Ocean Destratification in the Aftermath of a Snowball Earth

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work in progress

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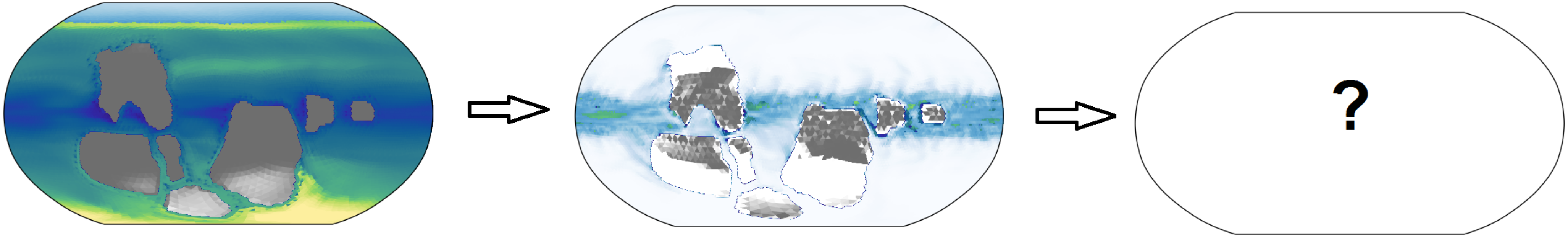


Motivation

- global glaciations followed by a strong greenhouse climate will lead to a strongly stratified ocean

  → how long will it take until the climate returns to its pre-snowball behavior?
  → how is the climate affected by the strong stratification?
  → what is the influence of the continental distribution on the destratification pathway?

(plots show annual mean mixed layer depths and sea-ice concentration over the ocean, as well as snow coverage over land)

Model

- coupled atmosphere-ocean general circulation model ICON (**ICO**sahedral **N**onhydrostatic model)

- resolution:
  - 320 km in the atmosphere, 47 levels
  - 160 km in the ocean, 40 levels

- two setups:
  - present-day (including mountains, vegetation and glaciers)
  - Marinoan (Flat topography, no vegetation, no glaciers. Continental distribution based on *Li et. al (2013)**)

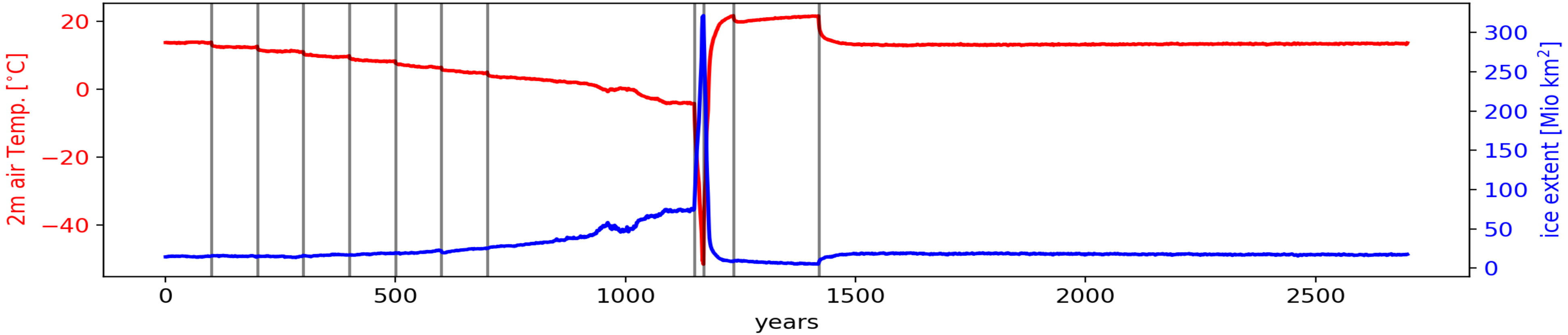
* Li, Cheng-Xiang; Evans, David A.; Halverson, Galen P. (2013): *Neoproterozoic glaciations in a revised global palaeogeography from the breakup of Rodinia to the assembly of Gondwanaland.* In: Sedimentary Geology 294, S. 219–232. https://doi.org/10.1016/j.sedgeo.2013.05.016

Procedure

1. Starting from a spun-up control run with pre-industrial (PI) greenhouse gases and solar forcing.

3. 20 years of reduced solar forcing in order to generate a near-global glaciation.

5. After the warming period CO_2 is set back to its PI value, so that the model is run with the exact same settings as the control run.

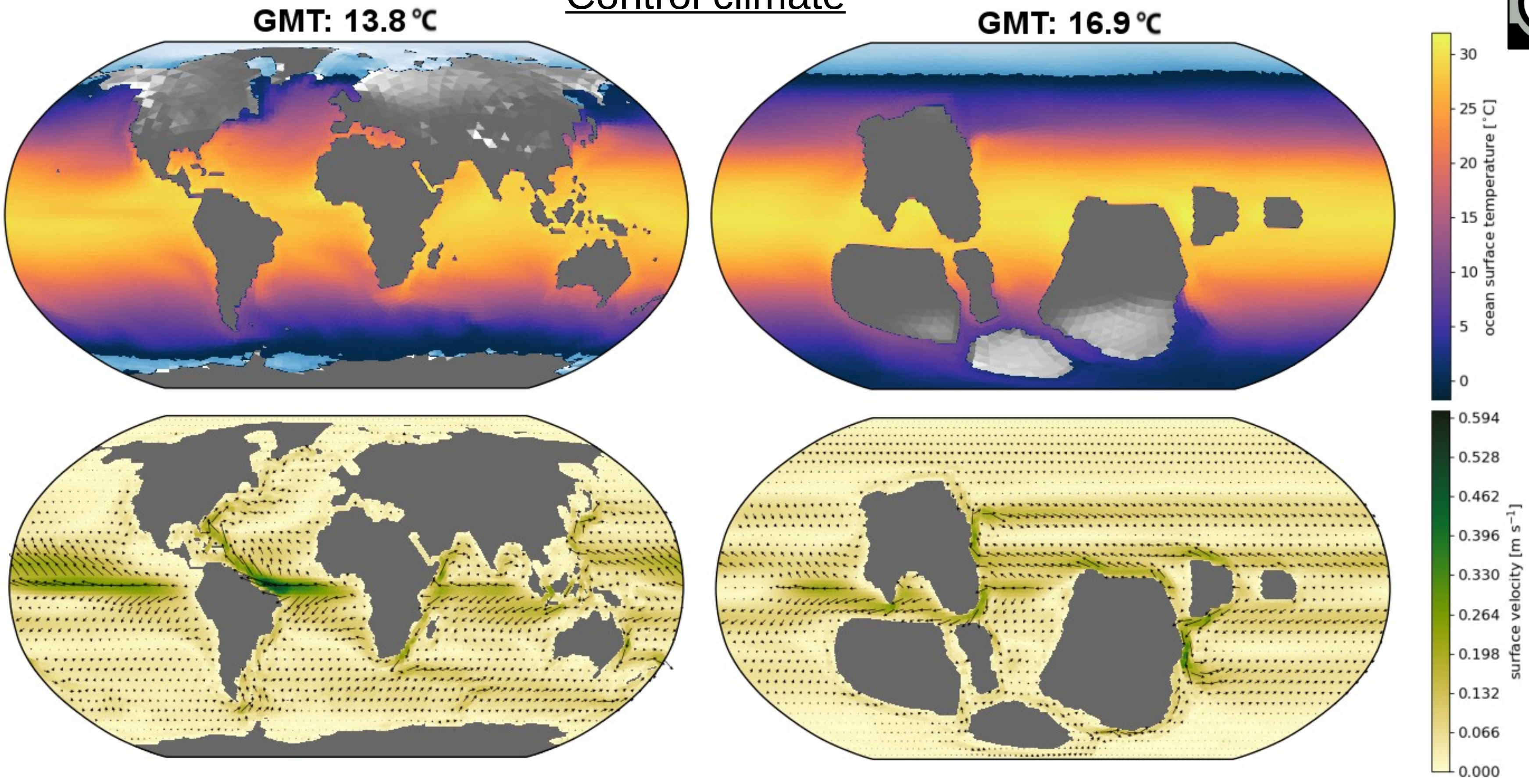


2. 7 consecutive halvings of CO_2 to reduce temperatures.

4. 250 years of warming, with CO_2 concentrations up to 8,896 ppm (32x PI).

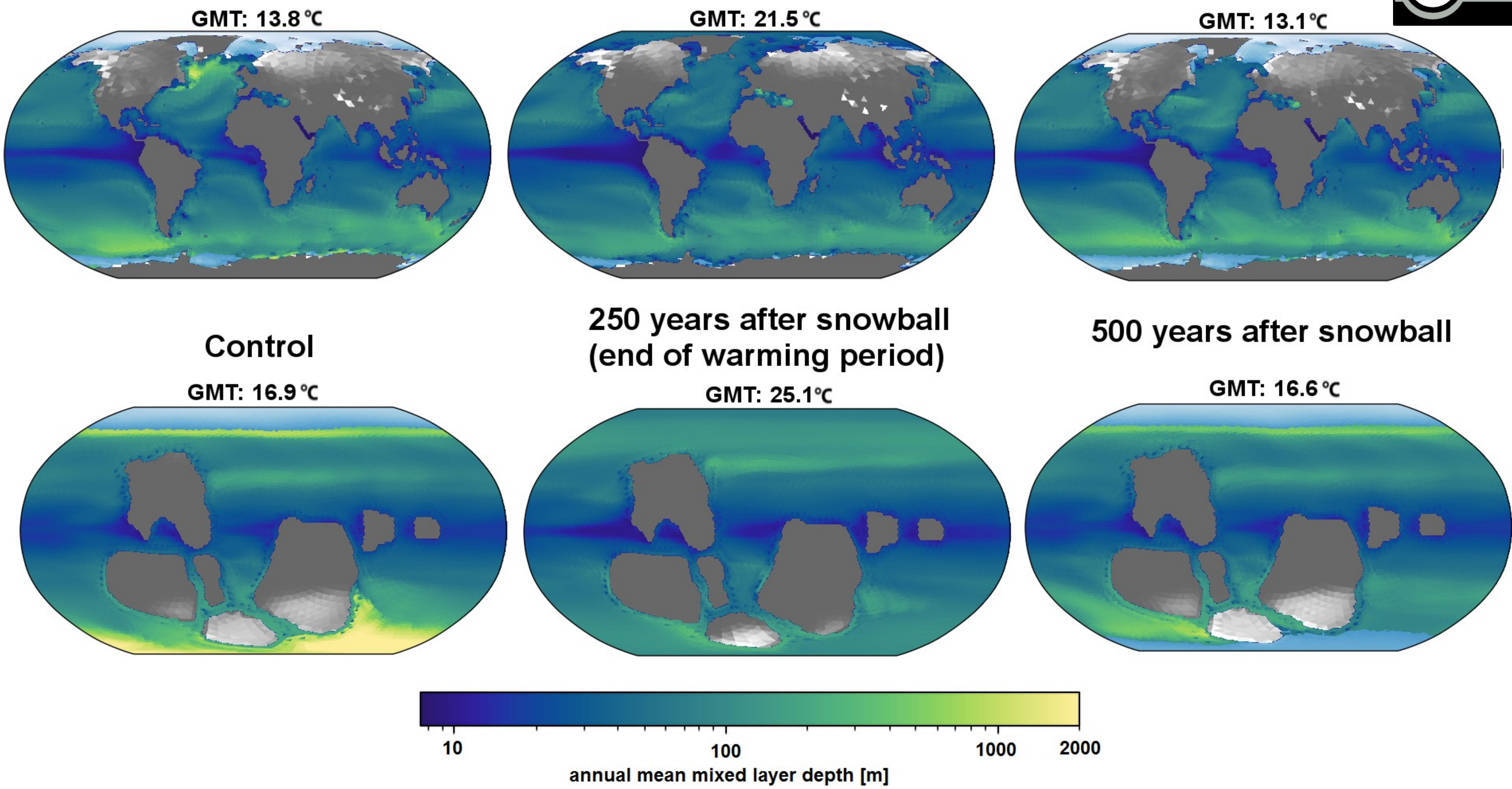
Note: The displayed procedure was heavily influenced by model instabilities during the extreme conditions of a snowball Earth. Hence, the very short period of global glaciation and a reduction in CO_2-concentration from 8896 ppm to 4448 ppm during the 250 years of warming.

Control climate

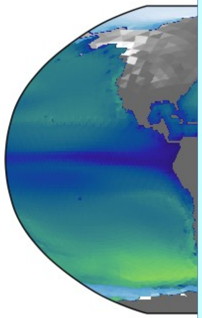
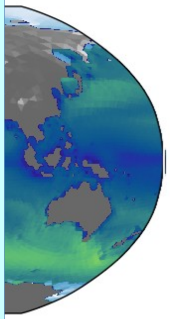


(GMT: global mean 2m air temperature. All shown surface maps represent annual mean values. In upper figures sea-ice concentration is displayed if >40% and white shading on land shows snow coverage for non-glacier grid cells on a scale from 0-0.1 m of water equivalent.)

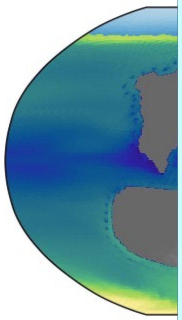
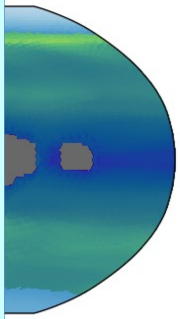
Mixed Layer Depths

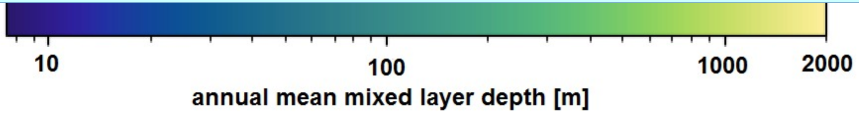


Mixed Layer Depths

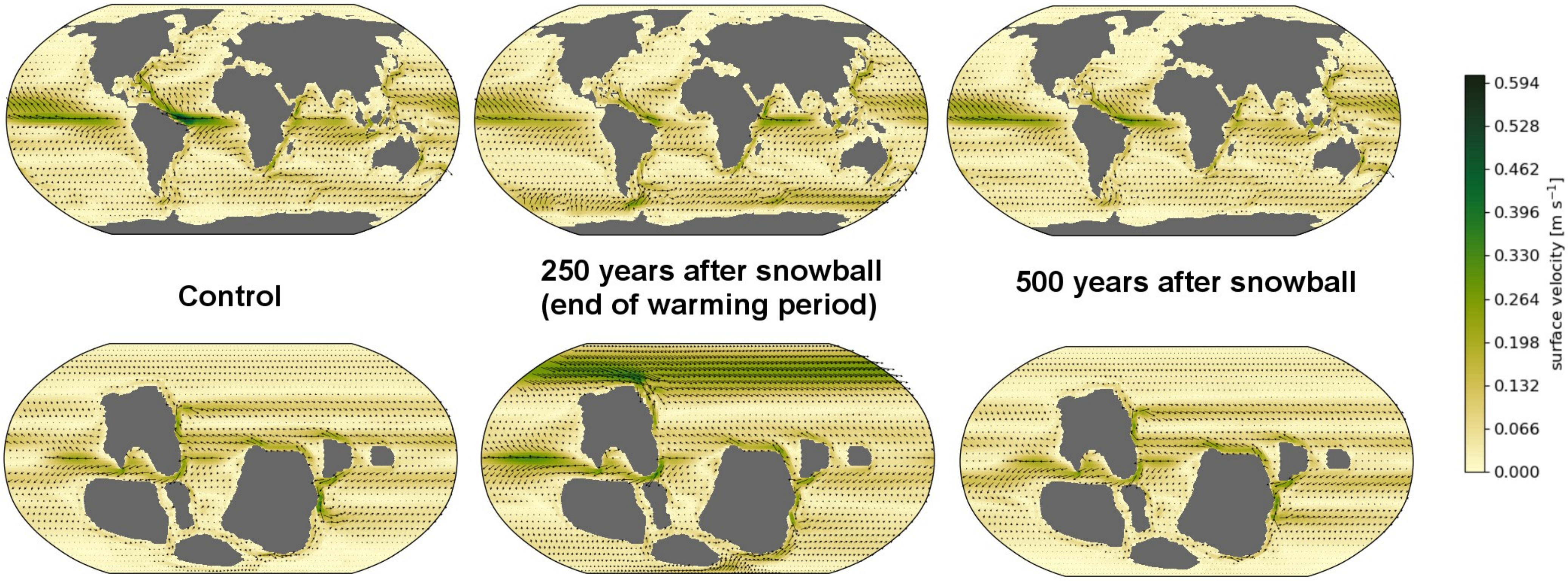



- The Marinoan setup is > 3 °C warmer under all conditions.
- Oceans are almost completely ice-free after 250 years of warming.
- First regions with increased mixed layer depths are circumpolar currents like the Southern Ocean or the northern circumpolar current in the Marinoan setup.
- Deep convection prevented in the present-day setup for the whole simulation length after the snowball (>1500 years).
- Temperatures drop lower than in the control run when CO_2 concentrations are set back to PI. This is likely because of weaker poleward heat transport due to missing convection.

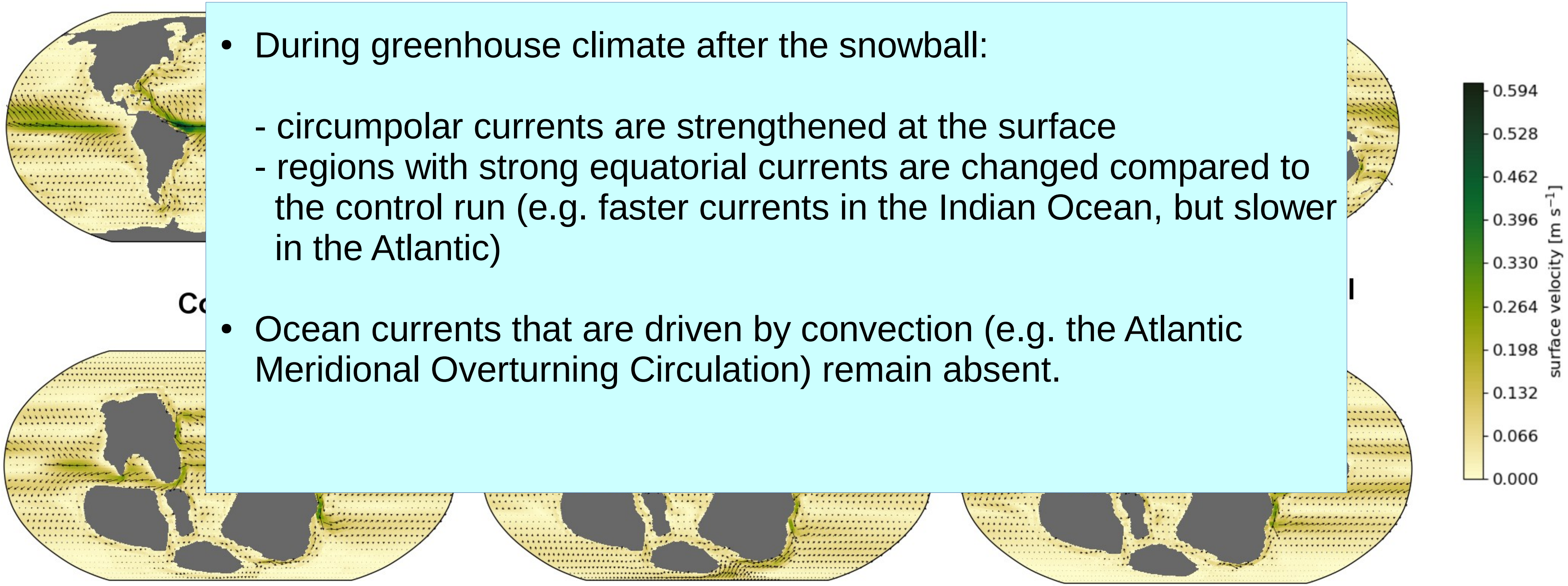





Surface Currents



Surface Currents

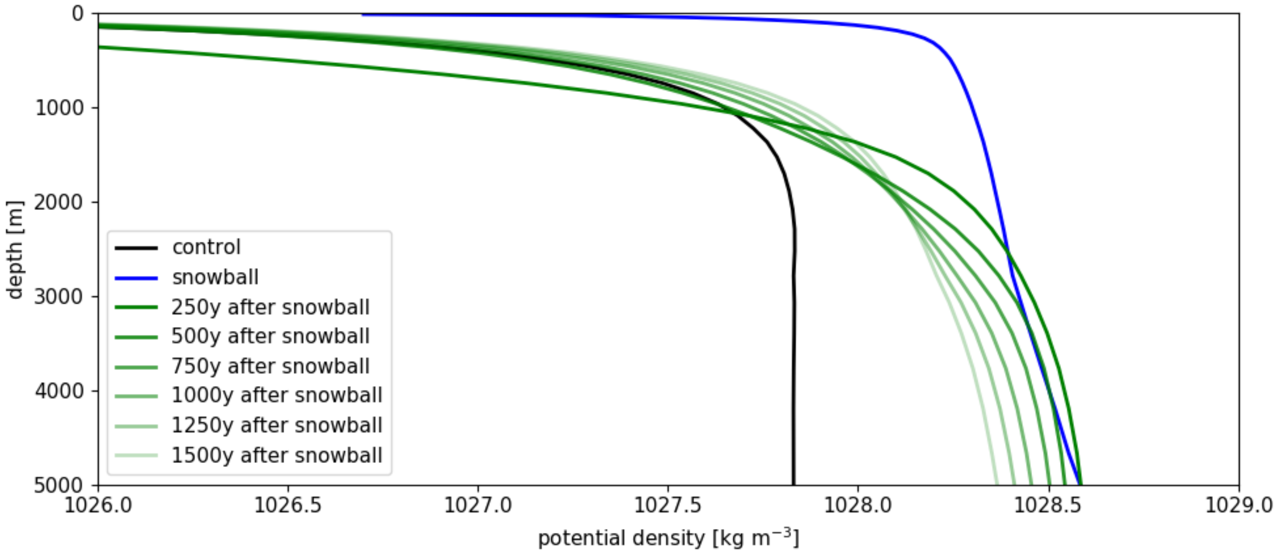


- During greenhouse climate after the snowball:

  - circumpolar currents are strengthened at the surface
  - regions with strong equatorial currents are changed compared to the control run (e.g. faster currents in the Indian Ocean, but slower in the Atlantic)

- Ocean currents that are driven by convection (e.g. the Atlantic Meridional Overturning Circulation) remain absent.

global mean vertical density profiles for the present-day setup



- ocean still stably stratified 1500 years after the melting of the snowball
- timescale of destratification estimated to be in the order of 5000 years in our model
- limited amount of sea-ice, missing land glaciers and the short warming period of 250 years likely underestimate the stratification in our model

Conclusions

- The Marinoan distribution of continents leads to a generally warmer (>3°C) climate in our model.
- During the greenhouse climate following the snowball, the strength of ocean surface currents differs from the control.
- Ocean stratification prevents convection, leading to reduced poleward heat transport and colder temperatures than in the control run.
- Destratification timescale is in the order of 5000 years in our model, but will likely be longer in a more realistic setup.

Thank you for your attention!