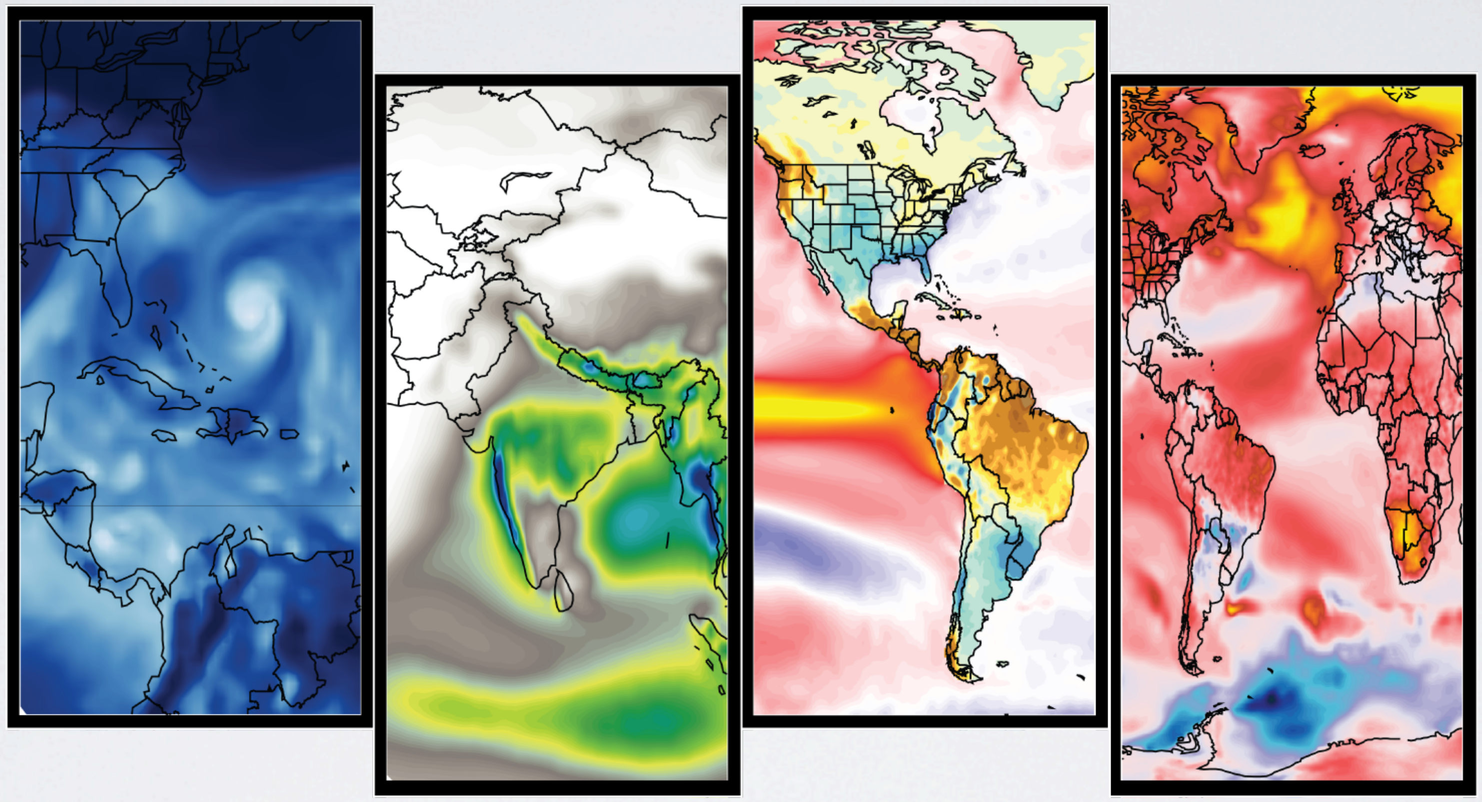
Towards Seasonal Predictions of Regional Hurricane Activity

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:

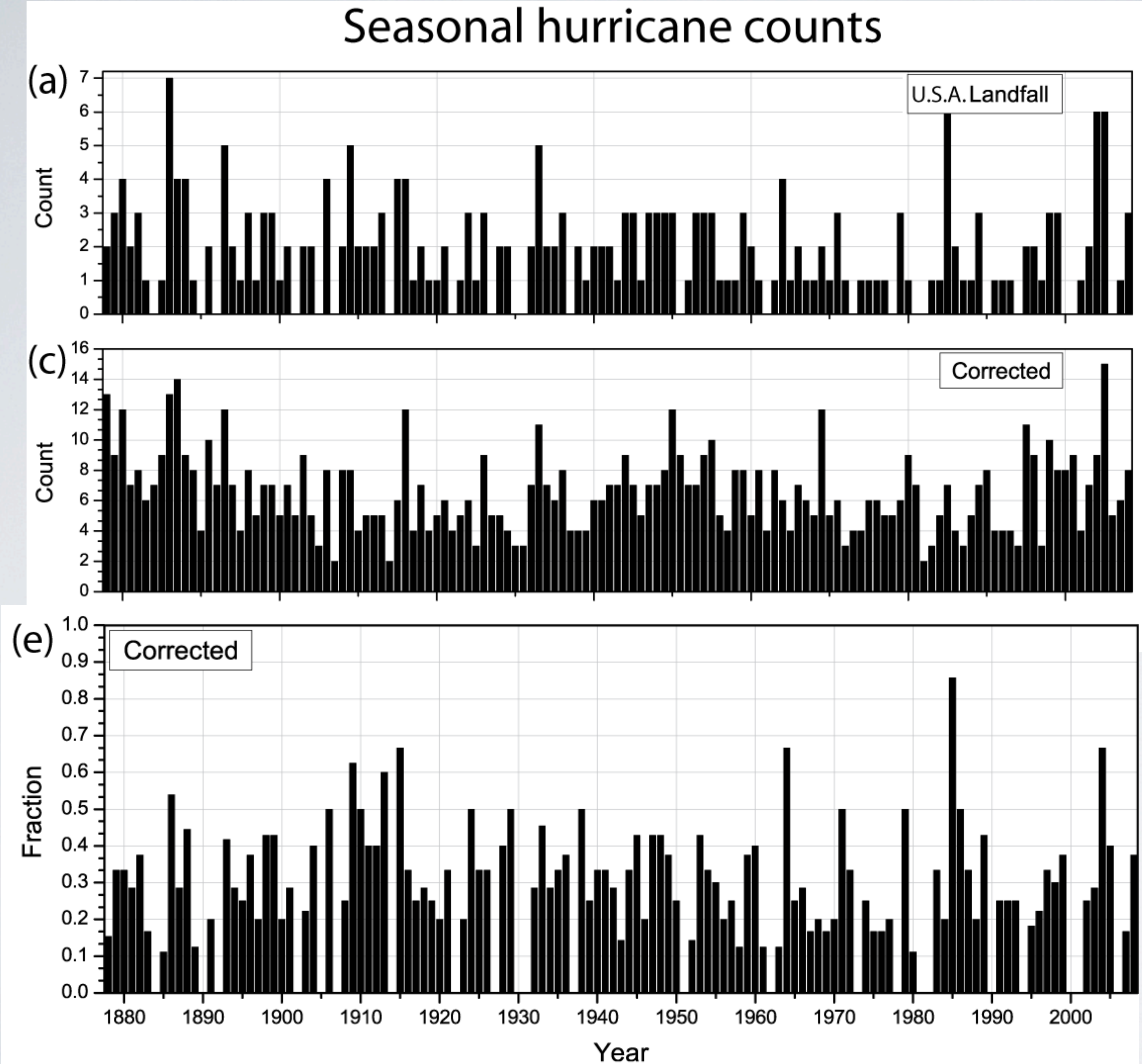
- Yield improved forecasts of large-scale climate
- Enable forecasts of regional climate and extremes

Outline

- Motivation
- Development of prediction model: focus on high atmospheric resolution
- Phase 1 of retrospective forecasts: ocean/sea ice initialize
- Next stages

Why make predictions?

- Pragmatic reasons: skillful predictions help support decisions by providing glimpses of the future.
- Scientific reasons: prediction is a fundamental element of scientific method, providing tests to hypotheses underlying them.



U.S. Landfalling Hurricanes

Basinwide Hurricanes

Fraction of Basinwide Hurricanes Making U.S. Landfall

Vecchi and Knutson (2011, J. Clim.); Villarini et al. (2012, J. Clim.)

Sources of & Limitations on Climate Predictability

Months to decades

hours to a month

Evolution of initial state of ocean/atmosphere.
Need good models and observations of present and past

Many decades to centuries

Climate response to forcing
(*e.g.*, CO_2, soot/dust, sun, volcanoes, land use)
need good models and estimates of forcing

Predictability has inherent limits: need to be probabilistic.

Elements of Climate Prediction System of Systems

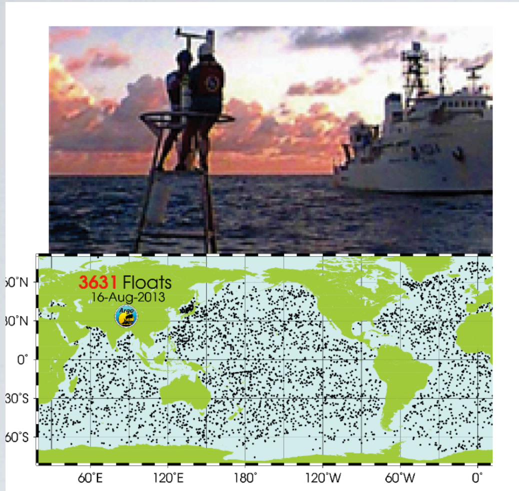
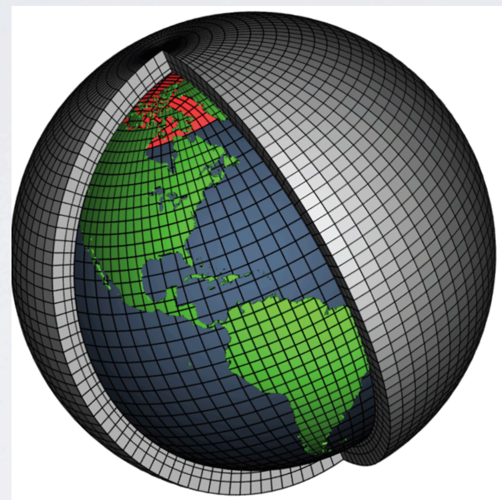
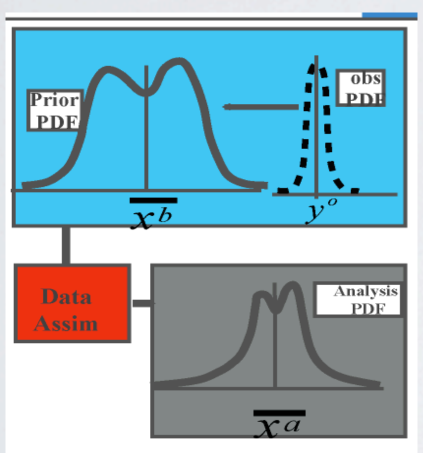


Image sources: NOAA/PMEL and Argo.ucsd.edu

Global climate observing system:
Sparse observations of many quantities across globe.



Dynamical modeling system:
Allows forward integration from present state, including expected changes in radiative forcing.



Data assimilation system:
Combines sparse observations with model, to estimate present state. Usually based on dynamical model.

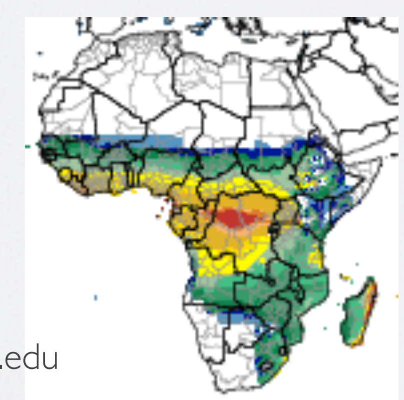
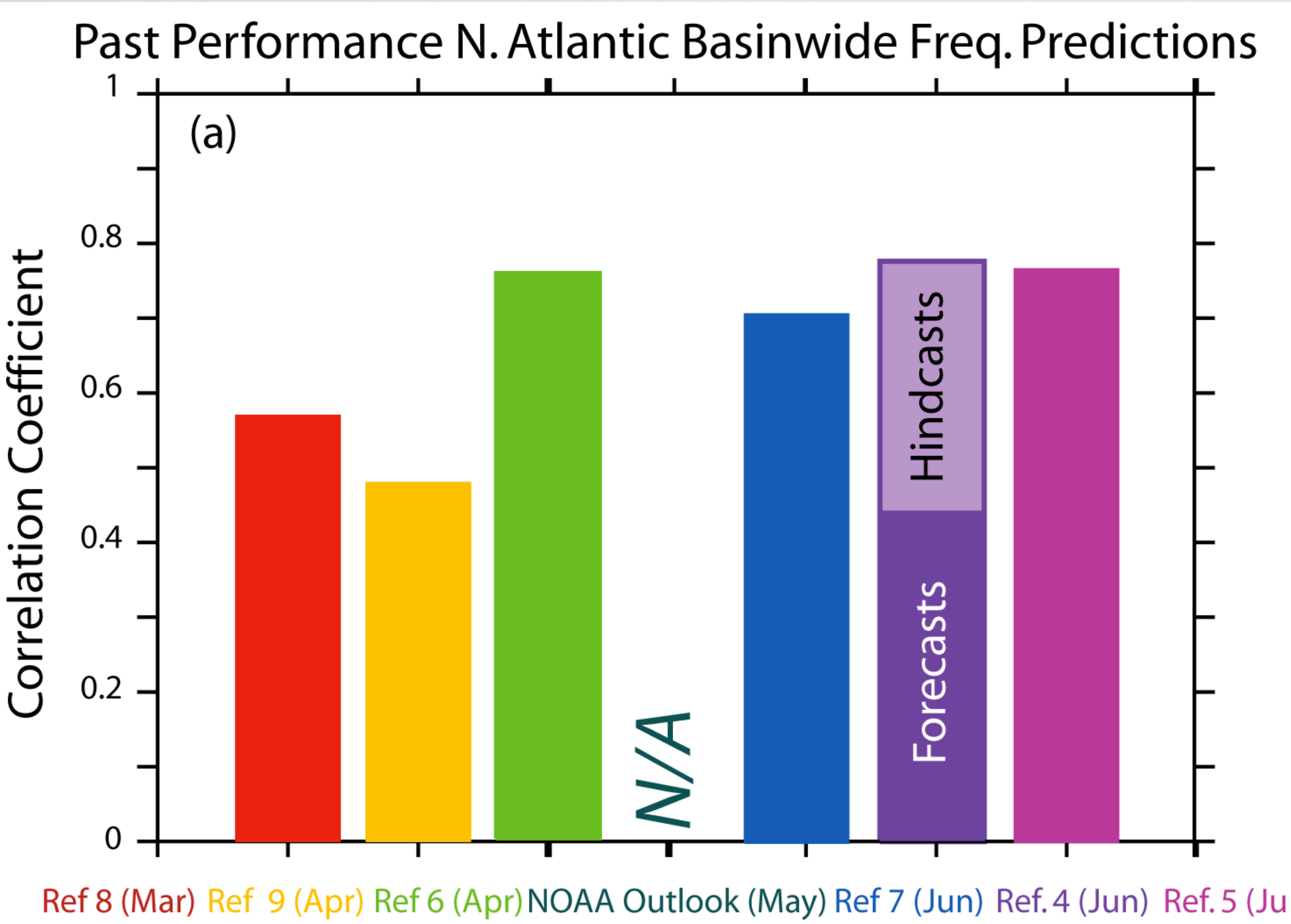


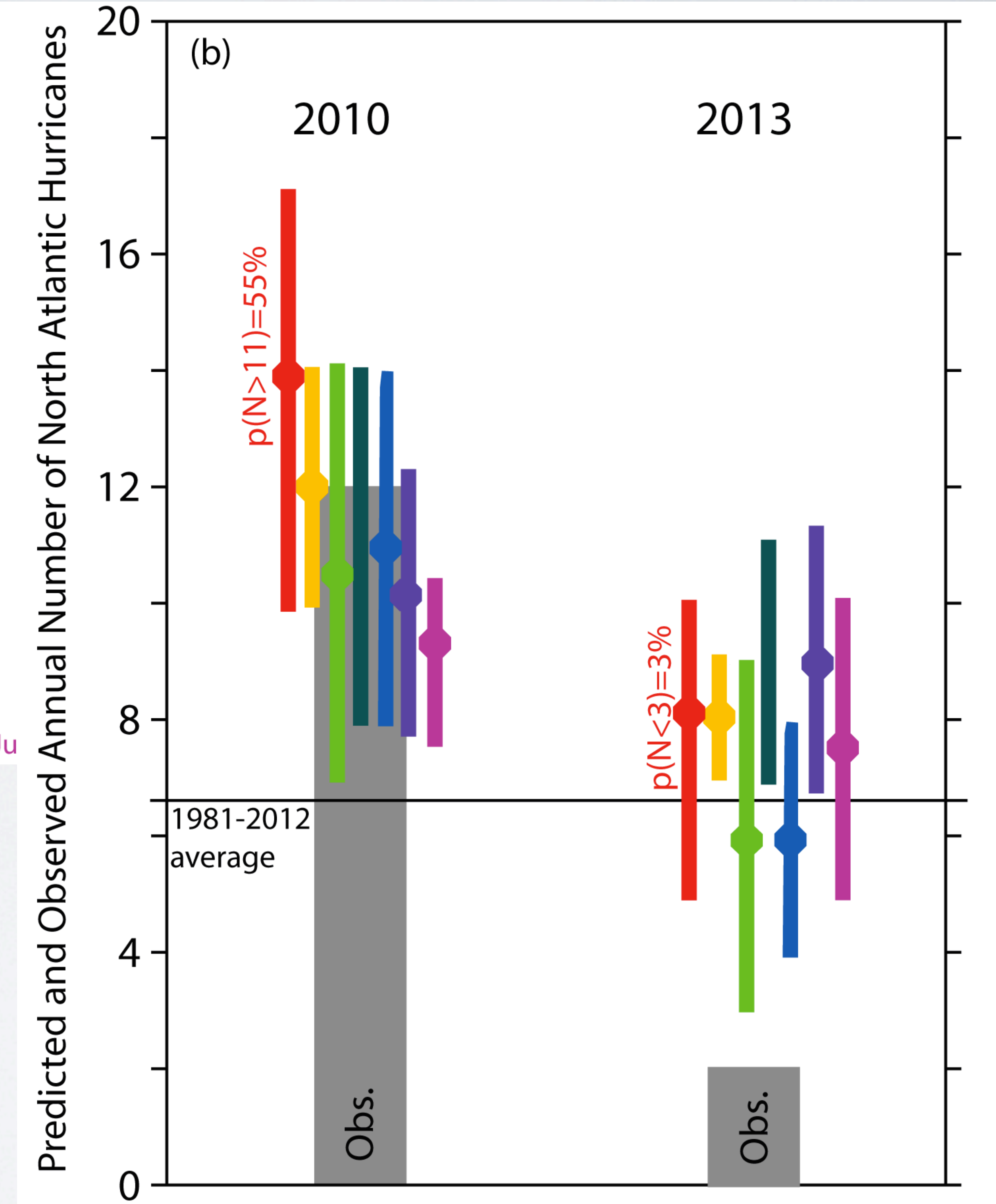
Image source: http://iridl.ldeo.columbia.edu

Analysis and dissemination system:
Take output from predictions and produce "useful" information, communicate predictions.

Predictions of Basinwide Hurricane Activity

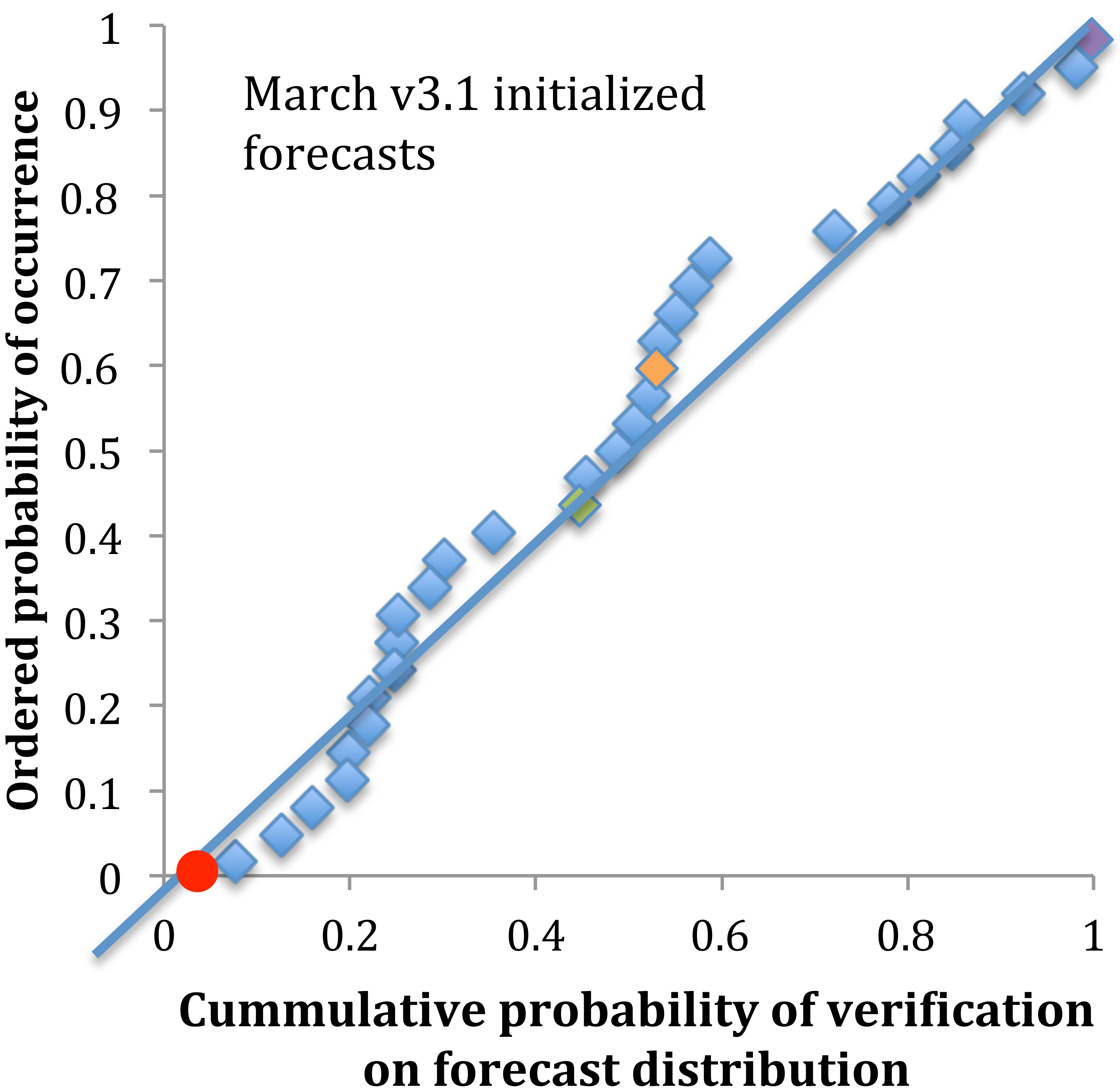


Statistical, dynamical and hybrid statistical-dynamical schemes regularly (and skillfully) predict seasonal hurricane activity.



Vecchi and Villarini (2014)

Even though 2013 has poor deterministic skill: Prediction PDF appears relatively well calibrated



Blue: prior to publication of method

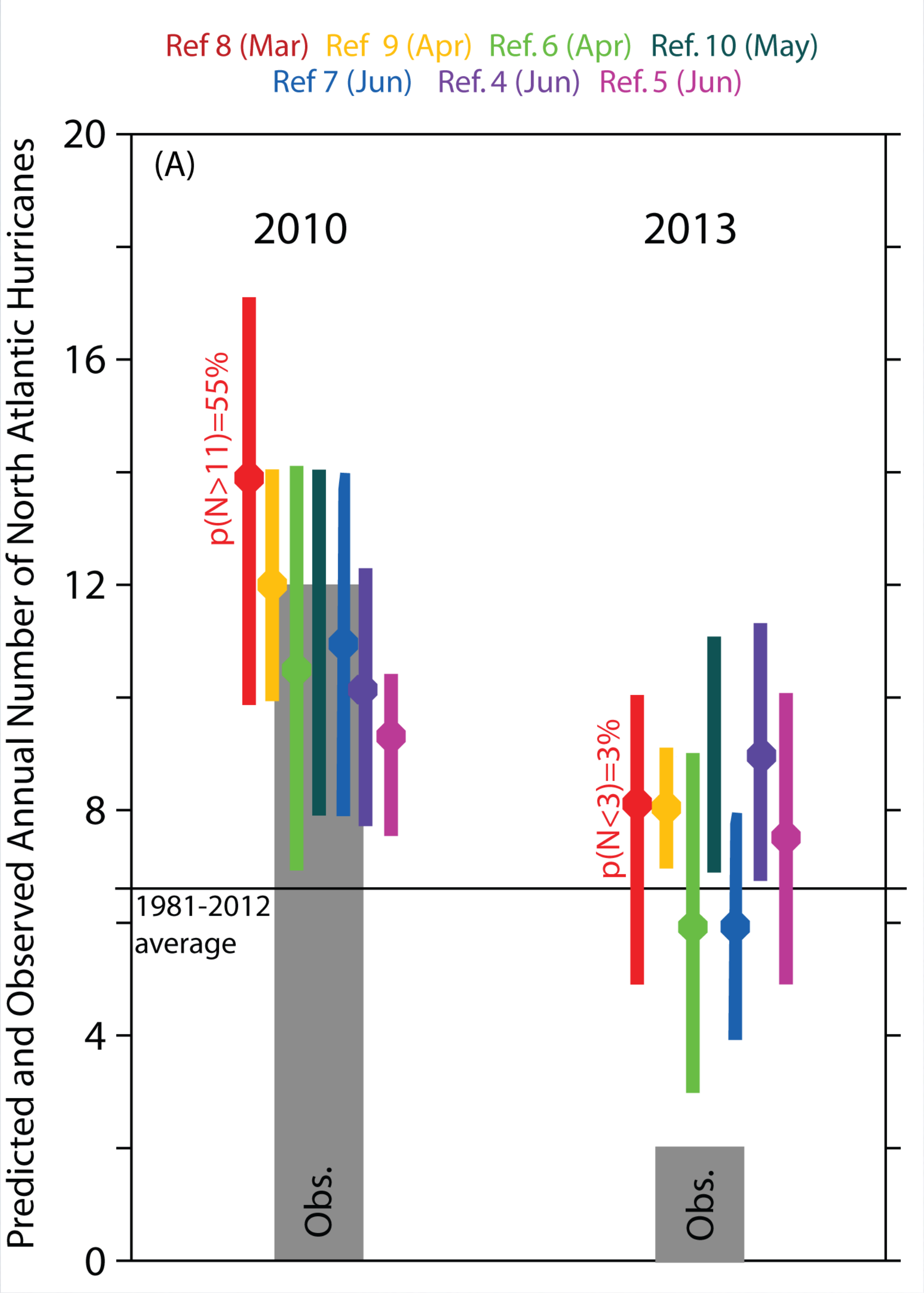
Colors: post-publication (2010-2012)

● 2013

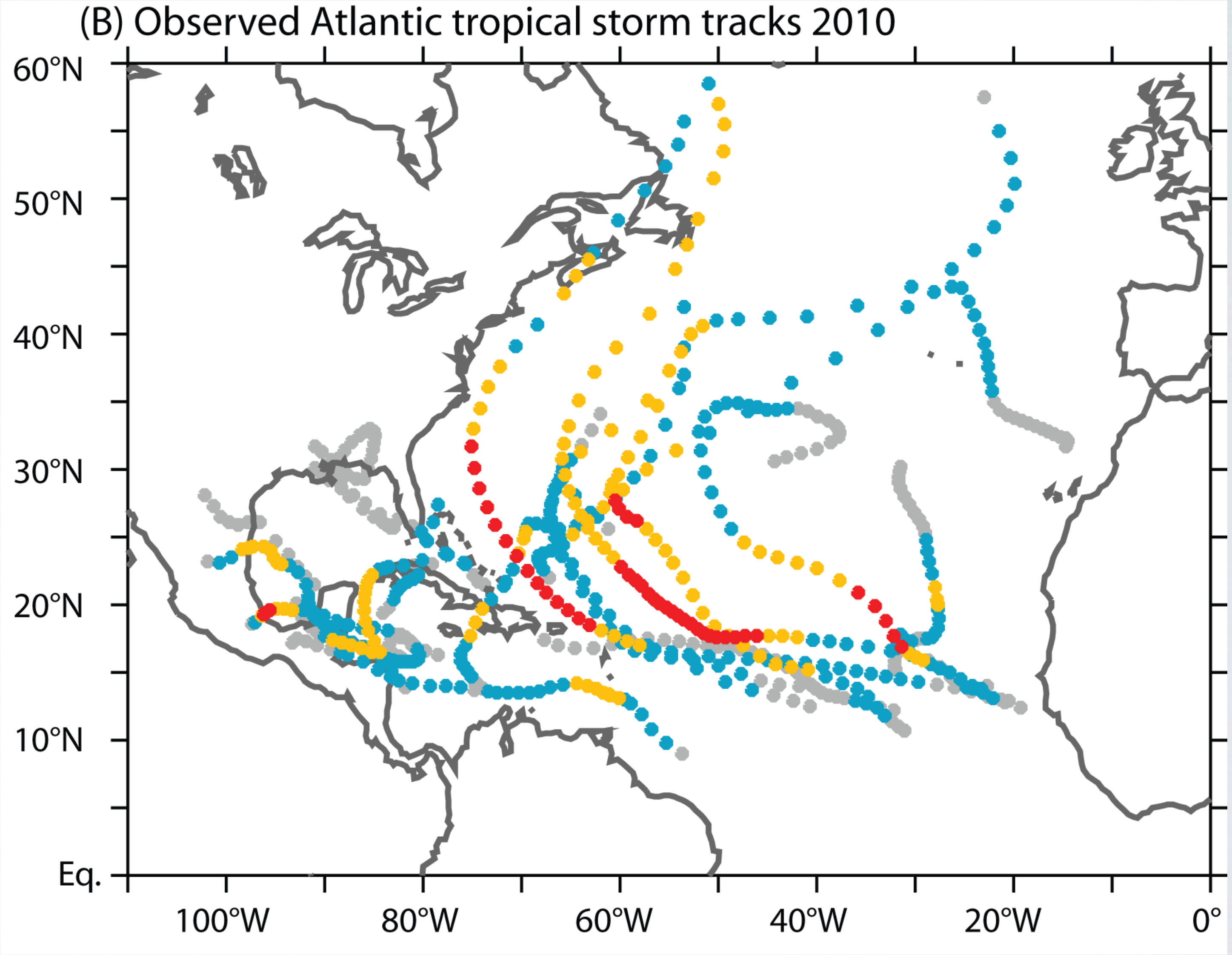
Make PDF, not mode, of TC activity the target

Update of Vecchi et al. (2011)

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

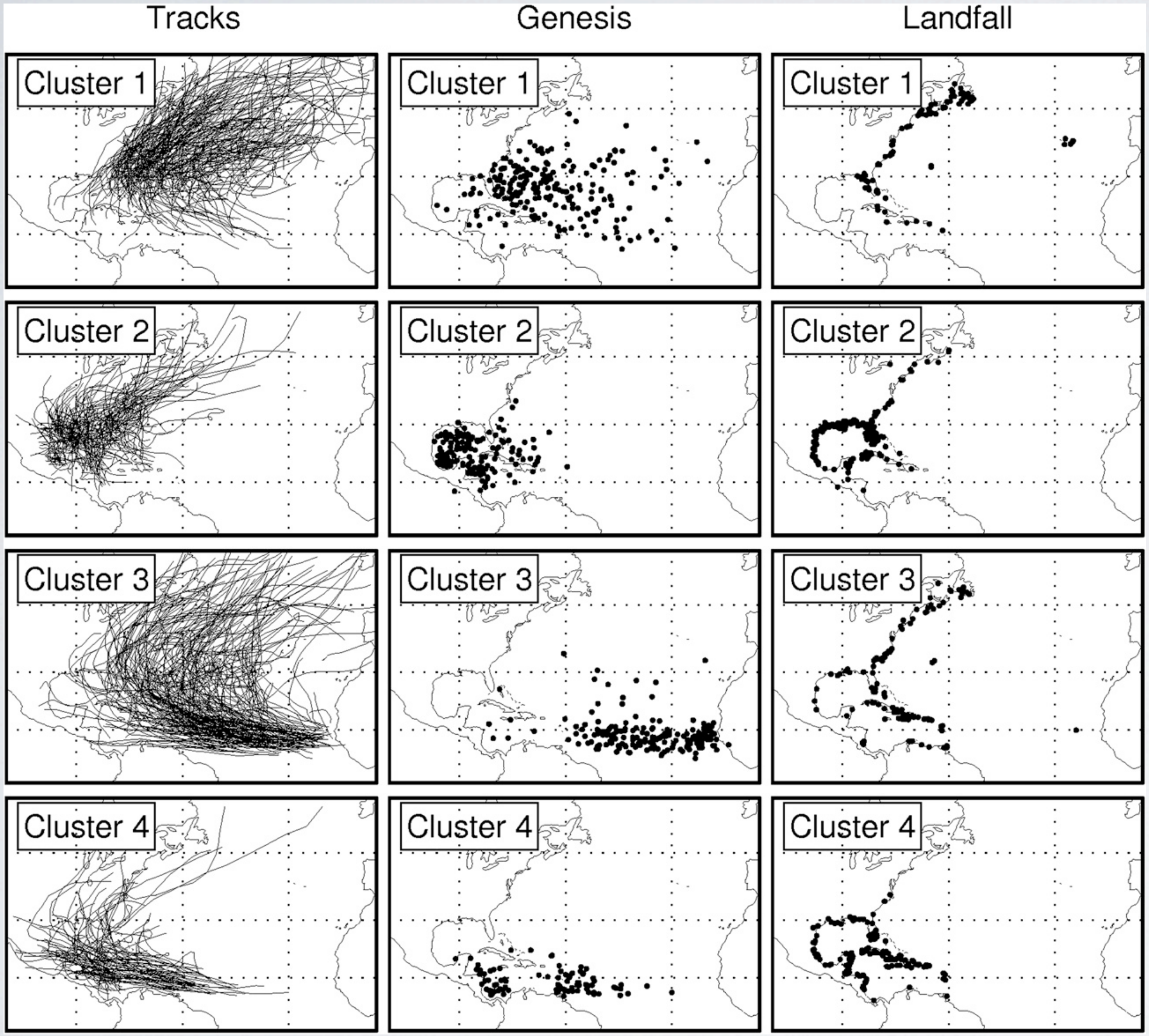


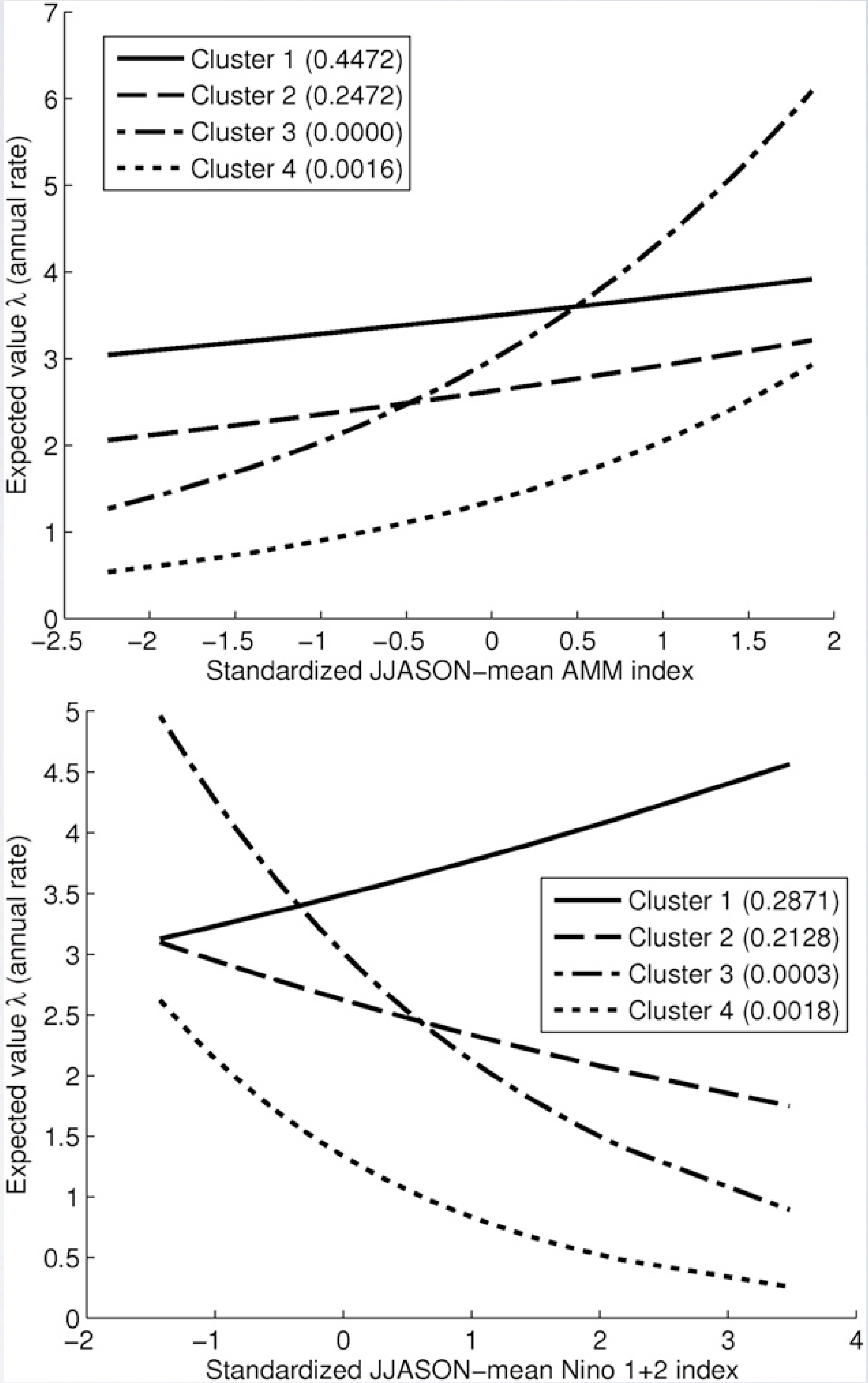
Can we reliably predict statistics of storms more regionally than "basin-wide"?



Vecchi and Villarini (2014)

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





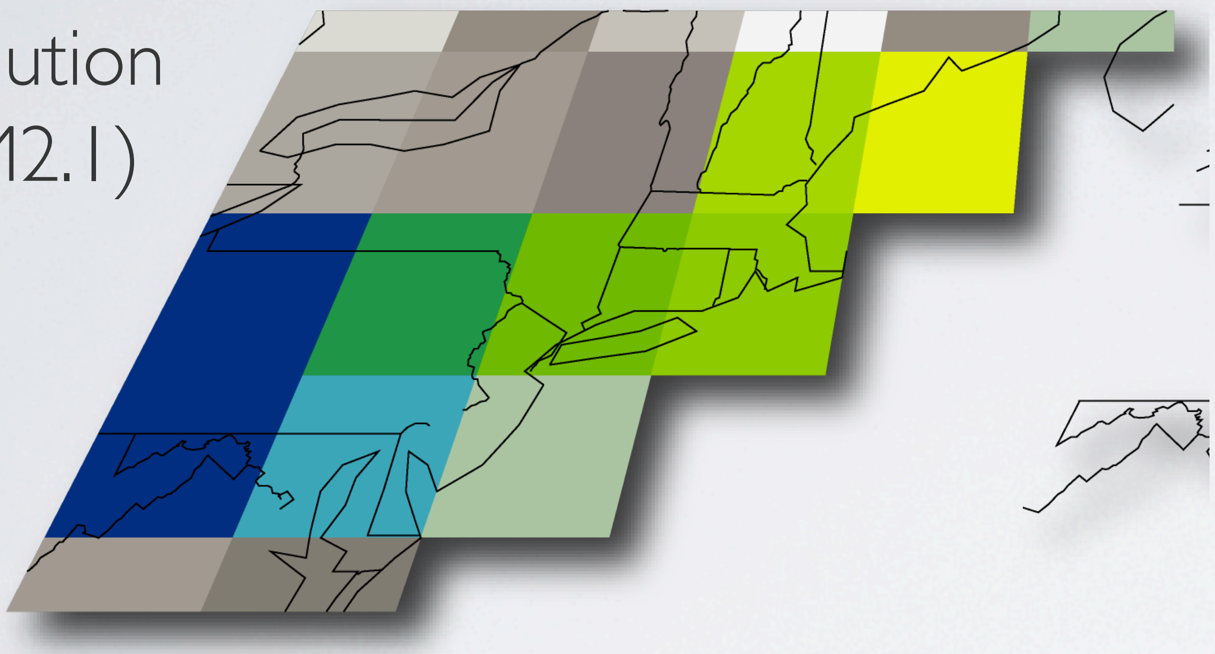
Kossin, Camargo and Sitkowski (2010)

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

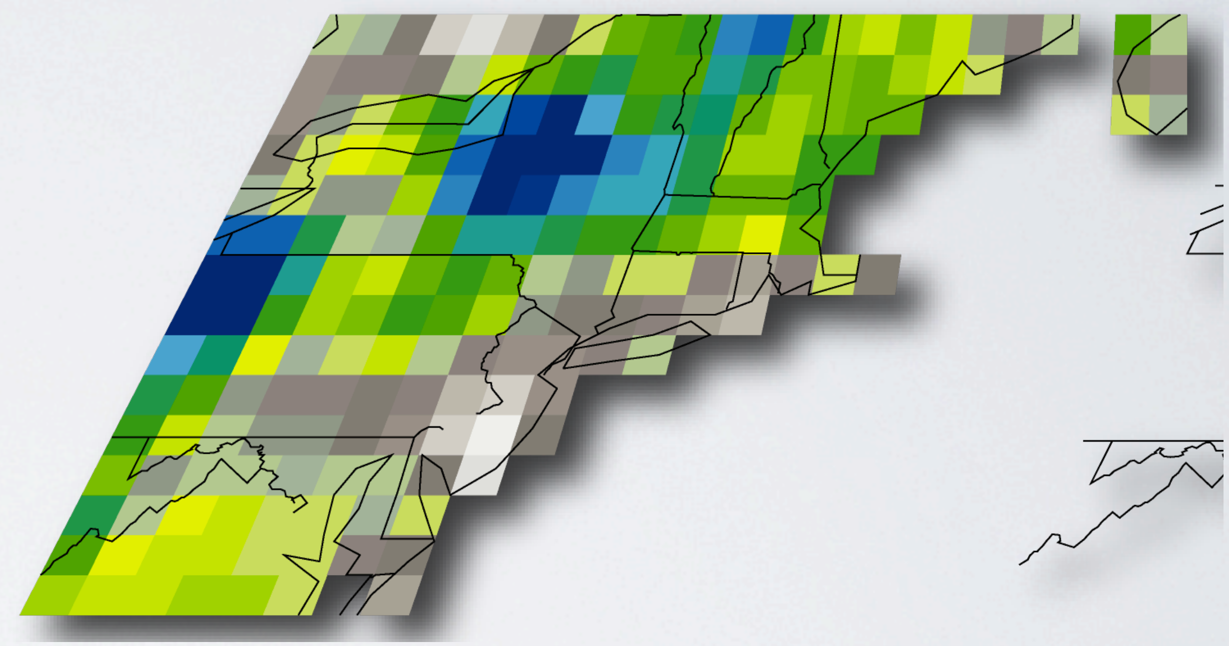
Goal: Build a seasonal to decadal forecasting system to:
- Yield improved forecasts of large-scale climate
- Enable forecasts of regional climate and extremes

Precipitation in Northeast USA

Medium resolution (CM2.1)



High resolution (CM2.5-FLOR)

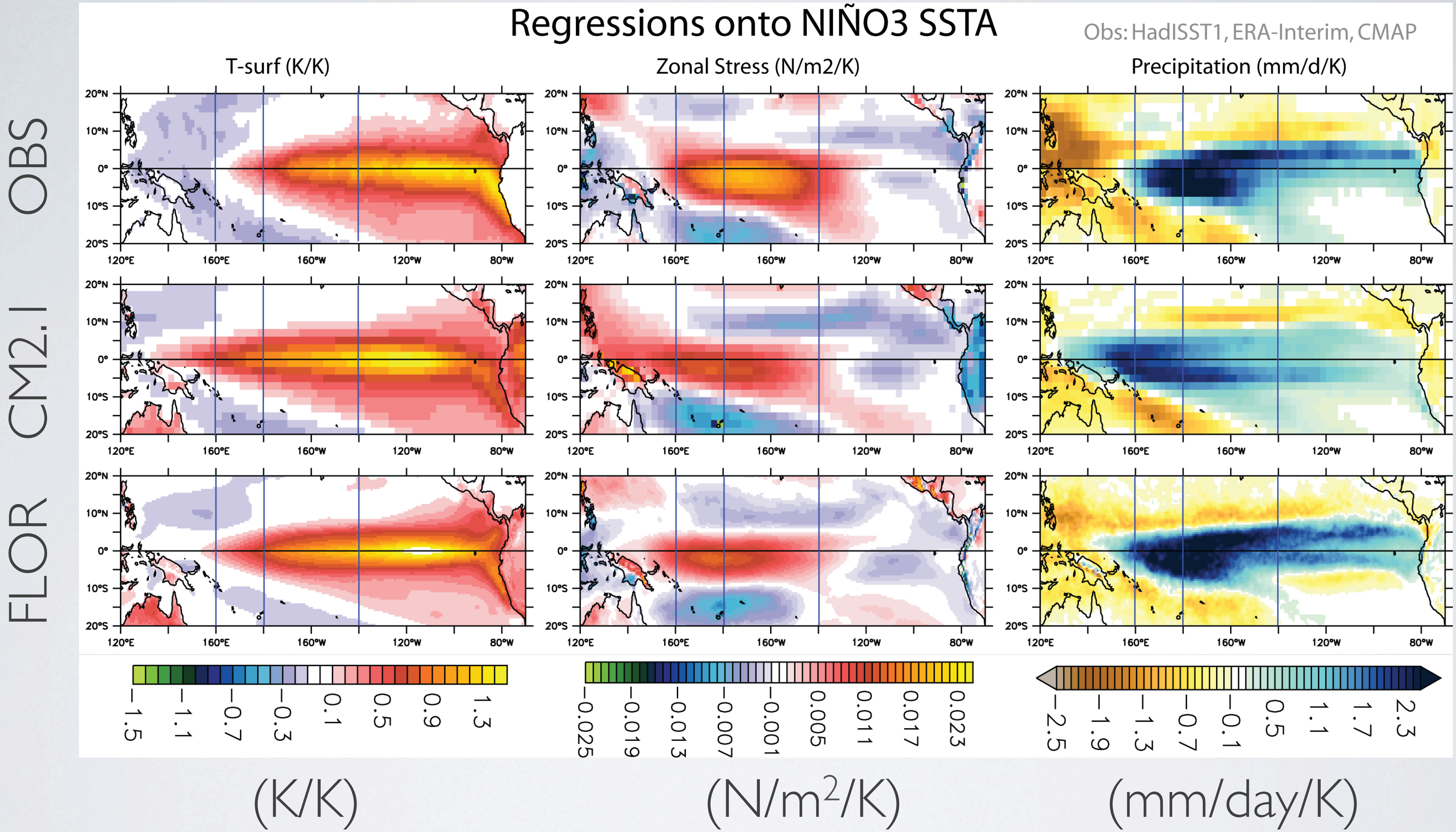


Delworth et al. (2012), Vecchi et al. (2014)

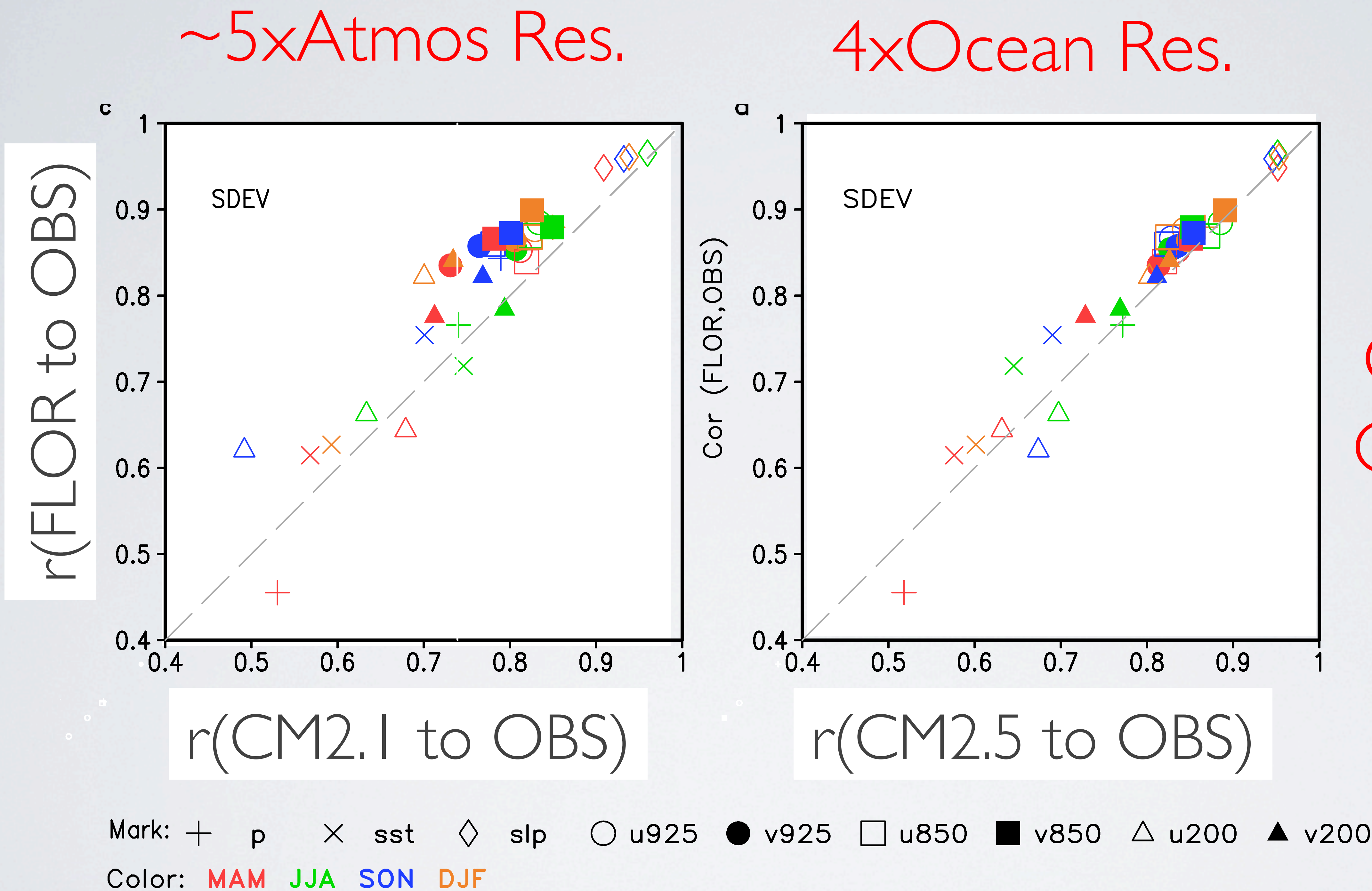
Modified version of CM2.5 (Delworth et al. 2012):
- 50km cubed-sphere atmosphere
- 1° ocean/sea ice (low res enables prediction work)

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

Structure of ENSO anomalies improved by atmospheric resolution



Hypothesis: Enhanced atmos./land resolution improves climate

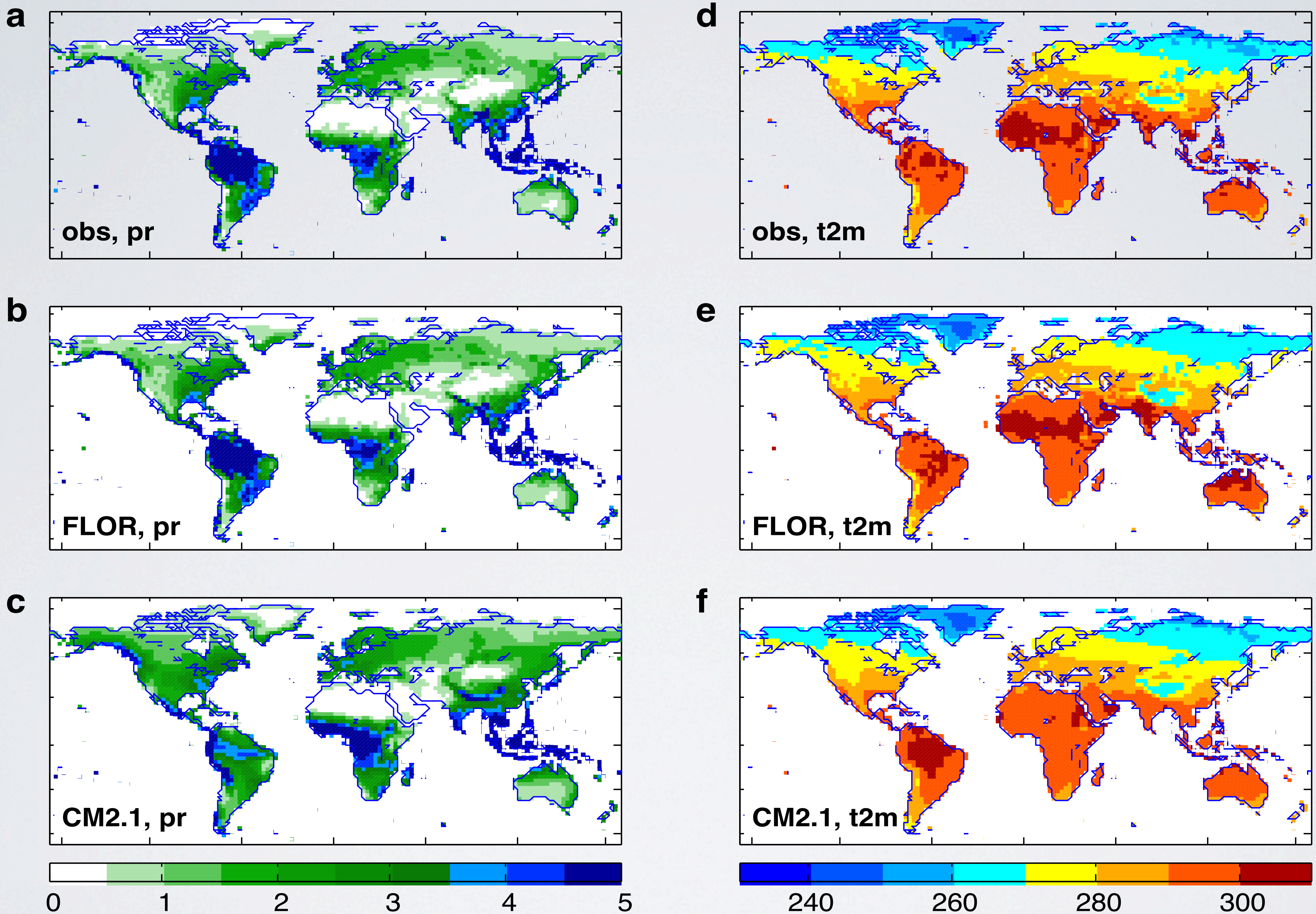


Spatial Correlation Of Standard Deviation

Figure: Lakshmi Krishnamurthy

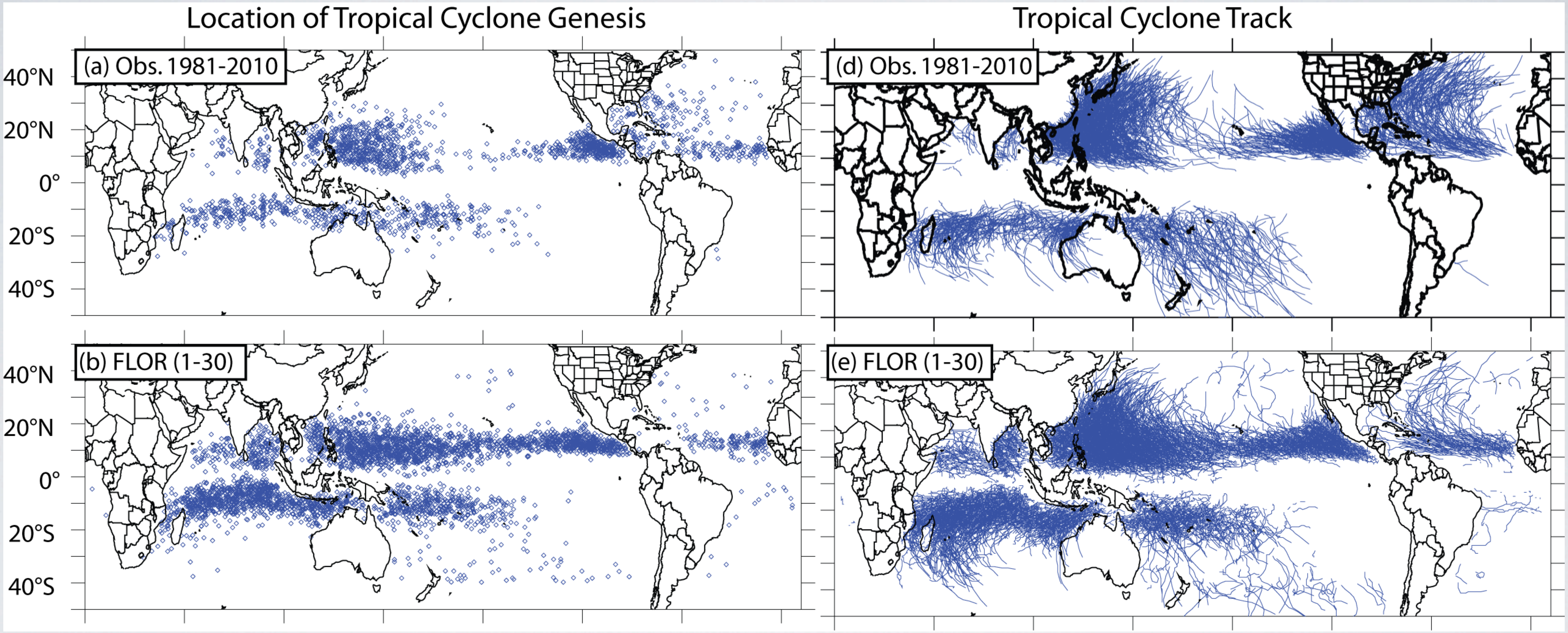
Jia et al. (2014, J. Clim.)

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.

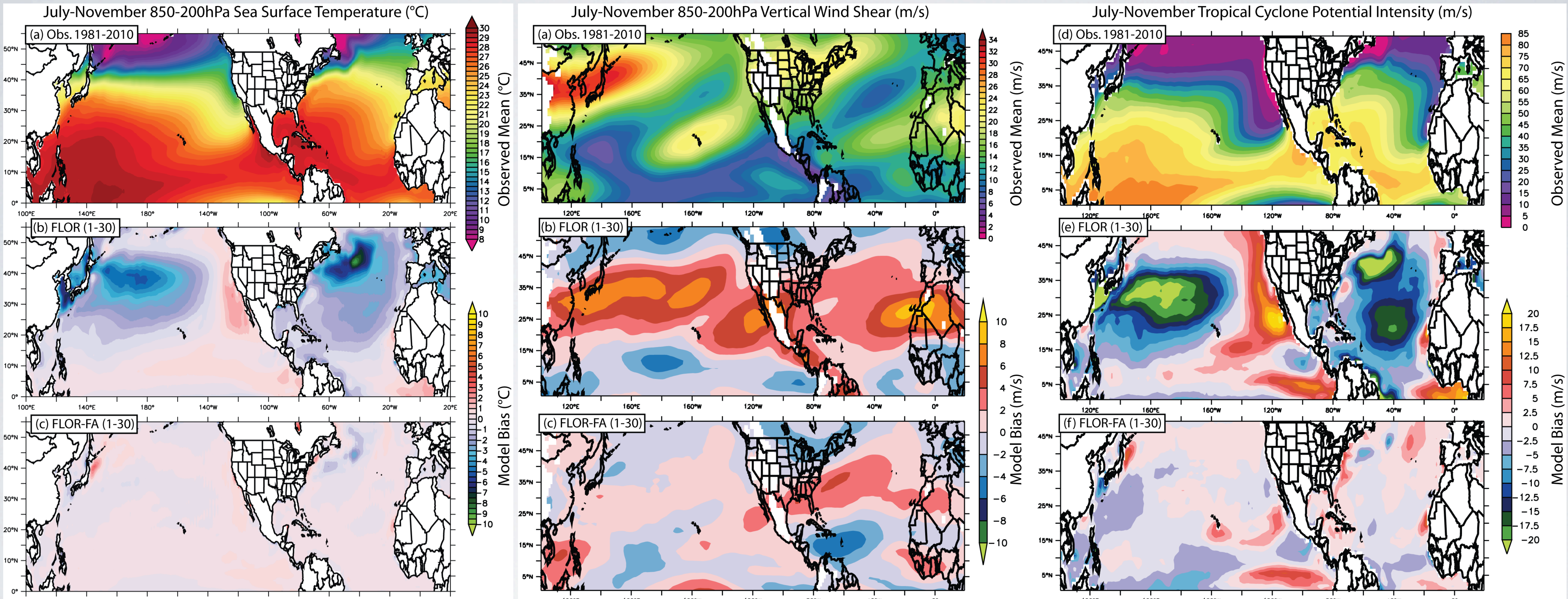
- **Methodology:** FA version of FLOR with climatological (once computed, independent of model state) adjustment to momentum, freshwater and enthalpy fluxes to ocean.

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

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

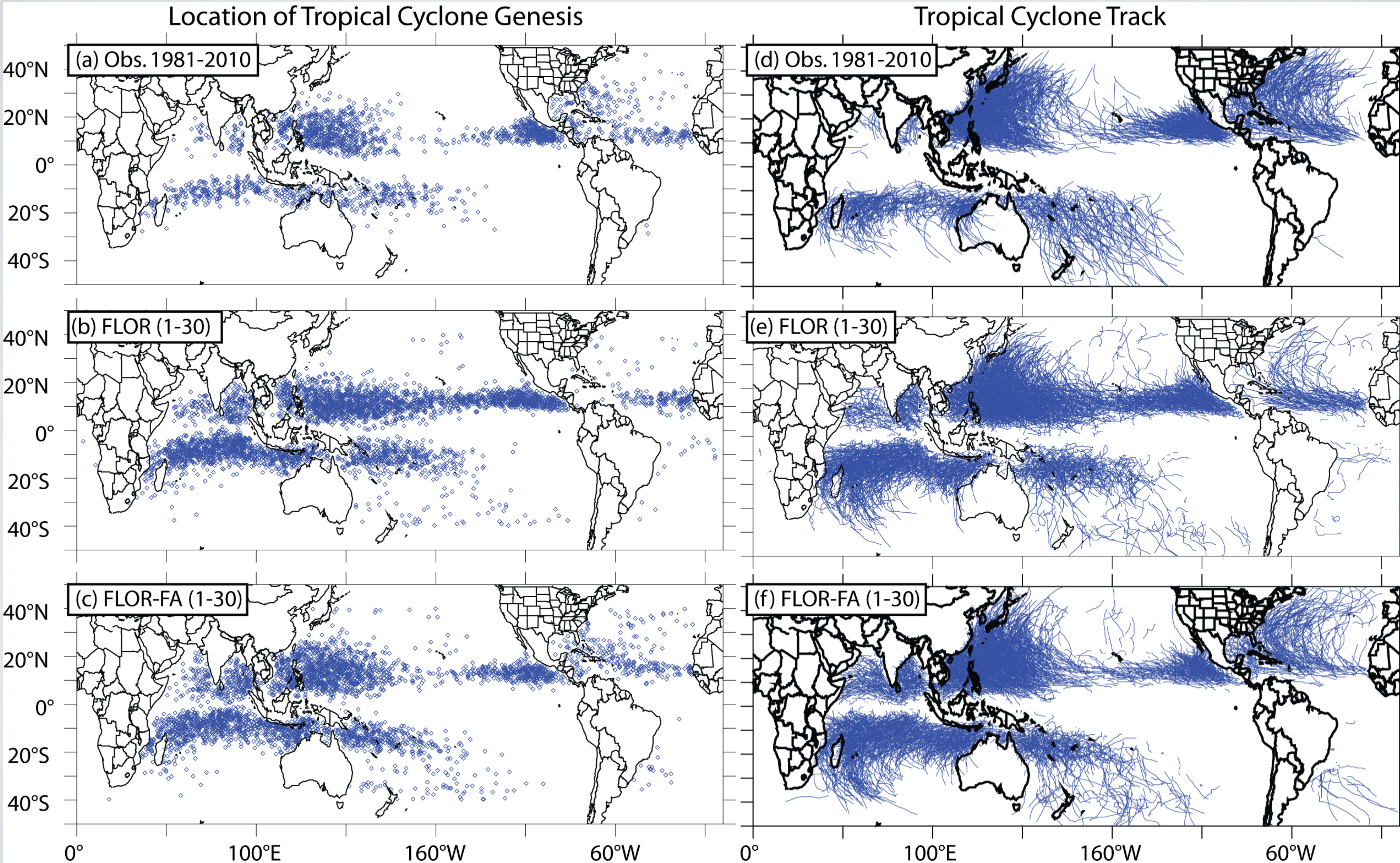
Large-scale biases in summer climate map onto some of TC biases

SST Shear Potential Intensity



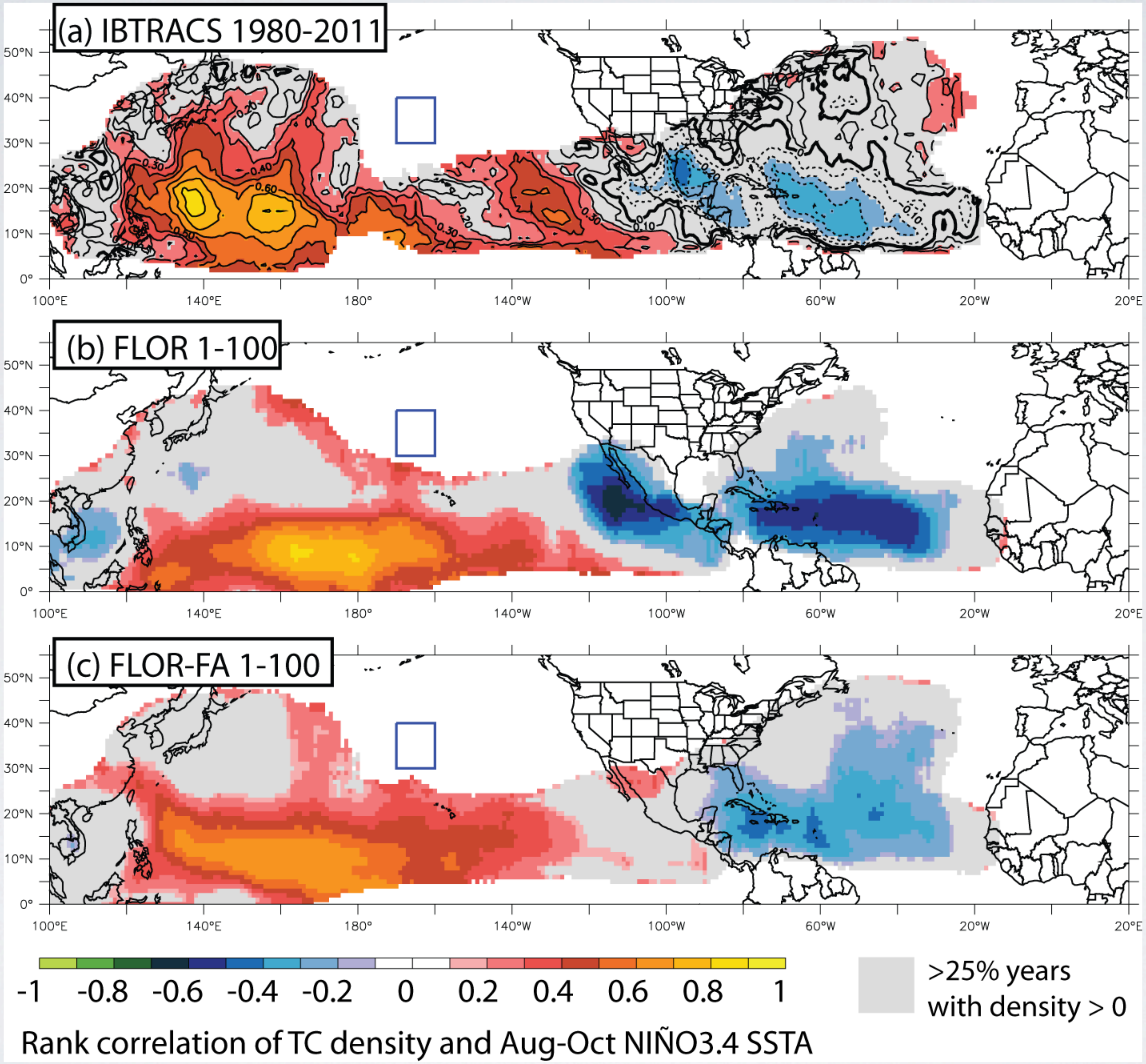
Vecchi et al. (2014)

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)

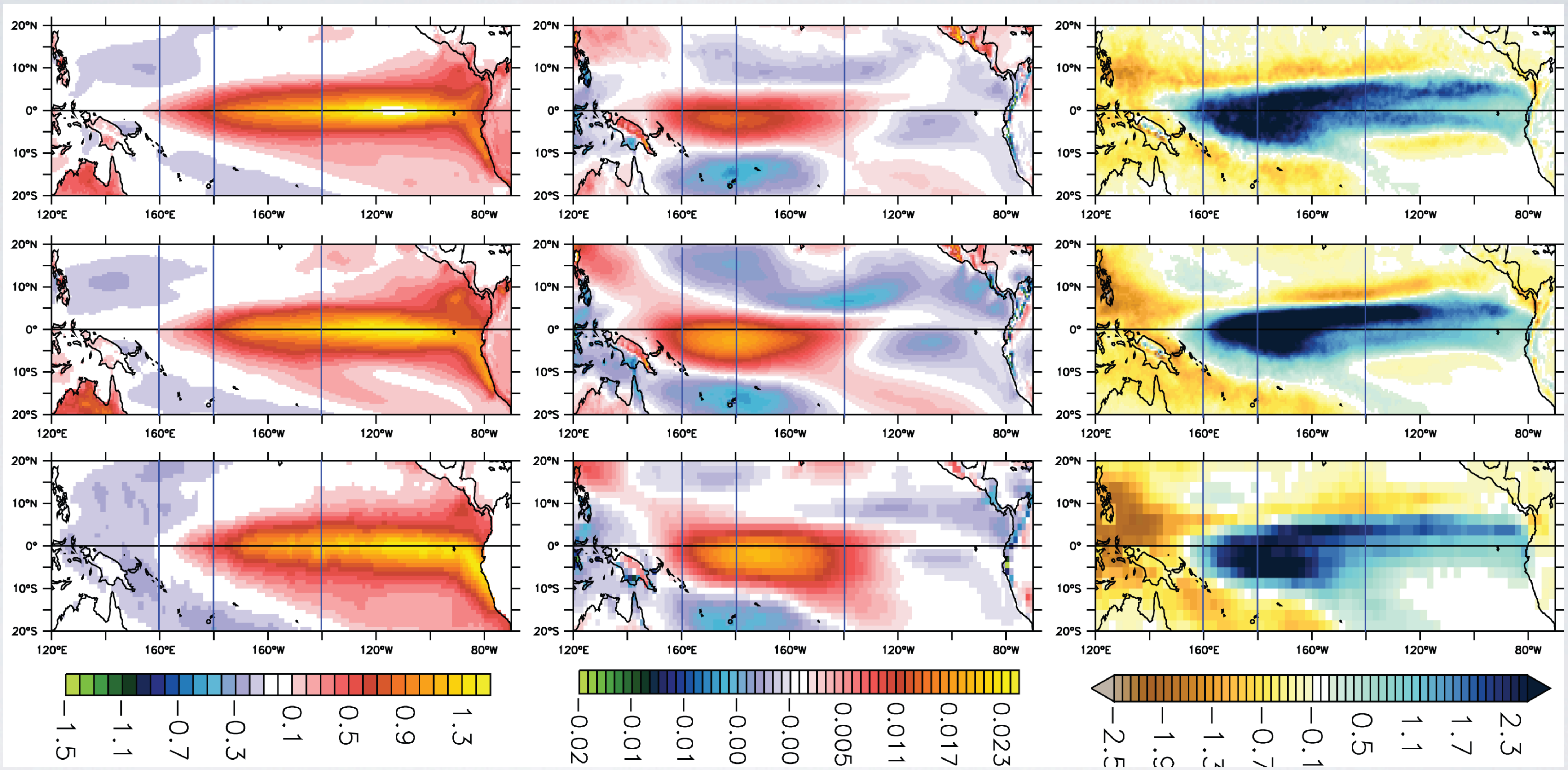
Structure of ENSO improves in FA, as does its phase-locking

Regression on NIÑO3 SSTA

FLOR -B01

FA- SST+τ

OBS

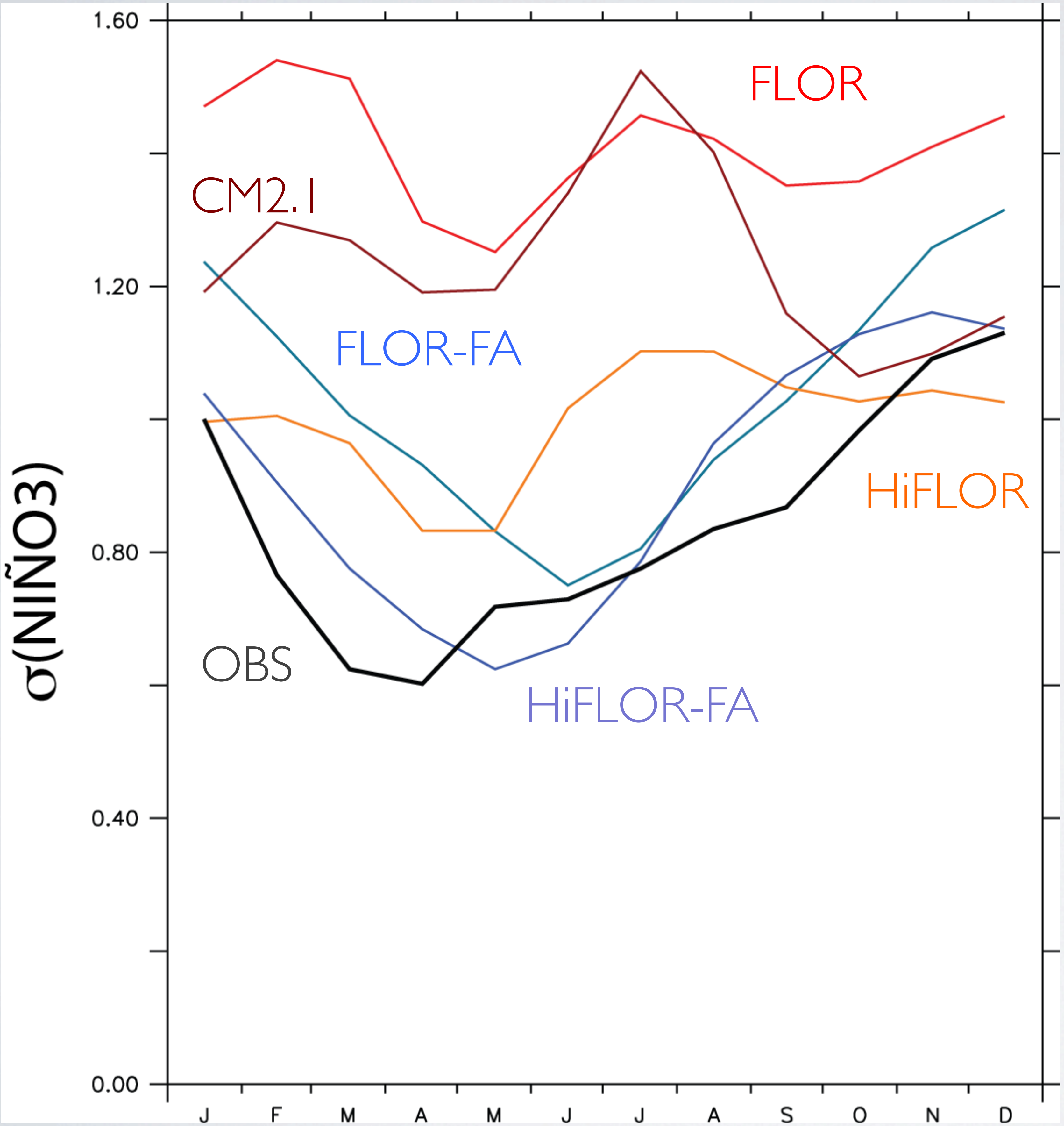


SST

Zonal Stress

Precip.

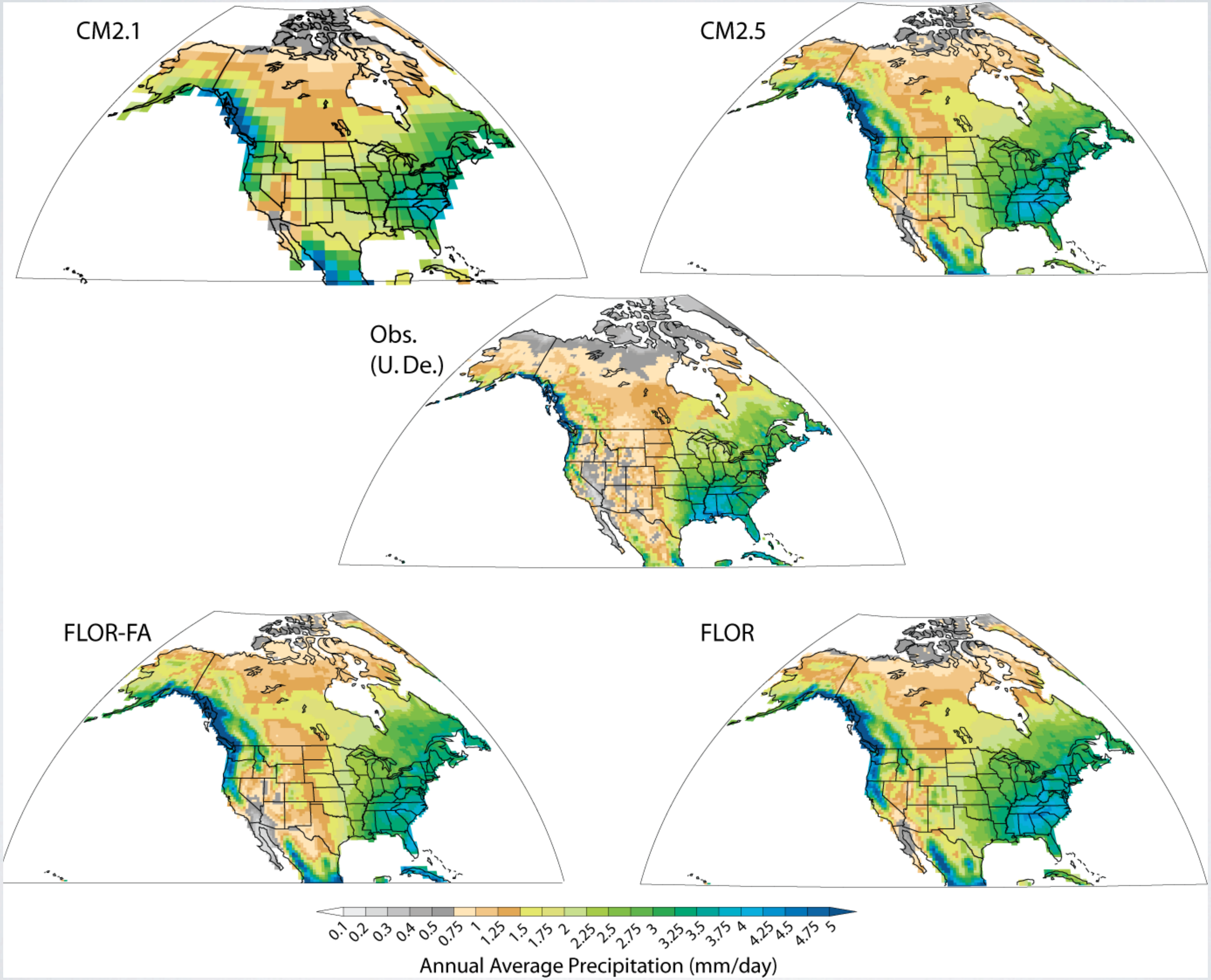
Atmospheric resolution/FA and ENSO phase locking



Artificially adjusting mean state biases improves phase locking of anomalies.

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

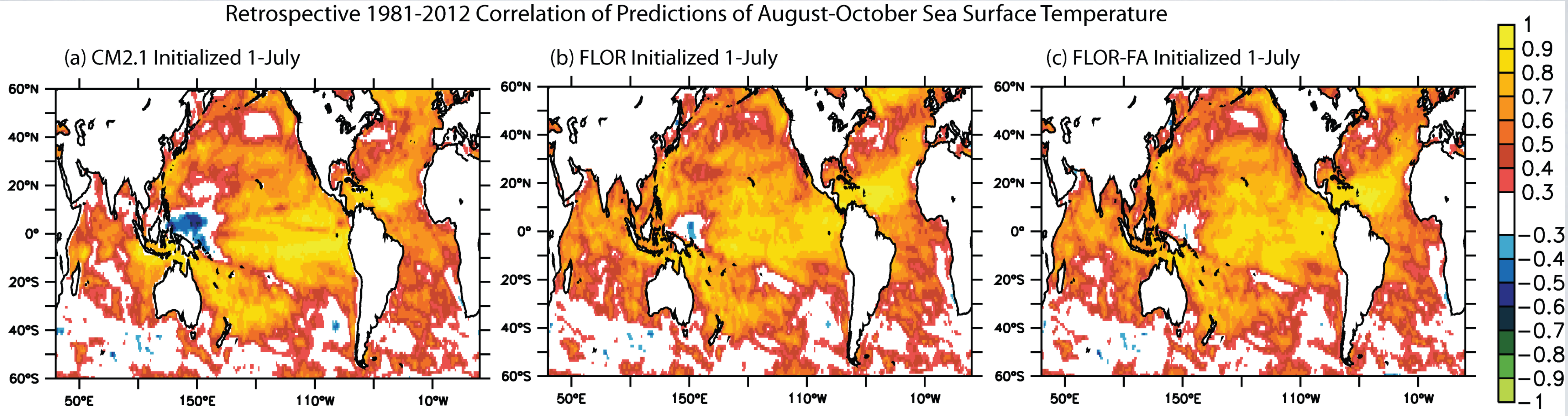
N. American precip improves from FA (look at E. and W. Texas)



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

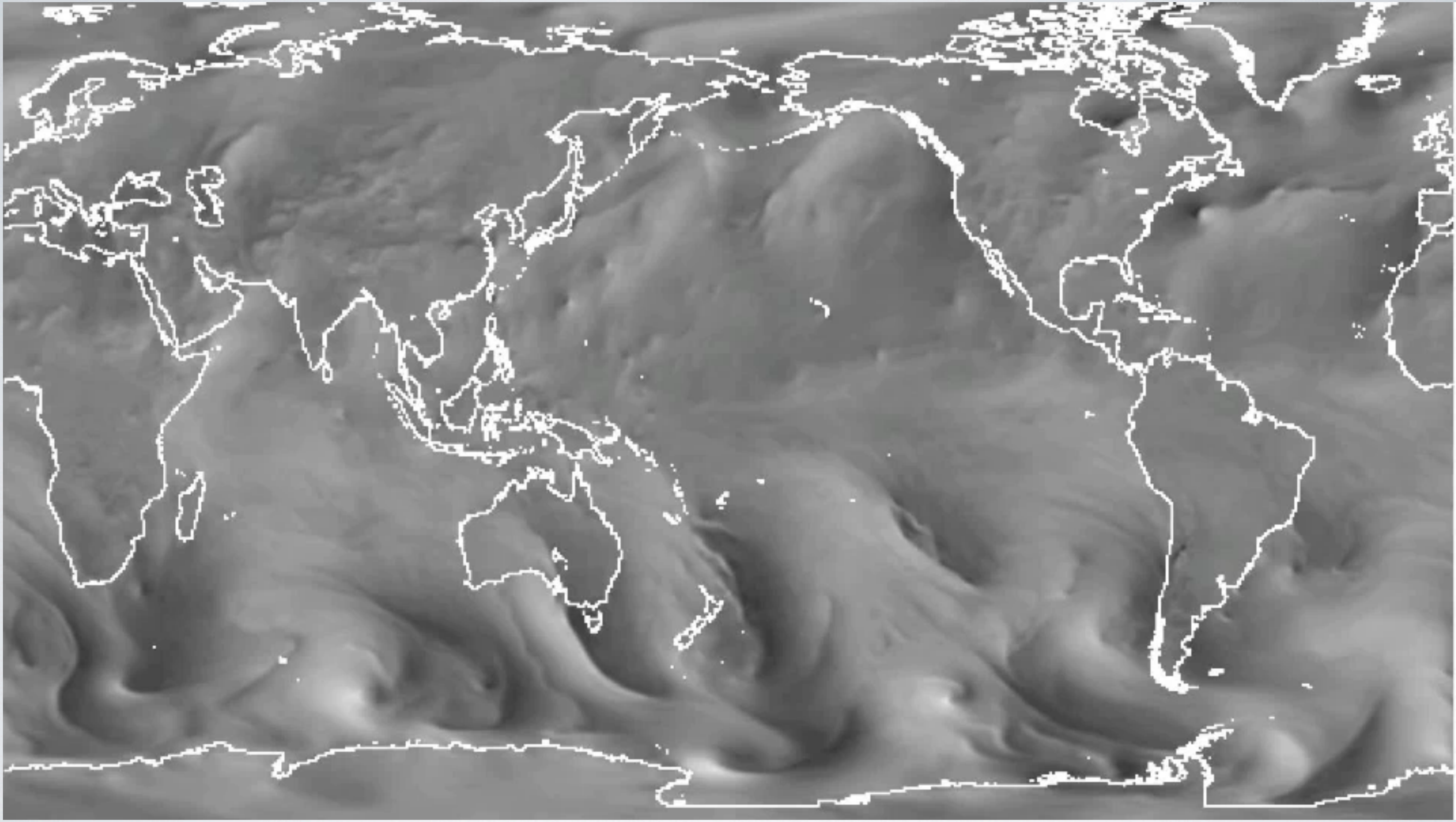


CM2.1 FLOR FLOR-FA

1981-2012 correl. of Aug-Oct SSTA predictions

Vecchi et al. (2014)

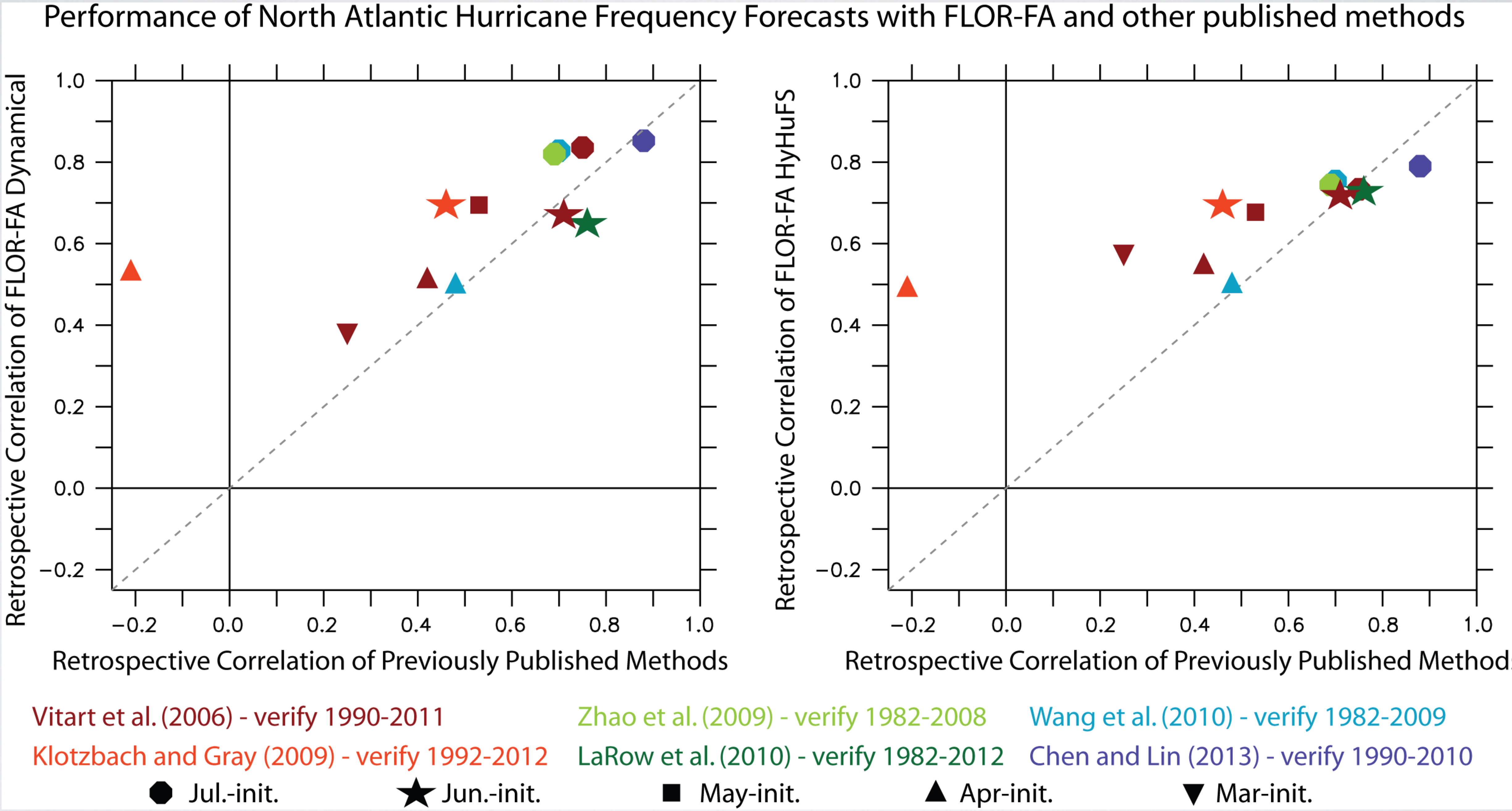
100 days of single ensemble of 10-m v from CM2.5-FLOR initialized 1-Aug-2005



4xdaily 1-Aug through 8-Nov 2005

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

FLOR-FA

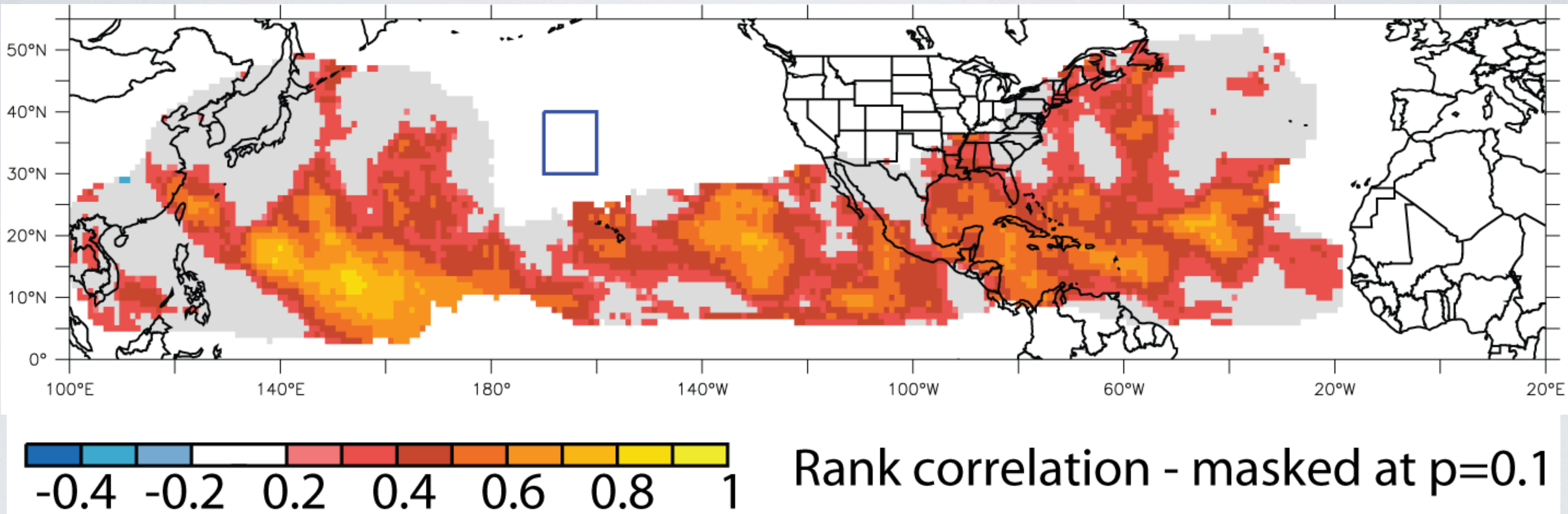


Other systems

Vecchi et al. (2014)

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

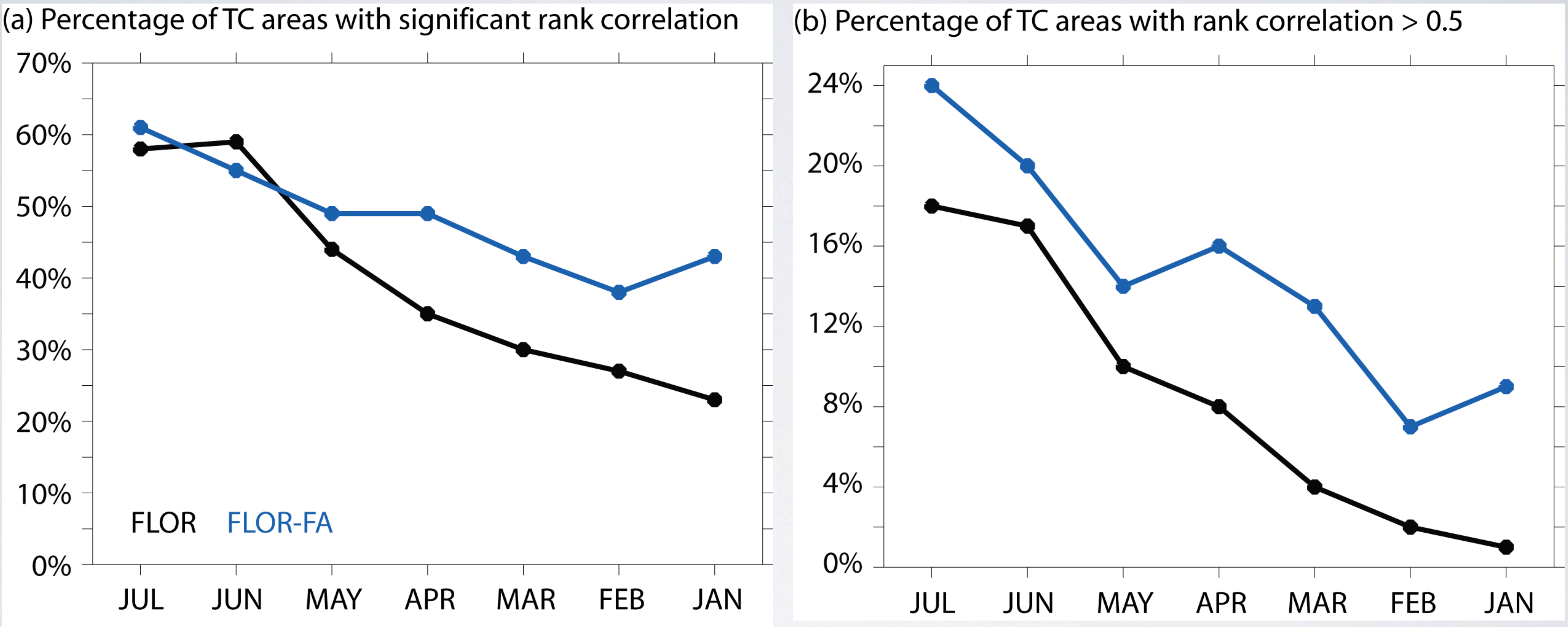
GFDL-FLOR 1981-2012 1-July Initialized Forecasts for July-December



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

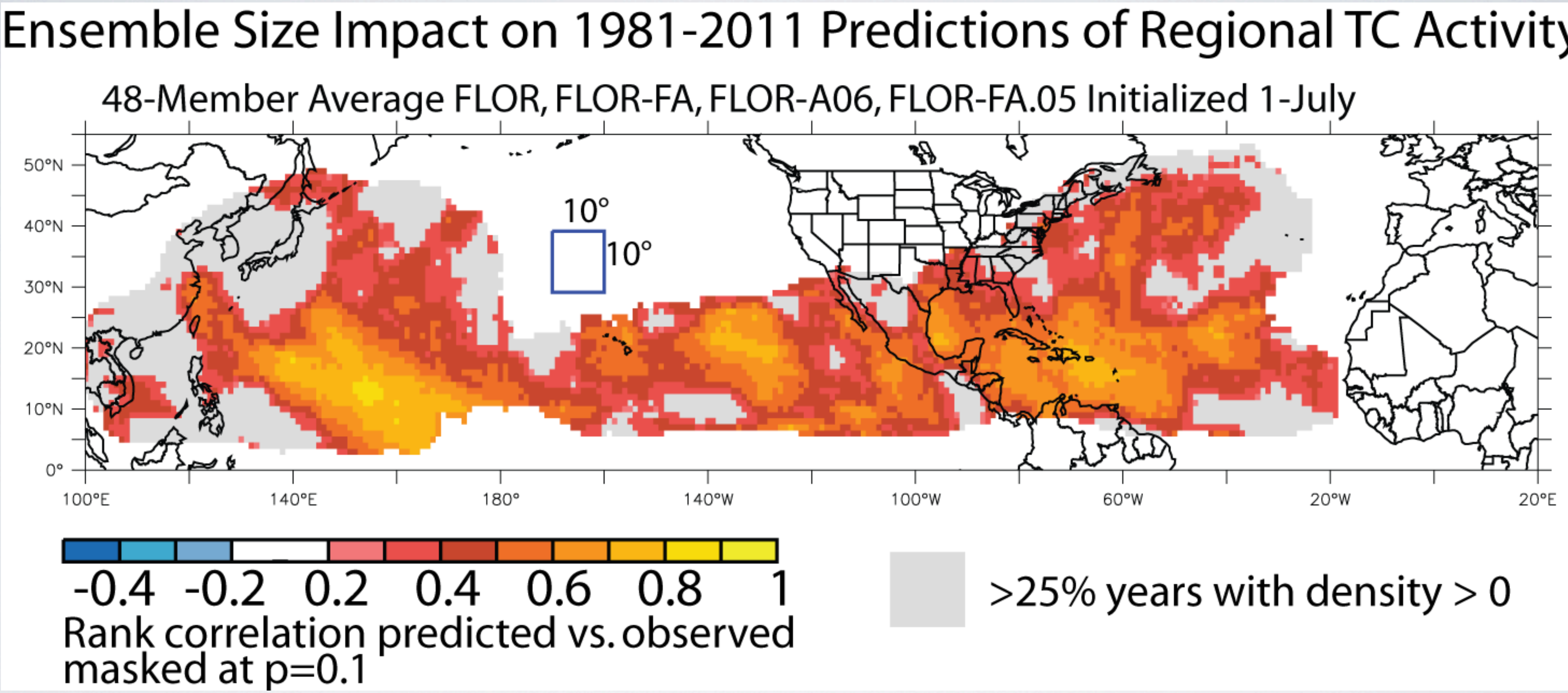
Vecchi et al. (2014, submitted)

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



Vecchi et al. (2014)

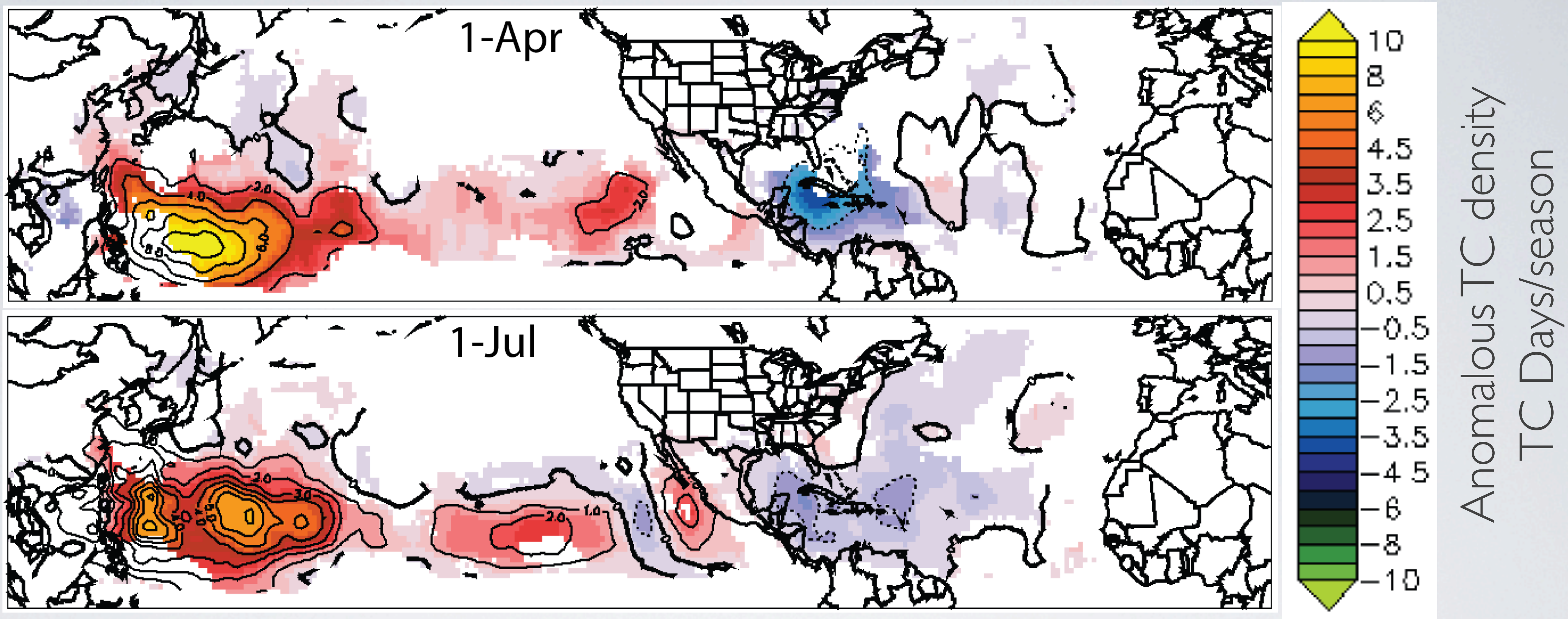
Increasing ensemble size from 12 to 48 improves regional TC predictions



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

Experimental seasonal TC density forecasts with GFDL-FLOR-FA

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

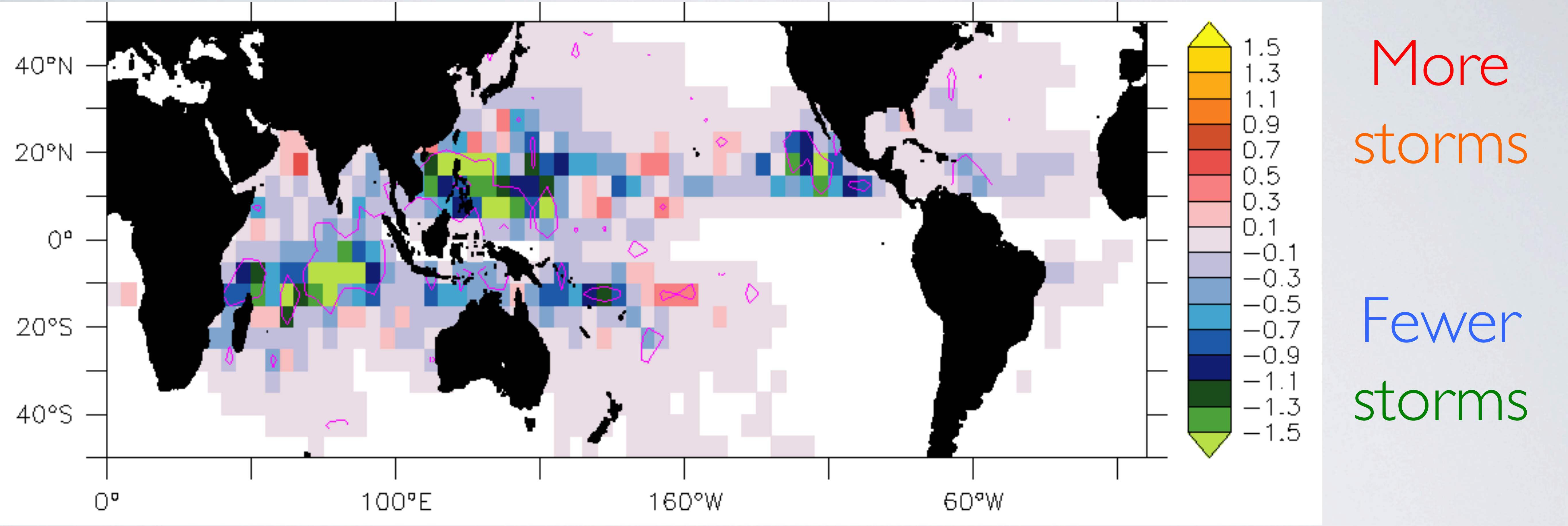


Forecasts of 2014 TC density anomaly with GFDL-FLOR-HAD13 initialized 1-April-2014 and 1-July 2014.

Contour: all values

Shade: locations with significant retrospective correlation

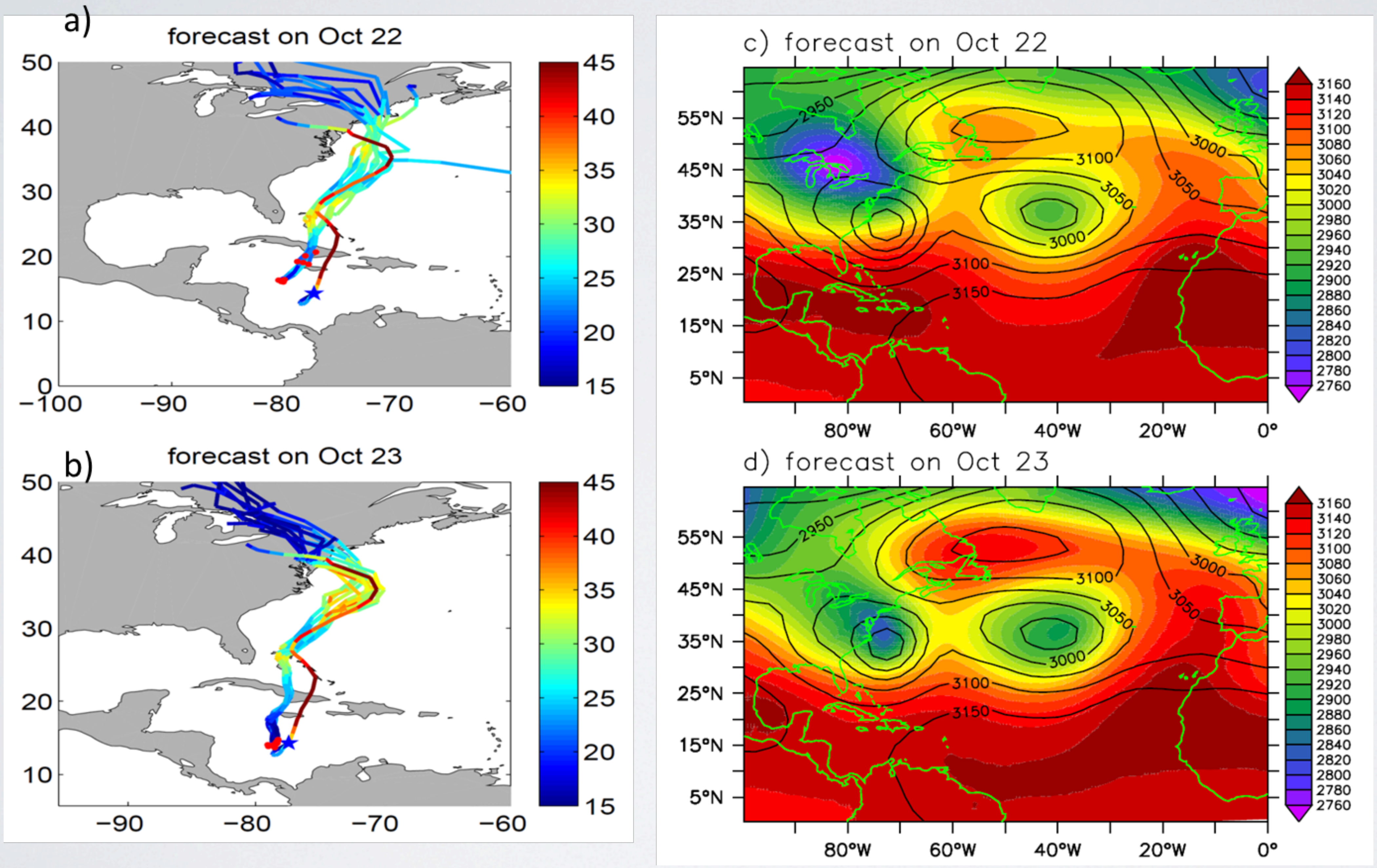
Towards seamless (or "lightly stitched") weather-to-centennial TC changes in high-resolution global coupled models



CM2.5 Tropical storm density response to CO_2 doubling

(Kim et al. 2014)

Seamless predictions: 5-7 days forecasts of Sandy with GFDL coupled model similar to FLOR



Xiang et al. (2014, MWR, in press)

Forecasts initialized 7 & 8 days before landfall capture track

Summary

- Increased atmospheric and land resolution, and better land model:
  Yields improved forecasts of large-scale climate
  Enables simulation and forecasts of regional climate and extremes

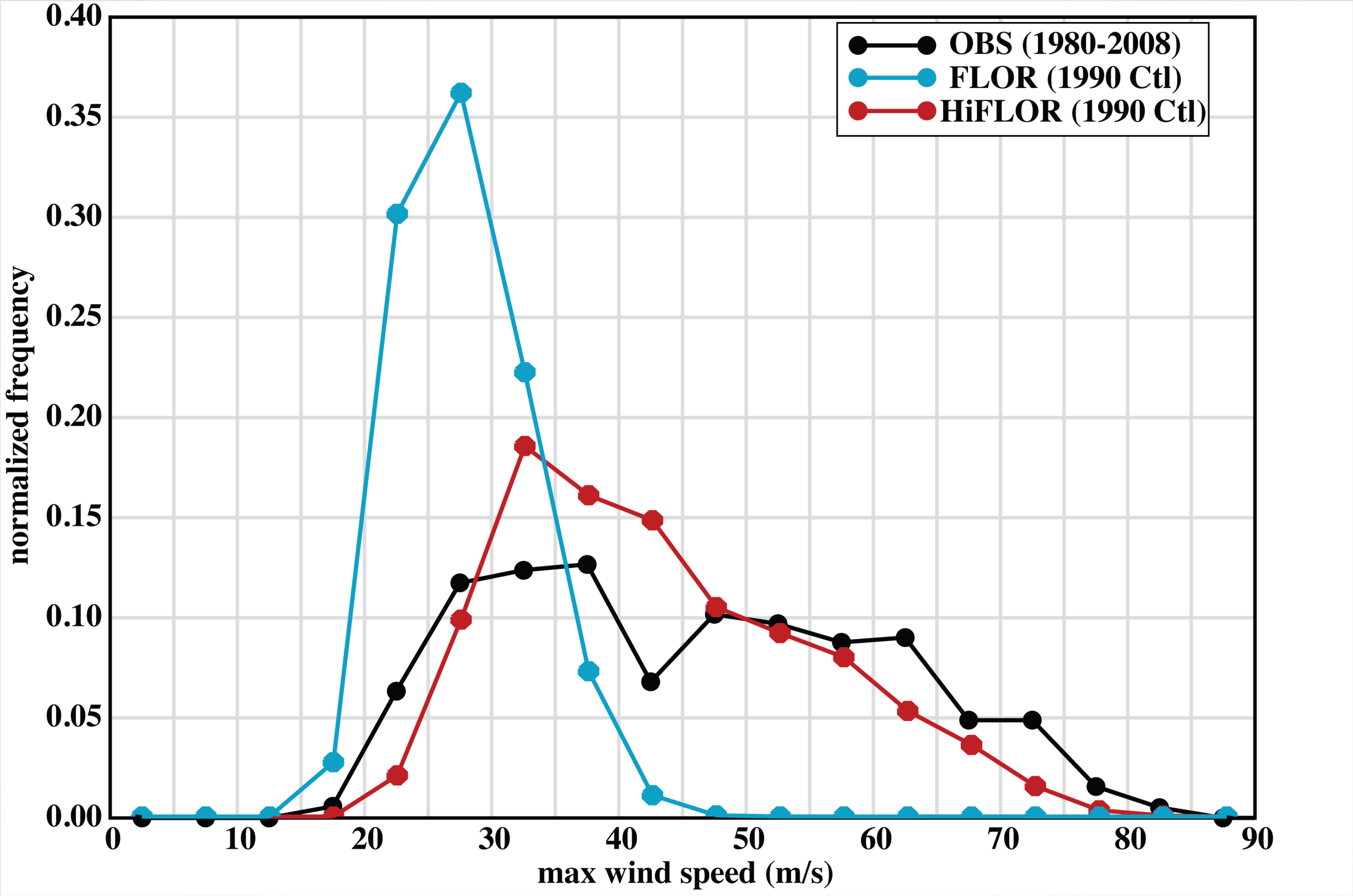
- Skillful seasonal predictions of TC activity at regional scales appear feasible
  Large (many 10s) ensembles appear desirable

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

Next Steps

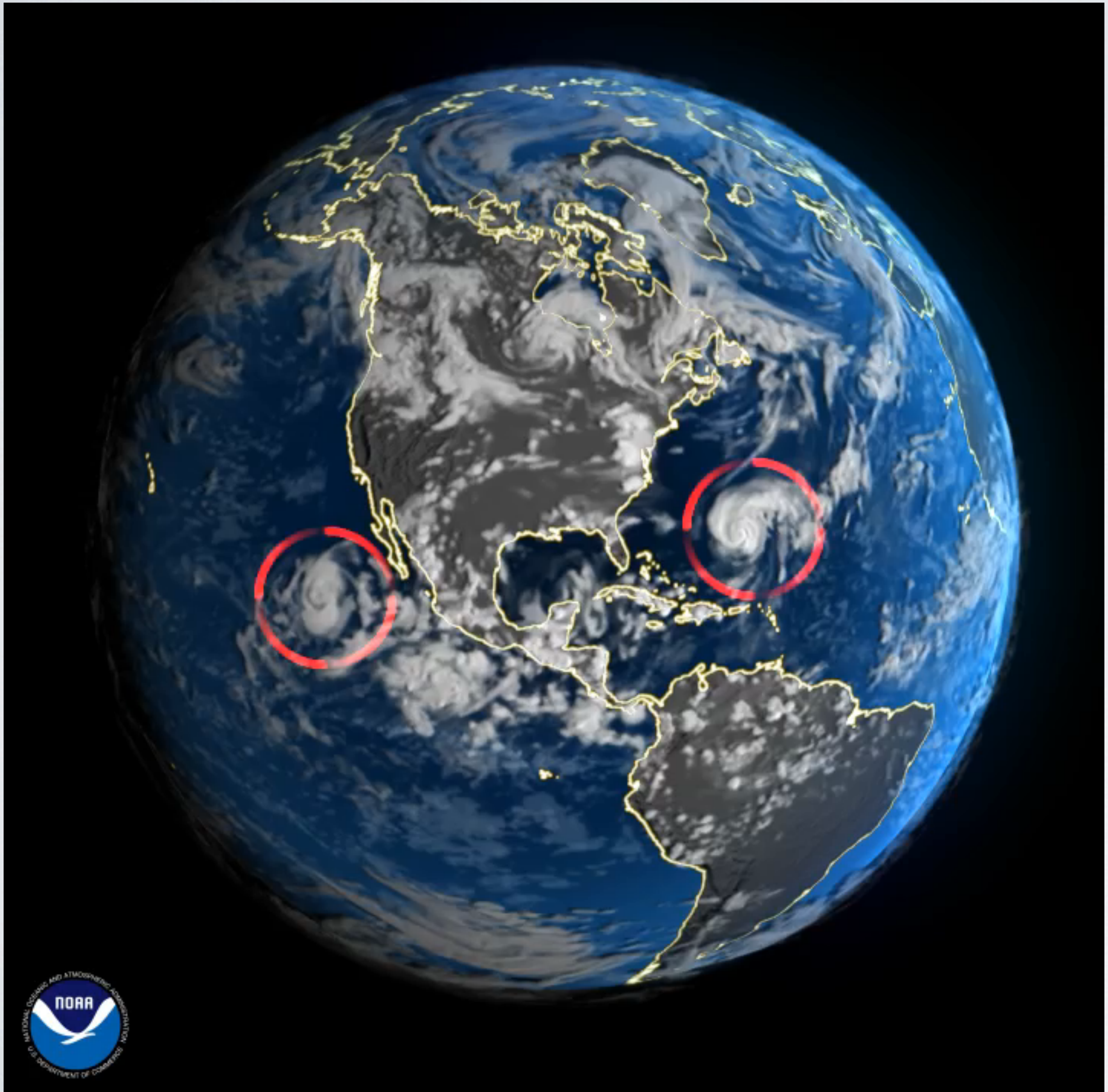
- Higher resolution to get to intensity

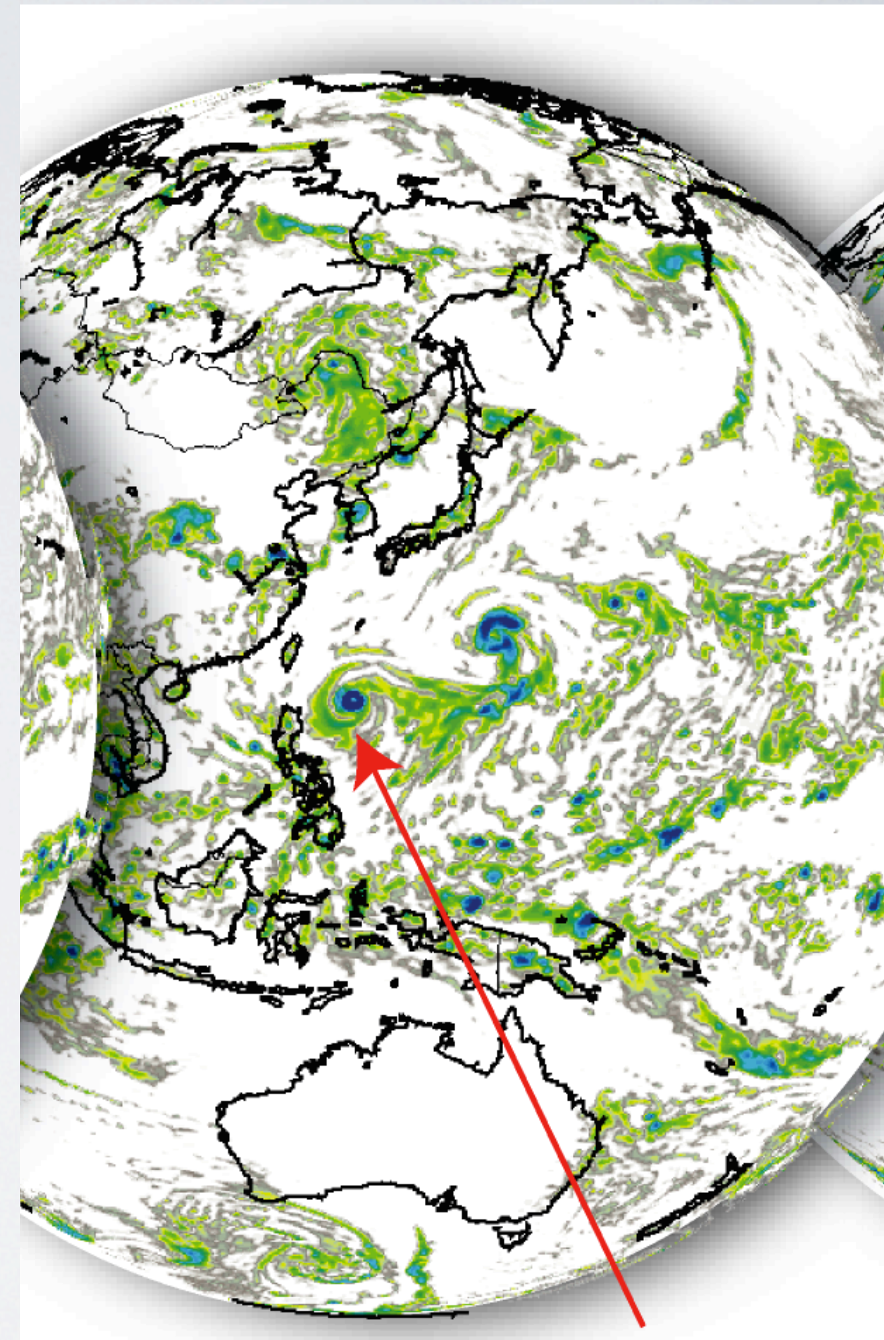
HiFLOR (25km version of FLOR)



Murakami et al. (2015, in prep.)

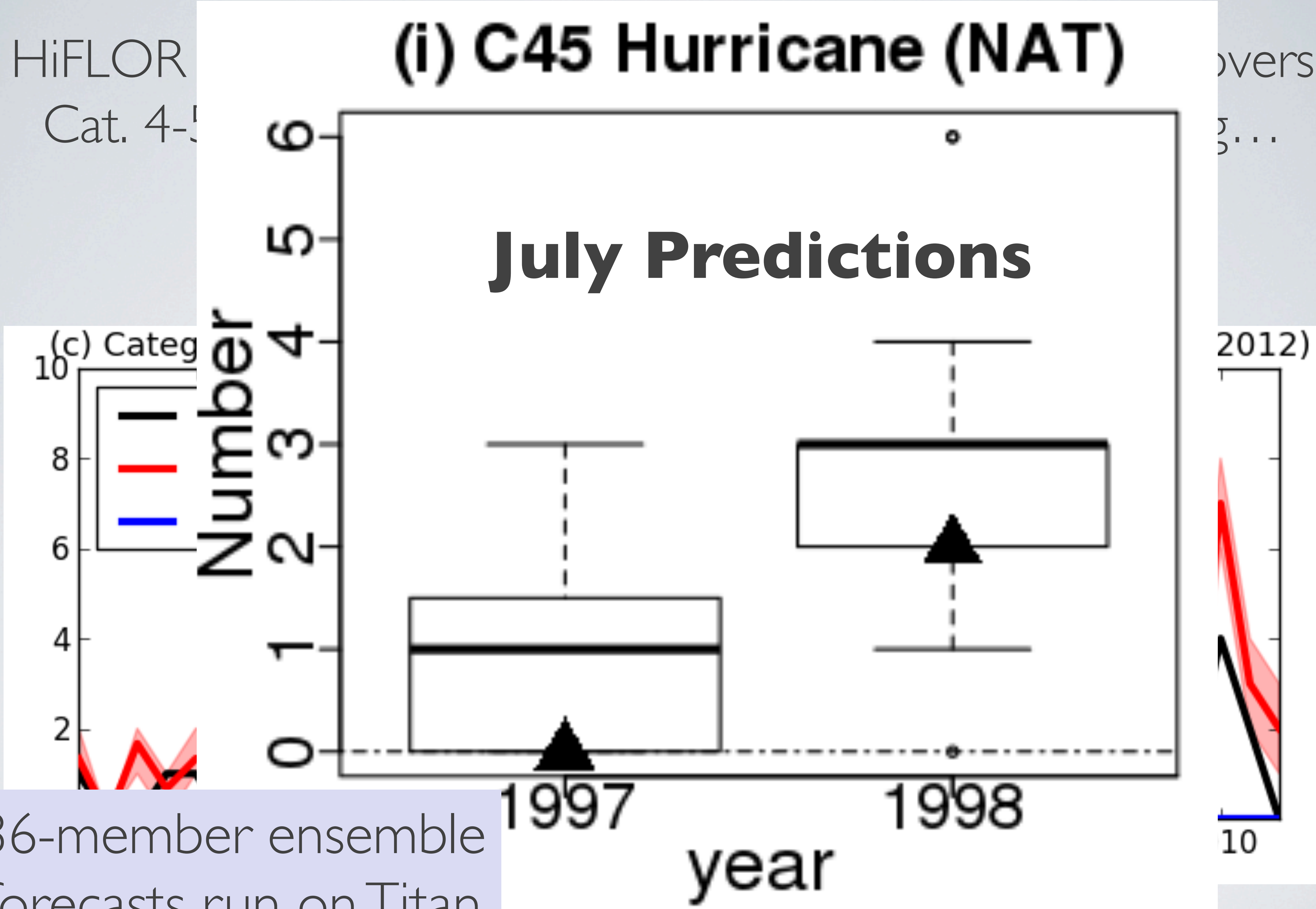
HiFLOR: doubling atmospheric resolution of FLOR (cost 6x) allows us model to simulate Cat. 4-5 TCs (most destructive storms)





10-Aug.: Cat. 5 Typhoon
(158 knot winds)

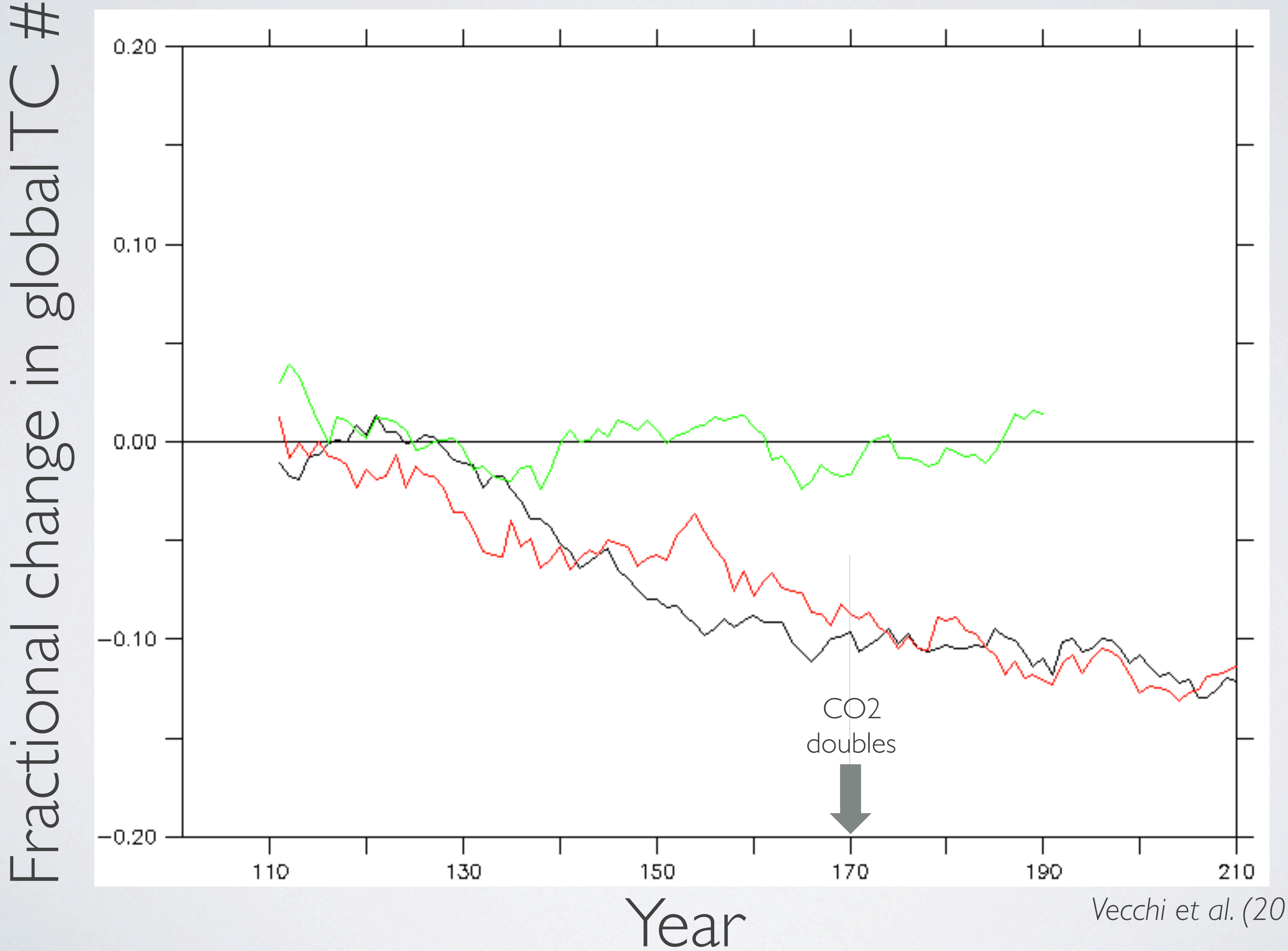
HiFLOR … overs
Cat. 4-5 … g…



36-member ensemble forecasts run on Titan (175,968 processors)

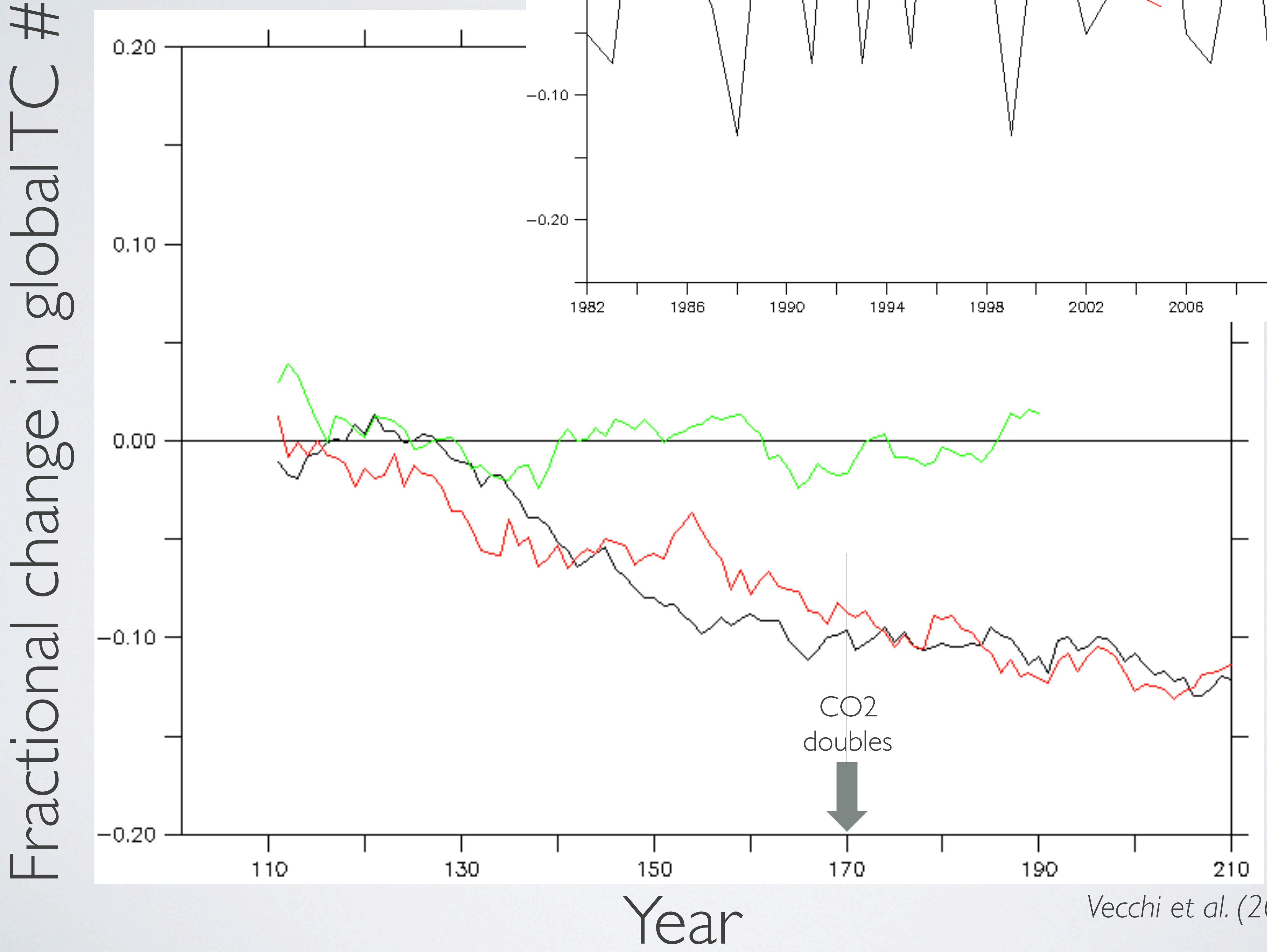
Murakami et al. (2015, in prep.)

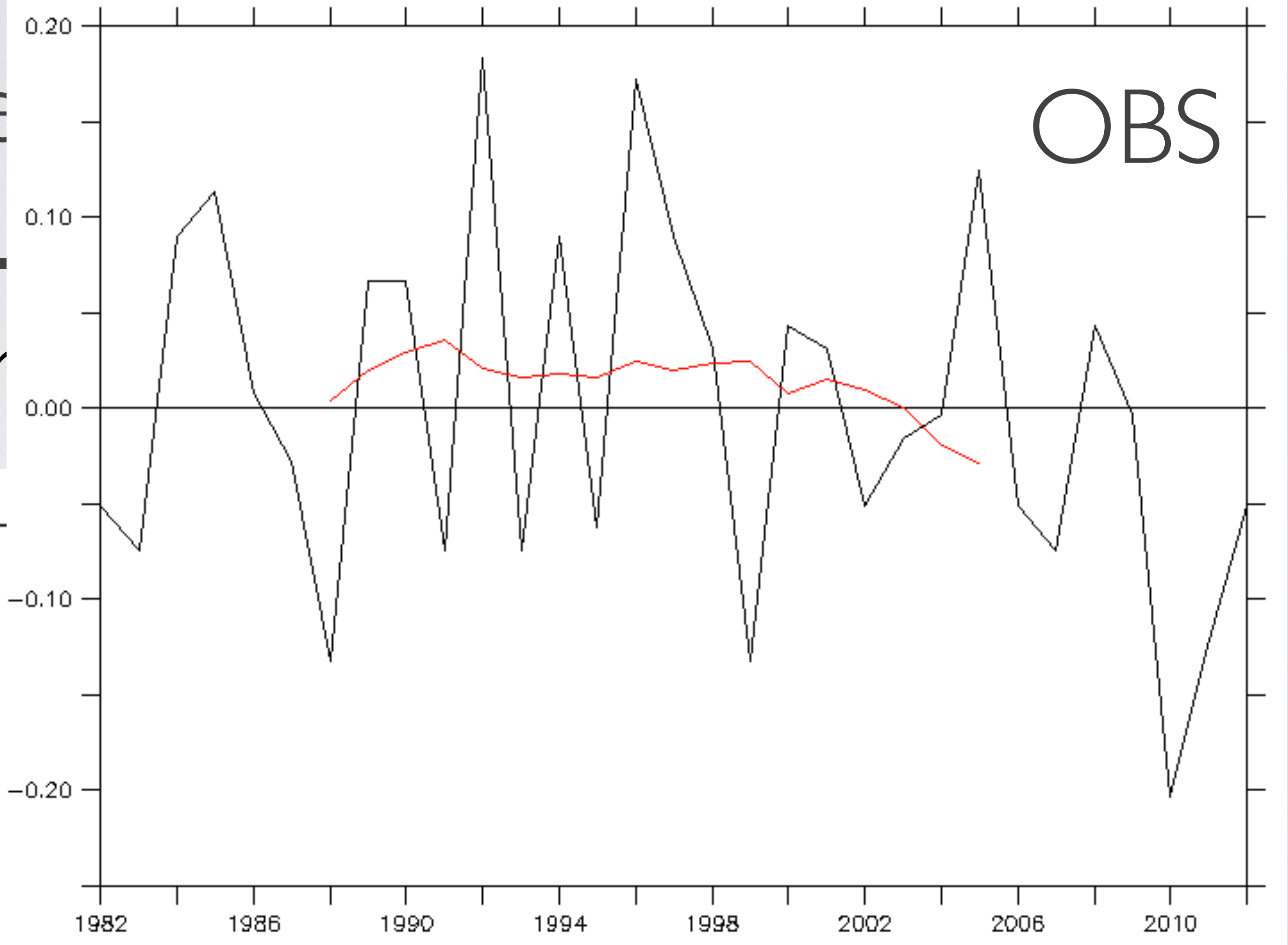
Global TC frequency decrease in response to 2xCO2 in 0.5° FLOR and FLOR-FA no change in 0.25° HiFLOR – why?



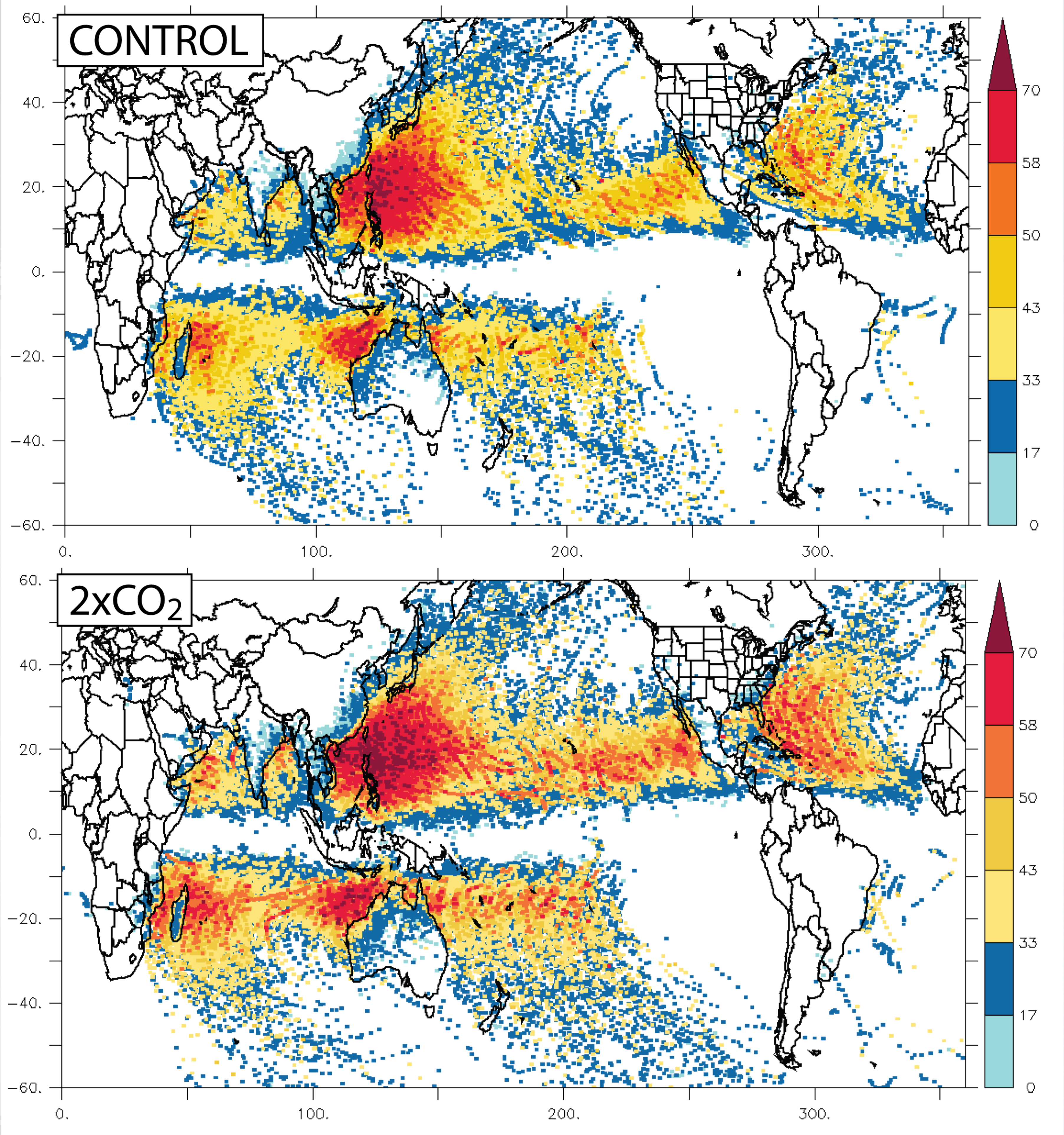
Vecchi et al. (2015, in prep.)

Global TC freque
2xCO2 in 0.
no change ir





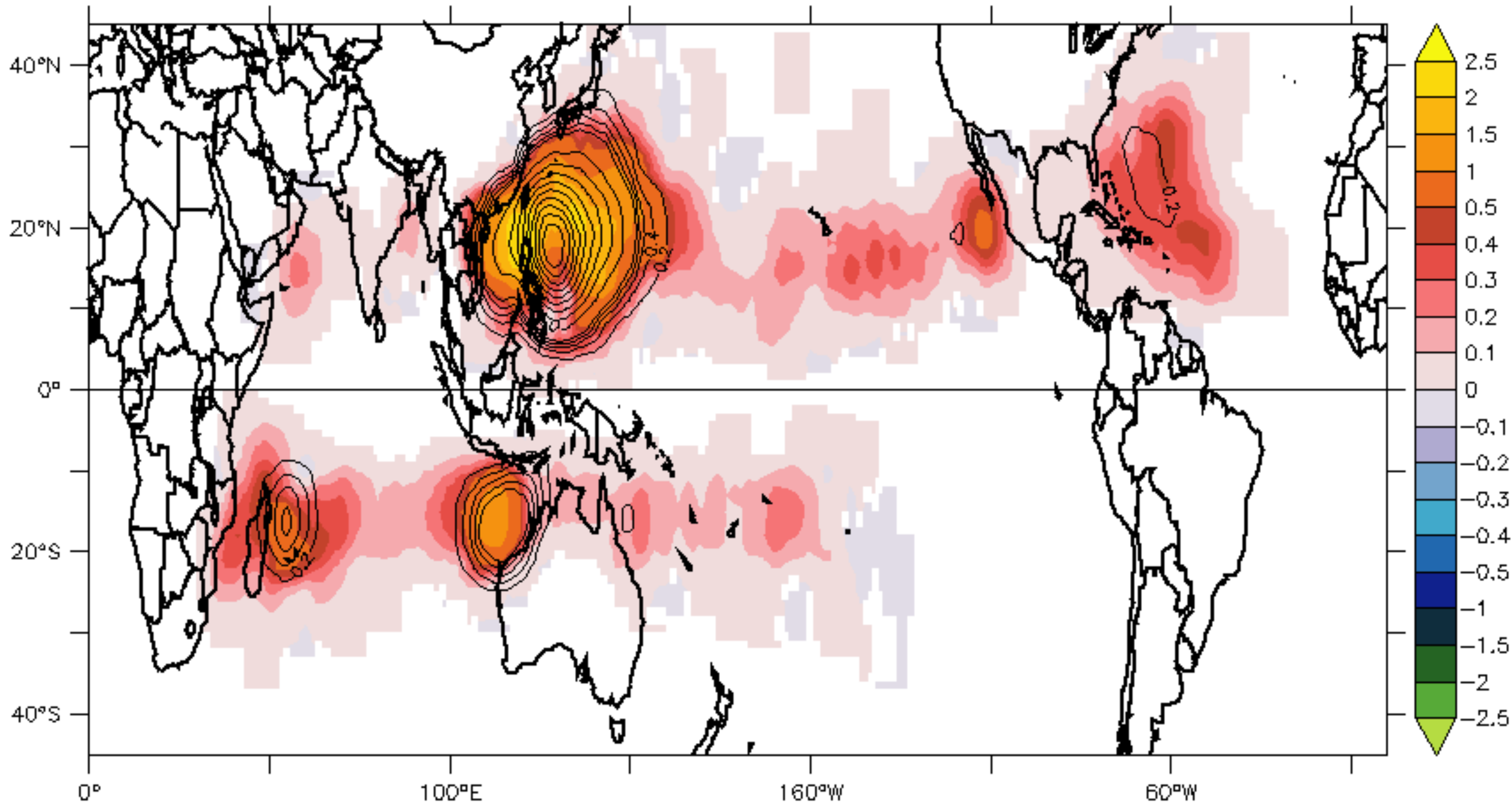
Vecchi et al. (2015, in prep.)



Increase in intensity from CO2 doubling in hiFLOR

Vecchi et al. (2015, in prep.)

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



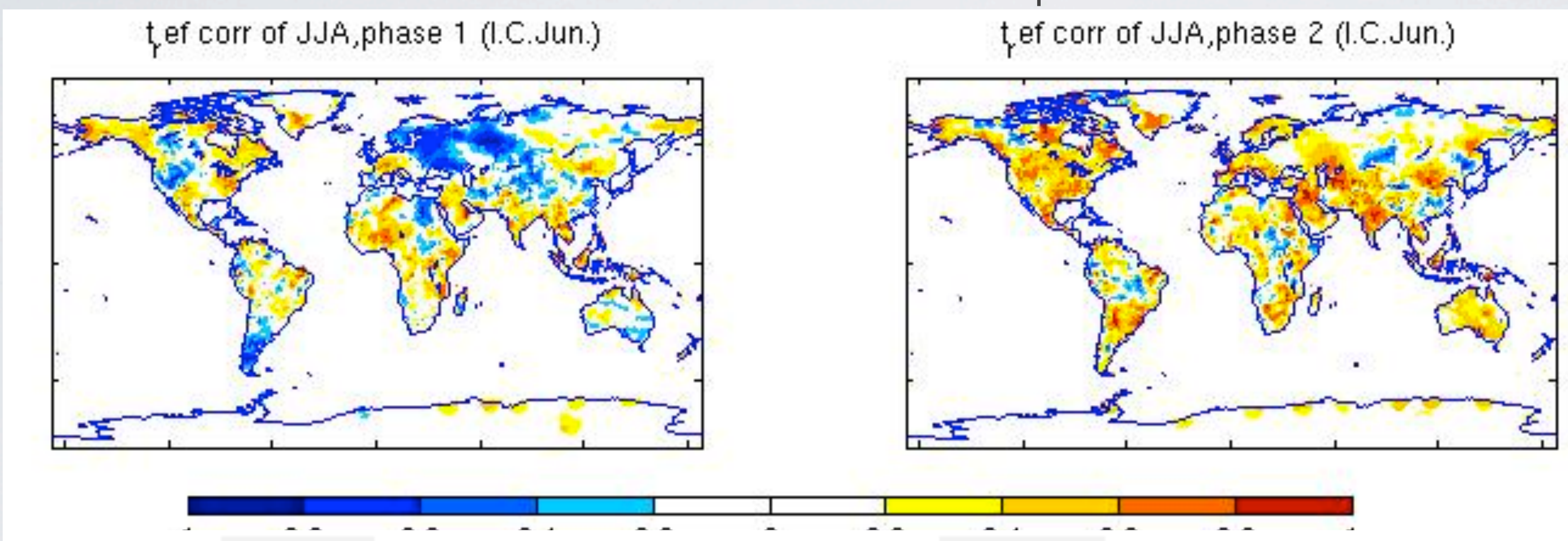
Vecchi et al. (2015, in prep.)

Next Steps

- Higher resolution to get to intensity

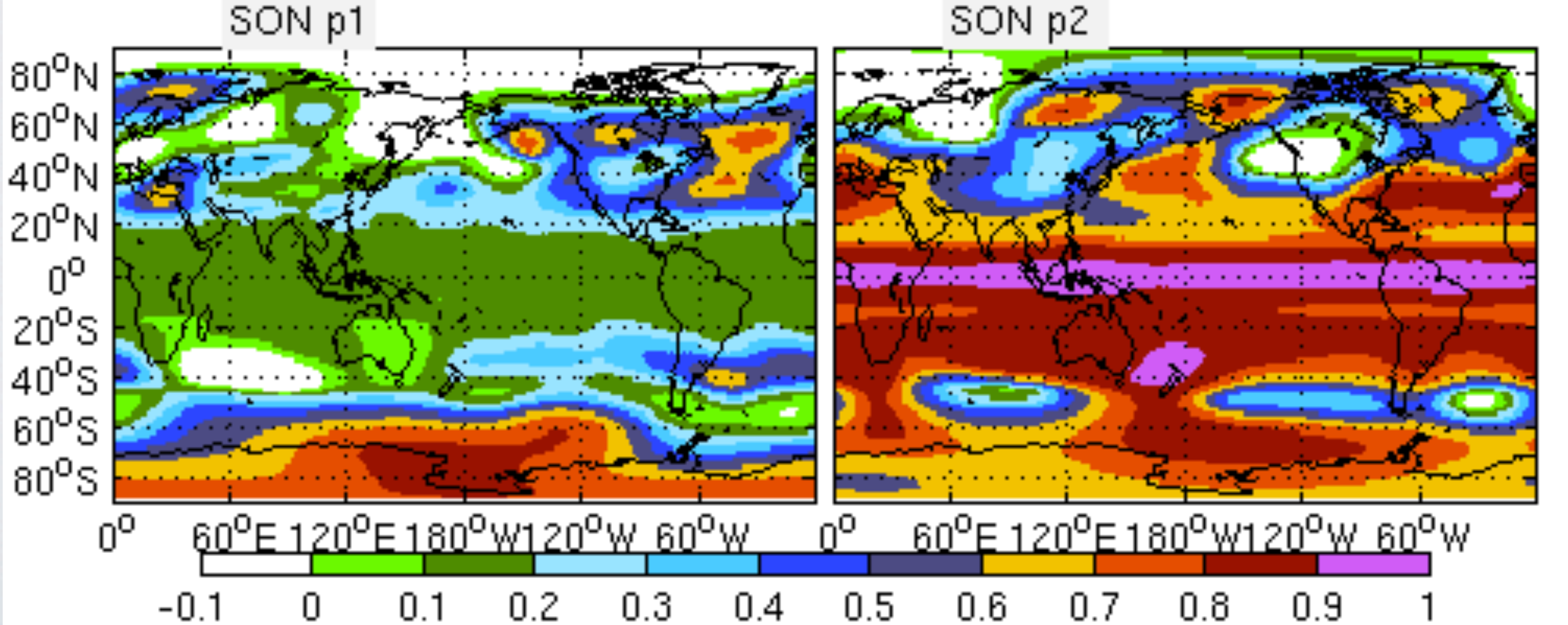
- Atmospheric initialization

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

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

Next Steps

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

References

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