Preface

The atmosphere and the oceans form a coupled system which constantly exchanges momentum, heat and water through the air-ocean interface. The interface and ocean waters are in endless motions of various scales, from micro-turbulence through to surface waves, tides, global currents and internal waves which are the subject of discussion in this book. In contrast to the surface waves, internal waves propagate through the whole fluid space not only horizontally, but also vertically. In general, ocean fluid is inhomogeneous in space and time due to differences in water temperature and salinity. The surfaces of the interface between warm and cold water or between fresh and salt water in a continuously stratified fluid are unstable. Oscillating interface forms waves which are of different type than those appearing on the free ocean surface. The amplitudes of gravity internal waves within the water column are usually considerably larger; the wavelengths are also much bigger than those of the ordinary surface waves.

Internal waves play a fundamental role for supporting the hydrological and energetic status of oceans. This fact results from the vertical structure of ocean waters. Temperature and salinity of waters differ considerably and cause a substantial variation of the water density. The internal waves generated by wind, pressure fluctuation or flow over the bottom topography, appear to be the principal cause of water mixing. Mean and eddy flows over topography generate internal lee waves, while tidal flows over topography generate internal tides. Vertical mixing enhances meridional heat flux in the ocean, playing an important role in affecting the earth's climate.

While internal waves were known to exist in the ocean in the early 1900s, it is only within the past five decades or so that technology has advanced to a point where large number of observations, also from space, are available. Internal waves move along interfaces as well as in fully three-dimensional space, and they are changing at a relatively fast temporal and small spatial scales, which makes them difficult to observe and include in weather and climate model. Also, the appearance of waves at the boundary surface between two water layers has for long escaped the attention of the observers, because even when the amplitude of the oscillation at the boundary surface is large, the free surface of the upper layer is only slightly disturbed and remains practically at rest.

In contrast to the ocean surface waves, the literature on the internal waves is not so numerous. Due to the high complexity and nonlinear nature of the phenomena, gravity internal waves remain a hydrodynamic process that is still not fully known. Solving the equations describing their evolution poses various mathematical challenges associated with singular boundary value problems and large amplitude dynamics. However, some available oceanographical textbooks and many papers include a discussion of internal gravity waves propagating at interfaces as well as in continuously stratified fluid. Different dynamics mechanisms, such as wave generation, propagation, nonlinear evolution and stability, are also described. The early theoretical results and observations have been summarised in the monographs by Krauss, Roberts and Phillips. In Roberts's monograph, a long list of locations of reported observations of internal waves till the year 1975 is given. In the more recent monograph by Sutherland, the approach taken there is to provide the physics and mathematics describing internal gravity waves in a way that is accessible to students who have been exposed to multivariable calculus and ordinary differential equations. A few books and many papers, mostly theoretical, on the internal gravity waves were also published in Russia, but due to the language barrier, some of these papers are unknown among the Western scientific community. For example, Miropolsky' monograph, originally published in Russia in the year 1982, has been published in English only in the year 2001.

Most of the professional literature dedicated to internal waves is focused on the deep ocean, and only a limited number of papers is dealing with shallow waters. Therefore, there is a need to bring the attention of marine community to specific mechanisms of internal waves propagated in the limiting water depth and over undulating shallow sea bottom. In this book an introduction to the physics and prediction of internal waves in shallow water is presented, taking an advantage of modern theoretical and experimental achievements published in professional literature, along with the author's results. The shallow water case requires a different approach than the deep sea for proper representation of the governing equations describing the internal waves propagation. Therefore, special attention in the book is given to the Korteweg-de Vries equation and its stable solutions in the form of the solitary and cnoidal waves. Another important objective of this book is an examination of various experimental methods for collecting and processing data on the internal waves. In particular, the experimental results obtained by moving sensors and thermistor chains in shallow waters in the Southern Baltic Sea are discussed in detail.

The book is designed for graduate students, Ph.D. students, postdoctoral students and scientists—physicists, engineers and ecologists working on sea environmental problems. The reader is assumed to have a working knowledge of calculus, and a knowledge of hydrodynamic concepts would be helpful. While the fundamental concepts of internal wave physics are given in great detail, some advanced topics are only overviewed. However, many illustrating examples, cross references and subject index are provided to make the book more efficient as a handbook.

The book structure can be summarised as follows: in Chap. 1, useful definitions related to the internal waves are given and the stability of water masses for different profiles of water density is explained. The main purpose of this chapter is to develop general governing equations for various characteristic internal wave parameters.

Chapter 2 deals with the special case of interfacial waves propagating in two-layer seas when the thermocline and pycnocline change very sharply with water depth. The analytical solutions for infinitesimal waves as well as solutions for large amplitude (Stokes' type solution) and long waves (solitary and cnoidal solution) are discussed in detail.

In Chap. 3, a more general case of the continuously stratified ocean is considered for constant water depth. The classical, as well as the variational type solutions of the basic governing equations for short and long internal waves are developed.

Chapter 4 deals with the propagation of internal waves over bottom irregularities and sloping continental shelves. The observation of breaking internal waves in the laboratory channels as well as numerical simulations for propagation of internal waves in a natural environment is described.

Chapter 5 is dedicated to the possible physical mechanisms of generation of the internal waves such as wind action, fluctuation of atmospheric pressure and local disturbances.

In Chap. 6 emphasis is placed on the methodology of the spectral representation of the internal waves in frequency and wavenumber space. In particular, an application of the Fourier Integral or Fourier-Stjeltjes Integral methods for experimental series, stationary in time or uniform is space, is provided. Moreover, using of the Wavelet Transform and Hilbert Transform techniques for non-stationary experimental data is illustrated.

Finally in Chap. 7, practical applications of theoretical methods developed in the previous chapters for the internal waves in the shallow Baltic Sea are described in detail. Various methods of the eigen-solutions of the vertical velocity equation for three-layer model of various density distributions are considered and many examples of the practical calculations are given. The available observations of internal waves with moving sensors and thermistor chains are described and the results of calculations are discussed and interpreted.

The book is supplemented with an extended list of relevant bibliography and subject index. Some figures in the book have been adapted from previously published figures, and this is indicated in the legends. I apologise for the inevitable errors which may occur in this book, despite my efforts to eliminate them. Please bring these errors to my attention.

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