The Near-Surface Layer of the Ocean

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The Near-Surface Layer of the Ocean

Structure, Dynamics and Applications

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Preface

Until the 1980s, a tacit agreement among many physical oceanographers was that nothing deserving attention could be found in the upper few meters of the ocean. The lack of adequete knowledge about the near-surface layer of the ocean was mainly due to the fact that the widely used oceanographic instruments (such as bathythermographs, CTDs, current meters, etc.) were practically useless in the upper few meters of the ocean. Interest in the near-surface layer of the ocean rapidly increased along with the development of remote sensing techniques. The interpretation of ocean surface signals sensed from satellites demanded thorough knowledge of upper ocean processes and their connection to the ocean interior.

Despite its accessibility to the investigator, the near-surface layer of the ocean is not a simple subject of experimental study. Random, sometimes huge, vertical motions of the ocean surface due to surface waves are a serious complication for collecting quality data close to the ocean surface. The supposedly minor problem of avoiding disturbances from ships' wakes has frustrated several generations of oceanographers attempting to take reliable data from the upper few meters of the ocean. Important practical applications nevertheless demanded action, and as a result several pioneering works in the 1970s and 1980s laid the foundation for the new subject of oceanography – the near-surface layer of the ocean.

In 1988, K.N. Fedorov and A.I. Ginzburg published a monograph "The Near-Surface Layer of the Ocean", which summarized many of the new results but which was printed in limited numbers. In 1992 this book was translated into English. Since the publication of Fedorov's book, this area of research has dramatically advanced. Numerous exciting new experimental and theoretical results have been obtained. The idea of the importance of the ocean-atmosphere coupling on small scales found its practical realization in the TOGA COARE program which took place between 1992 and 1994. The concept of one-dimensional upper ocean dynamics has been enriched with the consideration of three-dimensional spatial structures. In particular, spatially coherent organized motions are attracting more attention.

Our book provides a comprehensive account of the structures and dynamics of the near-surface layer of the ocean under different environmental conditions. Fedorov's pioneering monograph attempted to achieve this objective, but it had unfortunate gaps and redundancies. Now it is possible to provide a more coherent presentation of this important subject.

In this book, detailed treatment is given to the following topics: molecular sublayers, turbulence and waves, buoyancy effects, fine thermohaline structure of the near-surface layer of the ocean, spatially coherent organized motions having surface manifestations, and the high wind-speed regime. Although this selection of topics depends somewhat on the specific research interests of the authors, the monograph attempts to systematically develop its subjects from physical and thermodynamic principles. The accent on the analysis of the results from recent major air-sea interaction experiments (including the data collected by the authors) is our effort to ensure that the book comprises the most comprehensive and reliable sum of knowledge that has been obtained in this area of research. For the subjects that are related to the physics of the near-surface layer of the ocean but not covered in the book in sufficient detail (or not covered at all), the reader is referred to useful literature. Among these subjects are the biochemistry of surface films (*The Sea Surface and Global Change*, edited by P.S. Liss and R.A. Duce, 1997), surface wave dynamics (Donelan and Hui, 1990), atmospheric boundary-layer dynamics (Stull, 1988), mixed layer modeling (Kantha and Clayson, 2000), air-sea fluxes (Businger and Kraus, 1994; Csanady, 2001), and coupled ocean-atmosphere systems (Godfrey et al., 1998).

Chapter 1 introduces the reader to the main theme of the book—the near-surface layer of the ocean as an element of the ocean-atmosphere system. A general discussion of upper ocean dynamics and thermodynamics sets the stage for the content of Chapters 2–7. This discussion introduces the different processes that mix and restratify the upper ocean.

Very close to the air-sea interface, turbulent mixing is suppressed and molecular diffusion appears to dominate the vertical property transport. Viscous, thermal, and diffusive sublayers close to the ocean surface exist as characteristic features of the air-sea momentum, heat, and mass transport. Their dynamics, discussed in Chapter 2, can be quite complex due to the presence of surface waves, capillary effects, penetrating solar radiation, and rainfall.

Chapter 3 provides insight into dynamics of the upper ocean turbulent boundary layer. The turbulence regime is the key to understanding many other processes in the near-surface layer of the ocean. Because methodological issues of turbulence measurements near the ocean surface are still not resolved, we start Chapter 3 with analysis of the existing experimental approaches. (The measurement of wave-enhanced turbulence is a very important but specialized topic.) Analyses of turbulence observations reveal different (sometimes contradictory) points of view on the role of surface waves. Recent observations obtained under a wide range of environmental conditions allows us to explain and, in some cases, to reconcile different points of view.

The wave-induced turbulence does not depend directly on stratification effects, and it is therefore reasonable to analyze the stratification effects separately. The analysis of stratification effects on turbulence in Chapter 3 is based on some analogy between the atmospheric and oceanic turbulent boundary layers. This analogy has been employed in the studies of Steve Thorpe and Michael Gregg. It may only be observed starting from the depth where wave-breaking turbulence is not important. A discussion of the surface mixed layer versus the Ekman layer concept will illustrate the depth to which momentum supplied by the wind penetrates relative to where the base of the mixed layer is found.

Chapter 4 is devoted to the fine thermohaline structure of the near-surface layer. We consider the penetrative solar radiation and the impacts of the distribution of radiant heating on the mixed layer dynamics. Stable stratification in the near-surface ocean due to diurnal warming or rainfall can reduce the turbulence friction, which results in intensification of near-surface currents. Unstable stratification leads to convective overturning, which increases turbulent friction locally. In addition, discrete convective elements—analogs of thermals in the atmosphere—penetrate into the stably stratified layer below and produce non-local transport. Experimental studies at the equator have produced striking examples of local and non-local effects on the dynamics of the diurnal mixed layer and thermocline. The last section of this chapter demonstrates how the local (diffusive) and non-local (convective) transport can be parameterized and incorporated into one- or three-dimensional models. This chapter contains a few effective examples of spatial near-surface structures. These examples should motivate the reader to study in detail the relatively lengthy Chapter 5.

Chapter 5 is devoted to the coherent structures within the near-surface layer of the ocean. Spatially-coherent organized motions have been recognized as an important part of turbulent boundary layer processes. In the presence of surface gravity waves, the Ekman boundary layer becomes unstable to helical motions (Langmuir cells). "Wind-rows" can often be seen from space due to spray patches and have already been used in advanced remote sensing algorithms to determine the direction of near-surface winds. Ramp-like structures are a common feature of boundary layer flows; they are, however, oriented perpendicular to the wind direction, while Langmuir cells are roughly aligned with wind. The Langmuir cells and ramp-like structures entrain bubbles and can be traced with side-scan sonars. Other types of quasi-periodical structures in the near-surface ocean, such as freshwater lenses produced by rainfalls and near-inertial oscillations induced by moving storms may have distinct signatures in the sea surface temperature field. Sharp frontal interfaces are an intriguing example of self-organization. These interfaces are supposedly related to the subduction process and are of different nature in mid- and low-latitudes. Internal waves, resonant interactions between surface and internal modes, and billows in the diurnal thermocline also produce signatures on the ocean surface under certain conditions.

Chapter 6 addresses high wind speed conditions, when breaking waves intermittently disrupt the air-sea interface producing a two-phase environment—air-bubbles in water and sea spray in air. These two-phase mixtures alter the distribution of buoyancy forces, which may affect the air-sea dynamics. The volume nature of the buoyancy forces further complicates the dynamics. Section 6.1 describes air-bubbles in the near-surface layer of the ocean. Section 6.2 has extensive references to the works on sea-spray production. Effects of sea spray as well as air bubbles on air-sea exchanges in a tropical cyclone are the subjects of Section 6.3.

Chapter 7, the final chapter of this monograph, describes current and potential applications of the near-surface results. Among these applications are remote sensing of the ocean, marine optics, marine chemistry and biology, ocean acoustics, and air-sea gas exchange. The last section of this chapter contains possible application of the near-surface results to ocean general circulation and climate modeling.

The upper ocean processes obtain another level of complexity in coastal zones due to several possible additional factors, including river (and other freshwater) discharge, wider range of air-humidity and air-sea temperature differences, typically short wave fetch (for offshore winds), wave shoaling, refraction, and breaking, surface and bottom boundary layers merging approaching the coast, anthropogenic surfactants and other contaminants (sewage, nutrients). Suspended sediments (due to river outflows and to wave action) alter optical properties and stratification. Though some of the related issues are discussed throughout the book, no attempt is made in this book to present the near-surface processes of coastal zones in a systematic way.

This book is mainly directed toward research scientists in physical and chemical oceanography, marine biology, remote sensing, ocean optics and acoustics. To broaden the potential audience, we have tried to make the book interesting and informative for people with different backgrounds. We also try to keep its style as close as possible to a textbook format to make it of value for graduate studies in oceanography and environmental sciences.

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