

Coupling SST- Surface wind and intraseasonal to seasonal variability in West Africa Monsoon System

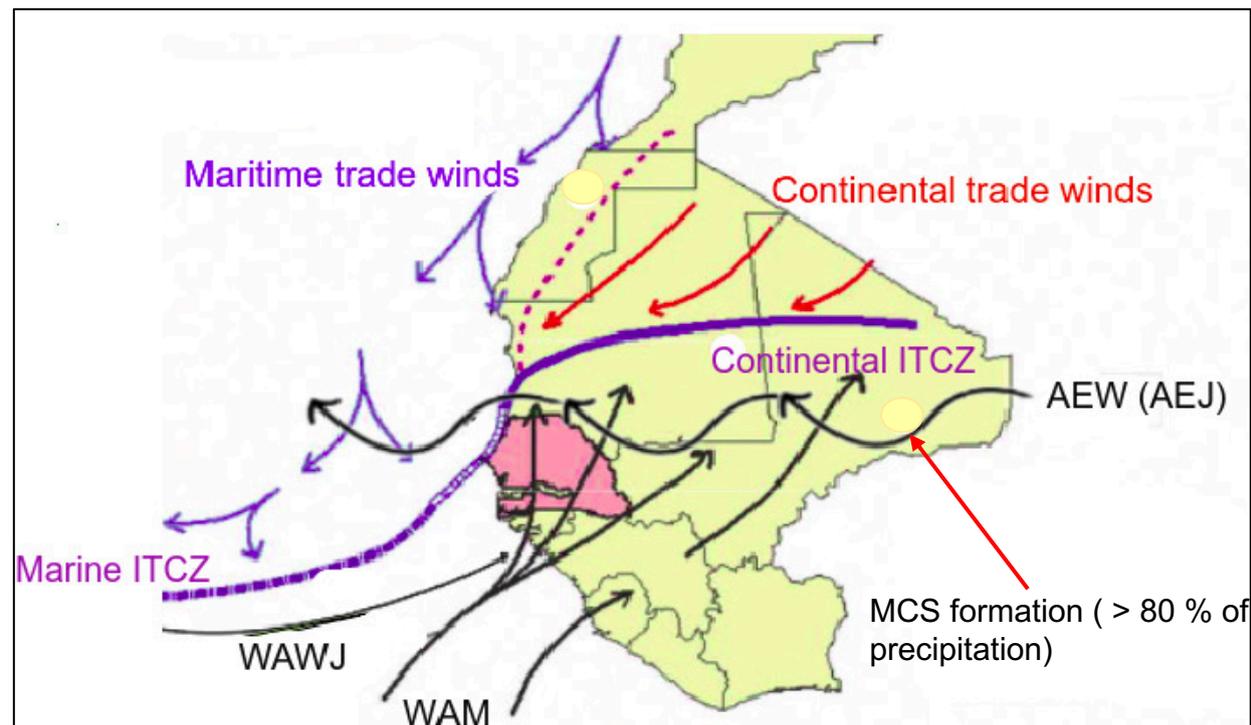
Mamadou Thiam

Supervisors: Gaelle de Coetlogon (LATMOS, SU), Bouya Diop (LSAOMED, UGB), Alessandra Giannini (LMD-ENS)



Motivations

Geographical context of West Africa (WA)



Low level { ITCZ = intertropical convergence zone
WAWJ = west african westerly jet
WAM = west african monsoon

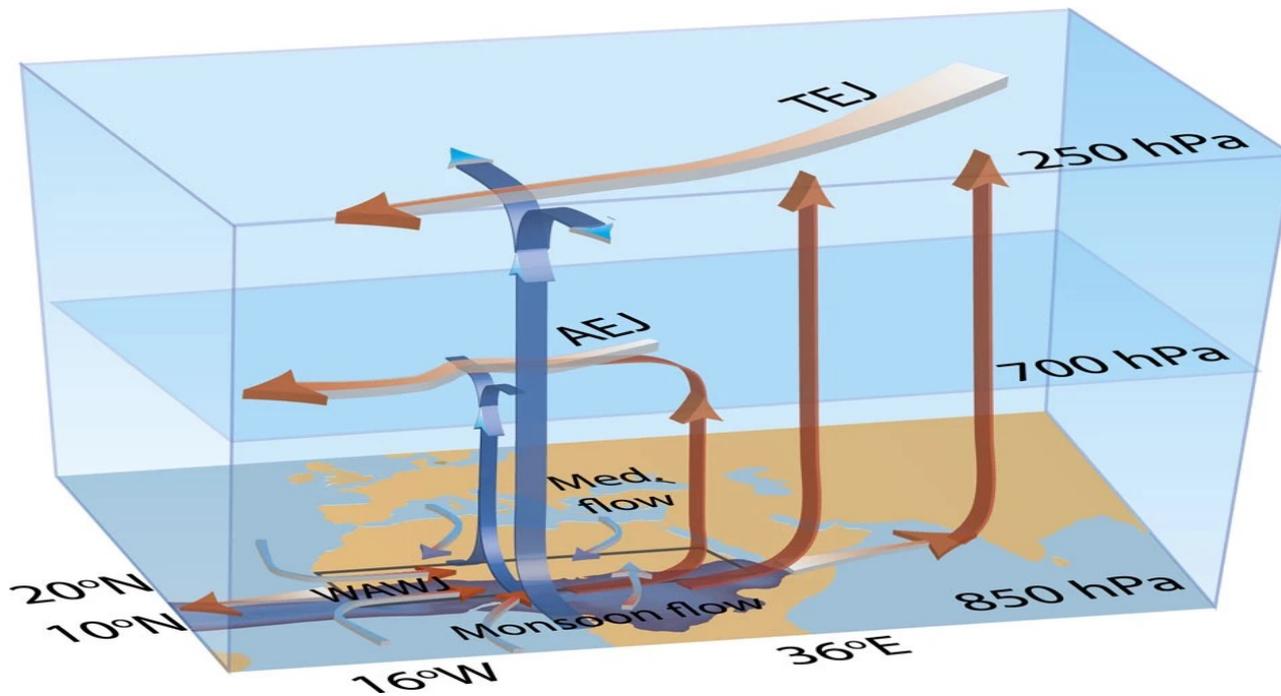
~ 700 hPa { AEW = African Easterly Wave
AEJ = African Easterly Jet
MCS = Mesoscale convective systems

From Garnier 1976

Sudano-Sahelian zone + opening onto the Atlantic
West African climate: between oceanic and continental influences

Motivations

West African Monsoon System

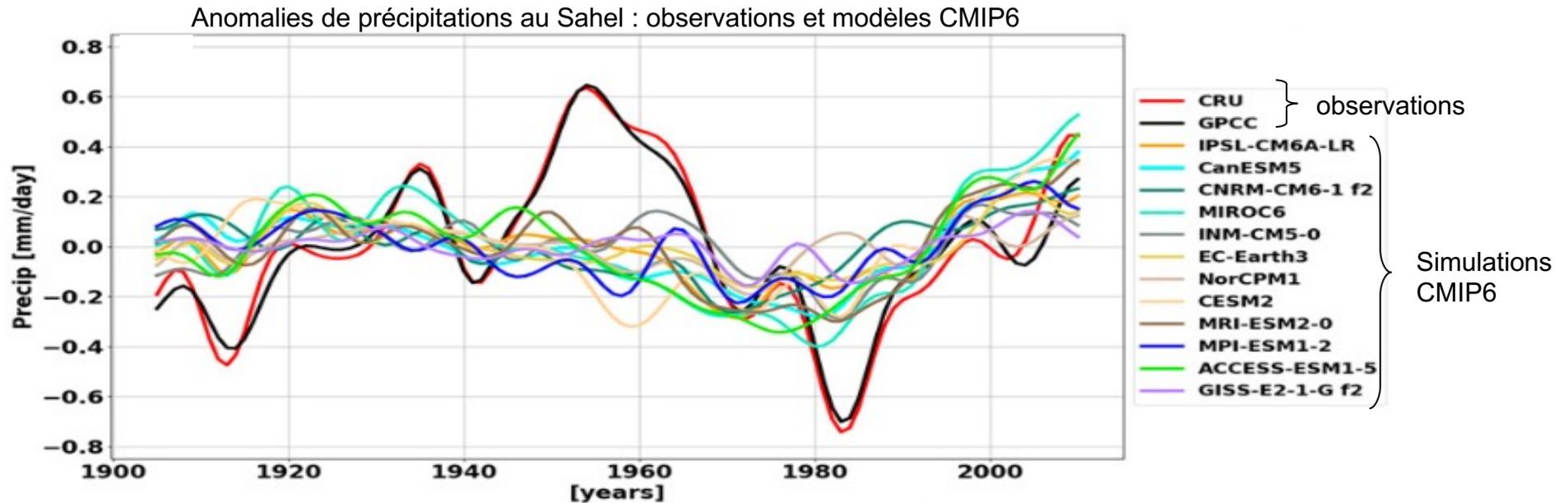


From Sheen et al. (2017)

{
WAWJ = west african westerly jet
WAM = west african monsoon
AEJ = African Easterly Jet
TEJ = tropical Easterly Jet

The climate of the Sahel is part of a very complex large-scale atmospheric circulation.

Motivations



From Ndiaye et al. 2023

Climate models still do not accurately represent the magnitude of observed precipitation in the Sahel.

=> Importance of better understanding the mechanisms behind these variabilities.

Motivations

Many studies highlight the crucial role of sea surface temperature (SST):

At the global scale, through atmospheric teleconnections:

the equatorial Pacific (El Niño–Southern Oscillation), the Mediterranean Sea, and North Atlantic Oscillation (Janicot et al., 2001 ; Rowel et al., 2001 ; Giannini et al., 2003...)

Motivations

Many studies highlight the crucial role of sea surface temperature (SST):

At the regional scale:

The equatorial Atlantic (Atlantic Niño)

The South Tropical Atlantic

The North Tropical Atlantic (NTA)

} Rainfall in the Gulf of Guinea and the Brazilian coasts (Polo et al., 2008 ; Losada et al., 2012 ; Worou et al., 2020...)

Motivations

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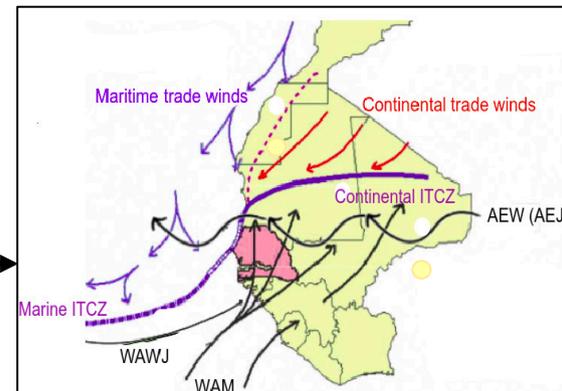
At the regional scale:

The equatorial Atlantic (Atlantic Niño)

The South Tropical Atlantic

The North Tropical Atlantic (NTA)

downstream



atmospheric disturbances (AEWs)

- Rainfall over the WA is insensitive to SST anomalies over the NTA (Vizy and Cook, 2000; Hagos and Cook 2008).
- Active response of NTA on precipitation in the Western Sahel (Wane et al. 2023), air-sea interaction signal around 10°N (Amaya et al., 2017),

Motivations

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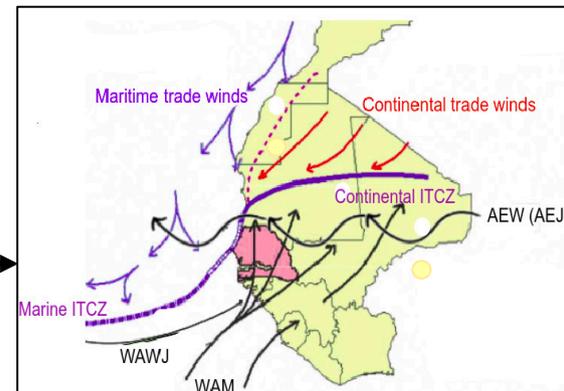
At the regional scale:

The equatorial Atlantic (Atlantic Niño)

The South Tropical Atlantic

The North Tropical Atlantic (NTA)

downstream



atmospheric disturbances (AEWs)

We investigate the atmospheric response to SST anomalies over the NTA.

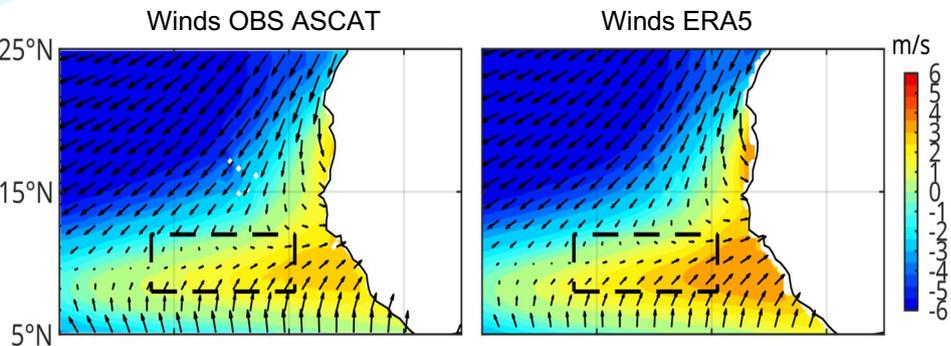
Outlines

- 1. Air-sea interaction in the Northeastern Tropical Atlantic during the summer WAM at intraseasonal time scales**
- 2. Anomaly in SST and atmospheric circulation associated with above-average seasonal rainfall in Senegal**

Outlines

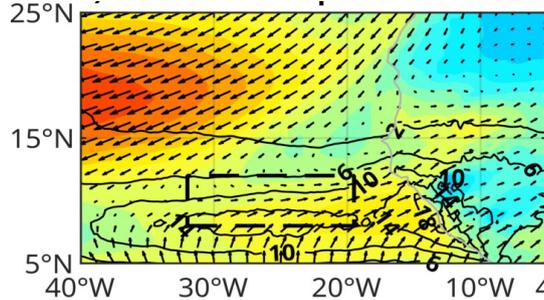
- 1. Air-sea interaction in the Northeastern Tropical Atlantic during the summer WAM at intraseasonal time scales**
2. Anomaly in SST and atmospheric circulation associated with above-average seasonal rainfall in Senegal

JAS mean OBS / ERA5 2009-2020



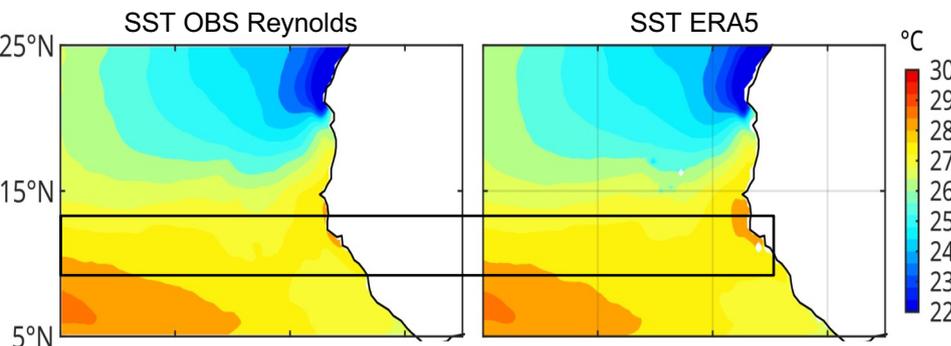
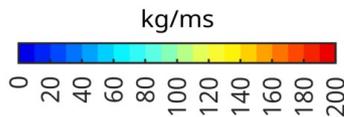
Westerly wind blowing toward the continent

ERA5 Moisture Transport (colors) / PPT (black contours)



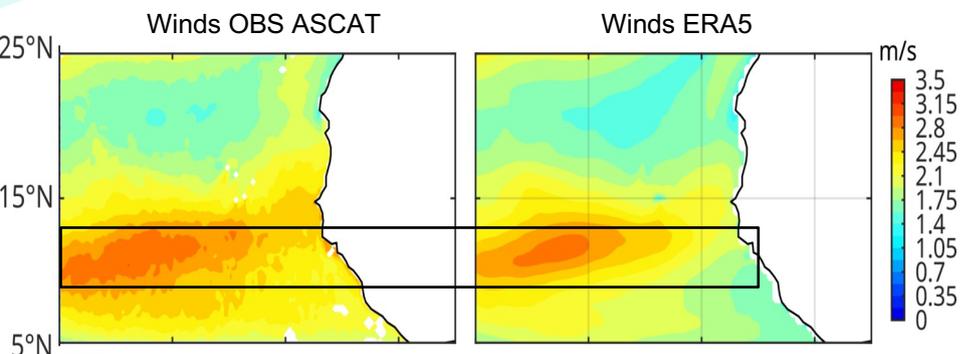
$$MT = \frac{1}{g} \int_{p_b}^{p_t} q \cdot \mathbf{U} \cdot dp$$

Moisture transport toward the continent and rainfall

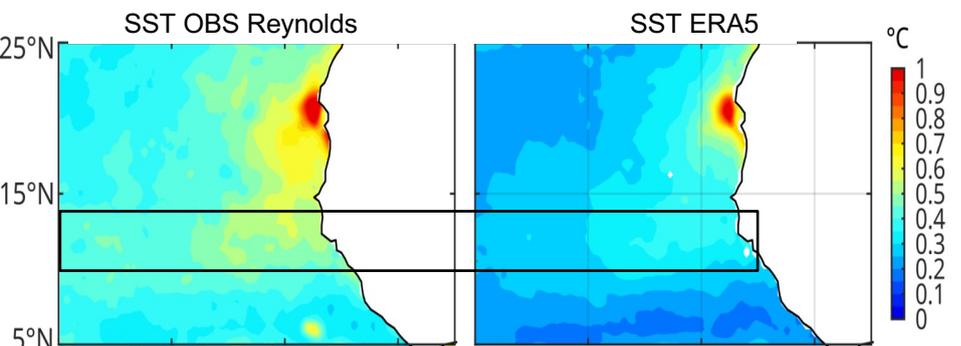
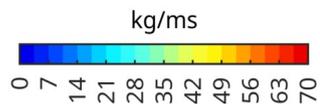
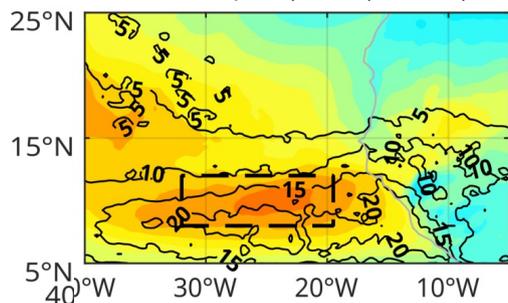


Warm SST between 27-28°C

Intraseasonal variability SST / S. winds



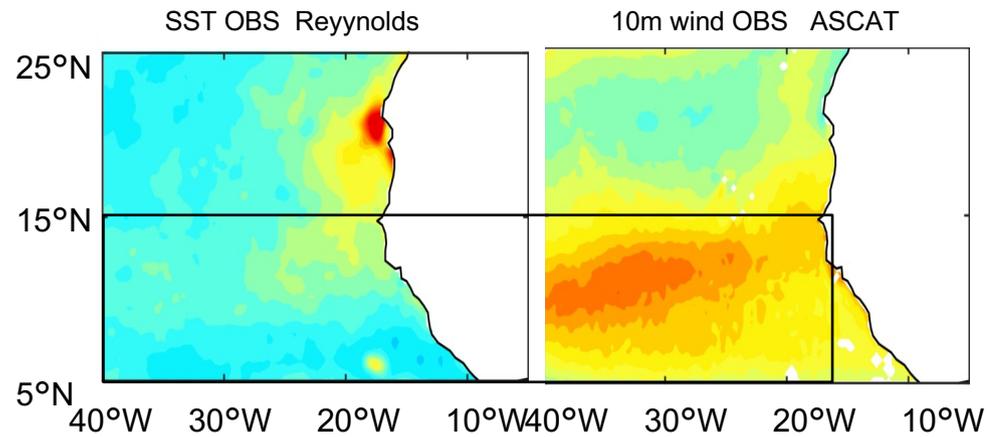
ERA5 Moisture Transport (colors) / PPT (black contours)



Strong intraseasonal variability of the surface wind influence the variability of moisture transport toward the continent

SST variability $\sim 0.5^\circ\text{C}$

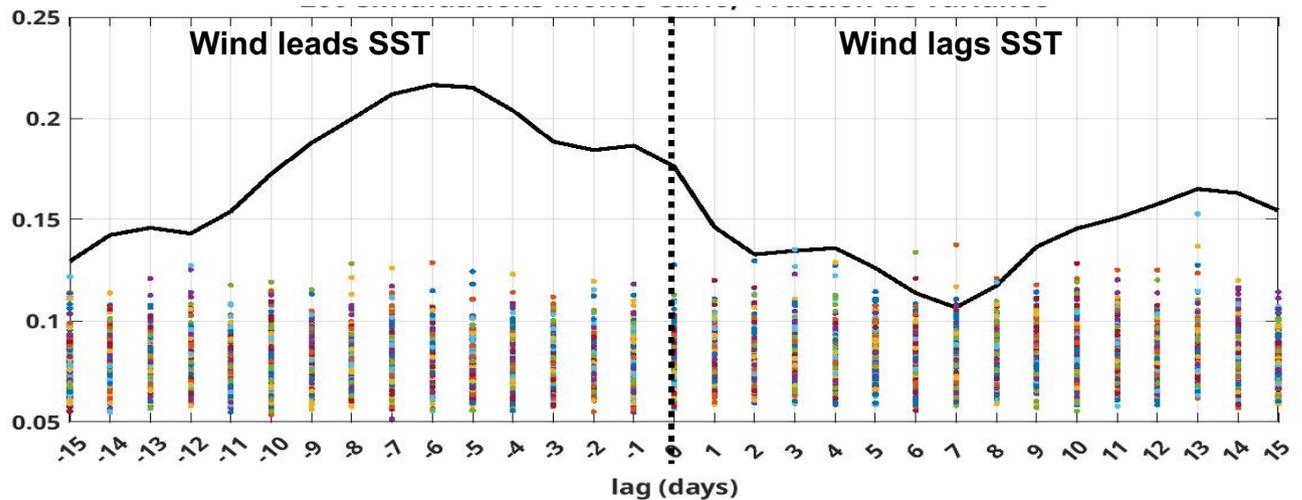
Intraseasonal SST / surface winds mode



Maximum covariance analysis between SST (JAS) and surface wind between 5°N and 15°N

Intraseasonal SST / surface winds mode

a) Covariance index of the leading mode as a function of the time lag between wind and SST



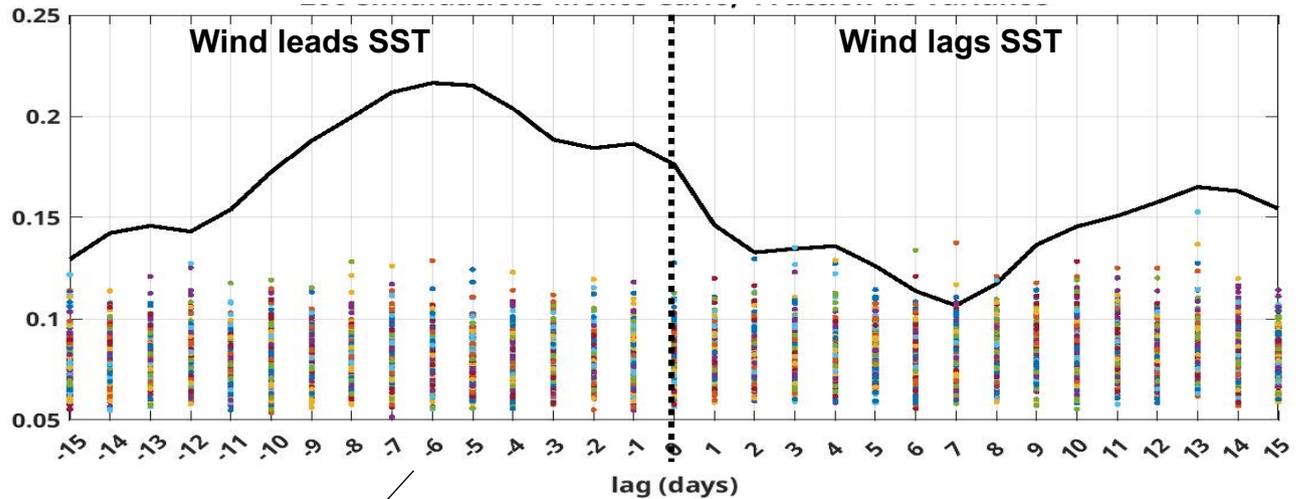
Observational data from **Reynolds SST** and **ASCAT zonal wind** for the **July–September period over 2009–2020** filtered intraseasonally (90-day high pass).

Monte-Carlo tests (200)

- * mode clearly more dominant when the atmosphere leads the ocean (negative lags),
- * less dominant but still significant for more than 2 weeks when the atmosphere lags.

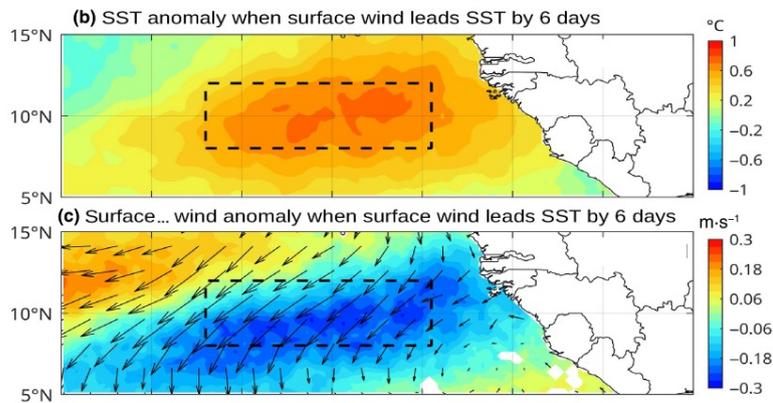
Intraseasonal SST / surface winds mode

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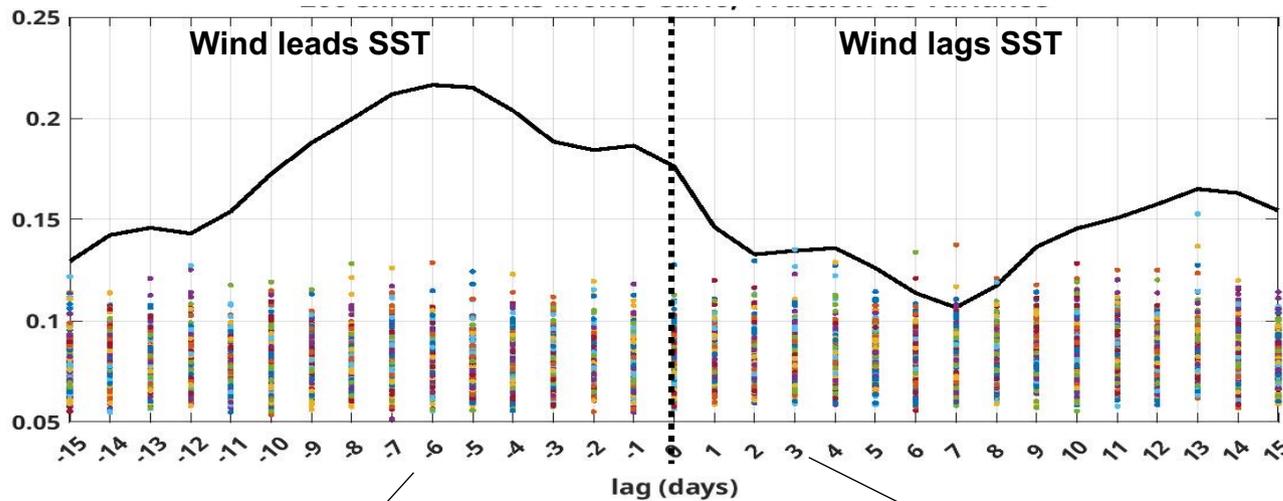
Observational data from Reynolds SST and ASCAT zonal wind for the July–September period over 2009–2020 filtered intraseasonally (90-day high pass).

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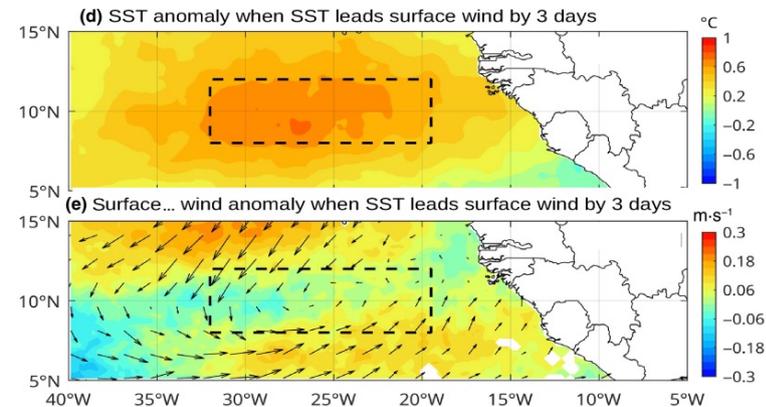
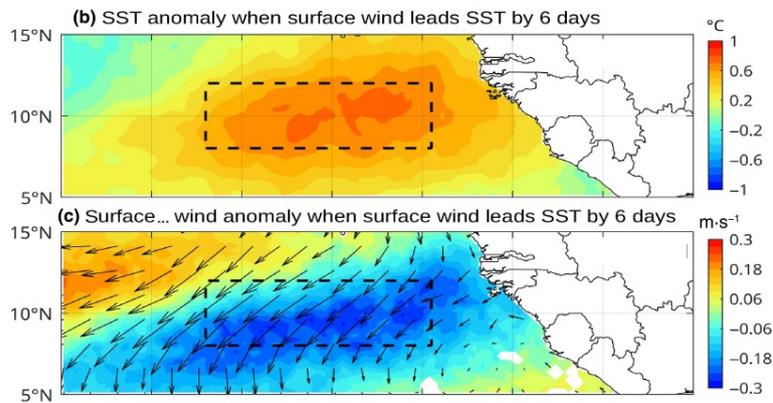
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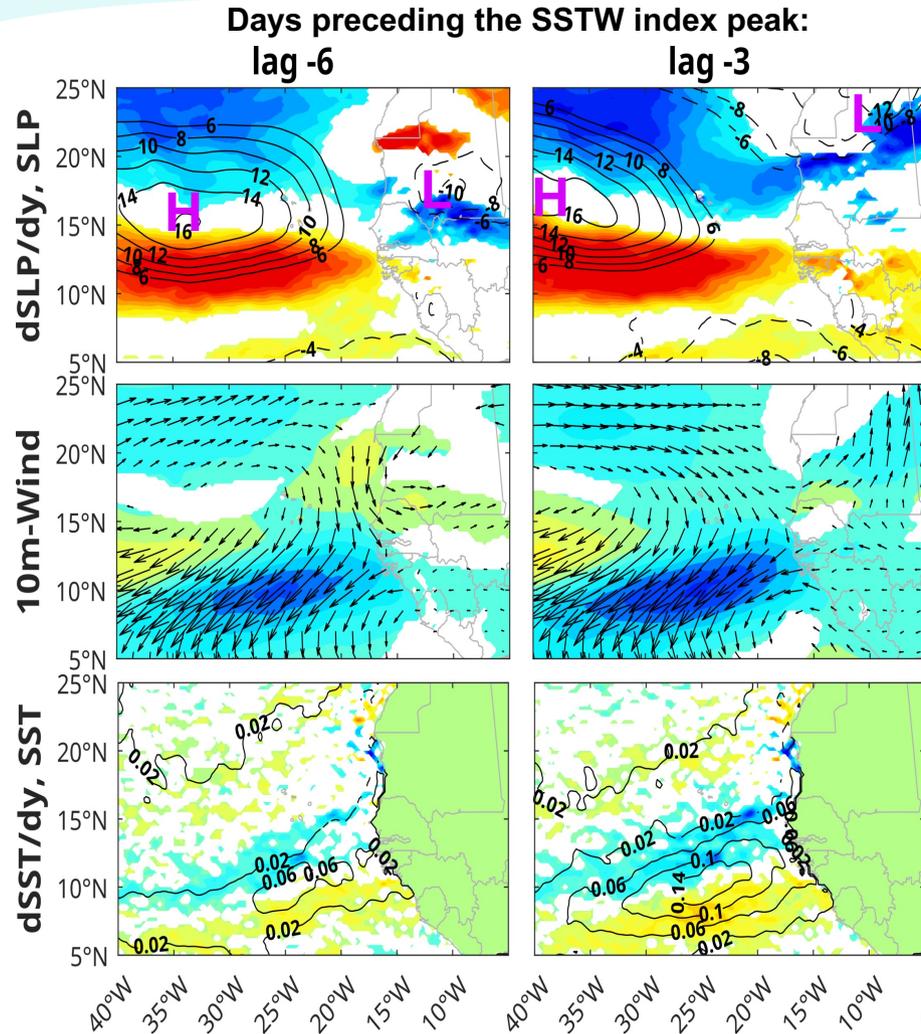
Monte-Carlo tests (200)



SSTW index : time serie in july, august, september (JAS) from filtered intraseasonally (90-day high pass)

Mechanism

ERA5 reanalyses (1 July to 30 September, 2000-2020): anomalies obtained from the linear regression onto the SSTW index

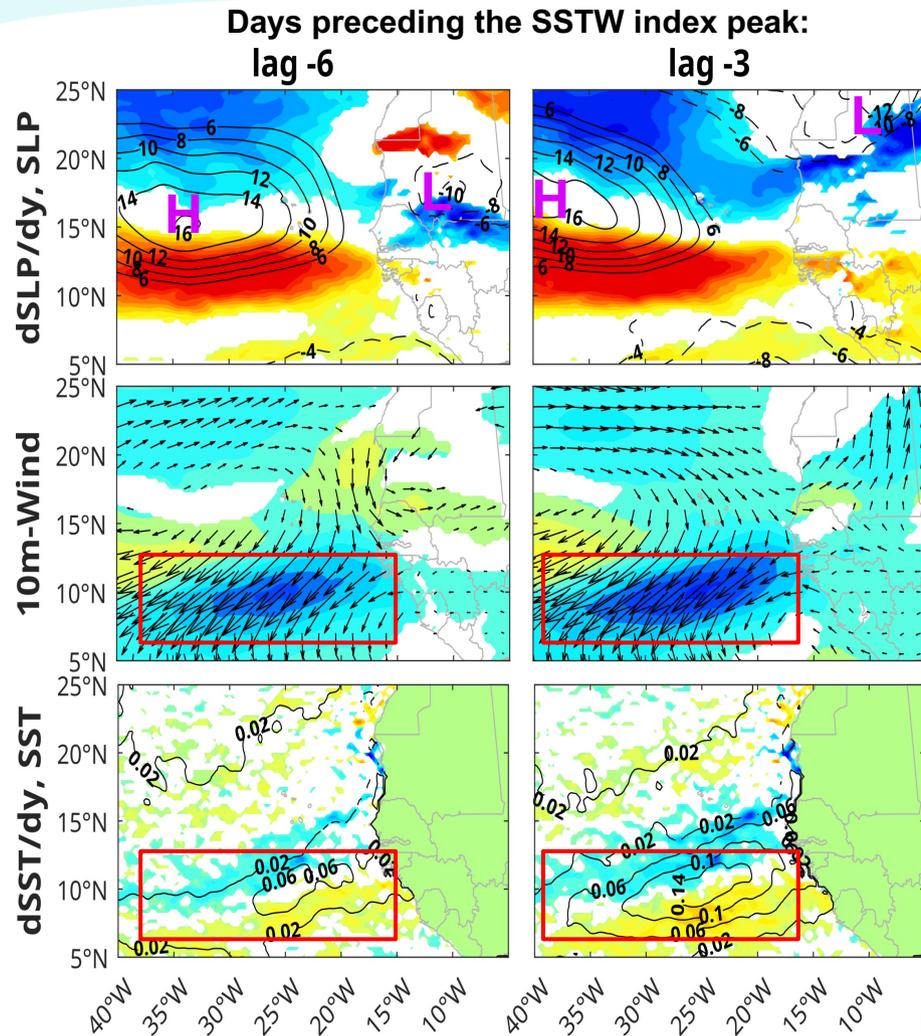


SLP: Sea level pressure
 $dSLP/dy$: meridional gradient of SLP

a positive pressure anomaly (high) forms between 10°N and 25°N and propagates westward, consistent with the passage of an easterly wave.

Mechanism

ERA5 reanalyses (1 July to 30 September, 2000-2020): anomalies obtained from the linear regression onto the SSTW index

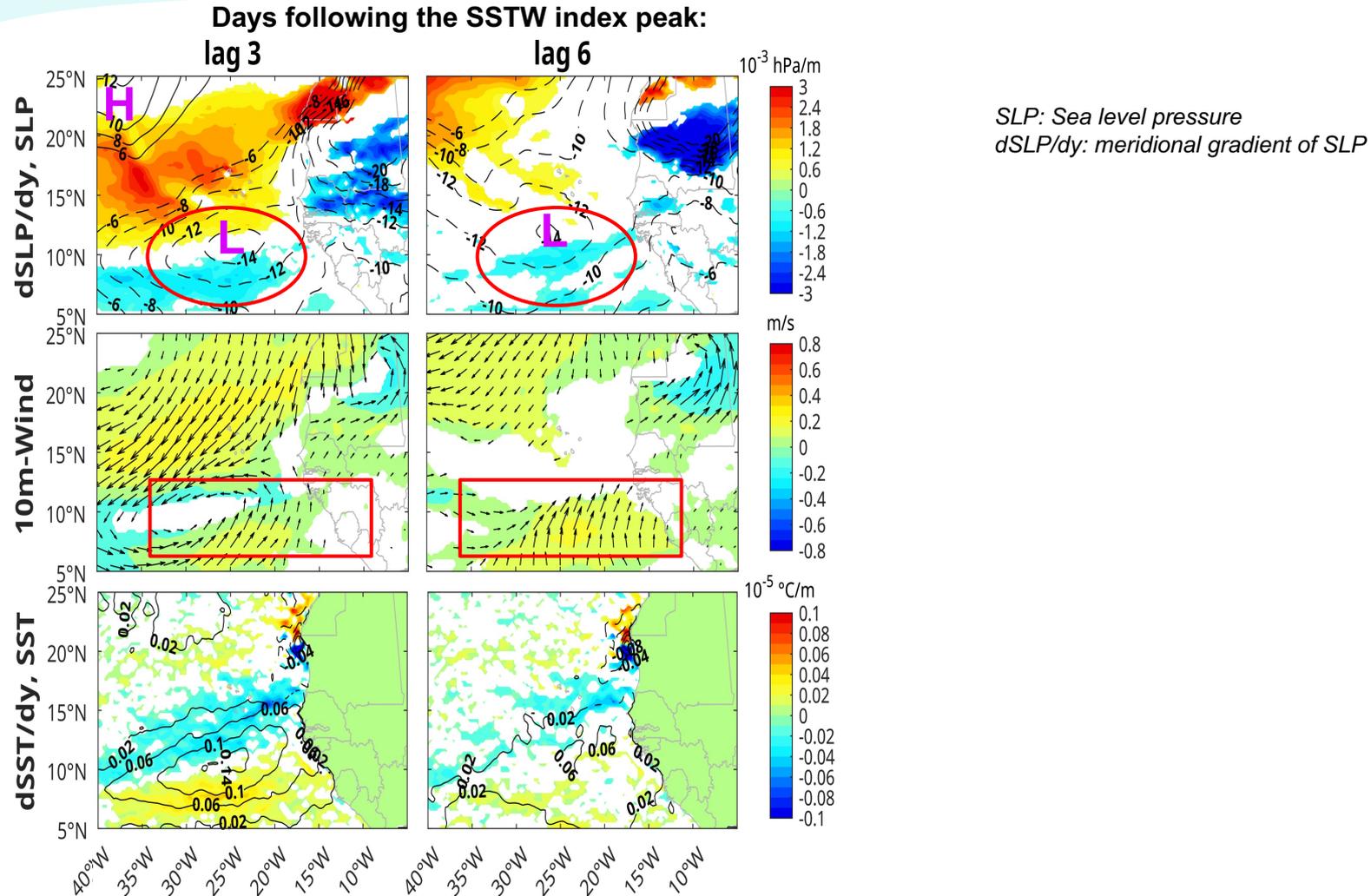


SLP: Sea level pressure
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Weakening of surface winds induces the warm SST anomaly observed between 5°N and 15°N.

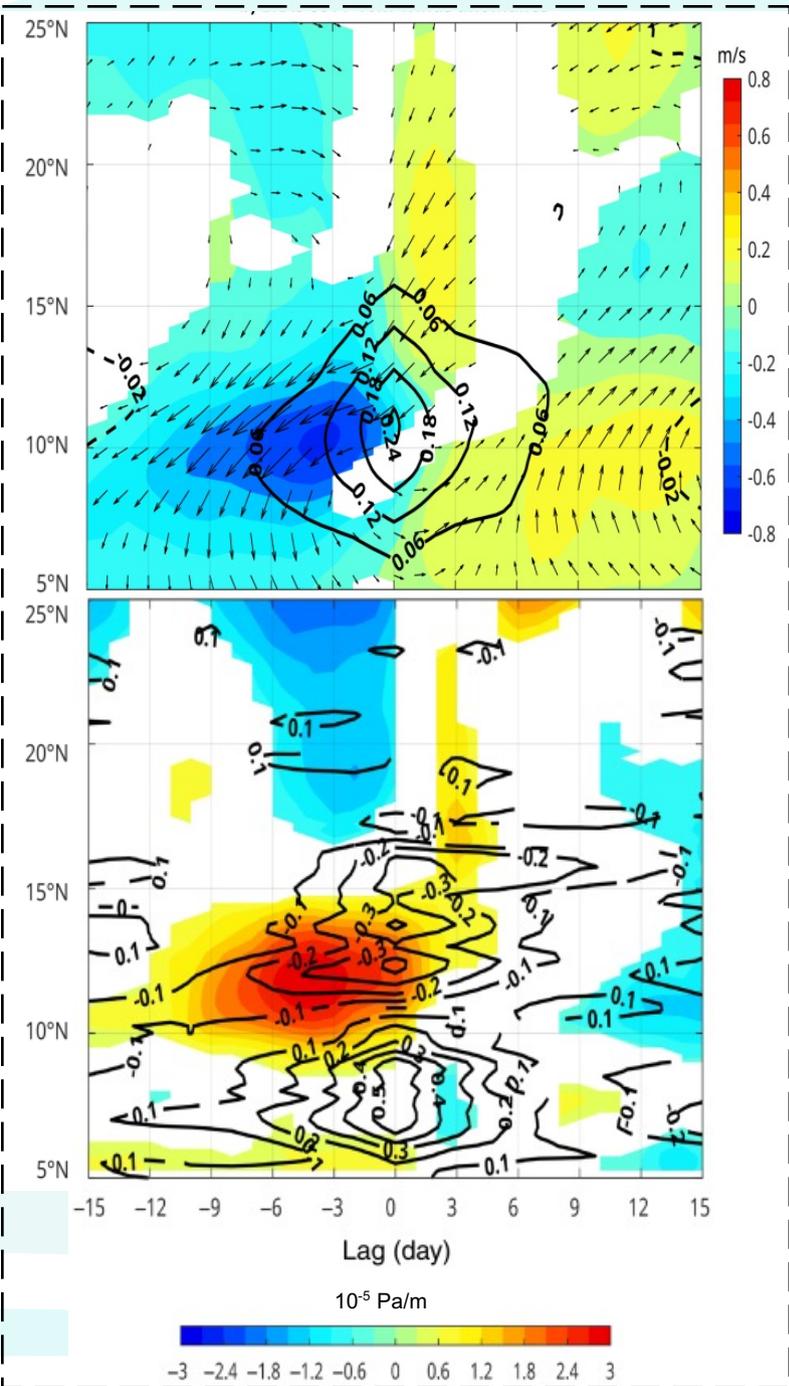
Mechanism

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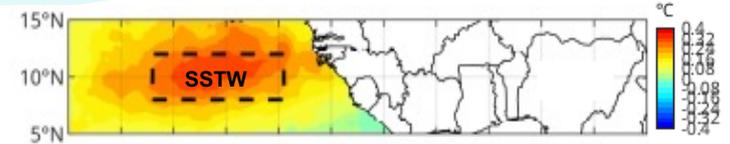


a low-pressure anomaly develops in the NTA region, accompanied by an acceleration of the surface winds slightly farther south

Mechanism



mean over 32°W–19°W



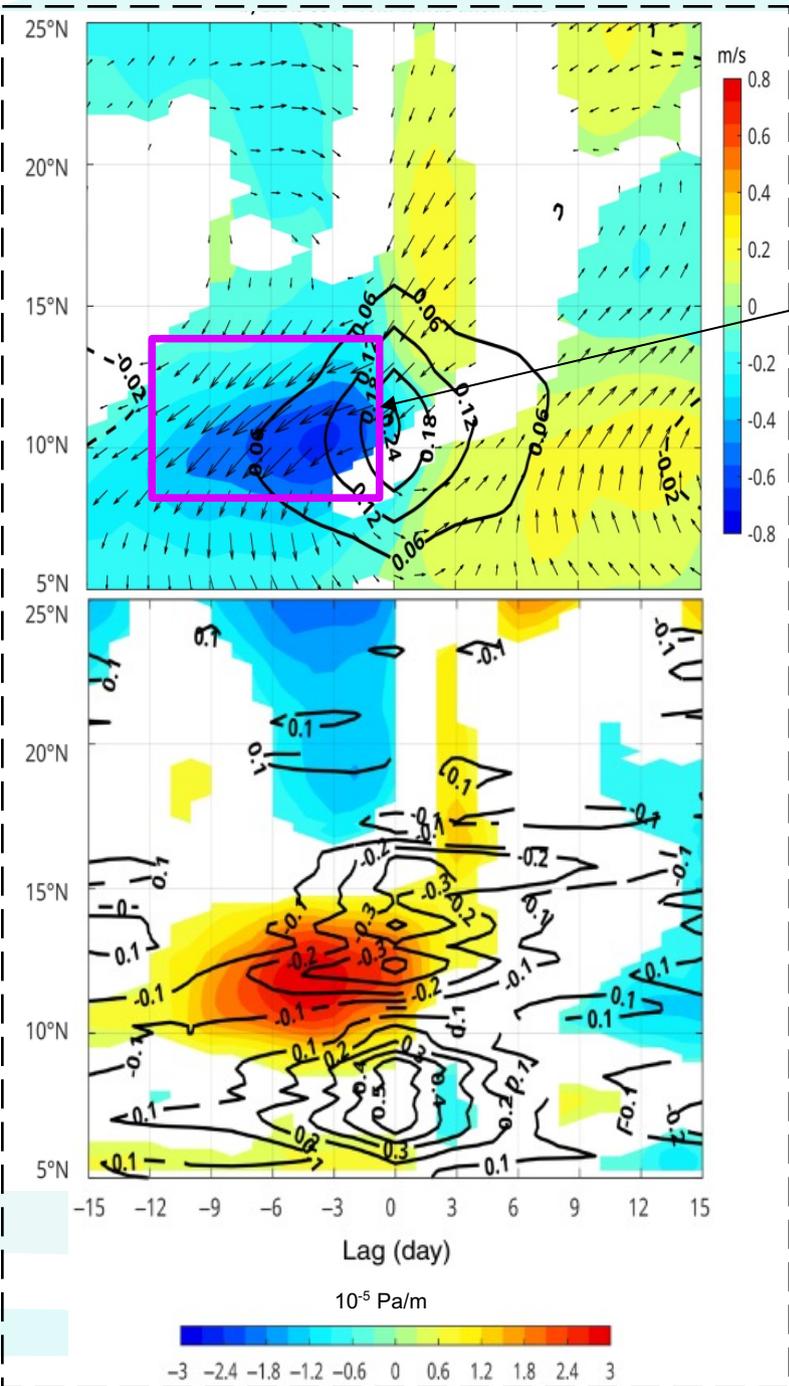
Surface winds anomalies (vitesse en couleurs, m/s)

SST anomalies (black contours, °C)

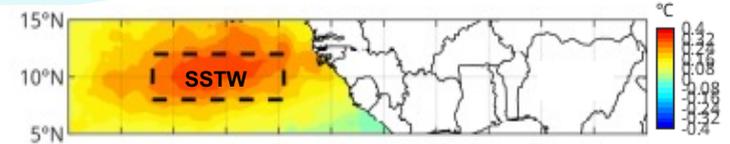
Meridian gradient of atmospheric surface pressure, $dSLP/dy$ (colors, 10^{-5} Pa/m)

Meridian gradient of SST, $dSST/dy$ (black contours, 10^{-5} °C/m)

Mechanism

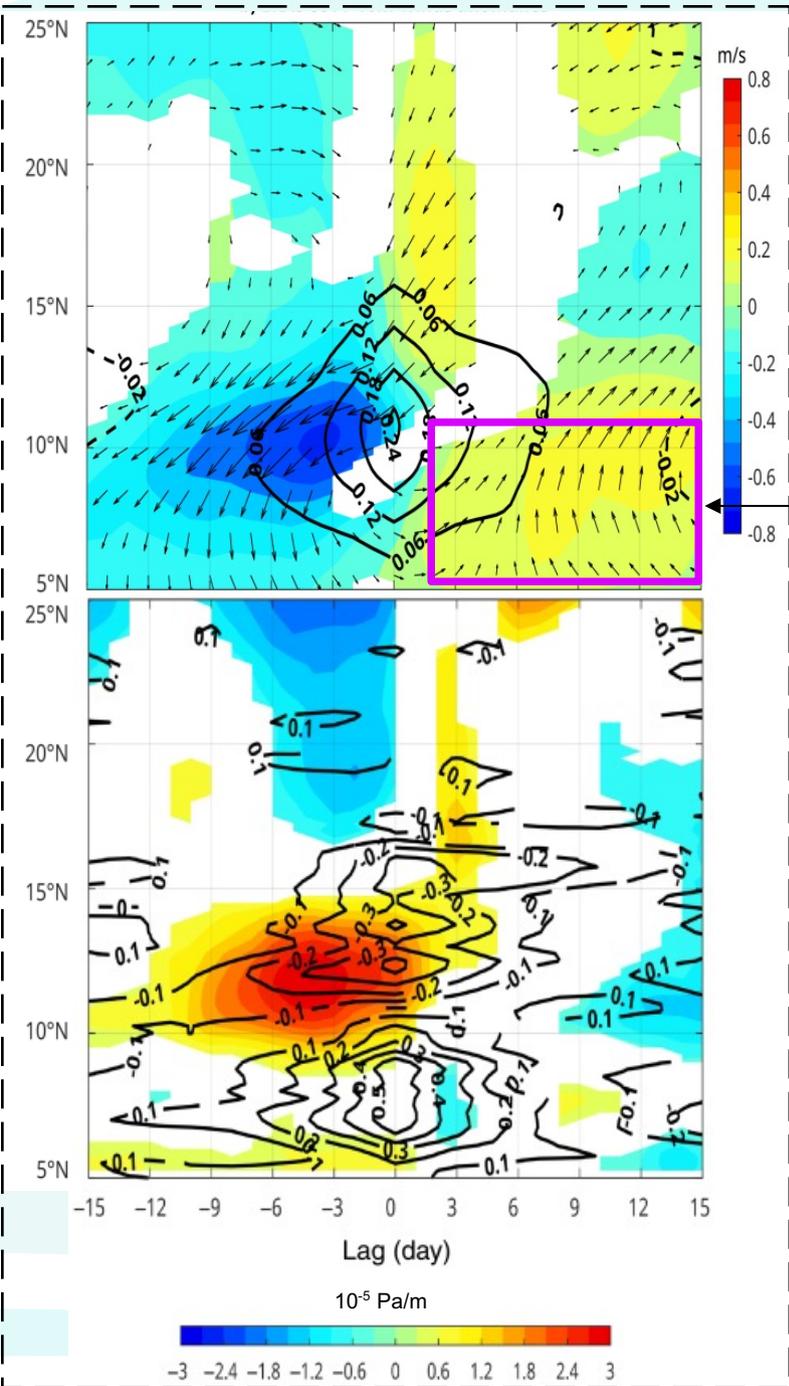


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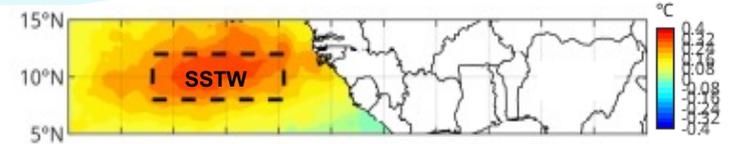


A wind anomaly that forces the SST anomaly,

Mechanism

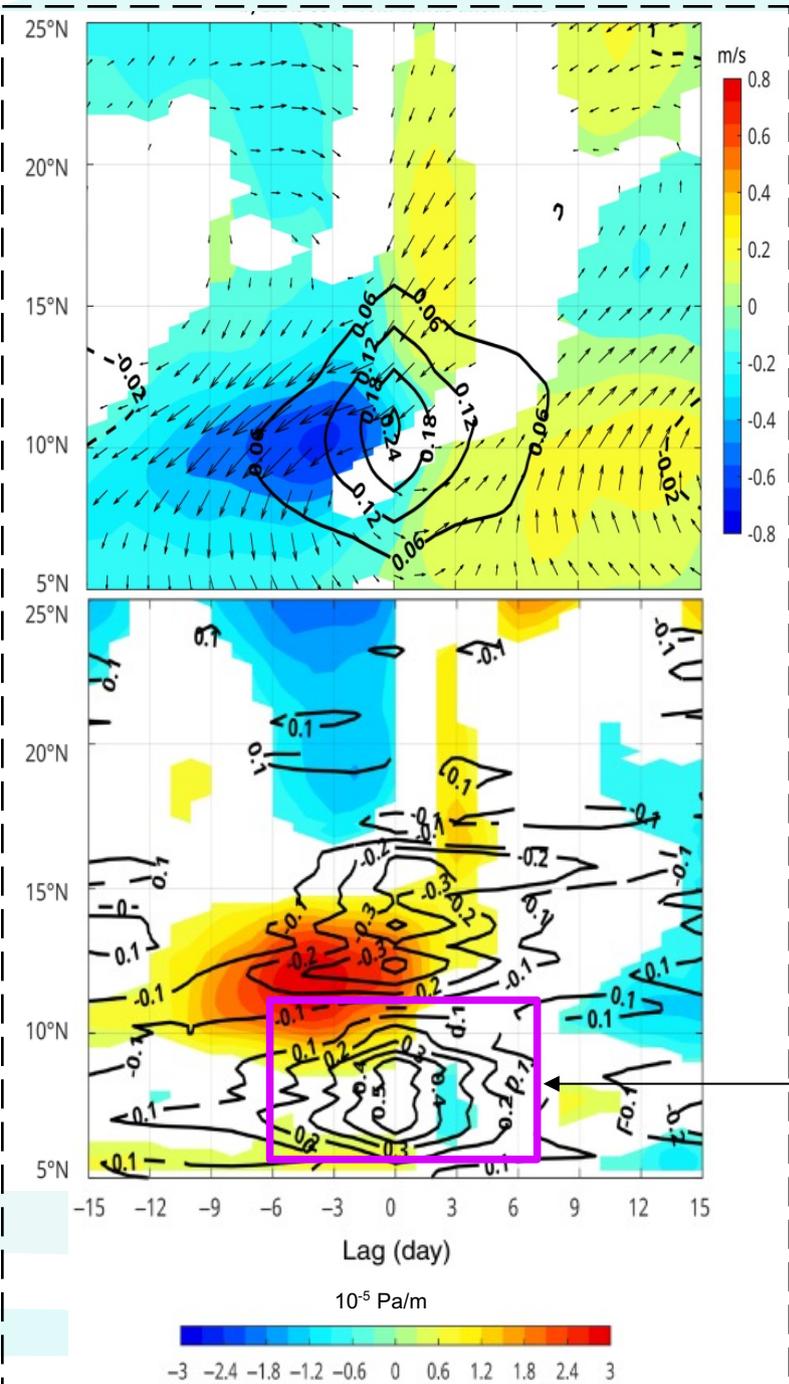


mean over 32°W–19°W

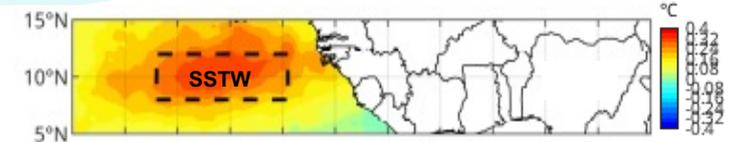


and the warm SST anomaly in turn accelerates the surface wind.

Mechanism

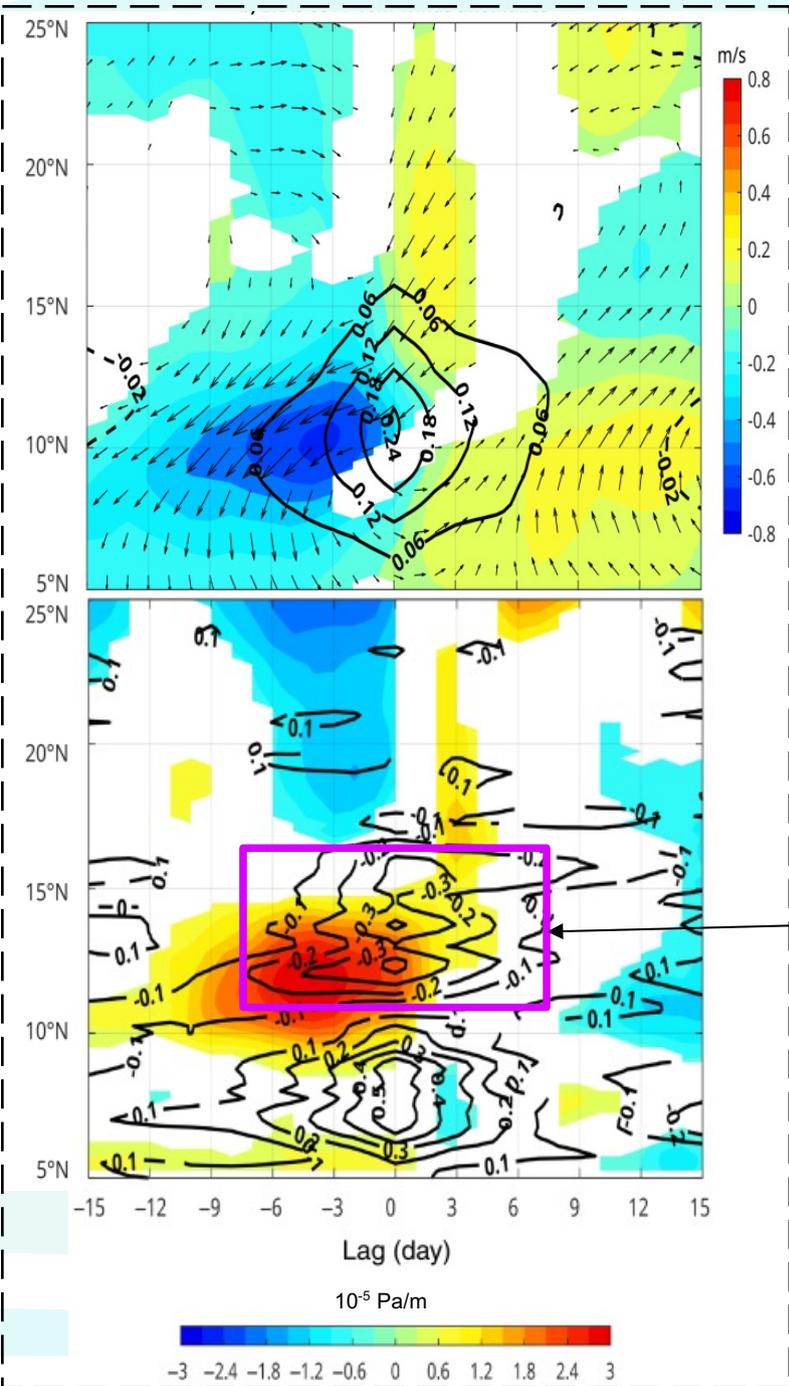


mean over 32°W–19°W

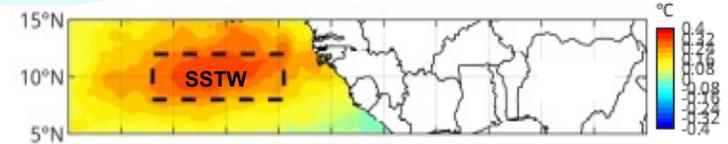


the positive $dSST/dy$ anomaly rapidly dampened the negative anomaly of $dSLP/dy$ (Lindzen et Nigam mechanism, Lindzen and Nigam, 1987) \Rightarrow **negative feedback**

Mechanism

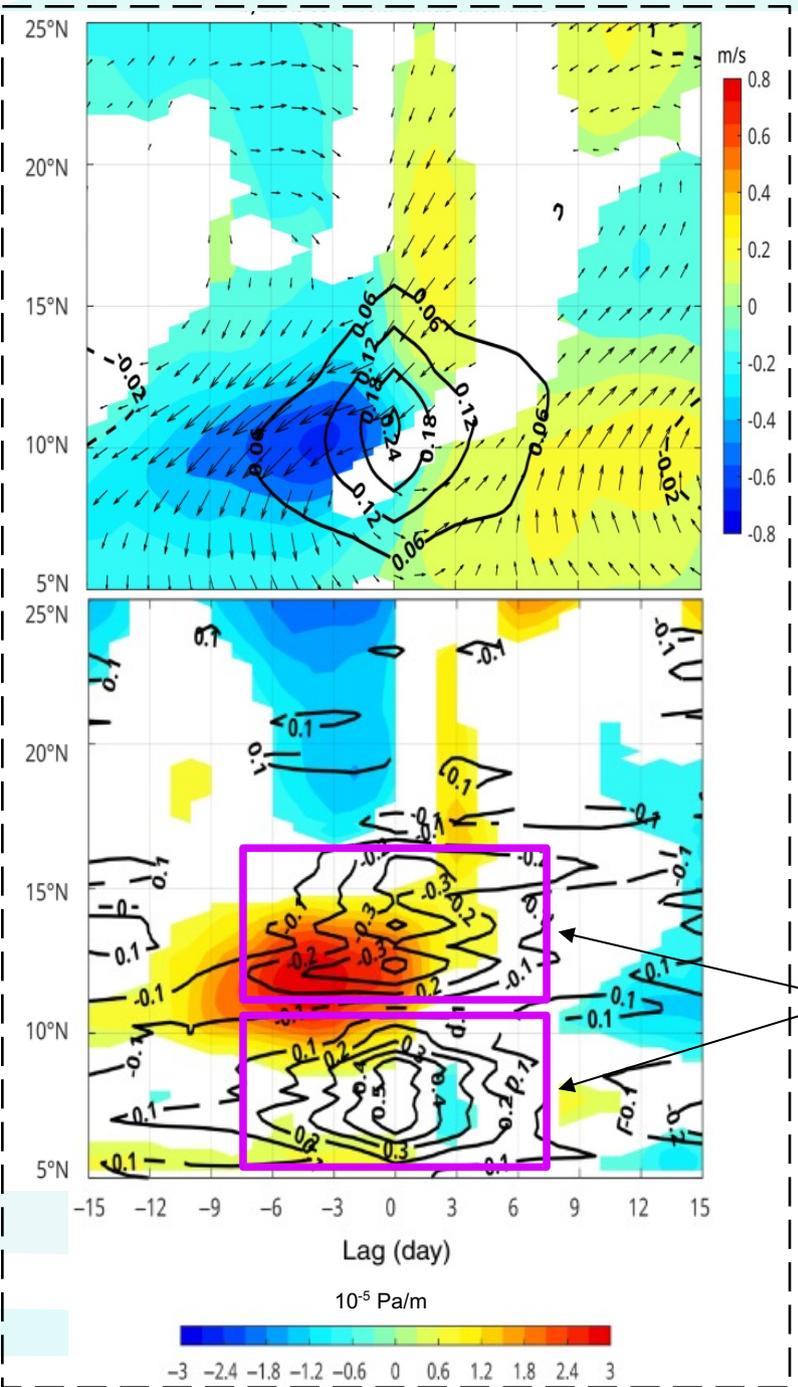


mean over 32°W–19°W

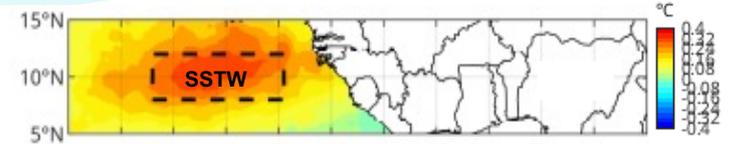


negative $dSST/dy$ anomaly maintains positive $dSLP/dy$ anomaly \Rightarrow **positive feedback**

Mechanism

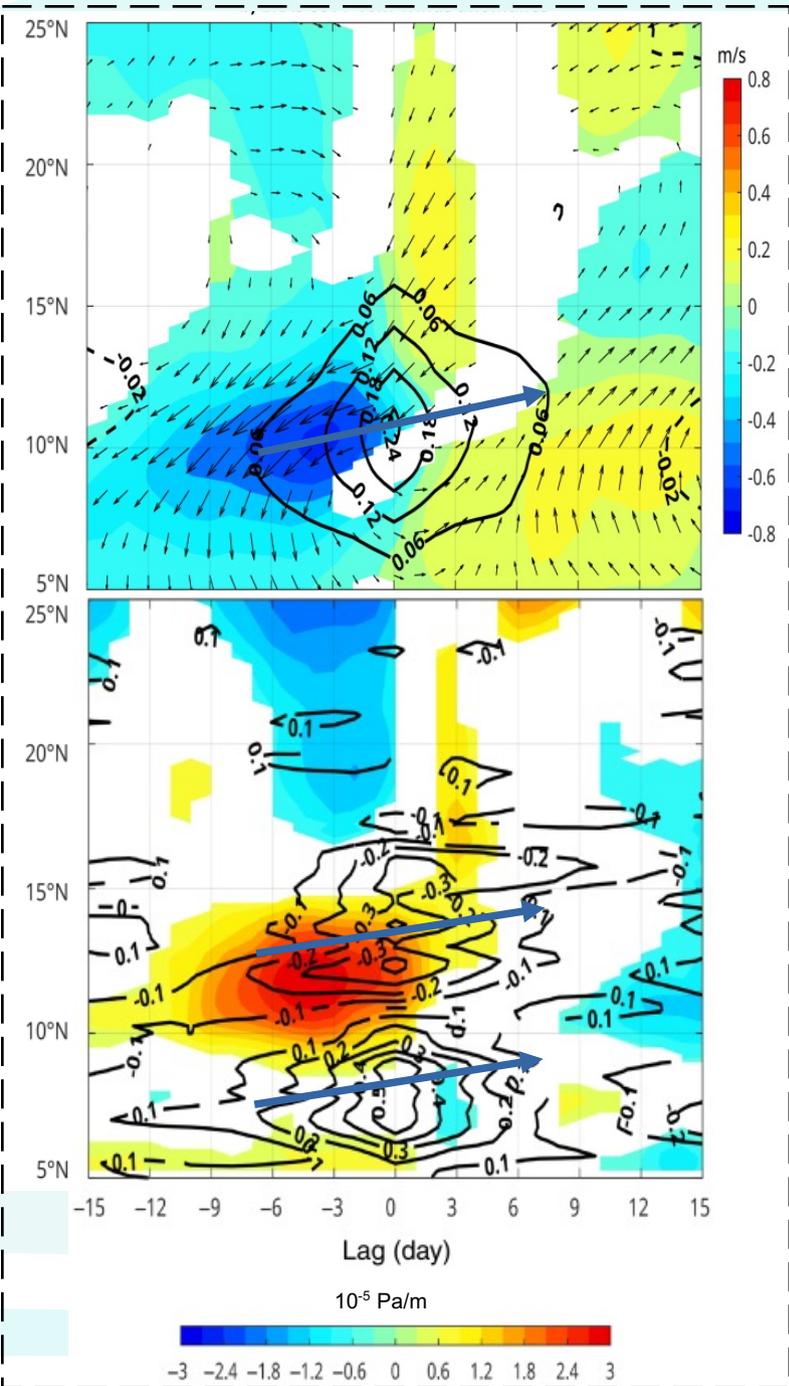


mean over 32°W–19°W

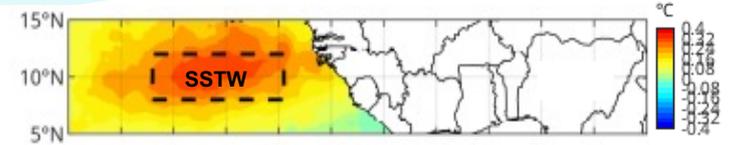


Anomalies sustained in the north and dampened in the south.

Mechanism



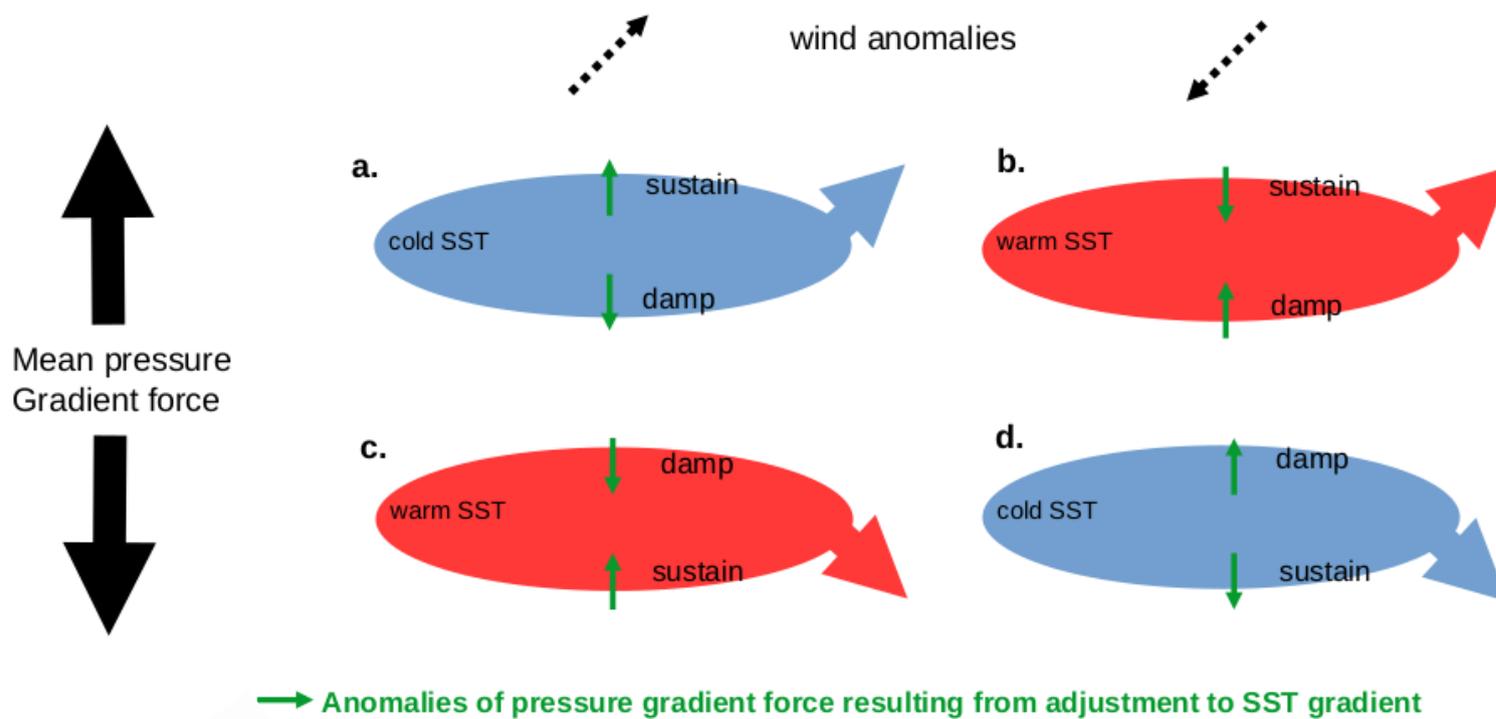
mean over 32°W–19°W



Northward propagation of the anomalies (200-400 km over two weeks)

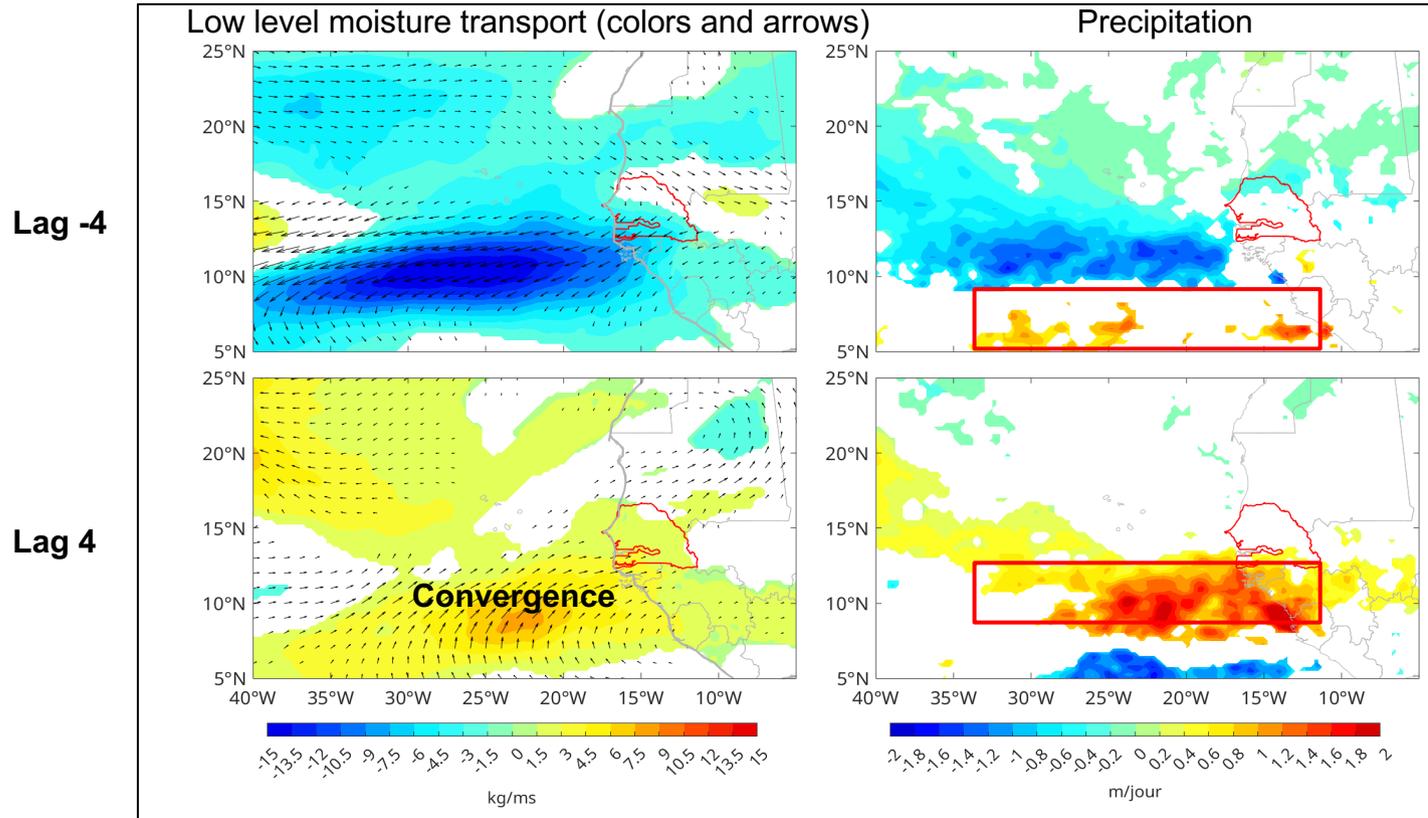
How the surface wind / SST gradient double

feedback mechanism tends to propagate the SST anomaly in the direction of the mean wind ?



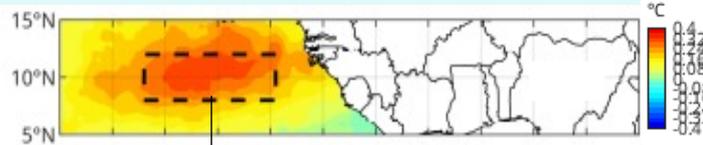
Low level atmospheric circulation response

ERA5 reanalyses (1^{er} July to 30th September, 2000-2020) anomalies obtained from the linear regression onto the SSTW index:

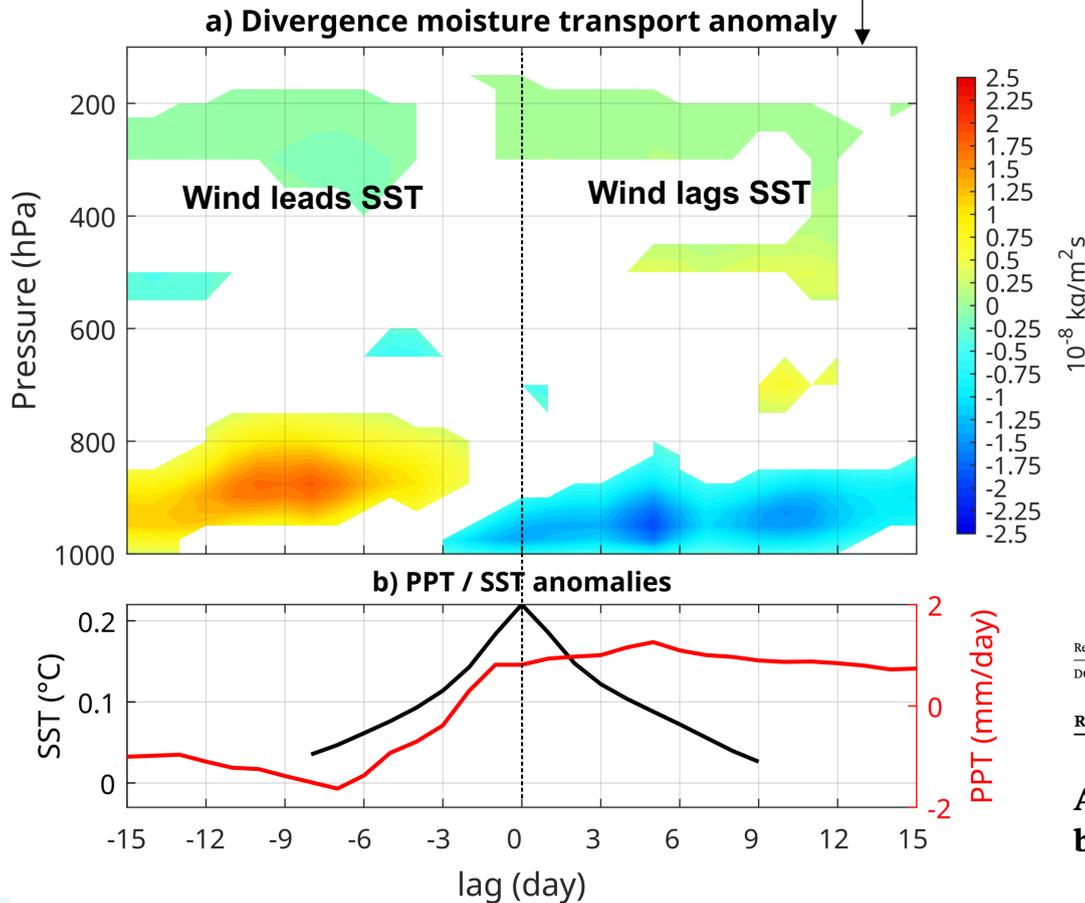


⇒ Northward propagation of rainfall anomalies over a few days.

Tropospheric response



mean over 32°W–19°W and 9°N–13°N



Main signal of moisture below the 700 hPa:

- * divergence of moisture at lags negative \Rightarrow anomaly of precipitation.
- * convergence of moisture transport from the surface after lag -3, forced by the warm anomaly.

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RESEARCH ARTICLE

Air–sea feedback in the northeastern tropical Atlantic in boreal summer at intraseasonal time-scales

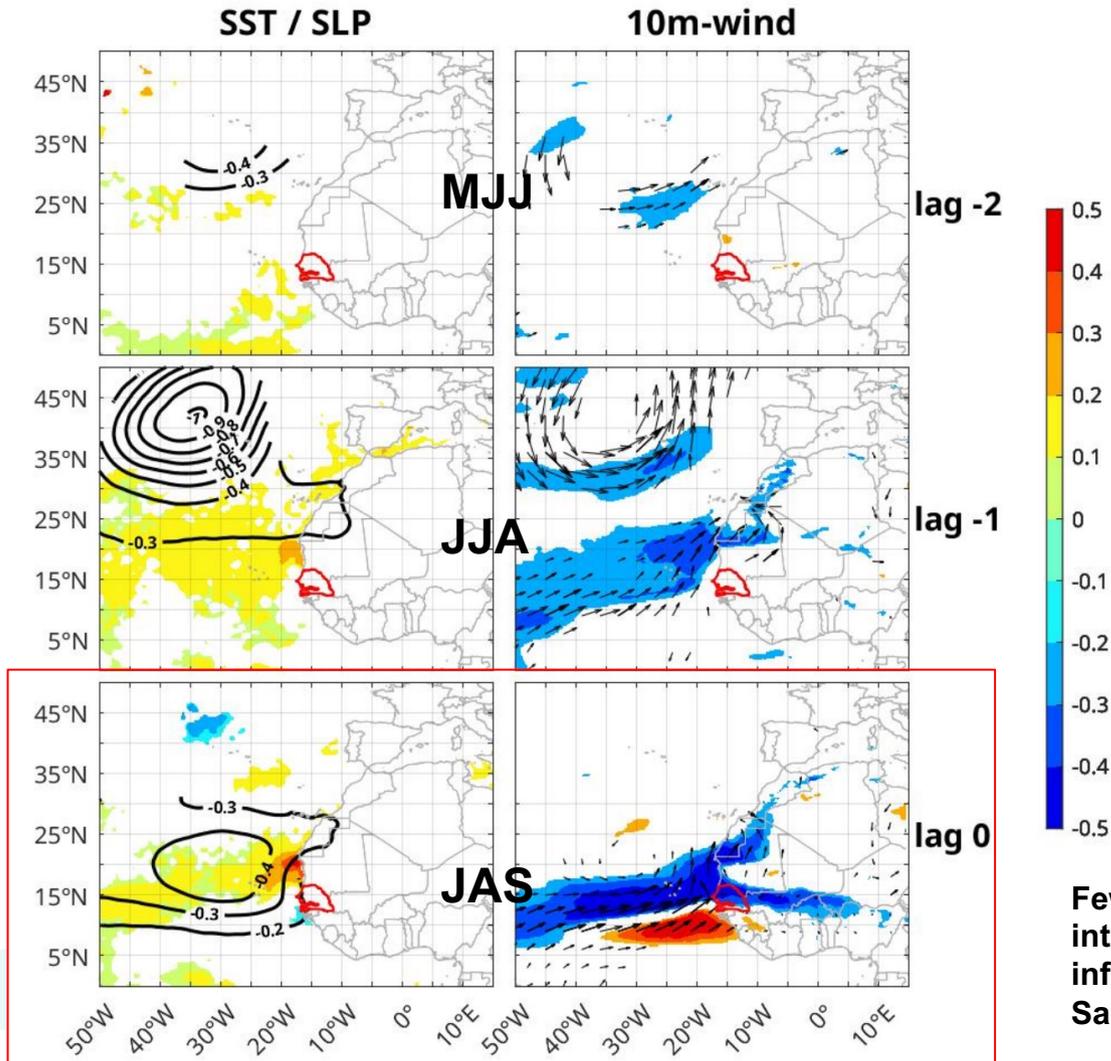
Mamadou Thiam^{1,2} | Gaele de Coetlogon² | Malick Wade¹ | Mamadou Sarr¹ | Bouya Diop¹

Outlines

1. Air-sea interaction in the Northeastern Tropical Atlantic during the summer WAM at intraseasonal time scales
2. **Anomaly in SST and atmospheric circulation associated with above-average seasonal rainfall in the western Sahel**

Anomalies associated with a wetter-than-average rainy season in Senegal ?

Linear regression on the principal component of seasonal precipitation in Senegal, ERA5, monthly JAS 1979–2018 (Thiam et al. 2024)



JGR Atmospheres

RESEARCH ARTICLE
10.1029/2023JD040513

- Key Points:**
- Wet summers in Senegal are preceded by La Niña events and warming in the Mediterranean but also by warming in the Northeastern Tropical Atlantic
 - Moisture transport convergence within a stronger West African Westerly Jet (WAWJ) explains this increase in precipitation
 - Feedback between the North Tropical Atlantic surface temperature and atmospheric pressure is proposed to explain this WAWJ acceleration

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Citation:
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Impact of the Sea Surface Temperature in the North-Eastern Tropical Atlantic on Precipitation Over Senegal

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¹Laboratoire des Sciences de l'Atmosphère et des Océans—Matériaux, Énergie et Dispositifs (LSAO-MED), Université Gaston Berger, Saint-Louis, Sénégal, ²Laboratoire Atmosphère et Observations Spatiales (LATMOS), Sorbonne Université, Paris, France

Abstract This study examines 40 years of monthly precipitation data in Senegal (1979–2018) using Climatic Research Unit observations and ERA5 reanalyses, aiming to understand the influence of oceanic and atmospheric factors on Senegal's precipitation in July, August and September (JAS). The variability of Senegal's precipitation is first compared with that of the broader Sahel region: although they share a significant portion of their variance, Senegal appears more closely related to the Northeastern Tropical Atlantic (NETA) Sea Surface Temperature (SST). A detailed examination of this region reveals that Senegal's increased precipitation is linked to the northward shift of the InterTropical Convergence Zone, consistent with numerous previous studies. Over the continent, this shift corresponds to a northward shift of the African Easterly Jet (AEJ) and, consequently, the mesoscale convective systems (MCSs) responsible for most precipitation. It seems primarily driven by the northward shift of the Heat Low. Over the ocean just west of Senegal, there is a comparable shift of the AEJ, accompanied by an increase in low-level moisture transport convergence within the West African Westerly Jet (WAWJ) which explains the majority of the increase in JAS precipitation in Senegal. This phenomenon is triggered by a negative pressure anomaly in the NETA, located above a positive SST anomaly; we suggest that the latter is the origin of the former, forming a feedback mechanism that potentially significantly influences Senegal's precipitation. The mechanism involves a geostrophic adjustment of the WAWJ to the southern gradients of the SST anomaly.

Plain Language Summary This study, spanning 40 years of monthly precipitation data in Senegal,

Warm SST , SLP - ⇒ 10m-wind, north of the ITCZ and warm the SST (positive feedback)

10m wind strengthen south ⇒ shift north of the ITCZ

Few weeks persistence on NETA coupled mode at intraseasonal time scale → probably has a significant influence on the seasonal cycle of precipitation in the West Sahel.

Conclusions

Intraseasonal coupled variability mode between SST and surface wind in the Northeastern Tropical Atlantic (NETA):

- * Warm SST anomalies are significantly covariant with a weakening of the surface wind north of 8°N and a strengthening to the south.
- * A reversal of the zonal wind occurs when wind responds to SST anomalies within 1 to 2 weeks ⇒ **negative feedback**.
- * The persistence of the signal is due to positive feedback north of the warm anomaly, which shifts the anomalies northward.
- * These intraseasonal mechanisms may partly control **the seasonal northward** migration of the ITCZ.

What's next ?

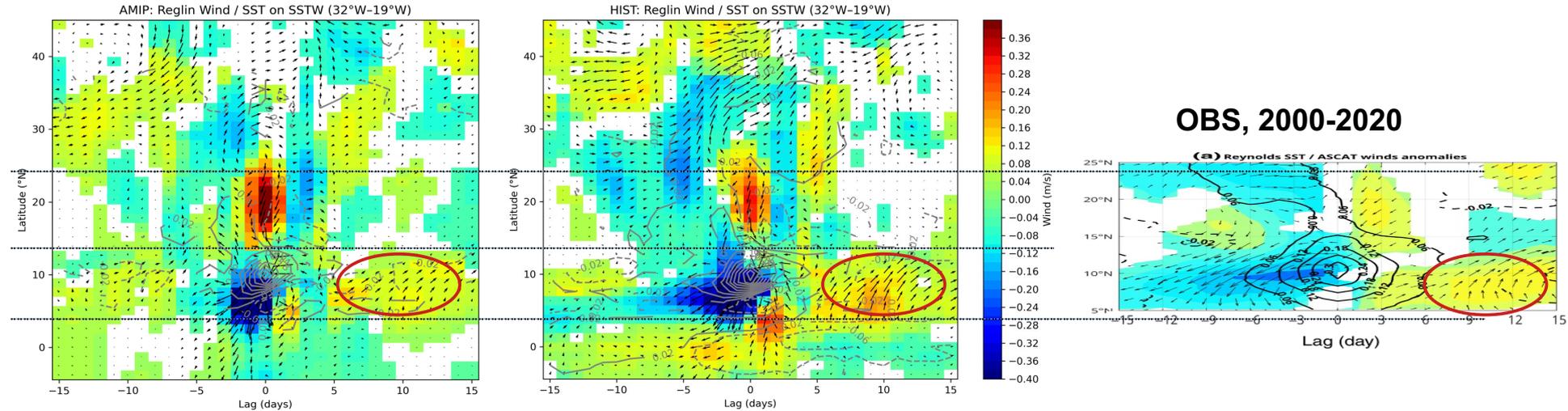
Can climate models represent the atmospheric response to local SST anomalies in the NETA?

Linear regression of air temperature and 10-m wind onto the SSTW index based on WAWJ air temperature, 1979–2014

AMIP

CMIP

OBS, 2000-2020



Greater atmospheric response on the coupled model than on the forced model

AMIP: Atmospheric model forced by observed SST
CMIP: Coupled ocean-atmosphere model



Thank you