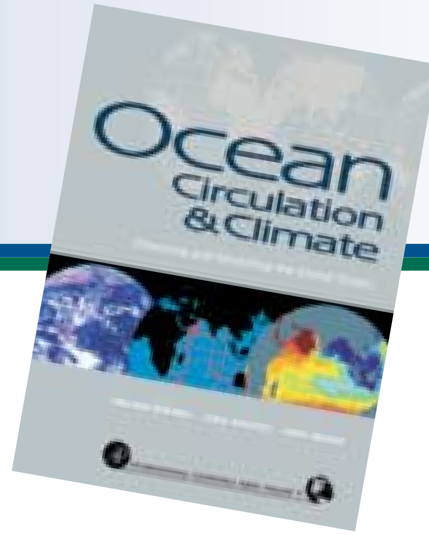
Book Reviews



Ocean Circulation and Climate: Observing and Modelling the Global Ocean

Edited by
Gerold Siedler, John Church and John Gould
Academic Press, AIP International Geophysics Series, Volume 77,
715 pages, ISBN 0-12-261351-7

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This book encapsulates the enormous progress made in the 1990s in understanding the ocean circulation and the role of the ocean in climate change. The basis for much of the knowledge used in the book is the World Ocean Circulation Experiment. (WOCE).

WOCE began in the late 1970s as part of the ocean component of the World Climate Research Programme (WCRP), which had the goal of understanding and predicting climate variability and climate change, including human influence on climate. In the 1980s a full observational and modeling program for WOCE was developed. From 1990 to 1997 the WOCE observational program was undertaken, which involved an international survey of most of the ocean. What resulted from the survey was the world's largest data set of ocean currents and physical and chemical ocean properties.

In 1998, at the end of the fieldwork program, a conference called "Ocean Circulation and Climate" was held in Halifax, Canada. This meeting heralded the beginning of the Analysis, Interpretation, Modelling and Synthesis (AIMS) phase of WOCE, which had the goal of investigating the role of the ocean in climate. Following the conference, Gerold Siedler, John Church and John Gould (who subsequently became the editors of this book) asked the plenary speakers and other distinguished scientists to contribute to this book. Let me say that the many contributors responded with both enthusiasm and thoughtfulness in their write-ups for the book!

As a result, the reader should be pleased that the book is not a "heavy-handed" (meant literally—this almost coffee table-size book weighs a lot with its 715 pages!) summary of WOCE's observational and analytical achievements. Instead the book takes the reader all the way from gaining a historical and scientific background before WOCE (with well-chosen color plates to accompany the text, which, by the way, would make good classroom presentation material), to identifying the outstanding questions and uncertainties still remaining after WOCE.

The organization of the book into seven well-chosen sections (rather than into 33 imposing chapters) lures the reader into reading a thematic section of several articles at any one time, rather than the whole book. The first thematic section, called the Ocean and Climate, by Hartmut Grassl sets the stage for the book. Grassl discusses why it is important to understand better the role of the ocean in climate change. Allyn Clarke, John Church and John Gould then use a global perspective to identify the oceanic processes and features that are important in defining the ocean's role in climate. They also introduce climate phenomena in which the ocean is known to play a significant role. B.J. Thompson, J. Crease and John Gould conclude the first section by presenting an enthusiastic account of the historical background of WOCE. They do this by taking the reader all the way from the origins in the 1960s and 1970s of WOCE to the implementation of WOCE. They then present their evaluation of WOCE by addressing whether WOCE was a success and what WOCE's legacy is.

Depending on the reader's interest, any of the other six sections could be chosen to be read next. These six sections have the following thematic titles: Observations and Models (Section 2), New Ways of Observing the Ocean (Section 3), The Global Flow Field (Section 4), Formation and Transport of Water Masses (Section 5), Large Scale Ocean Transports (Section 6), and Insights for the Future (Section 7).

In a new kind of innovative writing, Carl Wunsch unexpectedly leads off the second section in his Global Problems and Global Observations article by likening different views of the ocean to a kind of "multiple personality disorder" in which the different viewers do not recognize the existence of the others! The different personalities presented are: the descriptive oceanographer's classical ocean, the analytical theorists' ocean, the observers' highly variable ocean, and the high-resolution numerical modelers' ocean. While presenting the need for global-scale observations, he discusses what the global problems are by asking insightful questions such as "What do we know and where do we go from here?" Claus Böning and Albert Semtner give a thoughtful perspective on how high-resolution modeling of the thermohaline and wind-driven circulation has advanced. While models are increasingly successful in reproducing the major characteristics of mean-surface currents and mesoscale variability on intra-seasonal to international time scales, models have been less successful on longer-term aspects including the dynamics of the thermohaline circulation. Richard Wood and Frank Bryan address the question of why coupled ocean-atmosphere models are needed (answer: to understand or forecast processes that are longer than a month) and then focus on the coupled models being formulated to address ENSO, the North Atlantic Oscillation, and longer-term forced climate change such as solar variability or anthropogenic forcing.

In section 3, New Ways of Observing the Ocean, the transformation from using only shipboard hydrographic work and few direct observations to new ways of observing the ocean is presented. These include shipboard hydrography with ADCPs added, floats, satellite altimetry, scatterometry, air-sea fluxes and data management. B.A. King, E. Firing and T.M. Joyce discuss the advancement from hydrographic only measurements being routine before WOCE to hydrographic plus ADCP current measurements being viewed as routine after WOCE. This resulted in a successful one-time, global survey of the ocean during the observational phase of WOCE. Russ Davis and Walter Zenk give an excellent review of how ocean currents were traditionally determined. They then present the historical context for the WOCE float program, the methods and limitations of analysis, Lagrangian measurements, and the next frontier for float technology. Lee-Lueng Fu presents the new use of satellite altimetry for the ocean, which first took place during WOCE. The use of satellite altimetry was shown to play an important role for achieving a synthetic description of the ocean circulation. W. Timothy Liu and Kristina Katsaros present the use of satellite data for determining air-sea fluxes, while Eric Lindstrom and David Legler discuss how the WOCE global data system was developed and how it can be used as a prototype for other major data programs, such as the Global Ocean Data Assimilation Experiment (GODAE), Global Ocean Observing System (GOOS) and Global Climate Observing System (GCOS).

Using the WOCE results, the state of knowledge of the global surface and subsurface flow fields are presented in section 4, from the surface to the deep ocean, from the poles to the tropics, as well as the inter-ocean exchanges. Peter Niiler describes the new drifters used in WOCE, and summarizes the global data set of near-surface observations and calculations made with the data, including the mean circulation, the eddy energy distribution, and the wind-driven or Ekman currents. The interesting challenge of discussing the interior circulation of the ocean away from the equator and away from boundaries and with flow scales larger than the Rossby radius is taken on by D.J. Webb and N. Suginohara. Why a challenge you might ask? Because the question of addressing what governs the interior flow was likened by the authors as a "bit of a poisoned chalice", due to Joe Reid's 1981 remarks about there being "a large part of the ocean circulation for which we have very little information and very vague concepts". The authors address the interior ocean flow question by presenting challenging research "clues" from WOCE deep ocean measurements of tracers, turbulence, and satellite observations of tidal energy loss that suggest a new picture of the deep ocean with a patchy series of zonal jets steered by the deeper topography. In the chapter, the Tropical Ocean Circulation, J.S. Godfrey, G.C. Johnson, M.J. McPhaden, G. Reverdin and Susan Wijffels review the understanding of flow and water mass transformation patterns within the tropics of all three oceans. Nelson Hogg attempts to quantify the deep ocean in terms of transports of the deep western boundary currents in the various ocean basins, the interior circulation, and the time-dependent production of deep and bottom waters. The Antarctic Circumpolar Current (ACC) System is presented by Stephen Rintoul, Chris Hughes, and Dirk Olbers from the perspective of a flow in a zonally unbounded ocean. To better understand the ACC system, the full suite of observations, which include hydrography, tracers, altimetry, and moorings still needs to be synthesized. Models, which can better handle the interaction of strong currents and eddies with bottom topography, are needed as well. Finally Arnold Gordon discusses the Antarctic Circumpolar Current, the Bering Strait, the Indonesian Seas and the Agulhas Retroflection as important ocean pathways for inter-ocean exchange.

The Formation and Transport of Water Masses in section 5 covers the formation of water masses, their transport into the ocean interior, ocean stirring and mixing. William Large and A.J. Nurser discuss how surface fluxes drive diapycnal flow and use three years of WOCE data to try to understand denser mode and intermediate waters. John Toole and Trevor McDougall, in Mixing and Stirring in the Ocean Interior, discuss the tail of the ocean energy cascade, from the stirring role of mesoscale eddies and smaller scale motions to the mixing by turbulence and double diffusion. Recent progress in understanding the formation of thermocline water masses by combined vertical and horizontal flow, which is called subduction, is presented by James Price. Kimio Hanawa and Lynne Talley discuss the ventilation and generation of mode water, which is a layer of nearly vertically homogeneous water found over a relatively large geographical area. Deep convection and spreading as well as plumes (referred to as the mixing agent) are reviewed by John Lazier, Robert Pickart and Peter Rhines, based on advances made during the WOCE observing period. Dense northern overflows (north of 60º N) are discussed by Peter Saunders on the basis of recent WOCE results. In particular, sources, paths, transport means and variability of the overflows are reviewed as well as processes, analytical and numerical models of the overflow. Julio Candela frames the Mediterranean Water (MW) and global circulation into the perspective of the important contributions marginal seas such as MW make through their exchange with the major oceanic basins. The MW itself is first described, followed by its influence on the world's ocean thermohaline circulation and on climate. The article on transformation and age of water masses (by P. Schlosser, J.L. Bullister, R. Fine, W.J. Jenkins, R. Key, J. Lupton, W. Roether and W.M. Smethie, Jr.) presents preliminary results of the WOCE tracer survey, which provided the most extensive, global, high quality data sets for a variety of transient and "steady-state" tracers. Preliminary examination of the data suggests exciting new results on the physical climate system and biogeochemical processes. The use of tracers is discussed as important for providing an independent means of estimating water mass formation, for discussing the formation of dense waters around Antarctica, and for constraining rates of biogeochemical processes.

The Large-Scale Ocean Transports in section 6 covers the air-sea exchange, and the storage and horizontal transport of heat, freshwater and carbon. Harry Bryden and Shiro Imawaki discuss the global heat balance in terms of the traditional, residual and direct methods. Although WOCE had as a primary objective the making of direct estimates of ocean heat transport from transoceanic sections in each ocean basin, to date, evaluation of these transports from the WOCE measurements have been hampered by individual data sets not yet made available for general analysis. As a result, mainly large—scale inverse analyses using many sections have been made. The ocean transport of freshwater is likened by Susan Wijffels by the same historical perspective as for ocean heat transport, i.e. most estimates for freshwater are indirect rather than direct. The indirect estimates of oceanic freshwater transport and the large uncertainties of these estimates on model development are reviewed, followed by direct ocean estimates of freshwater transport and a comparison of the direct and indirect estimates. Like the heat budget estimates, the full potential of the WOCE data set for freshwater estimates is yet to be realized. The storage and transport of excess CO_2 in the oceans is presented by Douglas Wallace based on a one-time, comprehensive survey jointly undertaken by the Joint Global Ocean Flux Study (JGOFS) and WOCE. The rationale for this effort was to measure the global distribution of inorganic carbon in the oceans and subsequently to assess and advance the state-of-the-art in ocean carbon cycle modeling. Preliminary results suggest that within three years a global picture of the ocean's excess CO_2 inventory will be produced. Present results are revealing important areas of observation and model agreements as well as disagreements. For years to come, the survey will be viewed as a much needed baseline to gauge future inventory increases against.

The final chapter, Insights for the Future, presents the prospects for ongoing ocean and climate research, modeling, and monitoring. The key question of whether WOCE has achieved its objectives is addressed from three different perspectives: a synthesis of WOCE data perspective (addressed by Lynne Talley, Detlef Stammer and Ichiro Fukumori), a modeling perspective (addressed by J. Willebrand and Dale Haidvogel) and from an assessment of the representativeness of the WOCE data set (addressed by Bob Dickson, Jim Hurrell, Nathan Bindoff, Annie Wong, Brian Arbic, Breck Owens, Shiro Imawaki and Igor Yashayaev). The synthesis perspective acknowledges that WOCE contributed enormously to our ability to describe and understand the ocean, and to create the technical capability needed through the development and large-scale use of new observational methods, ocean models and state estimation. Major strengths are the comprehensiveness of the WOCE data set and the collection of many different types of complementary data and development of models and investigation expertise for every basin. Along with these contributions, the authors discuss thought provoking questions about WOCE such as: was it useful to have undertaken the whole exercise of observing the global ocean?; what would have been better done differently, if anything?; should global observations continue to be taken? The modeling perspective discusses the present states and future directions of numerical ocean circulation modeling. While ocean modeling advanced dramatically since WOCE, ocean climate models have changed only moderately. It appears that current coupled climate models are seriously misrepresenting many important ocean processes. As a result, important dynamical, thermodynamic and biogeochemical processes, such as narrow western boundary currents and coastal ecosystems, are presently unresolved in the climate models. In the final article on the representativeness of the WOCE data set, the authors state how the primary WOCE goal of compiling a coherent global ocean description has naturally led to the question of whether the new WOCE data set represents the long-term behavior of the ocean.

Suffice it to say that WOCE clearly represents the state of the ocean in the 1990s and that the ocean circulation has been better understood because of WOCE. The culmination of WOCE's achievement is this book, which is filled with the talents of 71 stimulating authors, who deserve the individual naming this review has given.

I recommend this book to those who enjoy the quest for ocean knowledge and who have enjoyed books like the *Evolution of Physical Oceanography*. Like that book, many chapters of this book individually encapsulate a knowledge of a large-scale oceanographic subject from its history to ongoing questions for future research. The book is a must for oceanographers, particularly physical oceanographers, and should be of high interest to atmospheric and climate scientists. As a teacher in both physical oceanography and in atmospheric science, I found the book very up-to-date, in its discussions on the large-scale ocean circulation. I also liked the many thought provoking questions that the authors produced along the way. I could see asking graduate students to read and discuss many of the subjects to give them an appreciation of the many ways in which our understanding of ocean circulation has come about, whether it be from a new instrument development to a new view of the ocean. Who knows? Maybe a graduate student, after reading Wunsch's perception of the views of the ocean circulation as a "multiple personality disorder", will be inspired to unite the different views of the ocean presented in this enjoyable book.

OCEANOGRAPHY

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Air-Sea Interaction: Laws and Mechanisms

By G.T. Csanady
Cambridge University Press
248 pp. ISBN 0521792592

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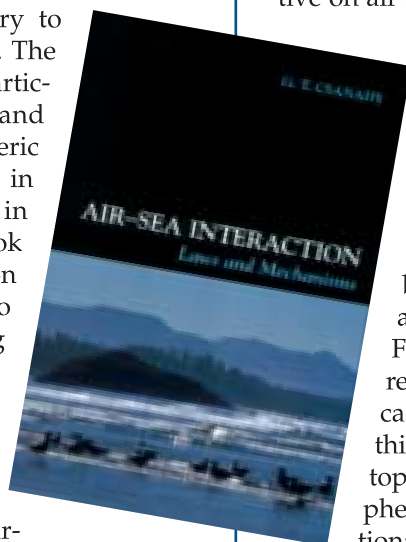
Gabe Csanady's 'Air-Sea Interaction: Laws and Mechanisms' provides a new and long needed perspective on air-sea interaction. This book discusses similarities and differences in the ocean and atmospheric boundary- layers, as well as the surface waves that are related to some of this interaction. Rather than focusing on one side of the interface or the other, it describes how both boundary layers act and interact on a wide range of spatial/temporal scales. The qualitative descriptions of boundary-layer processes, their evolution and forcing mechanisms are excellent. Furthermore, the writing style provokes the reader to think about these points. In some cases, atmospheric scientists are likely to find this provocation annoying: such as calling the top of the atmospheric mixed layer the 'atmospheric thermocline.' However, most of the additional thought comes easily due to the lucid and easily visualized descriptions.



Csanady provides an excellent synthesis of approaches and results. He explains or references the derivations far more thoroughly than is typical. This book a good reference despite being smaller and far more general than most other texts on air-sea interaction. The topics include descriptions of how air-sea interaction processes are linked to the evolution of related layers: the neighboring mixed layers as well as the ocean's thermocline and the inversion at the top of the atmospheric boundary. These topics are a great help in linking air-sea interaction processes to many other topics, and thereby making the topic of more interest to students whose focus is in other areas of atmospheric science and oceanography.

One of the great strengths of this book is Csanady's description of physical processes, and another is the description of interactions and balances between various processes. Plentiful illustrations enhance these descriptions. The physical mechanisms are also shown in terms of equations, which are usually well explained. One of the few difficulties with this book has to do with the numerical examples. Several colleagues who glanced at sections of the book found the numerical results to be questionable. This problem seems to stem from insufficient description of the spatial and temporal scale to which the examples apply. This flaw is relatively minor compared to the strengths of the book.