PHYSICAL OCEANOGRAPHY: DEVELOPMENTS SINCE 1950

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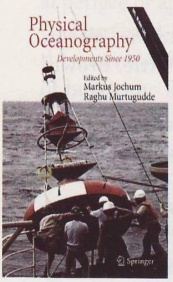
Much has been written about the development of meteorology since the early days of the Bergen School, but to my knowledge there has been little or nothing written about the more modern advances in oceanography [the reader is referred to Deacon (1971) for a treatment of early developments]. My first reaction upon picking up *Physical Oceanography: Developments Since 1950* was one of awe. Here were the giants I looked up to as a graduate student, penning their thoughts—memoirs, actually—on diverse aspects of the accelerated developments in oceanography following the stimulus of World War II. Thirteen chapters and thirteen pioneers of the field: Bruce Warren, Francis Bretheron, Kirk Bryan, Russ Davis, J. S. Godfrey, Mike McPhaden, Dennis Moore, Walter Munk, Joe Pedlosky, George Philander, Joe Reid, Carl Wunsch, and to cap it all off, a probing interview with Klaus Wyrtki. What we're talking about, euphemistically, is the horse's mouth. By and large, this volume is not a redundant collection of mostly overlapping narratives, because each author is unique in his contribution to the science and tells his story from that unique perspective—and to a great extent, about his own particular patches in the quilt of modern oceanography. Chapters intersect at critical junctures, such as the Mid-Ocean Dynamics Experiment (MODE), but always with different perspectives that lend depth and insight.



Although the emphasis in the book is on modern developments, the earlier history is not totally neglected. Warren sets the tone in the first chapter by giving us glimpses of how ocean circulation was viewed as early as Aristotle, and how that knowledge evolved up to World War II, first as geostrophic calculations based on property measurements, then the inferences made from water mass analysis, and finally the evolution of ocean physics itself. Bretherton picks up the baton by relating his experiences during the MODE experiment in the early 1970s. While MODE was a classic attempt to test concepts of geophysical fluid dynamics in a real-world exercise, Bretherton lets us view it as a key stage in the evolution of oceanography from a collection of disparate mavericks, each doing his or her thing for the collaborative group enterprise as we know it today. We then explore the early development of numerical ocean modeling (1960–90) as related by Kirk Bryan, with insightful descriptions of the roles played by the likes of L. F. Richardson, Joe Smagorinsky, Michael Cox, Adrian Gill, Claes Rooth, and George Philander, to mention only a few.

Successive chapters may be summarized more succinctly, but each contains similar interesting granularity. Davis traces the evolution of ocean-observing systems over 40 years—the successes and failures and the lessons learned. Godfrey looks at the progress in estimating heat fluxes and how they have been used to validate greenhouse warming models. McPhaden relates the evolution of El Niño–Southern Oscillation (ENSO) monitoring that culminated with the Tropical Atmosphere Ocean array and the multifaceted observing system of today. Moore examines progress in equatorial oceanography from an autobiographical perspective—including his work on ocean wave theory that has had such an impact on modeling and ENSO research. Munk gives an account of ocean acoustics leading to the application of acoustic tomography on the planetary scale. Pedlosky traces the history of thermocline theory from a personal perspective. Reid looks at the advances made in hydrography to understand circulation and water masses, and tries to understand why errors were initially made and answers went undetected. Finally, Wunsch gives his own perspective on the origins, planning, and execution of the World Ocean Circulation Experiment (WOCE).

I have saved two chapters for special treatment, because both compelled me to use my highlighter. In "Sextant to Satellite," George Philander ruminates about the rapid changes in technology, such as navigation, and their impact on oceanography. In the process of doing so, he illustrates how oceanography was transformed—in the United States, at least—from a "small science" endeavor to a "big science." As he has done throughout his career, he publicly muses about outgrowing issues that others will only discuss at conference mixers. He identifies and discusses trends, such as 1) the fact that research priorities once were determined at the level of researchers doing the work ("bottom up"), while managers and bureaucrats now hold sway to a much greater extent ("top down"); 2) the increasing imbalance between basic research (diminishing) and applied research (increasing); and 3) the

increasing role of politics and policy at all levels. Although the chapter is only 10 pages long, it merits two or three readings and considerable introspection.

In the last chapter, Klaus Wyrtki is interviewed by three of his friends and colleagues from Germany (Hans von Storch, Jürgen Sündermann, and Lorenz Magaard). This is an appropriate departure in format because Professor Wyrtki is as much a subject for reminiscence as a knowledgeable source. The interview must have been transcribed word-for-word from a recording because every nuance of Klaus's second-tongue English is faithfully preserved—including translated lapses into German—and the reading evokes images from my own past encounters with him. The interview starts with his early days as a student in Germany following World War II and explores his career forward through some of the most significant advances in oceanography, to wit: the identification and dynamical explanation of the Indonesian Throughflow, three-dimensional volume transport balances and the relation between basin scale upwelling and vertical diffusion, and the relation of Indian Ocean circulation to the Asian monsoon. But most revealing is how his earlier experiences with seiching in the Baltic and thermocline displacements in the Indian Ocean led into his seminal work on ENSO. The interviewers deftly lead Wyrtki into reflections on how his scientific thinking evolved, until during the ENSO phase he was able to readily integrate previously learned, elemental relationships into a conceptual whole. It's a fascinating insight into how the creative process works in science. There are, moreover, many comments in a more philosophical vein that have currency now—for example, on the role of serendipity in research. On science and the media, Wyrtki muses "We are hearing predictions that are being blown up by the press and of scientists making statements, which they cannot defend in the long run. This is dangerous for science." I can't reveal the rest; something must be reserved for the curious reader.

This book is an eclectic collection of science memoirs, which by its nature is meandering and incomplete when viewed as history. Yet, it is unique in its approach and has something for everyone. I recommend it highly for students and young scientists, both for historical curiosity and because it will help them to assimilate past lessons learned into their own careers. But I also recommend it for older scientists who have lived through many of the developments of the last half-century, and who may wish to reflect on their own careers in the context of the book.

—David B. Enfield

David Enfield is a research oceanographer at NOAA's Atlantic Oceanographic and Meteorological Laboratory in Miami, Florida. He conducts research on large-scale ocean–atmosphere interactions in the Pacific and Atlantic Ocean basins and their relationship to global climate.

REFERENCES

Deacon, M., 1971: *Scientists and the Sea 1650–1900: A study of Marine Science.* Academic Press, 445 pp.