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Why do some El Niños have no impact on tropical North Atlantic SST?

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[1] Warming of the Tropical North Atlantic (TNA) in boreal spring and early summer (April–June) following El Niño peaks in boreal winter is a well-known phenomenon that involves formation of the so-called atmospheric bridge (or teleconnection) from the Pacific. However, the existence of an El Niño in boreal winter does not guarantee a warm TNA in the following April–June (AMJ): for sixteen observed El Niño events that occurred during 1950–2005, the TNA (AMJ) remained neutral in six of them. A careful examination of the sixteen El Niño events leads to a hypothesis that if an El Niño ends before April, the TNA remains neutral. Here, we test this working hypothesis by performing multiple sets of ensemble model experiments using the NCAR atmospheric general circulation model coupled to a slab mixed layer ocean model. Analysis of the model experiments indicates that January–March (JFM) are the crucial months for the El Niño-induced warming of TNA. Therefore, if an El Niño does not continue throughout JFM, the atmospheric bridge connecting the tropical Pacific to the TNA is not persistent enough to force the TNA, thus the TNA remains neutral. Finally, our model experiments indicate even if an El Niño continues beyond JFM, the El Niño-induced warming of TNA in AMJ can be greatly reduced by Atlantic internal variability, and vice versa. **Citation:** Lee, S.-K., D. B. Enfield, and C. Wang (2008), Why do some El Niños have no impact on tropical North Atlantic SST?, *Geophys. Res. Lett.*, *35*, L16705, doi:10.1029/2008GL034734.

1. Introduction

[2] Earlier studies have shown that a large portion of the interannual SST variability in the tropical North Atlantic (TNA) during boreal spring and early summer (April–June) can be explained as a forced response to the remote influence of El Niño - Southern Oscillation (ENSO) [e.g., *Enfield and Mayer*, 1997]. The existence of an El Niño in boreal winter, however, does not guarantee a warm TNA condition in the following spring and early summer. Shown in Table 1 are sixteen observed El Niño events that occurred between 1950–2005. We use a threshold of 0.5°C for 3-month running mean of SST anomalies in the Niño3.4 region (5°N–5°S, 170°W–120°W) based on an improved extended reconstructed SST (ERSST2) data. An El Niño event is indicated when the threshold is met for a minimum of 5 consecutive over-lapping months. Hereafter, any month in the El Niño onset year is identified by suffix (0) whereas any month in the El Niño decay year is denoted by suffix (+1). Note that, for six out of sixteen El Niño events, the TNA in April–June (AMJ) remained neutral. It is known that the North Atlantic Oscillation (NAO), which is the dominant atmospheric variability over the North Atlantic in boreal winter, is partly responsible for weakening the lagged correlation of El Niño and TNA SST [e.g., *Czaja et al.*, 2002; *Enfield et al.*, 2006]. During 1957–1958 El Niño, for instance, a negative NAO pattern developed in the boreal winter of the El Niño peak. The negative NAO then reinforced the Pacific influence of the El Niño by further weakening the North Atlantic Subtropical High (NASH). During 1991–1992 El Niño, on the other hand, a positive NAO pattern developed in boreal winter of the El Niño peak and reversed the Pacific influence thus producing a slightly cold TNA condition.

[3] However, the TNA responses for 1963–1964, 1972–1973, 1976–1977, 1977–1978 and 2002–2003 El Niño events cannot be explained by using the El Niño and NAO dichotomy. In particular, 1972–1973 was a strong El Niño and nearly neutral NAO year, but the TNA was slightly cold. A similar situation occurred in 2002–2003 El Niño. It is even more puzzling for 1963–1964, 1976–1977 and 1977–1978 El Niño events. For those events, a negative NAO prevailed in boreal winter of the El Niño peak but the TNA remained neutral. Why do some El Niño events have no impact on the TNA SST under a neutral or even negative NAO condition? *Giannini et al.* [2004] suggested that the Atlantic Meridional Mode (AMM) in seasons prior to the mature phase of El Niño could interfere with or reinforce the El Niño-induced warming of the TNA. While we acknowledge the importance of preconditioning for predicting the El Niño-induced TNA warming, we look for an alternative answer by carefully inspecting the temporal evolutions of the sixteen El Niño events. Figure 1a shows the biennial life cycles of ten El Niño events followed by a warm TNA. Figure 1b is same as Figure 1a, but for six El Niño events that led to a neutral TNA.

[4] Previous studies have shown that boreal winter is the crucial time for the El Niño-induced atmospheric bridge to force the TNA [e.g., *Enfield and Mayer*, 1997]. This could be an important clue because five of six El Niño events that were followed by a neutral TNA died out between January and March (JFM) of El Niño (+1) year. On the other hand, seven of ten El Niño events that were followed by a warm TNA prevailed beyond March (+1) and many of them till late summer of El Niño (+1) year. Therefore, we can hypothesize that if an El Niño ends in March (+1) or earlier, the TNA remains neutral. But, it is also noted that two strongest El Niño events that occurred in 1982–1983 and 1997–1998 resulted in a warm TNA, whereas three weaker El Niño events that resulted in a warm TNA (1957–1958, 1968–1969 and 1969–1970) occurred under a negative NAO (Table 1.). Therefore, another competing hypothesis

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Table 1. TNA SST Index for AMJ(+1) and NAO Index for DJFM(0,+1) Following the Sixteen Observed El Niño Events That Occurred Between 1950 and 2005[a]

El Niño Year	TNA [AMJ(+1)]	NAO [DJFM(0,+1)]	El Niño & NAO Dichotomy
1957–1958	0.69(+)	−0.86(−)	O
1963–1964	−0.06	−1.38(−)	×
1965–1966	0.34(+)	−0.30	O
1968–1969	0.49(+)	−1.34(−)	O
1969–1970	0.40(+)	−0.52(−)	O
1972–1973	−0.09	0.35	×
1976–1977	−0.06	−0.98(−)	×
1977–1978	0.09	−0.46(−)	×
1982–1983	0.44(+)	0.95(+)	O
1986–1987	0.67(+)	−0.19	O
1987–1988	0.48(+)	0.48(+)	O
1991–1992	−0.11	0.57(+)	O
1994–1995	0.56(+)	1.34(+)	O
1997–1998	0.62(+)	0.05	O
2002–2003	0.18	0.04	×
2004–2005	1.04(+)	0.21	O

[a]TNA and NAO index values above 2/3 quantile are marked as positive (+), whereas those below 1/3 quantile as negative (−). Those TNA responses that can be explained by El Niño and NAO dichotomy are marked with "O" and those that cannot be explained with "×".

is that a weak-to-moderate strength El Niño has no impact on the TNA unless its remote influence is boosted by a negative NAO. As shown in Figure 1b, the peak Nino3.4 index averaged for the six El Niño events, which led to a neutral TNA, is about 1.4°C. Therefore, the peak Nino3.4 of 1.4°C must be categorized as a weak-to-moderate strength El Niño in order for the second hypothesis to be a valid one. In the following sections, we explore these two working hypotheses by using both observational data and an atmospheric general circulation model (AGCM).

2. Model Experiments

[5] The AGCM used in this study is the version 3.1 of the NCAR community atmospheric model coupled to a slab mixed layer ocean model (CAM3-SOM). The model is a global spectral model with a triangular spectral truncation of the spherical harmonics at zonal wave number 42 (T42). It is vertically divided into 26 hybrid sigma-pressure layers. Model experiments are performed by prescribing various composite evolutions of El Niño SSTs in the tropical Pacific region (15°S–15°N; 120°E-coast of the Americas) while predicting the SSTs outside the tropical Pacific using the slab ocean model. To prevent discontinuity of SST around the edges of the forcing region, the model SSTs of three grid points centered at the boundary are determined by combining the simulated and prescribed SST. Each ensemble consists of ten model integrations that are initialized with slightly different conditions to represent internal atmospheric variability.

[6] We have performed five sets of ensemble runs. In one experiment (EXP_CLM), the SSTs in the tropical Pacific region are prescribed with climatological SSTs. In the next experiment (EXP_CTR), the composite SSTs of the ten El Niño events, which led to a warm TNA, are prescribed in the tropical Pacific region. As shown in Figure 1a, Nino3.4 condition for this case becomes neutral (Nino3.4 < 0.5°C) in April (+1) but a weakly warm condition continues till July of El Niño (+1) year. The next three experiments are designed to test the first hypothesis. In one experiment (EXP_NEU), the composite SSTs of the six El Niño events, which led to a neutral TNA, are prescribed in the tropical Pacific region. The next two experiments are identical to EXP_CTR except that El Niño is completely terminated in January (EXP_JAN) or in March (EXP_MAR) of El Niño (+1) year. All five experiments are carried out for a two-year period starting from January of the El Niño onset year to December of the El Niño decay year.

3. Results

[7] Figure 2a shows the composite SST anomalies for AMJ (+1) of ten observed El Niño events that preceded a

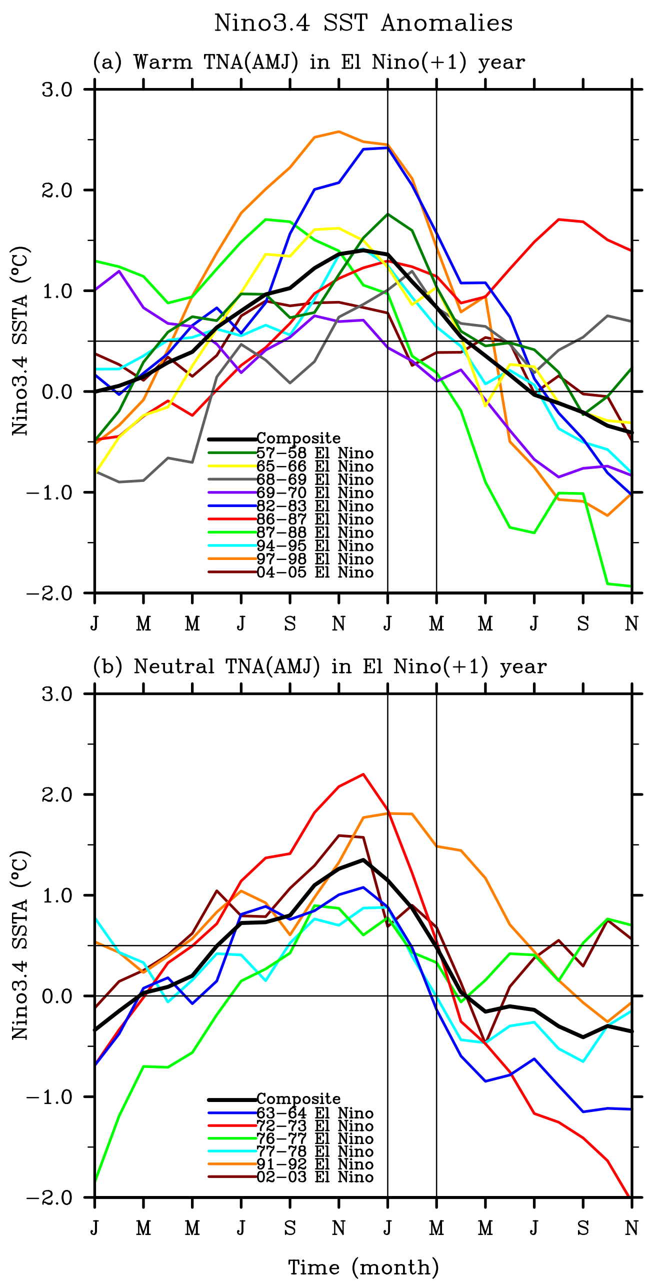

Figure 1. Nino3.4 index: biennial life cycles of (a) ten El Niño events followed by a warm TNA (AMJ) and (b) six El Niño events that led to a neutral TNA (AMJ).

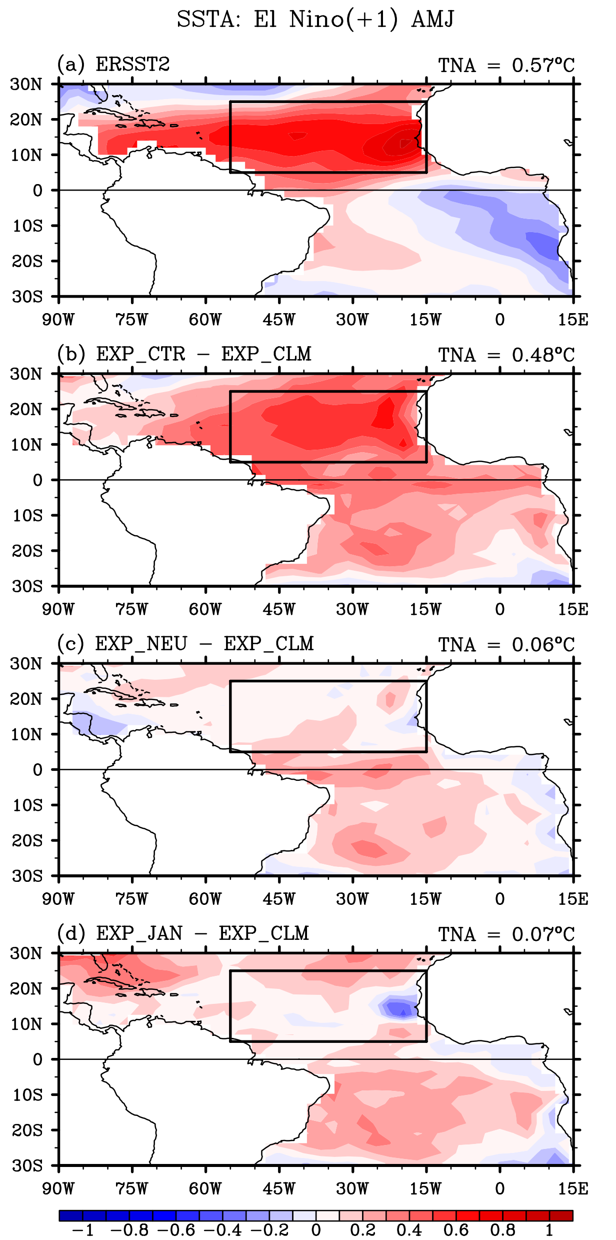

Figure 2. (a) Composite SST anomalies for AMJ (+1) of ten observed El Niño events that led to a warm TNA. Ensemble-mean SST anomalies for AMJ (+1) obtained from (b) EXP_CTR – EXP_CLM, (c) EXP_NEU – EXP_CLM and (d) EXP_JAN – EXP_CLM. The SST anomalies averaged over the TNA region are shown in the upper right corners. The 95% confidence levels are 0.21°C, 0.46°C, 0.45°C and 0.49°C for Figures 2a, 2b, 2c, and 2d, respectively.

warm TNA, whereas Figures 2b, 2c, and 2d show the simulated ensemble mean SST anomalies for AMJ (+1) obtained from EXP_CTR, EXP_NEU and EXP_JAN, respectively. EXP_CTR reasonably well simulates the warming of TNA in AMJ (+1), but the simulated SST response is biased in the southeastern Atlantic region. Focusing on the TNA region, the ensemble mean value of SST anomalies in the TNA box is 0.48°C, which is comparable to the observed value of 0.57°C. As shown in Figure 1a, the maximum Nino3.4 index for EXP_CTR is barely 1.4°C, which is almost the same as that averaged for the six El Niño events that led to a neutral TNA (Figure 1b). Therefore, we can conclude that a moderate strength El Niño (i.e., maximum Nino3.4 ~ 1.4°C) can result in a warm TNA in boreal spring (AMJ) and thus disqualifies our second hypothesis. On the other hand, the simulated TNA remains neutral (0.06°C) in EXP_NEU and thus supports our first hypothesis. Consistently, if the El Niño terminates abruptly in January (+1) (EXP_JAN) the simulated TNA also remains neutral (0.07°C). Even if the El Niño terminates abruptly in March (+1) (EXP_MAR), the simulated TNA response is only 0.22°C (not shown), which is much below 95% significance level. Hence, the model experiments support our first hypothesis that if an El Niño is terminated before April (+1) the TNA remains neutral in AMJ (+1).

4. Important Role of the Atmospheric Bridge in JFM (+1)

[8] The main conclusion so far is that a moderate strength El Niño (maximum Nino3.4 ~ 1.4°C) can result in a warm TNA in AMJ (+1) as long as it persists beyond March (+1). Now, we want to explore why El Niño in JFM (+1) is so important for the TNA warming in AMJ (+1). To answer this question, it is helpful to examine the temporal evolution of TNA response to El Niño as shown in Figure 3 for both observations and model simulations. It appears that the model is biased because the TNA warming occurs mainly from January (+1) to May (+1) in EXP_CTR whereas the observed TNA warming occurs from January (+1) to March (+1). However, this model bias does not prevent us from concluding that the TNA warming in JFM (+1) is important in both observation and model simulations. In the case of EXP_JAN, for instance, termination of El Niño in mid-January prevents the TNA from warming up during JFM (+1). Similarly, the TNA is only weakly warmed during JFM (+1) in EXP_NEU. For EXP_MAR, the TNA does warm up quickly till March (+1) as in EXP_CTR, but it quickly dissipates afterward thus the TNA remains nearly neutral in AMJ (+1) (0.22°C).

[9] Figure 4 shows the 200 hPa geopotential height and wind anomalies in JFM (+1) for (a) the NCEP-NCAR Reanalysis, (b) EXP_CTR – EXP_CLM, (c) EXP_NEU – EXP_CLM and (d) EXP_JAN – EXP_CLM. In the case of NCEP-NCAR Reanalysis, the composite map is produced based on the ten observed El Niño events followed by a warm TNA in AMJ (+1). Although the model is biased in some regions, the overall pattern of atmospheric bridge emanating from the tropical Pacific toward the TNA via the North Pacific and North America is reasonably well captured in EXP_CTR. But, more importantly, it is clear that the atmospheric bridge from the tropical Pacific to the TNA nearly vanishes if El Niño terminates in January (+1) (EXP_JAN). In the case of EXP_NEU, the atmospheric bridge still retains its overall structure but with a much-weakened amplitude compared to EXP_CTR. Therefore, we can conclude that JFM (+1) is the crucial season for the TNA warming in AMJ (+1) and that if an El Niño does not continue throughout JFM (+1), the atmospheric bridge that connects the tropical Pacific to the

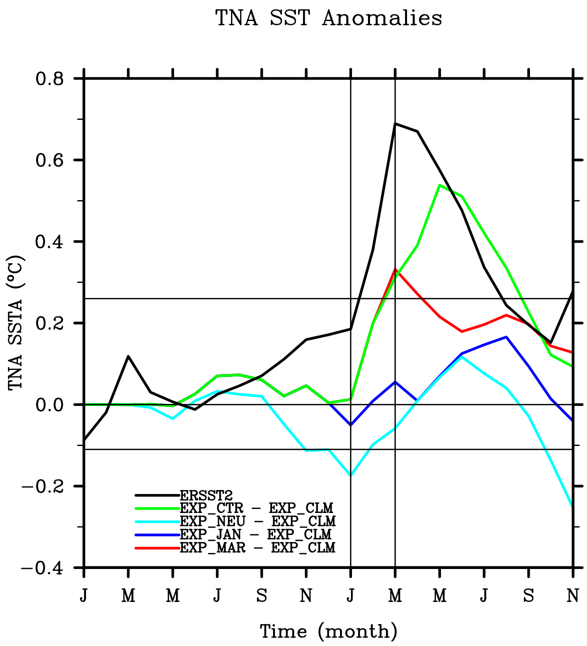

Figure 3. Time evolution of composite TNA SST anomalies of ten observed El Niño that led to a warm TNA in AMJ (+1) is shown along with the time evolutions of TNA SST anomalies from the model experiments.

TNA is not persistent enough to force the TNA, thus the TNA remains neutral.

5. Effect of Atlantic Internal Variability

[10] As discussed earlier, the El Niño-induced warming of TNA in AMJ (+1) is not very robust (only a 60% of occurrence) partially due to Atlantic internal variability such as the NAO. In order to better illustrate this point, we select 22 neutral ENSO years observed during 1950–2005 and divide them into one group that was followed by a warm TNA in AMJ and the other group that was followed by a cold TNA in AMJ. Figure 5a shows SST anomaly differences between these two groups. Similarly, we divide ten ensemble experiments for EXP_CTR into two groups, one with warmer-than-average AMJ (+1) TNA SST anomalies (>0.48°C) and the other with colder-than-average AMJ (+1) TNA SST anomalies (<0.48°C). Figure 5b shows SST anomaly differences between these two groups. In the case of the observations, the typical amplitude of TNA SST anomalies in AMJ produced by Atlantic internal variability is about 42% of the El Niño-induced warming. In the case of EXP_CTR, Atlantic internal variability can generate a TNA warming that is as large as the El Niño-induced warming. Therefore, we can conclude that the El Niño-induced TNA warming in AMJ (+) can be greatly reduced or enhanced by Atlantic internal variability.

6. Discussions

[11] This study show that the persistence of an El Niño beyond JFM (+1) is a primary determinant of the El Niño's teleconnection to the TNA and that Atlantic internal variability such as the NAO and AMM can disrupt or enhance the El Niño signal in agreement with *Enfield et al.* [2006]. However, there are clearly other factors that affect the El Niño-induced TNA warming. The main mechanism for the El Niño-to-TNA teleconnection is via the wave train that arcs across the Pacific-North American (PNA) region. This wave train may vary for a large number of reasons. The intrinsic atmospheric variability of the PNA pattern (independent of ENSO) is one such factor. *Ting and*

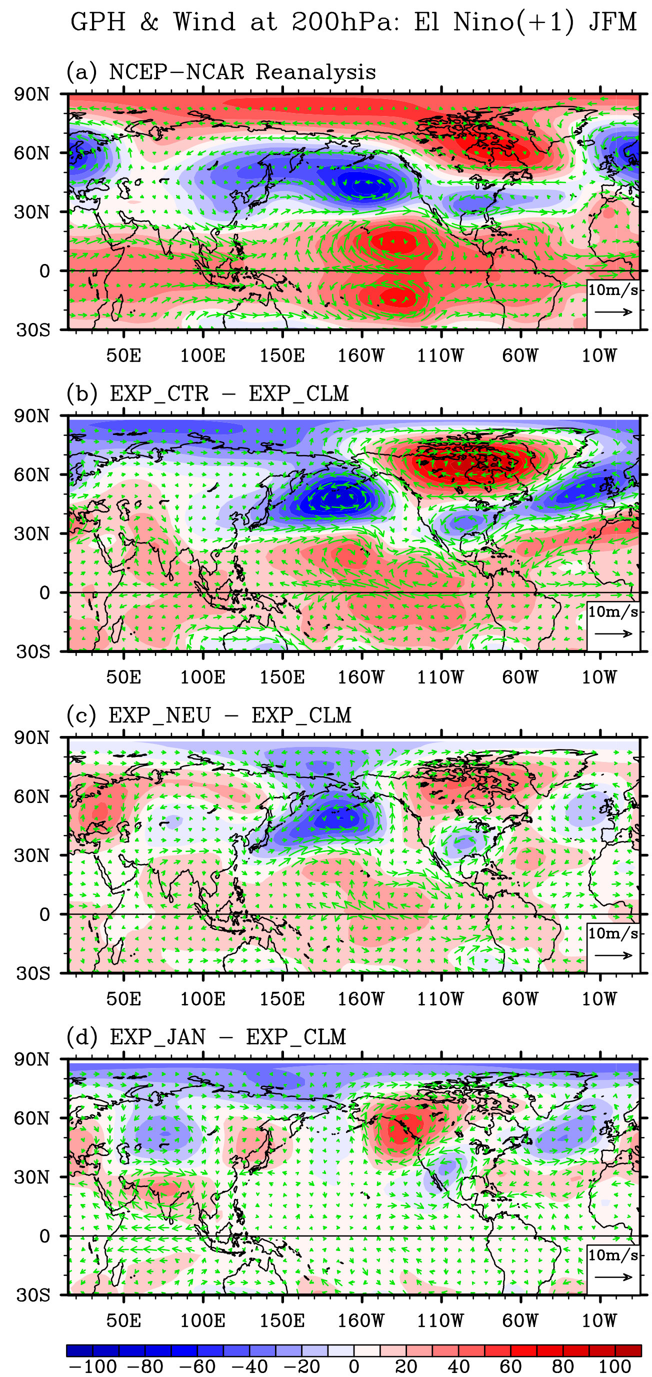

Figure 4. 200 hPa geopotential height and wind anomalies in JFM (+1): (a) composites of ten observed El Niño events that led to a warm TNA in AMJ (+1), and the ensemble-means obtained from (b) EXP_CTR – EXP_CLM, (c) EXP_NEU – EXP_CLM and (d) EXP_JAN – EXP_CLM.

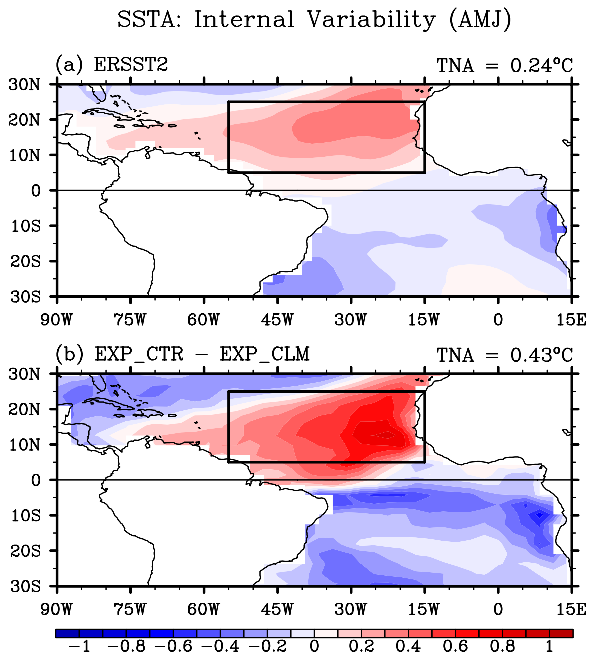

Figure 5. Twenty-two neutral ENSO years observed during 1950–2005 are divided into one group that were followed by warm TNA in AMJ and the other group that were followed by cold TNA in AMJ. (a) SST anomaly difference (divided by factor of 2) between these two groups is shown. Similarly, ten ensemble experiments for EXP_CTR are divided into two groups, one with warmer-than-average AMJ (+1) TNA SST anomalies (>0.48°C) and the other with colder-than-average AMJ (+1) TNA SST anomalies (<0.48°C). (b) SST anomaly difference (divided by factor of 2) between these two groups is shown.

Sardeshmukh [1993] showed that the PNA-like wave train is quite sensitive to the longitudinal position of the equatorial heating source (or SST). Related to this is that the El Niño-to-TNA teleconnection can be also affected by SST anomalies in the Indian Ocean [*Spencer et al.*, 2004]. Another point to note is that the NAO and AMM may not be completely independent of El Niño. For example, *Lau and Nath* [2001] suggested that the SST anomalies that form in the Atlantic in response to El Niño may feedback onto the atmosphere and thus may impact the NAO and AMM.

[12] We note some possible model biases in the simulated TNA response to El Niño. In particular, the TNA warming occurs from January (+1) to May (+1) in the model, whereas the observed TNA warming occurs mainly from January (+1) to March (+1). However, this model bias does not prevent us from concluding that the TNA warming in JFM (+1) is crucial in both observations and model simulations. It is also important to point out that CAM3-SOM has no skill simulating Ekman heat flux divergence or Atlantic-Niño. Probably due to the lack of ocean dynamics in the model, the simulated SST response to El Niño is too warm in the southeastern Atlantic region (Figure 2). It is quite possible that the model's failure in the southeastern Atlantic region may further reduce the Wind-Evaporation-SST feedback that may otherwise reinforce the TNA warming in the model.

[13] Finally, 2004–2005 El Niño is an interesting case for which our conclusion may be directly applicable. As shown in Figure 1a, the 2004–2005 El Niño was a weak-to-moderate strength event (maximum Nino3.4 ~ 0.9°C) but persisted much longer than usual beyond JFM (+1). Therefore, our study suggests that 2004–2005 El Niño event is at least partly responsible for the extremely warm TNA condition (1.04°C) in AMJ (+1), which is one of the major factors that contributed to the record-breaking Atlantic hurricane season.

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