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Tropical Pacific response to 20th century Atlantic warming

F. Kucharski,[1] I.-S. Kang,[2] R. Farneti,[1] and L. Feudale[1]

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[1] The analysis of a series of regionally coupled ocean-atmospheric simulations suggests that the Atlantic warming that has occurred in the 20th century may have reduced the concomitant warming in the eastern tropical Pacific. The Pacific response to the Atlantic warming shows La Nina-like features even in the presence of greenhouse gas (GHG) forcing. The physical mechanism for the Atlantic warming influence on the tropical Pacific is a change in the Walker circulation that results in easterly surface wind anomalies in the central-west Pacific. Coupled ocean-atmosphere processes then amplify the signal. The possibility of an Atlantic Ocean induced cooling of the eastern tropical Pacific is complementary to the hypothesis that the GHG forcing itself may have caused the observed relative eastern Pacific cooling. It is argued that the uncertainties in the projected future mean state in the Pacific may be partly due to the competition of the GHG induced warming and the Atlantic induced cooling. **Citation:** Kucharski, F., I.-S. Kang, R. Farneti, and L. Feudale (2011), Tropical Pacific response to 20th century Atlantic warming, *Geophys. Res. Lett.*, *38*, L03702, doi:10.1029/2010GL046248.

1. Introduction

[2] Climate projections for the future mean state of the tropical Pacific show large uncertainties [e.g., *Knutson and Manabe*, 1995; *Clement et al.*, 1996; *Meehl and Washington*, 1996; *Cane et al.*, 1997; *Cobb et al.*, 2003; *Collins et al.*, 2005; *Vecchi et al.*, 2006; *Fedorov et al.*, 2006; *Zhang and Song*, 2006; *Vecchi et al.*, 2008; *Collins et al.*, 2010]. Some physical arguments predict that the mean state in GHG forcing experiments is expected to be more La Nina-like. This is referred to as the 'ocean thermostat' [e.g., *Clement et al.*, 1996; *Cane et al.*, 1997] hypothesis. Others predict the eastern Pacific to warm more than the western Pacific due to a weakening of the Walker circulation [e.g., *Vecchi and Soden*, 2007a; *Vecchi et al.*, 2006].

[3] The SST reconstructions that are widely used to carry out Atmospheric General Circulation Model (AGCM) investigations show contrasting trends in the 20th century supporting either one or the other hypothesis [*Vecchi et al.*, 2008; *Parker et al.*, 2007]. Such mean state differences are expected to have important consequences for the projected global climate change signal, for example tropical cyclones may be dependent on the tropical Ocean mean state structure [e.g., *Vecchi and Soden*, 2007b] and the Indian Monsoon rainfall strongly depends on the mean tropical Walker Circulation [e.g., *Turner et al.*, 2005; *Annamalai et al.*, 2007; *Wang*, 2006a; *Kucharski et al.*, 2010].

[4] The Atlantic influence on the Pacific region is a relatively recent topic. On interannual timescales *Wang* [2006b], *Keenlyside and Latif* [2007], *Rodríguez-Fonseca et al.* [2009], *Wang et al.* [2009] and *Losada et al.* [2010] investigated the influence of the tropical Atlantic on the tropical Pacific Ocean and on ENSO events.

[5] On multidecadal timescales, the influence of the Thermohaline Circulation on the Pacific region and ENSO statistics has been recently investigated by *Dong and Sutton* [2007]. Also *Keenlyside et al.* [2008] emphasized the potentially important role of the Atlantic Ocean for global decadal predictability.

[6] The purpose of this paper is to analyse the influence of the observed warming in the Atlantic region on the tropical Pacific and therefore to shed more light on the current uncertainties about past and future trends in the tropical Pacific region.

2. Data, Model, Methodology

[7] As SST data we use the HadISST [*Rayner et al.*, 2003] dataset. To investigate the Atlantic forced response in the tropical Pacific region, we perform three ensembles of regionally coupled atmosphere-ocean simulations. The atmospheric component consists of the ICTP AGCM (see *Kucharski et al.* [2006, 2010] for configuration). The ocean component is an extended 1.5 layer reduced-gravity model [*Zebiak and Cane*, 1987; *Chang*, 1994; *Chang et al.*, 2006] with a resolution of 2° in longitude by 1° in latitude. In the configuration selected for this study, the AGCM and ocean model are coupled in the Indo-Pacific basin (30°S to 30°N). Elsewhere, climatological SSTs (that is every year the same annual cycle) are prescribed except for the Atlantic sector, where observed, monthly varying SSTs (HadISST) are prescribed. Different ensemble members differ in initial conditions. This configuration is similar to that used by *Rodríguez-Fonseca et al.* [2009]. The three ensembles, run for the period 1900 to 2000, are: one ensemble of ten members that includes prescribed observed CO2 concentrations [*Hegerl et al.*, 2007] (ATL_CO2), a five member ensemble that has constant CO2 concentrations (set to a value corresponding to 1950; ATL), and a five member ensemble that has prescribed observed CO2 concentrations, but climatological SSTs in the Atlantic region (NOATL_CO2).

[8] We also perform 4 sensitivity simulations of 100-year length each: A control simulation with constant CO2 concentrations at 1950 levels as above, but with climatological SSTs also in the Atlantic basin (CTR_NA), a control simulation coupled also in the Atlantic region (CTR), and two corresponding simulations with doubled CO2 concentrations (2xCO2_NA and 2xCO2), respectively.

[1]Earth System Physics Section, Abdus Salam International Centre for Theoretical Physics, Trieste, Italy.

[2]School of Earth and Environmental Sciences, Seoul National University, Seoul, South Korea.

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Table 1. Experiments Used in This Paper and Their Purpose

Experiment	Coupling	Forcing	Purpose
ATL_CO2	Indo-Pacific	Obs SST in Atl., clim. else; obs CO2	full forcing experiment
ATL	Indo-Pacific	Obs SST in Atl., clim. else; const. CO2	isolate Atlantic effect
NOATL_CO2	Indo-Pacific	clim. SST also in Atl.,; obs CO2	sensitivity to CO2 change
ATL_AGCM	no coupling	Obs SST in Atl., clim. else; const. CO2	atm. Atlantic influence
CTR_NA	Indo-Pacific	clim. SST in Atl.; const. CO2 (1950)	control
CTR	global tropics	const. CO2 (1950)	control
2xCO2_NA	Indo-Pacific	clim. SST in Atl.; doubled CO2	doubled CO2 response
2xCO2	global tropics	doubled CO2	doubled CO2 response

[9] A 10 member ensemble of AGCM simulations with observed SST forcing in the Atlantic region and climatological SSTs elsewhere is also conducted in order to isolate the pure effect of atmospheric teleconnection from the Atlantic region to the Pacific region (ATL_AGCM). The CO2 concentrations are set to a value corresponding to 1950. Table 1 summarizes the experiments used.

[10] All analysis is performed on annual mean data. To the transient simulations a 11-year running mean is applied subsequently. For the ensemble simulations, ensemble means are used for the analysis of the responses, and intra-ensemble variabilities are used to assess the statistical significance.

3. Results

[11] Figure 1 shows the time series of global mean 11-year running mean observed SST anomalies (black curve; averaged over 0° to 360° in longitudes, 50°S to 50°N), and the Atlantic mean SST (red curve; averaged over 290°E to 380°E, 50°S to 50°N). As is well known the global mean SST has increased throughout the 20th century with accelerated warmings in the early part and late part of the century. The Atlantic shows a very similar behaviour compared to the global mean, but with an overall stronger increase, which, however, is mainly based on the data sparse early period of the 20th century and thus less reliable.

[12] In the following, the Atlantic mean SST anomaly time series (ATLM) will be used in linear regression analysis, defined as covariance of the normalized ATLM index with several global fields. Figure 2a shows the regression of the SST from the HadISST data onto the ATLM index. As can be clearly identified, for this dataset the equatorial east Pacific warms substantially less than the other regions and even shows a slight cooling at about 150°W. The same analysis repeated with the ERSST dataset [*Smith and Reynolds*, 2004] on the contrary shows a stronger warming in the eastern equatorial Pacific (not shown). This result has been reported by *Vecchi et al.* [2008]. The regression of the modeled ATL_CO2 SSTs onto the ATLM index is shown in Figure 2b and shows similarities to the HadISST regression in that the equatorial eastern Pacific is warming less than the other parts of the tropical Pacific. However, there are also notable differences, for example the modeled cooling in the tropical south eastern Pacific and eastern Indian Ocean are not observed. The tropical Pacific mean SSTs (defined in region 120°E to 240°E and 30°S to 30°N) for the HadISST data and ATL_CO2 are shown in Figure 1 (green and blue curves, respectively) and both indicate reduced long-term warming with respect to the global mean and Atlantic SSTs in the early part of the 20th century.

[13] These results suggests that in our simulation the Atlantic warming provides an atmospheric teleconnection to the Pacific that induces a La Nina-like response.

[14] Figure 2d shows the regression of the SSTs from NOATL_CO2 onto the ATLM index. Clearly, our coupled model, if forced with observed CO2 only, shows a stronger warming in the eastern equatorial Pacific indicating that the mechanism in our model does not show similarities to the 'ocean thermostat' mechanism [*Clement et al.*, 1996; *Cane et al.*, 1997]. As suggested by *Lintner and Chiang* [2007] the atmospheric stability (relative humidity) outside the tropical Pacific region increases (decreases) as a result of the warming in the eastern Pacific, leading to overall reduced convection and increased net surface heatfluxes (not shown). This process would increase SSTs in the Atlantic region if SSTs were not held fixed. The same stability and humidity mechanism would cause a modest equatorial Pacific warming as response to the Atlantic warming, which, however, is not the dominant mechanism in our simulations. Although common practice in so-called 'pacemaker' experiments, a caveat of our simulations could be that the SST changes in the Atlantic region are prescribed and could lead to unphysical responses [e.g., *Bretherton and Battisti*, 2000], even if some feedback may be expected. Therefore, we perform the sensitivity experiments 2xCO2 and 2xCO2_NA. The responses compared to the corresponding control simulations are shown in Figure 2e (2xCO2-CTR) and Figure 2f (2xCO2_NA-CTR_NA). The relatively weaker modeled warming induced by the CO2 increase in the Atlantic region compared to the Pacific (0.83 K and 0.94 K, respectively) acts to reduce the warming in the eastern Pacific, as is shown by the difference of Figures 2e and 2f in Figure 2g.

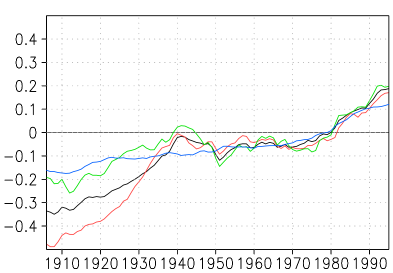

Figure 1. Time series of annual mean and 11-year filtered SST anomalies (with respect to the period 1961 to 1990); Global mean SST (black), Atlantic mean SST (red), tropical Pacific mean HadISST (green) and Pacific mean ATL_CO2 (blue). Unit are K.

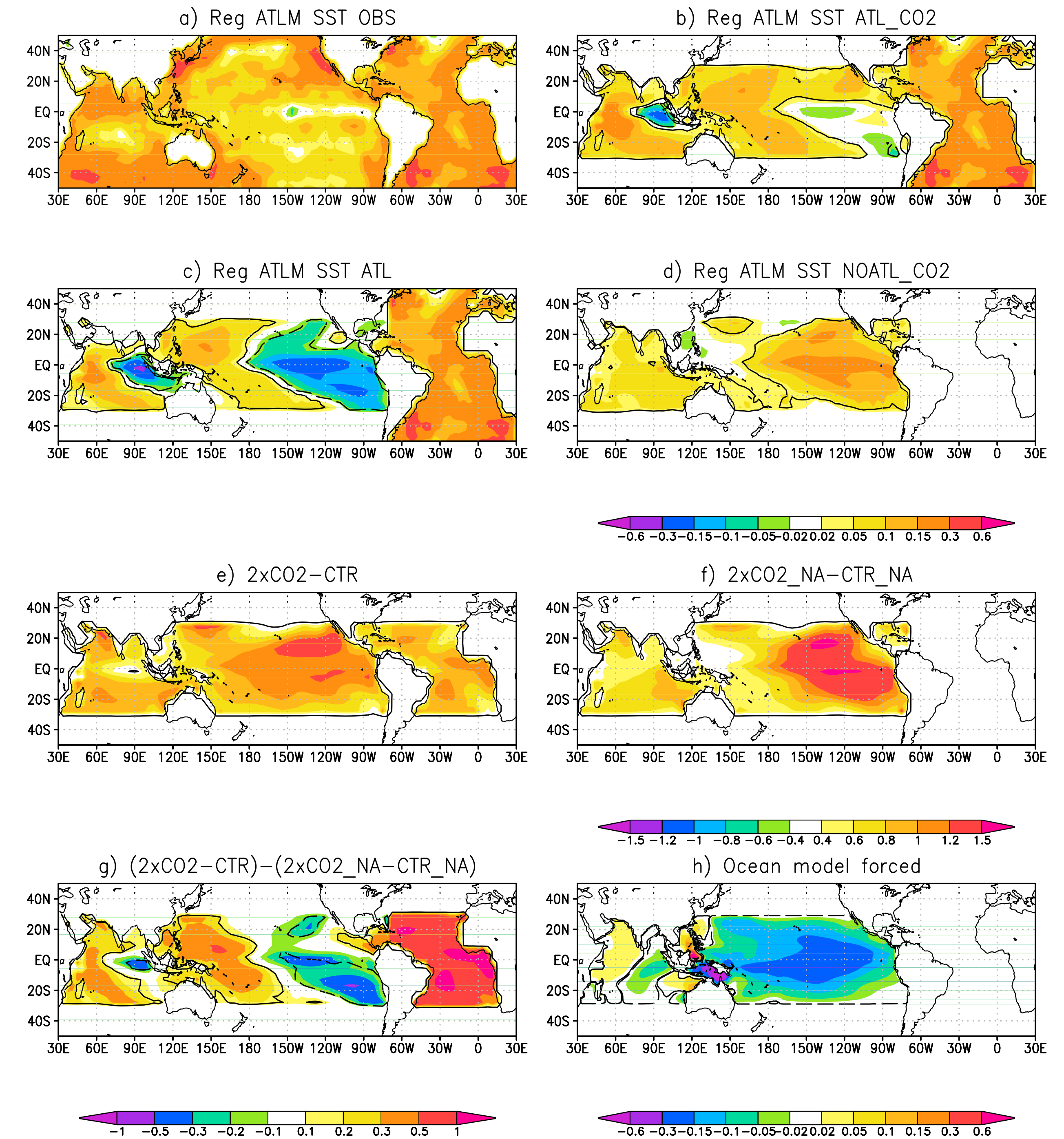

Figure 2. Regression of the HadISST Atlantic mean SST index of Figure 1 (ATLM; red curve) onto SSTs from (a) HadISST, (b) ATL_CO2, (c) ATL, (d) NOATL_CO2 and difference in SST, (e) 2xCO2-CTR, (f) 2xCO2_NA-CTR_NA, (g) Figure 2e–Figure 2f, and (h) response of ocean model to central-west Pacific wind stress forcing. Contours indicate anomalies that are significant at the 5% level. Units are K.

[15] The physical mechanism for the La Nina-like SST change in response to the Atlantic warming is similar to what has been reported by *Rodríguez-Fonseca et al.* [2009] on interannual timescale: the Atlantic warming modifies the Walker Circulation, leading to rising motion and upper-level divergence in the African-Indian Ocean region and sinking motion and upper-level convergence in the eastern-to-central Pacific region. The sinking motion leads to easterly surface wind anomalies in the central-to-western Pacific favouring a La Nina-type mean state. Figure 3a demonstrates this for our simulations (ATL), where the 200 hPa velocity potential (positive values correspond to upper-level convergence) and the 925 hPa wind regressions (arrows) onto the ATLM index are shown. The low-level easterly wind anomalies are consistent with the La Nina-type mean state response. A very similar signal, but weaker

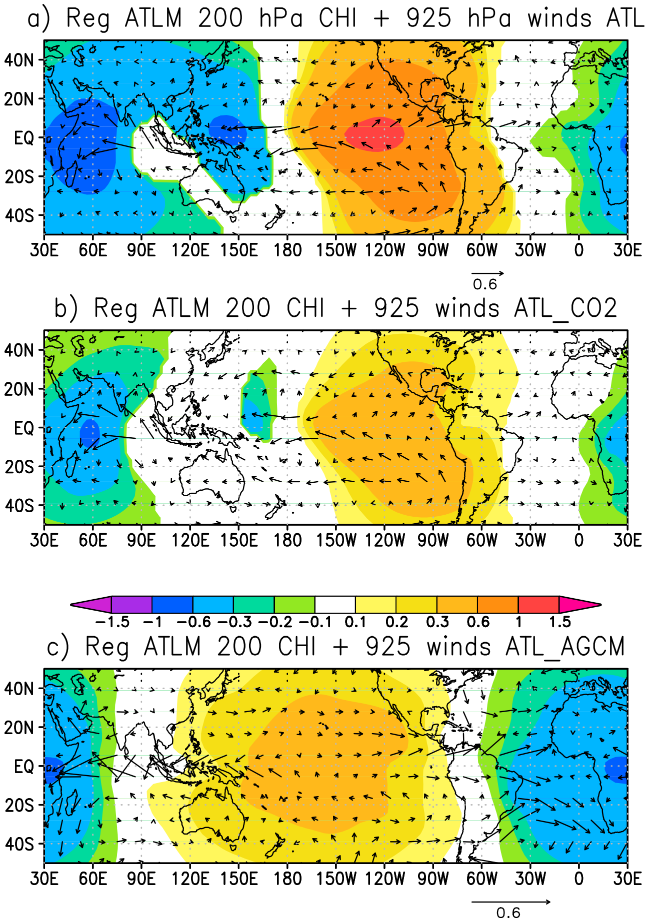

Figure 3. Regression of the HadISST Atlantic mean SST index of Figure 1 (ATLM; red curve) onto 200 hPa velocity potential and 925 hPa winds from (a) ATL, (b) ATL_CO2, (c) ATL_AGCM. All shaded anomalies are significant at the 5% level. Units are 10^6 m^2/s for velocity potential and m/s for winds.

in amplitude, is visible in the simulation with CO2 increase ATL_CO2 (Figure 3b), indicating a competing effect of the CO2 increase with the forcing from Atlantic warming.

[16] However, in the coupled simulation it is not possible to isolate the effect of the atmospheric Atlantic teleconnection, given that a positive feedback is at work in the equatorial Pacific region. To show that also the Atlantic forcing without the Indo-Pacific feedback induces a response that is consistent with our hypothesis of an atmospheric bridge, we repeat the regression analysis with the AGCM experiment ATL_AGCM (Figure 3c). The Atlantic warming leads indeed to upper-level convergence in the Pacific region and to low-level easterly wind anomalies. However, the whole pattern is shifted to the west and weaker, indicating that positive ocean feedback mechanisms play an important role to strengthen the tropical Pacific response to the Atlantic warming. In particular, the sinking induced by the Atlantic warming is shifted to the western Indian Ocean in ATL_CO2 with respect to ATL_AGCM, indicating that also adjustment processes (warming) in the Indian Ocean may play an important role. We have also verified that the eastern Pacific cooling can be reproduced if the uncoupled ocean model is forced in the central-west Pacific (120°E to 190°E) with wind stresses resulting from the wind regression shown in Figure 3c (Figure 2h).

4. Conclusions and Discussion

[17] We have shown that the Atlantic warming in the 20th Century may have reduced the Pacific warming using regionally coupled intermediate complexity GCM simulations. The Atlantic warming modifies the Walker circulation which in turn leads to sinking motion in the central-east Pacific and to easterly surface wind anomalies. These easterly surface wind anomalies initiate coupled ocean feedbacks in the equatorial Pacific that eventually evolve into a La Nina-like mean state. Adjustment processes in the Indian Ocean also play some role in modifying the Walker circulation response.

[18] The focus of this paper is to study the influence of the Atlantic warming on the tropical Pacific mean state. The Atlantic warming itself is likely GHG induced and may be also influenced by the Pacific and other factors. The Indian Ocean low-frequency variability could also be influencing the Atlantic region [*Bader and Latif*, 2003] and the Pacific region [e.g., *Terray*, 2010]. A cautionary note is related to the long-term trends of surface pressure reconstructions that are indicating a weakening of the Walker Circulation [*Vecchi et al.*, 2006]. However, this does not mean that there is no feedback from the Atlantic warming to the Pacific, which is the main focus of this paper. The structure of the response of our model to a CO2 doubling is not showing a La Nina-like response, and this is consistent with CMIP3 models [*Hegerl et al.*, 2007]. However, the feedback from the Atlantic warming redistributes the Pacific response substantially. Such a feedback from the Atlantic to the Pacific would be an important ingredient to understand climate changes. From the 1970s onward, there is a tendency for the SST gradient in the Pacific to strengthen. This is consistent that with an increased Atlantic warming in the same period.

[19] Future climate projections do show that the eastern Pacific is expected to warm more than the western Pacific [e.g., *Vecchi and Soden*, 2007a; *Held and Soden*, 2006]. This could be due to the expected smaller warming of the Atlantic Ocean, an interpretation that is also supported by the results from the CO2 doubling experiments.

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R. Farneti, L. Feudale, and F. Kucharski, Earth System Physics Section, Abdus Salam International Center for Theoretical Physics, Strada Costiera 11, I-34151 Trieste, Italy. (kucharsk@ictp.it)

I.-S. Kang, School of Earth and Environmental Sciences, Seoul National University, Sinlim-Dong, Kwanak-Gu, Seoul 151-742, South Korea.