On the stability of the Atlantic meridional overturning circulation during the last deglaciation

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Abstract

Based on a generalized stability indicator L, we explore the stability of the Atlantic meridional overturning circulation (AMOC) during the early stage of the last deglaciation. From the Last Glacial Maximum (LGM) to early Holocene, the AMOC experiences a collapse and a subsequent rapid recovery, which induces an anomalous freshwater divergence and later convergence across the Atlantic. These changes in AMOC and freshwater transport suggest a positive L, a negative basin-scale salinity advection feedback and, in turn, a mono-stable deglacial AMOC. A further decomposition of L shows that the AMOC stability is mostly determined by two terms, the salinity stratification at the southern boundary of the Atlantic (~34°S) at initial state and the change of stratification with the AMOC during the deglaciation. The former is distorted towards positive as a common-existing bias in climate models while the latter is also shown positive as a result of multiple climate feedbacks associated with the AMOC change.

Results

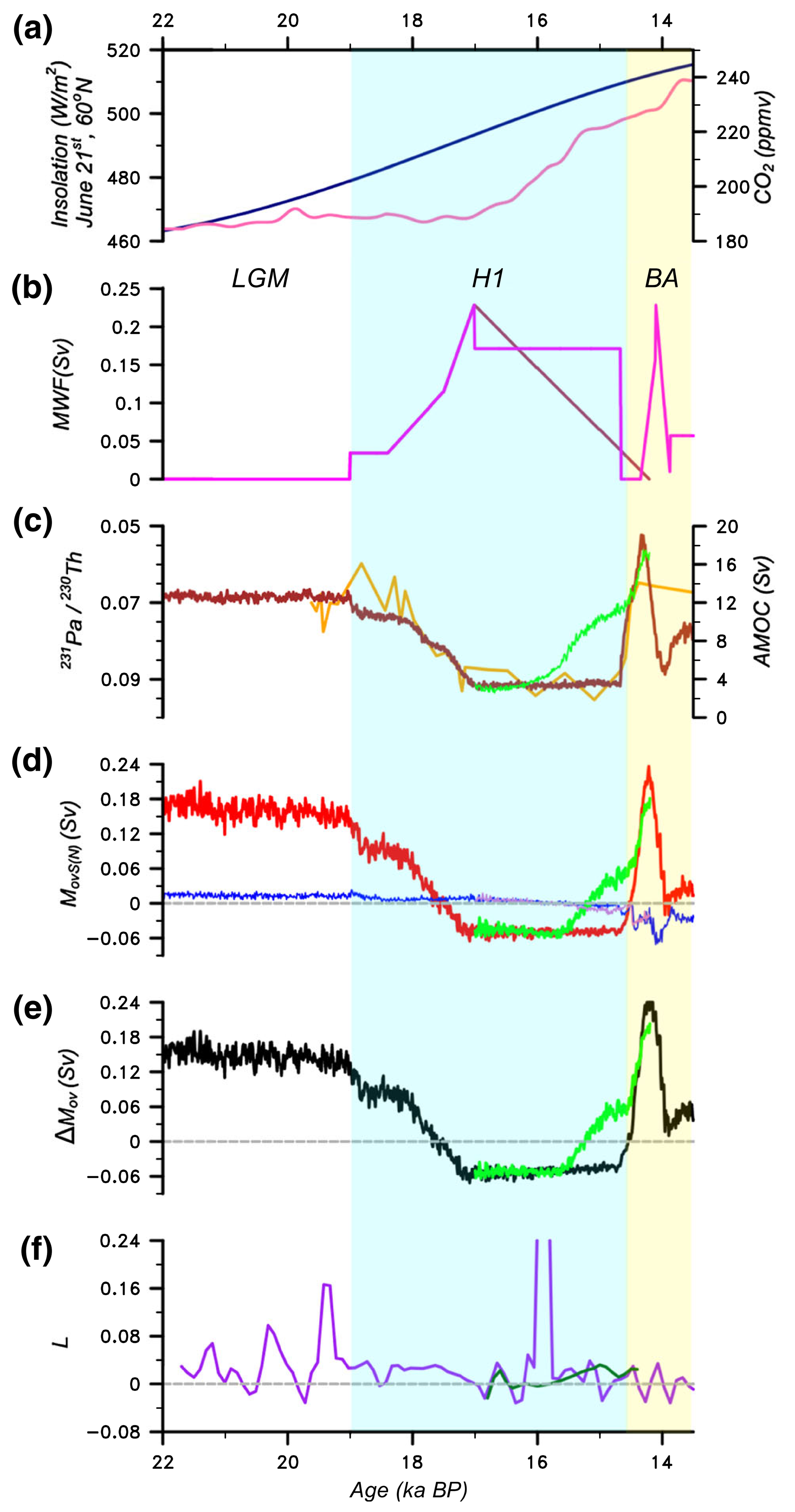

Figure 1. (a) The orbital and CO_2 forcing, (b) the melt-water forcing, (c) the AMOC, (d) the freshwater transports across the southern and northern boundaries, (e). the net freshwater transport and (f) the L in the TraCE-21 simulation.

Methods and Materials

The paleoclimate simulation: the TraCE-21simulation (Liu et al. 2009) by the NCAR CCSM3 .

The generalized stability indicator L (Liu et al. 2013)

$$L = \partial\overline{\Delta M_{ov}}/\partial\overline{\psi}$$

where $\overline{\psi}$ and $\overline{\Delta M_{ov}}$ are the AMOC strength and the net freshwater transport induced by AMOC from an (quasi-)equilibrium state. This generalized indicator represents a basin-scale salinity advection feedback related to the AMOC. A positive L indicates a negative feedback and a mono-stable AMOC, because an initial weakening (strengthening) of the AMOC will induce an anomalous freshwater convergence (divergence) and salinify (freshen) the Atlantic basin, which promotes (inhabits) the deep convection in the North Atlantic and leads to a strengthening (weakening) of the AMOC.

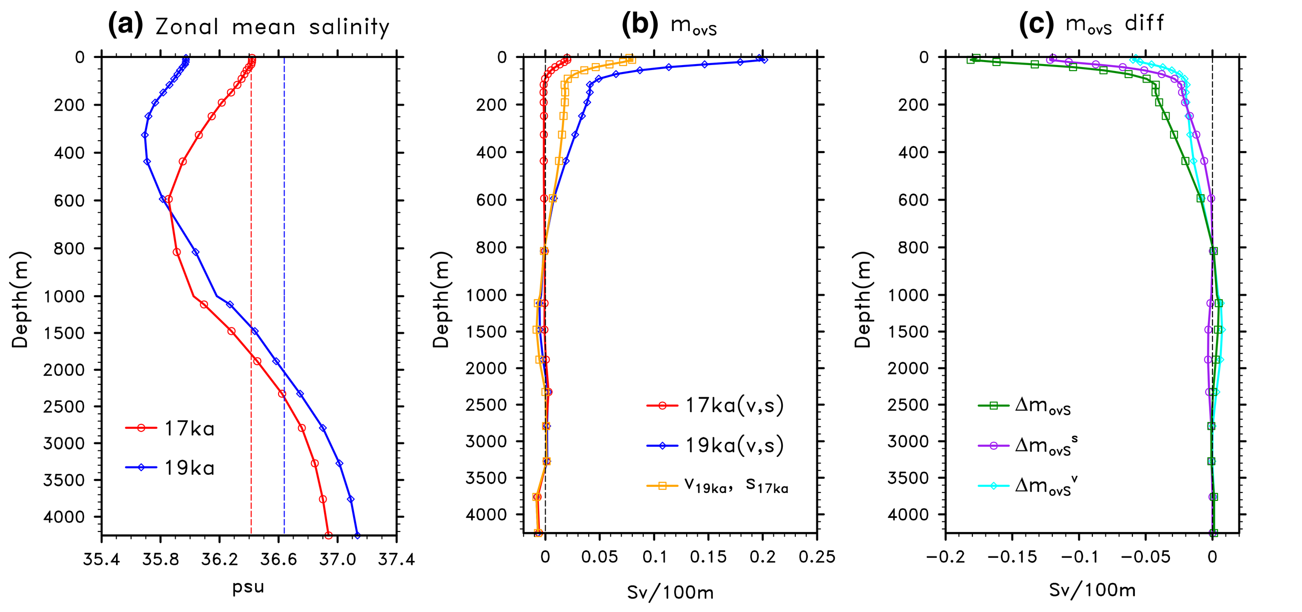

Figure 2. (a) Vertical profiles of a zonal mean salinity along 34°S, (b) the overturning freshwater transport at 17ka and 19ka, and(c) their difference.

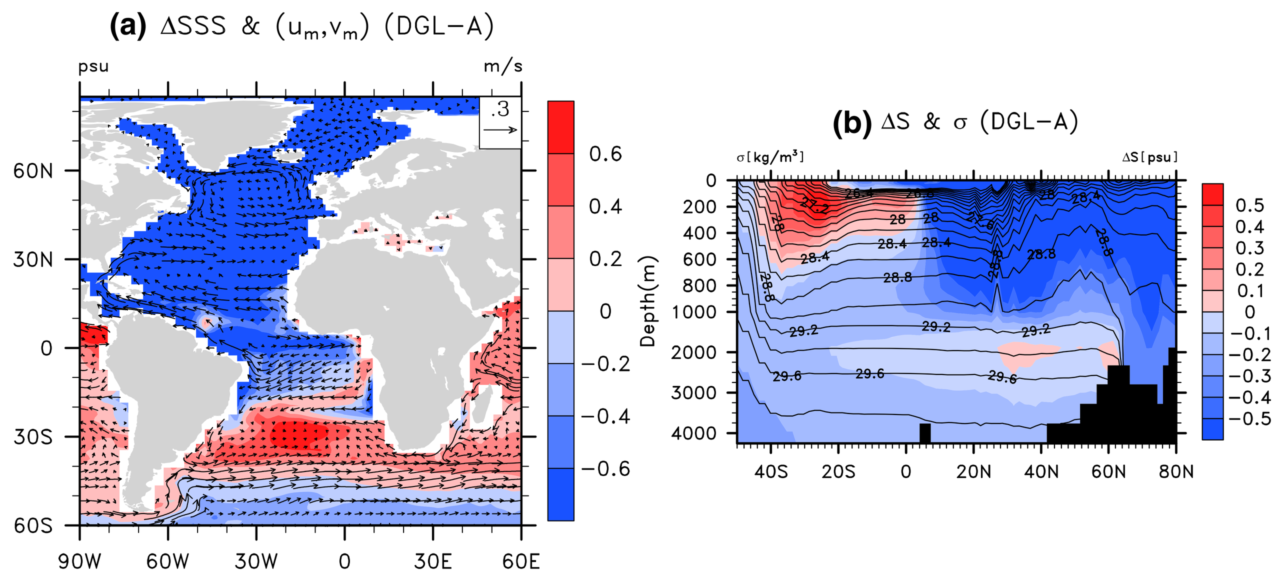

Figure 3. Changes in the sea surface salinity and current and (b) zonal mean salinity between 17ka and 19ka.

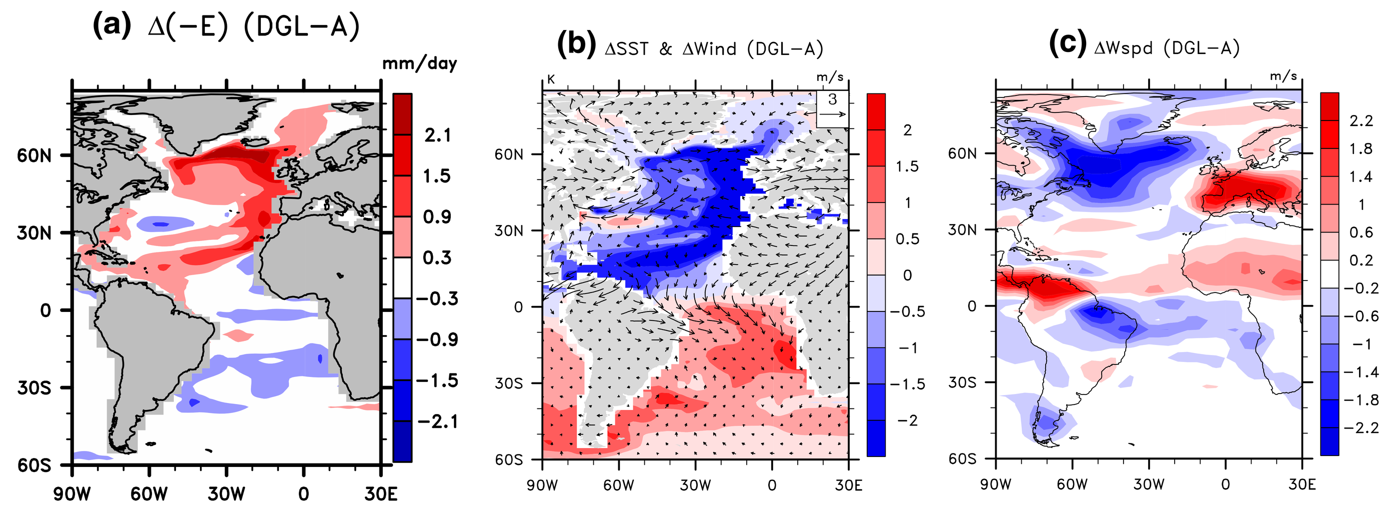

Figure 4. Changes in (a) evaporation, (b) sea surface temperature and wind and (c) wind speed between 17ka and 19ka.

Implications

The stability indicator L can be decomposed as

$$L = \partial\overline{\Delta M_{ov}}/\partial\overline{\psi} = \partial\overline{M_{ovS}^{NA}}/\partial\overline{\psi} + \partial\overline{M_{ovS}^{SO}}/\partial\overline{\psi} + \left(-\partial\overline{M_{ovN}}/\partial\overline{\psi}\right)$$

where

$$M_{ovS}^{NA} \approx (-1/S_0)\psi \cdot \Delta s$$

Δs denotes the salinity contrast between the upper and lower limbs of the AMOC, i.e., the salinity of the surface and thermocline waters minus the salinity of NADW. Thus L can be written as

$$L = (-1/S_0)\overline{\Delta s} + (-1/S_0)\overline{\psi} \cdot \left(\partial\overline{\Delta s}/\partial\overline{\psi}\right) + O(\mathcal{E}_{SO}) + O(\mathcal{E}_N)$$

The first term is the salinity stratification at the southern boundary of the Atlantic (~34°S) at initial state and the second term denote the change of stratification with the AMOC during the deglaciation. Both terms are positive due to different reasons.

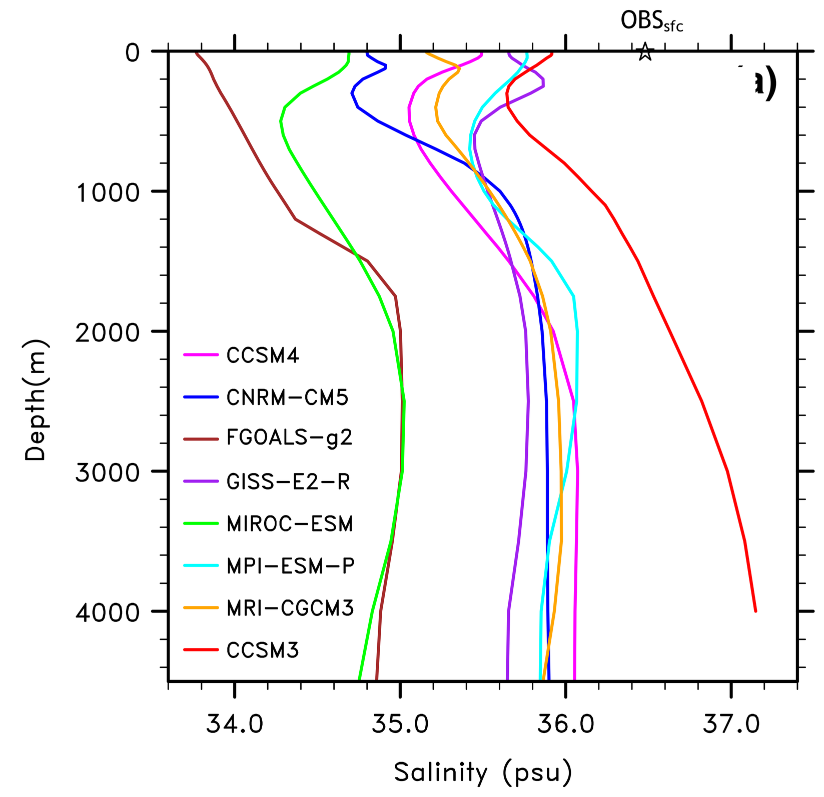

Figure 5. Vertical profiles of zonal mean salinity along 34°S at the LGM from seven CMIP5/PMIP3 CGCMs and CCSM3. The zonal mean SSS along 34°S from reconstructed dataset is shown as star.

Conclusions

A mono-stable AMOC is suggested in the TraCE-21 during the last deglaciation. Corresponding to an AMOC shutdown (from the LGM to H1) and later resumption (from H1 to the BA), an anomalous freshwater divergence and later convergence are induced by the AMOC in the Atlantic basin, which is mostly contributed by variations in the freshwater transport across 34°S. From 19 to 17ka, it switches from a freshwater import to a freshwater export as caused by two factors with about equal contributions, a reduced northward flow and a salinity increase in the surface and thermocline waters. The former results from the collapse of the AMOC while the latter is governed by a mechanism associated with climate feedbacks by the deglacial AMOC. Particularly, the cessation of the LGM AMOC in H1 causes a bipolar seesaw response as presents a SST warming in the South Atlantic. Evaporation thus enhances over 20–44°S due to a warmer SST, leading to a salinity increase in the surface and thermocline (via subduction of the South Atlantic mode water) waters at 34°S.

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References

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