The Antarctic and Greenland response to mid-Pliocene warm period climatic fields PlioMIP2

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TIPES TIPPING POINTS IN THE EARTH SYSTEM

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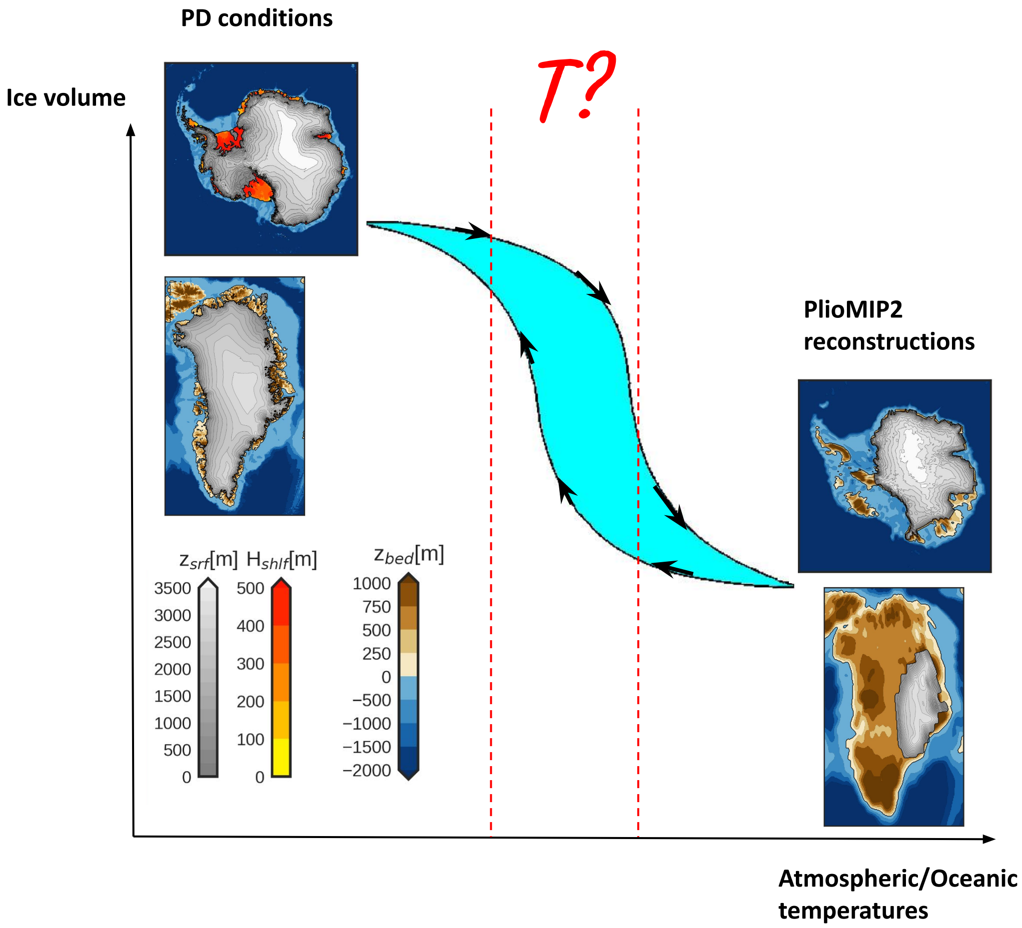
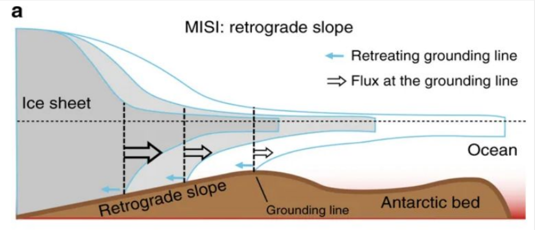
Tipping points in continental ice sheets



Positive feedback mechanisms

Antarctica - Marine Ice Sheet Instability



Pattyn, 2018

Greenland - Melt elevation feedback

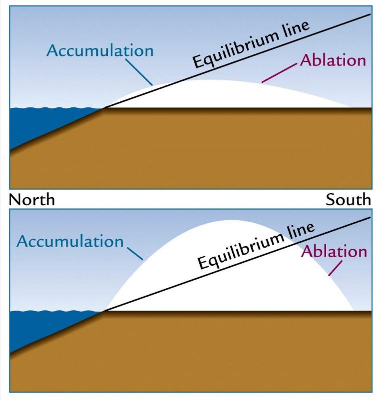


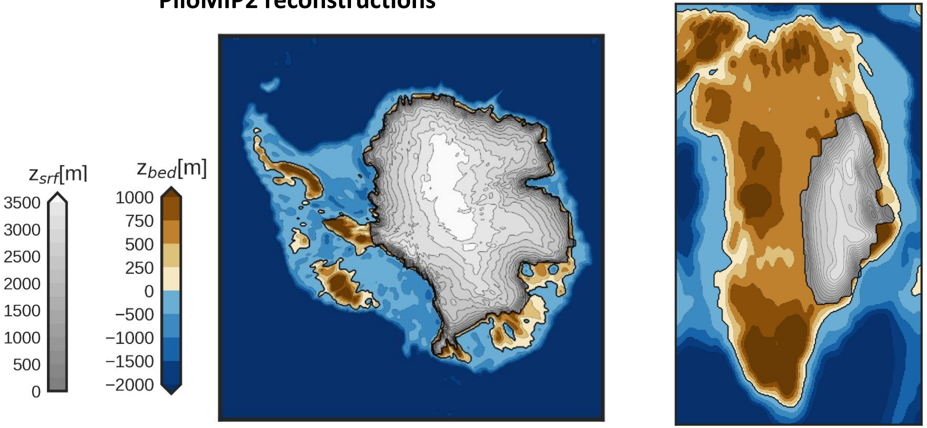
Figure from R. MacKay

The mid-Pliocene warm period

The **mid-Pliocene warm period** (mPWP, ~3 Ma BP):

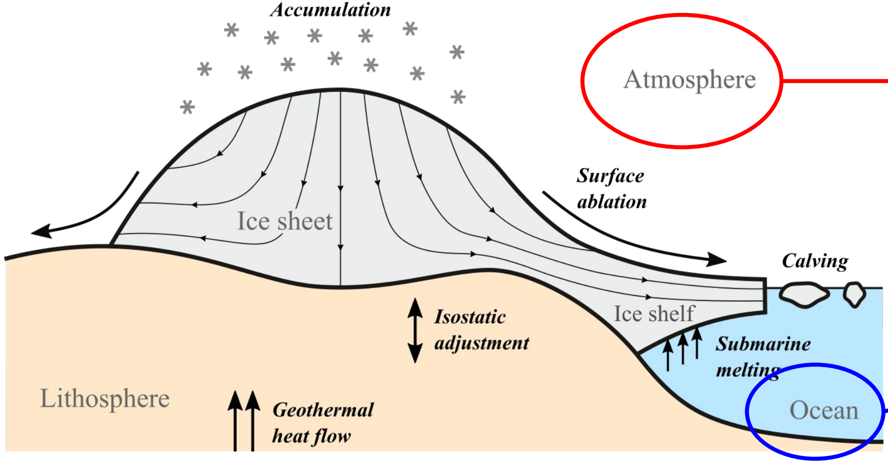
- CO_2 levels comparable to **PD (350-450 ppmv)**
- Global mean temperatures **2.5-4.0 degrees higher**
- Eustatic sea-level reconstructions **10-20 meters**

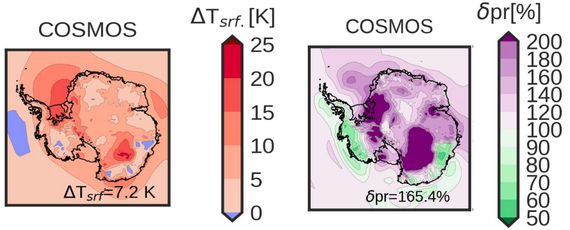
PlioMIP2 reconstructions

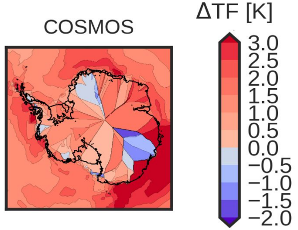


Forcing strategy:

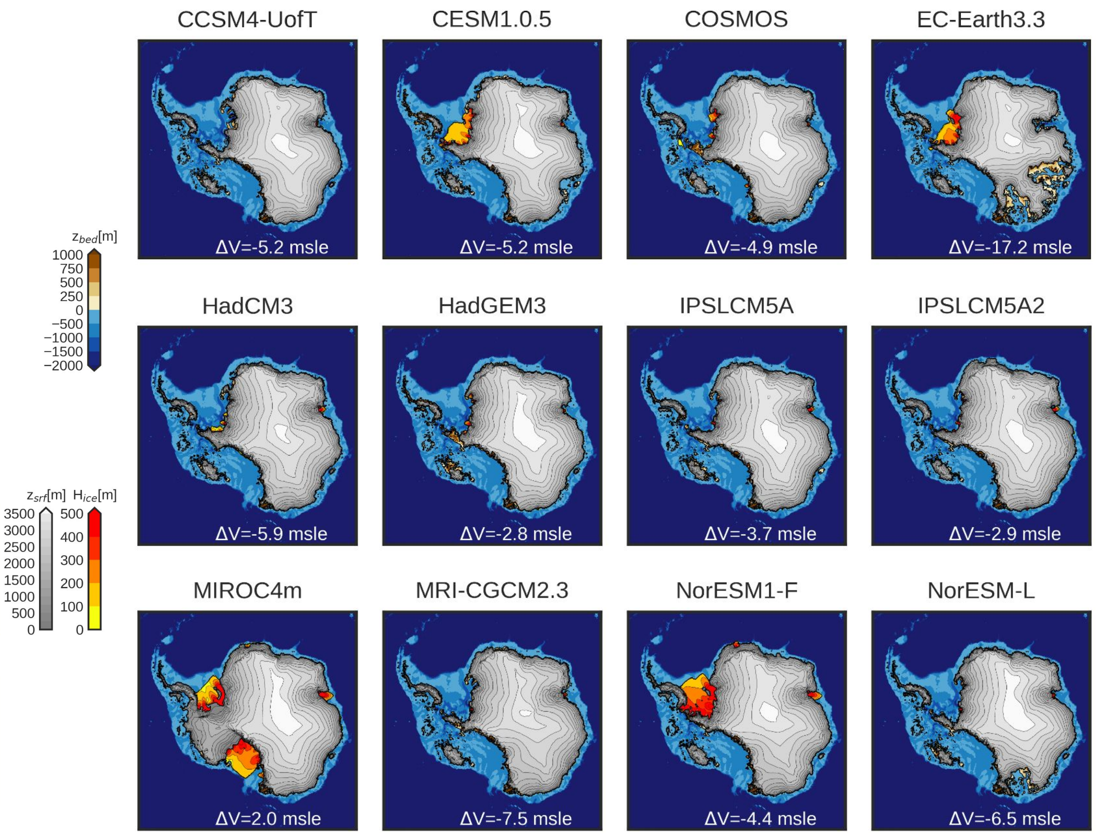
Yelmo ice-sheet-shelf model (Robinson et al., 2020) + PlioMIP2 climatologies (e.g. COSMOS)



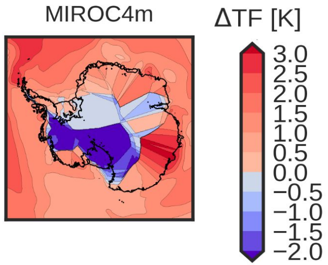




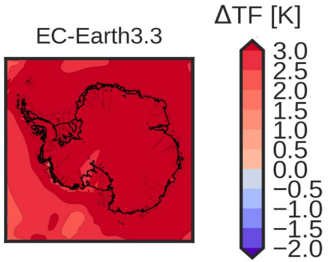
Yelmo results for the AIS



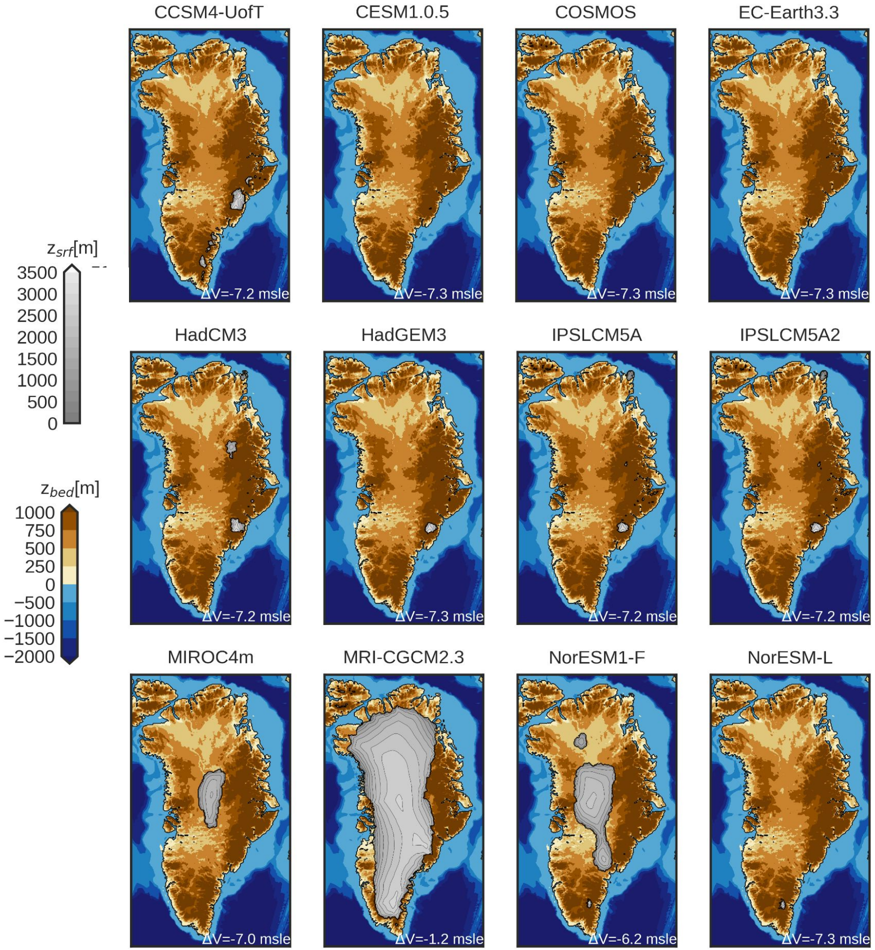
Trigger of a WAIS collapse?
WAIS collapses for all simulations except MIROC4m. Oceanic temperatures 1 degree warmer than PD are sufficient to trigger a WAIS collapse.



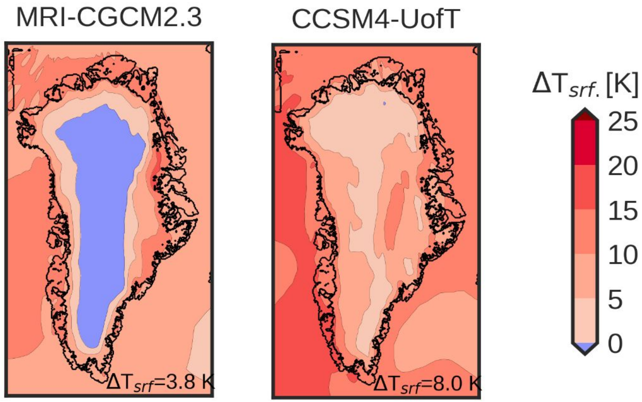
Trigger of a EAIS retreat?
EAIS marine regions retreat with a ~3 degree warmer ocean (EC-Earth3.3)



Preliminary Yelmo results for the GrIS



Trigger of a GrIS collapse?
An atmospheric warming of **~4 degrees** exceeds the tipping point. But low precipitation has also a strong impact.



Take-home messages

Conclusions:

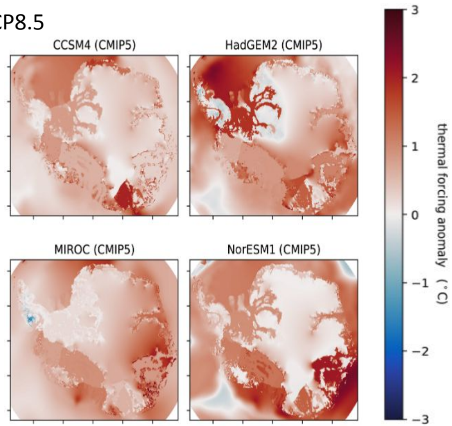
- The collapse of the WAIS is triggered with ~1 degree oceanic warming with respect to PD
- EAIS retreat of marine regions could be close to ~3 degree of oceanic warming
- The GrIS fully collapses for a 4 degree atmospheric warming, together with low precipitation wrt PD

Warming projections for the period 2081-2100:

These same models project more than **1 degree of warming** in vulnerable regions of the **AIS** for the coming future.

The most optimistic Greenland projections estimate an increase close to the tipping point for the end of the century and by far exceeded for the worst case scenario.

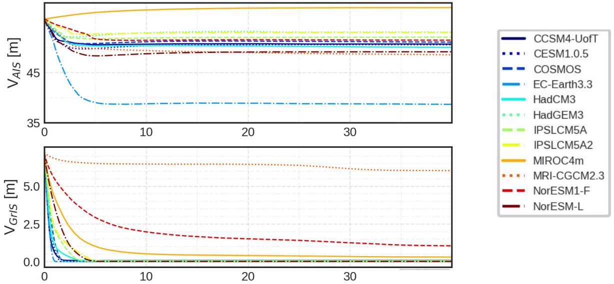
RCP8.5

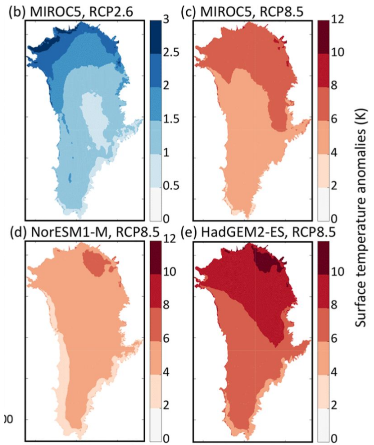


Lipscomb et al., 2021

Future work:

- Role of boundary conditions. E.g. Bedrock topography.
- Timing of the collapses



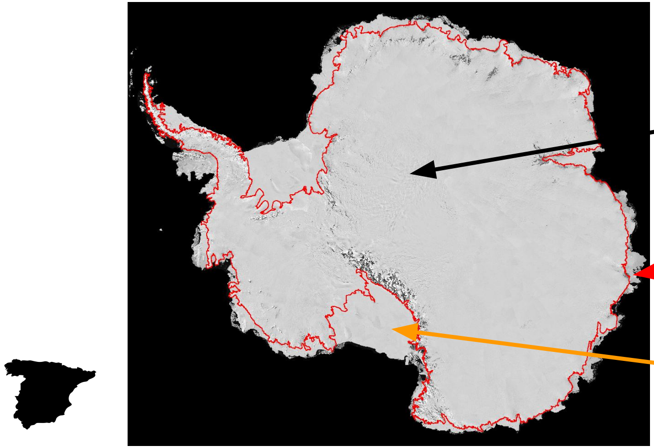


Nowicki et al., 2020

Thank you for your attention!

SÜD SHETLAND
SÜD ORKNEY
Coronation I.
Elephant I.
Clarence I.
Livingston I.
Bransfield Str.
JOINVILLE I.
LOUIS PHILIPP LAND
PALMER LAND
Bismarck Str.
Tristan da Cunha
Diego Alvarez od. Gough I.
Capstadt
Cap der guten Hoffnung
AFRIKA
ATLANTISCHER OCEAN
INDISCHER OCEAN
Bouvet I.
Thompson I.
Lindsay I.
Prinz Eduard Iⁿ.
Crozet Iⁿ.
Kerguelen I.
Mᶜ Donald I.
Heard I.
Sᵗ Paul
Neu Amsterdam
Süd Georgien
Sandwich Gruppe
Falkland Iⁿ.
Süd Orkney Iⁿ.
Süd Shetland Iⁿ.
Graham Land
Alexander I. Land
Peter I. Insel
Enderby Insel
Kemp Insel
Termination I.
Knox Land
GEORG IV. MEER
ANTARKTISCHER OCEAN
(SÜDLICHES EISMEER)
UNERFORSCHTES GEBIET
SÜD POL
SÜD AMERIKA
Cord. de los Andes
Montevideo
Rio de la Plata
Buenos Aires
Bahia Blanca
S. Matias Golf
Sᵗ George Golf
Valparaiso
Santiago
Concepcion
Valdivia
Chiloe
Juan Fernandez
Mas a fuera
Wellington I.
Hannover I.
Magalhaes Str.
Cap Horn
Diego Ramirez
Südl. Polarkreis
SÜD

The Antarctic Ice Sheet



NASA

Grounded ice:
Ice that whose base is in contact with the bedrock. Ice thickness at the interior can reach up to **4000 meters**. This ice contributes to sea-level rise.

Grounding line:
Separation between grounded and floating ice.

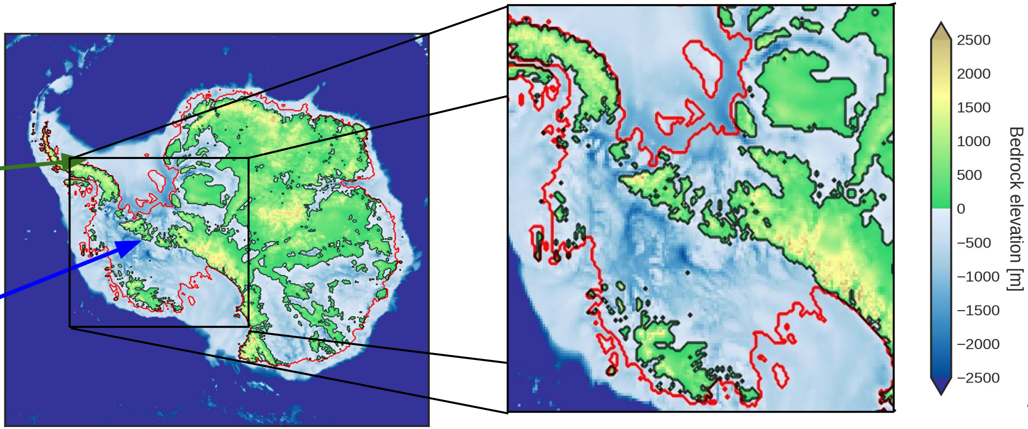
Floating ice shelves:
Floating ice does not directly contribute to sea-level rise, but can lead to inland ice acceleration due to the lost of buttressing effect. The AIS is surrounded by ~300 ice shelves with and ice thickness between **300-2500 meters**.

Grounded ice can lie on a bedrock either

above sea level (land-based ice sheet)

or

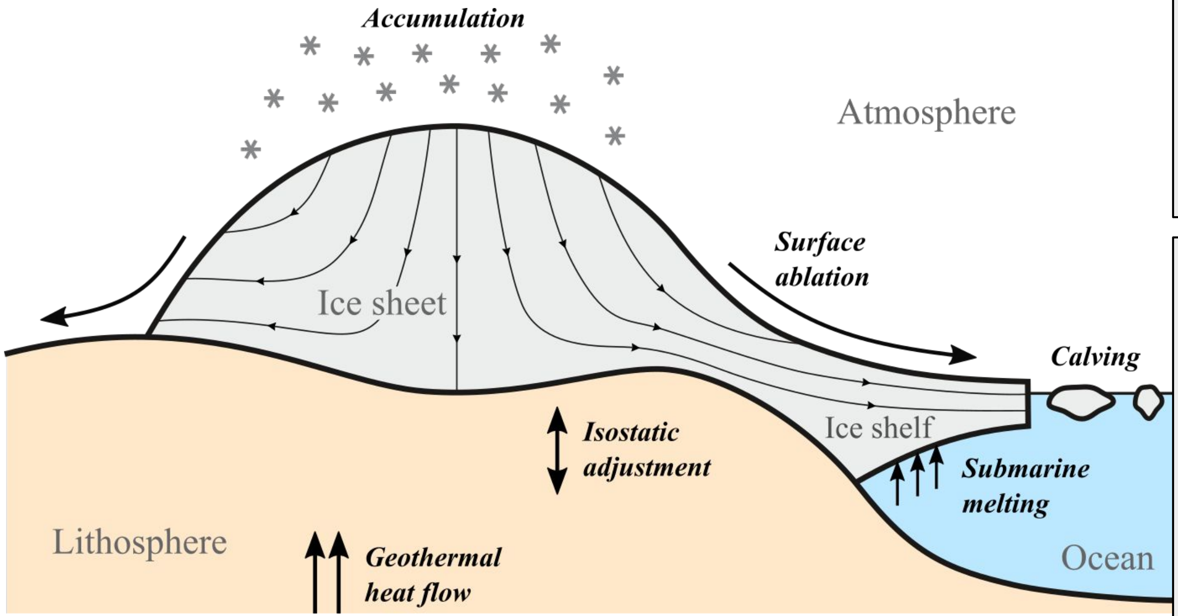
below sea level (marine-based ice sheet)



The **West Antarctic Ice Sheet (WAIS)** is a marine-based ice sheet over a **retrograde slope.**

Morlighem et al., 2020

Forcing strategy



(Robinson et al., 2020)

Atmosphere:

PD - Racmo2.3 ERAInt (*Dee et al., 2011*)

$$T^{atm} = T^{atm}_{PD} + \Delta T^{atm}_{PlioMIP2}$$

$$pr = pr_{PD} \delta pr_{PlioMIP2}$$

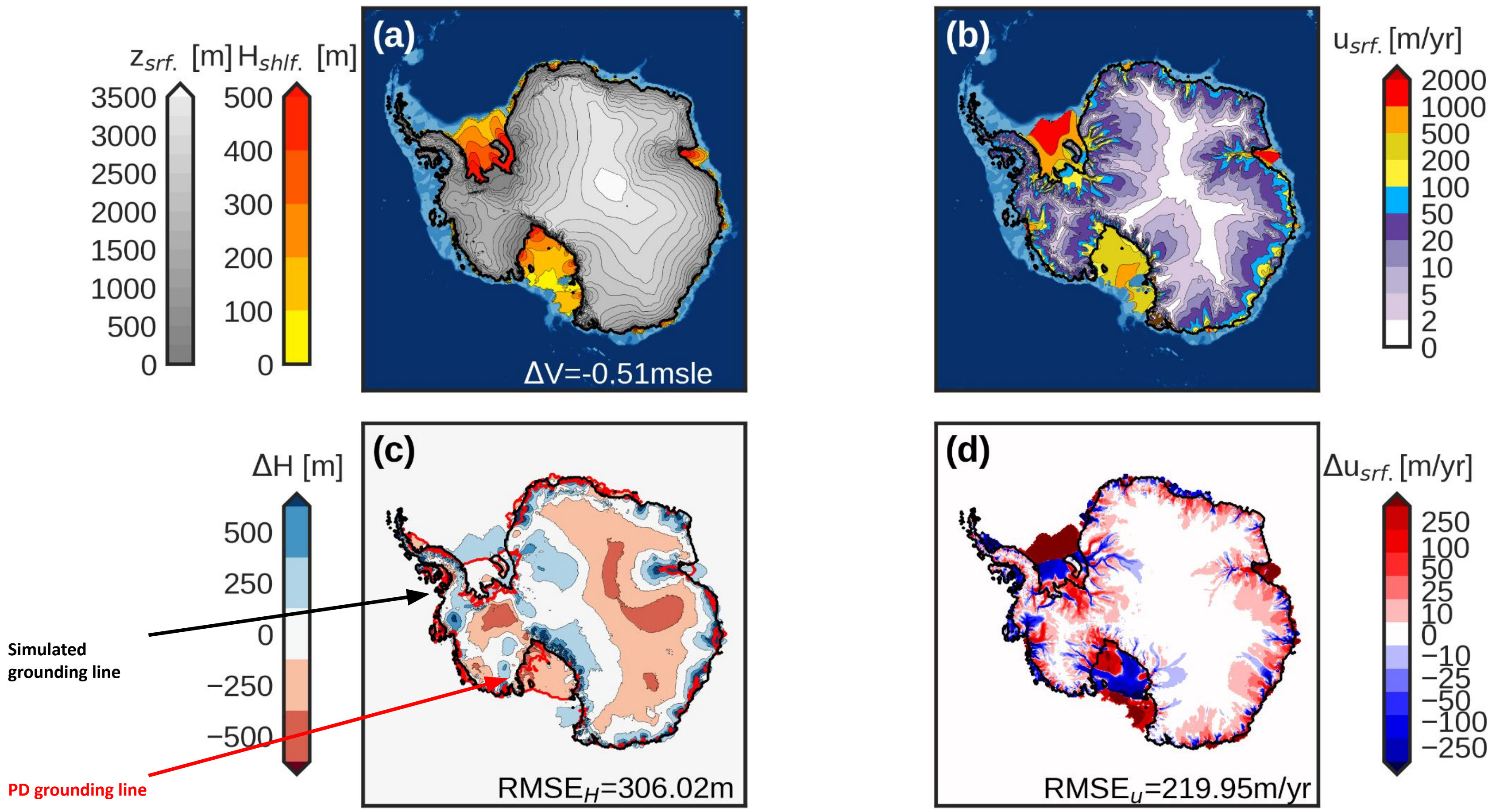
Ocean:

PD - ISMIP6 quadratic non-local (*Jourdain et al., 2020*)

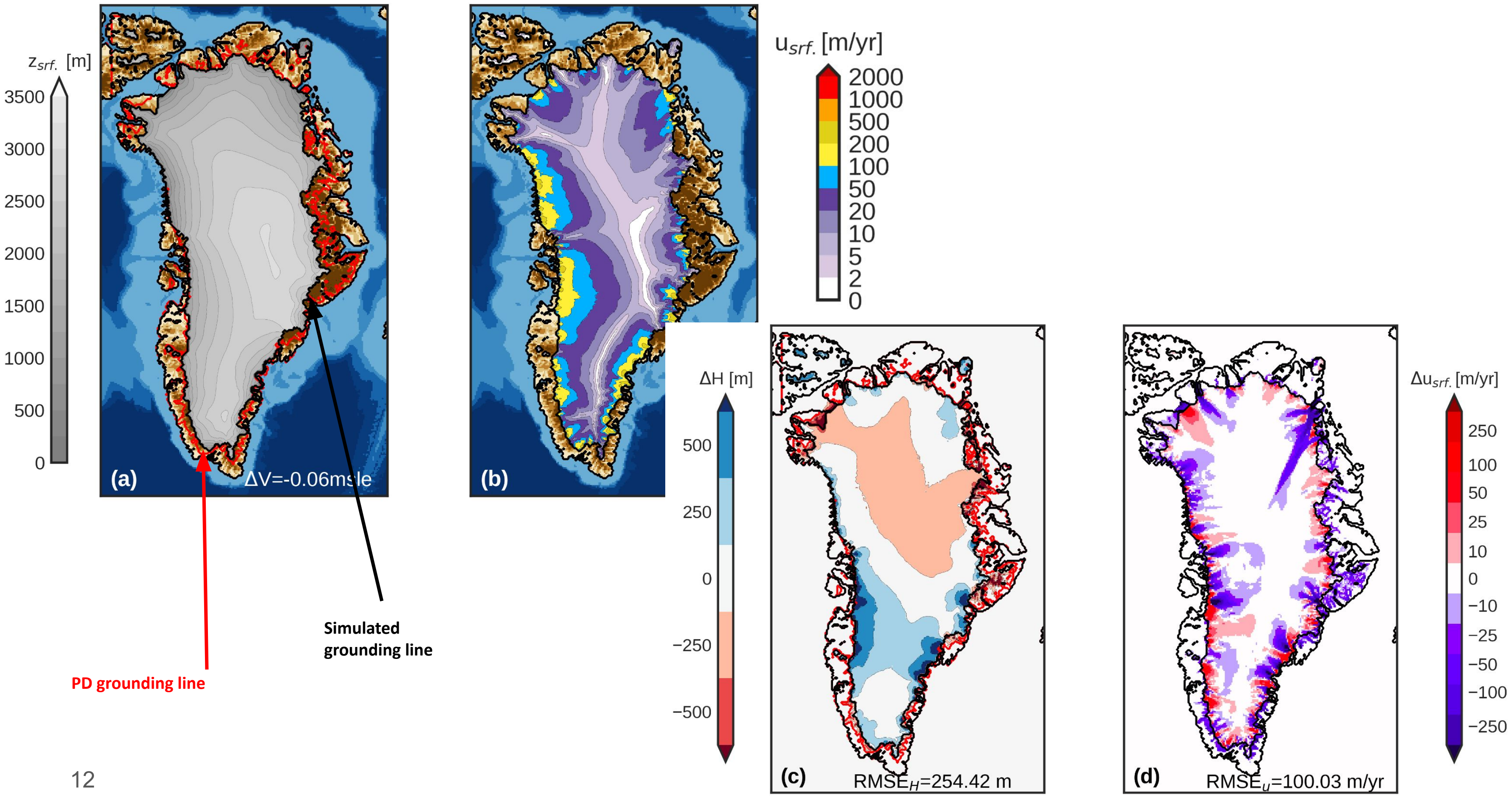
$$m(x,y) = \gamma_0 \times \left(\frac{\rho_{\mathrm{sw}} c_{\mathrm{pw}}}{\rho_{\mathrm{i}} L_{\mathrm{f}}} \right)^2 \times (\mathrm{TF}(x,y,z_{\mathrm{draft}}) + \delta T_{\mathrm{sector}}) \times |\langle \mathrm{TF} \rangle_{\mathrm{draft} \in \mathrm{sector}} + \delta T_{\mathrm{sector}}|$$

$$TF = TF_{PD} + \Delta TF_{PlioMIP2}$$

Simulated AIS PD

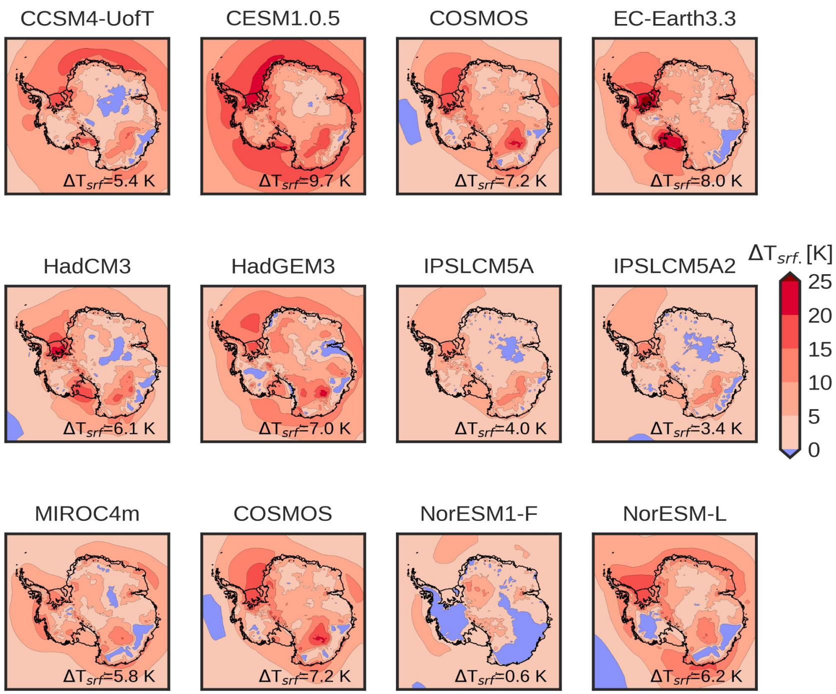


Simulated GrIS PD

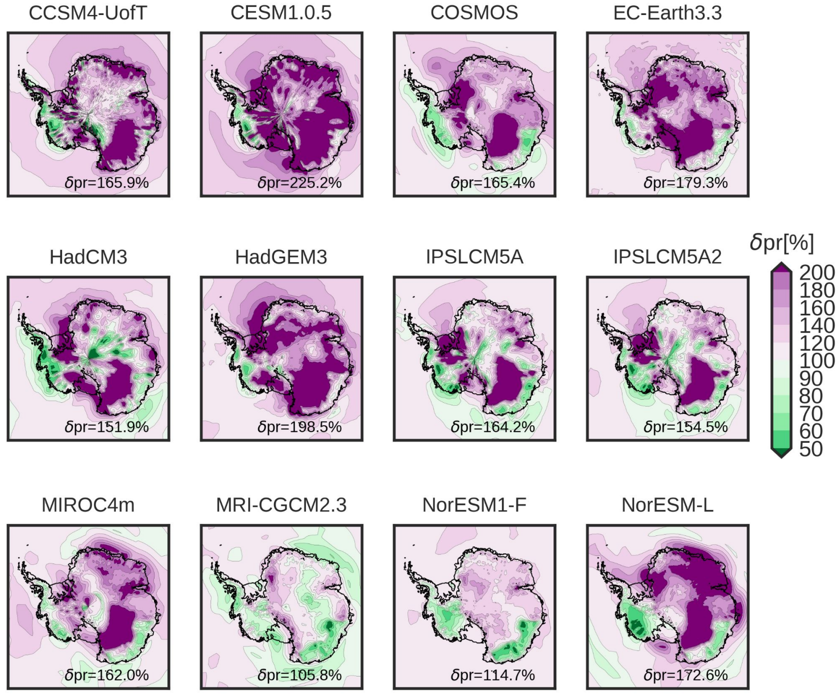


AIS climatologies mPWP

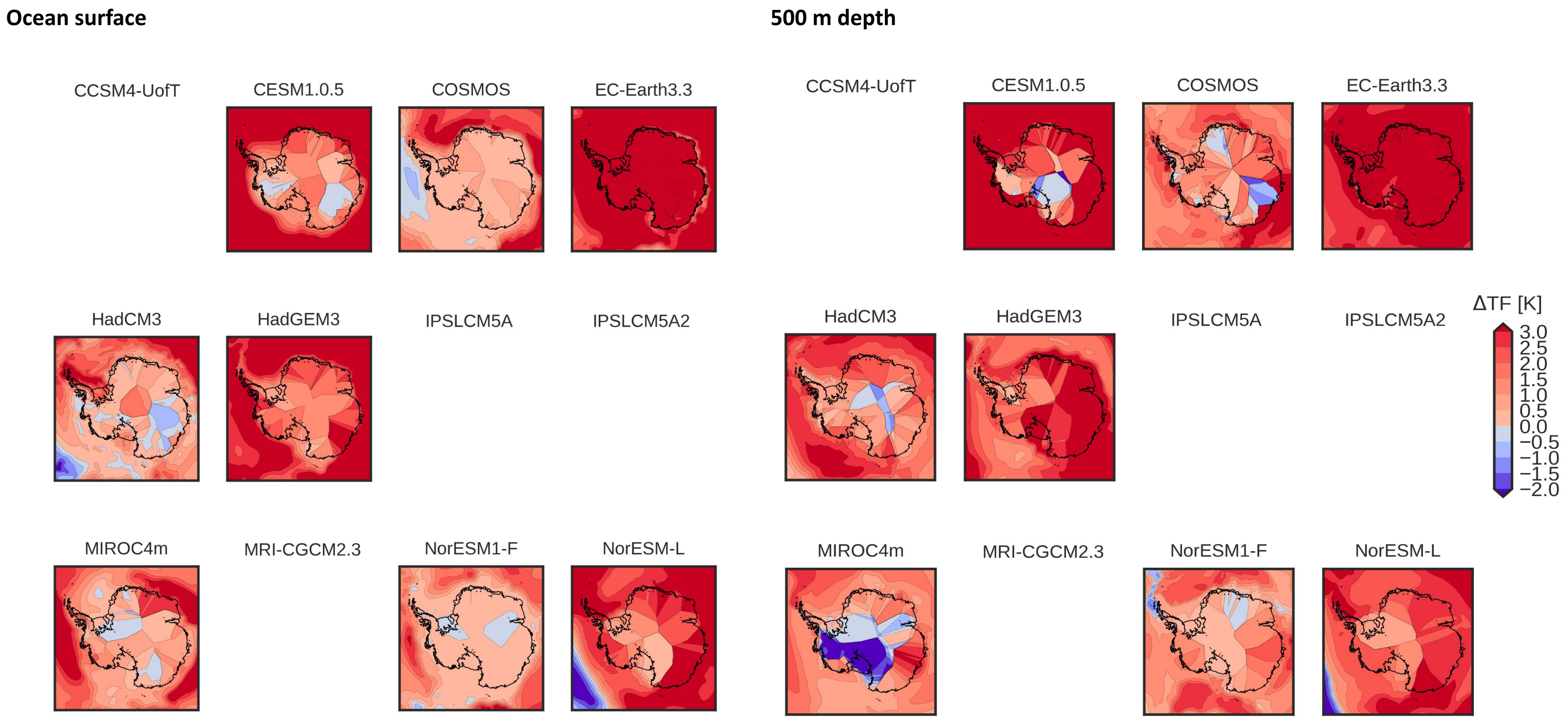
Surface anomaly temperature



Relative precipitation anomaly

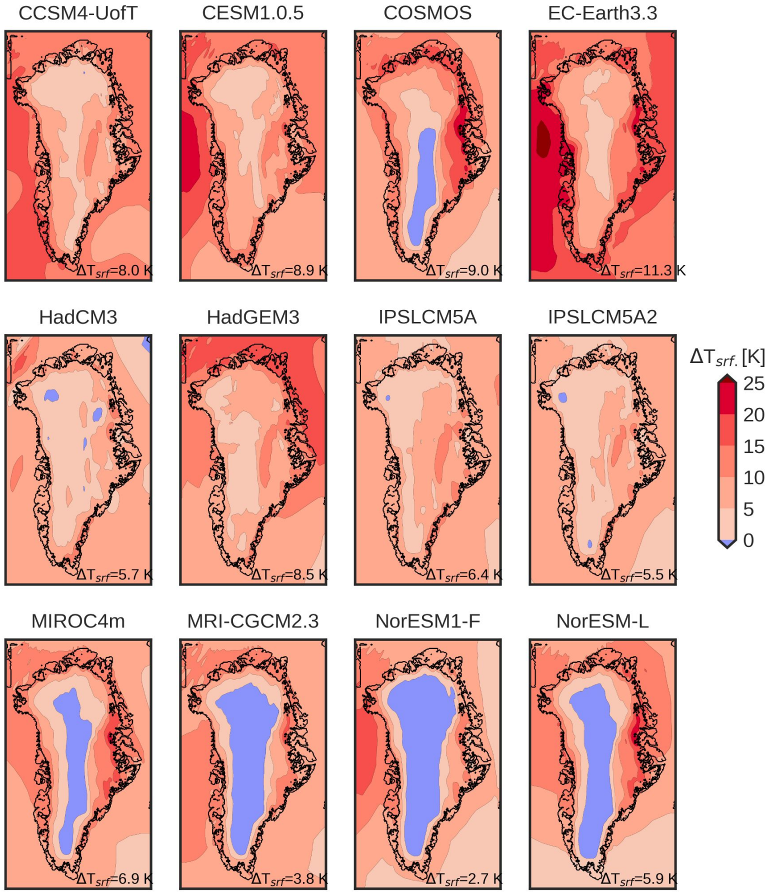


AIS thermal forcing mPWP

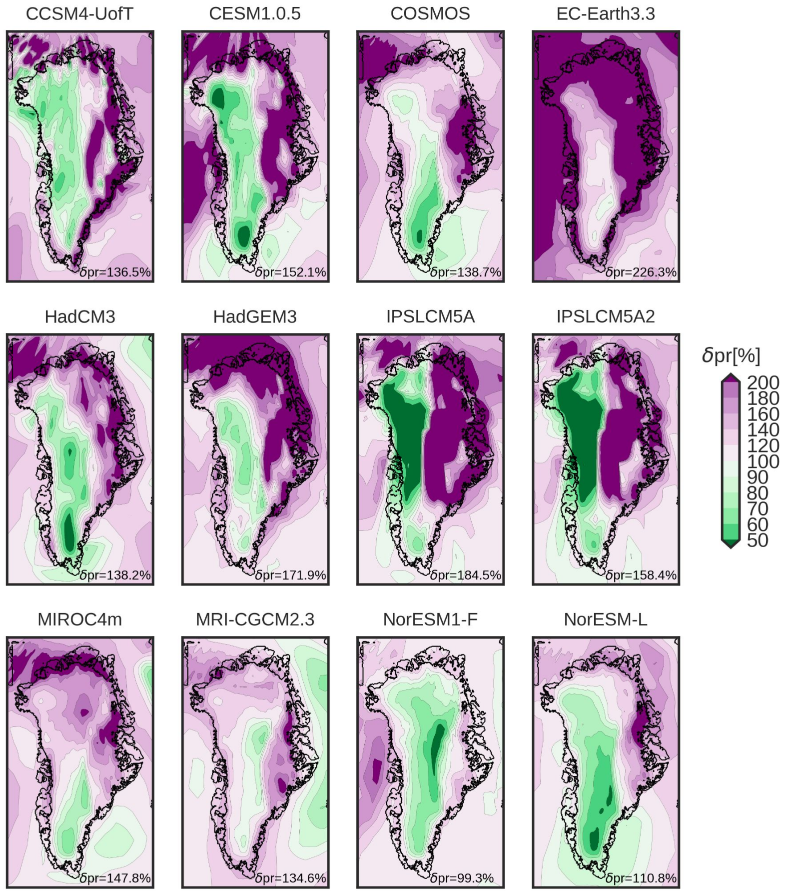


GrIS climatologies mPWP

Surface anomaly temperature



Relative precipitation anomaly



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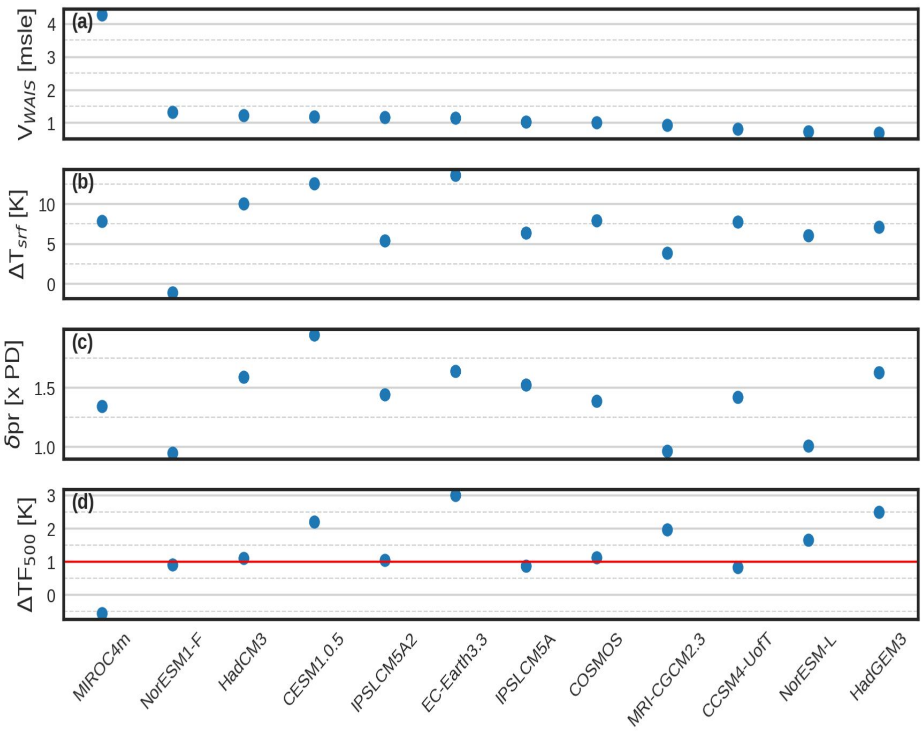

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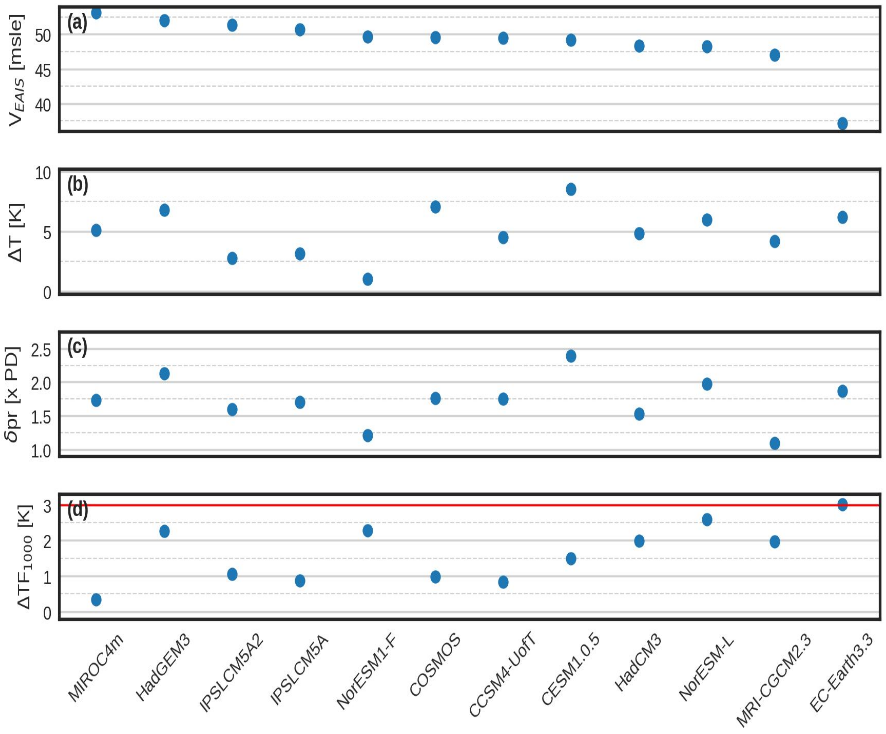
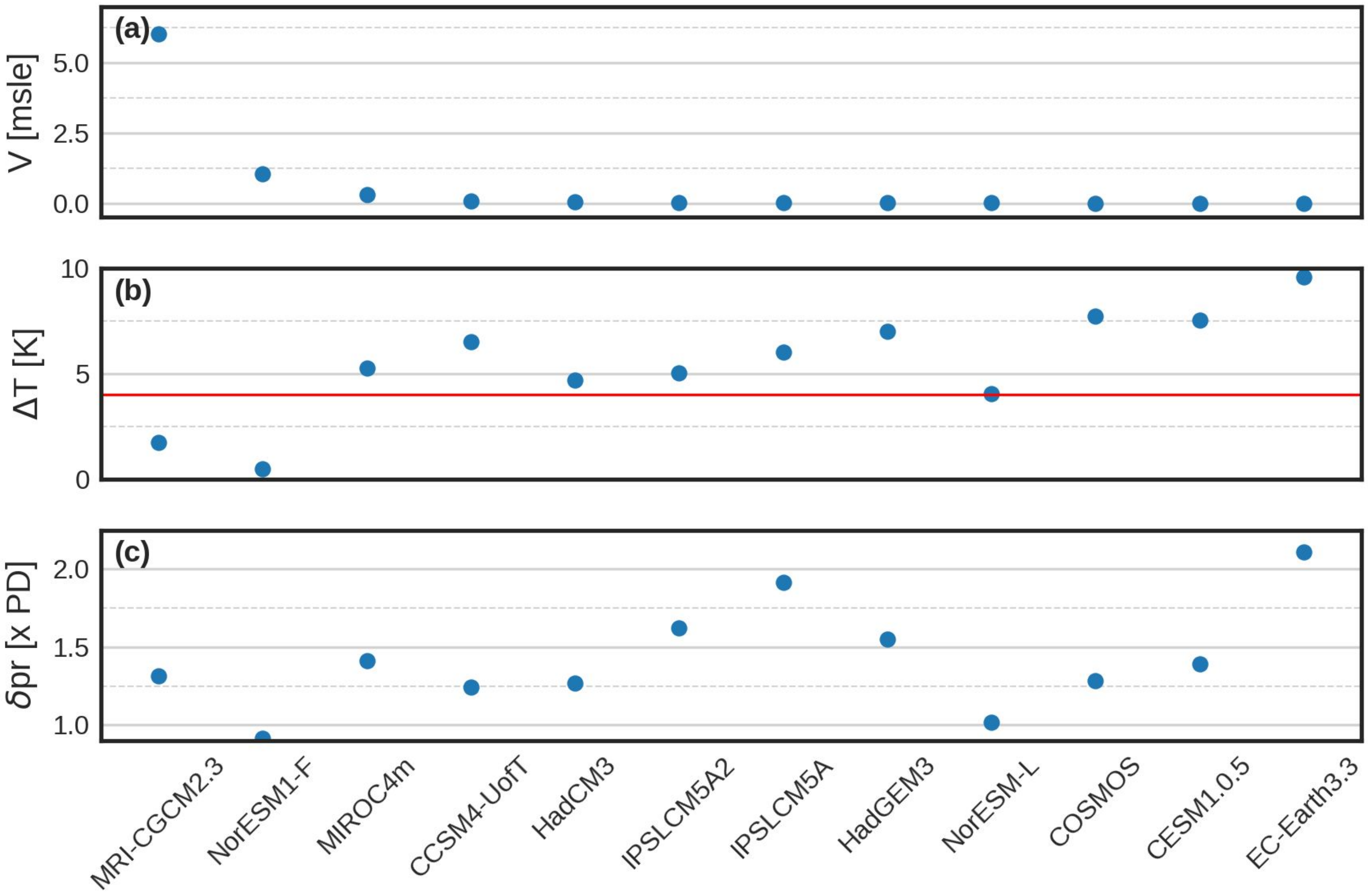


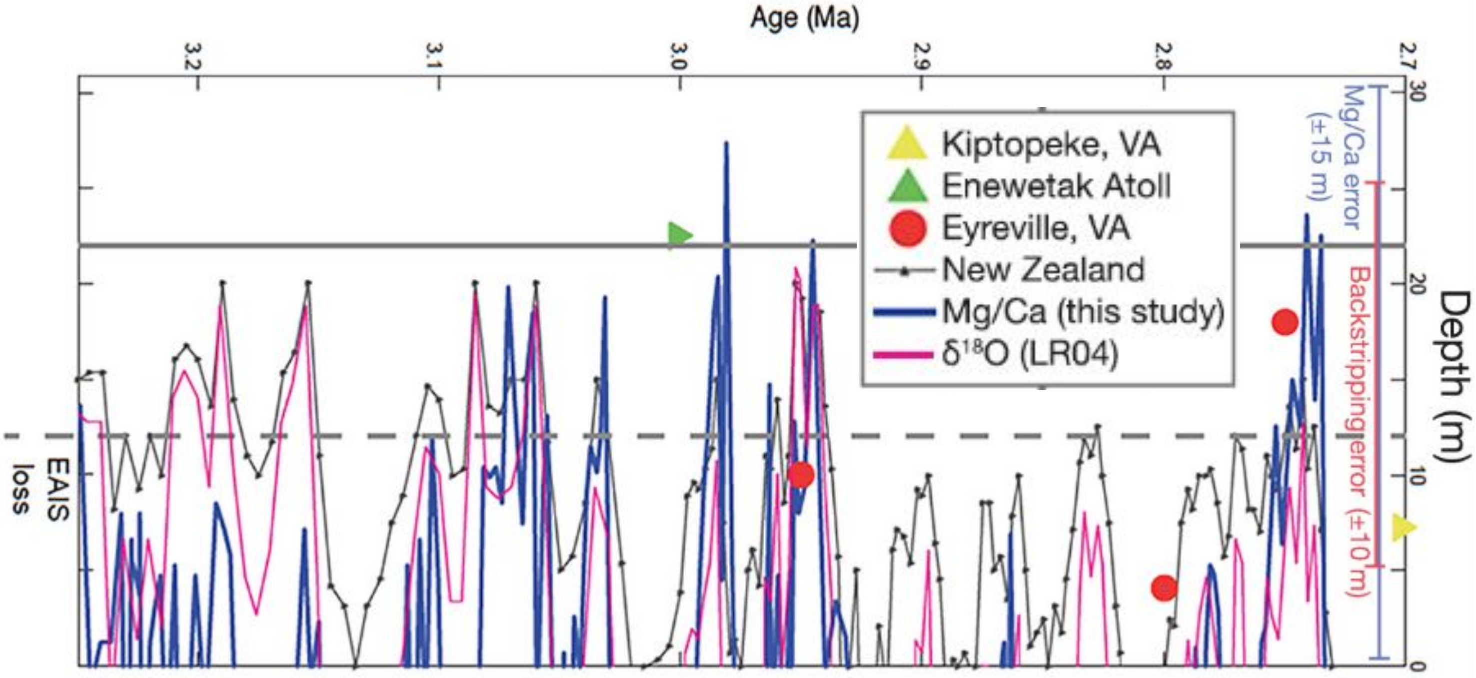
Preliminary Yelmo results for the GrIS



mPWP sea-level reconstructions

The **mid-Pliocene warm period** (mPWP, ~3 Ma BP) is the most recent period with CO2 levels comparable to **PD (350-450 ppmv)** and global mean temperatures **2.5-4.0 degrees higher.**

Eustatic sea-level reconstructions from the Pliocene estimate a sea level **15-20 meters higher than PD** with high uncertainty.

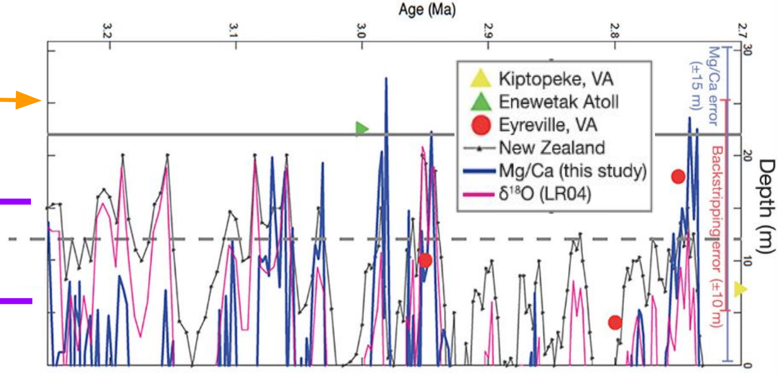


Miller et al., 2019

Contribution to sea-level rise

Model	AIS (m)	GrIS (m)	Total (m)
EC-Earth3.3	17.2	7.3	24.5
CESM1.0.5	5.2	7.3	12.5
COSMOS	4.9	7.3	12.2
CCSM4-UofT	5.2	7.2	12.4
HadCM3	5.9	7.2	13.1
HadGEM3	2.8	7.3	10.1
IPSLCM5A	3.7	7.2	10.9
IPSLCM5A2	2.9	7.2	10.1
MIROC4m	-2.0	7.0	5.0
MRI-CGCM2.3	7.5	1.2	8.7
NorESM1F	4.4	6.2	10.6
NorESM-L	6.5	7.3	13.8

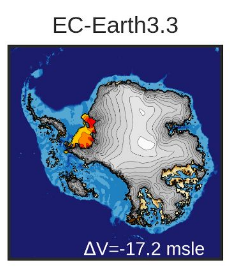
Sea-level reconstructions Pliocene:

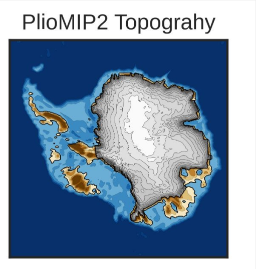


Miller et al., 2019

Did the EAIS melt?

Only the EC-Earth3.3 model gives a sea-level rise above 20 meters





Our results suggest that atmospheric forcing alone cannot explain a retreat in the EAIS that contributes to a slr > 20 m. Oceanic forcing is needed.

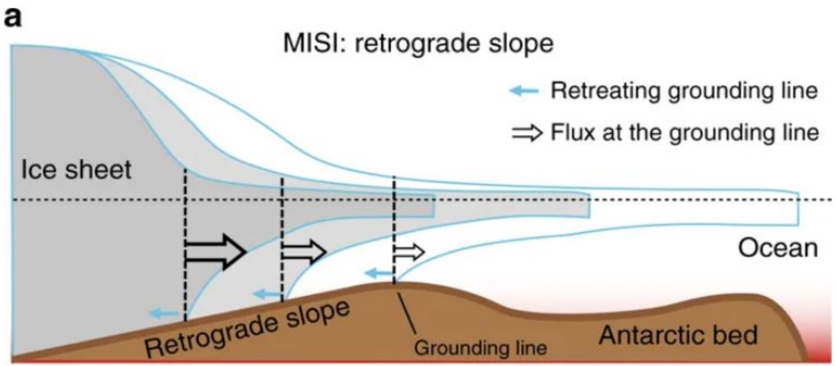
In year 2006, Christian Schoof applied boundary layer theory and came to the following conclusions:

- Given boundary conditions, there is a unique solution (analytical)
- Steady grounding lines cannot be stable on reverse bed slopes

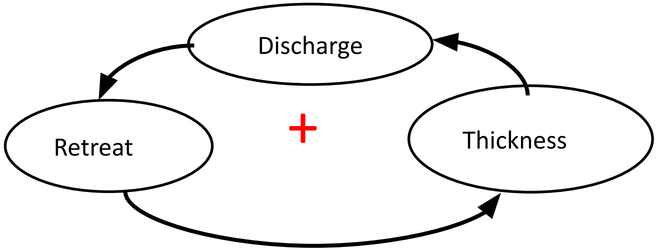
Flux at the grounding line

$$q_{\mathrm{g}} = \left[\frac{A(\rho_{\mathrm{i}} g)^{n+1} (1 - \rho_{\mathrm{i}}/\rho_{\mathrm{w}})^{n}}{4^{n} C_{\mathrm{s}}} \right]^{\frac{1}{m_{\mathrm{s}}+1}} \Theta^{\frac{n}{m_{\mathrm{s}}+1}} h_{\mathrm{g}}^{\frac{m_{\mathrm{s}}+n+3}{m_{\mathrm{s}}+1}}$$

Ice thickness at the grounding line



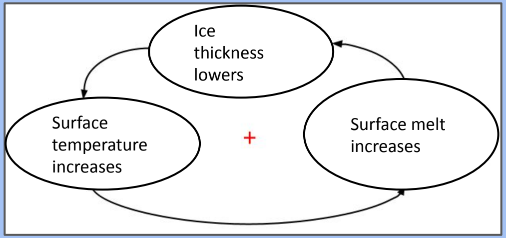
Pattyn et al. (2018)



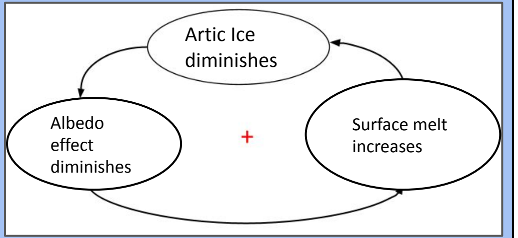
West Antarctic collapse: 3-5 m sea-level rise

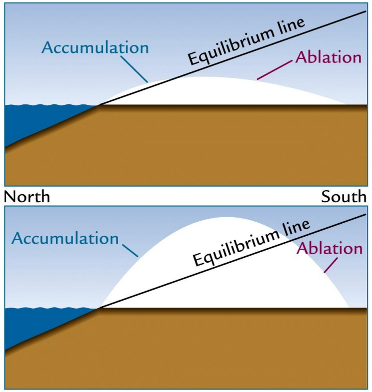
Several positive feedback mechanisms affect the Greenland Ice Sheet:

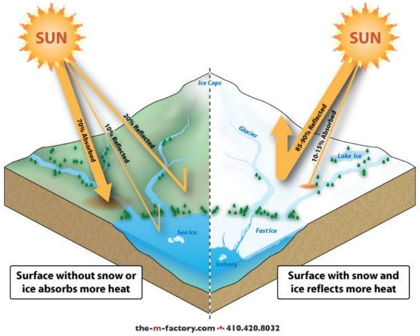
Ice - elevation



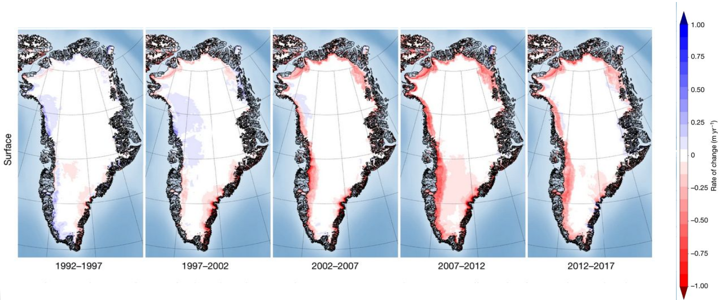
Ice - albedo

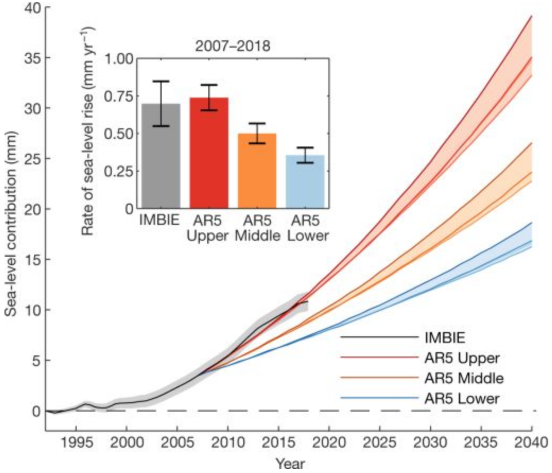






Observations and projections:





The IMBIE Team, 2018