GEOPHYSICAL RESEARCH LETTERS, VOL. 33, L12702, doi:10.1029/2006GL026324, 2006

An overlooked feature of tropical climate: Inter-Pacific-Atlantic variability

Chunzai Wang[1]

Received 16 March 2006; revised 9 May 2006; accepted 15 May 2006; published 16 June 2006.

[1] Both the tropical Pacific and Atlantic host an equatorial mode of interannual variability called the Pacific El Niño and the Atlantic Niño, respectively. Although the Pacific El Niño does not correlate with the Atlantic Niño, anomalous warming or cooling of the two equatorial oceans can form an inter-Pacific-Atlantic sea surface temperature (SST) gradient variability that induces surface zonal wind anomalies over equatorial South America and over some regions of both ocean basins. The zonal wind anomalies act to bridge the interaction of the two ocean basins, reinforcing the inter-Pacific-Atlantic SST gradient through atmospheric Walker circulations and oceanic dynamics. Thus, a positive feedback seems to exist for climate variability of the tropical Pacific-Atlantic Oceans and atmosphere system, in which the inter-basin SST gradient is coupled to the overlying atmospheric wind. Rainfall responds to the inter-Pacific-Atlantic SST gradient by showing an anti-symmetric configuration between the two equatorial oceans, suggesting that rainfall is sensitive to the equatorial inter-basin SST gradient, regardless of which ocean is anomalously warm or cold. **Citation:** Wang, C. (2006), An overlooked feature of tropical climate: Inter-Pacific-Atlantic variability, *Geophys. Res. Lett.*, *33*, L12702, doi:10.1029/2006GL026324.

1. Introduction

[2] The tropical Pacific and Atlantic Oceans share many common features in their climatology, including the northward-displaced intertropical convergence zone, the prevailing easterly trade winds, the associated eastward shoaling of the thermocline, and the eastern cold tongue along the equator, despite their differences in dimension and geometry (see a recent review by *Wang et al.* [2004]). Not surprisingly, both oceans feature a common equatorial mode of interannual variability called the Pacific El Niño and the Atlantic Niño [e.g., *Neelin et al.*, 1998; *Wang and Picaut*, 2004; *Zebiak*, 1993; *Xie and Carton*, 2004]. The growth of these interannual variations owes their existence to the Bjerknes positive ocean-atmosphere feedback mechanism [*Bjerknes*, 1969] that involves the interaction of ocean dynamics, atmospheric convection, and equatorial winds over each ocean basin. An initial positive SST anomaly in the east of an equatorial ocean changes the east-west SST gradient within the ocean basin and hence the strength of the atmospheric Walker circulation, resulting in weaker trade winds along the equator. The weaker trade winds in turn drive the ocean circulation changes that further reinforce the initial SST anomaly. This positive feedback leads the equatorial ocean to a warm state, i.e., the Pacific El Niño or the Atlantic Niño.

[3] The Pacific El Niño and the Atlantic Niño usually show the largest interannual SST variations in the Nino3 (4°S-4°N, 150°W-90°W) and Atl3 (4°S-4°N, 20°W-0°) regions where their standard deviations of SST anomalies are 0.85°C and 0.36°C, respectively. The standardized Nino3 and Atl3 SST anomaly indices (anomalies are divided by their standard deviations) are shown in Figure 1a. As pointed out by many studies [e.g., *Zebiak*, 1993; *Enfield and Mayer*, 1997], the Nino3 SST anomalies do not contemporaneously correlate with the Atl3 SST anomalies. The observed monthly SST data from 1950–2004 in Figure 1a show that the correlation between the Nino3 and Atl3 SST anomalies is nearly zero (0.04). That is, there is no contemporaneous linkage between the equatorial eastern Pacific and Atlantic SST anomalies. Anomalous extremes (warming or cooling) of the two equatorial oceans can be either in the same sign or opposite sign as well as in one ocean basin alone. In other words, as one equatorial ocean is warm (or cold), the other one can be either warm, cold or in a neutral condition.

[4] Despite no contemporaneous relationship, the equatorial eastern Pacific and Atlantic SST can form an SST gradient variability. The present paper emphasizes and investigates the east-west SST gradient between the two equatorial oceans. It shows that the inter-Pacific-Atlantic SST gradient induces surface zonal wind anomalies across equatorial South America, which may help bridge the interaction of the two ocean basins and play a role in tropical climate.

2. Data Sets

[5] Many data sets are used in this study. All of them are monthly data. The first is an improved extended reconstructed SST data on a 2° latitude by 2° longitude grid from 1950 to 2004 [*Smith and Reynolds*, 2004]. The second data set is the NCEP-NCAR reanalysis from 1950 to 2004 on a 2.5° latitude by 2.5° longitude grid [*Kalnay et al.*, 1996]. The third data is sea surface height (SSH) that merges European Remote Sensing (ERS) and TOPEX/Poseidon (T/P) altimetry observations [*Ducet et al.*, 2000], with a grid of 0.25° latitude × 0.25° longitude from 1993–2004. Finally, rainfall data between 1979–2004 is the precipitation product of the Global Precipitation Climatology Project

---

[1] Physical Oceanography Division, NOAA Atlantic Oceanographic and Meteorological Laboratory, Miami, Florida, USA.

Published in 2006 by the American Geophysical Union.

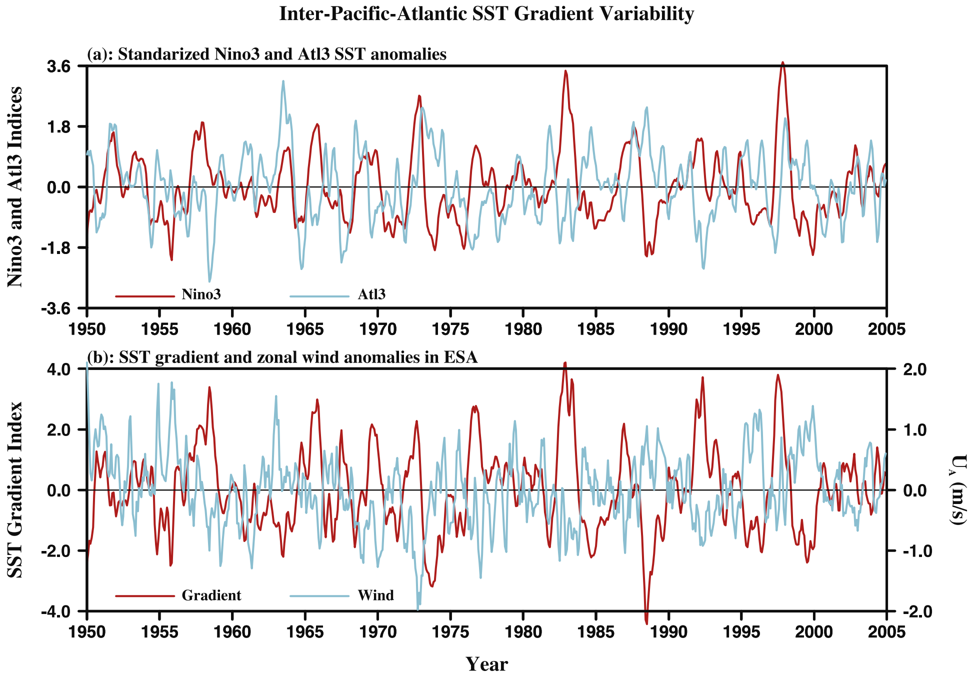

Figure 1. Time series of (a) standardized SST anomalies in the Nino3 (4°S-4°N, 150°W-90°W) and Atl3 (4°S-4°N, 20°W-0°) regions and (b) the difference between the standardized Nino3 and Atl3 SST anomalies and the 850-mb zonal wind anomalies (m/s) in the equatorial South America (ESA) region (5°S-5°N, 80°W-40°W). Standardized time series are calculated as SST anomalies divided by their standard deviations. A linear trend removal and three-month running mean are applied to the time series.

(GPCP) [*Adler et al.*, 2003] that blends satellite estimates and rain gauge data on a 2.5° latitude by 2.5° longitude grid.

3. Inter-Pacific-Atlantic SST Gradient Variability

[6] Although the equatorial eastern Pacific SST anomalies are not correlated with the equatorial Atlantic SST anomalies [e.g., *Zebiak*, 1993; *Enfield and Mayer*, 1997] (Figure 1a), the east-west SST gradient between the two equatorial oceans can induce surface zonal wind anomalies across equatorial South America, which may help bridge the interaction of the two ocean basins. The inter-Pacific-Atlantic SST gradient index, defined by the difference between the standardized Nino3 and Atl3 SST anomalies (Figure 1b), represents what is happening in both the equatorial eastern Pacific and Atlantic. To see whether or not the inter-Pacific-Atlantic SST gradient is associated with variability of the cross-South America zonal wind anomalies, we calculate the correlation between the inter-Pacific-Atlantic SST gradient index and the 850-mb wind anomalies (Figure 2a). Notice that for the monthly data between 1950–2004, the 95% significant level of correlation is about ±0.2, which accounts for serial correlation in the data [*Davis*, 1976]. In response to the inter-basin SST gradient variability, the cross-South America surface zonal wind anomalies are blowing from the colder to the warmer ocean basins. We also compute the time series of the 850-mb zonal wind anomalies in the region of equatorial South America (ESA) (5°S-5°N, 80°W-40°W), shown as the blue line in Figure 1b. The ESA zonal wind anomalies are approximately out of phase with the inter-Pacific-Atlantic SST anomaly gradient. Calculation shows that maximum correlation of −0.45 occurs when the wind anomalies lag the SST anomaly gradient by one month. Thus, the cross-South America zonal wind variability is associated with the SST gradient between the equatorial eastern Pacific and Atlantic.

[7] The causes of the zonal wind anomalies across ESA can be further examined by the distributions of SST and sea level pressure (SLP) associated with the inter-Pacific-Atlantic SST gradient (Figures 2b and 2c). When the SST anomalies are positively correlated in one ocean, the correlation in the other ocean basin is negative (Figure 2b). Correspondingly, the SLP anomalies also show a dipole pattern with a negative correlation in the eastern tropical Pacific and a positive value in the tropical Atlantic (Figure 2c). Since zonal SLP gradient determines surface zonal wind near the equatorial region [*Lindzen and Nigam*, 1987], the east-to-west (or westward) SLP gradient results in equatorial easterly wind anomalies over ESA and the equatorial Atlantic (Figures 2a and 2c). In the Pacific, the west-to-east (or eastward) SLP gradient is associated with strong equatorial westerly wind anomalies (Figures 2a and 2c), consistent with the wind distribution of Pacific warming.

[8] Can the cross-South America zonal wind anomalies in turn induce the changes in the equatorial eastern Pacific and Atlantic Oceans? The oceanic responses of SSH and SST anomalies to the ESA surface zonal wind anomalies are shown in Figure 3. SSH variation is a proxy for variability of the thermocline, with a positive (negative) SSH anomaly implying a deepened (shallowed) thermocline. Figure 3a indicates that equatorial easterly (westerly) wind anomalies over ESA are associated with the deepened (shallowed)

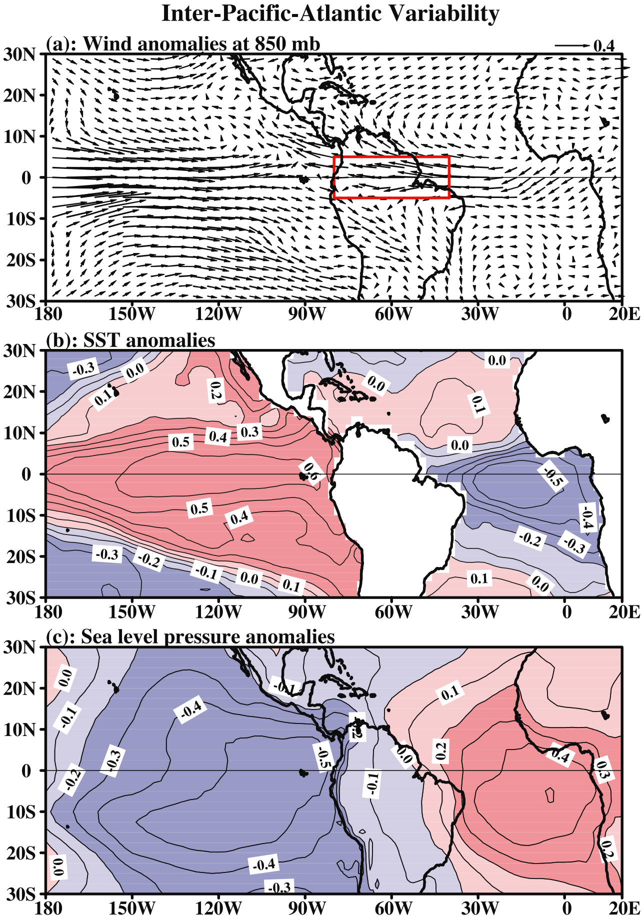

Figure 2. Correlation maps of (a) wind anomalies at 850-mb, (b) SST anomalies, and (c) sea level pressure anomalies with the inter-Pacific-Atlantic SST anomaly gradient index. The red rectangular box in Figure 2a represents the region where the cross-South America zonal wind anomalies are calculated and shown in Figure 1b. In Figures 2b and 2c, positive (negative) correlation is in red (blue) color. The dark red and dark blue represent correlation larger than 0.2.

thermocline in the equatorial eastern/central Pacific and the shallowed (deepened) thermocline in the equatorial eastern/central Atlantic. The variations of the thermocline are consistent with the fact that the ESA easterly (westerly) wind anomalies correspond to warm (cold) SST anomalies in the equatorial eastern Pacific and cold (warm) SST anomalies in the equatorial Atlantic (Figure 3b).

[9] The above results suggest an interaction between the equatorial eastern Pacific and Atlantic through the inter-basin SST gradient variability. Since the equatorial eastern Pacific Ocean and the equatorial Atlantic Ocean are separated by the landmass of northern South America, their interaction must be through induced variability of the atmosphere. The zonal Walker circulations driven by the zonal heating asymmetry may be responsible for the coherent picture of the equatorial Pacific and Atlantic. Information about the Walker circulation can be inferred from the distribution of atmospheric velocity potential and divergent wind. Figure 4a shows the correlation map of the upper tropospheric (200-mb) velocity potential and divergent wind anomalies with the inter-Pacific-Atlantic SST gradient index. Associated with the inter-Pacific-Atlantic SST variability are two zonal anomalous Walker circulation cells. The air anomalously ascends in the equatorial central/eastern Pacific and flows both westward and eastward in the upper troposphere. Over the equatorial Atlantic and western Pacific, the air anomalously converges and descends. At the lower troposphere, the air then anomalously converges toward the equatorial central/eastern Pacific (not shown) and forms the two Walker circulation cells [*Klein et al.*, 1999; *Wang*, 2002, 2005].

[10] The observational results seem to support a positive feedback mechanism in the tropical Pacific and Atlantic in which the cross-South America zonal wind variability is coupled to the SST gradient between the equatorial eastern Pacific and Atlantic. Suppose that there is a positive SST anomaly in the equatorial eastern Pacific or a negative SST anomaly in the equatorial Atlantic. The initial zonal SST gradient between the two equatorial ocean basins induces an east-to-west pressure gradient in the atmospheric boundary layer [*Lindzen and Nigam*, 1987] which results in equatorial easterly wind anomalies across northern South America. The cross-South America easterly wind anomalies extend eastward to the equatorial Atlantic and cool the equatorial Atlantic Ocean through oceanic dynamics [e.g., *Zebiak*, 1993; *Carton and Huang*, 1994] and then further enhance the initial inter-basin SST gradient. In the Pacific side, the cross-South America easterly wind anomalies (extending to the west coast of northern South America as shown in Figure 2a) may increase lower (upper) tropospheric convergence (divergence) in the equatorial eastern/

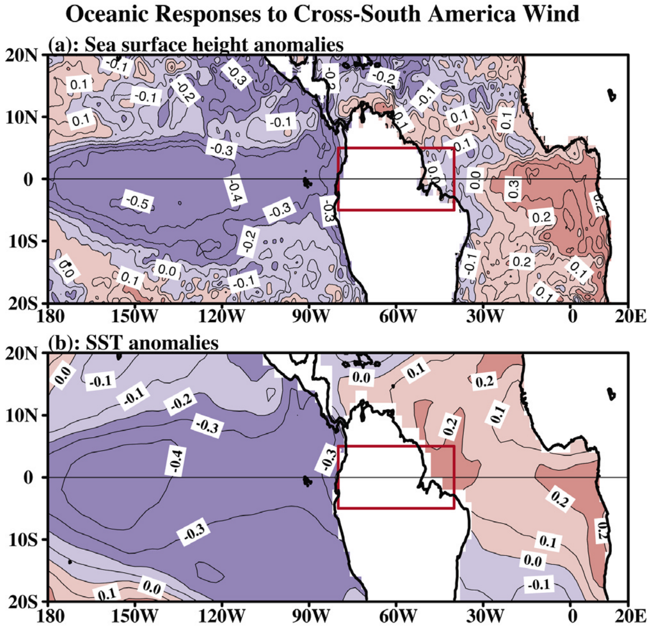

Figure 3. Oceanic responses to the cross-South America zonal wind anomalies. Shown are correlation maps of (a) sea surface height (SSH) anomalies and (b) SST anomalies with the 850-mb zonal wind anomalies in the equatorial South America region of 5°S-5°N, 80°W-40°W (red rectangular box). Positive (negative) correlation is in red (blue) color. The dark red and dark blue represent correlation larger than 0.2.

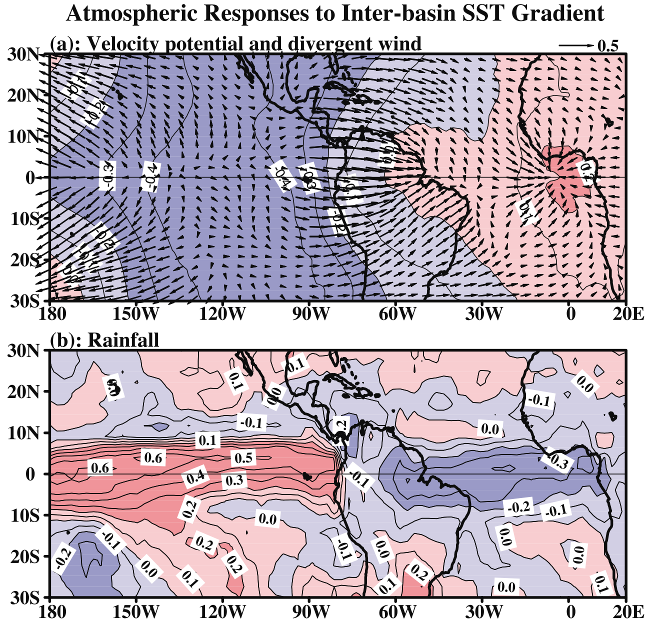

Figure 4. Atmospheric responses to the inter-Pacific-Atlantic SST gradient variability. Shown are correlation maps of (a) the 200-mb velocity potential and divergent wind anomalies and (b) rainfall anomalies with the inter-Pacific-Atlantic SST anomaly gradient index. Positive (negative) correlation is in red (blue) color. The dark red and dark blue represent correlation larger than 0.2.

central Pacific, and thus enhance the anomalous Walker circulation in the Pacific. The strengthening of the anomalous Pacific Walker circulation, added to that of the Bjerknes positive feedback within the Pacific, is associated with an increase of SST in the equatorial eastern/central Pacific. This also seems to enhance the initial inter-basin SST gradient. It thus suggests the existence of a feedback loop that involves the interaction between the inter-basin SST gradient and overlying atmospheric flow across northern South America.

[11] Finally, we examine the rainfall distribution associated with the inter-Pacific-Atlantic SST gradient. Figure 4b shows that the response of rainfall to the inter-Pacific-Atlantic SST gradient variability is an anti-symmetric configuration between the two equatorial ocean basins. The implication is that rainfall is sensitive to the equatorial SST gradient between the two ocean basins, regardless of which ocean is anomalously warm or cold. This explains why some studies show an oppositely signed rainfall pattern associated with equatorial SST anomalies [e.g., *Enfield and Alfaro*, 1999; *Giannini et al.*, 2000; *Chiang et al.*, 2000; *Munnich and Neelin*, 2005]. It is the east-west SST gradient between the two equatorial oceans that induces an anomaly in the east-to-west flow of air across northern South America and a corresponding direct circulation aloft between the two oceans, both of which can lead to a dichotomy in rainfall between the two oceans.

4. Summary and Discussion

[12] Our analyses show that anomalous warming or cooling of the equatorial Pacific and Atlantic Oceans can form an inter-Pacific-Atlantic SST gradient variability that induces surface zonal wind anomalies over ESA and over some regions of these ocean basins. The zonal wind anomalies act to bridge the interaction of the two ocean basins, reinforcing the inter-Pacific-Atlantic SST gradient through atmospheric Walker circulations and oceanic dynamics. Thus, a positive feedback seems to exist for climate variability of the tropical Pacific-Atlantic Oceans and atmosphere system.

[13] Rainfall associated with this inter-basin SST gradient variability shows an opposite pattern between the equatorial Pacific and Atlantic, suggesting that the rainfall is responding to the zonal SST gradient between the two oceans that results from anomalous extremes in either the basin alone or from dipole configurations. This is in a manner analogous to the tropical Atlantic meridional SST gradient variability that is associated with an anti-symmetric rainfall correlation between the tropical North Atlantic (TNA) and tropical South Atlantic (TSA); however, the TNA and TSA SST anomalies are mostly independent. It is the east-west SST gradient between the two oceans that induces an anomaly in the east-to-west flow of air across northern South America and a corresponding direct circulation aloft between the two oceans, both of which can lead to a dichotomy in rainfall between the two oceans. This paper also implies that tropical climate studies should at least consider the tropical Pacific and Atlantic Oceans, the atmosphere, and South America as a coupled system, rather than treat them as isolated entities.

[14] From our analyses, several points can be discussed. First, *Florenchie et al.* [2003, 2004] show that extreme warm episodes in the southeast tropical Atlantic Ocean, known as the Benguela Niños, are remotely generated by winds in the equatorial west-central Atlantic. Our analyses in Figure 3 are consistent with their result by showing that the SSH and SST anomalies along the southwest African coast are related to the zonal wind anomalies in ESA and the equatorial western Atlantic. Second, in this paper the inter-basin SST gradient index is defined by the difference between the standardized Nino3 and Atl3 SST anomalies. Using the non-standardized inter-basin SST gradient index does not change correlation patterns, but decreases the correlation amplitude in the tropical Atlantic and increases it in the tropical Pacific. Third, given that orography in South America can affect atmospheric circulation, the correlation of −0.45 between the inter-basin SST gradient and the ESA zonal wind anomalies is very impressive. Correlation of an individual ocean SST anomaly index alone (for example, Nino3 and Atl3) with the ESA zonal wind anomalies is smaller (−0.39 and 0.23, respectively; see Figure 3b). This suggests that the SST anomaly gradient between the two ocean basins is superior to the individual ocean SST anomaly for driving the atmospheric circulation across northern South America and that the inter-basin SST anomaly gradient is important for influencing tropical climate variability.

[15] **Acknowledgments.** I would like to thank two anonymous reviewers' and editor's (Chris Reason) comments and suggestions that are helpful. This work was supported by a grant from National Oceanic and Atmospheric Administration (NOAA) Climate Program Office and by the base funding of NOAA Atlantic Oceanographic and Meteorological Laboratory (AOML). The findings and conclusions in this report are those of the author(s) and do not necessarily represent the views of the funding agency.

References

Adler, R. F., et al. (2003), The version-2 global precipitation climatology project (GPCP) monthly precipitation analysis (1979-present), *J. Hydrometeorol.*, *4*, 1147–1167.

Bjerknes, J. (1969), Atmospheric teleconnections from the equatorial Pacific, *Mon. Weather Rev.*, *97*, 163–172.

Carton, J. A., and B. Huang (1994), Warm events in the tropical Atlantic, *J. Phys. Oceanogr.*, *24*, 888–903.

Chiang, J. C. H., Y. Kushnir, and S. E. Zebiak (2000), Interdecadal changes in eastern Pacific ITCZ variability and its influence on the Atlantic ITCZ, *Geophys. Res. Lett.*, *27*, 3687–3690.

Davis, R. E. (1976), Predictability of sea surface temperature and sea level pressure anomalies over the North Pacific Ocean, *J. Phys. Oceanogr.*, *6*, 249–266.

Ducet, N., P. Y. Le Traon, and G. Reverdin (2000), Global high-resolution mapping of ocean circulation from TOPEX/Poseidon and WRS-1 and -2, *J. Geophys. Res.*, *105*, 19,477–19,498.

Enfield, D. B., and E. J. Alfaro (1999), The dependence of Caribbean rainfall on the interaction of the tropical Atlantic and Pacific Oceans, *J. Clim.*, *12*, 2093–2103.

Enfield, D. B., and D. A. Mayer (1997), Tropical Atlantic sea surface temperature variability and its relation to El Niño-Southern Oscillation, *J. Geophys. Res.*, *102*, 929–945.

Florenchie, P., J. R. E. Lutjeharms, C. J. C. Reason, S. Masson, and M. Rouault (2003), The source of Benguela Niños in the South Atlantic Ocean, *Geophys. Res. Lett.*, *30*(10), 1505, doi:10.1029/2003GL017172.

Florenchie, P., C. J. C. Reason, J. R. E. Lutjeharms, M. Rouault, C. Roy, and S. Masson (2004), Evolution of interannual warm and cold events in the Southeast Atlantic Ocean, *J. Clim.*, *17*, 2318–2334.

Giannini, A., Y. Kushnir, and M. A. Cane (2000), Interannual variability of Caribbean rainfall, ENSO and the Atlantic Ocean, *J. Clim.*, *13*, 297–311.

Kalnay, E., et al. (1996), The NCEP/NCAR 40-year reanalysis project, *Bull. Am. Meteorol. Soc.*, *77*, 437–471.

Klein, S. A., B. J. Soden, and N. C. Lau (1999), Remote sea surface temperature variations during ENSO: Evidence for a tropical Atmospheric bridge, *J. Clim.*, *12*, 917–932.

Lindzen, R. S., and S. Nigam (1987), On the role of sea surface temperature gradients in forcing low-level winds and convergence in the tropics, *J. Atmos. Sci.*, *44*, 2418–2436.

Munnich, M., and J. D. Neelin (2005), Seasonal influence of ENSO on the Atlantic ITCZ and equatorial South America, *Geophys. Res. Lett.*, *32*, L21709, doi:10.1029/2005GL023900.

Neelin, J. D., et al. (1998), ENSO theory, *J. Geophys. Res.*, *103*, 14,262–14,290.

Smith, T. M., and R. W. Reynolds (2004), Improved Extended Reconstruction of SST (1854–1997), *J. Clim.*, *17*, 2466–2477.

Wang, C. (2002), Atlantic climate variability and its associated atmospheric circulation cells, *J. Clim.*, *15*, 1516–1536.

Wang, C. (2005), ENSO, Atlantic climate variability, and the Walker and Hadley circulations, in *The Hadley Circulation: Present, Past and Future*, edited by H. F. Diaz and R. S. Bradley, pp. 173–202, Springer, New York.

Wang, C., and J. Picaut (2004), Understanding ENSO physics-A review, in *Earth's Climate: The Ocean-Atmosphere Interaction*, *Geophys. Monogr. Ser.*, vol. 147, edited by C. Wang, S.-P. Xie, and J. A. Carton, pp. 21–48, AGU, Washington, D. C.

Wang, C., S.-P. Xie, and J. A. Carton (2004), A global survey of ocean-atmosphere interaction and climate variability, in *Earth's Climate: The Ocean-Atmosphere Interaction*, *Geophys. Monogr. Ser.*, vol. 147, edited by C. Wang, S.-P. Xie, and J. A. Carton, pp. 1–19, AGU, Washington, D. C.

Xie, S.-P., and J. A. Carton (2004), Tropical Atlantic variability: Patterns, mechanisms, and impacts, in *Earth's Climate: The Ocean-Atmosphere Interaction*, *Geophys. Monogr. Ser.*, vol. 147, edited by C. Wang, S.-P. Xie, and J. A. Carton, pp. 121–142, AGU, Washington, D. C.

Zebiak, S. E. (1993), Air-sea interaction in the equatorial Atlantic region, *J. Clim.*, *6*, 1567–1586.

C. Wang, Physical Oceanography Division, NOAA/AOML, 4301 Rickenbacker Causeway, Miami, FL 33149, USA. (chunzai.wang@noaa.gov)