

Geophysical Research Letters[®]



RESEARCH LETTER

10.1029/2021GL096149

Warm Phase of AMV Damps ENSO Through Weakened Thermocline Feedback

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Key Points:

- AMV weakens ENSO sea surface temperature anomalies by 10% and local ENSO precipitation anomalies by up to 45%
- The thermocline feedback in the tropical Pacific is weakened in boreal autumn, reducing ENSO growth rate
- AMV causes changes in the Pacific mean state that lead to wind stress anomalies being more confined in the west Pacific during ENSO onset

Supporting Information:

Supporting Information may be found in the online version of this article.

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Citation:

Trascasa-Castro, P., Ruprich-Robert, Y., Castruccio, F., & Maycock, A. C. (2021). Warm phase of AMV damps ENSO through weakened thermocline feedback. *Geophysical Research Letters*, 48, e2021GL096149. <https://doi.org/10.1029/2021GL096149>

Received 20 SEP 2021

Accepted 22 NOV 2021

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Abstract Interactions between ocean basins affect El Niño–Southern Oscillation (ENSO), altering its impacts on society. Here, we explore the effect of Atlantic Multidecadal Variability (AMV) on ENSO behavior using idealized experiments performed with the NCAR-CESM1 model. Comparing warm (AMV+) to cold (AMV−) AMV conditions, we find that ENSO sea surface temperature (SST) anomalies are reduced by ~10% and ENSO precipitation anomalies are shifted to the west during El Niño and east during La Niña. Using the Bjerknes stability index, we attribute the reduction in ENSO variability to a weakened thermocline feedback in boreal autumn. In AMV+, the Walker circulation and trade winds strengthen over the tropical Pacific, increasing the background zonal SST gradient. The background changes shift ENSO anomalies westwards, with wind stress anomalies more confined to the west. We suggest the changes in ENSO-wind stress decrease the strength of the thermocline feedback in the east, eventually reducing ENSO growth rate.

Plain Language Summary El Niño–Southern Oscillation (ENSO) is the dominant mode of year-to-year climate variability in the tropics and affects regional climates around the world. Understanding the drivers of ENSO behavior is important for its prediction. One influential factor is communication between ocean basins, such as the North Atlantic interaction with the tropical Pacific. In our work, we use idealized simulations that represent the positive and negative phases of the Atlantic Multidecadal Variability (AMV) to understand how sea surface temperature changes in the North Atlantic affect the dynamics of ENSO in the tropical Pacific. We find that both El Niño and La Niña events are weaker when the North Atlantic is warmer than usual, and vice versa. During the warm phase of the AMV (AMV+), the trade winds associated with the Walker circulation are localized in the west Pacific, directly impacting sea surface temperature patterns associated with ENSO events. Reduced wind stress in the eastern equatorial Pacific means that the upper ocean heat content is less perturbed in the AMV+ simulation, eventually feeding back to ENSO-related sea surface temperatures.

1. Introduction

El Niño–Southern Oscillation (ENSO) is the dominant mode of interannual climate variability in the tropics. The spatiotemporal characteristics of ENSO exhibit variations (Dieppois et al., 2021; Wittenberg, 2009) driven by chaotic atmosphere–ocean dynamics (Fedorov et al., 2003; Zhang et al., 2021) and sources of variability from outside the tropical Pacific (Meehl et al., 2001). Given the global reach of ENSO and its impacts (Diaz et al., 2001), understanding and predicting changes in ENSO is a major challenge for the scientific community.

In the last decade, it has become evident that climate variability and changes in other ocean basins can affect the tropical Pacific and ENSO (Cai et al., 2019). One example is the impact of Atlantic Multidecadal Variability (AMV) on the mean climate in the tropical Pacific (e.g., Ruprich-Robert et al., 2017). However, the extent to which AMV affects ENSO remains unclear (Dong & Sutton, 2007; Hu & Fedorov, 2018; Levine et al., 2017; Yu et al., 2015). On interannual time scales, sea surface temperature (SST) anomalies in the tropical North Atlantic alter tropical Pacific SSTs via subtropical teleconnections (Ham & Kug, 2015; Wang et al., 2017). Warm SST anomalies in the equatorial Atlantic are known to influence ENSO variability by strengthening the Walker circulation (Polo et al., 2014; Rodríguez-Fonseca et al., 2009). The intensified descending branch in the equatorial east Pacific reinforces the trade winds and supports the development of a La Niña event in the following winter.

Levine et al. (2017) found that the AMV alters both the seasonal and annual ENSO stability by changing the mean seasonal cycle in the tropical Pacific. In the relatively short observational record, they found evidence for reduced

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ENSO growth rate in boreal autumn and winter when the North Atlantic is anomalously warm, but their model experiments did not reproduce this and instead showed the opposite behavior. Zanchettin et al. (2016) identified a delayed response to the AMV in the tropical Pacific and suggested this could contribute to multidecadal ENSO variability. Both Zanchettin et al. (2016) and Levine et al. (2017) highlight that changes in thermocline dynamics are key to understanding the modulation of ENSO by the AMV. Despite this common finding, owing to the short observational record and different results from model studies, there remains uncertainty around the impact of the AMV on ENSO.

This study aims to advance understanding of the processes by which the AMV affects ENSO characteristics using idealized simulations performed with the NCAR-CESM1 climate model. The paper explores changes in the atmospheric and oceanic processes that are responsible for ENSO growth and decay using the Bjerknes stability index (hereafter BJ index). With this comprehensive approach, we are able to identify specific mechanisms involved in changes in ENSO under different AMV states.

This paper is laid out as follows: Section 2 describes the model, experimental design, and BJ index. The modulation of ENSO behavior by AMV is detailed in Section 3. Our results are discussed in Section 4, followed by the final remarks in Section 4.

2. Data and Methods

2.1. Climate Model Simulations

Simulations were performed with the NCAR-CESM1(CAM5) model (hereafter CESM1; Kay et al., 2015). All components of CESM1 have $\sim 1^\circ$ horizontal resolution. The atmospheric component CAM5.2 has 30 hybrid vertical levels. The ocean component POP2 has 60 vertical levels and a meridional mesh refinement down to $\sim 0.25^\circ$ near the equator. CESM1 simulates ENSO in good agreement with observations (Figure S2 in Supporting Information S1; DiNezio et al., 2017; Wu et al., 2021; Zhang et al., 2017).

To assess the impacts of the AMV on ENSO behavior, idealized experiments were performed in which warm (AMV+) and cold (AMV-) SST anomalies equivalent in amplitude but opposite in sign are imposed in the North Atlantic through surface relaxation (Figure S1 in Supporting Information S1; Castruccio et al., 2019; Ruprich-Robert et al., 2017). The imposed SST anomalies do not vary in time nor account for AMV seasonality. The simulations follow the protocol of the Decadal Climate Prediction Project Phase C Idealized AMV experiment (Boer et al., 2016), with the minor exception that the observed AMV pattern was computed from the ERSSTv3b (Smith et al., 2008) data set instead of ERSSTv4 (Huang & Xie, 2015).

Three ocean initial states are obtained from a preindustrial control simulation; the corresponding atmospheric conditions are perturbed at round-off level in the potential temperature field to obtain 10 different atmospheric initial conditions (Castruccio et al., 2019). This produces 30 ensemble members each integrated for 10 years, giving a total of 300 years for each AMV phase. The first 11 months of the simulation are discarded and the analysis presents results from the remaining period.

2.2. Analysis Methods

2.2.1. ENSO Definition

El Niño and La Niña events occur when SST anomalies in the Niño3.4 region (5°N – 5°S , 170°W – 120°W , cf. Figure 1a) exceed ± 0.5 K during boreal winter (from December to February, hereafter DJF) relative to the climatology of each simulation. This identifies 77 and 79 El Niños in the AMV+ and AMV- simulations, respectively. For La Niña, there are 91 events in AMV+ and 103 in AMV-.

To estimate the AMV modulation of ENSO impacts, we first estimate El Niño anomalies with respect to each AMV experiment mean state and then subtract the AMV- El Niño composite from AMV+ the El Niño composite:

$$\text{ENSO modulation} = (\text{El Niño}_{\text{AMV+}} - \mu_{\text{AMV+}}) - (\text{El Niño}_{\text{AMV-}} - \mu_{\text{AMV-}}), \quad (1)$$

where $\mu_{\text{AMV+}}$ and $\mu_{\text{AMV-}}$ are time averaged SSTs in the AMV+ and AMV- simulations, respectively. The AMV modulation of La Niña impacts is calculated following the same approach.

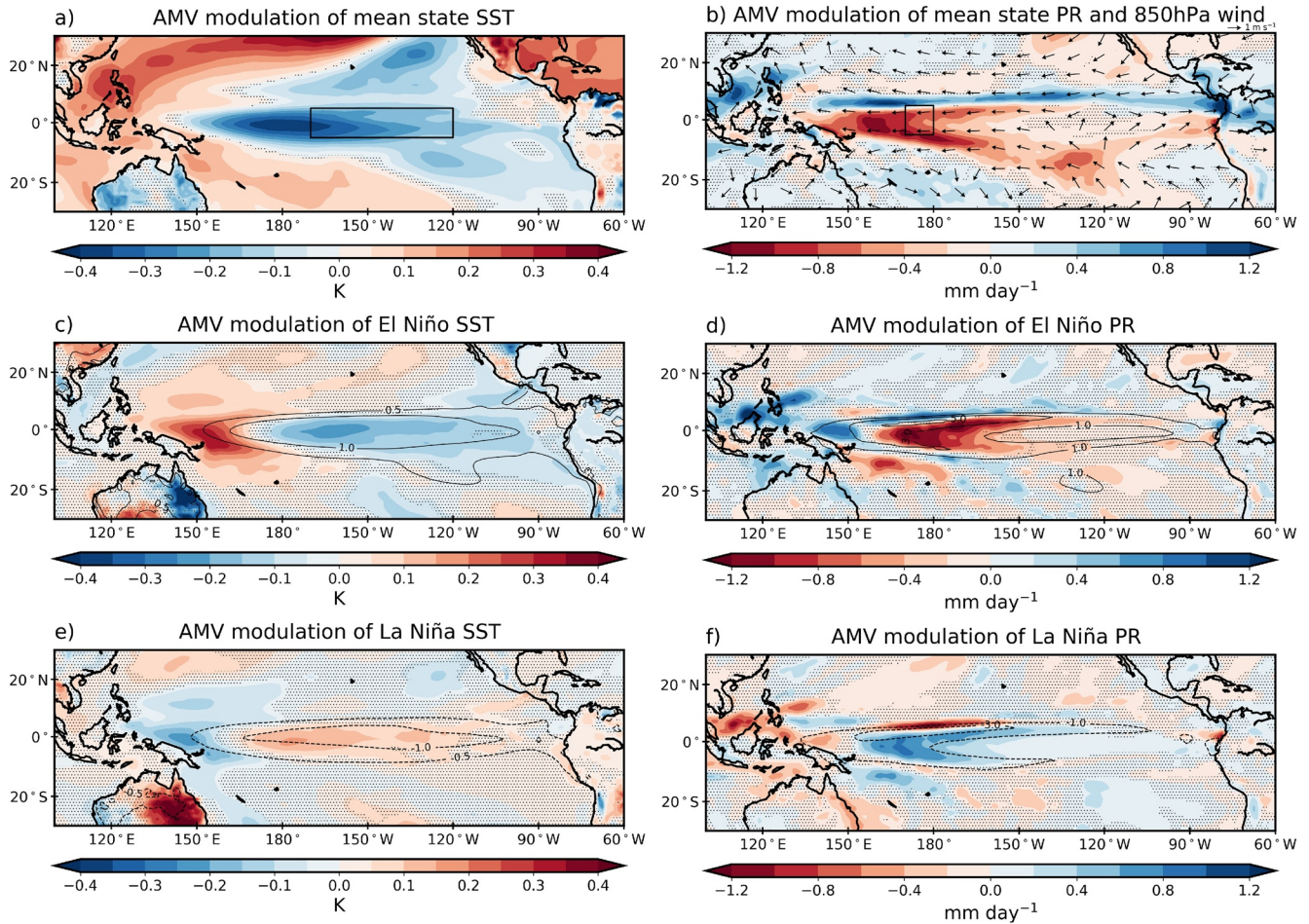


Figure 1. Anomalies for boreal winter (December–February; DJF). (top) Tropical Pacific mean state changes between Atlantic Multidecadal Variability (AMV)+ and AMV– in (a) sea surface temperature (SST) and (b) precipitation and 850 hPa winds. (middle) AMV modulation of El Niño (c) SST and (d) precipitation (shading); composite El Niño anomalies from AMV– overlaid in contours. (bottom) As in middle, but for La Niña. Black boxes in (a) and (b) denote the Niño3.4 region and the region used for the precipitation index, respectively. Note inverted color bars in the left and right columns. Stippling means not significance at the 95% confidence level.

2.2.2. The Bjerknes Stability Index

To examine the processes underpinning any changes in ENSO characteristics due to the AMV, we use the BJ index introduced by Jin et al. (2006), which is proportional to ENSO growth rate. This is based on the recharge oscillator model (Jin, 1997) and captures the main atmosphere and ocean processes responsible for ENSO growth and decay (Kim & Jin, 2011a). The BJ index has been widely used to compare ENSO behavior between different climate models (Kim & Jin, 2011a, 2011b), time periods (Lübbecke & McPhaden, 2013), and background states (Ferrett & Collins, 2019; Levine et al., 2017). The BJ index is defined as

$$2\text{BJ} = - \left[a_1 \frac{\langle \Delta \bar{u} \rangle_E}{L_x} + a_2 \frac{\langle \Delta \bar{v} \rangle_E}{L_y} \right]_{\text{CD}} - [\alpha_s]_{\text{TD}} + \left[\mu_a \beta_u \left\langle -\frac{\partial \bar{T}}{\partial x} \right\rangle_E \right]_{\text{ZA}} + \left[\mu_a \beta_w \left\langle -\frac{\partial \bar{T}}{\partial z} \right\rangle_E \right]_{\text{EK}} + \left[\mu_a \beta_h \left\langle -\frac{\bar{w}}{H_1} \right\rangle_E a_h \right]_{\text{TC}} \quad (2)$$

The ENSO growth rate is estimated as the sum of, from left to right, the current damping (CD), thermodynamic (TD), zonal advective (ZA), Ekman (EK), and thermocline (TC) feedbacks. Following previous studies (An et al., 2017; Guilyardi et al., 2009; Jin et al., 2006; Kim & Jin, 2011a, 2011b; Lübbecke & McPhaden, 2013), the BJ index terms are calculated using linear regression between variables across all years in the simulations. A full description of the equation is given in the Supporting Information S1.

The BJ index assumes linearity between variables and may therefore fail to represent processes that are nonlinear by nature, such as the dependence of shortwave fluxes on SSTs (see Figure S4 in Supporting Information S1; Graham et al., 2014; Lloyd et al., 2012). However, as discussed below, we find that for the feedbacks that are responsible for the AMV modulation of ENSO, the linear approximation is reasonable to first order (Figure S5 in Supporting Information S1). Despite certain simplifying assumptions used in the BJ index, it has been widely used and shown to be insightful for understanding ENSO behavior.

The relative contributions of the individual terms in the feedbacks in Equation 2 to the modulation of ENSO growth rate are calculated using a delta method where for a given term the difference between AMV+ and AMV− is multiplied by the AMV− value of all the other terms. The delta method applied to the thermocline feedback is as follows:

$$\begin{aligned}\Delta\mu_a &= (\mu_{AMV+} - \mu_{AMV-}) \times \beta_{h_{AMV-}} \times \frac{\bar{w}}{H_{1_{AMV-}}} \times a_{h_{AMV-}} \\ \Delta\beta_h &= \mu_{AMV-} \times (\beta_{h_{AMV+}} - \beta_{h_{AMV-}}) \times \frac{\bar{w}}{H_{1_{AMV-}}} \times a_{h_{AMV-}} \\ \Delta\frac{\bar{w}}{H_1} &= \mu_{AMV-} \times \beta_{h_{AMV-}} \times \left(\frac{\bar{w}}{H_{1_{AMV+}}} - \frac{\bar{w}}{H_{1_{AMV-}}} \right) \times a_{h_{AMV-}} \\ \Delta a_h &= \mu_{AMV-} \times \beta_{h_{AMV-}} \times \frac{\bar{w}}{H_{1_{AMV-}}} \times (a_{h_{AMV+}} - a_{h_{AMV-}}) \\ \sum \Delta TC &= \Delta\mu_a + \Delta\beta_h + \Delta\frac{\bar{w}}{H_1} + \Delta a_h\end{aligned}\quad (3)$$

Finally, to test whether the difference in ENSO impacts and feedbacks between AMV+ and AMV− is statistically significant at the 95% confidence level, we perform a nonparametric bootstrap test with replacement, subsampling 70% of years on each iteration repeated 10^4 times and where we assume that all years are independent from each other.

3. Results

3.1. AMV Modulation of Pacific Mean State and ENSO Variability

In boreal winter (DJF), warm AMV conditions drive tropical Pacific cooling of -0.23 K in the Niño3.4 region, with a minimum of -0.35 K near the dateline (Figure 1a). This response is consistent with modeling studies (Dong et al., 2006; Ruprich-Robert et al., 2017, 2018; Zanchettin et al., 2016), although CESM1 simulates a stronger tropical Pacific response than some other climate models for similar imposed AMV anomalies (Ruprich-Robert et al., 2021). The mean precipitation response to AMV+ (Figure 1b) shows that the Intertropical Convergence Zone (ITCZ) is shifted north in boreal winter, and the South Pacific Convergence Zone (SPCZ) is weakened. These changes in the tropical Pacific mean state are a signature of a strengthened Walker circulation (Lübbecke & McPhaden, 2013), a key mechanism in the tropical Pacific response to warm SSTs in the tropical Atlantic at any time scale (Ham & Kug, 2015; Kosaka & Xie, 2013; Meehl et al., 2011; Ruprich-Robert et al., 2017).

In DJF, AMV+ damps ENSO variability, reducing the magnitude of SST and precipitation anomalies in both El Niño and La Niña phases (Figures 1c and 1e). El Niño events in AMV+ have, on average, cooler SSTs in the central and eastern equatorial Pacific (hereafter EP), and relatively warmer SSTs in the west Pacific, as compared to AMV−. The Niño3.4 SST difference between AMV+ and AMV− is -0.17 K (13%). The modulation of La Niña SSTs by the AMV has a similar pattern with opposite sign and a slightly smaller amplitude: the La Niña composite Niño3.4 SST is 0.09 K (9%) warmer in AMV+. Hence, in CESM1 AMV modulates the amplitude of ENSO SST anomalies by around 10% in the Niño3.4 region.

The AMV modulation of ENSO SSTs is accompanied by modulation of precipitation anomalies in the equatorial Pacific. During AMV+, the area of maximum anomalous precipitation associated with El Niño shifts from the central to the western Pacific, with a reduction in precipitation anomaly of up to 1.15 mm day $^{-1}$ around the equator and between 170° E and 180° (Figure 1d) and an increase in precipitation anomalies over the warm pool

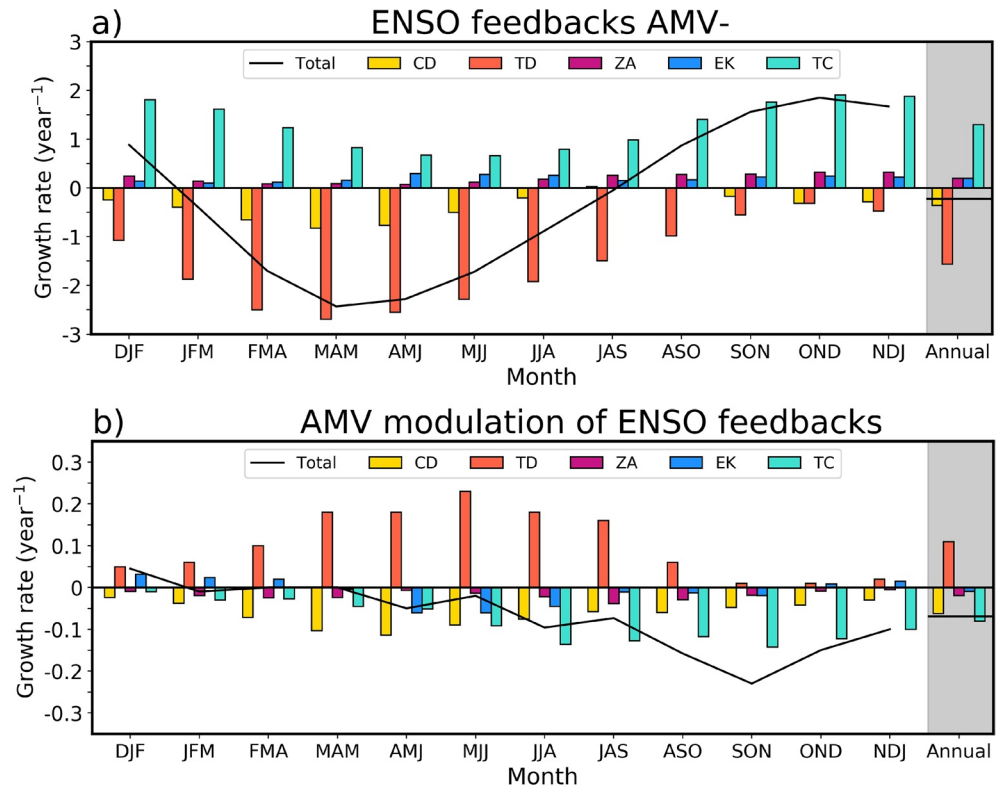


Figure 2. Annual cycle of El Niño–Southern Oscillation (ENSO) feedbacks expressed as growth rate (year^{-1}) in (a) the AMV– simulation, and (b) the difference between AMV+ and AMV–. Monthly values are smoothed with a 3-month running mean. Feedbacks are: current damping (CD, yellow), thermodynamic (TD, orange), zonal advective (ZA, magenta), Ekman (EK, dark blue), and thermocline (TC, light blue). The solid line denotes the total Bjerknes stability (BJ) index.

and the Maritime continent. This represents a statistically significant decrease in the central Pacific precipitation anomaly under El Niño by $\sim 40\%$ (see box in Figure 1b) as compared to AMV–. AMV modulates the precipitation response to La Niña in a similar way (Figure 1f). In this case, during AMV+, the precipitation anomaly decreases in the western equatorial Pacific and increases over the central Pacific by 0.65 mm day^{-1} (45%). Hence, in CESM1 the modulation by AMV of ENSO precipitation is proportionately larger than for SSTs. This can be explained by the nonlinear relationship between precipitation and SST in the Niño3.4 region. To test this nonlinearity, a simple regression model was built considering only El Niño events. This model shows that around 90% of the El Niño precipitation modulation by AMV can be explained by the SST modulation (not shown). Hence, the modulation by AMV of ENSO SST signal is of leading importance for the modulation of ENSO atmospheric response.

The decrease in ENSO variability simulated by CESM1 in AMV+ is consistent with observations (Levine et al., 2017; Lübbecke & McPhaden, 2014; Zanchettin et al., 2016). Our results are also consistent with the modeling study of Dong et al. (2006), but opposite to the ones of Levine et al. (2017). To further understand the modulation of ENSO by AMV, we next investigate the physical processes driving this modulation using the BJ index (cf. Section 2.2.2).

3.2. AMV Modulation of ENSO Feedbacks

CESM1 simulates a realistic seasonal cycle of ENSO growth rate in the reference AMV– simulation (Figure 2a), with a minimum of $\sim -2.4 \text{ year}^{-1}$ in spring and a maximum of $\sim 1.7 \text{ year}^{-1}$ in autumn (cf., solid black line). Maximum values of the BJ index in October–December coincide with the development and growth of ENSO events, whereas minimum values are reached in March–May, when ENSO decays. On average over the year, the ENSO growth rate simulated by CESM1 is -0.22 year^{-1} , which is very close to reanalysis-based estimates of -0.24 year^{-1} (Kim et al., 2014). The annual growth rate depends on the balance between positive and negative

feedbacks. The negative sign of the annual mean BJ index is dominated by the damping of SST anomalies by the thermodynamic feedback, peaking in early spring, which is composed of the sum of the surface heat fluxes. The thermocline feedback peaking in late fall is the main process that intensifies ENSO anomalies (Jin et al., 2020).

Consistent with the damped ENSO variability seen in Figure 1, AMV+ leads to a more negative annual mean ENSO growth rate by -0.07 year^{-1} (Figure 2b), which represents a $\sim 30\%$ decrease in magnitude compared to AMV-. The main contributions to the decreased annual ENSO growth rate in AMV+ are a weakened thermocline feedback (-0.08 year^{-1}) and a stronger current damping feedback (-0.06 year^{-1} ; Figure 2b). These changes are partly offset by a weakened (i.e., reduced damping) thermodynamic feedback by 0.1 year^{-1} . There are negligible changes in the Ekman feedback and zonal advective feedback due to AMV (see also Figure S3 in Supporting Information S1) and these will not be discussed further.

The AMV modulation of the thermodynamic feedback is strongest in boreal summer, contributing to an increase in growth rate of up to 0.23 year^{-1} in May–July. Of the two terms contributing to a reduced ENSO growth rate, the modulation of the current damping peaks in April–June. The modulation of the thermocline feedback by AMV dominates from boreal summer through early winter (JJA to NDJ) and therefore has a particular influence during the ENSO growth season. This suggests that the thermocline feedback is an important driver of the changes in ENSO behavior between AMV+ and AMV-.

Investigation of the contributions of individual terms in Equation 2 to the overall modulation of the BJ index feedbacks (Figure S3 in Supporting Information S1) reveals that the modulation of most terms is not strongly statistically significant. The main exception which is relevant to understanding the dampening of ENSO by AMV+ is the thermocline feedback, which is dominated by a statistically significant decrease in the magnitude of the regression between equatorial Pacific wind stress anomalies and the thermocline slope (β_h in Equation 2, orange bar Figure 3a). This leads to a reduction in ENSO growth rate by 0.1 year^{-1} . The finding that the AMV modulates ENSO through modifying how the thermocline slope responds to equatorial Pacific wind stress anomalies is in agreement with Zanchettin et al. (2016). We discuss in the following section how the AMV impacts on the equatorial Pacific mean state alter this relationship.

4. Discussion

A mean tropical Pacific cooling in response to a tropical Atlantic warming is well documented in the literature (Figure 4a). Warm tropical Atlantic SST anomalies intensify deep convection and lead to upper tropospheric mass divergence over the tropical Atlantic, which modifies the entire Walker circulation (Dong & Sutton, 2007; Ham & Kug, 2015; Martin-Rey et al., 2014; McGregor et al., 2014; Polo et al., 2014; Rodríguez-Fonseca et al., 2009; Ruprich-Robert et al., 2017, 2021; Zanchettin et al., 2016). This is associated with an intensification of the trade winds, which deepens the thermocline in the west Pacific and steepens the thermocline slope (Figure 3b; Kucharski et al., 2014; Meehl et al., 2021; Polo et al., 2014).

Differences in the mean state between AMV+ and AMV- damp ENSO in CESM1 mainly by a weakened thermocline feedback. The weaker thermocline slope sensitivity to equatorial Pacific wind stress (i.e., smaller β_h) can be explained by a decrease in ocean stratification associated with a deepening of the thermocline (Jin & An, 1999; Zebiak & Cane, 1987) and/or a change in the wind stress forcing pattern (Choi et al., 2011; Kang & Kug, 2002; Wang & An, 2002). Dong et al. (2006) found that intensified trade winds during AMV+ led to a deepened thermocline in the western and central tropical Pacific. They argue that this deepening reduces the development of subsurface temperature anomalies in response to wind stress (Zebiak & Cane, 1987), which eventually weakens ENSO. We also find the thermocline deepens by 0.6 m on average in the western tropical Pacific from late summer to early winter in AMV+ (Figure 3b). Conversely, the thermocline shallows by 0.7 m over the central and eastern equatorial Pacific, which following this logic would increase its sensitivity to wind stress anomalies. The climatological thermocline in this region is shallower than over the western Pacific and therefore potentially more responsive to wind anomalies (Castaño-Tierno et al., 2018). The shallowing of the thermocline in the central and eastern equatorial Pacific would therefore lead to an increase in β_h . Thus, we conclude that this mechanism cannot explain the ENSO response in our simulations.

Regarding the second mechanism, we find the pattern of wind stress anomalies associated with ENSO is modulated by AMV (Figure 3c). During AMV+, equatorial wind stress anomalies are stronger over the western Pacific

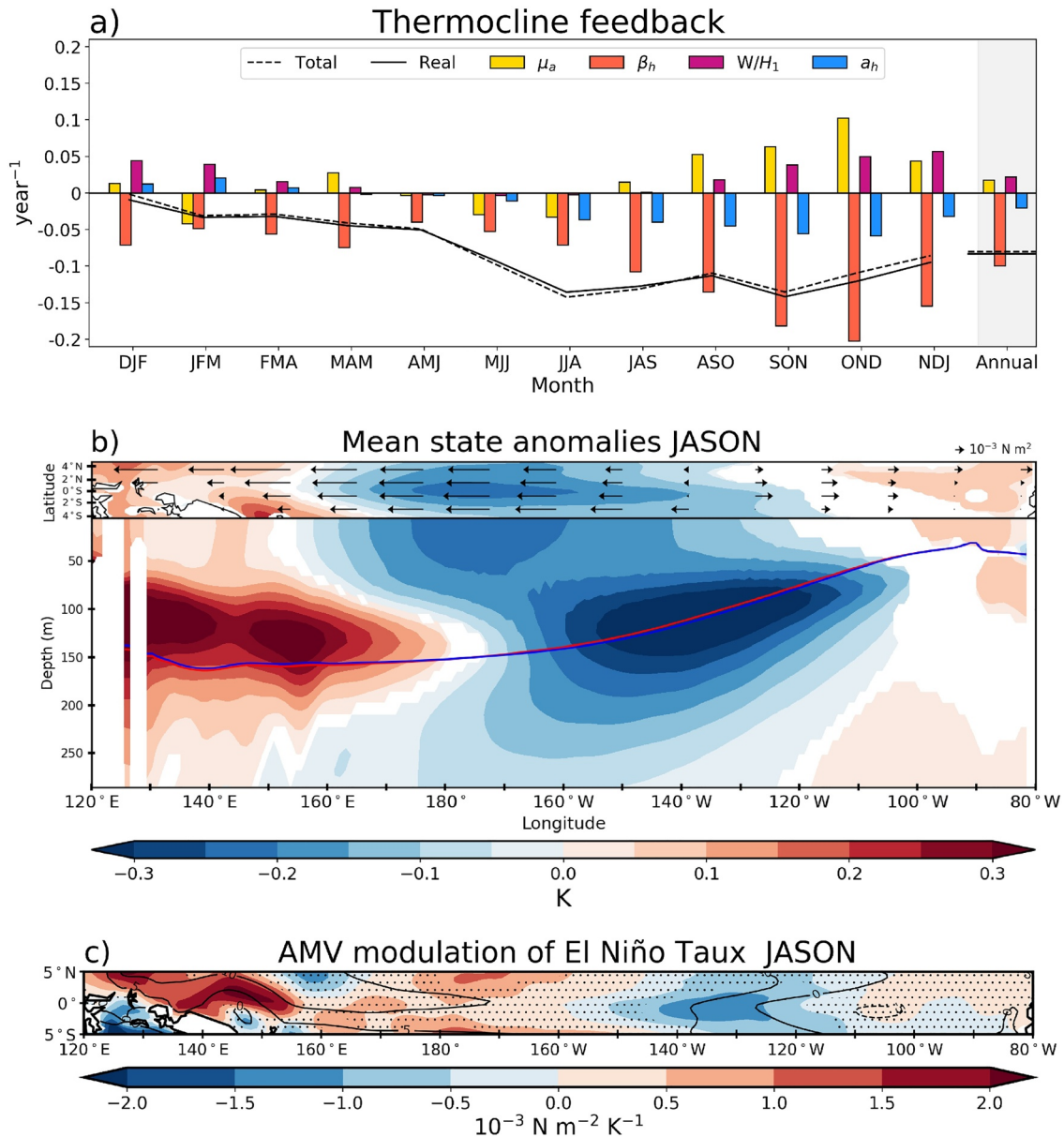
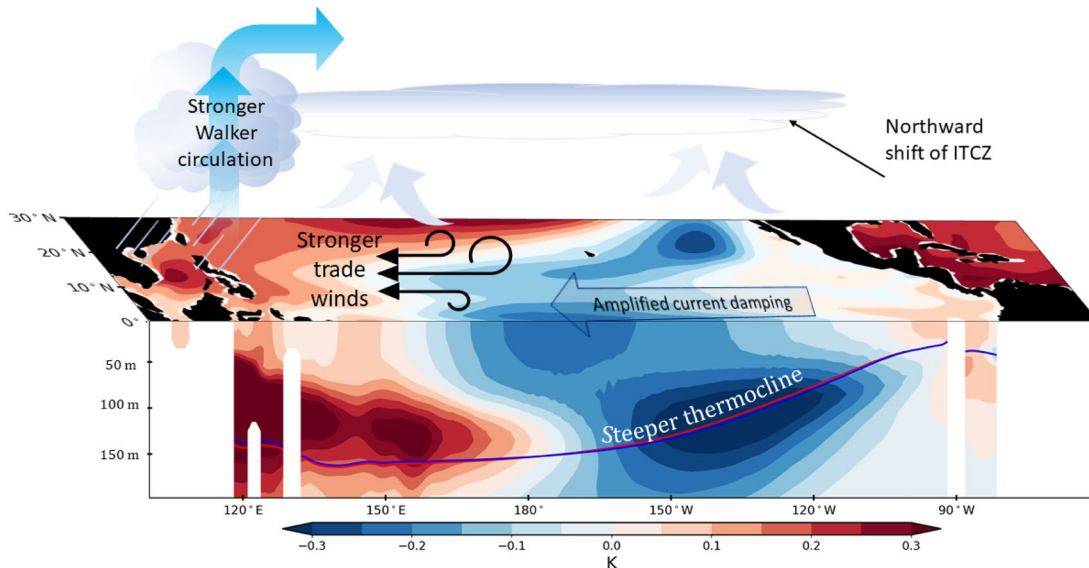


Figure 3. (a) AMV modulation of the thermocline feedback and contributions from individual terms. (b) Three-dimensional mean state ocean temperature differences (AMV+ minus AMV−) in the equatorial Pacific in JASON. White areas cover nonsignificant anomalies at the 95% confidence level. (top) Arrows are zonal wind stress anomalies; (bottom) red and blue lines show depth of 20°C isotherm in the AMV+ and AMV− states, respectively. (c) AMV modulation of equatorial wind stress in the JASON season prior to El Niño events. Anomalies are normalized by the mean Niño3.4 SST amplitude in AMV+ and AMV−, respectively. Black contours show wind stress anomalies in the AMV− simulation. Dotted areas show nonsignificant anomalies at the 95% confidence level.

but extend less to the east (between 150°W and 120°W), where the thermocline is shallower and therefore more sensitive to wind stress (Castaño-Tierno et al., 2018). We suggest this weakening of ENSO-wind stress anomalies in the region where the thermocline is more sensitive to wind forcing can explain the β_h decrease in AMV+. This conclusion aligns with previous studies that also find a reduction in ENSO variance associated with a steeper thermocline mean state in the equatorial Pacific (Fedorov & Philander, 2000; Hu & Fedorov, 2018; Lübbecke & McPhaden, 2014).

Following Lübbecke and McPhaden (2014), we argue that the decrease of the ENSO-wind forcing over the eastern Pacific in AMV+ is linked to a strengthening of the climatological zonal SST gradient (Figure 3b). Associated with the stronger zonal SST gradient in the tropical Pacific, the warmest SSTs are shifted westward compared

a) AMV modulation of ENSO feedbacks



b) AMV modulation of El Niño

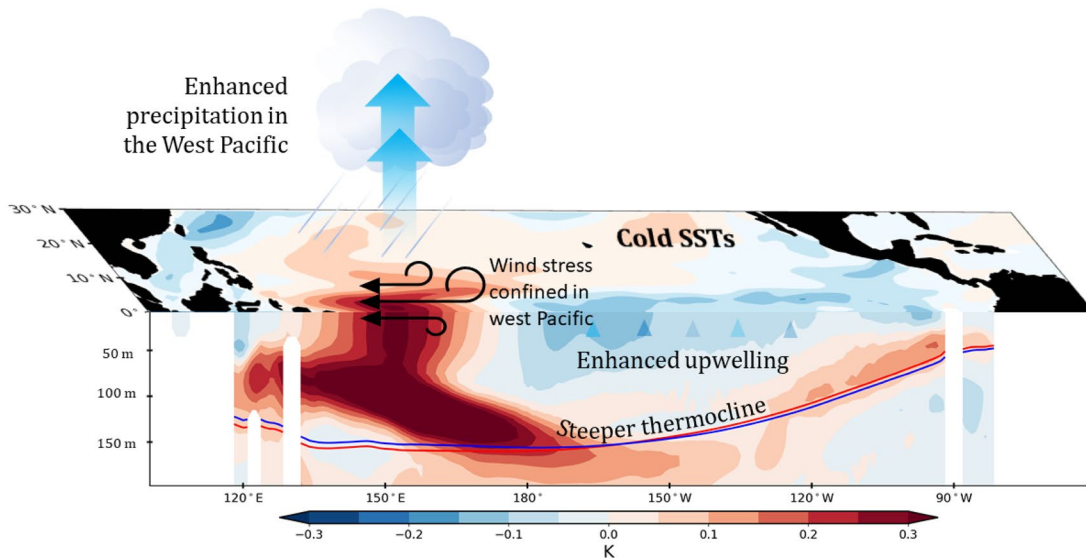


Figure 4. Schematic overlay of (a) the mean state changes due to AMV in the equatorial Pacific in JASON and (b) the climate response to El Niño modulated by the AMV in DJF. Shading shows ocean temperature anomalies. Red and blue lines in both panels show the 20°C isotherm in the AMV+ and AMV– experiments, respectively.

to AMV–. The response of deep convection to SST anomalies in the tropics is a function of the climatological SST, with stronger precipitation responses over climatologically warm SSTs (Graham & Barnett, 1987), so the ENSO precipitation and associated wind convergence anomalies are also expected to shift westward in AMV+.

With a similar experimental design but a different model, Levine et al. (2017) found that AMV+ increases ENSO growth rate and amplitude, in contrast to the modulation apparent in observations and found in our simulations. They suggest this discrepancy comes from a too sensitive thermocline feedback to SST anomalies in the eastern tropical Pacific in their model (Kim & Jin, 2011a). Nevertheless, this difference in behavior of models calls for a

multimodel analysis, which will be conducted in a future study using the AMV idealized experiments performed within the Component C of the Decadal Climate Prediction Project (Boer et al., 2016).

5. Conclusions

We have used idealized ensemble simulations with the CESM1 model where North Atlantic SSTs are restored toward observed warm (AMV+) and cold (AMV−) AMV states to investigate its impact on ENSO variability. Comparing AMV+ to AMV−, we find that warm North Atlantic conditions reduce the amplitude of SST anomalies associated with ENSO by around 10% in both El Niño and La Niña phases. ENSO precipitation anomalies decrease by a larger proportion of up to 45%. During AMV+, the trade wind slackening associated with El Niño are more confined to the west and are accompanied by a westward shift of the maximum SST and deep convection anomalies (Figure 4b).

Using the BJ index as a proxy for ENSO growth rate, we find that the decrease of ENSO variance under AMV+ conditions comes mainly from a decrease in the thermocline feedback in AMV+ and, to a smaller extent, by a decrease of the current damping feedback. We hypothesize that the decrease of the thermocline feedback in AMV+ results from the strengthened trade winds localized over the western equatorial Pacific, and associated steepening of the background thermocline, which increase the east-west mean SST gradient in the equatorial Pacific. In the equatorial east Pacific, climatological zonal ocean currents are weaker during boreal autumn in AMV+ compared to AMV−, as is the zonal SST gradient. During El Niño events, this increased zonal SST gradient prevents the convection and westerlies anomalies from propagating through the east where the thermocline is shallower and therefore more responsive to wind stress anomalies. It results in a weakening of the wind–thermocline relationship, which eventually reduces ENSO growth rate.

Our results show a substantial modulation of ENSO by AMV in the CESM1 model. The AMV modulation of ENSO growth rate is opposite to the projected changes under global warming (Collins et al., 2010). Decadal climate variability may therefore mask or amplify the signature of anthropogenic climate change and must be accounted for in future ENSO predictions. Changes to ENSO SST and precipitation variability are likely to have extratropical implications. Further work will explore the role of the AMV in the modulation of ENSO extratropical impacts and their variability.

Acknowledgments

P.T.-C. was supported by a PhD scholarship from the Natural Environment Research Council PANORAMA Doctoral Training Partnership (NE/S007458/1). Y.R.-R. was funded by the European Union's Horizon 2020 research and innovation program in the framework of the Marie Skłodowska-Curie grant INADEC (grant agreement 800154). A.C.M. was supported by the European Union's Horizon 2020 research and innovation program under grant agreement no. 820829 (CONSTRAIN project), by a NERC Independent Research Fellowship (NE/M018199/1) and The Leverhulme Trust (PLP-2018-278). F.C. was supported by the US National Science Foundation (NSF) under the Collaborative Research EaSM2 grant OCE-1243015 to NCAR and by the US National Oceanic and Atmospheric Administration (NOAA) Climate Program Office under the Climate Variability and Predictability Program grant NA13OAR4310138. Computing facilities were provided by the Barcelona Supercomputing Center and the University of Leeds. We thank Dr Gokhan Danabasoglu for his comments on an earlier version of this manuscript and two anonymous reviewers whose comments enriched this manuscript.

Data Availability Statement

Data from the AMV idealized experiments performed with the NCAR-CESM1 model can be found at the Climate Data Gateway (NCAR): <https://doi.org/10.26024/rn3t-ep30>.

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