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Coupling subglacial hydrology to basal friction in an Antarctic ice sheet model

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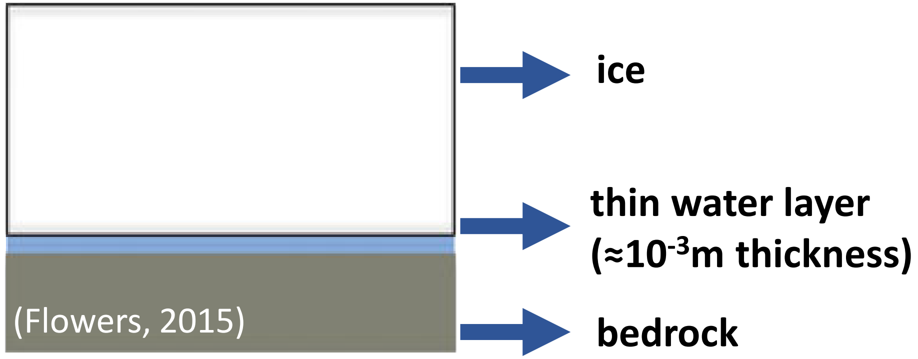
TAKE-HOME MESSAGE

Subglacial hydrology and basal sliding influence the sensitivity of the ice-sheet system on centennial time scales.

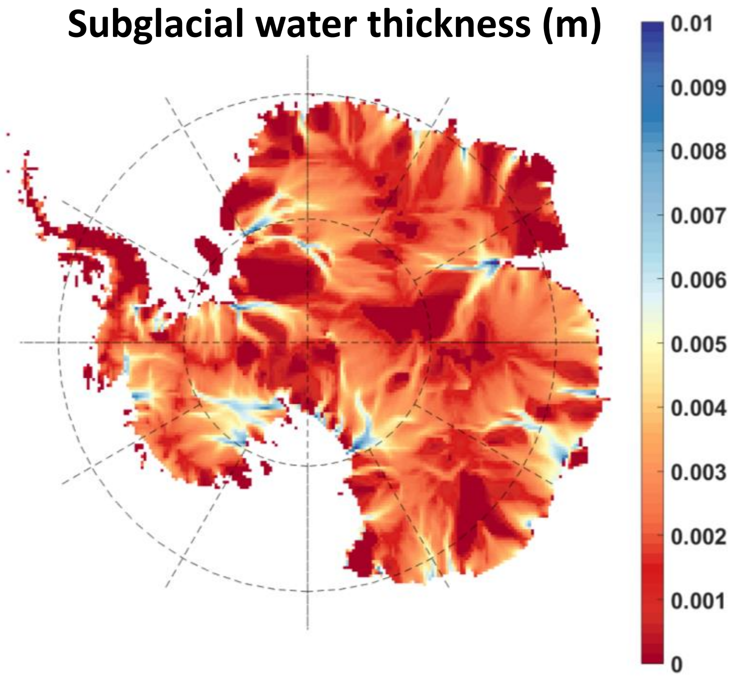
In this study we consider different parametrizations and representations of effective pressure and till water content at the base. We also consider different ways to **couple subglacial hydrology to basal sliding**.

OUR ICE-SHEET MODEL



f.ETISh (Pattyn, 2017)

- Hybrid SSA-SIA thermomecanical coupled model
- **Coupled** to a basic subglacial hydrology model (Lebrocq et al., 2009)
  - Water flow = Thin film of water
  - **Different coupling** parametrizations
  - In a **power-law** or a **Coulomb friction law basal** sliding



Subglacial water thickness obtained from an optimization in a power-law basal sliding with m = 2.

COUPLING HYDROLOGY AND SLIDING

4 representations of water content at the base … coupled with 5 different sliding laws

Sliding controlled by effective pressure (N_{eff})

N_{eff} function of the subglacial **water pressure**

OPTION 1 (Tsai et al., 2015)
→ Details on slide 5

OPTION 2 (Bueler and Brown, 2009)
→ Details on slide 6

N_{eff} function of the amount of **liquid water in the till**

OPTION 3 (Bueler and van Pelt, 2015)
→ Details on slide 7

In a Power-law basal sliding
with m = **1**, **2** or **3**

$$\tau_b = \beta^2 v_b$$

τ_b = driving stress
v_b = basal speed

$$\beta^2 = A^{-1} |\tau_d|^{1-m} N_{eff}^{\,p}$$

A = basal sliding factor (optimized)
m = sliding law exponent
p = N_{eff} exponent

In a Coulomb friction law basal sliding
with **2 different parametrizations of grounding line** flux (according to **Schoof, 2007a** or **Tsai et al., 2015**)

$$\tau_c = c_0 + (\tan\phi) N_{eff}$$

τ_c = yield stress
C_0 = till cohesion
(= 0 is further considered)
Φ = till friction angle (optimized)

Sliding controlled by flux of subglacial water

OPTION 4 (Goeller et al., 2013)
→ Details on slide 8

In a Power-law basal sliding
with m = **1**, **2** or **3**

$$\tau_b = \beta^2 v_b$$

τ_b = driving stress
v_b = basal speed

$$\beta^2 = A(\phi)^{m} |\tau_d|^{1-m}$$

A = basal sliding factor (function of suglacial water flux)
Φ = subglacial water flux
m = sliding law exponent

Not yet coupled to a Coulomb friction

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OPTION 1 (Tsai et al., 2015)

$$N_{eff} = po - pw = (rho*g*H) - pw$$

po = overburden pressure

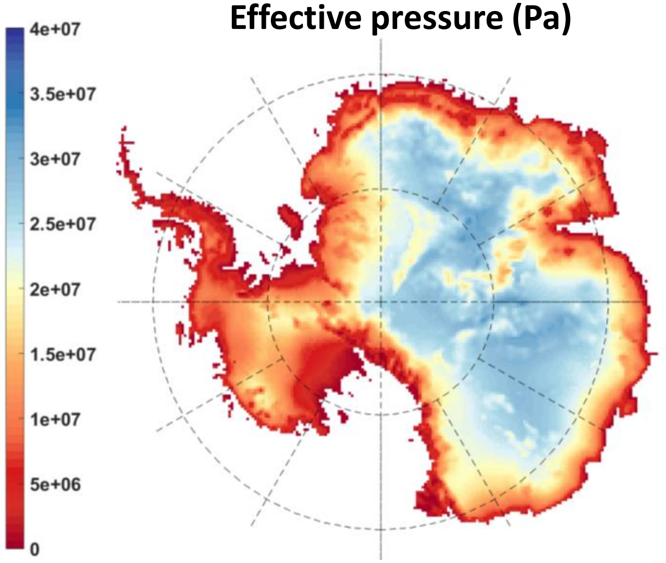
pw = subglacial water pressure

rho = ice density

g = gravity acceleration

H = ice thickness

Effective pressure (Pa)



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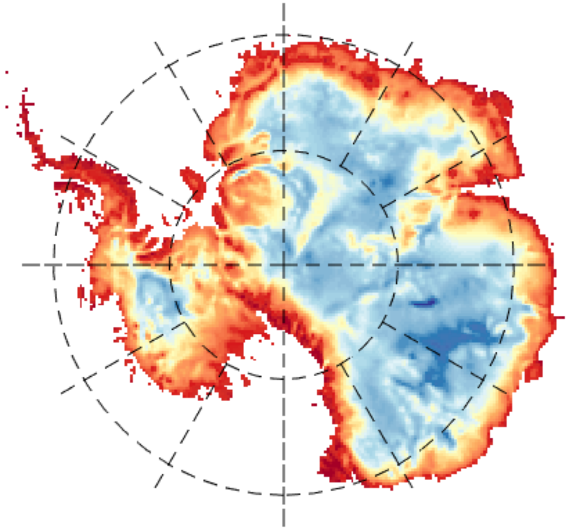
Overburden pressure (Pa)



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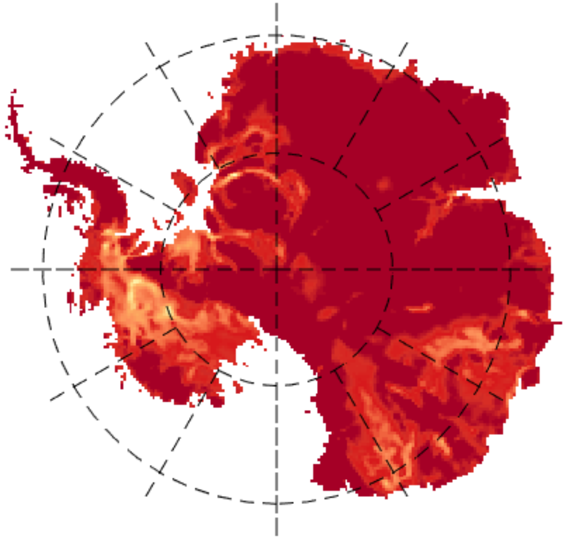
Subglacial water pressure (Pa)

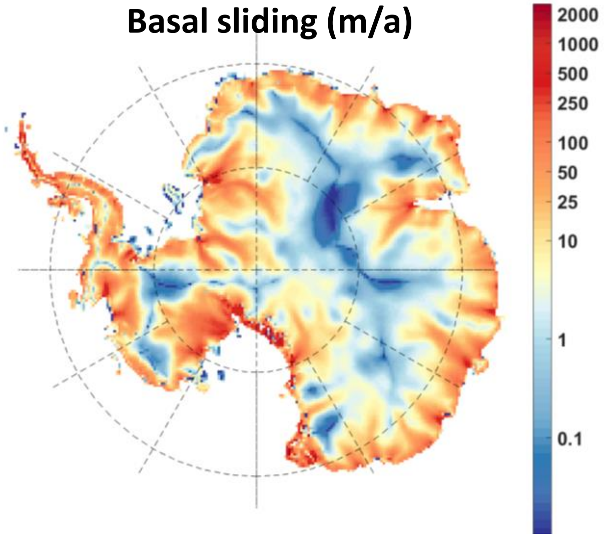


$$pw = -P_w \rho_{ss}\, g\, (b - z_{sl})$$

P_w = a fixed fraction of the po
ρ_{ss} = water density
g = gravity acceleration
b = bedrock elevation
z_{sl} = sea leavel

This formula is valid for $b - z_{sl} < 0$, otherwise pw = 0.

Basal sliding (m/a)



Subglacial water pressure is linked to the bed below sea level.

The figures show different parameters after an optimization in a power-law basal sliding with m = 2.

OPTION 2 (Bueler and Brown, 2009)

$$N_{eff} = po - pw = (rho * g * H) - pw$$

po = overburden pressure

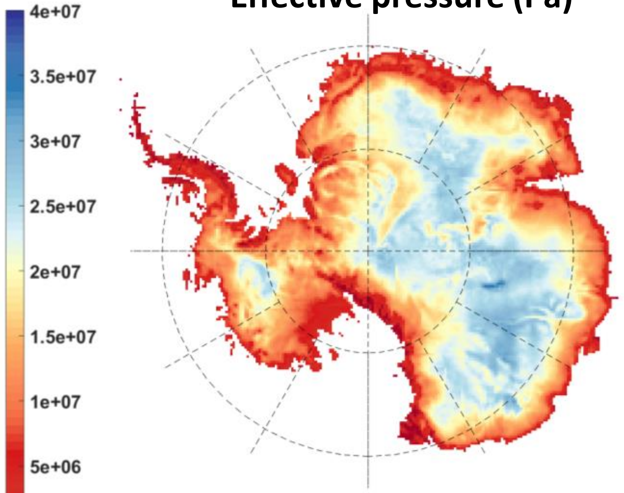
pw = subglacial water pressure

rho = ice density

g = gravity acceleration

H = ice thickness

Effective pressure (Pa)



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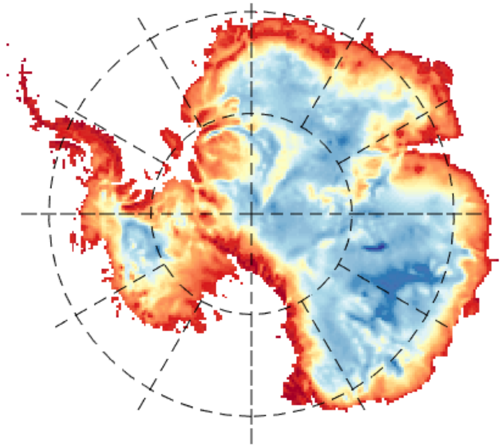
Overburden pressure (Pa)



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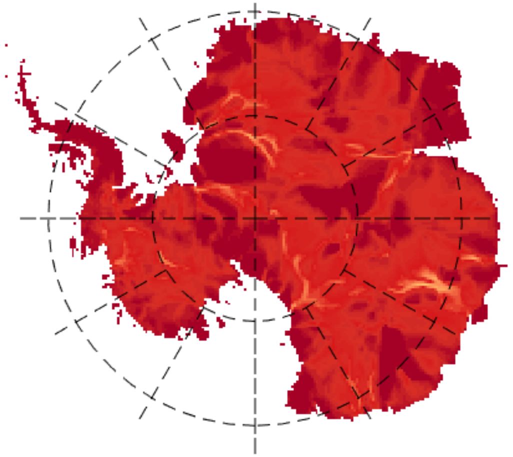
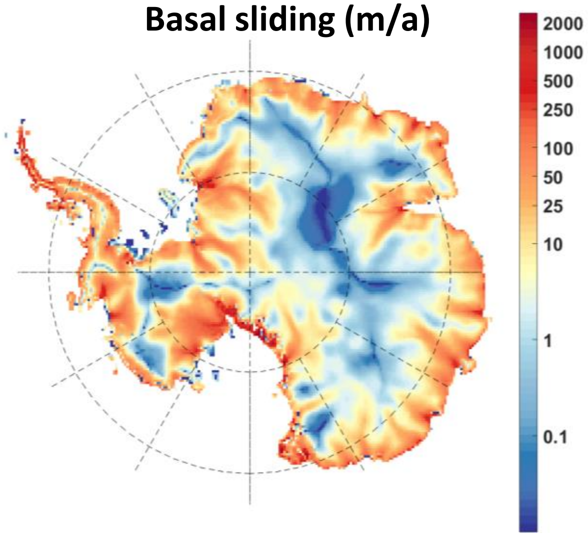
Subglacial water pressure (Pa)



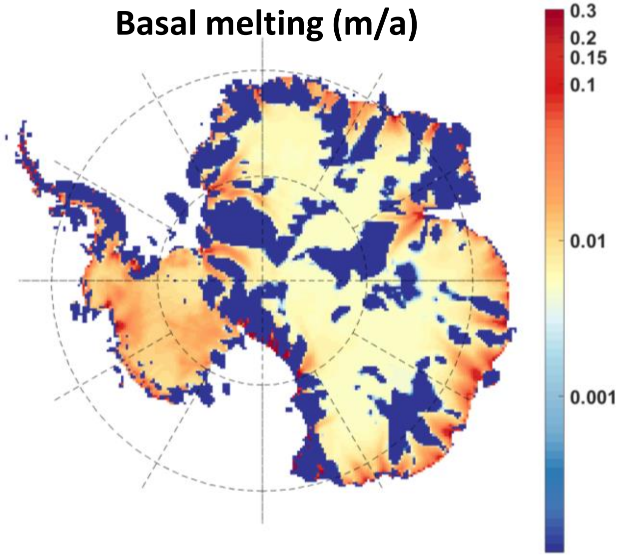
$$pw = 0.95 * \rho g h * (W/W_{max})$$

0.95 = fixed fraction of the po
W = stored liquid water thickness
W_{max} = max satured till thickness (fixed at 2m) which has an impact on the till weakening by pressurized water

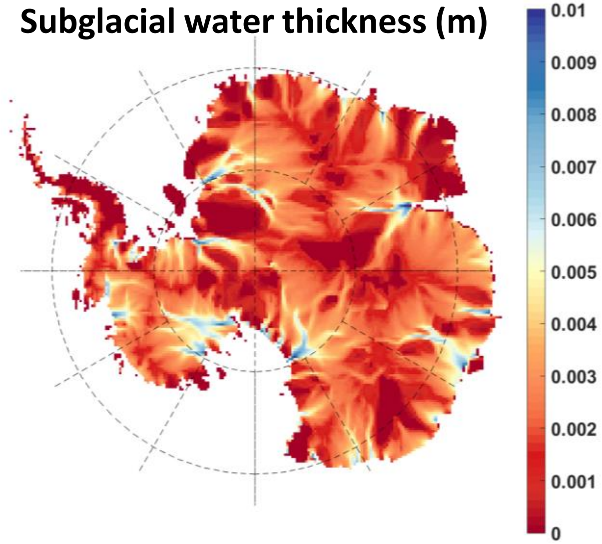
Basal sliding (m/a)



Basal melting (m/a)



Subglacial water thickness (m)



Subglacial water pressure is a function of the subglacial water thickness.

The figures show different parameters after an optimization in a power-law basal sliding with m = 2.

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$$\underline{N_{eff}}=N_0 * (\delta po/N_0)^s 10^{(e0/Cc)(1-s)}$$

OPTION 3 (Bueler and van Pelt, 2015)

e_0 = void ratio at a reference effective pressure N_0

δ=0.02

Cc = coefficient of compressibility of the till

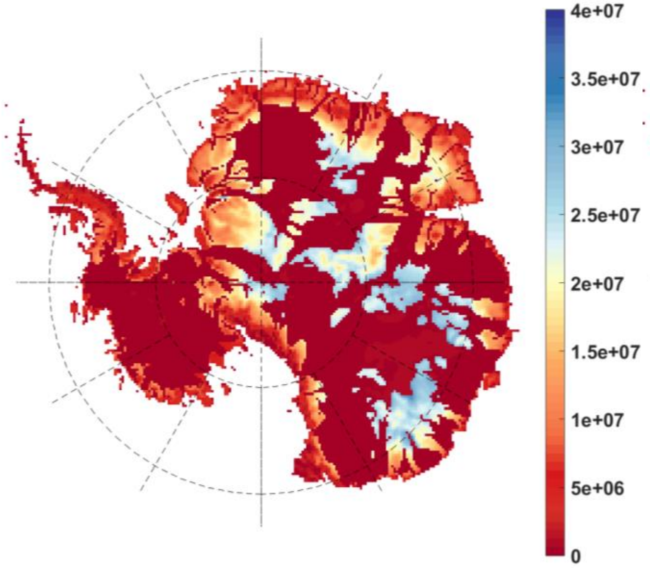
s = **Wtil** /Wmax

Wtil = active till layer thickness

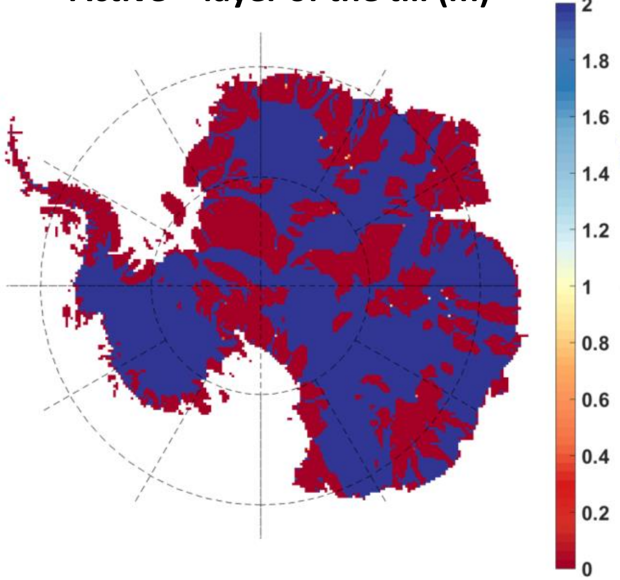
Wmax = max satured till thickness

with boundaries N = min {po,N}

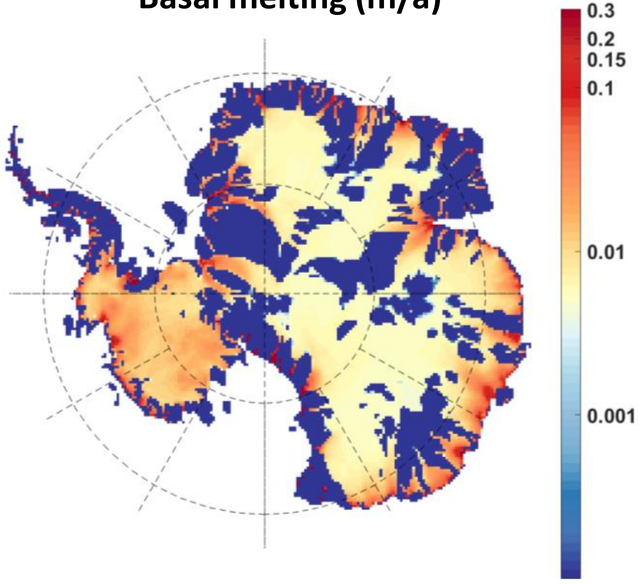
Effective pressure (Pa)



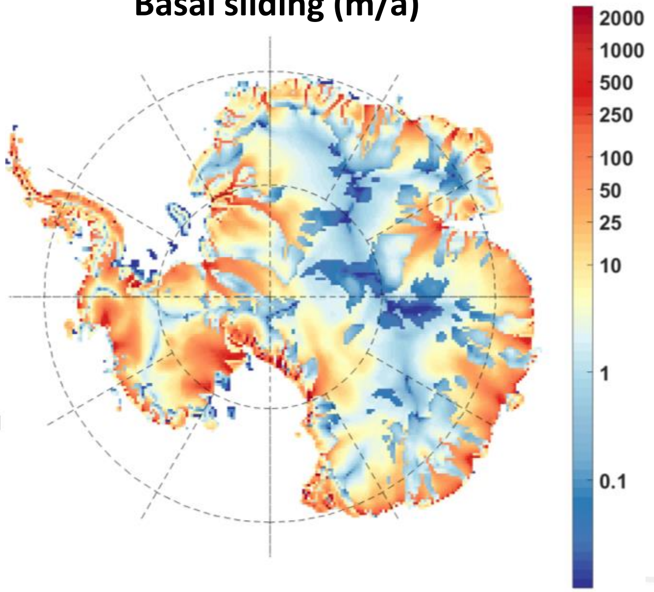
« Active » layer of the till (m)



Basal melting (m/a)



Basal sliding (m/a)



→ N_{eff} in the case of a deformable bed composed by a permeable till

→ Hydrological model of subglacial water drainage <u>within</u> an active layer of the till : W_{til}

The figures show different parameters after an optimization in a power-law basal sliding with m = 2.

OPTION 4 (Goeller et al., 2013)

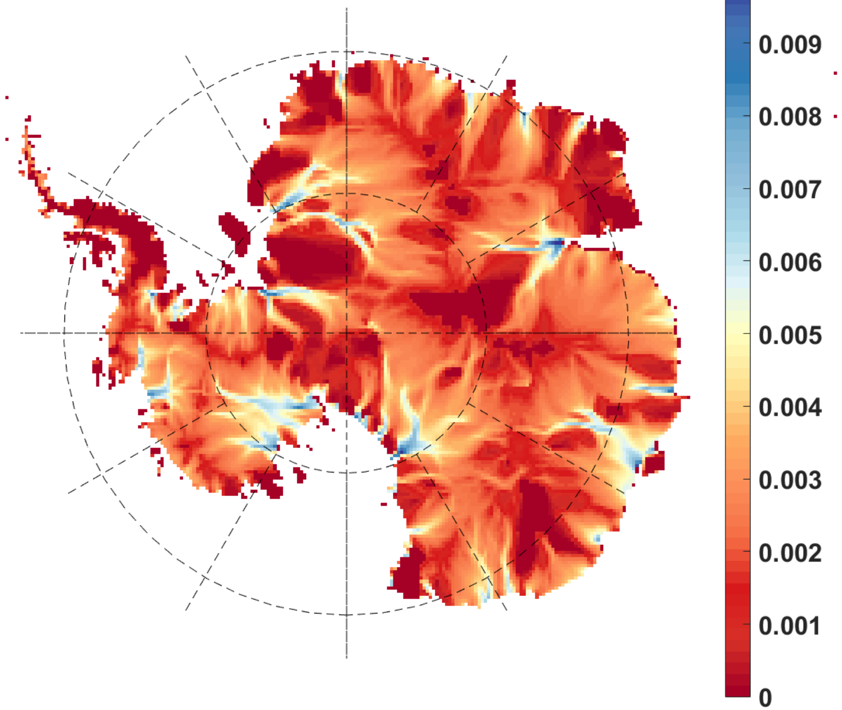
$$A(\phi) = A_0 * \exp^{-(\phi/m\phi 0)}$$

Φ = subglacial water flux

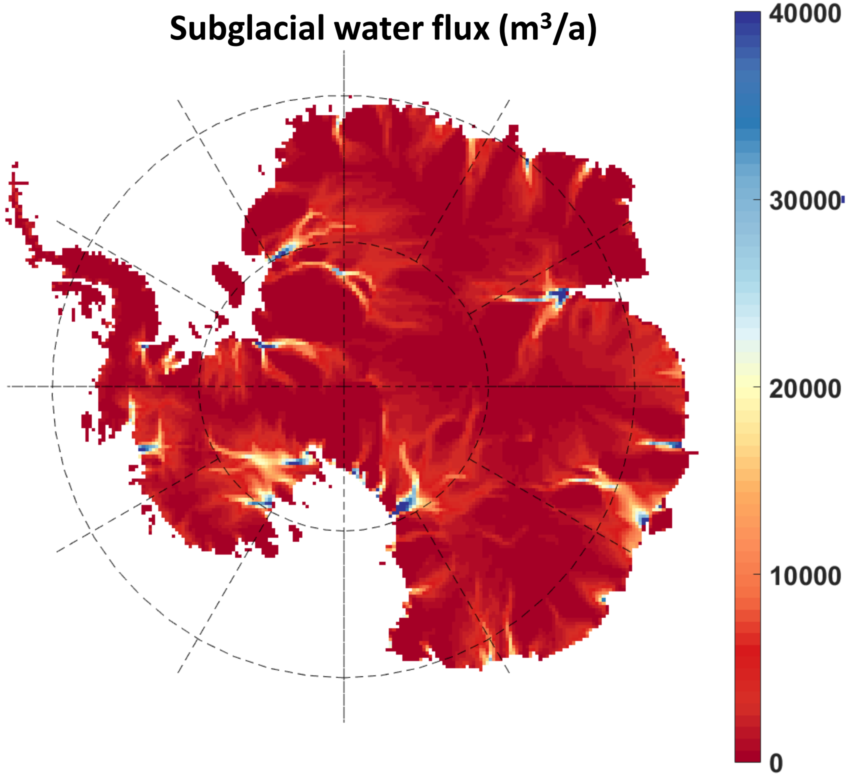
A = basal sliding factor

m = sliding law exponent

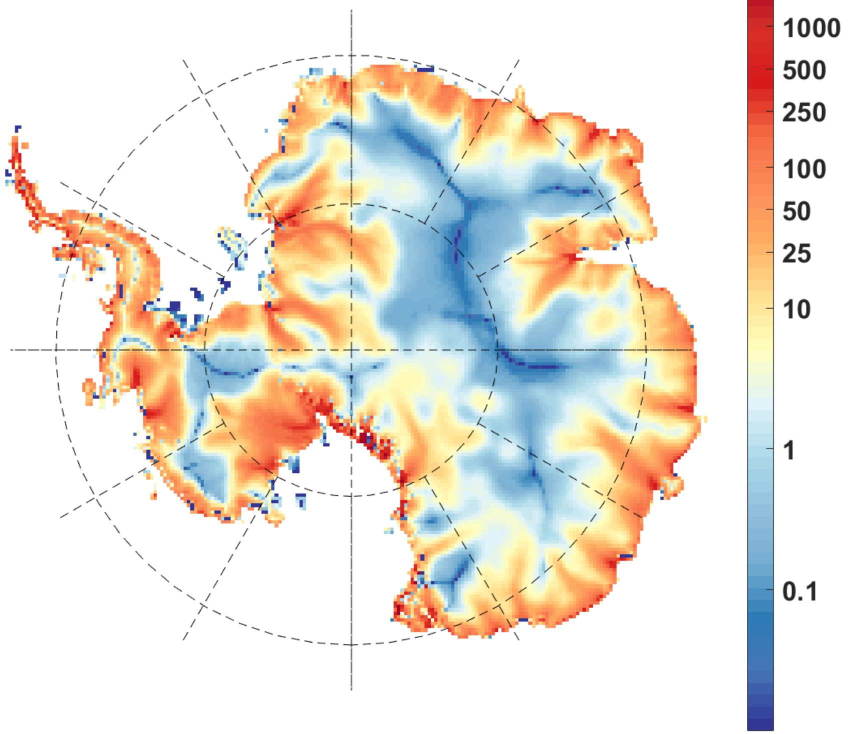
Subglacial water thickness (m)



Subglacial water flux (m³/a)



Basal sliding (m/a)



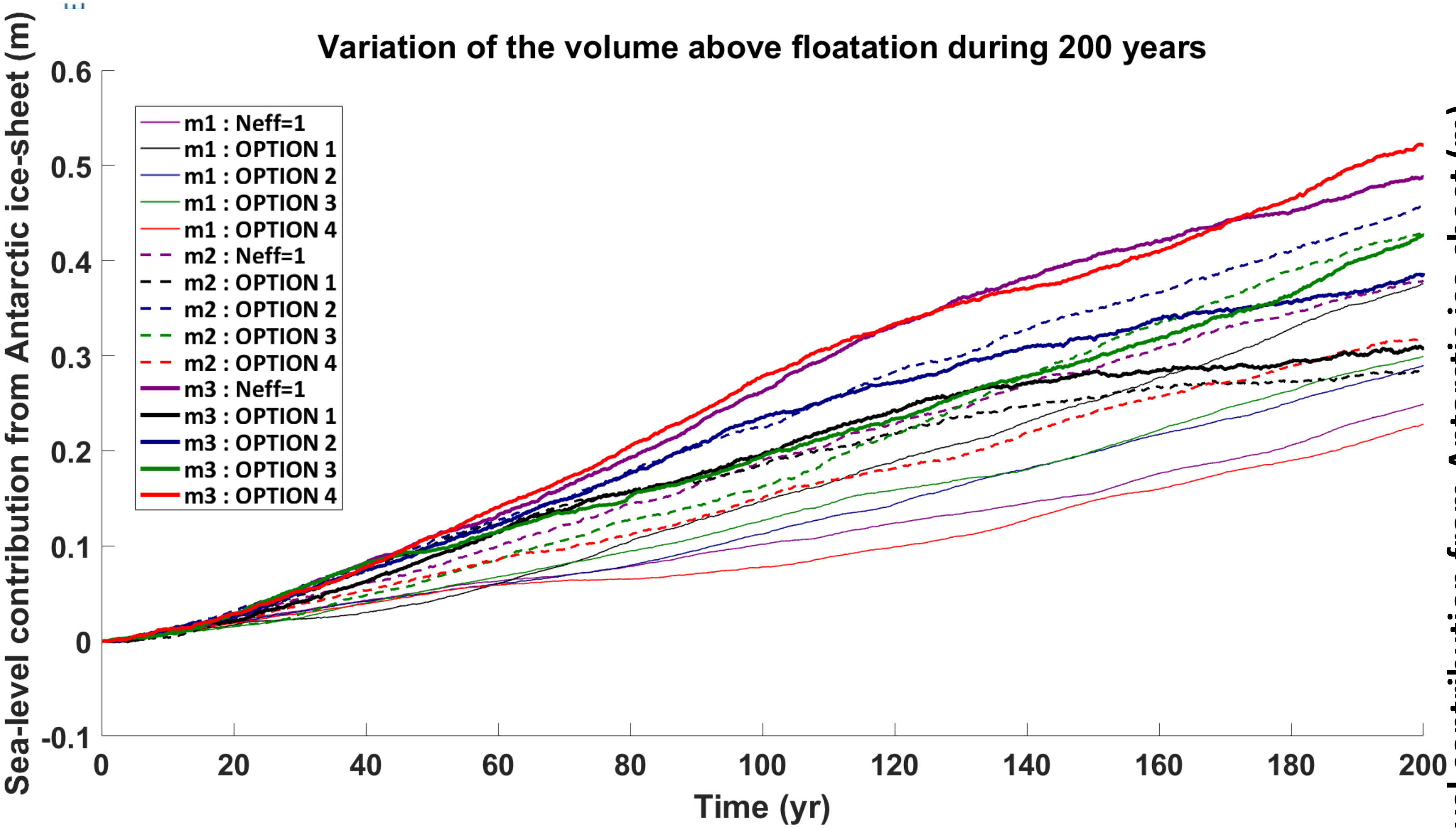
The figures show different parameters after an optimization in a power-law basal sliding with m = 2.

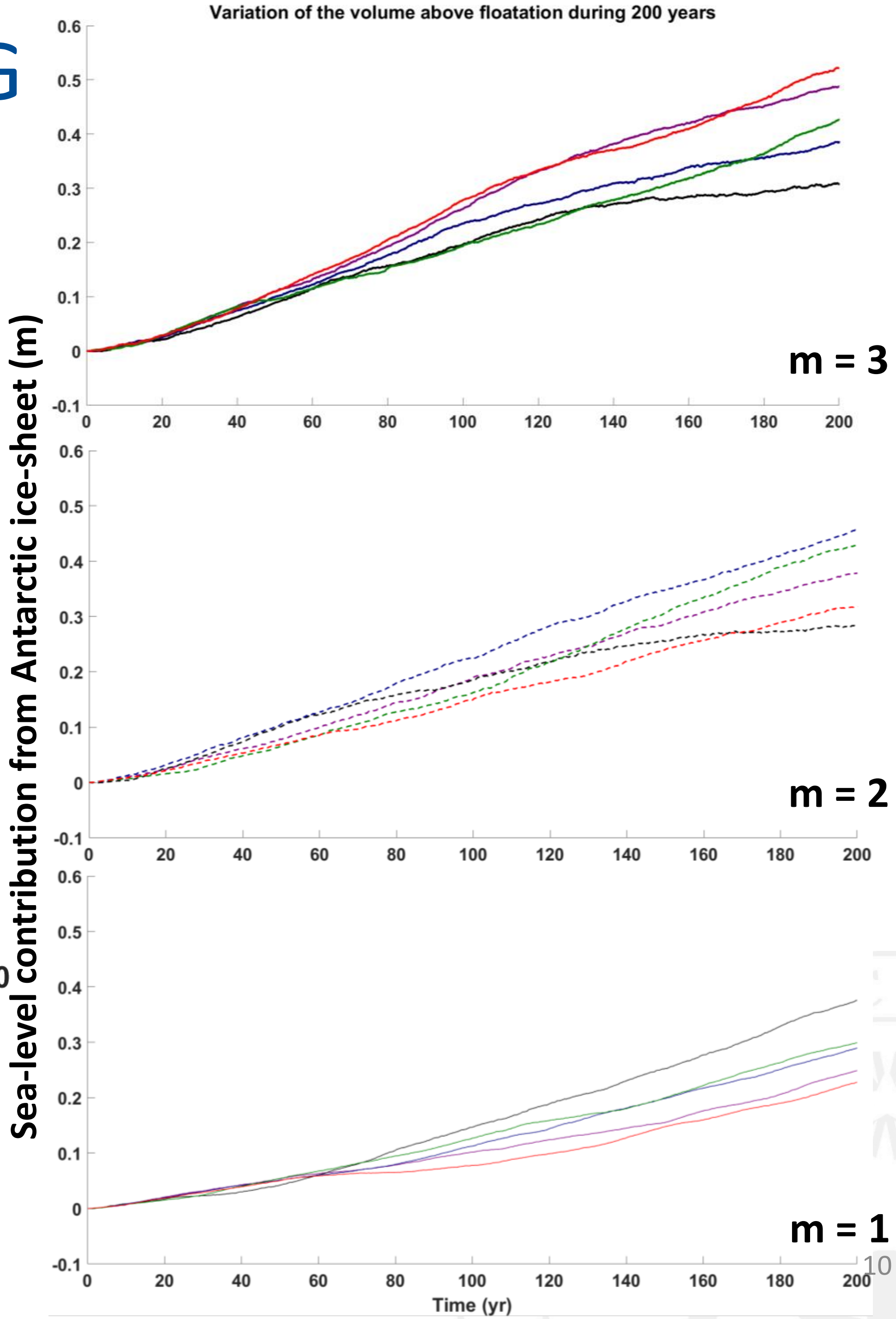
EXPERIMENTAL SET-UP

For each of our hydrology-sliding coupling options:

- Forward **200-yr** simulations, starting from present day configuration and forced by subglacial shelf-melt using the **PICO model** (Reese et al., 2018a) enhanced by factor 2 and 4.
  - Model initialised for present-day conditions through **optimization of basal coefficients** (Pollard and DeConto 2012b, Pattyn, 2017);
  - **Input data: present day** ice-sheet geometry (Bedmachine), surface mass balance (RACMO2), surface temperature (RACMO2) and geothermal heat flux (Shapiro and Ritzwoller);
  - **25 km** resolution.

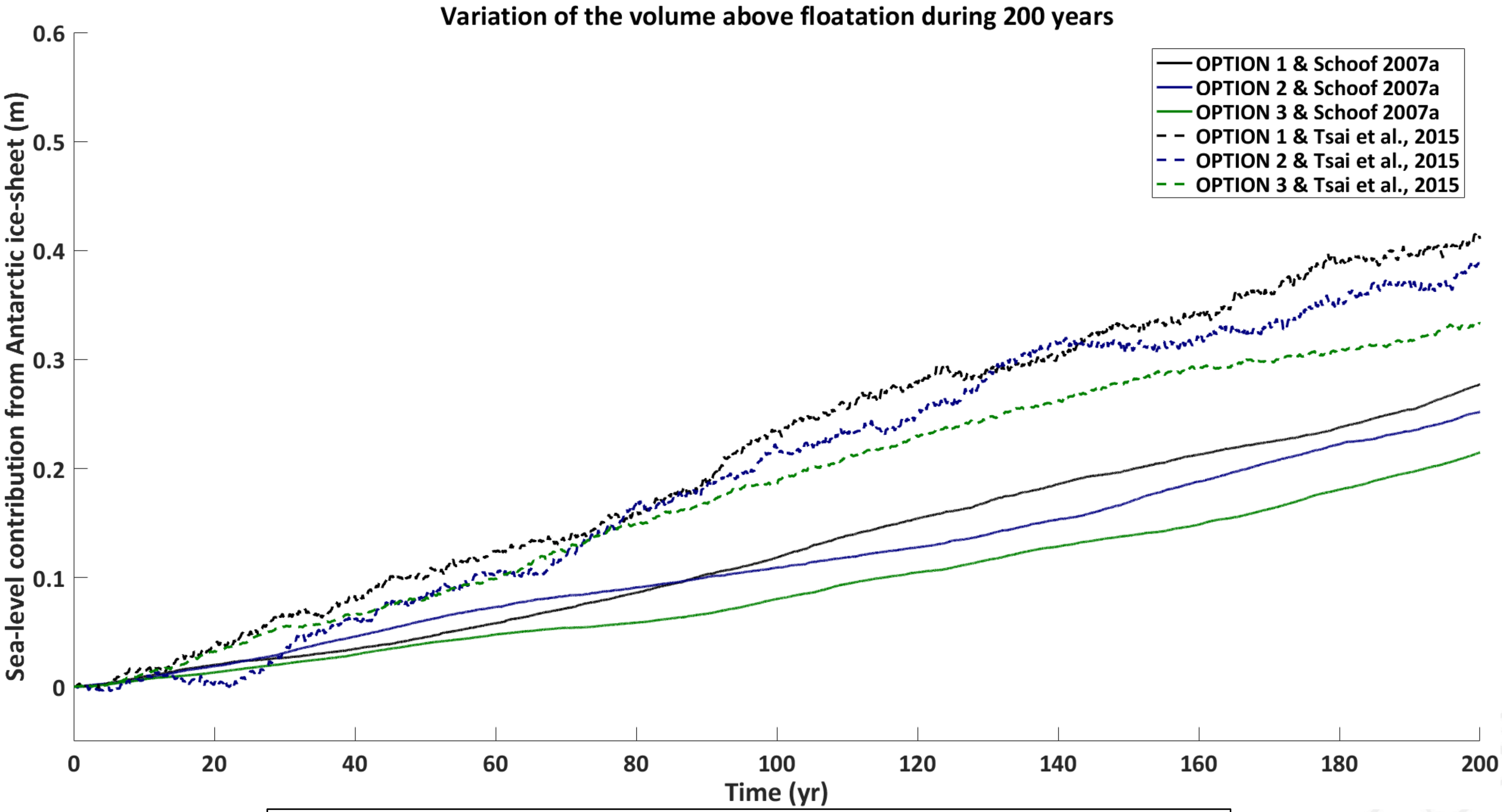
RESULTS: POWER-LAW SLIDING





- The variation of the **volume above floatation** is a good indicator of **ice-sheet sensitivity**
- To avoid the signal of different optimizations, we substracted the forcing experiment enhanced by factor 2 to the forcing experiment enhanced by factor 4
- The **purple curve** represents an Neff=1, wich means **no effects of subglacial hydrology**

RESULTS : COULOMB FRICTION LAW SLIDING



- The variation of the **volume above floatation** is a good indicator of **ice-sheet sensitivity**
- To avoid the signal of different optimizations, we substracted the forcing experiment enhanced by factor 2 to the forcing experiment enhanced by factor 4

CONCLUSION

Recent studies show that the **ice sheet sensitivity** increases with the **sliding law power** or the use of a **Coulomb friction law**.

Coupling with subglacial hydrology exhibits a more **complex relationship**.

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