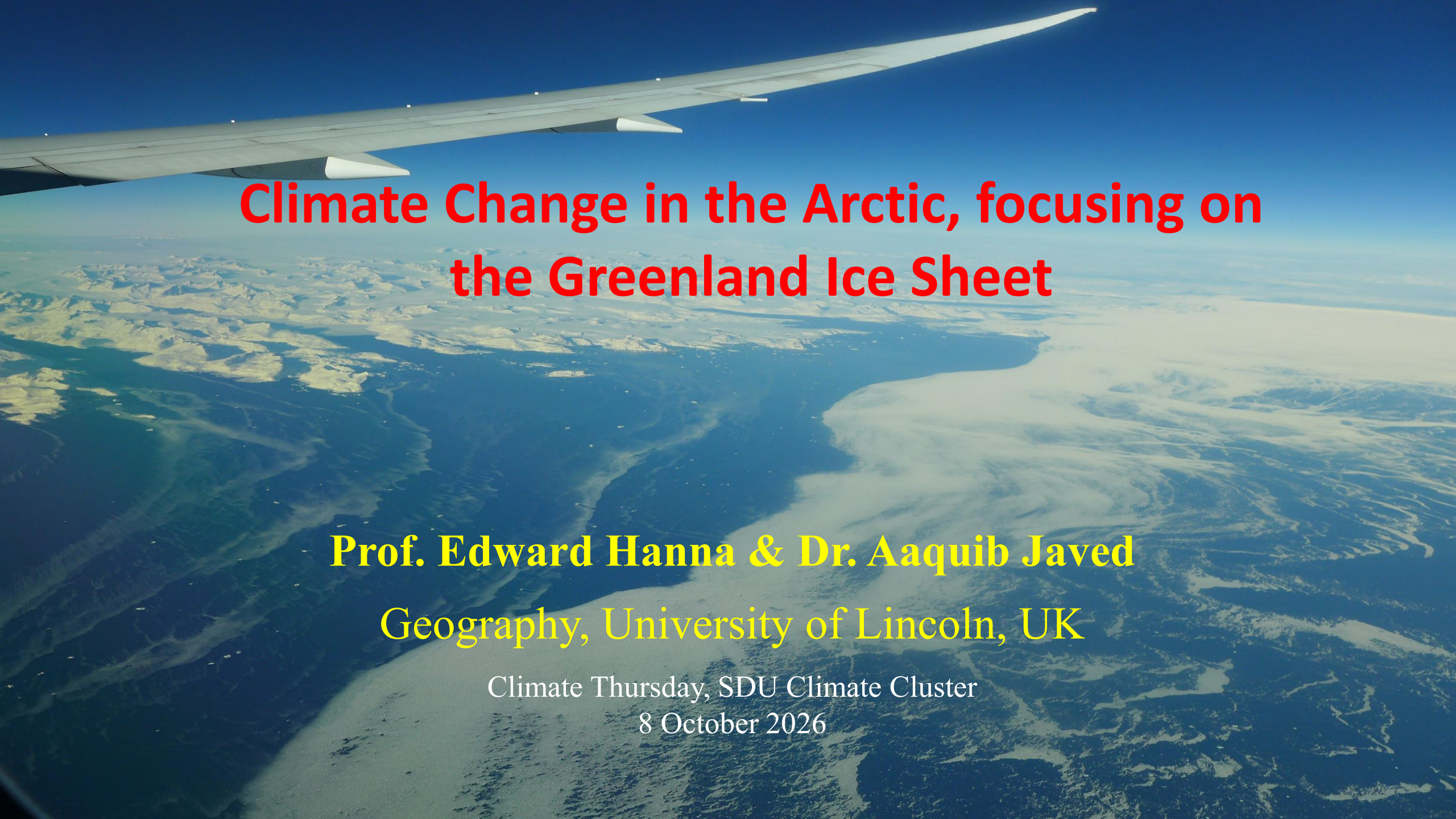


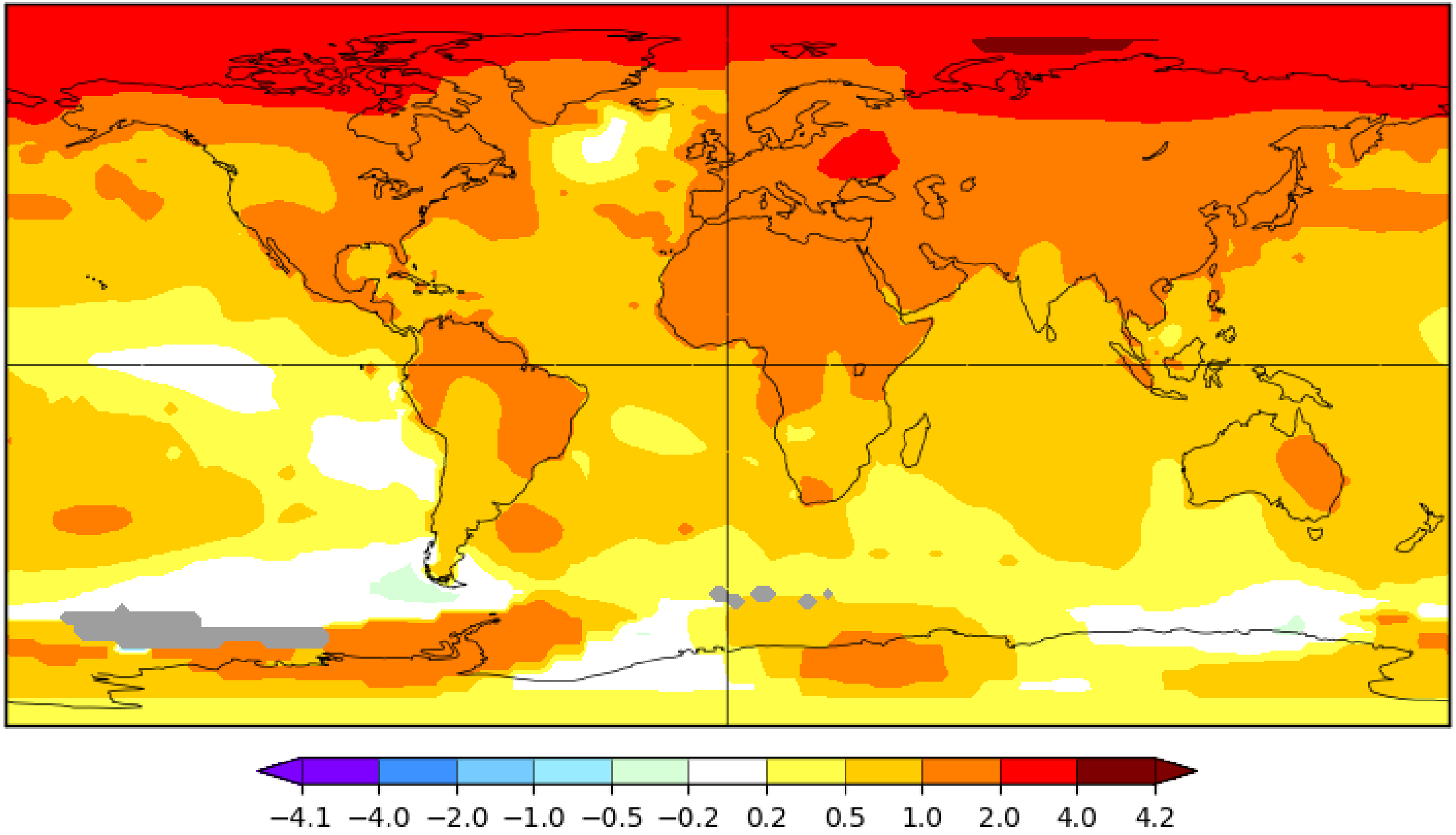
Climate Change in the Arctic, focusing on the Greenland Ice Sheet

Prof. Edward Hanna & Dr. Aaquib Javed

Geography, University of Lincoln, UK

Climate Thursday, SDU Climate Cluster
8 October 2026

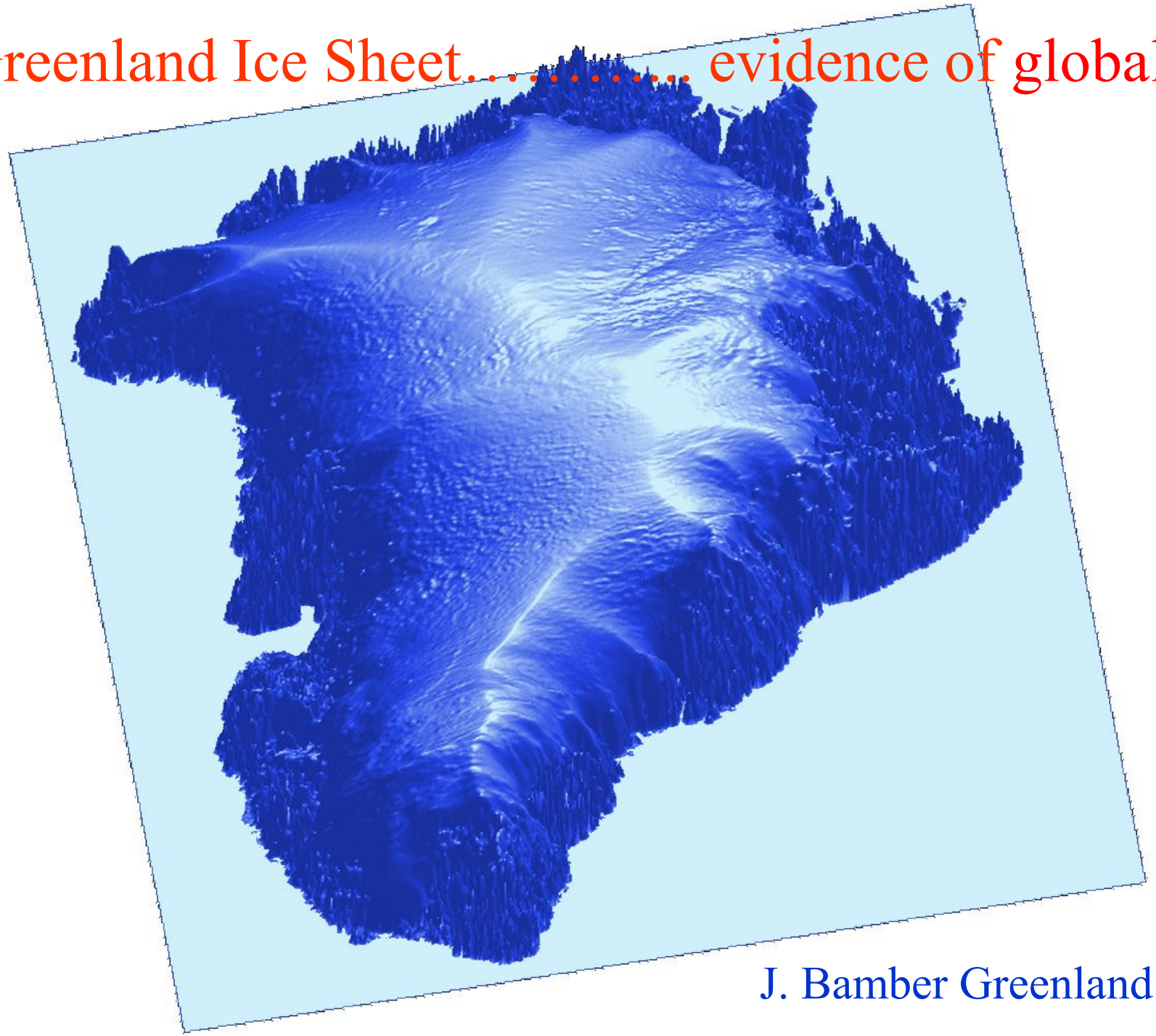
Annual J-D 2016-2025 L-OTI(°C) Anomaly vs 1951-2000 0.89



http://data.giss.nasa.gov/gistemp/maps

NASA GISS Surface Temperature Analysis

Greenland Ice Sheet……. evidence of global warming?



J. Bamber Greenland DEM

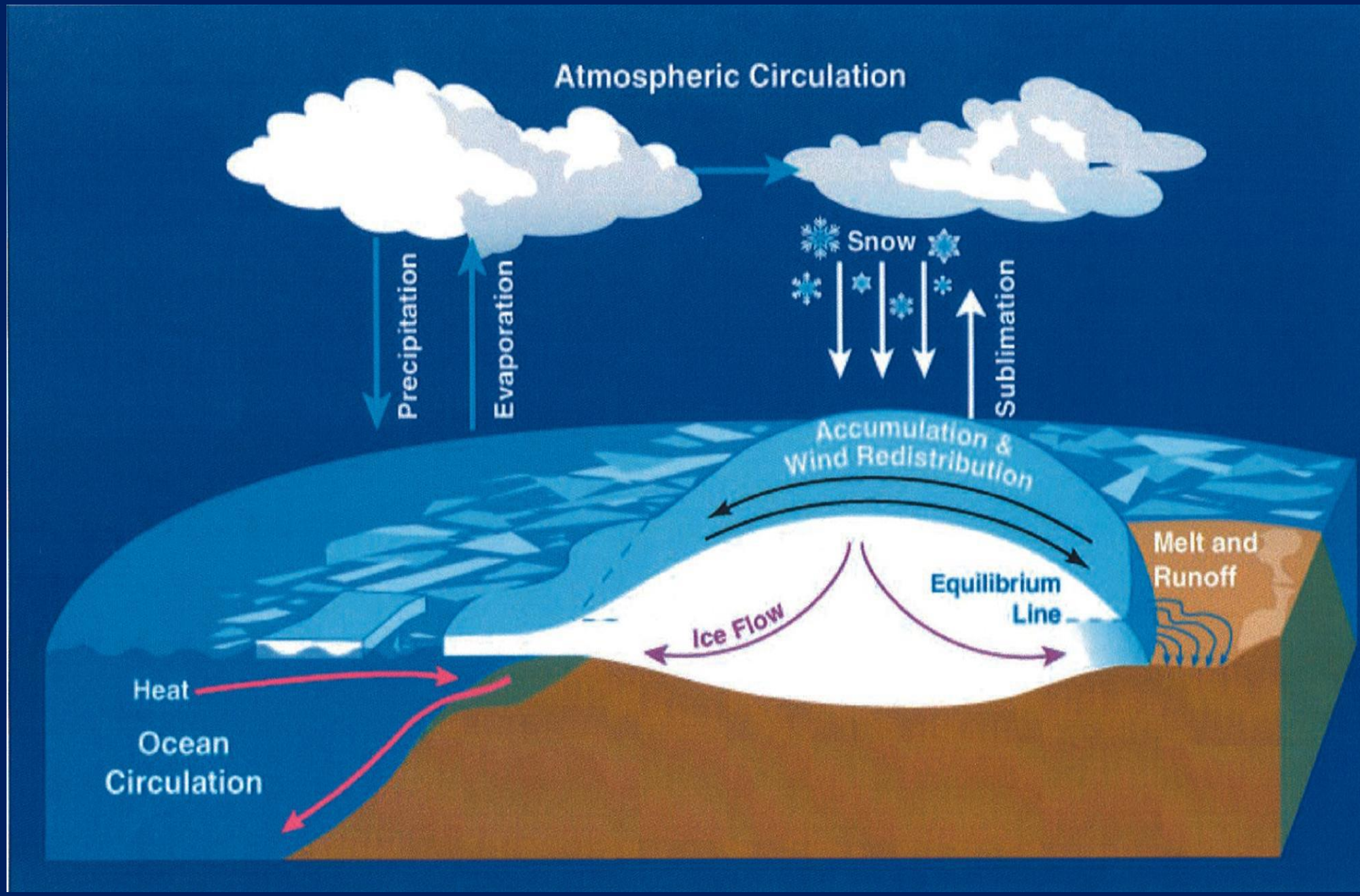


Ice sheet with individual mass balance components (Abdalati 2006)

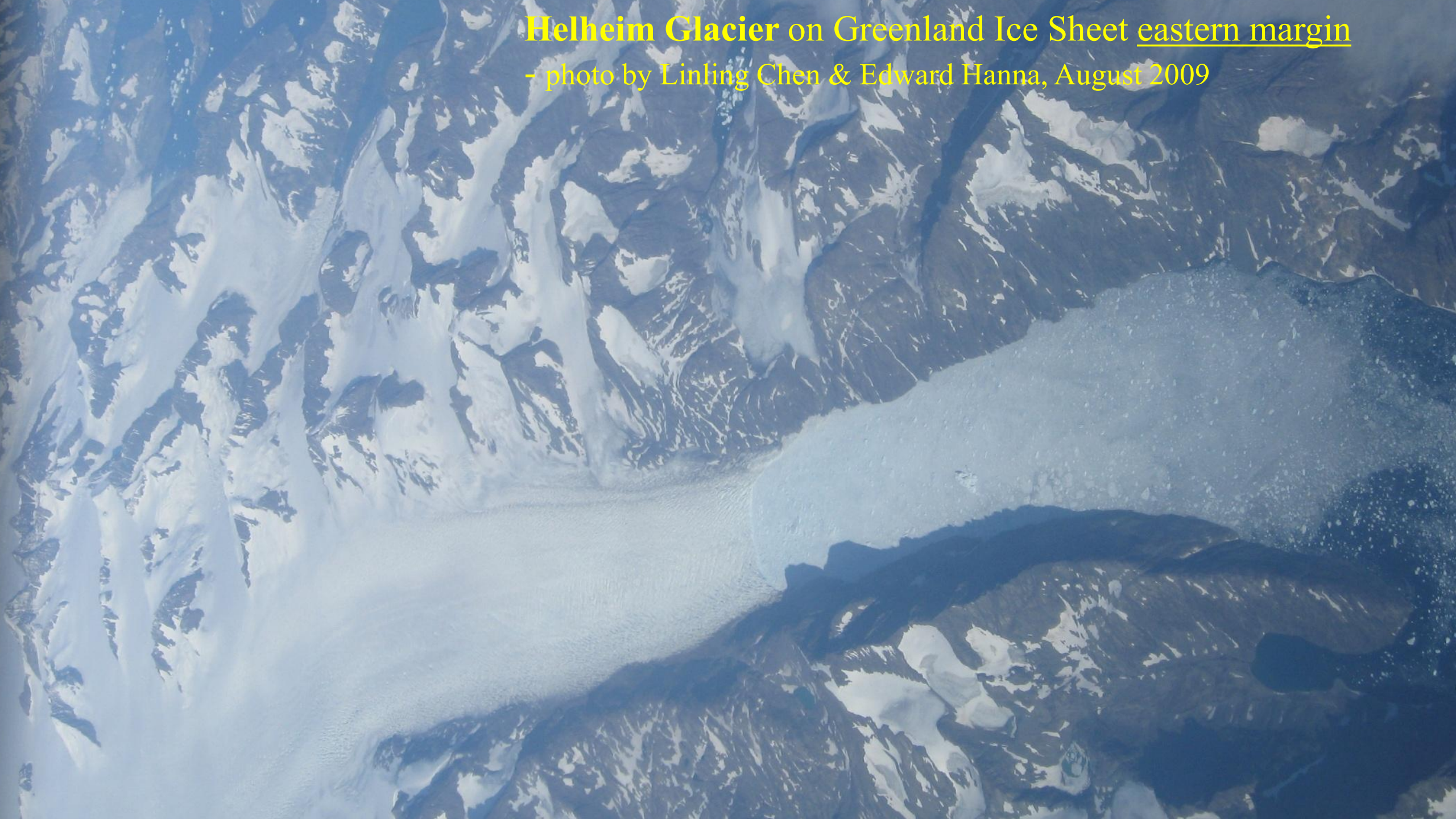
Surface mass balance = snow accumulation minus surface meltwater runoff.

There are also mass losses through ice flow/dynamics and iceberg calving.

Total mass balance = SMB + dynamics.




Mittivakkat Gletscher, August 2011



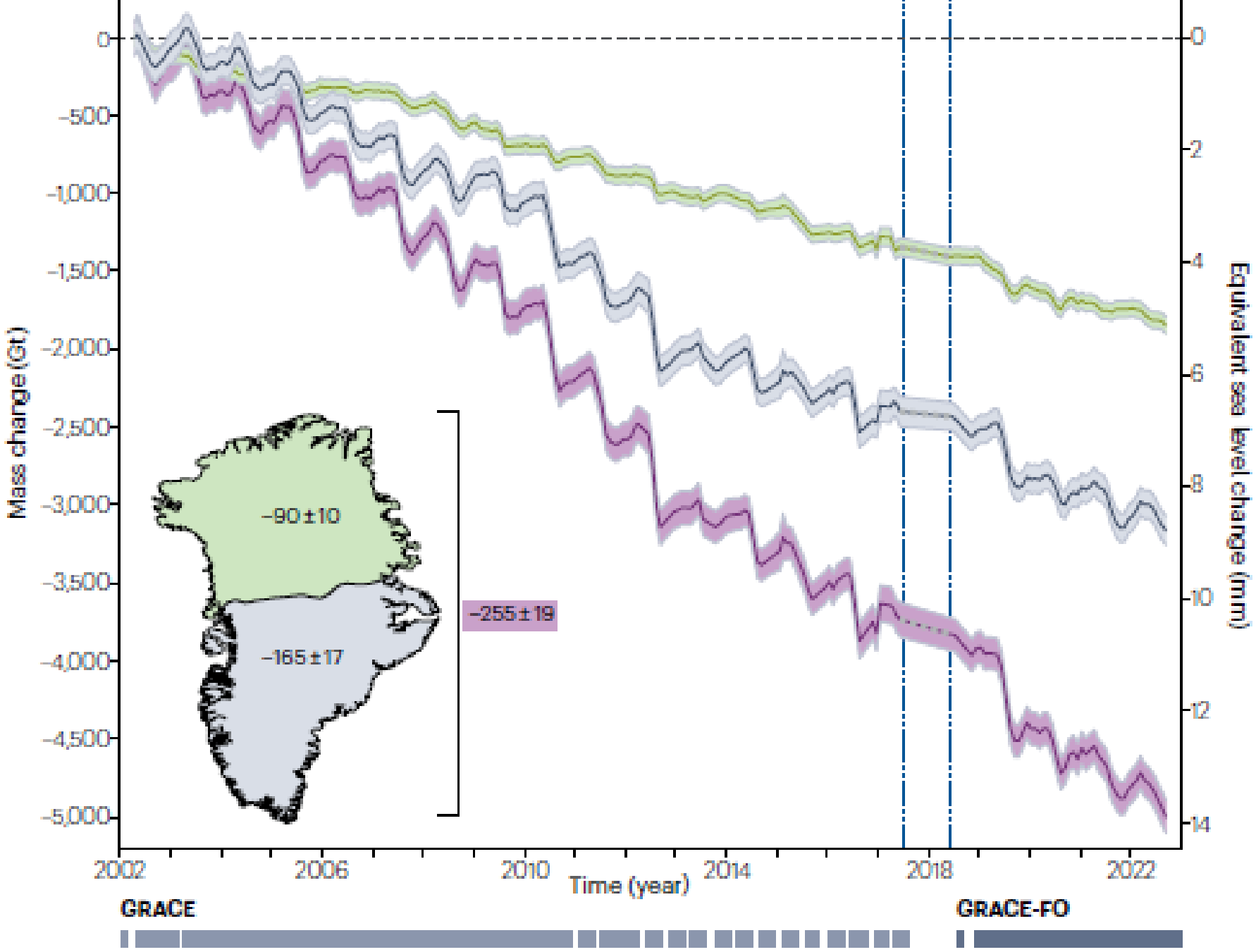
Helheim Glacier on Greenland Ice Sheet eastern margin

- photo by Linling Chen & Edward Hanna, August 2009


Sailing past a not so small bit of Helheim
(probably…), August 2011

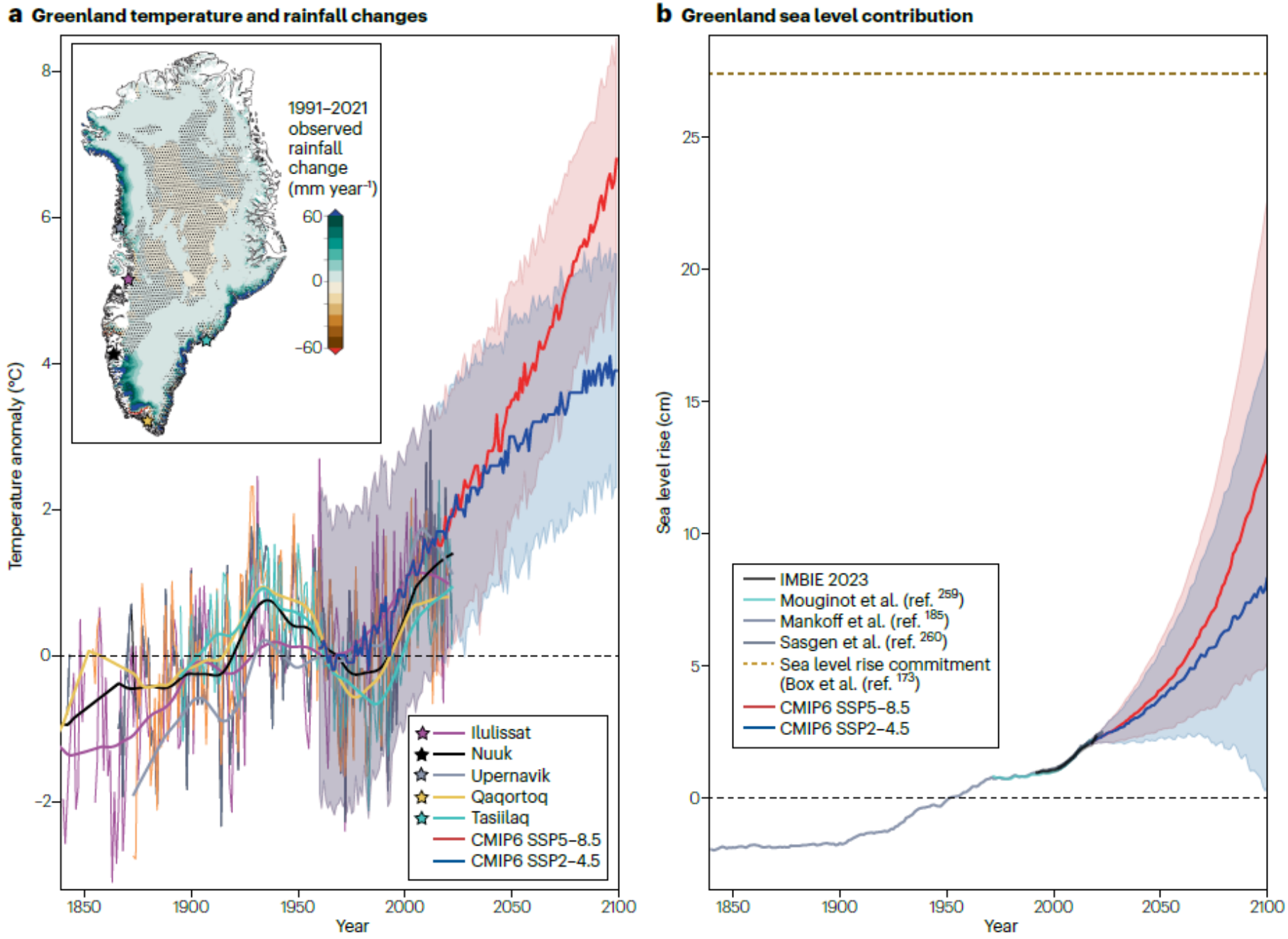
Monthly series of ice-sheet mass change and sea-level equivalent for 2002-2022 based on GRACE/GRACE-FO gravimetric satellite data

Figure from Ingo Sasgen, in Hanna et al. (2024) *Nature Reviews Earth & Environment*



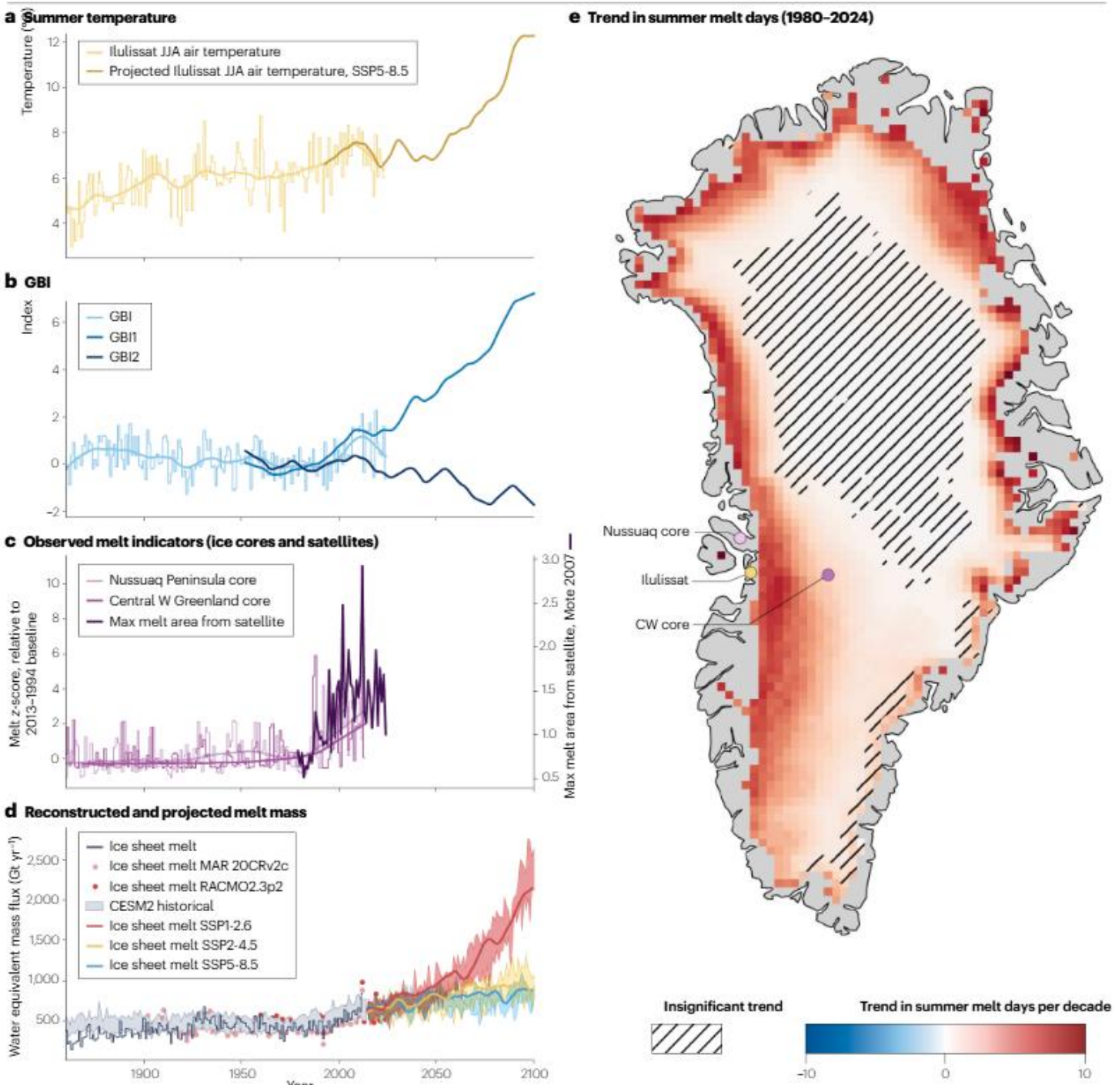
Past and future Greenland air temperature and sea-level contribution between 1850 and 2100

Figure from Jason Box, in Hanna et al. (2024) *Nature Reviews Earth & Environment*



Indicators of Greenland Ice Sheet melt

Figure from Hanna et al. 2026 *Nature Reviews Earth & Environment*, https://www.nature.com/articles/s43017-026-00800-3



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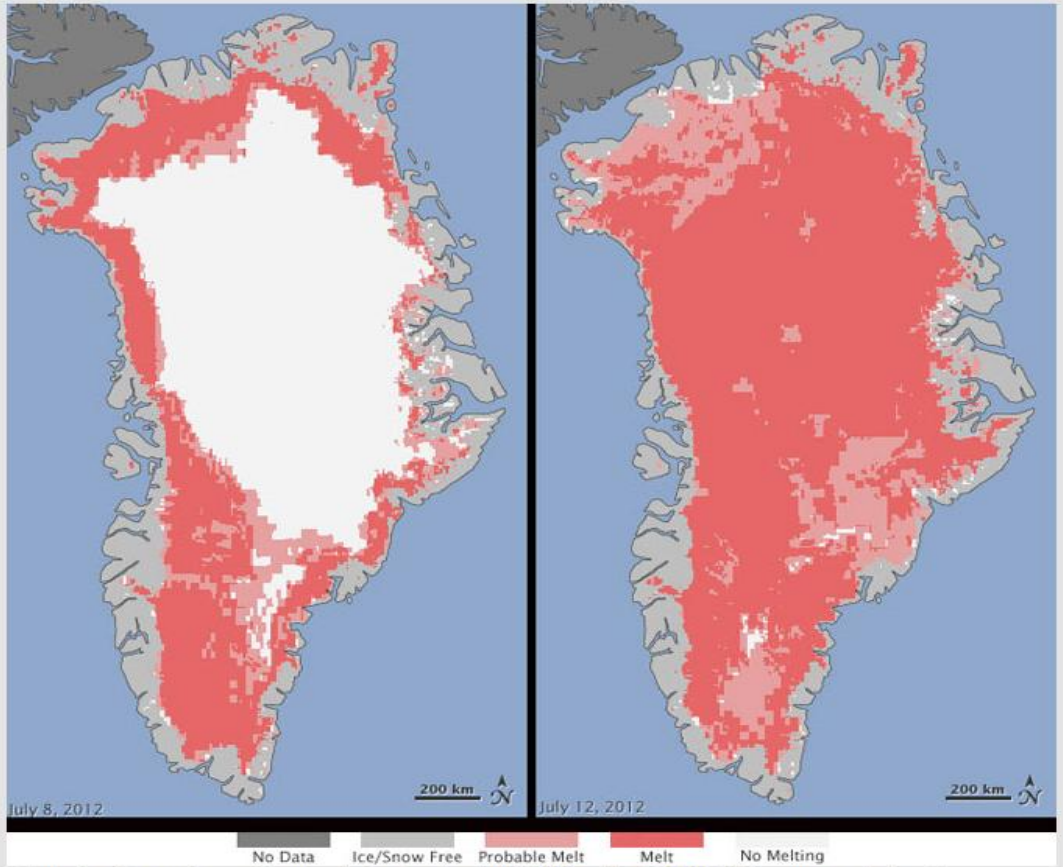


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Satellites See Unprecedented Greenland Ice Sheet Surface Melt

07.24.12



Extent of surface melt over Greenland's ice sheet on July 8 (left) and July 12 (right). Measurements from three satellites showed that on July 8, about 40 percent of the ice sheet had undergone thawing at or near the surface. In just a few days, the melting had dramatically accelerated and an estimated 97 percent of the ice sheet surface had thawed

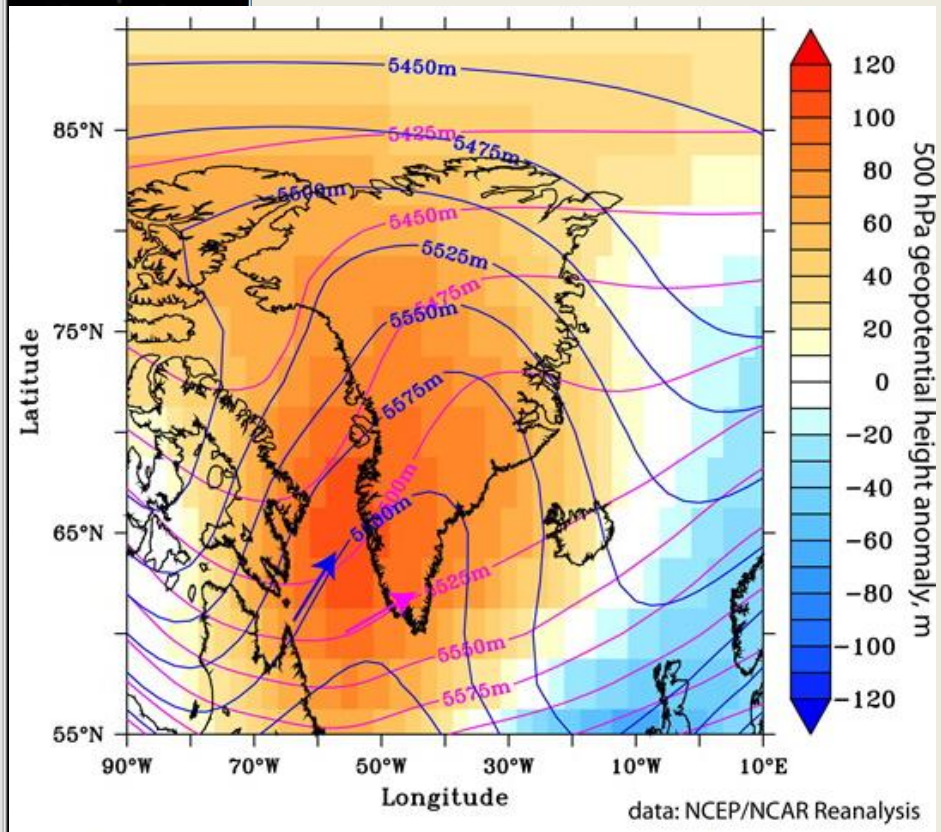


Fig. 5.15. Geopotential height (500 hPa) anomalies for June-August, 2012 (blue lines) referenced to the 1981-2010 mean (magenta lines). The arrow in the lower left quadrant shows that the prevailing upper air flow from the south advected warm air into Greenland. Data source: NCEP/NCAR Reanalysis version R1.

Greenland Ice Sheet and sea-level response under climate change from AD 1600 to 2100

Lead Research Organisation: University of Lincoln
Department Name: School of Geography

Go back

Overview Organisations People

Abstract

The Greenland Ice Sheet contains enough mass to raise global sea-level by seven metres. Greenland Ice Sheet mass loss arising from global warming is currently the main icy contributor to global sea-level rise and could contribute several tens of centimetres to global sea level by the year 2100, although this prediction is highly uncertain. Most recent studies show that surface mass balance (defined as net solid precipitation minus surface meltwater that runs off from the ice sheet) is the main part of 21st century Greenland Ice Sheet mass change; yet key gaps remain in our knowledge and understanding of Greenland Ice Sheet change at the multi-century timescale. Improved information on surface mass balance changes over space and time is needed to improve the reliability of computer models of ice-sheet flow and loss of ice via calving of icebergs (called ice dynamics). The present limited understanding of recent surface mass balance change resulting from the lack of constrained computer simulations, especially for time periods before the last 50 years or so, propagates through to unreliable estimates of future total mass balance (i.e. the sum of surface mass balance and ice dynamical changes) and therefore projections of sea level rise.

Most current Greenland Ice Sheet surface mass balance datasets do not extend back before around 1900, while the more sophisticated surface mass balance models tend to focus on relatively short periods since 1960 due to unavoidable requirements of large amounts of reliable, complex input data (for example those relating to surface heat and energy flows between the ice sheet's surface and the atmosphere) which are typically unavailable before the 1960s. Also, estimates of the ice dynamic portion of ice-sheet mass change are based on statistical relationships of ice output with recent climatology, which is unlikely to be representative of the pre-instrumental period or the future. Therefore, bridging the major gap in the understanding of Greenland Ice Sheet-climate interactions and effect on sea-level during the large climate shifts between Little Ice Age (around 1600 to 1850) and the 20th/21st Century is urgently needed to reduce the significant uncertainty propagating through to the global sea-level contribution of Greenland Ice Sheet changes during the rest of the Twenty First Century. Our proposal combines a wide range of models, observations and scientific expertise to address this key knowledge gap.

Funded Value:
£826,227

Funded Period:
Feb 24 - Aug 26

Funder:
NERC

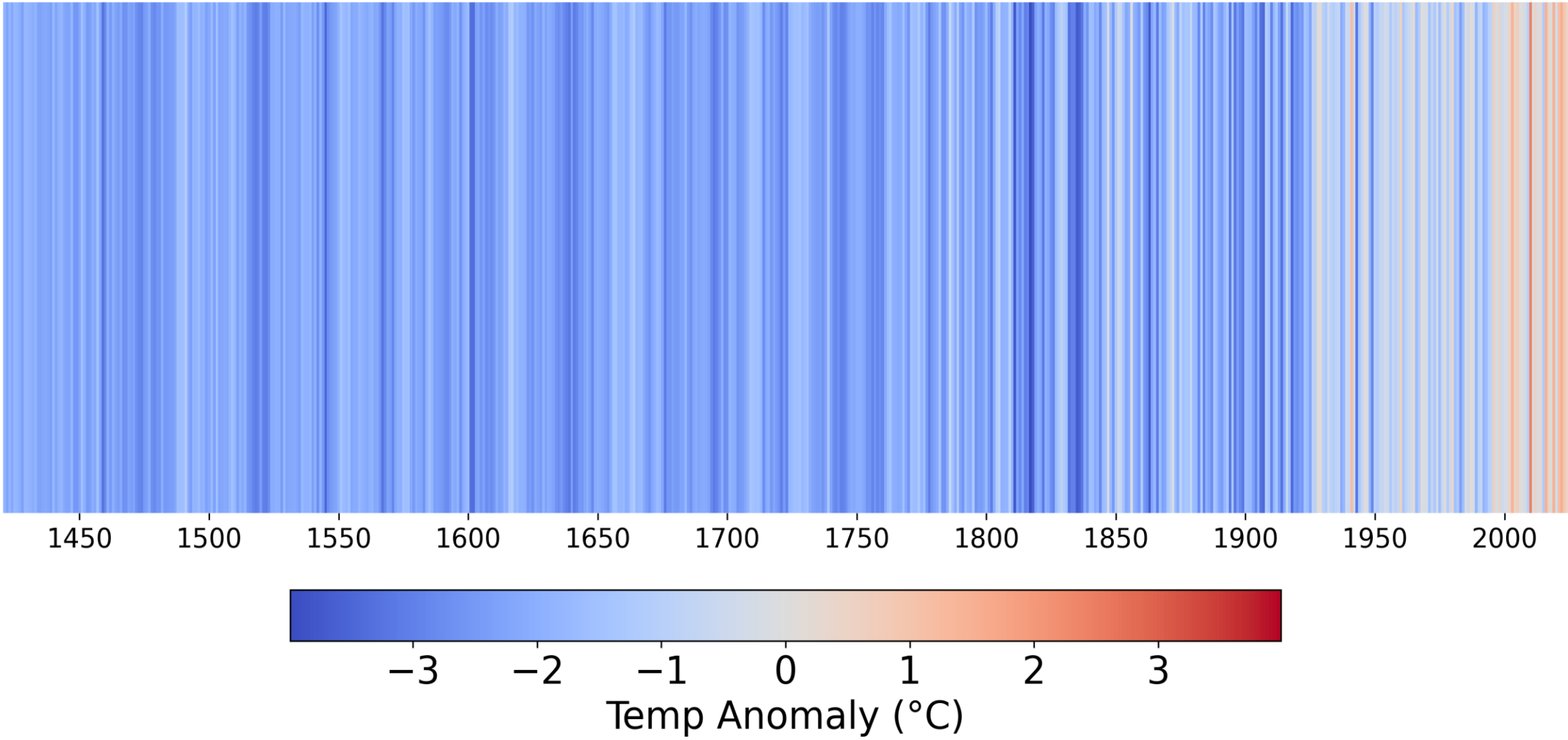
Project Status:
Active

Project Category:
Research Grant

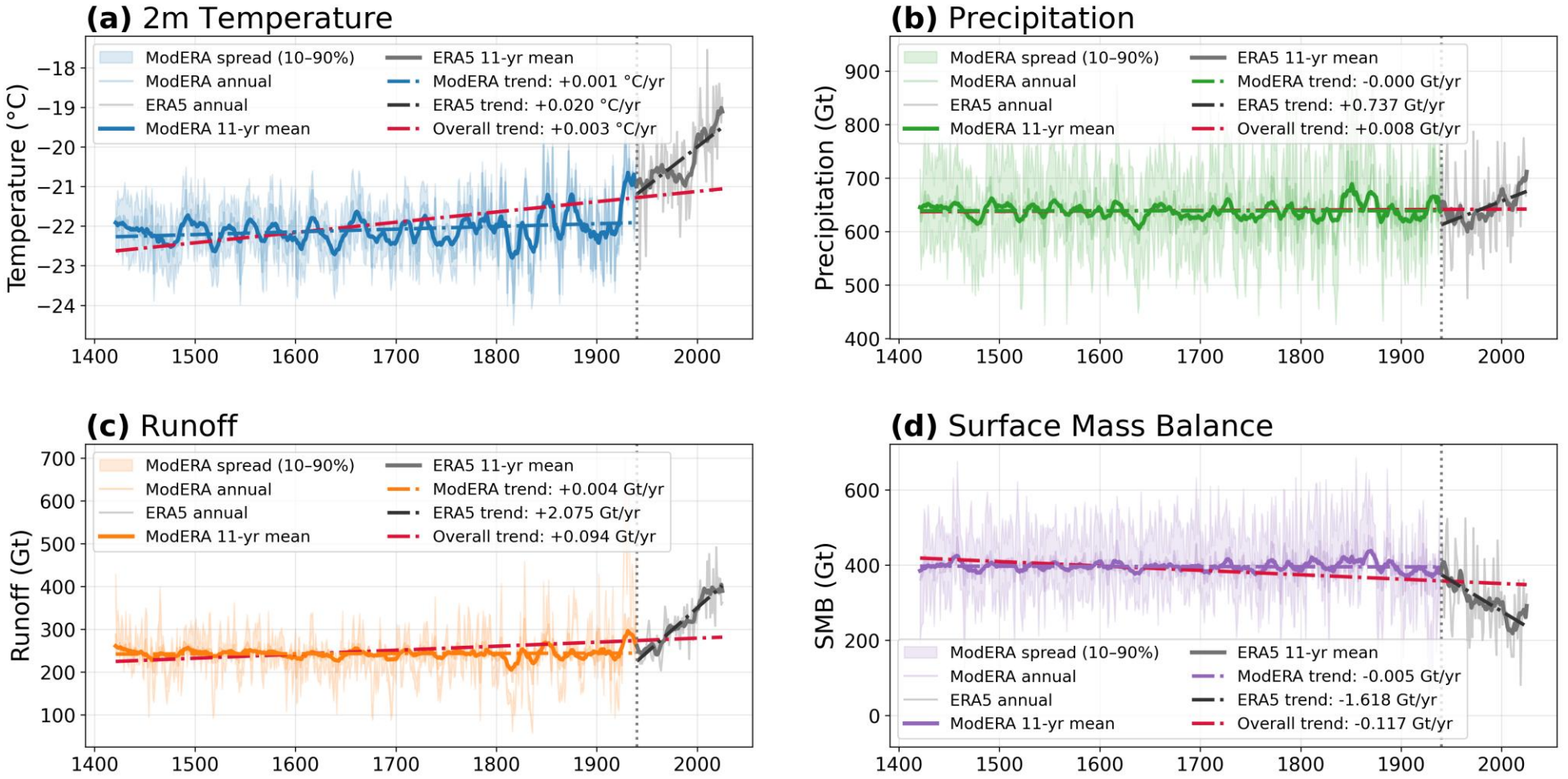
Project Reference:
NE/Y000129/1

Principal Investigator:
Edward Hanna

Greenland Ice Sheet mean yearly temperature anomaly, 1421-2024



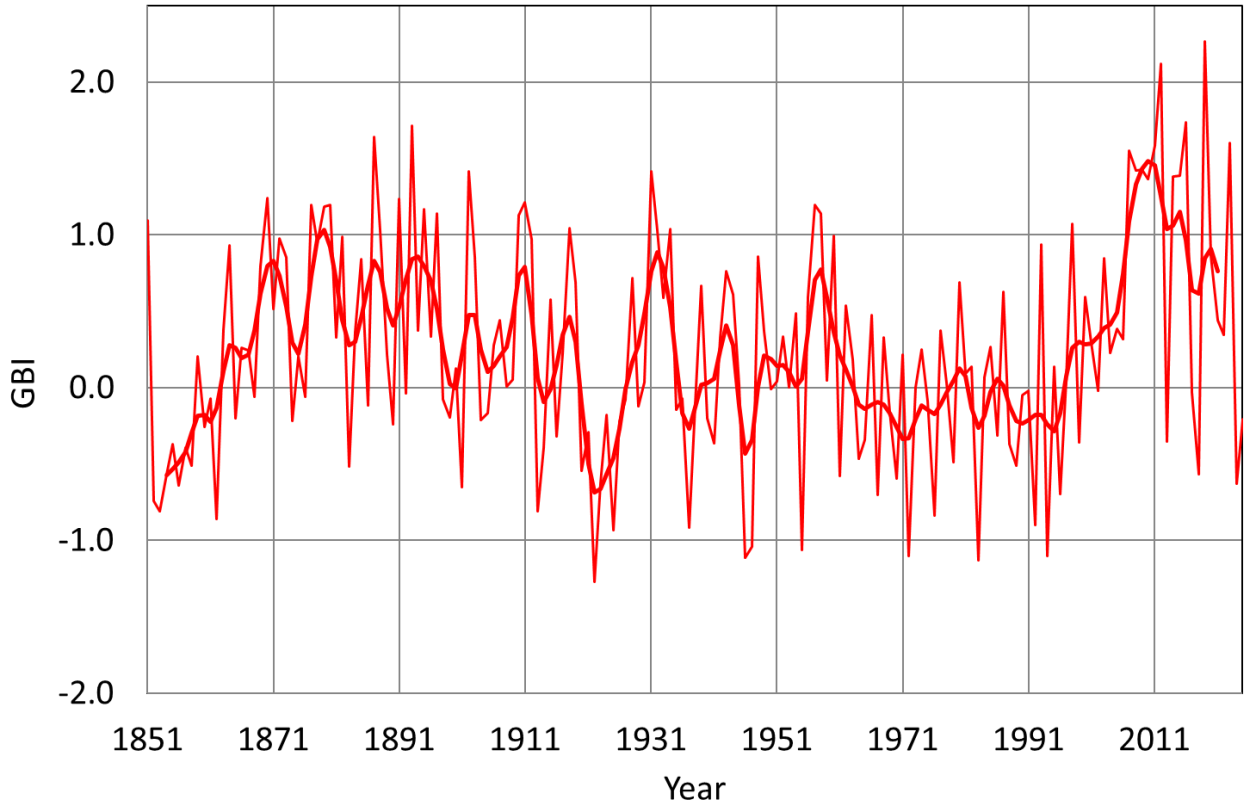
Six-Century Greenland SMB Evolution



(Javed et al., 2026; Under Review)

Recent Greenland SMB decline lies outside most of the six-century variability envelope

Recent record summer high pressure over Greenland



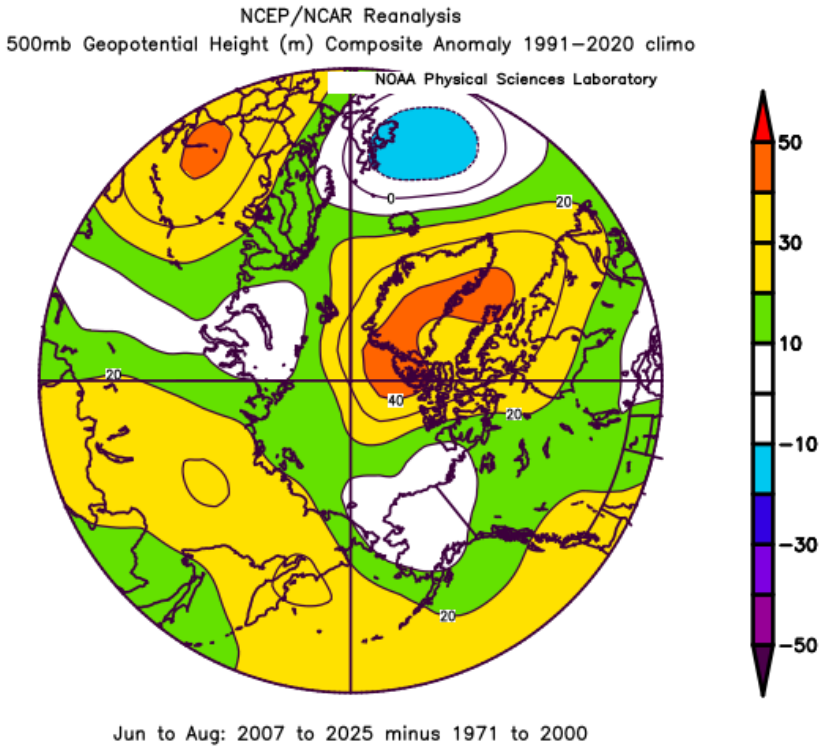
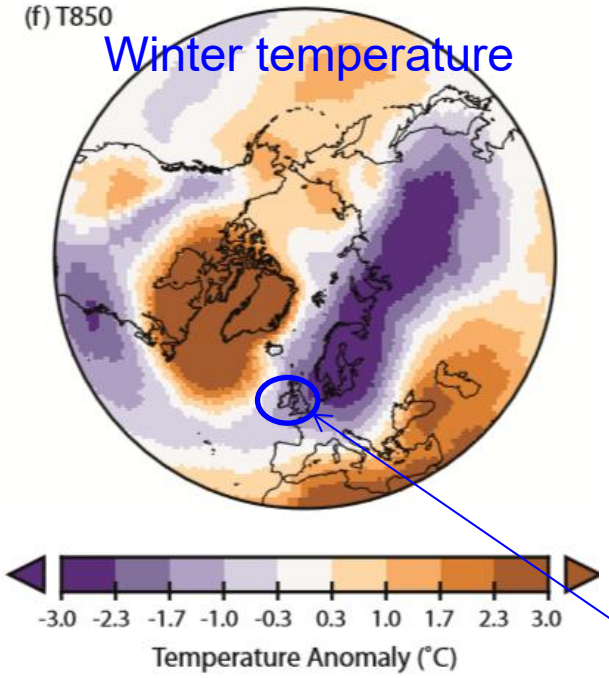
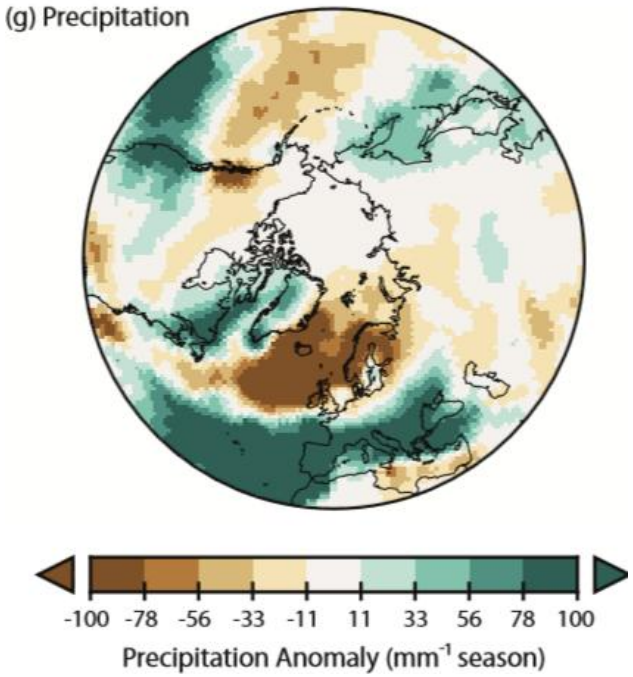


Figure Left/graph shows yearly and filtered values of summer **Greenland Blocking Index (GBI)** for 1851-2025, showing striking significant increase since 1990.

Right/map shows 500 hPa geopotential height anomaly difference for 2007-2025 average summer minus 1971-2000 average summer. Map highlights recent increase in atmospheric blocking over Greenland and decrease near British Isles.



Winter temperature



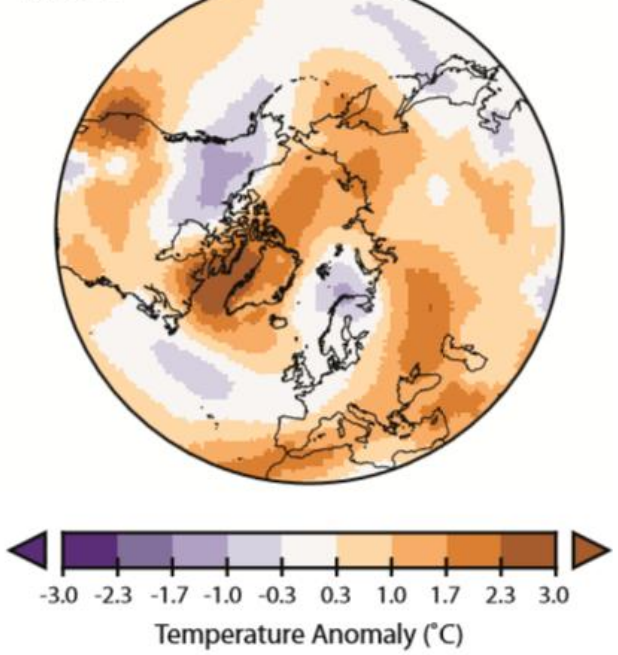
Greenland Blocking (GBI) impacts on mid-latitude weather

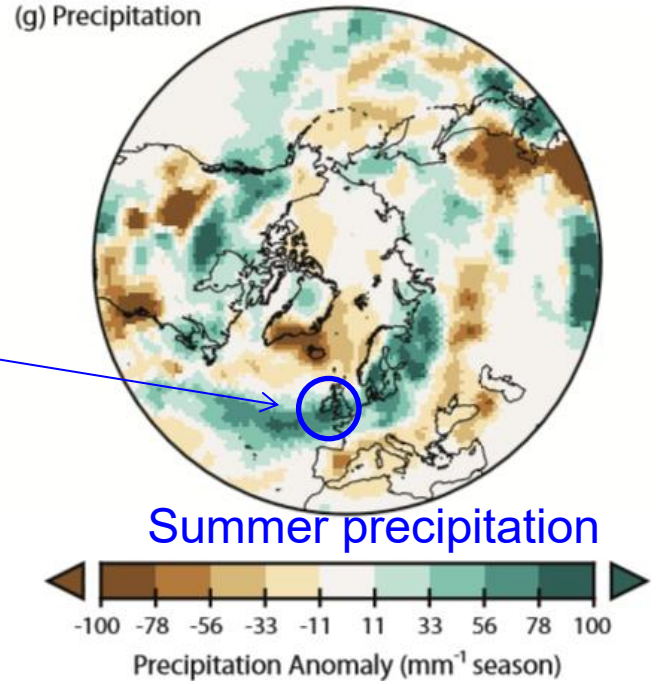
Near-surface temperature (top) and *precipitation (bottom)* anomalies for **winter (left)** and **summer (right)** for 10 highest minus 10 lowest Greenland Blocking years during 1851-2015.

Based on Twentieth Century Reanalysis v2c data.

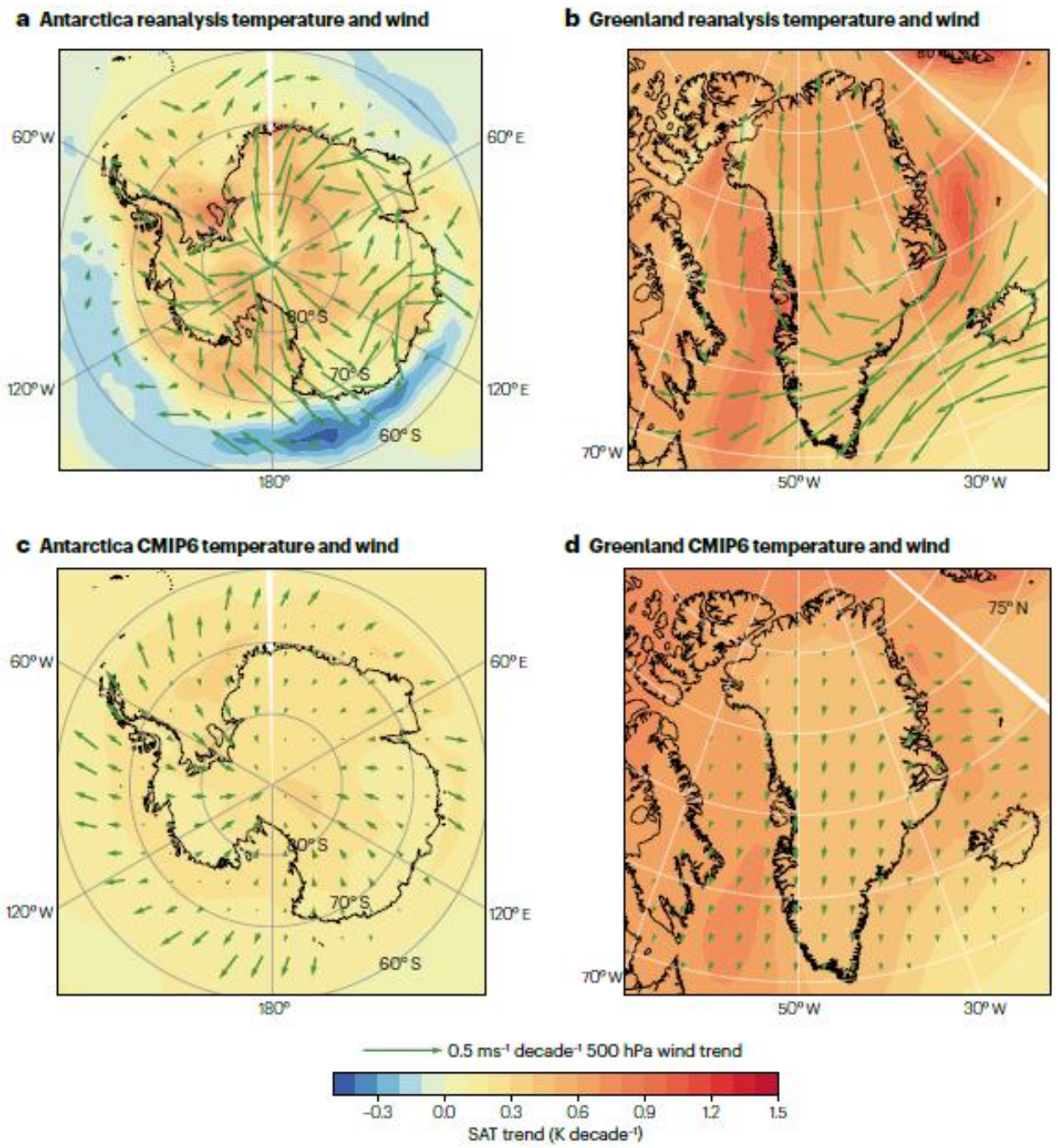
Note cold winters & wet summers over UK.

Hanna et al. (2016)





Summer precipitation



Atmospheric circulation and surface air temperature changes during 1979 to 2020

b: Annual mean surface air temperature (SAT, colour bar) and mid-troposphere (~5.5-km altitude) wind trends (green arrows) over Greenland in average of 4 'real world' meteorological reanalyses datasets.
a: Same but for Antarctica.

d:Temperature and wind trends in Greenland from average of 29 CMIP6 global climate models (GCMs).
c: Same but for Antarctica.

Winds poorly represented by GCMs for Greenland & Antarctic ice sheets.

Temperature poorly represented by GCMs for Antarctic Ice Sheet.

Figure from Daniel Topal, in Hanna et al. (2024)

Summary

*Greenland Ice Sheet is currently **largest single cryospheric contributor to global sea-level rise**. Rate of mass loss in last 2 decades about twice that of Antarctic Ice Sheets.

Short-term variations and extreme events can disproportionately affect long-term ice-sheet evolution! **Urgently need more complete study of different timescales of mass balance variability** from days to thousands of years.

Climate change and atmospheric circulation change over **Greenland can affect jet stream and Northern Hemisphere midlatitude extreme weather**.

*Atmospheric circulation over Greenland (and Antarctica) is misrepresented in computer model simulations - **need to urgently improve Global Climate Models** for ice-sheet projections.

***My research group has recently produced 600-year (1421-2025 CE) monthly Greenland Ice Sheet surface mass balance model simulation** (snowfall minus surface melt losses): a world-first i.e. 4x longer than previous published records.

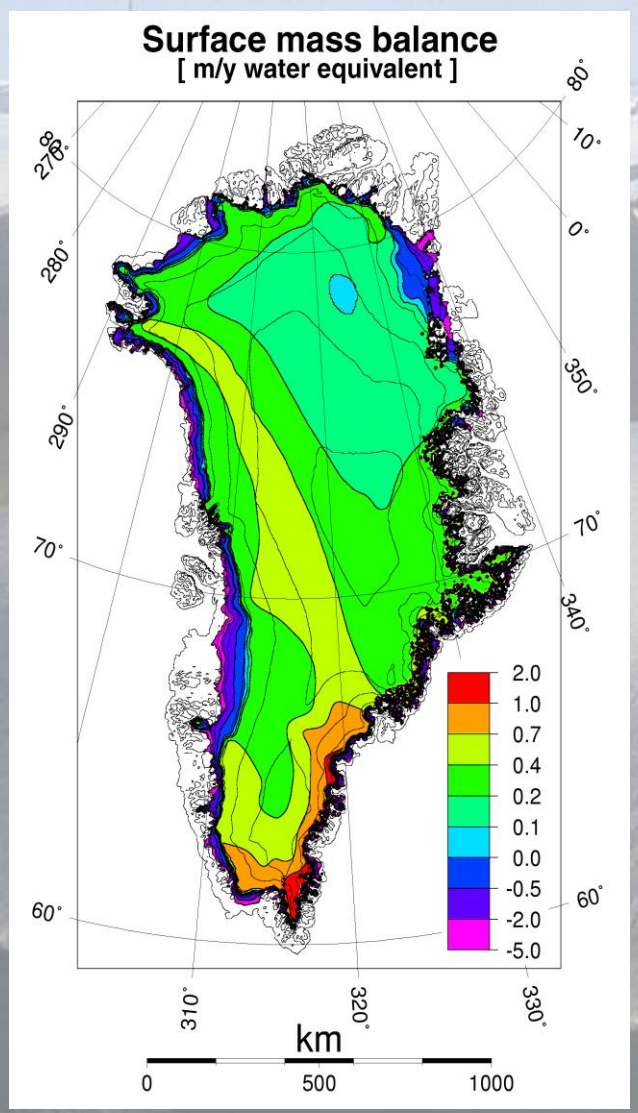
Thank you. Questions?



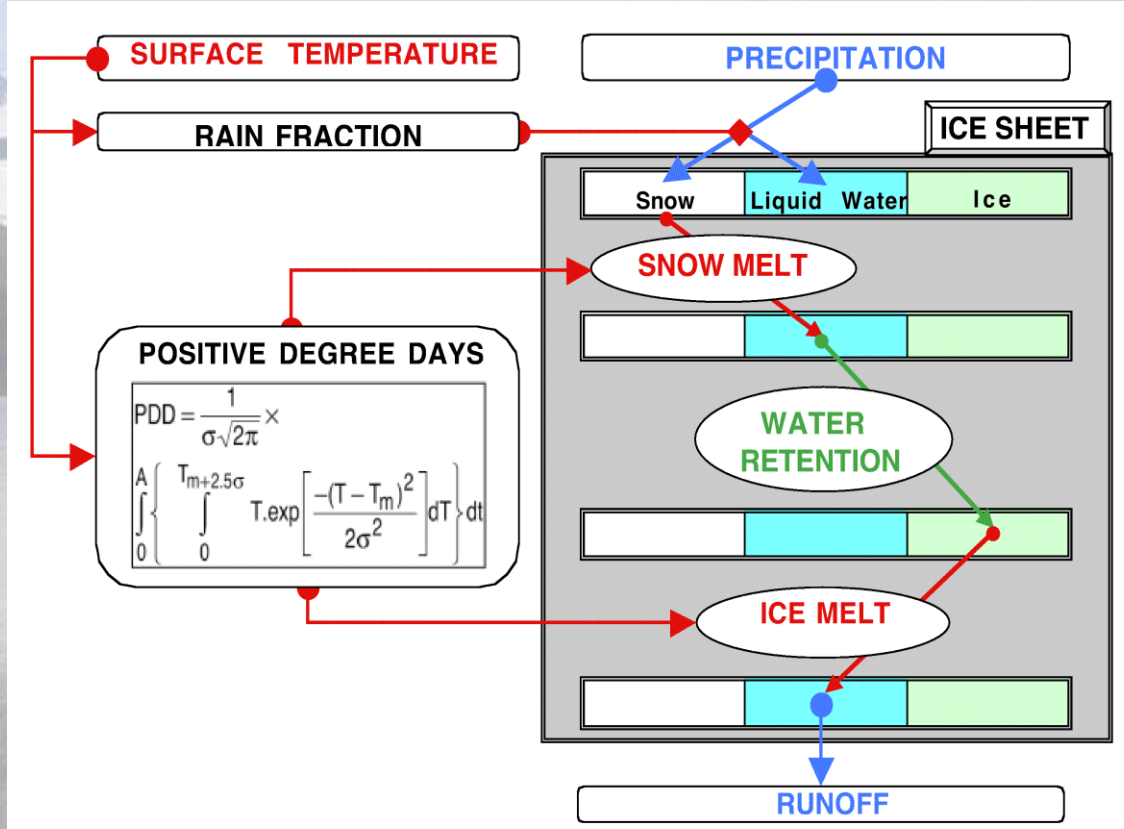
ehanna@lincoln.ac.uk

I acknowledge UKRI NERC grants NE/Y000129/1 & NE/W005875/1

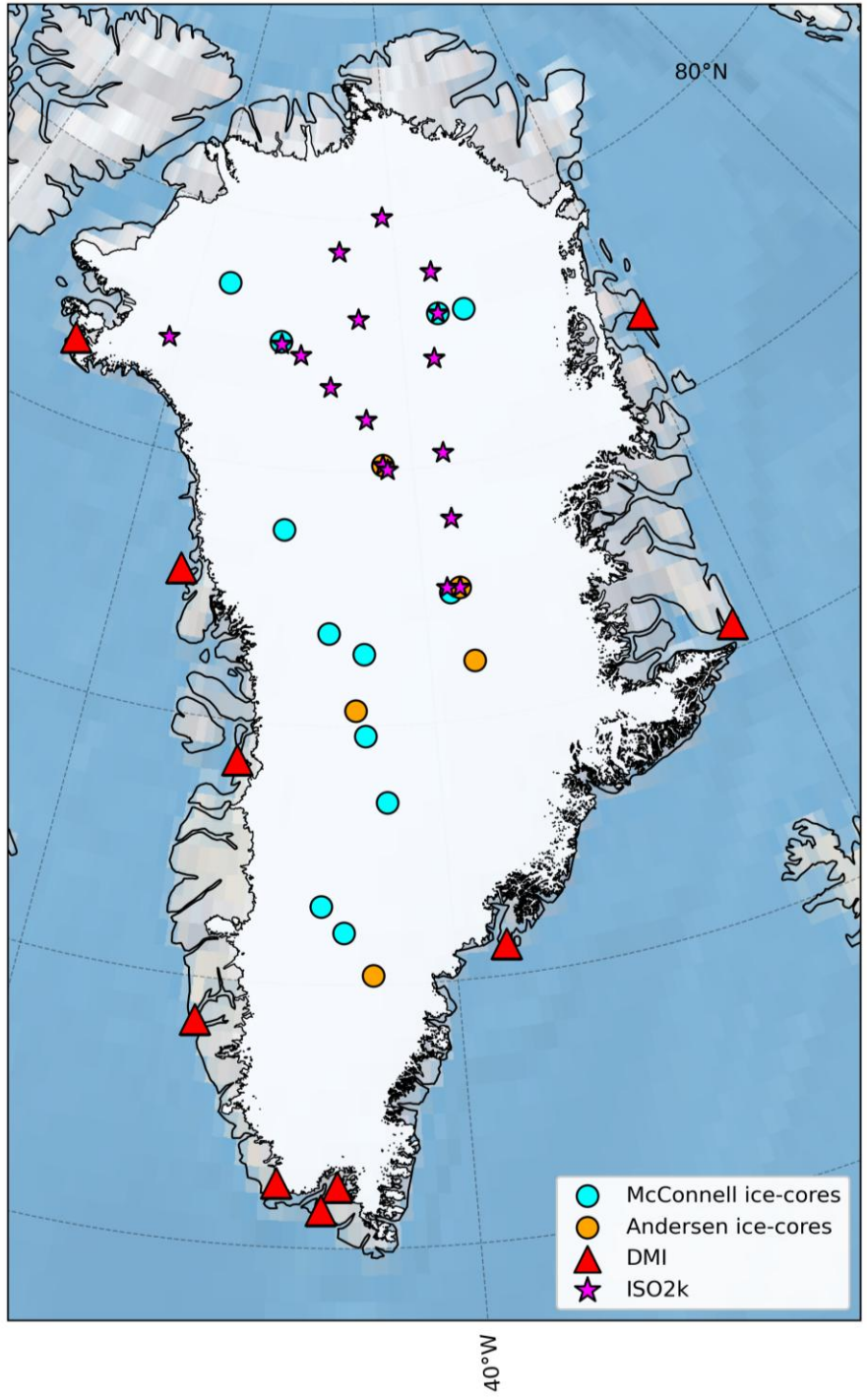
Modelling of meltwater runoff



Janssens, Huybrechts (2000) *Ann. Glac.*, Hanna et al. (2005, 2011)



- Meltwater runoff model calibrated for the present-day Greenland ice sheet
- Degree-day method efficient on high-resolution grids and for long (100 years+) time periods



Looking into the Past: Six Centuries of Greenland SMB

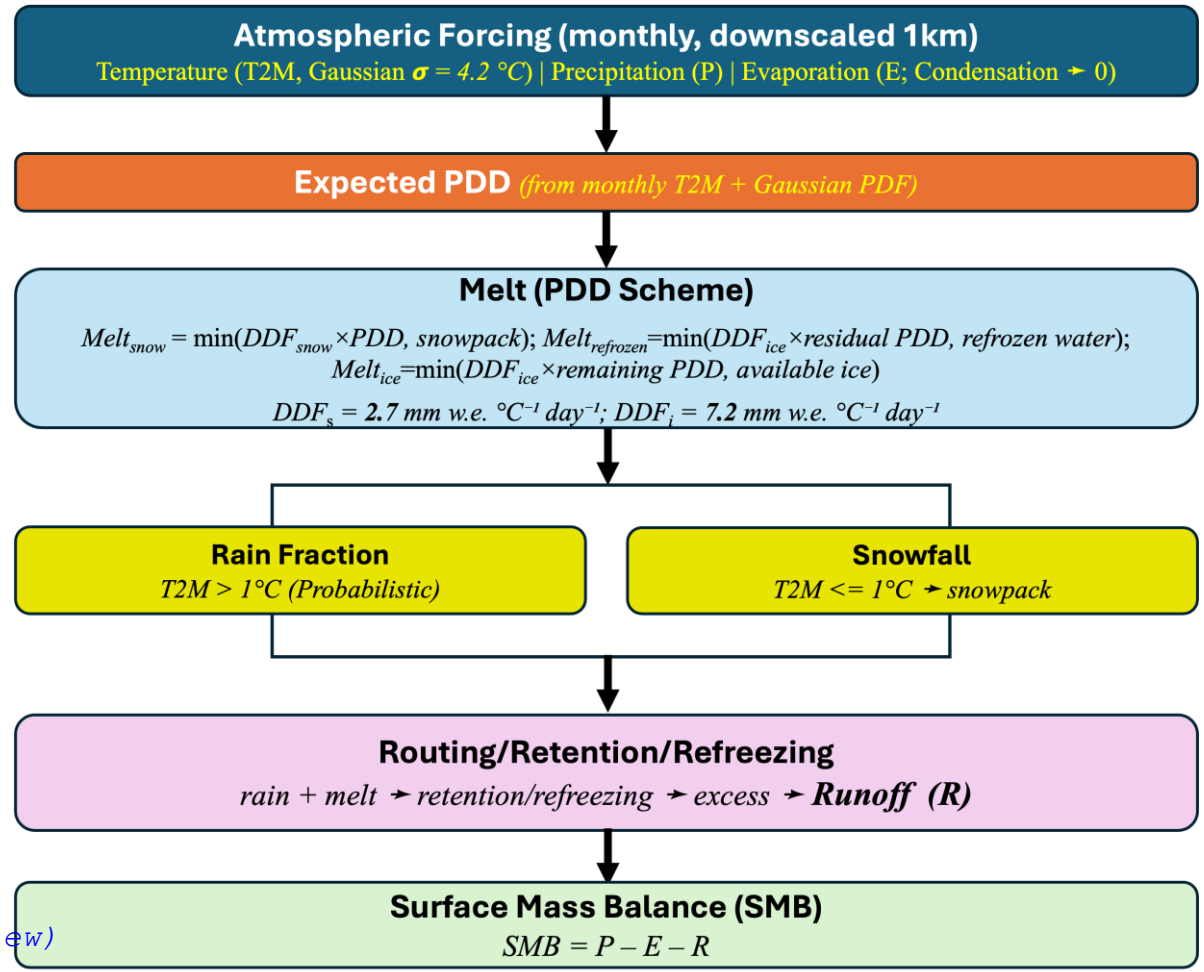
- Existing Greenland Ice Sheet (GrIS) SMB reconstructions extend only to ~1850 at best (e.g., Box *et al. 2013*; Fettweis *et al. 2017;* Mankoff *et al. 2021*), motivating extension back to earlier centuries.
- Aim is to create a homogenized, physically consistent SMB record by combining available reanalysis products with a unified PDD runoff/retention model.
- Deliver a novel monthly, 1-km whole-GrIS SMB (and other fields) to enable regional process studies, model evaluation, and long-term climate attribution.

(Javed et al., 2026; Under Review)

SMB Model Framework

- Positive Degree Day (PDD) modelling approach calculates SMB of GrIS.
- It estimates accumulation and runoff components based on degree days above freezing.
- PDD method is reliable and compares favourably against more complex energy-balance regional climate models.

(Javed et al., 2026; Under Review)



Analysis Period	***ERA5:*** 1940-2025; ***ModERA:*** 1421-2008 (20 ensemble members; *Valler et al. 2024*)
Temporal Frequency	monthly
Spatial Resolution	**Input:** ERA5 at 0.25°, ModERA at 1.875° **Output:** 0.01°

Bias Correction of ModERA datasets: Two-Stage Correction Framework

Stage-1: Fine-Scale Temporal Correction (1421-available)

Purpose

- Incorporate **high-frequency interannual variability** observed for Precipitation from ice-core & DMI station records.

Methodology

- Use station-based annual precipitation anomalies (relative to each station's mean climatology)
- **Interpolate** these anomalies spatially using **Gaussian Process Residual Correction**
- Correct ModERA annual totals by adding spatial anomaly patterns
- **Distribute** annual anomaly corrections **proportionally across each month's original fraction**

Key Feature

- Can be restricted to **desired range** if needed

(Javed et al., 2026; Under Review)

Stage-2: Baseline Bias Correction (1940–2008)

Purpose

- Correct large-scale, systematic bias relative to ERA5 reanalysis.

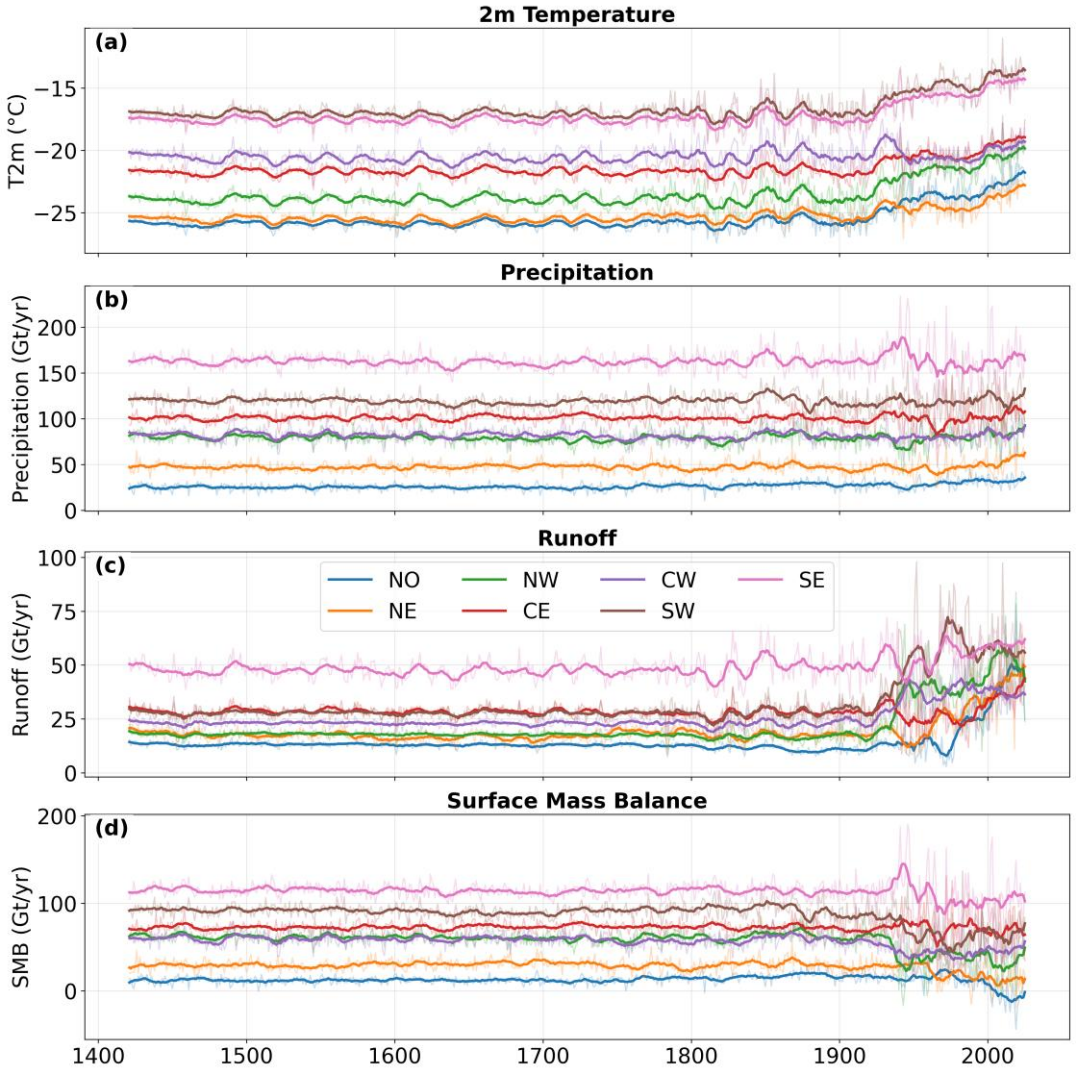
Methodology

- Compute **monthly mean difference** between ModERA and ERA5 (1940–2008)
- Apply this mean bias as a **uniform correction** across all periods (1421–2008)
- Retains **monthly variability** but adjusts long-term mean climatology

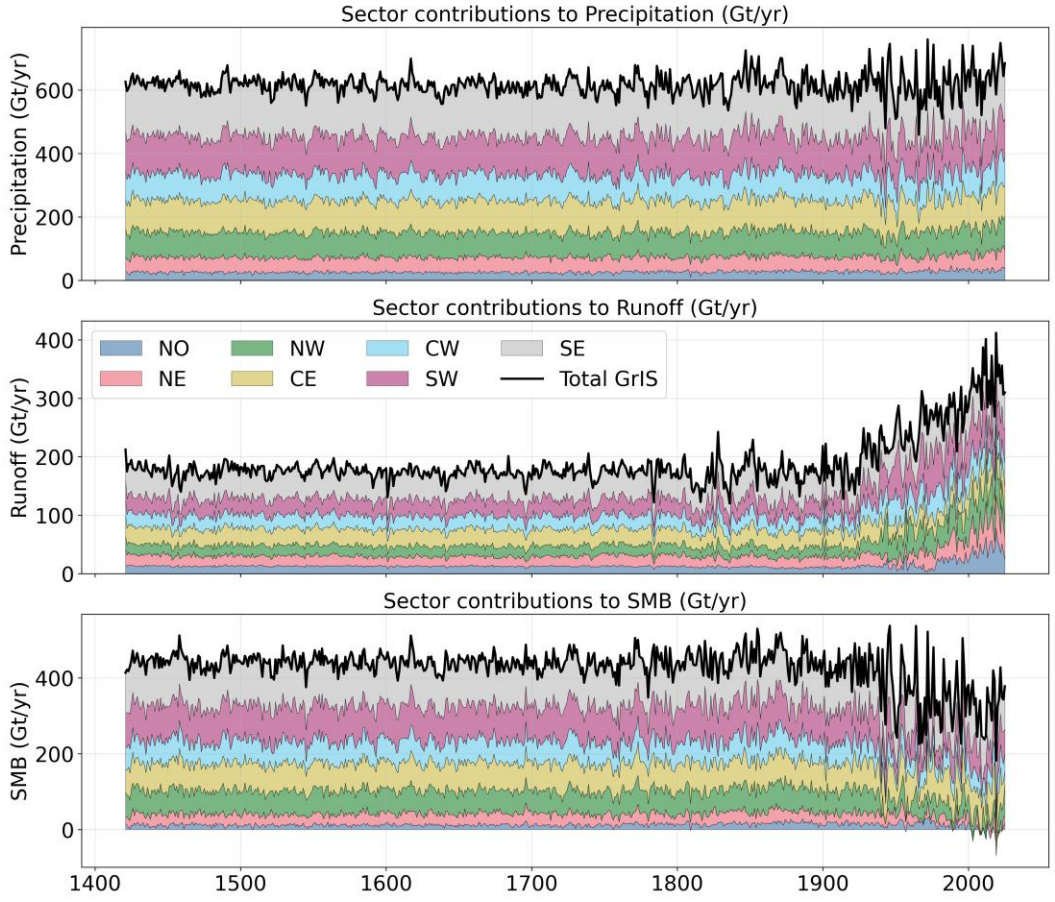
Key Assumption

- Large-scale climatological bias is **stationary over time**

Regional Contributions to SMB Change



(Javed et al., 2026; Under Review)

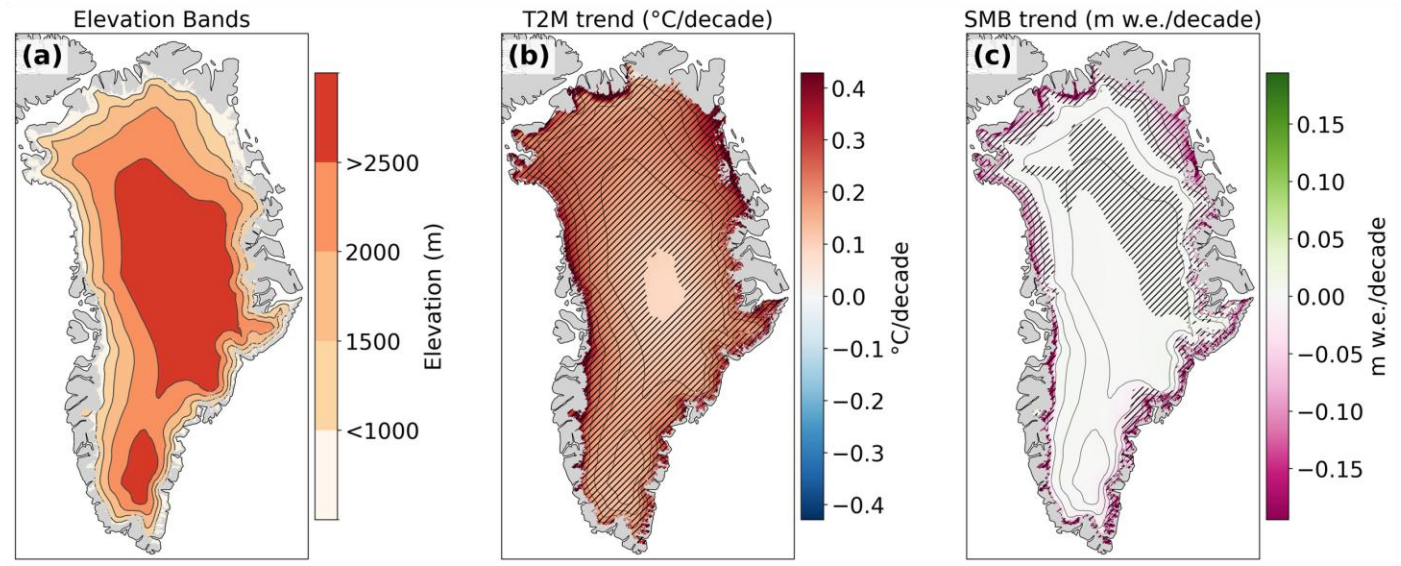


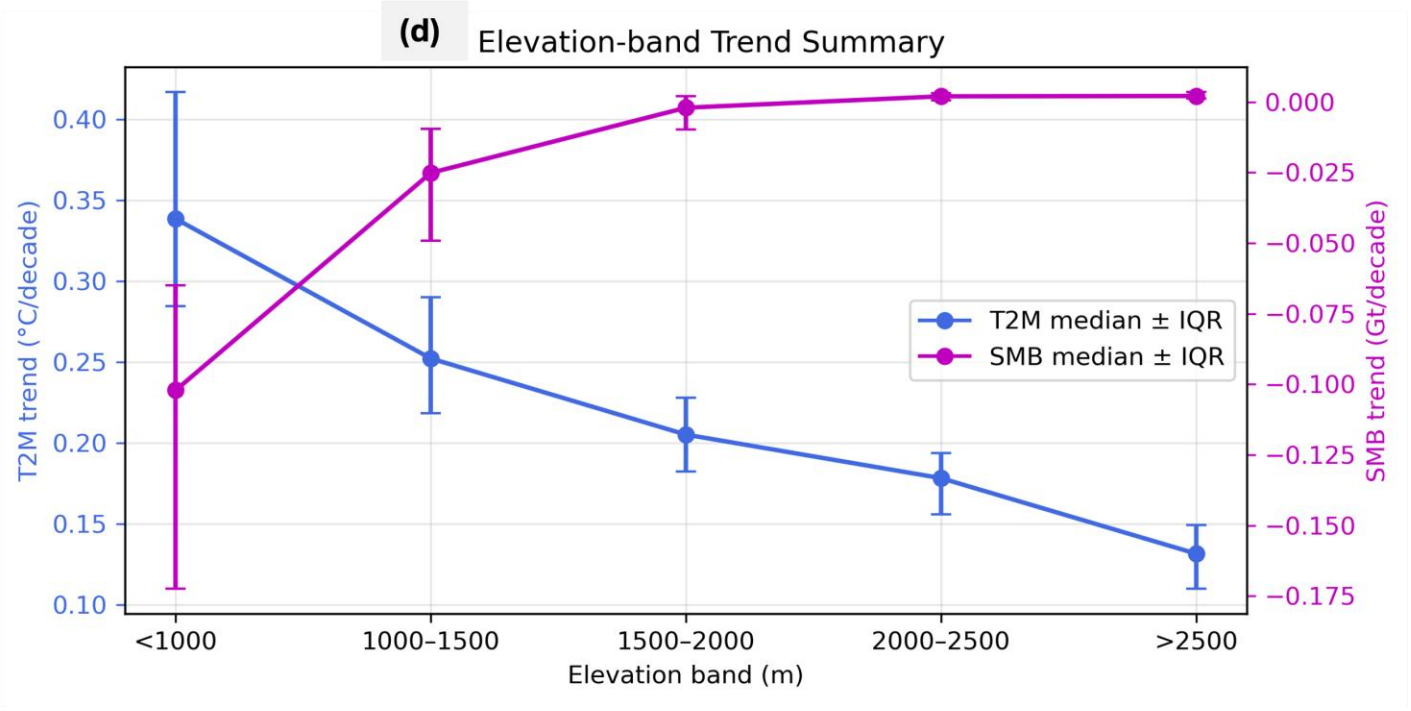
The SE sector provides the single largest contribution to total SMB variability (**26.7 ± 4.4 %**), followed by SW (**19.3 ± 4.9%**) and the central sectors CE and CW (together **~32%**). NW (**13.9 ± 2.8%**) contributes the highest among all northern sectors (NO: **3.0 ± 2.1%**, NE: **6.9 ± 2.1%**)

Elevation Dependence

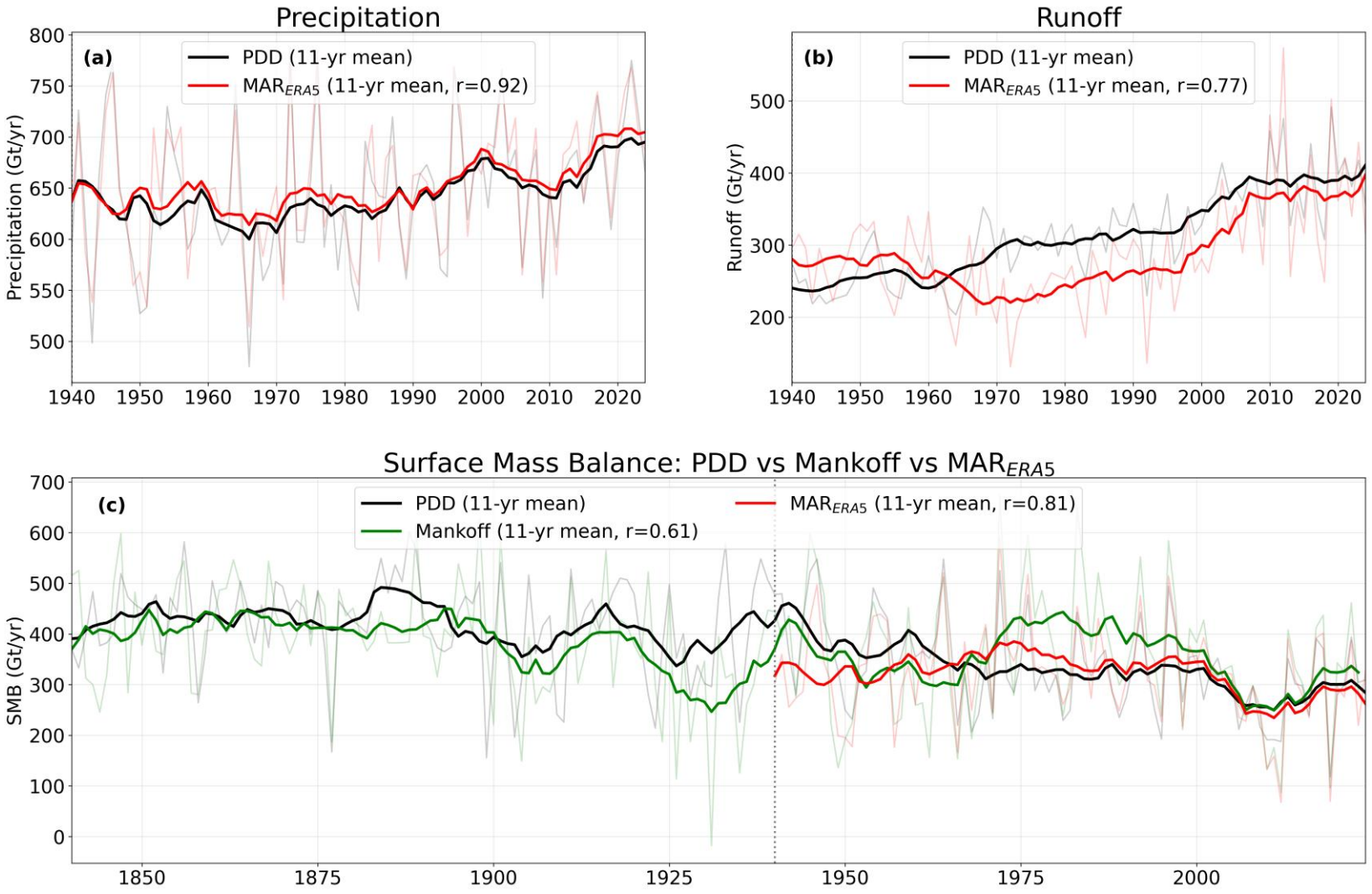
- Strongest warming occurs below 1000m elevation
- Low-elevation regions constitute only ~17% of total ice-sheet area but contribute ~61% of total SMB decline
- Recent Greenland SMB decline is exceptional in six-century context
- Modern Greenland mass loss reflects a thermodynamically driven transition toward sustained marginal melt dominance

(Javed et al., 2026; Under Review)





Evaluation Against Existing SMB Products



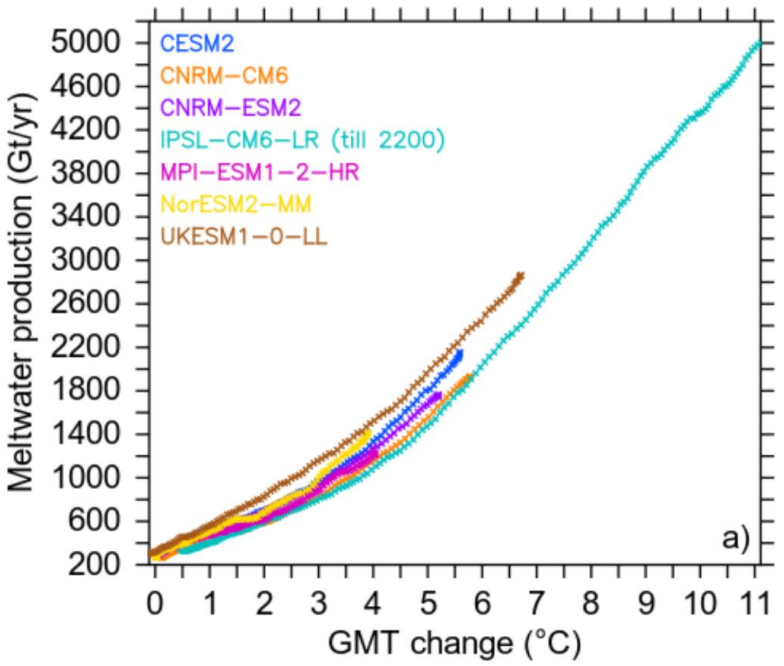
- PDD captures major melt events (e.g., post-2000 runoff increase)
- Reproduces long-term decline in SMB
- Extends Greenland SMB variability several centuries earlier than existing products

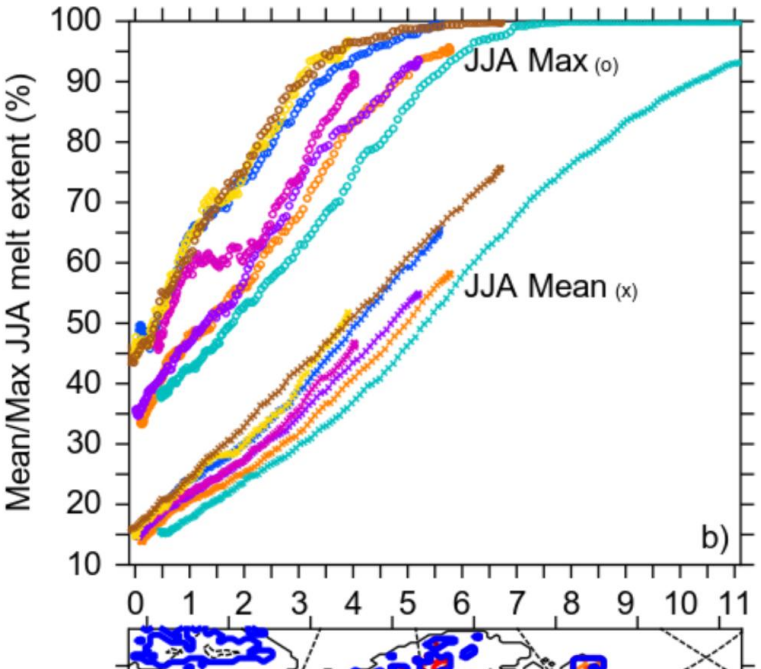
The reconstruction is physically consistent and well anchored to modern observations

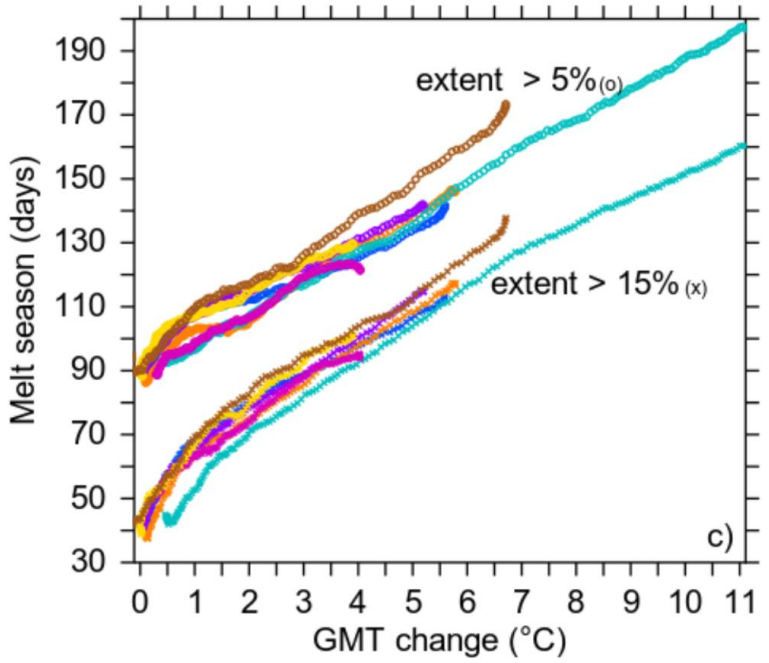
(Javed et al., 2026; Under Review)

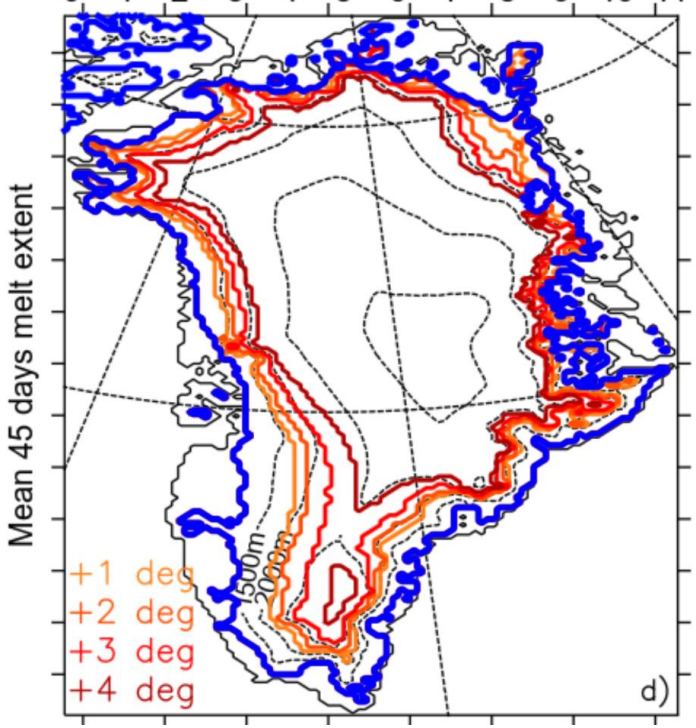
Future meltwater production evolution according to the MARv3.12 model using the present day topography and forced by 7 Earth System Models using SSP5-8.5 scenario until 2100 (until 2200 for the simulation forced by IPSL-CM6-LR).

From Xavier Fettweis in Hanna et al. in review.









A few relevant references

*Gregory, J.M., S.E. George, R.S. Smith (2020) Large and irreversible future decline of the Greenland ice-sheet. *The Cryosphere* 14, 4299-4322.

*Hanna, E. et al. (2021) Greenland surface air temperature changes from 1981 to 2019 and implications for ice-sheet melt and mass-balance change. *Int. J. Climatol.* 41 (S1), E1336-E1352]

*Hanna, E. et al. (2024) Short- and long-term variability of the Antarctic & Greenland ice sheets. *Nature Reviews Earth & Environment* 5, 193-210, https://rdcu.be/dx8WI

*Hanna, E. et al. (2025) *Status Brief: Current understanding of global sea-level rise.* WCRP CliC/WMO, Status Brief C_TRN_3_9a_TRN_again.pdf

*Hanna, E. et al. (2026) Past, present and future Greenland Ice Sheet surface melt, 1500-2200 CE. *Nature Reviews Earth & Environment*, in press.

*IPCC AR6 WG1 (2021) Chapter 2 Section 2.3.2.4, pages 346-348 (Ice sheet mass and extent), Chapter 3 Section 3.4.3.2 pp. 472-473 (Ice sheets), Chapter 9 Section 9.4 pages 1254-1273 (Ice sheets).

*Otosaka, I.N. et al. (2023) Mass balance of the Greenland and Antarctic ice sheets from 1992 to 2020. *Earth System Science Data* 15, 1597-1616.