EGU General Assembly
23-27 May 2022
Vienna, Austria & Online

Celebrating 30 years of integrated climate impact research at the Potsdam Institute.

The evolution of future Antarctic surface melt using PISM-dEBM-simple

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Scan for abstract

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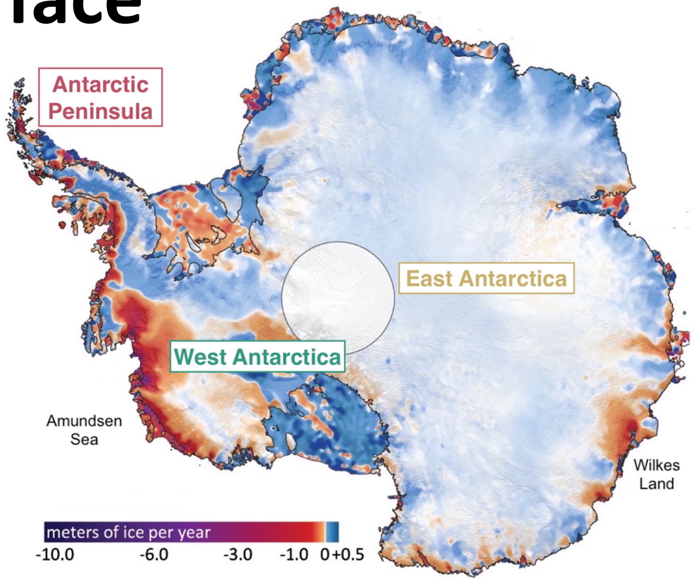
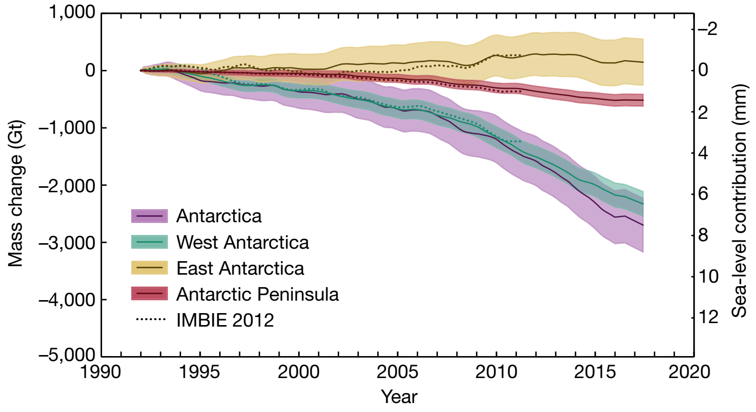
Antarctica is losing mass…
…but only little from the surface

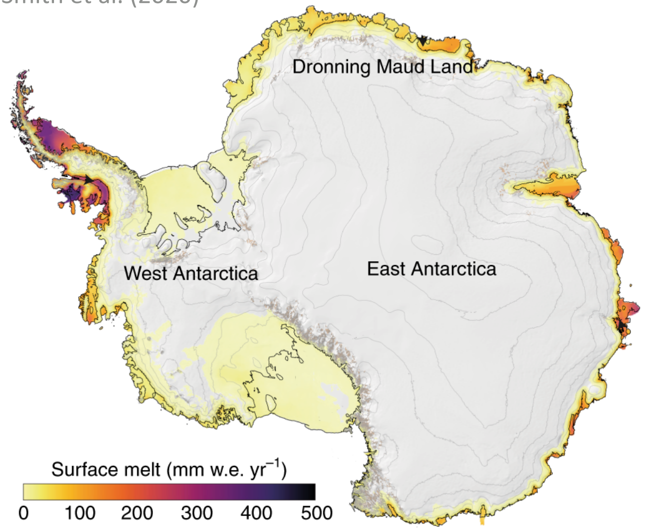
- Overall mass changes currently dominated by **Amundsen Sea Embayment sector of West Antarctica**, driven by **sub-shelf melting** and **ice discharge**
- **East Antarctica** close to balance, but contribution to overall mass change slightly positive in recent decades, as mass losses are compensated by enhanced snowfall
- Any **surface melt** restricted to low-elevation coastal zones **(Antarctic Peninsula & shelves)**, because average surface temperatures too low over most parts of the ice sheet



Smith et al. (2020)



IMBIE (2018)

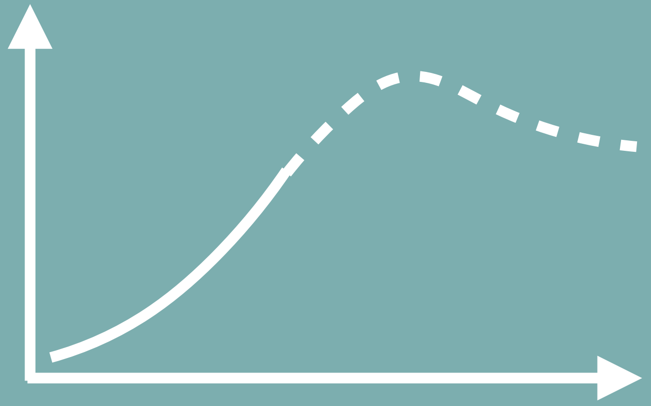


QuikSCAT / Bell et al. (2018)

Q: How is the surface mass balance going to change in the future?

- In 21st century projections, **increasing surface mass balance in East Antarctica outweighs increased discharge** even under high-end forcing scenarios
- However, in long-term warming simulations positive **surface mass balance trend shows peak and subsequent reversal**

  (e.g. Golledge et al., 2015; Golledge, 2020; Garbe et al., 2020)



Positive feedback mechanisms: Increased sensitivity to changes

- Owing to **melt–elevation feedback**, this effect can be enhanced once a surface lowering is triggered
- Melt also lowers surface reflectivity (albedo), in return causing more melt **(melt–albedo feedback)**
- Risk of **hydrofracturing** and/or **marine ice-cliff instability** driven by increased surface melt-water production

Thinning / surface lowering

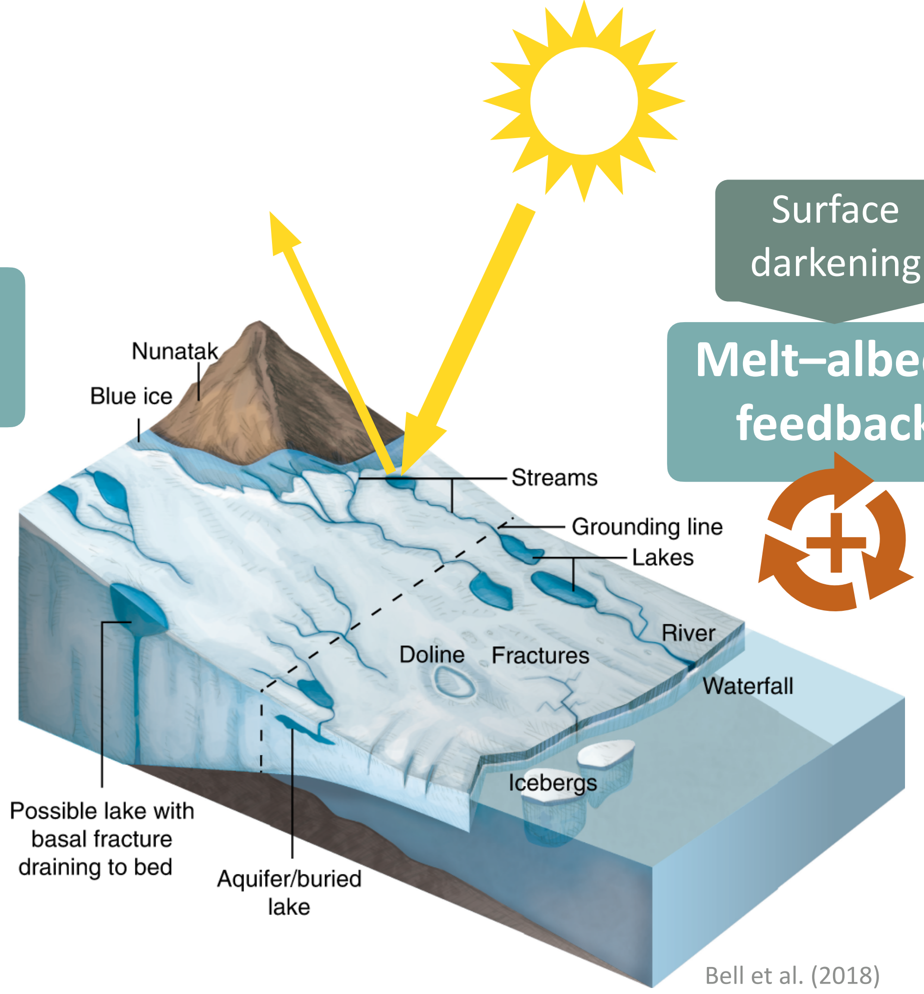
Melt–elevation feedback

Surface darkening

Melt–albedo feedback

Hydrofracturing

Marine ice-cliff instability



Bell et al. (2018)

“Filling the gap”: The diurnal Energy Balance Model (dEBM)

- Long-term simulations require fast models + need to account for feedbacks
- Gap between **process-based regional climate models** and **empirical temperature-index SMB schemes** in terms of computational efficiency versus physics-based process detail

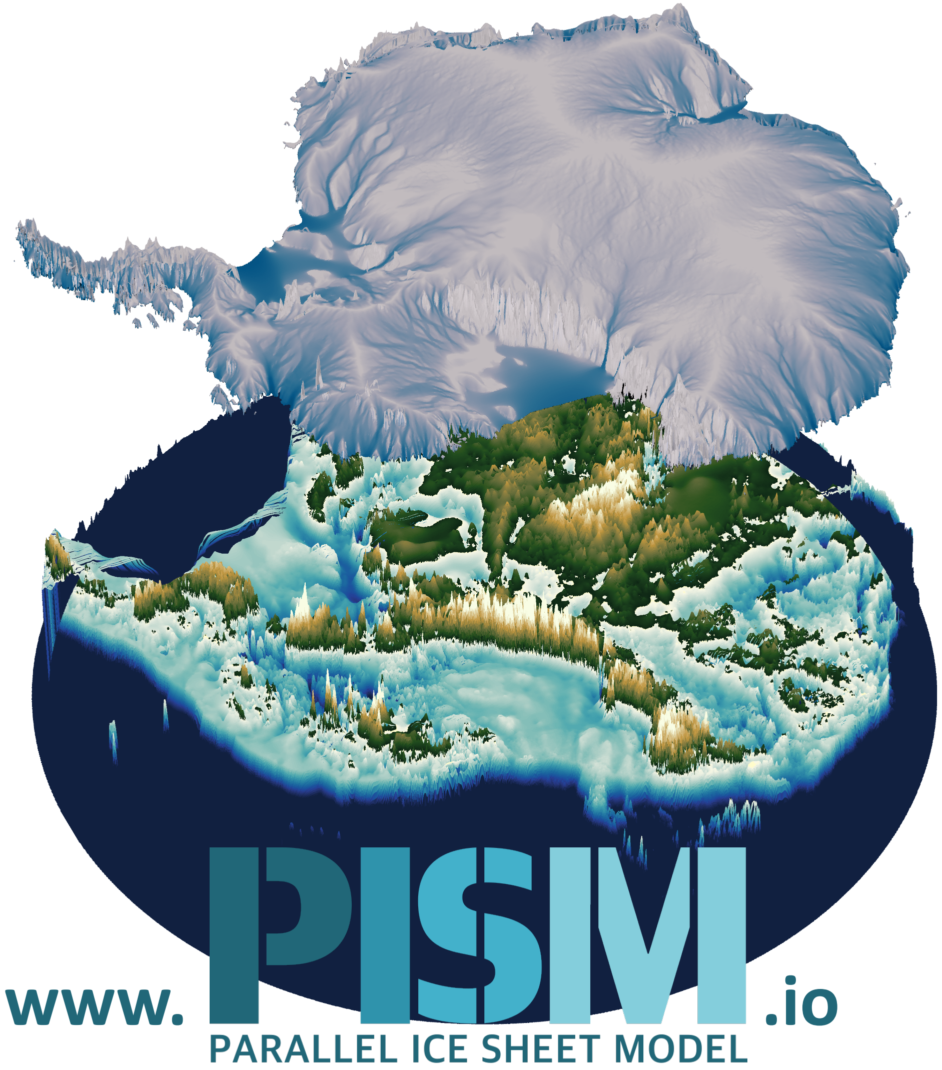
	Temperature-index schemes (e.g. PDD)	**dEBM-simple**	**RCMs** (e.g. RACMO)
Processes / feedbacks	🔴	🟡🟡	🟢🟢🟢
Comput. efficiency	🟢🟢🟢	🟢🟢🟢	🔴

- **dEBM-simple:** “simple” version of **diurnal Energy Balance Model** (Krebs-Kanzow et al., TC 2018; Zeitz et al., TC 2021)
  - ✓ Extends PDD approach to include influence of solar radiation
  - ✓ Atmospheric transmissivity parameterized based on surface altitude
  - ✓ Surface albedo parameterized as a function of melting, implicitly accounting for ice-albedo feedback
  - ✓ Requires only monthly temperatures and precipitation as input, yet accounts for diurnal energy cycle

$$M = \frac{\Delta t_\Phi}{\Delta t\,\rho_\mathrm{w}\,L_\mathrm{m}}\left[\overbrace{(1-\underset{\text{albedo}}{\alpha})\underset{\text{atm. transmissivity}}{\tau}\,\underset{\text{TOA insolation}}{SW_\Phi}}^{\text{insolation-driven melt}} + \overbrace{c_1\,T_\mathrm{eff}}^{\text{temperature-driven melt}} + \underset{\text{dEBM parameters}}{c_2}\right]$$

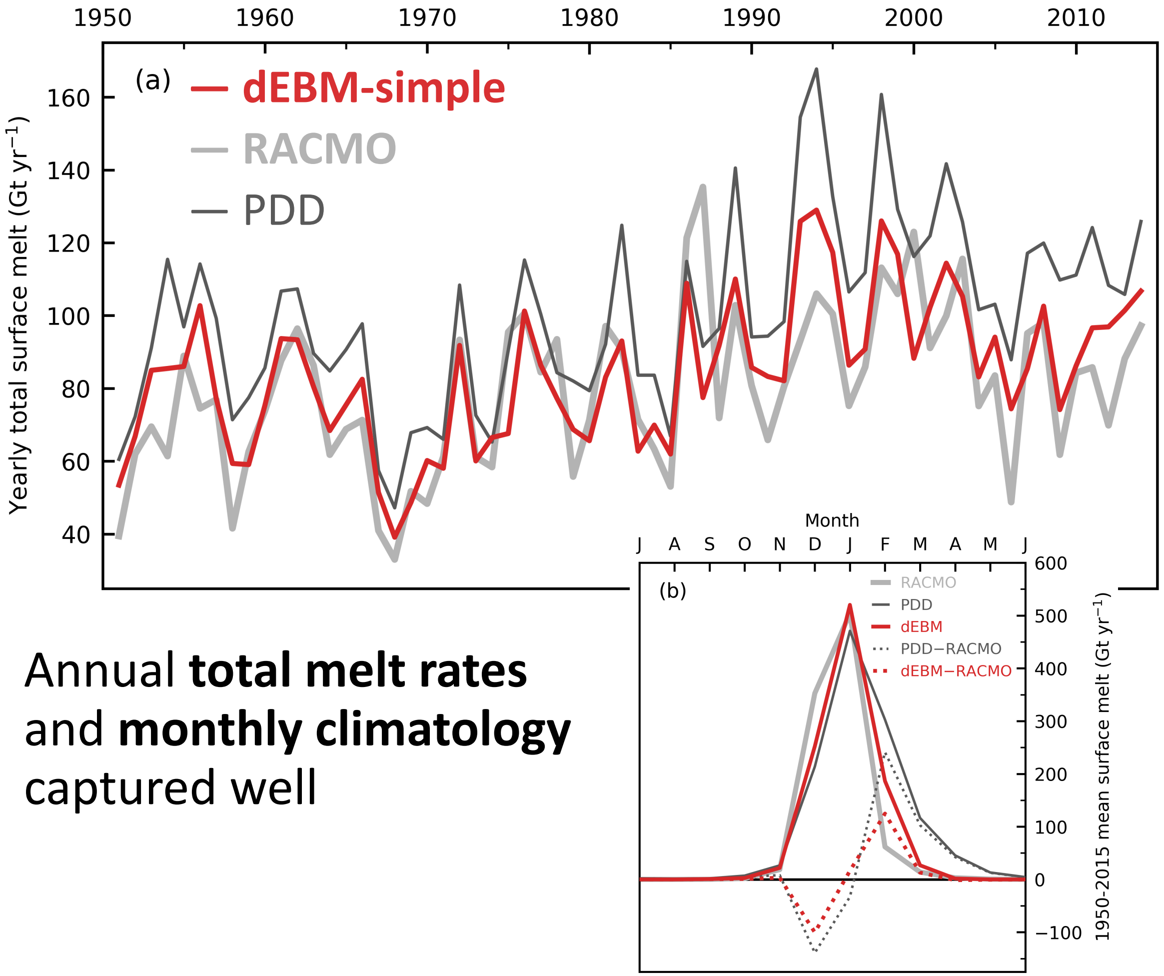
Ice sheet model framework:
The Parallel Ice Sheet Model

- We adopt dEBM-simple as surface mass balance module in the open-source **Parallel Ice Sheet Model (PISM)** and apply it in an Antarctic setup
    - Finite differences model
    - Regular grid (8 km)
    - Hybrid SIA + SSA ice flow
    - Thermo-dynamically coupled: ice temperatures and flow are solved
    - Includes: sub-shelf melt module, calving, GIA model, …



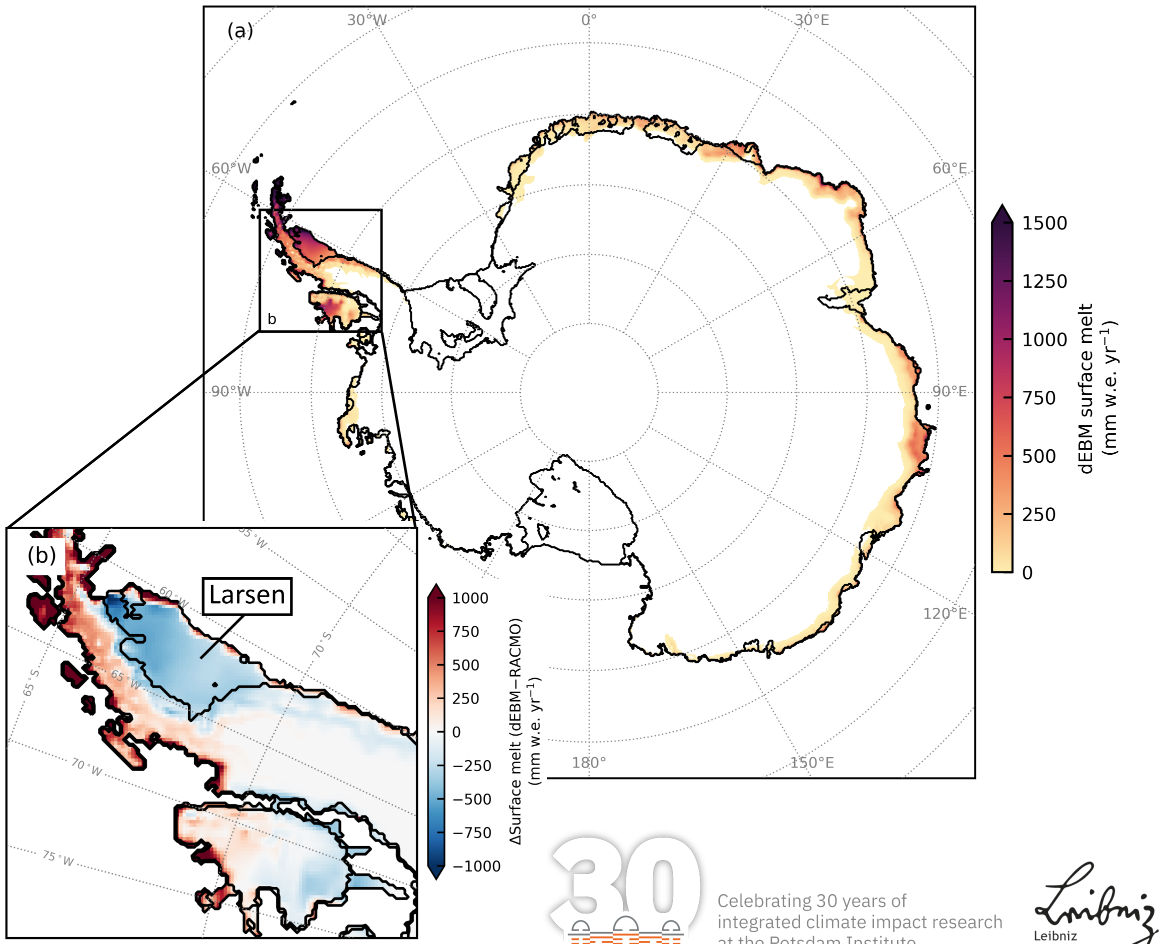
Calibration:
PISM-dEBM-simple reproduces Antarctic melt patterns

- Calibration to historical (1950-2015) melt patterns using RACMO



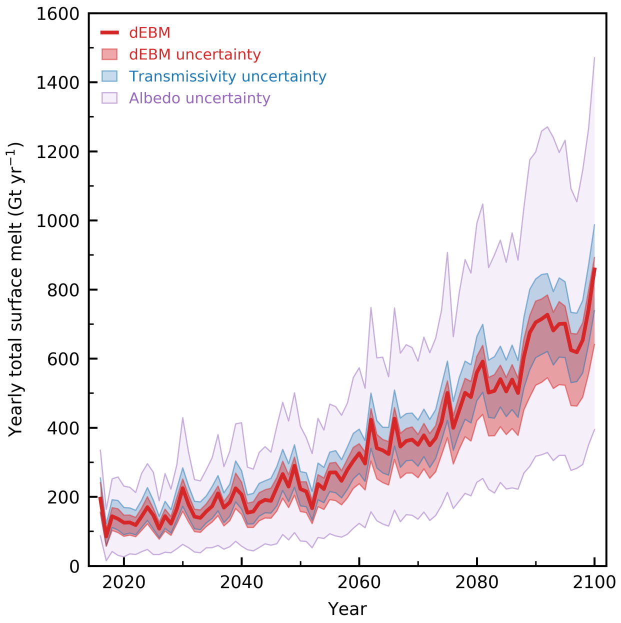
- Annual **total melt rates** and **monthly climatology** captured well

- Present-day (2005-2015 DJF mean) melt pattern close to RACMO; high melt rates slightly underestimated

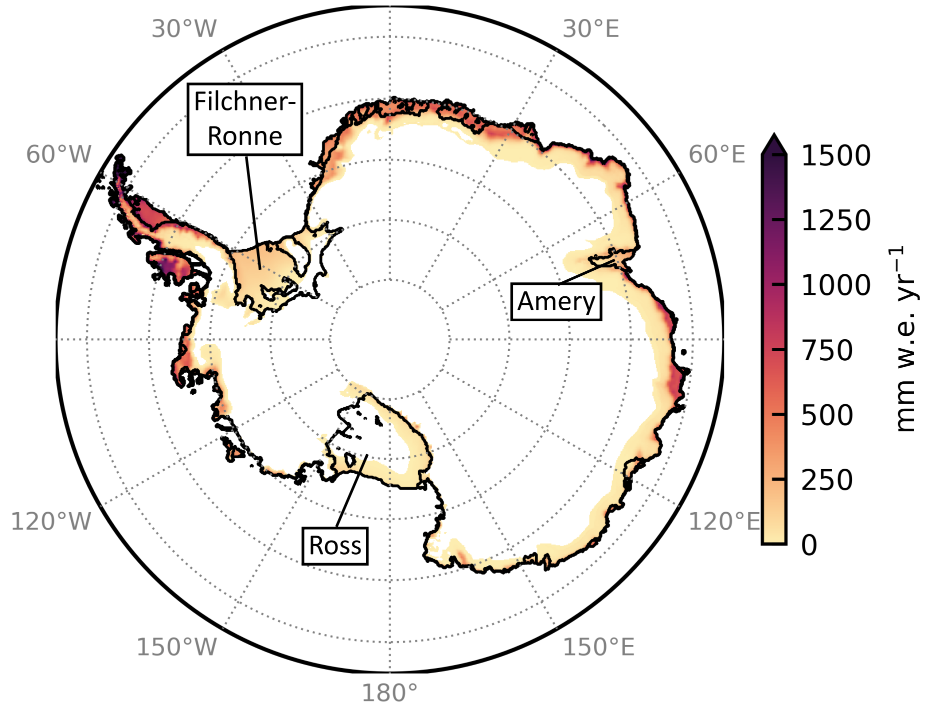


Idealized experiments:
Evolution of Antarctic surface melt until 2100

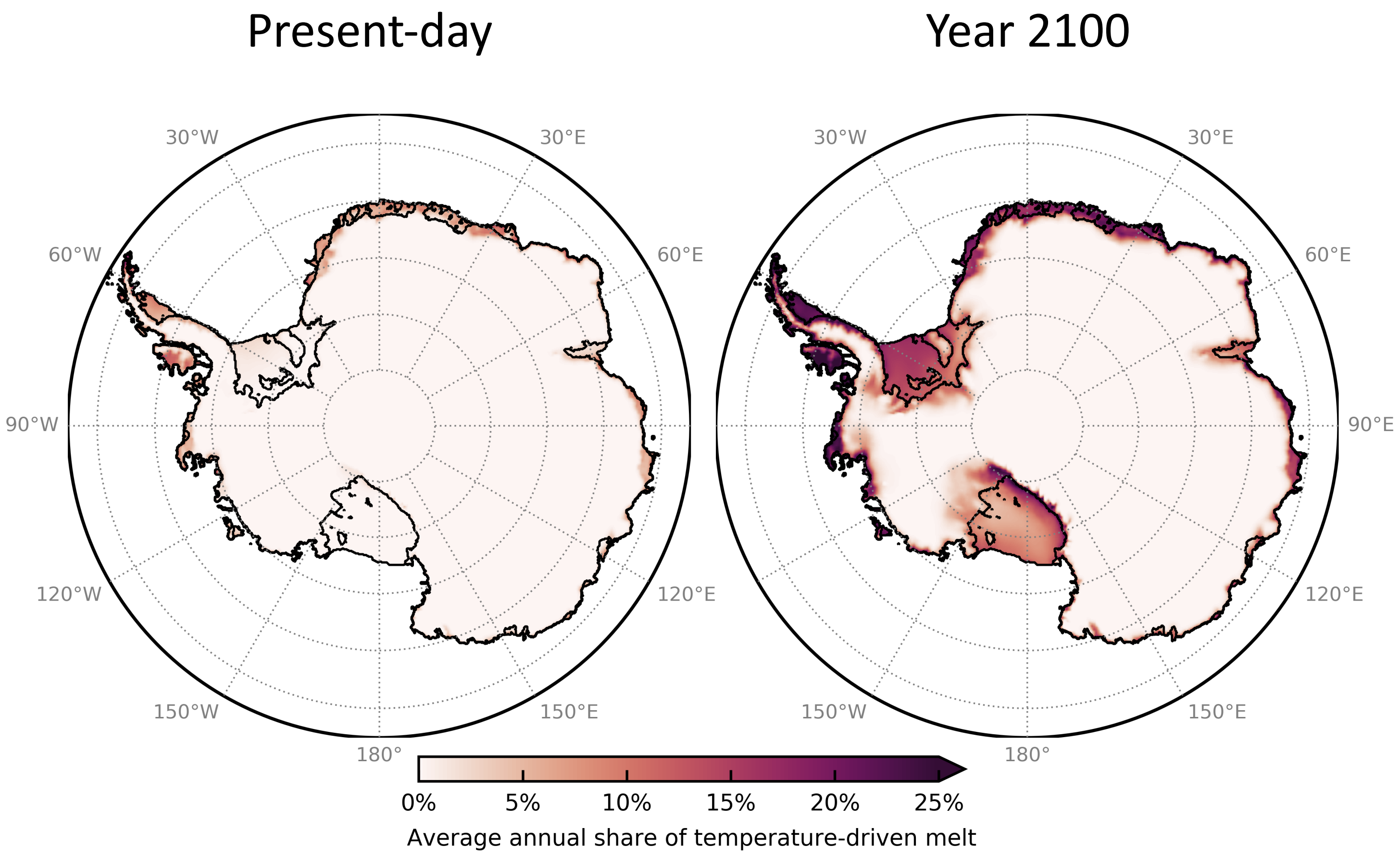
- **Idealized experiments:** prognostic 21^{st} century SSP5-8.5 simulations (no ocean warming!)
- Parametric uncertainty check via **sensitivity ensemble**
- **8-fold increase** in total surface melt in 2100 compared to today (reference run)
- Expansion of summer **melt area** to lower latitudes and higher elevations; large parts of Filchner-Ronne, Ross and Amery ice shelves
- **~140% increase** in total SMB
- However, considerable **uncertainty** of melt due to albedo parameterization



Year 2100



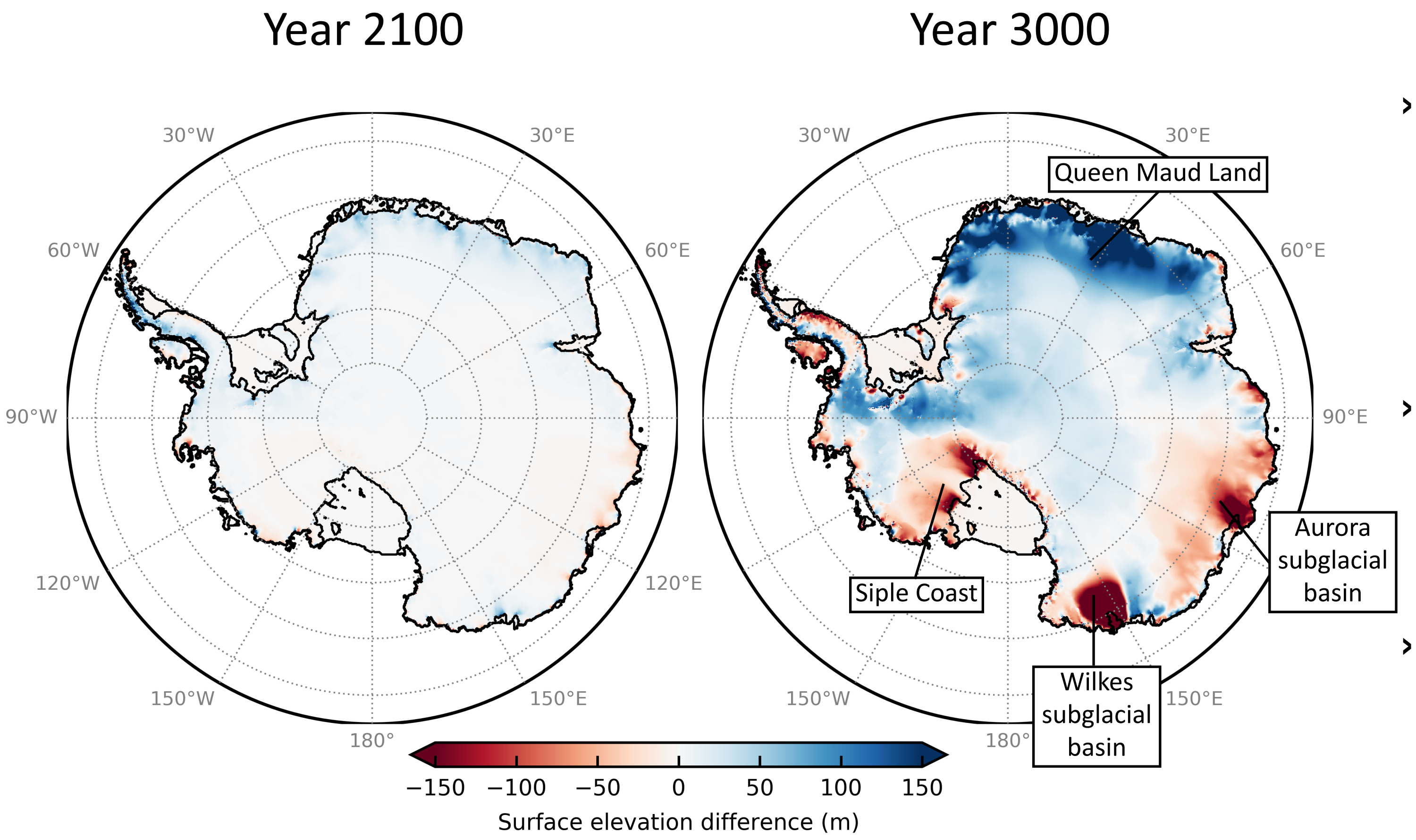
Temperature versus insolation: Increasing role of temperature-driven melt share



- On average, **insolation-driven melt** dominant over most parts of the ice sheet, as interior too cold
- At present, relative share of **temperature-driven melt** in total melt comparatively small, however, increases significantly (in magnitude and extent) by 2100

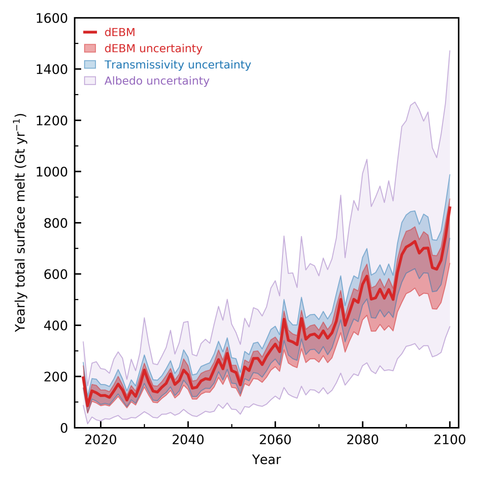
Long-term experiments:
Effects of enhanced surface melt on the ice sheet

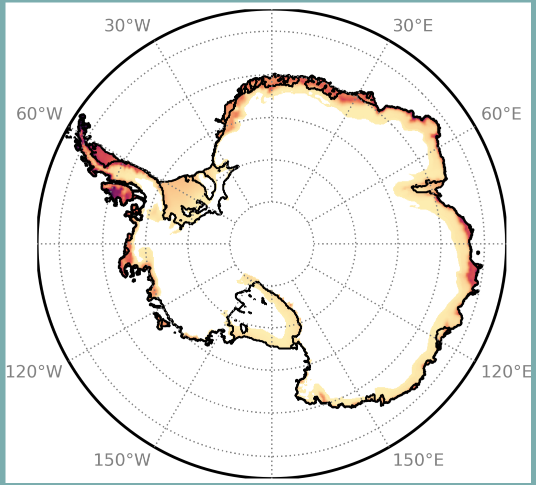
Results

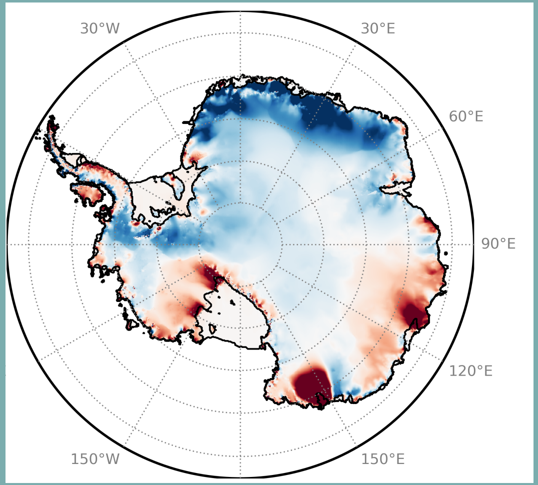


- Extending simulations at fixed end-of-century climatic boundary conditions until year 3000 reveals **strong influence of surface melt on ice topography & dynamics**
- Large-scale **reduction of surface altitude** in sensitive ice sheet regions in East and West Antarctica
(see also Golledge et al., GRL 2017)
- Enhanced by interplay of **melt–albedo feedback** as well as **melt–elevation feedback**

Take home:
Feedbacks matter on long time scales!







Finally…

- 📄 Manuscript in preparation *The Cryosphere*, to be submitted soon!
- 👨‍💻 Code will be made publicly available on GitHub / Zenodo
- ✍ Any questions? See online material or contact me: julius.garbe@pik-potsdam.de
  www.pik-potsdam.de/members/garbe/

Thanks!