Estimating Greenland ice sheet surface mass balance contribution to future sea level rise using the regional climate model MAR

X. Fettweis[1], H. Gallée[2], M. van den Broeke[3], M. Tedesco[4], J. van Angelen[3], J. Lenaerts[3], and M. Erpicum[1]

1 University of Liège, Belgium
2 LGGE, Grenoble, France
3 IMAU, Utrecht, The Netherlands
4 City College of New-York, USA

Vienna, 10.04.2013

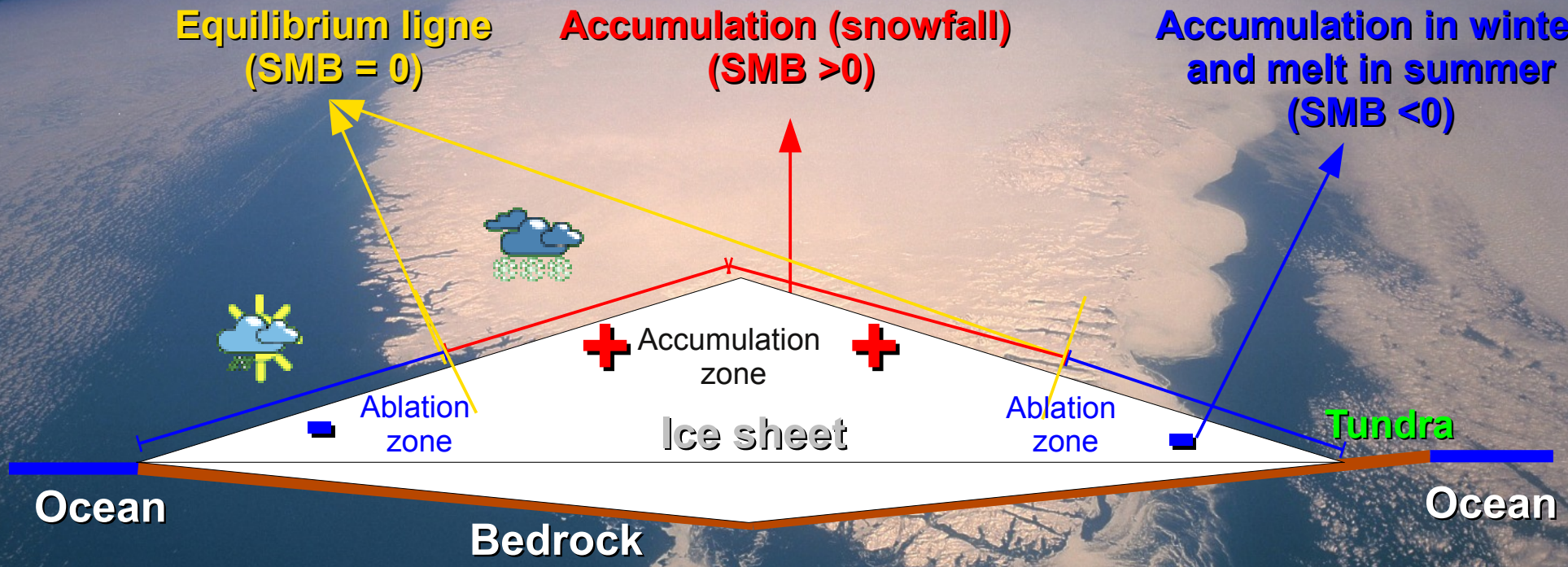
Plan

1. Introduction
2. Current climate
3. Future climate
4. Feedback elevation ?
5. Atmospheric Circulation change ?

Reference:
Fettweis, X., Franco, B., Tedesco, M., van Angelen, J. H., Lenaerts, J. T. M., van den Broeke, M. R., and Gallée, H.: Estimating the Greenland ice sheet surface mass balance contribution to future sea level rise using the regional atmospheric climate model MAR, *The Cryosphere*, 7, 469-489, doi:10.5194/tc-7-469-2013, 2013.

1. Introduction

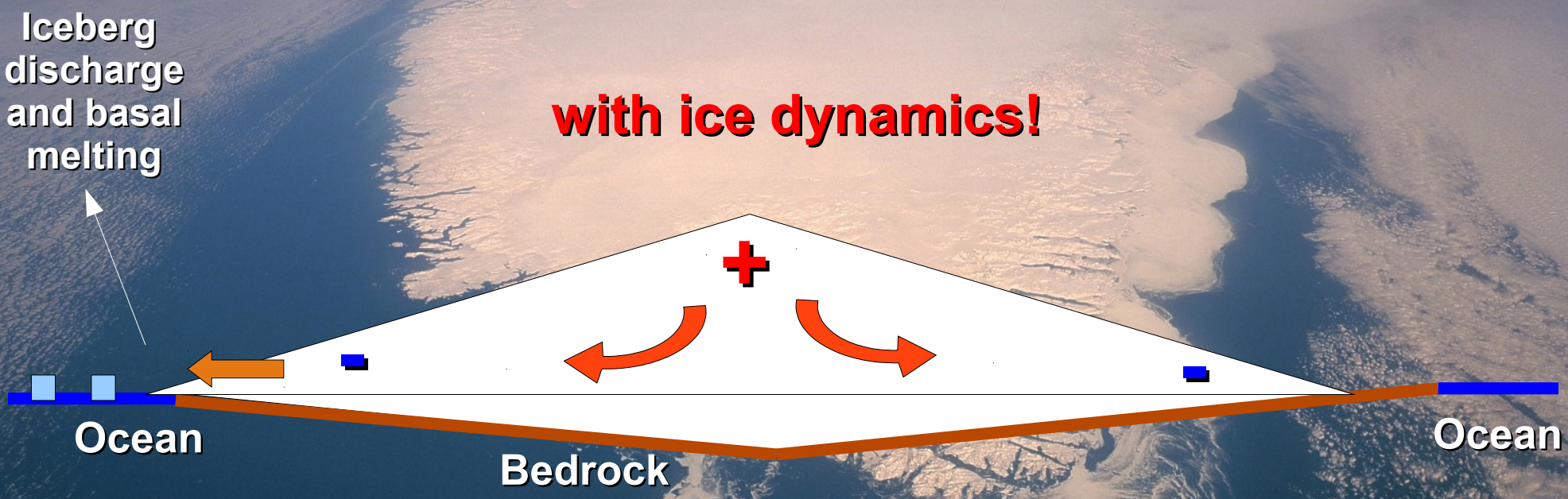
Surface Mass Balance (SMB) ~ accumulation – meltwater run-off



1. Introduction

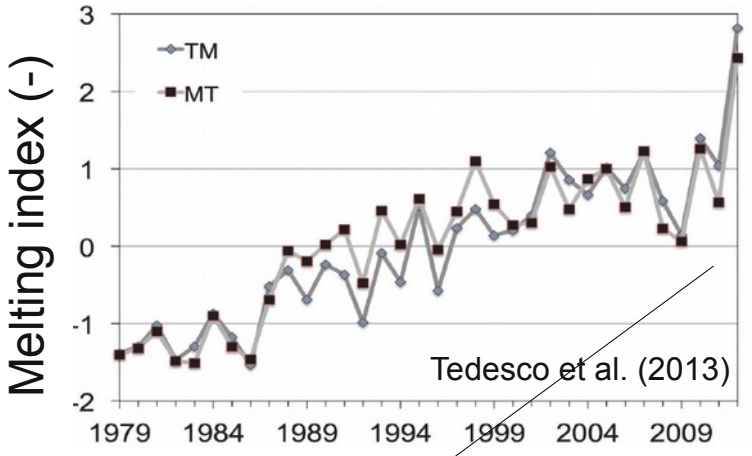
Ice sheet Mass Balance (IMB) ≃ accumulation – runoff – iceberg calving

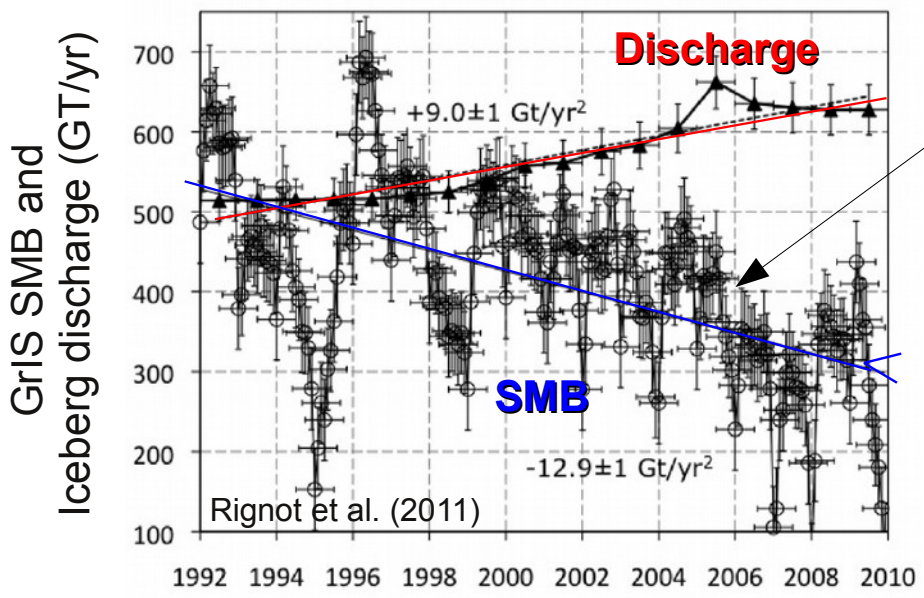
IMB ~ 0 until the 90s !



1. Introduction

Since the 90s, **Discharge ↗** **SMB ↘** ➡ **IMB < 0 !** **SLR > 0 !**





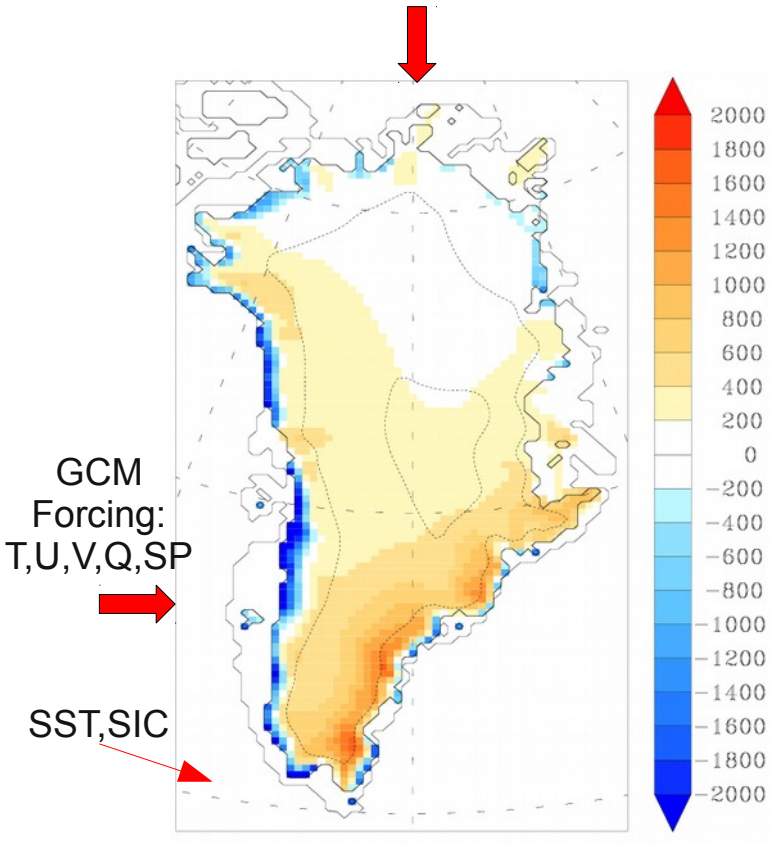
360 GT ~ 1 mm sea level equivalent

Future projections of SMB ?

The current highest mass loss rates are observed over the Greenland ice sheet (GrIS) !

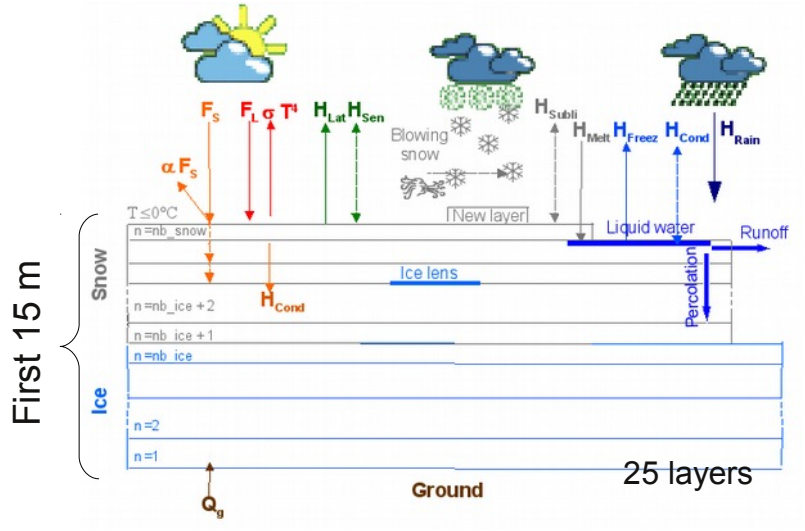
1. Introduction: MAR

Laboratoire de Glaciologie et Géophysique de l'Environnement
Hubert Gallée



1980-1999 annual SMB (mmWE/yr)
at a resolution of 25 x 25 km

Regional climate model **MAR** full coupled with a snow energy balance model



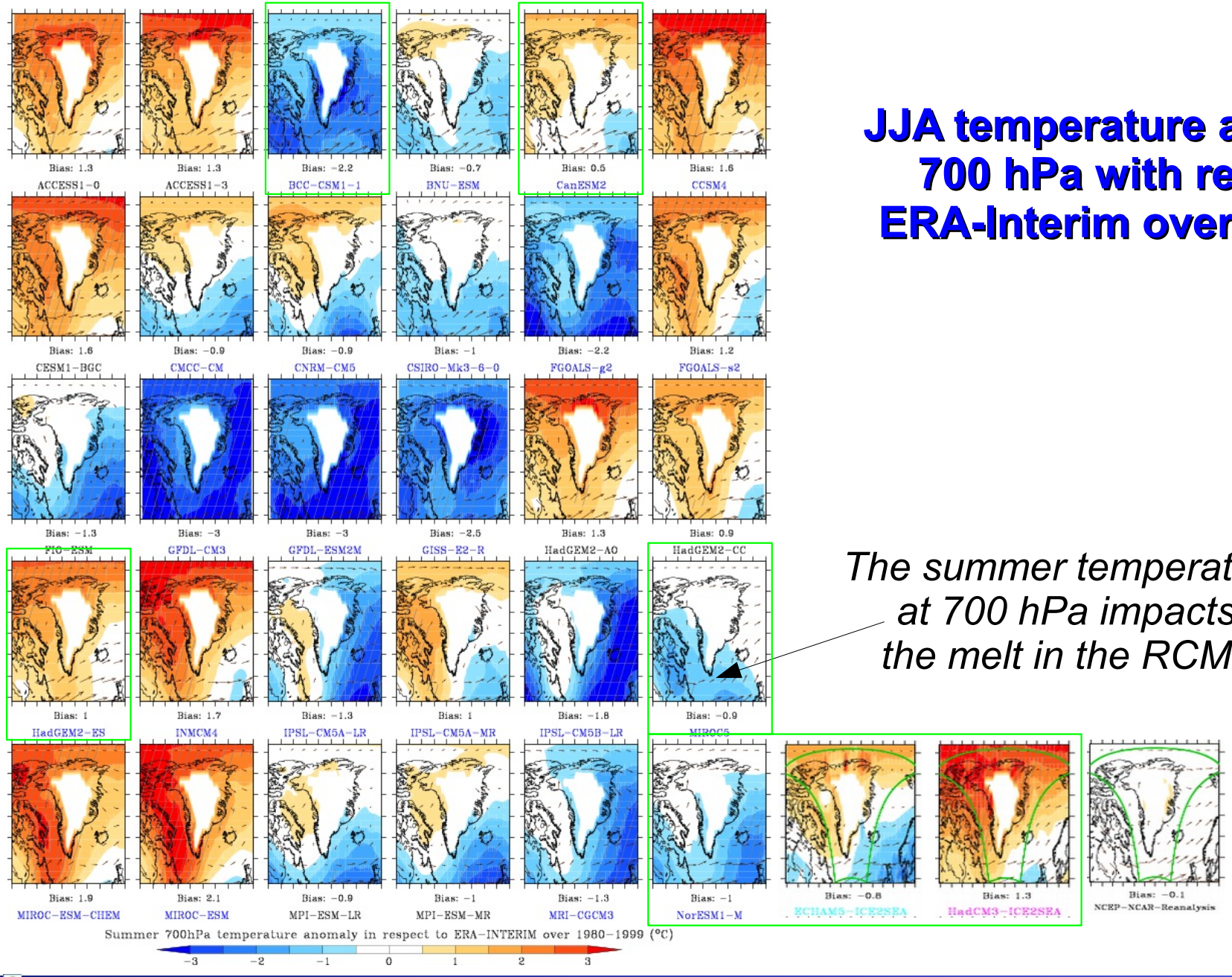
Validation

SMB: Tedesco et al. (2011), Franco et al. (2012), Rae et al. (2012), Vernon et al. (2013)
Temperature: Lefebre et al. (2005), Tedesco et al. (2012), Box et al. (2012),...
solar radiation: Box et al. (2012)
melt extent: Fettweis et al. (2006, 2007, 2011)
Albedo: Lefebre et al. (2003), Fettweis et al. (2005)

- MAR focuses only on the Surface Mass Balance (**SMB**) because it is not coupled with an ice sheet model (the topo is fixed)!
- MAR needs forcing from a GCM at its lateral boundaries + SST + sea ice.

RCM = regional climate model , **GCM** = general circulation model

2. Current climate: GCM (1/3)



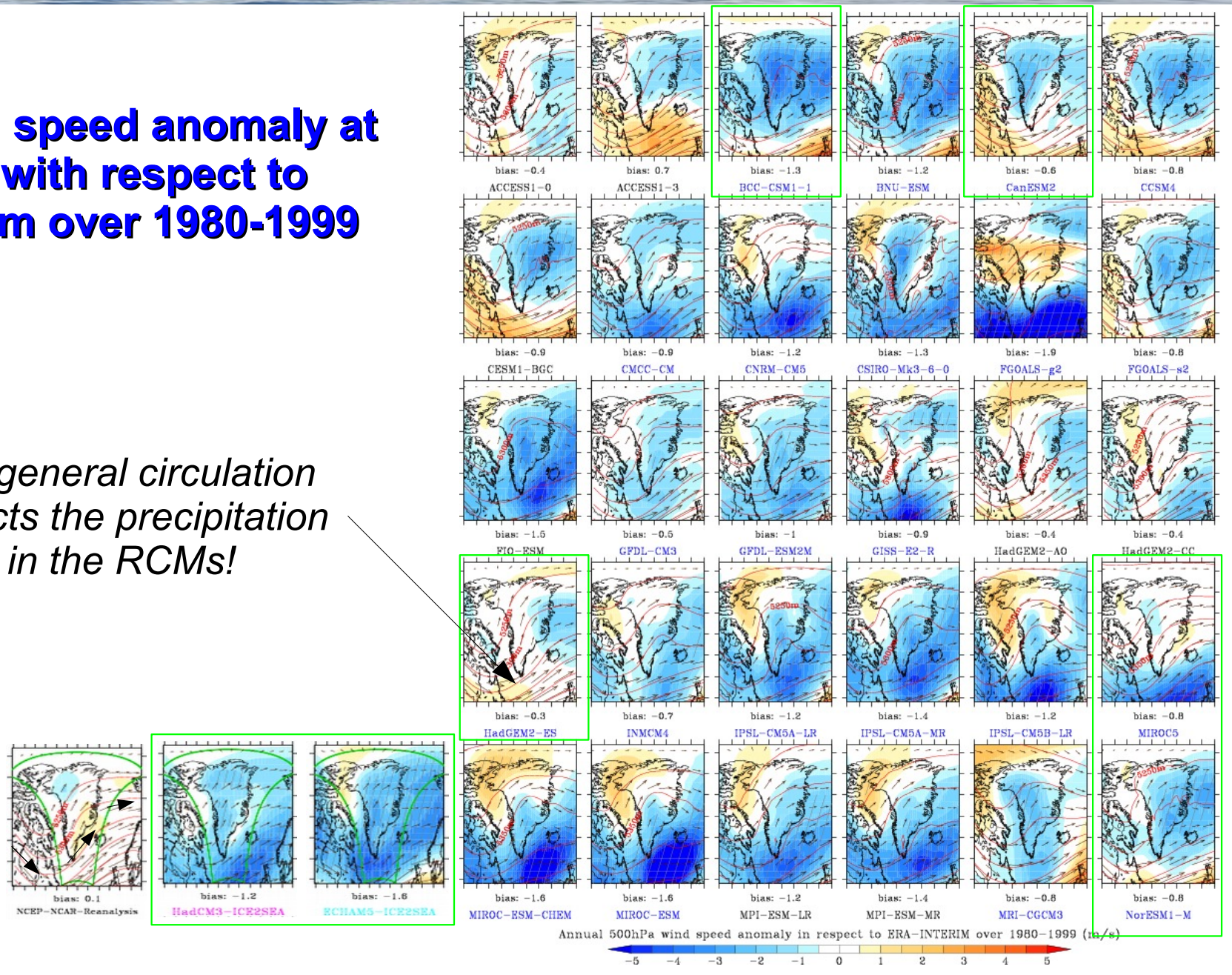
JJA temperature anomaly at 700 hPa with respect to ERA-Interim over 1980-1999

The summer temperature at 700 hPa impacts the melt in the RCMs!

2. Current climate: GCM (2/3)

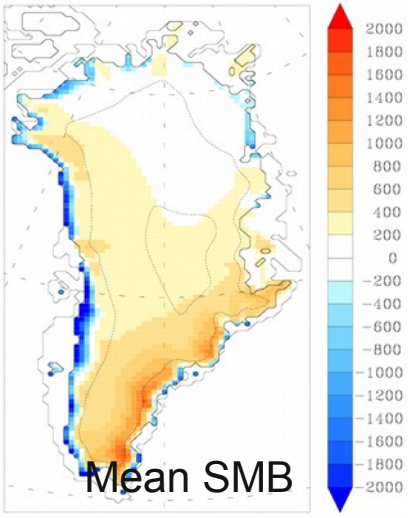
Annual wind speed anomaly at 500 hPa with respect to ERA-Interim over 1980-1999

The general circulation impacts the precipitation in the RCMs!

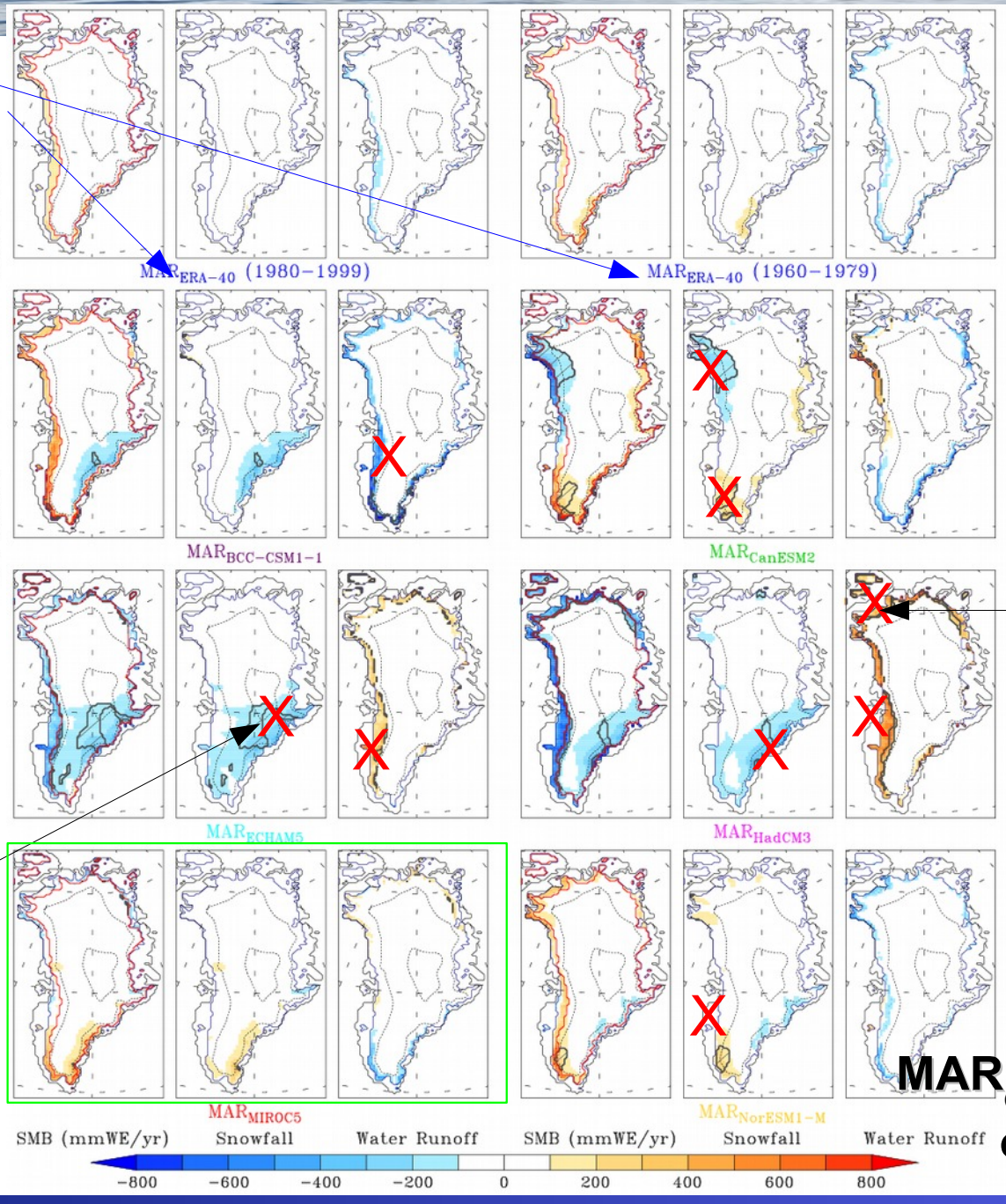


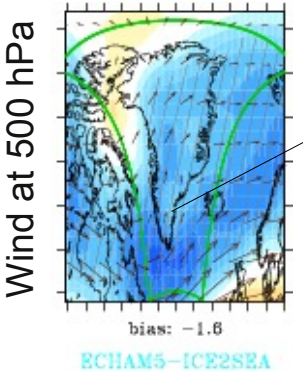
3. Current climate: MAR (3/3)

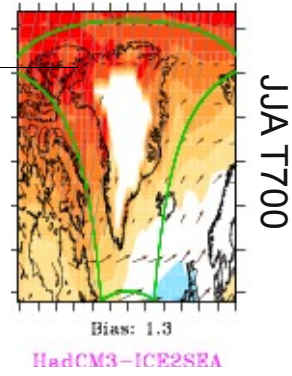
Independence of the reference period



$MAR_{ERA\text{-}INTERIM}$ over 1980-1999 (mmWE/yr)

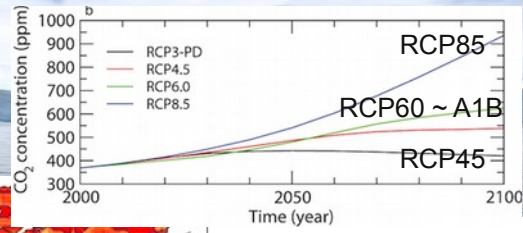






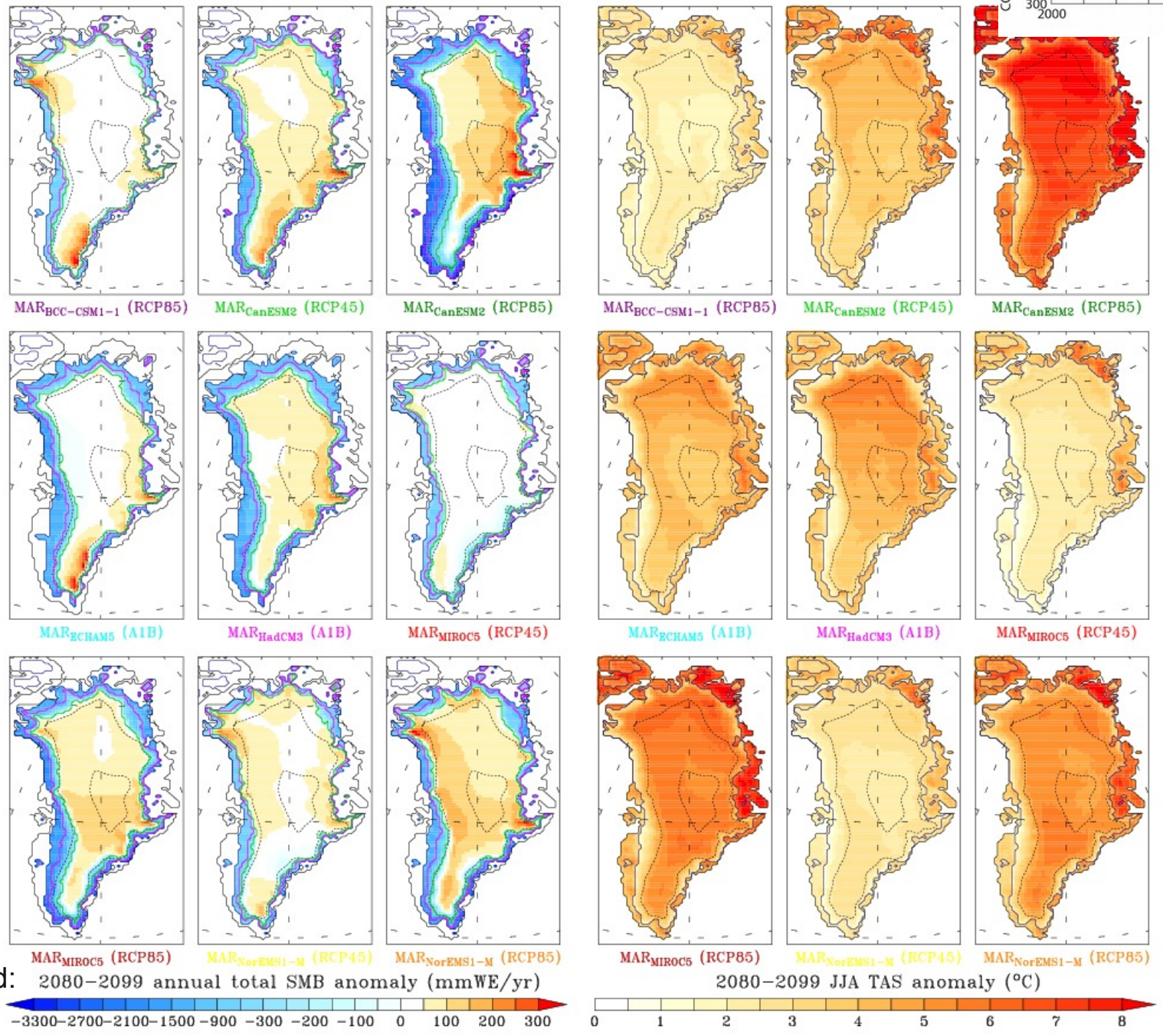
MAR_{GCM} vs $MAR_{ERA\text{-}INTERIM}$ over 1980-1999

3. Future climate (1/5)



2080-2099 annual SMB anomaly (mmWE/yr)

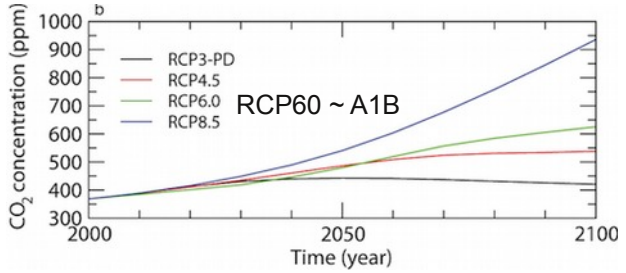
2080-2099 JJA near-surface temperature anomaly (°C)



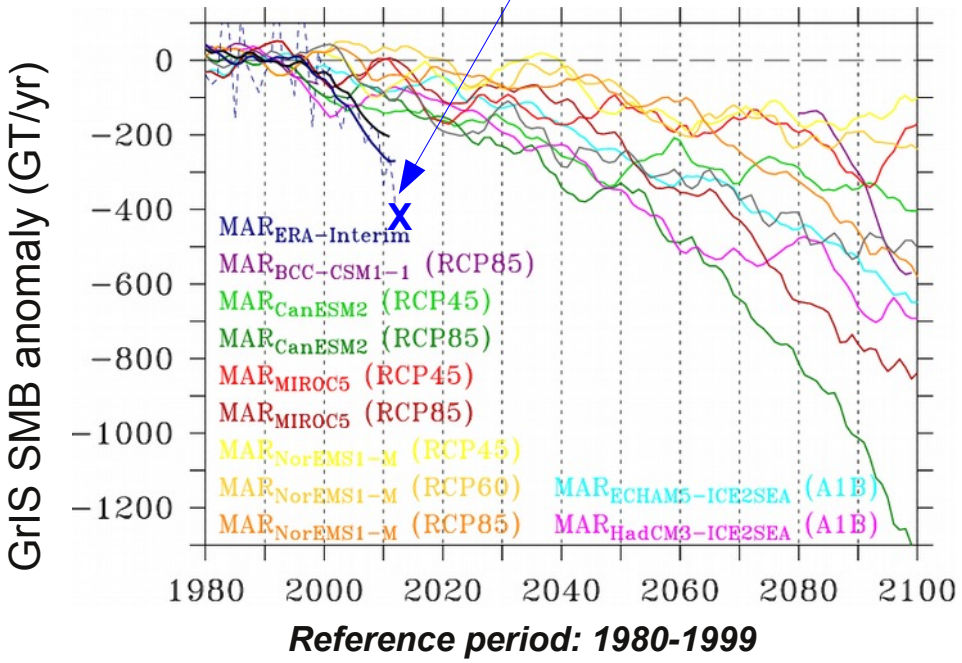
Reference period: 1980-1999

3. Future climate (2/5)

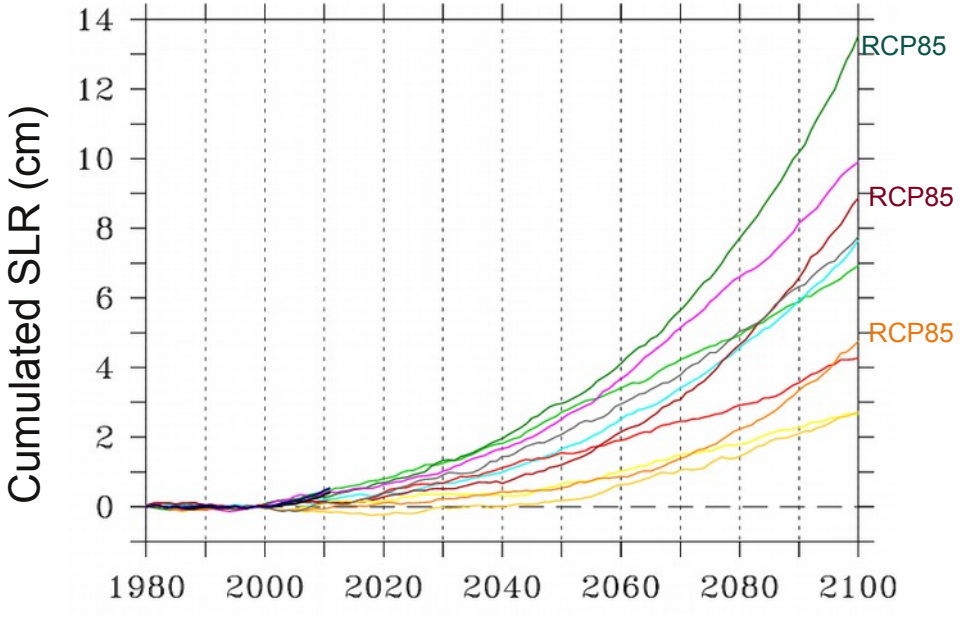
GrIS SMB time series and corresponding SLR



SMB ~ 0 GT/yr in 2012



Reference period: 1980-1999



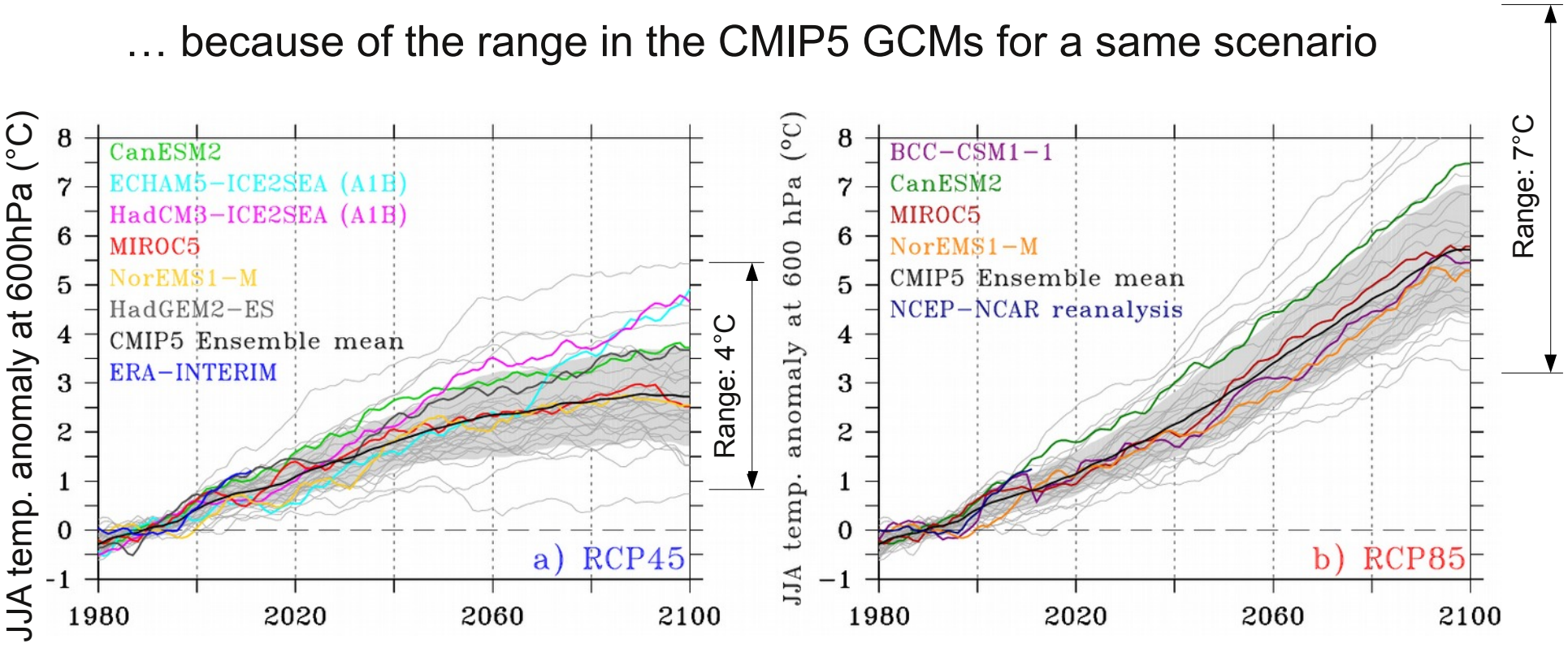
- 361 GT/yr ~ + 1 mm SLR/yr

1. Why do these simulations fail to simulate the current SMB decrease ?
2. Why is the range for a same scenario so wide ?

3. Future climate (3/5)

Why are the MAR-based future projections so diverging ?

… because of the range in the CMIP5 GCMs for a same scenario

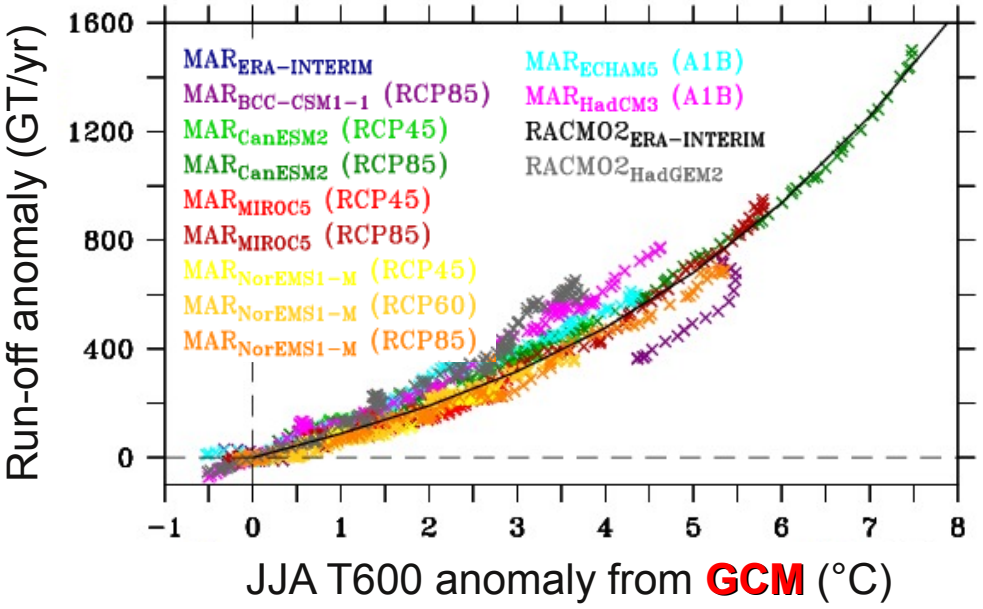


The JJA temperature at 600 hPa above Greenland drives the surface melt variability.

Scatter plots of SMB vs temperature changes.

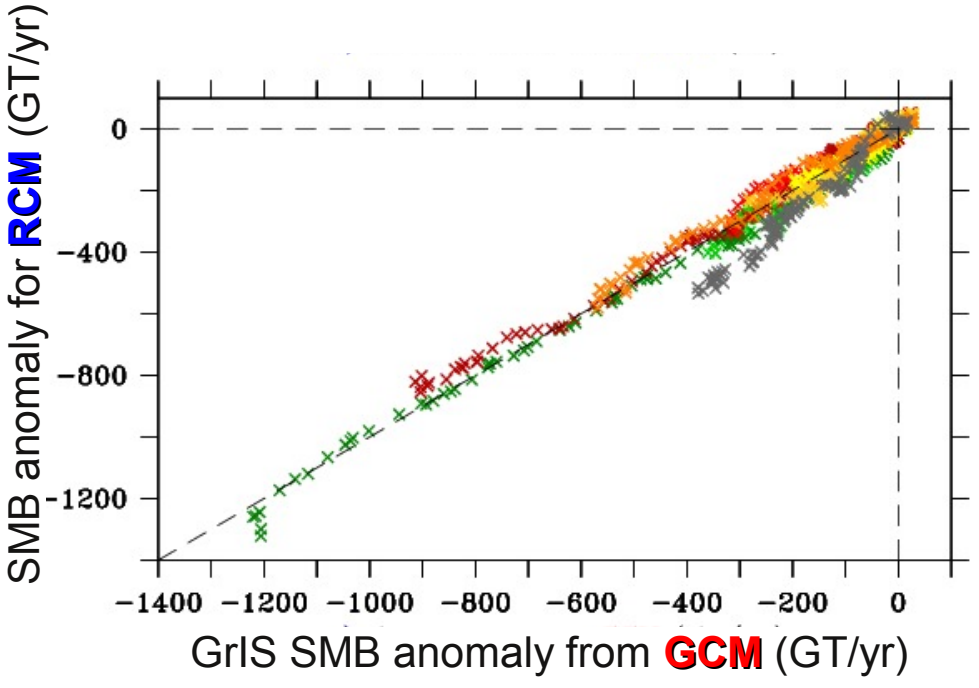
3. Future climate (4/5)

Run-off vs Temperature anomalies



1. Good consistence between the simulations because no circulation change is projected.

2. But depends on the ability to simulate the current melt.

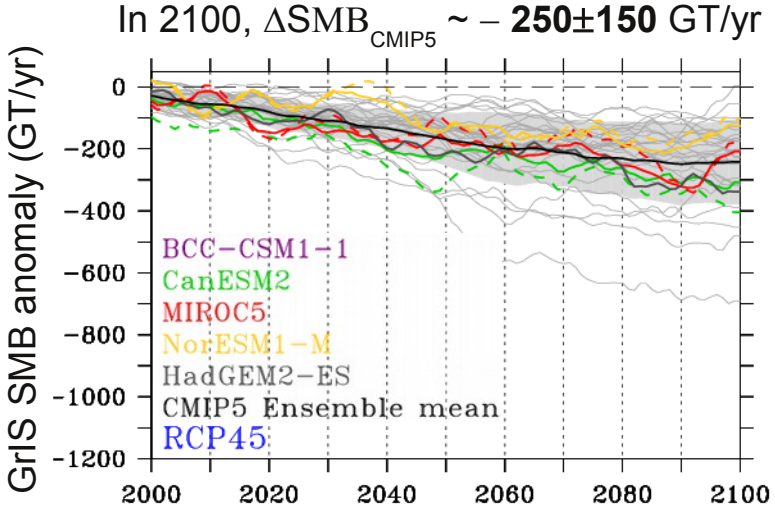


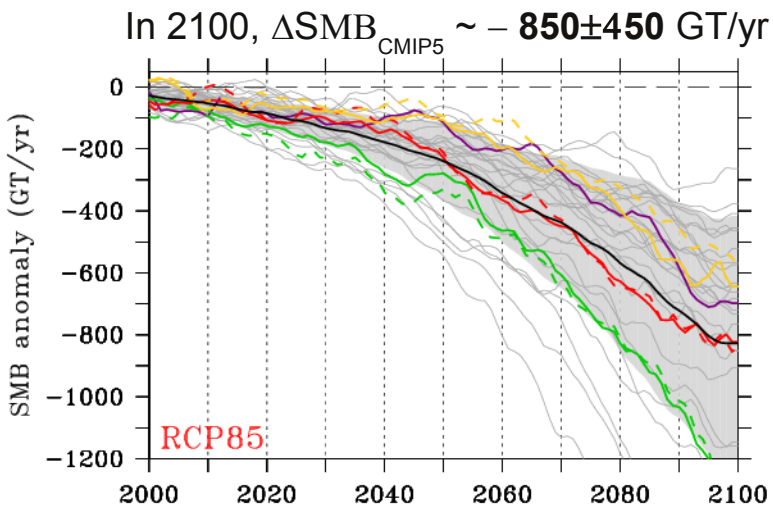
$$\Delta SMB_{CMIP5} \sim \Delta SF_{CMIP5} - \Delta RU(\Delta T600_{CMIP5})$$

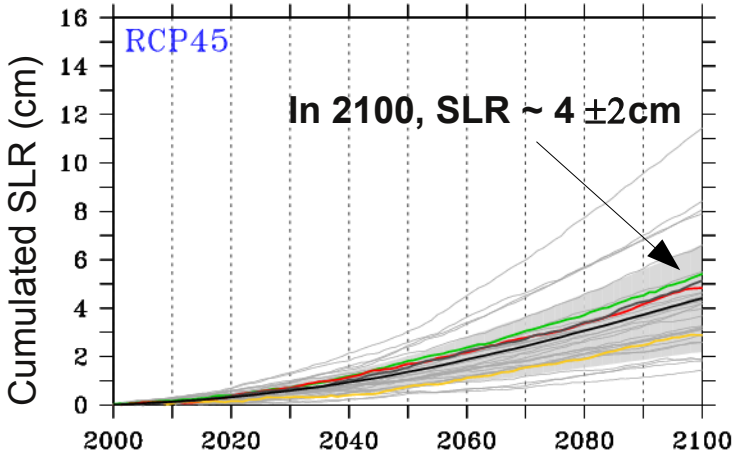
where ΔSF and ΔT600 are taken in the area 60°N-80°N, 60°W-20°W covering the Greenland ice sheet.

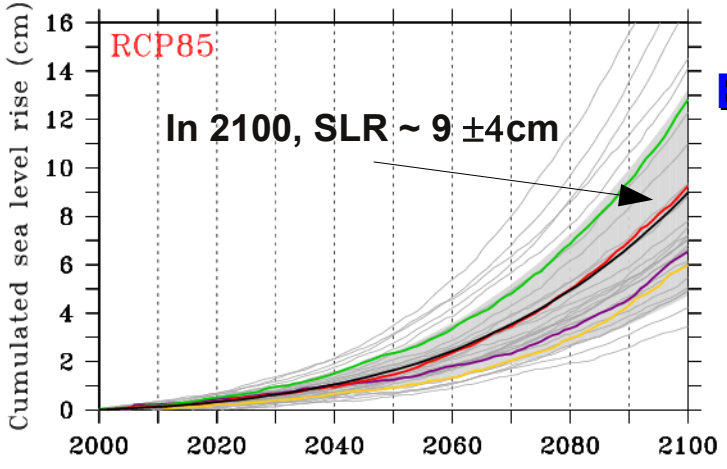
3. Future climate (5/5)

Uncertainties in our future projections









Uncertainties:

GCMs ~ 50 %

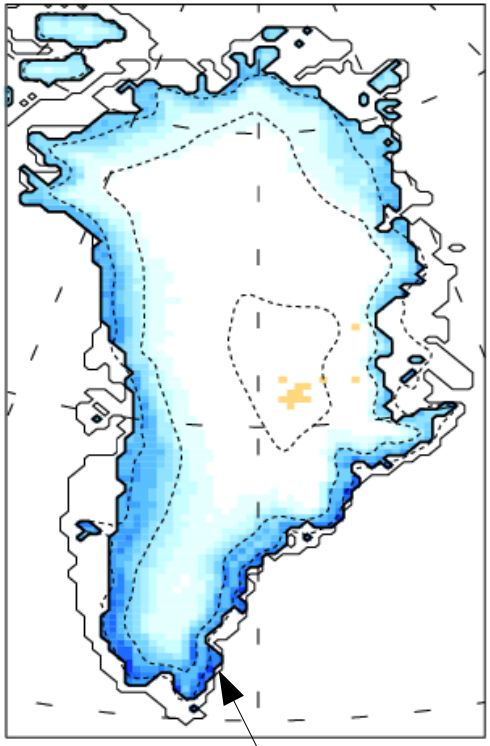
MAR ~ 10%
(Vernon et al., TC, 2013)

Elev. feedback ~ - 10 %

GrIS SMB anomaly and SLR from all CMIP5 models

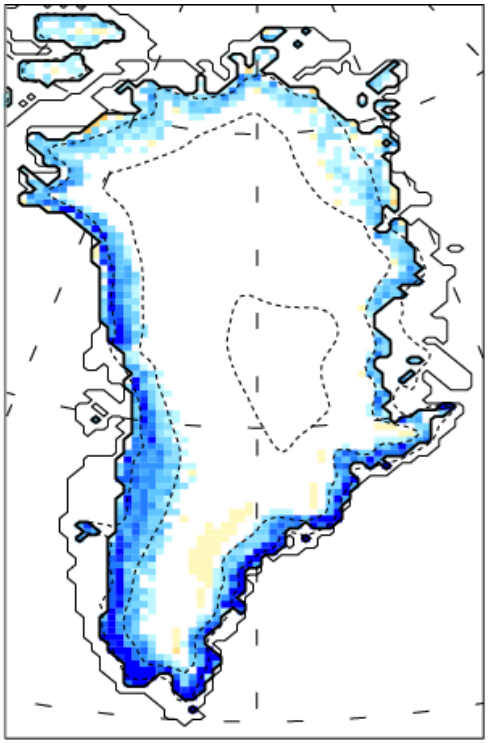
4. Elevation feedback ? (1/2)

SMB changes over 2080-2099 using a perturbed topography

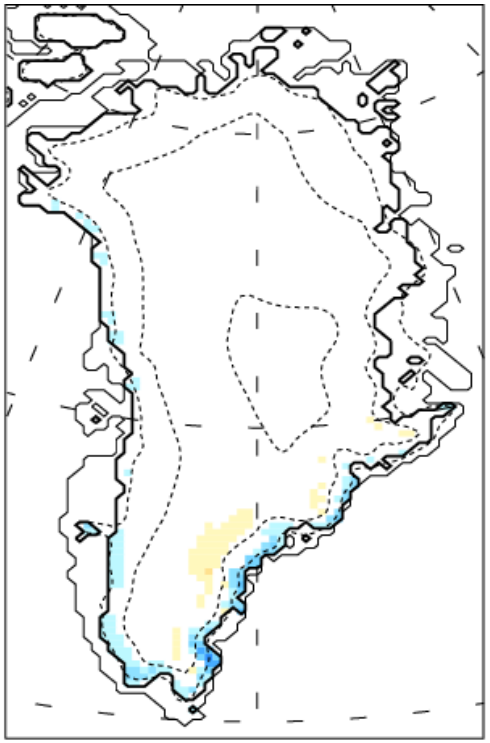


Topography changes (m)

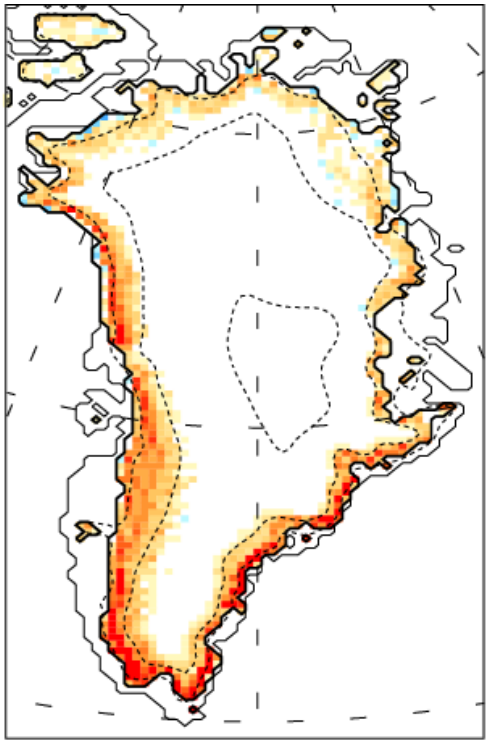
−100 −80 −60 −40 −20 0 20



SMB anomaly (mmWE/yr)



Snowfall anomaly



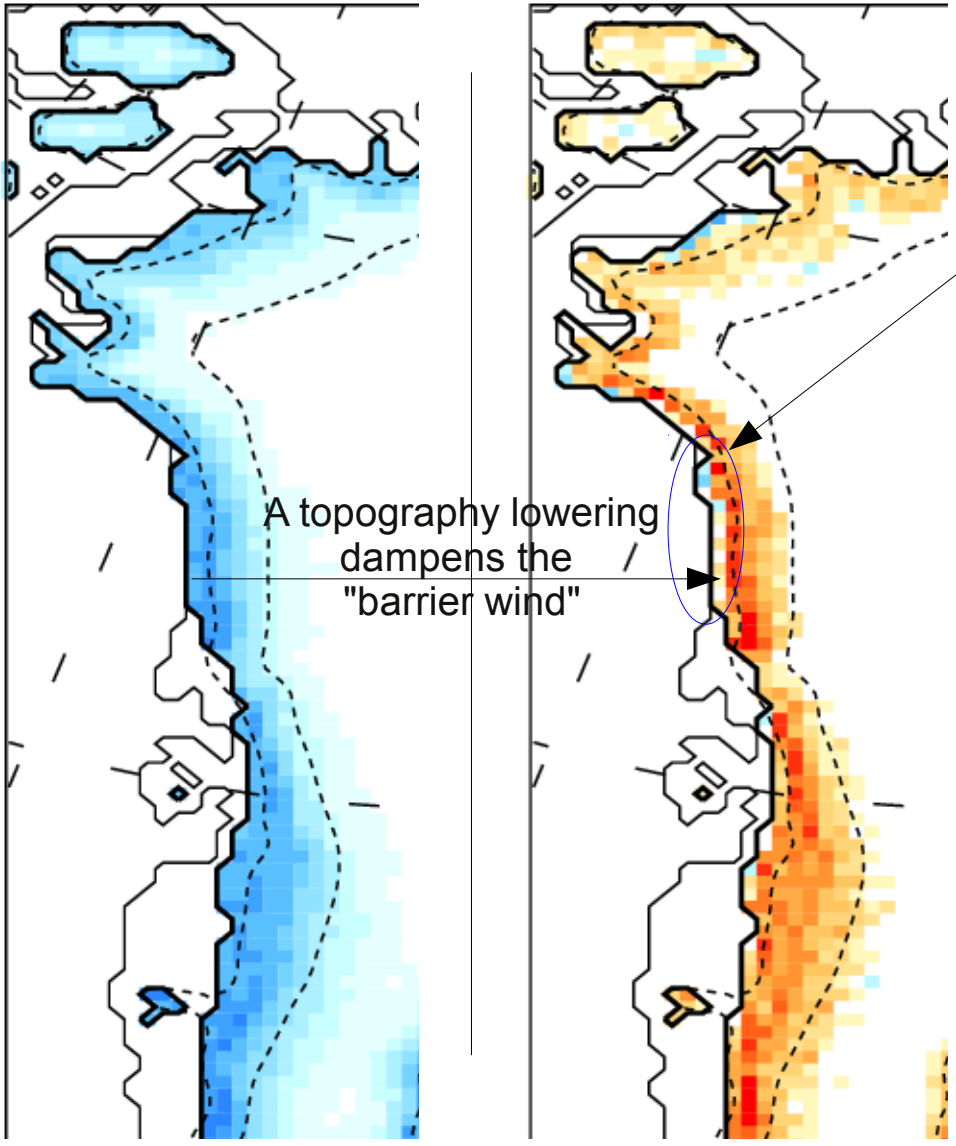
Run-off anomaly

−200 −160 −120 −80 −40 0 40 80 120 160 200

Topography changes equivalent to the cumulated surface height anomaly from 2000 to 2080 simulated by MAR forced by MIROC5 (RCP85)

With elevation feedback
ΔSMB – 5-15 %

4. Elevation feedback ? (2/2)



Topo anomaly

Run-off anomaly

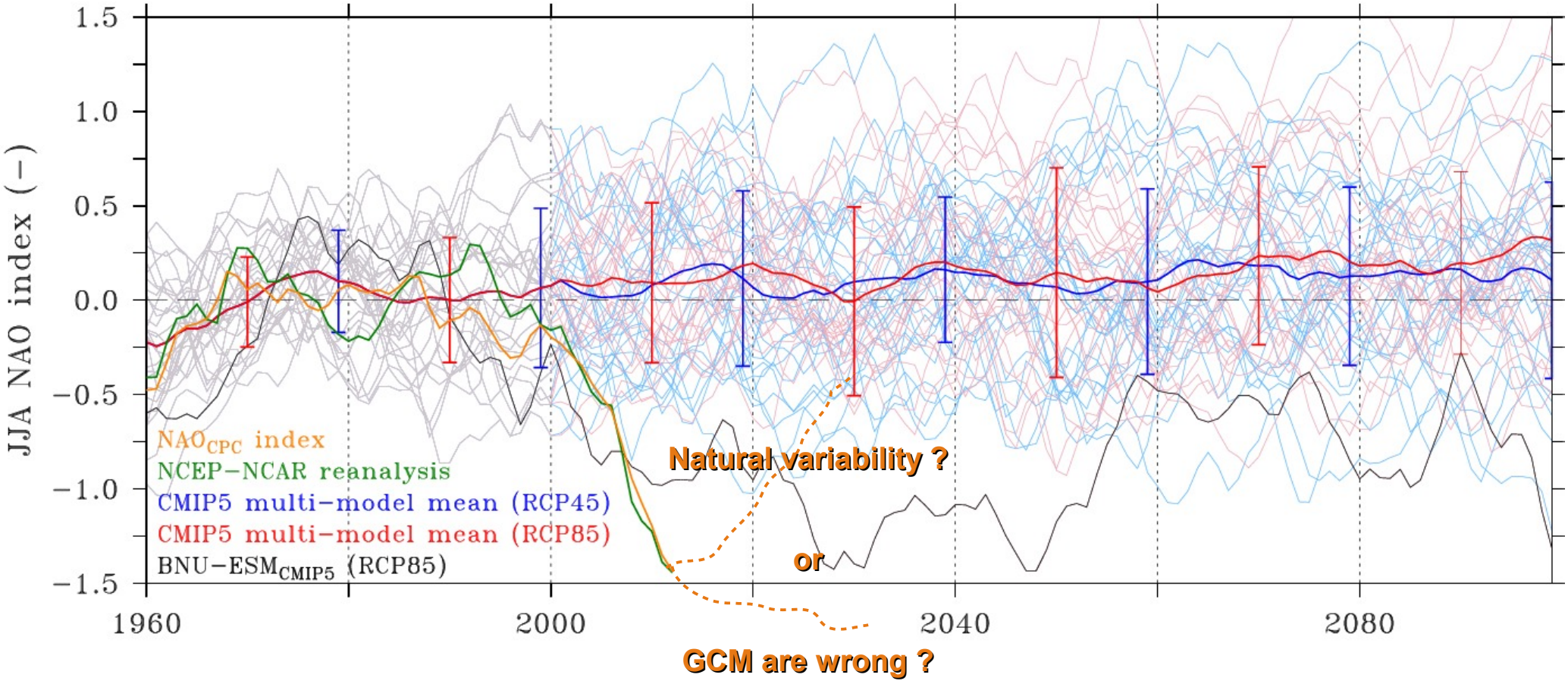
Run-off decrease !!

Δ SMB vs Δ Topo
is highly non-linear !!

A coupling with an
ice sheet model is needed.

5. Circulation changes ? (1/3)

Why don't our projections simulate the 2000's melt acceleration ?



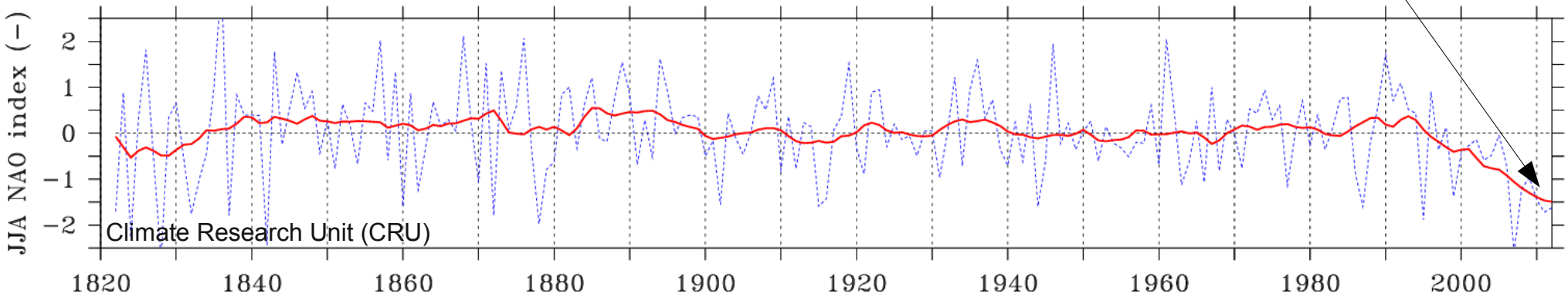
The CMIP5 GSMs do not project changes in the general circulation/NAO!

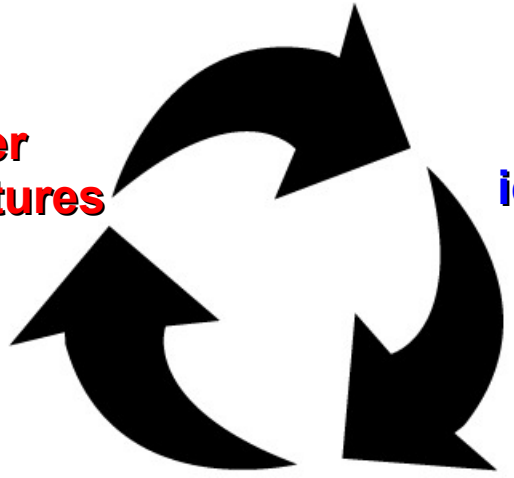
Reference: Fettweis, X., Hanna, E., Lang, C., Belleflamme, A., Erpicum, M., and Gallée, H.: Brief communication "Important role of the mid-tropospheric atmospheric circulation in the recent surface melt increase over the Greenland ice sheet", *The Cryosphere*, 7, 241-248, 2013.

More derails: see Poster CR3.2-B577 on Thursday (17h30-19h)

5. Circulation changes ? (2/3)

The probability of such a succession is quasi null!





higher temperatures

higher SST
lower sea ice cover (SIC)

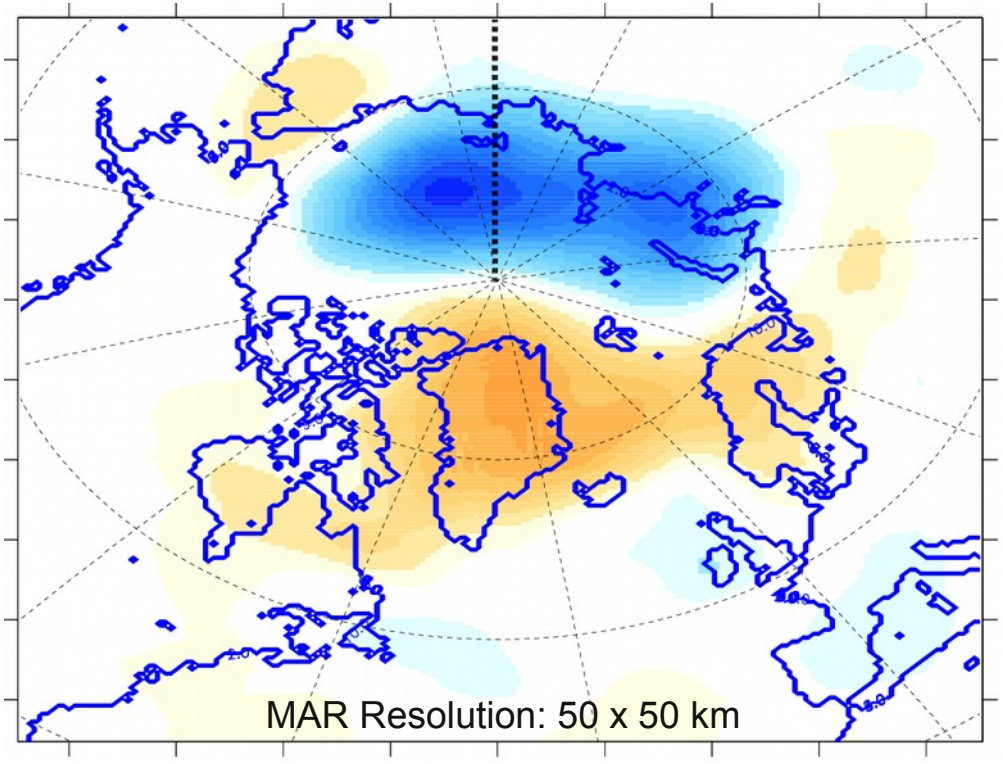
circulation change (NAO < 0)

What about this positive feedback ?

Pan (2005): Observed positive feedback between the NAO and the North Atlantic SSTA tripole, GRL.
Strong et al. (2009): Observed Feedback between Winter Sea Ice and the North Atlantic Oscillation, J. Climate.

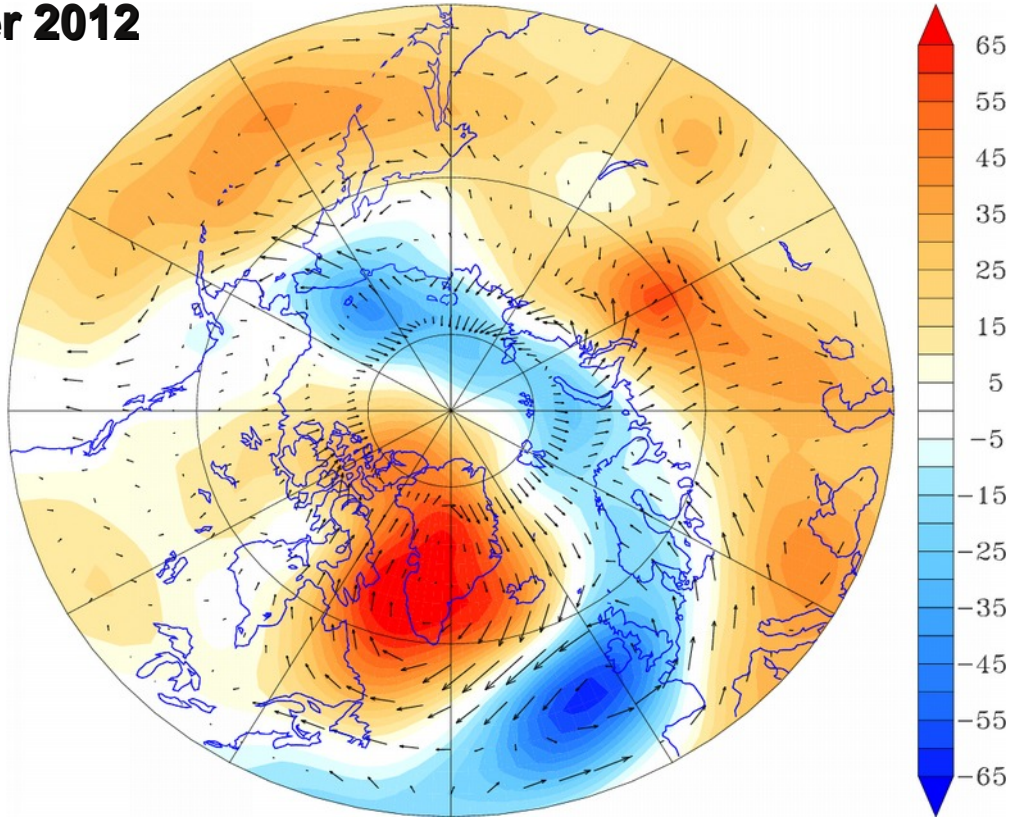
5. Circulation changes ? (3/3)

MAR seems to suggest that this SST-NAO feedback played a role over last summer!



Geopotential height (Z500) anomaly at 500 hPa simulated by MAR with respect to a MAR sensitivity experiment using the 1980-1999 averaged SST/SIC.

Summer 2012



Summer 2012 Z500 anomaly with respect to 1980-1999.

Conclusions:

- Large range in the SMB future projections due mainly to CMIP5-based uncertainties. In 2100, SLR from GrIS SMB: 2-20cm!!
- Importance of well simulating the current climate.
- The elevation feedback needs to be taken into account explicitly because it is not a positive feedback along the ice sheet margin !
- The current climate changes over Greenland are underestimated by the GCMs.

Next steps:

- Coupling MAR with ice sheet models (VUB, LGGE?, NASA-JPJ?) by using future scenario from MIROC5 for estimating ice sheet mass balance changes.
- More research is needed about the NAO-SST feedback.

Thanks !