Imbalance and accelerated melting of glaciers and ice caps (GIC)

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Background for the study

Global sea level rise is present c. 3 mm per year,

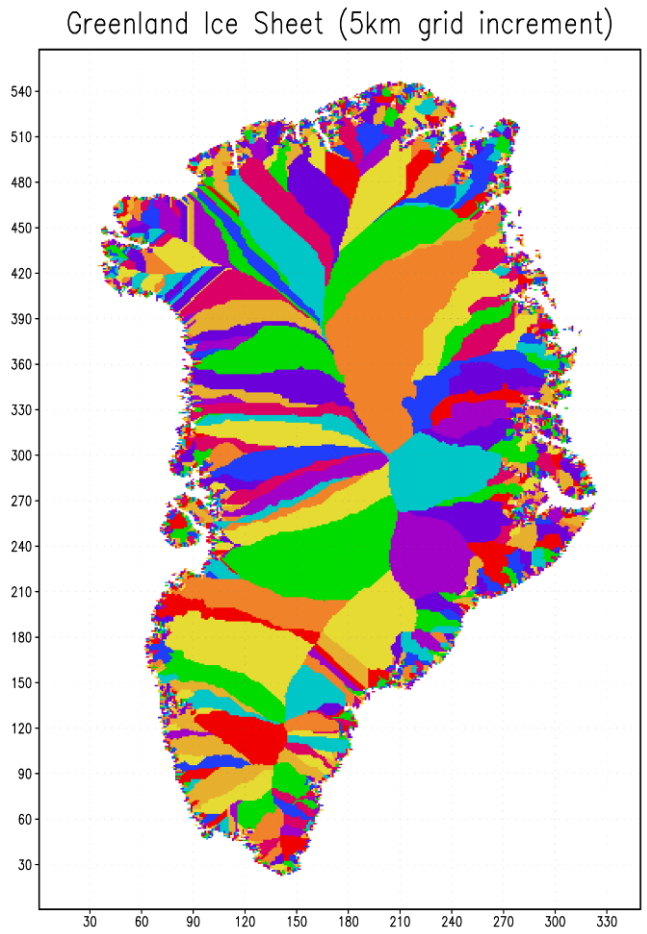
- GrIS and Antarctic ice sheets mass lose are combined raising sea level by about 1 mm per year,
- GIC mass loss is raising sea level by about 1 mm per year
- Thermal expansion is about 1 mm per year,

The number of Earth's GIC is estimated to 300,000 to 400,000.

We only have information from very few GIC about: net balance, AAR (accumulation area ratio), out of balance conditions, and contribution to global sea level rise etc...

Research plan:

- Local glacier study East Greenland (pilot project),
- Study of 142 glaciers and ice caps (1970-2009), and
- *Next step:* Simulations of GICs in Pan-Arctic (using CESM)



Mernild and Liston, in review

SMB studies:

Precip: 635–675 $km^3\ yr^{-1}$

Runoff: 340–400 $km^3\ yr^{-1}$

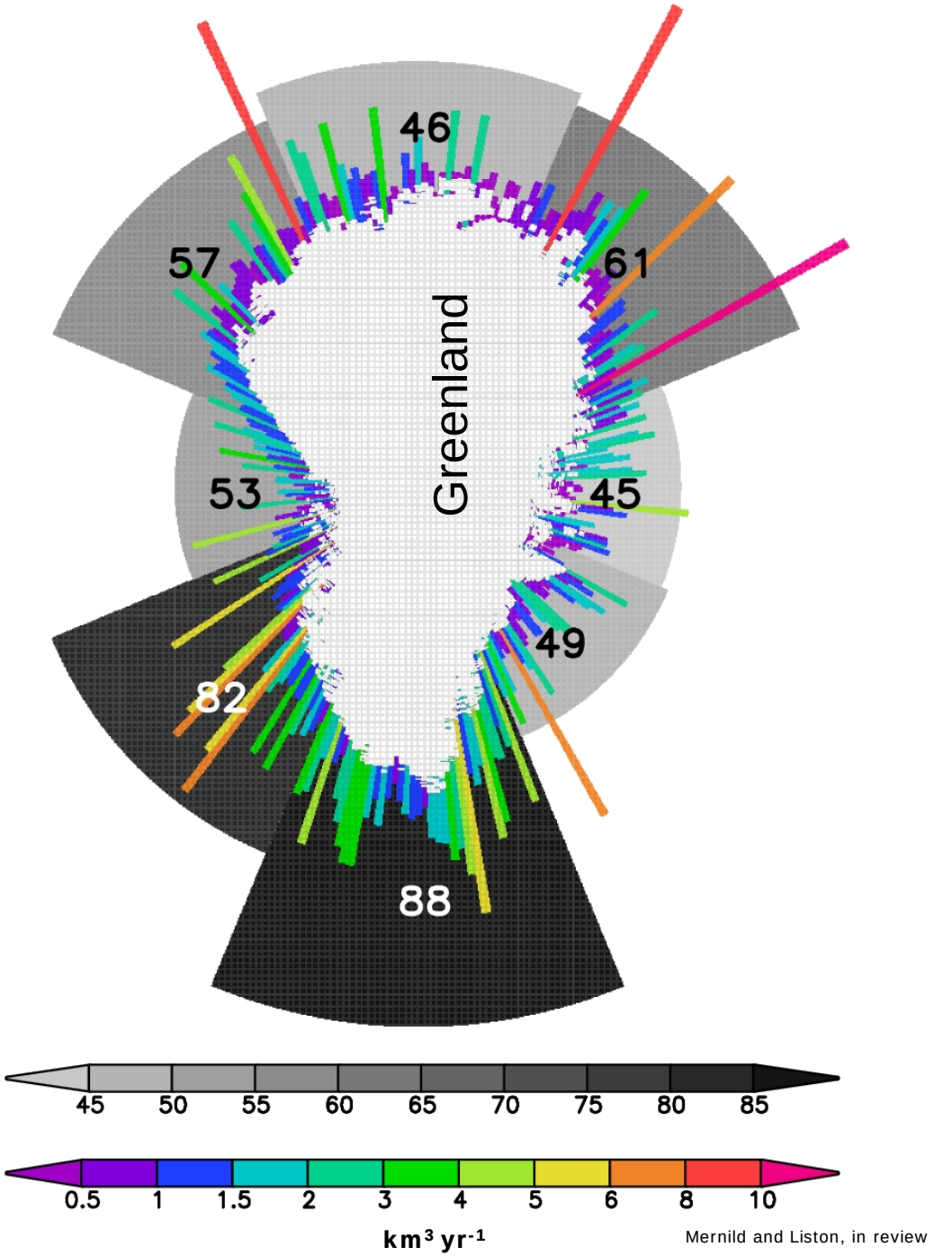
ΔStorage: 110–310 $km^3\ yr^{-1}$

Source: Box et al. 2006, Fettweis 2007, Hanna et al. 2008, Ettema et al. 2009, Mernild et al. 2009, 2010, 2011.

GrIS Studies:

Loss 250-350 $km^3\ y^{-1}$

Source: IPCC



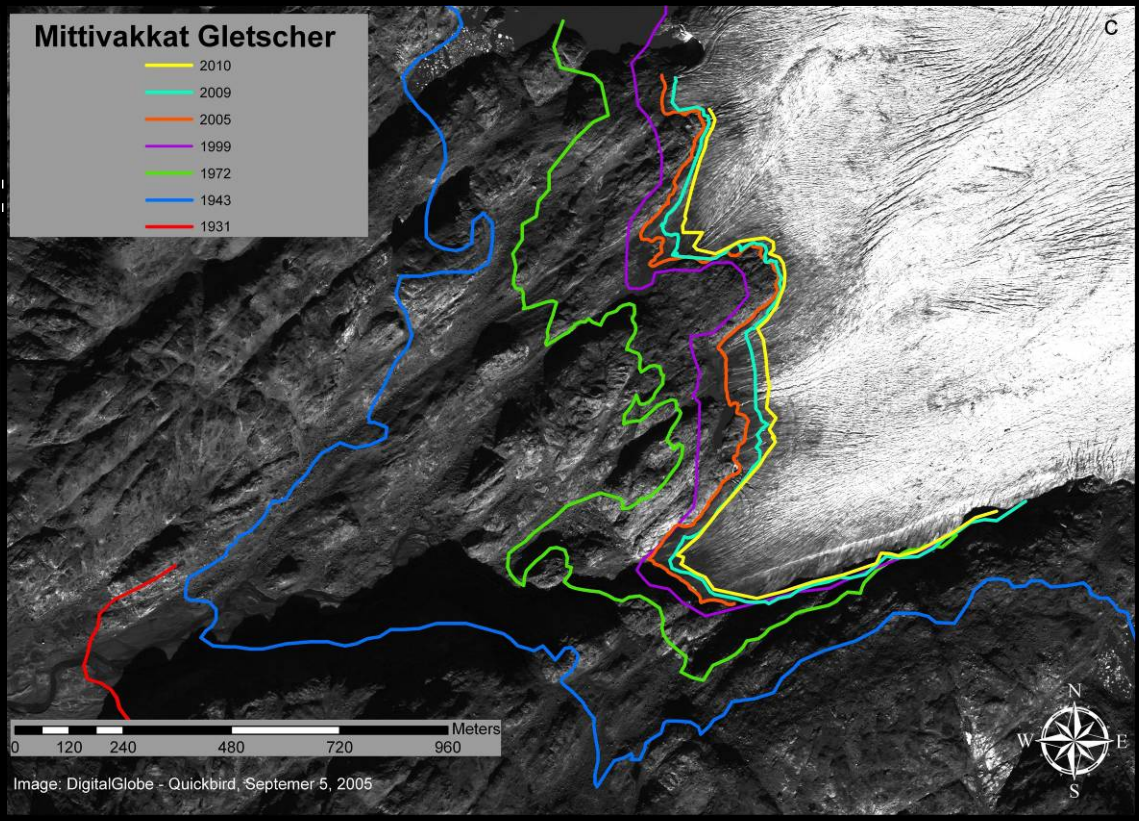
Mernild and Liston, in review

Limited knowledge about GIC – we need to understand net balance, AAR, out of balance conditions etc.

Source: Mernild

GIC mass loss, E Greenland (pilot project):

Mernild et al. 2011

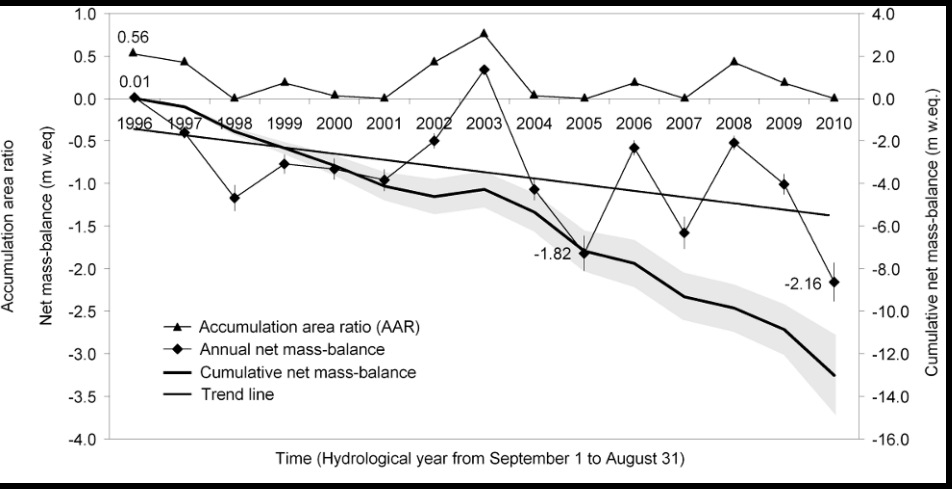


Mernild et al. 2011

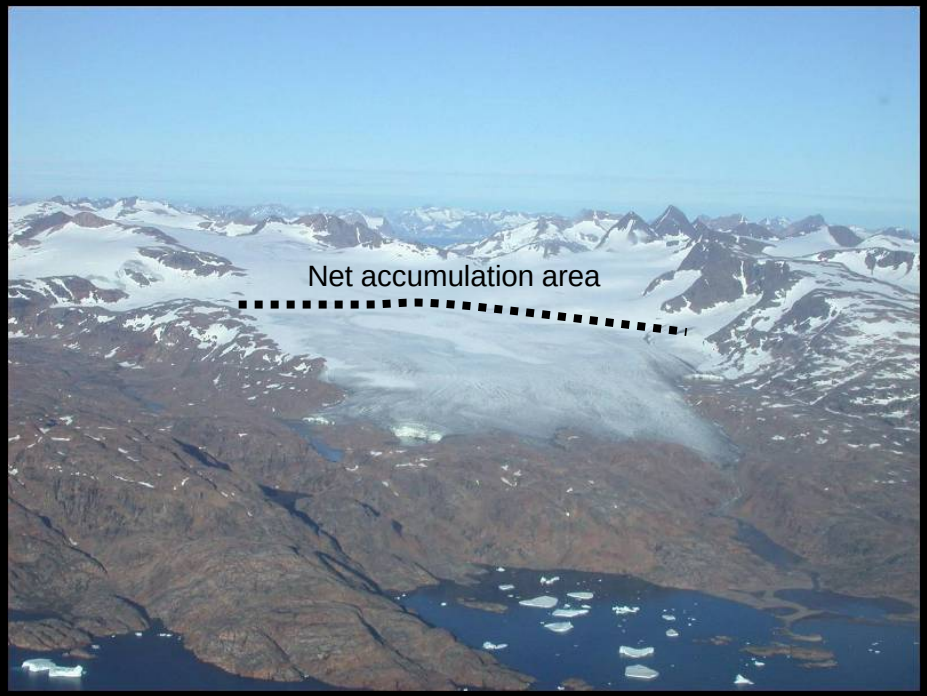
Mittivakkat Glacier is the only local glacier in Greenland where long-term observations of both surface mass balance and glacier front fluctuations are available: since 1931, the glacier terminus has retreated by about 1300 m, ~16 m yr^{-1}.

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,

A useful measure of glacier health is the AAR, the ratio of the net accumulation area to the total area. For a Glacier in balance with the climate, the AAR is equal to Its equilibrium value, AAR0.

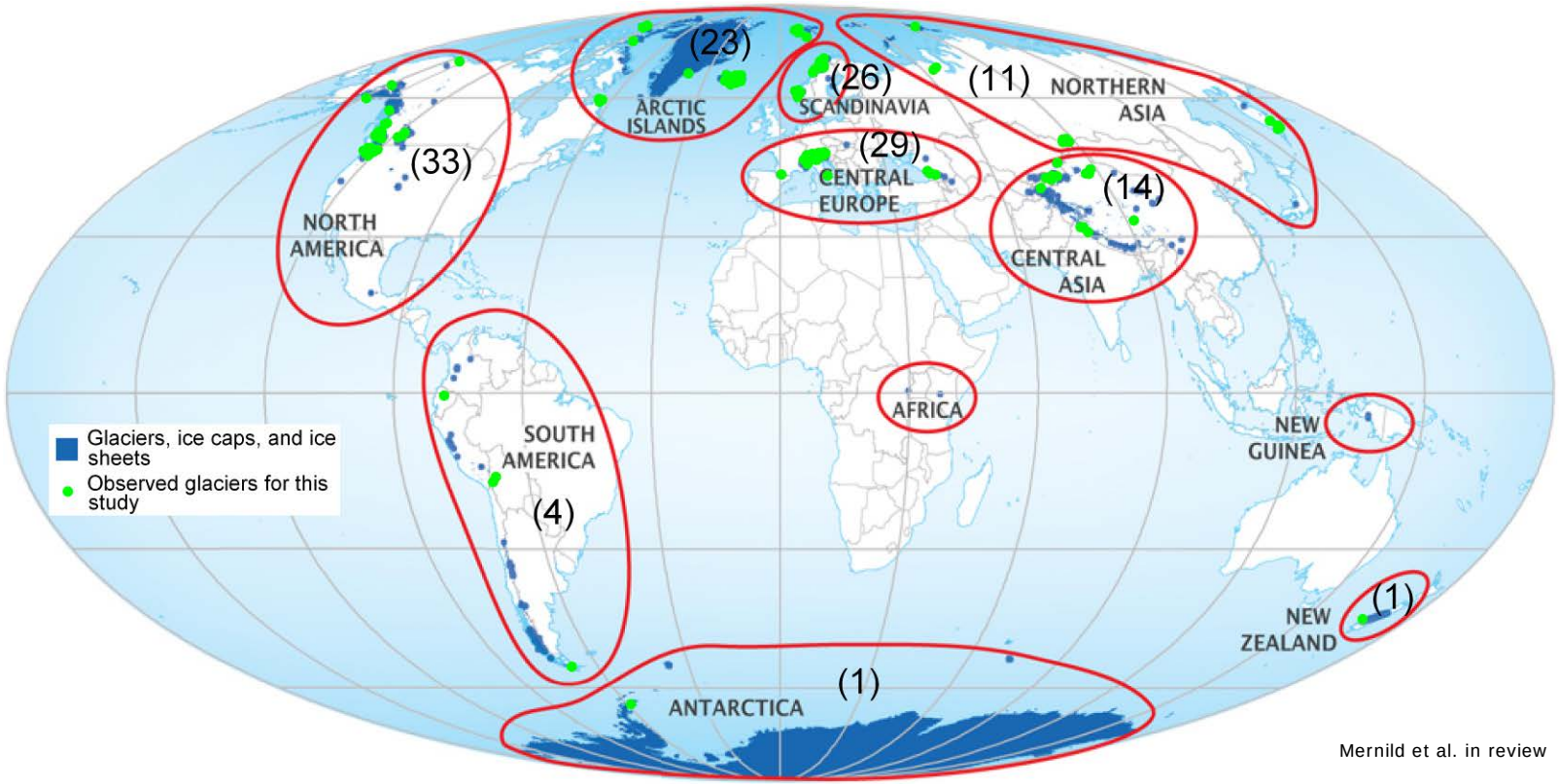
Mittivakkat Glacier AAR = 0.15
Global average AAR = 0.44±2% (Dyurgerov et al., 2009).

Mittivakkat Glacier AAR0 = 0.61
Global average AAR0 = 0.579±0.9 (Dyurgerov et al., 2009)

(α_r=AAR/AAR$_0$, where $p_s=\alpha_r-1$ and $p_v=\alpha_r^g-1$, 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.

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

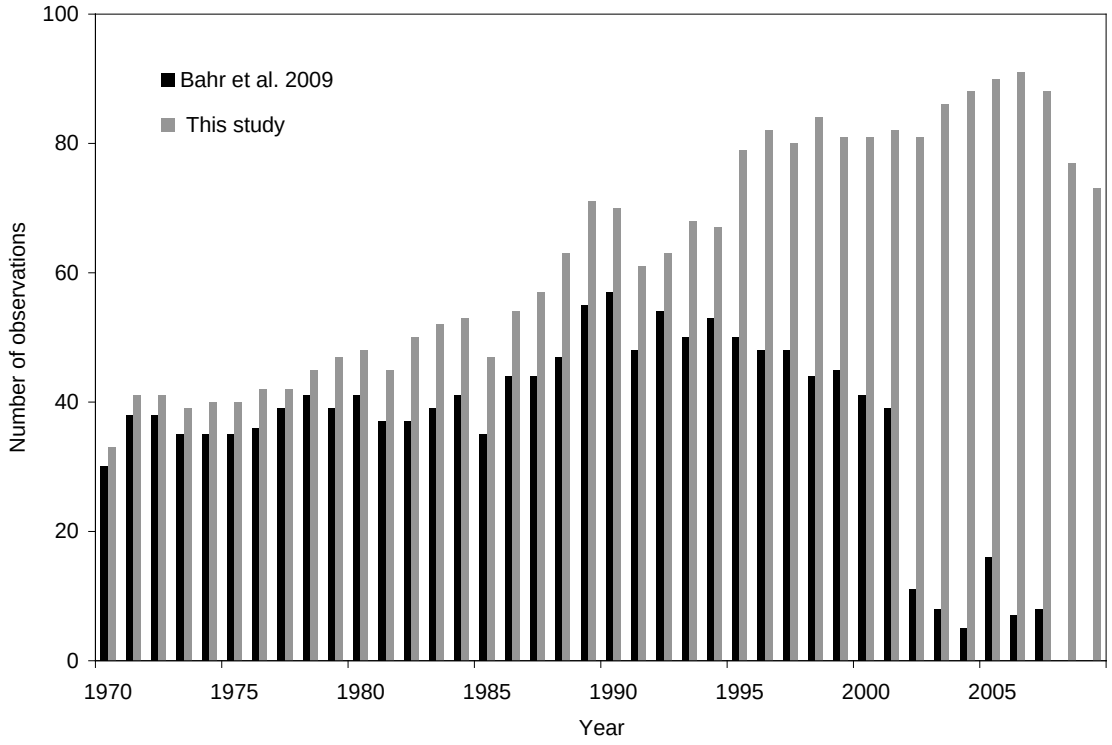


Geographical location of the n=142 observed glaciers (123) and ice caps (19) (green dots).

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:



Mernild et al. in review

Bahr et al. (2009):

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

Global AAR0 = 0.579±0.9 (Dyurgerov et al., 2009)

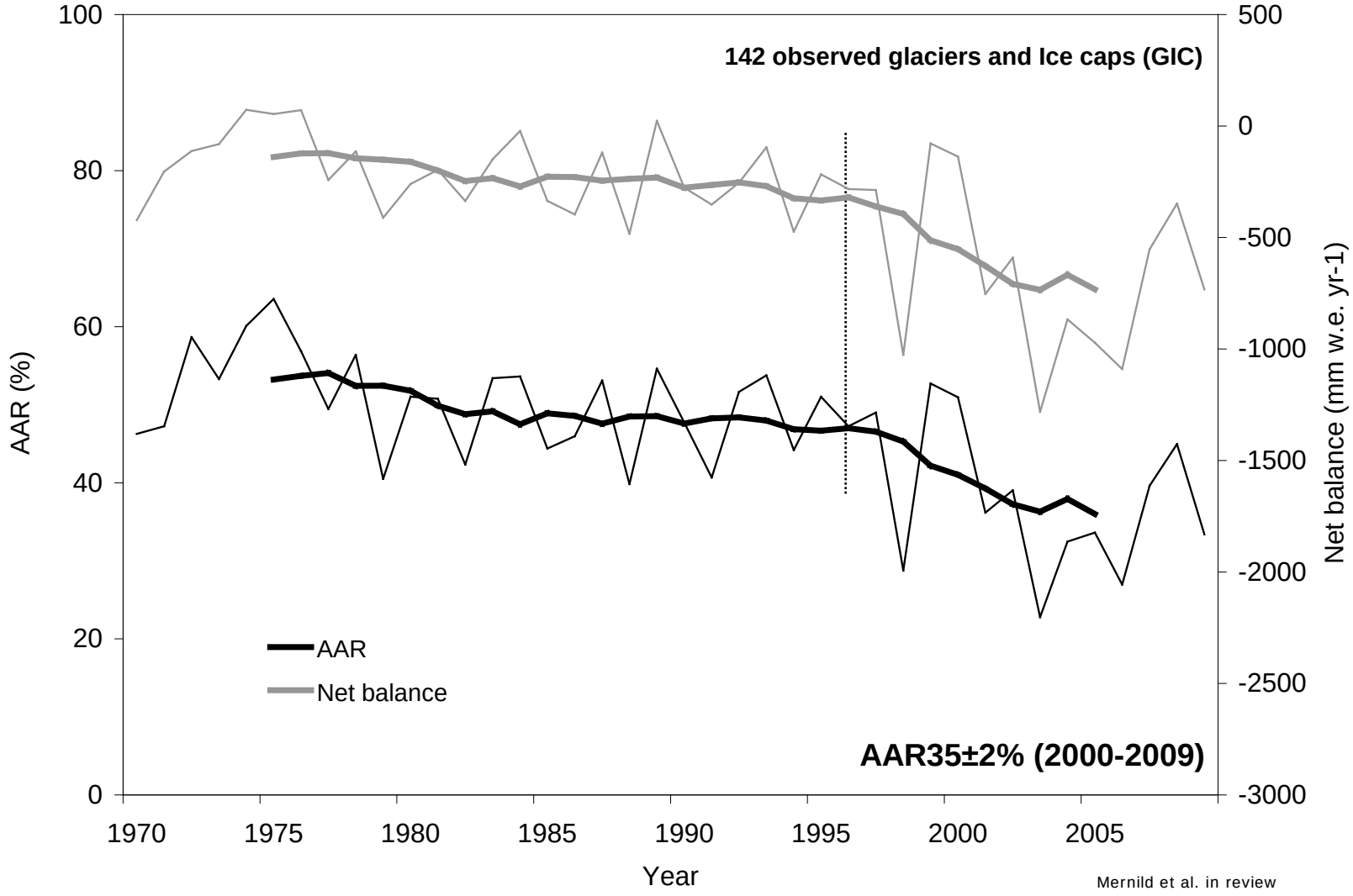
This study (updated dataset):

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:



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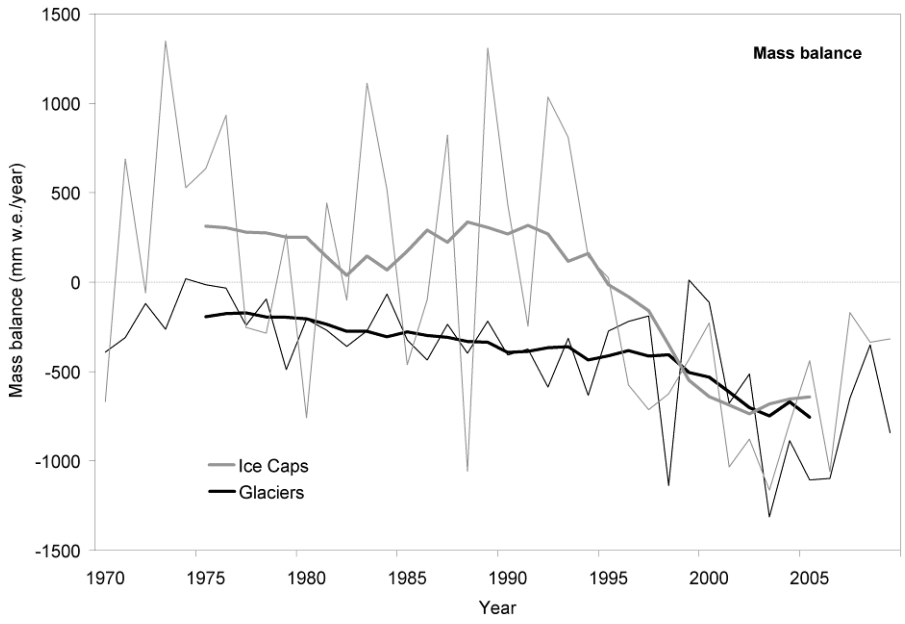
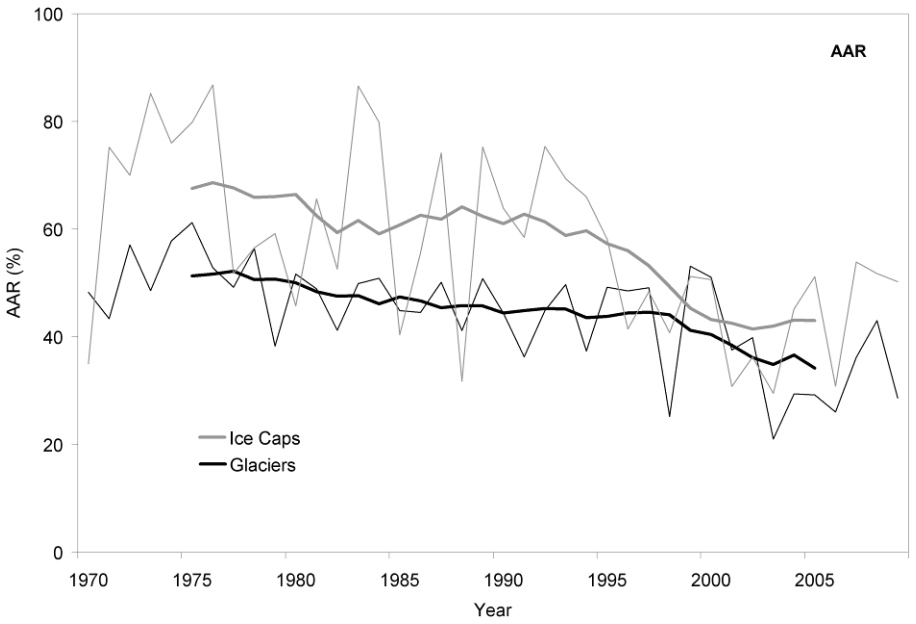




Mernild et al. in review

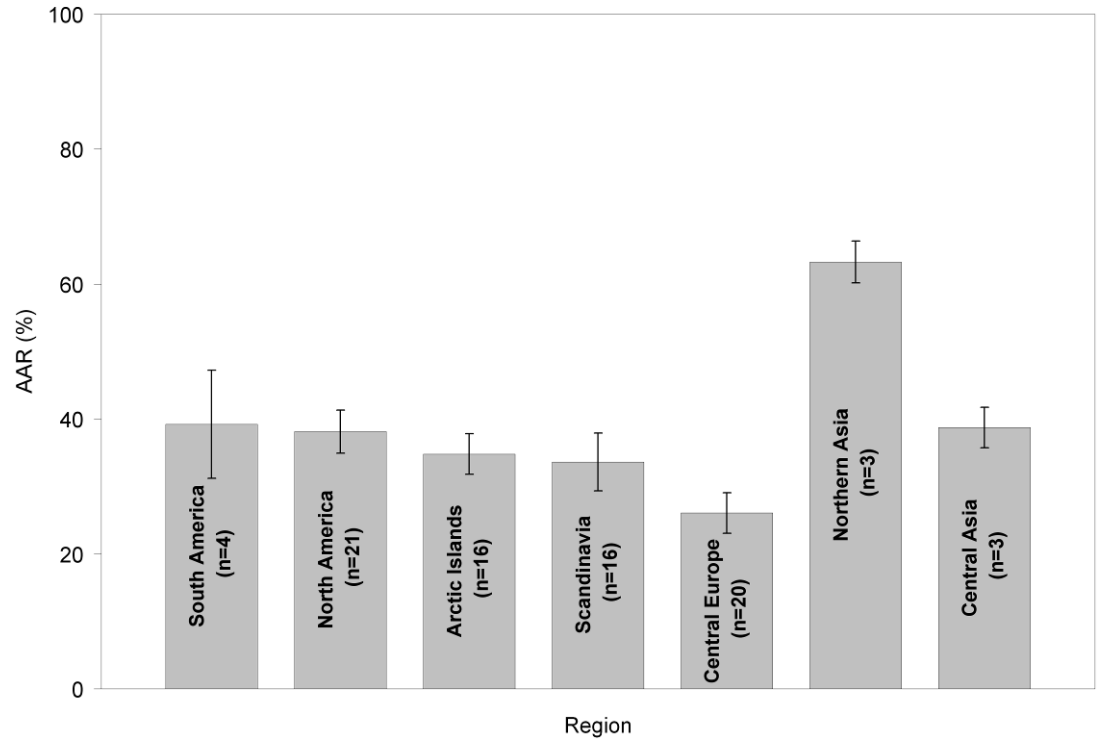
Glaciers:
AAR2000-2009: **33±2%**

Ice caps:
AAR2000-2009: **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)

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.

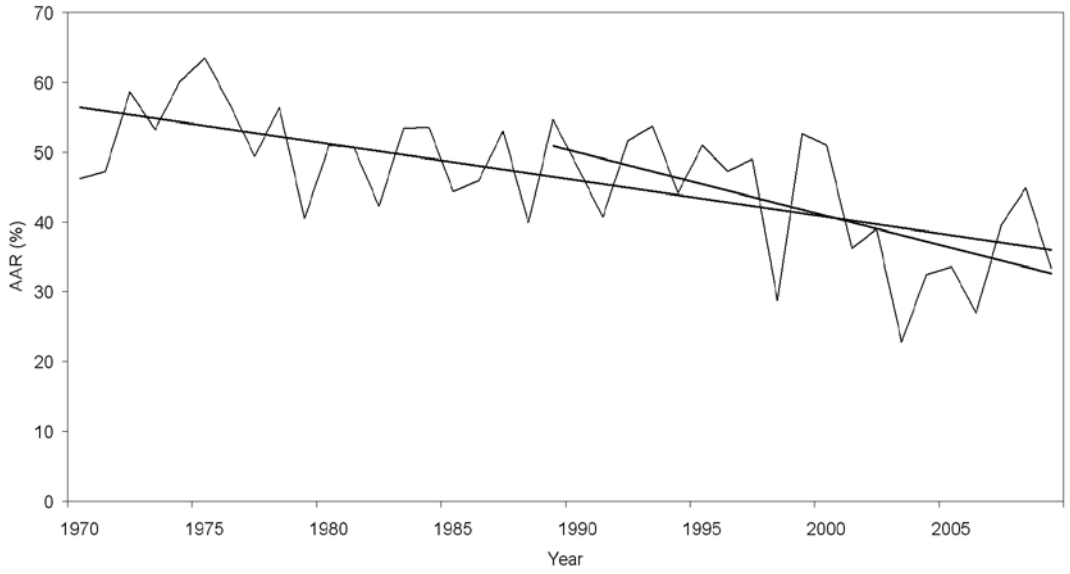
Projection based on the 1970-2009 trend:

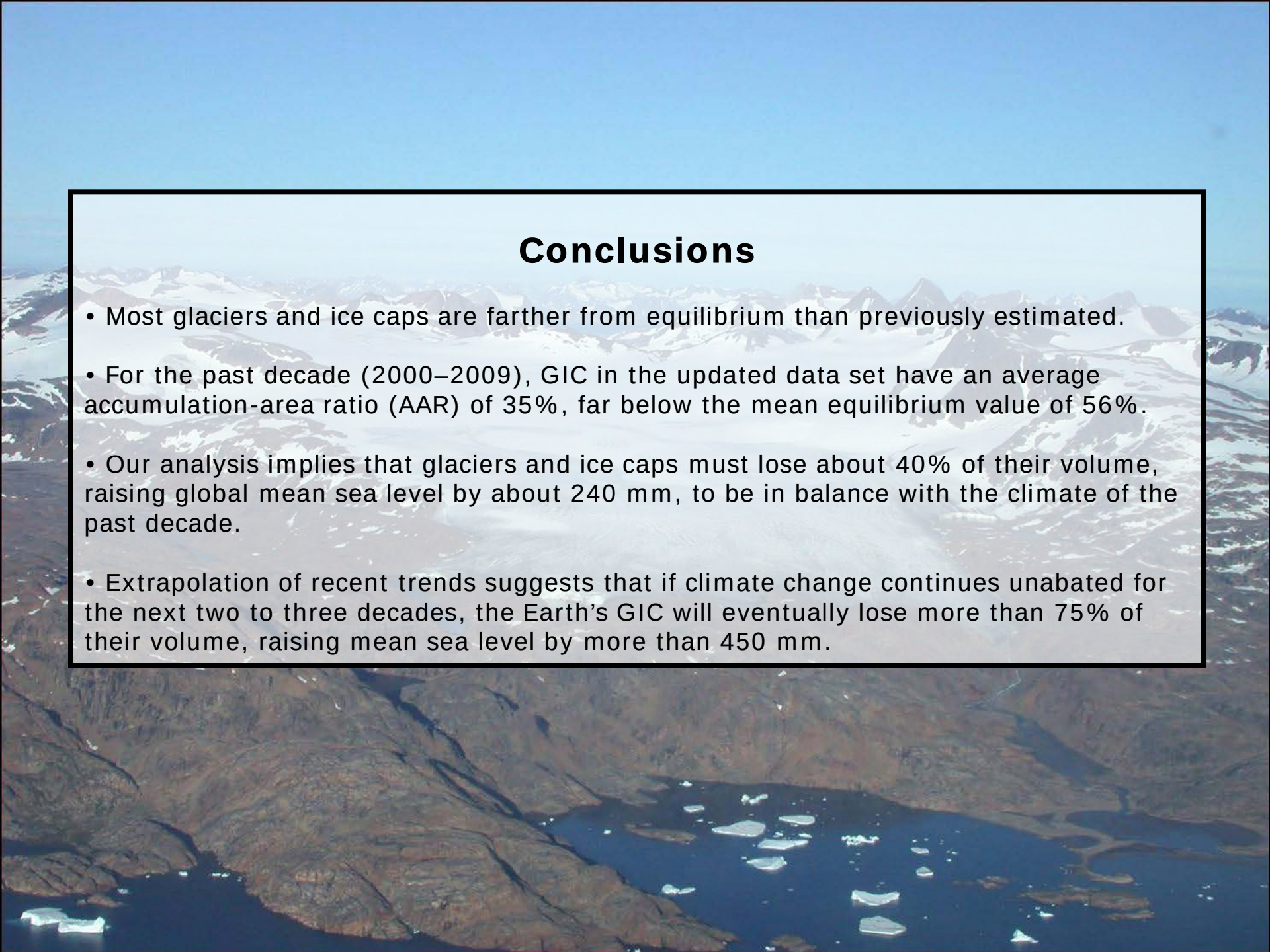
The 40-year AAR trend is **-0.52±0.10%/yr** and is significant at the 1% level.

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.