GEOPHYSICAL RESEARCH LETTERS, VOL. 33, L16708, doi:10.1029/2006GL026237, 2006

Impact of tropical Pacific variability on the mean North Atlantic thermohaline circulation

Vladimir A. Semenov[1,2] and Mojib Latif[1]

Received 8 March 2006; revised 3 July 2006; accepted 7 July 2006; published 30 August 2006.

[1] A series of 500 years long coupled general circulation model simulations has been performed, in which the sea surface temperatures (SSTs) in different tropical oceans have been prescribed from climatology. A statistically significant reduction by about one Sverdrup of the meridional overturning circulation (MOC) in the North Atlantic was found when the tropical Pacific SSTs do not vary interannually. Anomalously low salinities originating in the tropical Atlantic due to increased precipitation drive the reduction of the MOC. Climatological SSTs in the tropical Pacific lead to a "La Niña"-like state due to the nonlinear response of the atmosphere to SST anomalies. The shift of the mean atmospheric circulation in the tropical Pacific leads to a cyclonic anomaly over the eastern tropical Atlantic with a corresponding precipitation increase. The results suggest that changes in the SST variability of the tropical Pacific can drive changes in the mean state of remote regions. **Citation:** Semenov, V. A., and M. Latif (2006), Impact of tropical Pacific variability on the mean North Atlantic thermohaline circulation, *Geophys. Res. Lett.*, *33*, L16708, doi:10.1029/2006GL026237.

1. Introduction

[2] The Atlantic thermohaline circulation (THC), a key component of the global inter-ocean conveyor belt [*Broeker*, 1991], is important in forcing climate anomalies globally. It exhibits strong interdecadal variability and, as suggested by model simulations, may experience significant changes in response to global warming [e.g., *Gregory et al.*, 2005]. Different mechanisms for the interdecadal THC variability have been proposed [see, e.g., *Latif*, 1998; *Delworth and Mann*, 2000; *Vellinga and Wu*, 2004; *Jungclaus et al.*, 2005, and references therein]. Recently, coupled GCM simulations have shown that tropical processes may play an important role for the climate in the North Atlantic and, in particular for the THC [*Selten et al.*, 2004; *Vellinga and Wu*, 2004; *Bader and Latif*, 2005]. Changes of the tropical Pacific SSTs were found responsible for the THC stabilization in global warming experiments by affecting the fresh water flux in the tropical Atlantic through an "atmospheric bridge" [*Latif et al.*, 2000]. This process may also be responsible for part of the observed interdecadal variability of the THC [*Latif*, 2001].

[3] To investigate the role of the tropical oceans further, a series of partially coupled simulations with no interannual SST variability in the tropical part (20S-20N) of the different oceans has been performed. Thus, the simulated changes (relative to the fully coupled control run) are solely due to the missing interannual SST variability. Surprisingly, suppression of variability alone can lead to a significant change of the mean THC and subsequently to changes of the surface climate in the North Atlantic sector. This phenomenon is the focus of the present study.

2. Experimental Setup

[4] The coupled atmosphere-ocean model used in this study is ECHAM5/MPI-OM developed at the Max Planck Institute for Meteorology (MPI). The atmospheric component is ECHAM5, the latest version of the ECHAM (European Centre Hamburg) atmosphere model [*Roeckner et al.*, 2003]. In the current setup, the model has 19 vertical levels and a spectral resolution of T31, corresponding to a horizontal resolution of about 3.75° × 3.75°. The ocean model MPI-OM [*Marsland et al.*, 2003] is a primitive equation model (z-level, free surface) on a C-grid with variable horizontal resolution between 20 km in high latitudes and about 350 km in the Tropics. The model has 40 vertical levels and includes a Hibler-type dynamic/thermodynamic sea ice model and a river runoff scheme. The coupled model does not employ flux adjustment or any other corrections. The 1000 years long control integration [*Gregory et al.*, 2005] of the coupled model simulates a realistic mean meridional overturning circulation in the North Atlantic of 15.5 Sv, which is close to observational estimates (15.74 ± 1.6 Sv [*Lumpkin and Speer*, 2003]), and reasonable interdecadal variability with a spectral peak at about 45 years. Several 500 years long partially coupled simulations were performed starting from the year 500 of the control run. In these simulations, the upper layer oceanic temperatures in the tropical (20S-20N) Pacific (TP), Indian (TI), Atlantic (TA), and both the tropical Indian and Pacific (TPI) Oceans were prescribed from monthly varying climatologies calculated over the last 500 years of the control integration, thereby removing interannual SST variability in these regions. The drift of the tropical oceans SSTs for this period is less then 0.1K.

3. Results

[5] An index of the North Atlantic THC, the maximum meridional overturning circulation (MOC) in the North Atlantic at 30N, derived from the control and partially coupled simulations is presented in Figure 1. Only the tropical Pacific (TP) experiment has resulted in a significant

---

[1] Leibniz Institute for Marine Sciences at the University of Kiel, Kiel, Germany.

[2] Permanently at Obukhov Institute of Atmospheric Physics, Russian Academy of Sciences, Moscow, Russia.

0094-8276/06/2006GL026237

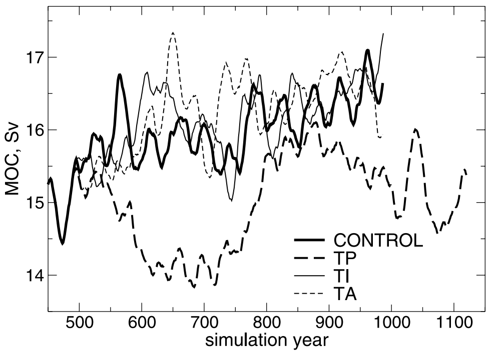

Figure 1. Maximum meridional overturning at 30N (Sv) in the control and partially coupled simulations, 25 years running means.

change of the mean MOC. A reduction from about 15.5 Sv to 14 Sv is simulated during the first 150 years of this experiment with a subsequent return to the mean control state and a further reduction thereafter. This experiment has been extended for other 150 years to enhance the statistical significance of the weakening. The MOC exhibits a multi-century oscillation with the mean, however, significantly lower than in the control experiment. This multi-century oscillation as well as changes in interdecadal variability (not shown) will be discussed in a forthcoming paper. The mean MOC strength for the whole length of the TP experiment amounts to 14.7 Sv as opposed to 15.5 Sv in the control run. The reduction of the MOC is significant at the 95% level according to a t-test.

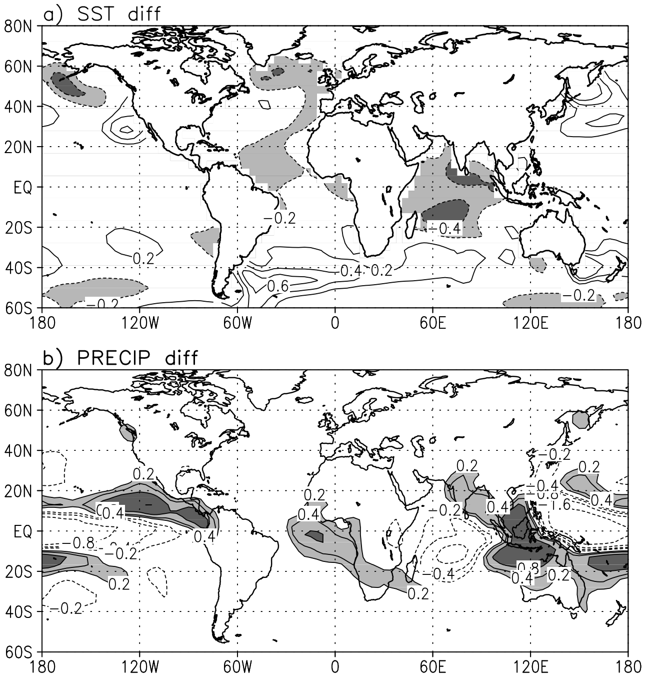

Figure 2. Annual mean changes (500 years means, TP-control) of (a) SST (K); contours are at −0.4, −0.2, 0.2, 0.4, 0.6, negative anomalies less than −0.2 are shaded, and (b) precipitation (mm/day); contours are at −1.6, −0.8, −0.4, −0.2, 0.2, 0.4, 0.8, positive anomalies greater than 0.2 are shaded.

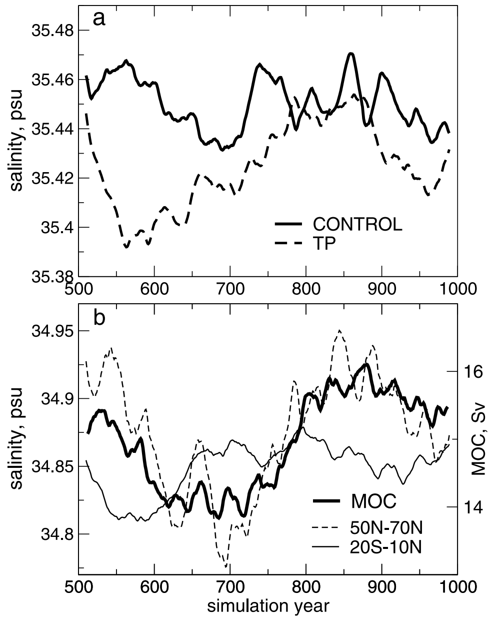

Figure 3. Upper ocean (0−400 m) salinities (psu) in the Atlantic: (a) basin average (30S−80N) for the TP and control experiments and (b) tropical Atlantic (20S−10N) and northern North Atlantic (50N−70N) for the TP experiment. Also shown is the MOC (from Figure 1, TP), thick line (Sv).

[6] Changes (relative to the control for the overlapping 500 years) of the annual mean SST and precipitation in the TP experiment are shown in Figure 2. The differences greater than 0.2 are statistically significant at the 95% level according to a t-test. An expected cooling corresponding to the THC weakening can be seen in the northern North Atlantic, with a magnitude reaching −0.4K south of Greenland. Some strong changes are also found in the northern North Pacific and in the Indian Ocean. The cold anomaly in the Indian Ocean exceeding −0.4K north of 30S (Figure 2a) may be important for the simulated MOC changes [*Hoerling et al.*, 2004; *Bader and Latif*, 2005]. In order to separate the impact of the Indian Ocean SST, another partially coupled simulation has been performed, in which both the Indian and Pacific Ocean SSTs have been set to climatology (TPI experiment). The MOC from this simulation (not shown) exhibits very similar behavior to the TP experiment, which implies that the SST variability in the Pacific is the major reason for the MOC reduction. Thus, only the TP experiment will be discussed in the following.

[7] The precipitation changes are characterized by a significant decrease over most of the equatorial Pacific, an increase over the Indonesian region (these changes are reminiscent of La Niña precipitation conditions) and a decrease over the Indian Ocean. In the Atlantic, a strong increase is found in the eastern tropical Atlantic, south of the equator. This precipitation increase exceeding 2 mm/day results in an increased fresh water flux into the tropical Atlantic of about 0.1 Sv (averaged for 20S−10N). The size of the fresh water anomaly is large enough to produce significant salinity anomalies when integrated over a sufficiently long time.

[8] As has been suggested in several studies [*Latif et al.*, 2000; *Latif*, 2001; *Vellinga and Wu*, 2004], salinity anomalies in the tropical Atlantic impact the salinity in the sinking region in the northern North Atlantic with some time delay. A characteristic timescale for the MOC to respond to the salinity anomaly in the Tropics in these studies was found to be of the order of 50 years. This seems to be also the timescale of the MOC weakening in the TP simulation (Figure 1). Time series of the upper ocean salinities (0–400 m) for the Atlantic from 30S to 80N are presented in Figure 3a for the control and TP experiments. Fast reduction of the basin mean salinity by about 0.05 psu can be seen initially together with a subsequent slow recovery. The basin-mean salinity changes are related to the modified fresh water flux into the tropical Atlantic, which is confirmed by correlation analysis (not shown). The salinities in the tropical Atlantic (20S–10N) and in the sinking region (50N–70N) are shown in Figure 3b. As expected, the MOC strength closely follows the salinities in the sinking region with the MOC decrease lagging the freshening in the tropical Atlantic by about 50 years. The salinity in the tropical Atlantic, after reaching its minimum after about 100 years, returns close to the control state, which can be explained by the reduced overturning reaching its minimum at that time.

[9] Other factors may also impact salinities in the sinking region. Arctic fresh water export dependent on sea ice dynamics and thermodynamics and hydrological balance in high latitudes can directly affect salinities in the sinking region [e.g., *Jungclaus et al.*, 2005]. Atmospheric variability in the northern North Atlantic can also drive the MOC changes [e.g., *Delworth and Greatbatch*, 2000]. However, in the TP experiment, no significant changes of the atmospheric circulation and hydrology in the northern Extratropics have been found.

[10] The warm and cold phases of the interannual variability in the tropical Pacific, El Niño and La Niña, do not exhibit symmetric SST patterns [see, e.g., *Rodgers et al.*, 2004]. Hence, a substitution of the variability by the climatology may result in a forcing by the residual "asymmetry" pattern. However, the atmospheric model forced by this pattern (obtained from the El Niño and La Niña composites of the control experiment) has not reproduced the precipitation increase in the tropical Atlantic.

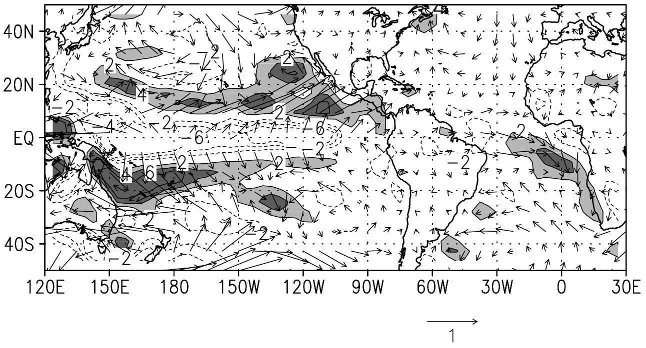

Figure 4. Atmospheric convergence at 850 mb (10^{-5} 1/s) and 10 m wind (m/s, arrows) differences between the TP and control simulations. Contours are at −6, −4, −2, 2, 4, 6, values greater than 2 are shaded.

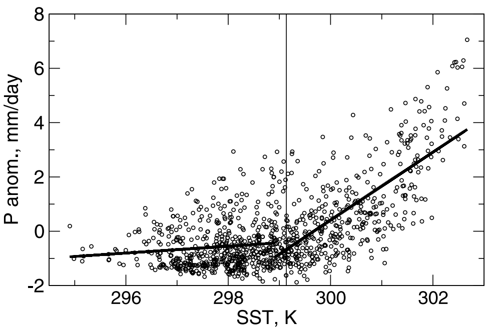

Figure 5. Scatter plot for the annual mean SST and precipitation anomalies in the region 5S–5N, 170E–170E. The lines are linear regressions for the SST anomalies below and above the SST mean.

[11] Figure 4 shows the low-level atmospheric convergence and surface wind difference between the TP and control simulations. The circulation changes in the TP experiment are characterized by a relaxation of the trade winds in the tropical Pacific, decreased convergence in the equatorial Pacific, and development of a cyclonic anomaly in the eastern tropical Atlantic. The latter is responsible for the precipitation increase in this region. A reason for such circulation changes in the tropical Pacific may be the nonlinear dependence of the tropical deep convection on SST [see, e.g., *Lau et al.*, 1997]. Such nonlinearity is also simulated by the coupled model. This is illustrated by the scatter diagram for precipitation and SST in the equatorial region around the date line (Figure 5). The changes of the atmospheric circulation over the tropical Pacific impact the circulation over the tropical Atlantic presumably by affecting the Walker circulation, although the exact mechanism of the response requires further analysis.

4. Conclusions

[12] It has been shown by specifically designed partially coupled experiments with a coupled ocean-atmosphere general circulation model that the presence of interannually varying SSTs in the tropical Pacific exerts a significant impact on the North Atlantic climate system, specifically the North Atlantic meridional overturning circulation (MOC). The MOC is significantly weaker in the experiment with no varying SST in the tropical Pacific relative that simulated in the control experiment. This leads to significantly colder SSTs in the North Atlantic, which in turn may have important consequences for the continental climates of North America and Europe. Thus, changes in the SST variance in the tropical Pacific can have effects on the mean climate state in remote regions such as the North Atlantic. This result demonstrates that the tropical SSTs may impact the Extratropics not only by atmospheric teleconnections but also through affecting oceanic circulation in a remote basin. We found also impacts of tropical Pacific SST variability on the variability of the MOC. These findings will be described in a forthcoming paper.

[13] **Acknowledgments.** This work was supported by the Sonderforschungsbereich 460 of the German Science Foundation (DFG)

and the European Union's DYNAMITE project. The model runs were performed at the German Climate Computing Center (DKRZ).

References

Bader, J., and M. Latif (2005), North Atlantic Oscillation response to anomalous Indian Ocean SST in a coupled GCM, *J. Clim.*, *18*, 5382–5389.

Broeker, W. G. (1991), The great ocean conveyor, *Oceanography*, *4*, 79–85.

Delworth, T. L., and R. J. Greatbatch (2000), Multidecadal thermohaline circulation variability driven by atmospheric surface flux forcing, *J. Clim.*, *13*, 1481–1495.

Delworth, T. L., and M. E. Mann (2000), Observed and simulated multidecadal variability in the Northern Hemisphere, *Climate Dyn.*, *16*, 661–667.

Gregory, J. M., et al. (2005), A model intercomparison of changes in the Atlantic thermohaline circulation in response to increasing atmospheric CO_2 concentration, *Geophys. Res. Lett.*, *32*, L12703, doi:10.1029/2005GL023209.

Hoerling, M. P., J. W. Hurrell, T. Xu, G. T. Bates, and A. S. Phillips (2004), Twentieth century North Atlantic climate change. Part II: Understanding the effect of Indian Ocean warming, *Climate Dyn.*, *23*, 391–405.

Jungclaus, J. H., H. Haak, M. Latif, and U. Mikolajewicz (2005), Arctic–North Atlantic interactions and multidecadal variability of the meridional overturning circulation, *J. Clim.*, *18*, 4013–4031.

Lumpkin, R., and K. Speer (2003), Large-scale vertical and horizontal circulation in the North Atlantic Ocean, *J. Phys. Oceanogr.*, *33*, 1902–1920.

Latif, M. (1998), Dynamics of interdecadal variability in coupled ocean-atmosphere models, *J. Clim.*, *11*, 602–624.

Latif, M. (2001), Tropical Pacific/Atlantic Ocean interactions at multidecadal time scales, *Geophys. Res. Lett.*, *28*, 539–542.

Latif, M., E. Roeckner, U. Mikolajewicz, and R. Voss (2000), Tropical stabilisation of the thermohaline circulation in a greenhouse warming simulation, *J. Clim.*, *13*, 1809–1813.

Lau, K.-M., H.-T. Wu, and S. Bony (1997), The role of large-scale atmospheric circulation in the relationship between tropical convection and sea surface temperature, *J. Clim.*, *10*, 381–392.

Marsland, S. J., H. Haak, J. H. Jungclaus, M. Latif, and F. Roeske (2003), The Max-Planck-Institute global ocean/sea ice model with orthogonal curvilinear coordinates, *Ocean Modell.*, *5*, 91–127.

Rodgers, K. B., P. Friederichs, and M. Latif (2004), Tropical Pacific decadal variability and its relation to decadal modulation of ENSO, *J. Clim.*, *17*, 3761–3774.

Roeckner, E., et al. (2003), The atmospheric general circulation model CHAM 5. Part I: Model description, *Rep. 349*, Max Planck Inst. for Meteorol., Hamburg, Germany.

Selten, F. M., G. W. Branstator, H. A. Dijkstra, and M. Kliphuis (2004), Tropical origins for recent and future Northern Hemisphere climate change, *Geophys. Res. Lett.*, *31*, L21205, doi:10.1029/2004GL020739.

Vellinga, M., and P. L. Wu (2004), Low-latitude freshwater influence on centennial variability of the Atlantic thermohaline circulation, *J. Clim.*, *17*, 4498–4511.

M. Latif and V. A. Semenov, Leibniz Institute for Marine Sciences at the University of Kiel, Düsternbrooker Weg 20, D-24105 Kiel, Germany. (vsemenov@ifm-geomar.de)