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SCIENCE OF WEATHER, CLIMATE AND OCEAN EXTREMES

JOHN E. HAY



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SCIENCE OF WEATHER, CLIMATE AND OCEAN EXTREMES

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Dedication

I am humbled and honoured to dedicate this book to:

John N. Rayner

John inspired my interest in climatology when I was an undergraduate in the Department of Geography, University of Canterbury, New Zealand. I am fortunate, indeed, to have walked through the scientific doors he opened for me. John was undertaking his own doctoral research at the time. It was his passion for research, as well as for life in general, that encouraged me to undertake doctoral studies overseas. Even before I had time to attend my graduation ceremony, and be awarded a BSc(Hons), I had taken his advice and started travelling.

John departed New Zealand soon after me, initially taking up an appointment as an Associate Professor at Ohio State University. He continued there until his retirement. John was Chair of the Department of Geography for 20 years, Director of Atmospheric Sciences for 10 years and State Climatologist for 11 years.

F. Kenneth Hare

Ken supervised the doctoral research I undertook at Kings College, University of London. I arrived there, expecting to study extreme rainfall events in East Africa. Unrest in that region caused those plans to be postponed. Ken kindly found some work for the 'naïve and inexperienced boy from the colonies'. Under his guidance, I was soon deeply immersed in researching the heat and water balance climatologies of North America. This launched my publishing career, with a co-authored paper in the Canadian

Geographer in 1971, and a co-authored chapter in the North American volume of the World Survey of Climatology, published by Elsevier in 1974.

I was exceedingly fortunate to be supported, mentored and motivated by a person who has been described, without exaggeration, as 'a giant in Canadian and international climatology, geography and environmental sciences'. After serving as a meteorologist during World War II, Ken joined McGill University as an assistant professor. In 1950, he was awarded a PhD in Geography from the Université de Montréal. Ken was appointed Dean of Arts and Science at McGill in 1962. In 1964, he was appointed Head of Geography at Kings College, and subsequently Master of Birkbeck College from 1966 to 1968, during which time he also served as president of the Royal Meteorological Society.

In 1968, Ken became the fifth president of the University of British Columbia. He subsequently became Professor of Geography and Physics at the University of Toronto, as well as Director of its Institute for Environmental Studies. From 1979 until 1986, he was Provost of Trinity College. From 1988 to 1995, Ken was the sixth Chancellor of Trent University. From 1992 until his death in 2002, Ken chaired Canada's national Climate Program Planning Board.

In 1978, Ken was appointed an Officer of the Order of Canada. He was promoted to Companion in 1987. During his illustrious career, Ken was awarded honorary degrees by 11 universities.

While I endeavour to follow in Ken's footsteps, I am a mere shadow of this great man.

Geert Jan van Oldenborgh

Even though I never met Geert Jan, our interactions, his publications and his many other contributions have had a significant

influence on the later years of my research and writing. After his untimely death in 2021, Geert Jan was described as 'a tireless advocate for inclusive science and a pioneer of event attribution science'. The world as a whole is all the poorer from his passing.

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Foreword

It seems that not a day goes by without the media reporting yet another extreme weather event. More and more often, these reported events are occurring close to home, in our country, if not our neighbourhood.

What does this trend reflect? Is it a media that is increasingly captivated by these events, perhaps aided by the modern ubiquity of dramatic video footage shot on mobile telephones by the people affected? Or is there a real upsurge in their frequency, intensity and resulting impacts?

While the media tends to focus on extreme weather events, longer-lasting climate extremes, such as droughts, receive less attention. This is despite their consequences being just as significant. The same applies to ocean extremes, although marine heatwaves are receiving more attention. The increased interest in marine heatwaves is not only a result of the growing awareness of the direct impact of ocean extremes on marine ecosystems but also because the increasing frequency and severity of marine heatwaves is paralleling the changes in atmospheric heatwaves and their serious consequences.

A single, authoritative and highly readable book that covers the full array of weather, climate and ocean extremes is long overdue, which is why I jumped at the opportunity to commission and publish the book you are currently reading. The book considers past changes in these extremes, often extending back to previous millennia,

as the evidence allows. In doing so, it provides robust evidence and explanations for the general increase in these extremes in the past. It also presents the key results of model-based future projections. These reveal how the same extremes are likely to change in the coming decades. Climate models also provide the opportunity to determine the extent to which observed changes in the frequency and intensity of the extremes can be attributed to human activities, rather than natural variability in the atmosphere–ocean system. This analysis can also be undertaken for an individual extreme event.

Science of Weather, Climate and Ocean Extremes is, therefore, a timely addition to Developments in Weather and Climate Science, the Royal Meteorological Society's new book series, published in partnership with Elsevier. Hay's contribution – drawing on his decades of unrivalled experience in academia, the private sector and governmental organisations – is consistent with the goal of the series being to combine the underpinning principles of the atmospheric, oceanic and climate sciences with recent developments in the field. Its multi-disciplinary approach brings together aspects of physics, mathematics, chemistry, computer science and other basic disciplines. In doing so, it cuts across these traditional subject boundaries, bringing together all the elements that are important for understanding atmospheric and ocean extremes. The book is thus an excellent

addition to the series. For this reason, I also look forward to Hay's next contribution to the series, with the forthcoming publication of

Managing the Consequences of Weather, Climate and Ocean Extremes in Our Warming World.

Dr Paul D. Williams

*Professor of Atmospheric Science
University of Reading
United Kingdom
and*

Editor

*Developments in Weather and Climate Science
The Royal Meteorological Society and Elsevier*

Acknowledgements

A large number of people and institutions have contributed to this work, either directly or indirectly. I fear that I may fail to acknowledge some of them or make totally inadequate references to those I do recognise. Please accept my apologies for any omissions.

I offer heart-felt thanks to my wife, Helen Henry, as well as to my daughter, Joanne, and to my son, Anthony. Your love, interest and practical support have kept me motivated and engaged during the research and writing process. Similarly, I acknowledge my grandchildren, Matthew and Cassandra.

The staff at Elsevier made the journey so much easier than it might have been, from

their initial suggestion that I write a book on climate extremes to the appearance in print of a much more nuanced book. For this I give special thanks to six of Elsevier's editorial team, namely Charlotte Kent, Amy Shapiro, Veronica III Santos, Bharatwaj Varatharajan, Narmatha Mohan and Peter Llewellyn. I deeply appreciate your patience, understanding and professionalism.

I also acknowledge my colleagues and the staff at the University of the South Pacific, the University of Auckland and Griffith University. I am especially thankful to the librarians and others who facilitated my access to electronic and other library resources and services.

SCIENCE OF WEATHER, CLIMATE AND OCEAN EXTREMES

A comprehensive reference which considers both past and anticipated future changes in atmospheric and marine extremes, including their causes and their attribution.

Science of Weather, Climate and Ocean Extremes presents an evidence-based assessment of the most important ways in which the build-up of greenhouse gases in the atmosphere is affecting the occurrence of extreme events in our atmosphere and oceans. This book examines how and why the frequency and magnitude of these extremes have changed over the past decades, centuries and millennia, as well as into the future. It also investigates the causes of these changes, as well as the drivers and attribution of extreme events. Relevant methods and techniques are also assessed.

The information is targeted, including by way of more detailed case studies from around the globe, as well as informative graphics. Material is presented in a cohesive and complete manner, due to the author's broad and in-depth subject area expertise.

This book will help professionals gain an authoritative, evidence-based, and practice-relevant understanding of the processes and conditions that result in significant risks to both human and natural systems, now and in the future. It not only highlights recent advances in understanding and practice, but also identifies the need and opportunities for further progress.

Key features:

- Investigates how and why atmosphere and ocean extremes have changed in the past, as well as into the future
- Assesses relevant methods and techniques
- The material is presented in a way that is accessible to both specialists and nonspecialists alike

Author's Biography

John Hay is an Adjunct Professor at the University of the South Pacific, Griffith University and the University of Auckland. He has over fifty years of experience in academia, the private sector and governmental organisations. His work has focused on bringing an interdisciplinary approach to the environmental sciences, and to technical- and policy-relevant assessments and guidance, especially regarding atmosphere and ocean extremes, variability and change.

He has worked as a consultant and advisor to many national governments and regional and international organisations. He is a recipient of the Nobel Peace Prize, awarded jointly to the Intergovernmental Panel on Climate Change (IPCC) and Al Gore, and of a prestigious fellowship from the Guggenheim Foundation.



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