Simulation of Tropical Cyclones Over 1880-2007 Using a 100km Global Atmospheric General Circulation Model

Gabriel Vecchi, Ming Zhao, Isaac Held

NOAA/GFDL, Princeton, NJ

Objective:

Given published successes in dynamically modeling recent TC history & interest in longer term changes of TCs:

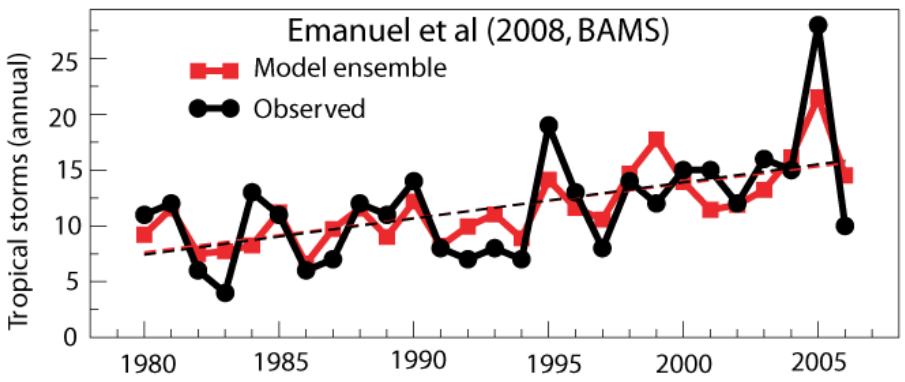
Can we use an SST-forced AGCM to recover century-scale changes in TCs?

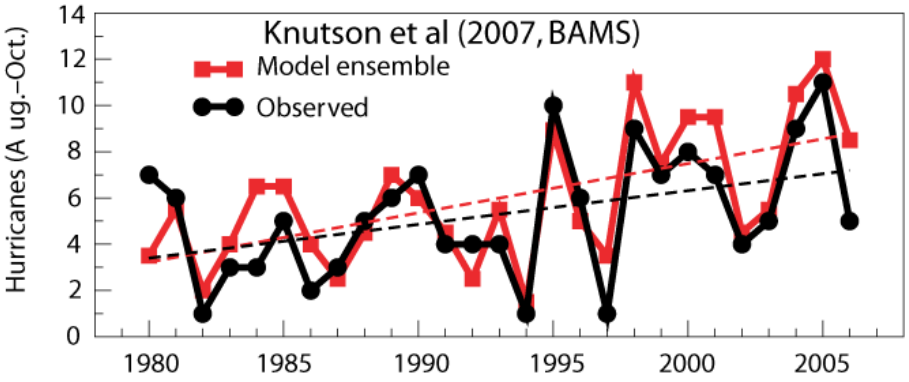
Or perhaps:

What are key factors limiting our ability to confidently use an SST-forced AGCM to recover century-scale changes in TCs?

Dynamical Models Exhibit Skill in Seasonal Basin-wide Hurricane Frequency

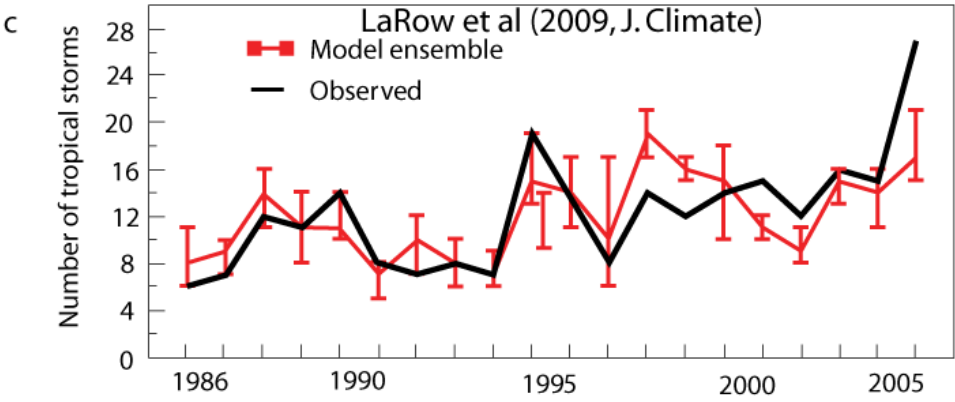
Statistical-dynamical hybrid model

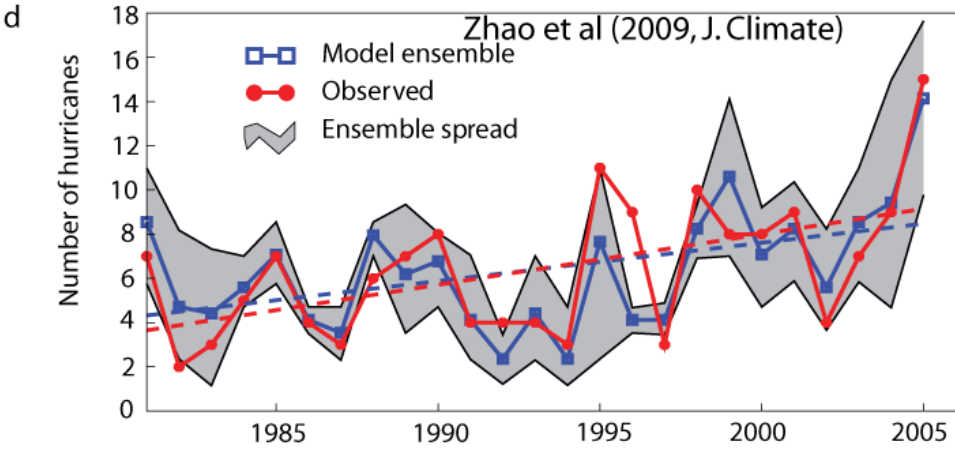




18-km regional model

100km SST-forced AGCM





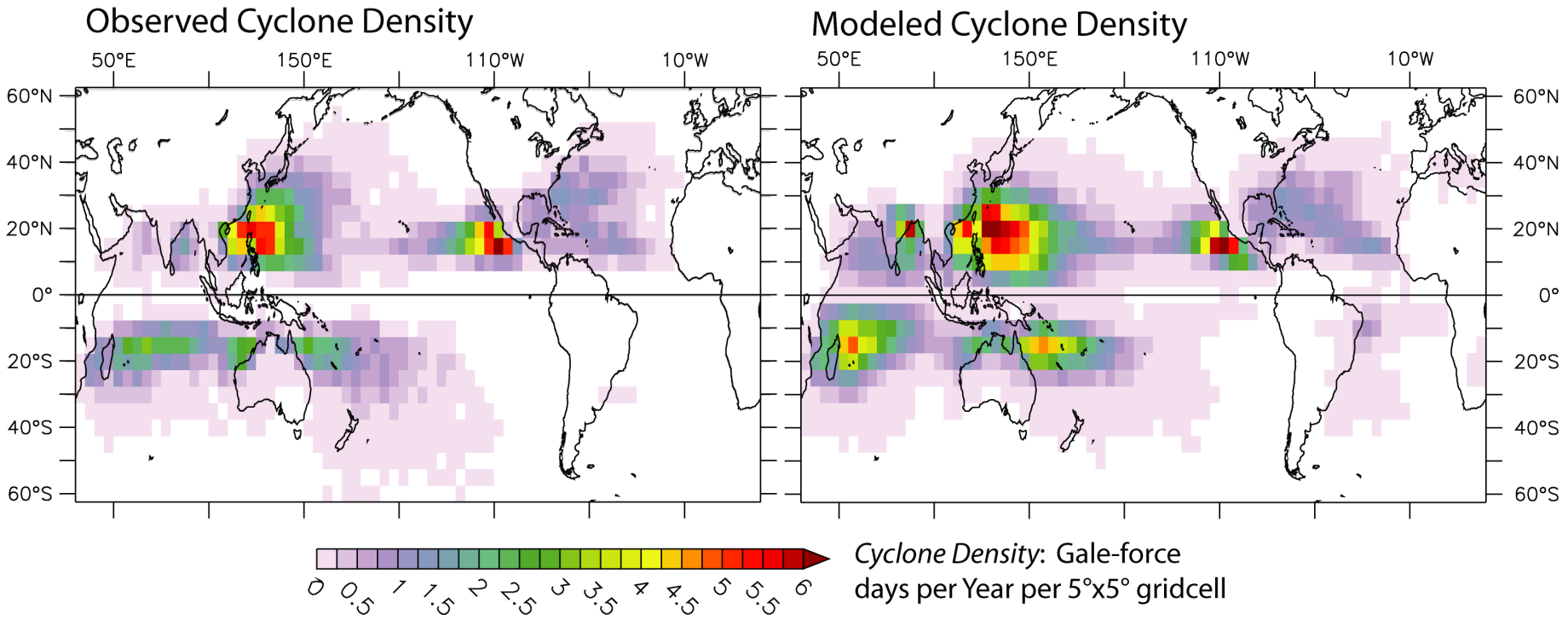
50km SST-forced AGCM

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

Methodology

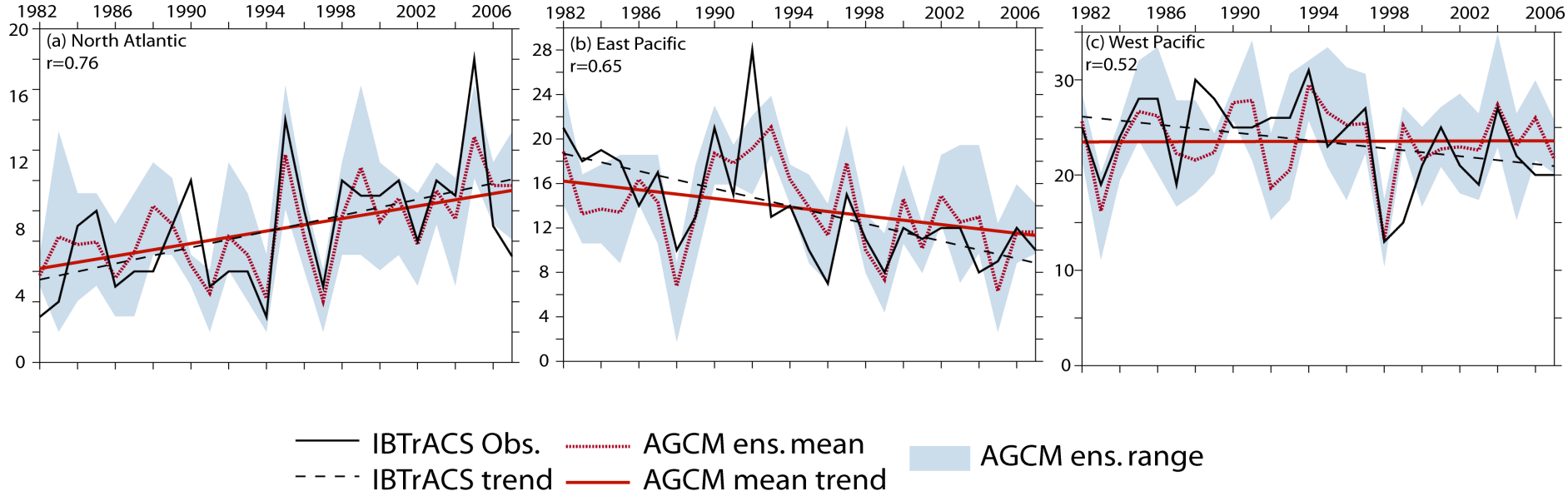
- Use 100km version of GFDL HiRAM
  - Zhao et al. (2009, 2010) use 50km version and recover many aspects of 1982-2008 TC frequency
- Force using SST, CO_2 and O_3
- Begin with 1982-2007 period, move to 1880-2007 integrations.
- Explore multiple SST reconstructions
- Compare to records of TCs lasting 2-days or longer (motivated by Landsea et al. 2010, Villarini et al. 2011.a)

100km Model Recovers General Global Climatological TC Distribution



Vecchi et al (2011, in prep)

When forced with HadISST, model recovers much of recent variability and trend

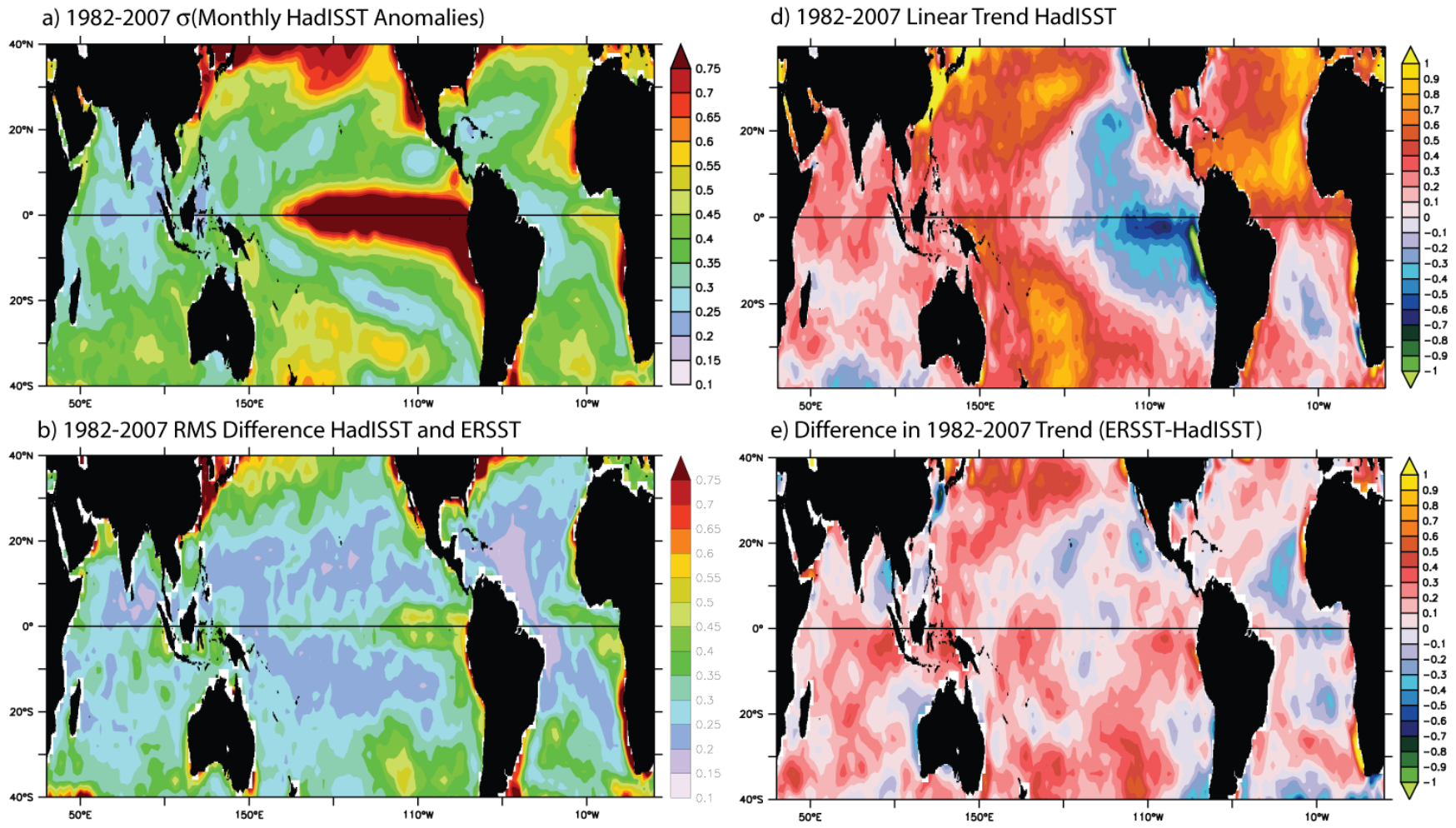


100km correlation & recent trend skill comparable to that of 50km model (Zhao et al. 2009, 2010)

Obs. consistent with inter- & intra-ensemble correlations; observations look like an additional ensemble member.

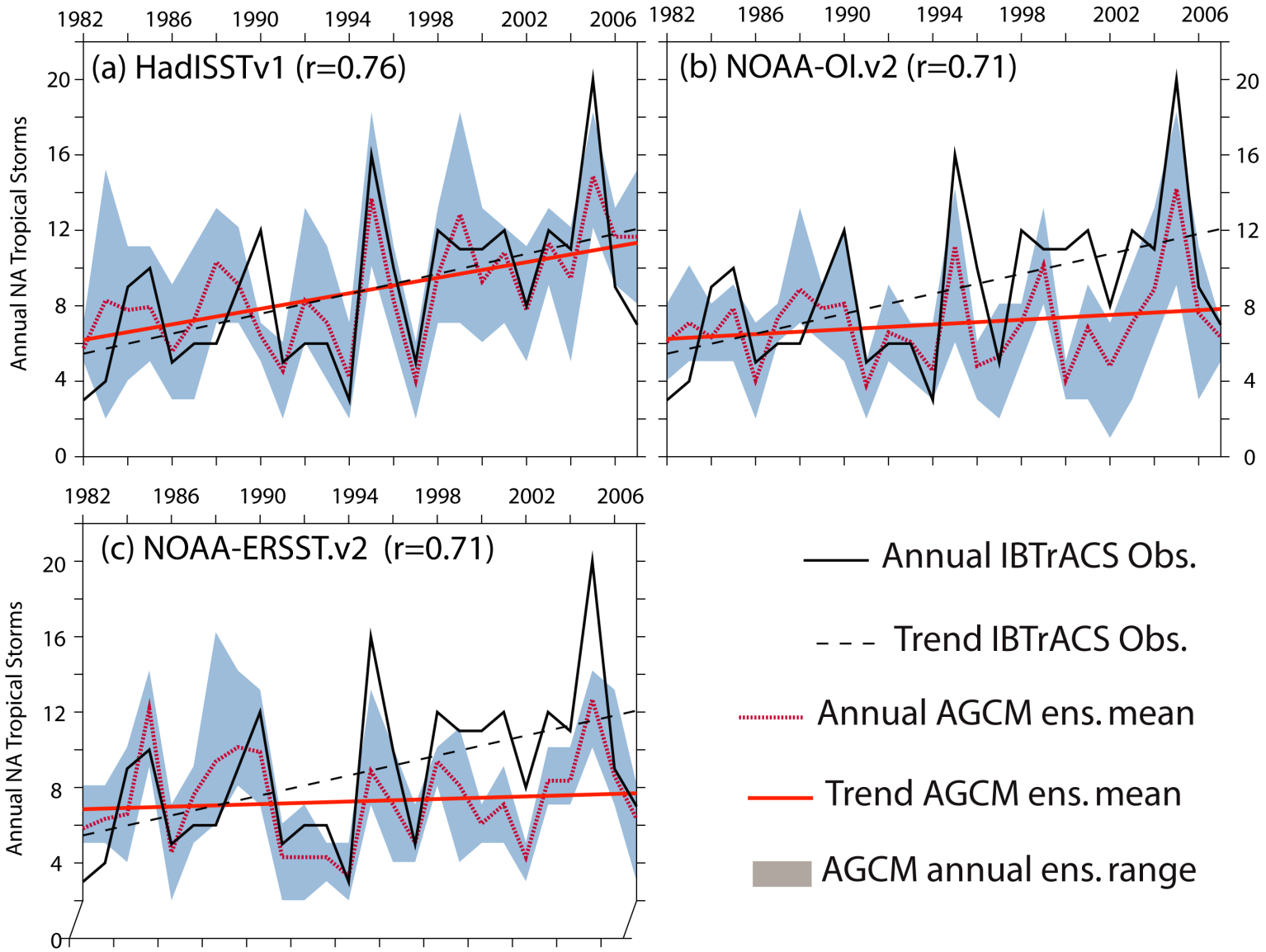
Vecchi et al (2011, in prep)

Over 1982-2007 (satellite SST era), SST reconstructions differ by tenths of °C



Vecchi et al (2011, in prep)

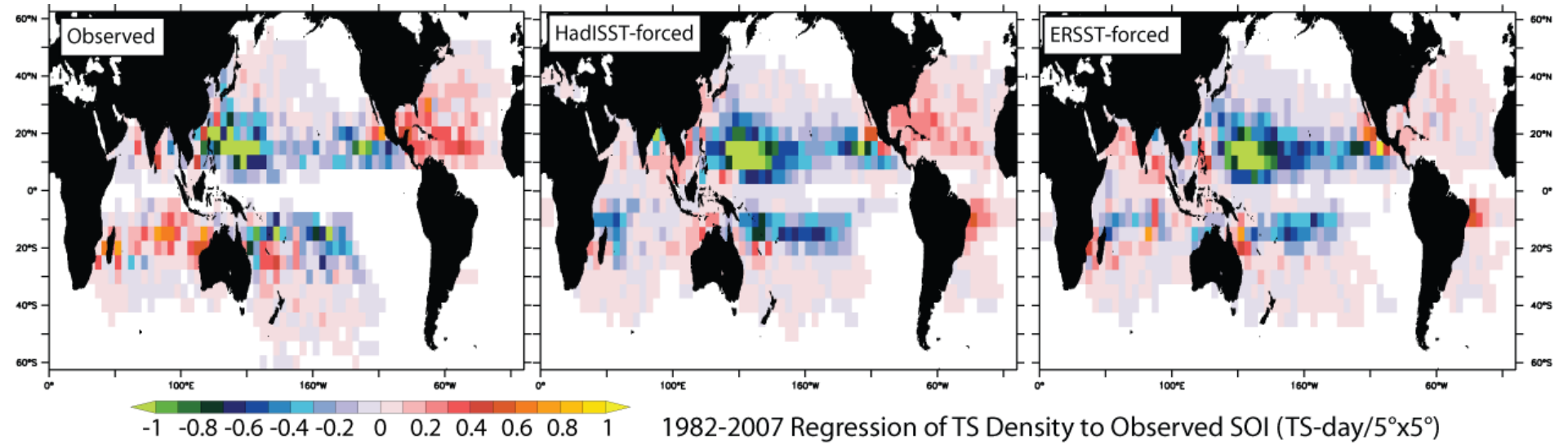
Recent Model NA Trend Extremely Sensitive to SST Used



Vecchi et al (2011, in prep)

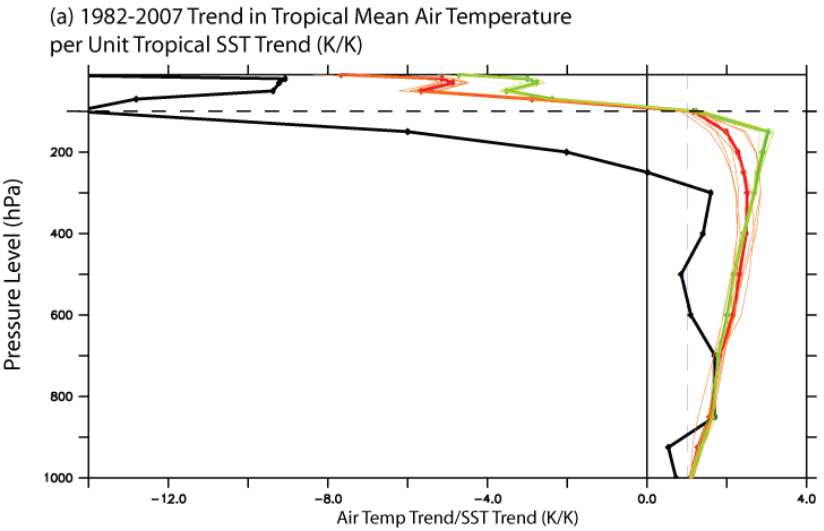
NA Regression to SOI Depends on SST Used.

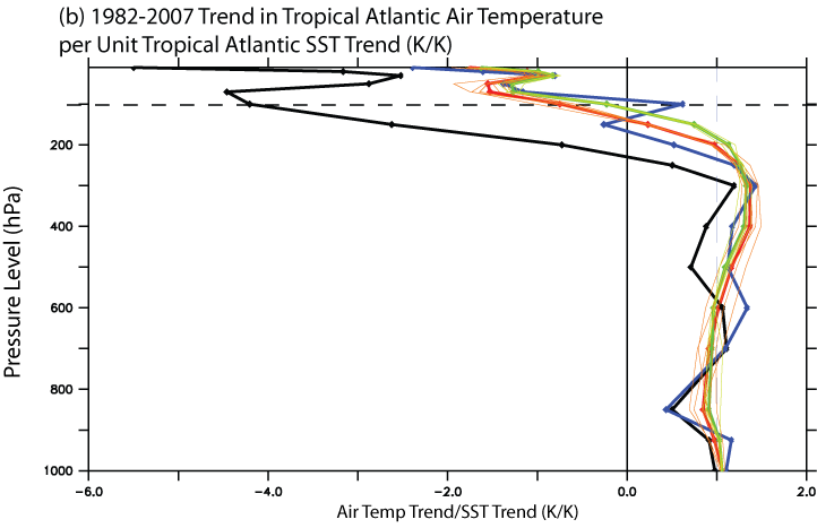
Interannual NA Frequency Correlation to Obs:
HadISST Forced: 0.76 ERSST Forced: 0.71

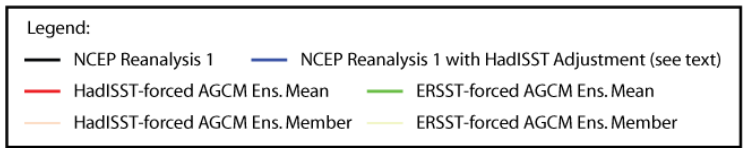


Vecchi et al (2011, in prep)

Should we have included volcanic aerosol forcing?



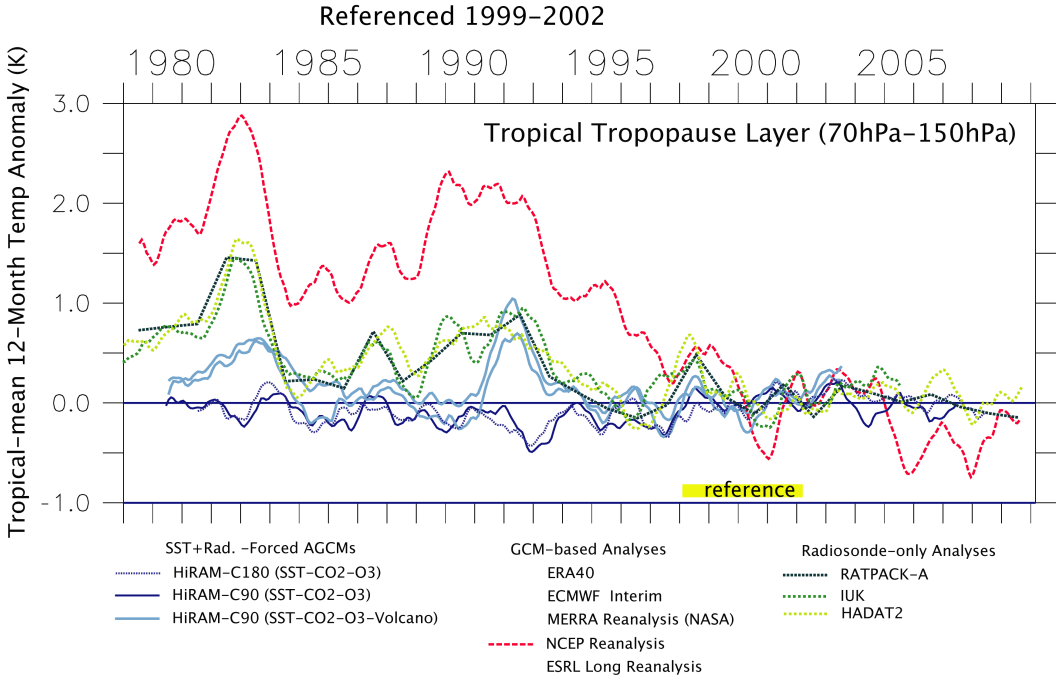




NCEP's cooling of upper trop. and TTL is influential in studies modeling NA TC Freq. (e.g., Emanuel et al. 2008, Knutson et al. 2008, Emanuel 2010, Garner et al. 2009)

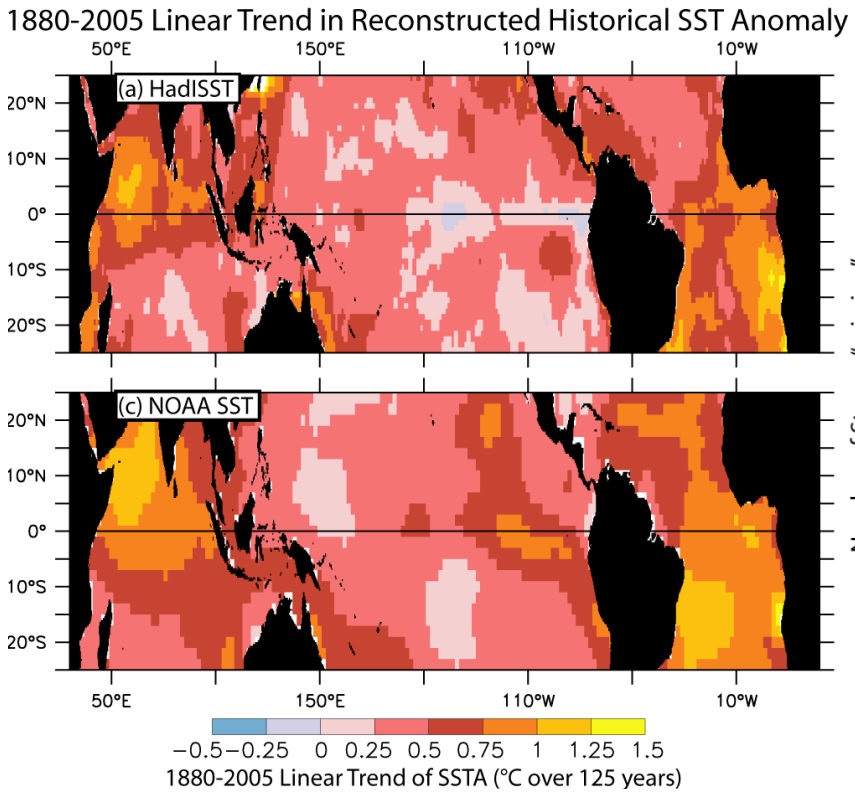
MY OPINION: NCEP trend likely spurious.

However, model recent TTL trend agrees with radiosondes better if include volcanoes.

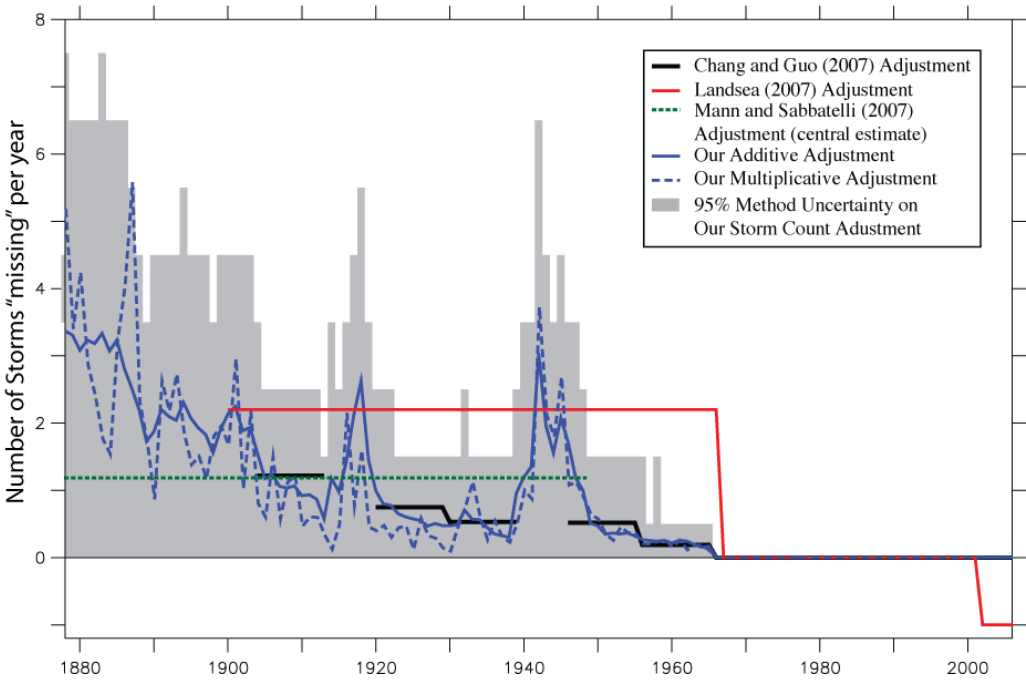


Cautiously proceed to century-scale runs

- SST known less well before 1982 – already an issue post-1982
- Observed storm frequency known much less well before 1970s or 1960s (depending on basin)
- We had already done integrations w/o volcanic aerosols – these computers don't exist anymore
- What other issues will creep up?



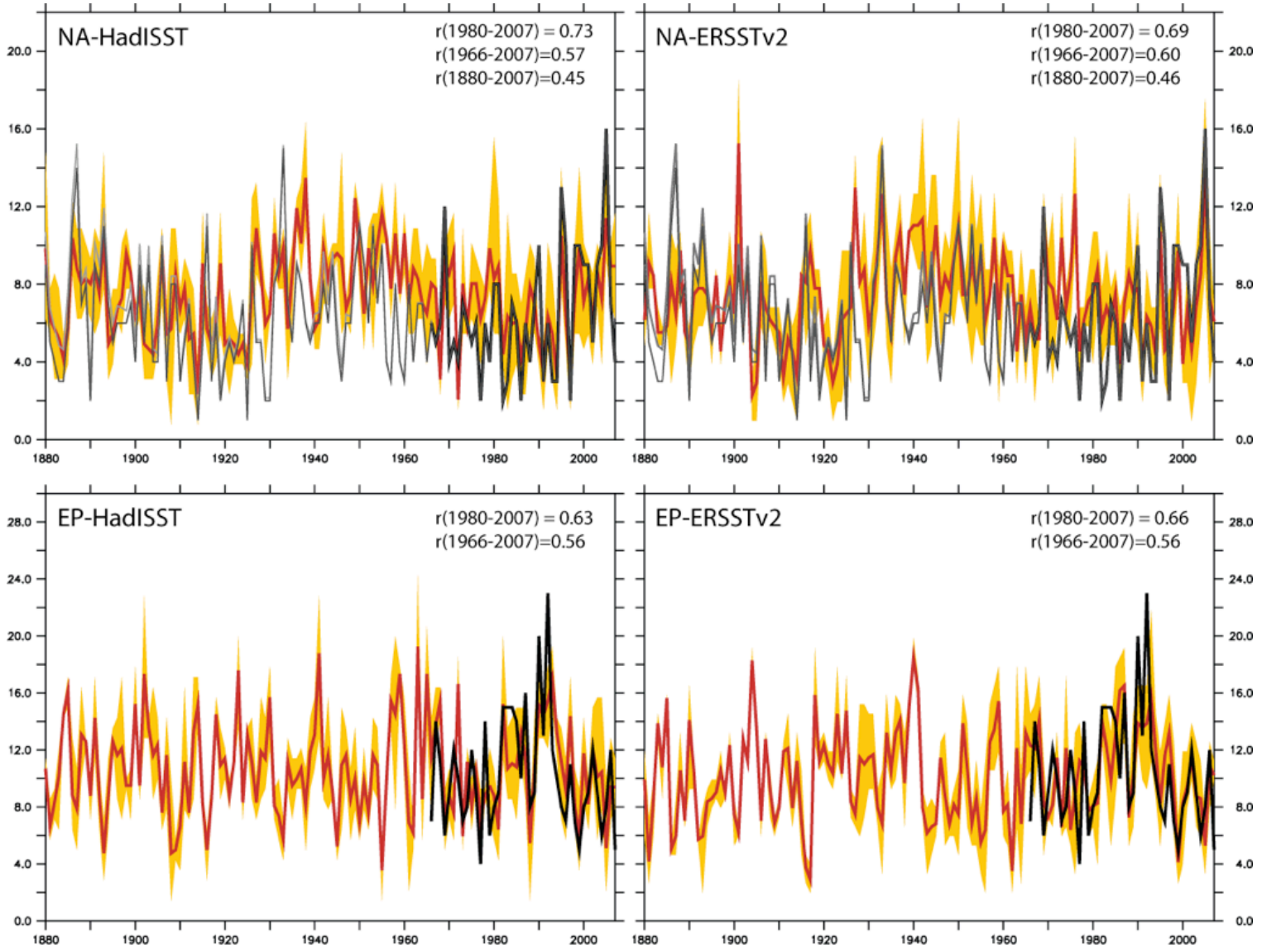
Vecchi and Soden (2007)



Vecchi and Knutson(2008)

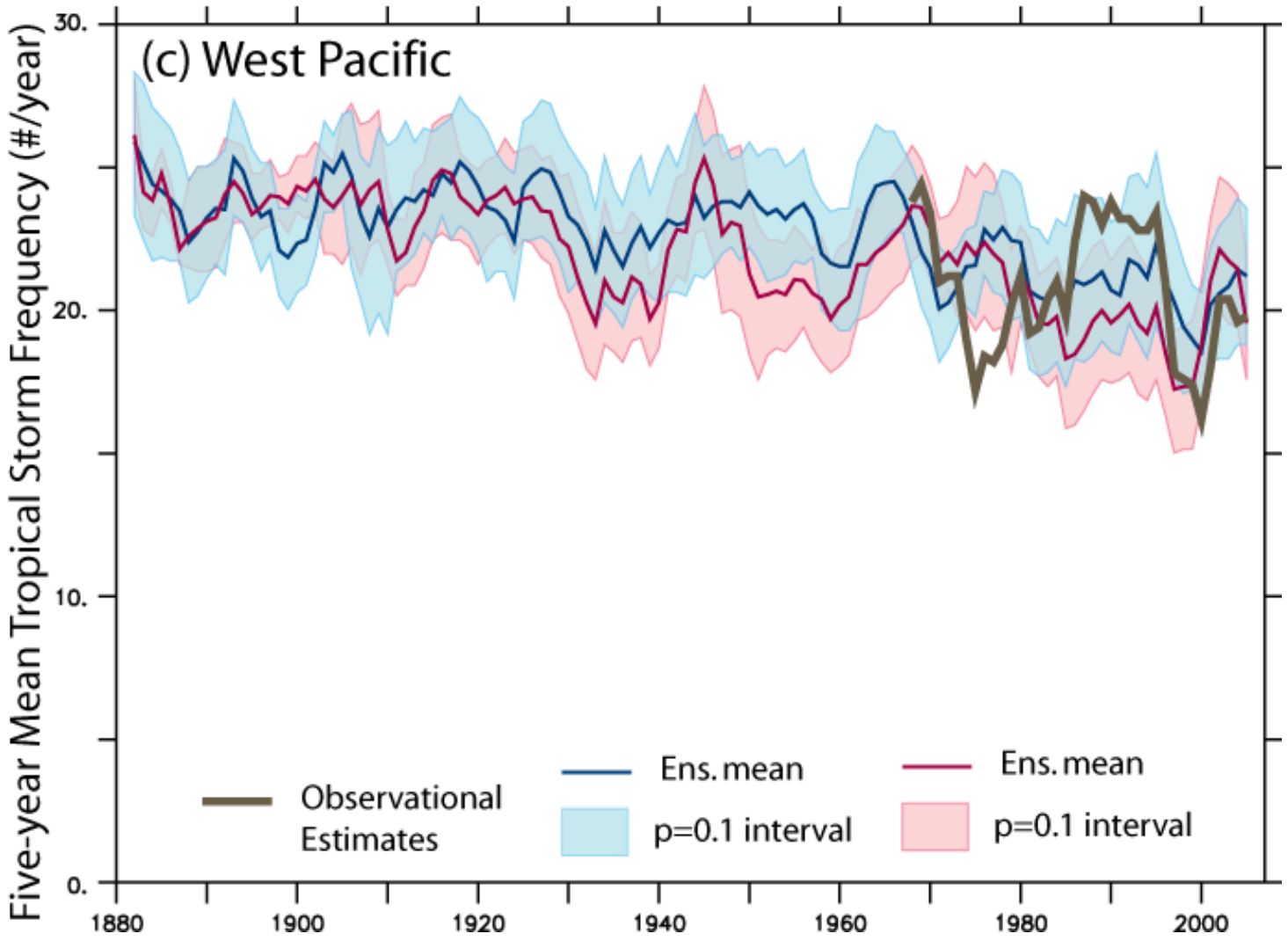
Century-Scale SST-Forced AGCM Hindcasts Appear to Exhibit Some Skill

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



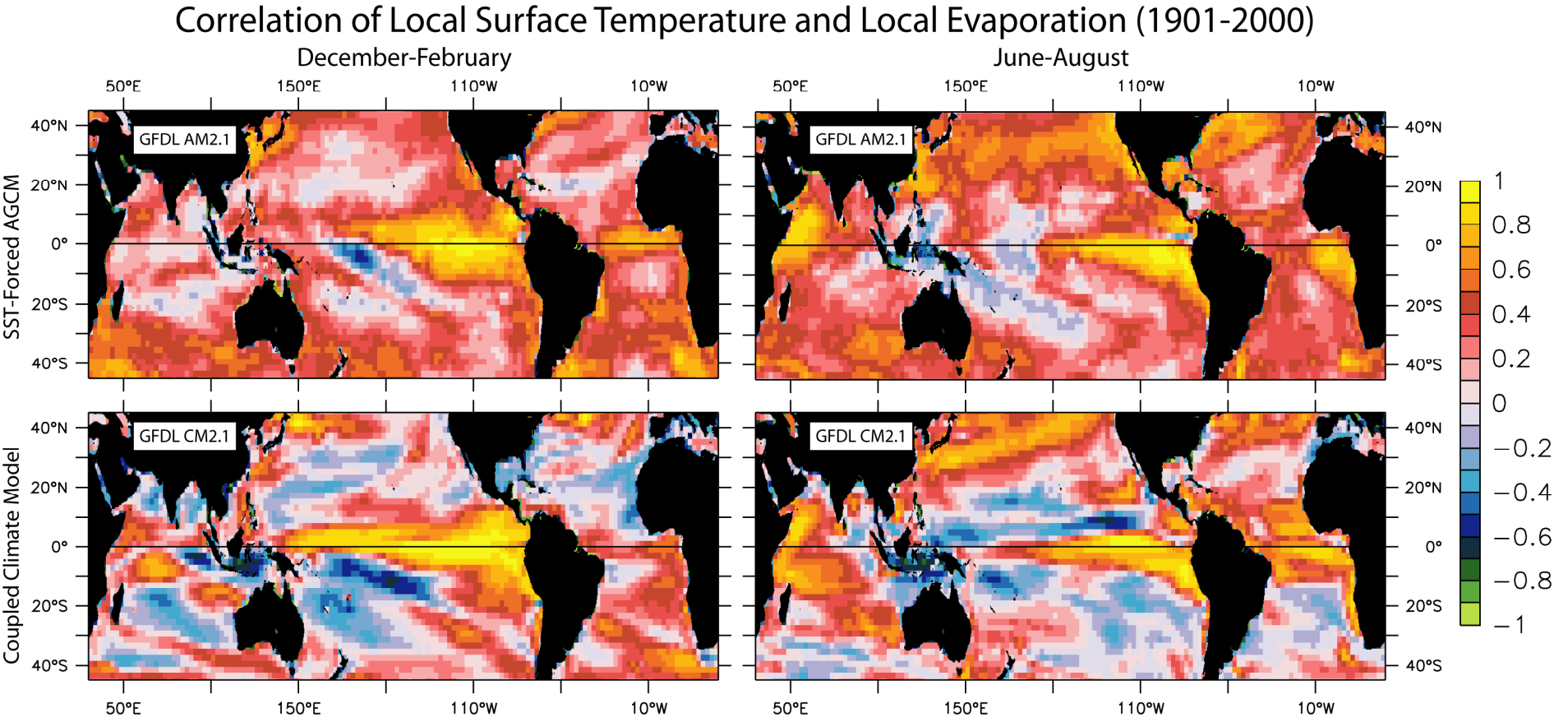
Vecchi et al (2011, in prep.)

AGCM Indicates Long-term Decrease in W. Pacific



Vecchi et al (2011, in prep.)

Model SST-Evaporation Correlation

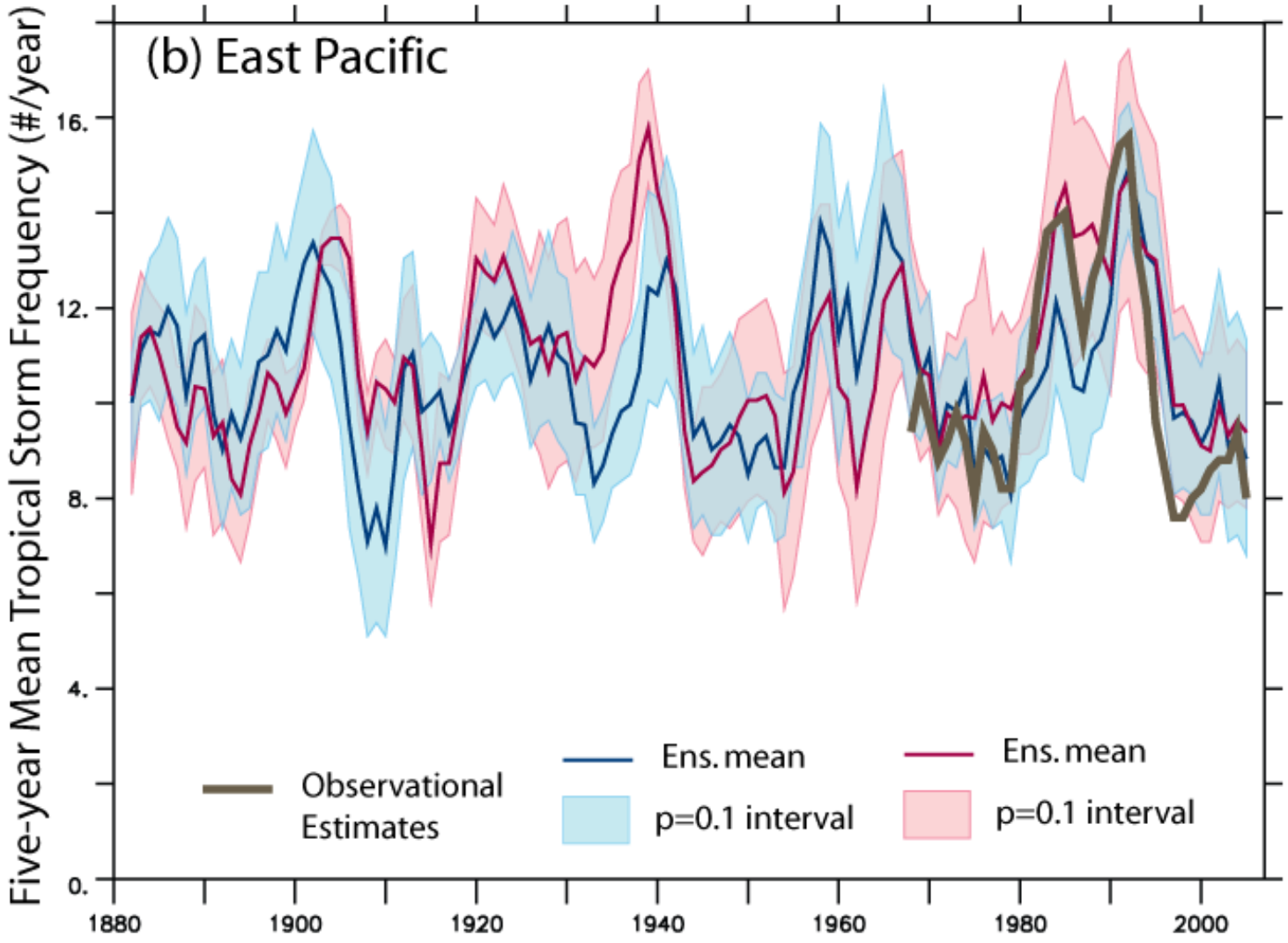


Cautious about over-interpreting modeled TC decrease in West Pacific, since AGCMs can show an incorrect relationship between SST and evaporation (and precip.) over Warm Pool (and elsewhere).

Kirtman and Vecchi (2011)

AGCM Indicates Substantial Decadal Variability in E. Pacific

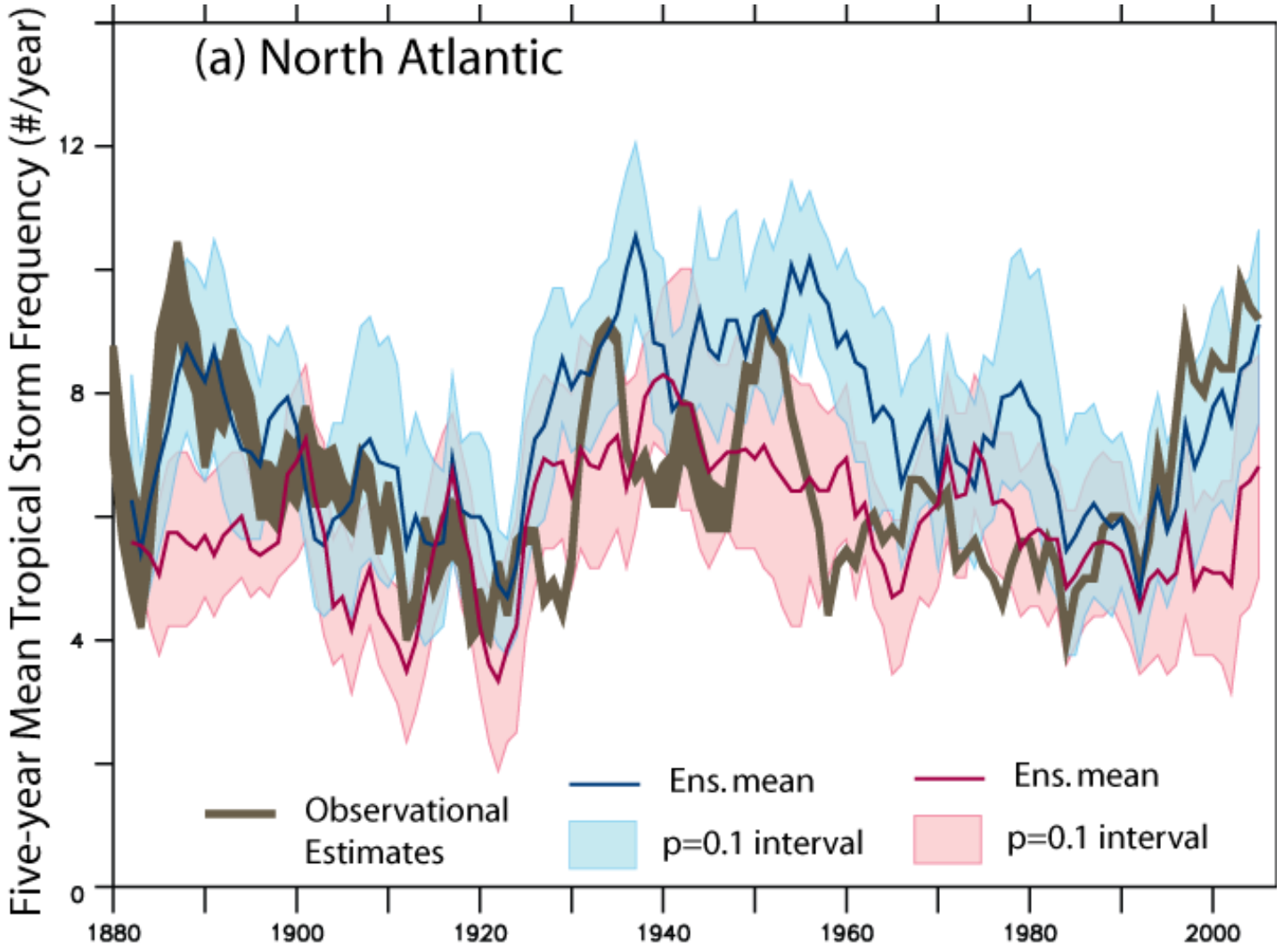
Recent decadal anti-correlation in EP & NA, but model does not show it long-term.



Vecchi et al (2011, in prep.)

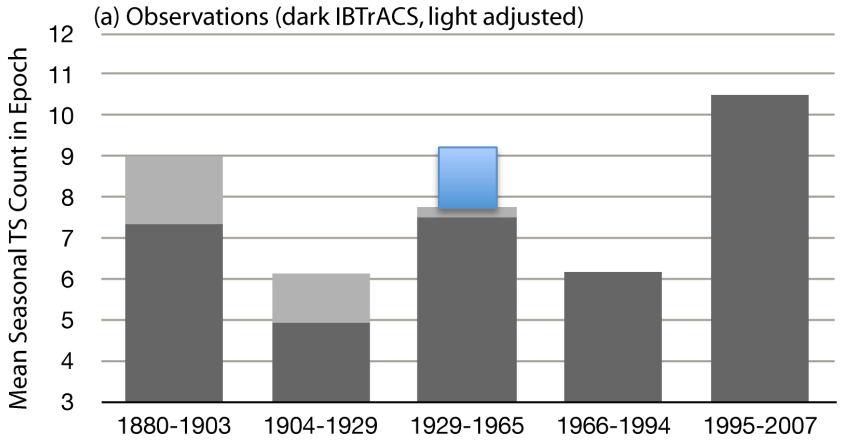
AGCM Indicates Substantial Multi-Decadal Variability in NA

Very sensitive to SST product. Does it agree with obs?

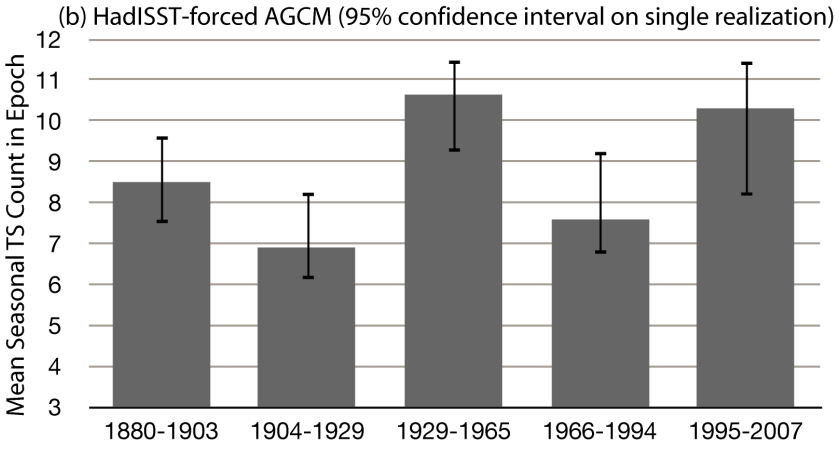


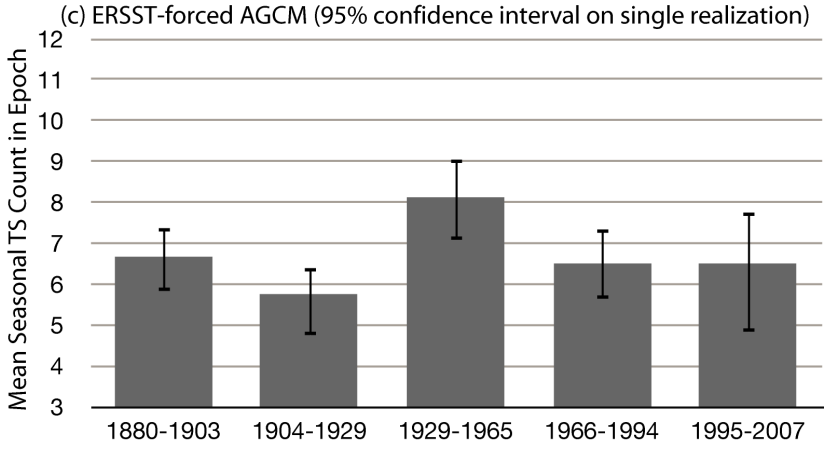
Vecchi et al (2011, in prep.)

ERSST-forced run fails to capture even basic character of past NA multi-decadal variability



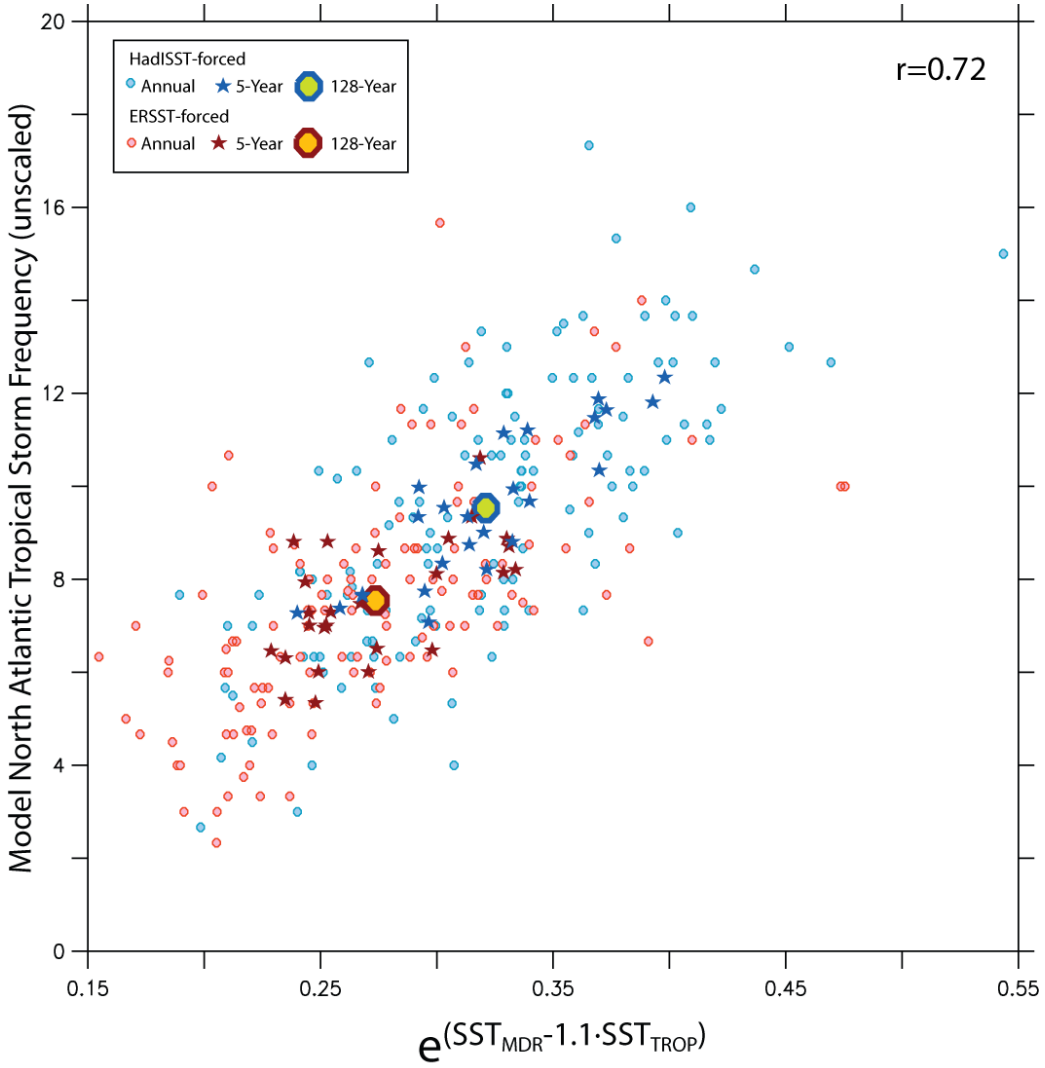
Possible number of new storms from HURDAT reanalysis (Hagen 2010)





Vecchi et al (2011, in prep.)

Differences between ERSST- and HadISST-forced runs consistent with model sensitivity and observed statistical relation to “relative MDR SST”.



Statistical model for Obs. TS frequency
Villarini et al (2010)

This statistical relationship also explains much of the inter-study spread in projections of NA 21st Century TS frequency (Villarini et al. 2011.b)

Summary

- 100km SST-forced AGCM can recover similar TS frequency (not intensity) skill as 50km version: climate controls on TS freq. at large (100s of km) scales?
- NA interannual correlation not strongly affected by inability to correctly capture trend, multi-decadal variability or aspects of ENSO response.
- Poor & Absent long-term TS records limit confidence in skill evaluation.
- Recent NA trend and century-length multi-decadal variability from SST-forced AGCM strongly sensitive to SST product used:
  - Consistent with model sensitivity and observed statistical relationship to patterns of SST.
  - Product of SST forcing? Use (semi-)coupled model?
  - Absence of relevant forcing (e.g., volcanoes)?
  - If 'correct' sensitivity: to predict "1995", need to predict SSTs better than we know them.
- AGCM show century-scale decrease in WP freq.
  - Consistent with 50km model sensitivity to CO2 directly and tropical warming.
  - How do we interpret given AGCM/warm pool issues?
- Model shows EP dominated by decadal variability, distinct from that in NA.

References

- Emanuel, K., R. Sundararajan and J. Williams, 2008: Hurricanes and global warming: results from downscaling ipcc ar4 simulations. Bull. Amer. Meteor. Soc., pp. 347–367.
- Emanuel, K., 2010: Tropical Cyclone Activity Downscaled from NOAA-CIRES Reanalysis, 1908-1958. J. Adv. Model. Earth Syst., 2, doi: 10.3894/JAMES.2010.2.1.
- Garner, S., I. Held, T. Knutson and J. Sirutis, 2009: The roles of wind shear and thermodynamic stability in past and projected changes of Atlantic tropical- cyclone activity. J. Climate.
- Hagen, A.B. (2010): A Reanalysis of the 1944-1953 Atlantic Hurricane Seasons- The First Decade of Aircraft Reconnaissance. M.Sc. Thesis, U. Miami, Miami, FL, 865pp.
- Kirtman, B. and G.A. Vecchi (2011): Why Climate Modelers Should Worry About Atmospheric and Oceanic Weather. In The Global Monsoon System: Research and Forecast, 2nd Edition. Chang, C.-P., Y. Ding, N.-C. Lau, R. H. Johnson, B. Wang, and T. Yasunari, Eds., World Scientific Series on Asia-Pacific Weather and Climate, Vol. 5, World Scientific Publication Company, 608 pp, pages 511-524.
- Knutson, T., J. Sirutis, S. Garner, I. Held and R. E. Tuleya, 2007: Simulation of the recent multidecadal increase of Atlantic hurricane activity using an 18-km-grid regional model. Bull. Amer. Meteor. Soc., pp. 1549–1565.
- Knutson, T.R., J.J. Sirutis, S.T. Garner, G.A. Vecchi and I.M. Held (2008): Simulated reduction in Atlantic hurricane frequency under twenty-first-century warming conditions, *Nature Geoscience*, doi:10.1038/ngeo202
- Knutson, Thomas R., J McBride, J Chan, K A Emanuel, G Holland, C Landsea, Isaac Held, J Kossin, A K Srivastava, and M Sugi (2010): Tropical cyclones and climate change. Nature Geoscience, 3, doi:doi:10.1038/ngeo779.
- Landsea, C.W., G.A. Vecchi, L. Bengtsson, and T.R. Knutson (2009): Impact of Duration Thresholds on Atlantic Tropical Cyclone Counts. *J. Climate* doi: 10.1175/2009JCLI3034.1
- LaRow, T., Y.-K. Lim, D. Shin, E. Chassignet and S. Cocke, 2008: Atlantic basin seasonal hurricane simulations. J. Climate, 21, 3191–3206.
- Rayner, R., D. Parker, E. Horton, C. Folland, L. Alexander and D. Rowel, 2003: Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century. J. Geophys. Res., 108, D14,4407,doi:10.1029/2002JD002670.
- Reynods, R., N. Rayner, T. Smith, D. Stokes and W. Wang, 2002: An improved in situ and satellite SST analysis for climate. J. Climate, 15, 1609–1625.
- Vecchi, G.A., and B.J. Soden (2007): Global Warming and the Weakening of the Tropical Circulation. *J. Climate*, v20(17), 4316-4340.
- Vecchi, G.A., M. Zhao, and I.M. Held (2011): Simulation of Tropical Cyclones Over the 1880-2007 Period Using a 100km Global Atmospheric General Circulation Model. *J. Climate (in preparation).*
- Vecchi, G.A., and T.R. Knutson (2008): On Estimates of Historical North Atlantic Topical Cyclone Activity. *J. Climate*, 21(14),3580-3600. Website with data access
- Villarini, G., G.A. Vecchi and J.A. Smith (2010): Modeling of the Dependence of Tropical Storm Counts in the North Atlantic Basin on Climate Indices. *Mon. Wea. Rev., 138(7), 2681-2705,* doi:10.1175/2010MWR3315.1
- Villarini, G., G.A. Vecchi, T.R. Knutson and J. A. Smith (2011.a): Is the Recorded Increase in Short Duration North Atlantic Tropical Storms Spurious? *J .Geophys. Res. (in press).*
- Villarini, G., G.A. Vecchi, T.R. Knutson, M. Zhao and J.A. Smith (2011.b): North Atlantic Tropical Storm Frequency Response to Anthropogenic Forcing: Projections and Sources of Uncertainty. *J. Climate (in press)*.
- Zhao, M., I.M. Held, S.-J. Lin, and G.A. Vecchi (2009): Simulations of global hurricane climatology, interannual variability, and response to global warming using a 50km resolution GCM. *J. Climate*, 22(24), 6653-6678, doi:10.1175/2009JCLI3049.1
- Zhao, M., I.M. Held and G.A. Vecchi (2010): Retrospective forecasts of the hurricane season using a global atmospheric model assuming persistence of SST anomalies. *Mon. Wea. Rev.,* doi: 10.1175/2010MWR3366.1.