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Book Reviews

Ice in the Ocean

by *P. Wadhams*
Gordon & Breech (2000)
ISBN 9056992961. 364 pages. £44/ $67

This book provides a much needed reference for graduate students and scientists working in the field of sea ice research. Much of what is currently known about sea ice is scattered among research papers, and *Ice in the Ocean* is a welcome summary of some of this research. The book provides a comprehensive overview of sea ice physical properties, including thermodynamics and dynamics, and the role of sea ice in global climate. It also includes a chapter on icebergs. Each chapter starts with a short narrative of field-work in the polar regions; these entertaining narratives describe the atmosphere of polar research, including the frustrations and successes of working in high latitudes. Interspersed in the discussion are historical notes, which provide a context for understanding the motivation behind much of the more recent research. As with any text where research is ongoing, there are some areas which are outdated or where there is not complete agreement with other experts in the field. The author has extensive experience in sea ice research, and a wide range of topics is included in the book. It is never possible to include all the details, and a useful section of the book is the comprehensive list of references which direct the reader to the original research papers, and suggestions for future reading. It is difficult to reproduce black and white photos of snow and ice well, and this book is no different; several of the photos are poorly reproduced, and many of them have no reference scale.

Chapter 1 gives a general overview of the physical setting of the polar oceans, including figures of the bathymetry and the general ocean circulation, and long-term atmospheric pressure fields. There is some rather dated material presented; for example the plots of ice extent only go to 1988, although data since that time is widely available. The discussion of the history of the Arctic Ocean exploration is interesting, and provides a bit of background to the reader about how far the research has progressed.

Chapter 2 reviews the ice formation process and discusses different types of sea ice. It is a good review of the basic physics of how sea ice forms and the processes which determine sea ice crystal structure and salinity. Several photos and figures of sea ice topography, vertical salinity profiles and surface features provide a good overview of sea ice for researchers just starting to work in the field. Much of this is an update from an earlier review by Weeks & Ackley (1982). This chapter also includes an introduction to ice scour (discussed more in Chapters 5 and 7), and a discussion of observations of polynyas.

The thermodynamics of sea ice are reviewed in Chapter 3. Sea ice thermal conductivity, diffusivity and extinction coefficients are discussed, followed by a comprehensive discussion of heat flux models. A discussion of the typical values used for estimating Arctic heat flux, and the sensitivity of the model to these input parameters is useful for anyone unfamiliar with the application of this type of model.

Chapter 4 provides a good overview of sea ice dynamics, including a review of some of the empirical equations and the more rigorous theories. It is a well structured chapter, with a review of the momentum balance followed by the solution for free drift. Different ice rheologies are discussed, and the application of these theories in computer models is presented. This chapter also includes a brief review of the earlier theories of polynya dynamics.

Chapter 5 reviews the theories which describe sea ice thickness distribution, one of the author's specialties. It first discusses the theory of ridging and sea ice thickness distribution, and provides examples from both the Arctic and Antarctic regions. The different techniques for measuring the ice thickness distribution are described, although ship-based ice observations, a common technique in the Antarctic, is not discussed. A review of the ice thickness distribution in the Arctic, and in the Weddell Sea, Antarctica is then presented. There is a lengthy discussion of ice scour and pipeline burial depths; a practical application of some of the theory.

The marginal ice zone (MIZ) is discussed in Chapter 6. The first half of the chapter focuses on the mechanics of wave/ice floe interaction within the MIZ. Wave attenuation models are discussed in relation to floe size distribution, as well as the mechanics responsible for ice bands which form due to off-ice winds. This is a current topic of research, and some of this theory is still being debated in the literature. A brief discussion of sea ice eddies is followed by a more detailed description of eddies which have been studied off East Greenland, and some of the mechanisms which may be responsible for the eddies. Theories describing pancake ice formation, and some of the research on the Odden ice tongue (Greenland Sea) are also presented.

Icebergs are discussed in Chapter 7. The primary source regions of icebergs are identified, followed by a discussion of iceberg size and shape and the physical properties of specific icebergs. Observed iceberg locations, and iceberg drift tracks are presented, including a figure showing the drift of several icebergs in the Weddell Sea. Melt and mechanical breakup of icebergs is briefly discussed, along with a theoretical prediction of iceberg breakup due to ocean waves. Iceberg scour is also mentioned (more detail on scouring theory is presented in Chapter 5). Estimates of the total iceberg volume in the Southern Ocean is compared to the mass balance of the Antarctic continent, to the volume of sea ice, and to their

impact on ocean salinity. Several pages are devoted to the use of icebergs as a fresh water source and for power generation, even including a schematic of a proposed method for towing icebergs, and a facility to process the icebergs.

The final chapter broadly discusses sea ice in relation to pollutants and the interaction of sea ice and climate. The initial part of the chapter provides a brief glimpse of sea ice biology and the impact of climate change. This topic could easily be the topic of an entire book, and this section provides a good introduction to the subject. The threat of a large oil spill is very real in the Arctic and several pages are devoted to the topic, including diagrams and a picture of the fate of oil which is released beneath the sea ice. The transport and fate of other contaminants found in Arctic sea ice is also discussed. Most of the remaining text is devoted to the complex interaction of sea ice and climate. The different feedback mechanisms are discussed, followed by the results from some global climate models (GCMs). This is a topic of considerable recent research, and it obviously not possible to review all of the results from numerous models. However, the discussion provides a good overview of the subject, and complexity of correctly incorporating all of the feedbacks and physical processes in GCMs. Observed changes in the Arctic sea ice cover are discussed, including some explanations for the changes and the relationship to the Arctic Oscillation and the North Atlantic Oscillation. The chapter concludes with a brief review of possible future methods of sea ice research including satellite remote sensing, field programmes and computer modelling.

V. LYTLE

References

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Physics of Ice

by *Victor F Petrenko and Robert W Whitworth*
Oxford University Press (1999)
ISBN 0198518951. 386 pages, £70

This book is concerned with a fascinating and complex material - ice. Its physical properties determine the nature of the world we live in. For example: atmospheric circulation is influenced by white snow at the poles reflecting back solar radiation; ocean circulation by salt rejection from floating sea ice. The landscape is transformed by the action of ice sheets and creatures great and small live in the ice-world - the cryosphere - using the properties of ice to their advantage. But why *is* snow white? Why is ice less dense than water? Why does it flow under stress? What stops ice freezing in cells? Why is ice so special? These are questions about ice physics, and this book provides a well-written and modern survey which should satisfy the curiosity of any scientist who has wondered about the role of ice in the Earth system.

It will also serve as a new reference work for ice physicists, with up-to-date reviews and references over a wide range of topics. Since it is some 25 years since Hobb's *Ice Physics* was published the new material is very welcome, but the classic groundwork is also covered in a clear and logical fashion which allows the book to stand on its own.

The book begins with a discussion of the water molecule, the hydrogen bond (which links the hydrogen nucleus and oxygen atom) and the crystal structure of ordinary ice. Careful reading is required, as there is much to digest, but the authors provide an excellent summary of key points at the end of Chapter 2 and the reader can move comfortably on to the next chapter, which deals with small displacements of atoms or molecules from their equilibrium sites in the ice lattice.

Chapter 3 begins with a summary of the macroscopic elastic and thermal properties of ice and then proceeds to explain how stretching and bending of bonds and vibration of the lattice give rise to these properties. The experimental techniques which can be used to investigate modes of vibration of the lattice (infrared absorption, Raman spectroscopy and inelastic scattering) are reviewed and there is a brief summary on modelling. The authors do not hide the difficulties involved but have managed to explain the nature of the methods used very clearly.

The next chapter opens with a typically clear and helpful comment: "Crystallography tells us about the arrangement of molecules, lattice vibrations depend on the intermolecular forces, but the electrical properties show how molecules turn round or protons flow through the lattice. Ice is the model material for studying such effects". The nervous reader may hesitate, but this exposition of the theory of the electrical properties of ice is in fact very accessible. Mercifully, there is no need to refer back to electrodynamics textbooks to refresh the memory, as there is a section on basic definitions to start with. After a section on the static susceptibility, Bjerrum defects are introduced to explain how polarisation and electric conduction are possible and a theoretical analysis of their behaviour is developed. As an interesting aside, the authors explain why water but not ice absorbs energy in a domestic microwave oven.

Because impurities in ice can generate defects, experimental studies using doped ice have given much valuable information on the electrical properties of ice. Conversely, electrical profiling has developed as a valuable technique for determining the concentration of certain combinations of chemical impurities in ice cores. This chapter will be especially interesting for all those glaciologists who have used electrical profiling instruments and want to know more about their theoretical background.

Chapters 6 and 7 deal with point defects, dislocations, stacking faults and grain boundaries in preparation for a discussion of the mechanical properties of ice. Here again the

authors introduce the subject from first principles, so that the reader can settle down to learn about ice without having to refer to general textbooks on dislocation theory for explanations. As this is a text on the *physics* of ice there is more emphasis on the microscopic processes that underlie the flow and fracture of ice than on the macroscopic behaviour but nevertheless, the brisk review of mechanical properties in Chapter 8 is useful and up-to-date with references to other more detailed reviews of the subject.

Chapter 9 on optical and electric properties is again brief but useful. The emphasis is on physical understanding of how electromagnetic waves interact with the structure and individual molecules of ice. A simple but effective diagram shows the parts of the spectrum where the frequency of the waves matches the frequency or time scales associated with processes in the ice (so energy is dissipated), separated by the "windows" in which ice is almost transparent. Here the reader can find out why deep crevasses look blue and why a thin section of polycrystalline ice shows a mosaic of different colours when place between crossed polars.

Chapter 10 is concerned with the physics of the surface of ice, which the authors suggest is probably the most complex and uncertain topic in the book. Many different experimental techniques have shown that surface properties of ice are very different to those of the bulk material. Besides pre-melting effects close to the melting point (from -1°C) there is also evidence of a quasi-liquid layer at lower temperatures (from -5°C). The cause of this behaviour is one of the major topics of current research in ice physics and this chapter will serve as a convenient introduction to the field.

The authors then turn with enthusiasm to the other phases of ice. They discuss crystalline and amorphous forms of pure ice and the clathrate hydrates in which molecules of other substances are caged in hydrogen-bonded water molecules. Here we discover that although ice Ih - the phase of ice found in the natural environment - expands on freezing, other phases do not. The Earth would be a very different place if one of these were the stable form.

How ice behaves on Earth and in the solar system is reviewed in a chapter which the authors hope will show the relevance of ice physics to glaciological research in general. Glaciologists who come to this book for information on ice physics may find this chapter odd, but it is not primarily intended for them - although the section on extraterrestrial ice should interest everyone. A brief final chapter deals with adhesion and friction, an intriguing topic with practical applications in design of sledges, skis and skates.

The book is beautifully written and produced. Experts in aspects of the physics of ice will no doubt disagree with some of the material, or feel that the balance is wrong, but the "glaciologist in the street" will be grateful for the authors' determination to be clear and their admirable capacity for communicating the essence of complex topics.

E.M. Morris

Mountains of Madness

by *John Long*
John Henry Press, Oxford (2000)
ISBN 0 309 07077 5. 250 pp. Price £17.95/$24.95.

Why would anyone wish to spit his teeth-cleaning rinse water into the communal frying pan? I am not sure that the question is answered in this book but it had some unexpected results. What John Long does reveal in *Mountains of Madness* is that he is a tremendous enthusiast for Antarctica and for the study of fossil fish. Indeed, it was the lure of untold riches, in the form of remarkably rich fish beds in the Devonian (380 million years ago) sedimentary rocks of the Transantarctic Mountains, that led him to Antarctica in the first place. Despite his first attempt being aborted, following an extended period of bad weather that prevented him from flying into the field, he went back to Antarctica the following season and was second-time lucky. The book is his account of his experiences and it attempts to be very open in revealing his thoughts and feelings as a newcomer to a continent and a way of life that breeds only two kinds of people - those who love and those who hate it.

Whilst this book is likely to find fascination with those who have not been fortunate to visit and work in Antarctica for themselves, I found too many irritations to make it an enjoyable read. The driving force for his visit was the quest for fossil fish. Once in the field, he is out on the rock exposures in all weathers, often by himself, when his companions with more experience are sitting out blizzards in the tent. Such behaviour led him into several scrapes, one of which could have been fatal. Yet one cannot fault the author for his enthusiasm and determination against all odds to collect his beloved fossil fish. At a time when geologists are forced to dumb down their language, to the extent that even words like 'magma' are being struck out of any text intended for all but the most specialist of audiences, the author is to be congratulated for managing to get so many technical terms past the editors. The richness of fossil names had me dusting off several of my university textbooks to remind me just what kinds of fish and trace fossils were being described. The author regales us with genus after genus, and with new species galore, yet there is not a single picture of these allegedly wonderful creatures. And that is a great shame. There are just four pages of colour photographs, lurking in the middle of the book; they are not indexed, they are not keyed into the text, and are all but inconsequential.

His quest for fossil fish is interspersed with reflections on what life was like in the Heroic Era of Antarctic exploration, and with references to communal readings of an Antarctic fantasy novel, titled *At the Mountains of Madness*. The true significance of the former to this particular story eluded me and the main role of the latter seems to have been to provide a title for the book.

Unfortunately, the book shows signs of being put together in a hurry and many 'facts' in the introductory chapters could

do with checking. The Antarctic Treaty ratified in 1961 did not preclude the economic mining or exploitation of resources in Antarctica. It was the Madrid Protocol of 1991 that did that; the original treaty avoided the issue. The first fossils found in the Antarctic region were not pieces of fossil wood brought back by a whaling captain from Seymour Island at the end of the nineteenth century. The first report of fossil material in Antarctica was in 1833 when James Eights recorded the occurrence of carbonised fossil wood on King George Island. Even for an old Antarctic hand, the provision of a map would help the reader to follow the story better. But "the map shown in this book" (p. 7) does not exist, which is perhaps just as well since it might have revealed that the Pensacola Mountains, said to be near the base of the Antarctic Peninsula are, in reality almost 1000 km away.

As for the story, if you can shut your mind to the irritations, *Mountains of Madness* does provide a modern window on working in Antarctica. And if you really want to know the significance of spitting in the frying pan, you will just have to read the book for yourself.

M.R.A. Thomson

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