

Contents

Preface	ix
The Student Experience	x
Teaching Tools	xii
Acknowledgments	xiii

PART 1 The Basics 1

Chapter 1 Introduction to Climatology 3

Meteorology and Climatology	4
Scales in Climatology	6
Subfields of Climatology	6
Climatic Records and Statistics	7
Summary	9

Chapter 2 Atmospheric Structure and Composition 11

Origin of the Earth and Atmosphere	12
Atmospheric Composition	13
Carbon Cycle	13
Constant and Variable Gases	15
Faint Young Sun Paradox	16
Atmospheric Structure	17
Summary	21

PART 2 Climatological Processes 23

Chapter 3 Controls on the Climate System .. 25

Latitude	26
Earth–Sun Relationships	28
Revolution	28
Rotation	28
Axial Tilt and Parallelism	28
Combined Effect of Revolution, Rotation, and Tilt	29
Distance to Large Bodies of Water	32
Circulation	33
Pressure	34
Wind	36

Surface Versus Upper-Level Winds	41
Vertical Motion	41
Cyclones and Anticyclones	42
Oceanic Circulation	44
Topography	46
Local Features	46
Putting It All Together: Spatial and Seasonal Variations in Energy	47
Summary	49

Chapter 4 Atmospheric Interactions with the Other “Spheres” 53

Ocean Circulation	54
Surface Currents	54
Deep Ocean Thermohaline Circulations	57
El Niño–Southern Oscillation Events	59
Walker Circulation	60
Historical Observations of ENSO	62
El Niño Characteristics	63
La Niña Characteristics	64
Global Effects	65
Effects in the United States	67
Relationship to Global Warming	69
Climatic Feedbacks in the Ocean	69
Volcanic Activity and Climate	70
General Effects	70
Aerosol Indices	71
Deforestation and Desertification	71
Cryospheric Changes	73
Ice on the Earth’s Surface	73
Feedbacks in the Cryosphere	74
Summary	75

Chapter 5 Energy, Matter, and Momentum Exchanges near the Surface 79

Properties of the Troposphere	80
Near-Surface Troposphere	80
Energy in the Climate System	81
Sun as Energy Source	81
Measuring Radiant Energy	87

Radiation Balance	90	Locations and Strength of Surface Midlatitude Features	141
Turbulent Fluxes	92	Putting It All Together: Surface Pressure Patterns and Impacts	141
Substrate Heat Flux	92	Modifications to the Idealized General Circulation: Upper-Level Airflow and Secondary Circulations ..	142
Energy Balance	93	Vorticity	143
Local Flux of Matter: Moisture in the Local Atmosphere	93	Constant Absolute Vorticity Trajectory	145
Atmospheric Moisture	93	Flow Over Mountainous Terrain	146
Moisture in the Surface Boundary Layer	95	Baroclinicity	147
Measuring Evapotranspiration	96	Rossby Wave Divergence and Convergence	147
Atmospheric Statics, the Hydrostatic Equation, and Stability	97	Rossby Wave Diffluence and Confluence	148
Statics and the Hydrostatic Equation	97	Polar Front Jet Stream	149
Atmospheric Stability	98	Mean Patterns of Rossby Wave Flow	151
Assessing Stability in the Local Atmosphere	99	Summary	153
Momentum Flux	102		
Putting It All Together: Thermal and Mechanical Turbulence and the Richardson Number	102		
Summary	104		
		PART 3 Climates Across Space 155	
Chapter 6 Global Hydrologic Cycle and Surface Water Balance	107	Chapter 8 Climatic Classification	157
Global Hydrologic Cycle	108	Early Attempts at Global Climatic Classification ...	158
Surface Water Balance	110	Classical Age of Climatic Classifications	159
Potential Evapotranspiration	111	Modified Köppen Climatic Classification System ...	159
Evapotranspiration	114	Thornthwaite Climatic Classification System	164
Precipitation	114	Other Global Classification Systems	166
Soil Moisture Storage	121	Genetic Classifications	167
Deficit	122	Air Masses and Fronts	169
Surplus and Runoff	122	Classification of Fronts	171
Putting It All Together: A Worked Example of the Surface Water Balance	124	Local and Regional Classifications	173
Types of Surface Water Balance Models	125	Quantitative Analysis to Derive Climatic Types ...	174
Water Balance Diagrams	126	Eigenvector Analysis	174
Drought Indices	126	Cluster Analysis	175
Summary	128	Hybrid Techniques	176
		Summary	176
Chapter 7 General Circulation and Secondary Circulations	131	Chapter 9 Extratropical Northern Hemisphere Climates	179
Circulation of a Nonrotating Earth	132	Climatic Setting of North America	180
Idealized General Circulation on a Rotating Planet ..	133	General Characteristics	180
Hadley Cells	133	Severe Weather	180
Polar Cells	134	Role of the Gulf of Mexico and the Low-Level Jet	182
Planetary Wind Systems	134	Effect of Mountain Ranges	182
Modifications to the Idealized General Circulation: Observed Surface Patterns	137	Effect of the Great Lakes	183
Land–Water Contrasts	137	Ocean Currents and Land–Water Contrast	184
Locations and Strength of Features in the Hadley Cells	138	Climatic Setting of Europe	185
Locations and Strength of Features in the Polar Cells	139	General Characteristics	185
		Effect of Ocean Currents	185
		Effect of Mountain Ranges	186
		Blocking Anticyclones	186

Climatic Setting of Asia	187
General Characteristics	187
Monsoonal Effects	187
Effect of Mountain Ranges	188
Effect of Coastal Zones on Climate	189
Regional Climatology	189
B—Arid Climates	189
C—Mesothermal Climates	198
D—Microthermal Midlatitude Climates	211
E—Polar Climates	222
H—Highland Climates	223
Summary	224
Chapter 10 Tropical and Southern Hemisphere Climates	229
Contrasts Between Extratropical and Tropical Atmospheric Behavior	230
Contrasts Between Northern and Southern Hemisphere Atmospheric Behavior	230
Climatic Setting of Africa	231
General Characteristics	231
Intertropical Convergence Zone	231
Air Mass and General Circulation Influences	232
Indian Ocean Dipole	234
Climatic Setting of Australia and Oceania	234
General Characteristics	235
El Niño–Southern Oscillation Influences	235
South Pacific Convergence Zone	236
Madden-Julian Oscillation	237
Quasi-Biennial Oscillation	238
Climatic Setting of Latin America	238
ENSO Contributions	239
Climatic Setting of Antarctica	240
Regional Climates	242
A—Tropical Climates	242
B—Arid Climates	253
C—Mesothermal Climates	256
E—Polar Climates	262
H—Highland Climates	265
Summary	267

PART 4 Climates Through Time 271

Chapter 11 Climatic Change and Variability: A Paleoclimatic Overview 273

Climatic Changes in Geological History	276
Temperature	276
Ice Ages and Sea Level	280
Recent Trends	280

How Do We Know What We Know About Past Climatic Changes?	283
Basic Principles	283
Radiometric Dating	284
Lithospheric and Cryospheric Evidence	285
Biological Evidence	288
Historical Data	289
Converging Proxy Evidence	290
Natural Causes of Climatic Change and Variability	290
Continental Drift and Landforms	290
Milankovitch Cycles	291
Volcanic Activity	293
Variations in Solar Output	294
El Niño–Southern Oscillation Events	296
Summary	297

Chapter 12 Modern Climatic Change 301

Global Warming	302
Greenhouse Effect	302
Greenhouse Gases	302
Urban Heat Island	307
Direct and Indirect Effects of Global Warming	309
Global Warming: The Great Debate	309
Atmospheric Pollution	312
Global Dimming	313
Atmospheric Factors Affecting Pollution Concentrations	313
Air Quality Legislation in the United States	314
Classifying Air Pollutants	314
By Response	314
By Source	315
Reactions and Attitudes to Climatic Change	319
Prevention	319
Mitigation	319
Adaptation	320
Continued Research	320
Summary	320

Chapter 13 Linking Spatial and Temporal Aspects of Climate Through Quantitative Methods 325

Computerized Climate Models	326
Types of GCMs	327
Representing the Earth–Ocean–Atmosphere System in GCMs	327
Data for GCMs	330
Seven Basic Equations	330
Navier-Stokes Equations of Motion	330
Thermodynamic Energy Equation	332
Moisture Conservation Equation	333
Continuity Equation	333

Equation of State.....	334
Similarities and Differences Between GCMs and Weather Forecasting Models.....	335
Limitations of Model Results	336
Statistical Techniques	336
Atmospheric Teleconnections	337
Extratropical Teleconnections in the Pacific: The Pacific Decadal Oscillation.....	337
Extratropical Teleconnections in the Atlantic Ocean.....	339
Teleconnections over North America.....	342
Summary.....	342

PART 5 Relationships Between Climate and Other Endeavors 345

Chapter 14 Applied Climatology, Climate Impacts, and Climatic Data 347

Climate Impacts	348
Impacts on Natural Systems.....	348
Impacts on Societal Systems	349
Impacts on Human Health and Comfort.....	350
Climate Vulnerability, Adaptability, and Resilience	350
Climatological Data Sources	351
Data Collection Agencies	351

Primary Versus Secondary Data.....	352
Secondary Data Sources for Applied Synoptic and Dynamic Climatological Studies	352
Secondary Sources for Applied Studies of the Climate System	359
Secondary Sources Well Suited to Studies in Paleoclimatology and Climate Change	359
Secondary Sources Well Suited to Studies in Physical Climatology	359
Summary.....	362

Chapter 15 Future of Climatology 365

Relationship Between Climatology and Meteorology	365
Interdisciplinary Work with Other Scientists	366
Interaction Between Climate Scientists and Nonscientific Professionals.....	366
Improved Atmospheric Data Availability and Display.....	367
Recognition of the Possibility for Rapid Climate Change	368
Climatology as Part of the Ultimate Goal of Sustainability	368
Summary.....	370

Glossary 371

Index..... 398