# Preface

The first manuscript of this book was written in 1984, during the sabbatical year of Dr. Luiz Bruner de Miranda, as approved by the Oceanographic Institute, São Paulo University (IOUSP-USP), and financed by the Brazilian fellowship program of the National Council for the Development of Science and Technology (CNPq). During that sabbatical, Mr. Miranda worked with Dr. Björn Kjerfve, Belle W. Baruch Institute of South Carolina University (USA), where he deepened his knowledge on estuarine dynamics. Since 1986, Dr. Miranda has continuously improved the first manuscript of this book to incorporate his graduate-level teachings of *Kinematics and Estuarine Dynamics*. This book's first edition (2002) was published in Portuguese by the São Paulo University's Editorial Board (Editora da Universidade de São Paulo (EDUSP)). In 2003, this edition won the first place in the *Exact Science, Technology and Informatics* category of the biennial year's book edition of the Brazilian Book Chamber (Câmara Brasileira do Livro). Since then, this book has also been adopted for teaching undergraduate-level students at IOUSP-USP. The second edition of this book was published in 2012 and, and with Dr. Kjerfve's encouragement, an extensively revised and updated English version of this book was approved by EDUSP.

Estuaries are transitional environments between the continent and the ocean where rivers empty into the sea, resulting in a measurable dilution of the saltwater. In natural conditions, estuarine water masses are more productive than rivers and ocean waters due to its hydrodynamic characteristics which arrest nutrients, seaweeds, and plants, thus stimulating the primary and secondary productivities in these fascinating water bodies.

Investigations of Swedish rivers (Götaelf river) published by F.L. Ekman in 1876, in the Nova Acta Reg. Soc., based on hydrographic and current measurements, indicated that the outflow of river water in the estuary was accompanied by an inflow of seawater in the lower layers with the circulation continuity provided by *upwelling* motions from the bottom water. However, it was only by the middle of the last century that these ecosystems, very much vulnerable to the human influence, were more intensively investigated. Ekman's investigations resulted in valuable scientific knowledge that contributed to the understanding of how estuaries

function, which is of fundamental importance to the management of this complex ecosystem. In physical oceanography, the estuaries investigations are based on (i) observational experiments in laboratory and in the field; (ii) data interpretation based on theoretical and semiempirical knowledge; (iii) analytical simulations; and (iv) numerical modeling.

About 60% of the great cities around the world were founded and have its development nearby estuaries. However, the estuarine water renewal and depuration of these environments are dependent on the interactions of physical, biologic, chemical, and geological processes not well known, and the direct and indirect introduction of substances and energy by the man may reach high concentration levels, causing the contamination of its waters with harmful influence on the living resources, danger to the human health, damage to the marine activities and fisheries, and reduction of its natural attraction.

In the Brazilian coastline with approximately 8500 km, there are thousands of estuaries, estuarine systems, and coastal lagoons, with extensions of a few kilometers up to hundreds of kilometers, bordered by swamp and mangroves. In the north of Brazil, we find one of the most spectacular deltaic estuarine systems formed by the Amazon river and in the south, the Patos lagoon, the biggest in the South America. The estuarine systems contributed to the development of great and small Brazilian cities, suffering modifications in its geometry and circulation and, consequently, in the processes of erosion, transport, and sedimentation, due to alteration in the hydrographic basin, the water's natural cycle, and its quality due to the human's activities during the last centuries.

Due to the great importance of these coastal environments in the Oceanographic Institute of the University of São Paulo (IOUSP), and in other Brazilian universities, there are disciplines, in the undergraduate and graduate levels, related to the estuarine studies. In this context, the objective of this book is to present twelve chapters an integrated coverage of the fundamental principles of the physical oceanography of estuaries based on scientific articles and classical and recent books written on estuarine physics and interrelated studies. In this book, we also try to permeate by our experience and expertise which was acquired in the interpretation of experimental results and publications in these fascinating transitional ecosystems in the past 60 years.

In Chap. 1, the reader will find the details of the importance of estuaries, its formation, and its recent geological age. In this chapter, it is also presented classical concepts and most recent definitions, as well as political actions and laws established to the estuaries preservations. In Chap. 2 are described the geomorphologic conditions and the forces imposed by the river discharge, tidal and density (salinity) pressure gradients and wind, and its influence on the circulation. In this chapter also have been introduced some characteristics of the tidal propagation in a uniform estuarine channel, as well as the velocity associated with this oscillating motion. Due to the great diversity of the estuaries and the possibility to forecast some general characteristics of the acting forces, circulation, and mixing processes, in Chap. 3 are presented the main criteria to estuaries classification taking into account its genesis, topographic characteristics, and vertical salinity stratification. The

classical stratification–circulation diagram, the most recent diagrams based on the Ekman and Kelvin estuarine numbers, and the prognostic estuary classification based on non-dimensional tidal and freshwater velocities are also presented.

Planning and execution of an oceanographic research in an estuarine environment are presented in Chap. 4, with the description of the main methods of measurement of hydrographic properties and currents. The methodology applied to reduce, coordinate, edit, and analyze the experimental data are also presented in this chapter. The main concepts evolved in the reduction and edition of observational data to calculate the advective and diffusive flux and transport of properties, which may also be applied to the concentration of conservative and non-conservative properties, are presented in Chap. 5.

Studies on the mixing processes in an estuary have the main objective to calculate the classical residence and flushing times of salt and other properties of concentrations introduced into estuaries. As the freshwater volume may be used, in the first approximation and steady-state conditions to forecast the longitudinal salinity variation and flushing times, in Chap. 6 are presented the so-called simplified methods of mixing.

The main concepts related to the momentum, mass, and salt conservation equations, which are the starting points to formulate the hydrodynamic equations governing the physical processes in an estuary, are presented in Chaps. 7 and 8. This formulation initiated with tridimensional equations is reduced to simplified equations to formulate the two- and one-dimensional analytical methods. Some applications of integrated formulations of the equations of continuity and motion are also presented in these chapters.

In Chaps. 9 and 10 are presented steady-state analytical solutions of one- and two-dimensional of the classical salt wedge and well-mixed estuaries. At the end of these chapters, solutions of the u-velocity component and salinity vertical profiles of these estuaries types are presented.

In Chap. 11, steady-state analytical solutions for one- and two-dimensional estuaries of the partially mixed type are presented, as well as some classical solutions to calculate the velocity and salinity profiles and the fundamental concepts related to the stratification–circulation diagram used in the estuary classification.

As estuaries are three-dimensional and time-dependent, to overcome the simplifications of simple geometry and steady-state formulations to calculate the estuarine circulation and salinity distributions, numerical models have been developed. These models integrated numerically at selected grid points spatially distributed in the system domain and the algebraic expression of governing partial differential equations using methods of finite difference or finite element in a curvilinear coordinate system with sigma or non-dimensional vertical coordinates. The main principles used in the numerical model applications and some results are presented in Chap. 12.

Programs in MATLAB® computational environment of the main analytical equations developed in this book's chapters, using the Morgan's SEAWATER library, may be accessed in the web site of the Laboratory of Coastal and Estuaries Hydrodynamics, LHiCo (Oceanographic Institute of São Paulo University).

São Paulo, Brazil — Luiz Bruner de Miranda
Gold Coast, Australia — Fernando Pinheiro Andutta
Sharjah, United Arab Emirates — Björn Kjerfve
São Paulo, Brazil — Belmiro Mendes de Castro Filho

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Bruner de Miranda, L.; Andutta, F.P.; Kjerfve, B.; Castro Filho, B.M. de

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