# Is West-Antarctica's Tipping Point a Fixed (Forcing) Value?

## Rate-Induced Tipping of the West-Antarctic Ice Sheet

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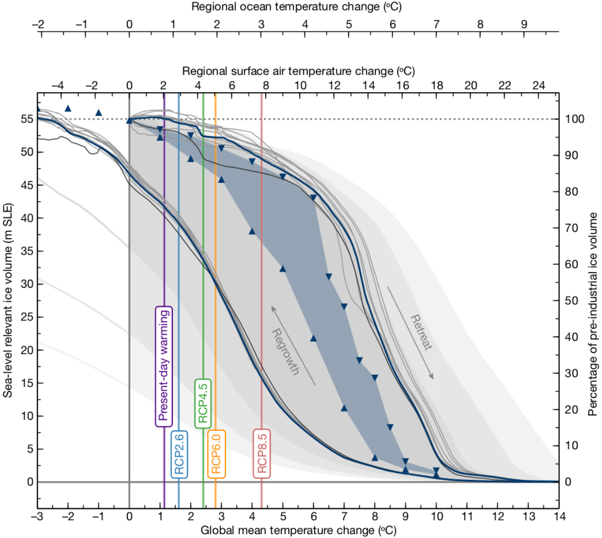
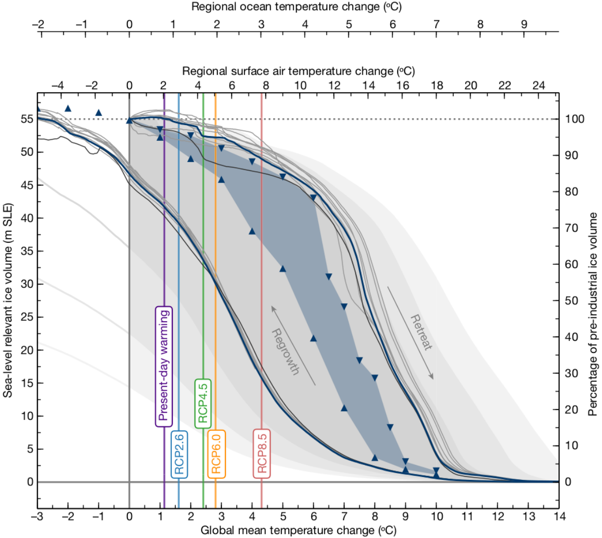
Institution: CriticalEarth, Universidad Complutense de Madrid




1: Hysteresis of the Antarctic Ice Sheet (AIS), as presented in [1].

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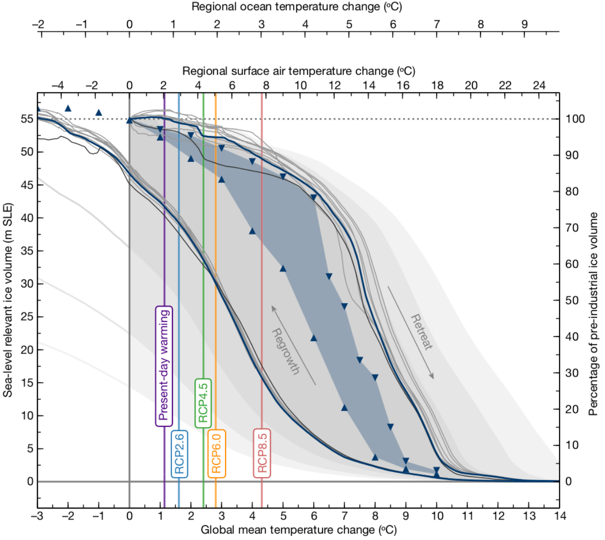
Focus on West-Antarctic Ice Sheet (WAIS)

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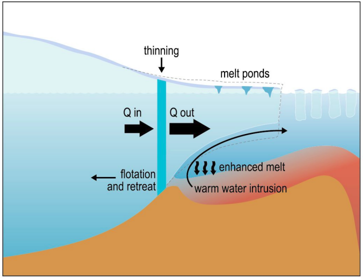
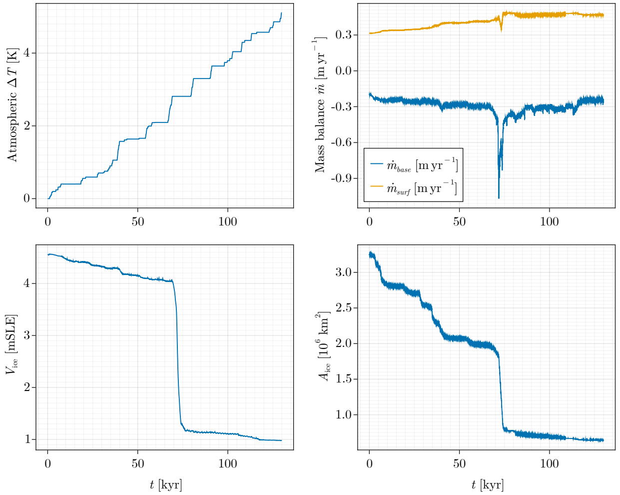



2: Schematic representation of marine ice-sheet instability [2].

Run equilibrium experiments on Yelmo [3], a state-of-the-art ice-sheet model.




3: Quasi-equilibrium forcing experiments (left) & resulting bifurcation diagram (right).

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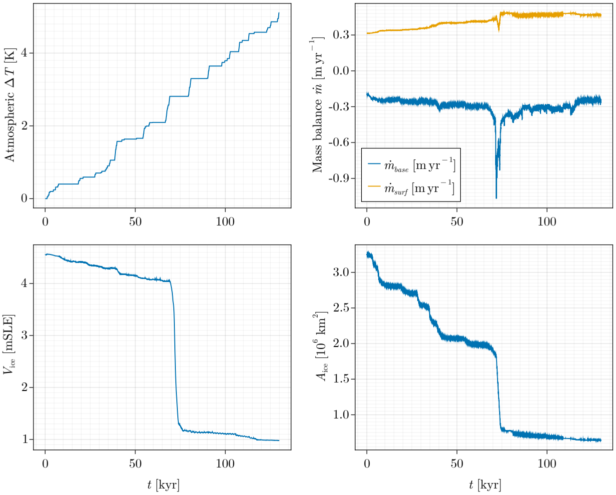


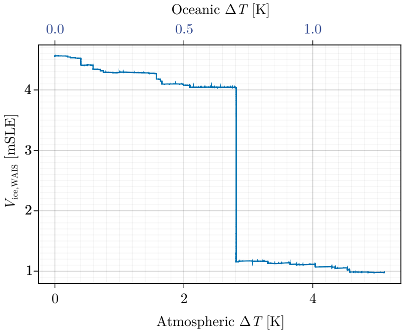


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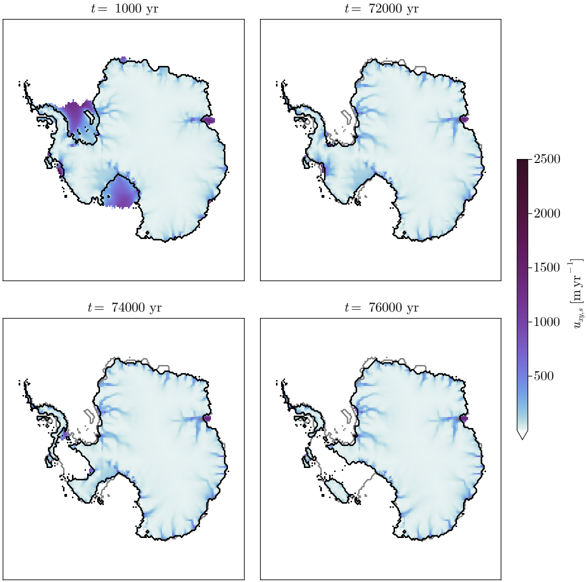
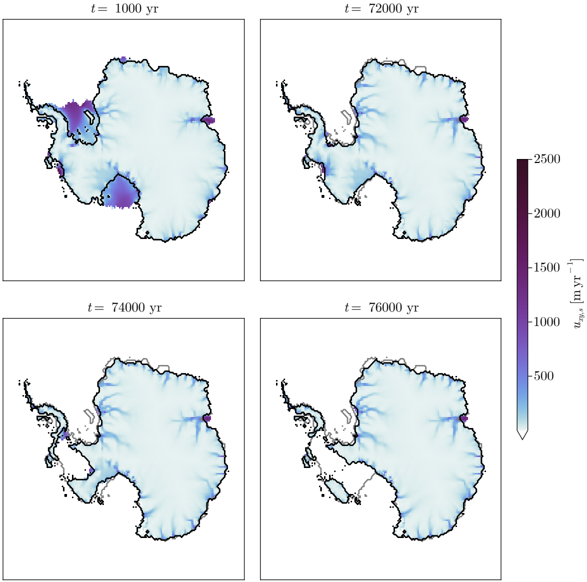



4: Velocity profiles of quasi-equilibrium experiments over AIS.

Amundsen region:

- Retrograde bedrock below sea level.
- No large shelves.
- Present-day observation of Antarctica: largest rate of ice loss recorded in Amundsen.

**Collapse in accordance with theory and observations!**

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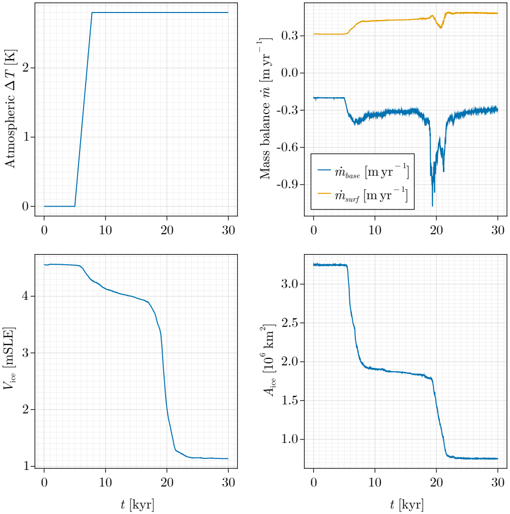
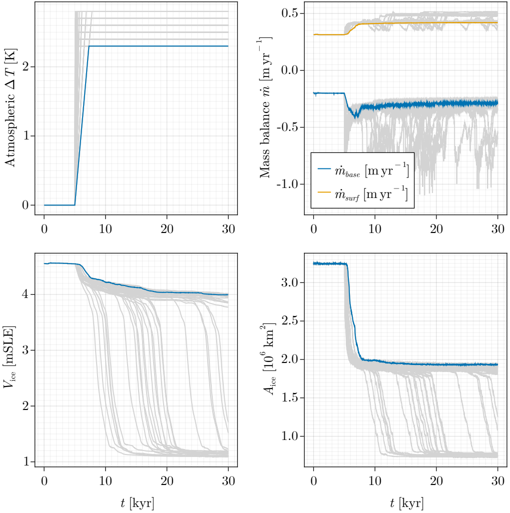
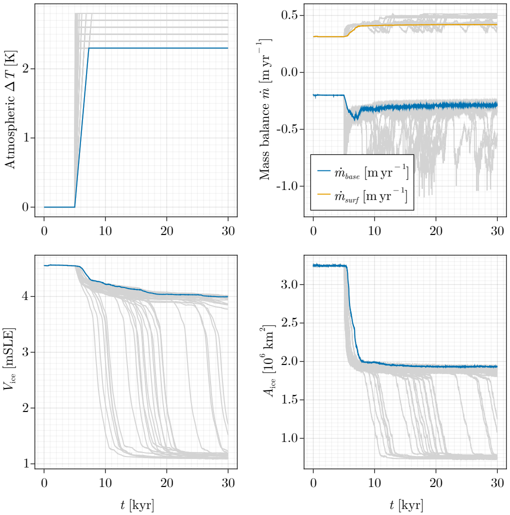



5: Exemplary run of a ramp experiment.




6: Ensemble results of a ramp experiments.

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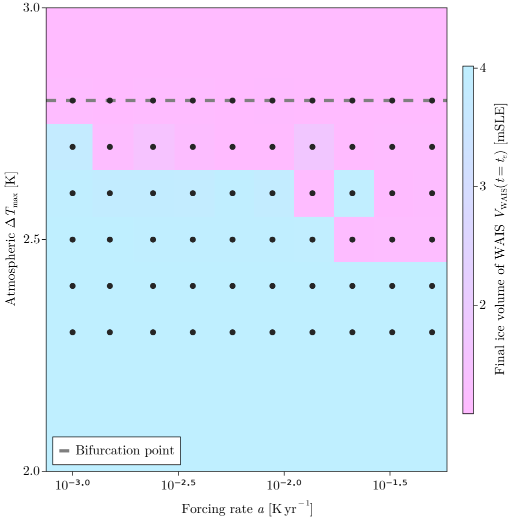
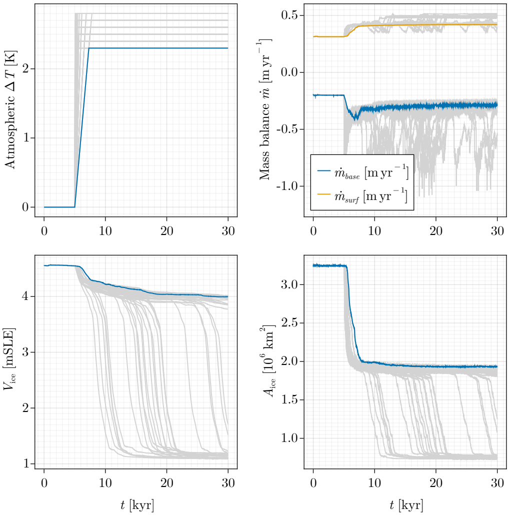



7: Rate-induced tipping in the ramp-parameter space.

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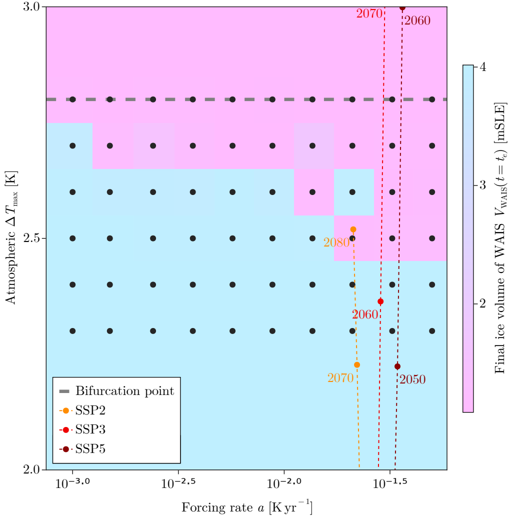


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Summary:

- Bifurcation: local oceanic $\Delta T = 0.7\,\mathrm{K}$, $\Delta V \simeq 3\,\mathrm{mSLE}$.
- Rate of WAIS-melting more than 4 times higher than present-day observations for total AIS.
- **Rate-induced tipping: $\Delta T$ 10% lower than bifurcation point and WAIS still tips**.
- **Human-made climate change: forcing rates that are large enough for effective lowering!**

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Thanks for your attention!

# References

[1] Julius Garbe, Torsten Albrecht, Anders Levermann, Jonathan F. Donges, and Ricarda Winkelmann.
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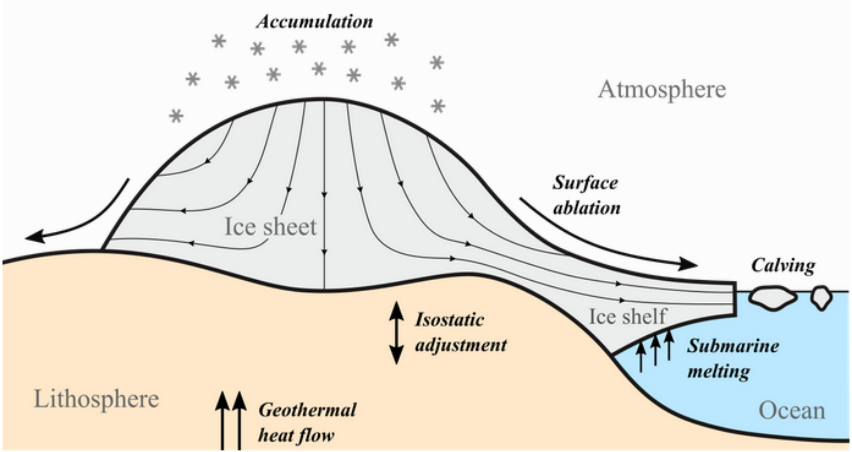
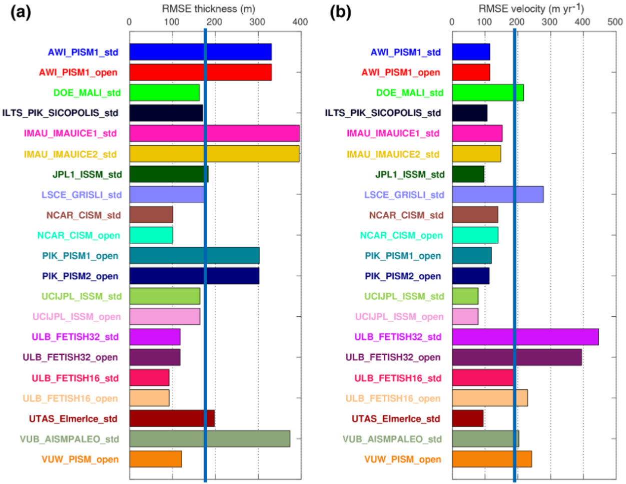
# Appendix



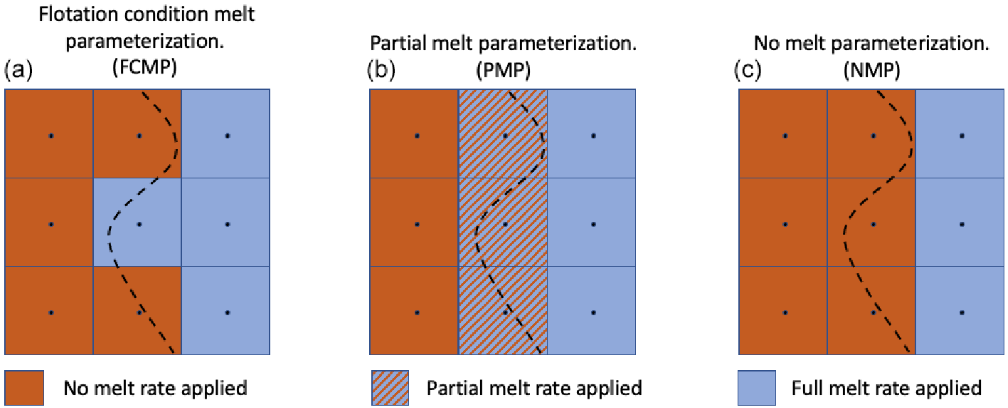

8: Schematic interactions at ice sheet boundaries [4].

YELMO 1.75:

- Thermomechanics solved with finite-difference.
- Resolution $\Delta x = 32\,\mathrm{km}$, adaptive $\Delta t$.
- Stand-alone $\rightarrow$ no ice-albedo and sea-level feedback. Other major feedbacks represented.
- Apply temperature anomalies to atmosphere, scale them to ocean with factor $\gamma = 0.25$.




9: Root-mean-square errors of ISMIP6 models [5].




10: Melt parametrisation options [6].

$$m_{\mathrm{GLP}} = \begin{cases} m & \text{If cell floats} \\ 0 & \text{Else} \end{cases} \tag{1}$$

$$m_{\mathrm{GLP}} = \phi_f^c \, m \tag{2}$$

Whenever cell partly grounded:

$$m_{\mathrm{GLP}} = 0 \tag{3}$$