Hysteresis of the Antarctic ice sheet with a coupled climate-ice-sheet model

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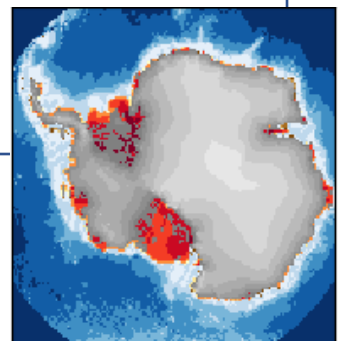
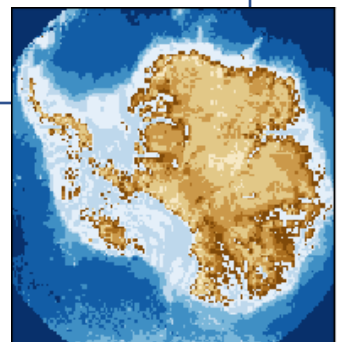
Methodology : two different initial conditions

Pre-industrial ice sheet
and climate



Ice free Antarctica configuration
High CO_2 levels
No Antarctic ice sheet
Bedrock → isostatic rebound



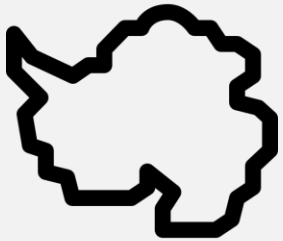
« melt branch »

« growth branch »

Methodology : Climate and Antarctic ice sheet modelling

GRISLI model

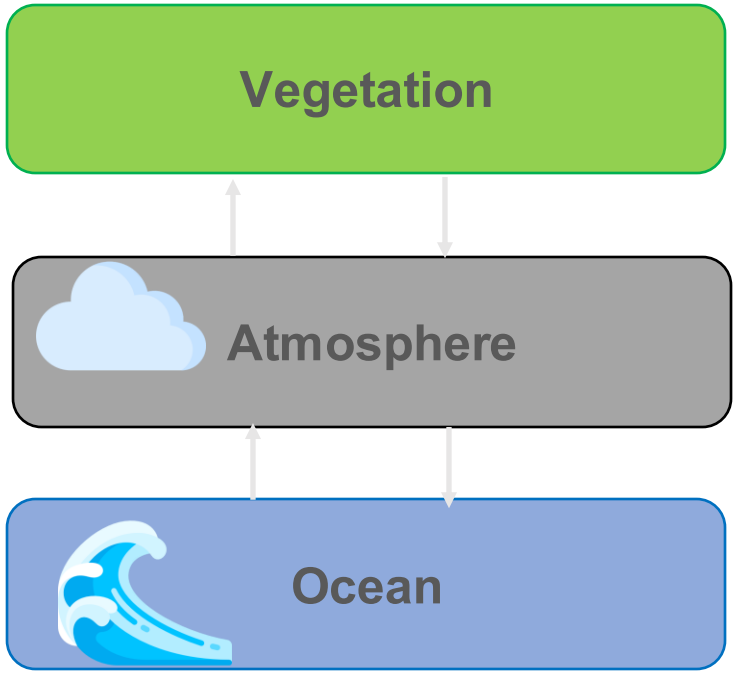
→ Ice sheet model
→ Shallow ice + shallow shelf approximation
→ 40km x 40km resolution
→ Quick to run



Antarctic ice sheet

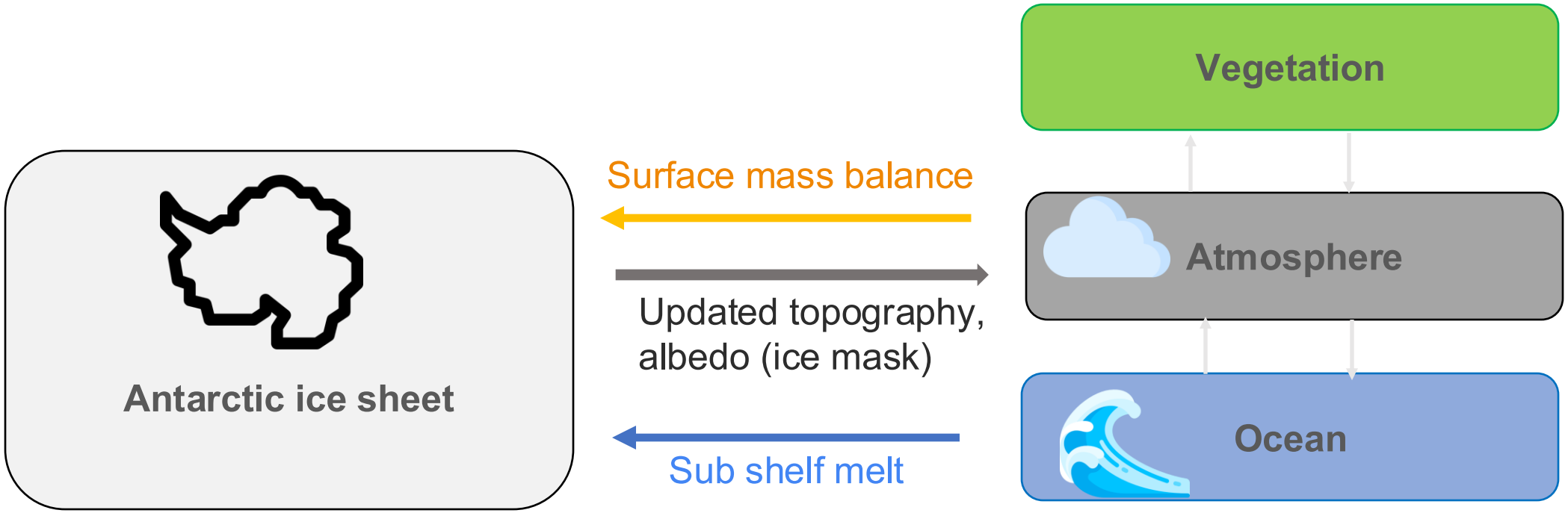
iLOVECLIM model

→Climate model of intermediate complexity
→ representation of the atmosphere, ocean and vegetation
→allows to perform multi-millenia simulations quickly



Methodology : Coupling of the climate and Antarctic ice sheet models

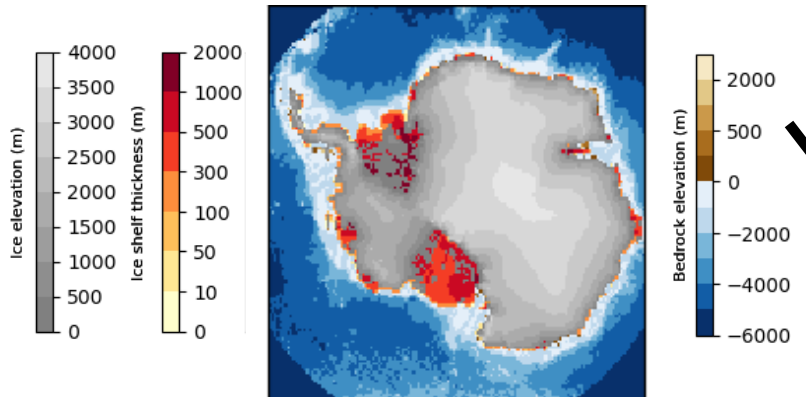
- Atmospheric coupling : accounting for the elevation-temperature and albedo-melt feedback.
- Asynchronous coupling (1 climate year – 100 ice sheet years)
- Equilibrium simulations with **fixed CO_2 levels and fixed pre-industrial insolation**



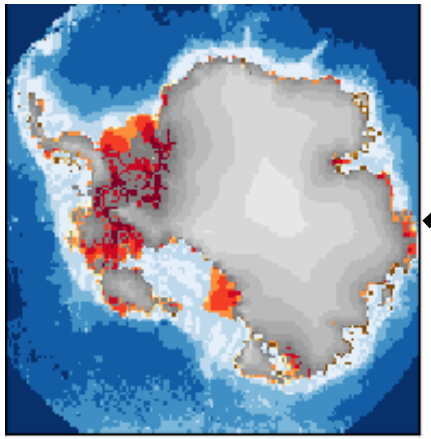
GRISLI model

iLOVECLIM model

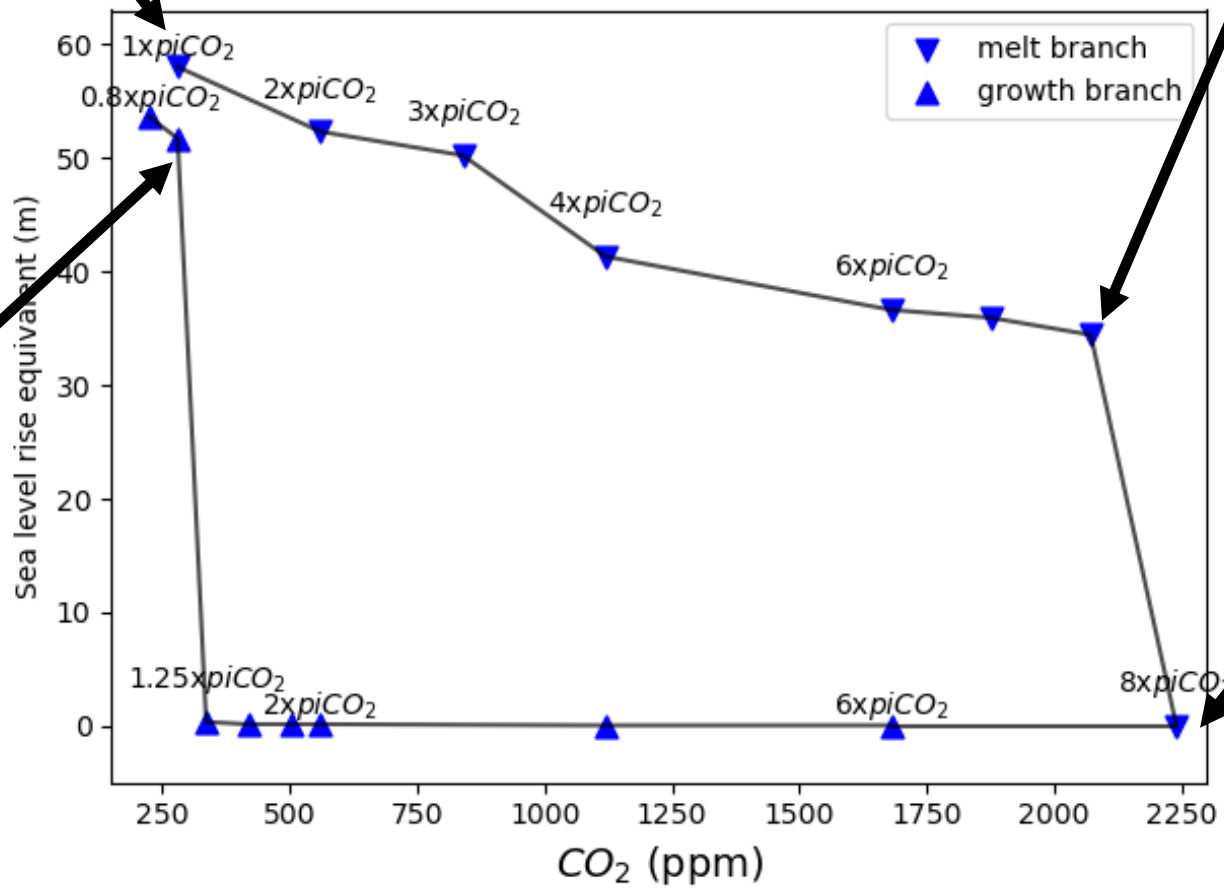
Results : hysteresis curve for pre-industrial insolation

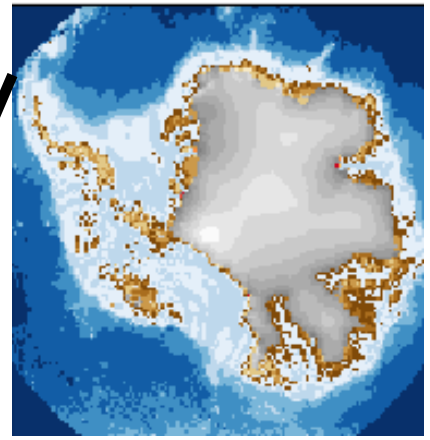


Pre-industrial ice sheet
1xpiCO_2 (280 ppm)

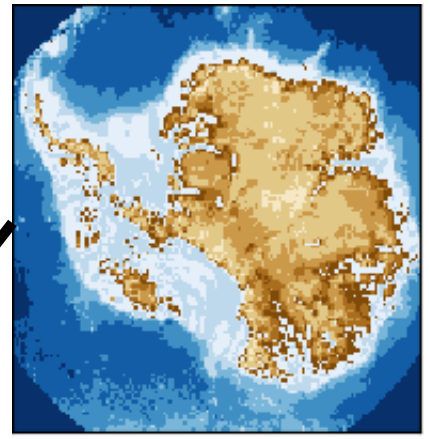


Growth branch
1xpiCO_2 (280 ppm)





Melt branch
7.4xpiCO_2 (2070 ppm)



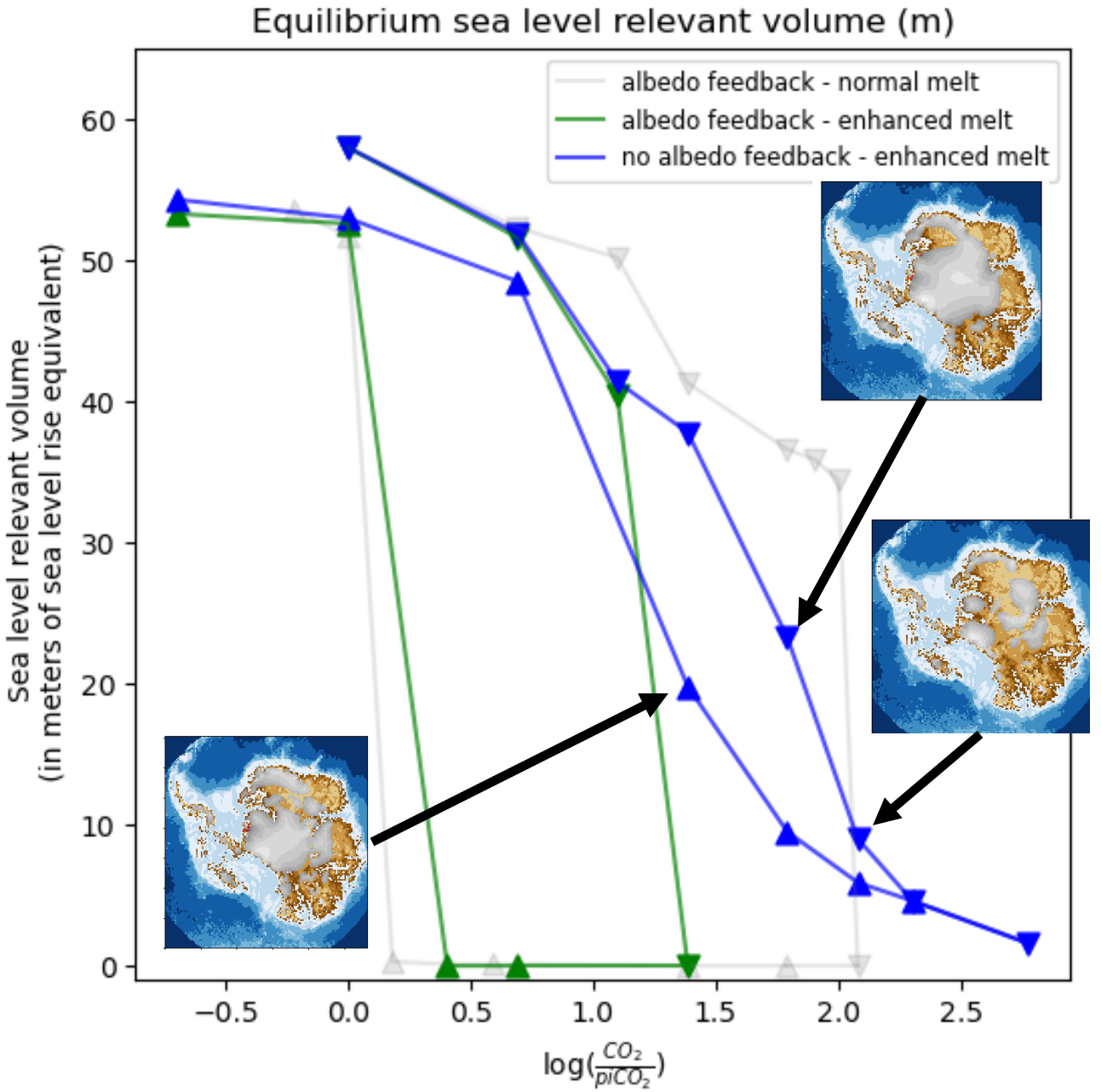
Melt branch
8xpiCO_2 (2240 ppm)

- Abrupt transitions, no intermediate state
- Hysteresis : equilibrium ice volume differs widely depending on the initial state

Results : role played by the albedo-melt feedback

- Sensitivity simulations with fixed albedo value for the ice sheet (no albedo—melt feedback)
- Comparison to simulations including the albedo-melt feedback
- Simulations with enhanced melt

→ **inclusion of the albedo-melt feedback gives rise to critical thresholds**,
leading to the complete loss of the Antarctic ice sheet or its almost complete regrowth, which are absent when the feedback is excluded.



Study limitations

- Simulations performed are **equilibrium simulations, with fixed CO_2 and insolation**

→ The Antarctic ice sheet might in fact never fully reach an equilibrium state, due to insolation changes

- **Simplified physics and coarse resolution of the atmospheric model**

→Potential overestimation of albedo-melt feedback effect and of the abruptness of the transitions

→Thresholds found are model specific : actual thresholds for Antarctic glaciation/deglaciation could be shifted.

Take home message

• In our setup including the albedo-melt feedback leads to critical CO_2 thresholds for the ice sheet melt or growth

→ This highlights the importance of accounting for the albedo-melt feedback in long-term simulations of the Antarctic ice sheet

Thank you for your attention !

For more details on the study :

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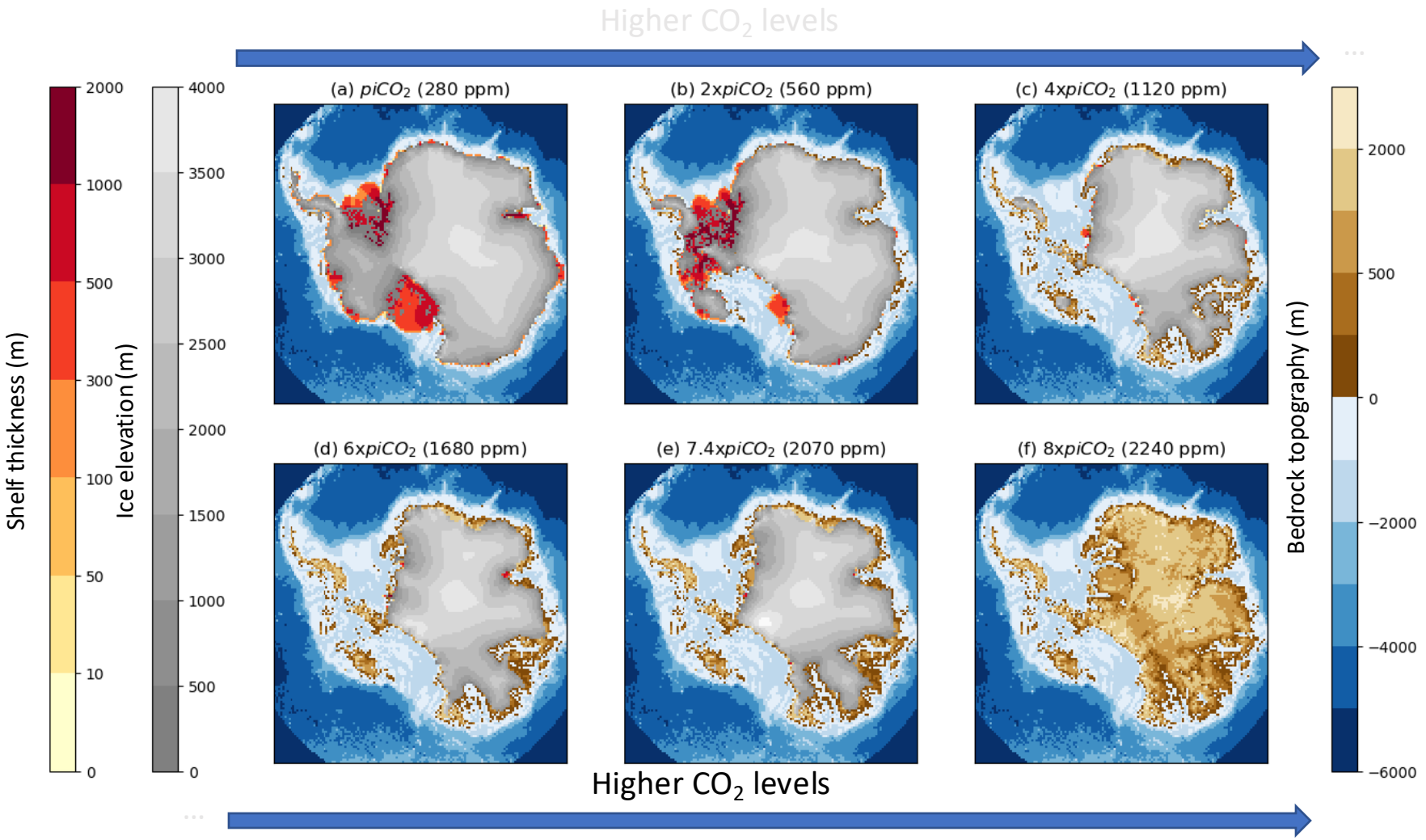
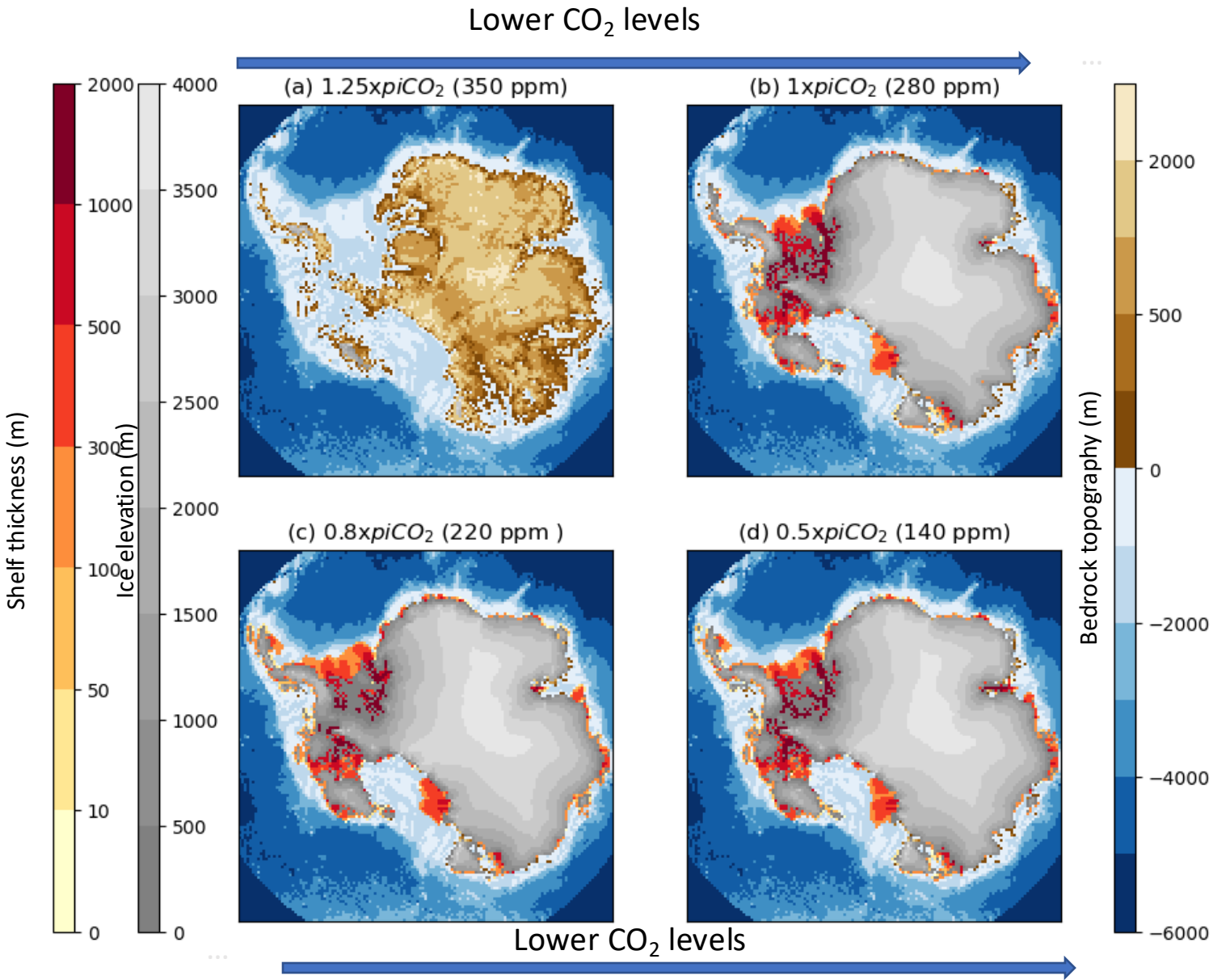
Additional slides

Equilibrium simulations : melt branch, pre-industrial insolation



- **Loss of almost all marine parts between 1x $piCO_2$ and 4x$piCO_2$**
- At **7.4x$piCO_2$, large grounded ice** sheet remains (East Antarctica)
- At **8x $piCO_2$,** the ice sheet has **completely disappeared**
- **Very abrupt transition in terms of CO_2 between a developped East Antarctic Ice Sheet and no ice sheet**

Equilibrium simulations : growth branch, pre-industrial insolation



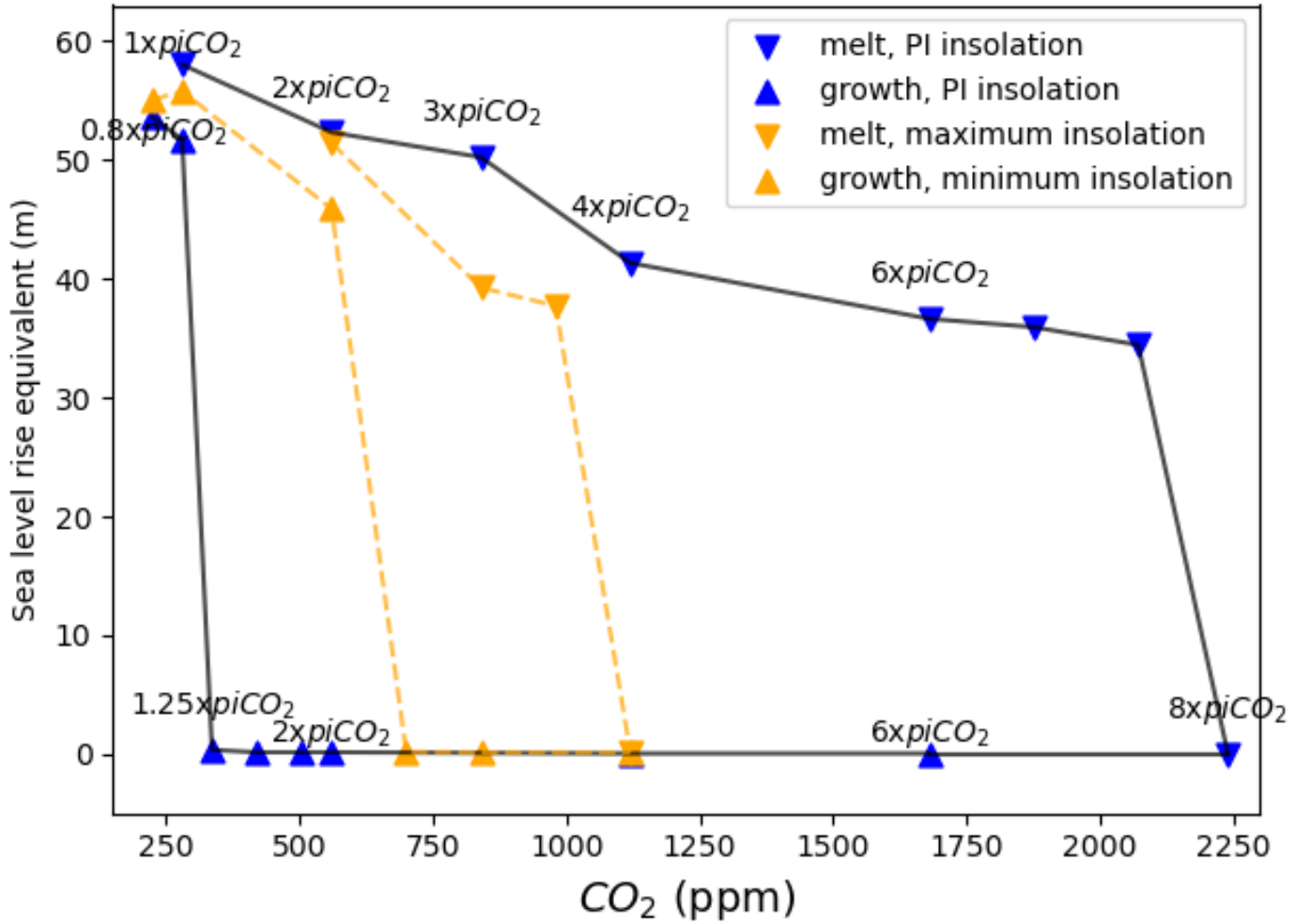
- No regrowth until levels ~1pixCO_2.
- Widespread regrowth : all East Antarctica covered, Ronne Filchner shelf came back
- Ice sheet does not come back to its PI extent
- **Very abrupt transition in terms of CO_2 between no ice sheet and a widely developed ice sheet**

Hysteresis curve with different insolation

- Simulations with different orbital configurations
- Maximum summer insolation for the melt branch
- Minimum summer insolation for the growth branch

➔Orbital configuration modulates the CO_2 threshold for Antarctic glaciation / deglaciation

➔Order of magnitude of CO_2 for Antarctic glaciation coherent with CO_2 data at the Eocene-Oligocene transition (~$3xCO_2$)



Role played by the albedo-melt feedback : quasi-transient simulations

- ‘Quasi transient’ simulations
- Start : climate equilibrated with 8xpiCO_2 levels, but fixed pre-industrial ice sheet.
- Fixed insolation and CO_2.
- With / without albedo-melt feedback

- Stabilizes in the case without albedo feedback
- Much stronger temperature increase with the albedo feedback

→ Elevation feedback with albedo-melt feedback >> Elevation feedback without albedo-melt feedback

→ (Elevation + albedo) feedback >> Elevation feedback + albedo feedback