Patterns of temperature change and tropical precipitation/ cyclones

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Summary

- Substantial progress has been made describing, understanding and attributing multi-decadal changes in global mean surface temperature.

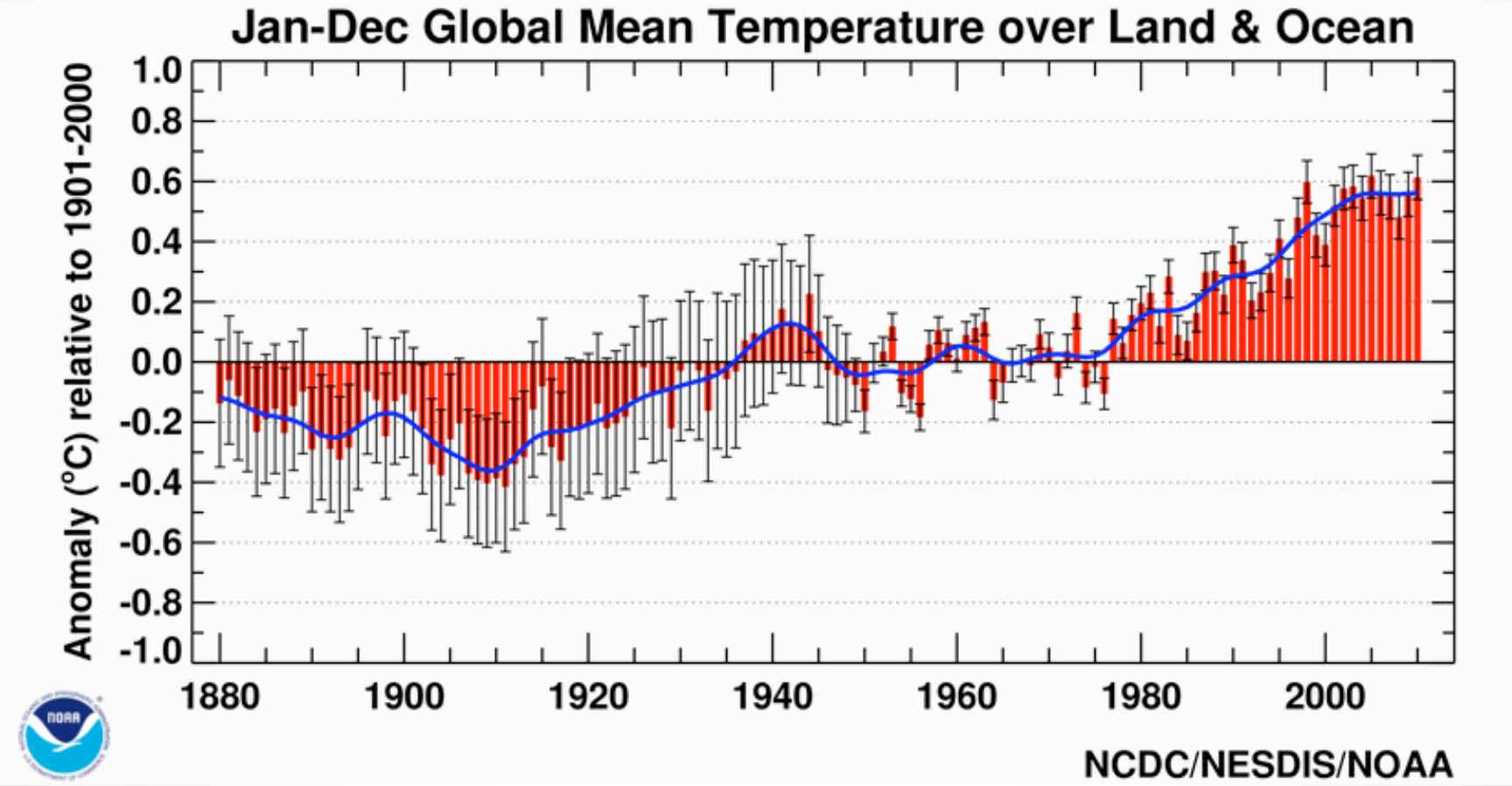
- However, for regional tropical precipitation and tropical cyclones the "patterns" of temperature change may be more relevant:
  - Patterns in space: SST change *relative* to tropical-mean key to tropical precip and cyclone response

  - Patterns in height/depth (stability and stratification changes)

  - Patterns in time (multi-year to decadal changes)

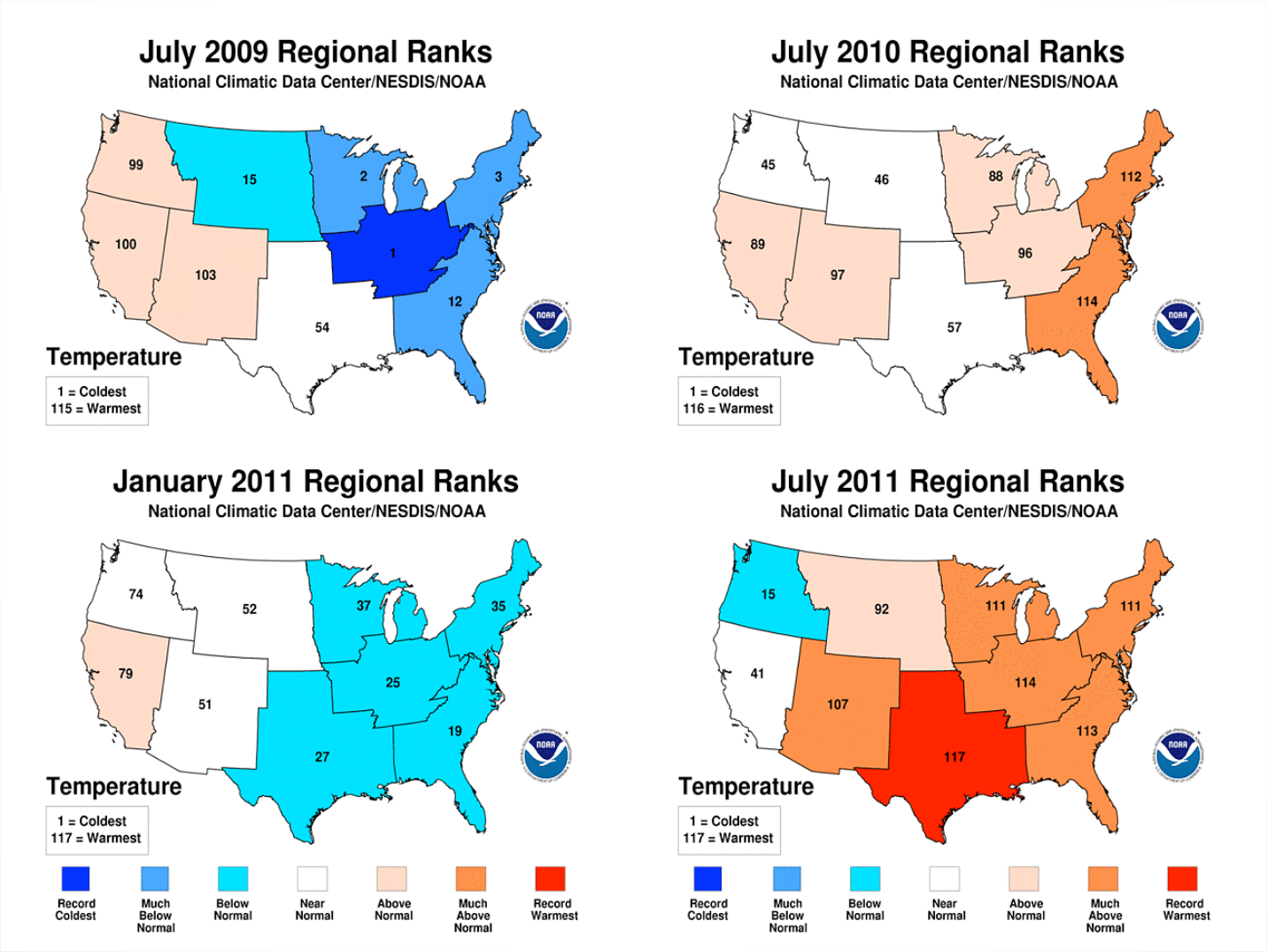
Global temperatures have shown clear long-term increase

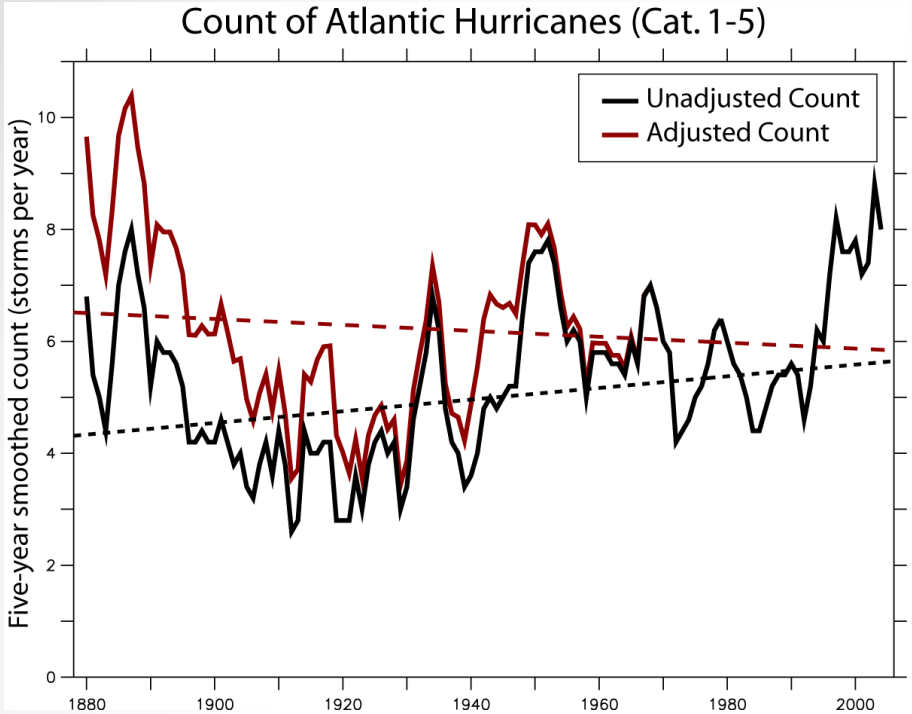
(seen in other datasets, CRU, GISS, etc)



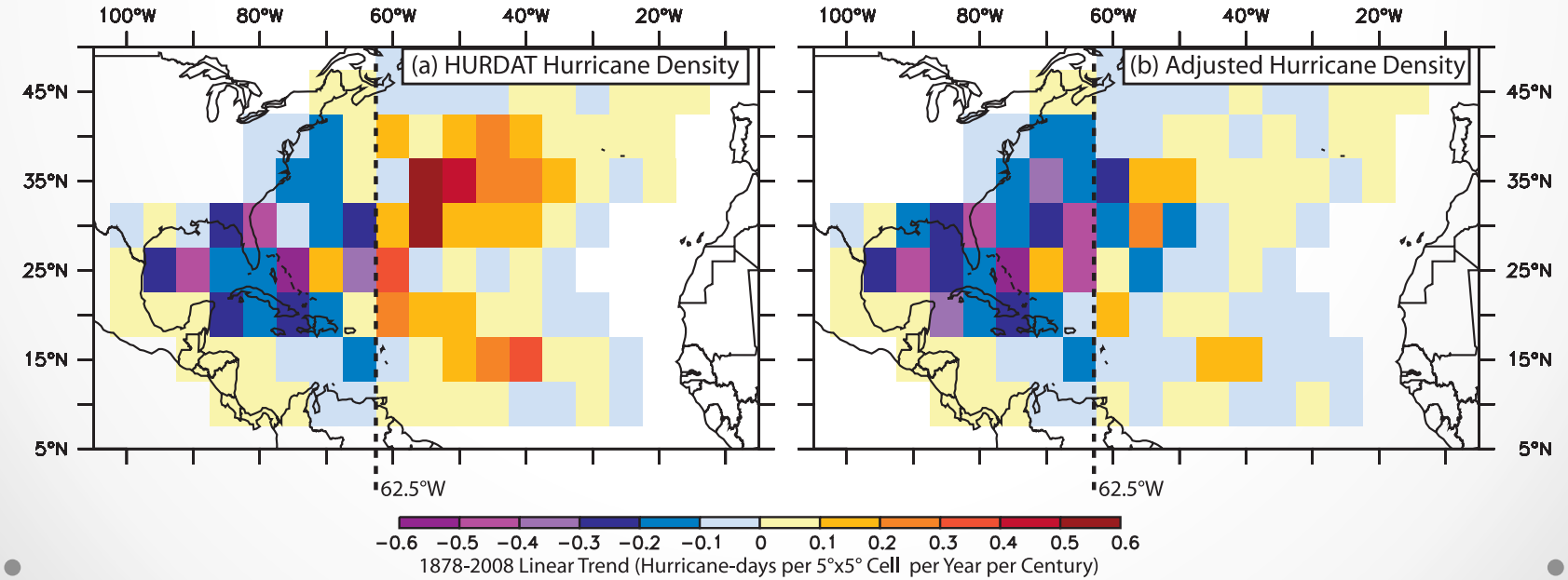
GCMs have exhibited skill in recovering these century-scale changes.

On monthly and regional scales, changes have been more nuanced



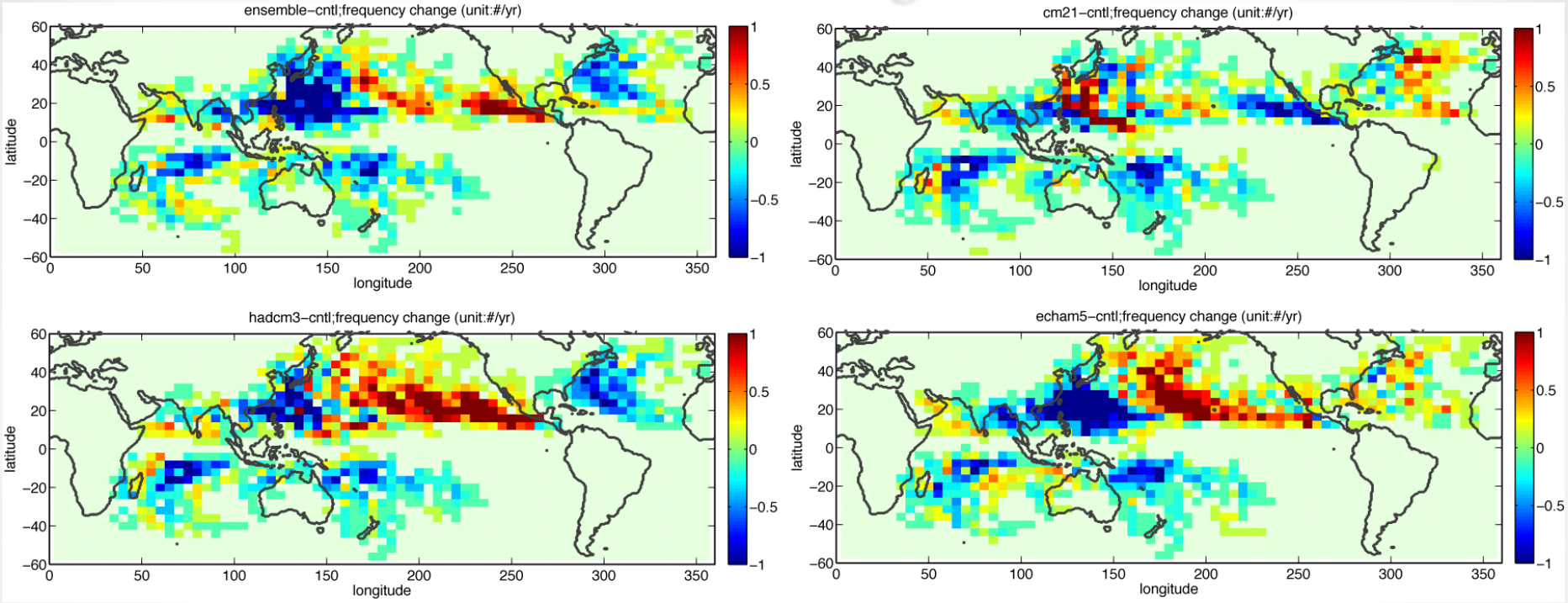


Observed hurricane changes: uncertain, not monotonic & spatially heterogeneous



Vecchi and Knutson (2011, J. Climate)

21st Cy response of TC frequency in single 50km global atmospheric model forced by four projections: uncertain, heterogeneous.



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.

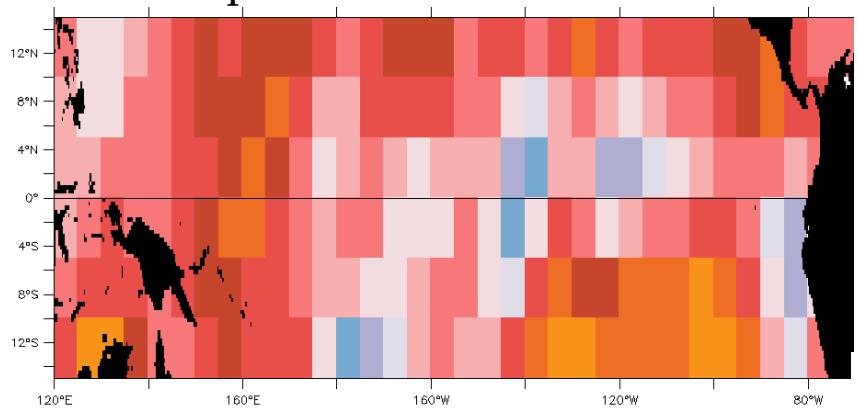
Sensitivity of response seen in many studies

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

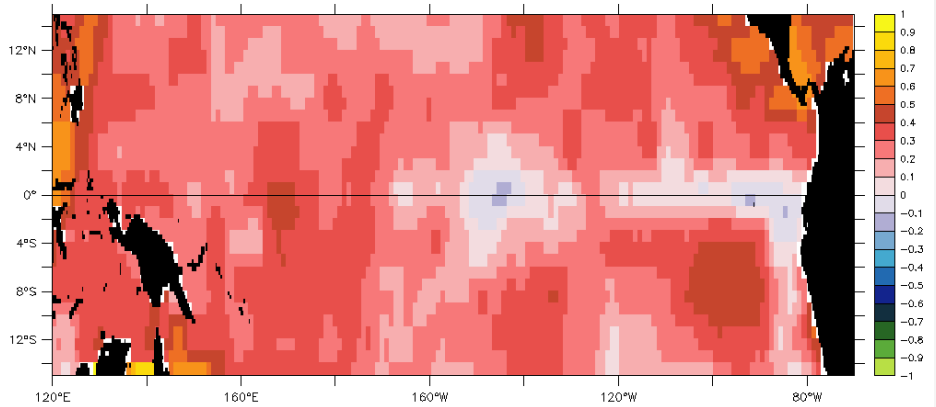
Long-term SST trends in Tropical Pacific Uncertain

Linear trends (1880-2005) in four SST estimates.

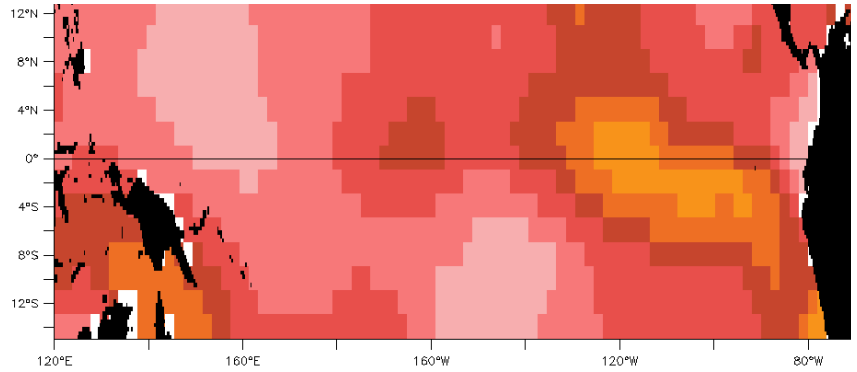
LDEO-Kaplan



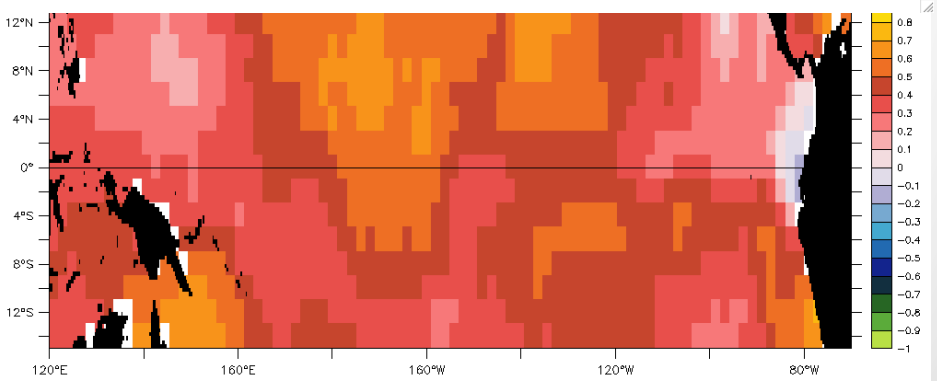
HadISST v.1



NOAA-ERSST v.2



NOAA-ERSST v.3

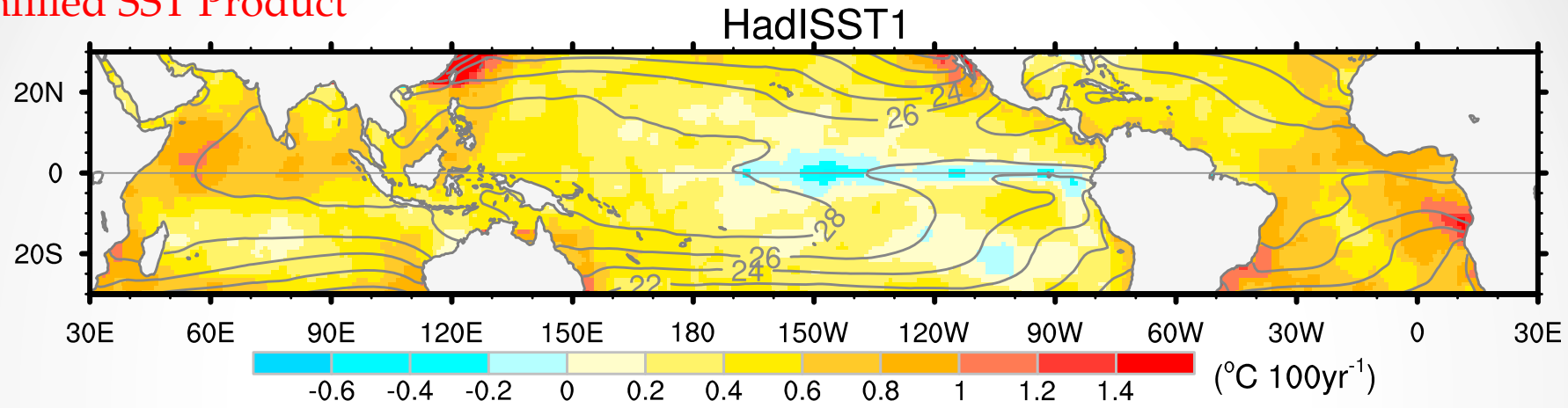


Overall warming seen in all. Structure dependent on reconsruction.

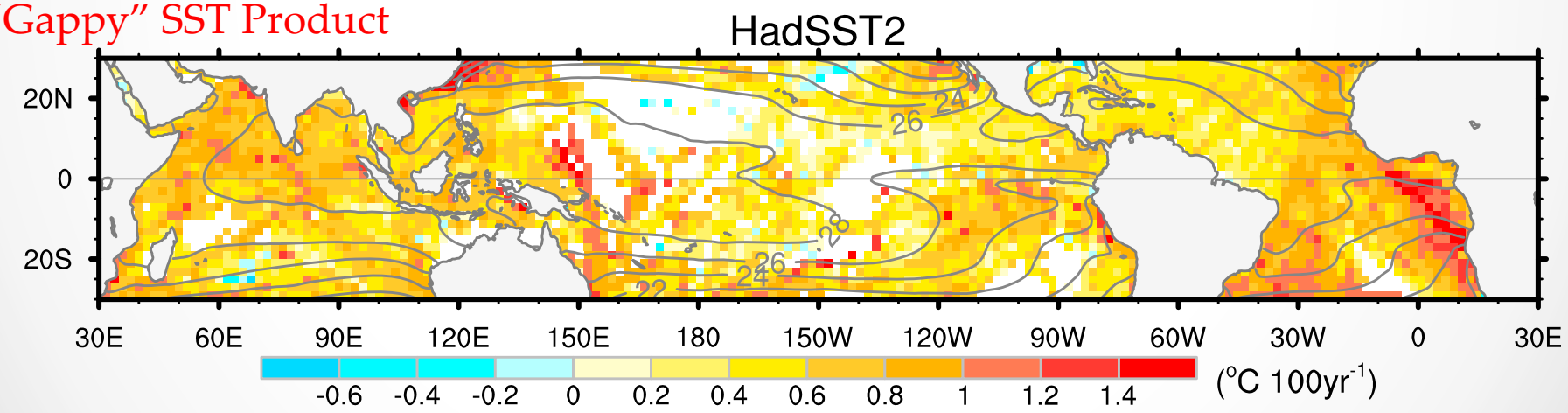
Adapted from Vecchi, Clement and Soden (2008, EOS)

Data infilling leads to differences in east Pacific SST trends

Infilled SST Product



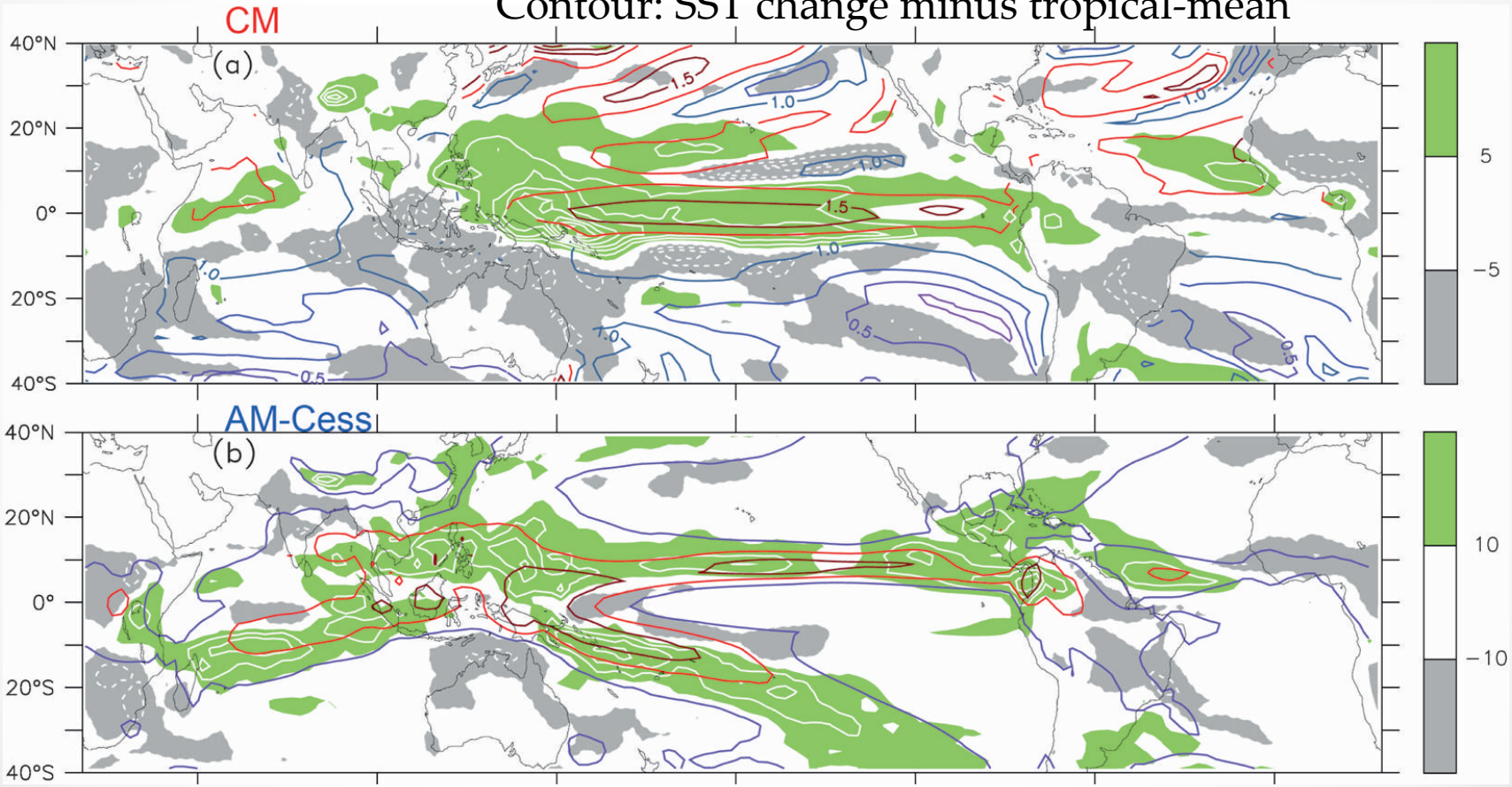
"Gappy" SST Product



Deser et al. (2010, GRL)

GFDL GCM precipitation response to 2xCO2 and 2°C Uniform Warming

Shade: Precip response to 2xCO2
Contour: SST change minus tropical-mean



Shade: Precip response to Uniform 2°C
Contour: Control precipitation

Xie et al. (2009, J. Clim.)

Free tropospheric temperature changes relatively uniform ("Weak Temperature Gradient" Hypothesis, Sobel et al 2001); changes in stability follow surface temperature changes relative to tropical-mean

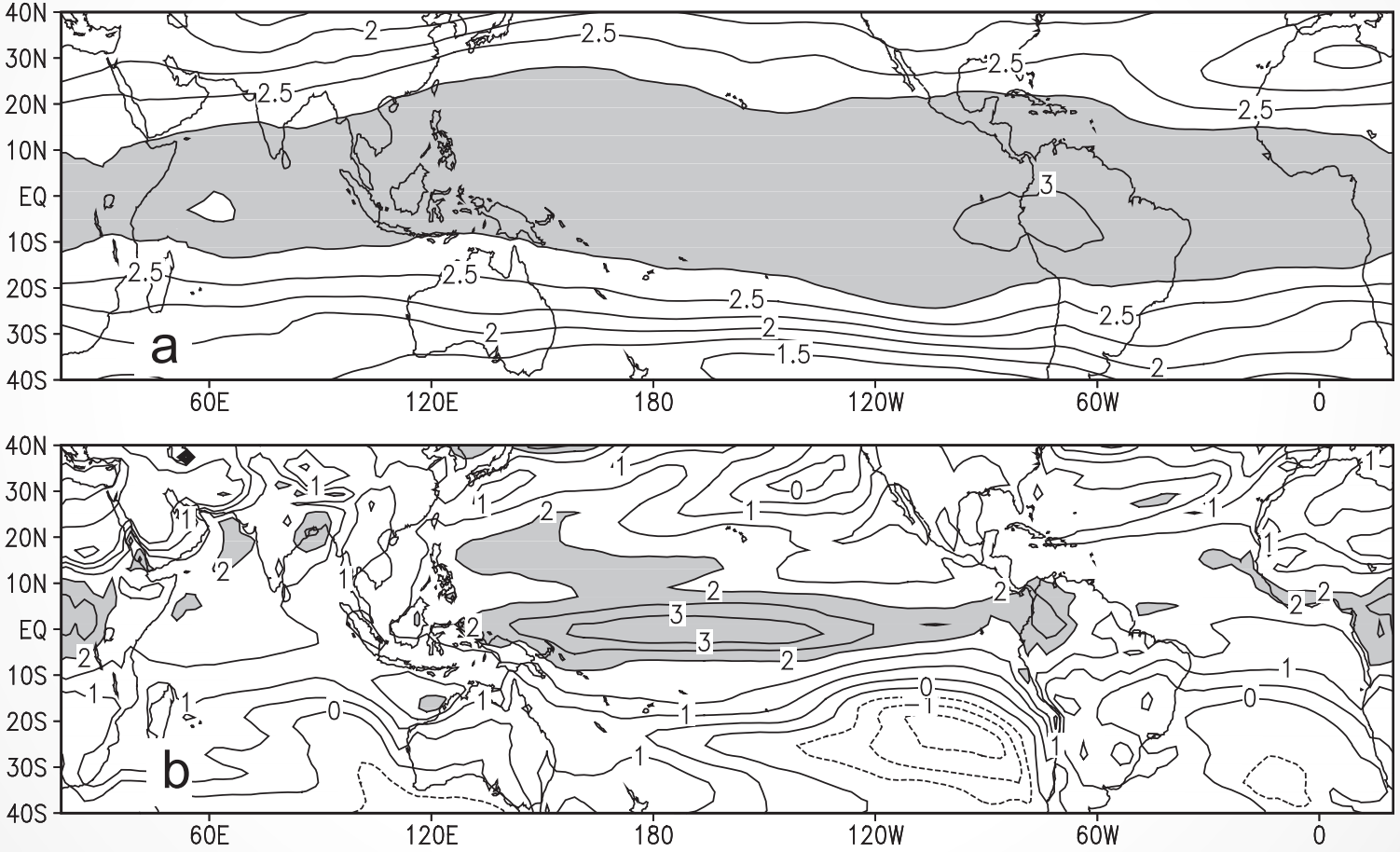
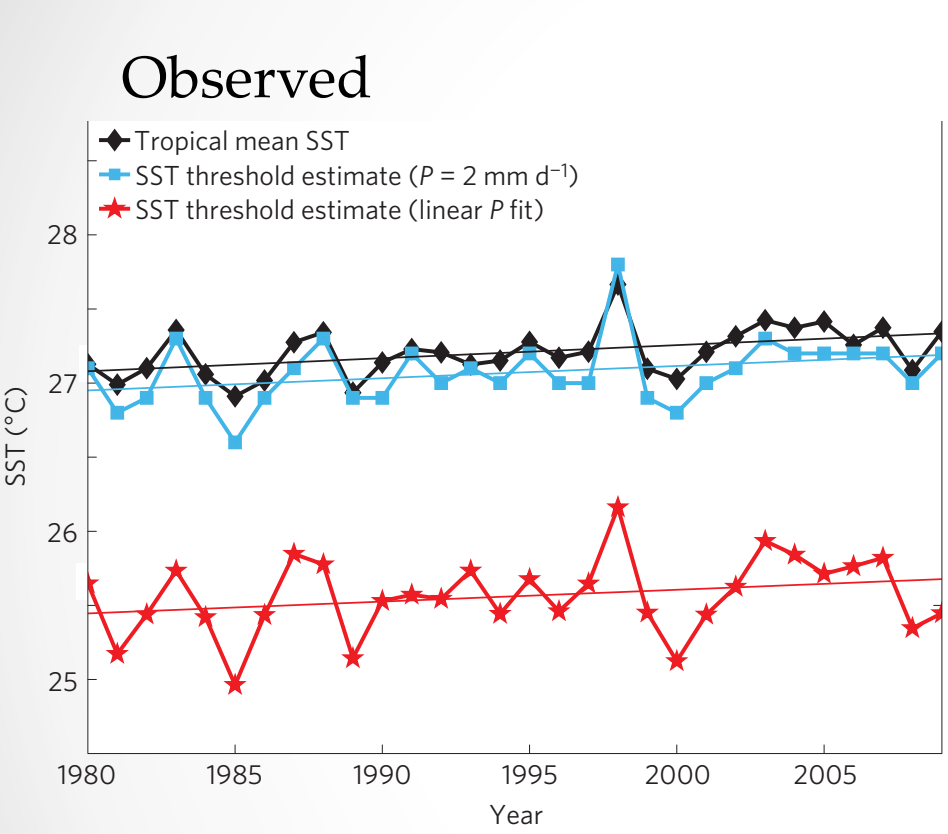


FIG. A1. Annual-mean change in CM2.1 A1B: (a) 300-hPa temperature (shading > 2.75 K) and (b) gross convective instability I_M/c_p (shading > 2 K).

Xie et al. (2009, J. Clim.)

"Threshold" for strong precipitation seems to follow tropical-mean SST in obs. and models



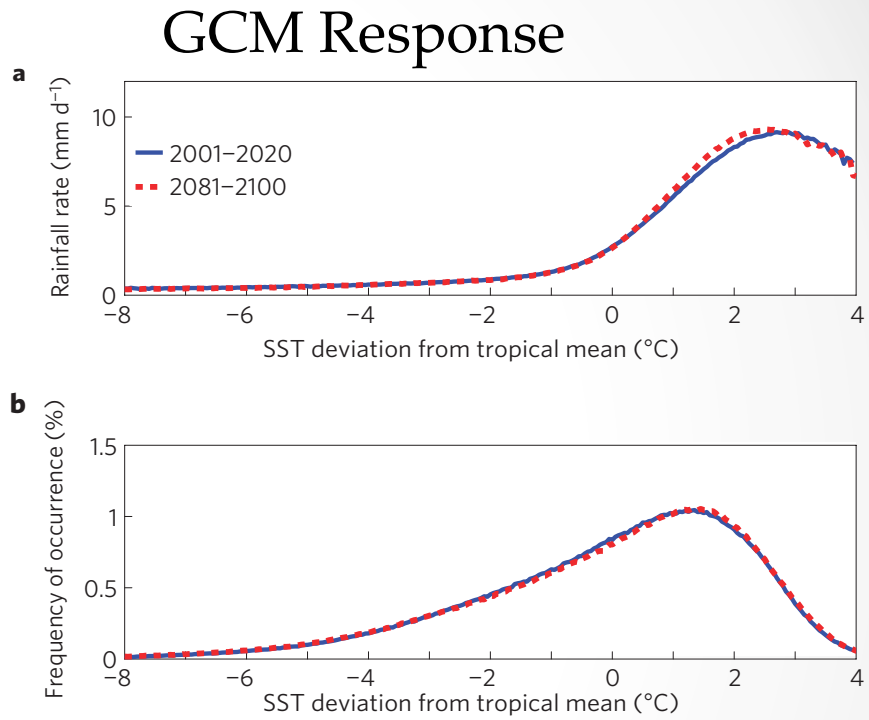


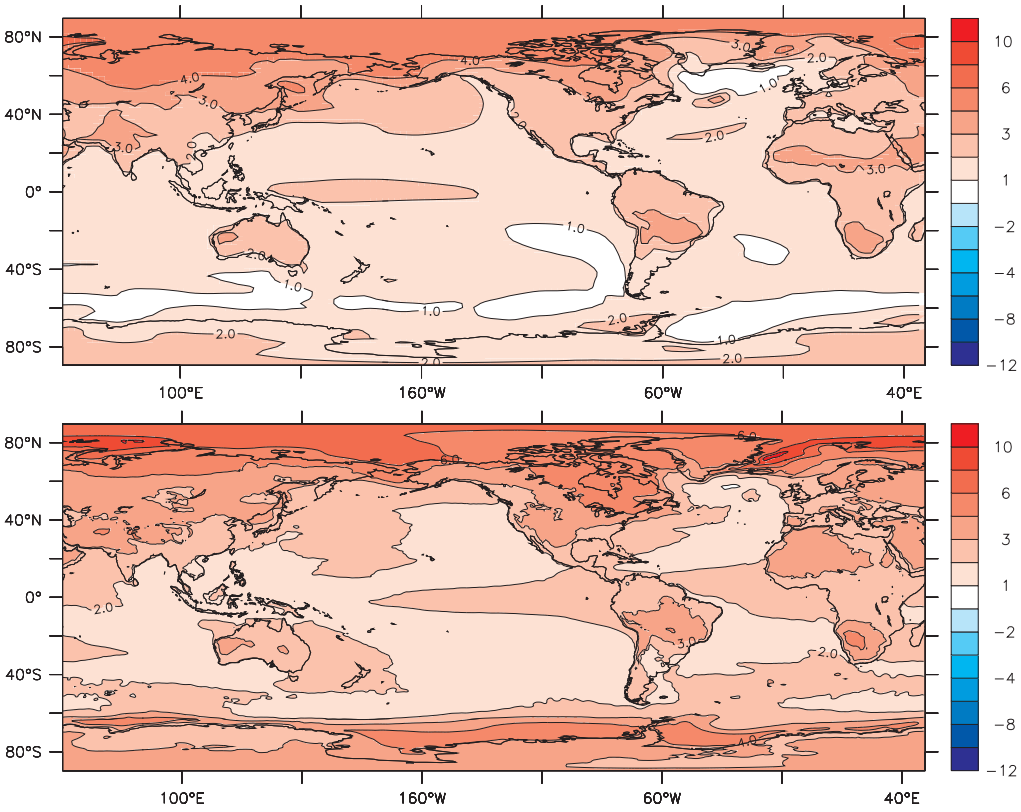
Figure 3 | Twenty-first-century changes in rainfall rate and SST frequency distributions. a,**b**, Ensemble mean rainfall rate as a function of SST (**a**) and SST frequency distribution (**b**) for 2001–2020 (blue, solid) and 2081–2100 (red, dashed) for the ten CMIP3 models of Fig. 2. SST is expressed as the deviation from the 20-year tropical mean.

Johnson and Xie (2010, Nature Geosci.)

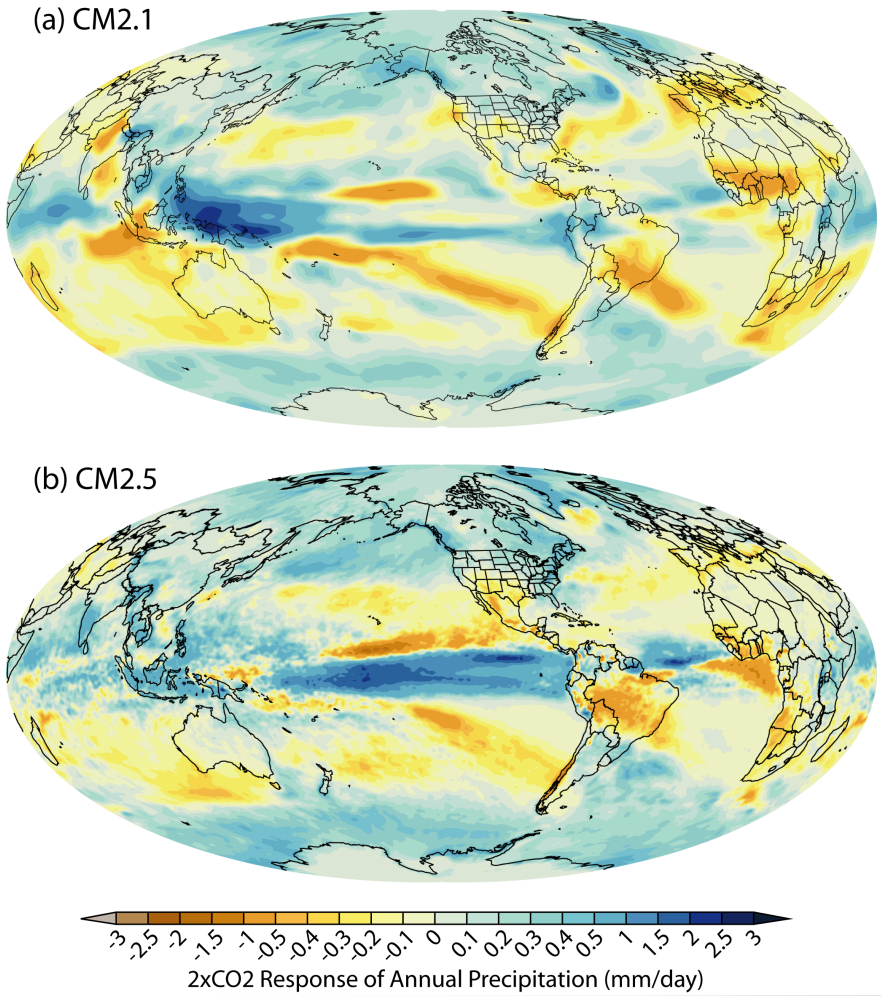
Response to 2xCO2 of models of different resolution:

- CM2.1 (1°Ocn, 2.5°Atm)
- CM2.5 (0.25°Ocn, 0.5°Atm)

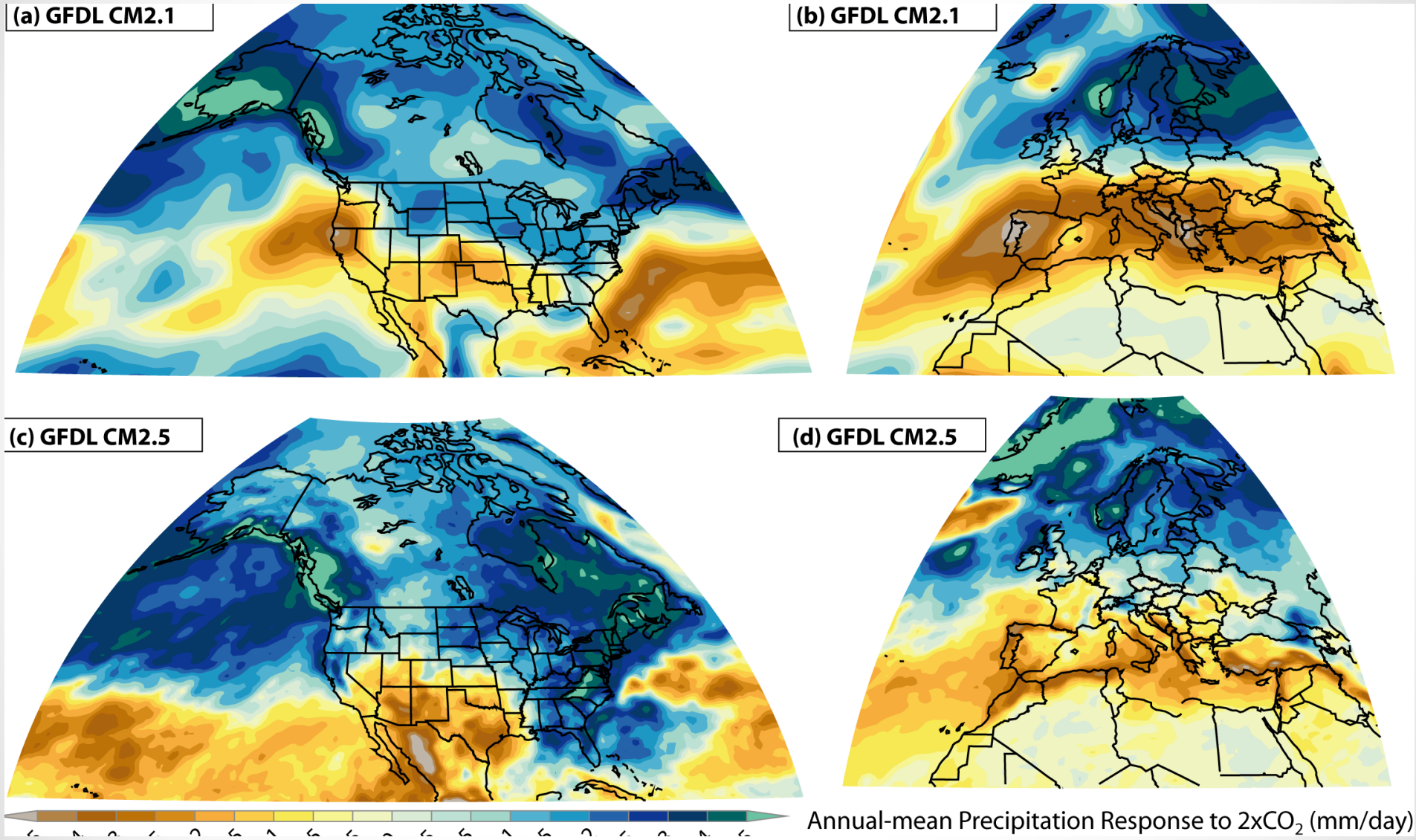
Precipitation



Surface Temperature



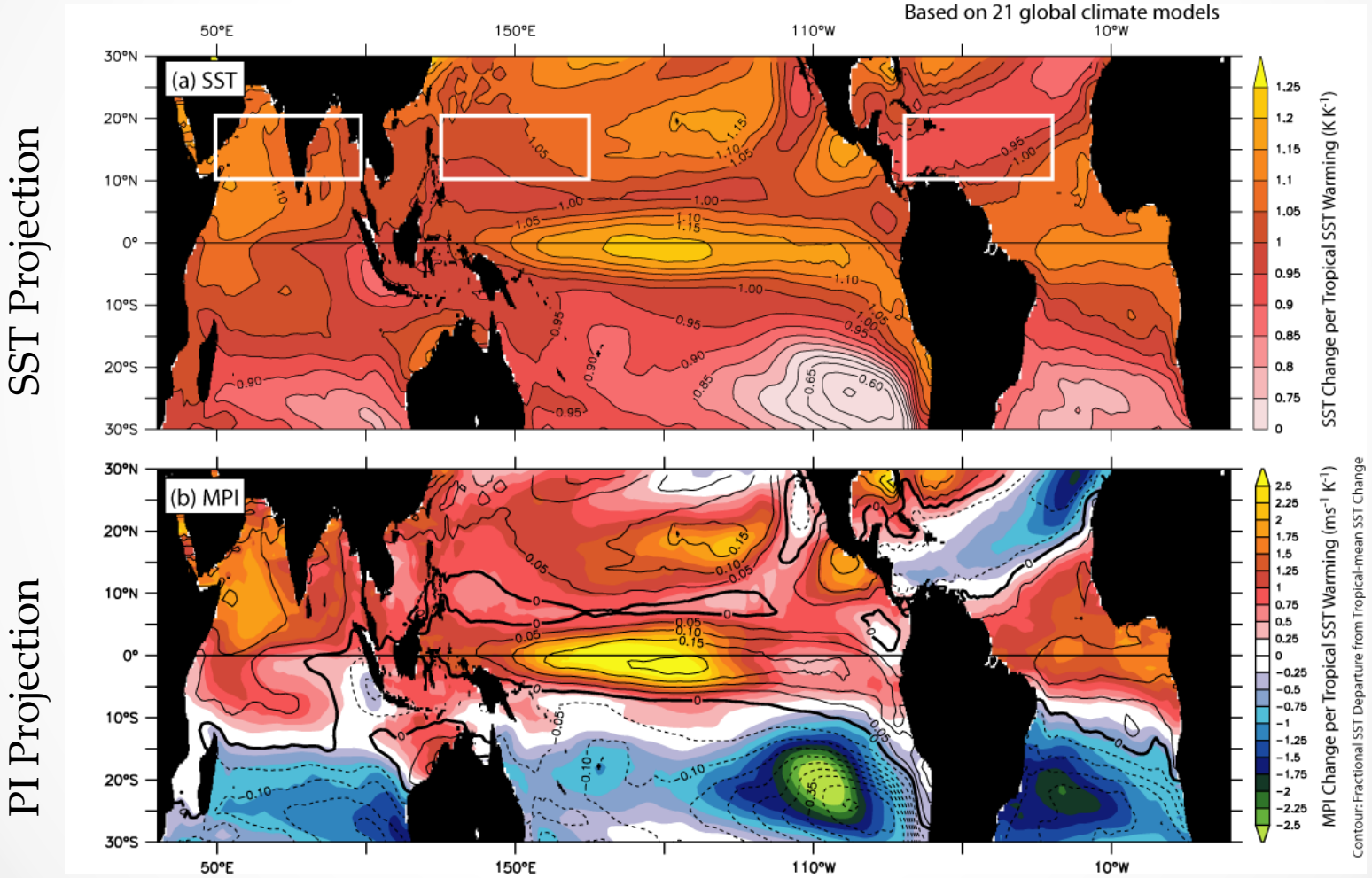
Delworth et al. (2011, J. Clim.)



Delworth et al. (2011, J. Clim.)

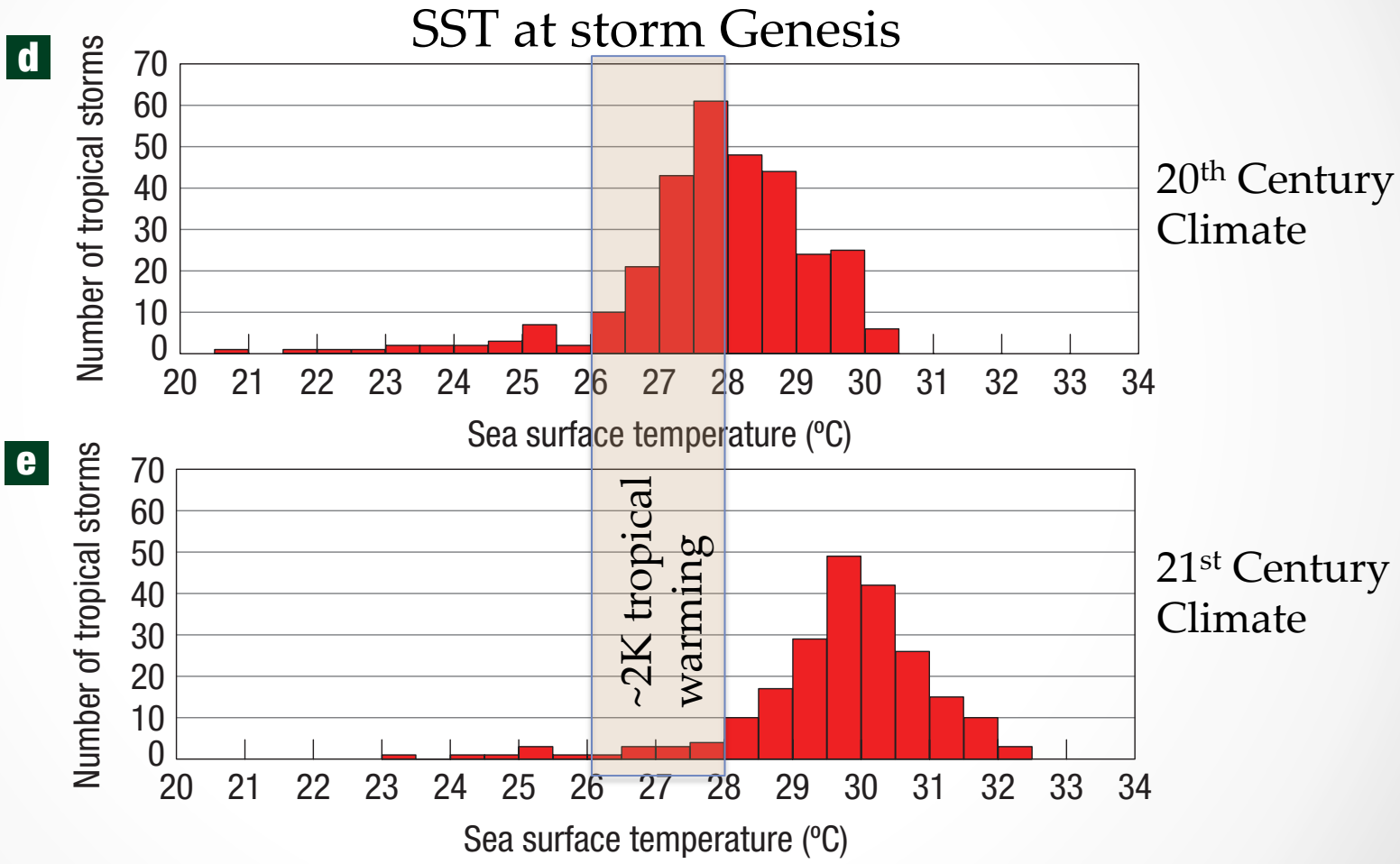
For related reasons tropical cyclone potential intensity tracks SST relative to tropical-mean, not local SST*

*global-mean PI changes still need to be explained.



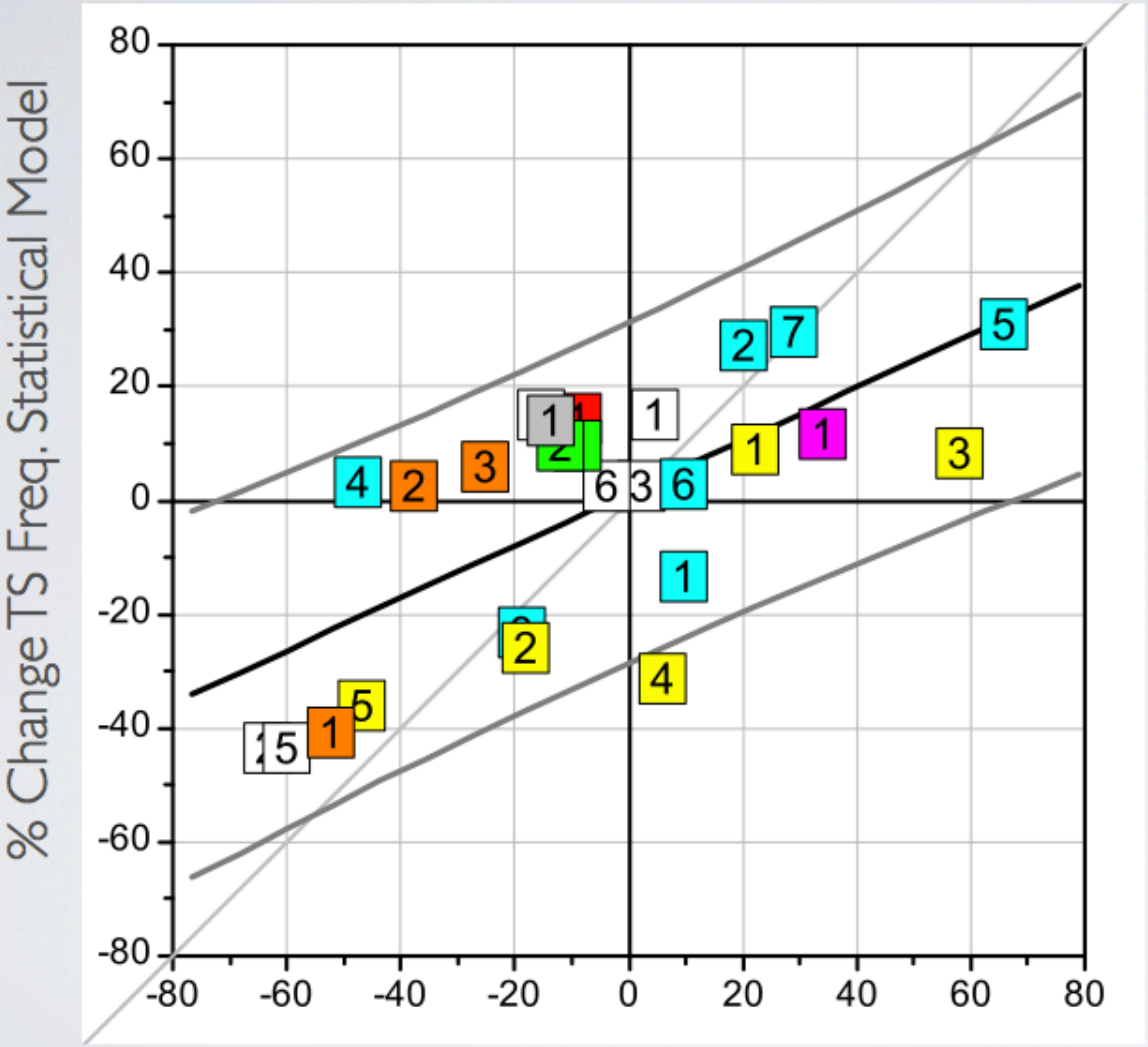
Vecchi and Soden (2007, Nature)

Modeled "threshold" for hurricane genesis also depends on tropical-mean SST



Knutson et al. (2008, Nature Geosci.)

Dynamical Models Exhibit Consistent Relationship To Large-Scale Through Statistical Model - All consistent with observations



Knutson et al. (2008)
1. GFDL CM2.1

Zhao et al. (2009)
1. GFDL CM2.1 (Reynolds)
2. UKMet HadCM3 (Reynolds)
3. Max Planck-ECHAM5 (Reynolds)
4. GFDL CM2.1 (HadISST)
5. UKMet HadCM3 (HadISST)
6. Max Planck-ECHAM5 (HadISST)

Emanuel et al. (2008)
1. NCAR CCSM3.0
2. CNRM-CM3
3. CSIRO-Mk3.0
4. Max Planck-ECHAM5
5. GFDL CM2.0
6. MIROC-Medres
7. MRI CGCM2.3.2

Oouchi et al. (2005)
1. MRI CGCM2.3

Bender et al. (2010)
1. UKMet HadCM3
2. Max Planck-ECHAM5
3. MRI CGCM2.3.2

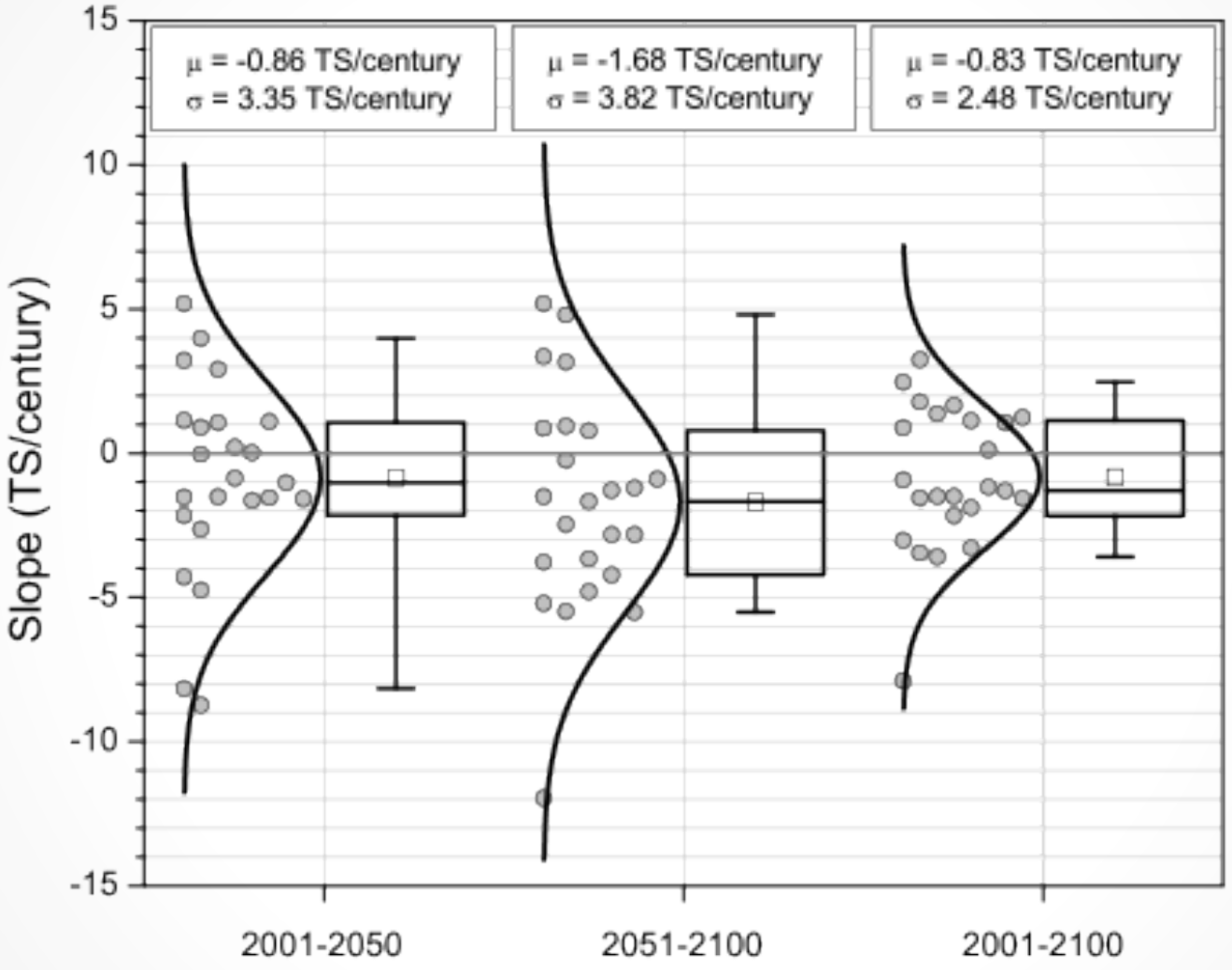
Bengtsson et al. (2007)
1. CNRM with T213 AGCM
2. CNRM with T959 AGCM

Gualdi et al. (2009)
1. INGV-ECHAM4 2×CO_2

Sugi et al. (2009)
1. MRI CGCM2.3.2 (20 km)
2. MIROC-Hires (20 km)
3. MRI CGCM2.3.2 (60 km)
4. MIROC-Hires (60 km)
5 CSIRO-Mk3.0 (60 km)

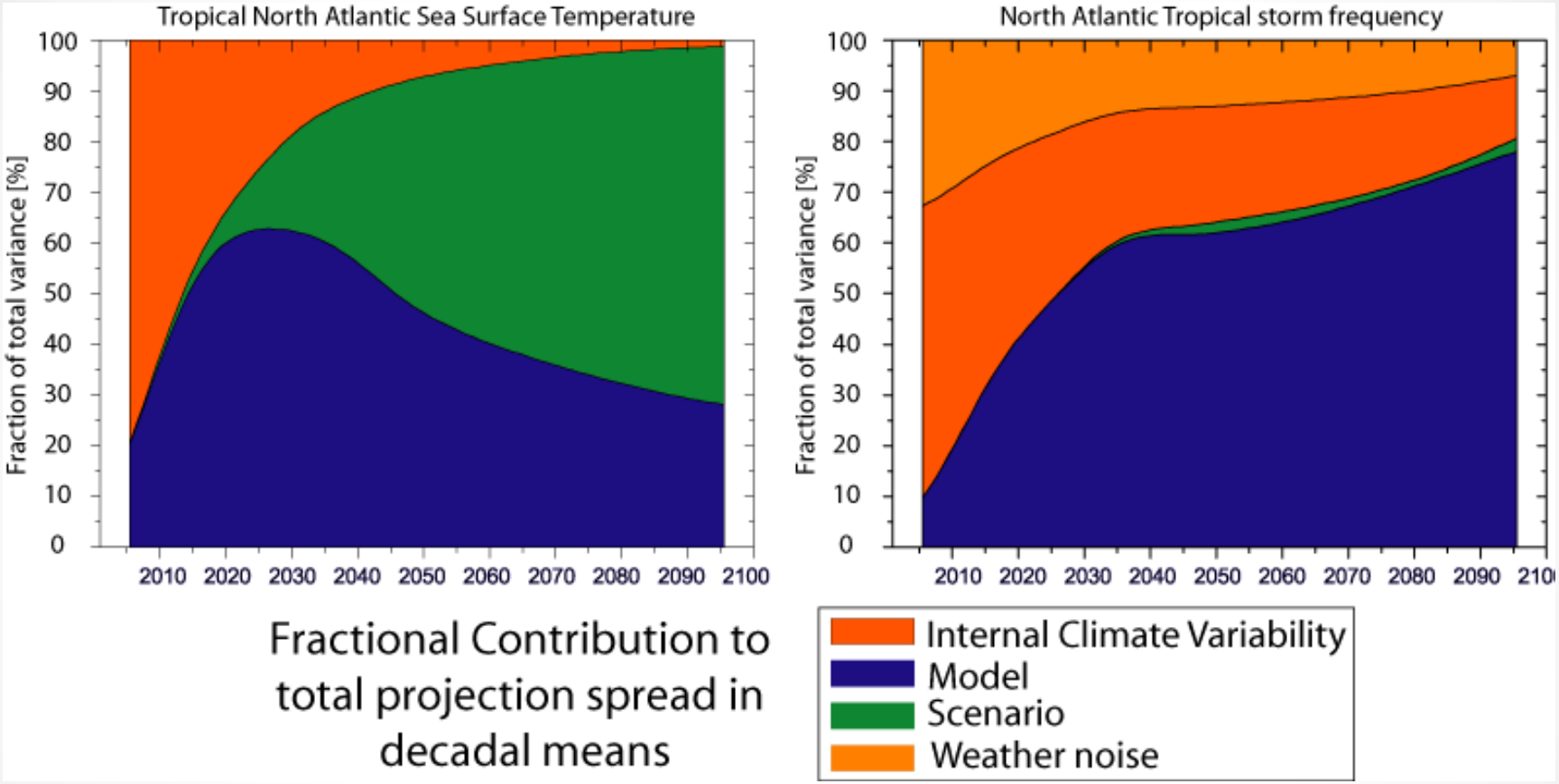
Villarini et al (2011, J. Clim. in press)

Statistical Projections of 21st Century NA TS Trends



Villarini et al (2011, J. Clim.)

Sources of uncertainty for relative SST change different from those to regional or global SST change



Uncertainties arising from differences in model response to forcing other key source of uncertainty for coming decades (whole century for TS's)

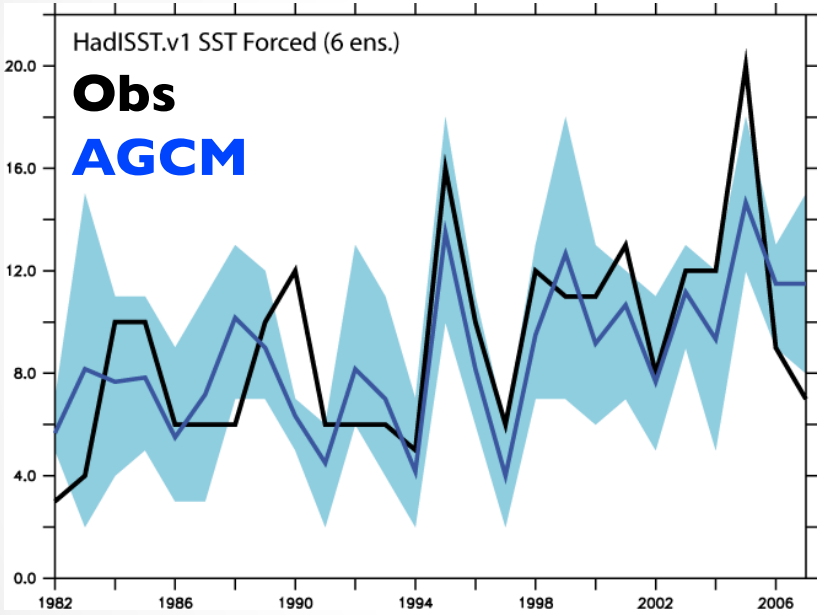
Analysis after Hawkins and Sutton (2009, BAMS)

Villarini and Vecchi (2011)

Because modeled hurricane counts depend on relative SST, trends sensitive to forcing used even over satellite SST era

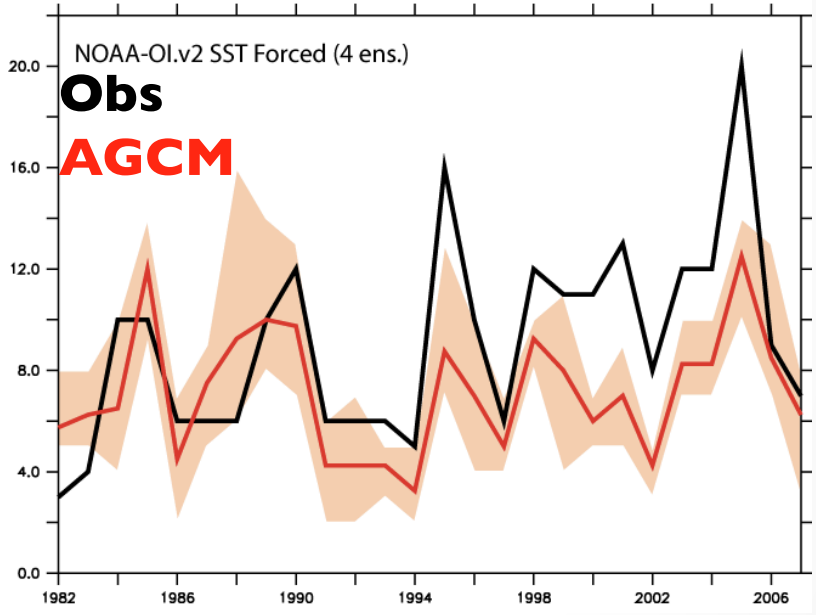
Tropical storm frequency response to same AGCM but different estimates of observed SST

HadISST forced



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

NOAA-OI.v2 forced



Vecchi et al (2011, in prep.)

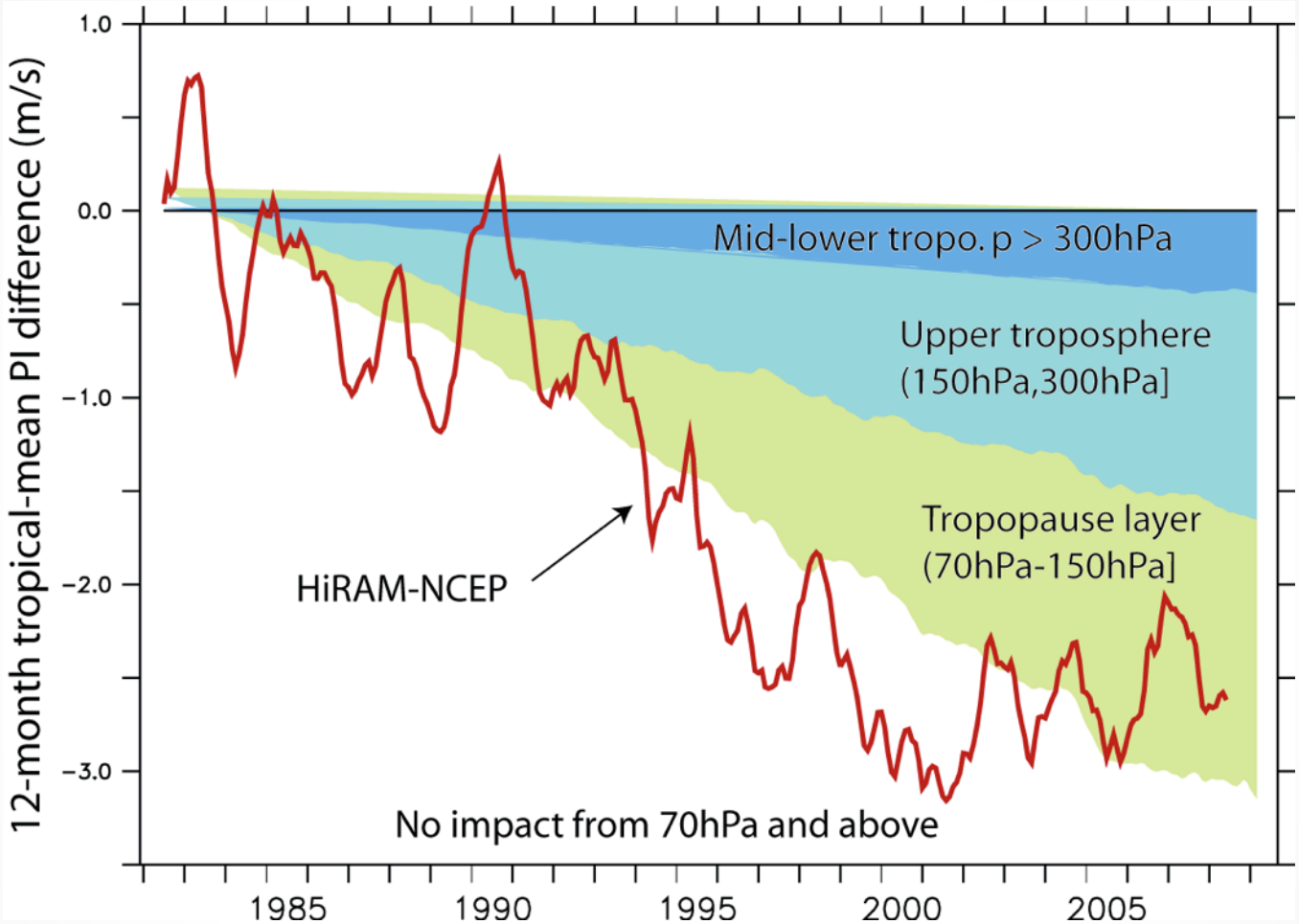
How do we confidently evaluate model skill in this context?

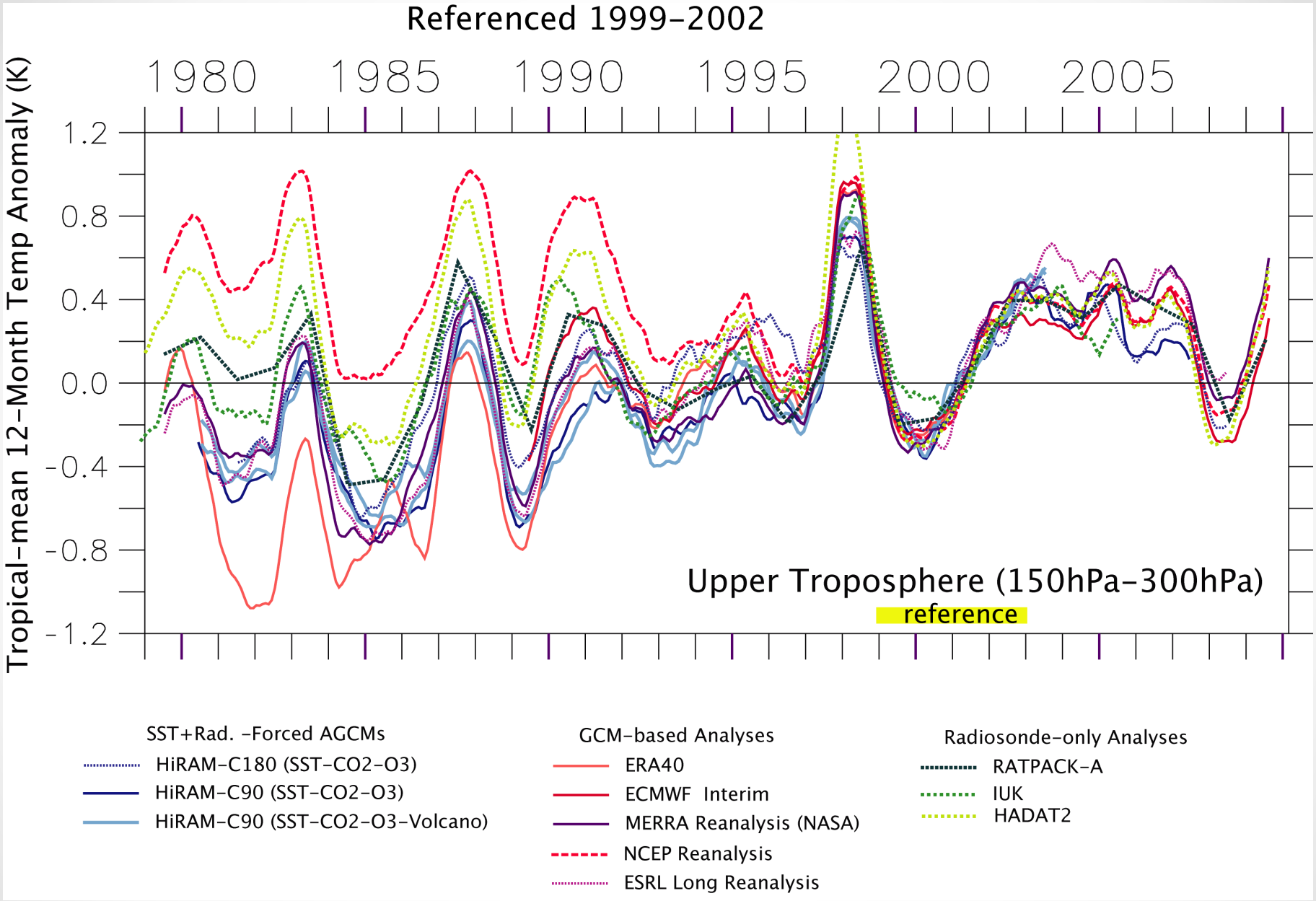
Vertical changes

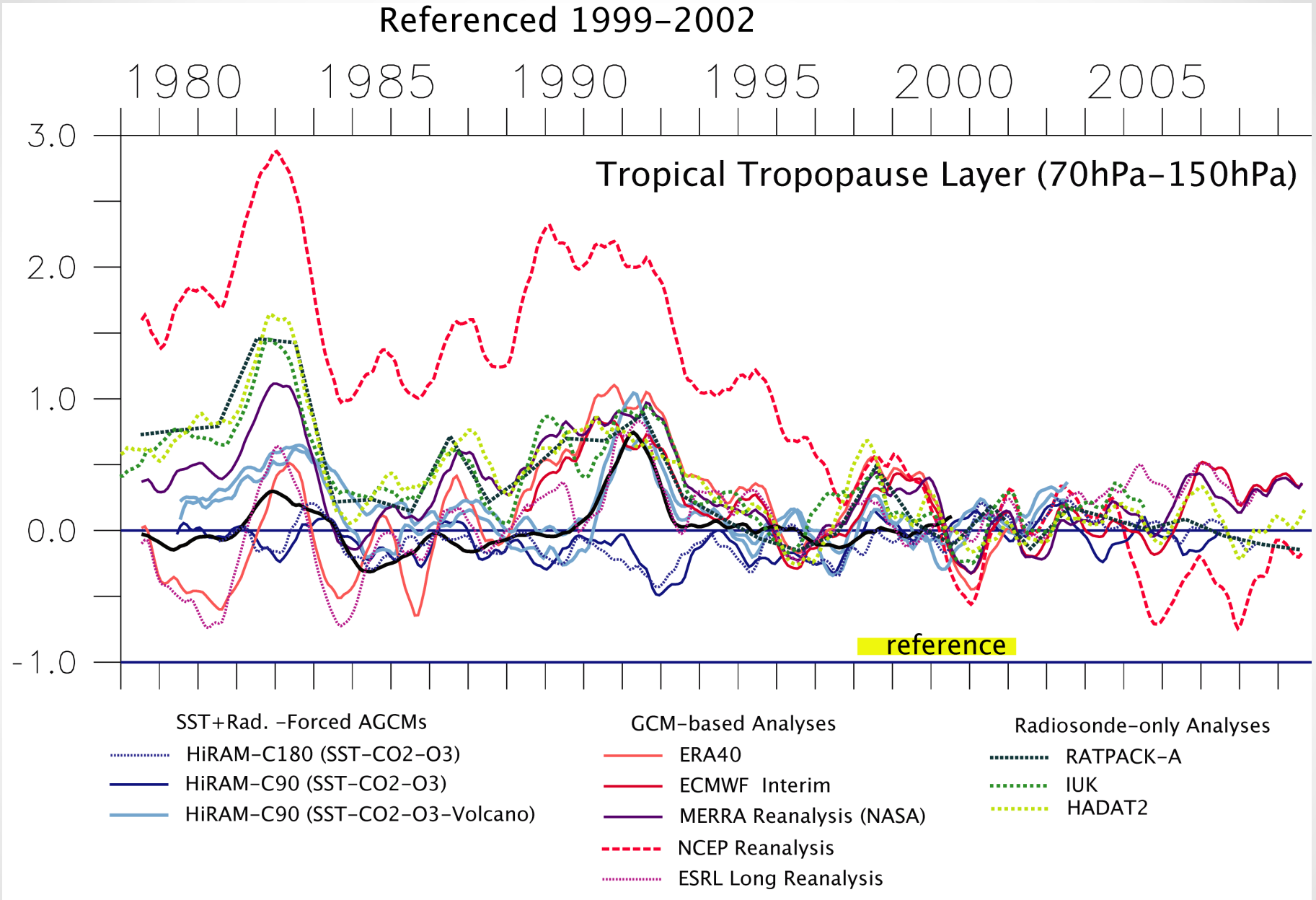
Changes in atmospheric stability impact potential intensity. Uncertainty in past changes to upper tropospheric temperature limit confidence in past (and future) PI changes.

Ocean near-surface thermal stratification key control on intensity of strongest cyclones. How does it change?

- PI Impact of swapping NCEP T-Trend with HiRAM T-Trend



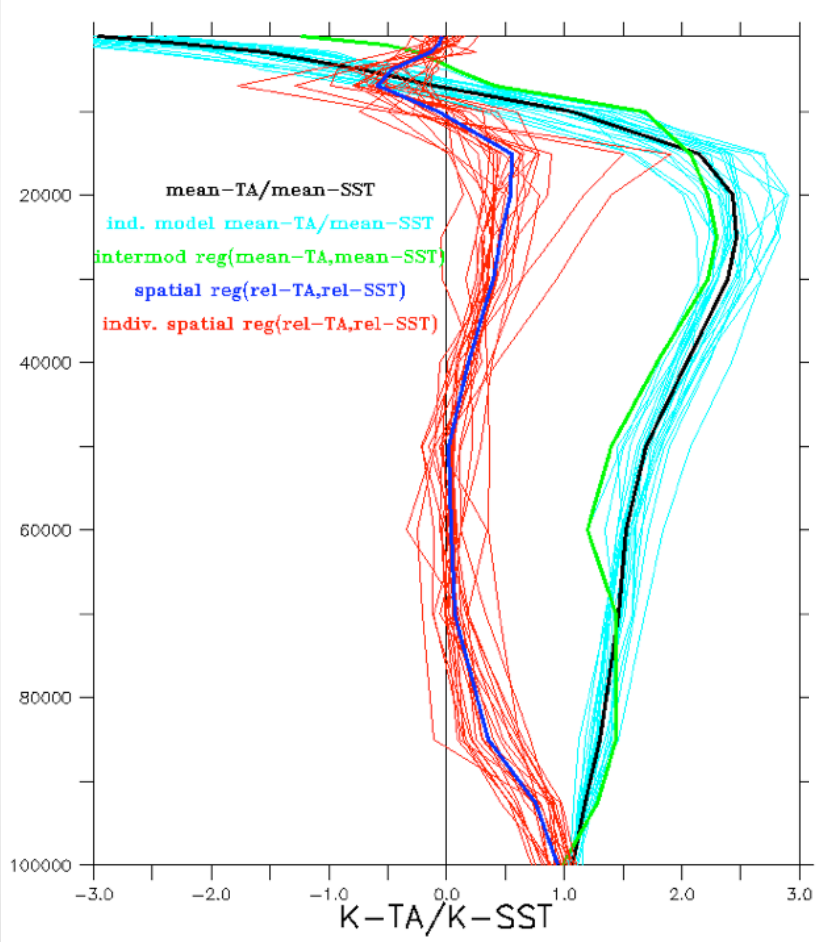

Referenced 1999-2002
1980
1985
1990
1995
2000
2005
1.2
0.8
0.4
0.0
-0.4
-0.8
-1.2
Tropical-mean 12-Month Temp Anomaly (K)
Upper Troposphere (150hPa-300hPa)
reference
SST+Rad. -Forced AGCMs
HiRAM-C180 (SST-CO2-O3)
HiRAM-C90 (SST-CO2-O3)
HiRAM-C90 (SST-CO2-O3-Volcano)
GCM-based Analyses
ERA40
ECMWF Interim
MERRA Reanalysis (NASA)
NCEP Reanalysis
ESRL Long Reanalysis
Radiosonde-only Analyses
RATPACK-A
IUK
HADAT2


Referenced 1999-2002
1980
1985
1990
1995
2000
2005
3.0
2.0
1.0
0.0
-1.0
Tropical Tropopause Layer (70hPa-150hPa)
reference
SST+Rad. -Forced AGCMs
HiRAM-C180 (SST-CO2-O3)
HiRAM-C90 (SST-CO2-O3)
HiRAM-C90 (SST-CO2-O3-Volcano)
GCM-based Analyses
ERA40
ECMWF Interim
MERRA Reanalysis (NASA)
NCEP Reanalysis
ESRL Long Reanalysis
Radiosonde-only Analyses
RATPACK-A
IUK
HADAT2

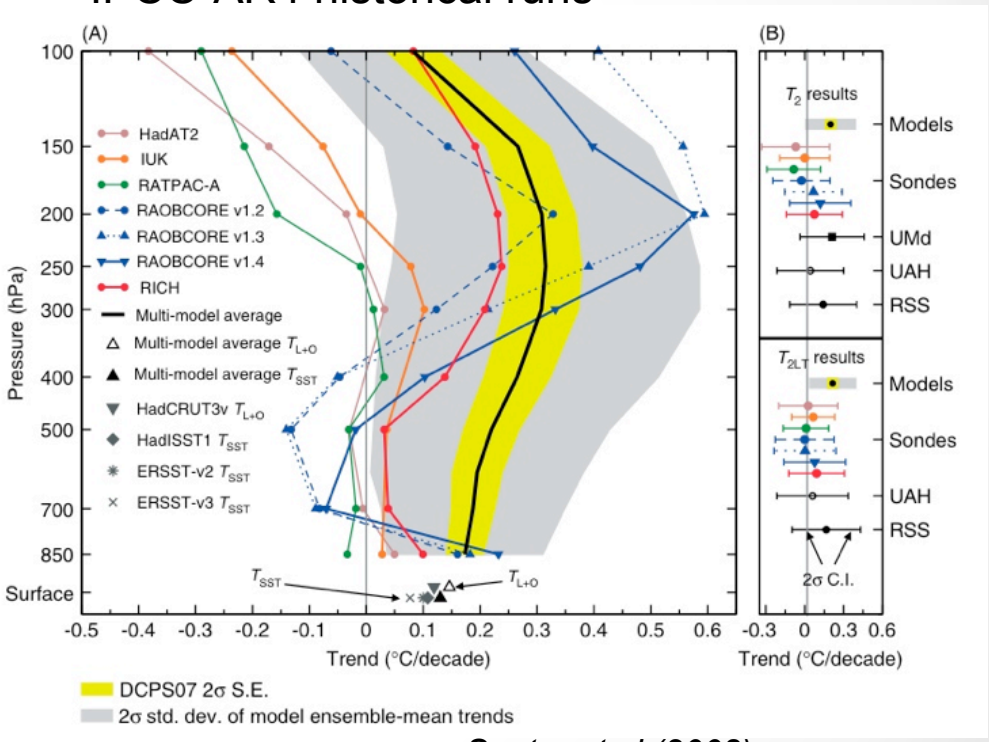
Do we know vertical structure of warming well enough?
Relatively small inter-model TA trend spread still gives large <PI'> spread (±2m/s)

For now: assume GCM lapse rate response "reasonable" estimate?

IPCC-AR4 21st Cy model response

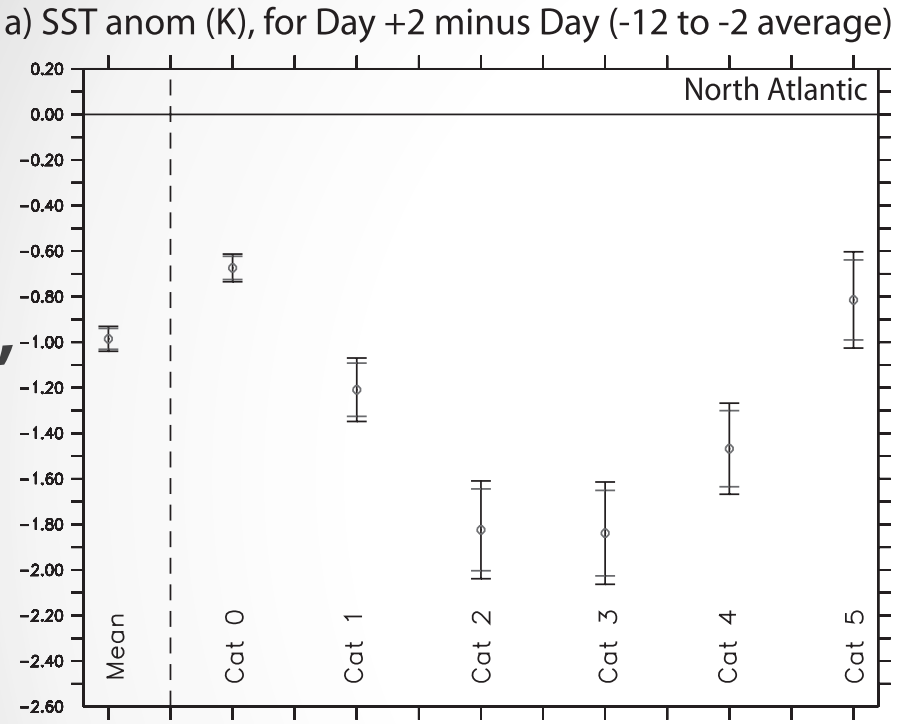


Observational estimates and IPCC-AR4 historical runs

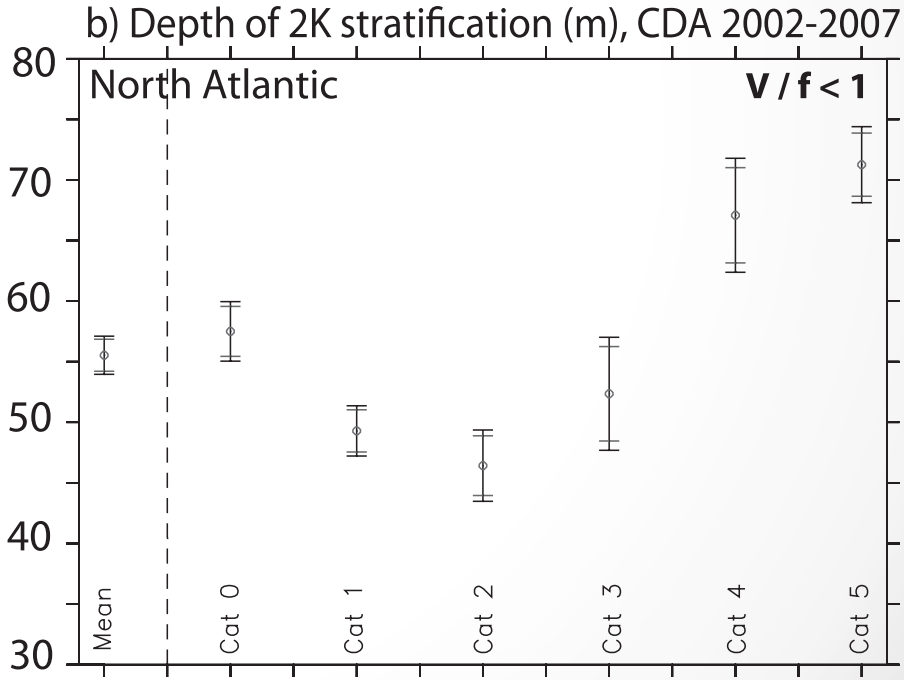


Santer et al (2008)

Intensity of most intense hurricanes impacted by ocean stratification



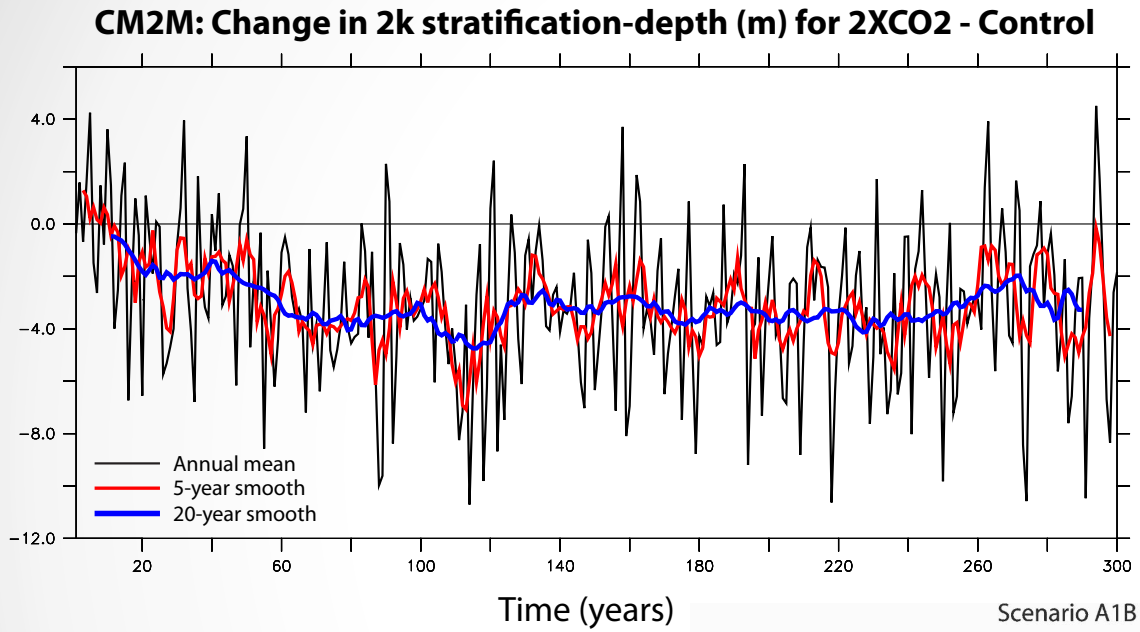
Ocean cooling following tropical cyclones has non-monotonic relationship to intensity, indicating ocean influence.



Strongest hurricanes tend to occur over water with light stratification (deep mixed layer).

Lloyd and Vecchi (2010, J. Climate)

MLD should decrease in mean from CO2, but what about regional patterns?

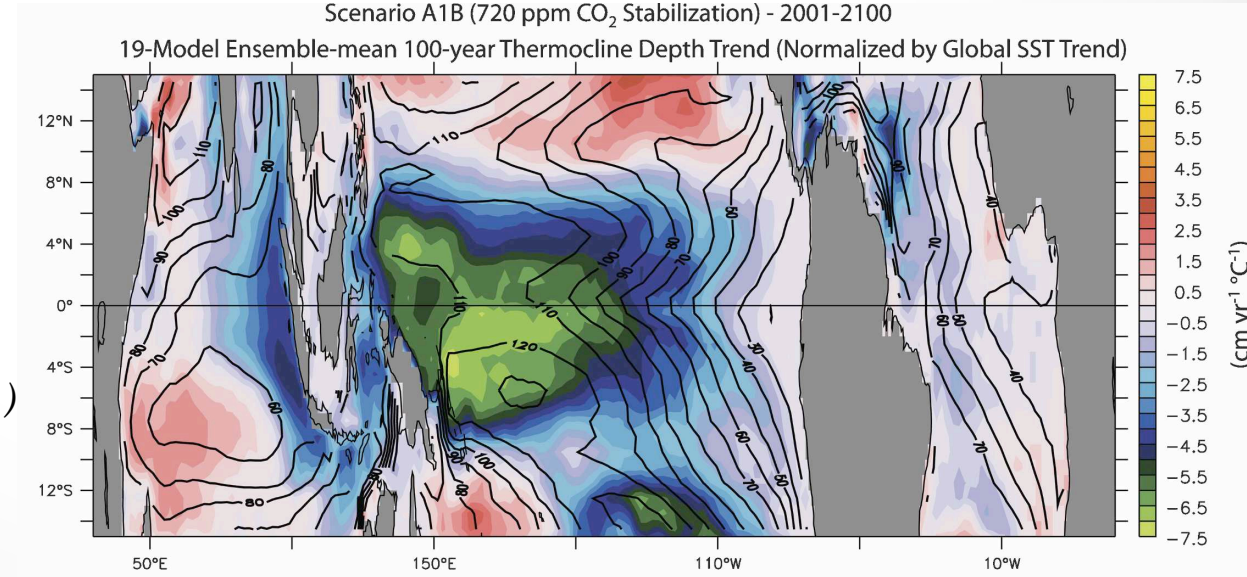


Thermodynamically-driven shoaling of mean mixed-layer

Lloyd (2011, PhD Thesis)

Changes in circulation can lead to local thermocline deepening

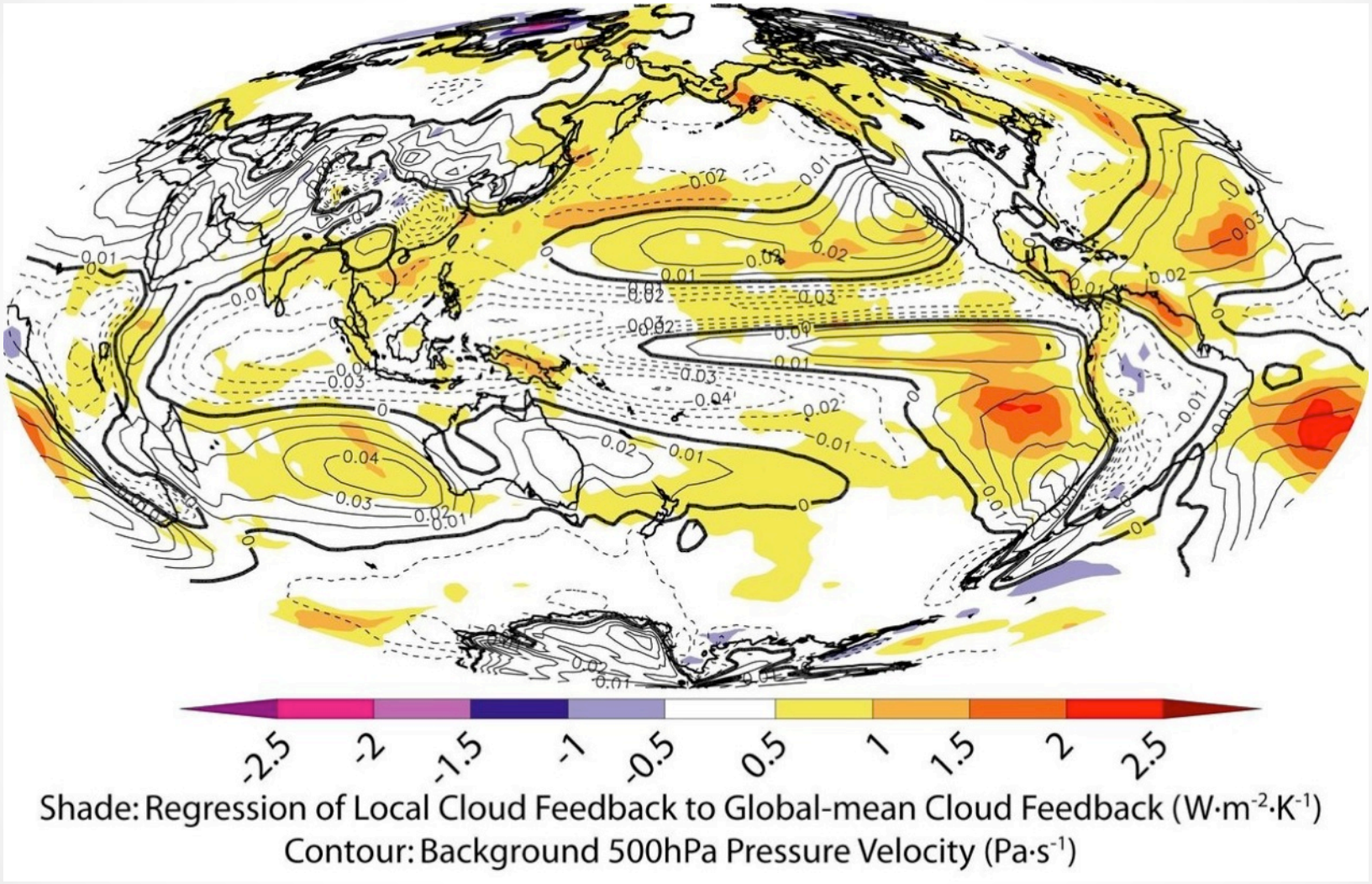
Vecchi and Soden (2007, J. Clim.)



Summary

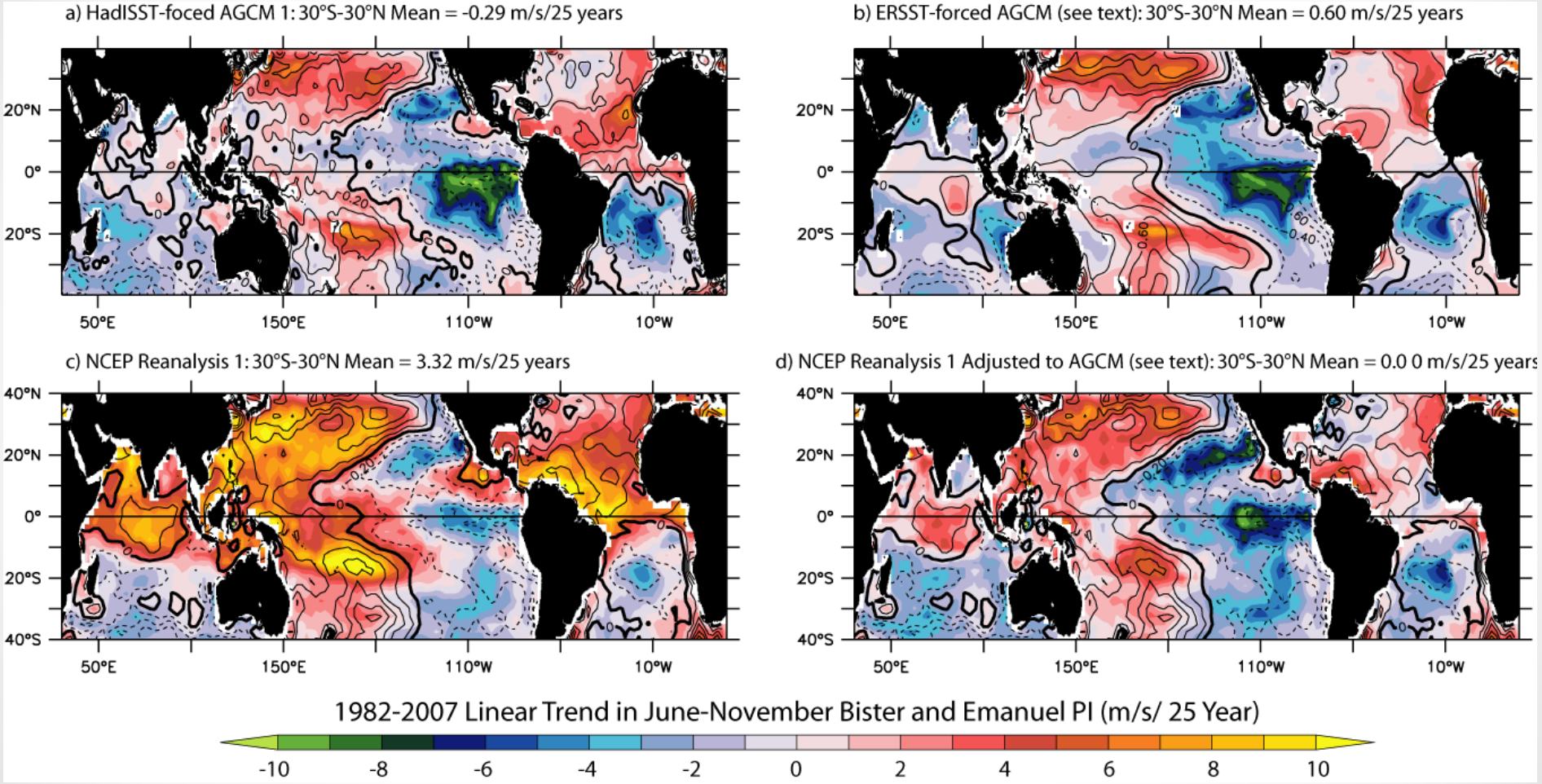
- For regional tropical precipitation and tropical cyclones the "patterns" of temperature change may be more relevant:
  - Patterns in space: SST change *relative* to tropical-mean key to tropical precip and cyclone response
  - Patterns in height/depth (atmospheric stability and ocean stratification changes)
  - Patterns in time (multi-year to decadal changes)
- The past character of "patterns" of change is less well known.
- The potential mechanisms impacting "patterns" more varied (redistribution, non-uniform radiative forcing, non-uniform response to uniform forcing, etc.

Regional changes important to global mean: Cloud Feedbacks

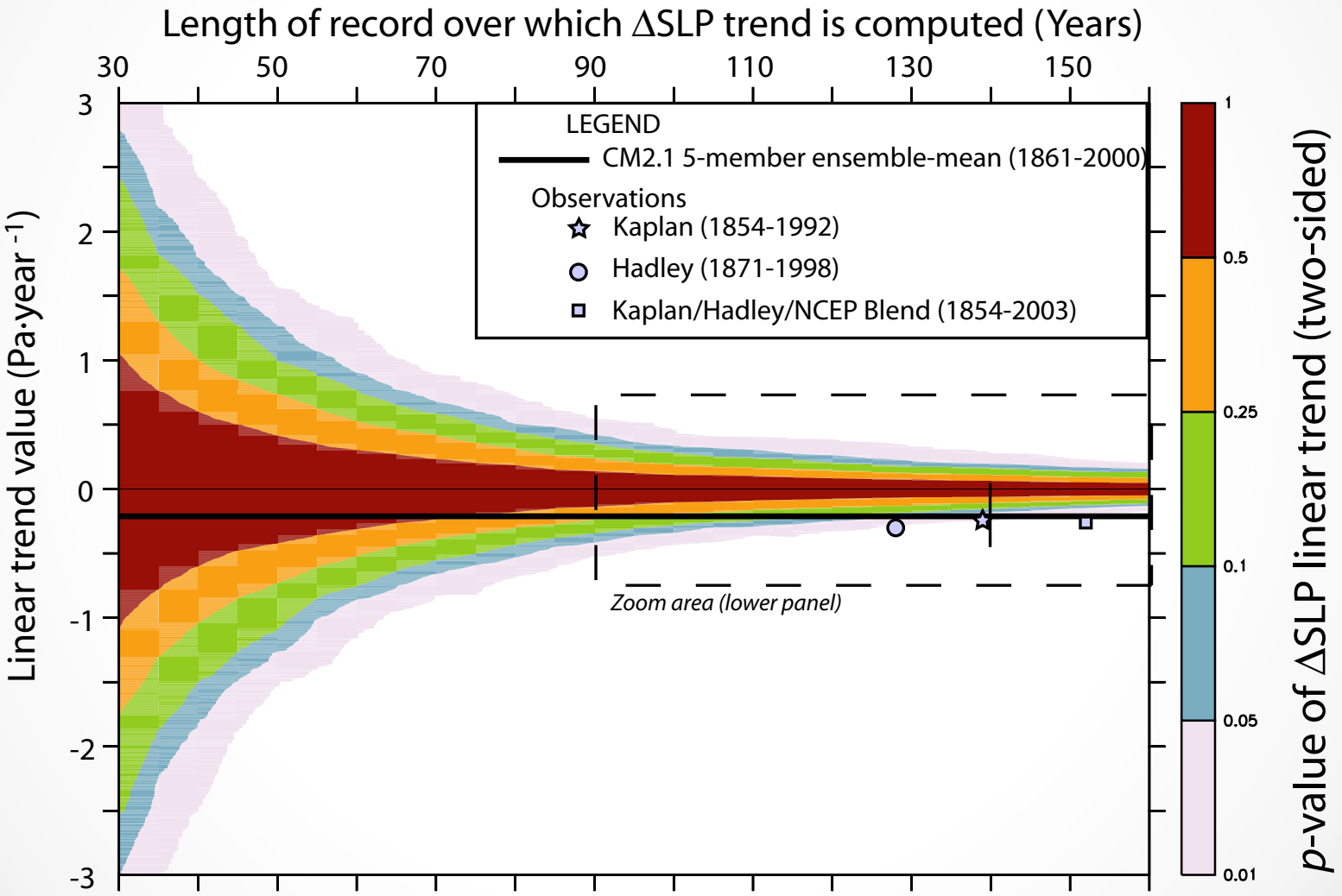


Soden and Vecchi (2011, GRL)

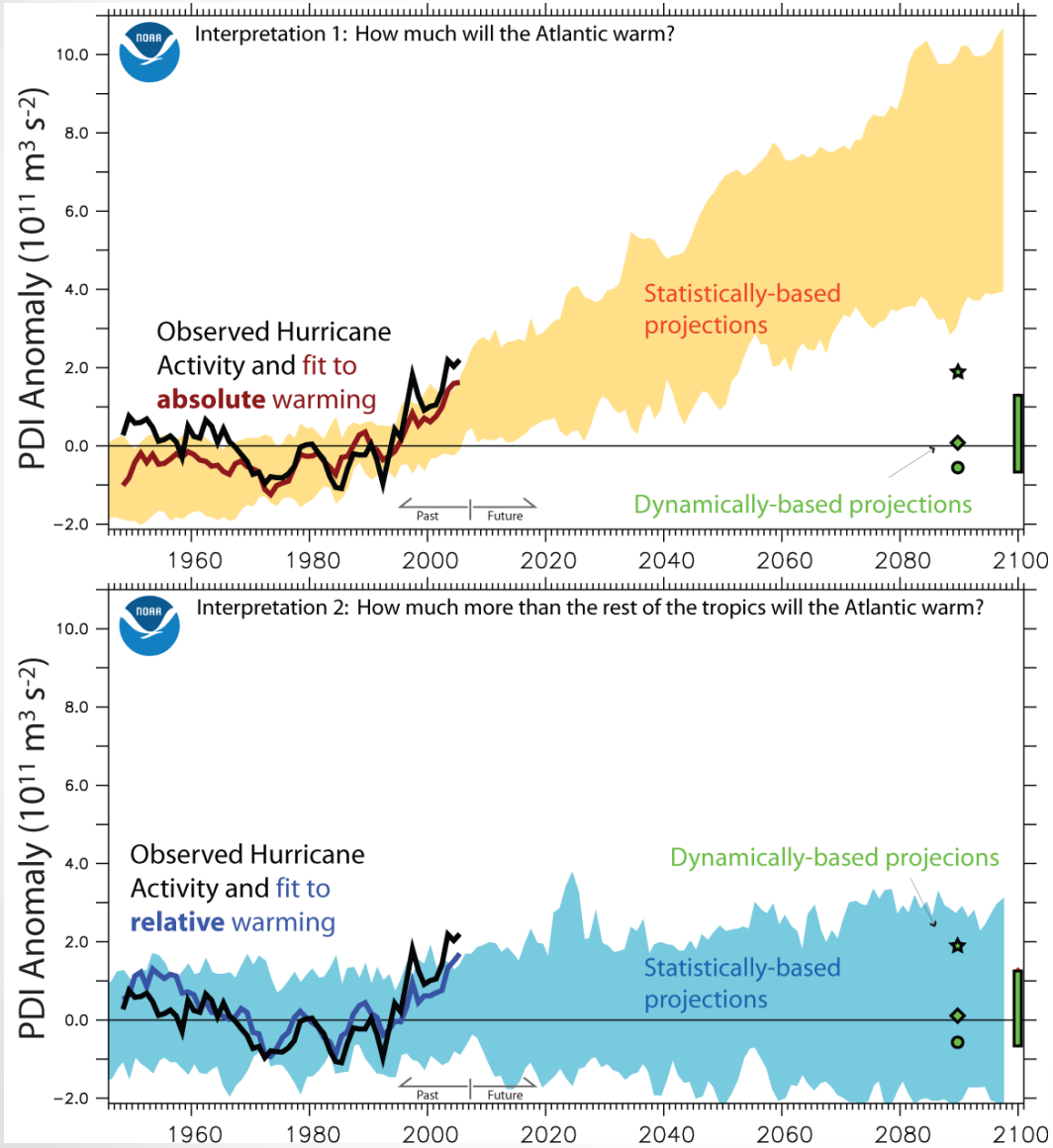
Differences in HiRAM/NCEP Tropical-mean lapse rate trends largely explain differences in 1982-2006 potential intensity trends



On multi-decadal and shorter timescales internal variability can dominate Walker Circulation changes



Both absolute an relative SST consistent with recent hurricane changes, only relative SST consistent with dynamical models (*e.g.*, Vecchi et al. 2008, Villarini et al. 2011) and homogenized century scale hurricane records (Villarini et al. 2010)



Observed Activity
Absolute Atlantic Temperature

Dynamical Model Projections

Observed Activity
Relative Atlantic Temperature

Vecchi, Swanson and Soden (2008, Science)