Statistical Downscaling and Bias Correction for Climate Research

Statistical downscaling and bias correction are becoming standard tools in climate impact studies. This book provides a comprehensive reference to widely used approaches, and additionally covers the relevant user context and technical background, as well as a synthesis and guidelines for practitioners. It presents the main approaches including statistical downscaling, bias correction and weather generators, along with their underlying assumptions, skill and limitations. Relevant background information on user needs and observational and climate model uncertainties is complemented by concise introductions to the most important concepts in statistical and dynamical modelling. A substantial part is dedicated to the evaluation of regional climate projections and their value in different user contexts. Detailed guidelines for the application of downscaling and the use of downscaled information in practice complete the volume. Its modular approach makes the book accessible for developers and practitioners, graduate students and experienced researchers, as well as impact modellers and decision makers.

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to our families

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Preface

Statistical downscaling and bias correction are becoming a core element of climate impact studies. They are often intended to and have the potential to inform costly and far-reaching real-world adaptation decisions. The international statistical downscaling community, however, is not organised to meet this challenge, partly because the field is inherently interdisciplinary. Major methodological contributions come from climatologists, impact modellers – in particular hydrologists – and statisticians, all with their different scientific backgrounds, experiences and interests. No consensus exists on the appropriate use and evaluation of different methods; the underlying assumptions are often not explicitly spelled out, rarely are they tested. The downscaling language is, not surprisingly, far from being unified and varies from community to community and region to region.

A number of review articles have been published (e.g. Hewitson and Crane 1996, Zorita and von Storch 1997, Wilby and Wigley 1997, Onof et al. 2000, Fowler et al. 2007, Maraun et al. 2010*b*, Wilks 2010, Teutschbein and Seibert 2012, Maraun 2016), but some are becoming outdated. They are mostly narrow in scope and in general serve as a literature overview rather than an in-depth introduction to the subject. The IPCC has published a guidelines document on statistical downscaling (Wilby et al. 2004), and one textbook exists on empirical statistical downscaling by Benestad et al. (2008), as well as some book chapters, for example, in Willems et al. (2012). These contributions, however, are limited to some of the approaches in use and provide a mostly technical view of the subject. Other books like the recent contribution by Wilby (2017) cover a broad overview of climate change and society but only briefly lay out the concepts and methods of statistical downscaling. A book that presents the full range of statistical downscaling approaches in some depth and puts these methods into a broader context was missing. Thus, developers and users of downscaling or PhD students starting to work in the field were essentially forced to read review papers, individual papers or book chapters. This book attempts to close this gap.

The first aim of the book is to introduce the main approaches of statistical downscaling – namely perfect prognosis, model output statistics (which is often simply a bias correction), weather generators and some hybrid approaches. We present the most widely used methods that have been developed within these classes and discuss the underlying assumptions and how their structure affects their skill.

The second aim of the book is to provide readers with the necessary background knowledge. We review subjects such as regional climate and climate change itself, the needs of users of climate information, the necessary basics of statistical and dynamical modelling and the uncertainties of climate projections.

The third aim of the book is to present guidance for practical applications both for downscalers and users of downscaled information. We therefore discuss a framework to evaluate downscaling approaches, review the most comprehensive evaluation studies and synthesise the discussions of the book into a list of guidelines. The main focus of the book is on climate change studies, but of course many of the concepts are applicable to seasonal or decadal climate predictions as well.

Given the scope of the book, we have tried to write it such that it is accessible to different audiences: first, to experienced users and developers who need a reference or who are interested in the broader context of downscaling. Second, to researchers starting to work in the field, such as PhD students or advanced MSc students, who may look for an introduction to the different approaches and their performance but also require a concise overview of the relevant background knowledge in, for example, statistics. And third, to users of downscaling information, such as impact modellers or climate service providers, who require an overview of statistical downscaling and who seek guidance on the limitations and applicability of the different approaches in a decision-making context.

The book is divided into three parts: Part I provides the broad context and background, with more generally accessible chapters on, for example, user needs or climate model uncertainties and two more technical chapters on statistical and dynamical modelling. The latter two chapters require some background in undergraduate maths and statistics but are not required to follow the main ideas in the other parts of the book. Part II of the book introduces the different statistical downscaling approaches and their limitations – it is mainly a reference. Part III discusses the performance of statistical downscaling, links to the ongoing debate about the limitations of regional climate modelling and provides practical guidelines. Readers who are mainly interested in practical applications may start reading the introduction and could then jump directly to Chapter 18. They will then be directed to the different chapters for more in-depth discussions.

With the book, we also attempt to unify the statistical downscaling language. Even though the terminology may be scattered and sometimes misleading in climate change research, a more or less well-defined language exists in the numerical weather-prediction community. At first, the terms used in that community might sound unfamiliar for someone from the climate community. But the use of, for example, ‘model output statistics’ as a broader term for bias correction techniques has been tested for several years in international initiatives and has been proven useful. We therefore use this language, with some climate-specific adjustments, throughout this book. But we refer to widely used terms where they are suitable. The aim is to use familiar language as much as possible whilst being as precise as necessary. For the mathematical parts of the book, we have decided to stay as close as possible to common notation. That is, our notation is local and differs from chapter to chapter. For instance, in the statistical

chapters x refers to a predictor, whereas in the dynamical modelling chapter x refers to a space coordinate.

We hope that this book contributes to integrating the community, stimulates discussions within and beyond the community and fosters the improvement and development of statistical downscaling.

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This book summarises much of what we have learned about downscaling over the last 10 years. We have acquired much of this knowledge through discussions with colleagues. These discussions helped sharpen our arguments, inspired further research or changed our prior beliefs. Without these discussions, this book would not have been possible. The first of these discussions started at the international workshop on statistical downscaling at the University of East Anglia in May 2009. Since then several initiatives have provided platforms for scientific debate: the European VALUE initiative, funded as EU COST Action ES1102, the international CORDEX-ESD activities and related workshops and, unfortunately for a short time only, the US NCPP initiative on developing a downscaling vocabulary. We are greatly thankful for all the discussions at the meetings, the numerous tele-conferences and the joint writing of papers. To name but a few, we would like to thank, in alphabetical order, Joe Barsugli, Rasmus Benestad, Maria Laura Bettoli, Richard Chandler, Jens Christensen, Jonathan Eden, Jesús Fernandez, Andreas Fischer, Tilmann Gneitung, Galia Guentchev, José Gutierrez, Bill Gutowski, Stefan Hagemann, Alex Hall, Elke Hertig, Bruce Hewitson, Heike Hübener, Radan Huth, Chris Jack, Ian Jolliffe, Sven Kotlarski, Linda Mearns, Christel Prudhomme, Ingo Richter, Ole Rössler, Mathias Rotach, Ted Shepherd, Pedro Soares, Thordis Thorarinsdottir, Heimo Truhetz, Claudia Volosciuk, Mathieu Vrac, Daniel Walton, Rob Wilby and Renate Wilcke.

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