Earth Syst. Sci. Data Discuss., 5, 351–363, 2012
www.earth-syst-sci-data-discuss.net/5/351/2012/
doi:10.5194/essdd-5-351-2012

Open Access Earth System Science Data Discussions

Twenty-one years of mass balance observations along the K-transect, West Greenland

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Received: 6 April 2012 – Accepted: 27 April 2012 – Published: 14 May 2012

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Published by Copernicus Publications.

Abstract

A 21-yr record is presented of surface mass balance measurements along the K-transect. The series covers the period 1990–2011. Data are available at 8 sites along a transect over an altitude range of 390–1850 m at approximately 67° N in West Greenland. The surface mass balance gradient is on average 3.8×10^{-3} m w.e. m^{-1}, and the mean equilibrium line altitude is 1553 m a.s.l. Only the lower 3 sites within 10 km of the margin experience a significant increasing trend in the ablation over the entire period. Data are available at: http://doi.pangaea.de/10.1594/PANGAEA.779181.

1 Introduction

Over the last 10 yr our understanding of the mass balance of the Greenland ice sheet improved considerably due to satellite observations. Changes in the gravity field, radar altimetry and inferometry data combined with regional climate models contributed to this (e.g. Rignot and Kanagaratnam, 2006; Thomas et al., 2008; Wouters et al., 2008; Van den Broeke et al., 2009a). Longer records of the surface mass balance are sparse, in particular for the ablation region. Here we present a compilation of data from ground observations as measured along the K-transect over the last 21 yr. Figure 1 shows the K-transect where IMAU (Institute for Marine and Atmospheric research Utrecht) started 21 yr ago with mass balance observations, GPS measurements (Van de Wal et al., 2008) and later observations by automatic weather stations. It is the longest record of ground based surface mass balance measurements in Greenland. Several short series of observations exist (e.g. Thomsen, 1987; Braithwaite and Olesen, 1989; Reeh, 1991), but they are all limited in length. Nevertheless those data are important because they are located in widely different climatological regions.

The paper is an update of the work presented by Van de Wal et al. (1996, 2005), and Greuell et al. (2001) who presented mass balance data covering shorter periods. Combined with the weather station data these data have also been used for several

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validation studies of mass balance models. An overview of the weather station data has been presented by Van den Broeke et al. (2008, 2009b, 2011). Here we present the surface mass balance data and discuss the spatial and temporal pattern.

2 Surface mass balance measurements

Eight sites are visited for mass balance measurements and redrilling of stakes every year, mostly in late August. Six sites are located in the ablation area, one near the equilibrium line altitude and one in the accumulation zone. The record for the highest site is a few years shorter and some values are averaged over 2 yr because visits to the site failed several times due to logistical constraints. At each site at least two stakes are maintained throughout the entire period. Data shown in Table 1 and in the figures are the mean values of the individual stake readings and always represent one mass balance season. Data are not reduced to a fixed date, but measurements are usually carried out in late August. Length changes are converted to surface mass balance by assuming an ice density of 900 kg m^{-3}, except at the highest site where snow and firn is at the surface. There density measurements are carried out. Sites near the margin have been relocated a few times because of crevasse zones and data at the lowest two sites are therefore reduced to a fixed elevation. The mass balance data for the other sites are not corrected for the small height differences due to ice flow or stake replacement. The largest uncertainty in the measurements in the lower region is caused by the rough surface topography. It is estimated that annual values at these sites have an uncertainty (1σ) of 20 cm w.e. Ignoring other systematic uncertainties this implies a negligible error for the annual average over the entire transect as it is based on data from 7 sites.

2.1 Mass balance as a function of time

Figure 2 shows the interannual variability of the average mass balance along the transect. Every site has been given an equal weight and Site 10 has been neglected because the record is incomplete. Weighing the records proportional to the distance between the neighbouring points yields a similar variability but on average less ablation because the higher points cover larger areas (Van de Wal et al., 2005). The trend in the observation is small ($0.04\,\mathrm{m\,yr^{-2}}$) and barely significant ($r = 0.49$) and the highest ablation took place in 2010 (Tedesco et al., 2011).

It has been argued that satellite elevation changes for Greenland (e.g. Krabill et al., 2004) indicate that the marginal areas of Greenland are thinning and the central parts are thickening over the period 1993–2003. This finding was based on measurements intervals from 1993–1998, 1997–2001, 1997–2002 and 2002–2003. If we consider the trend in the mass balance for the individual sites as shown in Fig. 3, we can confirm that the ablation near the margin (S4, S5, SHR) increases over time. Reproducing the analysis to the identical 4 periods as Krabill et al. (2004) used, shows that the last period, which is the mass balance year 2002–2003, is indeed larger than the other three periods. So although a strict comparison of the finding by Krabill et al. (2004) is not convincing due to the limited temporal coverage, the increased thinning near the margins as presented by Krabill et al. (2004) is confirmed by the enhanced ablation over the entire period in the lower ablation zone. This implies an increasing mass balance gradient and hence an increase of the sensitivity of the mass balance for future changes (e.g. Oerlemans et al., 2001).

2.2 Mass balance as a function of elevation

Figure 4 presents the surface mass balance as a function of elevation over the ablation area. From the figure we can conclude that on average the mass balance decreases linearly with elevation. In absolute sense the variability near the margin is larger than near the equilibrium line, leading to the divergence of the pattern in Fig. 4. During some years the ablation at Site 7 (1110 m) is higher than at Site 6 (1010 m), which is likely related to local variations in the albedo of the surface (e.g. Greuell and Knap, 2000 and Wientjes et al., 2011). Most ablation took place during the season 2009–2010 and the

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smallest ablation record has been measured over the season 1991–1992. The average mass balance gradient is 3.8 mm w.e. m^{-1} over the ablation area.

Based on the data close to the equilibrium line (Site 8, Site 9 and Site 10, if available) we calculated for every year the height of the equilibrium line. We included a small correction for height changes due to ice displacement over the course of time. This height correction is not larger than plus or minus 9 m in a single year. On average the equilibrium line altitude is 1553 m a.s.l., just above Site 9. The yearly values of the equilibrium line height are presented in Fig. 5a. Figure 5b shows the cumulative mass balance at Site 9. The figure indicates that the site is close to the equilibrium line (mean −0.1 m w.e. yr^{-1}), with a few consecutive negative values at the end of the series.

3 Conclusions

We have presented a data set of surface mass balance over a period of 21 yr along a transect in West Greenland. Data can be used for validation of satellite observations and regional climate models both with respect to the interannual variability as well as the mass balance gradient with elevation. Furthermore data can be used for validation of satellite estimates of equilibrium line altitude or melt extent both important quantities for assessing changes in the Greenland ice sheet.

Acknowledgements. Many people contributed to the fieldwork over time, in particular we like to mention Dirk van As and Alun Hubbard who assisted in the field wherever possible over the last few years. This project was financed over time by Utrecht University, and several grants from the Dutch Science foundation including the Spinoza Program and the Netherland Polar Programme. Over the last few years the project has also been funded by a grant from the Royal Academy of Science (KNAW) to J. Oerlemans.

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Table 1. Surface mass balance measurements (in m w.e.) along the K-transect at 67° N. Distances are presented in kilometres from the western ice margin. Values at S4 are recalculated to a height of 383 m a.s.l. Bold values are outside the 2σ interval with respect to the 20 yr mean (1990–2010) and standard deviation.

	Site 4 383 (m a.s.l.) 3 km	Site 5 490 (m a.s.l.) 6 km	SHR 710 (m a.s.l.) 14 km	Site 6 1010 (m a.s.l.) 37 km	Site 7 1110 (m a.s.l.) 52 km	Site 8 1260 (m a.s.l.) 63 km	Site 9 1520 (m a.s.l.) 91 km	Site 10 1850 (m a.s.l.) 143 km
1990–1991	−4.23	−3.64	−3.20	**−2.77**	−1.75	−1.47	−0.26	
1991–1992	**−2.14**	**−2.03**	**−1.52**	−1.02	−0.30	0.08	0.46	
1992–1993	−3.05	−3.04	−2.71	−1.54	−1.60	−0.14	0.23	
1993–1994	−3.58	−3.49	−3.08	−1.37	−1.06	−0.45	0.10	
1994–1995	−4.41	−4.00	−3.52	−1.70	−1.78	−1.09	−0.05	0.01
1995–1996	−4.04	−2.87	−1.95	−0.93	−0.47	−0.03	0.40	0.49
1996–1997	−4.40	−3.87	−3.30	**−2.84**	−1.64	−0.88	−0.02	0.27
1997–1998	−4.08	−4.08	−3.22	−1.59	−1.57	−0.97	−0.01	0.29
1998–1999	−4.55	−3.77	−3.35	−1.46	−1.30	−0.86	−0.17	0.06
1999–2000	−4.17	−3.31	−2.70	−1.26	−1.05	−0.51	−0.06	0.26
2000–2001	−4.58	−3.66	−3.16	−1.03	−0.98	−0.49	0.16	0.57
2001–2002	−4.23	−3.29	−2.95	−1.30	−1.55	−0.93	0.17	0.29
2002–2003	−5.04	−3.89	−3.29	−1.97	−1.77	−1.07	−0.53	0.11
2003–2004	−4.68	−3.99	−3.53	−1.47	−1.73	−0.66	0.01	0.45
2004–2005	−4.28	−3.63	−3.24	−1.28	−1.57	−0.17	0.08	0.45
2005–2006	−4.17	−3.70	−2.97	−1.50	−1.13	−0.23	0.08	0.39
2006–2007	−4.7	−4.19	−3.55	−2.00	−2.30	−1.16	−0.68	0.04
2007–2008	−4.29	−4.10	−3.54	−1.48	−1.36	−0.44	0.02	0.21
2008–2009	−3.97	−3.38	−2.84	−1.34	−1.47	−0.22	0.23	0.20
2009–2010	**−5.9**	**−5.12**	**−4.39**	**−2.95**	**−2.99**	**−1.93**	**−1.01**	0.20
Mean 90–10	−4.22	−3.65	−3.10	−1.58	−1.45	−0.64	−0.03	0.27
standard deviation	0.76	0.63	0.62	0.54	0.60	0.50	0.36	0.17
2010–2011	−3.81	−4.23	−3.21	−2.08	−1.59	−1.89	−0.84	

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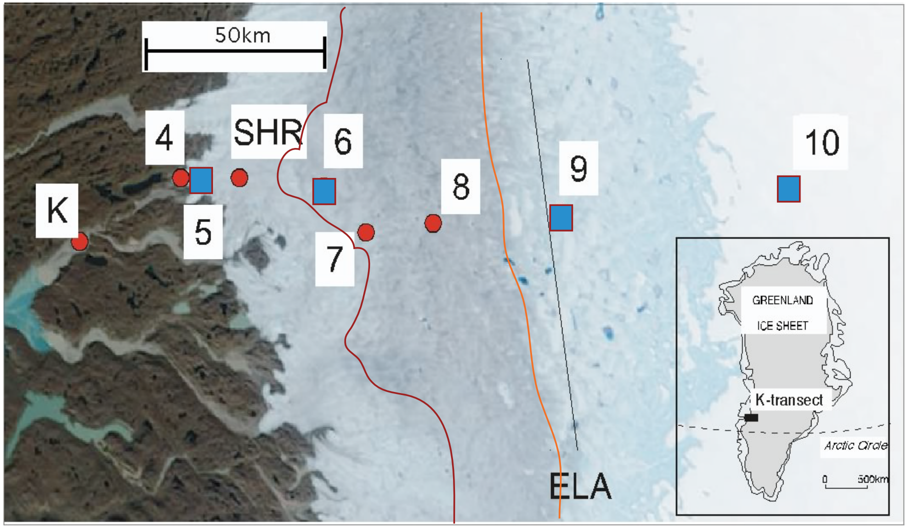

Fig. 1. The K-transect in West Greenland. The sites 4, 5, SHR, 6, 7, 8, 9 and 10 are mass balance sites. The blue squares indicate the position of the IMAU weather stations. The equilibrium line altitude is located close to site 9. The two coloured lines indicate the dark zone where albedo is lower than in the surrounding areas (Wientjes and Oerlemans, 2010; Wientjes et al., 2011).

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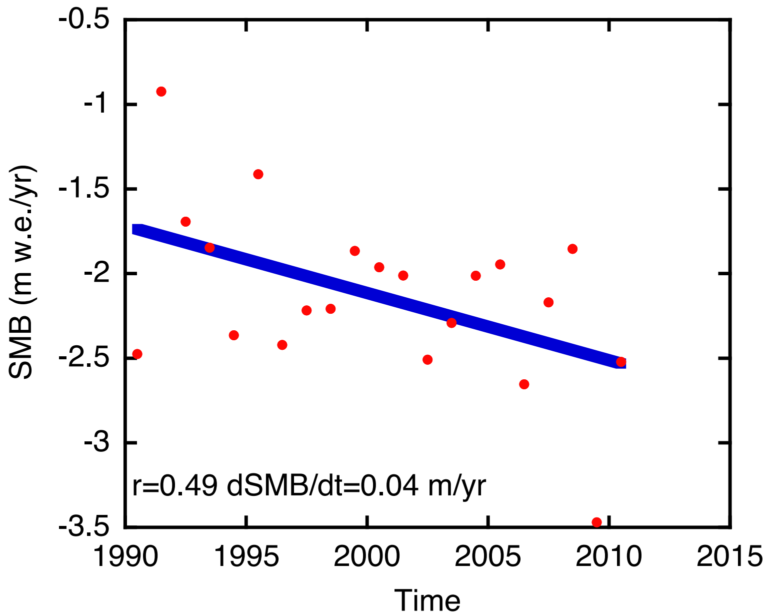

Fig. 2. The surface mass balance averaged (S4–S9) over the transect as a function of time. dSMB dt^{-1} is the gradient in the surface mass balance.

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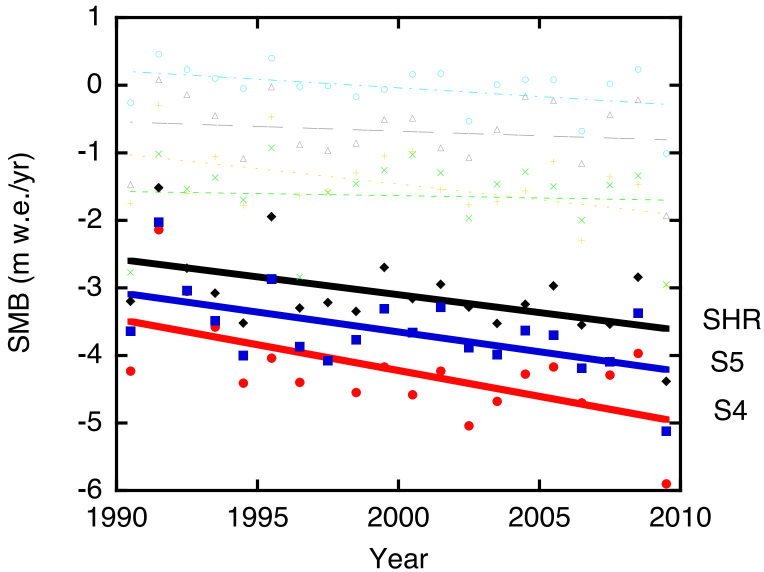

Fig. 3. Temporal evolution of the individual surface mass balance sites. Ablation increases over time only near the margin of the ice sheet. Dotted lines are sites higher on the transect with no significant trend over time.

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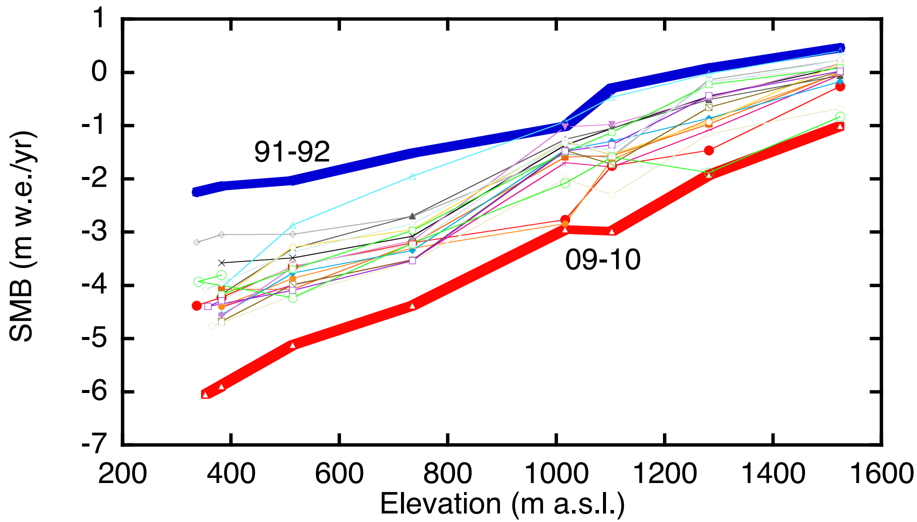

Fig. 4. Surface mass balance as a function of elevation for each individual year starting in 1990. The lowest surface mass balance was recorded the second year and the highest during the season 2009–2010, both are indicated with thick lines.

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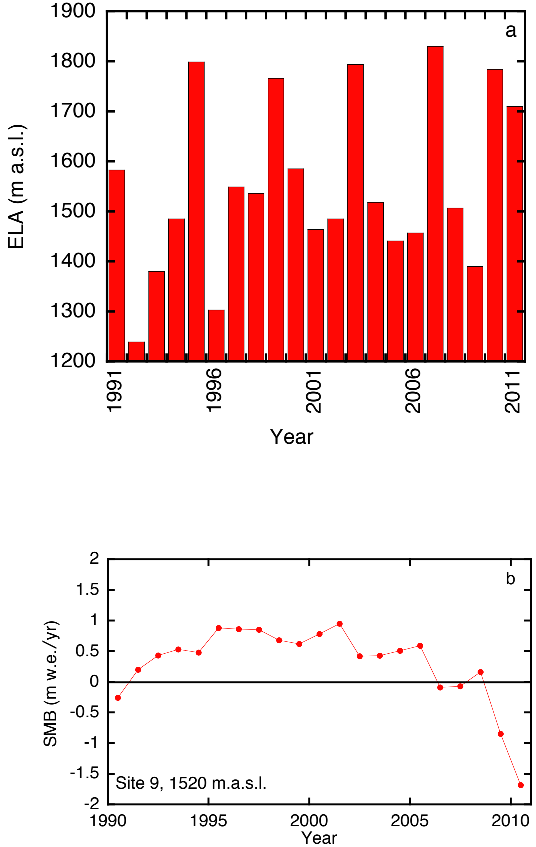

Fig. 5. (a) Equilibrium line altitude as a function of time **(b)** Cumulative surface mass balance near the equilibrium line indicating an extension of the ablation zone over the last few years.

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