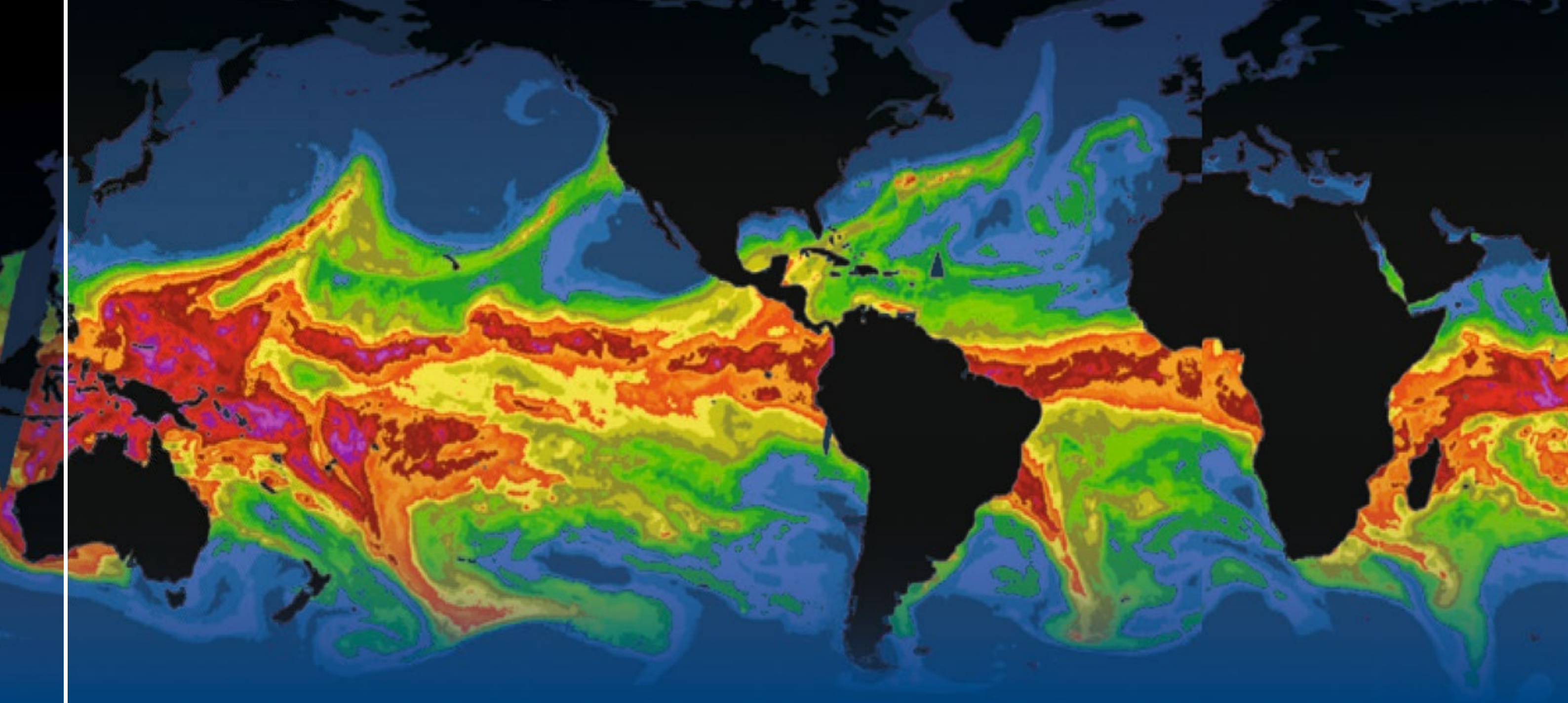

F. Martin Ralph · Michael D. Dettinger
Jonathan J. Rutz · Duane E. Waliser *Editors*

Atmospheric Rivers

Springer

Atmospheric Rivers

F. Martin Ralph • Michael D. Dettinger
Jonathan J. Rutz • Duane E. Waliser
Editors

Atmospheric Rivers

Springer

Editors
F. Martin Ralph
Center for Western Weather and Water Extremes
Scripps Institution of Oceanography
University of California–San Diego
La Jolla, CA, USA

Jonathan J. Rutz
Science and Technology Infusion Division
National Weather Service
Salt Lake City, UT, USA

Michael D. Dettinger
Retired, U.S. Geological Survey
Carson City, NV, USA

Duane E. Waliser
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA, USA

ISBN 978-3-030-28905-8 ISBN 978-3-030-28906-5 (eBook)
https://doi.org/10.1007/978-3-030-28906-5

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

This book is dedicated to those who came before us, who discovered these rivers in the sky, and to those who will ride them into the future.

Foreword

I agreed to write this foreword because I was motivated by the scope and breadth of the research related to atmospheric rivers (ARs) in this volume. It is my pleasure to recommend this scholarship, which represents the first comprehensive collection of research on the increasingly important phenomenon of ARs. It is both a benchmark for the field now and a springboard for future discoveries.

ARs are "increasingly important" because they are basic to extratropical dynamics of weather and climate and they are increasingly recognized as causes of precipitation totals and extremes in many regions of the world. This volume describes the observations, models, and analyses that are the basis of current understanding of ARs; their global distributions and impacts; the roles of ARs in extratropical meteorology and climatology; forecasting issues and the likely effects of climate change on future ARs; and some nascent applications of AR science.

As a result of research over the past 10 to 15 years, and rapidly advancing and heightened scientific and public awareness, we now know that a significant fraction of the annual precipitation on the western side of continents in the Northern and Southern Hemispheres, as well as extreme precipitation events, occurs in conjunction with landfalling ARs. As a result of those extreme precipitation events, from a practical and operational perspective, it is critical to be able to distinguish the smaller subset of ARs that may be associated with dangerously high-impact precipitation events from the larger and weaker group of ARs that pose no immediate danger to public safety.

For example, based on reliable records dating back to 1921, the all-time wettest water year (1 Oct–30 Sep) on record in northern California occurred during 2016–2017, when the northern Sierra's record rainfall occurred in conjunction with multiple landfalling ARs between December 2016 and April 2017. The record rainfall in February 2017 contributed to concerns about the safety of Oroville Dam on the Feather River. Water-level heights behind the Oroville Dam rapidly increased, damaging the main spillway as excessive water began to overtop it. As the rains continued, the emergency spillway was additionally damaged by erosion. This resulted in heightened concerns that a concrete weir around the dam could fail—which could have caused a devastating 10-meter-high wall of water to surge down into the Feather River and all the way to the Central Valley, potentially flooding communities downstream (see Chap. 7).

To facilitate the identification of this kind of high-impact AR, Ralph et al. (2019) have constructed an AR impact scale based on the magnitude and duration of the integrated water vapor transport (IVT) along ARs that should facilitate the identification of and communications about these ARs. This sort of scale is important because duration and IVT matter. I usually pay attention to ARs when the associated IVT first becomes >250 kg m^{-1} s^{-1}—and I give them my undivided attention when the IVT becomes >1000 kg m^{-1} s^{-1} (see detailed information on this AR scale in Chap. 8).

The last 10 to 15 years of AR research have also heightened the scientific community's understanding of important synoptic-scale and meso-scale aspects of ARs and have resulted in better knowledge of the relationships among ARs, tropical moisture exports (TMEs), and warm conveyor belts (WCBs) (see Chap. 2). This overall increased knowledge about ARs has culminated in the formal approval of an AR definition that appeared in the glossary of the

American Meteorological Society in 2017 (see Chap. 3, Sect. 3.1). This integration of AR science into these other, more traditional aspects of mid-latitude meteorology puts AR science on a firmer footing for future research and is described here by several of the leaders in the fields of AR, TME, and WCB science.

Of course, in the end, given these newly recognized risks of extreme precipitation and hazards that ARs can pose, and the key role in extratropical climate dynamics that they play, forecasting ARs is of growing importance. Currently, we are not able to properly forecast the global and regional distribution of ARs beyond a few days. This limitation is one likely source of the current limitations on predictability of precipitation amounts or types (e.g., snow, sleet, freezing rain, and rain). Verification studies of forecast models have shown that they can better predict the probability of precipitation rather than precipitation amounts or types. The practical implication of this is that precipitation amounts remain hard to forecast, so that forecasters are better able to distinguish between the occurrence of wet and dry days, and are somewhat less able to predict how much precipitation will fall, given the occurrence of a wet day. In an increasing range of settings globally, it is now recognized that forecasts of cold-season precipitation amount and type are limited by uncertainties about the following:

- the strength and location of upstream low- and upper-level jets
- the extent of the coupling between the low-level and upper-level jets
- where the nose of the low-level jet that transports AR moisture poleward will intersect a surface boundary
- the overall structure and configuration of the horizontal and vertical precipitation-producing circulations associated with a progressive upstream upper-level trough

AR representations and forecast ability in modern weather and climate models are described in Chap. 6.

As a result of these (and other) key findings and issues covered within, this book should appeal to a broad spectrum of readers interested in both basic and applied research opportunities, and in undergraduate and graduate education; operationally oriented readers; resource managers; and federal, state, and local emergency management officials as well as technically oriented public officials. Among these readers may be the next generation of AR researchers.

Lance Bosart
Distinguished Professor,
Department of Atmospheric and Earth Sciences,
University at Albany, SUNY

Preface

This book is intended to summarize the state of the science of atmospheric rivers (ARs) and its application to practical decision-making and broader policy topics. It is the first book on the subject and is intended to be a learning resource for professionals, students, and indeed anyone new to the field, as well as a reference source for all.

We first envisioned the book during the heady days of 2013 when the Center for Western Weather and Water Extremes was being planned and established. However, right from the start, we recognized that the effort required would exceed that of any single or couple of authors, and that the book would surely benefit from a broad range of perspectives and knowledge from a variety of leaders of atmospheric-river science from around the world. Consequently, the first step toward this book was to organize workshops addressing various aspects of AR science that we were able to co-opt, in part, for recruitment of, and discussions among, possible contributing authors. This led to the diverse authorship team that ultimately wrote this book, as well as our engagement of an experienced publication and book editing team. Among the strategies agreed to by the contributing authors, one key decision was that the book would focus mostly on results that have already been published and would emphasize figures and references from those formal publications. Where vital, new information has been developed and incorporated. Each chapter was led by a few expert lead authors recruited by the four of us, and those chapter leads recruited contributions from other experts on the chapter topic. Each chapter was reviewed by other specialists who were not part of its authorship team, generally including one highly technical expert and one reviewer intended to represent members of a broader audience. This helped ensure the accuracy of interpretations as well as high standards and accessibility of presentation. We, the editors of the book, reviewed all chapters at various stages of composition and layout.

Given currently high levels of interest in ARs in the scientific community as well as by the public, we hope that the book will be a useful starting place for many readers. Writing a book about a topic that is as new and that is advancing as quickly as AR science is today (in 2018) poses many difficult challenges but, with the help of the large team of expert authors who have contributed, we believe that, with this book, we are providing a firm foundation for future expansion and advances in this important field.

La Jolla, CA, USA	F. Martin Ralph
Carson City, NV, USA	Michael D. Dettinger
Salt Lake City, UT, USA	Jonathan J. Rutz
Pasadena, CA, USA	Duane E. Waliser

Acknowledgements

Co-Editors

- F. Martin Ralph, Editor-in-Chief (Scripps Institution of Oceanography, CW3E)
- Michael D. Dettinger (United States Geological Survey; Retired) *MDD's contributions in chapters 5 and 7 were undertaken as a research hydrologist for the U.S. Geological Survey Water Mission Area.*
- Jonathan J. Rutz (National Oceanic & Atmospheric Administration/National Weather Service)
- Duane E. Waliser (National Aeronautics and Space Administration/Jet Propulsion Laboratory) *DEW's contribution to this study was carried out on behalf of the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.*

The co-editors acknowledge the diligent efforts of all the authors and co-authors to the chapters of this book, without which—of course—this book would not exist. Thanks for sticking with us.

Chapter authors/contributing authors: Michael Alexander, Michael L. Anderson, Deniz Bozkurt, Gilbert Compo, Jason M. Cordeira, Dale A. Cox, Francina Dominguez, Bin Guan, Huancui Hu, Jay Jasperse, David A. Lavers, Alexander Gershunov, Irina Gorodetskaya, Bin Guan, Peter Knippertz, Paul J. Neiman, Kelly M. Mahoney, Benjamin J. Moore, William Neff, Florian Pappenberger, Alexandre M. Ramos, David S. Richardson, Lawrence J. Schick, Harald Sodemann, Ryan Spackman, Hans Christian Steen–Larsen, Andreas Stohl, Maria Tsukernik, Raúl Valenzuela, Maximiliano Viale, Andrew J. Wade, Heini Wernli, Allen B. White, Gary A. Wick, Ervin Zsoter

We acknowledge the generous support from the following entities that allowed this book to be conceived of, developed, and produced.

Funders/sponsors: This book would not have been possible without funding from the "Water Operations Technical Support: Research to Investigate Atmospheric Rivers (AR) and the Feasibility of Developing and Using AR Forecast Capabilities to Inform Reservoir Operations Within the USACE" project led by the Center for Western Weather and Water Extremes at UC San Diego's Scripps Institution of Oceanography. This Forecast-Informed Reservoir Operations program is sponsored by and collaboratively executed with researchers from the US Army Engineer Research and Development Center (ERDC) and water management professionals from the US Army Corps of Engineers (USACE).

We also acknowledge the persistence and efforts of the publication team who polished our contributions into this final form.

Publication team: Lauren Muscatine, Managing Editor (UC Davis), Mary Beth Sanders, Designer (Metography), Sheila Chandrasekhar, Developmental Editor (Persuasive Pages)

The co-editors would also like to acknowledge those individuals who provided guidance, critique, and mentorship throughout their careers.

Finally, the co-editors would like to acknowledge the original advance made by Yong Zhu and Reginald E. Newell (1998) who not only identified an intriguing and important phenomena for study, but were insightful enough to also provide a descriptive name that is well posed scientifically as well as attractive and intuitive for the broader community and public.

Contents

List of Figures