ICEBERGS

Their Science and Links to Global Change

Icebergs are a prime example of an environmental phenomenon that brings together multiple disciplines in the polar sciences, from the physics of calving and melting to the geology of their solid deposits and sea-floor interactions. Icebergs are also increasingly seen to play key roles in past and present climate change in causing the addition of freshwater to the ocean, in providing invaluable information through their debris, in fertilising the polar oceans and in increasing hazards to Arctic travel and development.

This book gives a comprehensive, multidisciplinary view of icebergs and their interaction with the Earth system, from the physical and biological interaction with the ocean and climate to how iceberg detritus informs us about past Earth history. It also examines societal and cultural aspects of icebergs, in terms of the risks, such as iceberg tsunamis and giant icebergs, and how techniques such as remote sensing, radar and modelling are used to monitor these iceberg hazards, as well as the opportunities, including the use of icebergs as a freshwater source. The book concludes by considering how these risks and opportunities might develop in the future.

With extensive illustrations and key links to online resources, *Icebergs* is a valuable reference for academic researchers and graduate students studying oceanography, cryospheric science, climatology and environmental science.

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Preface

There must be very few people who have not heard of the sinking of the Titanic. Icebergs are an archetypal menace of the natural world, not on the scale of tsunamis and hurricanes perhaps, but often feared, nonetheless. However, icebergs are far more than just a natural hazard; they are interesting in their own right, both scientifically and historically.

This book explores the rich story behind icebergs and their science. It starts by retelling the famous story of the Titanic sinking, but from a unique perspective – that of the life of the iceberg responsible. The first few chapters consider the science behind the general life profile of icebergs, including their impact on the physics and biology of the ocean. The central core of the book then considers how the sea-floor detritus left by icebergs as they melt can tell us much about the past of our planet, whether transitions from glacial to interglacial periods or the more long-term tectonic evolution of the planet's geography and climate over the past billion years. We finally return to the risks, and opportunities in the form of freshwater, presented by icebergs and explore what the future might hold for the interaction between humanity and icebergs.

My own journey culminating in this finished book has been a long one, with the first notes being made in 2002, but the first words not committed to disk until January 2014, following a halt while I moved from Norwich to Sheffield, and then, before long, spent six years as Head of the Department of Geography.

This fascination with icebergs extends even further back. As a PhD student in the early 1980s, I gained my first exposure to the mathematical mysteries of iceberg motion and melting through my supervisor, Ernie Tuck, who, as an applied mathematician interested in ship hydrodynamics, was keenly following the, then current, debate about the possible use of towed icebergs as sources of freshwater in arid regions. A different break then occurred when I scientifically moved from being an applied mathematician to an ocean modeller, and moved to Britain. Following prompting by Brian Funnell and Nick Shackleton to turn these skills

towards a new way of understanding the past ocean through modelling, in the mid-1990s I realised an excellent approach to infer the unobservable glacial past was to match models with a tracer of ocean flow, namely, the detritus left on the sea floor by passing, and melting, icebergs.

Thus began a strong thread within my research career which continues to this day. The use of icebergs, their debris or meltwater, whether real or hypothetical, has proven to be a fruitful way in which to examine marine climate change on a range of timescales from the past to the future. Now, as global warming and retreating Arctic summer sea-ice encourages physical, economic and geopolitical movement to the North, icebergs are attaining new relevance in risk and cultural terms.

Both the long journey of iceberg science and the shorter journey of the preparation of this book have needed the help of many individuals. The development of my approach to iceberg science over twenty years owes a lot to too many people to mention individually, so I give my thanks to these all collectively. However, a few people have played particularly close roles in this development including postdocs Martin Wadley, Richard Levine, David Wilton, Vladimir Ivchenko and Tom Cropper; PhD students Rupert Gladstone, Ros De'Ath, Tiago Silva, Clare Green and Jen King; Masters students Luis Duprat and Ambrose McCarron; and colleagues John Johnson, David Stevens, Keith Nicholls, Martin Siegert, Richard Hall, Bob Marsh, Visakan Kadirkamanathan, Steve Billings, Edward Hanna, Hua-Liang Wei, John Andrews and Mike Rogerson.

The shorter, but no less arduous, journey to the finished book could also not have been achieved without a lot of assistance. I'd therefore like to thank Susan Francis and her team at CUP for having faith in the idea and supporting its realisation, Gill Tyson and David McCutcheon for crafting the many, many diagrams, Rob Ashurst and Alan Smalley for assistance with the ice-rafted debris analysis and photography, Kristen St. John for providing the data on which Figure 6.8g was based, Andrew Sole for providing the clues to the switch from marine to terrestrially terminating glaciers in Greenland, Andy Hodson for reading a draft of Chapter 4 and Edward Hanna for allowing me to use the photograph that is now on the front cover of the book. Finally, I must especially thank my wife, Jane, who not only helped me start off on the right track by reading the first draft of Chapter 1 but has put up with twenty years of me talking about icebergs, a task which, for a social scientist, must have often been pure misery!

Acknowledgements

Many of the people who directly or indirectly helped with the research that underlies this book over the last two decades, or who graciously allowed me to use photographs or diagrams have already been acknowledged in the Preface. However, a book like this would be unable to be written without access to a range of data sources as well. Satellite data used in the figures came from several sources. The European Space Agency enabled me to gain projects with both the German Space Agency (DLR), from whom I had a quota of Terrasar-X SAR images, and the Canadian Space Agency, who provided an even larger quota of invaluable Radarsat-2 SAR imagery. The National Ocean and Atmosphere Administration's (NOAA) MODIS satellite enabled me to regularly use visible imagery and ocean colour data. Many of these data benefited from analyses produced by the Giovanni online data system, developed and maintained by the NASA GES DISC.

Another source of useful climate data was the UK Meteorological Office, and specifically their www.metoffice.gov.uk/hadobs climate data website. Longer-term data, stretching back into the early Quaternary, was frequently obtained from the PANGAEA database (www.pangaea.de), an invaluable repository for most of the data produced as preparation for papers on marine core interpretation.

A source of information that was unexpected when I started writing was the online old document archive of the Internet Archive (archive.org) programme. This contains a cornucopia of material, which enabled me to get a real insight into the early history of the discovery of icebergs and the polar regions.

Icebergs has covered a wide range of topics and been an enjoyable exploration during the writing. While I've tried to cross-check material, any errors that have crept in are my responsibility. However, I hope that readers will find this as interesting a book to read as I did to write!