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Supporting Information for

Deterministic role of salinity advection feedback in the multi-centennial variability of AMOC revealed in an EC-Earth simulation

Ning Cao[1,2,3], Qiong Zhang[2,3*], Katherine Elizabeth Power[2,3], Frederik Schenk[3,4], Klaus Wyser[3,5], and Haijun Yang[6,7]

[1]College of Ocean and Meteorology and CMA-GDOU Joint Laboratory for Marine Meteorology, Guangdong Ocean University, Zhanjiang, 524088, China

[2]Department of Physical Geography, Stockholm University, Stockholm, 10691, Sweden

[3]Bolin Centre for Climate Research, Stockholm University, Stockholm, 10691, Sweden

[4]Department of Geological Sciences, Stockholm University, Stockholm, 10691, Sweden

[5]Swedish Meteorological and Hydrological Institute (SMHI), Norrköping, 60176, Sweden

[6]Department of Atmospheric and Oceanic Sciences and Institute of Atmospheric Science and CMA-FDU Joint Laboratory of Marine Meteorology, Fudan University, Shanghai, 200438, China

[7]Shanghai Scientific Frontier Base for Ocean-Atmosphere Interaction Studies, Fudan University, Shanghai, 200438, China

*Corresponding author: Qiong Zhang (qiong.zhang@natgeo.su.se)

Supplementary Text.

Text S1. The calculation of seawater density.

The seawater density is calculated using the TEOS-10 Gibbs function (TEOS-10: international Thermodynamic Equation of Seawater 2010, www.teos-10.org, which is also used in EC-Earth3 climate model) and potential density is calculated using the same function with respect to the reference pressure of zero dbar.

The density of ocean water can be approximated by linear dependencies on temperature and salinity, so the seawater density changes (ρ') can be simply decomposed into temperature and salinity induced density components.

$$\rho_T{}' = -\alpha\bar{\rho}T'$$
$$\rho_S{}' = \beta\bar{\rho}S'$$
$$\rho' = \rho_S{}' + \rho_T{}'$$

In these equations, $\rho_T{}'$ ($\rho_S{}'$) denotes the temperature (salinity) induced density component, $\bar{\rho}$ denotes the timely mean density and S' (T') is the anomaly of salinity (temperature). The appropriate thermal expansion coefficient (α) and the appropriate saline contraction coefficient (β) of seawater are calculated from Absolute Salinity (SA) and Conservative Temperature (CT) using the function based on TEOS-10. This function uses the computationally-efficient 75-term expression for specific volume in terms of SA, CT and p (Roquet et al., 2015). This 75-term equation has been fitted in a restricted range of parameter space and is most accurate inside the "oceanographic funnel" described in McDougall et al. (2003).

In Figure S1 and S2, the AMOC-related sea water density variations are shown. The density anomaly is most pronounced in the subpolar area of North Atlantic as well as in the Arctic. Decomposed results show that the seawater density anomaly in the subpolar area of North Atlantic is dominated by salinity variations.

References:

Roquet F, Madec G, McDougall T J, et al., 2015. Accurate polynomial expressions for the density and specific volume of seawater using the TEOS-10 standard. Ocean Modelling, 90: 29-43.

McDougall, T.J., D.R. Jackett, D.G. Wright and R. Feistel, 2003: Accurate and computationally efficient algorithms for potential temperature and density of seawater. J. Atmosph. Ocean. Tech., 20, 730-741.

Text S2. Responses of AMOC to increased CO_2 forcing.

In the main text, we use a control simulation using the EC-Earth3-LR model under pre-industrial forcings. The atmosphere constituents are held constant at 1850 conditions. The simulation is initialized by a pre-run steady restart file (the output of approximately 500-year pre-industrial control simulation) and is integrated for 2000 years. To investigate the sensitivity of multi-centennial climate variability to global warming, we also conduct two experiments by changing the CO_2 concentration to 400 ppm (E400) and 560 ppm (E560) at the same start year as the E280 experiment (E280), which are integrated for more than 3000 years. The last 2000-year outputs of the three simulations are used in this work.

The AMOC time series in three experiments and the spectrums are shown in Figure S3. The mean strength of AMOC weakens with the increasing of CO2 concentration. The multi-centennial variability is significant in all these simulations with the dominant oscillation periods around 100-300 years, although the oscillation amplitude is suppressed.

Supplementary Figures.

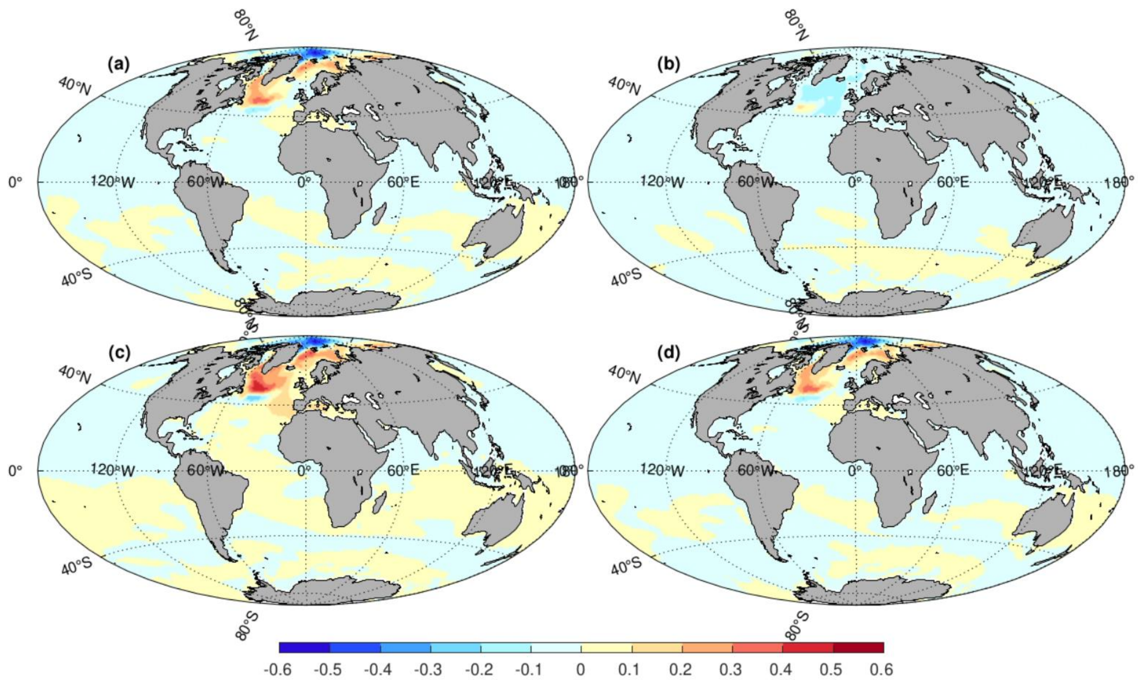

Figure S1. The regression of surface layer (a) seawater density, (b) temperature-induced density change, (c) salinity-induced density change and (d) the sum of both temperature and salinity induced density changes, onto the low-pass filtered AMOC series. Units: kg m^{-3} per Sv.

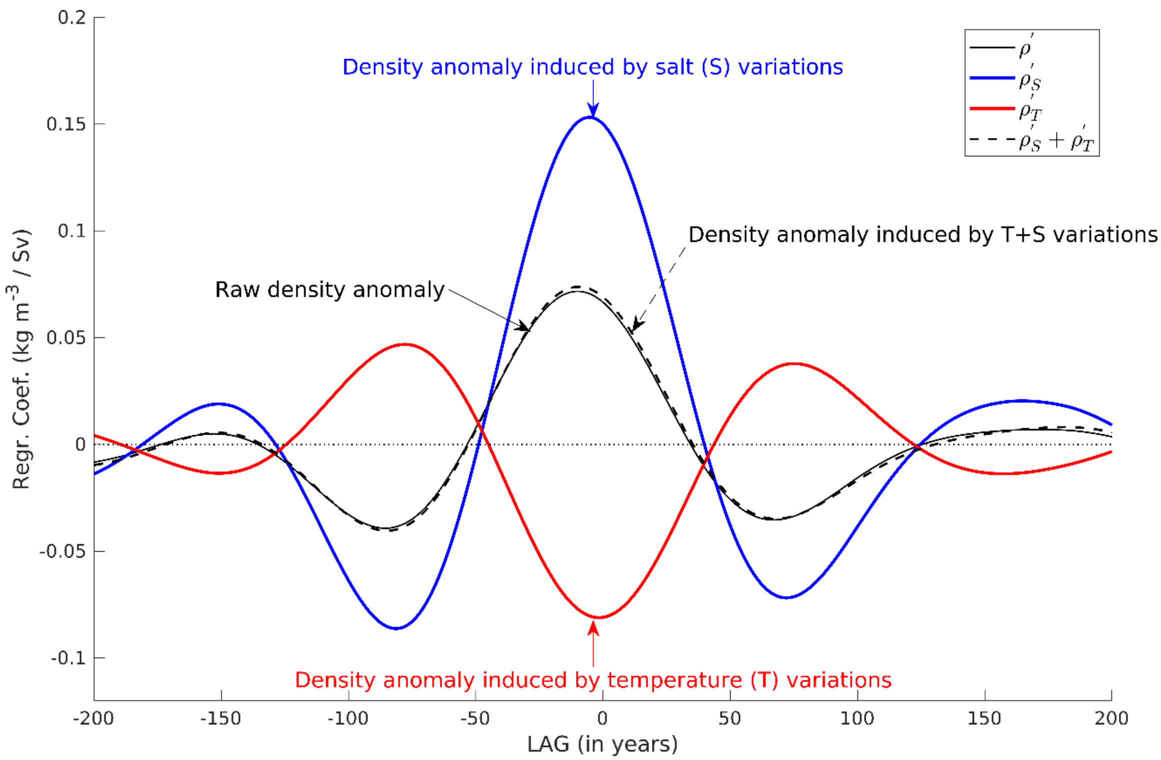

Figure S2. Regression coefficients of various quantities versus the low-pass filtered AMOC series. The x-axis is time in years, representing the leads or lags relative to the maximum AMOC. Negative (positive) values on the x-axis denotes time before (after) a maximum of the AMOC (occurring at lag 0). The black curve denotes seawater density regression coefficients averaged vertically over the upper 100 meters and in the horizontal from 70°W to 10°E, and from 50°N to 80°N. The blue curve indicates regressions for the component of density attributable to salt variations and the red curve indicates the component of density attributable to temperature variations. The black dashed curve indicates the sum of both temperature and salinity induced density variations.

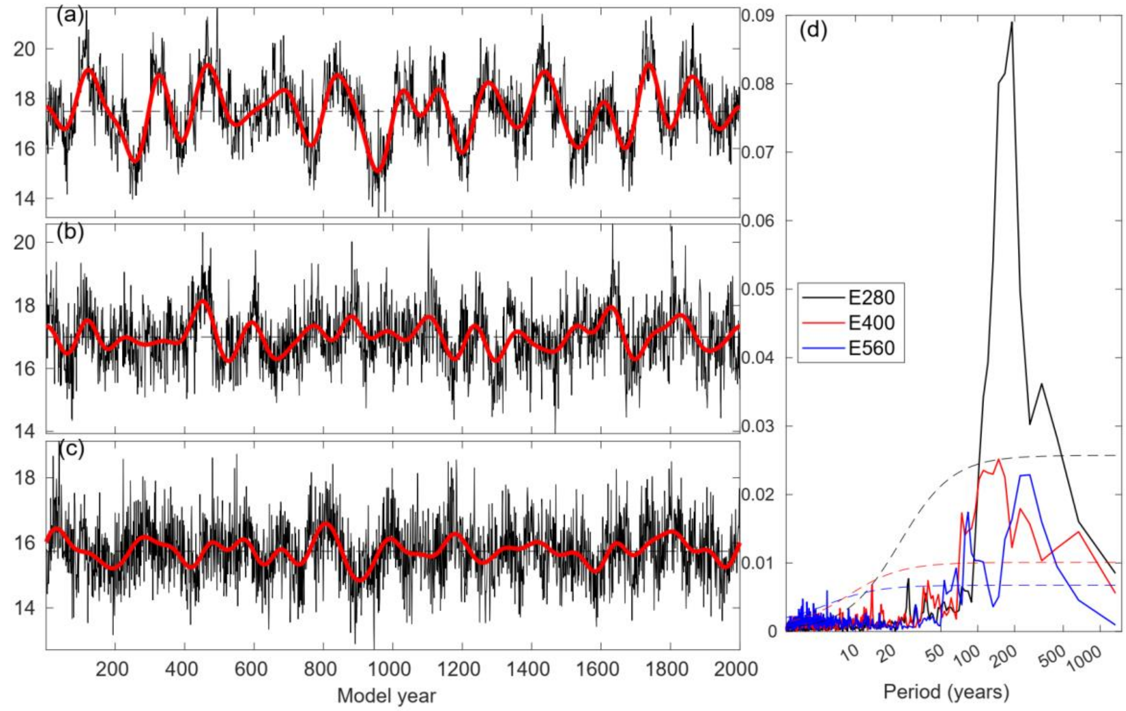

Figure S3. (a~c) Maximum AMOC time series in three experiments with different CO2 concentrations in the atmosphere, 280 ppm, 400 ppm and 560 ppm. The bold red curves indicate the low-filtered series (using the Lanczos method with 201 weights and a cutoff period of 100 years); (d) Spectra analysis on the AMOC time series, in which the dashed curves indicate the 95% confidence level.