

ATMOSPHERE—OCEAN INTERACTIONS

VOLUME 2

WIT*PRESS*

WIT Press publishes leading books in Science and Technology.

Visit our website for the current list of titles.

www.witpress.com

WIT*eLibrary*

Home of the Transactions of the Wessex Institute, the WIT electronic-library provides the international scientific community with immediate and permanent access to individual

papers presented at WIT conferences. Visit the WIT eLibrary at

<http://library.witpress.com>

International Series on Advances in Fluid Mechanics

Objectives

The field of fluid mechanics is rich in exceptional researchers worldwide who have advanced the science and brought a greater technical understanding of the subject to their institutions, colleagues and students.

This book series has been established to bring such advances to the attention of the broad international community. Its aims are achieved by contributions to volumes from leading researchers by invitation only. This is backed by an illustrious Editorial Board who represent much of the active research in fluid mechanics worldwide.

Volumes in the series cover areas of current interest and active research and will include contributions by leaders in the field.

Topics for the series include: Bio-Fluid Mechanics, Biophysics and Chemical Physics, Computational Methods for Fluids, Experimental & Theoretical Fluid Mechanics, Fluids with Solids in Suspension, Fluid-Structure Interaction, Geophysics, Groundwater Flow, Heat and Mass Transfer, Hydrodynamics, Hydronautics, Magnetohydrodynamics, Marine Engineering, Material Sciences, Meteorology, Ocean Engineering, Physical Oceanography, Potential Flow of Fluids, River and Lakes Hydrodynamics, Slow Viscous Fluids, Stratified Fluids, High Performance Computing in Fluid Mechanics, Tidal Dynamics, Viscous Fluids, and Wave Propagation and Scattering.

Series Editor

M. Rahman

DalTech, Dalhousie University, Halifax,
Nova Scotia, Canada

Assistant Series Editor

M.G. Satish

DalTech, Dalhousie University, Halifax,
Nova Scotia, Canada

Honorary Editors

C.A. Brebbia
Wessex Institute of Technology
UK

L.G. Jaeger
DalTech, Dalhousie University
Canada

L. Debnath
University of Texas-Pan American
USA

Associate Editors

E. Baddour
National Research Council of Canada
Canada

R. Grimshaw
Loughborough University
UK

S.K. Bhattacharyya
Indian Institute of Technology
Kharagpur, India

R. Grundmann
Technische Universität Dresden,
Germany

A. Chakrabarti
Indian Institute of Science
India

R.C. Gupta
National University of Singapore
Singapore

S.K. Chakrabarti
Offshore Structure Analysis, Inc
USA

D. Hally
Defence Research Establishment
Canada

M.W. Collins
Brunel University West London
UK

M.Y. Hussaini
Florida State University
USA

G. Comini
Università di Udine
Italy

D.B. Ingham
University of Leeds
UK

J.P. du Plessis
University of Stellenbosch
South Africa

S. Kim
University of Wisconsin-Madison
USA

H.J.S. Fernando
Arizona State University
USA

B.N. Mandal
Indian Statistical Institute
India

T. Matsui
Nagoya University
Japan

A.C. Mendes
Universidade de Beira Interior
Portugal

T.B. Moodie
University of Alberta
Canada

M. Ohkusu
Kyushu University
Japan

E. Outa
Waseda University
Japan

W. Perrie
Bedford Institute of Oceanography
Canada

H. Pina
Instituto Superior Tecnico
Portugal

H. Power
University of Nottingham
UK

D. Prandle
Proudman Oceanographic Laboratory
UK

K.R. Rajagopal
Texas A & M University
USA

D.N. Riahi
University of Illinois-Urbana
USA

P. Škerget
University of Maribor
Slovenia

G.E. Swaters
University of Alberta
Canada

P.A. Tyvand
Agricultural University of Norway
Norway

R. Verhoeven
Ghent University
Belgium

M. Zamir
The University of Western Ontario
Canada

ATMOSPHERE—OCEAN
INTERACTIONS
VOLUME 2

Edited by

W. Perrie

Bedford Institute of Oceanography, Canada

WITPRESS Southampton, Boston



OCEAN—ATMOSPHERE INTERACTIONS
VOLUME 2

Series: Advances in Fluid Mechanics, Vol. 39

Edited by

W. Perrie

Bedford Institute of Oceanography, Canada

Published by

WIT Press

Ashurst Lodge, Ashurst, Southampton, SO40 7AA, UK

Tel: 44 (0) 238 029 3223; Fax: 44 (0) 238 029 2853

E-Mail: witpress@witpress.com

<http://www.witpress.com>

For USA, Canada and Mexico

WIT Press

25 Bridge Street, Billerica, MA 01821, USA

Tel: 978 667 5841; Fax: 978 667 7582

E-Mail: infousa@witpress.com

<http://www.witpress.com>

British Library Cataloguing-in-Publication Data

A Catalogue record for this book is available
from the British Library

ISBN: 1-85312-929-1

ISSN: 1353-808X

Library of Congress Catalog Card Number: 2001096403

No responsibility is assumed by the Publisher, the Editors and Authors for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products, instructions or ideas contained in the material herein.

© WIT Press 2006.

Printed in Great Britain by *****

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of the Publisher.

Contents

Preface	xiii
Chapter 1	
On parameterizations of air–sea fluxes.....	1
<i>W.M. Drennan</i>	
1 Introduction.....	1
2 Turbulent fluxes and the Monin–Obukhov similarity theory.....	2
3 Measuring turbulent fluxes	5
3.1 Direct methods	5
3.2 Indirect methods—inertial dissipation	6
3.3 Indirect methods—profile	7
3.4 Indirect methods—bulk.....	7
4 Field data.....	8
5 Momentum flux.....	11
5.1 Light winds: gustiness and smooth flow	11
5.2 The effect of sea state: wave age and steepness.....	13
5.3 Sea state effects: swell.....	17
6 Scalar fluxes	20
7 Discussion.....	23
Chapter 2	
Satellite-based observations of surface turbulent stress during severe weather.....	35
<i>M.A. Bourassa</i>	
1 Introduction.....	35
2 Satellite observations of surface winds.....	37
2.1 Physics of scatterometry.....	37
2.2 Calibration and equivalent neutral winds.....	39
2.3 Determining stress from scatterometer winds	40
3 <i>In situ</i> data.....	40

4	Flux model	41
4.1	Momentum roughness length	42
4.2	Displacement height	43
5	Comparisons with observations	44
6	Applications to scatterometry	47
7	Conclusions.....	47

Chapter 3

Similarity and dissimilarity in air–sea momentum and CO₂ transfers: the nondimensional transfer coefficients in light of the windsea

Reynolds number	53
------------------------------	-----------

Y. Toba, S. Komori, Y. Suzuki & D. Zhao

1	Introduction.....	54
2	Present status of air–sea transfer coefficients.....	56
2.1	Momentum transfer (drag) coefficient	56
2.2	CO ₂ transfer velocity.....	57
3	Wind–windsea equilibrium and nondimensional windsea boundary layer variables.....	58
3.1	Wind–windsea equilibrium: similarity laws of windsea	58
3.1.1	The 3/2-power law.....	59
3.1.2	One-dimensional windsea frequency spectral form.....	60
3.1.3	Physical implications	60
3.2	Fundamental dimensional considerations	61
3.3	Windsea Reynolds number: fundamental parameter of the windsea boundary layer.....	62
4	Drag coefficient in light of the windsea Reynolds number.....	64
4.1	Laboratory data: laminar–turbulent boundary layer transition.....	64
4.2	Field data: shift of critical point with dynamical contamination.....	68
5	Nondimensional CO ₂ transfer velocity as a function of the windsea Reynolds number.....	71
5.1	Nondimensional CO ₂ transfer velocity.....	71
5.2	Similarity and dissimilarity between momentum and gas transfers.....	72
5.3	Similarity in laboratory and field data relating C _D and k _L	74
6	Conclusions.....	75

Chapter 4
Applications of synthetic aperture radar in marine meteorology 83
T.D. Sikora, G.S. Young, R.C. Beal, F.M. Monaldo & P.W. Vachon

1	Introduction.....	83
1.1	Horizontal scales of atmospheric processes	84
1.2	Turbulent transfer and SAR	84
2	SAR image analysis in the study of marine meteorological phenomena.....	86
2.1	Microscale phenomena.....	86
2.1.1	Convective cells.....	86
2.1.2	Buoyancy-driven/shear-organized roll vortices.....	88
2.1.3	Inflection-point-induced rolls	89
2.1.4	Shear-driven gravity waves	89
2.2	Mesoscale phenomena.....	90
2.2.1	Topographically driven gravity waves	90
2.2.2	Mesoscale convective cells.....	91
2.2.3	Polar mesoscale cyclones.....	94
2.2.4	Tropical cyclones.....	94
2.3	Macroscale phenomena.....	99
2.3.1	Fronts.....	99
2.3.2	Extratropical cyclones	100
3	SAR-generated near-surface wind speed images.....	102
3.1	Alaska SAR demonstration	105
4	SAR meteorology: a historical perspective and a look into the future	105

Chapter 5
Relationship between oceanic energy fluxes and surface winds during tropical cyclone passage 115
L.K. Shay & S.D. Jacob

1	Introduction.....	116
2	Observations	120
2.1	Wind structure.....	120
2.2	Velocity profiles.....	121
2.3	Maximum energy levels.....	121
3	Vertical wavenumber spectra.....	122
3.1	Garrett–Munk comparisons.....	123
3.2	Rotary spectra.....	123
3.3	Energy partitioning.....	124
3.4	Energy fluxes.....	125
4	Relationship to forcing structure.....	127
4.1	Approach.....	127
4.2	Comparisons.....	129

5	OML current simulations	132
5.1	Model configuration	132
5.2	Surface stresses	132
5.3	Comparisons.....	133
6	Concluding remarks	137
Chapter 6		
Midlatitude storm impacts on air–sea CO₂ fluxes		143
<i>W. Perrie, W. Zhang, X. Ren, Z. Long & J. Hare</i>		
1	Introduction.....	143
2	Model description	144
3	Case study: extratropical Hurricane Gustav	145
4	Air–sea gas transfer velocity.....	149
5	Gas transfer velocity and CO ₂ air–sea flux	150
6	Concluding remarks	151
Chapter 7		
Extratropical transition of tropical cyclones in the North Atlantic		155
<i>J.L. Evans & R.E. Hart</i>		
1	Introduction.....	156
2	A basic primer on TC formation and structure	158
3	Atlantic TC and ET climatology	159
4	Intraseasonal and interbasin variation in ET and proposed favorable environments.....	164
5	A typical Atlantic ET case study: Hurricane Floyd (1999).....	167
6	Operational definitions of ET onset and completion.....	171
6.1	Identification of ET onset.....	171
6.2	Identification of ET evolution and completion.....	172
6.3	Definition of ET onset and completion using the CPS.....	172
6.3.1	Hurricane Floyd (1999)	174
6.3.2	Tropical storm Hernan (2002) and Hurricane Bonnie (1998).....	175
6.4	Storm life cycle mapped in terms of the CPS.....	178
7	Summary	179
Chapter 8		
Historical and possible future changes of wave heights in northern hemisphere oceans		185
<i>X.L. Wang & V.R. Swail</i>		
1	Introduction.....	186
2	Datasets and methodologies.....	186
2.1	Datasets	186
2.2	Redundancy analysis	188

2.3	GEV analysis.....	189
2.4	Trend analysis	190
3	Historical changes of wave heights.....	192
4	Climate change scenarios of wave heights.....	199
4.1	Wave height climate change scenarios for the North Atlantic	202
4.2	Wave height climate change scenarios for the North Pacific	205
5	Concluding remarks	210
Index	219

Preface

The purpose of this second volume on atmosphere–ocean interactions is to present several of the key mechanisms that are important for the development of marine storms. Understanding atmosphere–ocean interactions has taken on increased importance in recent years, as increased levels of population and human development are reached in coastal areas. Human activities that depend on the oceans, for a variety of interests, require improvements in operational forecasts for marine weather and ocean conditions, and associated marine climate. Factors influencing storm intensity and development are related to small-scale atmosphere–oceanic features. Large-scale climate change may affect environmental factors related to storm climatologies. These topics are presented as separate chapters that are self-contained, to a large extent.

The book consists of eight chapters. Chapters 1–5 are concerned with marine observations and understanding their parameterizations as they relate to atmosphere–ocean systems. Chapters 6–8 consider some of the implications of these parameterizations, as related to applications in coupled atmosphere, ocean, and wave model systems.

Chapter 1 presents a review of the state of the art of parameterizations for air–sea turbulent fluxes. A data set of eddy-correlation fluxes compiled during eight field experiments, and representing a wide range of conditions, is used to investigate traditional bulk flux parameterizations (i.e., wind-speed dependent momentum coefficient, constant sensible and latent heat coefficients), including the effects of sea state. Chapter 2 examines the influence of waves on surface stress and related parameterizations of momentum roughness length. Wave-related impacts on the near surface atmospheric boundary conditions are also considered. In light of laminar–turbulent regimes at the air–sea interface related to local wind and wind waves, Chapter 3 considers the challenge of deriving a better parameterization for the CO₂ transfer between the atmosphere and the oceans. Consideration is given to nonlinear coupling of waves with local wind drift and turbulence, caused by the wind and wind-wave breaking at the air–sea interface. Chapter 4 reviews the marine meteorological capacities of synthetic aperture radar (SAR), particularly the attributes of its potential in the study of air–sea interaction. Examples include marine meteorological phenomena routinely imaged by SAR such as microscale cellular convection, microscale roll vortices, microscale gravity waves, mesoscale gravity waves, mesoscale convection, polar mesoscale cyclones, tropical cyclones, macroscale fronts,

and extratropical cyclones. Chapter 5 reviews the three-dimensional current and temperature structures excited by the passage of tropical cyclones, over the scales of the atmospheric forcing. Relations between the internal wave fluxes and atmospheric winds are shown to be consistent with established observations and parameterizations of the air–sea momentum flux. Chapter 6 applies established parameterizations for air–sea fluxes of heat and momentum to coupled ocean–atmosphere wave simulations for hurricanes and investigates the sensitivity of estimates of air–sea CO₂ exchange rates as influenced by storm-related processes. Chapter 7 considers extratropically transitioning tropical cyclones beginning from their tropical formation, the conditions under which they evolve, and their spatial and temporal distributions. The discussion includes the need for synoptic support for the initial intensification of tropical cyclones, followed by a strong energy source as transition occurs. Chapter 8 estimates changes of wave heights, based on observed and possible future changes in the North Atlantic and in the North Pacific. Both oceans had significant changes in both winter and fall seasonal means and extremes of significant wave heights during 1958–1997; they are also projected to have significant changes in the 21st century. The rate and sign of the projected future changes appear to be quite dependent on the forcing conditions, and the rate of increase in the greenhouse gases forcing.

I am very thankful to my colleagues for their invaluable contributed chapters, without which this book would not be possible, to Drs. Peter Smith and John Loder at BIO for encouraging me to bring together this volume, to Prof. Matiur Rahman at Dalhousie University for supporting me in the preparation of this volume, and to the Panel on Energy Research and Development of Canada for providing funding support for this project. I would like to dedicate the volume to my wife Chi and family for their continuing patience, and to the memory of my parents, John and Clara Perrie.

W. Perrie
Dartmouth, Nova Scotia
2006