Review

VAN DER VEEN CJ (2013) *Fundamentals of glacier dynamics,* 2nd edn. CRC Press, Boca Raton, FL. 389pp. ISBN-10 1-439835-66-1, ISBN-13: 978-1-439-83566-1; hardback, US$120.95

It is hard to believe that 14 years have passed since C.J. van der Veen released the first edition of his highly regarded *Fundamentals of glacier dynamics*. Most scientists who are interested in glaciers and ice sheets will have a well-thumbed edition of this text on their shelves, if not their desk. My personal copy is one of the most dog-eared and coffee-stained textbooks in my library, as a result of heavy use in a graduate course in physical glaciology.

It is a new century, however, and the glaciological literature has exploded in the 2000s. Several factors are involved, including burgeoning global interest in glacier and ice-sheet response to climate change, advances in remote sensing of the cryosphere and dramatic recent developments in the Greenland and Antarctic ice sheets. Hence there is ample motivation for an update, but it is legitimate to ask: how much has our understanding of the fundamentals of glacier dynamics really changed? Coffee stains aside, I was not so sure that my copy of the first edition was in need of replacement.

I now know. The first edition has been thoroughly supplanted. In part, there really have been new insights, particularly with respect to fracture dynamics, calving processes, drainage of surface water to the ice-sheet bed, outlet glacier dynamics and higher-order (i.e. full-Stokes) modelling of glaciers and ice sheets. Beyond this, though, in my opinion the second edition offers a more mature, contemplative and insightful treatment of glacier dynamics. Van der Veen writes authoritatively and it is obvious (and impressive) that he has published in most of the areas that he covers in the text. The quality and relevance of the many helpful figures illustrate this well; they have been generated by the author using his own models and specifically designed to illuminate the material. Van der Veen also writes thoughtfully, and the reader can deeply benefit from his (sometimes meandering) musings on topics such as the resistive stress framework, basal sliding, glacier hydrology, calving and the nature of the modelling enterprise. The author has given serious thought to these fundamental issues in glaciology, and many more. Despite my intention to gloss over some sections of the text in the interests of an expeditious review, I was consistently slowed down by the desire to read Van der Veen's discussions and interpretations with great care. I am the richer for it.

Structurally, the text proceeds very logically. As a graduate textbook for students of glacier dynamics, one can work through the book from start to finish without jumping around or omitting much of the presentation. Van der Veen dives right in, without sentimentality or gushing elaborations on the splendour or societal relevance of glaciers. Chapter 1 is a mathematical primer on tensor and error analysis. This is entirely appropriate for the audience that will embrace this text. Chapter 2 discusses the rheology of glacier ice, and chapter 3 covers the essentials of stress balance. Thus equipped, chapters 4 and 5 examine glacier, ice-sheet and ice-shelf dynamics for various idealized and real-world examples. Chapters 3–5 form the heart of the book; to my mind they are essential reading for any student of physical glaciology or anyone engaged in modelling or measuring glacier flow. Over the years I have been slowly abandoning my glaciological roots and my preference for deviatoric stresses, but Van der Veen has now completely won me over as to the benefits of recasting the glacier stress balance in terms of 'lithostatic' (glaciostatic) and 'resistive' stresses. The distinction from deviatoric stresses is subtle, and I have traditionally thought of it as just a mathematical transformation rather than a different way of thinking about glacier mechanics. Resistive stresses offer genuine intuitive insights about glacier flow, however, and I suspect that these will endure with this textbook as one of Van der Veen's glaciological legacies.

The remaining chapters of the book can be treated more individually, but the range of topics should also be on every glaciologist's reading list: glacier thermodynamics, surface energy balance, basal flow, glacier hydrology, fracturing and calving, temporal evolution of ice masses (i.e. mass balance and the continuity equation), surging, glacier modelling and some integrative, concluding notes on interpretation of observations. There are pearls throughout these chapters, but I found the presentation and content to be a bit uneven through here. One could quibble with some details, such as the suggested solar constant of 1395 $W\,m^{-2}$. This is perhaps not the go-to reference for surface energy balance or glacier–climate processes (nor does it aim to be), and I found the discussion on subglacial hydraulics to be confusing and inverted. Concepts of water potential are used before they are introduced, and without a rigour to match the loving treatment of ice mechanics. There are some controversial assertions, such as 'water pressure cannot become larger than the ice overburden pressure' (in contrast to numerous observations of artesian springs on glaciers, both naturally and from boreholes that connect to pockets of pressurized water at the bed). The subsequent analysis of subglacial discharge applies only to marine-terminating drainage systems, but this was unclear and seems unnecessarily restrictive; I lost the thread through here.

These complaints are easily compensated by the new chapter on fracture mechanics, crevasses and iceberg calving. This content alone makes it worth upgrading to the second edition, and I would place bets that this will be the most highly cited section of the text. Topics in this chapter are at the edge of recent glaciological insights and observations concerning some ineffably important processes: for example, meltwater penetration through cold ice; ice-shelf collapse; tidewater glacier instabilities; outlet glacier dynamics in Greenland and Antarctica; and rates of dynamical discharge of these ice sheets in a warmer world. These are complex processes that have been beyond the reach of most glacier modelling efforts to date; ideas in this chapter about how one might model these processes will be carefully studied and many of them are likely to be embraced.

Van der Veen does an admirable job of keeping the book focused and manageably sized, at 389 pages, including the references. Part of the trick here is the delicate balance that he has struck in being thorough without being comprehensive. As he states early in the text, he does not make an effort to conduct a full literature review; rather, he leans heavily on a number of important papers. This selectivity means that

some exceptional and relevant contributions have been missed. Overall, though, the reference list offers an excellent distillation of the literature on glacier and ice-sheet dynamics. It includes a good balance of new results (e.g. Schoof, Nick, Joughin) and classical works, heavily sampling Nye, Lliboutry, Budd and Weertman, along with a good dose of Kamb, Clarke, Raymond and Hooke. There is an understandable slant towards the author's own ideas and publications, but one benefit of this is that the enduring voice of the author's close mentor and colleague, Ian Whillans, resonates throughout the text.

Another way that Van der Veen manages to keep the text focused is by knowing what he *did not* want it to be. He does not try to duplicate *The physics of glaciers* (Cuffey and Paterson, 2010), but keeps the focus on a rigorous but accessible development of glacier mechanics and glacier flow processes. In doing so, he stays on message and graciously sticks to his strengths, such as in the discussion on till deformation: 'It falls outside the scope of this book to discuss all relevant observations and theories. Indeed, this is a task better left to scientists with greater expertise in this area.' Throughout the text, there is a healthy respect for the richness and complexity of glacier processes, and the many places where theory and observations fall short.

Fundamentals of glacier dynamics is not an easy read. Discussions are dense and sometimes circle back on themselves, so I often found myself reading things twice. Insofar as equations are a measure of a subject's complexity, this text is fairly impressive, with 971 numbered equations distributed over the book's 11 chapters (88 ± 31 per chapter). Sometimes this feels a bit gratuitous, as in the detailed analysis of creep closure of tunnels that is incongruously placed in chapter 2. In general, the development of equations throughout the text walks one through the essential theory, but omits enough steps that the only real way to follow it is to break out pencil and paper and fill in the gaps, deriving the results yourself with Van der Veen's presentation as a guard rail. Doing so reveals the occasional notational error (e.g. in section 3.2, 'Interpreting the force balance'), but the final result is not in question and many of the small errors that pervaded the first edition have been eradicated. This is also true of the writing, despite a worrying grammatical error on line 4 of page 1. I found few such errors through the rest of the text.

Given the author's vested interest and involvement in most research areas covered in the text, one needs to be a little cautious with respect to objectivity. This is not a dry, arm's-length literature review of glacier dynamics. While Van der Veen offers a reasonable balance on most topics, his own views shine through and he is not hesitant to share his opinions. The book is all the better for this; one does not have to agree with him, but Van der Veen has carefully considered these topics, and it is worth reading his analysis. This point is mainly a concern for those just entering into glacier studies; they will have to depart from the text and delve into the literature on some topics to fully appreciate some of the differing perspectives.

Overall, this book will have a long shelf life as both an advanced textbook and as a reference book for essential equations and theoretical results. It is one of a handful of textbooks – I count only five – that I need two copies of, one for my own office and one for the graduate student 'library' in my lab; I will need to reference my copy too frequently to lend it out.

REFERENCE

Cuffey KM and Paterson WSB (2010) *The physics of glaciers*, 4th edn. Butterworth-Heinemann, Oxford

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