Hydroclimatology

Perspectives and Applications

Hydroclimatology provides a systematic structure for analyzing how the climate system causes time and space variations (both global and local) in the hydrologic cycle. Changes in the relationship between the climate system and the hydrologic cycle underlie floods, drought, and possible future influences of global warming on water resources. Land-based data, satellite data, and computer models contribute to our understanding of the complex time and space variations of physical processes shared by the climate system and the hydrologic cycle.

Blending key information from the fields of climatology and hydrology – which are not often found in a single volume – this is an ideal textbook for students in atmospheric science, hydrology, Earth and environmental science, geography, and environmental engineering. It is also a useful reference for academic researchers in these fields.

MARLYN L. SHELTON is Professor Emeritus of Atmospheric Science at the Department of Land, Air and Water Resources, University of California, Davis, USA. He is a member of the American Water Resources Association, the Association of American Geographers, and the Association of Pacific Coast Geographers. He has been elected as a Woodrow Wilson Dissertation Fellow and a Fellow of the Ohio Academy of Science. He has authored and co-authored 4 previous books, published numerous scientific papers, and served as an associate editor for the *Journal of the American Water Resources Association* from 1991 to 1999. He has given interviews to newspapers and television stations on topics such as climate change, EI Niño, floods, drought, and air quality, and has presented lectures and workshops for the US Forest Service and the Natural Resources Conservation Service.

Hydroclimatology

Perspectives and Applications

MARLYN L. SHELTON
University of California, Davis, USA

CAMBRIDGE UNIVERSITY PRESS

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, São Paulo, Delhi

Cambridge University Press
The Edinburgh Building, Cambridge CB2 8RU, UK

Published in the United States of America by Cambridge University Press, New York

www.cambridge.org
Information on this title: www.cambridge.org/9780521848886

First published 2009

Printed in the United Kingdom at the University Press, Cambridge

A catalog record for this publication is available from the British Library

Library of Congress Cataloging in Publication data
Shelton, Marlyn L.
Hydroclimatology : perspectives and applications / M. L. Shelton.
p. cm.
Includes bibliographical references.
ISBN 978-0-521-84888-6
1. Hydrologic cycle. 2. Climatology. 3. Hydrometeorology. I. Title.
GB848.S54 2009
551.48–dc22

2008040772

ISBN 978-0-521-84888-6 hardback

Contents

Preface

Droughts, floods, heatwaves, and other extreme weather events often have disastrous consequences for society and for the infrastructure that provides our goods and services. An increasing global population with an increasing population occupying areas subject to extreme weather events has heightened awareness of the potential impact of climate and weather and extreme events on our daily lives. This new awareness is occurring at a time when a consensus in the scientific community supports the idea of climate change and that at least a part of the change in recent decades is due to human activity. Against this backdrop we have advances in satellite and computer technology that permit us to examine natural processes in ways that were not possible in the recent past. Hydroclimatology is an area that benefits from these advances as it endeavors to improve understanding of the linkages between the climate system and the hydrologic cycle.

A global view provides a sense of the immensity and complexity of the Earth's climate system and the hydrologic cycle. An important suite of climatic processes involves atmospheric moisture, atmospheric energy storage in the form of latent heat, and energy transport by the atmosphere. The heating and cooling of the atmosphere and atmospheric motion define a climatic perspective easily related to the atmospheric branch of the hydrologic cycle that is dominated by moisture transport accomplished by the mobile atmosphere. At regional and local scales, additional processes are introduced into the climatic and hydrologic cycle perspectives as land surface differences exert strong influences on the exchanges of energy and mass between the Earth's surface and the atmosphere. Climate-related fluxes at the Earth's surface are vertically oriented, and hydrologic processes are altered by the character of soil and vegetation. The perspectives of climate and the hydrologic cycle at the Earth's surface have separate sets of variables that complement atmospheric processes but require different observational data.

Hydroclimate incorporates the atmosphere, the oceans, and the land surface and how these realms are coupled by exchanges of energy, mass, and momentum. A comprehensive treatment of the physical processes involved in linking the atmosphere, oceans, and land surface is complicated by our incomplete understanding of many of the natural processes and their variable nature at different time and space scales. Since many earth science sub-disciplines are involved, choices must be made to keep the topic manageable. Consequently, an effort is made in this book to provide a sense of the complexity and interconnectedness of hydroclimatic processes without going into excessive detail in any one area.

This book is intended for students studying atmospheric science and/or climatology and those specializing in hydrology. Chapters 1 and 2 set the conceptual structure of hydroclimatology. Two climate paradigms are introduced to complement the recognized atmospheric and terrestrial branches of the hydrologic cycle and their links with the climate system. Measurement and estimation of hydroclimatic variables are addressed in Chapters 3, 4, and 5. Atmospheric data in Chapter 3 are familiar to atmospheric science students, while data measurements at the Earth's surface covered in Chapter 4 are familiar to hydrology students. Remote sensing in Chapter 5 focuses on satellite and radar data specifically relevant to hydroclimatic analysis. Chapter 6 addresses the runoff process and is intended to provide background in hydrology for atmospheric science students. Hydrology students will benefit most from the spatial and temporal variability of atmospheric phenomena and the interaction of surface and atmospheric events emphasized in Chapters 7 and 8. Floods and drought, Chapters 9 and 10, respectively, provide opportunities for all students to examine the circumstances surrounding the occurrence of extreme weather events and the role played by complex atmospheric circulation features and distant climatic circumstances that influence these events.

The goal of this book is to promote understanding of hydroclimatic diversity, the link between climate and the water resource, and the possible influence of climate change on the future hydroclimate and water resource. Recent hydroclimatic studies utilize contemporary data observation methodologies and improved estimation techniques to achieve expressions of relevant variables. Complex scientific questions arise in efforts to understand the relationships between the climate system and the hydrologic cycle. The impacts of natural climate variability and human-induced change contribute to the complexity. Floods, drought, desertification, agriculture and food production, municipal and industrial water supplies, and water quality are some of the areas requiring carefully formulated plans for sustaining future development. Floods and drought addressed in Chapters 9 and 10 illustrate the character of the complex

problems. Faced with such challenges, hydroclimate provides a structure for systematic analysis of atmospheric, hydrologic, and biologic variables related to these areas of human concern.

The analytical perspective employed in this book is based on principles that portray hydroclimate as the relationship between flows or exchanges of energy and moisture between the atmosphere and the Earth's surface. The water balance provides the operational framework for characterizing hydroclimate, the spatial and temporal variations of hydroclimate, and hydroclimate resulting from altered future conditions. Real-world hydrologic events occur within the context of a history of climatic variations in magnitude and frequency. These events have the best chance of being understood when analyzed within the spatial framework of regional and global networks of changing atmospheric circulation patterns and land surfaces processes.

The late Professor Douglas B. Carter shared his vision of climate expression with me, and his vision became the foundation for the dual-climate paradigm developed in this book. The book concepts evolved from 10 years of teaching undergraduate and graduate students in ATM 115 and ATM 215 at the University of California, Davis. I profited greatly from student comments and from discussions with my colleagues at UC Davis for which I am grateful. I am indebted to David Jones who applied his professional skills in extracting data from many digital data archives and converting the data into attractive and informative global and regional maps. The competence, courtesy, and patience of Matt Lloyd and the other staff of the Cambridge University Press were invaluable in the preparation of this book.

This book is dedicated to my family. I am especially indebted to my wife, Sue, whose love, encouragement, understanding, and assistance were constant during the book's lengthy preparation. My son, Kirk, daughter-in-law, Rachel, and my grandchildren, Scott and Emma, are the promise that the continuing search for understanding of God's magnificent world is in good hands.