

# EXPERIMENTAL S-I HURRICANE FORECASTS FROM WINTER

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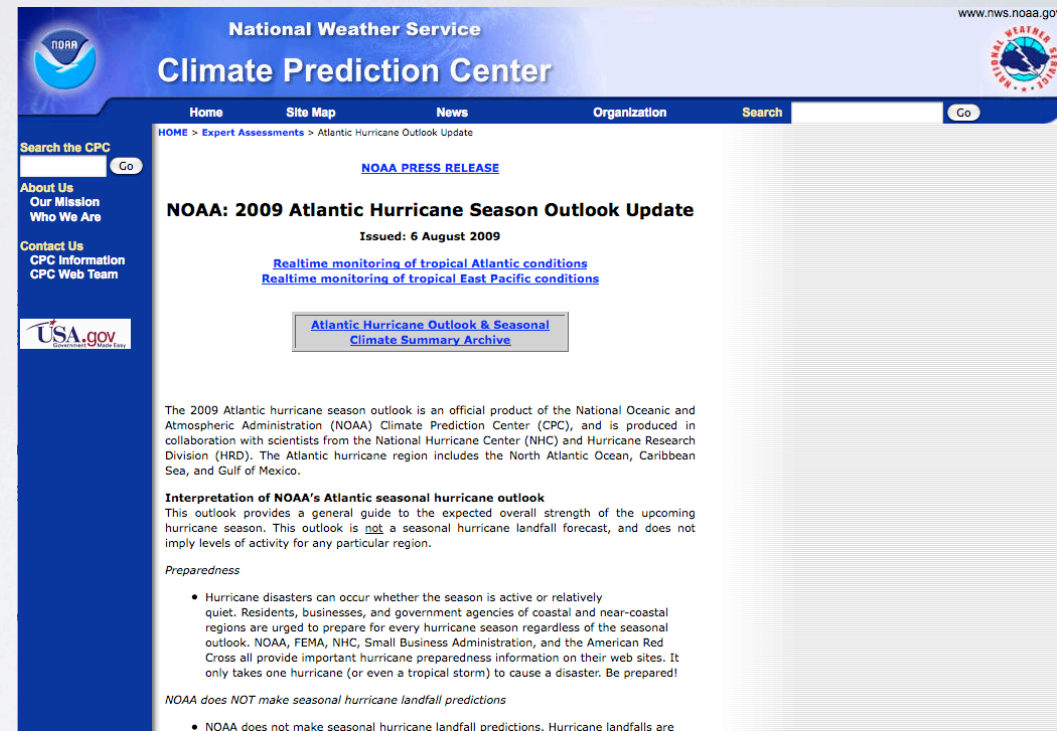
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# SEASONAL HURRICANE FORECASTS INITIALIZED IN BOREAL MID-SPRING TO EARLY-SUMMER ARE: FEASIBLE, POTENTIALLY SKILLFUL AND MADE

- 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 the URL "www.nws.noaa.gov". Navigation links for "Home", "Site Map", "News", "Organization", and "Search" are visible. A search bar is present with a "Go" button. 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 box contains the text "Atlantic Hurricane Outlook & Seasonal Climate Summary Archive". The main text explains that the 2009 Atlantic hurricane season outlook is an official product of the National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center (CPC), produced in collaboration with scientists from the National Hurricane Center (NHC) and Hurricane Research Division (HRD). It defines the Atlantic hurricane region and provides an interpretation of the outlook, stating it is a general guide to the expected overall strength of the upcoming hurricane season and does not imply levels of activity for any particular region. A "Preparedness" section lists 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." It also states that NOAA, FEMA, NHC, Small Business Administration, and the American Red Cross provide important hurricane preparedness information on their web sites. A final note states: "NOAA does NOT make seasonal hurricane landfall predictions." and "NOAA does not make seasonal hurricane landfall predictions. Hurricane landfalls are



GOAL:

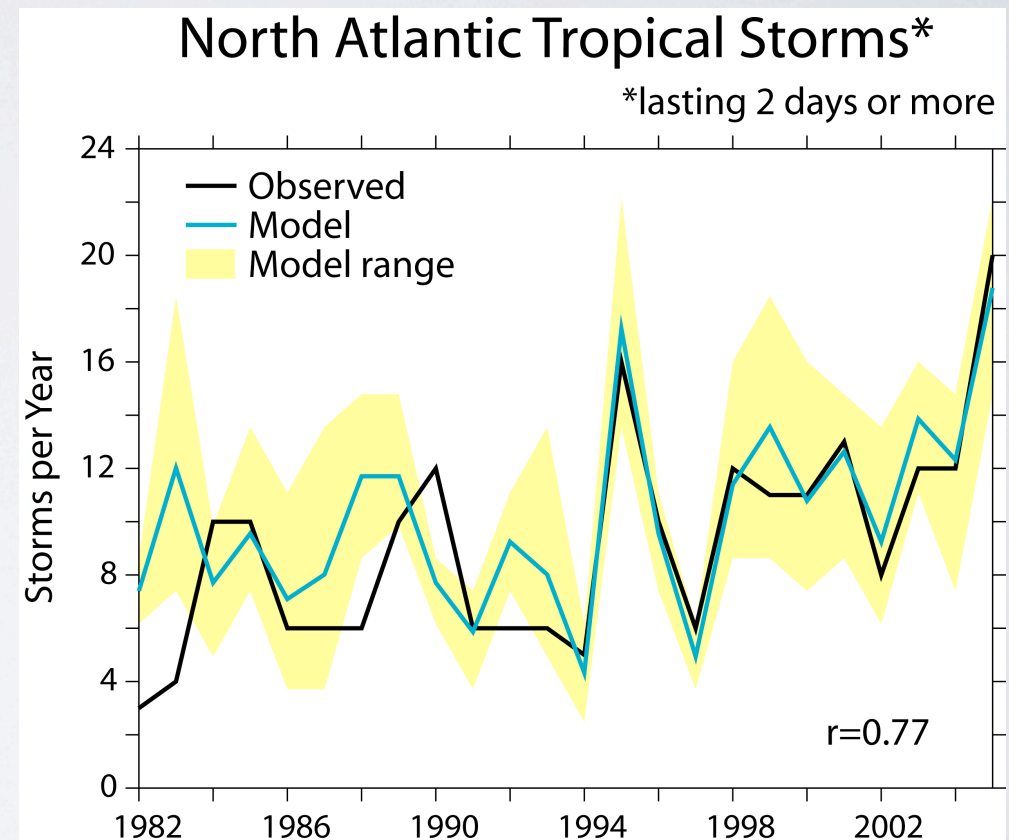
USE **UNDERSTANDING** DEVELOPED BY  
EXPLORING THE CONNECTION OF  
**HURRICANES TO ANTHROPOGENIC CLIMATE  
CHANGE** IN ORDER TO PUSH WINDOW OF  
NORTH ATLANTIC **SEASONAL** HURRICANE  
FORECASTS TO **WINTER**, WITH **SKILL** AND  
QUANTIFIED **UNCERTAINTY**

# GFDL C-X HIRAM GCMS

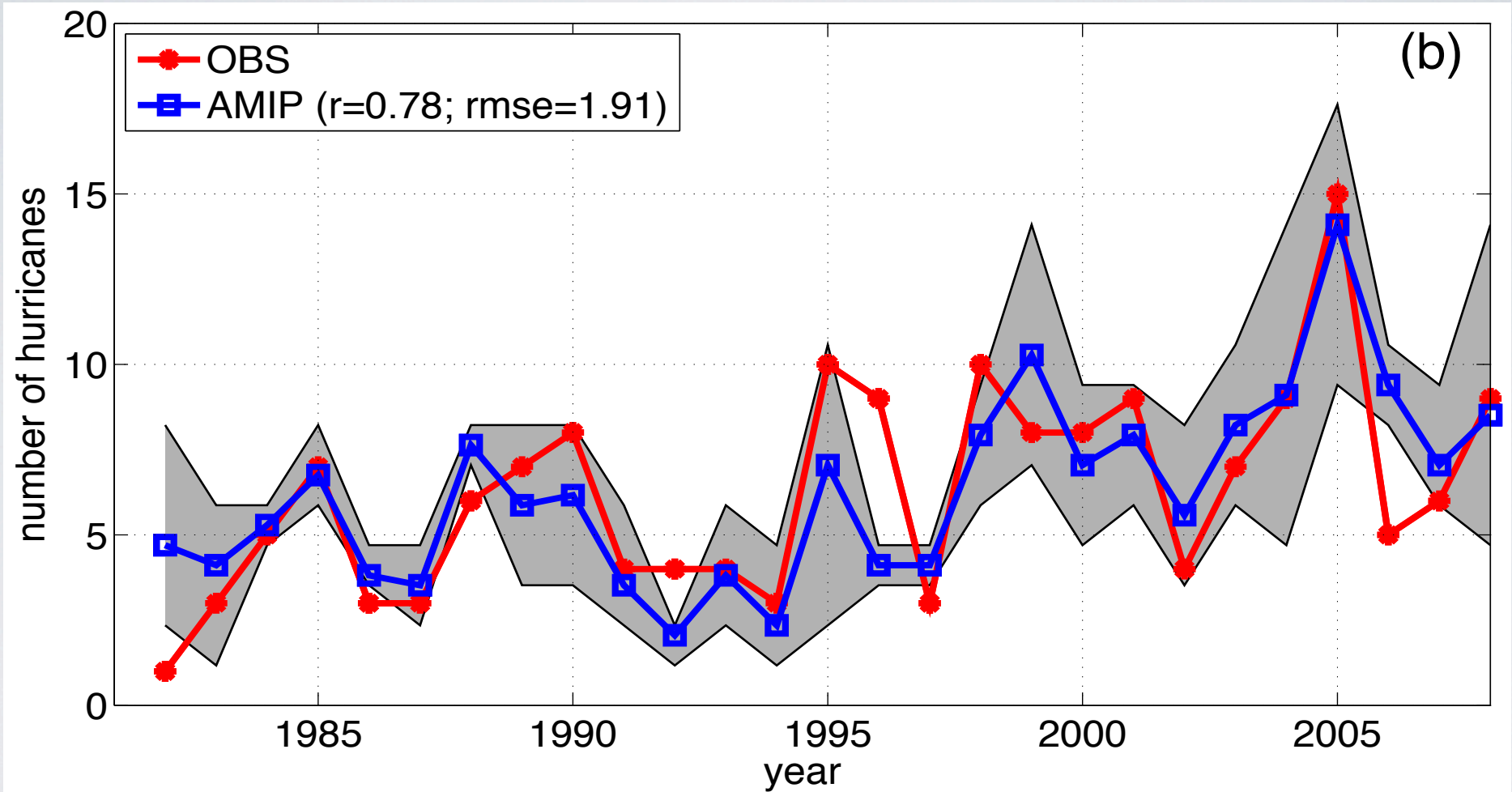
Family of global atmospheric models designed for better-representing tropical cyclone frequency. **C90 - 1°**, **C180=1/2°**, C360=1/4°, C720=1/8°  
*Ref. Zhao et al (2009, J. Climate; 2010, MWR)*

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°



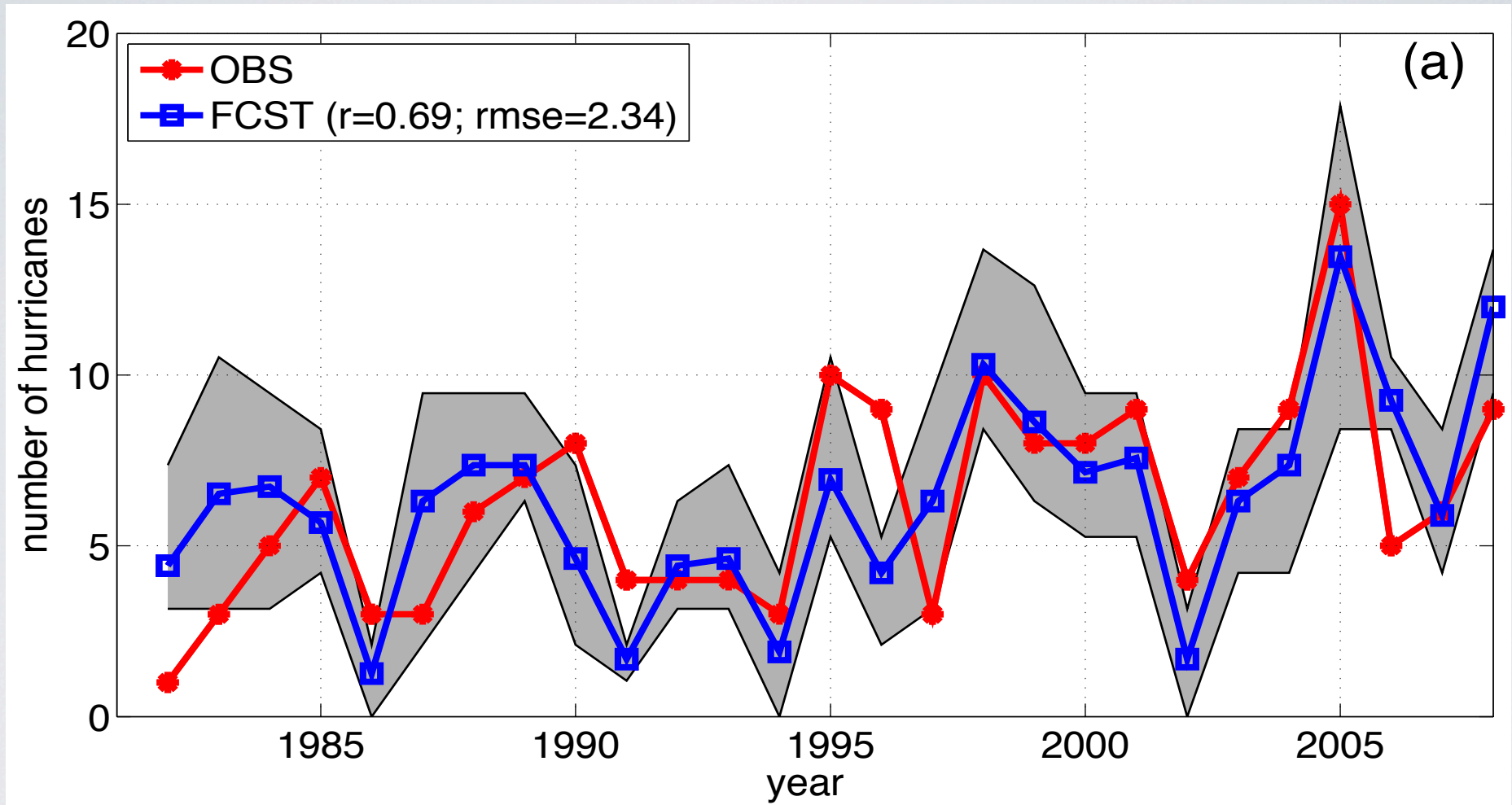
# HIRAM C180 AGCM FORCED WITH SSTs RECOVERS NA HURRICANE COUNTS



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.)*

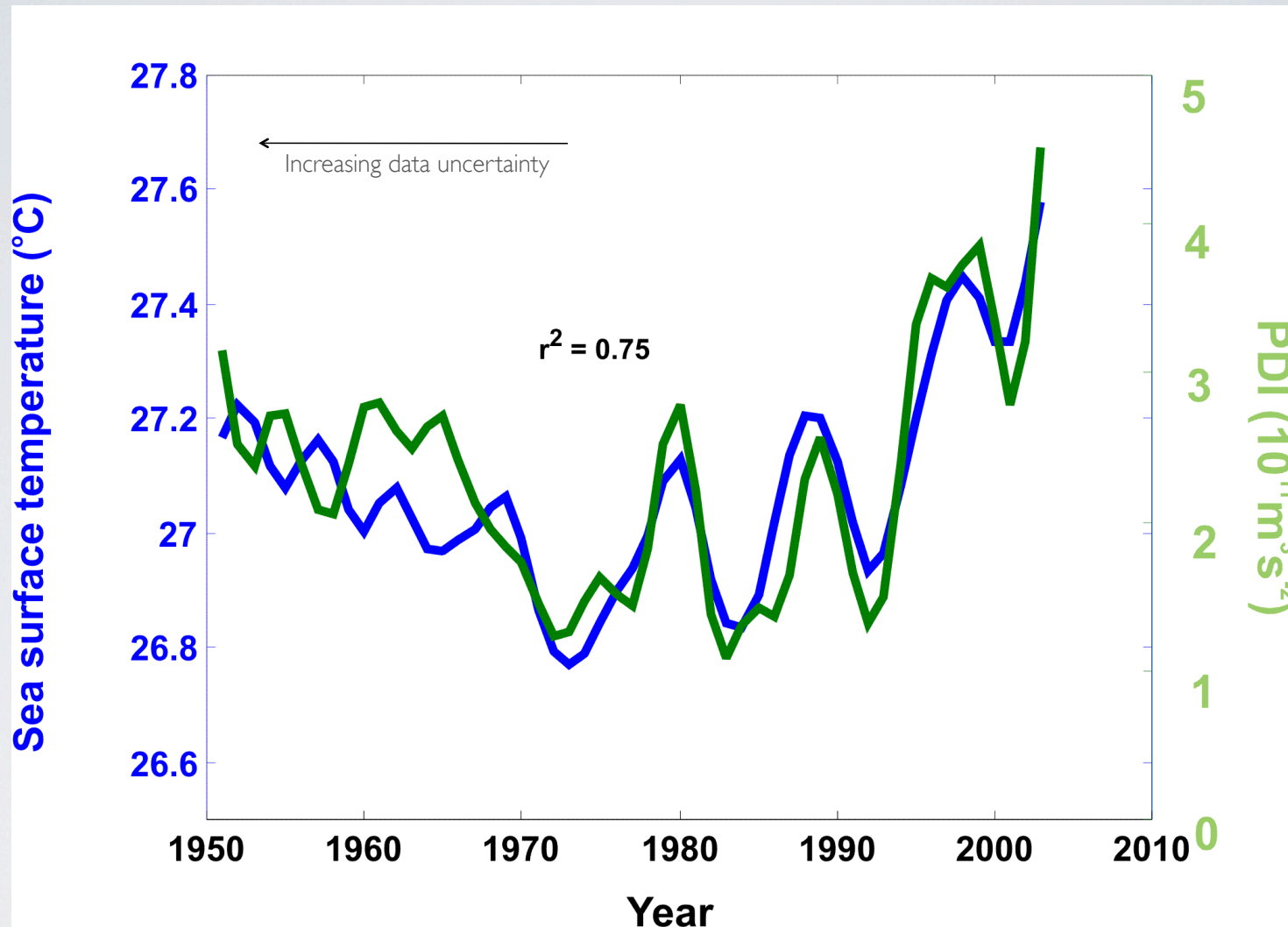
COST OF RUNNING THOUSANDS OF RETROSPECTIVE FORECASTS WITH HIRAM-C I 80 IS PROHIBITIVE.

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-C I 80 SUGGESTS WE SHOULD LOOK AT SST,  
BUT WHAT PART OF SST?

# LOOK AT ATLANTIC SST

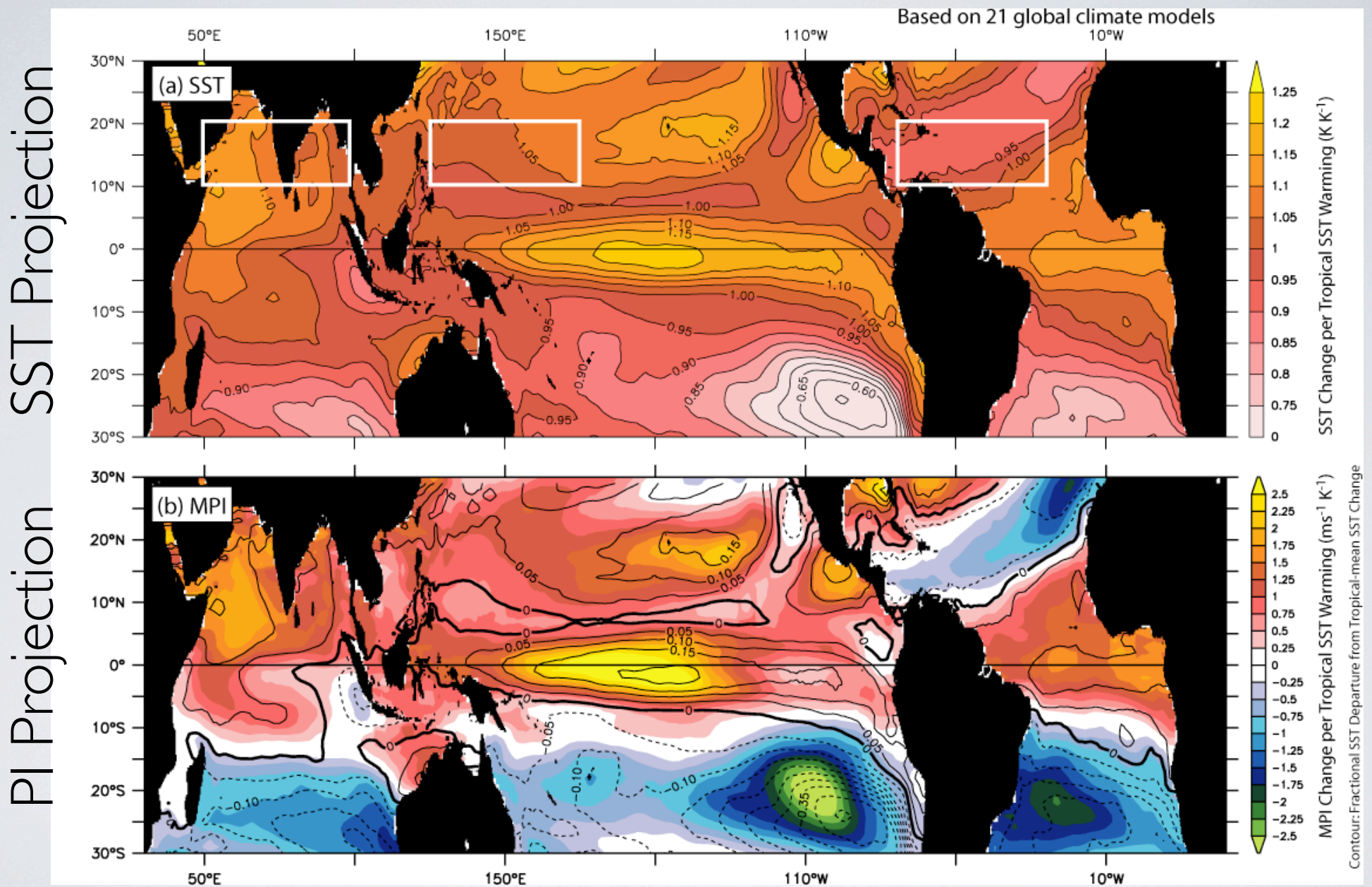


Source: Emanuel, J. Climate (2007).

PDI is proportional to the time integral of the cube of the surface wind speeds accumulated across all storms over their entire life cycles.



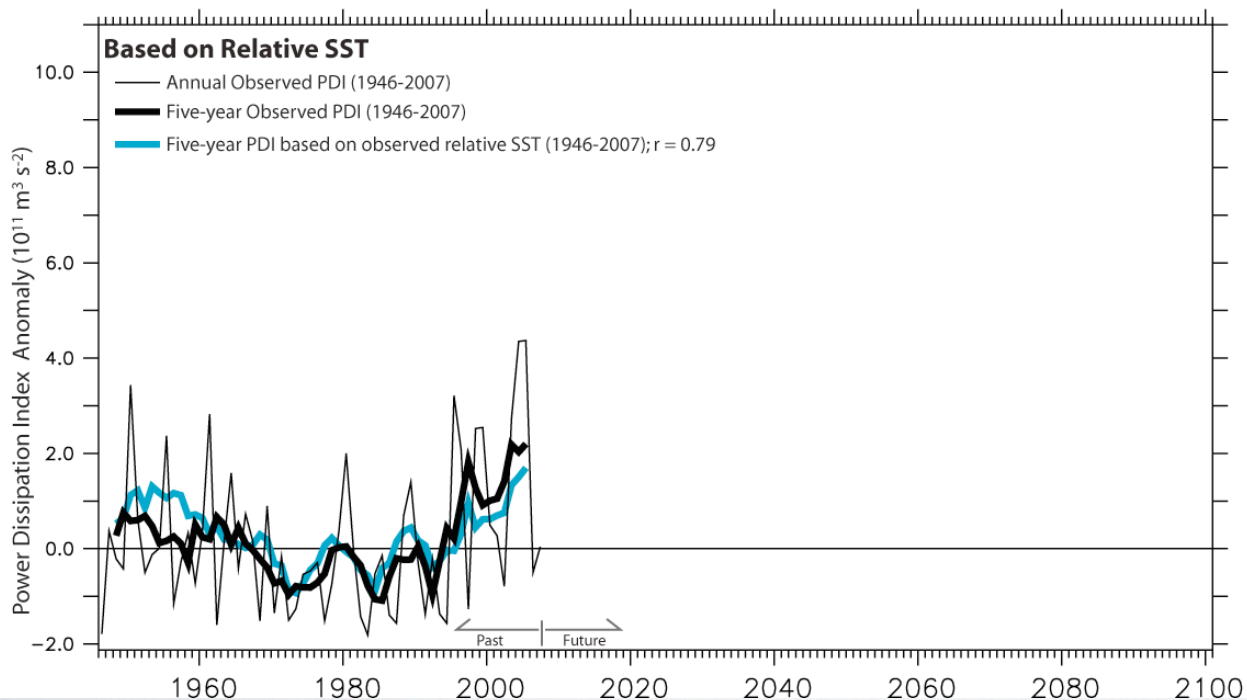
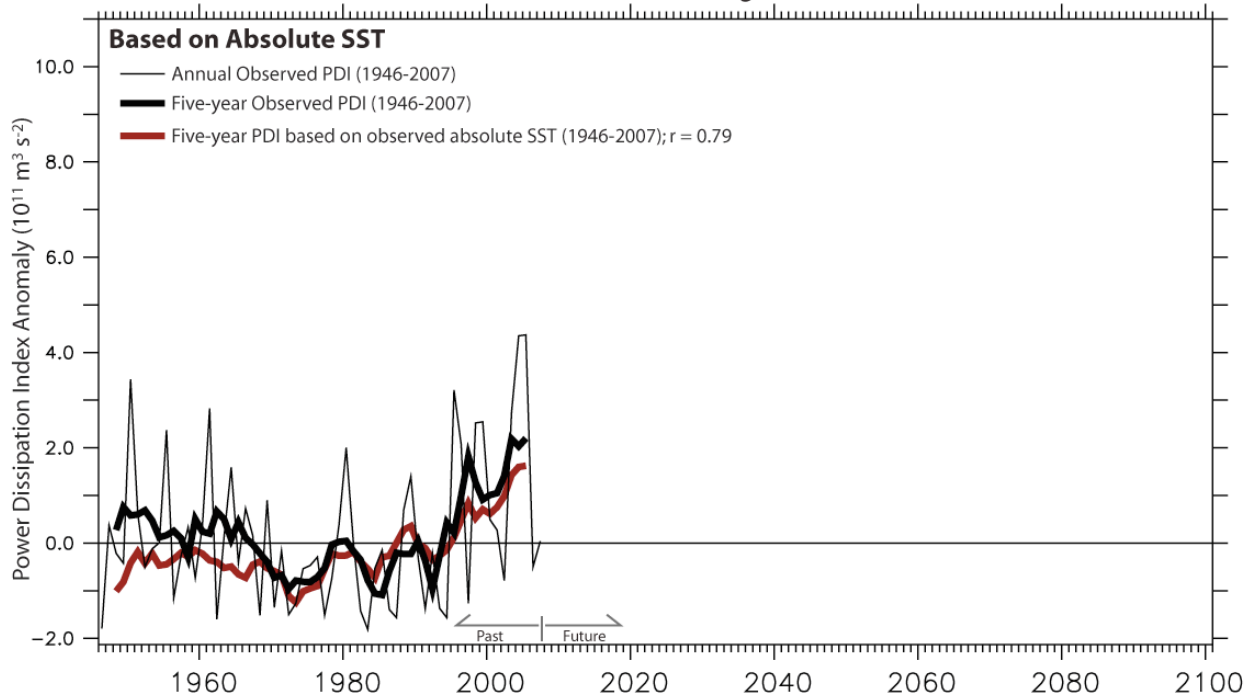
# POTENTIAL INTENSITY DOES NOT TRACK SST, BUT RELATIVE SST



Vecchi and Soden (2007, Nature)

# 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.

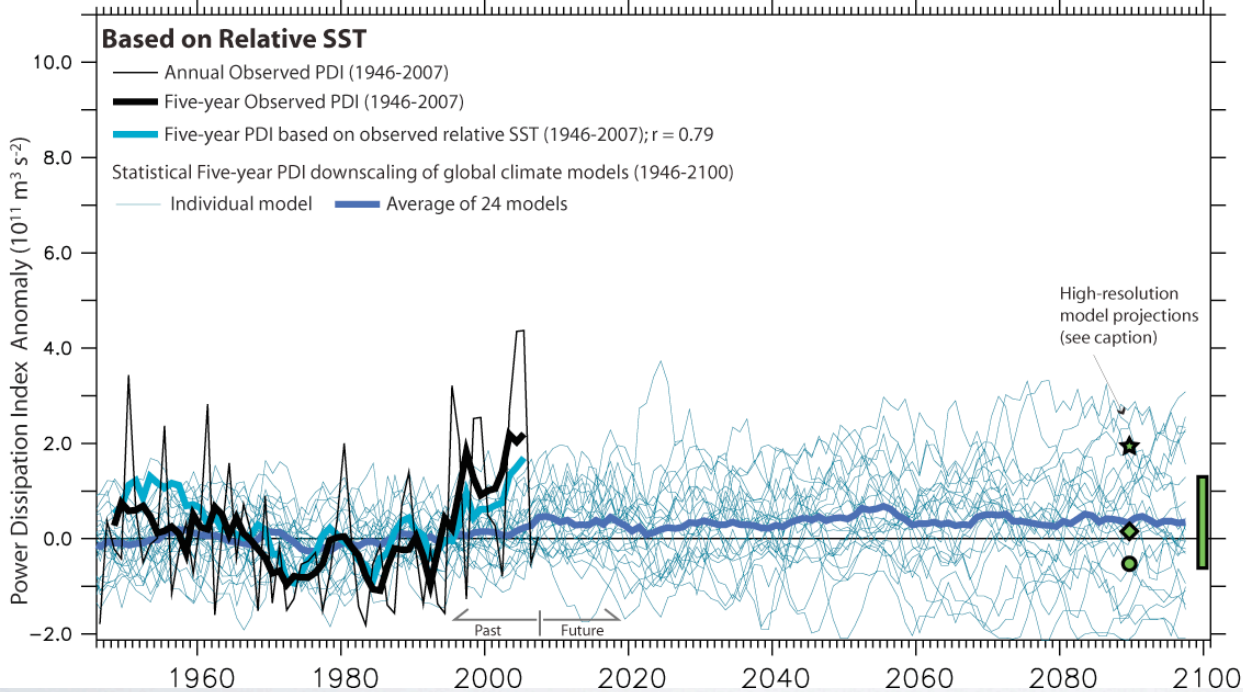
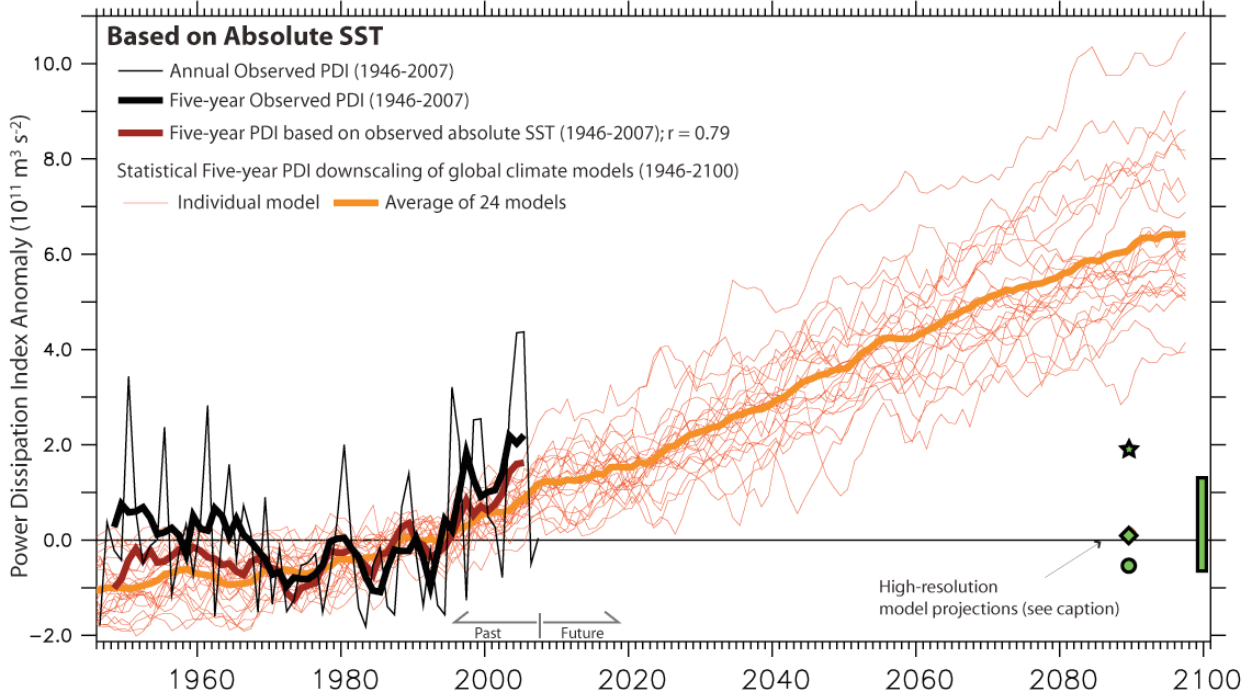
## Relative MDR SST If causal, cannot attribute.

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

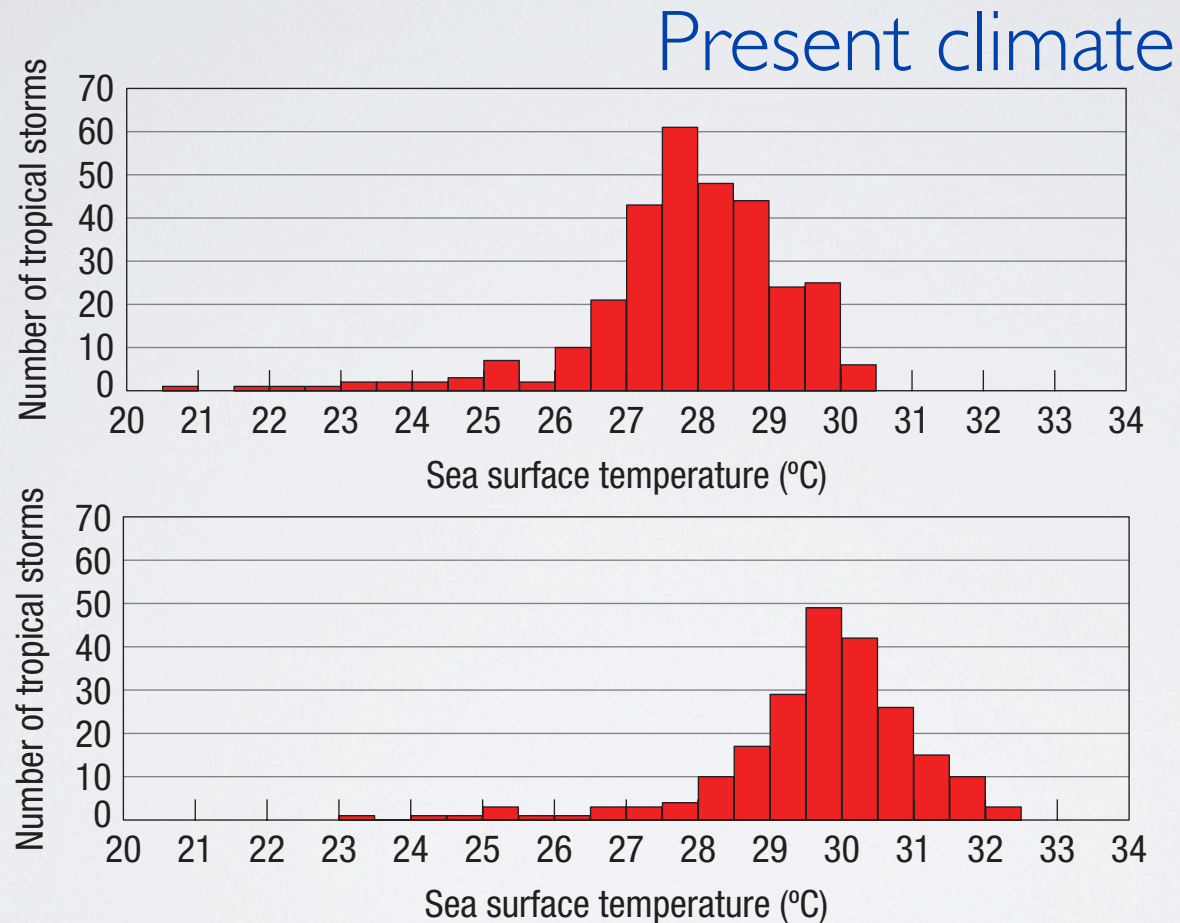
Emanuel et al (08), Knutson et al (08)  
 Oouchi et al (06), Bengtsson et al (07)

Relative SST  
 Model Rel. SST

Vecchi, Swanson and Soden  
 (2008, Science)

# TEMPERATURE “THRESHOLD” OF TC FORMATION INCREASES WITH GLOBAL WARMING

Ocean temperature when cyclone forms:

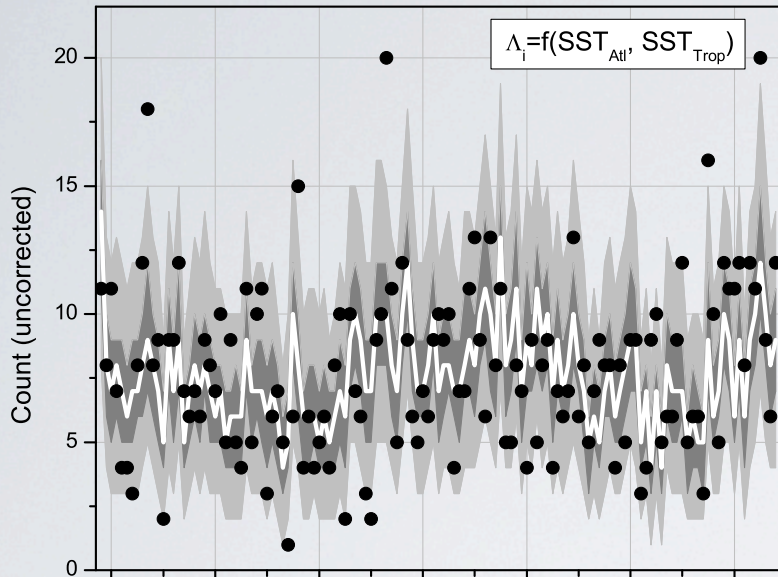


Shift is  
tropical-mean  
warming

Warmed climate



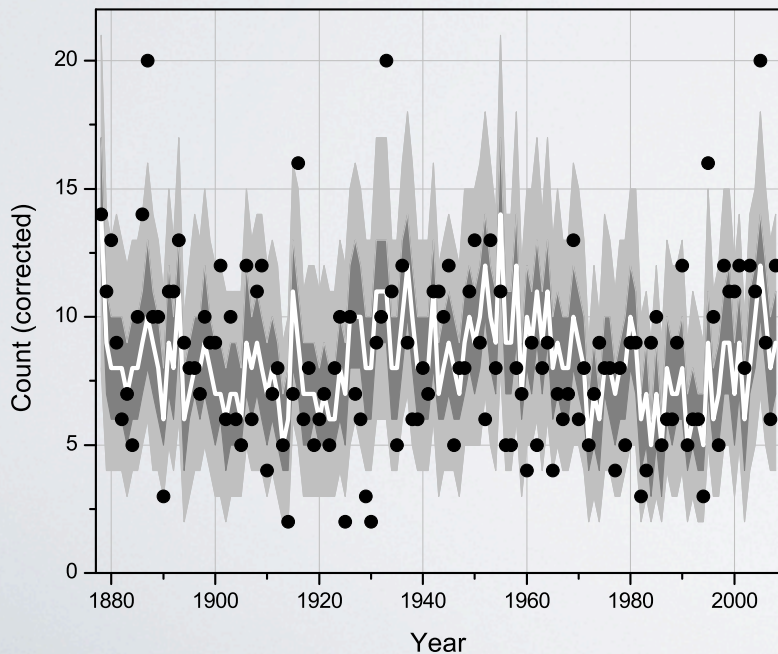
# Build statistical model of basin-wide tropical storms using Atlantic and Tropical-mean SST as covariates



Atlantic SST increases frequency.

Tropical-mean SST reduces frequency.

Factors in fit (w/standard error)

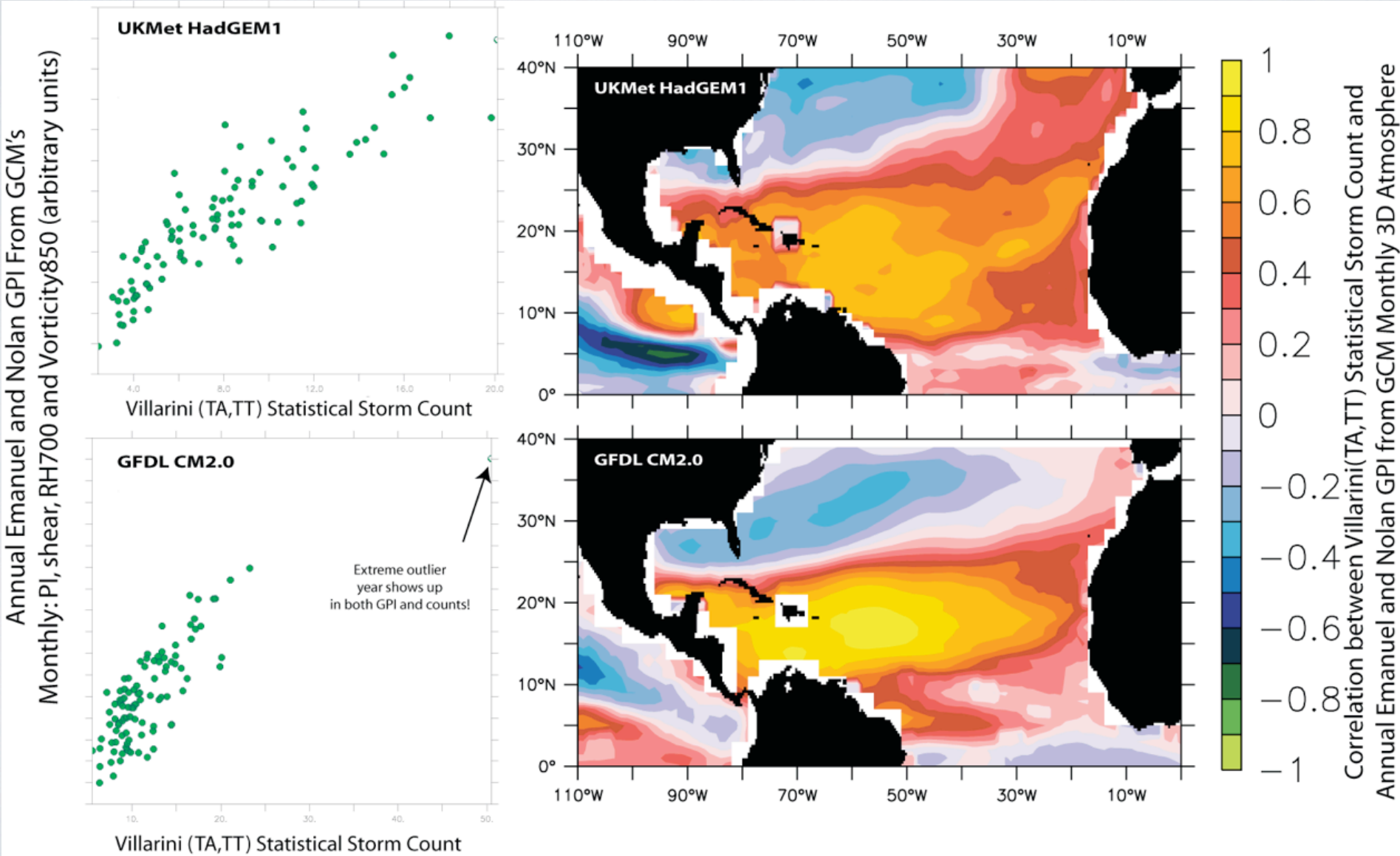


	Uncorrected	Corrected
Intercept	2.03 (0.03)	2.11 (0.03)
	2.03 (0.03)	2.10 (0.03)
$SST_{Atl}$	1.13 (0.20)	1.05 (0.15)
	1.05 (0.15)	1.02 (0.14)
$SST_{Trop}$	-0.98 (0.23)	-1.22 (0.22)
	-0.91 (0.20)	-1.05 (0.19)

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

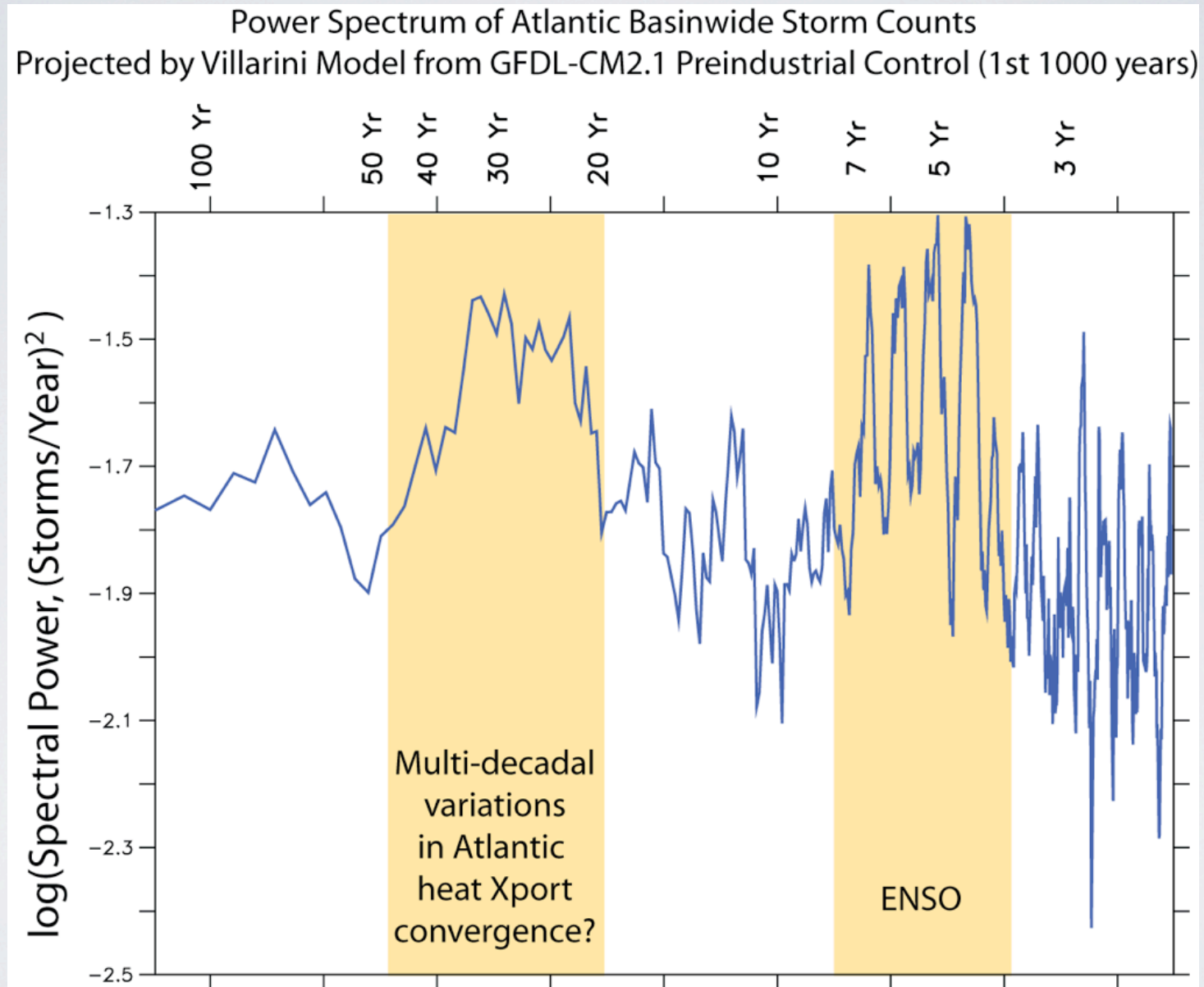
# Two SST index statistical model vs. complex (using shear, potential intensity, mid-trop RH, vorticity) statistical model applied to GCMs

Villarini et al (2010, MWR) model vs. Emanuel and Nolan (2004, AMS) model

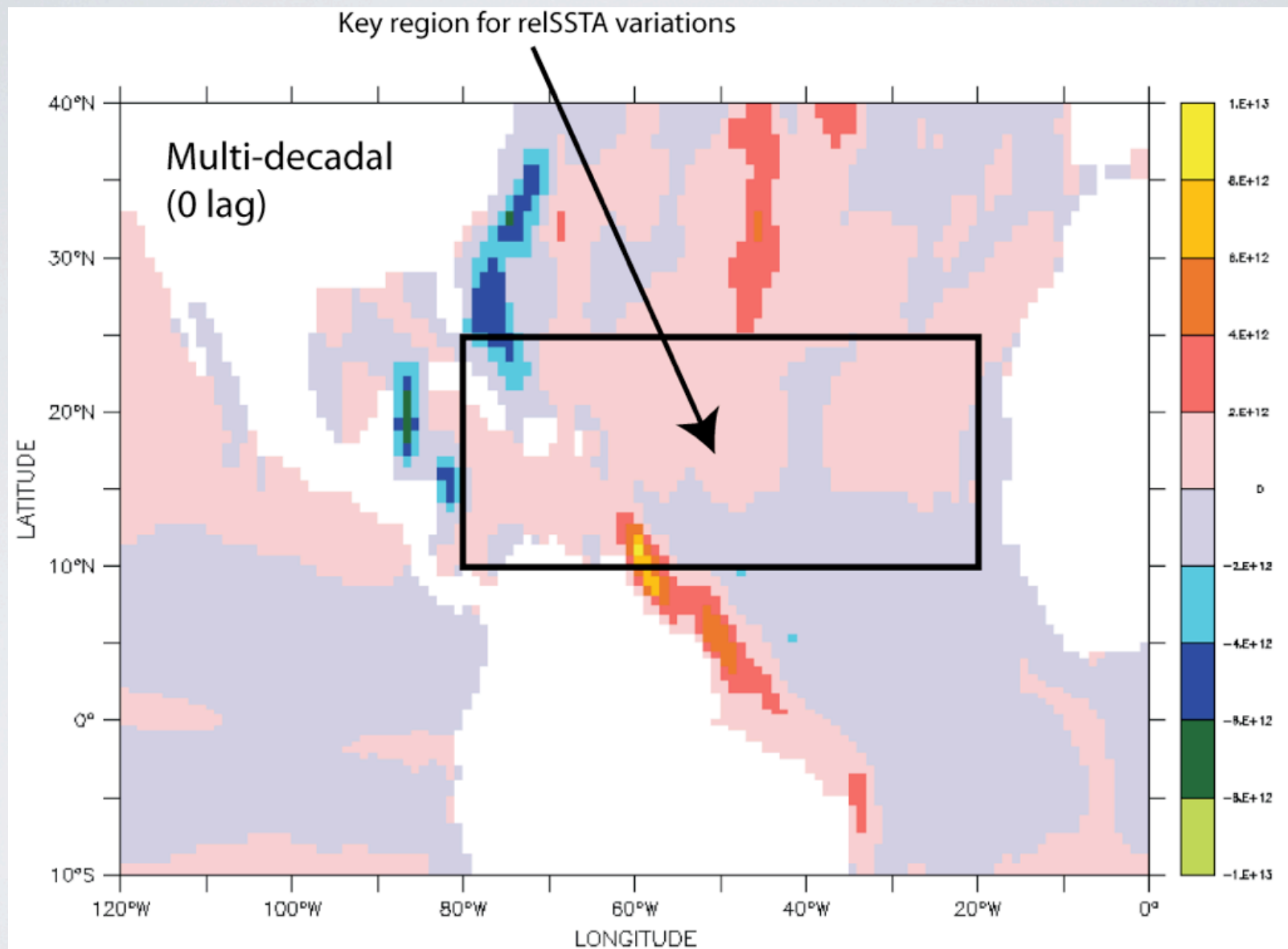




# Statistical downscaling of 2,000 year CM2.1 Control



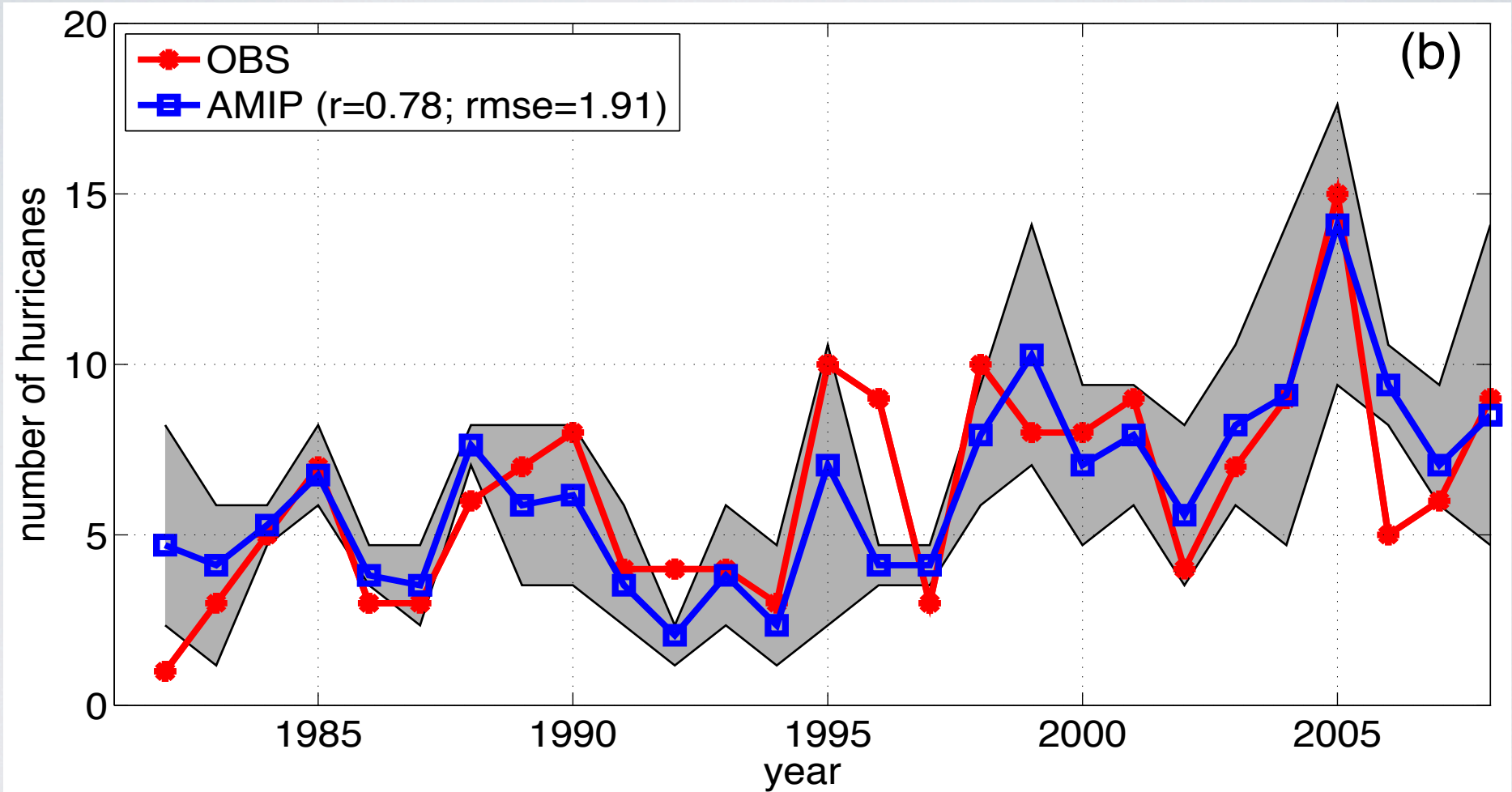
# Statistical counts and ocean heat transport



2000-Year Linear Least-squares Regression of Villarini Model Atlantic Basinwide TS Counts onto Vertically-integrated Meridional Ocean Heat Transport - CM2.1 Preindustrial Control



# HIRAM C180 AGCM FORCED WITH SSTs RECOVERS NA HURRICANE COUNTS

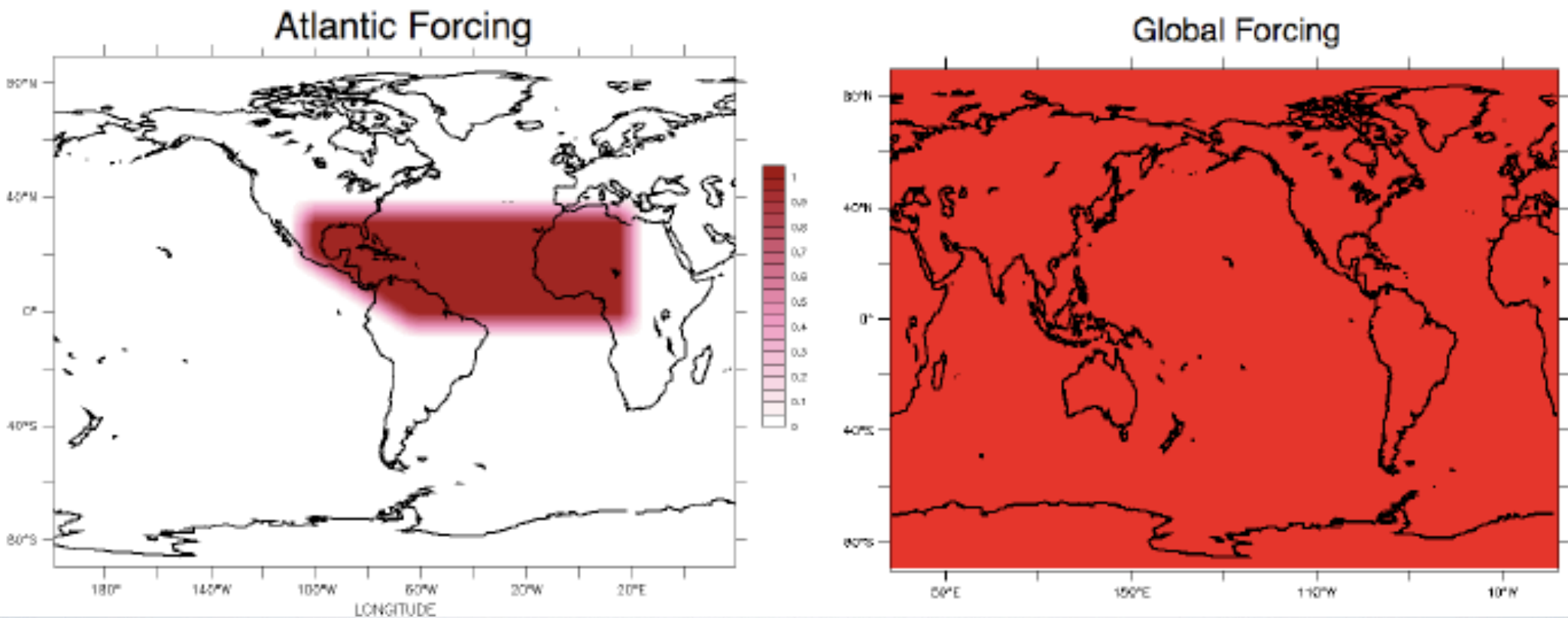


Zhao et al. (2009, J. Climate), Zhao et al. (2010, MWR, Sub.)

# IDEALIZED FORCING EXPERIMENTS

If local SST the dominant control, as opposed to relative SST:

- Similar Atlantic Response to Atlantic and Uniform F'cing
- Little Pacific Response to Atlantic compared to Uniform

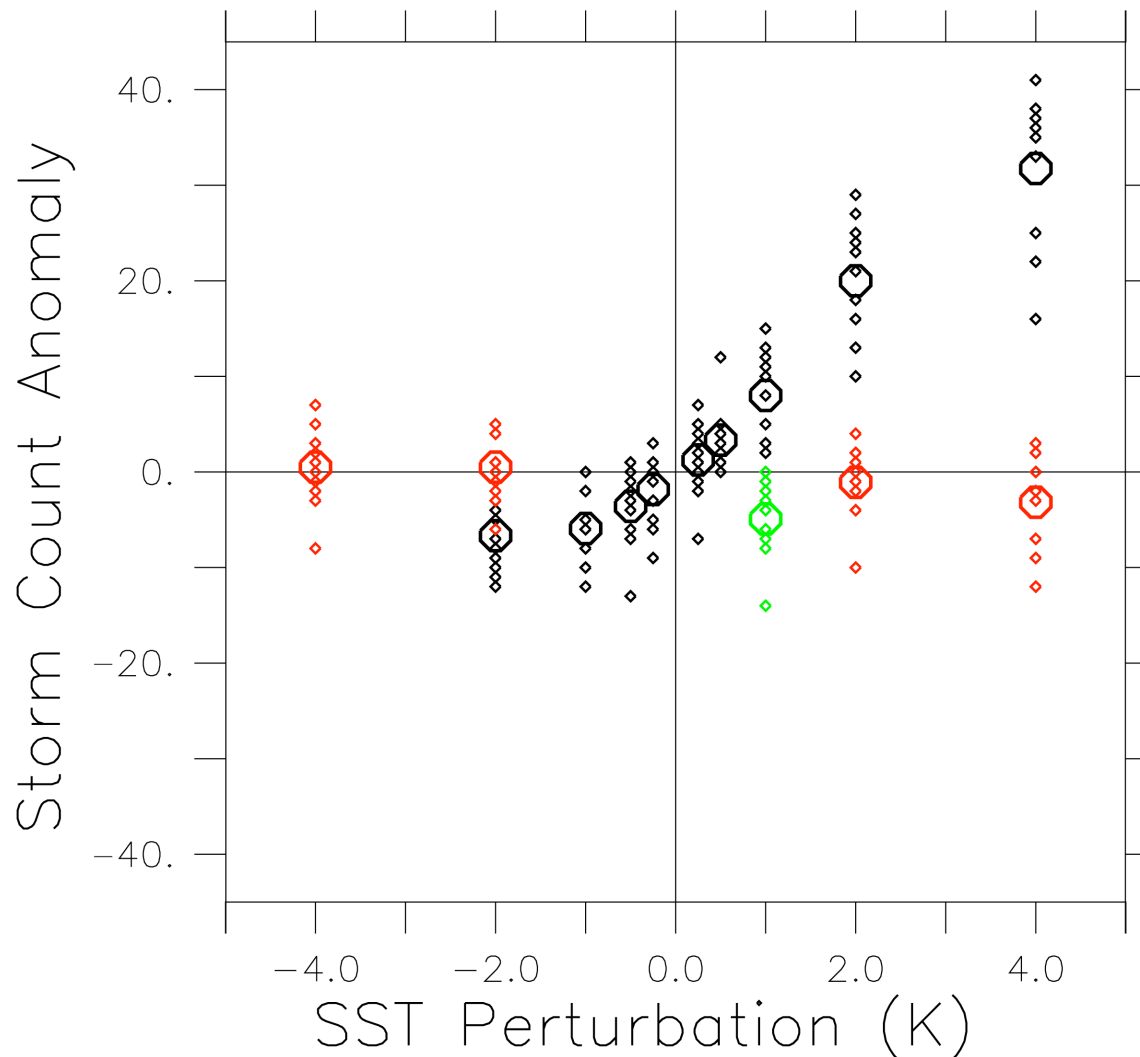




# NORTH ATLANTIC RESPONSE TO IDEALIZED SST

Change in Annual NA Storms from Idealized SST:

NATL, GLO, EQU



Atlantic Forcing

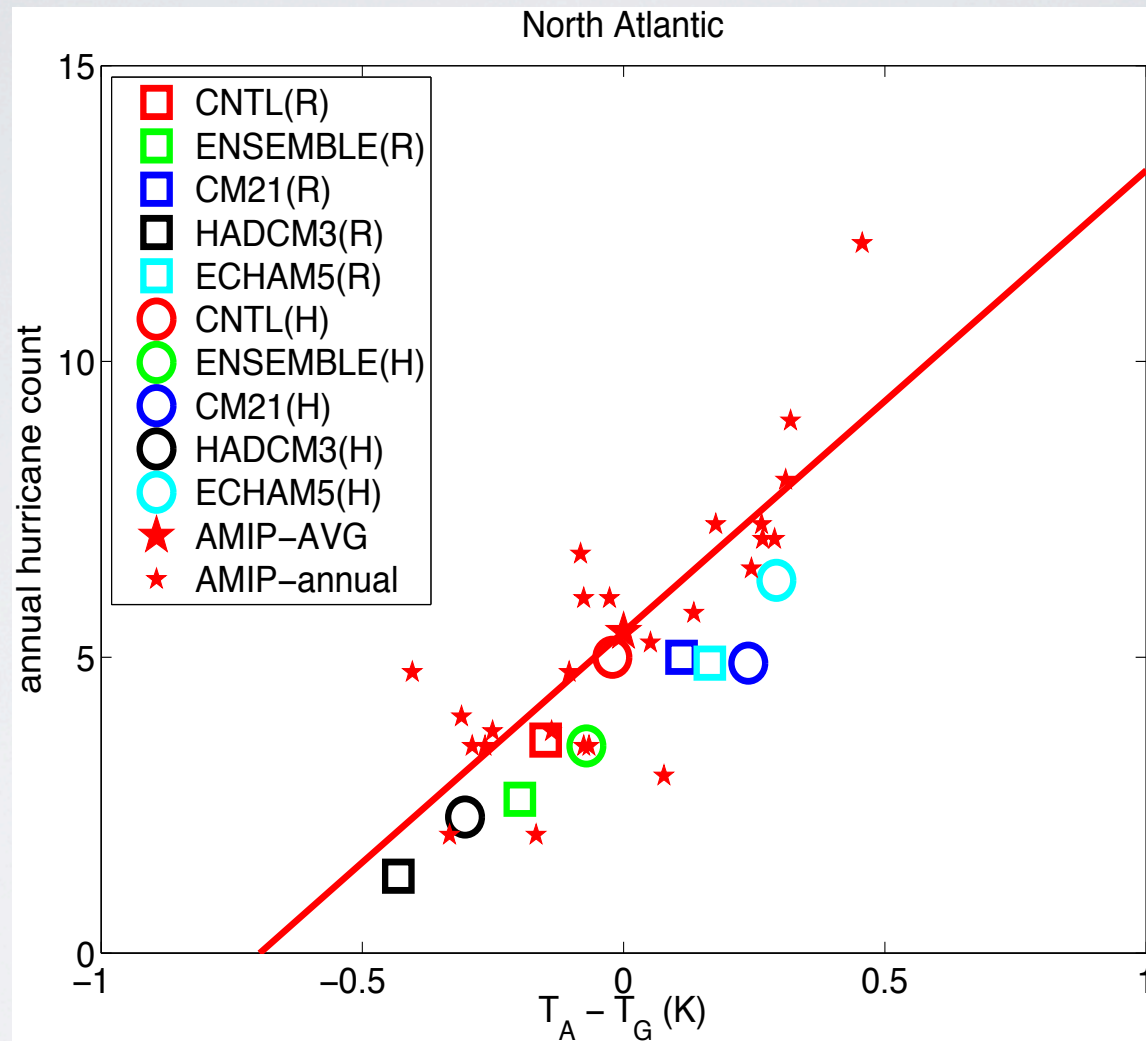
Uniform Forcing

Near-equatorial  
Forcing

Similar TS frequency  
response to:  
0.25° local warming  
4° global cooling

*Vecchi et al (2010, in prep.)*

# HIRAM C I 80 (AND OBSERVATIONS + CONTROLS TO LARGE-SCALE) SUGGEST RELATIVE SSTA SHOULD BE A GOOD HURRICANE INDEX

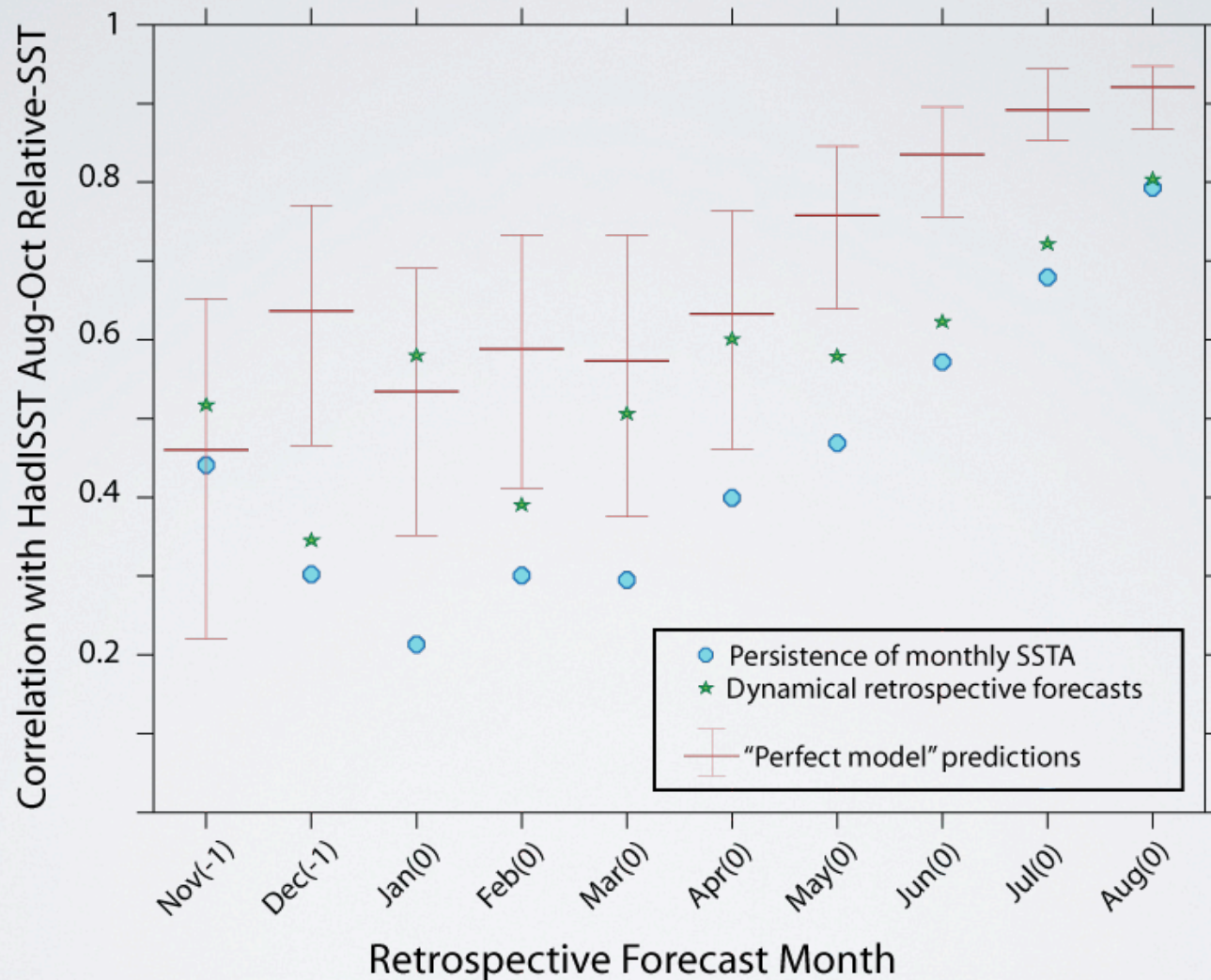


Zhao *et al.* (2009, *J. Climate*), Zhao *et al.* (2010, *MWR*, Sub.)  
&

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)



# GFDL-CM2.1 EXPERIMENTAL SEASONAL-INTERANNUAL FORECAST SYSTEM SUGGESTS RELATIVE-SST MAY BE PREDICTABLE



Forecast and initialization system of Zhang et al (2007, MWR)

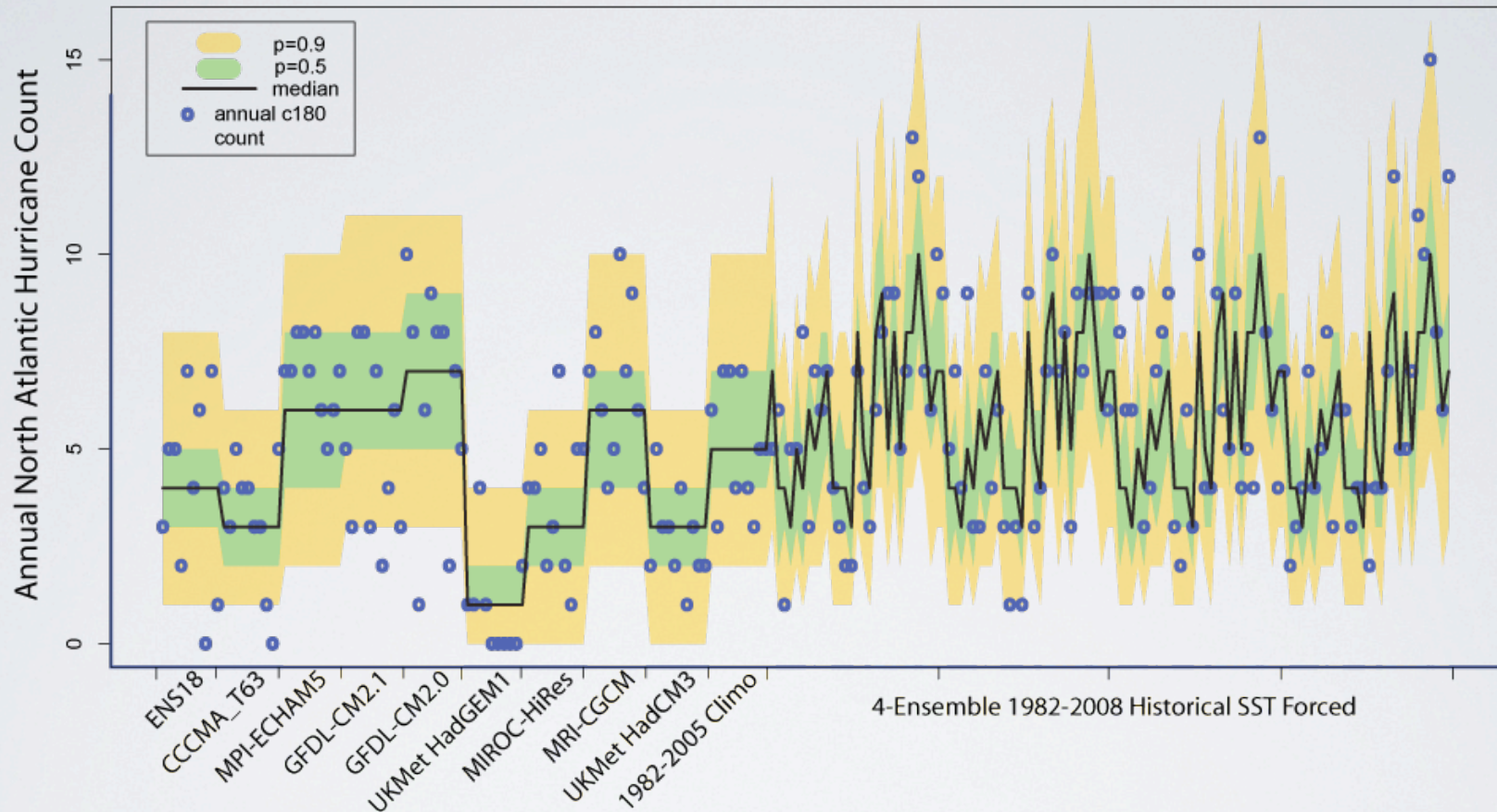
# BUILD A SEASONAL HURRICANE FREQUENCY FORECAST SCHEME

- 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 forecast to 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



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

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

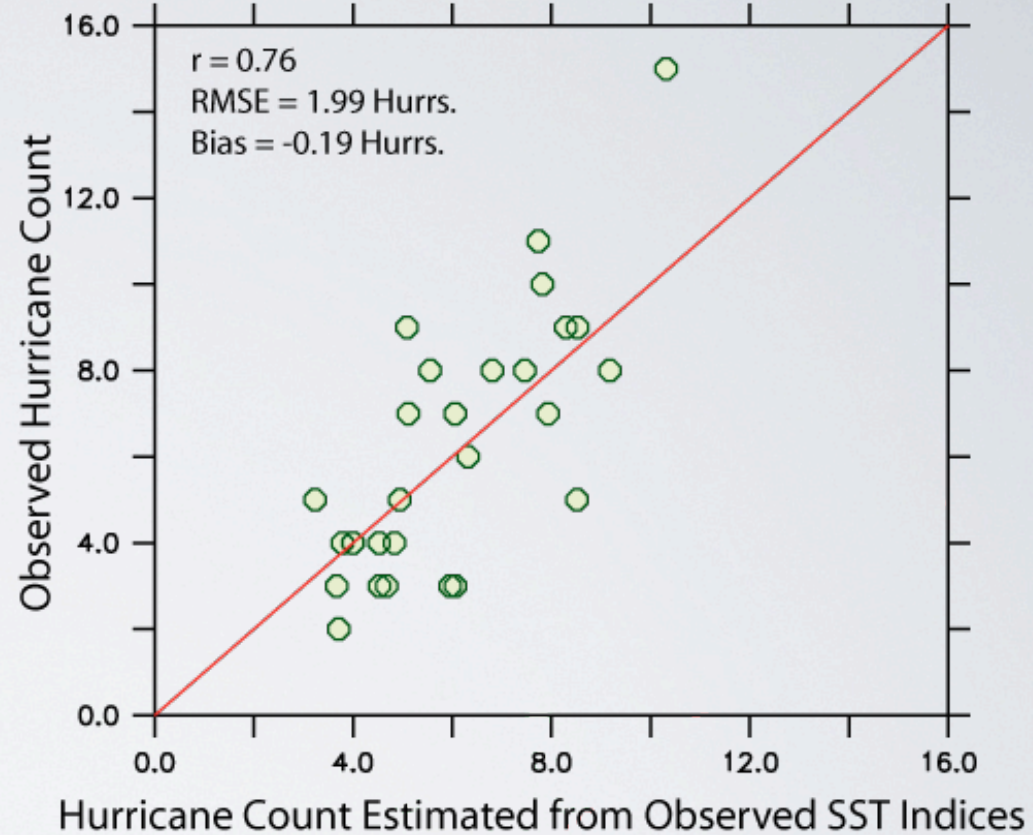
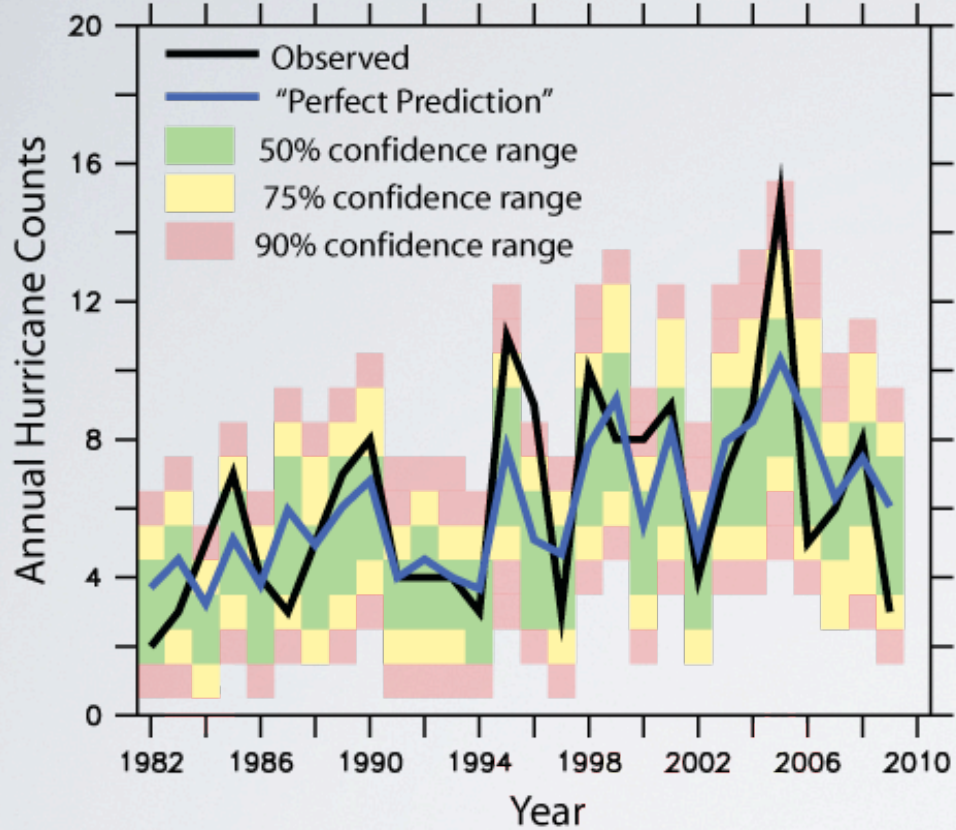
Vecchi *et al.* (2010, in prep.)

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



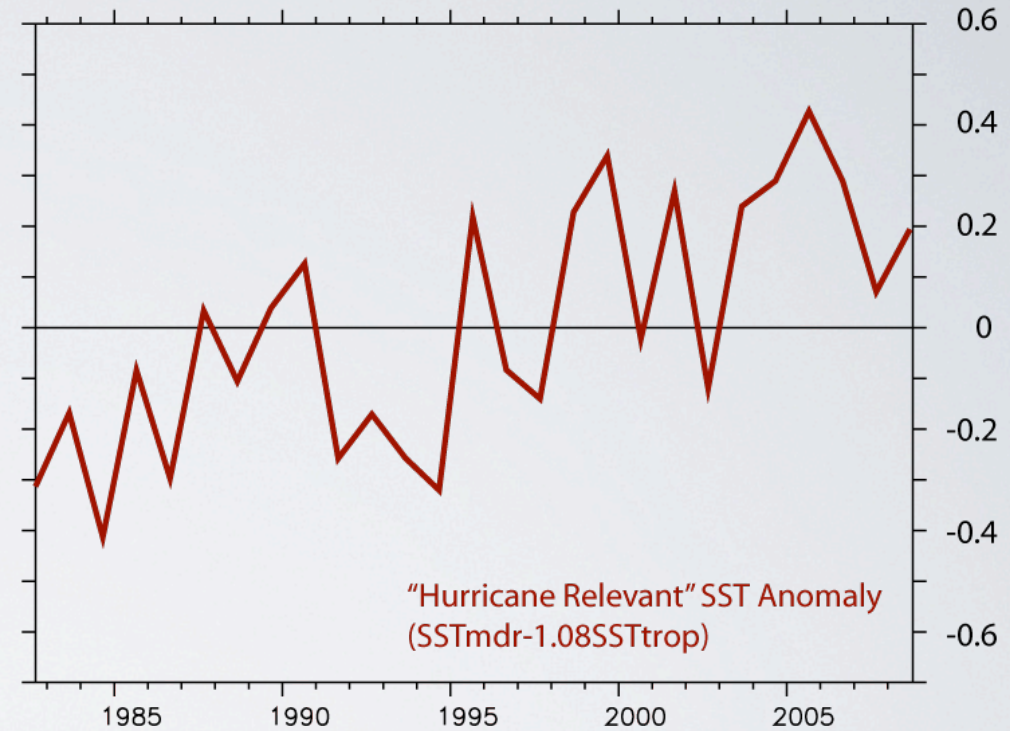
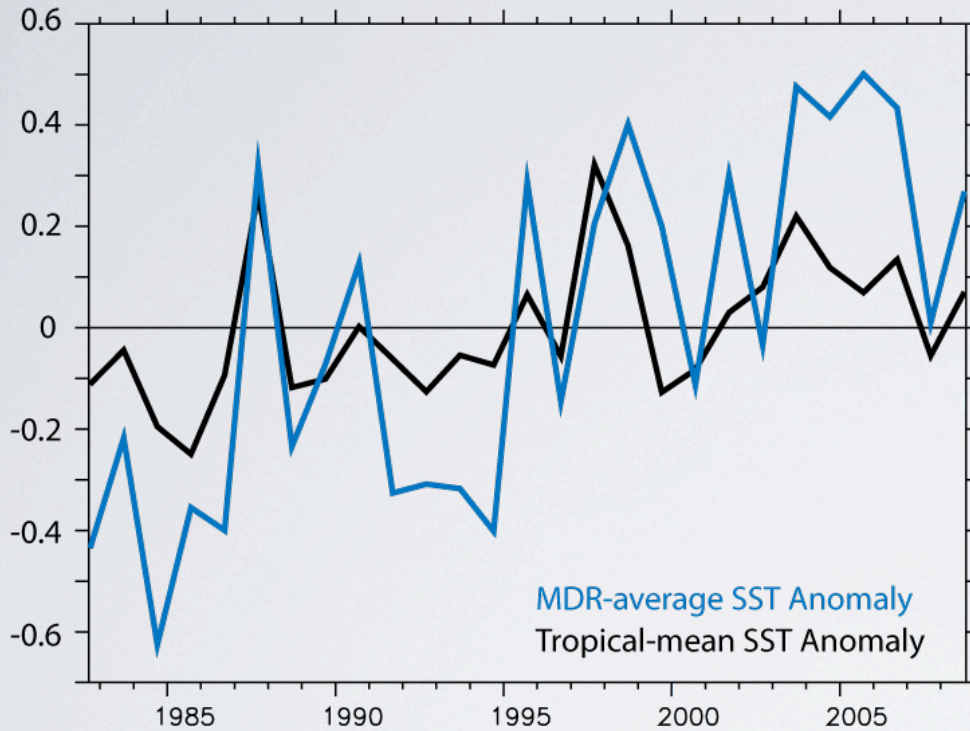
# FIT OF HIRAM-C I 80 EMULATOR TO OBS. PERFORMS WELL

## Application of Hurricane Frequency Statistical Model to Observed SST Indices



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

# 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.



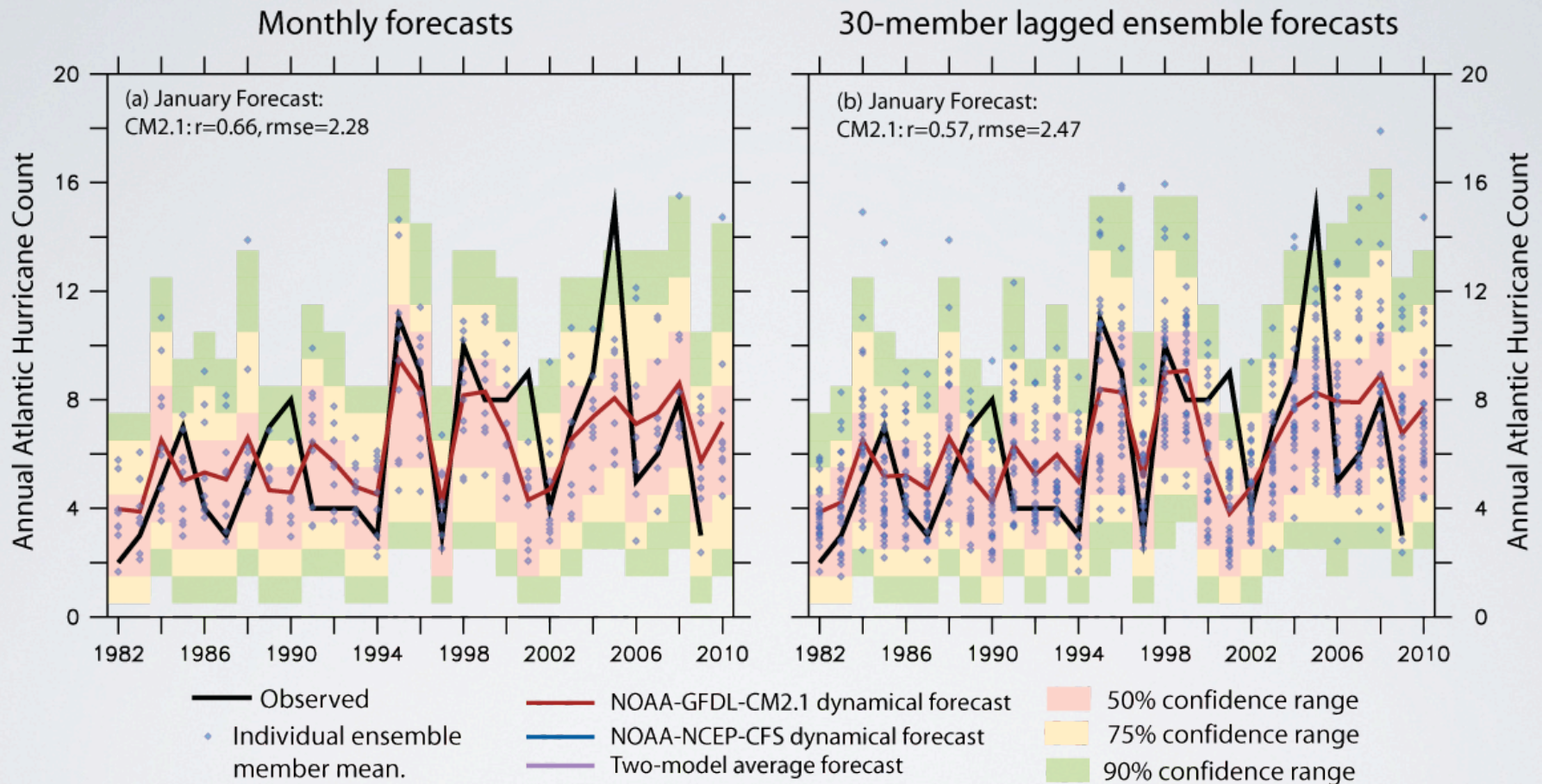
# EXPLORE TWO SYSTEMS TO FORECAST THE SST INDICES

- 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



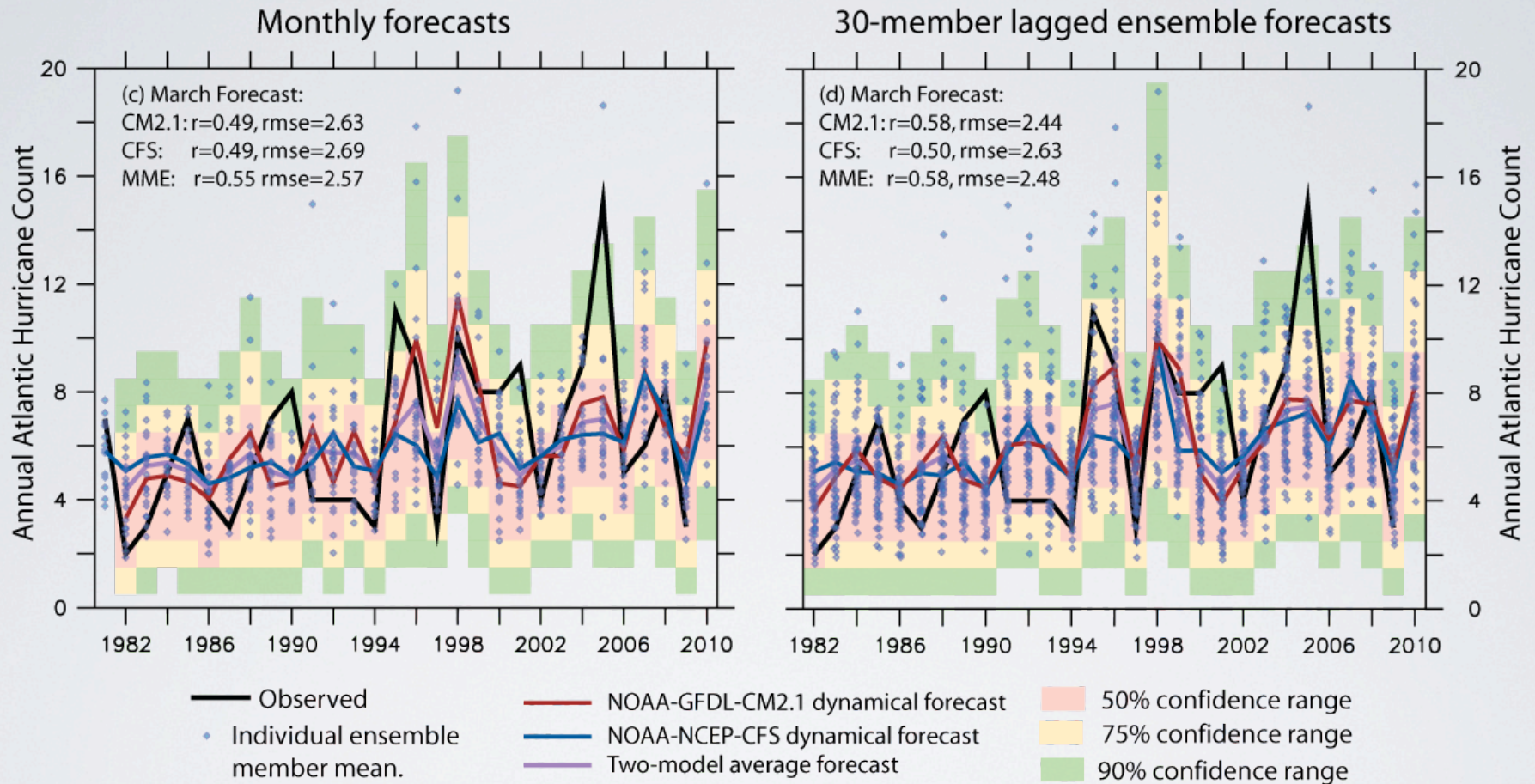
$$p(C=k) = \int_{-\infty}^{\infty} p(C=k \mid \text{relSSTA}=x) \cdot p(\text{relSSTA}=x) dx$$

$p(\text{relSSTA}=x)$  from CM2.1 ensemble

Vecchi *et al.* (2010, in prep.)



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



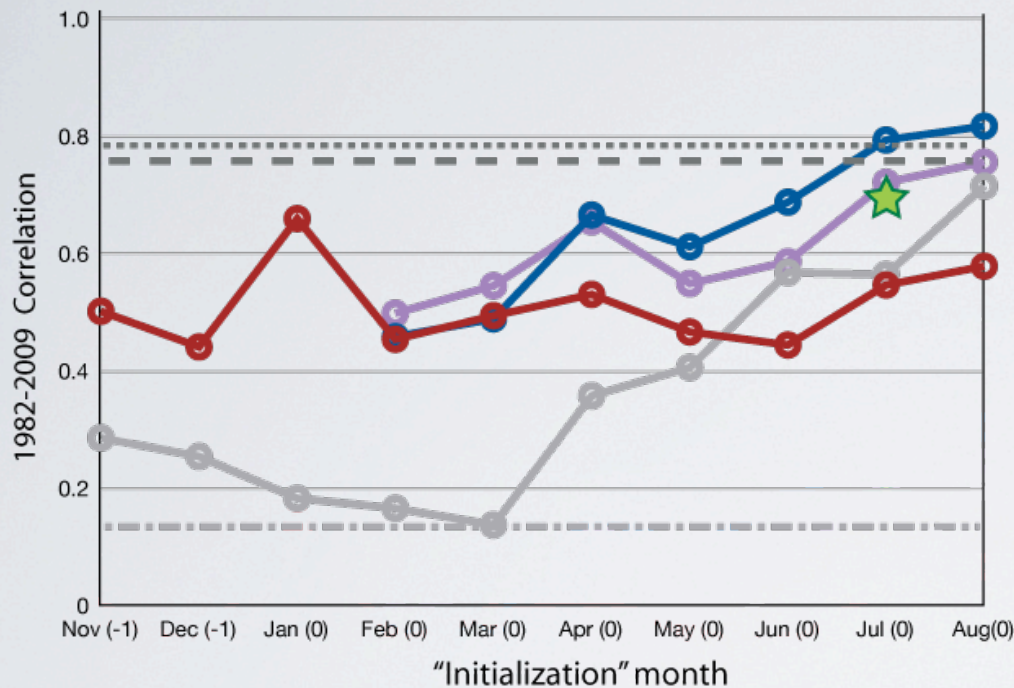
$$p(C=k) = \int_{-\infty}^{\infty} p(C=k \mid relSSTA=x) \cdot p(relSSTA=x) dx$$

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

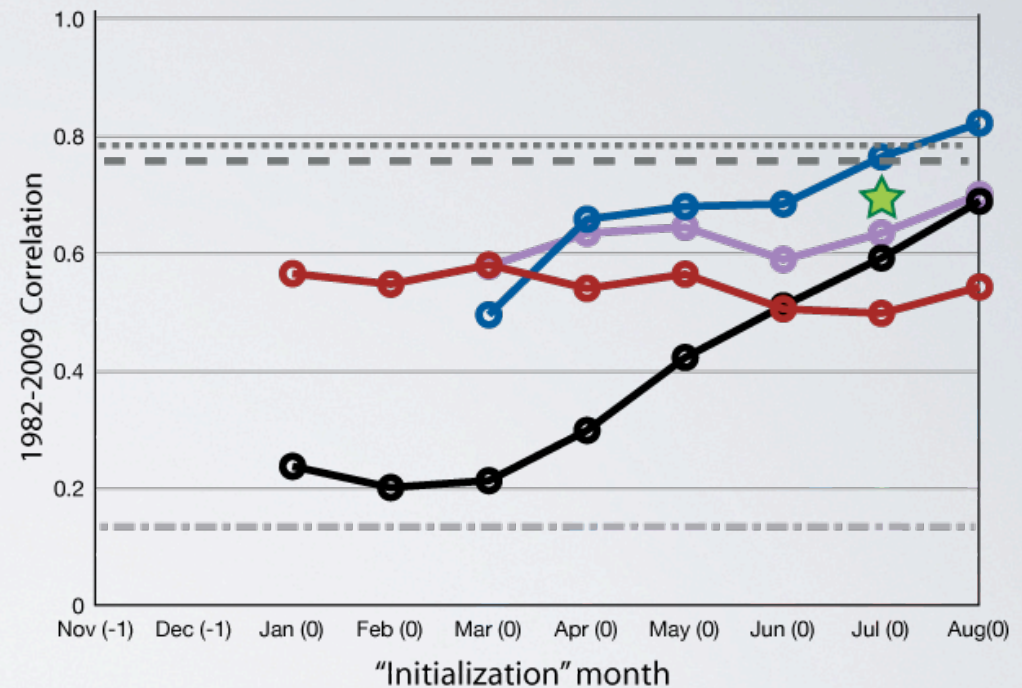
Vecchi *et al.* (2010, in prep.)

# 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, in prep.)



# SYSTEM INDICATES ACTIVE 2010

	<i>Mean Count (hurr)</i>	<i>Median (hurricanes)</i>	<i>p(count&gt;6)</i>	<i>p(count&gt;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

## 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 (SSTMDR and SSTTROP) 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.
- Skill in retrospective hurricane frequency forecasts from CFS for short leads is “better than perfect”
- Room for improvement in SST forecasts that would lead to improved hurricane outlooks.
- How far back can we push it? Was 1982-2009 exceptionally predictable?