Surface wind-stress threshold for glacial Atlantic overturning

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Introduction

- Atlantic meridional overturning circulation (AMOC) shows large spread in last glacial maximum (LGM, ca. 21 kyr BP) climate simulations, e.g. PMIP2: ±40% range in LGM minus present AMOC strength *[Weber et al., 2007].*

- Reconstructions: glacial AMOC strength values ranging from a decrease of up to 30% to a slight increase *[Marchal et al., 2000; Lynch-Stieglitz et al., 2007].*

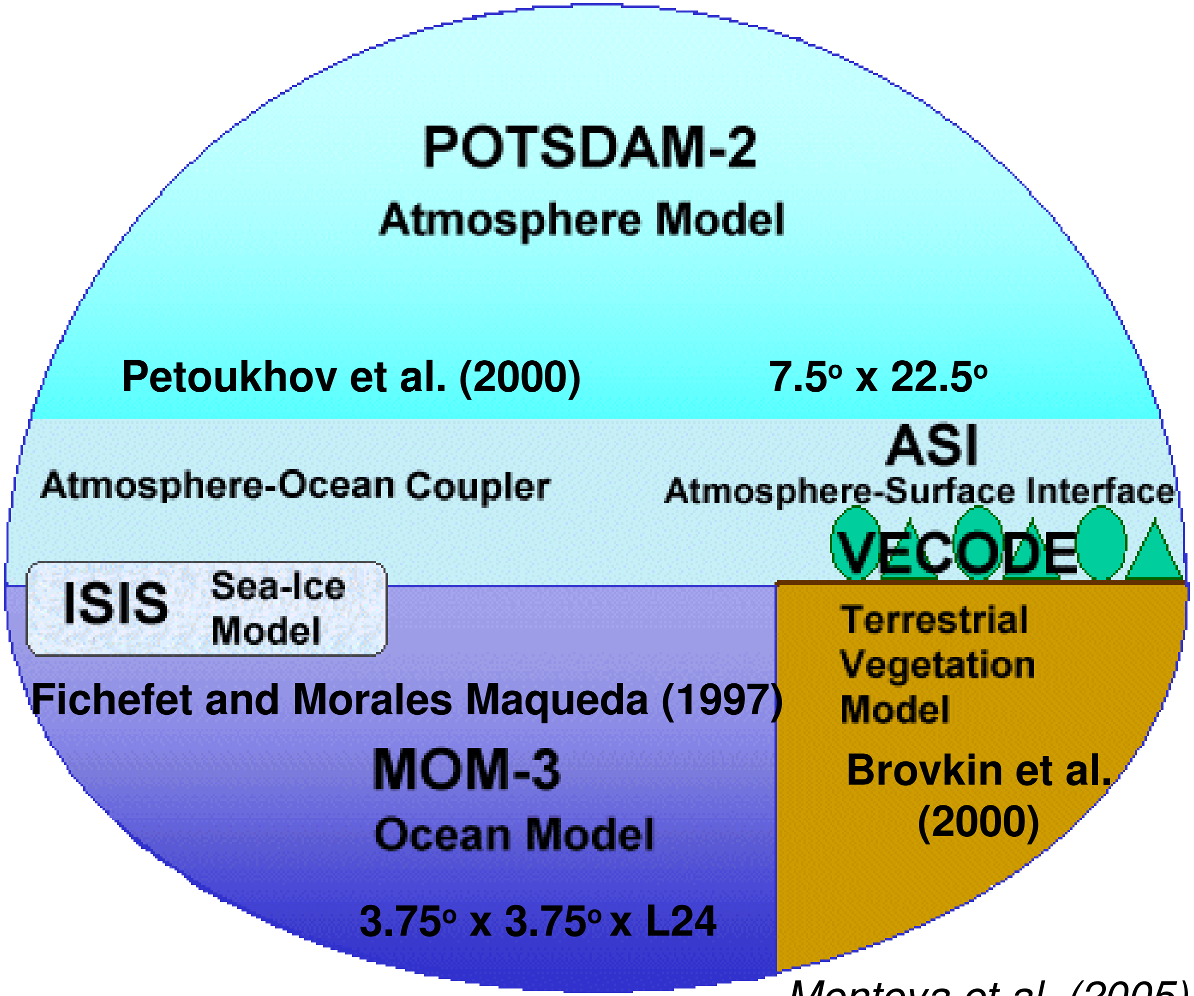
- Investigating glacial AMOC requires assessment of its driving mechanisms (surface winds, vertical mixing *[Kuhlbrodt et al., 2007]).*

- Stronger glacial meridional surface temperature gradients and increased glacial aerosol concentrations have led to assumption of glacial surface winds enhanced by ≥ 50% [*Crowley and North,1991]*. Yet, enhanced aerosols might also reflect changes in sources, e.g. enhanced aridity and aloft rather than surface temperature gradients might be more relevant to surface winds *[Toggweiler 2008].* Models show enhanced westerlies but not uniformly enhanced surface winds (e.g. *Hewitt et al. [2003]; Otto-Bliesner et al. [2006]*).

- Thus, glacial wind-stress poorly constrained.

- Here we assess impact of surface winds uncertainty on LGM AMOC strength.

CLIMBER-3α



POTSDAM-2
Atmosphere Model

Petoukhov et al. (2000)

7.5° x 22.5°

Atmosphere-Ocean Coupler

ASI
Atmosphere-Surface Interface

VECODE

ISIS **Sea-Ice Model**

Fichefet and Morales Maqueda (1997)

MOM-3
Ocean Model

3.75° x 3.75° x L24

Terrestrial Vegetation Model

Brovkin et al. (2000)

Montoya et al. (2005)

PMIP2 boundary conditions for LGM:

Insolation

Equivalent CO_2 = 167 ppmv

Peltier (2004) ICE-5G ice-sheet reconstruction

Land-sea mask

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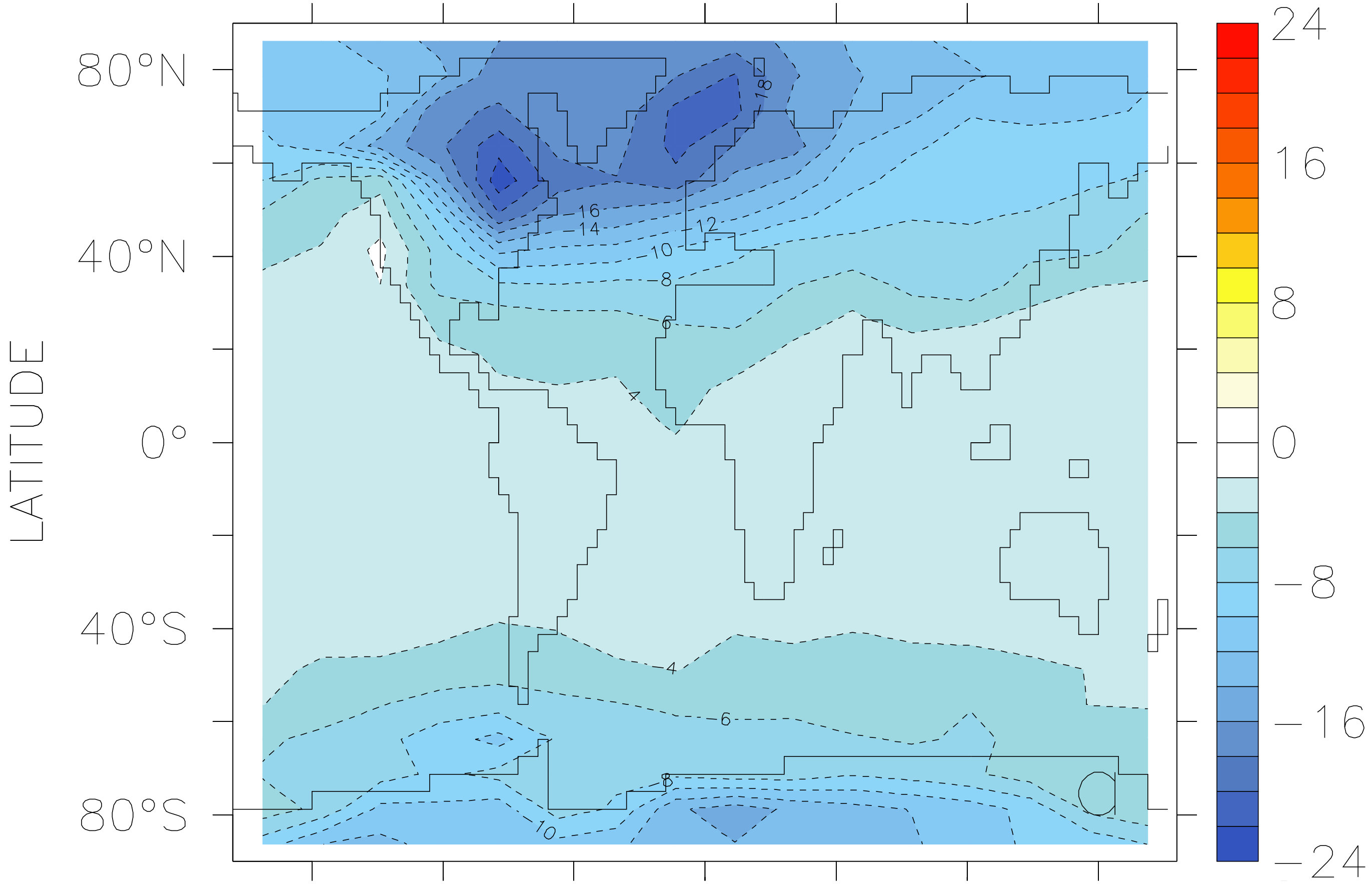
Global salinity enhanced by 1psu

Ocean bathymetry, vegetation and river runoff routing unchanged with respect to Holocene

To investigate sensitivity to surface wind-stress:
Model integrated to equilibrium with *Trenberth et al. [1989]* surface wind-stress climatology × factor α Є [0.5, 2] (LGMα).

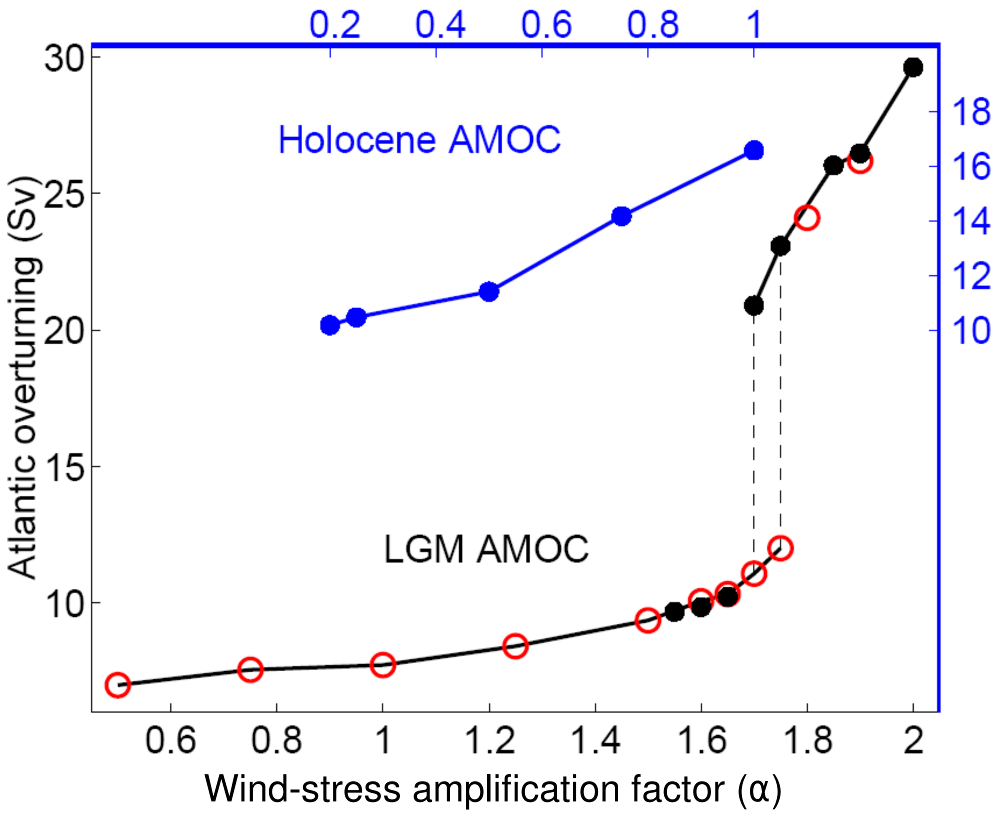
Mean annual surface air temperature difference (SAT)
LGM1.0 (surface wind-stress: *Trenberth et al. [1989]*) - Holocene (K).



Global ΔSAT Є [-5.9 K (LGM0.5), -4.1 K (LGM2.0)]

Tropical ΔSST Є [-2.0 K (LGM0.5), -2.6 K (LGM2.0)]

(halfway between 1-2 K *[CLIMAP 1976]* and 4-5 K *[Guilderson et al. 1994]* estimates; consistent with recent models & alkenone data *[Rosell-Melé et al. 2004]).*

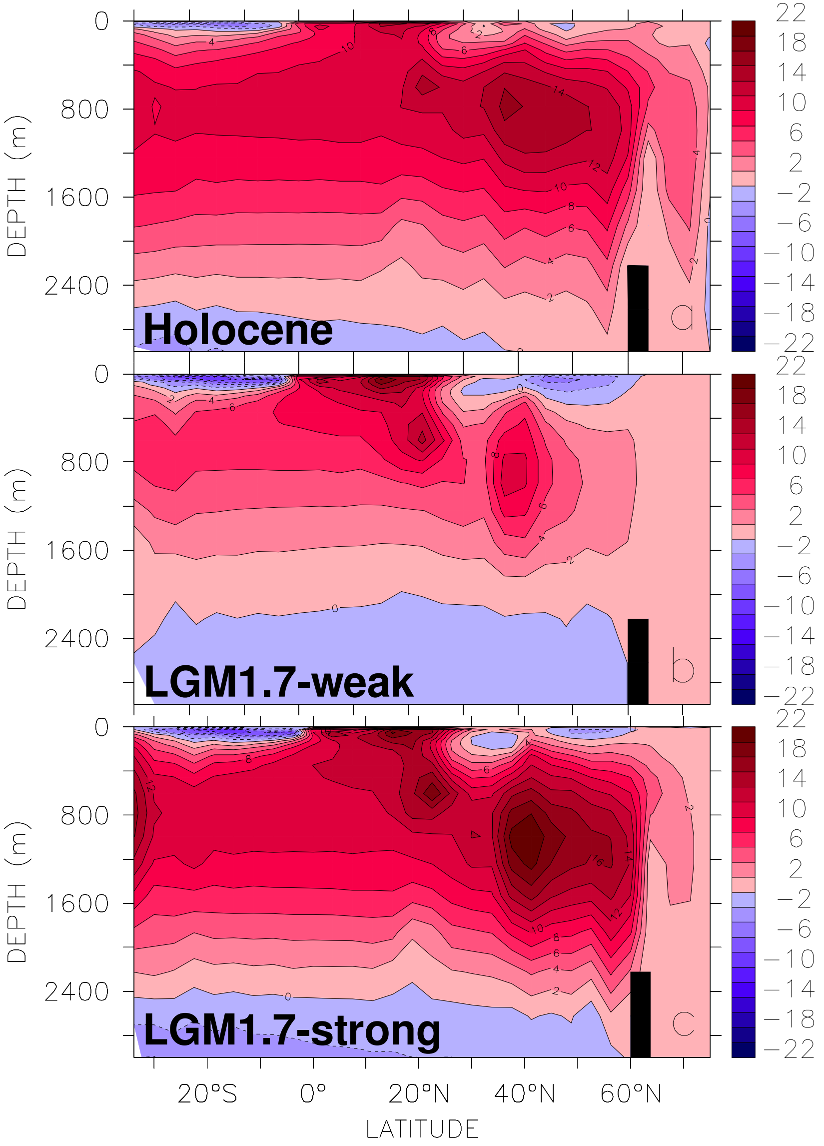


○ LGMα-weak (initial conditions: LGM1)

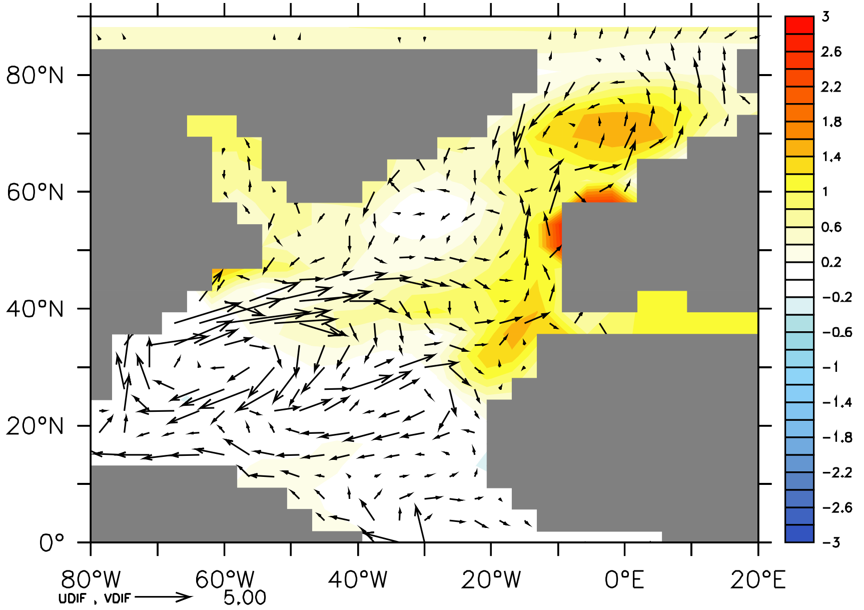
● LGMα-strong (initial conditions: LGM2)

$\alpha \equiv \alpha_c = 1.7$

Atlantic meridional overturning circulation (AMOC, Sv)



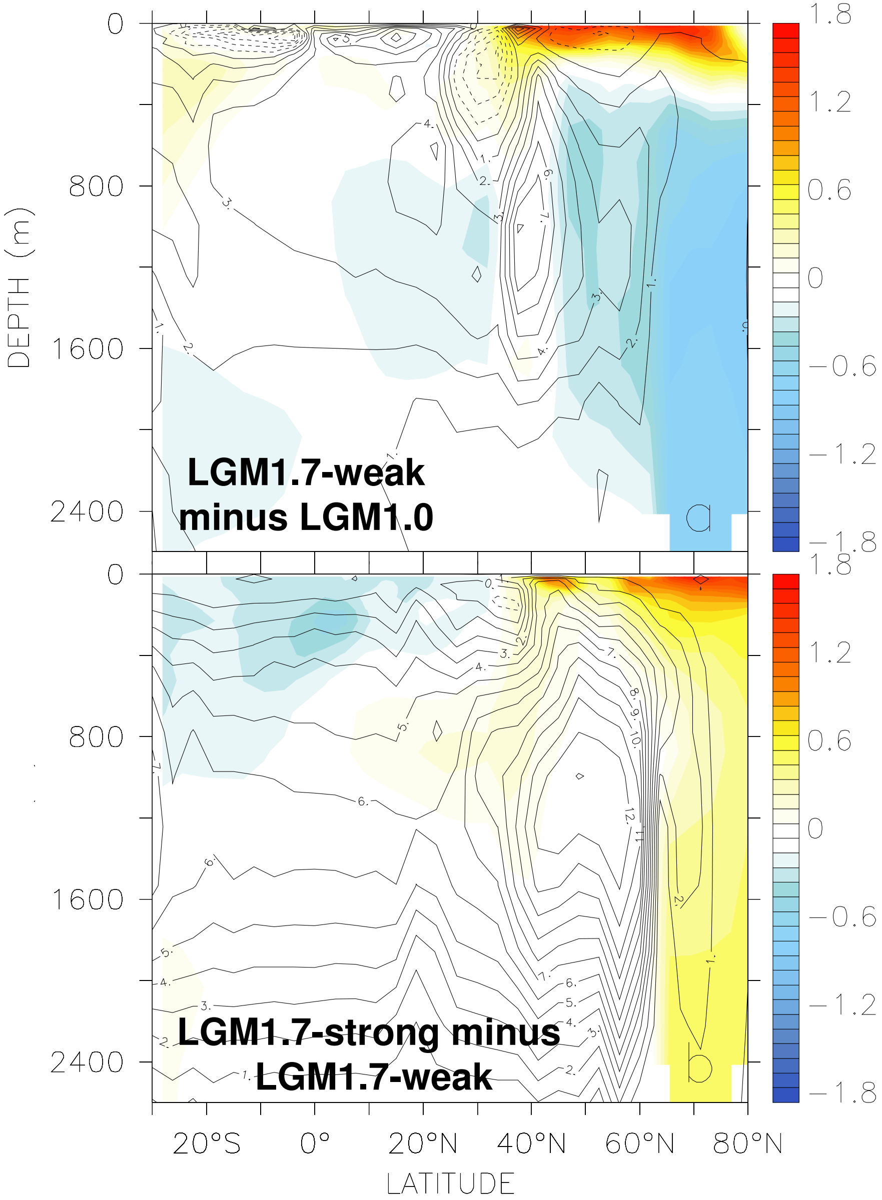
Difference in salinity (psu) and surface currents (cms-1) averaged from 0-300 m



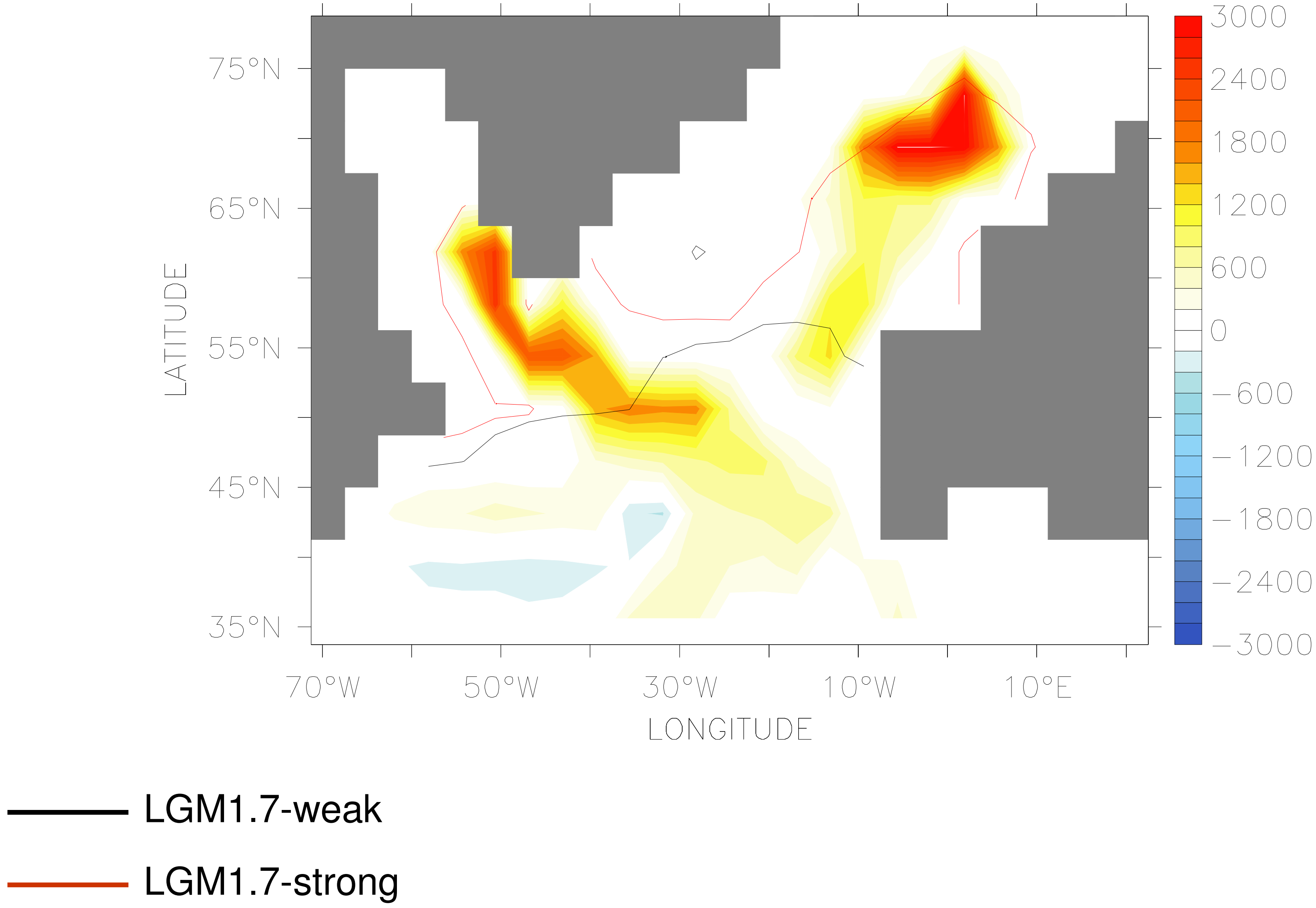
LGM1.7-weak minus LGM1.0

Enhanced subtropical and subpolar horizontal gyre circulation + positive salinity advection feedback increase salt transport to the North Atlantic in upper ocean.

Difference in salinity (psu) and AMOC (Sv) in Atlantic

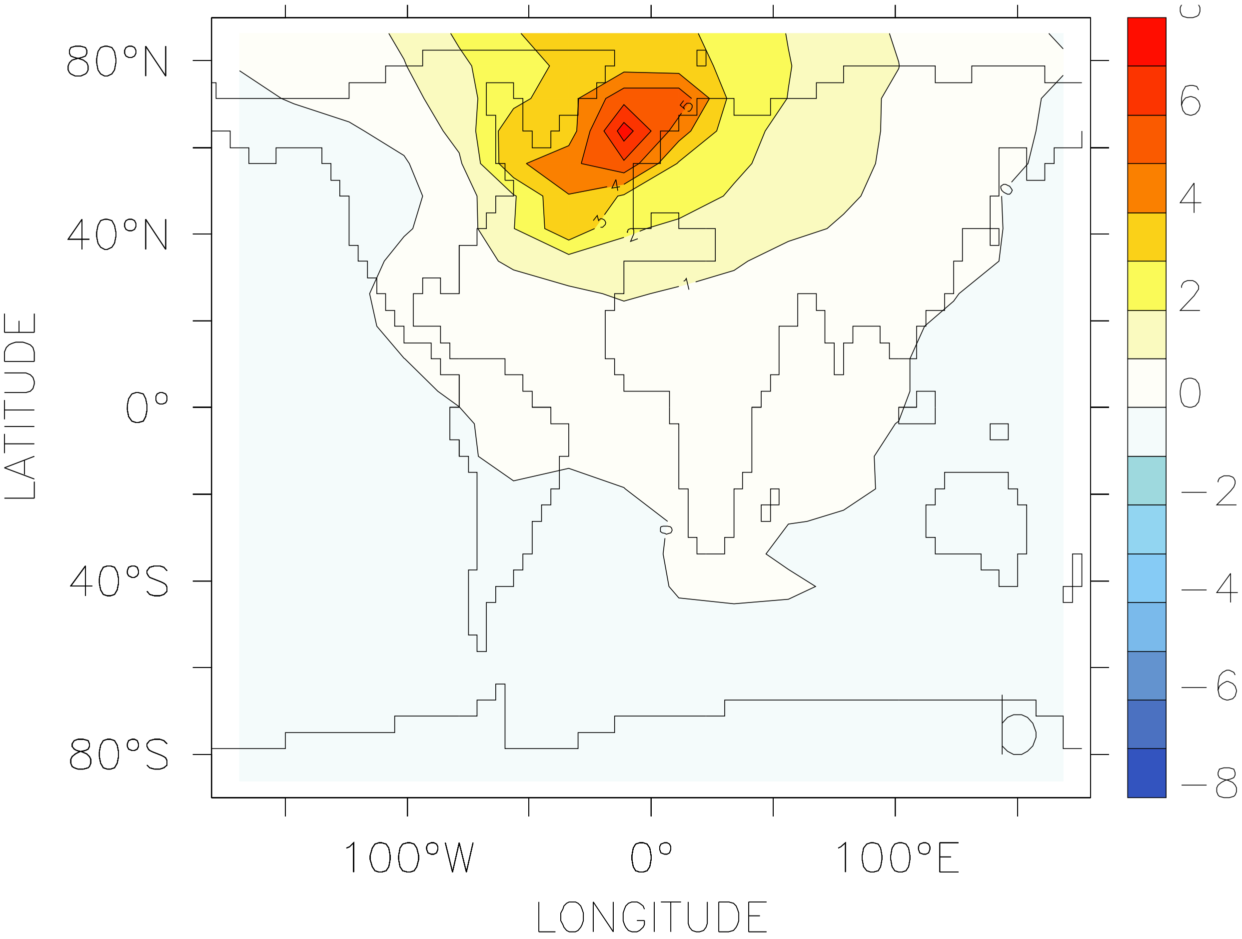


Difference in maximum mixed layer depth (m)
LGM1.7-strong minus LGM1.7-weak (shaded)
& 80% January-April sea-ice concentration contour



Mean annual surface air temperature (SAT)

LGM1.7-strong minus LGM1.7-weak (K)



ΔSAT pattern consistent with that expected during abrupt climate changes of the last glacial period, in particular Dansgaard-Oeschger (DO) events, suggesting these might have been triggered by changes in surface wind strength leading to latitudinal shifts in North Atlantic deep water formation sites.

Summary

- We have investigated the sensitivity of LGM climate simulations to global changes in oceanic surface wind-stress by prescribing these to be proportional to present day observations.

- Caveats: regional wind-stress differences, atmospheric variability not taken into account.

- LGM AMOC strength increases with the surface wind strength, exhibiting a threshold behavior.

- In the North Atlantic pattern and magnitude of the temperature difference between strong and weak AMOC states are consistent with those expected during abrupt climate changes of the last glacial period, in particular DO events.

Conclusions

- If the glacial climate were close to a threshold, small changes in surface wind strength might promote DWF in the Nordic Seas and induce large regional temperature anomalies associated with strong sea ice retreat.

- Our results thus point to a potentially relevant role of changes in surface wind strength in glacial abrupt climate change.

Montoya, M., and A. Levermann (2008):
Surface wind-stress threshold for glacial Atlantic overturning,
Geophys. Res. Lett. L03608, doi:10.1029/1007GL032560.