Accelerated melting and disappearance of glaciers and ice caps

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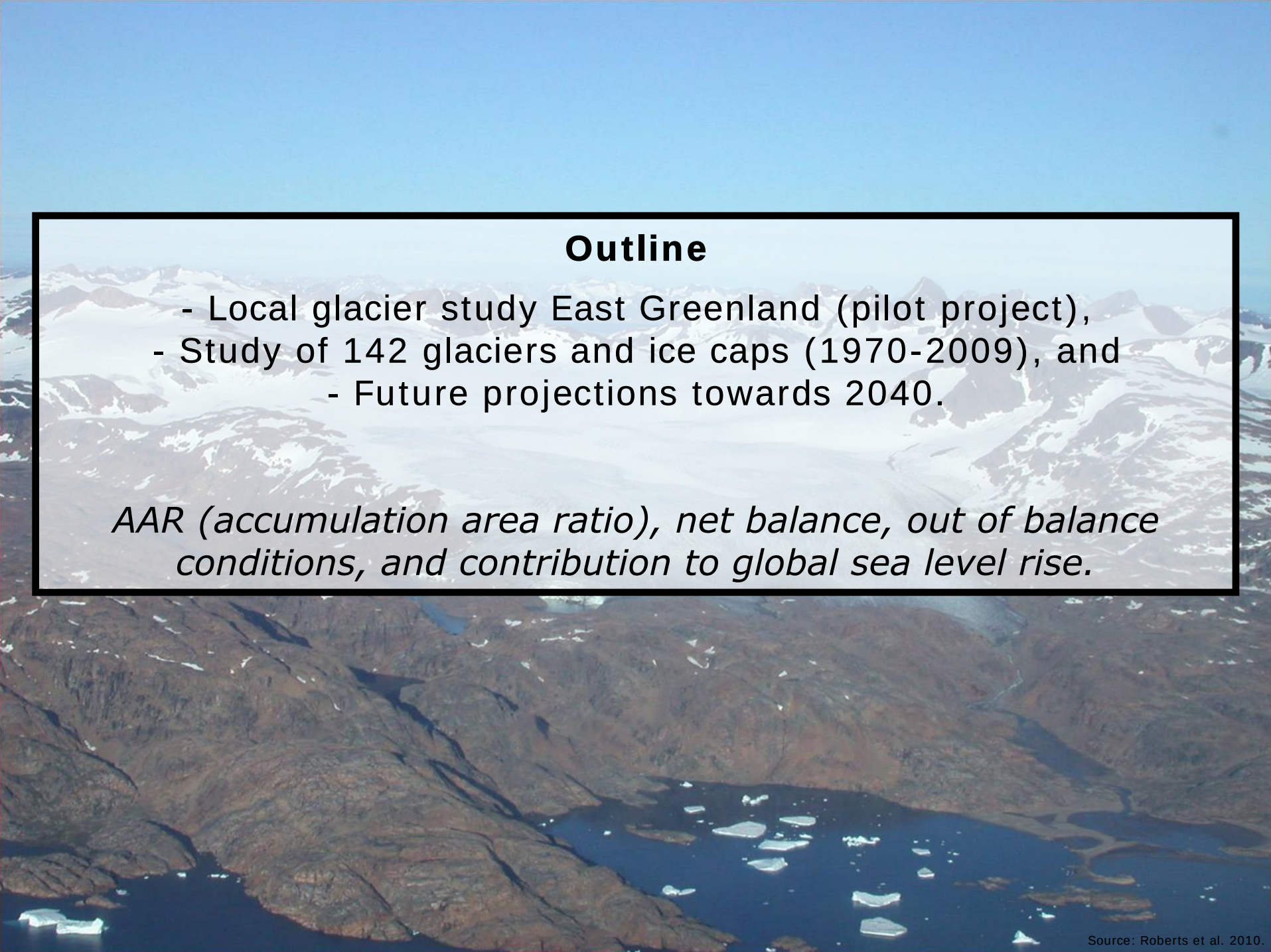


Outline

- Local glacier study East Greenland (pilot project),
- Study of 142 glaciers and ice caps (1970-2009), and
- Future projections towards 2040.

AAR (accumulation area ratio), net balance, out of balance conditions, and contribution to global sea level rise.

Source: Roberts et al. 2010.

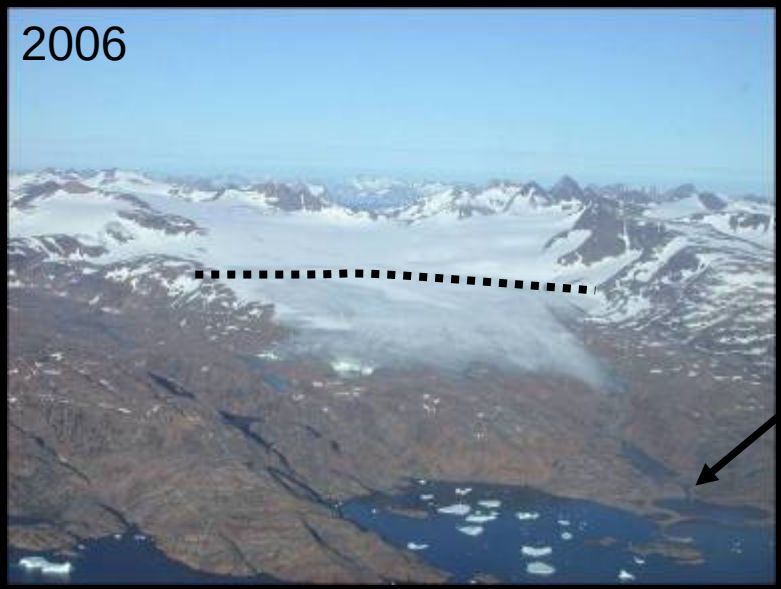
Local glaciers and ice caps mass loss:

Source: M. Nolan, University of Alaska Fairbanks (UAF).

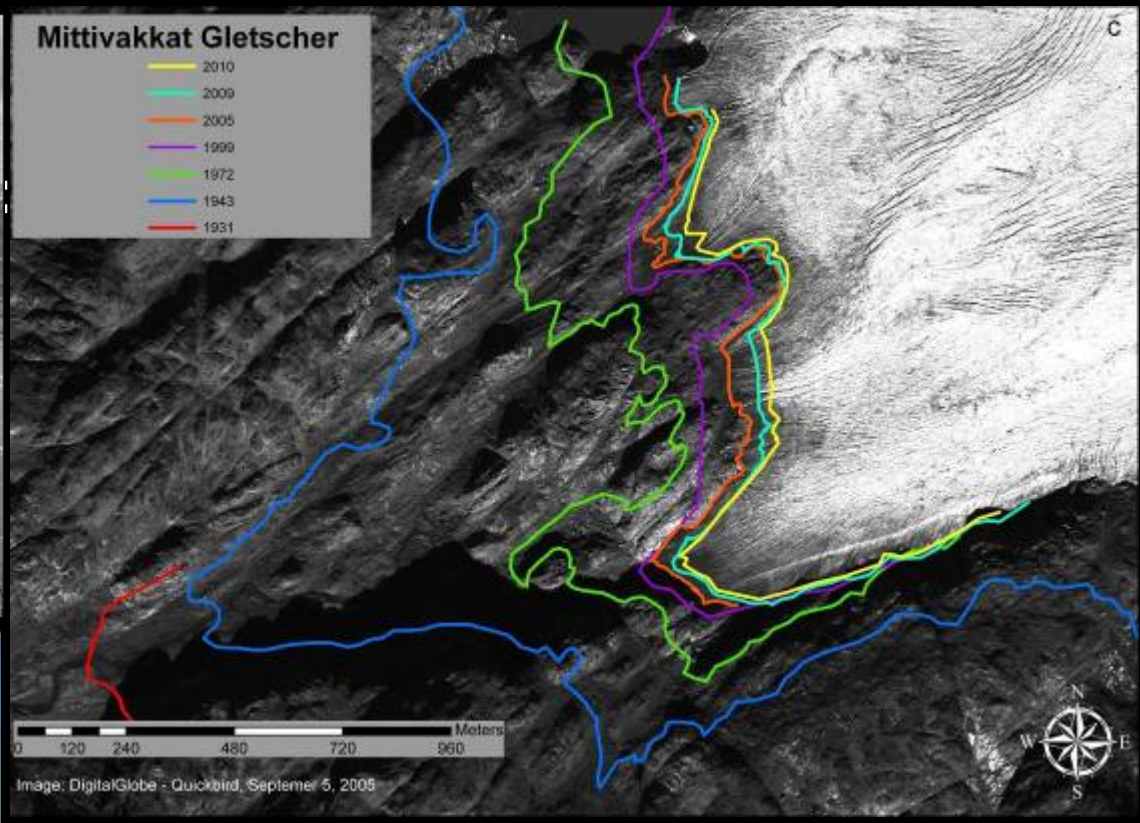
Source: UAF.

Source: S. Mernild, LANL.

Local glacier mass loss, E Greenland (pilot project):



Mernild et al. 2011

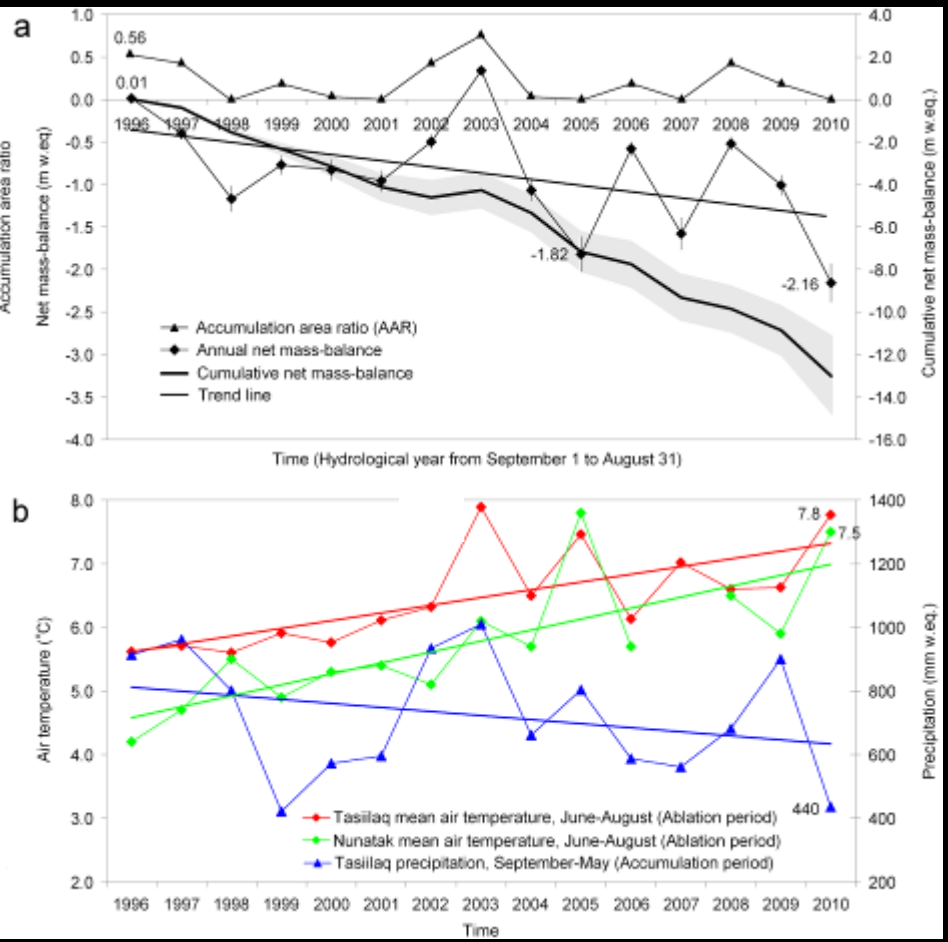


Mernild et al. 2011

Mittivakkat Glacier is the only local glacier in Greenland where long-term observations of both surface mass balance and glacier front fluctuations are available: since 1931, the glacier terminus has retreated by about 1300 m, ~16 m yr^{-1}.

The GIC contribution is about one-third of the total rate of sea-level rise.

Local glacier mass loss, E Greenland (pilot project):



Mernild et al. 2011.

In 13 of the last 15 years, the Mittivakkat Glacier had a negative surface mass balance,

AAR (accumulation area ratio) = 0.15
Global average AAR = 0.44±2% (Dyurgerov et al., 2009)

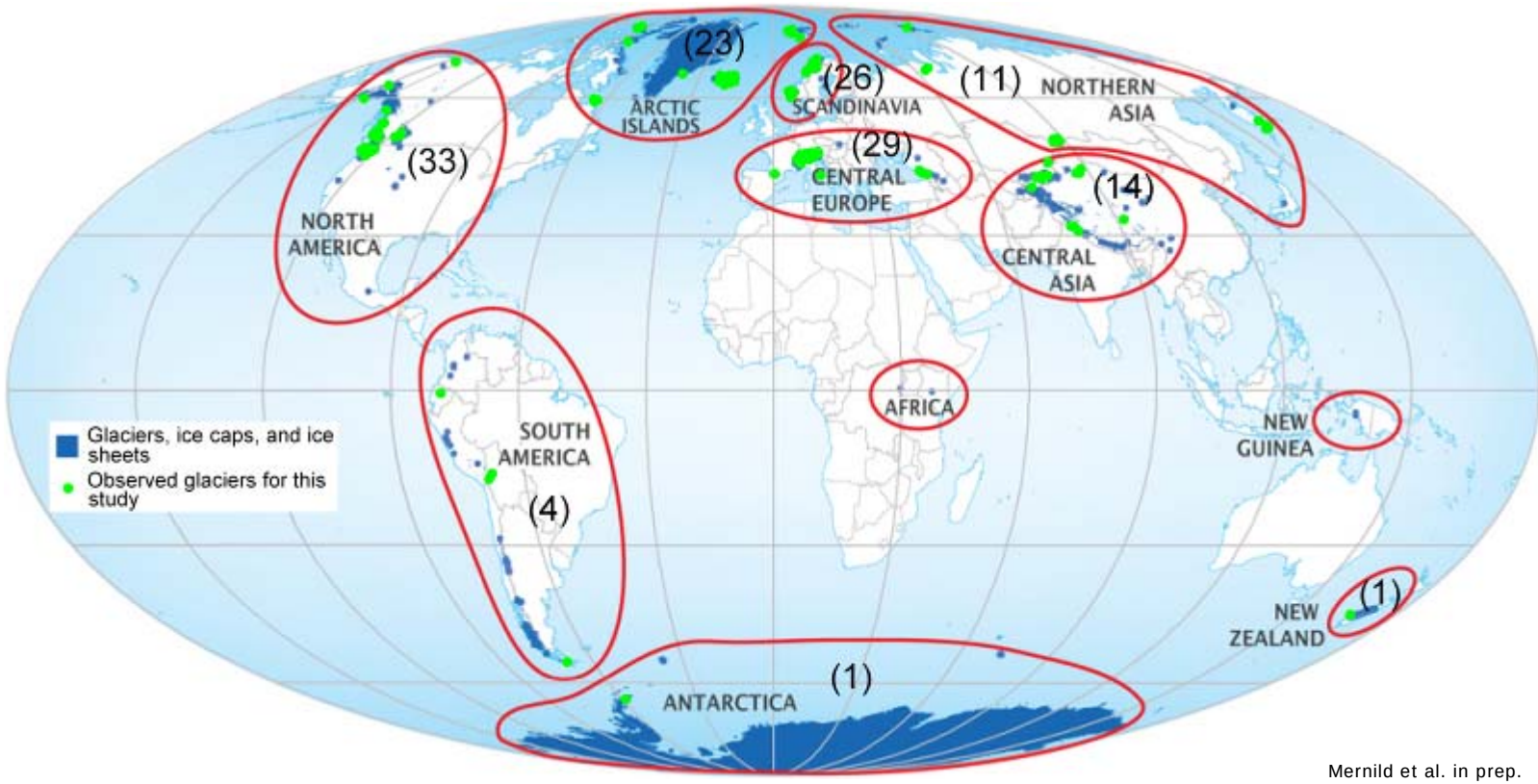
AAR0 (for a glacier in balance with its local climate, the average mass balance is zero and the AAR is equal to its equilibrium value, AAR0) = 0.61
Global average AAR0 = 0.579±0.9 (Dyurgerov et al., 2009)

(a_r=AAR/AAR$_0$, where p_s=a_r–1 and p_v=a_r^g–1, where p_s is the fractional area change, p_v is the fractional volume change, and g=1.36 is an empirical constant) (Bahr et al. 2009)

Since 1995 the Mittivakkat Glacier is significantly out of equilibrium and will likely lose approximately 60% of its area and 70% of its volume, even in the absence of further climate change.

Mittivakkat Glacier is representative of many hundreds of local glaciers found in East Greenland outside the Greenland Ice Sheet, and these observations quantitatively document the general retreat of local glaciers in Southeast Greenland under ongoing climate warming.

142 observed glaciers and ice caps in Nine macro-regions:



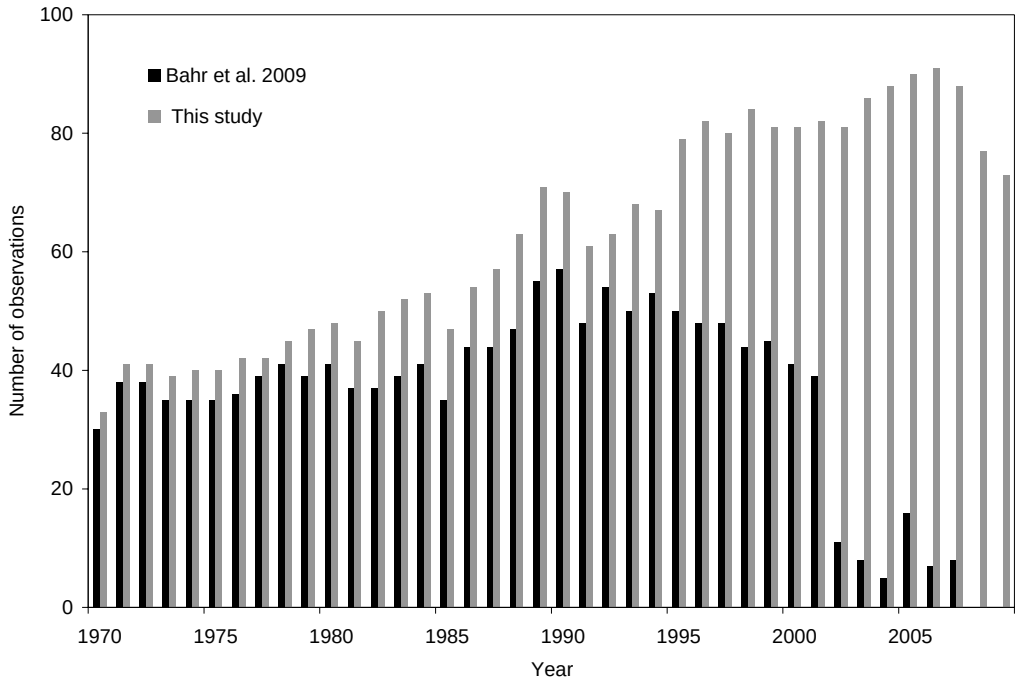
Mernild et al. in prep.

Geographical location of the n=142 observed glaciers (123) and ice caps (19) (green dots). Eleven glaciated macro-regions are illustrated, and the number of glaciers and ice sheets within each region are shown in the brackets: nine of out eleven macro-regions does include observed glaciers for this study.

This is a small fraction of the Earth's estimated 300,000 to 400,000 glaciers and ice caps.

Source: modified from ESRI Digital Chart of the world (DCW) and World Glacier Monitoring Service (WGMS).

142 observed glaciers and ice caps:



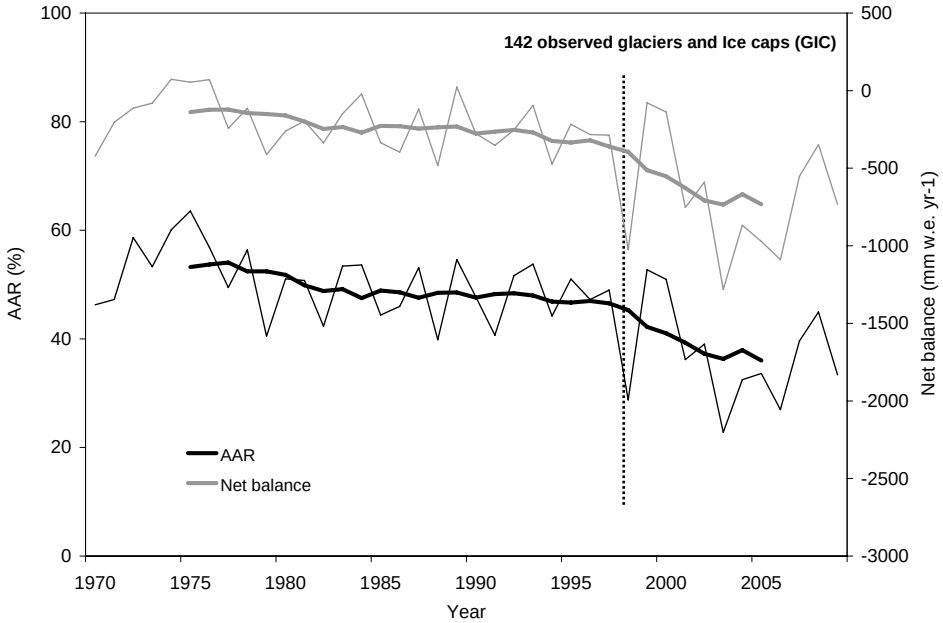
Bahr et al. (2009): varying from 30-57 1970-2001, 16 or fewer from 2002 to 2006).

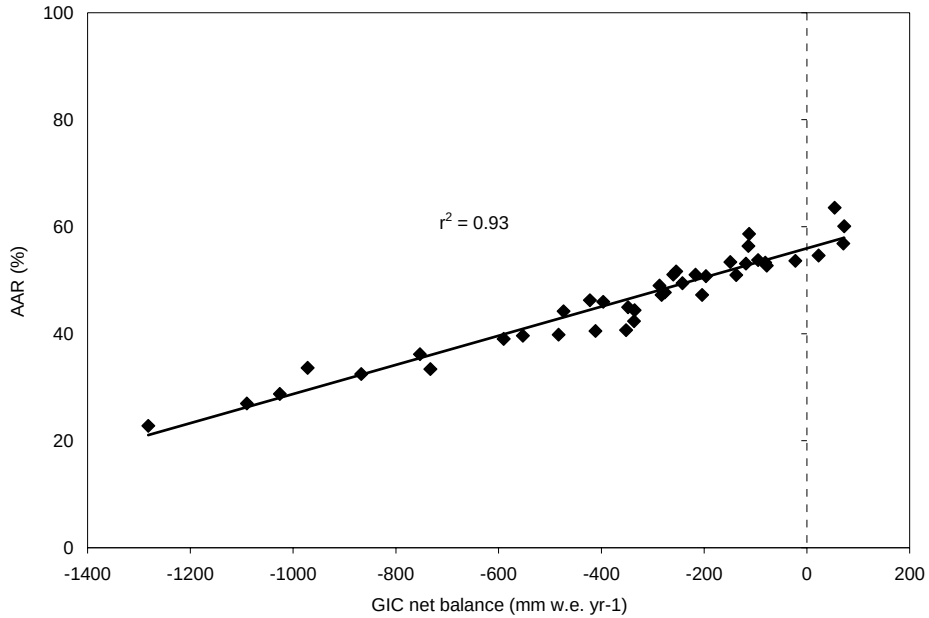
AAR=44±2% (1997-2006), not including AAR values equals zero.

This study (updated dataset): varying from 33-91, **AAR37±2% (1997-2006)**
AAR35±2% (2000-2009)

Most of the new GIC are located in North America, the Arctic (mainly Iceland and Svalbard), Scandinavia, and central Europe. The updated data set also includes glaciers in Greenland, Antarctica, and Patagonia, which were not represented in the earlier data set.

142 observed glaciers and ice caps:





<u>54 GIC are common to the two data sets (1997-2006):</u>

To test the sensitivity of the choice of GIC, AAR was calculated:
Bahr et al. 2009 = **45±2%**
Updated dataset = **38±2%** (includes AAR values equals zero)

142 observed glaciers and ice caps:

AAR0 was determined for each GIC by linear regression of the AAR with the mass balance. The updated data set includes only GIC for which the regression is statistically significant at the 10% level or better.

Updated dataset (only glaciers and ice caps with significant AAR0):

AAR1970-1979 (n=36): **54±3%**
AAR 1980-1989 (n=40): **48±3%**
AAR 1990-1999 (n=60): **44±2%**
AAR2000-2009 (n=84): **35±2%**

Glaciers:
AAR2000-2009 (n=67): **33±2%**

Ice caps:
AAR2000-2009 (n=17): **42±2%**

Treating glaciers and ice caps separately, the data suggest that glaciers must lose **51±3%** of their volume, whereas ice caps must lose **32±6%** of their volume, to reach equilibrium with current climate conditions.

With this assumption, the Earth's GIC (47% glaciers and 53% ice caps) are expected to lose **41±3%** of their volume under present-day climate conditions, raising global mean sea-level by **246±18 mm** SLE (Bahr et al. 160 mm SLE)

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AAR2000-2009 (n=84): **35±2%** **(n=29): 36±3%**

29 GIC that have continuous records (at least five observed Values per decade) since 1970

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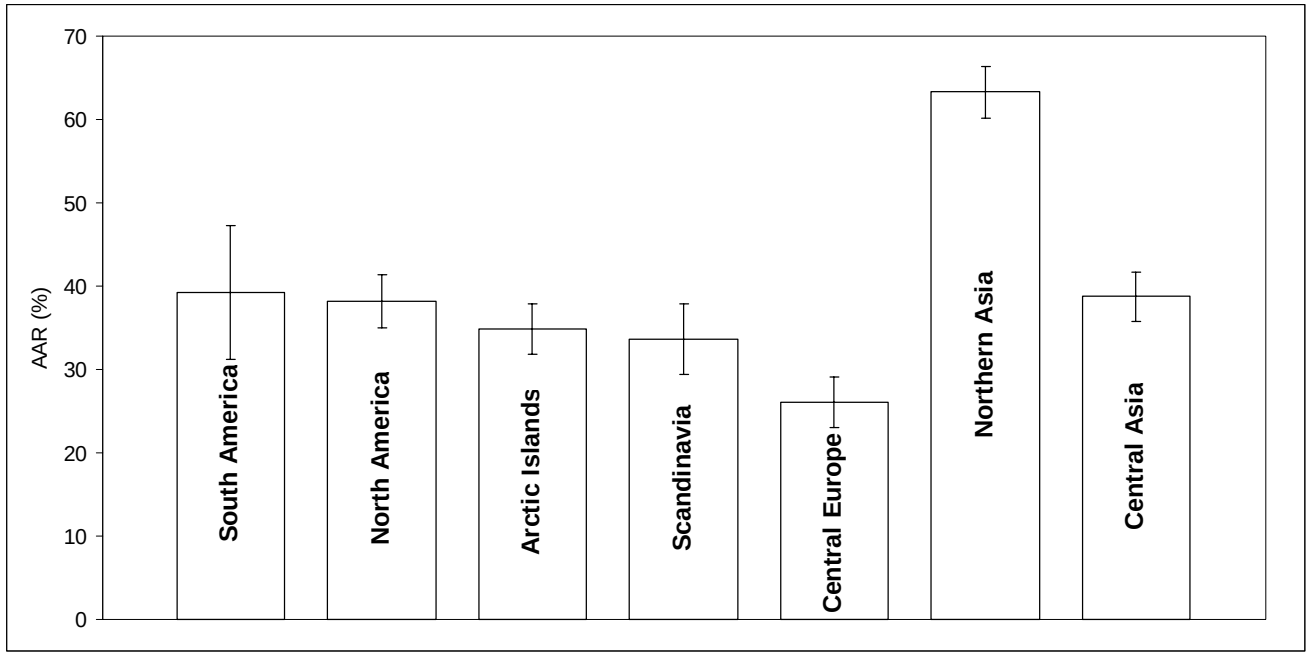
Mean and standard error of AAR for the seven glaciated macro-regions, containing at least 4 GIC



AAR (2000-2009) = 35±2%

S. America: 39±8

N. America: 38±3

Arctic Islands: 35±3

Scandinavia: 34±4

C. Europe: 26±3

N. Asia: 63±3

C. Asia: 39±3

2040-projection of glaciers and ice caps

The Earth is expected to warm significantly during the next several decades (IPCC 2007), making it likely that long-term GIC volume losses will be much larger than estimates based on the climate of 2000-2009.

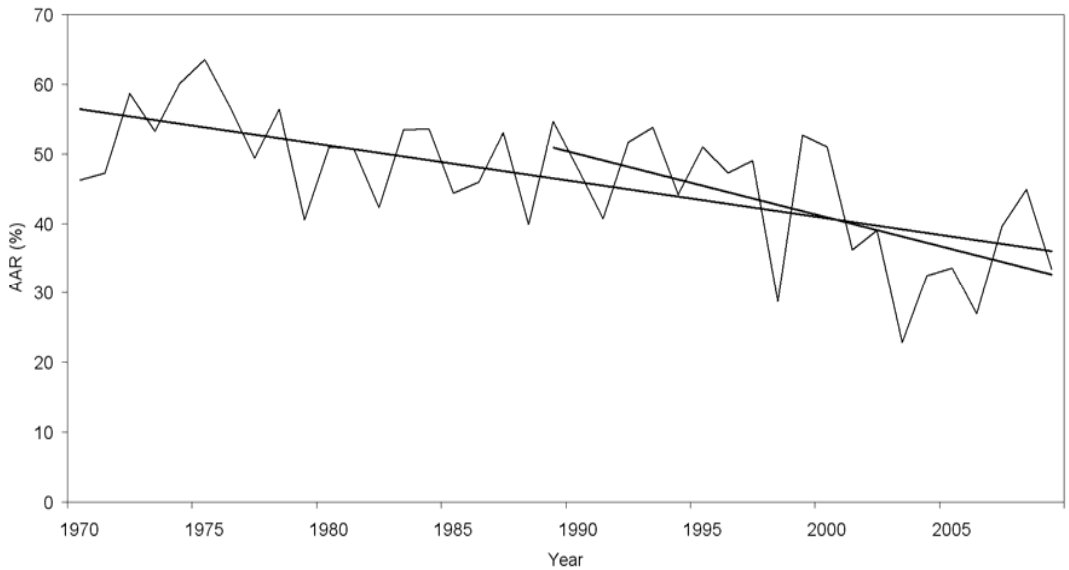
Projection based on the 1970-2009 trend:

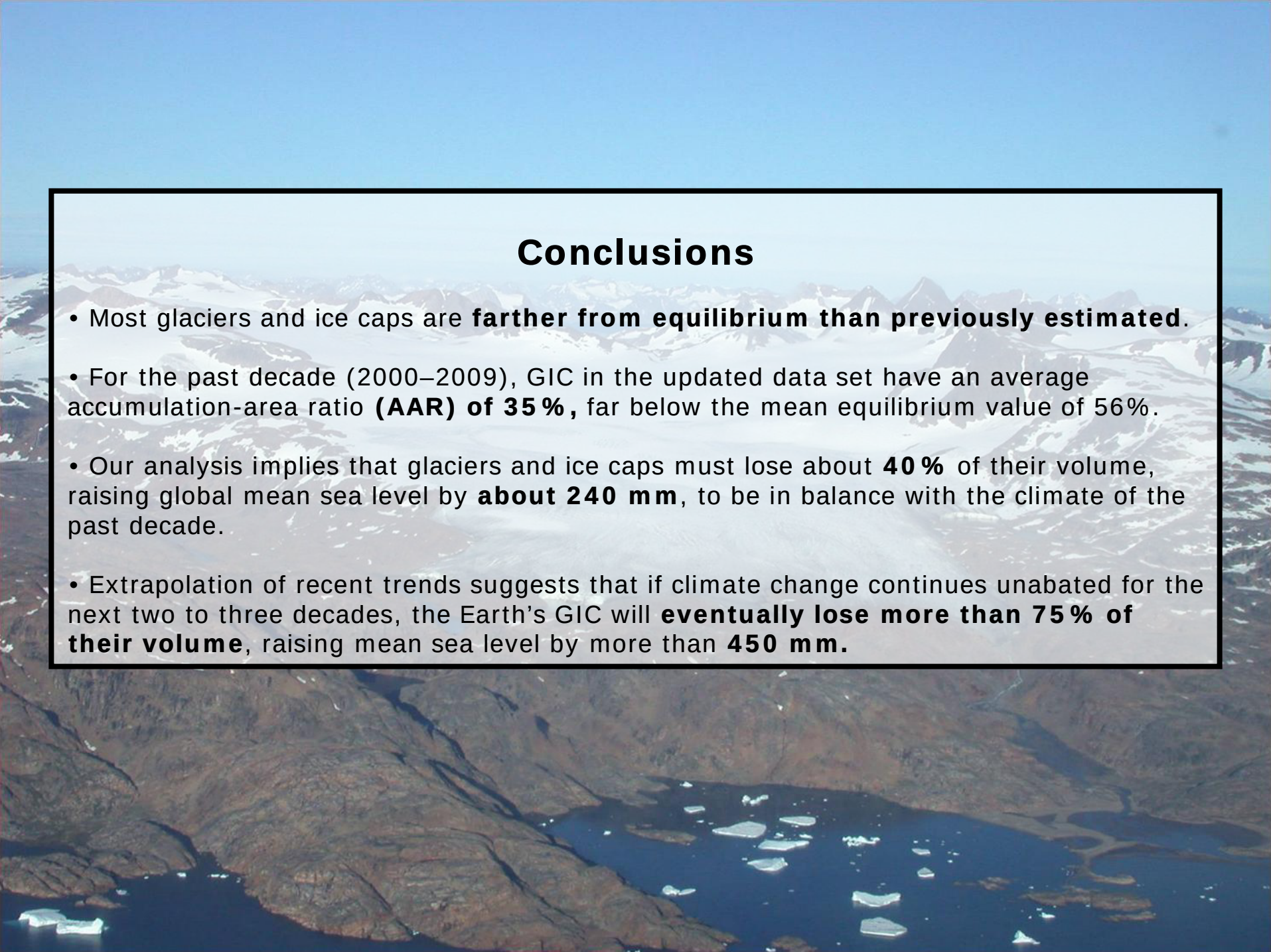
The 40-year AAR trend is **-0.52±0.10%/yr** and is significant at the 1% level.

The mean AAR for 2000–2009 is 35±2%. Taking this as the 2005 value and extending the 40-year trend – the projected **AAR in 2040 goes to 17% (half of today's value),** and volume loss to 72% (three-fourths of the Earth's current GIC volume. Raising mean sea level by more than **450 mm SLE**.

Projection based on the 1990-2009 trend:

The 20-year AAR trend is **-0.91±0.10%/yr** and is significant at the 1% level. Using the steep trend **AAR will go to 17% in 2025**.





Conclusions

• Most glaciers and ice caps are **farther from equilibrium than previously estimated**.

• For the past decade (2000–2009), GIC in the updated data set have an average accumulation-area ratio **(AAR) of 35%,** far below the mean equilibrium value of 56%.

• Our analysis implies that glaciers and ice caps must lose about **40%** of their volume, raising global mean sea level by **about 240 mm**, to be in balance with the climate of the past decade.

• Extrapolation of recent trends suggests that if climate change continues unabated for the next two to three decades, the Earth's GIC will **eventually lose more than 75% of their volume**, raising mean sea level by more than **450 mm.**