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

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Abstract

The 2017 hurricane season was extremely active with six major hurricanes, the third most on record. The sea-surface temperatures (SSTs) over the eastern Main Development Region (EMDR), where many tropical cyclones (TCs) developed during active months of August/September, were ~0.96°C above the 1901–2017 average (warmest on record): about ~0.42°C from a long-term upward trend and the rest (~80%) attributed to the Atlantic Meridional Mode (AMM). The contribution to the SST from the North Atlantic Oscillation over the EMDR was a weak warming, while that from ENSO was negligible. Nevertheless, ENSO, the NAO, and the AMM all contributed to favorable wind shear conditions, while the AMM also produced enhanced atmospheric instability.

Compared with the strong hurricane years of 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 unusually warm SST in the EMDR together with the long fetch of the resulting storms in the presence of record-breaking OHC were key factors in driving the strong TC activity in 2017.

Data

SST: the Merged Hadley-NOAA Optimal Interpolation SST (1° × 1°), 1901-2017.
Atmospheric reanalysis data: the NASA Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA–2) (0.625° longitude ×0.5° latitude resolution).
Ocean heat content (OHC) (0-300m): Derived from Version 1 of the NASA Global Modeling and Assimilation Office Ocean Data Assimilation System (GMAO ODAS).
TC track data: NASA EarthData Global Hydrology Resource Center (GHRC).

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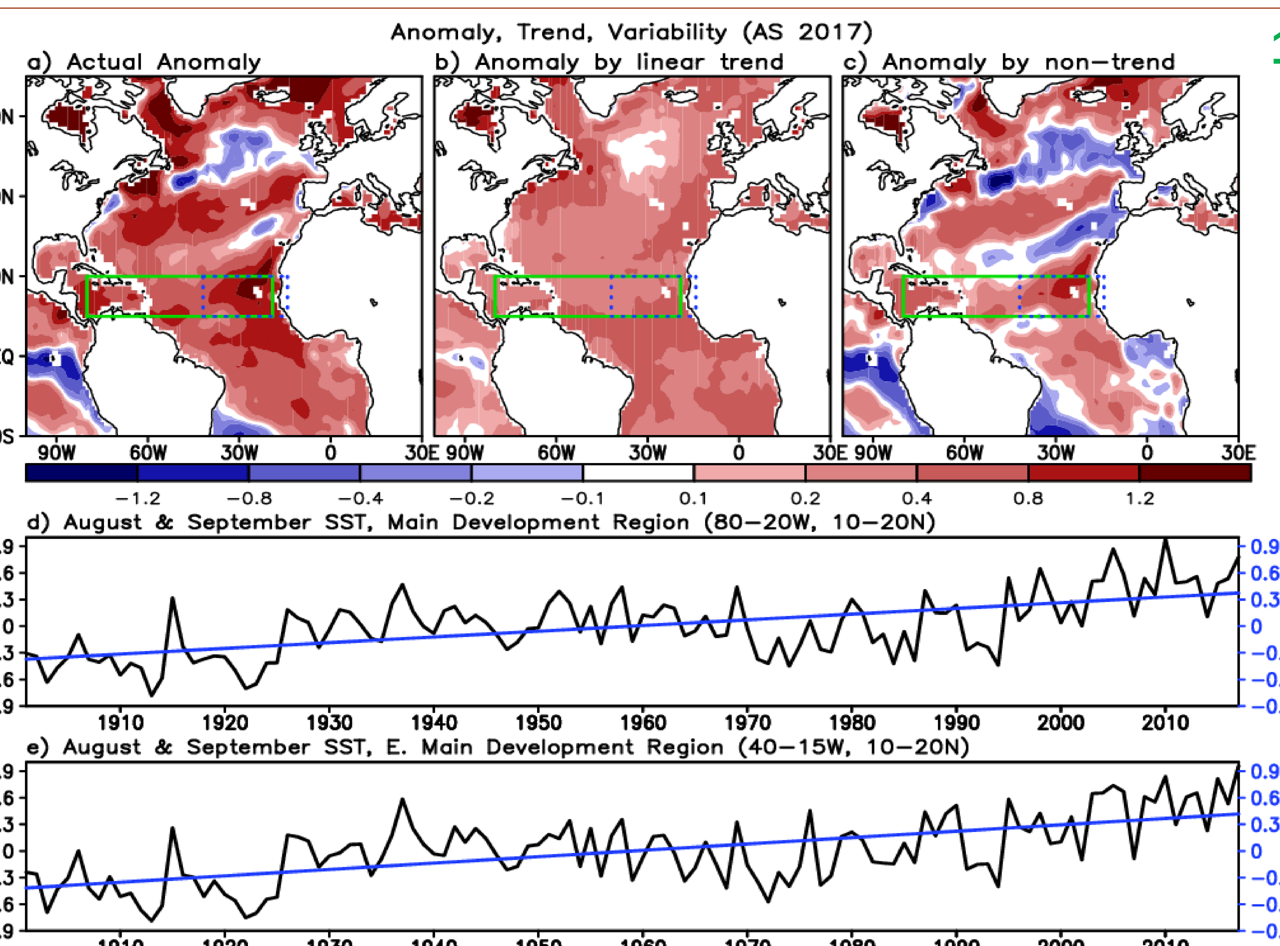
North Atlantic SST anomalies (Aug/Sep 2017)

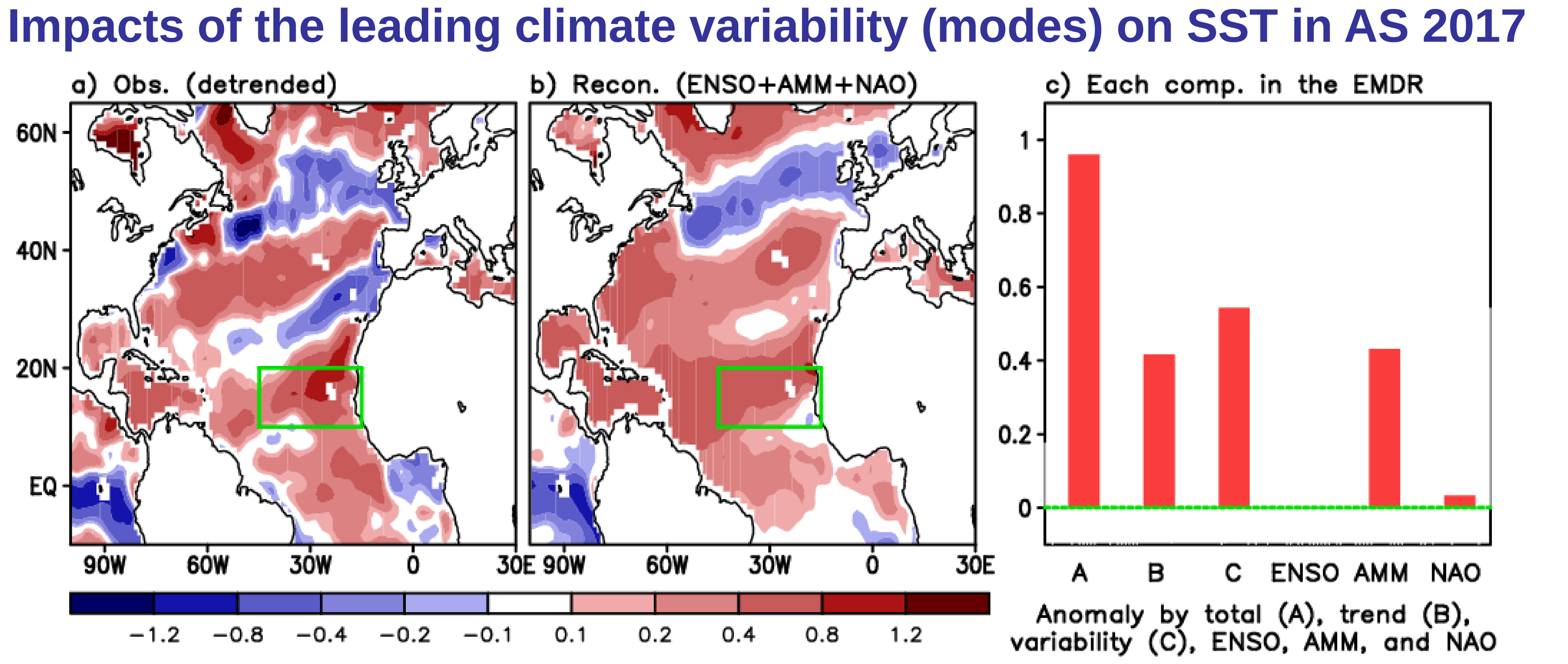
Main Development Region (MDR)

Eastern MDR



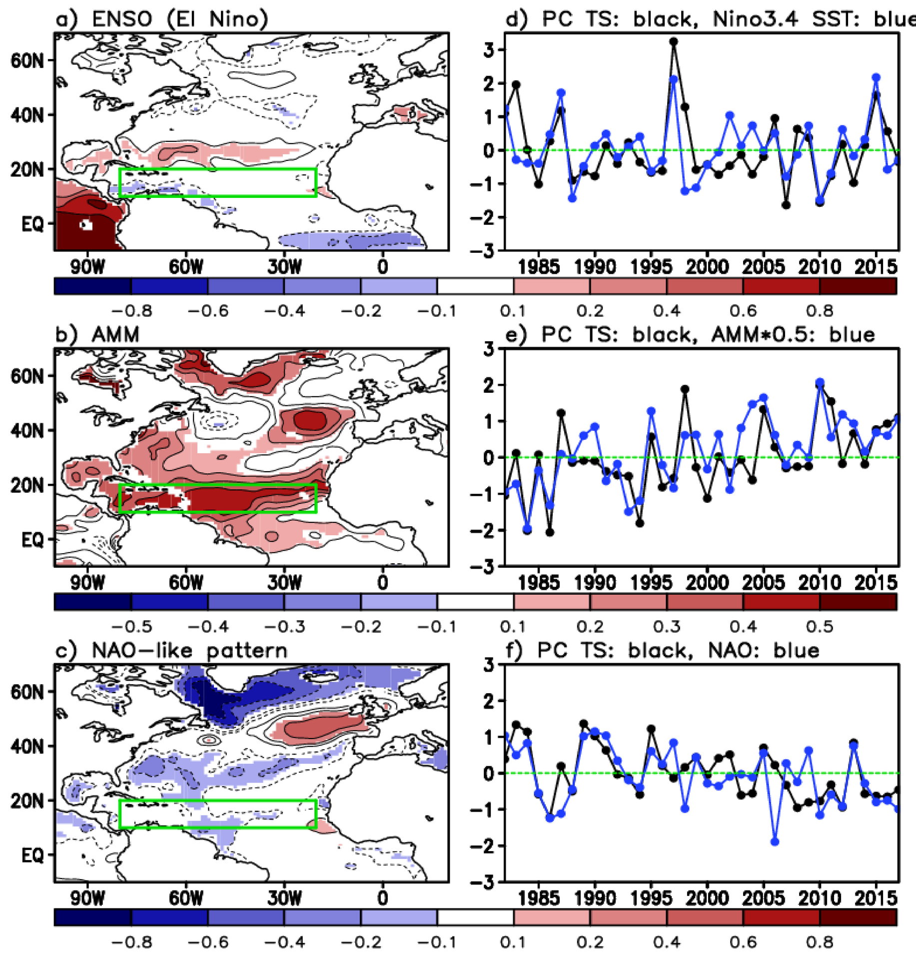
The time series: The long-term trend contributions to the SST anomalies over the MDR and the EMDR region during 2017 are ~0.37 and ~0.42°C, respectively (blue lines). The non-trend contributions are ~0.41 and ~0.54°C, respectively. The MDR SST is the third highest in 2017, following 2010 and 2005. SST 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). With a climatological value of 26.82°C, this anomaly translates to a record warm SST value of ~27.8°C.

3 Impacts of the leading climate variability (modes) on SST in AS 2017



The bar charts compare the SST anomalies over the EMDR with the anomalies reconstructed from the individual modes, showing that ~80% of the SST anomaly (0.54°C, third bar) reflects the positive phase of the AMM (~0.43°C, fifth) in AS 2017, with only a very weak positive contribution from the NAO (sixth). The contribution from ENSO, which was in near neutral (or weak La Niña) phase, is negligible .

2 The leading climate modes (REOF SST (detrended))

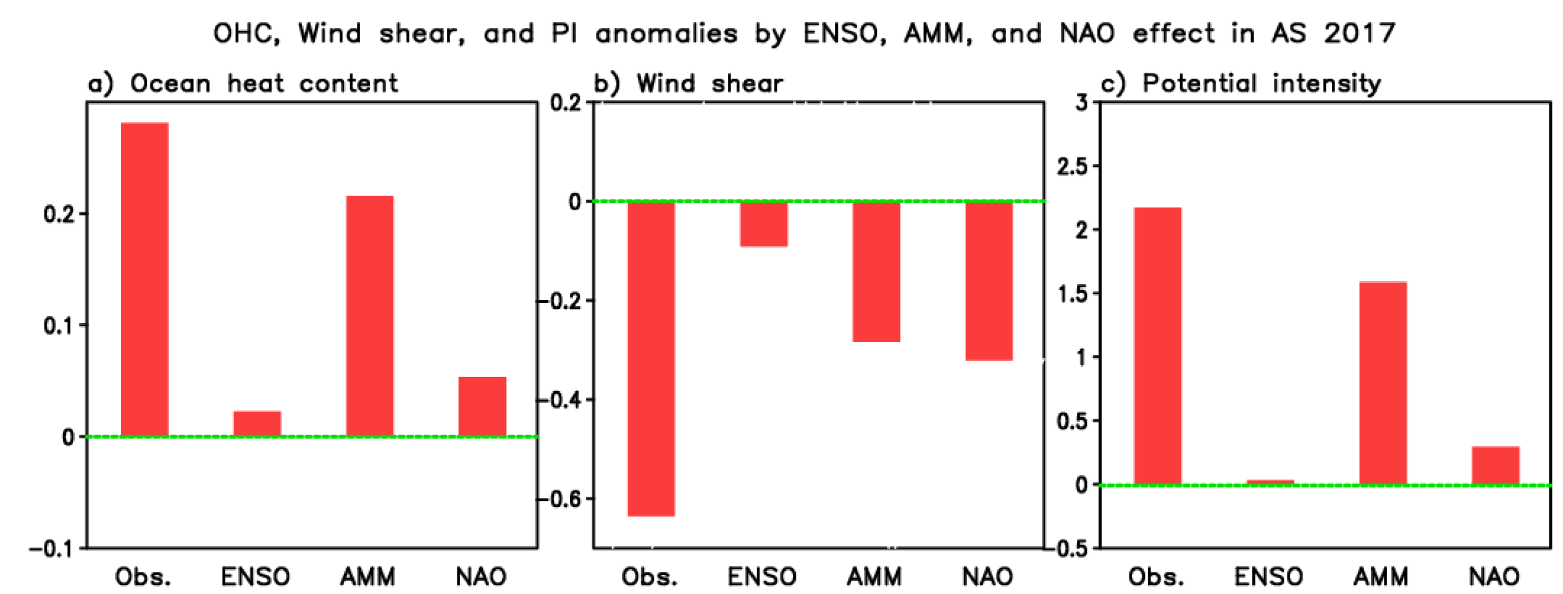


The El Niño mode: positive SST anomalies over the tropical eastern Pacific, with near zero or negative anomalies across the MDR, indicating unfavorable conditions for the TC genesis.

The (+) AMM: positive SST anomalies over most of the Northern Atlantic covering the MDR. Both 2005 and 2010 experienced large (+) phases of the AMM. 2017 is also characterized by a (+) phase of the AMM.

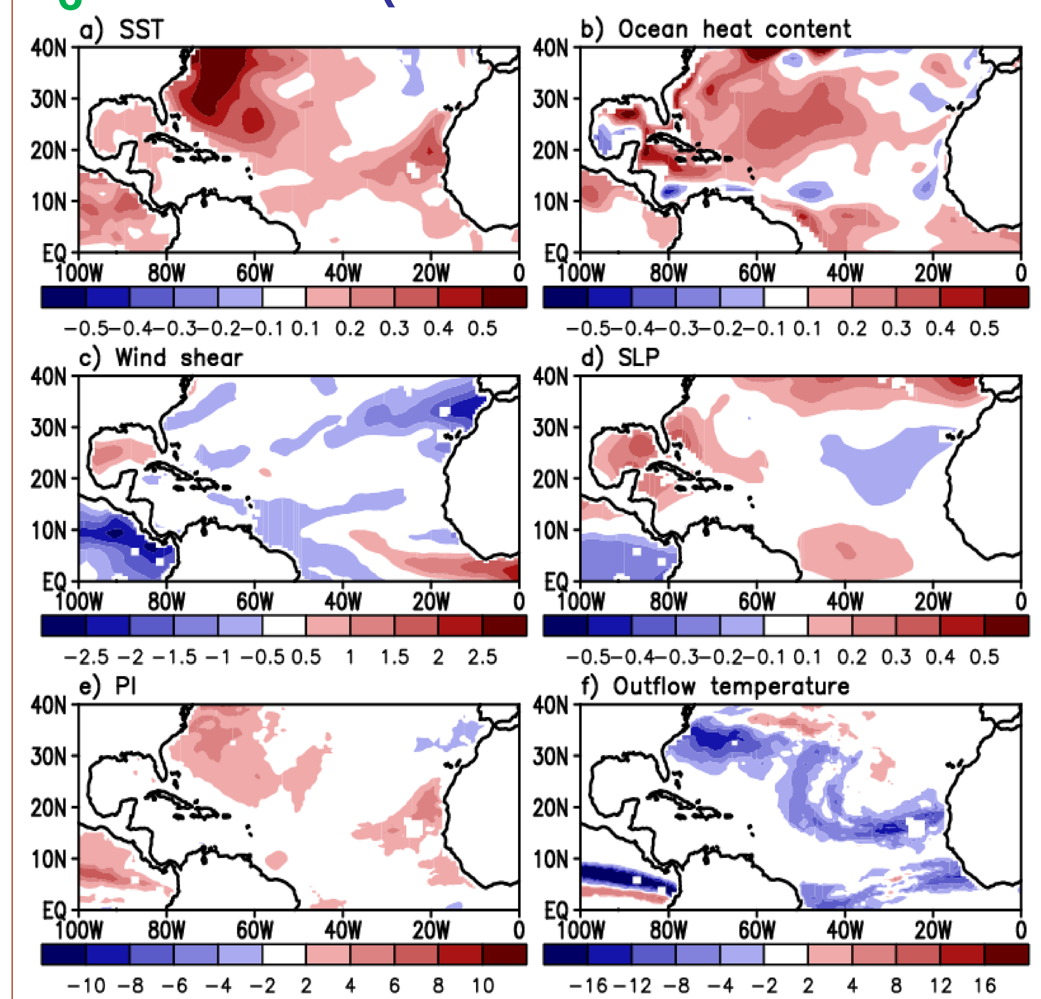
The (+) NAO: North-South tripole structure over the extra-tropical Atlantic. A negative or near zero SST anomaly dominates the MDR. The modest amplitude negative NAO in 2017 indicates a positive impact on the TC activity.

4 Impacts of the leading climate modes on OHC (ocean impact), wind shear (dynamical impact), and potential intensity (PI) (thermodynamical impact) over the EMDR



The leading climate modes drive higher OHC, weaker wind shear and a vertically more unstable atmosphere than average in AS 2017. We also see that the reconstructed anomalies (the right three bars in each panel) are generally close to the actual detrended anomalies (the left bar in each panel). The AMM is the key factor driving the ocean and thermodynamic impacts. In contrast, the wind shear, known to also be dynamically linked to the jet stream, atmospheric pressure and circulation fields associated with ENSO and the NAO, is influenced by all three climate modes.

6 Trend (over the recent active TC seasons, 1995-2017)



Ocean (SST&OHC) tends to show stronger trend than atmospheres. Wind shear and outflow temperature is getting weaker and cooler, though the magnitude is not large over the MDR,. The upward trend in the OHC is primarily observed over the western-central North Atlantic and, unlike for the atmospheric quantities (c-f), has a distribution that is quite similar to the distribution of the 2017 OHC rankings (figure on the bottom of this poster).

7 Discussion

Changes: Observations show the upward trend in SST and OHC, and downward trend of temperature near the tropical tropopause in recent decades and the associated cooling of the TC outflow temperature.

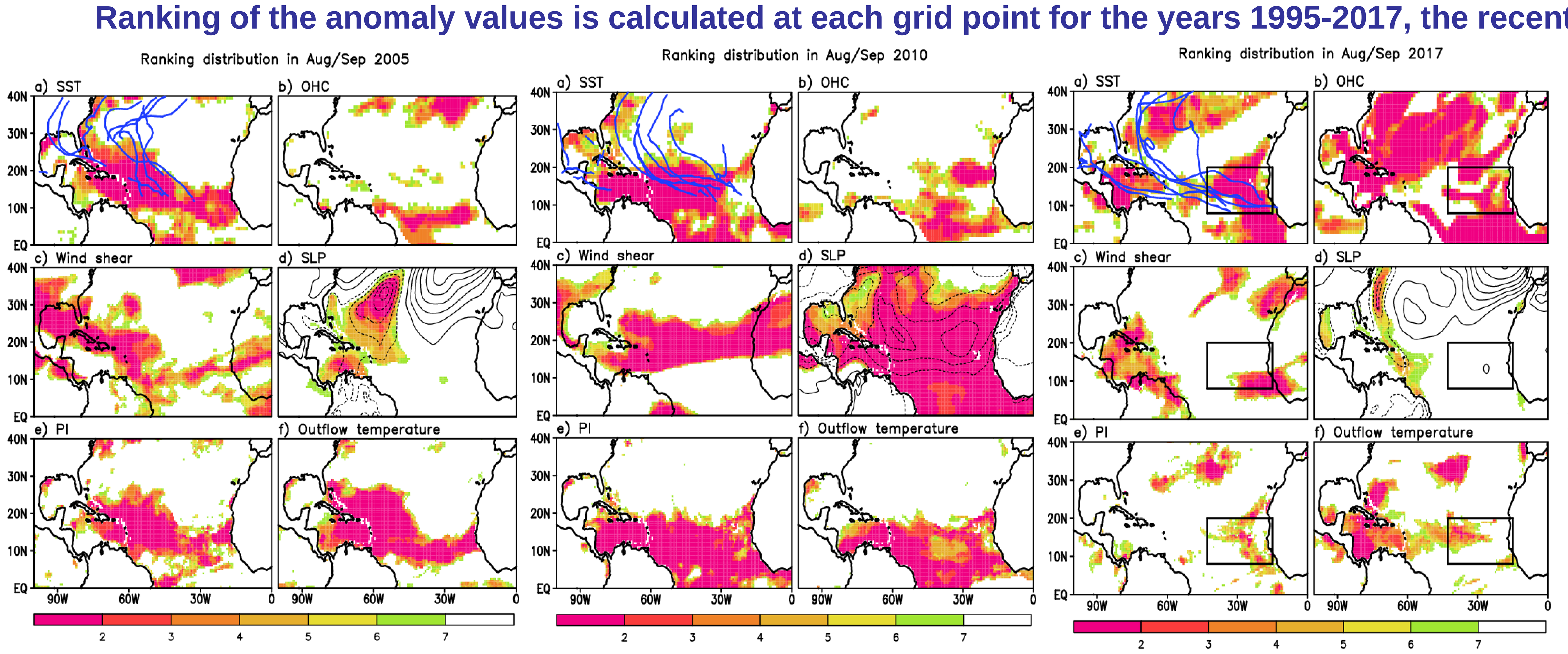
Variability: Even in the presence of climate change characterized by increasing SST/OHC, gradual warming alone may not play the dominant role, and the leading modes of climate variability largely determine the extremes in seasonal TC activity.

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/OHC from which the major modes of climate variability deviate.

The 2005 and 2017 hurricane 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.

5 Comparisons with other extremely active hurricane seasons (2005 and 2010)

Ranking of the anomaly values is calculated at each grid point for the years 1995-2017, the recent period of above-average TC activity



Note: SLP, wind shear, and upper-level outflow temperature are ranked in the order of low to high, while the SST, OHC, and PI are ranked from high to low, because weaker and higher heat/moisture potentials are favorable for TC activity.

Atmosphere: more favorable for TC activity in 2005 and 2010. Ocean condition is more favorable in 2017.

The relatively larger amplitude of the AMM during 2005 and 2010 compared with 2017 appears to be why the highly favorable atmospheric conditions for strong TC activity extended across much of the North Atlantic during those years while that was not the case for 2017. More favorable OHC conditions in 2017 appears to be associated with the increasingly more important role of the trend (see figures on the upper-right corner of this poster). The larger OHC in 2017 is the combined effect of the trend (most pronounced over the western-central North Atlantic) and the leading modes of climate variability including the AMM that have influences spanning the North Atlantic.