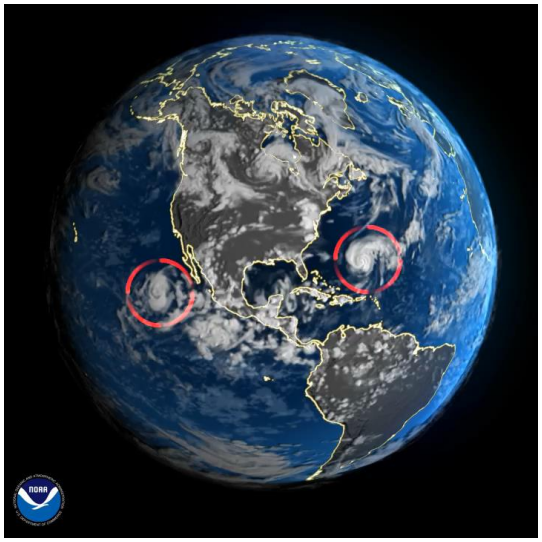
Identifying United States Hurricane Risk with Changing Climate



GFDL-HiFLOR Simulation

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Symposium on Hurricane Risk in a Changing Climate

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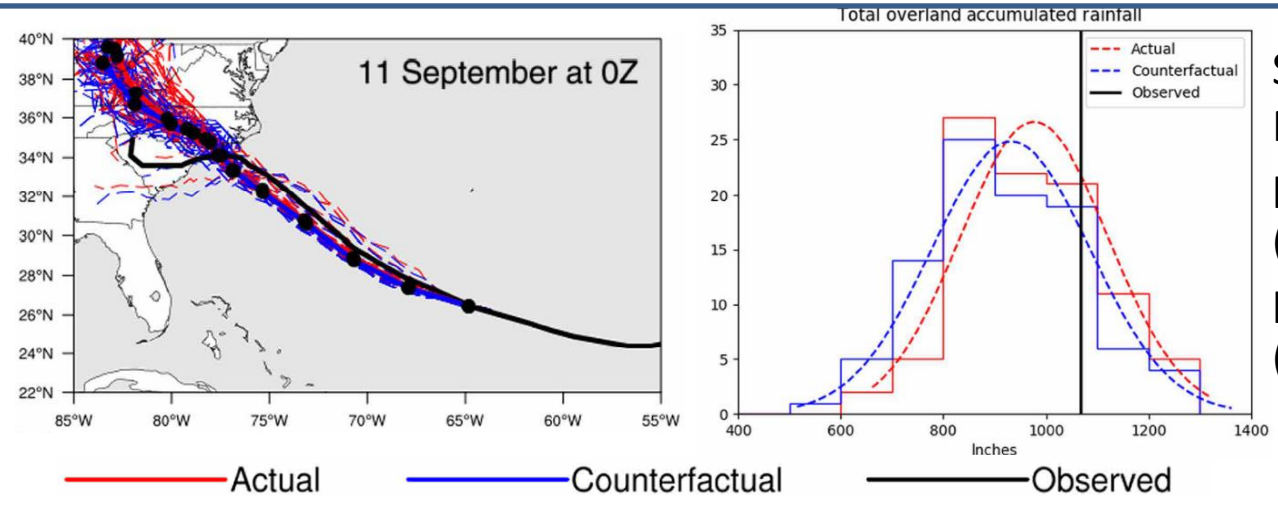
Motivation

Many studies project increased intensity of tropical cyclones in a warmer climate.



Simulated Hurricane Florence with a present-day climate (actual, red) and preindustrial climate (counterfactual, blue)

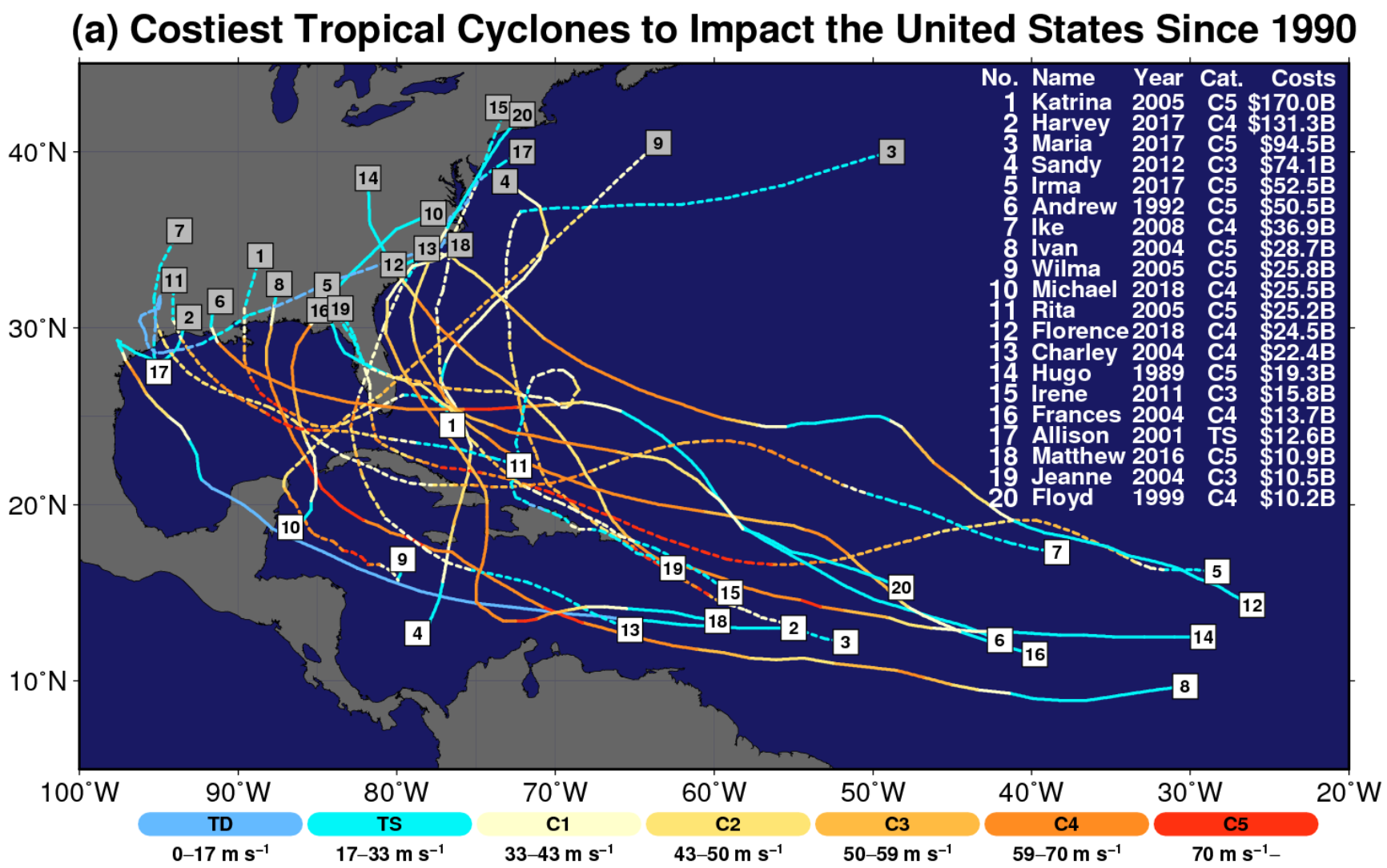
Reed et al. (2020)

Pseudo-warming experiments showed the increased intensity of tropical cyclones that made landfall over the United States due to anthropogenic climate change (e.g., Patricola et al. 2019; Reed et al. 2020).

A pseudo-warming experiment is useful to estimate the effect of global warming on storm intensity changes but is not telling about frequency of occurrence of the storm.

An open question is **if these costliest landfalling hurricanes might have occurred more or less frequently under a warmer climate**.

The top 20 costliest hurricanes to analyze

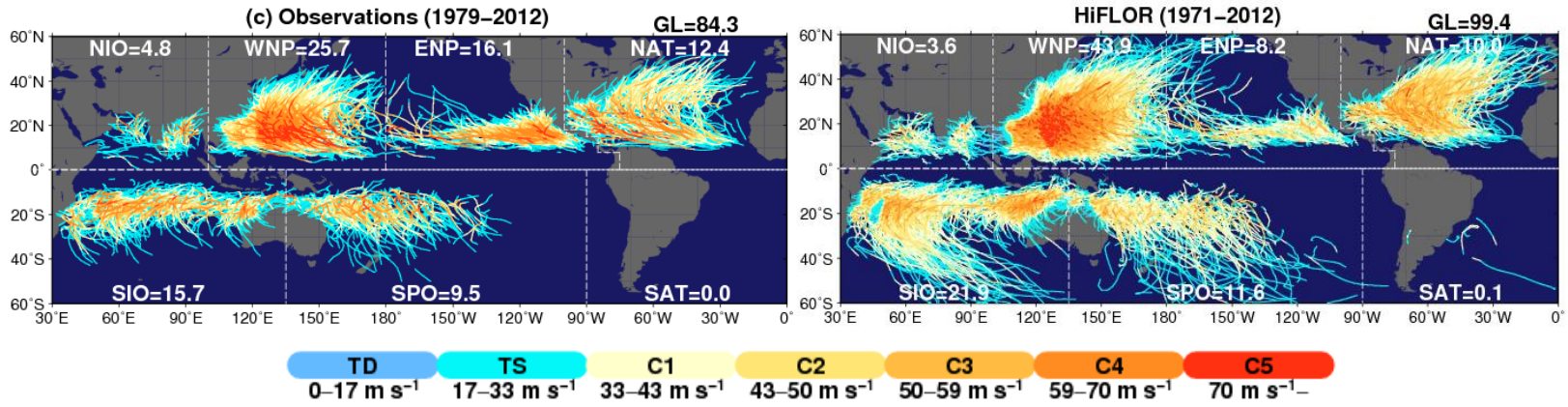


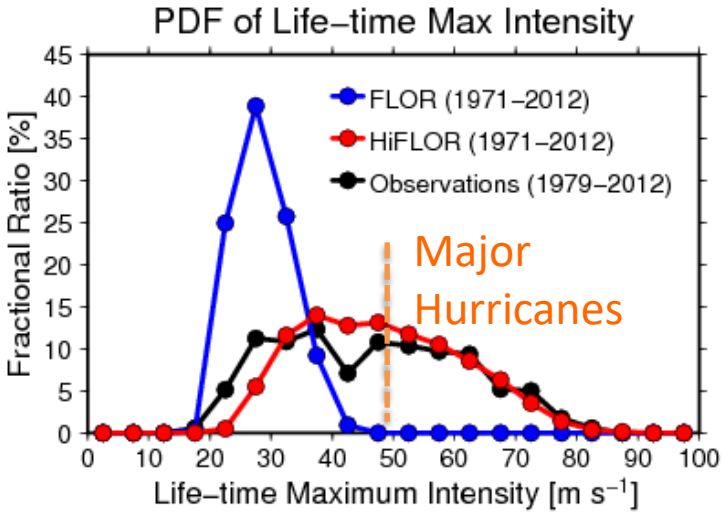
- The top 20 costliest US hurricanes since 1990 were evaluated.
- We attempt to estimate the effect of anthropogenic warming on their occurrence of frequency in addition to the intensity and translation speed.

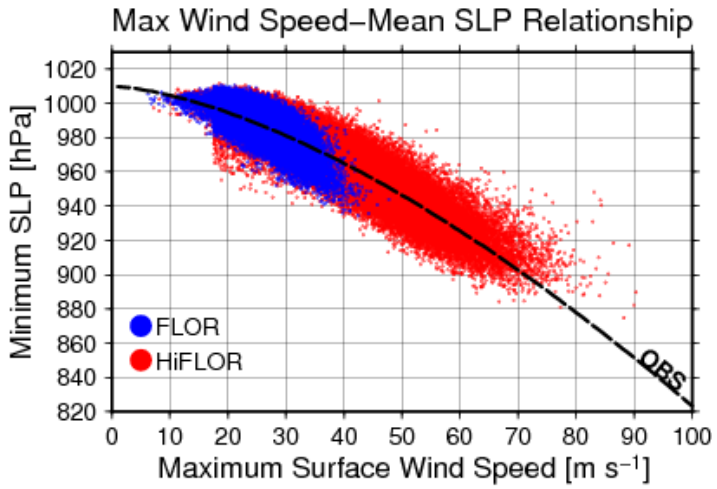
A high-resolution dynamical model –HiFLOR-

GFDL-HiFLOR: A global atmosphere-ocean fully coupled dynamical model

Horizontal Resolution: 25-km for atmosphere/land & 1° for ocean/ice components



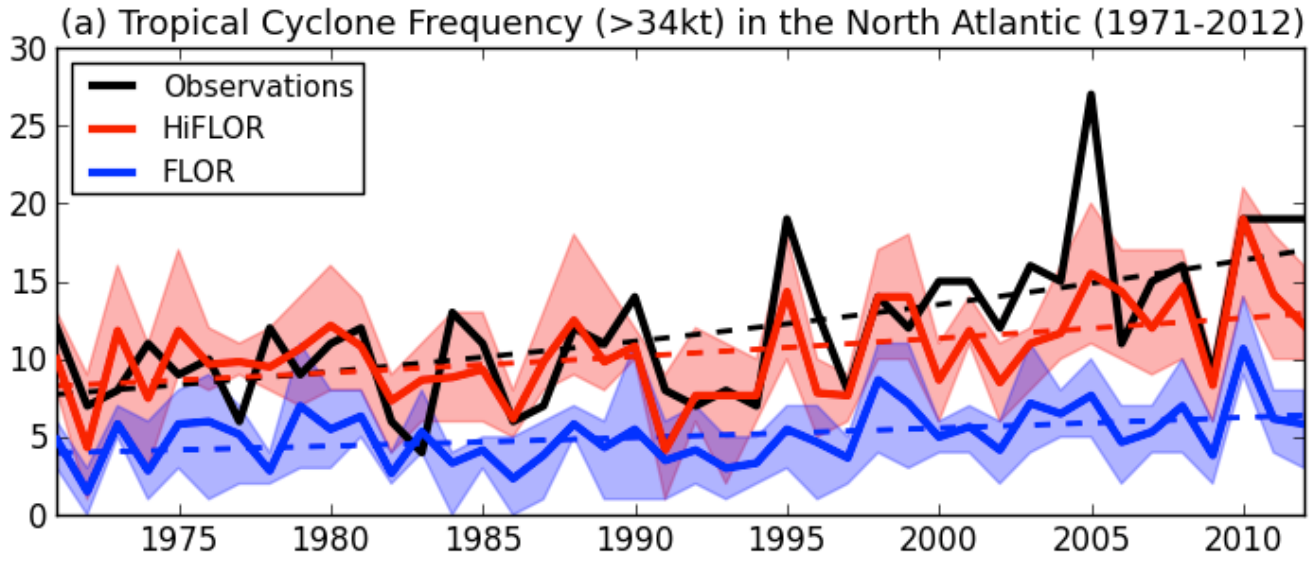




HiFLOR can simulate major hurricanes with reasonable storm structure.

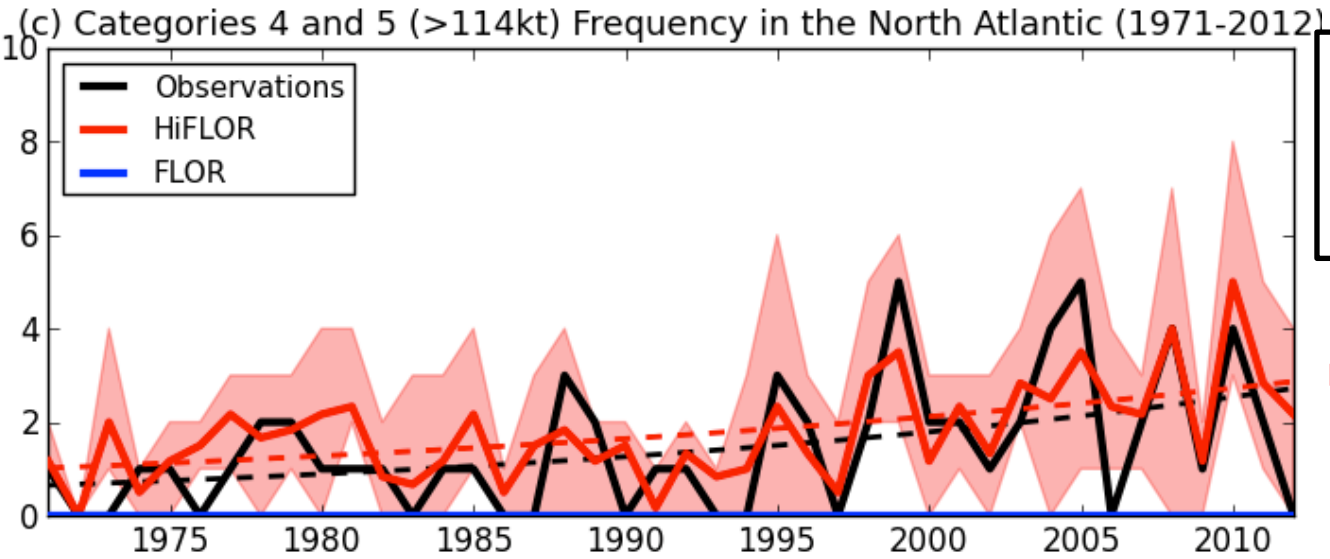
Reasonable cat 4-5 simulations using HiFLOR

Observed SSTs were forced for the model (FLOR: 50-km mesh model, HiFLOR: 25-km mesh model)



r=0.68 (HiFLOR vs Obs)

r=0.59 (FLOR vs Obs)



For the first time, a global coupled model could simulate the observed interannual variation of Cat 45 hurricanes.

r=0.71 (HiFLOR vs Obs)

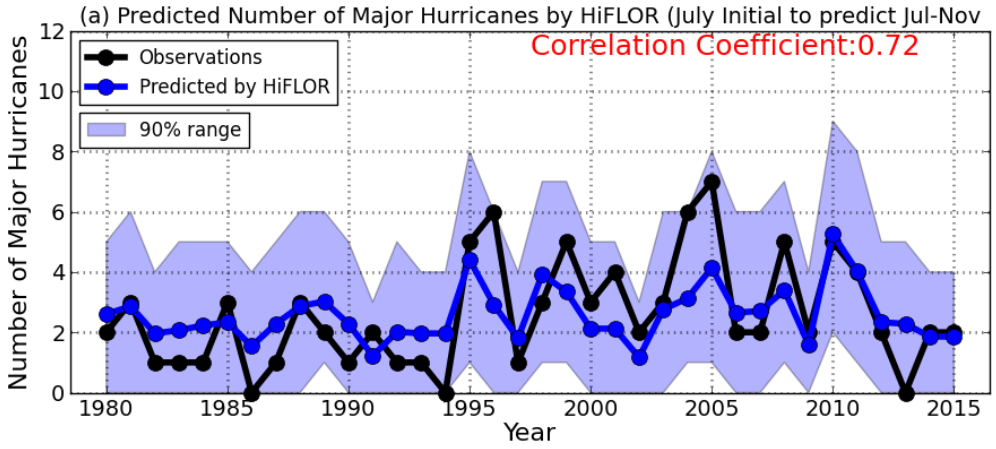
r=N/A (FLOR vs Obs)

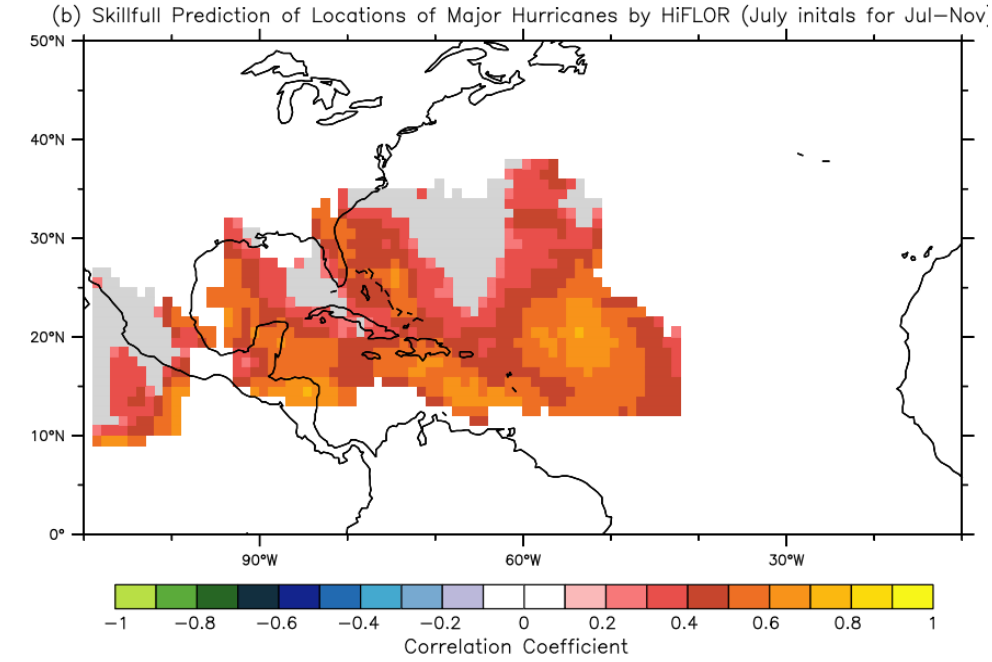
Murakami et al. (2015, J. Climate)

Skillful seasonal forecast of major hurricanes

Retrospective seasonal forecast of major hurricanes using HiFLOR

Initialized on July 1st to predict major hurricanes in the following July-November by HiFLOR





The number of major hurricanes is predictable (r=0.72) a few months in advance

Skillful prediction of locations of major hurricanes.

Realtime seasonal predictions by HiFLOR are provided to CPC and NHC to support their hurricane seasonal outlook.

Murakami et al. (2016, J. Climate)

The climate model simulations used in this study

We conducted long-term climate simulations with the fixed levels of anthropogenic forcing using HiFLOR.

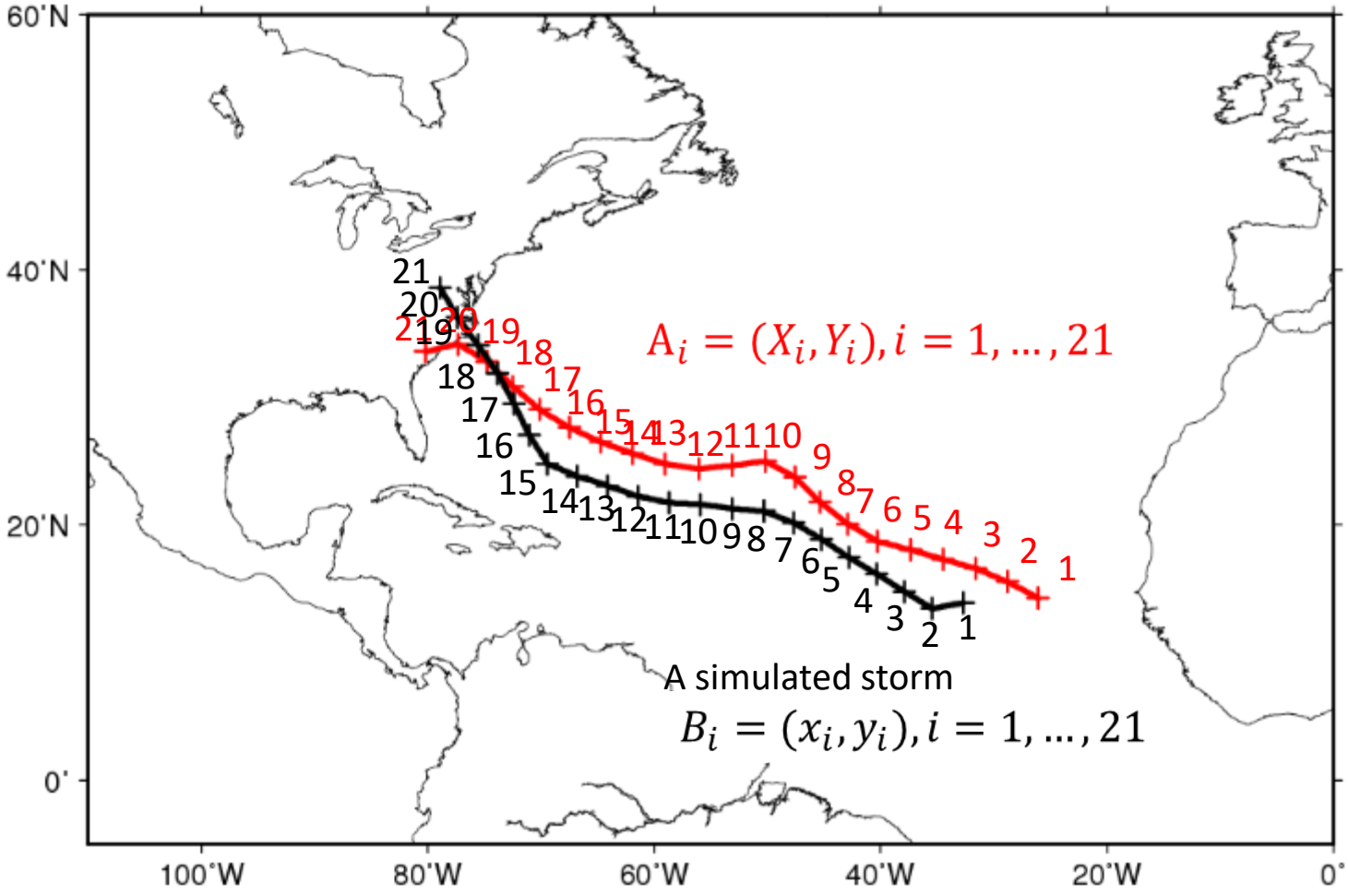
Name	Simulation years	Fixed level of anthropogenic forcing level	Mean climate to represent
1860Cntl	1,500	1860	Pre-industrial
2015Cntl	200	2015	Present-day

Name	Simulation years	Fixed level of anthropogenic forcing level	Mean climate to represent
CLIMO	70	Mean of 1986-2005	Present-day
RCP4.5	70	Mean of 2081-2100 Climate under RCP4.5	The end of this century

Bhatia et al. (2018, *J. Climate;* 2019, *Nat. Comm*), Vecchi et al. (2019, *Clim. Dyn.)*

Using 6-hourly output, we tracked simulated TCs using a few criteria such as wind speed (17.5 m/s), warm core (2K), and duration (36 hours).

How to pick up the costliest hurricanes in a simulation?

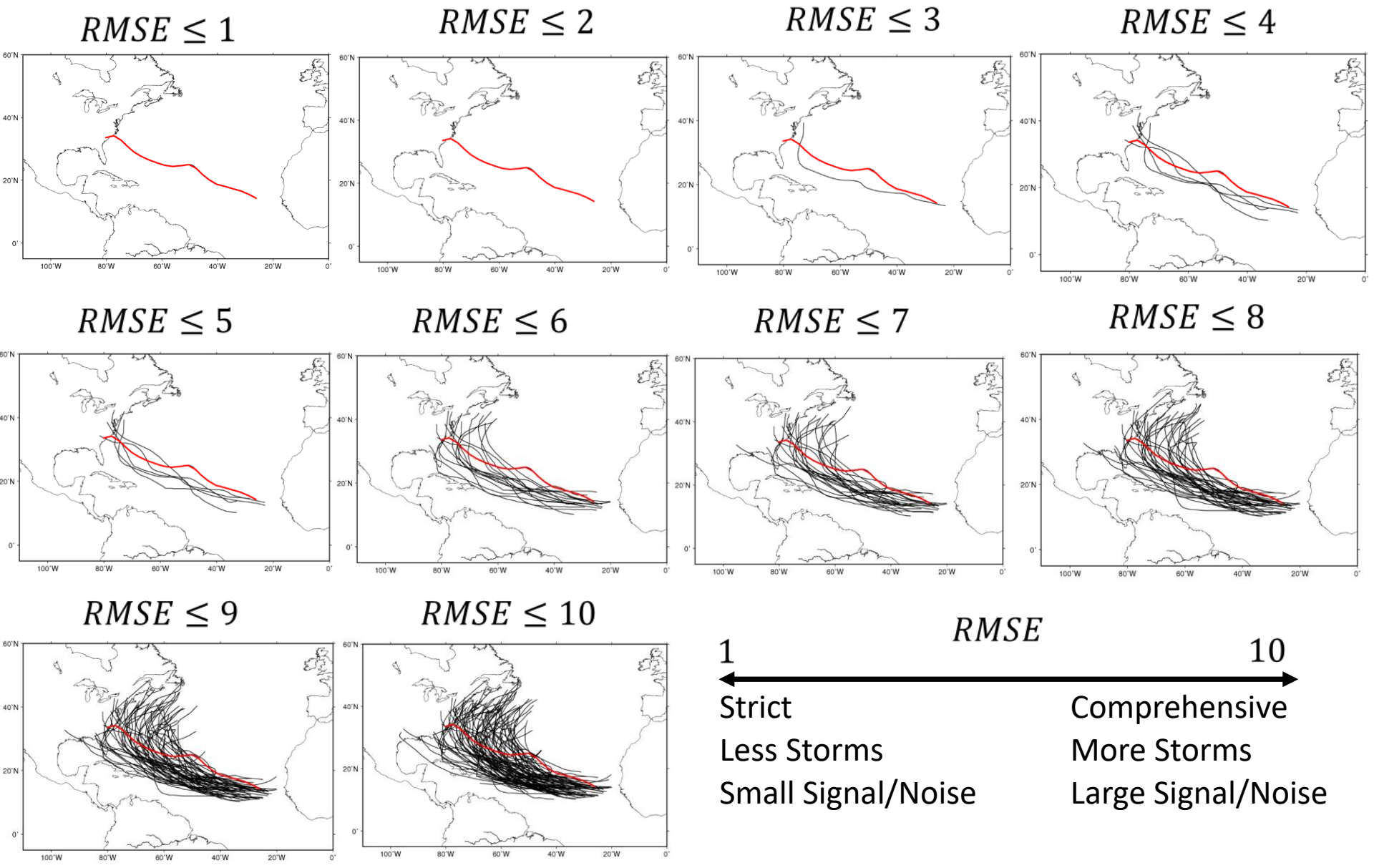


Florence-like storms in the HiFLOR

$$RMSE(A,B) = \left(\sum_{i=1}^{21} (x_i - X_i)^2 + (y_i - Y_i)^2 \right)^{0.5}$$

RMSE represents the degree of similarity of the locations and shape to a reference storm.

How to pick up the costliest hurricanes in a simulation?



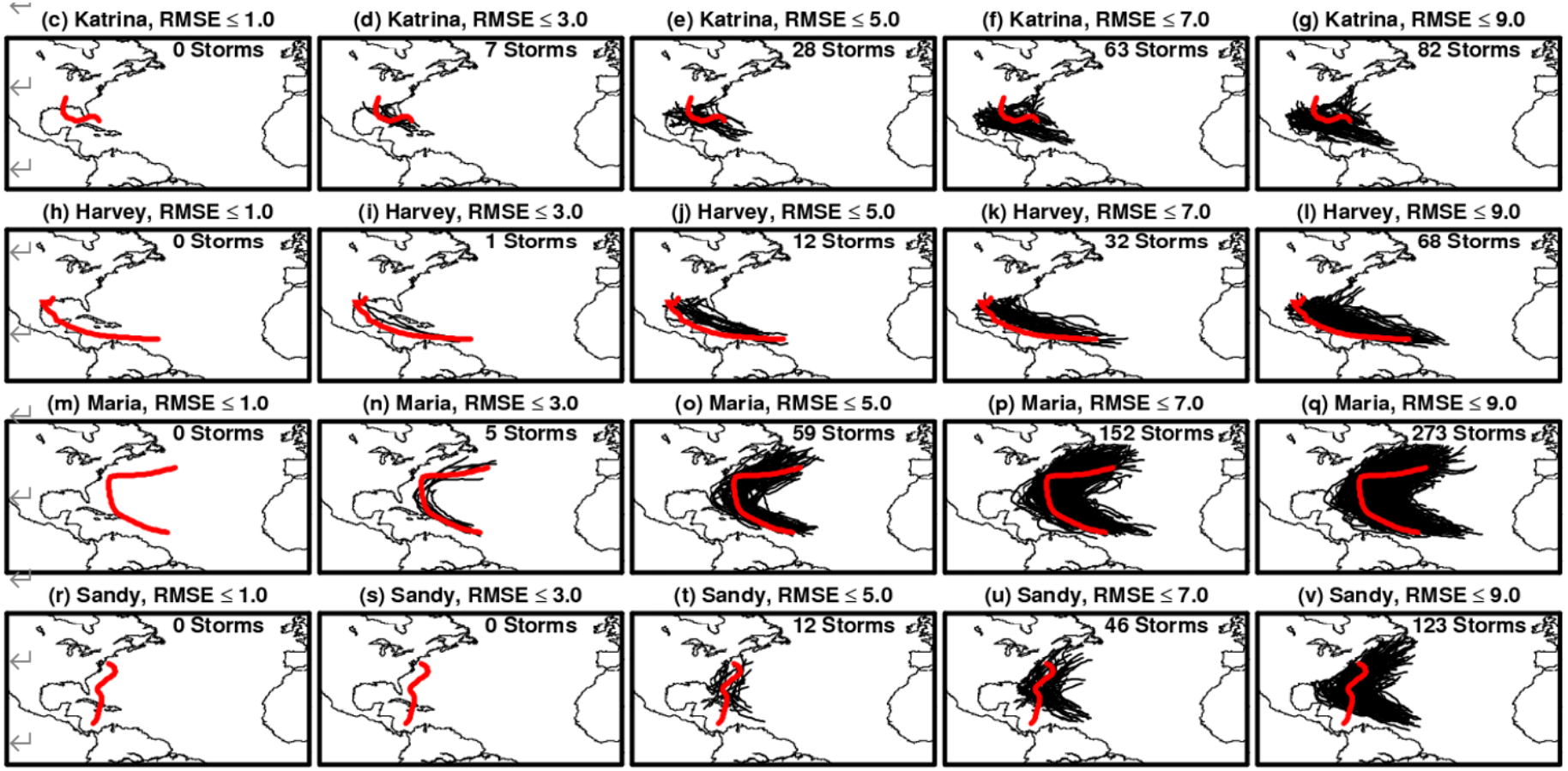
$RMSE$

1 — 10

Strict	Comprehensive
Less Storms	More Storms
Small Signal/Noise	Large Signal/Noise

How to pick up the costliest hurricanes in a simulation?

Because most of the costliest hurricanes were major hurricanes, we only pick up simulated storms with major hurricane categories (≥96kt) in the HiFLOR simulations.



1 — *RMSE* — 10

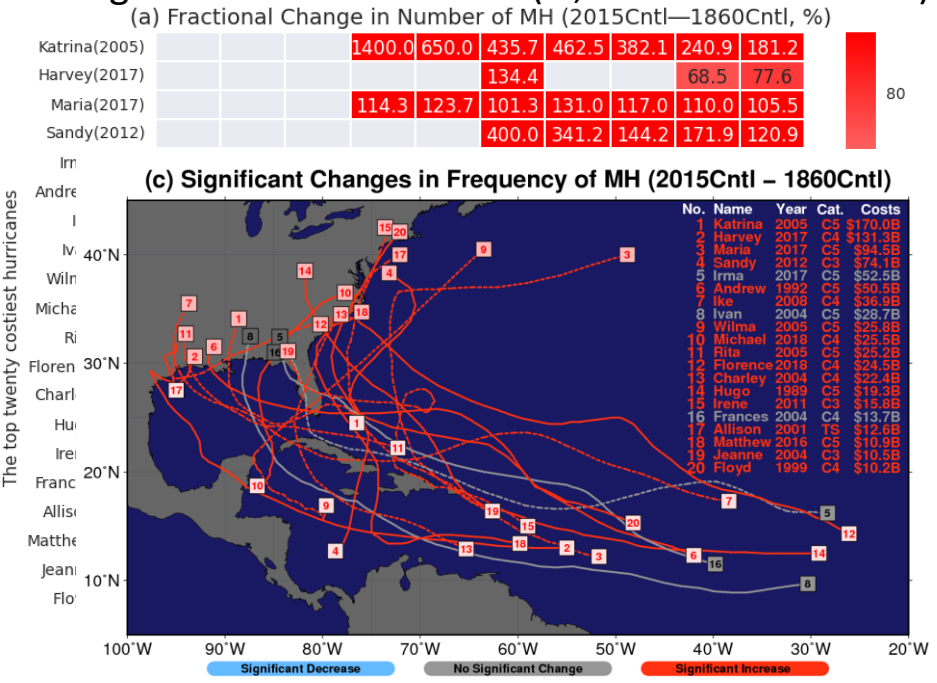
Strict
Less Storms
Small Signal/Noise

Comprehensive
More Storms
Large Signal/Noise

Projected changes in the number of the costliest hurricanes

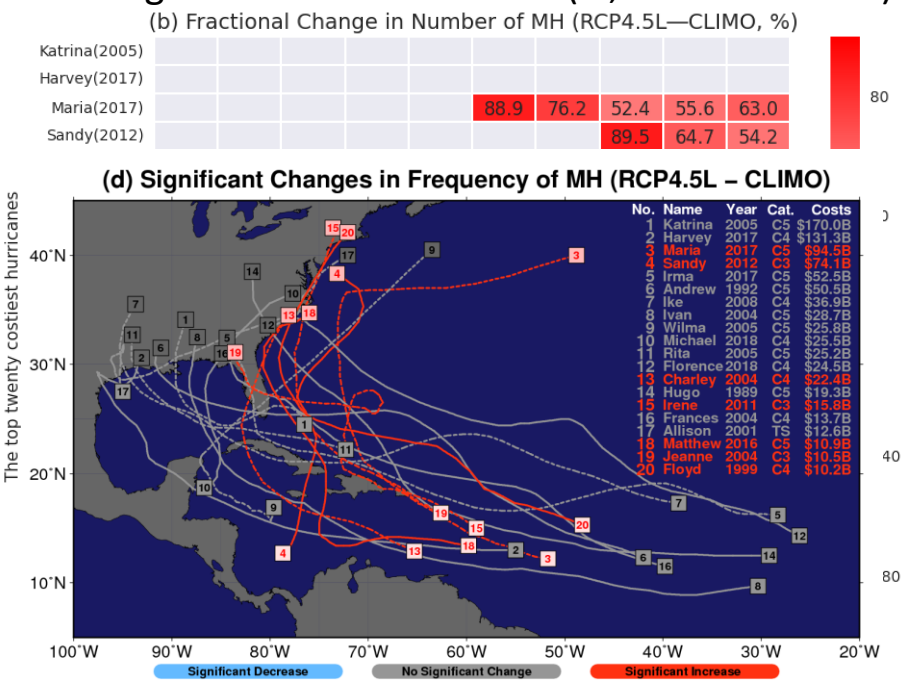
Present-day - Preindustrial

Changes in Number of Storm (%, 2015Cntl-1860Cntl)



Future (RCP4.5) – Present-day

Changes in Number of Storm (%, RCP4.5-CLIMO)



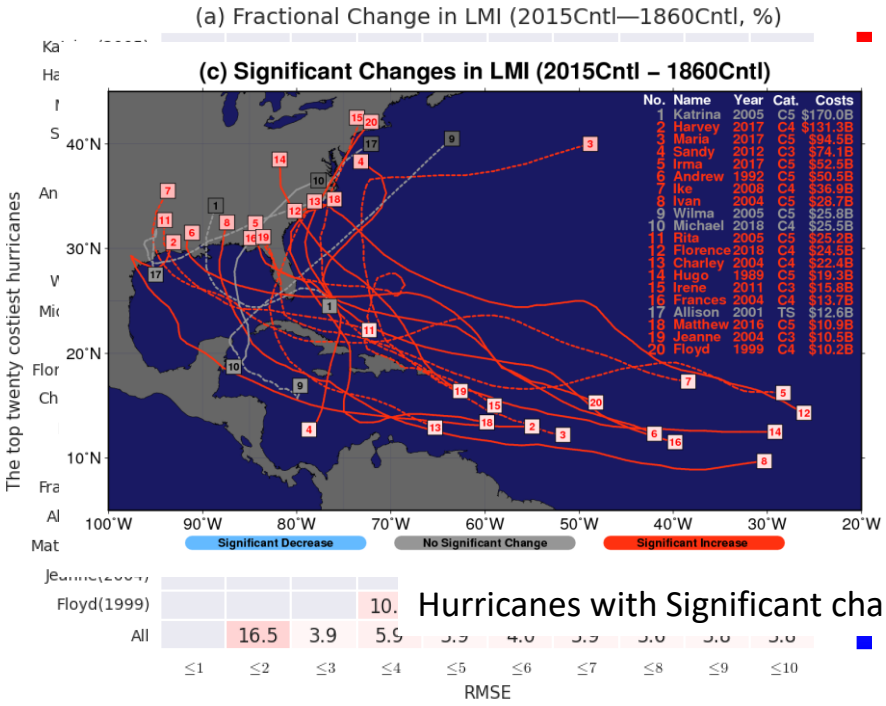
Only the changes with statistical significance at 95% level are shown
Hurricanes with Significant change (red) for any of RMSEs

- Generally, the frequency of occurrence of the costliest storms increases by increased anthropogenic forcing with some dependency on the hurricanes (e.g., +92% increase for RMSE≤5)
- Changes between pre-industrial and present-day (left) are more significant than the future changes (right).

Projected changes in the lifetime maximum intensity (LMI)

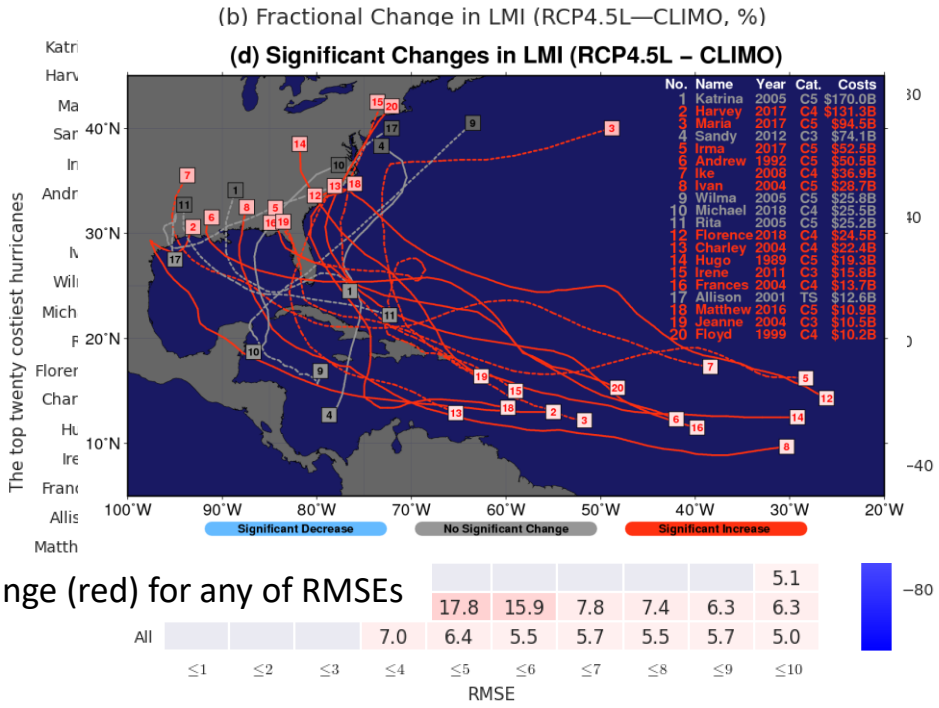
Present-day - Preindustrial

Changes in Number of Major Hurricanes
(%, 2015Cntl-1860Cntl)



Future (RCP4.5) – Present-day

Changes in Number of Major Hurricnaes
(%, RCP4.5-CLIMO)



Hurricanes with Significant change (red) for any of RMSEs

Only the changes with statistical significance at 95% level are shown

- Lifetime maximum intensity would be more intense by increasing greenhouse gases (e.g., +4~6% increase for RMSE ≤5)

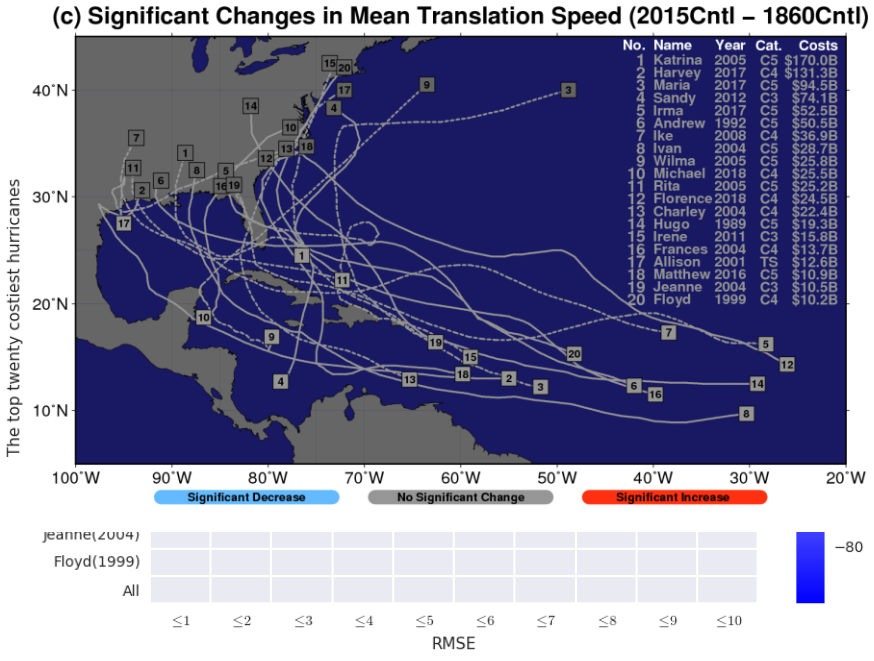
Projected changes in the mean translation speed

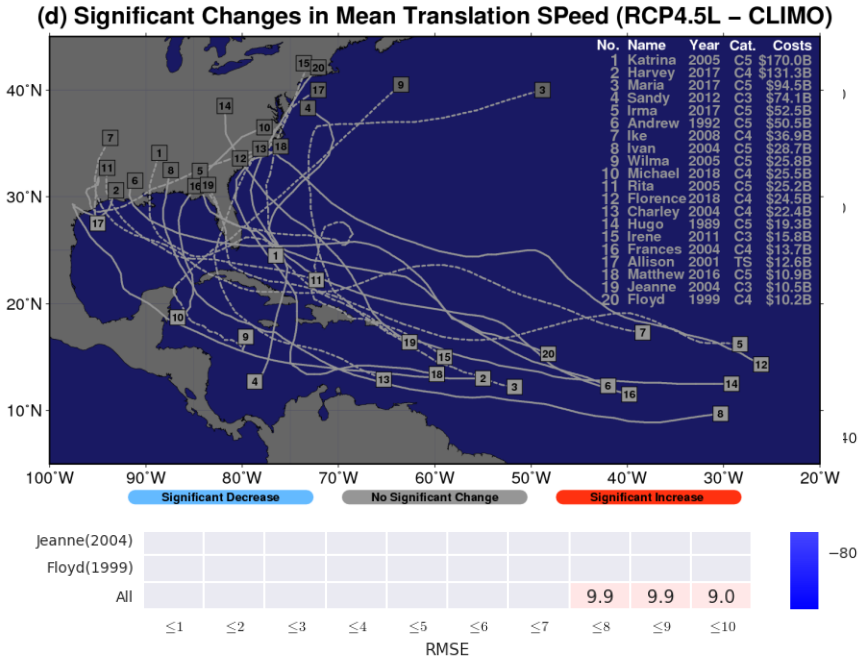
Present-day - Preindustrial

Future (RCP4.5) – Present-day

Changes in Number of Major Hurricanes (%, 2015Cntl-1860Cntl)

Changes in Number of Major Hurricnaes (%, RCP4.5-CLIMO)

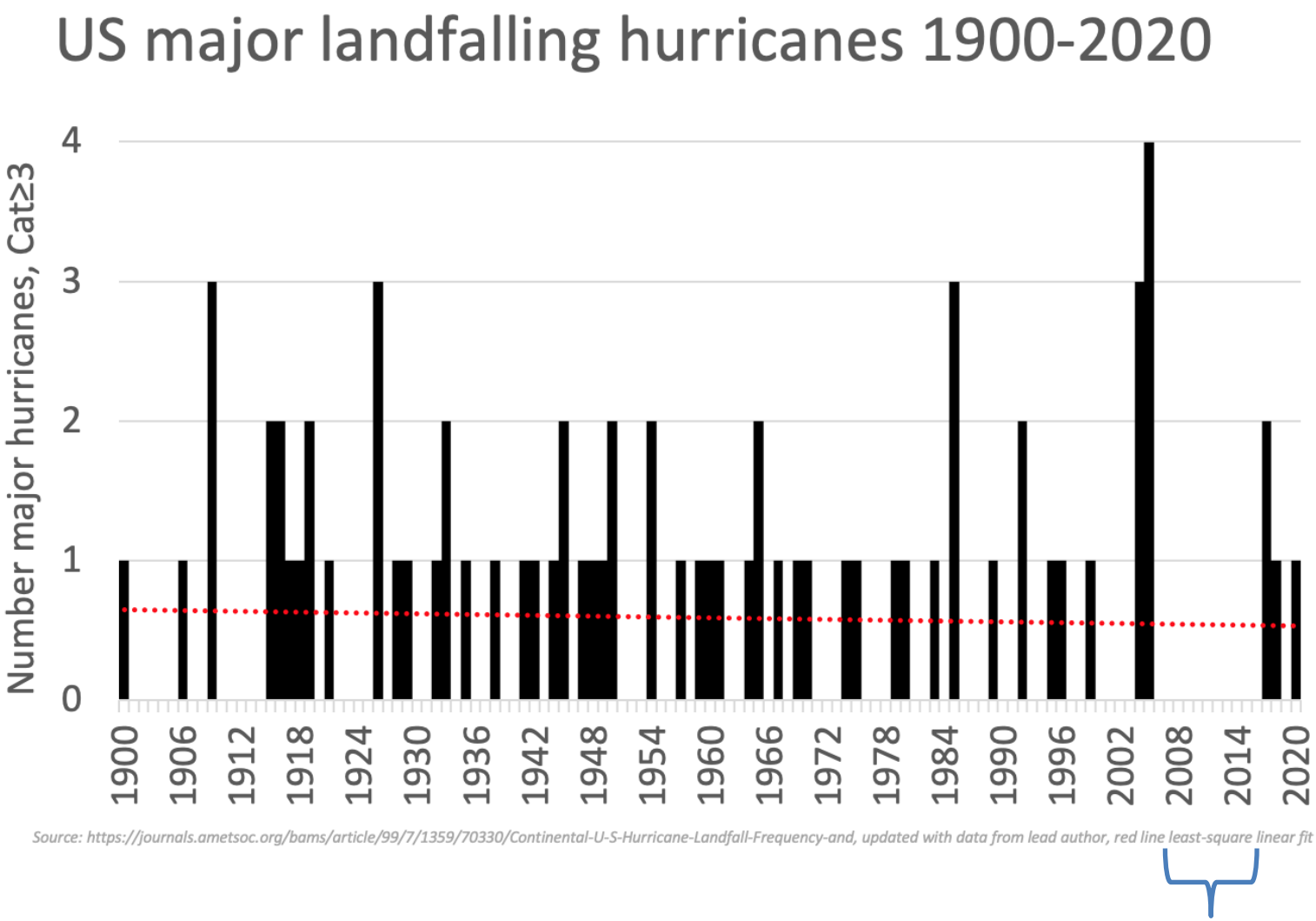




Only the changes with statistical significance at 95% level are shown

- No significant changes in the mean TC translation speed for the simulated costliest hurricanes.

Major Hurricane Landfall Drought (2006-2015)



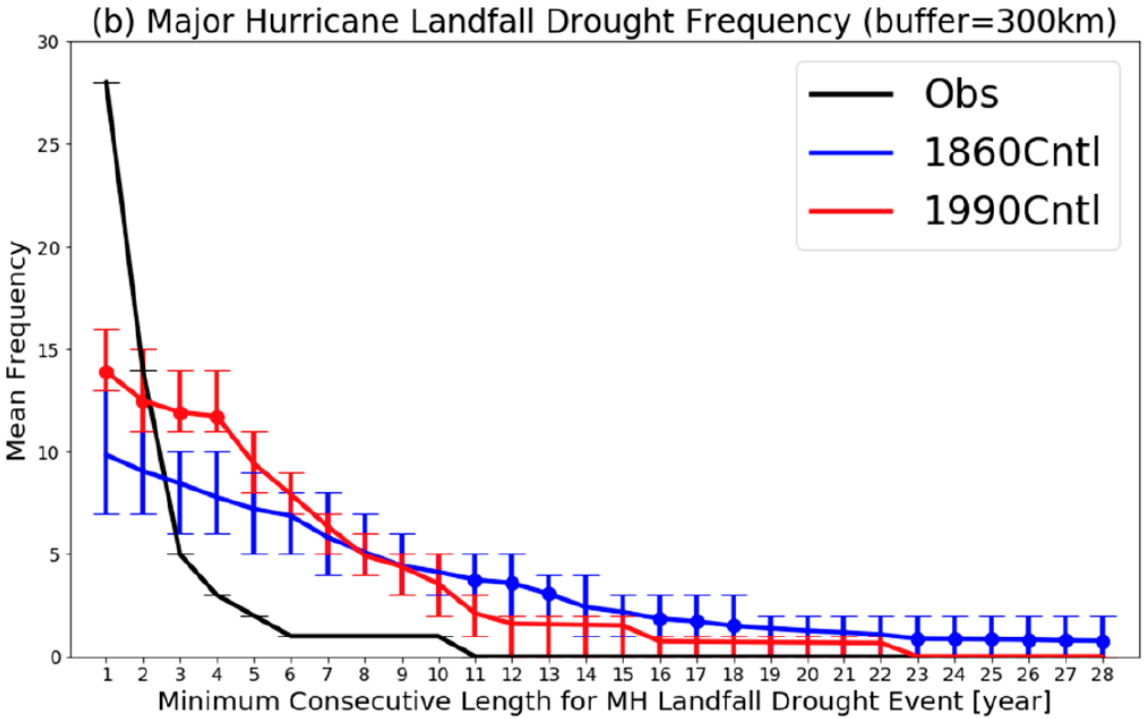
No major hurricane landfall in the consecutive 10 years (2006-2015)

Any relation with increasing anthropogenic forcing?

Levin and Murakami (2016)

Major Hurricane Landfall Drought (2006-2016)

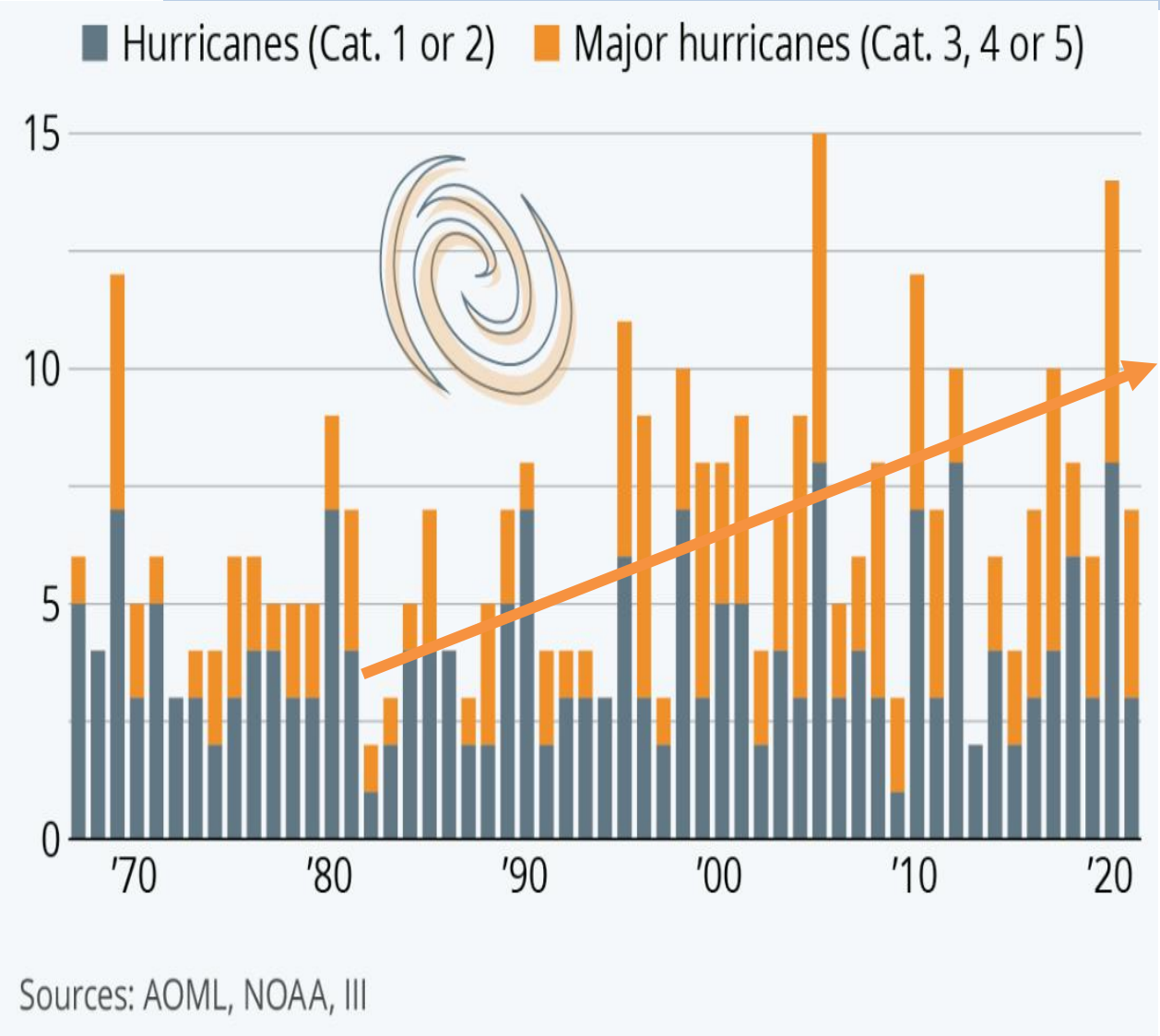
Name	Simulation Years	Fixed CO_2 Level	Mean Climate to Represent
1860Cntl	1,500	286 ppmv	Pre-industrial Climate
1990Cntl	300	354 ppmv	Present-day Climate



HiFLOR shows decreased frequency of major hurricane landfall drought events with increasing anthropogenic forcing.

Levin and Murakami (2016)

Observed and simulated trends in the NA major hurricanes (1980-2018)



Increasing basin-total major hurricanes in the North Atlantic since 1980.
Is this trend related to natural variability (AMO?) or anthropogenic forcing (CO_2, aerosols)?

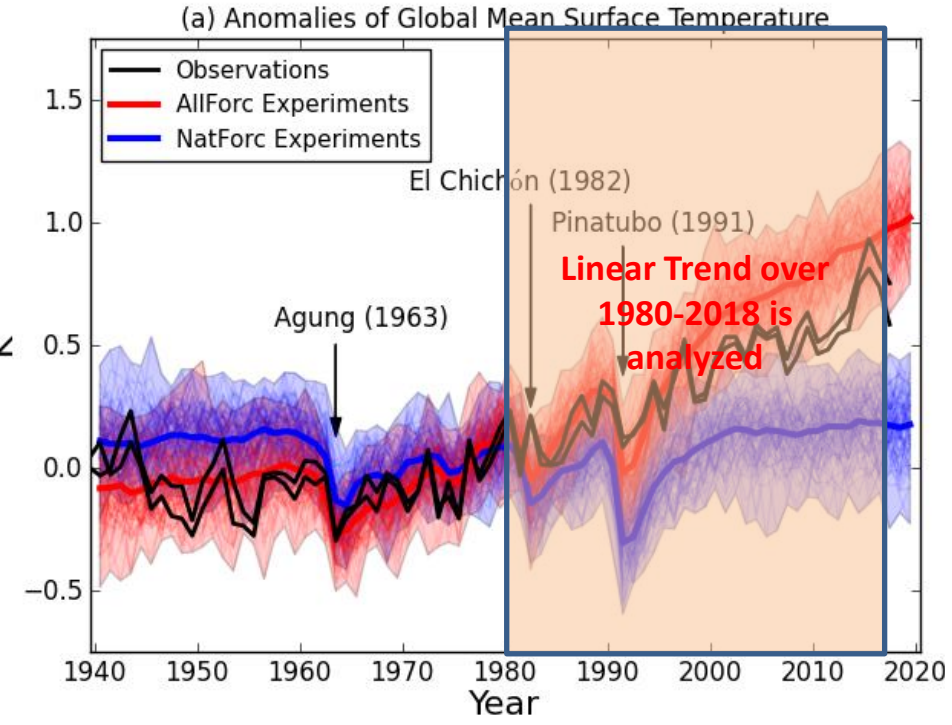
Observed and simulated trends in the NA major hurricanes (1980-2018)

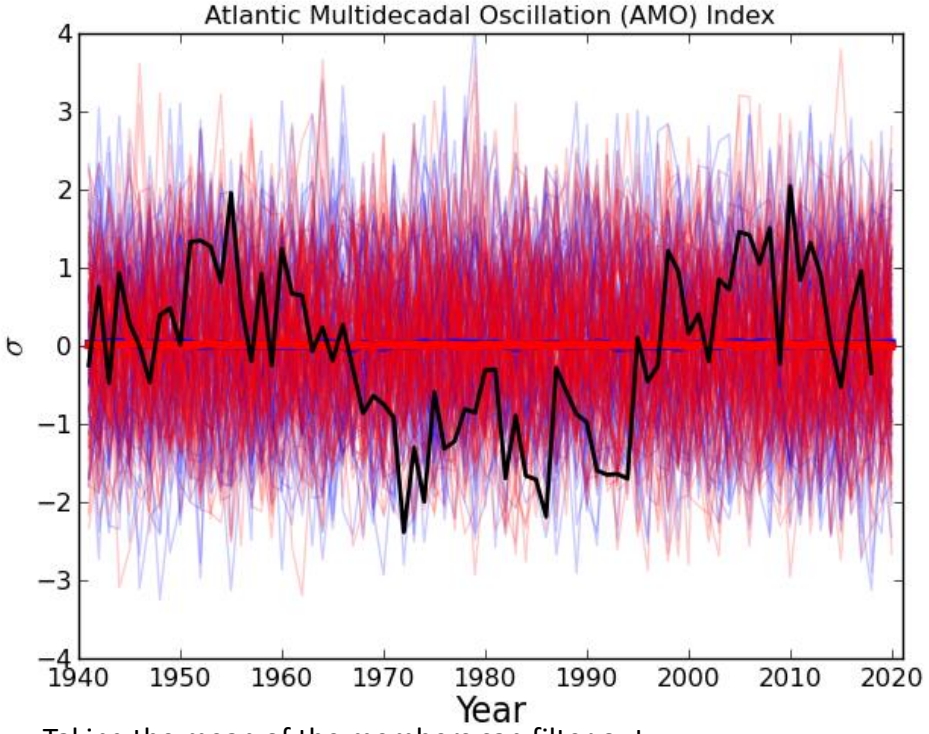
AllForc: Historical simulations by prescribing time-varying external forcing (green-house gases, aerosols, volcanic forcing, and solar constant)

15 ensemble member using HiFLOR

NatForc: As in AllForc, but only with time-varying volcanic forcing and solar constant.

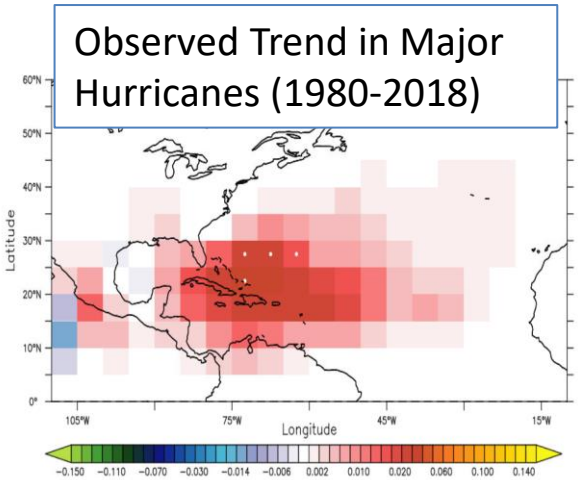
15 ensemble members using HiFLOR

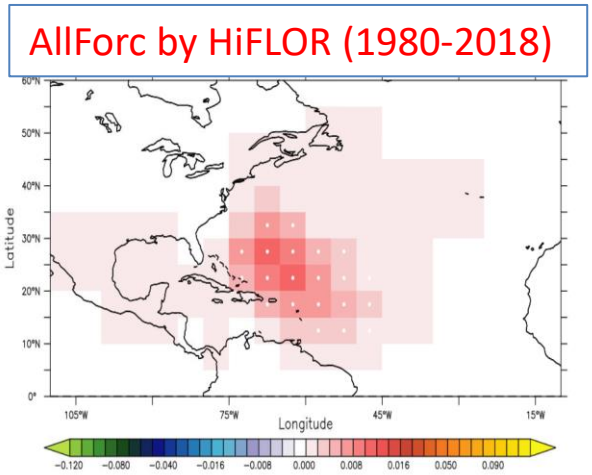


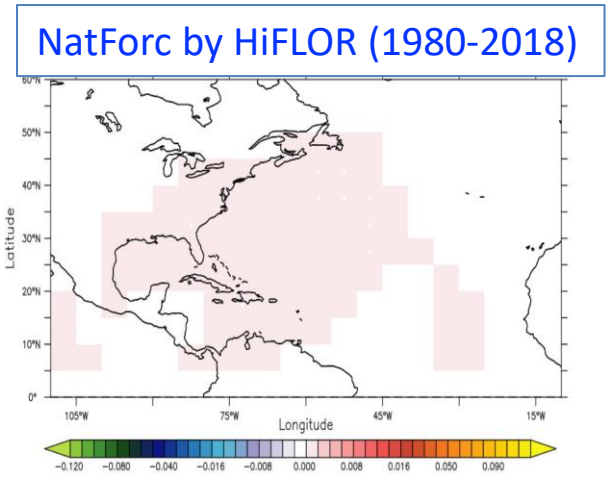


Taking the mean of the members can filter out the effect of internal variability such as AMO

Observed and simulated trends in the NA major hurricanes (1980-2018)







Indicating a substantial impact of anthropogenic forcing (e.g., greenhouse gases and aerosols) on the positive trends in the North Atlantic major hurricanes since 1980.

Takeaway Messages

- Both the occurrence and mean lifetime maximum intensity of the top 20 costliest hurricanes may increase due to increased anthropogenic forcing, but no significant changes in the mean translation speed.
- HiFLOR doesn't project increased events of major hurricane landfall drought by increasing anthropogenic forcing.
- The large-ensemble simulations suggest that increased anthropogenic forcing plays an important for the increasing frequency of occurrence of NA major hurricanes since 1980.
- Quantitative assessment of the changes in major hurricane risk using a dynamical model is still challenging by the substantial uncertainties such as insufficient model resolution, biases, experimental design, and insufficient simulation length, etc.