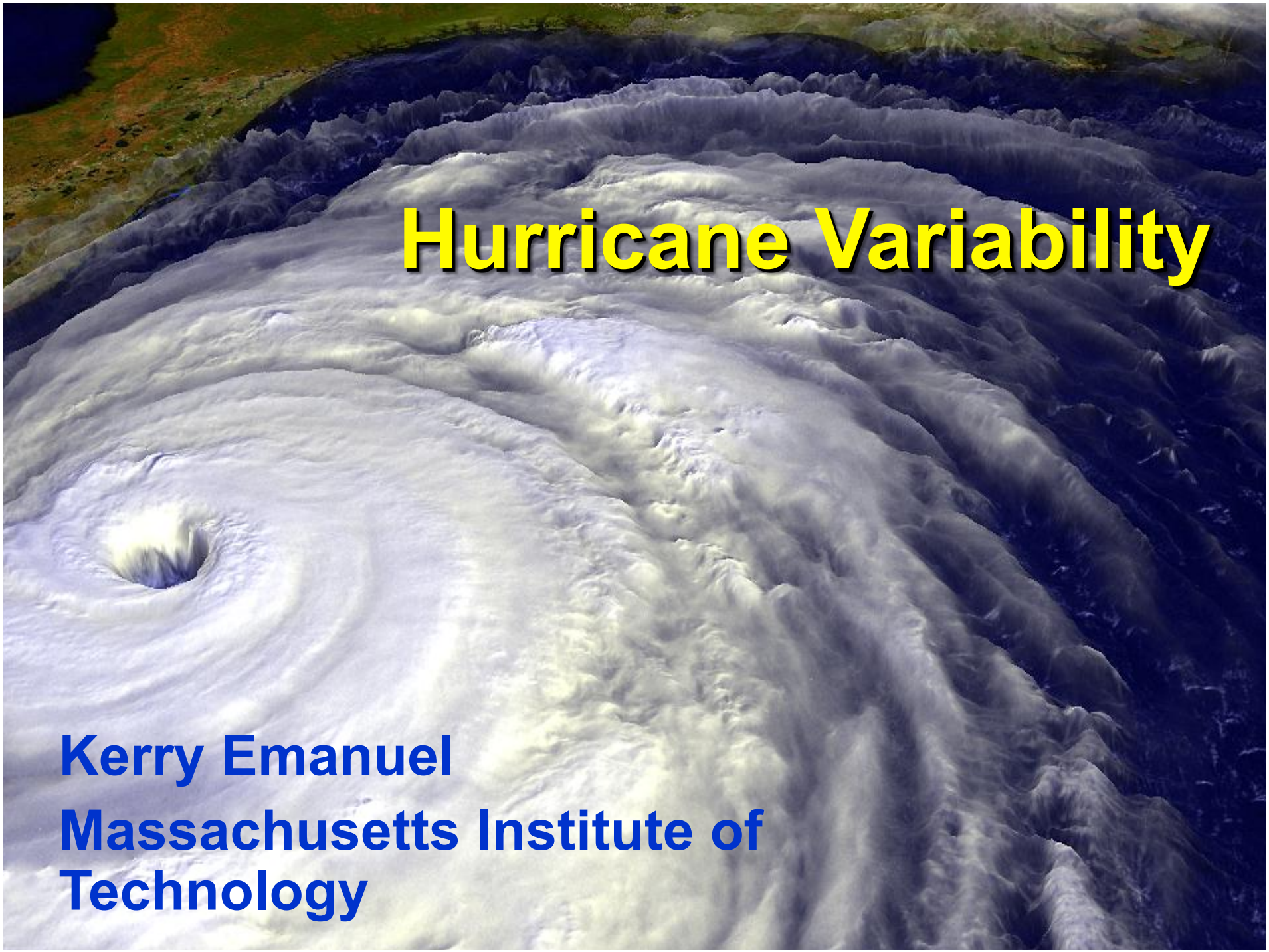


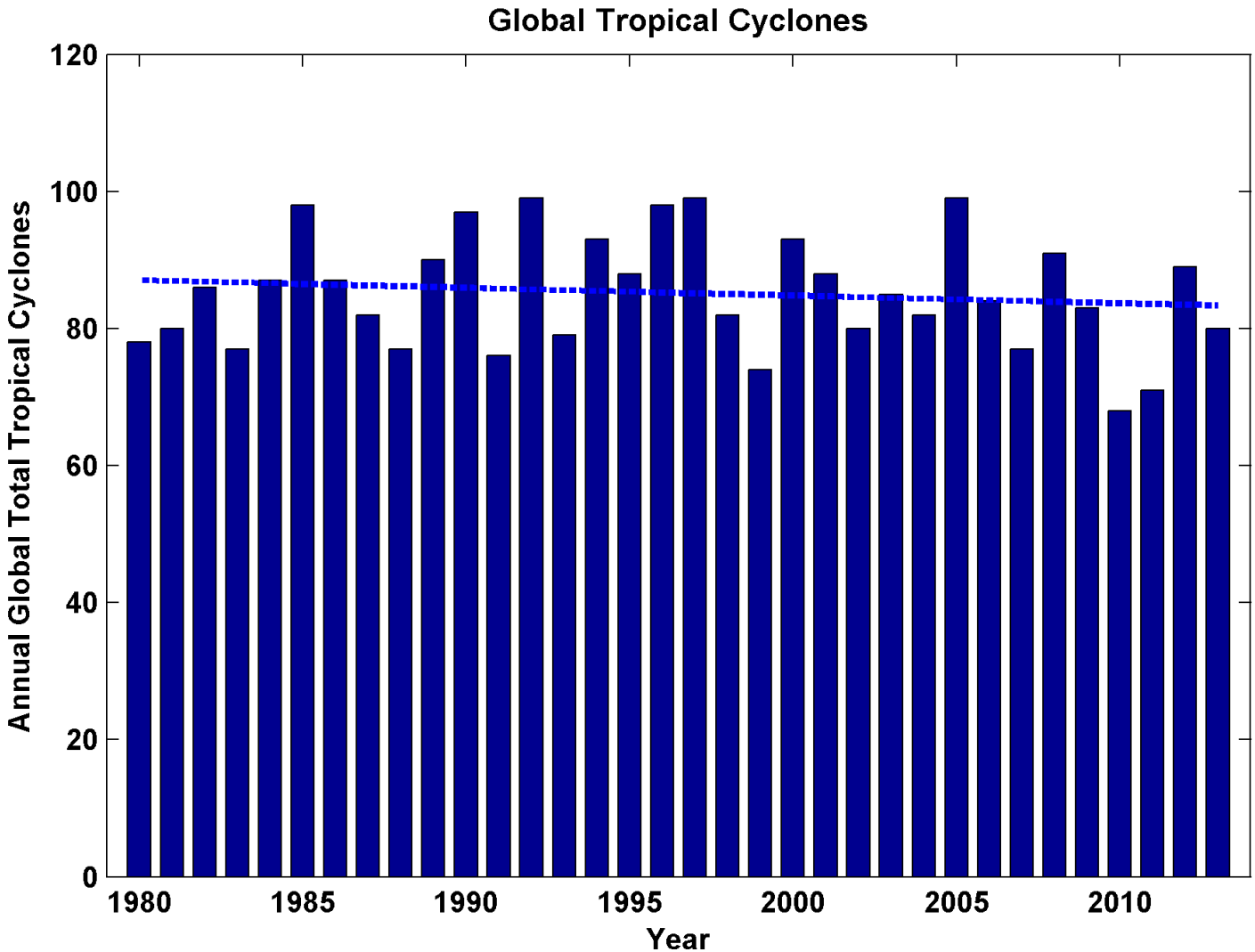
# Hurricane Variability

Kerry Emanuel
Massachusetts Institute of Technology

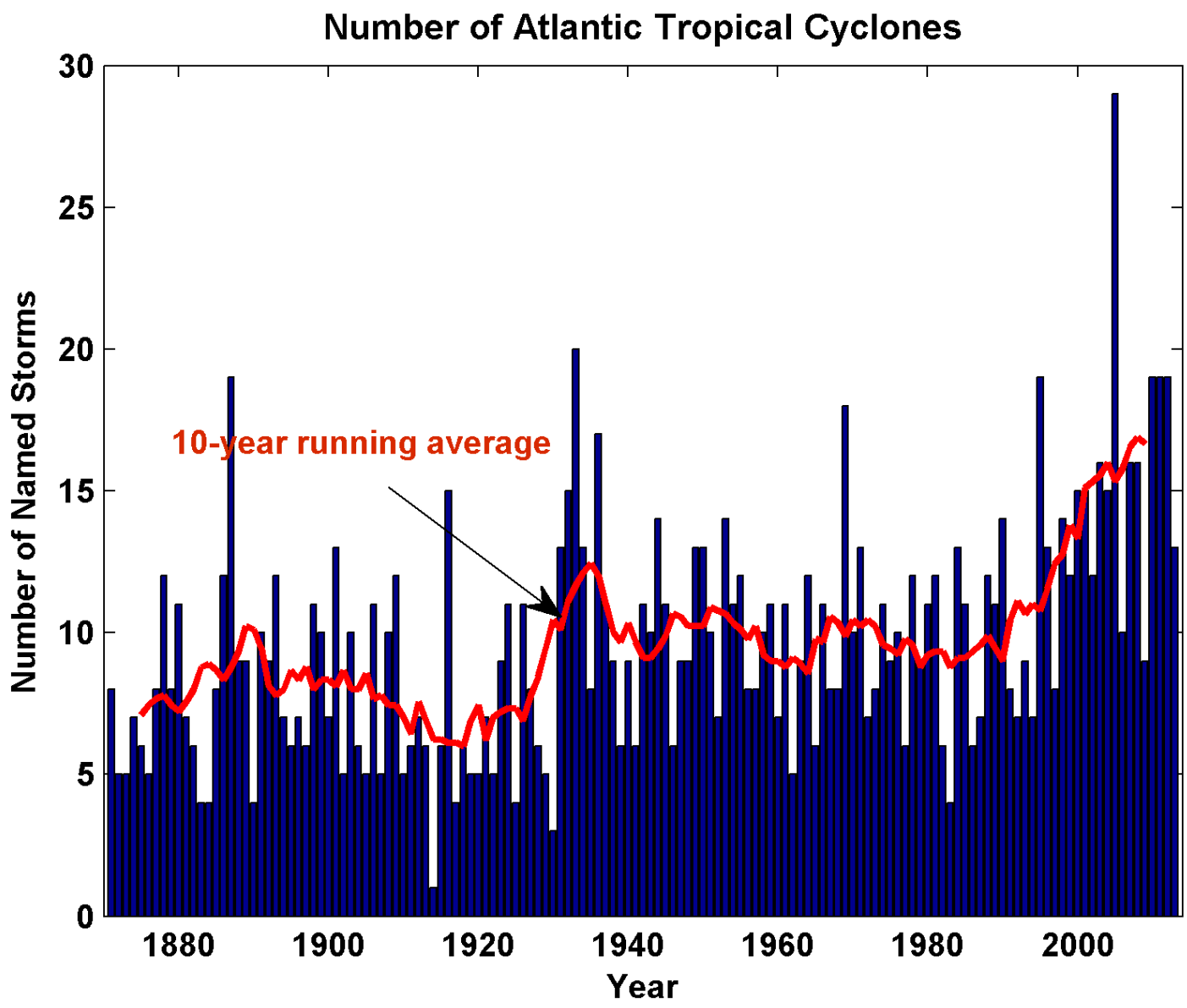
# Program

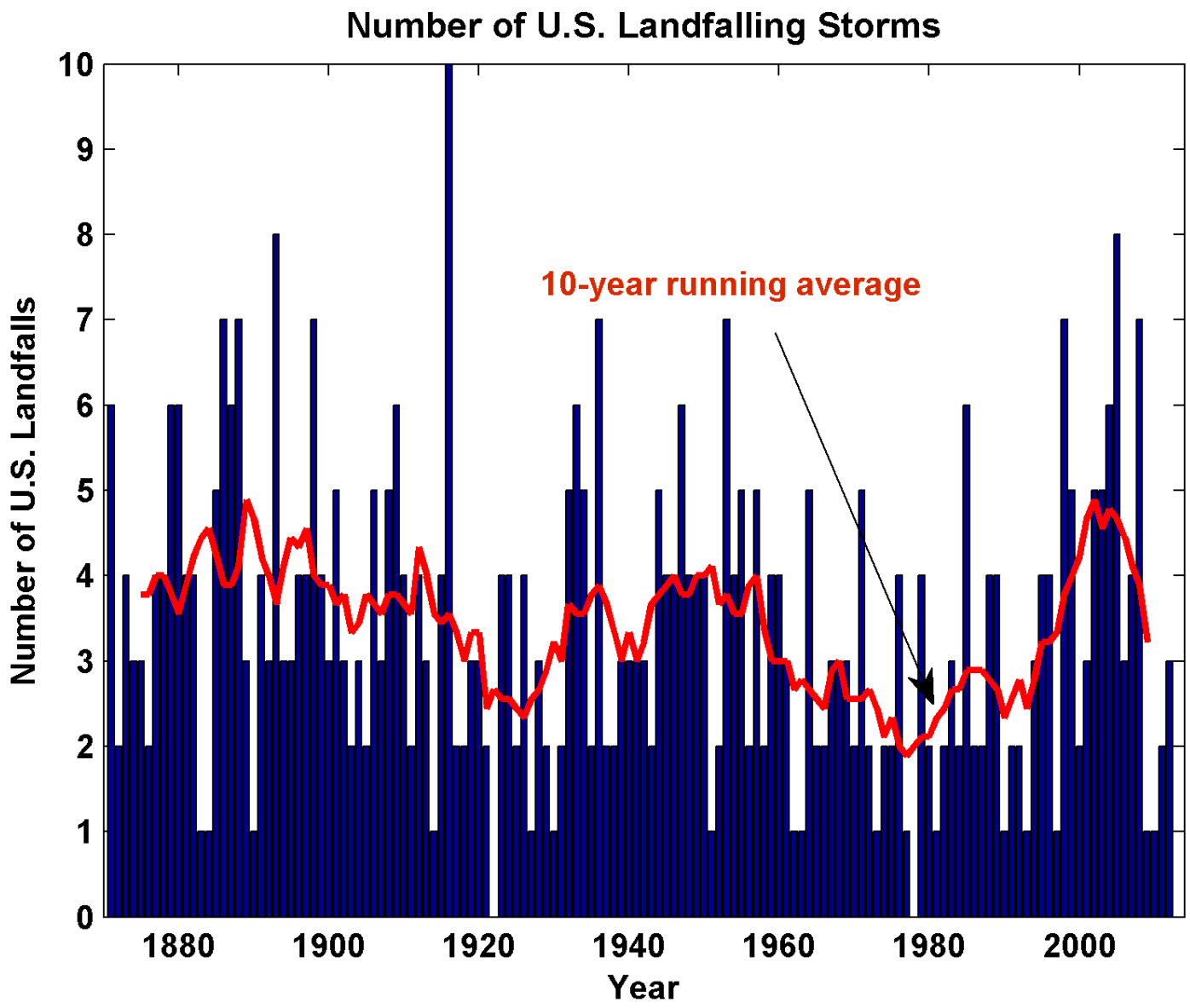
- **Natural variability of Atlantic Hurricanes**
- **Hurricanes and global warming**

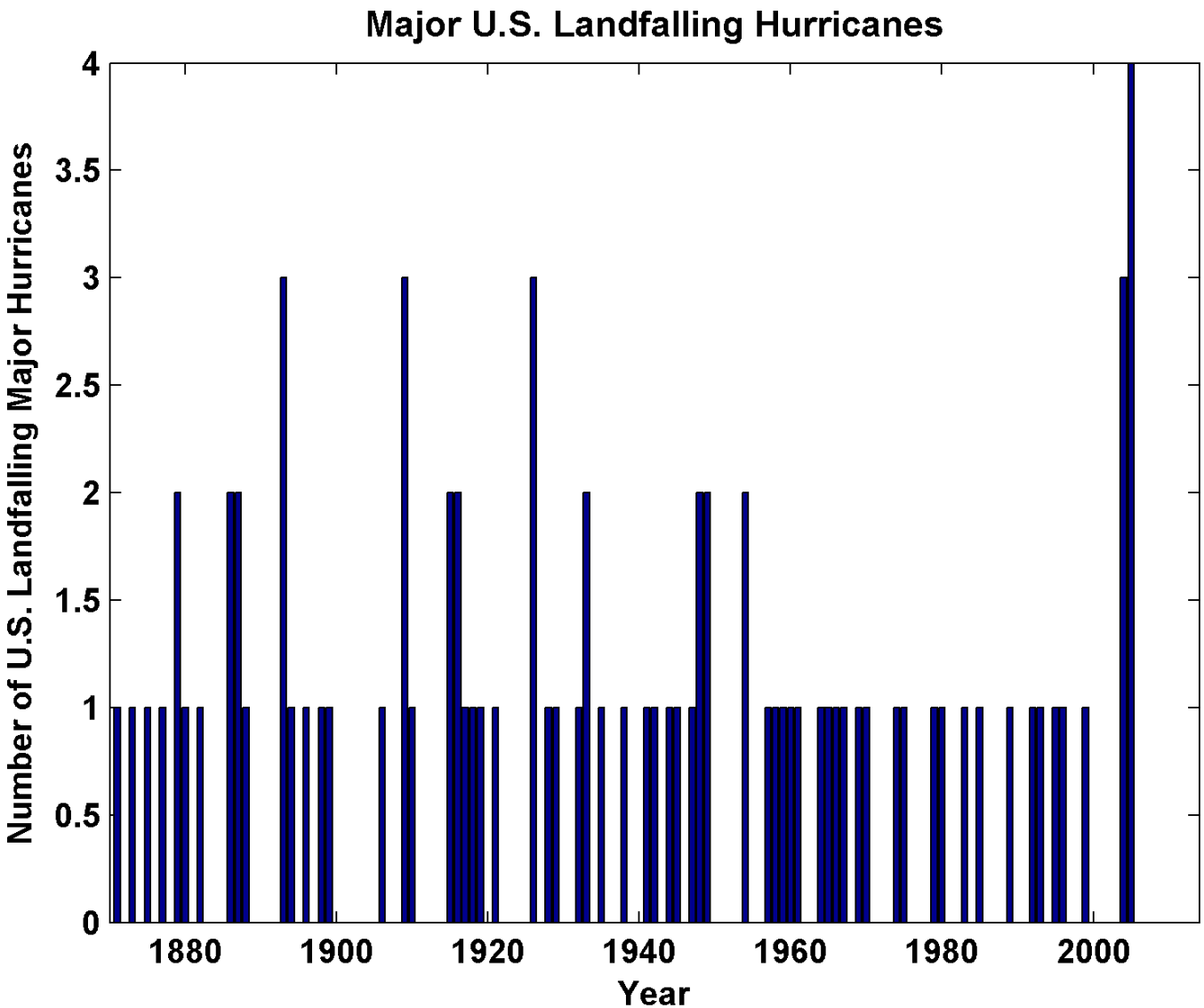
# Global Tropical Cyclone Frequency, 1980-2013




**Data Sources: NOAA/TPC and NAVY/JTWC**


Number of Atlantic Tropical Cyclones
Number of Named Storms
Year
10-year running average
0
5
10
15
20
25
30
1880
1900
1920
1940
1960
1980
2000

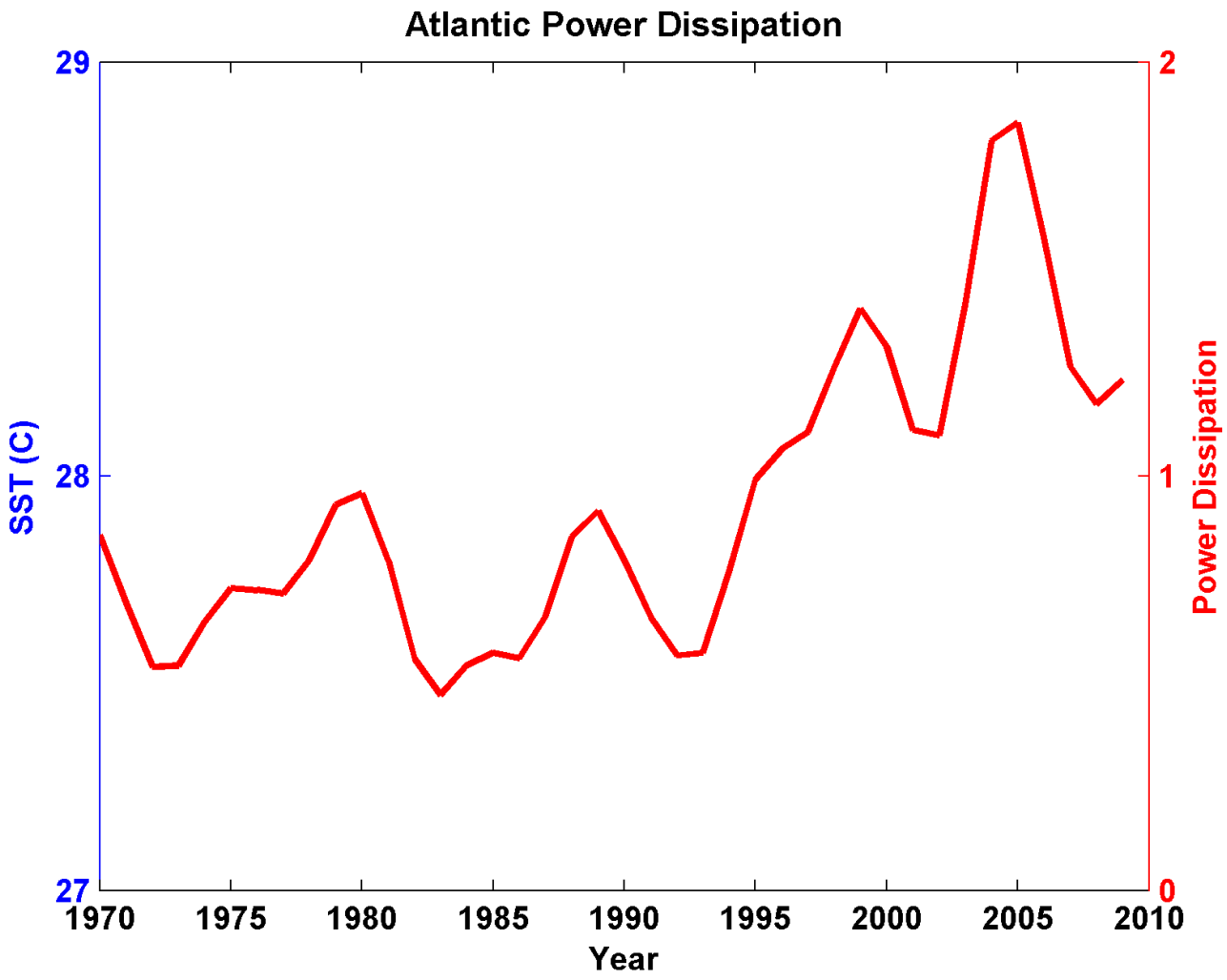

Number of U.S. Landfalling Storms
10-year running average
Number of U.S. Landfalls
Year
0
1
2
3
4
5
6
7
8
9
10
1880
1900
1920
1940
1960
1980
2000



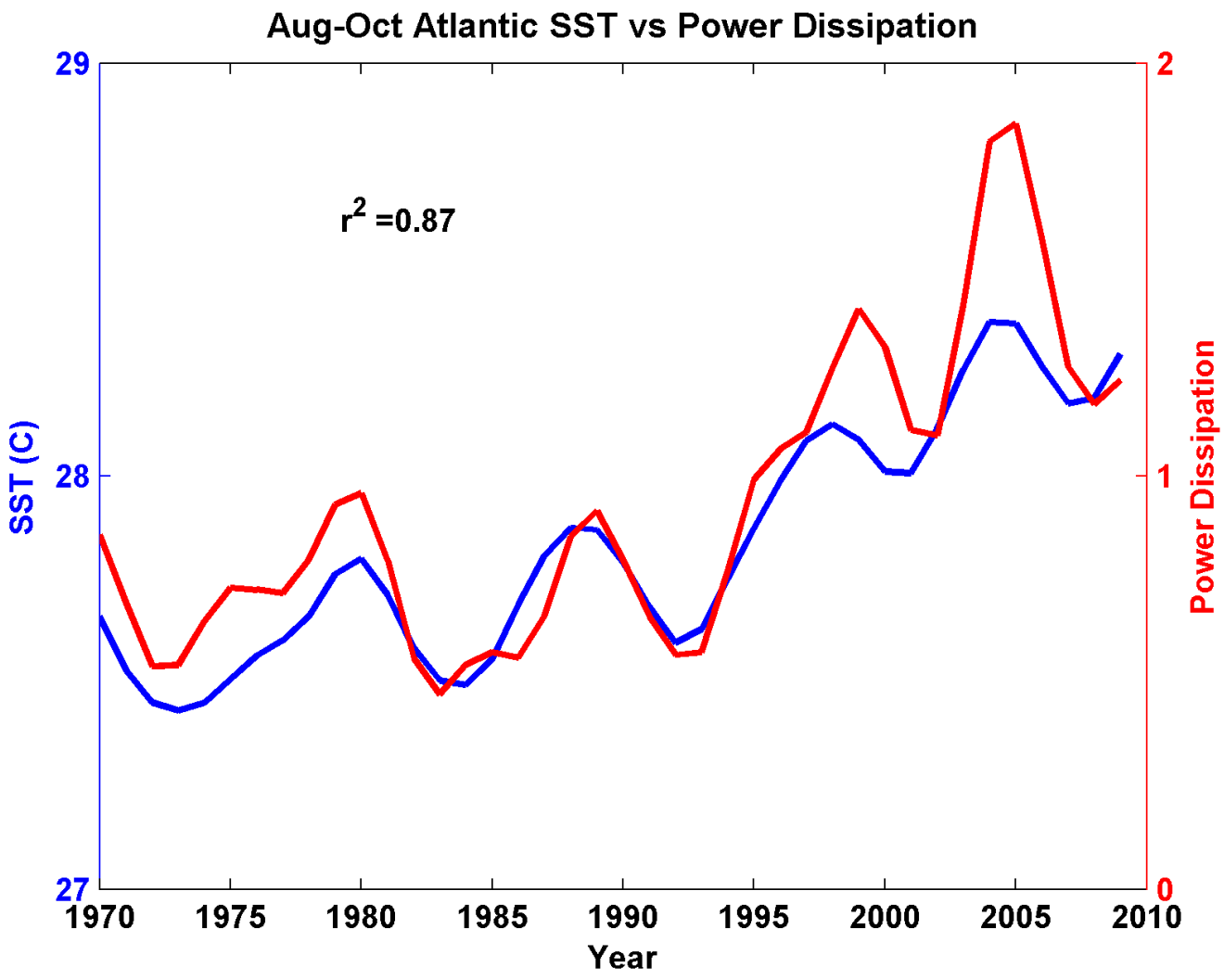

3% chance of run of 7 or more years with no major U.S. landfalls, if process is random (Poisson)

# Hurricanes and Climate Change

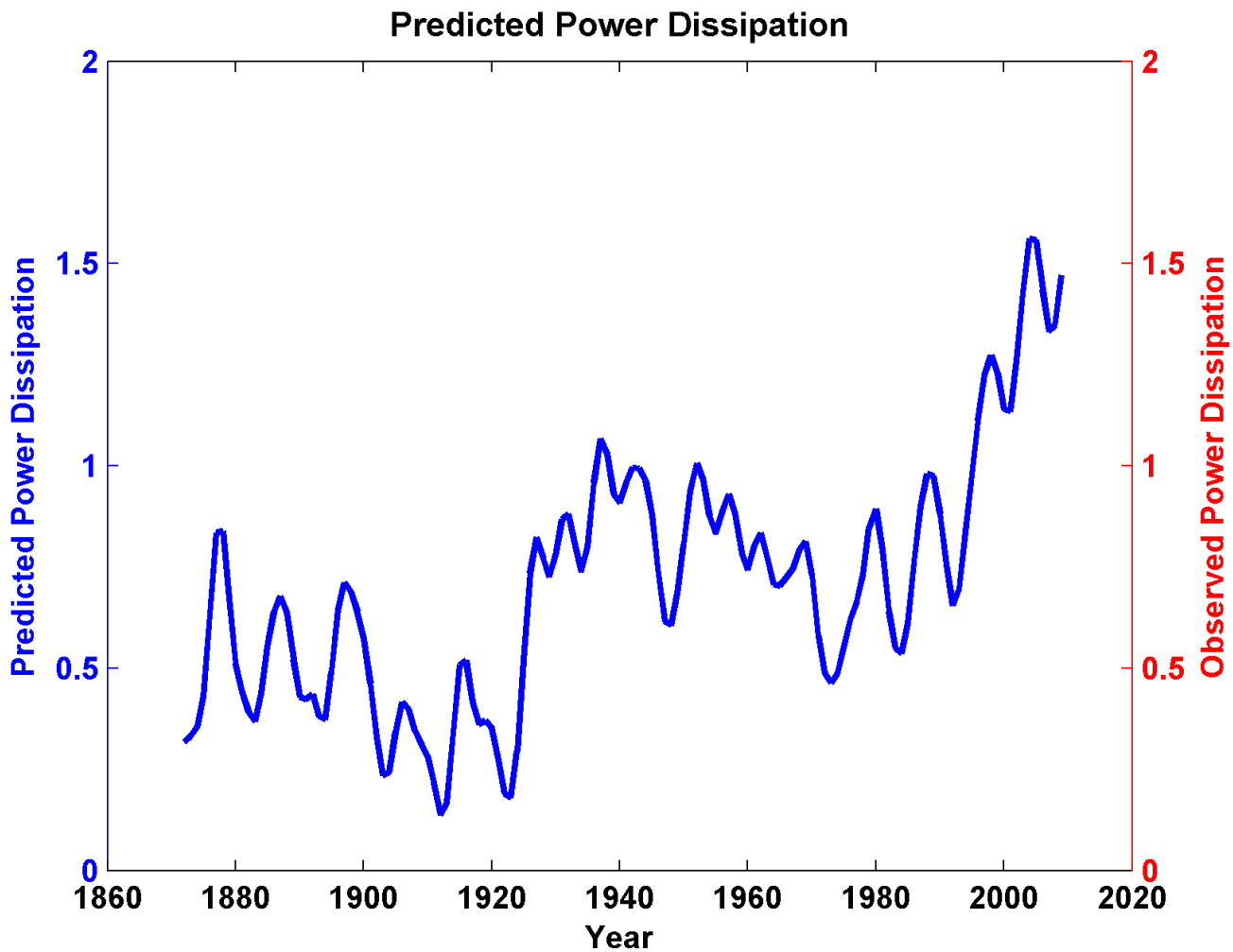
# Atlantic Storm Maximum Tropical Cyclone Power Dissipation during an era of high quality measurements, 1970-2011 (smoothed with 1-3-4-3-1 filter)



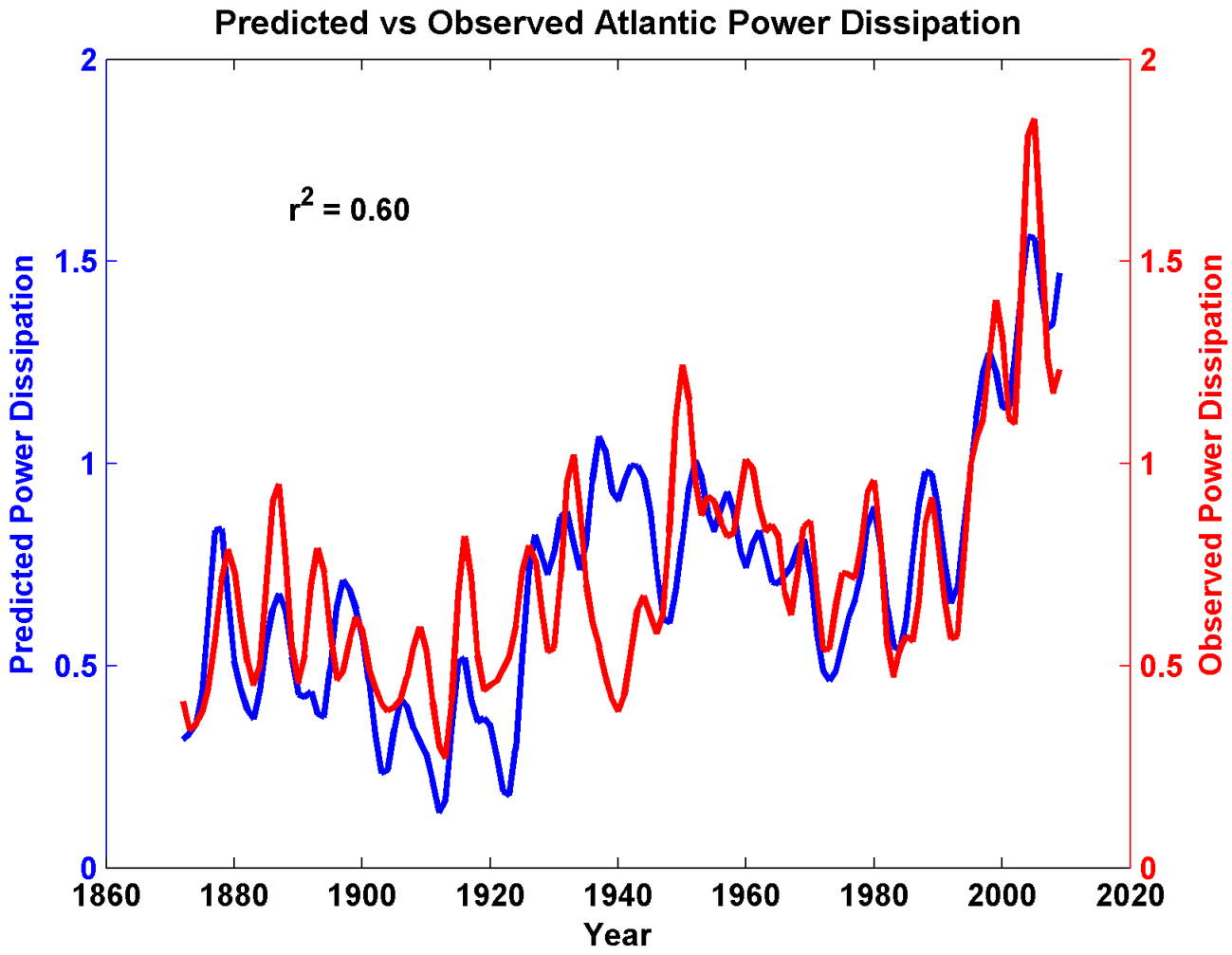
# Atlantic Storm Maximum Tropical Cyclone Power Dissipation and Sea Surface Temperature during an era of high quality measurements, 1970-2011 (smoothed with 1-3-4-3-1 filter)



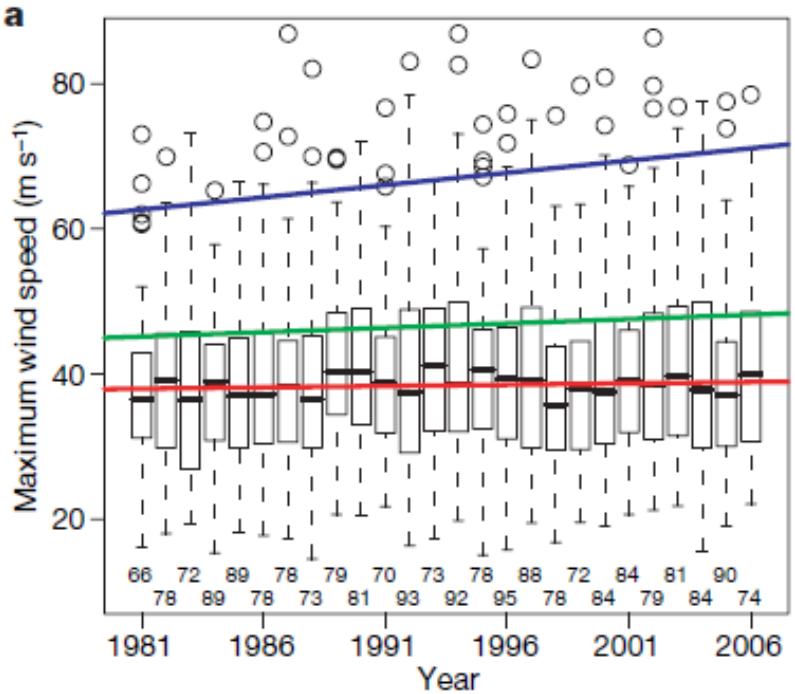
# Use Linear Regression to Predict Power Dissipation back to 1870 based on SST:



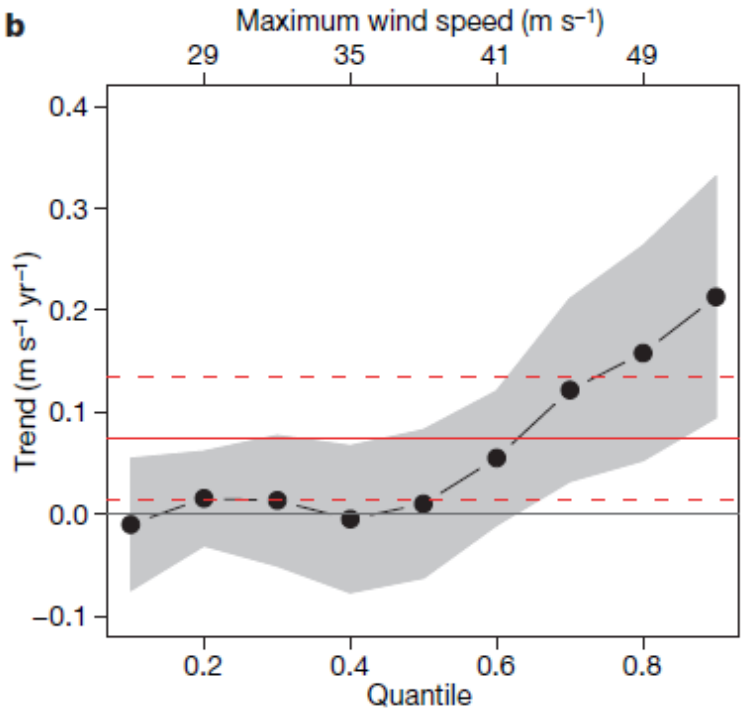
# Now Compare to Observed Storm Maximum Power Dissipation



# Analysis of satellite-derived tropical cyclone lifetime-maximum wind speeds



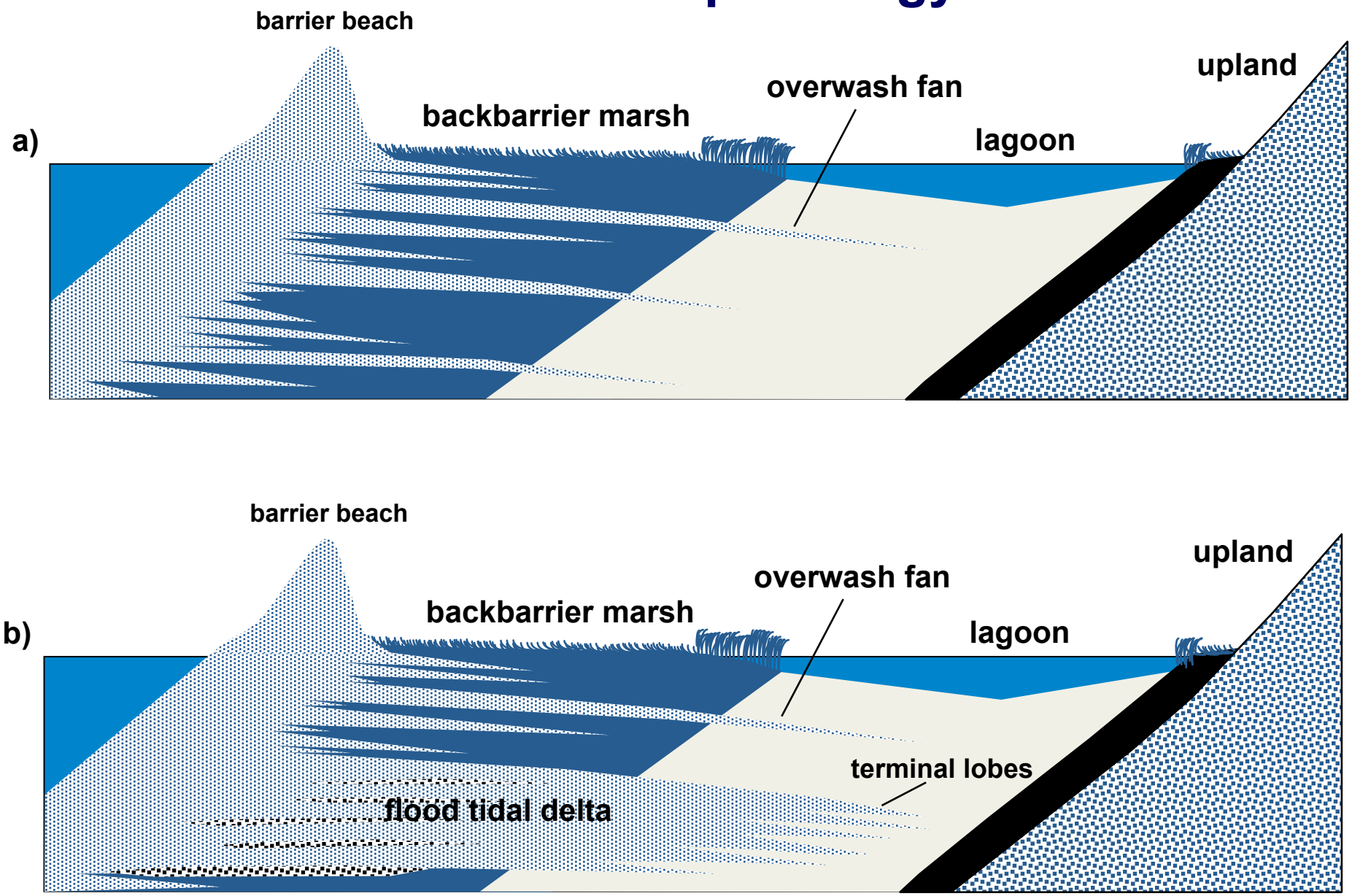

Box plots by year. Trend lines are shown for the median, 0.75 quantile, and 1.5 times the interquartile range



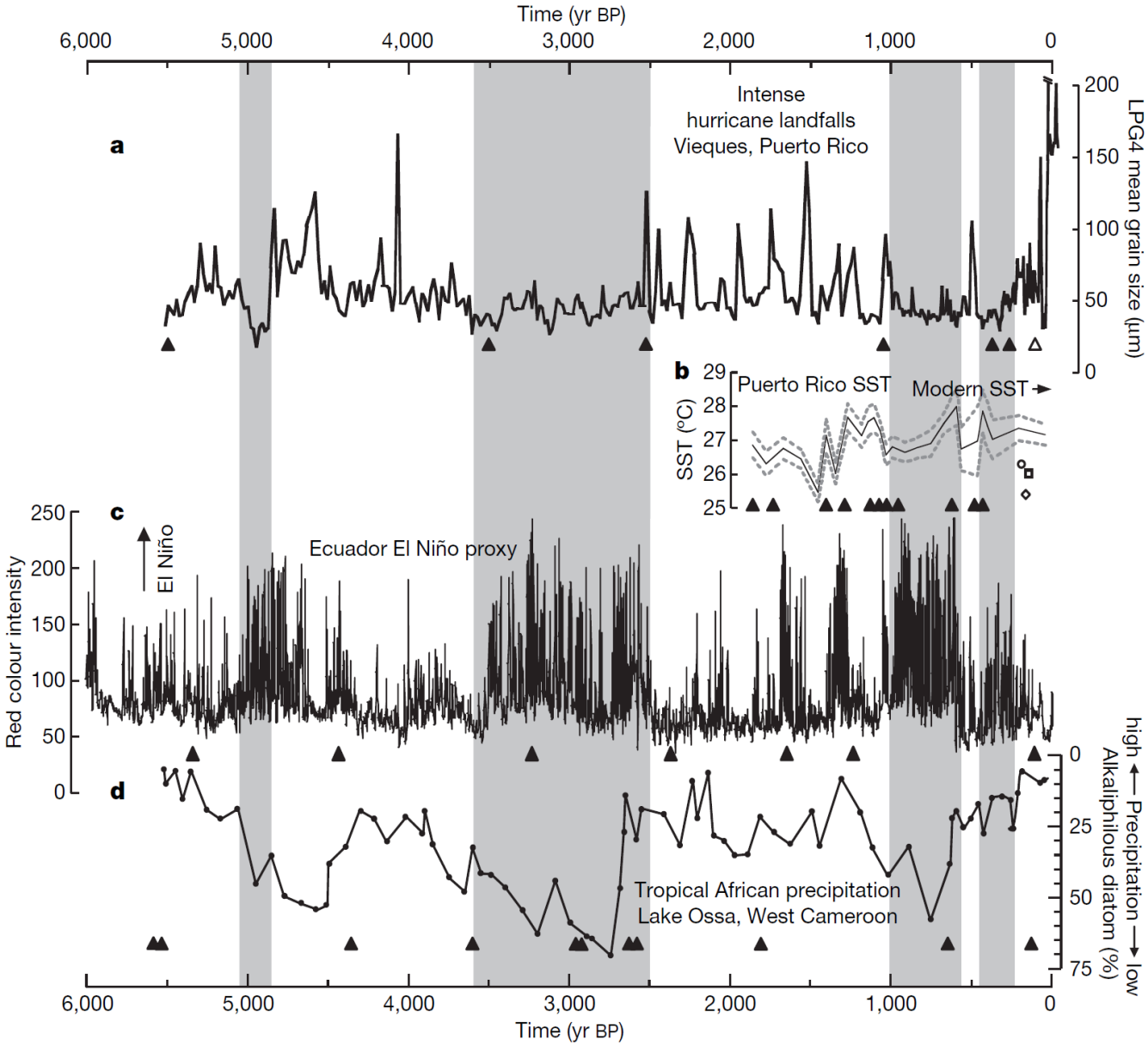

Trends in global satellite-derived tropical cyclone maximum wind speeds by quantile, from 0.1 to 0.9 in increments of 0.1.

Elsner, Kossin, and Jagger, *Nature*, 2008

# Paleotempestology



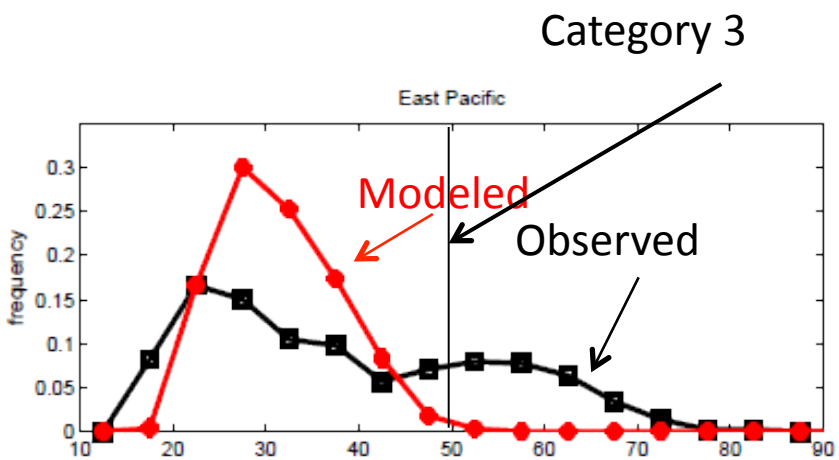

Source: Jeff Donnelly, WHOI




Jeffrey P. Donnelly and Jonathan D. Woodruff, *Nature*, 2007

# Risk Assessment by Direct Numerical Simulation of Hurricanes: The Problem

- The hurricane eyewall is a front, attaining scales of ~ 1 km or less
- At the same time, the storm's circulation extends to ~1000 km and is embedded in much larger scale flows
- The computational nodes of global models are typically spaced 100 km apart




Histograms of Tropical Cyclone Intensity as Simulated by a Global Model with 50 km grid point spacing. (Courtesy Isaac Held, GFDL)

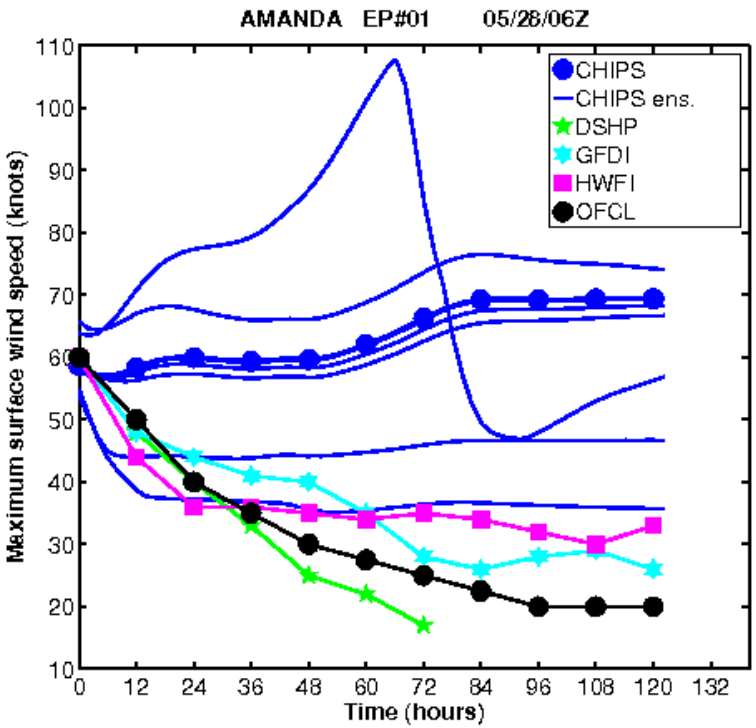
**Global models do not simulate the storms that cause destruction**

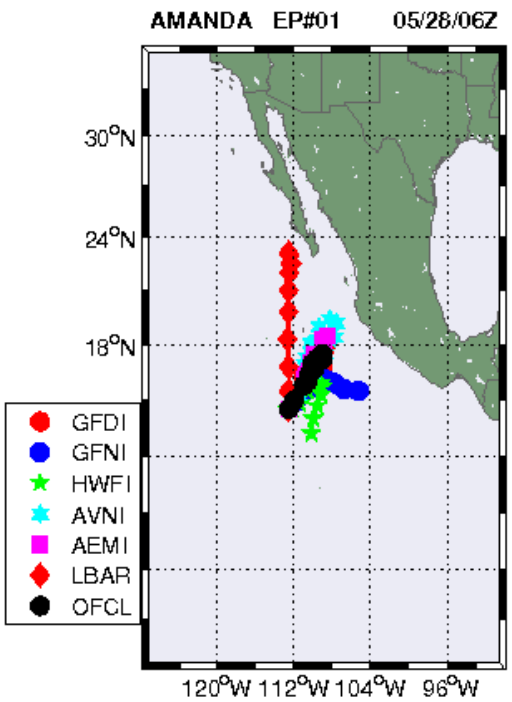
## Solution:
## Embed a very simple hurricane model, coupled to the ocean, inside climate models

- Coupled Hurricane Intensity Prediction System (CHIPS) developed at MIT during 1990s
- Has been used to make real-time forecasts of tropical cyclone intensity globally since late 1990s
- http://wind.mit.edu/~emanuel/storm.html

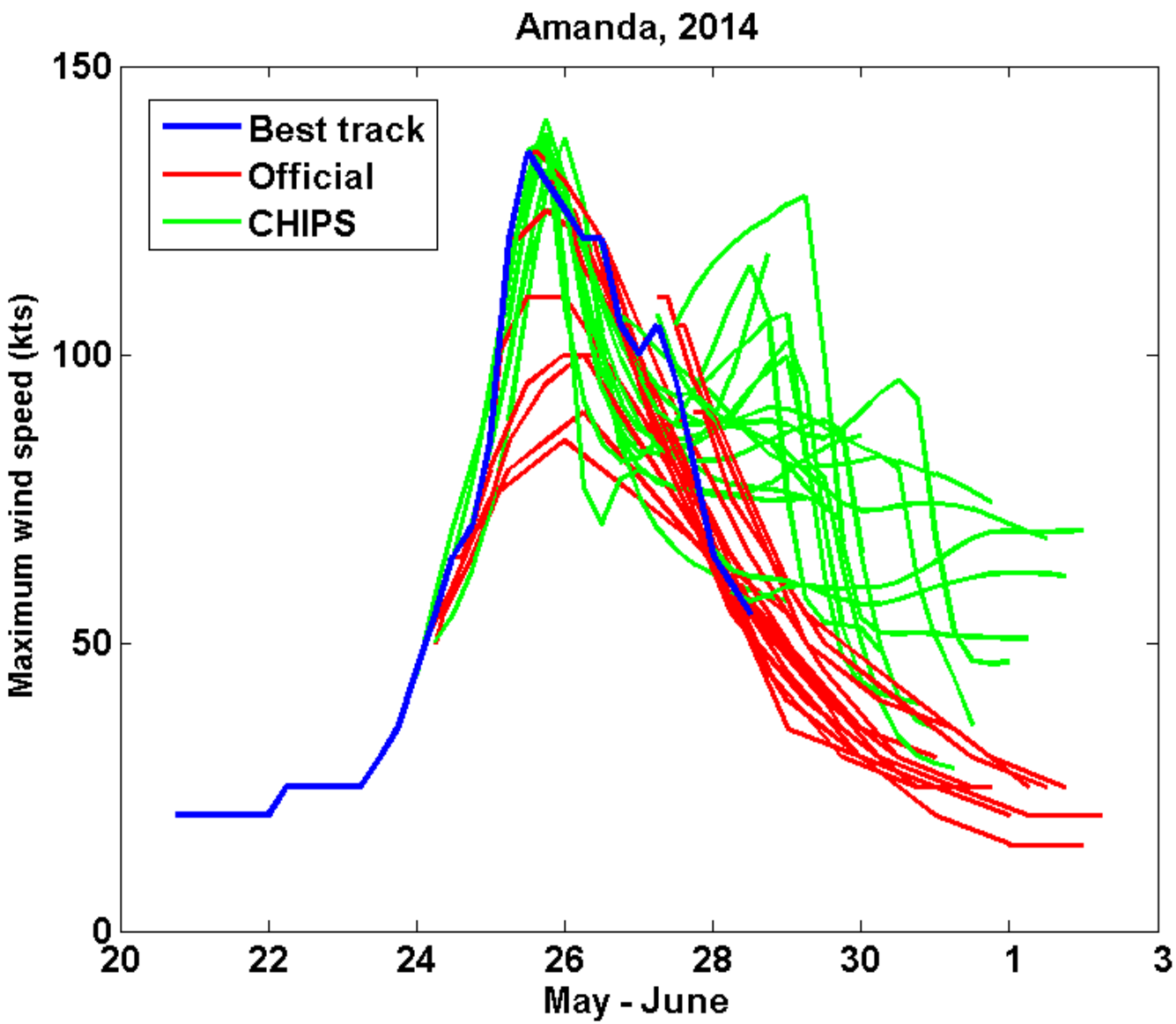
## Tropical Cyclone Track and Intensity Forecasts and Guidance

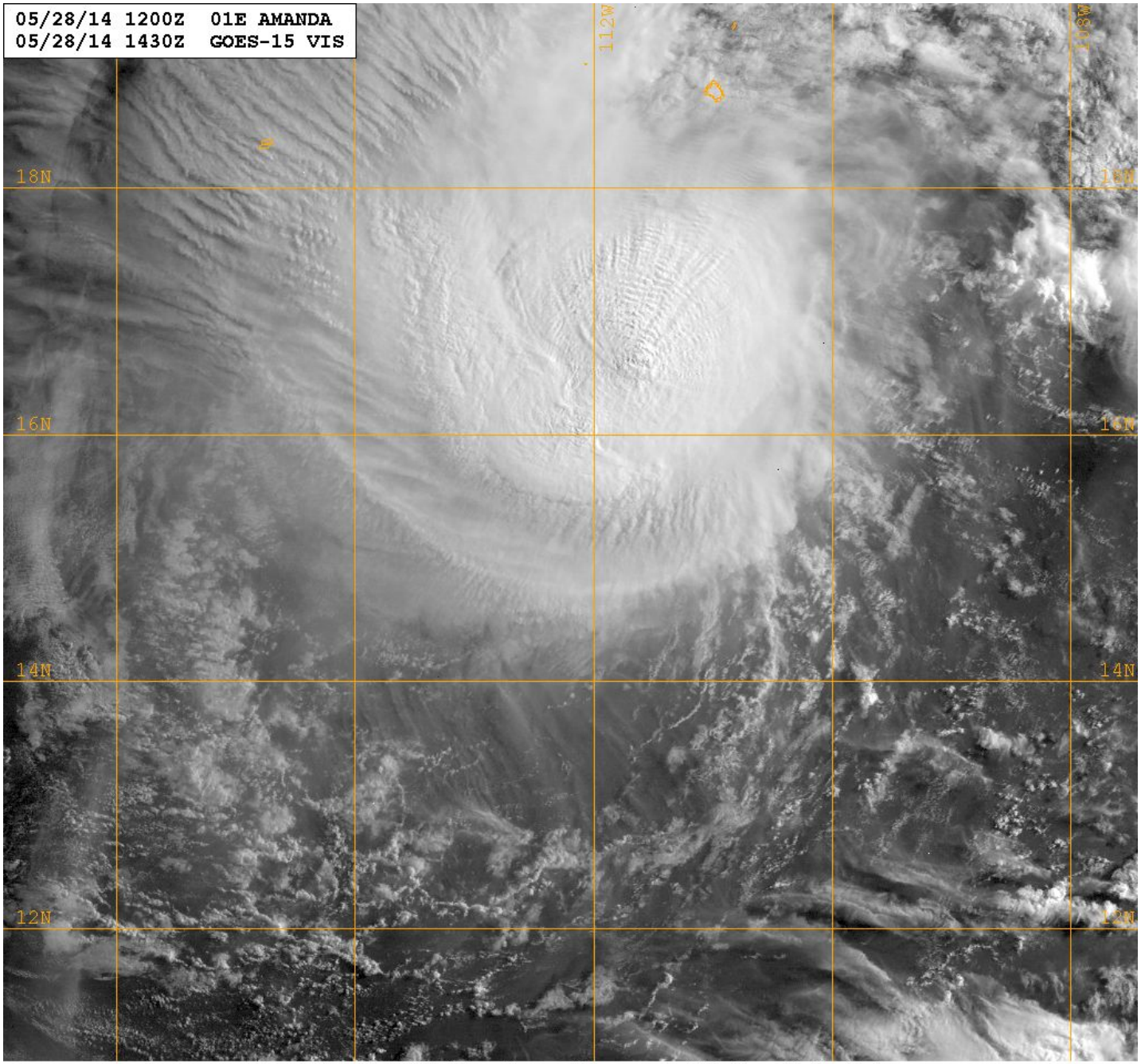
**Disclaimer:** The tropical cyclone objective aids displayed on this web site are collected from multiple forecast centers and may or may not be the most current data available to the operational forecast centers. The MIT tropical meteorology group obtains these forecasts for research purposes and assumes no responsibility for their use in the forecasting of tropical cyclones. Concerned individuals or organizations should confirm these forecasts with official sources.



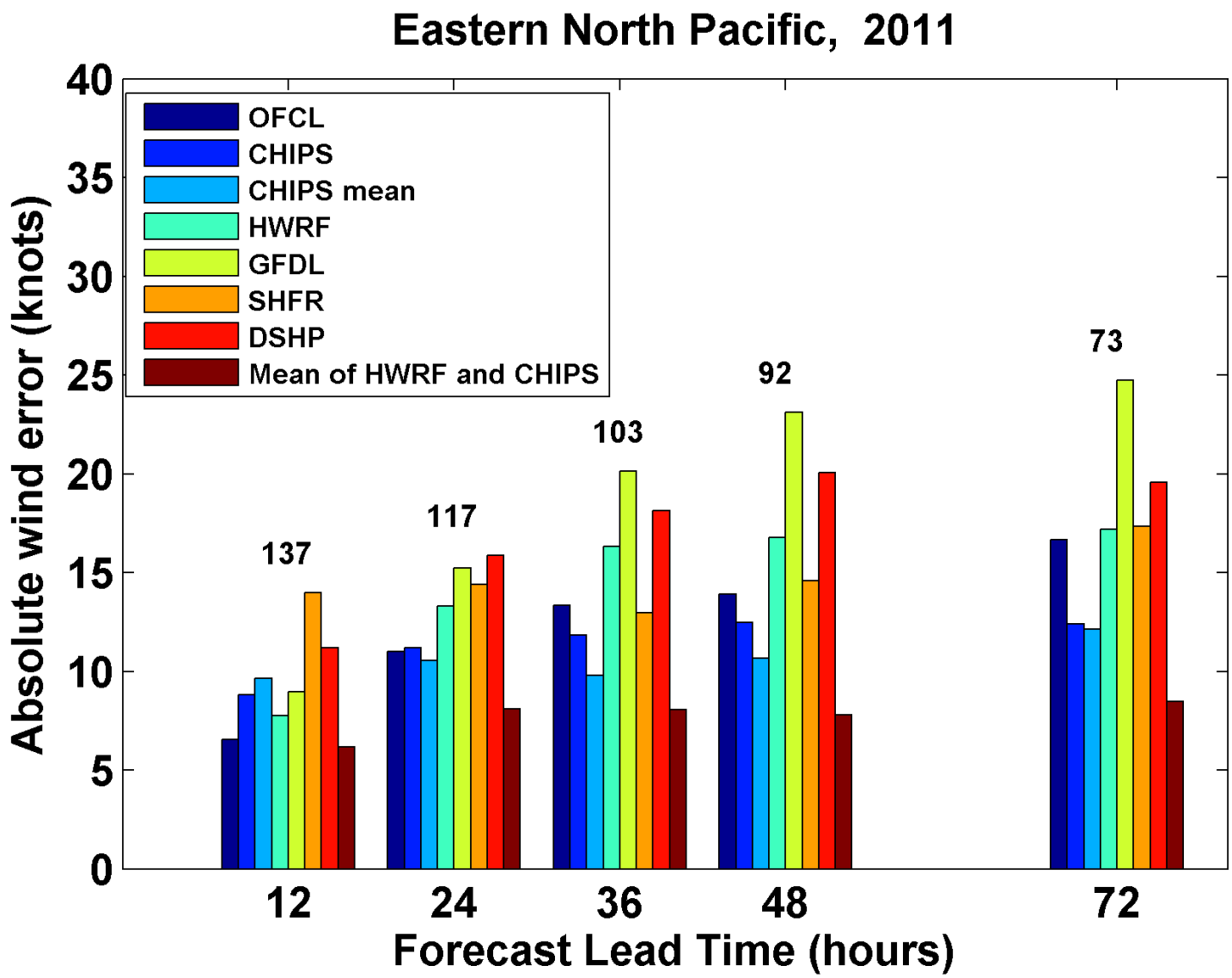




http://wind.mit.edu/~emanuel/storm.html


Amanda, 2014
Best track
Official
CHIPS
Maximum wind speed (kts)
150
100
50
0
20
22
24
26
28
30
1
3
May - June




Naval Research Lab http://www.nrlmry.navy.mil/sat_products.html
<-- Visible ( Sun elevation at center is 22 degrees) -->


Eastern North Pacific, 2011
OFCL
CHIPS
CHIPS mean
HWRF
GFDL
SHFR
DSHP
Mean of HWRF and CHIPS
137
117
103
92
73
Absolute wind error (knots)
0
5
10
15
20
25
30
35
40
12
24
36
48
72
Forecast Lead Time (hours)

# How Can We Use This Model to Help Assess Hurricane Risk in Current and Future Climates?

# Risk Assessment Approach:

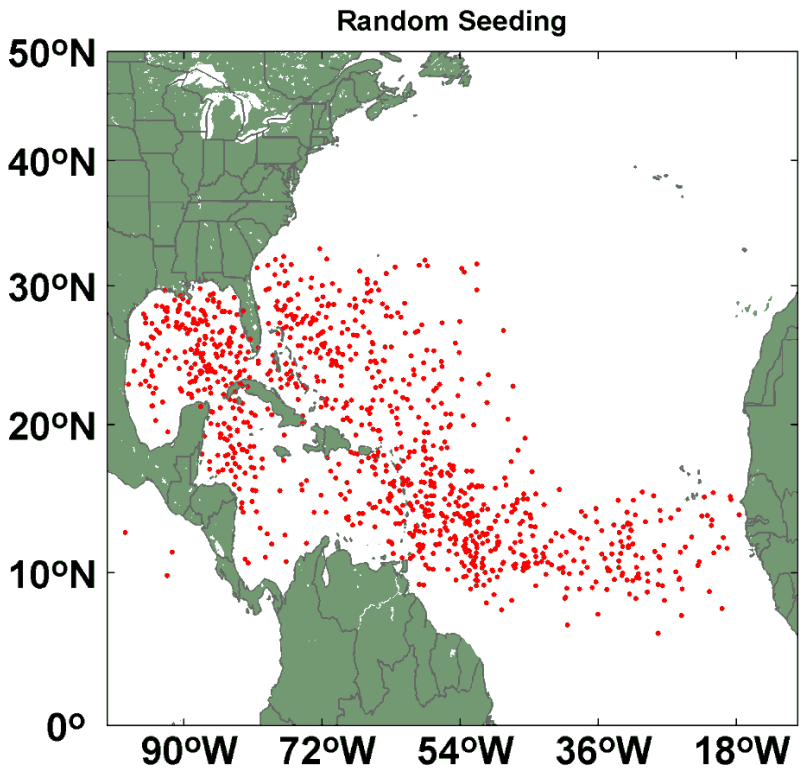
- **Step 1**: Seed each ocean basin with a very large number of weak, randomly located cyclones
- **Step 2**: Cyclones are assumed to move with the large scale atmospheric flow in which they are embedded, plus a correction for beta drift
- **Step 3**: Run the CHIPS model for each cyclone, and note how many achieve at least tropical storm strength
- **Step 4:** Using the small fraction of surviving events, determine storm statistics

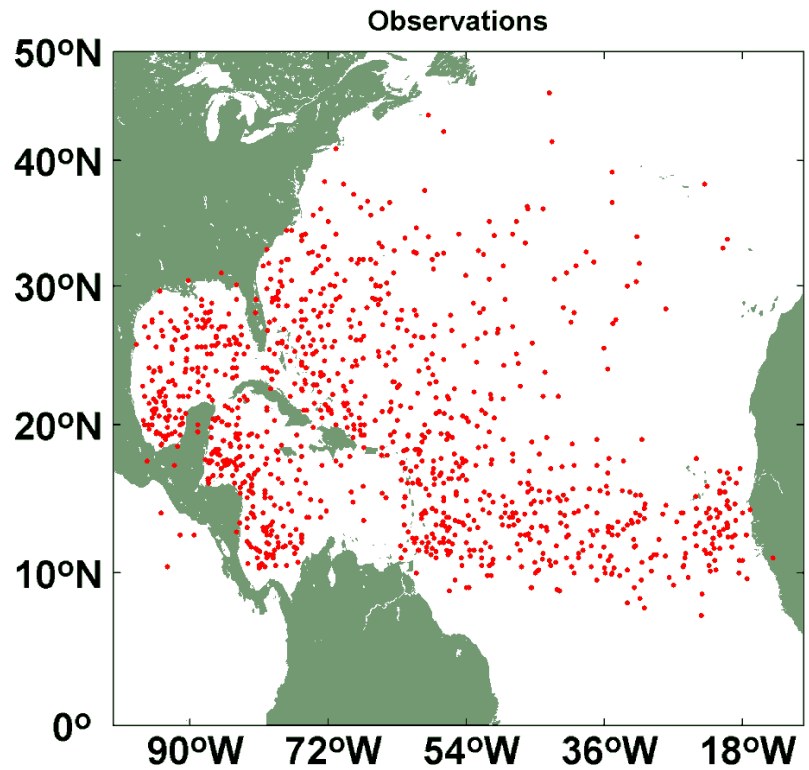
Details: Emanuel et al., *Bull. Amer. Meteor. Soc*, 2008

# Synthetic Track Generation: Generation of Synthetic Wind Time Series

- **Extract winds from climatological or global climate model output**
- **Postulate that TCs move with vertically averaged environmental flow plus a "beta drift" correction**
- **Approximate "vertically averaged" by weighted mean of 850 and 250 hPa flow**

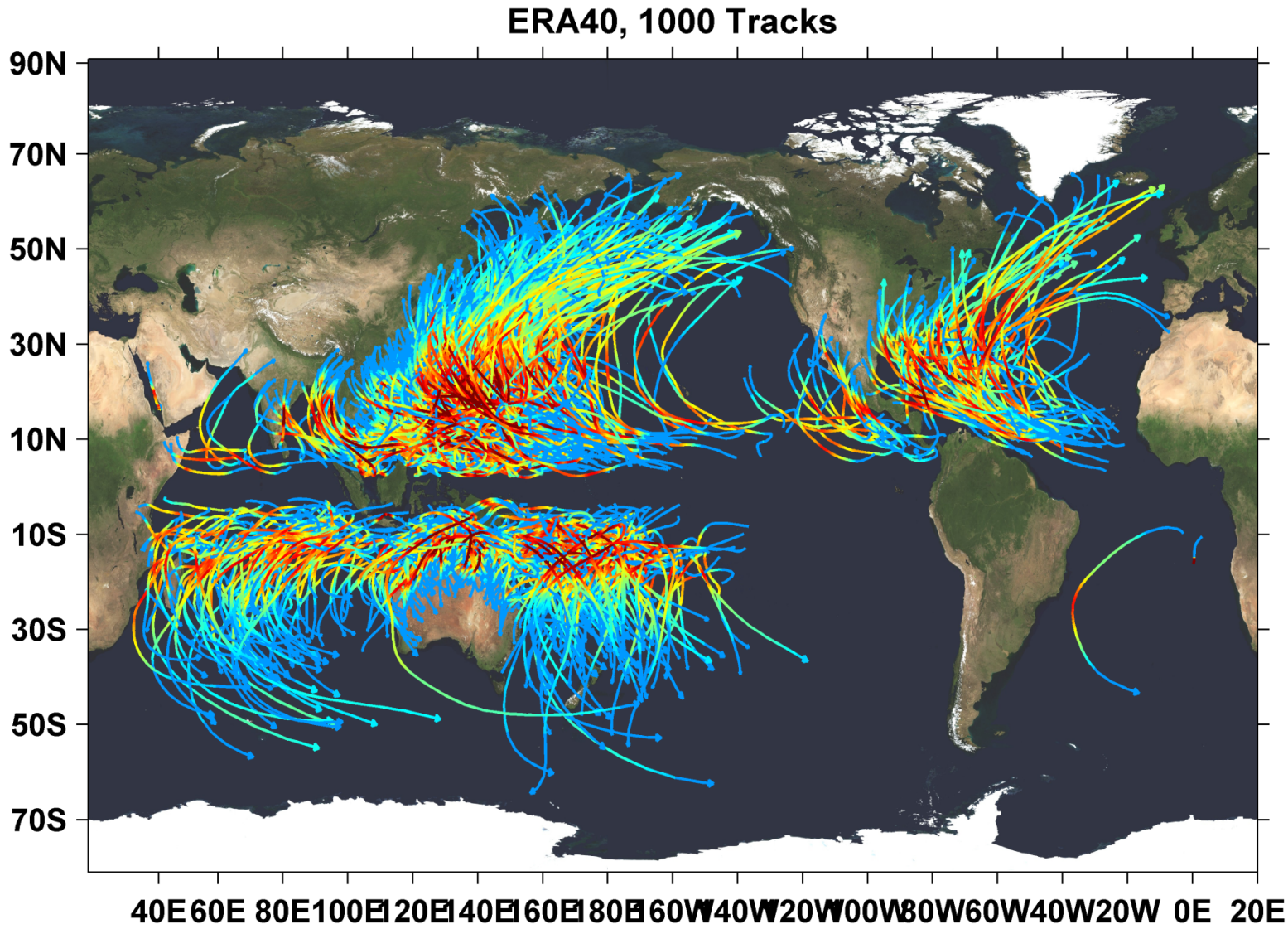
# Comparison of Random Seeding Genesis Locations with Observations



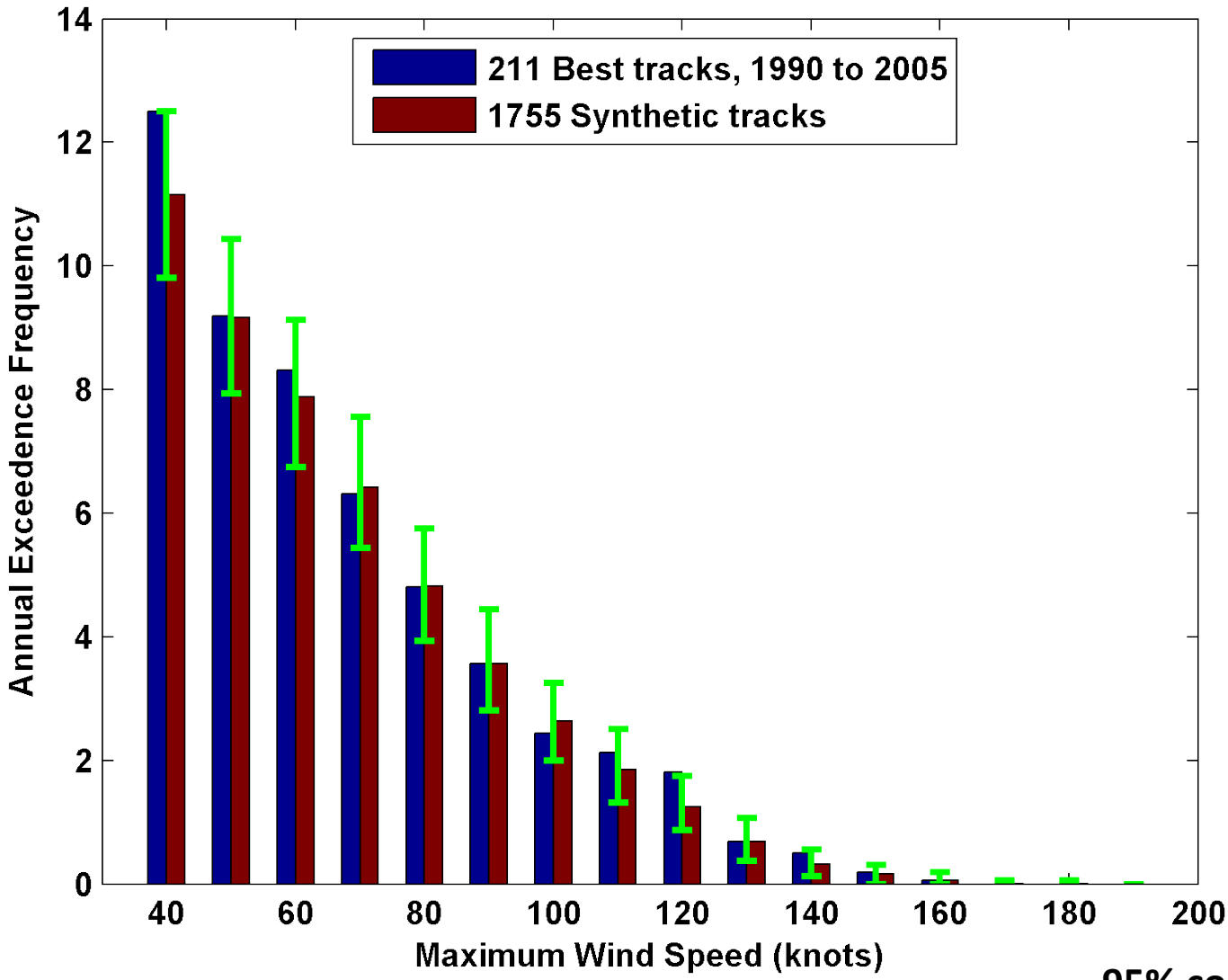



# Calibration

- **Absolute genesis frequency calibrated to globe during the period 1980-2005**

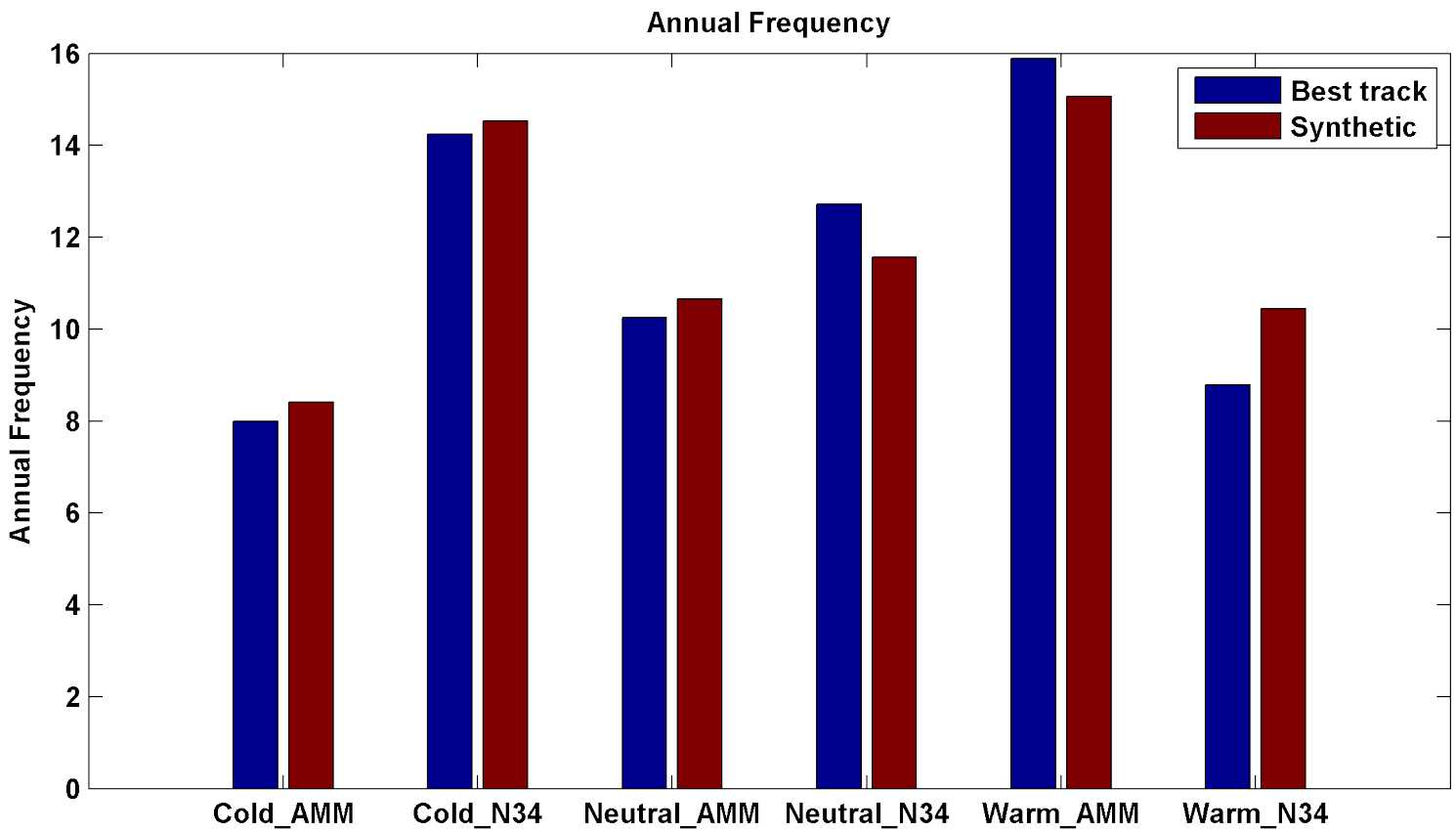

ERA40, 1000 Tracks
90N
70N
50N
30N
10N
10S
30S
50S
70S
40E 60E 80E 100E 120E 140E 160E 180E 160W 140W 120W 100W 80W 60W 40W 20W 0E 20E

# Cumulative Distribution of Storm Lifetime Peak Wind Speed, with Sample of 1755 Synthetic Tracks

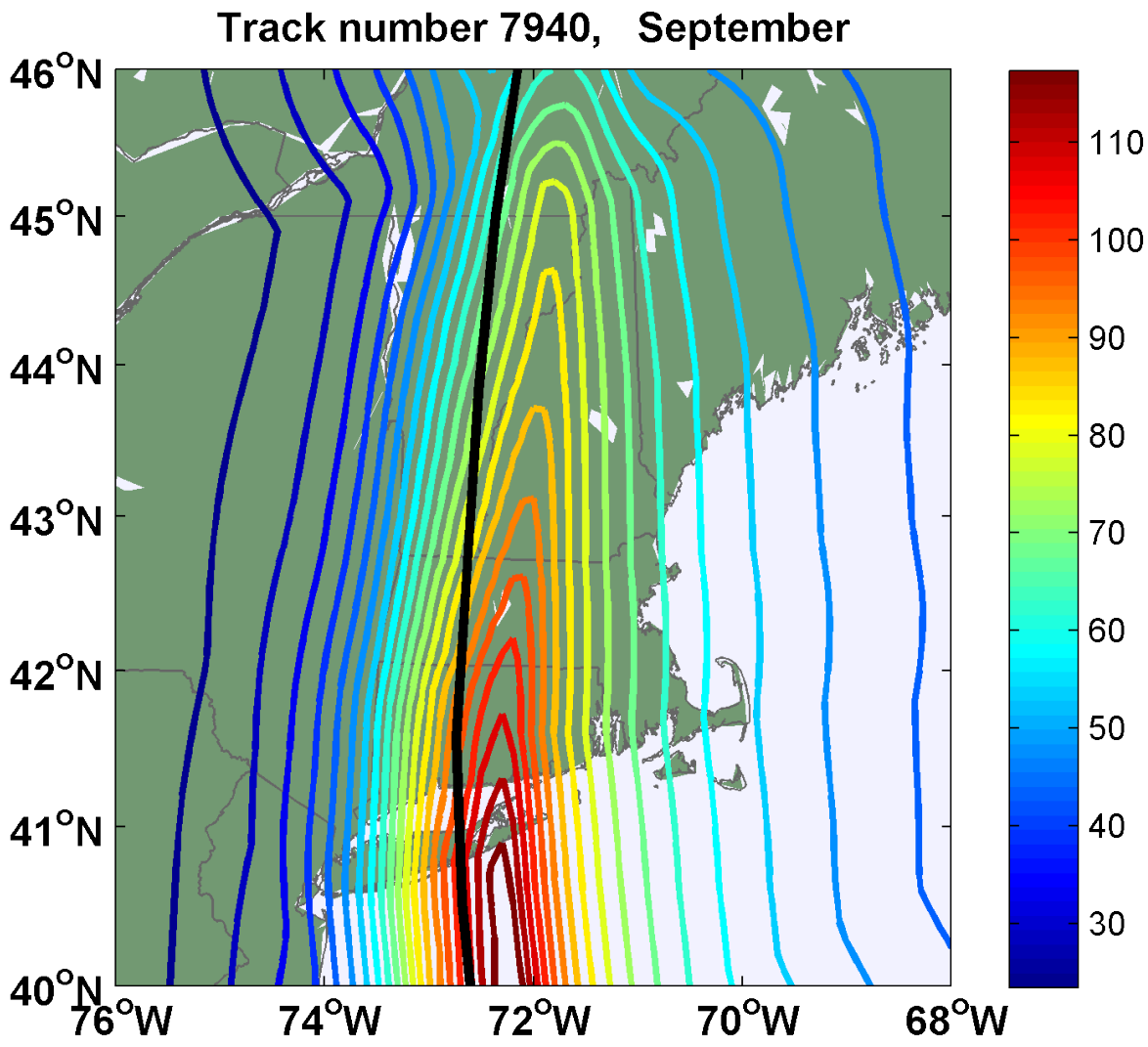



95% confidence bounds

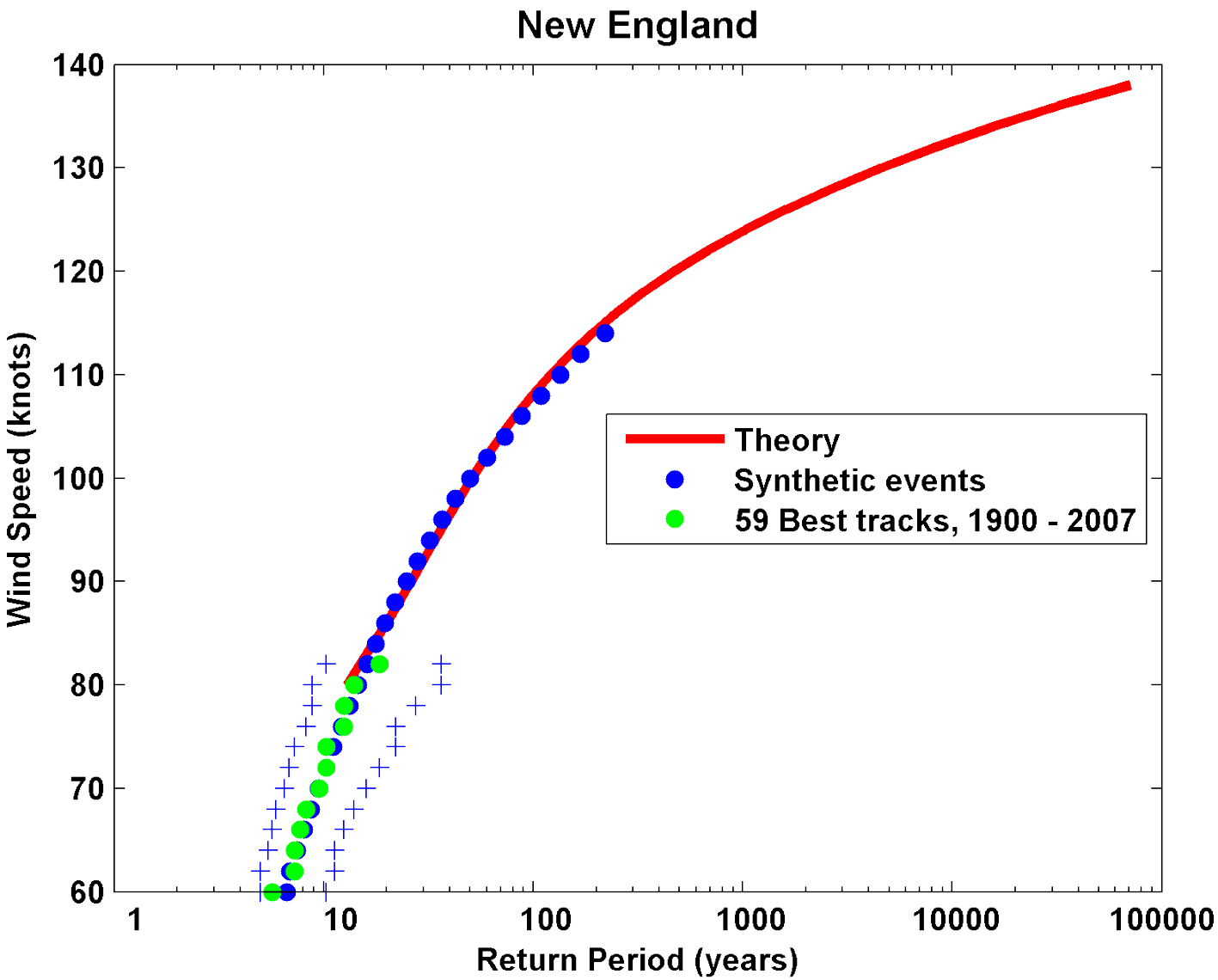
# Captures effects of regional climate phenomena (e.g. ENSO, AMM)



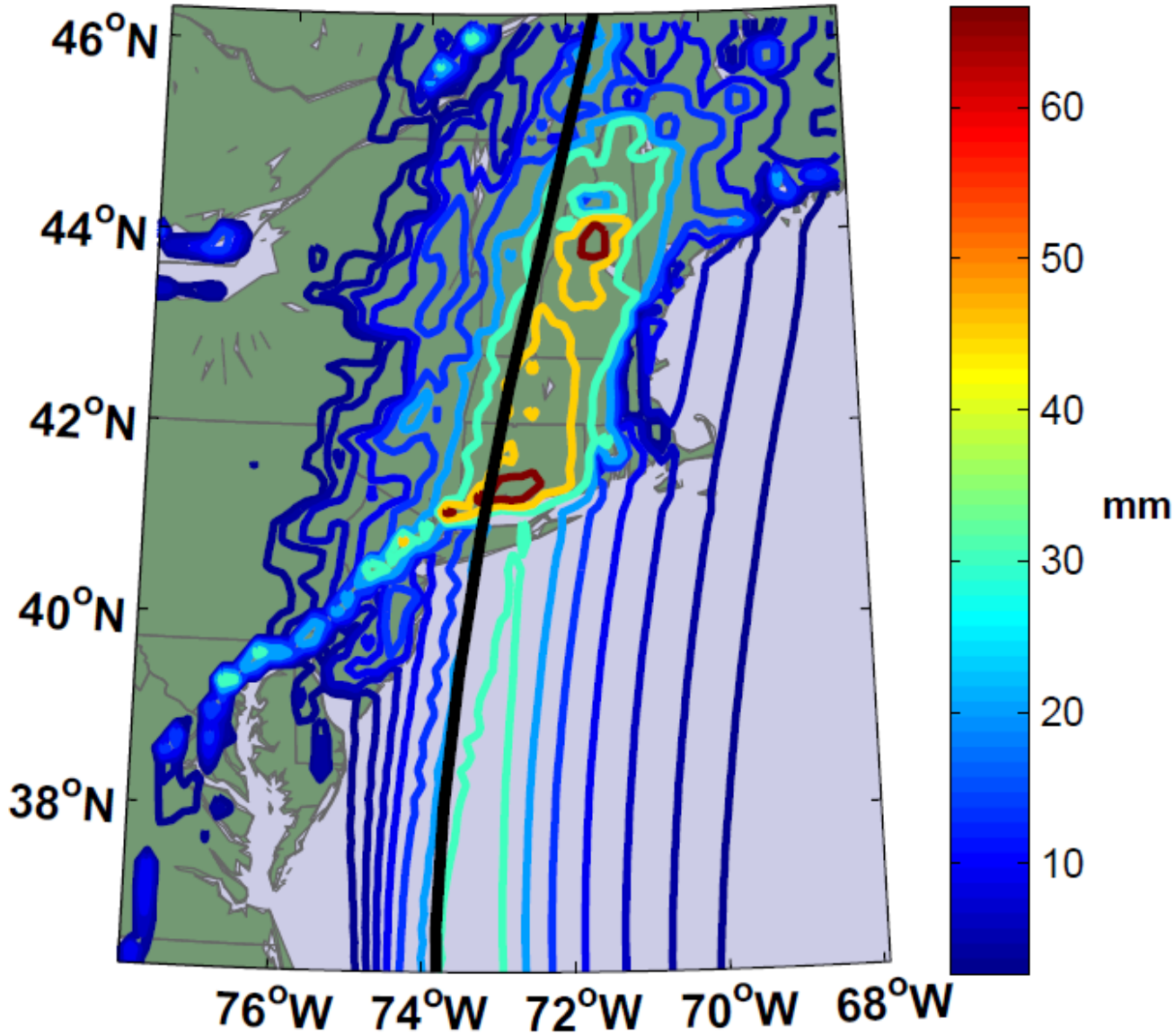
# Sample Storm Wind Swath



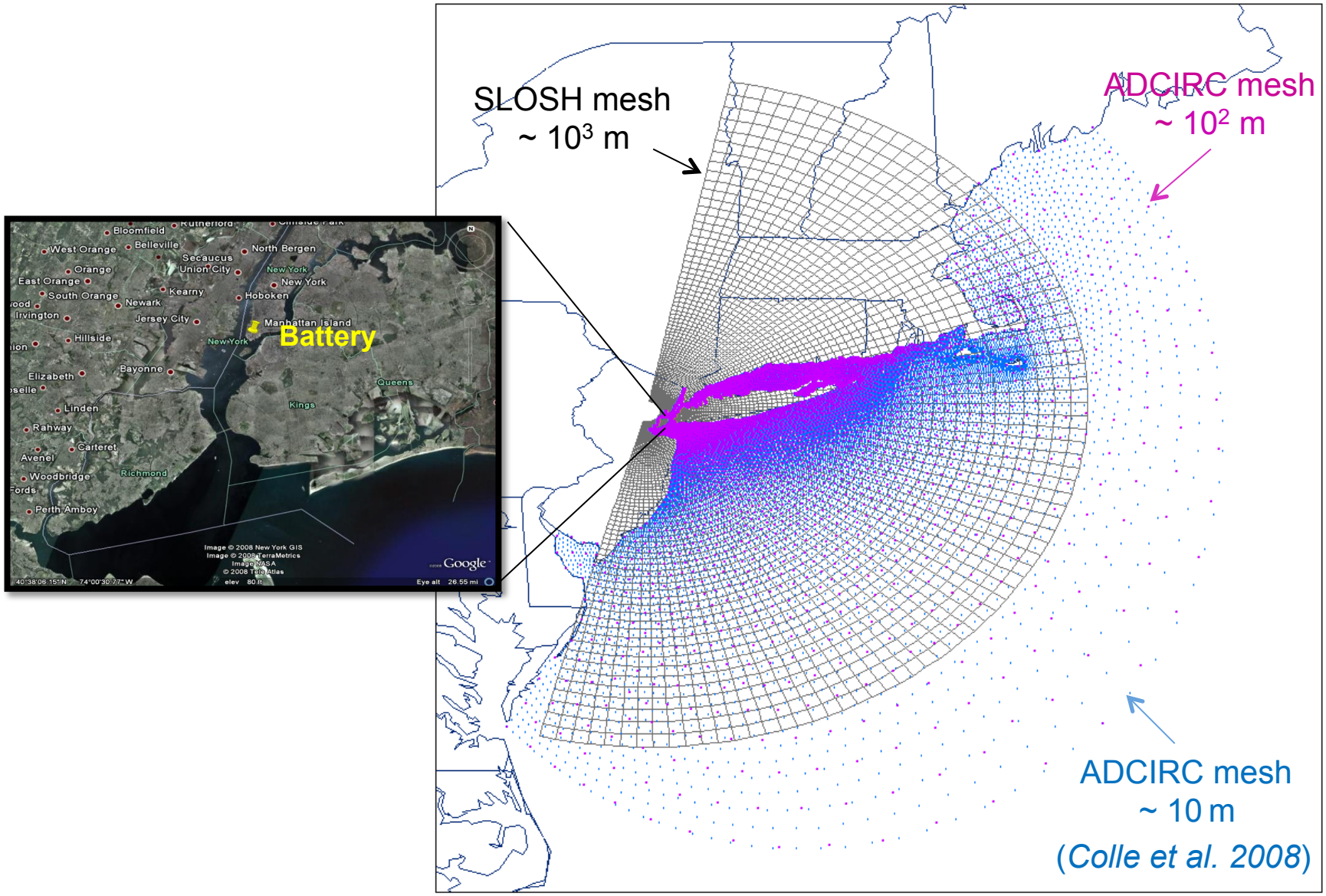
# Return Periods

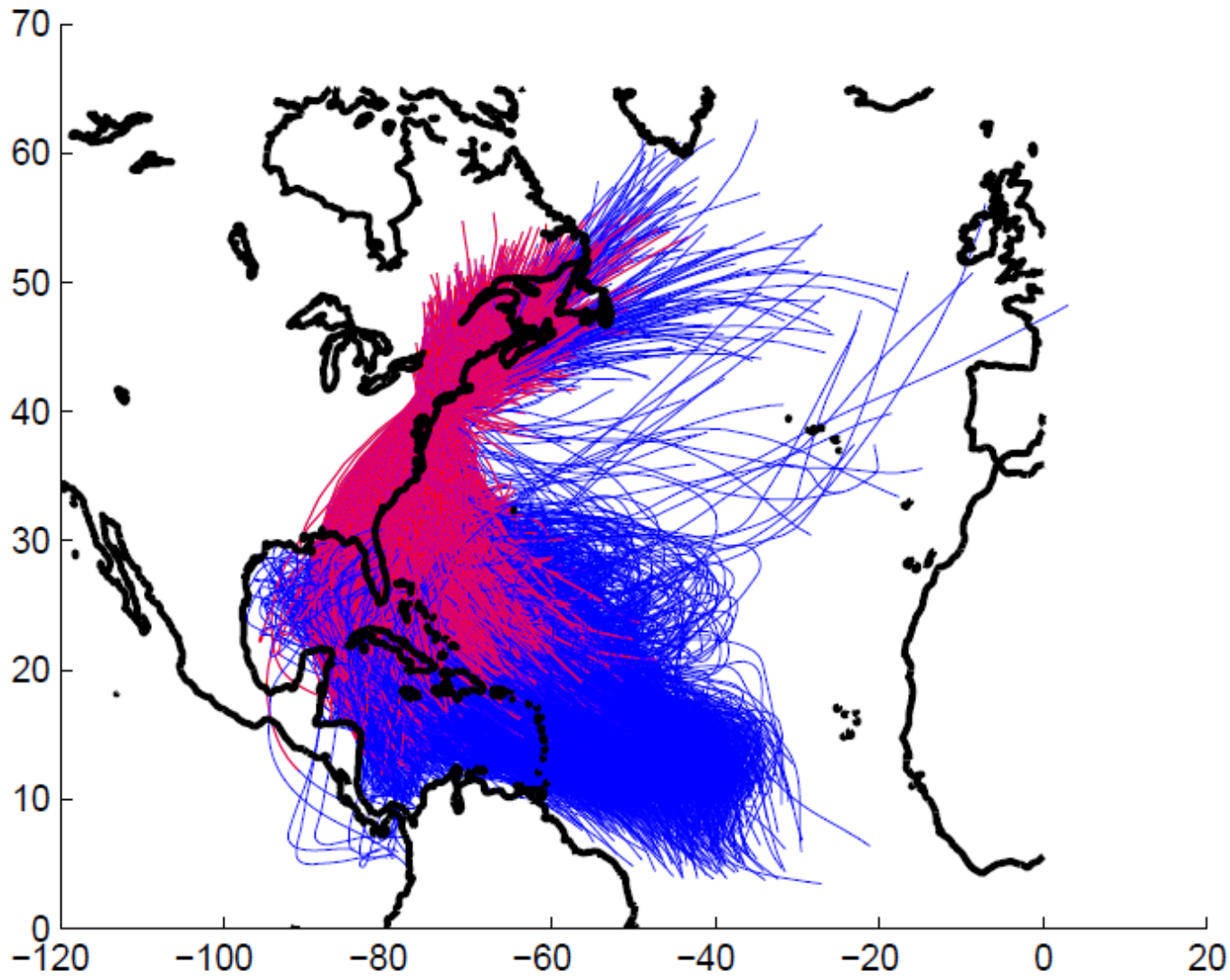


# Accumulated Rainfall (mm)

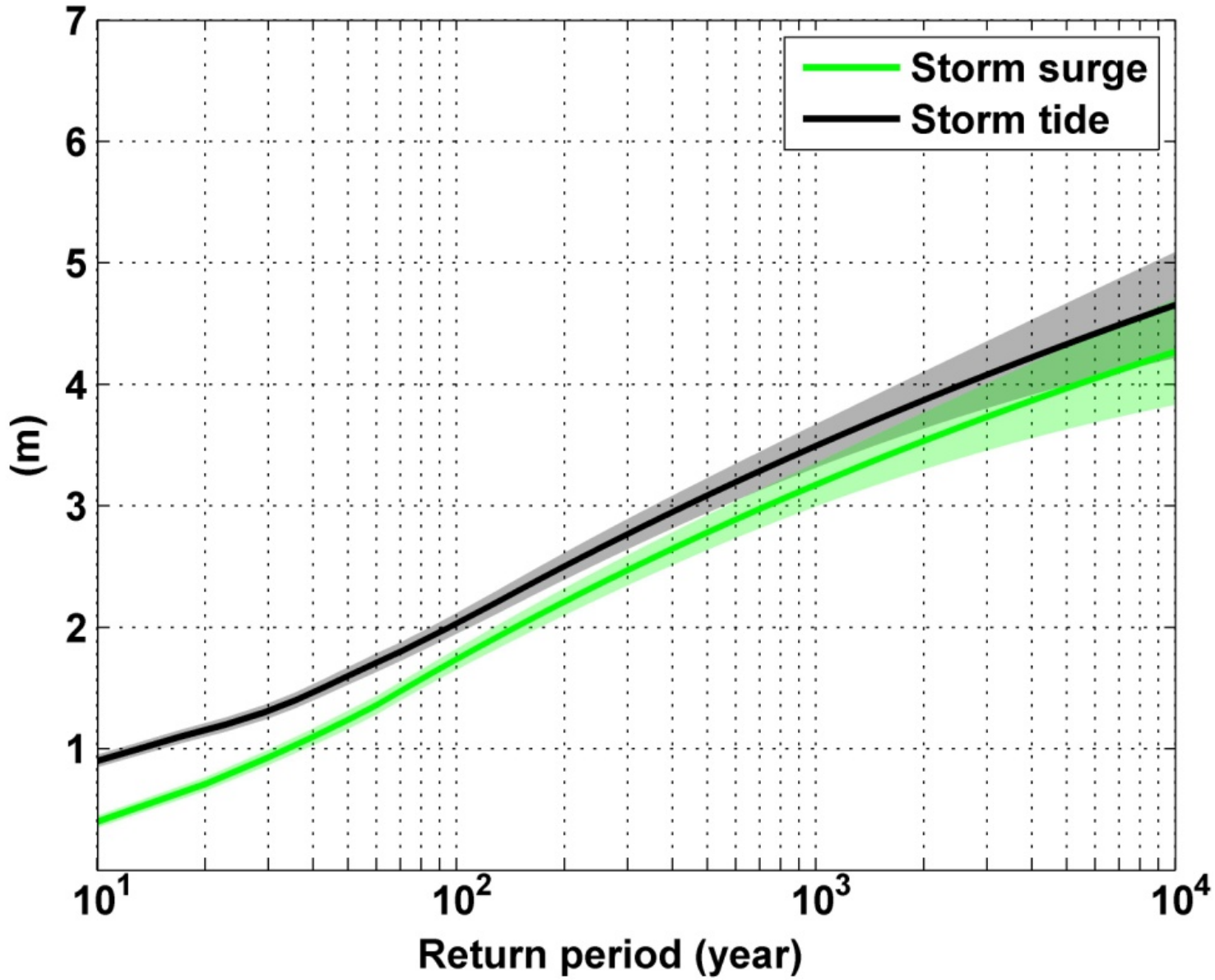


# Storm Surge Simulation






**5000 synthetic storm tracks under current climate. (Red portion of each track is used in surge analysis.)**

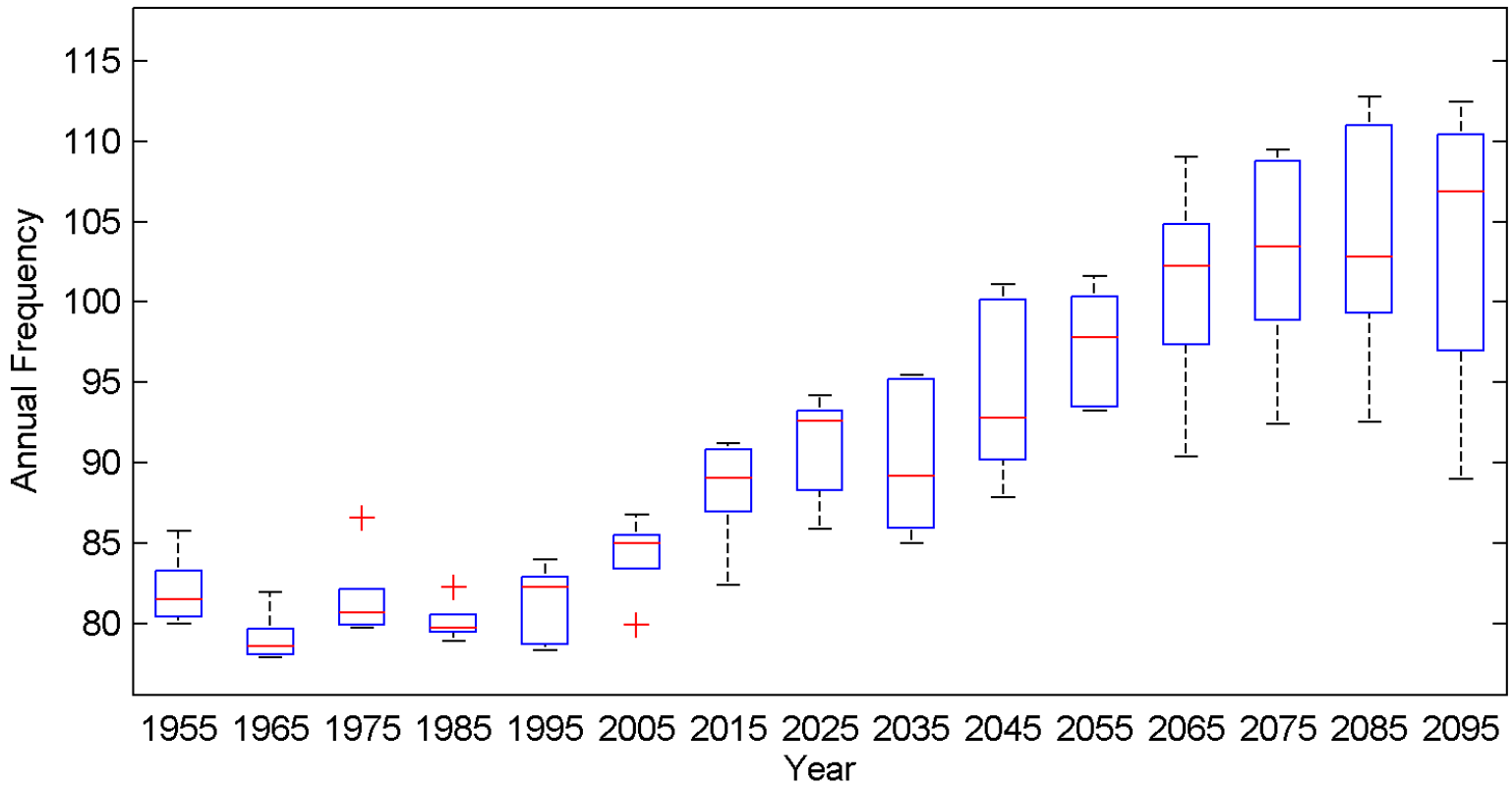

Storm surge
Storm tide
(m)
7
6
5
4
3
2
1
$10^1$
$10^2$
$10^3$
$10^4$
Return period (year)

# Taking Climate Change Into Account

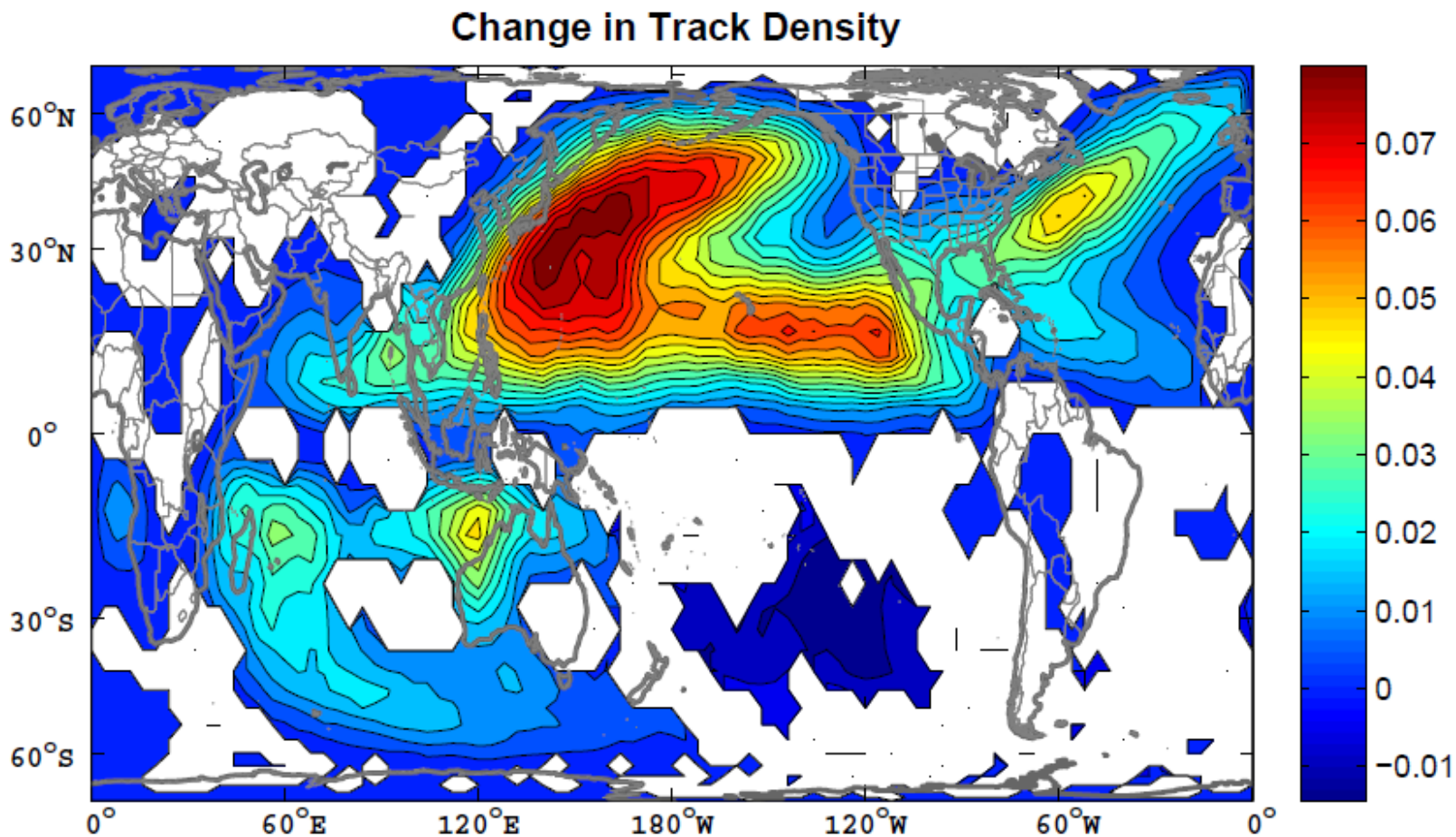
# Downscaling of AR5 GCMs

- GFDL-CM3
- HadGEM2-ES
- MPI-ESM-MR
- MIROC-5
- MRI-CGCM3

**Historical:** 1950-2005, **RCP8.5** 2006-2100

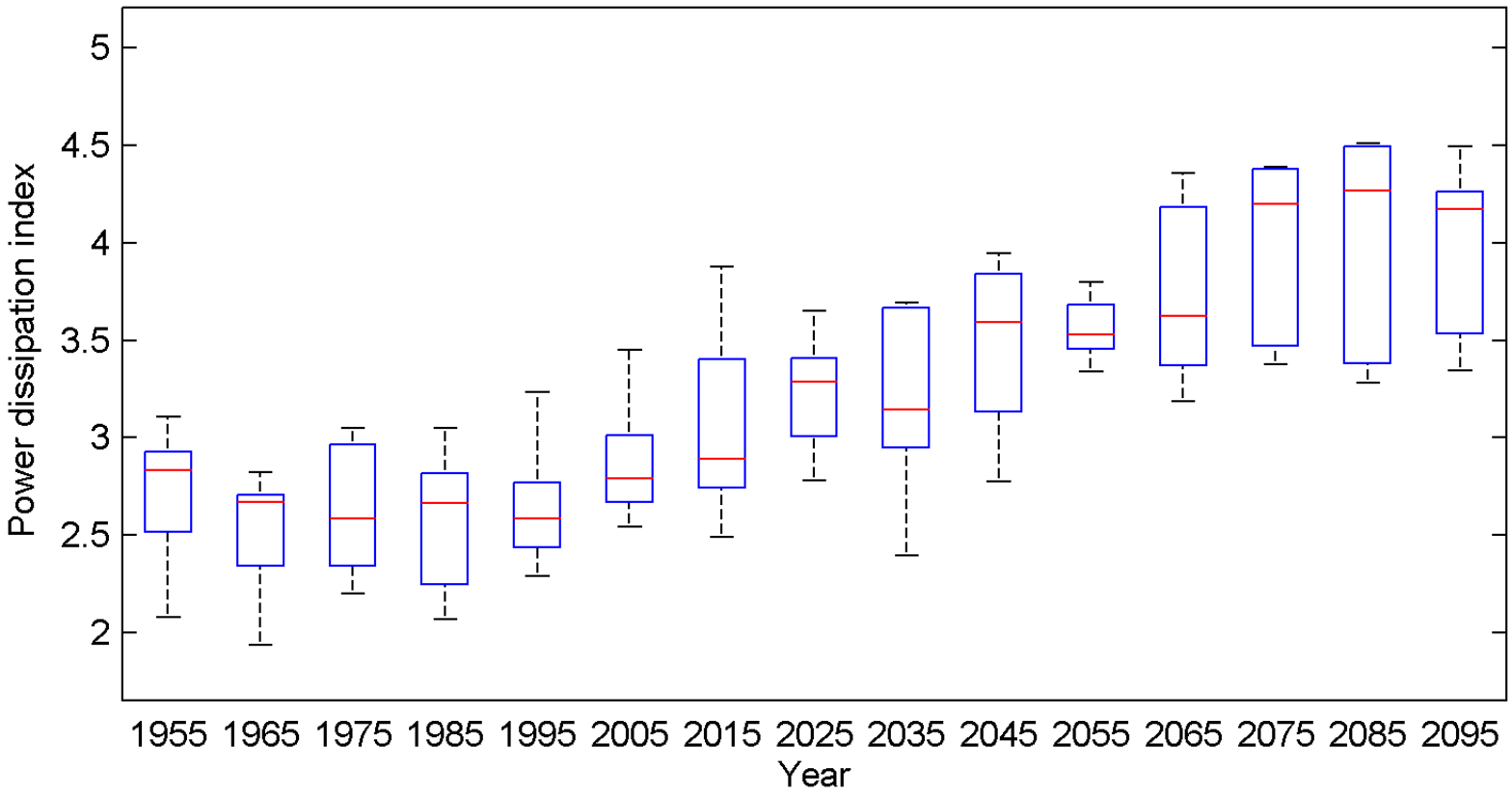



Global annual frequency of tropical cyclones averaged in 10-year blocks for the period 1950-2100, using historical simulations for the period 1950-2005 and the RCP 8.5 scenario for the period 2006-2100. In each box, the red line represents the median among the 5 models, and the bottom and tops of the boxes represent the 25$^{th}$ and 75$^{th}$ percentiles, respectively. The whiskers extent to the most extreme points not considered outliers, which are represented by the red + signs. Points are considered outliers if they lie more than 1.5 times the box height above or below the box.

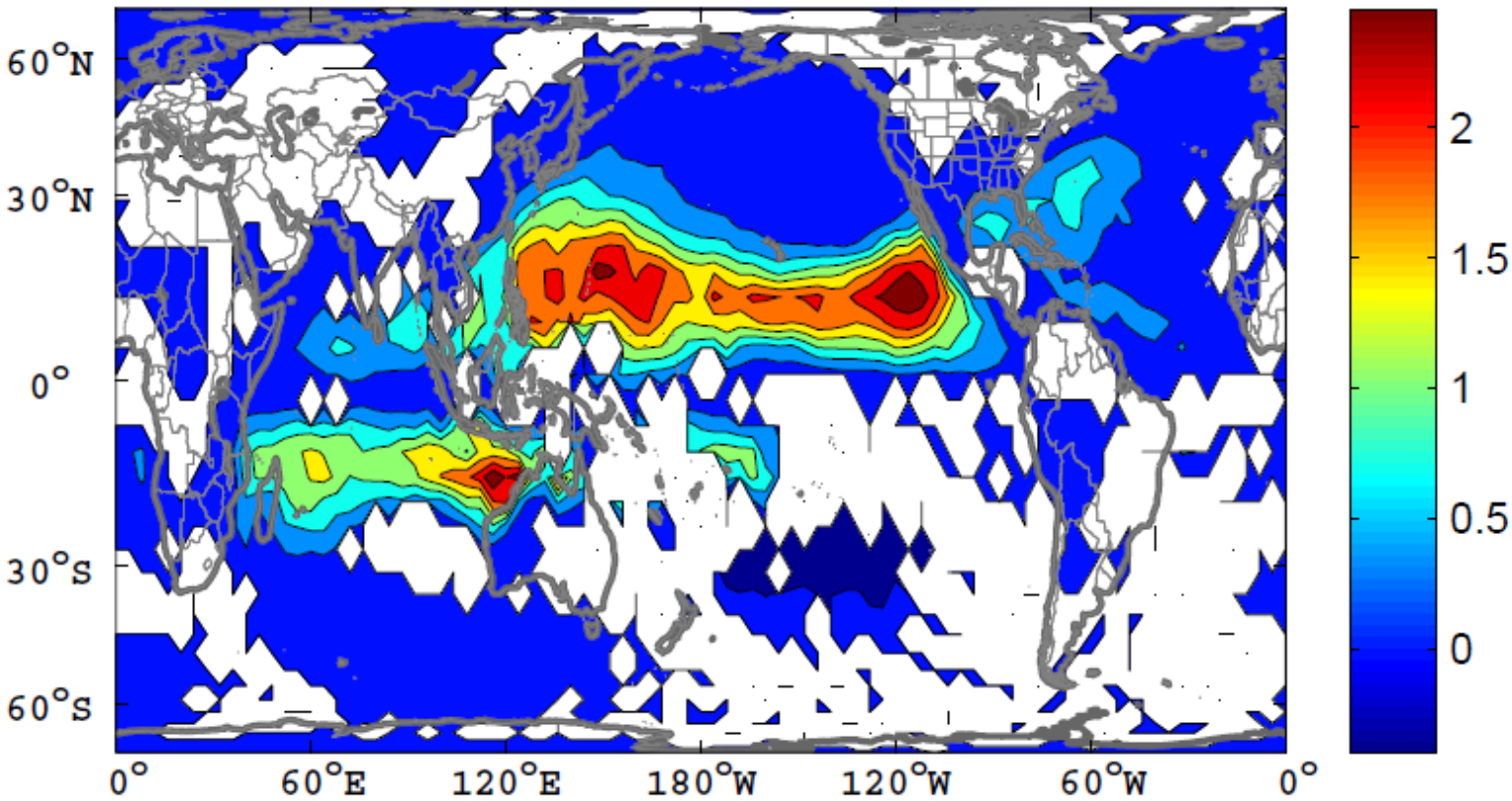



**Change in track density, measured in number of events per 4° X 4° square per year, averaged over the five models. The change is simply the average over the period 2006-2100 minus the average over 1950-2005. The white regions are where fewer than 4 of the 5 models agree on the sign of the change.**

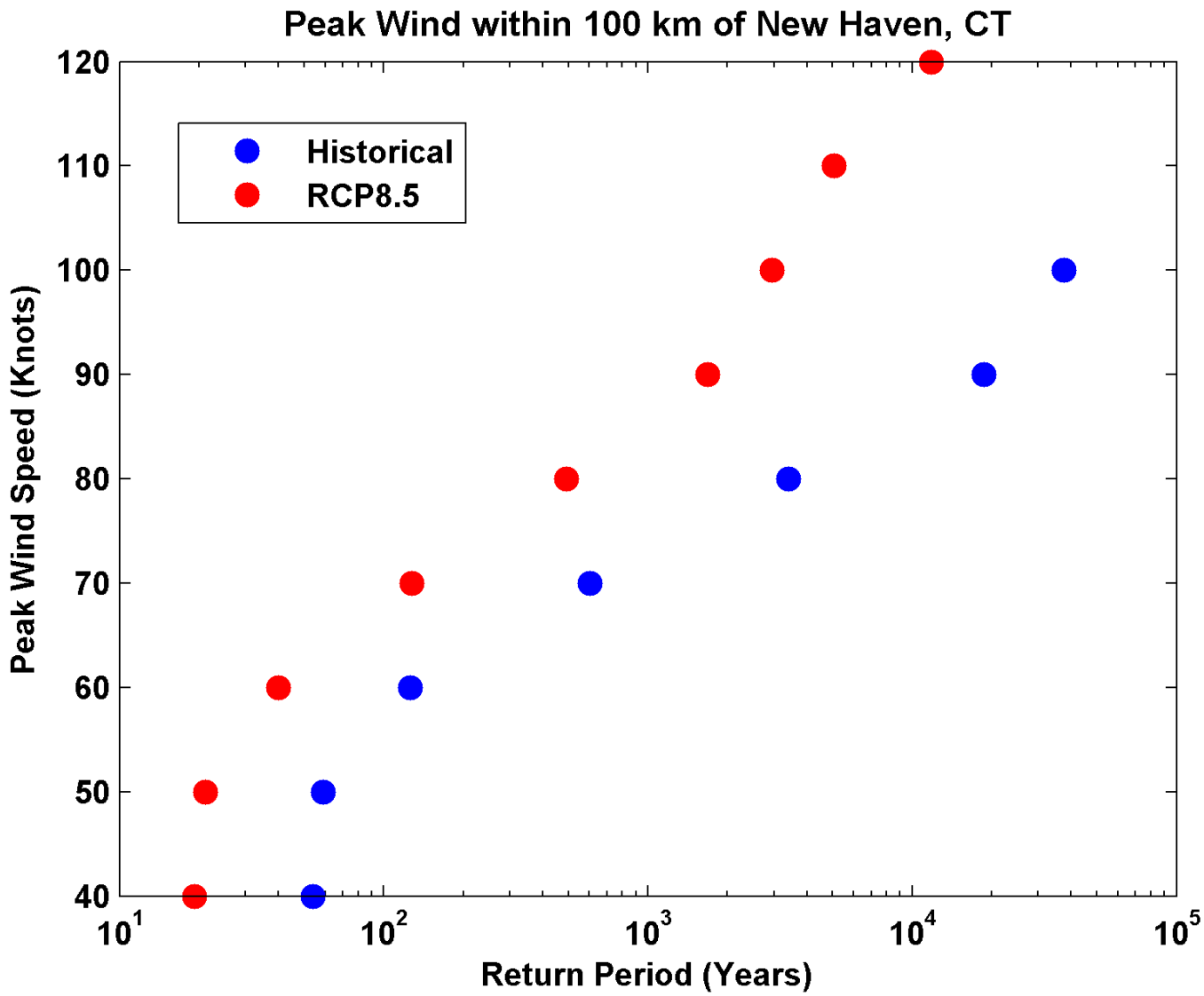
# Global Tropical Cyclone Power Dissipation



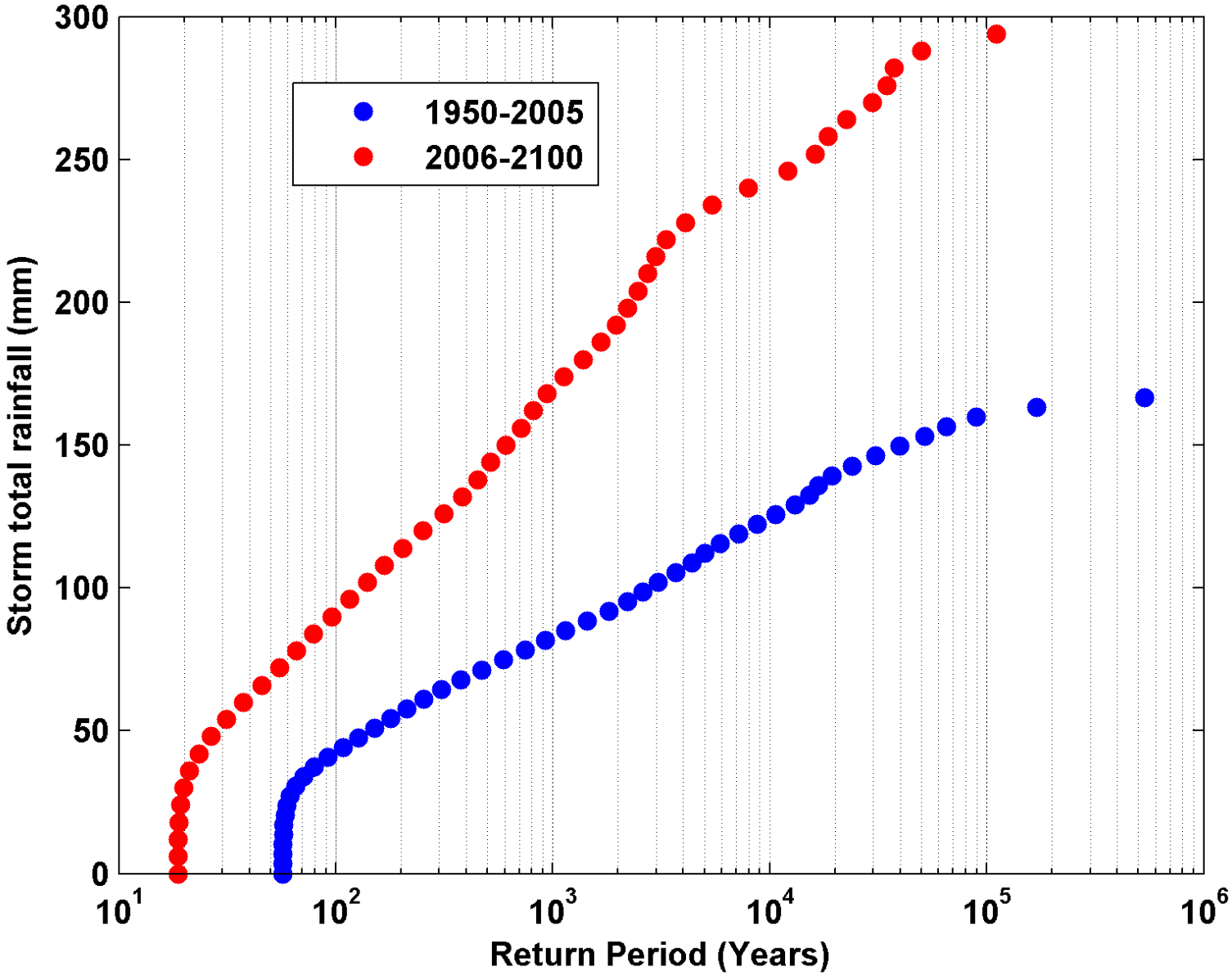
# Change in Power Dissipation



# Return Periods based on GFDL Model

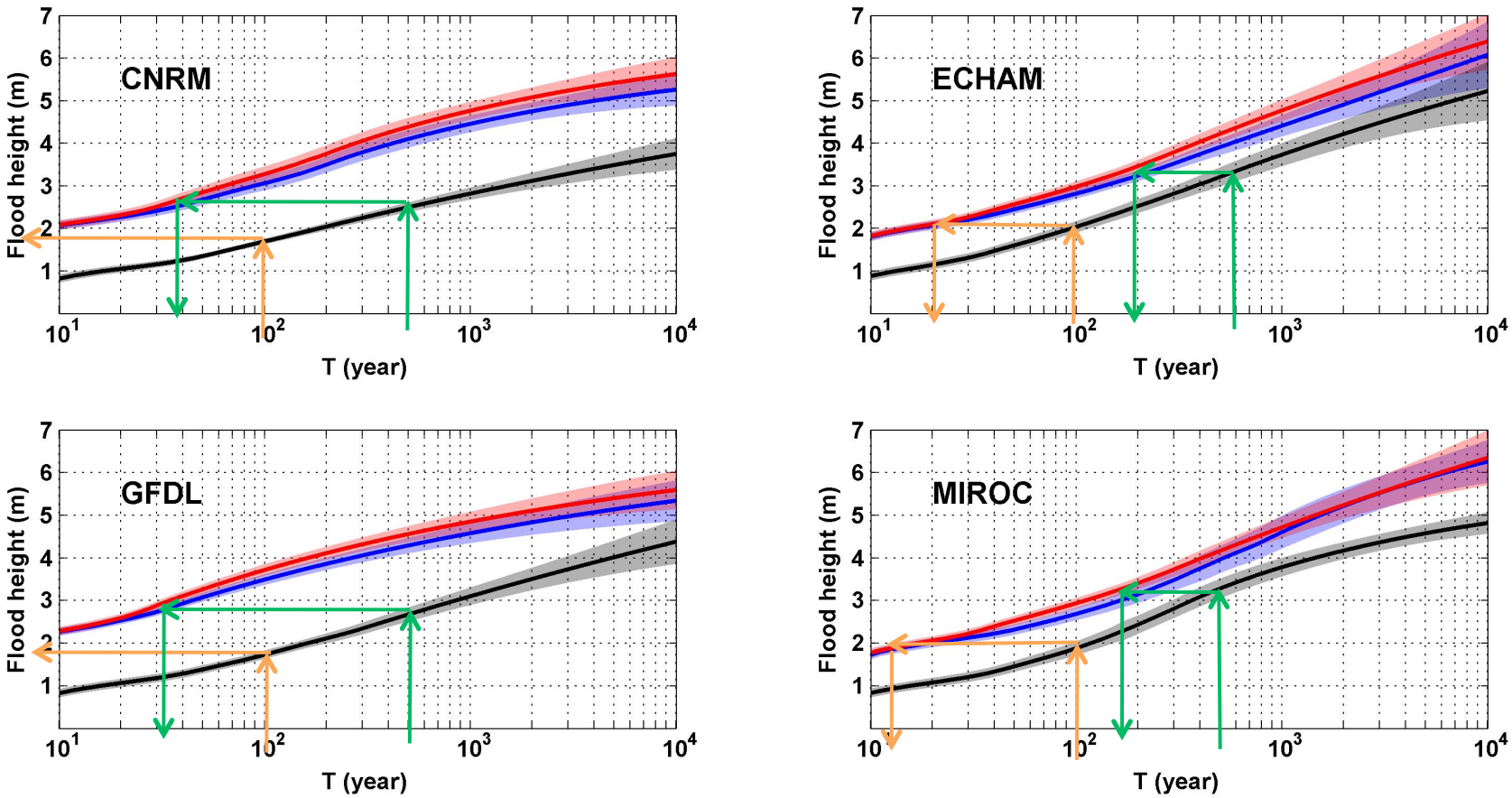


# Return Periods of Storm Total Rainfall at New Haven
# GFDL Model



# GCM flood height return level

## (assuming SLR of 1 m for the future climate )



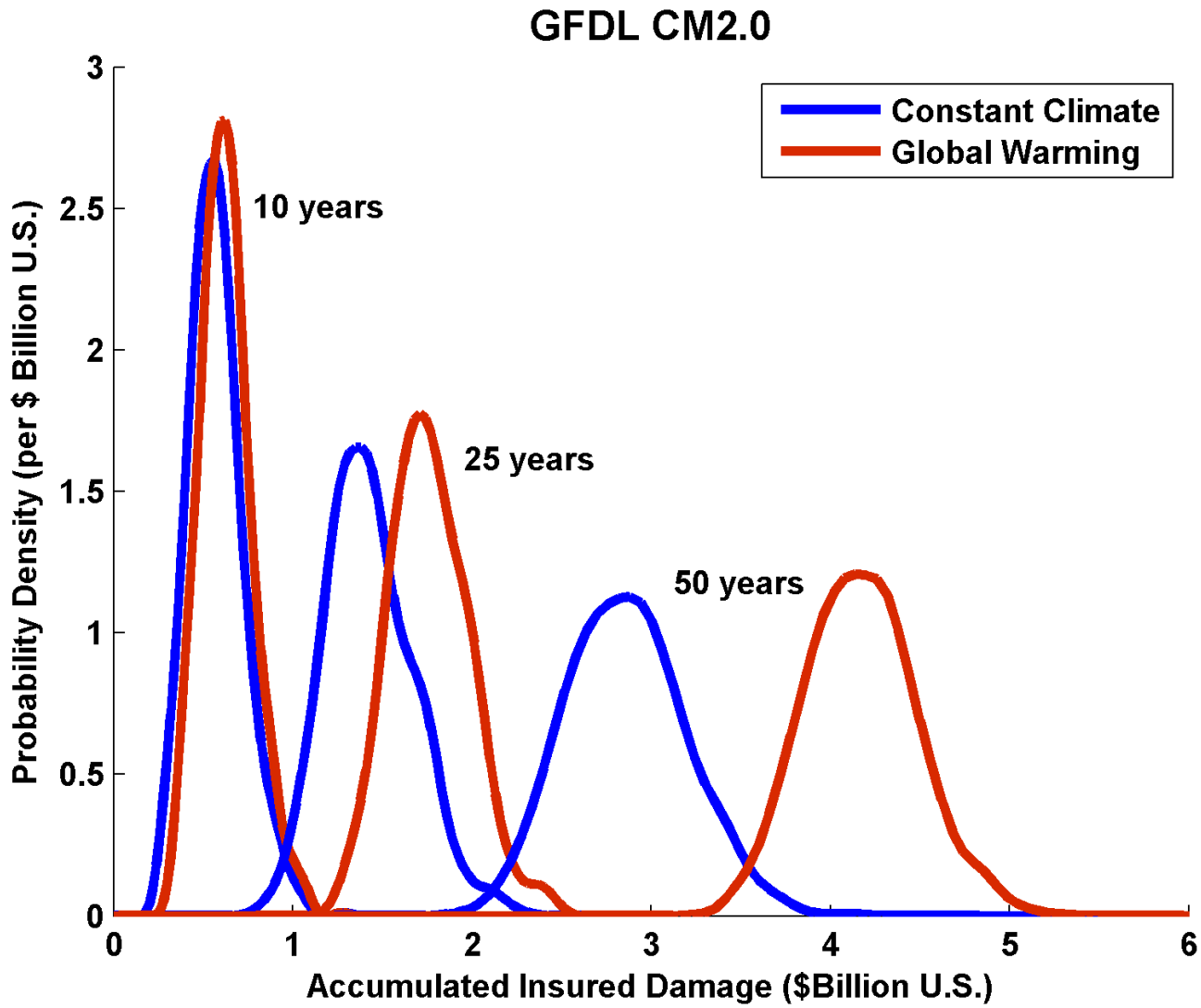

**Black: Current climate (1981-2000)**

**Blue: A1B future climate (2081-2100)**

**Red: A1B future climate (2081-2100) with $R_0$ increased by 10% and $R_m$ increased by 21%**

*Lin et al. (2012)*

# Projections of U.S. Insured Damage




Emanuel, K. A., 2012, *Weather, Climate, and Society*

# Summary

- Global hurricane frequency is stable, and not well understood
- Most destruction in U.S. done by major hurricanes at landfall
- Low numbers:  no possibility of seeing climate signal; no possibility of seasonal forecasting
- Consensus that global warming will increase incidence of high intensity hurricanes, and cause more hurricane-related flooding