Multi-decadal Trends in Cyclone and Hurricane Evolution in the Tropical North Atlantic Ocean

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RATIONALE & PURPOSE

- In 2017, Hurricane Maria caused $94.4 billion in damages in Puerto Rico, taking almost 3,000 lives and devastating its 3.4 million residents [1].
- Since 1980, 238+ tropical weather events caused over **$1 billion damage per storm**, totaling over **$1.5 trillion** in damage in the past 38 years [2].

QUESTIONS

- How do trends in tropical cyclone (TC) evolution differ between the west and east sub-basins of the tropical North Atlantic over the past decades?
- What environmental factors are associated with these trends and the differences between the two sub-basins?

METHODS

DATA

- Satellite data from 1980-2017 (38 years).
- **WIND SPEEDS**: National Hurricane Center (NHC) Best Track Data [3].
- **SEA SURFACE TEMPERATURE (SST)**: NOAA Optimally Interpolated Reynolds SST [4].
- **HUMIDITY, VERTICAL WIND SHEAR**: ERA-Interim atmospheric data [5].

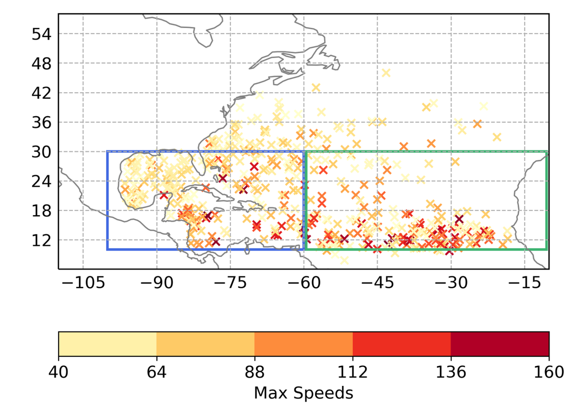

Figure 1. Western Tropical Atlantic (WTA) outlined in blue, Central and Eastern Tropical Atlantic (CETA) in green. Analyses over each sub-basin and the combined Tropical Atlantic (TA).

TIME-SERIES METRICS

- **POWER DISSIPATION INDEX (PDI)** [6]
  - **Aggregate**: Power dissipated over TC lifetime was added for all TCs in each hurricane season.
  - **Normalized**: Aggregate PDI was divided by the number of storm hours per season.
- **INTENSIFICATION PERIOD**
  - Defined from 34 knot minimum threshold to lifetime maximum wind speed.
  - **Intensification Time (IT)**: duration of period.
  - **Intensification Rate (IR)**: average rate of intensification during period.
- **WIND VARIABILITY INDEX (WVI)**
  - Tests performed on **median** and **95th percentile** data for each year.
  - **Spatial distribution** in WVI "heat maps."

$$WVI = \sqrt{\frac{1}{n}\sum(\Delta V - \Delta V_m)^2}$$

- ΔV: Change in surface wind speed between adjacent 6-h periods.
- ΔV_m: Mean change in wind speed over the 72-h period.
- n: Number of 6-h periods in the interval (n=12 for 72-h intervals).

ENVIRONMENTAL COMPARISONS

- Heat: SEA SURFACE TEMPERATURE.
- Moisture: RELATIVE HUMIDITY (500, 700, 950 hPa).
- Wind: VERTICAL WIND SHEAR (850-200 hPa).

RESULTS & DISCUSSION

POWER DISSIPATION INDEX (PDI)

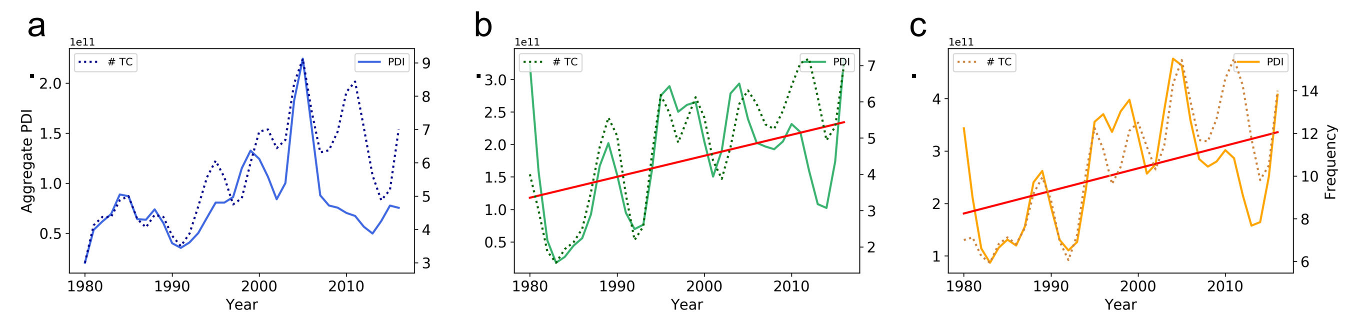

Figure 2. Aggregate PDI (solid line) and TC frequency (dotted line) for (a) WTA, (b) CETA, and (c) TA.

- PDI peak in 2005 [6], especially for (a) WTA and (c) TA.
- Pre-2005 **upward trend** remains for the **(b) CETA and (c) TA**, but is negated by data from 2006-2017 for the (a) WTA.
- Correlation with TC frequency indicates that aggregate PDI values depend largely on the number of TCs in each season.
  - Corroborated by a lack of normalized PDI trend in all sub-basins.

INTENSIFICATION PERIOD (IT/IR)

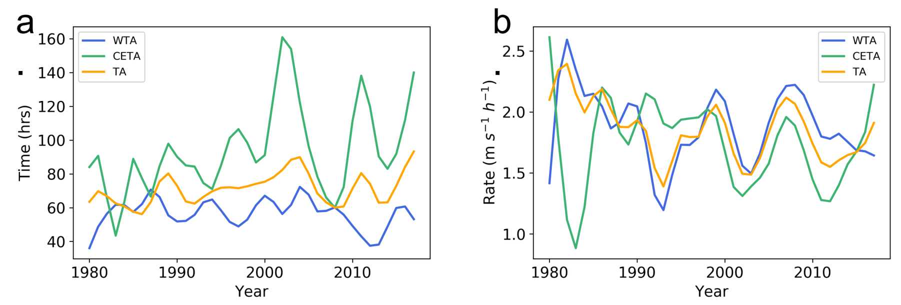

Figure 3. (a) IT and (b) IR trends in each sub-basin.

- **Increase in (a) IT** in the **CETA** sub-basin.
- **Decrease in (b) IR** for the **TA** combined sub-basin.
  - No (b) IR trends for individual WTA and CETA sub-basins, indicating that IR trends are spread across the TA.

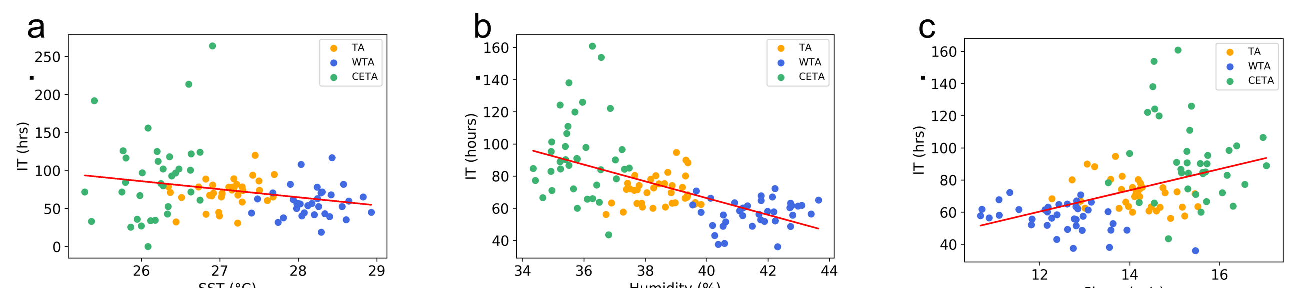

Figure 4. Correlation between IT and (a) SST, (b) 500 hPa relative humidity, and (c) vertical wind shear.

- Compares IT to environmental factors.
- **The environmental conditions that are more conducive to TC formation tend to result in lower ITs.**
  - Negative correlation with (a) SST and (b) humidity.
  - Positive correlation with (c) vertical wind shear.

WIND VARIABILITY INDEX (WVI)

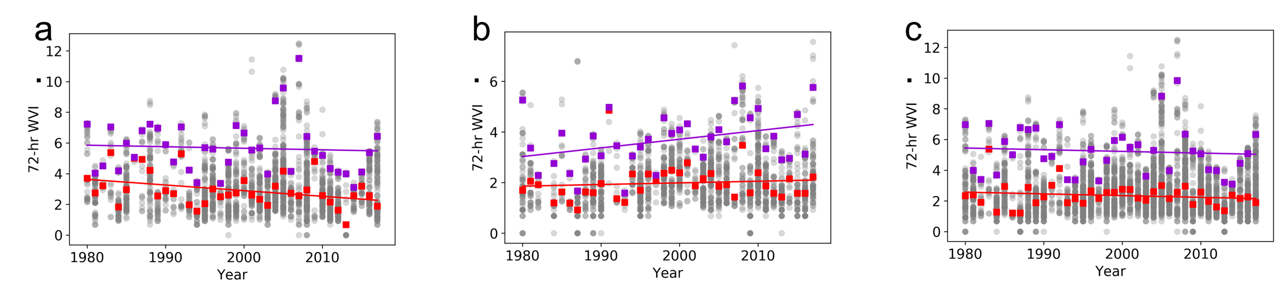

Figure 5. Median (red) and upper 95th percentile (purple) of WVI magnitudes for each year. Each gray dot is one 72-hour interval.

- **Decreasing median WVI for (a) WTA.**
  - Little to no long-term trend in average wind speed fluctuations.
- **Increasing 95th percentile for (b) CETA.**
  - The most variable 72-h storm intervals are changing less predictably over time.
- **No trend in (c) TA.**
  - Trends in the WTA and CETA cancel.

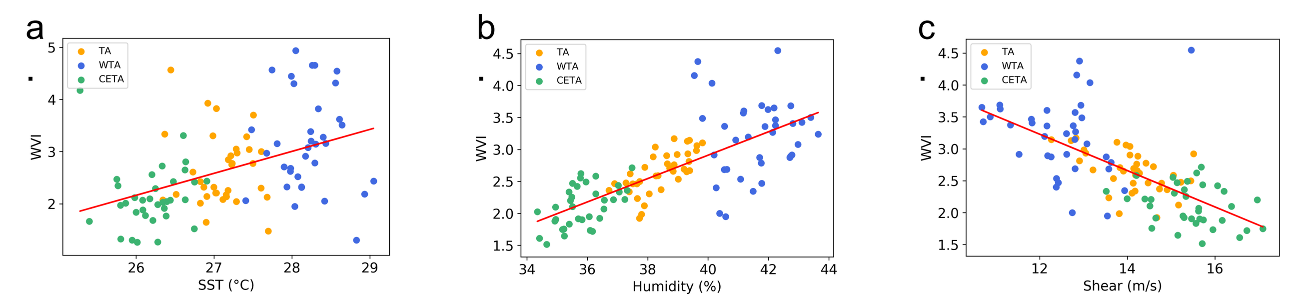

Figure 6. Correlation between WVI and and (a) SST, (b) 500 hPa relative humidity, and (c) vertical wind shear.

- Compares WVI to environmental factors.
- **The environmental conditions that are more conducive to TC formation tend to result in higher WVIs.**
  - Positive correlation with (a) SST and (b) humidity.
  - Negative correlation with (c) vertical wind shear.

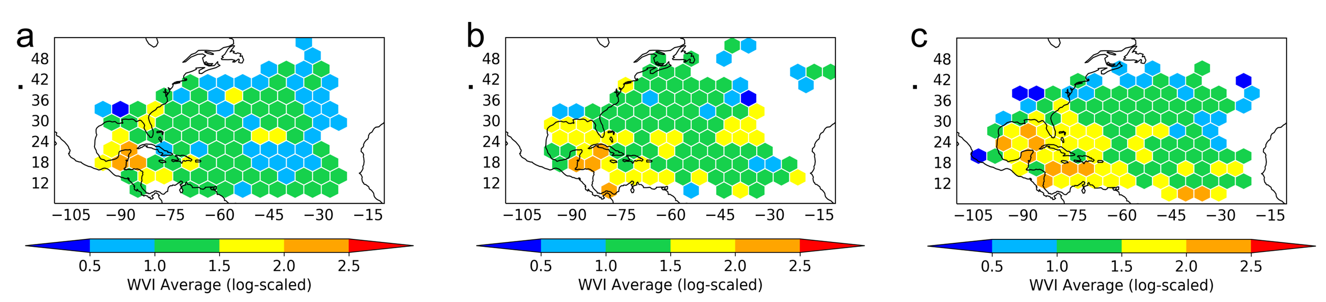

Figure 7. Spatial averages of WVI magnitudes for years with (a) low, (b) medium, and (c) high annual average TC lifetime maximum speed.

- Data is divided based on TC maximum wind speeds averaged over season.
- 2D histogram ("heat map") of WVI values.
- **(c) High-intensity years have higher WVI values.**
- **Higher WVI values tend to be concentrated in the WTA,** especially in the Caribbean Sea and Gulf of Mexico.
- Bootstrap t-test confirms higher WVI values in WTA compared to CETA.

RESULTS

Table 1. Linear regression statistical tests. Most of the significant long-term trends were found in the CETA. Differing trends between sub-basins imply possible effects of different environmental conditions.

	WTA	CETA	TA
Aggregate PDI	P = 0.082	**P = 0.013 inc.** R^2 = 0.164	**P = 0.007 inc.** R^2 = 0.189
Normalized PDI	P = 0.239	P = 0.725	P = 0.140
Max. Wind Speed	P = 0.097	P = 0.994	P = 0.137
IT	P = 0.148	**P = 0.009 inc.** R^2 = 0.178	**P = 0.020 inc.** R^2 = 0.146
IR	P = 0.257	P = 0.060	**P < 0.001 dec.** R^2 = 0.331
WVI	**P = 0.016* dec.** R^2 = 0.150 * Median.	**P = 0.043** inc.** R^2 = 0.112 ** 95th perc.	P = 0.580* * Median

CONCLUSION

- Tropical Atlantic:
  - Peak wind intensity not changing over time.
  - Average buildup time (IT) increasing over time.
- WTA: little to no trends, only in wind variability (WVI).
- CETA: increasing activity in power (PDI), IT, and WVI.
- TA: sub-basin IR trends combine, WVI trends cancel.
- In years with higher average cyclone intensity, higher WVI magnitudes in the Caribbean Sea and Gulf of Mexico indicate that these areas suffer from less predictable cyclone intensification over time.

EXPERIENCE COMPONENTS

- **Description**: Research on hurricane trends in the North Atlantic Ocean.
- **Challenges and obstacles encountered**: One of the most difficult components of this research project was accounting in discrepancies in data origin, such as changes in data collection technologies.
- **Benefits and takeaways**: This project helped me understand climate trends from a scientific perspective, as well as the implications of these trends on populations like Puerto Rico.
- **Recommended steps**: Other students can look through existing scientific literature regarding TC trends. Universities can support this and similar research by providing access to weather databases, which would also help encourage more students to embark on similar research experiences.

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