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The Cryosphere Discussions

Brief Communication: Greenland's shrinking ice cover: "fast times" but not that fast

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Abstract

A map of Greenland in the 13th edition (2011) of the *Times Comprehensive Atlas of the World* made headlines because the publisher's media release mistakenly stated that the permanent ice cover had shrunk 15 % since the previous 10th edition (1999) revision. The claimed shrinkage was immediately challenged by glaciologists, then retracted by the publisher. Here we show: (1) accurate maps of ice extent based on 1978/1987 aerial surveys and recent MODIS imaging; and (2) shrinkage at 0.019 % a^{-1} in $\sim$50 000 km^2 of ice in a part of east Greenland that is shown as ice-free in the *Times Atlas*.

1 Introduction

The Times Comprehensive Atlas of the World, *13th edition*, published 15 September 2011, shows much less ice in Greenland than its predecessor, last revised in 1999. The publisher's media release stated that "*in the last 12 years, 15 % of the permanent ice cover (around 300 000 sq km) of Greenland ... has melted away*", attributing this shrinkage to climate change. However, comparison with satellite imagery from 2011 confirmed that the new ice margin was wrong and implied much more shrinkage than reported scientifically. A mistake of this magnitude in an authoritative source, if not corrected, will propagate and can undermine public confidence in accurate reports of cryospheric change.

2 The *Times Atlas* mistake and the scientific response

The Greenland map and media release from the publisher, HarperCollins, were, as far as we know, prepared without consultation with glaciologists. The response to the media release was initially modest. News reports quoted unquestioningly its claim of 15 % ice loss and its headline, "*Atlas turning Greenland "green"*". However these reports

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prompted immediate vigorous discussion on cryolist.org, an open listserver for glaciologists. Recognizing the probable consequences if the mistake were not corrected, and having learned from the repercussions of an earlier mistake about the disappearance of Himalayan glaciers, glaciologists familiar with Greenland spent several days clarifying the facts. The UK Science Media Centre coordinated two press releases comprising statements from glaciologists, and alerted journalists on 19 September. A widening media response made it clear in most cases that Greenland was losing ice but that a scientific perspective was out of line with the new map.

Responding to media scrutiny and to inquiries from scientists, the publisher at first "stood by" its new map, but admitted on 22 September that it could be "misleading". HarperCollins remains on record as claiming (incorrectly) "*there is no clarity in the scientific . . . community on this issue.*"

HarperCollins gave its data source as NSIDC (National Snow and Ice Data Center, University of Colorado, Boulder, Colorado). NSIDC reported, and HarperCollins confirmed, that HarperCollins had not consulted NSIDC about Greenland. Scientists at NSIDC and at the Scott Polar Research Institute, University of Cambridge, noted a resemblance between the new ice margin and a map of ice-sheet *thickness* on the NSIDC interactive web page *Atlas of the Cryosphere* (http://nsidc.org/data/atlas). The gridded map of thickness was based on airborne ice-penetrating radar surveys during the 1990s and 1970s (Bamber et al., 2001). The surveys provided limited coverage of the ice-sheet periphery and almost no coverage of glaciers detached from the ice sheet. Another layer within the NSIDC web page shows "glacier outlines" which enclose most of the ice cover, including parts omitted from the ice-thickness grid. The *Atlas of the Cryosphere* data are readily downloadable and thoroughly documented.

We have reproduced closely the ice topography and margin depicted in the *Times Atlas* by contouring the thickness grid, as downloaded from NSIDC, and treating the 500-m isopach as if it were the margin.

Scientists cannot possibly challenge all of the innumerable misunderstandings and misrepresentations of their work in public discourse. Distinguishing manifest, ignorable nonsense from falsehoods that might take root in the public mind is difficult, but the magnitude of and apparent authority behind this particular mistake seemed to warrant a rapid and firm response. The eventually constructive reaction of HarperCollins, which not only withdrew its mistaken claim but also produced a new map to be included in the *Times Atlas* as an insert, shows the value of such a response. No less than grotesque trivialization, grotesque exaggeration of the pace or consequences of climate change needs to be countered energetically.

3 Ice distribution in Greenland

To satisfy the need for a current map of Greenland ice cover, we prepared Fig. 1, which combines a recent 250-m-resolution MODIS image mosaic of Greenland with the ice margin seen on air photos from 1978 and 1987. Aerophotogrammetric maps produced by the Geological Survey of Denmark and Greenland (GEUS) and the Kort og Matrikelstyrelsen (KMS) at scales of 1 : 100 000 and 1 : 250 000 were reviewed, and the ice margin, primarily at marine-terminating outlets, was updated to summer 2011 using NASA LANCE Rapid Response MODIS imagery (Citterio and Ahlstrøm, 2011). The update at 128 sites detected a net combined area loss of $2560 \pm 260\,\text{km}^2$ excluding known glacier surges, which can have a large impact on glacier extent in surge cluster regions (Jiskoot et al., 2003; Citterio et al., 2009). The observed area shrinkage rate of $\sim 92\,\text{km}^2\,\text{a}^{-1}$ from the 1980s to 2011 reflects slower changes at land-terminating parts of the margin than the rapid retreats of outlet-glacier termini summarized in Sect. 4. The full-scale vector map of the ice margins is still being finalized at GEUS, but major changes of Jakobshavn Glacier and Petermann Glacier are visible at the scale of Fig. 1.

The 2011 ice margin of Fig. 1 encloses the ice sheet and both conterminous and detached ice bodies, with a total area of $1.801 \pm 0.016 \times 10^6\,\text{km}^2$. The uncertainty is one 250 m MODIS pixel along the entire ice margin, combined with inaccuracies, assumed to be independent error sources, arising from the reduced map scale of this preliminary dataset.

An alternative Greenland land surface classification yields a Greenland glacierized area of $1.824 \pm 0.016 \times 10^6$ km^2, which represents the average and standard deviation of 12 annual classifications of daily late summer MODIS images at 1.25 km resolution (http://bprc.osu.edu/wiki/Mapping_Land_Ice). The time series does not indicate a strong ice area trend (-535 ± 1379 km^2 a^{-1}, $R = -0.122$, $1-p = 0.294$). The 12 area anomalies correlate negatively with summer average air temperatures ($R = -0.229$, $1-p = 0.527$) after Box et al. (2009) and positively with accumulation rates ($R = 0.186$, $1-p = 0.443$) after Fettweis (2007), suggesting that interannual variability in snow patches may influence the results. Another estimate of the area of permanent ice cover is 1.765×10^6 km^2, which was determined as the union set of all pixels that were always classified as ice in all 12 yr; we have not assessed an uncertainty pending further work.

An earlier area estimate of 1.756×10^6 km^2 derived from a 1 : 2 500 000 map (Weng, 1995) omitted minor glaciers (Weidick, 1995), but is indistinguishable from the smaller of our new estimates.

A 4 % range among these area estimates suggests that over decadal periods it will be hard to resolve shrinkage rates ~0.1 % a^{-1}. The differences might be partly a result of resolution and differential omission of very small glaciers and partly due to residual inclusion of persistent snow patches. Detailed analysis of finer resolution Landsat data is progressing (Rastner et al., 2011) and may resolve shrinkage rates below lat 81° N. Current information makes it clear that Greenland-wide shrinkage is <<22 000 km^2 a^{-1} (1.4 % a^{-1}), as the *Times Atlas* had implied

4 Greenland's ice shrinkage and mass budget

Greenland has not lost 15 % of its ice area since 1999, but it has exhibited net ice loss. Published measured shrinkage and retreat rates are few, but are available from a number of regional studies, summarized here.

Between 2000 and 2010, the termini of 39 of the widest outlet glaciers shrank at a combined rate of 117 km^2 a^{-1} (Box and Decker, 2011). Seale et al. (2011) measured the terminus fluctuations during 2001–2008 of 31 outlet glaciers in east Greenland. South of 69° N, 11 termini shrank at 11.5 $km^2 a^{-1}$; north of 69° N, 20 termini shrank at 4.8 $km^2 a^{-1}$. Termini in the south actually advanced during 2005–2008. Howat and Eddy (2011) determined a mean retreat rate from 2000–2010 of 0.11 $km\,a^{-1}$ for 210 tidewater outlet glaciers. Whereas glacier widths are unspecified, their mean loss rate is consistent with the results for 2000–2006 of an earlier island-wide appraisal by Moon and Joughin (2008), and with rates reported in passing by Joughin et al. (2010). Although Moon and Joughin concentrated on the termini of outlet glaciers, for the purpose of estimating measurement error they located 20 stretches of land-terminating margin, with an average width of 3.5 km, where there was no discernible change. We know of only one study that reports fluctuations of land-terminating portions of the margin. Near Jakobshavn Glacier in west Greenland, Sohn et al. (1998) measured land terminating retreat rates of 0.016–0.040 $km\,a^{-1}$ (mean 0.026 $km\,a^{-1}$) between 1962 and 1992.

On Disko Island and the adjacent mainland of west Greenland, mean retreat rates between 1953 and 2005 were 0.008 $km\,a^{-1}$ for non-surging glaciers and 0.020 $km\,a^{-1}$ for quiescent surge-type glaciers (Yde and Knutsen, 2007); the faster retreat of the latter may in part reflect recovery from surges.

We estimate a plausible magnitude for the Greenland-wide shrinkage rate by multiplying the length of the ice margin by a typical retreat rate chosen from the literature; doing so does not give the actual shrinkage rate (which remains to be measured precisely) but offers a point of comparison with the *Times Atlas*. At the 250 m resolution of MODIS, the outlines of all the ice bodies in Greenland measure 1×10^5 km. Some outlet glaciers are retreating rapidly, but they account for a tiny fraction of the ice margin. If the average retreat rate measured by Sohn et al. (1998) is typical, it yields a loss rate of 0.14 $\%\,a^{-1}$ if applied to the whole Greenland ice perimeter divided by Greenland ice area; or 0.006 $\%\,a^{-1}$ if applied to the Jakobshavn drainage basin frontal length divided by that basin's area; these rates are, respectively, one or more than two orders of magnitude slower than implied by the *Times Atlas*.

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Mass-balance measurements supplement our understanding of area changes. Monitoring has started at A. P. Olsen ice cap and Freya Glacier in Northeastern Greenland, but the only current, published series of whole-glacier in-situ measurements is from the 17.6-km^2 Mittivakkat Glacier in Southeastern Greenland (Mernild et al., 2011). Its average balance rate was $-950\,kg\,m^{-2}\,a^{-1}$ between 1998/99 and 2009/10 and accelerated by $-79 \pm 52\,kg\,m^{-2}\,a^{-2}$ over the period. In contrast, Rinne et al. (2011) report a balance rate during 2004–2008 from altimetry of $0 \pm 52\,kg\,m^{-2}\,a^{-1}$ for an ice cap, the 8849-km^2 Flade Isblink, in Northeastern Greenland. Estimates of ice-sheet mass loss have been made from a suite of satellite observations. Figure S2 (adapted and updated from Alley et al., 2010) provides a composite estimate of the secular trend of mass balance, from various sources. Diverse, independent techniques (repeat satellite gravity, altimetry and mass-budget calculations) yield a broadly consistent signal of significant and accelerating loss. For example, Zwally et al. (2011) estimated the average mass-balance rate of the ice sheet as $-171 \pm 4\,Gt\,a^{-1}$ during 2003–2007. Rignot et al. (2011) estimated the balance over two decades; during 1999–2009 the average rate was $-217 \pm 51\,Gt\,a^{-1}$, accelerating at $-21.9 \pm 1\,Gt\,a^{-2}$.

5 Shrinkage and retreat in Central East Greenland

Here we describe changes in a part of Central East Greenland that the *Times Atlas* mistakenly depicted as ice-free. The region ($\sim 68^\circ$–72° N) is topographically complex, with $\sim 50\,000\,km^2$ of glaciers, mainly surge-type (Jiskoot et al., 2003), that are not part of the Greenland Ice Sheet.

GEUS digital ice polygons in Fig. S3 portray tidewater margins (checked against the original KMS air photos from 1981 and 1987) from the 1980s (http://kmswww3.kms.dk/gronland/gronland_english.htm). Tidewater margins during summer 2000, 2001, 2004 and 2005 were digitized from Landsat7 ETM+ and ASTER L1B scenes. Outlines of entire glaciers were digitized semi-automatically from mosaicked scenes from 2000 and 2001 (Jiskoot et al., 2011). The resulting polygons were taken as reference areas.

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Changes in tidewater terminus area between 1981/1987 and 2000/2001 were obtained for 113 glaciers; and between 2000/2001 and 2004/2005 for 78 glaciers.

Between 1981/1987 and 2000/2001, shrinkage due to glacier terminus retreat totalled $30.7 \pm 4\,\mathrm{km}^2$ ($1.9\,\mathrm{km}^2\,\mathrm{a}^{-1}$); 84 termini retreated and 29 advanced (Fig. S3a). Almost all termini changed $< 0.5\,\mathrm{km}^2$ over this 14–20 yr period. Of the four glaciers advancing $> 0.5\,\mathrm{km}^2$, two were due to surges (Jiskoot et al., 2011; Fig. S4a). Between 2000/2001 and 2004/2005, glacier shrinkage totalled $26.3 \pm 3\,\mathrm{km}^2$ ($5.7\,\mathrm{km}^2\,\mathrm{a}^{-1}$). About half the glaciers retreated significantly; only one advanced significantly ($> 0.1\,\mathrm{km}^2$; Fig. S3b). Disregarding the surging Sortebrae (Fig. S4a), shrinkage rates doubled, from $2.1\,\mathrm{km}^2\,\mathrm{a}^{-1}$ (1980s to 2000/2001) to $3.9\,\mathrm{km}^2\,\mathrm{a}^{-1}$ (2000/2001 to 2004/2005); including Sortebrae, the average tripled. For glaciers measured over both periods (76, total area $29\,842\,\mathrm{km}^2$), the average shrinkage rate was $0.006\,\%\,\mathrm{a}^{-1}$ between 1981/1987 and 2000/2001, and $0.019\,\%\,\mathrm{a}^{-1}$ between 2000/2001 and 2004/2005. Glaciers along the Blosseville Coast have the highest shrinkage rates (Fig. S3), some losing $0.5\,\%\,\mathrm{a}^{-1}$, and greatest thinning rates and accelerations (Joughin et al., 2010).

To examine, at higher resolution, decadal-scale length changes for one part of this region, we subtracted a 2002 from a 2009 scene (Fig. S5). The scenes form a near-anniversary pair, thus minimizing illumination differences and increasing sensitivity to surface changes. The results show a pattern of dominant retreat of both tidewater and land-terminating glaciers, and over a wide range of glacier sizes. Of these, 49 glaciers showed measurable retreat, 6 showed small advances, and 4 showed no significant change. Mean retreat rates are $0.010\,\mathrm{km}\,\mathrm{a}^{-1}$ and $0.020\,\mathrm{km}\,\mathrm{a}^{-1}$ for, respectively, 39 land-terminating glaciers and 20 tide-water glaciers.

6 Conclusions

Called to action by the Times Atlas mistake, we have produced a comprehensive, small-scale map of Greenland's ice margin; have reviewed published estimates of ice shrinkage in Greenland and produced new measurements; and have shown new details of glacier retreat in central east Greenland. We demonstrate prevalent net losses for all glacier types, large and small, surge and non-surge, tidewater and land-terminating. Some measurements of shrinkage, retreat and mass loss suggest interannual variability; many demonstrate accelerating change, but the rates are one or more orders of magnitude less than in the *Times Atlas*.

The *Times Atlas* mistake was unfortunate and avoidable. The publisher could have made a much better map, and in consultation with glaciologists has now done so. The publisher corrected the mistake quickly because the scientific community reacted immediately to the incorrect description of climate-related change in public media. We hope that as a result public trust in science is strengthened.

Supplementary material related to this article is available online at: http://www.the-cryosphere-discuss.net/5/3207/2011/tcd-5-3207-2011-supplement.pdf.

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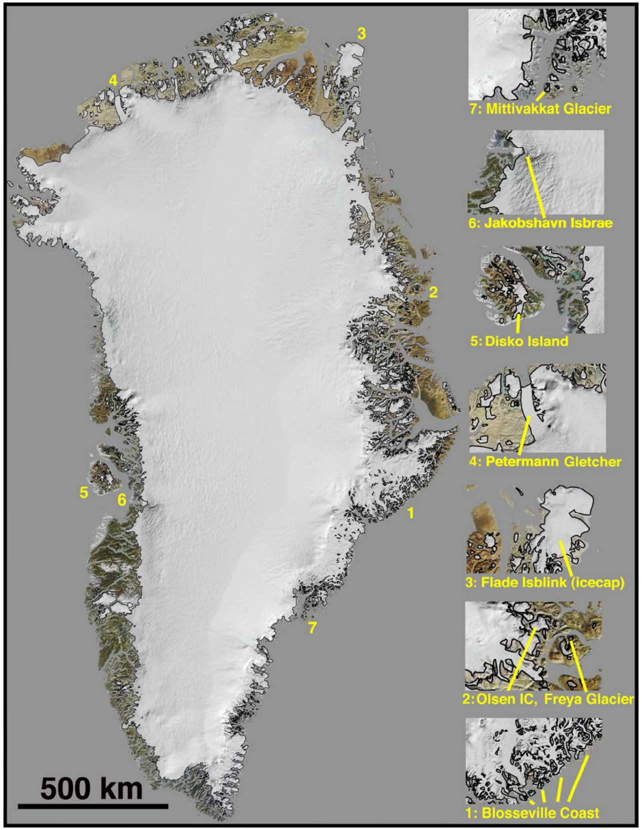

Fig. 1. Greenland ice outlines, simplified from outlines to be reported by Citterio and Ahlstrom (2011), overlain on a 250-m MODIS mosaic of Greenland made by Paul Morin. See Supplement Fig. S1 for a full resolution, unannotated version and further details. Insets highlight glaciers and icecaps discussed in the text.

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