THOMAS, D.N. and G.S. DIECKMANN, *eds*. 2010. *Sea ice. Second edition.* Oxford, Wiley-Blackwell. 621pp. ISBN-10: 1-4051-8580-5, ISBN-13: 978-1-4051-8580-6, hardback, £88.99/US$108.

As a 'mature' glaciologist who has worked on sea ice for more than 15 years, I have slept for a long time with the excellent *Geophysics of sea ice* (Untersteiner, 1986) by my bedside. Pioneering work by colleagues such as S. Ackley, D. Garrison, C. Sullivan and R. Horner had suggested for quite a while that sea ice is not 'just another form of ice with inorganic impurities in it' but a true, extremely complex, ecosystem. Since the early 2000s, however, multidisciplinary research on sea-ice ecosystems has started to move at a much faster pace. The first edition of this book, *Sea ice: an introduction to its physics, chemistry, biology and geology* (Thomas and Dieckmann, 2003), crystallized this progress and quickly became indispensable for the new generation of students involved in sea-ice research. This second edition, as underlined by the author of its foreword, Dr S. Ackley,

> reflects the explosive growth in the field of sea ice science, continuing now at a seemingly exponential rate, even since the first edition in 2003. The number of chapters has increased to 15, with 6 completely new chapters. All other chapters have been heavily revised and updated, including some new authors or additional co-authors. All chapters, in their extensive reference lists, reflect the recent development of the field with only a few references (less than 10% in most cases) from prior to 1980. With the high number of citations after 2003, the book gives the new information that has come out in the past few years and further validates the need for the new version of the book at this time.

The introductory chapter gives an overview of the growing awareness within our society of the importance of sea ice, not only in the context of the rising consciousness of the potential imprint of mankind on the evolution of the Earth's climate (and its socio-economic consequences), but also in terms of the implications the wealth of recent new findings will have for future scientific and technological developments. After a short section on the history of sea-ice exploration, this chapter reminds us of the main impacts sea ice has on the ocean and the atmosphere, and how its properties differ between the Arctic and the Antarctic. Then it briefly discusses how the sea-ice microenvironment might be very similar to some extraterrestrial systems and a possible harbour for life's origin. Industrial applications of cold active and cold adapted enzymes and other organic compounds typical of sea ice are also brought into perspective.

In the excellent chapter 2, the microscale physics of growth and decay of the sea-ice cover is presented, providing the key physical background for understanding large-scale sea-ice properties, life and geochemical processes discussed in the following chapters. We learn how sea ice differs from lake ice and how impurities affect ice growth and texture depending on its mode of formation. Desalination processes and pore microstructure are described and how they control sea-ice permeability, a crucial parameter for heat and matter exchanges with the atmosphere and the ocean. Although depicted in filigree, I think the much debated 'mushy-layer theory' of sea-ice growth could have been more clearly presented for a wider audience and discussed. There follows a clear description of sea ice's main physical properties, which will be of great interest to the sea-ice remote-sensing and modelling community. Finally, simple sea-ice growth models are discussed, with a focus on thermodynamic processes. Here, too, one may regret that the general principles of large-scale sea-ice models are not presented, although a separate chapter would surely have been required for this.

Chapter 3 is new and very welcome. Not designed as an exhaustive treatise covering all ice–ocean interactions, it focuses on examples illustrating sea-ice–ocean interactions such as the formation of the Arctic halocline or the role of polynyas (ice factories) in generating dense bottom waters. A short introduction gives a general oceanographic description discussing the relationship of main water masses to sea-ice distribution. I missed a summary figure showing typical vertical distributions of these water masses, which would be useful for young students discovering the subject. An interesting final section addresses new tools for future oceanographic sampling in sea-ice covered areas (e.g. autonomous underwater vehicles and seal-transported conductivity–temperature–depth sensors).

Regular estimates of polar-wide sea-ice thickness distributions are a priority today, as they are expected to be a highly sensitive indicator of climate change. Chapter 4 shows how difficult it is to obtain these estimates, partly because of the mixed thermodynamic/dynamic origin of observed ice thicknesses and the remoteness of these areas. The authors present the different methods used to determine ice thickness locally and regionally and show how complementary these methods are, promising satellite technologies resting on extensive validation from field measurements. Present-day global sea-ice thickness and interannual and decadal variability are also discussed.

Chapter 5 is an outstanding new addition to the book. Anyone who works on sea-ice biogeochemistry today realizes that snow on sea ice strongly affects not only the energy balance of the sea-ice cover, but equally drastically the biological activity and the exchanges of matter (especially gases) with the atmosphere. Yet previously there was no recent comprehensive and accessible review of our current knowledge of the sea-ice snow cover. After an extensive description of snow types on sea ice and of the snowpack properties, this chapter presents global and regional snow-depth distributions and discusses their potential impacts for remote sensing and ecology.

Chapter 6 thoroughly updates the trends in large-scale variations in sea-ice extent/area from satellite imagery, which have changed dramatically since the first edition in 2003. I particularly enjoyed the wealth of information in the colour-coded ice-concentration monthly anomaly maps which are self-explanatory.

Chapters 7–11 are dedicated to the organisms living 'in' and 'on' sea ice. The dichotomy between 'microbiology' and 'macrobiology' presented in the first edition is now extended into three different chapters. Starting with bacteria and viruses – probably the least-known compartment of the sea-ice biota, partly because of the difficulty of sampling – we learn about their abundance, diversity and distribution and their inclusion in or loss from the sea ice as the seasons change. There is also a focus on their adaptation to sea ice and how they thrive in 'frontier' environments such as frost flowers.

Chapter 8 moves on to primary producers. The habitats and biodiversity of sympagic autotrophes are described,

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together with their physiological adaptations to sea-ice constraints. Primary production is estimated to be 4% and 20% of the total productivity of Antarctic and Arctic waters respectively. Unfortunately, the section on numerical modeling of the sea-ice ecosystem is considerably shorter than in the first edition, but this is compensated by an interesting section on the genetics and genomics of sea-ice algae, which enhances our understanding of their specific adaptations to this extreme environment.

Within the complex microbial communities of sea ice, single-celled eukaryotic microorganisms displaying heterotrophic ability are the major consumers of bacterial and algal biomass. These are the focus of chapter 9. Here too, DNA sequencing is actively developed, continuously changing our perception of their evolutionary relationships with other eukaryotic organisms such as phototropic protists. Their diversity and abundance are described and trophic activities and biogeochemistry discussed.

Moving up one trophic level, chapter 10 explores the sea-ice meiofauna (i.e. metazoans living all their life cycle within the sea ice (e.g. copepods, nematods and turbullarians)) and macrofauna (generally larger (e.g. euphausiids, amphipods or fish) and limited by the size of the brine channels), the latter forming a key component of the diet of many species at the top of the trophic chain. The diversity and biochemical adaptations of both metazoan communities are described. Further attention is paid to case studies of life cycles and the role of sea ice for the Antarctic krill, with potential consequences for climate variability.

Chapter 11 describes sea ice as a critical habitat for marine mammals and birds, exploring the adaptations that allow these warm-blooded, air-breathing vertebrates to remain in ice-covered waters throughout the year. Focus is also placed on the potential implications of global climate change for those pagophilic (ice-loving) species.

Chapter 12 introduces the complex world of sea-ice biogeochemistry. It starts with abiotic modifications of the chemical composition of sea water during sea-ice growth, for bulk ice and brine salinity, dissolved gases, mineral inclusions (with special focus on calcium carbonate) and pH. Modifications linked to the biological activity of sympagic organisms are then discussed at length, with areas attracting increasing interest such as the sink for CO_2, the source for dimethyl sulphide (both climatically significant gases) or the production of exopolymeric substances (EPS)/transparent exopolymer particles (TEP) (gel-like organic substances), with recently discovered important impacts for organism attachment', crystal geometry, iron adsorption or sea-ice permeability, among others. The chapter closes with a discussion of the significant problem of discriminating spatial from temporal variability in field datasets.

The palaeo-sea-ice distribution is reconstructed in chapter 13, which is organized geographically (Antarctic vs Arctic). For both polar regions, sea-ice extent proxies are presented and updated (including recent developments in biomarkers) and palaeo-sea-ice reconstructions are presented for the last 2.6×10^6 years in the Antarctic and up to the initiation of sea ice ($\sim 46 \times 10^6$ years ago) in the Arctic.

Chapters 14 and 15 are both new, and enlarge the sea-ice topic to nonpolar regions and extraterrestrial environments. Chapter 14 presents a comprehensive review of the latest developments in sea-ice research in, for example, the Aral, Azov and Baltic Seas, the Sea of Okhotsk and Hudson's Bay. Emphasis is placed on the characteristics of these non-polar sea-ice ecosystems (always seasonal) and the organism communities that form them. Chapter 15 suggests that the 'extreme' physical characteristics of the sea-ice environment and the specific organic biogeochemical compounds that characterize it (e.g. EPS and antifreeze proteins (AFP)) could be a plausible analogue to astrobiological environments occurring on icy planets such as Europa or the past surface of Mars. The chapter focuses on 'premelting' (ensemble of microscale physical and chemical processes maintaining a liquid film between ice crystals below the normal melting temperature) that characterizes sea ice as a 'mushy layer'. It discusses interactions of this complex medium with the organic compounds that partly fill it, and the implications for crystal growth and sea-ice permeability. Although I am convinced of the crucial importance of these processes and of the need to understand them better, I found the heading of this chapter somewhat misleading, given the restricted part of the discussion truly devoted to astrobiological aspects.

The first edition of this book was a tour de force of multidisciplinarity, gathering an unprecedented wealth of information in a single volume, supported by a large number of top-quality figures and photographs. The second edition succeeds in maintaining this high standard and has fully kept pace with the exponentially rising number of publications that have appeared during the last 5 years (so much so that I am wondering what to do with the five new copies of the first edition that recently entered our department's library). With the recently published *Field techniques for sea ice research* (Eicken and others, 2009) focusing on field and experimental techniques for sea-ice measurements (a topic only briefly touched on in the present book) and the freshly announced (and long-awaited) new book *On sea ice* from our esteemed colleague W. Weeks (Weeks, 2010), a young researcher tempted by the exciting world of sea ice should be fully equipped to move science forward.

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