Simulation, Prediction, and Attribution Study for Tropical Cyclones Using GFDL HiFLOR Model

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Murakami et al. (2015, 2016, J. Climate),
Murakami et al. (2018, Science),
Vecchi et al. (2019, Clim. Dyn.)

BCCR/GFI Seminar

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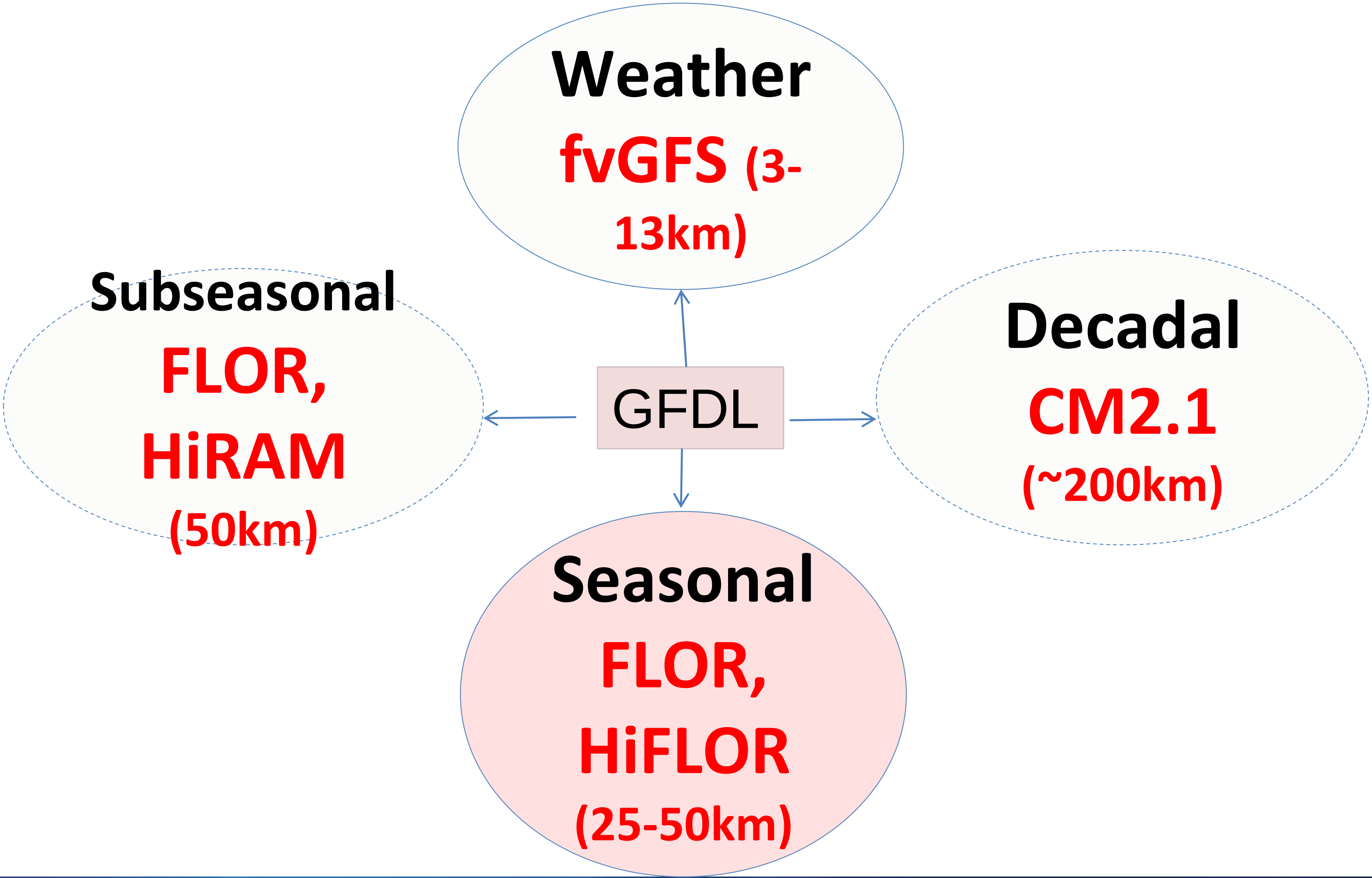
GFDL Dynamical Models for Predictions



Motivation

- Tropical cyclones (TCs) have large societal and economic impacts on the United States (and many other countries)

Disaster Type	Number of Events	Percent Frequency	CPI-adjusted Losses ($ billions)	Percent of Total Loss	Average Event Cost ($ billions)
Drought	21	12.4	199	19.1	9.5
Flooding	19	11.2	86	8.3	4.5
Freeze	7	4.1	25	2.4	3.6
Severe Storm	65	38.2	143	13.7	2.2
Tropical Cyclone	34	20.0	530	50.9	15.6
Wildfire	12	7.1	26	2.5	2.2
Winter Storm	12	7.1	35	3.4	2.9

Table: Damage cost from U.S. Billion-dollar disaster events (1980-2013)

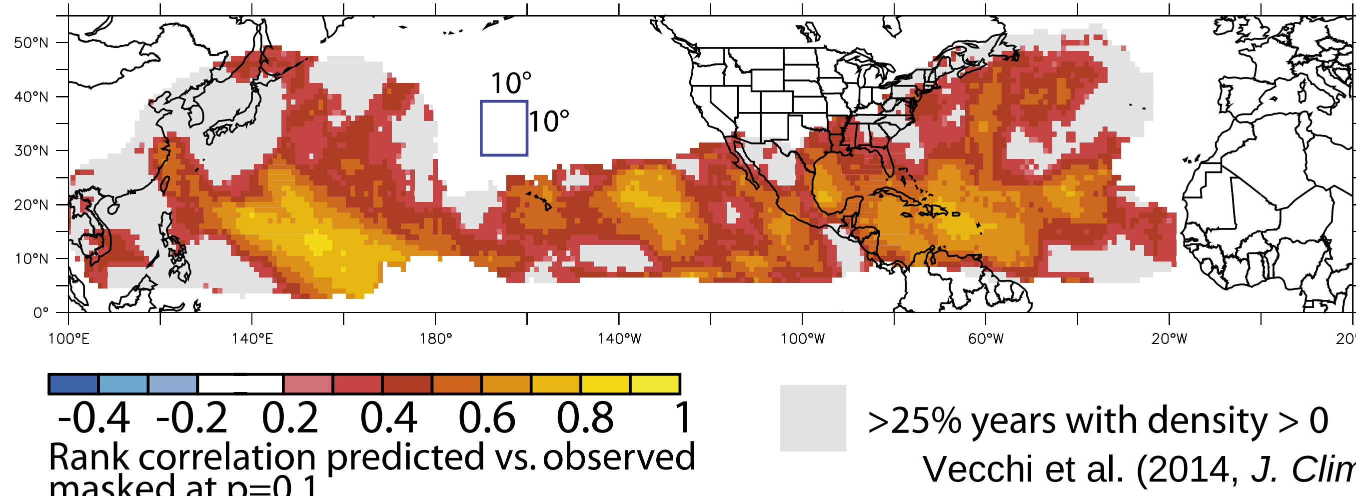
Smith and Matthes (2015, Natural Hazards)

- About **85%** of the total TC damage has been caused by the intense hurricanes (Saffir-Simpson Categories 4 and 5; hereafter C45)

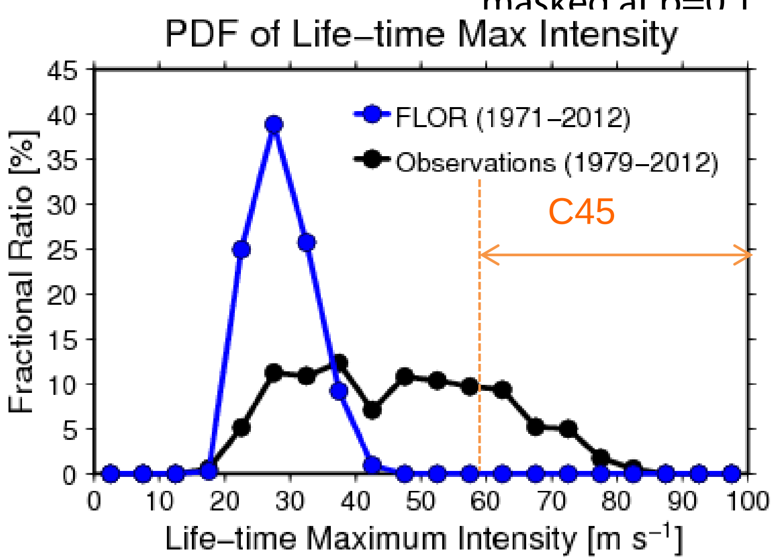
C45 Hurricane: Hurricane with lifetime maximum surface wind ≥60m/s (113kt)

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



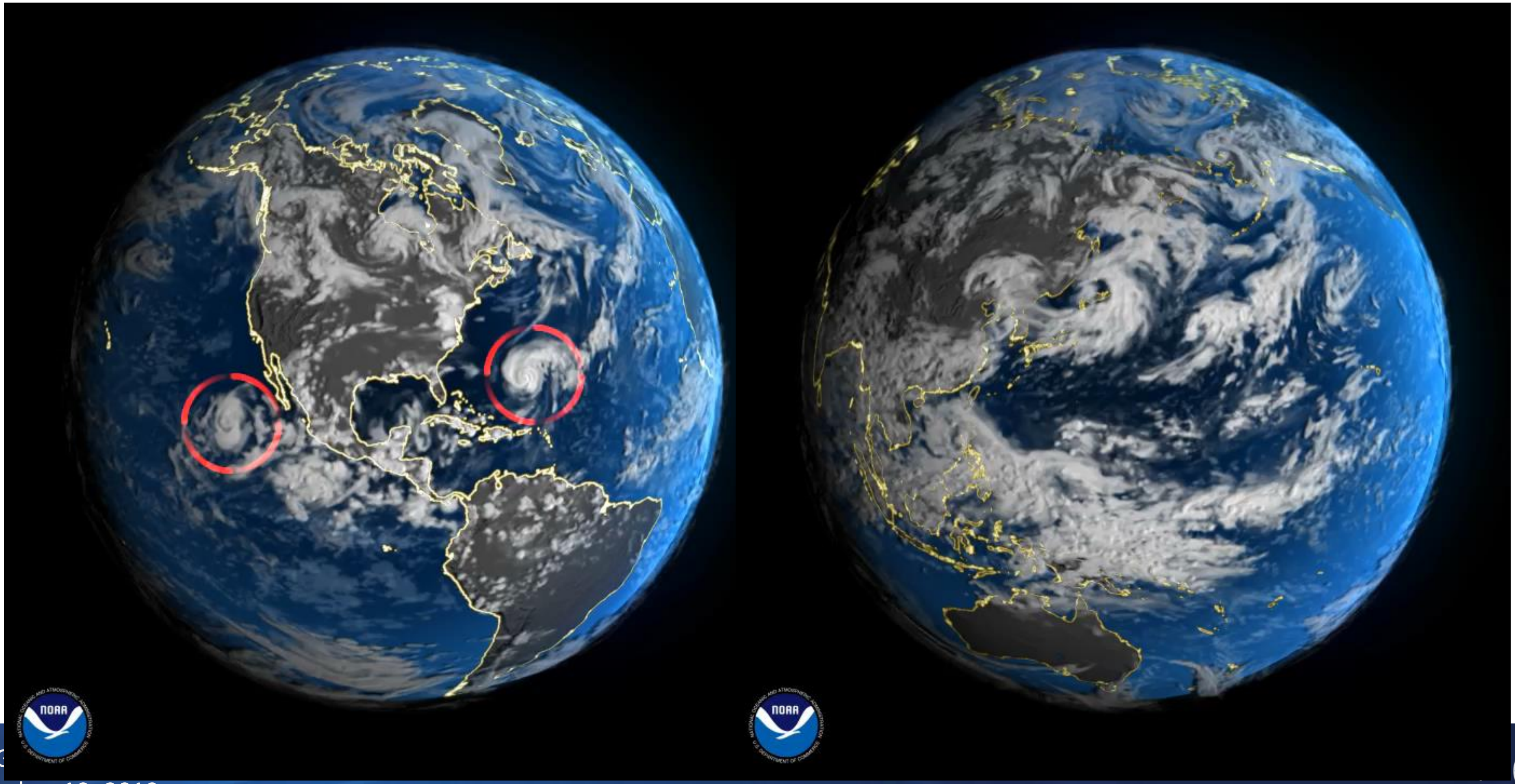
Vecchi et al. (2014, *J. Climate*)
Zhang, G. et al. (2019, *GRL*)



- FLOR has skill in predicting hurricanes a few months in advance
- FLOR critically underestimates frequency of C45 hurricanes.

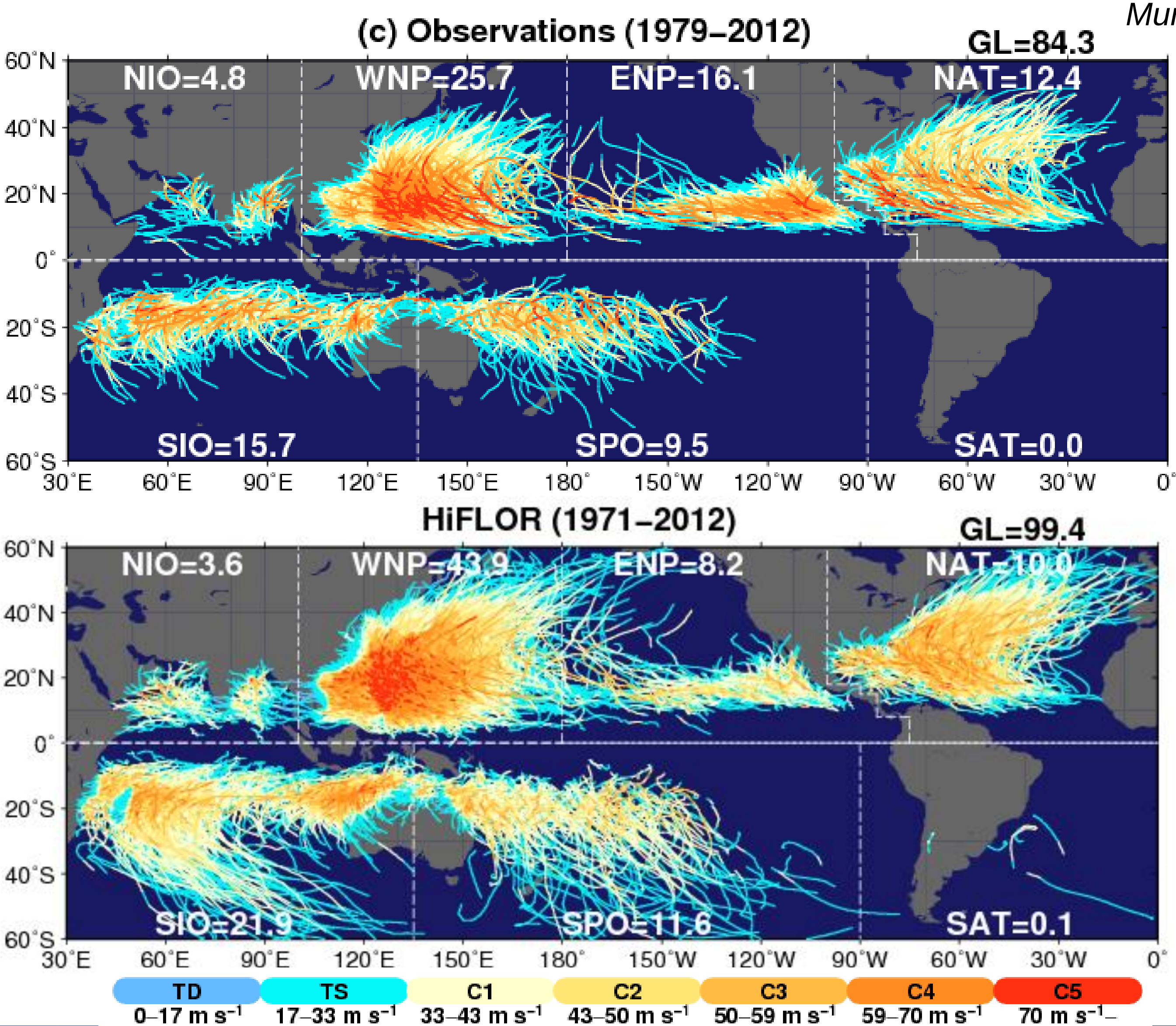
HiFLOR – A New High-Resolution CGCM

	FLOR	HiFLOR
Base Model	AM2.5 (Atmosphere model of CM2.5), MOM4 (Ocean model of CM2.1)	
Resolution	Atmosphere：**50 km**, L32 Ocean: 100 km, L50	Atmosphere：**25 km**, L32 Ocean: 100 km, L50



SST Restoring Experiments by FLOR and HiFLOR

Murakami et al. (2015, J. Climate)



<u>Restoring Experiment:</u>
Observed time-varying SST is restored at 5-day timescale for the period 1971–2012.

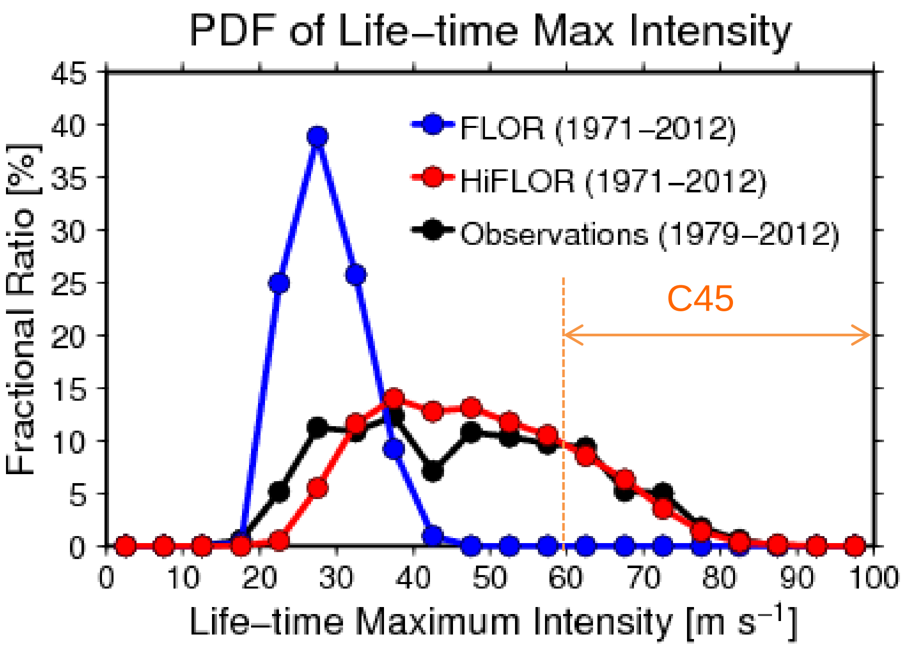
FLOR underestimates TC intensity

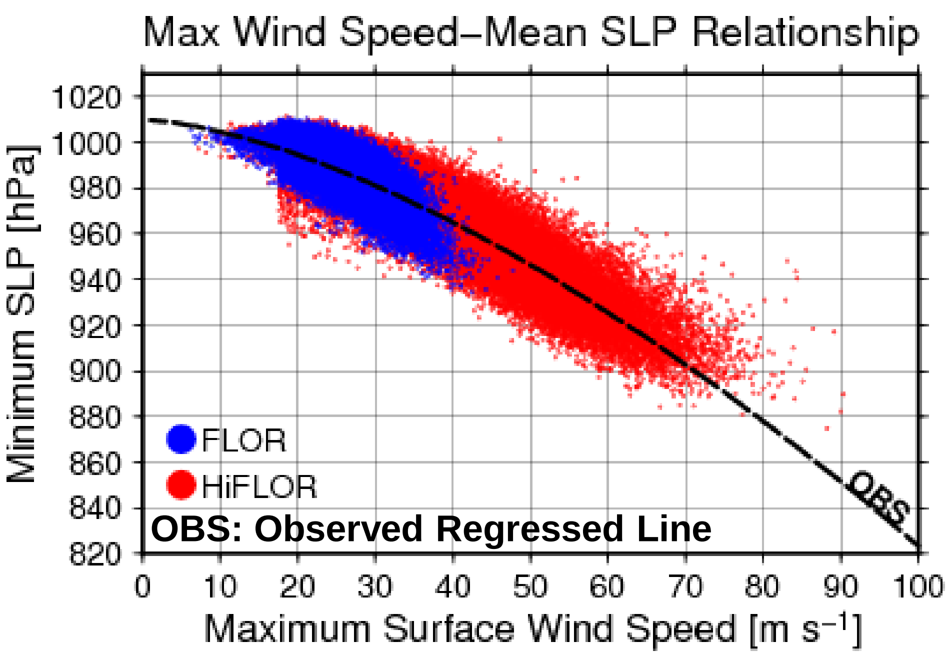
HiFLOR improved TC intensity

Number: Annual mean TC frequency

Simulated TC Intensity

Murakami et al. (2015, J. Climate)

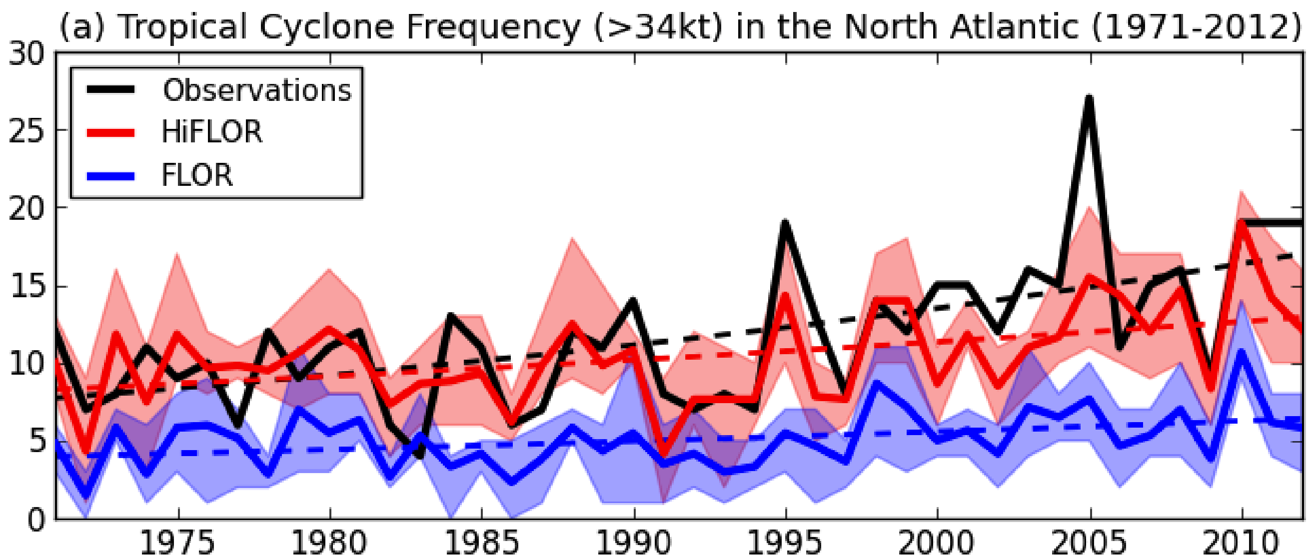




- HiFLOR can simulate C45 hurricanes.
- TC structure is reasonably simulated in terms of Maximum Wind Speed– Mean SLP relationship.

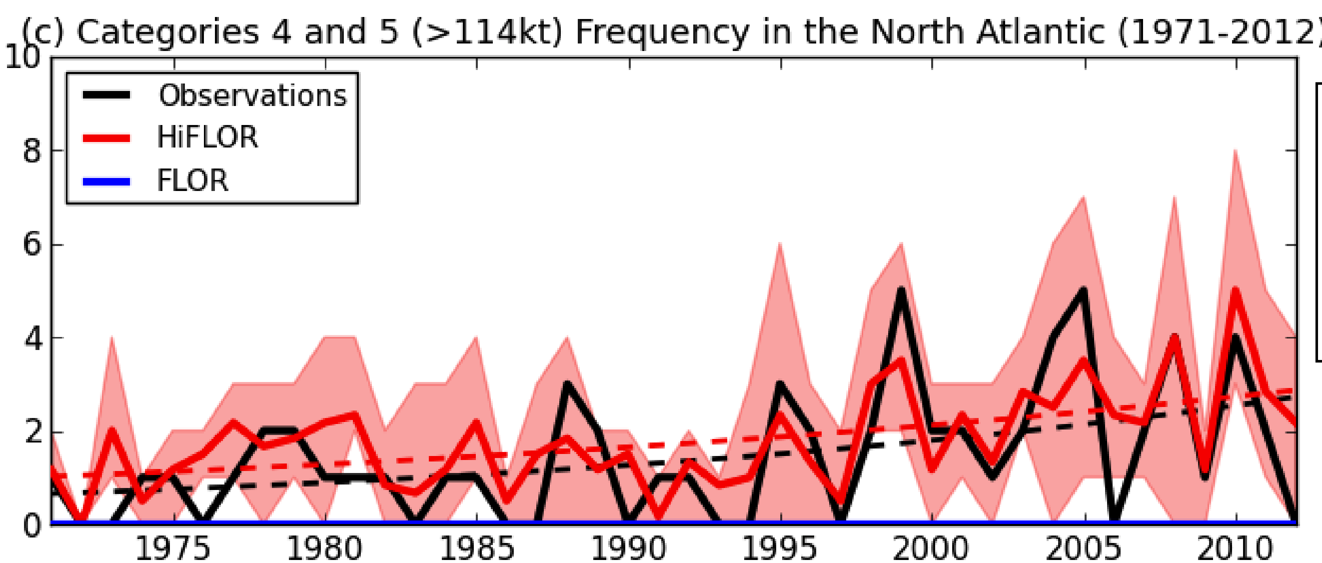
Interannual Variation of North Atlantic Storms

Murakami et al. (2015, J. Climate)



r=0.68 (HiFLOR vs Obs)

r=0.59 (FLOR vs Obs)



It is for the first time that a global coupled model could simulate observed interannual variation of C45 hurricanes.

r=0.64 (HiFLOR vs Obs)

r=N/A (FLOR vs Obs)

Interannual Variation for Global Ocean Basins

Murakami et al. (2015, J. Climate)

Correlation Coefficients (Observed vs Model, 1971–2012)

Model	N.Indian	WN.Pacific	EN.Pacific	N.Atlantic	S.Indian	S.Pacific
(a) All TSs (>34kt, 1971-2012)						
HiFLOR	−0.27	**+0.35**	**+0.49**	**+0.68**	**+0.38**	**+0.31**
FLOR	+0.01	**+0.55**	**+0.41**	**+0.59**	+0.02	+0.23
(b) Hurricanes (>64kt, 1971-2012)						
HiFLOR	+0.04	+0.17	**+0.51**	**+0.77**	**+0.51**	+0.23
FLOR	+0.01	**+0.55**	+0.27	**+0.68**	+0.11	+0.02
(c) Categories 4 and 5 (>114kt, 1971-2012)						
HiFLOR	**+0.38**	+0.24	**+0.31**	**+0.64**	**+0.32**	+0.18
FLOR	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*

95% Significant

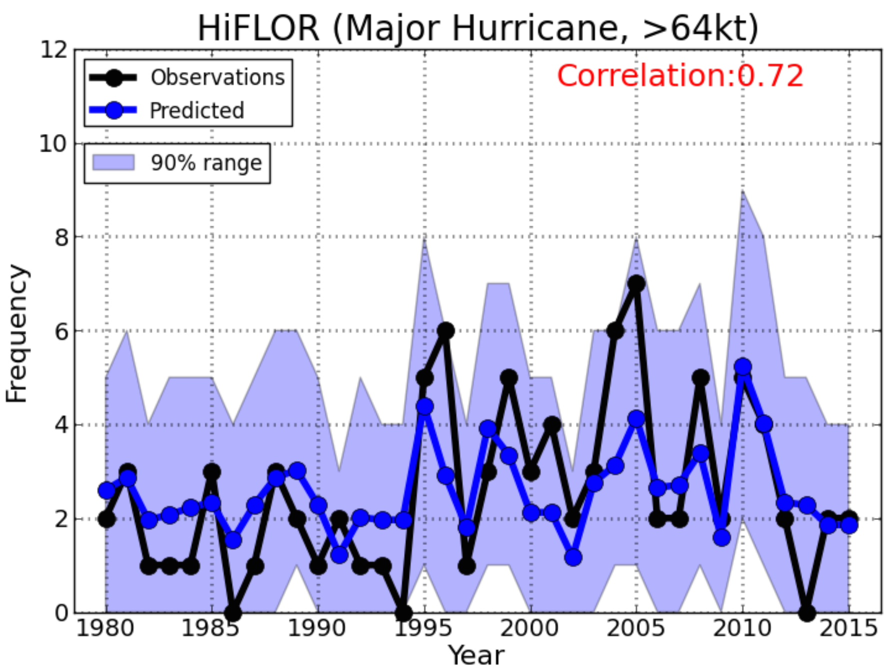
HiFLOR shows higher skill than FLOR in all the ocean basins, except for WNP

Retrospective Seasonal Prediction by HiFLOR (Major Hurricanes)

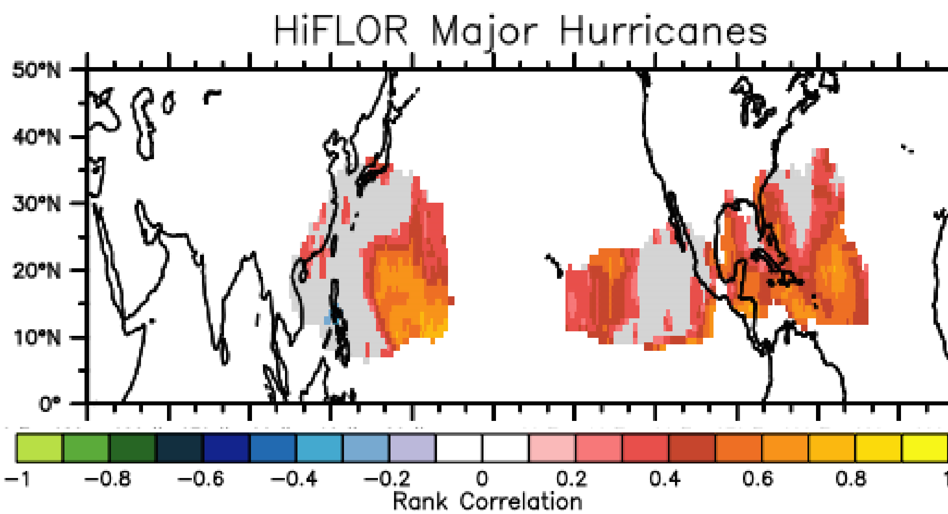
Murakami et al. (2016, J. Climate)

Model	HiFLOR
Period	1980–2015, mainly focus on TC prediction for July–November
Initial	July (Leal Month=0–4), Ocean is initialized, but atmosphere is not initialized.
Ensemble	24 Ensemble Members

Major Hurricanes in the North Atlantic



Skill in Predicting Major Hurricane Density

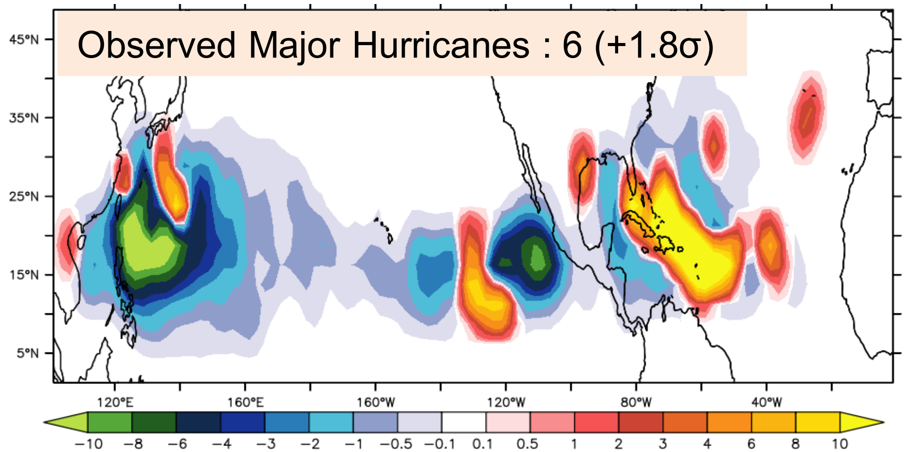


HiFLOR shows skillful prediction for major hurricanes

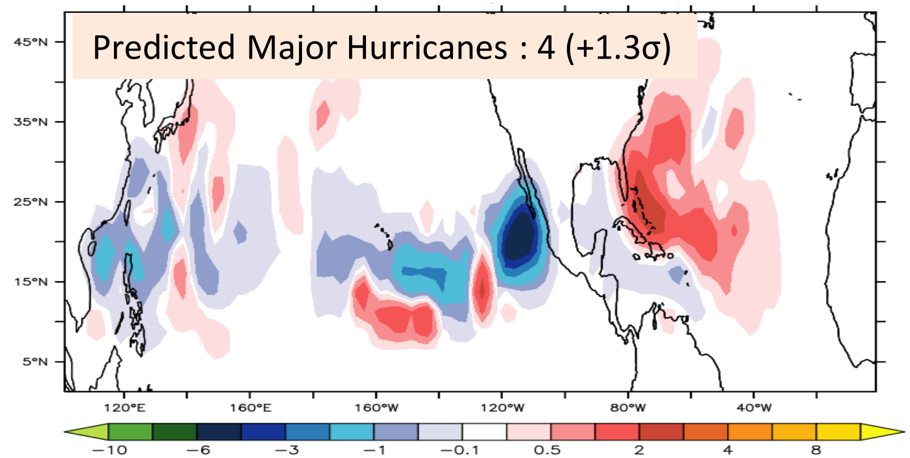
Real-Time Prediction for the 2017 Summer Season

Murakami et al. (2018, Science)

Observed MH Density Anomaly in 2017

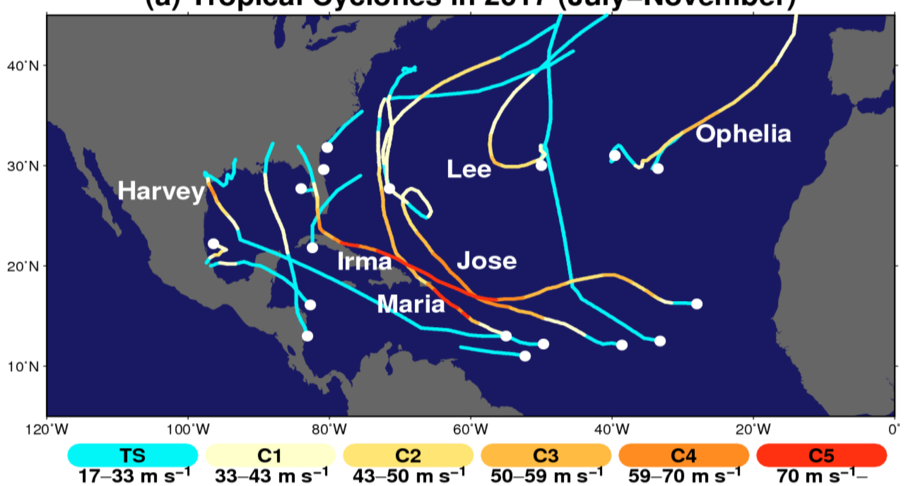


Predicted MH Density Anomaly in 2017



Observed Storm Tracks in 2017

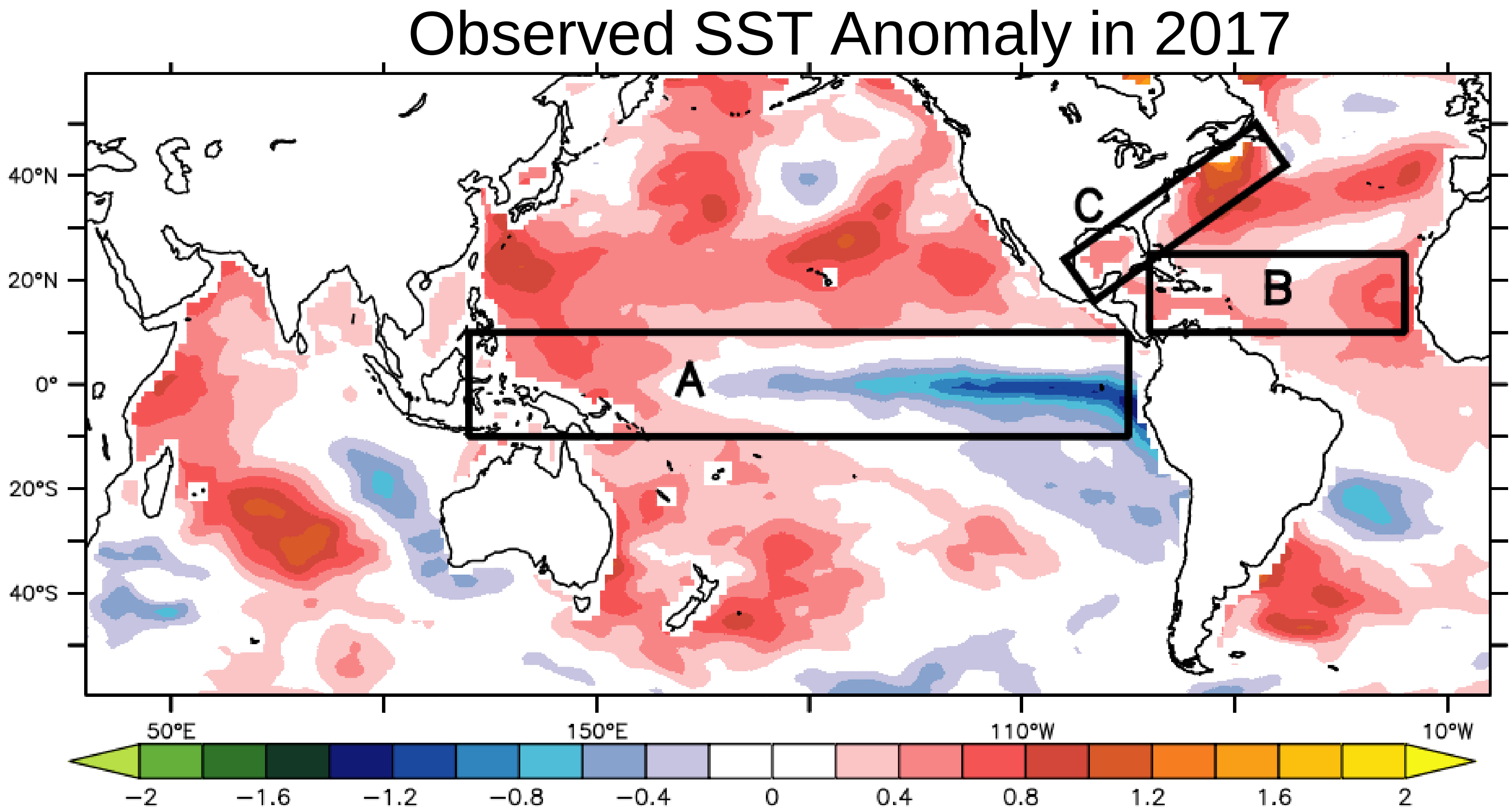
(a) Tropical Cyclones in 2017 (July–November)



Example of HiFLOR prediction from July Initial

What caused the active 2017 MH season?

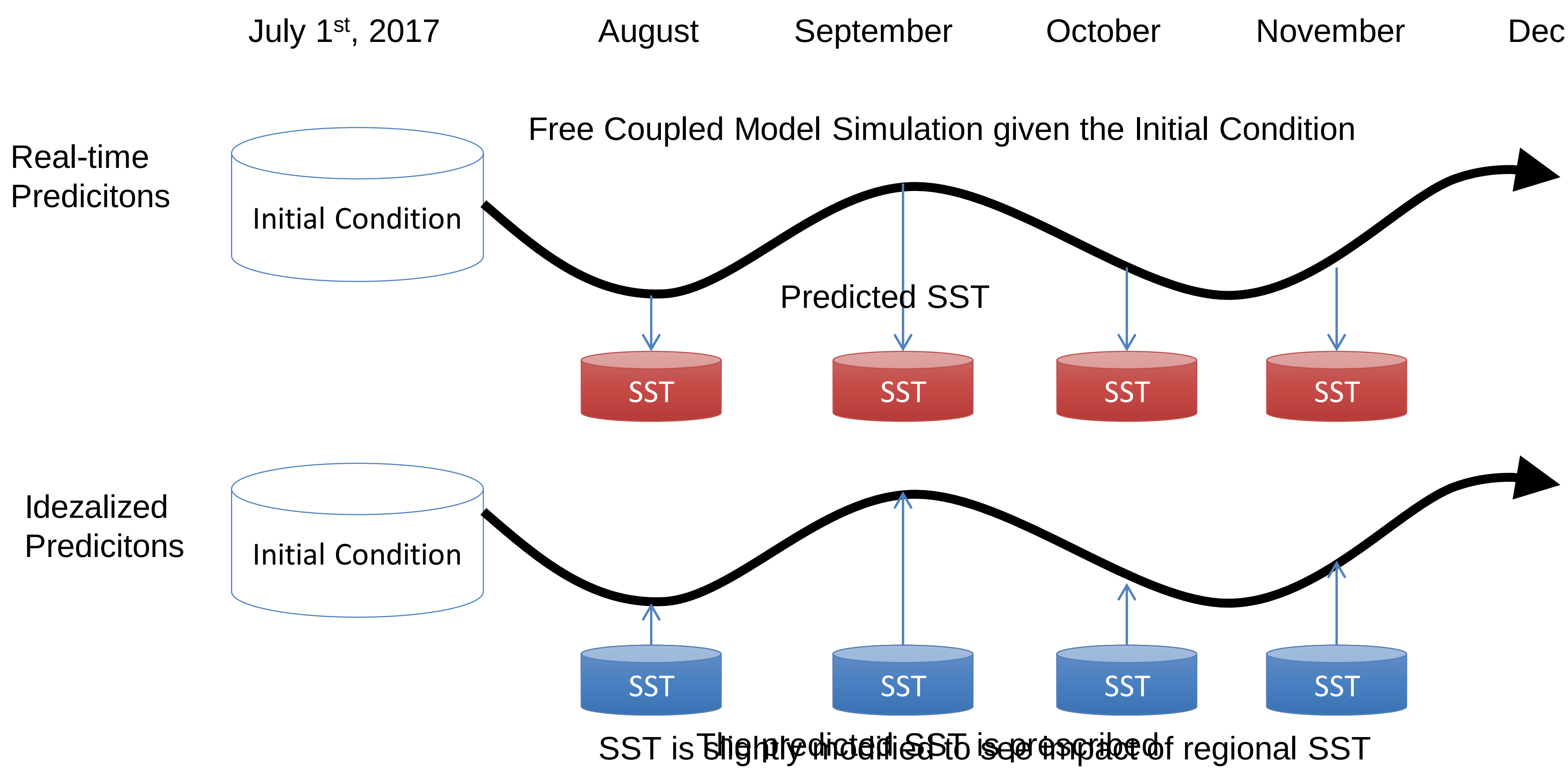
Murakami et al. (2018, Science)



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

Idealized Seasonal Predictions

Murakami et al. (2018, Science)



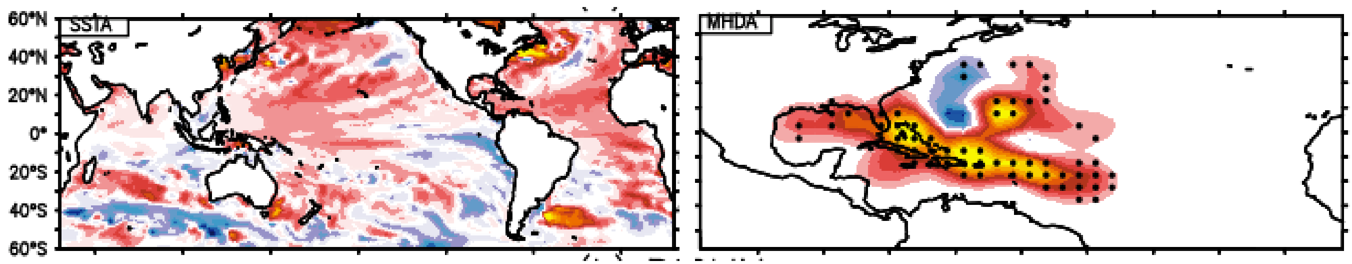
We call this type of experiments as “real-time attribution” because we can examine causes for active hurricane season even as hurricane season is underway.

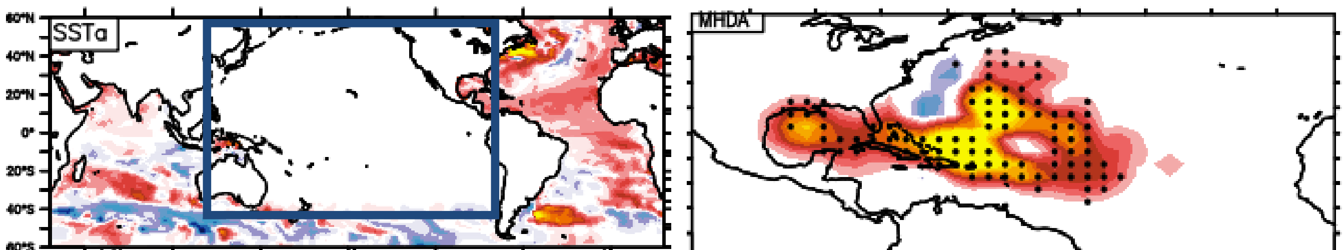
Idealized SST-Prescribed Seasonal Prediction

Murakami et al. (2018, Science)

Prescribed SST Anomaly

Predicted Major Hurricane Density Anomaly

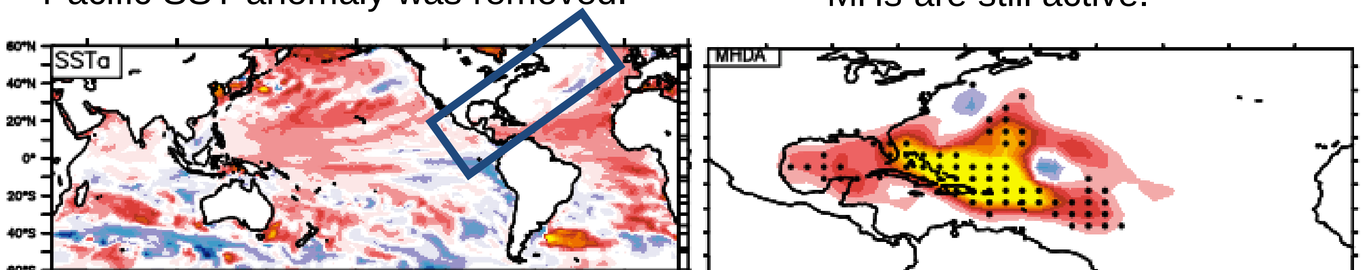




Pacific SST anomaly was removed.

MHs are still active.

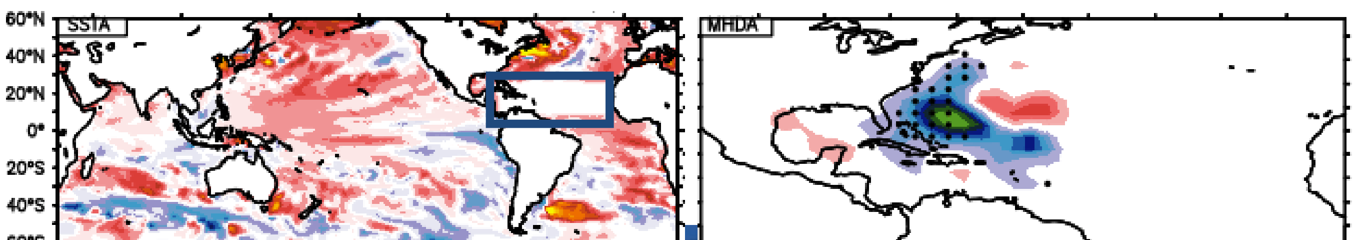
A. Moderate La Niña?



SSTa off the coast of US was removed.

MHs are still active.

C. Warmer off the coast of North America?



B. Warmer Tropical Atlantic?

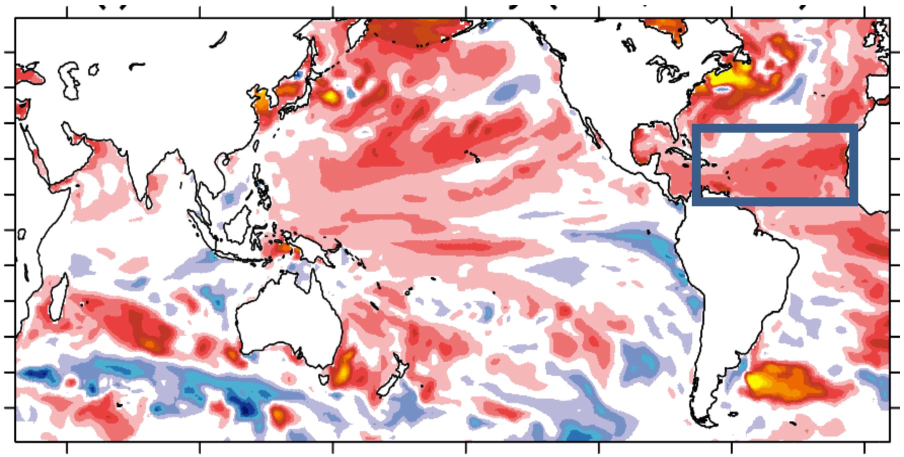
SSTa in the tropical Atlantic was removed.

MHs reduced.

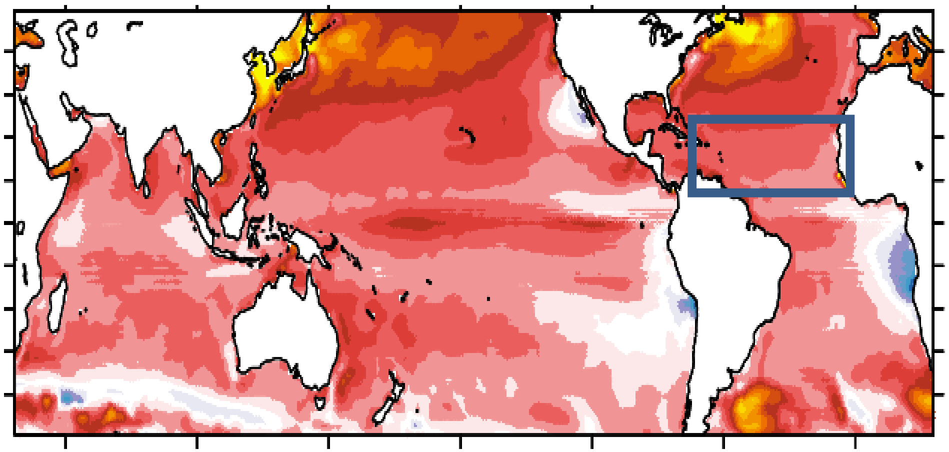
Potential Impact of Global Warming on the 2017 Major Hurricane Activity

Murakami et al. (2018, Science)

2017 SST Anomaly



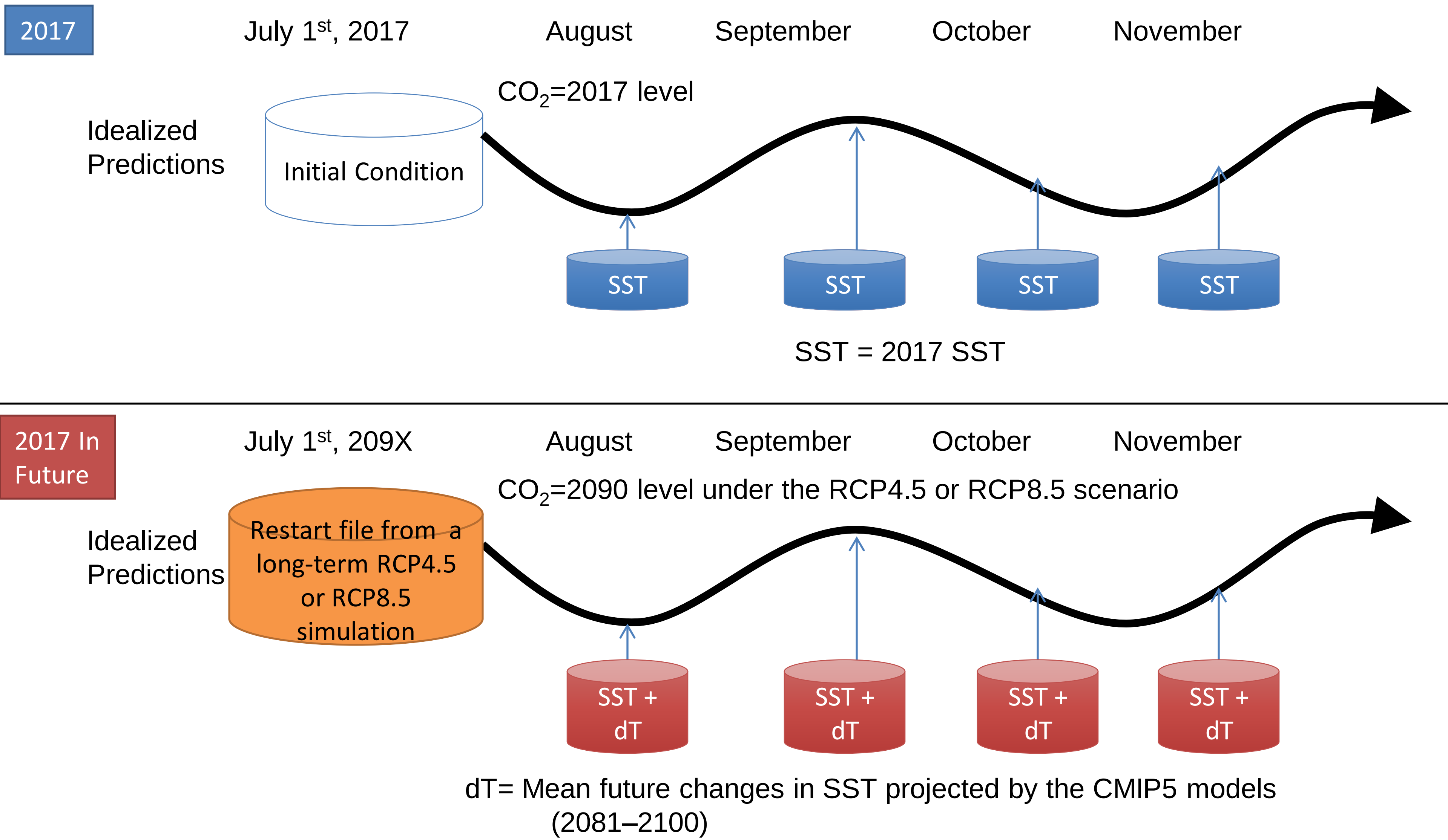
Mean SST change projected by CMIP5 models under RCP4.5
(2080-2099 minus 2015-2025)



Will we see more major hurricanes if we experience a similar summer like 2017 in the future?

Idealized Seasonal Prediction for 2017 Assuming at the end of 21st century

Murakami et al. (2018, Science)



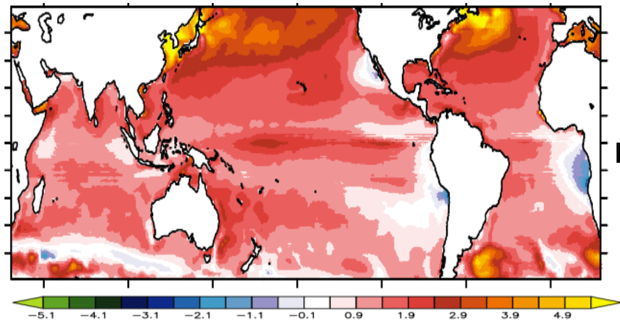
Idealized Prescribed SST Experiments in the Future

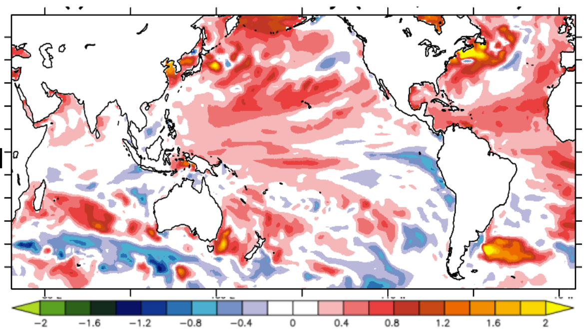
Murakami et al. (2018, Science)

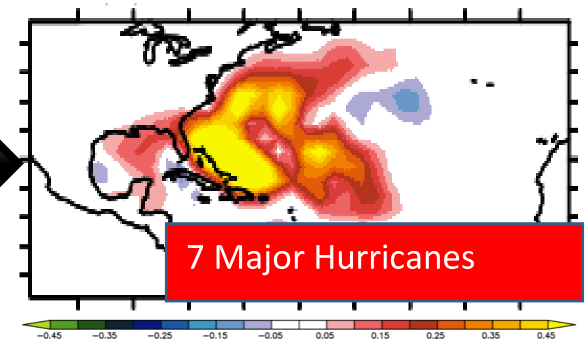
RCP4.5
(2080-2099 minus 2015-2025)

2017 SST Anomaly

Projected MH Density Anomal





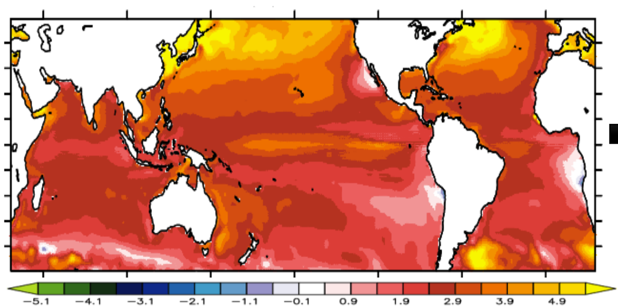


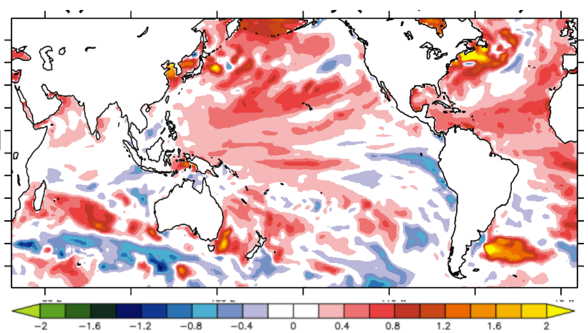
& CO_2 = 533 ppm

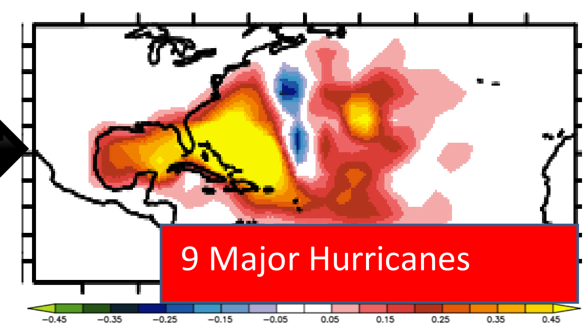
RCP8.5
(2080-2099 minus 2015-2025)

2017 SST Anomaly

Projected MH Density Anoma



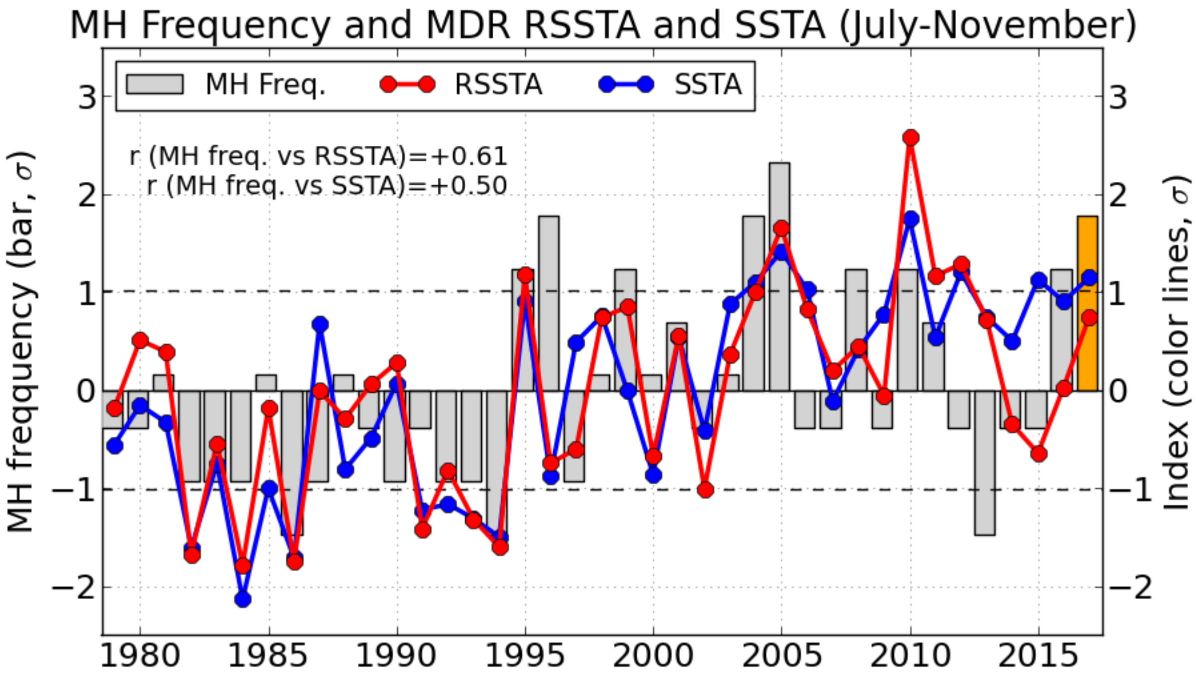




& CO_2 = 840 ppm

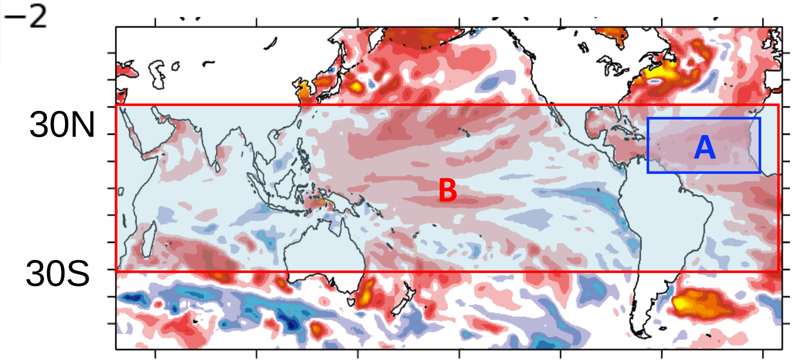
More active MH season than the 2017 summer is projected in the future even with the same spatial patterns of 2017 SST anomaly, resulting in **amplifying the risk of MHs**.

Local SSTA or Relative SSTA?



SSTA: Local SST Anomaly (A)

RSSTA: Relative SST Anomaly (A-B)

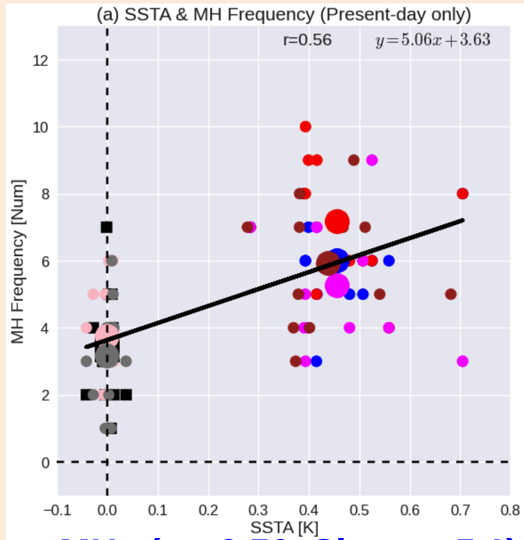


Observed number of MHs (gray bars) is correlated with both **tropical Atlantic (10–25°N, 80–20°W) SST anomaly (SSTA, r=+0.50)** and **tropical Atlantic SST relative to tropical mean (*30°S–30°N*) (RSSTA, r=+0.61)**

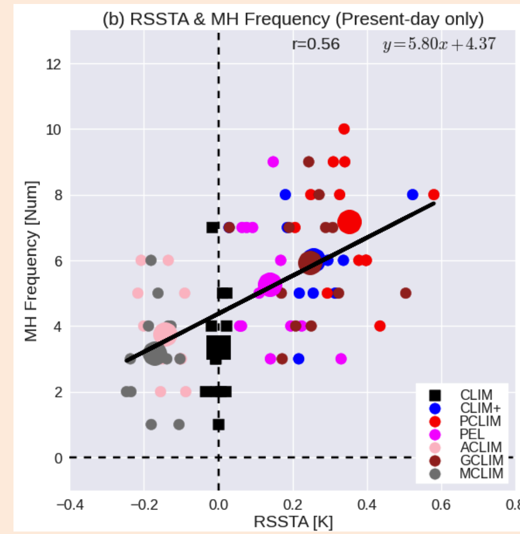
Murakami et al. (2018, Science)

Local SSTA or Relative SSTA?

2017 Experiments only

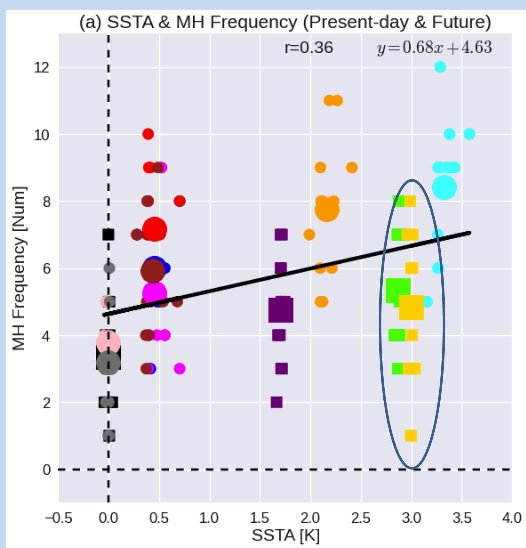


SSTA vs MHs (r=+0.56, Slope=+5.1)

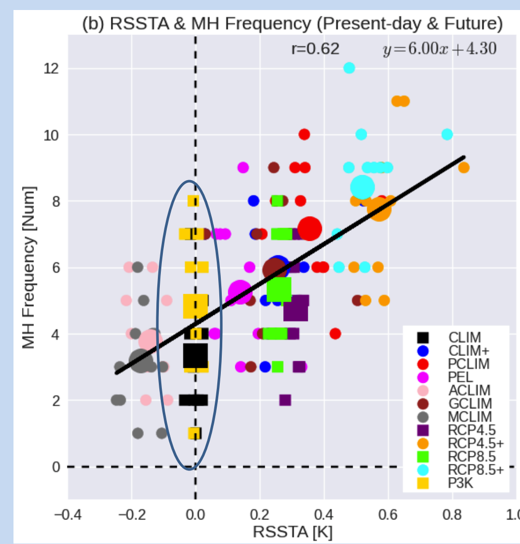


RSSTA vs MHs (r=+0.56, Slope=+5.8)

2017 Experiments
& Future Experiments



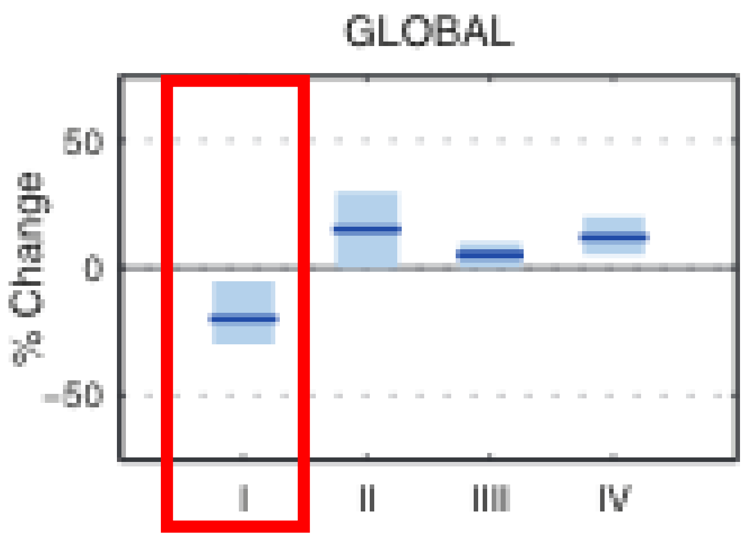
SSTA vs MHs (r=+0.36, Slope=+0.7)



RSSTA vs MHs (r=+0.62, Slope=+6.0)

Previous Studies on Future Changes in Global TC Frequency

Expected percent change in the average over period 2081–2100 relative to 2000–2019



I. Global TC Frequency (decrease)
II. Mean TC Intensity (increase)
III. Mean TC Precipitation (increase)
IV. Global C45 Frequency (increase)

IPCC AR5 Chapter 14

IPCC AR5 Assessment Summary

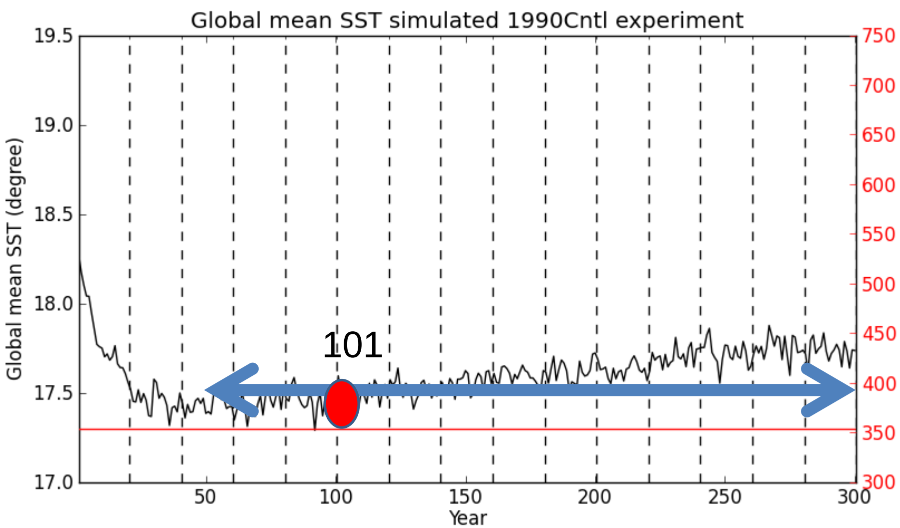
It is ***likely*** that the global frequency of tropical cyclones will either **decrease** or remain essentially **unchanged**.

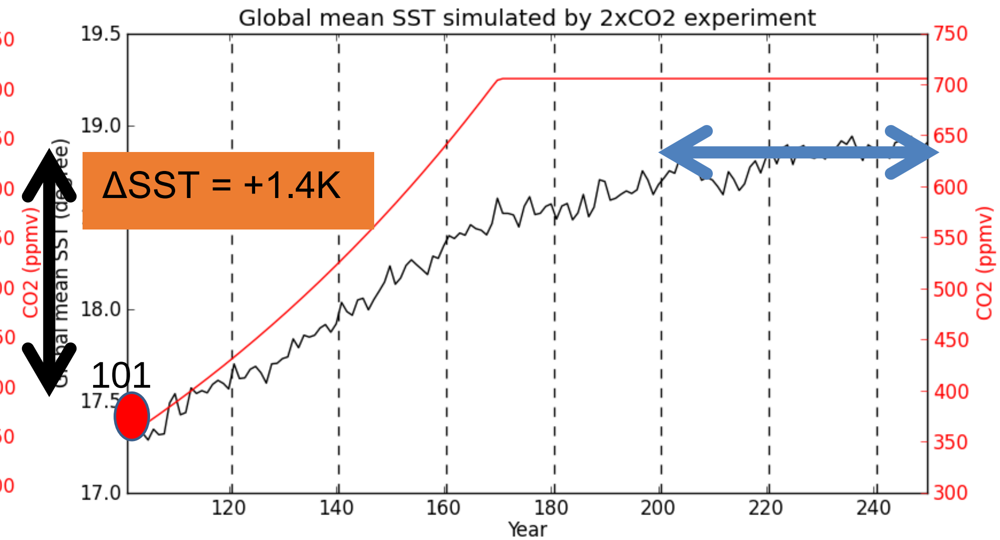
However, most of the models considered for this assessment were with **50–100 km mesh** (medium or low resolution).

What about HiFLOR (25-km mesh)?
Any difference from FLOR (50-km mesh)?

Changes in Global Tropical Cyclones by 2xCO2 Experiments

Vecchi et al. (2019 Clim. Dyn.)





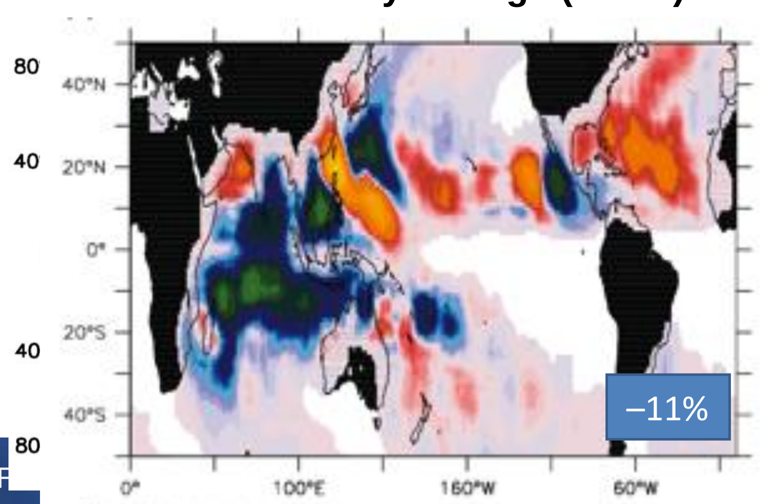
1990Cntl Experiment (300-yr simulation)

- Fixed Forcing at 1990 level (CO2=350ppmv)

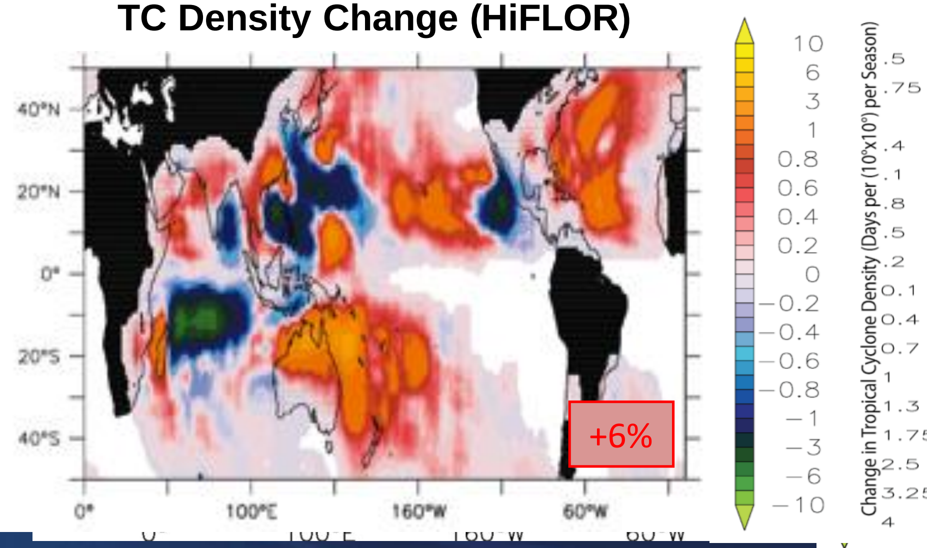
Transient +1%/yr CO2 Experiment

- +1% CO2 increase up to 2xCO2 (at year 171) then fixed

TC Density Change (FLOR)



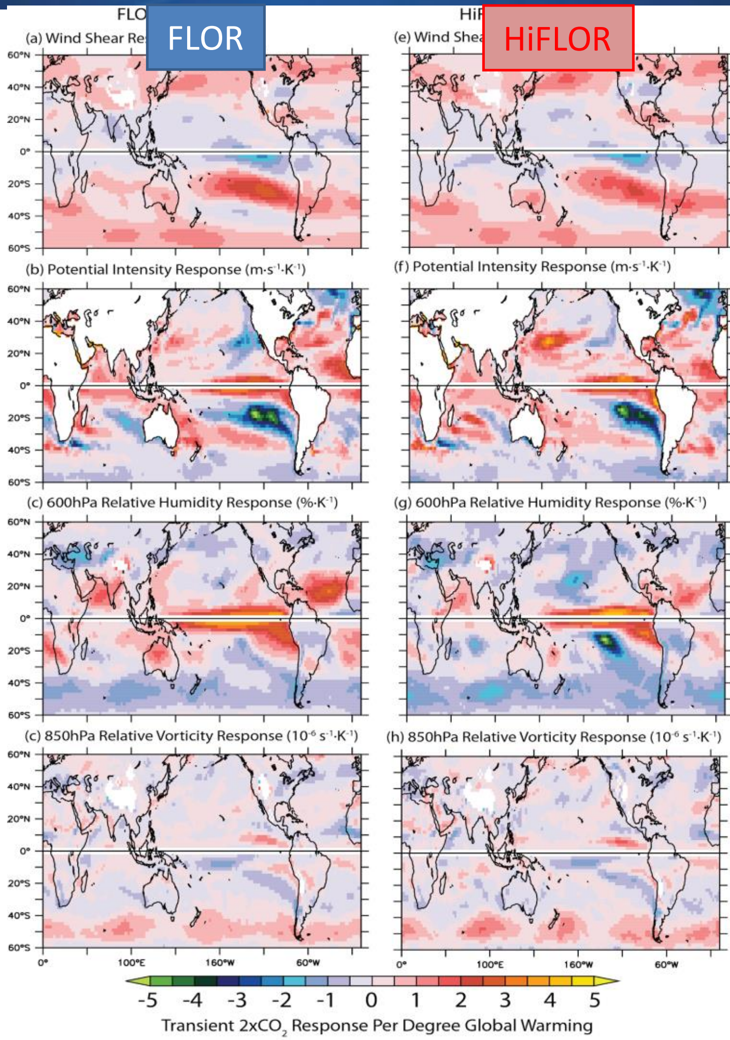
TC Density Change (HiFLOR)



Why did HiFLOR project increases in global TCs?

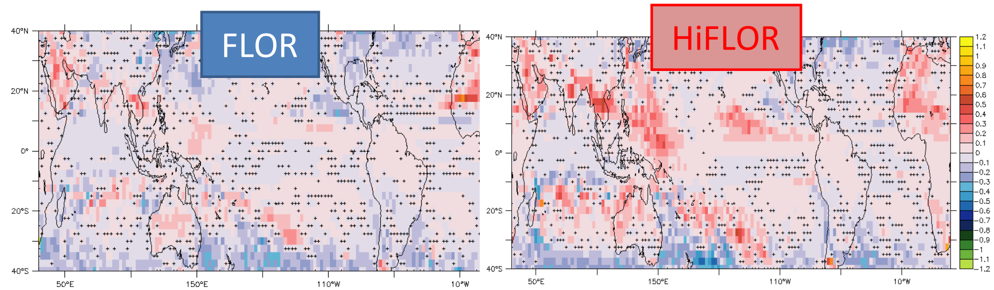
Vecchi et al. (2019 Clim. Dyn.)

Vertical Wind Shear	
MPI	
RH_{600}	
Vort 850	



Large-scale parameter cannot explain the difference in projected changes in TC frequency between FLOR and HiFLOR

Difference in Variance of 3-10-day vort850



An increase in "seeds" could be a critical factor for the projected increase in global storms in HiFLOR

Global TC number (N) = T x P

T: Number of trial (seeds)

P: Probability (large-scale environment)

	dN	dT	dP
FLOR	↓	↑	↓
HiFLOR	↑	↑	↓

Summary

1. HiFLOR can simulate C45 hurricanes as observed.

2. HiFLOR has skill in predicting major hurricanes a few months in advance.

3. The active 2017 major hurricanes were controlled by the tropical ocean surface warming in the North Atlantic.

4. Future changes in relative SST anomaly is a key for future changes in major hurricanes in the North Atlantic.

5. HiFLOR is a unique model to project an increase in number of global tropical cyclones in a warmer climate. A possible reason for the increase could be an increase in number of tropical-cyclone seeds.