# Contents


Preface page ix
Introduction xi

CHAPTER 1 Weather Variables 1

1.1 Temperature 1
1.1.1 Heat and Temperature 2
1.1.2 Thermometers 3
1.1.3 Temperature Measurements 3
1.1.4 Temperature Scales 3
1.1.5 Radiosonde Profiles 4

1.2 Pressure 5
1.2.1 Force and Pressure 6
1.2.2 Atmospheric Pressure 7
1.2.3 Vertical Distribution of Pressure 7
1.2.4 Barometers 8
1.2.5 Pressure Units 9
1.2.6 Some Useful Numbers 9

1.3 Wind 10
1.3.1 Measuring Wind 10
1.3.2 Reporting Wind 12
1.3.3 Additional Sources of Wind Information 13

1.4 Precipitation 13

1.5 Weather Stations 14
Summary 16

CHAPTER 2 Spatial Representations of Weather Data 17

2.1 The Station Model 17

2.2 Surface Maps 20
2.2.1 Isotherms and Temperature Maps 20
2.2.2 Temperature Fronts 21
2.2.3 Isobars and Pressure Maps 22
2.2.4 Highs, Lows, Ridges, and Troughs 22

2.3 Upper-Level Maps 25

2.4 Radar 28

2.5 Satellites 29
2.5.1 Visible Satellite Images 30
2.5.2 Infrared Satellite Images 31
2.5.3 Water Vapor Images 32
2.5.4 Geostationary Satellites 33
2.5.5 Polar-Orbiting Satellites 35
Summary 38

Appendix 2.1 Important Satellite Cloud Signatures 39

Appendix 2.2 Contiguous USA Reference Map 41

CHAPTER 3 Our Atmosphere: Origin, Composition, and Structure 42

3.1 Aspect 42

3.2 Composition 42

3.3 Origin and Evolution 43

3.4 Future Evolution 45

3.5 Vertical Structure 47
Summary 49

Appendix 3.1 Dynamic Equilibrium 50

CHAPTER 4 Heat and Energy Transfer 51

4.1 Conduction 51

4.2 Convection 52

4.3 Radiation 53

4.3.1 The Nature of Electromagnetic Radiation 54
4.3.2 Temperature and Radiation 55

4.4 Radiative Interactions 55
4.4.1 Absorption 57
4.4.2 Reflection 57
4.4.3 Scattering 58
4.4.4 Radiative Equilibrium 58
4.4.5 Selective Absorbers 60
4.4.6 A Window to the Sky 60
4.4.7 The Greenhouse Effect 61

4.5 Radiation and Weather 66
4.5.1 Heat Imbalance 66
4.5.2 Seasonal Variations 68
4.5.3 Diurnal Variations 68
4.5.4 The Influence of Clouds 71
4.5.5 Land–Ocean Contrasts 72
Summary 73

**CHAPTER 5 Water 75**

5.1 The Water Cycle 75

5.2 Saturation 76

5.3 Humidity 77

5.4 Relative Humidity 78

5.5 Humidity and Temperature 79
5.5.1 Relative vs. Absolute Humidity 80
5.5.2 Condensation 80

5.6 Dew Point Temperature 82

5.7 Applications of the Dew point Temperature 83
5.7.1 Surface Weather Maps 83
5.7.2 Meteograms 85
5.7.3 Radiosonde Profiles 87
5.7.4 Back to Relative Humidity 87
5.7.5 How to Saturate 88
Summary 88

**CHAPTER 6 Cloud Formation 90**

6.1 Adiabatic Processes 92

6.2 Adiabatic Processes in the Atmosphere 93

6.3 Dry Adiabatic Lapse Rate 94

6.4 Relative Humidity 95

6.5 Moist Adiabatic Lapse Rate 96

6.6 Orographic Lifting 97

6.7 Lifting by Convergence 101

6.8 Frontal Lifting 101

6.9 Convection 102
6.9.1 Stable Air 102
6.9.2 Unstable Air and Thermals 104
6.9.3 Stable vs. Unstable 104
6.9.4 Fair-Weather Cumulus Clouds 106
6.9.5 Conditional Instability and Cumulonimbus 109
Summary 112

Appendix 6.1 A Cloud Family Album 113

**CHAPTER 7 Precipitation 117**

7.1 Warm vs. Cold Clouds 117

7.2 Collision and Coalescence 118

7.3 Ice-Crystal Growth 119

7.4 Precipitation Types 121
Summary 123

Appendix 7.1 Some Optical Phenomena 124

**CHAPTER 8 Wind 126**

8.1 Force and Acceleration 126

8.2 Pressure Gradient Force 127

8.3 Sea Breeze and Land Breeze 128

8.4 Coriolis Force 130

8.5 Geostrophic Wind 131

8.6 Gradient Wind 134

8.7 Surface Winds 135

8.8 Friction 138

8.9 Topography 140
8.9.1 Mountain Breeze and Valley Breeze 140
8.9.2 Katabatic Winds 143
Summary 143

**CHAPTER 9 Global Wind Systems 145**

9.1 The Averaged Atmosphere 146
9.1.1 Surface Temperature 146
9.1.2 Upper-Level Heights 148
9.1.3 Surface Pressure 151
9.1.4 Precipitation 151

9.2 The Single-Cell Model 152

9.3 The Three-Cell Model 154

9.4 Some Large-Scale Circulations 155
9.4.1 West Coast vs. East Coast 155
9.4.2 Antarctica 157
9.4.3 The Sahel 157
9.4.4 The Indian Monsoon 158
9.4.5 El Niño 159
Summary 165

**CHAPTER 10 Air Masses, Fronts, and Midlatitude Cyclones 167**

10.1 Air Masses 167

10.2 Fronts 168
10.2.1 Stationary Fronts 169
10.2.2 Cold Fronts 169
10.2.3 Warm Fronts 169
10.2.4 Occluded Fronts 170
10.2.5 Large-Scale Influences on Cyclone Structure, and the T-bone Model 171

10.3 Midlatitude Cyclone Development 172
10.3.1 The Life Cycle of a Midlatitude Cyclone 172
10.3.2 Vertical Structure of Cyclones 174
10.3.3 The February 2014 Cyclone 177
10.3.4 Where do Cyclones Form? 184
Summary 185

Appendix 10.1 Southern Hemisphere Midlatitude Cyclones 186

Appendix 10.2 The Bergen School of Meteorology 187

**CHAPTER 11 Thunderstorms and Tornadoes 188**

11.1 Ordinary Thunderstorm 188

11.2 Severe Thunderstorm 190

11.3 Lightning and Thunder 192

11.4 Supercells 193

11.5 Tornadoes 196
11.5.1 Description 196
11.5.2 Tornado Development 196

11.5.3 Tornado Alley 198
Summary 199

**CHAPTER 12 Tropical Cyclones 201**

12.1 Facts and Figures 201

12.2 Tropical Cyclone Structure 204

12.3 Tropical Cyclone Development 208
12.3.1 Tropical Easterly Wave 208
12.3.2 Tropical Depression 208
12.3.3 Tropical Storm 209
12.3.4 Tropical Cyclone (Hurricane) 210
12.3.5 Tropical Cyclone Decay 210

12.4 Conditions for Tropical Cyclone Development 211
Summary 211

**CHAPTER 13 Weather Forecasting 213**

13.1 Weather Forecasts and Uncertainty 214

13.2 Prognostic Equations 214

13.3 Ensemble Forecasting 217

13.4 Chaos and Weather Prediction 220

13.5 From Forecast Grids to Reliable Forecast Values 222

13.6 Making a Forecast 223
13.6.1 Medium to Long-Range Forecasting 224
13.6.2 Seasonal Outlook 226
Summary 226

**CHAPTER 14 Air Pollution 227**

14.1 Pollutants 227
14.1.1 Gases and Compounds 228
14.1.2 Particulates 228
14.1.3 Photochemical Smog 228

14.2 Wind and Stability 229

14.3 Large-Scale Patterns 232

14.4 Topography 232
Summary 233

**CHAPTER 15 Climate Change and Weather 234**

15.1 Past and Future 235

15.2 Changing Composition 236

15.3 A Warmer World 237

15.4 An Altered Water Cycle 237

15.5 Changing Global Wind Systems 239

15.6 Midlatitude and Tropical Cyclones in a Warmer World 240

15.7 Beyond Weather 241

15.8 The Forecast 241
Summary 242

**Glossary 244**
**References 256**
**Credits 257**
**Index 260**