominate, and even corrupt, many aspects of the science.

Mathematics is the natural language of fluid dynamics, and its employment in oceanography and climate is essential. Writing a book about these subjects without mathematics is somewhat like writing one about Chinese poetry for readers who cannot read that language. Nonetheless, I have tried to keep the mathematics to a minimum, mainly describing what it says rather than deriving it. What theory is presented here is intended primarily to make the observations intelligible, to provide insight, and not to be rigorous or particularly accurate.

What is *not* known is emphasized relative to what is essentially “fact.” Most textbooks tell the reader what is thought to be known and true. But the unknowns and the puzzles are much more interesting than what everyone agrees on. In any case, a serious student of ocean

¹Examples where the theory was available but not applied until the right observations appeared includes the existence of the equatorial countercurrent and undercurrents; fine and microstructure in the assumed smooth temperature and salinity profiles; the intense high-latitude barotropic variability; the near-universal internal wave spectrum; the ubiquitous internal tide, etc.

physics should read this book alongside one of the more theoretical textbooks mentioned above. Whether the presentation here falls between the two stools of too little or too much theoretical framework will be judged by the reader.

Readers will also notice many omissions and nonuniformities of coverage. This subject is now so large that a comprehensive coverage by a single author may no longer be possible. Among many other interesting, important topics, only tangential attention is paid to the coastal ocean: the mixed-layer, marginal seas including the Arctic, Mediterranean, and Caribbean, the Southern Ocean, sea ice or high latitudes generally, and near-equatorial dynamics. Paleoceanography is discussed only where it provides some useful context for modern change. In the last analysis, the material reflects mainly my own interests over the past fifty plus years and thus is perhaps best regarded as a personal statement as to what has seemed most intriguing.

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