Modulation of El Nino-Southern Oscillation by weakening of the North Atlantic Thermohaline Circulation

Soon-Il An[1] and Axel Timmermann[2]

[1]Department of Atmospheric Sciences, Yonsei University, Korea
[2]International Pacific Research Center, University of Hawaii, USA

1. Introduction

The Atlantic part of the seiches can in fact explain the millennial-scale dynamics of the north-south interhemispheric temperature contrast observed in ice cores during Marine Isotope Stage 3 (MIS3; 60 000-25 000 yr B.P.) as shown by Knutti et al. (2004). Based on a coupled global atmosphere-ocean-sea ice simulation for the Last Glacial Maximum, Timmermann et al. (2005) suggested that the observed millennial-scale synchronous behavior between Pacific warm pool salinity variations and the so-called Dansgaard-Oeschger events in the North Atlantic can be attributed to global oceanic baroclinic waves triggered by glacial meltwater pulses in the North Atlantic [so-called Heinrich events]. Related geostrophic surface transport anomalies carry saline water to the North Pacific with implications for deep convection and the setup of a Pacific intermediate thermohaline circulation cell, in agreement with the modeling results of Saenko et al. (2004). Such a reorganization of the Pacific large-scale oceanic circulation may have important influences also for ENSO dynamics. This efficient oceanic global wave adjustment mechanism contrasts the recently proposed millennial-scale SuperENSO hypothesis (Stott et al. 2002), which suggests that millennial-scale tropical Pacific SST anomalies trigger changes in the atmospheric circulation with subsequent influence on North Atlantic climate, thereby leading to an atmospheric synchronization of Pacific and Atlantic climate change on millennial time scales.

2. Global baroclinic ocean adjustment

The oceanic connection between the North Atlantic and tropical Pacific mentioned above works as follows: Density changes in the North Atlantic lead to a global readjustment of the thermohaline circulation. This readjustment is established by the propagation of coastally and equatorially trapped Kelvin waves (Cessi et al. 2004) and shelf waves (Mysak 1980). After propagating from the North Atlantic to the equator, these waves are forced to travel along the equator toward the coast of Africa, where they split into a northern and southern branch. While moving poleward, they radiate Rossby waves, which readjust the interior transport of the North and South Atlantic after reaching the western boundary. The southern wave branch travels around the southern tip of South Africa into the Indian Ocean and subsequently the Pacific Ocean. Important stages of the global baroclinic adjustment process to an initial North Atlantic density anomaly take place within a few years to decades (Cessi et al. 2004), whereas a very fast intertia- gravity wave signal can be traced in the Pacific even months after the initial North Atlantic buoyancy shock. The overall sea level and thermocline depth changes can be described in terms of a standing wave pattern—a global seiche (Cessi et al. 2004). This wave adjustment mechanism is schematized in Fig. 1 .

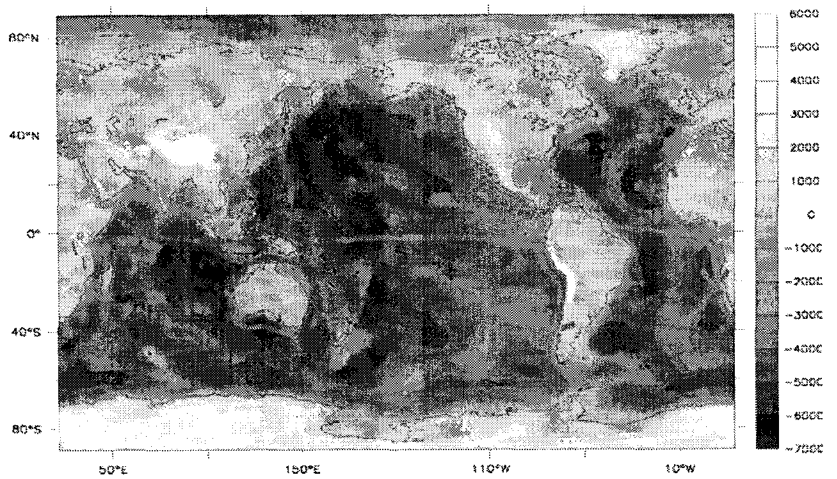

FIG. 1. Schematics of Kelvin wave propagation due to a density perturbation in the northeastern North Atlantic.

3. Experimental setup

a. *Control experiment for glacial maximum conditions*

The ECBILT-CLIO last glacial maximum (LGM) simulation performed here utilizes the ice sheet topography, an ice sheet-albedo mask, reduced CO2 concentrations (200 ppm), modified orbital forcing, and an LGM vegetation index for which the deforested soils and plant cover are replaced by their respective glacial albedos. The inclusion of the ice sheet increases the albedo by more than 60% in North America and Europe.

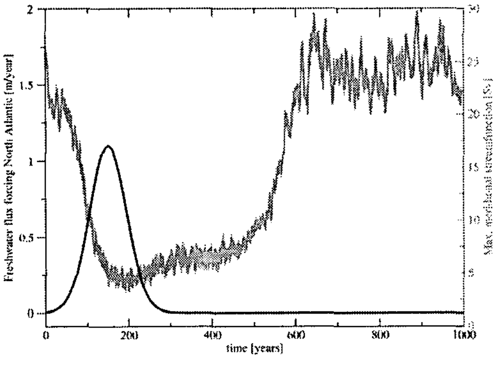

Fig. 2 Maximum of the meridional streamfunction (red) (in Sv) in the North Atlantic for the transient freshwater experiment MW and freshwater flux (m yr−1) forcing averaged over the North Atlantic from 40° to 60°N.

b. *Freshwater perturbation experiment for glacial maximum conditions*

At the core of our analysis is a transient glacial meltwater (MW) experiment, which simulates the response of the global climate to a North Atlantic density perturbation, such as, for instance, Heinrich Event II (23 ka ago). A 300-yr-long2 Gaussian-shaped freshwater anomaly is injected into the North

Atlantic between 40° and 60°N (see Fig. 2). The equivalent global sea level rise of this hydrological forcing amounts to about 8 m.

4. THC influence on ENSO

The simulated thermocline depth anomalies during the THC shutdown may have the potential to change the properties of ENSO, as speculated by Goodman (2001). A mean equatorial and off-equatorial deepening are expected to reduce ENSO instability as suggested by An et al. (2004).

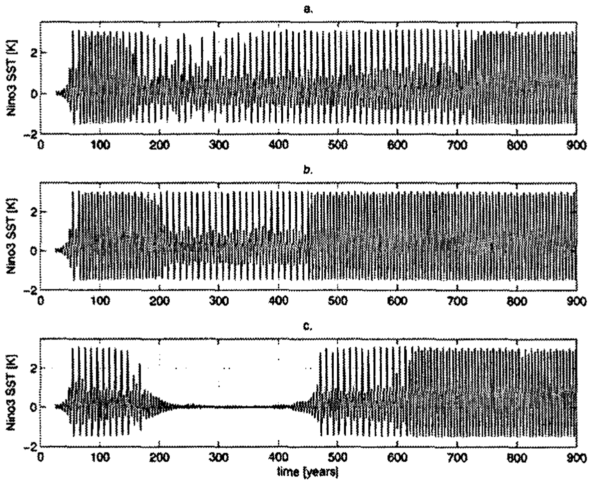

FIG. 3. Transient response of ENSO to THC-induced changes: Niño-3 SST anomaly (SSTA) time series (K) simulated by the intermediate ENSO model. The background thermocline depth is updated every year, such as to capture the spatiotemporal behavior of thermocline changes in the MW experiment. The simulation uses (top) one-third of the MW thermocline perturbation, (middle) two-thirds of the perturbation, and (bottom) the full thermocline anomaly. These different perturbations correspond to a 6-, 12-, and 18-Sv change of the maximum of the meridional streamfunction in the North Atlantic.

Here, we perform a forward simulation of the deterministic intermediate ENSO model forced by transient changes of the thermocline depth anomaly, as simulated by the ECBILT-CLIO MW experiment. In this transient simulation, a diagnosed smoothed (running mean of 5yr) tropical Pacific thermocline depth anomaly from the ECBILT-CLIO MW experiment is added each year to the prescribed observed annual mean background state of the intermediate ENSO model domain. The transient simulation results are depicted in Fig. 3 for three different thermocline forcing amplitudes (1/3, 2/3, and the full amplitude, as shown in Fig. 2). The unperturbed ENSO (years 800–900) is characterized by a 4–5-yr periodicity and regular, slightly skewed oscillations (El Niño amplitude is larger than La Niña amplitude). For relatively large thermocline depths, weak and strong El Niño events alternate at the time scale of 4–5 yr, whereas large El Niño events occur only once in about 9–10 yr. The intermediate ENSO model used here does not simulate the observed irregularity of ENSO due to a lack of stochastic and annual cycle forcing. Furthermore, it neglects higher-order baroclinic modes as well as extratropical influences. In Fig. 3 we observe that a complete shutdown of the North Atlantic THC leads to a complete shutdown of ENSO variability. Smaller thermocline depth anomalies (Fig. 3 , top and middle) have an influence on spectral characteristics of ENSO but not so much on the amplitude of the self-sustained ENSO oscillation. This result, however, depends crucially on the atmosphere-ocean coupling strength used by the intermediate ENSO model.

5. Conclusions

We presented modeling evidence for an oceanic teleconnection that connects multidecadal- to millennial-scale thermocline anomalies in the North Atlantic with anomalies in the other ocean basins. Initially a freshwater anomaly in the North Atlantic triggers a collapse of the THC that is partly established by wave adjustments in the global oceans. Triggered thermocline anomalies in the Pacific do not only have the effect of making the warm pool saltier due to geostrophic transport changes (Timmermann et al. 2005) but also weaken ENSO activity considerably, even in the self-sustained supercritical oscillation regime. These changes are due to an overall zonal mean deepening of the tropical thermocline in the Pacific.

References

An, S.-I., A. Timmermann, L. Bejerano, F.-F. Jin, F. Justino, Z. Liu, H. Goosse, and S. Tudhope, 2004: Modeling evidence for enhanced El Niño-Southern Oscillation amplitude during the Last Glacial Maximum. Paleoceanography., 19, PA4009, doi:10.1029/2004PA001020.

Cessi, P., K. Bryan, and R. Zhang, 2004: Global seiching of thermocline waters between the Atlantic and the Indian-Pacific Ocean Basins. Geophys. Res. Lett., 31, L04302, doi:10.1029/2003GL019091.

Goodman, P. J., 2001: Thermohaline adjustment and advection in an OGCM. J. Phys. Oceanogr., 31, 1477-1497.

Knutti, R., J. Flückiger, T. Stocker, and A. Timmermann, 2004: Strong hemispheric coupling of glacial climate through freshwater discharge and ocean circulation. Nature., 430, 851-856.

Mysak, L., 1980: Recent advances in shelf wave dynamics. Rev. Geophys. Space Phys., 18, 211-241.

Saenko, O. A., A. Schmittner, and A. J. Weaver, 2004: The Atlantic-Pacific seesaw. J. Climate., 17, 2033-2038.

Stott, L., C. Poulsen, S. Lund, and R. Thuell, 2002: Super ENSO and global climate oscillations at millenial time scales. Science., 297, 222-226.

Timmermann, A., U. Krebs, F. Justino, and H. Goosse, 2005: Mechanisms for millennial-scale global synchronization during the last glacial period. Paleoceanography, 20 (4), PA4008, doi: 10.1029/2004PA00109.