

Modulation of tropical cyclones by natural climate variability

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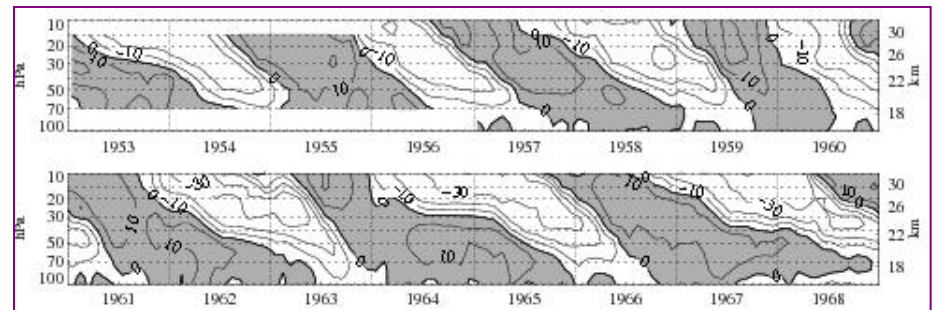
Tropical cyclones and natural variability

- To understand how tropical cyclones will change in future climate, we need first to understand how they respond to natural climate variability.
- Our research focuses on response of TCs to natural tropical modes on intraseasonal-interannual time scales: MJO, ENSO, QBO.
- Outline of this talk:
 1. Influence of the stratospheric quasi-biennial oscillation (QBO) on TCs
 2. A new empirical index for tropical cyclogenesis

1. QBO and tropical cyclones

Gray (1984) first pointed out a statistical relationship between the QBO and Atlantic tropical cyclones. More TCs in westerly phase. Chan (1995) found relationship in Western Pacific; relationships reported by many others in other basins.

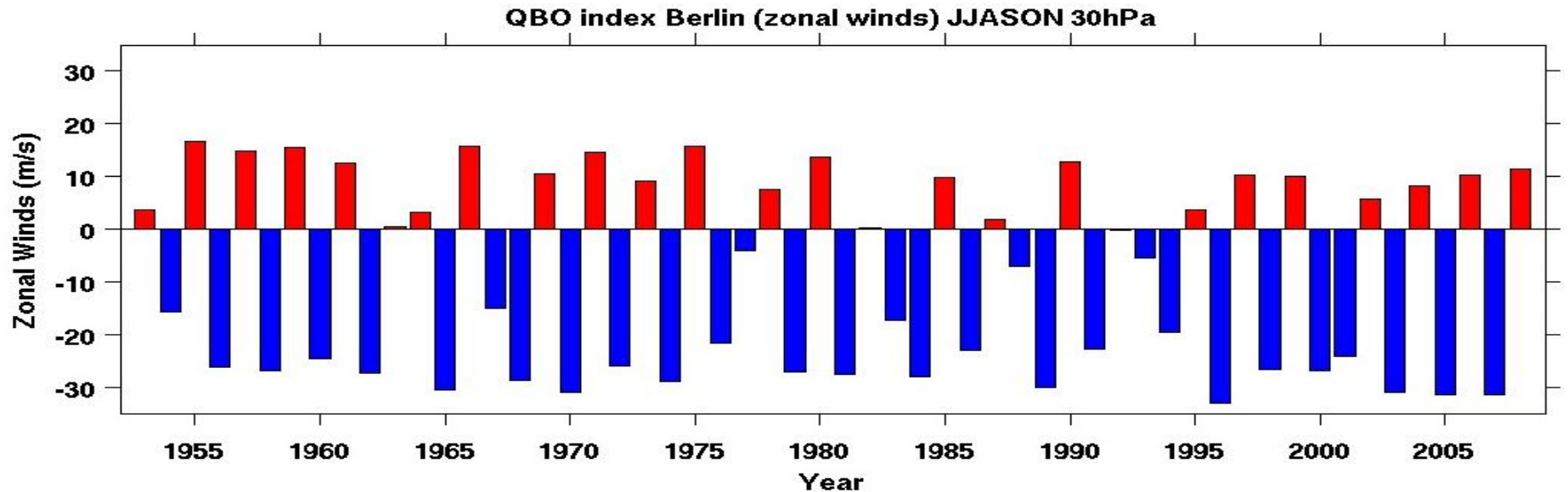
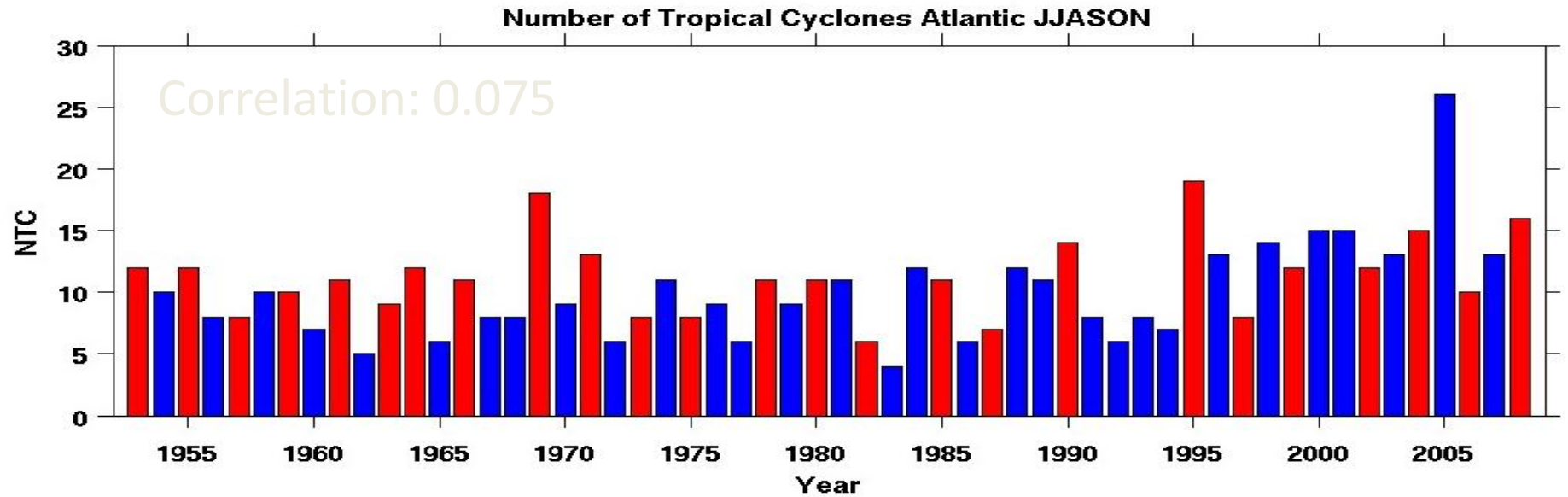
Time-height plot of equatorial Stratospheric zonal wind showing Quasi-biennial oscillation (QBO)



This relationship is interesting because the physics are unclear. How does the stratosphere affect TCs? The QBO shear is restricted to very high levels. The temperature perturbations are of the wrong sign for a stability argument (lower stratosphere is warm in westerly QBO phase)

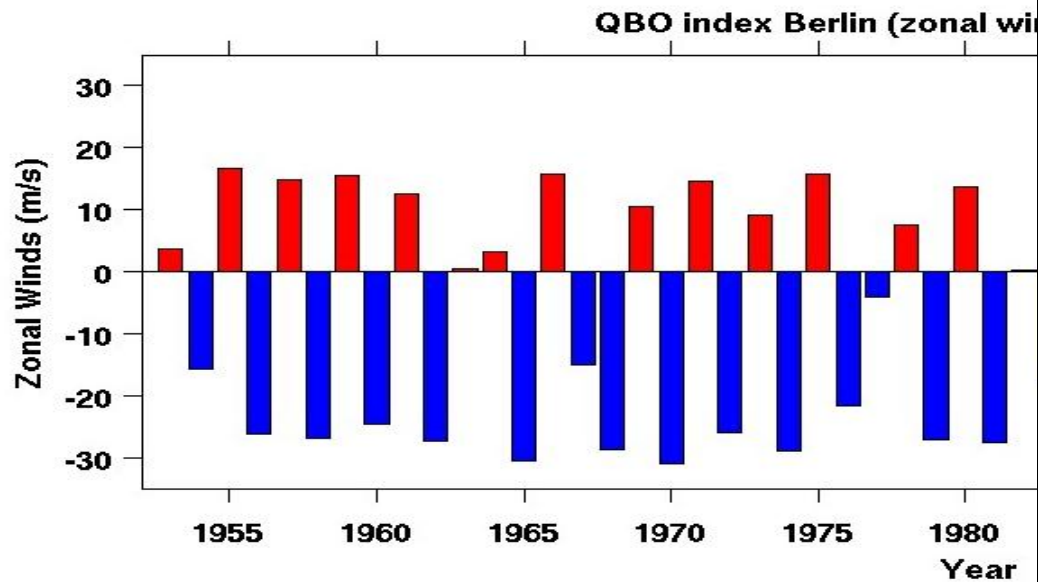
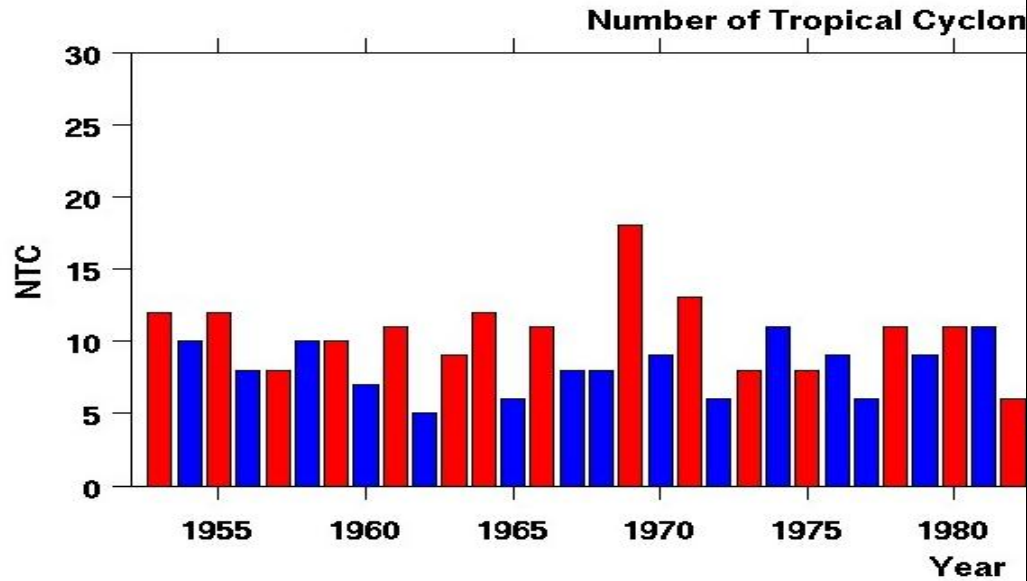
Here, we revisit the statistical relationship, using the longer data record now available.

Atlantic NTC and QBO



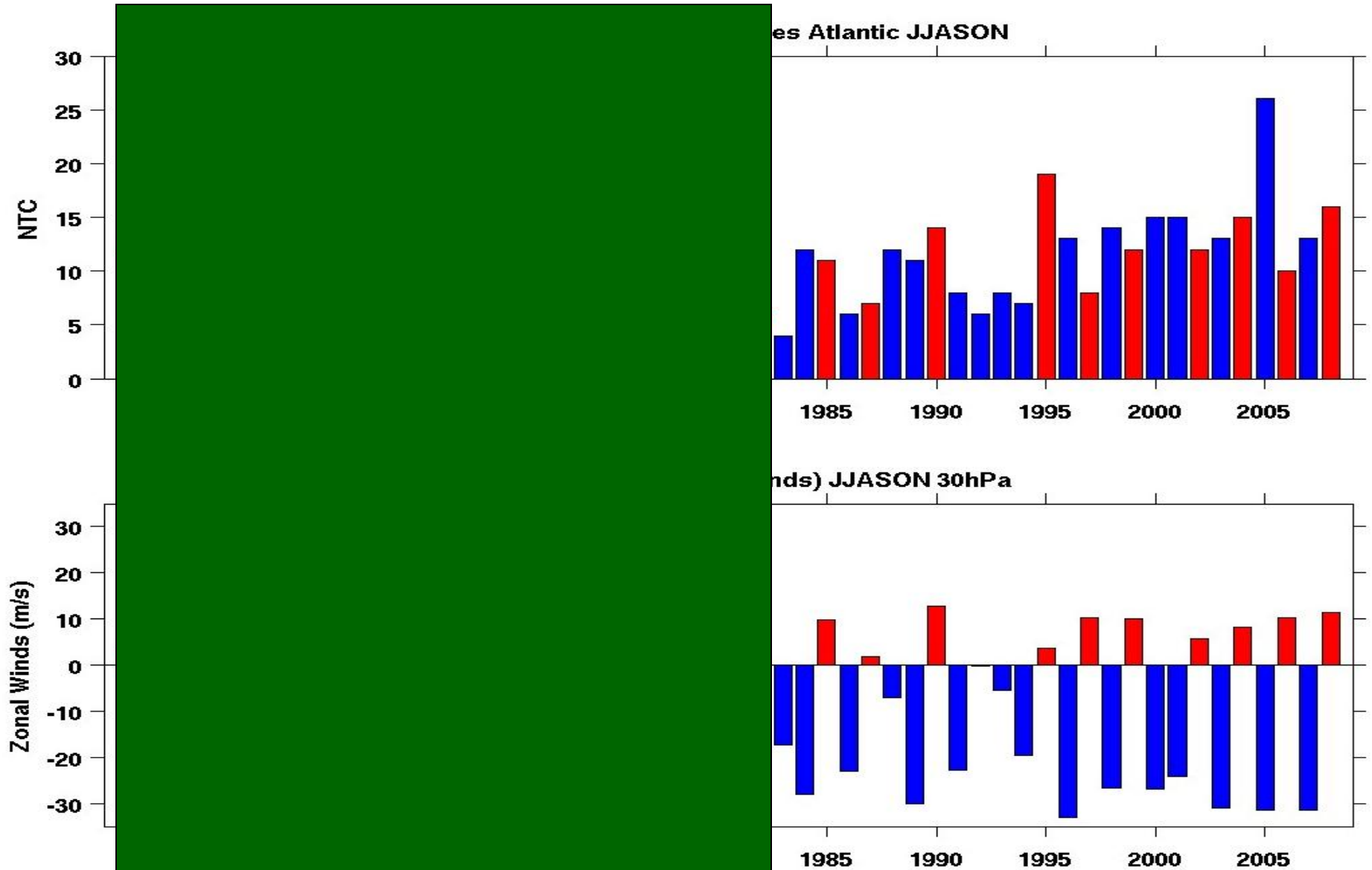
Atlantic NTC and QBO

Correlation 1953-1982: 0.44

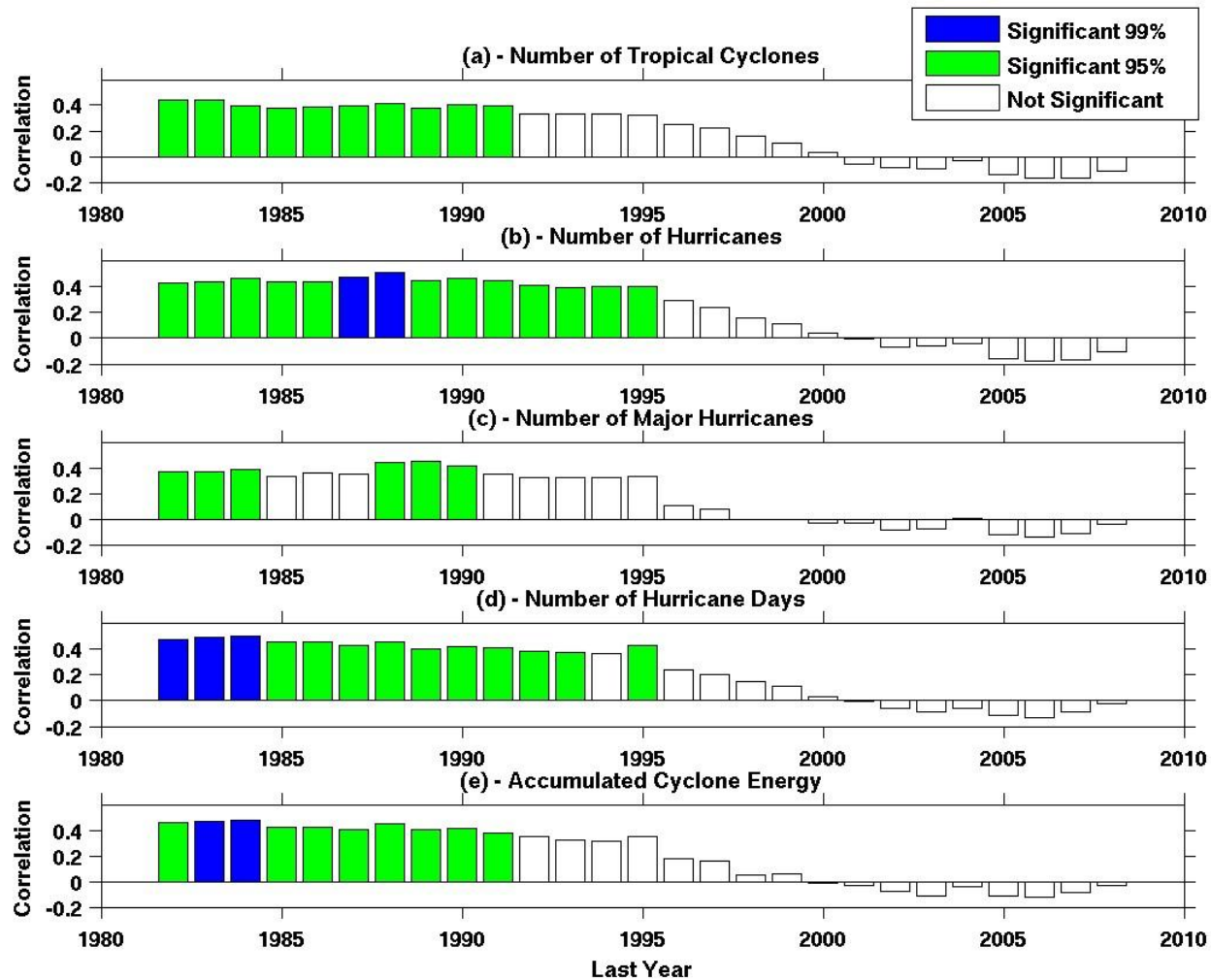


Atlantic NTC and QBO

Correlation 1983-2008: -0.12

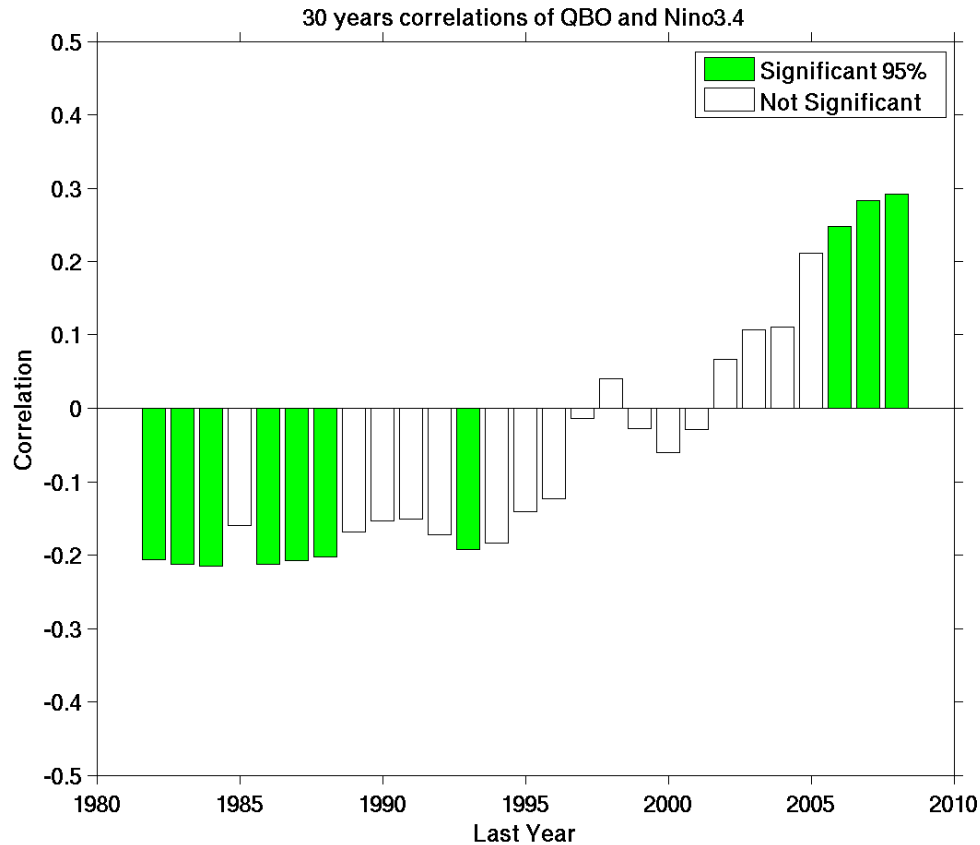


Running 30-year correlation coefficients between QBO and Atlantic TC indices. 30-year period ends at date shown on x-axis.



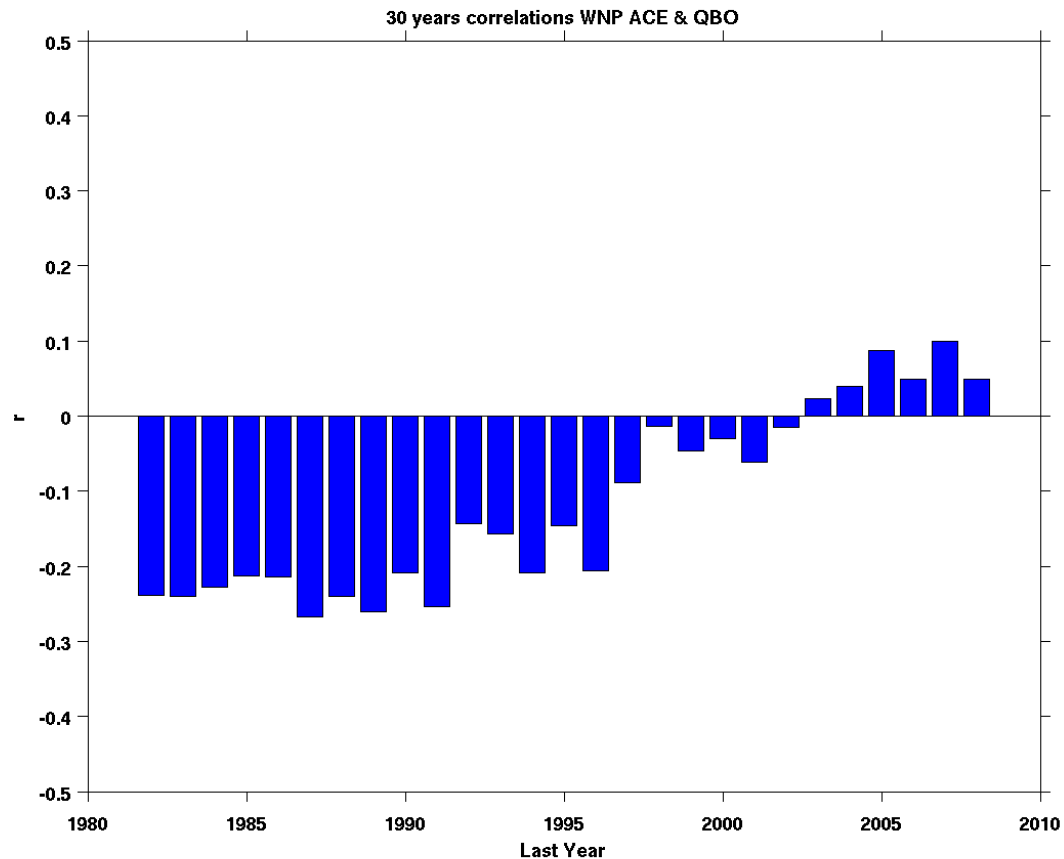
Why does the relationship change? We don't know, but it's suggestive that the QBO-ENSO relationship changes around the 1980s.

Running correlation of QBO index and Nino3.4, for 30 year periods ending in year shown on x axis



In the western north Pacific, the correlation (never large to begin with) also vanishes in the more recent record.

Western North Pacific ACE and QBO 30 Year correlations



2. A new empirical index for tropical cyclogenesis

- There is no theory for TC genesis
- climate control on TC number can be studied using empirical indices – empirical functions of large-scale variables fit to observed probability of genesis (Gray)
- We have made use of Emanuel and Nolan (2004) GPI
- But GPI has some issues:
 - ✧ derivation is partly subjective and thus not reproducible
 - ✧ performance is not perfect (e.g., Atlantic MDR is too weak)
 - ✧ Are the predictors optimal? Can we get either better results, or equally good results with less work?

Here we develop an index using a clear, objective and reproducible method, Poisson regression. We also choose different predictors:

- Relative SST (local SST minus tropical mean) rather than potential intensity
- Column-integrated relative humidity rather than single level
- Different vorticity predictor

Absolute vorticity 850 hPa

For reference, Emanuel-Nolan GPI is

$$\text{GPI} = |10^5 \eta|^{3/2} (\mathbf{H}/50)^3 (V_{\text{pot}}/70)^3 (1+0.1V_{\text{shear}})^{-2}$$

200-850 hPa wind shear

600 hPa relative humidity

TC potential intensity (Emanuel)

Poisson Regression

- Model tropical cyclogenesis events per time per area by a Poisson distribution:

$$P(N=n) = e^{-\mu} \mu^n / n!$$

- Poisson linear regression model for expected value μ is

$$\mu = \exp(\mathbf{b}^T \mathbf{x} + \log(\cos\phi))$$

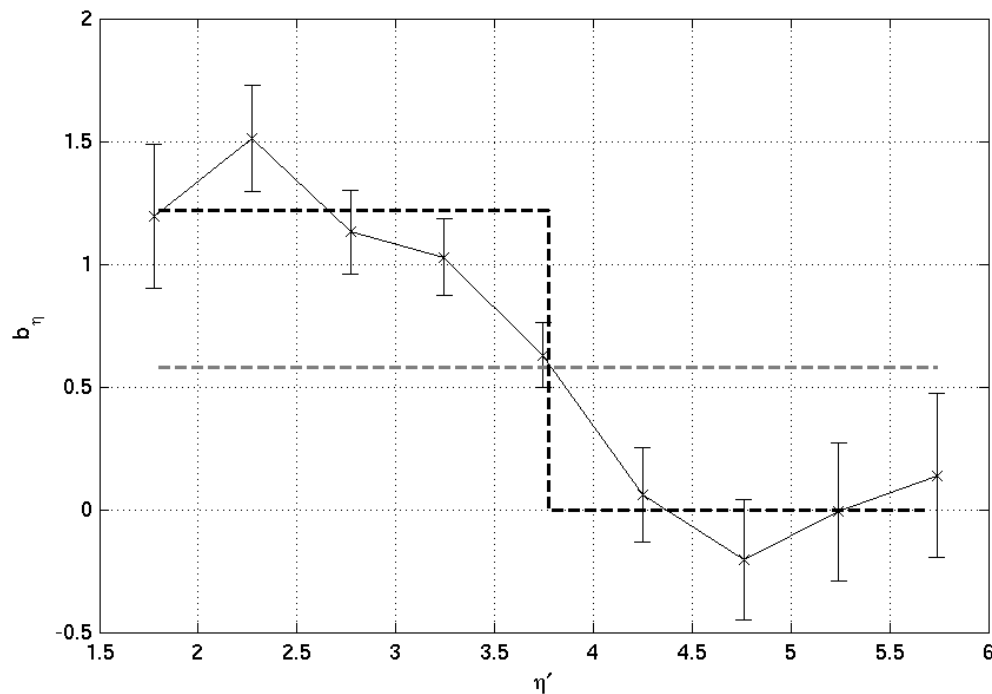
- Coefficients (\mathbf{b}) are chosen to maximize the log-likelihood, using seasonally-varying climatology
- Four parameters make up \mathbf{x} - similar to Emanuel's GPI:
 - Absolute vorticity at 850hPa
 - Relative humidity at 600hPa / column relative humidity
 - Vertical shear between 200hPa & 850hPa
 - Relative SST (difference SST and tropical mean SST)

Summary of parameters used compared to Emanuel GPI

- **Column** relative humidity W/W^* , instead of single-level RH
 - W = SSM/I column-integrated water vapor path (daily average)
 - W^* = saturation value of W computed from reanalysis temperature
- **Relative SST** instead of PI – much simpler and easier to compute, has similar information (Vecchi and Soden 2008) and even gives slightly better performance
- Vertical shear is unchanged (magnitude of 200-850 hPa shear)
- Still use absolute vorticity at 850 hPa, but with one change...

If the fit to derive the index is done separately for different vorticity bins, the coefficient for vorticity shows strong variation – genesis becomes insensitive to vorticity when it is greater than $\sim 4 \times 10^{-5} \text{ s}^{-1}$ (value of f at about 20N)

coefficient of
absolute vorticity
in the index



Mean absolute vorticity (dominated by f)
Units 10^{-5} s^{-1}

Best fit TCG index:

$$\text{TCGI} = \exp(-11.18 + 1.22 \min(|\eta|, 3.7)) + 0.10 H + 0.52 \text{RSST} - 0.12 V_s$$

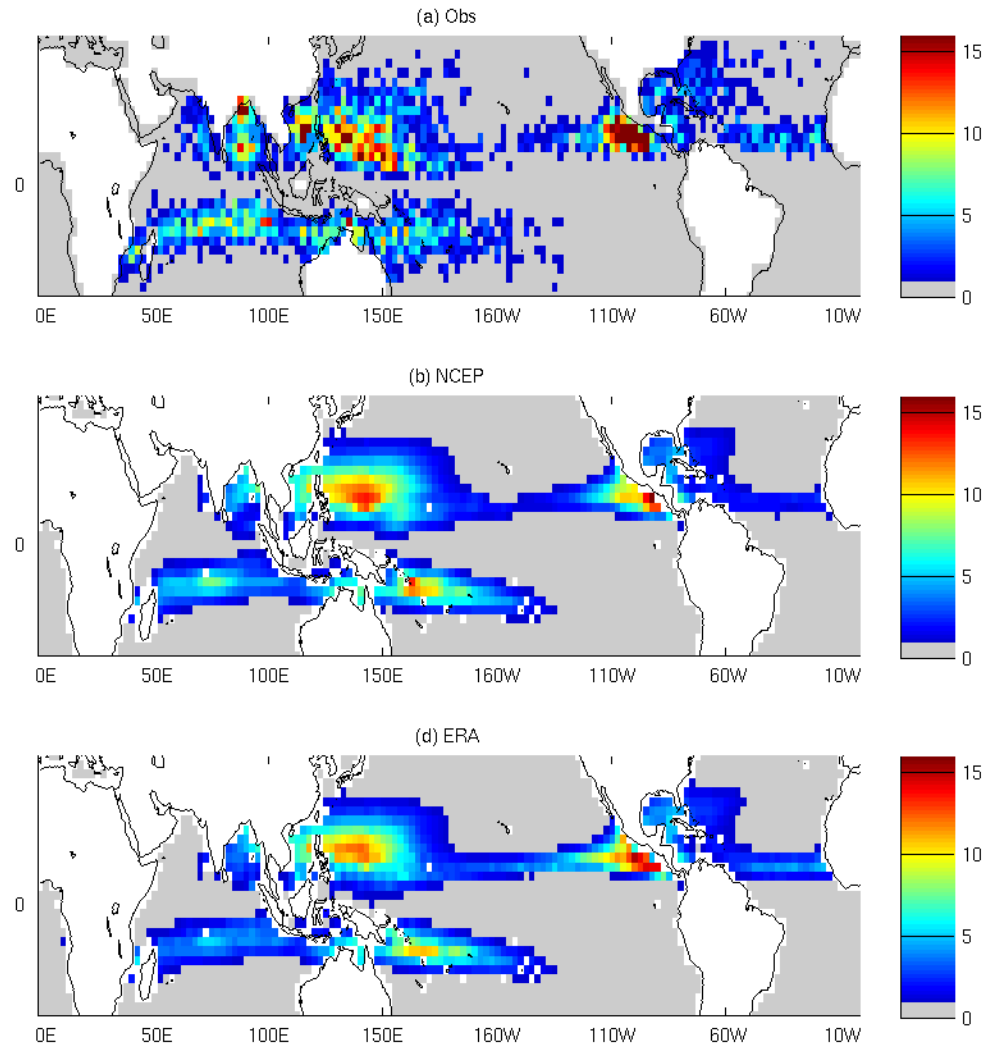
$|\eta|$ = absolute vorticity (850hPa) x 10^5

H = column relative humidity

RSST = relative SST (SST - mean tropical SST)

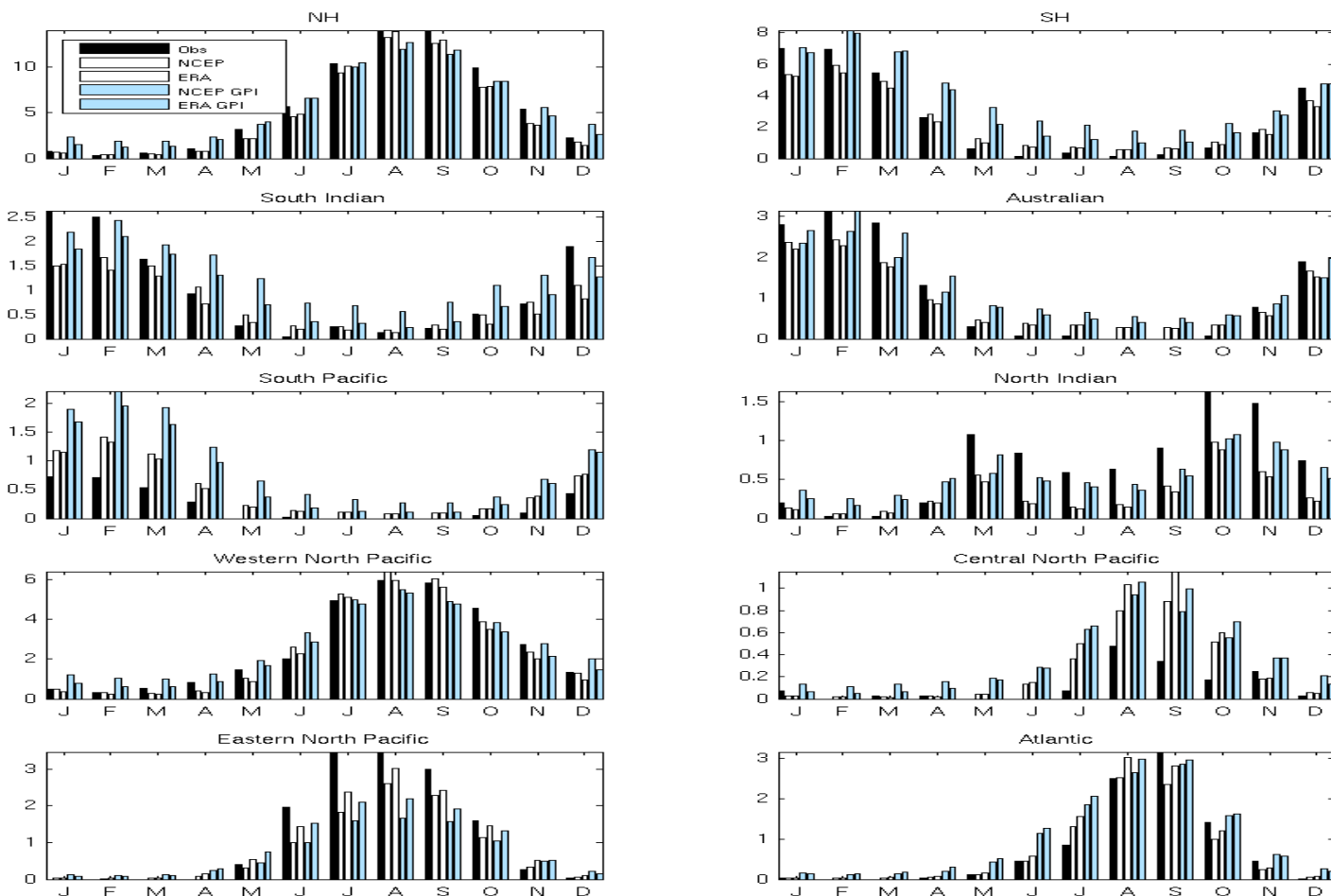
V_s = vertical shear (200hPa and 850hPa)

Comparison of observed climatological TCG density to index (index derived from either NCEP or ERA40)



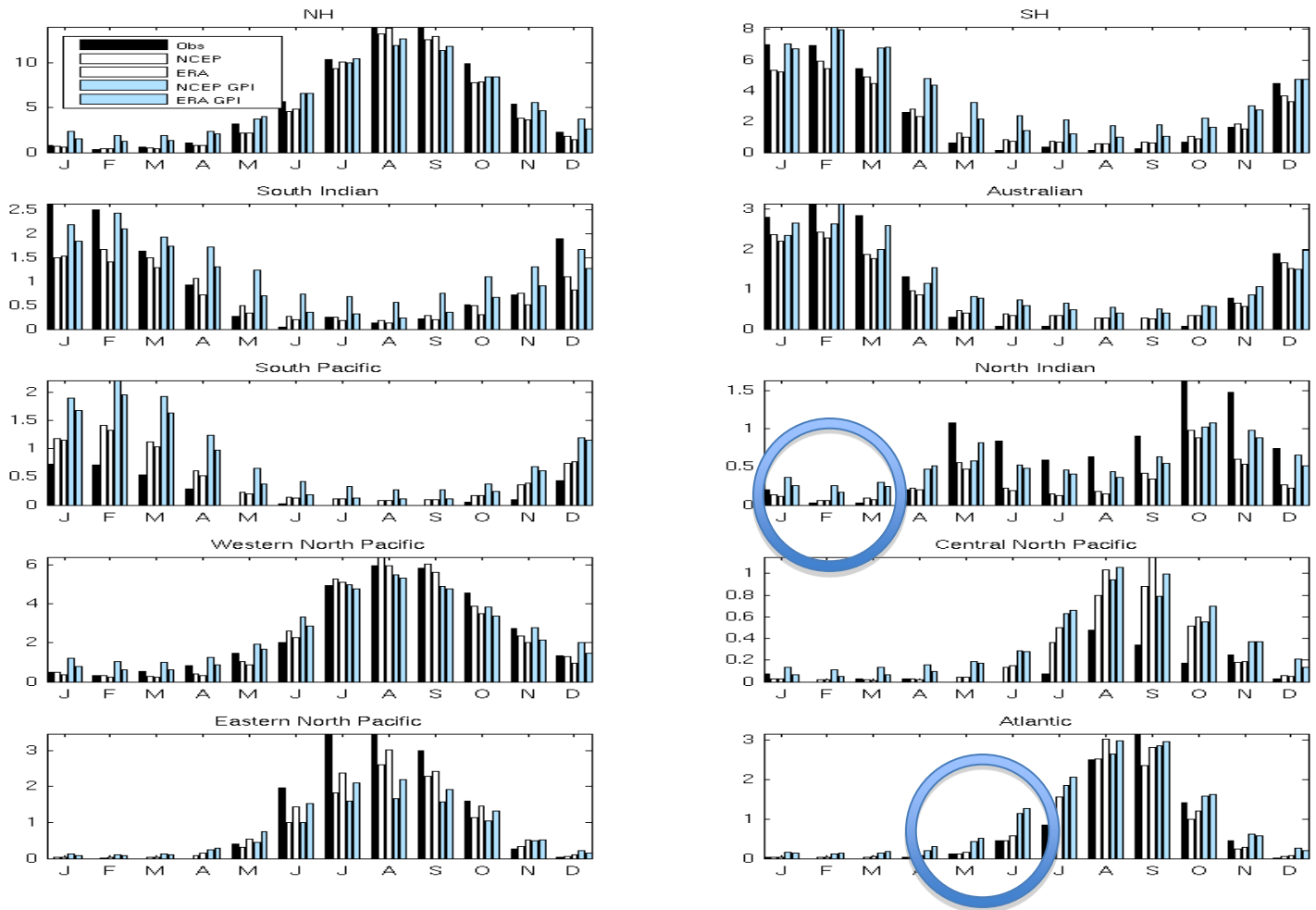
Performance of index is comparable to Emanuel GPI, but improved in some respects

Annual cycles for each basin and both hemispheres



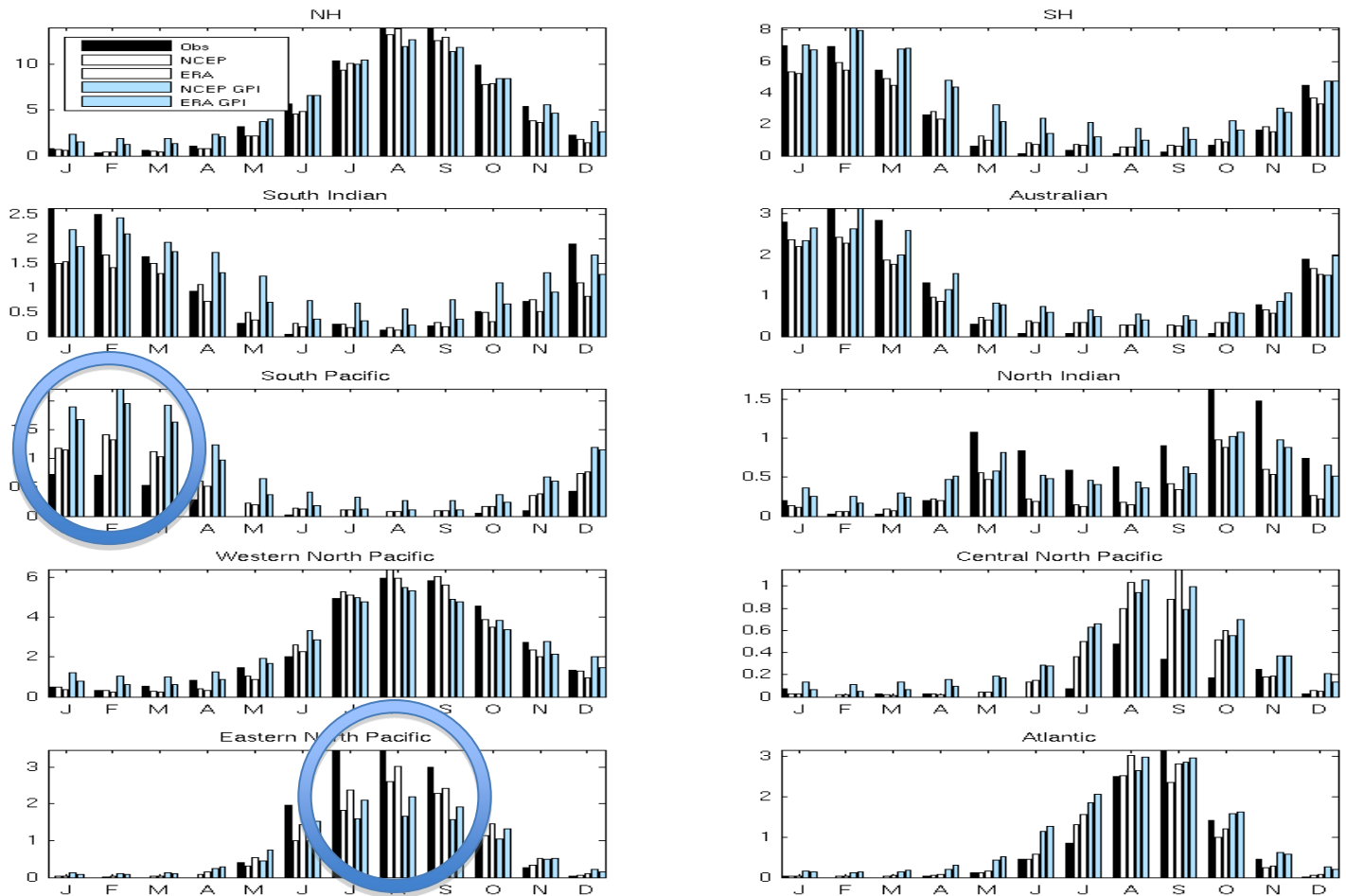
E.g., GPI tends to overestimate genesis probability at times when it's small

Annual cycles for each basin and both hemispheres



GPI underestimates peak season in Eastern Pacific, overestimates in south Pacific

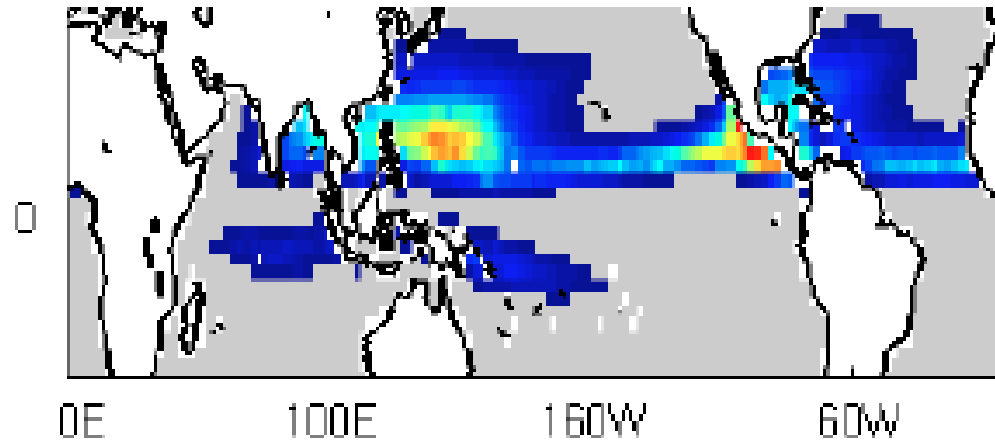
Annual cycles for each basin and both hemispheres



Use of clipped absolute vorticity strengthens N. Atlantic and NE Pacific, and shifts WNP genesis maximum south – all of which is in better agreement with obs

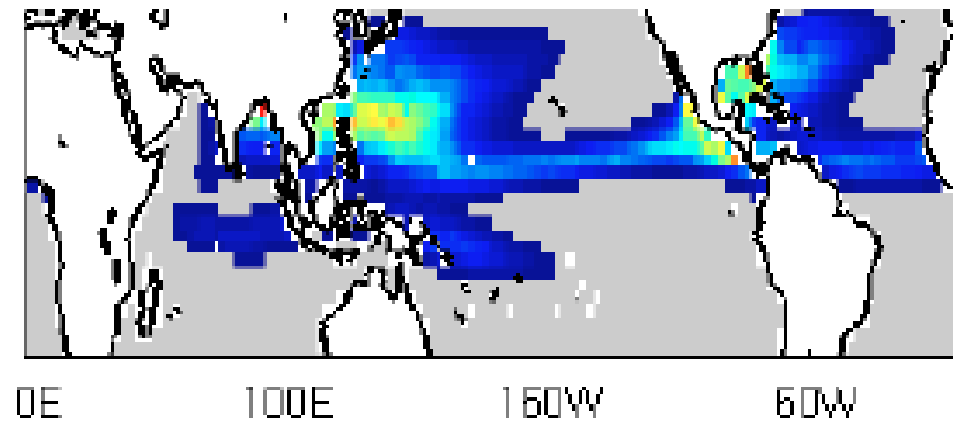
(d) ASO ERA

Clipped vorticity



(j) ASO ERA AV

unclipped vorticity



Conclusions

- **QBO:** With longer record, QBO is not significantly correlated with TCs in Atlantic (or any other basin). The correlation from 1950s-80s remains hard to explain (but may be a result of ENSO...)
- **Index, 1:** We have presented a new index for TC genesis. Its performance incrementally improves on the Emanuel GPI. Biggest change is the use of clipped vorticity.
- **Index, 2:** The clipped vorticity result tells us something about physics of genesis – environmental vorticity ceases to be a rate-limiting factor in genesis once it is sufficiently large (equal to f at about 20 degrees latitude)

Camargo, S. J., and A. H. Sobel: Revisiting the influence of the quasi-biennial oscillation on tropical cyclone activity. *J. Climate*, in press.

Tippett, M. K., S. J. Camargo and A. H. Sobel: A Poisson regression index for tropical cyclone genesis and the role of large-scale vorticity in genesis. *J. Climate*, submitted.

www.columbia.edu/~ahs129/pubs.html