MASS BALANCE OF THE CRYOSPHERE

The cryosphere can be loosely defined as comprising all the frozen water and soil on the surface of the Earth. This book focusses on two key components of this environment: land ice (in the form of ice sheets, caps and glaciers) and sea ice. These components have been identified as important indicators of climate change on timescales ranging from years to millennia.

Early chapters cover the theory behind field-based and satellite observations, and modelling of mass balance, providing the reader with a thorough grounding in all the concepts and issues presented later in the book. The rest of the book reviews our current understanding, from modelling and observational perspectives, of the present and predicted future mass balance of the cryosphere.

This book is an important reference for all scientists working in the fields of climate change, environmental sciences and glaciology, and provides a valuable supplementary text for senior undergraduate and graduate courses in glaciology. It has been written by leading authors in the field, and is fully integrated to provide a coherent, cross-referenced and consistent exposition on the subject.

Jonathan Bamber did a degree in Physics at the University of Bristol before undertaking a Ph.D. in glaciology at the University of Cambridge. Since then he has been a lecturer at University College London in the Department of Space and Climate Physics, and is currently Reader in physical geography in Bristol. With some 20 years experience in airborne and satellite remote sensing of the polar regions, he is the author of over 70 articles on this topic, in addition to a number of articles relating to more general applications of Earth observation. He has undertaken fieldwork in Antarctica, the Arctic and Karakoram, in collaboration with the German Polar Research Centre, AWI and NASA. He is currently President of the Cryospheric Sciences section of the European Geosciences Union.

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Observations and Modelling of Contemporary and Future Changes

edited by

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Contents

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Foreword

The regions of the great ice caps in the Arctic and Antarctic are places of stunning beauty. Also, being tantalizingly remote and largely unspoilt by human interference, they hold compelling fascination and interest. However, these are not the only reasons for their study. Compared with the rest of the Earth's surface, they are of importance far beyond what might be expected from their comparative size. The changing balance in the cryosphere between the accumulation and ablation of ice has dominated the Earth's climatic history through the quasi-regular ice ages of the last million years – extending also to earlier epochs about which rather less is known. The world's coastal regions have been enormously affected as this changing balance has led to large excursions of sea level. For instance, at the end of the last ice age, 20 000 years or more ago, the sea level was lower than today by about 120 metres.

The long-term driving influence on the mass of ice in the polar regions, either in the form of sea ice or locked in the ice caps, has been the regular oscillations in key features of the Earth's orbit around the Sun, namely its eccentricity, the tilt of the Earth's axis and the time of year when the Earth is closest to the Sun. These features change with periods varying from about 20 000 years to about 100 000 years, and combine to cause substantial variations in the amount of solar energy that reaches the polar regions at different times of year, most particularly in the northern summer. It is these variations, as recognized first by James Croll in 1867 and later studied extensively during the 1920s by the Serbian scientist Milutin Milankovitch, that have triggered the growth and decay of the ice sheets. The influence of these ice sheets has extended far beyond the polar regions. For instance, as the ice sheets have grown, large areas of land in the northern hemisphere have been covered over many millennia, and as they have receded the fresh water released has strongly affected the ocean circulation.

Turning to more recent times, during the last two decades we have all become increasingly aware of the way in which the climate is being affected by human activities. It is the burning of fossil fuels that results in emissions of large quantities of the greenhouse gas carbon dioxide into the atmosphere that is leading to substantial warming of the Earth's climate and therefore to climate change at a rate that has probably not been experienced on Earth

for at least 10 000 years. It is imperative to find out in as much detail as possible how the sea ice and the ice sheets are reacting to this anthropogenic warming and how they are, in turn, influencing its impact. Are the ice sheets growing because of increased snow fall or are they beginning to melt down because of the increased temperature? Is the stability of the great ice sheets of Antarctica at risk because of the changes that are taking place? How is the deep ocean circulation affected by the changes in fresh-water input? And so on.

This book is written by international experts in the scientific disciplines involved – especially those of physics and dynamics applied particularly to ice but also to the atmosphere and the ocean that surround the ice. The primary tools of observations and modelling feature large in its chapters as a state of the art description is provided about many aspects of the cryosphere, its behaviour and evolution. Answers to some of the important questions are beginning to emerge, and this volume provides an important synthesis of current knowledge.

John Houghton

Preface

In 2000, Tony Payne and I organized a session at the annual congress of the European Geophysical Society on the mass balance of the cryosphere. It was clear from the impressive scientific breakthroughs presented at this meeting and also in the recent literature that major progress has been achieved in this subject over the last decade. This is a result of advances in both observational technology through new satellite and airborne hardware, and our modelling capability, and through improvements in computational power and physical understanding. As a consequence, it was timely and fitting to embark on producing a comprehensive review of what we know about the theory behind measuring and modelling mass balance and the actual results from the latest observations and model simulations. In this respect, the book is unique, in that it combines both the theory and the results in a single text. Twenty-three expert authors have contributed to seventeen chapters covering sea ice, glaciers and ice sheets in five thematic sections. Although this is an edited volume, each chapter is extensively cross-referenced and forms part of a fully integrated text. In addition, the chapters were externally peer-reviewed to ensure the highest scientific standards. Part I of this book is designed to offer a comprehensive, yet compact, reference text on the theory and practice of measuring mass balance. Part II is a parallel section on modelling, and Parts III–V comprise detailed and comprehensive reviews of what we know, from both measurements and modelling, about the current and predicted behaviour of sea ice, ice sheets, glaciers and ice caps.

A book of this kind requires the effort of a group of dedicated and committed people with wide ranging expertise. Many thanks are due to all the authors, some of whom have had to wait a long time to see their material in print. I would also like to thank the editors and staff at CUP, the external reviewers and, in particular, our copy editor Irene Pizzie, for their perseverance and professionalism. Finally, I would like to acknowledge the generous sponsorship of the European Space Agency and National Aeronautics and Space Administration for their contribution to the cost of colour reproduction.

Jonathan Bamber