OERLEMANS, J. 2010. *The microclimate of valley glaciers*. Utrecht, Utrecht University. Igitur, Utrecht Publishing & Archiving Services. 138pp. ISBN 987-9-039-35305-5, paperback. Available free from j.oerlemans@uu.nl and as free download from http://igitur-archive.library.uu.ni.

In eight chapters this book gives first a survey of the connections of microclimate and mass balance, then a basic survey of data with very well-chosen examples from the many field campaigns undertaken by the Institute for Marine and Atmospheric Research Utrecht (IMAU) in the past 25 years in the Alps, Scandinavia, Iceland, Greenland and Svalbard. Glacier wind is treated as a problem of boundary layer meteorology and is linked to the valley wind system and larger-scale weather. The surface albedo of glaciers is treated as a key variable in the energy balance of snow and ice. Basics of the surface energy flux, ablation and balance rate include simple and more sophisticated balance models and their application to real glaciers. Chapter 6, 'A mass balance model for valley glaciers', emphasizes the role of solar radiation and gives recipes for its parameterization which is applied to Nigardsbreen, Norway, in chapter 7. The book closes with a chapter on the meteorological aspects of the mass balance of maritime and continental glaciers. The title of the book would seem to restrict its content to valley glaciers; this is broadly the case, but larger ice fields like Greenland, Vatnajökull, Iceland, and Nigardsbreen are not excluded.

The book is well organized, clearly written and remarkably well illustrated. It is not a basic text or a book for beginners, but I would recommend it as a companion text for graduate class work, or for those who are fairly familiar with glaciers but need a better understanding of climate–glacier relations.

Not surprisingly this publication has much in common with chapters 3 and 4 of Oerlemans's *Glaciers and climate change* (Oerlemans, 2001). The new presentation is more concise while enlarging on and updating practical applications of the models described. Its list of references includes many rarely cited papers in glacial meteorology. It does not always go back to primary literature but seems to prefer easily accessible recent publications and, understandably, work by IMAU scientists, which has been abundant in the past 25 years.

In the introduction (chapter 1) Oerlemans touches on the history of glacier observation and glacier mapping and explains their importance for sea level and as detectors of climate change in general. He explains mass balance, the classification of glaciers, the problems of practical work and of defining conventional parameters. Mass-balance profiles are explained and presented for glaciers in various climatic conditions. In a section on the energy budget of the upper layer of a glacier, fluxes inside the glacier (e.g. meltwater refreezing and penetration of solar radiation) are included and metamorphism is briefly mentioned. The zonation of snow and ice is shown in figure 1.12. Ever since Benson (1962) described and classified the facies or zones of snow and ice on the Greenland ice sheet, his scheme has been printed in many papers and textbooks. Although Oerlemans is the first author I know of who introduced arrows for 'large-scale ice motion', his figure will still challenge the reader to follow the variation of accumulation, density, water content, melting, percolation and refreezing as a function of (t,x,z) in one two-dimensional diagram.

The glacier microclimate as the central theme of the book is well introduced and illustrated. Emphasis is placed on the conditions for glacier wind and its interplay with the valley wind system including slope winds, and the free atmosphere or large-scale weather.

Chapter 2 presents a basic survey of data. 'The climatic setting of glaciers around the world differs widely'. This is well documented with records of temperature and their annual range, annual precipitation and sunshine hours of five stations from the high Arctic to the tropics. High-resolution time series of solar, longwave and net radiation, humidity, temperature, wind speed and surface height are given for five days in summer and five days in winter including overcast and clear-sky conditions, and are meteorologically well explained.

Annual cycles of global and net radiation, temperature and relative humidity are presented for Storbreen, Norway, Vadret da Morteratsch, Switzerland, and Breiðamerkurjökull, Iceland, and are interpreted in terms of the large-scale, maritime and continental climate (which is again the topic of the last chapter). I agree with the author that 'the data show that operating AWS [automatic weather stations] on glaciers is rewarding and provides valuable insight', to which I would add 'and sometimes may be cumbersome and physically strenuous'.

Oerlemans takes care to point out the difference between vertical and elevational gradients of meteorological variables and compares the latter on Pasterze, Austria, on Vatnajökull and in Greenland. For the same three sites this survey of data presents full years of 30 min averages of wind speed, wind direction and air temperature. The chapter ends with a display of the characteristic differences of the daily course of air temperature at a valley station, on a glacier and on a mountain top, which beautifully confirms the first, occasional 19th-century measurements on other Alpine sites.

In chapter 3, on glacier wind, the author says, 'A well developed glacier wind is characterized by a distinct wind maximum at a height 5 to 10 m'. On a glacier, this maximum cannot be covered with permanent instrumentation, for practical reasons. In some of the IMAU experiments, therefore, low meteorological masts were combined with tethered balloons. In the most productive campaign on Pasterze, 200 balloon soundings were made up to heights 500–1000 m above ground. In 63% of cases, the wind maximum was observed below 13 m on the meteorological mast; the maximum speed was well correlated with the height of the maximum ($R = 0.78$) and less with the temperature at 13 m ($R = 0.49$). Further characteristics are pointed out with time–height diagrams of wind speed, temperature and specific humidity in the lowest 50 or 500 m, the latter showing the transition to the valley wind system.

A section on the Pasterze wind records lays out the basics of katabatic flow and compares the classic Prandtl model with solutions for height-dependent eddy diffusivity. While these aspects of boundary layer meteorology may seem theoretical to readers in the ice community, a numerical glacier wind model and parameterizations of surface fluxes give the reader a better orientation and can immediately be applied to mass-balance calculations.

In chapter 4 the surface albedo of glaciers is treated in a collection of very instructive figures, nearly all from IMAU authors. They include spectral change of flux, extinction of solar radiation and the flux divergence in snow and ice; large datasets of reflected versus incoming solar radiation in

Norway and the Alps, both showing the marked change of albedo from snow to ice; a 3 year record of daily albedo values and snow depth on Vadret da Morteratsch; and daily albedo in 11 summer seasons on Morteratsch.

Simple albedo models, variously using snow, firn and ice albedo and two kinds of decay scales, are tested with these datasets. The results show surprisingly little change in correlation coefficients (0.88–0.93) and root-mean-square differences (0.087–0.067).

The chapter includes the conversion from Landsat Thematic Mapper spectral bands to broadband albedo and gives examples of the spatial variation of satellite-derived albedo on Morteratsch and its change during the melt season.

In chapter 5, surface energy fluxes and ablation are treated in a standard way. Although not all readers might agree with Oerlemans' distinction between flux and balance, this has very little impact on our understanding of the presentation. Series of 4 years of surface energy fluxes evaluated from AWS on three glaciers appear very similar at first glance but reveal differences in latitude and maritime/continental conditions in Norway and Switzerland. When parameterized with a truncated cosine function, these differences are strong in the means, less in the amplitudes and least in the phase shift.

Under the heading 'The components of the energy balance', surface roughness is treated or parameterized in a fairly rough way (either 0.13 mm for snow or 0.75 mm for ice), but the turbulent fluxes are shown to be of minor importance (fig. 5.5). In this figure, refreezing is also an order of magnitude smaller, but in the densification it may have been underestimated. 'Hence refreezing only affects the temperature in the snowpack, not the density.' In individual cases I would check this carefully, as percolation and refreezing of meltwater means advection of mass and thus a change in density.

A simple mass-balance calculation in section 5.4 offers a valuable tool that is missing in most textbooks. The model may be simple, but it promotes interpretation and understanding of measured mass balances. Here it is applied to Nigardsbreen and to alpine conditions. In the last paragraph on p. 95, the author emphasizes his own pioneering contribution to mass-balance modelling, but he only very briefly enters the discussion of more sophisticated mass-balance models.

Oerlemans rightly states that 'Model calibration is necessary, because it is not possible to calculate the absolute mean specific balance of a glacier from meteorological input data, simply because the accuracy of such data is limited' (p. 96). I would add that not only their accuracy, but the representativity of meteorological data measured at one point, and their applicability to an entire glacier, are limited, and that boundary conditions like albedo and roughness of the ice need calibrating.

I remember many interesting public discussions concerning distributed energy balance versus degree-day factor, both of which have their merits. On p. 96 we read 'In view of the results from energy balance studies on glaciers ... the validity of a temperature index must be questioned.' This would have been a good point at which to introduce a quantitative comparison of methods as shown on p. 71 for albedo models.

Chapter 6 presents a mass-balance model for valley glaciers. The definition of the cumulative balance rate in equation (6.1.1) uses a time integral over accumulation and ablation rate and adds a third term for the mass changes due to turbulent fluxes which probably should be included in the former two terms. Otherwise this is a very user-friendly chapter giving background information on the geometry of solar radiation, its seasonal and latitudinal variation and how it impinges on sloped surfaces. The clear-sky transmissivity as a function of altitude and cloudiness measured on Pasterze in the 1990s fits the pioneering measurements of Sauberer (1955) very well. The empirical relations given in this chapter for radiation fluxes are valuable tools for energy-balance work in alpine conditions.

The temperature-dependent part of the surface energy flux is convincingly summarized in figure 6.7 with several years of 30 min averages for three glaciers, all of which show a distinct kink at 0°C and a flux increase in the positive temperature range that likely depends on surface slope.

The application of this model to Nigardsbreen 1964–2003 in chapter 7 is a very helpful exercise for all who want to become familiar with the modelling routine. The final chapter introduces the concept of seasonal sensitivity characteristics, i.e. the monthly change of mass-balance rate with changes in temperature or precipitation, and uses it to define the transition from maritime to continental mass-balance conditions of glaciers.

This is a book with a large spectrum of topics in glacial meteorology, with useful simplifications and parameterizations, with very well-chosen illustrations and some theoretical foundations that require previous contact with glaciology and micrometeorology.

I like it and I have given it to all my graduate students.

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