Impact of mid-glacial ice sheets on the recovery time of the AMOC: Implications on the frequent DO cycles during the mid-glacial period

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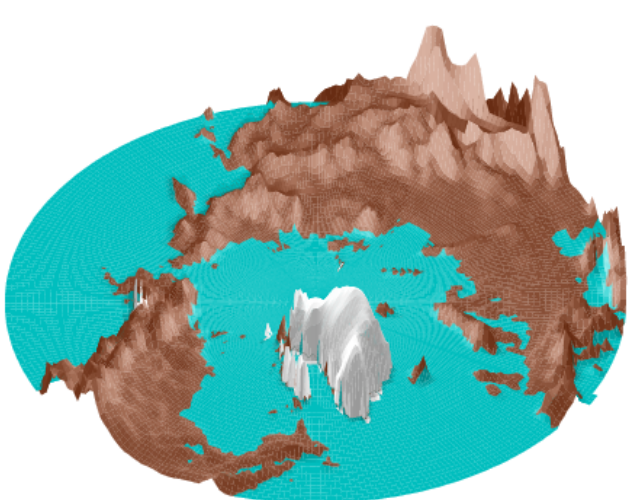
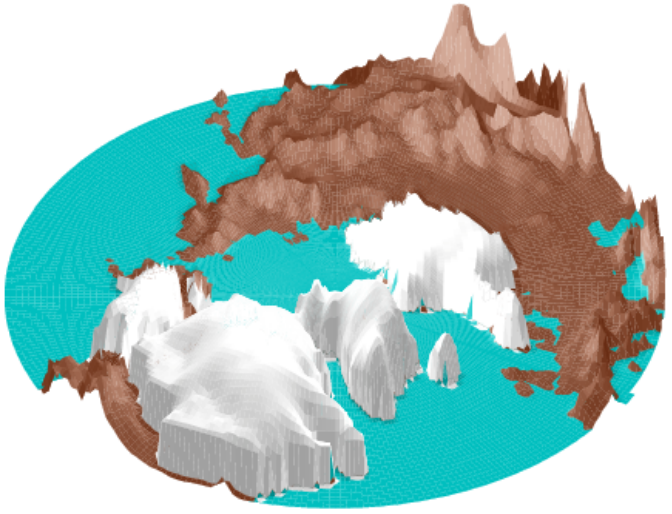




Summary

Question (slide 3-4):
Durations of stadial are shorter in MIS3 compared with MIS5, despite the stronger global cooling in MIS3. Why?

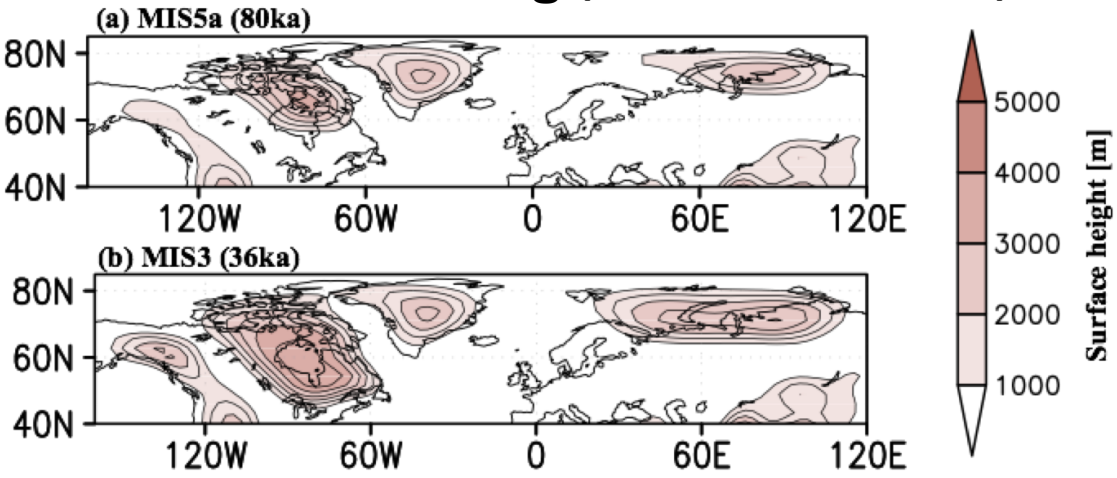
Hypothesis (slide 5):
Difference in ice sheet between the two period play a role by affecting the AMOC?

Method (slide 6-8):
Perform hosing experiments with an AOGCM under 3 climates (MIS3, MIS5a, and MIS3 with MIS5a ice sheet) and compare recovery time of AMOC

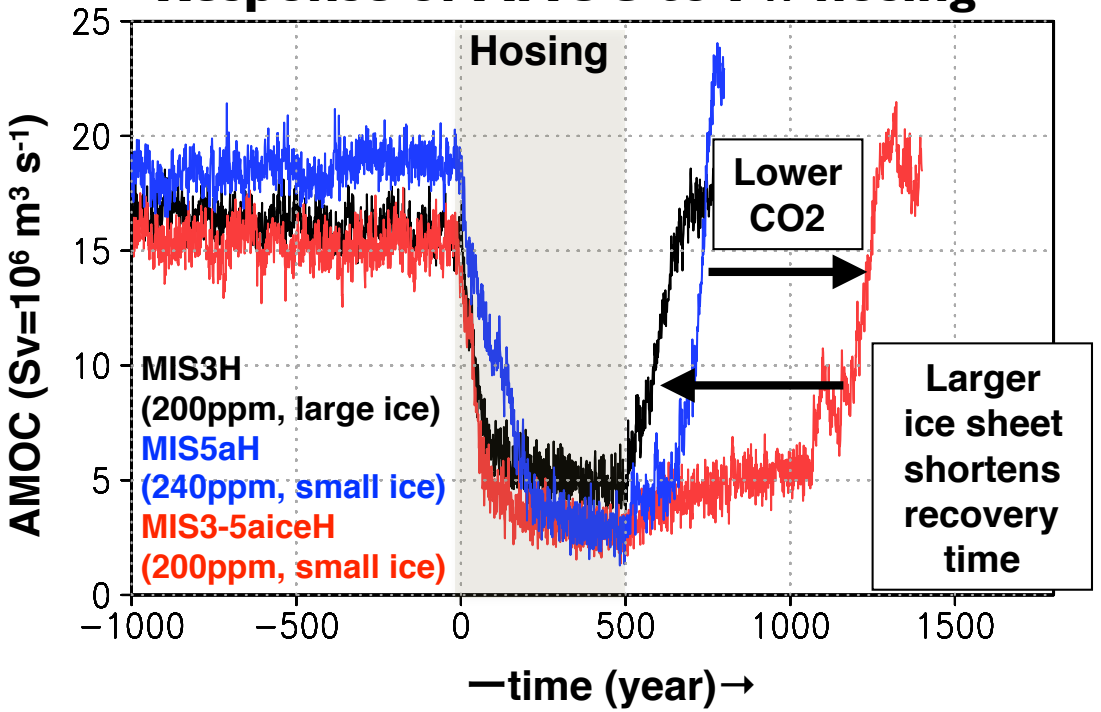
Result (slide 9-10):
Larger MIS3 ice sheet shortens recovery time of AMOC by intensifying surface winds over North Atlantic

Message (slide 11):
Ice sheet reconstruction prior to LGM is important to interpret proxies

Ice sheet forcing (Abe-Ouchi et al. 2013)



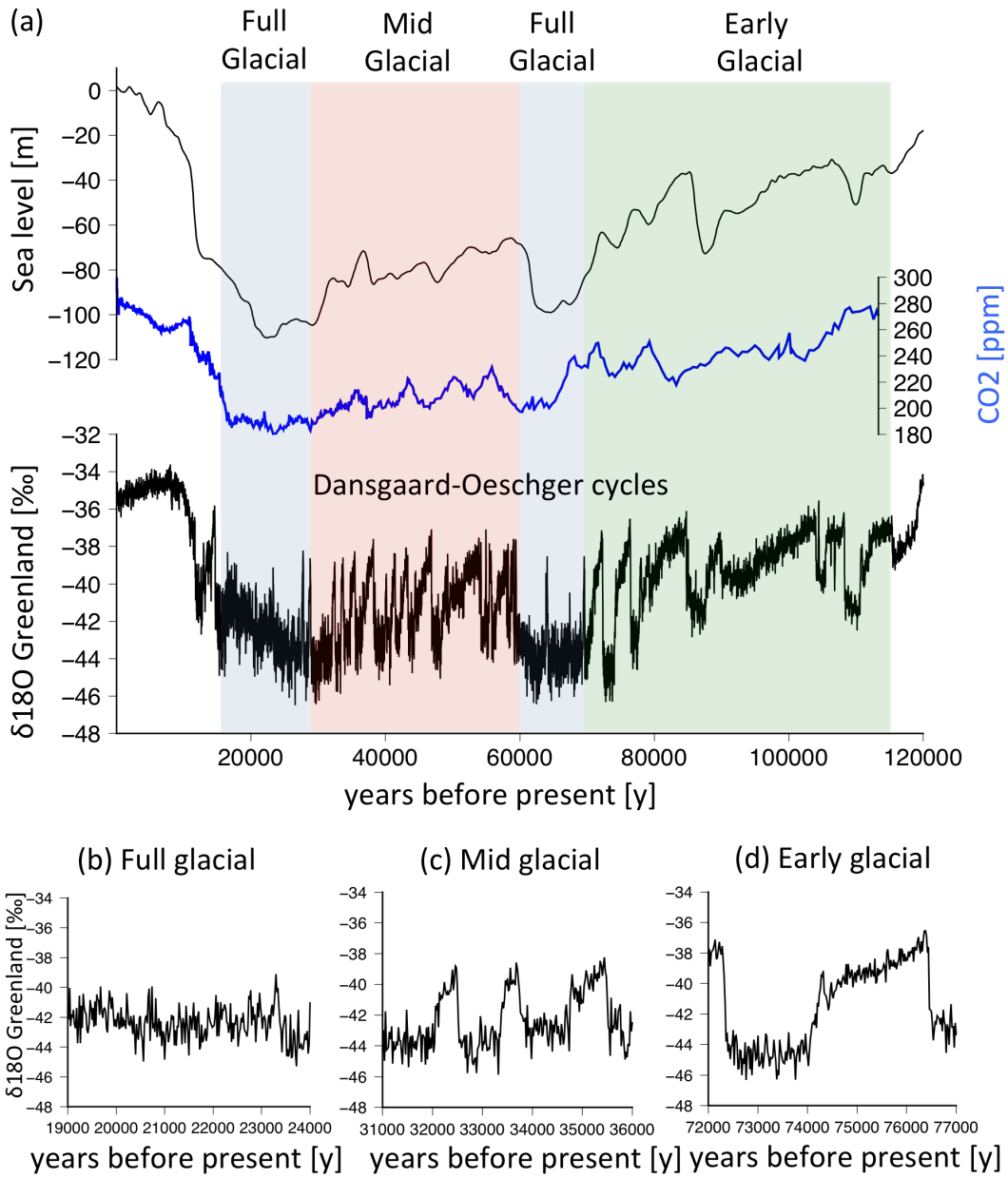
Response of AMOC to Fw hosing



Millennial time-scale climate variability over glacial period

- Millennial time-scale climate shift between two contrasting modes, interstadial and stadial, occurred during glacial period (Ganopolski and Rahmstrof 2002,Kindler et al. 2014, Kawamura et al. 2017)
- Related to changes in the Atlantic Meridional Overturning Circulation (AMOC)(Piotrowski et al. 2005, Henry et al. 2016)
- Duration of climate modes varies over the glacial period (Buizert and Schmittner 2015, Lehmann and Ditlevsen 2019)

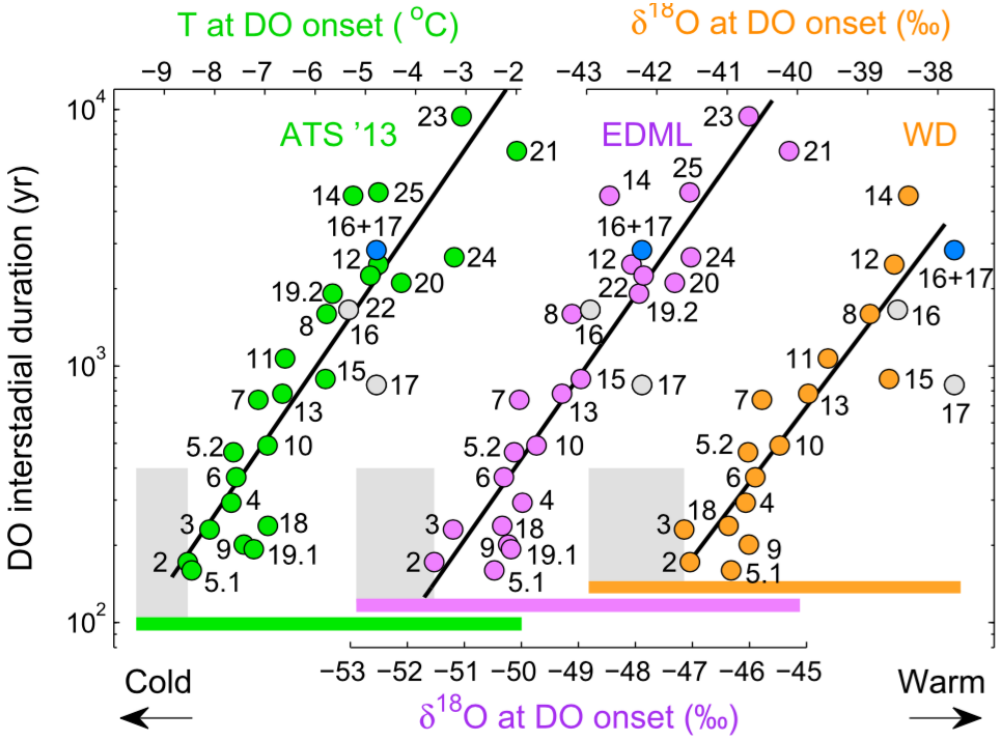
What controls the duration (stability) of climate modes ?



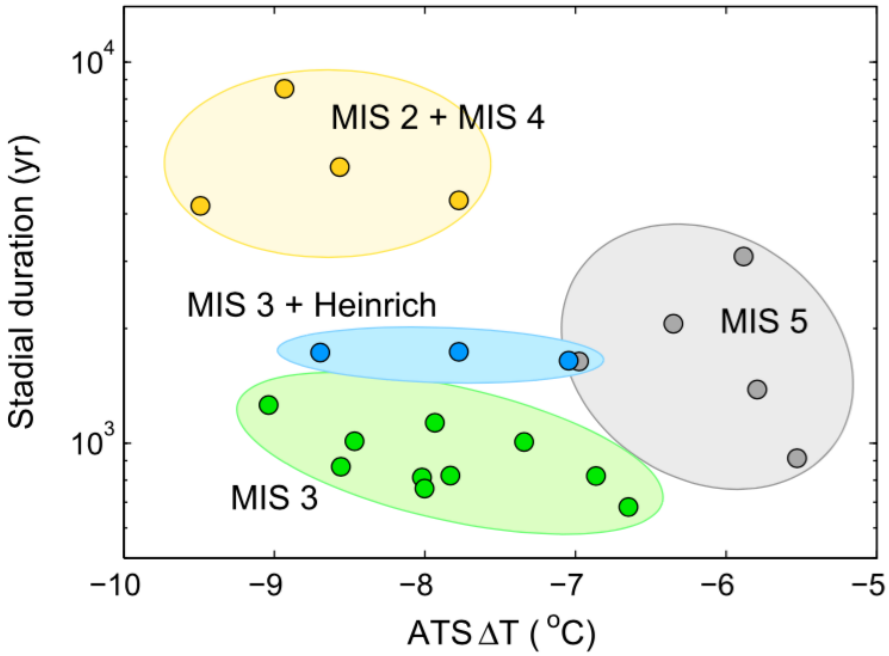
(a) Changes in ice volume (sea level, Grant et al. 2012), CO_2 (Beleiter et al. 2015) and Greenland ice core $\delta^{18}O$ (a proxy of temperature, Rasumussen et al. 2012) over the last glacial-interglacial cycle, and characteristics of typical DO cycles during (b) full glacial, (c) mid glacial and (d) early glacial. Data of Rasumussen et al. (2012) is used

Effect of global cooling on the duration of climate modes

Duration of Interstadial V.S. Antarctic temperature



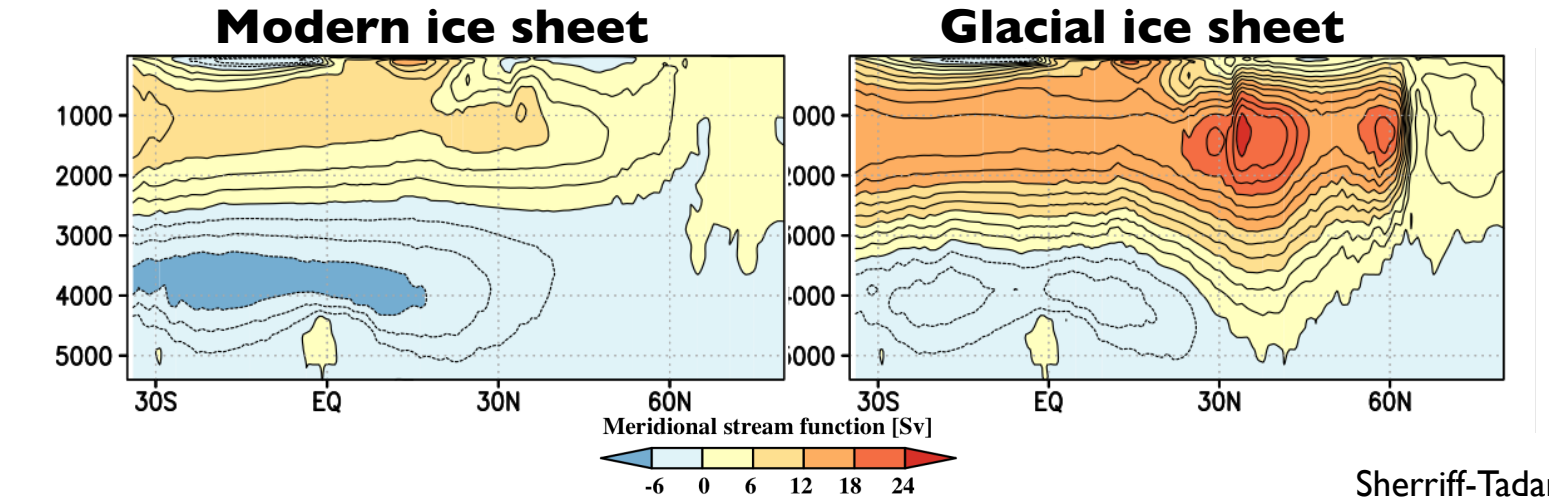
Duration of Stadial V.S. Antarctic temperature



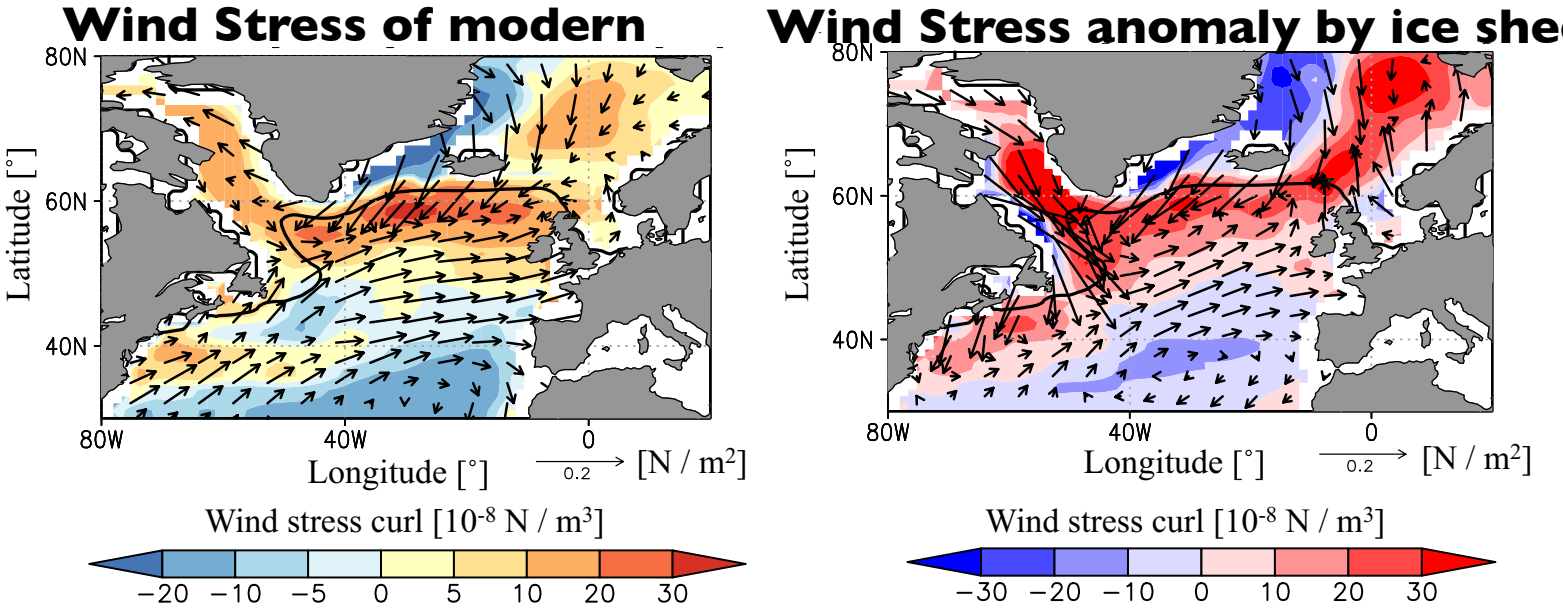
Buizert and Schmittner 2015

- CO2/Antarctic temperature controls the duration of interstadial climate through affecting the AMOC (Buizert and Schmittner 2015, Kawamura et al. 2017)
- No strong relationship between CO / global cooling and the duration of stadial (Buizert and Schmitner 2015) . **Other forcing play a role?** (Lohmann 2019)

Possible climate forcing: Glacial ice sheets



Sherriff-Tadano et al. 2018



- Glacial ice sheets intensify the AMOC by strengthening surface winds and oceanic salt transport (e.g. Kawamura et al. 2017, Sherriff-Tadano et al. 2018)
  →May play a role in inducing shorter stadials during MIS3 compare to MIS5

Objective and Method

Objective:

- Assess the impact of mid-glacial ice sheet on the duration of the stadial climate (AMOC) to improve understand of millennial time-scale climate variability as well as ice sheet-climate interactions

Method:

- Conduct numerical experiments with atmosphere ocean coupled general circulation model under two ice sheet configurations

Model: MIROC4m AOGCM (Hasumi and Emori 2004)

- Resolution:atmosphere~300km, Ocean~100km
- The model version utilized in this study are used extensively for modern climate, paleoclimate (Obase and Abe-Ouchi 2019 GRL, O'hisi et al. 2020 CPD, Chan and Abe-Ouchi 2020 CPD), and future climate studies (Yamamoto et al. 2015 GBC).
- It also reproduces the AMOC of LGM reasonably well (Sherriff-Tadano and Abe-Ouchi 2020 JC).

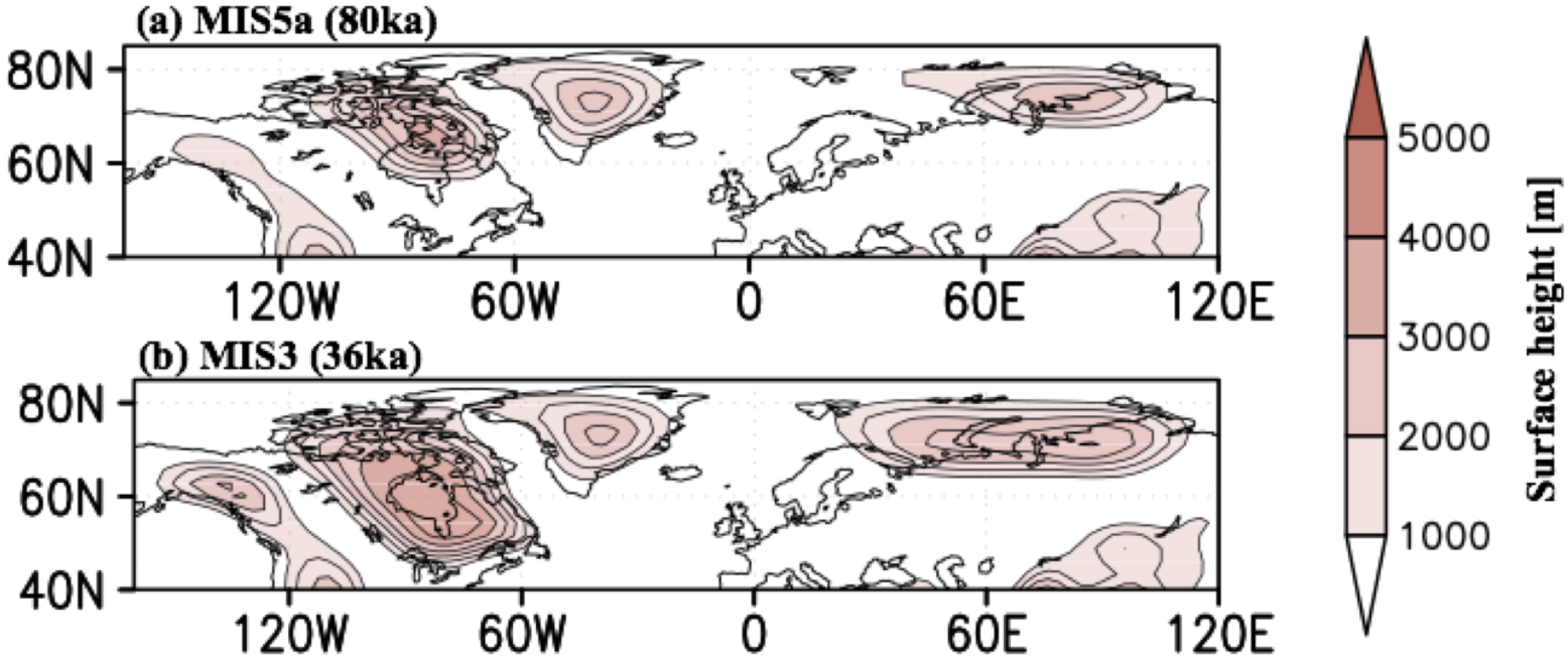
Experimental design

1. Three simulations are integrated for more than 2000 years (MIS3H, MIS5aH, MIS3-5aiceH (MIS3 with MIS5a ice sheet))
2. Freshwater of 0.1 Sv is applied over the northern North Atlantic for 500 years to trigger an initial weakening of the AMOC (e.g. Kawamura et al. 2017)
3. Stop the freshwater hosing
4. Impact of ice sheets on the duration of stadial is assessed by comparing the recovering time

Table 1: Forcing and boundary conditions of the climate simulations.

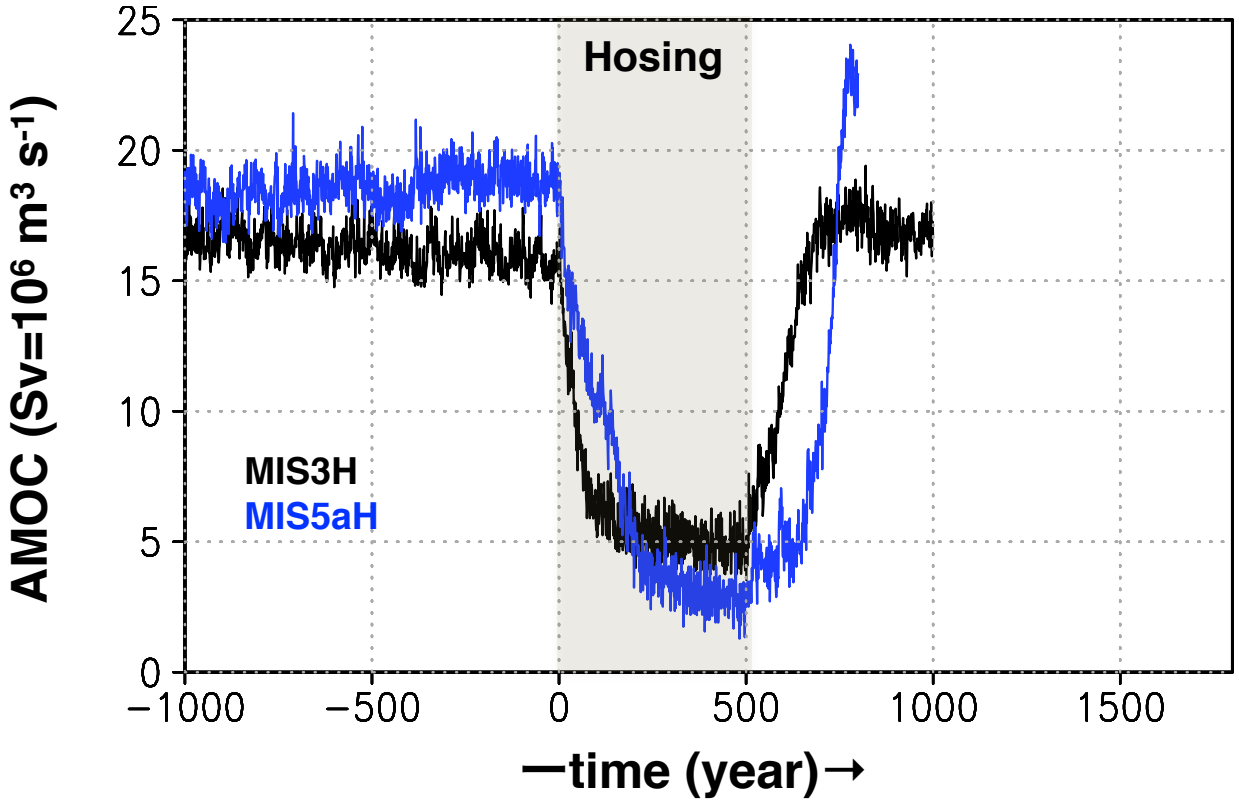
Name	CO2	Ice sheet	Obliquity	Precession	Ecc
MIS5aH	240 ppm	80ka	23.175	312.25	0.0288
MIS3H	200 ppm	36ka	22.754	251.28	0.0154
MIS3-5aiceH	200 ppm	80ka	22.754	251.28	0.0154

Ice sheet forcing



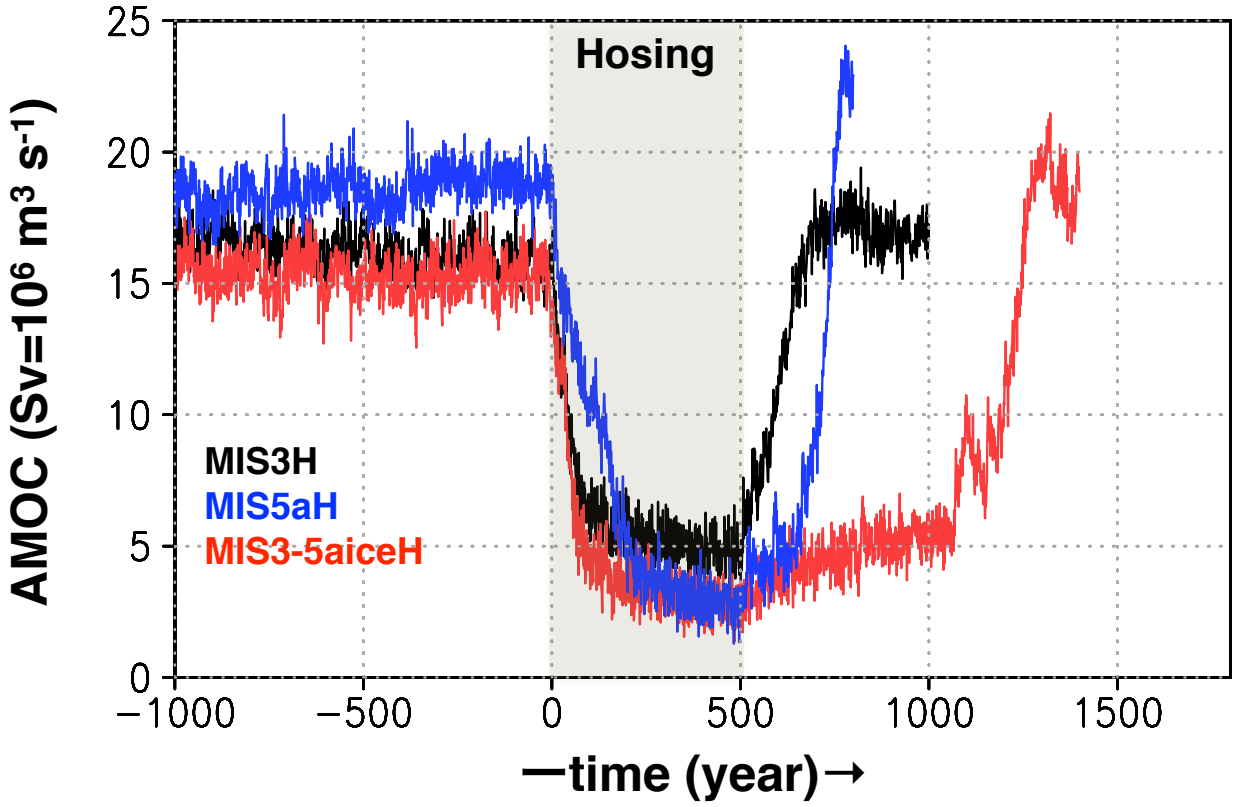
- Ice sheet forcing is taken from simulated results of an ice sheet model Icies (Abe-Ouchi et al. 2007 CP, 2013 Nature)
- Main difference appears over the North America, where MIS3 ice sheet has larger extent

Response of AMOC to Fw hosing: Comparison of MIS3 & 5a



- AMOC remains in a vigorous mode in MIS3 & 5a before hosing
- Fw hosing causes a drastic weakening of the AMOC
- Duration of stadial (weak AMOC) is slightly shorter in MIS3 compared with MIS5a, which is consistent with ice core data (Buizert and Schmittner 2015)

Response of AMOC to Fw hosing: Effect of mid-glacial ice sheet



- MIS3-5aiceH shows a longer duration of stadial (weak AMOC)
- Comparison of MIS3H and MIS3-5aiceH shows that the larger MIS3 ice sheet shortens the duration of stadial
- Comparison of MIS5aH and MIS3-5aiceH shows that the lower CO2 increases the duration of stadial

Discussion & Conclusion

- Ice sheet may play a role in causing shorter stadial during MIS3 compare to MIS5
- Larger ice sheets shortens the duration of stadial (weak AMOC mode) by increasing sea surface salinity over the deepwater formation region, which destabilize the weak AMOC and increases the probability of the initiation of deepwater formation. (not shown)
- During MIS2, 4, ice sheets may play secondary role in determining the duration of the stadial.
- There is a large uncertainty in the ice sheet configuration prior to LGM. Further evaluation of the mid-glacial ice sheet effect should be conducted using different ice sheet reconstructions.

References

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