Net Effect of Ice–Sheet–Atmosphere Interactions Reduces Transient Miocene Antarctic Ice Sheet Variability

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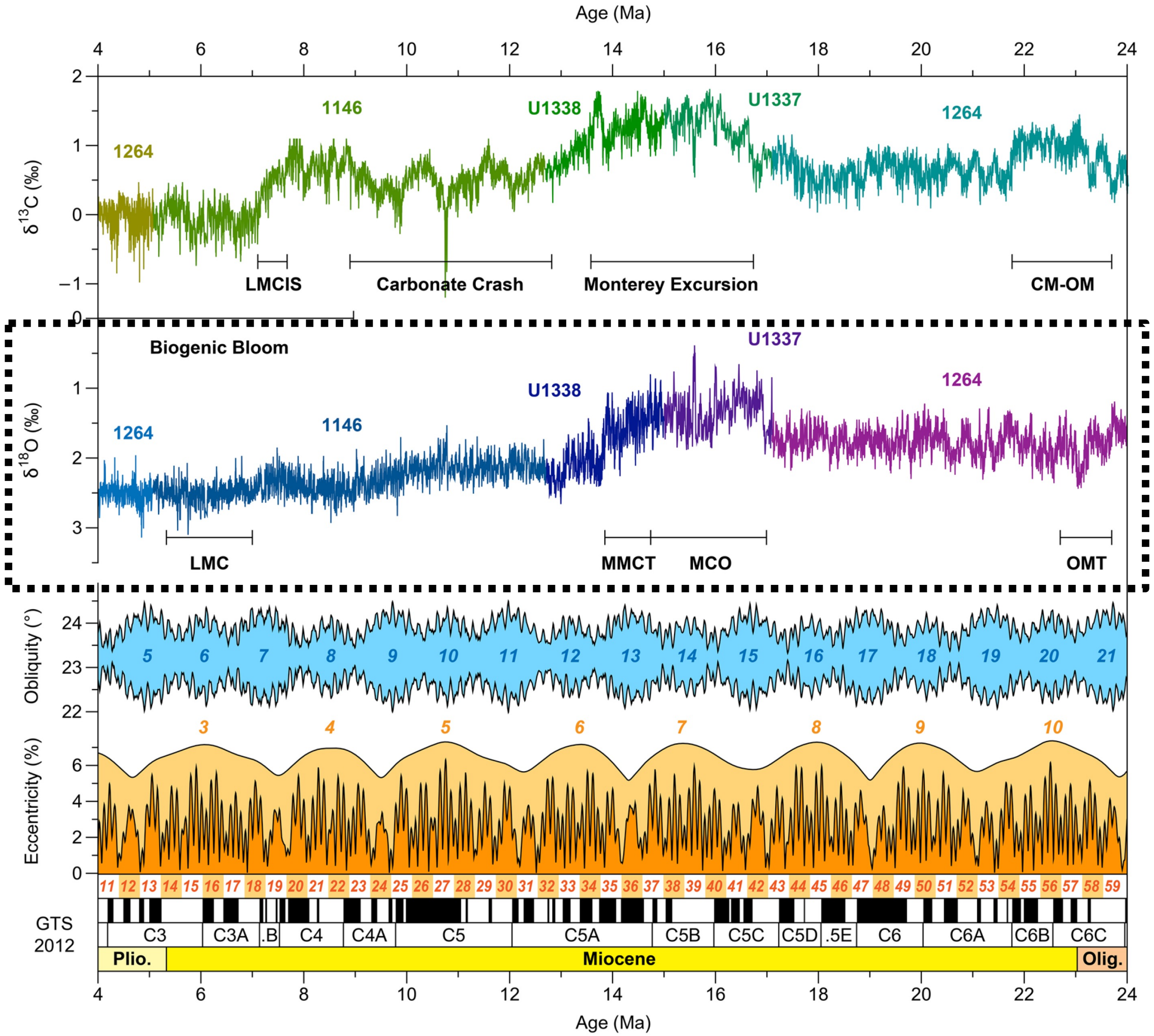
INTRODUCTION: MIOCENE (23 - 14 MYR AGO)

Benthic $\delta^{18}O$ levels vary strongly during the warmer-than-modern early- and mid-Miocene (23 to 14 Myr ago), suggesting a dynamic Antarctic ice sheet (AIS).

So far, however, realistic simulations of the Miocene AIS have been limited to equilibrium states under different CO_2 levels and orbital settings.

Earlier transient simulations lacked *ice-sheet - atmosphere interactions*, and used a present-day rather than Miocene Antarctic *bedrock topography*.



[Steinthorsdottir et al., 2020, P&P]

METHODOLOGY

Here, we quantify the effect of ice-sheet - atmosphere interactions, running the ice sheet model IMAU-ICE using warm and cold climate forcing from Miocene simulations by the general circulation model GENESIS.
We also implement recent reconstructions of Miocene Antarctic bedrock topography in IMAU-ICE.

forcing climate

IMAU-ICE

Ice sheet/shelf (SIA/SSA)
ITM scheme
Miocene bedrock topo

← precipitation
atmospheric T

GENESIS

Miocene topography
Interactive vegetation
PD insolation

WARM
High CO_2
No ice

COLD
Low CO_2
Large EAIS

Burls et al., 2021, P&P

↓

Simulate Antarctic ice sheet

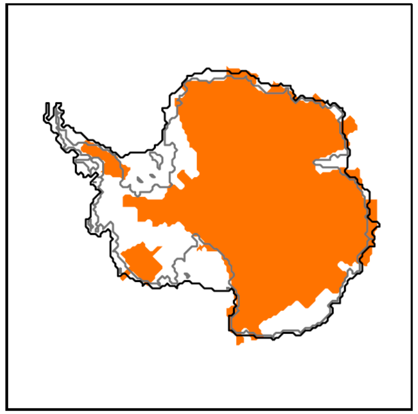
METHODOLOGY: MATRIX METHOD

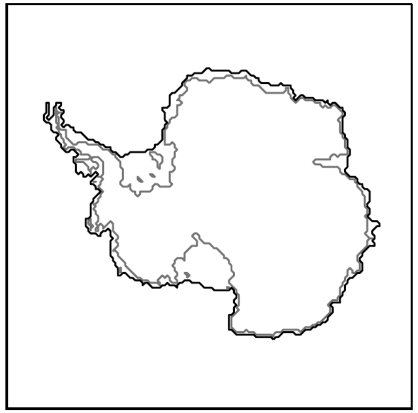
i = CO_2

840 ppm

280 ppm

Utilising a recently developed matrix interpolation method enables us to interpolate the climate forcing between warm and cold conditions based on CO_2 levels (between 280 and 840 ppm) as well as varying ice sheet configurations (between no ice and a large East Antarctic ice sheet) (**REF**).
-> Hence, this includes a representation of *ice-sheet-atmosphere interactions*





j = ice

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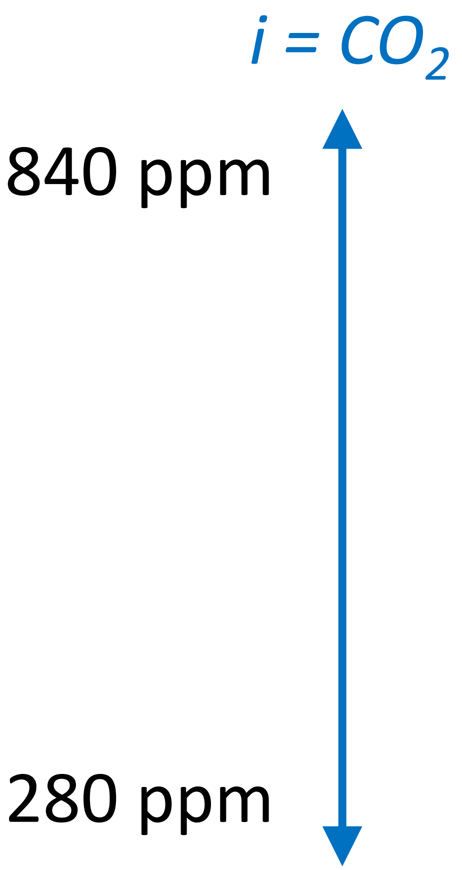
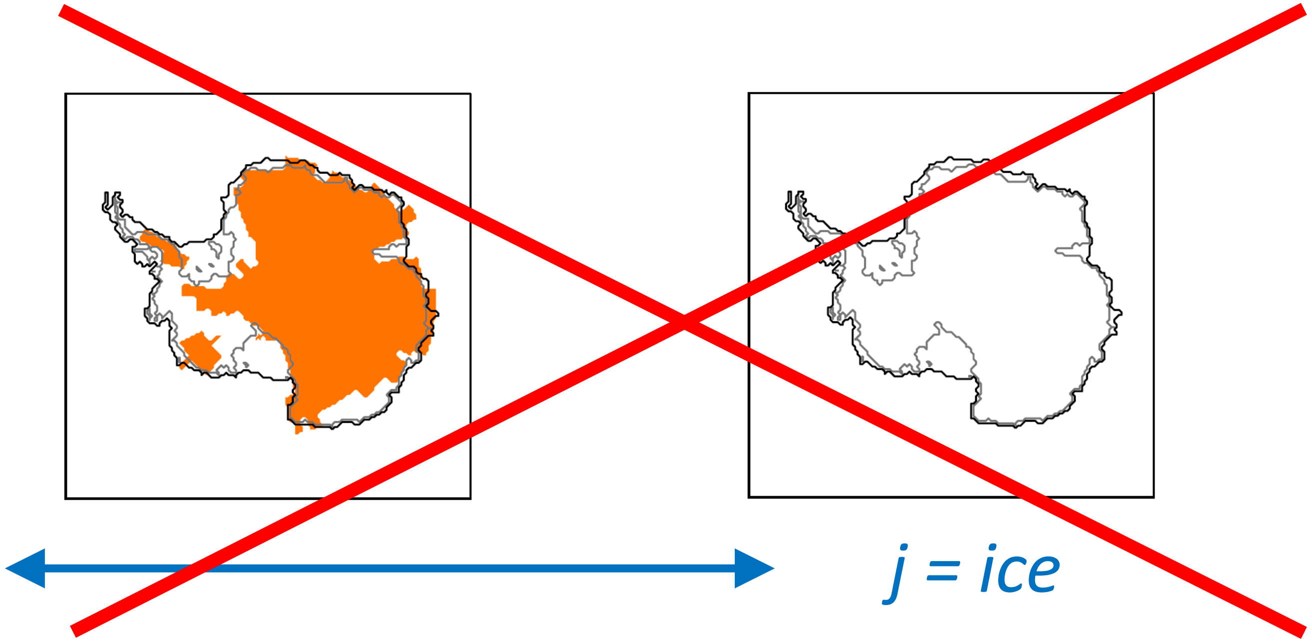
Berends et al., 2018; *Stap et al., 2022, The Cryosphere*

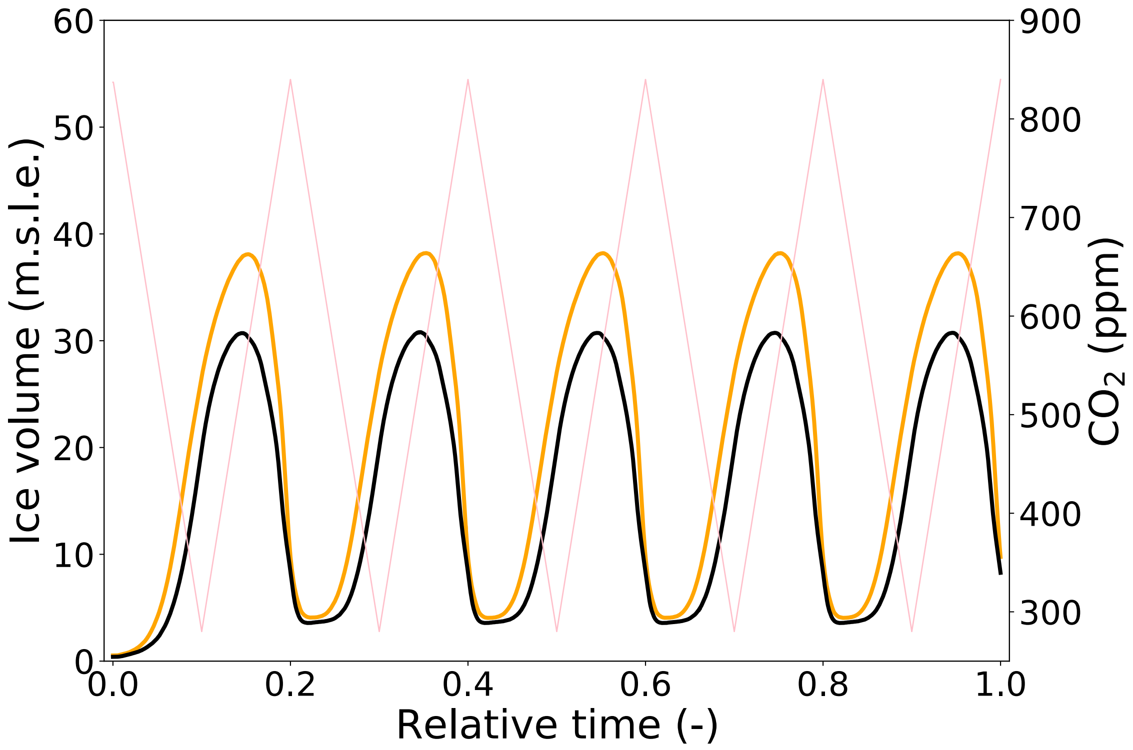
METHODOLOGY: INDEX METHOD

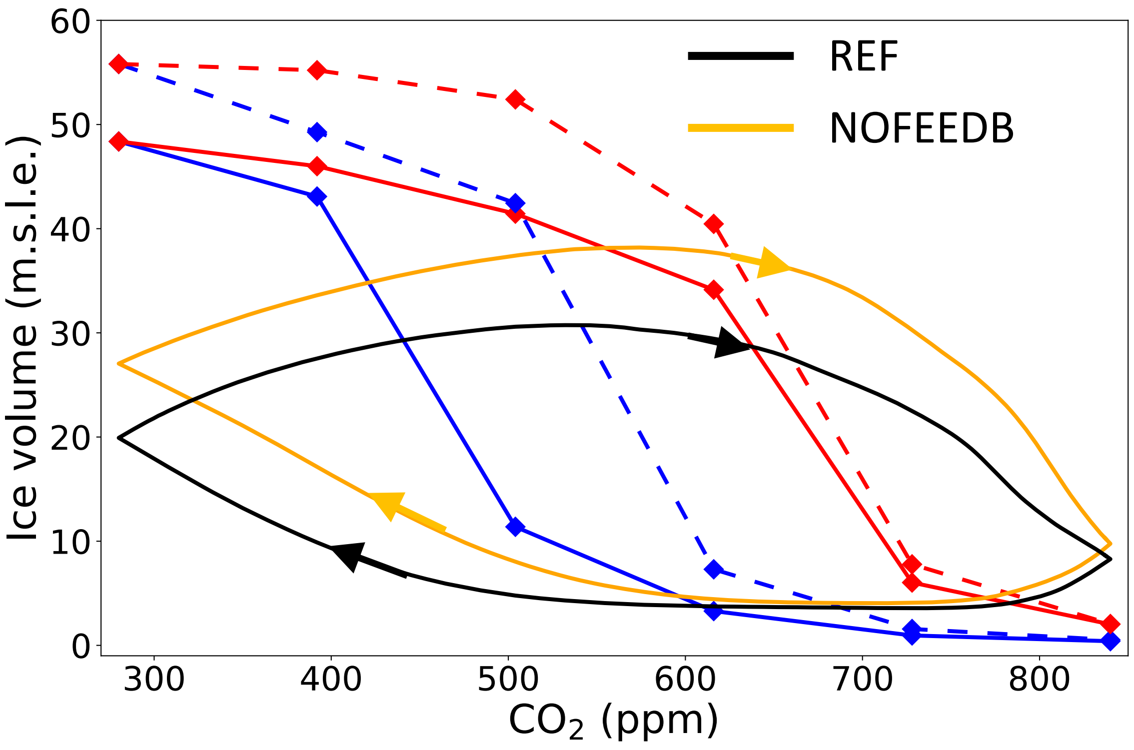


We compare our REF results against results generated by a simpler index method, which does not include ice-sheet-atmosphere interactions. The interpolation in that case is only based on externally forced CO_2 (**NOFEEDB**).



RESULTS: ICE-SHEET – ATMOSPHERE INTERACTION





We conduct equilibrium simulations (150 kyr constant CO_2) starting from non-glaciated (blue dots) and glaciated (red) conditions. We also perform transient simulations, where CO_2 levels are gradually varied over time (pink). Resulting transient ice volume is shown by **black** and orange lines, arrows indicate progression direction.

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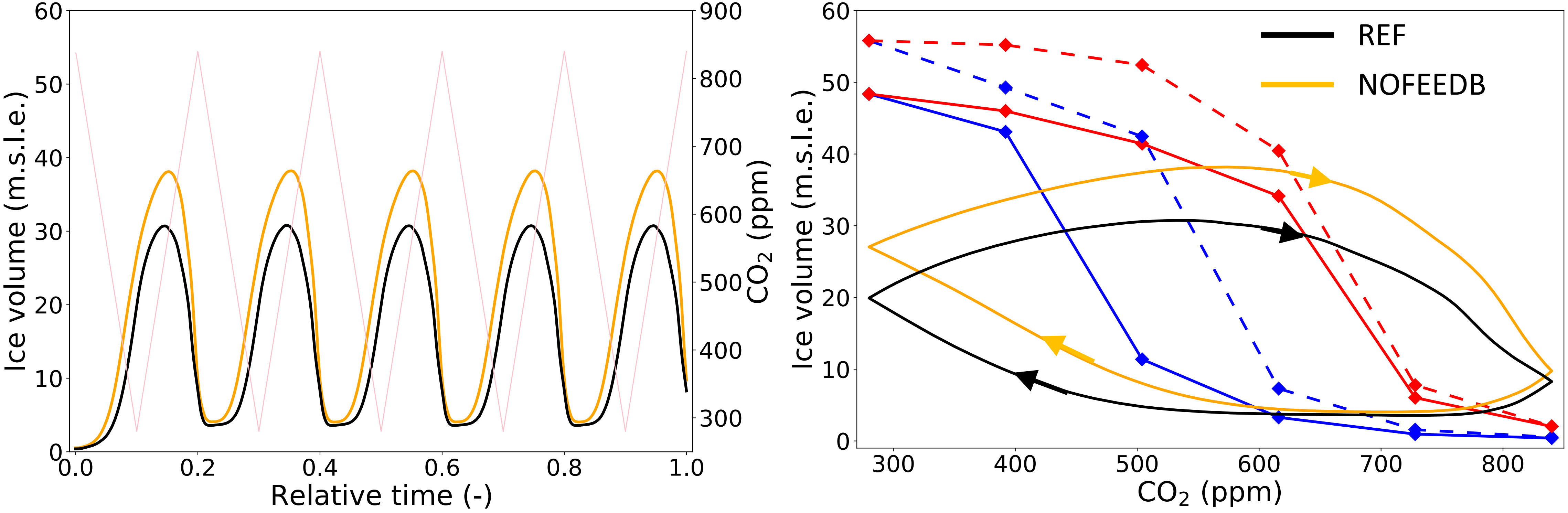
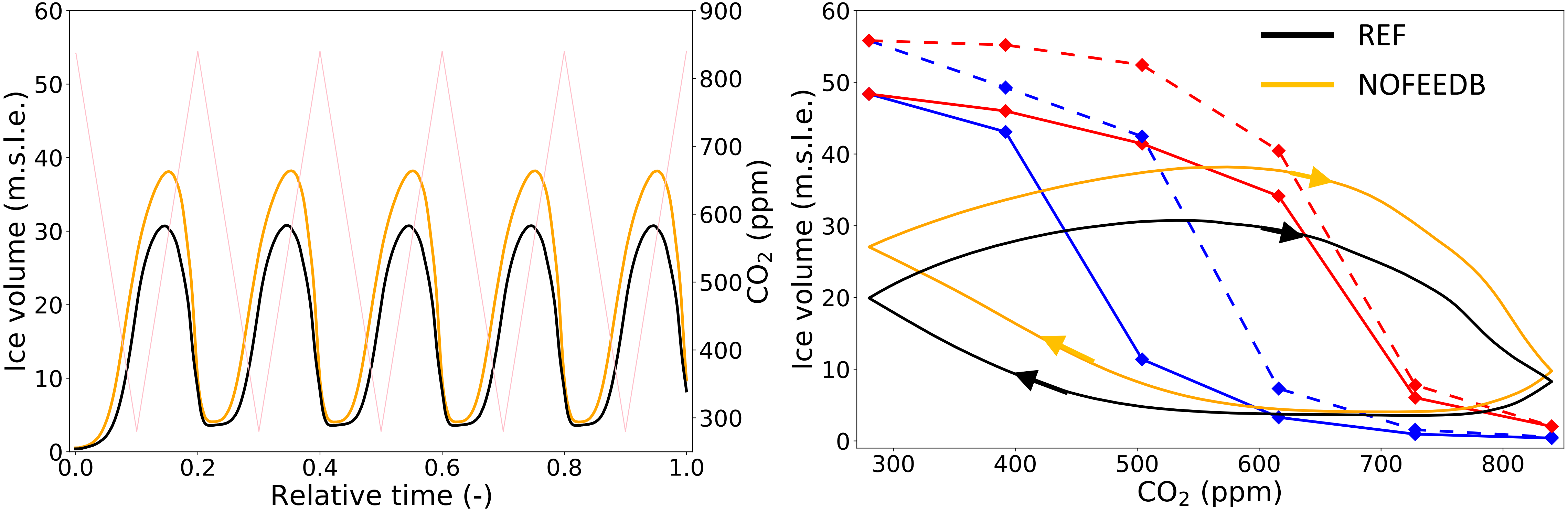
Stap et al., 2022, The Cryosphere

RESULTS: ICE-SHEET – ATMOSPHERE INTERACTION



We find that the positive albedo-temperature feedback, partly compensated by a negative feedback between ice volume and precipitation, **increases hysteresis** in the relation between CO_2 and ice volume.
R.h.s. phase-space figure: solid (REF) vs. dashed (NOFEEDB).

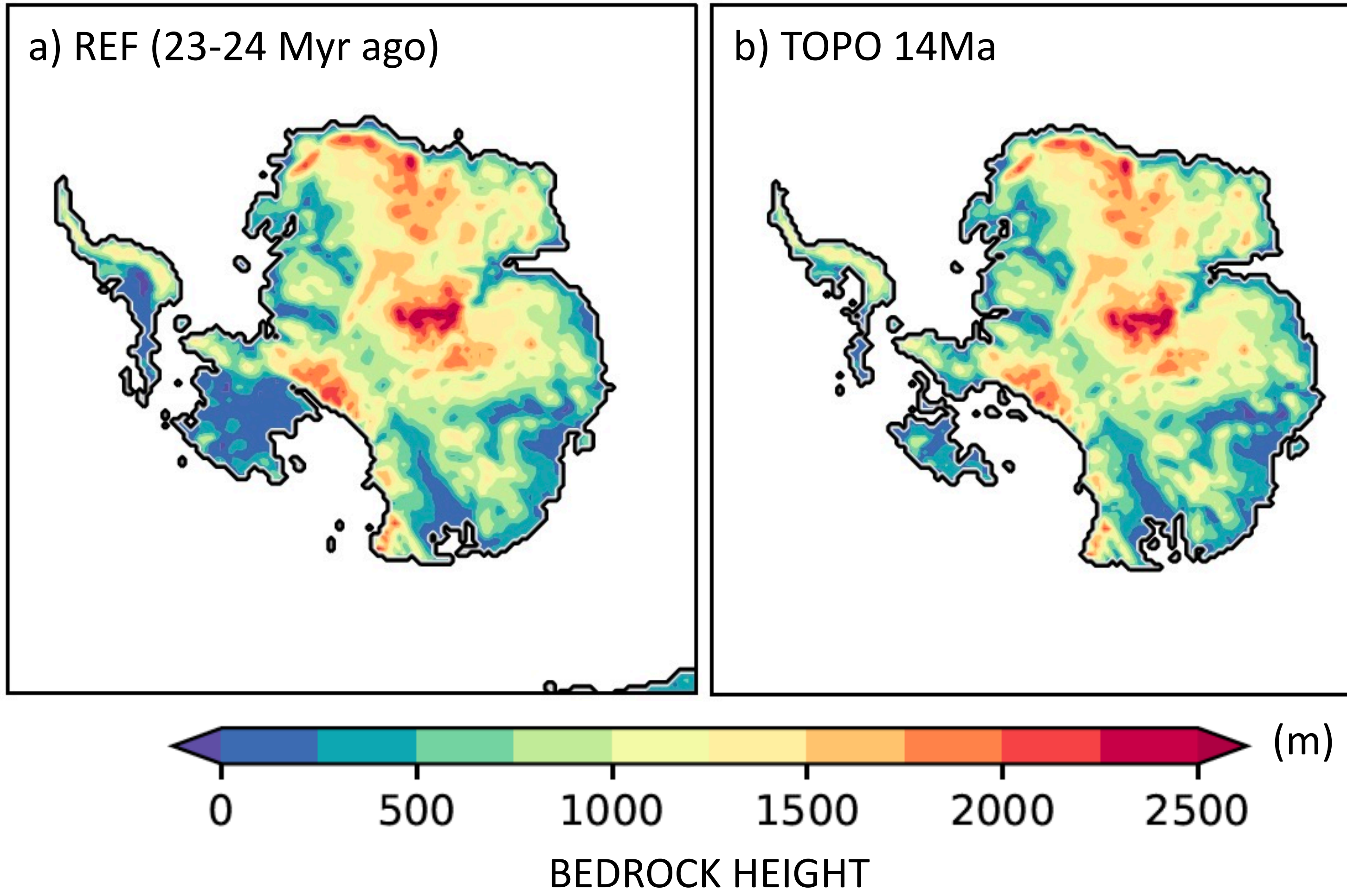
RESULTS: ICE-SHEET – ATMOSPHERE INTERACTION



Forced by quasi-orbital 40-kyr forcing CO_2 cycles, the ice volume variability **reduces by 21%** when ice-sheet-atmosphere interactions are included, compared to when forcing variability is only based on CO_2 changes.

Stap et al., 2022, The Cryosphere

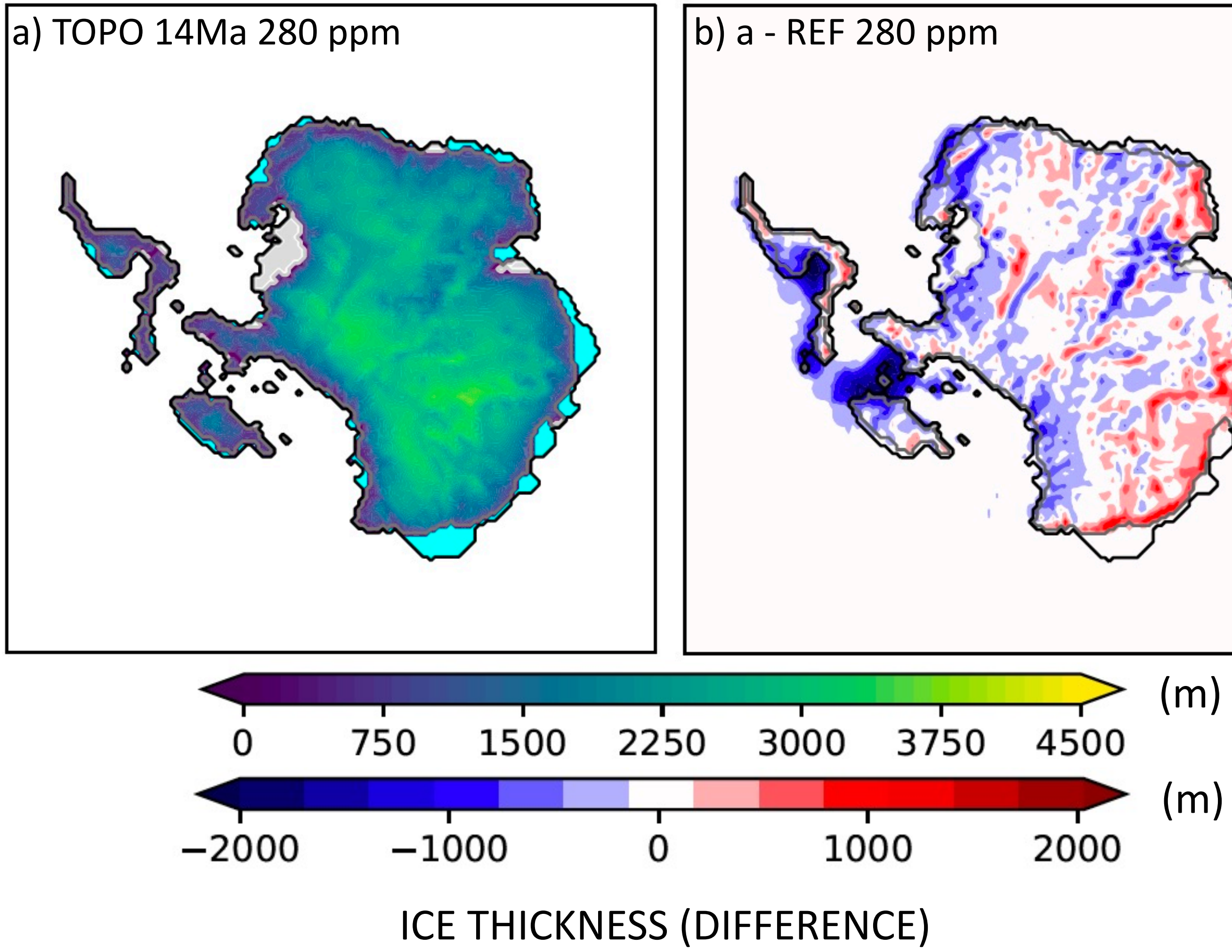
INPUT BEDROCK TOPOGRAPHY



We also compare our REF results, which use a bedrock topography pertaining to the early Miocene, to results obtained using a bedrock topography pertaining to the late Miocene. Over time, the West Antarctic continent became more subducted.

[Hochmuth et al., 2020 data set]

RESULTS: BEDROCK TOPOGRAPHY



The more subducted West Antarctic continent leads to impeded ice-sheet build-up. At the lowest CO_2 level, the equilibrium ice volume is ~4 m.s.l.e. (8%) smaller than in the REF case.

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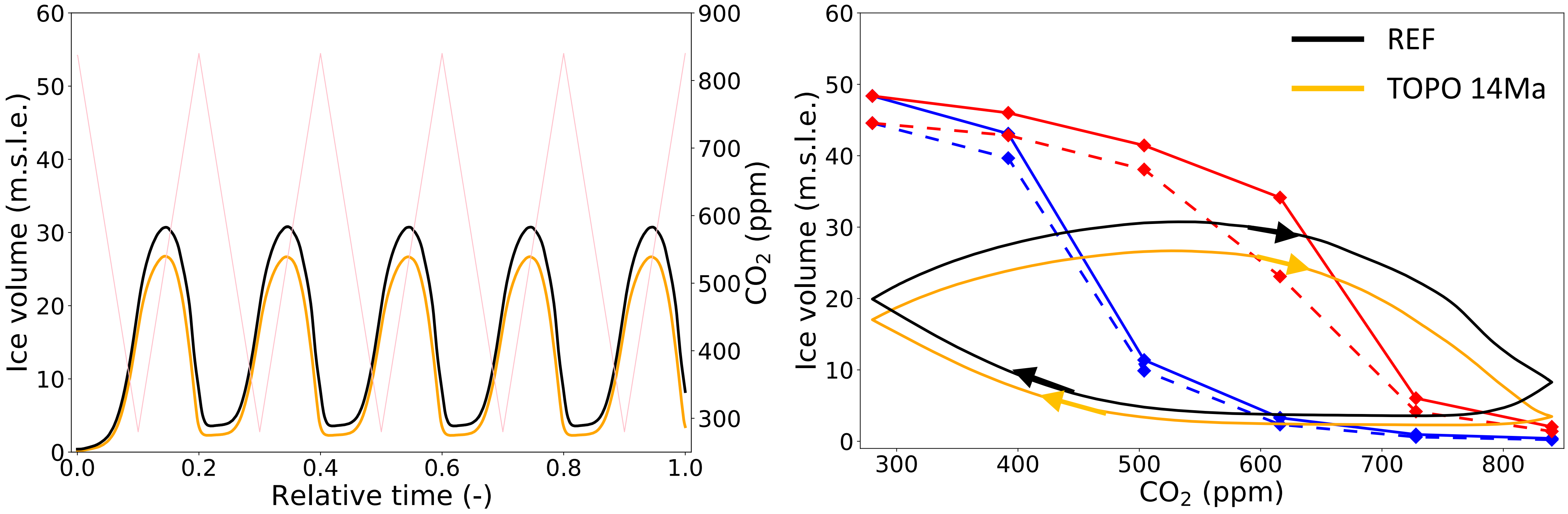
Stap et al., 2022, The Cryosphere

RESULTS: BEDROCK TOPOGRAPHY



Evolving bedrock topography during the early- and mid-Miocene reduces ice volume variability by 10%, under equal 40-kyr cycles of atmosphere and ocean forcing.

Stap et al., 2022, The Cryosphere

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