

2 7 KL15-HAL

An Introduction to Severe Storms and Hazardous Weather

Jeffrey B. Halverson
Illustrations by **Thomas D. Rabenhorst**



 **Routledge**
Taylor & Francis Group
LONDON AND NEW YORK

earthscan
from Routledge

Designed cover image: © Getty Images

First published 2024

by Routledge

4 Park Square, Milton Park, Abingdon, Oxon OX14 4RN

and by Routledge

605 Third Avenue, New York, NY 10158

Routledge is an imprint of the Taylor & Francis Group, an informa business

© 2024 Jeffrey B. Halverson

The right of Jeffrey B. Halverson to be identified as author of this work has been asserted in accordance with sections 77 and 78 of the Copyright, Designs and Patents Act 1988.

All rights reserved. No part of this book may be reprinted or reproduced or utilised in any form or by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying and recording, or in any information storage or retrieval system, without permission in writing from the publishers.

Trademark notice: Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation without intent to infringe.

British Library Cataloguing-in-Publication Data

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

ISBN: 978-1-032-38423-8 (hbk)

ISBN: 978-1-032-38424-5 (pbk)

ISBN: 978-1-003-34498-8 (ebk)

DOI: 10.4324/9781003344988

Typeset in Times New Roman
by Apex CoVantage, LLC



Printed and bound in Great Britain by
TJ Books Limited, Padstow, Cornwall

Contents

Acknowledgments xiii

PART I INTRODUCTORY PRINCIPLES 1

CHAPTER 1 Introduction to Severe Storms and Societal Impacts 3

- Introduction to Severe and Hazardous Weather 3
- Billion-Dollar Weather Disasters in Recent Years 4
- Geographical Distribution of Storms and Weather Hazards Across the United States 8
- Long-Term Trends in Weather Disasters 8
- U.S. Severe Weather Fatalities 9
- How This Book Is Organized 11
- Summary 12

CHAPTER 2 Meteorological Primer, Part I: Pressure and Wind Relationships 14

- Introduction 14
- Sea-Level Atmospheric Pressure Is the Weight of the Overlying Air Column 14
- Pressure Gradient Is the “Motor” That Generates Wind 15
- But There’s a Twist: Earth Spins, So We Must Introduce the Coriolis Effect 18
- Horizontal Variations in Air Temperature Give Rise to a Pressure Gradient 19
- Global Atmospheric Circulation: A Giant Atmospheric Heat Engine 20
- Giant Wind-Producing Systems, Called Extratropical Cyclones and Anticyclones, Are Generated by Waves in the Jet Stream 27
- Many Small-Scale Wind Circulation Systems Are Associated With the Generation of Severe Storms and High-Impact Weather 35
- Summary 44

CHAPTER 3 Meteorological Primer, Part II: Moisture and Precipitation in Storms 48

- Introduction 48
- Common Measures of Atmospheric Humidity: Dew Point Temperature and Relative Humidity 48
- How Air Becomes Saturated 52
- Growth of Cloud Droplets and Rain in Clouds 58
- Growth of Ice Crystals and Snow in Clouds 59
- Atmospheric Stability and the Formation of Thunderstorms and Layer Clouds 60
- Common Precipitation Types in Summer and Winter Settings 66
- Summary 71

Contents

CHAPTER 4	Meteorological Observations and Forecasting	75
	Introduction	75
	Surface Observations and Analysis Charts	75
	Upper-Air Observations and Charts	79
	Satellites Used in Meteorology	83
	Weather Radar and Lightning Detection	86
	Numerical Weather Prediction	92
	Forecast Offices and Specialty Prediction Centers	96
	Summary	98
PART II WEATHER HAZARDS GENERATED BY LARGE-SCALE ATMOSPHERIC VORTICES		101
CHAPTER 5	Structure, Energetics, and Climatology of Extratropical Cyclones vs Hurricanes	103
	Introduction	103
	Tropical Cyclones Include Both Tropical Storms and Hurricanes and Occasionally Impact the United States	107
	Beyond Purely Extratropical and Tropical Cyclones, There Is a Broad Spectrum of Cyclone Types That Can Transform From One to Another	110
	Extratropical and Tropical Cyclones Derive Their Energy From Different Sources	112
	Climatology of Tropical and Extratropical Cyclones	118
	Extratropical and Tropical Cyclones Produce a Characteristic Pattern and Type of Severe Weather Impacts	124
	Summary	131
CHAPTER 6	Genesis, Evolution, and Intensification of Extratropical Cyclones and Hurricanes	133
	Introduction	133
	Hurricane Genesis and Intensity	133
	Hurricane Intensification and Weakening	137
	Measures of Hurricane Strength, Size, and Energy	139
	Hurricanes and Climate Change	143
	Challenges of Making Accurate Hurricane Forecasts	145
	Development and Intensification of Extratropical Cyclones	152
	Extratropical Cyclones and Global Warming	153
	Extratropical Cyclone Mechanics: Fronts and Conveyor Belts	153
	Intense Extratropical Cyclones by U.S. Region	155
	Summary	165
CHAPTER 7	Winter Weather Hazards: Arctic Air Outbreaks, Nor'easters, Blizzards, Lake Effect Snow, and Ice Storms	168
	Introduction	168
	U.S. Distribution of Snow, Ice, and Cold Hazards	168
	Formation of Heavy Snow and Ice	174
	Sources of Subfreezing Air Required for Snow Formation	174
	Intense Snowstorms Created by Extratropical Cyclones	179
	Lake Effect Snows	189
	Ice Storms	193
	Forecasting Heavy Snow and Ice	194
	Snowfall Impact Scales	197
	Summary	200
CHAPTER 8	Landfalling Hurricanes: Coastal and Inland Devastation	202
	Introduction	202
	Hurricanes Weaken in a Characteristic Manner Moving Into Higher Latitudes and Over Land, While Producing Several Mechanisms of Coastal and Inland Damage	203

One of the Most Deadly and Destructive Elements in a Landfalling Hurricane Is the Storm Surge	205
Hurricane Wind Damage Has Several Aspects, Including a Sustained Wind Component and Periodic Gusts to Higher Wind Speed	211
Freshwater Flooding Is One of the Most Deadly Aspects of a Landfalling Tropical Cyclone	224
Tropical Cyclones Entering Their Post-Tropical Phase Can Still Create Devastating Inland Impacts	227
Summary	246

PART III SEVERE LOCAL STORMS AND THEIR WEATHER HAZARDS 249

CHAPTER 9 Structure and Evolution of Ordinary Thunderstorms	251
Introduction	251
There Are Three Types of Ordinary Thunderstorms: Single Cells, Multicells, and Squall Lines	251
Atmospheric Convection Moves Warm Air Upward, Sometimes Producing Hazardous Weather as a Result	253
Formation of Rainfall, Lightning, and the Downdraft Are Related Processes	254
High-Based Thunderstorms Are Common in the High Plains and Can Trigger Wildfires	256
Wind Shear – The Change in Winds With Altitude – Helps Organize and Strengthen Thunderstorms	258
The Life Cycle of a Single, Ordinary Thunderstorm Cell Is Well-Defined, With a Series of Stages	260
The Downdraft, Creating Surges of Strong Wind, Forms During the Thunderstorm’s Mature Stage	267
Multicell Thunderstorms Are Large, Long-Lived Ensembles of Single Thunderstorm Cells Evolving as a System	270
Squall-Line Thunderstorms Can Be Thought of as “Rolling Thunder”	273
Stratiform Rain Region in a Squall Line Produces Widespread Rain That Can Linger for Hours	276
The Climatology of Thunderstorms in the United States Is Characterized by Strongly Contrasting, Regional Variations	278
Summary	285
CHAPTER 10 Severe Thunderstorms, Emphasizing Supercells and Damaging Hail	287
Introduction	287
How a Thunderstorm Becomes Severe	287
Types of Severe Thunderstorms	288
Categories of Severe Weather Generated by Thunderstorms	289
Seasonal Occurrence of Severe Local Storms	291
Geographic Distribution of Thunderstorm Hazards	293
Supercells: The Severe Thunderstorm Archetype	295
Supercell Formation	302
Large and Damaging Hail	308
Societal Impacts of Severe Thunderstorms	313
Summary	319
CHAPTER 11 Tornadoes: Structure, Evolution, and Genesis	322
Introduction	322
Tornado Classifications	322
Fundamental Tornado Structure, Wind-Generating Forces, and Spin	323
Novel Insights Into Tornado Structure and Wind Speed	332
Tornado Wind Loads and Aerodynamic Forces Causing Structural Failure	336
Theories of Tornado Formation	340
Summary	354

Contents

CHAPTER 12 Tornado Outbreaks, Detection, Warning, and Societal Response 356
Introduction 356
U.S. Tornado Database: Surveying and Ranking Tornadoes 356
Tornado Climatology: Geography and Seasonality of U.S. Tornado Distribution and Frequency 363
Long-Term Trends in Tornado Frequency, Property Damage, and Mortality 367
Tornado Outbreaks, Past and Present: When Twisters Make the Evening News 369
Tornado Detection, Watches, and Warning 373
Tornadoes, Society, and the Media: Skywarn, Crowd Sourcing, and Pocket Doppler 381
Summary 385

CHAPTER 13 Violent Thunderstorm Downdrafts: Downbursts and Derechos 388
Introduction 388
First Blast of Wind: The Thunderstorm Gust Front 390
Deadly Bubble of Destruction: The Downburst 393
Types of Severe Thunderstorms Producing Downbursts 398
Derechos In-Depth 399
Societal Impacts of Downbursts and Derechos 411
Summary 415

CHAPTER 14 Science of Flash Floods 417
Introduction 417
Geographical Distribution and Nature of Flash Floods 418
Gathering Atmospheric Moisture: "Priming the Keg" for a Flash Flood 420
Common Types of Storm Systems That Produce Flash Floods 424
Summertime Mountain Flash Floods: Examples From the Rockies and Appalachians 432
Flash Flood Damages, Detection, and Trends 438
Summary 442

Afterword 444
Appendix: Heat Waves 445
Index 449