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**Abstract**

Herfried Hoinkes (1916–1975) was a glacier researcher and university teacher who made great contributions to the early development of modern glaciology but I concentrate on his work on the mass balance of an Austrian glacier Hintereisferner. In a series of paper from 1962 to 1975, he showed that the mass balance is strongly correlated with positive degree-day (PDD) totals extrapolated from a nearby climate station. He achieved further improvements in correlations by accounting for fresh snowfall on the glacier. Hoinkes’ work was done during a period of fluctuating mass balance regime which, since 1985, has been replaced by a trend to increasingly negative mass balance, but I show that his balance-PDD correlation is still valid today. I put Hoinkes’ work into a broader geographical context with spatial correlations of mass balance and air temperature anomalies across the Alps and into a broader methodological context with a discussion of some developments since his work.

**Zusammenfassung**

Herfried Hoinkes: Ein Pionier der Gradtagmethoden zur Berechnung der Massenbilanz von Gletschern aus der Lufttemperatur


1. Introduction

Herfried Hoinkes (1916–1975) was a glacier researcher and university teacher (Ambach, 1976). As president of the International Commission of Snow and Ice (ICSI) in the early stages of the International Hydrological Decade (1965–74) he made a distinguished contribution to international glaciology, and presided over many new developments (Hoinkes, 1968). These included development of mass-balance terminology (Hoinkes and Rudolph, 1962a; Meier, 1962; Anonymous, 1969), UNESCO working papers on methodology, and establishment of the Permanent Service on Fluctuations of Glaciers (PSFG) to archive glacier data from all over the world and re-distribute them to potential users (Kasser, 1967). His 1970 paper (Hoinkes, 1970) taught us all that there are different ways of measuring the mass balance of a glacier: (a) as an average of stake and snow pit measurements at many points over the glacier; (b) as a volume change assessed by geodetic methods; and (c) as the residual in the water balance equation. Hoinkes (1970) was also a pioneer in mass-balance modelling, which had not been attempted by many at that time. For example, Krenke and Khodakov (1966) modelled annual ablation with a cubic function of summer temperature anomaly and Liestøl (1967) modelled mass balance with a multiple-regression model using summer temperature anomaly and annual precipitation at a nearby climate station. We take all of these things for granted now but glaciologists of Hoinkes’ generation had to start the ball rolling, i. e. the influence of Hoinkes is still detectable in recent work on Austrian glaciers (Hofinger and Kuhn, 1996; Kuhn et al. 1997; Kuhn et al. 1999; Kuhn, 2003; Kuhn et al., 2009; Fischer, 2010; Abermann et al. 2011).

Hoinkes’ first scientific work was on the energy balance at the glacier surface (Hoinkes, 1953, 1954 and 1955; Hoinkes and Untersteiner, 1952; Ambach and Hoinkes, 1963). His goal was to study the physical processes governing the melt at the glacier surface using the theories of turbulence and radiative transfer that were then available. Instrumentation and logistics were relatively primitive and the work was very laborious (Ambach, 1976). From 1956, Hoinkes was a Professor at the University of Innsbruck and the leader of a long-term study on the mass balance of Hintereisfener, Ötztaler Alps, following initial work by Schimpp (1958). One detects here a shift in emphasis from micro- to meso-scales. A quote from Hoinkes (1955)
illustrates his then understanding of the relation between the two scales: “In recent years many authors, on the basis of careful studies, have come to the conclusion that summer temperature is to be regarded as the most important factor influencing the behaviour of glaciers. This result is not in contradiction to the results of the measurements which are given here (according to which radiation is the main source of energy for the ablation of the alpine glaciers) so long as it is not combined with the idea that the greater heat exchange from air to ice during a hot summer is sufficient to account for the greater ablation.” In the six decades since this statement, there is little or no evidence to contradict the importance of radiation as a source of ablation energy but, as I show below, Hoinkes’ own later work on Hintereisferner underlines the importance of “greater heat exchange from ice to air during a hot summer” as an important factor in greater ablation.

In the present paper, I discuss Hoinkes’ pioneering work in relating the mass balance of the Austrian glacier Hintereisferner to air temperature variations at a nearby climate station expressed as positive degree-day totals. For present purposes, the degree-day method in glaciology involves the assumption that melting only occurs at air temperatures close to or above the melting point of ice (Braithwaite, 2011). The first statement of this principle was made by Finsterwalder and Schunk (1887) in connection with their work on Suldenferner in the South Tyrol. Kurowski (1891) also made early use of this principle to estimate the vertical gradient of ablation on Alpine glaciers, and Zingg (1951) applied degree-day methods to snowmelt. In his various papers, Hoinkes does not cite any references to earlier work on degree-day methods so we do not know from where he got his ideas.

As part of the discussion, I update some of Hoinkes’ results using recent mass-balance data for Hintereisferner from the World Glacier Monitoring Service (http://www.wgms.ch) and using data from the nearby climate station at Vent (http://doi.pangaea.de/10.1594/PANGAEA.806582). I also use some results, published or unpublished, from a recent data analysis (Braithwaite et al., 2013). Many of Hoinkes’ papers which I cite were published in the “red book” series of the International Association of Hydrological Sciences. Digital copies of these publications can be downloaded from http://iahs.info/Publications-News/paper-search.do.

2. Preliminary work on Hintereisferner

No idea comes out of empty air, and in the present section I try to analyse the thinking that lead Hoinkes to his degree-day approach. I put Hoinkes’ work on Hintereisferner up to 1975 into its longer-term context in Fig. 1 which shows the cumulative mass balance of Hintereisferner since the start of measurements in 1953. Such plots are good for illustrating trends, and changes in trends. Up to mid-1980s there was a moderate trend towards increasingly negative mass balance, interrupted by some years with strong positive balances. The latter prompted a somewhat premature announce-
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ment of a new period of glacier advance (Patzelt, 1985) but there was an abrupt shift after 1985 towards even stronger negative mass balance that continues today, and may well continue into the foreseeable future until Hintereisferner disappears together with most Alpine glaciers.

Hoinkes and Rudolph (1962a) discuss the first nine years of glaciological measurements on Hintereisferner. Much of the methodology was novel then, and their terminology has now been superseded by Anonymous (1969) and Cogley et al. (2011).

Hoinkes and Rudolph (1962b) discuss the climate of Hintereisferner. Over the years 1952–1959, air temperature readings were taken on and around the glacier for 673 days, with shorter periods of measurement for short-wave radiation, and even full energy balance for 102 days. Comparing these data with readings at the long-term climate station at Vent (at 1900 m a. s. l. and about 10 km down valley from the glacier) allowed the authors to extrapolate short-wave radiation and air temperature to the

Fig. 1: Cumulative mass balance of Hintereisferner, Ötztaler Alps, 1953–2011.
glacier for nine balance years (1953–1961). The data are listed in Table III in Hoinkes and Rudolph (1962b) together with a precipitation climatology in Table IV of the same publication. It is sobering to think that such climate data are only available for a small minority of modern glaciers with measured mass balance. With the availability of modern data loggers, simple climate elements like air temperature, humidity, precipitation and global radiation (or sunshine duration) should certainly be measured as part of any routine mass-balance programme.

Despite their impressive glacier-climate dataset, Hoinkes and Rudolph (1962b, p. 27) are somewhat downbeat in their conclusions: “... there is no single climatic element responsible for the changing mass-balance of glaciers, but rather a combination of climatic elements, which is signified by the German word ‘Witterungscharakter’ (character of weather conditions).” We might agree that “This result is
not a very satisfactory one, even though it does not contradict the findings of the heat-balance studies, viz radiation as the main energy source for ablation (Hoinkes, 1955). It is interesting that “… the effective duration of the ablation period is a good description of the ‘Witterungscharakter’” but we are warned that we should not casually extrapolate present results to other glaciers as “… mass balance figures for the Hintereisferner, as given in the present paper, are not readily applicable to other glacierized areas”.

An anonymous referee of an early draft of Braithwaite et al. (2013) expressed scepticism about extrapolation of air temperatures from low-lying climate stations to the altitudes where glaciers are found. I had always regarded this issue as settled by Hoinkes et al. (1962b) but I provide a further demonstration, if really needed, in Fig. 2. The three high altitude stations are Säntis (2500 m a. s. l.), Zugspitz (2962 m a. s. l.) and Sonnblick (3106 m a. s. l.) which may a priori better reflect conditions near the average ELA of Alpine glaciers than low-lying stations. However, the 3-station and 10-station anomalies are remarkably similar for most years with almost perfect agreement for the extremely warm 2003 summer. This is good agreement in spite of the wider horizontal coverage of the low-lying stations.

3. Hoinkes and the degree-day method

In a rather magisterial survey of international glaciology, Hoinkes (1968) says “Glaciers have frequently been quoted as sensitive indicators of climatic variations. This general statement has neither been challenged seriously nor has it been proved satisfactorily, mostly due to a lack of adequate meteorological and glaciological data.”

The somewhat pessimistic assessment above is nicely offset by another paper in the same symposium (Hoinkes et al, 1968) that introduces a positive degree-day statistic extrapolated from the climate station Vent (1900 m a. s. l.) to the terminus of Hintereisfer (2400 m a. s. l.). The statistic is used in a discussion of the mass balance of Hintereisferner in contrasting years, Hoinkes et al. (1968) say “… melting conditions at the terminus of Hintereisferner commence with daily mean temperature at Vent > 3°C. Melting prevails over the whole basin with temperature at Vent > 10°C”. Their procedure to calculate a positive degree-day total is as follows: “From the mean daily temperature at Vent 3°C was subtracted; these reduced temperatures were added together for the ablation season; taking negative values as zero. Snow was considered to occur on the glacier whenever there was precipitation in Vent and when temperature during precipitation in Vent was below 3°C. As a threshold for precipitation 3 mm was chosen, corresponding to about 5 cm of fresh snow. It was estimated that about two positive degree days were necessary to melt this amount of snow before melting of the glacier ice could continue. From the onset of precipitation two positive degree days were subtracted from the cumulated temperature, for each 3 mm of precipitation.
In this way for each ablation season a cumulative curve of degree-days was obtained which is called the (TS)-curve.

We could carry out the above computation with an Excel spreadsheet or a few lines of Matlab code on a microcomputer. Hoinkes et al. (1968) devised a graphical procedure to avoid the tedious manual calculations necessary without a microcomputer. Hoinkes et al. (1968) achieve an impressive correlation between “net ablation” (net balance with positive sign) and their (TS) statistic. I am here highlighting Hoinkes’ pioneering work on degree-day methods but Hoinkes et al. (1968) address several other interesting topics: vertical gradient of mass balance, retreat of transient snowline and the role of different “weather types” in linking macroscale climate to microscale heat budget. If anyone is writing a new paper on these topics they should certainly read Hoinkes et al. (1968) to see what has already been said.

The degree-day approach was further refined by Hoinkes and Steinacker (1975a), reporting work up to 1970. In this paper a series of “corrections” are applied to the positive degree-day total extrapolated to 2400 m a. s. l. and then correlated with Hintereisferner mass balance for 17 balance years 1952/53 to 1968/69. The data are summarized in Table 1 in Hoinkes and Steinacker (1975a): (a) the positive degree-day total at 2400 m a. s. l. (TS) gives a correlation coefficient $r = -0.72$ (explained variance 52%); (b) correction for fresh snow in summer over the whole glacier (TS 3°) gives $r = -0.76$ (58%); (c) correction for new snow in summer on the upper part of the glacier (TS 9°) gives $r = -0.81$ (65%); (d) correction for winter snow over the whole glacier gives $r = -0.85$ (73%); (e) a further correction for reduced degree-day totals for the start and end of the melt season gives $r = -0.91$ (83%). The improvement in correlation is very impressive. With access to a microcomputer, a modern worker might just run some kind of distributed degree-day model (Braithwaite et al. 2002) and miss the educational value of the step-by-step approach.

Hoinkes and Steinacker (1975b), reporting work up to 1974, add a further three years of mass balance data to the analysis but get generally similar results. Interestingly, there is a first hint of the use of a computer in presenting a regression between mass balance and degree-day total. Sadly, Herfried Hoinkes died just after preparing the paper Hoinkes and Steinacker (1975b) so we will never know what further ideas he may have had in his mind.

The mass balance of Hintereisferner is plotted against positive degree-day total in Fig. 3 using data up to 2011. The correlation coefficient $r = -0.87$ (explained variance 75%). This confirms that the good correlations found by Hoinkes et al. (1975a and 1975b) are still valid even though conditions may have changed in other ways. For Fig. 3, I have changed the method for calculating positive degree-days from that used by Hoinkes et al. (1975a and 1975b). He used the sum of positive values of daily mean temperatures. This is open to the criticism (Arnold and McKay, 1964) that it does not take account of melting conditions during part of a day with negative daily mean temperature or take account of freezing conditions during part of a day with positive daily mean. I overcome these problems by using daily minimum and maximum tem-
temperatures to calculate positive degree-day totals, although it does not make too much difference to the final results.

I intend studying the correlation between the mass balance of Hintereisferner and positive degree-day totals in more detail in a future paper and I hope to draw inferences that will be valid for other, less well documented, glaciers.

4. How representative is Hintereisferner mass balance?

Hoinkes and Rudolph (1962b) warn against applying results from Hintereisferner to other glaciers but, after doing a lot of work at one site, it is quite natural to see how far results can be applied elsewhere, and Hoinkes et al. (1968) compare Hintereisferner
mass balance with data from several other Austrian glaciers. The comparison is made for several contrasting years: 1963/64 (highly negative balance), 1964/65 (highly positive) and 1965/66 (moderately positive). Good agreement was found between temperature anomalies for the different years at 7 high-lying climate stations across the Alps. Hoinkes et al. (1968) say “This is good proof of the representativeness of the observations carried out at Vent and Rudolfshütte for glacierized altitudes in the Alps”.

Hoinkes’ original correlation between mass balance of Hintereisferner (HIN) and annual positive degree-day total (PDD) is extended in Table 1 by the addition of further variables. These are the mass balances of the two nearby glaciers (Kesselwandferner and Vernagtferner), and mean temperature anomalies for different lengths of summer (June-August, June-September and May-September). The snow accumulation at 2900 m a. s. l. (SNO) is estimated as the annual sum of daily precipitation at Vent with air temperatures below +6 ºC.

There are high correlations between the mass balances at the three glaciers, r = 0.91 to 0.94, reflecting their close proximity and generally similar climatic settings. The mass balances of all three glaciers are highly (negatively) correlated with positive degree-day total PDD, r = –0.86 to –0.90. The high correlation between HIN and KES (r = 0.92) in no way contradicts the generally accepted wisdom that Kesselwandferner has a more positive mass balance on average than Hintereisferner (Kuhn et al., 1985). The mass balances of all three glaciers are weakly (positively) correlated with the estimated snow accumulation SNO, r = 0.24 to 0.37.

In his own work, Hoinkes stressed the correlation between mass balance and PDD while other workers have used mean temperature anomalies for the summer period, e. g. Braithwaite et al. (2013), as being more convenient to use, or more accessible, than PDD. Correlations of the mass balances (HIN, KES and VER) with the temperature anomalies $T_{68}$, $T_{69}$ and $T_{59}$ are somewhat weaker, i. e. –0.77 to –0.83, than those with PDD, i. e. –0.86 to –0.90, but are still strong enough to be useful. The high correlations between PDD and the temperature anomalies express “local linearity” as there is good evidence (Reeh, 1991) of a nonlinear relation between PDD and temperature anomaly. For the range of temperature variations at a single altitude, 2900 m a. s. l. for PDD in the present case, the relationship can be treated as linear but if we were plotting degree-day factors at different altitudes we would need to account for nonlinearity.

Hoinkes and Rudolph (1962b) suggest a mid-May to mid-September melt season for the snout of Hintereisferner, suggesting a most appropriate temperature anomaly between 4-month $T_{69}$ and 5-month $T_{59}$ anomalies, e. g. 4.5-month anomaly as used by Braithwaite et al. (2013) However, the correlations between mass balance and the different temperature anomalies are very similar so the precise choice of temperature anomaly is not a critical issue. If we follow Reeh (1991) and assume that seasonal temperature variations follow a sine curve the relation between the different anomalies become exact.
**Table 1:** Correlations between mass balances of Hintereisferner (HIN), Kesselwandferner (KES) and Vernagtferner (VER) and temperature parameters extrapolated to 2900 m a. s. l. from the climate station at Vent: Mean June–August temperature (T68), mean June–September temperature (T69), mean May–September temperature (T59), and annual positive degree-day total (PDD). SNO is the annual sum of precipitation at Vent with temperatures below 6 °C. Period of record is 1965–2010 and sample size is 46 years for all correlations.

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<th></th>
<th>HIN</th>
<th>KES</th>
<th>VER</th>
<th>T68</th>
<th>T69</th>
<th>T59</th>
<th>PDD</th>
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<td>+0.91</td>
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<tr>
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<td>+0.94</td>
<td>−0.77</td>
<td>−0.80</td>
<td>−0.77</td>
<td>−0.86</td>
<td>−0.86</td>
<td>+0.36</td>
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<tr>
<td>VER</td>
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<td>−0.86</td>
<td>−0.81</td>
<td>−0.83</td>
<td>−0.90</td>
<td>−0.77</td>
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<tr>
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<tr>
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<tr>
<td>T59</td>
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**Fig. 4:** Correlations between mass balances of eight Alpine compared with distance between glaciers. Sources of data and location map are in Braithwaite et al. (2013).
The high correlations between the three glaciers in Table 1 are put into the broader context of mass balance variations on eight glaciers across the whole Alpine region (Fig. 4). Sources of data and location map are Braithwaite et al. (2013). The data for Fig. 4 are for the period 1961–1990 when there was little or no trend in mass balance to unduly ‘force’ the inter-glacier correlations. Mass balances are generally highly correlated ($r > 0.8$) for closely located glaciers (within 100 km) and quite weak for glaciers on the opposite sides of the region, i.e. Fig. 4 suggests a degree of spatial autocorrelation. This result contrasts with the suggestion of similar mass balance variations across the whole region (Reynaud, 1980): if the latter were strictly true, the correlation-distance line would be horizontal.

Correlations for summer temperature anomaly at 13 climate stations across the whole Alpine region are plotted against inter-station distance in Fig. 5. The data for Fig. 5 are for 1961–1990 when there was little trend of increasing temperature. Temperature anomalies are generally highly correlated ($r > 0.8$) for stations within about 300 km from each other and are still $> 0.7$ even at distances of 500 km. Hoinkes et al.

![Fig. 5: Correlations between summer temperature anomalies at 13 climate stations in and around the Alps compared with distances between stations. Anomalies are averages of June-September $T_{69}$ and May–September $T_{59}$ anomalies and sources of data and location map are in Braithwaite et al. (2013).](image-url)
(1968) would probably have explained these high correlations in terms of mesoscale weather variability.

Inter-station correlations for temperature are generally higher than inter-glacier correlations for mass balance, while we know that inter-station correlations are low for precipitation. As glacier mass-balance variations are controlled by both temperature and precipitation, we might speculate that precipitation variations degrade the high correlations that might be expected if mass balance depended only upon temperature. From Figs. 4 and 5, it is clear that results from Hintereisferner should be broadly representative of locations within about 200 km but not applicable to the whole Alpine region. The present network of mass balance measurements within the Alps has grown in a rather chaotic way, mainly as the result of initiatives by enthusiastic small groups rather than bureaucratic organs, but a rational and statistically efficient network could be devised by geostatistical methods using correlations between glaciers as shown in Fig. 3.

5. Degree-day methods after Hoinkes

I never actually met Hoinkes but much of my glacier-climate work was inspired by his work. For example, his success in correlating annual mass-balance with positive degree-day totals encouraged me to compare glacier melt with air temperature for shorter periods (Braithwaite, 1977 and 1981). I was challenging the implicit idea (Hoinkes, 1955) that “greater heat exchange from air to ice” is not sufficient to account for ablation variations. I took this as downplaying of the role of turbulent heat fluxes in ablation variations. My study used data from two glaciers in northern Canada: White Glacier, Axel Heiberg Island (Andrews, 1964; Havens et al., 1965; Müller and Roskin-Sharlin, 1967; Müller and Keeler, 1969) and Sverdrup Glacier, Devon Island (Keeler 1964; Müller and Keeler, 1969).

When I joined the staff of the Geological Survey of Greenland (GGU) in 1979, I persuaded colleagues Poul Clement and Ole B. Olesen to add daily ablation measurements to their routine programmes at Nordbogletscher (1978–1983), South Greenland, and Qamanârssûp sermia (1979–1986), West Greenland, and I continued the measurements at the latter station when I took over responsibility in 1981 (Braithwaite and Olesen, 1989; Braithwaite, 1995). I was also able to make relatively short visits to North Greenland in 1993 and 1994 (Braithwaite et al 1998a & 1998b) to collect shorter ablation-temperature series to compare with the longer series at Nordbogletscher and Qamanârssûp sermia.

The correlations between short-term ablation variations and daily mean air temperature (at screen level 1.5 to 2 m above the surface) from the above studies are summarized in Fig. 6. The presentation of the data in four sub-plots involves some pooling of data from different studies, e.g. four short series from two sites in Fig. 6a and two series from different sites in Fig. 6d. Even the long series plotted in Figs. 6b
Braithwaite (2012) splits the original data up into shorter sub-sets for the same sites and analyses variations in intercept and slope for ablation-temperature regression equations. There are two sub-sets (of 14 and 23 d respectively) where ablation-temperature correlation is very low, possibly reflecting large measurement errors for short-term ablation, or a short-term peculiarity in the energy balance. My decision to pool the data as I have done in Fig. 6 reflects my belief that a simple relation between ablation and air tem-

Fig. 6: Daily ablation versus daily mean temperature for (a) Arctic Canada, (b) South Greenland, (c) West Greenland and (d) North Greenland. Sources of data are in the text.
perature should not be expected for periods of only a few days with generally similar weather conditions.

Taking the regression equations in Fig. 6a to Fig. 6d as representing ablation-temperature conditions for periods of many days, or even several seasons, we can see that intercepts are very small, 1–7 mm d\(^{-1}\). In three out of four cases, the intercepts are not significantly different (at 5 % level) from 0 mm d\(^{-1}\). These small intercepts are consistent with the idea there is on average little or no ablation at air temperatures below 0 ºC. However, Kuhn (1987) does remind us that melting may occur over a wide range of air temperatures, and there are quite a few points in Fig. 6b and 6c where melt rates of 20–30 mm d\(^{-1}\) occur at air temperatures below 0 ºC. It is also a matter of observation that ice surfaces in Greenland, just like in the Alps, can remain frozen for part of a summer day, depending on weather conditions, even when air temperatures are over 0 ºC.

Slopes in Fig. 6a to Fig. 6d are very similar to each other, i.e. 5.7–7.7 mm d\(^{-1}\) K\(^{-1}\). Taken together with the small intercepts, the presents results are consistent, in round numbers, with degree-day factors of about 6 to 8 mm d\(^{-1}\) K\(^{-1}\) for Arctic and Greenland glaciers. From energy balance considerations (Ambach, 1988; Braithwaite, 1981 and 1995) the main contribution to this ablation-temperature sensitivity is from sensible heat flux, with a smaller contribution from incoming long-wave radiation from clear and cloudy skies, and little contribution from short-wave radiation. These results are consistent with temperature-sensitivities from Hintereisferner (Kuhn, 1979), e.g. an average of 1.68 MJ m\(^{-2}\) d\(^{-1}\) K\(^{-1}\) for sensible heat flux and only 0.28 MJ m\(^{-2}\) d\(^{-1}\) K\(^{-1}\) for incoming long-wave radiation. Braithwaite (1980) converts the sum of these two components to equivalent melt rate units (5.9 mm d\(^{-1}\) K\(^{-1}\)), which is comparable with published degree-day factors, and suggests that Kuhn (1979) should be credited with demonstrating the physical basis of the degree-day factor. Outgoing long-wave radiation from the glacier surface is a large component in the energy balance but nearly constant throughout the melting season so its temperature-sensitivity must be very small.

Hoinkes’ use of the degree-day concept has led many workers to apply the concept in all parts of world, reviewed by Hock (2003). Fig. 7 summarises degree-day factors reported in the literature. The confidence intervals for Nordbogletscher and Qamanâr̃ssûp sermia (Braithwaite, 1995) refer to month-to-month variations, the confidence interval for snowmelt at Weissfluhjoch refers to season-to-season variations (de Quervain, 1979), and all other confidence intervals refer to site-to-site variations. Hoinkes et al. (1975a) quotes degree-day factors of 2.5 and 9.0 mm d\(^{-1}\) K\(^{-1}\) for snow and ice respectively. It is interesting that the former is on the low side of the range for “snow” in Fig. 7 while the latter is on the high side of the “ice” range. Braithwaite (1995) shows that the surface energy balance predicts high and low degree-day factors for ice and snow surfaces respectively, while Zhang et al. (2006) discuss possible geographical variations in degree-day factor, presumably reflecting geographical variations in energy balance.

The design of Fig. 7 implies a binary classification of glacier surfaces into snow and ice classes but Juen et al. (2014) extend the degree-day concept to debris-covered
surfaces. According to Fig. 2 in their paper, degree-day factor starts (a) at about 6 mm d\(^{-1}\) K\(^{-1}\) for zero debris cover, (b) increases slightly for very thin (0.01 m?) debris cover, and then (c) decays to well under 1 mm d\(^{-1}\) K\(^{-1}\) for debris covers greater than about 0.3 m. In accord with the classic Østrem curve, (a) agrees with known degree-day factors for fairly clean ice, (b) probably reflects the increased radiation absorption due to reduced albedo, and (c) reflects the insulating effect of the debris layer. Further work in this area will be most welcome!

6. Reflections

Herfried Hoinkes died in service as a busy university teacher and researcher (Ambach, 1976). He did not have time for the mature reflection that is the privilege of any
researcher who reaches the safe haven of a reasonable pension with enough mental energy to think back on past work. I see a clear gap between Hoinkes’ comments on the physics of the melt process (Hoinkes, 1955) and the relative success of his degree-day method for predicting year-to-year variations in glacier mass balance (Hoinkes et al. 1975a and 1975b). The missing link between the two areas is a correct interpretation of the role of air temperature in melt processes on scales of a few days to many years. Had he lived longer, I have no doubt that he would have closed this gap in a satisfactory manner.

The thesis of the present paper is that (a) incoming radiation (short- and long-wave) is a major source of ablation energy, as shown by Hoinkes and other workers, and that (b) increased heat transfer from the air to glacier surfaces, mainly by turbulent sensible flux, is a major cause of increased melting in the last 2–3 decades with rising air temperatures. Statement (b) may seem to contradict something that Hoinkes once wrote (Hoinkes, 1955) but we have to acknowledge that we owe much of our present knowledge and understanding of glacier mass balance variations to the work of H. Hoinkes (1916–1975).

7. Acknowledgements

In one of his articles, Hoinkes wrote “Special thanks are due to the numerous collaborators in the field, mostly undergraduates and graduates from the University of Innsbruck, who offered their help on a voluntary basis”. Aside from Herfried Hoinkes, my own glacier-climate work has been inspired and encouraged by other Austrian glaciologists: Walter Ambach and Michael Kuhn. I now hold an Honorary Senior Research Fellowship (2013–2016) at the University of Manchester that allows me access to a small office, an informal “glacier lunch” club (Philip Hughes and Jason Dortch), ITC facilities, a first-class draughtsman (Graham Bowden), and one of the best university libraries in the UK.

8. References


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