

Preface for the Second Edition

The first edition of our book, “The Near-Surface Layer of the Ocean” was the first monograph to provide a comprehensive account of the structures and dynamics of the near-surface layer of the ocean under different environmental conditions. The rationale for publishing a second edition is that this area of research continues to see remarkable advancement. Pioneering satellite missions by ESA and NASA to measure sea surface salinity have been launched. The newest generation of synthetic aperture radar (SAR) satellites has provided unprecedented, meter-scale horizontal resolution of fine features on the sea surface. In addition, the computational fluid dynamics (CFD) type models have recently been introduced for upper ocean research, opening new opportunities to understand processes involved in formation of fine scale features and their visibility to SAR. Passive acoustic methods for monitoring short sea surface waves (and potentially effects of surfactants) have obtained significant development due to pioneering works by Walter Munk with observations from deep-sea hydrophones. Study of the Deepwater Horizon oil spill in the Gulf of Mexico has generated unique data sets on fine scale structure and dynamics of the near-surface layer of the ocean.

In this second edition, we have preserved the overall structure of the monograph. As in the first edition, detailed treatment is given to the following topics: molecular sublayers, turbulence and waves, air-sea exchanges, buoyancy effects, fine thermohaline structure of the near-surface layer of the ocean, spatially-coherent organized motions and other processes having surface manifestations, and the high wind-speed regime.

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. This chapter has been supplemented with an overview of numerical methods for modeling mixing in the upper ocean including computational fluid dynamics (CFD) models, which are effective new tools for studying three-dimensional processes in the near-surface layer of the ocean and across the air-sea interface. Statistical description of surface waves has been extended to introduce wave form stress and kinetic energy flux to waves from wind.

The dynamics of the aqueous viscous, thermal, and diffusive sublayers at the air-sea interface are discussed in Chap. 2 updated with new developments in chemistry,

biology, and physics of surface films. CFD modeling of the viscoelastic properties of surface films due to presence of surfactants is another new topic in this chapter. In addition, we describe a new approach to studying the bacterial content of the sea surface microlayer using DNA analysis in conjunction with SAR remote sensing techniques.

Chapter 3 is devoted to upper ocean turbulence, which is the key to understanding many other processes that are responsible for the structure of the near-surface layer of the ocean. This chapter has been updated with the new results on wave-induced turbulence that emerged since the publication of the first edition. Progress in studying upper ocean turbulence is significantly hampered by technological challenges; we discuss this problem throughout the chapter. At this point, none of the existing sensor systems is capable of providing reliable measurements of turbulence levels within active wave breakers due to high concentrations of air bubbles. In fact, a significant part of the wave kinetic energy dissipates within wave breakers. In concluding remarks to Sect. 3.4 we discuss a possible new approach to address this problem using high-resolution 3D sonar technology.

Chapter 4 presents the fine thermohaline structure of the near-surface layer of the ocean. It has been updated with a discussion of new approaches to modeling the diurnal cycle of sea surface temperature (SST) using CFD. A somewhat more detailed consideration is now given to the near-surface layer of the ocean in polar seas.

Chapter 5 is devoted to spatially-coherent organized motions in the near-surface layer of the ocean. A new theoretical insight into physics of spiral structures on the sea surface has been added. The resonant interaction of density-driven currents in the near-surface layer of the ocean with ambient stratification has been reproduced with a CFD model. We have updated the section on Langmuir circulation and an alternate mechanism is now discussed.

Chapter 6 discusses the air-sea interface under tropical cyclone conditions. Dramatic development in this area of research is associated with the recent finding that whitecap coverage does not exceed 10% of the sea surface area even under very high wind speed conditions. New data support the mechanism of direct disruption of the air-sea interface under very high wind speed conditions, which was hypothesized in the first edition of our book. The resulting two-phase transition layer has been included in a unified parameterization for the drag coefficient.

The biggest changes in the second edition are in Chap. 7, which is a result of the rapid widening of potential applications of near-surface ocean research results. Sections on remote sensing of the ocean, ocean acoustics, air-sea gas exchange and climate studies have been significantly updated. The updates include interpretation of natural and artificial features on the sea surface in SAR imagery. A new section on remote sensing of oil spills has been added.

This book is mainly directed toward researchers in physical and chemical oceanography, marine biology, remote sensing, ocean optics, and ocean acoustics. We anticipate that more specialists will need to be prepared to work in this and related areas of research. We have therefore attempted to make it of value for graduate studies in oceanography and environmental sciences.

Acknowledgments for the Second Edition

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Preface for the First Edition

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 adequate 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 Chaps 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 Chap. 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 Chap. 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 Chap. 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 Chap. 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 sonar. 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. Sect. 6.2 describes air-bubbles in the near-surface layer of the ocean. Sect. 6.3 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 Sect. 6.4.

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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