

Reviews

CUFFEY, K.M. and W.S.B. PATERSON. 2010. *The physics of glaciers. Fourth edition.* Amsterdam, etc., Academic Press. 704pp. ISBN-10: 0-123694-61-2, ISBN-13: 978-0-123-69461-4, hardback, £60.99/€71.95/US\$99.95.

For the reader in a hurry, the new Cuffey and Paterson fourth edition of *The physics of glaciers* defines the science of glaciers even better than the first three editions, and is a must-read for students and professionals in the field.

During the International Glaciological Society's Third International Symposium on Antarctic Glaciology in 1981 at The Ohio State University, where I was a student, the late, great Ian Whillans introduced me to Stan Paterson. We had a nice chat, and Stan asked some friendly but perceptive questions about my work with Ian on firn from Dome C. Afterwards, I asked Ian the key question, 'Was that *the* W.S.B. Paterson?!?' Then I ran off to tell my wife Cindy, who was helping with the meeting, that I had actually spoken to *the* Paterson, author of *The physics of glaciers*.

For a student of glaciers then, the *Journal of Glaciology* (with the relatively new *Annals*) dominated the literature, but it was a jigsaw puzzle of information. Paterson supplied the picture on the puzzle box, putting the information into an orderly form that gave us confidence we could make sense of this wonderful field. Everything fit together in *The physics of glaciers*, with the key references and equations embedded clearly in text presented in lucid English, leading to the important applications. The book in many ways defined the field: 'What is a glacier scientist?' could be answered, 'Someone who reads and contributes to the *Journal* and knows Paterson.' Many a professor replied to the student question, 'Where can I find . . .?', with the one-word answer 'Paterson'.

For later years, the professors had to supply a little additional information. In the Sherlock Holmes adventure *The valley of fear* (Doyle, 1914, chapter 1), the great detective was briefly stymied by a keyless cipher from his informant, Porlock, because Holmes and Watson had already updated their copy of *Whitaker's Almanack* for the new year but Porlock was still using the old one. Similarly, detailed information required specifying which edition of Paterson was most relevant, the 1969 original, the 1981 second edition or the 1994 third edition. This was worth the effort, though: the updates closely tracked the rapid growth of the field. Furthermore, they offered the possibility that your research would be validated through citation by Paterson.

But, as Stan appeared less frequently in the journals and at the meetings on glaciers, it seemed that the field had outgrown its definer. Numerous other valuable books were written, covering parts of the field in greater depth, or covering broader topics at a more introductory level, and a well-stocked library should include these. For advanced topics, I have often relied on Hooke's *Principles of glacier mechanics* (now in its second edition, 2005), as well as Van der Veen's *Fundamentals of glacier mechanics* (1999), the relatively new *Dynamics of ice sheets and glaciers* from Greve and Blatter (2009), and even the idiosyncratic view in Hughes' *Ice sheets* (1998). Hambrey and Alean's *Glaciers* (second edition, 2004), Benn and Evans' *Glaciers and glaciation* (second edition, 2010) and Knight's *Glacier*

science and environmental change (2006) are among those that successfully cast broader nets.

We have recommended many of these books to our students, and placed them on reserve in the library. But we still followed Paterson for our advanced students, while wondering whether it was proper to require a textbook more than a decade old in such a fast-changing field.

Fortunately, Cuffey and Paterson's fourth edition of *The physics of glaciers* solves the problem. This major rewrite of the classic text smoothly integrates the latest results with the bedrock of our field: roughly one-third of the material is new, one-third heavily revised and one-third lightly updated. The lucid, accessible presentation and the intellectual rigor of the earlier editions are not only preserved, but enhanced. At 693 pages plus references, this is not a light book, but the economy of presentation is noteworthy; others would have used many more words to say less.

Consider, for example, figure 3.1, which merges adaptations of several of the diagrams from Hobbs' (1974) *Ice physics* to explain the molecular structure of ice in a single half-page. The strong basis for adopting a dependence of strain rate on the stress cubed is well presented in section 3.4, together with a recalibration to more-accurate numerical values.

Discussions of global warming often involve changes in glaciers, because they are so easy to see. But glaciers also figure prominently in misstatements about global warming, because so many processes are involved. The reality of modern discourse required a major upgrade to several sections of the text. For example, chapters 4 and 5 on mass-balance processes deliver wonderfully for the serious student. Figure 4.6 by itself should go a long way toward removing confusion among those who are looking for answers. Note that this is not a reprint of someone else's figure but a novel synthesis of diverse data from scattered sources that clarifies important concepts.

Similar advances are scattered throughout the book; rather than simply reprinting a previously published figure in a 'they said this' review, the new book synthesizes and advances. Many of the individual pieces could have been published as stand-alone refereed papers. The careful reader will find numerous nuggets of wisdom, and jumping-off points for further research.

For review material, the book relies heavily on comprehensive yet concise tables. Note, for example, the inclusion of relevant thermodynamic parameters for mass-balance modeling in table 5.1, the compilation of transfer coefficients for melting surfaces in table 5.5, the residence times for hydrological reservoir models in table 6.1, the long list of measured basal-slip rates of glaciers in table 7.1 and the drag factors in table 7.2 as part of the trove of useful information, carefully referenced, throughout the book.

There are really too many other good parts to describe in this short review. A few more high points include:

Glaciology is increasingly expected to produce projections of sea-level change. ('How will sea-level rise depend on the number of gigatons of CO₂ emitted?') The necessary knowledge of ice-sheet basal lubrication will require targeted borehole and surface geophysical studies, but these are simply too slow to map a whole ice

sheet. Thus, inversion/data assimilation from remotely sensed surface velocity and driving stress will be essential (e.g. Joughin and others, 2001) but eventually should include the evolving basal hydrological system. Section 7.4 provides a fine starting point for doing so, building on new insights into deforming beds in section 7.3.

Relatively few dedicated fieldworkers have been trying to characterize large tidewater glacier fronts with small research budgets for a long time. Now that important Greenlandic outlets have switched from ice-shelf to tidewater-cliff calving, the broader community is suddenly much more interested. Sections 4.6.2 (calving), 8.8 (flow) and 11.5 (changes at the margin) are welcome on this topic.

Chapters 13–15, on ice sheets in the Earth system, their role in sea-level change, and the paleoclimatic records in ice cores, really tie the science to society in a constructive and timely manner, and will be of broad interest to anyone who cares about climate change. I would have been forced to generate table 15.3 for a skeptical government official were it not already in the book.

In any effort this large, there must be something to complain about. It is unfortunate that references were banished to an online site. Fortunately, while downloading the references, the user is greeted by PowerPoint versions of all of the figures, an errata sheet and a document that traces each reference back to where it is used. Thus, if you remember Walder (1982) on collapse of films to channels in subglacial water flow, you'll immediately be directed to p. 209, while looking up the classic Budd and Jacka (1989) synthesis on ice deformation will guide you to the important material on pp. 53, 54, 65, 73, 75 and 78.

The interested reader will find much else to enjoy in this book. For example, by using square brackets for grouping, and curved parentheses for arguments of functions, the equations are easier to read than typical. The appendix on stress and strain will be a favorite of students in classes extending far beyond glaciology.

In short, *The physics of glaciers* by Cuffey and Paterson is at once instructive and authoritative, a textbook and a

reference source. It is a towering intellectual achievement that, quite simply, defines the science of glaciers. Modern students may not be as easily impressed as I was three decades ago, but I expect that in addition to bragging about talking to 'the W.S.B. Paterson', students will be celebrating meeting 'the K.M. Cuffey' for a long time to come.

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