Quantification of factors impacting seawater and calcite $\delta^{18}O$ during Heinrich Stadials 1 and 4*

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*The results shown are based on Bagniewski et al., 2015

Motivation

Oxygen isotope composition of foraminiferal calcite shells ($\delta^{18}O_c$) collected from ocean sediment cores depends on temperature and isotopic composition of the water ($\delta^{18}O_w$) in which the shells form. Large freshwater fluxes, such as those caused by melting icebergs during Heinrich events introduce a distinct $\delta^{18}O_w$ signal into the North Atlantic. In addition, the meltwater leads to a significant weakening of the Atlantic Meridional Overturning Circulation (AMOC).

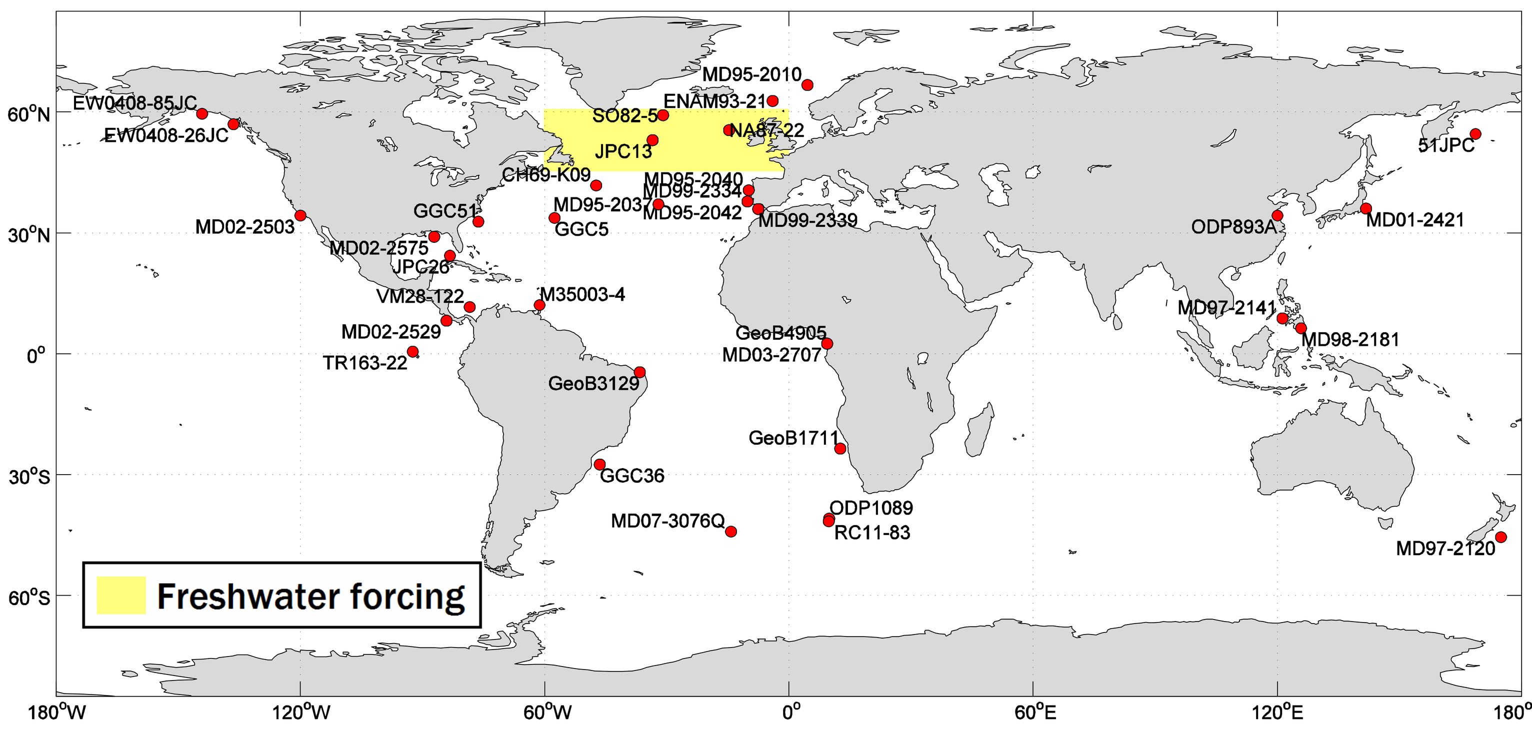
In this study, we simulate a Heinrich Stadial with an oxygen-isotope-enabled Earth System Climate Model and analyse the respective impact of the three main contribution factors to $\delta^{18}O_c$ variations recorded in foraminifera: the addition of ^{18}O depleted meltwater in the North Atlantic and its propagation ("meltwater effect"); $\delta^{18}O_w$ anomalies due to changes in circulation, precipitation, and evaporation ("circulation and climate effect"); and the changes in water temperature ("temperature effect"). Model results are compared with 36 sediment cores covering Heinrich Stadials 1 and 4.

Model: UVic ESCM

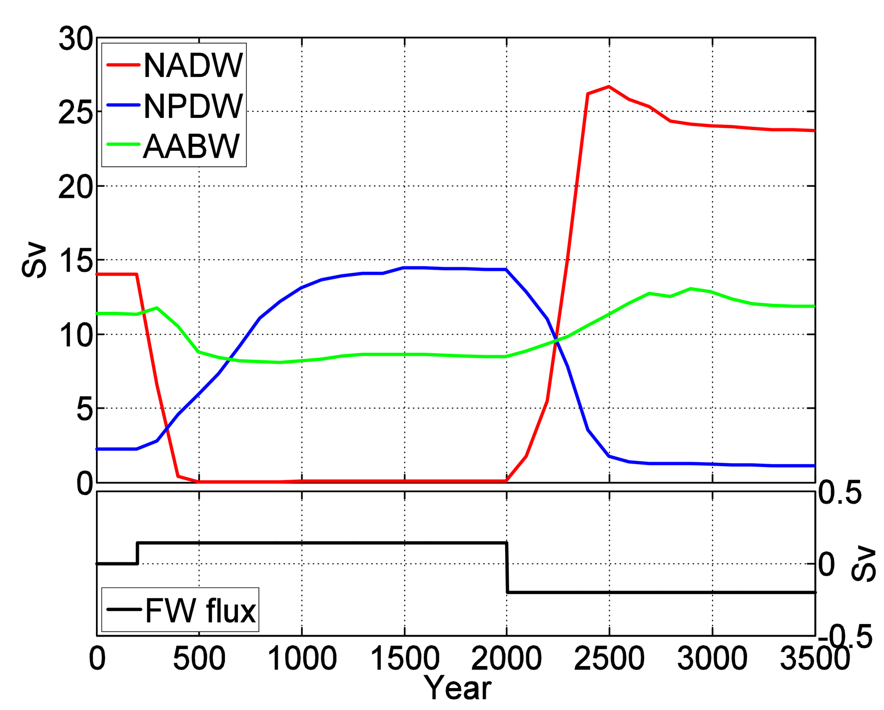
The University of Victoria Earth System Climate Model (UVic ESCM) has a 3.6° x 1.8° spherical grid resolution. Its ocean general circulation component (MOM2) has 19 vertical levels and is coupled to a vertically integrated, 2-D atmospheric energy-moisture balance model, a dynamic-thermodynamic sea ice model, a sediment model and a dynamic global vegetation model MOSES/TRIFFID (Weaver et al., 2001). UVic ESCM also includes stable water isotopes, $H_2{}^{18}O$ and $H_2{}^{16}O$, which are integrated into the ocean, atmosphere, land-surface, and sea-ice components of the model (Brennan et al., 2012, 2013).

Experimental set-up

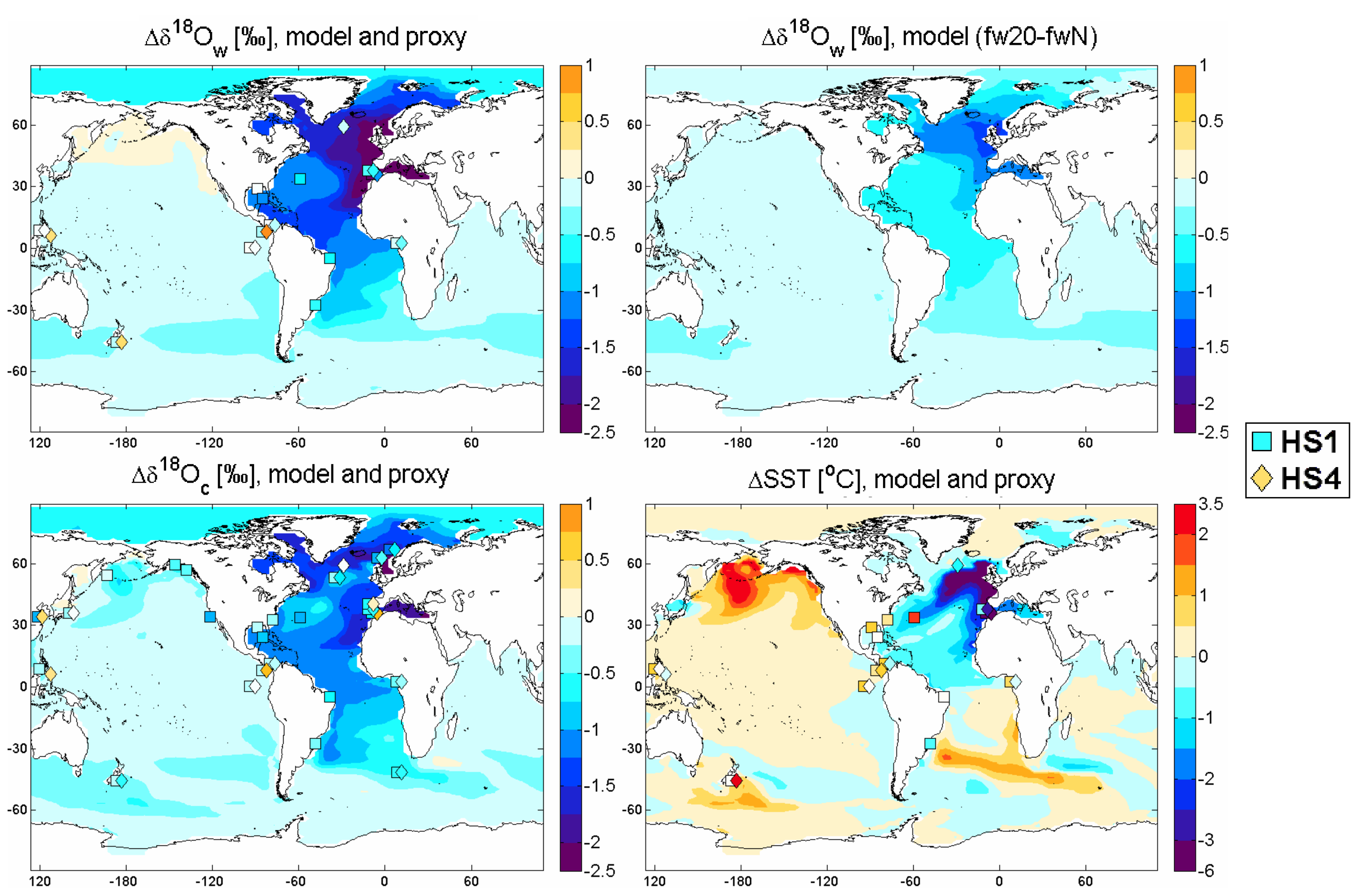
- 0.14 Sv of freshwater added into the North Atlantic over 1800yrs
- followed by salt flux into the North Atlantic to resume the AMOC
- fw20 simulation: isotopic signature of meltwater = -20‰
- fwN simulation: no isotopic signature of meltwater
- LGM boundary conditions (orbital configuration, CO_2, ice sheets)
- Ocean $\delta^{18}O$ initialized to 1.2‰, above the pre-industrial seawater value of 0.1‰ (to account for LGM enrichment)



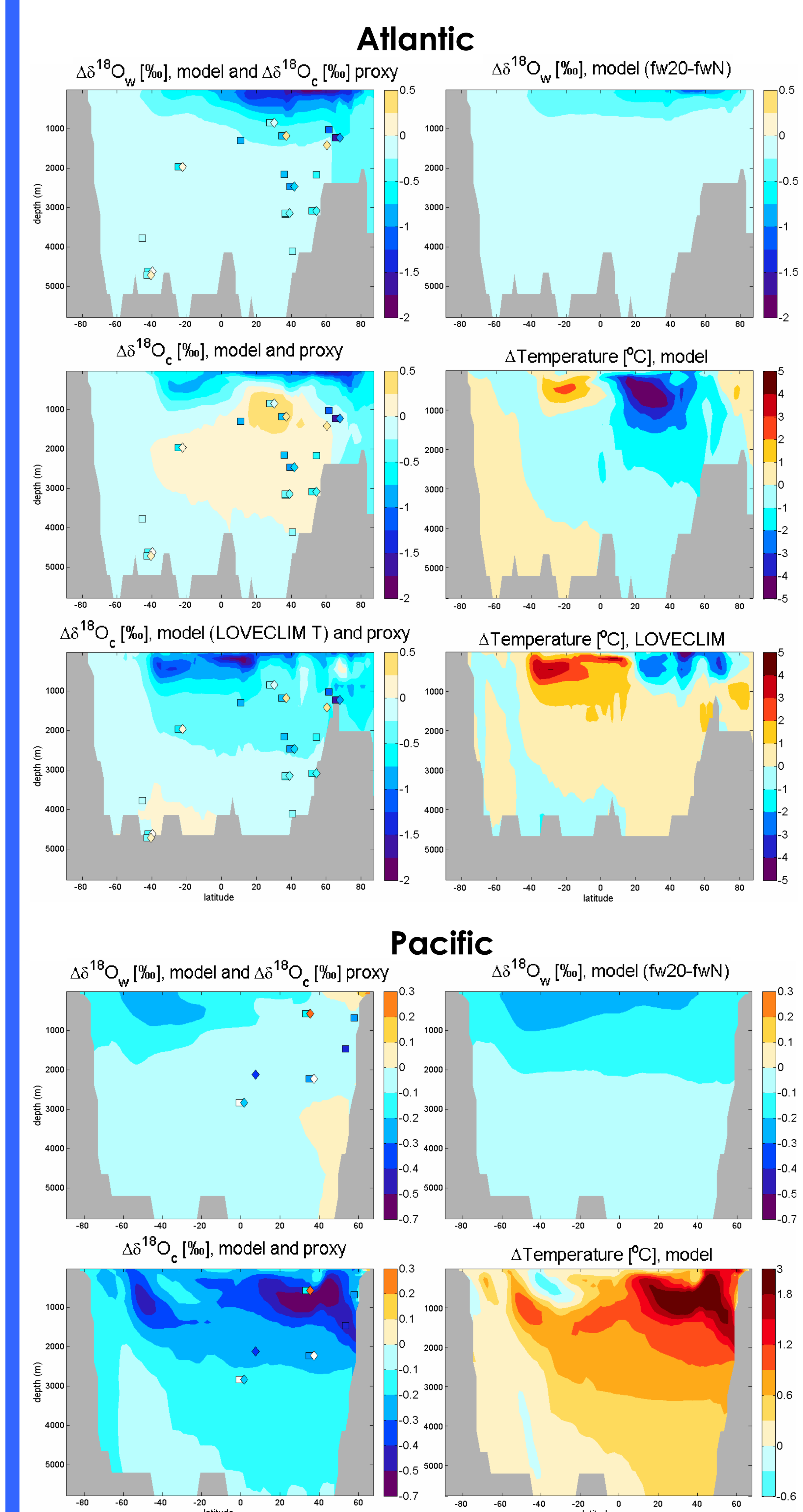
Changes in ocean circulation



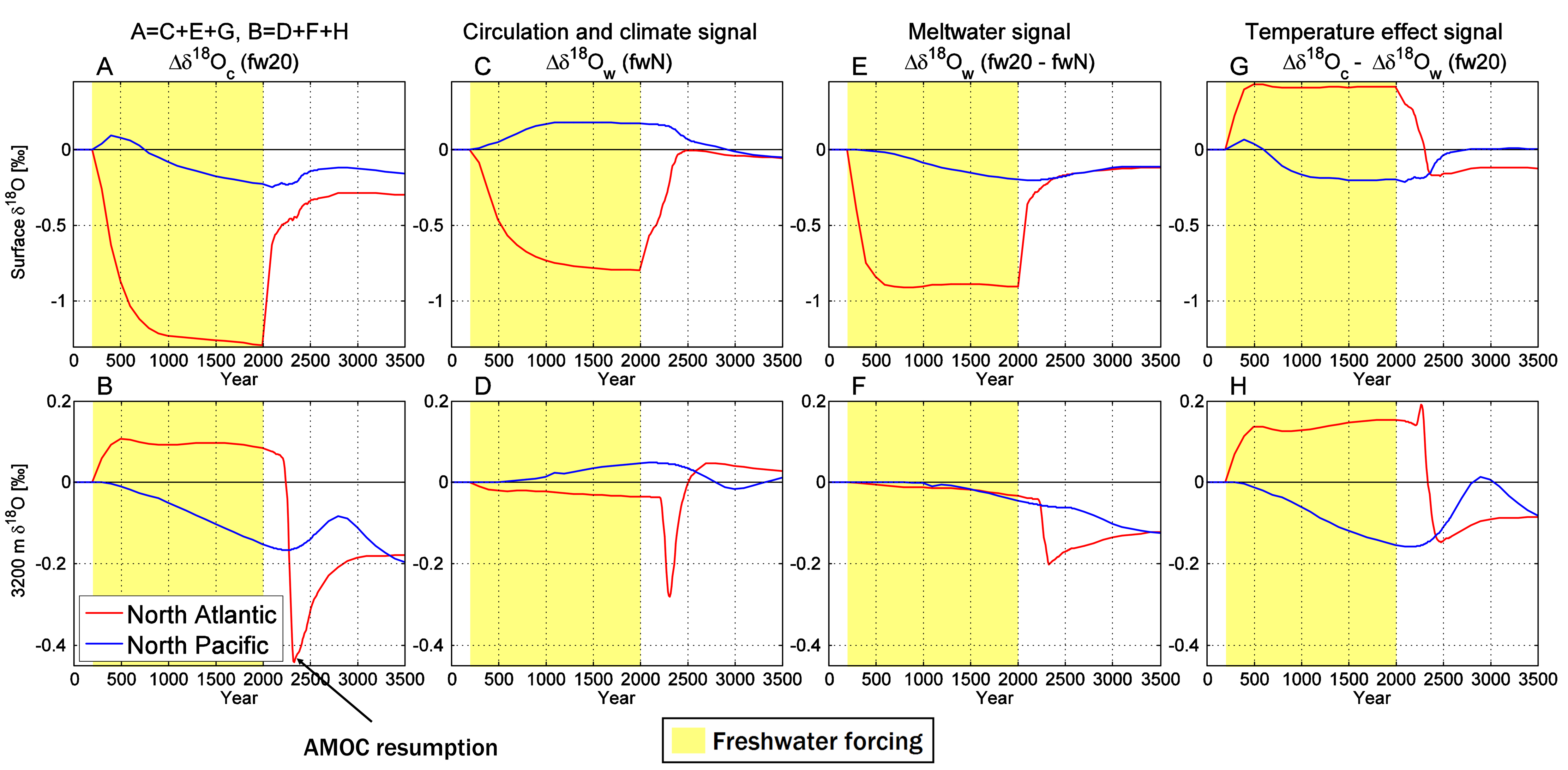
Surface $\delta^{18}O$ and SST anomalies (year 2000)



$\delta^{18}O$ and oceanic temperature anomalies (year 2000)



Factors impacting $\delta^{18}O_C$



Conclusions

- Changes in surface $\delta^{18}O_c$ can be equally attributed to the three contributing factors ("temperature effect", "circulation and climate effect" and "meltwater effect").
- Changes in deep ocean $\delta^{18}O_c$ are mainly dictated by the "temperature effect".
- The fact that the simulated subsurface $\delta^{18}O_c$ increase in the Atlantic is in better agreement with HS4 records than with HS1 records indicates that subsurface Atlantic circulation might have been different during the two stadials.
- At the end of the Heinrich stadial we simulate a ~0.5‰ $\delta^{18}O_c$ decrease in the deep North Atlantic, which resembles anomalies found in several North Atlantic cores. In contrast to a theory attributing these anomalies to sea ice variability and the resulting brine rejection (Vidal et al., 1998; Dokken and Jansen, 1999), our results suggest that the anomalously low $\delta^{18}O_c$ surface waters were transiently advected to the deep North Atlantic during a rapid AMOC recovery.

References

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