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The effects of climate uncertainty on the stability of the Antarctic ice sheet during the mid-Pliocene warm period

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In the framework of the Geo.Sim education program.

Introduction

The stability of the Antarctic ice sheet during warmer-than-present time periods is still a matter of debate. While the vulnerability of the West Antarctic ice sheet under warmer climates receives support from both paleo-data and modeling studies, potential response of the East Antarctic ice sheet is less clear. In this context, the mid-Pliocene warm period serves as an ideal interval for studying the behaviour of the ice sheet under conditions comparable to those projected for the end of this century.

Methods

We use the ice sheet-shelf model SICOPOLIS (Sato and Greve, 2012, de Boer et al., 2014) to simulate the geometry and dynamics of the Antarctic ice sheet during the mid-Pliocene warm period, forced by multiple climatologies obtained from the PlioMIP results (Haywood et al., 2013). Our simulations start from spun-up initial configurations based on the present-day BEDMAP2 dataset (Fretwell et al., 2013) and the PRISM3 Pliocene reconstruction (Dowsett et al., 2010), and run under steady-state climate conditions until an equilibrium is reached.

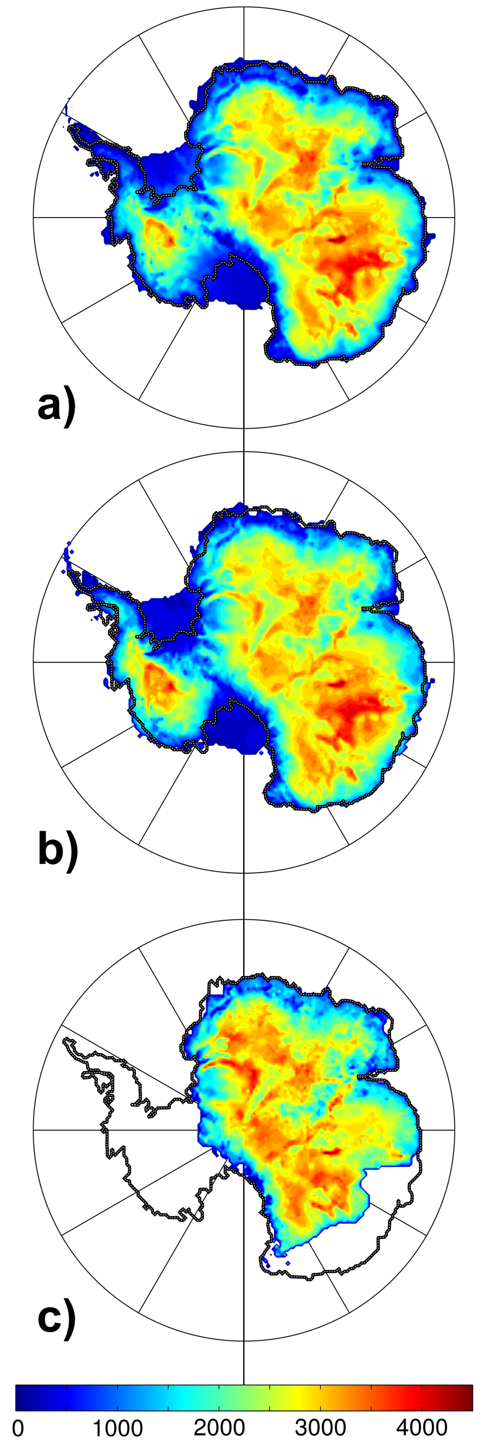


Figure 1: Ice thickness distribution.

a)** Present-day observed from BEDMAP2. In all figures, dashed line marks **observed, modern grounding-line position.

***b)** Present-day control run, after 100.000 years under constant, modern climate conditions from the HadCM3 atmosphere-ocean general circulation model.*

***c)** Pliocene reconstruction from PRISM3, used as an intial configuration during the spin-up procedure.*

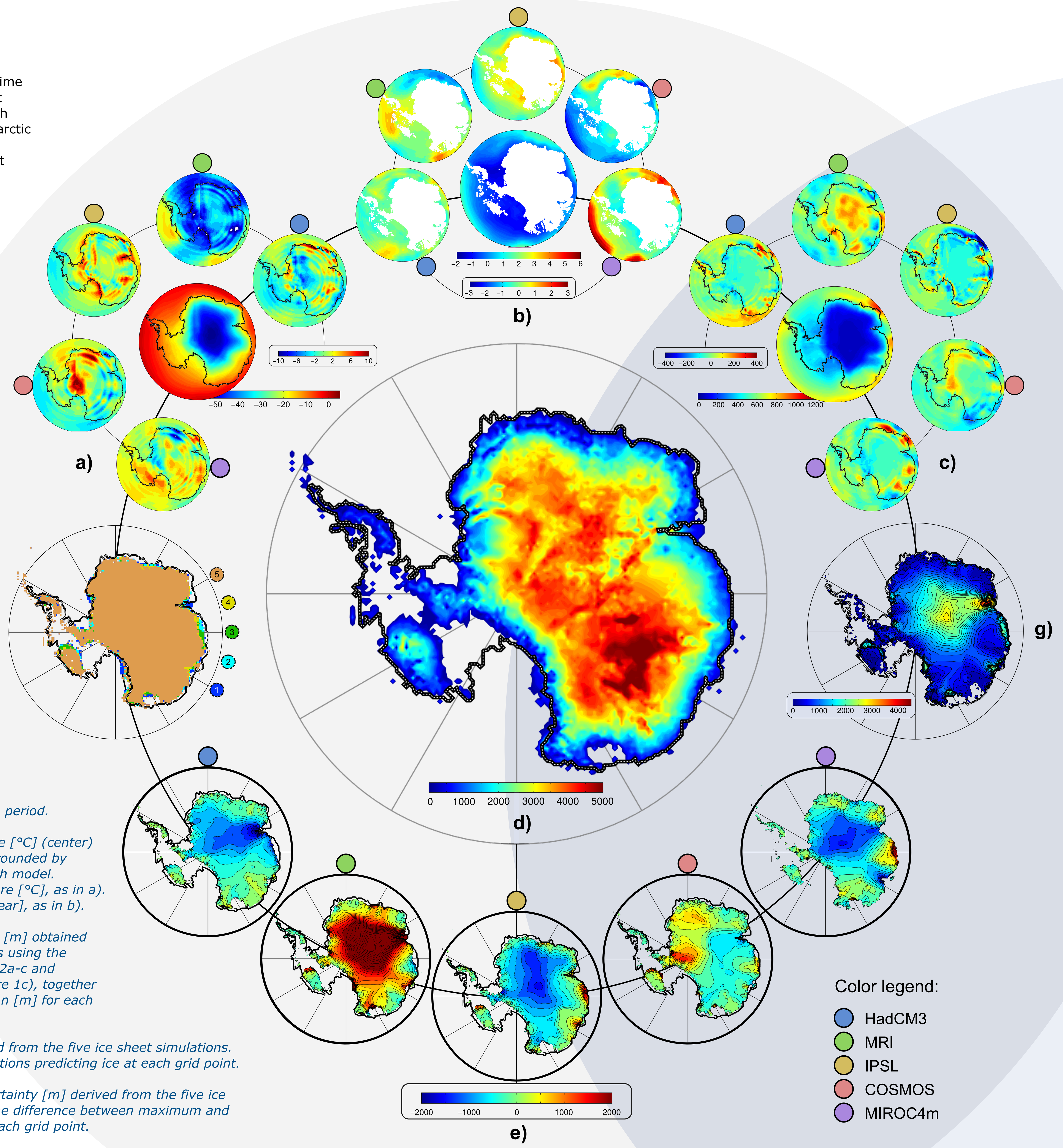


***Figure 2:** The mid-Pliocene warm period.*

***a)** Mean near-surface temperature [°C] (center) from the five climate models, surrounded by departures from the mean for each model.*
***b)** Mean surface ocean temperature [°C], as in a).*
***c)** Mean precipitation rate [mm/year], as in b).*

***d)** Mean ice thickness distribution [m] obtained from the five ice sheet simulations using the Pliocene forcing shown in Figures 2a-c and PRISM3 initial configuration (Figure 1c), together with **(e)** departures from the mean [m] for each simulation.*

***f)** Areal extent uncertainty derived from the five ice sheet simulations. Colors show the number of simulations predicting ice at each grid point.*

***g)** Ice thickness distribution uncertainty [m] derived from the five ice sheet simulations, computed as the difference between maximum and minimum predicted thickness at each grid point.*

Influence of initial ice sheet configuration

As shown in Figure 2, none of the climate forcings reproduces the areal extent of the PRISM3 reconstruction. Furthermore, the choice of the initial configuration itself (PRISM3) may play an important role in shaping ice sheet's margins, due to intrinsic limitations of large-scale models. To test this hypothesis, we run a set of simulations starting from the spun-up present-day configuration based on BEDMAP2 (Figure 1b), imposing the five Pliocene climate forcings on it.

Figure 3:

***Upper row:** Mean ice thickness distribution [m] obtained from ice sheet simulations imposing the Pliocene forcing data (Figure 2a-c) on an initialized present-day ice-sheet (Figure 1b).*

***Bottom row:** Ice thickness distribution uncertainty [m] derived from the ice sheet simulations, computed as in Figure 2g.*

***a)** Using all climate models*
***b)** Exluding the MRI model*
***c)** Departures from the mean thickness (b), as in Figure 2e.*

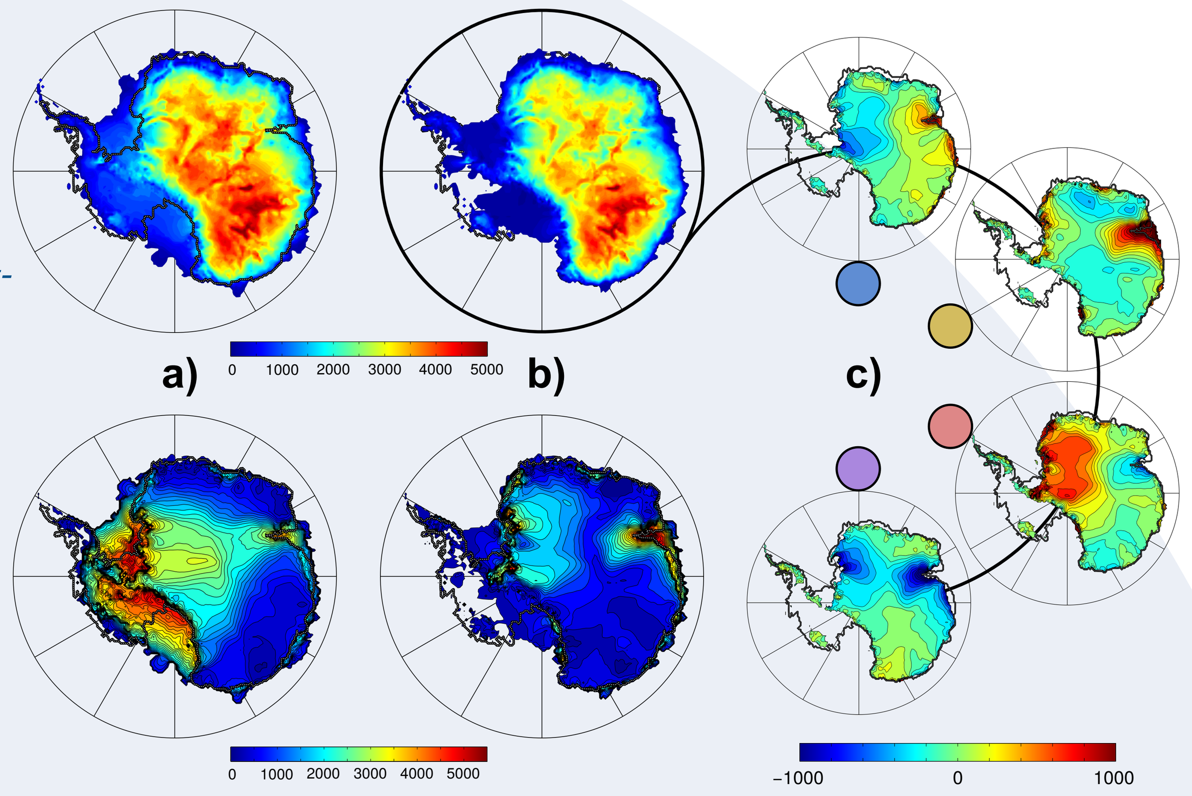
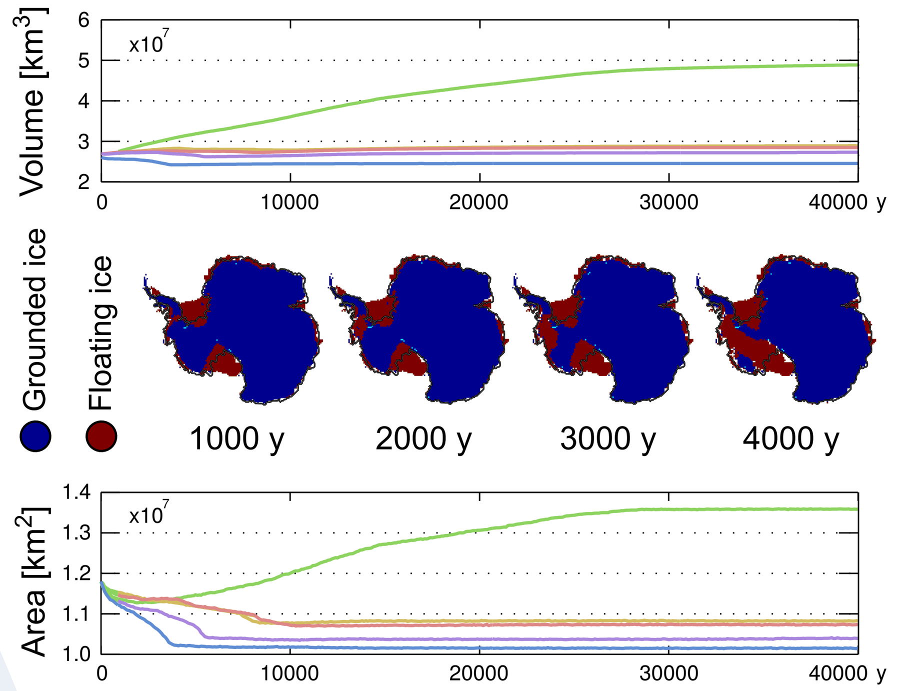


***Figure 4:** Evolution of grounded ice volume and ice area for the ice sheet simulations shown in Figure 3. Also shown is the areal extent evolution of present-day Antarctica until collapse of the West Antarctic ice sheet, when forced with the HadCM3 Pliocene forcing data. Colors as in Figures 2 and 3.*



Influence of individual climate variables

Given high surface elevations and low temperatures in the Antarctic interior, a few degrees increment in surface temperature may not cause higher surface melt rates. Furthermore, precipitation rates are shown to increase in warmer conditions, possibly leading to ice volume increases across the severe East Antarctic continent. To evaluate individual effects of increased precipitation and warmer climate conditions on the Antarctic ice sheet, we run a set of simulations imposing Pliocene forcing only from selected climate variables, while keeping the rest at the present-day level.

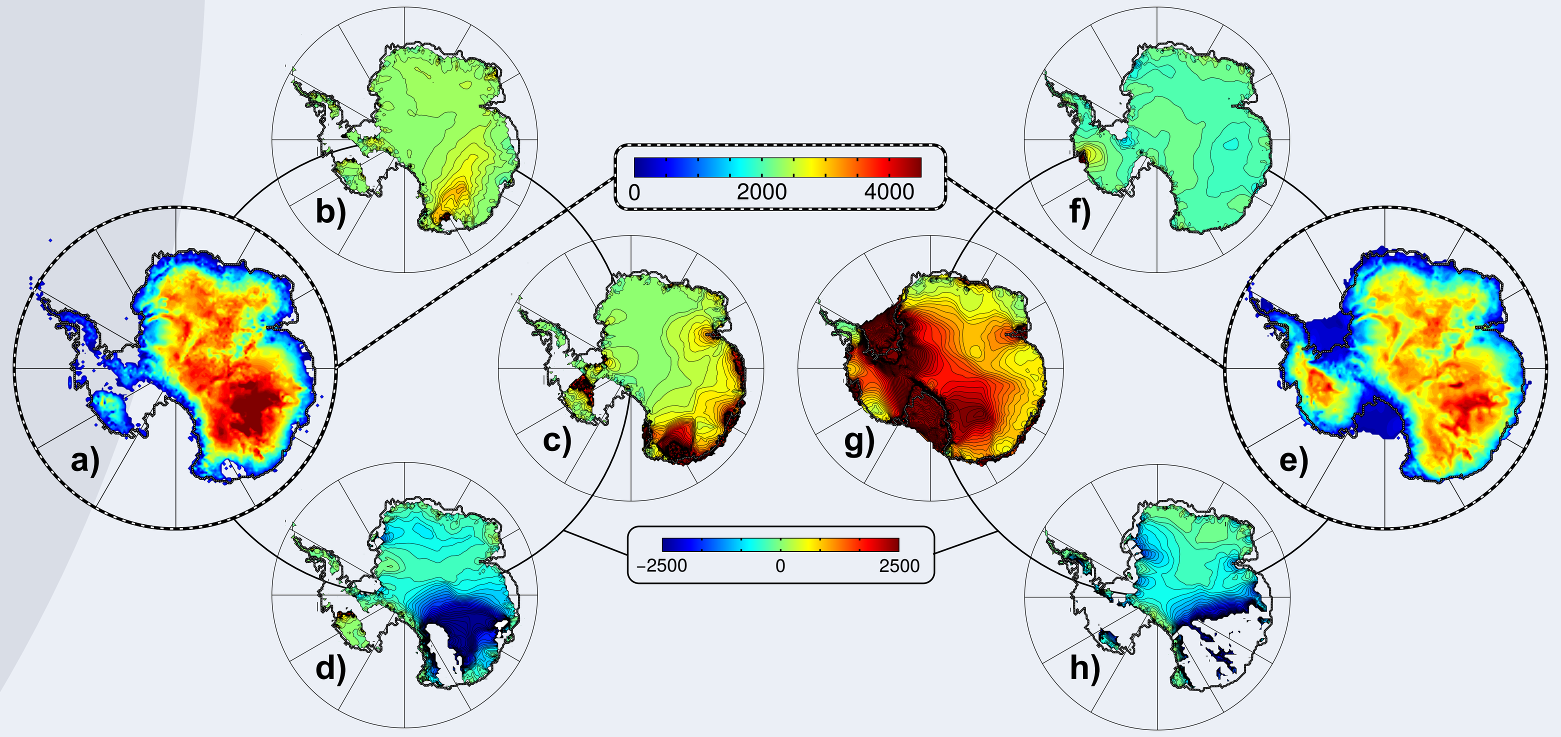


***Figure 5:** Ice thickness distributions [m] obtained from ice sheet simulations imposing the forcing data from HadCM3 on Pliocene- and present-day initialized ice-sheets (Figures 1b-c), sorrounded by differences in ice thickness [m] from ice sheet simulations forced by predetermined combinations of Pliocene and present-day climate variables.*

***a)** PRISM3 forced by Pliocene climate conditions*
***b)** Replacing surface temperatures by modern values*
***c)** Replacing ocean temperatures by modern values*
***d)** Replacing precipitation rates by modern values.*
***e)** BEDMAP2 forced by modern climate conditions*
***f)** Replacing surface temperatures by Pliocene values*
***g)** Replacing precipitation rates by Pliocene values*
***h)** Replacing ocean temperatures by Pliocene values.*

Summary

West Antarctica remains largely ice-free under a wide range of potential mid-Pliocene conditions, suggesting that the ice sheet in this area is highly vulnerable to warmer-than-present climates. At the same time, the East Antarctic ice sheet shows no signs of potential collapse, contrasting with hypotheses that cast doubt on its stability during the Pliocene.

Forcing the present-day Antarctic ice-sheet with mid-Pliocene conditions causes the collapse of the WAIS within 3000 to 8000 years. However, increased precipitation largely compensates for the loss of ice, from West Antarctica by increasing the volume of the East Antarctic ice sheet.

Our experiments suggest that atmospheric surface temperatures do not play a central role in the ice evolution of the Antarctic continent during warmer-than-present time periods, as opposed to increased precipitation rates and ocean temperatures, with the latter as the major cause of grounding line retreat.

References

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