# EXPERIMENTAL S-I HURRICANE FORECASTS FROM WINTER

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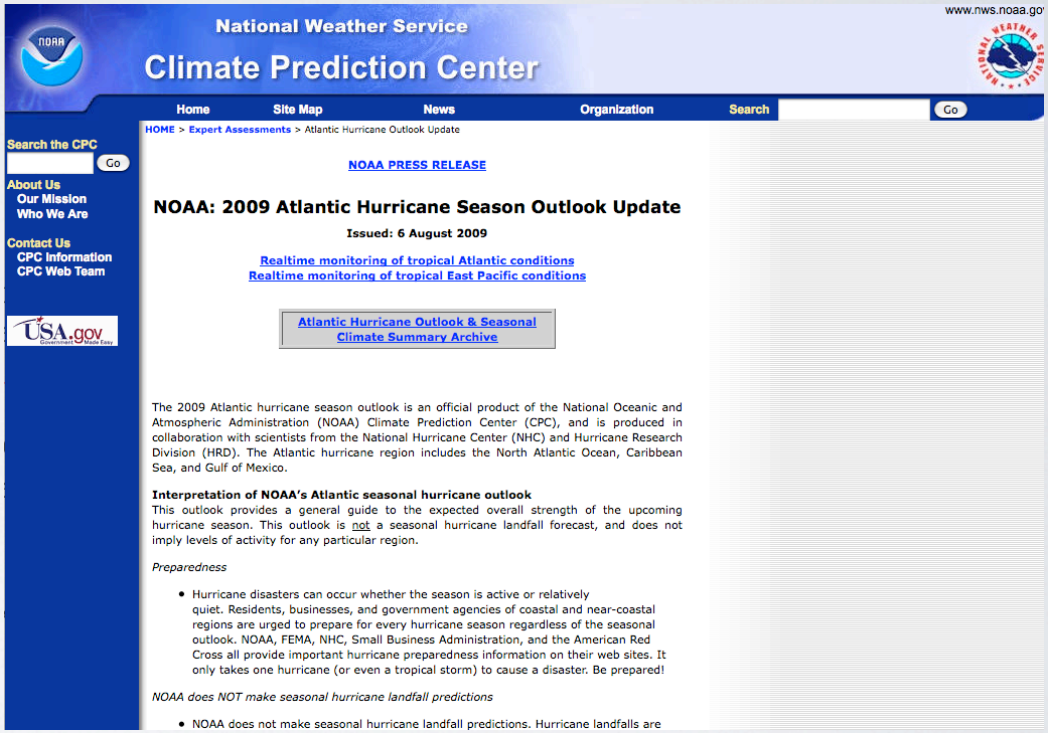
# Seasonal Hurricane Forecasts Initialized in Boreal mid-Spring to early-Summer Are: Feasible, Potentially Skillful and Made

- 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)



# 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**

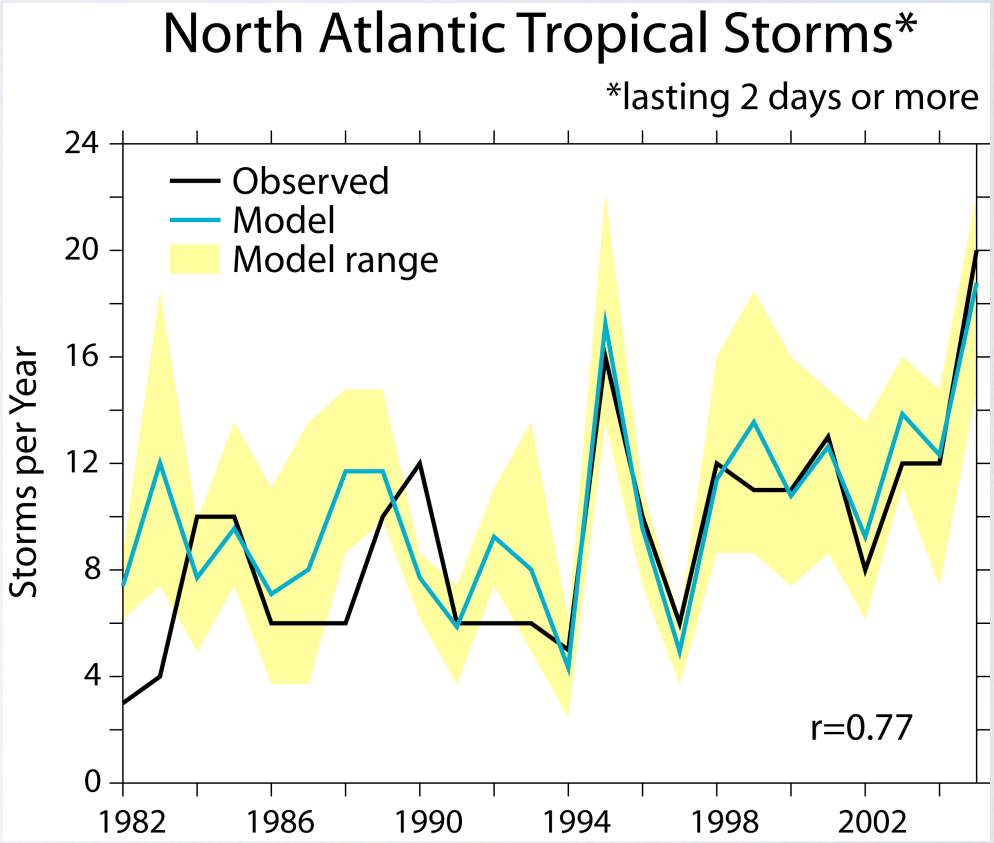
# GFDL C-X HIRAM GCMS

Family of global atmospheric models designed for better-representing tropical cyclone frequency. **C90 - 1°, C180=1/2°**, C360=1/4°, C720=1/8°

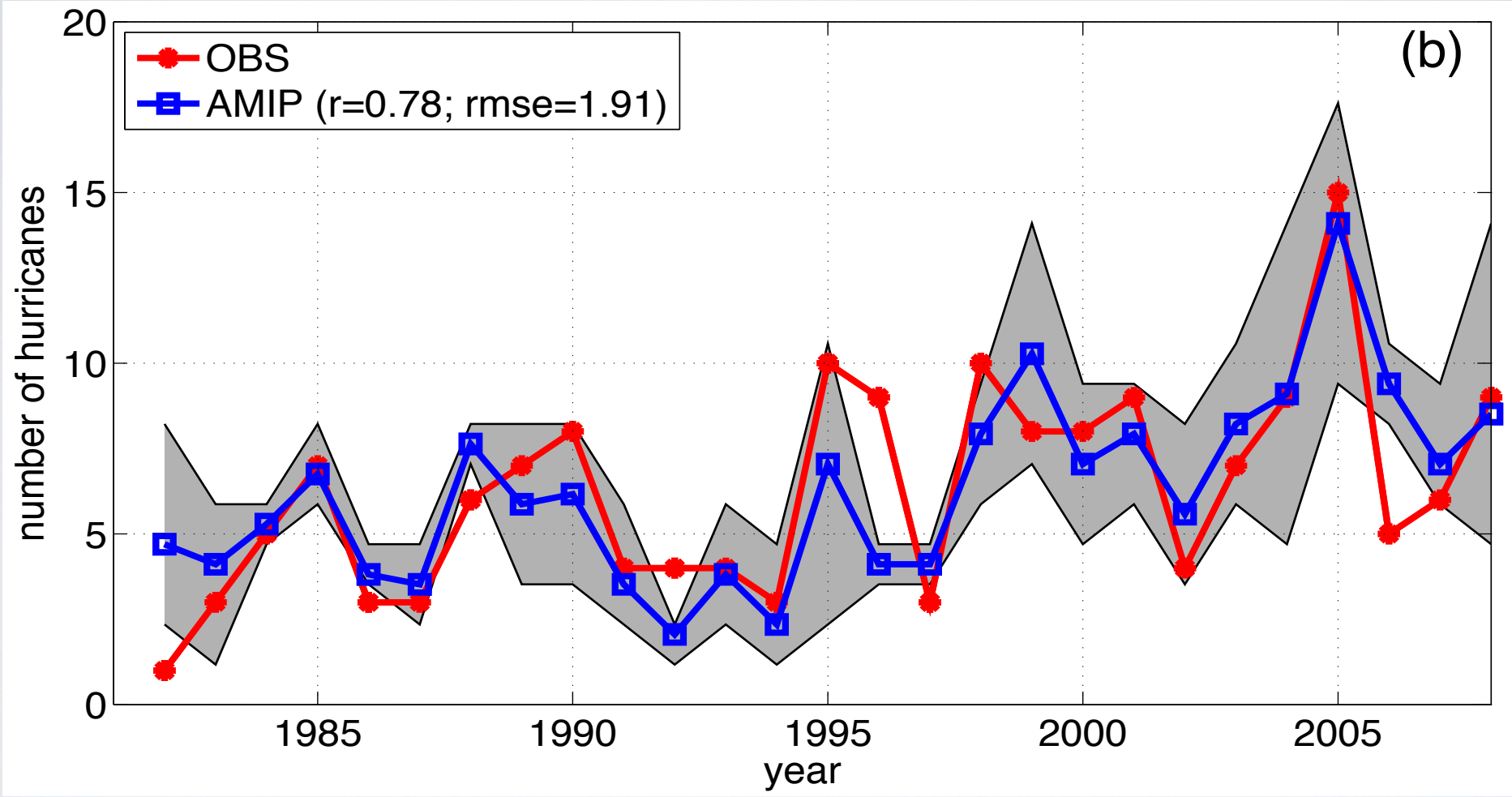
*Ref. Zhao et al (2009, J. Climate; 2010, MWR)*

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°

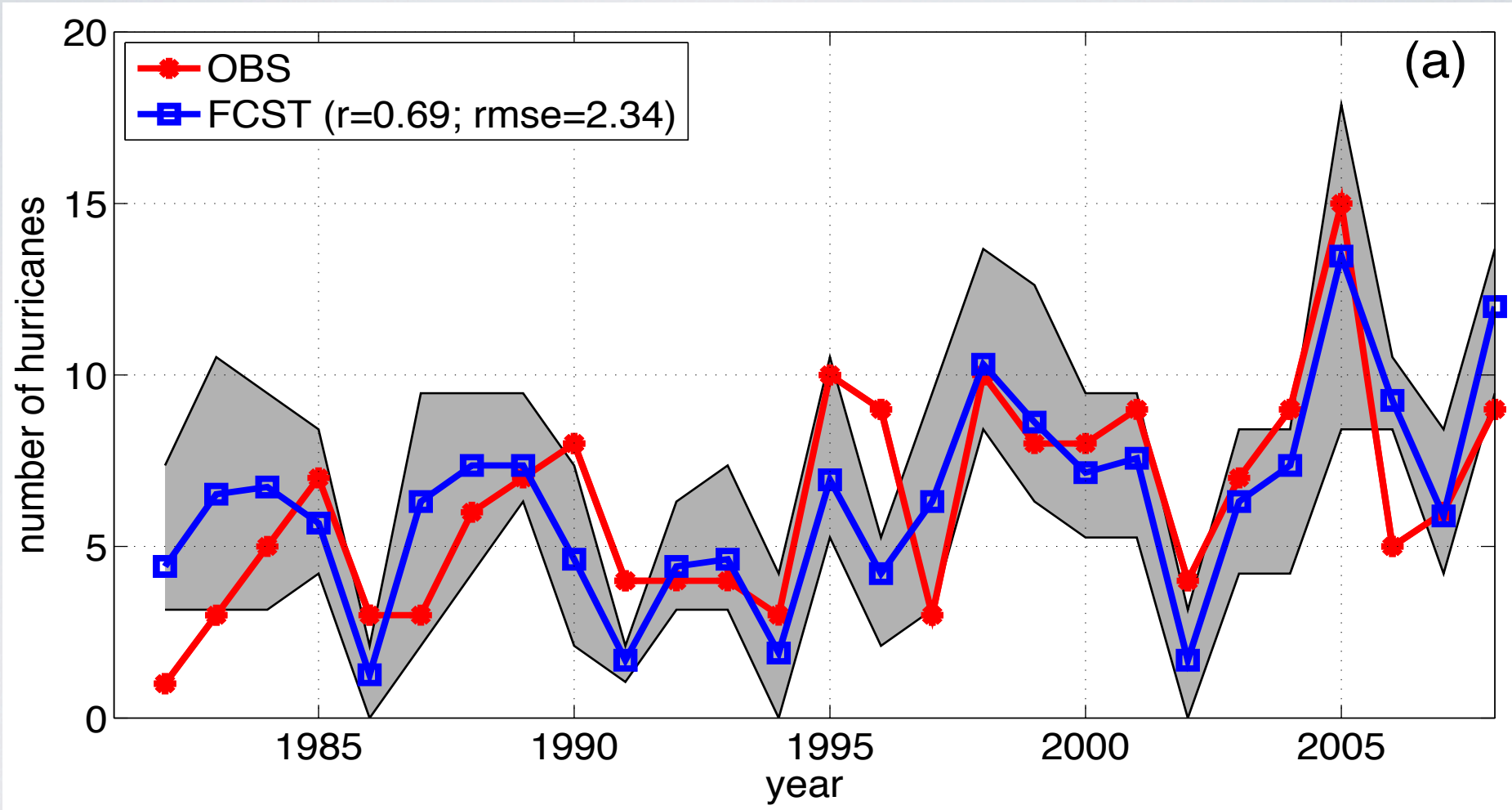


# HiRAM C180 AGCM Forced with SSTs Recovers NA Hurricane Counts




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.)

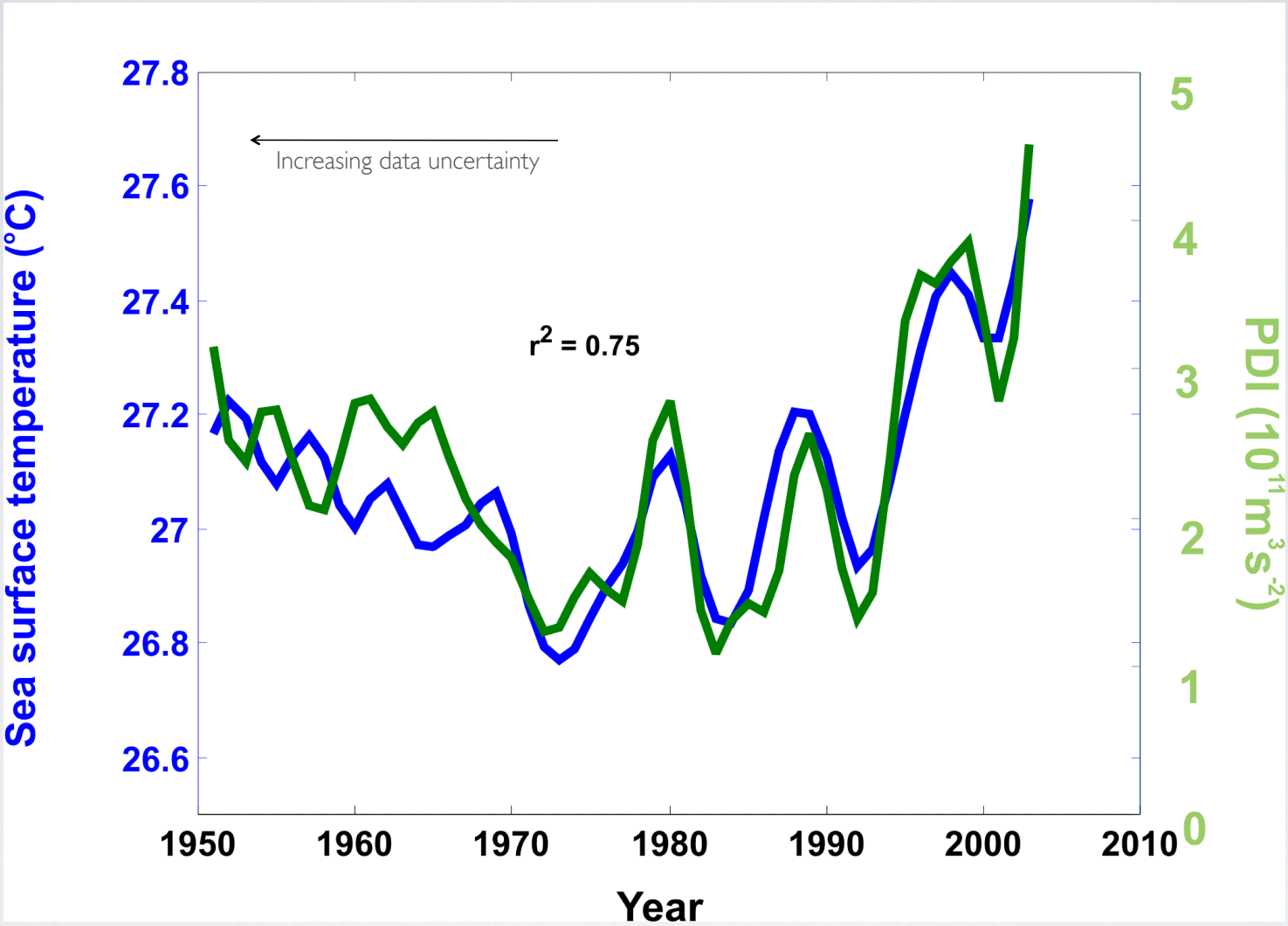
Cost of Running Thousands of Retrospective Forecasts with HiRAM-C180 is Prohibitive.

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-C180 suggests we should look at SST,
but what part of SST?

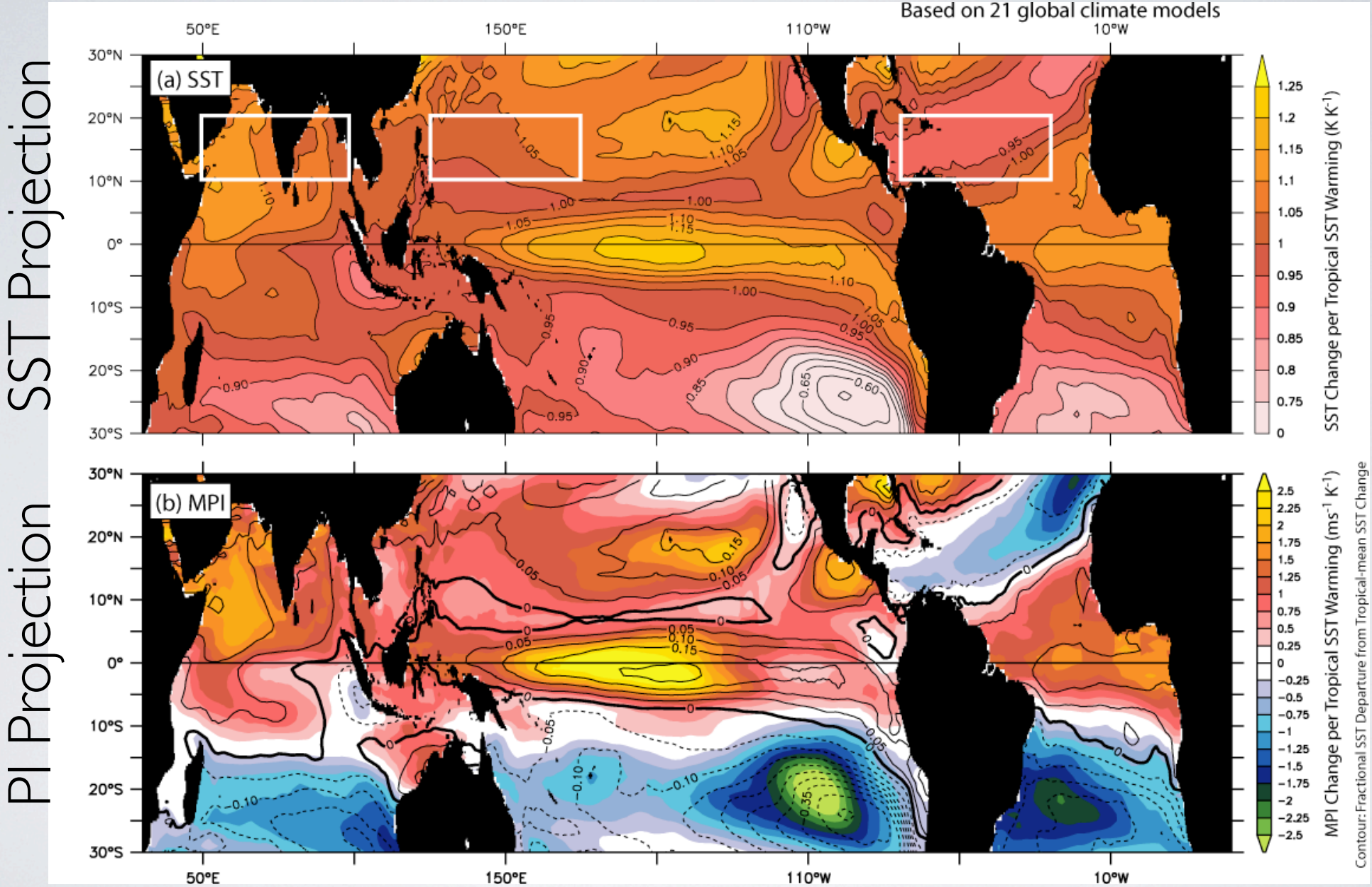
# Look at Atlantic SST



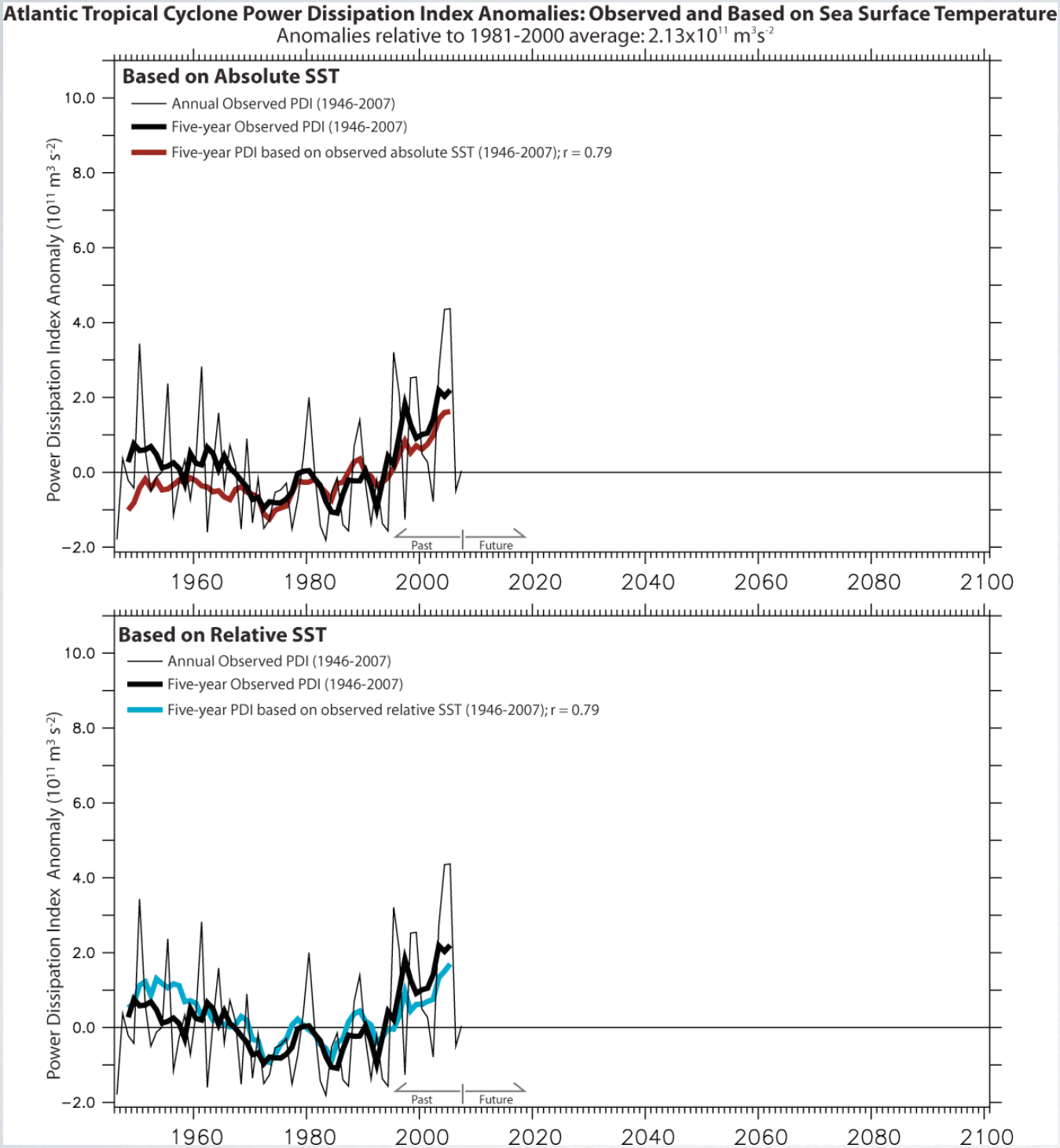

Source: Emanuel, J. Climate (2007).

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)




# Observed Activity

## Absolute MDR SST

see also Emanuel (2005)

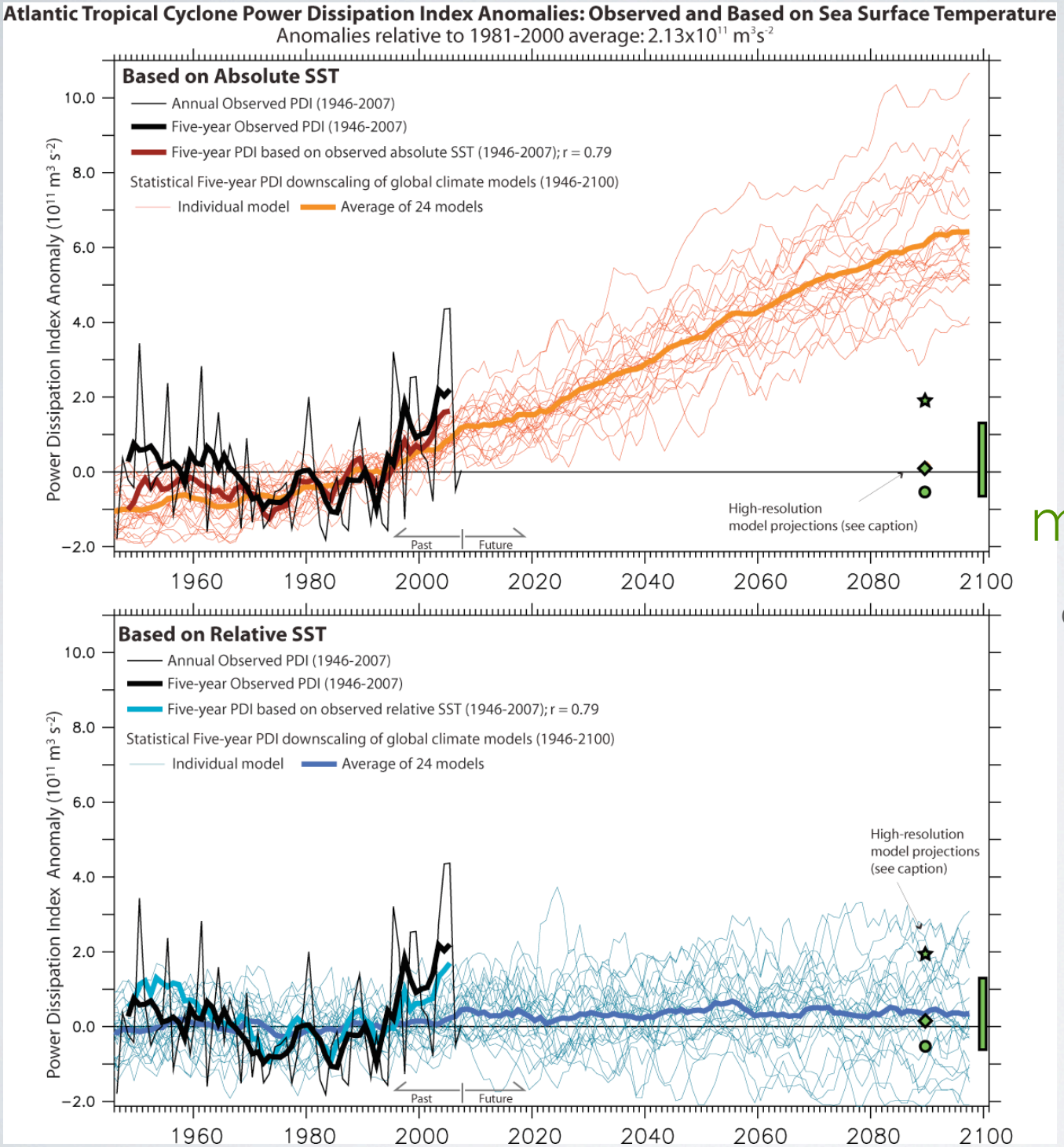
If causal, can attribute to GHG.

## Relative MDR SST

If causal, cannot attribute.

see also Swanson (2008)

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




# 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

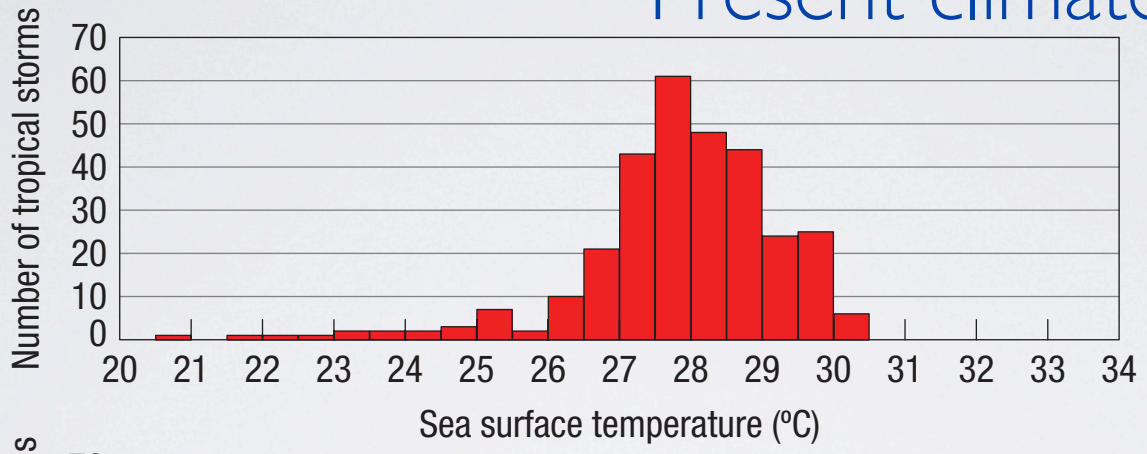
## Model Rel. SST

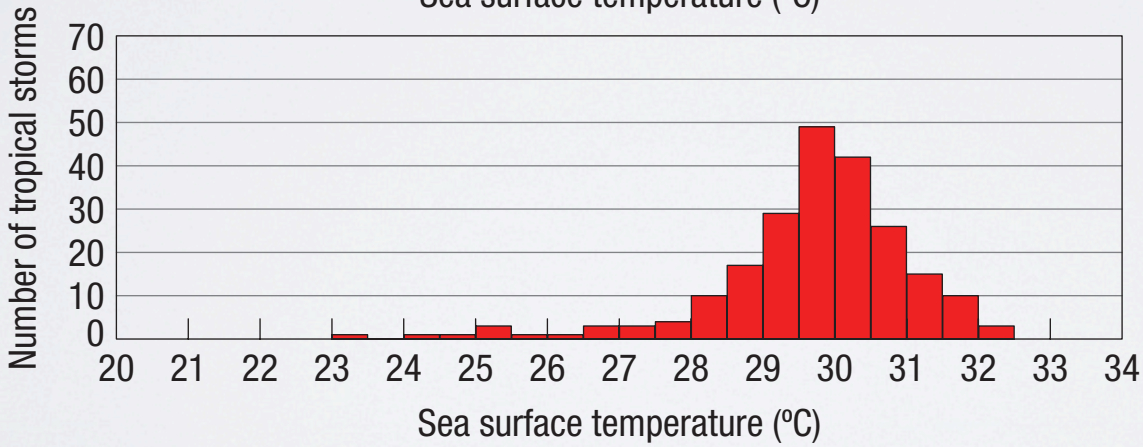
*Vecchi, Swanson and Soden (2008, Science)*

# TEMPERATURE "THRESHOLD" OF TC FORMATION INCREASES WITH GLOBAL WARMING

## Ocean temperature when cyclone forms:

Present climate



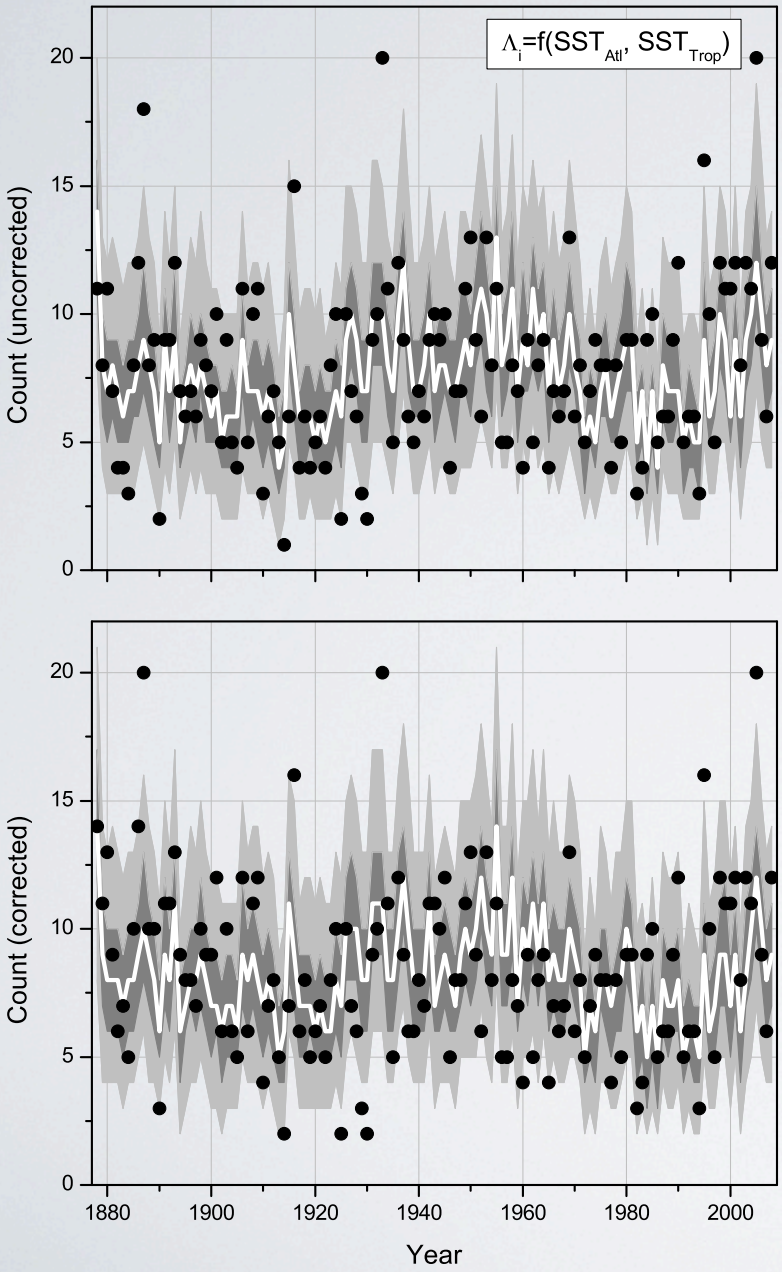




Warmed climate

Shift is tropical-mean warming

*Knutson et al (2008, Nat. Geosci.)*

# 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.

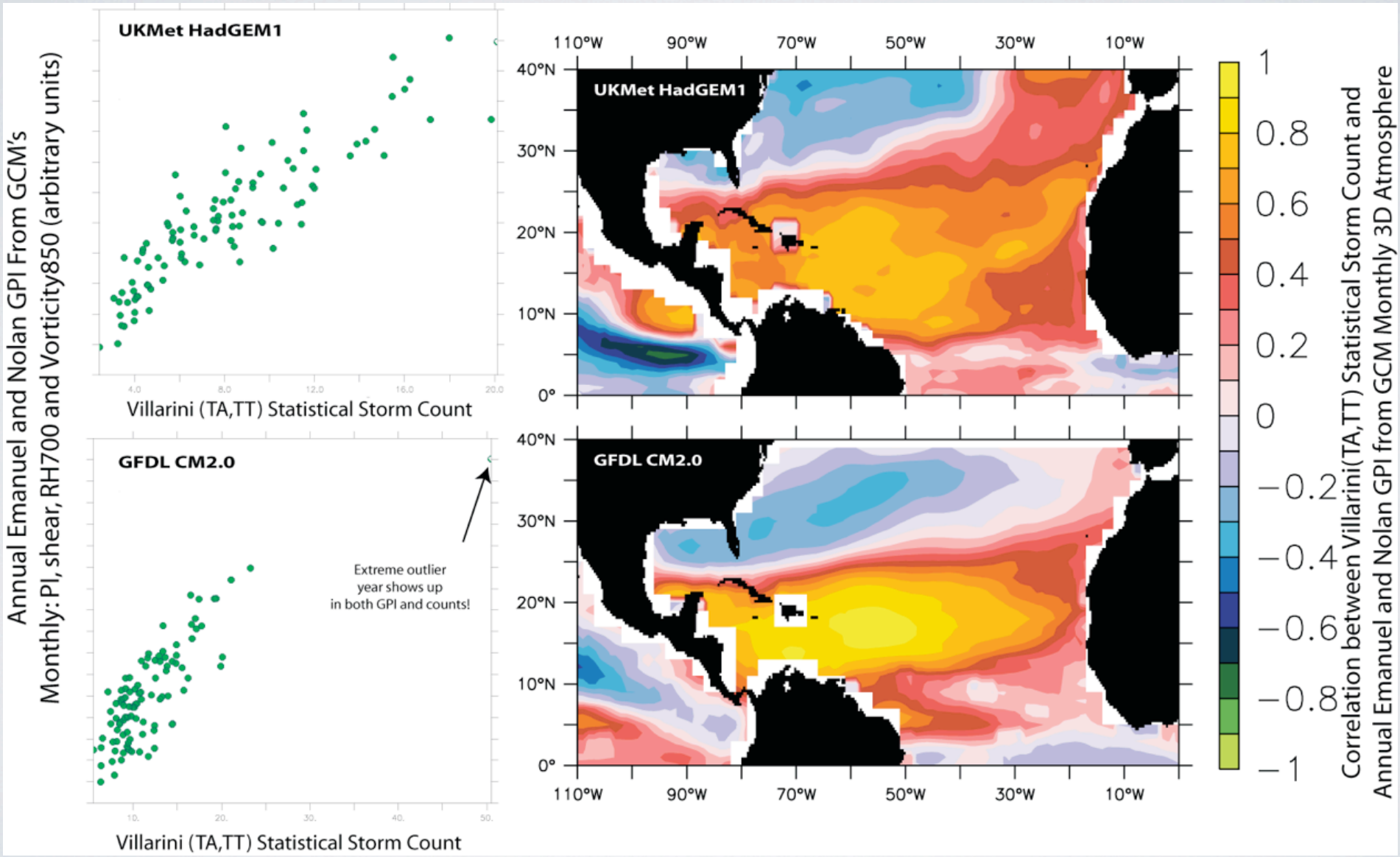
Factors in fit (w/standard error)

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

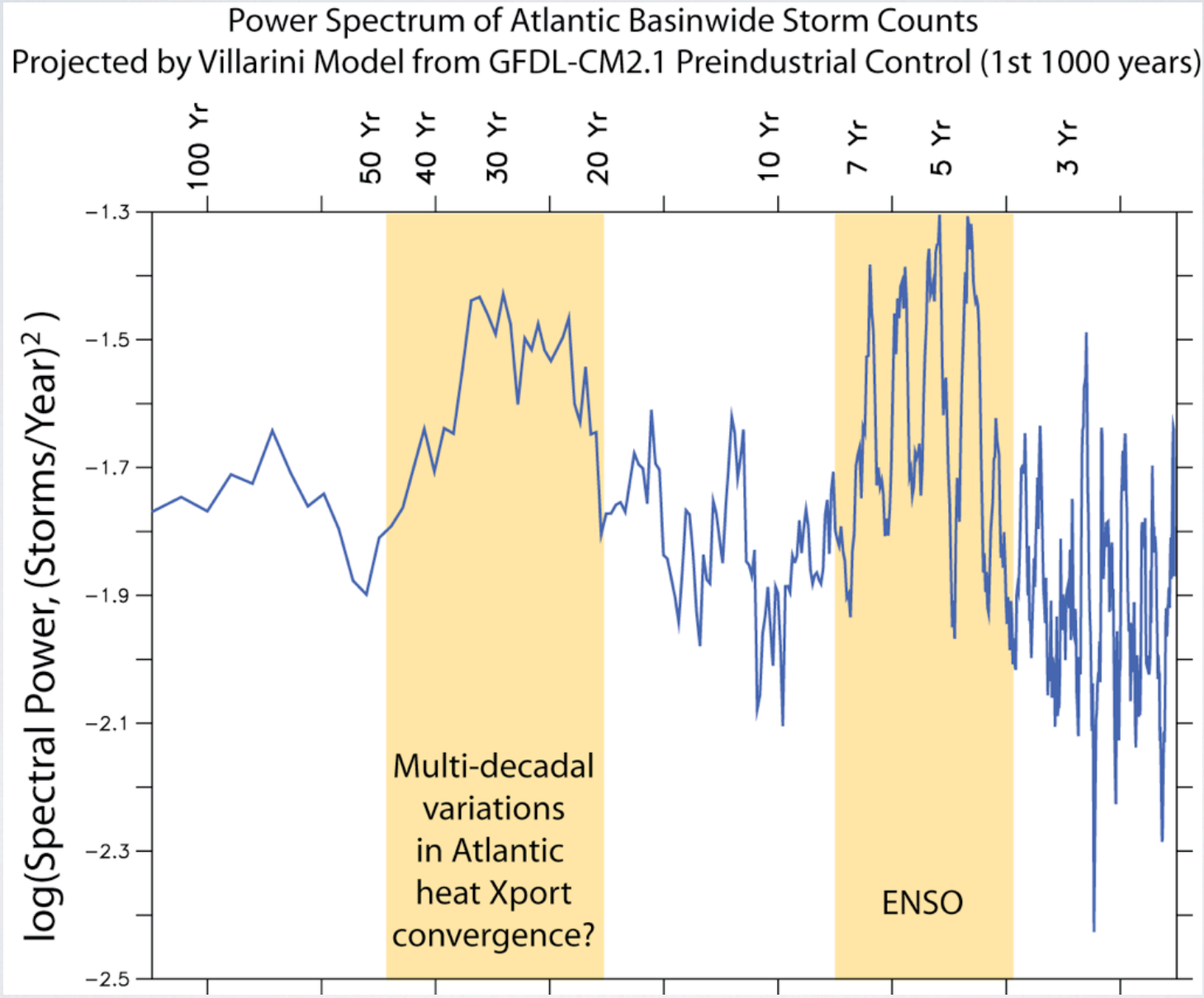
Villarini, Vecchi and Smith (2010, MWR, in press)

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

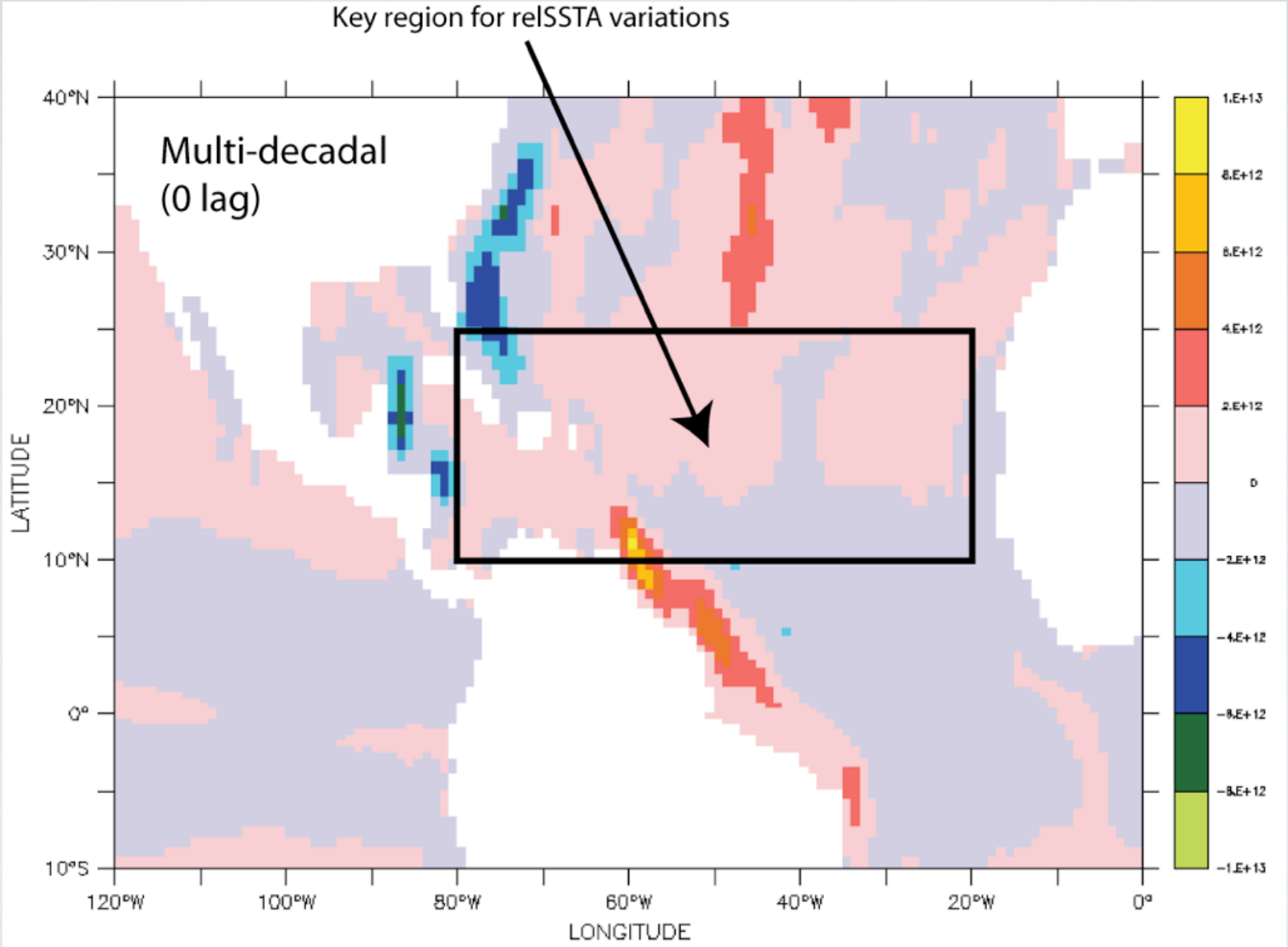
Villarini et al (2010, MWR) model vs. Emanuel and Nolan (2004, AMS) model



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

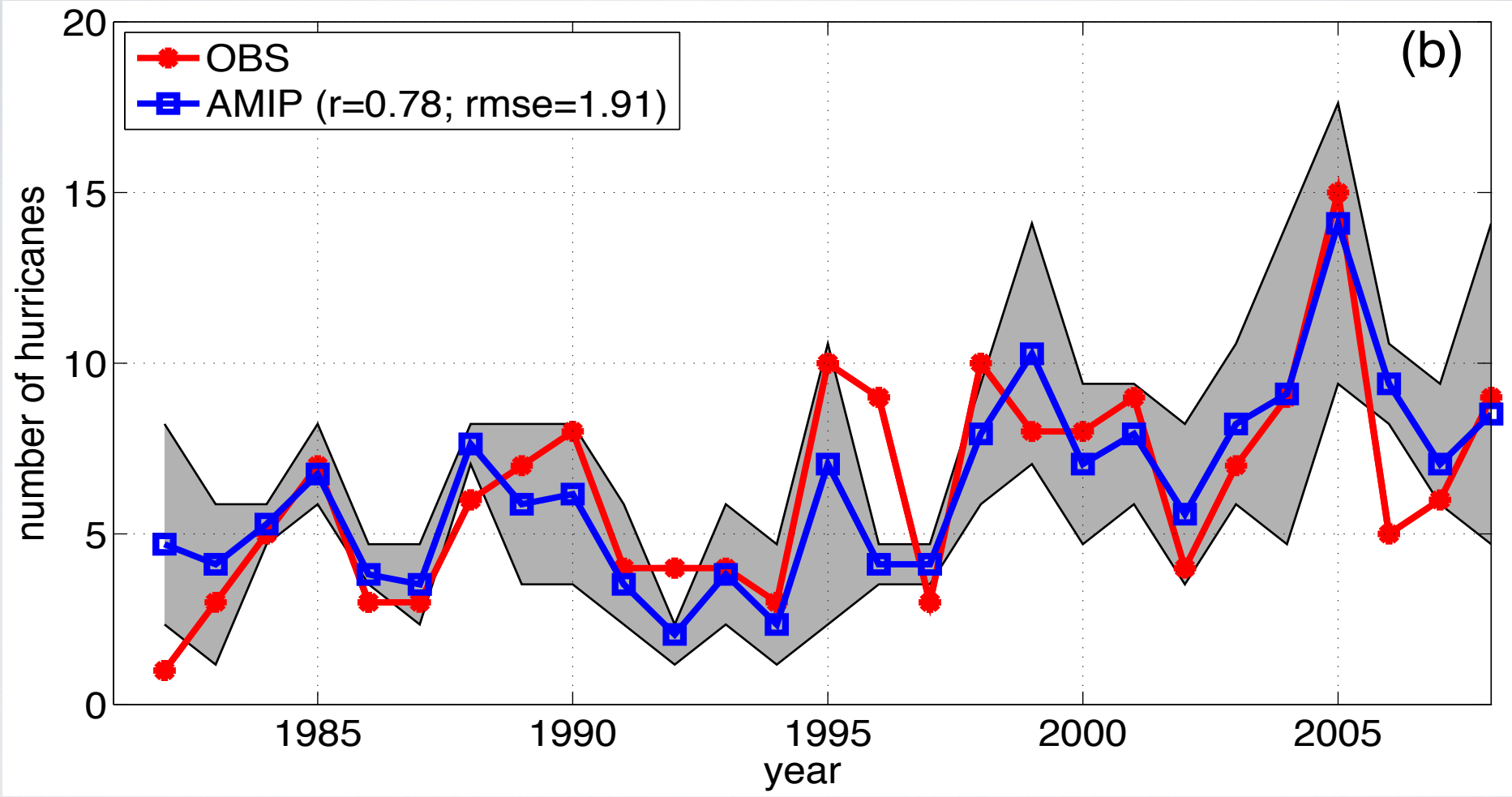


# Statistical counts and ocean heat transport




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

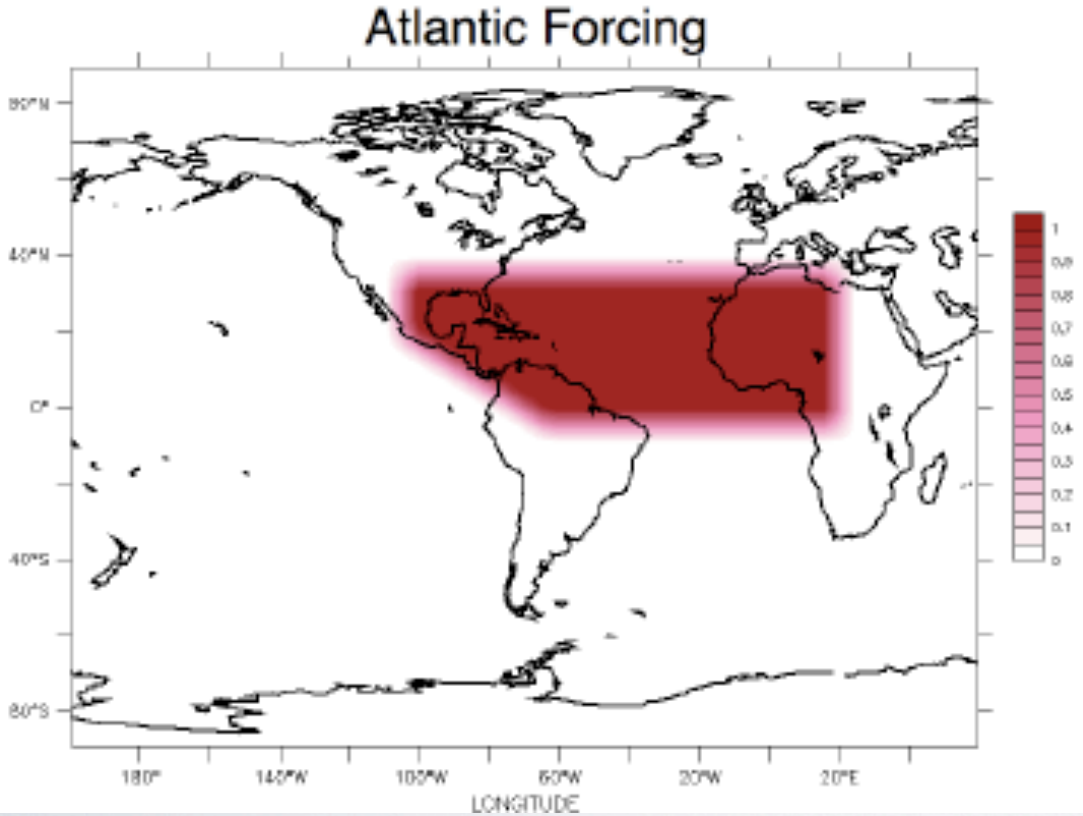


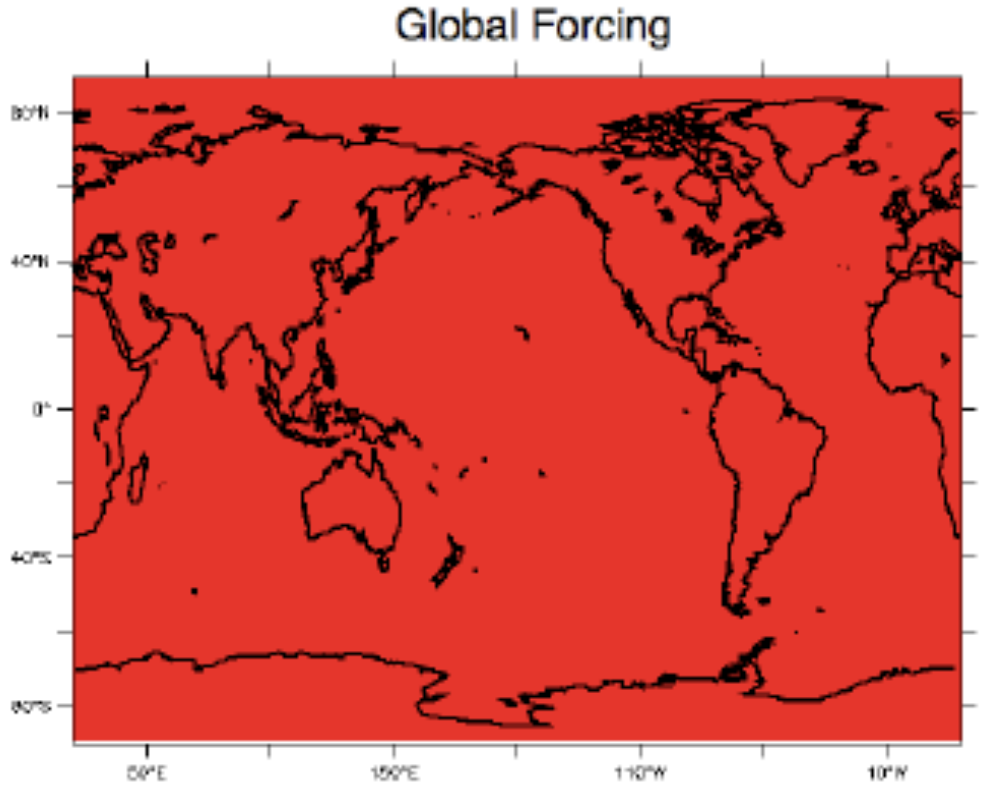

Zhao *et al.* (2009, J. Climate), Zhao *et al.* (2010, MWR, Sub.)

# Idealized Forcing Experiments

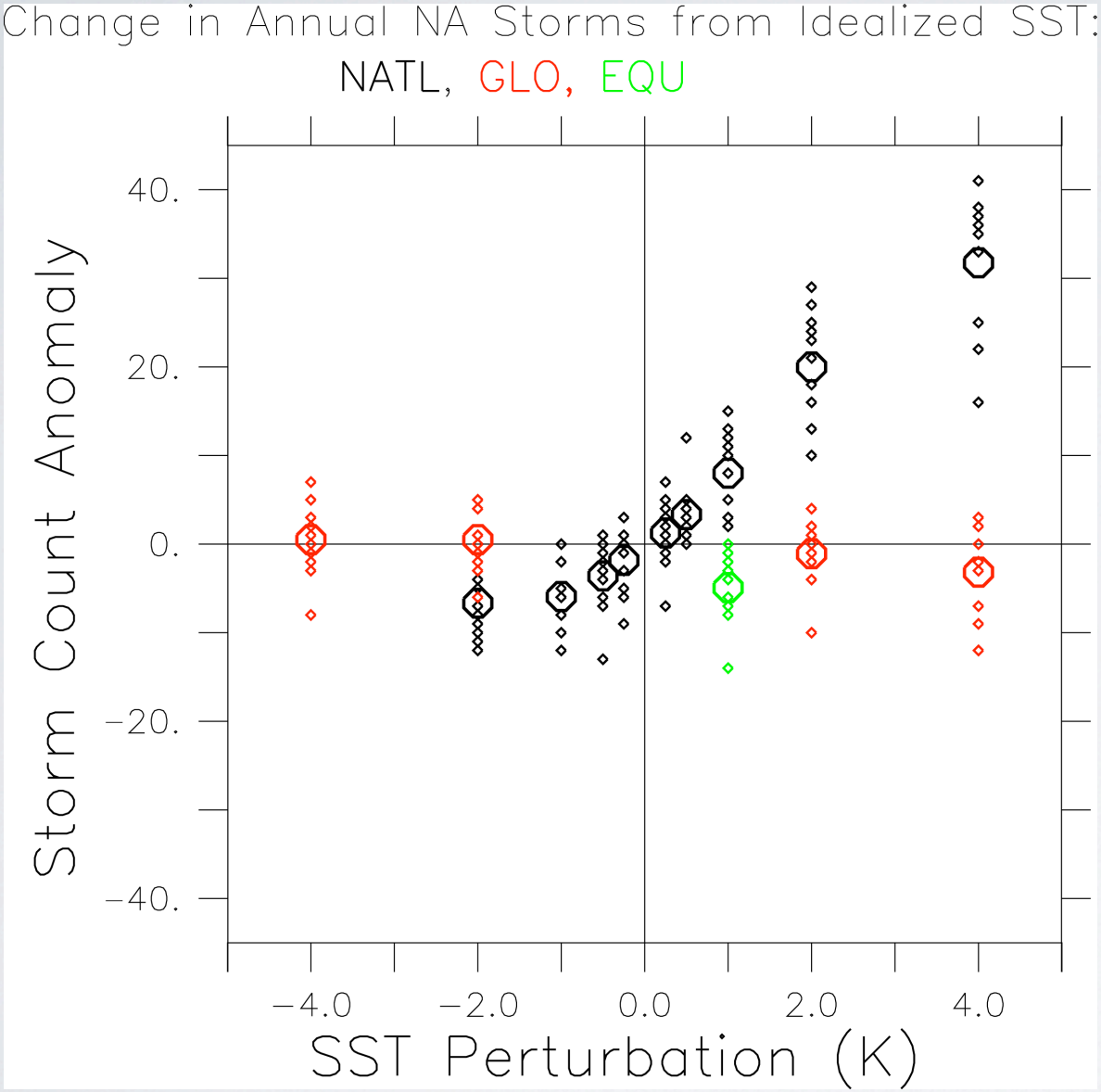
If local SST the dominant control, as opposed to relative SST:

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



# North Atlantic Response to Idealized SST




Atlantic Forcing

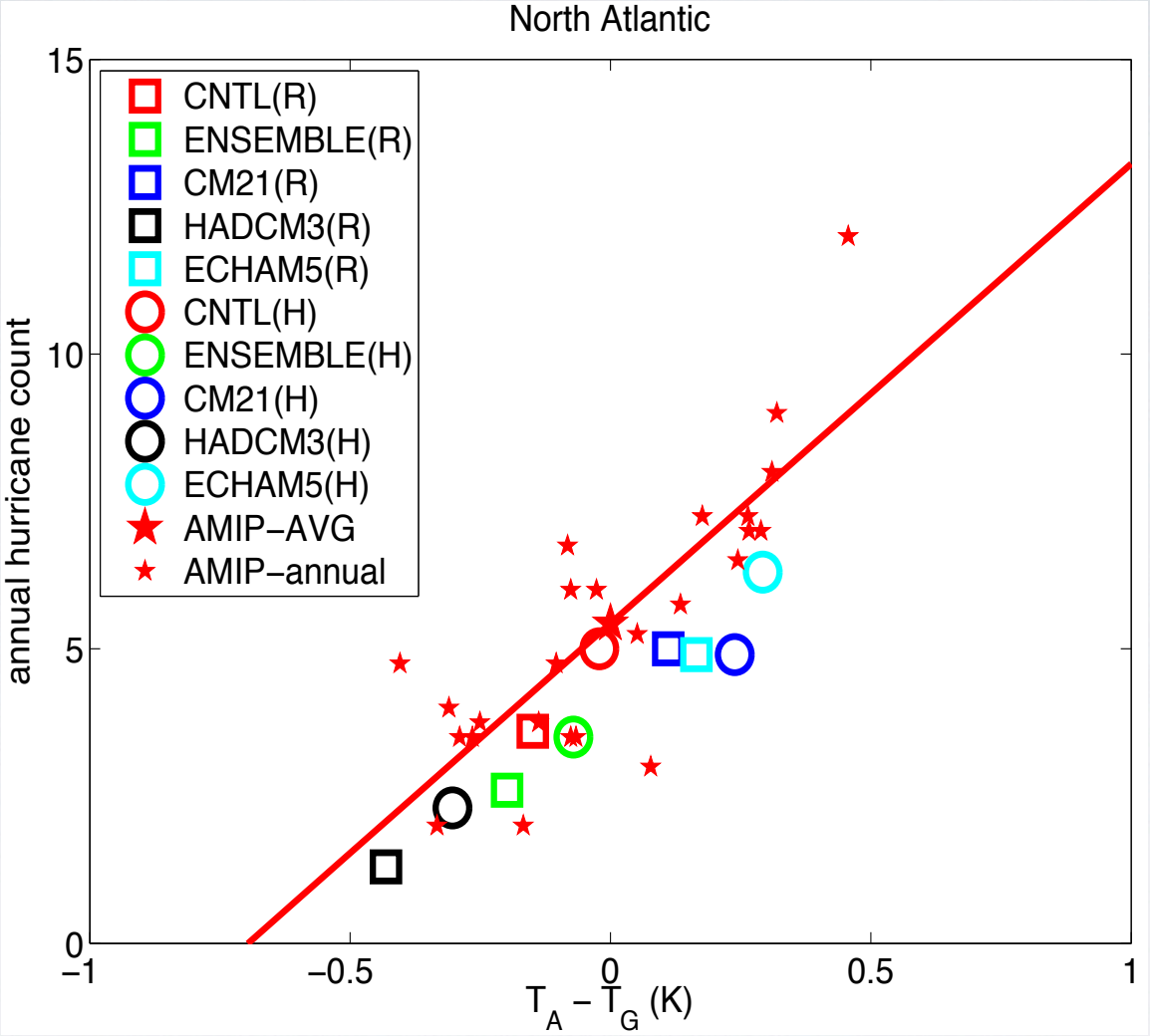
Uniform Forcing

Near-equatorial Forcing

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

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

# HiRAM C180 (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.)

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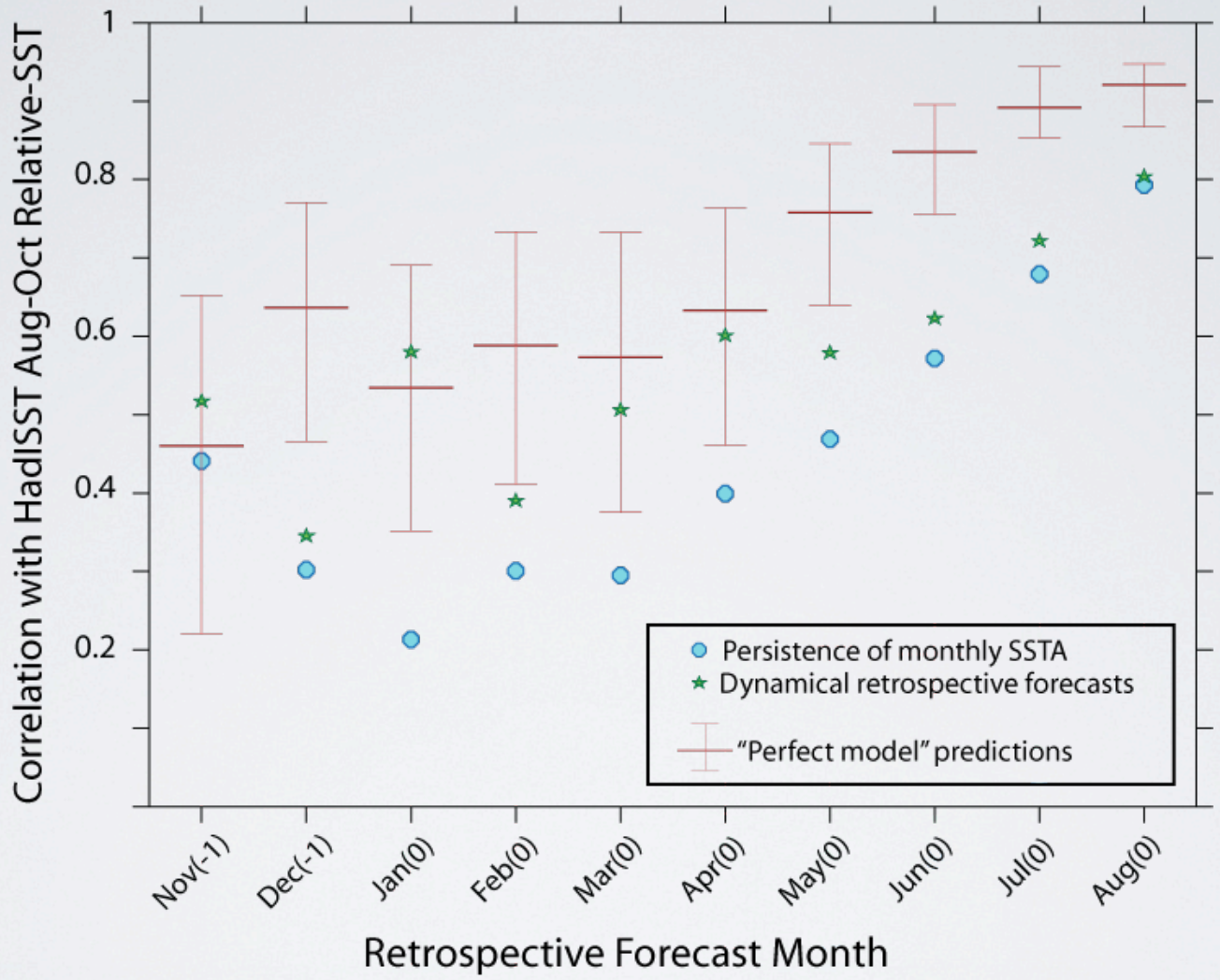
Latif et al (2007, GRL), Vecchi and Soden (2007, Nature), Knutson et al (2008, Nature Geosci.), Swanson (2008, G3), Vecchi et al (2008, Science), Villarini et al (2010, MWR, in press)

# GFDL-CM2.1 Experimental Seasonal-Interannual Forecast System Suggests Relative-SST may be Predictable

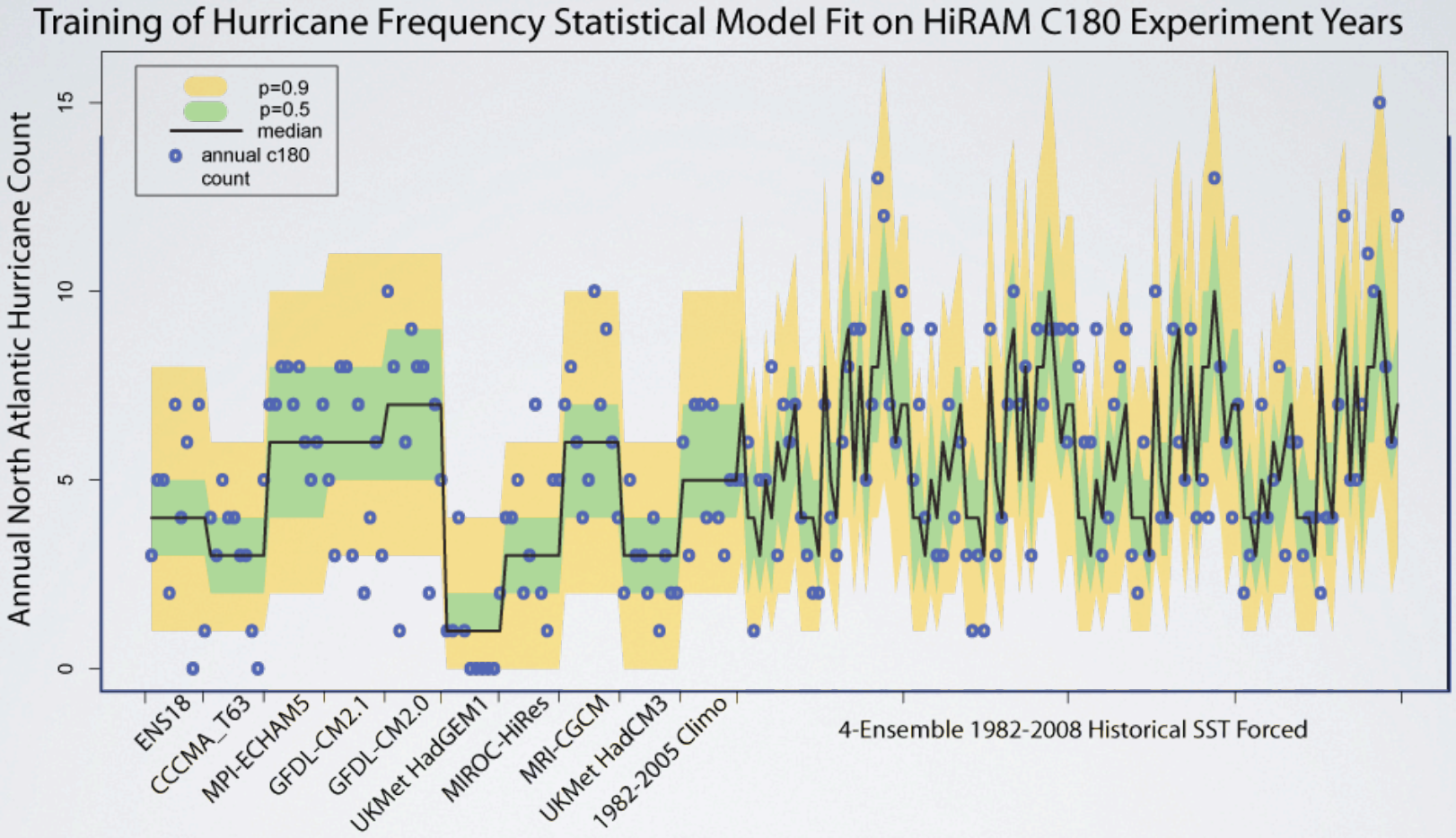



Forecast and initialization system of Zhang et al (2007, MWR)

# Build a Seasonal Hurricane Frequency Forecast Scheme

- Build a statistical emulator of HiRAM-C180, two predictors:
  - $SST_{MDR}$ (SST anomaly 80°W-20°W, 10°N-25°N)
  - $SST_{TROP}$ (SST anomaly 30°S-30°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)



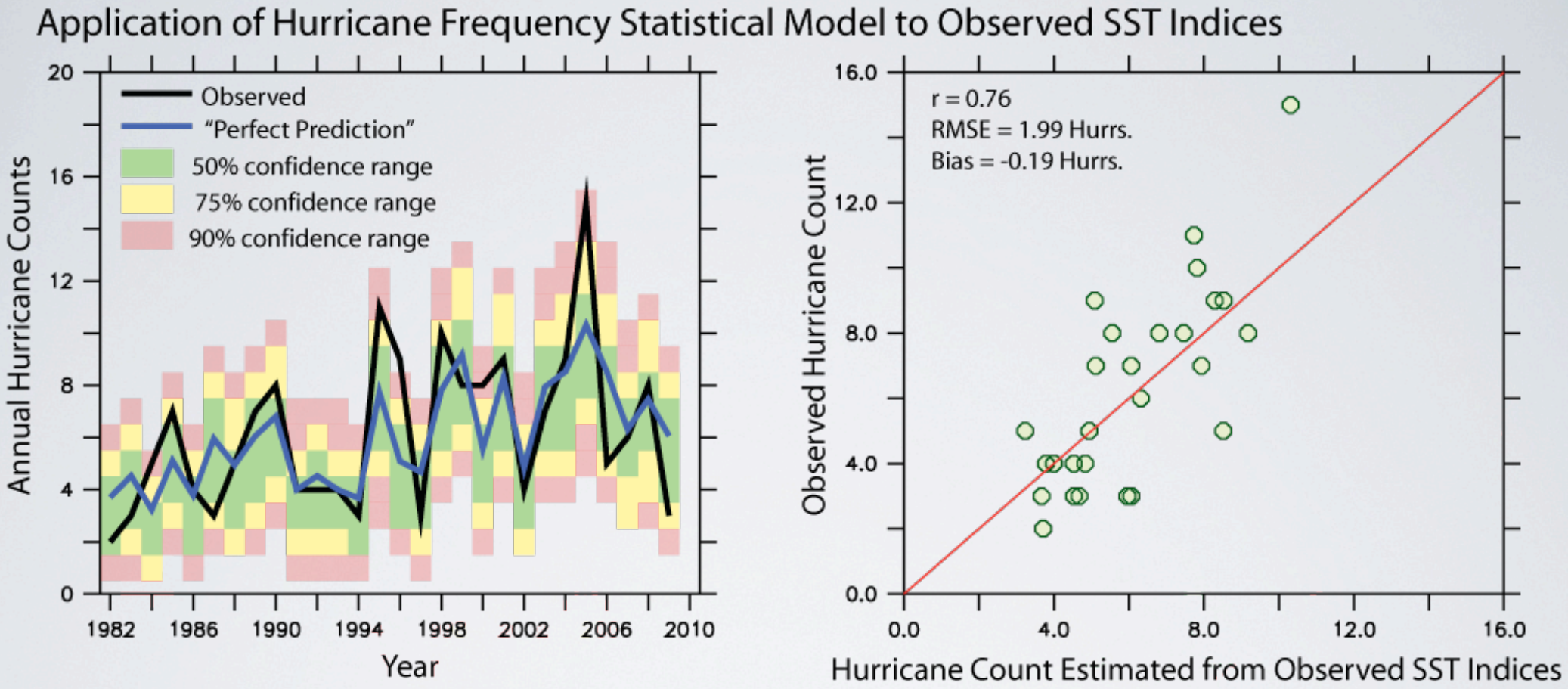

$$p(C=k \mid \boldsymbol{\lambda}) = \boldsymbol{\lambda}^{k} \cdot e^{-\lambda}/k! \qquad \boldsymbol{\lambda} = e^{(a+b \cdot SSTmdr + c \cdot SSTtrop)}$$

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

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

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

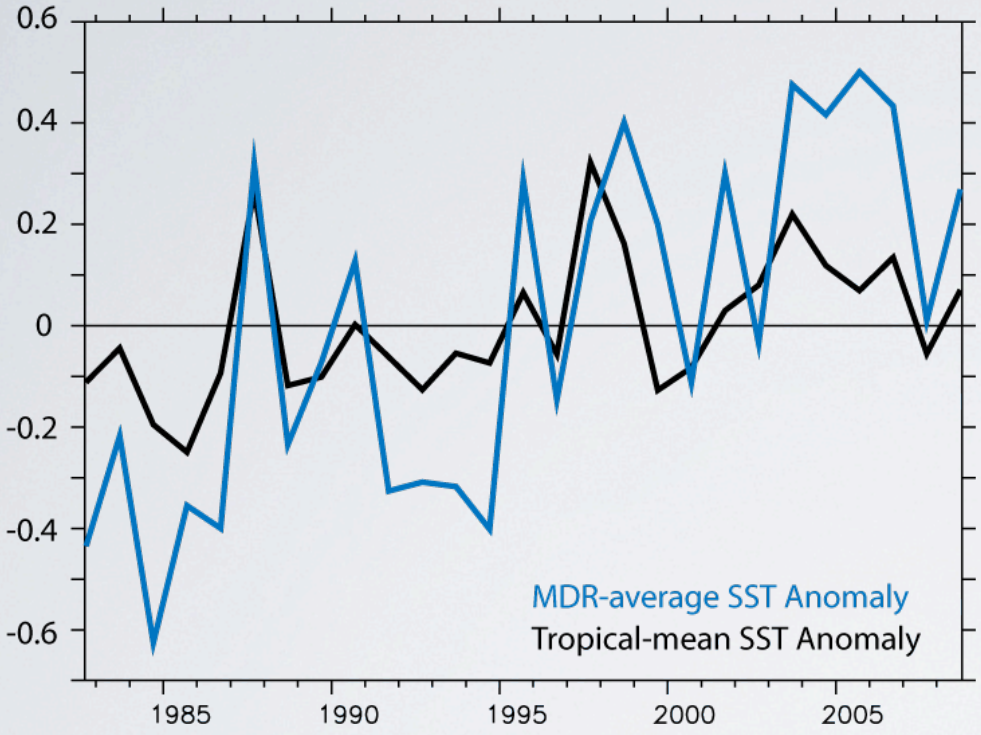
# Fit of HiRAM-C180 Emulator to Obs. Performs Well

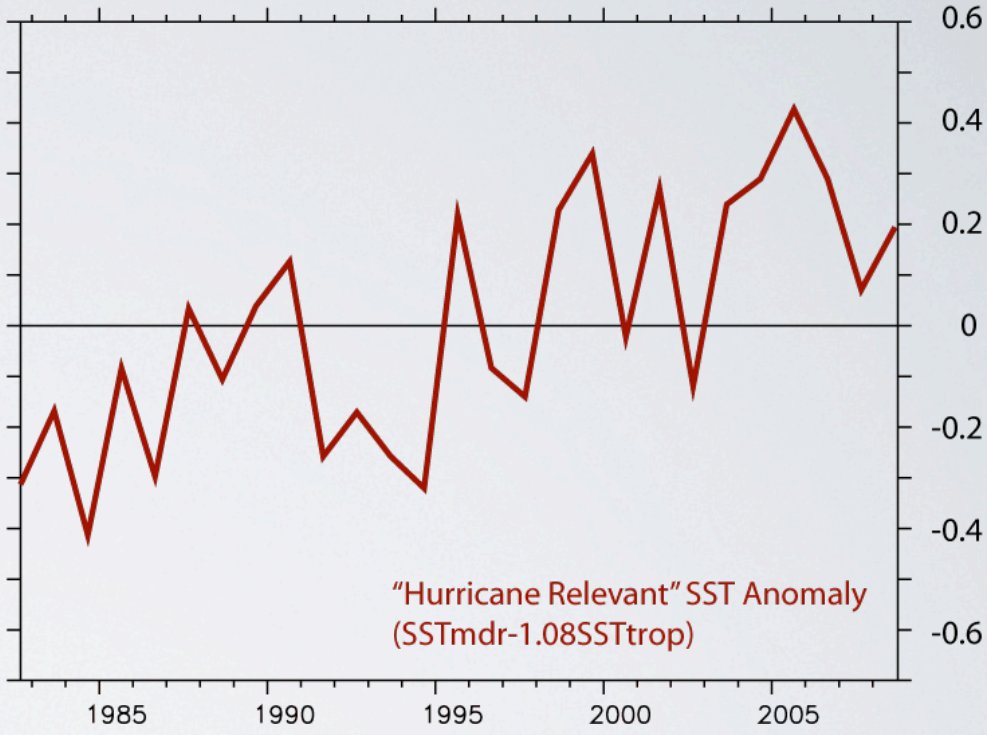



HiRAM-C180 with full SST gives r=0.78, RMSE=1.91

Cannot justify additional predictors at this time

# SST Index Relevant to Hurricanes Complex, More than ENSO and Atlantic SST



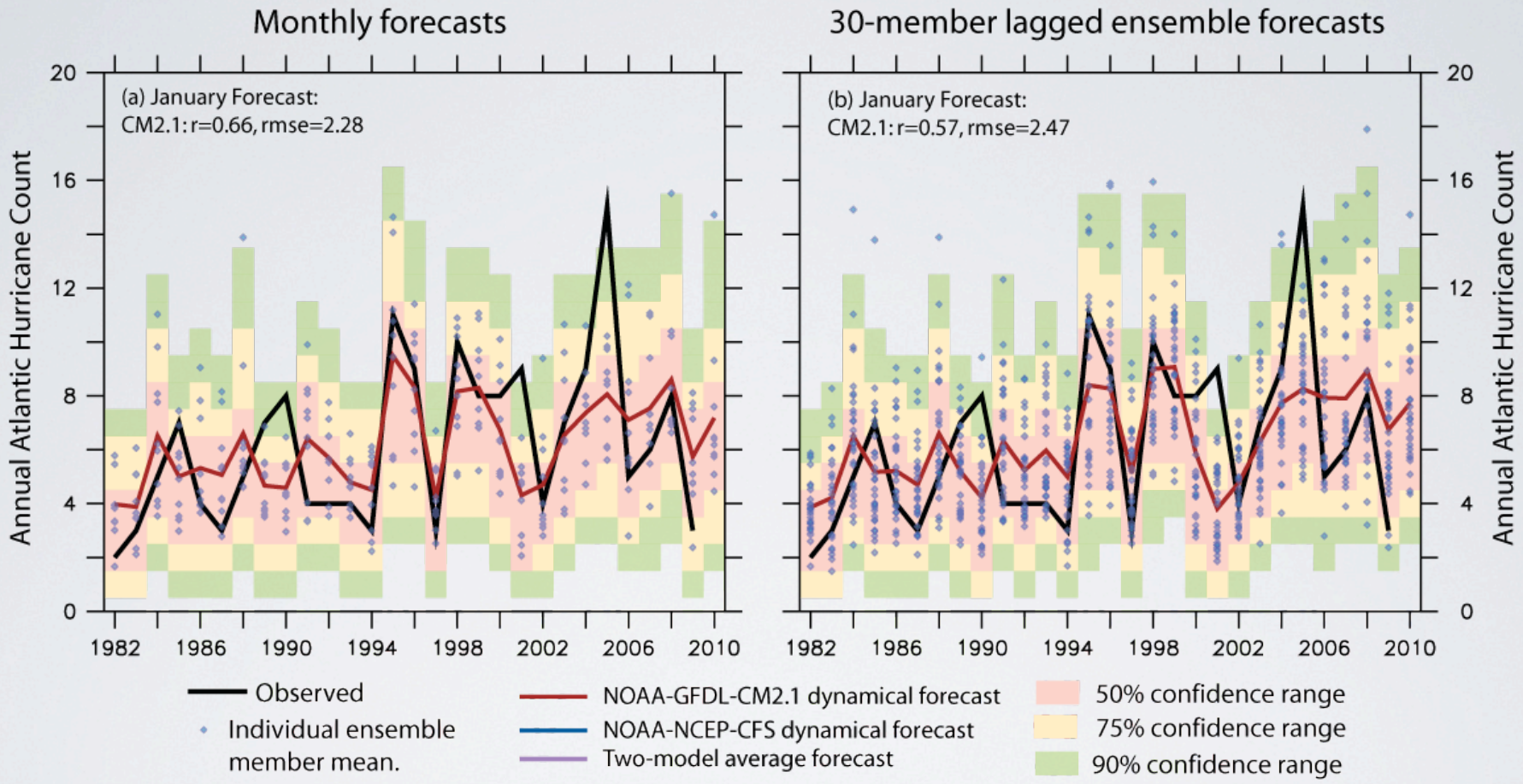




$SST_{MDR}$ and $SST_{TROP}$ share a recent trend, but amplitude differs.
$SST_{TROP}$ more than ENSO, trend, warm mid-2000's, etc.

# 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

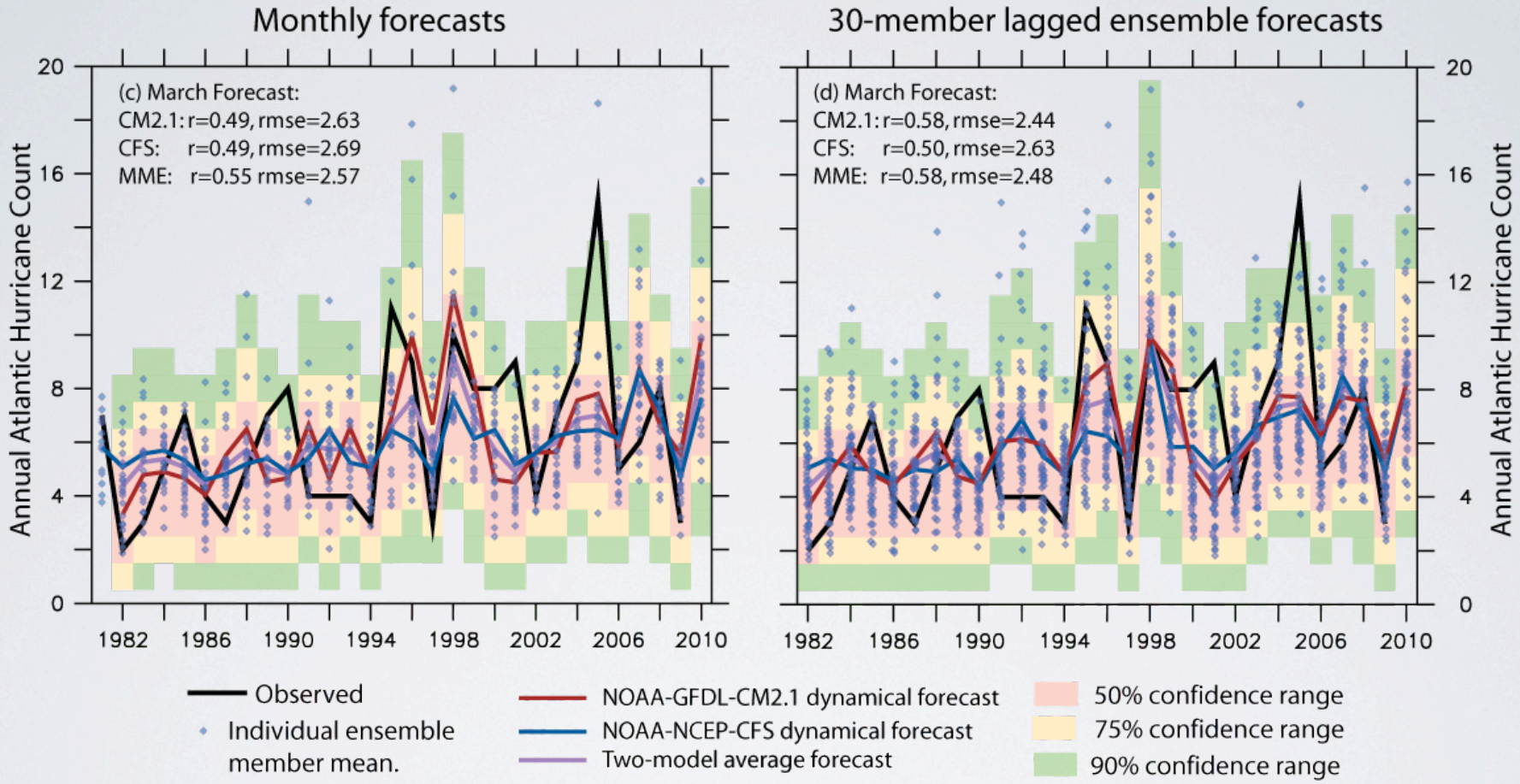



$$p(C=k) = \int_{-\infty}^{\infty} p(C=k \mid \text{relSSTA}=x) \cdot p(\text{relSSTA} = x)\, dx$$

p(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

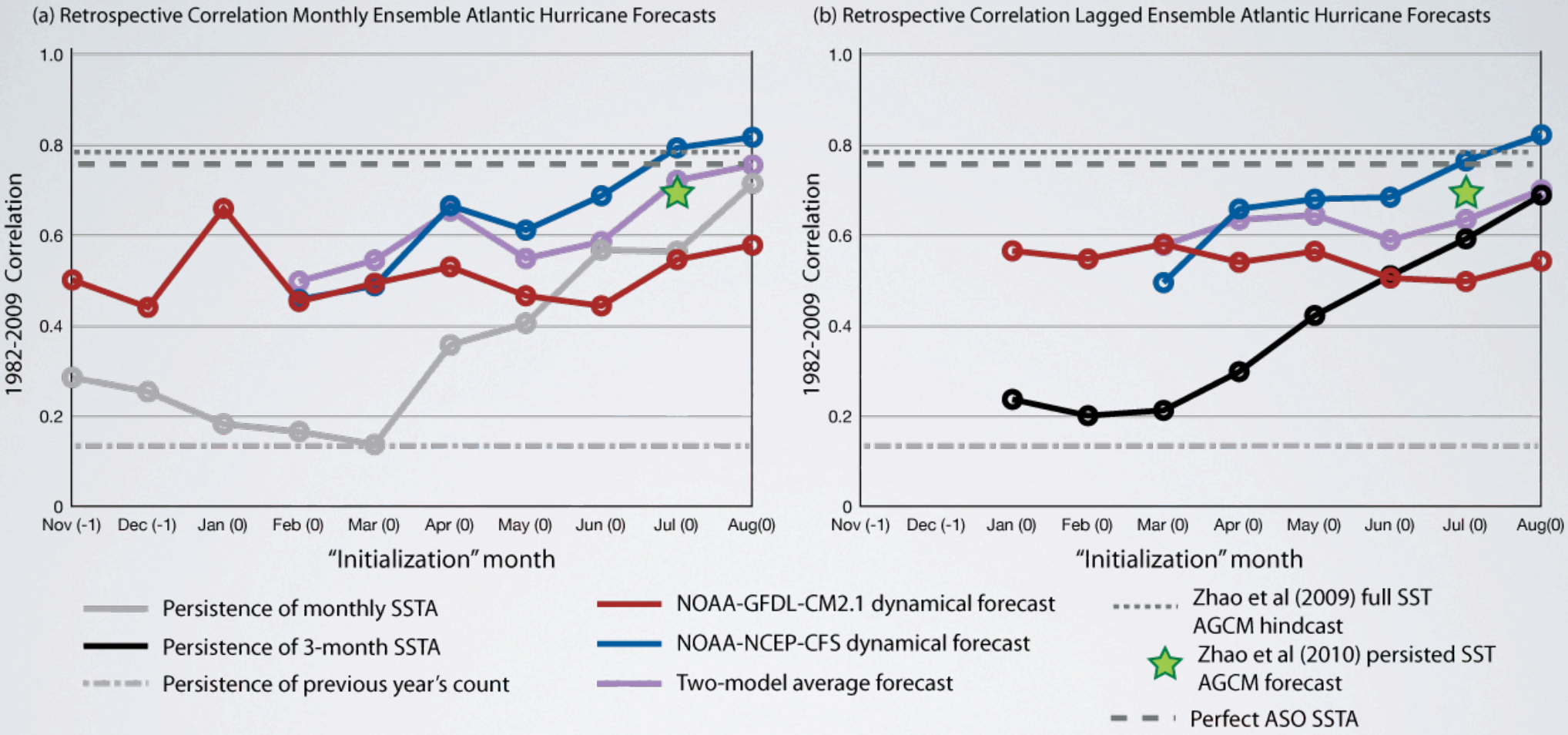



$$p(C=k) = \int_{-\infty}^{\infty} p(C=k \mid \text{relSSTA}=x) \cdot p(\text{relSSTA} = x)\, dx$$

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




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

# System Indicates Active 2010

| | *Mean Count (hurr)* | *Median (hurricanes)* | *p(count>6)* | *p(count>10)* | *p(count≤3)* |
|---|---|---|---|---|---|
| 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, in prep.)

# 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?