CAMBRIDGE

Cambridge University Press
978-1-108-79146-5 — Statistical Analysis of Climate Extremes
Manfred Mudelsee
Frontmatter
More Information

Statistical Analysis of Climate Extremes

The risks posed by climate change and its effect on climate extremes are an increasingly pressing societal problem. This book provides an accessible overview of the statistical analysis methods that can be used to investigate climate extremes and analyze potential risk. The statistical analysis methods are illustrated with case studies on extremes in the three major climate variables: temperature, precipitation, and wind speed. The book also provides datasets and access to appropriate analysis software, allowing the reader to replicate the case-study calculations. Providing the necessary tools to analyze climate risk, this book is invaluable for students and researchers working in the climate sciences, as well as risk analysts interested in climate extremes.

MANFRED MUDELSEE is founder of the research company Climate Risk Analysis, and a visiting scientist at the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research. His research focuses on how climate change is related to extreme climate and weather. He is a member of the European Geosciences Union and International Association for Mathematical Geosciences.

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-108-79146-5 — Statistical Analysis of Climate Extremes
Manfred Mudelsee
Frontmatter
More Information

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-108-79146-5 — Statistical Analysis of Climate Extremes
Manfred Mudelsee
Frontmatter
More Information

Statistical Analysis of Climate Extremes

MANFRED MUDELSEE
Climate Risk Analysis
and
Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research

CAMBRIDGE
UNIVERSITY PRESS

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-108-79146-5 — Statistical Analysis of Climate Extremes
Manfred Mudelsee
Frontmatter
More Information

CAMBRIDGE
UNIVERSITY PRESS

University Printing House, Cambridge CB2 8BS, United Kingdom

One Liberty Plaza, 20th Floor, New York, NY 10006, USA

477 Williamstown Road, Port Melbourne, VIC 3207, Australia

314–321, 3rd Floor, Plot 3, Splendor Forum, Jasola District Centre,
New Delhi – 110025, India

79 Anson Road, #06–04/06, Singapore 079906

Cambridge University Press is part of the University of Cambridge.

It furthers the University's mission by disseminating knowledge in the pursuit of education, learning, and research at the highest international levels of excellence.

www.cambridge.org
Information on this title: www.cambridge.org/9781108791465
DOI: 10.1017/9781139519441

© Manfred Mudelsee 2020

This publication is in copyright. Subject to statutory exception and to the provisions of relevant collective licensing agreements, no reproduction of any part may take place without the written permission of Cambridge University Press.

First published 2020

Printed in the United Kingdom by TJ International Ltd, Padstow Cornwall

A catalogue record for this publication is available from the British Library.

Library of Congress Cataloging-in-Publication Data
Names: Mudelsee, Manfred, 1962- author.
Title: Statistical analysis of climate extremes / Manfred Mudelsee.
Description: New York : Cambridge University Press, 2020. | Includes bibliographical references and index.
Identifiers: LCCN 2019040870 (print) | LCCN 2019040871 (ebook) | ISBN 9781108791465 (paperback) | ISBN 9781139519441 (epub)
Subjects: LCSH: Climatic extremes. | Climatic extremes–Case studies. | Climatic changes. | Climatic changes–Case studies. | Natural disasters. | Natural disasters–Case studies.
Classification: LCC QC981.8.C53 M83 2020 (print) | LCC QC981.8.C53 (ebook) | DDC 551.6072/7–dc23
LC record available at https://lccn.loc.gov/2019040870
LC ebook record available at https://lccn.loc.gov/2019040871

ISBN 978-1-108-79146-5 Paperback

Additional resources for this publication at www.cambridge.org/mudelsee

Cambridge University Press has no responsibility for the persistence or accuracy of URLs for external or third-party internet websites referred to in this publication and does not guarantee that any content on such websites is, or will remain, accurate or appropriate.

CAMBRIDGE

Cambridge University Press
978-1-108-79146-5 — Statistical Analysis of Climate Extremes
Manfred Mudelsee
Frontmatter
More Information

To my family: Friederike, Tom-Luis, and Mathilda

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-108-79146-5 — Statistical Analysis of Climate Extremes
Manfred Mudelsee
Frontmatter
More Information

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-108-79146-5 — Statistical Analysis of Climate Extremes
Manfred Mudelsee
Frontmatter
More Information

Contents

Preface *page* xi

1 Introduction 1
Reading Material 8

2 Data 10
2.1 Event Times 10
2.1.1 Elbe Winter Floods 11
2.2 Peaks Over Threshold 14
2.2.1 Potsdam Wind Speed 15
2.3 Block Extremes 16
2.4 Detection of Extremes 17
2.4.1 Threshold Placement 17
2.4.2 Block Length Selection 19
Exercises 22
Reading Material 26

3 Methods 27
3.1 Stationary Processes 27
3.1.1 GEV Distribution 28
3.1.2 GP Distribution 29
3.1.3 Return Level, Return Period, and Risk 30
3.1.4 Heavy-Tail Distributions 35
3.2 Nonstationary Poisson Process 38
3.2.1 Kernel Occurrence Rate Estimation 38
3.2.2 Bandwidth Selection 39
3.2.3 Boundary Bias Correction 42

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-108-79146-5 — Statistical Analysis of Climate Extremes
Manfred Mudelsee
Frontmatter
More Information

3.2.4 Confidence Band Construction 42
3.2.5 Cox–Lewis Test 45
Exercises 47
Reading Material 49

4 Floods and Droughts 50
4.1 Case Study: Elbe Floods 50
4.1.1 Data Quality 51
4.1.2 Reservoirs 54
4.1.3 Further River Training 56
4.1.4 Land Use 56
4.1.5 Climate 57
4.2 Case Study: Monsoon Droughts 58
4.2.1 Detection 60
4.2.2 Occurrence Rate Estimation 62
4.3 Outlook 63
4.4 Summary for the Risk Analyst 66
Reading Material 67

5 Heatwaves and Cold Spells 68
5.1 Indices 68
5.2 Case Study: European Heatwaves 77
5.2.1 Action Measures 77
5.2.2 Occurrence Rate Estimation 84
5.2.3 Other Measures 87
5.2.4 Absolute versus Calendar Day Percentiles 91
5.3 Case Study: Cold Spells at Potsdam 93
5.3.1 Late Frost 94
5.4 Outlook 98
5.5 Summary for the Risk Analyst 100
Reading Material 102

6 Hurricanes and Other Storms 103
6.1 Case Study: US Landfalling Hurricanes 103
6.1.1 Database 104
6.1.2 Risk Analysis 112
6.1.3 Sensitivity Analysis 117
6.2 Case Study: Paleo Hurricanes 118
6.2.1 Occurrence Rate Estimation 120

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-108-79146-5 — Statistical Analysis of Climate Extremes
Manfred Mudelsee
Frontmatter
More Information

6.3 Case Study: Storms at Potsdam 121
6.3.1 Stationarity 123
6.3.2 Nonstationarity 124
6.4 Outlook 129
6.5 Summary for the Risk Analyst 131
Reading Material 133

Appendix A Climate Measurements 135
A.1 Temperature 135
A.2 Precipitation 136
A.3 Wind Speed 137
Reading Material 138

Appendix B Natural Climate Archives 139
B.1 Speleothems 139
B.2 Lake Sediment Cores 141
B.3 Tree-Rings 141
B.4 Other Natural Archives 141
B.5 Dating of Natural Archives 145
Reading Material 147

Appendix C Physical Climate Models 149
C.1 Earth System Models 149
C.2 Uncertainties and Model–Data Comparisons 151
Reading Material 151

Appendix D Statistical Inference 152
D.1 Estimation 152
D.1.1 Mean and Standard Deviation, Standardization 154
D.1.2 Linear Regression 157
D.1.3 Nonlinear Regression 158
D.1.4 Monte Carlo Experiments 161
D.2 Hypothesis Tests 162
Reading Material 164

Appendix E Numerical Techniques 165
E.1 Optimization 165
E.2 Parallel Computing 168
E.3 Random Numbers 169
Reading Material 171

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-108-79146-5 — Statistical Analysis of Climate Extremes
Manfred Mudelsee
Frontmatter
More Information

Appendix F Data and Software 172
F.1 Data 172
F.2 Software 172

Appendix G List of Symbols and Abbreviations 174

References 179
Index 195

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-108-79146-5 — Statistical Analysis of Climate Extremes
Manfred Mudelsee
Frontmatter
More Information

Preface

Climate extremes cost human lives. They do harm to the economy. Examples are the Elbe flood in 2002, the European heatwave in 2003 or hurricane Katrina in 2005. The big question is how global climate change influences climate extremes. This plagues decision-makers as well as climate researchers.

This book shows how the big question can be approached using a scientific method: the statistical analysis of climate data. But the analysis is a challenge, since climate is a complex system and data are uncertain. As scientists, we have to deliver our answers with uncertainty measures (error bars) and also have to carry out computer simulations (sensitivity studies) for assessing the robustness of our results. This book shows how to do this. It is written for students, university teachers, risk analysts, and researchers.

Chapter 1 introduces you to the climate system and extremes therein. Chapter 2 informs about the various data types and methods to detect extremes. Chapter 3 details the statistical analysis tools. On the basis of this arsenal, we examine three types of climate extremes: floods and droughts (Chapter 4), heatwaves (Chapter 5), and hurricanes and other storms (Chapter 6). These examinations proceed as exemplary case studies to help you replicate the findings and carry out your own analyses. There is more information on measurements (Appendix A), climate archives (Appendix B), climate models (Appendix C), statistical inference (Appendix D), and numerical techniques (Appendix E). You can also find a description of how to access data and software (Appendix F) and a list of abbreviations and mathematical symbols (Appendix G).

To the student: Start with Chapters 1–3. Take your time to do the exercises at the end of Chapters 2 and 3. Then select from the applications (Chapters 4–6) as you please. Consult the Appendix if needed. The "Personal Reflections" about humans (including myself) and research, which are distributed

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-108-79146-5 — Statistical Analysis of Climate Extremes
Manfred Mudelsee
Frontmatter
More Information

throughout the book, are written for you. Consider also the "Reading Material" at the end of each chapter.

To the teacher: The main part of the book (Chapters 1–6) is designed such that it can be taught in about twenty hours. The exercises (at the end of Chapters 2 and 3) can be done as homework. The solutions to the exercises are on the website for this book. The extra time, beyond twenty hours, should be filled with computer tutorials on the replication of the book's case studies and the analysis of own data.

To the risk analyst (and other people under time pressure): Chapters 4 to 6 show in case studies how you may wish to analyze own data. The statistical analysis tools are accessible via the website for this book. Each of those chapters has at the end a section entitled "Summary for the Risk Analyst" that briefs you on the chapter's content and assesses options for near-future climate risk prediction. Consult Chapters 2 and 3 if in need of more information on data and methods, respectively.

To the researcher: Consider the case studies in Chapters 4–6 as an encouragement of your own work. Each of those chapters has at the end a section entitled "Outlook" that assesses the state of knowledge and indicates how the case studies can be extended. The given software (Appendix F) should facilitate this.

The book's website address is www.manfredmudelsee.com/textbook.

I can be electronically approached via the book's website. I would be very pleased to receive your feedback on the book: level, length, coverage, style, things to put in and things to omit. Bear in mind that humans are not perfect and that in climate science we jointly proceed to coming closer to examining the climate reality.

My work on this book benefitted from research work done previously by others including: Friedrich-Wilhelm Gerstengarbe on data from the observatory Potsdam, Michael Börngen and Gerd Tetzlaff on documentary flood data, Thomas Stocker and the rest of the IPCC on the Fifth Assessment Report, Stuart Coles on the statistical analysis of extremes and, finally, Bradley Efron and Peter Hall on the Poisson process and bootstrap resampling. I am thankful also for the influence over the past decades of my colleagues in climate research including: Gerald Haug, Gerrit Lohmann, Michael Schulz, and Martin Trauth.

Lisa Bennett was a wonderful proofreader of the first version. I thank her and also the team responsible at Cambridge University Press for their professional support and convenient communication: Sarah Lambert, Tricia Lawrence, Matt Lloyd, Zoë Pruce, and Vinithan Sedumadhavan.

Finally, I thank my family for their patience and loving support.

© in this web service Cambridge University Press www.cambridge.org