# An Environmental Explanation for the Recent Increase in Tropical Cyclone Intensification


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***Building on work from Bhatia et al. (2019) and Bhatia et al. (2018)***

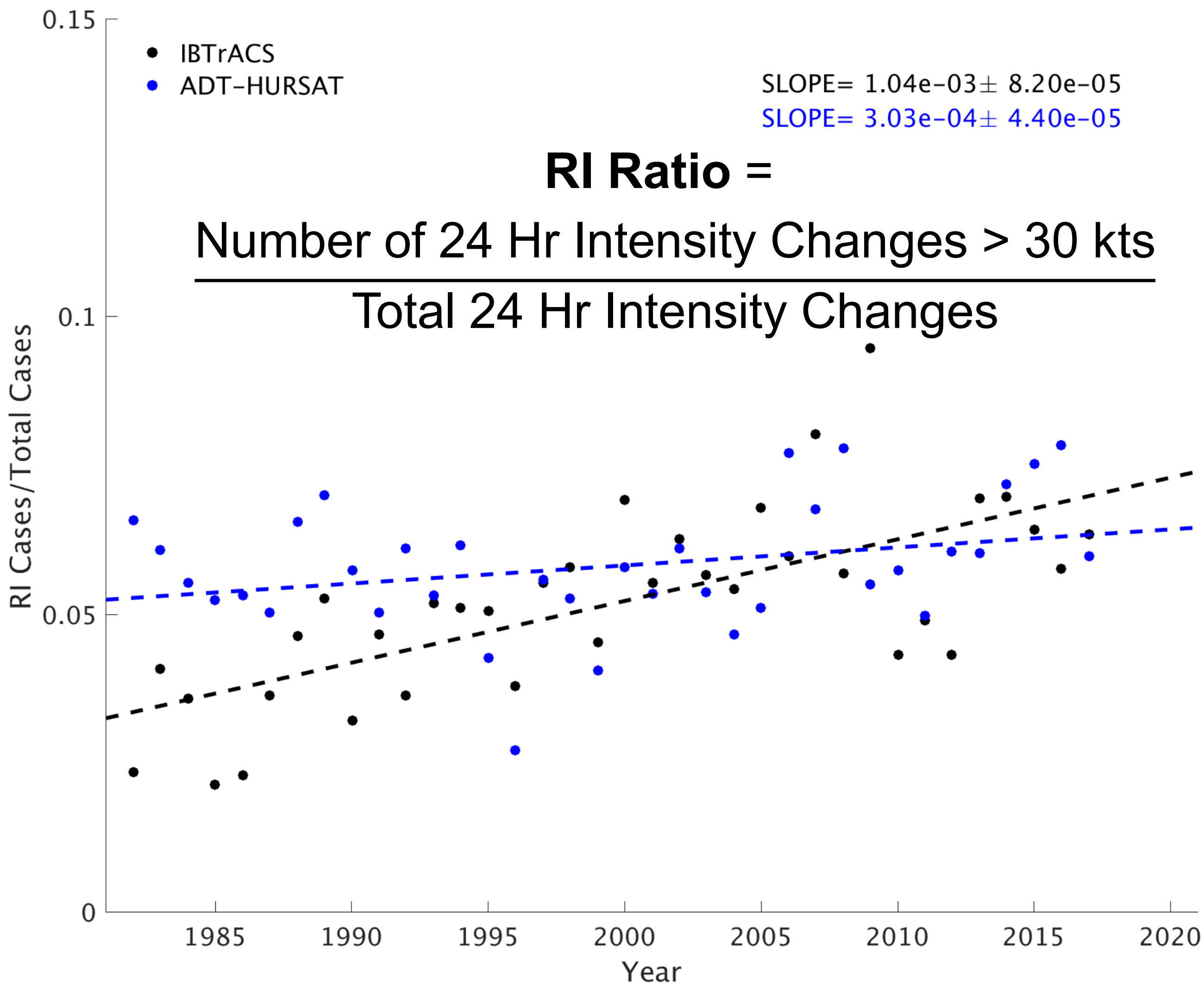
# Has the Intensification Rate of Tropical Cyclones Increased in Recent Years?

<u>**Yes**</u>

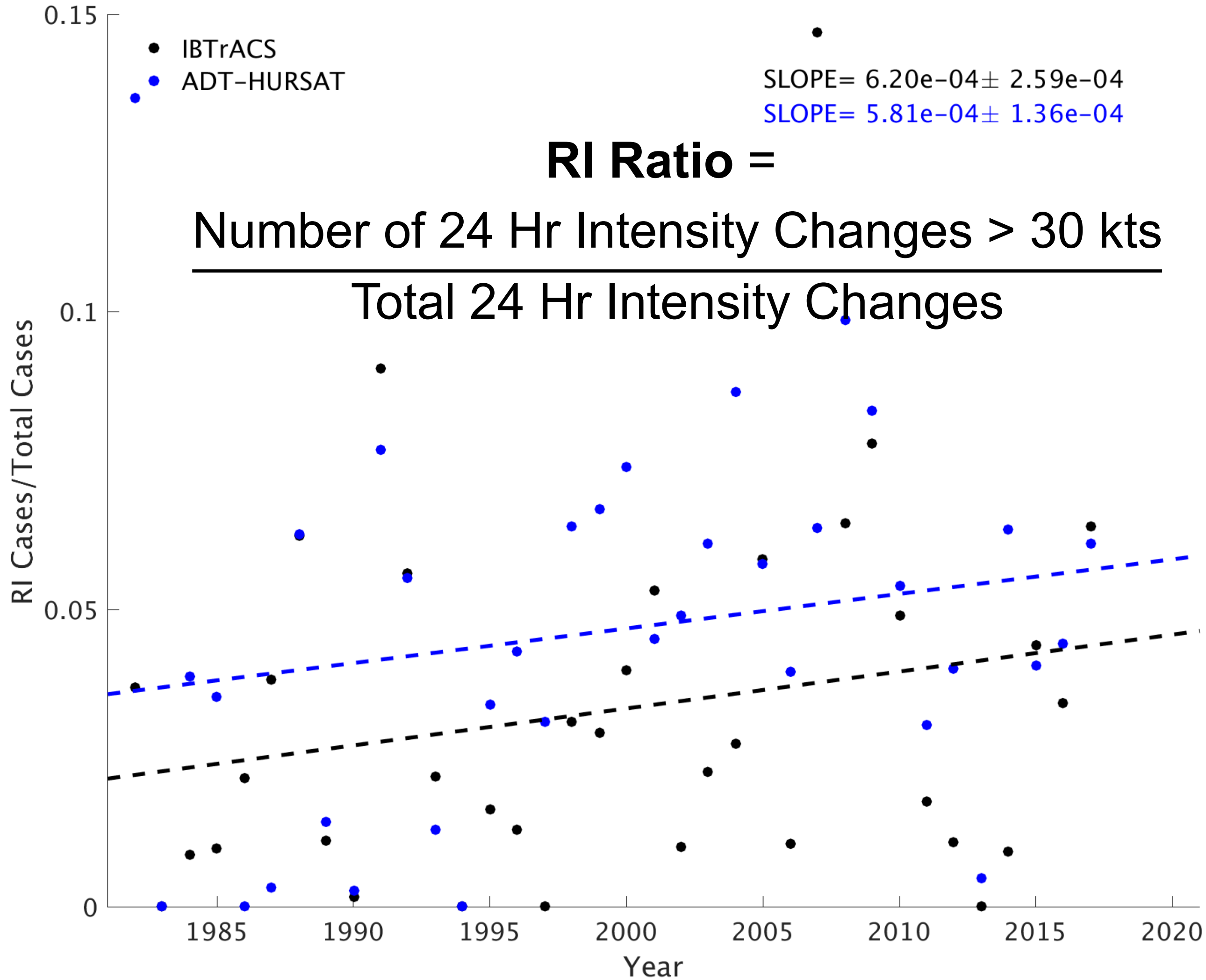
# Observational Datasets (1982-2017)

- Advanced Dvorak Technique (ADT)-Hurricane Satellite B1 (HURSAT)
  - Wind speeds are produced every three hours to the nearest tenth of a Dvorak “T-number” (between 1-3 knots)
  - Horizontal resolution of 8 km
  - **Temporally and spatially homogeneous data**
- International Best Track Archive for Climate Stewardship (IBTrACS)
  - Best track intensity and position estimates are recorded every six hours to the nearest 5 knots (1 kt = 0.514 m $s^{-1}$)
  - 0.1° latitude/longitude horizontal resolution
  - **Temporal and spatial inconsistencies**

# Global Rapid Intensification (RI) Ratio Trends



# Atlantic Rapid Intensification (RI) Ratio Trends



# Can Observational Trends Be Explained By Natural Climate Variability?

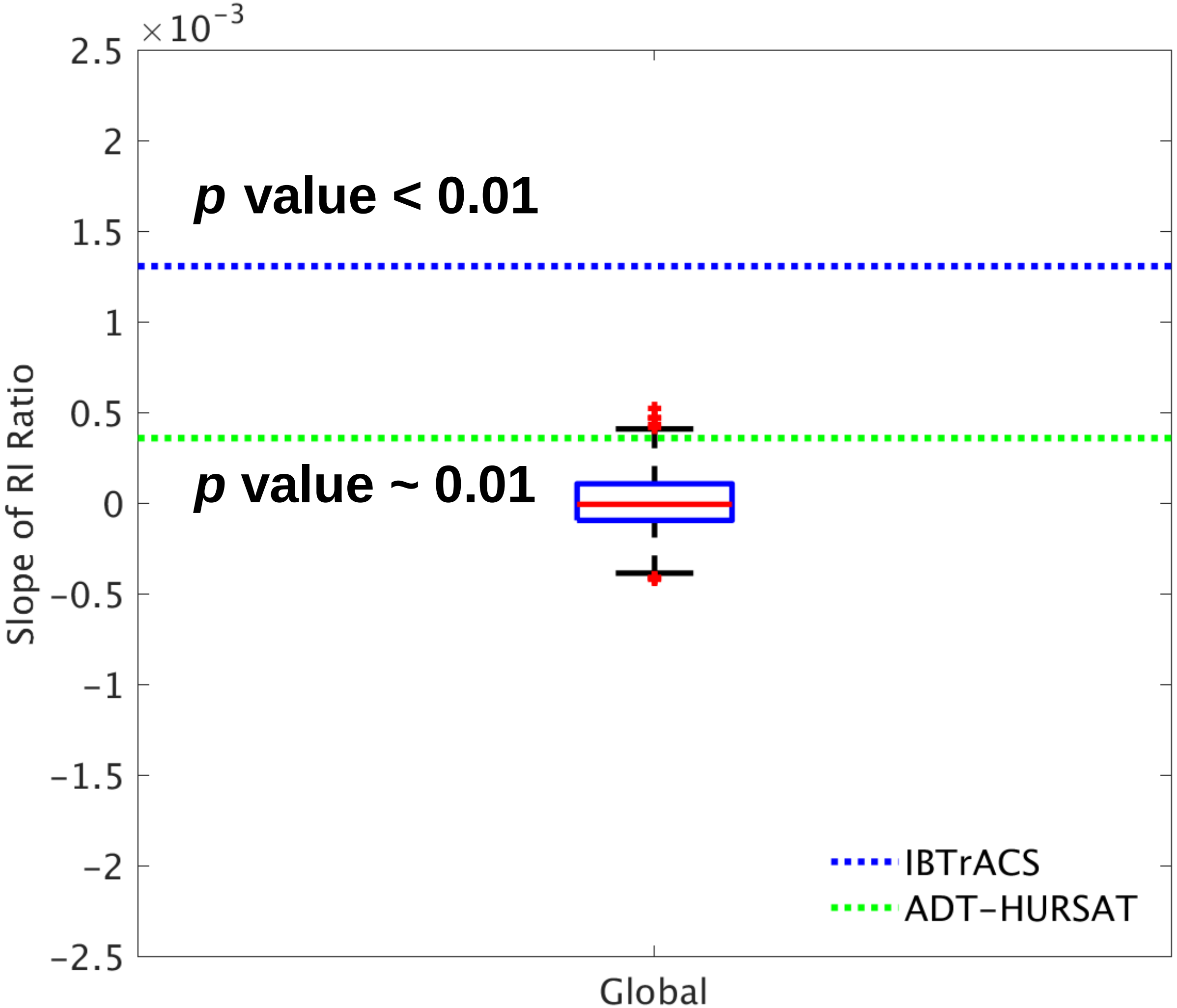
**No**

# High-Resolution Forecast-Oriented Low Ocean Resolution (HiFLOR) Model

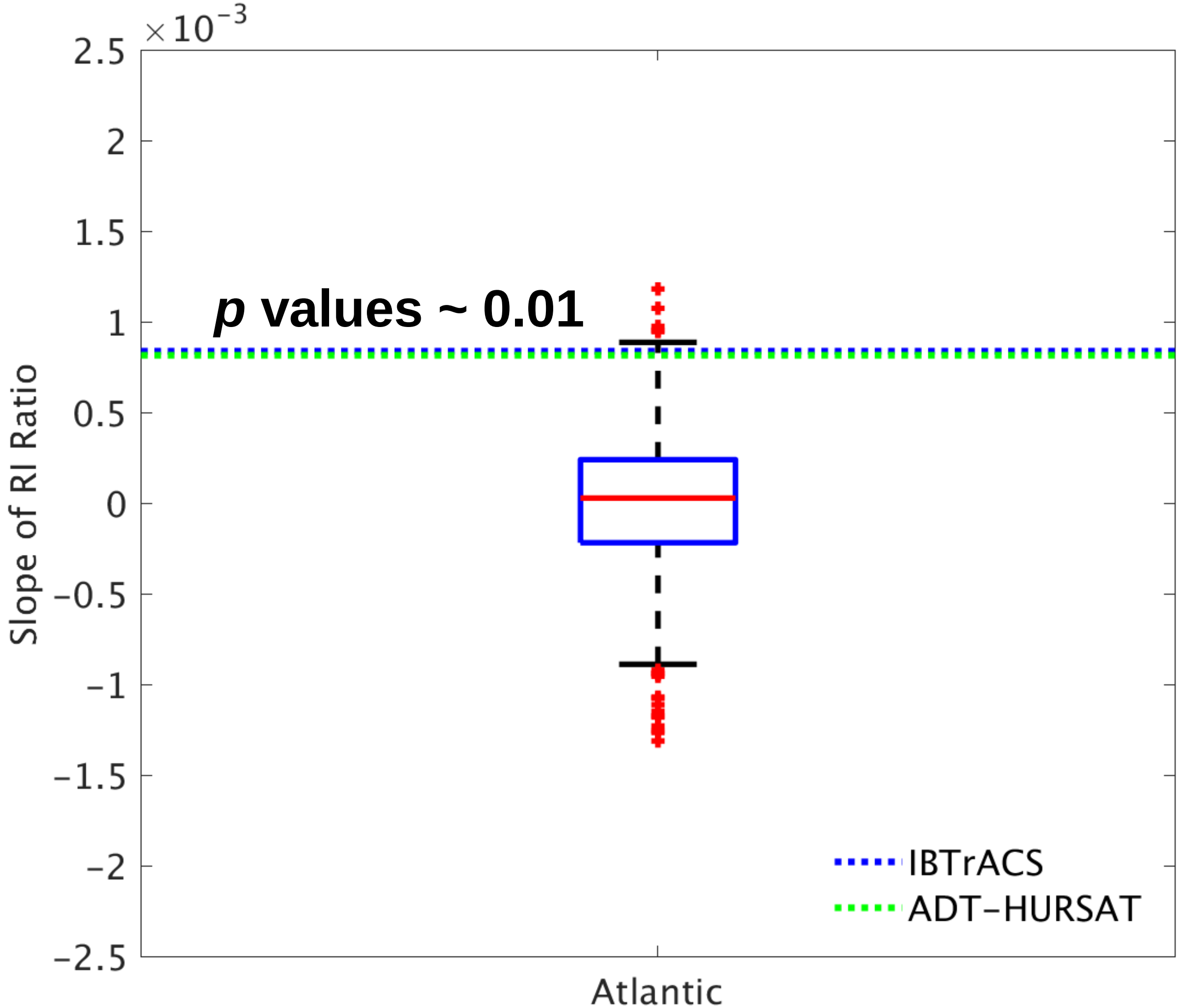
- High-resolution atmospheric/land model (0.25° × 0.25°) coupled to low-resolution oceanic/sea ice model (1° × 1°)
- We use four control simulations in which anthropogenic forcing was fixed at years 1860, 1940, 1990, and 2015
- The simulations vary in length and the first fifty years of each simulation were discarded to avoid model drift:
  - 1860 (1500 years)
  - 1940 (200 years)
  - 1990 (300 years)
  - 2015 (200 years)

**Each of the four simulations is split up into overlapping 36-year periods, and the slope of each period is calculated**

# Global RI Ratio: Observed Trend vs. 1860CTL Natural Variability



# Atlantic Basin RI Ratio: Observed Trend vs. 1860CTL Natural Variability



# RI Ratio

Percent Difference Between 1940CTL and 1860CTL

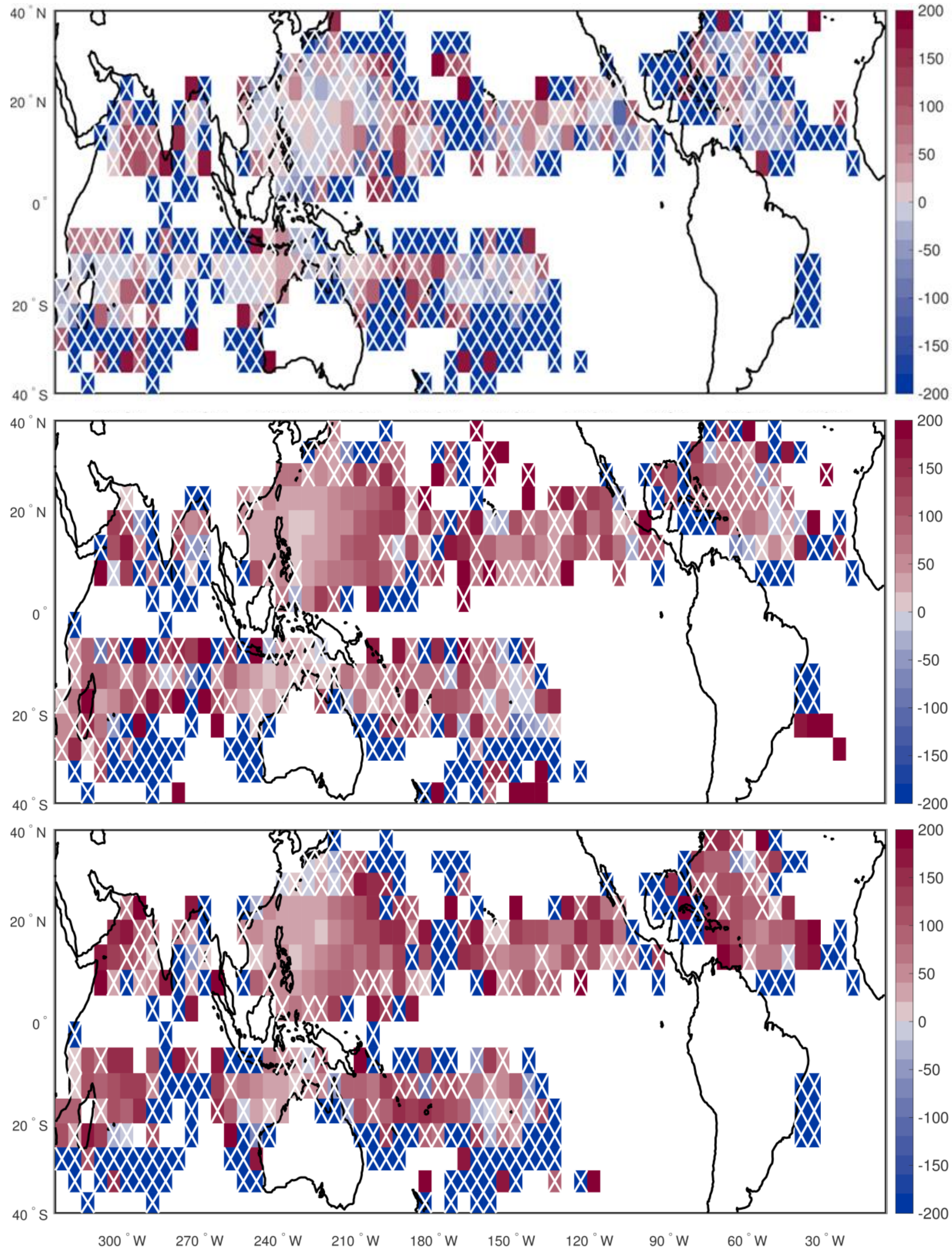
**9.7%**

Percent Difference Between 1990CTL and 1860CTL

**34.7%**

Percent Difference Between 2015CTL and 1860CTL

**38.2%**



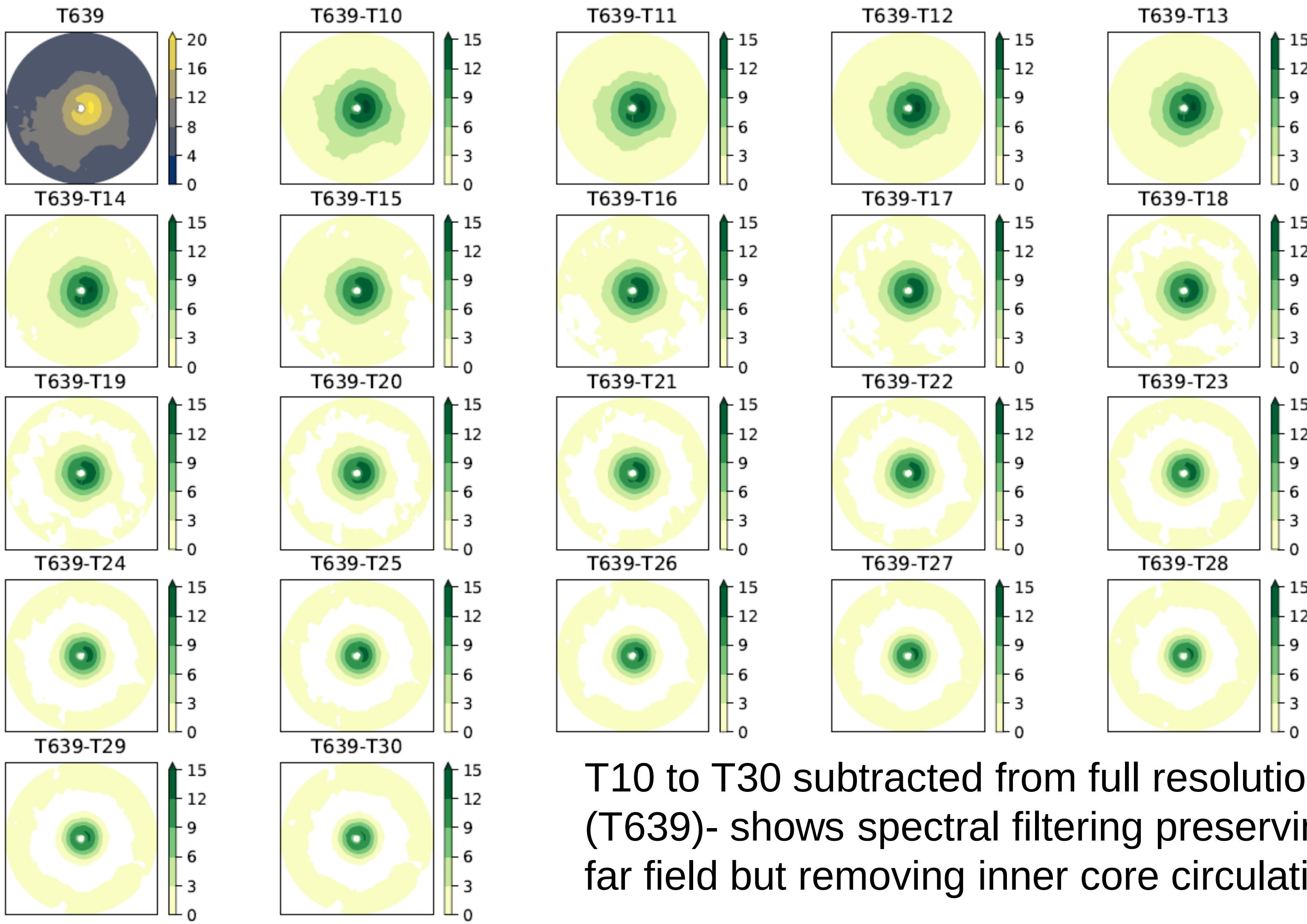
# Are The Environments Surrounding Storms Becoming More Favorable For Intensification?

**Looks Likely but More Analysis Needed**

# ERA5 Reanalysis Data

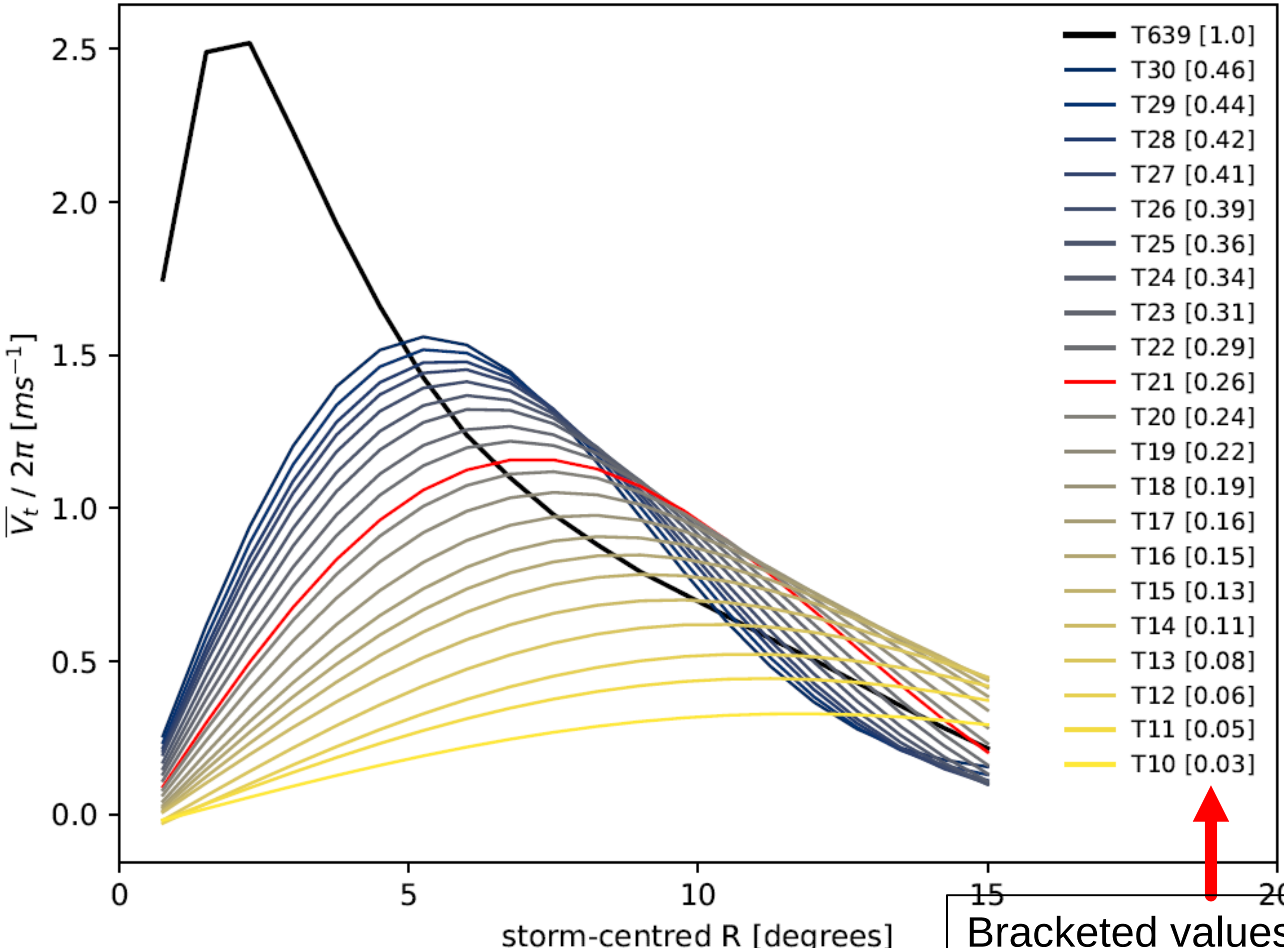
- Three environmental variables analyzed:
  - Sea Surface Temperature (Skin temperature)
  - Wind Shear (850-200 mb)
  - Relative Humidity (averaged between 850,700, and 600 hPa)
- Values averaged in a $5^{o}$ box around storm center
- 1982-2017 6-hourly data paired with all available northern hemisphere intensity change cases from IBTrACS that meet latitude and longevity criteria
- T21 spectral filtering used to remove spatial scales associated with storm circulation and preserve environmental signature

# Wind Speed Difference Composite for all TCs



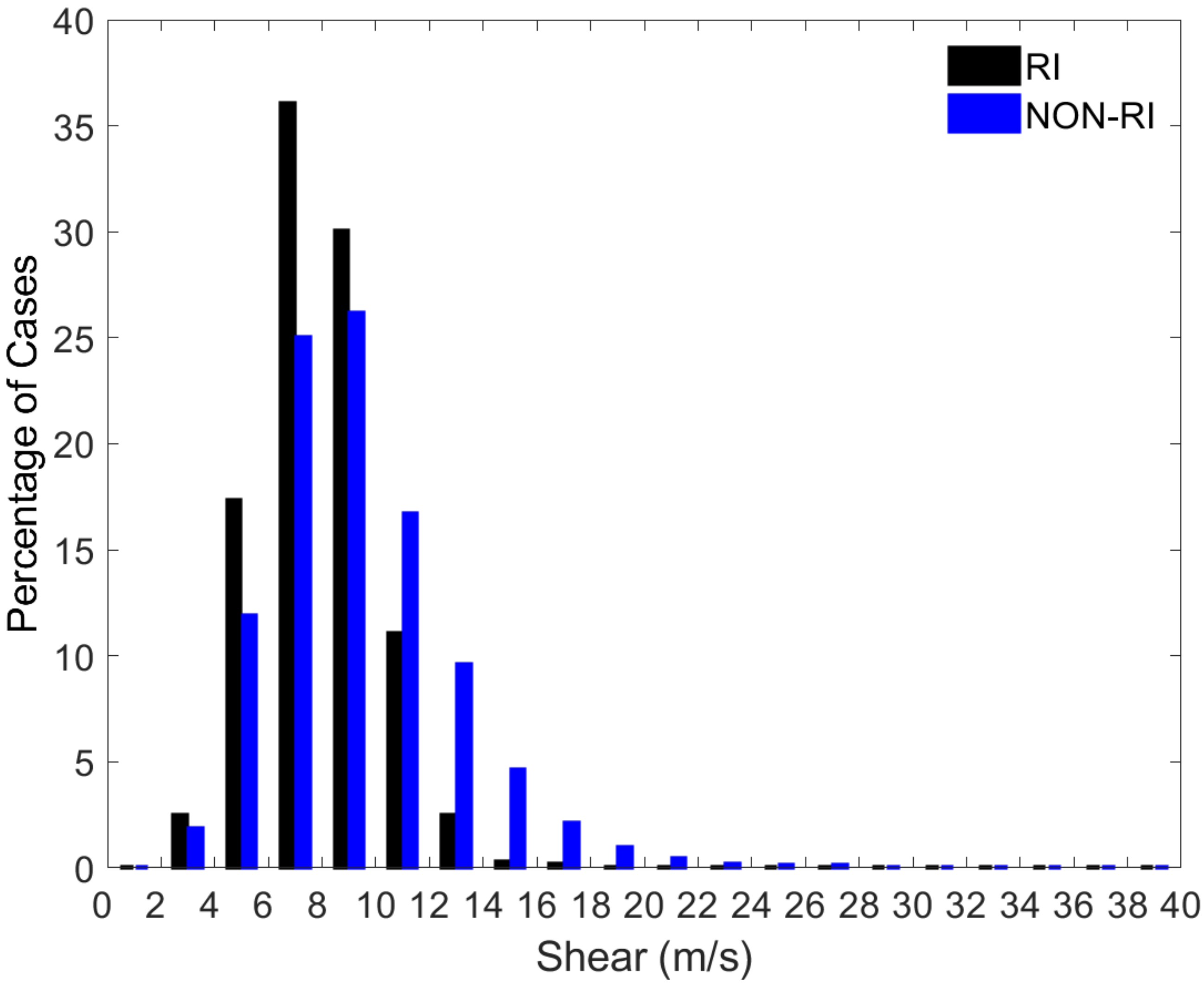

T10 to T30 subtracted from full resolution (T639)- shows spectral filtering preserving far field but removing inner core circulation

# Circulation Composite for Different Spectral Resolutions

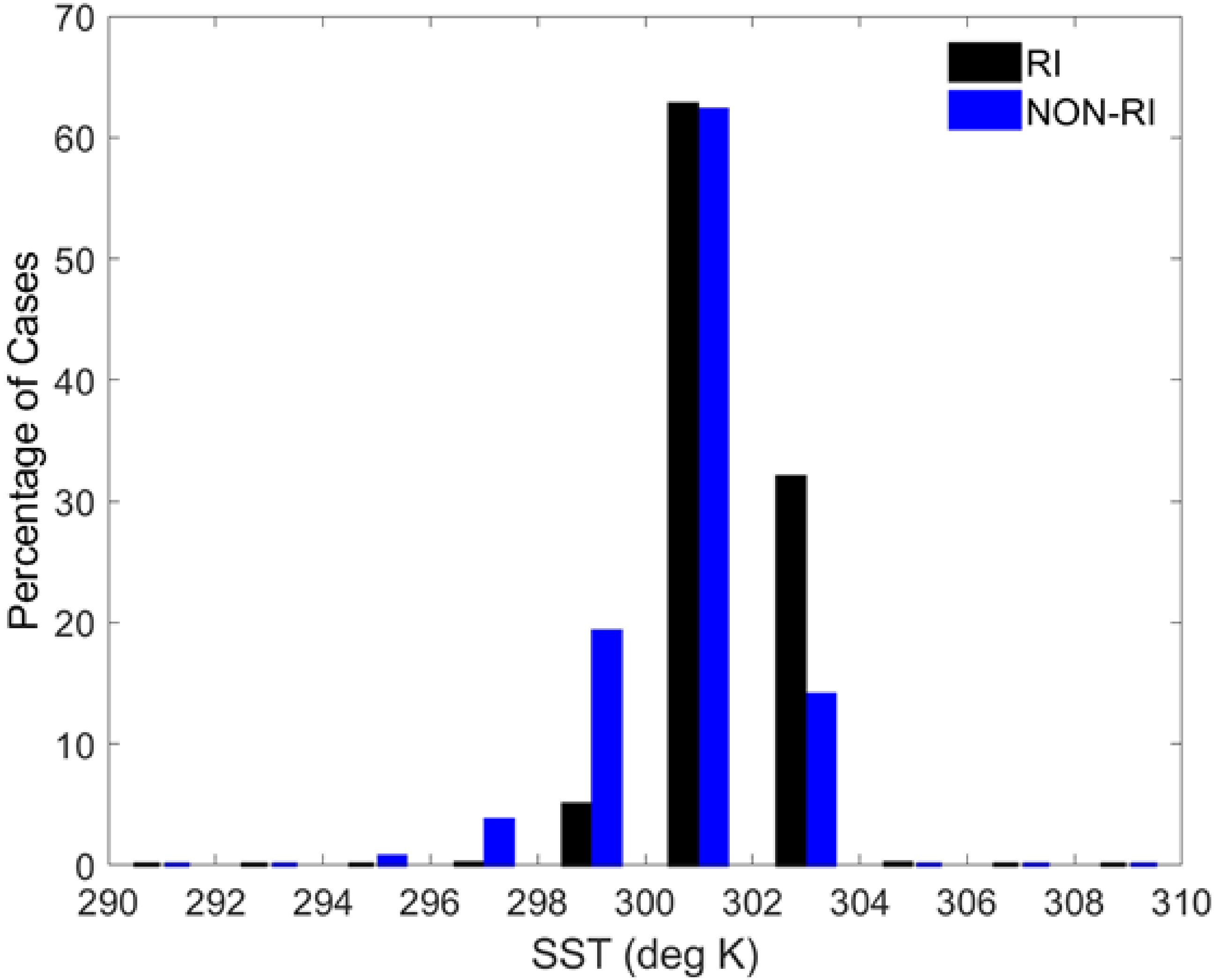



Bracketed values indicate proportion of circulation remaining after filtering

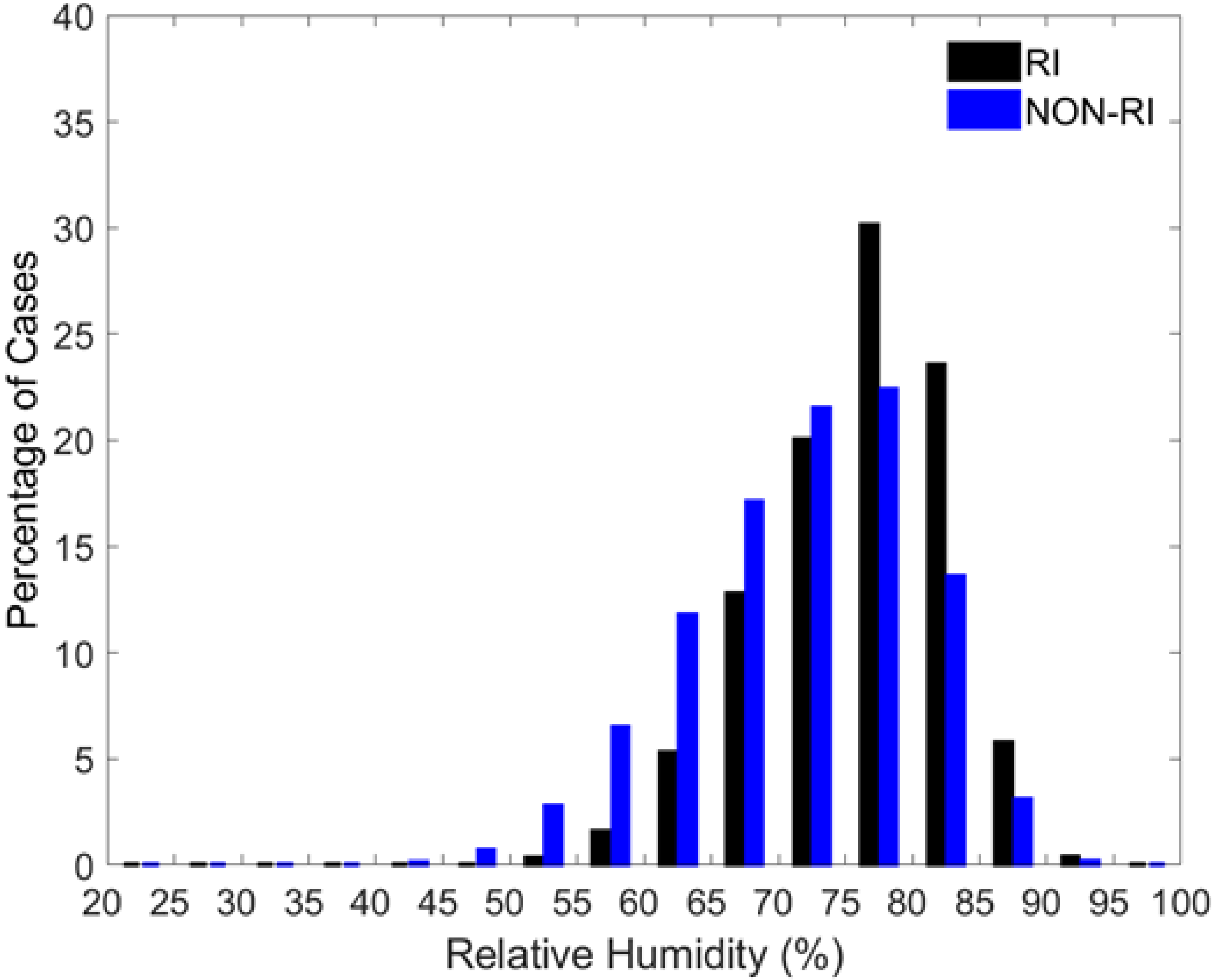
# Northern Hemisphere RI vs. Non-RI Behavior: Shear



# Northern Hemisphere RI vs. Non-RI Behavior: SST



# Northern Hemisphere RI vs. Non-RI Behavior: Relative Humidity



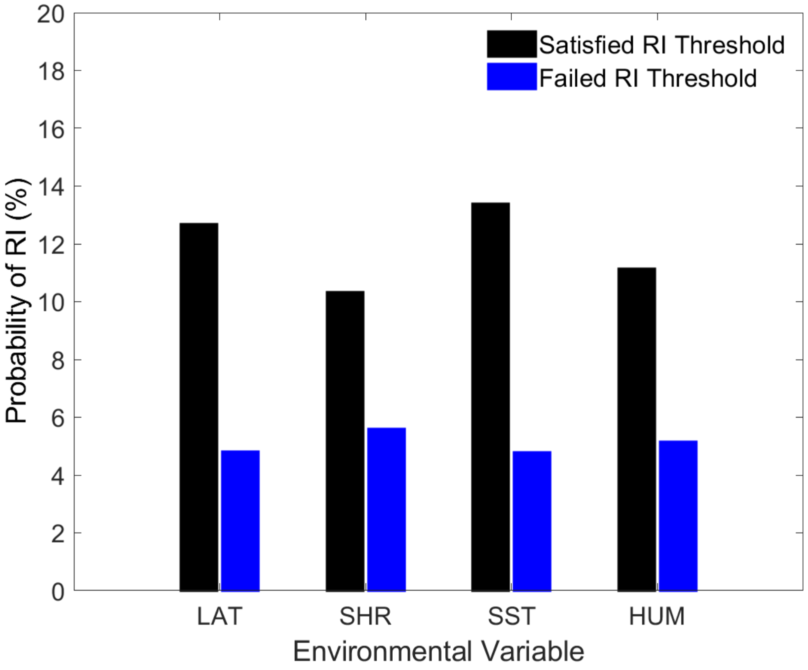
# RI Probability vs. Threshold Exceedance

- Following the approach of Kaplan and DeMaria (2003), mean magnitudes of the initial (*t* = 0 h) synoptic variables of the RI and non-RI samples were calculated. RI mean values are used as thresholds.

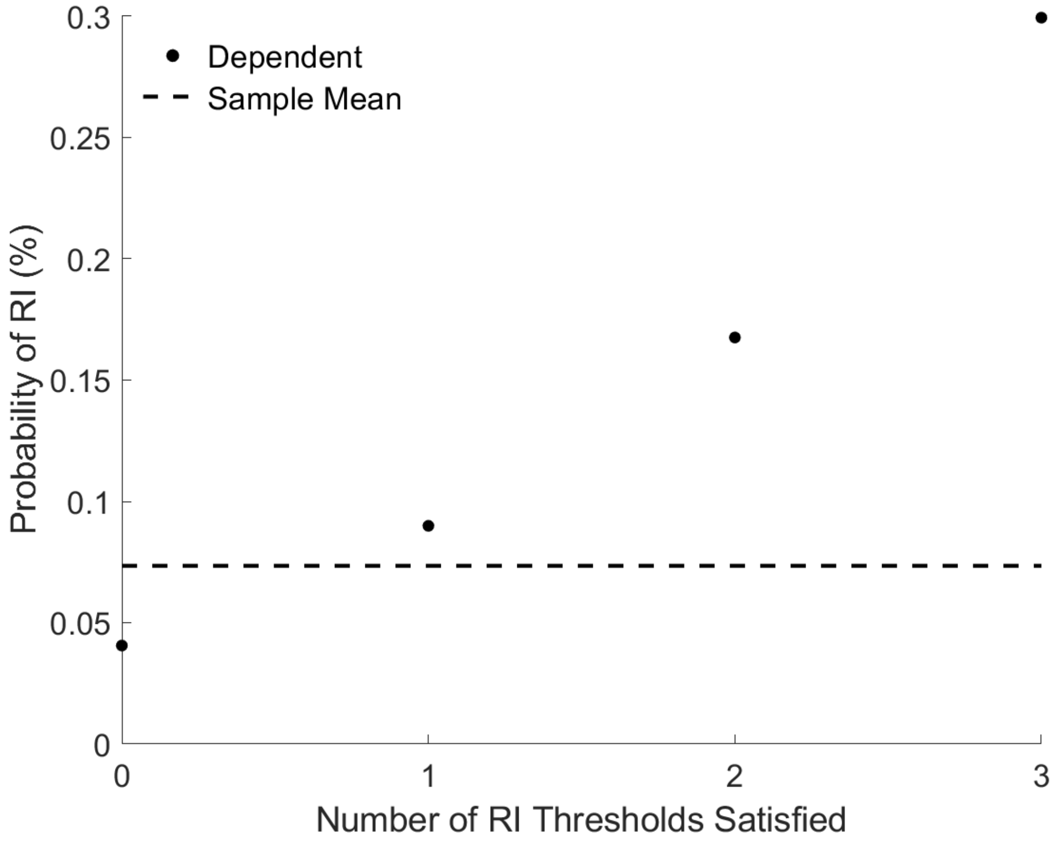
- Statistically significant differences were found to exist between the means of the RI and non-RI samples (*corresponds to 99% significance)

- When RI thresholds are satisfied, the probability of RI at least doubles.

| Variable | RI | Non-RI |
|---|---|---|
| SST (deg K)* | 301.57 | 300.73 |
| HUM (%)* | 75.83 | 71.67 |
| SHR (m/s)* | 7.81 | 9.33 |

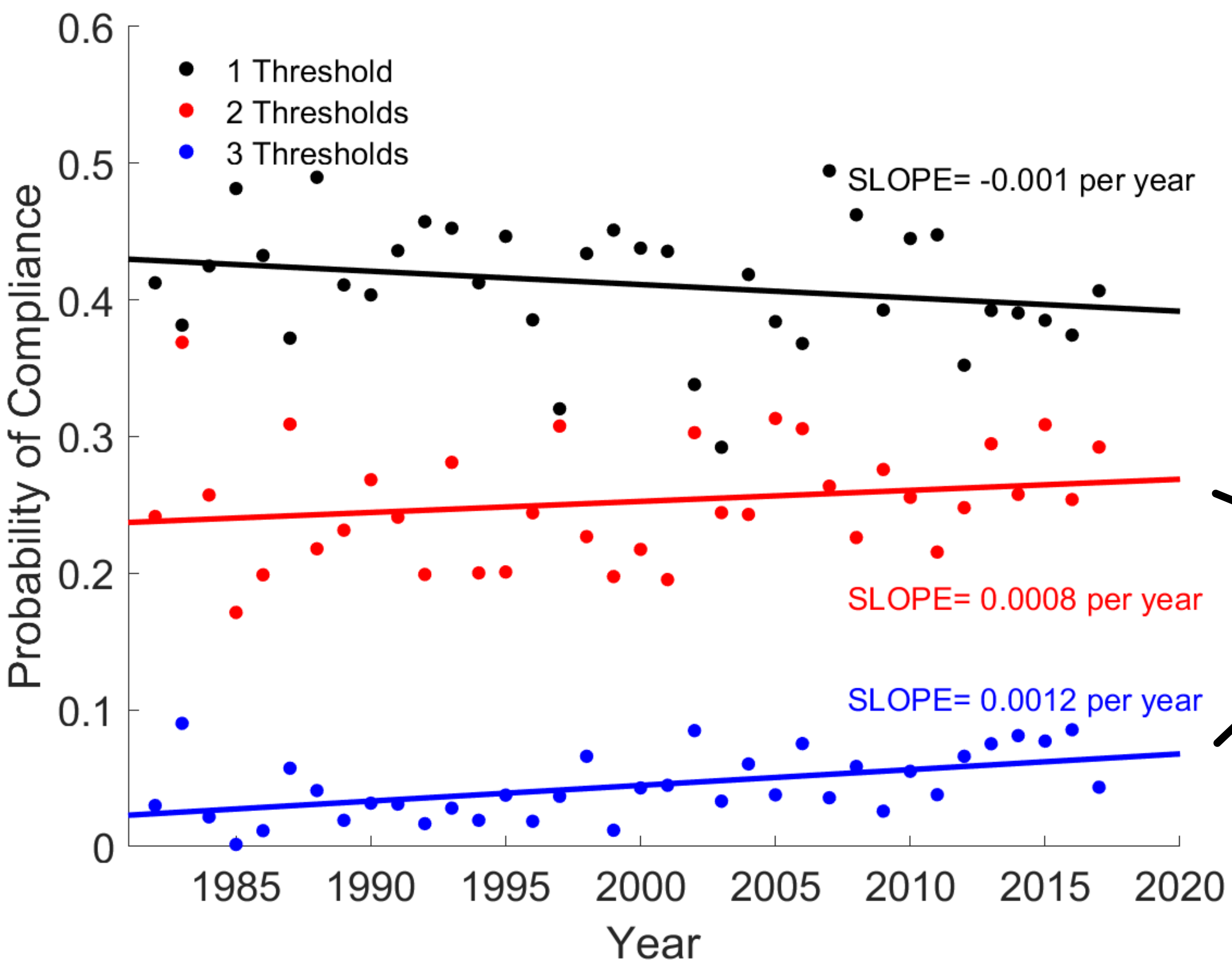


# Multiple Thresholds Satisfied = Higher Probability of RI




- Following Kaplan and DeMaria (2003), the composite probability of RI determined for 1982-2017 northern hemisphere cases. The probabilities are provided as a function of the total number of the three (, SHR, SST, and HUM) RI predictor thresholds that were satisfied. The sample mean probability of RI is also shown for reference.

# 1982-2017 Proportion of Cases with Thresholds Being Satisfied




The percentage of cases where 2 or 3 RI thresholds are satisfied are increasing during the time series.

# Conclusions

- After extending the work of Bhatia et al. (2019), natural variability cannot explain the slope in ADT-HURSAT or IBTrACS RI ratio between 1982-2017 in the Atlantic basin or globally, which suggests anthropogenic warming has already contributed to the increased acceleration rates of TCs.

- Storm-centered (temporally and spatially) ERA5 environmental parameters: shear, relative humidity, and sea surface temperature appear to be connected to the probability of rapid intensification.

- Initial findings suggest a detectable upward trend in the frequency of these environmental parameters exceeding key thresholds. Additional analysis is required to understand whether favorable situations for intensification are becoming significantly more probable due to climate change.

# Future Work

- Sensitivity testing of spectral filtering and radial averaging for environmental variables
- Inclusion of potential intensity and relative SST as predictors of RI
- More methodical threshold analysis for environmental variables
- Use other GCMs to model natural variability of climate system (environmental variables and intensity change)

# EXTRA SLIDES

# Storm Selection Criteria

- To be included in the 24-hour intensity change analysis, TCs must:
  - be detectable for at least 72 hours and exceed wind speeds of 34 knots for at least 36 hours
  - be located over the ocean at the beginning and end of the 24-hour period
  - stay between 40ºN and 40ºS and above 34 knots at the beginning and end of the 24-hour period

# Summary of Observational Trends

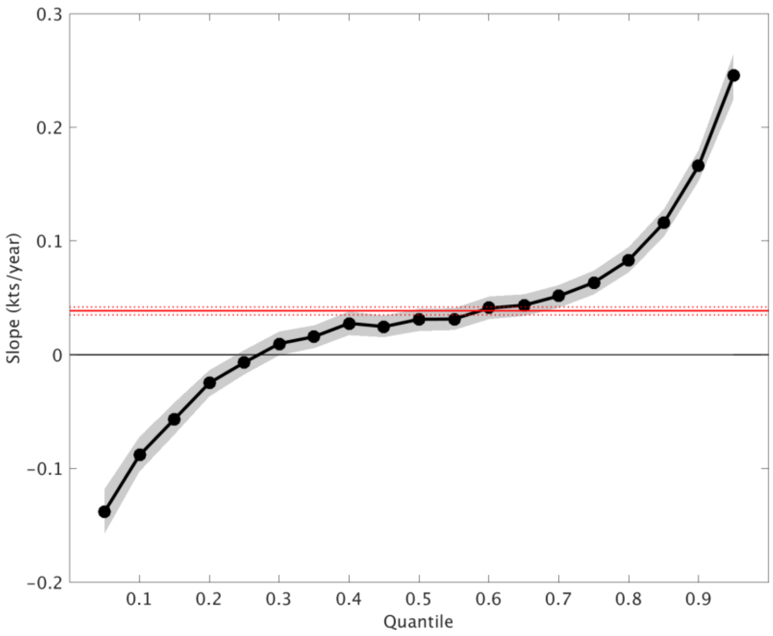
- Between 1982-2017, there is:
  - a significant upward trend in the global RI ratio for IBTrACS and ADT-HURSAT (but much smaller)
  - a significant, almost identical, upward trend in Atlantic basin RI ratio for IBTrACS and ADT-HURSAT
- These observations are likely caused by the:
  - spatial and temporal heterogeneities in IBTrACS
  - coarse resolution and documented issues with scene-type changes (from non-eye to eye) in ADT-HURSAT
  - phase of the Atlantic Multidecadal Oscillation (AMO) switching to positive in the 1990s

# High-Resolution Forecast-Oriented Low Ocean Resolution (HiFLOR) Model

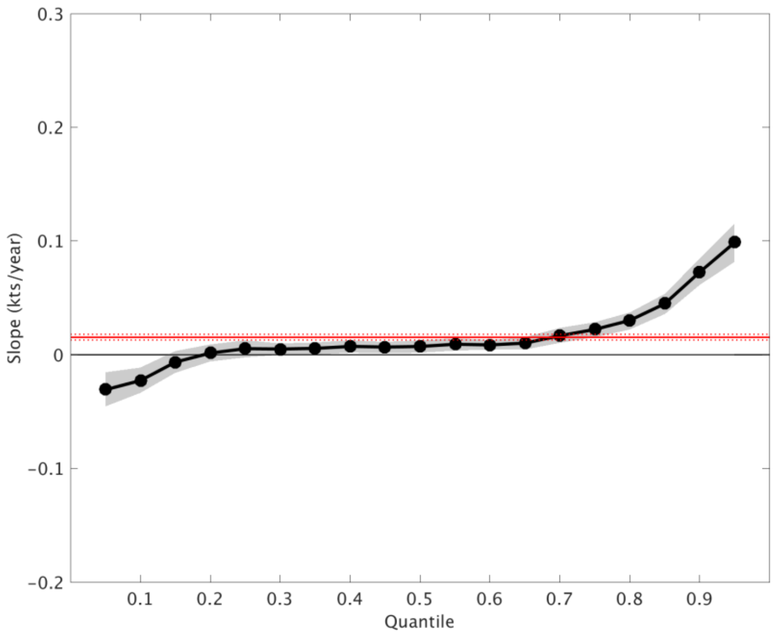
- Bhatia et al. (2018) and Murakami et al. (2015) demonstrated HiFLOR is one of the only CGCMs to capture category 4 and 5 hurricanes and the highest intensification rates
- Murakami et al. (2015, 2016) and Zhang et al. (2016) showed that HiFLOR is able to represent interannual climate variability and its influence on TCs
- Delworth et al. (2017) showed that a coarser resolution version of HiFLOR captures Atlantic Meridional Oscillation (AMO) well

# Global Quantile (5% bins) Regression

## IBTRACS

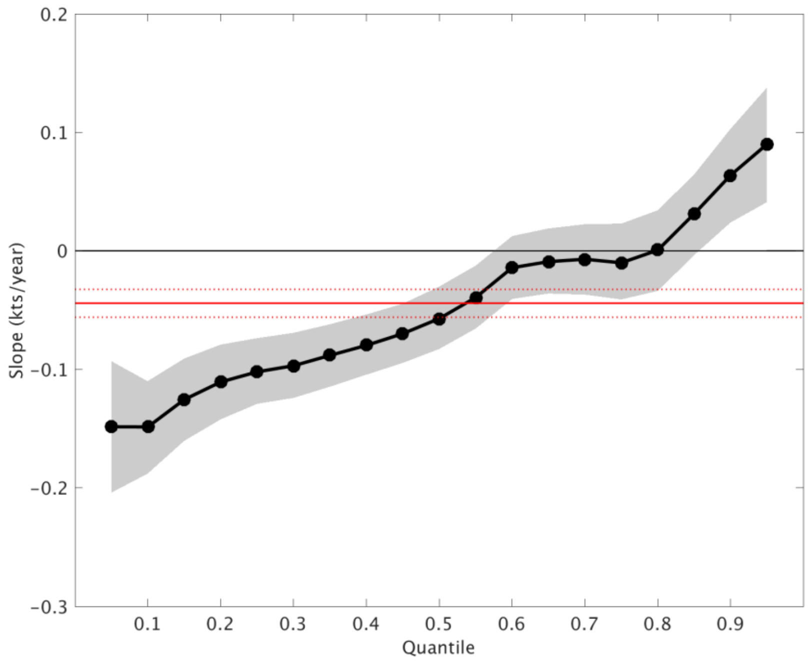



## ADT-HURSAT

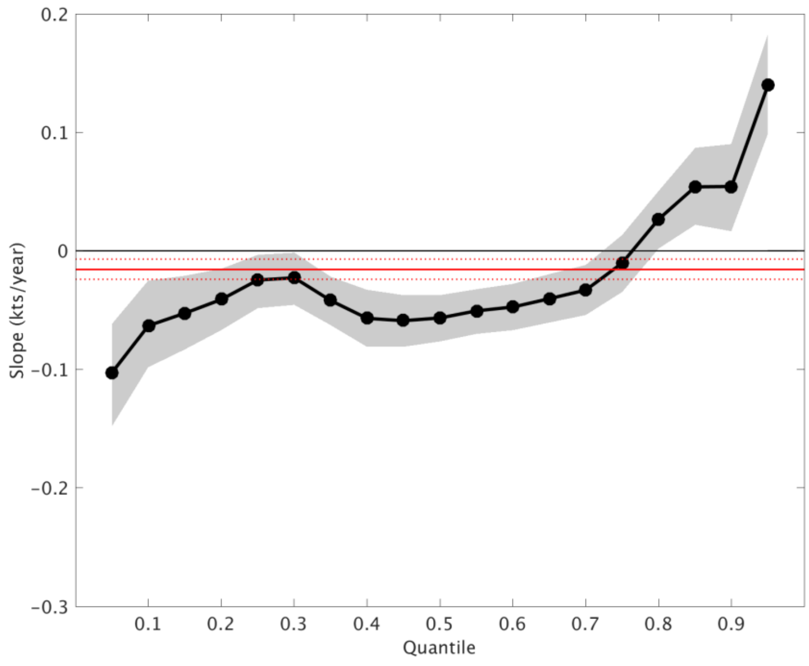


# Atlantic Quantile (5% bins) Regression

**IBTRACS**




**ADT-HURSAT**

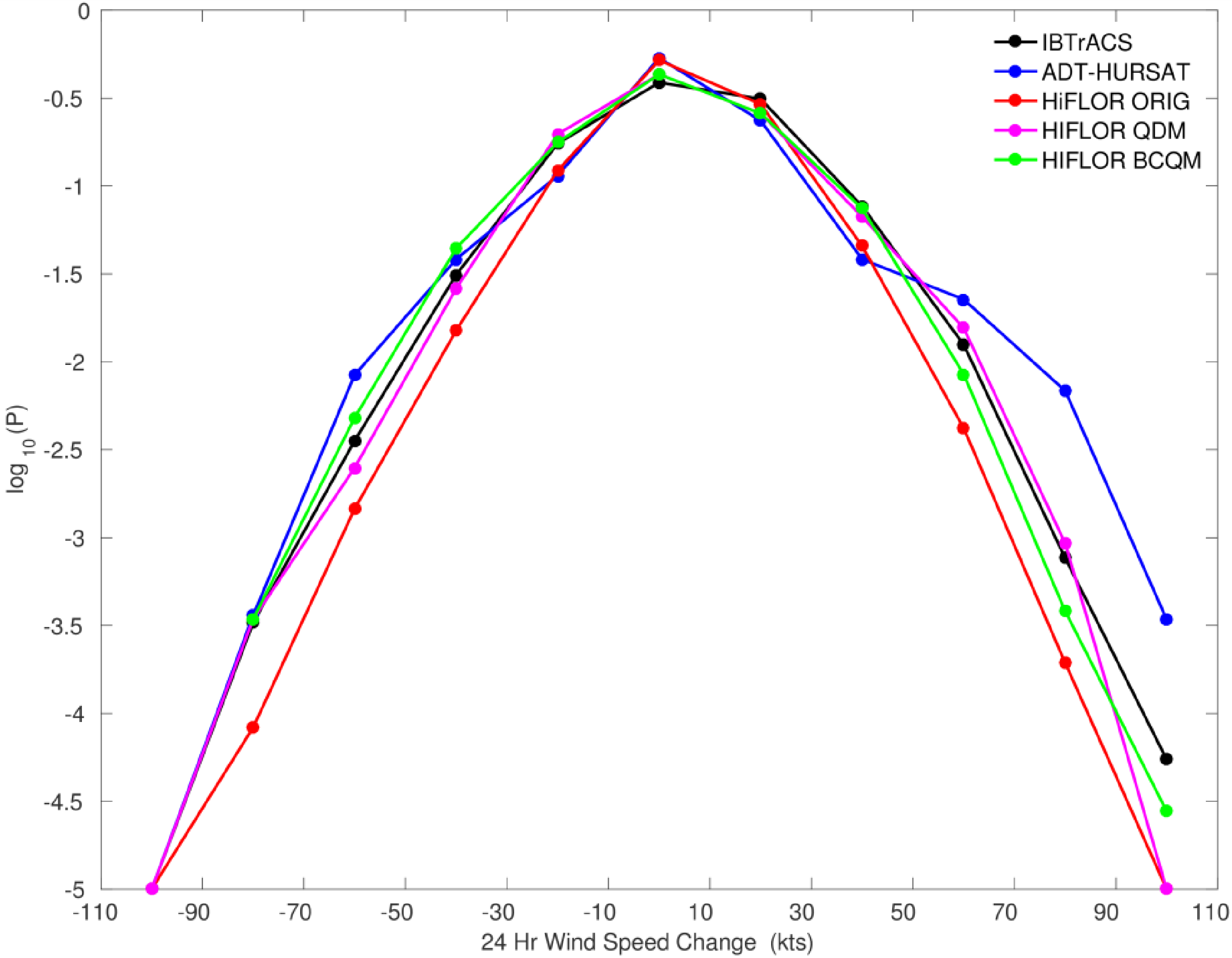


# Quantile Mapping

- Quantile mapping bias correction algorithms are commonly used to correct biases in different meteorological fields from climate models

- Two techniques are tested here:
  - Bias Correction Quantile Mapping (BCQM)- one of the simplest in a class of methods that involve mapping the characteristics of the cumulative distribution functions between observations and models as a means of establishing transfer relationships
  - Quantile delta mapping (QDM)- preserves relative changes in the quantiles between historic and future data

# Global Comparison of Intensification with Quantile Mapping



# Atlantic Basin Comparison with Quantile Mapping