Modeling Hurricane Extremes at Weather and Climate Scales

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Summary

- ***What is an Extreme Hurricane?***
- ***Hurricane intensity and climate change***

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National Center for Atmospheric Research

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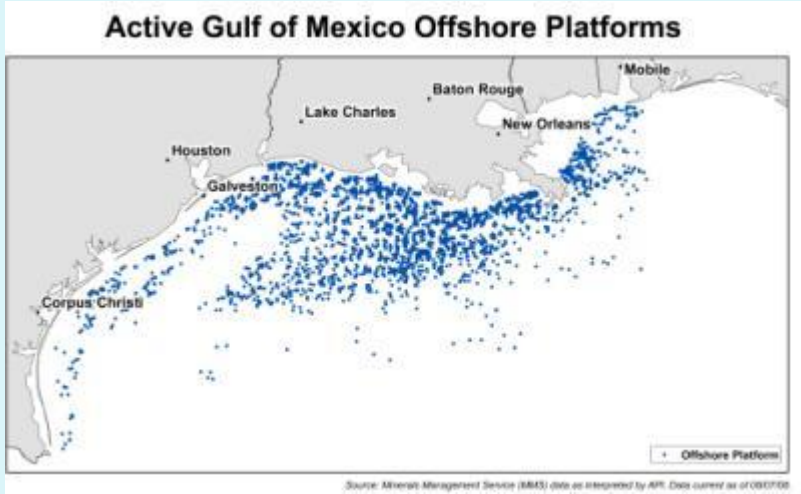
Willis Hurricane Index

- Provides an assessment of hurricane damage to off-shore facilities (1993 $) using readily available hurricane parameters: intensity, RMW, RHW, translation speed.

$$WHI = \left(\frac{v_m}{65}\right)^3 + 5\left(\frac{R_h}{50}\right) + 5\left(\frac{v_t}{15}\right)^{-2}$$

$$For\ v_m > 65,$$

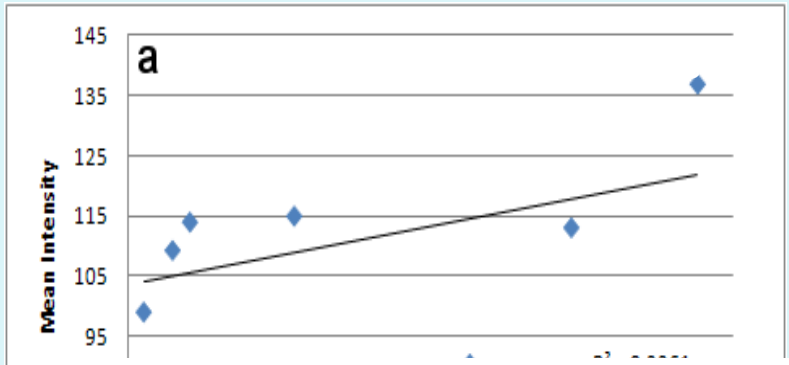
$$If\ v_t < 7, v_t = 7,$$

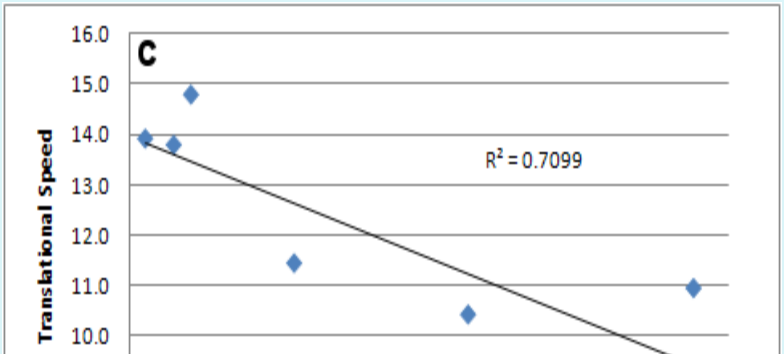


(Units: kt and nm)

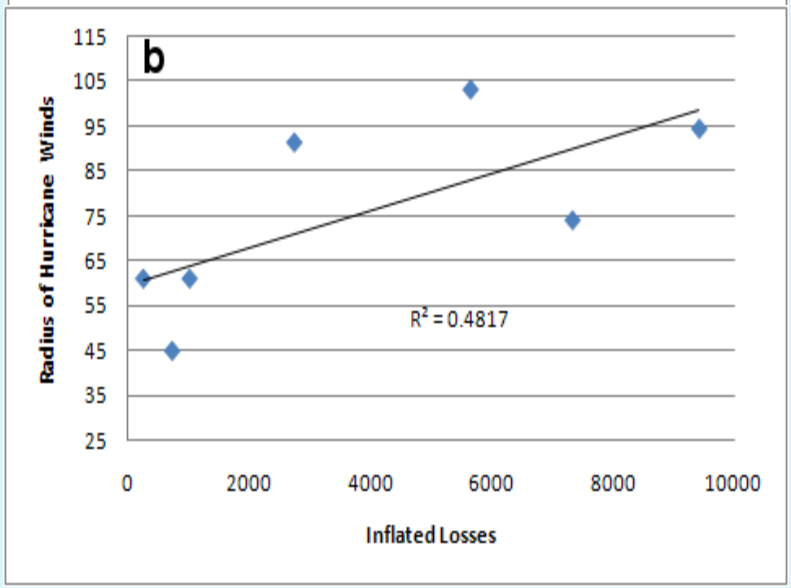
Explains >90% of the damage variance (dependent data)

WHI Parameter Importance





Perhaps we should reconsider what constitutes and extreme hurricane



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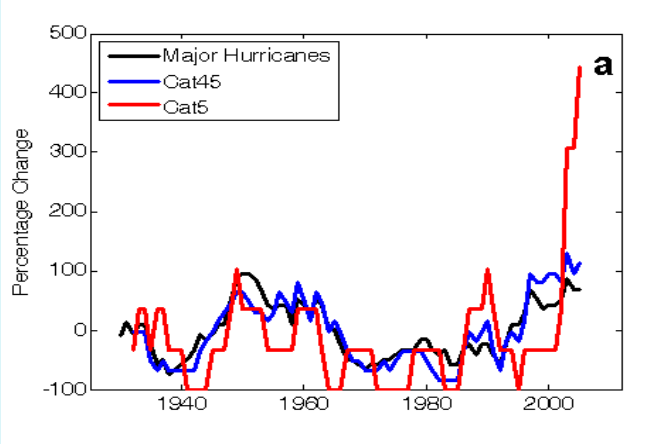
Intense Hurricanes and Climate Variability and Change

Expected Climate Trends

- Hurricane wind speeds, rainfall intensity and storm surge levels are likely to increase (CCSP SAP 3.3 2008, Knutson et al 2010);
  - *Maximum intensity by ~1-8% or 2-11 m/s per degree C.*
  - *Rainfall Rate by 6-18% per degree C.*
- Neither of which can be quantified with the current observing system, and there is virtually no forecast information on size;

But: Cat4-5 hurricanes may increase by 50-80% (Bender et al 2009, Knutson et al 2010).



(Holland 2010)

Extreme Value Theory

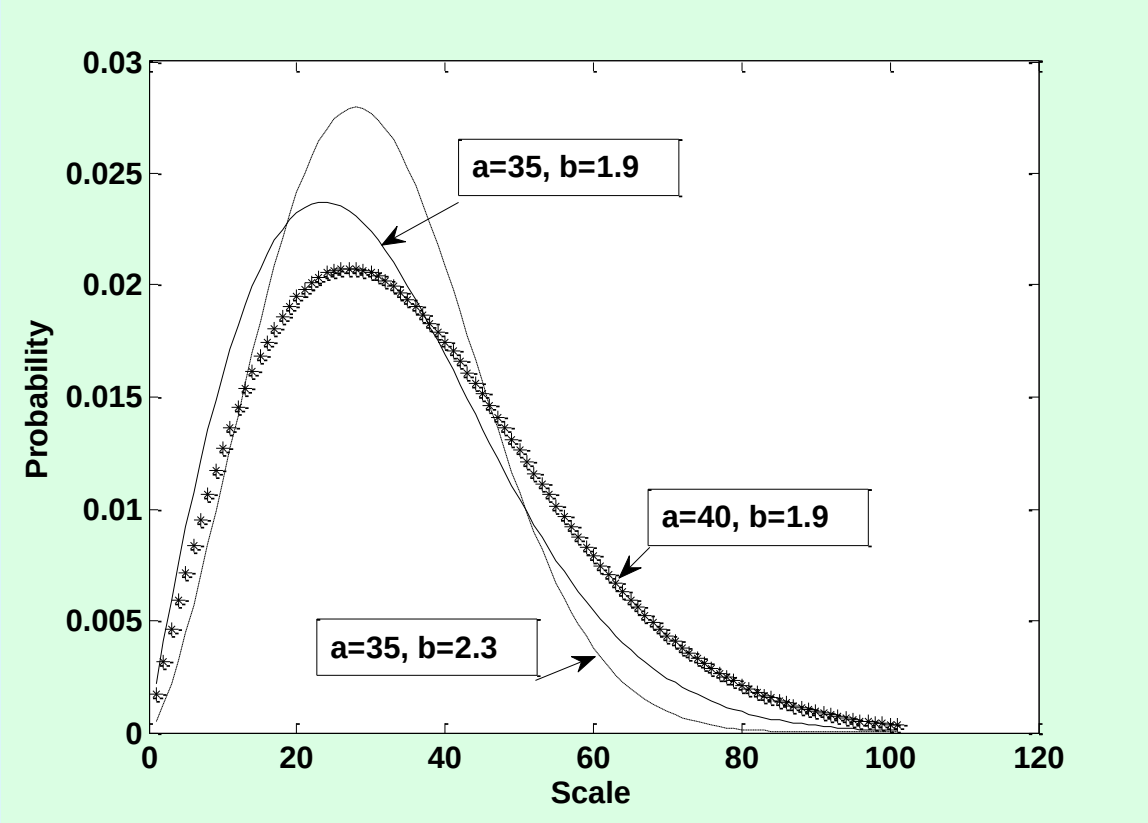
We utilize the Weibull distribution for which the CDF and PDF are:

$$CDF = f(x) = 1 - e^{-\left(\frac{x}{a}\right)^b}$$

$$PDF = f'(x) = \frac{b}{a}\left(\frac{x}{a}\right)^{b-1} e^{-\left(\frac{x}{a}\right)^b}$$

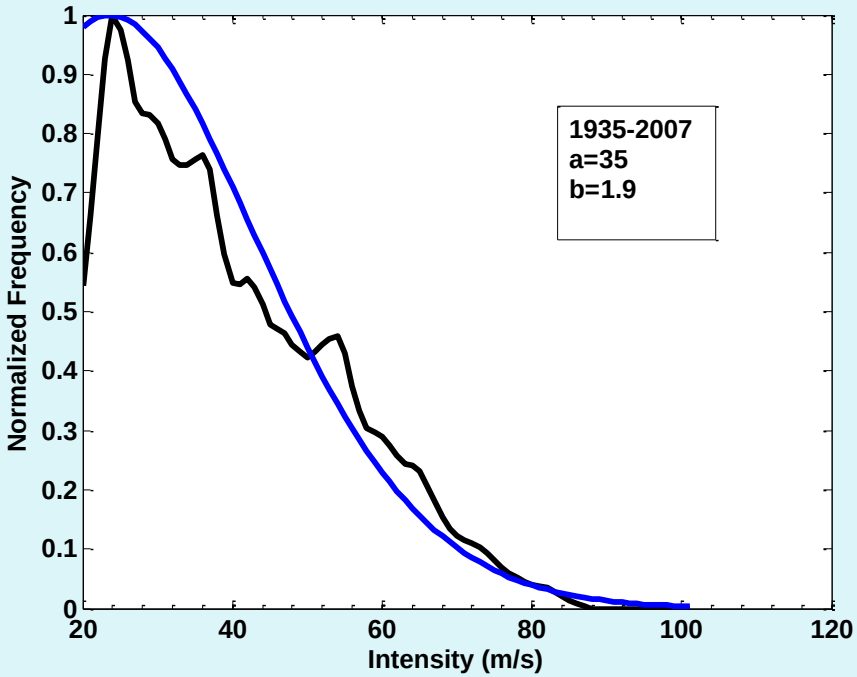
Where parameters a and b determine the scale and the shape, respectively.

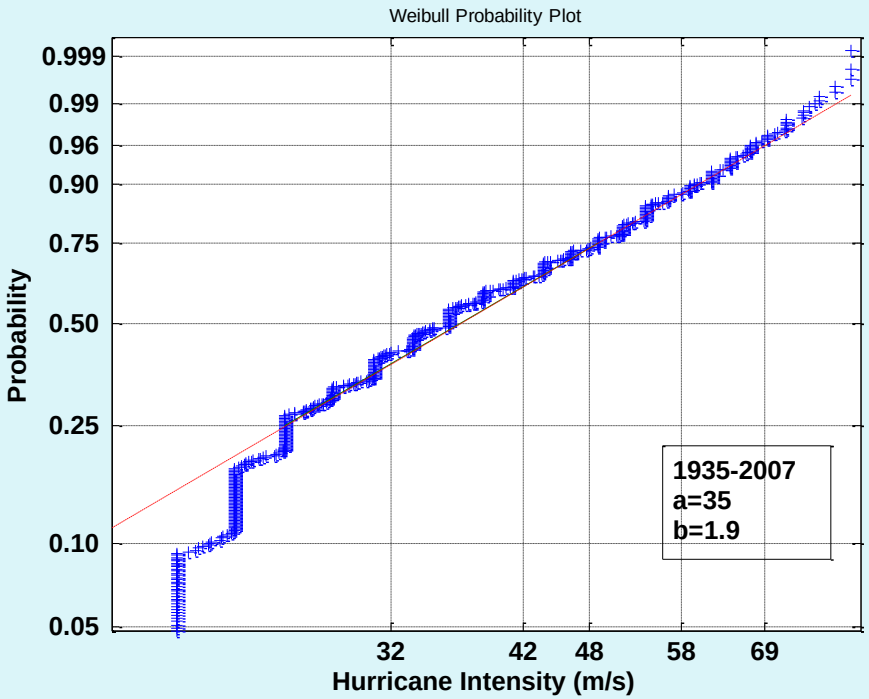
Scale and Shape Variations



Scale, a, is related to the population mean and variance and shape, b, almost exclusively to the inverse of the variance (SD α a/b).

Application to Atlantic Hurricanes





PDF (Normalized, HURDAT Smoothed)

CDF with Weibull fit: a=35, b=1.9

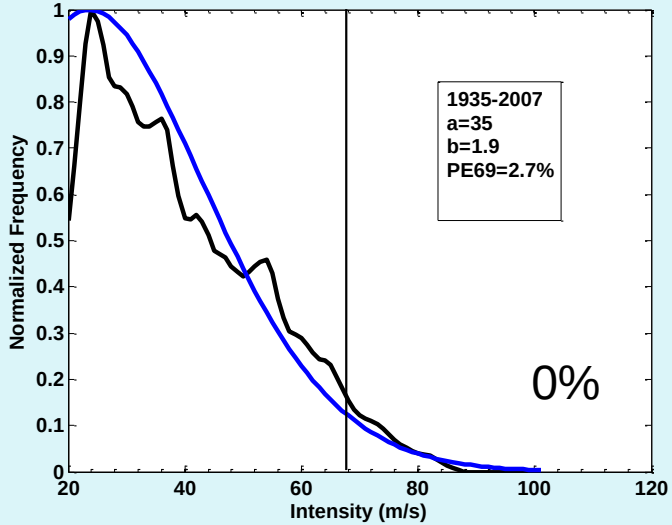
Excedent Probability

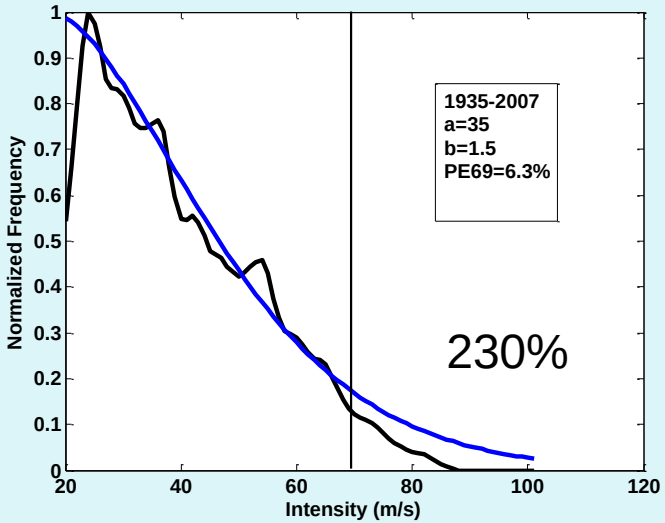
- We are interested in the probability of exceeding a threshold event, E{x>c},

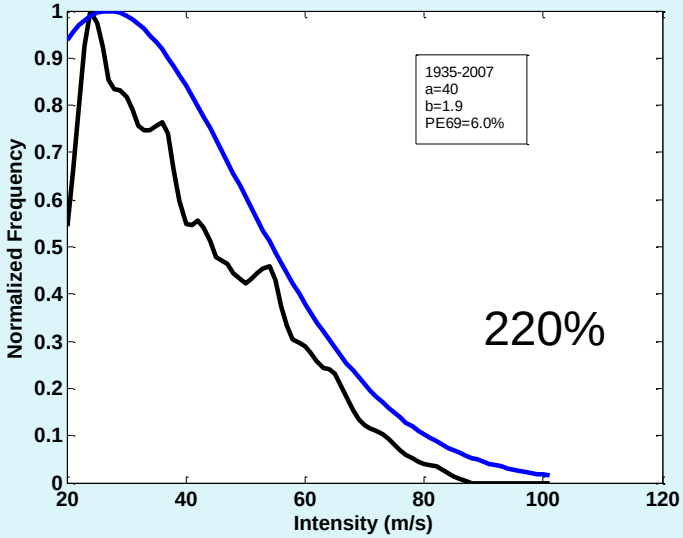
$$P(E\{x > c\}) = 1 - f(c) = e^{-\left(\frac{c}{a}\right)^b}$$

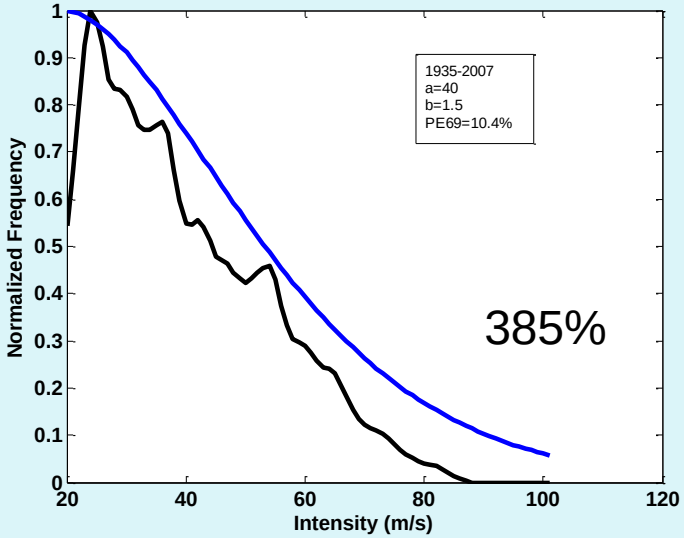
- The excedent likelihood decreases as the event becomes rarer (c/a increases), and/or the population less variable (b increases).

Impact of Changes to the Scale and Shape Parameters

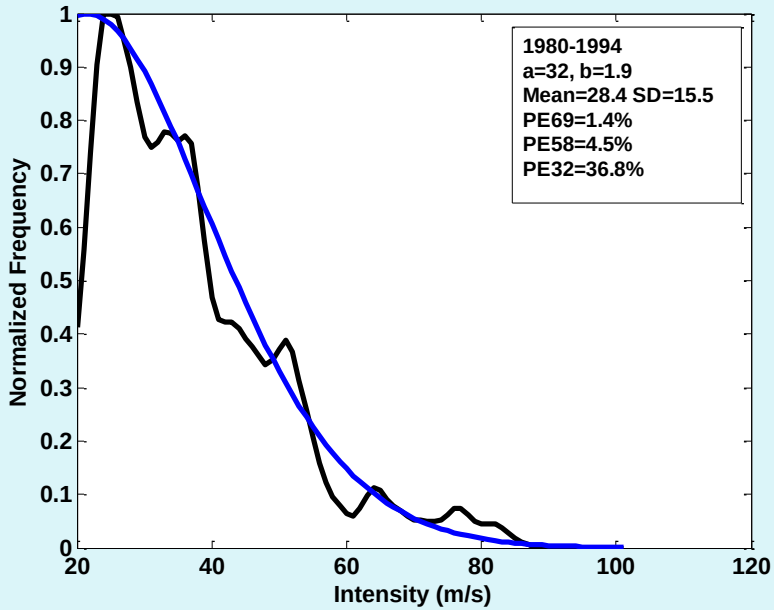


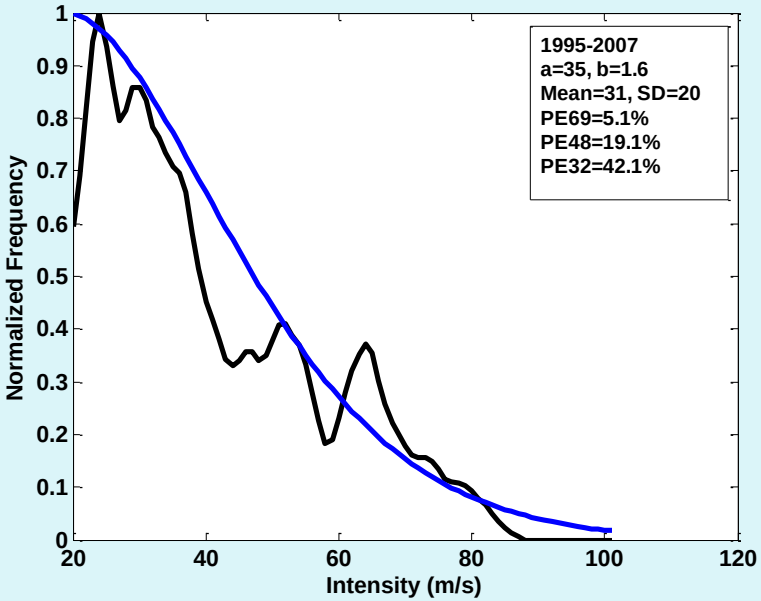






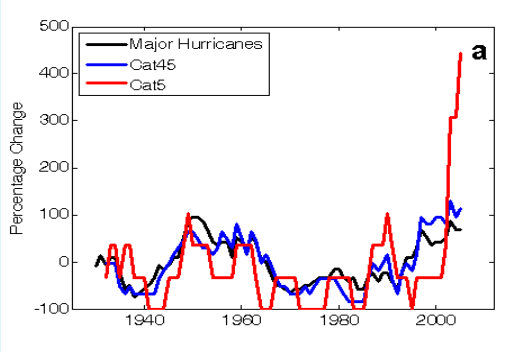
1980-1994 vs 1994-2007





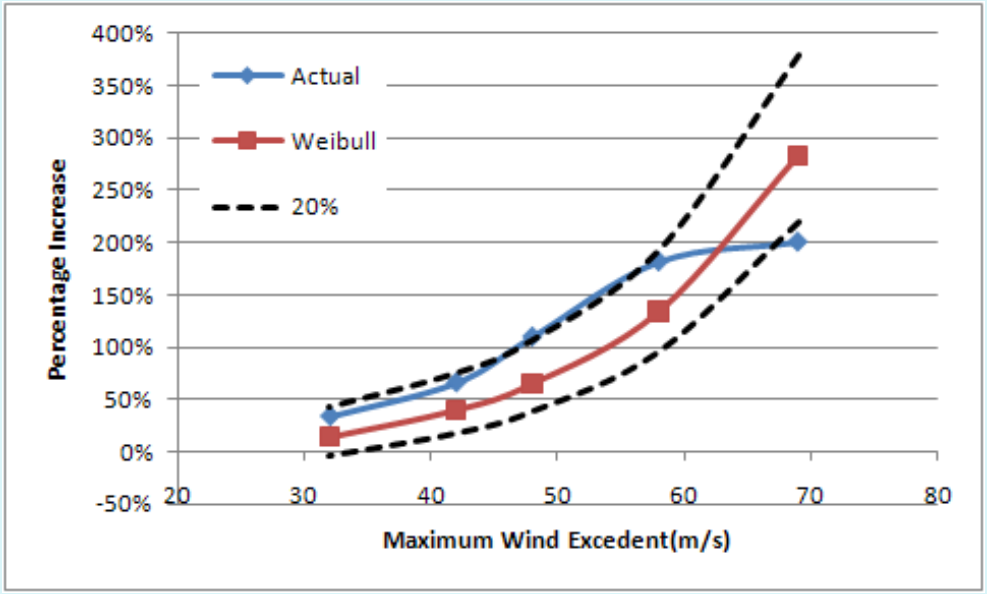
Comparing 1980-1994 with 1994-2007, a mean intensity change of ~2-3 m/s and a SD change of ~4-5 m/s leads to an increased probability of Cat 5 hurricanes of ~3.5 times! This is equivalent to moving from 1 Cat 5 every 3-5 years to 1 every year.

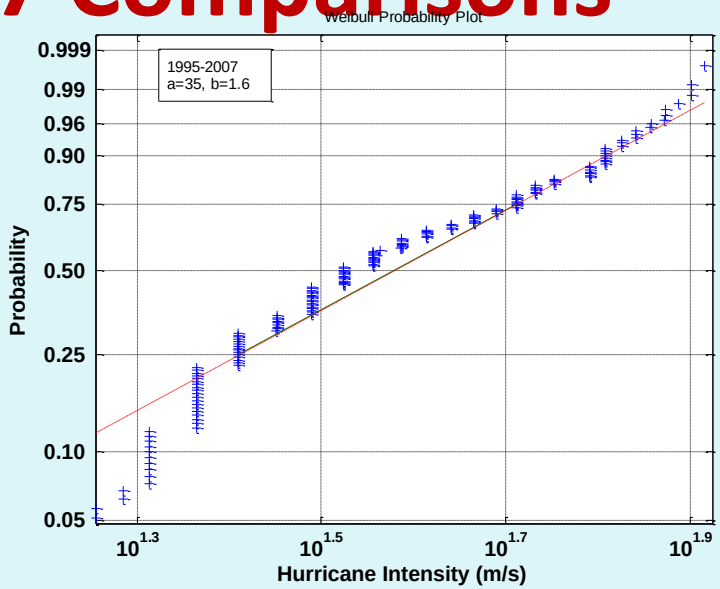
(Caveat on ability to fit the observed distribution.)

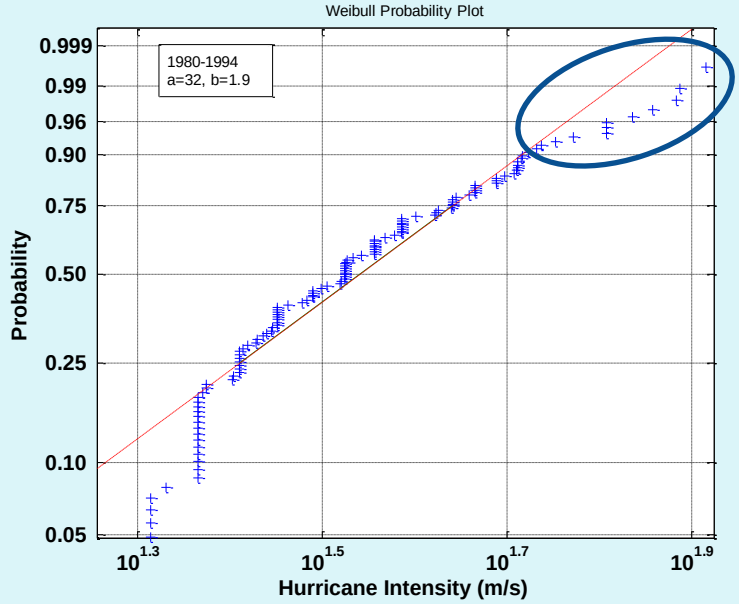


1980-1994/1995-2007 Comparisons

Change 1980/1994 to 1995/2007







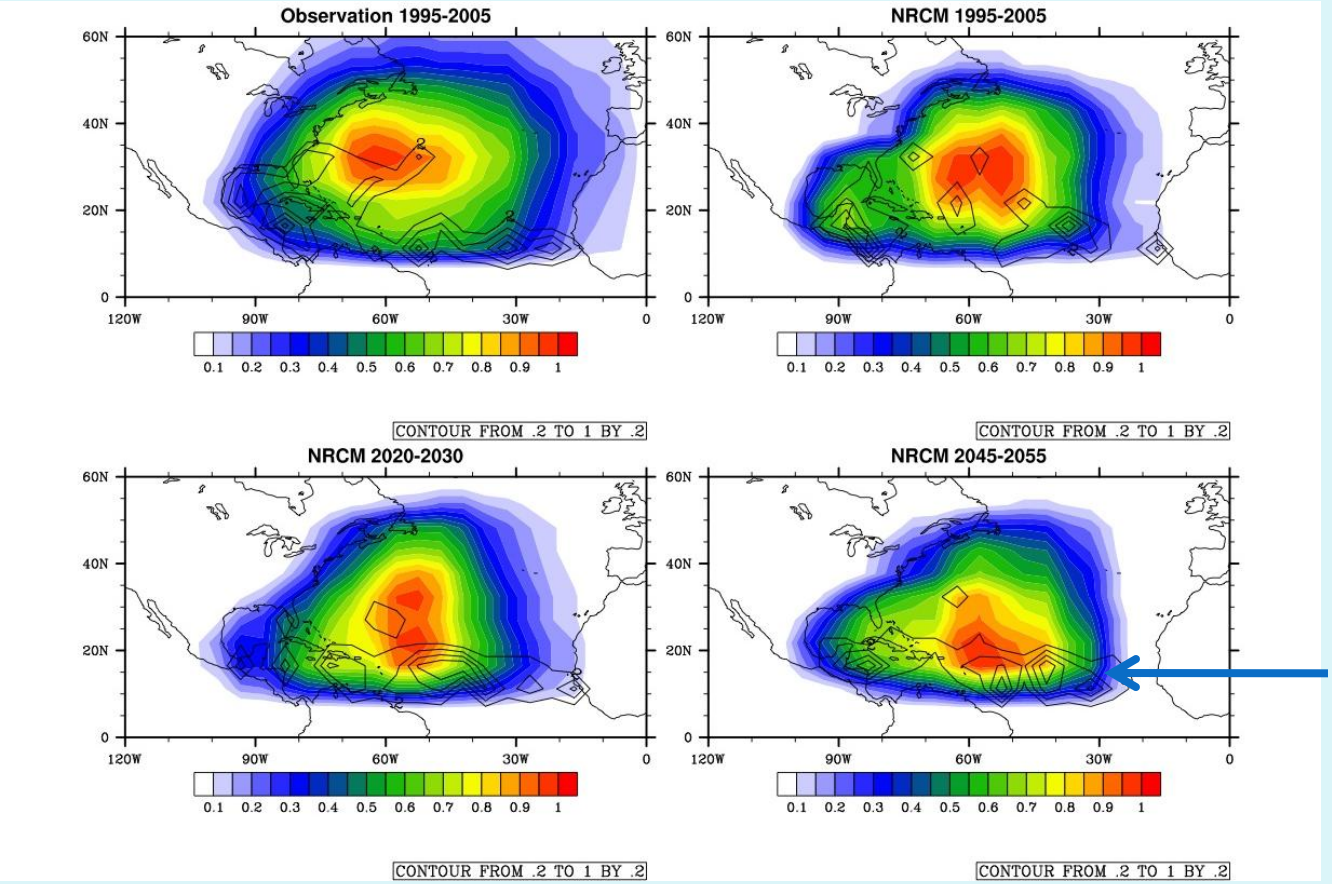
Comparison with Bender et al (2009)

- Bender et al:
  - *Mean intensity increase +0.7% (~2.5 m/s)*
  - *Cat4-5, +78% increase in numbers*
- Applying EVT to 1995-2007 conditions:
  - *Mean intensity increase of 2.8 m/s gives ~35% increase in Cat4-5;*
  - *Additional increase in SD of 5 m/s gives ~60% increase in Cat4-5.*

Potential Impact of Climate Variability and Change

- Assume a mean wind intensity increase of 2-3 m/s per ^{o}C global ocean warming, then:
  - *Cat 5 hurricane frequency increases by ~70% for each ^{o}C warming;*
- Assume in addition that the variance also increases, say, by 2-3 m/s in standard deviation, then:
  - *Cat 5 hurricane frequency increases by ~150% for each ^{o}C warming!*
- *These mean and SD changes are below the current observational resolution.*

Equatorward Movement of Hurricanes



(Holland et al 2010)

Longer periods over warmer oceans implies more intense tropical cyclones and a substantial increase in the most intense ones.

Note the increase in "Cape Verde Hurricanes"!

Summary

- What constitutes an “extreme” hurricane should perhaps be revisited;
- Extreme value theory predicts that changes in extremes will be >>> than those in the mean or variance;
- This is supported by both current observations and recent modeling results;

- These lead to the idea that:
  - *“Extreme weather may thus provide a bellwether for climate change”.*