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MASS BALANCE MEASUREMENTS IN THE SØNDRE STRØMFJORD AREA IN THE PERIOD 1990–1994

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With 5 figures

ABSTRACT

We present four years of mass balance measurements for a transect in the ablation zone of the Greenland ice sheet (near Søndre Strømfjord, West Greenland). The measurements cover an altitude range of 337 to 1524 m. The mean equilibrium line-altitude is found to be 1424 m. The largest balance gradient is found just below the equilibrium line. This is a consequence of the albedo pattern, showing the smallest values in the middle of the ablation zone and not at the ice margin.

MASSENBILANZMESSUNGEN IM GEBIET DES SØNDRE STRØMFJORD 1990–1994

ZUSAMMENFASSUNG

Der vorliegende Bericht behandelt vier Jahre lang durchgeführte Massenbilanzmessungen für ein Profil in der Ablationszone des Grönland-Eisschildes in der Nähe von Søndre Strømfjord, Westgrönland. Die Messungen umfassen einen Höhenspiegel zwischen 337 und 1524 m. Die mittlere Höhe der Gleichgewichtslinie liegt bei 1424 m. Der größte Bilanzgradient wurde unmittelbar unter der Gleichgewichtslinie gefunden. Das ist eine Folge des Albedomusters, das die kleinsten Werte in der Mitte der Ablationszone und nicht an der Eisgrenze zeigt.

INTRODUCTION

The GIMEX (Greenland Ice Margin EXperiment), started in 1989, has now delivered a valuable data set to study the relation between glacier mass balance and characteristics of the overlying atmospheric boundary layer. Along a transect near Søndre Strømfjord mass balance measurements have been performed since 1990, and two micrometeorological experiments were carried out in the summers of 1990 and 1991. The set-up of the meteorological experiments and the stake network are shown in Figure 1. An overview of the meteorological work has been given in Oerlemans and Vugts (1993) and more specific results have been discussed in a series of papers in a special issue of Global and Planetary Change Vol. 9 (e.g. Duynkerke and Van den Broeke, 1994; Henneken et al., 1994; Van den Broeke et al., 1994; Van de Wal and Russell, 1994). Here we present the results of four years of mass balance measurements, together with a global meteorological interpretation.

The study area is characterised by relatively high ablation and low accumulation. When taking data from the map of Ohmura and Reeh (1991), the annual accumulation increases from 0.22 m at 337 m to 0.26 m at 1524 m a. s. l. (above sea level). It is not clear, however,

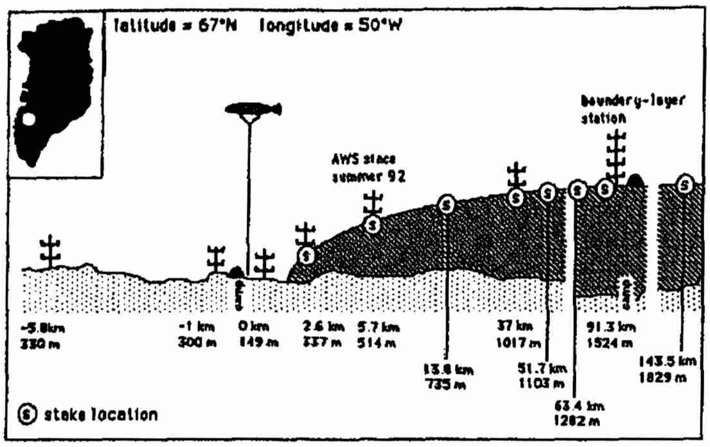

Fig. 1: Set-up of the glacio-meteorological work during GIMEX (Greenland Ice Sheet Margin EXperiment). Meteorological stations placed along a west-east transect perpendicular to the ice margin. Listed at each site: distance to reference point, surface elevation in 1992. AWS is the automatic weather station. S are locations of stakes used for mass balance measurements

how large the error bars are. Annual mean temperature ranges from about –4 °C at 337 m a. s. l. to about –14 °C at 1524 m a. s. l. The elevation and coordinates of the individual sites were measured by means of 3D-differential GPS in 1990, 1991 and 1992. The area is of particular interest as the equilibrium-line altitude is judged to be one of the highest in Greenland.

MASS BALANCE MEASUREMENTS

Mass balance readings were made on nine locations spanning an altitude range from 337 to 1524 m a. s. l. On each location readings were made at 2–3 stakes at the end of the ablation season, between the 5th and 23th of August (for site 9 between 21st of July and 16th of August), yielding time intervals ranging form 348 to 379 days. The specific balance has been obtained by averaging the different stake readings at a specific location. Although one can argue about the best method to calculate the yearly mean specific balance from irregular time-intervals, we simply divided the time interval by 365 days and multiplied this value with the measured height difference along the stake to obtain the yearly mean specific balance. Another method would be to calculate the cumulative balance through the year with an energy balance model and use these results to compile the measurements from irregular time intervals to yearly mean values. Such a method may be attempted in the future. A density of 900 kg/m^3 has been used to convert the measurements from m ice to m water equivalent (m we). Based on differences between stakes at one location, we estimate the relative error in the yearly mean specific balance to be 10 %. The measurements for the balance years 1990/1991 to 1993/1994 are presented in Figure 2 and Table 1.

A simple linear fit using all locations shows annual mass balance gradients ranging from 2.3×10^{-3} to 3.6×10^{-3} m we/m. This is comparable with other measurements in West Greenland, see Thomsen (1987) for the Påkitsoq area (69° N), Braithwaite (1983) for Qa

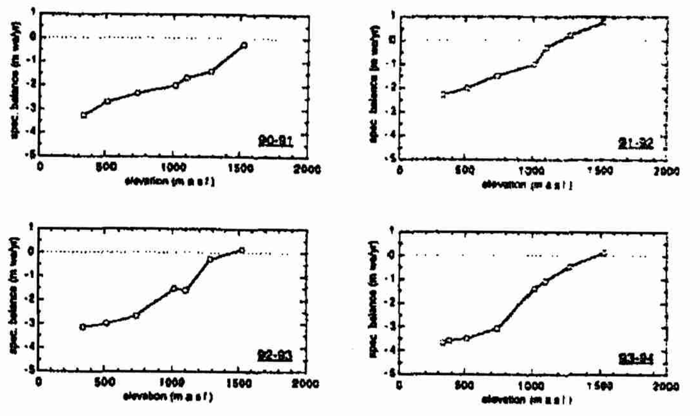

Fig. 2: Specific balance as a function of elevation for the period 1990–1994

Table 1: Mass balance measurements for the period 1990–1994. The specific balance is expressed in m water equivalent. The uncertainty is the standard deviation if more than 1 stake is used to calculate the specific balance. If only one measurement was available a relative error of 10 % has been assumed. Elevations are from three-dimensional differential GPS measurements made in 1992

Location	Elevation m a. s. l.	1990–1991	1991–1992	1992–1993	1993–1994
Site 4	337	3.26 ± 0.22	2.28 ± 0.10	3.14 ± 0.31	3.57 ± 0.36
Site 5	514	2.69 ± 0.27	2.00 ± 0.20	2.99 ± 0.03	3.48 ± 0.10
Site relais	735	2.33 ± 0.23	1.49 ± 0.21	2.66 ± 0.04	3.07 ± 0.34
Site 6	1017	2.00 ± 0.02	1.00 ± 0.03	1.51 ± 0.01	1.37 ± 0.14
Site 7	1103	1.67 ± 0.17	0.29 ± 0.01	1.58 ± 0.06	1.07 ± 0.25
Site 8	1282	1.40 ± 0.14	−0.23 ± 0.02	0.28 ± 0.03	0.46 ± 0.02
Site 9	1524	0.25 ± 0.03	−0.79 ± 0.01	−0.15 ± 0.03	−0.15 ± 0.03

manânarssûp Sermia (64.5° N) and Weidick (1984) for West Greenland. These authors mention mass balance gradients from 2 to 4.5×10^{-3} m we/m. A closer inspection of the measurements presented in Figure 2 indicates an increasing gradient in the course of the four years. More years of measurements are needed to see to what extent this reflects the natural interannual variability.

Table 2: Equilibrium-line altitudes for the period 1990–1994

Balance year	equilibrum-line (altitude m a. s. l.)
1990–1991	1575
1991–1992	1205
1992–1993	1440
1993–1994	1465

The different profiles of the specific balance lead to equilibrium-line altitudes as presented in Table 2. The equilibrium-line altitude has been calculated by linear extrapolation or interpolation between the two measurements which are closest to the equilibrium line in a particular year. Using a linear fit based on all data points would result in an overestimation of the equilibrium line altitude, because the mass balance gradient increases in the upper part of the ablation area. This is clearly shown in Figure 3, where the mean specific balance over the period 1990–1994 is plotted. The data suggest that the ablation area can be divided into two parts with a different characteristic gradient of the specific balance. The lower part has a gradient of 1.8×10^{-3} m we/m yr, the upper part of 3.3×10^{-3} m we/m yr, nearly twice as high as the lower part. Although the number of data points used to partition the ablation area in a lower and upper part are limited, there are reasons to believe that the difference in gradient is a real feature of a climatological nature. Similar deviations from a constant gradient have also been observed along the EGIG profile (Ambach, 1979). Moreover, as described below, the interpretation of the meteorological data obtained in the summer of 1991 support the view.

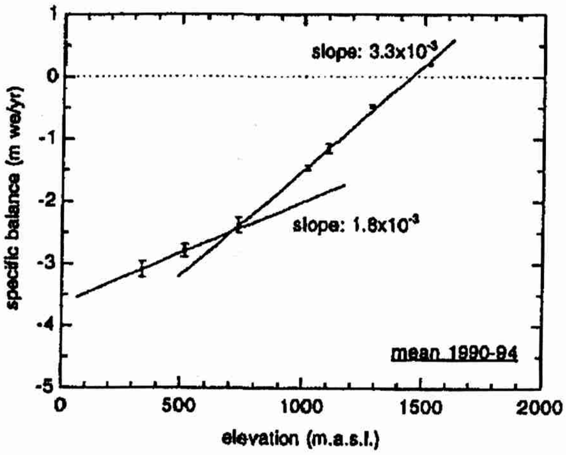

Fig. 3: Mean specific balance averaged over the 4 balance years. The two numbers in the figure are the mass-balance gradients with respect to elevation for the lower and upper ablation area

As a start a closer look will be given to the measurements of the albedo. In Figure 4a one can observe large differences in the albedo from place to place and during the ablation season (Oerlemans and Vugts, 1993). A very low daily mean albedo can be observed at site 6, especially later in the melt season. Near the ice margin, at sites 4 and 5, the albedo is rather constant throughout the whole summer. At site 9, close to the equilibrium-line, the presence of snow leads to higher values of the albedo. The construction of albedo patterns from NOAA-AVHRR images (Knap and Oerlemans, 1996) makes clear that the albedo differences between sites 4, 5, 6 and 9 reflect a large-scale pattern and are not the consequence of sampling errors. In the satellite image shown in Figure 4b, a distinct band of low albedo runs parallel to the edge of the ice sheet. This band is present during a large part of the melt season (Knap and Oerlemans, 1996).

Variations of the albedo have an important effect on the energy budget of the ice surface, and thus lead to significant differences in the amount of melt. The net shortwave

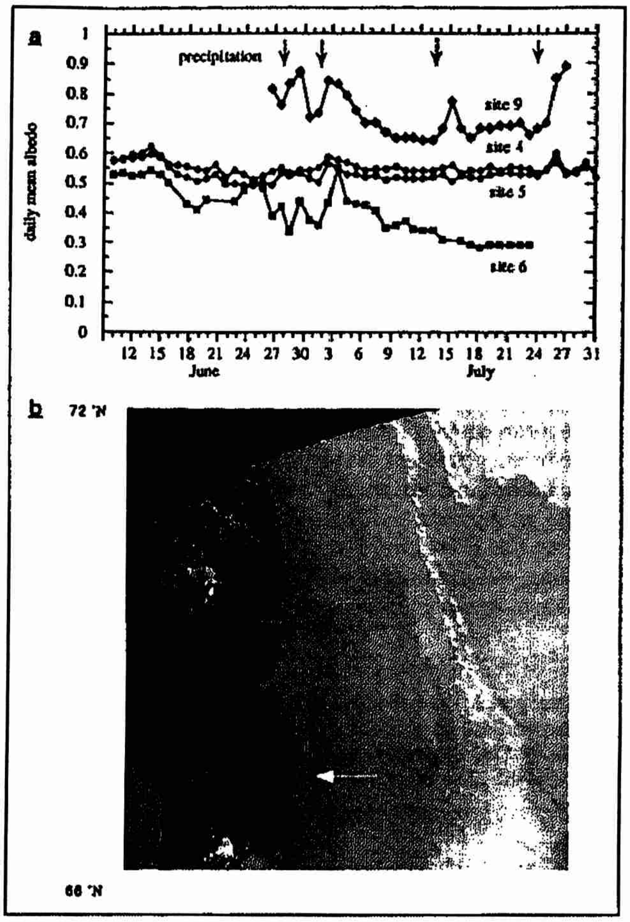

Fig. 4: Daily mean values of the surface albedo at sites 4, 5, 6, 9 (on the ice sheet), and 3 (tundra) during the summer of 1991 (a). AVHRR image (visible channel 2) from the NOAA-11 satellite showing a distinct band of low albedo on July 25, 1991 (b)

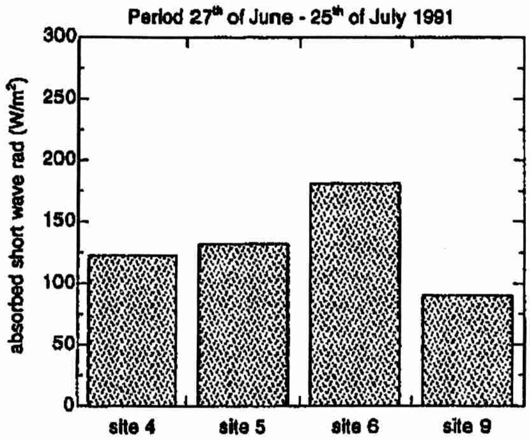

Fig. 5: Absorbed shortwave radiation as measured at the various sites

radiation balance as measured in the period June 27 to July 25 1991 at sites 4, 5, 6 and 9 is presented in Figure 5. The absorbed shortwave radiation is rather similar for site 4 and 5 as a result of small differences in albedo. Higher in the ablation area a large gradient in the absorbed shortwave radiation can be observed due to the large albedo differences between site 6 and site 9. Over the period considered, the absorbed shortwave radiation at site 6 is twice as high as at site 9 (in spite of the fact that the global radiation is slightly larger at site 9). More detailed energy balance calculations, not discussed here, indeed shown that the relatively large ablation at site 6 can entirely be attributed to the low albedo.

EPILOGUE

In summary, from four years of mass balance measurements along the Søndre Strømfjord transect, we conclude that:

- the mean equilibrium-line altitude is relatively high (1424 m)
- the balance gradient is largest just below the equilibrium line
- the interannual variability is large.

The programme will be continued in the next five years. In the summer of 1994 the stake net has been extended to include a site at about 1800 m, i.e. well above the equilibrium line. An automatic weather station placed in the ablation zone in 1992 (see Fig. 1) will help to interprete the data (to understand the interannual variability, in particular).

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