# Tropical Cyclone Prediction and Attribution

**Presented by**
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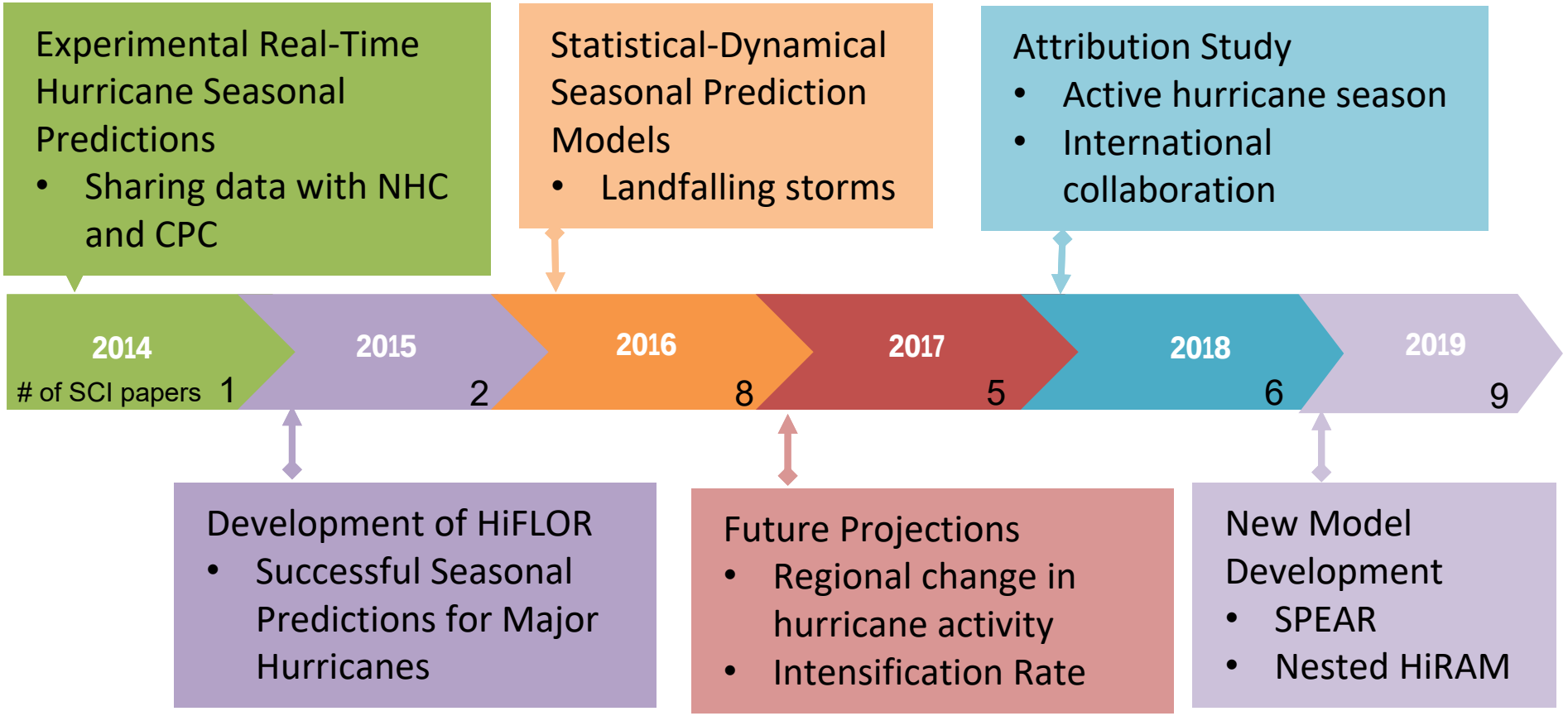
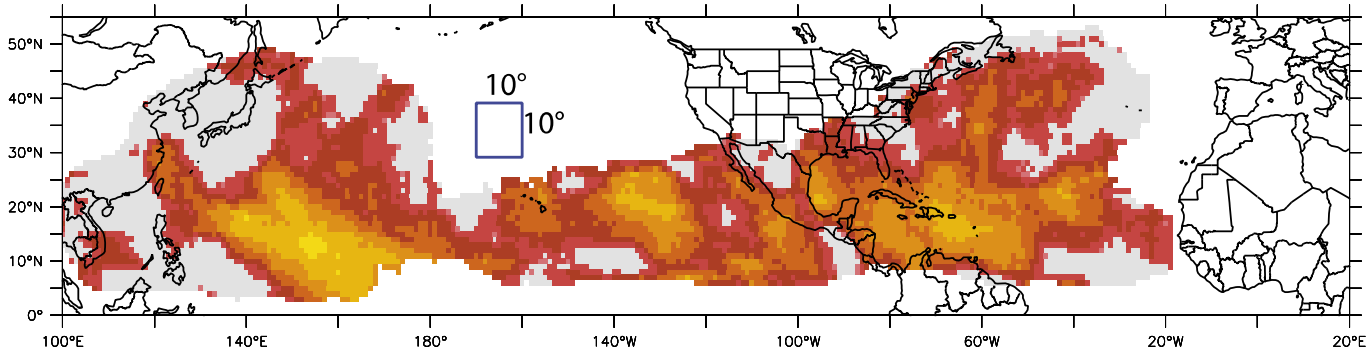
# Motivation and Achievements Since 2014

Developing a dynamical model that has skill in **predicting hurricanes, especially intense hurricanes at seasonal time scale** is central to NOAA's mission and highly relevant to society.



# Seasonal Hurricane Predictions by FLOR

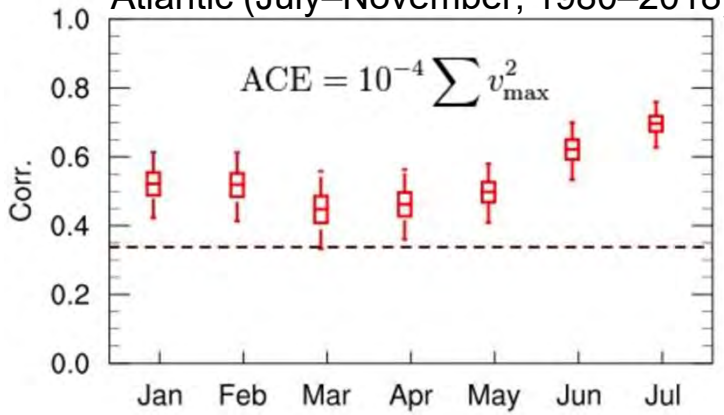
CM2.5: Fully coupled model with 50km-mesh atmosphere and 0.25° ocean/sea ice
FLOR : Fully coupled model with **50km**-mesh atmosphere and **1°** ocean/sea ice




-0.4 -0.2 0.2 0.4 0.6 0.8 1
Rank correlation predicted vs. observed masked at p=0.1

>25% years with density > 0
Vecchi et al. (2014, *J. Climate*)
Zhang, G. et al. (2019, *GRL*)

Prediction skill for ACE over North Atlantic (July–November, 1980–2018)

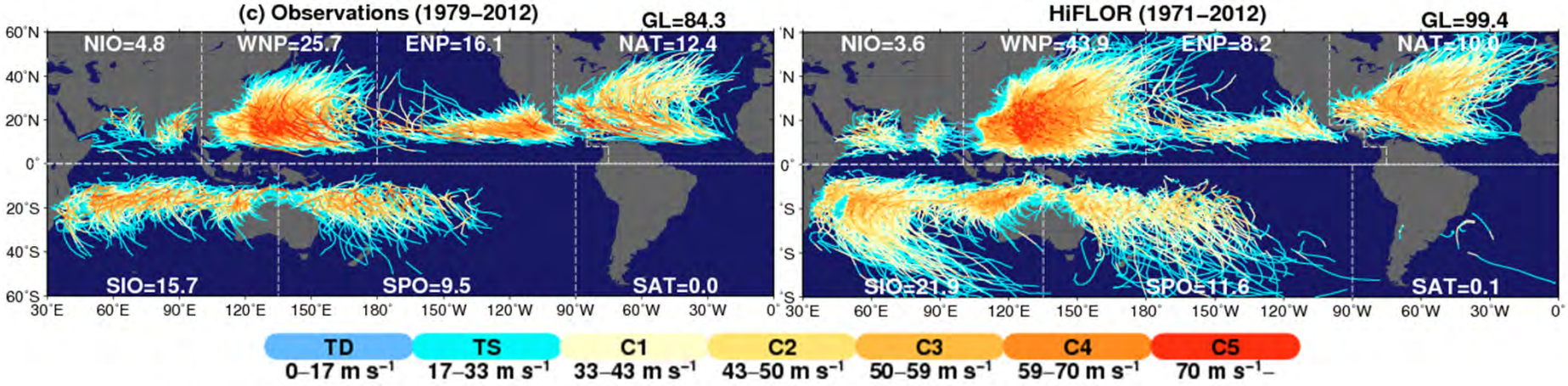


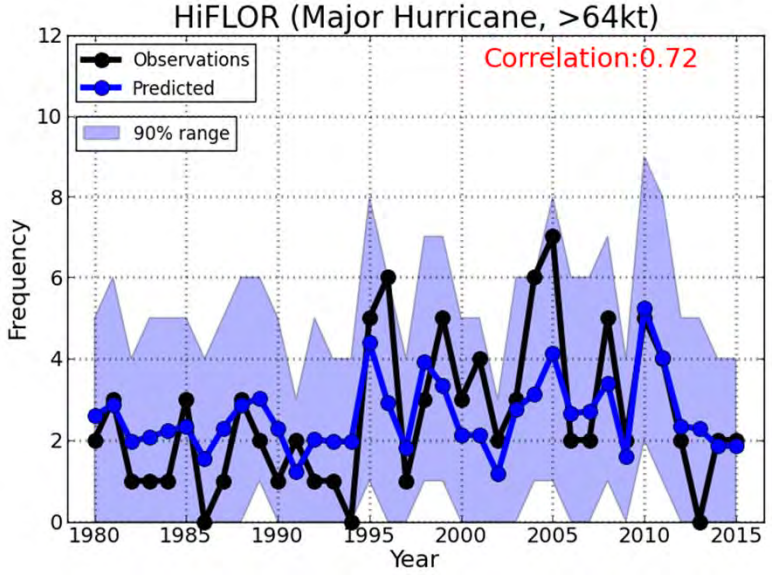

- FLOR has skill in predicting hurricanes a few months in advance
- The real-time hurricane forecasts are shared with the experts in NHC and CPC to support their seasonal hurricane outlook.

Zhang, G. et al. (2019, *GRL*)

# Major Hurricane Seasonal Predictions by HiFLOR

FLOR : Fully coupled model with 50 km-mesh atmosphere and 1° ocean/sea ice
HiFLOR: Fully coupled model with **25 km**-mesh atmosphere and 1° ocean/sea ice




HiFLOR shows skillful prediction for frequency of major hurricanes a few months in advance in the North Atlantic (r=0.72).

Murakami et al. (2015, 2017, *J. Climate*)

# Development of Statistical-Dynamical Seasonal Prediction Models

**Dynamical Predictions**


Future Prediction

Predicted Large-scale Fields

Tracking Hurricanes

Predicted Hurricanes

Verification

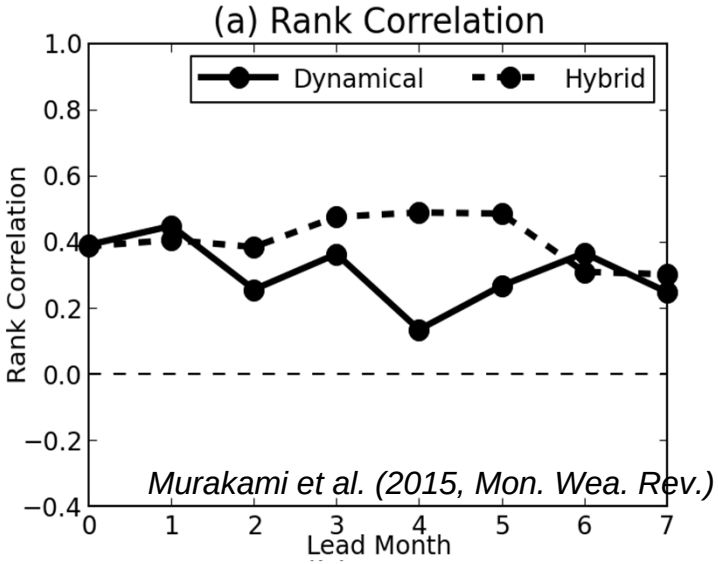
Training

**Statistical-Dynamical (Hybrid) Predictions**

Predicted Hurricanes

Observed Hurricanes

Landfalling Hurricane Seasonal Predictions over US

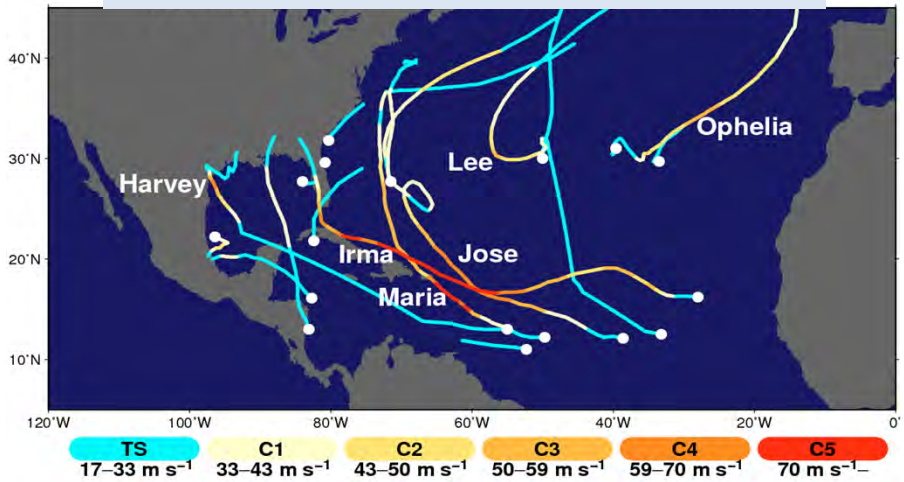



| Target | Paper |
|---|---|
| Landfalling Hurricanes in US | Murakami et al. (2015, *Mon. Wea. Rev.*) |
| Landfalling Typhoons in East Asia | Zhang W. et al. (2016, *JAMES*, 2017, *J. Climate*) |

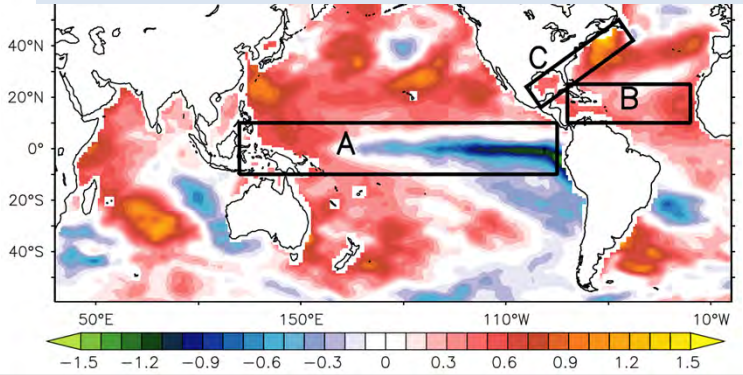
WMO encourages seasonal forecast groups to consider using new techniques like statistical-dynamical modeling (Klotzbach et al. 2019, *Trop. Cyclone Res. Rev.*) inspired by our studies.

# Real-time Attribution

## Observed Storm Tracks in 2017



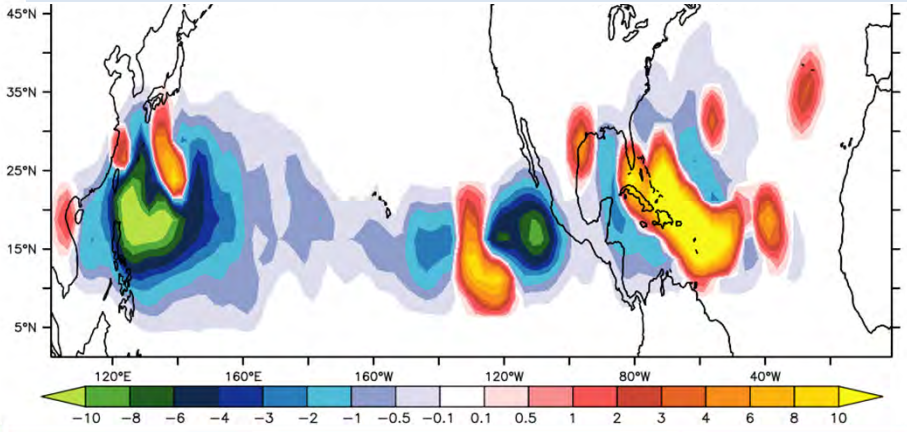

## Observed SST Anomaly in 2017



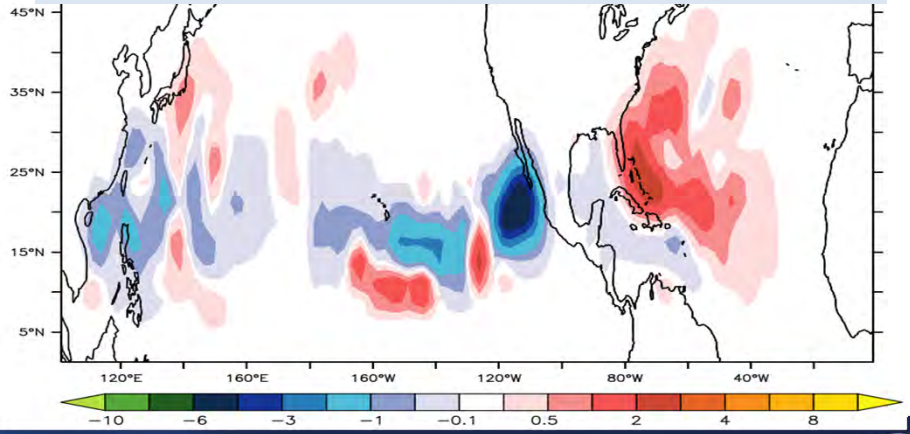

What caused the active major hurricanes in North Atlantic?

A. Moderate La Niña?
B. Warmer Tropical Atlantic?
C. Warmer off the coast of North America?

## Observed Major Hurricane Density Anomaly in 2017




## Seasonal Predictions by HiFLOR Initialized from 1 July 2017





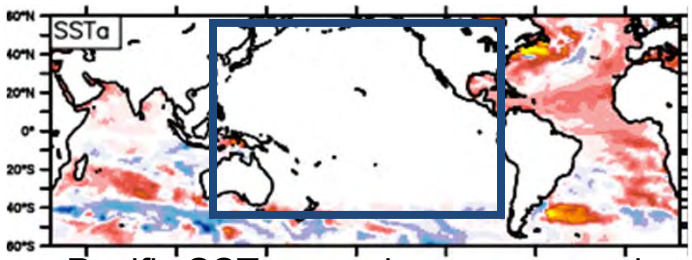

Murakami et al. (2018, *Science*)

# Real-time Attribution

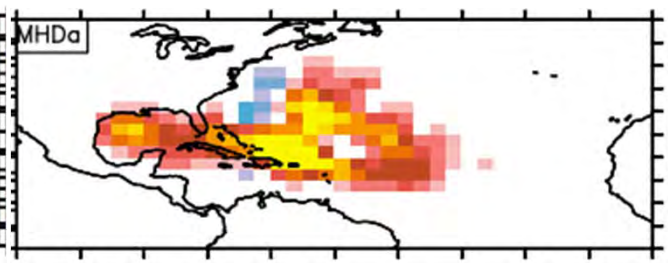
Murakami et al. (2018, *Science*)

Prescribed SST Anomaly

Predicted Major Hurricane Density Anomaly

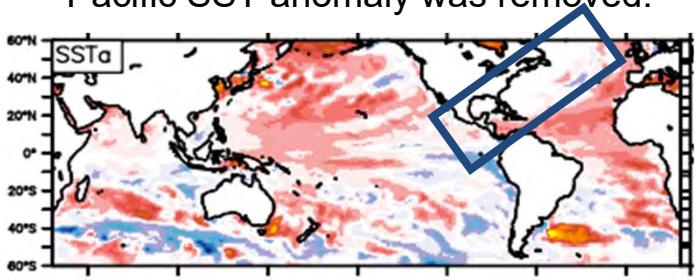



Pacific SST anomaly was removed.

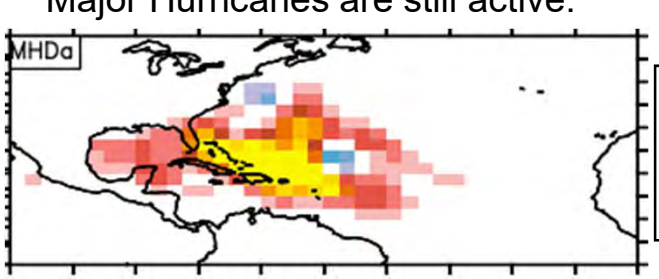



Major Hurricanes are still active.

A. Moderate La Niña?

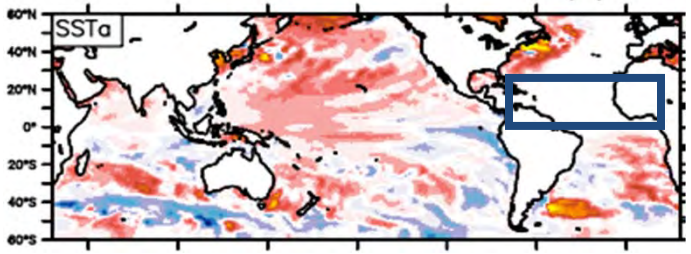



SSTa off the coast of US was removed.

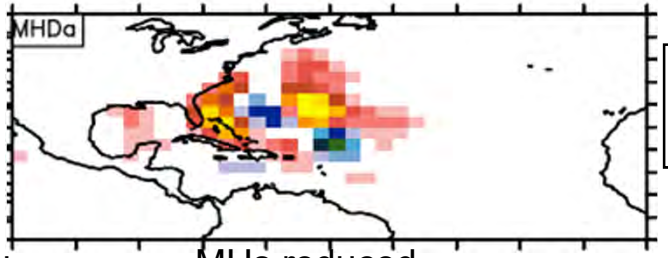



Major Hurricanes are still active.

C. Warmer off the coast of North America?




SSTa in the tropical Atlantic was removed.




MHs reduced.

B. Warmer Tropical Atlantic?

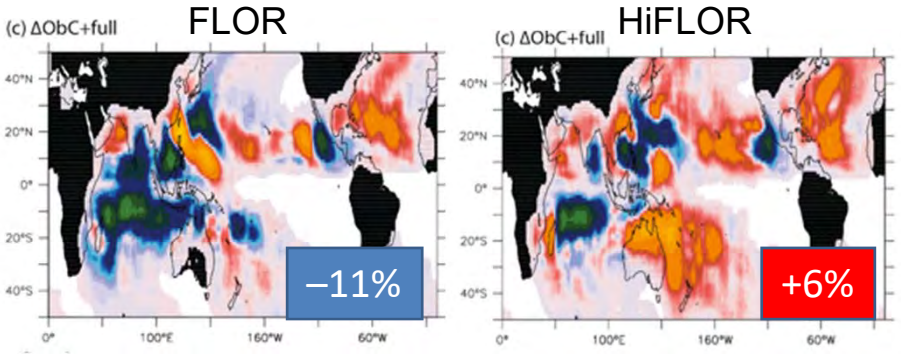
- Responded to 13 Media Interviews (e.g., *The Washington Post*, *News Week*, *NHK*)
- The same method was applied to the active 2018 typhoon season in the Western North Pacific under the International collaboration with JAMSTEC and MRI (Qian et al. 2019, *GRL*, in press).

# Future Projections on Hurricanes

We conducted a number of climate simulations using FLOR and HiFLOR to address potential impact of anthropogenic forcing on hurricane activity.

| Projection Target | Result | Publication |
|---|---|---|
| Central Pacific Hurricanes | Projected to increase in the future | Murakami et al. (2015, *BAMS*)<br>Murakami et al. (2017, *J. Climate*) |
| Arabian Sea Cyclones | | Murakami et al. (2016, *Nat. Clim. Change*) |
| Intensification Rate of Hurricanes | | Bhatia et al. (2019, *Nat. Comm.*) |
| Major Hurricanes in North Atlantic | | Murakami et al. (2018, *Science*) |
| Mediterranean Hurricanes | | González-Alemán (2018, *GRL.*) |
| Landfalling Tropical Cyclone Rainfall | | Liu et al. (2018, *J. Climate*) |

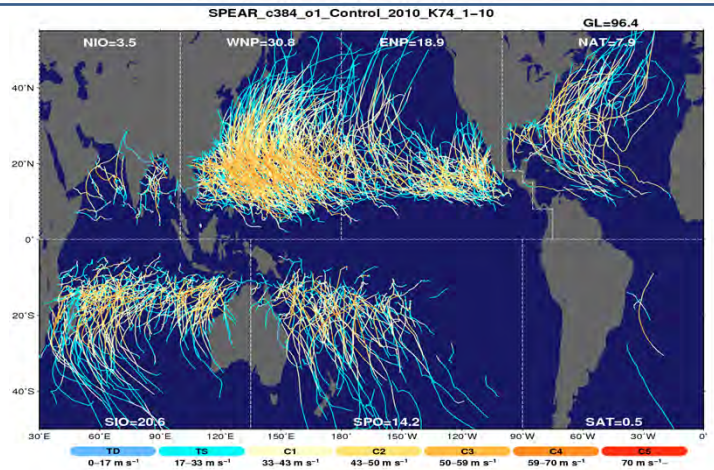
**Tropical Cyclone Density Change by Doubling $CO_2$**

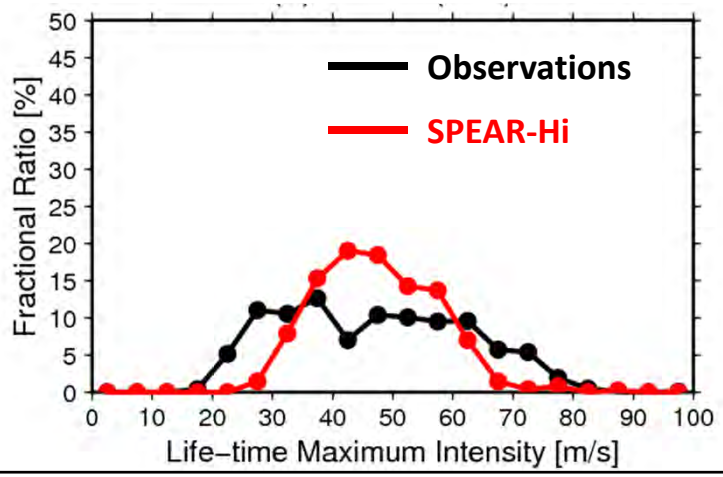



HiFLOR projects an increase in frequency of global tropical storms, whereas FLOR projects a decrease in global frequency.

Vecchi et al. (2019, *Clim. Dyn.*)

# Future Challenging and Model Development



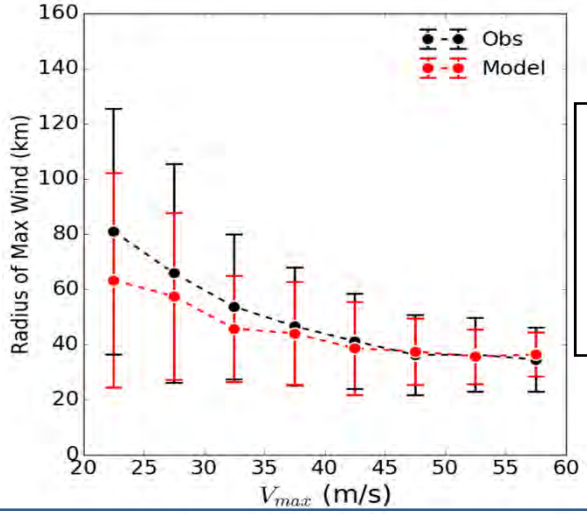




SPEAR-Hi (C384, 25-km), a next generation seasonal prediction model, is under development. Preliminarily, we obtained reasonable storm intensity and global distribution of storms.

## Global-to-regional two-way-nested Grid

Harris and Lin (2012, *Mon. Wea. Rev*)

## Hurricane Inner-core Size Distribution




Hurricane structure is predictable using a fine-resolution nested global model.

Gao et al. (2019, *JAMES*)

# Summary

1. **Over the last 5 years, skill in seasonal predictions of hurricanes has been significantly improved by development of dynamical and statistical-dynamical models.**
2. **Under the great societal interests in ongoing increases in extreme events like hurricanes, we developed a new real-time attribution method to identify the key SST precursors.**
3. **Projected future changes were investigated by taking advantage of the realistic simulations of hurricanes and major hurricanes by the GFDL dynamical models.**
4. **Development of next generation seasonal hurricane forecast models is work in progress. Our new challenge will be improving prediction skill of storm structure, intense hurricanes, and landfalling storms at seamless time scales.**