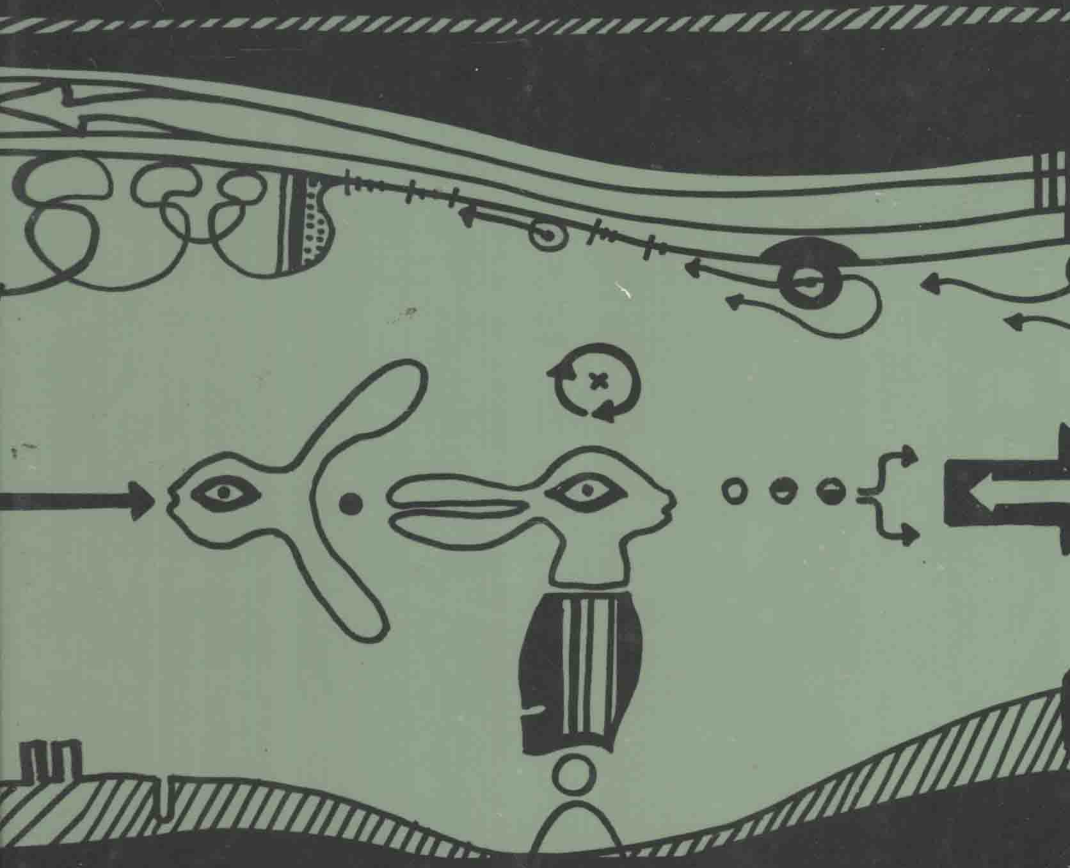
# Advances In Environmental Fluid Mechanics



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Editors

World Scientific

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# Advances In Environmental Fluid Mechanics

*To Ljuba Nedeljković, physist from Belgrade.*

Dragutin T. Mihailovic

*To Susanna and Federico. To my parents.*

Carlo Gualtieri

# Preface

We live in a changing world. This thought expresses a historical fact entirely present in man's consciousness regardless of whether we consider him as an individual or a social human being. The awareness about the changing world always introduces an amount of anxiety into man's life that can be defined by the following question: whether man can preserve the existing world for the future of his children. To preserve this world for the future of our children, we must all strive for sustainable development - a development that meets the needs of the present generation without compromising options and resources the future generations will use to meet their own needs. It implies environmentally sound development in societies and regions free from threats to life and property. Human security is an essential ingredient of sustainability, which is increasingly threatened by extreme events, both natural and human-induced.

These sentences give insight into the question: Why is there now a focus on environmental problems ? One particular answer can be found in a hierarchy of the main scientific problems for the 21st century as seen by the community mostly consisting of physicists, biologists, chemists, engineers and human science communities. According to them, in the 21st century the scientific community will be occupied by the problems linked to environmental ones that are primarily expressed through problem of climate changes and related issues. A unique characteristic of these problems is their close connection with the questions of the survival of individual human beings on the Earth. This is the first time in the history of science that environmental problems take their place at the front of science – from fundamentals to applications. This science could be defined from the point of view of many single sciences. However, the definition given in Random House Dictionary as "*the branch of science concerned with the physical, chemical, and biological conditions of the environment and their effect on organisms*" can be accepted as the broadest one, because it implicitly includes its main feature – its interdisciplinary nature. The field of environmental science is abundant with various interfaces and is the right place for the application of new fundamental approaches leading towards a better understanding of environmental phenomena. Therefore, we will slightly evolve the above definition, by setting the focus on the concept of the *environmental interface*, defined as an interface between two either abiotic or biotic environments which are in relative motion exchanging energy and substances through physical, biological and chemical processes and fluctuating temporally and spatially. In that sense we define environmental science as "*the branch of science concerned with the interactions in environmental interfaces regarded as the natural complex systems*" that will be exploited in this book. Environmental science encompasses issues such as climate change, biodiversity, water quality, ground water contamination, use of natural resources, waste management, sustainable development, disaster reduction, air pollution, and noise pollution. It is built from many sciences including environmental fluid mechanics as one of the core components.

Environmental fluid mechanics (EFM) is the scientific study of transport, dispersion and transformation processes in natural fluid flows on our planet Earth, from the microscale to the planetary scale. Stratification and turbulence are two essential ingredients of environmental fluid mechanics. Stratification occurs when the density of the fluid varies spatially, as in a sea breeze where masses of warm and cold air lie next to each other or in an estuary where fresh river water flows over saline seawater. Turbulence is the term used to characterize the complex, seemingly random motions that continually result from instabilities in fluid flows. Turbulence is ubiquitous in natural fluid flows because of the large scales that these flows typically occupy. The processes studied by environmental fluid mechanics greatly affect the quality of natural ecosystems and are largely investigated using modeling techniques and software packages.

The objective of this book is to bring together scientists and engineers working in research institutions, universities and academia, who engage in the study of theoretical, modelling, measuring and software aspects in environmental fluid mechanics. It is intended to provide a forum for the participants to obtain up-to-date information, and exchange new ideas and expertise through the presentations of up-to date and recent overall achievements in this field. In this regard, a mixing of professionals from a wide spectrum of different areas is promoted focusing on the EFM theoretical, modeling and experimental approaches, including the issues of software design and measurements.

The book is organized in two broad parts: Theoretical and Modeling Aspects (Part One) and Applicative, Software and Experimental Issues (Part Two). Part One has seven chapters covering various theoretical and modeling aspects of EFM, such as turbulent dispersion, stable atmospheric boundary layers, calculation of albedo on complex geometries, stratified turbulent flows, viscous flow induced by wave propagation over bed ripples, aquatic turbulent flow over rough boundaries and exchange processes in environmental interfaces regarded as biophysical complex systems. Part Two addresses in eight chapters a broad range of EFM applicative issues, such as source identification in atmospheric pollution, fate and transport of mercury in aquatic systems, exchange processes in a river with dead zones, flow resistance in vegetated channels, contaminant intrusion in a water supply network, ecological modeling of coastal waters, integration of spatio-temporal data for fluid modeling in a Geographical Information System (GIS) environment and long-term measurements of energy budget components and trace gas fluxes between the atmosphere and different types of ecosystem.

Part One starts with a chapter by N. Mole, P.C. Chatwin and P.J. Sullivan, that deals with the dispersion of contaminants in turbulent flows at high Péclet number, where both turbulent advection and molecular diffusion were considered to derive exact results for moments and the probability density function (pdf) of concentration for the hypothetical case of zero diffusivity. Also, the results for the moments were modified to account for the presence of slowly acting diffusion. Finally, the authors demonstrated that many of the results obtained with this approach agree well with experimental observations. Following this, the chapter by D.T. Mihailovic and I. Balaz investigates an aspect of dynamics of energy flow based on the energy balance equation. Also, two illustrative issues important for the modelling of interacting environmental interfaces regarded as complex systems were addressed. These were the use of algebra for modelling the autonomous establishment of local hierarchies in biophysical systems and the numerical investigation of coupled maps representing exchange of energy, chemical and other relevant biophysical quantities between biophysical entities in their surrounding environment. The next chapter, by B. Grisogono, is devoted to the atmospheric boundary layer (ABL), which is the lowest part of the atmosphere that is continuously under the influence of the underlying surfaces through mechanical (roughness and shear) and thermal effects (cooling and warming), and the overlying, more free layers. Its proper characterization and modeling is very important in both short- or medium-range weather forecasting and applied micrometeorological studies. The author investigated an inclined strongly stratified stable ABL proposing an improved *z-less* mixing length scale model and a new generalized *z-less* mixing length-scale model. In Chapter 4, V. Fuka, J. Brechler and A. Jirk studied the impact of vertical temperature stratification on a 2D laminar flow structure, modeled via the Boussinesq approximation and by varying the Froude number (Fr). Later, they reviewed several approaches in treating turbulence in modeling studies, with an emphasis on an implicit large-eddy simulation. The results of Taylor–Green vortex computations, performed by using this method, were compared in terms of kinetic energy dissipation rate, probability density functions of turbulent fluctuations, and 3D energy spectra with the results of a direct numerical simulation at moderate Reynolds numbers. The chapter by R.J. Schindler and J.D. Ackerman deals with turbulent flow over rough boundaries, which is a common appearance in nature and the subject of high interest in a range of disciplines. Since recent technological advances have increased our ability to model, visualize and measure flow structure over complex boundaries, the authors reviewed the experimental evidence for rough boundary/flow interactions across different disciplines, pointing out that different approaches have led to the adoption of a variety of parameters that are used to describe boundary roughness, and different criteria were used to evaluate the relative effects of boundary roughness. Furthermore, they stressed that much of the experimental data relates to idealized surfaces or is taken in low Reynolds number flows, and cannot be generally applied to aquatic flows over natural surfaces. In the chapter following this, A.A. Dimas and G.A. Kolokythas present the results of numerical simulations of the free-surface flow, developing by the propagation of nonlinear water waves over a rippled bottom. The flow was assumed to be two-dimensional, incompressible and viscous and the simulations were based on the numerical solution of the Navier-Stokes equations subject to the fully-nonlinear free-surface boundary conditions and appropriate bottom, inflow and outflow boundary conditions. Results pointed out that over the rippled bed, the wave boundary layer thickness increased significantly, in comparison to the one over a flat bed, due to flow separation at the ripple crests, which generates alternating circulation regions. Second, the effect of ripple height and Reynolds number on the distribution of wall shear stress and drag forces was investigated. Part 1 is closed with the chapter by D. Kapor, A. Ćirišan and D.T. Mihailovic that presents a general approach for the calculation of aggregated albedo in complex geometries, where analytic solution is not available. Thus, an efficient numerical procedure, the so-called *ray-tracing Monte Carlo* approach, was developed and tested for known analytical solutions. Later, this method was applied to a two-patch grid cell with a square geometrical distribution and with different heights of its parts. Comparison with the results from conventional approaches pointed out remarkable changes in values of sensible and latent heat fluxes, as well as the corresponding surface temperature.

Part Two begins with the chapter by B. Rajković, M. Vujadinović and Z. Gršić, in which are proposed two methods for locating a possible source of air pollution that combine measurements and inverse modeling based on Bayesian statistics. In both methods a puff model was used to generate the pollutant concentration field and the synthetic observations at predefined measuring points using real meteorological data. In the first approach, the position of the possible source was found with an iterative process, defined as the maximum of probability density function from an ensemble of possible sources. The second approach used a library of records and scenarios, with combinations of values for the meteorological and emission parameters in the problem. The next chapter, by T. Weidinger, L. Horváth and Z. Nagy, presents the status of micrometeorological research activity in Hungary, field measurement programs and instrumentation and flux calculation methodology. Later, the chapter illustrates the development of the new Hungarian basic climatological network for the detection of the possible effects of future climate change, which consists of the standard climate station measurements, soil, radiation, energy budget and $CO_2$ flux measurements. The chapter by L. Matejicek presents a case study focused on dust dispersion above a surface coal mine which demonstrated the ability of GIS methods to manage, pre-process, post-process and to visualize all the pertinent data. As remote sensing helped to identify and classify the coal mine surface in order to map erósion sites and other surface objects, Global Positioning System (GPS) was used to improve the accuracy of the erosion site boundaries and to locate other point emission sources such as excavators, storage sites, and line emission sources such as conveyors and roads. Wind flow and dust dispersion modeling was successfully integrated in the GIS environment. The chapter by P.A. López-Jiménez, J.J. Mora-Rodríguez, V.S. Fuertes-Miquel and F.J. Martínez-Solano studied pathogen intrusion in water distribution systems by using both experimental and numerical methods. Pathogen intrusion occurs when negative pressure conditions are achieved in the systems, allowing the entrance of water around a leak, causing a problem of water quality. First, laboratory experimental works were carried out. Experimental results were successfully compared with numerical results obtained with Computational Fluid Dynamics (CFD) methods. Issues about the calibration process are also discussed. The chapter by C. Gualtieri deals with the 3D steady-state and time-variable numerical simulations of the flow in a rectangular channel with a lateral square cavity representing a dead zone of a river. This geometry was previously experimentally studied. The exchange coefficient between the main flow and the dead zones was calculated both from the transverse velocity data along the dead zone-main channel interface and from the temporal decay of the concentration of a tracer that was homogeneously injected in the dead zone. Analysis of the flow field demonstrated that the numerical simulations qualitatively reproduced the observed flow patterns but underestimated the exchange rate between the dead zone and the main stream, whereas the concentration data were in better agreement with the experimental data. The chapter by A. Massoudieh, D. Zagar, P.G. Green, C. Cabrera-Toledo, M. Horvat, T.R. Ginn, T. Barkouki, T. Weathers and F.A. Bombardelli covers fate and transport of mercury in aquatic systems. First the chapter identifies the various processes that are potentially important in mercury fate and transport as well as knowledge and uncertainty about these processes. Second, an integrated multi-component reactive transport modeling approach was proposed to capture several of the processes. This integrated modeling framework includes the coupled advective-dispersive transport of mercury species in the water body, both in dissolved phase and as associated to mobile suspended sediments. Some results for the application of the model to the Colusa Basin Drain in California were also presented. The chapter by J.F. Lopes and A.C. Cardoso presents the results of a 3D numerical study of the distribution of temperature and phytoplankton biomass in the near-shore Aveiro coastal zone (Portugal). The study area is located on the western coast of the Iberian Peninsula, characterized by meteorological conditions of strong north/northwest prevailing winds, which favour the upwelling of nutrient enriched waters resulting from the divergences associated with the Ekman transport and, therefore, generating high nutrient availability. The results showed that the model was able to reproduce the horizontal and vertical temperature and chlorophyll-a (*Chl-a*) patterns. Also, they demonstrated the setup of a layer of cold water along the coastal side and the increasing of the declivity of the thermocline and the nutricline toward the coast. The model successfully predicted the values for the maximum *Chl-a* concentration and the depth of the inshore subsurface chlorophyll maximum. The last chapter by S. De Felice, P. Gualtieri and G. Pulci Doria deals with the calibration of a new simplified experimental method to evaluate absolute roughness of vegetated channels. The method is based on boundary layer measurements in a short channel rather than on uniform flow measurements, as usual. The proposed method can be applied to any kind of rough bed, but it is particularly useful in vegetated beds where long channels are difficult to prepare. The results are successfully compared with literature data demonstrating that the proposed method can provide a reliable prediction of absolute roughness in vegetated channels.

The Editors wish to thank all the chapter authors for their continuous and dedicated effort that made possible the realization of this book. The Editors are also grateful to the anonymous reviewers of the project for their thoughtful and detailed suggestions that have improved both the contents and presentation of this book. The Editors finally acknowledge with gratitude the assistance of the Editorial Office of World Scientific and, especially, of Dr.Elena Nash.

Dragutin T. Mihailovic
Carlo Gualtieri

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**Carlo Gualtieri** is currently Assistant Professor in Environmental Hydraulics at the Hydraulic, Geotechnical and Environmental Engineering Department of the University of Napoli *Federico II*, Italy. He received a B.Sc. in Hydraulic Engineering at the University of Napoli *Federico II*, where he received also a M.Sc. in Environmental Engineering. He finally received a Ph.D. in Environmental Engineering at the same University. He has 88 peer-reviewed scientific papers, including 19 publications in scientific journals, 4 book chapters, 44 publications in conference proceedings, and 21 other refereed publications in subjects related to environmental hydraulics and computational environmental fluid mechanics, with over 60 papers, experimental investigations of two-phase flows, water supply networks management and environmental risk. He is also co-author of 2 textbooks on Hydraulics and author of a textbook on Environmental Hydraulics. He is co-editor of the book *Fluid Mechanics of Environmental Interfaces* published by Taylor & Francis in 2008. He is member of the Editorial Board of the journals *Environmental Modelling and Software (Elsevier)* and *Environmental Fluid Mechanics (Springer).* He contributed as manuscript editor for *Environmental Modelling and Software*, as reviewer in several scientific journals (e.g. *Environmental Fluid Mechanics, Environmental Modeling and Software, Journal of Environmental Engineering ASCE, Journal of Hydraulic Engineering ASCE, Journal of Hydraulic Research IAHR, Advances in Water Resources, Experiments in Fluids, Ecological Modelling, Environmental Science & Technology, Journal of Coastal Research*) and as external examiner for Ph.D thesis in foreign countries. He co-organized sessions dealing with environmental fluid mechanics in international conferences, such as *iEMSs 2004*, *iEMSs 2006*, *EMS 2007*, *iEMSs 2008* and *EGU 2009*. He is also active as expert reviewer for research funding agencies in several countries. He is member of the International Scientific Advisory Board of the EU project *RRP-CMEP*, of the *American Society of Civil Engineers* (ASCE), of the *International Association of Hydraulic Engineering & Research* (*IAHR*) and of the *International Environmental Modelling & Software Society (iEMSs).*

**Dragutin T. Mihailovic** is the Professor of the Meteorology and Biophysics at the Department of the Vegetable and Crops, Faculty of Agriculture, University of Novi Sad, Serbia. He is also the Professor of the Modelling Physical Processes at the Department of Physics, Faculty of Sciences at the same university and the Visiting Professor at the State University of New York at Albany. He teaches various theoretical and numerical meteorology courses to Physics and Agriculture students. He received a B.Sc. in Physics at the University of Belgrade, Serbia, his M.Sc. in Dynamics Meteorology at the University of Belgrade and defended his Ph.D. Thesis in Dynamics Meteorology at the University of Belgrade. He is head of the Center for Meteorology and Environmental Modelling (CMEM) which is the part of the Association of Centers for Multidisciplinary and Interdisciplinary Studies (ACIMSI) of the University of Novi Sad where he has teaching activities. His main research interests are the surface processes and boundary layer meteorology with application to air pollution modelling and agriculture. Recently, he has developed an interest for (i) analysis of occurrence of the deterministic chaos at environmental interfaces and (ii) modelling the complex biophysical systems using the category theory.

## Contributors

**Josef Ackerman** is the Associate Dean of the Faculty of Environmental Sciences at the University of Guelph, Canada, where he administers an interdisciplinary faculty that serves all academic units at the university. He is an Associate Professor in the Department of Integrative Biology where he conducts research on the physical ecology of aquatic plants and animals, as well as environmental issues. Most of this research is focused on small-scale fluid dynamic and ecological processes. He holds adjunct faculty positions in the School of Engineering at Guelph and the Environmental Science & Engineering Programs at the University of Northern British Columbia. Before coming to Guelph, he was a faculty member at the UNBC, where he played a leading role in founding the university's environmental science and environmental engineering programs and held the Canada Research Chair in *Physical Ecology and Aquatic Science*. He is currently an Associate Editor of the journals *Limnology & Oceanography* and *Aquatic Sciences.*

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**Ana Cirisan** is a postgraduate student of Meteorology and Environmental Modelling at the Center for Interdisciplinary and Multidisciplinary Studies and Developmental Research (ACIMSI) at the University of Novi Sad, Serbia. She is a young researcher - scholarship holder on the project *Modelling and numerical simulations of complex physical sistems* ON141035 funded by Ministry of Science and Environmental Protection. Ana Cirisan is also included on the FP6 project (RRP-CMEP, ON043670) at the Center for Meteorology and Environmental Predictions, Faculty of Sciences, University of Novi Sad. Her main research interest is the numerical weather forecast and modeling of atmospheric processes.

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**Sergio De Felice** was graduated with honours in 2004 in Civil Engineering, major Hydraulics, at the University of Napoli *Federico II*, Italy, defending a research thesis about *Interactions between turbulent boundary layer and vegetated surfaces through LDA technique*. He received his PhD in 2009 from the same University defending the thesis *Experimental study on the hydrodynamic characteristics of a vegetated channel*. His publication record holds 11 products, including: 4 textbooks, 1 paper in a national journal, 4 papers in international conferences, and 2 papers in national conferences. His research interests are: tuning and implementation of LDA devices and Labview systems, turbulent flows, boundary layer flows, vegetated beds flows.

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**Vladimír Fuka** is currently a Ph.D. student of meteorology at Department of Meteorology and Environment Protection, Faculty of Mathematics and Physics, Charles University in Prague, Czech Republic. His dissertation topic deals with the airflow modelling in the complex geometry areas with the main stress given to turbulence. He presented results of his work at several international meetings.

**Timothy Ginn** graduated from Purdue University, USA, with a Ph.D. in Civil Engineering in 1988 and is now Professor in the Faculty of Civil and Environmental Engineering at University of California, Davis, USA. Before joining the UC Davis Faculty in 1996, Dr. Ginn was employed as a senior research scientist at the Pacific Northwest National Laboratory of the U.S. Department of Energy. His research integrates modeling approaches into collaborative efforts targeting multicomponent and multiphase fate and transport, in the contexts of contaminant hydrology, population dynamics, water disinfection, colloid filtration, groundwater age, and inverse problems.

**Peter Green** is from the University of California, Davis, USA, where has been a researcher in the Department of Civil and Environmental Engineering since 2000. His degrees are in Chemistry from Stanford University and the Massachusetts Institute of Technology, and he works on a variety of water quality and air quality projects, including collaborations with ecologists and clinical researchers. Current research covers organic pollutants (volatile and non-volatile) as well as metals other than mercury. Ongoing projects involve mercury and children's health. A 2006 publication on the microbial methylation of mercury has been widely cited.

**Branko Grisogono** got his B.S. and M.S. in physics, geophysics with meteorology at the University of Zagreb, Croatia, in 1983 and 1987,