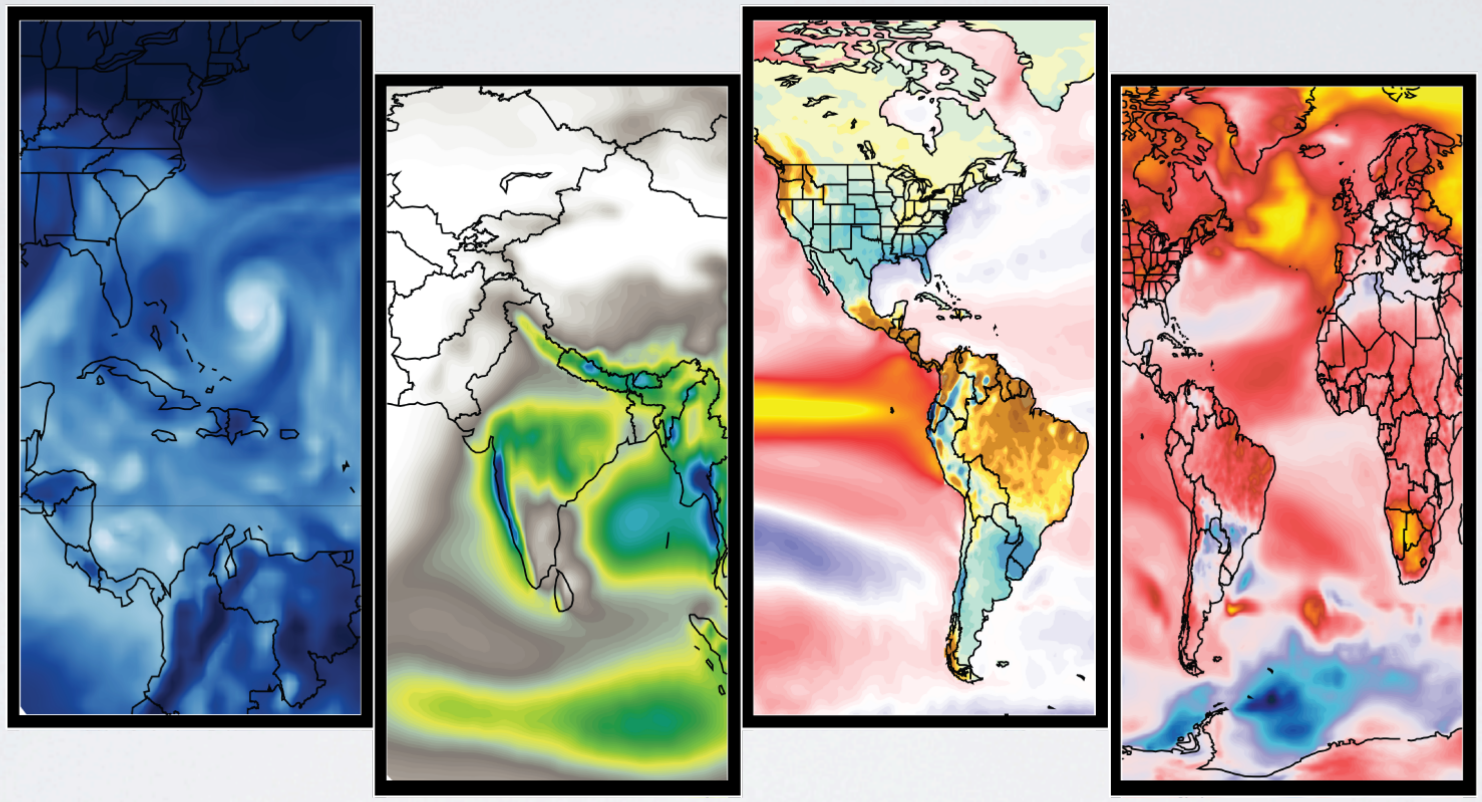
Towards a unified system for understanding, predicting and projecting regional hurricane activity

NOAA/GFDL Climate Variations and Predictability Group



Hypothesis: Enhanced resolution & corrected large-scale climate improve simulation and prediction of regional climate & extremes.

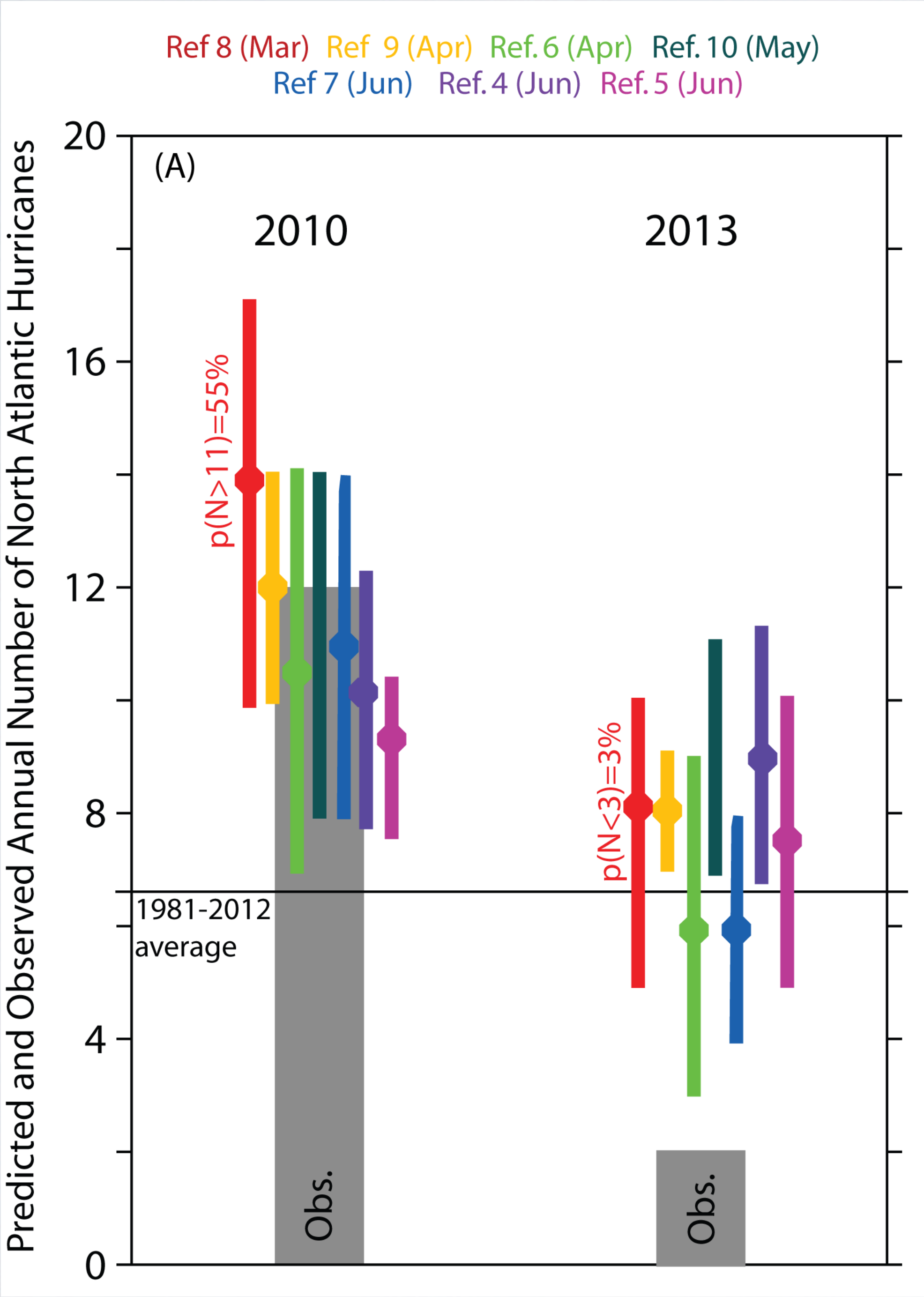
Practical Goal: Build a seasonal to multi-decadal forecasting system to:

- Yield improved forecasts of large-scale climate
- Enable forecasts of regional climate and extremes

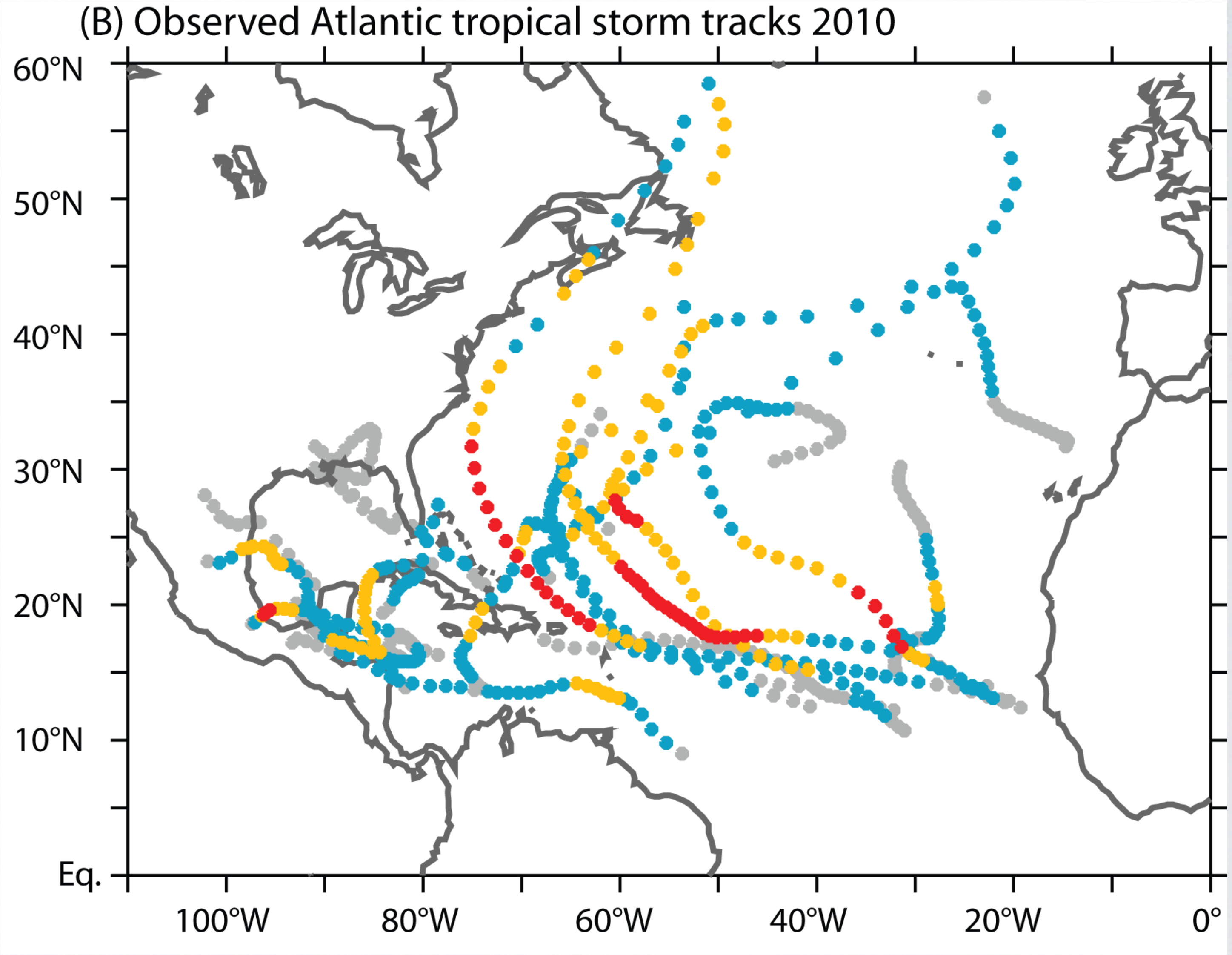
Outline

- Motivation
- Development of prediction model:
  focus on high atmospheric/land resolution
- Seasonal tropical cyclone prediction
- Response of tropical cyclone to radiative forcing
- Next stages

Correct predictions of basin-wide active 2010 but not of U.S. landfall absence

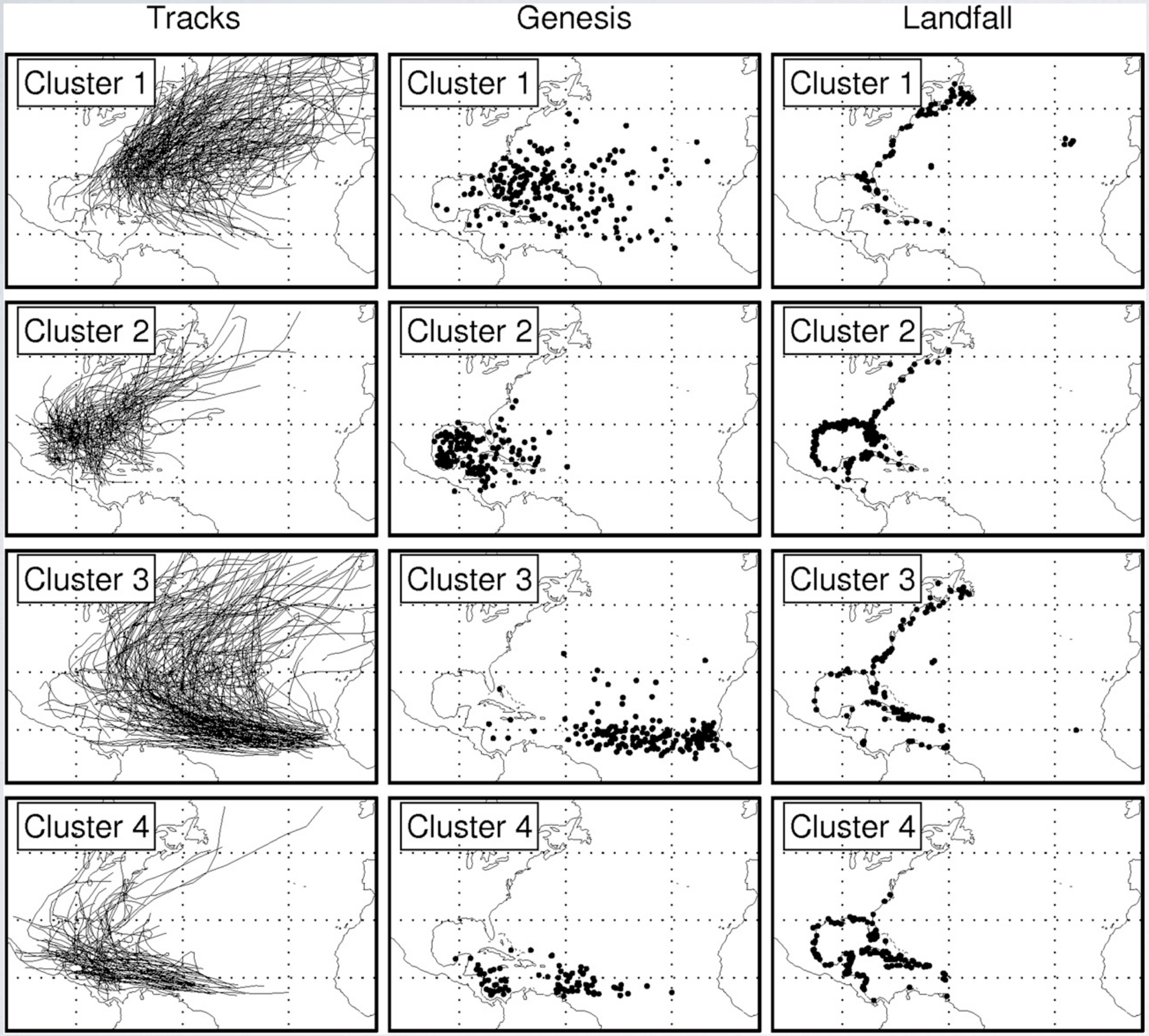


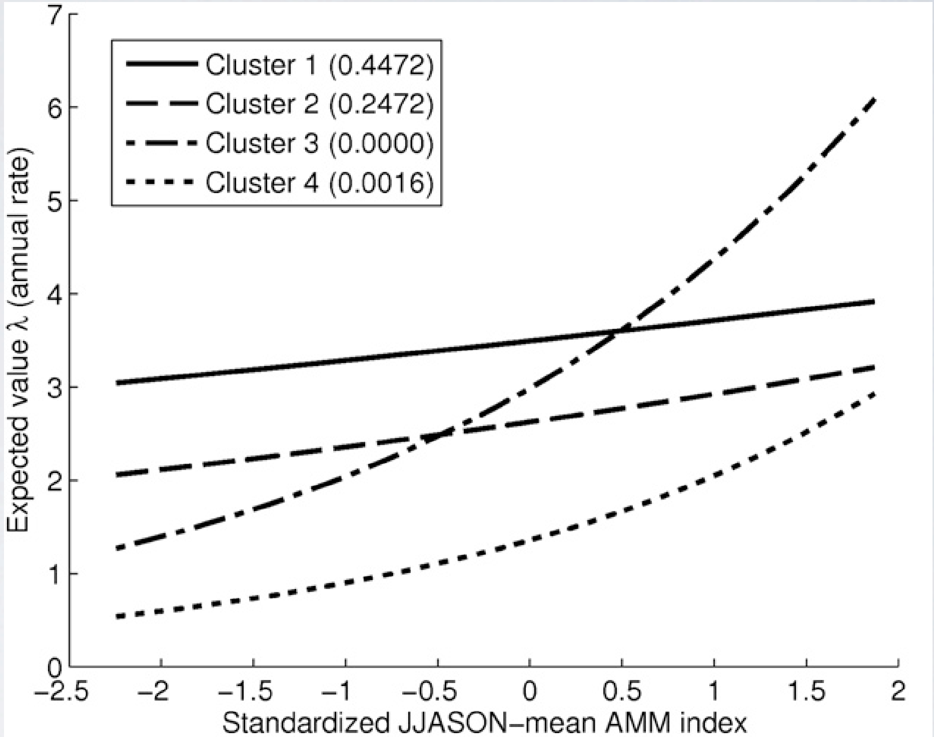
Can we reliably predict statistics of storms more regionally than "basin-wide"?

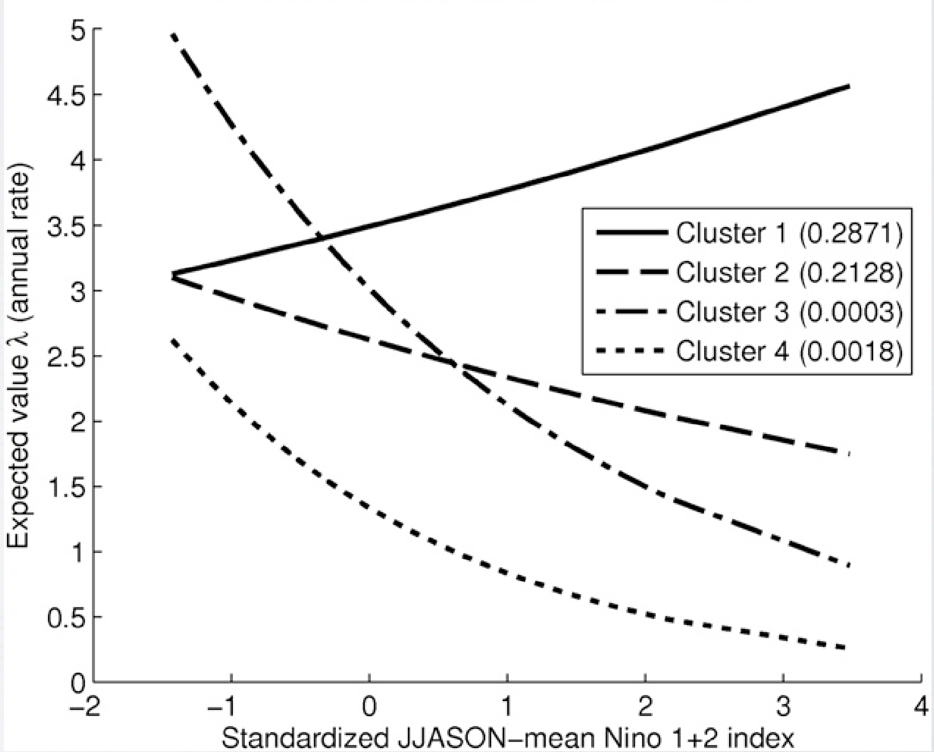


Vecchi and Villarini (2014)

Different "types" of Atlantic storms exhibit different relation to large-scale variations







Kossin, Camargo and Sitkowski (2010)

GFDL FLOR: Experimental high-resolution coupled seasonal to decadal prediction system

Goal: Build a seasonal to decadal forecasting system to:

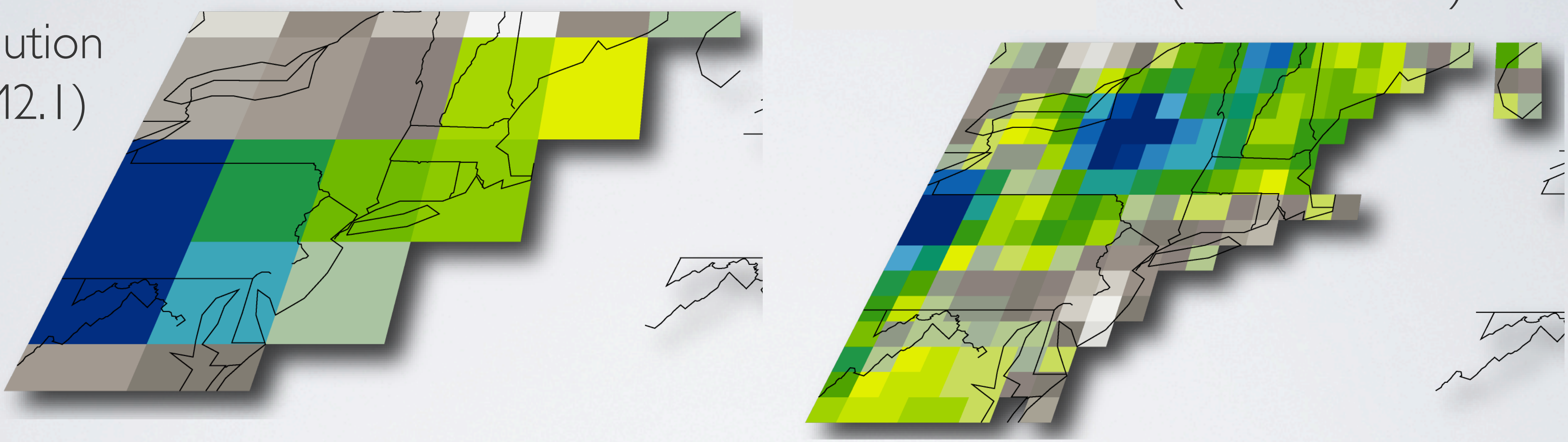
Yield improved forecasts of large-scale climate

Enable forecasts of regional climate and extremes

Precipitation in Northeast USA

Medium resolution (CM2.1)

High resolution (CM2.5-FLOR)



Delworth et al. (2012), Vecchi et al. (2014)

Modified version of CM2.5 (Delworth et al. 2012):

- 50km cubed-sphere atmosphere
- 1° ocean/sea ice (low res enables prediction work)

~15-18 years per day. Multi-century integrations. 15,000+ model-years of experimental seasonal predictions completed and being analyzed.

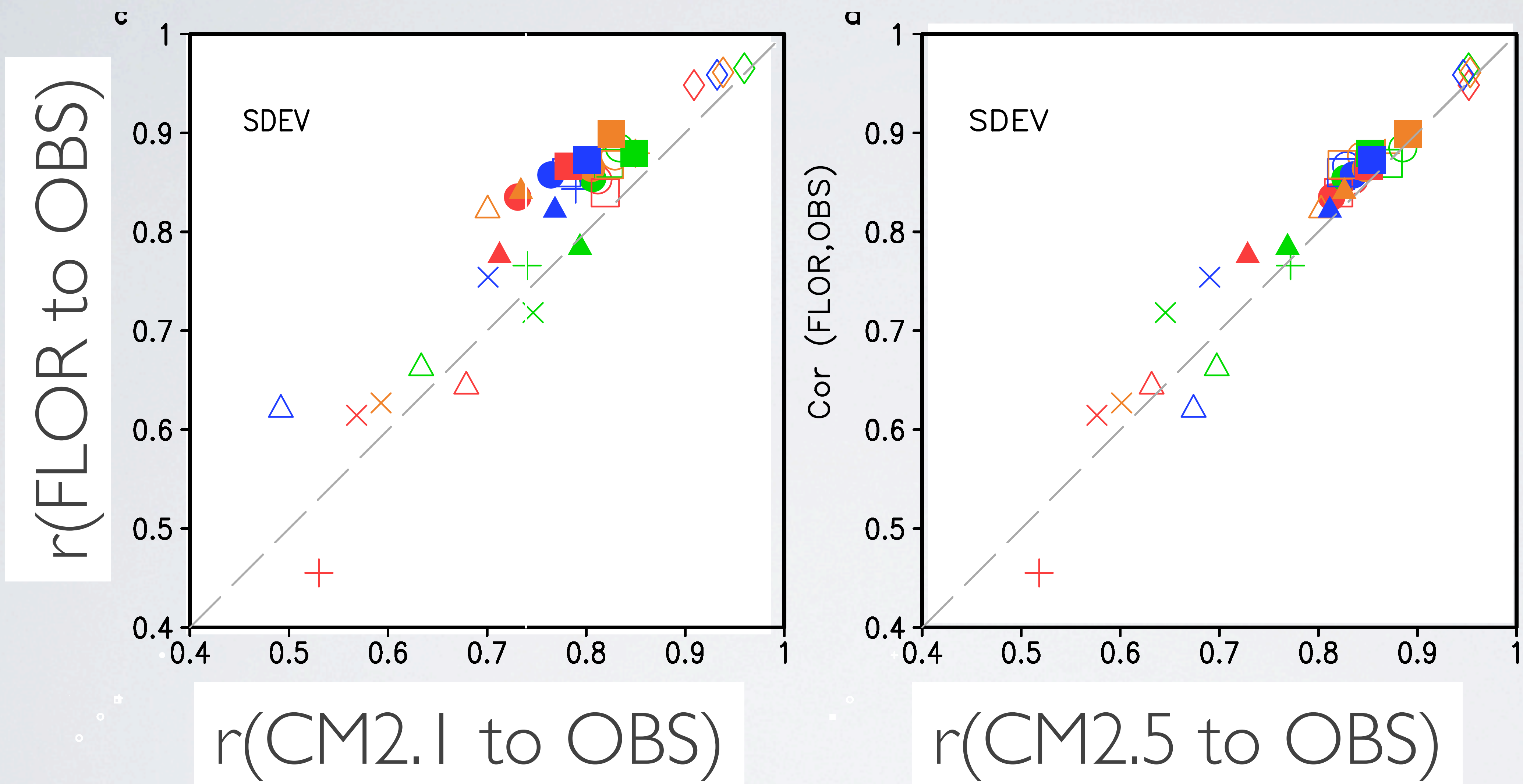
FLOR being used to explore broad range of problems

- Real-time seasonal predictions (through NMME)
- Sea ice variability and prediction (Msadek et al. 2014)
- Land precip and temp prediction (Jia et al. 2015) and attribution (Jia et al. 2015, in prep.)
- Extratropical storm prediction (Yang et al. 2015.a) and attribtuion (Yang et al. 2015.b)
- Tropical storm event attribution (Murakami et al. 2015)
- Hydrological response to hiatus (Delworth et al. 2015)
- PDO mechanisms, predictability and teleconnections (Zhang and Delworth 2015)
- Great Plains low level jet, TC and monsoon sensitivity to ENSO (Krishnamurthy et al. 2015.a, .b, .c)
- Global-mean response to 2xCO2 (Winton et al. 2014)
- Regional sea level change
- ENSO mechanisms (Choi et al. 2015, Wittenberg et al. 2015)
- Snow variability and change (Kapnick et al. 2015)
- Extratropical transition (Liu et al. 2015)
- Typhoon relation to large-scale climate (Zhang et al. 2015)
- Predictability in marine ecosystems (Stock et al. 2015)
- Extreme precip and drought…Etc.

Hypothesis: Enhanced atmos./land resolution improves climate

~5xAtmos Res.

4xOcean Res.



Mark: + p × sst ◇ slp ○ u925 ● v925 □ u850 ■ v850 △ u200 ▲ v200

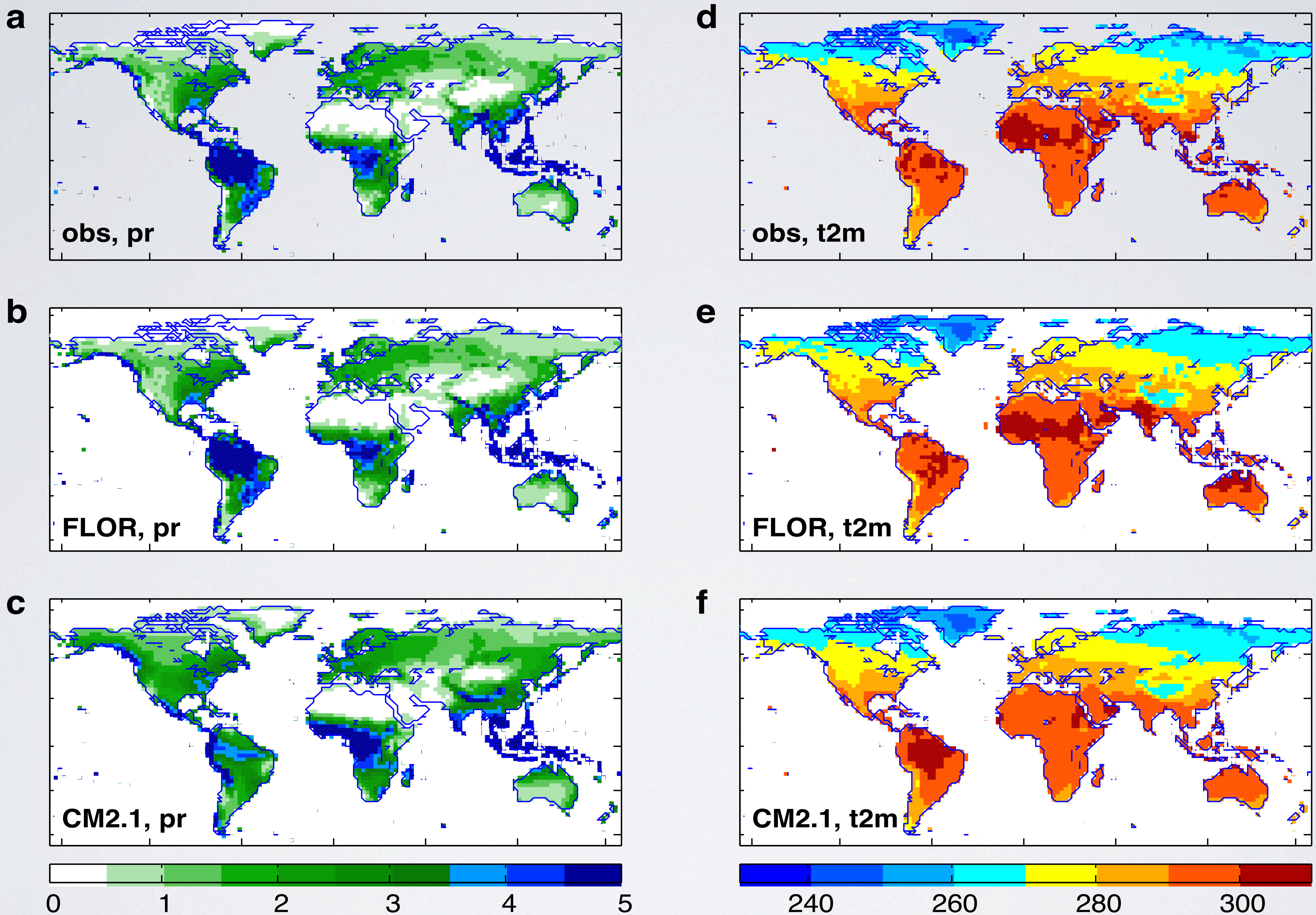
Color: MAM JJA SON DJF

Spatial Correlation Of Standard Deviation

Figure: Lakshmi Krishnamurthy

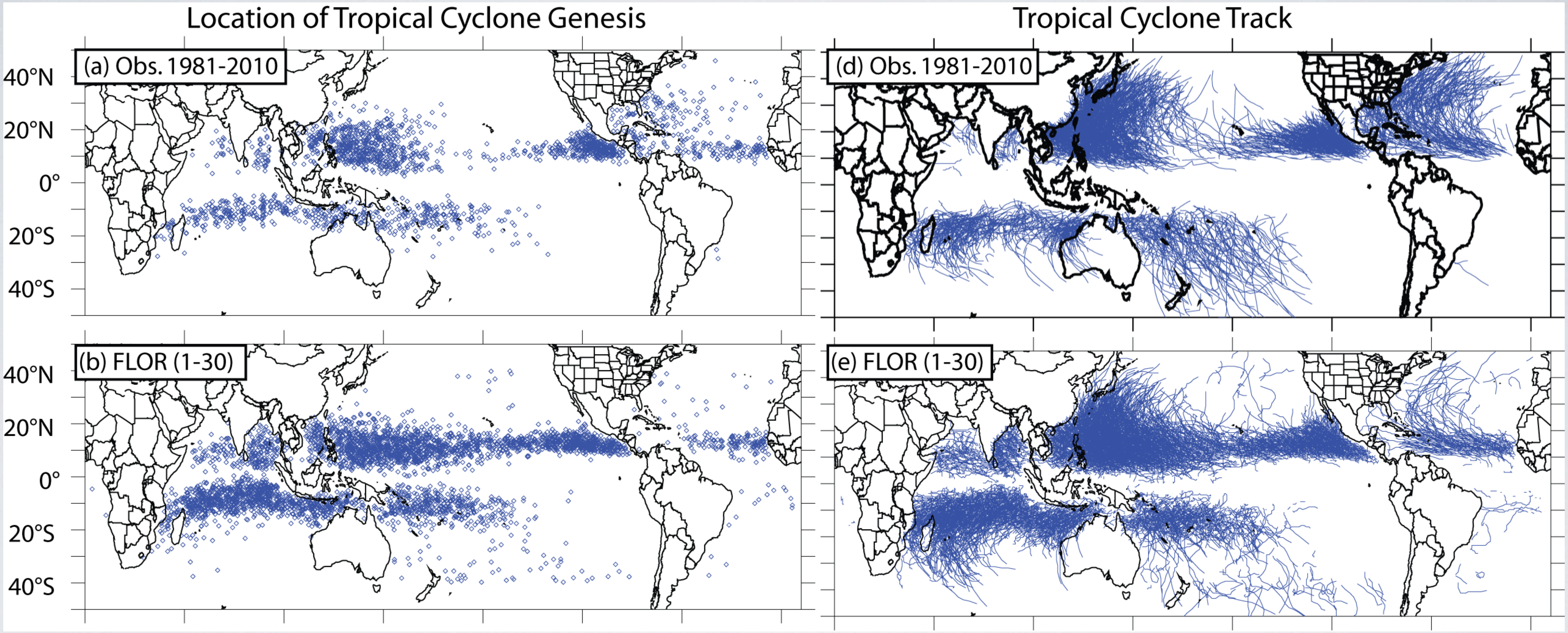
Jia et al. (2014, J. Clim.)

FLOR improves simulation of land Ts and Pr over CM2.1



Jia et al. (2014, J. Clim.)

TC tracks in FLOR decent for a coupled model (better than CM2.5)



Vecchi et al. (2014)

Flux adjustment for predictions of regional TC activity

- **Hypothesis:** Biases in large-scale climate degrade simulation and prediction statistics of regional and extreme climate, flux adjustment will lead to improvements – particularly at longer leads.

- **Methodology:** FA version of FLOR with climatological (once computed, independent of model state) adjustment to momentum, freshwater and enthalpy fluxes to ocean.

  Repeat simulations and predictions with FLOR-FA, compare to FLOR.

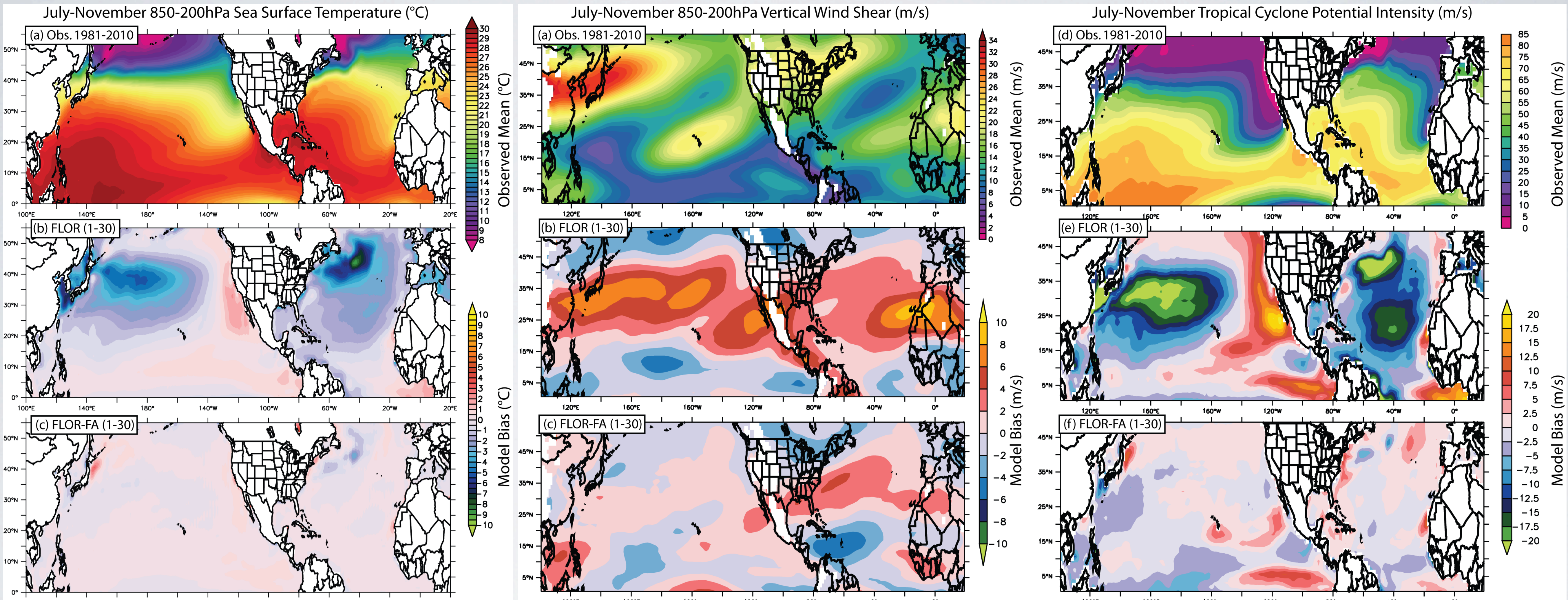
Vecchi et al. (2014, J. Climate).

Large-scale biases in summer climate map onto some of TC biases

SST

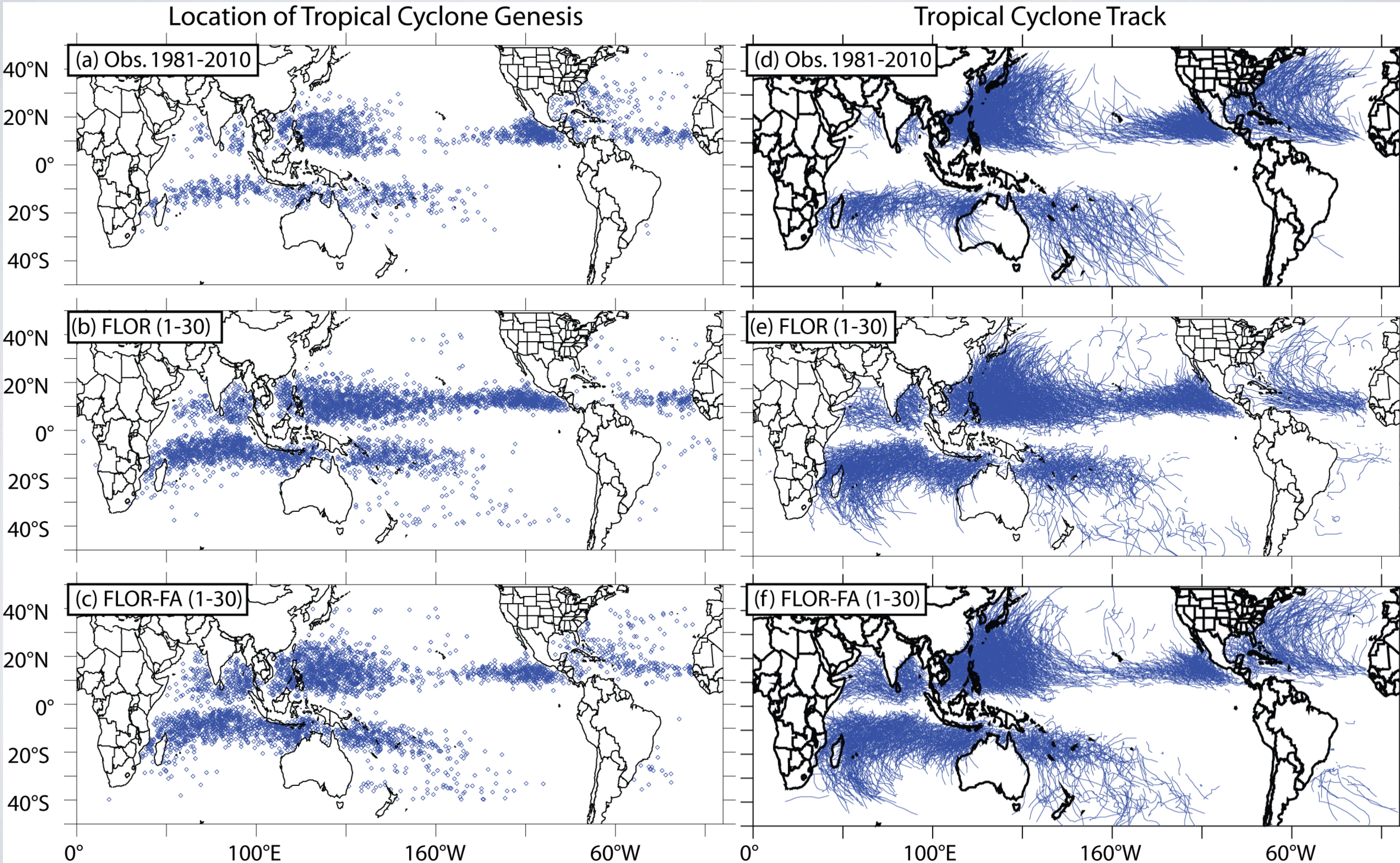
Shear

Potential Intensity



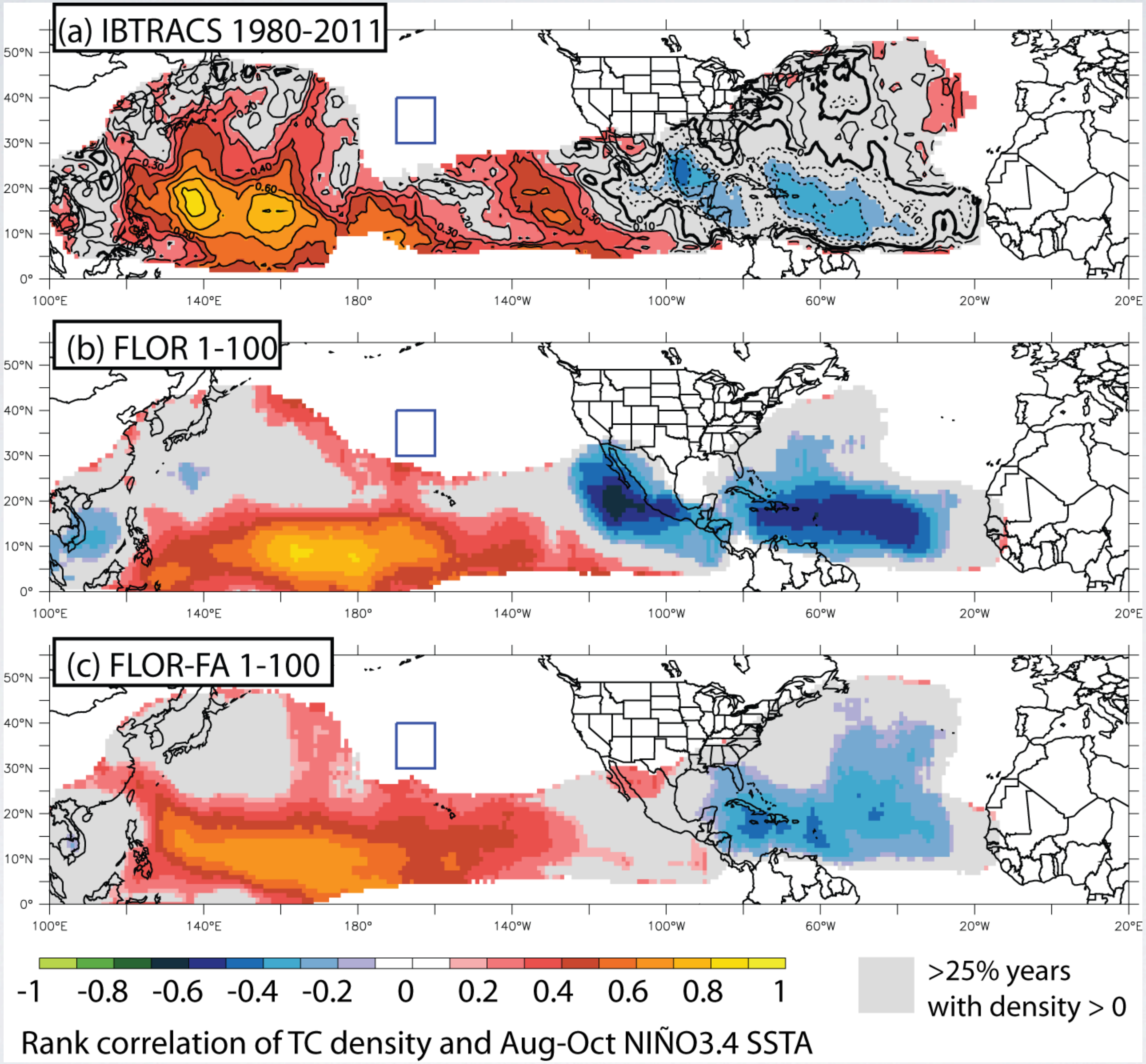
Vecchi et al. (2014)

TC tracks in free-running FLOR-FA improved over FLOR particularly in North Pacific and North Atlantic



Vecchi et al. (2014)

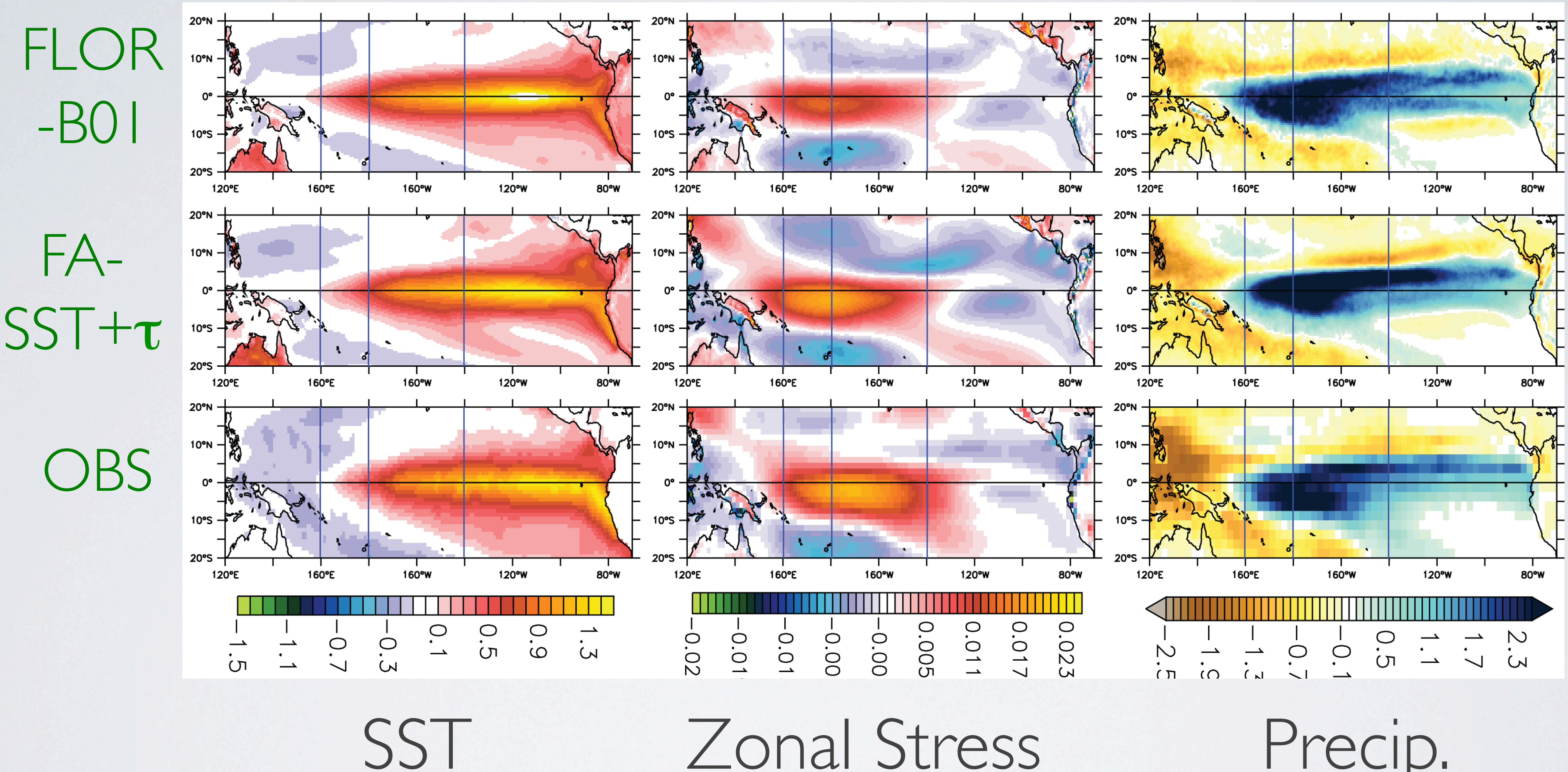
TC density relation to NIÑO3.4 improved in FLOR-FA: due to improvements in simulation of El Niño



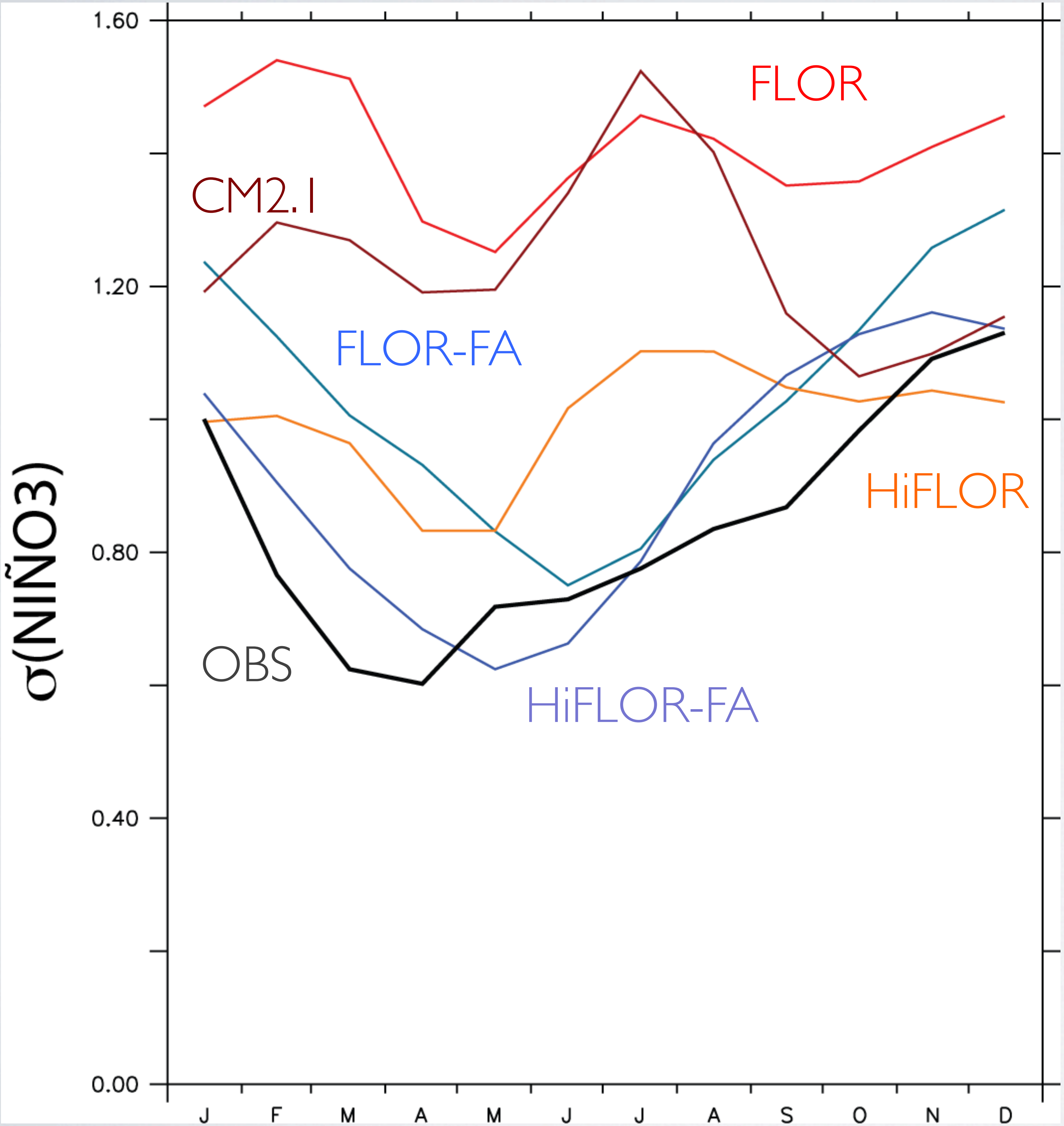
Vecchi et al. (2014)

Structure of ENSO improves in FA, as does its phase-locking

Regression on NIÑO3 SSTA



Atmospheric resolution/FA and ENSO phase locking

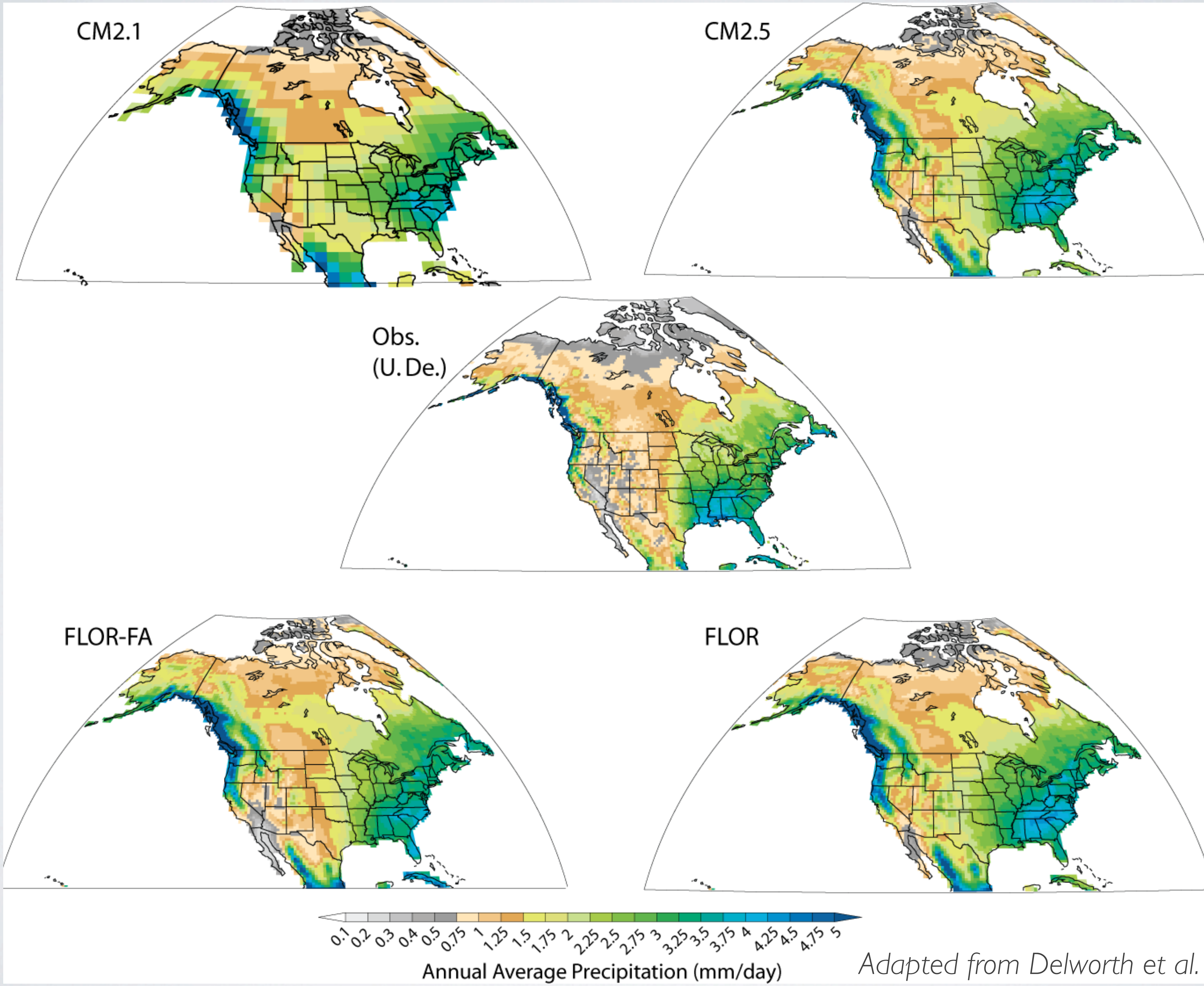


Artificially adjusting mean state biases improves phase locking of anomalies.

Appears in part related to onset: seasonality of WWEs improved…

Adapted from Krishnamurthy et al. (2015, in press)

N. American precip improves from FA (look at E. and W. Texas)

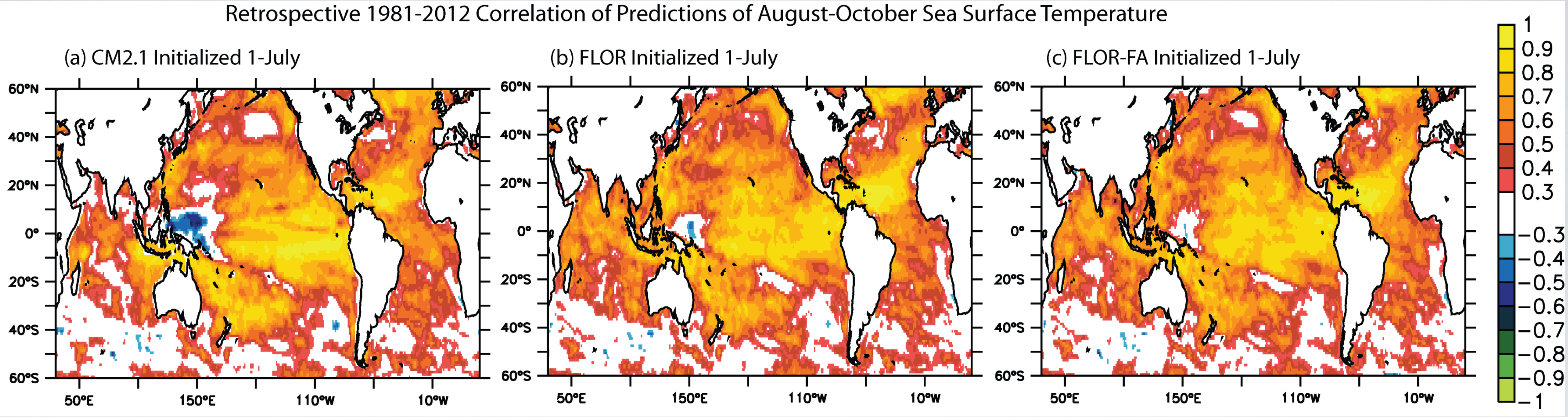


Adapted from Delworth et al. (2015)

FLOR Seasonal Predictions (phase 1)

- 1980-2013 retrospective forecasts (12-member ensemble)
- Ocean & sea ice initialized from CM2.1 EnKF3.1 Assimilation
- Atmosphere and land initialized from ensemble of AGCM (*i.e.*, only information contained in SST and radiative forcing in atmos/land Ics)
- Done with two versions of FLOR (A06 & B01, differ in ocean physics) – will discuss B01
- These retrospective forecasts and future real forecasts to be submitted to NMME starting March 2014

Retrospective predictions of ASO SST no worse in FLOR-FA than FLOR – both somewhat better than CM2.1

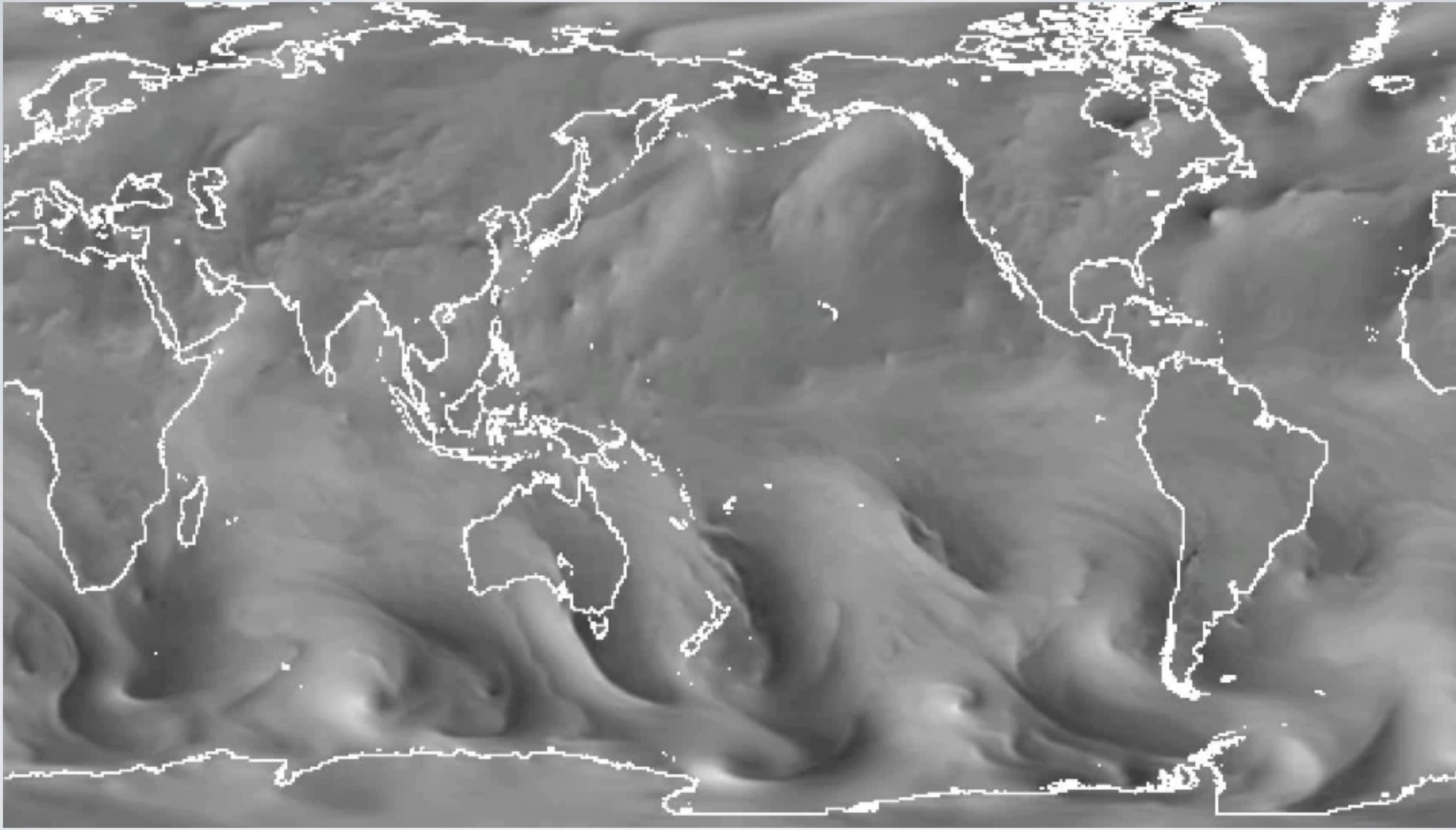


CM2.1 FLOR FLOR-FA

1981-2012 correl. of Aug-Oct SSTA predictions

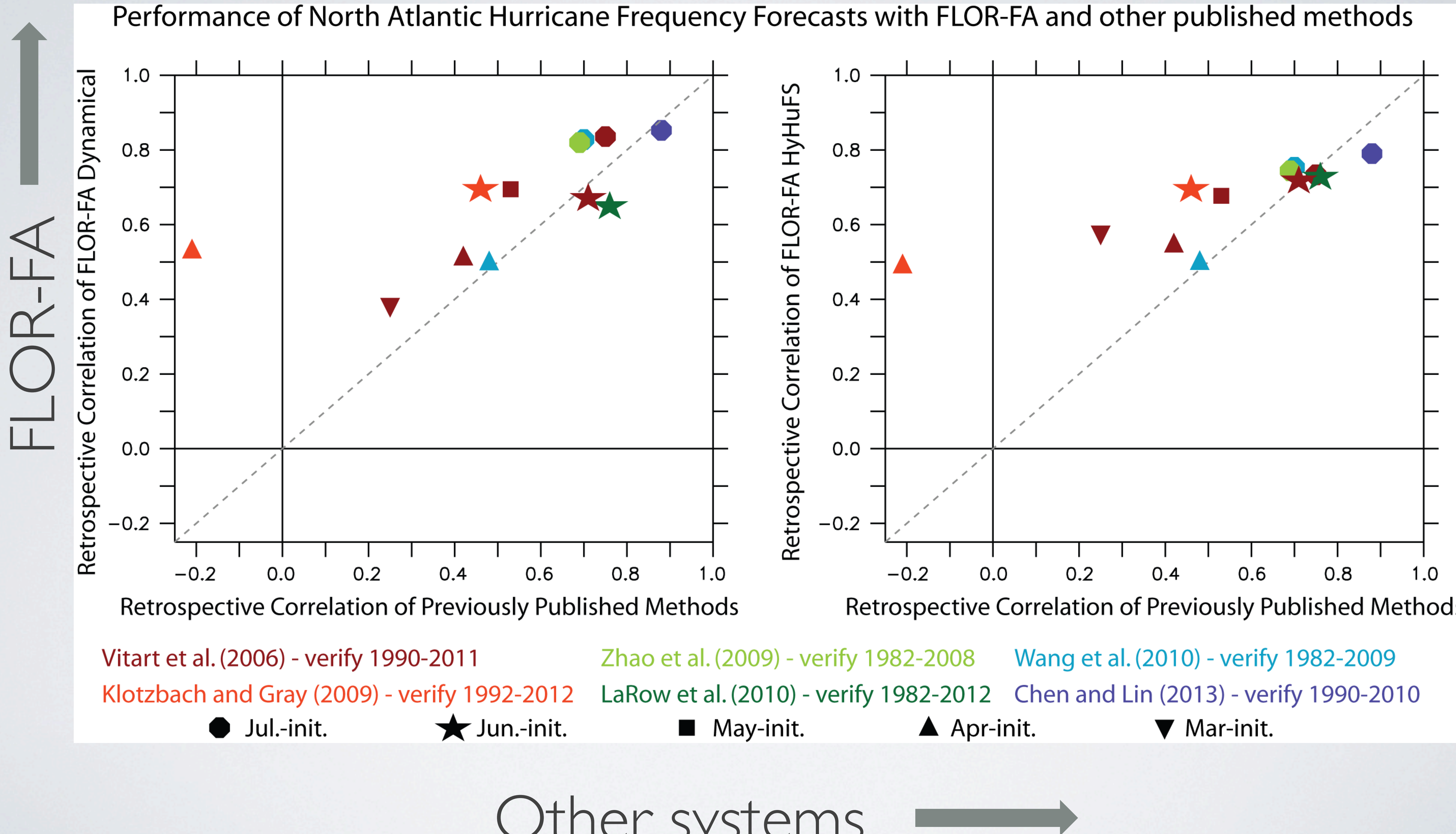
Vecchi et al. (2014)

100 days of single ensemble of 10-m v from CM2.5-FLOR initialized 1-Aug-2005



4xdaily 1-Aug through 8-Nov 2005

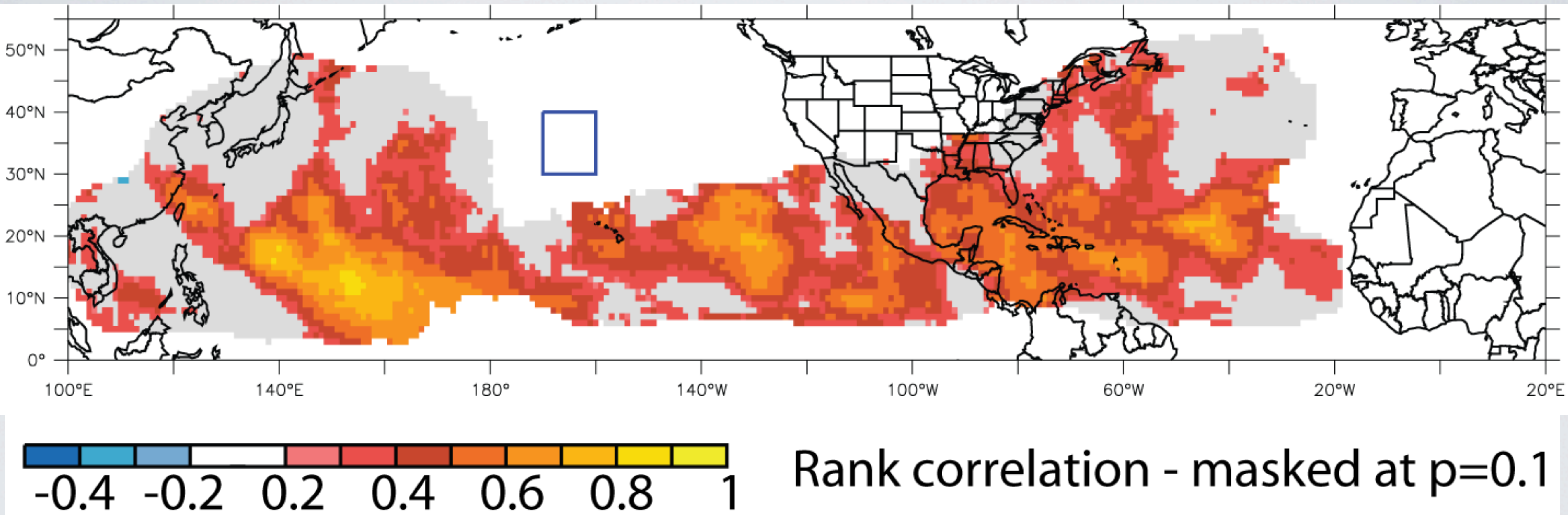
FLOR-FA is among best NA hurricane seasonal prediction systems (symbol above diagonal: FLOR-FA nominally 'better')



Vecchi et al. (2014)

Can we reliably predict statistics of storms more regionally than "basin-wide" number?

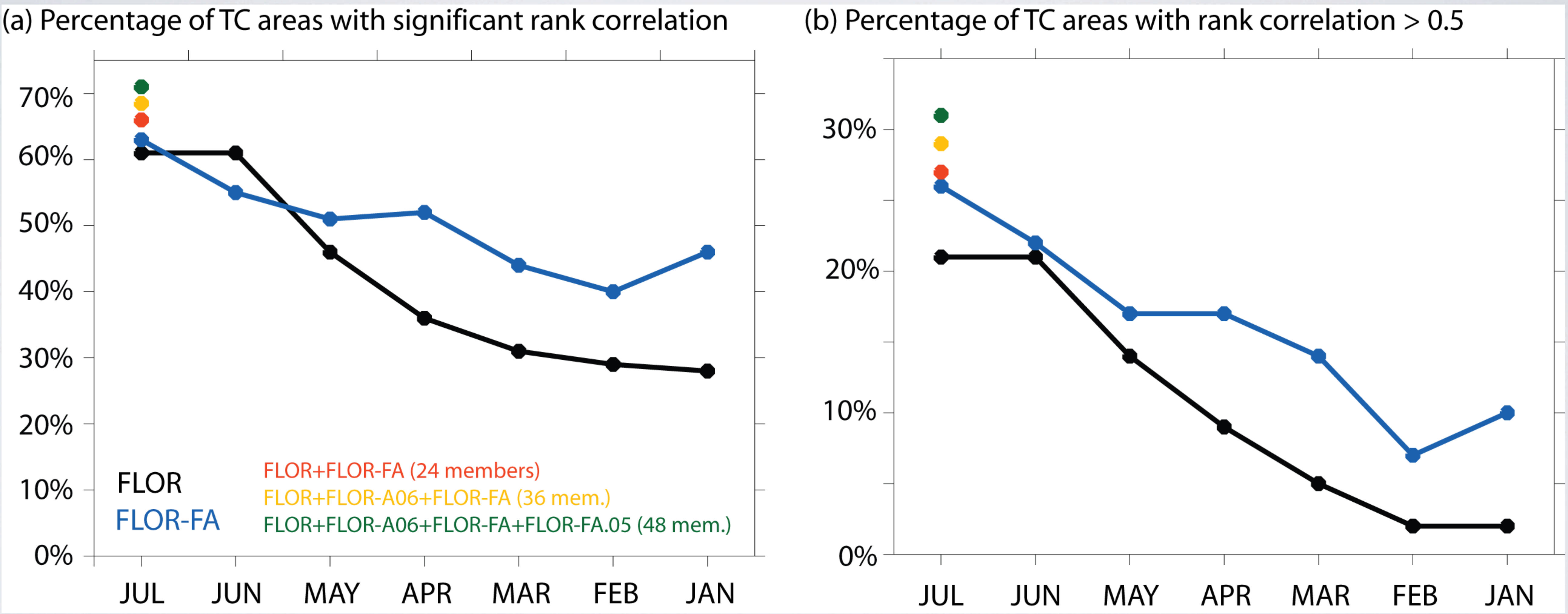
GFDL-FLOR 1981-2012 1-July Initialized Forecasts for July-December



Rank correlation: Can experimental FLOR forecasts distinguish years with many and few storms passing within 10°x10° of a point.

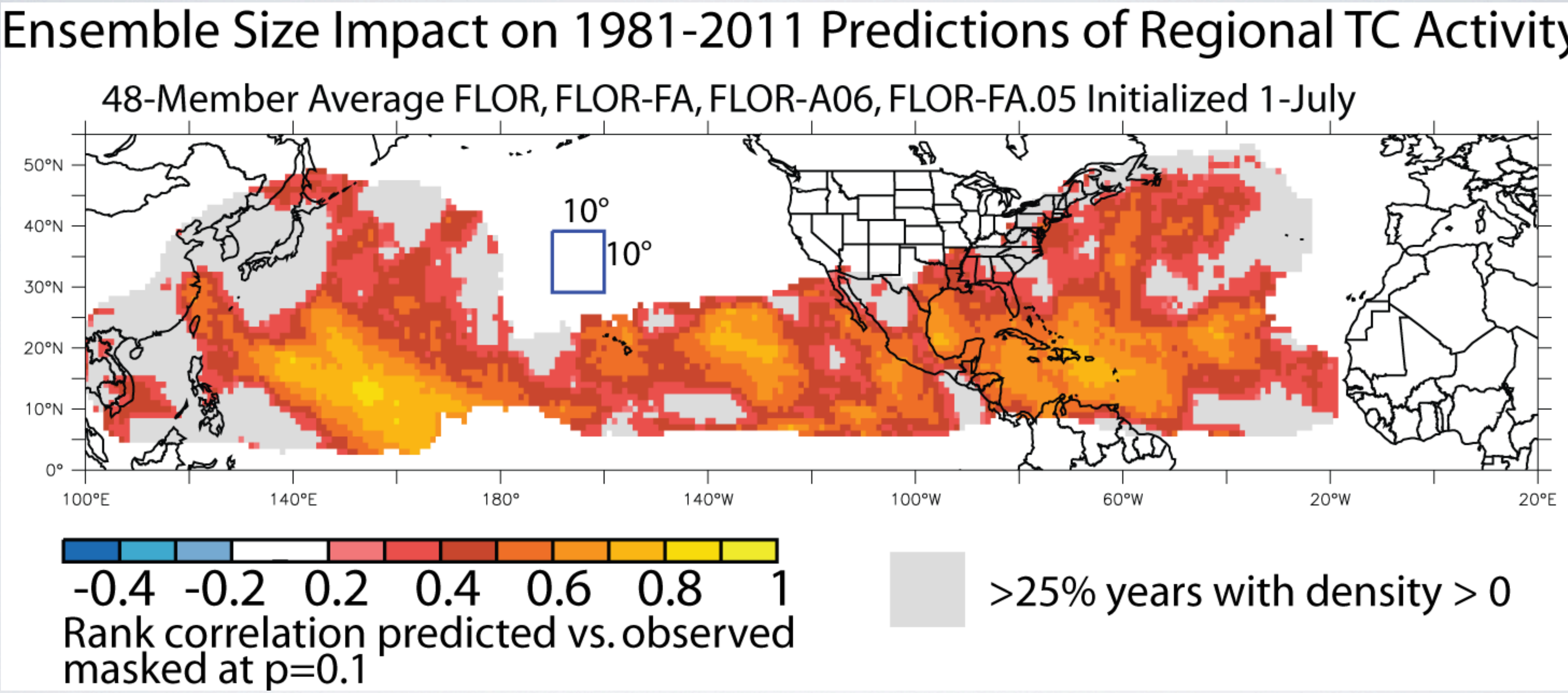
Vecchi et al. (2014, submitted)

FLOR-FA outperforms FLOR at predictions of regional (and basinwide) TC activity – particularly at long leads



Vecchi et al. (2014)

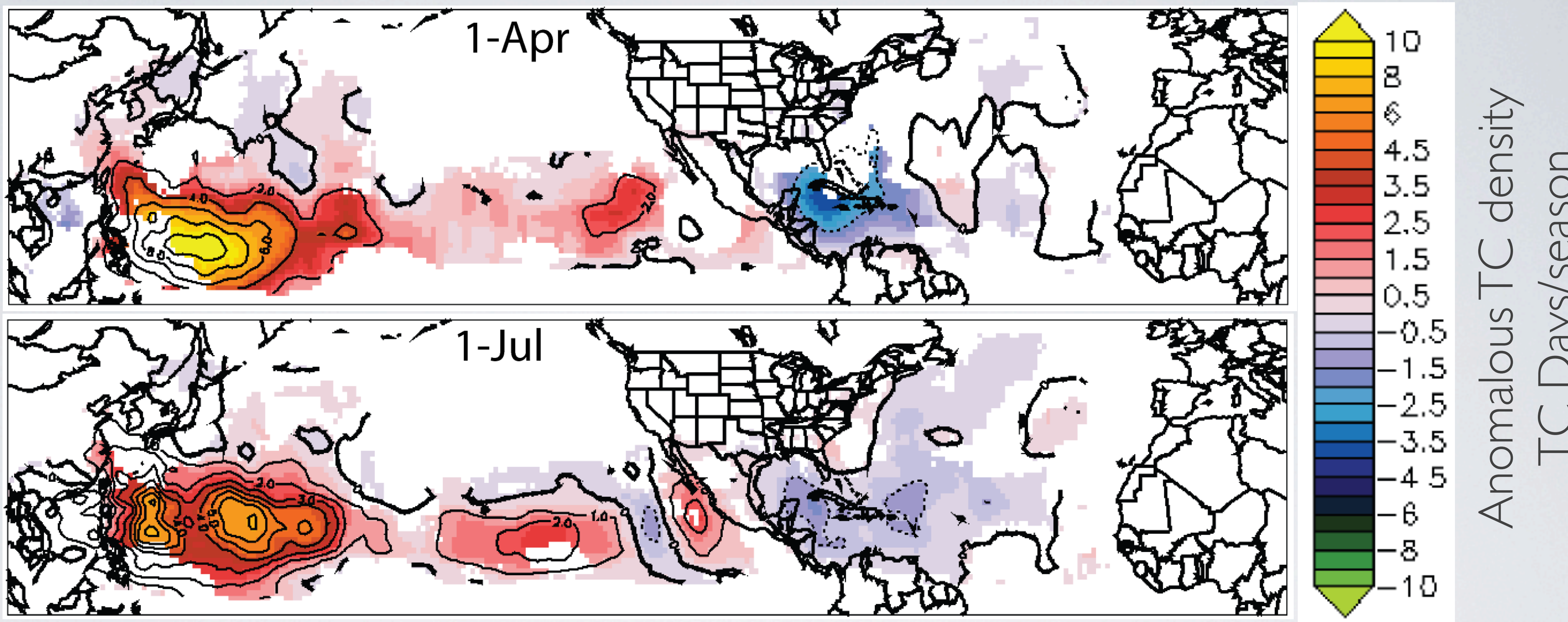
Increasing ensemble size from 12 to 48 improves regional TC predictions



***EXPERIMENTAL RESEARCH PRODUCT – NOT AN OFFICIAL OUTLOOK ***

Experimental seasonal TC density forecasts with GFDL-FLOR-FA

(Vecchi et al. 2014, J. Clim. in press)

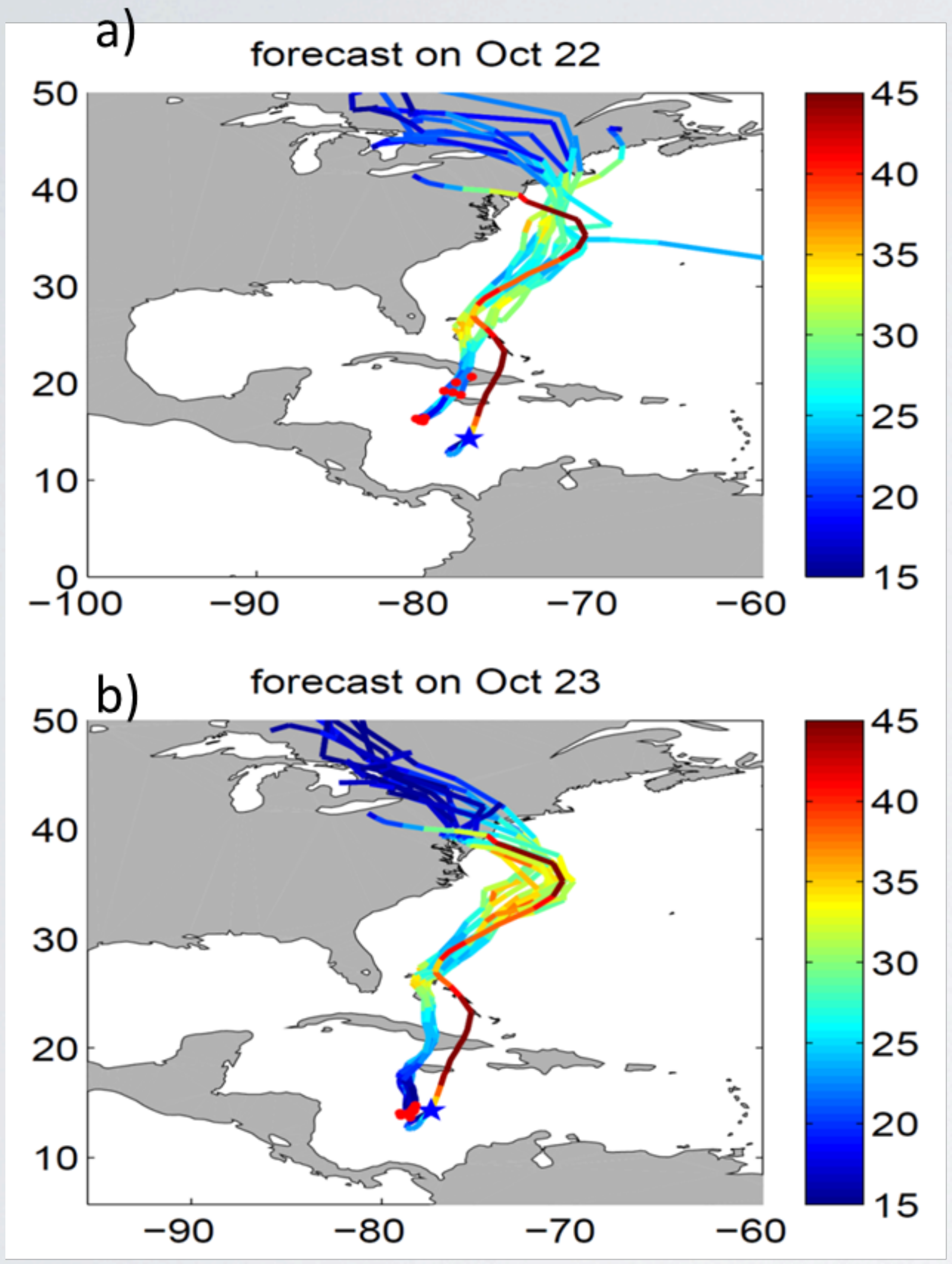


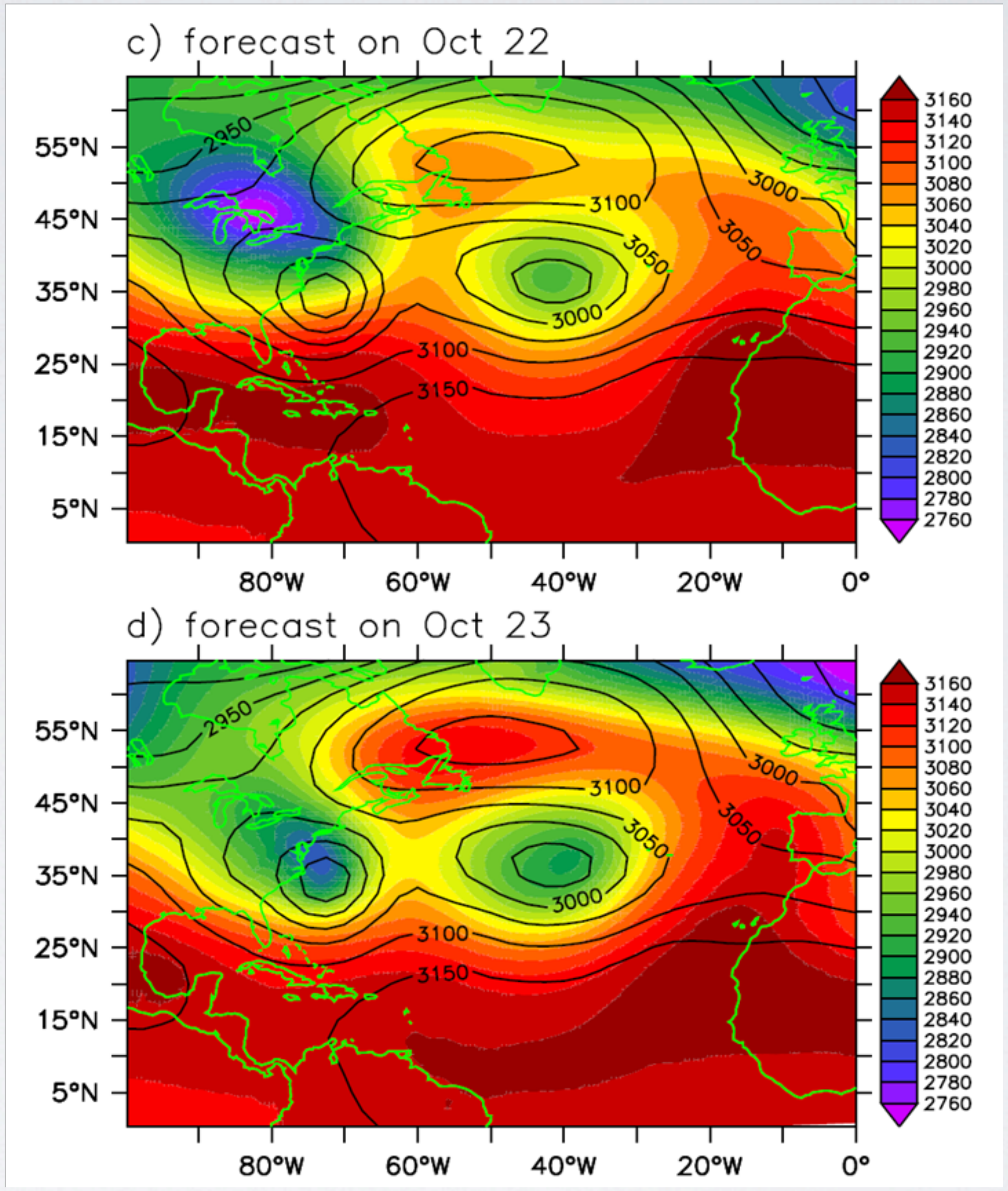
Forecasts of 2014 TC density anomaly with GFDL-FLOR-HAD13 initialized 1-April-2014 and 1-July 2014.

Contour: all values

Shade: locations with significant retrospective correlation

Seamless predictions: 5-7 days forecasts of Sandy with a version of FLOR

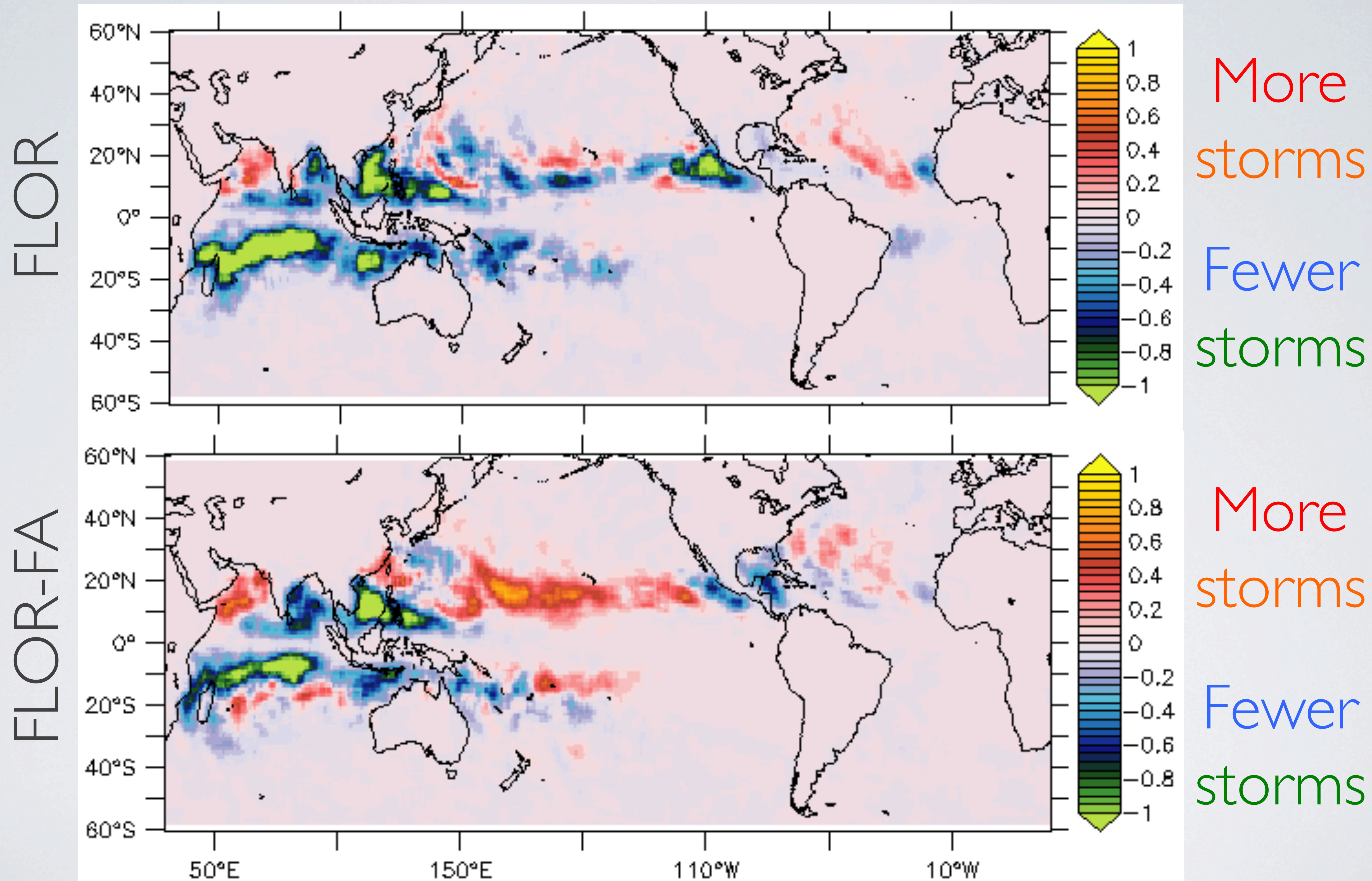




Xiang et al. (2015, MWR)

Forecasts initialized 7 & 8 days before landfall capture track

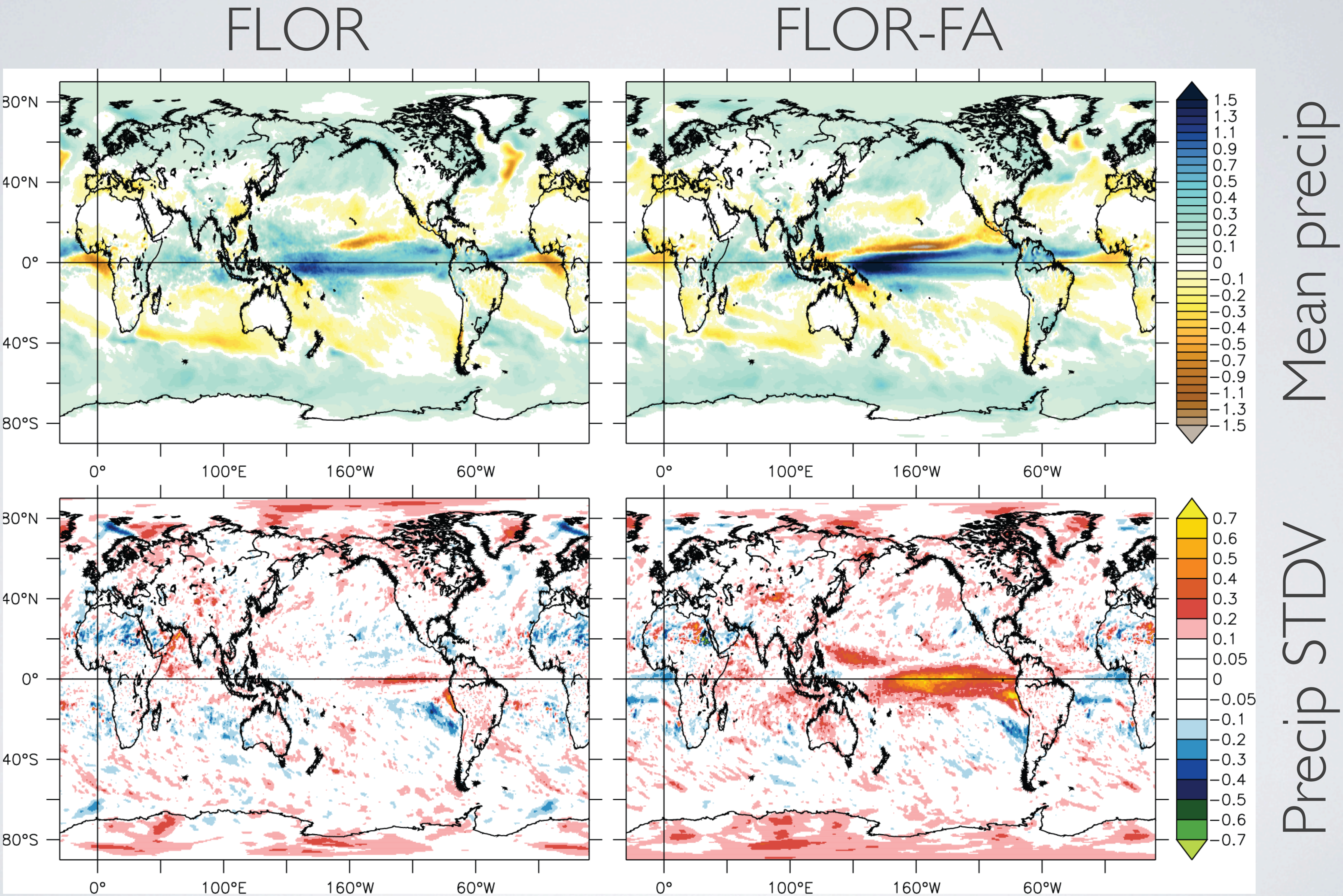
Towards unified system for weather-to-centennial TC changes in high-resolution global coupled models



Tropical storm density response to CO_2 doubling

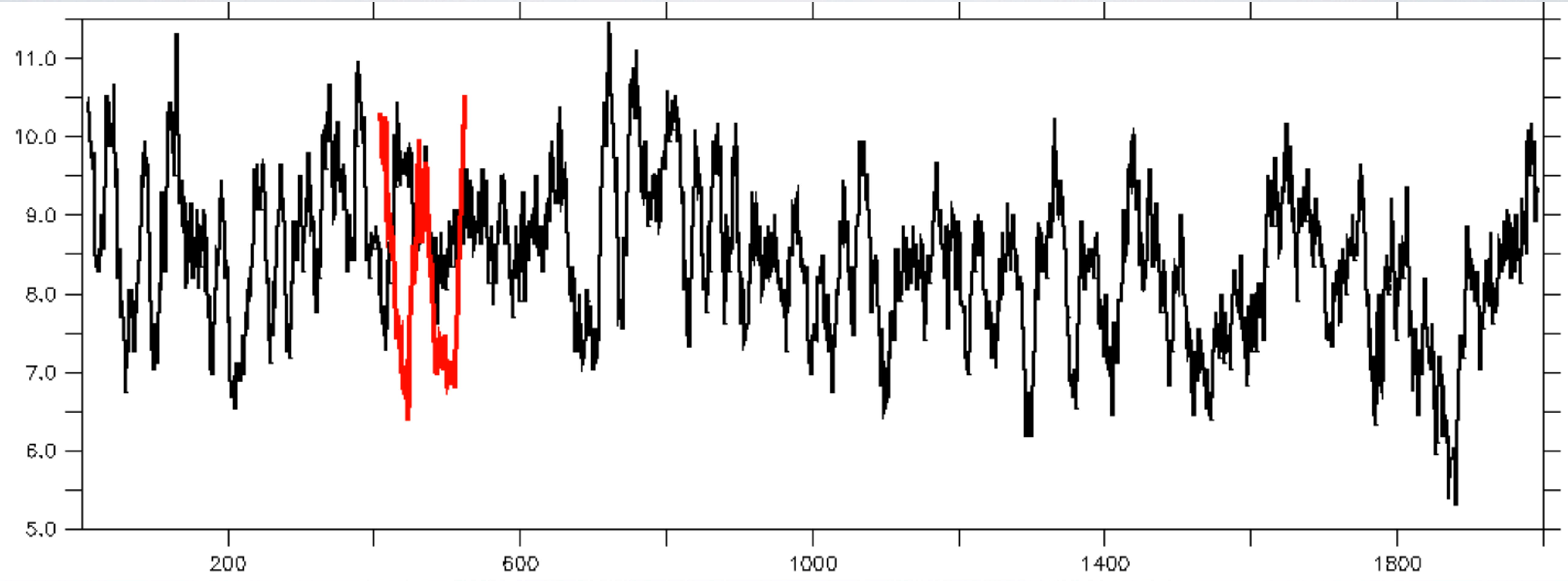
Vecchi et al. (in prep)

CO2-driven response of Precip mean and standard deviation



Vecchi et al. (in prep)

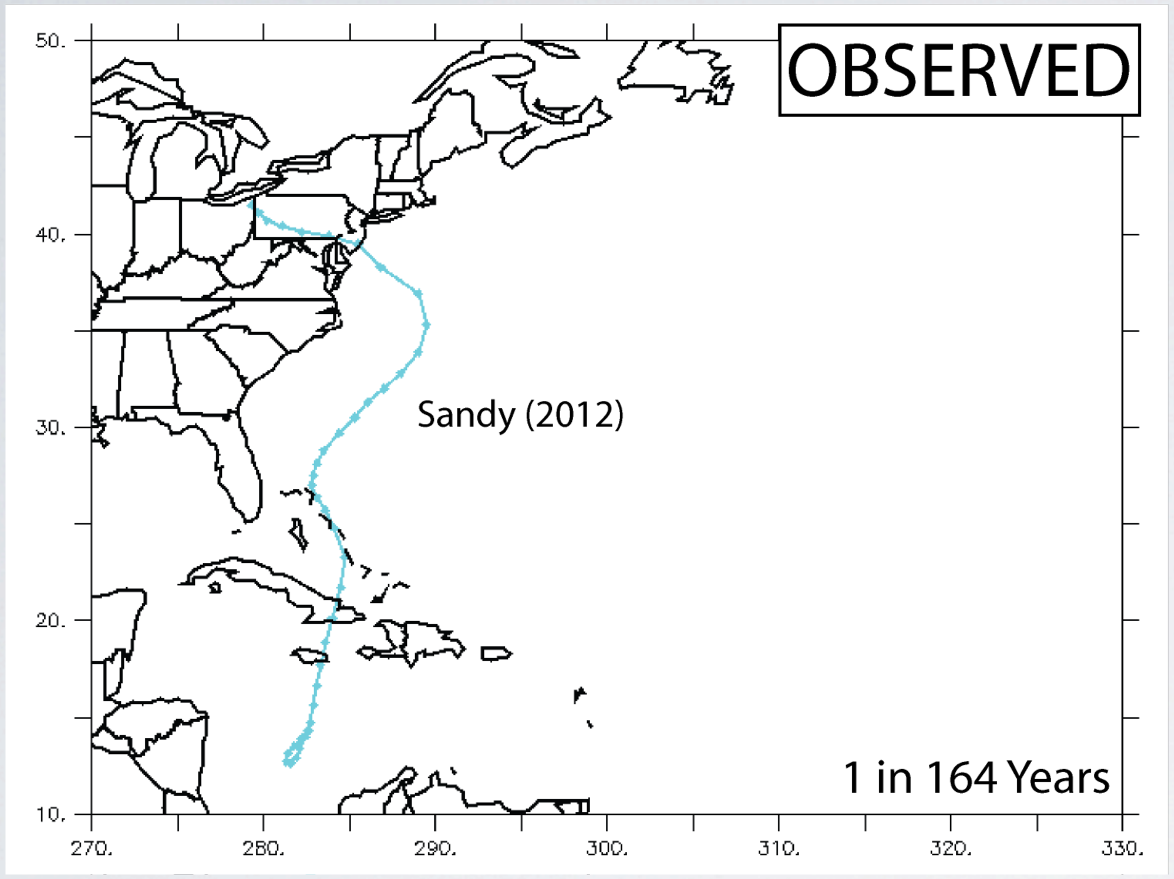
2000-year 1860 control with FLOR-FA shows large multi-decadal Atlantic TC variability (in part tied to AMOC), reminiscent of observed

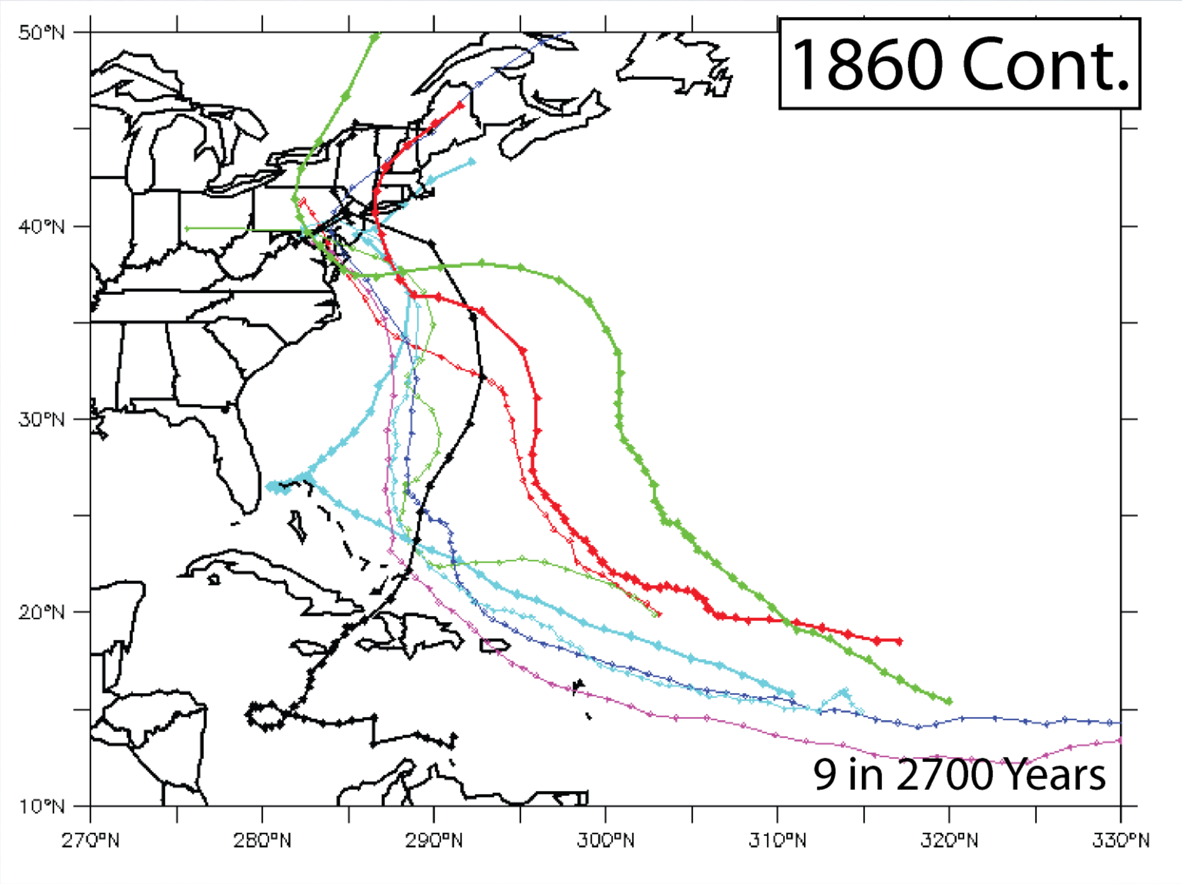


15-year running counts: FLOR and obs.

Vecchi et al. (in prep)

FLOR Produces "Sandy-like" storms



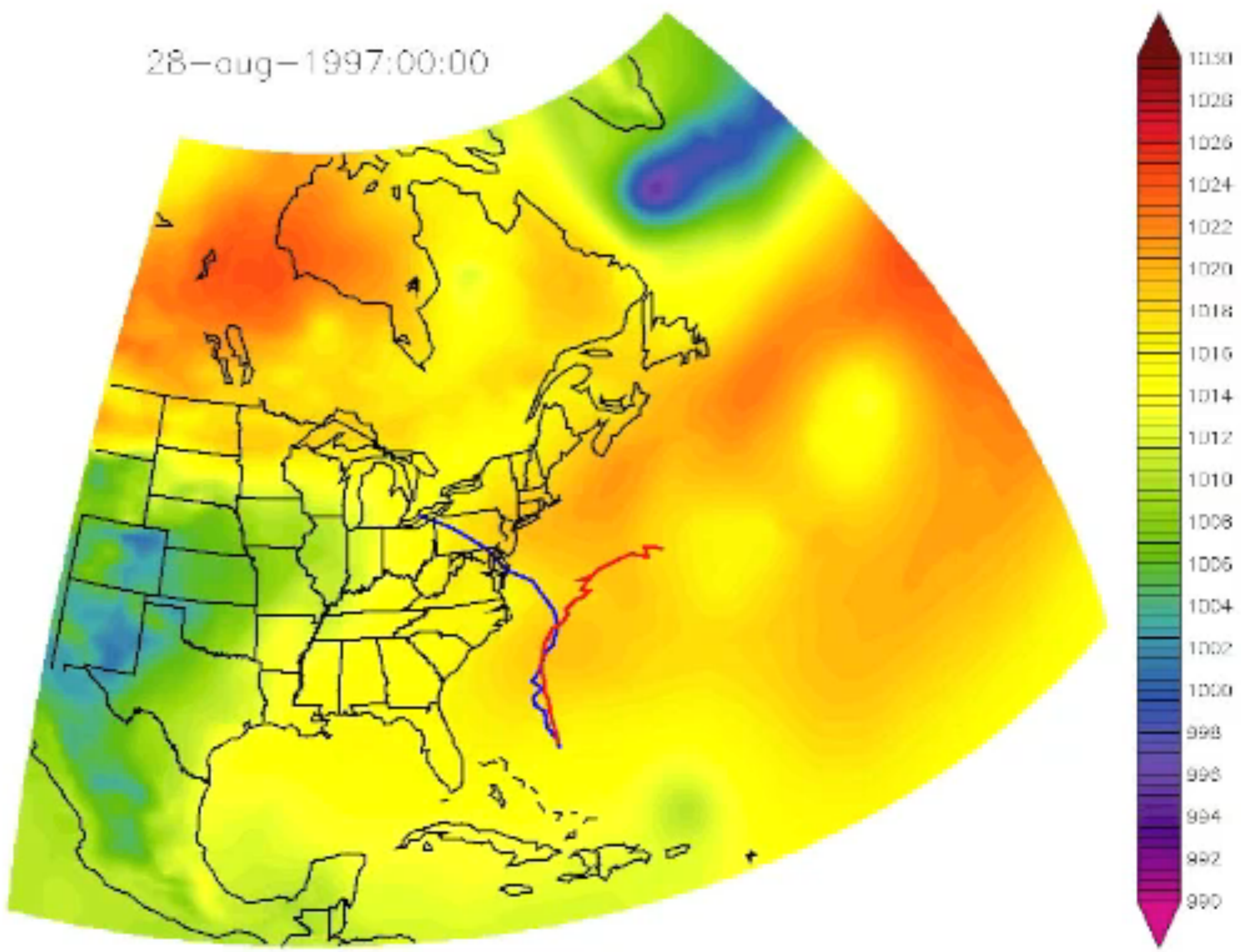


Storms that:

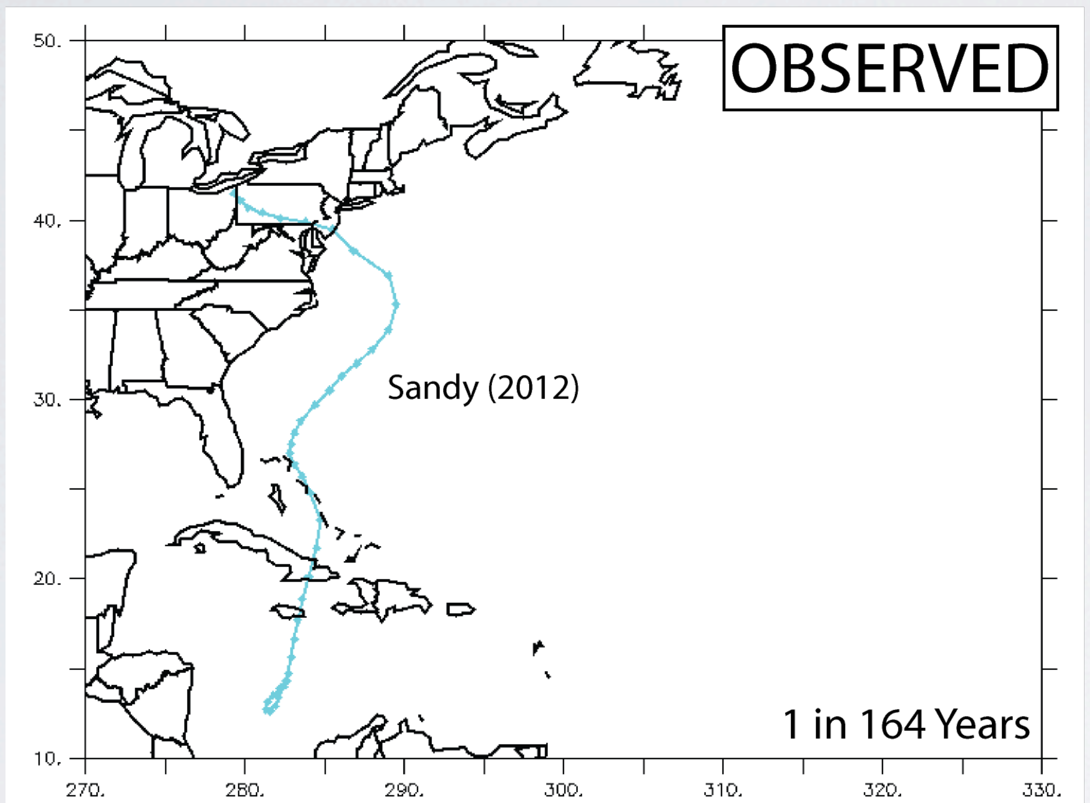
- Hit "NJ" (38°-41°N) heading to west
- Exceed 20m/s prior to landfall
- Form in tropics
- Move mostly north/northeastward and off-shore 25-35°N

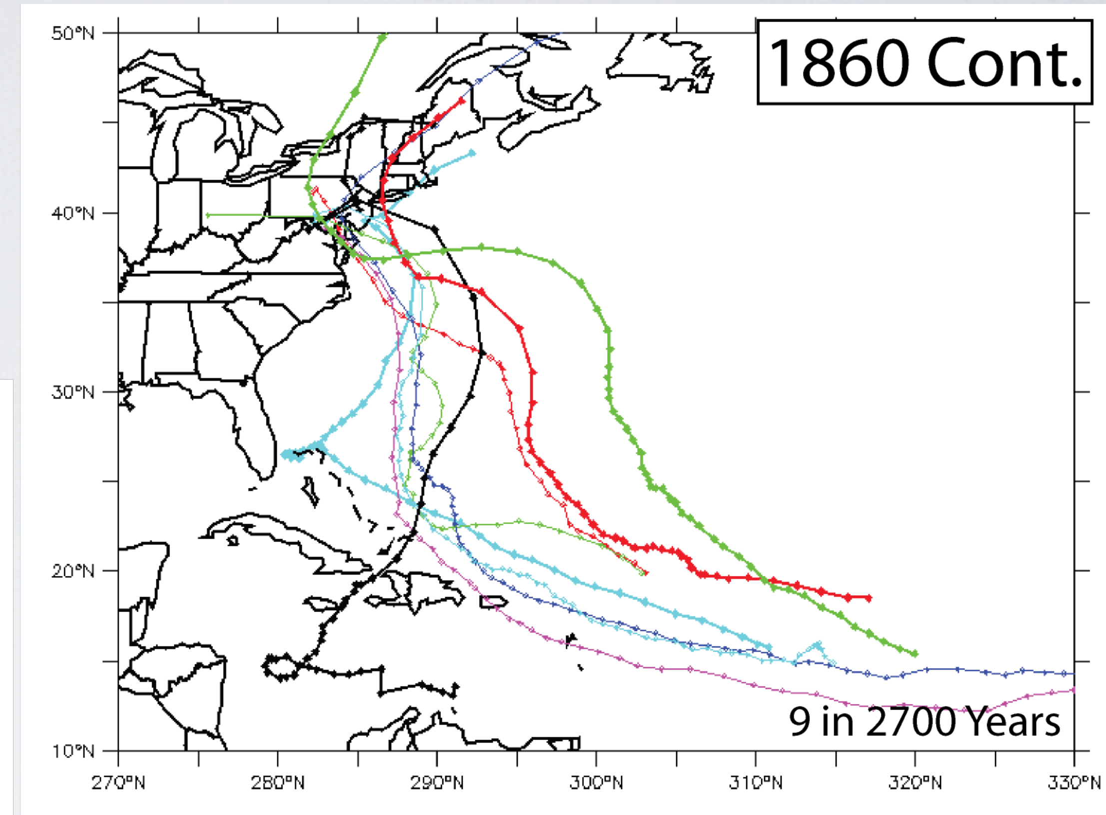
Vecchi et al. (in prep)

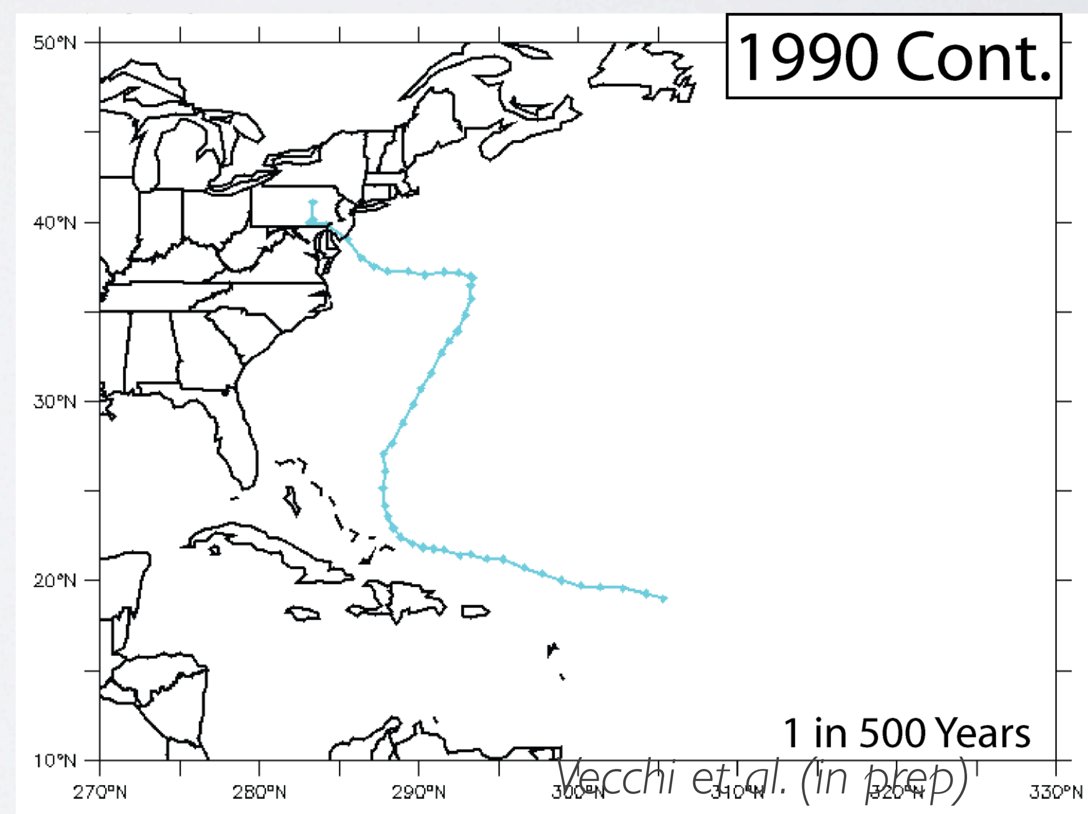
Sandy-like storm from FLOR: tropical/extra-tropical interaction



No increase in odds of "Sandy-like" storm in FLOR-FA from historical radiative forcing







Vecchi et al. (in prep)

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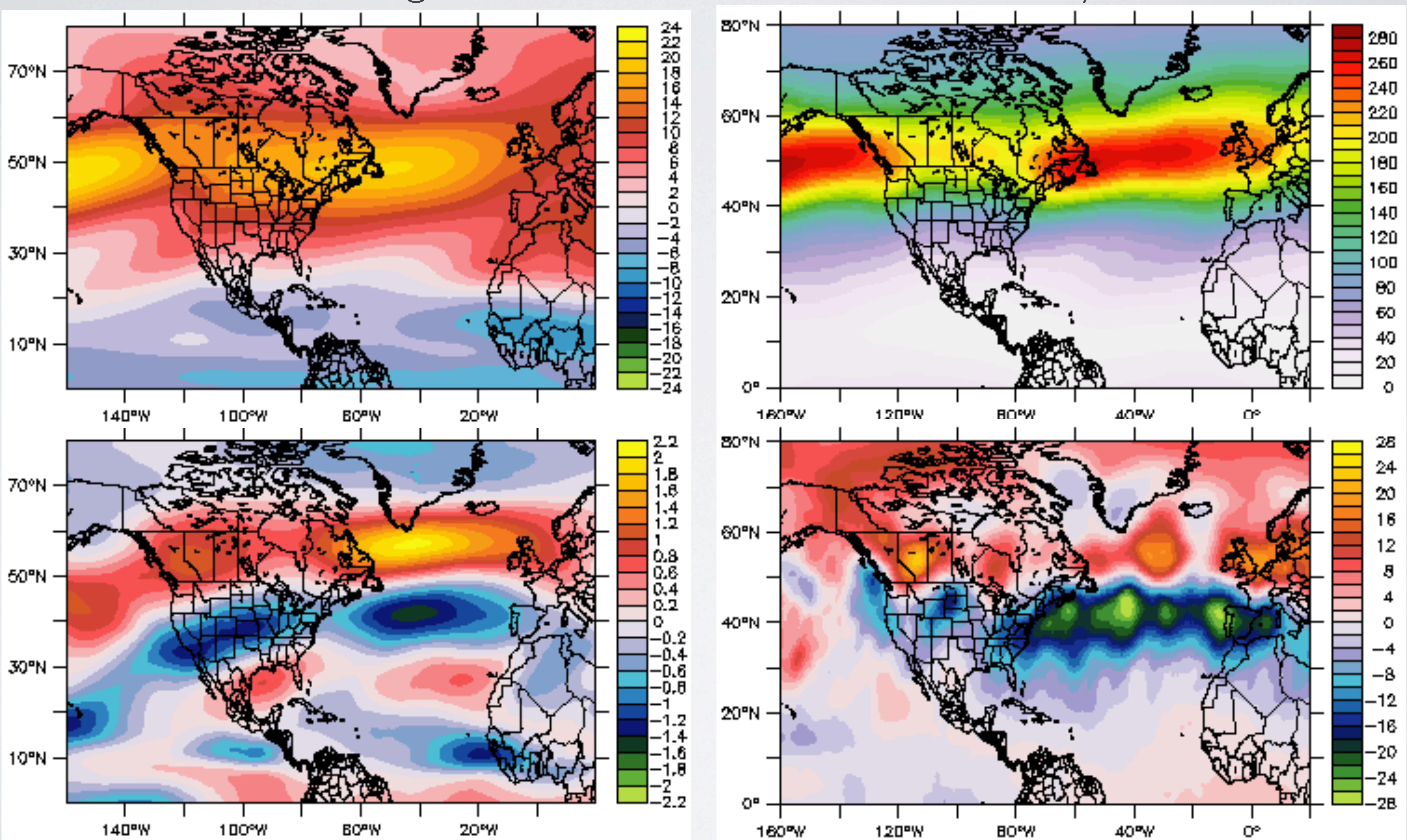
Poleward shift of westerlies and storm track (1990 vs. 1860): reduced eastward steering but reduced chance of T-ET interaction

Zonal Steering Flow | 250hPa v eddy variance

1990 Control

1990-1860



Vecchi et al. (in prep)

Summary

- Increased atmospheric and land resolution, and better land model:
  Improved forecasts of large-scale climate
  Simulation and forecasts of regional climate and extremes

- Skillful seasonal predictions of TC activity at regional scales appear feasible
  Large (many 10s) ensembles appear desirable

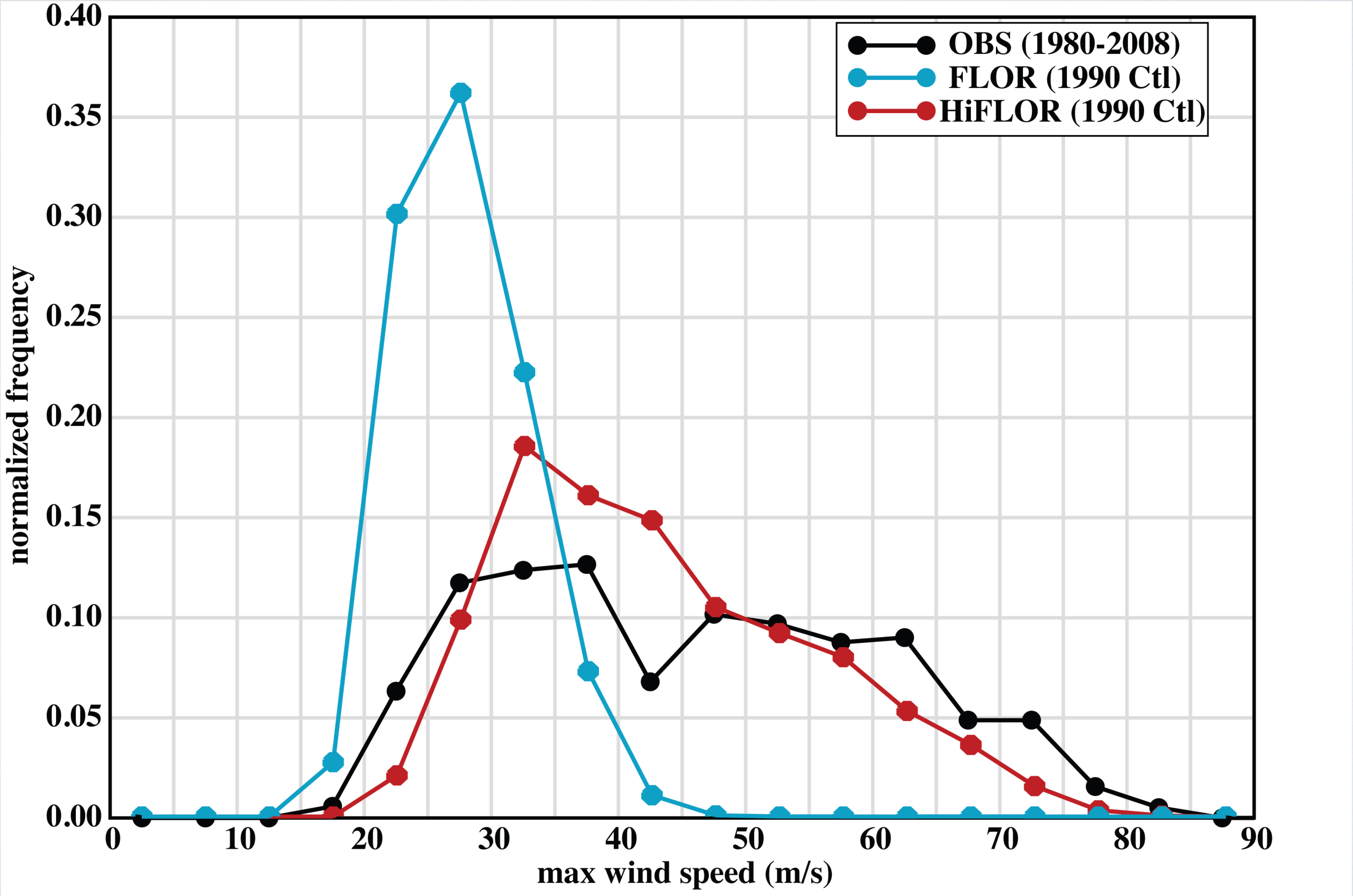
- Flux adjustment improves simulation and seasonal prediction of regional climate and extremes.
  FA adds one season to skill in regional TC prediction
  For what problems is FA a net negative?

- High-res coupled model can be applied to weather to centennial climate change problems
  Understanding and D&A of extreme event changes
  To what extent should prediction skill enhance confidence on projections?

Next Steps

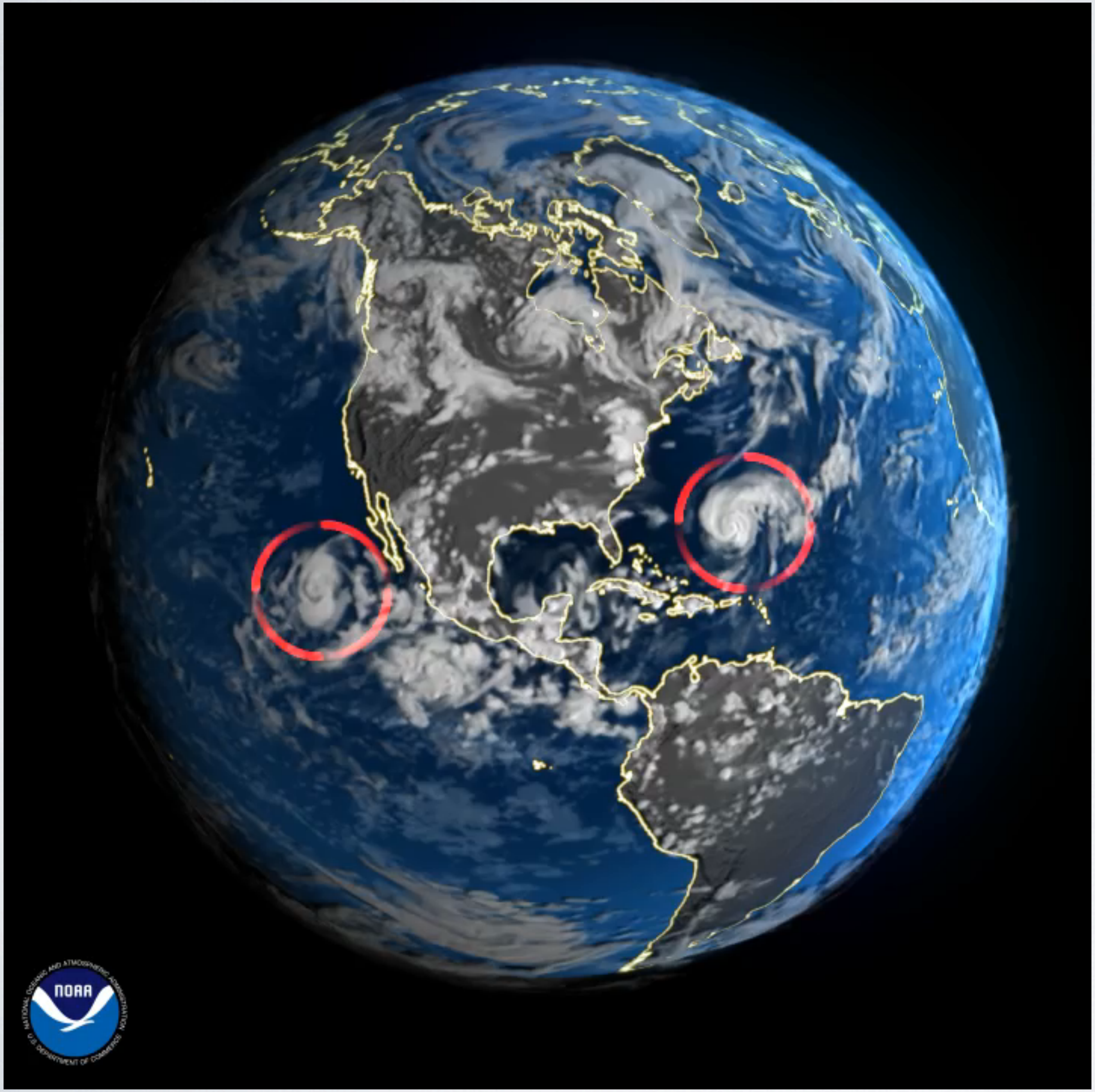
- Higher resolution to get to intensity

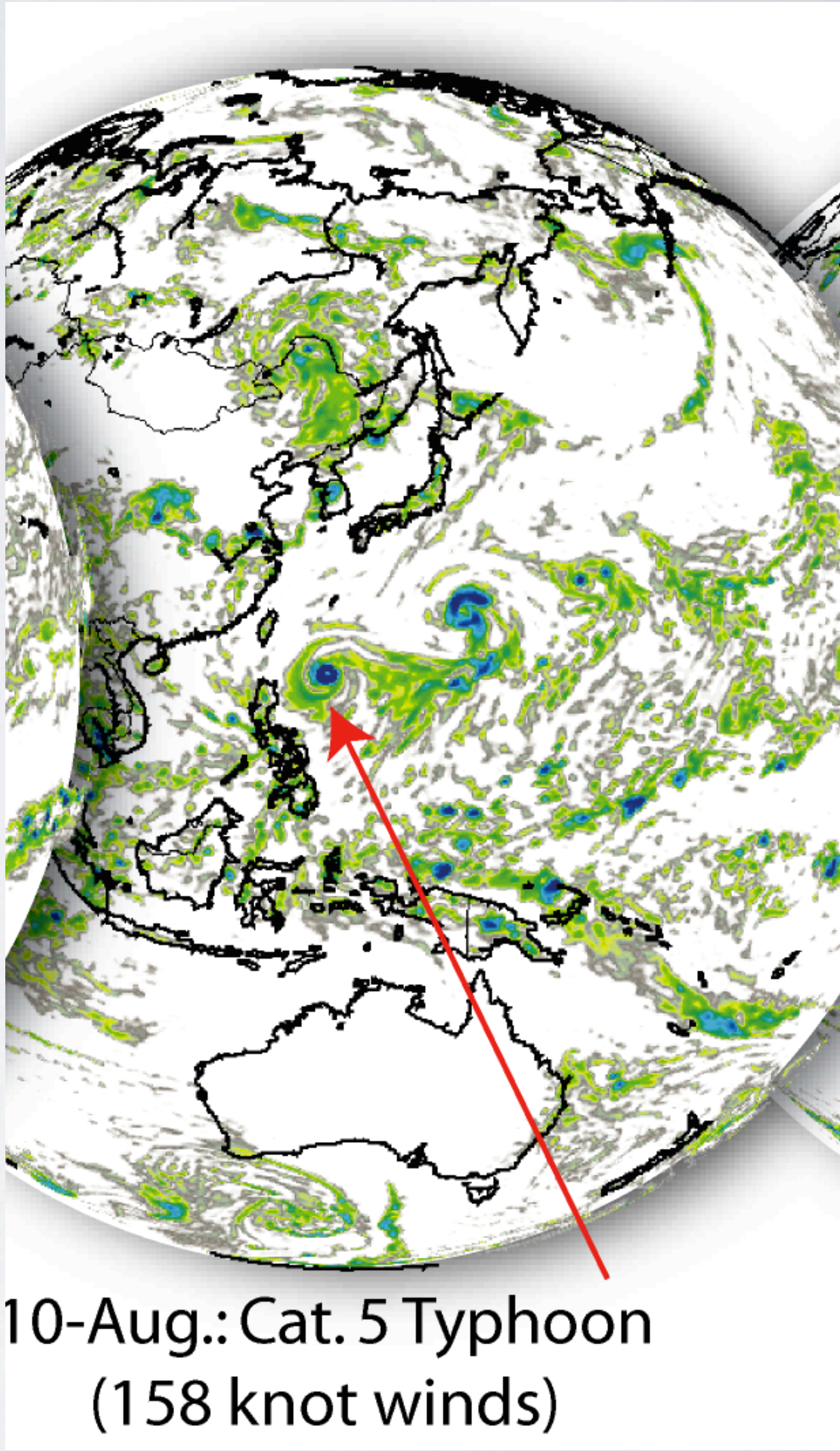
HiFLOR (25km version of FLOR)



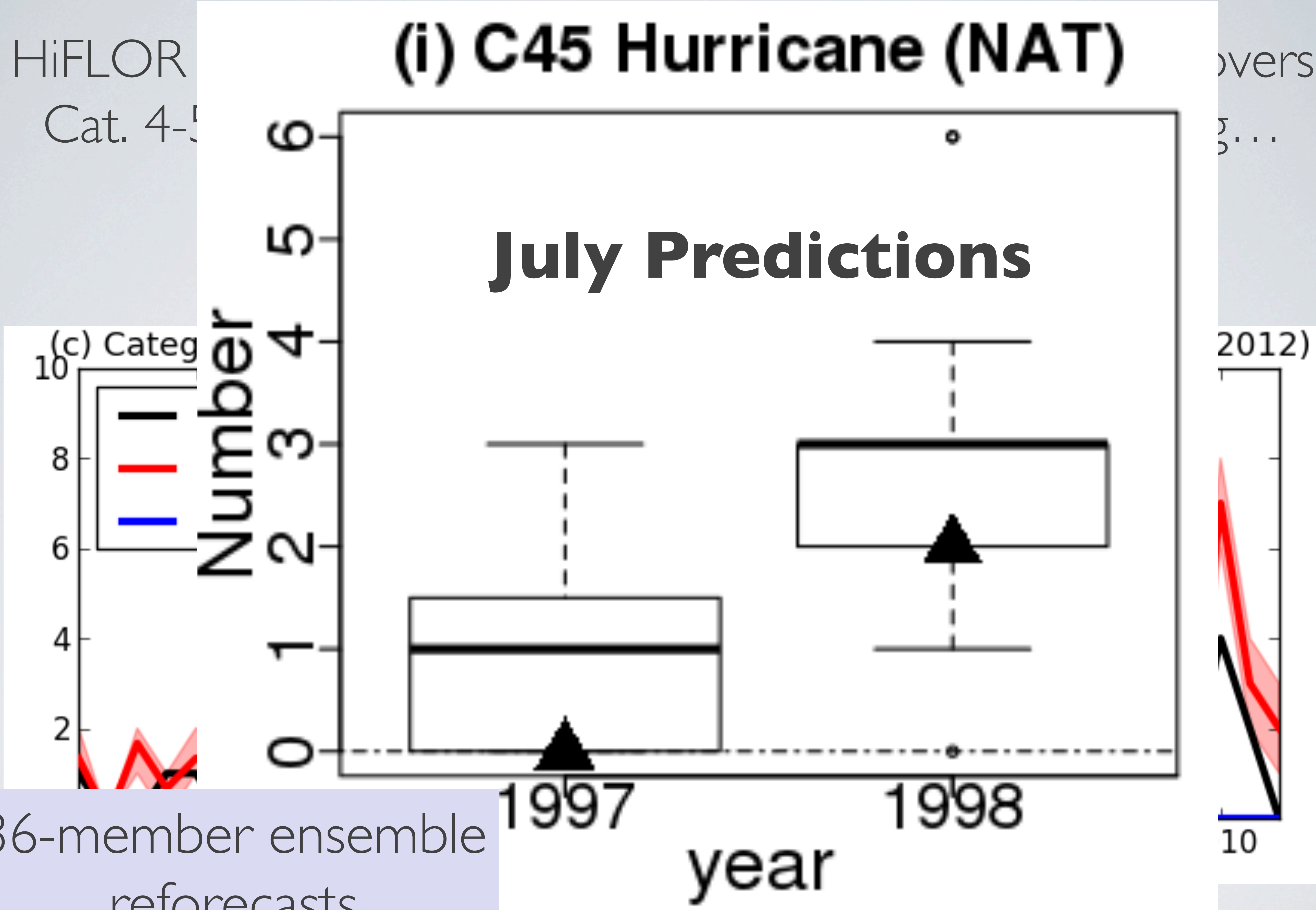
Murakami et al. (2015, submitted)

HiFLOR: doubling atmospheric resolution of FLOR (cost 6x) allows us model to simulate Cat. 4-5 TCs (most destructive storms)





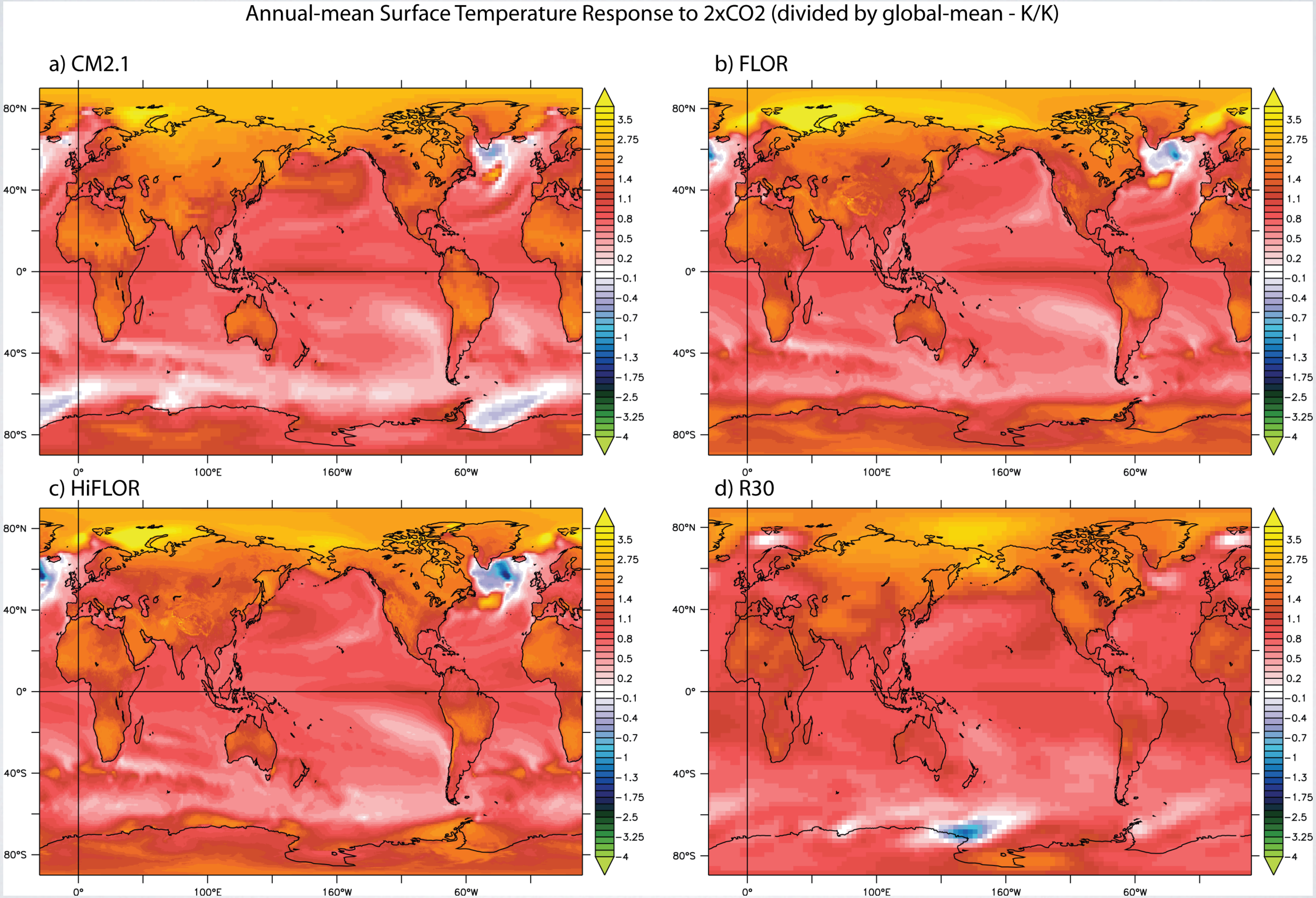
HiFLOR … overs
Cat. 4-5 … g…



36-member ensemble reforecasts

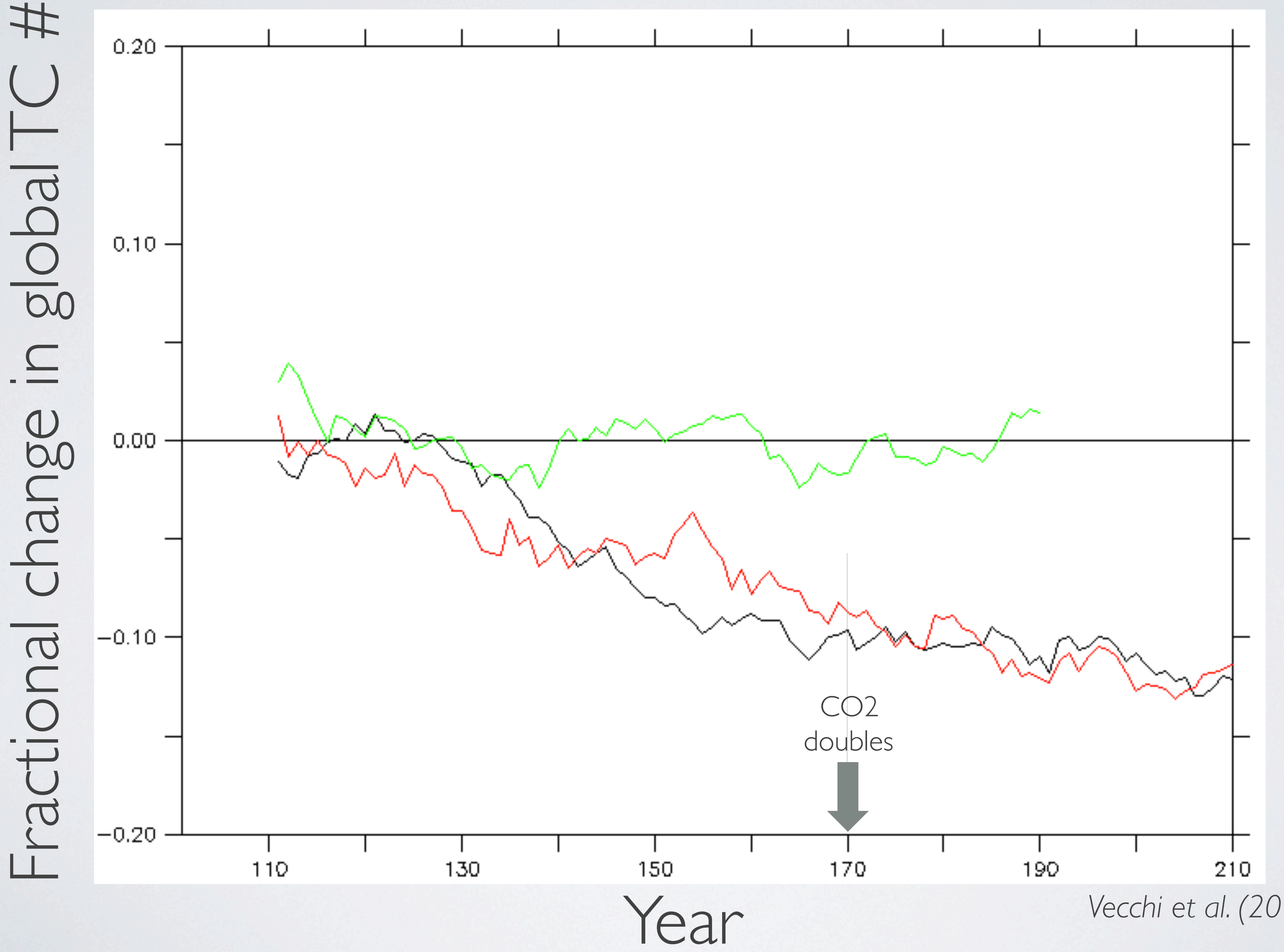
Murakami et al. (2015)

No fundamental difference between FLOR and HiFLOR in large-scale response to CO2 (e.g., SST)



Vecchi et al. (2015, in prep.)

Global TC frequency decrease in response to 2xCO2 in 0.5° FLOR and FLOR-FA no change in 0.25° HiFLOR – why?

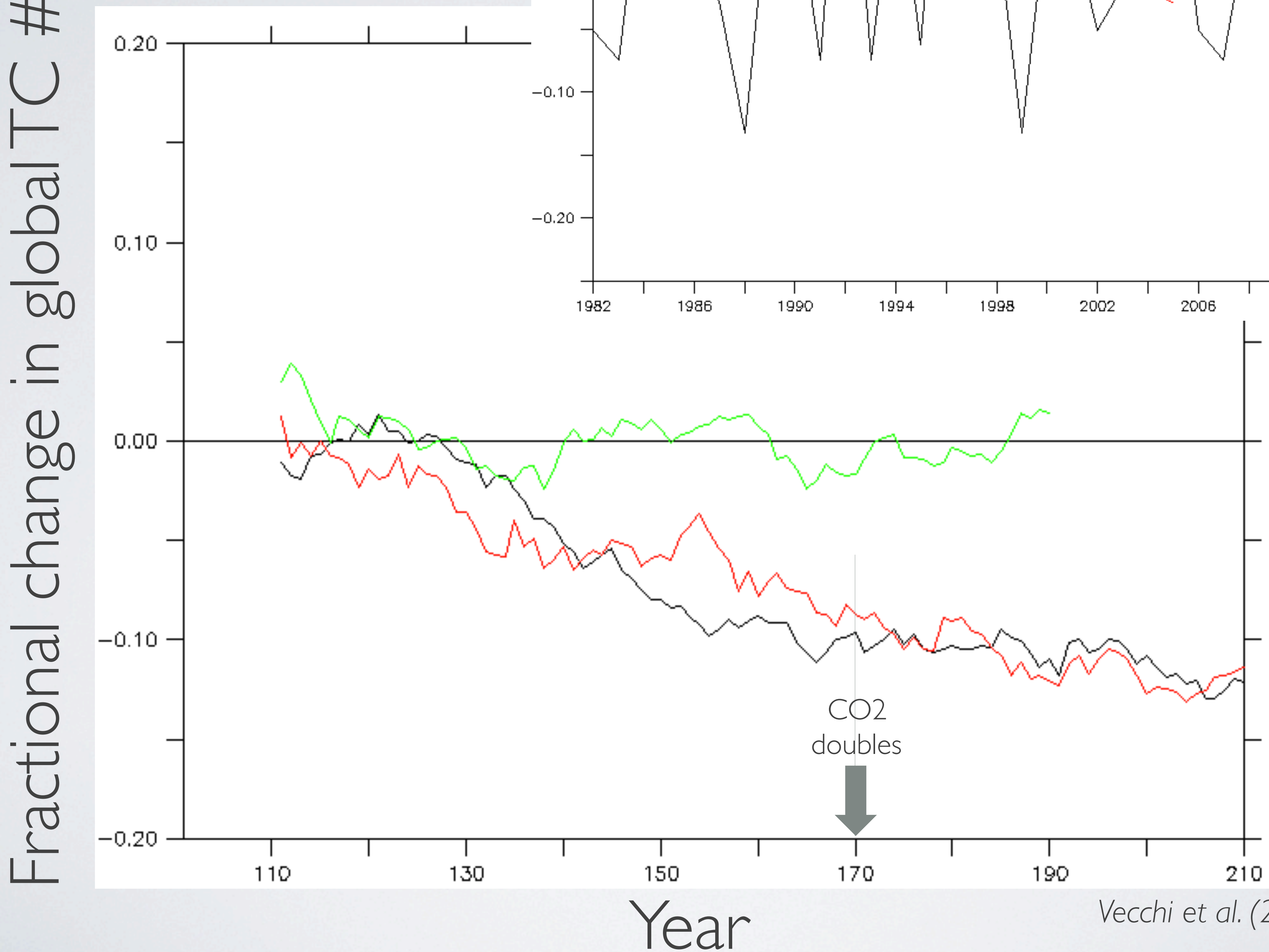


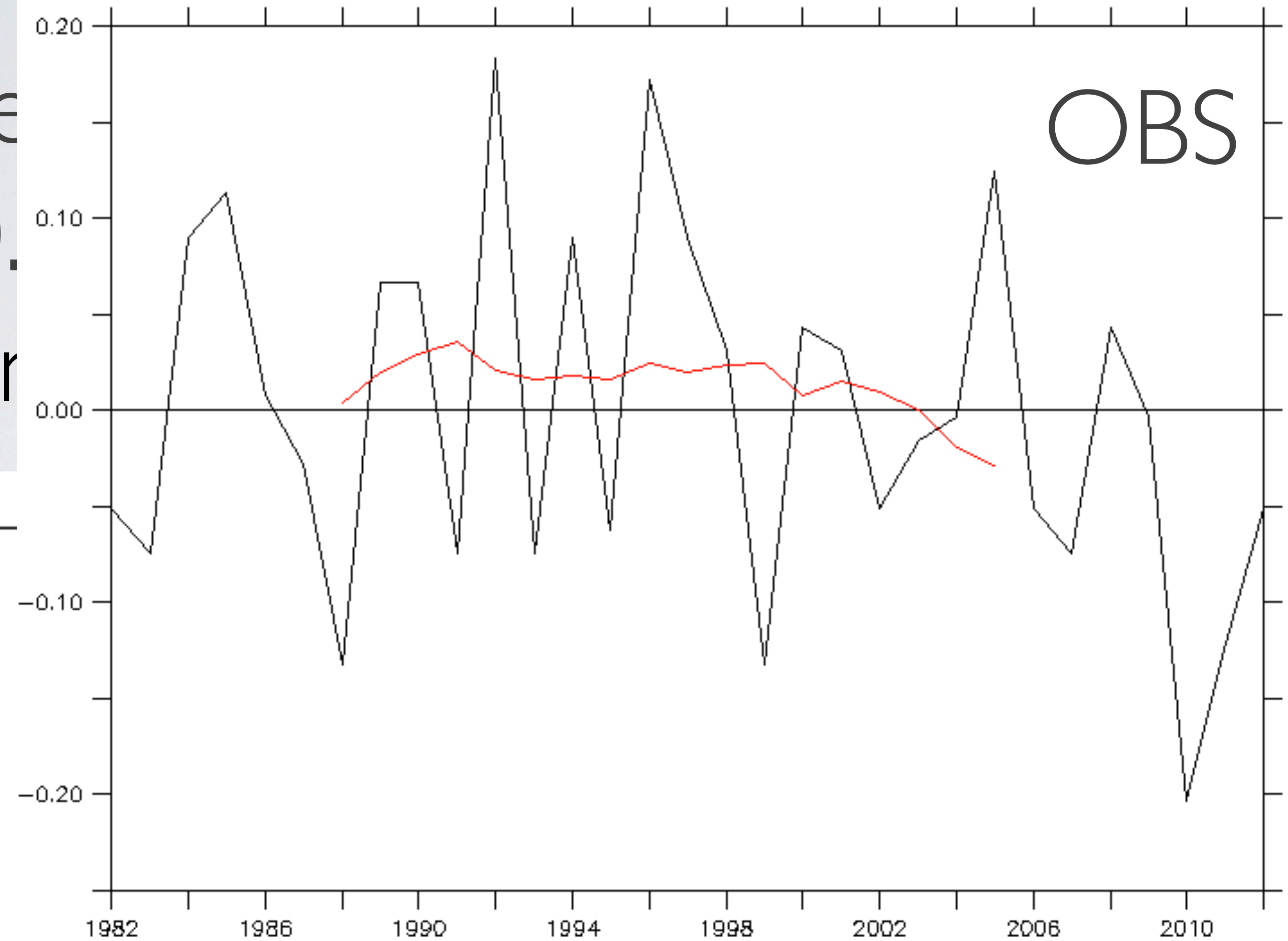
Vecchi et al. (2015, in prep.)

Global TC freque

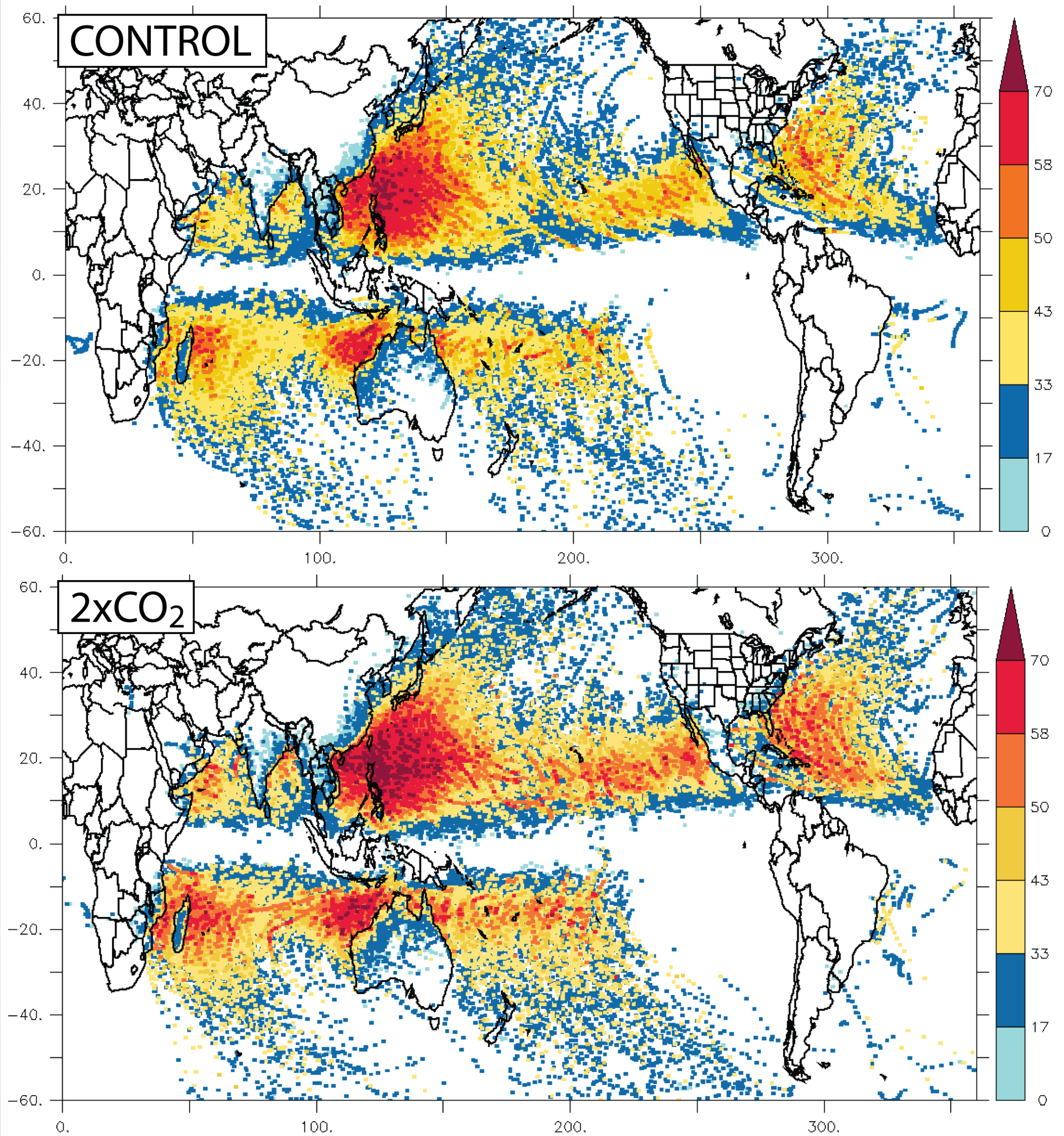
2xCO2 in 0.

no change i





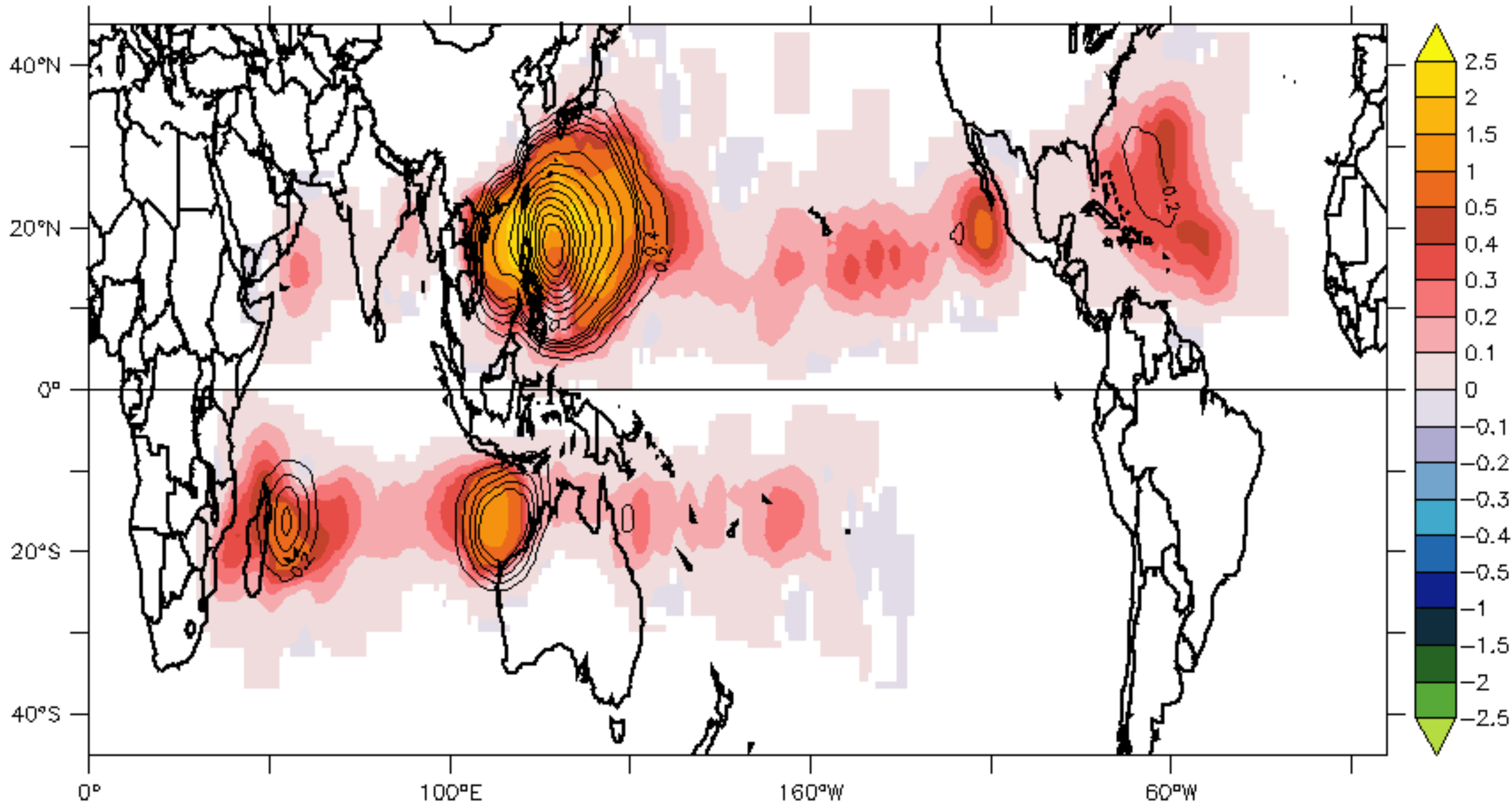
Vecchi et al. (2015, in prep.)



Increase in intensity from CO2 doubling in hiFLOR

Vecchi et al. (2015, in prep.)

Density increase of Cat 3-4-5s in all basins

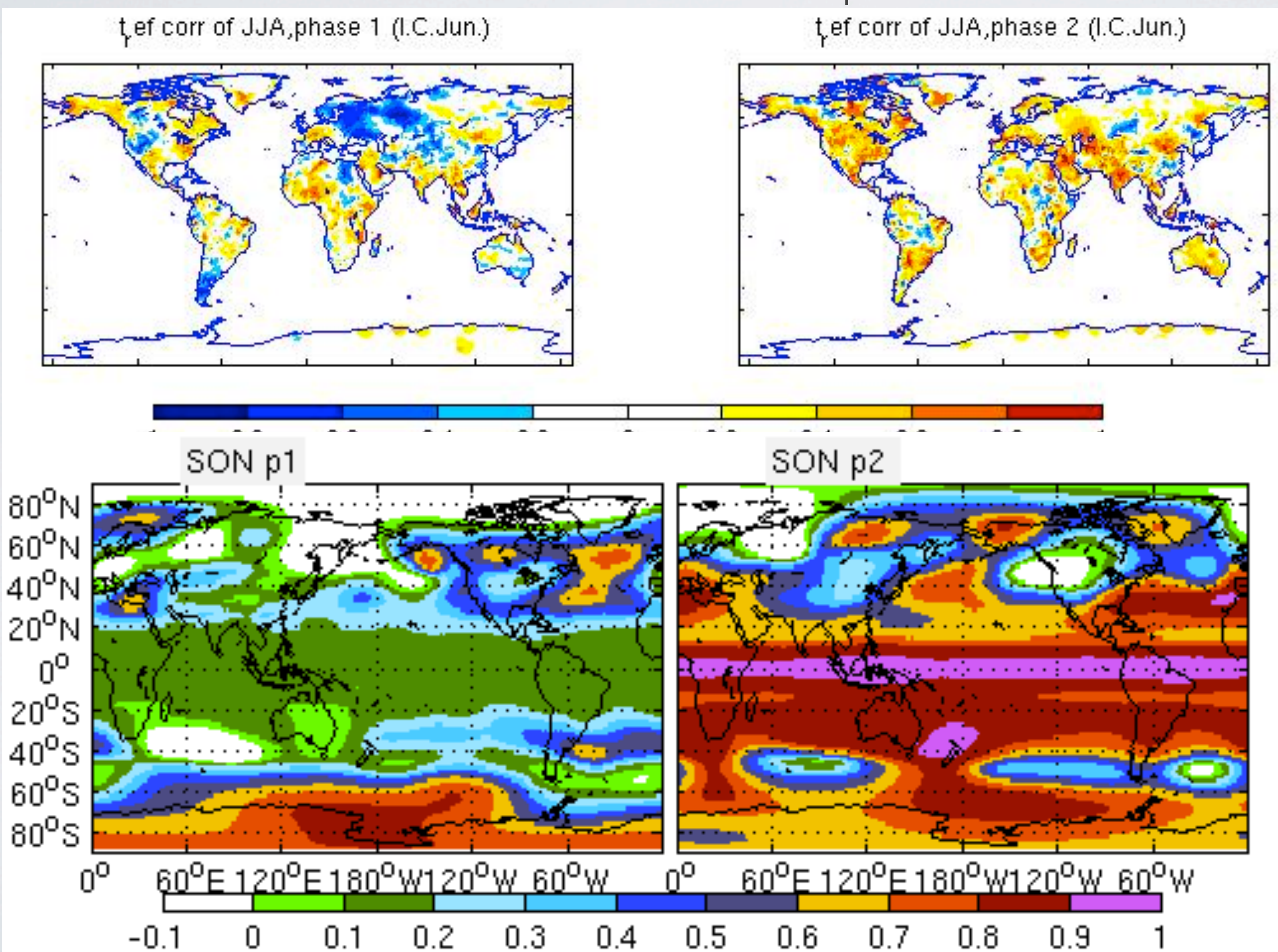


Vecchi et al. (2015, in prep.)

Next Steps

- Higher resolution to get to intensity
- Atmospheric initialization

Ocean Init — Atmosphere & Ocean Init



June-August
Surface temperature

Analysis: Liwei Jia

September-November
50hPa heights

Analysis: Xiaosong Yang

Next Steps

- Higher resolution to get to intensity
- Atmospheric initialization
- Assimilation built on FLOR:
  Goal: initial state in better balance (reduce drift)
  Computationally expensive

Next Steps

- Higher resolution to get to intensity
- Atmospheric initialization
- Assimilation built on FLOR
- Make predictions more explicitly probabilistic :
  How do we build an error model?

Next Steps

- Higher resolution to get to intensity
- Atmospheric initialization
- Assimilation built on FLOR
- Make predictions more explicitly probabilistic
- Higher "top": what is the role of stratospheric processes in the variation/change and prediction of extremes?