Simulation, Prediction, and Attribution Study for Tropical Cyclones using GFDL HiFLOR

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GFDL/Princeton AOS

Topics

HiFLOR Model Evaluation

Murakami et al. (2015, J. Climate)

- Categories 4 and 5 hurricanes
- Innterannual variations, cold-wakes, MJO

Seasonal Prediction of Tropical Cyclones

- Seasonal prediction skill *Murakami et al. (2016, J. Climate)*
- Statistical-Dynamical model *Murakami et al. (2016, Mon. Wea. Rev.)*

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- Positive trend in C45 hurricanes in the North Atlantic *(in prep)*

will not be presented today:

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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)

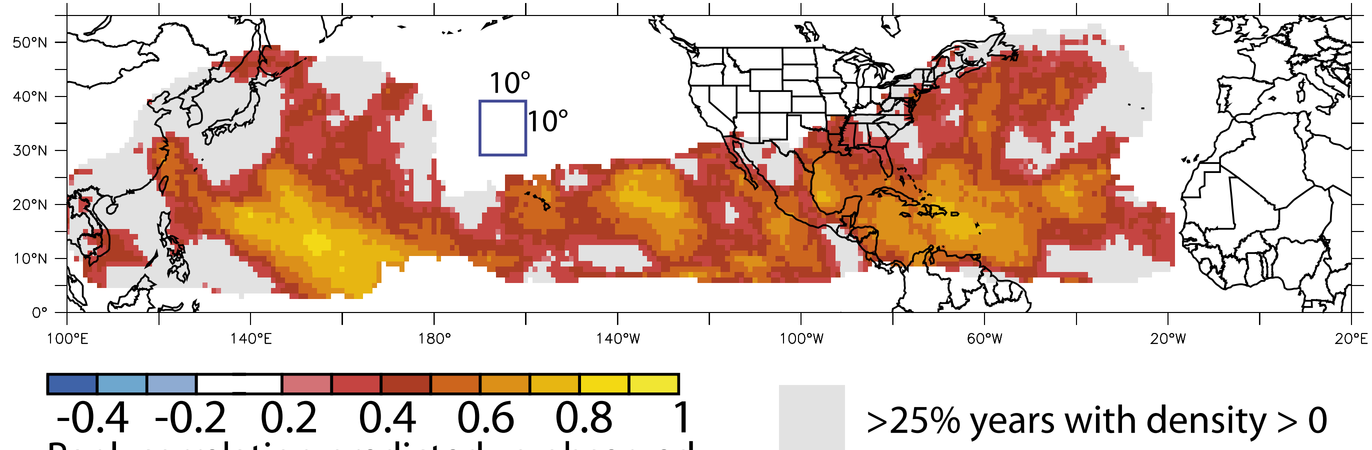
Smith and Matthes (2015, Natural Hazards)

- 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)

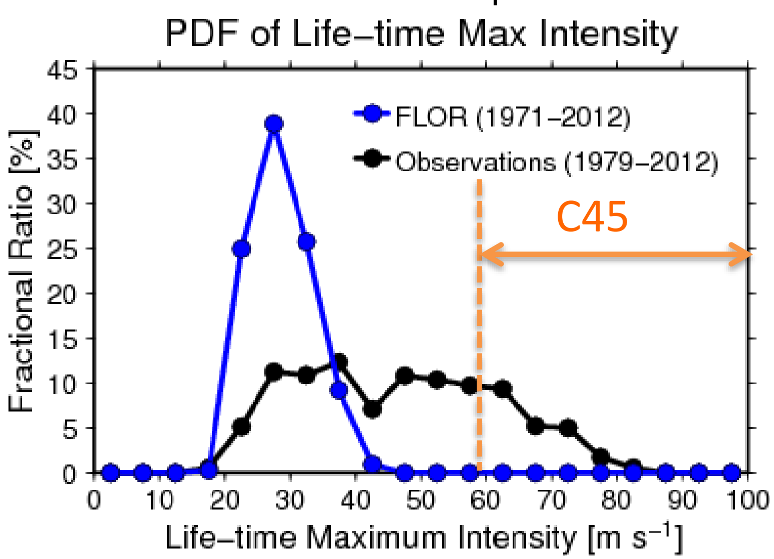
GFDL FLOR: Forecast-oriented Low Ocean Resolution version of CM2.5

- 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
- FLOR is a TC-permitting model



Rank correlation predicted vs. observed masked at p=0.1

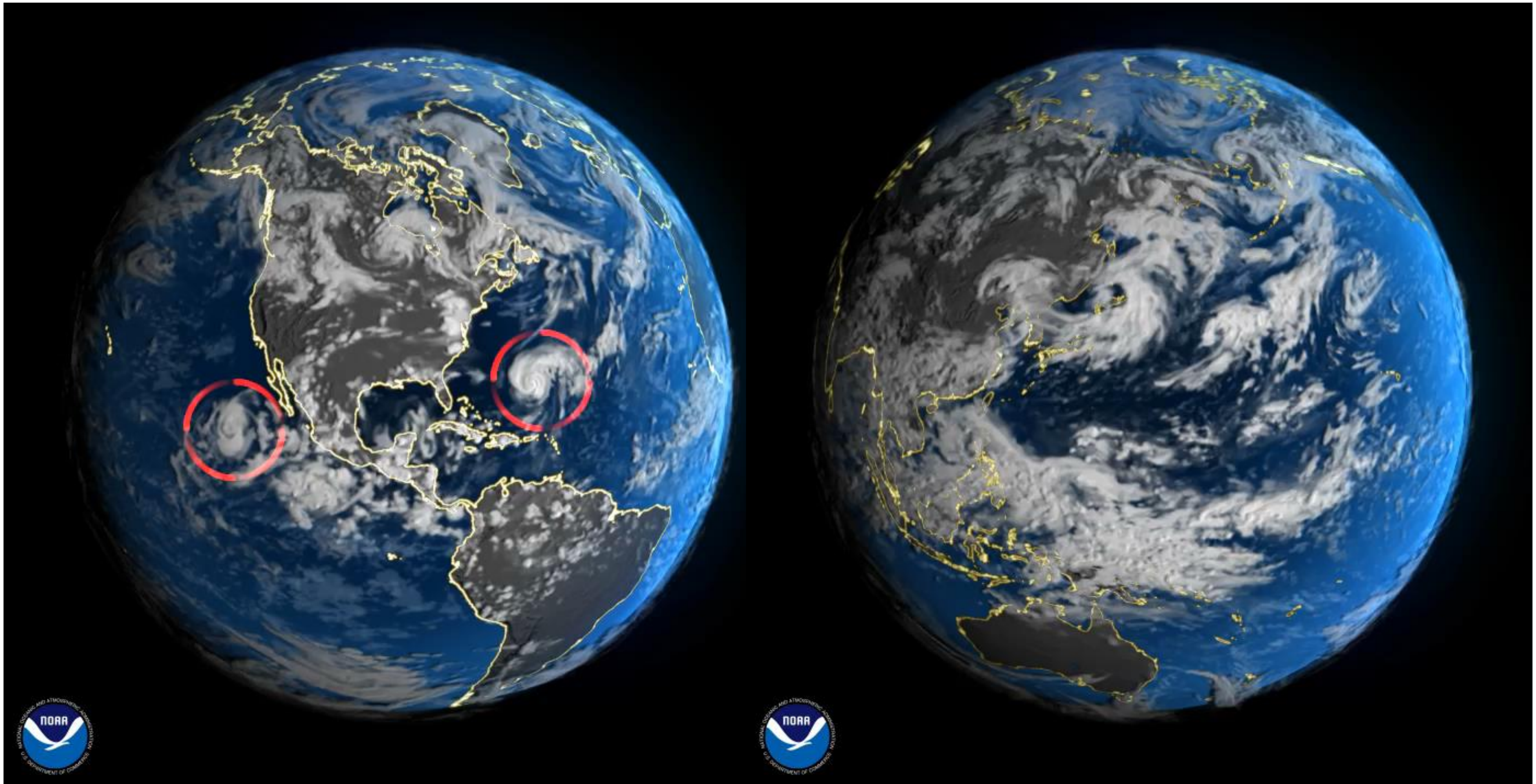
Vecchi et al. (2014, J. Climate)



FLOR critically underestimates frequency of C45 hurricanes.

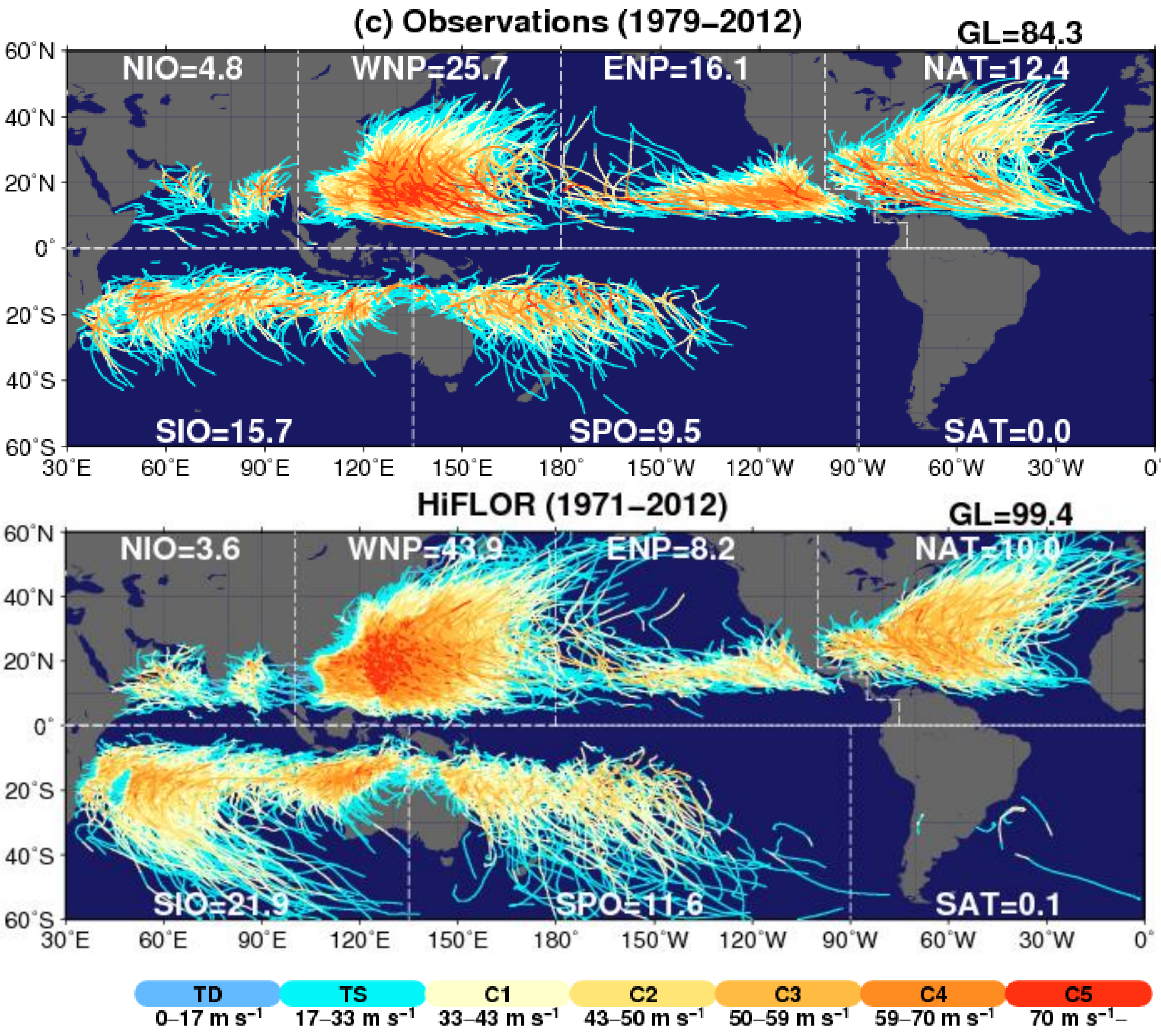
GFDL Coupled Models (FLOR and HiFLOR)

	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, JC)



Restoring Experiment:

Observed time-varying SST is restored at 5-day timescale for the period 1971–2012.

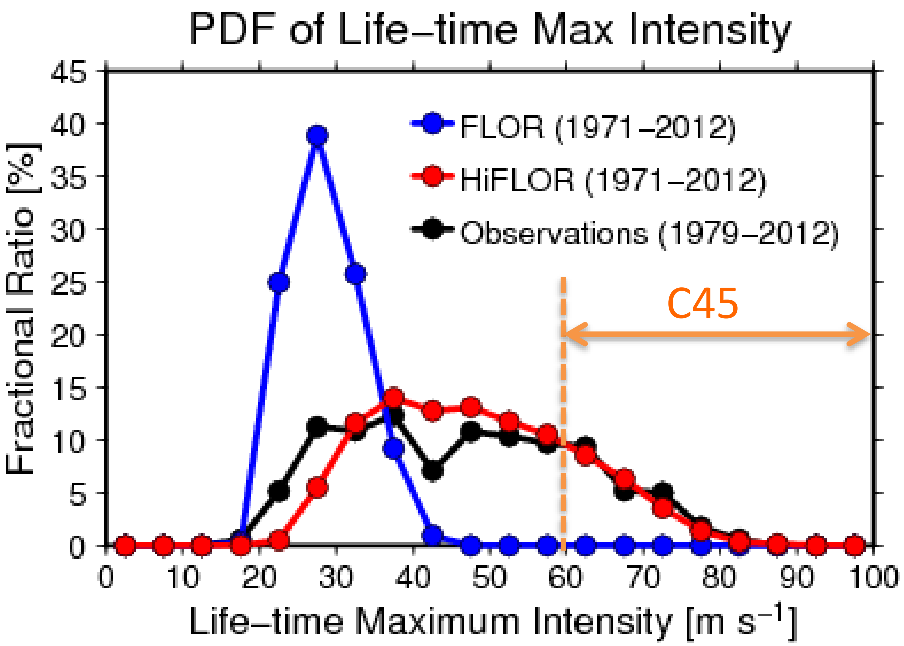
FLOR underestimates TC intensity

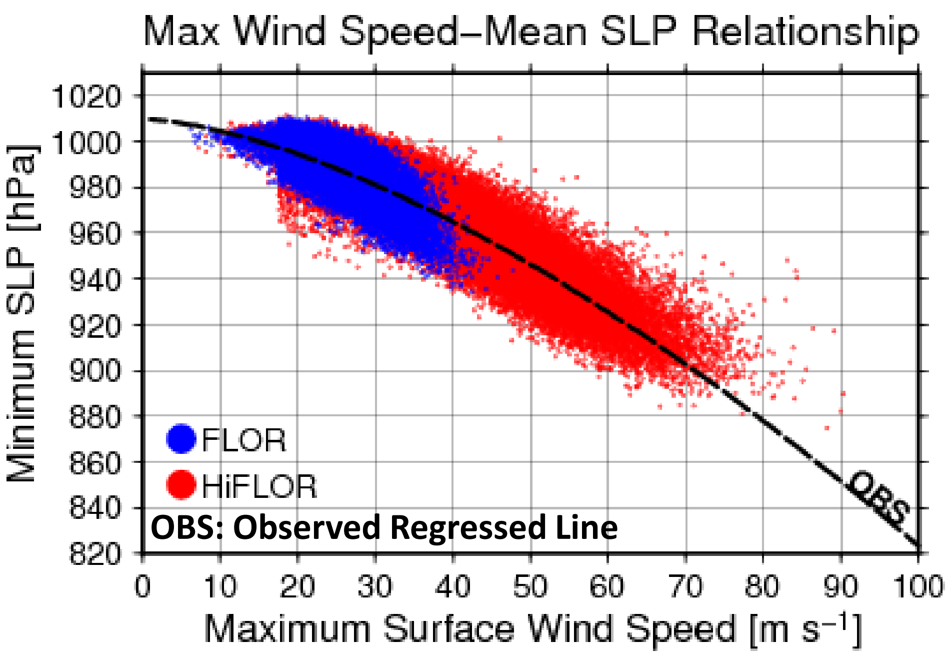
HiFLOR improved TC intensity

Number: Annual mean TC frequency

Simulated TC Intensity

Murakami et al. (2015, JC)

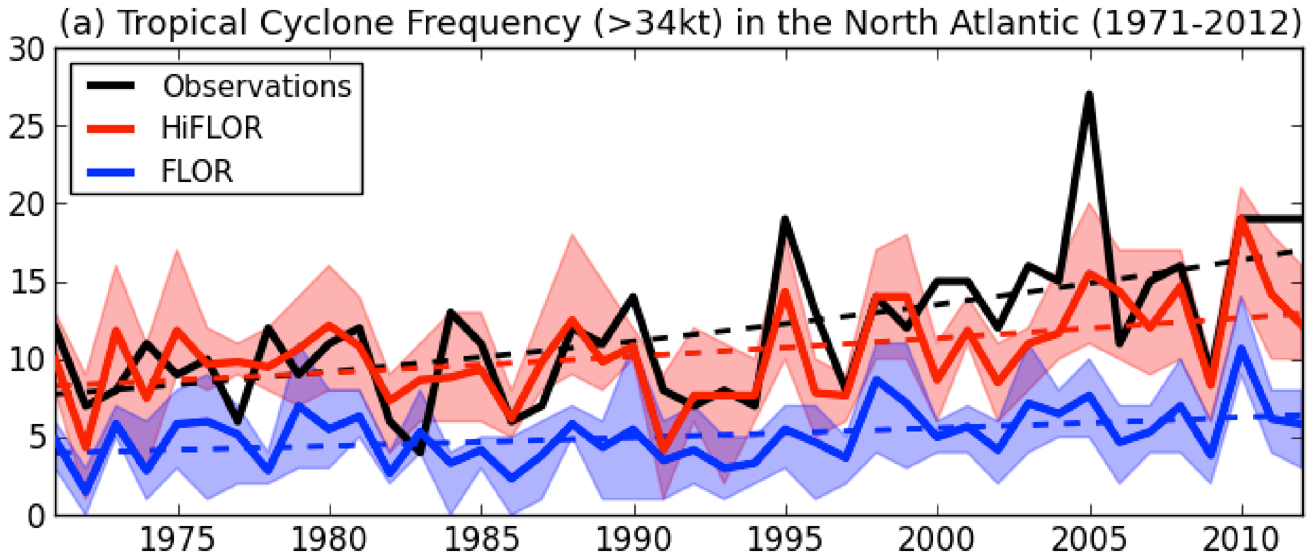




- HiFLOR can simulate C45 hurricanes.
- TC structure is reasonably simulated in terms of Maximum Wind Speed– Mean SLP relationship.

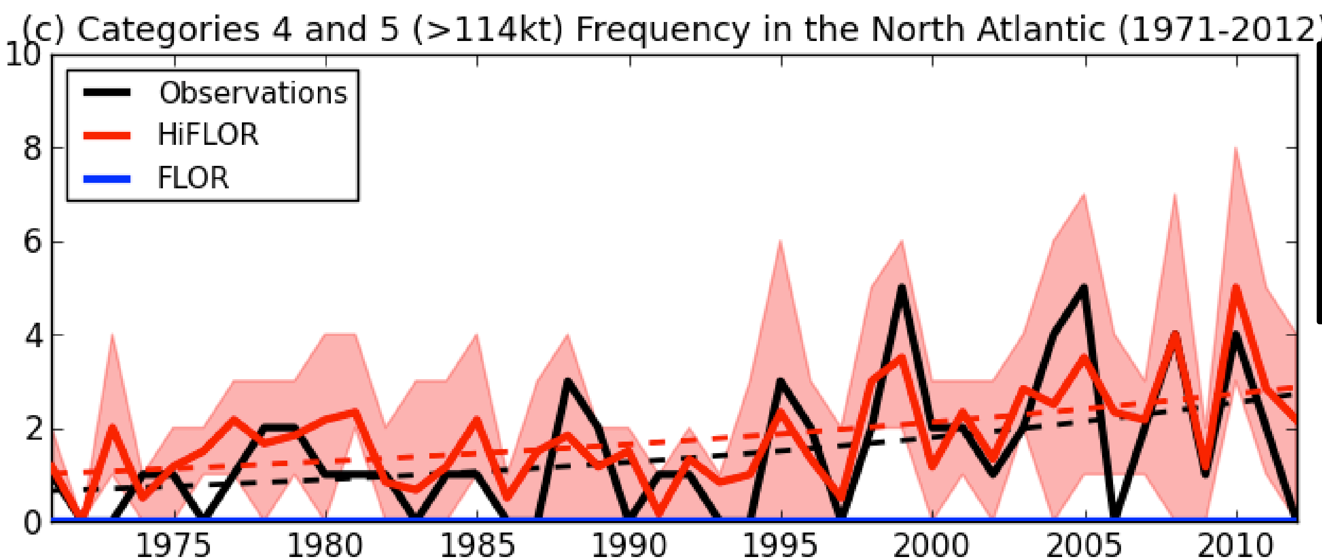
Interannual Variation of North Atlantic Storms

Murakami et al. (2015, JC)



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, JC)

Correlation Coefficients (Observed vs Model, 1971–2012)

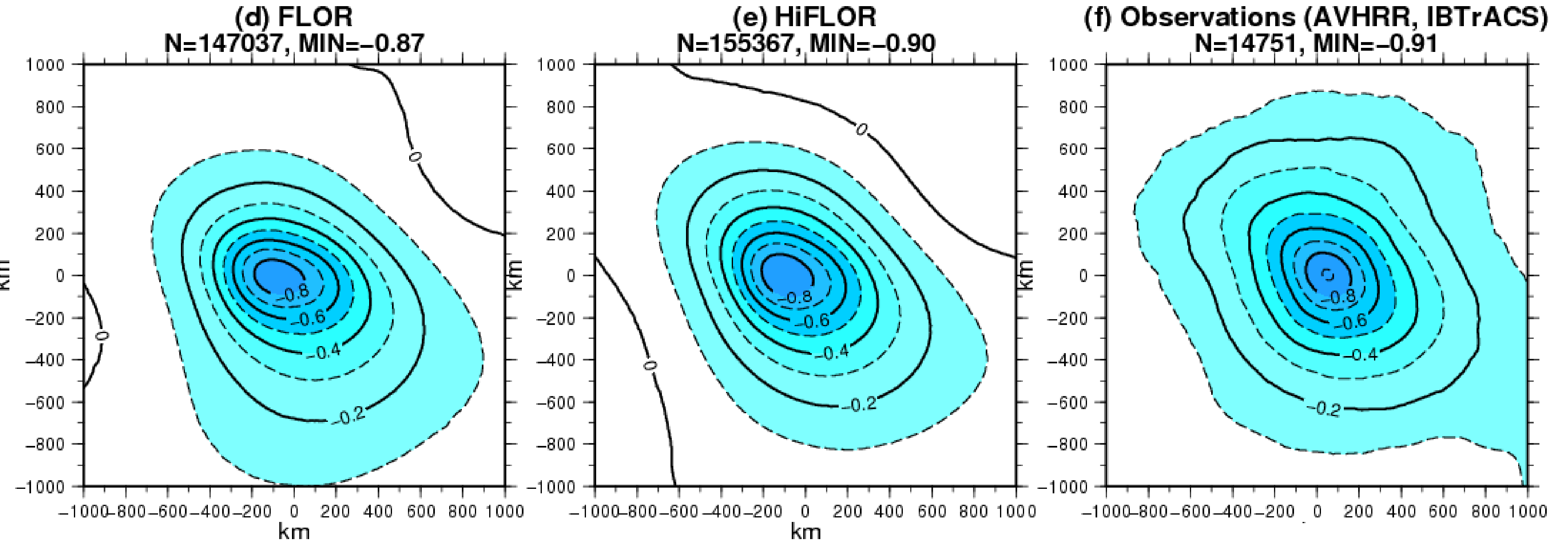
Model	N.Indian	WN.Pacific	EN.Pacific	N.Atlantic	S.Indian	S.Pacific
(a) All TSs (>34kt, 1971-2012)						
HiFLOR	−0.27	**+0.35**	**+0.49**	**+0.68**	**+0.38**	**+0.31**
FLOR	+0.01	**+0.55**	**+0.41**	**+0.59**	+0.02	+0.23
(b) Hurricanes (>64kt, 1971-2012)						
HiFLOR	+0.04	+0.17	**+0.51**	**+0.77**	**+0.51**	+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

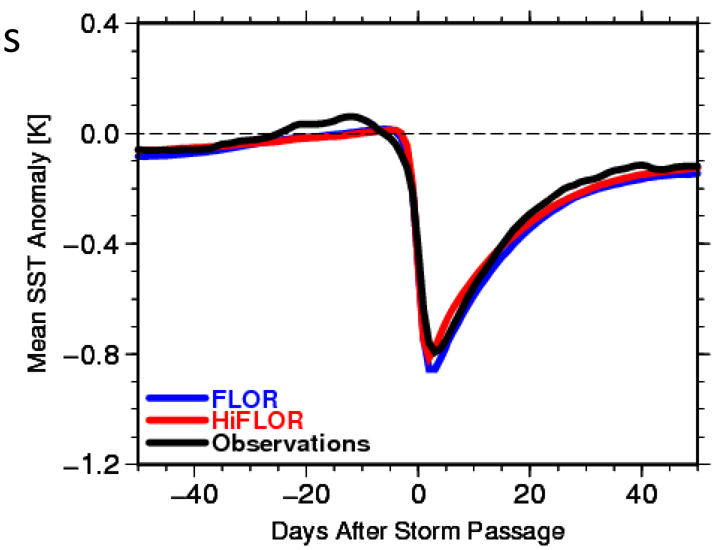
HiFLOR shows higher skill than FLOR in all the ocean basins, except for WNP

Storm-Induced Cold Wakes (From 300-yr Control Free Run)

Murakami et al. (2015, JC)



Composites of SST anomaly 2-days after storm passages



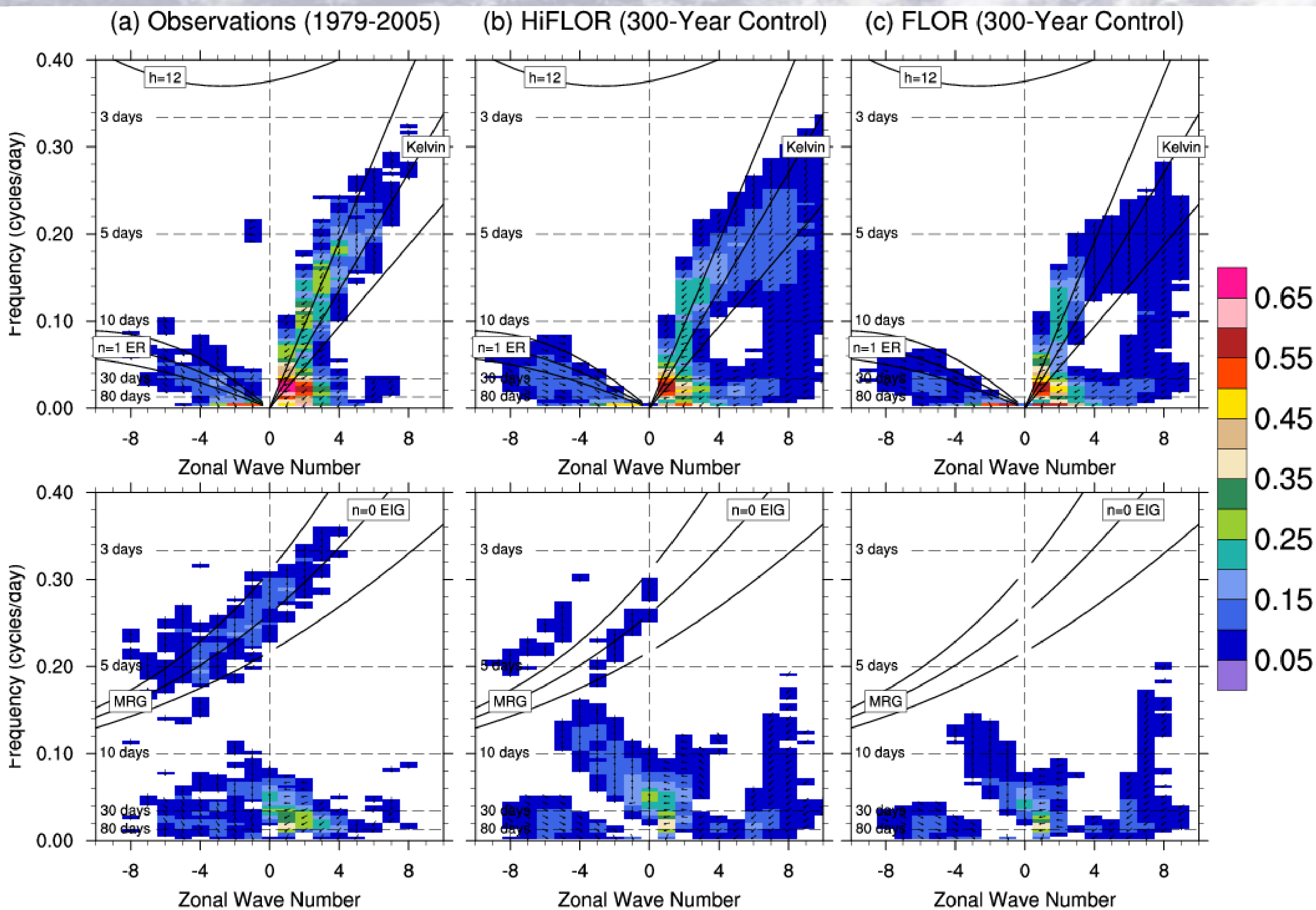
<u>Cold-Water Wakes</u>

Local cold SST anomaly relative to the SST average over 2–12 days before the storm passages.

Both models reproduce magnitude of observed cold wakes and its temporal evolution.

MJO

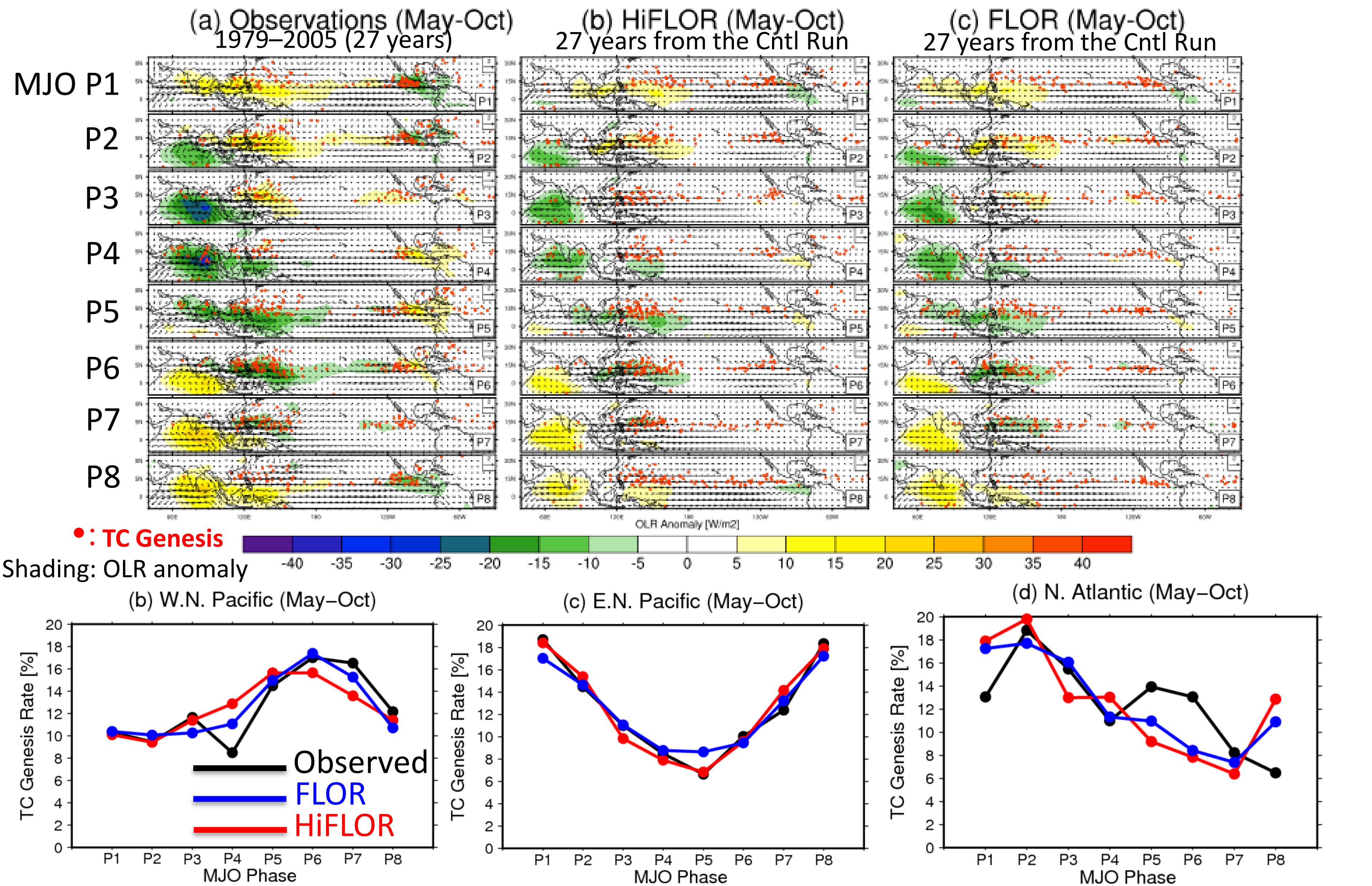
Murakami et al. (2015, JC)



Both models show strong signals in the period range of 30–80 days (MJO).

TC Genesis Modulated by MJO

Murakami et al. (2015, JC)



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Retrospective Seasonal Forecast

Murakami et al. (2016, JC)

Models	HiFLOR and FLOR (no flux adjustment)
Period	1980–2015, mainly focus on TC prediction for July–November
Initial	July (Leal Month=0), June (Lead Month=1),…., January (Lead Month=6) #**Ocean is initialized using the Ensemble KF.** **Atmosphere is not initialized** **(derived from the AMIP simulations for FLOR, 1990-Cntl exp for HiFLOR)**
Ensemble	12 Ensemble Members (3 different Atm. with 12 different Ocn.)
Prediction Targets	North Atlantic: • Basin total TC frequency (Tropical Storms, ≥17m/s), • Basin total C45 frequency (Category 4 and 5 Hurricanes, ≥58m/s) • Landfall TC frequency over US and Caribbean Islands • Basin total Accumulated Cyclone Energy (ACE)# • Basin total Power Dissipation Index (PDI)#
Skill Score	Rank Correlation, Root-mean-square-error (RMSE)

ACE (PDI) is defined as an integrated quantity of square (cube) of maximum surface wind velocity throughout the lifetime of tropical cyclones.

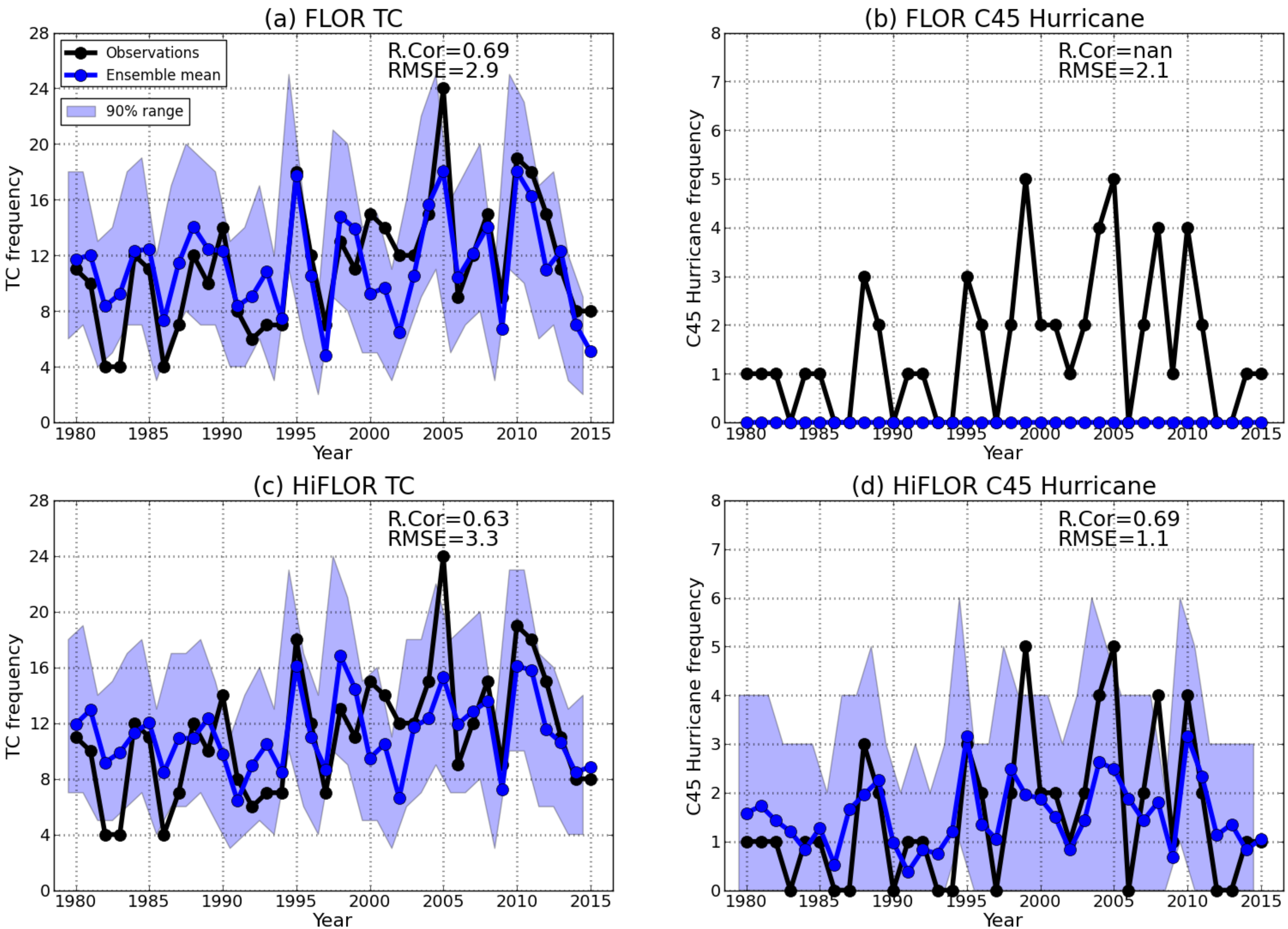
$$ACE \equiv \sum_{n=1}^{N}\sum_{t=1}^{T} w_{\max}^{2}(n,t) \qquad PDI \equiv \sum_{n=1}^{N}\sum_{t=1}^{T} w_{\max}^{3}(n,t)$$

N: Total TC genesis number

T : Life span for each TC

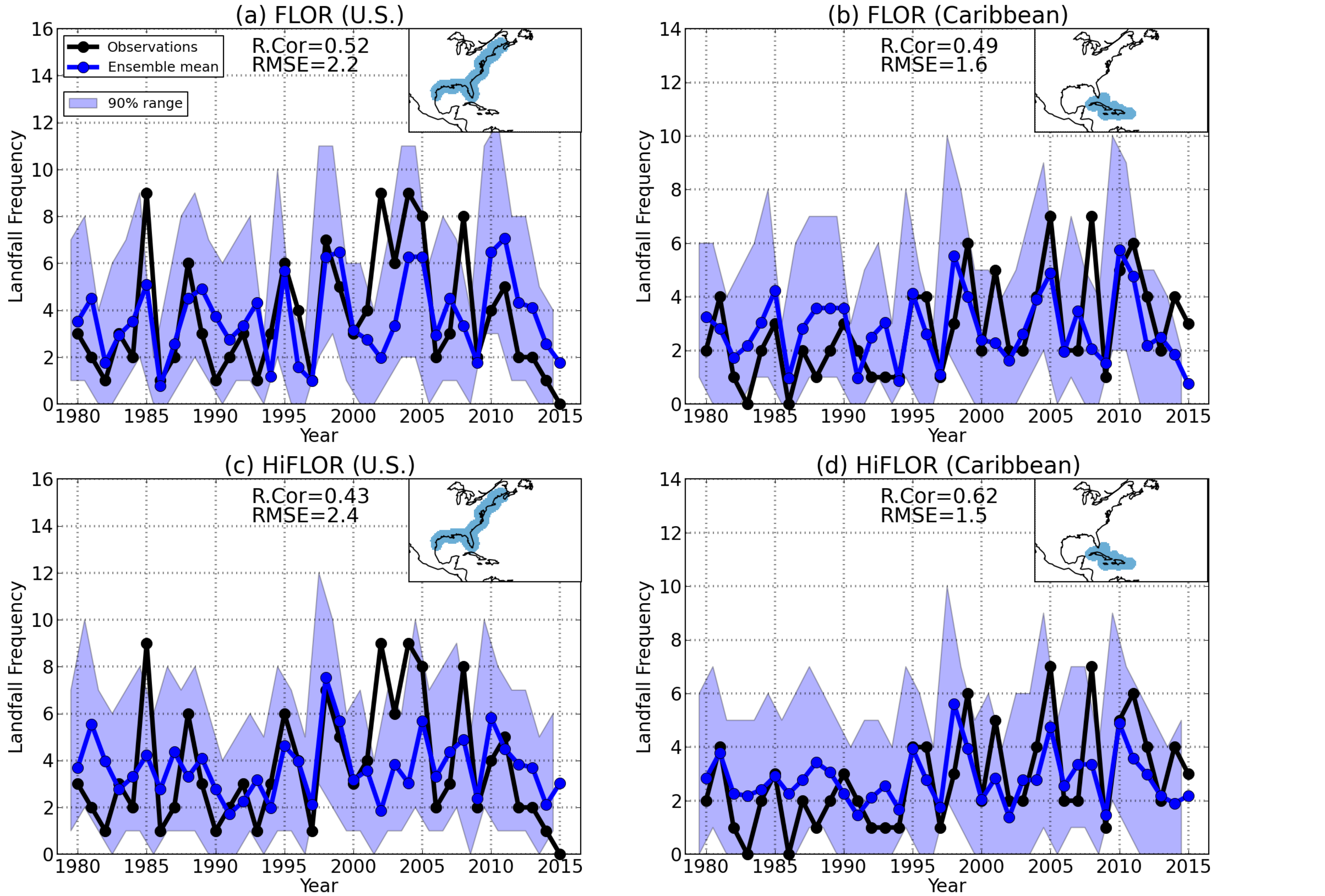
Skill in Prediction from July Initial Forecasts (Lead Month=0)

Murakami et al. (2016, JC)



Skill in Prediction from July Initial Forecasts (Landfall)

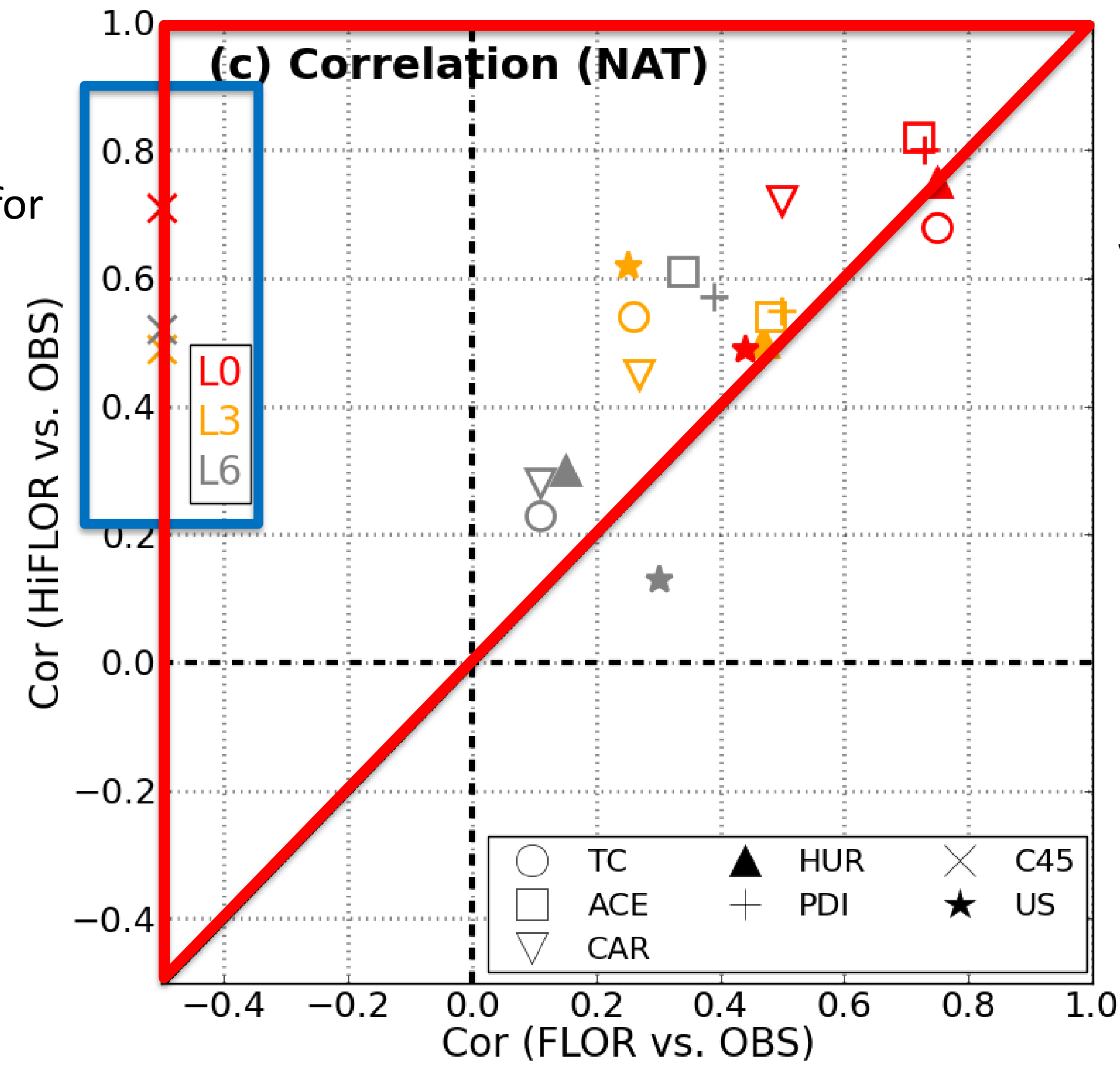
Murakami et al. (2016, JC)



Comparisons of Prediction Skill between HiFLOR and FLOR

Murakami et al. (2016, JC)

HiFLOR shows significant skill for C45 hurricanes even at 3 and 6 lead months

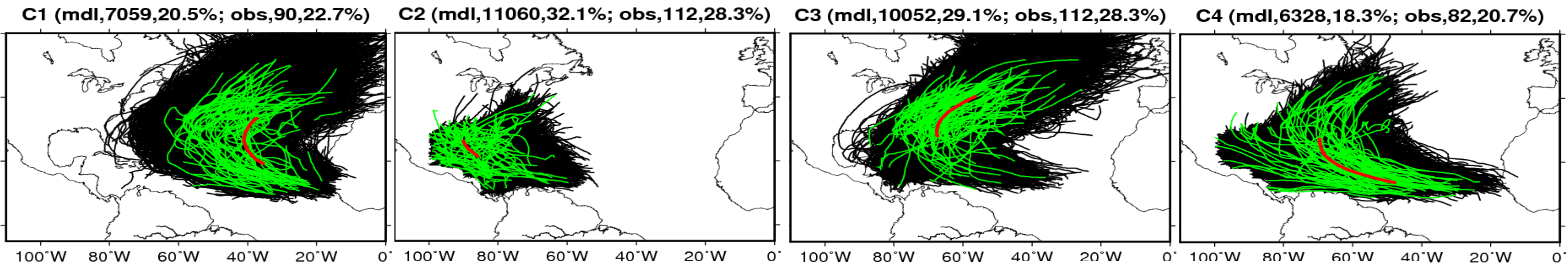


HiFLOR shows higher prediction skill than FLOR for most of the variables

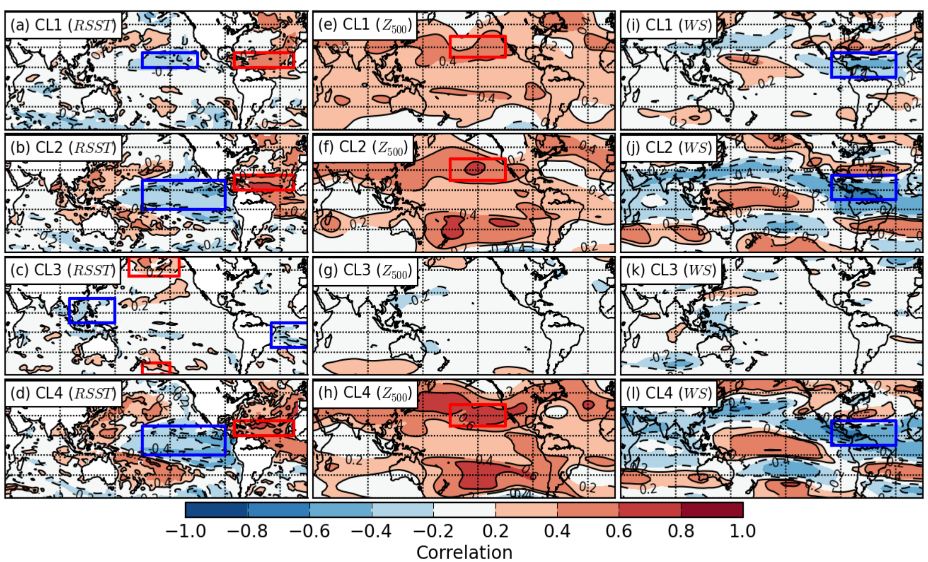
Developing Statistics-Dynamical (Hybrid) Model

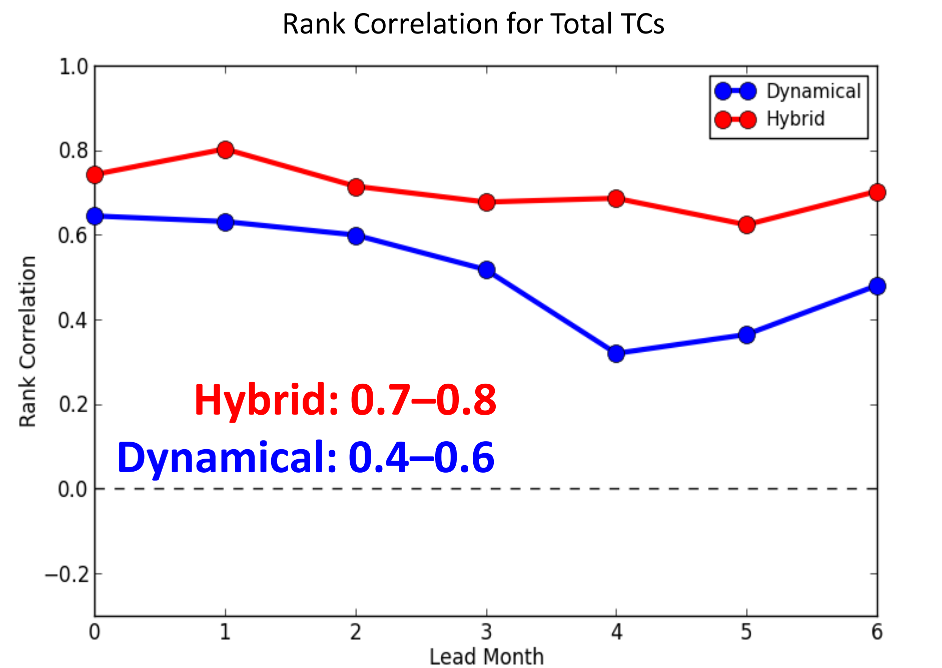
Murakami et al. (2016, MWR)

We developed a **statistical-dynamical Poisson regression model** for the better skill in predicting basin-total TC frequency as well as regional TC activity



Predictors





Statistics-Dynamical Model for Landfall Ratio

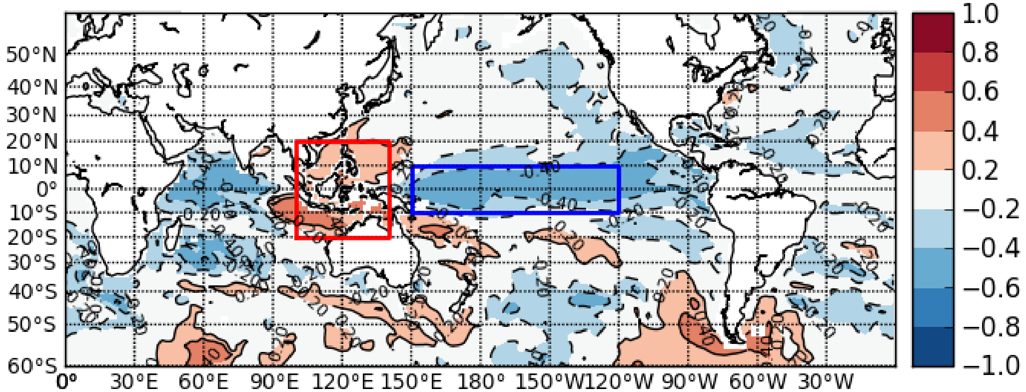
Murakami et al. (2016, MWR)

If we can predict landfall ratio# for US, we can predict landfall frequency

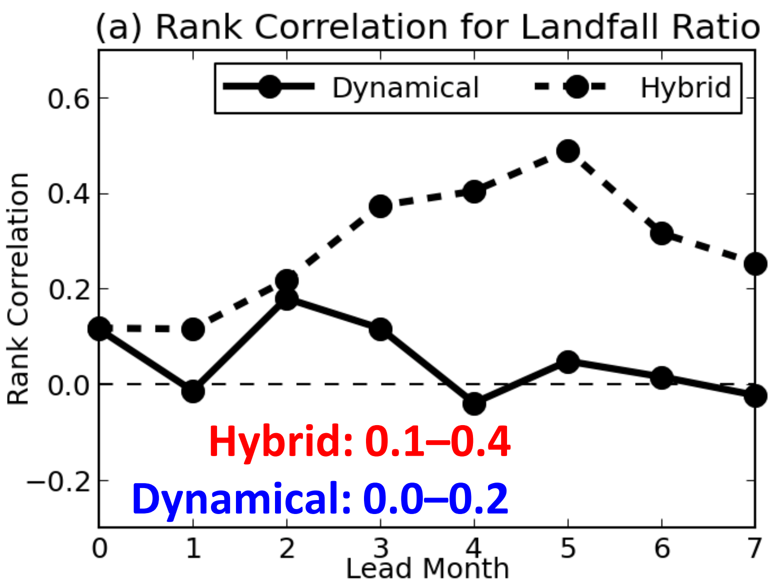
Landfall ratio = Landfall TC freq. over US / Basin-total TC freq

We also developed a **statistical-dynamical Binomial regression model** to predict landfall ratio

Predictors (SST anomaly)



Higher landfall ratio during La Nina years



Prediction score has been improved by the hybrid model, but still low.

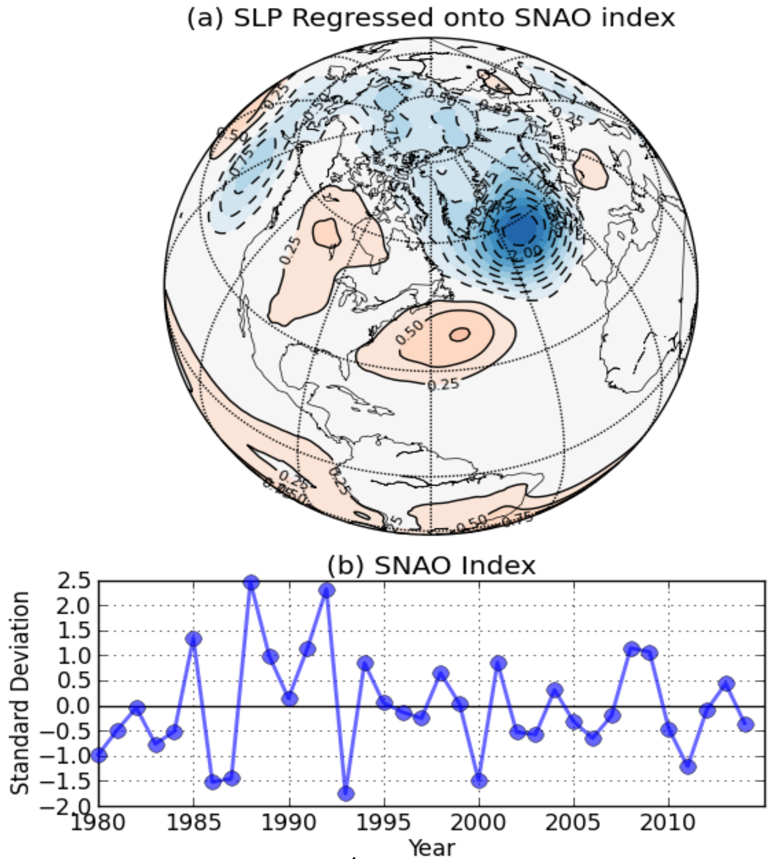
Controlling Factors for TC Landfall Ratio over US

Murakami et al. (2016, MWR)

What controls landfall ratio?

Index	Correlation (L. Ratio vs Index)
Nino-3.4 (Jul–Nov)	–0.24
AMM (Jul–Nov)	+0.07
AMO (Jul–Nov)	+0.19
NAO (May-June)	+0.12
SNAO (Jul–Aug)	+0.40

Summertime NAO (SNAO) shows the highest correlation with the landfall ratio.



SNAO is defined as the 2nd EOF mode of summertime (July–August) mean sea-level pressure over the extratropical North Atlantic (25–70°N, 70°W–50°E).

Understanding mechanism and predictability of SNAO is a key for accurate prediction of TC landfall.

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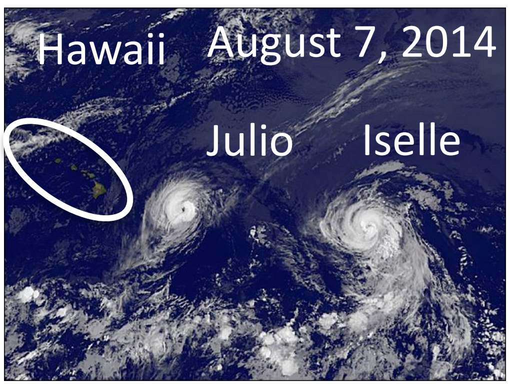
Attribution Study for Extreme TC Events

When we see a significant extreme event, season, or trend, it is natural to ask if it was caused by anthropogenic forcing or natural variability.

Using the large ensemble simulations by **FLOR**, our previous studies addressed the factor responsible for the following extreme TC seasons.

2014 active Hawaiian hurricane season

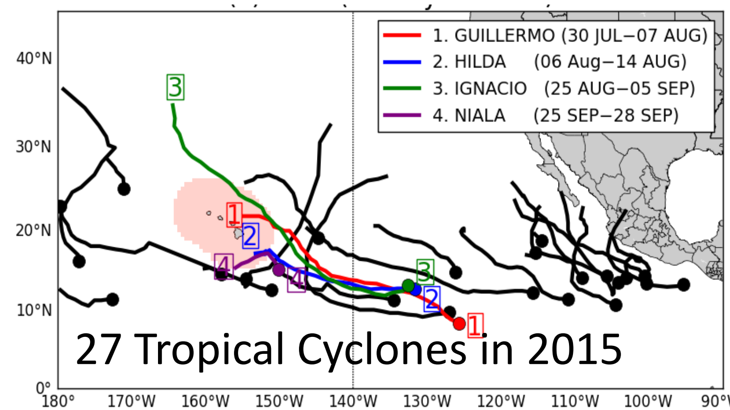


Three storms approached near Hawaii

Caused mainly by **anthropogenic forcing**, partially by **El Nino**

Murakami et al. (2015, BAMS)

2015 active eastern Pacific hurricane season



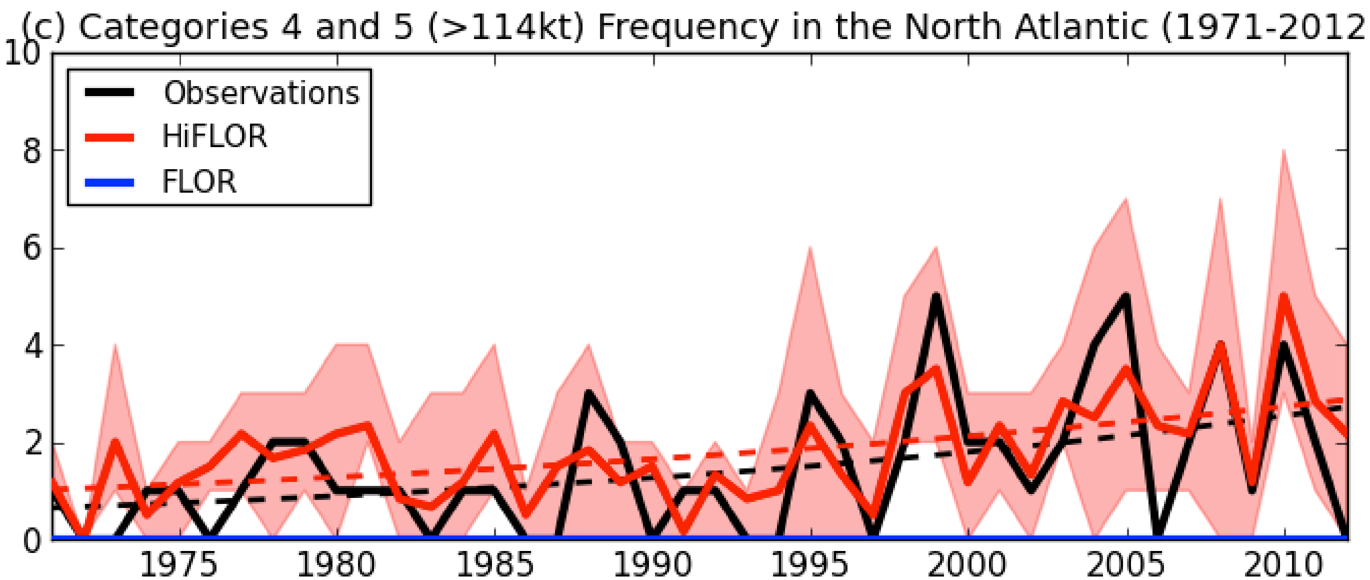
Historical record of TC number

Caused by the combined effect of **anthropogenic forcing** and positive phase of **Pacific Meridional Mode (PMM)**

Murakami et al. (2017, JC), 2016 GFDL seminar

Attribution Study for the Positive Trend in C45 Hurricanes in the North Atlantic

Murakami et al. (in prep)



Observations (black line) show a significant positive trend in the frequency of C45 hurricanes.

The cause of the trend has been disputed

Due to **global warming**

Emanuel 2005, Webster et al. 2005; Anthes et al. 2006; Hoyos et al. 2006; Mann and Emanuel 2006; Trenberth and Shea 2006; Holland and Webster 2007; Mann et al. 2007

Due to **multi-decadal variability**

Goldenberg et al. 2001; Pielke et al. 2005; Bell and Chelliar 2006

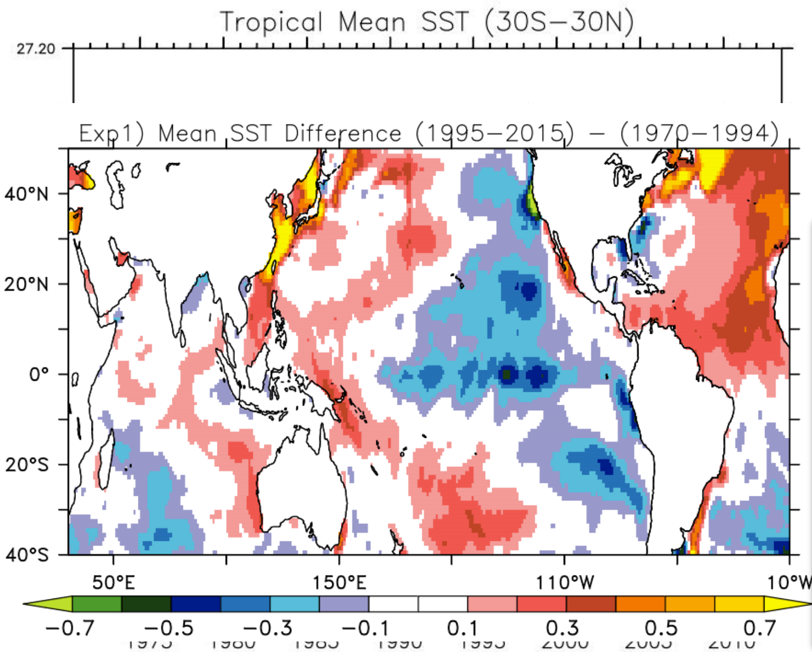
Uncertain due to limited observed record

Landsea et al. 2006; Landsea 2007

Now that HiFLOR (red line) could reproduce the observed trend of C45 hurricanes, we tried to address the cause of the trend by some idealized experiments

Attribution Study for the Positive Trend in C45 Hurricanes in the North Atlantic

Murakami et al. (in prep)

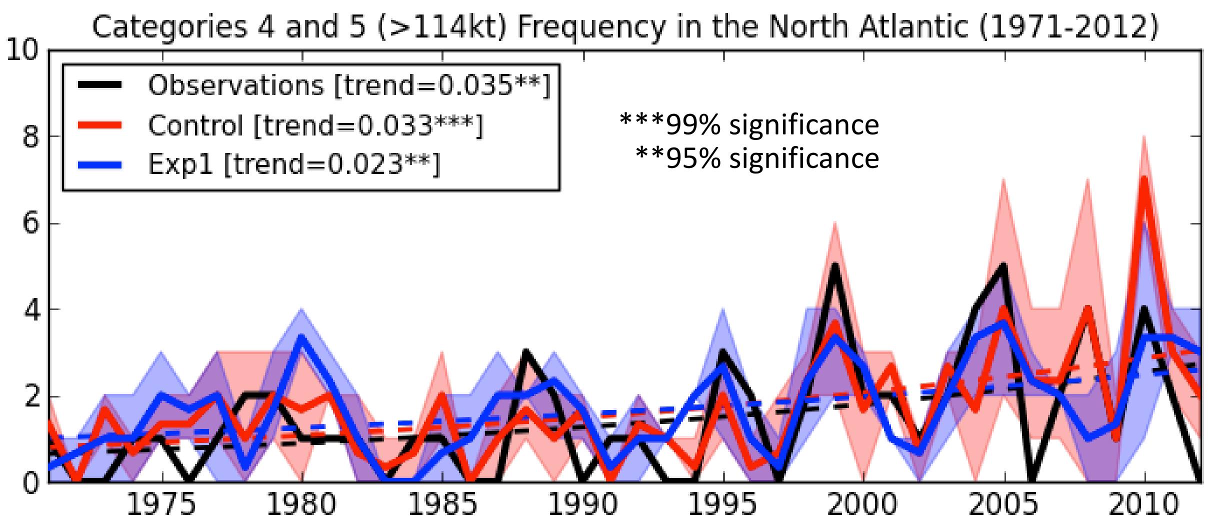


Observations show a positive trend in the tropical mean SST (30°S–30°N)

Exp1: Tropical mean anomaly is removed

(i.e., $SST(x,y,t) - \overline{SSTA_{30S\text{-}30N}}(t)$)

Anthropogenic forcing is set at the 1860 level (no time varying).

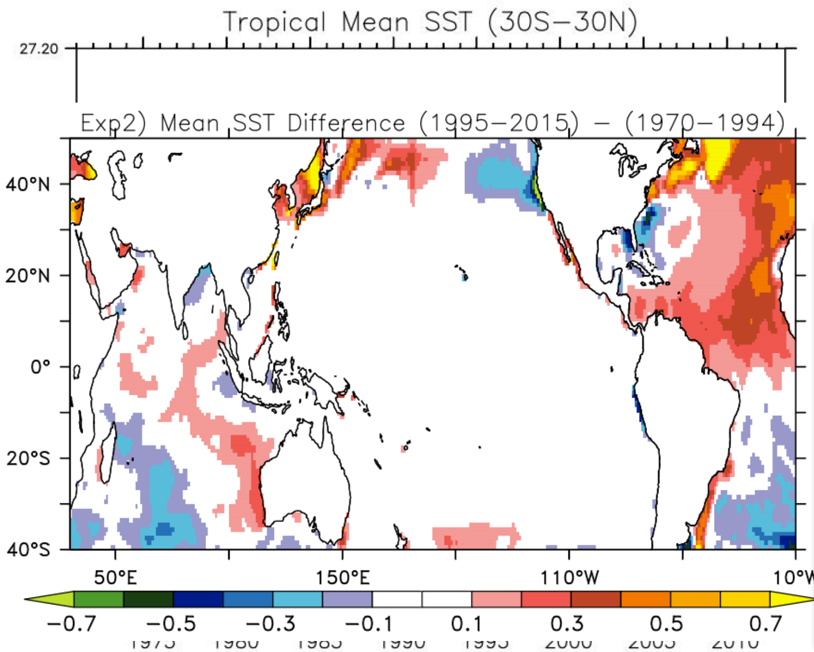


The trend is still significant.

Global warming might have not caused the positive C45 trend.

Attribution Study for the Positive Trend in C45 Hurricanes in the North Atlantic

Murakami et al. (in prep)



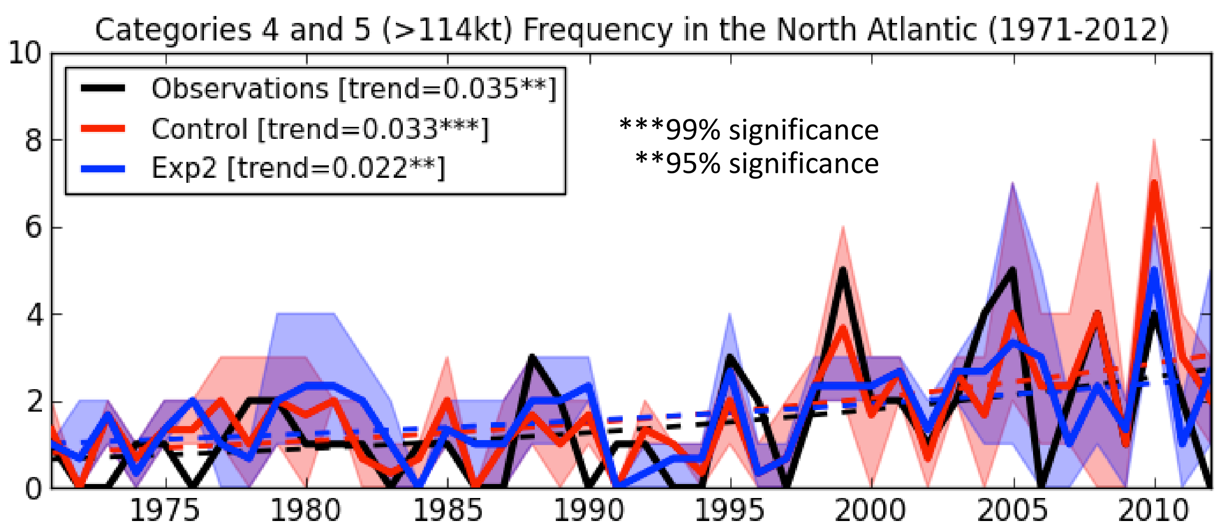
Observations show a positive trend in the tropical mean SST (30°S–30N)

Exp2: Tropical mean anomaly is removed

(i.e., $SST(x,y,t) - \overline{SSTA_{30S-30N}}(t)$)

Anthropogenic forcing is set at the 1860 level (no time varying).

Replace Pacific SST with the climatological mean

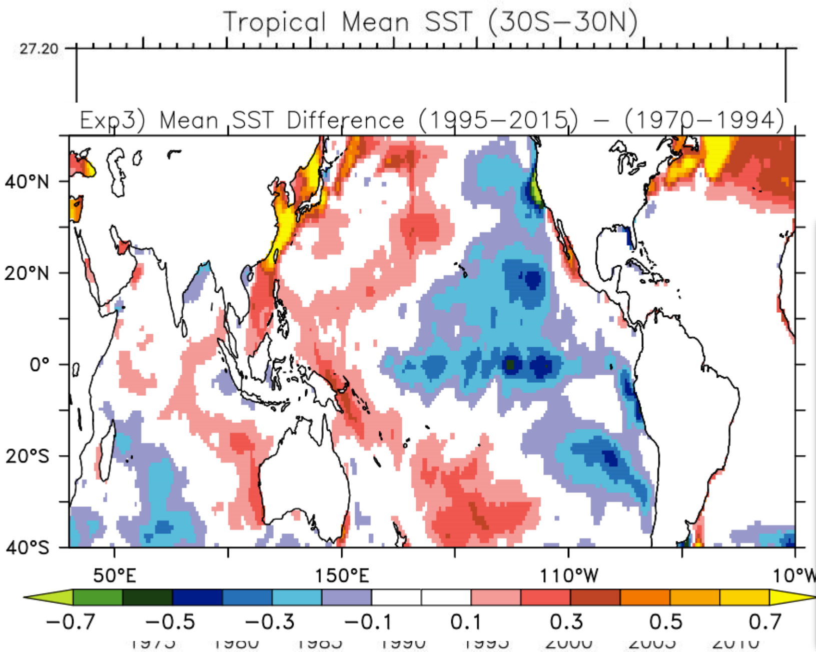


The trend is still significant.

Decadal change in Pacific does not affect the C45 trend.

Attribution Study for the Positive Trend in C45 Hurricanes in the North Atlantic

Murakami et al. (in prep)

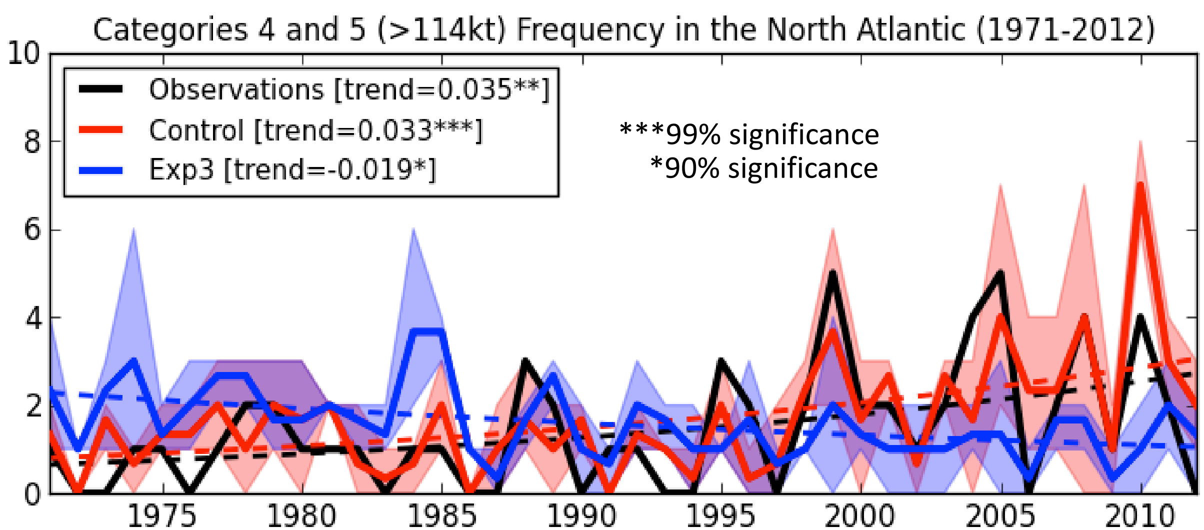


Observations show a positive trend in the tropical mean SST (30°S–30°N)

Exp3: Tropical mean anomaly is removed (i.e., $SST(x,y,t) - \overline{SSTA_{30S-30N}}(t)$)

Anthropogenic forcing is set at the 1860 level (no time varying).

Replace Atlantic SST with the climatological mean



The trend become negative.

Decadal change in tropical Atlantic does affect the C45 trend.

Summary (1/2)

HiFLOR Model Evaluation

- HiFLOR can simulate C45 hurricanes as observed
- Both HiFLOR and FLOR reasonably simulate TC structure, cold-wakes, MJO, and modulation of TC genesis by MJO

Seasonal Prediction of Tropical Cyclones

- HiFLOR has potential to predict C45 hurricanes a few months (or a half year) in advance
- Frequency of basin-total TCs frequency and landfall TC frequency can be improved through the statistical-dynamical model
- Prediction of SNAO is a key to improve landfall prediction

Summary (2/2)

Attribution Study of Tropical Cyclones

- The positive trend in C45 hurricanes in the North Atlantic was due to natural decadal variability such as AMO, but not due to the anthropogenic forcing

Possible Future Works

- Improving seasonal prediction of landfall TC

  Model Development (both dynamical and hybrid), Atmospheric Initialization

- Event attribution (What caused Hurricane Sandy, Katrina, etc?)

End

Special thanks to the v-group members!