HURRICANE ATTRIBUTION, PREDICTIONS & PROJECTIONS

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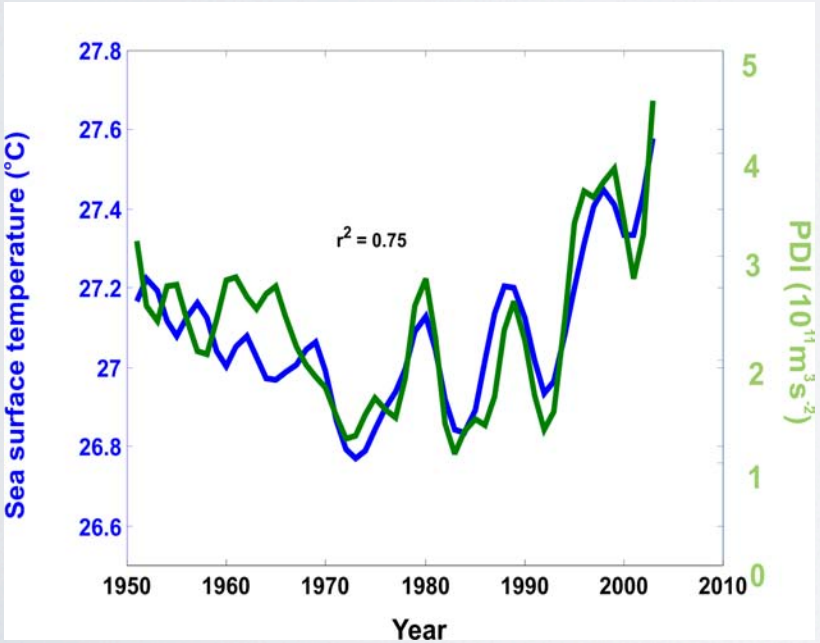
1-NOAA-GFDL; 2-NOAA-NCEP; 3-Princeton U.; 4-U. Miami; 5-U. Wisc.-Milw.; 6-Old Dominion U.

Image: NASA.

North Atlantic tropical cyclones

- Recent increase in activity
  - Including extreme 2004-2005 seasons
- Why? Implications for future?



Emanuel (2007, J. Clim.)

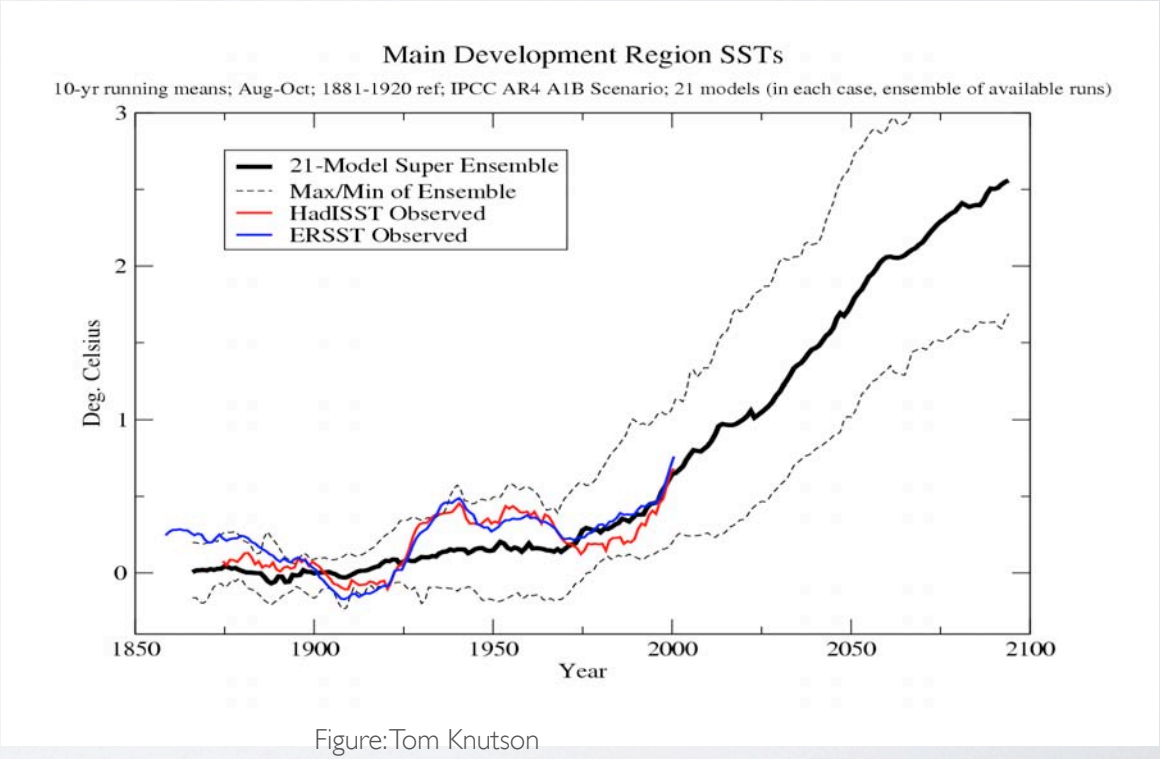
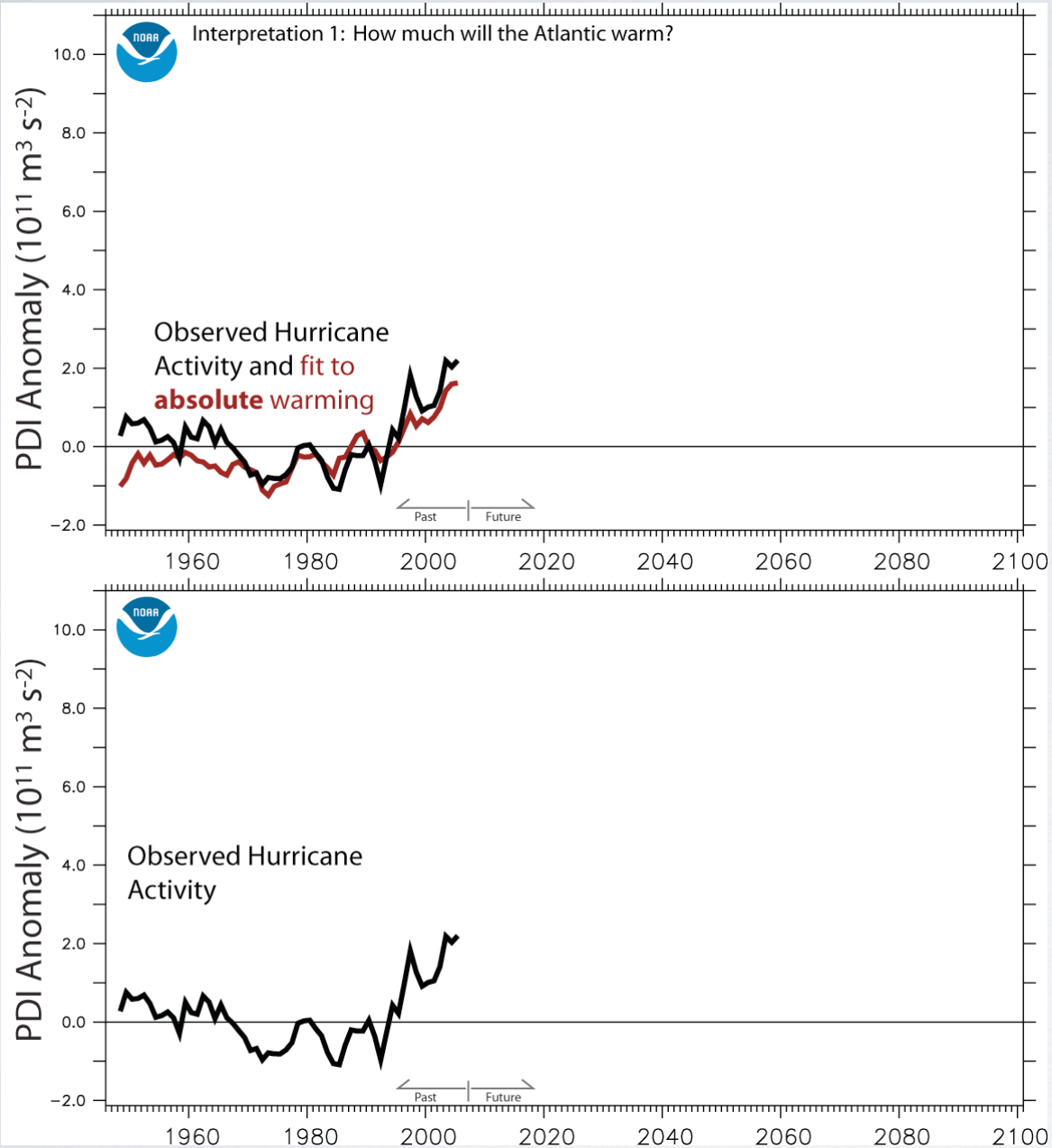


Figure: Tom Knutson

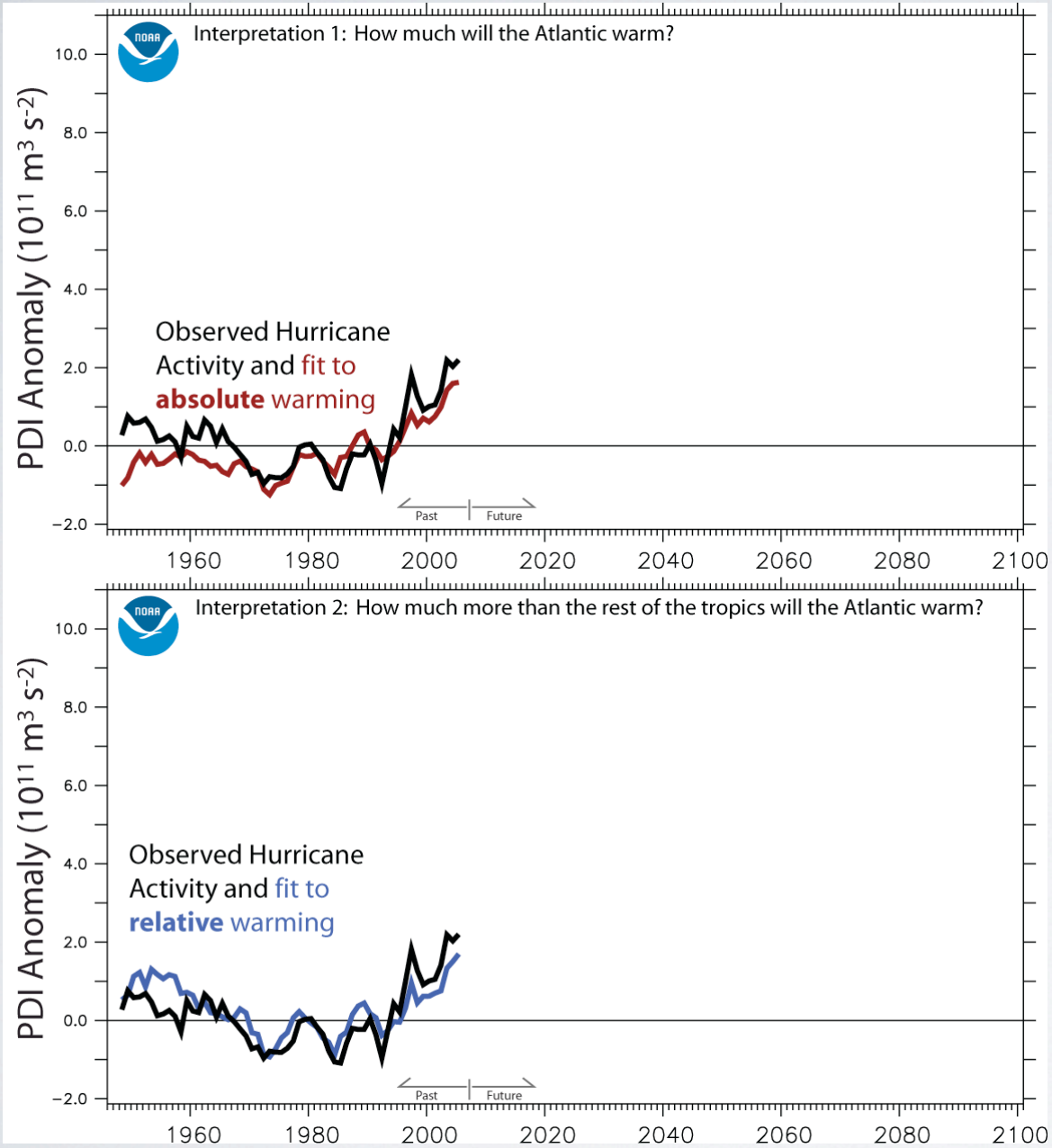
One Temperature Predictor of Atlantic Hurricane Activity



Observed Activity
Absolute Atlantic Temperature

Vecchi, Swanson and Soden (2008, Science)

Two Temperature Predictors of Atlantic Hurricane Activity

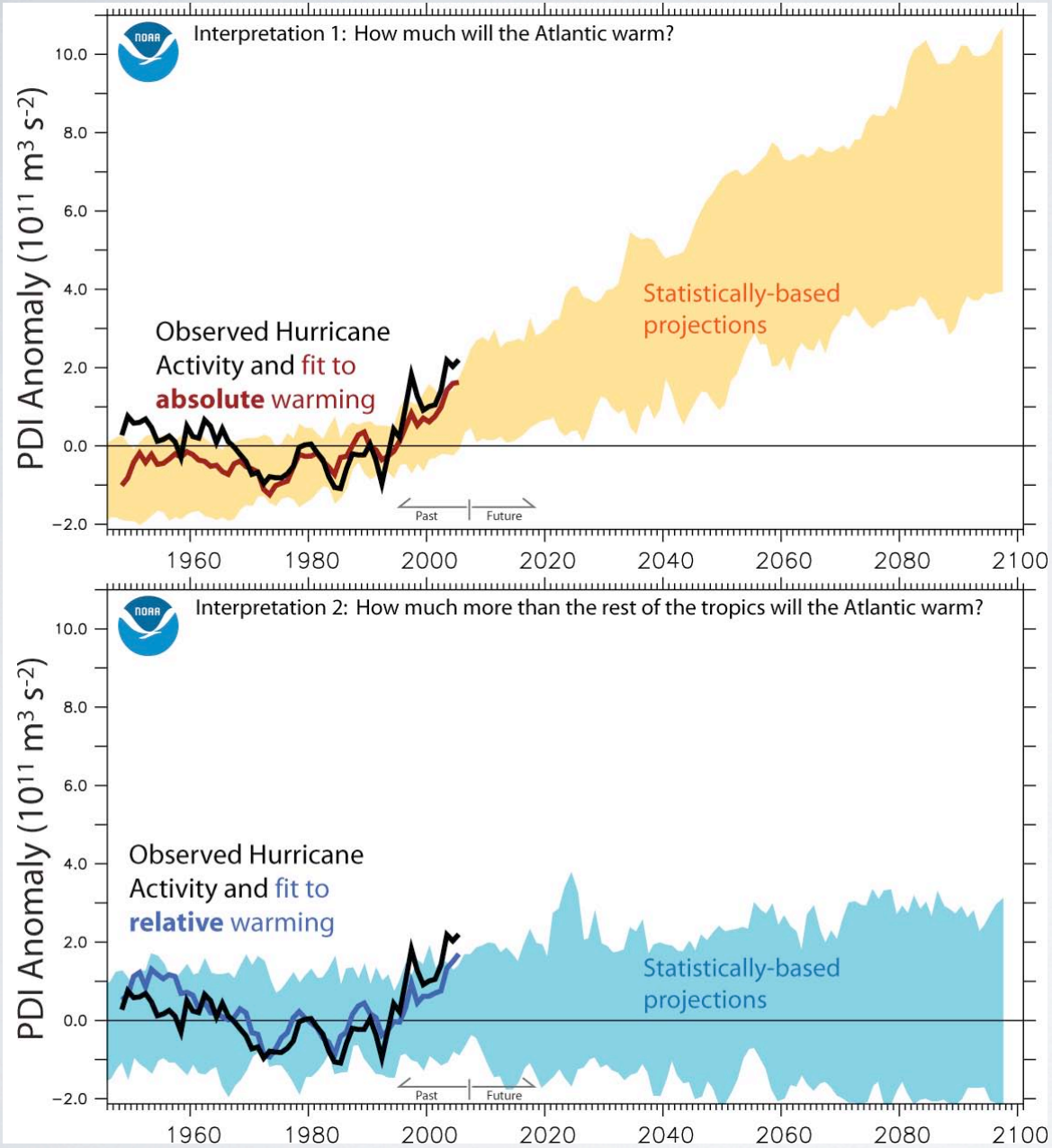


Observed Activity
Absolute Atlantic
Temperature

Observed Activity
Relative Atlantic
Temperature

Vecchi, Swanson and Soden (2008, Science)

Two Statistical Projections of Atlantic Hurricane Activity



Observed Activity
Absolute Atlantic
Temperature

Observed Activity
Relative Atlantic
Temperature

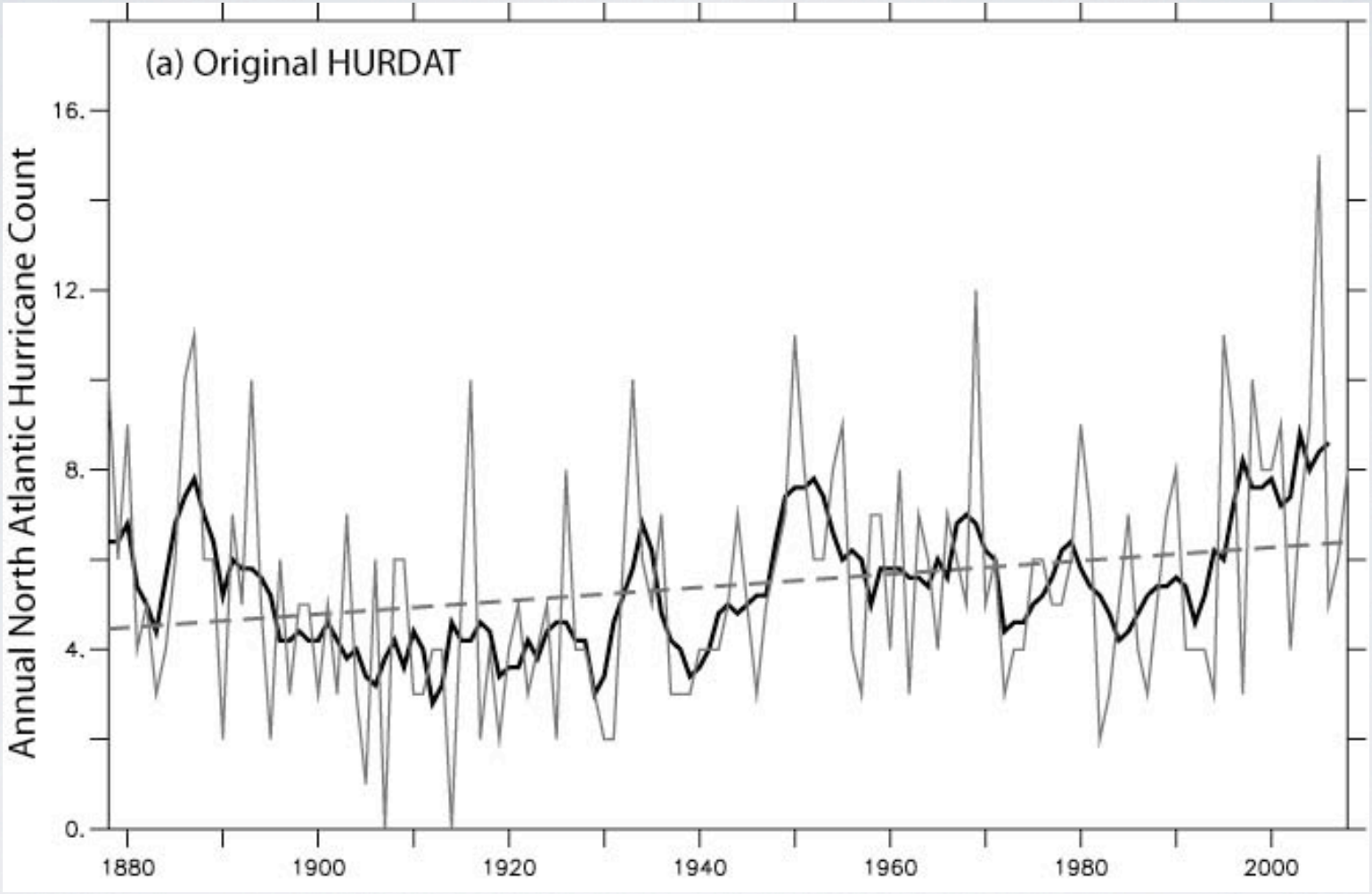
Vecchi, Swanson and Soden (2008, Science)

Outline

- Historical Atlantic TS & Hurricane Record
- Downscaling Techniques
- Extended Range S-I Hurricane Predictions
- Attribution of Recent TS Frequency Increase
- Response of Hurricanes to Radiative Forcing
- Internal Climate Variability and NA Hurricane Frequency
- Note of caution
- Summary

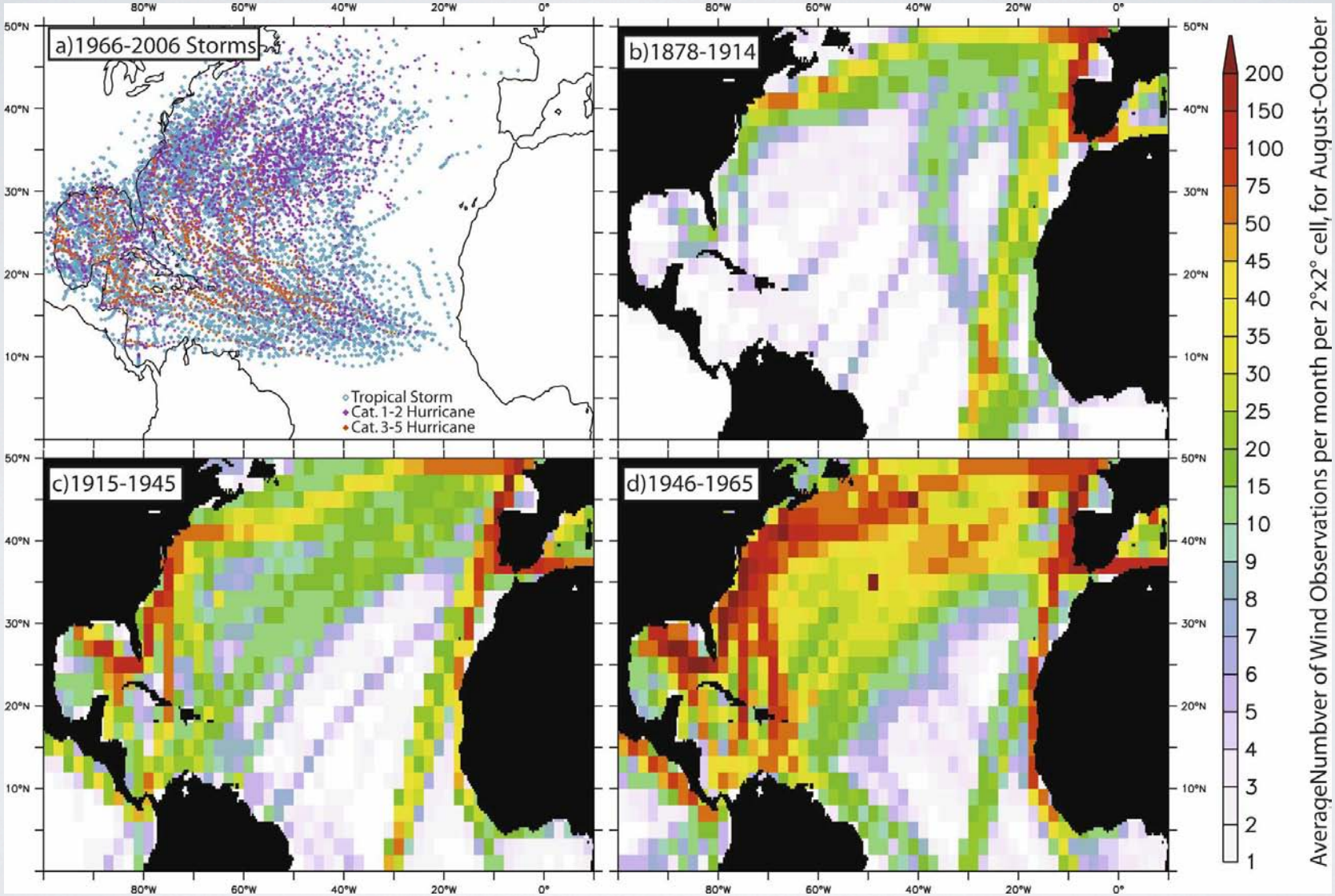
Recorded NA Hurricanes Show Clear Increase

But was there really an increase?



Vecchi and Knutson (2010)

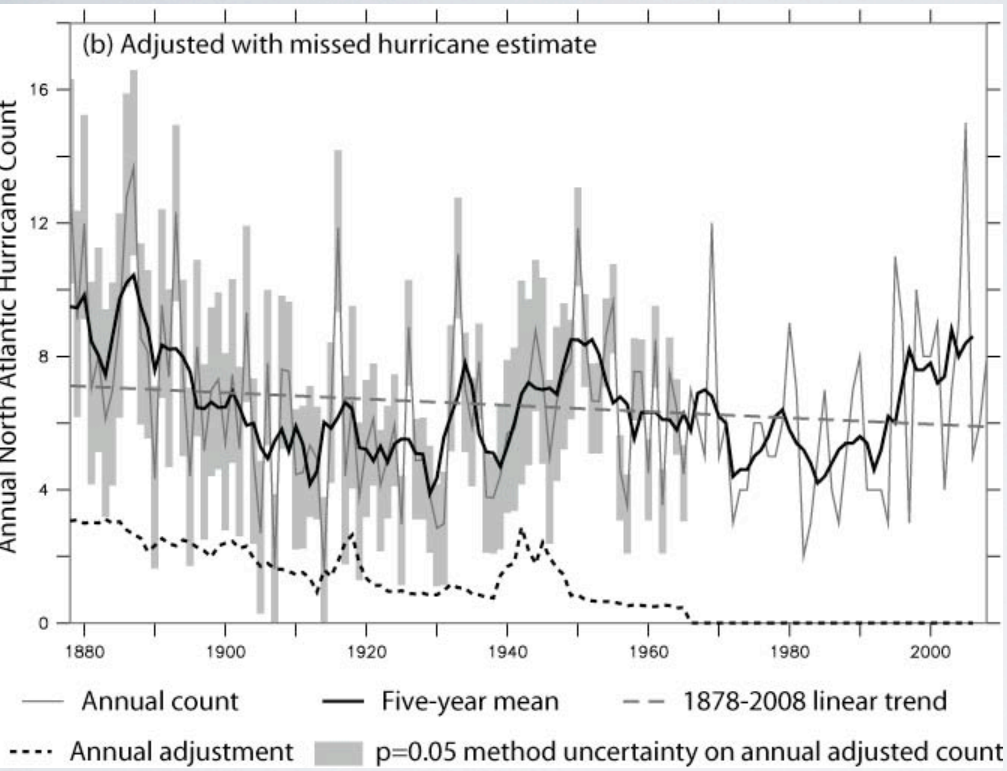
ABILITY TO OBSERVE CYCLONES HAS ALSO CHANGED WITH TIME: E.G., SHIP TRACK DENSITY



Vecchi and Knutson , J. Climate, 2008.

Observed NA Hurricane Frequency Changes

NA Basinwide Hurricane Record



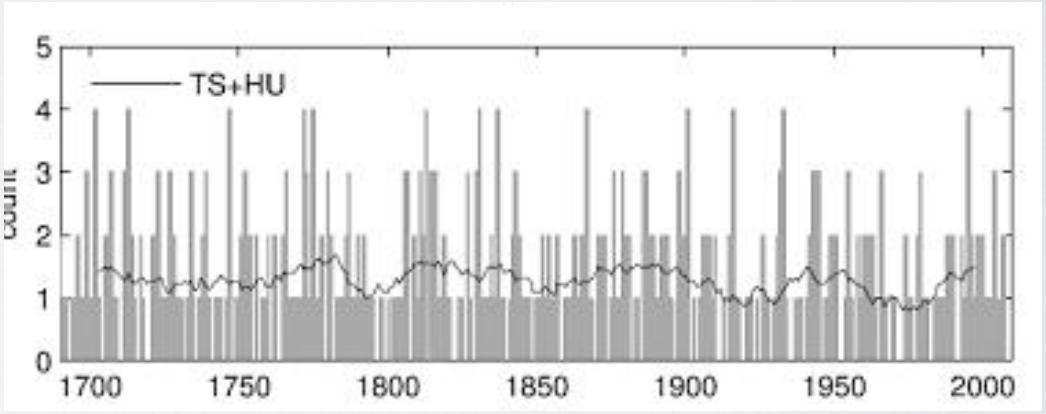
Vecchi and Knutson (2010)

Record Uncertain

Many timescales

Centennial Trend Unclear

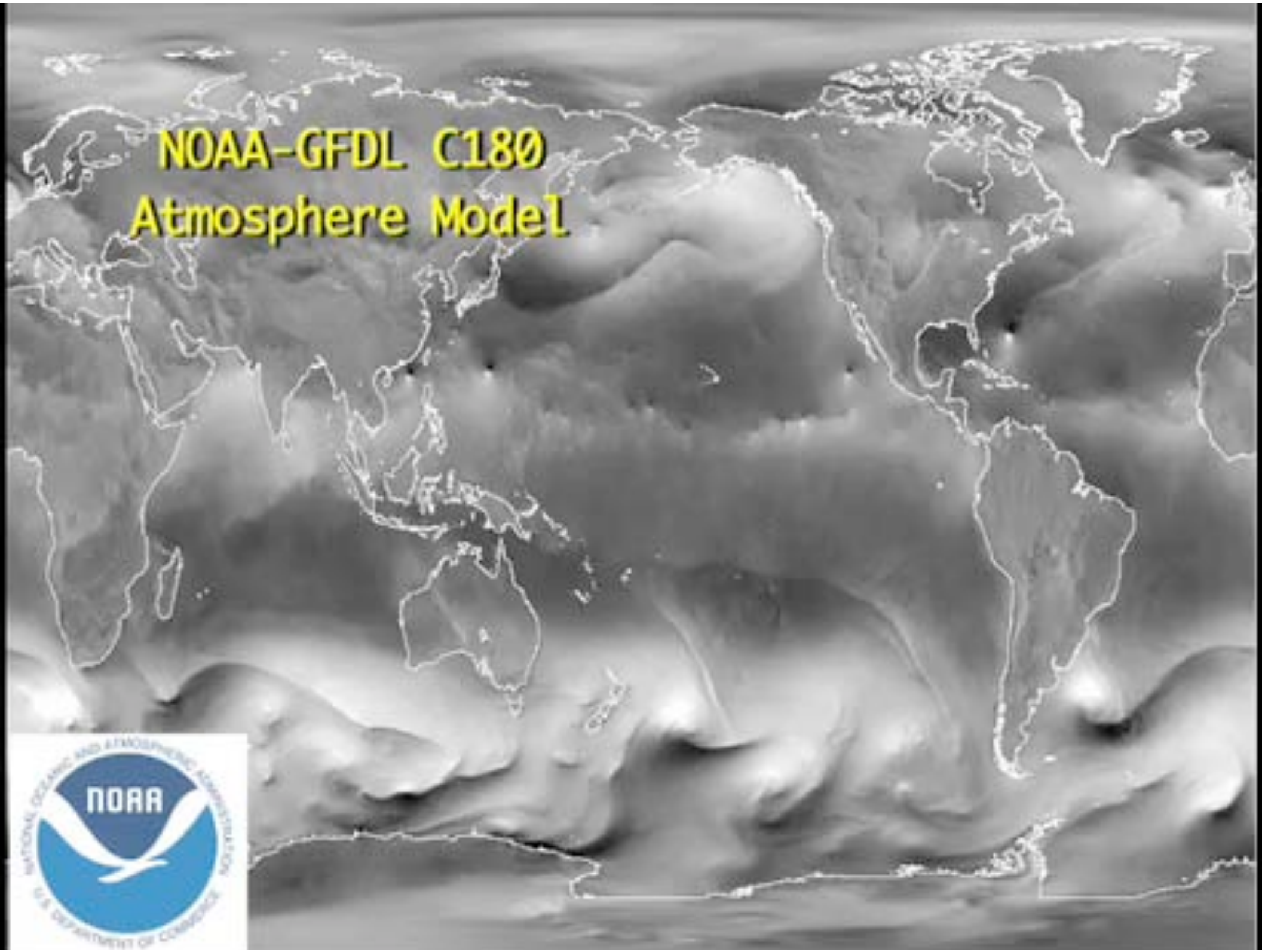
Document-based reconstruction of Antilles TS and HU



Chennoweth and Divine (2008)

Various efforts to homogenize instrumental TC record (e.g., Landsea 2007, Chang and Guo 2007, Mann et al 2007, Vecchi and Knutson 2008, Landsea et al 2010, Vecchi and Knutson 2010).

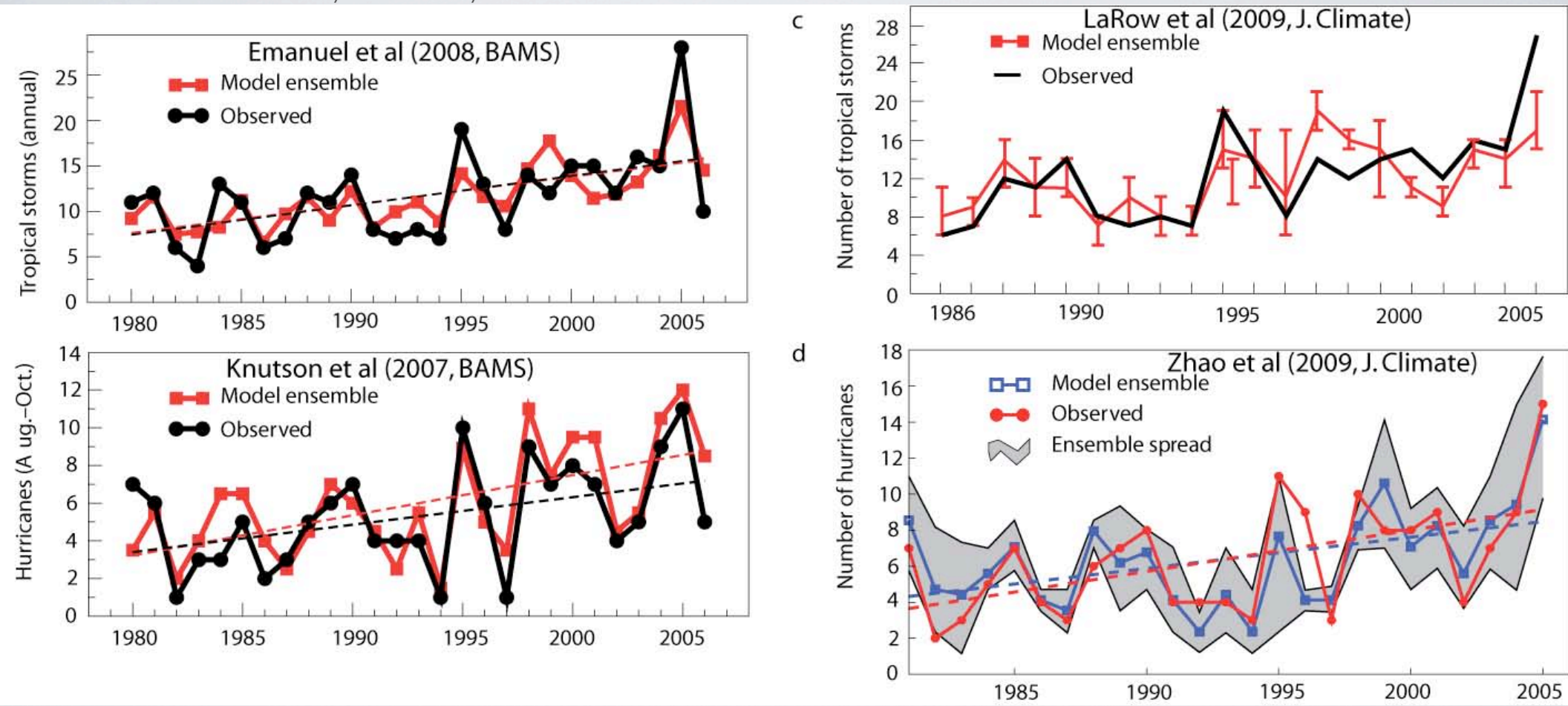
Data Archeology and Paleo-proxy Indicators Complement Instrumental Records (e.g., Chennoweth and Divine 2008, Mann et al 2009)


NOAA-GFDL C180
Atmosphere Model
NOAA

Dynamical Models Exhibit Skill in Seasonal Basin-wide Hurricane Frequency

Statistical-dynamical hybrid model

100km SST-forced AGCM



18-km regional model

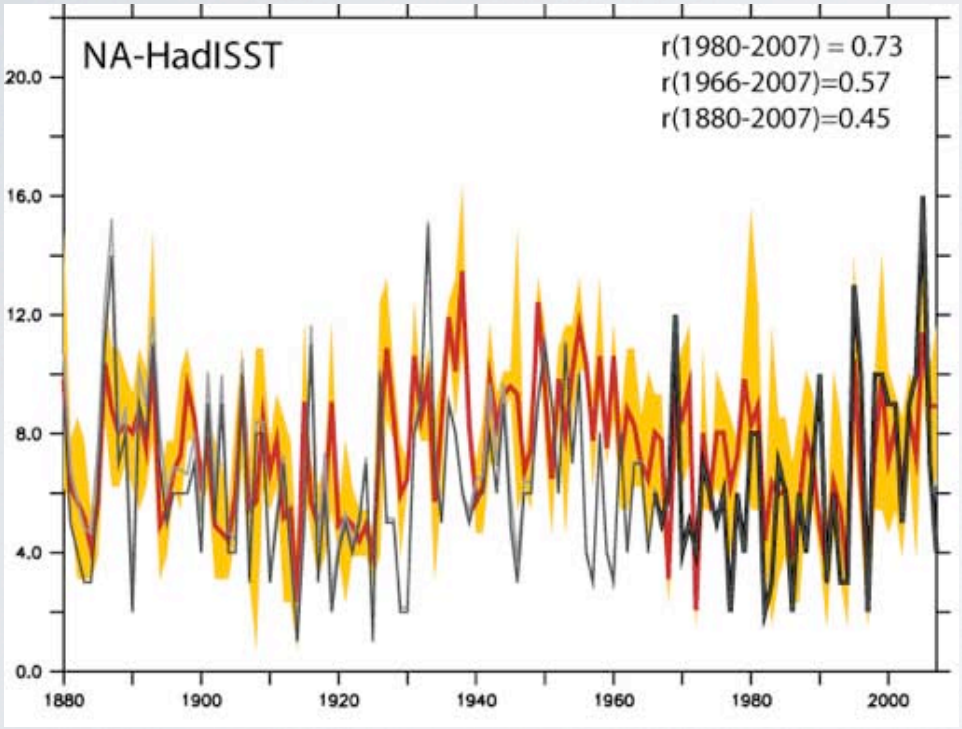
50km SST-forced AGCM

Figure adapted from Knutson et al (2010, Nat. Geosci.)

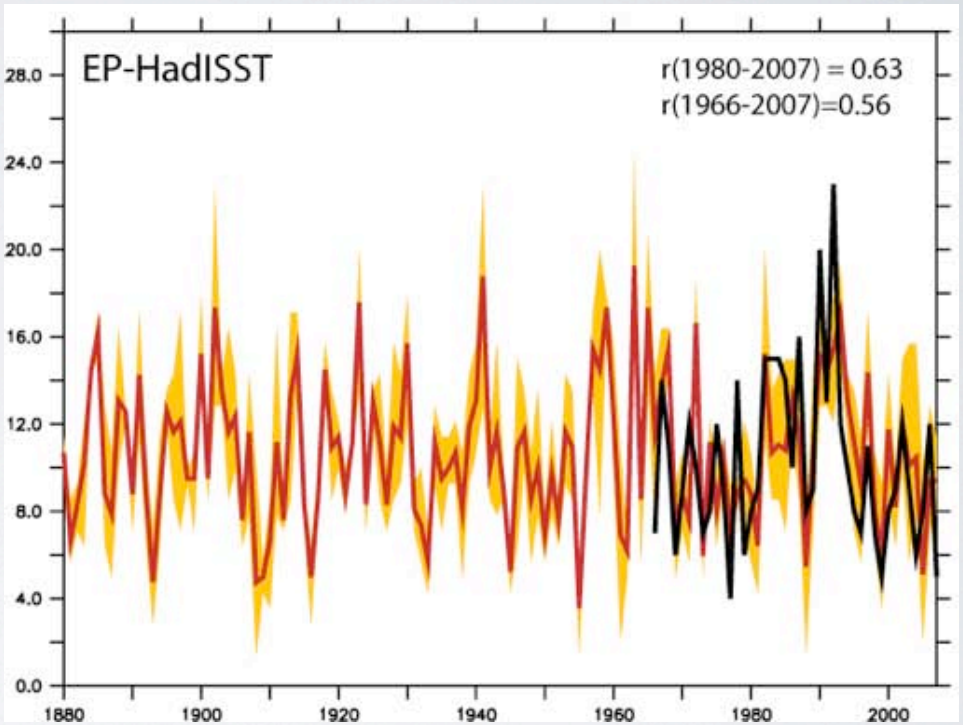
Skill in Century-Scale SST-Forced AGCM Hindcasts

Using 100km version of Zhao et al (2009, J. Clim.) AGCM

North Atlantic TC

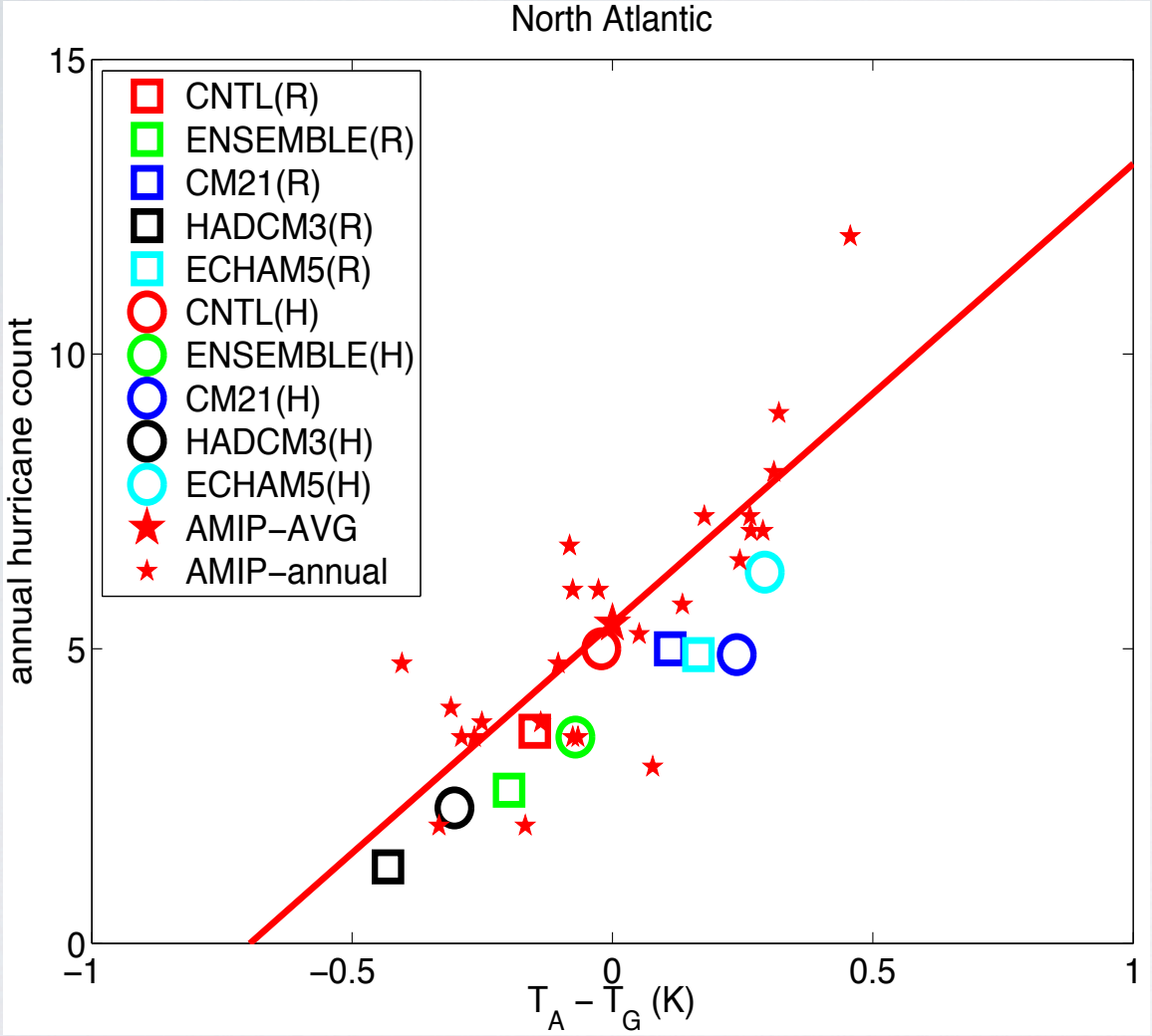


East Pacific TC



Vecchi, Zhao and Held (2010, in prep.)

HiRAM C180 (and observations + controls to large-scale) Suggest **Relative SSTA** as a Predictor



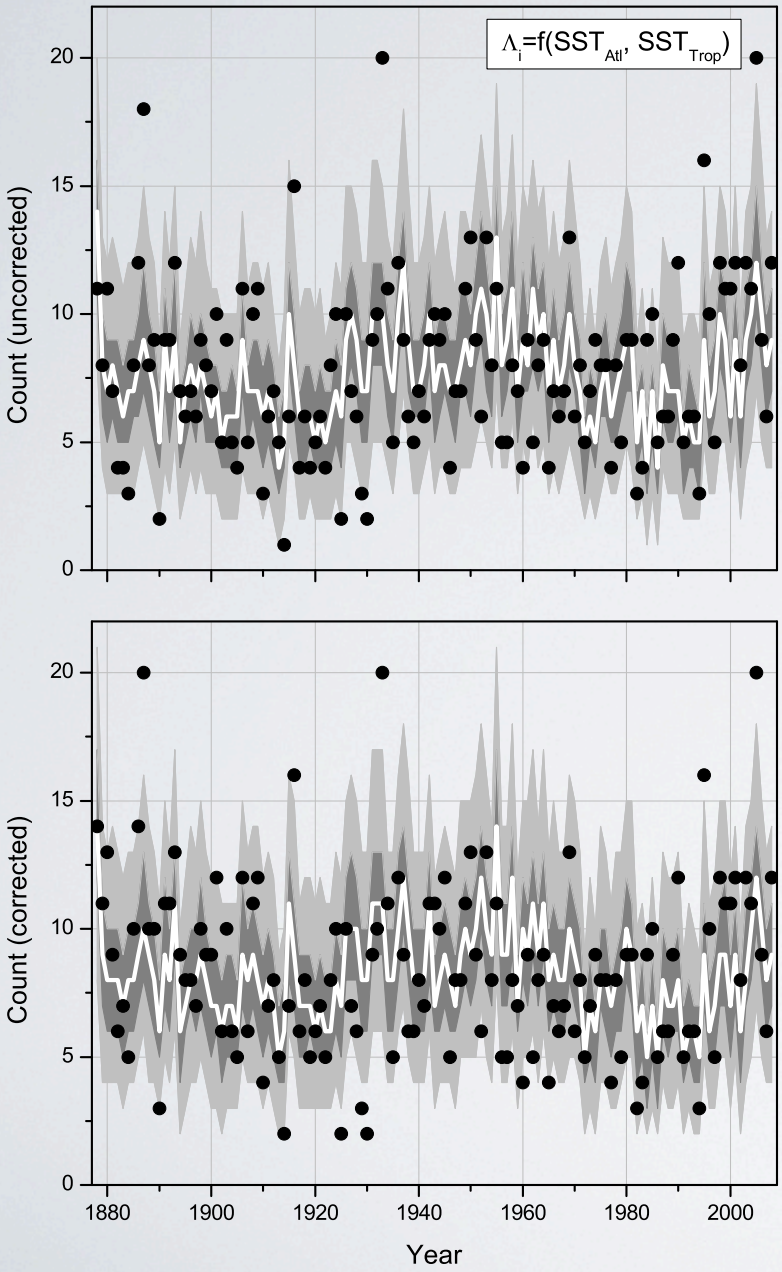
Relative SSTA = Atlantic SSTA minus Tropical SSTA

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)....

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



Atlantic SST increases frequency.

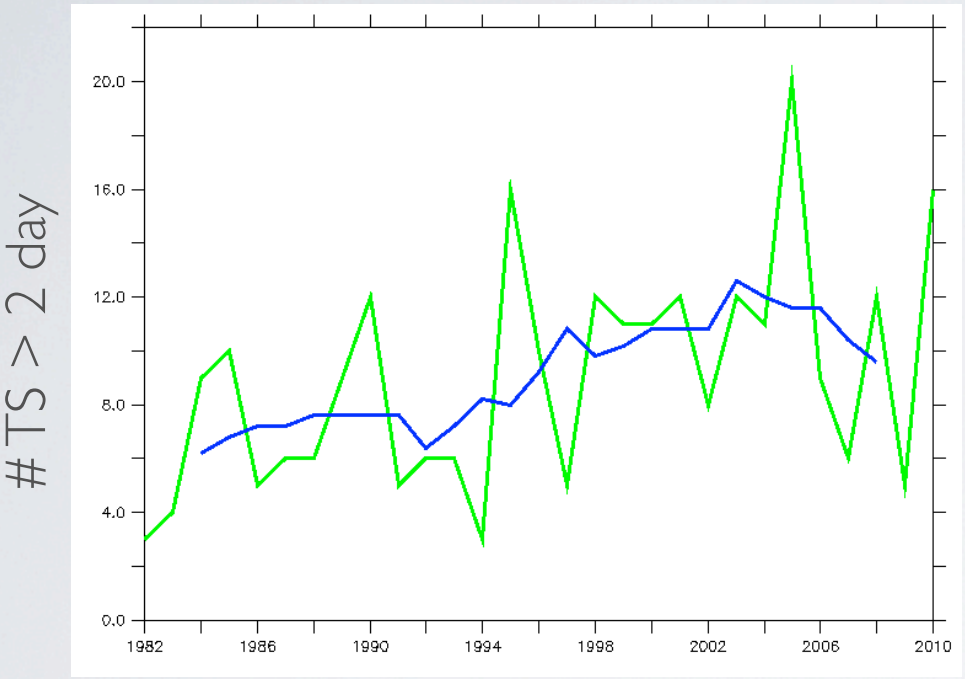
Tropical-mean SST reduces frequency.

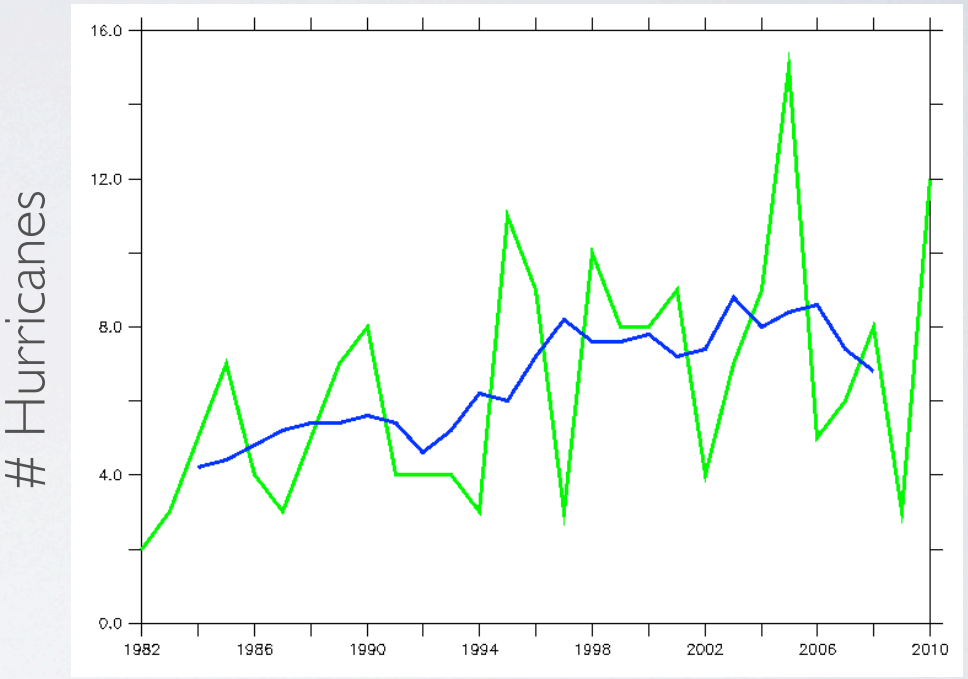
Factors in fit (w/standard error)

	Uncorrected	Corrected
Intercept	2.03 (0.03) 2.03 (0.03)	2.11 (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) -0.91 (0.20)	-1.22 (0.22) -1.05 (0.19)

Villarini et al. (2010, MWR)

Attribution of Recent NA Tropical Storm Frequency Increase

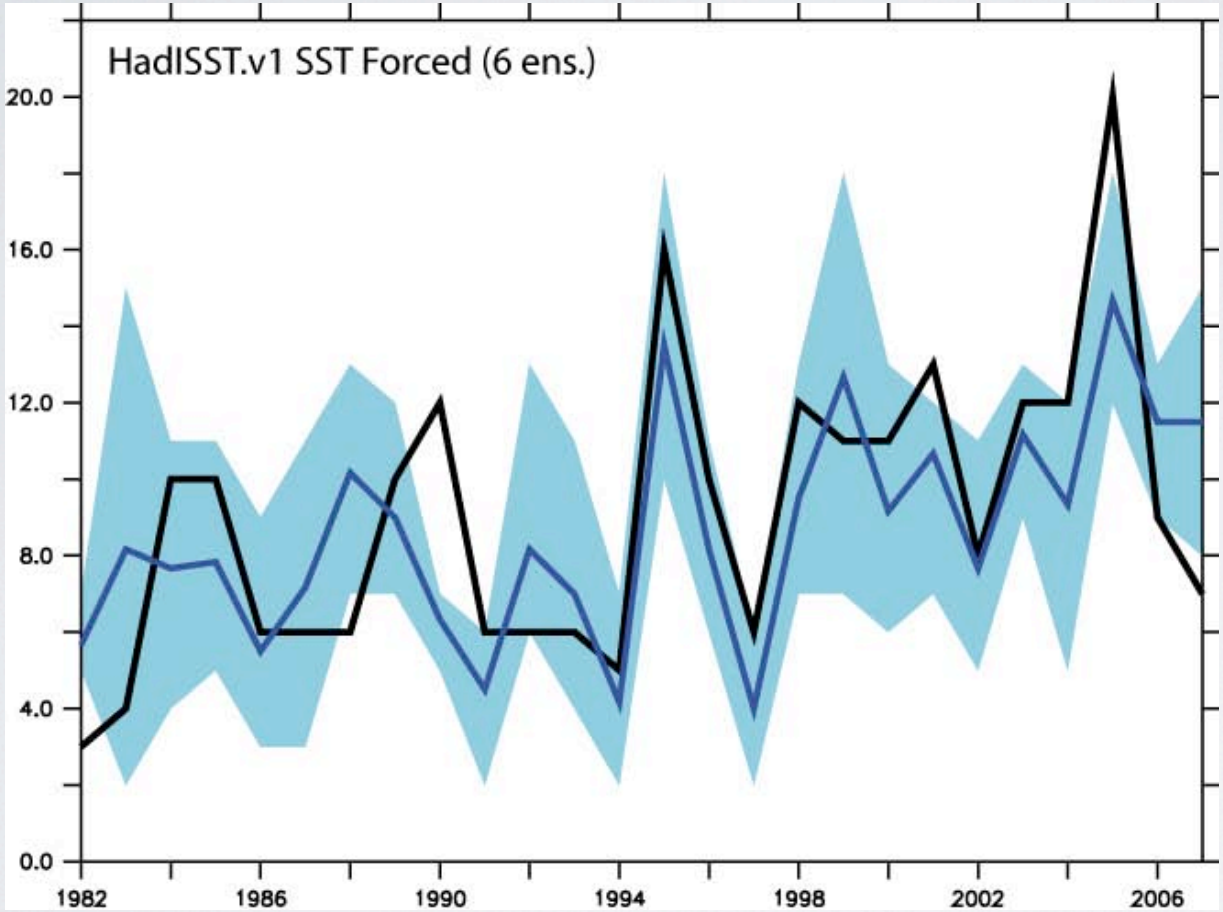




Almost a doubling in TS and hurricane frequency after 1994. What were the key factors?

Attribution of Recent TS Frequency Increase in North Atlantic

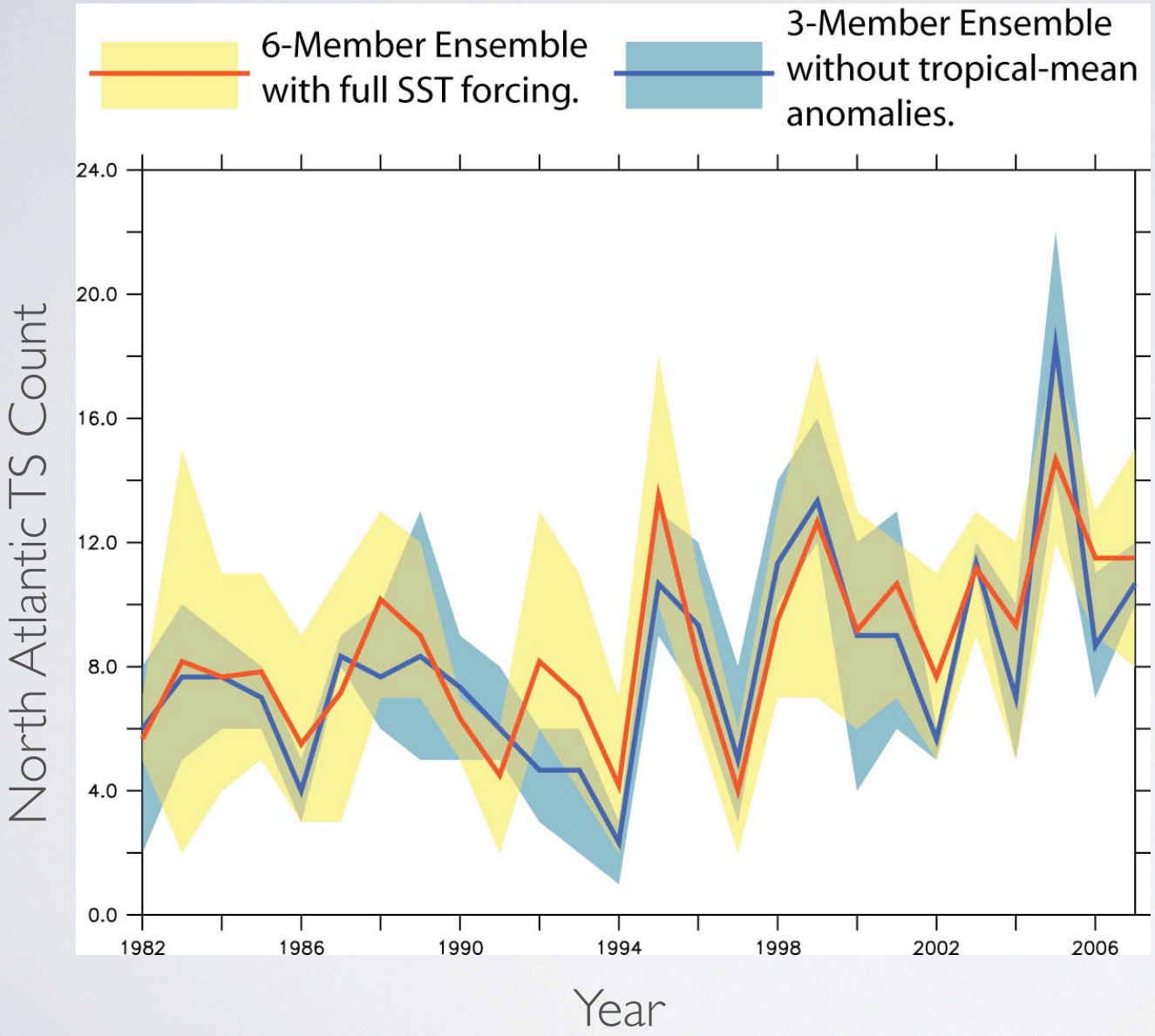
100km GFDL-HiRAM AGCM recovers recent NA TS Trend when forced with HadISST.v1 SST



What aspect of SST drove increase?

Vecchi, Zhao and Held (2011, in prep.)

NA TS Increase not Driven by Uniform Component of Recent SST Warming



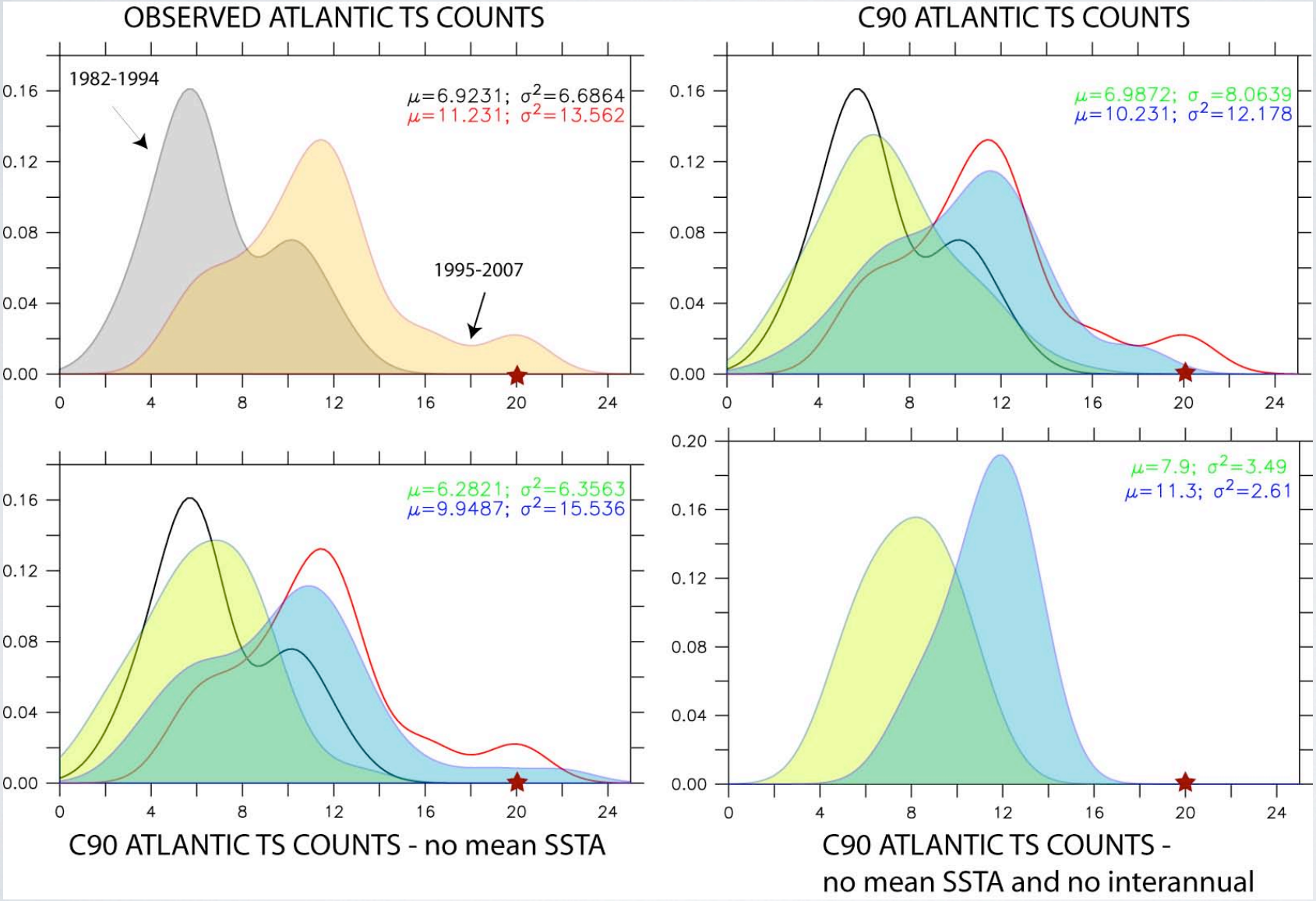
100km AGCM 1982-2007 North Atlantic tropical storm count not sensitive to removing tropical-mean SSTA forcing.

Vecchi, Delworth, Zhao and Held (2011, in prep.)

1982-94 AND 1995-2007 PDFS OF NA TS COUNT*

* lasting two days or more

★ 2005 Observed

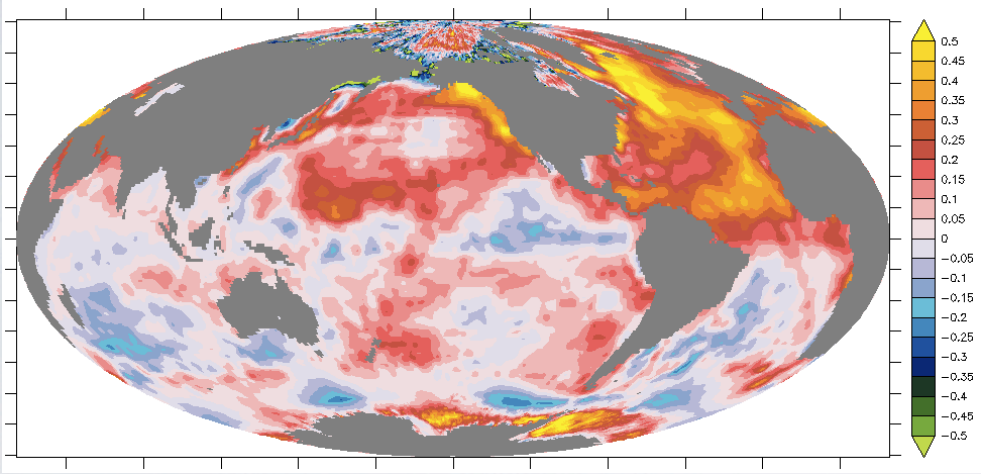


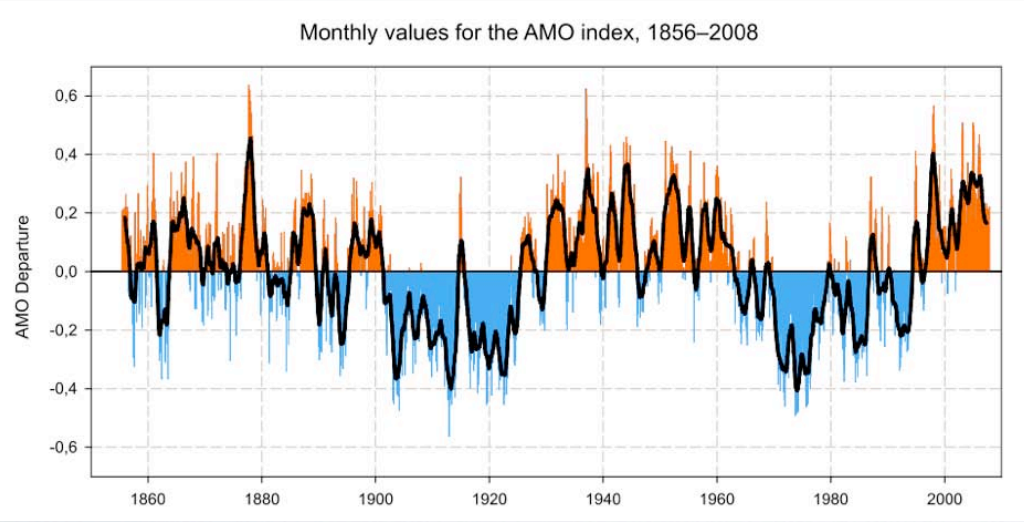
Vecchi, Delworth, Held and Zhao (2011, in prep.)

SHIFT IN MEAN TS COUNTS ATTRIBUTABLE TO "AMO" SST CHANGE ACROSS 1994-1995

What drove this SST change? Internal variability? Aerosols? Combination?

1995-2007 minus 1982-1994 "AMO" SSTA Forcing

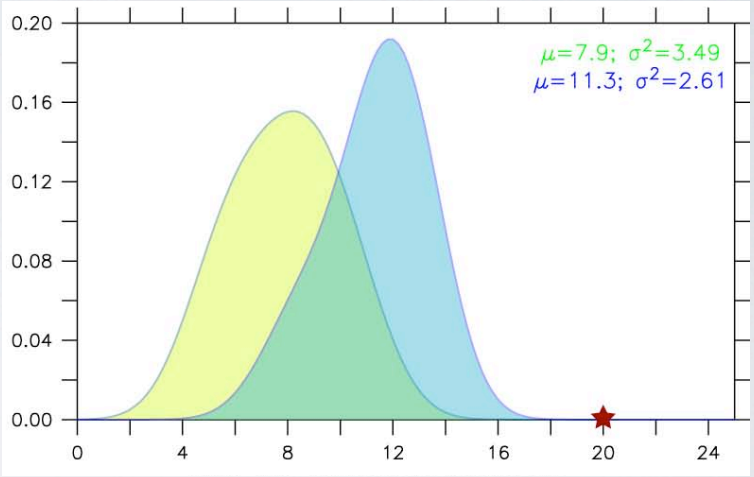




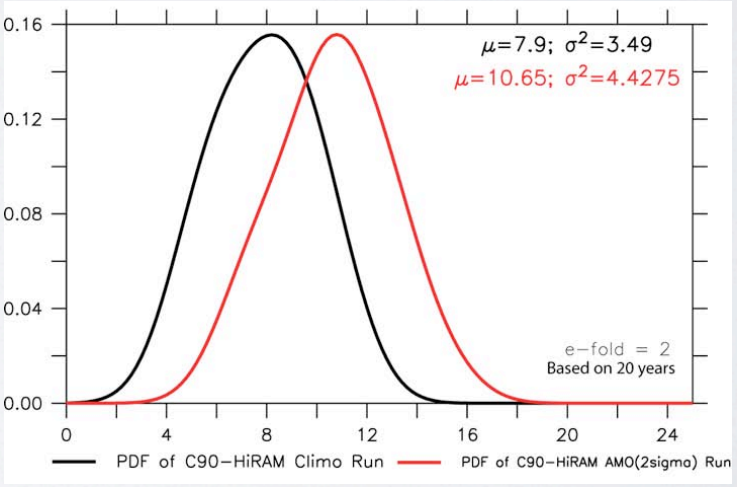
AMO Index: Regression of SST onto NA SST

Knight et al (2005)

Response to decadal shift



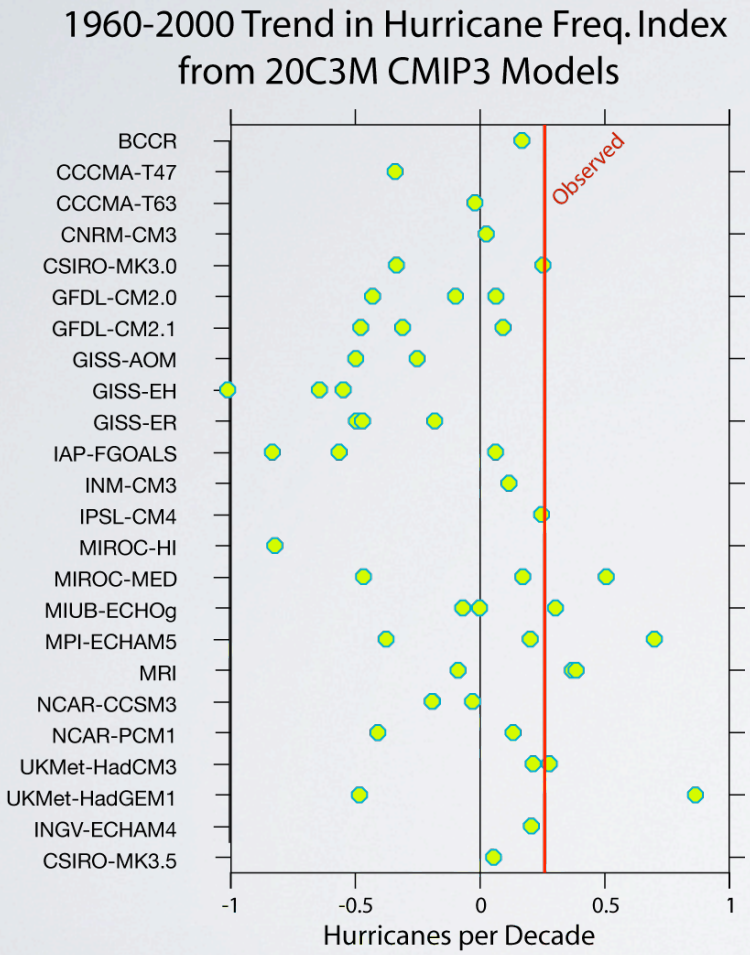
Response to "AMO" forcing

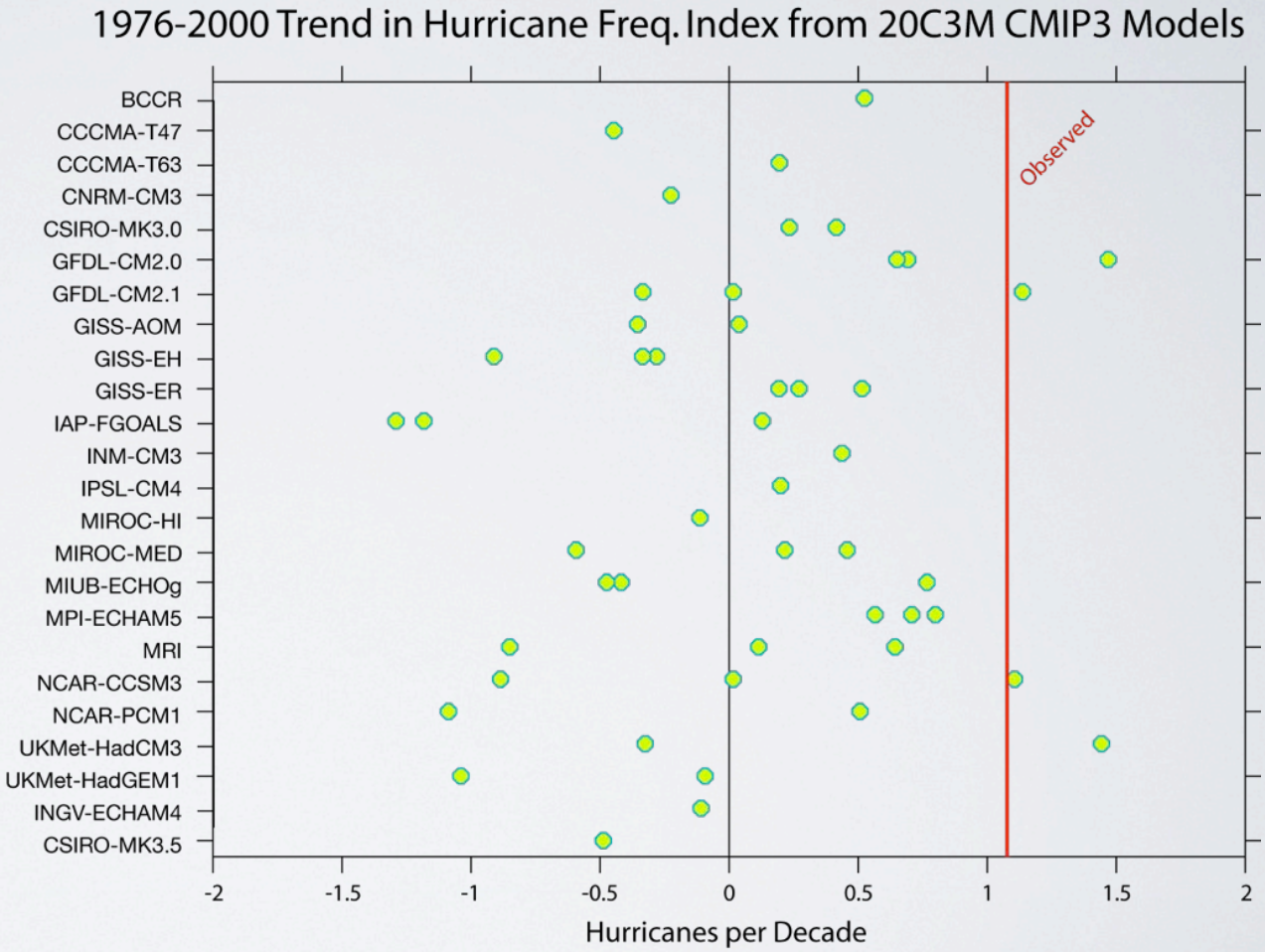


Vecchi, Delworth, Held and Zhao (2011, in prep.)

Recent Increase Not Robustly "Forced" in CMIP3 Models

Recent trend in statistical hurricane model applied to CMIP3 20c3m runs



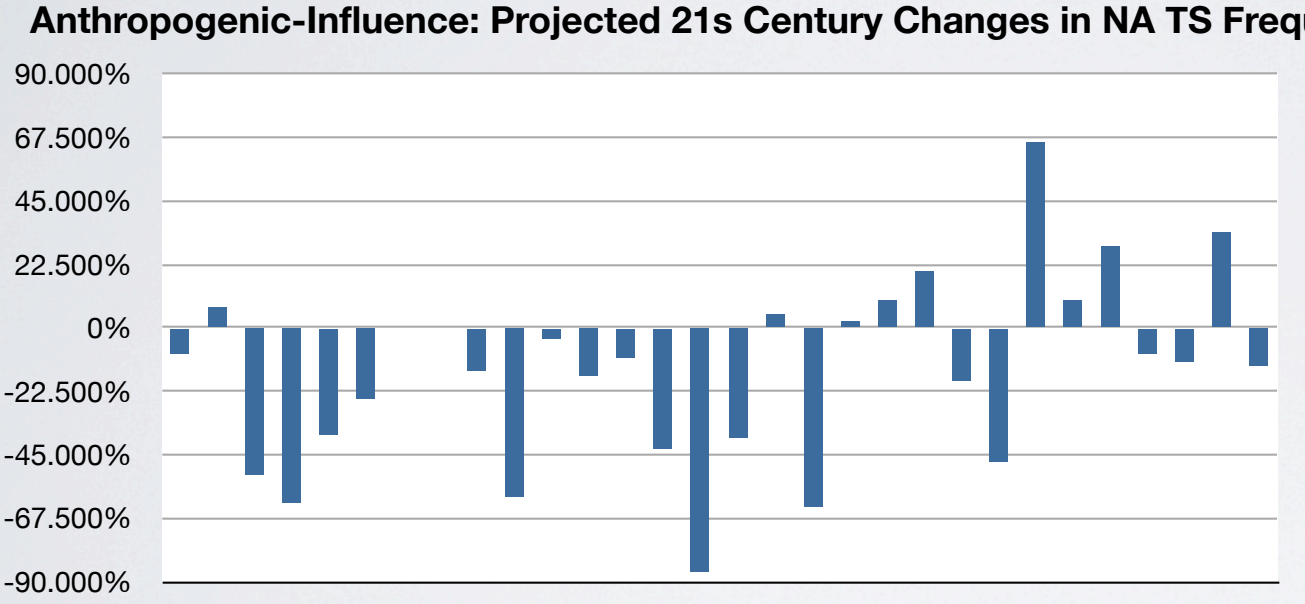


Response of NA TS Frequency to Radiative Forcing

Divergence of 21st Century projections of TS Frequency

- Even sign of NA TS frequency response to GHG unclear: Not big help in decadal predictability (yet?)

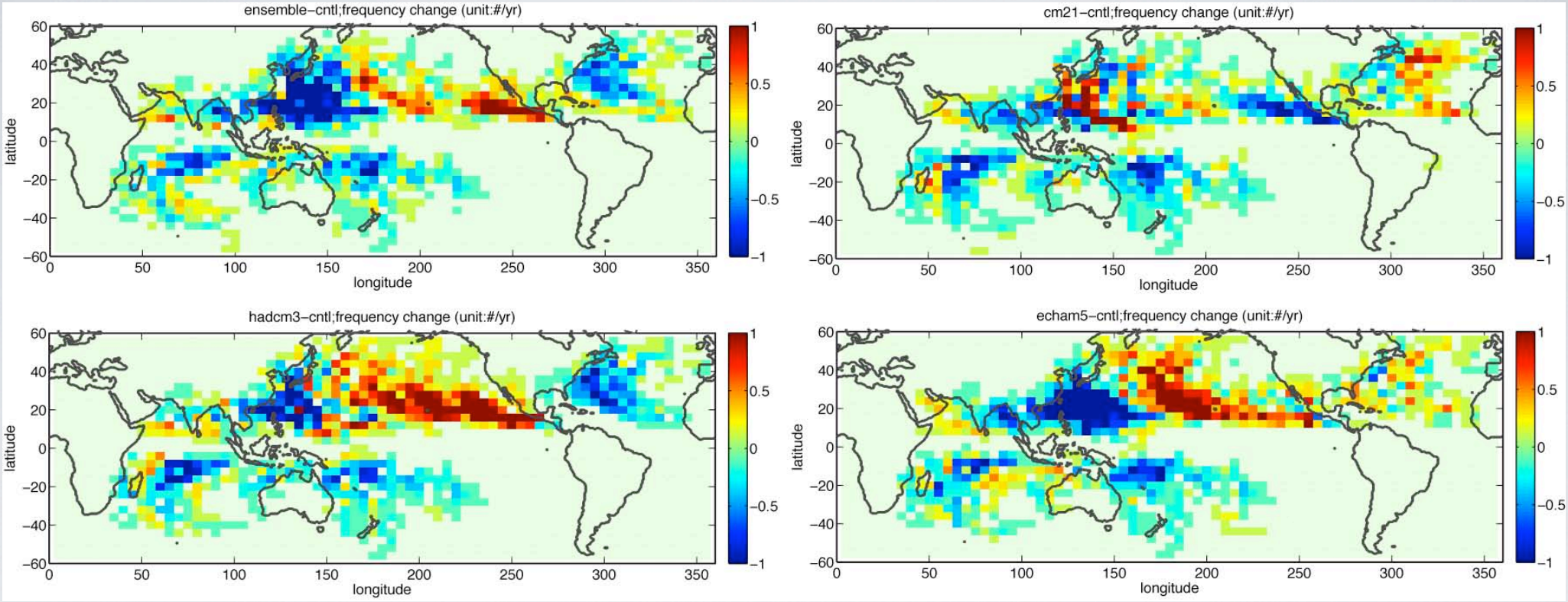
- Various studies downscale different coupled models, and over different periods



Oouchi et al (2005)
Bengtsson et al (2007)
Emanuel et al (2008)
Knutson et al (2008)
Zhao et al (2009)
Gualdi et al (2009)

Is there any consistency in the various projections?

21ST CENTURY HURRICANE ACTIVITY CHANGE: FOUR POSSIBILITIES



Red/yellow = increase
Blue/green = decrease

Adapted from Zhao et al. (2009, J. Climate)

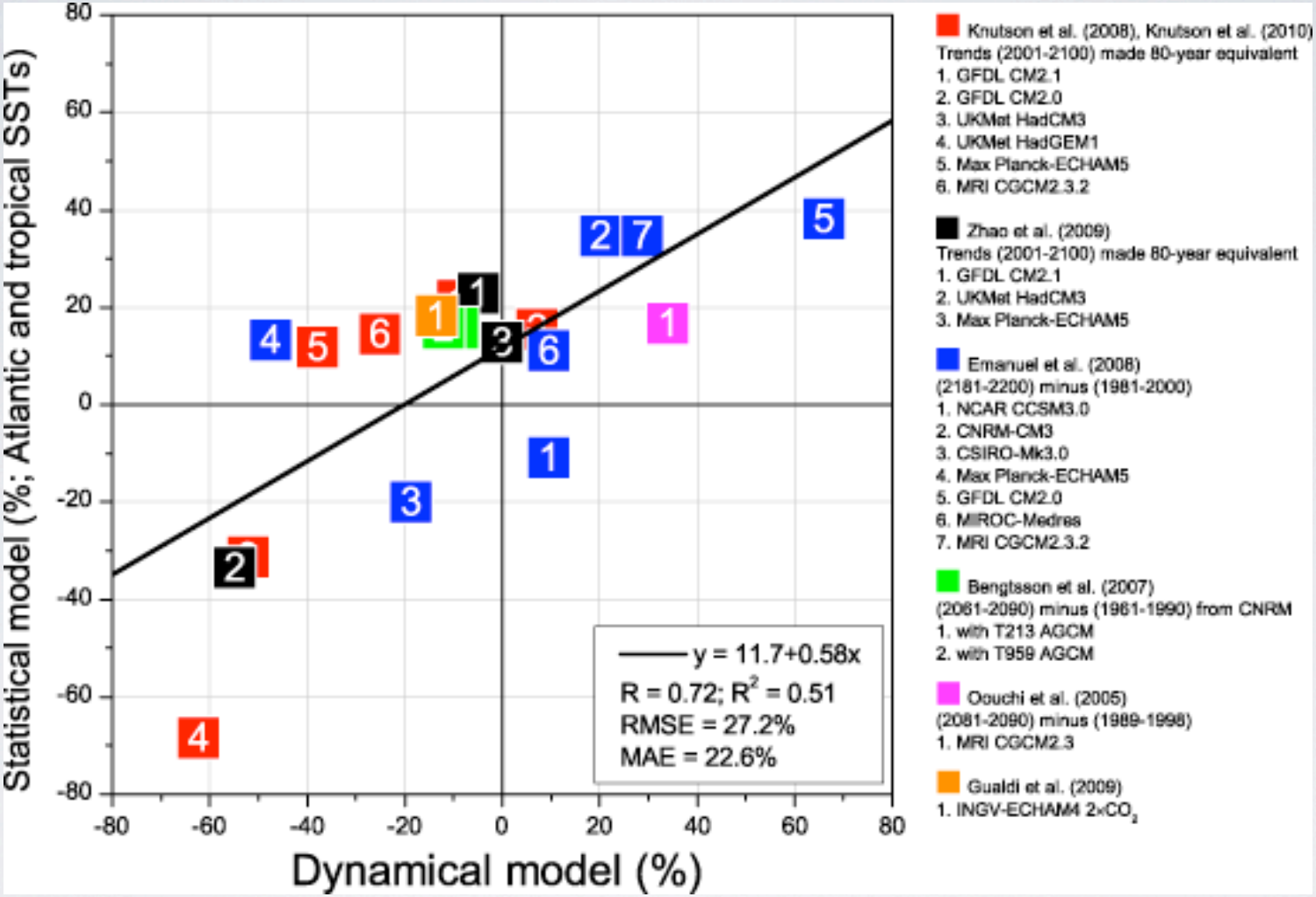
Regional increase/decrease much larger than global-mean.

Pattern depends on details of ocean temperature change.

Sensitivity of response seen in many studies

e.g., Emanuel et al 2008, Knutson et al 2008, etc

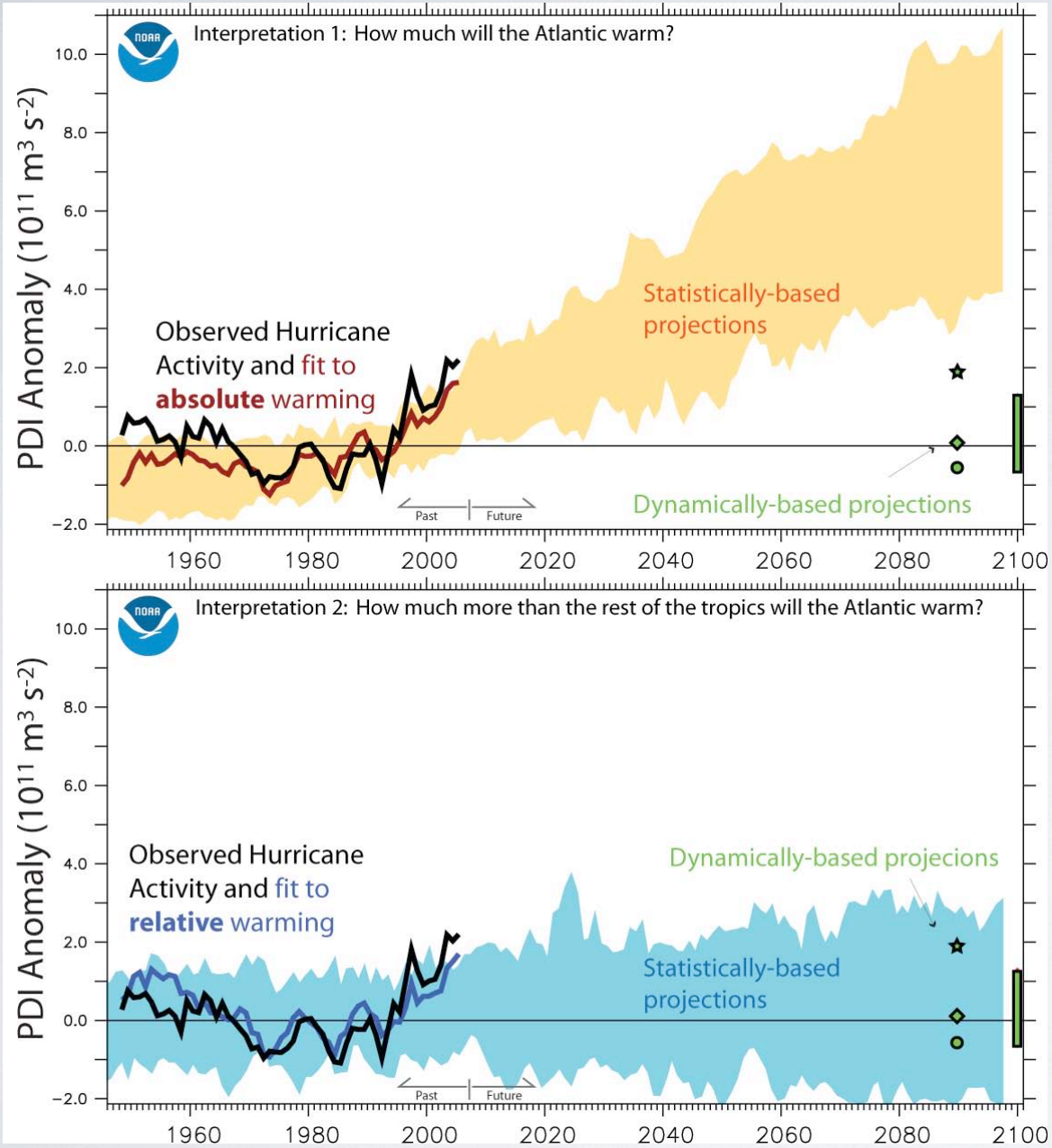
DYNAMICAL MODELS EXHIBIT CONSISTENT RELATIONSHIP TO MDR AND TROPICAL SSTS - ALL CONSISTENT WITH OBSERVATIONS



Villarini et al (2011, J. Clim. in press)

Poisson model of 2-day duration TS (vertical) vs. dynamical downscaling results (horizontal)

…Add Dynamical Projections of Atlantic Hurricane Activity



Observed Activity
Absolute Atlantic Temperature

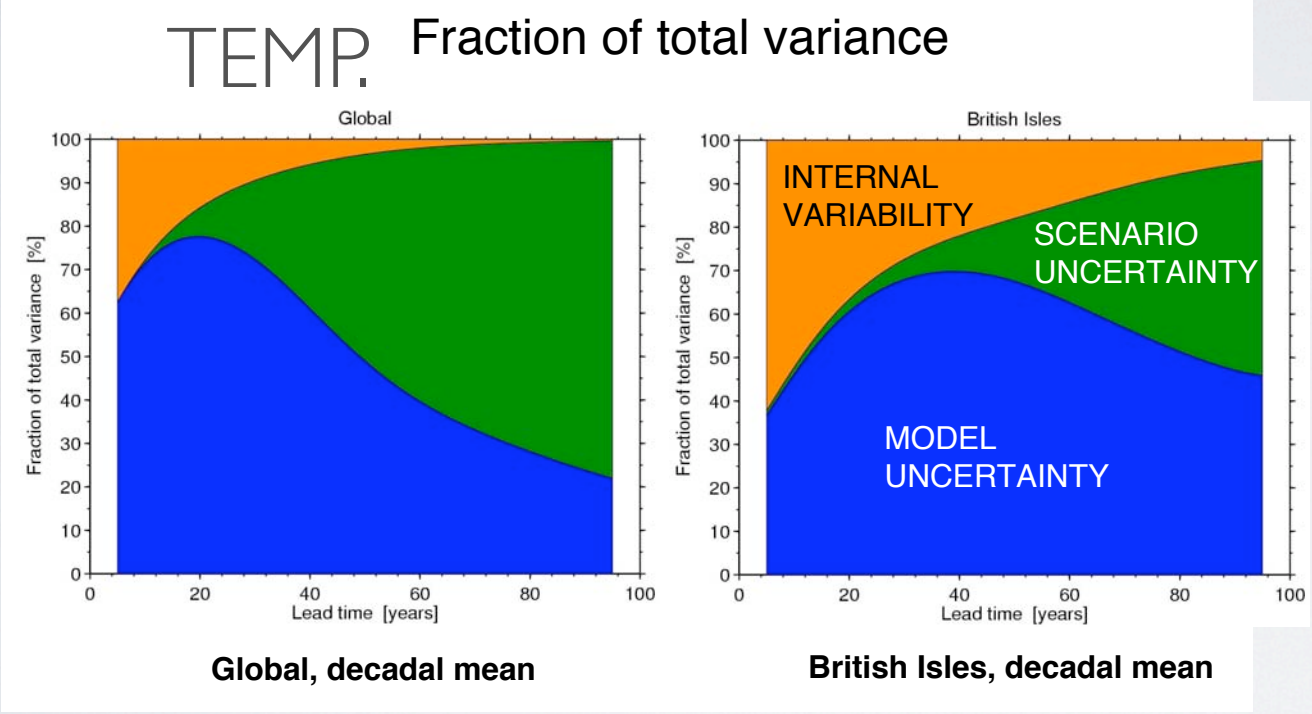
Dynamical Model Projections

Observed Activity
Relative Atlantic Temperature

Vecchi, Swanson and Soden (2008, Science)

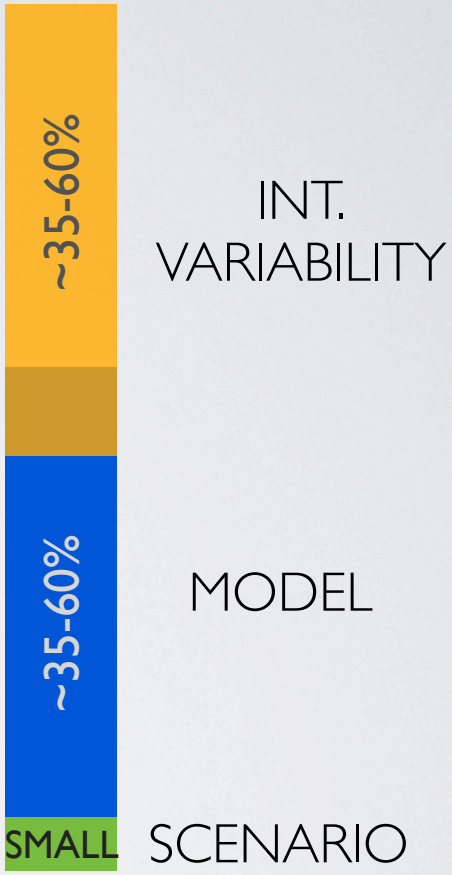
NA Hurrs Projections: Internal Variability A Primary Source of Uncertainty Even in 100-year Trends

TEMP.



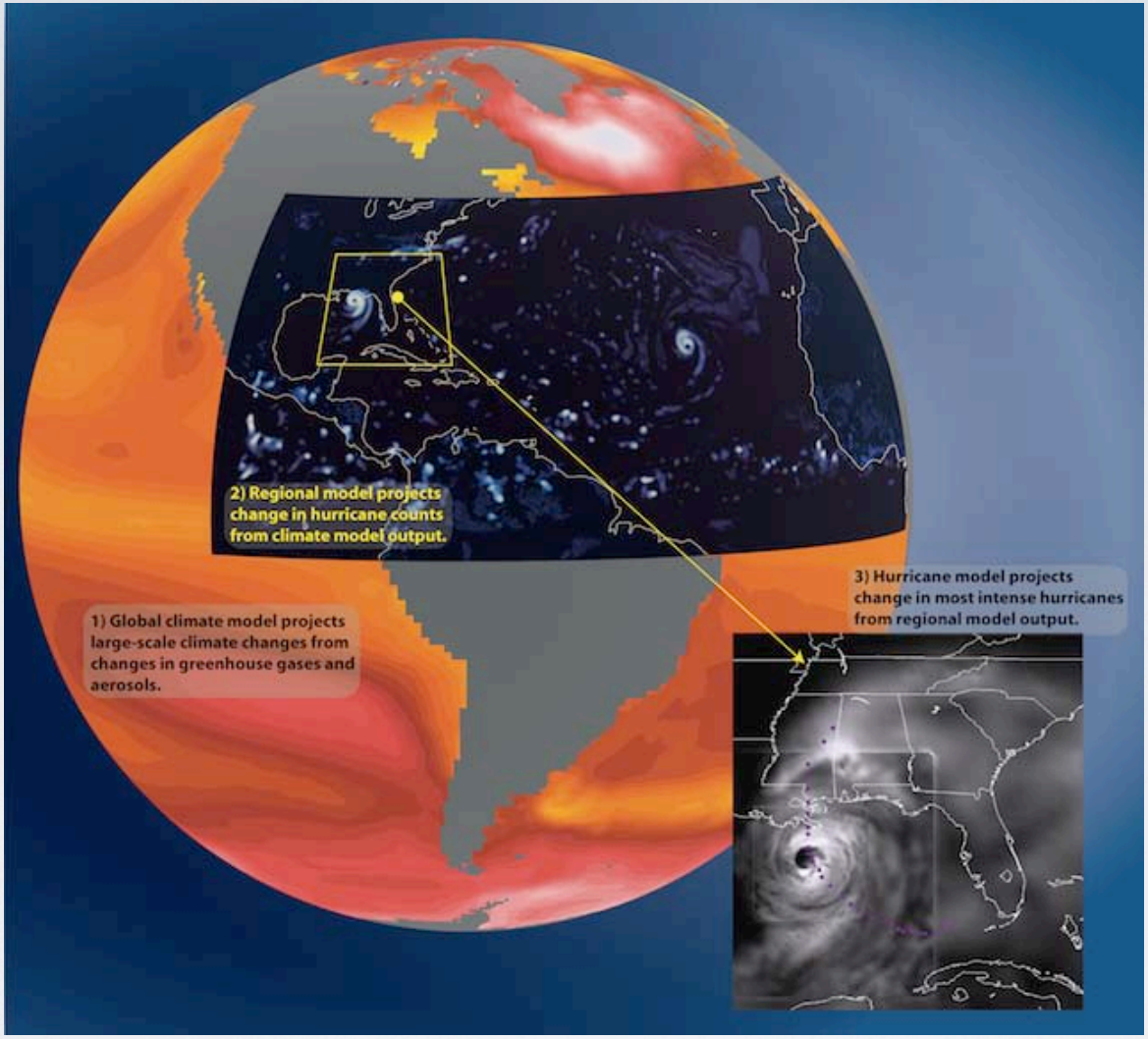
Hawkins and Sutton (2009)

TS COUNTS



Estimate of relative uncertainty sources for 2001-2100 trends in NA TS Counts (adapted from Villarini et al 2011, in press)

STRONGEST CYCLONES PROJECTED WITH DOUBLE DOWNSCALING

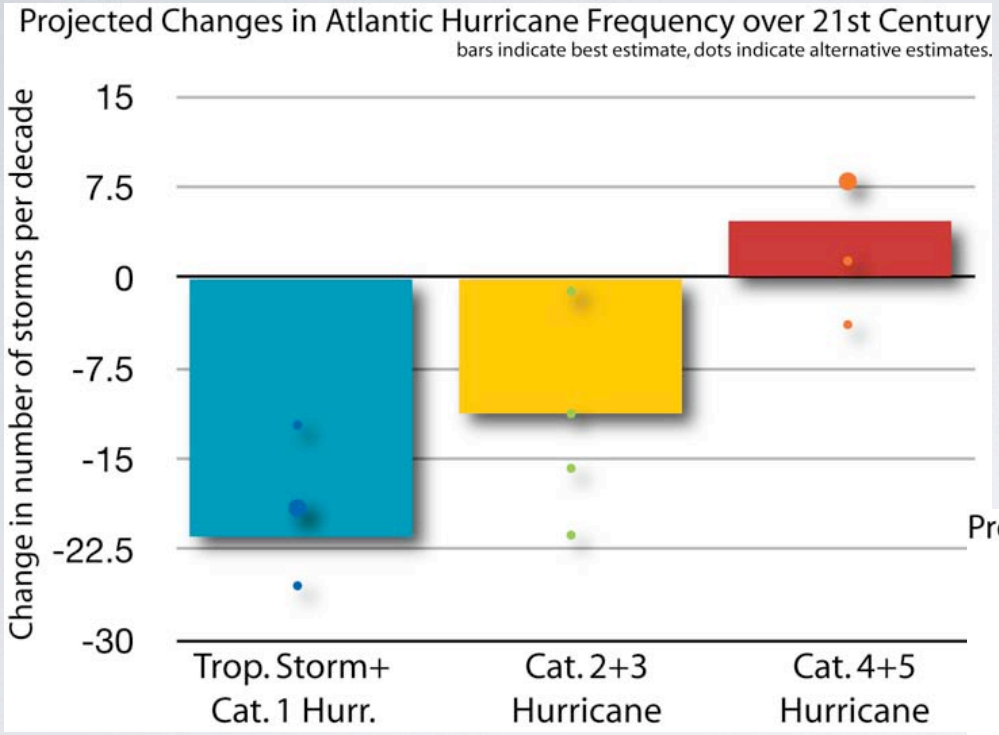


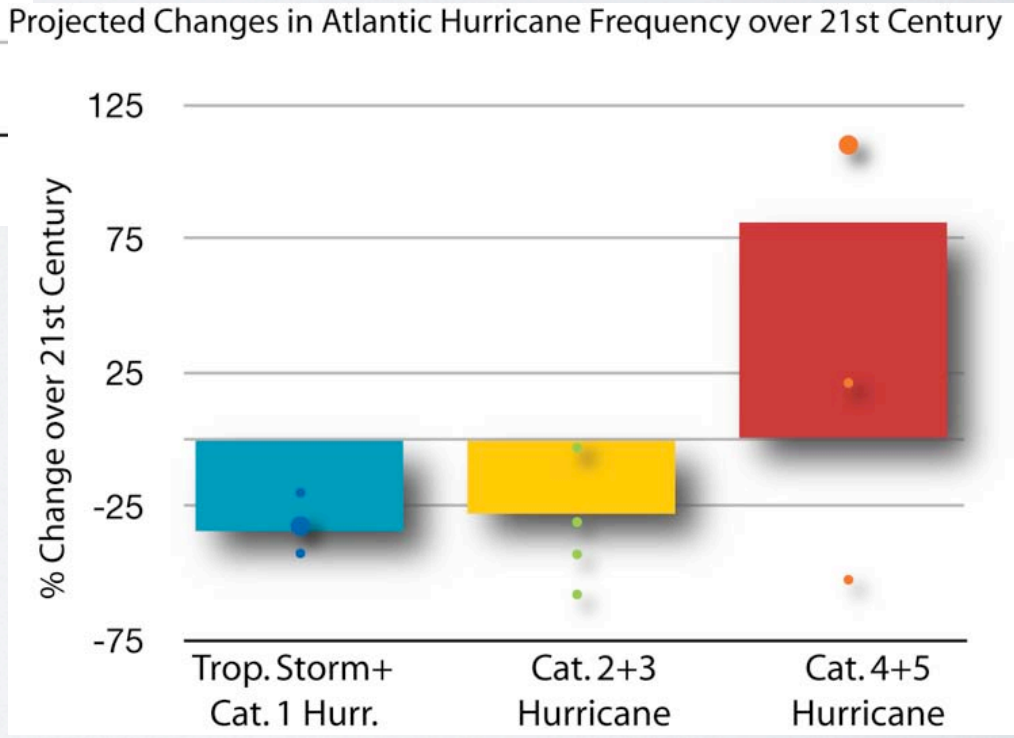
Adapted from
Bender et al (2010, Science)

Global Climate Models -> Regional Model -> Hurricane model

Large-scale TS Frequency Intensity

OVERALL FREQUENCY DECREASE, BUT STRONGEST STORMS MAY BECOME MORE FREQUENT





Adapted from Bender et al (2010, Science)

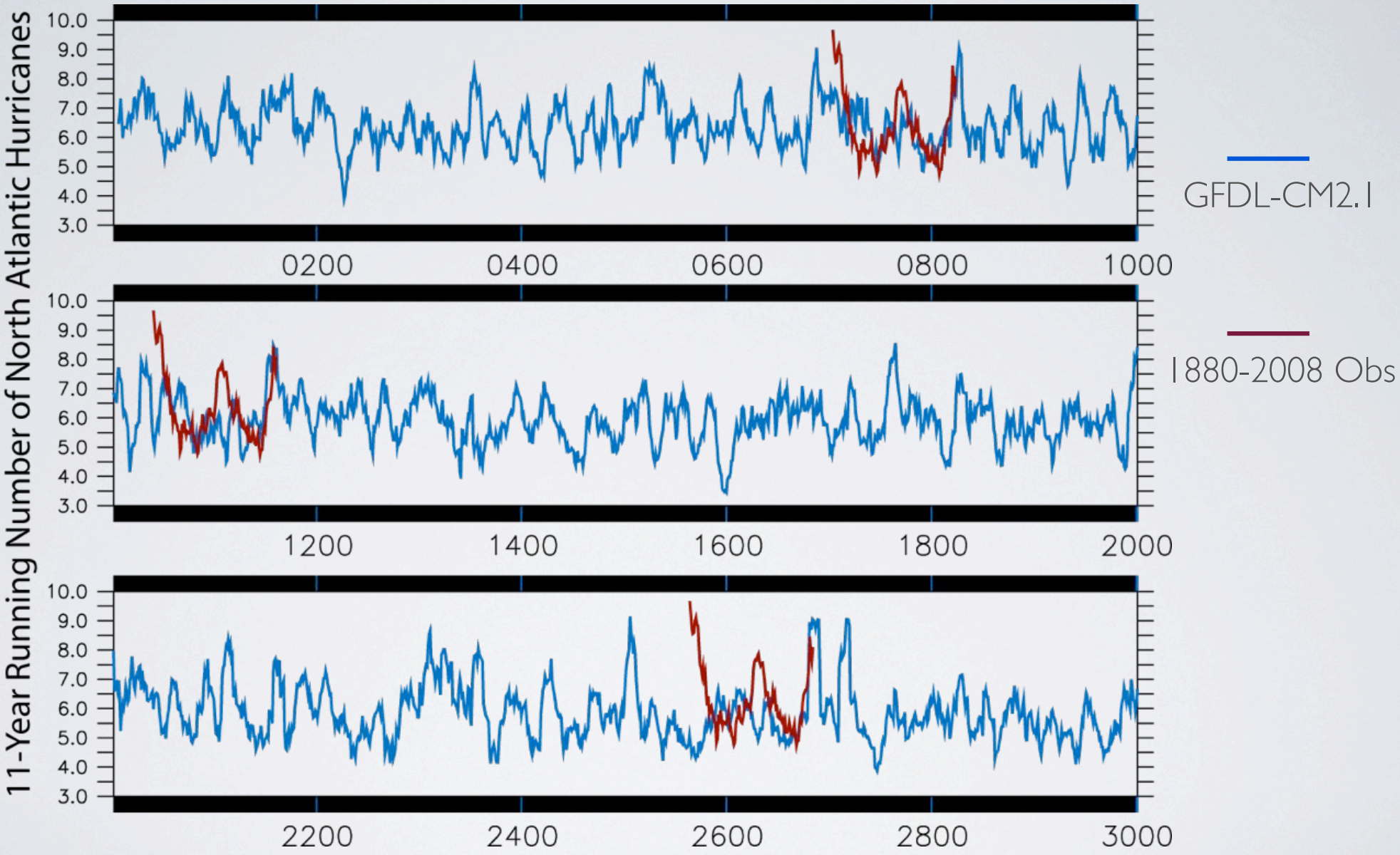
Internal Climate Variability and North Atlantic Hurricanes

Apply statistical model for NA hurricane frequency built from sensitivity of 50km AGCM to 4,000 years of GFDL-CM2.1 output.

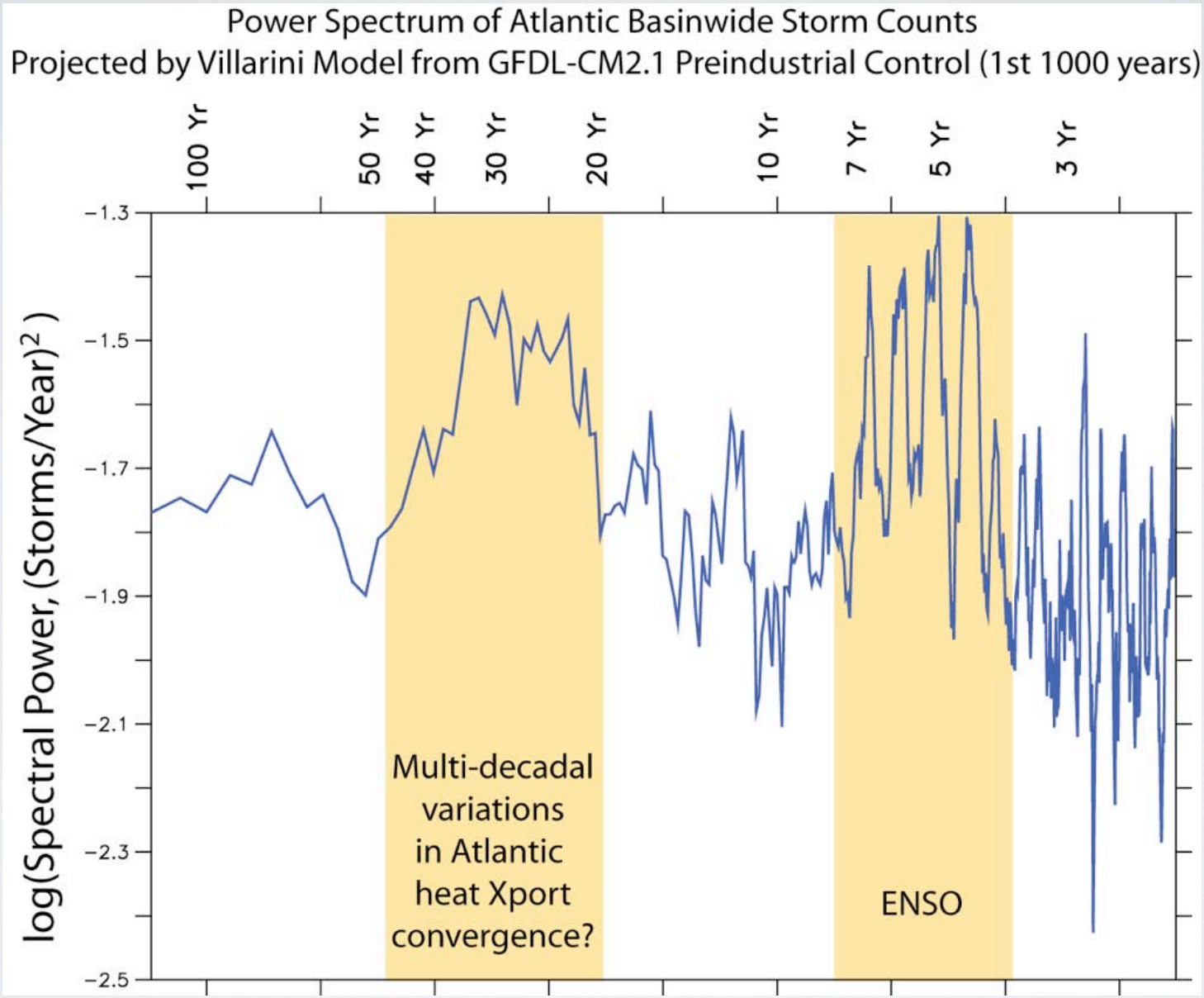
Statistical model uses two predictors:

- Tropical Atlantic SST
- Global Tropical SST

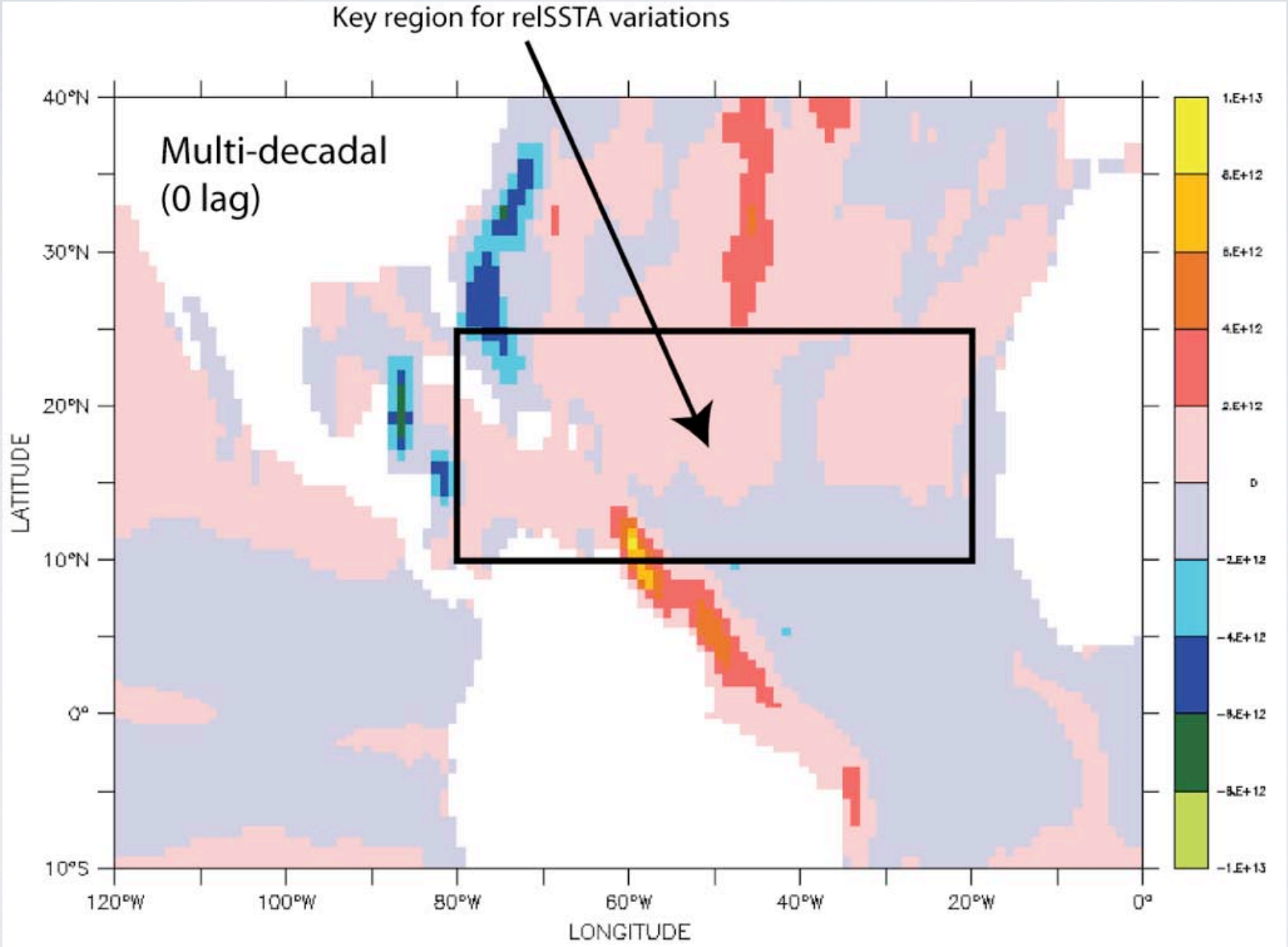
Statistical storm counts in GFDL CM2.1 Preindustrial-Control Run



Statistical TS Counts in 2,000 year CM2.1 Control

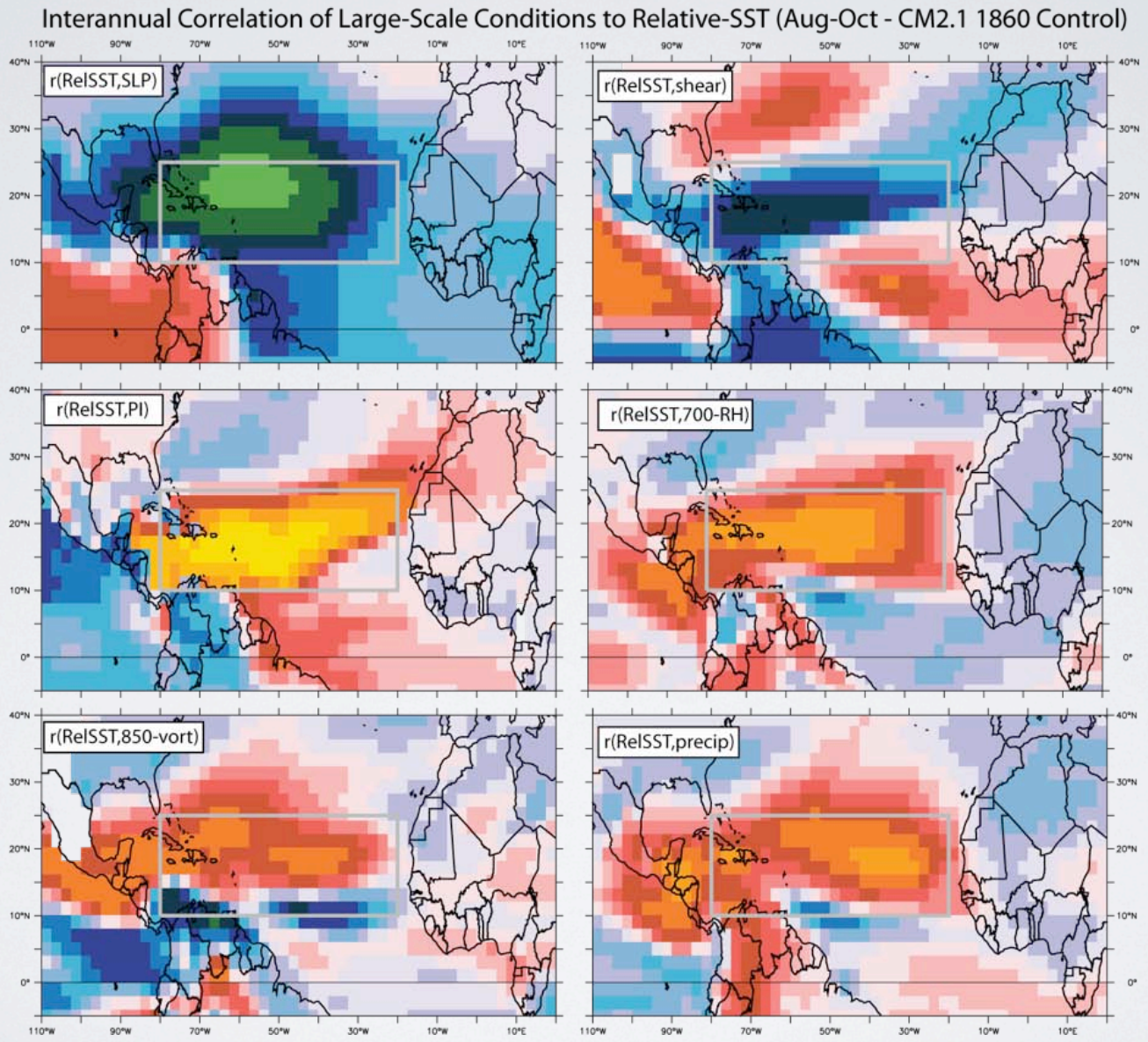


Statistical counts and meridional ocean heat transport



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

Hurricane-Relevant Large-Scale Conditions Co-vary Constructively With Relative-SST



SLP

Shear

PI

700hPa RH

850hPa vort.

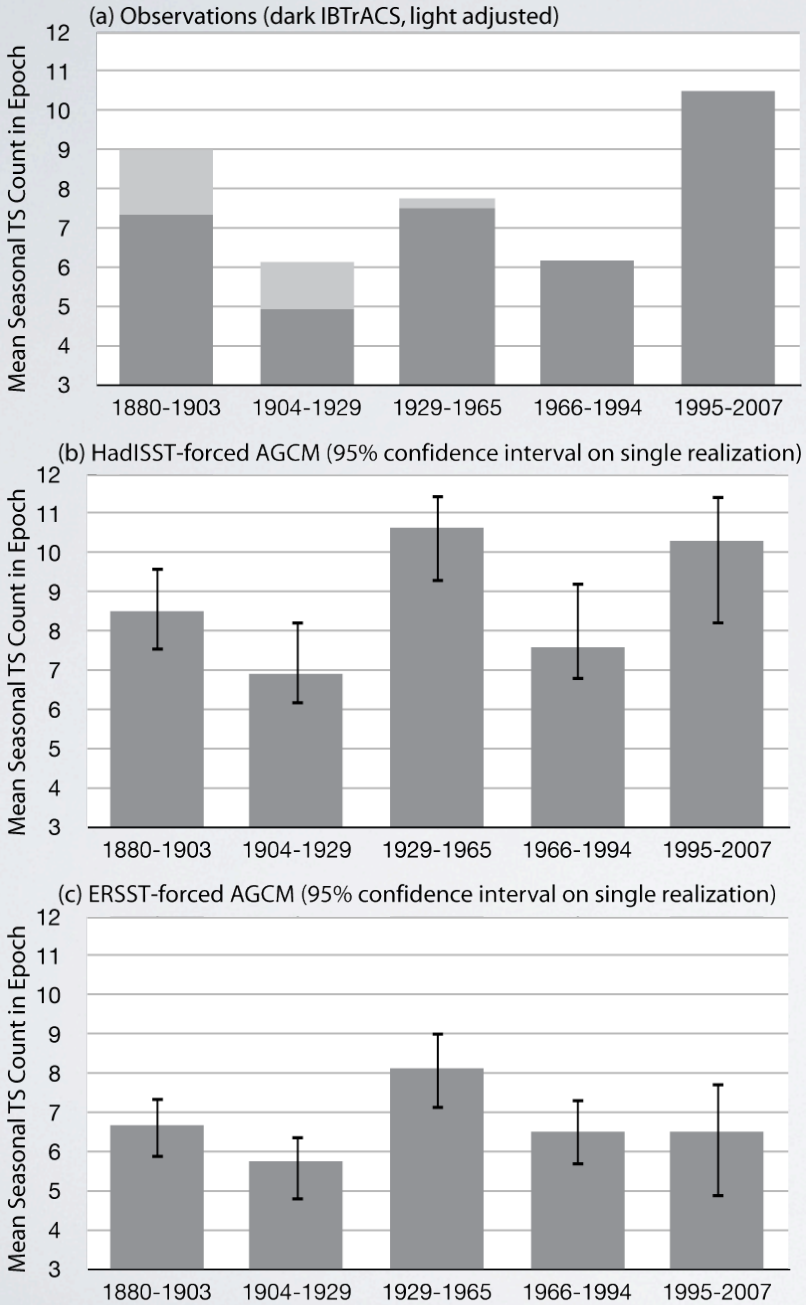
Precip

Sensitivity to SST Uncertainty

If AGCM sensitivity (and relative-SST statistical models) correct:

We may need to predict decadal SST changes better than we know past changes.
(even over the satellite-SST era;1982-2010)

Ability of AGCM to Recover Multi-decadal TS Variability Depends on SST Forcing



Observed

HadISST-Forced AGCM

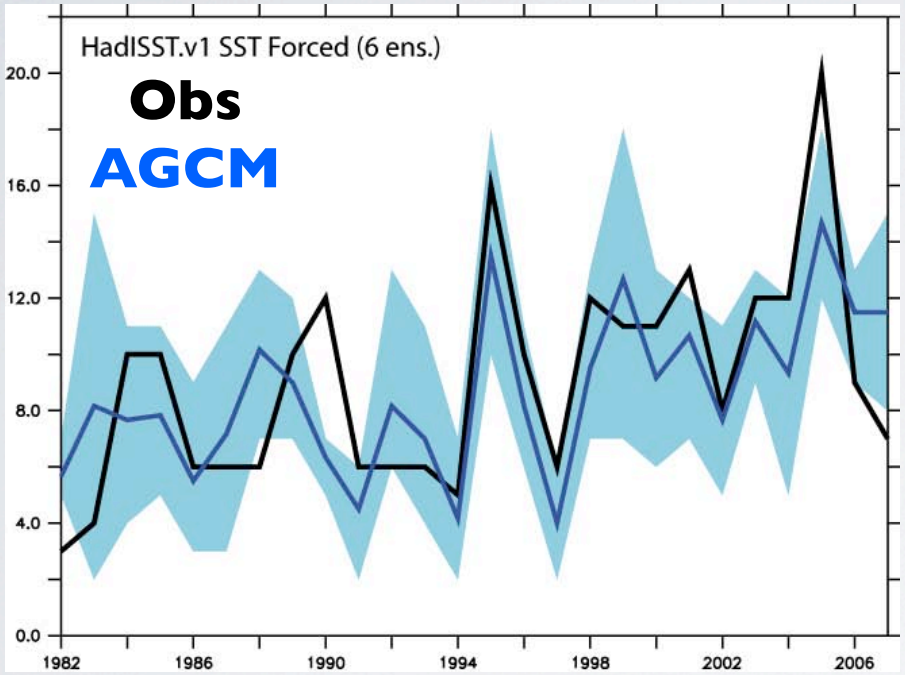
ERSST-Forced AGCM

Vecchi, Zhao and Held (2011, in prep.)

Model Response Exhibits Sensitivity To Forcing Used

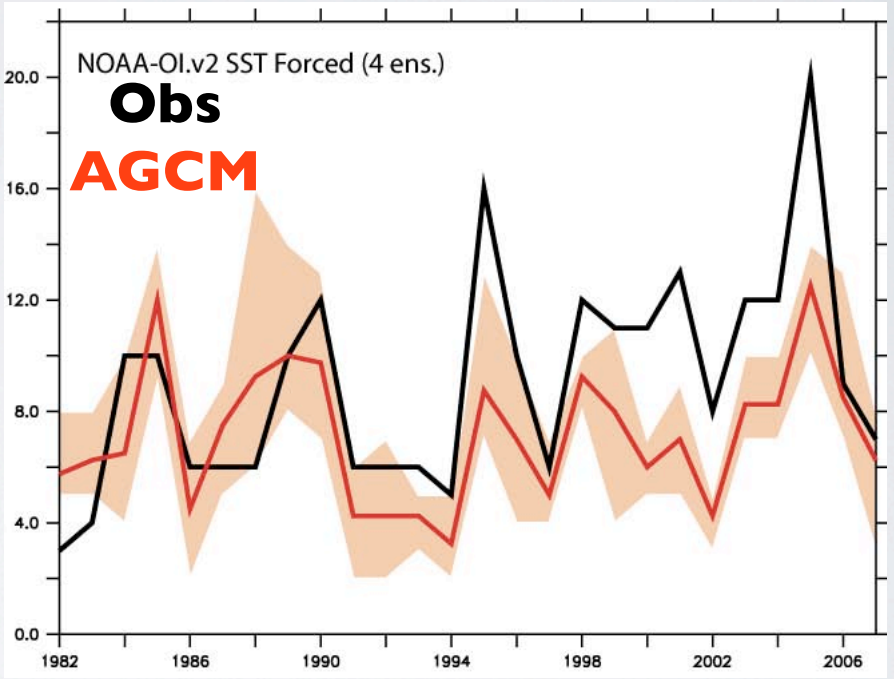
Tropical Storm Frequency Response to Same
AGCM but different estimates of observed SST

HadISST forced



AGCM is 100km version of Zhao et al (2009, J. Clim.)

NOAA-OI.v2 forced



Vecchi, Zhao and Held (2011, in prep.)

How do we evaluate model skill in this context?

Summary

- 1982-2007 TC increase in NA due to pattern of SST change
  (what drove pattern? Not robustly associate with forcing in CMIP3 models; consistent with internal variability in CMIP3 models)

- Hybrid hurricane forecast system exhibits skill from November of previous year

- Projected radiative forcing not big source of predictability in frequency.

- Internal variability and systematic model differences dominant source of uncertainty even in 100-year trends.

- In CM2.1 decadal hurricane frequency variability associated with tropical Atlantic oceanic changes.

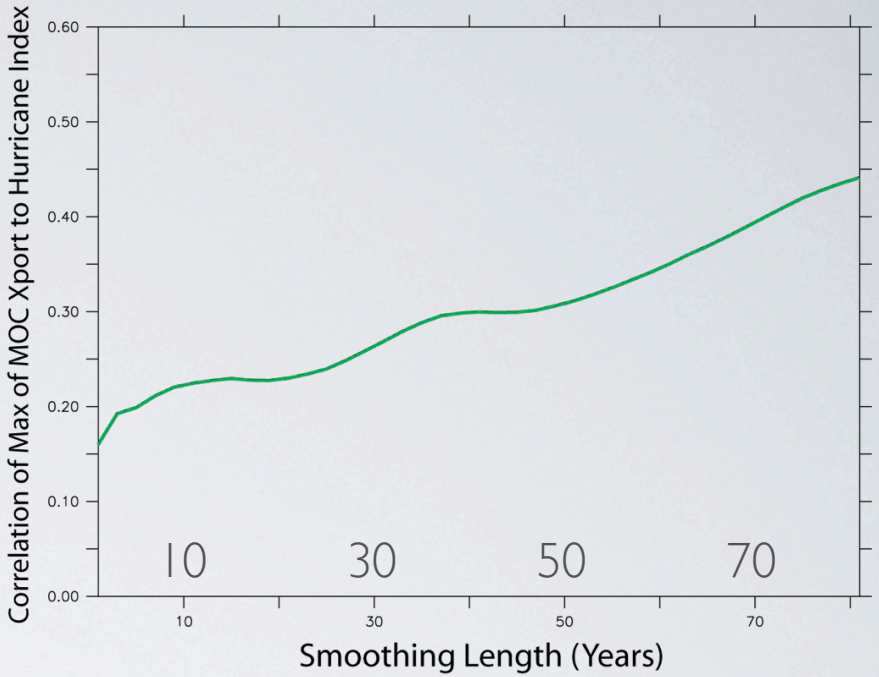
- ***If sensitivity in high-res GCM correct, may need to predict decadal SST patterns better than we know past changes.***

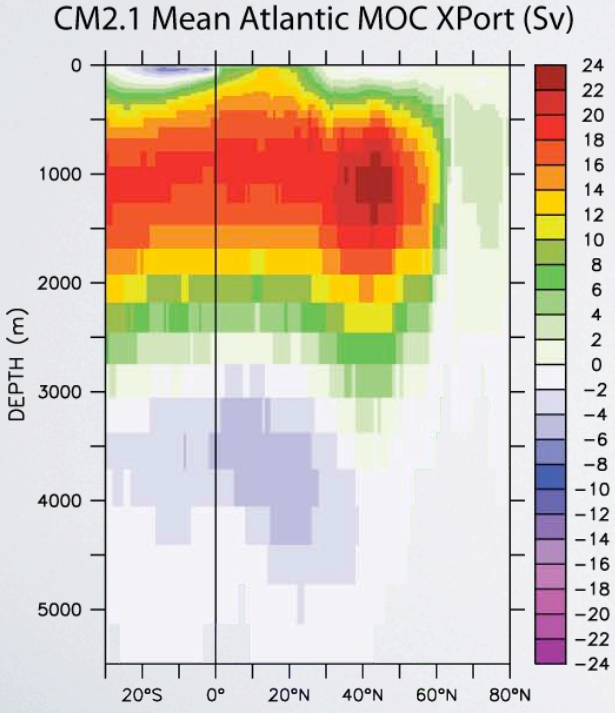
Gabriel.A.Vecchi@noaa.gov

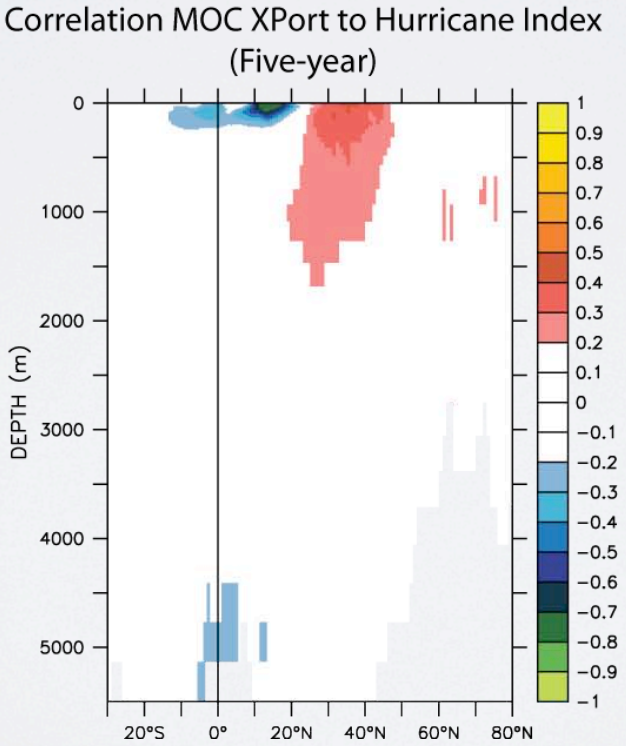
BINKY SLIDES

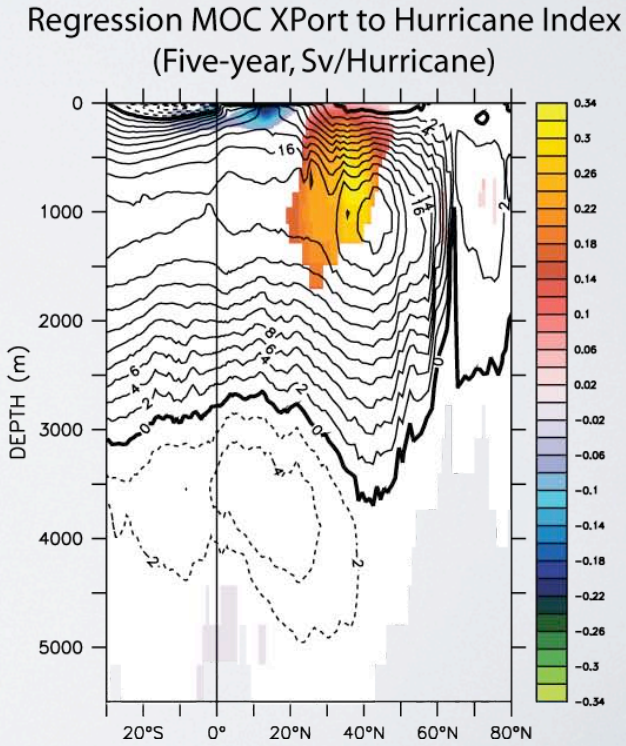
Hurricane Index Correlated with max(MOC) at lowest frequencies (centennial).

At decadal timescales perhaps related to shifts in MOC max & shallow changes.



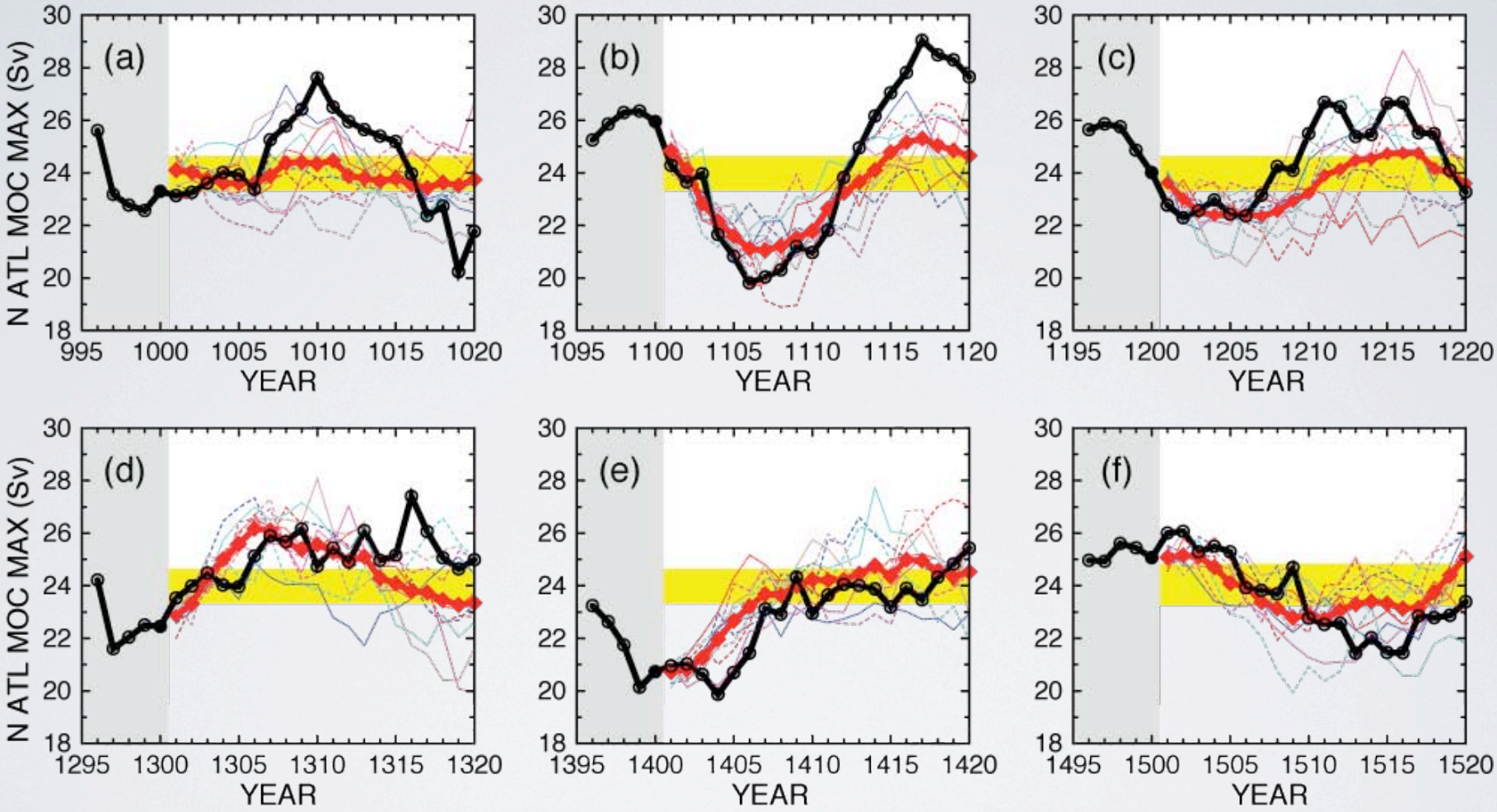






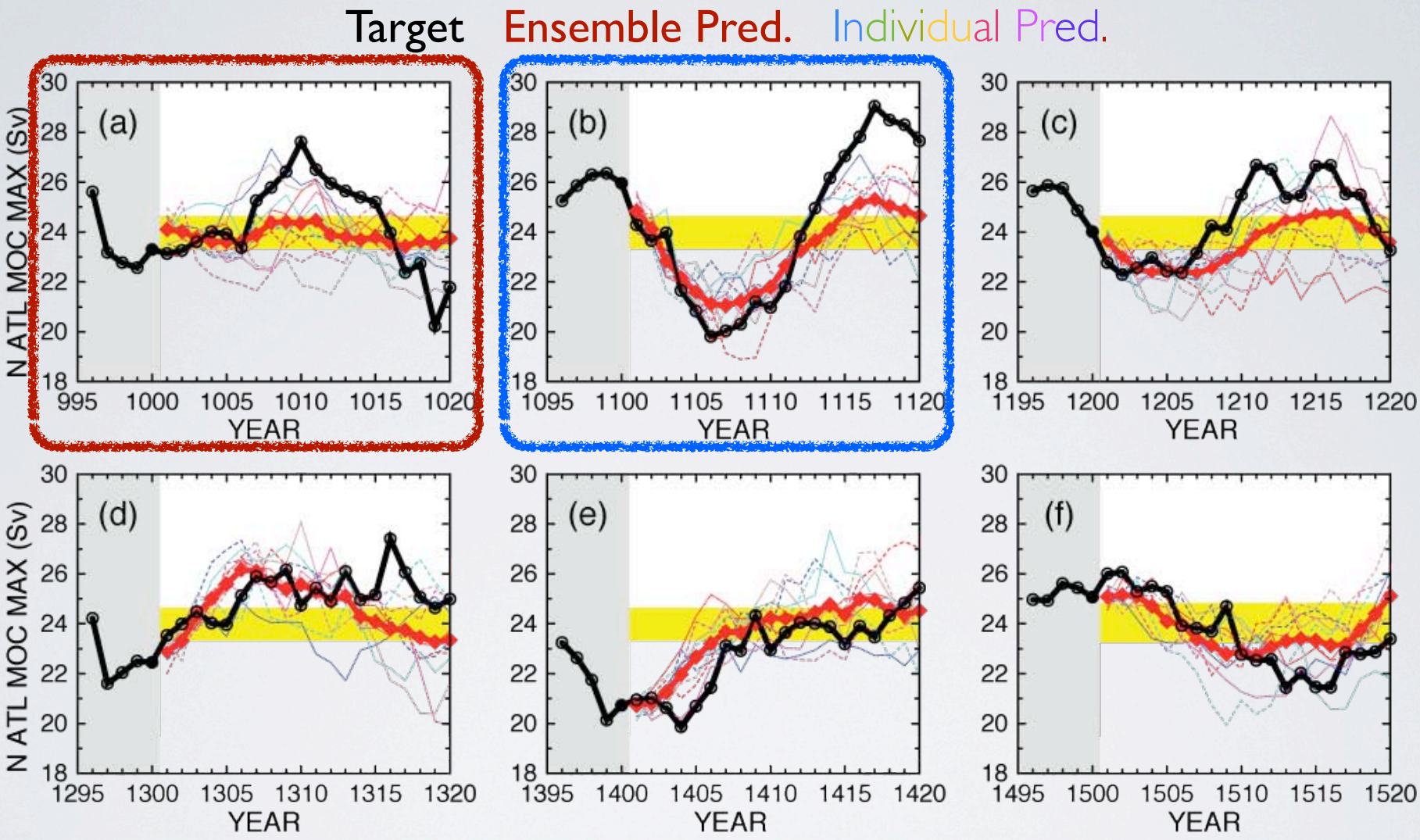
In GFDL-CM2.1 Perfect Model/Perfect Obs. Experiments: MOC Predictability Appears to Vary (see Poster #5)

Target Ensemble Pred. Individual Pred.



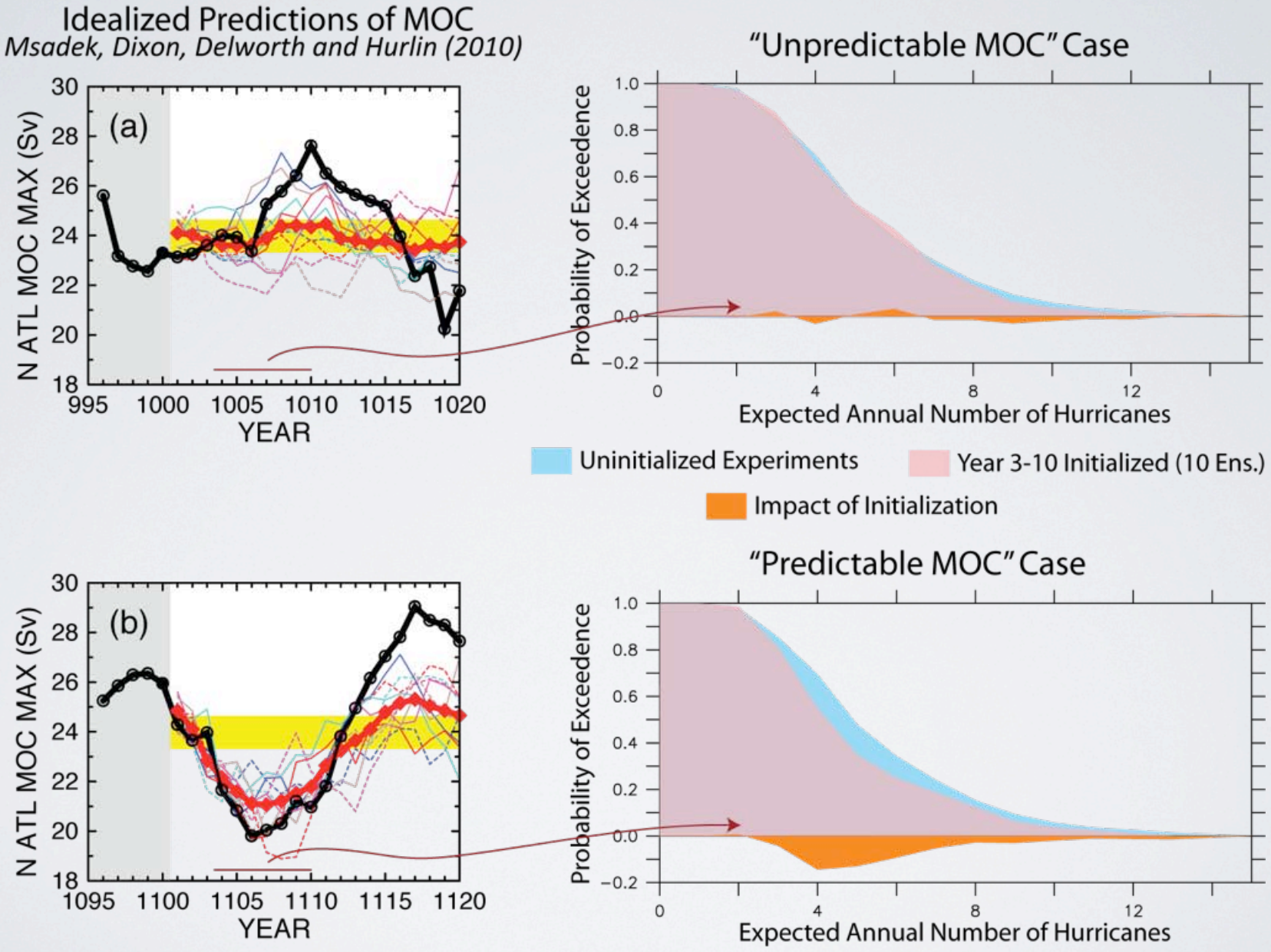
Msadek, Dixon, Delworth and Hurlin (2010, GRL).
ASSESSING THE PREDICTABILITY OF THE AMOC

In GFDL-CM2.1 Perfect Model/Perfect Obs. Experiments: MOC Predictability Appears to Vary (see Poster #5)



Msadek, Dixon, Delworth and Hurlin (2010, GRL).
ASSESSING THE PREDICTABILITY OF THE AMOC

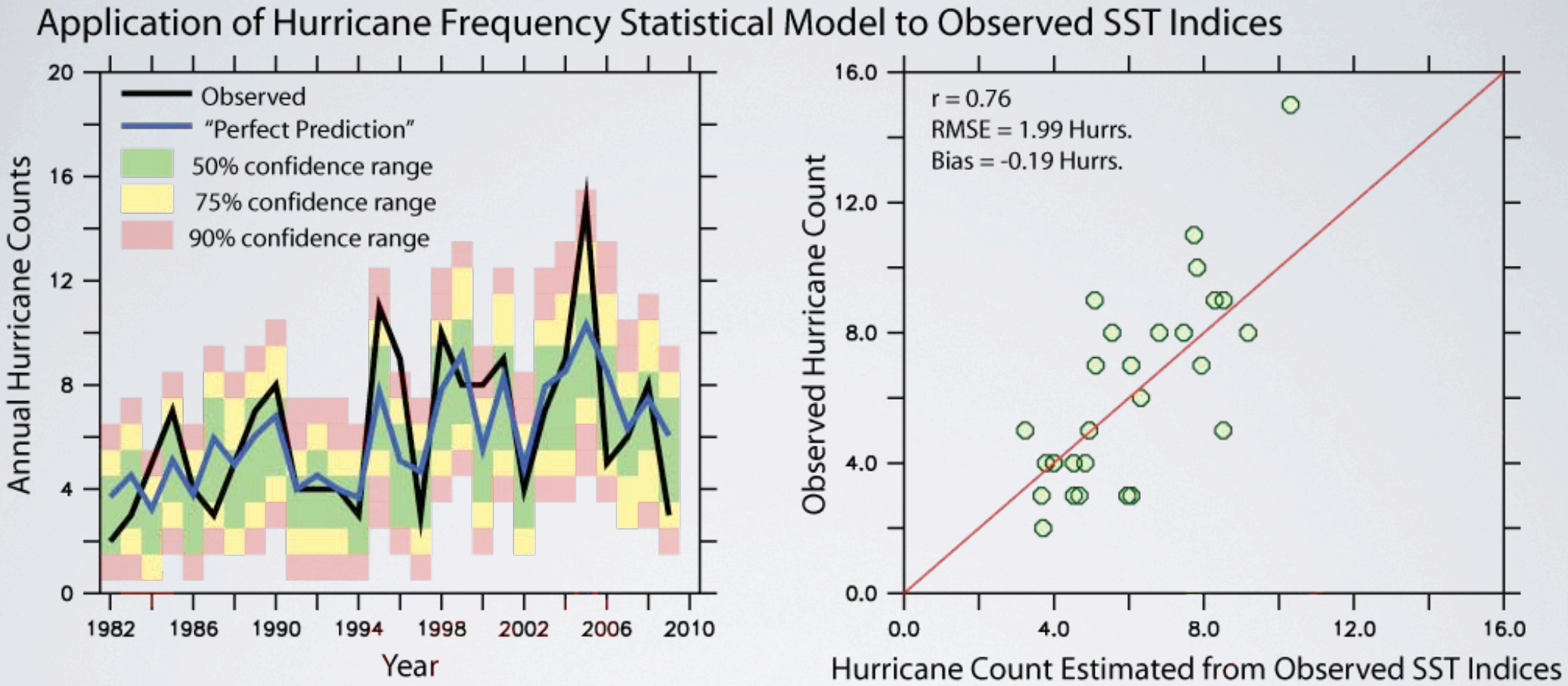
Comparing Two Cases in CM2.1: Hurricane Index Has Some Predictability When MOC Does



Seasonal Hurricane Frequency Forecast Scheme

- Build a statistical emulator of HiRAM-C180, training on AGCM response to broad range of climates (projections, past climate, idealized forcing)
- 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 (GFDL-CM2.1 and NCEP-CFS) to predict two indices
- Convolve PDF of SST forecasts with PDF from statistical model.

Fit of HiRAM-C180 Emulator to Obs. Performs Well

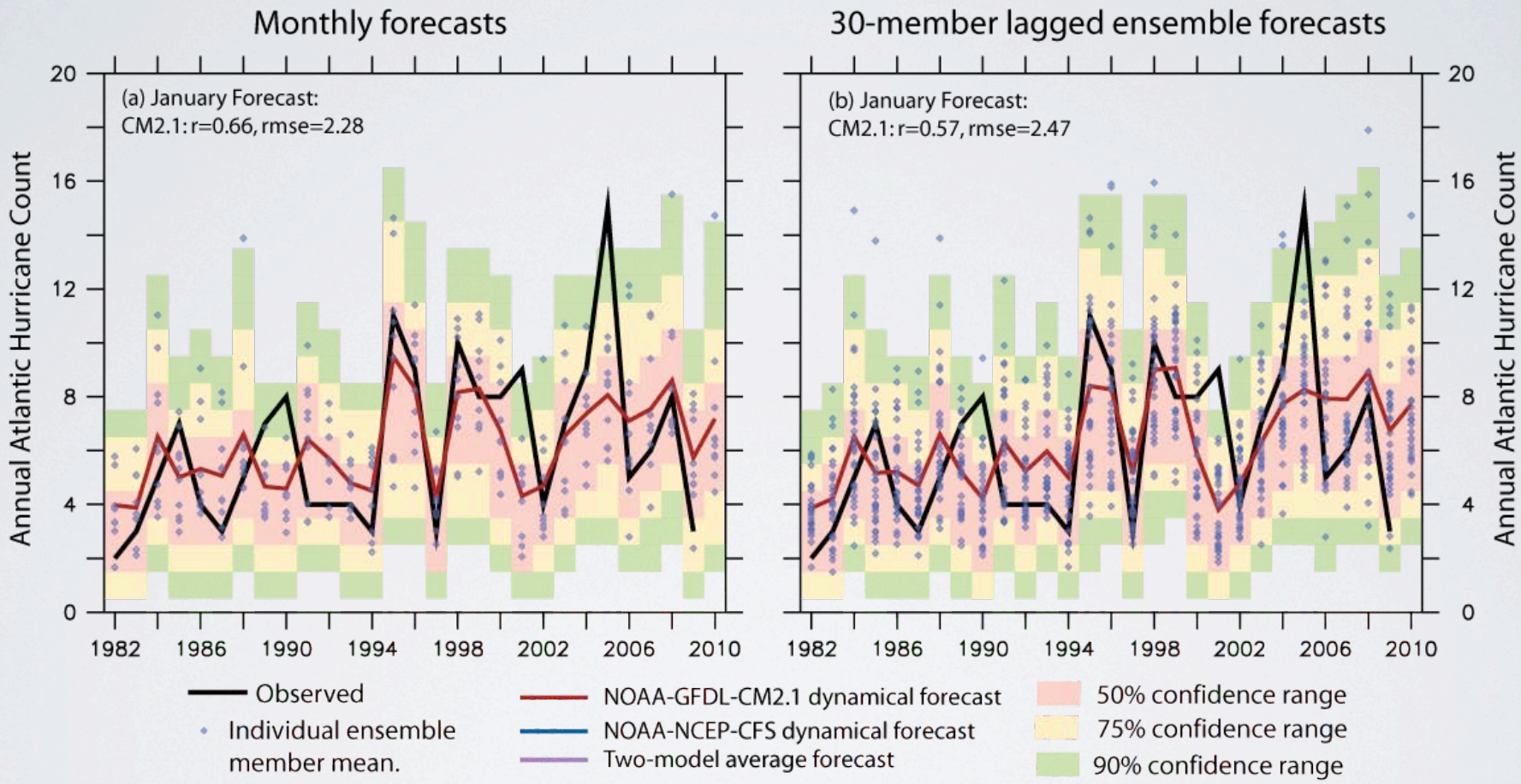


HiRAM-C180 with full SST gives r=0.78, RMSE=1.91

Cannot justify additional predictors at this time

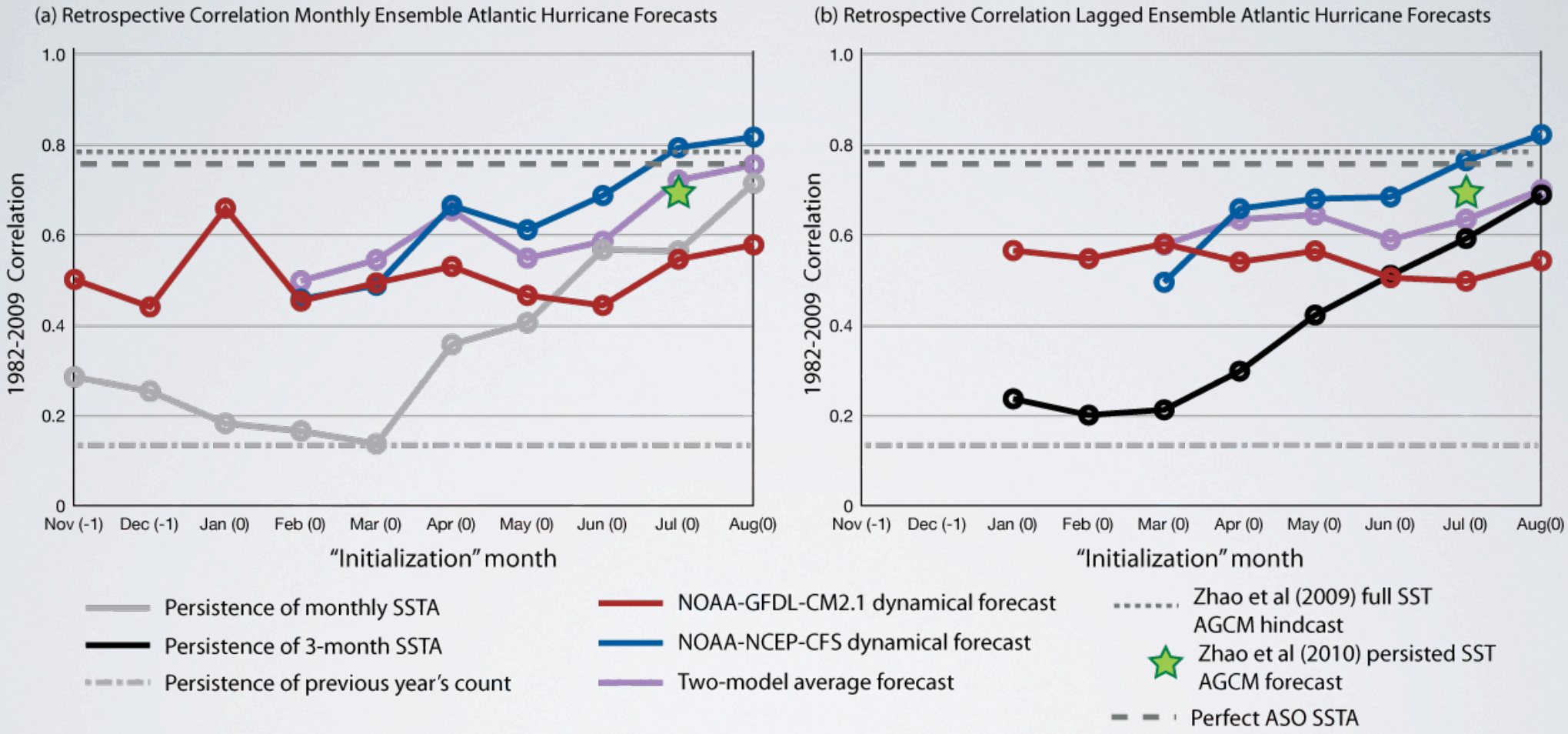
Vecchi *et al.* (2010, MWR submitted)

Statistical-Dynamical Hurricane Frequency Retrospective Forecasts Initialized January Exhibit Skill



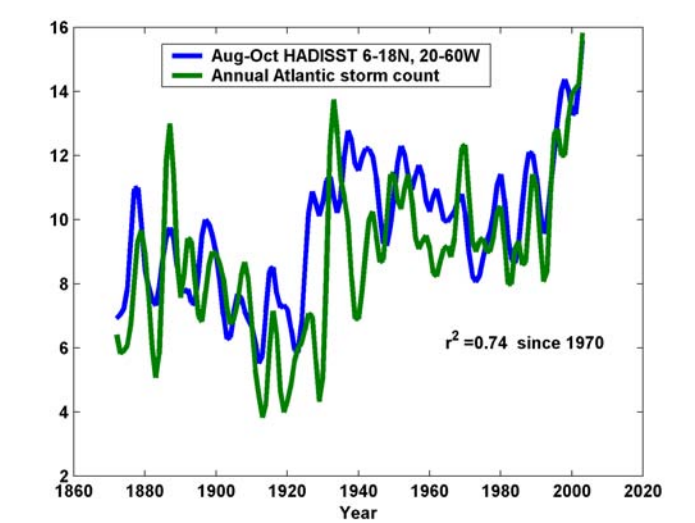
Vecchi *et al.* (2011, MWR in press)

Hybrid (Statistical-Dynamical) Forecast System Exhibits Potential for Multi-season Lead Forecasts

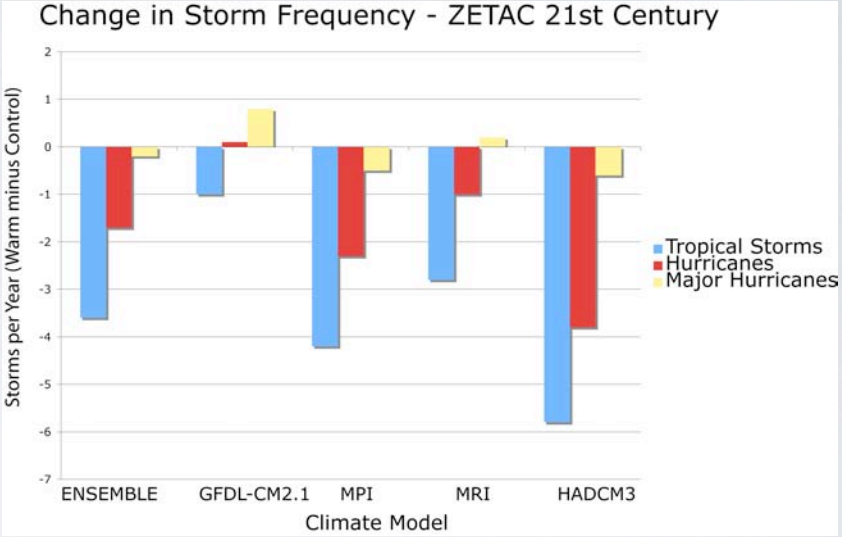


Vecchi et al. (2011, MWR in press)

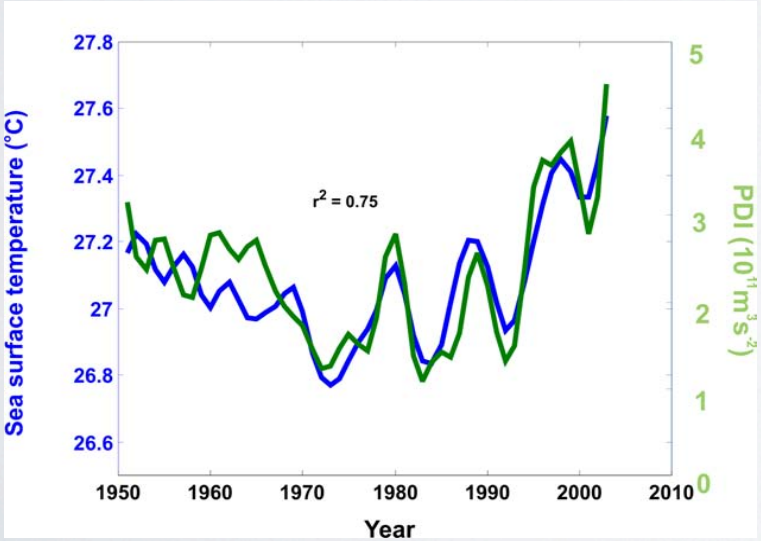
Is the historical Atlantic TS record consistent with dynamical model projections of a weak (and possibly negative) sensitivity to warming?



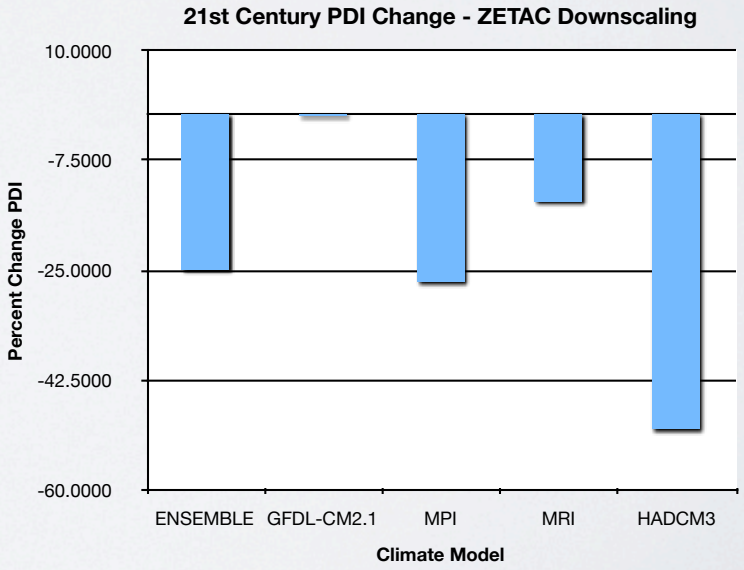
Source: Emanuel (2006); Mann and Emanuel (2006) EOS. See also Holland and Webster (2007) Phil. Trans. R. Soc. A



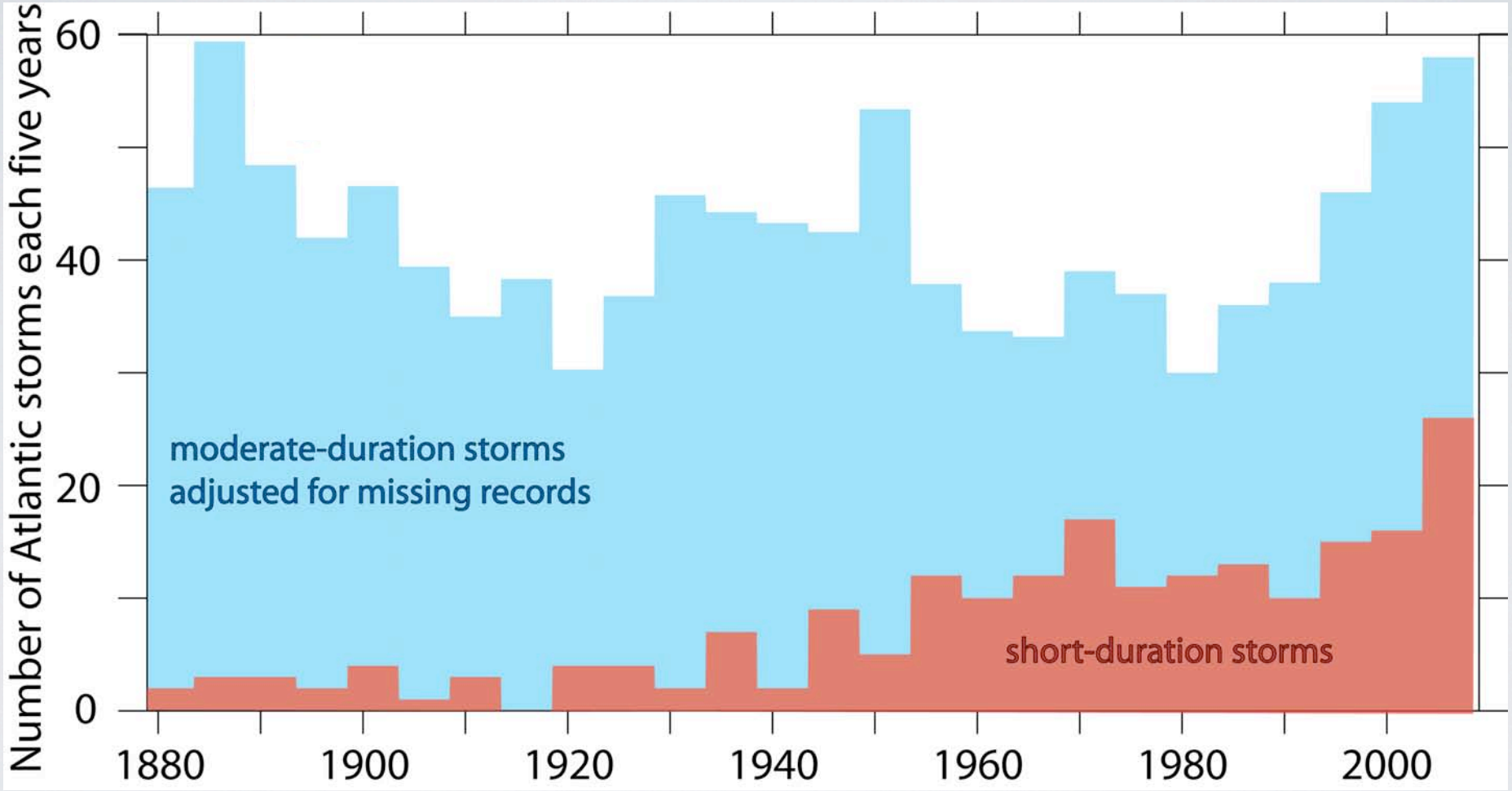
Source: Knutson et al (2008, Nature Geosci.) Knutson et al (2010, in prep.)



Emanuel (2007, J. Clim.)



Atlantic tropical storms (< 2 day duration) show a strong trend. Storms of >2 day duration - adjusted for "missing storms" - do not show a trend.



Adapted from Landsea et al (2010, J. Climate)