Modulation of Tropical Basin Interactions

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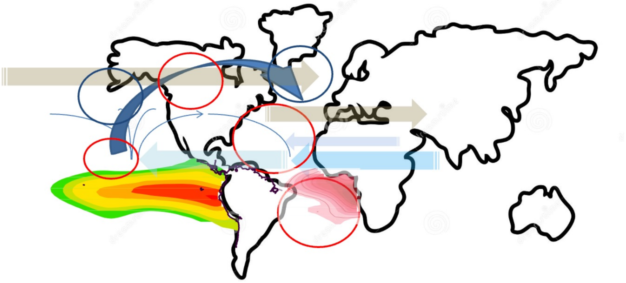
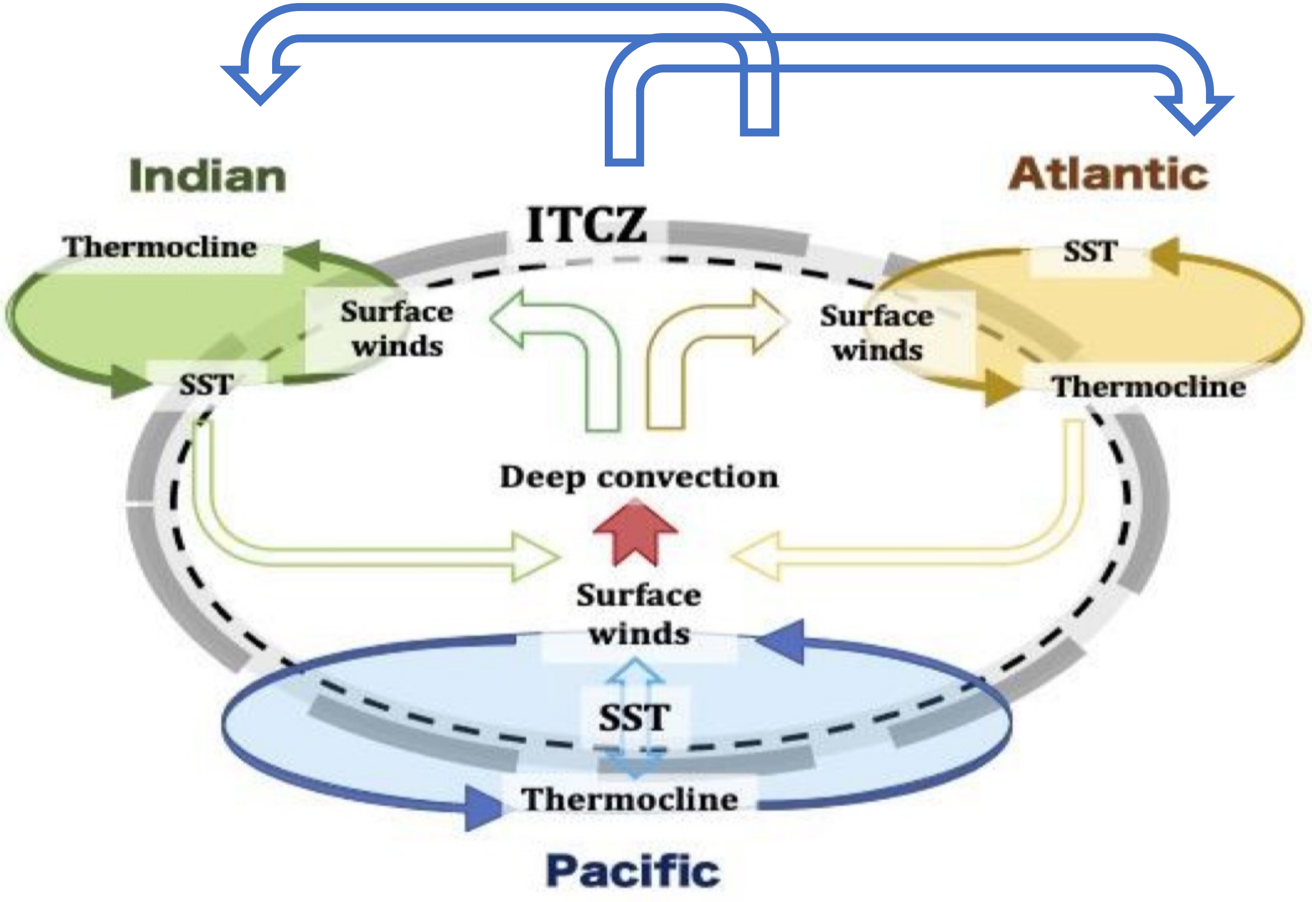
TROPA-UCM excellent group



Outline

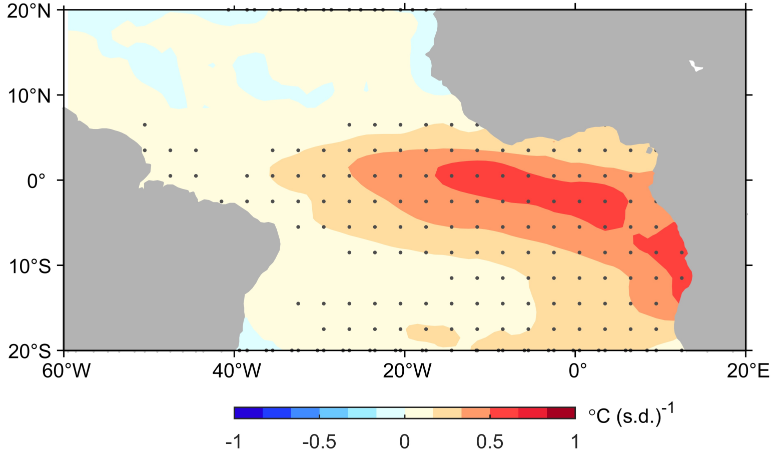
1. Stationarity of Tropical basin interactions
   - Atlantic -Pacific
   - Pacific –Indian
   - Indian-Atlantic
2. Mechanisms
   a) Changes in the modes
   b) Changes in the background state



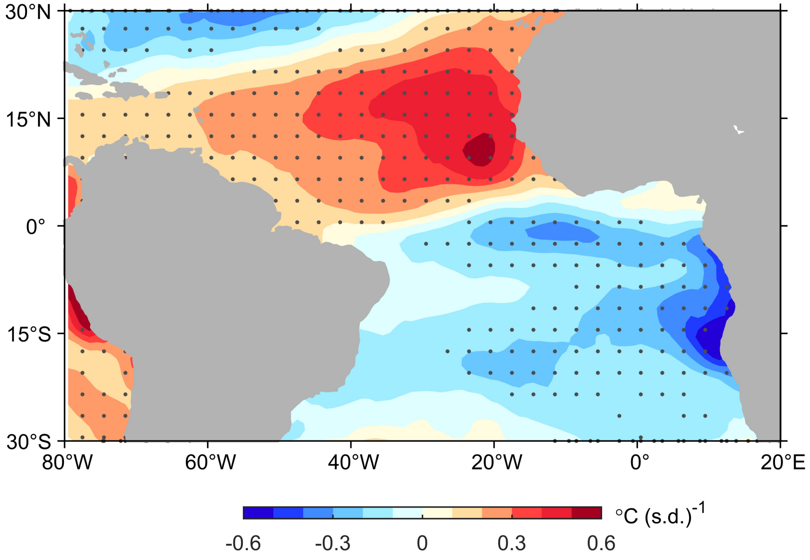
Observational studies have identified enhanced ENSO predictability from Tropical Atlantic and Indian ocean Variability modes

Nevertheless, this enhancement only takes place during some particular decades

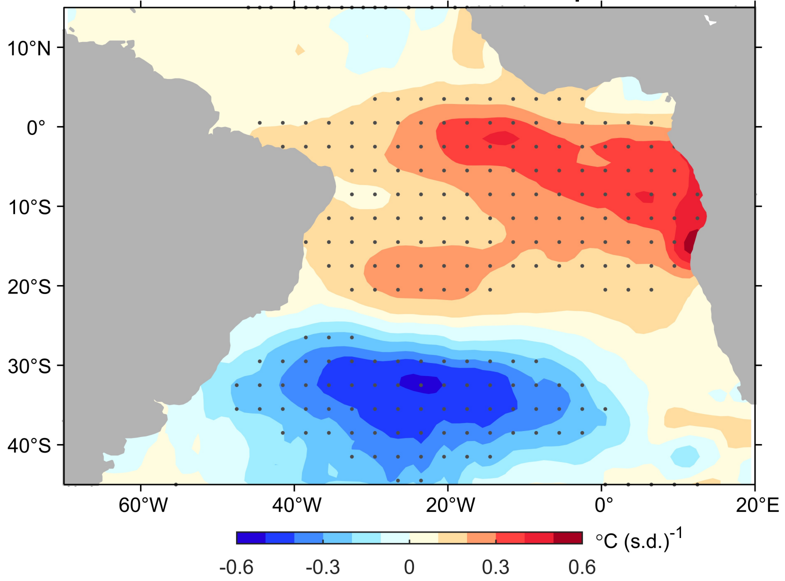
Stationarity of Tropical basin interactions


Atlantic Niño

JJA and ONDJ


AMM Atlantic Meridional Mode

MAM


SAOD South Atlantic Ocean Dipole

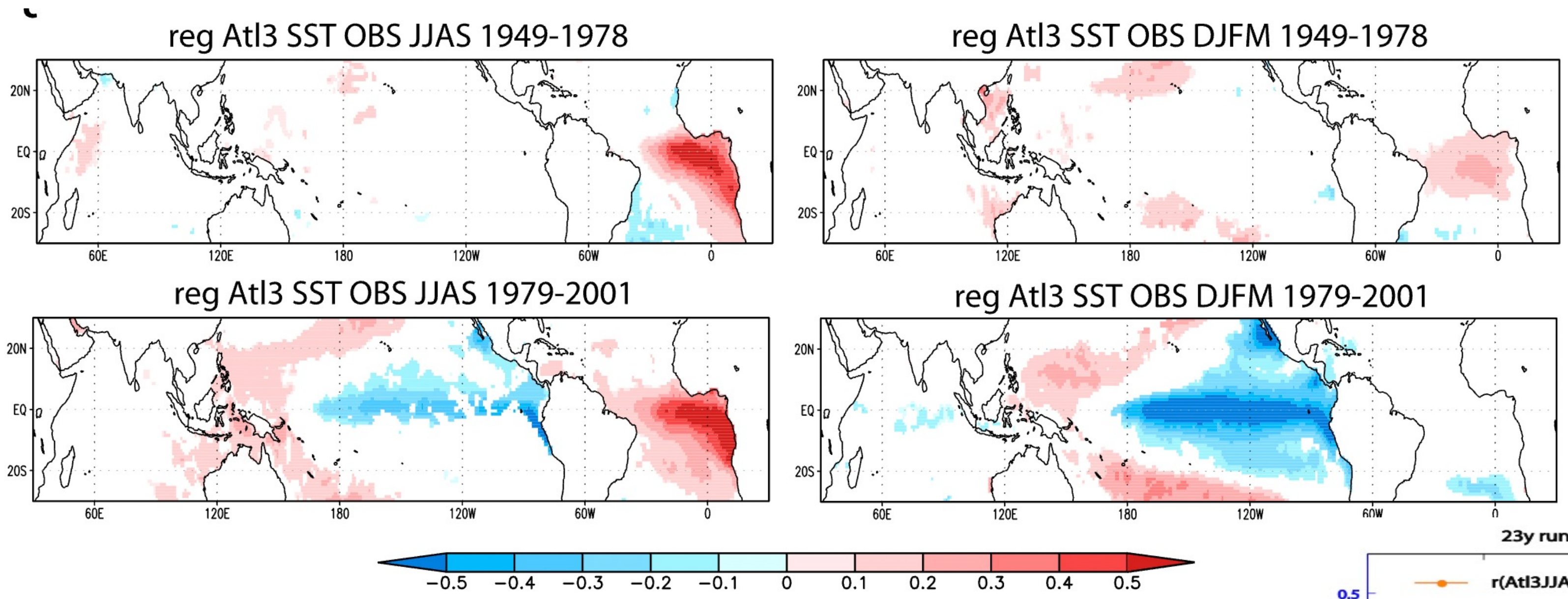
MJJA

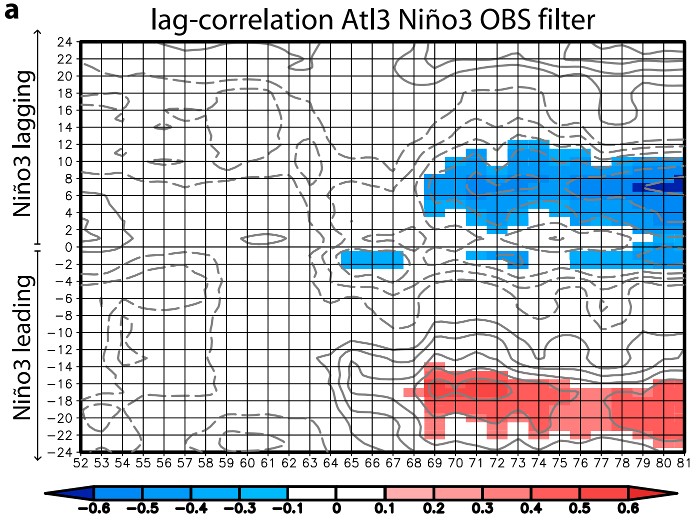
The Atlantic exhibits different modes of variability, peaking in different seasons

Boreal Summer Atlantic Niño ➔Pacific

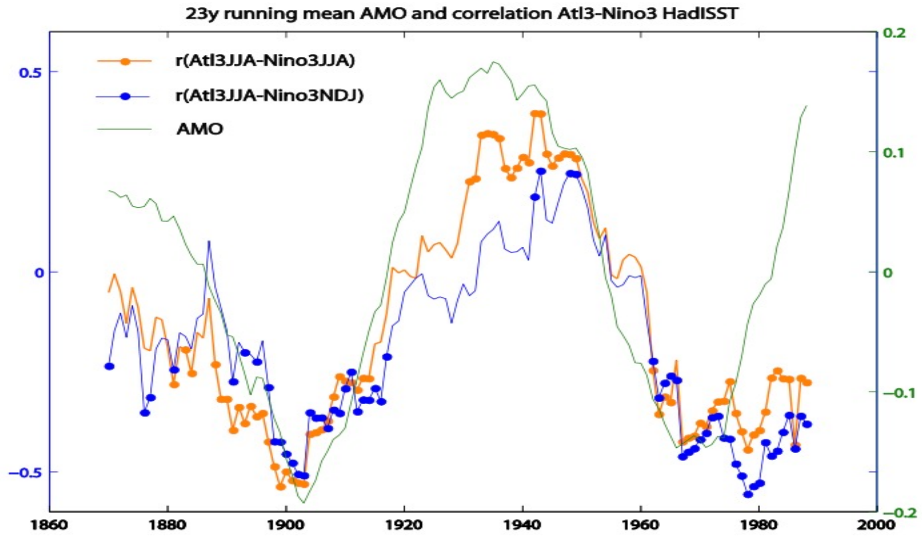
ENSO impact on Atlantic Niño seems to be inconsistent

Rodríguez-Fonseca et al (2009), Polo et al. (2015) ➔ Atlantic Niño impact on ENSO occurs since 1970's



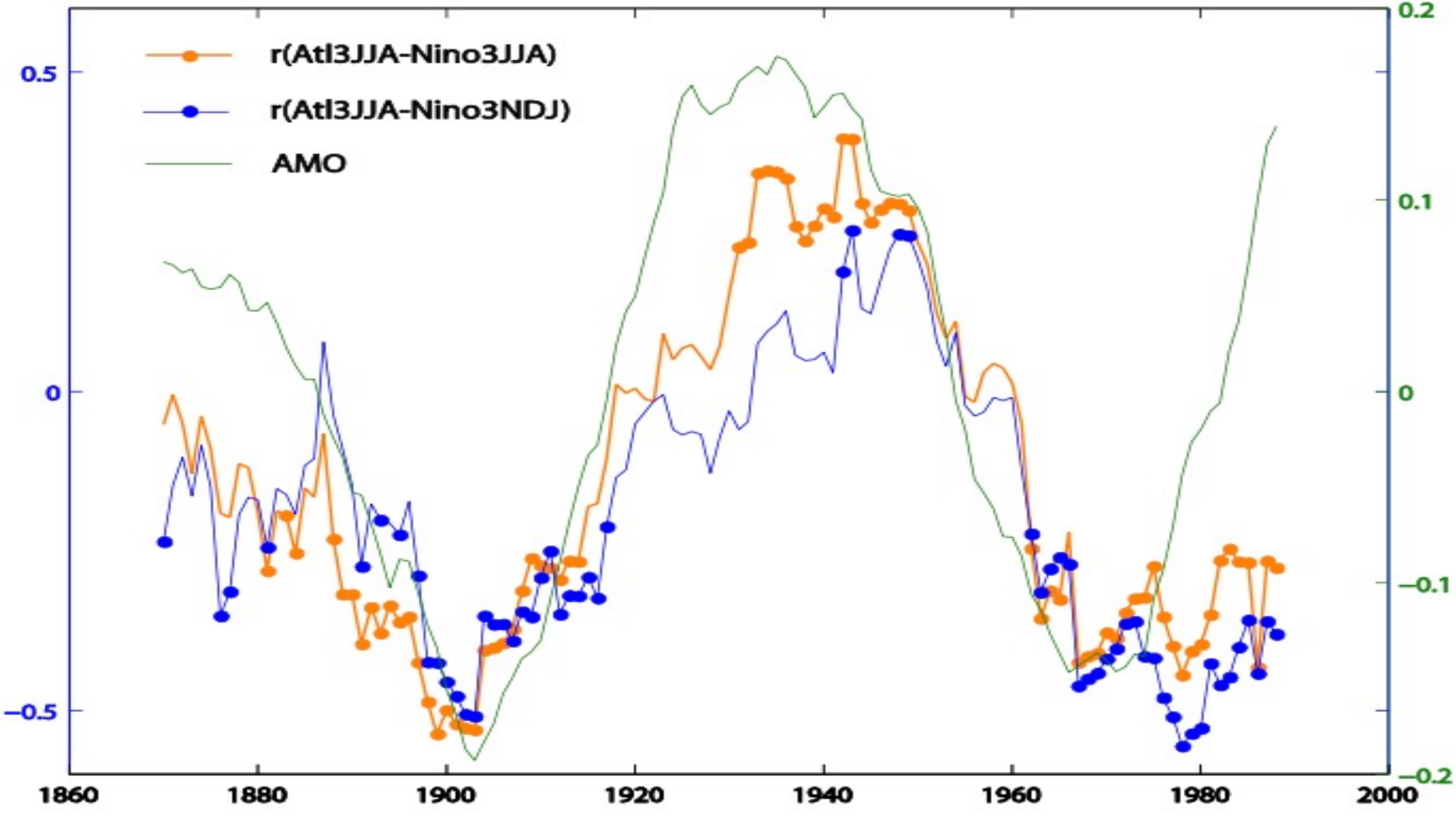


From Rodriguez-Fonseca et al., 2009



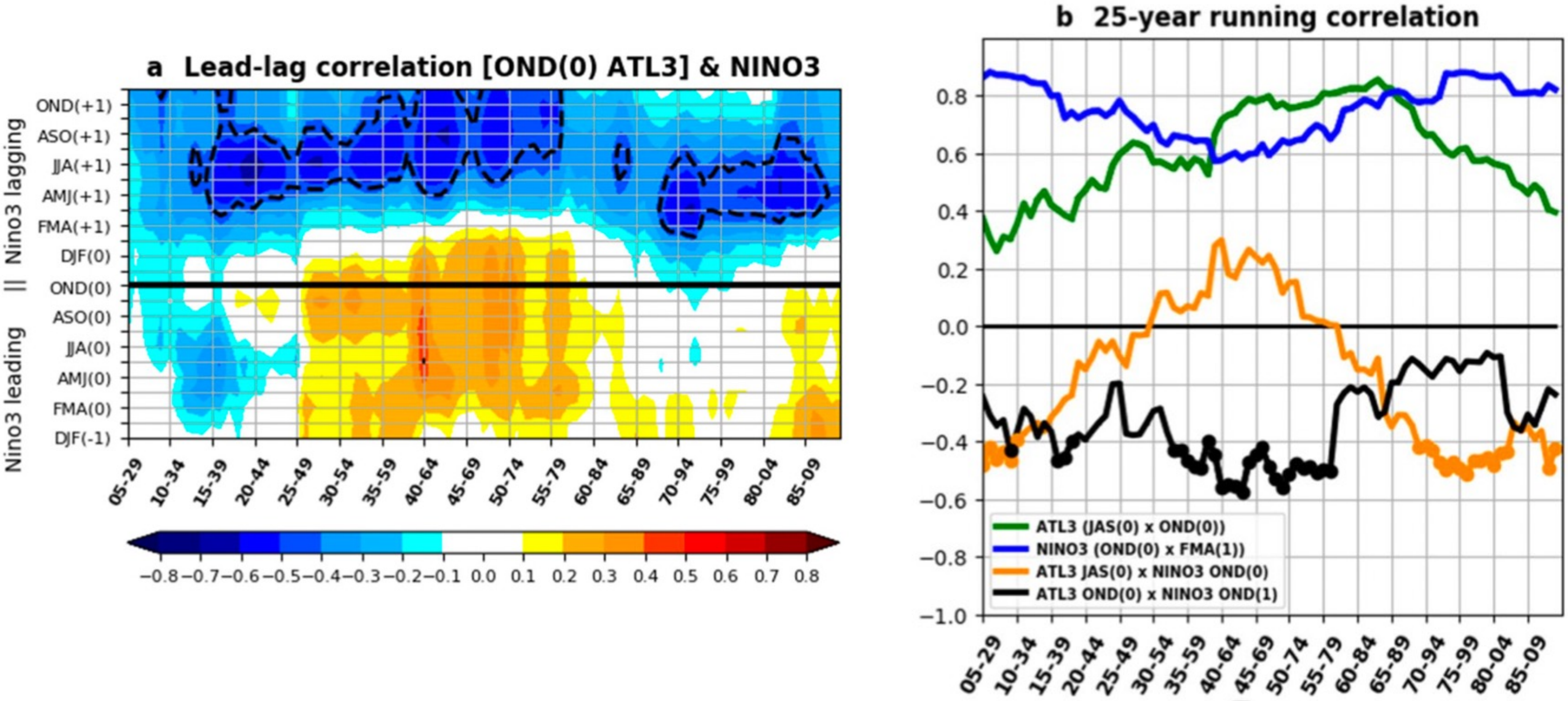
From Polo et al.2015

23y running mean AMO and correlation Atl3-Nino3 HadISST

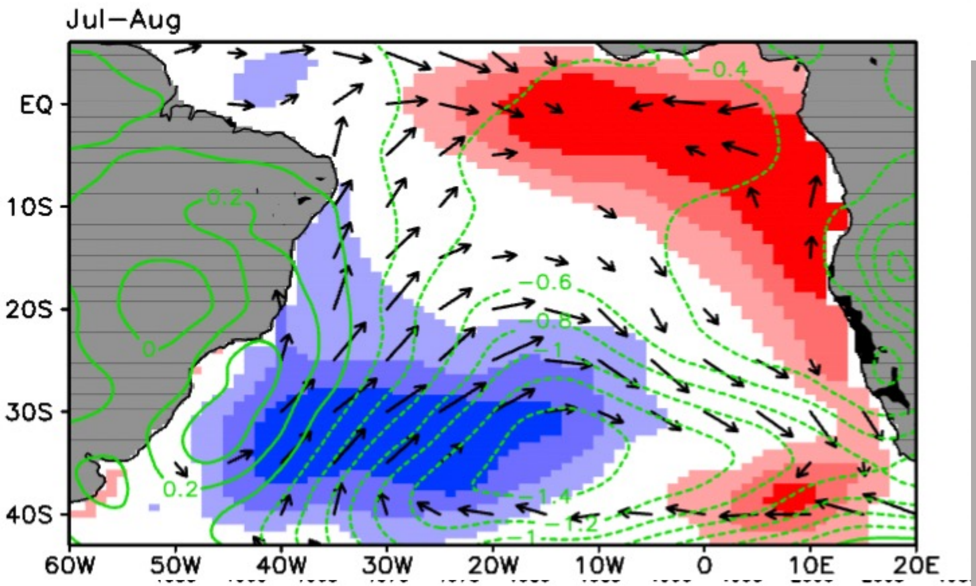


Boreal winter Atlantic Niño ➔ Pacific

- Gbo et al (2022) ➔ Winter Atlantic Niño precedes ENSO in some decades



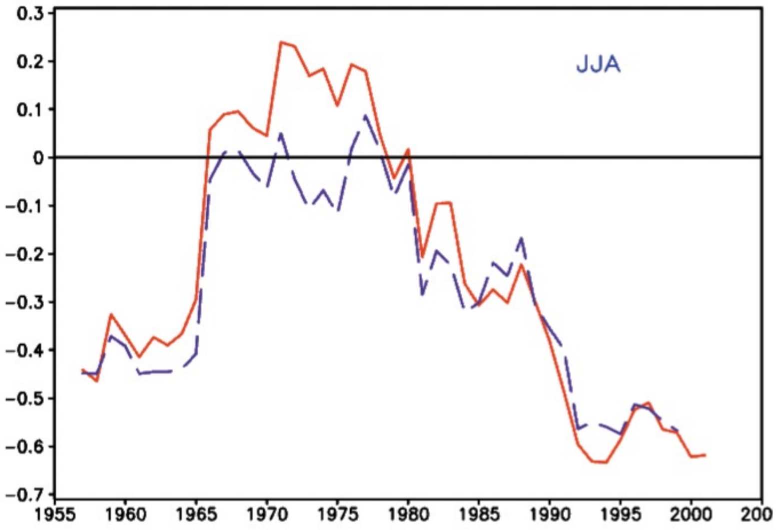
SAOD summer ➔ Pacific

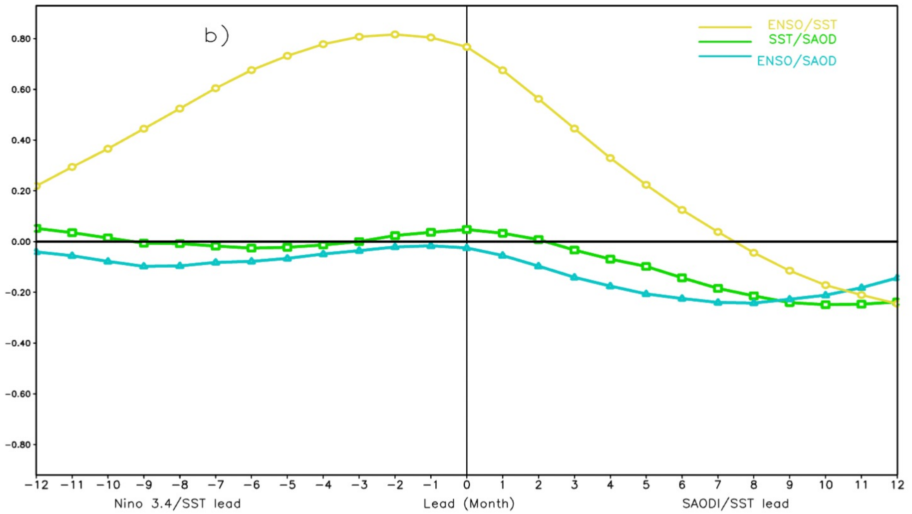


Nmamchi et al 2011➔ **South Atlantic Dipole** (SAOD)peaks in July-August.

The relation between poles is not stationary.
It is more prominent in the last decades

Its relation to ENSO is **weak** (r = - 0.25)

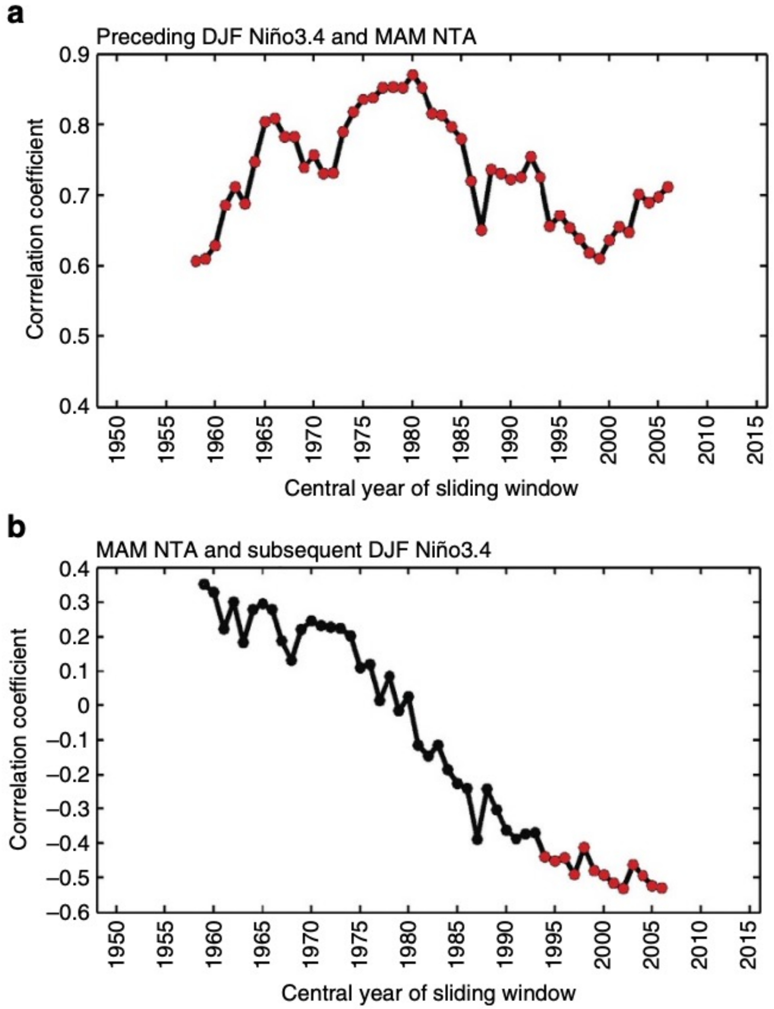


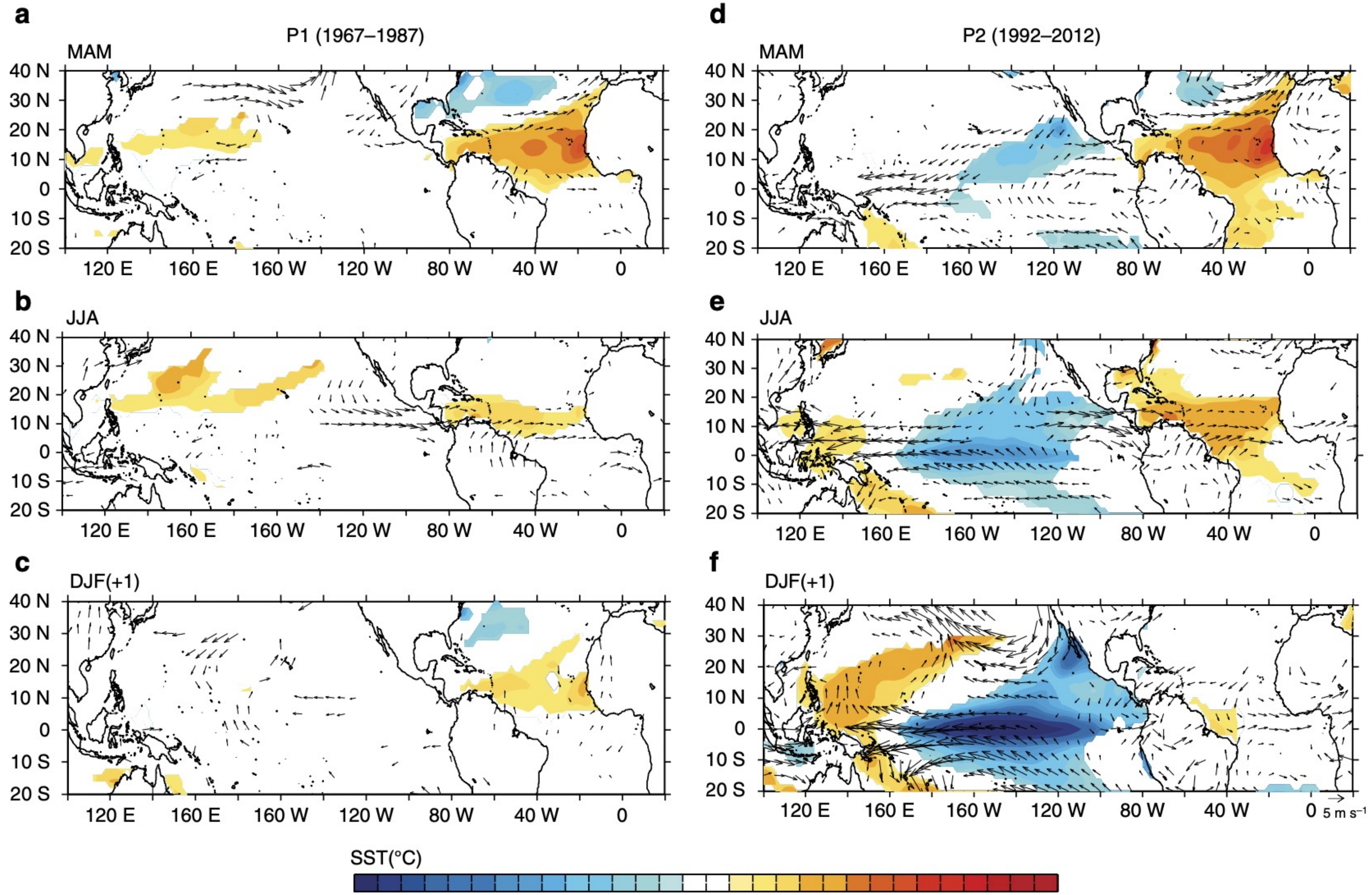


Tropical North Atlantic Niño ➔ Pacific

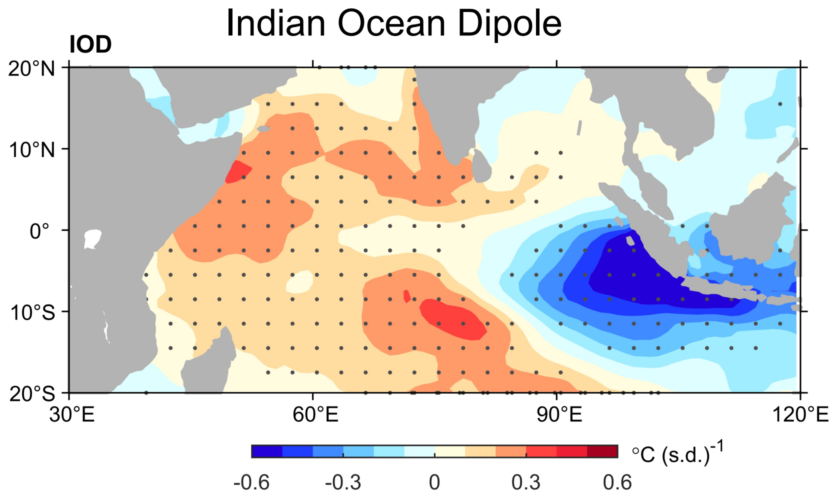
Ham et al. (2013 a,b) ➔ North Tropical Atlantic variability (TNA) impact on ENSO
Wang et al., 2017 ➔ The relation is enhanced from the 1990's (positive AMV)

ENSO impact on TNA is robust

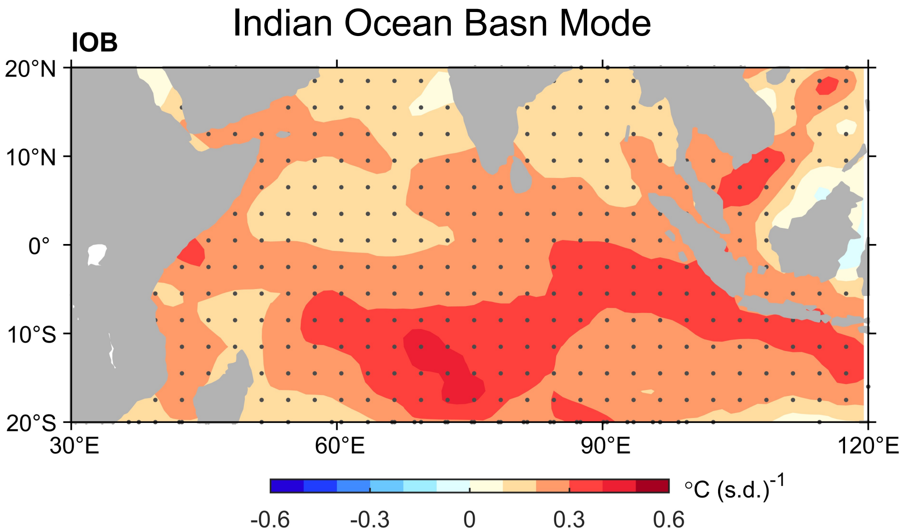




Indian Ocean➔ Pacific


Indian Ocean Dipole

SON

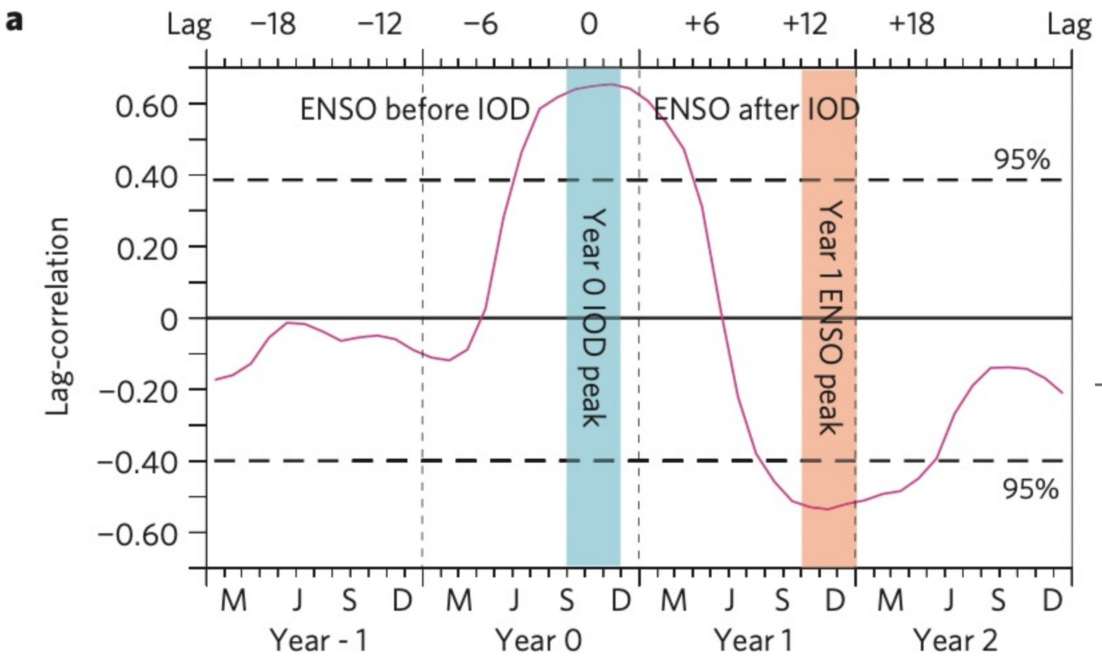

Indian Ocean Basn Mode

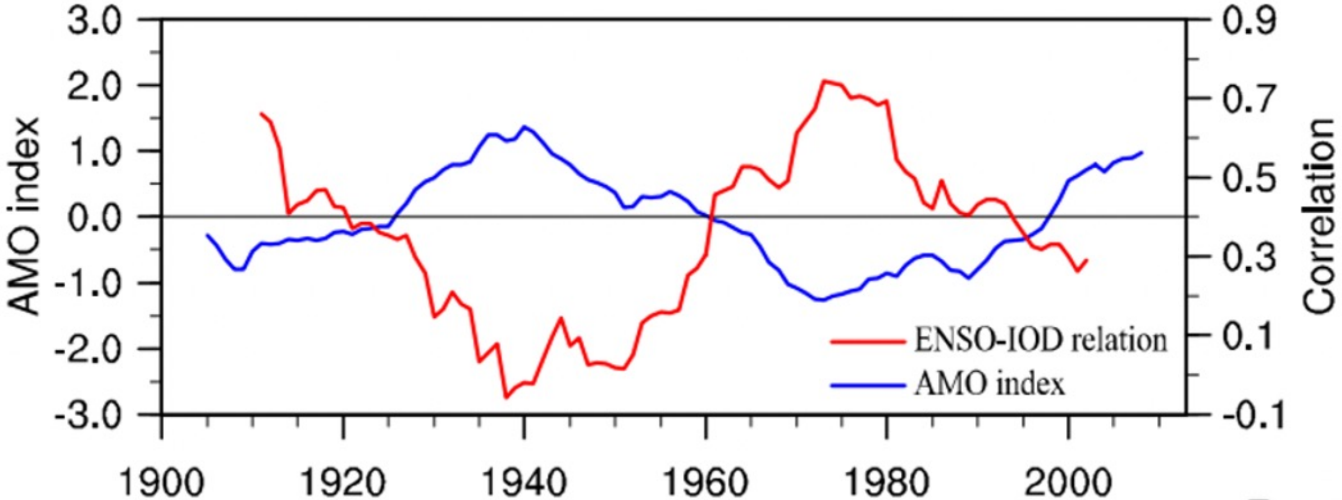
DJF

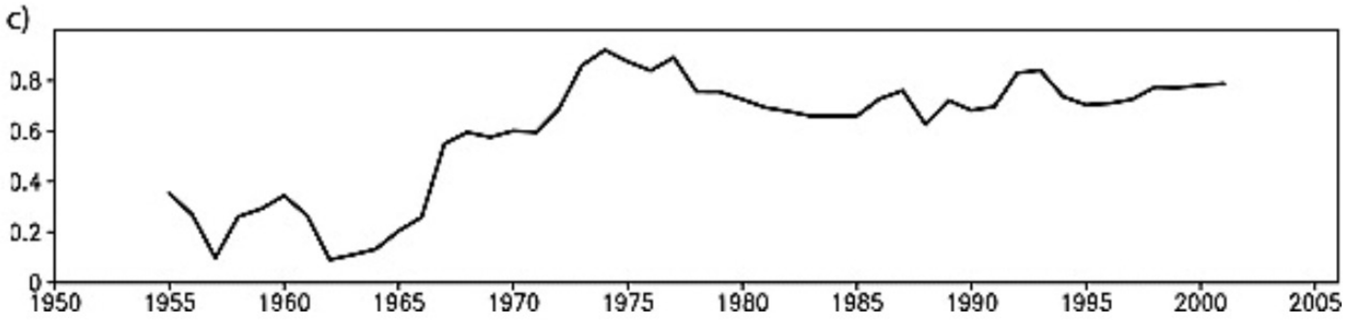
IOD ➔Pacific

- Izumo, T. et al (2010)➔ negative phase of the Indian Ocean Dipole anomaly is an efficient predictor of El Niño 14 months before its peak, and similarly, a positive phase in the Indian Ocean Dipole often precedes La Niña. **Period used: 1981-2008**

Schott et al., (2009; Yuan & Li, 2008)➔ The relation occurs occurs from the **1970's (AMV-?)**





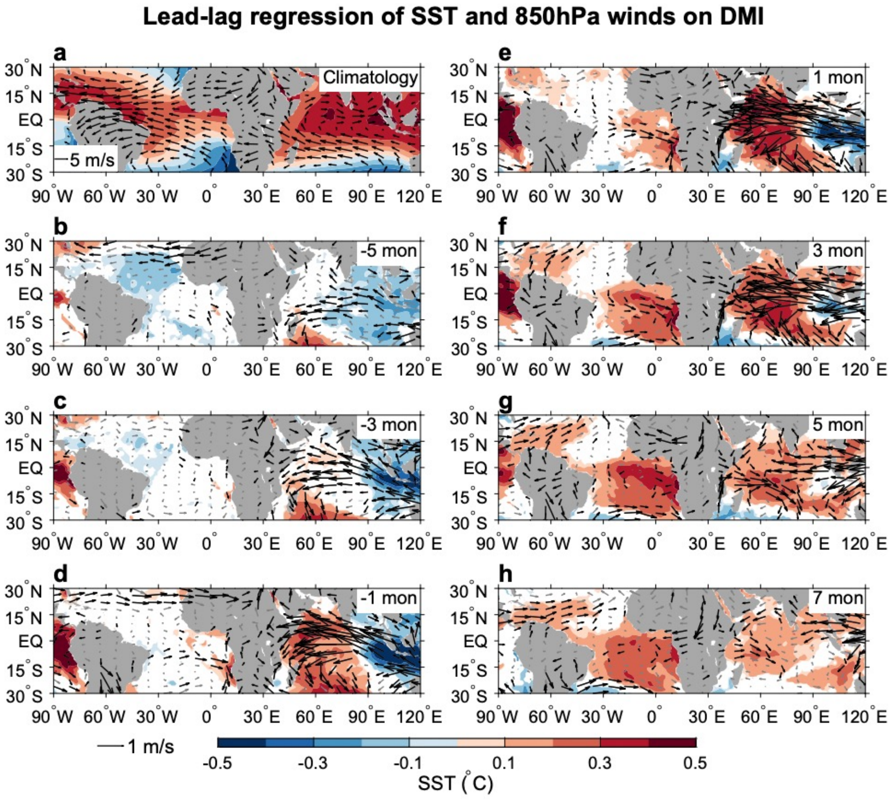


Indian Ocean➔ Atlantic

- Zhang & Han (2021)➔ IOD impact on Winter Atlantic Niño.

Most of the Atlantic Niño events that peak from December to January are associated with the pIOD forcing
Similarly, the Atlantic Niña events associated with the negative IOD (nIOD) also tend to peak during October–February

In addition to the triggering effect, the pIOD forcing also seems to affect timing of the Atlantic Niño.



The enhanced rainfall in the western tropical Indian Ocean during positive IOD weakens the easterly trade winds over the tropical Atlantic, causing warm anomalies in the central and eastern equatorial Atlantic basin and therefore triggering the Atlantic Niño
(recent decades, no studies about multidecadal modulation, but increase skill in recent decades)

- **Observations** show these relations are **non stationary**, ocurring ONLY in **some particular decades**:

- **IOD and summer Atlantic Niño impact on AMV negative phase.**
- **TNA and Winter Atlantic Niño in AMV positive phase.**

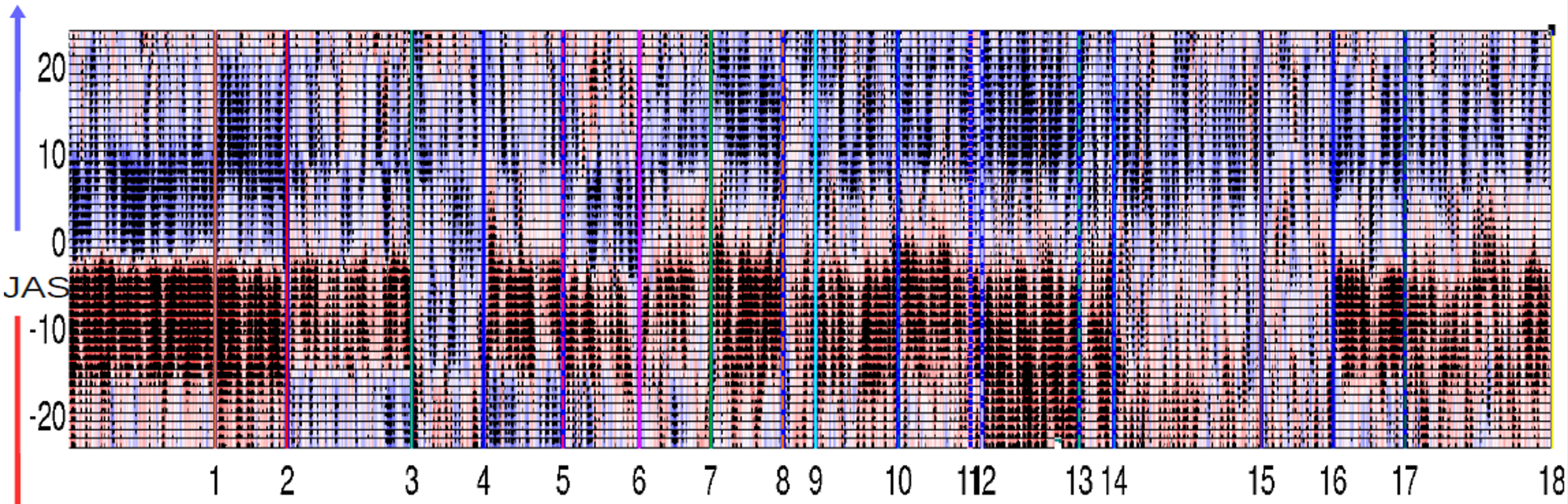
Cai et al, 2019 ➔

“*the robustness of the tropical interanual interbasin modulation and the causes are still open questions* “

There is a need for sensitivity experiments

- AGCMN experiments
- Pacemaker experiments
- Coupled models
- Prediction models

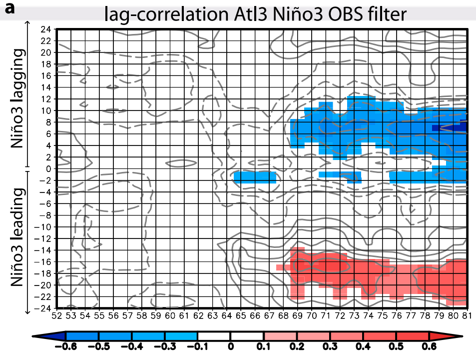
CMIP5 modesl: Lead-lag 21 window correlation between JJAS Atl4 and Niño3



1 CanESM2
2 CCSM4
3 CNRM-CM5
4 CSIRO-Mk3
5 GISS-E2-R
6 GISS-E2-H
7 GFDL-ESM2G
8 GFDL-ESM2M
9 HadGEM2-CC
10 HadGEM2-ES
11 inmcm4
12 MIROC4h
13 MIROC5
14 MIROC-ESM
15 MPI-ESM
16 MRI-CGCM3
17 NorESM1
18 IPSL-CM5

Niño3 leading

Atl4 leading



For the AtlNi-ENSO connection the relation is robust and appears in some decades...

Mechanisms

2 posible mechanisms

- Changes in the interanual variability modes

- Changes in the background atmospheric and oceanic conditions
  - Changes in the thermocline slope
  - Changes in the stratification
  - Changes in the variability

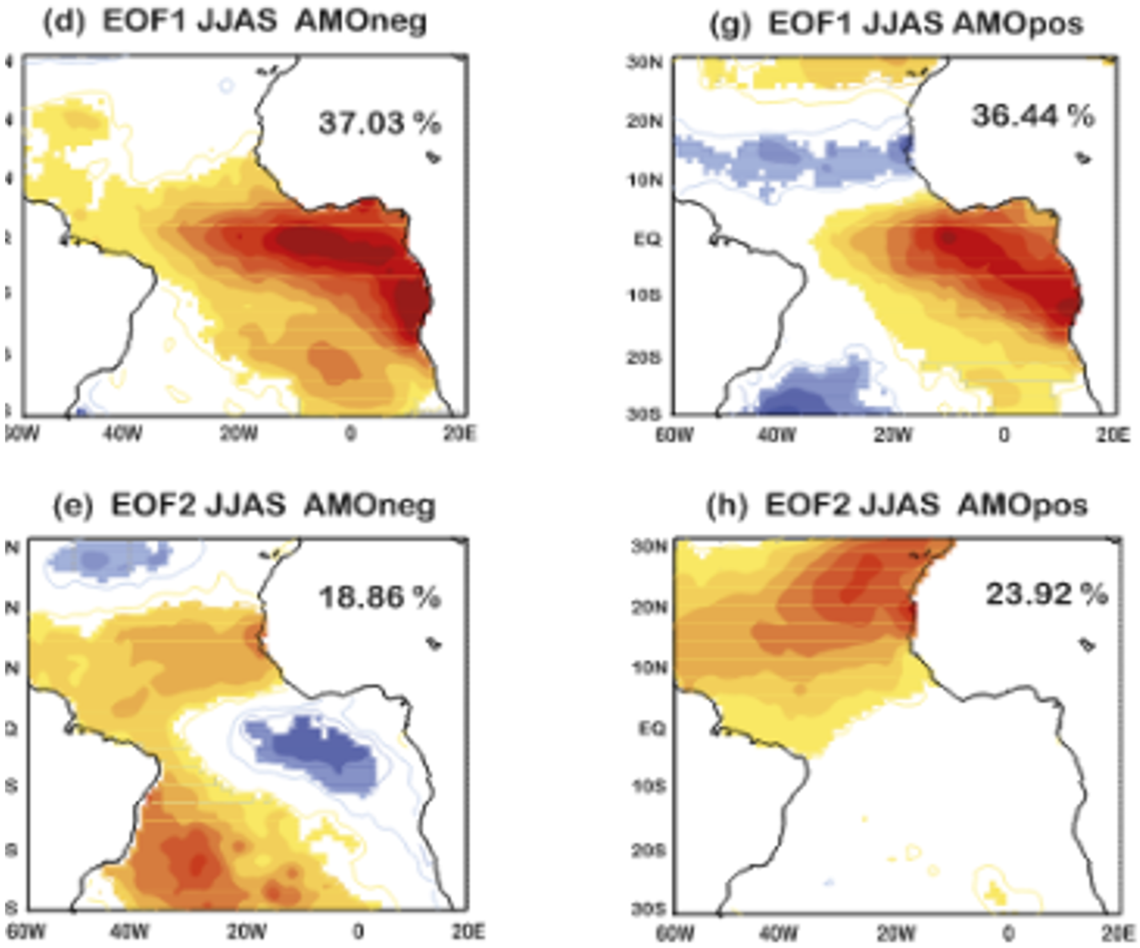
  They can be driven by decadal variability or by stochastic processes

- Both

Changes in the interanual variability modes

Boreal Summer Atlantic Niño
➔Pacific

Martín del Rey et al.(2019)
Different modes in different AMV phases



Martín del Rey et al. (2014; 2019)
➔equatorward ITCZ , negative AMV. The mode impact on ENSO

Changes in the interanual variability modes

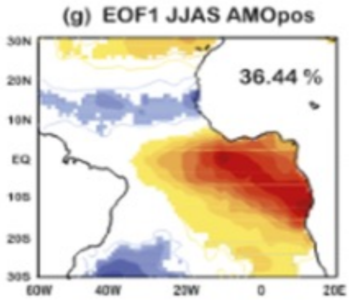
Different configurations, different impacts

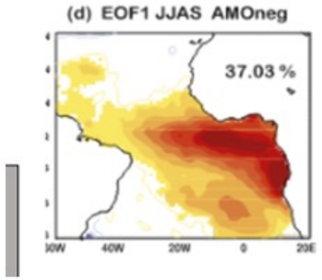
Boreal Summer Atlantic Niño ➔Pacific

Losada et al (2010) y Losada y Rodríguez-Fonseca (2016)

Atmospheric response.

Each mode produces a different teleconection over the Pacific as the convection is displaced


(g) EOF1 JJAS AMOpos


(d) EOF1 JJAS AMOneg

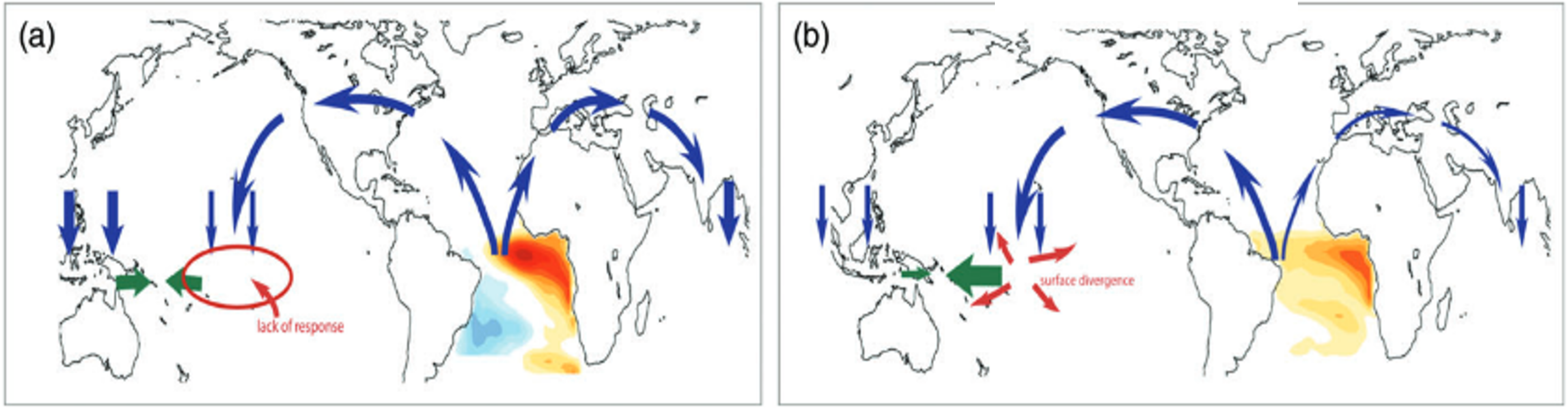


FIGURE 3 Decadal change of the Atlantic Niño pattern and its impact. SST anomalies of the Atlantic Niño pattern during boreal summer before (a) and after (b) the 1970s and a schematic representation of the respective impact on the Pacific and Indian Oceans

Role of the convection

The **summer Atlantic- Niño** effect on ENSO was stronger during early- and late-Twentieth Century

Winter Atlantic-Niño was dominant during the mid-Twentieth Century.

Park et al (2023) ➔ the prerequisite for the lagged relationship between Atlantic-Niño and ENSO events is events is an intensifed and westward expansion of convection, inducing an atmospheric teleconnection toward the Pacific, and resulting in ENSO.

Such an argument seems reasonable since tropical South America is one of the main rising branches of the Walker circulation, likewise maritime continent and eastern Africa.

During AMV+ the western eq. Atlantic is warmer and in AMV- the summer Atlantic Niño has a westward extension

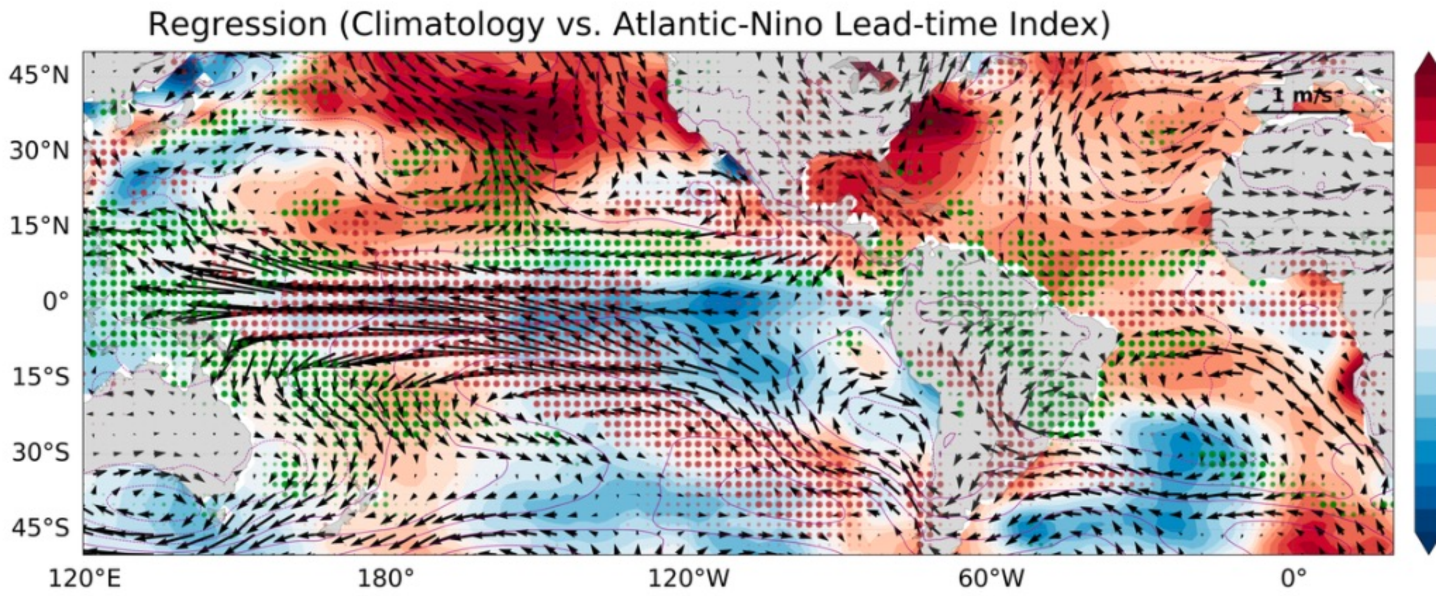


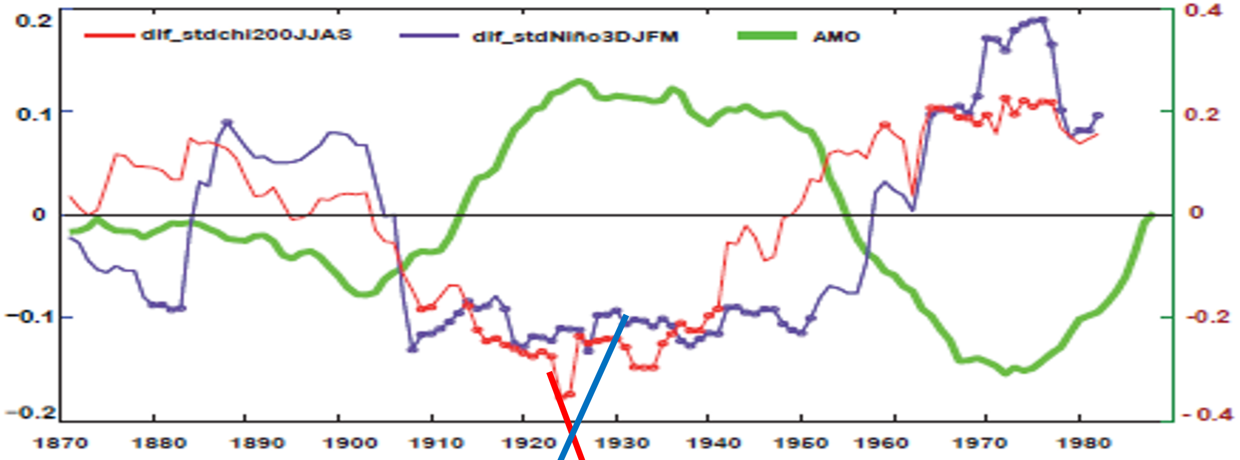
Figure 4

Atlantic-Niño lead-time associated climatological mean state. (a) Long-term (300-month) climatolog mean SST (shading), low-level wind (vectors), precipitation (green and brown crosses for positive an negative), and SLPA (contour) regressed onto the Atlantic Niño lead-time index for the period 1885–
indicated as a red curve in Fig. 1a.

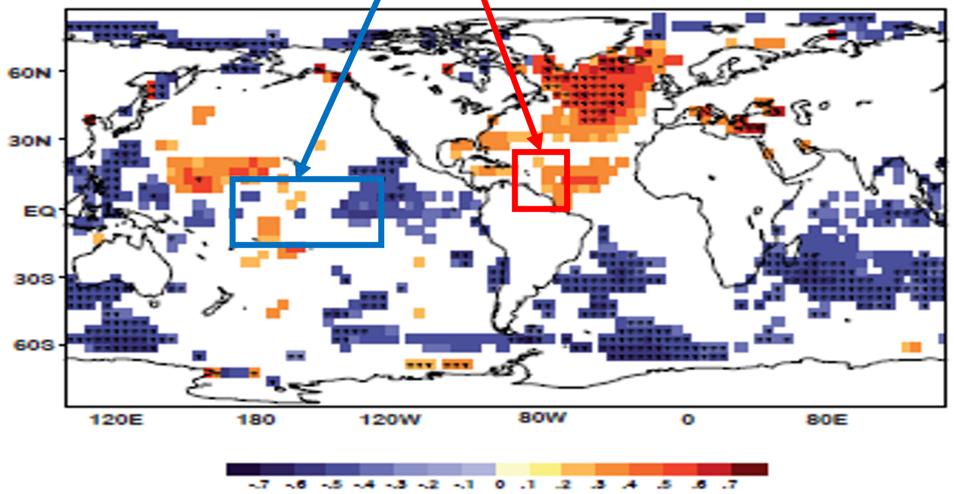
Changes in the background conditions

Martin del Rey et al. (2014) ➔ The Atlantic-Pacific is a mode that takes place under negative AMO phases, when both the variability of the convection over the Atlantic and of the Pacific SST increases

(a) MULTIDECADAL CHANGES ATLANTIC VELOCITY POTENTIAL AND PACIFIC SST VARIABILITY



(b) CORRELATION MAP AMO SST GLOB 1871-2001



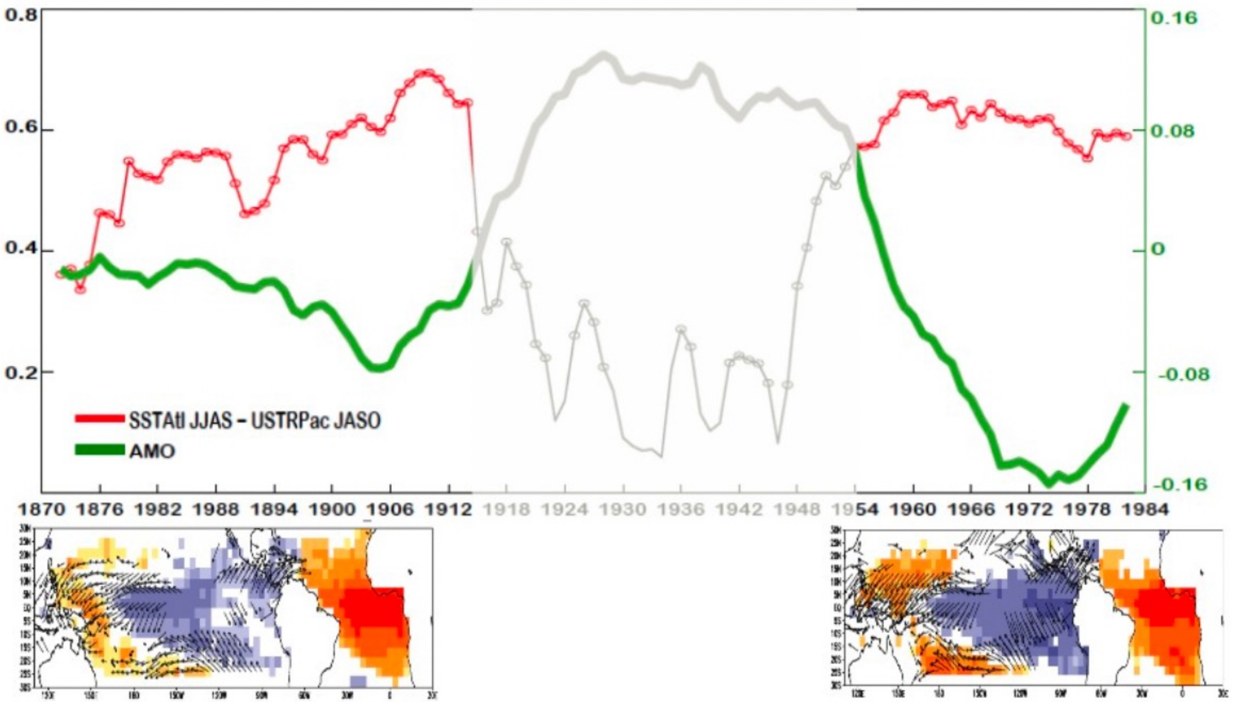
Changes in the background conditions

Peace Maker Experiments;

Boreal Summer Atlantic Niño ➔Pacific

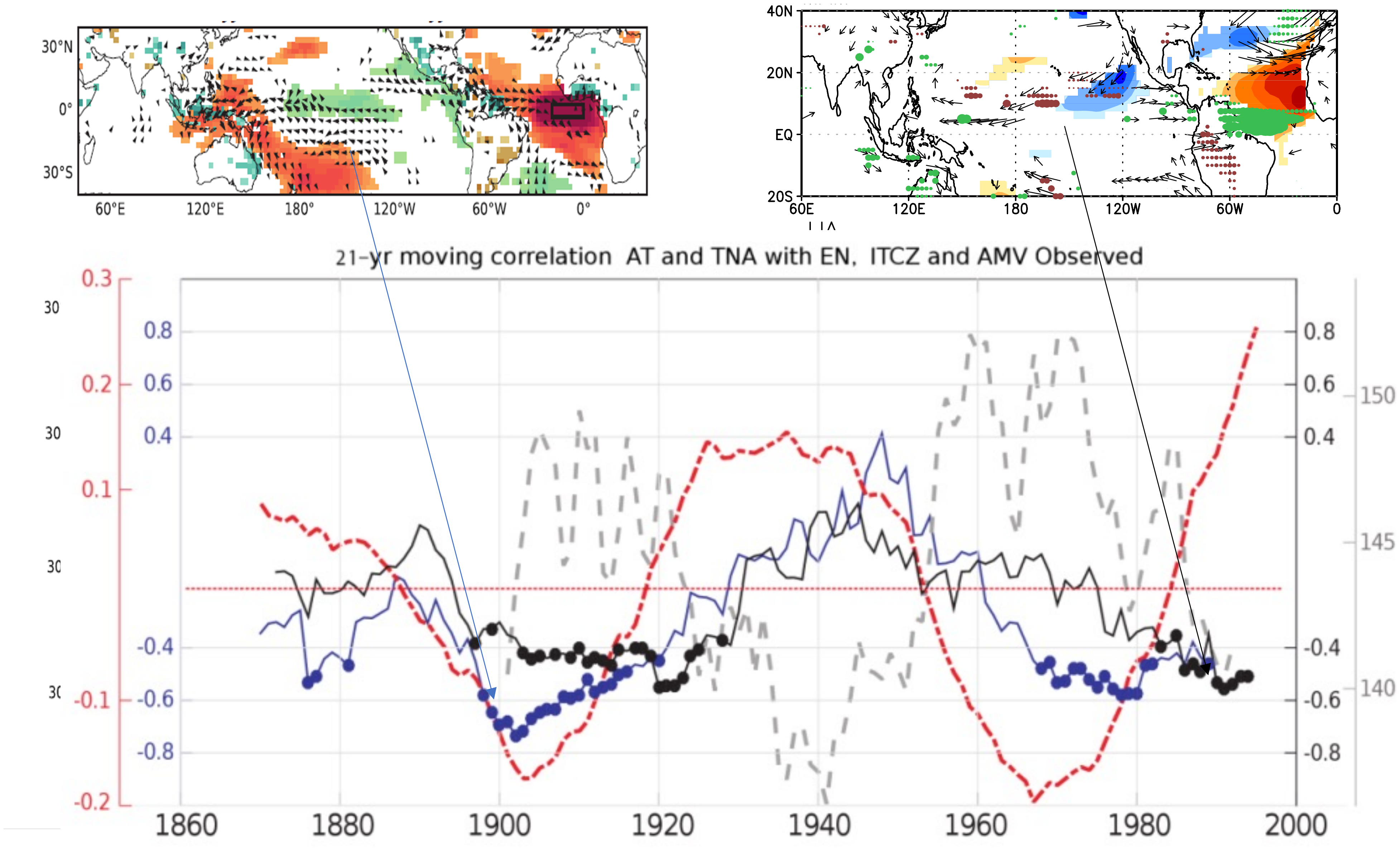
There is a non-stationary behaviour of the Atlantic Niño influence on the tropical Pacific variability . Observed multidecadal modulation

... in fact, it only shows up during the first and last decades of the 20th century (negative AMO phases)



Partially-coupled simulation SimAtlVar

Martín-Rey et al. 2014


21-yr moving correlation AT and TNA with EN, ITCZ and AMV Observed

Changes in the ITCZ

Losada et al. (2022) ➔ importance of the ITCZ location on Atlantic impact on ENSO

Coupled model experiments introducing modification of the ITCZ by changes in the incomming solar radiation (reduction)

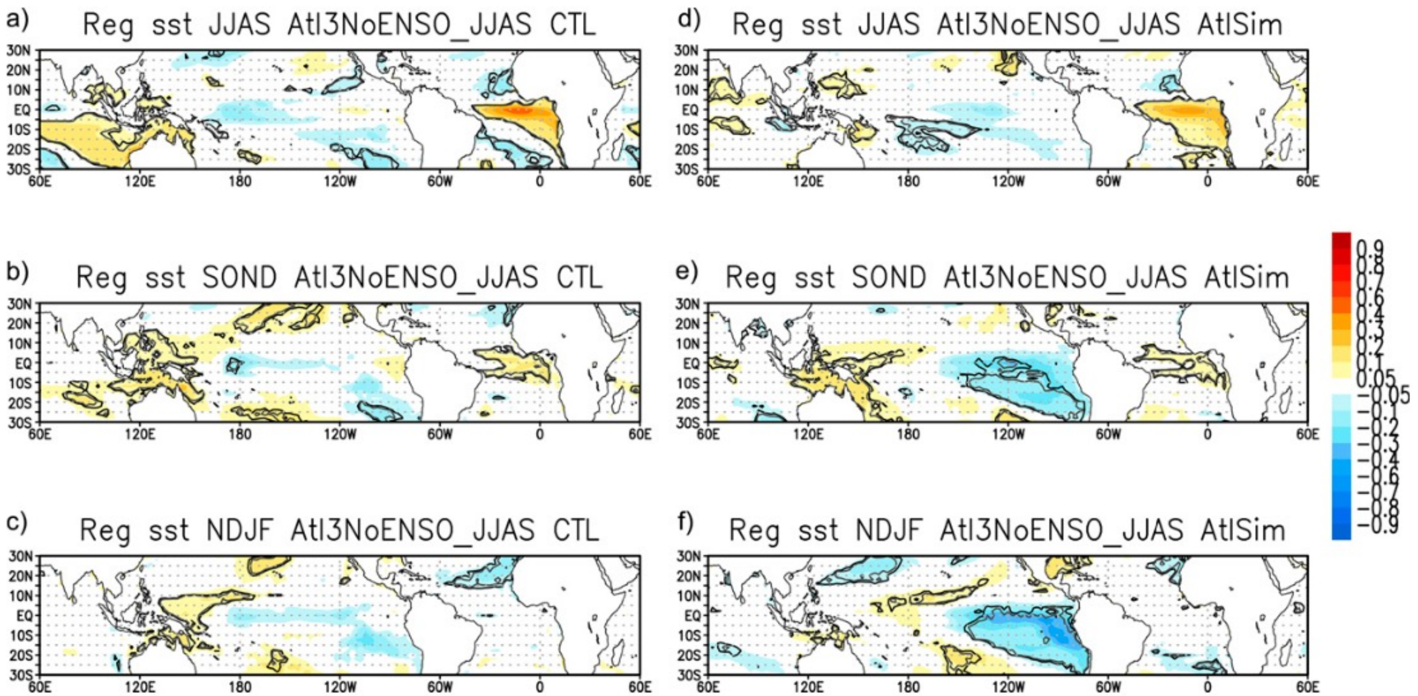
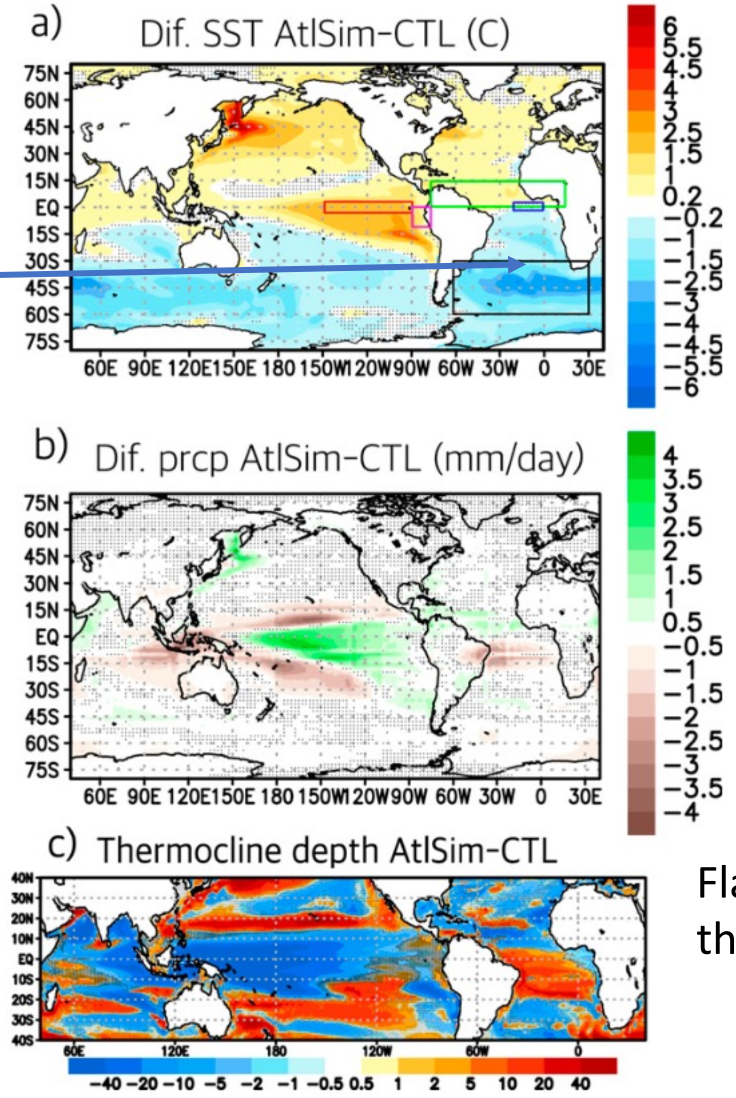


FIG. 4. Regressions of the (a),(d) JJAS, (b),(e) SOND, and (c),(f) NDJF SST (°C) onto the JJAS Atl3 index for (left) CTL and (right) AtlSim. Gray (black) contours show significant correlations at the 95% (90%) level.



Warmer E-Pac

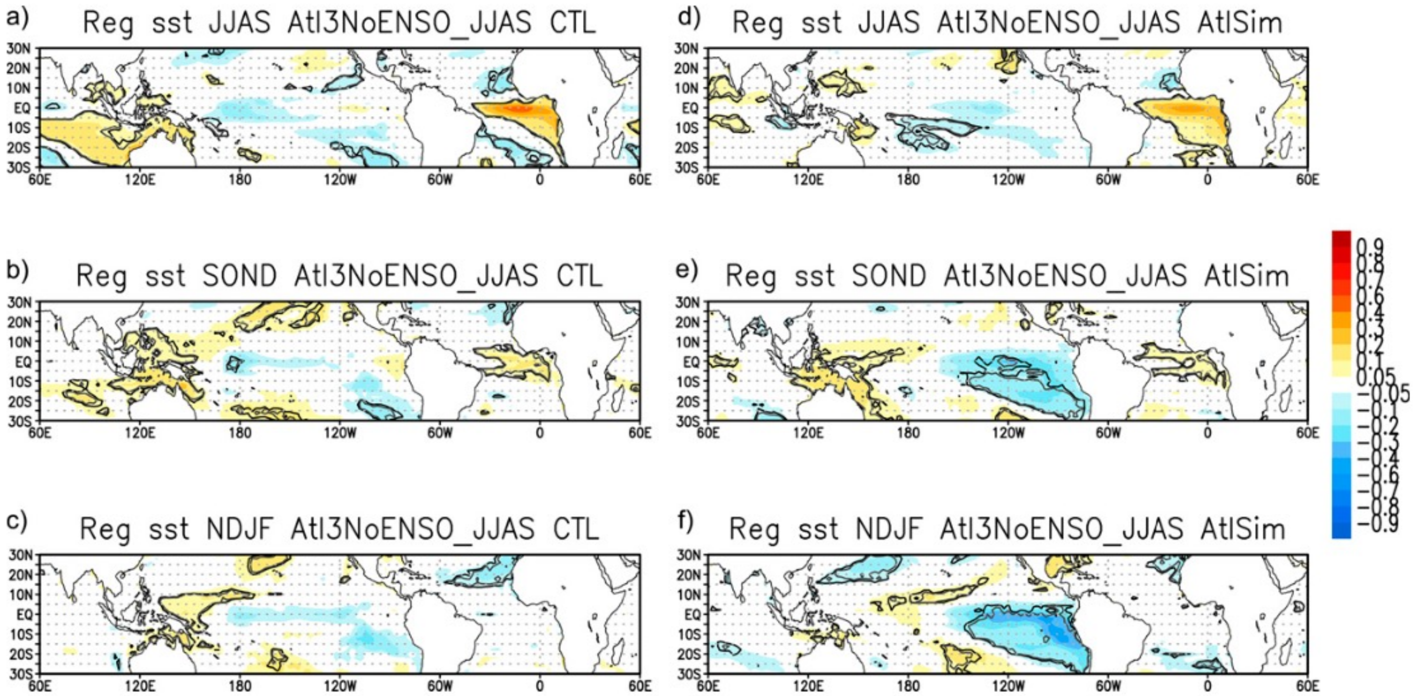
higher rainfall

Flatter Pac thermocline

FIG. 1. Differences in annual (a) SST (°C), (b) precipitation (mm day^{-1}), and (c) thermocline depth (m) in AtlSim with respect to CTL. Not-dotted regions show significant differences at the 95% level. Boxes in (a) denote the regions for the incoming SW reduction (black), Atl3 index (blue), NTA index (green), Niño-3 index (red), and Niño-1+2 index (magenta). Positive (negative) values in (c) mean deeper (shallower) thermocline for AtlSim.

Changes in the ITCZ

Losada et al. (2022)➔ The location of the convection to the west of the Equatorial Atlantic enhances the impact of Atlantic Niño on ENSO



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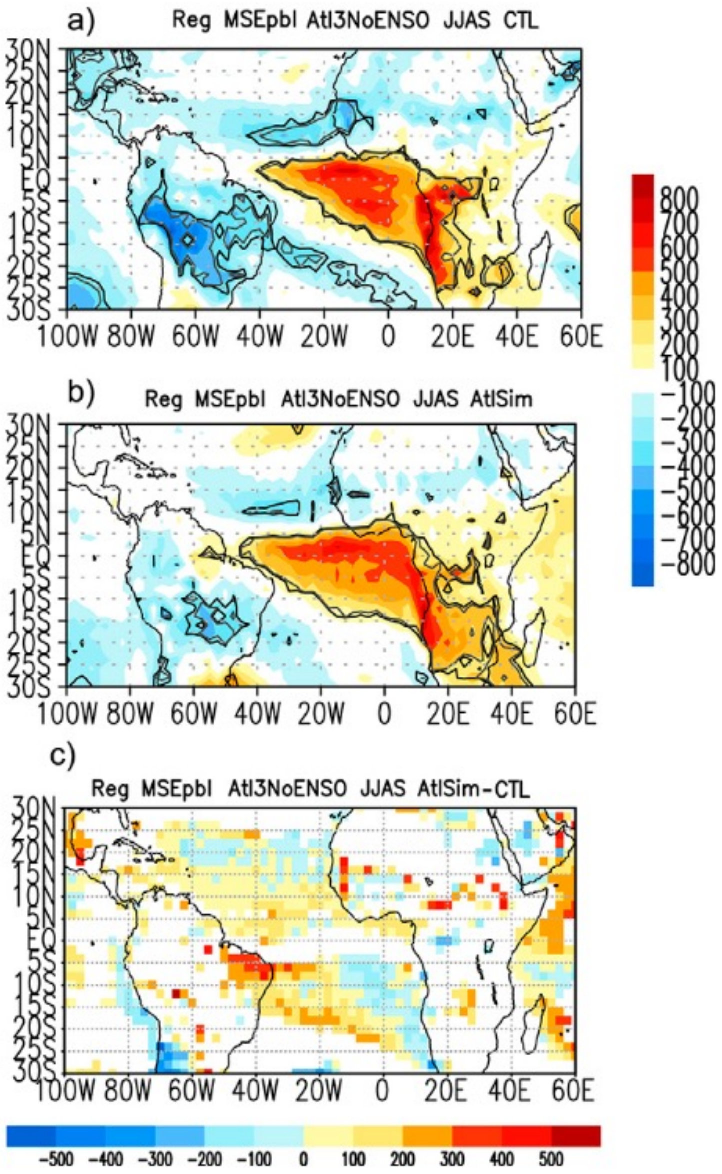


FIG. 5. Regression of the JJAS MSE in the PBL ($m^2 s^{-2}$) onto the JJAS Atl3 index for (a) CTL and (b) AtlSim. Gray (black) contours show significant correlations at the 95% (90%) level. (c) Significant differences between (a) and (b) at the 95% level.

Pacemaker Experiments

Bin et al (2022) ➔ Pacemaker experiments imposing the observed sea surface temperature over the tropical Atlantic **from 1970 onwards** (ACCESS-CM2)

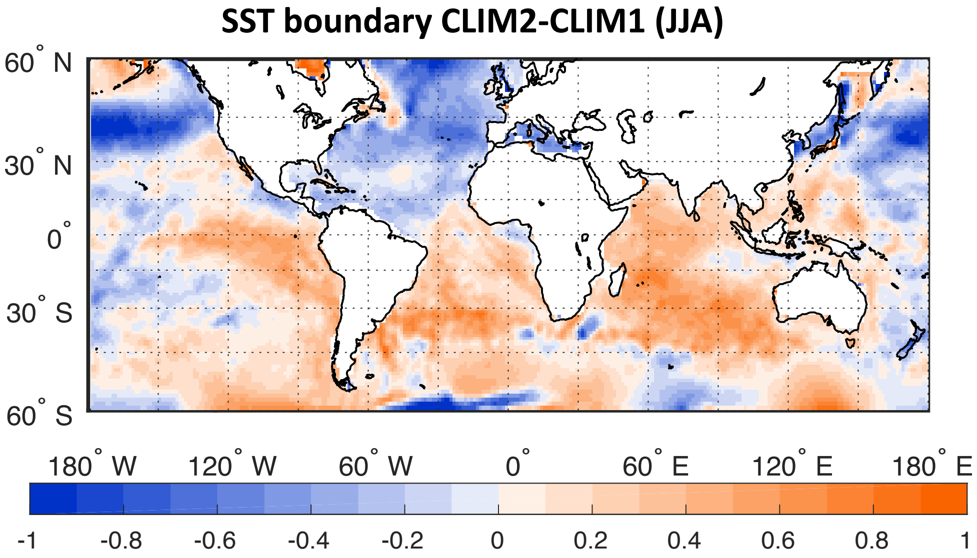
The pacemaker experiment significantly:

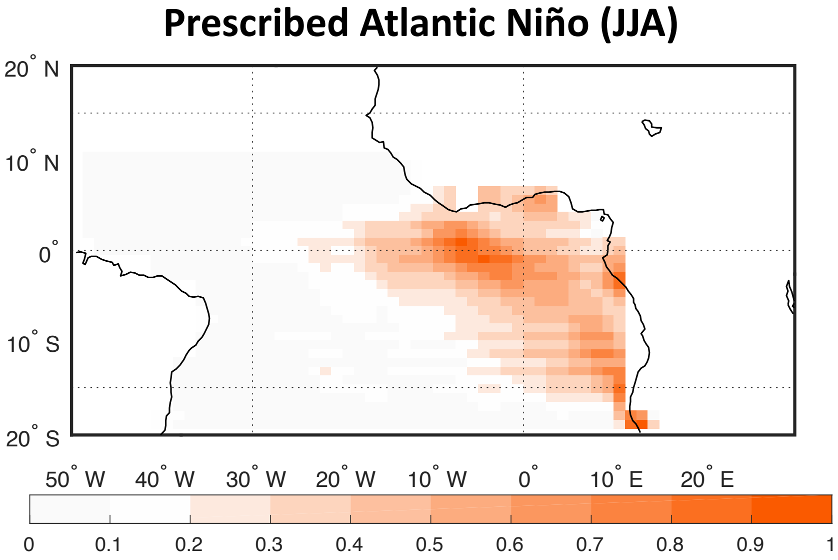
- improves the impact of the Atlantic Niño/Niña on ENSO.
- More realistic ENSO periodicity (close to the observed 5 years periodicity) compared with the control runs, thus suggesting that capturing the influence from equatorial Atlantic variability is important for an improved ENSO simulation.

Changes in the background conditions

AGCM Experiments

Experiment	Prescribed SST boundary
CLIM1	Mean observed global SSTs for the period 1950-1960 (positive AMV phase)
CLIM2	Mean observed global SSTs for the period 1975-1985 (negative AMV phase)
ATL1	As CLIM1 including an Atlantic Niño
ATL2	As CLIM2 including an Atlantic Niño


SST boundary CLIM2-CLIM1 (JJA)


Prescribed Atlantic Niño (JJA)

Svendsen et al (2023) ➔ Is the atmospheric response to an Atlantic Niño different given different background climatologies?

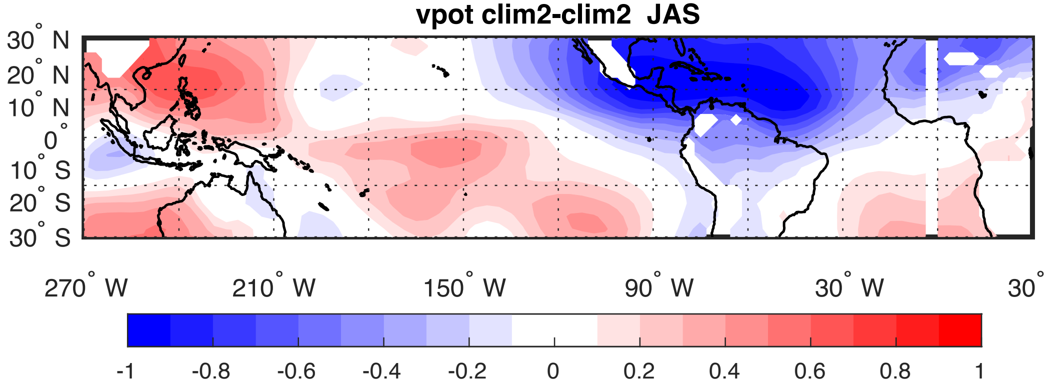
Changes in the background conditions

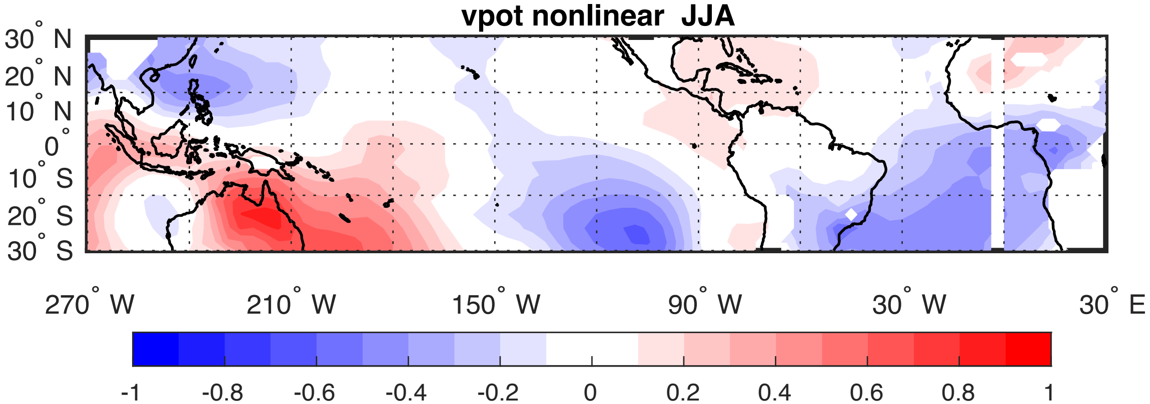
AGCM Experiments

Difference due to climatology
CLIM2-CLIM1 (MME mean)

Multimodel Ensemble Mean of the
Non-Linear Response

925 hPa





- Equatorward shift of the ITCZ

Divergence

Convergence

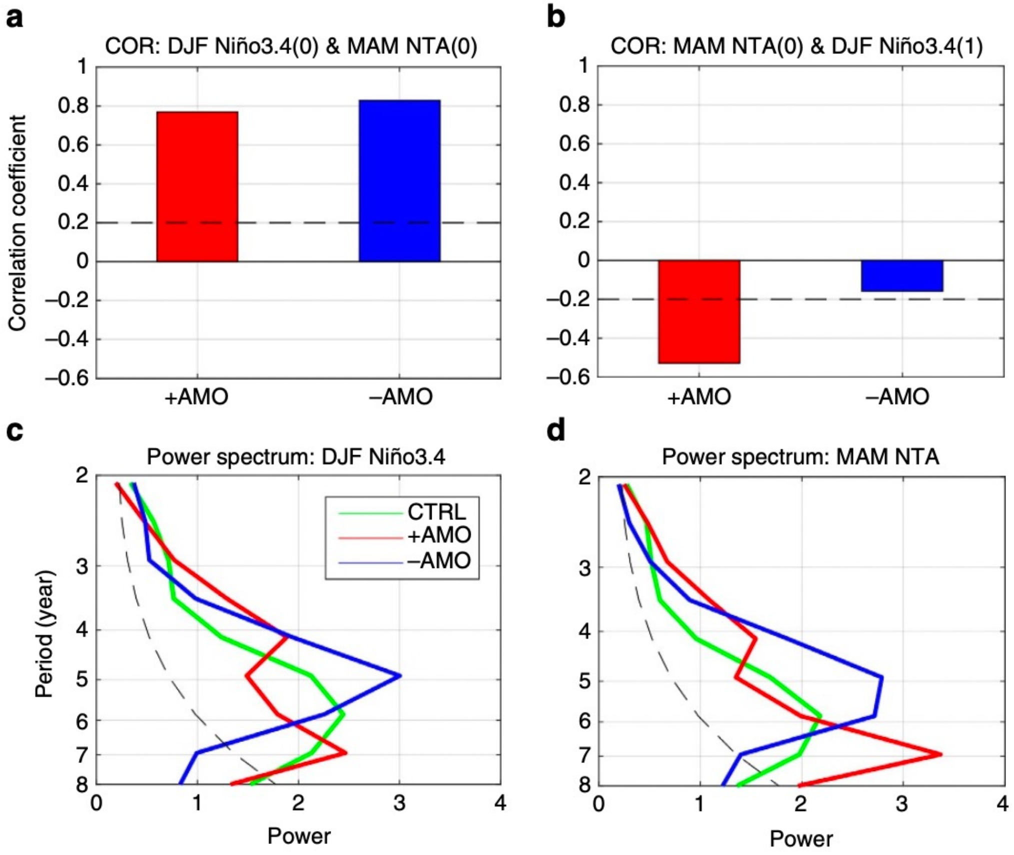
Filles contours: more than 50% of ensembles members have the same sign

Colored shading only where 2/3 of ensemble members agree on sign

Svendsen et al (2022, under review)

TNA ➔Pacific

Wang et al. 2017➔
This relation is specially absent before the 1990's. After the 1990's it seems to be enhancing quasi-bienial variability. Role of AMV?



sensitivity experiments for AMO+ and AMO-

The capacitor effect

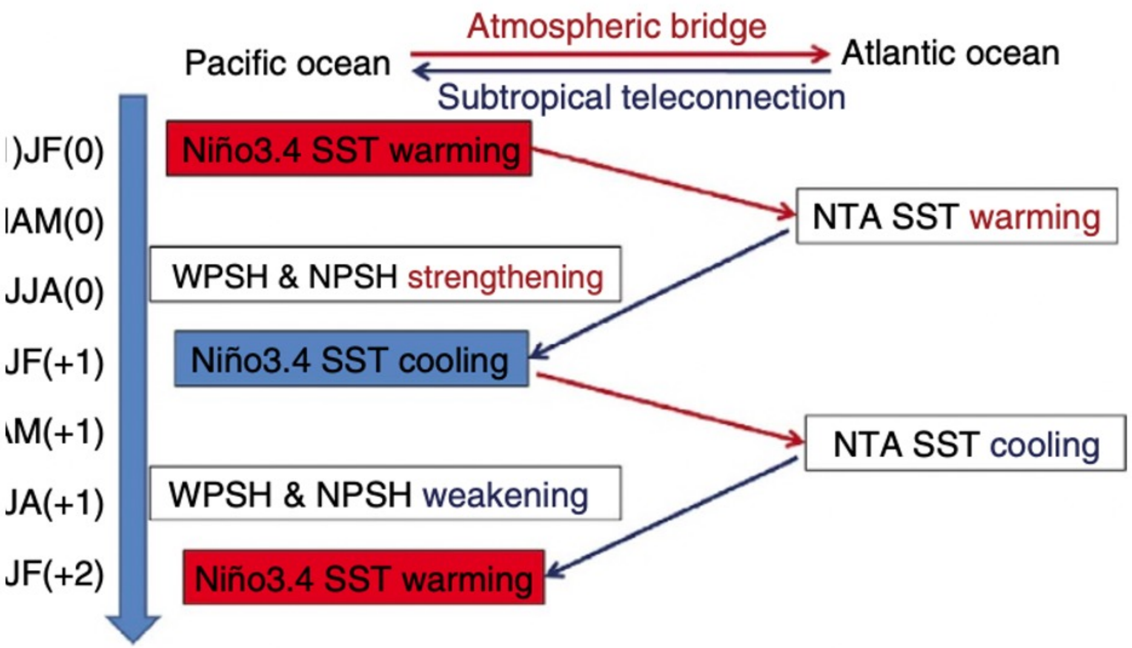


Figure 4 | A schematic diagram showing the biennial cycle of the ENSO induced by the Atlantic capacitor effect.

TNA ➔ Pacific

Wang et al (2017) ➔ Role of AMV+
Accompanying the warmer SSTs ➔ enhanced convection and precipitation along the ITCZ that extends from the Atlantic to the eastern Pacific.
Stronger ITCZ after the early 1990s ➔ more likely capable of channelling the Atlantic influence into the eastern subtropical Pacific.

The possible interference of a global warming trend may be a reason why the previous positive phase of the AMO (during the 1930s–1960s) was not accompanied by enhanced Atlantic–Pacific interactions.

TNA ➔Pacific

Is the capacitor effect is spurious?

- Zhang et al (2021): the results of their cross-correlation analysis among SST anomalies in the TNA and ENSO are consistent with a one-way Pacific to Atlantic forcing, being the **TNA impact on ENSO spurious**

- The notion of NTA serving as precursor for ENSO is therefore equivalent to simply saying that an El Niño is precursor to the next La Niña
- The possible NTA precursor leading to improved ENSO predictability and capacitor arguments remain spurious

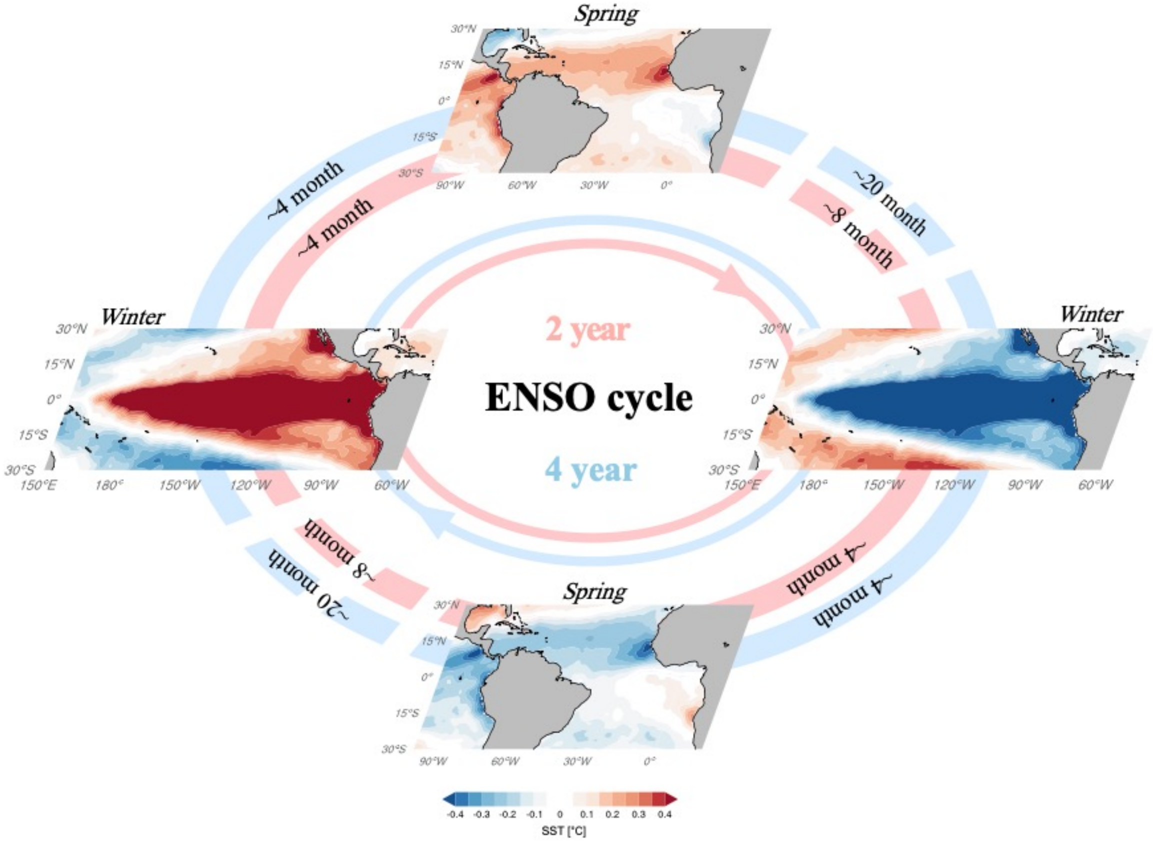


Fig. 4 Schematic trans-basin relationships between tropical Pacific and North Atlantic oceans regulated by the ENSO periodicity. In the quasi-biennial ENSO cycle (red loop), an El Niño condition in boreal winter (left panel) leads to positive North Tropical Atlantic (NTA) warming during subsequent spring (upper panel) at a ~4-month lead time, which in turn can see a La Niña formation (right panel) typically following El Niño in the subsequent winter, showing a statistical ~8-month lead time of the NTA. Likewise, a La Niña condition in boreal winter (right panel) gives rise to the following spring NTA sea surface temperature (SST) cooling (lower panel) with a lag of ~ 4 months, which is often followed by an El Niño formation (left panel), corresponding to a statistical ~8-month lead time of the NTA. The same applies for the quasi-quadrennial ENSO cycle (blue loop) except for the negative correlation of NTA SST variability with the following ENSO event by ~20 months.

TNA ➔Pacific

Ding et al. 2023➔ North Atlantic Oscillation control de NTA impact on ENSO

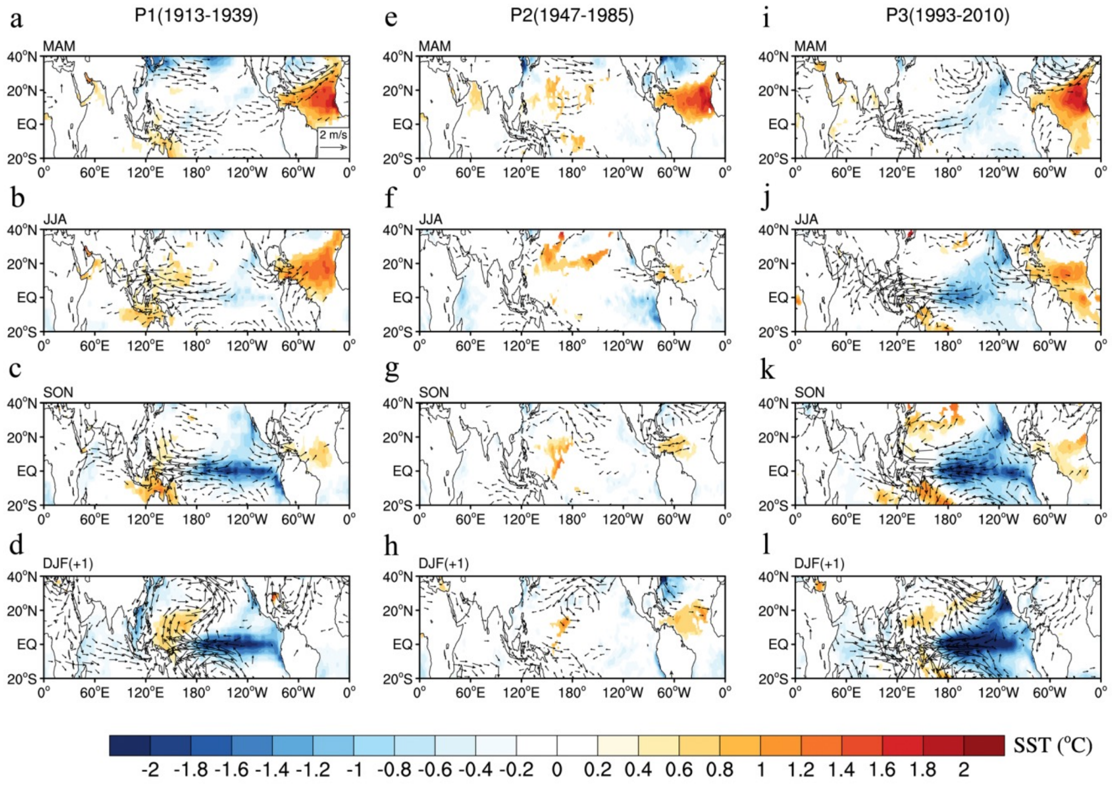
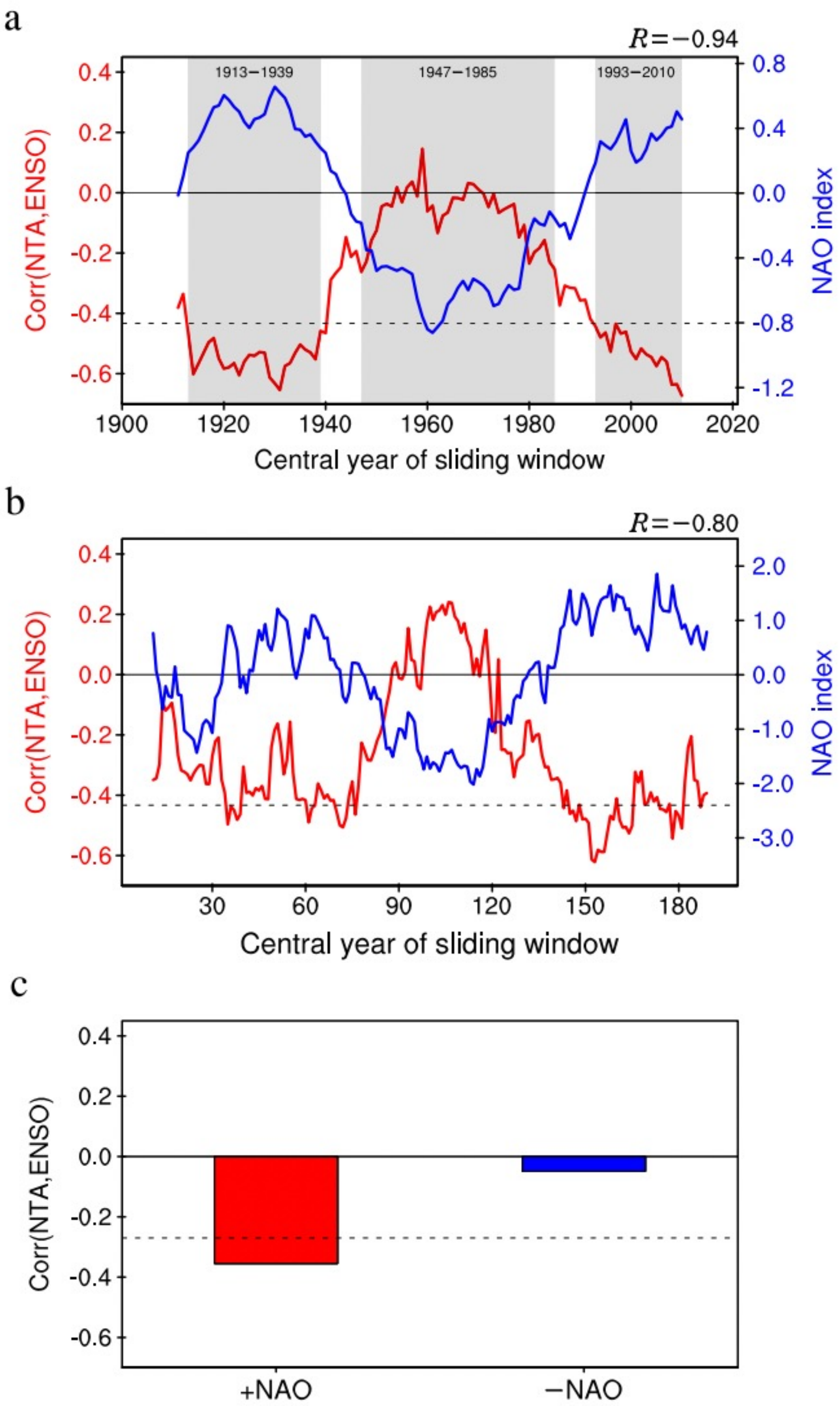
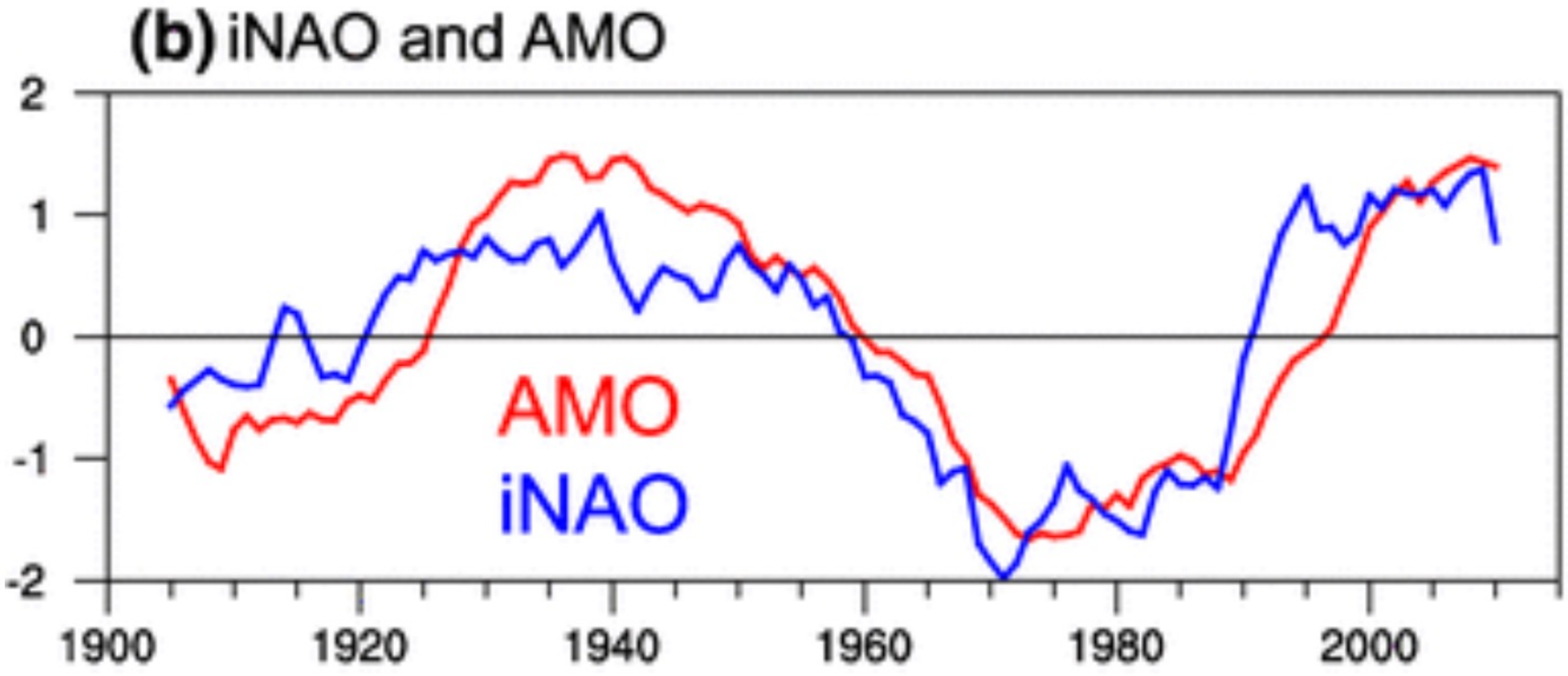


Fig. 3 | Regressions with respect to the spring North Tropical Atlantic (NTA) sea surface temperature (SST). a–d Regressions of SST (shading) and 850-hPa winds (vectors) with respect to the MAM0 NTA SST index during 1913–1939 (P1) for MAM0 (**a**), JJA0 (**b**), SON0 (**c**), and D0JF1 (**d**) seasons. **e–h** As in **a–d**, but during 1947–1985 (P2) for MAM0 (**e**), JJA0 (**f**), SON0 (**g**), and D0JF1 (**h**) seasons. **i–l** As in **a–d**, but during 1993–2010 (P3) for MAM0 (**i**), JJA0 (**j**), SON0 (**k**), and D0JF1 (**l**) seasons. The impact of the previous winter (D−1JF0) El Niño-Southern Oscillation (ENSO) has been removed from the MAM0 NTA SST index using linear regression with respect to the Niño3.4 index. Only 850-hPa winds and SST anomalies significant at the 95% confidence level are shown.

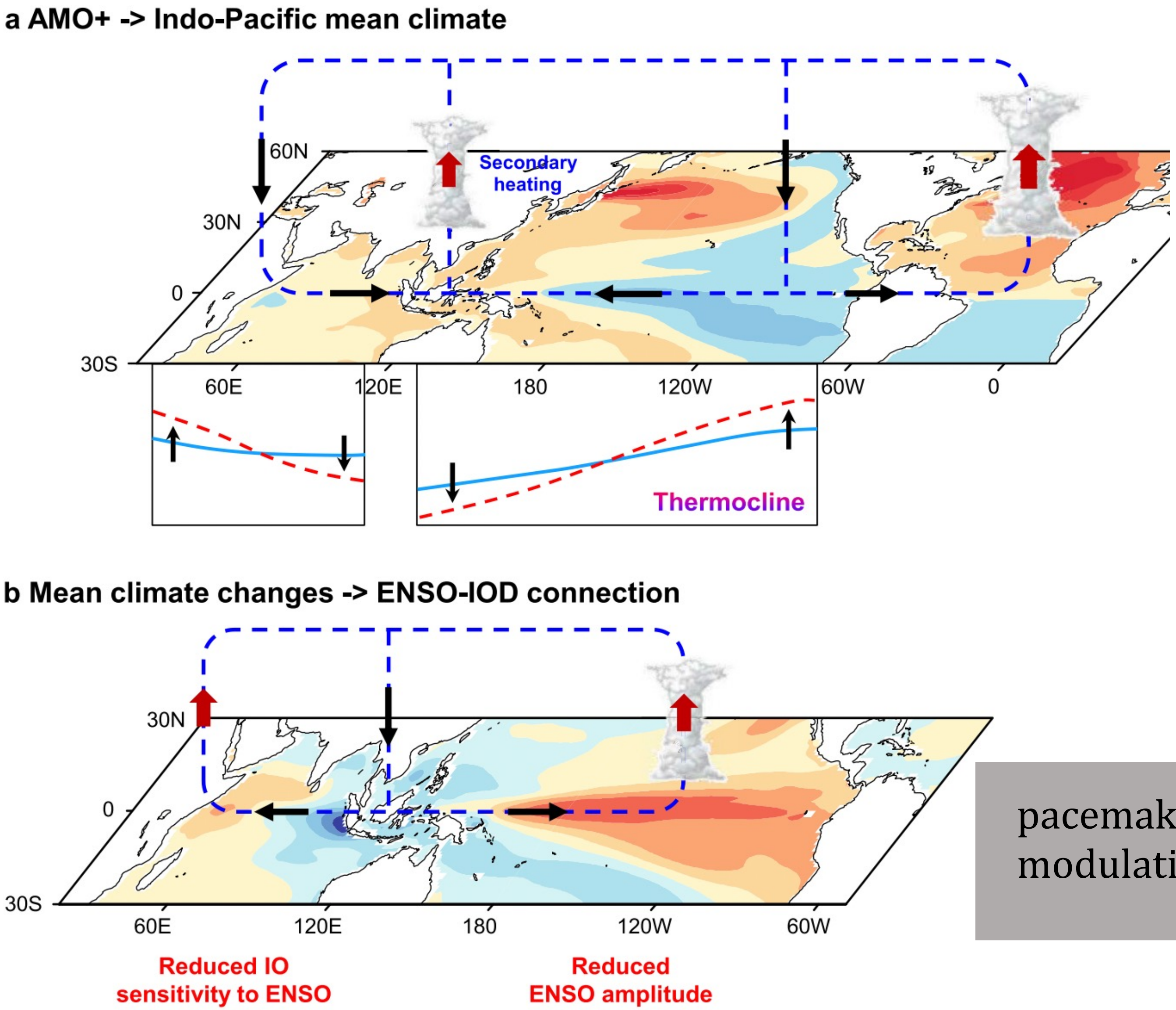




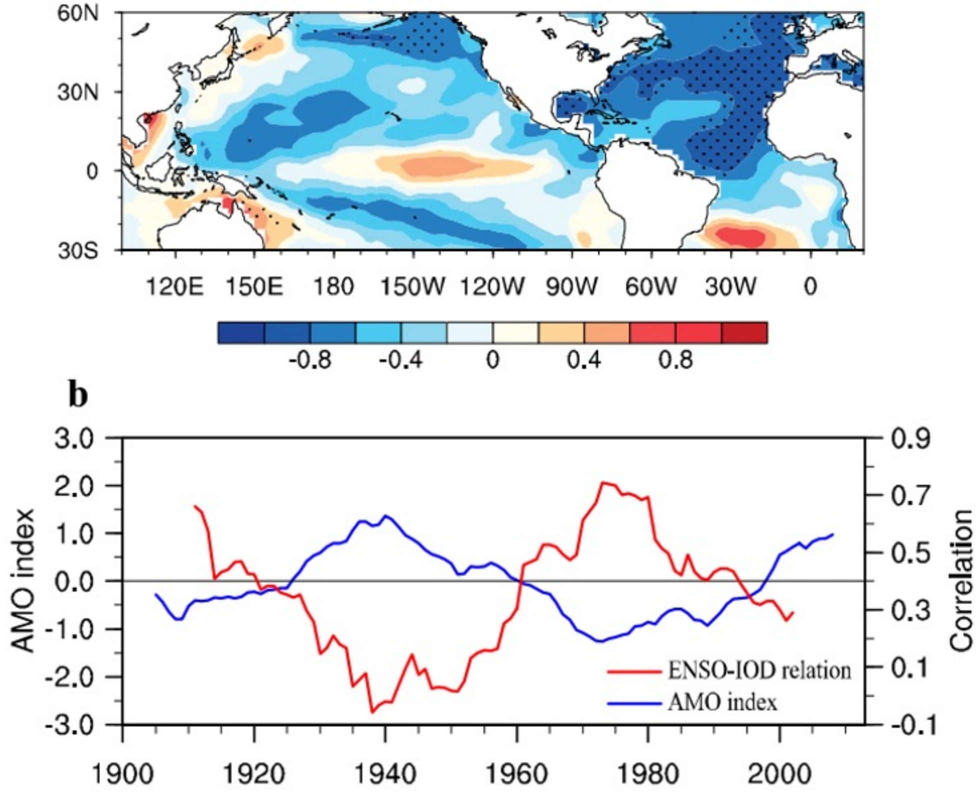
The relationship between NAO and AMO in the observations. a Lead–lag correlations between the NAO and AMO indices for the period 1900–2015 based on decadally filtered (red) and unfiltered (blue) time series. Negative (positive) lags indicating the NAO leading (lagging) AMO. Red (blue) dashed lines denote the 95% confidence levels for filtered (unfiltered) time series using the effective numbers of degrees of freedom. b The decadally filtered AMO index and the time-integrated NAO (referred to as iNAO in the text) for the period 1900–2015. The two indices are scaled to unit variance and the long-term linear trends are removed

IOD➔ENSO

Xue et al (2022) ➔ The ENSO–IOD relationship is found to be time-varying and linked to the AMO, with AMO warm (cold) phases corresponding to weakened (strengthened) ENSO–IOD relationship.


a AMO+ -> Indo-Pacific mean climate

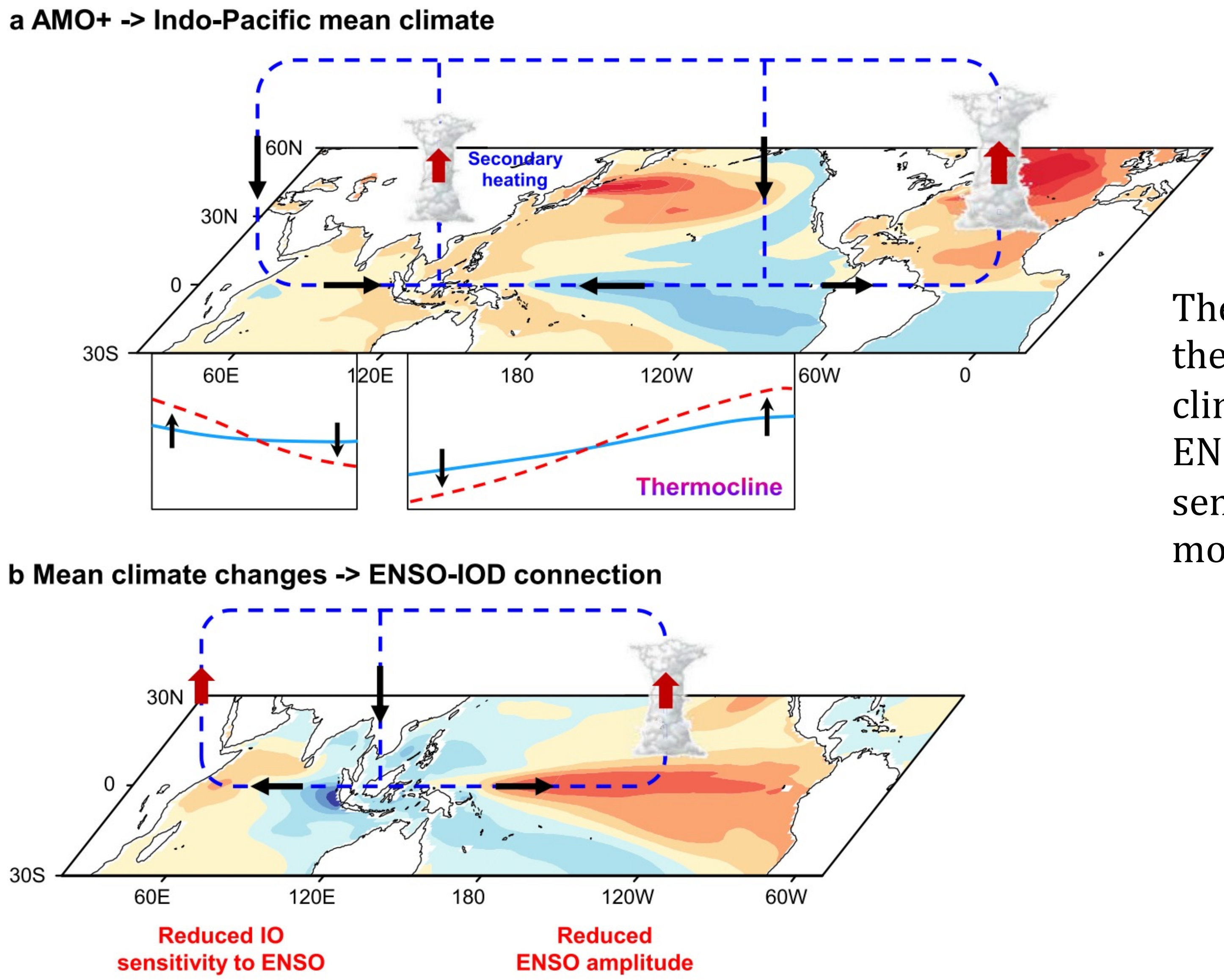
b Mean climate changes -> ENSO-IOD connection



pacemaker simulations well reproduce the observed modulation of AMO on ENSO–IOD relation

IOD→ENSO

Xue et al (2022) → The ENSO–IOD relationship is found to be time-varying and linked to the AMO, with AMO warm (cold) phases corresponding to weakened (strengthened) ENSO–IOD relationship.



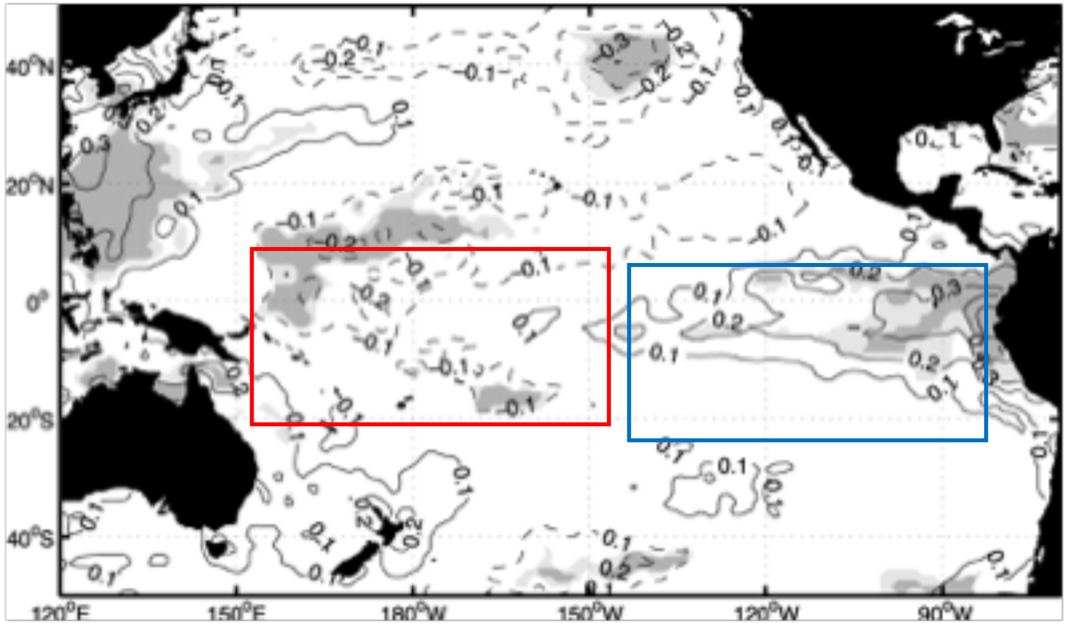
The modulation is found to occur through the AMO induced Indo-Pacific mean climate changes, which influence both the ENSO amplitude and the Indian Ocean sensitivity to ENSO forcing, thereby modulating the ENSO–IOD relationship

Figure 5. Schematic representation of Atlantic Multidecadal Oscillation (AMO) modulating the El Niño–Southern Oscillation (ENSO)–Indian Ocean Dipole (IOD)

Changes in ENSO characteristics

Rogers et al. (2003)➔ asymmetry in ENSO during some decades produces changes in the mean state. Stronger Niños than Niñas

The mean state configuration promotes a background state with warmer anomalies in the east and cold in the west



The warm pool is able to cool during El Niño if strong easterlies cause evaporation or upwelling anomalies. However, it is unable to get much warmer than about during la Niña 30ºC because of the effect of cloud feedbacks.

The far eastern equatorial Pacific can warm during El Niño if the thermocline gets deep. But it does not cool (as much) during La Niña because wind anomalies are mostly confined to the central Pacific

Relation to PDO? Is the PDO the reddening of ENSO?

Fedorov et al. (2013) A remaining question arises
Is it the PDO/IPO modulating ENSO, or is it ENSO modulation that is responsible for the decadal variability?

Dong et al. (2003)➔ AMV produces changes in Equatorial Pacific variability

Warming of the North Atlantic and cooling of the south Atlantic leads to a reduction in ENSO variability.

The deeper equatorial thermocline weakens
The coupled instability through which ENSO events grow
[e.g.,Zebiak and Cane, 1987], and reduces ENSO variance

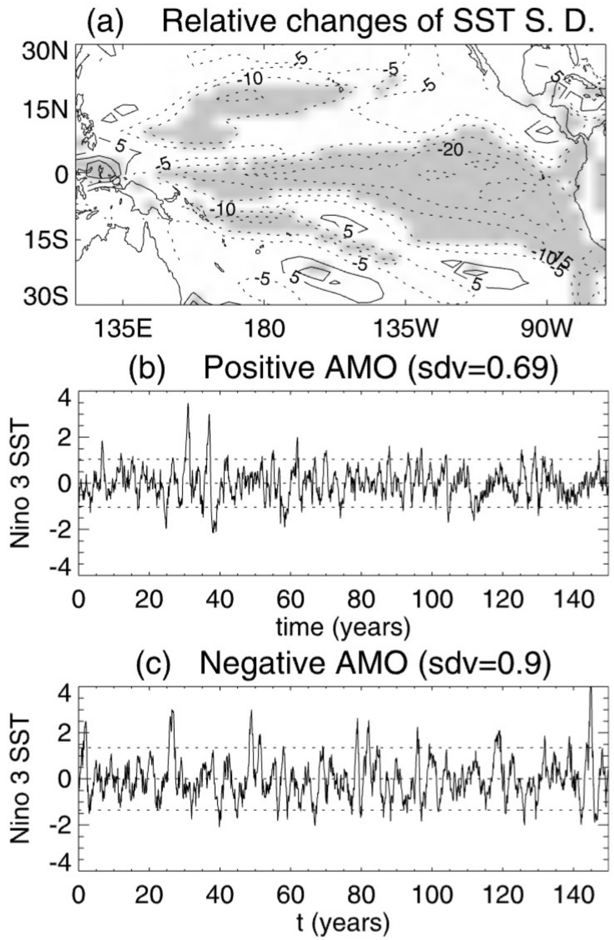


Figure 3. (a) Percentage changes of monthly SST standard deviation between positive and negative AMO experiments. Shading indicates significant changes at 95% confidence level using F-test. (b) and (c) Monthly Nino 3 SST anomalies with thin dotted lines being 1.5 standard deviation limits. The error of Nino 3 standard deviation for 150 year sections based on an 1800 year HadCM3 simulation is 0.053°C.

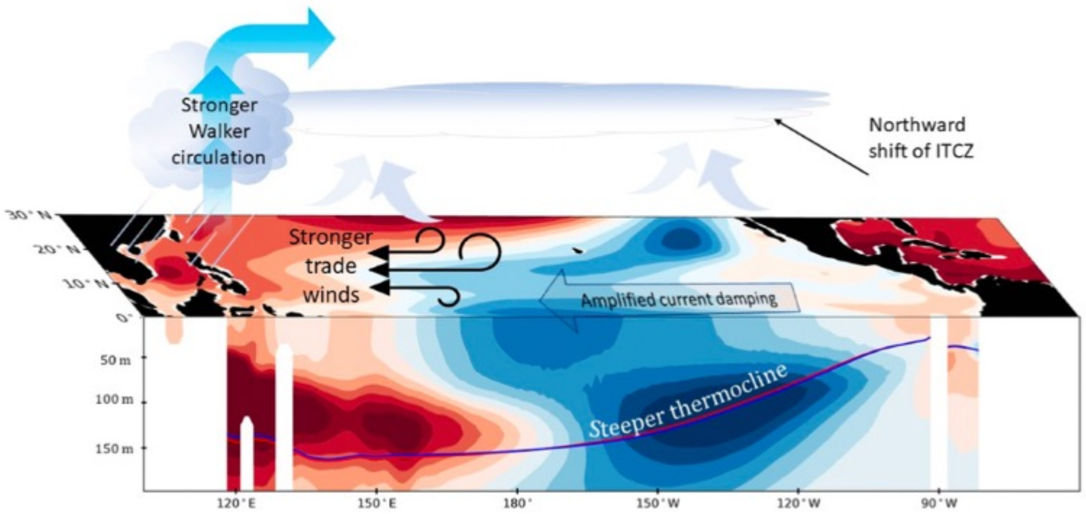
Trascasa et al. (2022) ➔ sensitivity experiments with AMV positive and negative

El Niño and La Niña events are weaker when the North Atlantic is warmer than usual, and vice versa.

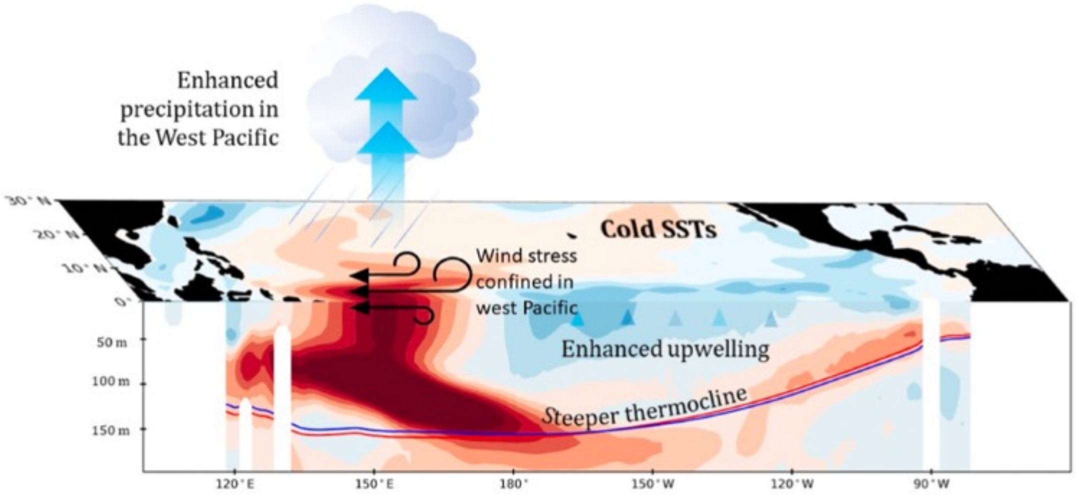
During the warm phase of the AMV (AMV+), the trade winds associated with the Walker circulation are localised in the west Pacific, directly impacting sea surface temperature patterns associated with ENSO events.

Reduced wind stress in the eastern equatorial Pacific means that the upper ocean heat content is less perturbed in the AMV+ simulation, eventually affecting ENSO-related sea surface temperatures.

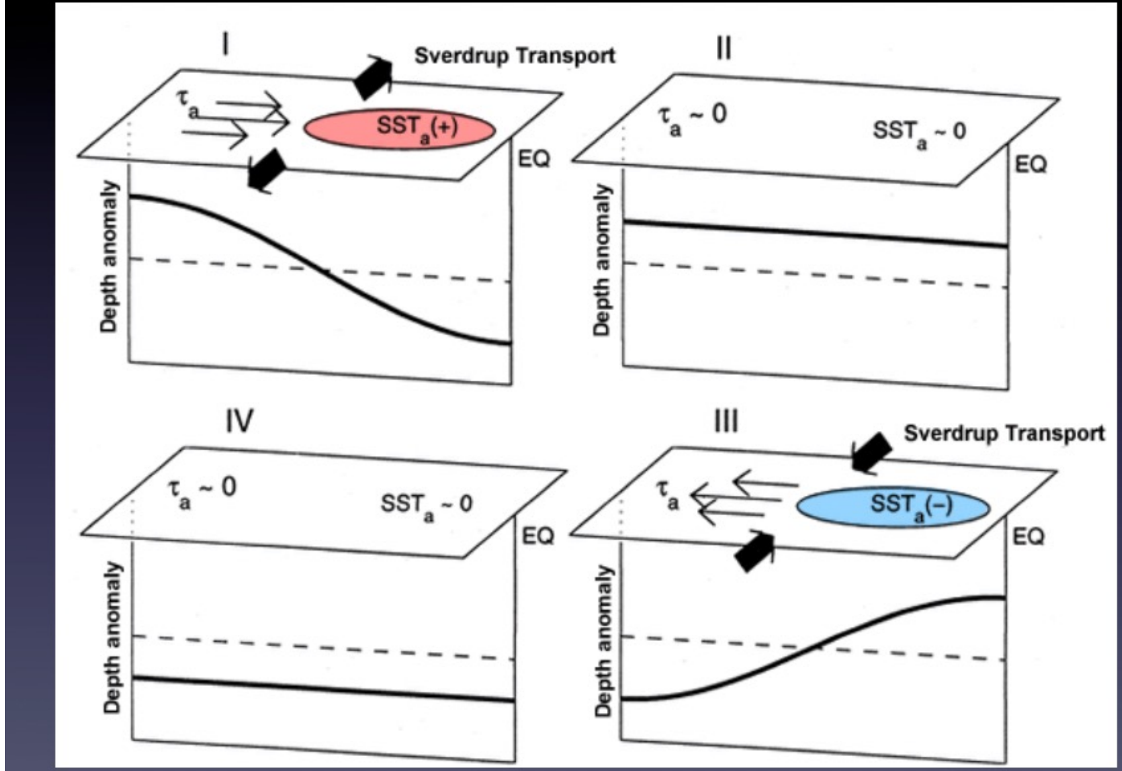
a) AMV modulation of ENSO feedbacks



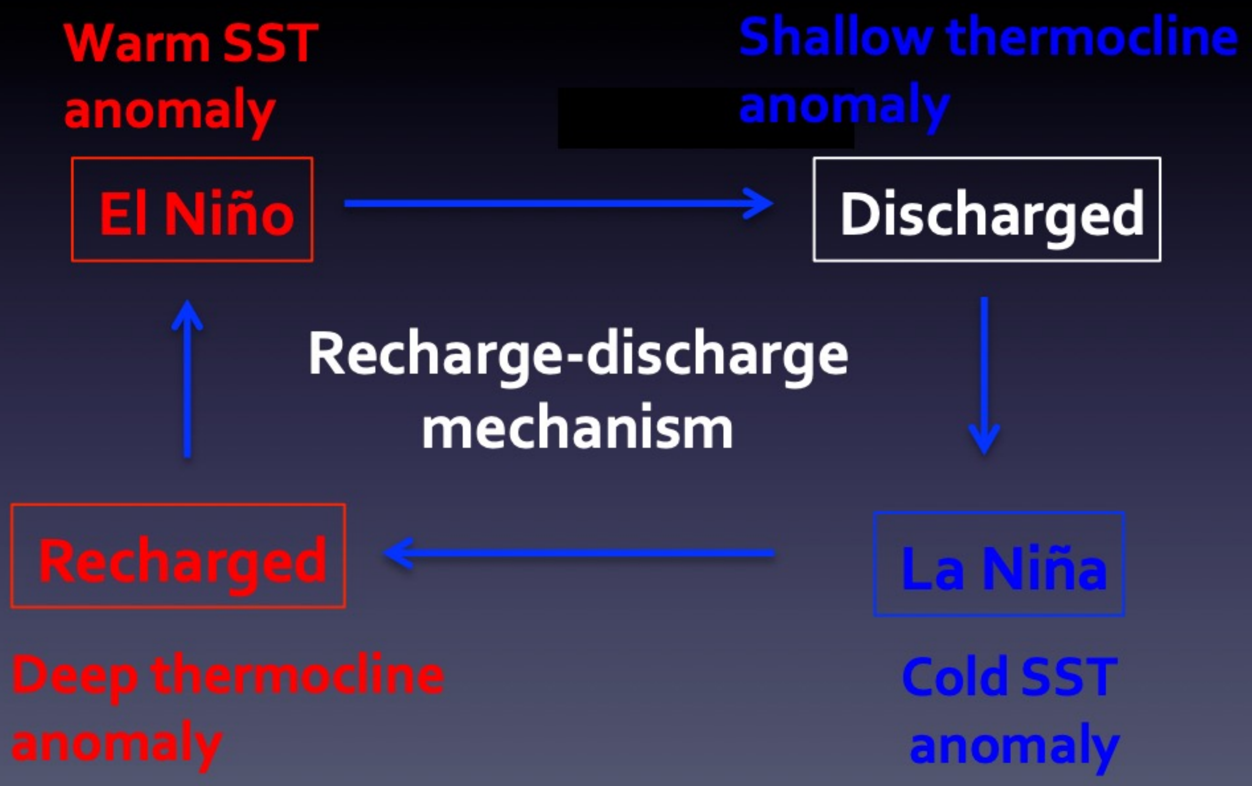
b) AMV modulation of El Niño



The recharge oscillator model (Jin 1997) is based on the cyclic recharge-discharge process of the upper ocean equatorial heat content and is **based on the coupling between SST and thermocline.**



Schematics: Meinen and McPhaden 2000


Warm SST anomaly

El Niño

Shallow thermocline anomaly

Discharged

Recharge-discharge mechanism

Recharged

La Niña

Deep thermocline anomaly

Cold SST anomaly

Changes in the Pacific Mean State

Model parameters

a_{11} = SST growing rate

a_{12} = coupling of h to SST

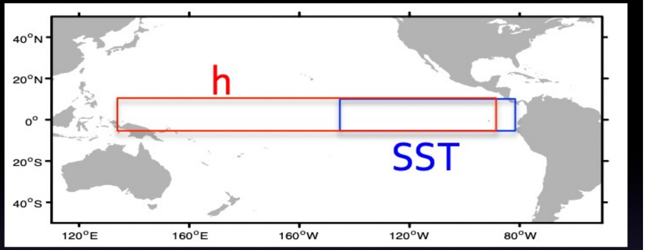
a_{21} = coupling of SST to h

a_{22} = h growing rate

SST Niño3 region

$$\frac{d}{dt}SST = a_{11}SST + a_{12}h + N_T$$

$$\frac{d}{dt}h = a_{21}SST + a_{22}h + N_h$$



h = zonal average of equatorial Pacific thermocline depth

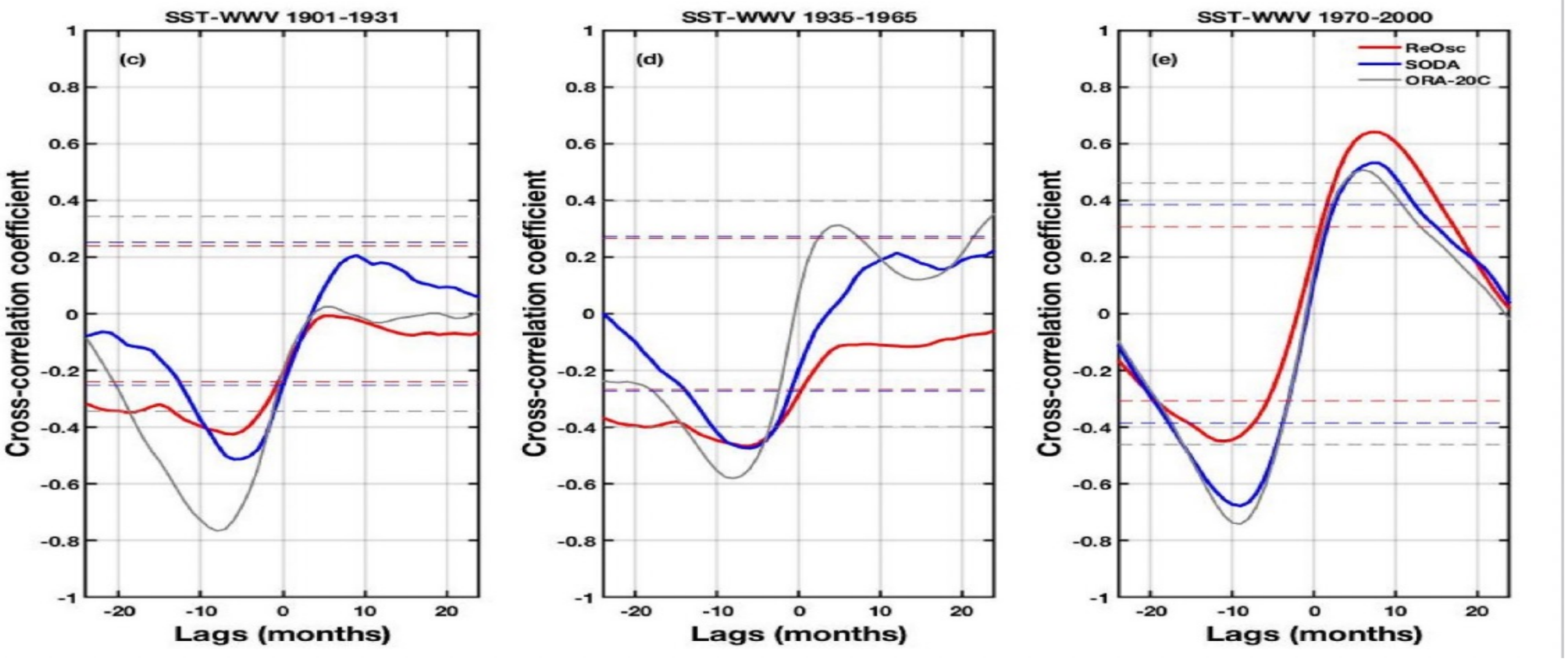
Crespo et al. (2022) ➔ The Recharge Oscillator is a good model for representing ENSO from the 1970’s

Crespo-Miguel et al (2023) ➔

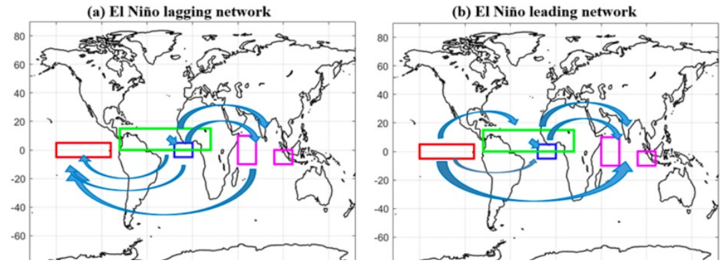
1901-1931

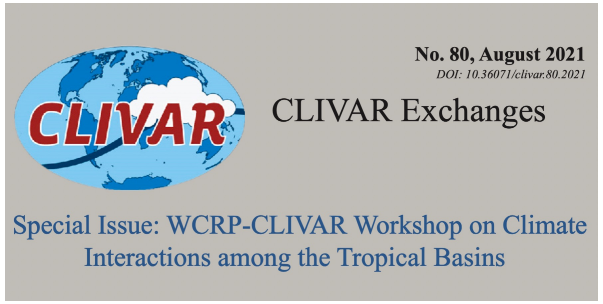
1935-1965

1970-2000



Pantropical ➔ Pacific




No. 80, August 2021

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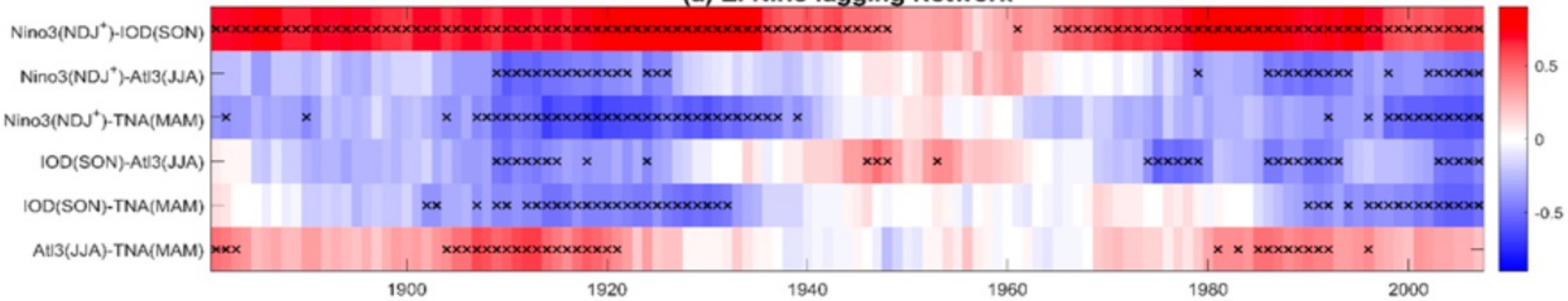
CLIVAR

CLIVAR Exchanges

Special Issue: WCRP-CLIVAR Workshop on Climate Interactions among the Tropical Basins

(a) El Niño lagging Network



(b) El Niño leading Network

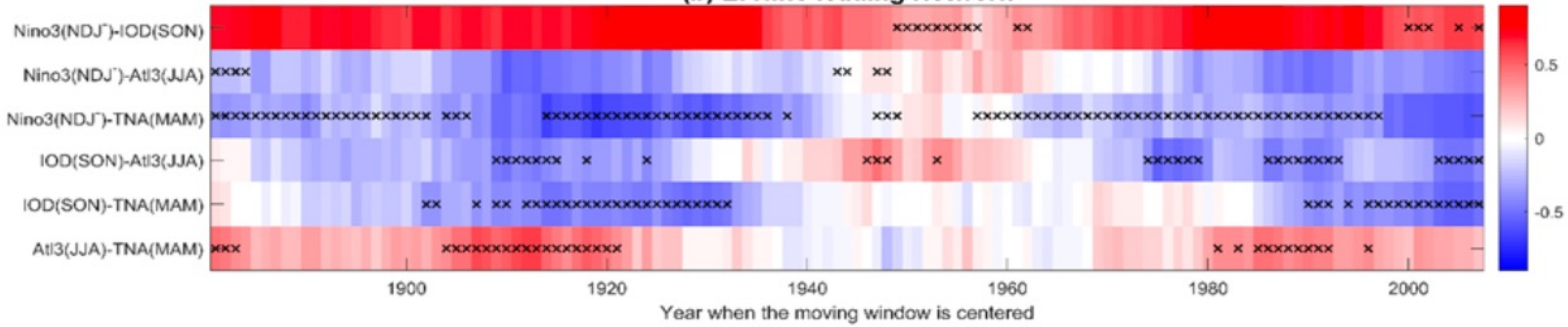


Figure 3: Running correlations between each pair of network nodes in a) when ENSO lags the rest of nodes (ENSO is centered in the NDJ season after (NDJ+) the trimester when the rest of the nodes are centered) and b) when ENSO leads the rest of nodes (ENSO is centered in the NDJ season before (NDJ-) the trimester when the rest of the nodes are centered). The asterisk marks the windows when correlation is statistically significant based on a one-tailed t-test with a 95% confidence interval

Martin et al (2021). Clivar Exchanges

Conclusions

The influence of tropical basins on the El Niño-Southern Oscillation (ENSO) exhibits a non-stationary behavior, as indicated by observational data.

Notably, the boreal winter Atlantic Niño and spring Tropical North Atlantic (TNA) impact during positive Atlantic Multi-decadal Variability (AMV+).

Conversely, the boreal summer Atlantic Niño and fall Indian Ocean Dipole (IOD) impact during negative AMV (AMV-)

Modeling efforts have been dedicated to unraveling the underlying mechanisms behind these modulations.

One key factor lies in understanding how changes in the Pacific's mean state and variability play a crucial role in Tropical Basin Interactions (TBI).
AMV, for instance, can significantly alter the Pacific's mean state and variability, leading to increased ENSO variability during AMV- phases.

Stochastic processes also contribute to low-frequency variability in the Pacific, causing changes in the mean state.

Asymmetries in ENSO further contribute to the decadal variability observed in the Pacific basin.

- The impact of boreal summer Atlantic Niño and IOD on ENSO becomes prominent during decades characterized by higher equatorial Pacific variability, warmer Eastern Equatorial Pacific, flatter thermocline, and an equatorward shift of the Intertropical Convergence Zone (ITCZ).
- This could be due to AMV- or other processes (equatorward shift of ITCZ due to extratropical influence).

- The location of convection in the Atlantic is also crucial in understanding TBI. Westward displacement of convection in the Atlantic (associated with the Atlantic Niño) plays a significant role in influencing ENSO.
- Regarding the TNA impact on ENSO, it occurs during positive North Atlantic Oscillation (NAO) / positive AMV.
- The validity of the capacitor effect in this context remains a subject of question and further investigation.