

CONTENTS

Preface	v
1. Introduction	1
1.1 History	1
1.2 The Lay-Out	3
1.3 Concepts and Definitions	3
1.3.1 The problem: What is downscaling and why downscaling	3
1.3.1.1 What is downscaling?	3
1.3.1.2 Why downscaling?	8
1.3.2 Notations	10
1.3.3 Definitions	12
1.3.4 Anomalies in ESD	18
1.4 Further Reading	19
1.5 Examples	19
1.6 Exercises	20
2. Downscaling Strategies	22
2.1 Different Approaches	22
2.1.1 Dynamical downscaling	22
2.2 Philosophy Behind ESD	24
2.2.1 Considerations	26
2.2.2 A physics-inspired view	32
2.2.3 A purely statistical view	34
2.3 What is “Skillful Scale”?	34
2.4 Further Reading	39
2.4.1 Dynamical versus empirical–statistical downscaling	39

2.5	Examples	41
2.5.1	Geostrophic balance	41
2.5.2	Basic preprocessing	41
2.6	Exercises	44
3.	Predictors and Preprocessing	45
3.1	Choosing Predictors	45
3.2	Circulation Indices	46
3.2.1	Stationarity	48
3.2.2	The North Atlantic Oscillation (NAO)	49
3.2.3	Autocorrelation and degrees of freedom	49
3.2.4	Empirical orthogonal functions	50
3.2.5	Varieties of EOF analysis	57
3.2.5.1	Rotated EOFs	57
3.2.6	Complex and frequency-domain EOFs	58
3.2.6.1	Complex EOFs	58
3.2.6.2	Frequency-domain EOFs	59
3.2.6.3	Extended EOFs	59
3.2.6.4	Mixed-field and common EOFs	59
3.2.7	EOF in ESD	60
3.3	Further Reading	61
3.4	Examples	62
3.4.1	Basic EOF analysis	62
3.4.2	Mixed-field EOFs	62
3.4.3	Extended EOFs	63
3.5	Exercises	64
4.	Linear Techniques	67
4.1	Introduction	67
4.2	Linear Multivariate Methods	69
4.3	Regression	70
4.3.1	Multivariate regression models	71
4.4	Canonical Correlation Analysis	73
4.4.1	Classical CCA	73
4.4.1.1	Linear relationships from the model based on CCA	75
4.5	Singular Vectors	76
4.6	Further Reading	78

4.7	Examples	78
4.7.1	CCA	80
4.8	Exercises	84
5.	Nonlinear Techniques	85
5.1	Introduction	85
5.2	The Analog Model	85
5.2.1	Caveats	86
5.3	Classification Methods	90
5.3.1	Cluster analysis	91
5.4	Neural Nets	93
5.5	Further Reading	93
5.6	Examples	96
5.6.1	Analog model (Fig. 5.8)	96
5.6.2	Clustering	97
5.7	Exercises	97
6.	Predictions and Diagnostics	98
6.1	Common Notations and Definitions	98
6.2	Predictions	99
6.3	Trends	100
6.3.1	Test for trends	101
6.3.1.1	Trend-testing based on Spearman rank coefficient	101
6.3.1.2	Mann–Kendall rank correlation statistics	101
6.3.1.3	Trend testing based on student’s <i>t</i> -test	102
6.4	Diagnostics	102
6.5	Statistical Inference	103
6.5.1	Confidence intervals for rejection	103
6.5.2	Student’s <i>t</i> -test	104
6.5.3	<i>F</i> -statistics	104
6.6	Quality Control	105
6.7	Model Skill	108
6.8	Evaluation Techniques	108
6.8.1	Anomalous correlation	109
6.8.2	The R^2 score	109
6.8.3	Root-mean-square-error	110

6.8.4	Representative statistical distributions	111
6.9	Cross-Validation	111
6.10	Further Reading	113
6.11	Examples (Fig. 6.7)	113
6.11.1	Illustration of cross-validation	113
6.11.2	Using ESD to validate cyclone counts	114
6.11.3	ESD to reconstruct historical climate records	116
6.11.4	The objDS-function	116
6.11.5	Prediction pattern	118
6.11.6	Simple trend-fit	120
6.11.7	Scatter plot and correlation	120
6.12	Exercises	120
7.	Shortcomings and Limitations	122
7.1	Level of Variability	124
7.2	Model Stationarity	125
7.2.1	“Perfect model” simulation	126
7.2.2	“Historical” simulation	126
7.2.3	Minimizing risk of nonstationarity	127
7.2.4	Consistency	128
7.2.5	Take-home messages	130
7.3	Examples	131
7.4	Exercises	133
8.	Reducing Uncertainties	134
8.1	Cascading Uncertainties	134
8.2	De-Trending in the Calibration	136
8.3	Using Different Predictands	138
8.4	Optimal Number of Predictors	138
8.5	Trends versus Time Slices	139
8.6	Domain Choices	141
8.7	Spatial Coherence	142
8.8	Projection of EOFs	144
8.9	The Common EOF Frame	144
8.9.1	Adjustment and bias corrections	146
8.10	Further Reading	146
8.11	The Example Illustrating Huth’s Paradox	148
8.12	Exercises	148

9.	Downscaling Extremes and PDFs	149
9.1	Outliers and Extremes	149
9.2	Robustness and Resistance	150
9.2.1	Estimators	151
9.3	Probability Density Functions	151
9.3.1	What is probability distribution and why use it?	151
9.3.2	Normal/Gaussian distribution	152
9.3.3	The exponential distribution	153
9.3.4	Gamma distribution	154
9.4	Extreme Values	156
9.4.1	iid-test	158
9.5	Downscaling Extreme Indices	160
9.5.1	Generalized linear models	160
9.5.1.1	Maximum likelihood estimation	161
9.6	Downscaling PDFs	162
9.6.1	Downscaling PDFs for temperature	163
9.6.2	Downscaling PDFs for daily precipitation	163
9.7	Further Reading	168
9.8	Examples	169
9.8.1	iid-test	169
9.8.2	Downscaling PDFs for normal distribution	169
9.8.3	Downscaling PDFs exponential distribution	170
9.9	Exercises	172
10.	Weather Generator	173
10.1	Weather Generator	174
10.2	Richardson Type WG for Precipitation	175
10.3	Downscaling Based on WG	176
10.4	Examples	177
10.4.1	Coin-flipping	177
10.5	Exercises	177
11.	Implementing ESD	179
11.1	Numerical Tools	179
11.1.1	R	179
11.1.1.1	clim.pact	179
11.1.1.2	Rclim	181

11.1.2	SDSM	181
11.1.3	ClimateExplorer	181
11.1.4	ENSEMBLE-S2D	181
11.2	Gridding the Results	182
11.2.1	Kriging	182
11.2.2	Residual kriging	182
11.2.3	GIS-packages	186
	Acknowledgments	188
	Appendix	189
	References	201
	Index	213