

On the Atmospheric Response to SST Anomalies Associated with the Atlantic Warm Event during 1984

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ABSTRACT

The impact of sea surface temperature (SST) anomalies observed during the Northern Hemisphere spring of 1984, which include the growing phase of an intense Atlantic warm event on the atmospheric circulation over the tropical Atlantic and Pacific is investigated using the nine-layer, low resolution version of the UCLA general circulation model. This impact is contrasted with that for the same period during 1983, when SST anomalies include the decaying phase of the strongest Pacific El Niño on record. Results obtained in control and anomaly simulations, consisting, respectively, of extended integrations with and without the observed SST anomalies, are analyzed.

It is found that simulated anomalies in the atmospheric circulation corresponding to 1984 include low-level westerlies over the equatorial Atlantic and easterlies over the equatorial Pacific. There are centers of anomalous low-level convergence and divergence off the northeast coast of Brazil and equatorial Brazil, respectively, which are associated with positive and negative precipitation anomalies. Differences between results corresponding to 1984 and 1983 show the impact of El Niño over the Pacific. Further, positive precipitation anomalies over the equatorial Atlantic shift from generally north of the equator in 1983 to south of the equator in 1984 (dry and wet years for northeast Brazil, respectively).

These simulated anomalies and interannual differences in the atmospheric circulation are in good general agreement with those observed. This agreement strongly suggests that the atmospheric anomalies observed during the northern springs of 1984 and 1983 over the tropical Atlantic and Pacific were primarily due to the SST anomalies.

1. Introduction

An intense and large-scale event of warm sea surface temperature (SST) anomalies developed in the equatorial Atlantic Ocean during the Northern Hemisphere (NH) spring of 1984. Philander (1986) contrasted the observed SST in the Atlantic during June 1984 and June 1983 to emphasize the higher values for 1984 in the eastern part of the equatorial basin and along the eastern continental margin consistent with reduced upwelling there. These features are similar in many respects to conditions in the Pacific during an El Niño event. Philander pointed out that warm SST anomalies in the equatorial Atlantic are primarily associated with meridional local displacements in anomalous precipitation, while those in the Pacific are associated with zonal displacements in anomalous precipitation. He

related the warm SSTs in the central and southeastern equatorial Atlantic during 1984 to weak surface winds over these regions. He also reported that 1984 was anomalously wet over northeast Brazil, particularly in spring, while drought in the Sahel continued to worsen through the fall of 1984. Nobre and de Oliveira (1986) reported that 1983 was anomalously dry over northeast Brazil and studied in detail the temporal evolution of this drought from January through July. Lamb et al. (1986) showed that the SST anomalies in the equatorial Atlantic during 1984 were not unique, but rather have occurred intermittently since the late 1940s.

An excellent description of the differences between the observed atmospheric circulations during 1983 and 1984 in the Atlantic sector was given by Horel et al. (1986). We highlight their findings for the NH spring:

- 1) Winds at 850 mb (200 mb) over the equatorial Atlantic during 1984 were westerly (easterly) as compared to those during 1983.
- 2) Sea level pressure over the equatorial Atlantic during 1984 was significantly lower than during 1983.
- 3) The ITCZ over the equatorial Atlantic during 1984 was more active and located farther south than in 1983.

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4) Precipitation over a large region of northeast Brazil during 1983 (1984) was about one-half (one and one-half) of the long-term mean.

Moura and Shukla (1981) used the general circulation model (GCM) of the Goddard Laboratory for Atmospheric Sciences to study the impact of SST anomalies in the tropical Atlantic on northeast Brazil drought. The idealized SST anomalies they used have a pattern that resembles the observed anomalies during dry years in northeast Brazil, namely cold (warm) anomalies prevailing south (north) of the equator. Their results suggest that these anomalies were associated with anomalous thermally direct overturnings in the atmosphere. They found anomalous sinking motion over regions with cold SST anomalies and anomalous rising motion over those with warm SST anomalies, resulting in a northward shift of the ITCZ. Consequently, moisture flux divergence, and to a lesser extent decreased evaporation, over the cold SST anomalies contributed to reduced precipitation over northeast Brazil.

Palmer (1986) used a version of the United Kingdom Meteorological Office GCM, in the perpetual-July mode, to study the impact on Sahel rainfall of the composite SST difference between wet and dry periods for that region. He found that this SST difference results in a reduction of Sahel rainfall, and that such a reduction is larger than that associated with the components

of the composite SST over the Atlantic, Pacific, and Indian oceans separately. The Atlantic component Palmer used has a similar pattern to, but weaker intensities than, the SST anomalies observed during 1984. This component was associated with enhanced precipitation over northeast Brazil and substantially reduced precipitation across the North Atlantic and the Sahel.

In this note, we use a version of the UCLA GCM to investigate the atmospheric response to SST anomalies observed during the NH spring of 1984, when the Atlantic warm event was in its growing phase, and to contrast this response with that for the NH spring of 1983, when the Pacific El Niño was in its decaying phase. In the GCM, changes in boundary conditions can be confined to the SST. We focus on the tropical Atlantic and Pacific where observed circulations were highly anomalous during those periods. We examine spring, when the Atlantic ITCZ is normally farthest south and rainfall over northeast Brazil is normally largest. Interannual changes for spring in the strength of the ITCZ and in its southward shift can result in either flood or drought affecting that region.

2. Simulations and model description

Our strategy consists of comparing simulations in which the prescribed SST includes and excludes the observed anomalies. The simulations are performed

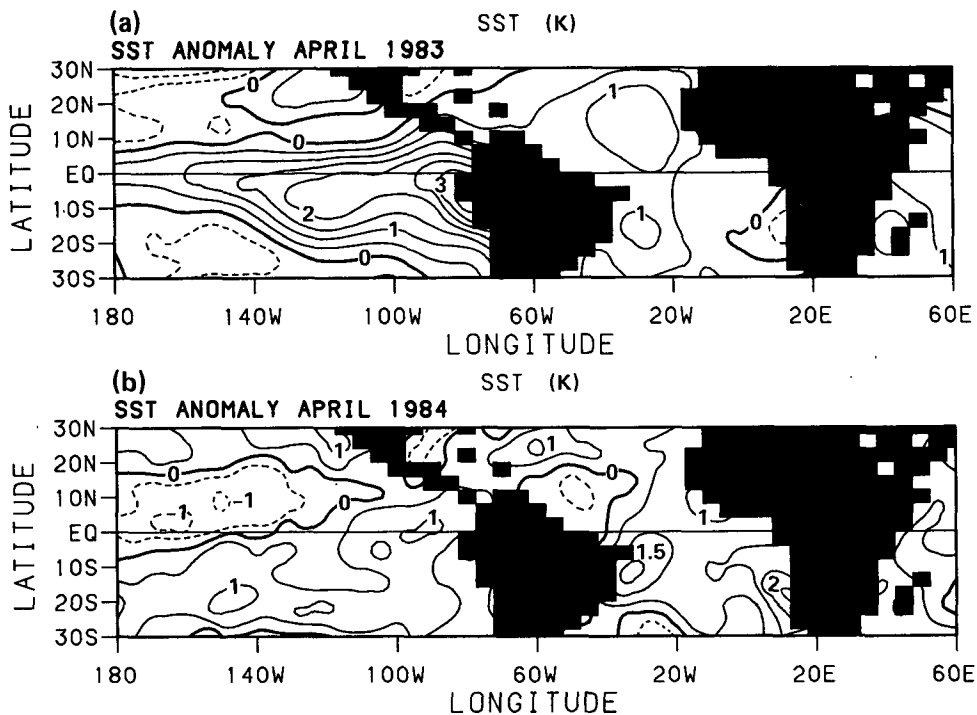


FIG. 1. Observed sea surface temperature anomalies (K) for (a) April 1983 and (b) April 1984. Contour interval is 0.5 K.

with the nine-layer, low resolution (4° lat by 5° long) version of the UCLA GCM, which is described in Suarez et al. (1983). In the "control" simulation, which starts from initial conditions corresponding to those observed on 1200 UTC 1 October 1982, SST is taken from a seasonally evolving climatology compiled from observations. In the "anomaly" simulation, which starts from the same initial conditions as the control, SST includes observed anomalies for the global oceans superimposed on the climatology. Monthly values at each grid point for climatological and anomalous SST are linearly interpolated to obtain daily values. All observed fields are taken from the U.S. National Meteorological Center analyses.

The anomalous SST distributions for April 1983 and April 1984 over the region we focus on for this study are shown in Fig. 1. The corresponding distributions for March and May are very similar to those shown in Fig. 1. During April 1983, there are large positive SST

anomalies along the equatorial Pacific in association with the decaying phase of El Niño, with highest values off the coast of northern Peru. There are also generally weak warm and cold SST anomalies in the equatorial western and southeastern Atlantic, respectively. During April 1984, the equatorial Pacific shows warm SST anomalies in its eastern part remaining from 1983, and cold anomalies near 160°W . The southern equatorial Atlantic shows an extended region of warm SST anomalies with highest values along the coast of Africa and Brazil; the latter are present also in 1983. There were weak cold SST anomalies along the northern coast of South America.

3. Selected results

Our results are organized in the form of NH spring (March through May) mean difference fields between those corresponding to (a) the anomaly for 1984 (AS84)

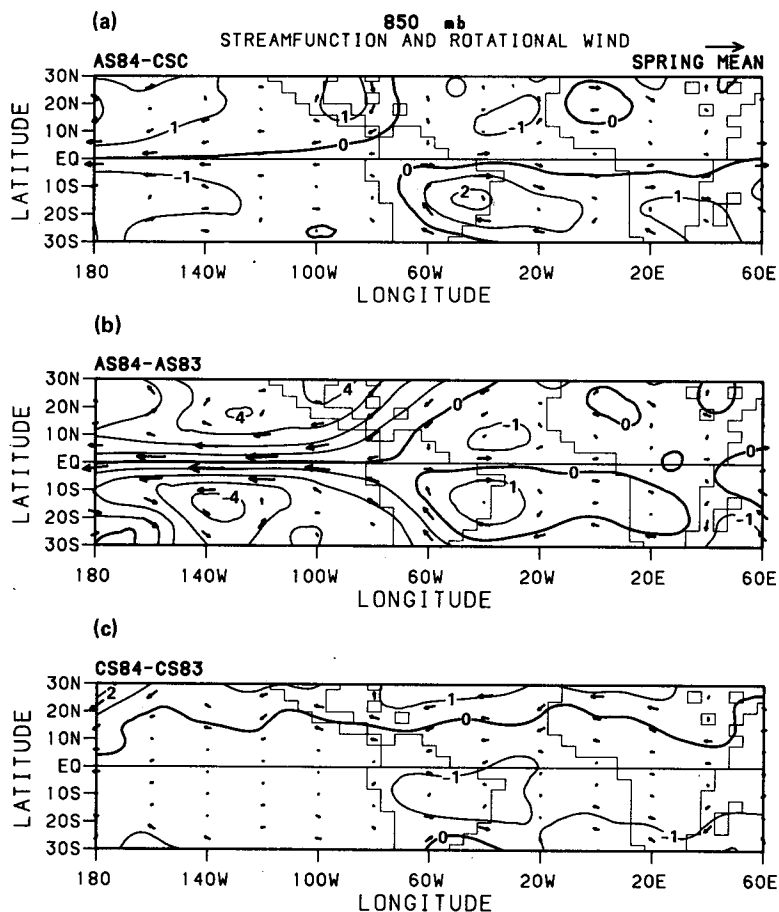


FIG. 2. Spring (March through May) mean streamfunction and rotational wind differences at 850 mb for (a) anomaly simulation for 1984 and climatology for the control simulation; (b) anomaly simulation for 1984 and anomaly simulation for 1983; (c) control simulation for 1984 and control simulation for 1983. Contour interval is $1.0 \times 10^6 \text{ m}^2 \text{ s}^{-1}$; reference arrow, 4 m s^{-1} .

and climatology for the control (CSC), (b) AS84 and the anomaly for 1983 (AS83), and (c) the control for 1984 (CS84) and the control for 1983 (CS83). Consequently, (a) depicts primarily the simulated atmospheric response to the SST anomalies during 1984, which include the Atlantic warm event; (b) depicts the difference between the atmospheric response to the SST anomalies during 1984 and 1983, the latter of which include the Pacific El Niño; and (c) provides a representation of the interannual simulated variability which is not due to SST anomalies.

Spring mean differences for the streamfunction and rotational component of the wind at 850 mb are shown in Fig. 2. Differences between AS84 and CSC (Fig. 2a) show that there are anomalous westerly winds over the equatorial Atlantic from Brazil to Africa, and anomalous easterlies over the southwest Atlantic associated with the SST anomalies during 1984 which include the Atlantic warm event. These anomalous rotational

winds are associated with an anomalous cyclonic circulation centered over southern Brazil. Over the equatorial Pacific, there are anomalous easterly winds consistent with the observed strengthening of the trade winds during 1984 (Philander, 1986). There are significant differences between the streamfunction and rotational winds obtained in AS84 and AS83 (Fig. 2b). In the eastern equatorial Pacific, the large rotational wind differences are primarily due to anomalous westerlies in AS83 associated with the SST anomalies which include the Pacific El Niño. In the Atlantic, rotational wind differences are similar to those shown in Fig. 2a, suggesting they are primarily due to the corresponding anomalies in AS84. Interannual differences in the spring mean streamfunction and rotational winds at 850 mb for the control simulation (Fig. 2c) are generally very small, particularly in the tropics, demonstrating that the differences shown in Figs. 2a and b are not due to the model's inherent variability.

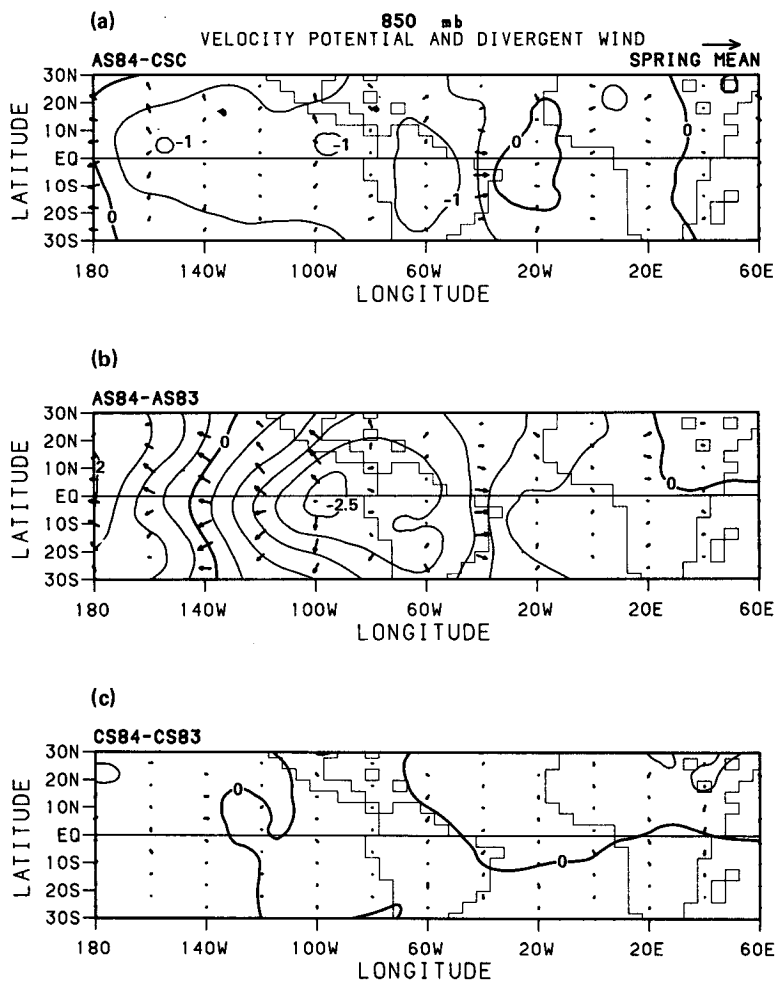


FIG. 3. As in Fig. 2 except for velocity potential and divergent wind. Contour interval is $0.5 \times 10^6 \text{ m}^2 \text{ s}^{-1}$; reference arrow, 2 m s^{-1} .

Spring mean differences for the velocity potential and divergent component of the wind at 850 mb are shown in Fig. 3. Apparent in Fig. 3a is the dipole pattern in the Atlantic sector consisting of anomalous convergence in the west-central Atlantic extending across the equator, and divergence over equatorial central South America. Other centers of anomalous divergence are over northwest Africa and along the equatorial Pacific around 90° and 150°W. The pattern of convergence at 200 mb (not shown) is nearly opposite to that at 850 mb, revealing that areas of low-level anomalous convergence and divergence are associated with anomalous rising and sinking motion through most of the troposphere, respectively. Differences between AS84 and AS83 (Fig. 3b) display large values, particularly in the equatorial Pacific. The major contribution to the divergence differences at 850 mb along the eastern equatorial Pacific is from anomalous convergence in AS83 associated with the warm SST

anomalies corresponding to the Pacific El Niño during 1983. Again, divergent wind differences in the Atlantic are primarily contributed to by the corresponding anomalies in AS84. Interannual differences in the spring mean velocity potential and divergent winds at 850 mb for the control simulation (Fig. 3c) are very small everywhere and not well organized.

Precipitation anomalies in AS84 (Fig. 4a) are substantial over the western Atlantic along the northeastern and eastern coasts of South America. Positive anomalies exceed 3 mm day^{-1} off the coast of northeast Brazil, while negative anomalies exceed 2 mm day^{-1} over equatorial Brazil. Regions of large positive and negative anomalous precipitation closely correspond to those of large anomalous low-level convergence and divergence, respectively (Fig. 3a). Interestingly, the warm SST anomalies along the equatorial and southwest coasts of Africa have a negligible local effect on the anomalous precipitation. Precipitation differences

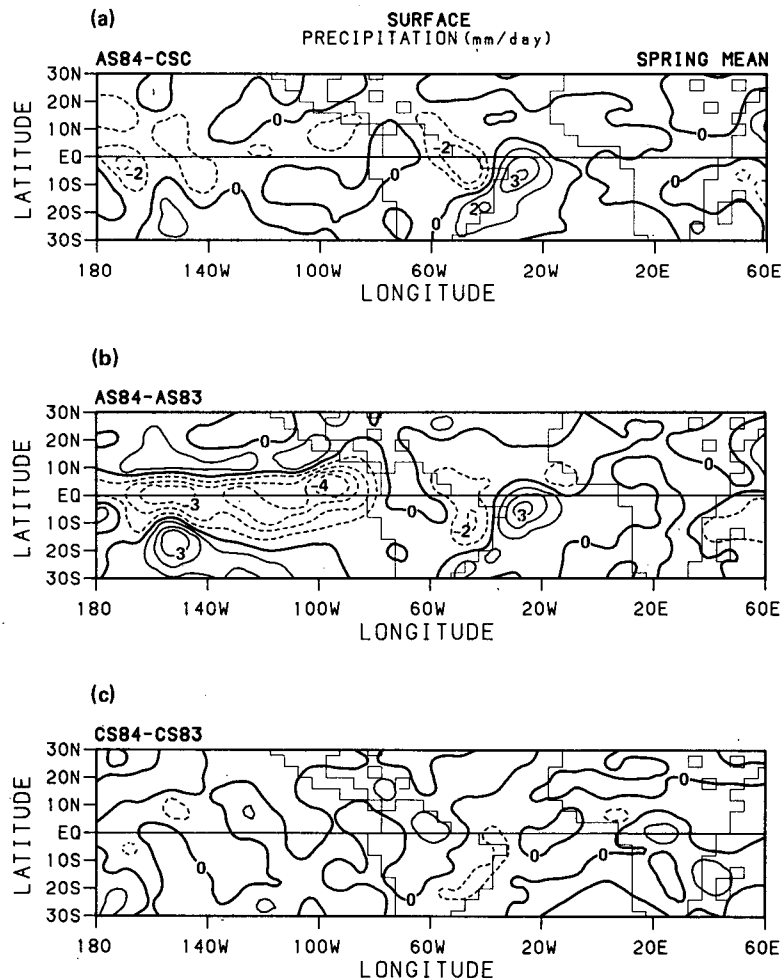


FIG. 4. As in Fig. 2 except for precipitation. Contour interval is 1 mm day^{-1} .

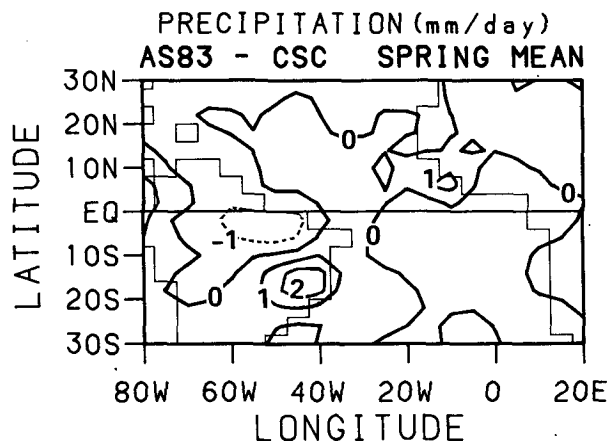


FIG. 5. Spring (March through May) mean precipitation difference for anomaly simulation for 1983 and climatology for the control simulation.

between AS84 and AS83 (Fig. 4b) are large and negative over the equatorial Pacific, reflecting the anomalous precipitation in AS83 associated with the warm SST anomalies during the 1983 Pacific El Niño. Precipitation is greater (less) over the equatorial south (north) Atlantic in AS84 as compared to AS83. A comparison of Fig. 4a and Fig. 5 shows a general southward shift in positive precipitation anomalies over the equatorial Atlantic, from north of the equator in AS83 to south of the equator in AS84. As found by Shukla and Wallace (1983) and confirmed by Mechoso et al. (1987), anomalous tropical precipitation is mostly balanced by anomalous moisture flux convergence rather than by in situ evaporation. Interannual differences in precipitation for the control simulation (Fig. 4c) are generally small.

4. Summary

We have used the nine-layer, low resolution version of the UCLA GCM to examine the impact of observed SST anomalies during the NH spring of 1984 on the atmospheric circulation over the tropical Atlantic and Pacific, and to contrast this impact with that for the NH spring of 1983. The former period includes the growing phase of an intense Atlantic warm event, and the latter includes the decaying phase of the strongest Pacific El Niño on record. For the purposes of this study, we have analyzed results obtained in two extended simulations from initial conditions corresponding to 1200 UTC 1 October 1982: one with the SST prescribed to evolve as in the observed climatology and the other with the SST including observed anomalies ("control" and "anomaly" simulations, respectively).

A comparison between results corresponding to the NH spring of 1984 obtained in the control and anomaly

simulations showed that there were anomalous low-level westerly winds over the equatorial Atlantic associated with an anomalous cyclonic circulation over southeast Brazil, and anomalous low-level easterly winds over the equatorial Pacific. Further, a dipole of anomalous low-level convergence-divergence with centers off the northeast and north coasts of Brazil was associated with enhanced and reduced precipitation, respectively.

A comparison of the results corresponding to the NH springs of 1984 and 1983 showed significant differences. Over the Pacific, these differences had the pattern expected in association with El Niño during 1983. There were low-level westerly wind differences over the equatorial Pacific, and low-level convergence differences along the equator west of Peru associated with large precipitation differences there. Precipitation differences over the equatorial Atlantic were consistent with a general southward shift in positive precipitation anomalies from north of the equator during the NH spring of 1983 to south of the equator during the NH spring of 1984. If their sign is changed precipitation differences over the equatorial Atlantic resemble anomalies obtained by Moura and Shukla (1981), suggesting that they are associated with SST changes from 1983 to 1984 over this region. Over the equatorial Atlantic and Pacific, regions with simulated maxima in anomalous precipitation were, in general, associated with warm SST anomalies. The converse was not necessarily true, as shown by the negligible impact of warm SST anomalies on precipitation anomalies along the equatorial and southwest coasts of Africa during 1984. Over northwest Africa and the Sahel, simulated anomalous precipitation corresponding to the NH springs of 1983 and 1984 was small, as expected, since spring is a dry season in those regions. In all cases, simulated precipitation anomalies were mostly balanced by anomalous moisture flux convergence.

Simulated anomalies and interannual differences in the atmospheric circulation over the tropical Atlantic and Pacific are in good agreement with those observed during the NH springs of 1983 and 1984. Such agreement strongly suggests that those observed anomalies and interannual differences are primarily due to SST anomalies.

Our results correspond to only one pair of control-anomaly simulations. They can be taken as representative, however, since the simulation with SST anomalies shows much stronger, coherent circulation anomalies and interannual differences than that with climatological SST. Furthermore, previous numerical experiments of the kind reported here (e.g., Palmer, 1986) have shown that the tropical response to SST anomalies is highly significant.

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