Genesis Parameters, Genesis Thresholds, and Mid-Level Humidity

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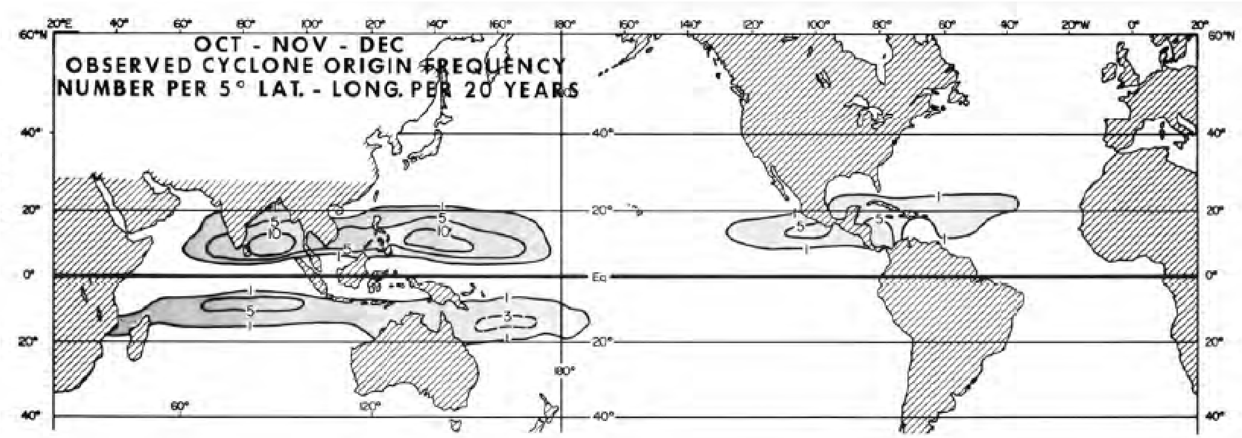
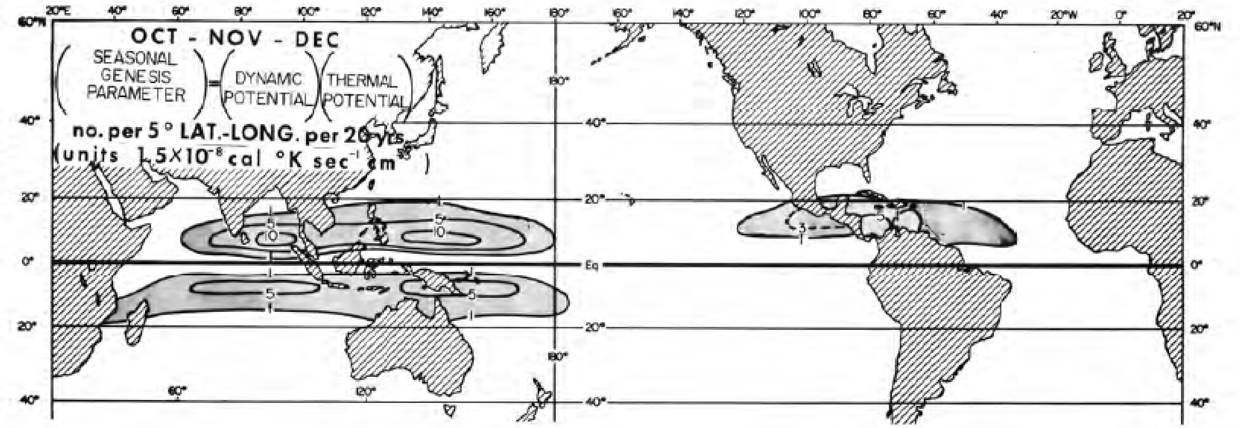
I. Background

- A "genesis parameter" is an attempt to correlate large-scale, environmental variables with annual or seasonal frequency of TC formation, e.g., Gray (1975):





$$GP = \left\{ f \times (\zeta + 5) \times \left(\left| \frac{\delta V}{\delta p} \right| + 3 \right)^{-1} \right\} \times \left\{ E_{Ocean} \times \left(\frac{\partial \theta_e}{\partial p} + 5 \right) \times max\left[\frac{\text{RH} - 40}{30}, 1 \right] \right\}$$

- Since then, a number of other genesis parameters have been developed, e.g.,

Emanuel and Nolan (2004): $GP_{EN} = \left|10^5\eta\right|^{3/2}\left(\frac{\mathrm{RH}}{50}\right)^3\left(\frac{V_{pot}}{70}\right)^3(1+0.1\times V_{\mathrm{shear}})^{-2}$

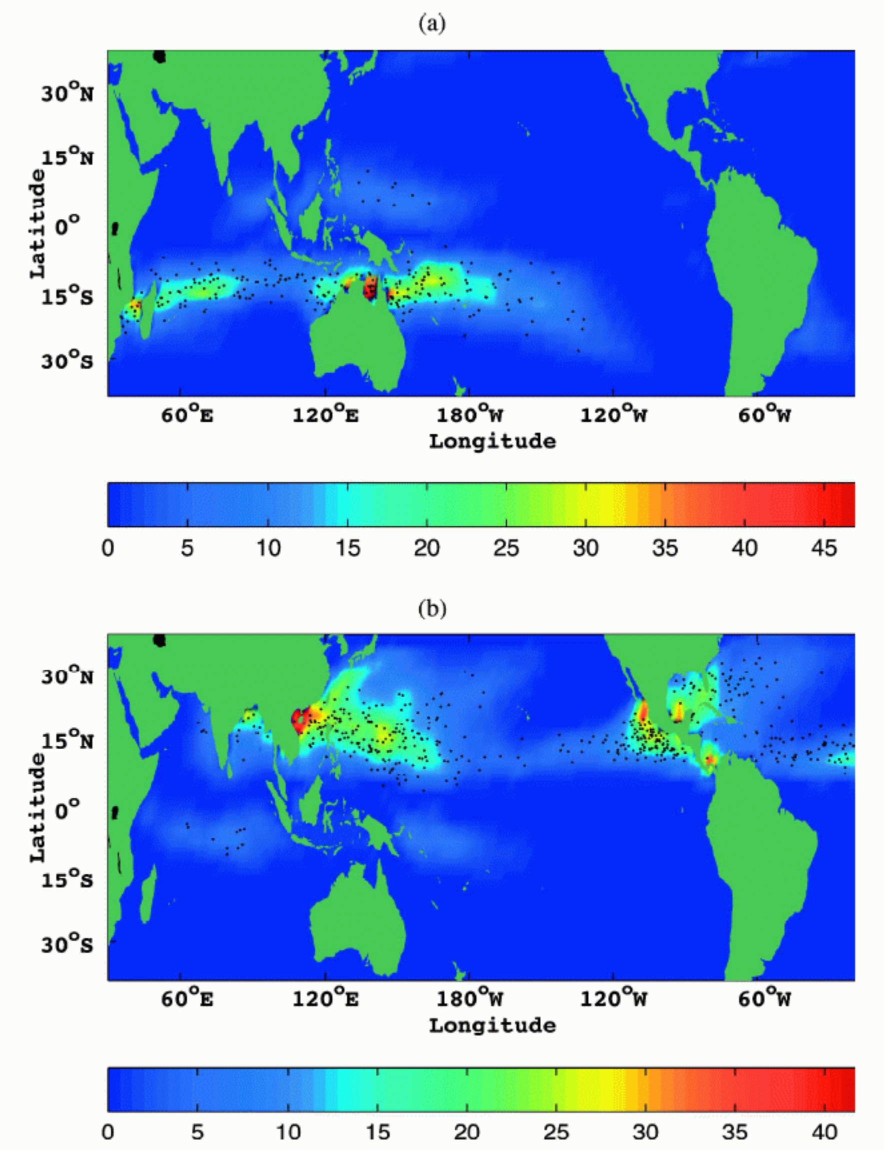


FIG. 1. Genesis potential index climatology in (a) February and (b) September. The black dots show individual genesis events over the period from (a) 1970 to 2004 and (b) 1970 to 2005.

Figure from
Camargo, Emanuel, Sobel (2007).

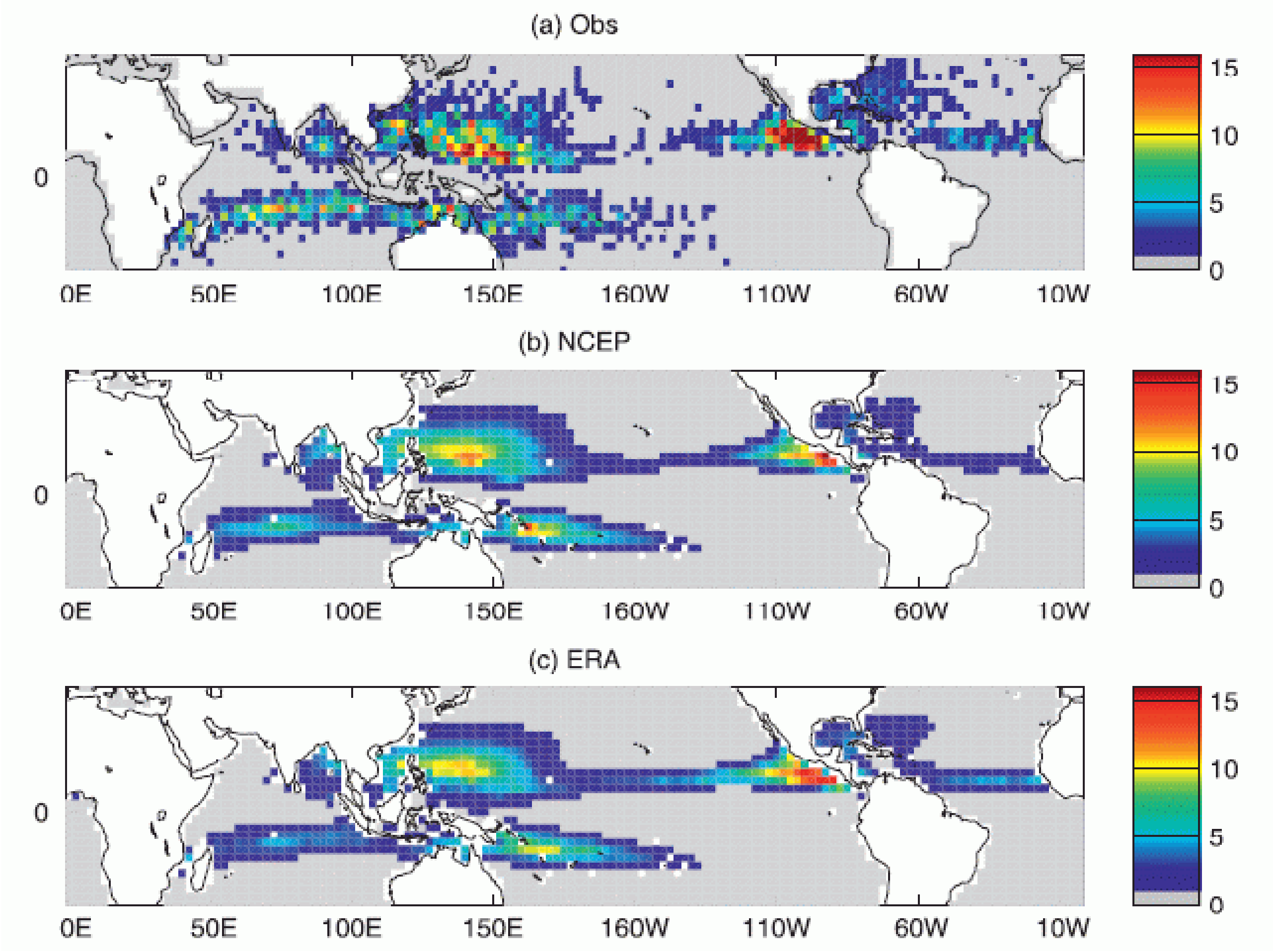
They used this GP to diagnose
the mechanisms of ENSO
influence on TC activity.

Emanuel (2010) revised the genesis index to:

$$GP_{E10} = |\eta|^3 \chi^{-4/3} \{\max[(V_{pot} - 35)^2, 0]\}(25 + V_{\text{shear}})^{-4}$$

Tippett, Camargo, Sobel (2011) derived a GP based on a Poisson regression:

$$GP_T = \exp(b + b_\eta \eta + b_{RH} RH + b_{R\text{-}SST} R\text{-}SST + b_{\text{shear}} V_{\text{shear}} + \log\cos\phi)$$



II. A New Approach

- Of course, the GP approach reflects a number of assumptions:
  - * The influence of each parameter is independent of the values of the others
  - * The number and strength of pre-cursor disturbances does not matter (some evidence for this)
  - * Mean values can be used a consistent proxy for more favorable conditions (PDF does not vary with location or season)

II. A New Approach

- Of course, the GP approach reflects a number of assumptions:
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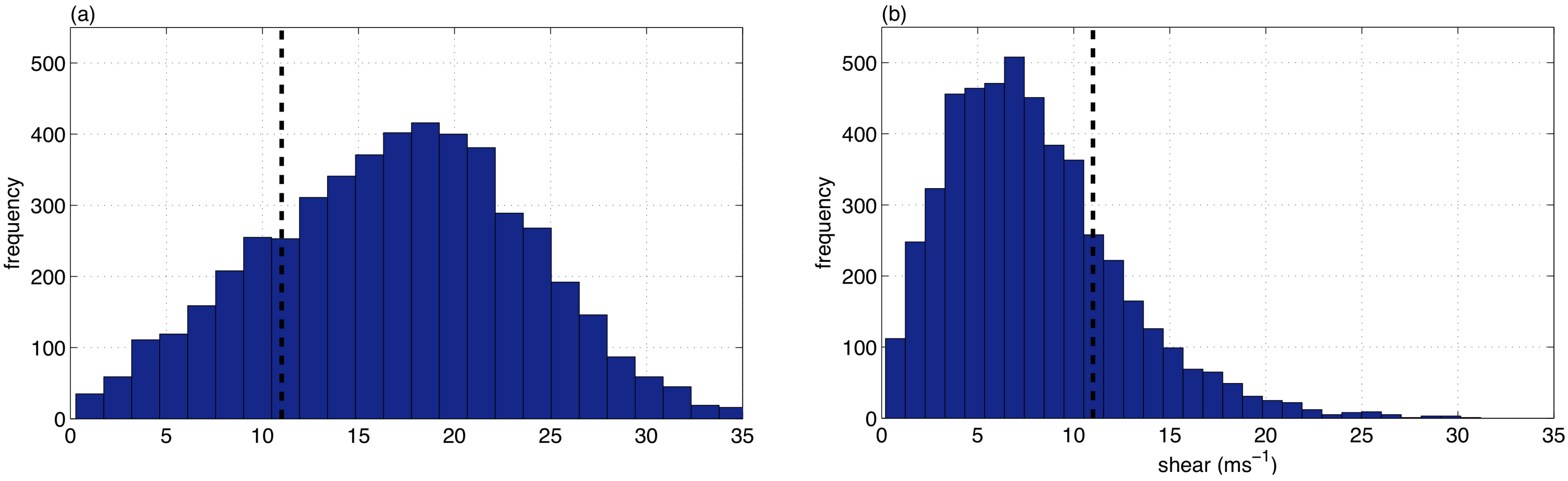
But in fact - the shapes of these PDFs can vary substantially:



- With the last issue in mind, we have developed an alternate approach: the *genesis frequency index*:

$$\text{GFI} = f_{\text{Vpot}} \times f_{\text{shear}} \times f_{\text{RH}} \times f_{\eta}$$

where each *f* is the frequency that each parameter is above or below some *threshold value* that will permit TC genesis - given that all the other parameters are highly favorable.

- The GFI formula is very flexible: one can remove or add parameters without reformulation

- For now we are also neglecting the issue of generating disturbances

- To build the GFI, we need to:

  1) Identify a highly favorable but realistic atmospheric environment, where each parameter is in its "most advantageous but realistic" (MABR) state.

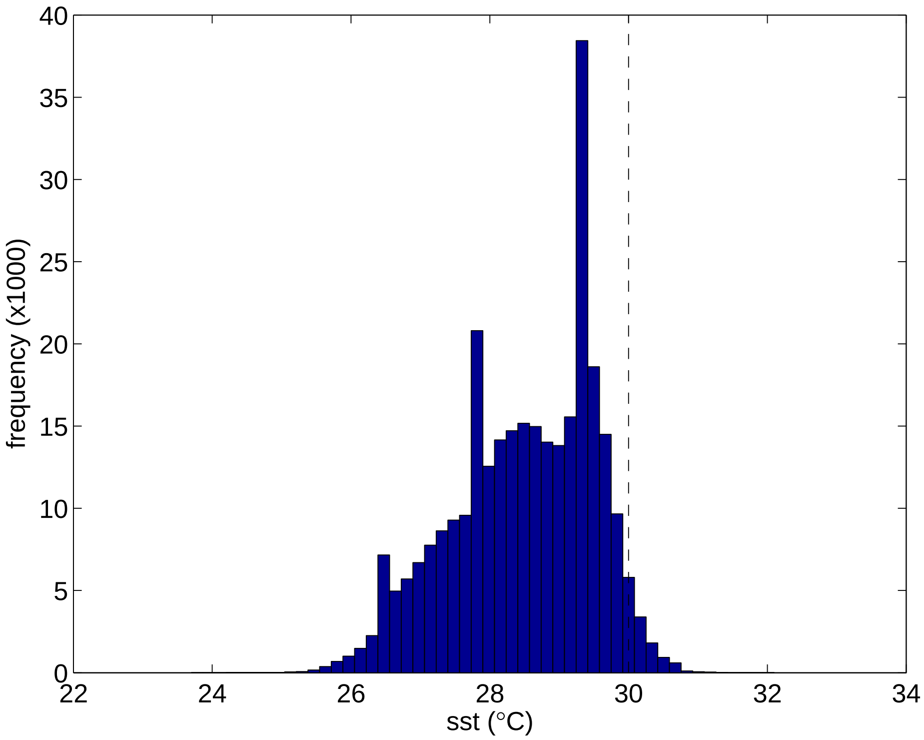
  2) For each parameter, we adjust it toward a more unfavorable value while holding the other parameters in the MABR state, until TC genesis can not occur.

     To identify when genesis is not possible, we use idealized numerical simulations.

  3) Compute from reanalyses the frequency that each of the parameters is above or below the threshold value.

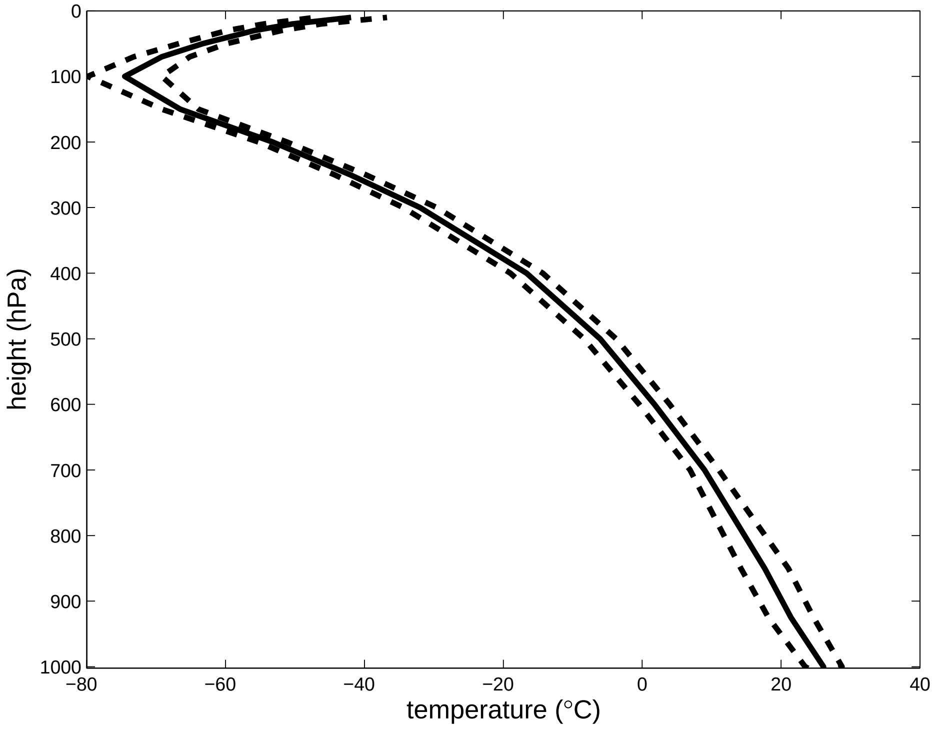
III. Constructing the MABR Environment

- The thermodynamic component of the MABR environment is a combination of SST, temperature profile, and humidity profile.



September Atlantic MDR
SST Histogram

MABR SST = 30 C

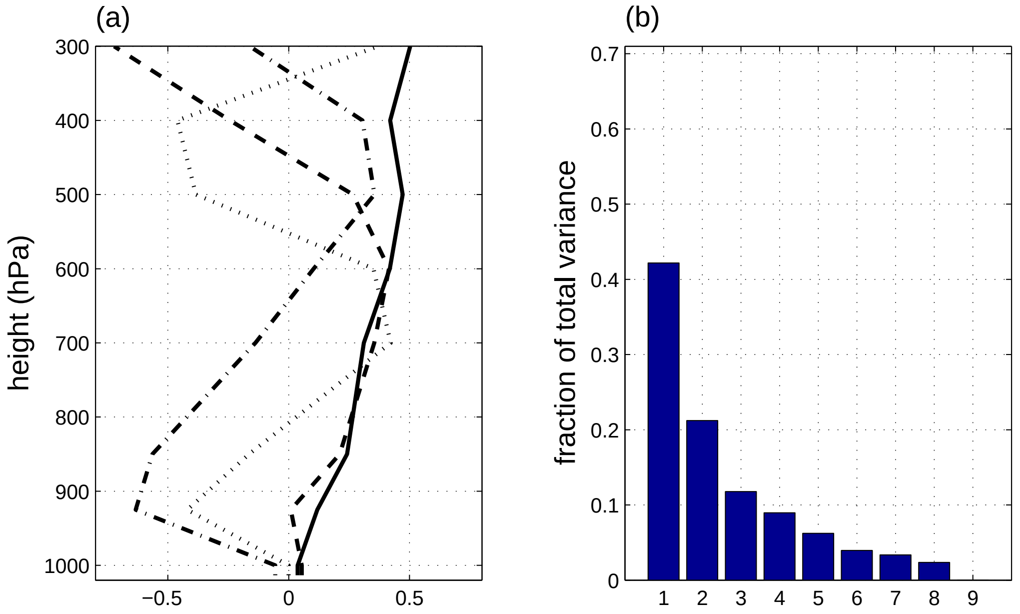


Mean September sounding
and +/- one standard deviation

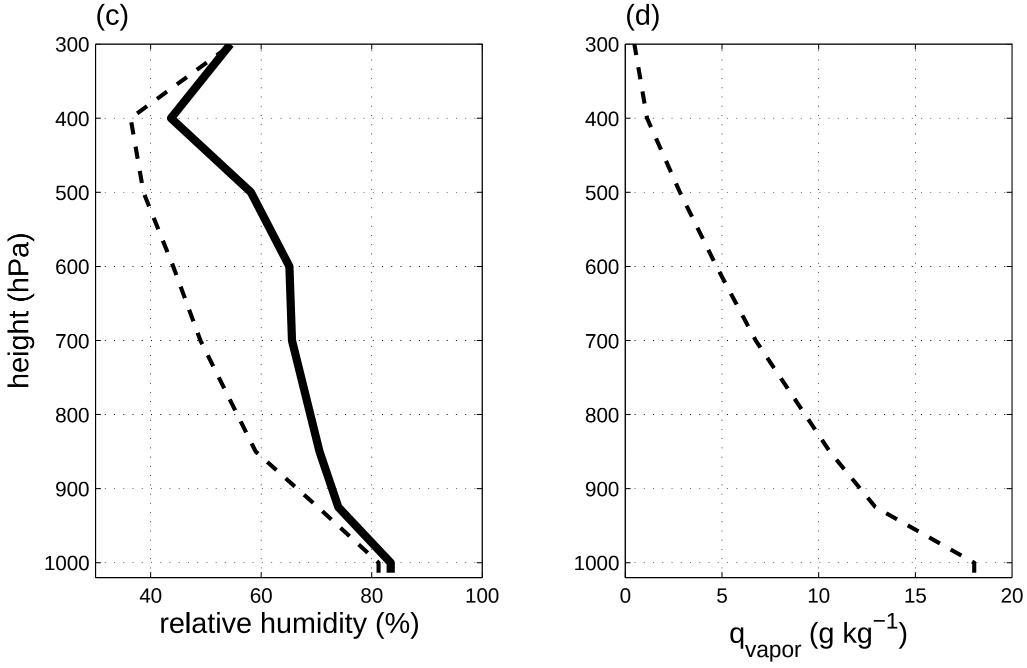
We use the mean sounding

- For humidity, we construct a moistened profile as follows:

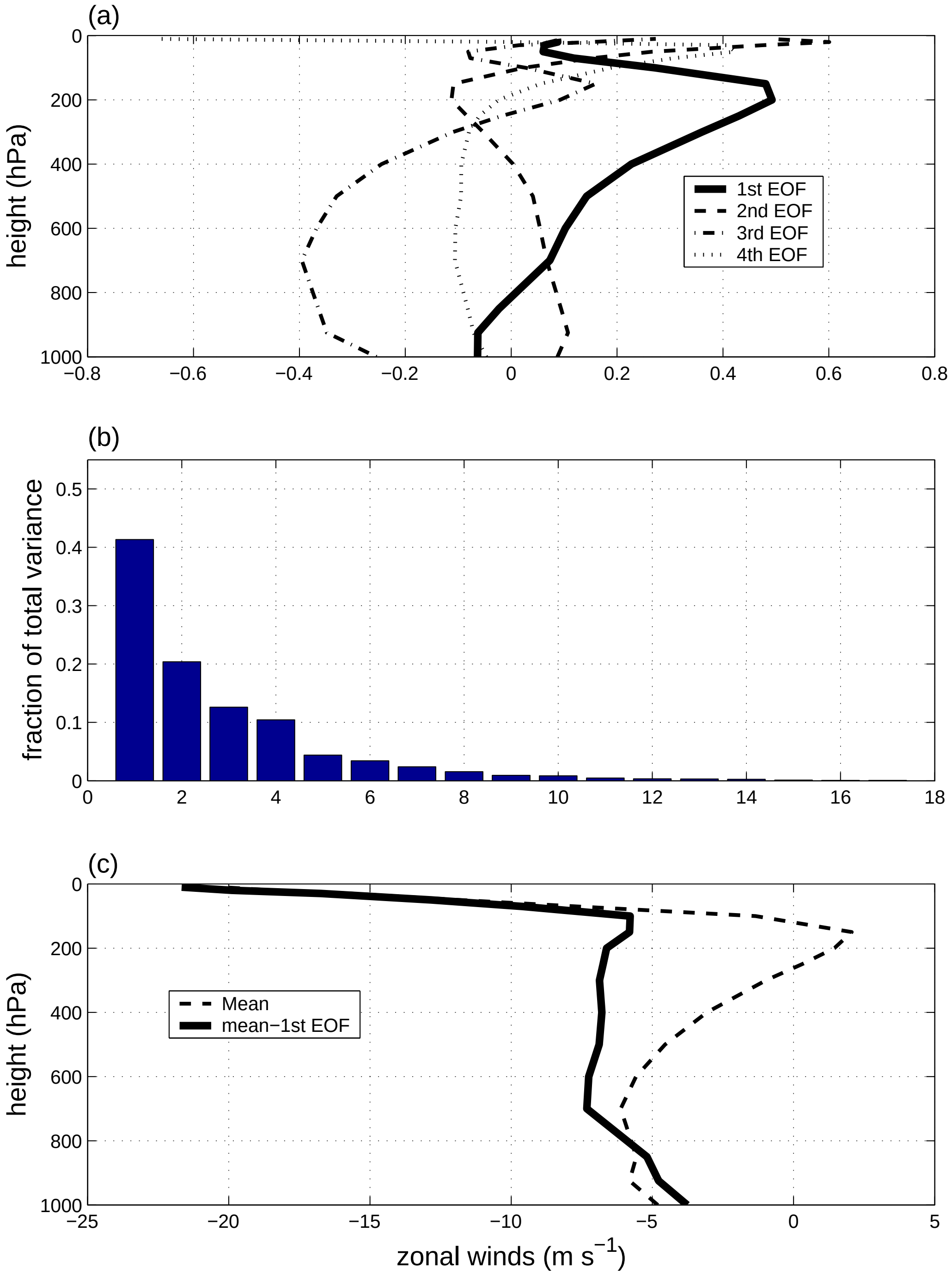
EOFs of
variations
in q_{vapor}



Mean RH
and
mean plus
1st and 2nd
EOFs



- For wind shear, a similar approach:



IV. Finding the Threshold Values

- To find the threshold value where TC genesis cannot occur, we use idealized numerical simulations with the WRF model:

  * Doubly-periodic *f*-plane at 15 N, domain size 4320km x 4320km

  * Nested, vortex-following grids with 18/6/2km resolution.

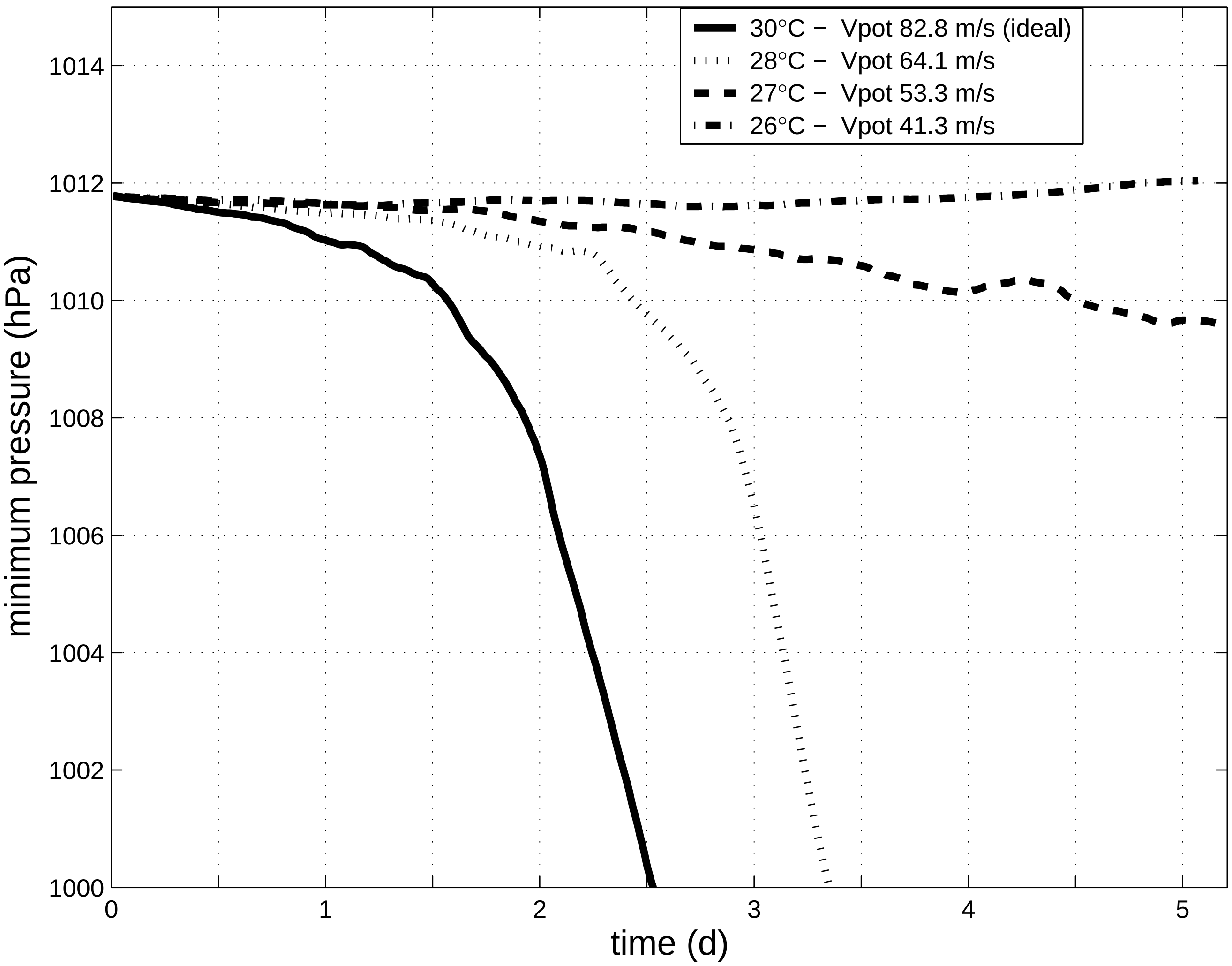
  * No cumulus parameterization, 6-class microphysics

  * MABR SST, sounding, and wind shear profiles

  * Initial condition: A weak vortex with peak tangential flow of 12 m/s at mid-levels, 6 m/s at surface.

  (Same surface pressure anomaly as pre-depression waves in Atlantic.)

Finding the threshold: V_{pot}

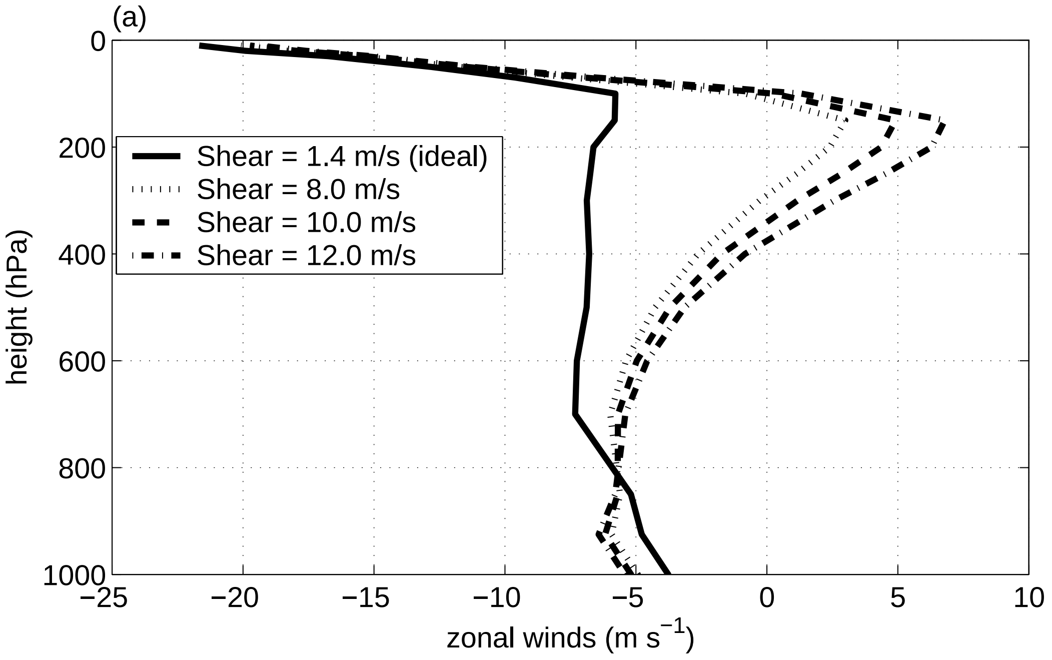


- We vary V_{pot} only by varying SST.

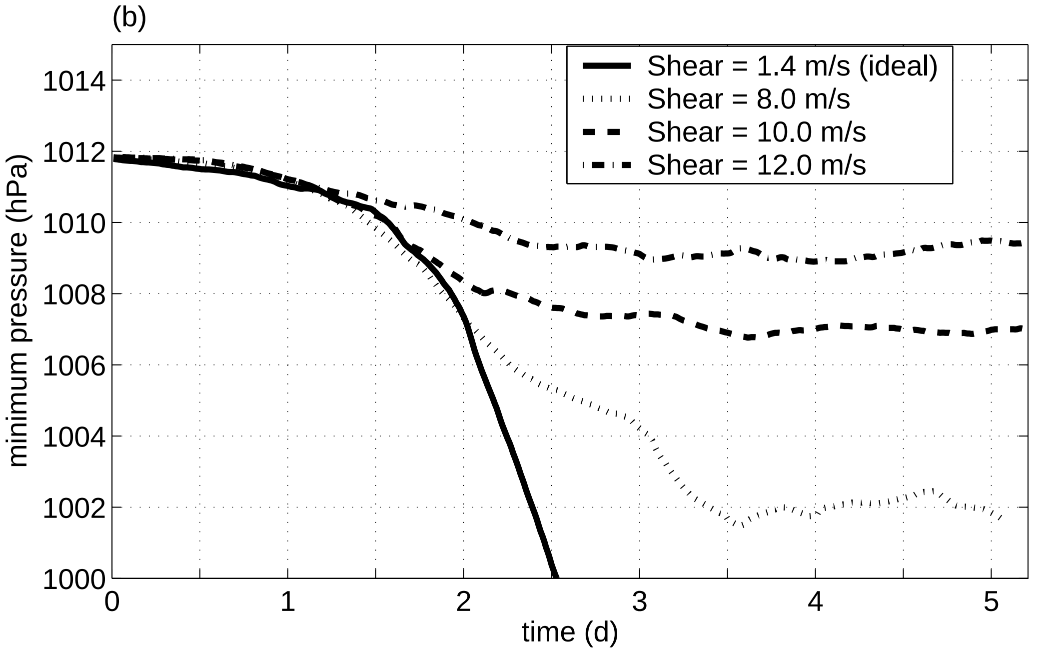
If the pressure does not fall and stay below 1010 hPa, genesis has failed.

From these results, the threshold for V_{pot} is set to 47 m/s.

Finding the threshold: Wind Shear

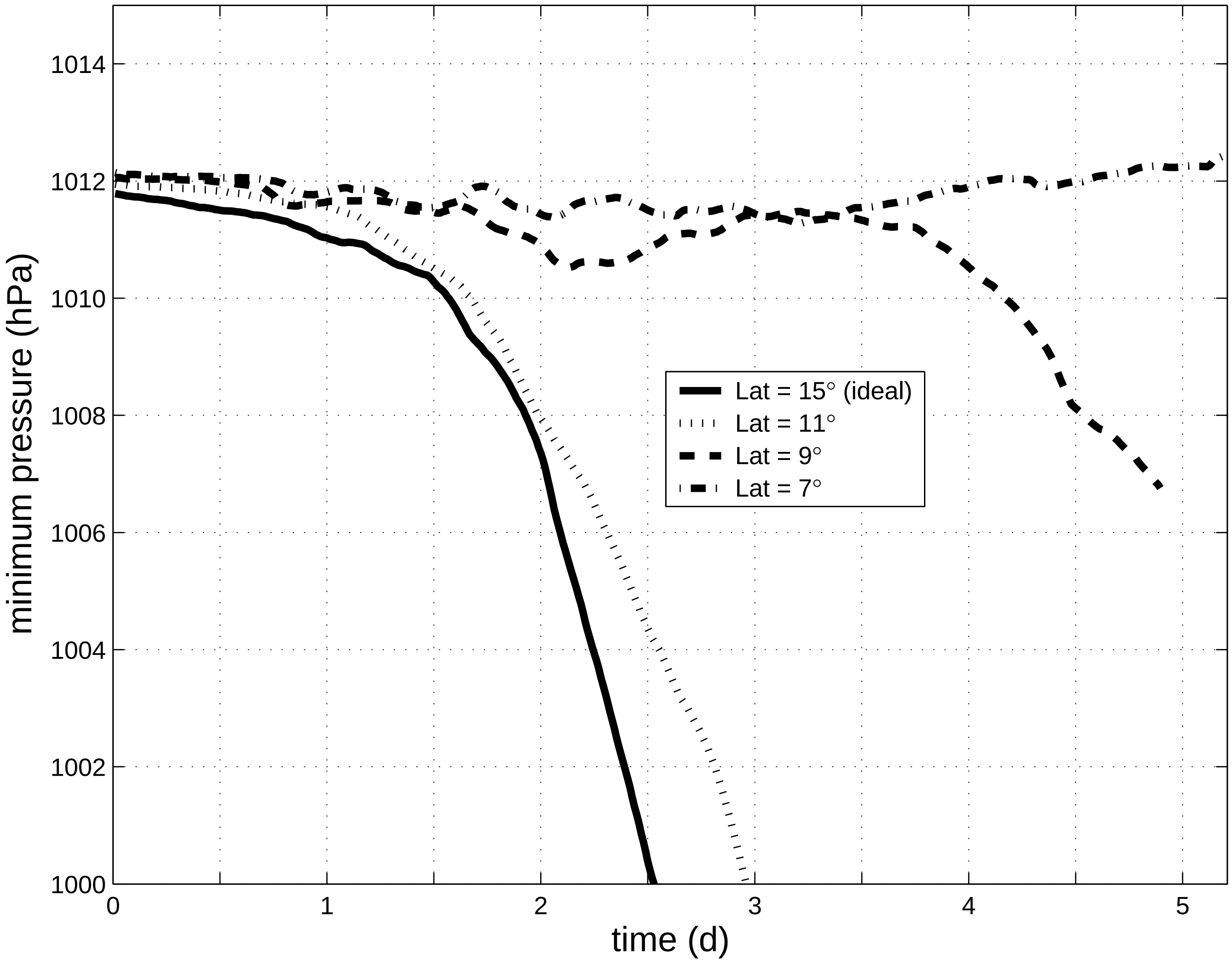


Shear varied by varying amplitude of 1st EOF



Threshold value 11 m/s

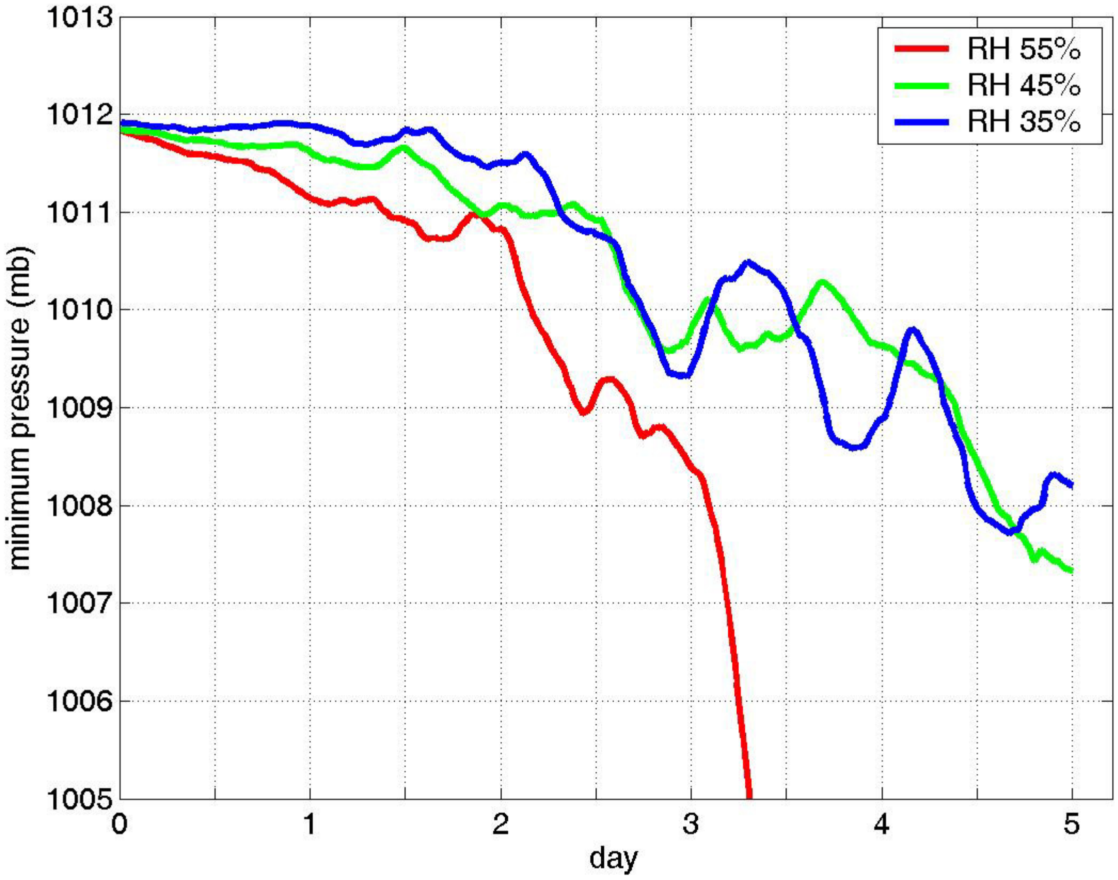
Finding the threshold: Environmental Vorticity



- Rather than trying to model horizontal wind shear, we use planetary vorticity as a proxy for environmental absolute vorticity.

The environmental absolute vorticity threshold is set to $2.0\text{x}10^{-5}\ \text{s}^{-1}$ (~ 8N).

Finding the threshold: Humidity



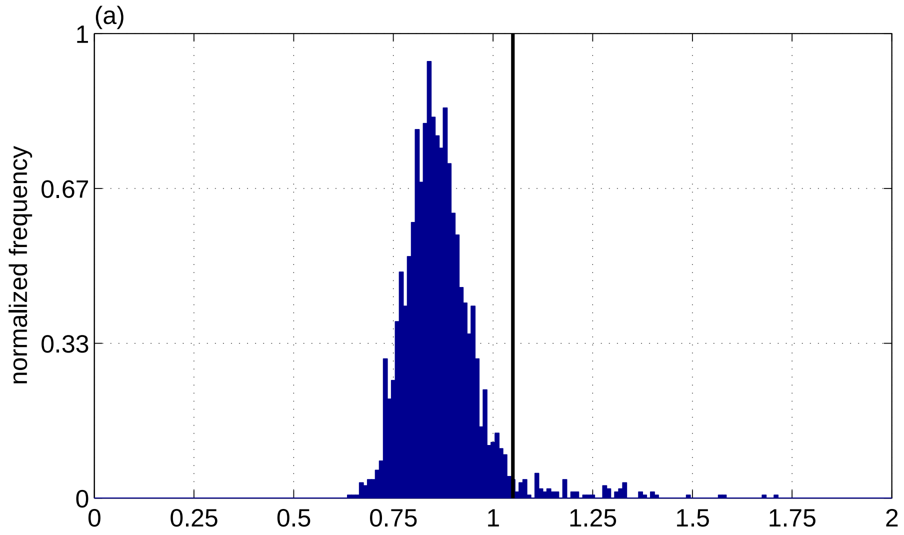
All simulations develop, even for RH_{600} --> 0 (!)

- Our method does not work for humidity.

With very low (MABR) shear, convection in the disturbance can easily saturate the core. Shear is necessary for dryness to prohibit genesis.

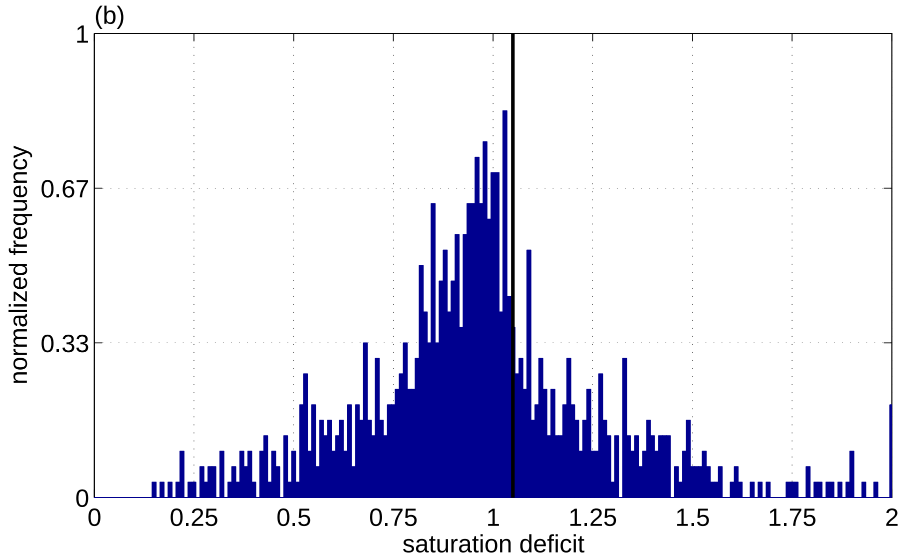
- We fall back on a purely empirical approach to find the threshold.

Our humidity variable is the normalized saturation deficit: $\mathrm{NSD} = \dfrac{q^*_{600} - q_{600}}{q^*_{SST} - q_{1000}}$



Histogram of NSD around TC genesis events

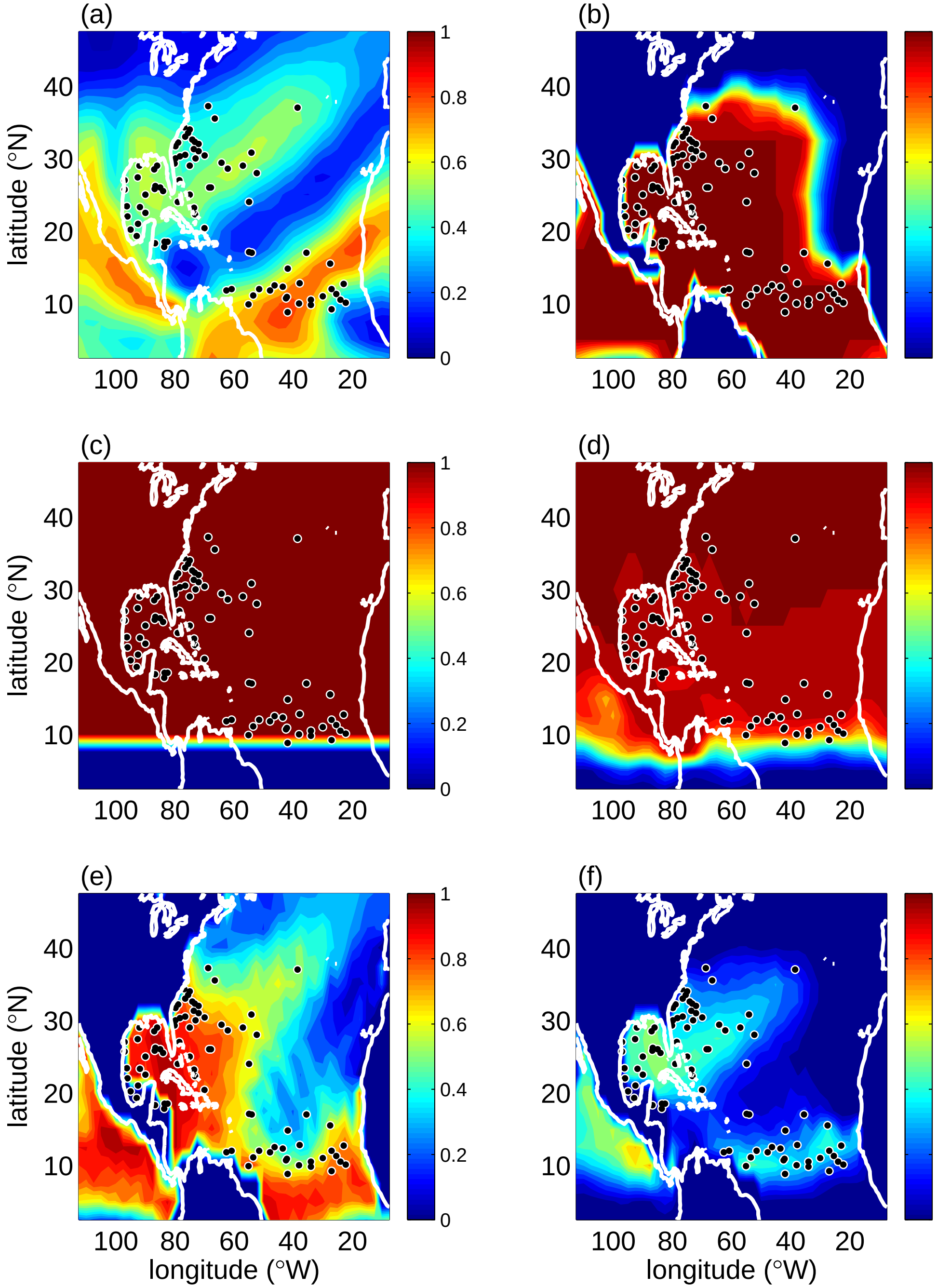
Threshold is mean plus two standard deviations



NSD from randomly sampled locations in TC genesis regions and seasons

V. Results: Putting it all together

July 1969-2008



Shear < 11

$V_{pot} > 47$

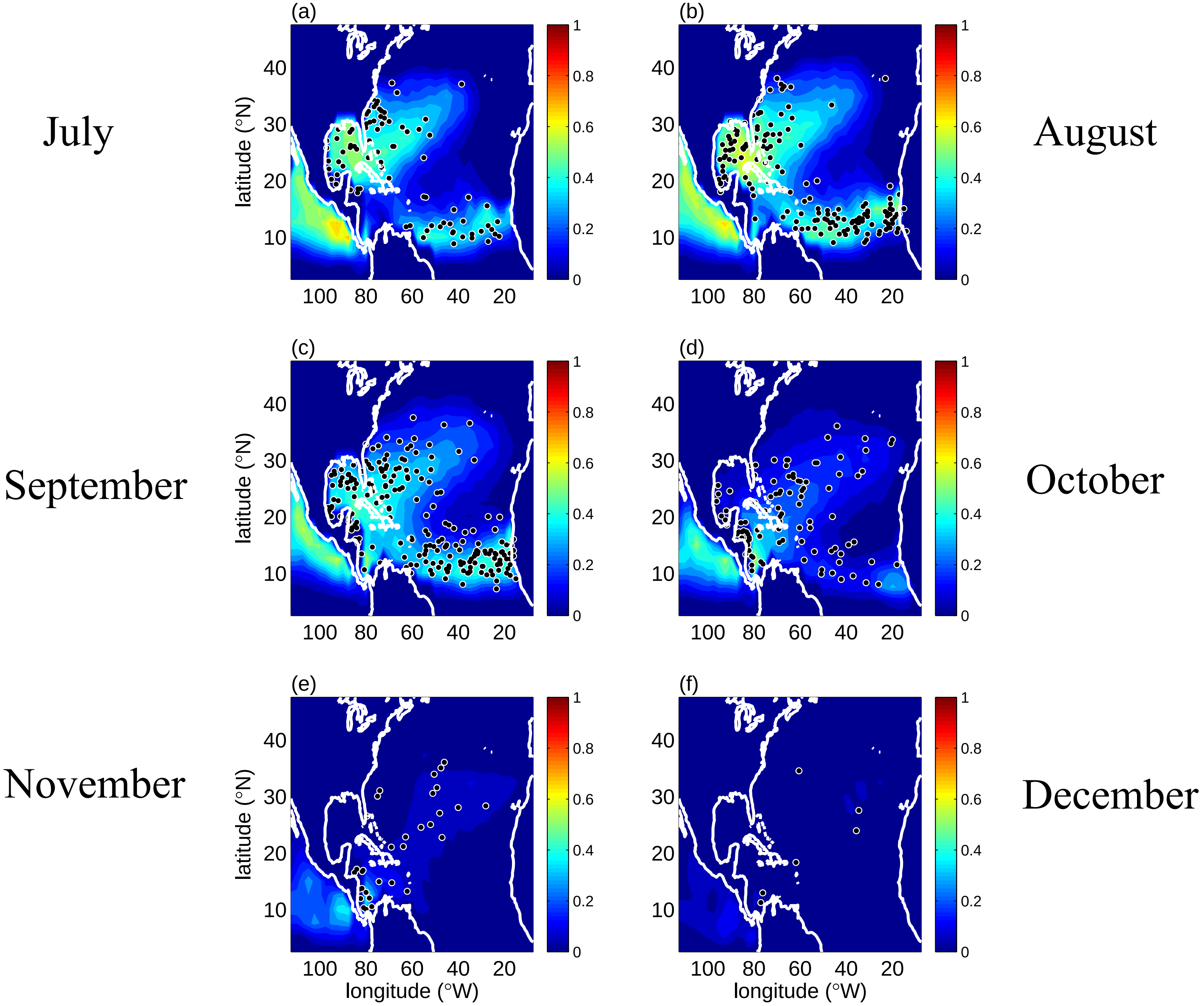
Lat > 8N

$\eta > 2.0\text{x}10^{-5}$

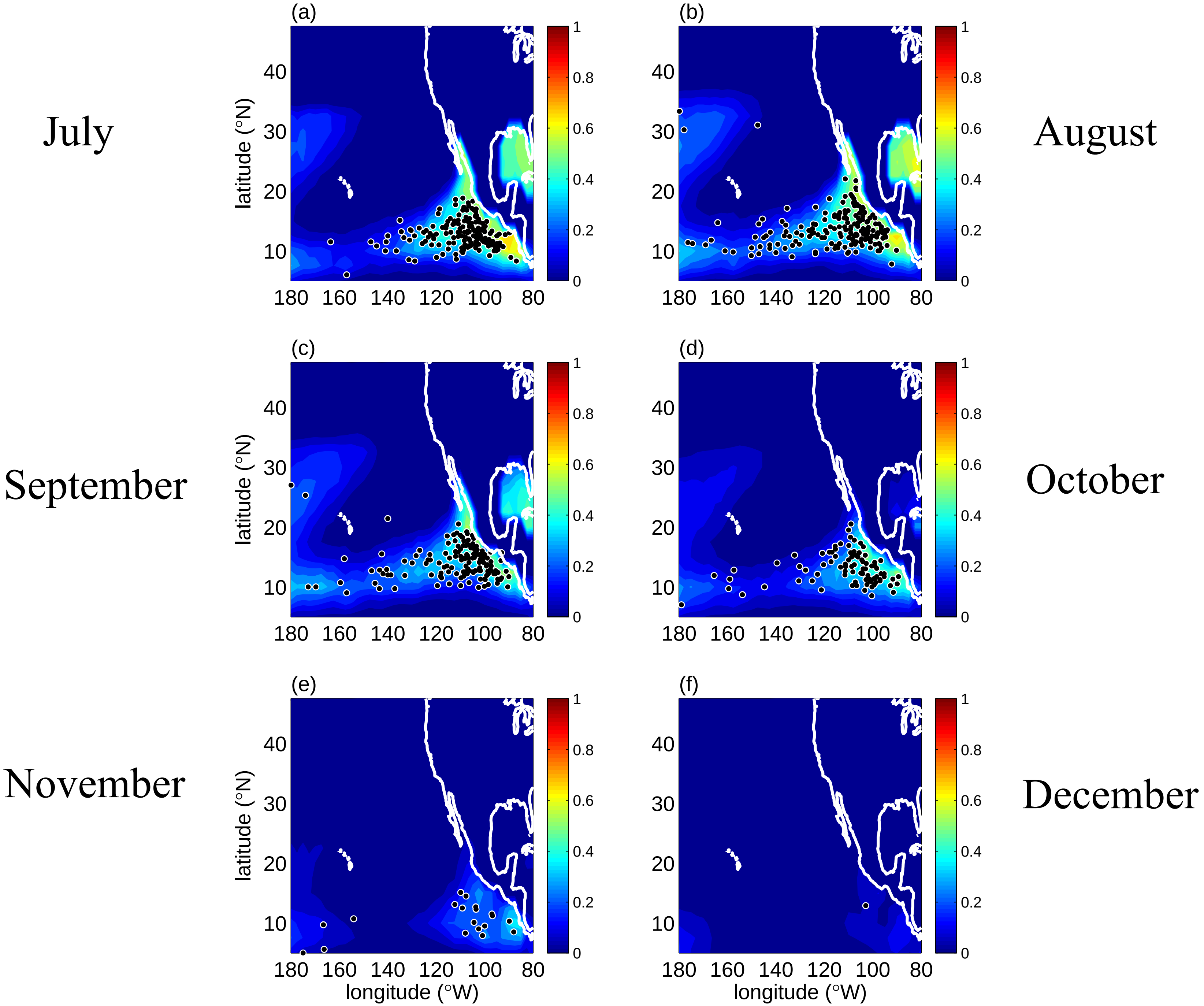
NSD > 1.05

(a) x (b)
x (d) x (e) = GFI

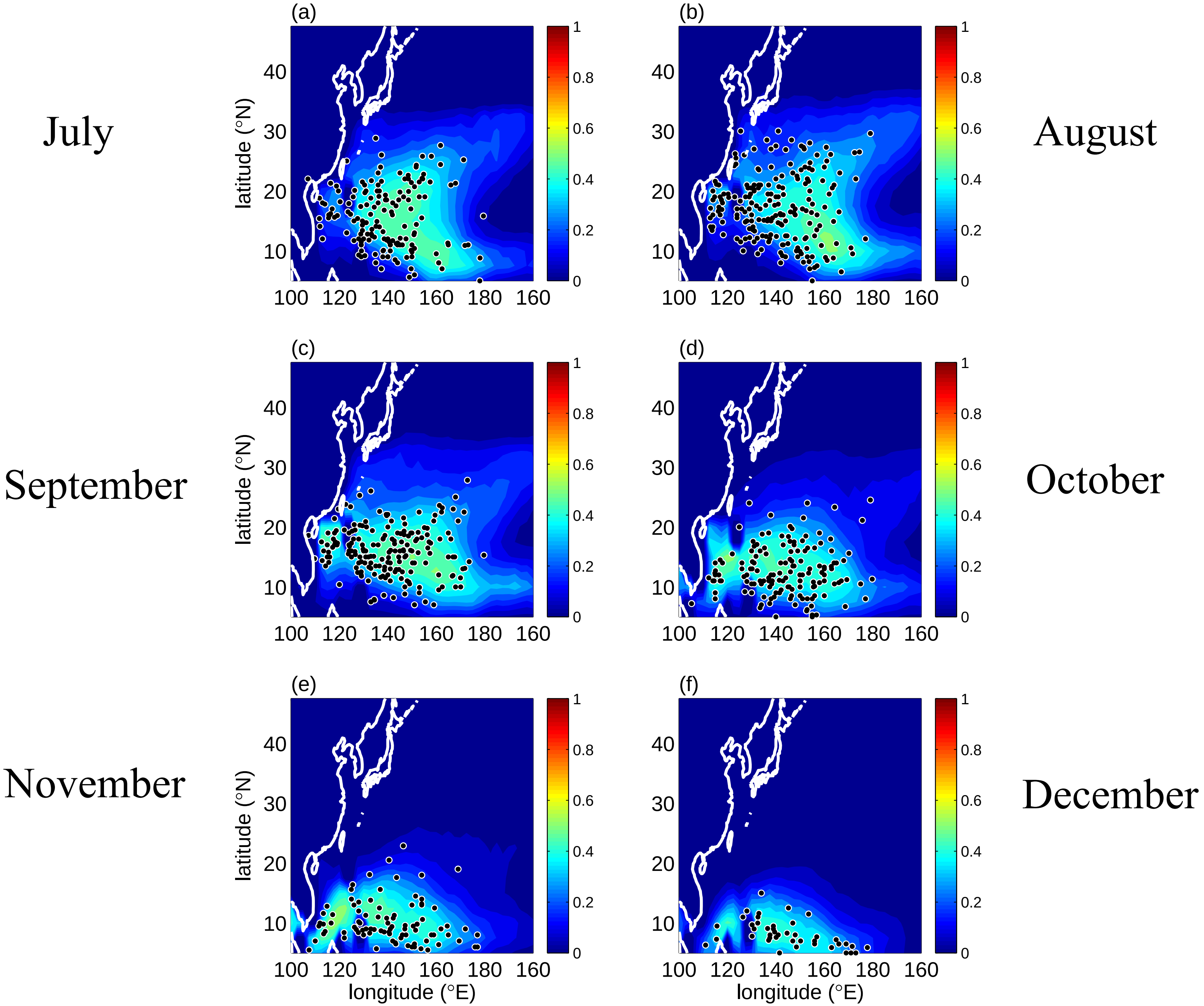
GFI: Atlantic



GFI: East Pacific



GFI: West Pacific

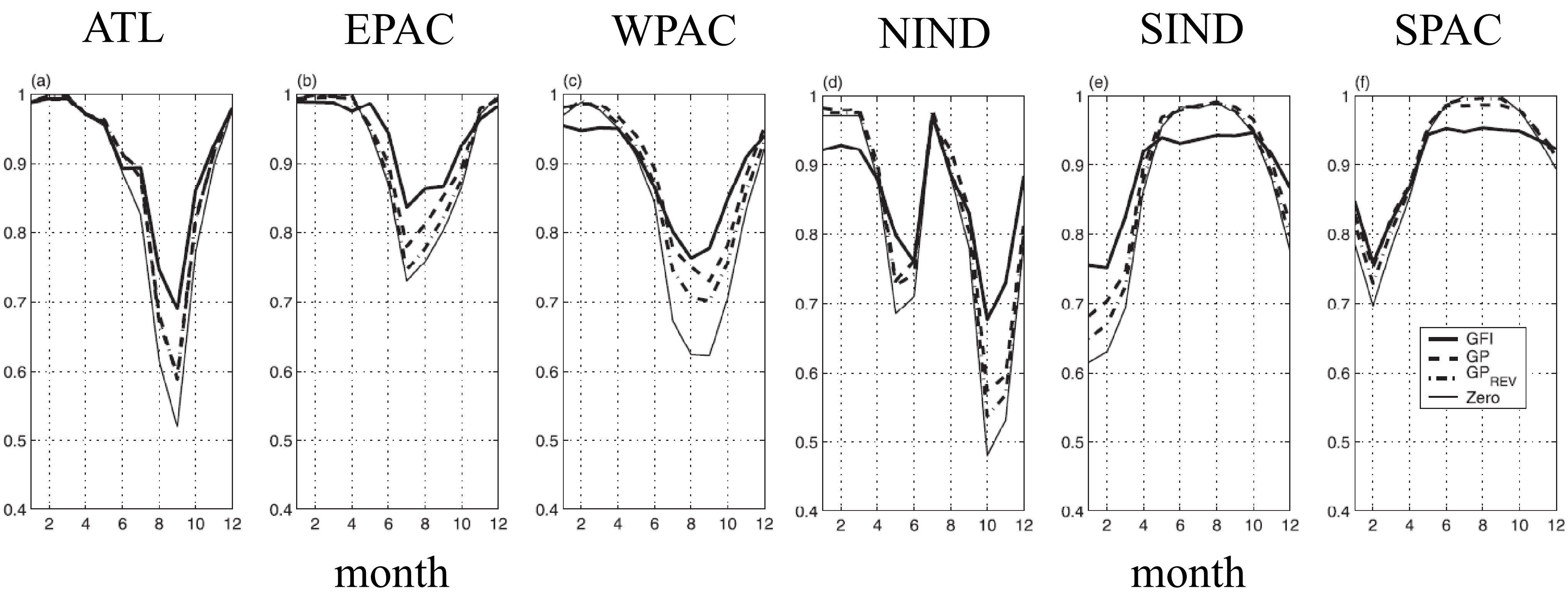


- An objective assessment of spatial correlations:

  * Each basin is divided into n $10° \times 10°$ boxes.

  * In each basin, $\text{score} = \left(\sum_{i=1}^{n} (\text{index}_i - \text{TCcount}_i)^2 / n \right)^{1/2}$,

  where (index_i) and (TCcount_i) are normalized by maximum values in all basins for all seasons.



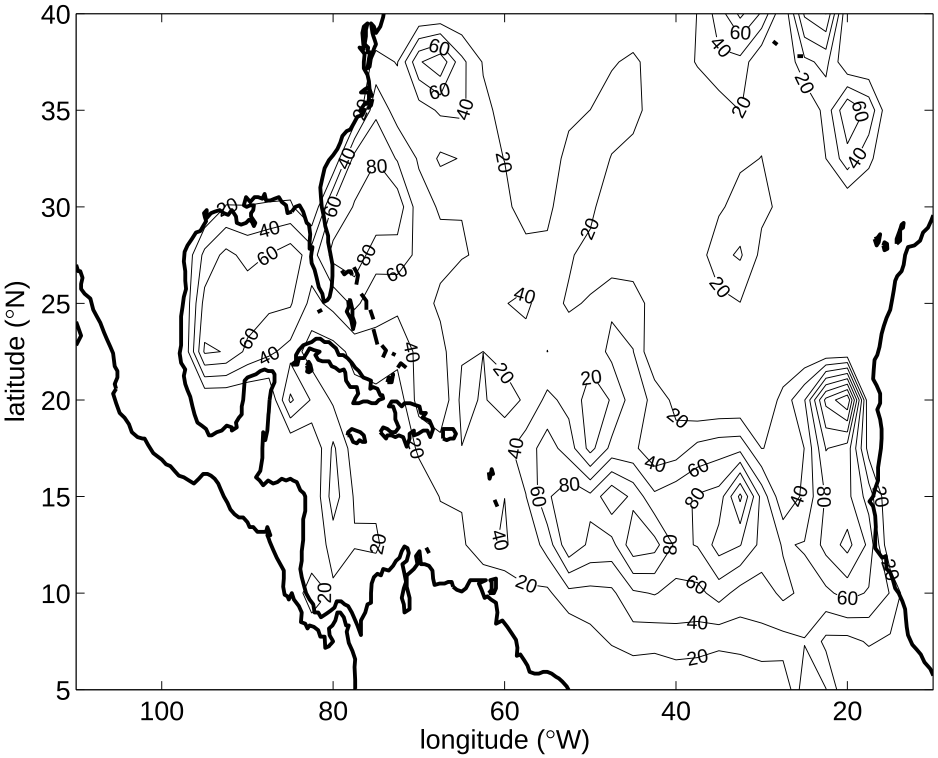
VI. Applications

$$\mathrm{GFI} = f_{\mathrm{Vpot}} \times f_{\mathrm{shear}} \times f_{\mathrm{RH}} \times f_{\eta}$$

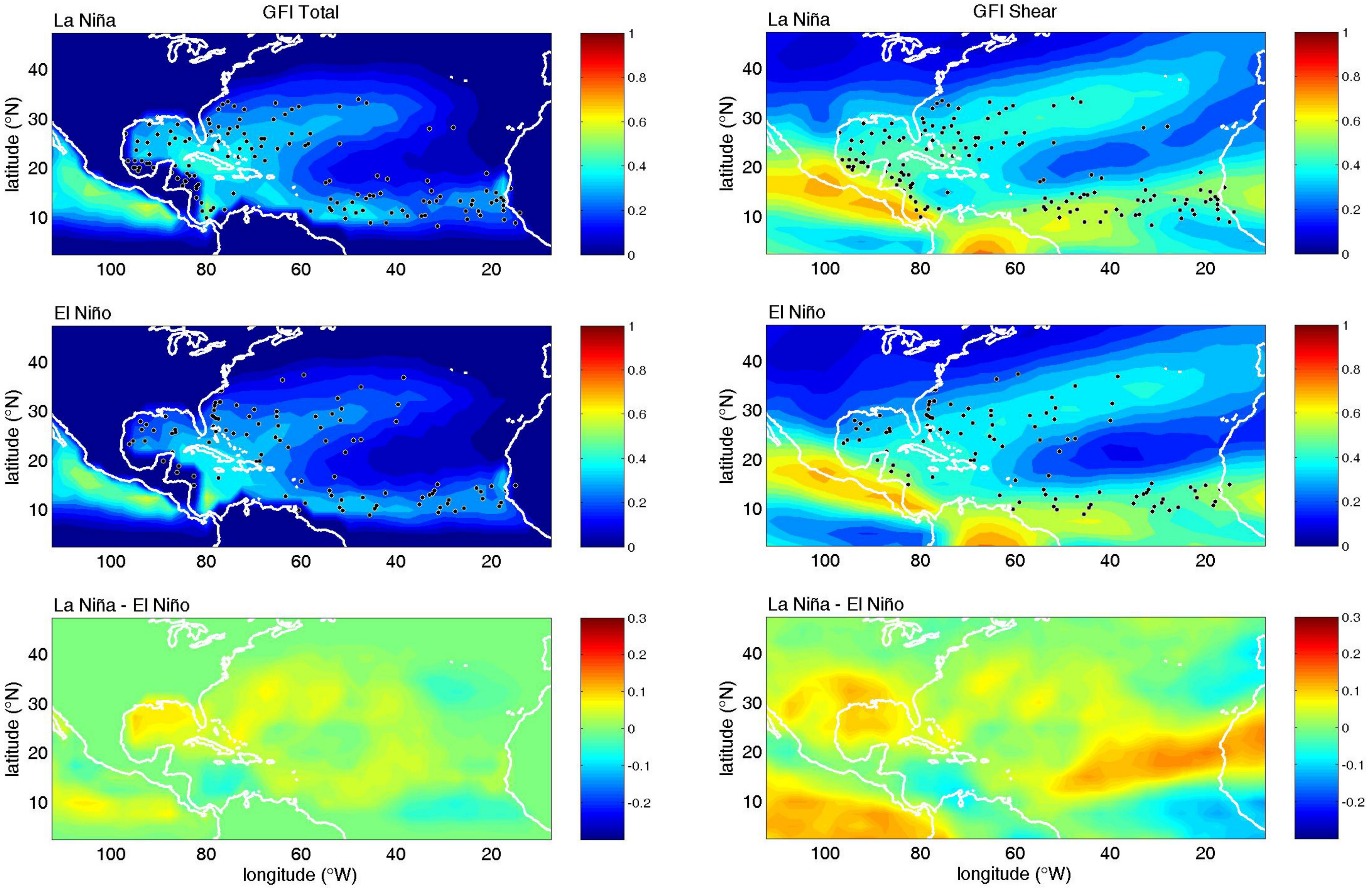
- As in the development of the GPs, we have neglected the frequency of initiating disturbances.

  If we had a good count, we could simply attach it to the end of the GFI to get a prediction of actual TC numbers.

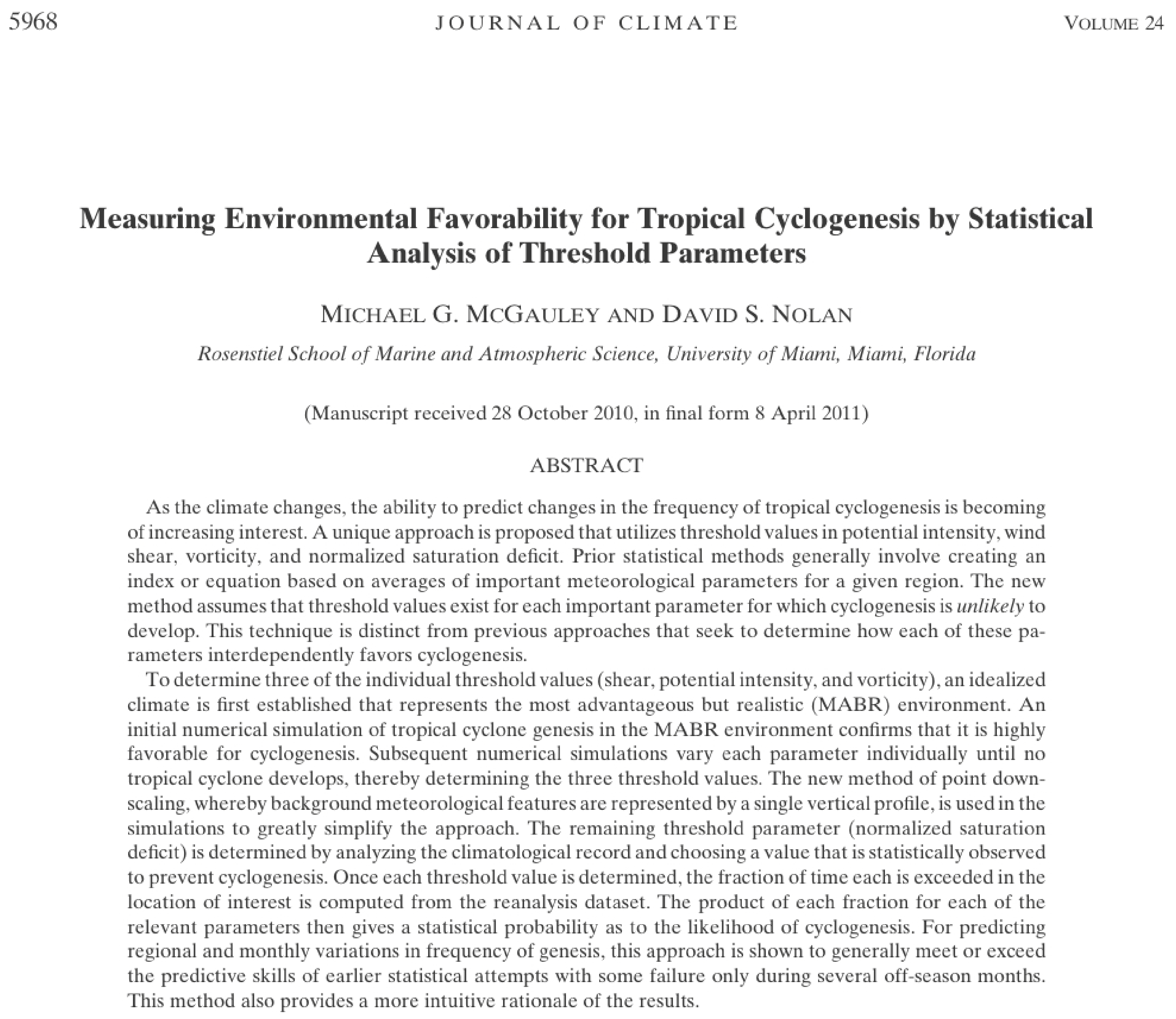
  Assuming the GFI is perfect, we can back out the number of disturbances:



As in Camargo et al. (2007) and Vecchi and Soden (2007), the GFI could be used to diagnose changes due to ENSO and/or climate change.



All details and further discussion can be found in our publication:



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Measuring Environmental Favorability for Tropical Cyclogenesis by Statistical Analysis of Threshold Parameters

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ABSTRACT

As the climate changes, the ability to predict changes in the frequency of tropical cyclogenesis is becoming of increasing interest. A unique approach is proposed that utilizes threshold values in potential intensity, wind shear, vorticity, and normalized saturation deficit. Prior statistical methods generally involve creating an index or equation based on averages of important meteorological parameters for a given region. The new method assumes that threshold values exist for each important parameter for which cyclogenesis is *unlikely* to develop. This technique is distinct from previous approaches that seek to determine how each of these parameters interdependently favors cyclogenesis.

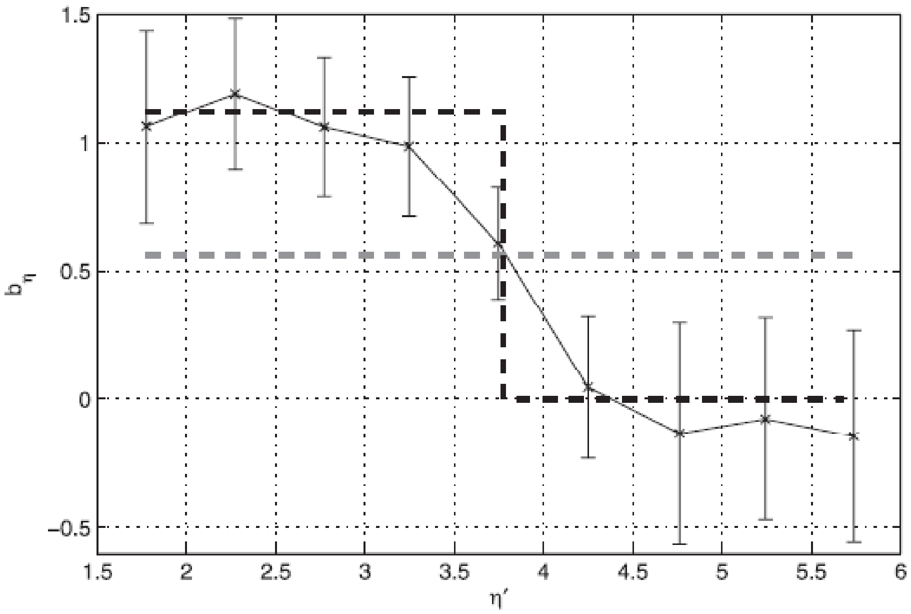
To determine three of the individual threshold values (shear, potential intensity, and vorticity), an idealized climate is first established that represents the most advantageous but realistic (MABR) environment. An initial numerical simulation of tropical cyclone genesis in the MABR environment confirms that it is highly favorable for cyclogenesis. Subsequent numerical simulations vary each parameter individually until no tropical cyclone develops, thereby determining the three threshold values. The new method of point downscaling, whereby background meteorological features are represented by a single vertical profile, is used in the simulations to greatly simplify the approach. The remaining threshold parameter (normalized saturation deficit) is determined by analyzing the climatological record and choosing a value that is statistically observed to prevent cyclogenesis. Once each threshold value is determined, the fraction of time each is exceeded in the location of interest is computed from the reanalysis dataset. The product of each fraction for each of the relevant parameters then gives a statistical probability as to the likelihood of cyclogenesis. For predicting regional and monthly variations in frequency of genesis, this approach is shown to generally meet or exceed the predictive skills of earlier statistical attempts with some failure only during several off-season months. This method also provides a more intuitive rationale of the results.

VII. Ongoing Work

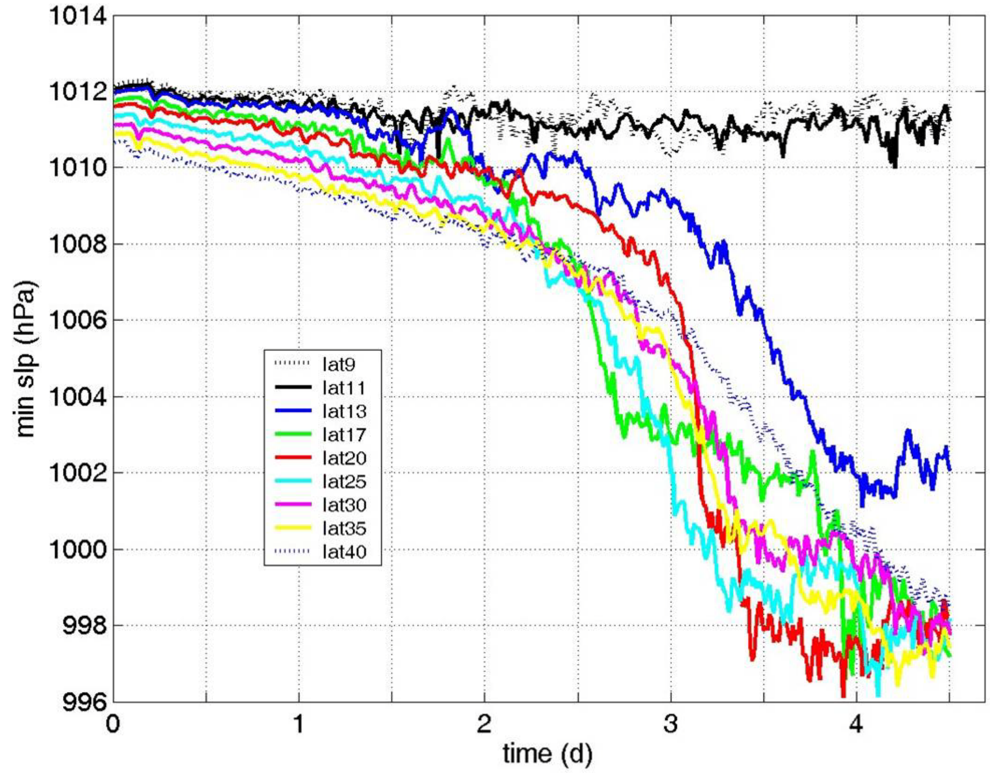
- Both statistical analyses and idealized simulations show that:

  1) A sufficient environmental vorticity is needed for genesis, but

  2) Increasing beyond that value does not further favor genesis.

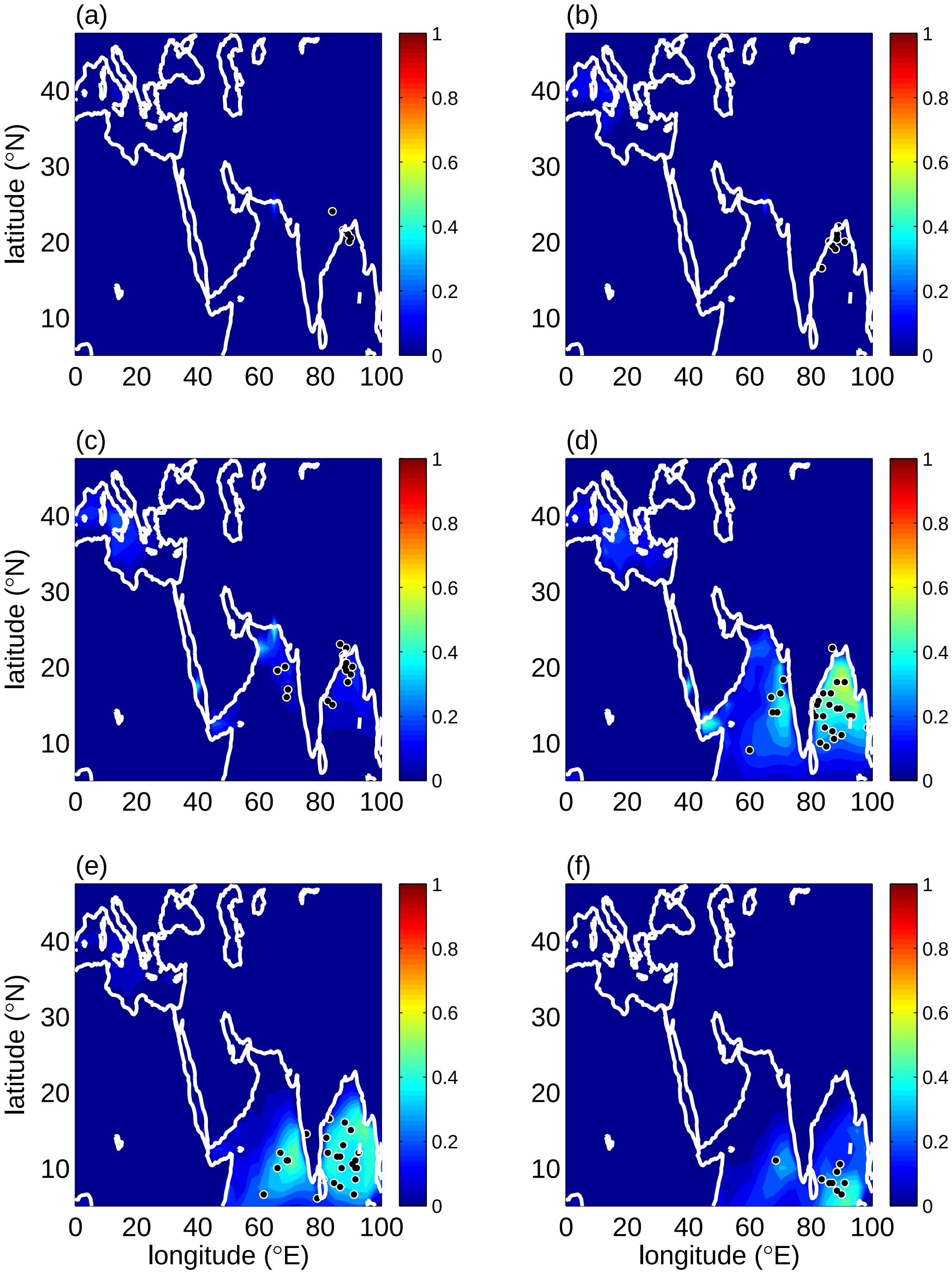


Tippett et al. (2011)



- What physical processes are limiting development - on either side of the threshold?

GFI: Northern Indian



July

August

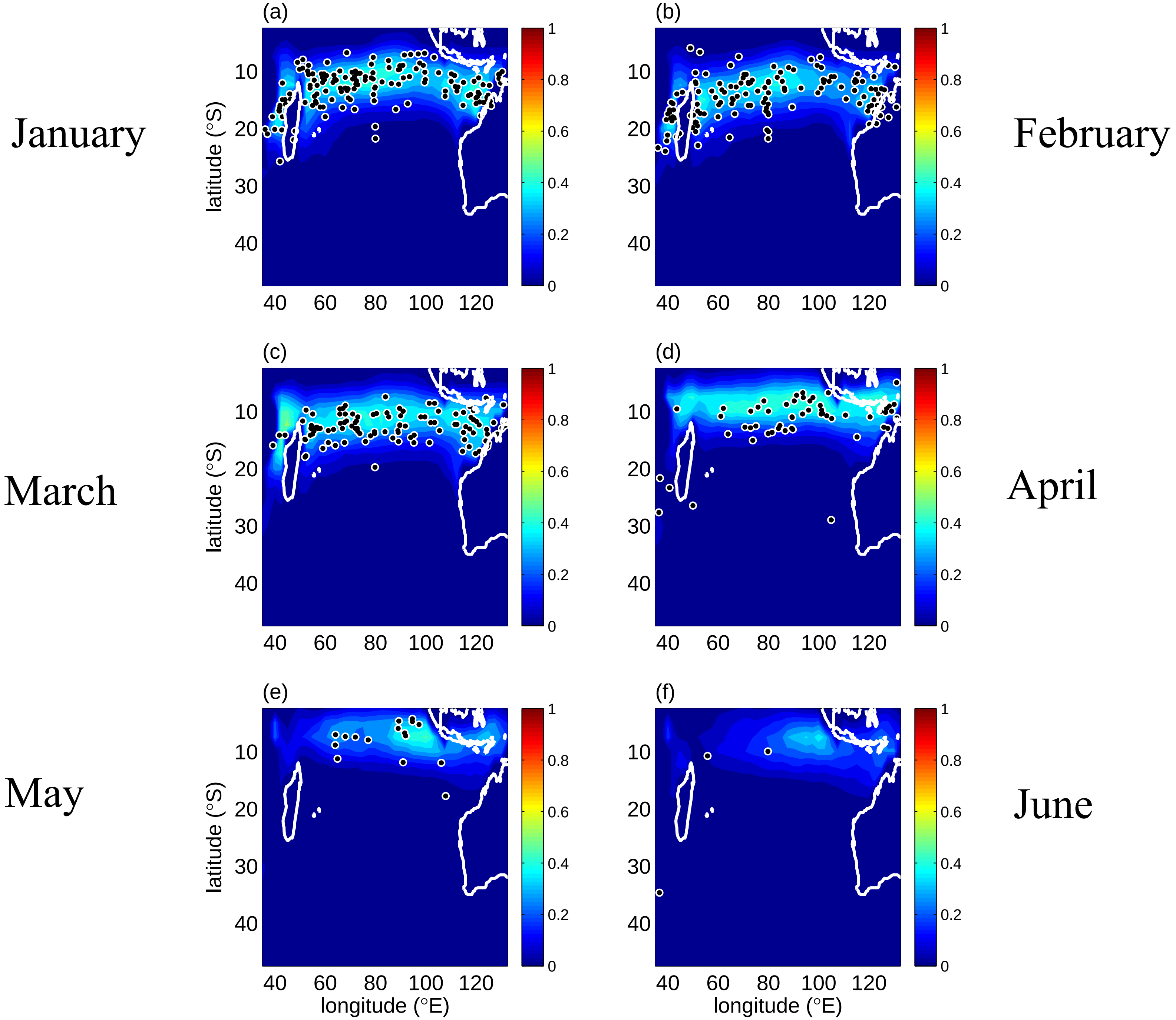
September

October

November

December

GFI: Southern Indian



GFI: Southern Pacific