

EXPERIMENTAL S-I HURRICANE FORECASTS FROM WINTER

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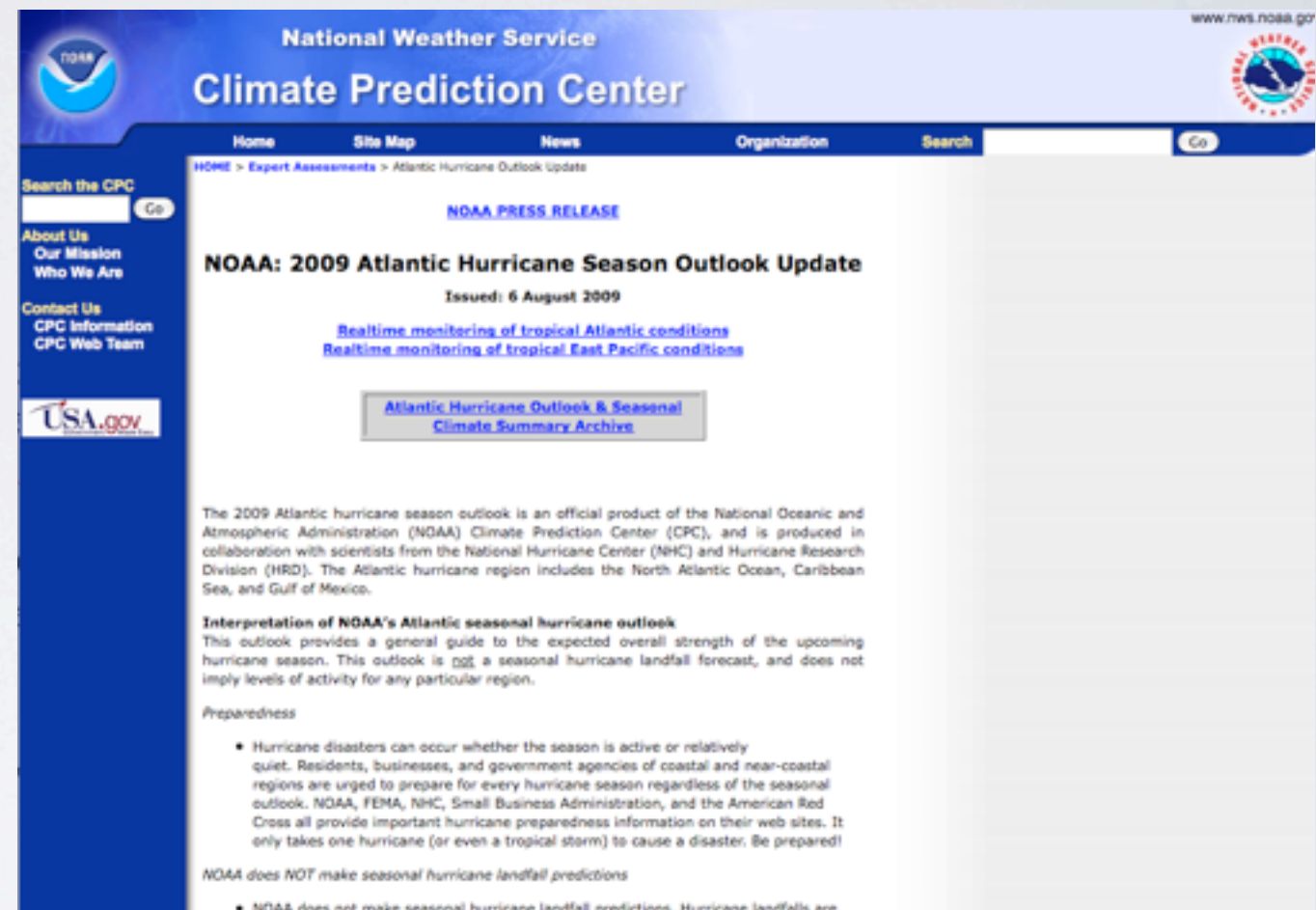
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SEASONAL HURRICANE FORECASTS INITIALIZED IN BOREAL MID-SPRING TO EARLY-SUMMER ARE: FEASIBLE, POTENTIALLY SKILLFUL AND MADE

- Statistical prediction schemes (e.g., Gray, Klotzbach and Gray, Elsner et al)
- Dynamical prediction schemes (e.g., Vitart , Vitart et al)
- Hybrid schemes (e.g., Wang et al, LaRow et al, Zhao et al)



The screenshot shows the NOAA Climate Prediction Center website. The header includes the NOAA logo, the text "National Weather Service Climate Prediction Center", and navigation links for Home, Site Map, News, Organization, and Search. A search bar is also present. The main content area features a "NOAA PRESS RELEASE" section titled "NOAA: 2009 Atlantic Hurricane Season Outlook Update", issued on 6 August 2009. Below the title are links for "Realtime monitoring of tropical Atlantic conditions" and "Realtime monitoring of tropical East Pacific conditions". A button labeled "Atlantic Hurricane Outlook & Seasonal Climate Summary Archive" is also visible. The text below the button states: "The 2009 Atlantic hurricane season outlook is an official product of the National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center (CPC), and is produced in collaboration with scientists from the National Hurricane Center (NHC) and Hurricane Research Division (HRD). The Atlantic hurricane region includes the North Atlantic Ocean, Caribbean Sea, and Gulf of Mexico." It also includes a section for "Preparedness" with a bullet point: "Hurricane disasters can occur whether the season is active or relatively quiet. Residents, businesses, and government agencies of coastal and near-coastal regions are urged to prepare for every hurricane season regardless of the seasonal outlook. NOAA, FEMA, NHC, Small Business Administration, and the American Red Cross all provide important hurricane preparedness information on their web sites. It only takes one hurricane (or even a tropical storm) to cause a disaster. Be prepared!" and a note: "NOAA does NOT make seasonal hurricane landfall predictions".

GOAL:

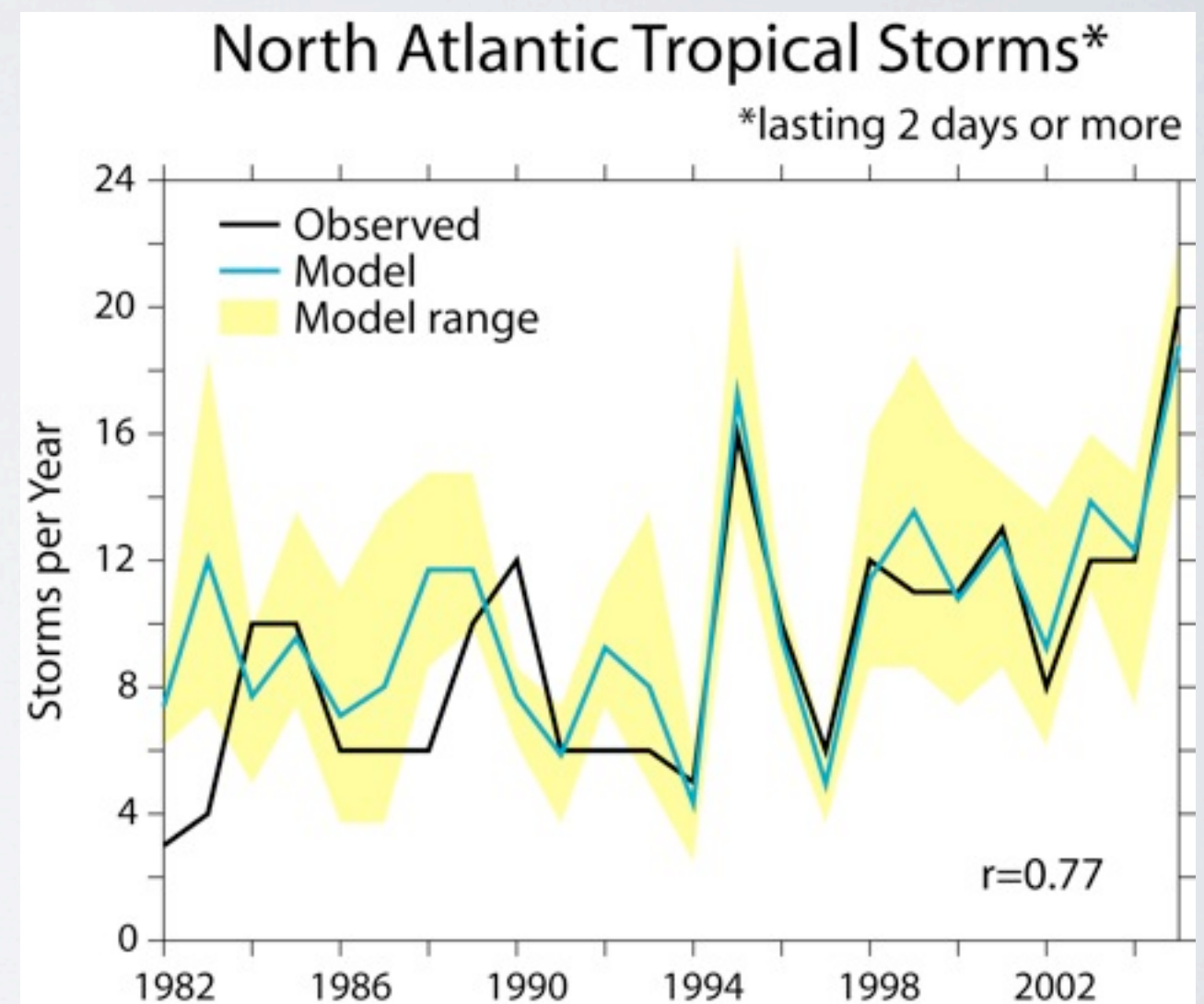
USE UNDERSTANDING AND TOOLS
DEVELOPED FOR EXPLORING THE LINK OF
CLIMATE CHANGE AND HURRICANES TO PUSH
WINDOW OF NORTH ATLANTIC **SEASONAL**
HURRICANE FORECASTS TO **WINTER**, WITH
SKILL AND QUANTIFIED UNCERTAINTY

GFDL C-X HIRAM GCMS

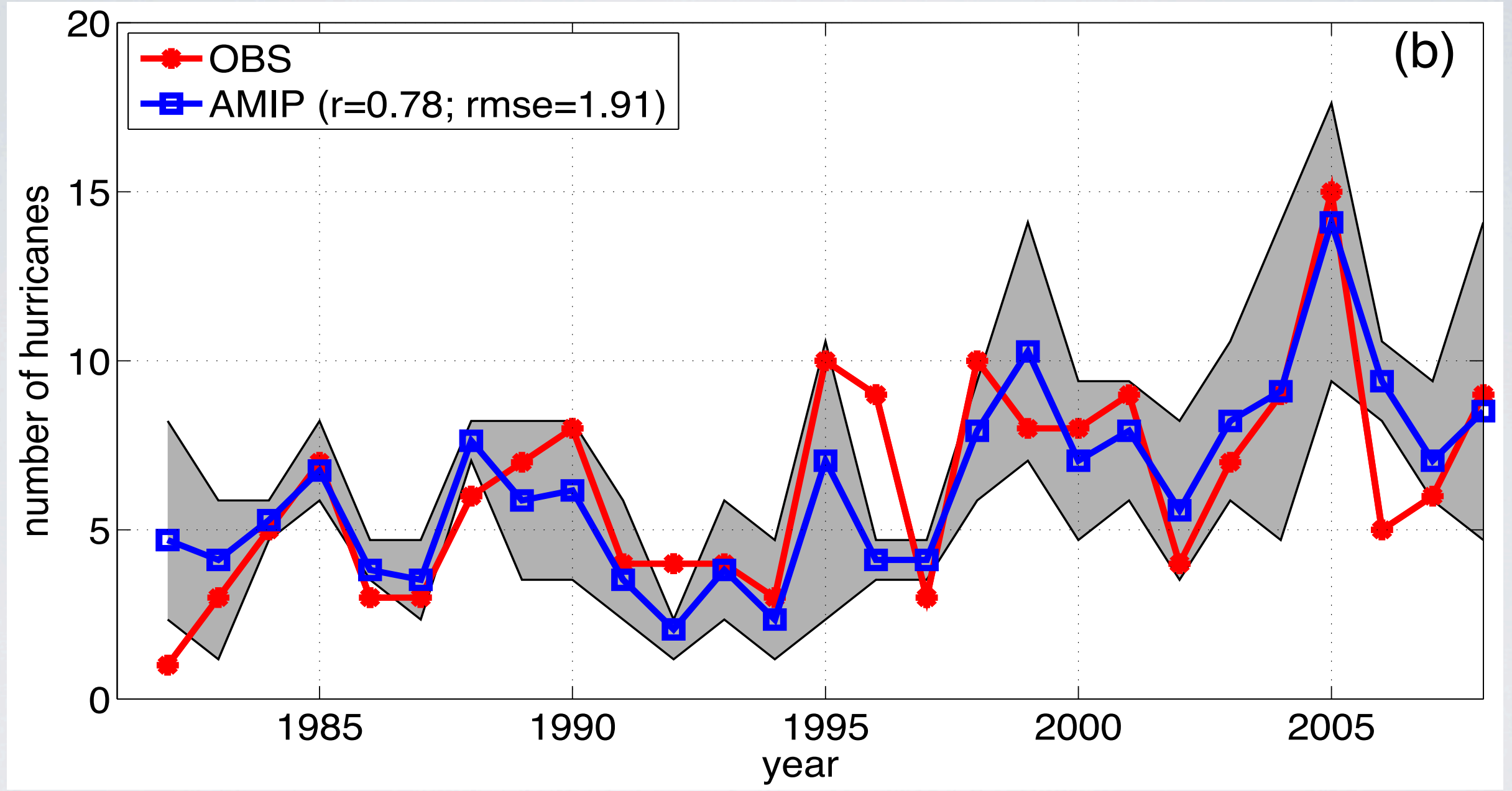
Family of global atmospheric models designed for better-representing tropical cyclone frequency. **C90 - 1°**, **C180=1/2°**, C360=1/4°, C720=1/8°, C2000=5km
Ref. Zhao et al (2009, J. Climate; 2010, MWR)

Adapted from AM2 with:

- Deep convection scheme adapted from Bretherton, McCaa and Grenier (MWR, 2004)
- Cubed sphere dynamical core
- Changes to parameterizations of cloud microphysics
- C90 Atm. resolution of 1°x1°

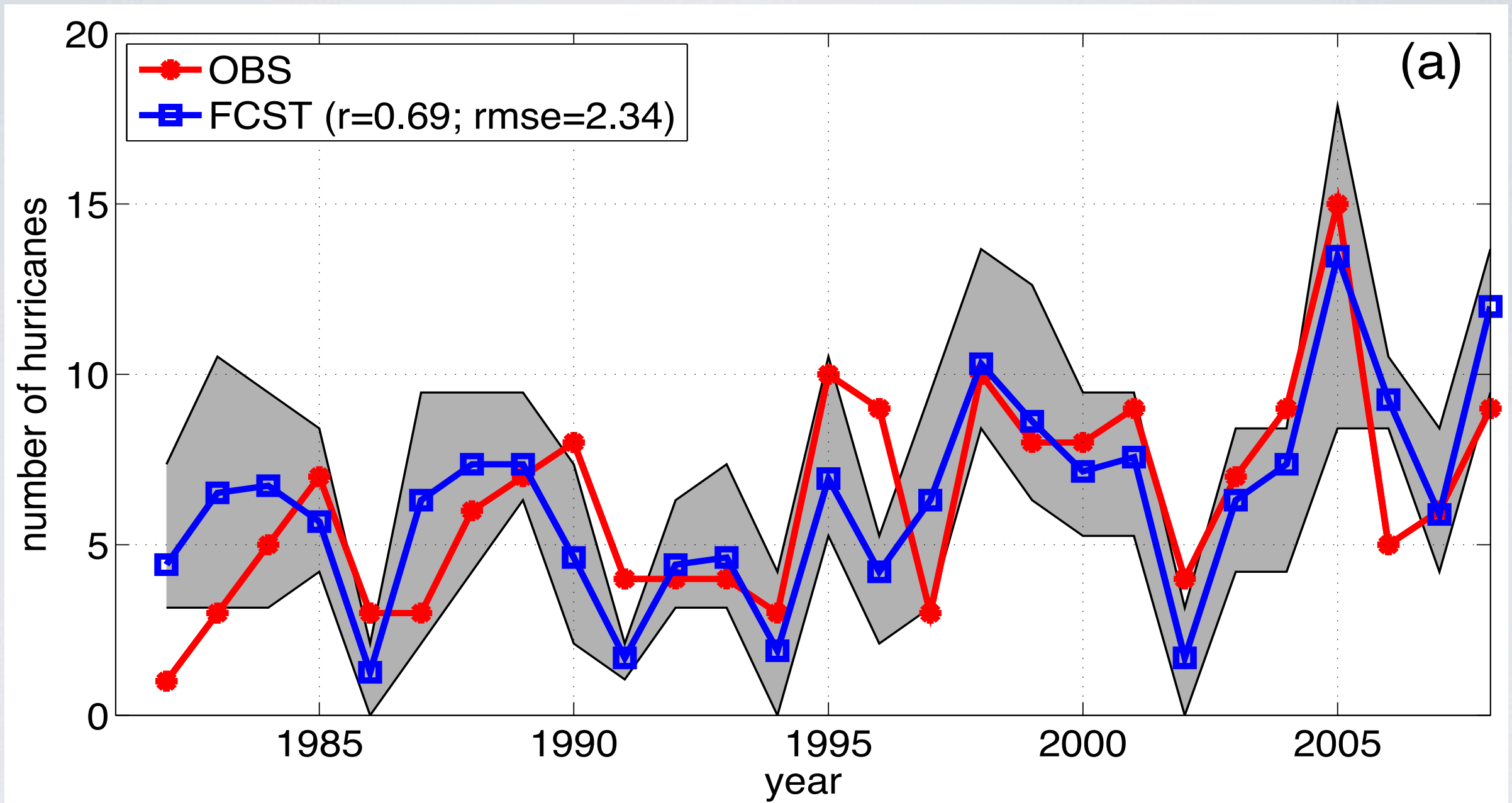


HIRAM C180 AGCM FORCED WITH SSTs RECOVERS NA HURRICANE COUNTS



Zhao et al. (2009, J. Climate), Zhao et al. (2010, MWR, Sub.)

WITH PERSISTED JUNE SST ANOMALIES (RETROSPECTIVE JULY FCST.), HIRAM C180 AGCM RECOVERS NA HURRICANE COUNTS



Can we extend lead by forecasting SST?

Zhao et al. (2010, MWR, Sub.)

COST OF RUNNING THOUSANDS OF RETROSPECTIVE FORECASTS WITH HIRAM-CI80 IS PROHIBITIVE.

NEED TO BUILD A STATISTICAL EMULATOR OF THE AGCM.

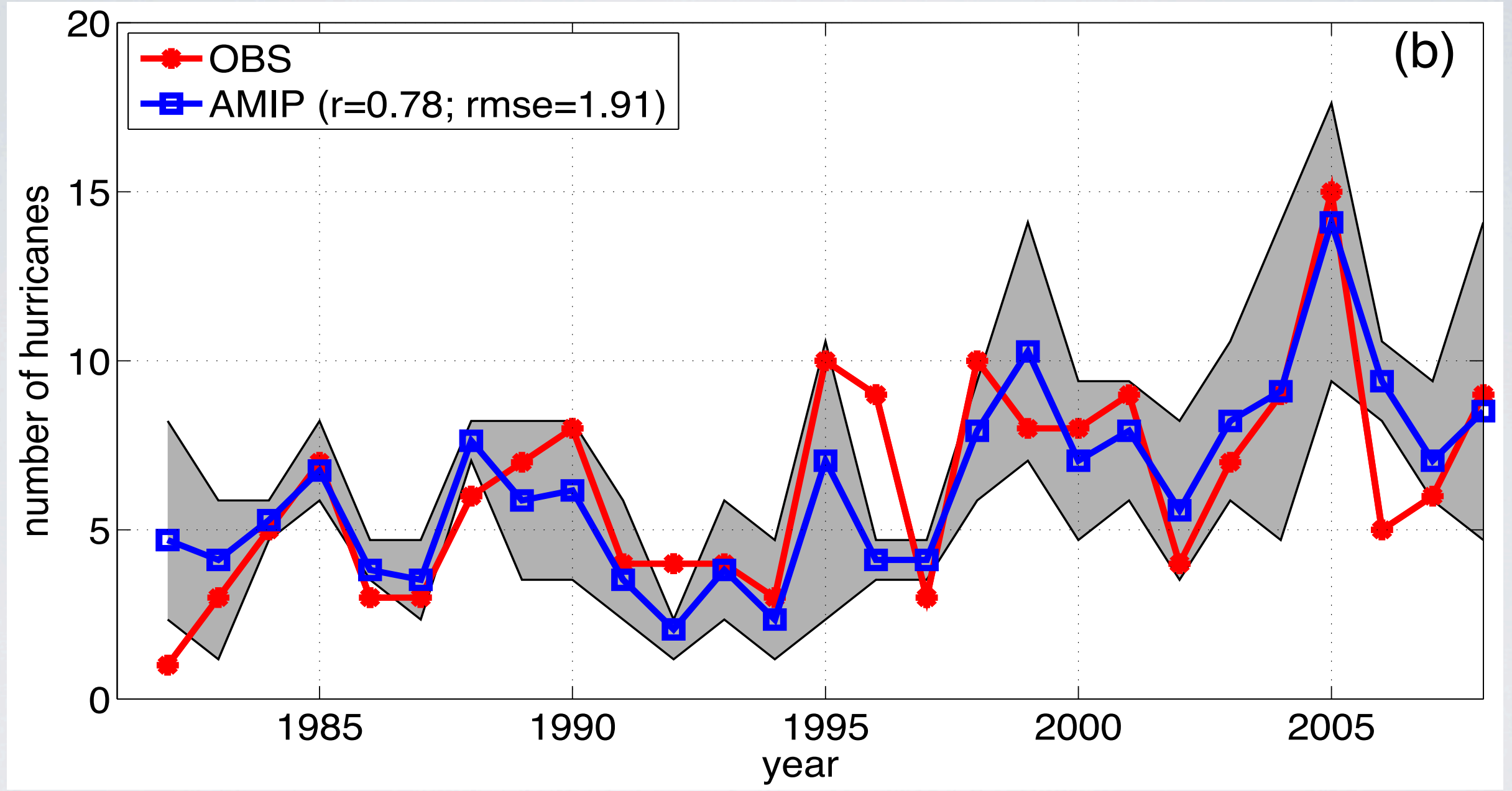
SO: WHAT IS A GOOD PREDICTOR OF HURRICANE FREQUENCY?

CATCH: IT SHOULD BE PREDICTABLE ITSELF.

HIRAM-CI80 (AND OTHER HI-RES GCMs),
SENSITIVITY OF LARGE-SCALE CONDITIONS,
ANALYSES OF LONG-TERM OBSERVATIONS SUGGEST TWO
PREDICTORS:

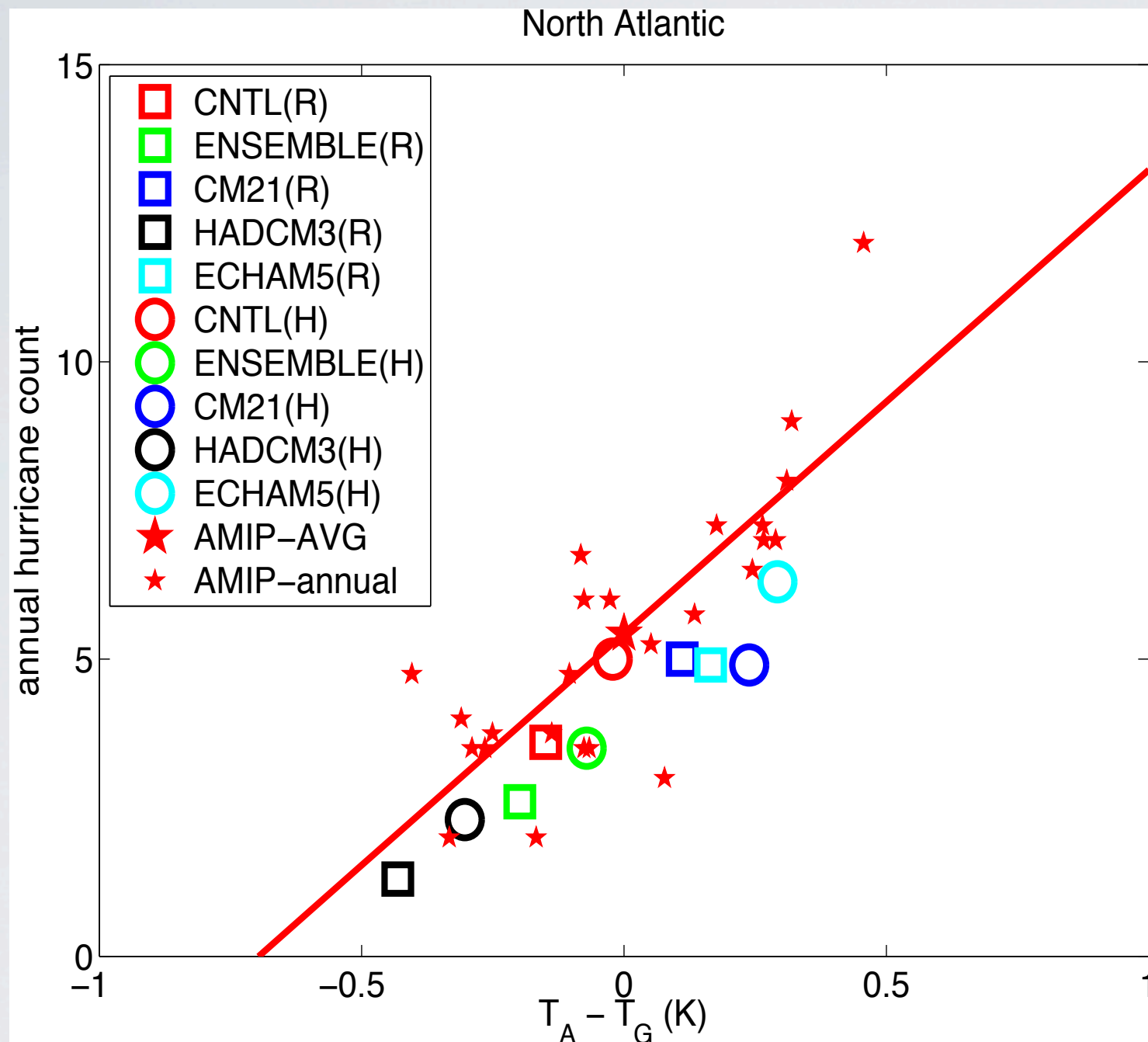
ATLANTIC SST AND **GLOBAL-TROPICAL SST**

HIRAM C180 AGCM FORCED WITH SSTs RECOVERS NA HURRICANE COUNTS



Zhao et al. (2009, J. Climate), Zhao et al. (2010, MWR, Sub.)

HIRAM C I 80 (AND OBSERVATIONS + CONTROLS TO LARGE-SCALE) SUGGEST **RELATIVE SSTA** AS A PREDICTOR



Relative SSTA =
Atlantic SSTA minus
Tropical SSTA

Zhao et al. (2009, J. Climate), Zhao et al. (2010, MWR, Sub.)

&

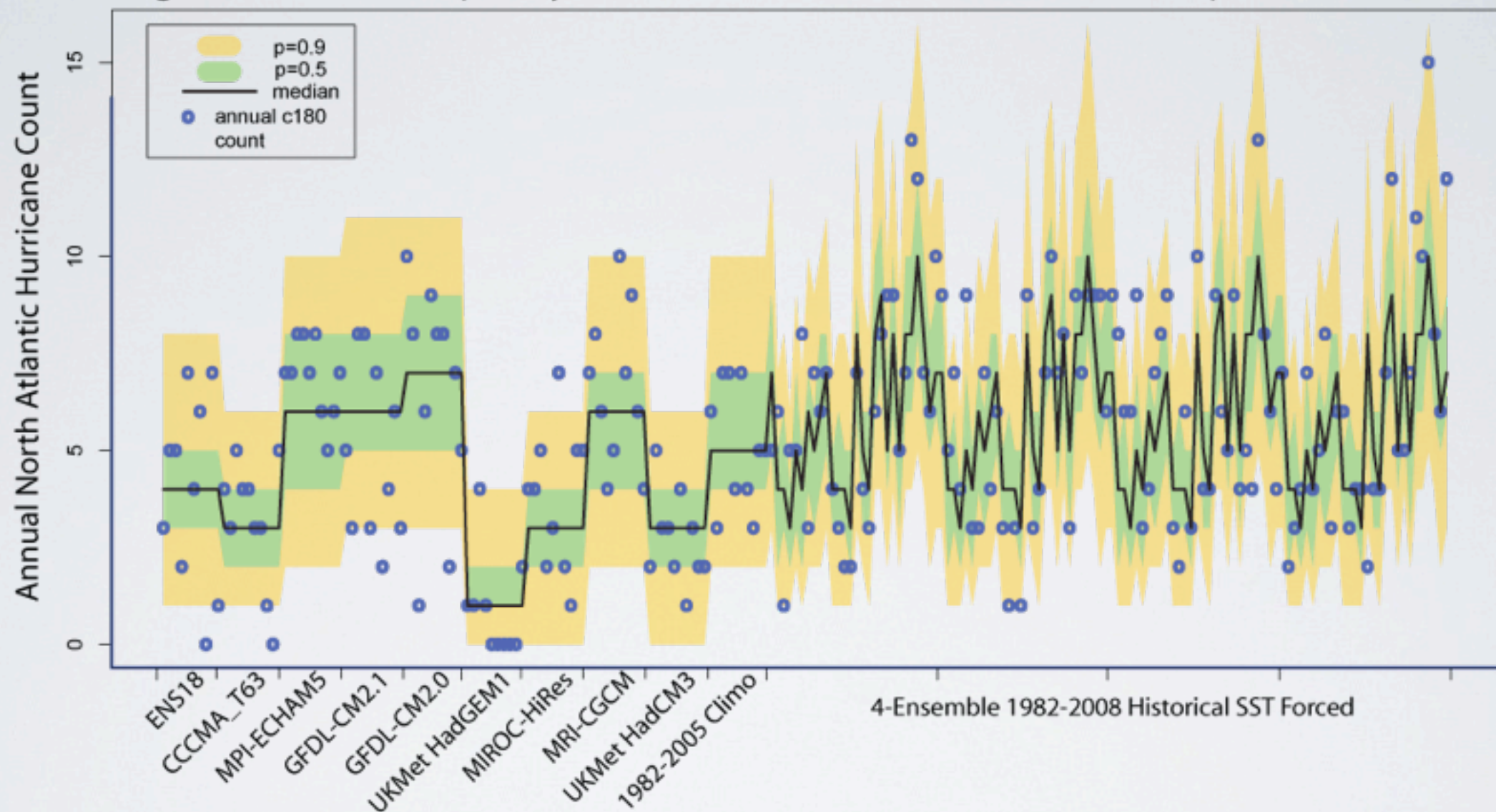
Latif et al (2007, GRL), Vecchi and Soden (2007, Nature), Knutson et al (2008, Nature Geosci.), Swanson (2008, G3), Vecchi et al (2008, Science), Villarini et al (2010, MWR, in press)

SEASONAL HURRICANE FREQUENCY FORECAST SCHEME

- Build a statistical emulator of HiRAM-C I 80, two predictors:
 - SST_{MDR} (SST anomaly $80^{\circ}W-20^{\circ}W$, $10^{\circ}N-25^{\circ}N$)
 - SST_{TROP} (SST anomaly $30^{\circ}S-30^{\circ}N$)
- Use S-I forecast models to predict two indices
- Convolve PDF of SST forecasts with PDF from statistical model.

BUILD A STATISTICAL EMULATOR OF C180-HIRAM USING ASO ATLANTIC MDR AND TROPICAL-MEAN SSTA (POISSON)

Training of Hurricane Frequency Statistical Model Fit on HiRAM C180 Experiment Years



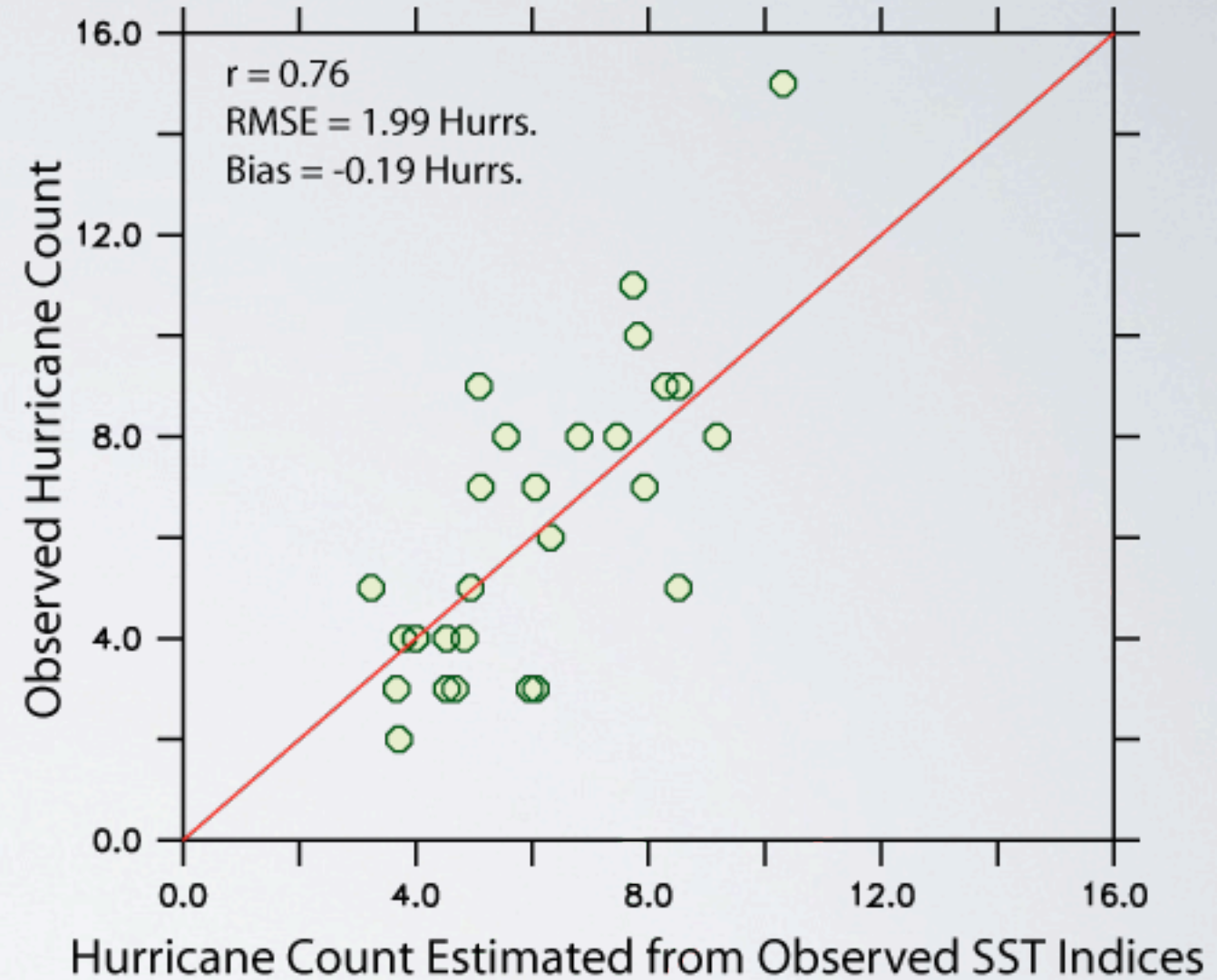
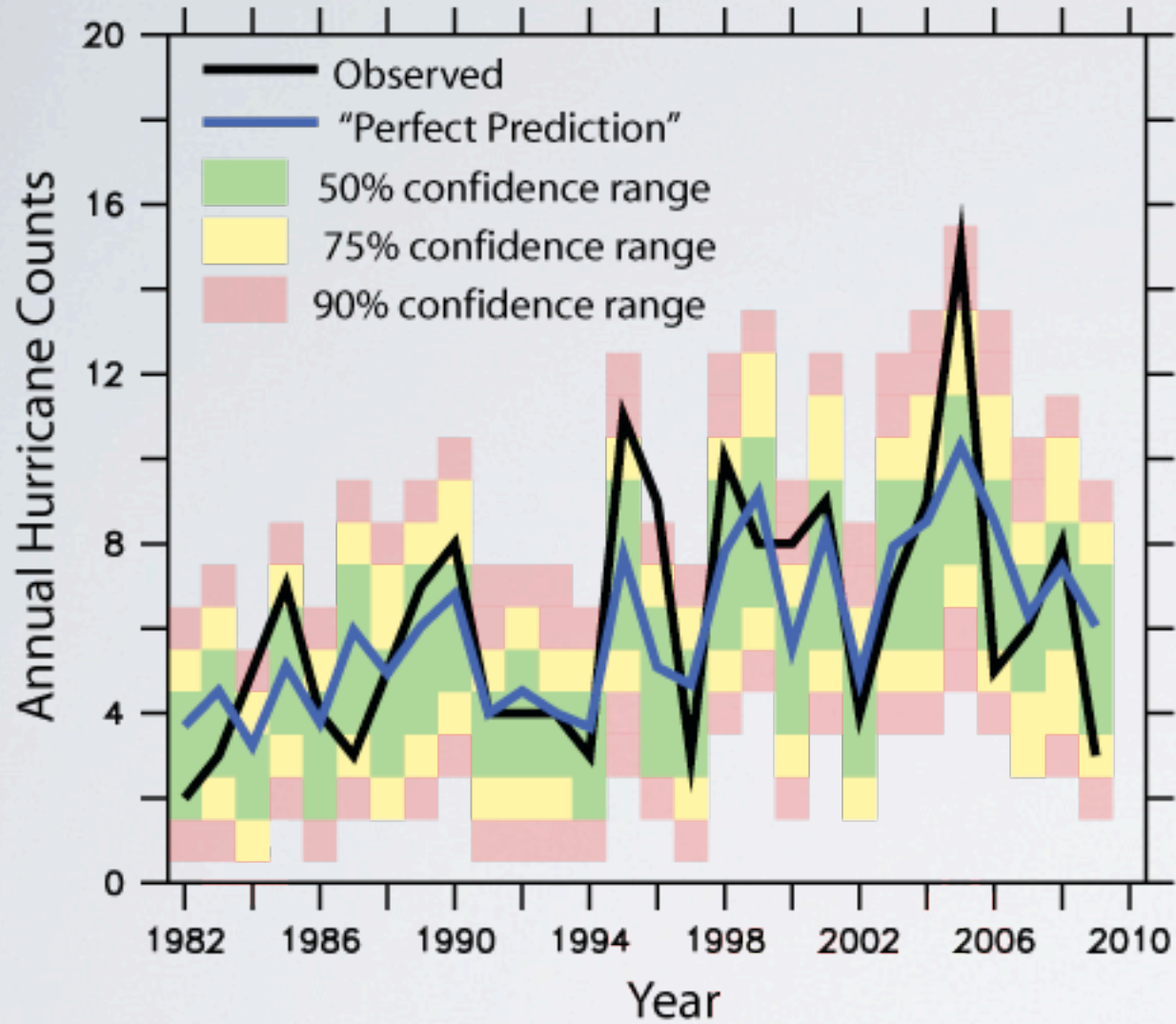
$$p(C=k | \lambda) = \lambda^k \cdot e^{-\lambda}/k! \quad \lambda = e^{(a+b \cdot SST_{mdr} + c \cdot SST_{trop})}$$

$$a = 1.707 \quad b = 1.388 \quad c = -1.521$$

Vecchi et al. (2010, MWR submitted)
see Villarini et al (2010, MWR in press) for methodology

FIT OF HIRAM-CI 80 EMULATOR TO OBS. PERFORMS WELL

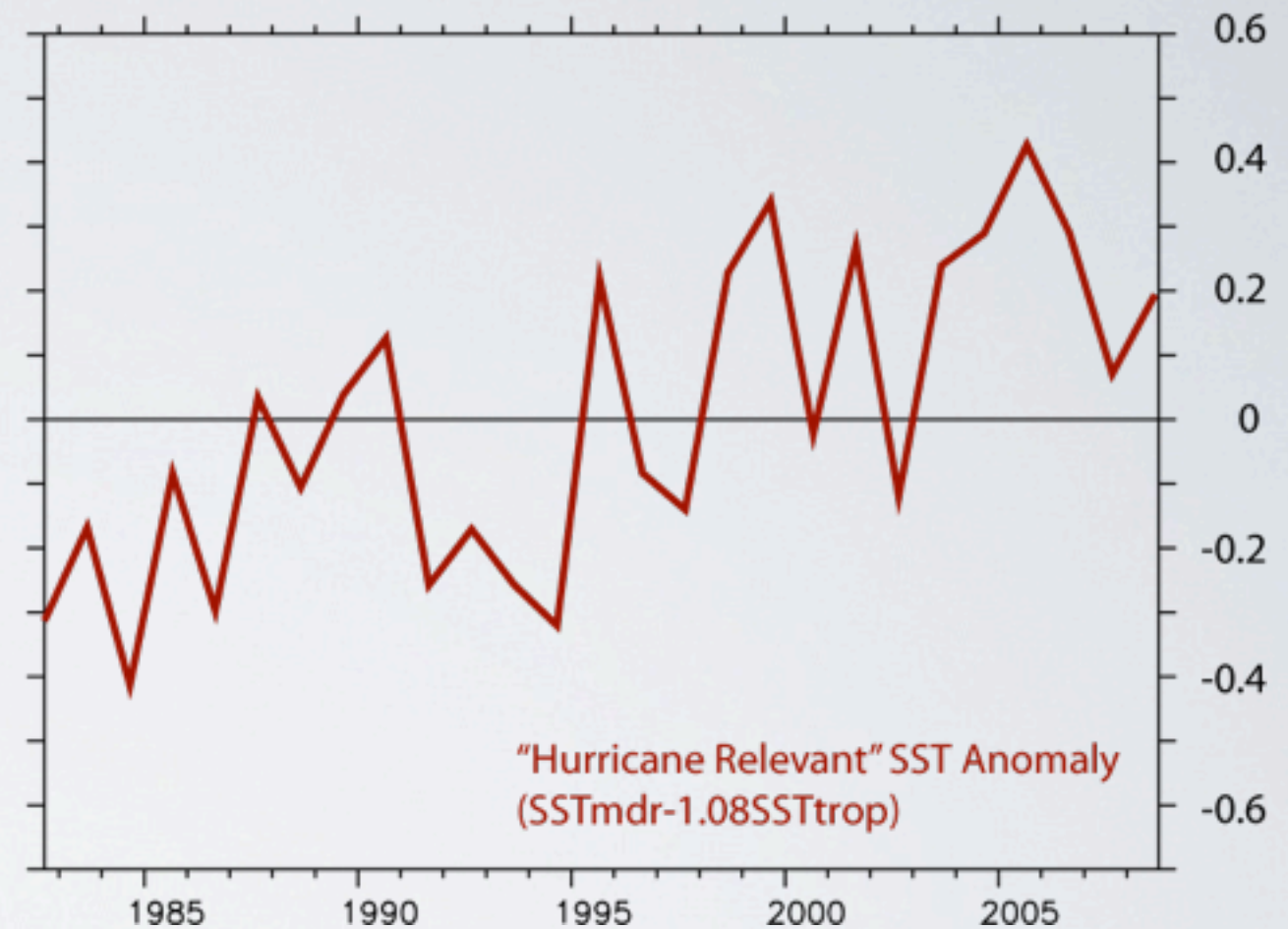
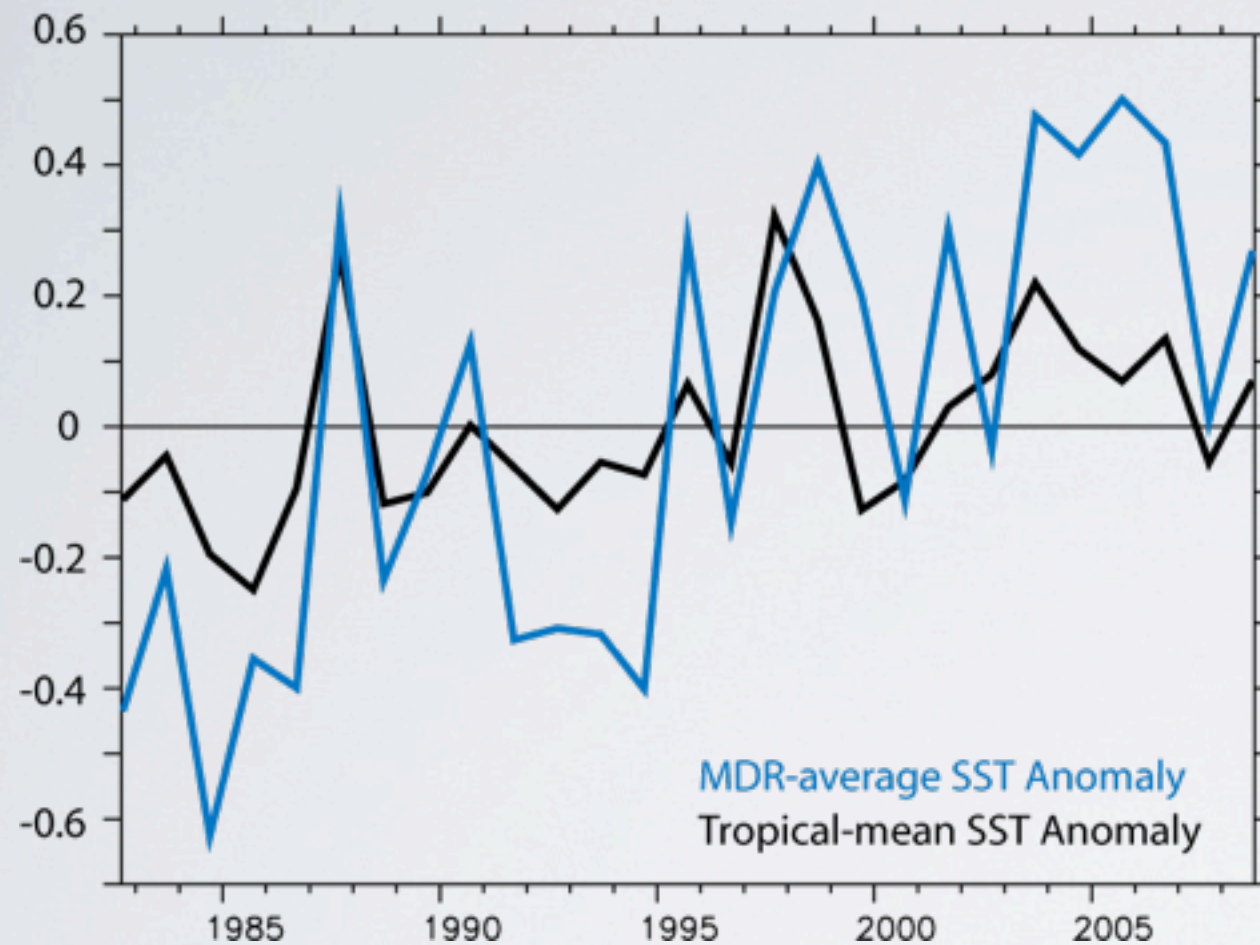
Application of Hurricane Frequency Statistical Model to Observed SST Indices



HiRAM-CI 80 with full SST gives $r=0.78$, $RMSE=1.91$
Cannot justify additional predictors at this time

Vecchi et al. (2010, MWR submitted)

SST INDEX RELEVANT TO HURRICANES COMPLEX, MORE THAN ENSO AND ATLANTIC SST



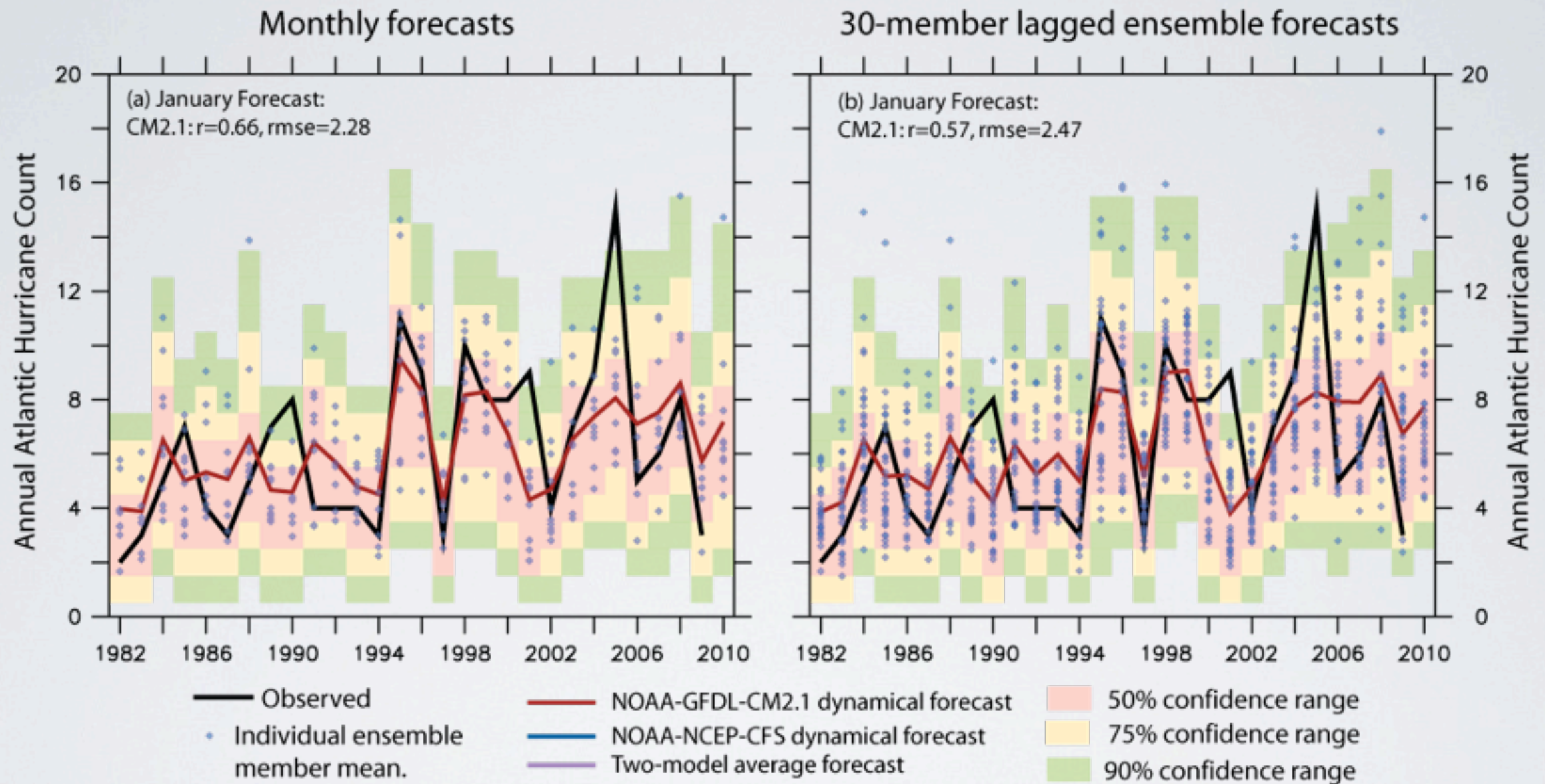
SST_{MDR} and SST_{TROP} share a recent trend, but amplitude differs.
 SST_{TROP} more than ENSO, trend, warm mid-2000's, etc.

EXPLORE TWO SYSTEMS TO FORECAST THE SST INDICES

- GFDL-CM2.1 Experimental Forecast System:
 - Ensemble Kalman Filter initialization of GFDL-CM2.1 - Zhang et al (2007), Delworth et al (2006)
 - 12-month retrospective and forward forecasts
 - Basis of GFDL's efforts to understand decadal predictability
- NCEP-CFS Operational S-I Forecast System:
 - GFS atmosphere and MOM3 ocean, initialized to NCEP (atm/land) and GODAS (ocn) - Saha et al (2006)
 - Nine-month retrospective and actual forecasts
 - Used operationally at NCEP

APPLY STATISTICAL HURRICANE FREQUENCY MODEL TO CM2.1

RETROSPECTIVE FORECASTS OF JANUARY SST



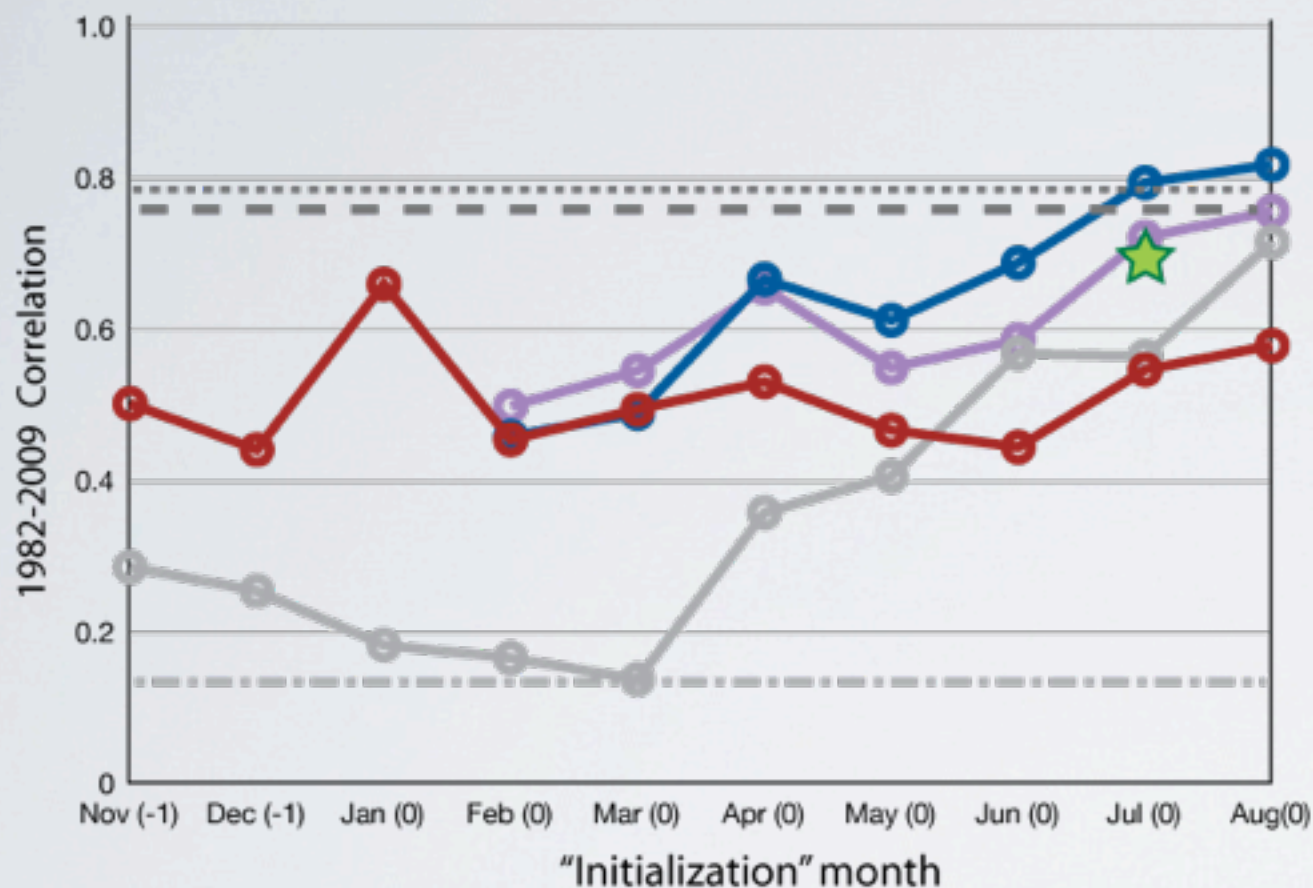
$$p(C=k) = \int_{-\infty}^{\infty} p(C=k \mid relSSTA=x) \cdot p(relSSTA=x) dx$$

$p(relSSTA=x)$ from CM2.1 ensemble

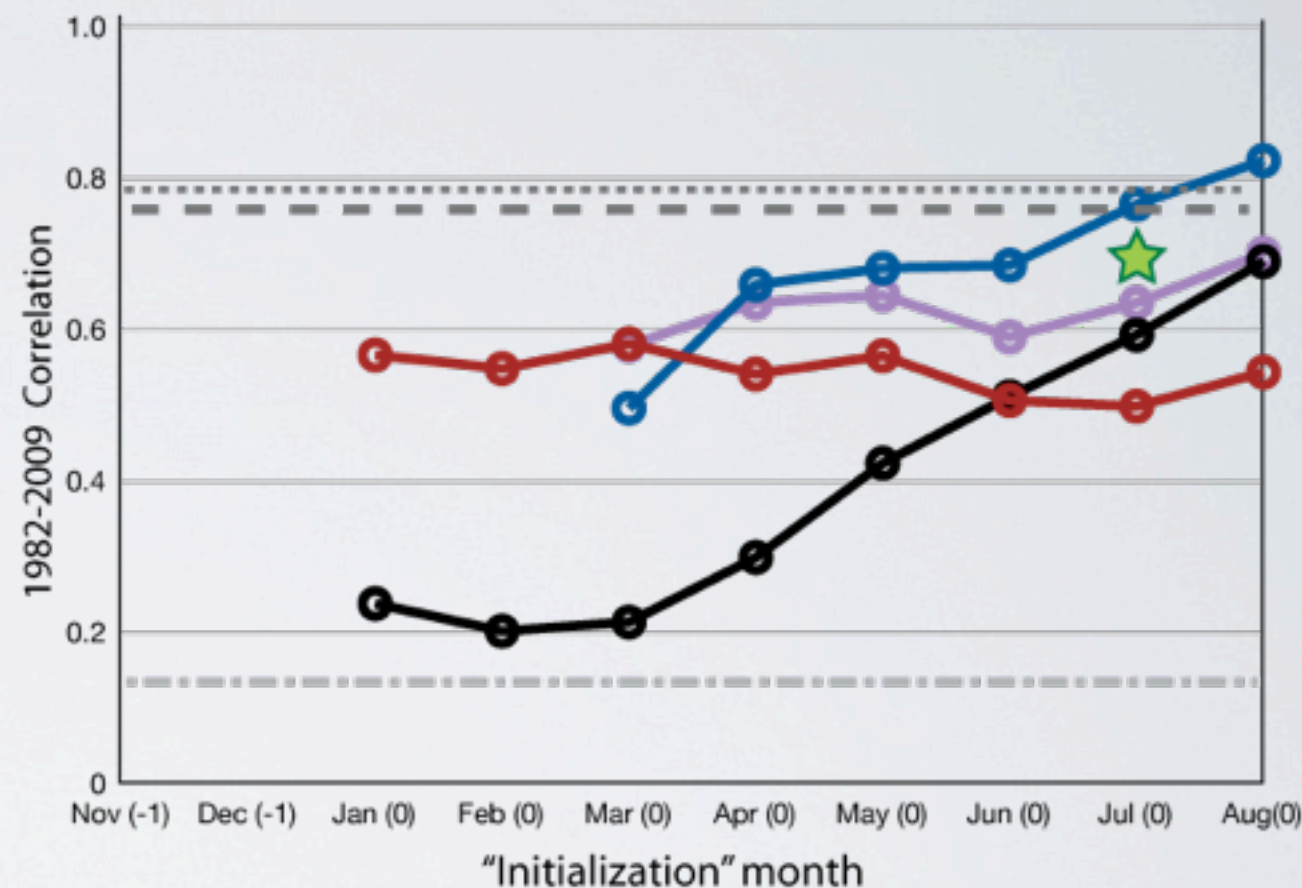
Vecchi et al. (2010, MWR submitted)

HYBRID (STATISTICAL-DYNAMICAL) FORECAST SYSTEM EXHIBITS POTENTIAL FOR MULTI-SEASON LEAD FORECASTS

(a) Retrospective Correlation Monthly Ensemble Atlantic Hurricane Forecasts



(b) Retrospective Correlation Lagged Ensemble Atlantic Hurricane Forecasts

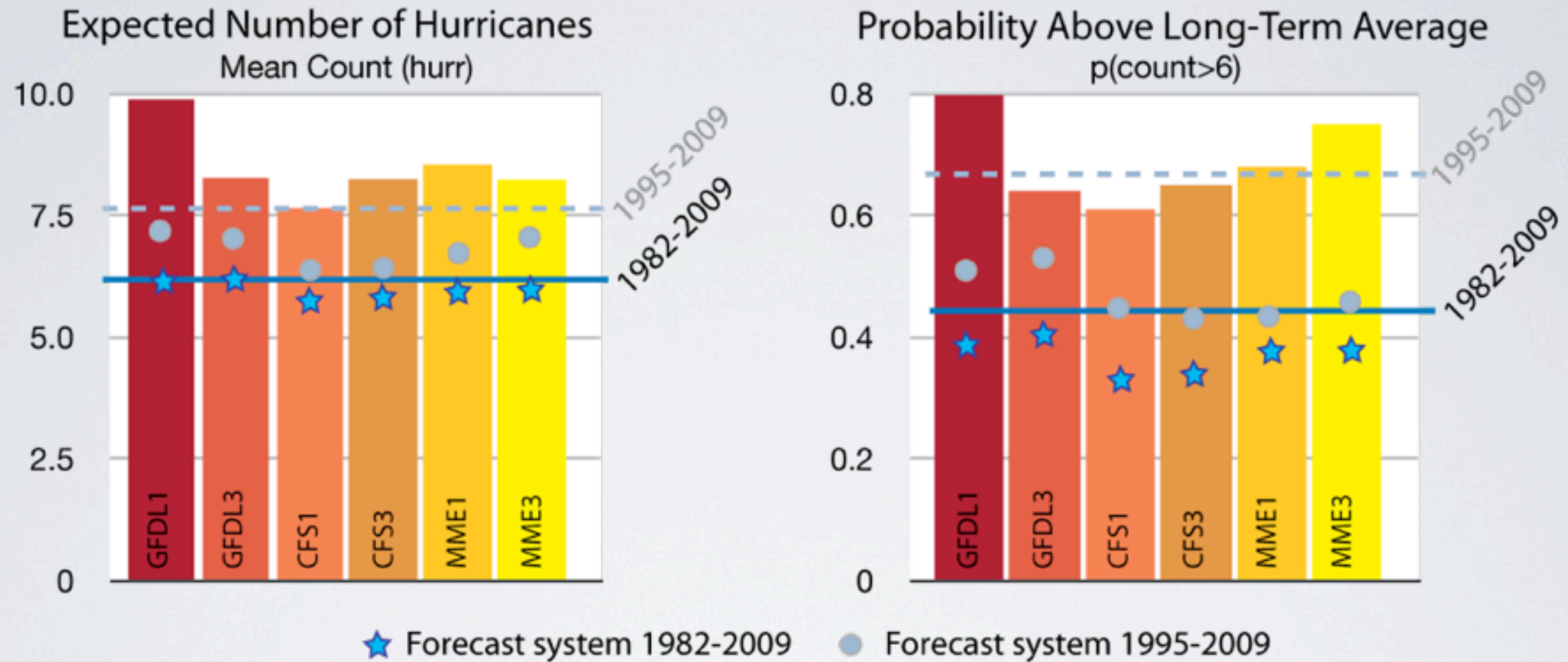


- Persistence of monthly SSTA
- Persistence of 3-month SSTA
- - - Persistence of previous year's count
- NOAA-GFDL-CM2.1 dynamical forecast
- NOAA-NCEP-CFS dynamical forecast
- Two-model average forecast
- Zhao et al (2009) full SST AGCM hindcast
- ★ Zhao et al (2010) persisted SST AGCM forecast
- - - Perfect ASO SSTA

Vecchi et al. (2010, MWR submitted)

HURRICANE FORECASTS INITIALIZED MARCH 2010

SYSTEM ANTICIPATES ACTIVE 2010

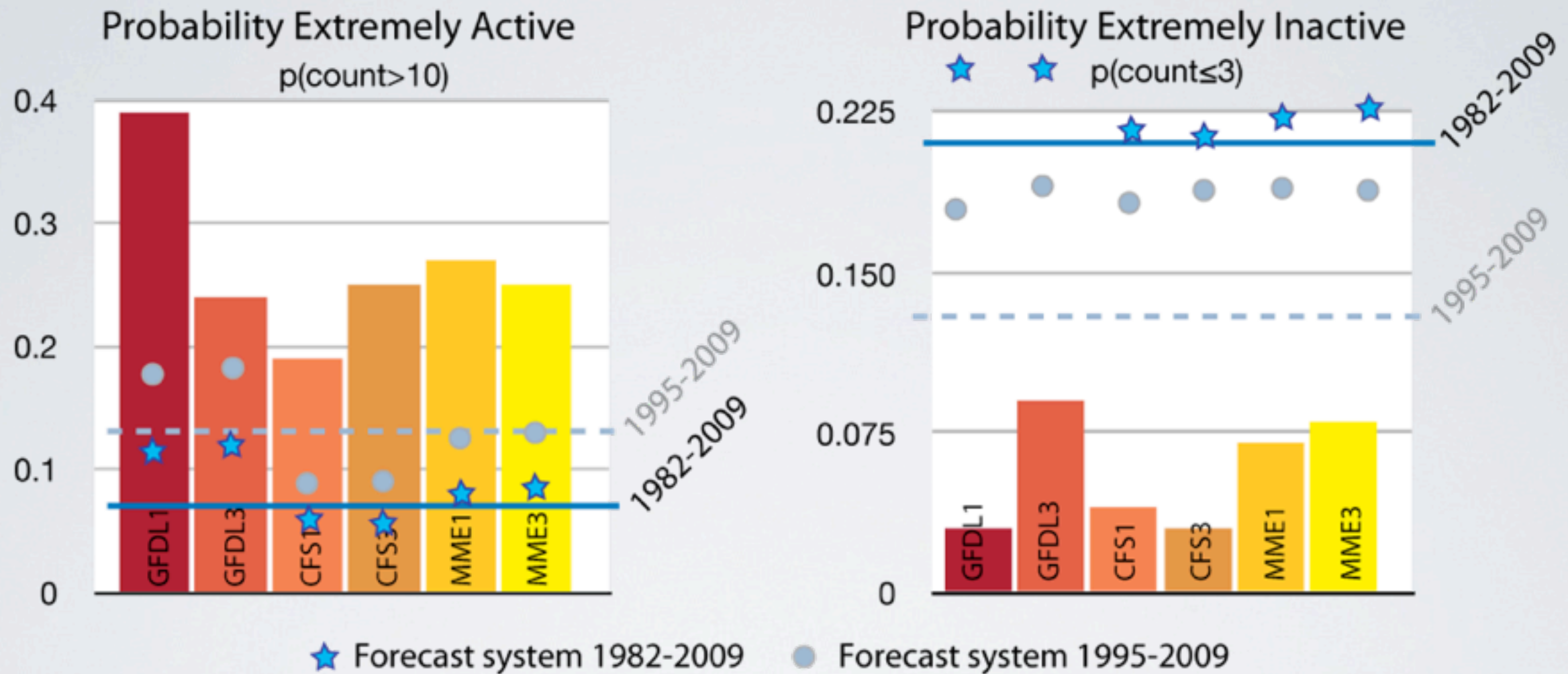


Experimental forecasts suggests 2010 season likely to be above average in hurricane frequency

Vecchi et al (2010, MWR submitted)

HURRICANE FORECASTS INITIALIZED MARCH 2010

SYSTEM ANTICIPATES ACTIVE 2010



Experimental forecasts for 2010 season
 large increase in probability of an extremely active year

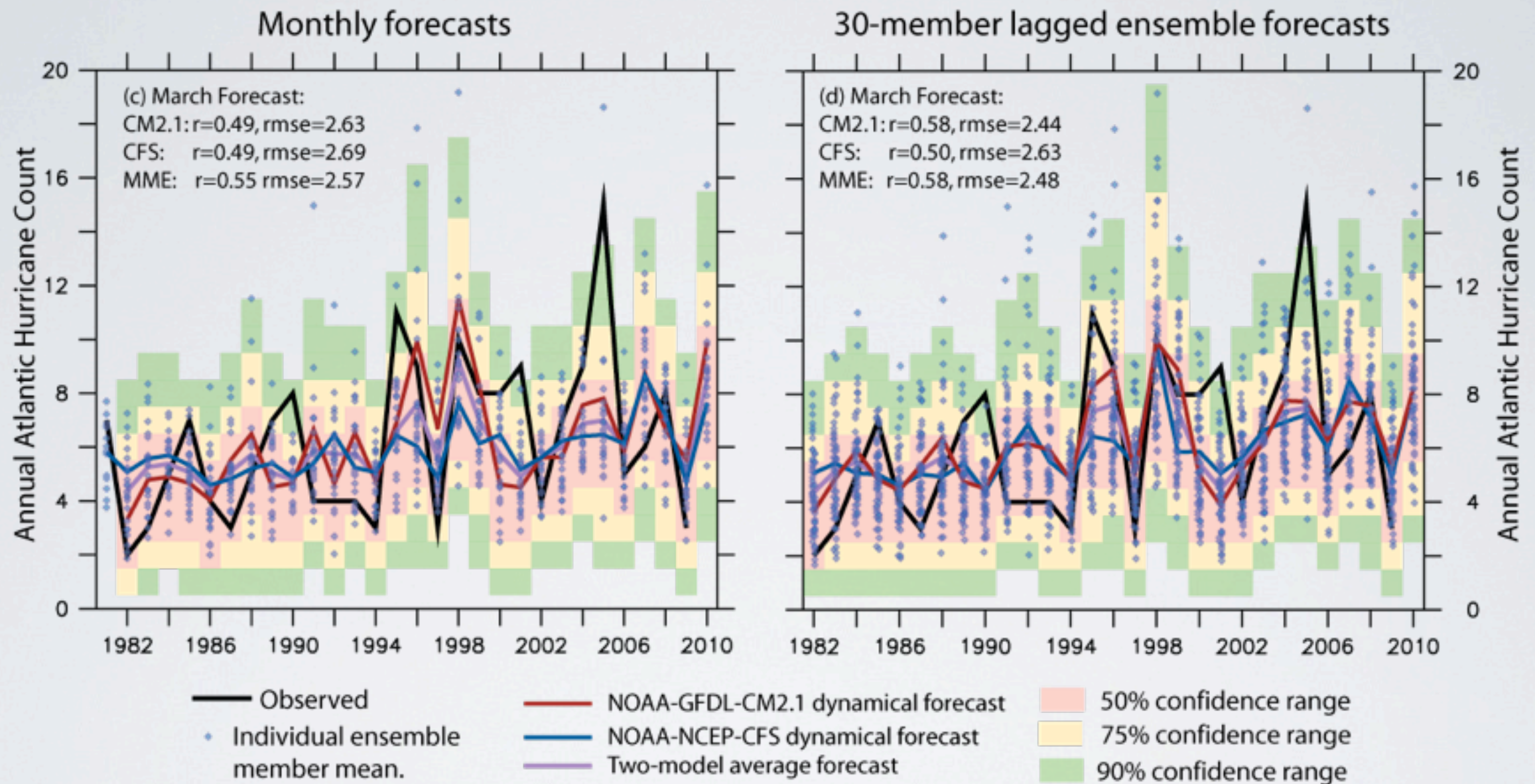
Vecchi et al (2010, MWR submitted)

SUMMARY

- Used understanding built assessing AGW/hurricane connection to build S-I hurricane frequency forecast system
- SST contains a great deal of the information about seasonal Atlantic hurricane activity:
 - Two indices (SST_{MDR} and SST_{TROP}) in ASO contain most
- Existing S-I forecast systems can predict these SST indices with skill from as early as November of the previous year, consistently predicting active 2010 since Nov. 2009.
- “Perfect” retrospective skill from CFS on short leads
- Room for improvement long-range (>6 month) hurricane outlooks from improved SST forecasts.
- How far back can we push it? Was 1982-2009 exceptionally predictable? Can we predict other quantities (efforts at Cat3-5, Cat4-5 and landfall)

BINKY SLIDES

APPLY STATISTICAL HURRICANE FREQUENCY MODEL TO CM2.1 AND CFS RETROSPECTIVE FORECASTS OF MARCH SST



$$p(C=k) = \int_{-\infty}^{\infty} p(C=k \mid relSSTA=x) \cdot p(relSSTA=x) dx$$

$p(relSSTA=x)$ from CM2.1 and CFS ensemble

Vecchi *et al.* (2010, MWR submitted)

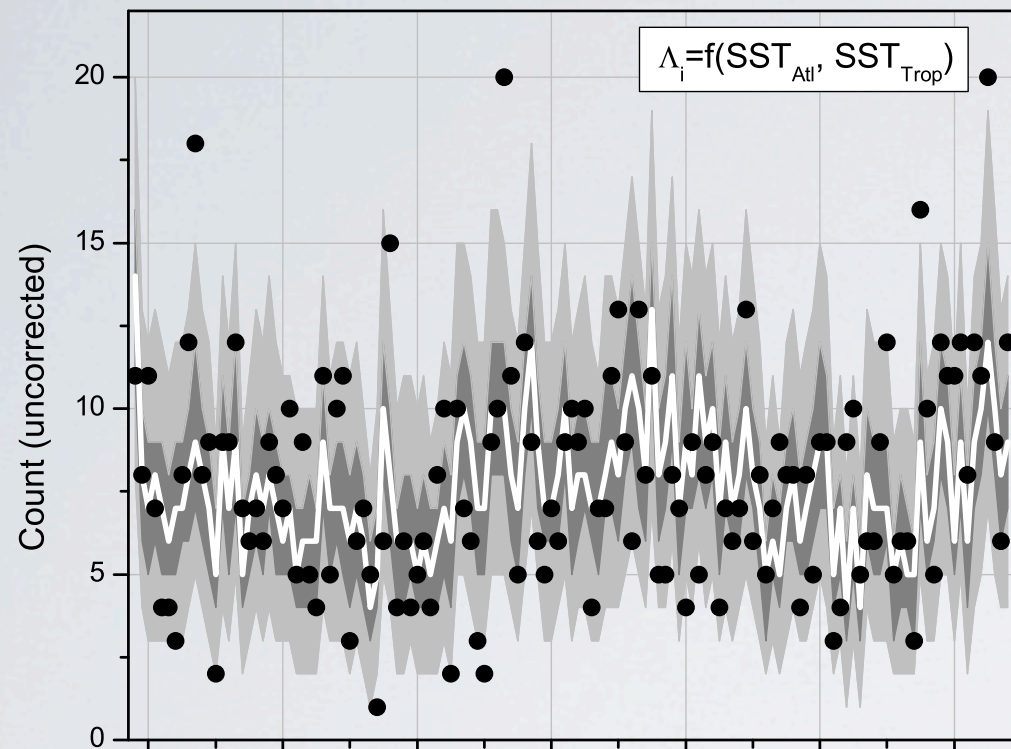
HURRICANE FORECASTS INITIALIZED MARCH 2010

SYSTEM INDICATES ACTIVE 2010

	<i>Mean Count (hurr)</i>	<i>Median (hurricanes)</i>	<i>p(count>6)</i>	<i>p(count>10)</i>	<i>p(count≤3)</i>
Observed 1982-2009	6.21	5	0.46	0.07	0.21
GFDL-CM2.1 Simple Ens.	9.88	9	0.80	0.39	0.03
GFDL-CM2.1 Lagged Ens.	8.27	8	0.64	0.24	0.09
NCEP-CFS Simple Ens.	7.64	7	0.61	0.19	0.04
NCEP-CFS Lagged Ens.	8.24	8	0.65	0.25	0.03
Two-model Simple Ens.	8.54	8	0.68	0.27	0.07
Two-model Lagged Ens.	8.23	8	0.75	0.25	0.08

Vecchi et al (2010, MWR submitted)

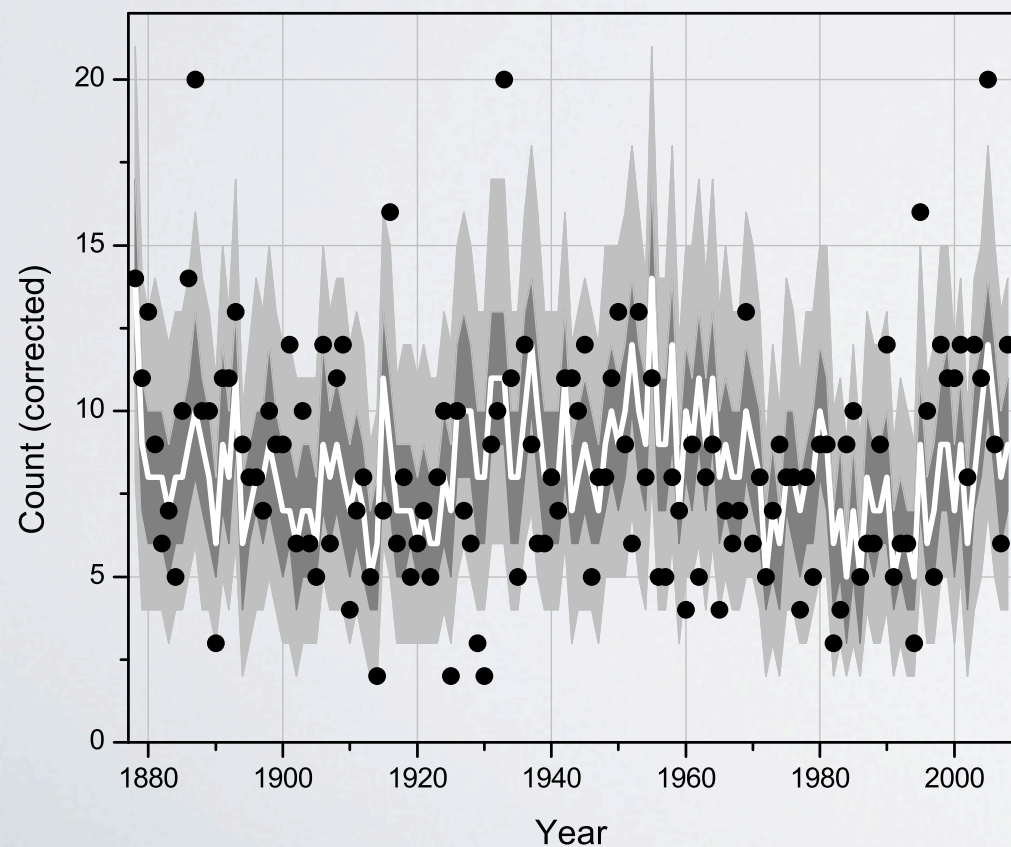
Build statistical model of basin-wide tropical storms using Atlantic and Tropical-mean SST as covariates



Atlantic SST increases frequency.

Tropical-mean SST reduces frequency.

Factors in fit (w/standard error)

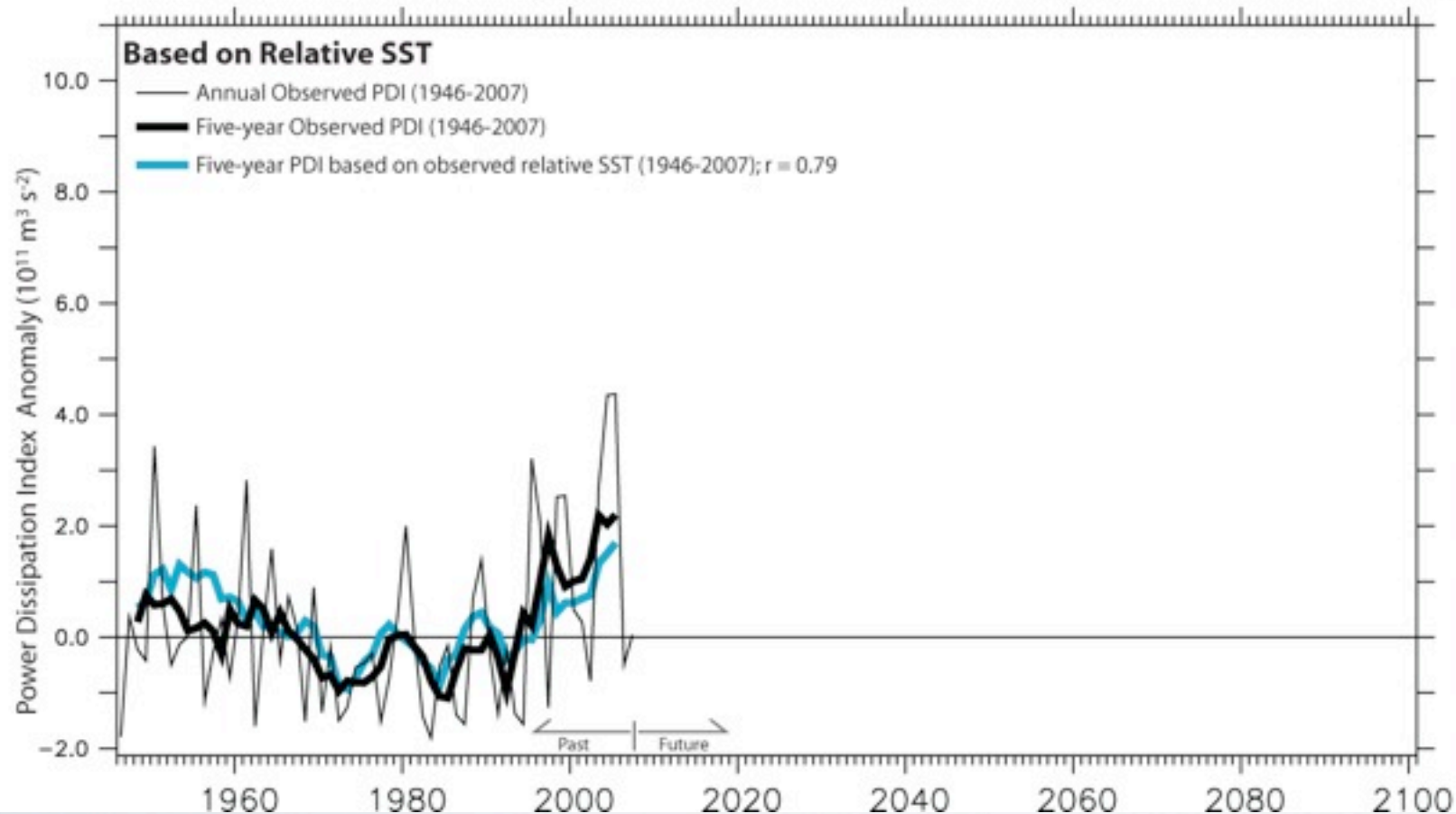
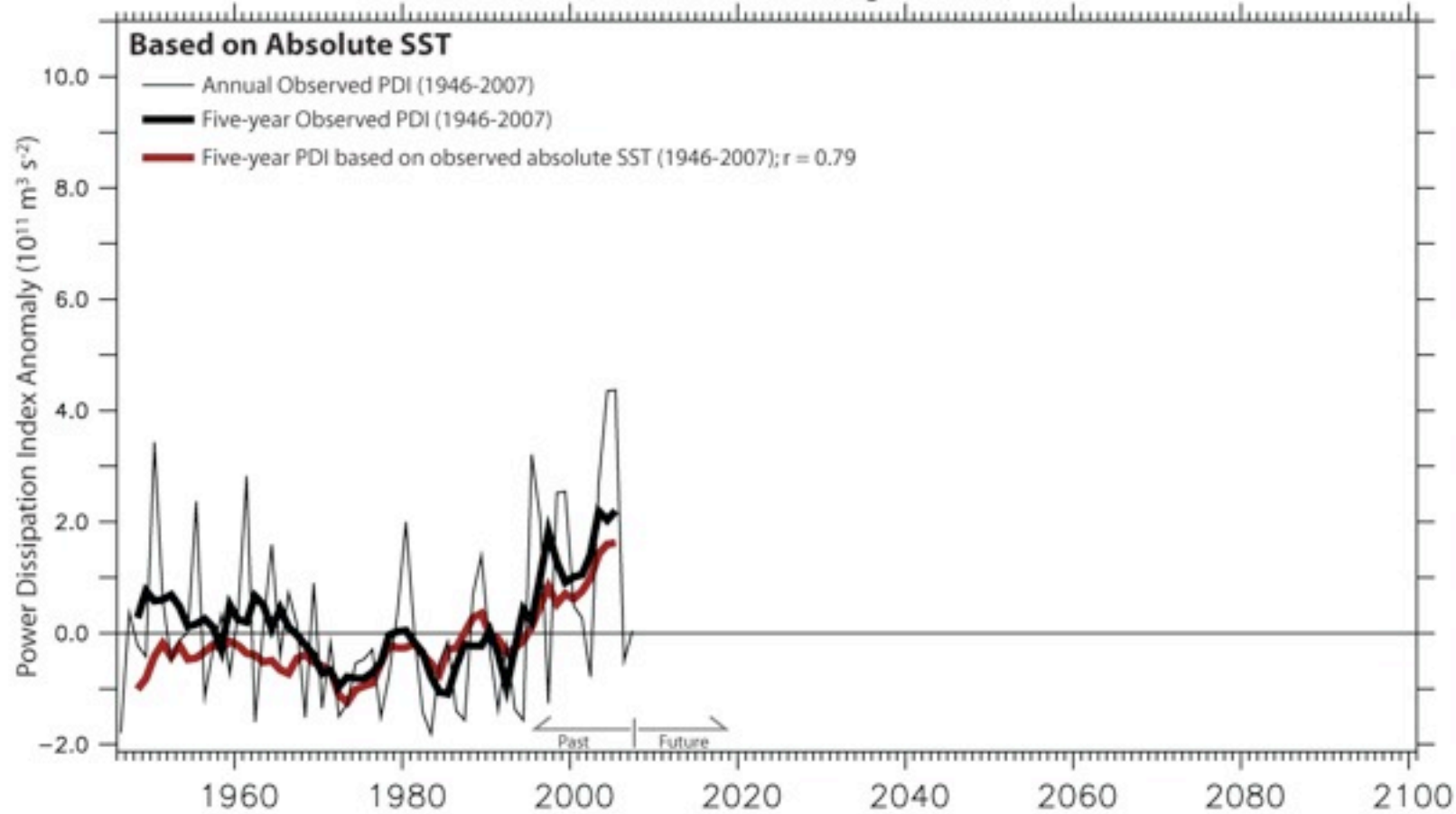


	Uncorrected	Corrected
Intercept	2.03 (0.03)	2.11 (0.03)
	2.03 (0.03)	2.10 (0.03)
SST_{Atl}	1.13 (0.20)	1.05 (0.15)
	1.05 (0.15)	1.02 (0.14)
SST_{Trop}	-0.98 (0.23)	-1.22 (0.22)
	-0.91 (0.20)	-1.05 (0.19)

Villarini, Vecchi and Smith (2010, MWR, in press)

Atlantic Tropical Cyclone Power Dissipation Index Anomalies: Observed and Based on Sea Surface Temperature

Anomalies relative to 1981-2000 average: $2.13 \times 10^{11} \text{ m}^3 \text{ s}^{-2}$



Observed Activity Absolute MDR SST

see also Emanuel (2005)

If causal, can attribute to
GHG.

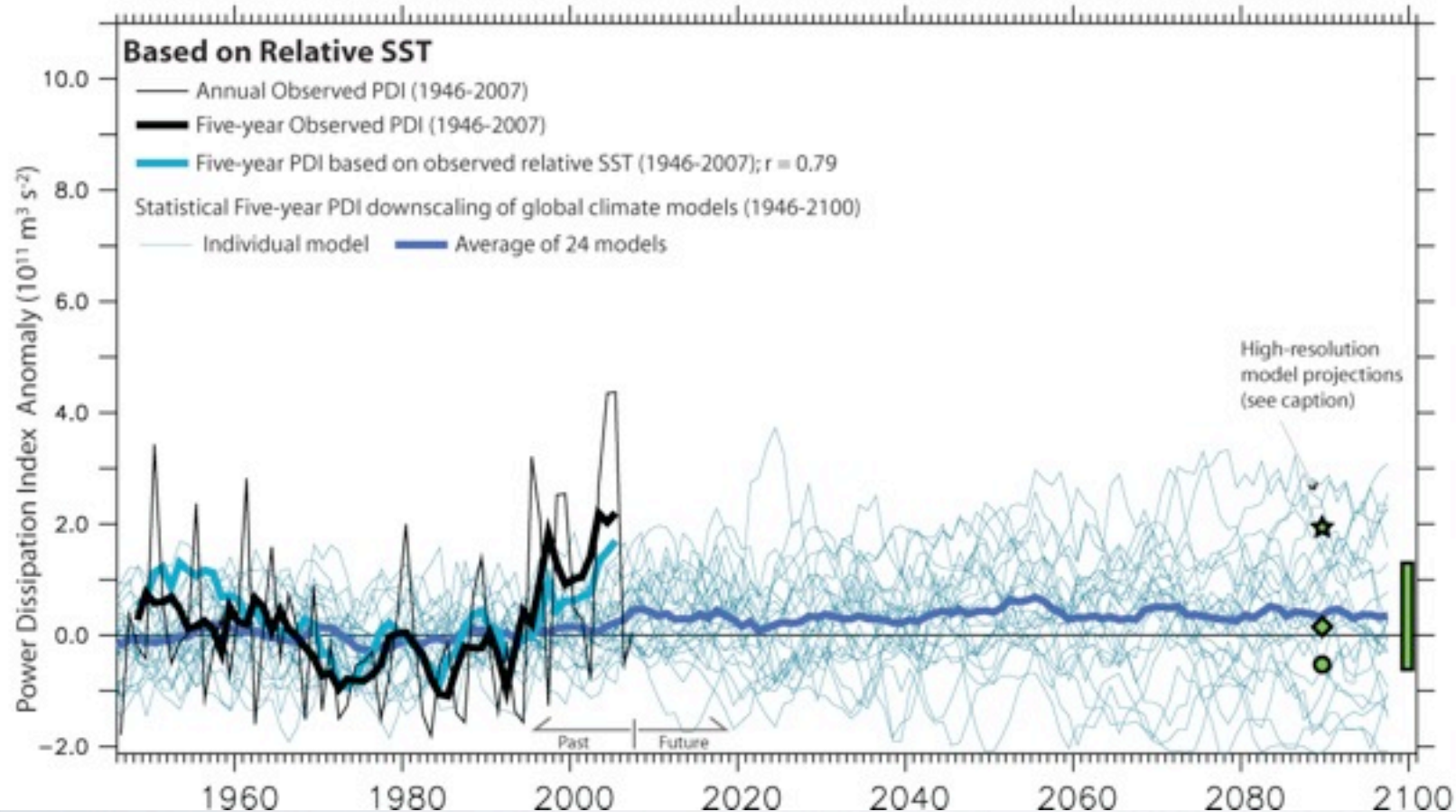
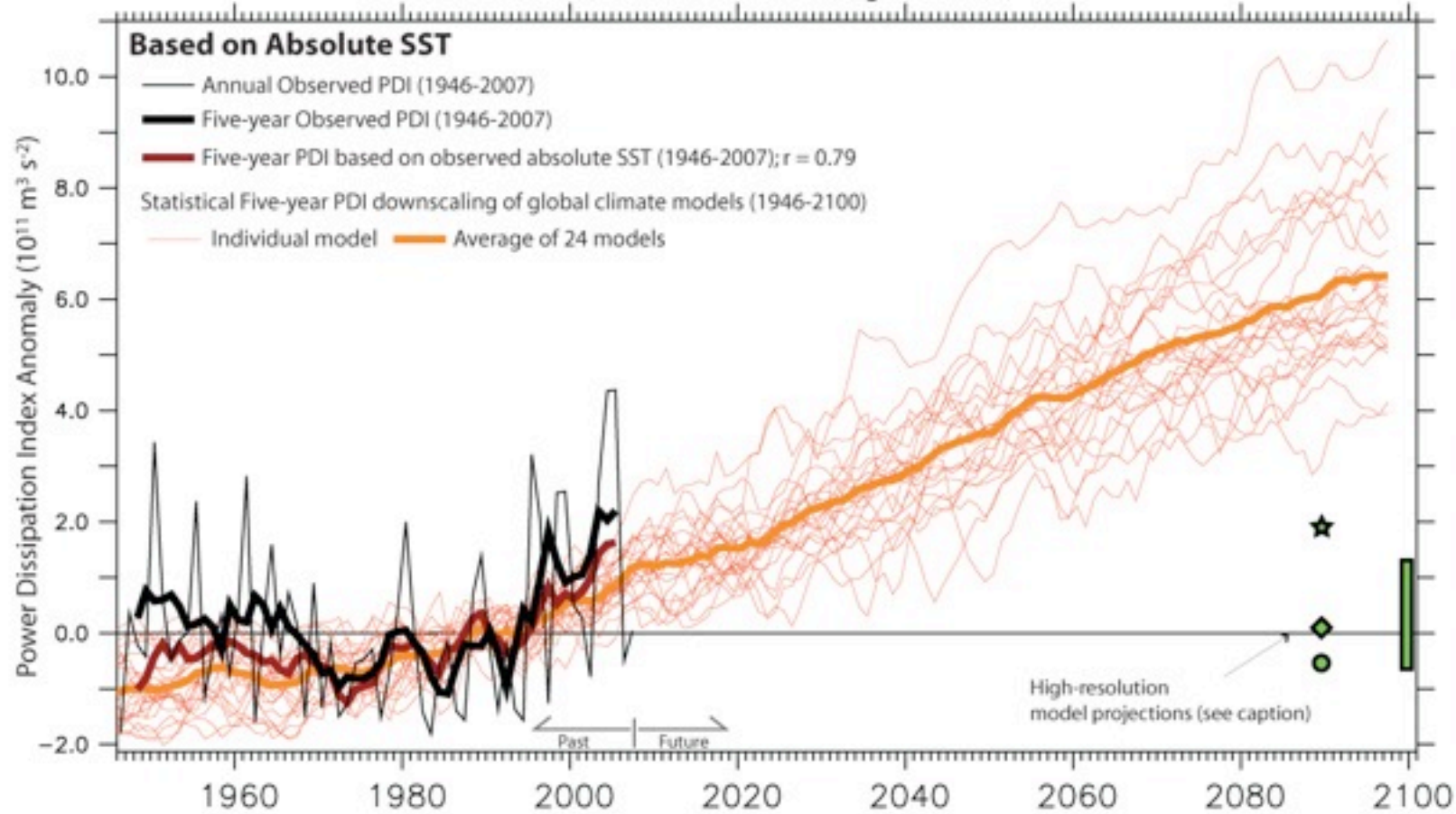
Relative MDR SST If causal, cannot attribute.

see also Swanson (2008)

*Vecchi, Swanson and Soden
(2008, Science)*

Atlantic Tropical Cyclone Power Dissipation Index Anomalies: Observed and Based on Sea Surface Temperature

Anomalies relative to 1981-2000 average: $2.13 \times 10^{11} \text{ m}^3 \text{ s}^{-2}$



Observed Activity

Absolute SST

Model Abs. SST

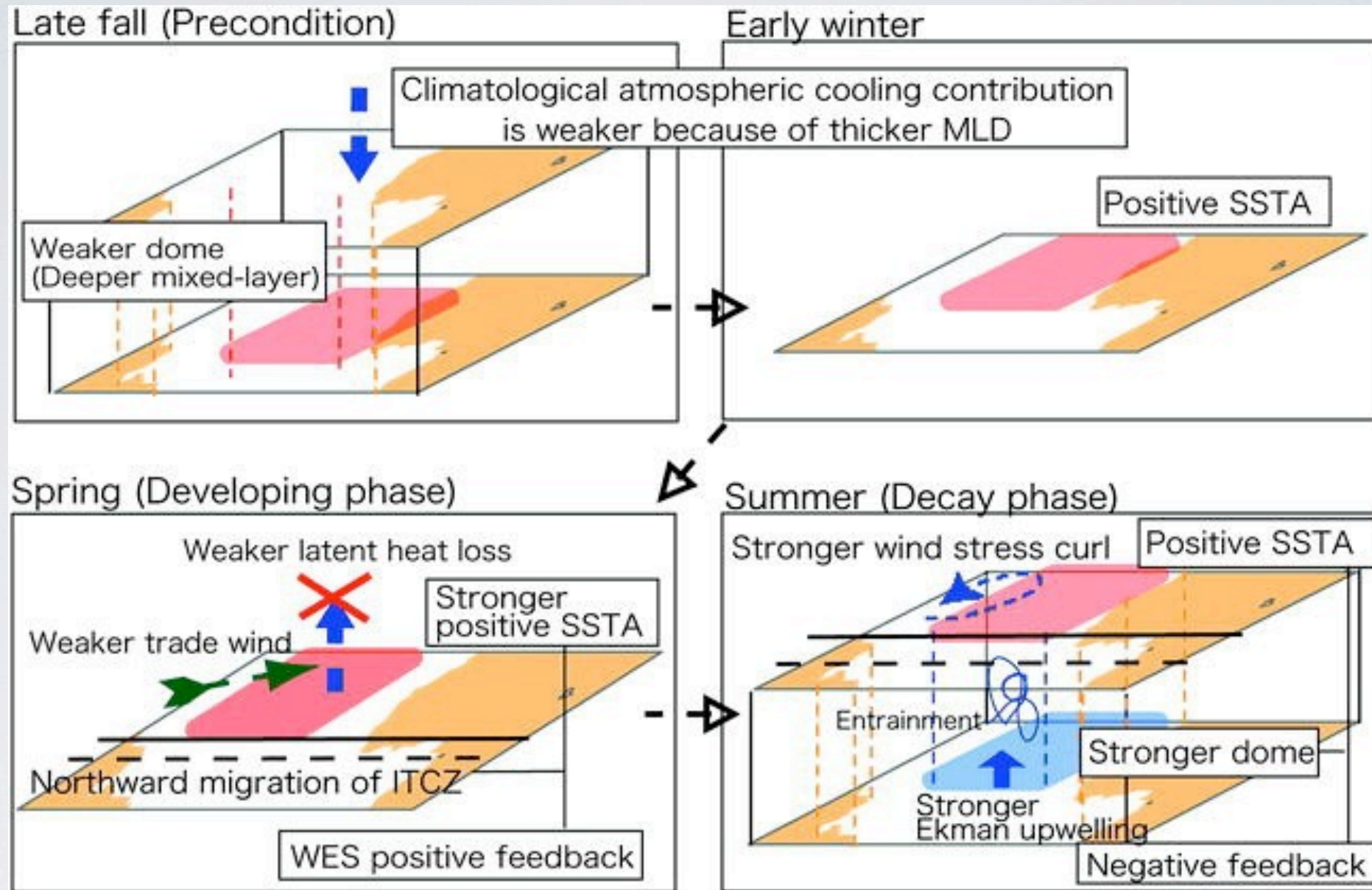
High-resolution model activity change

Emanuel et al (08), Knutson et al (08)
Oouchi et al (06), Bengtsson et al (07)

Relative SST
Model Rel. SST

Vecchi, Swanson and Soden
(2008, Science)

PROCESSES CONTROLLING TROPICAL ATLANTIC VARIABILITY ARE SEASONALLY DEPENDENT



Doi et al. (2010, J. Climate)

HURRICANE-RELEVANT LARGE-SCALE CONDITIONS CO-VARY CONSTRUCTIVELY WITH RELATIVE-SST

Interannual Correlation of Large-Scale Conditions to Relative-SST (Aug-Oct - CM2.1 1860 Control)

