Greenland Ice Sheet: Increased coastal thinning


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1. Introduction

[1] Repeated laser-altimeter surveys and modelled snowfall/summer melt show average ice loss from Greenland between 1997 and 2003 was \(80 \pm 12\) km\(^3\) yr\(^{-1}\), compared to about \(60\) km\(^3\) yr\(^{-1}\) for 1993/94–1998/99. Half of the increase was from higher summer melting, with the rest caused by velocities of some glaciers exceeding those needed to balance upstream snow accumulation. Velocities of one large glacier almost doubled between 1997 and 2003, resulting in net loss from its drainage basin by about \(20\) km\(^3\) of ice between 2002 and 2003. INDEX TERMS: 1640 Global Change: Remote sensing; 1863 Hydrology: Snow and ice (1827); 4556 Oceanography: Physical: Sea level variations.


2. Methods

[4] Our estimates of surface-elevation change rates (\(\Delta h/\Delta t\)) are from comparison of ATM measurements, with elevation accuracy of \(\sim 10\) cm for flight lines of several hundred km [Krabill et al., 2002]. Recent surveys focussed on coastal regions in order to investigate areas undergoing most rapid changes so overall coverage is sparser than for 1993/4 and 1998/9 surveys, with higher-elevation coverage confined to the northern half of the ice sheet. At lower elevations, a strong seasonal elevation change is associated with brief periods of intense summer melting followed by slow thickening from snow accumulation and seaward ice motion. Consequently, comparison is best between surveys made during the same season. Most surveys were in May (exceptions were June/July 1993 and 1998), so we show results obtained by comparing recent data with surveys from 1997 and later, but not 1998. Results (Figure 1) show small changes in \(\Delta h/\Delta t\) for high-elevation regions compared to earlier surveys, but a general trend towards thinning, possibly resulting from interannual variability in snow-accumulation rates [Davis et al., 2001].

[5] At lower elevations, thinning rates increased in most coastal regions, except in the SE. Here, the ice thickened by more than \(1\) m between May 2002 and May 2003, compared to thinning averaging \(10–40\) cm yr\(^{-1}\) between 1993 and 1998 (Figure 2). This can be explained only by an approximate doubling in local precipitation in an area where accumulation rates are the highest in Greenland due to prevailing easterly winds, frequent cyclogenesis in and near Fram Strait, relatively low latitude, high moisture availability from an often warm ocean, and most importantly, orographic enhancement against steep coastal slopes. Precipitation commonly exceeds \(1–2\) m of water yr\(^{-1}\) in the SE, mostly in winter [Cappelen et al., 2001]. Unusually high accumulation in SE Greenland in 2002–3 is supported by an accumulation model driven by ECMWF (mainly ERA-40) analyses [Hanna et al., 2001, 2002; also observed andmodelled Greenland Ice Sheet snow accumulation, 1958–2003, and links with regional climate forcing, submitted to Journal of Climate, 2004, hereinafter referred to as Hanna et al., submitted manuscript, 2004]. Modelled snowfall, corrected for evaporation/sublimation, for the area

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1NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.
2Department of Geography, University of Sheffield, Sheffield, UK.
3Alfred-Wegener Institut für Polar- und Meersforschung, Bremerhaven, Germany.
4Also at Departement Geografie, Vrije Universiteit Brussel, Brussels, Belgium.
5Danish Meteorological Institute, Copenhagen, Denmark.
6Byrd Polar Research Center (BPRC), Ohio State University, Columbus, Ohio, USA.
7EG&G, Inc., Wallops Flight Facility, Wallops Island, Virginia, USA.
8Also at Centro de Estudios Científicos, Valdivia, Chile.

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shown in Figure 1 was 1.21 m of water for June 2002–May 2003, or 75% (3.5 standard deviations) above mean annual June–May (1958/9–2002/3) accumulation of 0.69 m. This is unprecedented in at least the last 46 years of available analysis/model data, and in more than 100 years, based on data from nearby ice cores shown in Figure 1 (J. R. McConnell, personal communication, April 2004). The 0.5 m water equivalent of additional accumulation represents about 1.5 m depth of snow with density $\rho = 330$ kg m$^{-3}$, in good agreement with observed thickening during the same period.

[6] Unusually high 2002/03 accumulation was almost certainly due to exceptionally high winter cyclonic activity over SE Greenland; mean sea level pressure charts (NCEP Operational dataset) show $\sim$5 to $\sim$10 mb anomalies over S Greenland from November 2002 to March 2003. The synoptic pattern over the northern North Atlantic was also exceptional based on records since at least 1990, and local snowfall should return to lower, near-‘normal’ values (Hanna et al., submitted manuscript, 2004). However, enhancement of SE Greenland precipitation and more inter-annual variability with greater frequency of highly anomalous snowfall, may be hallmarks of ongoing climatic change [Church et al., 2001; Huybrechts et al., 2004].

[7] Despite extremely high 2002–03 snowfall in the SE, Figure 1 shows enhanced thinning of most coastal regions, consistent with recent summer temperatures considerably higher than for 1993–98, which were already warmer than the longer-term 1961–90 averages (Figure 1). We estimated total ice-sheet melt losses (runoff) during 1993–98 and 1997–2003, by comparing ECMWF-based estimates of runoff, corrected for variable snowfall and for water retained after percolation into surface snow [Huybrechts et al., 2004; Janssens and Huybrechts, 2000], with equivalent values for 1961–90. A monthly version of a degree-day runoff/retention model [Huybrechts et al., 2004] was used, with surface air temperature and precipitation/evaporation from ECMWF analyses, to calculate monthly runoff on a $5 \times 5$ km grid. Surface air temperatures, corrected for orography errors in the ECMWF model, agree within $\pm 1^\circ$C with weather station data. For 1961–90, runoff resulting from this approach was equivalent to $305 \pm 33$ km$^3$ yr$^{-1}$ of ice, very close to the average (315 km$^3$ yr$^{-1}$) of several other model results [Church et al., 2001; Huybrechts et al., 2004]. Resulting estimates of net ice loss associated with melting/snowfall anomalies were $35 \pm 5$ km$^3$ yr$^{-1}$ for 1993–98, and $46 \pm 7$ km$^3$ yr$^{-1}$ for 1997–2003. Although these estimates are approximate, they indicate that melt losses increased over recent years.

[8] The 1993–98 excess runoff is about two thirds of the 51 km$^3$ yr$^{-1}$ ice loss estimated by interpolation between measurements of elevation changes from repeat laser-altimeter surveys during this period [Krabill et al., 2000], but not including thinning rates >1 m yr$^{-1}$ that were unlikely to be representative of less active surrounding ice. Instead, values were interpolated between measured thinning <1 m yr$^{-1}$ and near-coastal thinning calculated as that caused only by anomalous melting consistent with warmer summers [Krabill et al., 2000; Abdalati et al., 2002].
draining to the bed [Zwally et al., 2002]. Such lubrication may be occurring on Kangerdlussuaq Gletscher on the eastern side of the ice sheet (Figure 1) with no floating tongue [Thomas et al., 2000], where 1993–98 thinning rates (up to 10 m yr\(^{-1}\)) decreased between 1998 and 2001, and then increased to their former values. However, observed thinning rates here do not show any simple correlation with summer temperatures (and therefore melt-water abundance) at a nearby coastal weather station. They are more suggestive of sporadic, brief periods of glacier acceleration and very rapid thinning. This may imply ponding of water beneath the glacier until some threshold is reached, when velocities increase very rapidly and alter the glacier “plumbing” sufficiently to allow seaward drainage of the meltwater. Warming summers are likely to increase the frequency of such events. 

[16] In order to estimate total losses from the ice sheet between 1997 and 2003, we assume that those resulting from dynamic changes were similar to those during 1993–98 (24 ± 10 km\(^3\) yr\(^{-1}\)) plus the ice lost from Jakobshavn Isbrae (10 ± 2 km\(^3\) yr\(^{-1}\)). Together with runoff losses for the same period of 46 ± 7 km\(^3\) yr\(^{-1}\) of ice, this implies a net loss of 80 ± 12 km\(^3\) yr\(^{-1}\) averaged over 1997–2003. By 2002–03, Jakobshavn losses had risen to ~20 km\(^2\) yr\(^{-1}\), approximately balancing the positive effects of anomalously high accumulation in the southeast that year. Moreover, we assumed that recently-increased thinning rates were solely caused by increased melting, apart from Jakobshavn Isbrae. Consequently, our estimated total loss may be conservative, during a period when losses progressively increased. Thus, rates of ice loss from Greenland since 1997 were 35% higher than for 1993/4–98/9, with more than half from increased runoff and the remainder from progressively increased losses by dynamic thinning. Associated sea-level rise then increased to their former values. However, observed thinning rates here do not show any simple correlation with summer temperatures (and therefore melt-water abundance) at a nearby coastal weather station. They are more suggestive of sporadic, brief periods of glacier acceleration and very rapid thinning. This may imply ponding of water beneath the glacier until some threshold is reached, when velocities increase very rapidly and alter the glacier “plumbing” sufficiently to allow seaward drainage of the meltwater. Warming summers are likely to increase the frequency of such events. 

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from Jakobshavn Isbrae were probably initiated by weakening and break-up of its floating ice tongue. But for other thinning glaciers without floating extensions, increased velocities may result from enhanced basal lubrication as more surface melt water drained to the bed during recent warmer summers. Detailed observations of fast glaciers have shown velocity to increase soon after intense melt events [O’Neel et al., 2001]. Similar behaviour has been confirmed for slower-moving parts of GrIS [Zwally et al., 2002], and we can expect this process to continue in a warming climate. Moreover, the rapid response of Jakobshavn Isbrae to changes in its floating extension is indicative of what we might expect as Antarctic ice shelves start to break up [De Angelis and Skvarca, 2003].

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References

W. Abdalati and W. Krabill, NASA/GSFC, Greenbelt, MD, USA.
(waleed.abdalati@nasa.gov; william.b.krabill@nasa.gov)
J. Cappelen, Danish Meteorological Institute, Lyngbyvej 100, DK-2100 Copenhagen, Denmark. (j@dmi.dk)
B. Csatho, BPRC, 1090 Carmack Road, Ohio State University, Columbus, OH 43210-1002, USA. (csatho.1@osu.edu)
E. Frederick, S. Manizade, C. Martin, J. Sonntag, R. Swift, R. Thomas, and J. Yungel, E&G&I, Inc., NASA Wallops Flight Facility, Wallops Island, VA 23377, USA. (earlh@osb.wifi.nasa.gov; manizade@osb.wifi.nasa.gov; martin@osb.wifi.nasa.gov; sonntag@osb.wifi.nasa.gov; swift@osb.wifi.nasa.gov; thomas@osb.wifi.nasa.gov; yungel@osb.wifi.nasa.gov)
E. Hanna, Department of Geography, University of Sheffield, Sheffield S10 2TN, UK. (ehanna@sheffield.ac.uk)
P. Huybrechts, Departement Geografie, Vrije Universiteit Brussel, Pleinlaan 2, B-1050 Brussel, Belgium. (phuybre@vub.ac.be)