

Climate Change

**THE SCIENCE OF
GLOBAL WARMING AND
OUR ENERGY FUTURE**

Second Edition

EDMOND A. MATHEZ and JASON E. SMERDON

COLUMBIA UNIVERSITY PRESS NEW YORK

CONTENTS

PREFACE *xi*

Prologue 1

Weather and Climate 1

The Climate System 2

Climate Change: Separating Facts from Fears 5

Thinking About the Future in the Face of Uncertainty 8

The Story 9

PART I. THE CLIMATE SYSTEM

1. The Atmosphere 13

The Composition of Air 13

The Compressibility and Pressure of Air 15

Mechanisms of Heat and Mass Transfer 16

The Thermal and Compositional Layering of the Atmosphere 21

The General (Global) Circulation of the Atmosphere 29

Key Points in This Chapter 40

2. The World Ocean 43

Important Properties of Water 44

The Ocean's Layered Structure 49

The Ocean's Surface Currents 53

Global Flows of Water Through the Ocean 57

The Hydrological Cycle 63

Key Points in This Chapter 65

3. Ocean-Atmosphere Interactions 69

Exchanges at the Ocean-Atmosphere Interface 69

The El Niño-Southern Oscillation 71

Other Modes of Ocean and Atmosphere Variability 88

Key Points in This Chapter 97

4. The Carbon Cycle and How It Influences Climate 101

- Reservoirs of Carbon 104
- The Carbon Cycle 105
- The Acidification of the Ocean 118
- Uncertainties in the Carbon Cycle 126
- Key Points in This Chapter 128

PART II. CLIMATE CHANGE AND ITS DRIVERS**5. The Concept of Radiation Balance, a Scientific Framework for Thinking About Climate Change 133**

- Electromagnetic Radiation 136
- The Greenhouse Effect 142
- Earth's Radiation Balance 143
- Geographical and Seasonal Variations in Energy Balance 152
- Key Points in This Chapter 160

6. Radiative Forcing, Feedbacks, and Some Other Characteristics of the Climate System 163

- Radiative Forcing 163
- Greenhouse Gases as Forcing Factors 164
- Aerosols 171
- Land-Use Change 174
- Natural Forcing Factors 175
- Feedbacks 182
- Tipping Points 188
- Committed Warming 189
- Key Points in This Chapter 190

7. Learning from the Climate of the Distant Past 193

- The Ice Age and Paleoclimatology 193
- Earth's Orbital Characteristics and Milankovitch Theory 197
- Five Million Years of Climate 202
- One Hundred Thousand Years of Climate Change 211
- A Lesson from the Distant Past: The Paleocene-Eocene Thermal Maximum 220
- Key Points in This Chapter 224

PART III. CONSEQUENCES OF CLIMATE CHANGE**8. The Climate of the Recent Past and Impacts on Human History 229**

- Climate Proxies 229
- Early to Mid-Holocene Climate Change and Human Development 238
- The Rise and Fall of Civilizations 246
- Key Points in This Chapter 260

9. Observing the Change 265

- A Century of Warming 266
- Precipitation and Drought 275
- Why Some Water Supplies Are in Jeopardy 283
- Severe Storms and Other Extreme Events 284
- The Sensitive Arctic 290
- Key Points in This Chapter 302

10. Greenland, Antarctica, and Sea-Level Rise 305

- Recent Sea-Level Rise and the Factors Contributing to It 306
- The Greenland Ice Sheet 313
- The Antarctic Ice Sheets 318
- Future Sea-Level Rise 321
- Key Points in This Chapter 328

PART IV. THE FUTURE**11. Climate Models and the Future 333**

- What Are Climate Models? 334
- Peering into the Future 346
- Responding to Our Climate Future 351
- Key Points in This Chapter 352

12. Climate Change Risk in an Unknowable Future 355

- Climate-Emissions Uncertainties 355
- What Is Risk? 357
- Some Properties of Climate Change Risk 360
- Climate Change and Human Strife 365
- Key Points in This Chapter 372

13. Energy and the Future 375

- Electricity Circa 2017 377
- Coal: A Vast Enterprise 380
- Natural Gas: A Bridge Fuel? 390
- The Nuclear Option 395
- Wind and Solar Power: Icons for the Future 404
- What About Hydropower? 413
- Intermittent Power and the Electrical Grid 416
- Key Points in This Chapter 418

Epilogue 421

NOTES 425

GLOSSARY 453

BIBLIOGRAPHY 463

INDEX 489