A regional atmospheric warming threshold for irreversible Greenland ice sheet mass loss

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main points

- When ice sheet retreats on land, SMB < 0 is required for continued mass loss
- Using RACMO2, we find that a **regional warming** of 4.5 °C is required to reach this threshold for the current GrIS geometry
- This regional warming threshold is translated to a global threshold using the CMIP5 / CMIP6 archives
- This conforms to **global warming** of 2.7 °C, which is reached in 2055 for rcp8.5 and never for rcp2.6
- Our methodology is conservative, as it ignores dynamical feedbacks

ice sheet mass balance

$$MB = SMB - D, \text{ with } D \geq 0$$

SMB = surface mass balance

D = discharge

stages of deglaciation

Stage 1. loss of ice shelves, grounding line retreat (D increasing, SMB > 0)

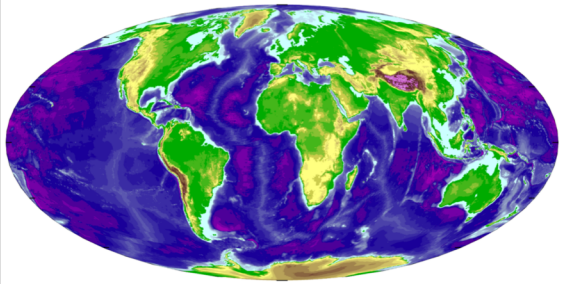
Stage 2. loss of ocean contact, retraction onto land (D decreasing, SMB > 0)

Stage 3. deglaciation by surface melt only (SMB < 0)

Here, we consider a warming threshold for which 5-year averaged **SMB = 0**, as a proxy for **Stage 3**.

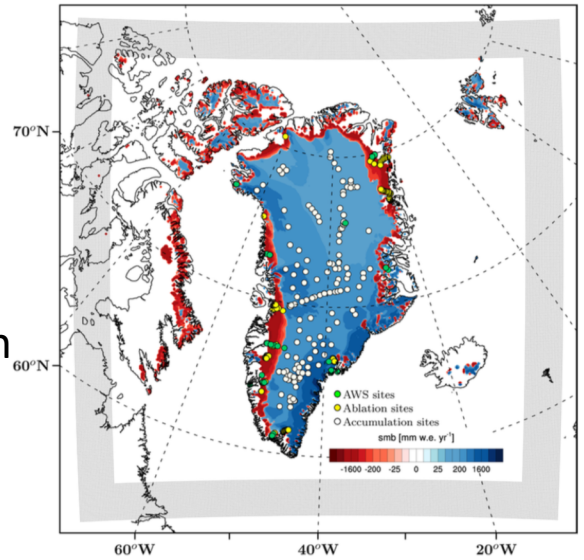
method

CESM2, rcp 8.5 scenario



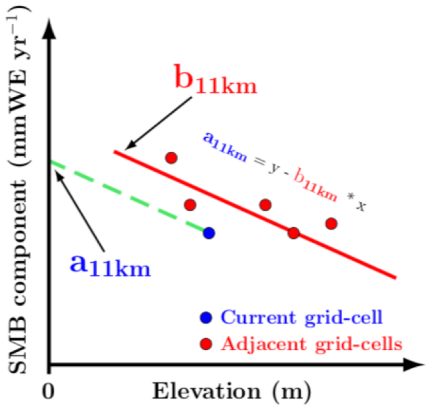
dyn. downscaling
no bias correction

RACMO 2.3p2 11 km



stat. downscaling

1 km SMB



regional warming threshold SMB = 0

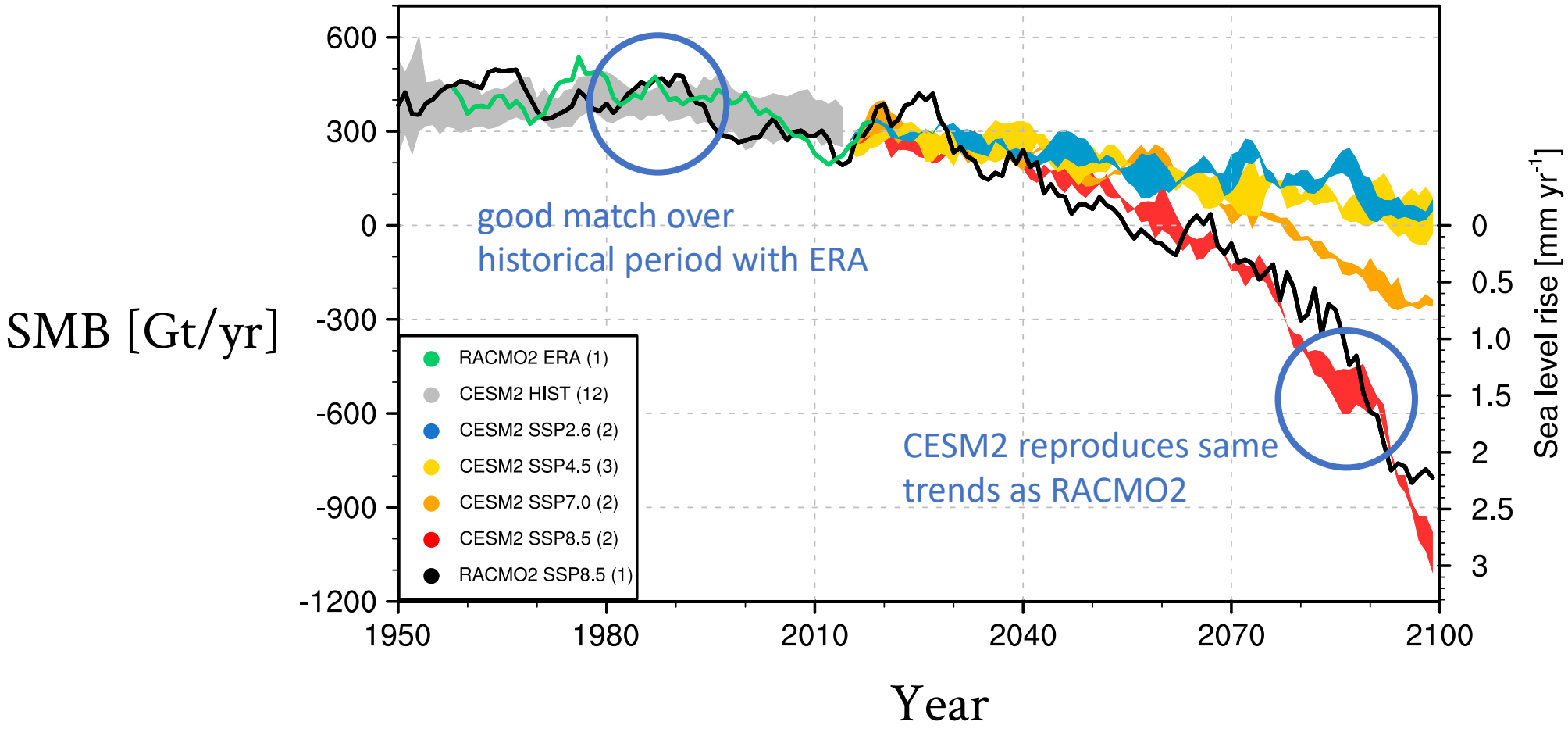
CMIP archive

global warming threshold SMB = 0

Earth figure by Plumbago - English Wikipedia, CC BY 2.5, https://commons.wikimedia.org/w/index.php?curid=3460093

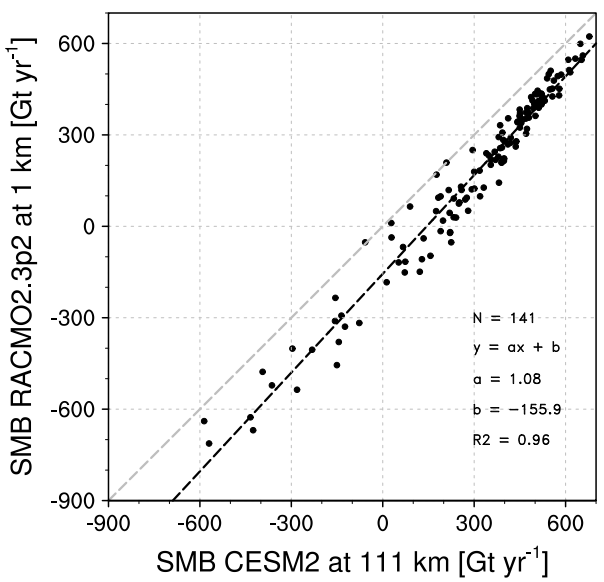
Black line = RACMO SMB
Colored = CESM SMB*

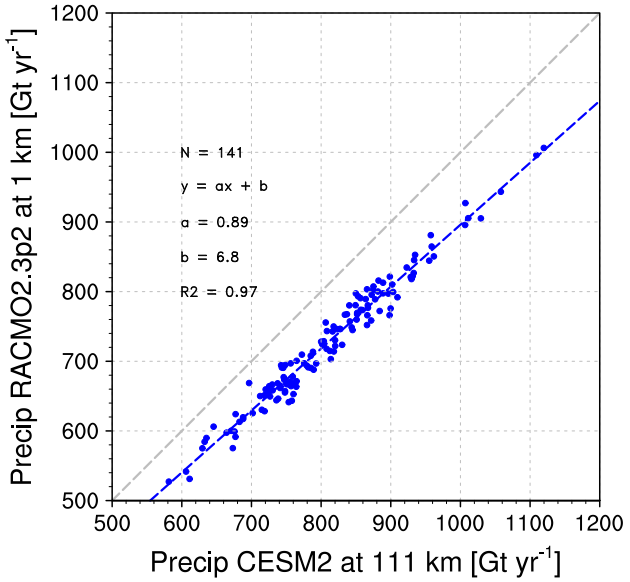
* = corrected as SMB = $PR_{corr} - RU_{corr} - SU_{corr}$

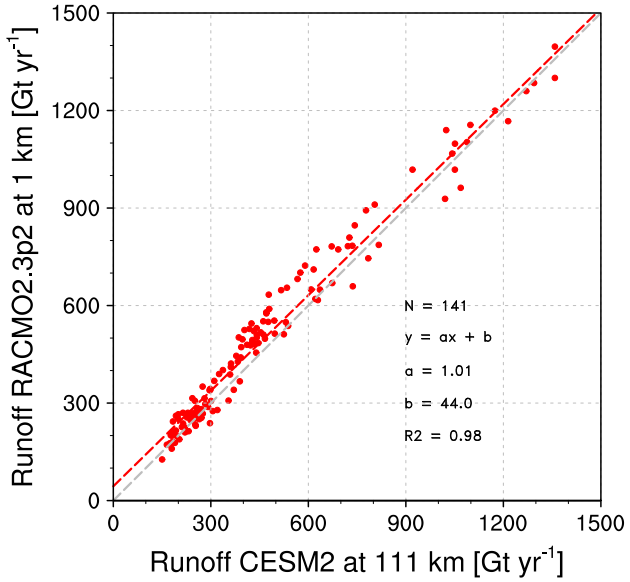


‘correction method’ for CESM SMB based on RACMO transient SSP5-85 run

- correction per SMB component
- largest correction in precip
- overall, good correlation between RACMO and CESM

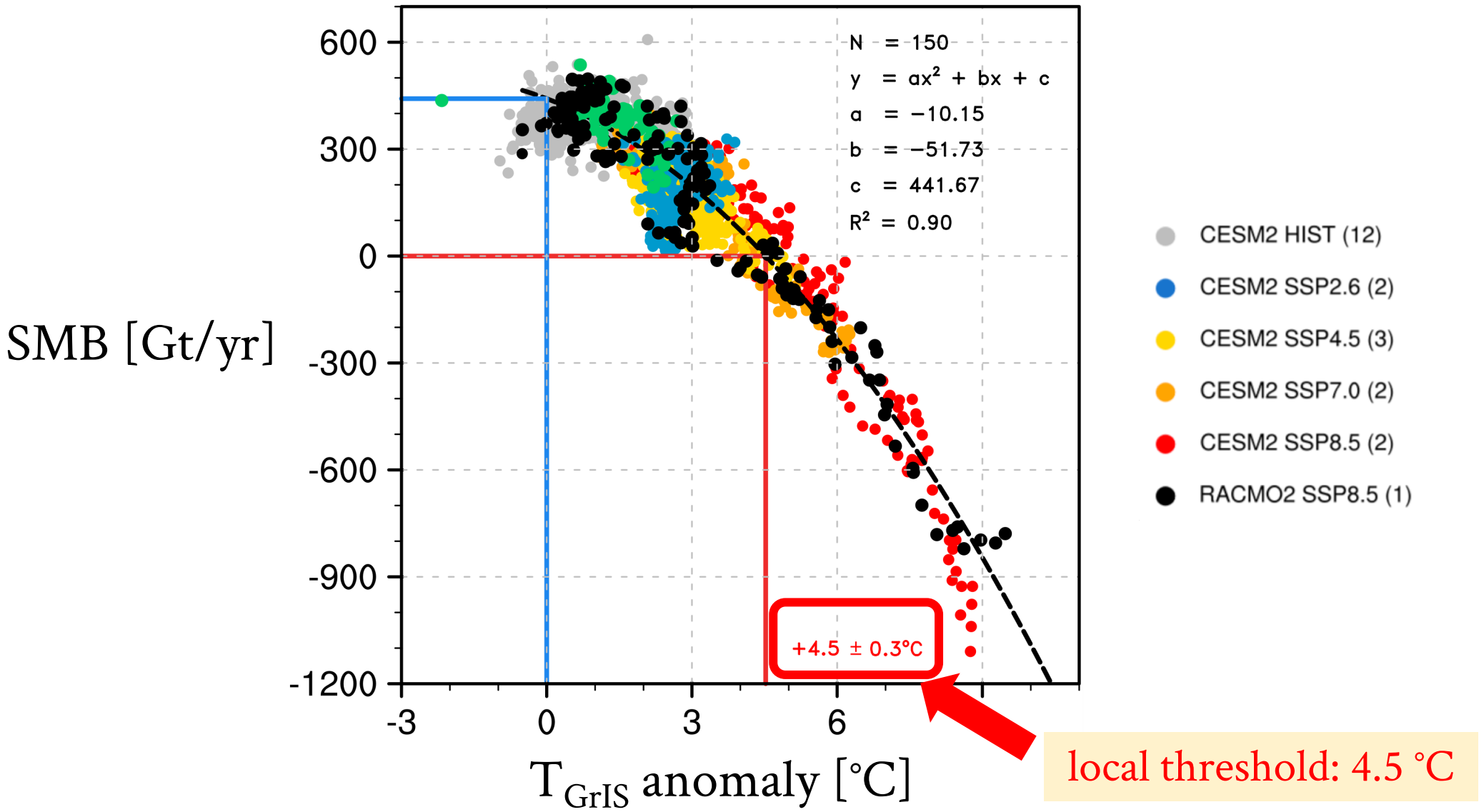






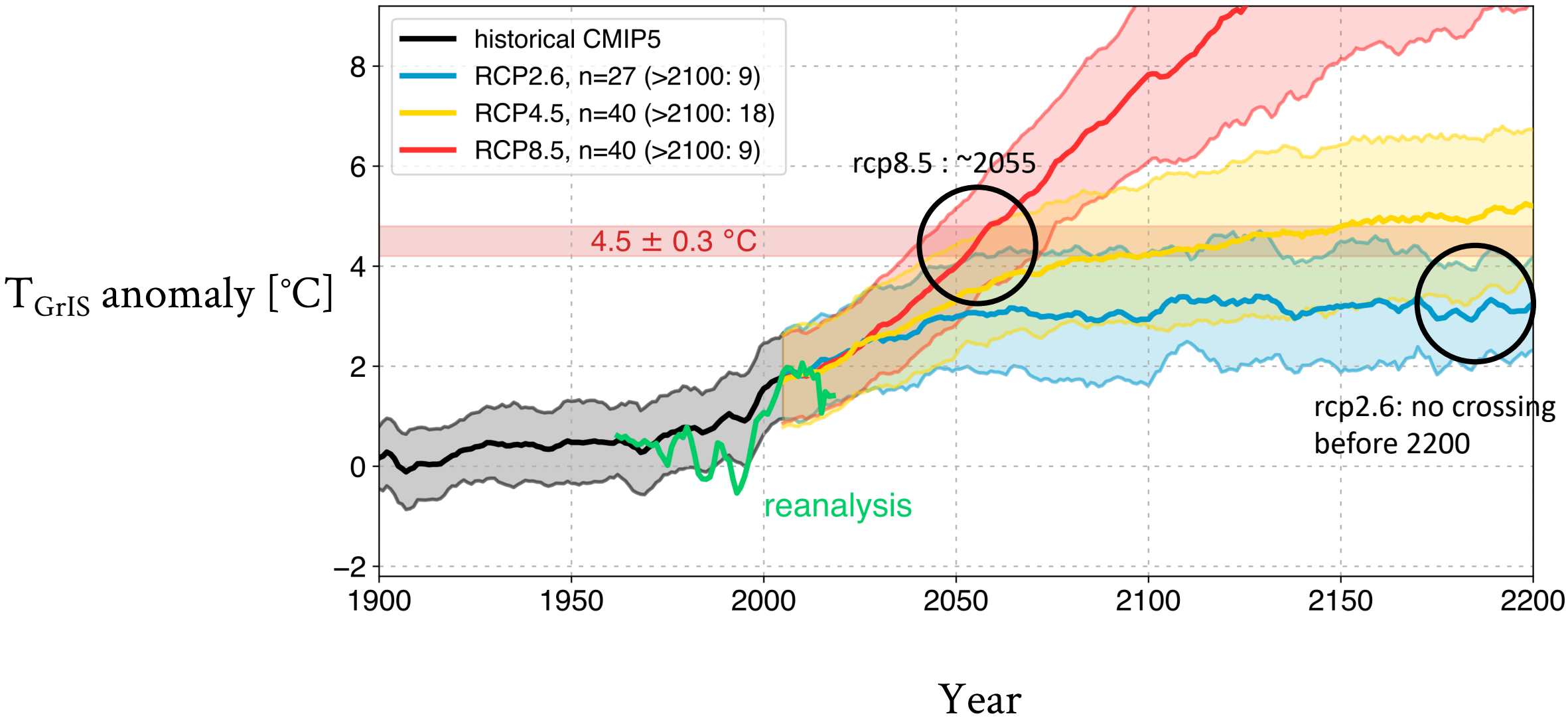
regression to local temperature

relative to 1850-1899

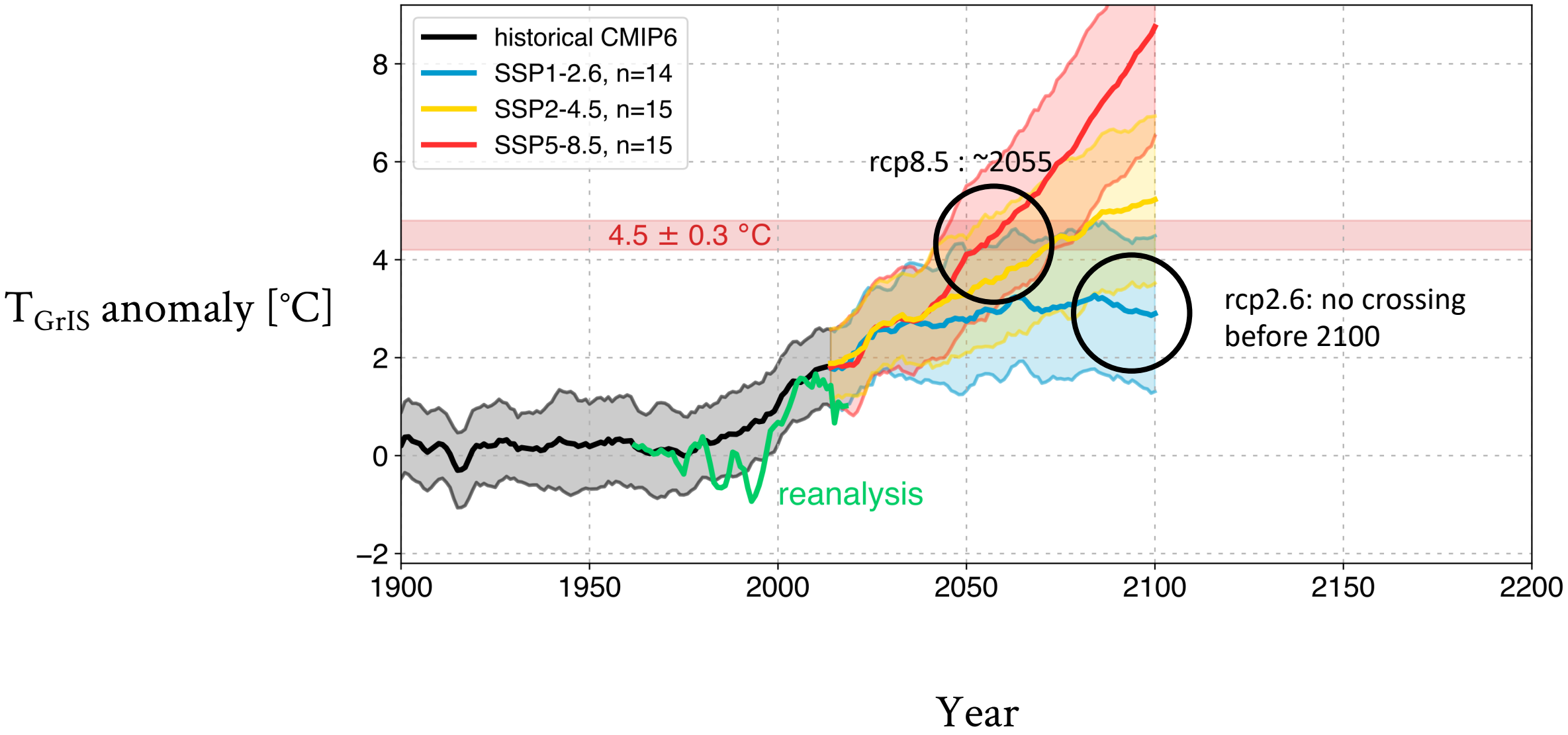


local threshold: 4.5 °C

SMB = 0 threshold timing, CMIP5

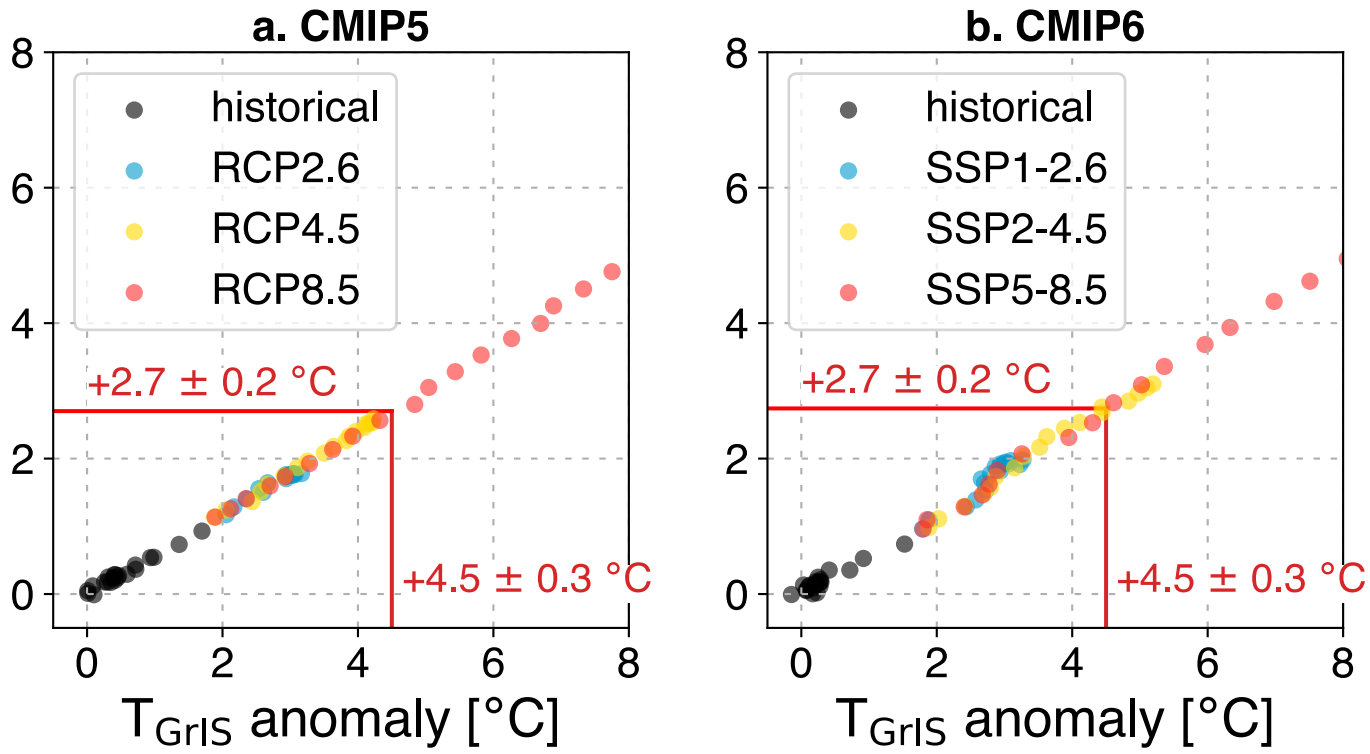


SMB = 0 threshold timing, CMIP6



global threshold: 2.7 °C

ΔT_{Global} [°C]



pros / cons of our method

- SMB from state-of-the-art RCM
- “correction method” to increase sampling with CESM data
- year of crossing is independent of CESM2 model (uses CMIP)
- simple to understand

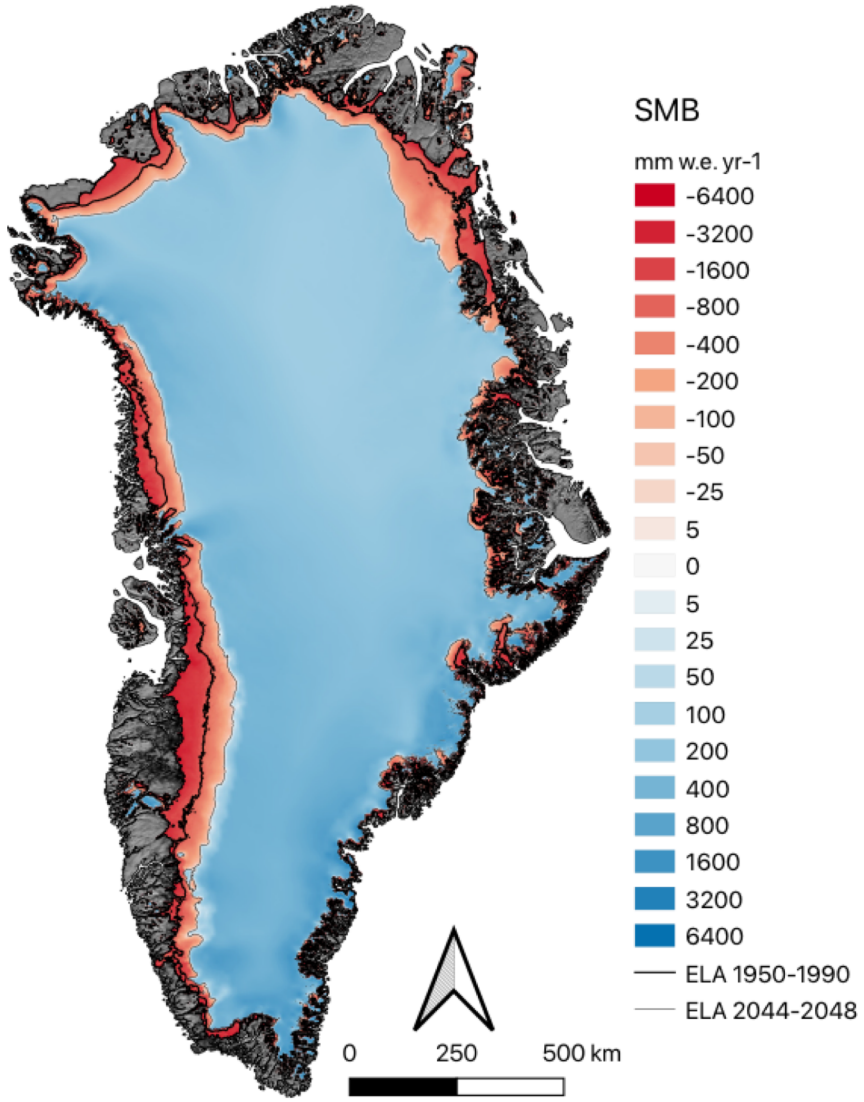
- single transient RCP 8.5 run to inform “correction method”
- CMIP ensemble is currently unweighted
- no elevation feedback, ice retreat
- **conservative estimate;** likely, deglaciation ‘tipping point’ is reached sooner than SMB=0

References

- Article current in review for Communications Earth and Environment
  https://www.nature.com/commsenv/
- CESM2 climate and SMB: van Kampenhout et al., 2020
- RACMO 2.3p2 SMB: Noël et al., 2018
- RACMO 2.3p2 with CESM forcing Noël et al., 2020

Extra slides

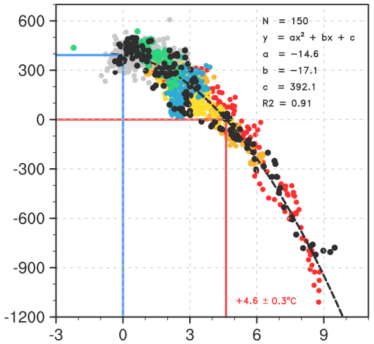
SMB field around time when SMB = 0



1 km resolution (downscaled)
years 2044-2048
in RACMO2 rcp 8.5 simulation

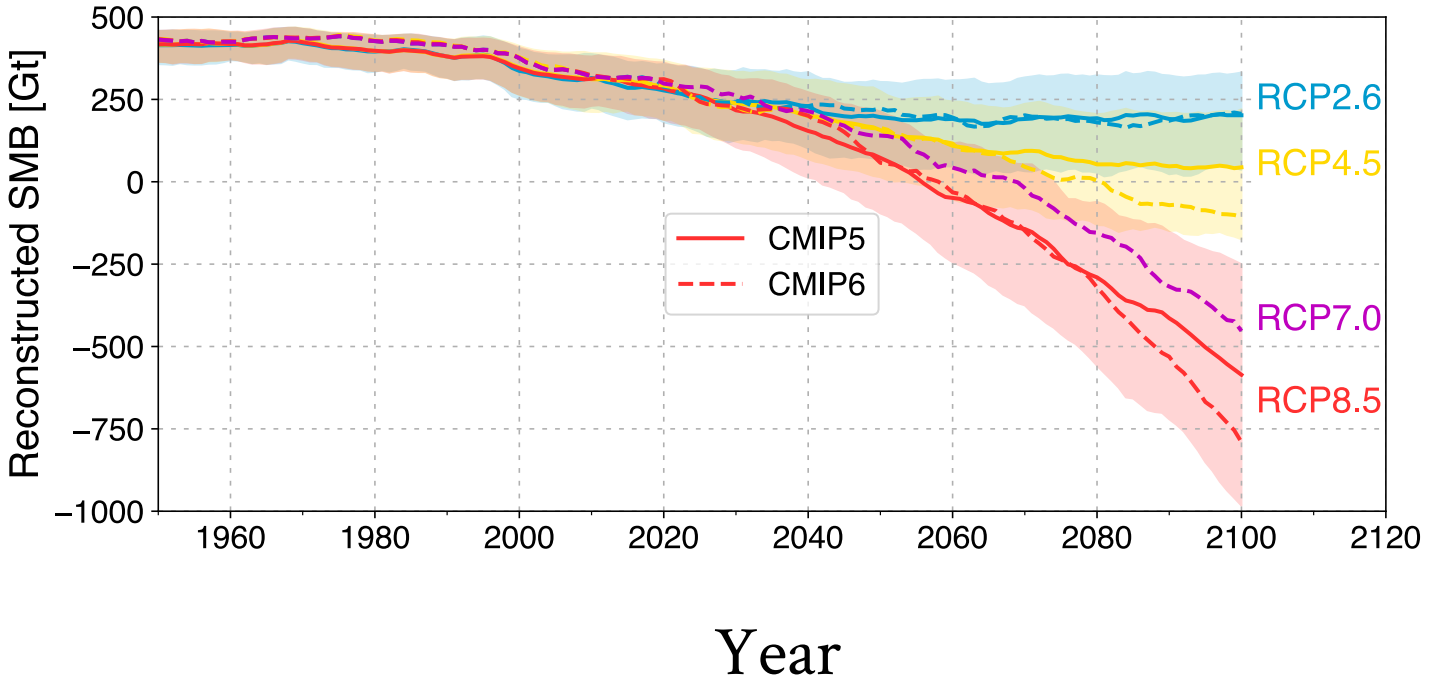
reconstructed SMB for CMIP models

using the quadratic relationship from earlier



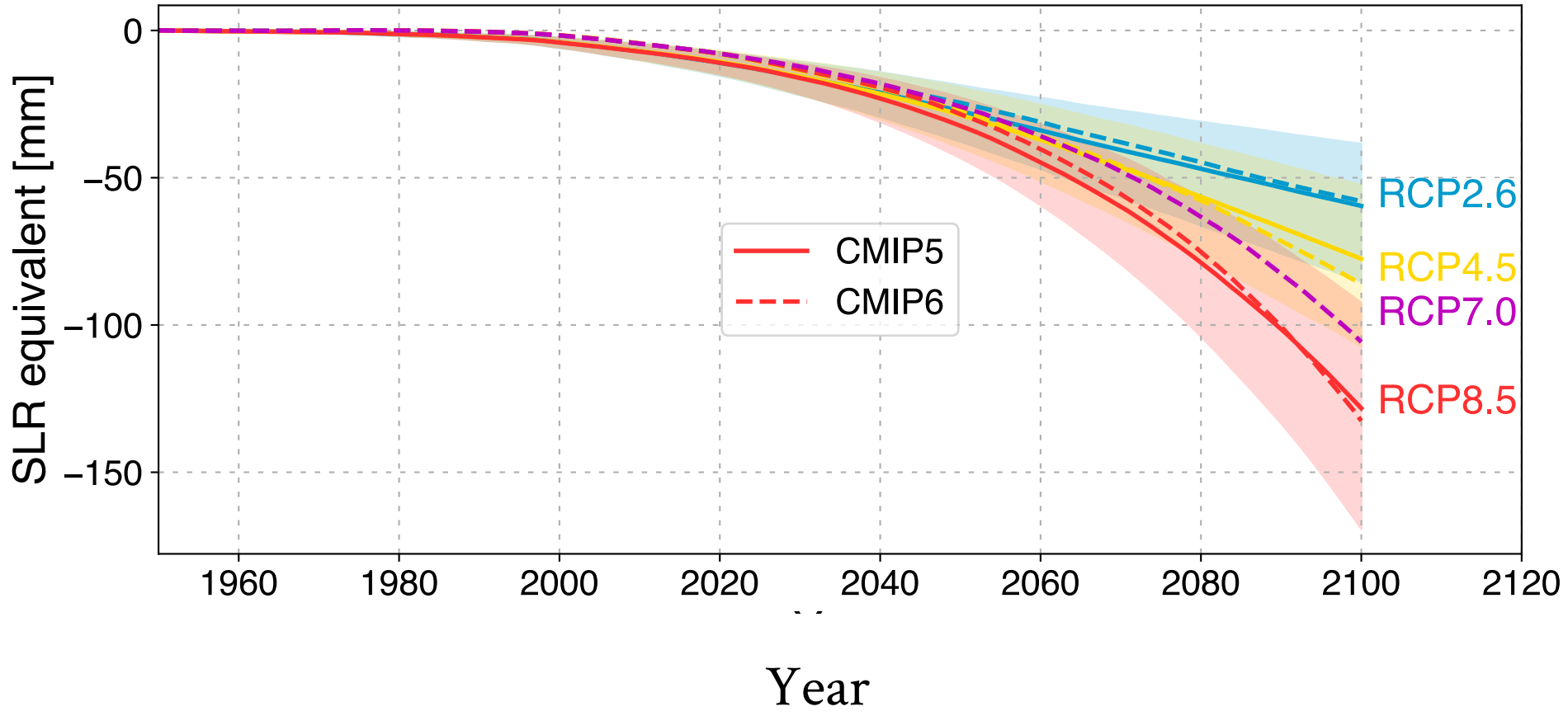
$SMB = a \cdot x^2 + b \cdot x + c$

with $x = \Delta T_{GrIS}$



Year

reconstructed sea level for CMIP models



sea level rise contribution
GrIS SMB only

scenario	IPCC AR5 table 13.5	our study CMIP5	our study CMIP6
rcp 2.6	3 [1-7]	5 [3-9]	5 [2-9]
rcp 4.5	4 [2-9]	7 [3-11]	7 [3-11]
rcp 8.5	7 [3-17]	10 [6-16]	10 [5-17]

Sea level rise contribution from Greenland SMB. Values are in cm and represent the increase in 2081-2100 relative to 1986-2005 for the various RCP greenhouse gas scenarios. Listed is the ensemble median and likely range. Our likely range represents the 5-95 percentile range, which is obtained by scaling the standard deviation by a factor of 1.645, a valid approximation under the assumption that the ensemble spread is normally distributed.