Attribution, Prediction and Projection of Hurricane Activity Changes

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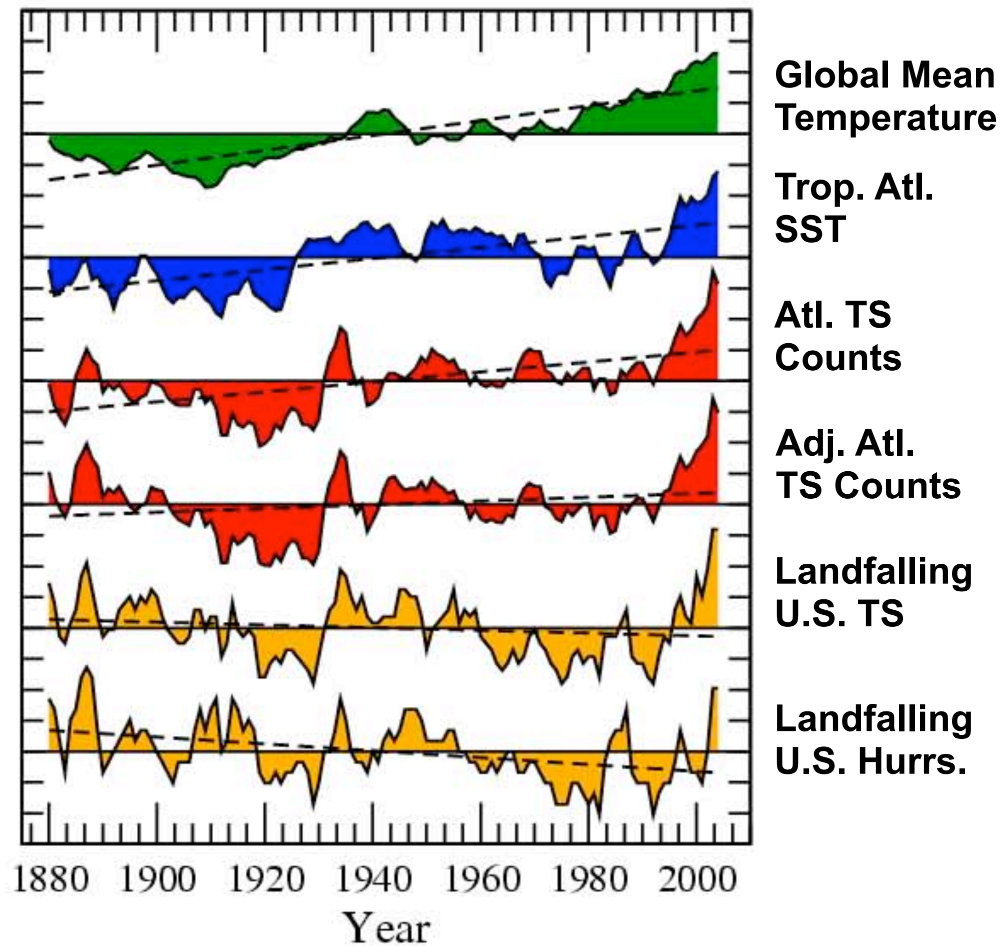
1-GFDL; 2-Princeton/AOS; 3-U. Miami; 4-U. Wisc.-Milw.; 5-Princeton U.; 6 - Old Dominion U.

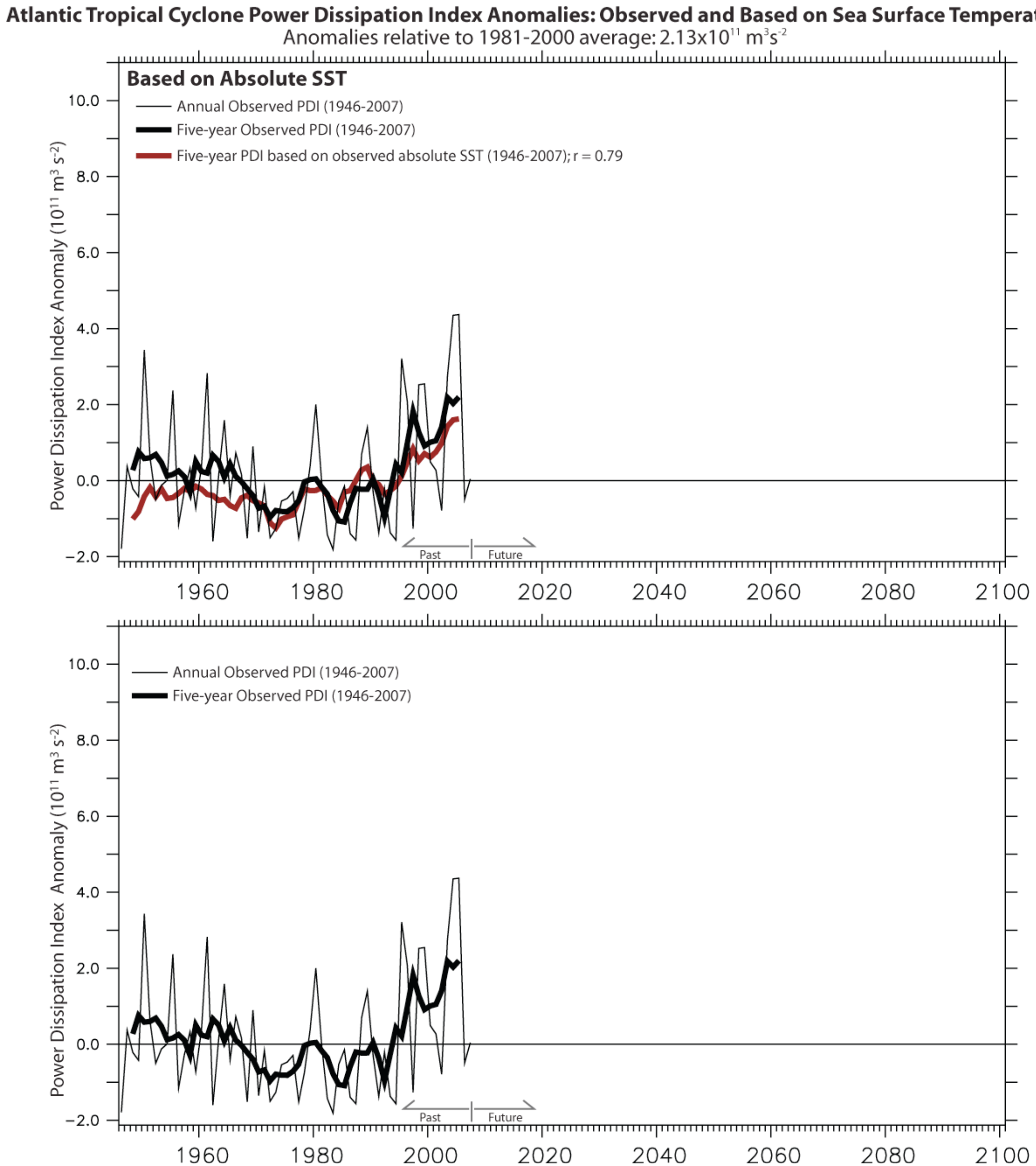
- What has driven recent changes in hurricane activity?
- Tools to predict/project and understand hurricane activity changes

Measure of Activity

- Which measure?
  - Hurricane count
  - Landfalling storm count
  - Extremes in intensity
  - Shifts in mean intensity
  - Integrated intensity
  - Etc...
- Must balance demand with current ability to detect/ attribute and predict.
  - Obs, models and theory limit.
- Must communicate differences



Vecchi and Knutson (2008, J. Clim.)



see also Emanuel (2005)

Observed Activity

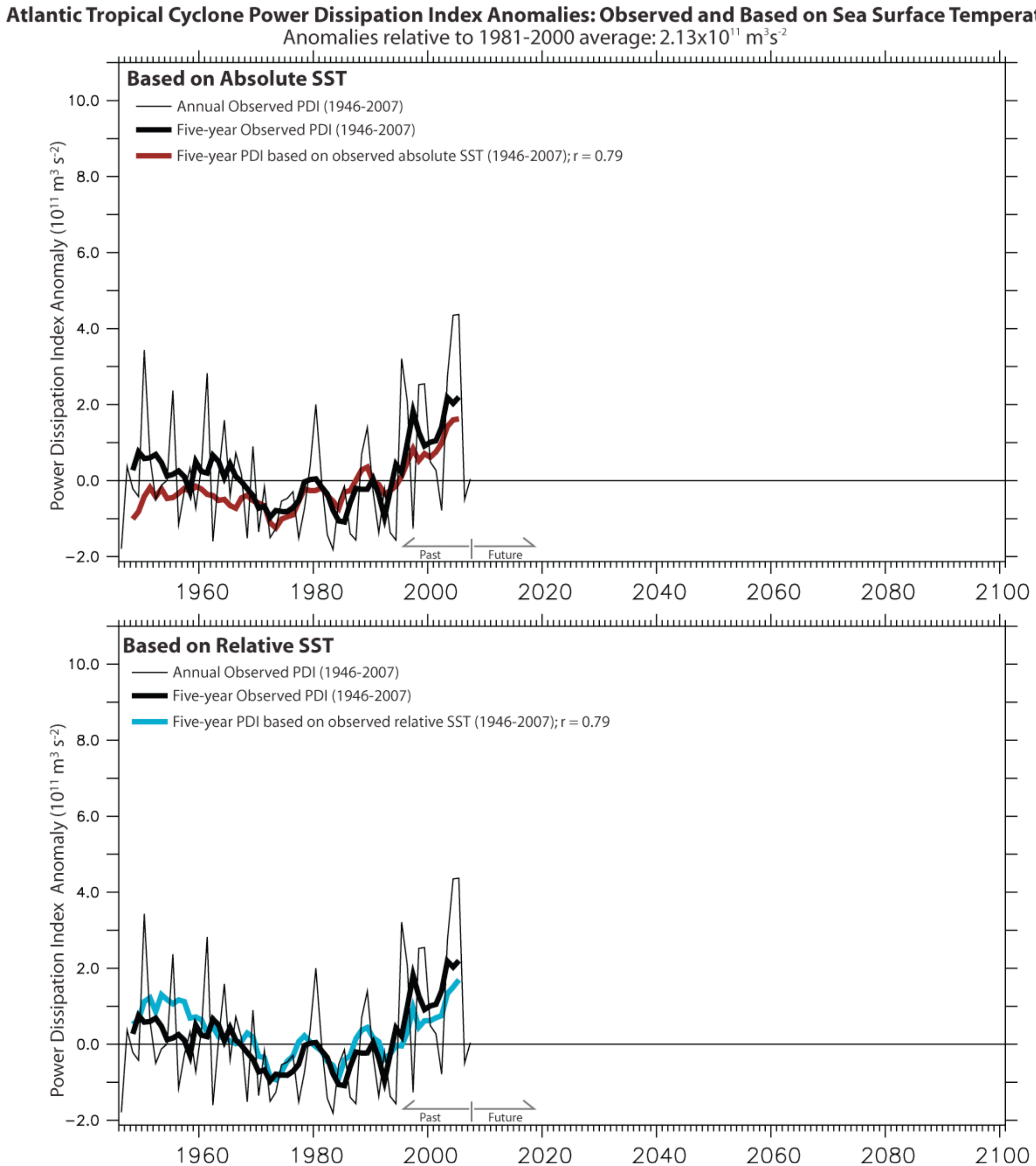
Absolute MDR SST

If causal, can attribute to GHG.

e.g. CCSP-3.3

Storm count*duration has been principal control of historical PDI changes (Maue and Hart (2007))

Vecchi, Swanson and Soden (2008, Science)



see also Emanuel (2005)

Observed Activity

Absolute MDR SST

If causal, can attribute to GHG.

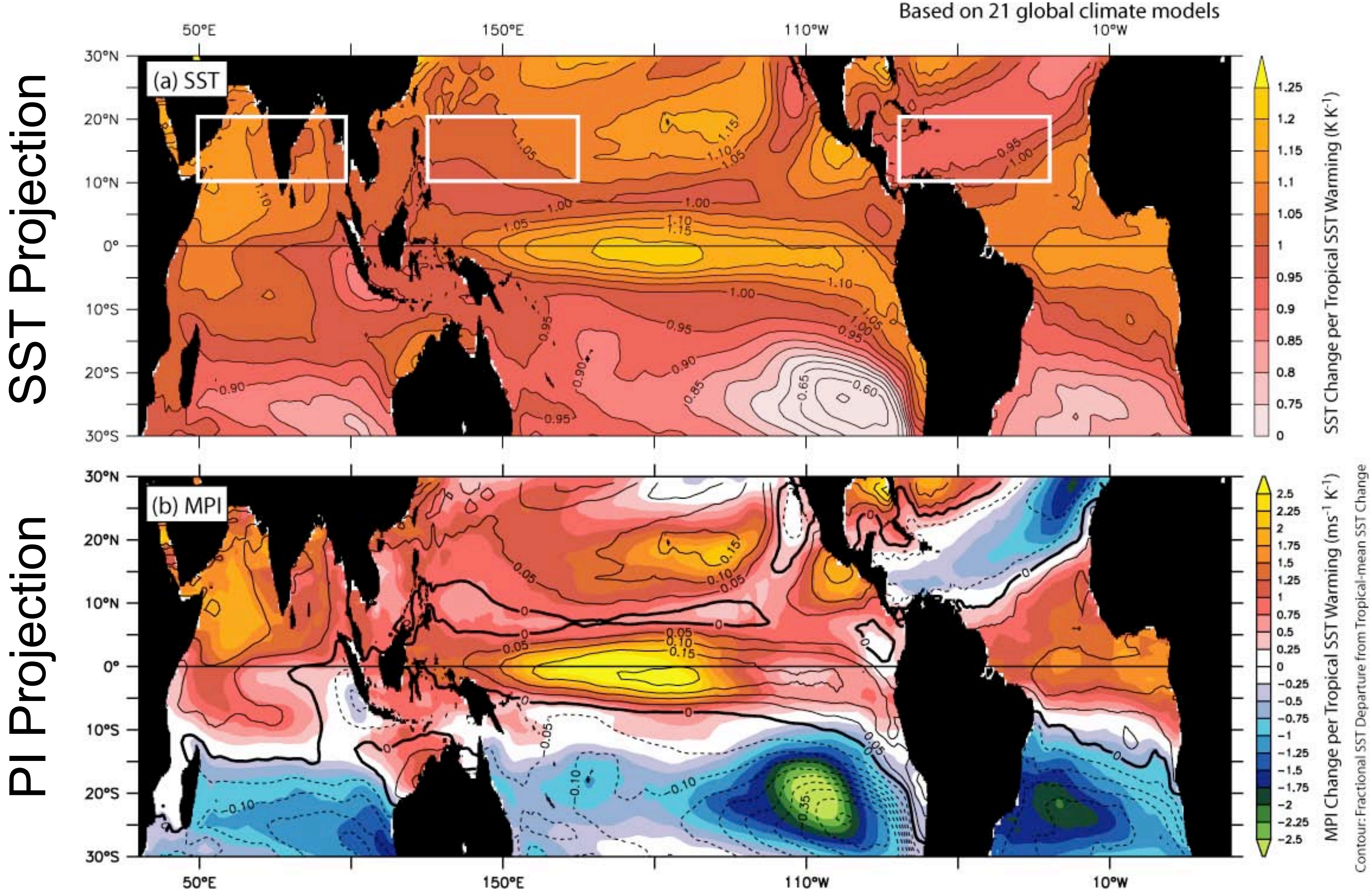
see also Swanson (2008)

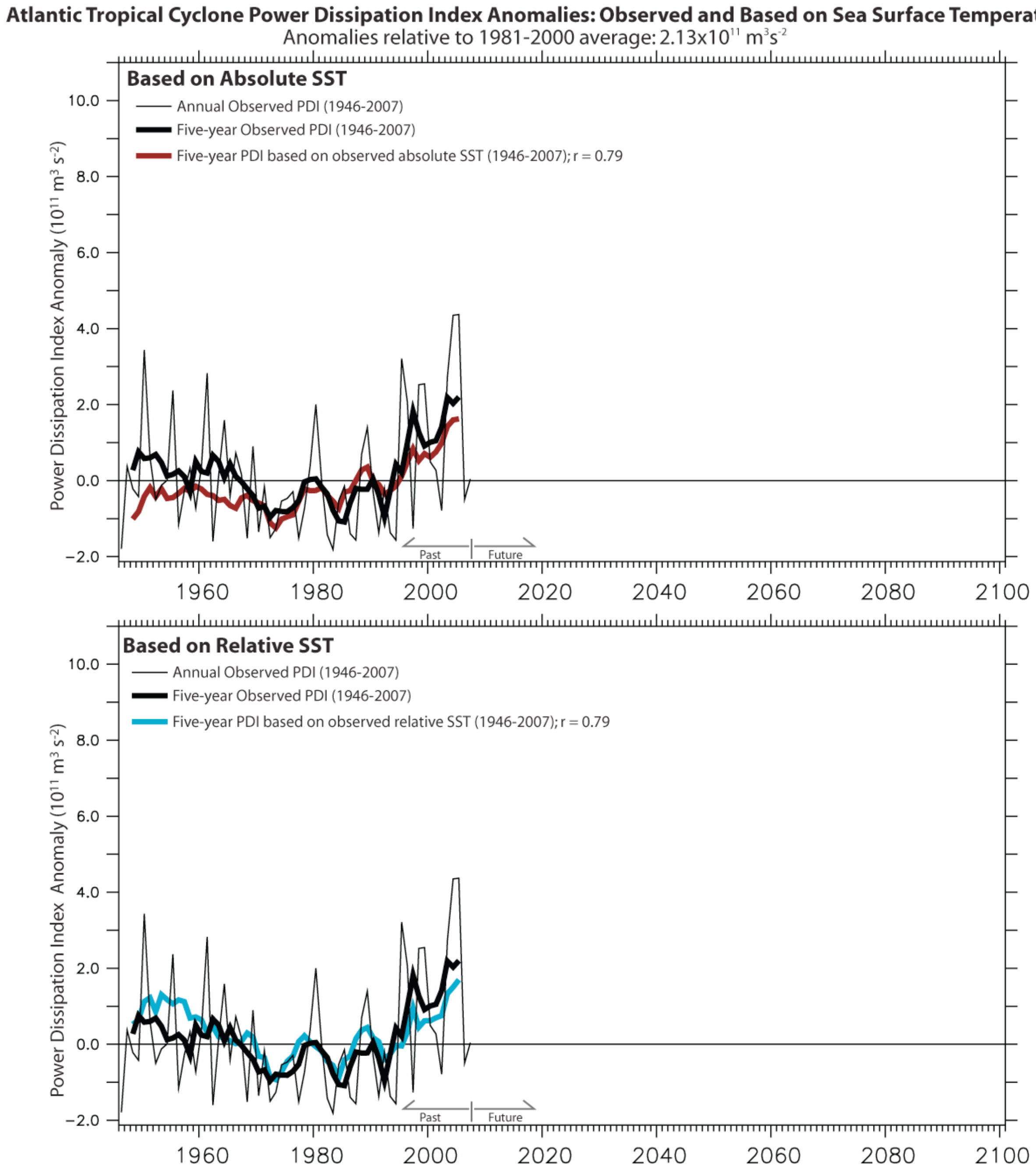
Relative MDR SST

If causal, cannot attribute.

Vecchi, Swanson and Soden (2008, Science)

Potential intensity does not track SST, but relative SST





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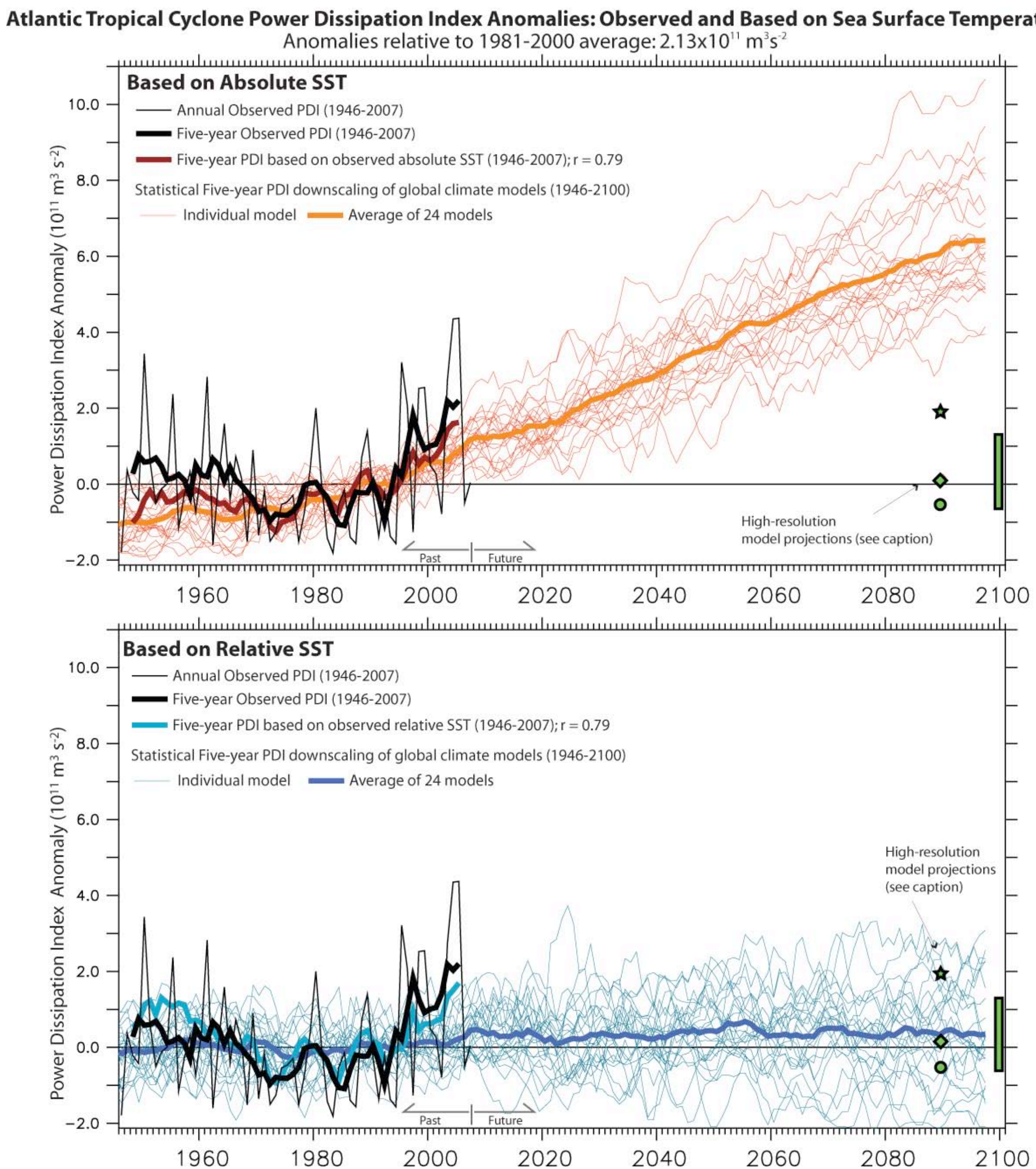


Observed Activity

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

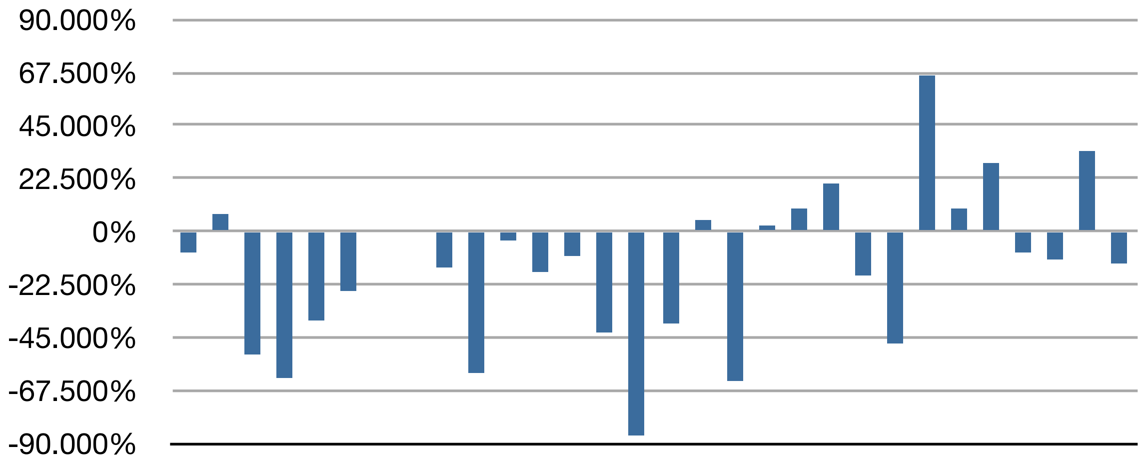
Model Rel. SST

Vecchi, Swanson and Soden (2008, Science)

Decadal predictability from GHG forcing?

- Relationship between GHG and SST/Heat Content robust:
  - Committed warming and future GHG emissions give some predictability to SST/HC predictions.
- Even sign of relationship between GHG and NA hurricane frequency unclear:
  - Not big help in decadal predictability

Anthropogenic-Influence: Projected Changes in NA TS Frequency

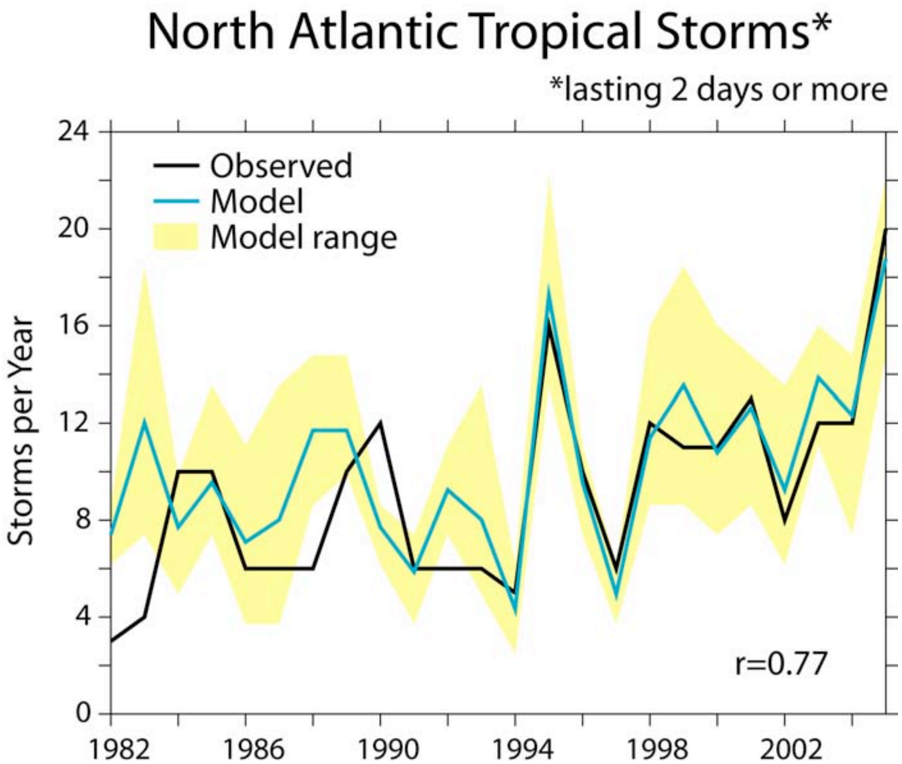


Oouchi et al (2005), Bengtsson et al (2007), Emanuel et al (2008), Knutson et al (2008), Zhao et al (2008)

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)

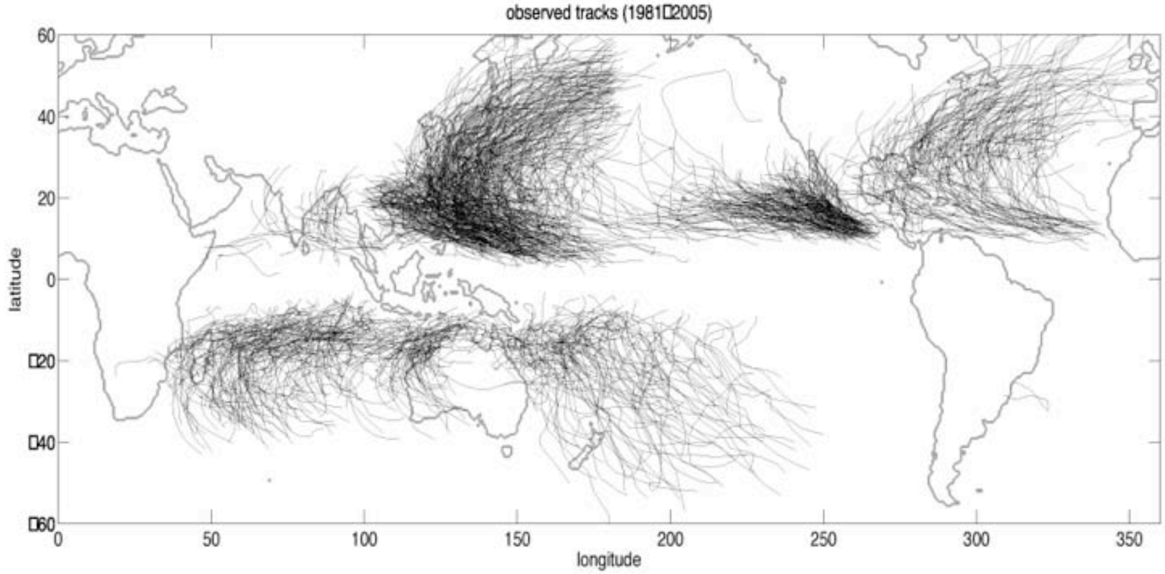


Adapted from AM2 with:

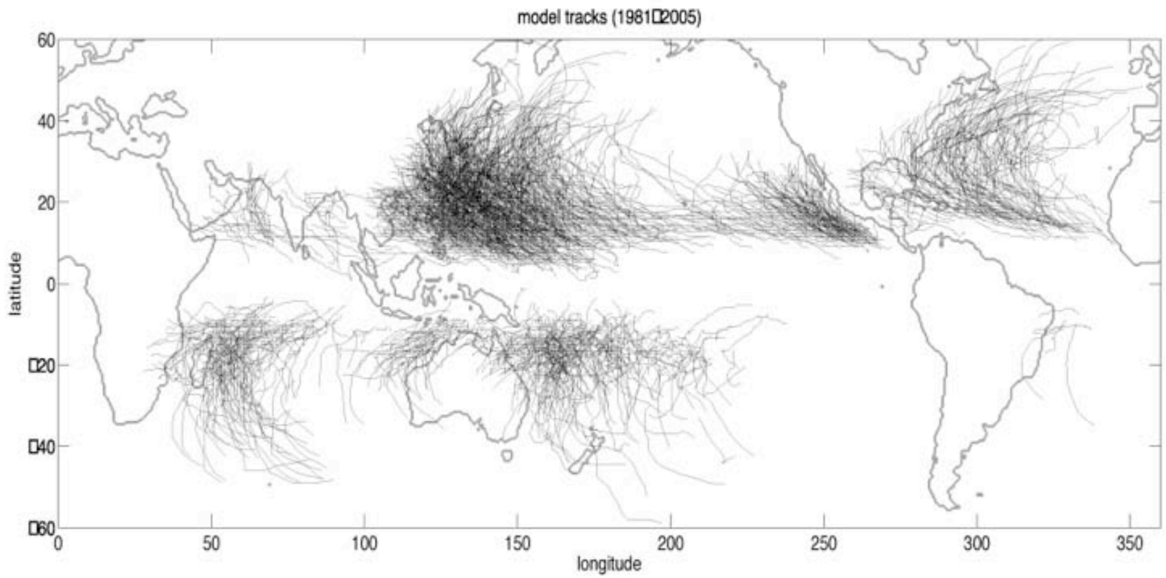
- Deep convection scheme adapted from Bretherton, McCaa and Grenier (MWR, 2004)
- Cubed sphere dynamical core
- Changes to parameterizations of cloud microphysics
- C90 Atm. resolution of 1°x1°

Model recovers many aspects of observed hurricane tracks

Observed



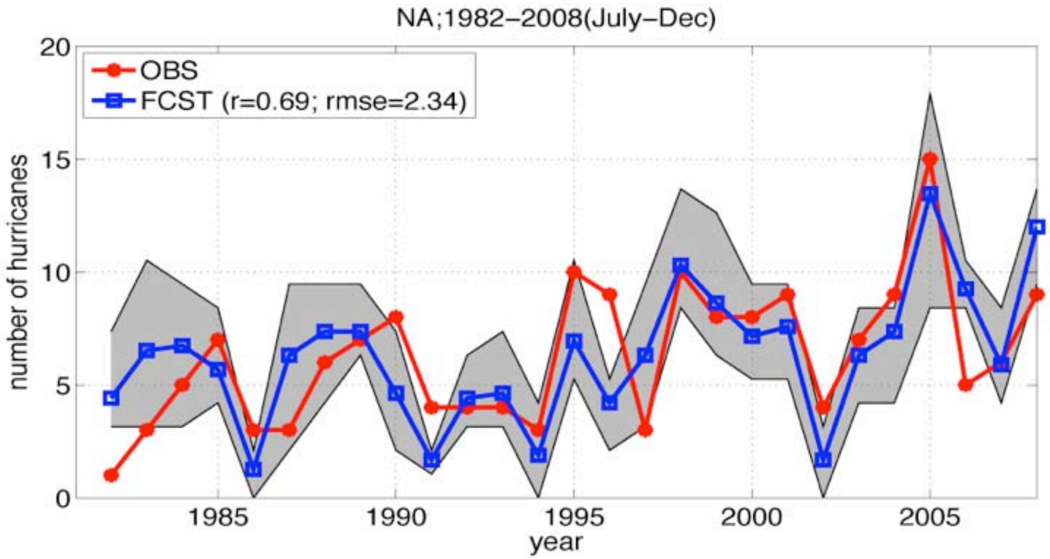
C180 Model



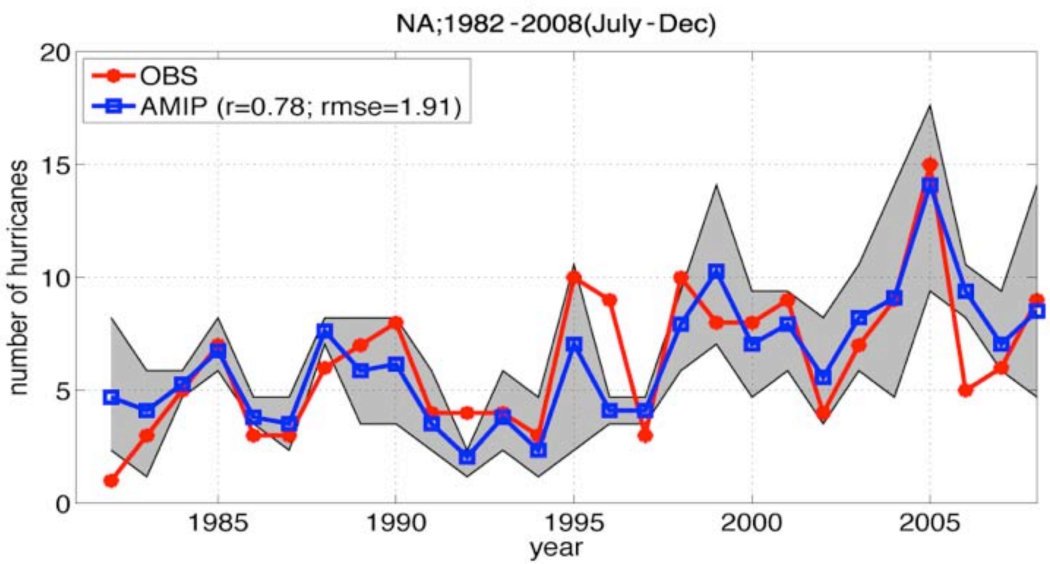
Zhao et al (2009, J. Climate)

Retrospective NA Hurricane Forecast With Persisted June SSTA

FCST
r=0.69



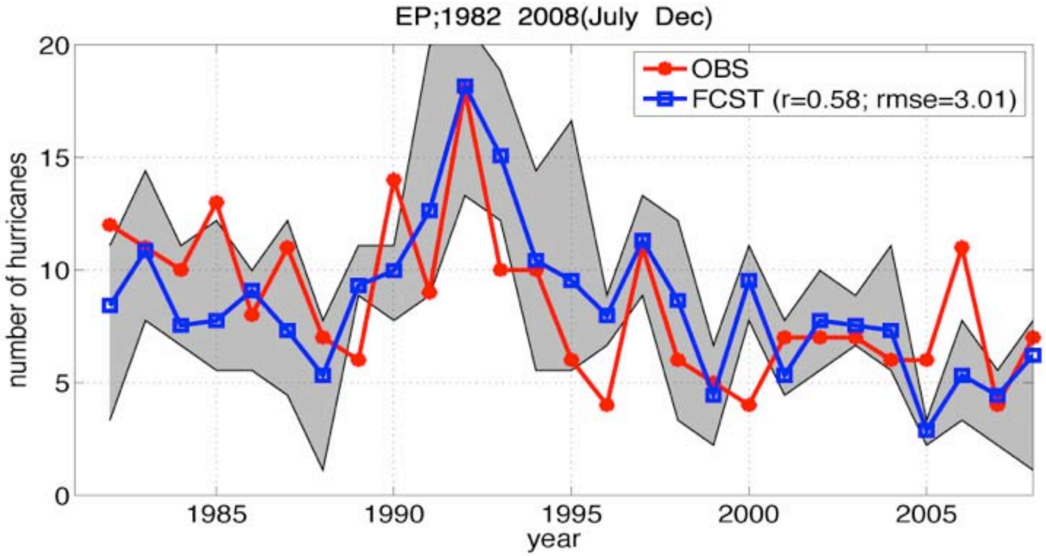
AMIP
r=0.78



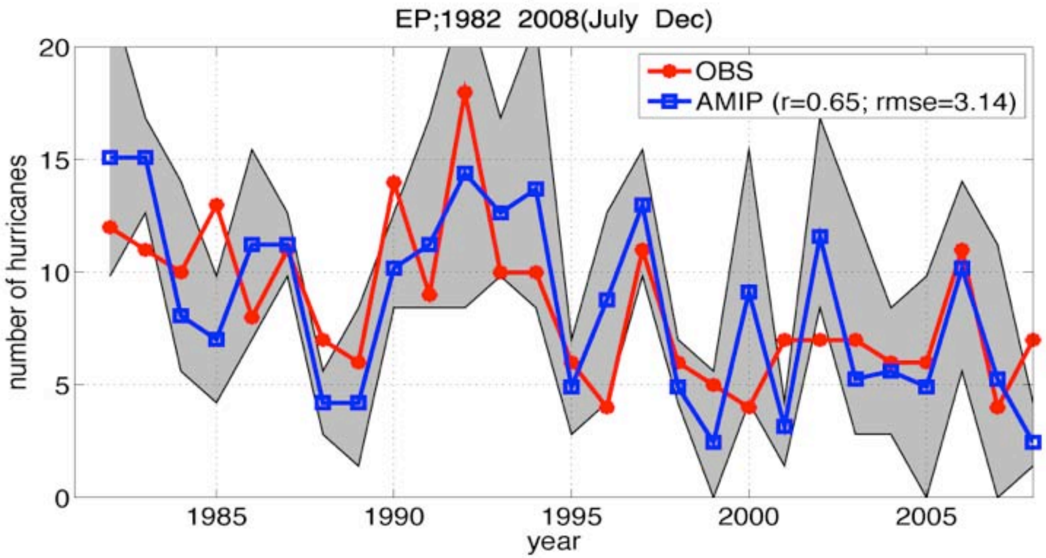
Zhao, Held and Vecchi
(2010, MWR Submitted)

Retrospective EP Hurricane Forecast With Persisted June SSTA

FCST
r=0.58



AMIP
r=0.65

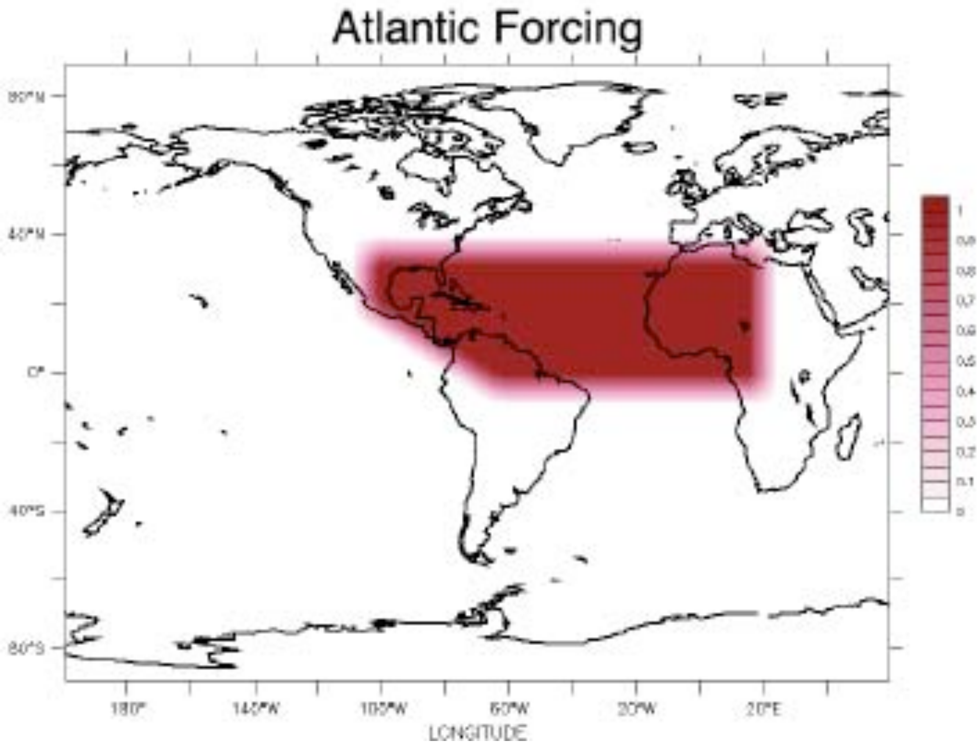


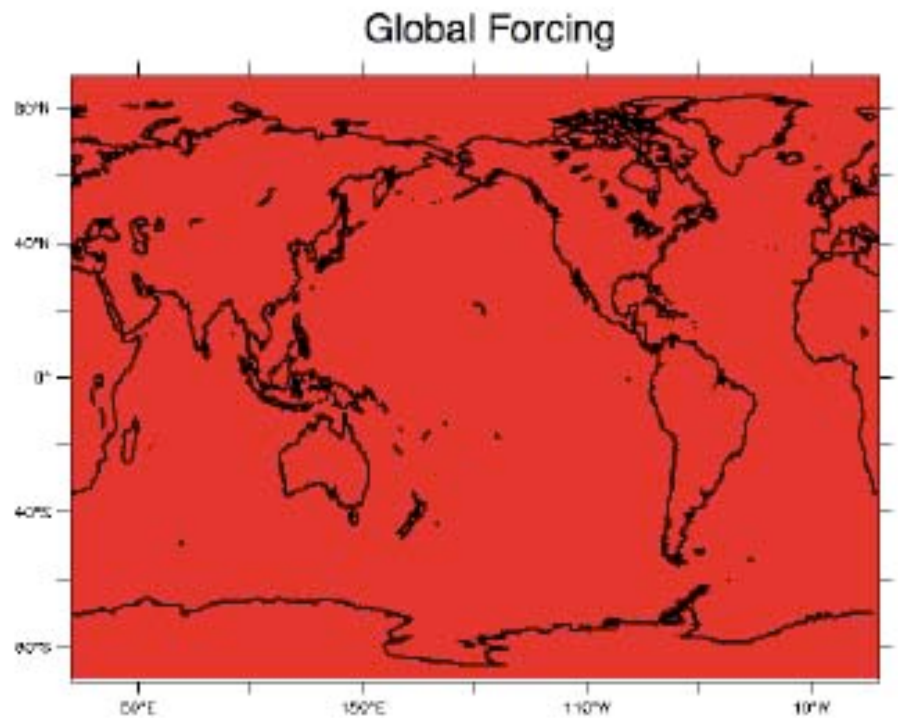
Zhao, Held and Vecchi (2010, MWR Submitted)

Idealized Forcing Experiments

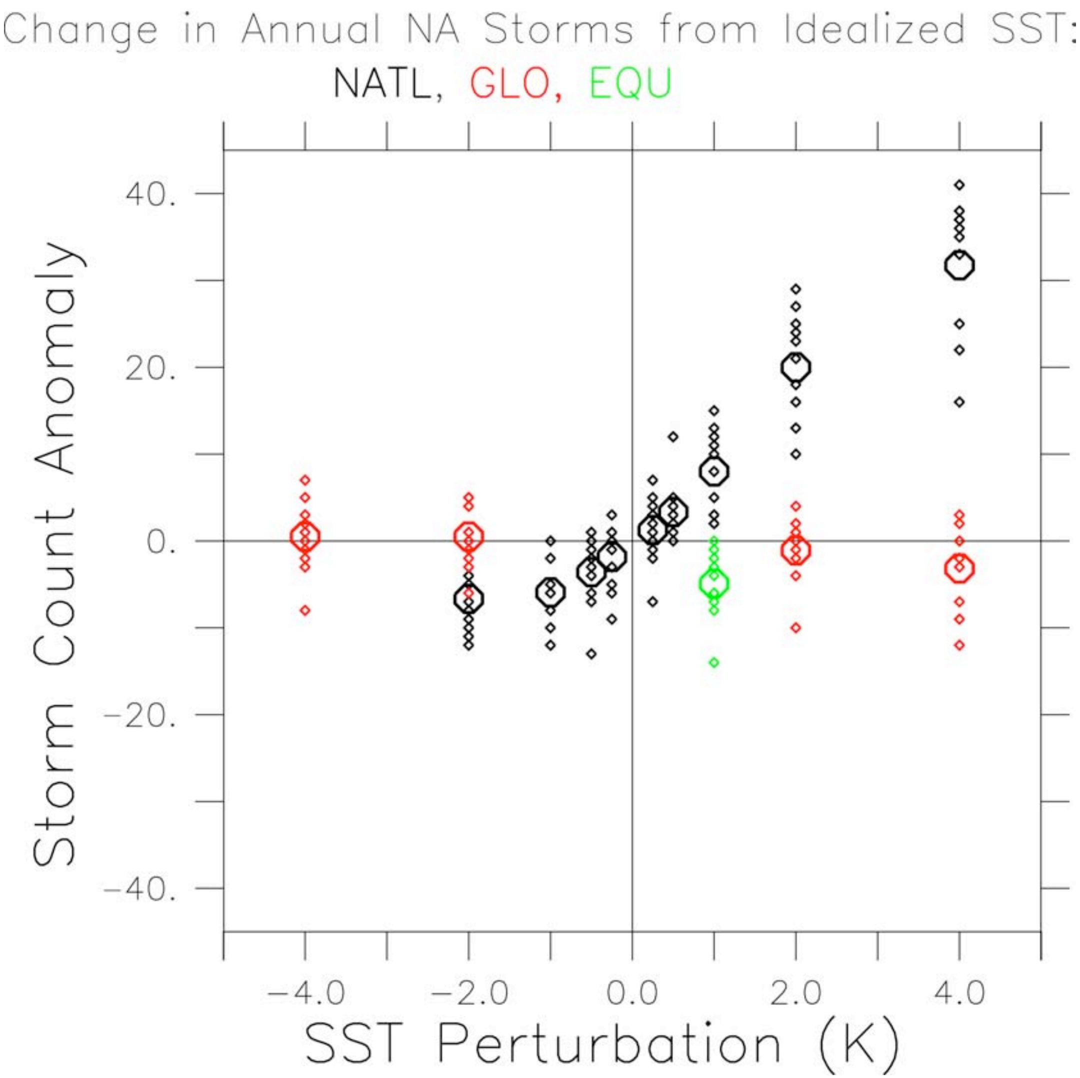
If local SST the dominant control, as opposed to relative SST:

- 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

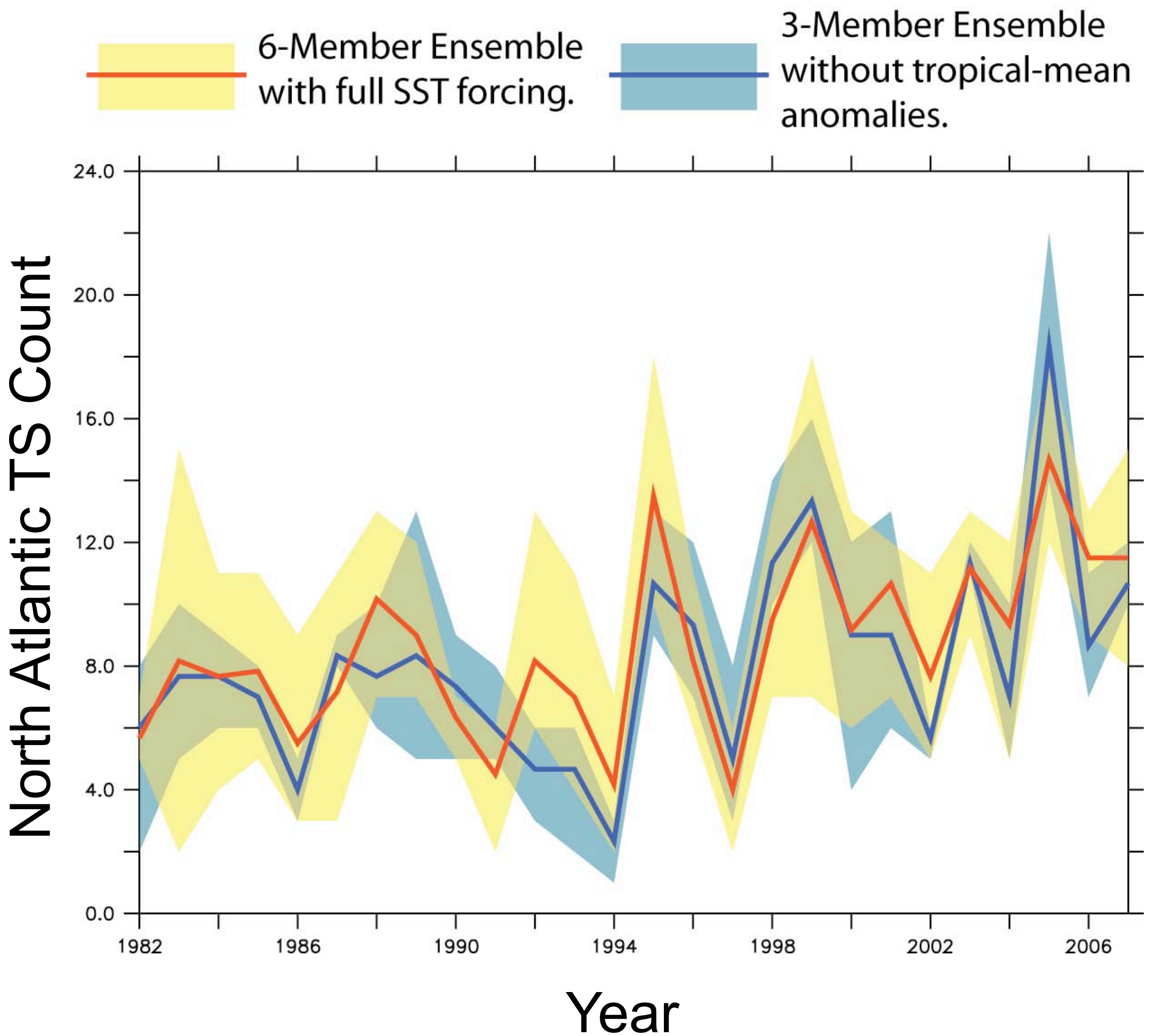
Uniform Forcing

Near-equatorial Forcing

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

Vecchi et al (2010, in prep.)

AGCM with and without tropical-mean SST change



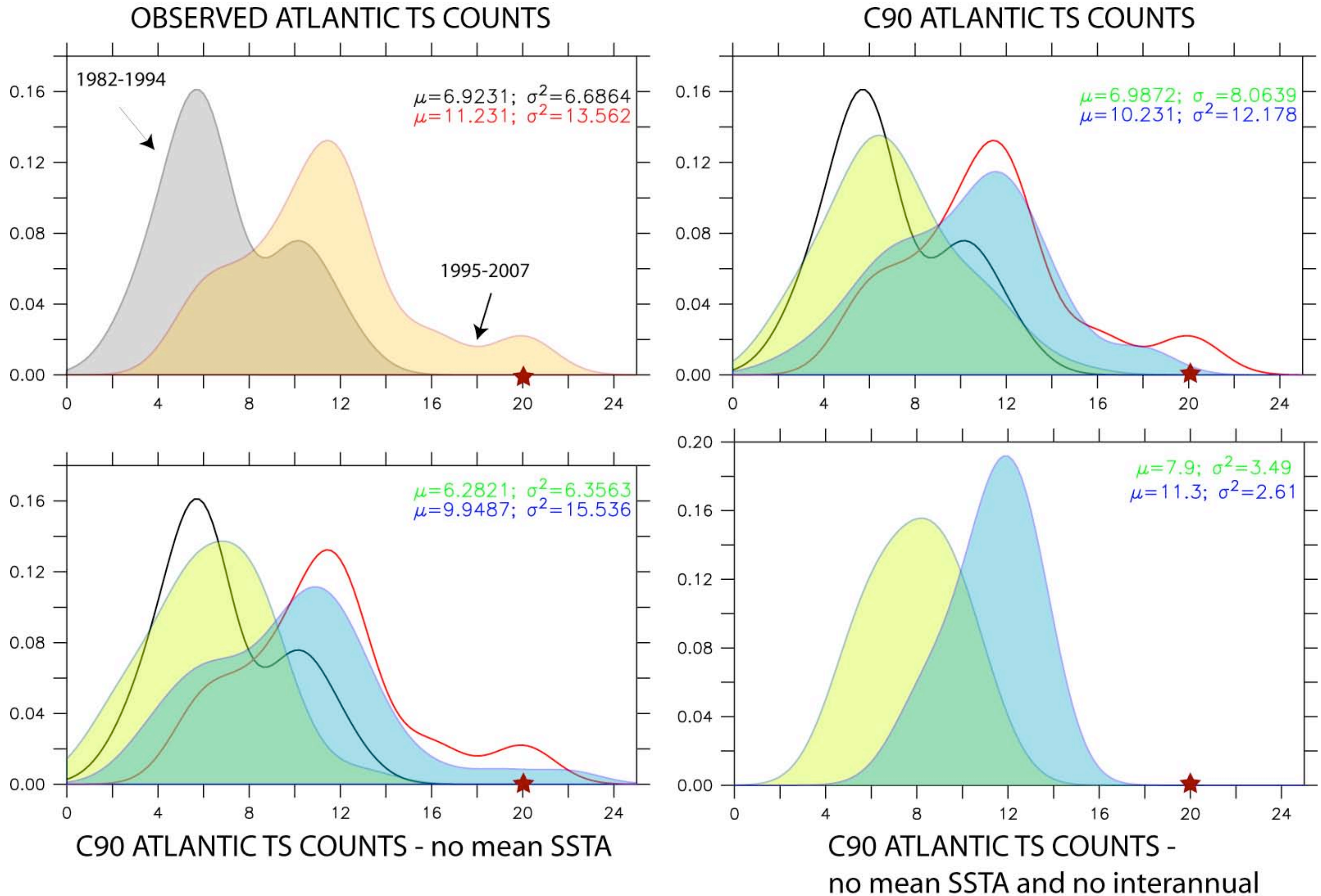
100km AGCM 1982-2007 North Atlantic tropical storm count not sensitive to removing tropical-mean SSTA forcing.

Vecchi et al (2010, in prep.)

1982-94 and 1995-2007 PDFs of NA TS Count*

* lasting two days or more

★ 2005 Observed

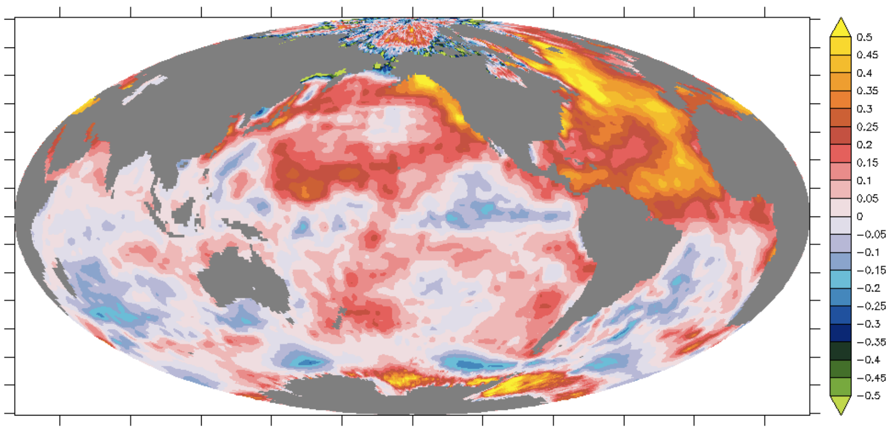


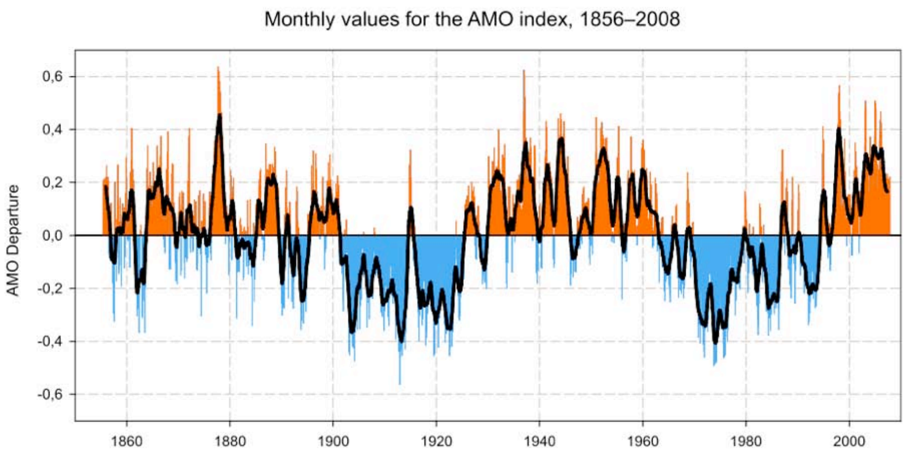
Vecchi et al (2010, in prep.)

Shift in mean TS counts attributable to "AMO" SST change across 1994-1995

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

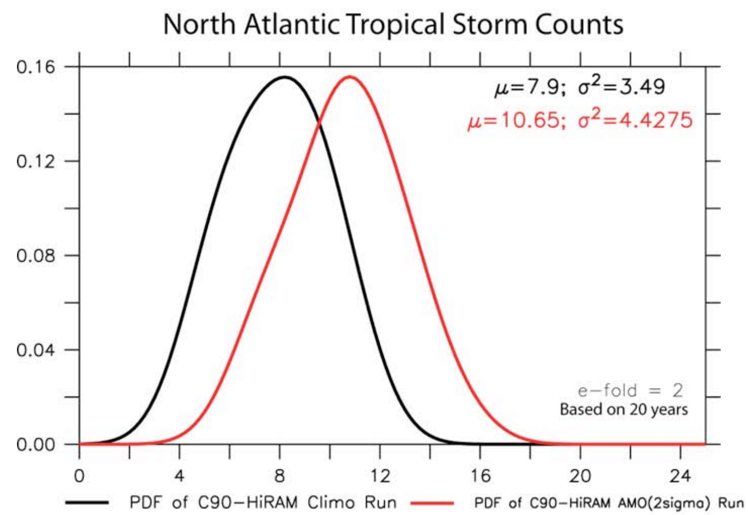
1995-2007 minus 1982-1994 "AMO" SSTA Forcing

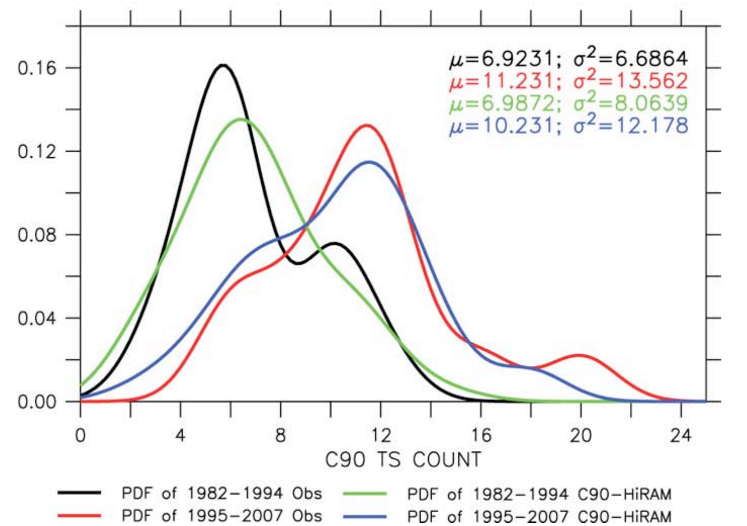




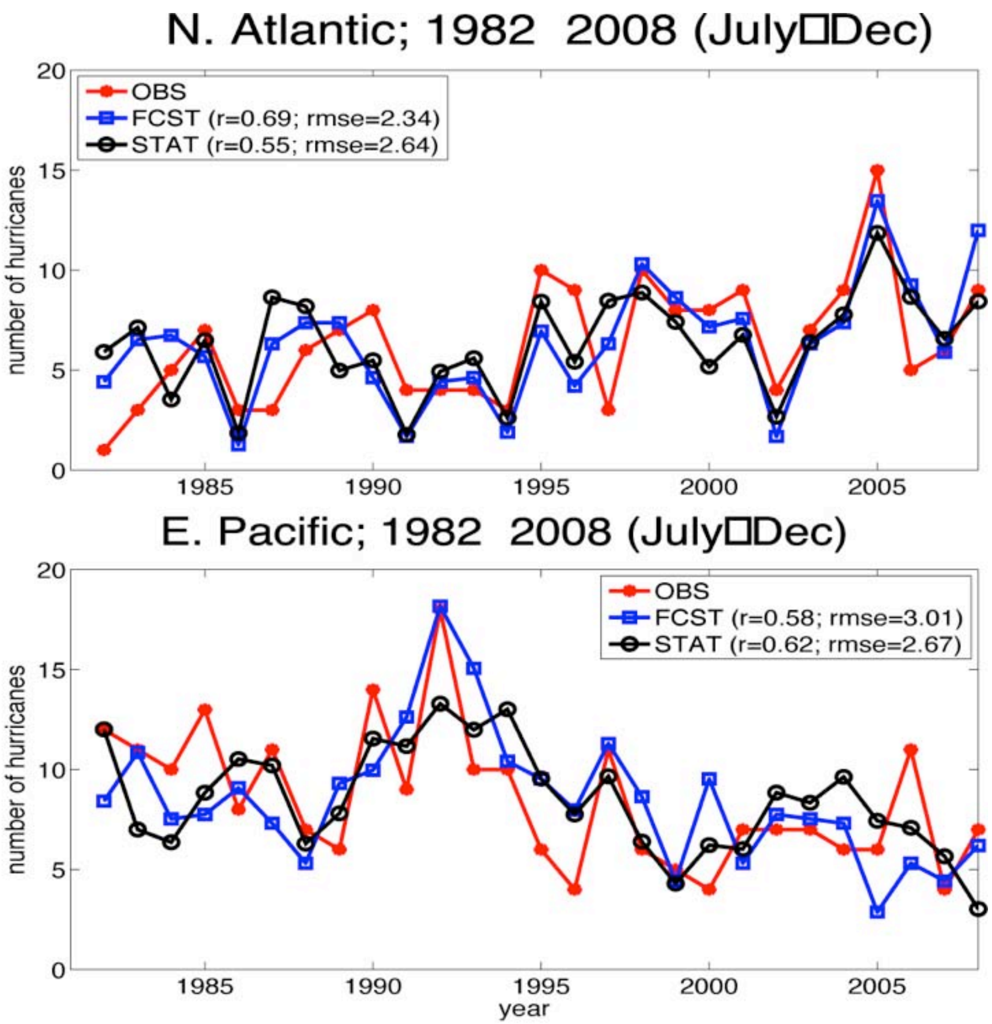
AMO Index: Regression of SST onto NA SST

Response to "AMO" forcing



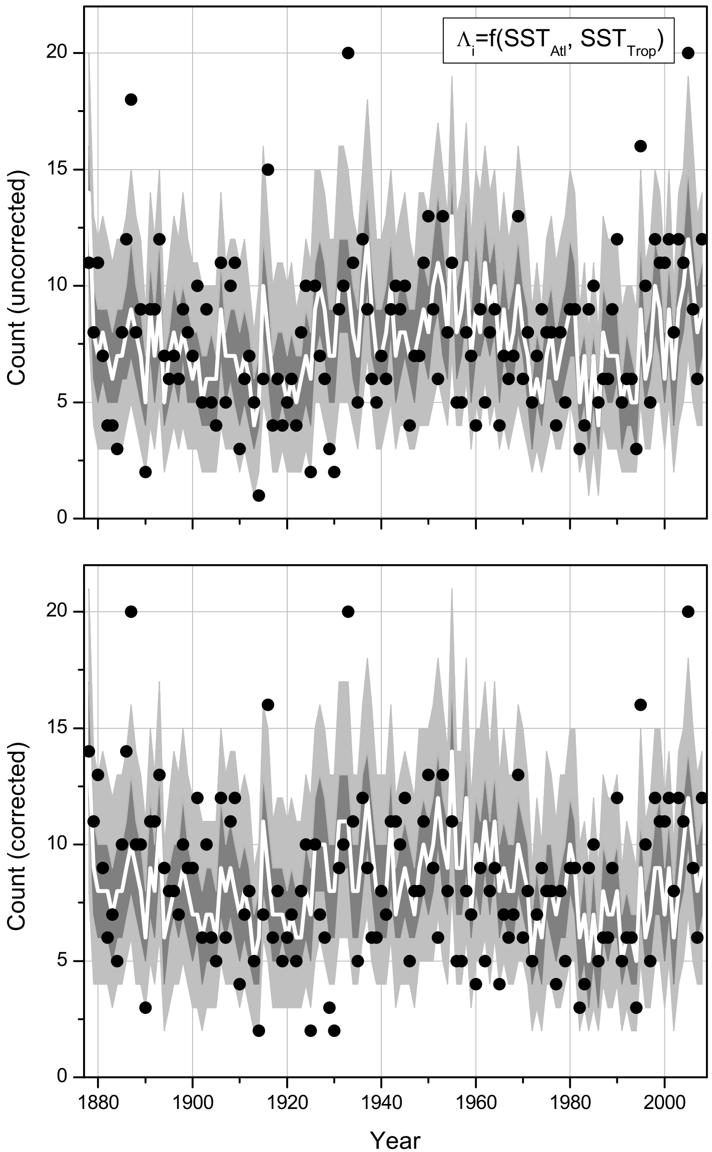


Simple statistical seasonal forecast persisting June relative SSTA performs well



Linear regression on June relative SSTA recovers much of persisted SSTA GCM hurricane frequency predictions.

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



Atlantic SST increases frequency.

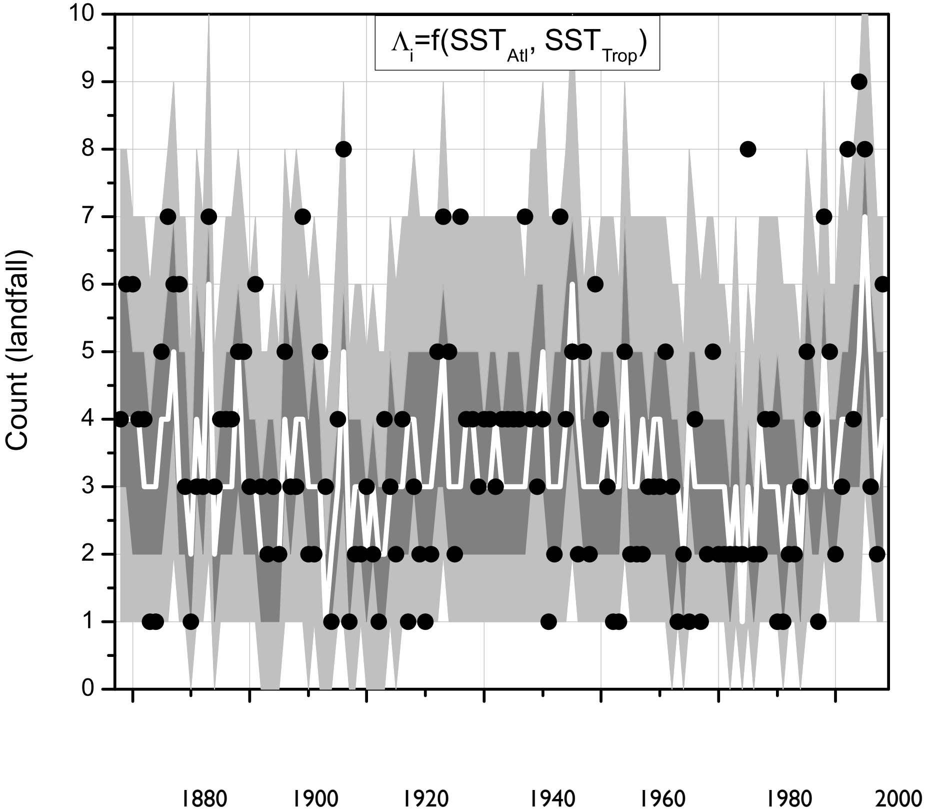
Tropical-mean SST reduces frequency.

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, Vecchi and Smith (2010, MWR, Submitted)

Statistical model of U.S. landfalling tropical storms using Atlantic and Tropical-mean SST as covariates



Villarini, Vecchi and Smith (2010, MWR Submitted)

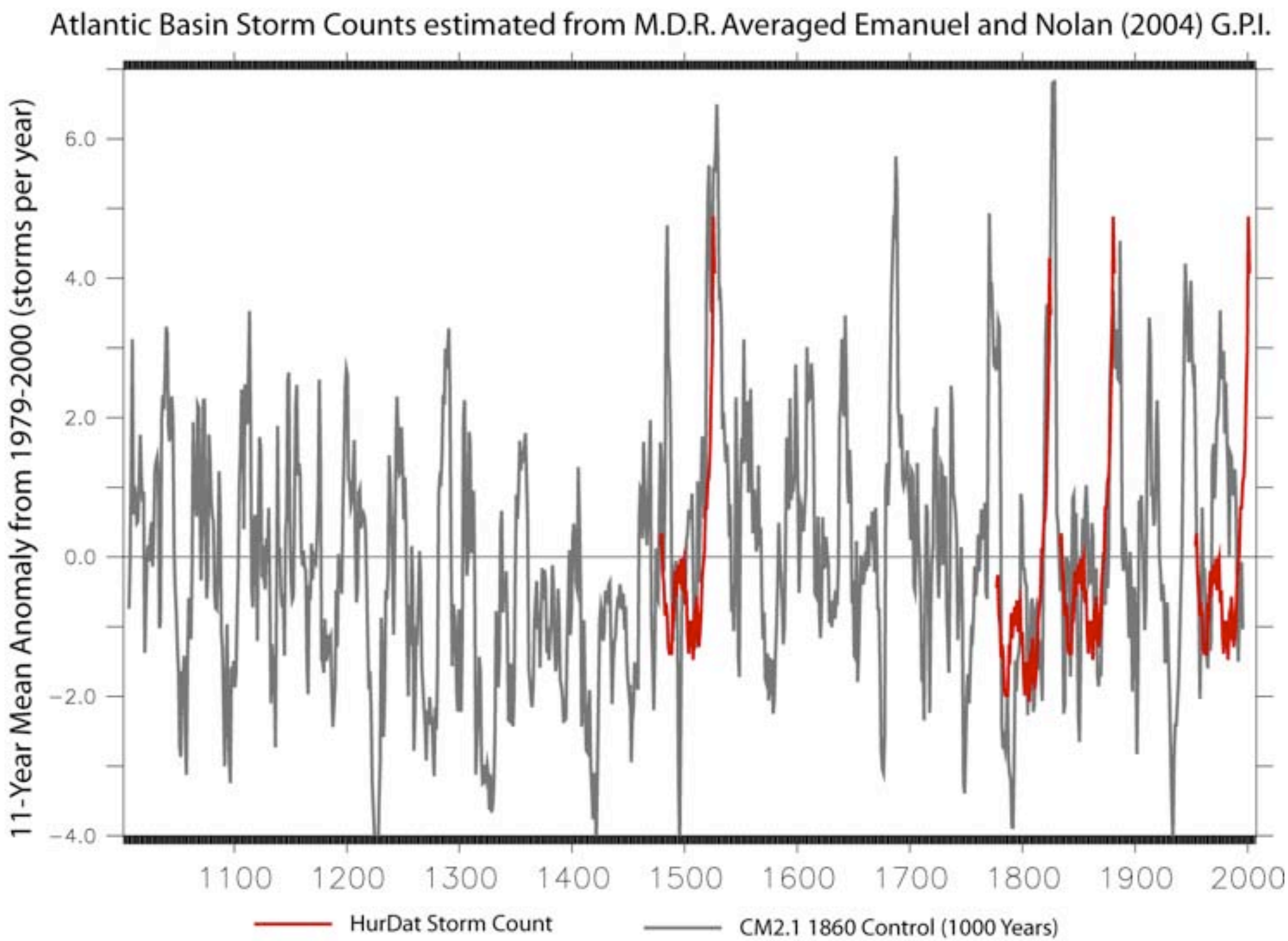
Atlantic SST increases frequency.

Tropical-mean SST reduces frequency.

Factors in fit (w/standard error)

	Landfall
Intercept	1.24 (0.05) 1.24 (0.05)
NAO	- -
SOI	- -
SST_{Atl}	0.89 (0.24) 0.86 (0.22)
SST_{Trop}	-0.89 (0.34) -0.86 (0.30)

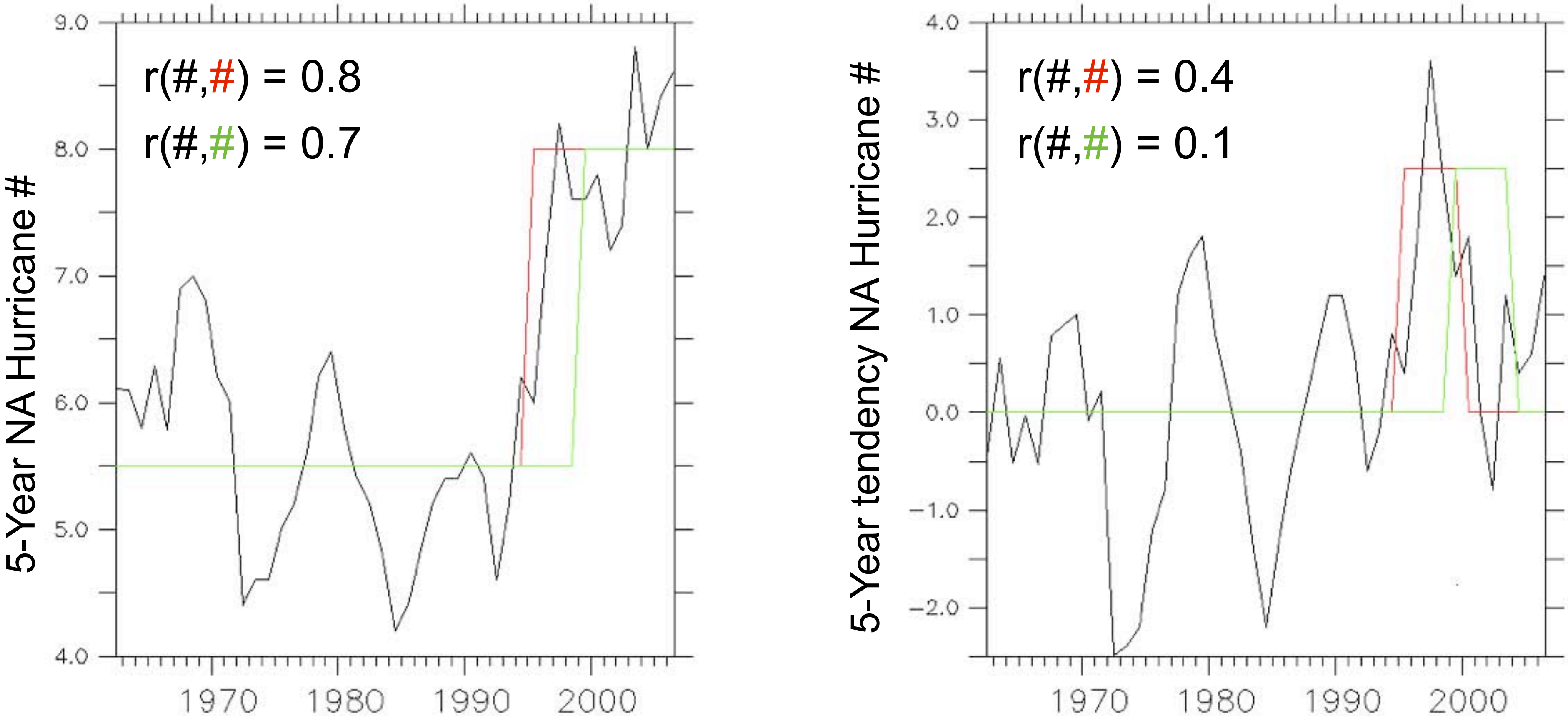
Statistical storm counts in unforced CGCM ("noise/internal variability") GFDL CM2.1 1860-Control Run



Conclusions

- It is premature to conclude that human activity--and particularly greenhouse warming--has already had an impact on Atlantic TS/HU frequency or PDI.
  - Not clear that “committed warming” adds to decadal TC predictability
- Atlantic TS/HU frequency and PDI appear controlled by SST changes in the Atlantic relative those in other basins:
  - Need to attribute and predict pattern of SST change
  - To develop confidence in predictions must understand mechanisms: what controls regional SST patterns? (for CO_2 response see LeLoup and Clement 2009 GRL, Xie et al 2010 J. Clim.).
- Persistence of rel-SSTA forecasts from June feasible in EP and NA.
- 1994-95 change in mean TS freq. attributable to “AMO-ish” SST change
  - What drove SST?
  - When can we expect it to swing back (or even further out)? Are last few years sign of end?
  - What about shift in variance?

How do we evaluate our retrospective decadal hurricane forecasts? Also issue for other quantities.



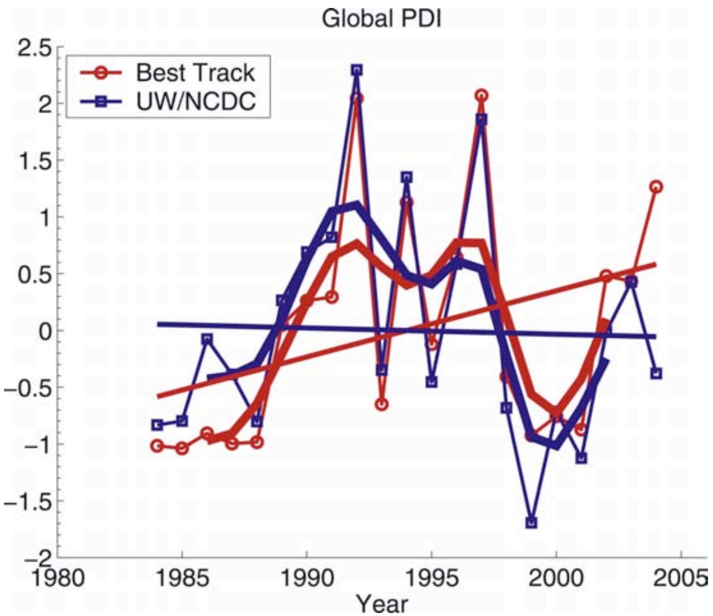
HURDAT

“94-95 Skill” Climate Persistence Forecast

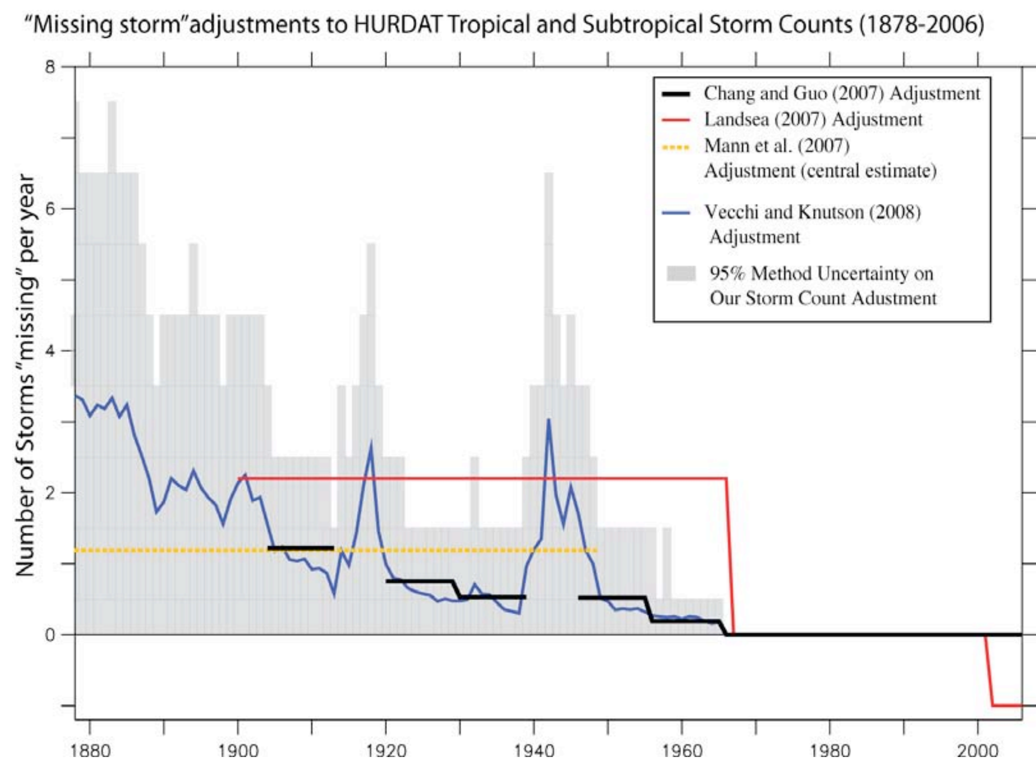
“94-95 No-Skill” Climate Persistence Forecast

Observations

- Hurricane databases **NOT** built as climate data records.
- Efforts must continue to:
  - Identify issues
  - Homogenize when possible
  - Estimate uncertainty

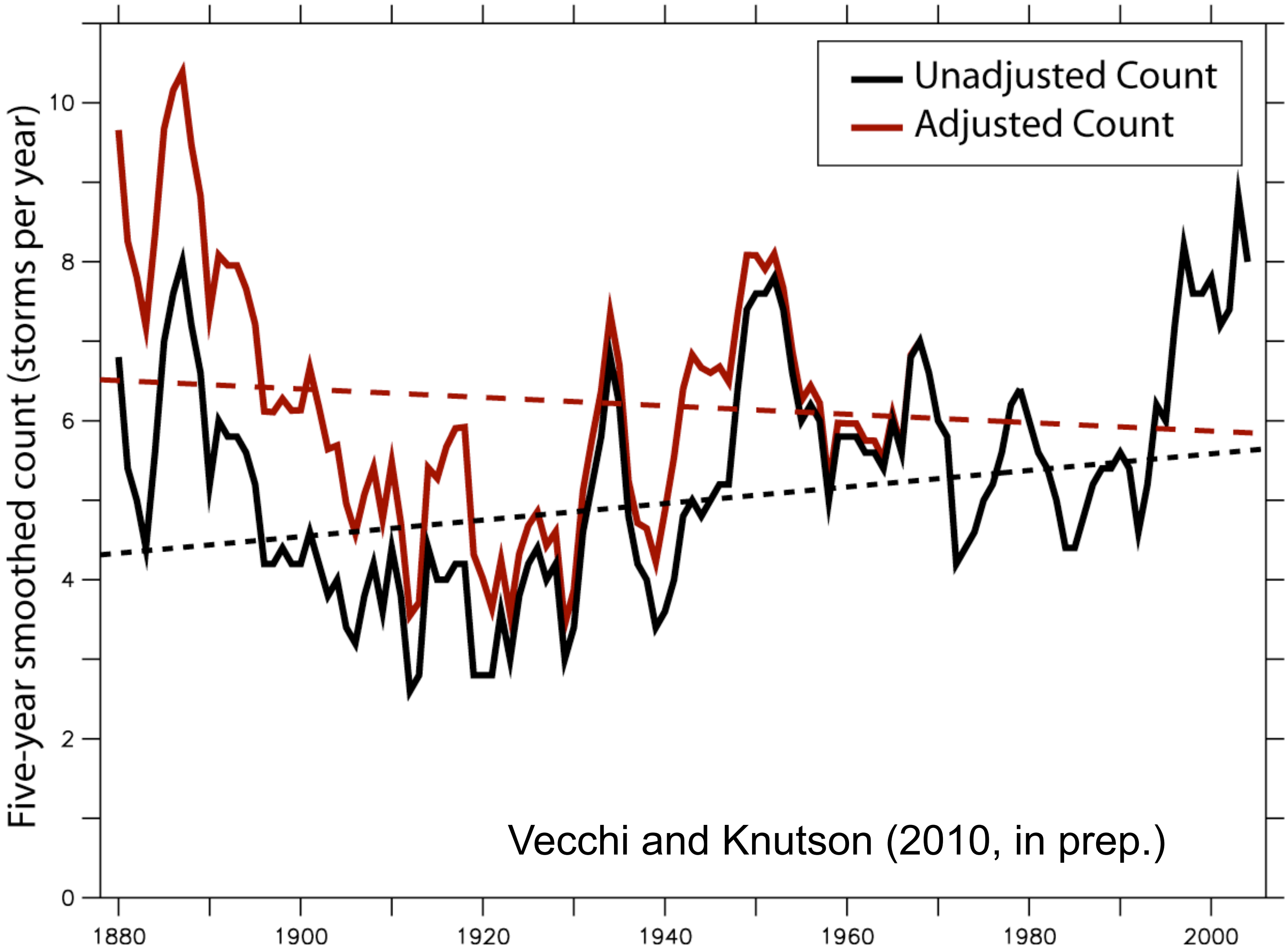


Kossin et al (2007, GRL)



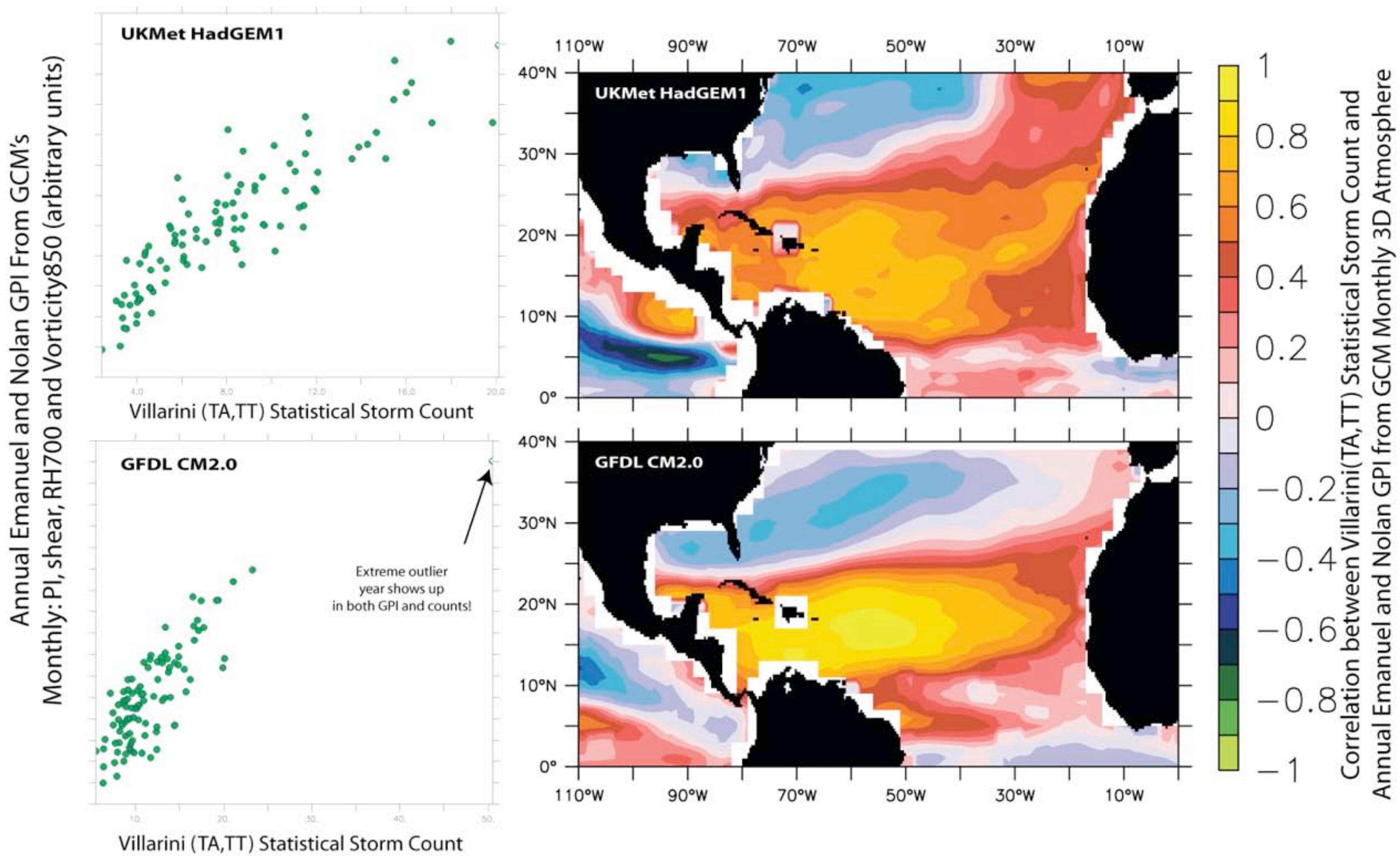
Vecchi and Knutson (2008, J. Clim.)

Count of Atlantic Hurricanes (Cat. 1-5)

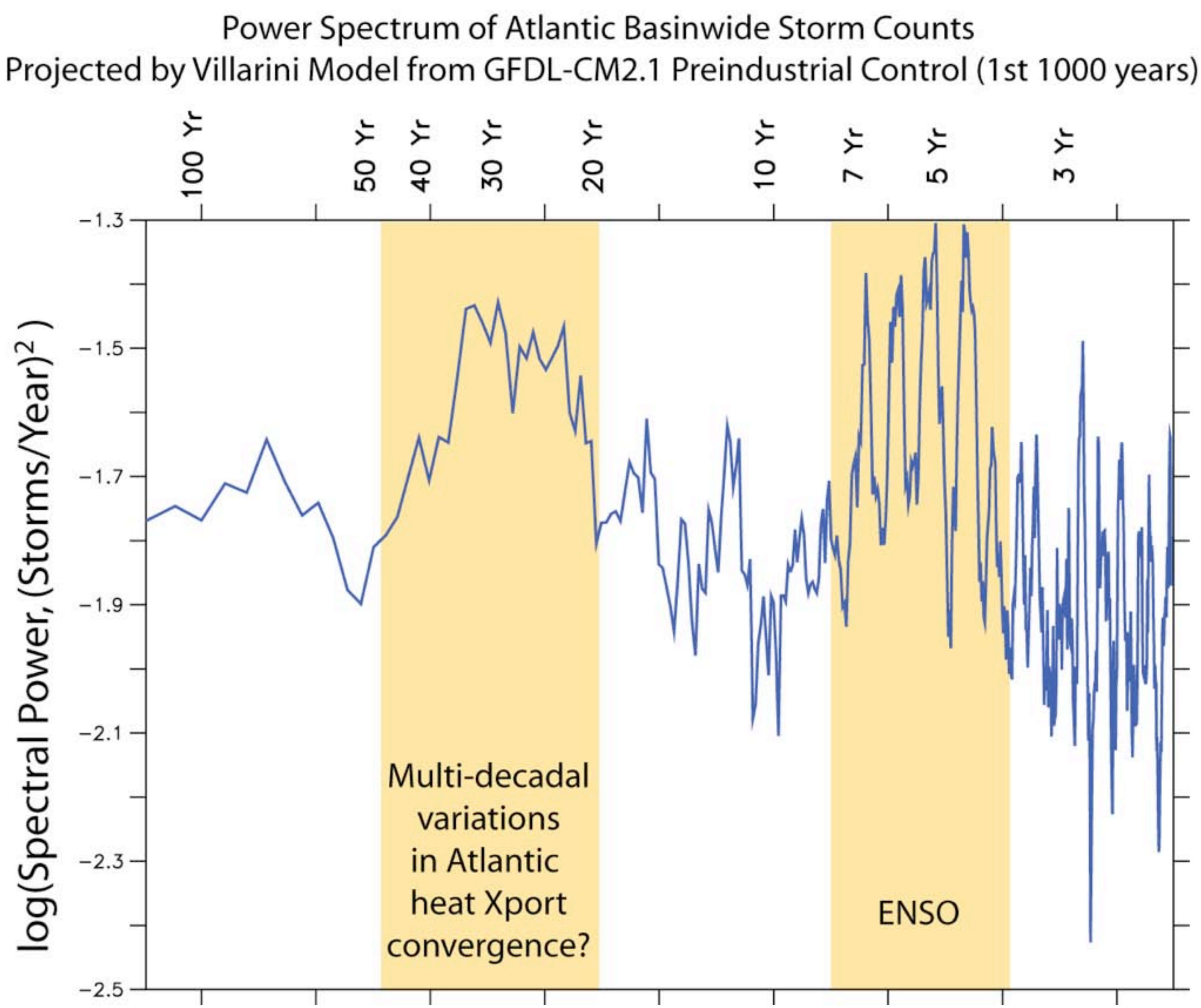


Adjustment changes sign of hurricane count trend

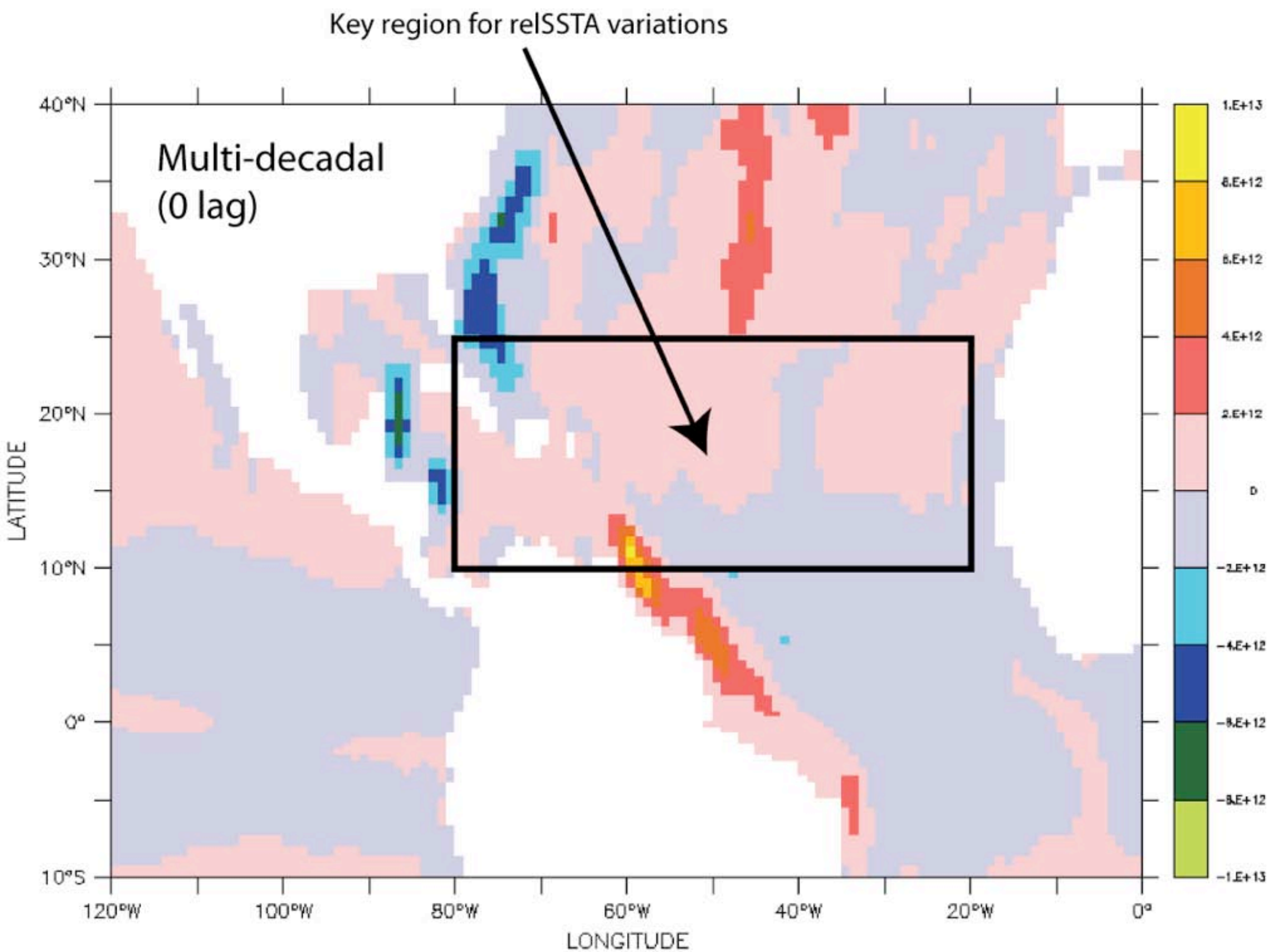
Statistical downscale vs. complex statistical model in GCMs



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