

Preface ix How to Use This Book xi New to This Edition xiii Acknowledgments xv

## CHAPTER 1: THE BASICS: METEOROLOGICAL ANALYSIS 1

Introduction 1

Measuring the Fundamentals: The Where, the When, and the Warmth  $\,2\,$ 

Spatial Scales: Going the Distance 2

Time Scales: Synchronized Sands Through the

Hourglass 3

Temperature Scales: A Matter of Degrees 3

Mathematical Tools: How to Crunch Numbers and Like It  $\,4$ 

Converting Units: Just for Good Measure 5 Scientific Notation: Reform School for Numbers 5 Statistics: From the Mean to the Extreme 7

Weather Analysis: Spatial Tools 9 Focus on Optics: Sky Lights 10

Topographic Maps: Elevating the Discussion on Isoplething 11

Isoplething Weather Data: Seeing the Forest from the

Trees 12
Caution! Gradient Ahead: Weather Conditions May
Change Rapidly 15

The Station Model: Templates of Local Observations 16 Weather Folklore and Commentary 20

### **CHAPTER 2: SOLAR AND TERRESTRIAL RADIATION 35**

Introduction 35

Radiation: The Good, the Bad, and the Ugly 35

The Electromagnetic Spectrum: More Than Meets the

*Eye* 35

Temperature and Radiation: The Movers and the Shakers 37

Balance of Radiation: The Ins and Outs of Energy 38

Heating the Atmosphere, From the Ground Up 40

The Solar Energy Budget: Savings and Loans 41

Focus on Optics: Why Is the Sky Blue? 41

Conduction and Convection: Touch and Go 42

The Greenhouse Effect: The Major Leagues of Atmospheric Heating 43

Satellite Imagery: Look, Up in the Sky, It's a Rocket, It's a Jet, No It's . . . 45

Visible Cloud Imagery: Say Cheese! 46

Infrared Satellite Imagery: It Goes Out Through the Atmospheric Window 48

Water Vapor Imagery: Near-Sighted Vision 49

Guidelines for Interpreting Clouds on Satellite Imagery 50

Radar: Echoes from a Storm (Not a Biography of MASH's Corporal O'Reilly) 50

Conventional Radar: Boomerang Microwaves 50 Doppler Radar: Conventional Radar Plus 51

#### **CHAPTER 3: TEMPERATURE 69**

Introduction 69

Seasons: Like a Pinball Game, They Depend on Tilt 69 Global Controllers of Temperature: Location, Location, Location 70

Latitudinal Gradients: Another Boxing Lesson 70

Ocean Currents: Giant Gyres that Team with the Wind 71

Weather Folklore: The Dog Days of Summer 71 More Uneven Heating: Land Versus Water 72

Temperature and Altitude: If Mountaintops Are Closer to

the Sun, Why Are They Colder? 73

A First Look at Fronts: At the Leading Edge of Hot and Cold 75

Temperature Measurement: The Right Way and the Wrong Ways 76

Thermometers: Keep Them in the Shade 76 Weather Folklore: Animal Thermometers 77 Focus on Optics: Subsuns and Sun Pillars: Magical Mirrors 79

### CHAPTER 4: SURFACE PATTERNS OF PRESSURE AND WIND 93

Introduction 93

Pressure as a Weight: How to Read the Scales 94

Correction to Sea Level: Getting Rid of Elevation 95

Isoplething Sea-Level Pressure: Seeing the Forest from
the Trees 96

Circulations of Air Around Highs and Lows: Some are Clockwise, Others are Not 98

Weather Folklore: Of Swallows and Bats 99

Pressure Gradient Force: The Leader of the "Pack" 99

Friction: Whoa Nellie! 100

Apparent Forces: Your Bottom Deceives You 100

Coriolis Force: As the World Turns 101

Surface Air Flow: Diagrams of Football Plays in

Meteorology 103

Fronts Revisited: Fitting into the Pressure Pattern 104

Upper-Air Weight Controls: Tipping the Scales 106 Focus on Optics: The Inferior Mirage: A Piece of the Sky 109

#### **CHAPTER 5: PRESSURE AND WIND PATTERNS** ALOFT 127

Introduction 127

Pressure Patterns Aloft: A Blueprint of the Sky 127 Patterns of Heights and Isobars Aloft: Telling the Same Story 129

Wind Directions Aloft: Hard-Hat Meteorology 129 The Geostrophic Wind: A Simple Survey of Air in Transit 130

Wind Speeds Aloft: Call the Plumber! 131 Continuity: A Universal Plumbing Principle 131 The Mid-Latitude Jet Stream: A Narrow Pipe Within a Broad Conduit 132

Jet Streaks: Constrictions in Already Narrow Plumbing Pipes 134

### CHAPTER 6: THE ROLE OF WATER IN WEATHER 153

Introduction 153

Hydrologic Cycle: Tortoise and the Hare 153

Water: You Can Check Out, But You Can Never Leave 155 Temperature: The Warden of Evaporation 155 Vapor Pressure Gradient: The Parole Board for Net Evaporation 156

Focus on Optics: The Color of Clouds: Of "Star Trek" and Milk 157

Invisible Moisture: The Gaseous Ghost That Appears as Clouds 157

Recipe for Clouds: A Little Mixing, A Little Cooling 158 Assessing Moisture: Making a Point about Dew Point 161 Weather Folklore: The Hair Hygrometer 164

### **CHAPTER 7: STABILITY, CLOUDS AND** PRECIPITATION 179

Introduction 179

A Test for Buoyancy: The Sky's the Limit 180 Stability: Nudge and Judge 180 Stability and Instability: Cold or Warm Bottoms 181 Latent Heat of Condensation: Keeping a Balanced Budget 183

Categorizing Clouds and Precipitation:

Stable Versus Unstable 184

Clouds and Precipitation in an Unstable Atmosphere: Heap-Like and Convective 185

Weather Folklore: Making Dew 186

Clouds and Precipitation in a Stable Atmosphere: Layered and Stratiform 187

When Convection Encounters a Stable Layer (or viceversa): Confrontational Clouds 187

Focus on Optics: The Superior Mirage: Phantom of the Arctic 188

### **CHAPTER 8: THUNDERSTORMS 201**

Introduction 201

Lightning and Thunder: Birthright of the Thunderstorm 201

Lightning Formation: The Shocking Truth 202

Thunder: Atmospheric Rumbles 203

Lightning Safety: Avoiding Hair-Raising Situations 205

Origins of Thunderstorms: To Be, or Not to Be 206 Instability and Lifting: The Preludes to Thunderstorm Development 206

Weather Folklore: Lightning Never Strikes the Same Place Twice 207

Thunderstorm Climatology: Blooming Where You're Planted 207

Air-Mass Thunderstorms: Convective Classics 210

Structure: A Life in Three Acts 211 The Mesoscale Convective Complex (MCC): Nocturnal Giant of the Plains 213

Thunderstorm Accessories: A Potpourri of Weather Dangers 216

Flash Flooding: The Number-One Thunderstorm Killer 216

Hail: The White Plague 219

Microbursts: Dangerous Breaths from the Skies 222

Postscript: Look Skyward 223

Focus on Optics: Rainbows: Branding the Sky 224

# CHAPTER 9: TROPICAL WEATHER, PART I: PATTERNS OF WIND, WATER AND WEATHER 239

Introduction 239

Hadley Cell: Monotonous Cycle 240

Asymmetric Trades: Kinks in the Necklace 241

Speedy Trades: A Hare in a Land of Tortoises 243

El Niño: The Trades Falter 245

The Tropical Eastern Pacific: Normally Chilled 245

El Niño: Changing of the Guard 246

Weather Impacts from El Niño: Near and Far 247

Postscript: Solving the Length-of-Day Mystery 249

Weather Commentary: Abnormal Is Actually Normal 250

### CHAPTER 10: TROPICAL WEATHER, PART II: HURRICANES 265

Introduction 265

Hurricanes: The Greatest Storms on Earth 267

Tropical Seas: Fueling Hurricane Engines 267

Low-Level Spin: Engaging Rotary Engines 269

Tuning Heat Engines: Sputtering to Humming 270

Weather Folklore: What a Difference a Day Makes 271

Latent Heat Feedback: Amplifying the Storm 271

Hurricane State Inspection: A Look Under the Hood 272

Subtropical Highs: The Steering Wheel for

Hurricanes 274

Hurricane Arsenal: Formidable Foe 275 Hurricanes: Passing the Baton of Heat 276

# CHAPTER 11: MID-LATITUDE I: LINKING SURFACE WITH UPPER-AIR PATTERNS 293

Introduction 293

Weight-Conscious Lows: High Intake with Strenuous Exercise 294

Assessing Upper-Air Convergence and Divergence: Air Parcels Become Figure Skaters 294 Upper-Air Vorticity Patterns: Putting a Different Spin on Ridges and Troughs 296

Staying Lean: Keeping the Weight Off 298

### CHAPTER 12: MID-LATITUDE II: THE CYCLONE MODEL 317

Introduction 317

Birth of a Low: Which Comes First, the Chicken or the Egg? 317

The First Domino Falls: Upper-Level Divergence 317 Cold and Warm Air Advection: A Follower and a Leader 318 Self-Development: Determining the Destiny of Low Pressure 319

Cold Advection: Dig That Trough! 320

Lows (and Highs) on the Move: Not Helpless Sticks in a Fishing Stream 320

Occlusion: The End of Weight-Watching 322

Cyclone Model Weather: As the Low Goes 324

Weather Ahead of an Approaching Warm Front: Lowering and Thickening Clouds 325

The Cold Conveyor Belt: On the Up and Up 326

Cold Front Weather: Curdling Clouds Above a Wedge of Cheese 326

Dry Conveyor Belt: Fools Rush in Where Angels Fear to Tread 328

Focus on Optics: Sun Dogs: Heeling at their Master's Side 330

## CHAPTER 13: MID-LATITUDE III: SPAWNING SEVERE WEATHER 363

Introduction 363

Mid-Latitude Lows: Striking the Match That Sparks Severe Weather 363

Vertical Wind Shear: A Referee That Keeps Updrafts and Downdrafts from Clinching 364

Attack Formations of Severe Thunderstorms:

Three-Pronged Assault 366

Squall Lines: Nature's Blitzkrieg 366 Derechos: Look Out Loretta! 366

Tornadoes: Last but Not Least 369

Mid-Latitude Lows: To Them, Air Masses Are Mere Pawns 369

Tuwns 309

Forecasting Tornadoes: Triangulating Targets Around Mid-Latitude Lows 371

Final Perspective on Severe Thunderstorms: The Media and Chicken Little 371

#### **CHAPTER 14: A CLOSER LOOK AT TORNADOES 387**

Introduction 387

Land of Tornadoes: There's a Time and a Place 388

Speed Vertical Wind Shear and More Tilting: Upping the Odds for Tornadoes 390

Stretching the Mesocyclone: Atmospheric Aerobics— "Twist, One, Two, Three" 391

May 3, 1999: A Day of Infamy in Central Oklahoma 393

The Chase: Close Encounters of the Tornadic Kind 394

Chasing Tornadoes: Driving into a Wall 395

Weather Instruments Versus Tornadoes: Getting Blown Away 396

Assessing Tornado Speeds: Giving Up the Chase 397

Tornado Safety: What to Do When a Twister Chases

Chasing Tornado Myths: Elusive Hearsay 398

Waterspouts, Fire Funnels, and Dust Devils: Whirlwind Cousins 400

Dust Devils: Tasmanian Devil 400

Waterspouts: Tasmanian Devils on the Sea 401 Funnels of Fire: Whirls of Hot Embers 401

Postscript 401

Weather Commentary: Are There More Tornadoes *Today?* 402

#### **CHAPTER 15: MID-LATITUDE IV:** NUMERICAL WEATHER PREDICTION 411

Introduction 411

Computer Simulations: Forecasting Gambit 412 Playing Weather on the Computer: There's No Avoiding "Gridlock" 413

Four-Panel Progs: X's and N's Instead of X's and O's 415 Model Consensus: All for One, and One for All 418 Forecaster's Motto: Know Thy Model's Limitations 419 The Aviation Model: Alternative Computing 421

Medium-Range Forecasting: Sticks in a Stream 421 Medium-Range Forecasting: The Cyclone Model Comes in Handy 422

Ensemble Forecasting: Spaghetti Plots 423

Seasonal Outlooks: Much More Than a Crystal Ball 424 Statistical Techniques: We End as We Began— Pattern Recognition 424

### **CHAPTER 16: MID-LATITUDE V: OPERATIONAL WEATHER FORECASTING 461**

Introduction 461

Temperature Forecasting: Where Have You Gone Joe DiMaggio? 461

Departures from Climatology: Out of the Ballpark 462 Temperature Forecasting for All Seasons: The Cal Ripkin of Forecasting Techniques 463

Predicting Warm-Season Highs: Like Stealing Signs from the Third-Base Coach 463

Predicting Cold-Season Highs: Relief from the Bullpen 464

Predicting Nighttime Lows: To Bunt or Swing for the Fences? 464

Apparent Temperatures: Heat Index and Wind Chill 467

Precipitation Forecasting During Summer: There's No Crying in Baseball (or Weather Forecasting) 468

There's Some Order in Chaos: Subtleties of the Game 468

Flash Floods: Suicide Squeeze 469

Forecasting Wintry Precipitation: Snow-Outs Instead of Rain-Outs 471

Forecasting Ice: Sleet Is Winter's Designated Hitter 472 Snowstorms: Like a Baseball Field, There Needs to be a "Dug Out" 474

Predicting Snow Accumulations: Stepping Up to the Plate With the Game on the Line 475

Forecasting Lake-Effect Snow: Like Trying to Hit a Knuckle Ball 477

Postscript: Apprentice Weather Forecasting 479

### **CHAPTER 17: THE HUMAN IMPACT ON WEATHER** AND CLIMATE 497

Introduction 497

The Enhanced Greenhouse Effect: Too Much of a Good Thing? 498

Carbon Dioxide: Better Watch Where You Put Your Carbon 498

Other Greenhouse Gases: Carbon-Copy Warming 500 Temperature Trends Over the Last Century: More Ups Than Downs 502

Global Warming: A Result of the Enhanced Greenhouse? 503

Future Trends: Modeling into the Unknown 505

Ozone Depletion: Not Enough of a Good Thing? 507 Weather Commentary: Why the Greenhouse Effect Is NOT Like a Blanket 507

Ozone: A Primer 508 CFCs: Revisited 508

The Antarctic Ozone Hole: Cold and Alone 510 A Wider View of Ozone: Global Trends 511

Land Use Change: Impact on Weather and Climate 513 Deforestation: Cutting Across Natural Cycles 513 The Climate of Cities: Islands Unto Themselves 514

Closing Thoughts: The Speed of Change 516 Focus on Optics: Red Skies and Volcanoes: Twilight Tides of Erupting Crimson 517

### **ELECTRONIC RESOURCES AND** ADDITIONAL PRINT RESOURCES 527

**GLOSSARY 531** 

INDEX 543