CHAPTER 1

Introduction

Study of the ocean circulation is a problem in fluid dynamics. Traditionally, however, descriptions of the oceanic general circulation have begun with pictures of the large-scale temperature, salt, and oxygen and other chemical tracer properties of the deep sea. This approach rests on good historical and logical grounds: until recent times, the only properties measurable on a global basis were these scalar "tracers." Furthermore, their overall distributions have proved remarkably stable in time, and in turn that has made it possible to combine data over many decades to achieve global pictures from shipboard measurements.

In contrast, this book begins with an emphasis on the time-varying flow field as observed from a variety of modern instruments. The more traditional discussion of the time-average properties of velocity, temperature, and salinity is postponed. These latter are to be set into a context more relevant to an observer coping with a changing velocity field. Conventional pictures showing the large-scale temperature, salinity, and related distributions led to the concept of the ocean circulation as a quasi-geological phenomenon, with little or no change occurring either spatially or temporally. In the process, sometimes it was forgotten that the ocean is a fluid, and not a series of slabs sliding over one another unrelated to the equations of physics. As long as the study of the circulation was primarily of interest to academic physical oceanographers, the consequences of this distortion were of little practical consequence. Today, however, the circulation is widely regarded as an essential element in the understanding of the climate system and as a dominant factor in such politically charged phenomena as global change, sea level, and biological variations. But misconceptions concerning the very character of the circulation generate unrealistic programs for climate forecasting, observing the ocean, interpreting the record of past climate, and a host of related practical issues such as the management of fish populations.[1]

The term "oceanography" historically denoted a descriptive science, paralleling "geography"—with its heavy emphasis on terrain, crops, economic assets, regional particulars,

[1] A conspicuous example is the folklore postulating that the Gulf Stream can "turn off."

etc.[2] That traditional beginning is today recalled in "descriptive oceanography," to distinguish it from the wider subject employing the dynamical equations with much mathematics. Every region, depth, season, and probably year in the ocean is distinct from all others. A very large and growing literature exists depicting the elements and eccentricities of many geographical regions. Most of that subject is omitted here—rather, the focus is on those elements that can be understood in a more global context, because of their generality or exceptionality. But the reader must understand that no clear distinction exists between the regional- and global-scale descriptions, be it verbal or mathematical, and too much should not be made of the division.

Physical oceanography can no longer be encompassed in a single manageable volume, and I make no claim to being expert in more than a fraction of it. References are provided that should permit a reader interested in pursuing a subject in greater depth to do so by starting with the various papers and books cited. No serious attempt has been made to provide a historically correct attribution to the originator of an idea, and when a reference is given, unless explicitly stated otherwise no implication is intended that it refers either to the first, or even the most important, discussion. These references might be regarded as the analog of navigational beacons: they are neither the channel nor a shoal, but indicators of where those are to be found. Parts of the field are undergoing rapid development as I write, with new papers appearing weekly. Obsolescence in a book must be expected, with the navigational markers being more like bread crumbs in a world of birds and rainfall. Modern electronic search tools now permit easy access to both the earlier and later literature. Occasionally, a historical sketch is provided where it enables a better understanding of some concept.

My intention has been to make the book self-contained if not comprehensive; specific references to the fluid dynamics literature (e.g., Tritton, 1988; Kundu and Cohen, 2008) and to the more theoretical textbooks noted in the preface are provided so that the reader can locate a fuller derivation, a wider discussion, or illuminating applications. Much useful material can be found in the recent compendium of Siedler et al. (2013); like most multiauthor collections (there more than seventy), it is neither easily digested nor without internal contradictions.

By employing "boxed" discussions and appendices, I have tried to make the basic concepts, borrowed from a wide variety of subfields, at least heuristically sensible and have provided references for anyone who would like to know more. Thus sketches are provided of the singular value decomposition, the Radon transform, Bessel functions, etc. Within the text, in many cases, results are simply stated; in others, where the derivation is particularly easy or interesting or illuminating, it is at least sketched. I do not claim to have been consistent. The ocean and climate are nonlinear systems, a property one must always remember. Nonetheless, this book leans almost completely on linear mathematics on the grounds that most intuition and insight are built that way, and as has been found across the sciences, linear analyses often have skills well beyond their formal domain of validity.

Only elementary statistical methods are employed: sample means and variances, spectral estimates, etc.—just enough to get by on, given the existence of useful handbooks dealing with a variety of powerful techniques. Historically, oceanography and climate have almost never raised issues in which very fussy statistical tests were required—if apparent signals were so weak as to require powerful tests, they usually proved unimportant compared to much more

[2]Soviet Union scientists, in particular, made an attempt to substitute the more logical "oceanology" as the correct parallel terminology to the scientific subjects of biology, geology, etc., but the label was never accepted in the West; see Hall, 1955; Carruthers, 1955.

conspicuous, and still unexplained, signals. Many statistical methods exist for extracting weak signals from noise. In practice, however, oceanographic and climate measurements are usually subject to such basic problems as calibration drifts, sampling distribution changes, unknown external contributors, small sample size, and poorly understood statistical characteristics (e.g., they are never truly Gaussian, never truly statistically stationary) such that results dependent upon the use of elaborate methodologies should continue to be regarded as very tentative unless subjected to careful study of their sensitivity to the underlying assumptions. Common sense is useful. For example, if a process is obviously non-Gaussian, don't use ordinary statistical tests that assume it is normally distributed. The future belongs to the Bayesians, but as these methods have not yet broadly been used in the ocean literature, no explicit use of them is included.

Organization of a book such as this presents a conundrum. Discussion of instruments and measurements is almost impossible without some understanding of how the data are used—and that requires some theoretical background. But much of the theory is not very compelling without an understanding of what is measurable. Ocean variability is not interpretable without knowledge of the time-mean circulation—suitably defined—and that in turn is determined in part by the variability. A linear narrative is thus not possible—leading to a need for parallel and iterative discussions; the reader can expect to jump around among chapters. The book opens with a description of measurement methods, followed by a qualitative description of both the time mean and variability. A chapter sketching the variability theories leads to one discussing observations. Later chapters then turn attention to the more traditional ideas about the time-mean circulation.

TERMINOLOGY

Many scientists are impatient with discussions of terminology ("It's just semantics"). But precise language is an essential shorthand. Furthermore, unnecessary jargon is a serious obstacle to the exchange of ideas within the field, and much more so with neighboring disciplines. Muddled thinking is often most immediately apparent in the choice of language. Anyone who has worked in oceanography for awhile will have had the experience of reading through a paper or sitting through a talk before recognizing that one's growing bewilderment and confusion resulted from some careless or unorthodox use of the label for a concept. Examples abound. For example the term "barotropic velocity" has at least six different incompatible definitions, and a very large amount of unnecessary confusion has ensued by their sometimes unthinking, undefined use. A number of examples are discussed in Appendix C.

AN OPEN MIND

Most textbooks are directed at explaining to their readers the facts of the subject. One interpretation of the central role of science is in its overthrowing what "everyone knows." In the grand scheme of things, everyone once knew that the Sun orbitted around the Earth, that the geological record was the result of the Noachian Flood, and that species were immutable. Many scientists share the human need for near-religious faith in what they "know" about the world, to the point that dogmatism becomes a major obstacle to understanding. In physical oceanography, as with all fields, many examples exist of somewhat plausible ideas being converted into a kind of faith-based science. The advice by Chamberlin (1890) to *always* maintain multiple scientific hypotheses remains most sensible.