Seasonal Forecasts of Category 4 and 5 Hurricanes and Landfalling Tropical Cyclones using a high-resolution GFDL Coupled Climate Model

Hiroyuki Murakami, Gabriel A. Vecchi, Gabriele Villarini, Thomas L. Delworth, Richard Gudgel, Seth Underwood, Xiaosong Yang, and Wei Zhang, and Shian-Jiann Lin

GFDL/Princeton AOS

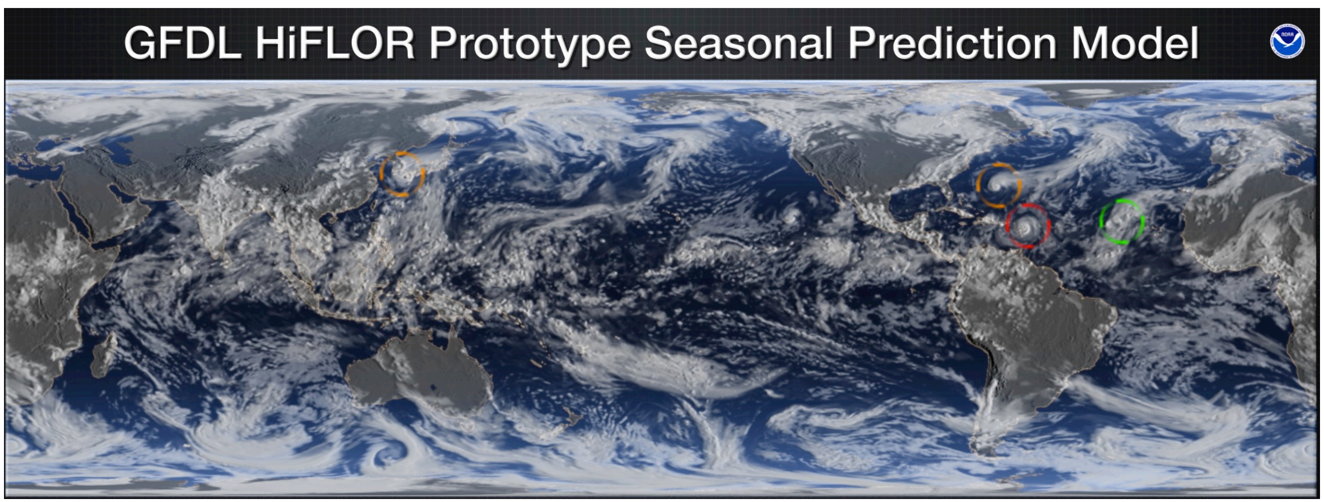
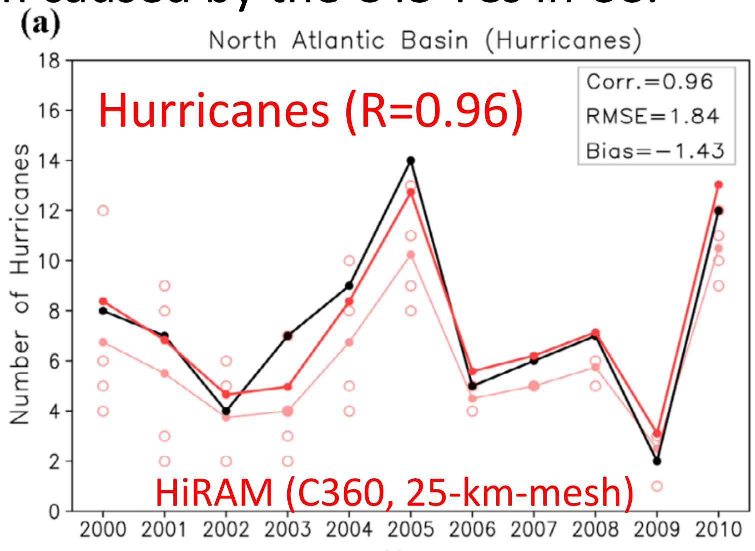


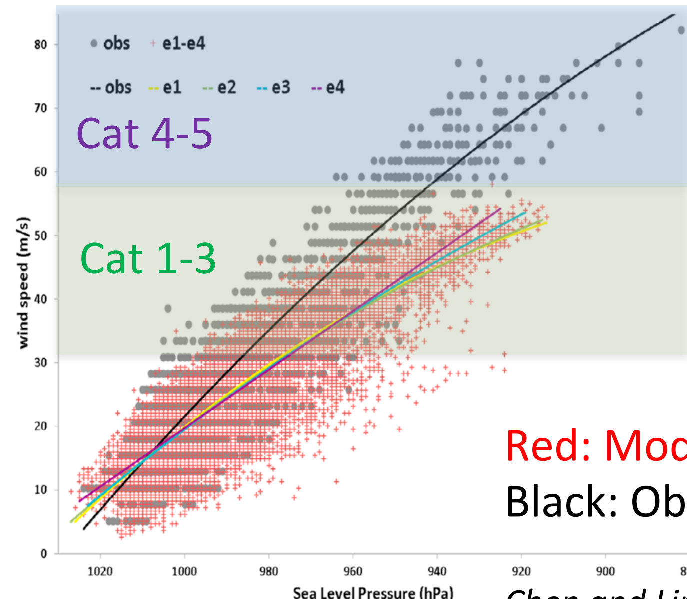
Fig: Clouds from a HiFLOR simulation, showing three hurricanes in the Atlantic and one in West Pacific. (Figure Remik Ziemlinski) Animation available here: http://www.gfdl.noaa.gov/video/hiflor_flat_v7_aug-dec.mp4

Remained Issues for Seasonal Forecast of Tropical Cyclones (TCs)

1. Prediction of the most intense TCs (e.g., Category 4-5) at seasonal timescale is challenging, but important given the fact that **85%** of total TC damage has been caused by the C45 TCs in US.



Chen and Lin (GRL, 2011)



Chen and Lin (GRL, 2011)

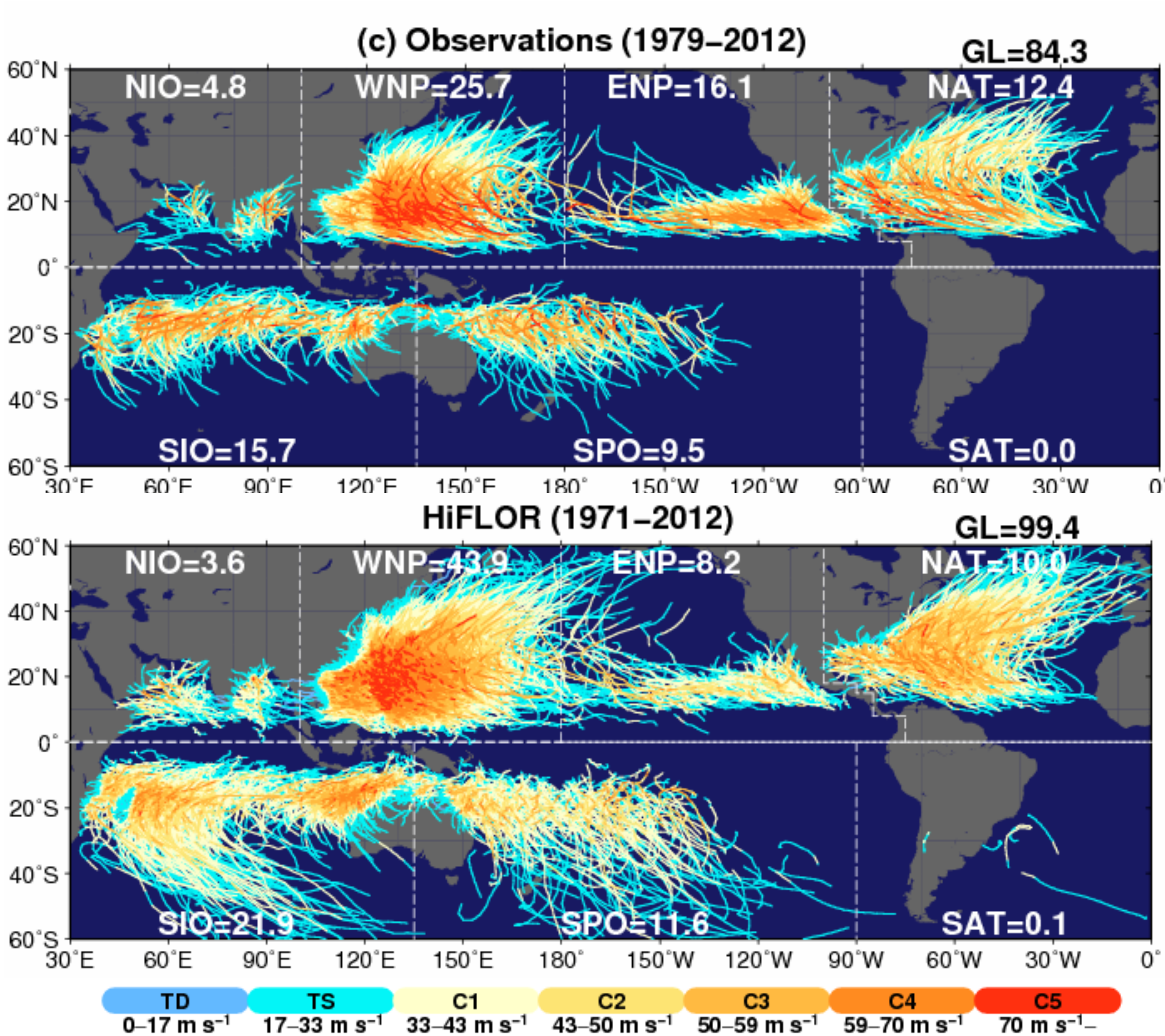
2. Seasonal prediction of landfalling TCs is still challenging.

Authors	Model	Lead Month	Correlation between observed vs predicted landfalling TCs
Elsner et al. (2006)	Statistical	6	+0.35 (over US)
Kim et al. (2015)	Statistical-Dynamical	1	+0.56 (over New York State)
Yan et al. (2015)	Statistical	1	+0.60 (over US)
Murakami et al. (2016)	Statistical-Dynamical	2-5	+0.50 (over US)

GFDL Coupled Models (FLOR and HiFLOR)

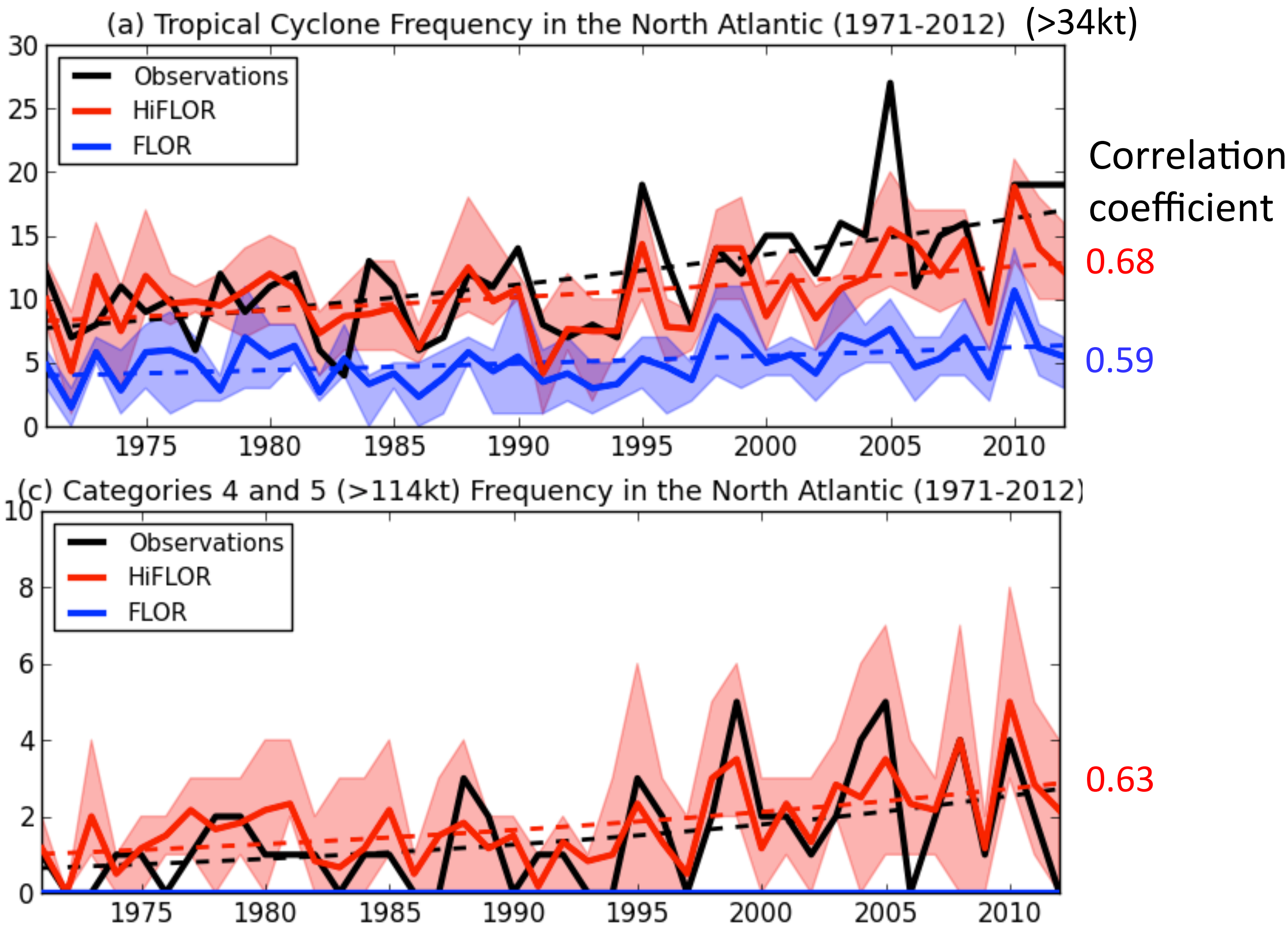
	FLOR	HiFLOR
Atmosphere	AM2.5 (Atmosphere model of CM2.5)	
Ocean	MOM4 (Ocean model of CM2.1)	
Resolution	Atmosphere : **50 km**, L32 Ocean: 100 km, L50	Atmosphere : **25 km**, L32 Ocean: 100 km, L50
Dynamics	Hydrostatic, finite difference Dynamical core (Mesinger et al. 1988) with higher-order advection scheme	
Convection	Relaxed Arakawa-Schubert (RAS, Moorthi and Suarez 1992)	
Radiation	Freidenreich and Ramaswamy (1999) Every 3 hour.	
Land Surface	Land Dynamics model (LM3; Milly et al. 2014)	
Minor Changes	"Cubed-sphere" grid (Lin 2004; Putman and Lin 2007)	C384 Dynamics (CM4 base): terrine filter.
Simulation Speed	**16-yr simulation per day** using 4000 CPUs	**4-yr simulation per day** using 6000 CPUs

Improved Simulation of Tropical Cyclones



Historical Experiment: SST is restored to observed monthly data at 10-day time scale.

Interannual Variation of Tropical Storms and Cat 4-5 hurricanes in the North Atlantic



It is for the first time that a global coupled model reproduces observed interannual variation of C4-5 hurricanes.

Motivation and Methodology

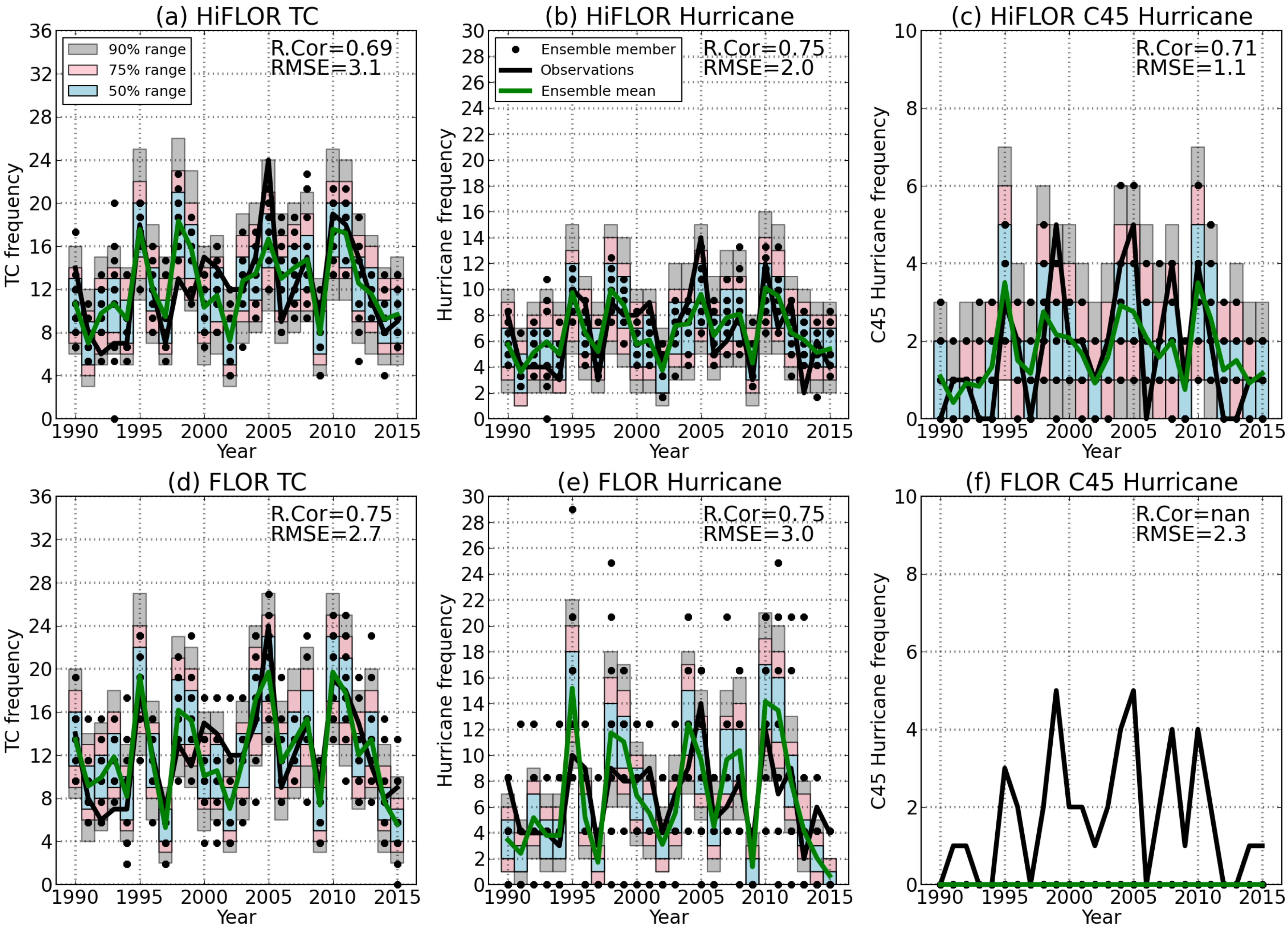
Motivation

Evaluating retrospective seasonal prediction of TCs (especially for landfalling and C45 TCs in the North Atlantic) by HiFLOR

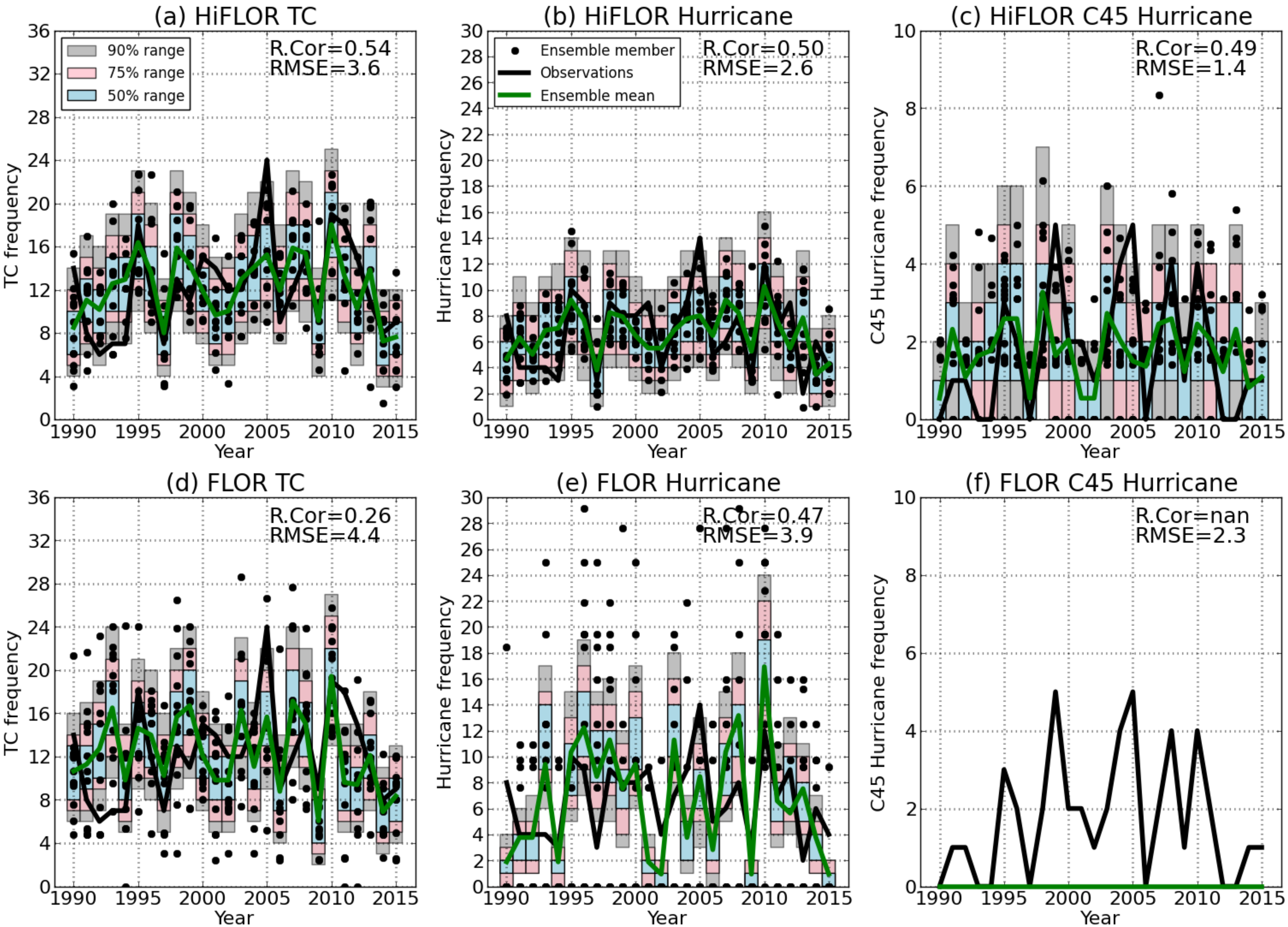
Methodology

Models	HiFLOR and FLOR
Period	1990–2015, mainly focus on TC prediction for July–November
Initial	July (Leal Month=0), April (Lead Month=3), and January (Lead Month=6) #Ocean is initialized using the Ensemble KF. Atmosphere is not initialized (derived from AMIP). 12 Ensemble Member
Observations	IBTrACS (1990–2014) and Unisis (2015) for TC data, JRA-55 reanalysis (1990–2015) for atmospheric data, HadISST (1990–2015) for SST data
Storm Category	TC (Tropical Storms, ≥34kt or ≥17m/s), HUR (Hurricanes, ≥64kt or ≥33m/s), C45 (Category 4 and 5 Hurricanes, ≥ 113kt or ≥58m/s)
Storm Detection	HiFLOR (WS≥17.50 m/s, Warm Core≥2.0K, Duration≥36 hours), FLOR (WS≥15.75 m/s, Warm Core≥1.0K, Duration≥36 hours)
Skill Score	Correlation, Root-mean-square-error (RMSE), Mean-square-skill-score (MSSS)

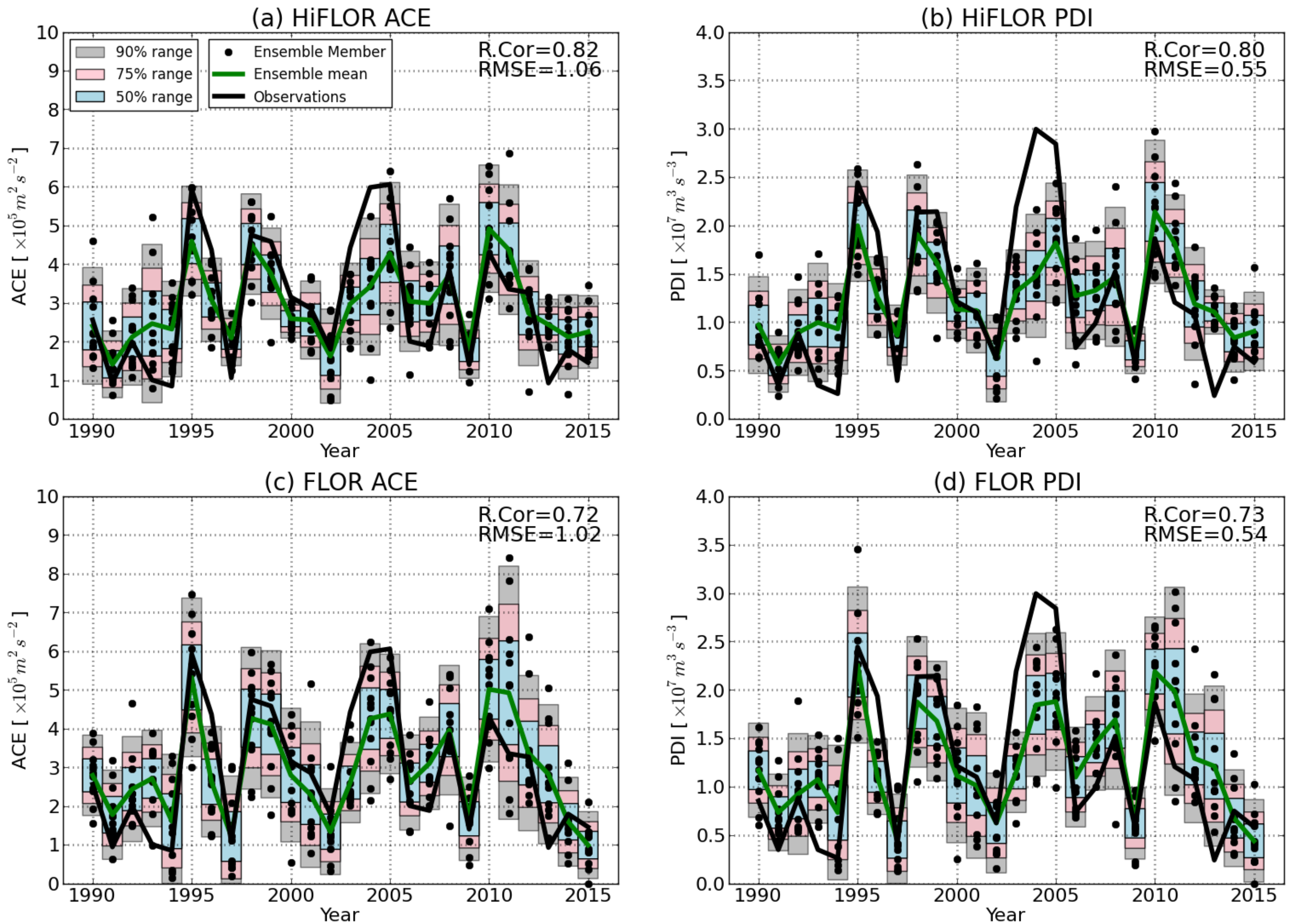
Skill in Retrospective TC Prediction for Each Intensity Category (North Atlantic, July Initial Forecast (L0))



Skill in Retrospective TC Prediction for Each Intensity Category (North Atlantic, April Initial Forecast (L3))



Skill in Retrospective TC Prediction for ACE and PDI (North Atlantic, April Initial Forecast (L0))

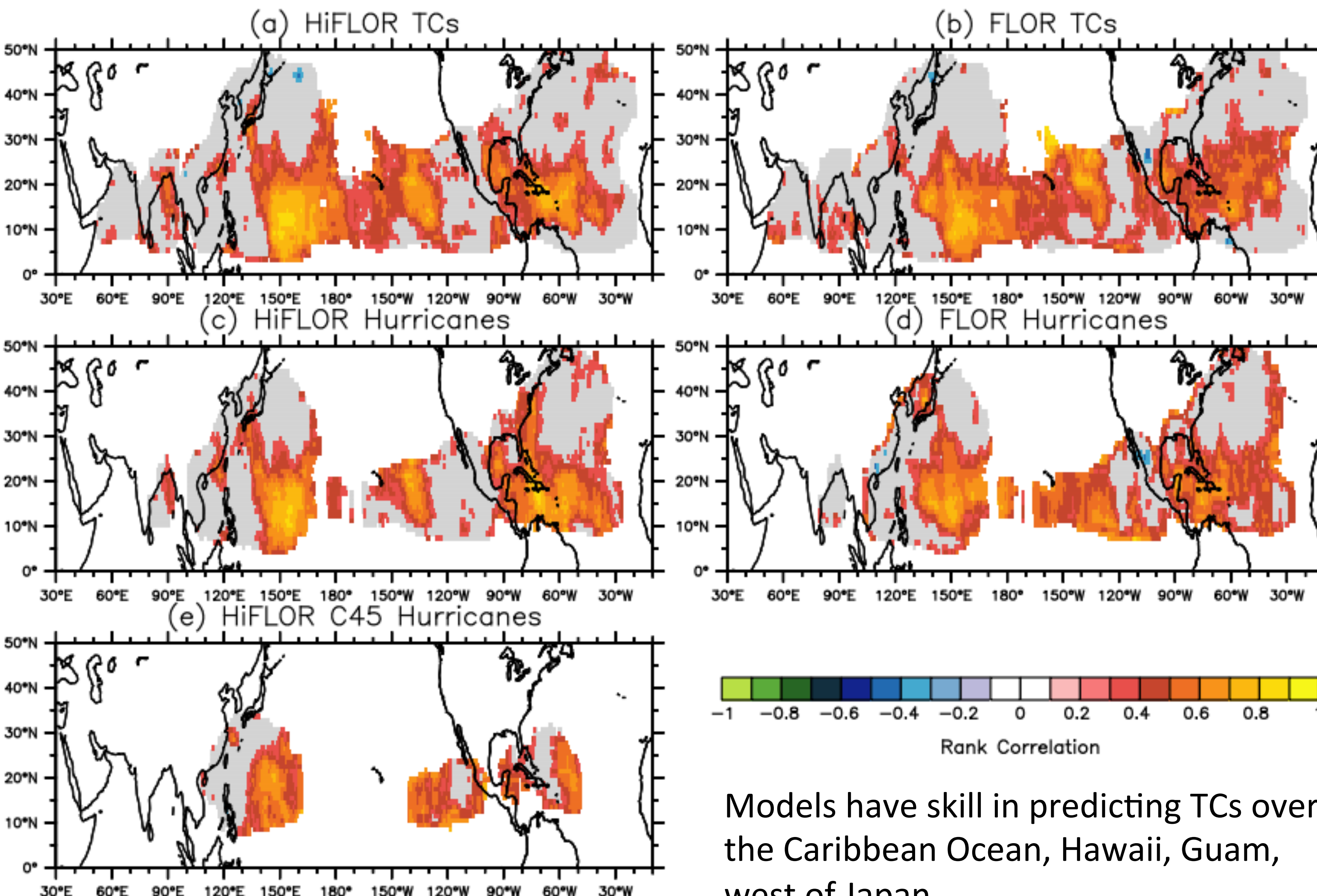


ACE (PDI) is defined as an integrated quantity of square (cube) of maximum surface wind velocity throughout the lifetime of tropical cyclones.

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

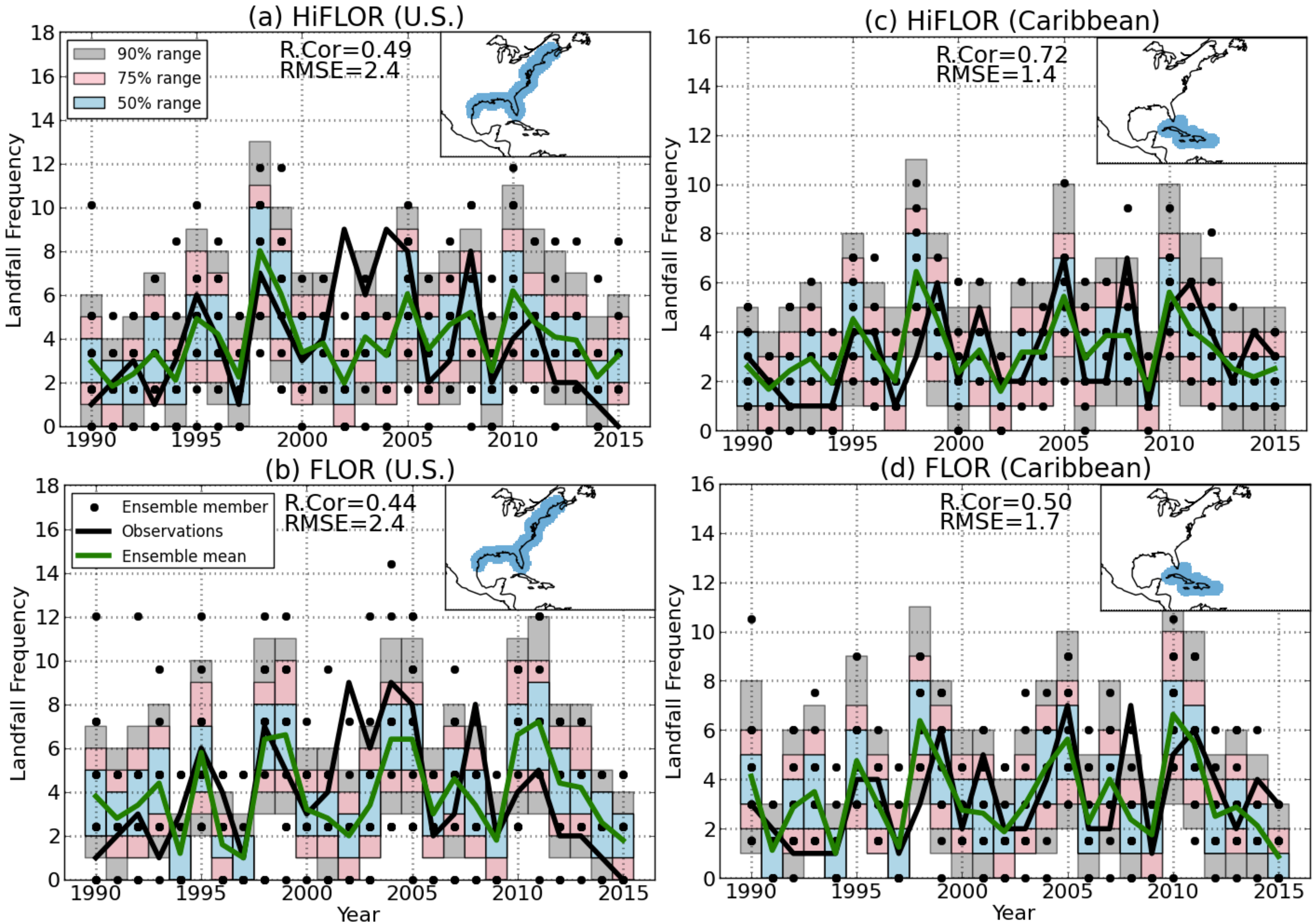
N: Total TC genesis number
T : Life span for each TC

Locations where the models have skill in predicting TC frequency (July Initial (L0))



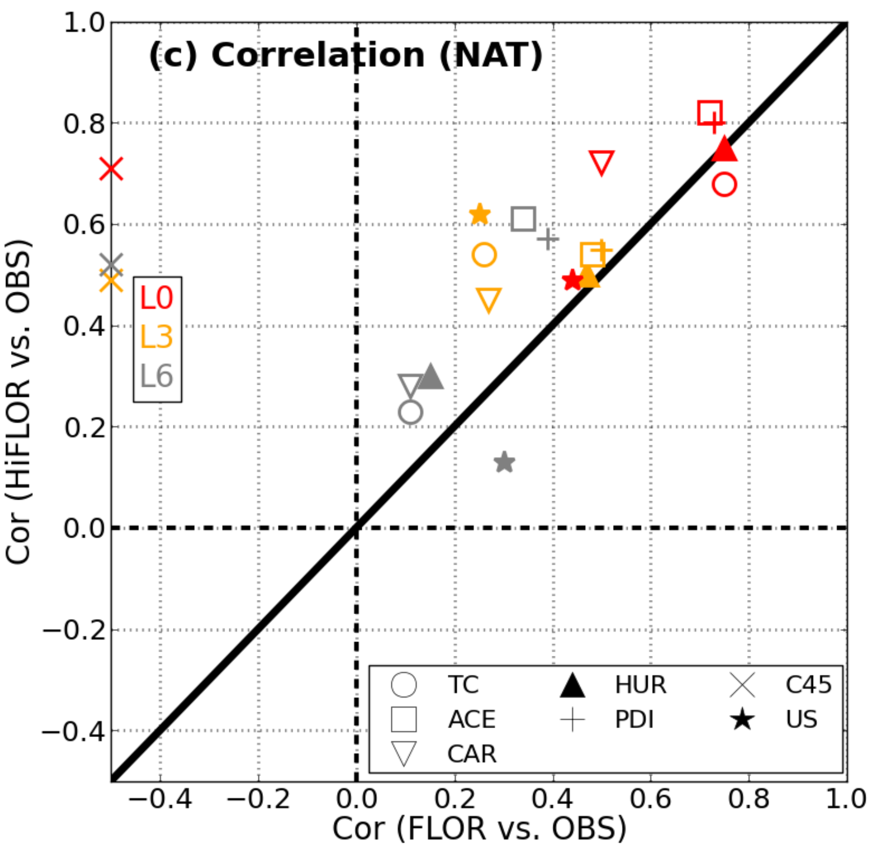
Models have skill in predicting TCs over the Caribbean Ocean, Hawaii, Guam, west of Japan.

Skill in Retrospective Landfalling TC Prediction (July Initial Forecast (L0))



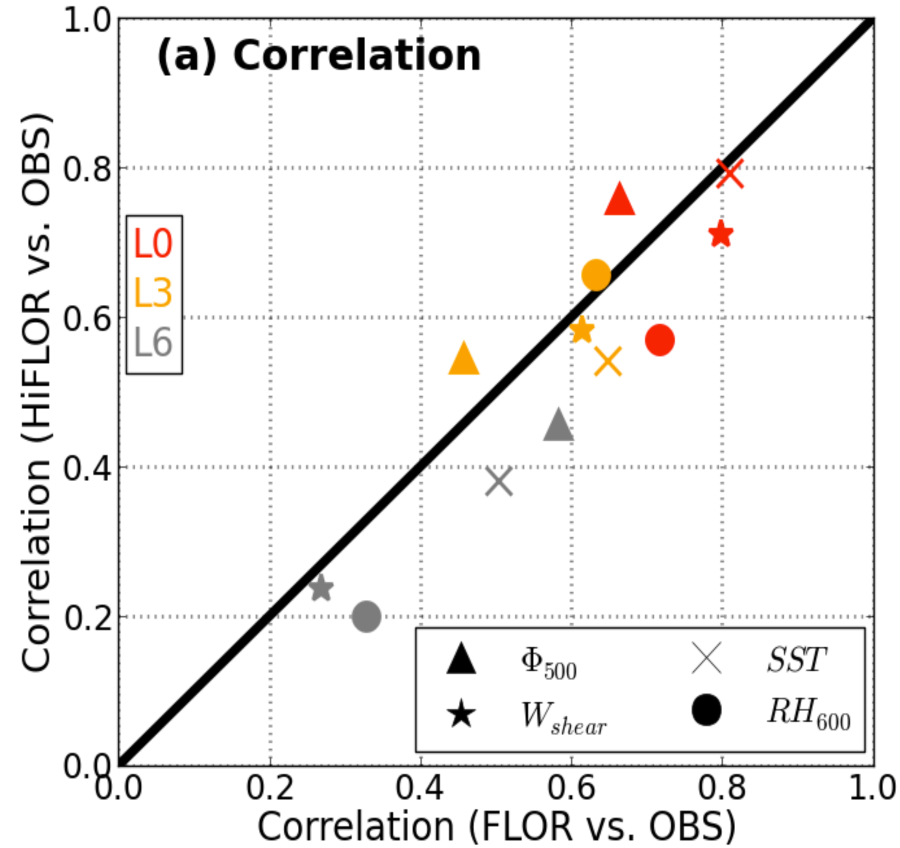
Comparison of Prediction Skill between HiFLOR and FLOR

TC Activity



HiFLOR is better than FLOR

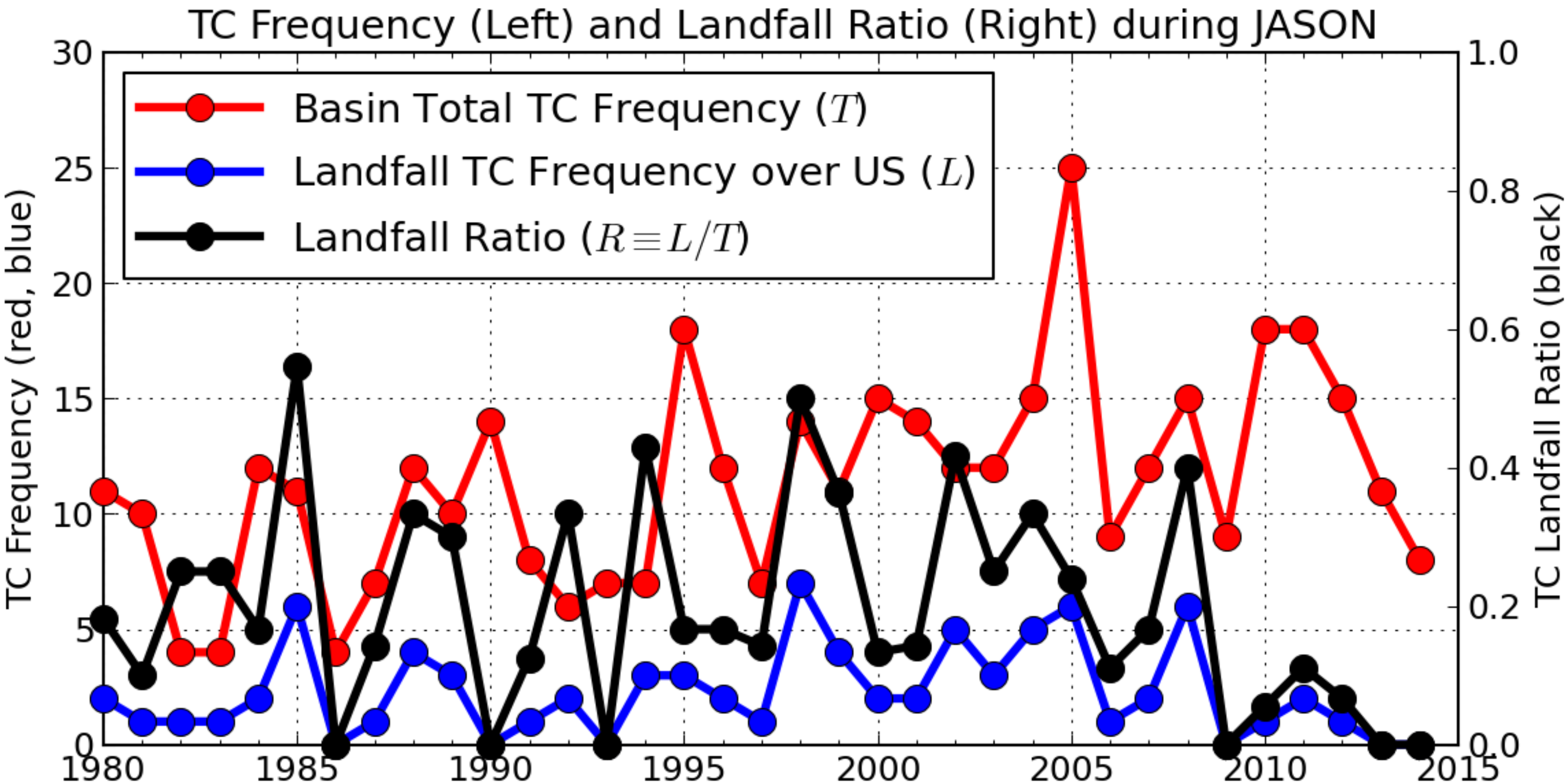
Key Large-scale Parameters



HiFLOR and FLOR are comparable

Better prediction of TC activity by HiFLOR than FLOR is not caused by the better representation of large-scale parameters, but by the better representation of TCs themselves given the same large-scale conditions through an increase in the horizontal resolution.

Observed Landfall Ratio over US



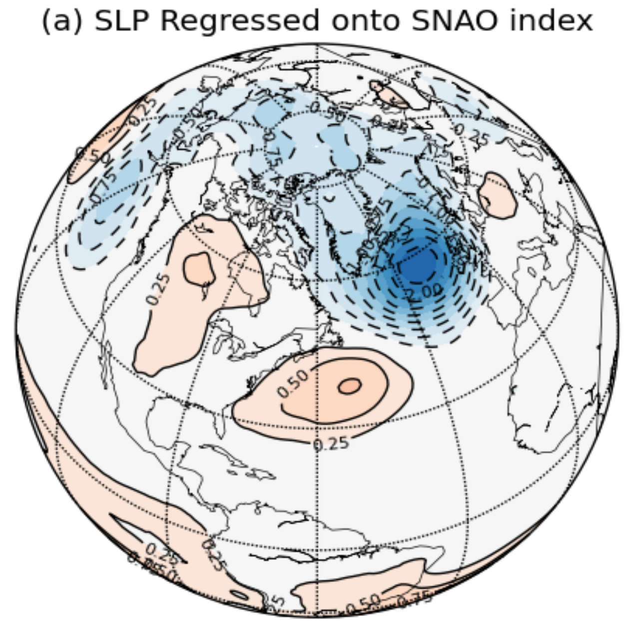
Correlation between R and T is **0.07**.

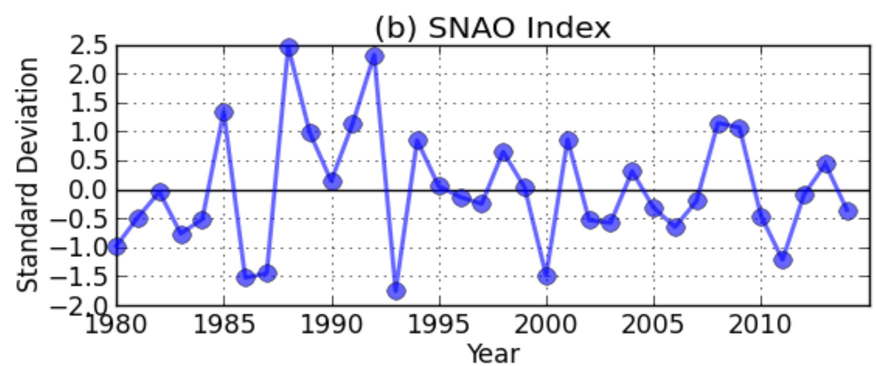
Landfall ratio is irrelevant to the basin total TC frequency.

What Controls Observed Landfall Ratio?

Index	Correlation (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 observed landfall ratio.

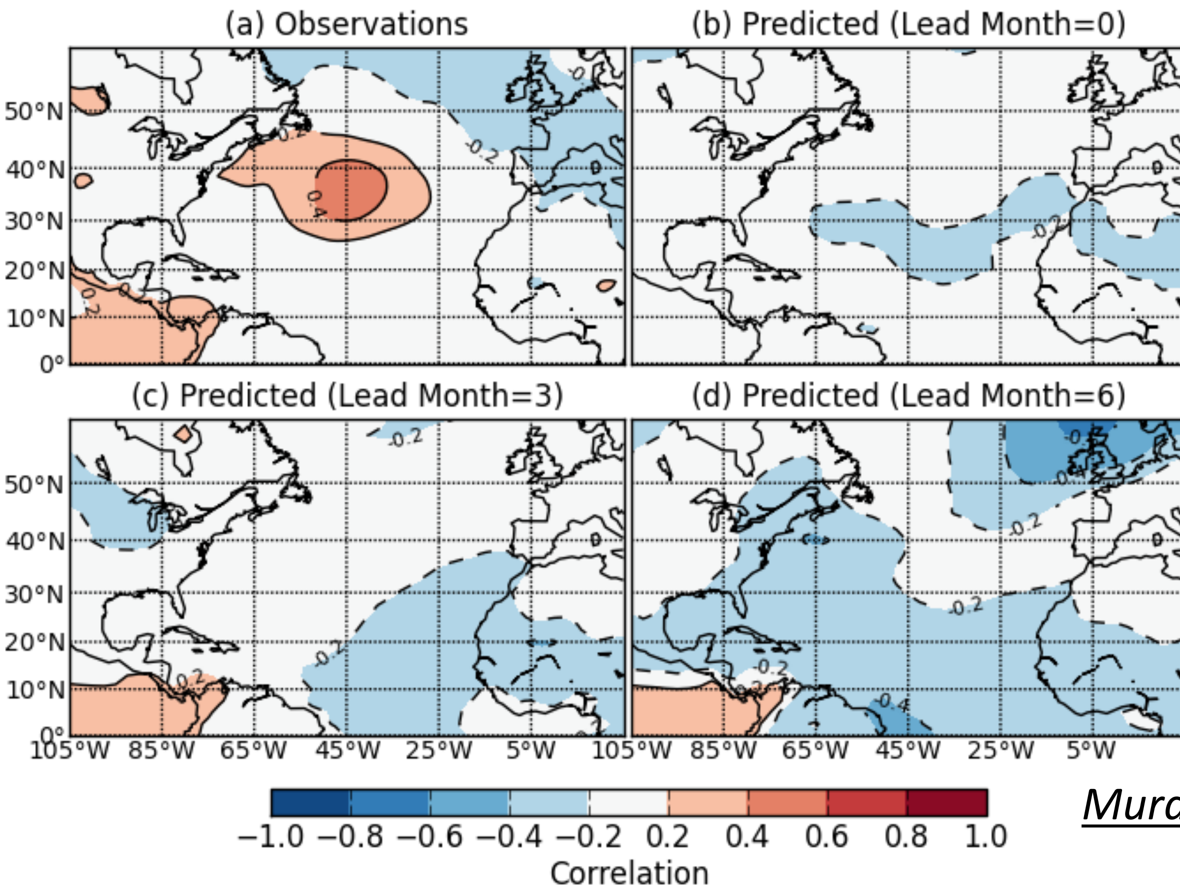




SNAO is defined as the 2nd EOF mode of summertime (July–August) mean sea-level pressure over the extratropical North Atlantic (25–70N, 70W–50E).

Murakami et al. (MWR, in press)

No Skill in SNAO Prediction



Correlation map between observed mean TC landfall ratio over US during July–November and observed/predicted mean SLP anomalies during July–August.

Murakami et al. (MWR, in press)

Models have no skill in predicting SNAO.

Understanding the mechanism of SNAO and improvement of SNAO prediction is required.

Summary

- HiFLOR can skilfully predict year-to-year variations in the **intense hurricanes of C45** in the Atlantic a few months in advance (**r=0.7** for forecasts on 1-July, with July-November being peak hurricane season).

- The high-resolution predictions exhibited significant skill in predicting landfalling TCs in the **Caribbean (r=0.7) and Continental United States (r=0.5)**.

- Improvements in seasonal TC prediction between FLOR and HiFLOR principally due to improved simulation of TCs and the TC response to large-scale climate drivers from increased atmospheric resolution.

- Summertime NAO is a key factor for the landfall TC prediction over US.