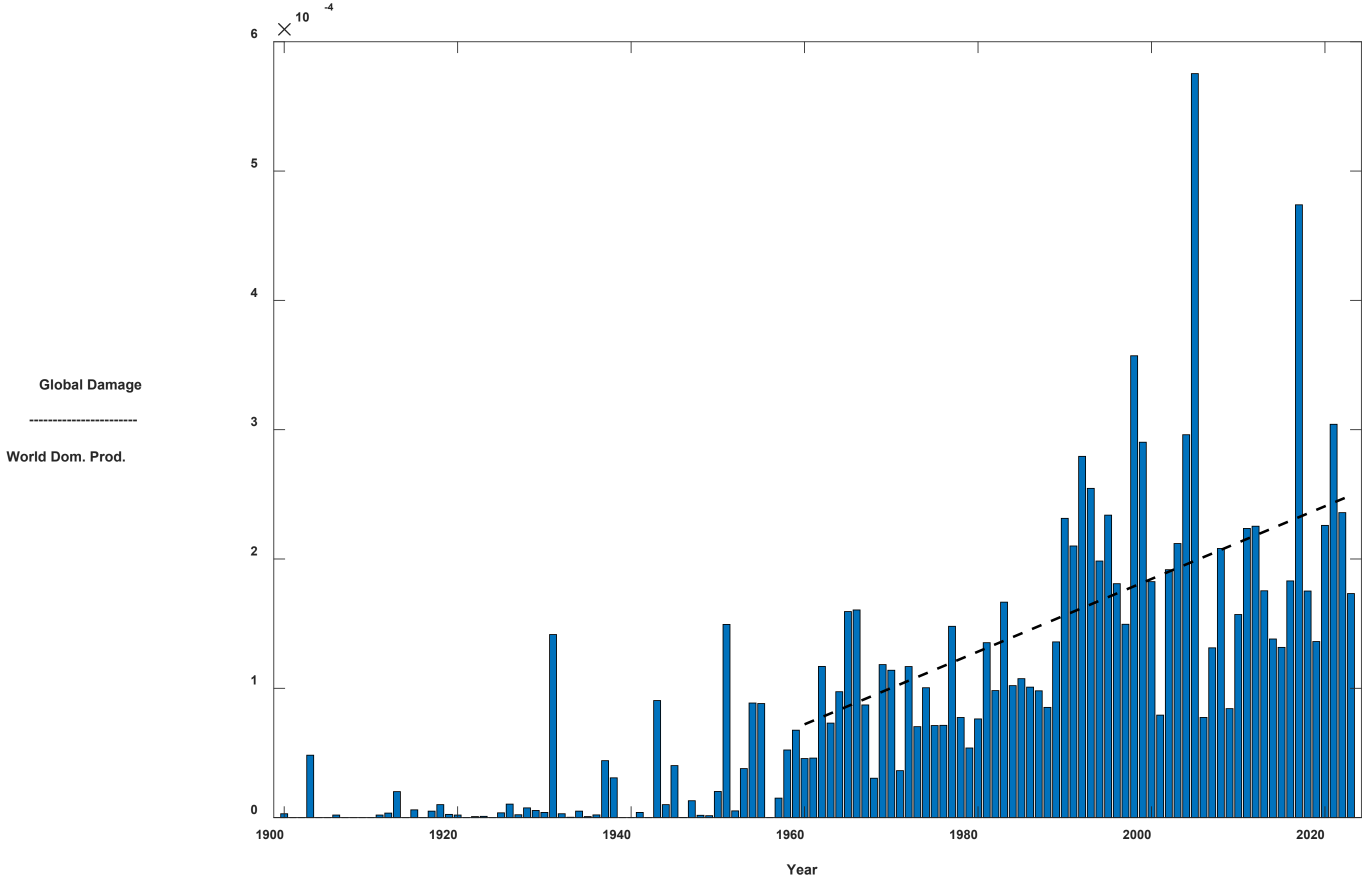
The Changing Tropical Cyclone Risk Landscape

Kerry Emanuel
Lorenz Center
Massachusetts Institute of Technology

Program

- Past trends in TC activity and loss
- The case for using physics, as encoded in numerical models, to quantify TC risk in the current and future climates
- Modeling TC loss: The importance of volatility

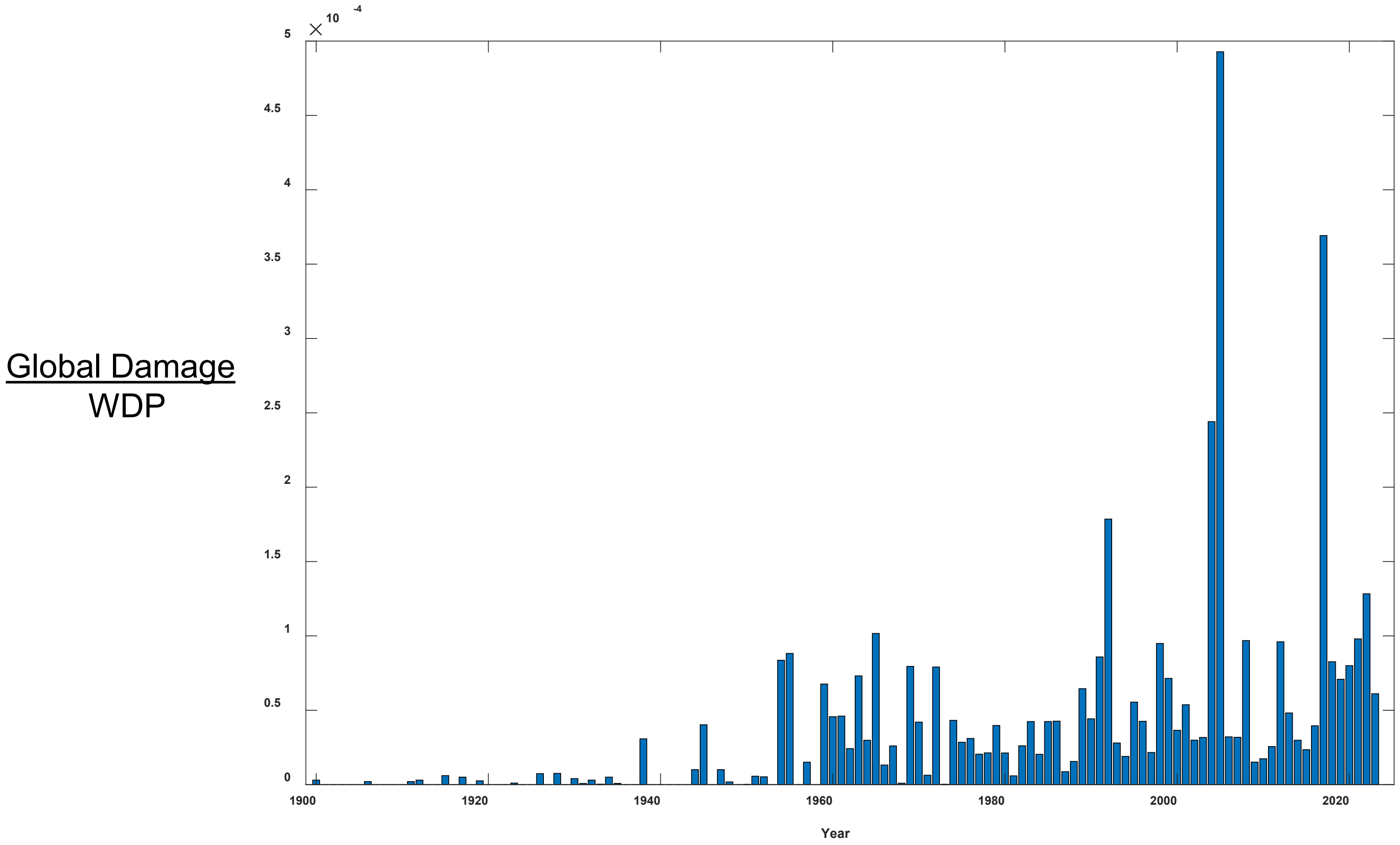
Global Damage Normalized by Gross World Product
Storms, droughts, floods, wildfires



- 270% increase since 1970
- **Population of TC-prone regions increased by ~200%**
- Suggests that climate change *may* have contributed to increasing damage

EM-DAT, 2024: The OFDA/CRED International Disaster Database
http://www.emdat.be/.

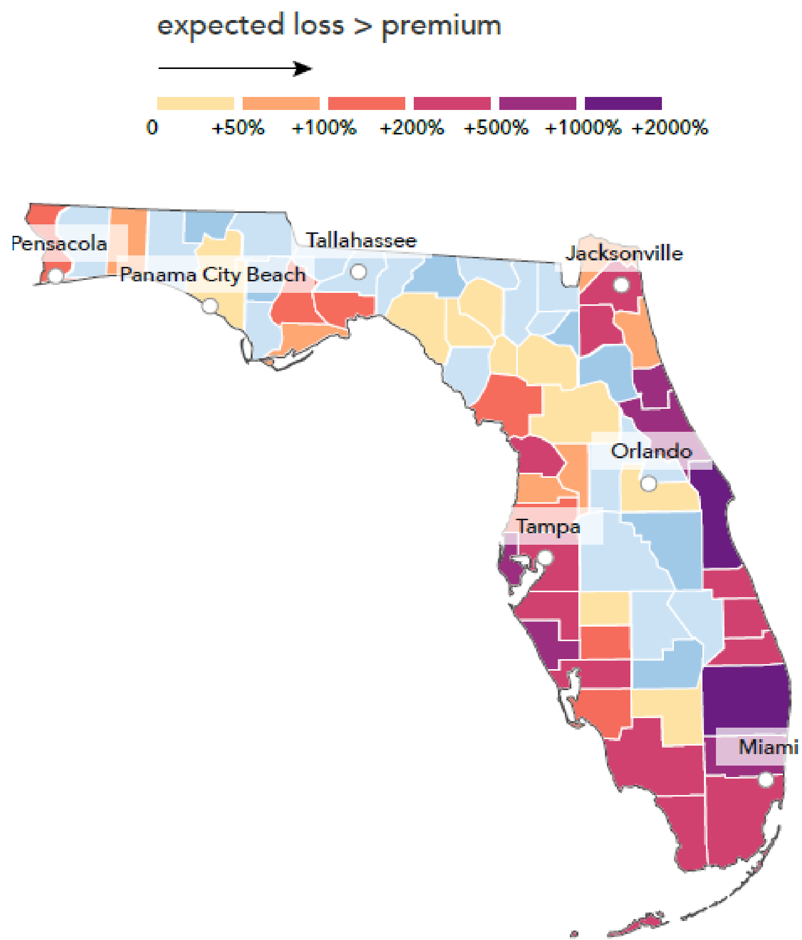
Global Damage Normalized by Gross World Product
Tropical Cyclones



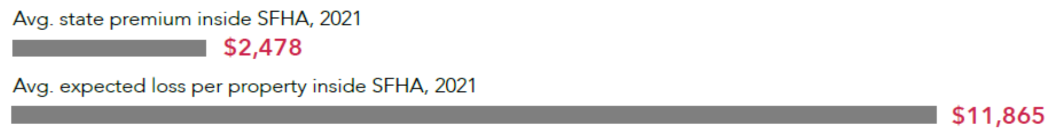
Two trends to contend with:

- Demographic
- Climate Change

Avg. expected loss per property vs avg. premium, all zones, 2021



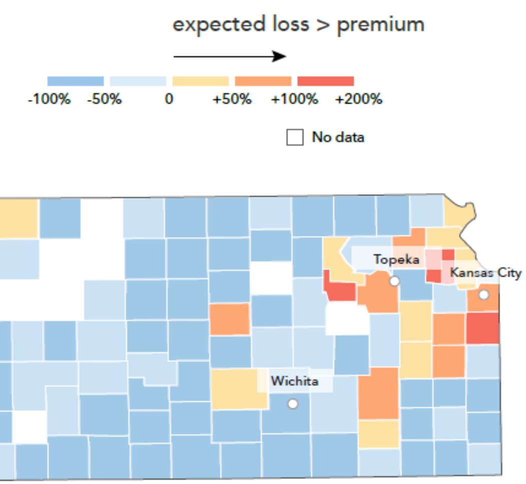
SFHA=special flood hazard area



Whose paying for this?

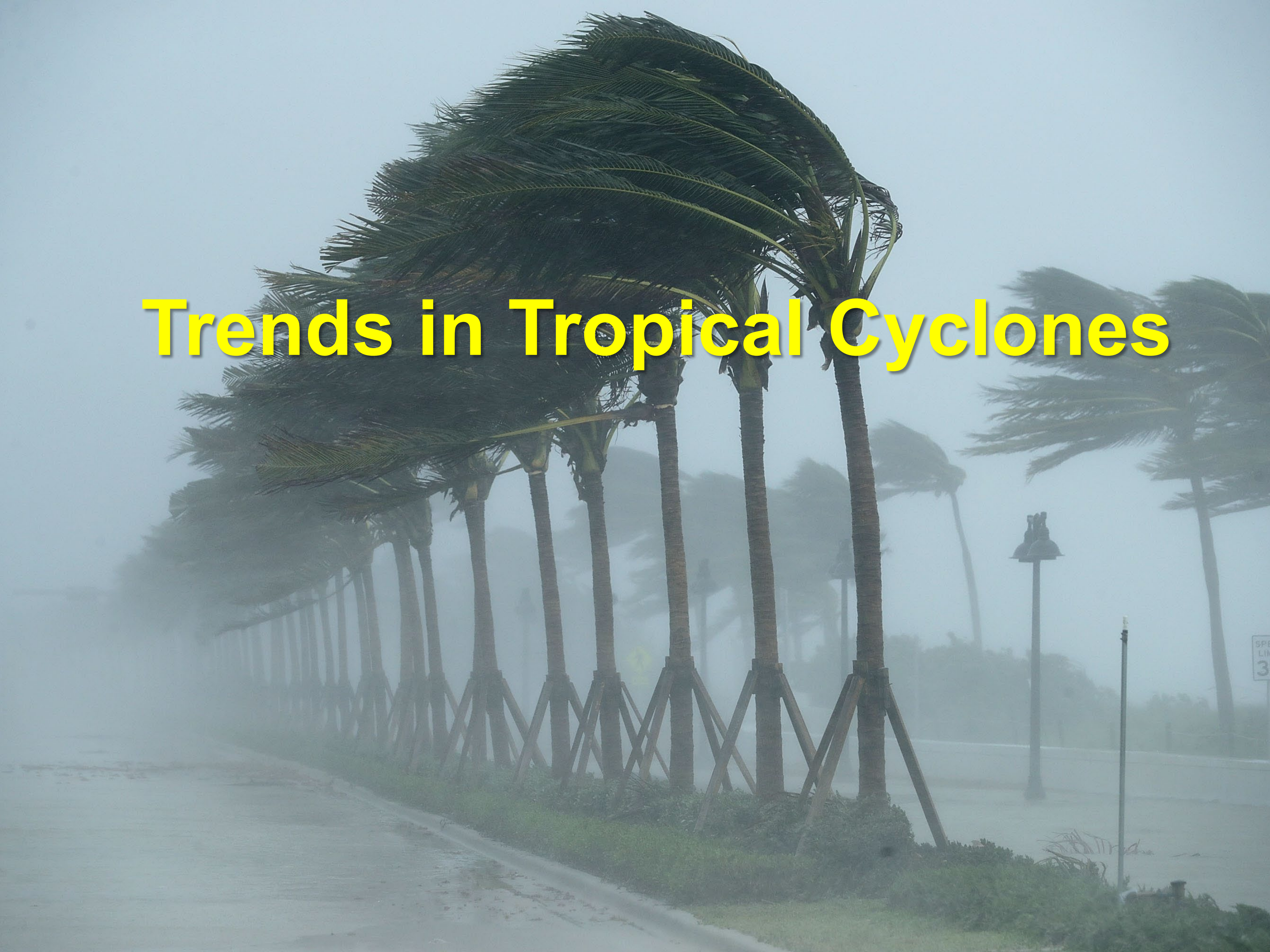
Kansas!

Avg. expected loss per property vs avg. premium, all zones, 2021



Courtesy First Street Foundation

Trends in Tropical Cyclones



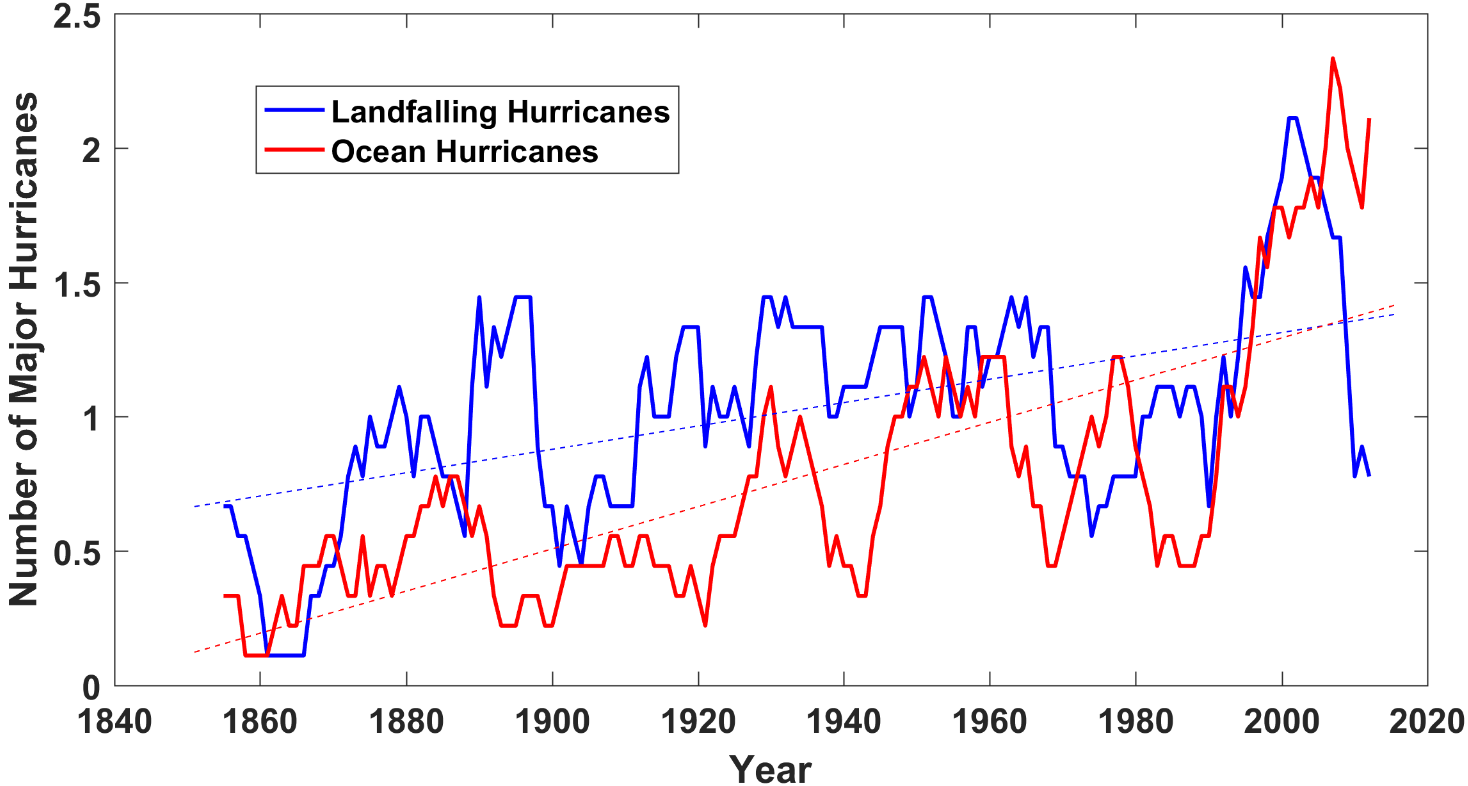
Global Hurricane Records

- Global detection of tropical cyclones dates back to about 1970
- Before 1980, hurricane records outside the Atlantic region are very poor
- Even today, satellite-based estimates of intensity and rain are not of high quality

What Are Atlantic Historical TC Records Based On?

- Pre-1943: Anecdotal accounts from coastal cities and ships
- 1943: Introduction of routine aircraft reconnaissance in Atlantic, western North Pacific
- 1958: Inertial navigation permits quantitative measurement of wind speed at flight level
- 1970: Complete global detection by satellites
- 1978: Introduction of satellite scatterometry

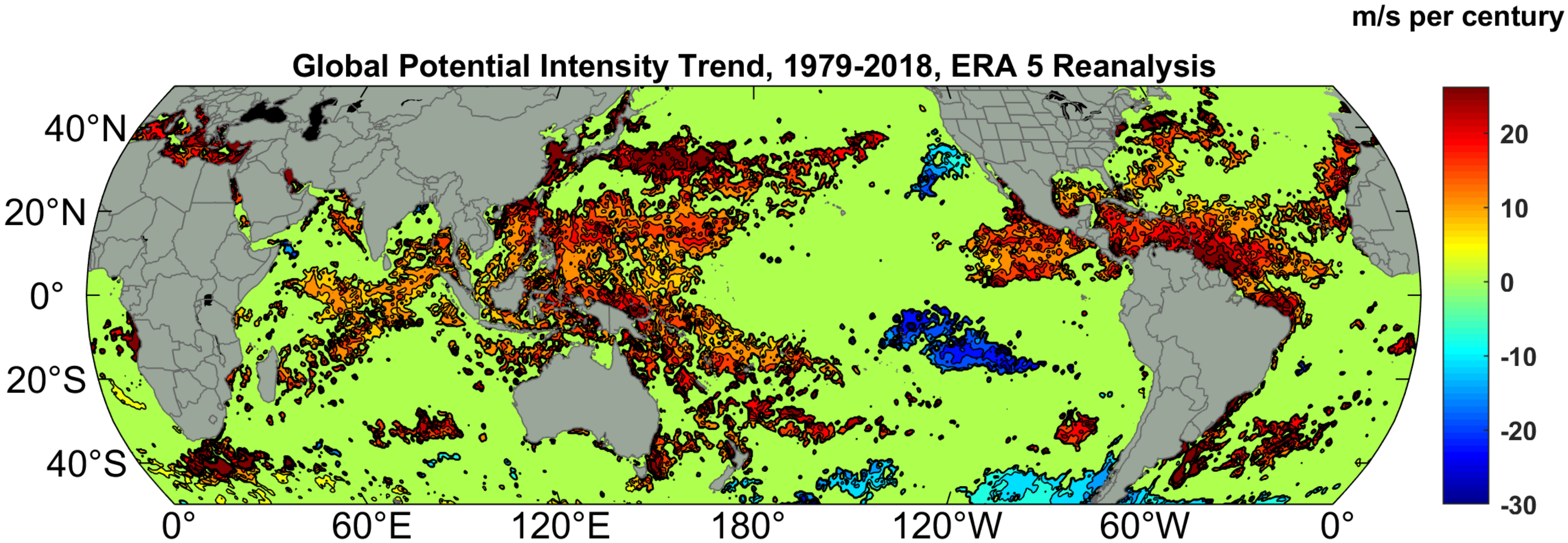
Historical Records:
Prior to ~1970, Many Storms Were Missed



Major hurricanes in the North Atlantic, 1851-2016, smoothed using a 10-year running average. Shown in blue are storms that either passed through the chain of Lesser Antilles or made landfall in the continental U.S.; all other major hurricanes are shown in red. The dashed lines show the best fit trend lines for each data set.

Potential Intensity Trend, 1979-2018, ERA 5 Reanalysis

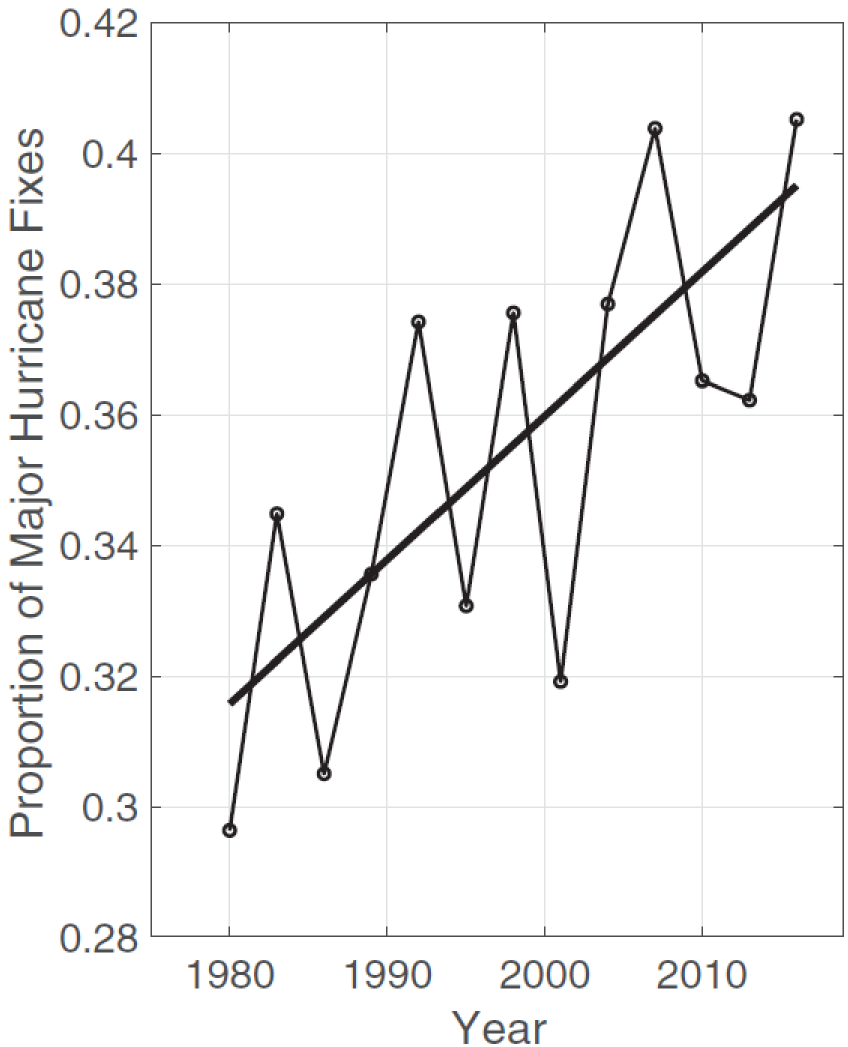
Potential intensity is a thermodynamic upper bound on TC wind speeds, easily calculated from climate data



(Trend shown only where p value < 0.05)

Simple physics suggest that potential intensity should increase by 15-20% per doubling of CO_2 (result published in *Nature* in 1987)

Satellite-derived proportion of major hurricane fixes



Time series of fractional proportion of global major hurricane estimates to all hurricane estimates for the period 1979–2017. Each point, except the earliest, represents the data in a sequence of 3-y periods. The first data point is based on only 2 y (1979 and 1981) to avoid the years with no eastern hemisphere coverage. The linear Theil−Sen trend (black line) is significant at the 98% confidence level (Mann−Kendall P value = 0.02). The proportion increases by 25% in the 39-y period (about 6% per decade).

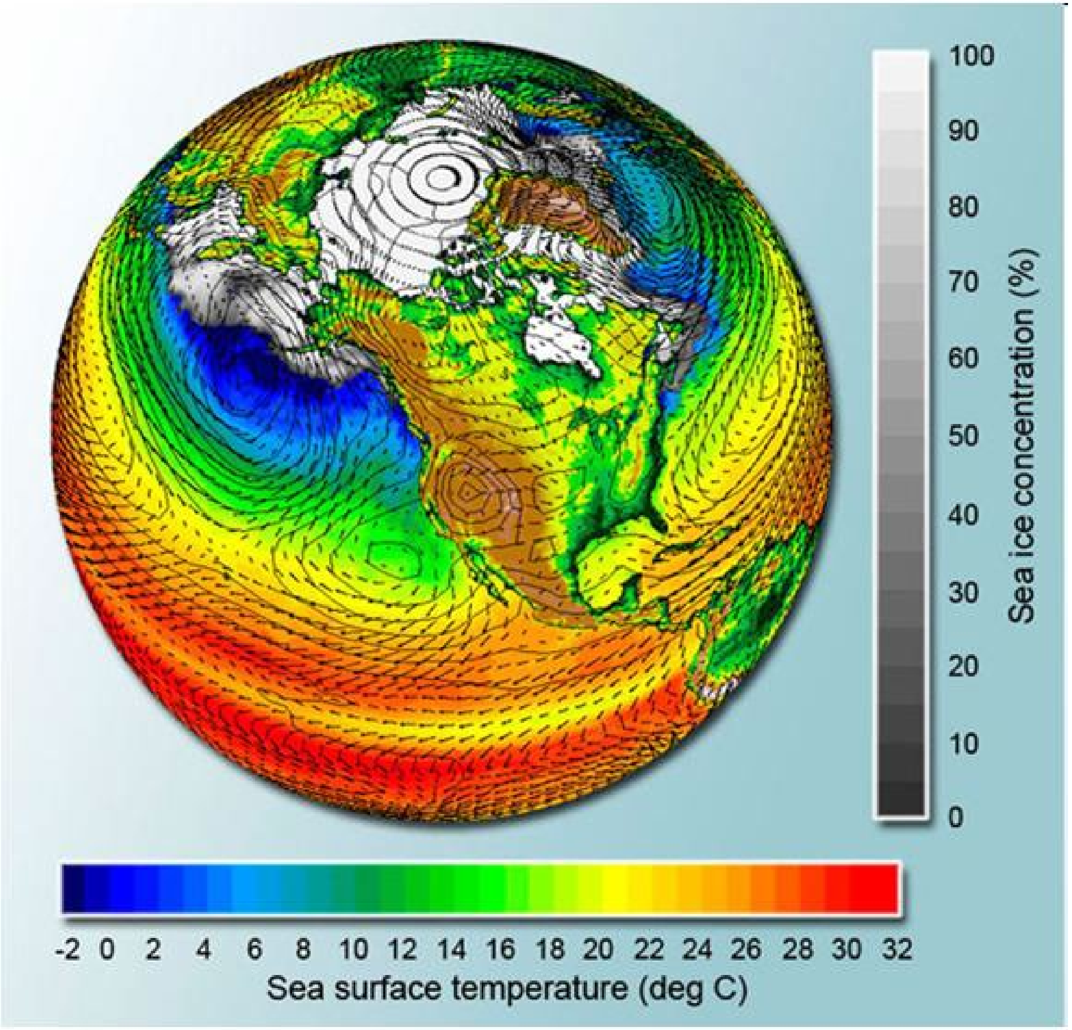
Kossin et al., *PNAS*, 2020

Flawed Basis of Current Risk Modeling

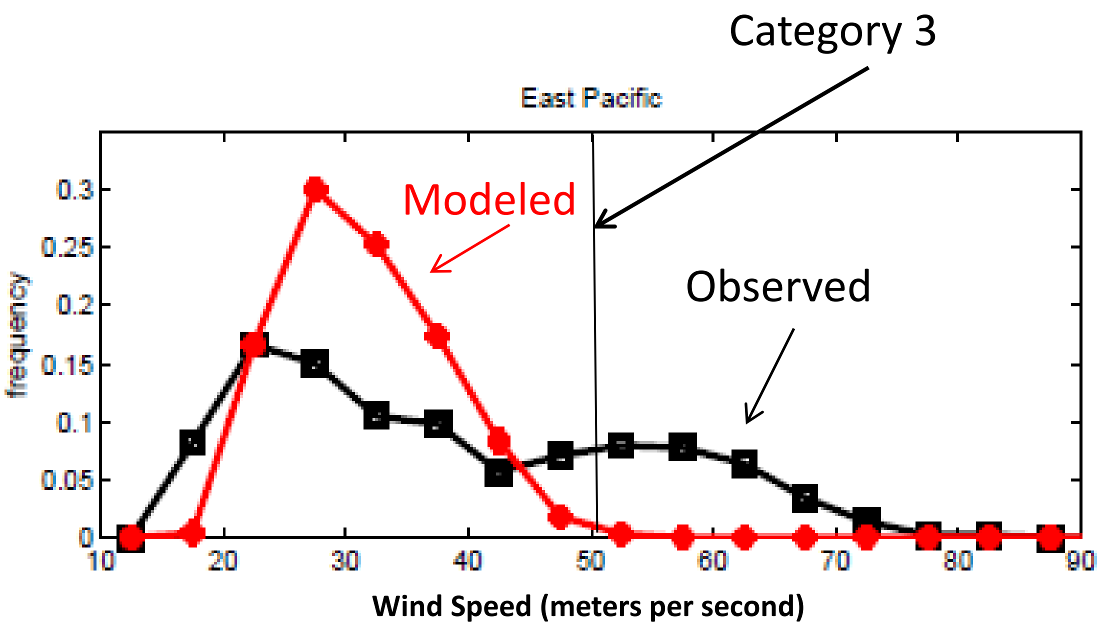
- Most current risk assessments are based on historical statistics
- Historical records are flawed and too short
- Moreover, **the past 50-150 years is a poor guide to the present owing to climate change that *has already occurred***
- **We need to bring physics to bear on weather hazard risk**
- Climate and weather researchers are getting more involved in physical modeling of risk
- Government and the insurance/reinsurance industries should encourage this development

Applying Physics to Risk

Global climate models can potentially simulate droughts and heatwaves…..



…. but are far too coarse to simulate, e.g., destructive hurricanes



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

Detailed, high-resolution modeling suggests grid spacing of no more than 3 km required

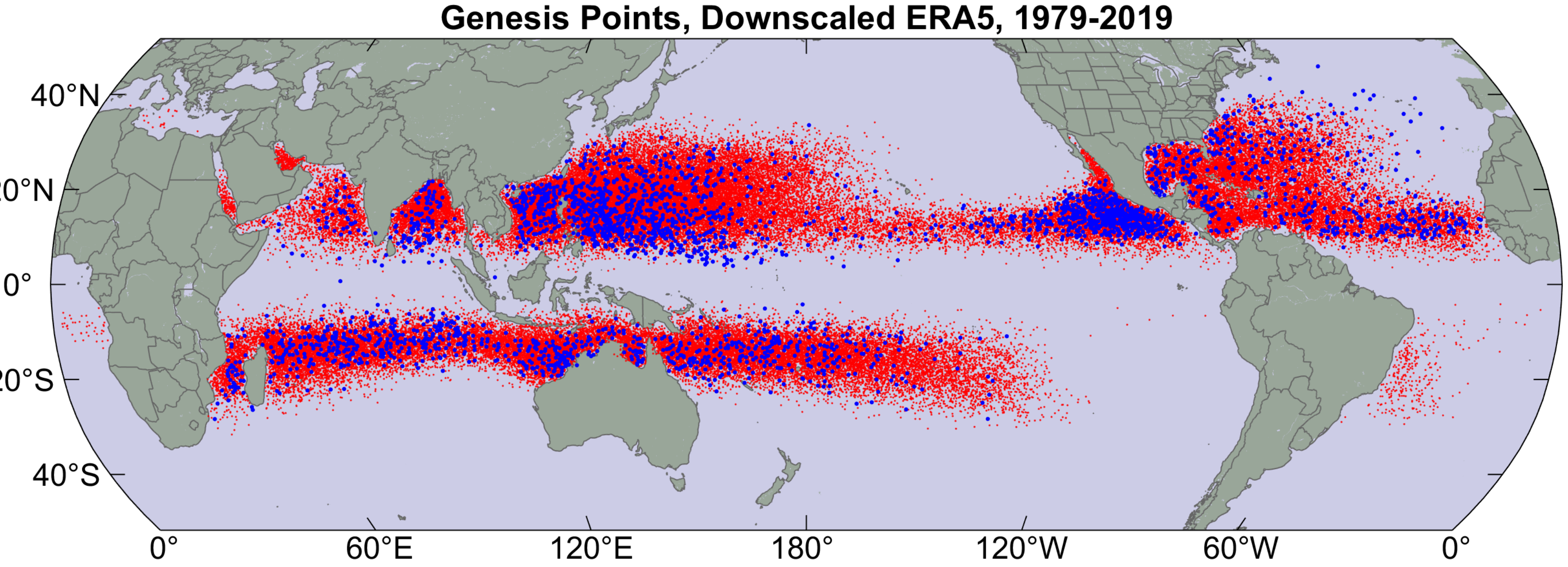
HighResMip: Grid spacings of 20-200 km (NICAM has short run at 14 km)

We need high resolution ***and*** O(1000 yr) simulations

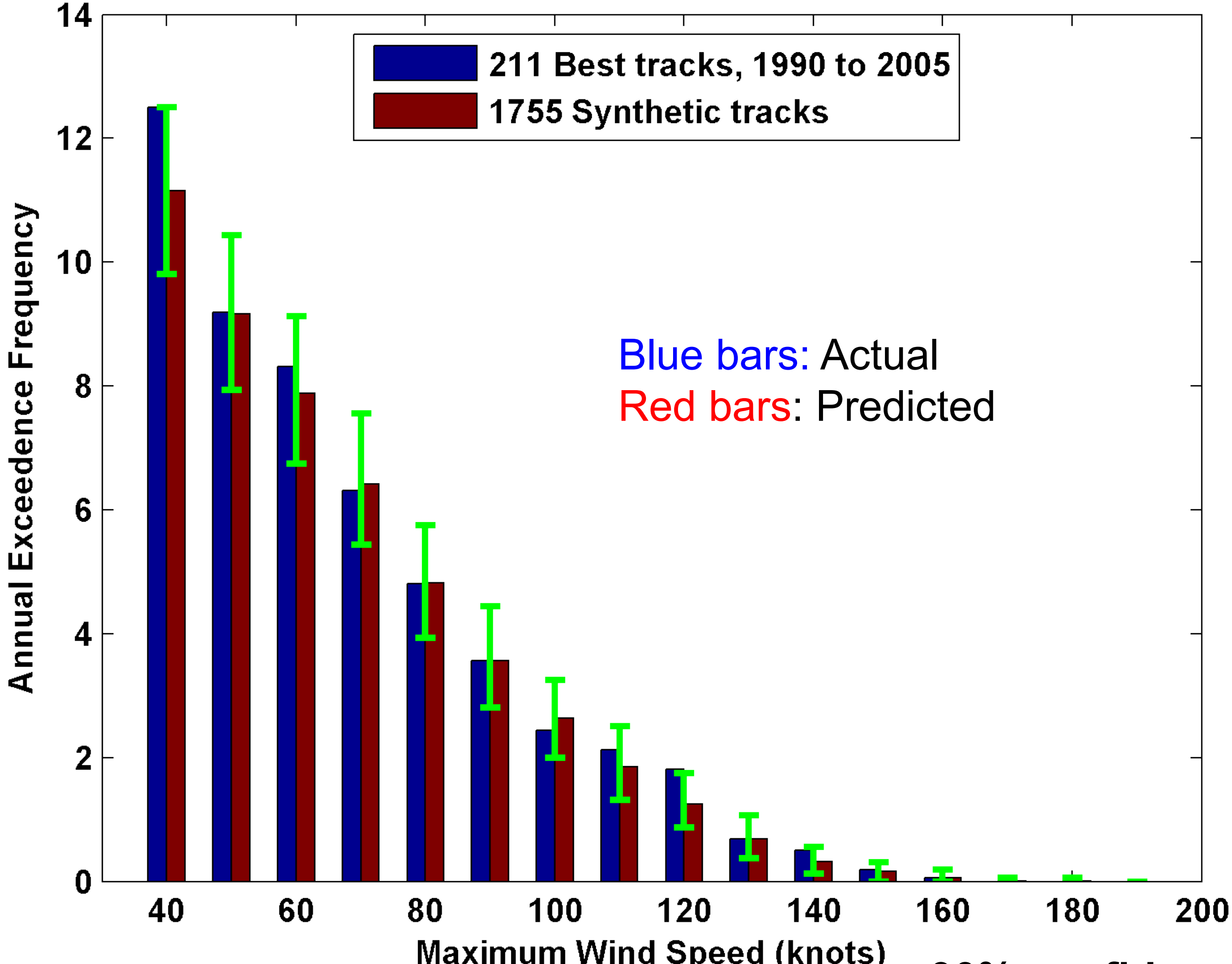
Using Physics to Assess Hurricane Risk (Downscaling)

- Reliable, global records of coarse-scale climate are robust and widely available
- Cull from these datasets the key statistics known to control tropical cyclone generation, movement, and intensity evolution
- Bootstrap these key statistic to create unlimited synthetic time series of the hurricane-relevant environmental variables
- Use these to drive specialized, very high resolution *physical hurricane models* (algorithms for solving governing equations)
- Extensively evaluate the results against historical hurricane data
- Exact same method can be applied to output of climate models

Origin points of successful seeds (red); observed genesis locations (blue)

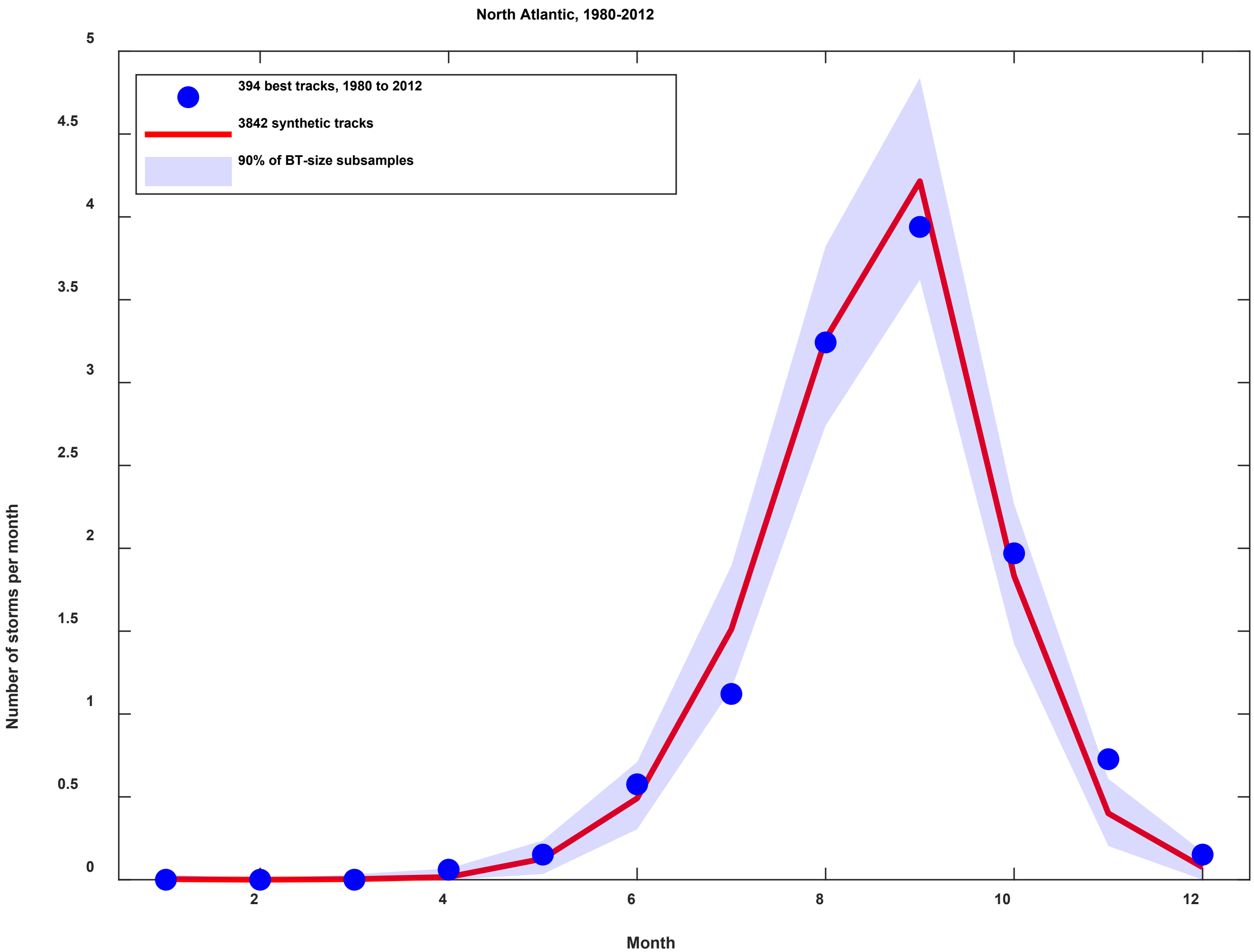


Cumulative Distribution of Storm Lifetime Peak Wind Speed, with Sample of 1755 Synthetic Tracks

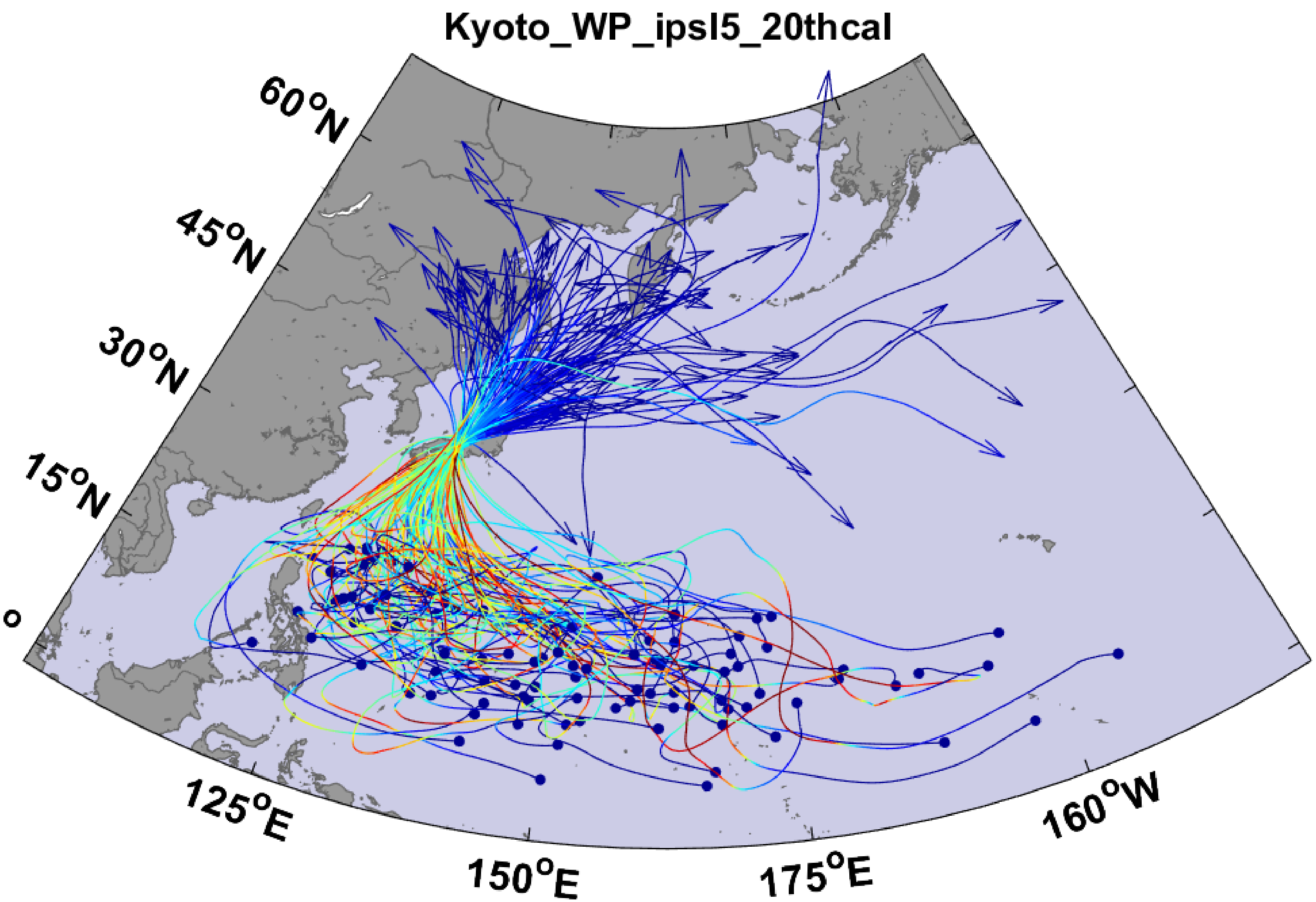


90% confidence bounds

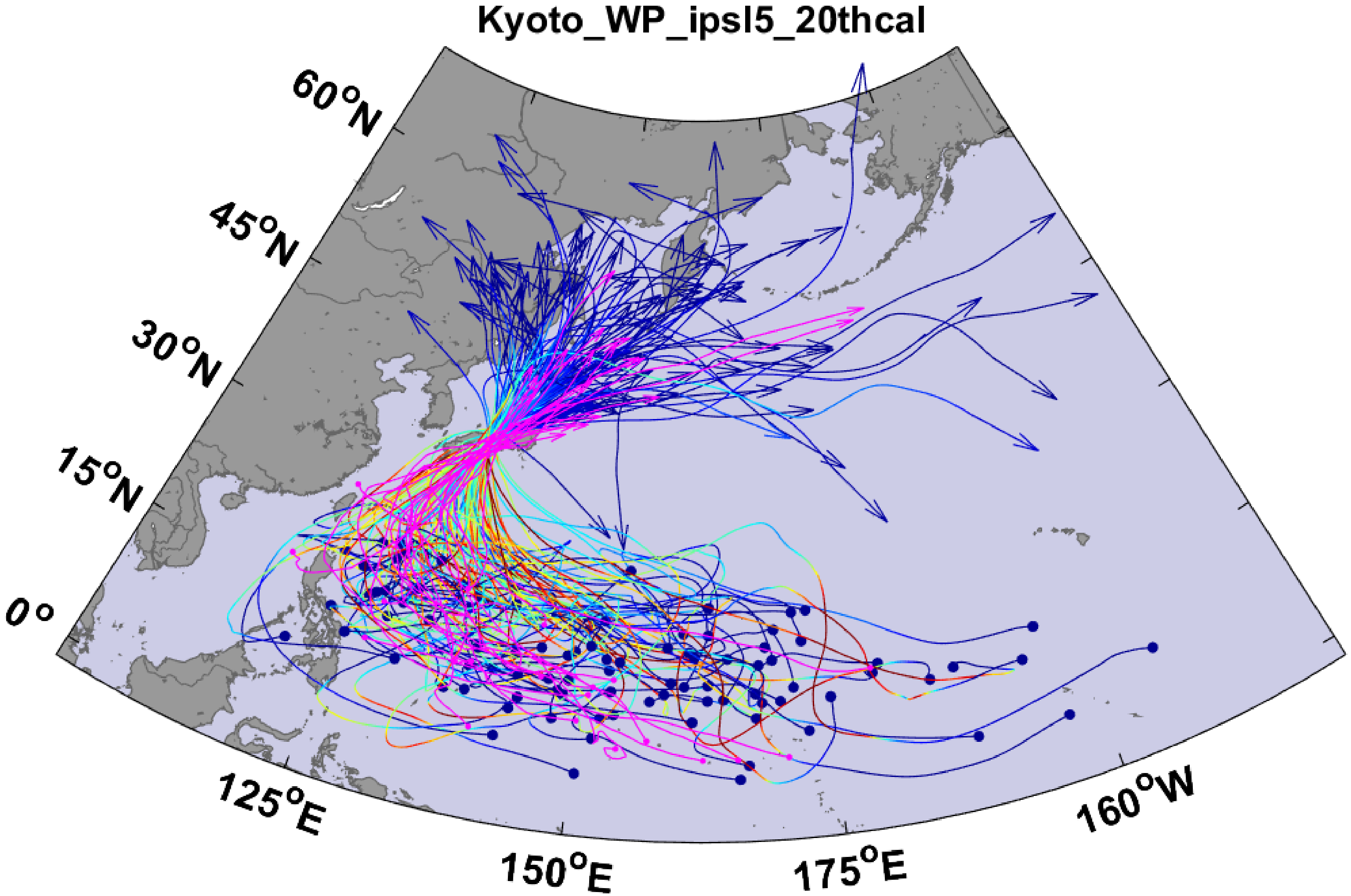
Atlantic Annual Cycle



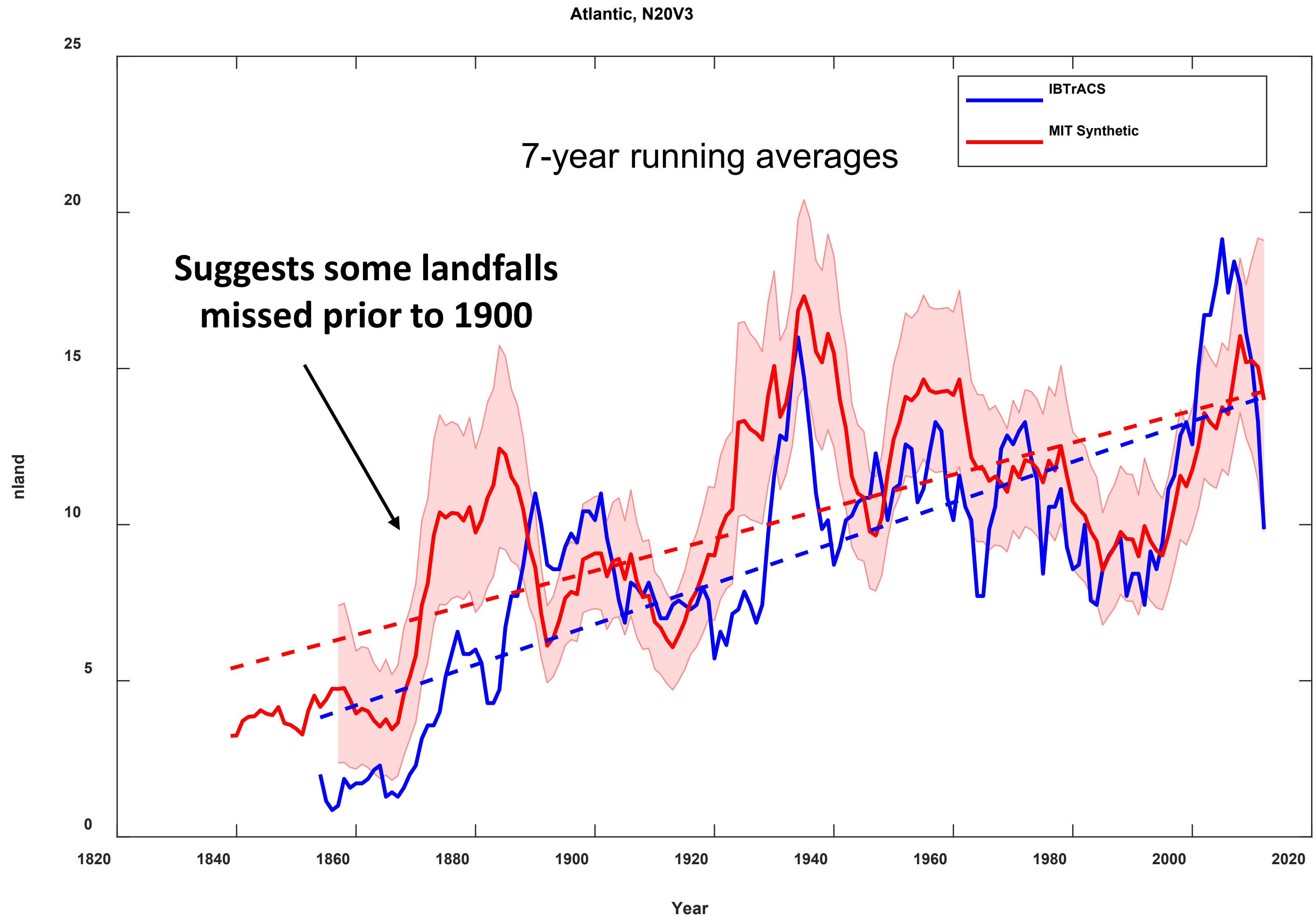
Example:
Top 100 out of 2000 TCs Affecting Kyoto, 1981-2000



Same, but with top 20 historical tracks

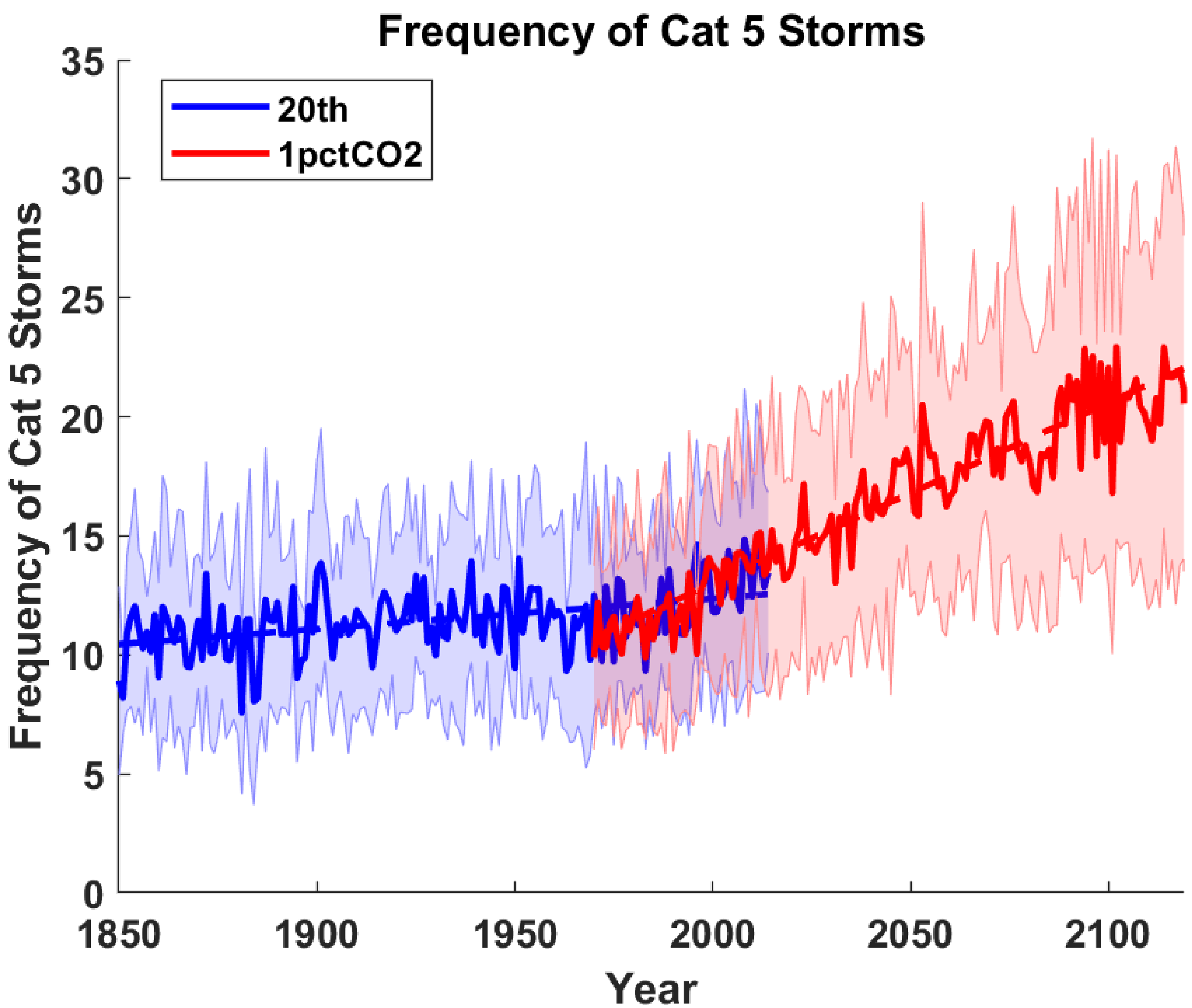


All Landfalls, NOAA 20th Century v.3

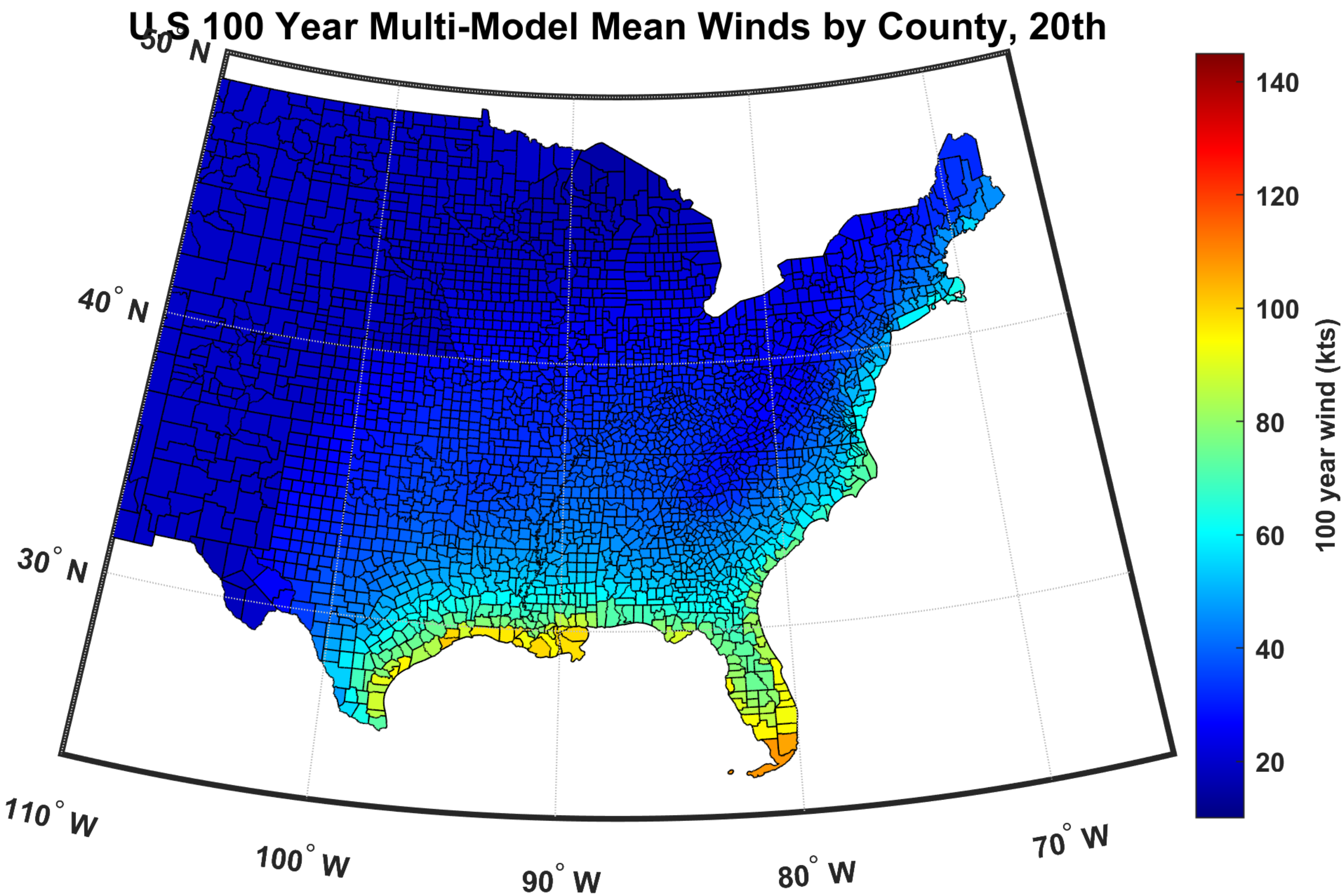


Application to Global Climate Change Simulations:

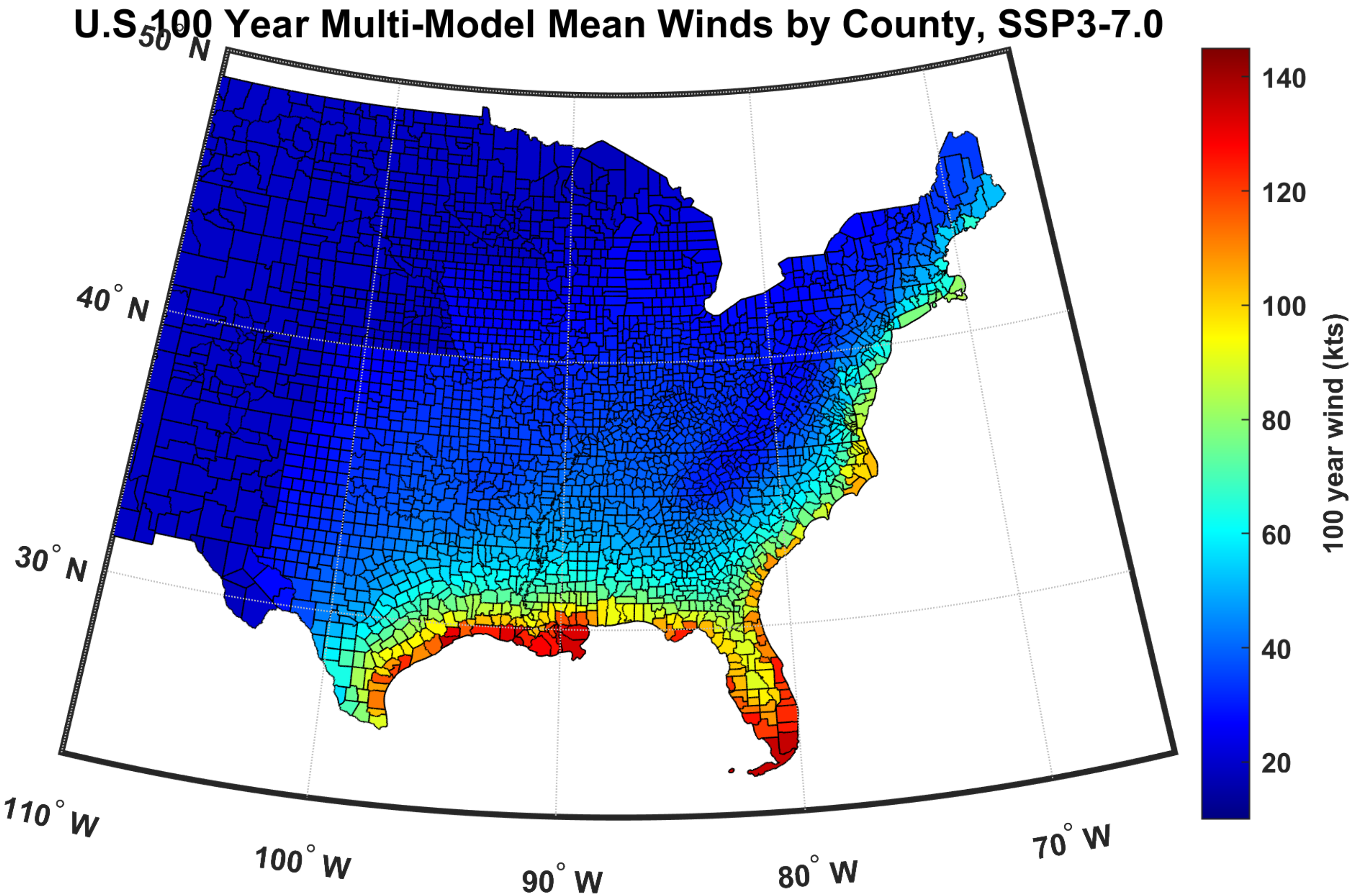
Global CAT 5 Tropical Cyclone Frequency from 8 Current Generation (CMIP6) Climate Models



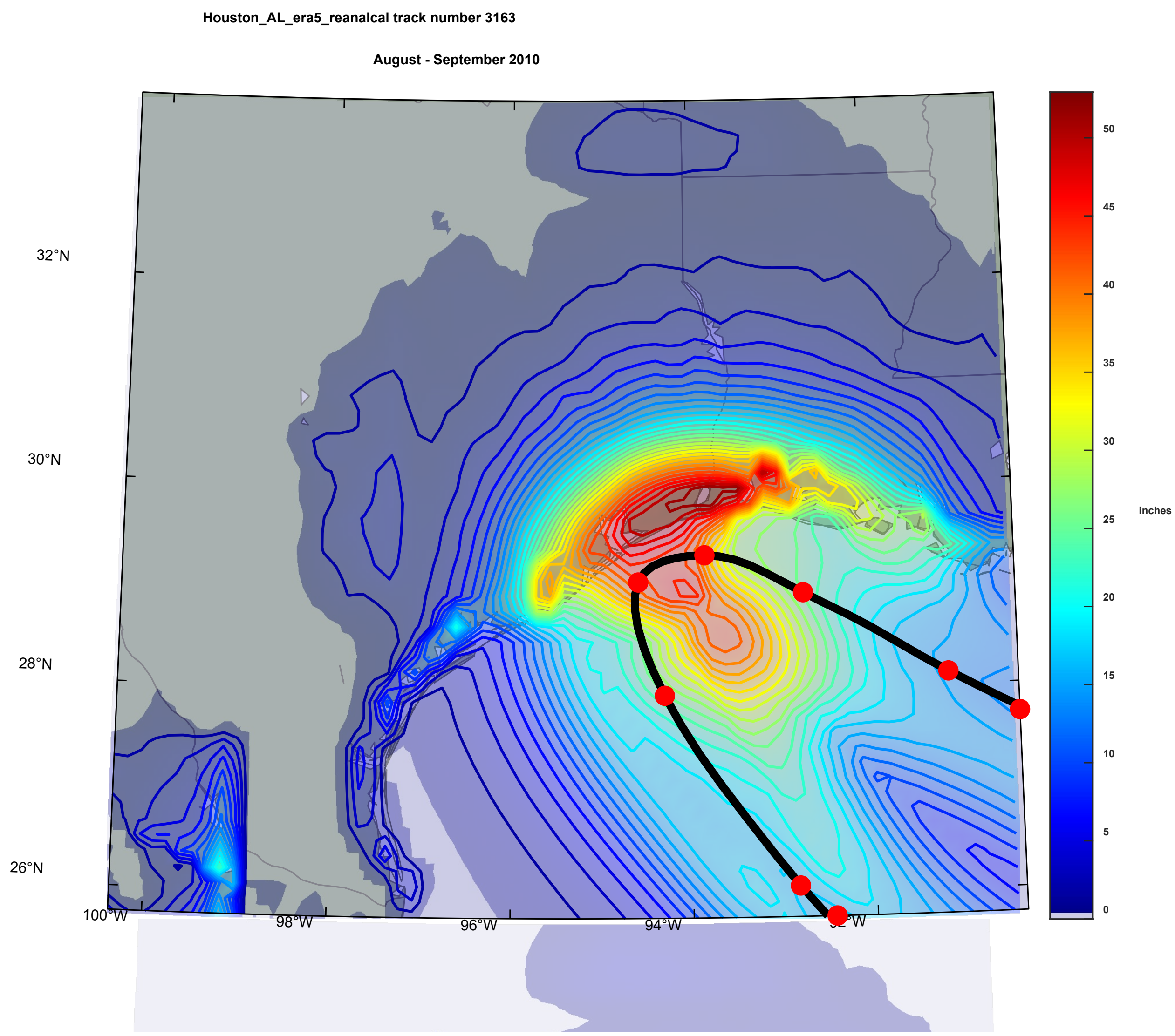
100-year hurricane peak wind based on downscaling 8 CMIP6 climate models, 1984-2014



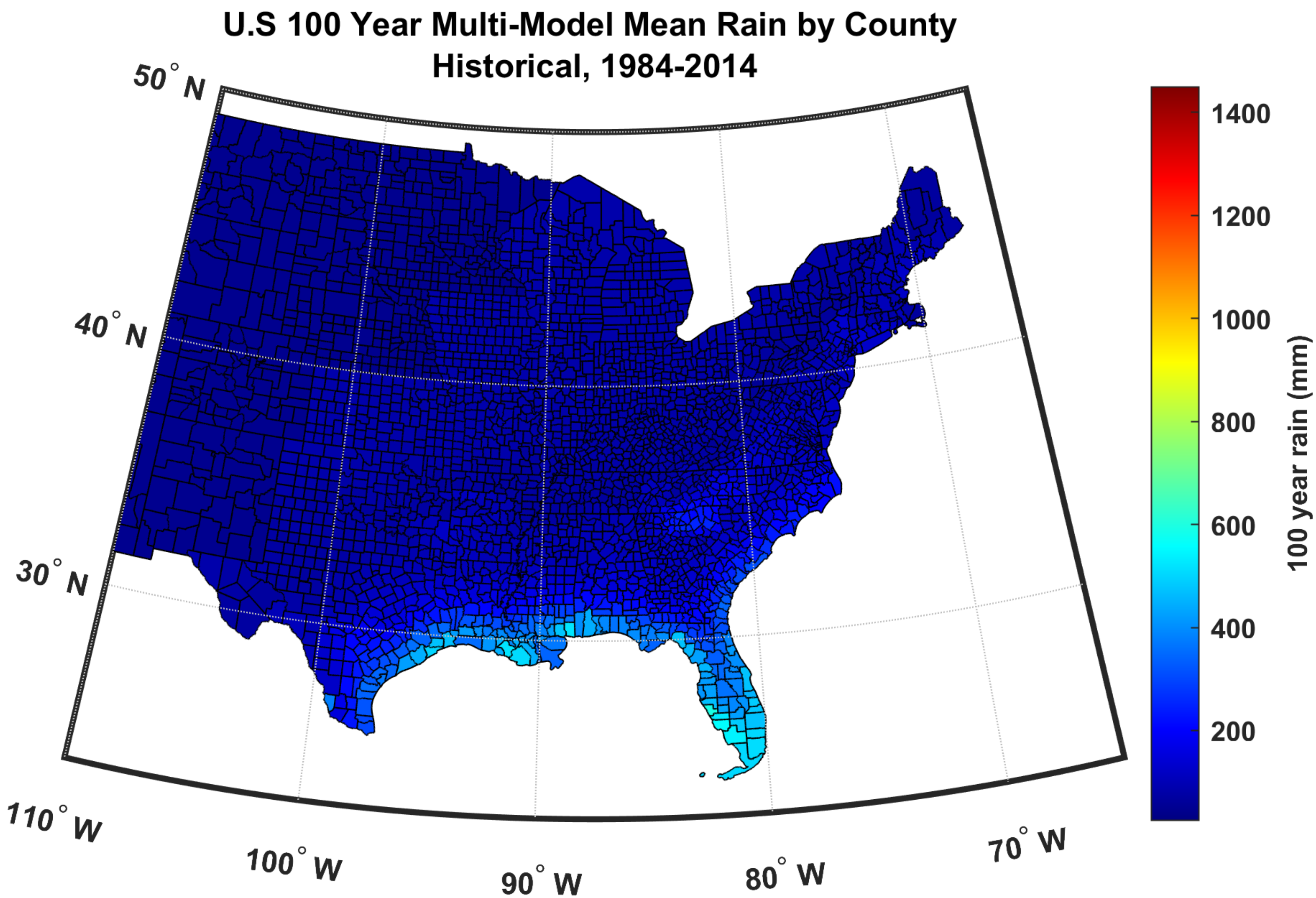
100-year hurricane peak wind based on downscaling 8 CMIP6 climate models, 2070-2100



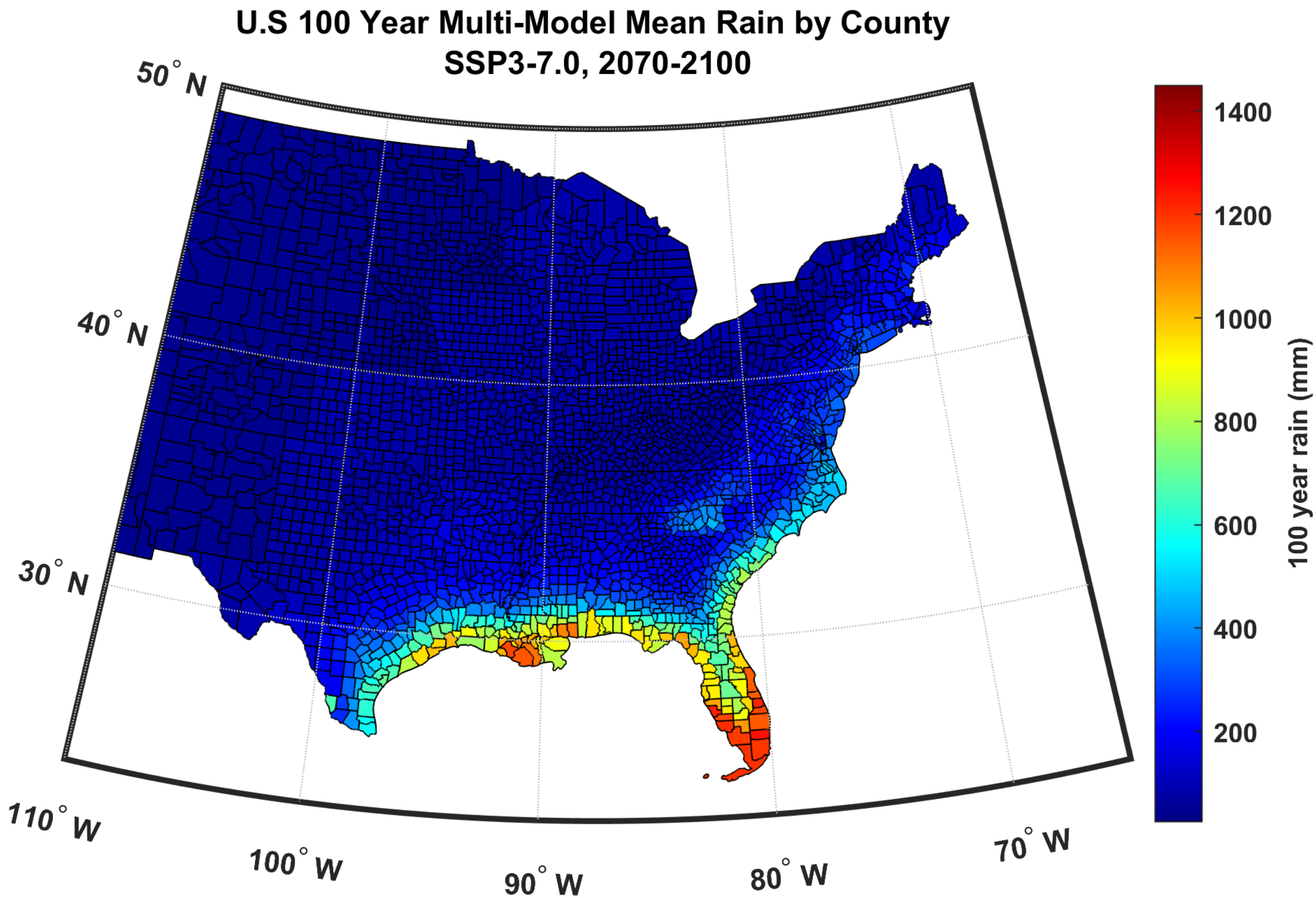
2,000 year rain event for Houston

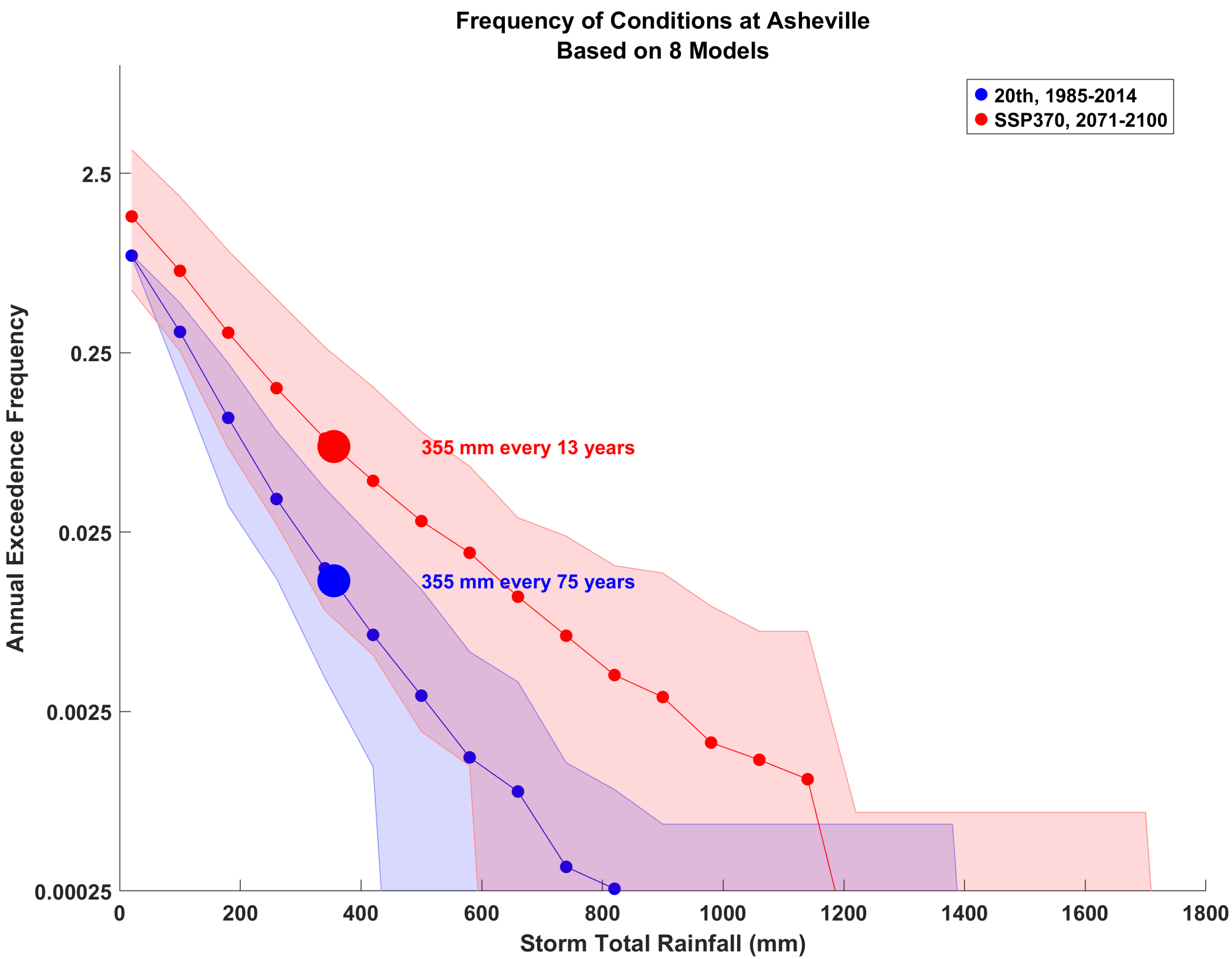


100-year hurricane storm total rain based on downscaling 8 climate models, 1984-2014

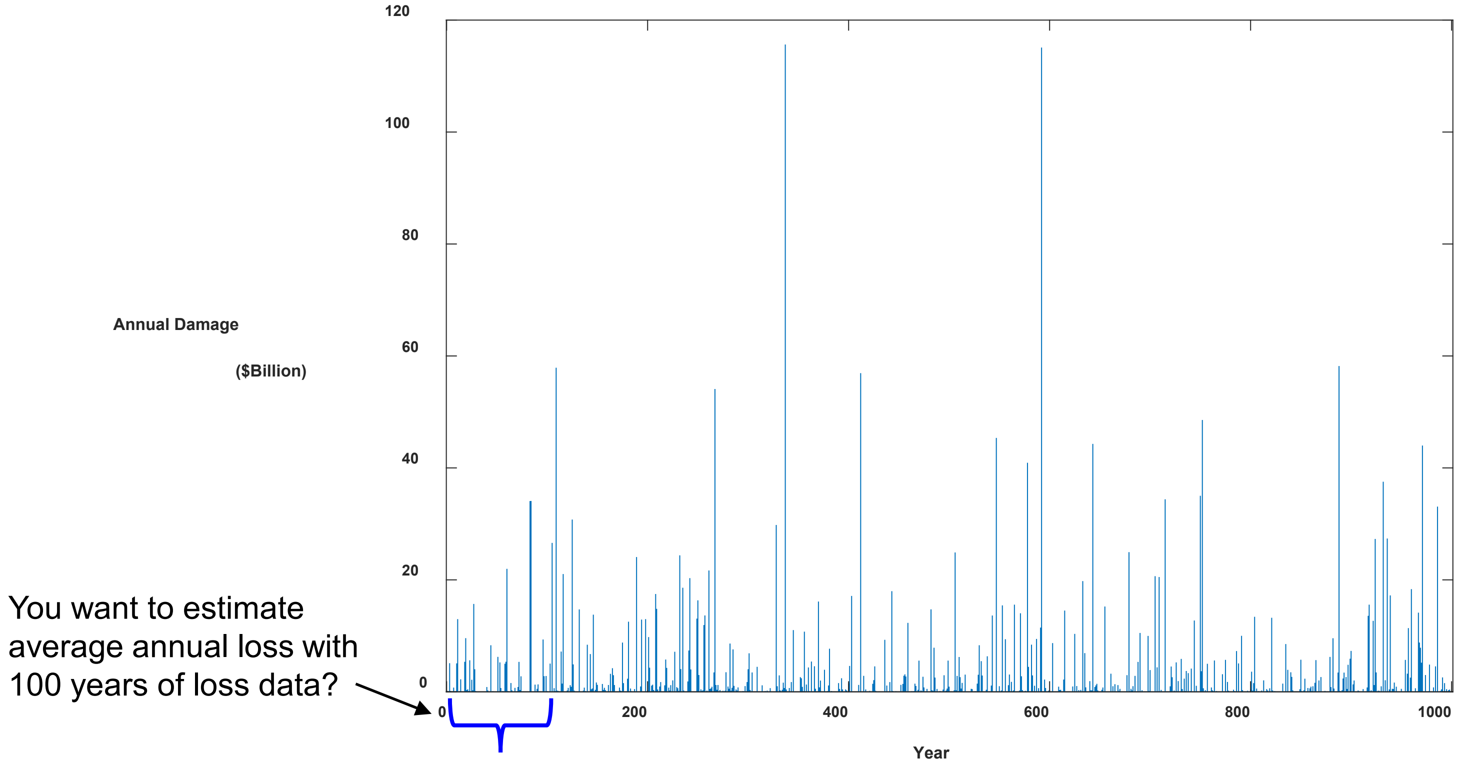


100-year hurricane storm total rain based on downscaling 8 climate models, 2070-2100




Frequency of Conditions at Asheville
Based on 8 Models
20th, 1985-2014
SSP370, 2071-2100
355 mm every 13 years
355 mm every 75 years
Annual Exceedence Frequency
2.5
0.25
0.025
0.0025
0.00025
0
200
400
600
800
1000
1200
1400
1600
1800
Storm Total Rainfall (mm)

Use very large set of synthetic hurricanes to construct many 1,000-year times series of wind damage to a portfolio of properties in coastal U.S. valued at $1.8 trillion. (Here is 1 out of 10,000 such series:)

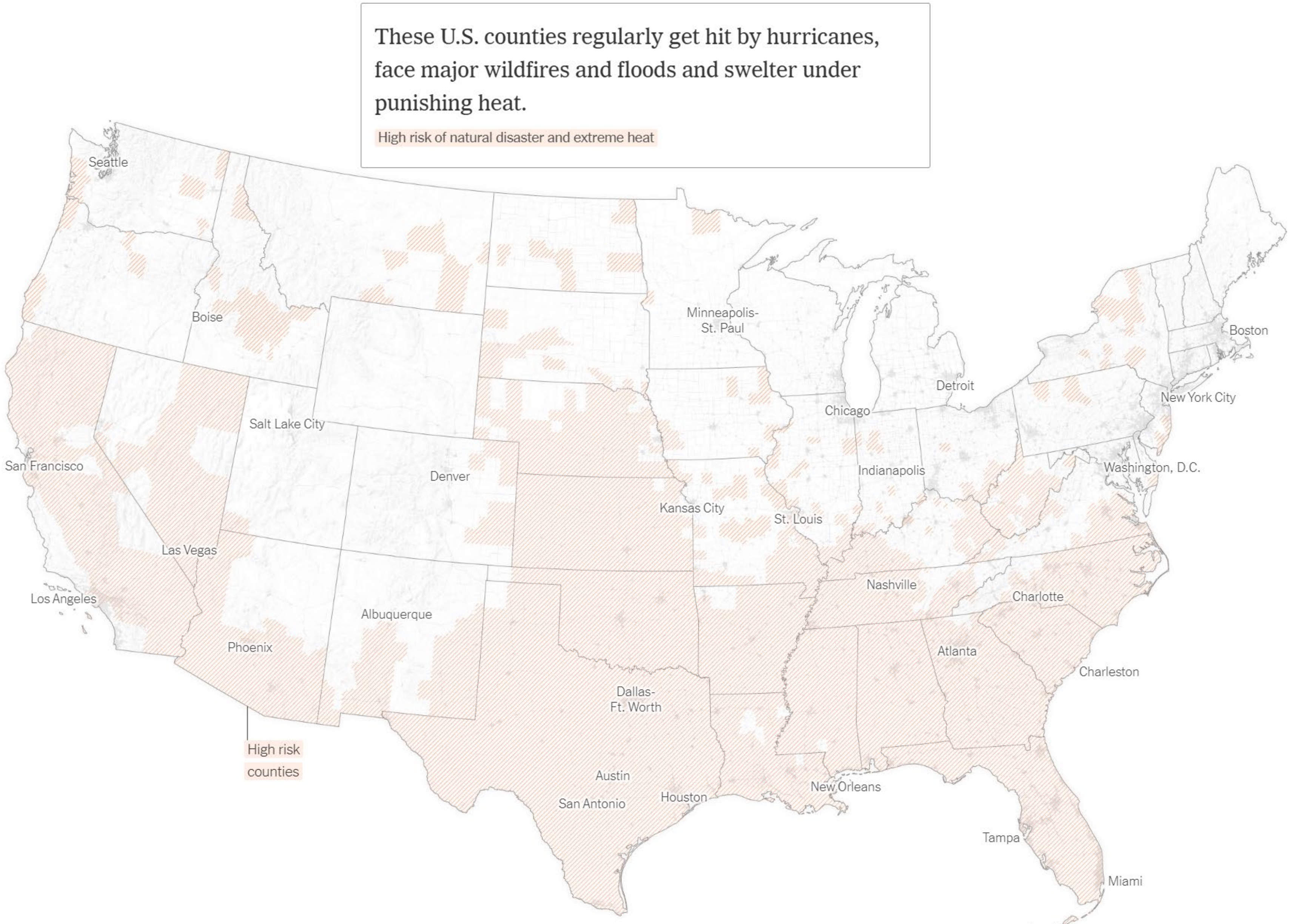


- Even with this very large portfolio, volatility masks any plausible climate change signal for at least 50 years
- Climate signals in loss data over the past 50 years are almost certainly not detectable

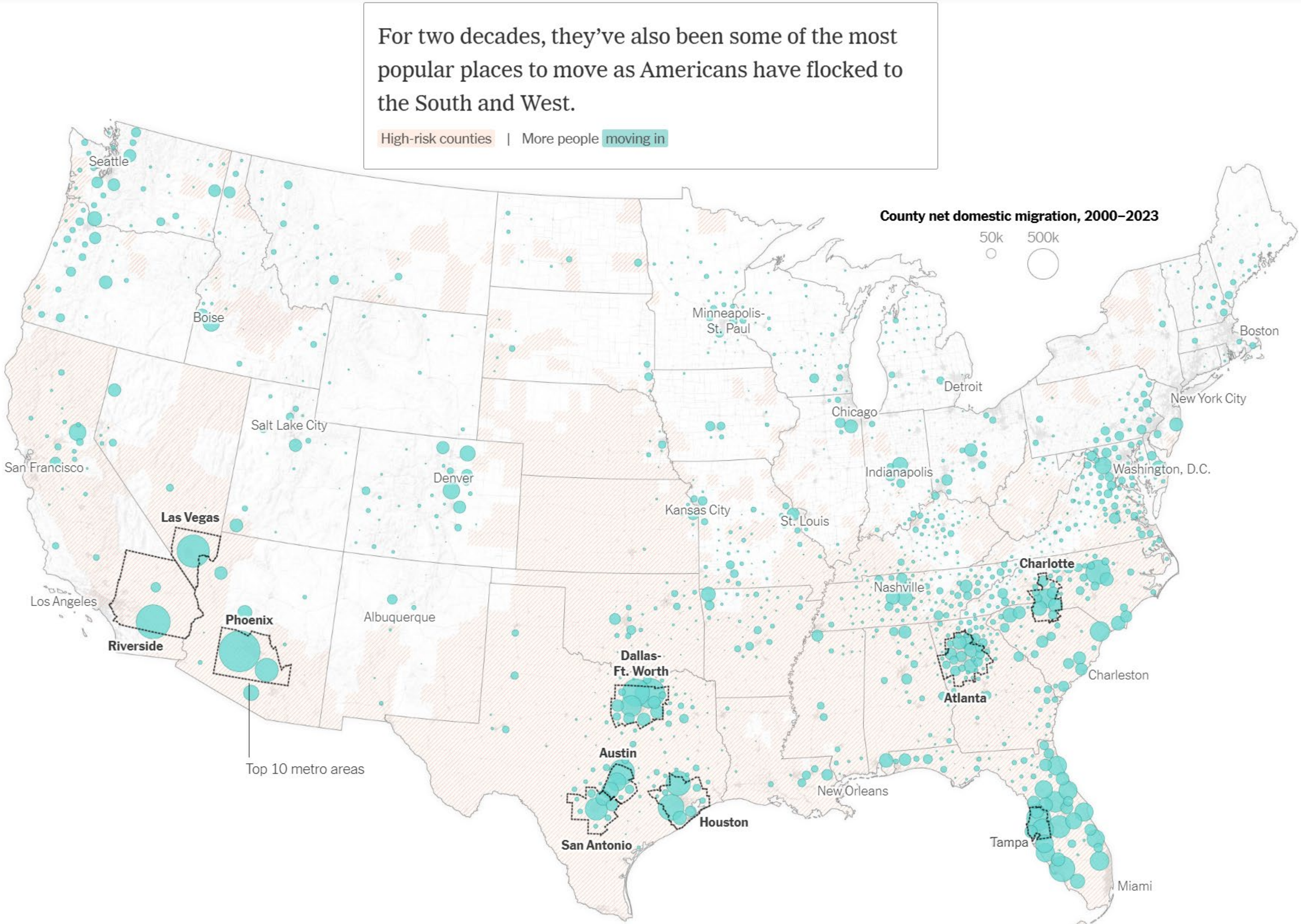
Summary

- Historical hurricane and loss records are not fit for purpose in estimating current risk
- Atmospheric and climate modelers are starting to apply physics-based models to natural hazard risk
- These models generally show rising risk in response to climate change, especially hurricane-induced flood risk
- Annual hurricane wind losses, even over all of the U.S., are extremely volatile

Spare Slides



Source: New York Times



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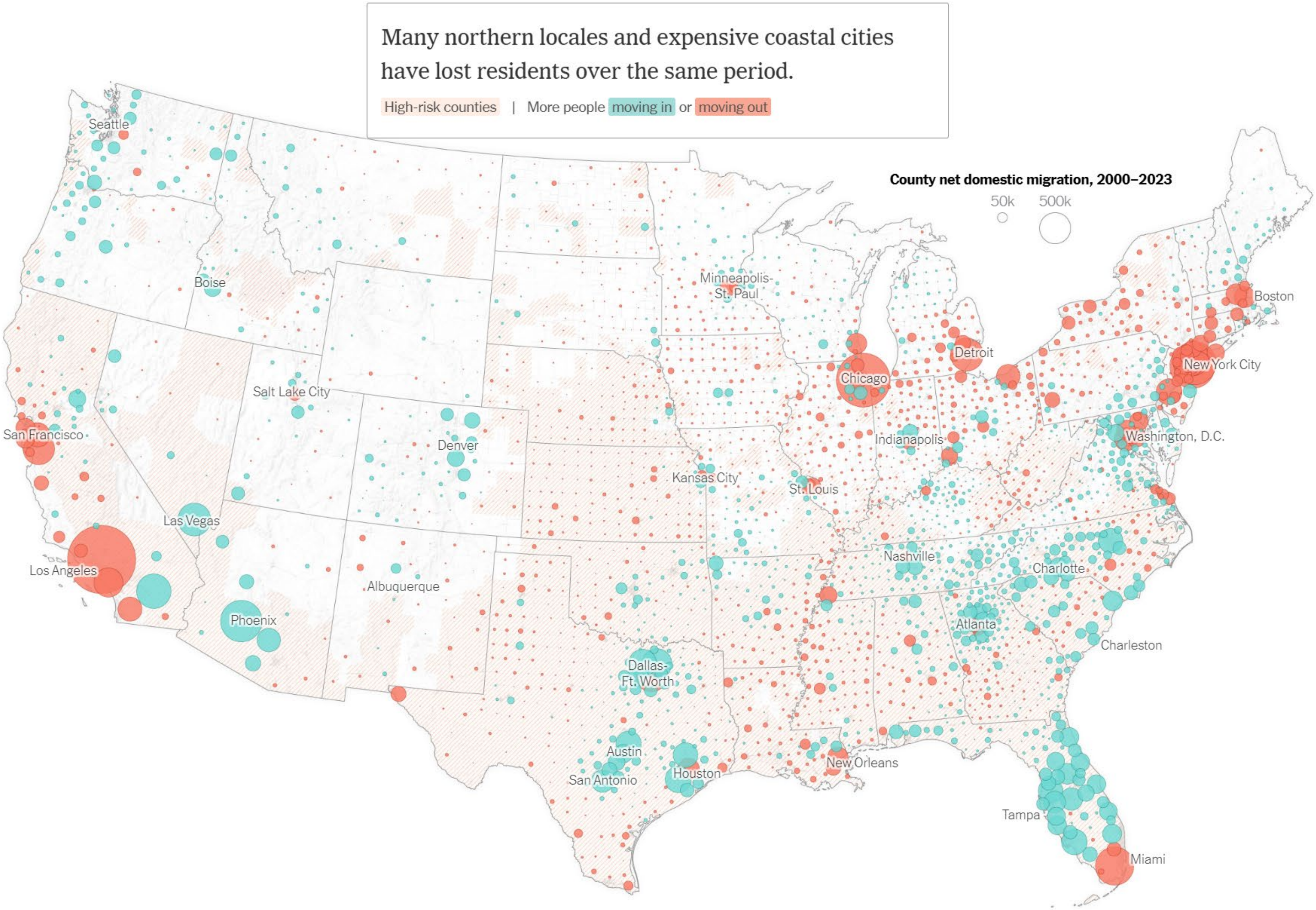

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