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## COMMENTARY

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### Key Points:

- It remains debatable whether the Pacific SST response to increasing GHGs will be El Niño-like or La Niña-like in the future
- During the past century, enhanced Indian Ocean warming has reduced the Pacific warming via interbasin ocean thermostat mechanism
- A competing hypothesis involving Atlantic-Pacific teleconnections is discussed to emphasize the pantropical response to increasing GHGs

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## Pantropical Response to Global Warming and the Emergence of a La Niña-Like Mean State Trend

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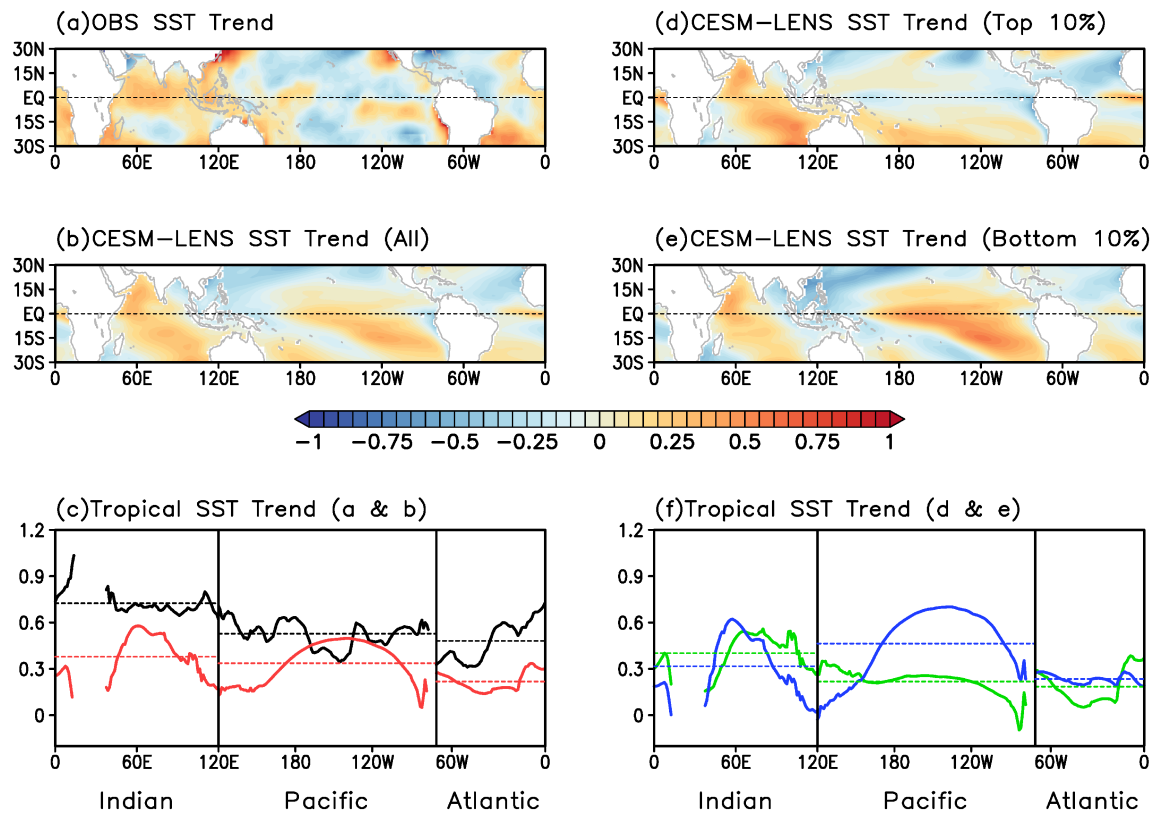
**Abstract** A recent study by Zhang et al. (2019, <https://doi.org/10.1029/2019GL084088>) proposes “an interbasin ocean thermostat mechanism” to support the hypothesis that enhanced Indian Ocean warming during the past century has reduced the Pacific warming response to increasing greenhouse gases. In this commentary, we review the proposed mechanism in a broader perspective and discuss a potential role of Atlantic Ocean in modulating the future Pacific warming response to emphasize the interactive response of the pantropical atmosphere-ocean to increasing greenhouse gases.

**Plain Language Summary** During the past century, the tropical Pacific Ocean has warmed significantly less than the other tropical oceans in response to increasing greenhouse gases. A recent study by Zhang et al. (2019, <https://doi.org/10.1029/2019GL084088>) proposes a new mechanism to help explain how enhanced Indian Ocean warming during the past century has reduced the Pacific warming response. In this commentary, we review the proposed mechanism in a broader perspective and discuss large-scale atmospheric responses in the Indian, Pacific, and Atlantic basins and their interactions to increasing greenhouse gases. We also discuss how the future weakening of the Atlantic Ocean circulation may influence the Pacific warming response.

### 1. Background

A robust feature in the Coupled Model Intercomparison Project (CMIP) model projections of future climate is a weakening of the Walker circulation that results from a larger rate of increase in atmospheric water vapor relative to the increase in global precipitation in response to increasing global temperature (Held & Soden, 2006; Vecchi & Soden, 2007). The weakening of the Walker circulation and associated reduction in Pacific trade winds suppresses equatorial Pacific upwelling, producing either an El Niño-like or zonally broad equatorial Pacific warming trend in CMIP models (Collins et al., 2010; DiNezio et al., 2009). Supporting these model results, some observational sea surface temperature (SST) and sea level pressure data sets during the instrumental period (1900s to present) show similar trend patterns (Deser et al., 2010; Tokinaga et al., 2012; Vecchi et al., 2006).

However, other observational SST data sets and some reanalysis products show warming trend with La Niña-like zonal structure during the instrumental period (Karnauskas et al., 2009) and a strengthening of the Walker circulation over the past several decades (Chung et al., 2019; Sohn et al., 2013). Due to strong natural variability, these trends are sensitive to the time period considered, and there is uncertainty in determining long-term trends from observations (Bordbar et al., 2017). Nevertheless, there is a physically consistent hypothesis to explain suppressed warming in the eastern equatorial Pacific and the associated strengthening of the Walker circulation in response to increasing greenhouse gases (GHGs): an ocean dynamic thermostat mechanism (Clement et al., 1996). Recently, Zhang et al. (2019) proposed a new mechanism to expand the original ocean thermostat theory in support of the hypothesis that the Indian Ocean warming plays a vital role in suppressing the equatorial Pacific warming response to increasing GHGs (Luo et al., 2012). Here, we summarize the proposed mechanism, starting from a brief introduction to the ocean thermostat hypothesis. Then, we discuss the pantropical response to increasing GHGs from a broader perspective, highlighting the possible role of the slowing Atlantic Meridional Overturning Circulation (AMOC) in modulating the future Pacific warming response.



**Figure 1.** SST trends during 1920–2005 derived from (a) the composite mean of the three observational SST data sets (HadISST, Kaplan SST, and ERSST) and from (b) the 41-member ensemble mean of CESM-LENS. The spatially averaged tropical SST trends (30°S to 30°N, 0–60°E) are removed in (a) and (b) to help visual comparison. Tropical SST trends over the Indian Ocean (20°S to 20°N), equatorial Pacific (10°S to 10°N), and Atlantic Ocean (10°S to 30°N) derived from the composite mean of the three observational SST data sets (black solid line) and 41-member ensemble mean of CESM-LENS (red solid line) are shown in (c). The dotted lines indicate the average for each basin. Tropical SST trends from the composites of the top 10% and bottom 10% ensembles in CESM-LENS, ranked based on the interbasin warming contrast between the Indian Ocean (50–120°E, 20°S to 20°N) and the eastern equatorial Pacific (180–90°W, 10°S to 10°N), are shown in (d) and (e), respectively. Panel (f) is same as (c) but for the top 10% (green lines) and bottom 10% ensembles (blue lines).

## 2. Interbasin Ocean Thermostat Hypothesis

The main argument of the ocean thermostat hypothesis is that the cold water tongue in the eastern equatorial Pacific warms less than the western equatorial Pacific in response to increasing GHGs due to an enhancement of the vertical thermal gradient across the base of the surface mixed layer and associated entrainment cooling. The zonal gradient of SST is thus enhanced along the equatorial Pacific, triggering Bjerknes feedback to further amplify the entrainment cooling and the zonal SST gradient (Clement et al., 1996). In support of the ocean thermostat hypothesis, Seager et al. (2019) argued that the cold SST bias in the cold tongue region that exists in the majority of CMIP models produces excessive SST sensitivity to radiative warming in the cold tongue region and thus causes the El Niño-like trend in those models. However, Li et al. (2016) reported a contradicting result that an excessive westward extension of the cold tongue causes the La Niña-like trend in some models. Therefore, it remains debatable whether the Pacific SST response to increasing GHGs will be El Niño like or La Niña like in the future.

Zhang et al. (2019) proposed a new hypothesis that supports the La Niña-like trend seen in some observations and model projections. In contrast to earlier studies that focused on processes within the equatorial Pacific, Zhang et al. (2019) explored the possible role of the tropical Indian Ocean in modulating the equatorial Pacific SST response to increasing GHGs. They noticed that despite large uncertainties in the Pacific SST warming trend among different observational SST data sets, all show stronger warming of the tropical Indian Ocean than the equatorial Pacific Ocean since 1920 (Figures 1a and 1c). The accompanying negative sea level pressure anomalies in the Indian Ocean and western Pacific produce easterly wind anomalies in the equatorial Pacific, enhancing upwelling and evaporative cooling. The net result is a suppression of

equatorial Pacific warming in response to increasing GHGs (Luo et al., 2012). Zhang et al. (2019) also performed several atmosphere-ocean coupled model experiments with and without the Indian Ocean warming to confirm their hypothesis. They still invoke the ocean thermostat mechanism as the primary initiator of the interbasin SST warming contrast between the Indian Ocean and the equatorial Pacific Ocean; thus, their hypothesis is referred to as an interbasin ocean thermostat mechanism.

### 3. Natural Variability Versus Forced Response

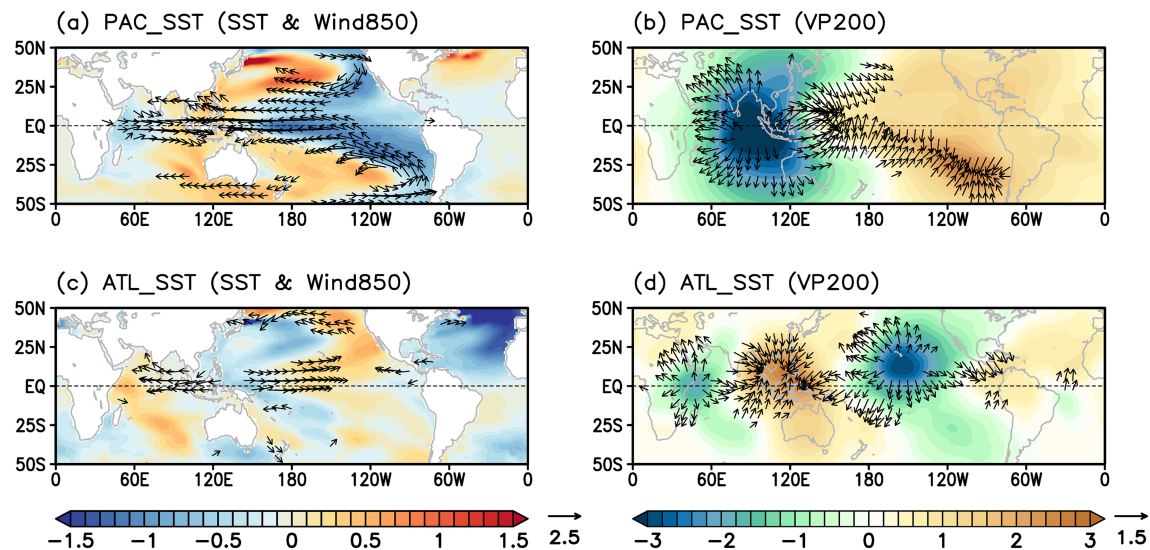
Zhang et al. (2019) used three observational SST data sets, all of which show larger warming in the Indian Ocean than in the equatorial Pacific since 1920, thus strengthening the interbasin SST warming contrast between the Indian Ocean and the equatorial Pacific. Figures 1a and 1b show tropical SST trends over the period 1920–2005 derived from the composite mean of the three observational SST data sets and from the 41-member ensemble mean of the National Center for Atmospheric Research (NCAR) Community Earth System Model Large-Ensemble Simulation (CESM-LENS; Kay et al., 2015) under the historical scenario, respectively. The tropical Indian Ocean warms more than the equatorial Pacific Ocean during the study period according to the observations (Figure 1c). In contrast, the tropical Indian Ocean and the central and eastern equatorial Pacific warm more than the western Pacific and Indonesian Seas in Community Earth System Model Large-Ensemble Simulation (Figure 1c). However, as shown in Figures 1d–1f, the SST warming contrast between the Indian Ocean and the eastern equatorial Pacific in the top 10% of the ensembles (i.e., four ensemble members with the largest interbasin warming contrast) is comparable to that from the observations. Given that some of the model ensembles can reproduce the observed interbasin SST warming trend, it is premature to entirely disregard the possibility that the interbasin SST warming contrast shown in the observational SST data sets is a result of natural variability.

### 4. Potential Impact of Slowing AMOC on the Pacific Warming

Perhaps the most important lesson from Zhang et al. (2019) is that nonlocal processes should be considered to better understand the Pacific warming response to increasing GHGs. However, there is no clearly identified mechanism through which the Indian Ocean can trigger an extended period of cooling or suppressed warming in the Pacific. In fact, within the framework of the interbasin ocean thermostat mechanism, the Indian Ocean acts as an amplifier of the interbasin SST warming contrast that is initiated by processes internal to the Pacific. In contrast to the passive role played by the Indian Ocean, the Atlantic Ocean may potentially play a more active role, given that the projected slowing of the AMOC may result in suppressed warming of the tropical North Atlantic (Kucharski et al., 2011; Zhang & Delworth, 2005)

Previous studies (Dong et al., 2006; Sun et al., 2017; Wang et al., 2010) have shown that cold SSTs in the tropical North Atlantic weaken the ascending motion aloft, which in turn produces anomalous ascending motion over the tropical Northcentral Pacific and Southeast Pacific. The resulting low-level westerly wind anomalies in the central equatorial Pacific are reinforced by suppressed upper-level divergence over the Maritime Continent (Li et al., 2015; Sun et al., 2017). Therefore, as shown in Figure 2, these Atlantic-driven atmospheric anomalies over the Indo-Pacific Oceans could strengthen or interfere with the Pacific-driven trend or variability (Kucharski et al., 2011; Li et al., 2015; McGregor et al., 2014).

However, it is not entirely clear whether the slowdown of the AMOC leads to an El Niño-like mean state trend. For instance, some water-hosing experiments with coupled models showed a southward displacement of the intertropical convergence zone (ITCZ) in the Atlantic and Pacific, producing an El Niño-like response (Timmermann et al., 2007; Wu et al., 2008; Zhang & Delworth, 2005). This result is also consistent with previous studies that linked the tropical southeastern Pacific warm SST bias in CMIP models to the weak AMOC and North Atlantic cold SST bias (Wang et al., 2014). However, in some other models, the ITCZ response to the slowing AMOC is restricted to the Atlantic basin (Vellinga & Wood, 2008). Even in the models with a robust southward displacement of the Pacific ITCZ, the region of increased SST tends to be located slightly south of the equator, with weaker cold SST anomalies north of the equator. Additionally, a recent modeling study showed an interesting possibility that the enhanced Indian Ocean warming has been playing a role in sustaining the AMOC from slowing down (Hu & Fedorov, 2019). Therefore, although it is possible that the projected weakening of the AMOC may contribute to an El Niño-like warming trend, a more in-



**Figure 2.** Partial regression coefficients of (a) SST (shading, K) and winds at 850 hPa (vectors,  $\text{m s}^{-1}$ ), (b) velocity potential (shading,  $10^5 \text{ m}^2 \text{ s}^{-1}$ ) and divergence winds at 200 hPa (vectors,  $\text{m s}^{-1}$ ) on the 11-year running mean (a, b) eastern equatorial Pacific SST ( $180\text{--}90^\circ\text{W}$ ,  $10^\circ\text{N}$  to  $10^\circ\text{S}$ ) and (c, d) North Atlantic SST ( $70\text{--}0^\circ\text{W}$ ,  $0\text{--}70^\circ\text{N}$ ), derived from 1,100 model years of CESM-LENS under preindustrial constant  $\text{CO}_2$  level. The sign of regression coefficients is reversed.

depth study is needed to clarify to what extent the projected AMOC slowdown may interfere with or reinforce the Indo-Pacific warming response to increasing GHGs.

## 5. Where to Go From Here?

An important conclusion is that tropical atmosphere-ocean processes in the three oceans should be considered all together to assess their interactive response to increasing GHGs. For instance, as summarized in a recent review paper (Cai et al., 2019), the warm phase of the Atlantic Multidecadal Oscillation during the past two decades contributed to the strengthening of the Pacific trade winds, which caused an extended period of colder than normal SSTs in the Pacific and warmer in the Indian Ocean (Li et al., 2015; McGregor et al., 2014). Therefore, future studies on the Pacific warming should consider nonlocal processes from the Indian and Atlantic Oceans and their interactions with local processes. However, due to the large amplitudes of equatorial Pacific and Atlantic SST biases in CMIP models, it is challenging to accurately attribute future Pacific warming to nonlocal influences from the Indian and Atlantic Oceans. A top priority has been, and should continue to be, reductions in coupled model biases. At the same time, it is important to understand exactly how and to what extent the Pacific warming can be obscured by local and nonlocal bias patterns in CMIP models (Li et al., 2016; Seager et al., 2019; Wang et al., 2014). Given that global climate variability and extreme weather events are closely tied to the frequency and amplitude of El Niño–Southern Oscillation and that these characteristics are modulated by the Pacific mean state (Lim et al., 2019), it is crucial to project accurately the pantropical warming response to increasing GHGs.

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