Contents

Preface *page* xii
Acknowledgements xv

1 Introduction 1

1.1 Statistical Downscaling and Bias Correction in a Nutshell 2
1.2 How to Read This Book 5

Part I Background and Fundamentals

2 Regional Climate 9

2.1 Large- and Planetary-Scale Processes 9
2.2 Regional to Microphysical Processes 12
2.3 Regional Climate Variability and Change 13
2.4 Further Reading 15

3 History of Downscaling 16

3.1 Downscaling in Weather Forecasting 16
3.2 Concerns about Climate Change 17
3.3 Early Downscaling in Climate Research 17
3.4 The 1990s and 2000s 20
3.5 Recent Developments 21
3.6 Further Reading 23

4 Rationale of Downscaling 24

4.1 What Is Downscaling? 24
4.2 Statistical Aspects of Regional Climate 25
4.3 Requirements for a Downscaling Model 29
4.4 Requirements for the Downscaled Model 29
4.5 Further Issues 30
4.6 Further Reading 32

5 User Needs 33

5.1 Context 33
5.2 General Requirements 35
5.3 User Groups 36
5.4 User-Specific Needs 37
5.5 Further Reading 40

6 Mathematical and Statistical Methods 41

6.1 Random Variables and Probability Distributions 41
6.2 Parameter Estimation 55
6.3 Regression Models 61
6.4 Stochastic Processes 70
6.5 Pattern Methods 74
6.6 Further Reading 86

7 Reference Observations 87

7.1 Predictand Data 87
7.2 Predictor Data 93
7.3 Further Reading 95

8 Climate Modelling 96

8.1 Model and Simulation Types 96
8.2 Dynamical Core of General Circulation Models 100
8.3 Numerical Integration 107
8.4 Parameterisations 109
8.5 Performance of Climate Models 117
8.6 Further Reading 122

9 Uncertainties 123

9.1 Types of Uncertainties in Climate Projections 123
9.2 Assessment of Uncertainties 128
9.3 Further Reading 132

Part II Statistical Downscaling Concepts and Methods

10 Structure of Statistical Downscaling Methods 135

10.1 Perfect Prognosis versus Model Output Statistics 135
10.2 Deterministic and Stochastic Downscaling 137
10.3 Marginal, Temporal and Multivariate Structure 139
10.4 Further Reading 140

11 Perfect Prognosis 141

11.1 Assumptions 142
11.2 Methods 142
11.3 Structural Skill and Limitations of PP Methods 148
11.4 Predictands 155
11.5 Predictors 155
11.6 Model and Predictor Selection 164
11.7 A Cookbook for Developing a PP Model 166
11.8 Further Reading 169

12 Model Output Statistics 170

12.1 Terminology and Relationship with Numerical Weather Prediction 171
12.2 Bias Definition 172
12.3 Assumptions 173
12.4 Methods 173
12.5 Structural Skill and Limitations 179
12.6 Predictors 187
12.7 Bias Correction and Downscaling 188
12.8 Bias Correction and Mislocations 192
12.9 Modification of the Climate Change Signal 195
12.10 A Cookbook for Bias Correction 197
12.11 Further Reading 200

13 Weather Generators 201

13.1 Assumptions 201
13.2 Methods 202
13.3 Structural Skill and Limitations of Weather Generators 212
13.4 Using Weather Generators for Climate Change Projections 216
13.5 Further Reading 219

14 Other Approaches 220

14.1 Statistical-Dynamical Downscaling and Emulators 220
14.2 Separating Bias Correction and Downscaling 222
14.3 Further Reading 224

Part III Downscaling in Practice and Outlook

15 Evaluation 227

15.1 The Regional Climate Change Context 228
15.2 Evaluation Diagnostics 229
15.3 Standard Evaluation Experiments 231

15.4 Experiments to Evaluate Trends 233
15.5 Cross-Validation 236
15.6 Assessing Added Value 237
15.7 Evaluating Bias Correction Methods 238
15.8 Further Reading 241

16 Performance of Statistical Downscaling 242

16.1 Representing Marginal Aspects 243
16.2 Representing Temporal Aspects 245
16.3 Representing Spatial Aspects 250
16.4 Representing Multivariable Aspects 252
16.5 Representing Extremes 254
16.6 Representing Climate Change 257
16.7 Synthesis 258
16.8 Further Reading 262

17 A Regional Modelling Debate 263

17.1 Are Climate Models Fit for Purpose? 263
17.2 Can Bottom-Up Approaches Reduce Uncertainties? 266
17.3 Further Reading 268

18 Use of Downscaling in Practice 269

18.1 Assessing the Relevance of Climate Change 270
18.2 Assessing the Climate Information Requirements 270
18.3 Choosing the Driving GCMs 271
18.4 Choosing the Downscaling and Bias Correction Options 272
18.5 Interpretation of the Results 274
18.6 Need for Interdisciplinary Co-Operation 276
18.7 Preparing Data for Downscaling Portals 278
18.8 Climate Information Distillation 278
18.9 Ethical Responsibility 279
18.10 Further Reading 279

19 Outlook 281

19.1 Research to Complement Ongoing Downscaling Applications 282
19.2 Progress in Dynamical Modelling 285
19.3 Progress in Statistical Methods 286
19.4 Thinking Out of the Box 287
19.5 Concluding Remarks 288

Appendix A: Methods Used in This Book 290

Appendix B: Useful Resources 293

B.1 Statistical Downscaling Software Packages and Portals 293
B.2 Programmes and Initiatives 294
B.3 Observational Data Sets 296

References 303
Index 342