The Roles of Climate Change and Climate Variability in the 2017 Atlantic Hurricane Season

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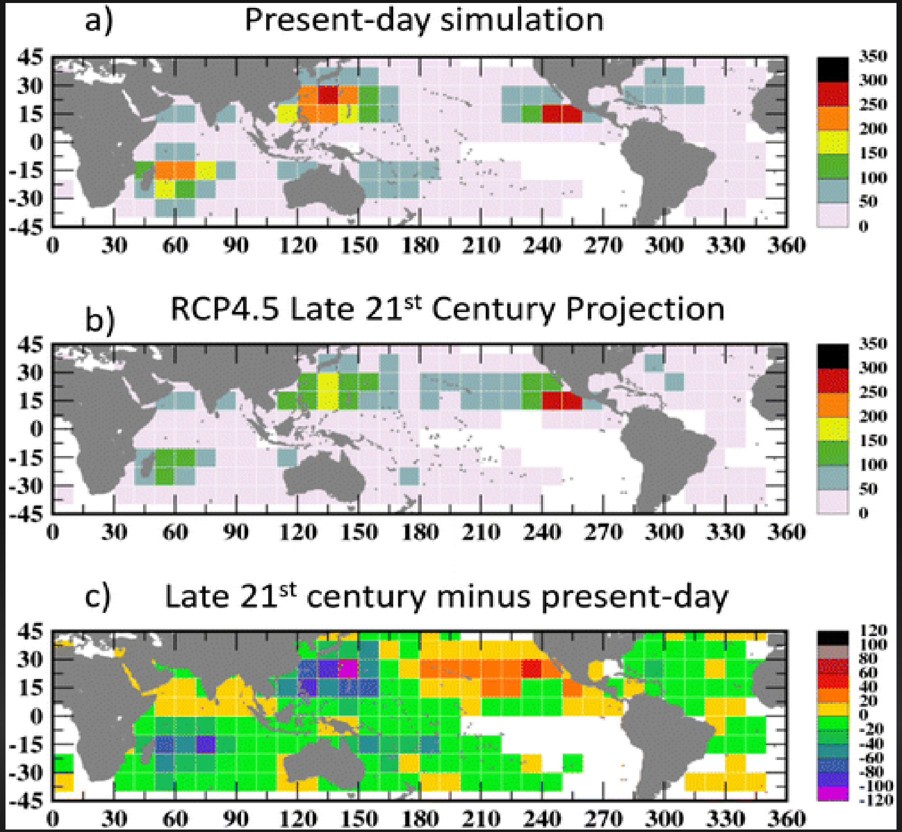
Extremely active Atlantic hurricane season in August/September 2017

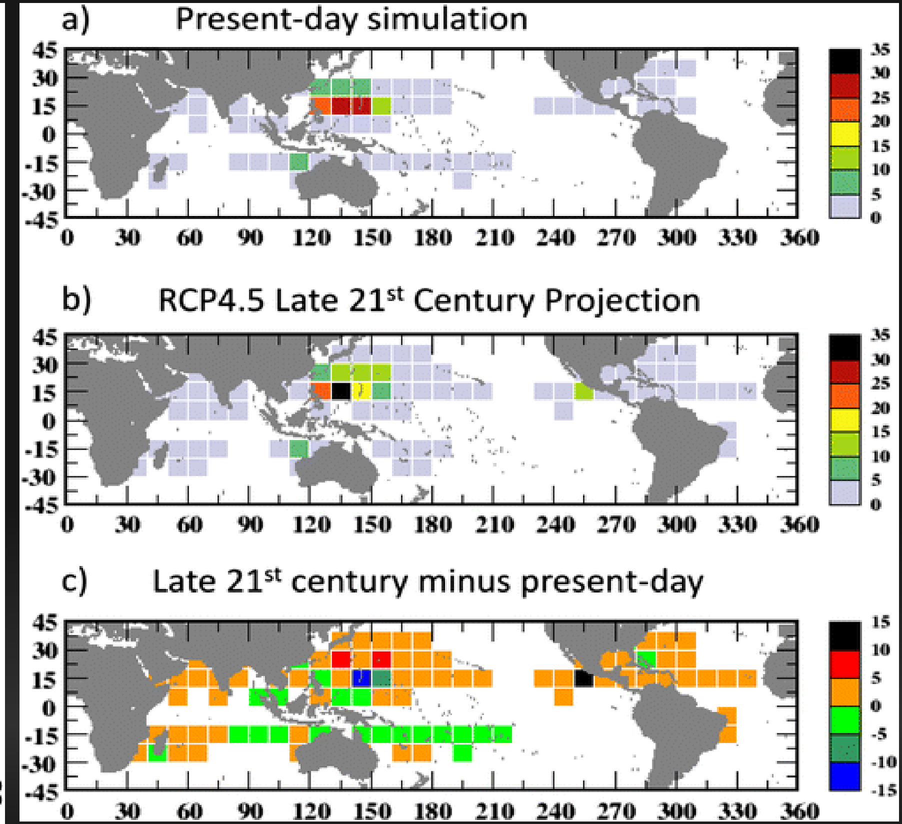
1. **Six major hurricanes** (two of them Category 5 (Irma and Maria)).
2. **The third highest number of major hurricanes** (exceeded only by the 1961 and 2005).
3. **10 consecutive named storms have strengthened into hurricanes.**
4. **Quick growth to hurricane level** and **long life times** (Harvey, Irma, Jose, and Maria).
5. **The fourth largest total accumulated cyclone energy (ACE)** since 1950.
6. **The ACE for September 2017: the largest ACE in a single month** in the Atlantic basin.

Tropical cyclone activity under climate change (previous study)

The number of storms



Intense storms (Cat. 4 & 5)



Present (P)

Climate change (CC)

CC minus P

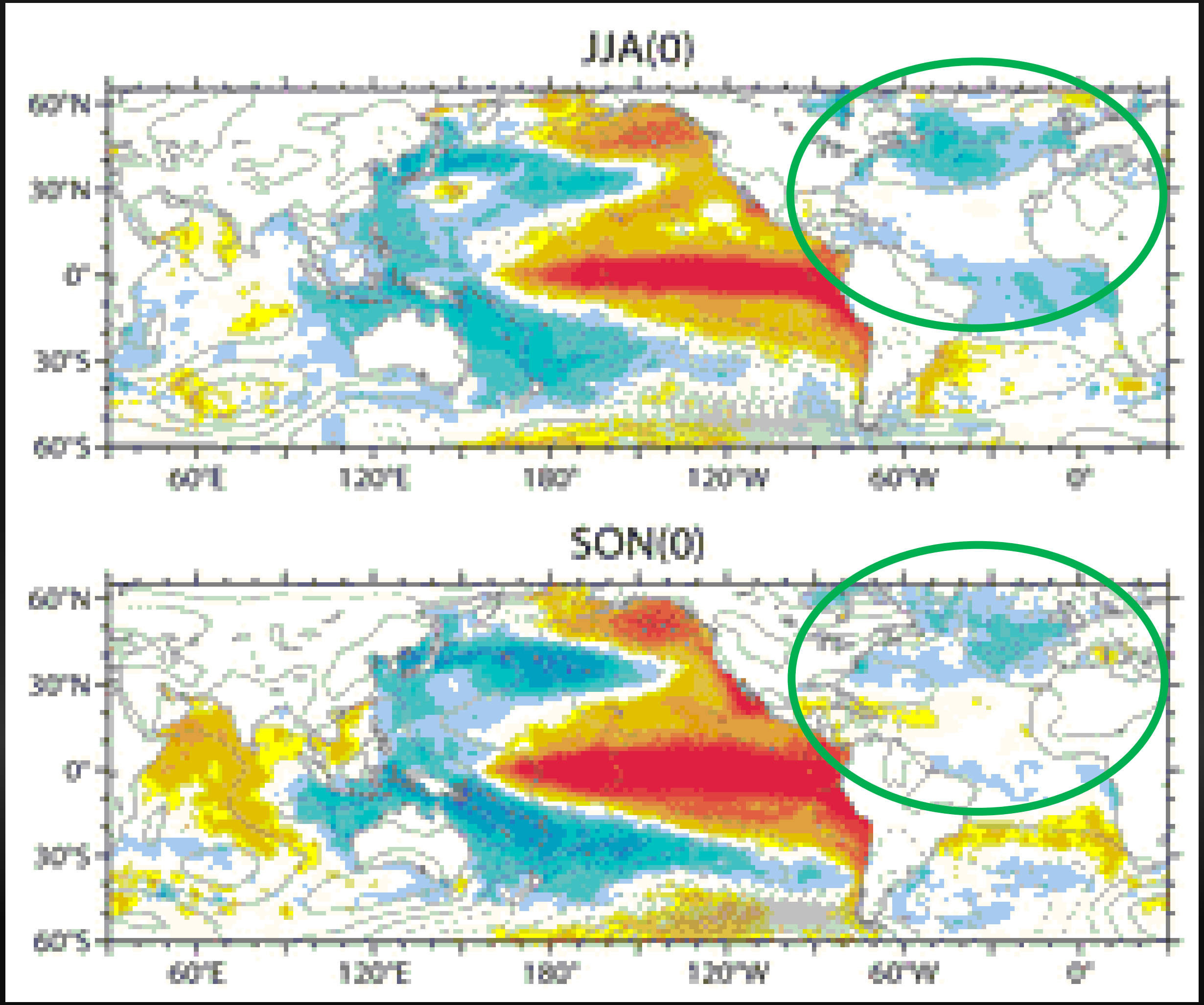
Knutson et al. (2015)
J. Climate

Fewer TCs in a warmer climate, but also an increase in the number and occurrence days of very intense TCs.

Large consumption of the evaporating moisture → more possibility of intense TCs → large cooling effect over ocean → less TC genesis

Wind current slowed down by climate change → slowly moving TCs

The leading climate variability that impacts the North Atlantic TC activity

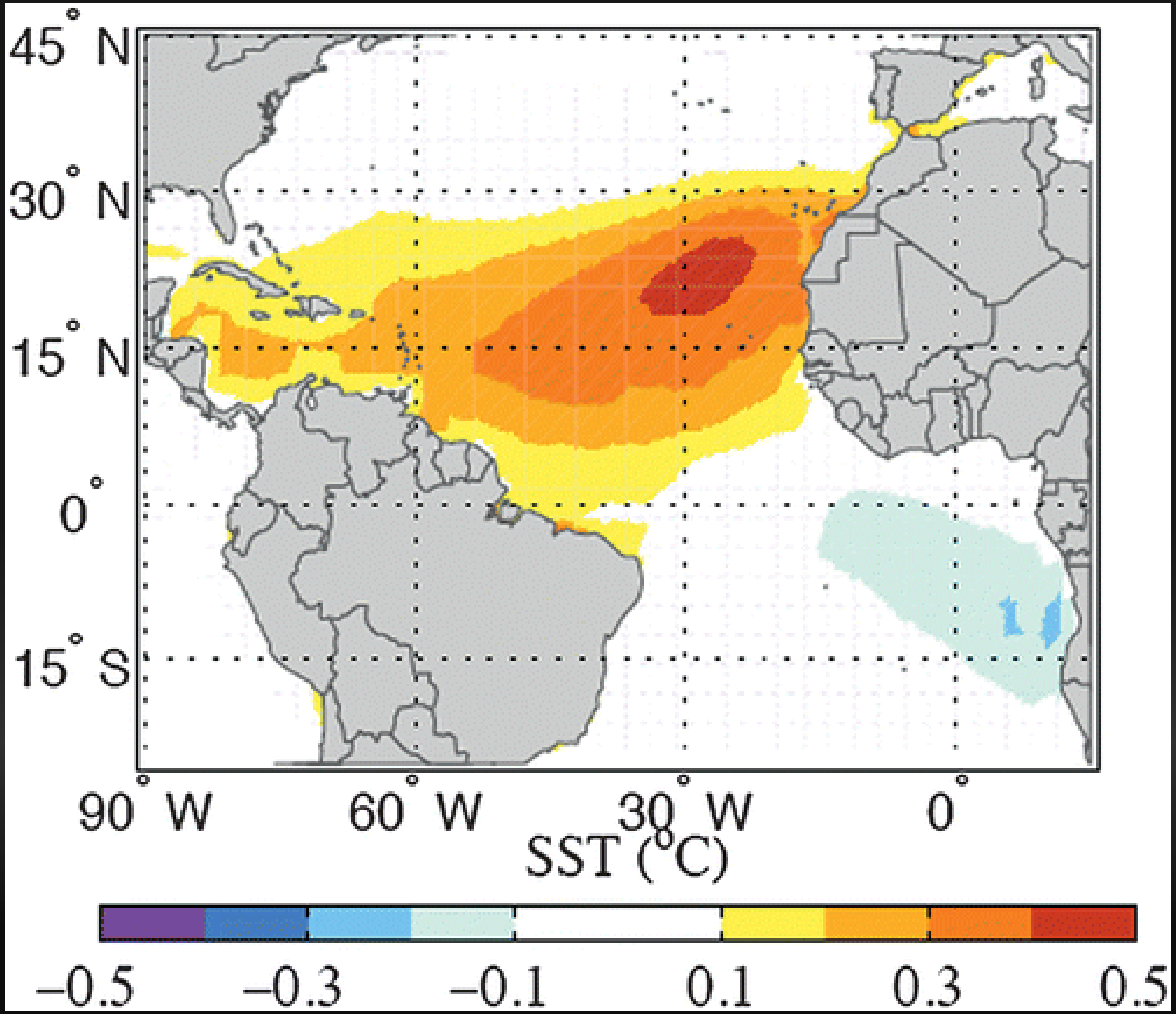


Deser et al. (2010) Annu. Rev. Mar. Sci.

ENSO

The positive phase of the ENSO (El Niño) during the Atlantic hurricane season (June – November) : positive SST anomalies over the tropical eastern Pacific, with near zero or negative anomalies across the Main development region, indicating unfavorable conditions for the TC genesis over the North Atlantic, and vice versa for the negative phase of the ENSO (La Niña).

The leading climate variability that impacts the North Atlantic TC activity



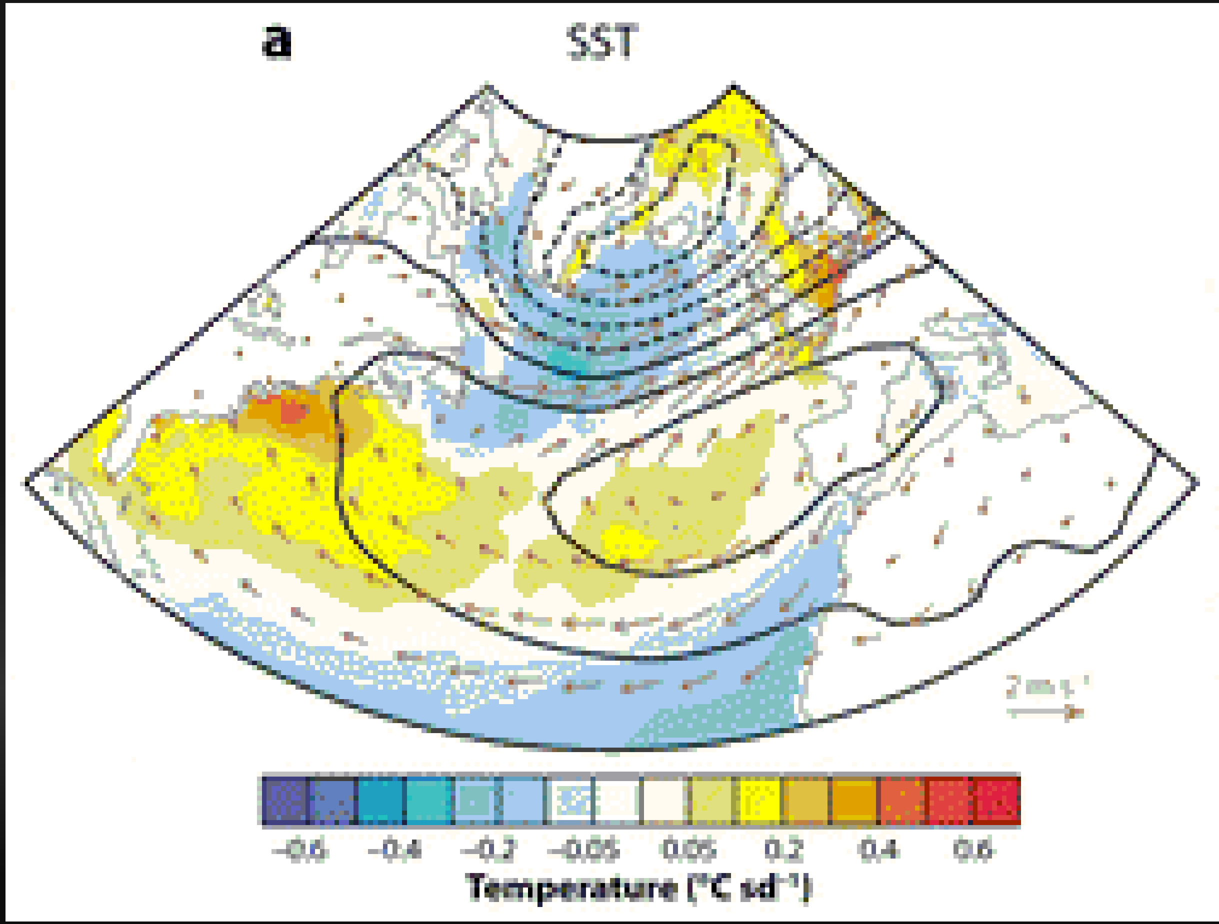
Smirnov and Vimont (2011) J. Climate

Atlantic Meridional Mode

The positive phase of the AMM is characterized by positive SST anomalies over most of the Northern Atlantic covering the Main Development Region, indicating favorable conditions for the TC genesis over the North Atlantic, and vice versa for the negative phase of the AMM.

Atlantic Multidecadal Oscillation (AMO), representative of the North Atlantic SST condition, similar to the AMM, also impacts the North Atlantic TC activity significantly on decadal time scale.

The leading climate variability that impacts the North Atlantic TC activity

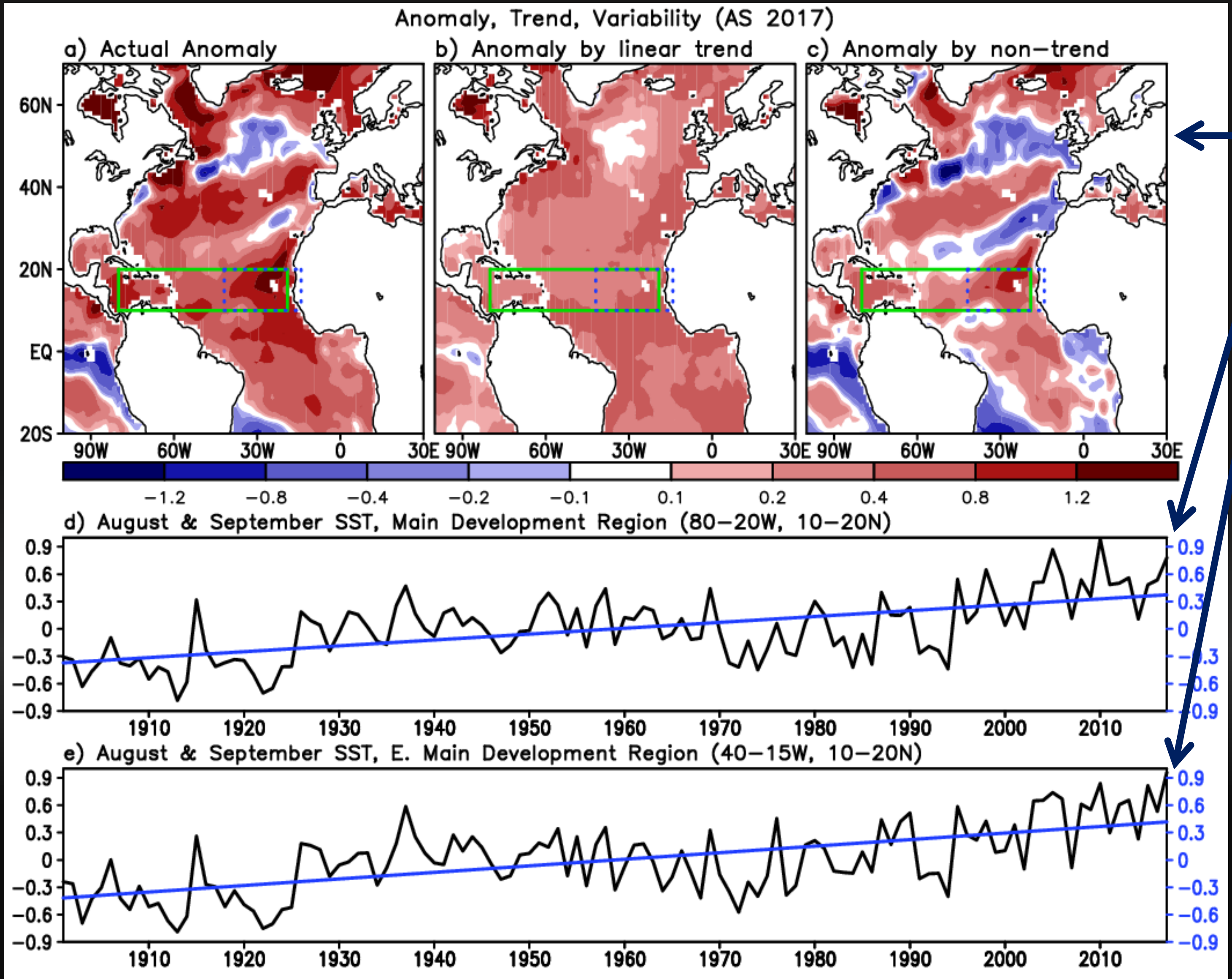


Deser et al. (2010) Annu. Rev. Mar. Sci.

North Atlantic Oscillation

The positive phase of the NAO : includes the well-known North-South tripole structure over the extra-tropical Atlantic. A negative SST anomaly (shaded) dominates the Main Development Region (MDR), which is not favorable for strong TC activity. The negative phase of the NAO is known to be more favorable for TC genesis over the MDR.

The role of climate change in 2017 (signal in sea surface temperature)



North Atlantic SST anomalies (actual, trend, non-trend) in Aug/Sep 2017

Main Development Region (MDR)

Eastern MDR

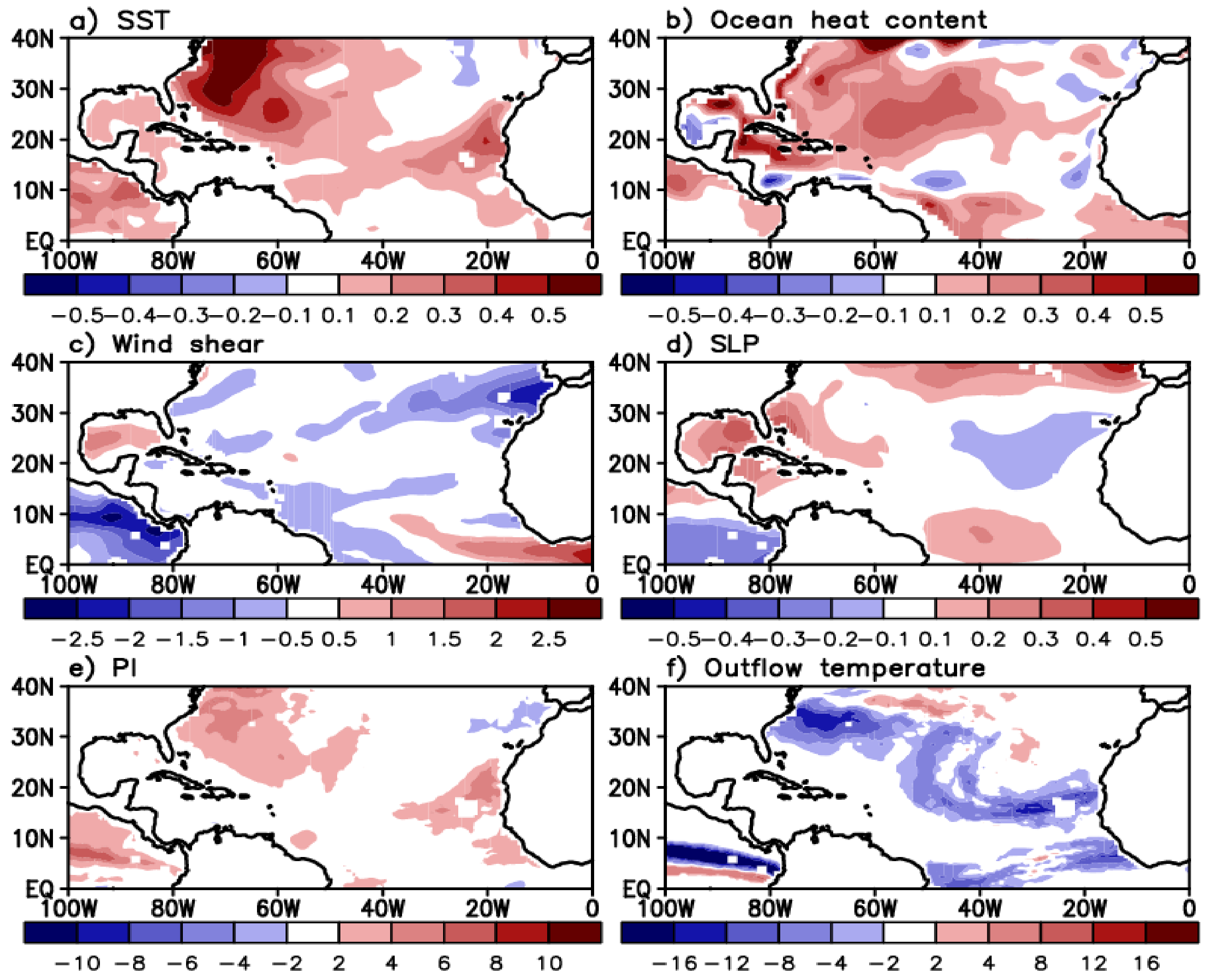
The long-term trend (climate change signal): ~0.37 (MDR) and ~0.42°C (EMDR).

Non-trend: ~0.41 (MDR) and ~0.54°C (EMDR).

The third highest MDR SST, following 2010 and 2005. SST anomaly in the EMDR, where tropical disturbances developed and grew to be major hurricanes during AS 2017 (e.g., Harvey, Irma, Jose, Lee, and Maria), is the highest on record (~0.96°C).

The role of climate change

Trend distributions of SST & ocean heat content (ocean), wind shear & sea level pressure (dynamical impact), and potential intensity and outflow temperature (thermodynamical impact)



Ocean (SST&OHC) shows larger trend than atmosphere. Wind shear and outflow T is getting weaker and cooler.

The upward trend in the OHC is primarily observed over the western-central North Atlantic, associated with maintaining warm ocean surface and strengthening of hurricanes as they traverse the Atlantic.

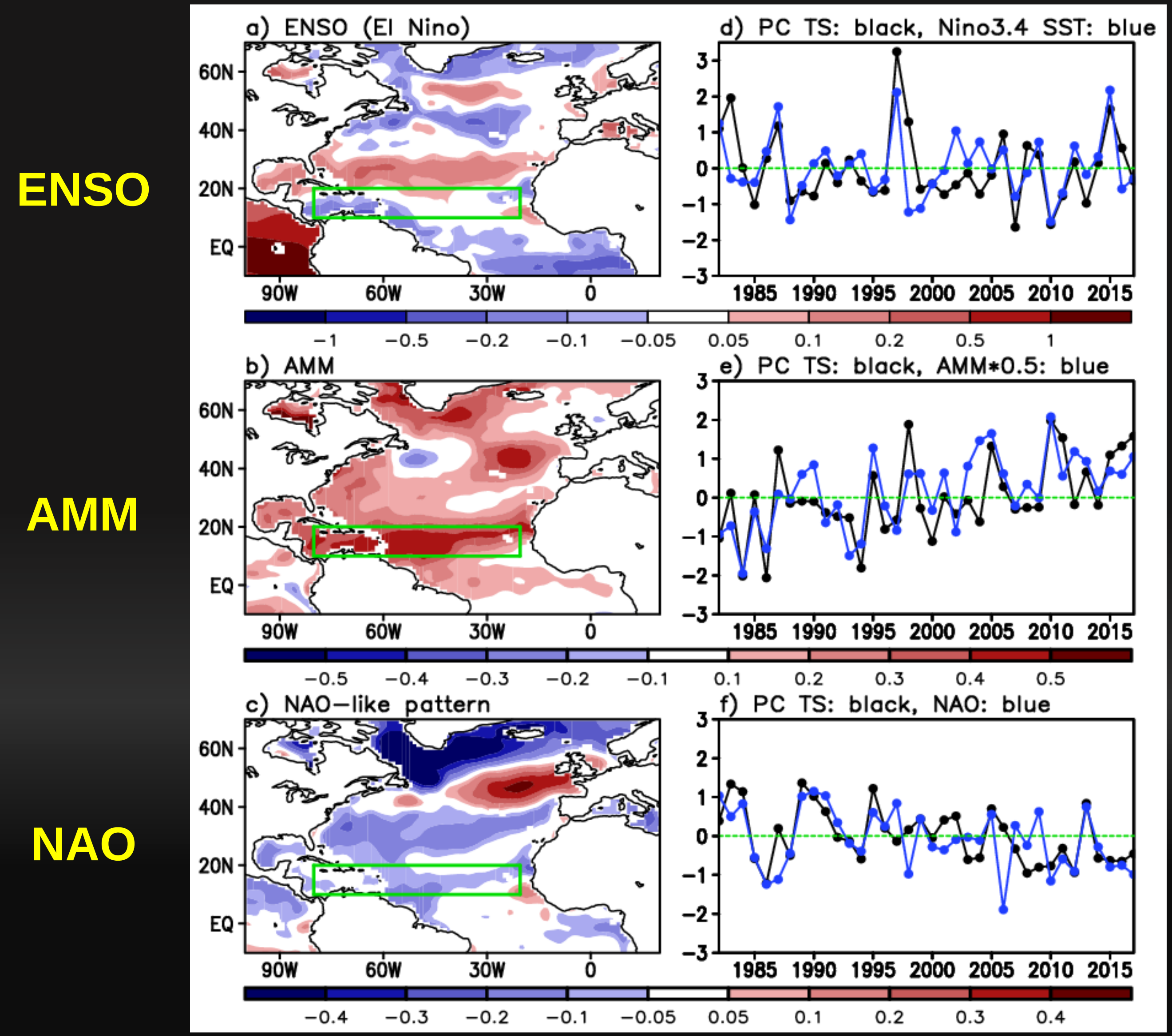
REOFs for capturing the leading modes of climate variability

In order to assess the contributions of the leading modes of climate variability to the SST anomalies, we decompose the SST anomalies in terms of Rotated Empirical Orthogonal Functions (REOFs) for the August/September months over the period 1982-2017.

The climate change signal has been first removed for the period 1901–2017 to solely investigate the climate variability, and the resulting SST for the period 1982–2017 is applied to the REOF analysis.

We extract the spatial patterns of the leading climate modes (left panel on the next page) and corresponding time series (right panel, called Principal Component time series) that present interannual variation of each climate mode.

The role of climate variability (the three leading climate modes)



ENSO: The weak La Niña (or near neutral) conditions in 2017 are manifested in the small amplitude of this PC.

AMM: SST in 2017 is characterized by a large positive phase of the AMM that contributed to a favorable environment for TC activity, but the magnitude is a little smaller than those for 2005 and 2010.

NAO: The modest amplitude negative NAO in 2017 indicates that the NAO is likely to have had a positive impact on the TC activity.

Reconstruction of the anomaly explained by each leading mode

We assess quantitatively how much of the detrended anomaly of SST and other key variables in 2017 is explained by a combination of ENSO, the AMM, and the NAO modes.

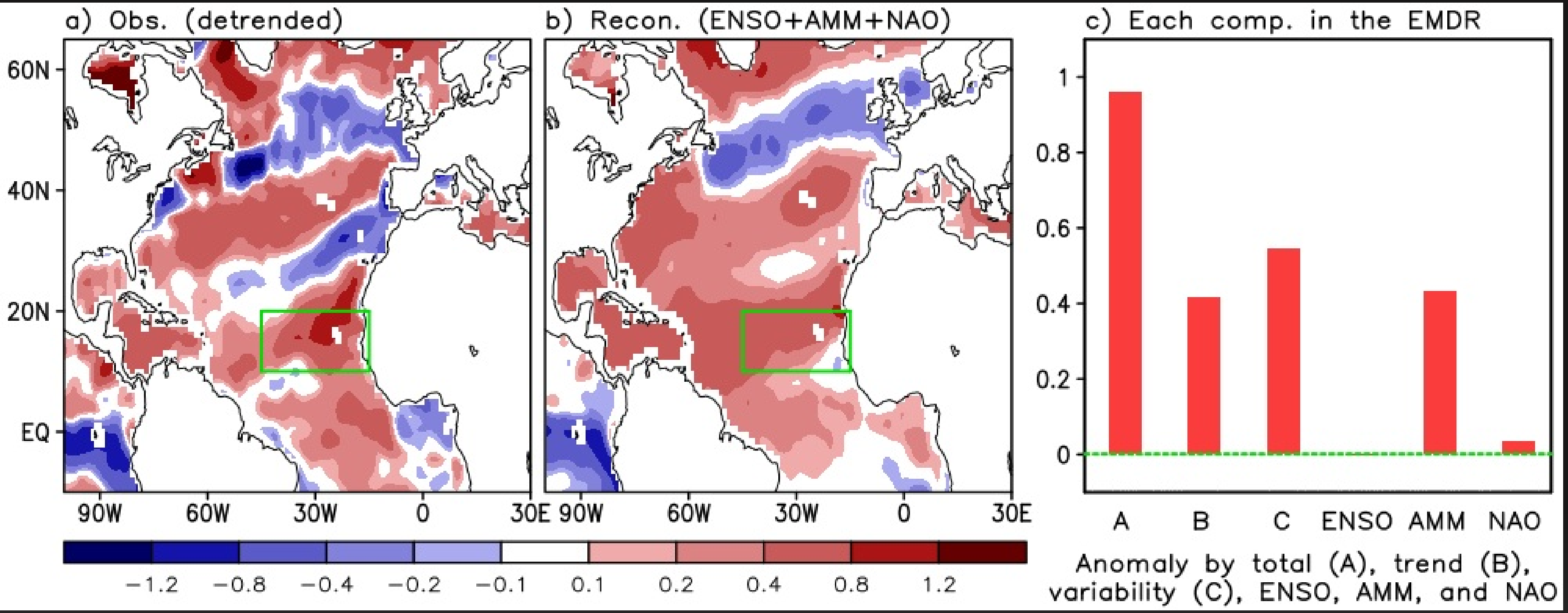
For example, the reconstructed SST_{ENSO} (x, y, t) anomaly determined by the ENSO mode at (x, y) and time t is

$$SST_{ENSO}(x, y, t) = REOF\_ENSO(x, y) \cdot PC\_ENSO(t)$$

where REOF_ENSO (x, y) is the unnormalized REOF SSTs for the ENSO mode and PC_ENSO (t) is the normalized (detrended) PC time series.

This calculation is repeated for the other two modes over 1982–2017. This procedure helps quantify the effectiveness of the leading modes in reconstructing the observed anomaly each year.

The role of climate variability (SST anomaly)



EMDR SST contributed by total, trend, non-trend, and each mode

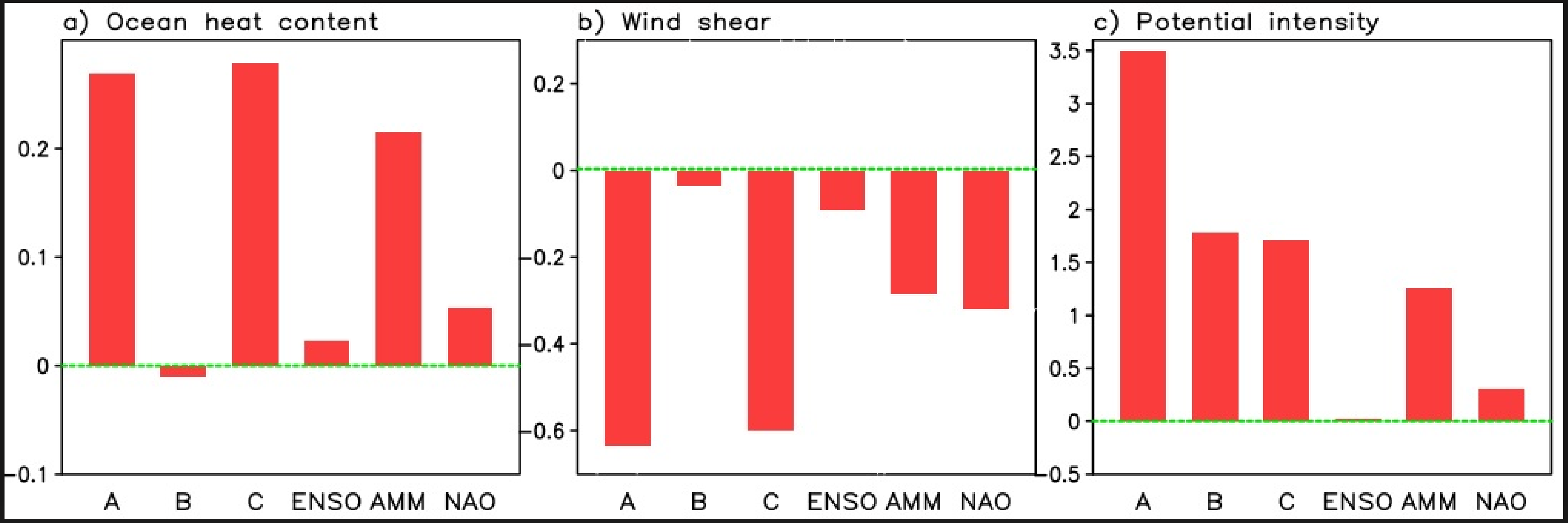
non-trend comp. **ENSO+AMM+NAO**

The SST anomaly over the Eastern Main Development Region (EMDR) in AS 2017

0.96 (total) (A) = 0.42 (by trend) (B) + 0.54 (by non-trend) (C)

Contribution by the leading climate modes over the EMDR (reconstructed from the individual modes)
Non-trend SST anomaly explained by the AMM is ~0.43 (of the 0.54 by non-trend). ENSO impact on the EMDR SST is very weak, and there is a weak positive contribution of the NAO.

The role of climate variability



Ocean heat content (Ocean)

Vertical wind shear (Dynamics)

Potential intensity (Thermodynamics)

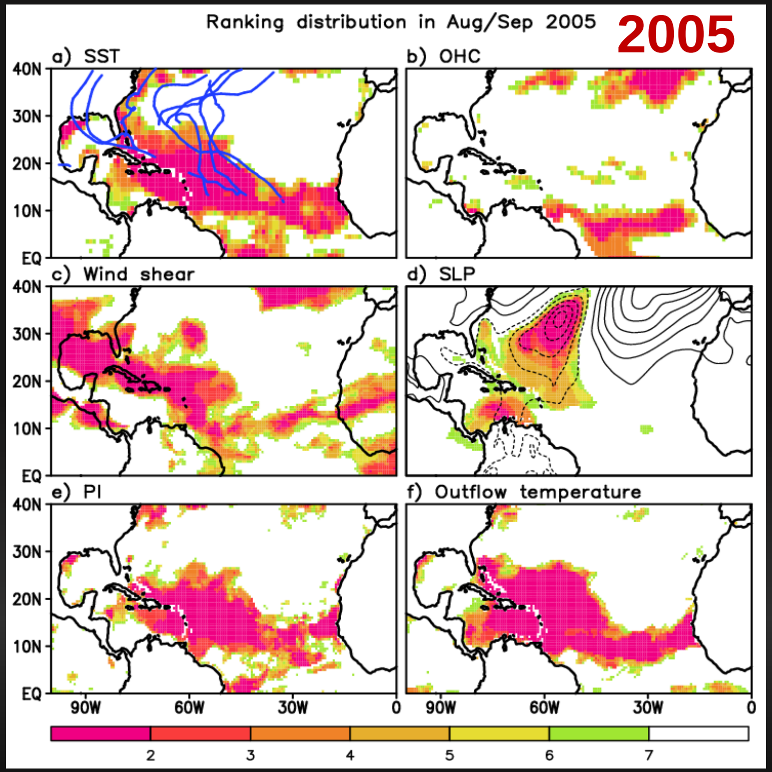
a) Three climate modes have a positive impact on OHC. The OHC is important as it acts to maintain the warm ocean surface and facilitates the strengthening of the TCs as they traversed the Atlantic.

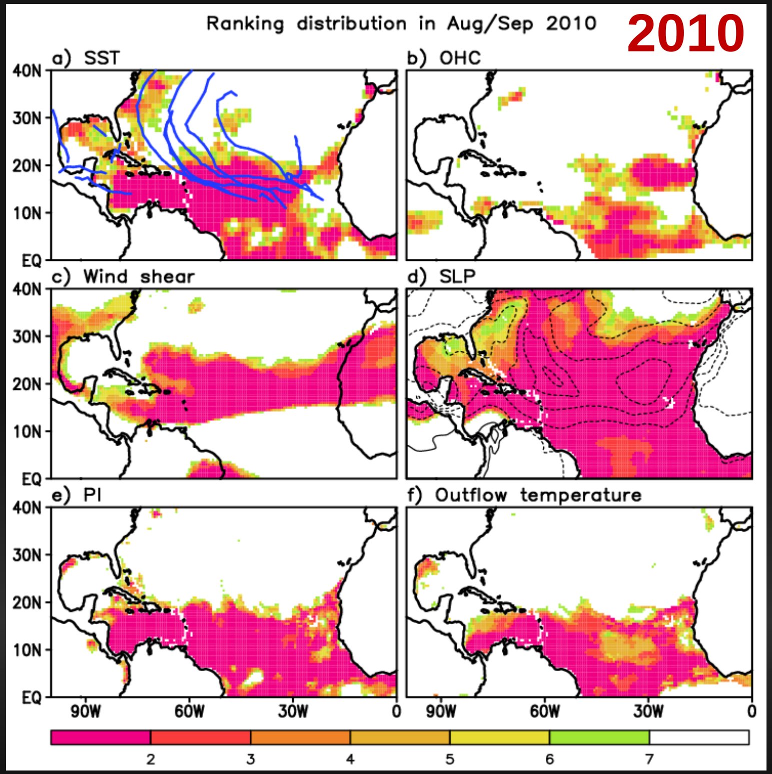
b) and **c)**: The leading climate modes drive weaker wind shear and unstable atmosphere.

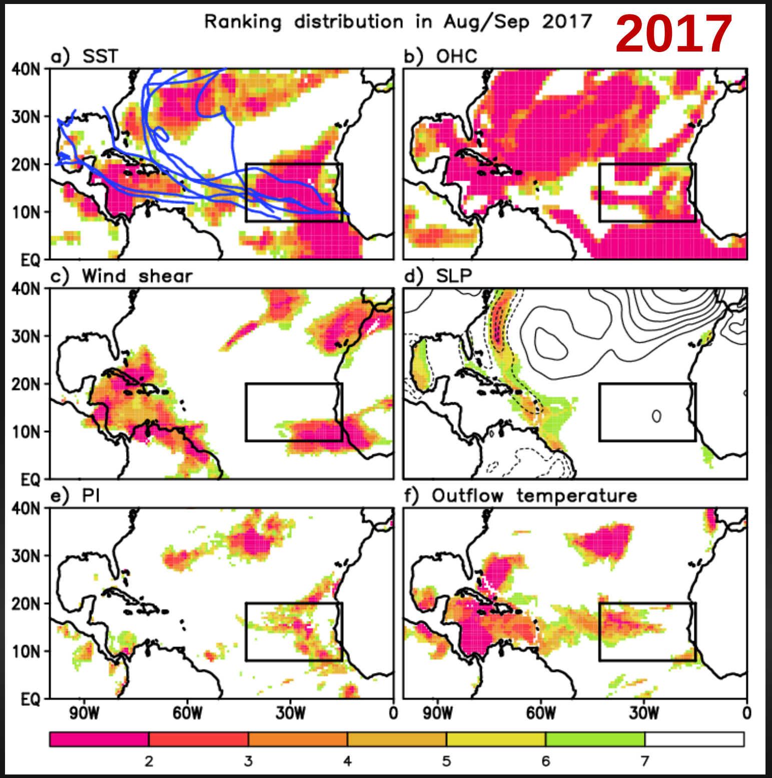
The AMM is the key factor driving the ocean and thermodynamic impacts (a,c). In contrast, the wind shear linked to the jet, pressure, and circulation associated with the ENSO & NAO is influenced by all three climate modes.

Comparison with other extremely active seasons (2005 and 2010)
(Climate change + Climate variability)

Ranking value distributions of the key quantities. Ranking values closer to 1,2,3 (red shaded region) indicate very favorable condition for tropical cyclone activity.







Ocean (SST & OHC)

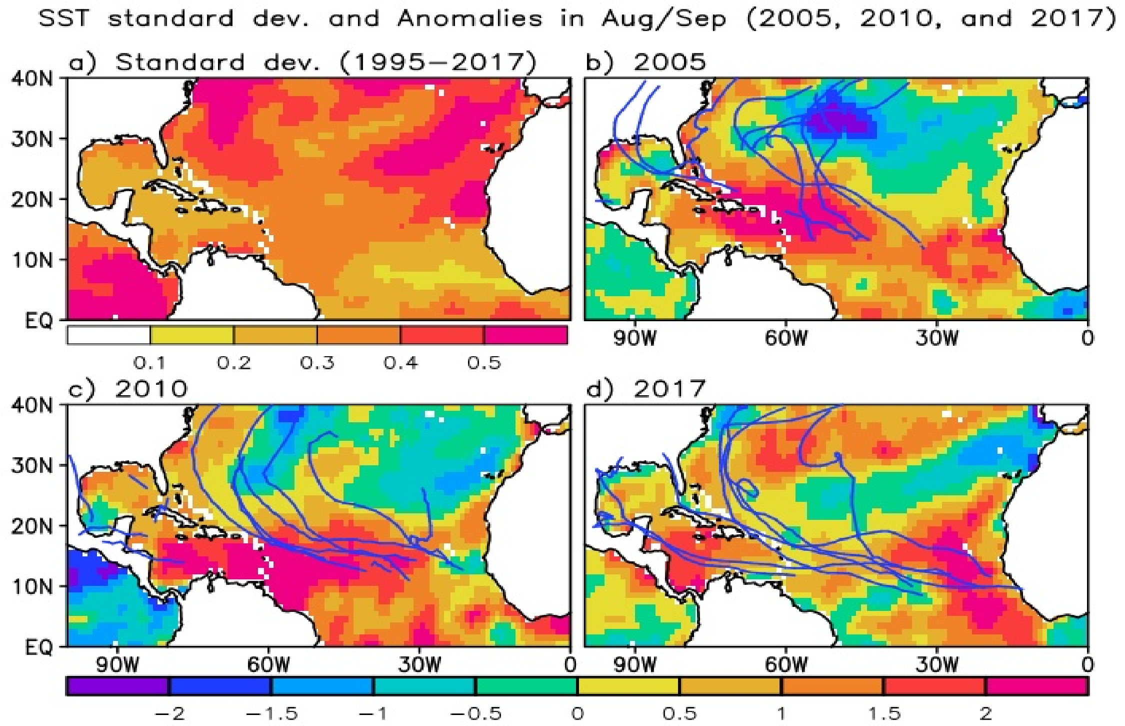
Atm.

Ocean plays more key role in 2017. Warm sub-surface keep the SST warm : strong & long life time hurricanes

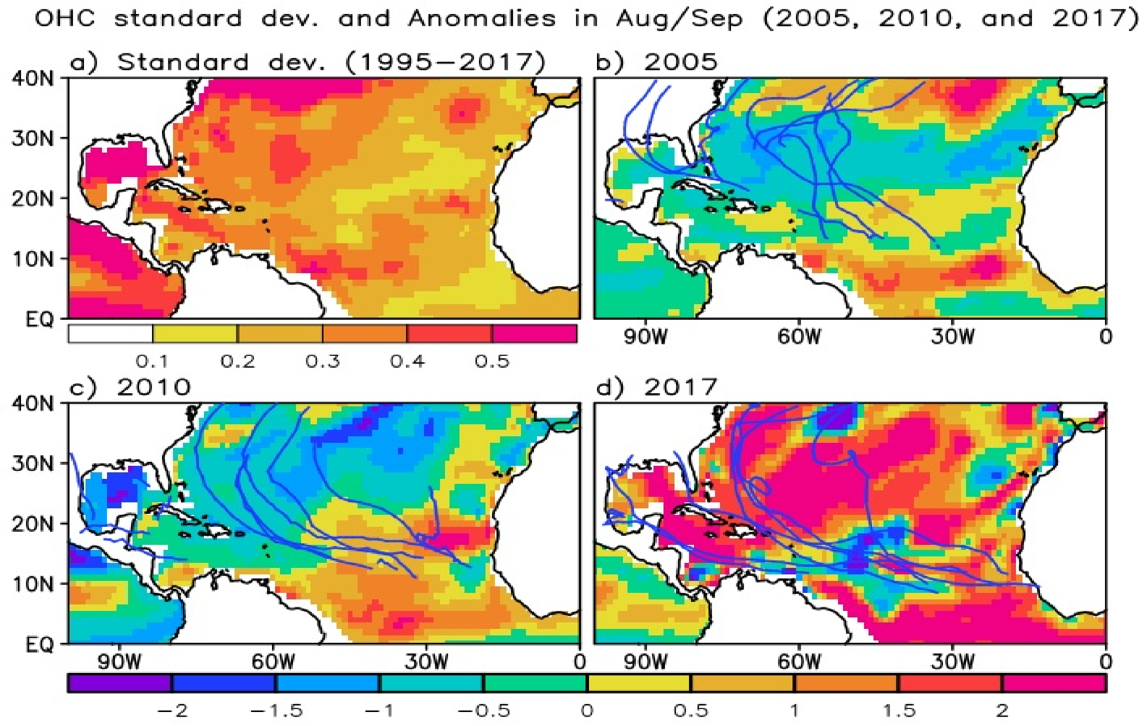
Atmosphere is also favorable for hurricane activity, but less prominent than 2005/2010. Smaller magnitude of the Atlantic Meridional Mode (climate variability) than 2005/2010 is the main reason

SST and Ocean heat content anomalies (2005, 2010, and 2017)

SST



Ocean heat content



The largest SST anomalies are confined to the west in 2005 and to the east in 2017, while 2010 shows large SST anomalies over much of the MDR. Similarly standardized OHC anomalies match well the rankings shown in previous slides, supporting that the three years have unique OHC distributions, causing different impacts on TC activity.

Conclusions

The record-setting warm SST was found over the EMDR in AS 2017, driven primarily by the climate change signal (~0.42 °C above the 1901–2017 average) and the AMM that accounted for 80% of the additional (beyond the trend) warming of ~0.54 °C.

ENSO, the NAO, and the AMM all contributed to favorable wind shear conditions, while the AMM also produced enhanced atmospheric instability.

Compared with 2005/2010, the ocean heat content (OHC) during 2017 was larger across the tropics, with higher SST anomalies over the EMDR and Caribbean Sea.

On the other hand, the dynamical/thermodynamical atmospheric conditions, while favorable for enhanced TC activity, were less prominent than in 2005/2010 across the tropics.

The results suggest that both climate change (warm SST with the long fetch of the resulting storms in the presence of record breaking OHC) and variability (three climate modes of variability) play a role in driving the strong TC activity in 2017.

Discussions

Even in the presence of climate change characterized by increasing SST, it is the leading modes of climate variability that largely determine the extremes in seasonal TC activity, in that they are associated with both the thermodynamical and dynamical conditions favorable (or unfavorable) for TC development (e.g., strong TC seasons in 2005 and 2010, and weak TC seasons in 2013 (NAO), 2014 and 2015 (ENSO))

Nevertheless, we can expect that climate change will play an increasingly important role in determining extremely active years in that it provides an increasingly warmer baseline in SST from which the major modes of climate variability deviate.

The 2005 and 2017 TC seasons (both characterized by a positive AMM, and weak NAO and ENSO) appear to be consistent with such an interpretation. During those years, the tropical Atlantic SSTs and the major hurricane counts are comparable, despite a relatively smaller magnitude of the positive phase of the AMM in 2017 than in 2005, indicating an increasingly greater role for climate change.

For more information:

Lim, Y.-K., S. D. Schubert, R. Kovach, A. M. Molod, and S. Pawson, 2018: The roles of climate change and climate variability in the 2017 Atlantic hurricane season. *Scientific Reports,* 8, doi:10.1038/s41598-018-34343-5