The Hurricanes of 2017: Weather as Usual or an Ominous Sign?

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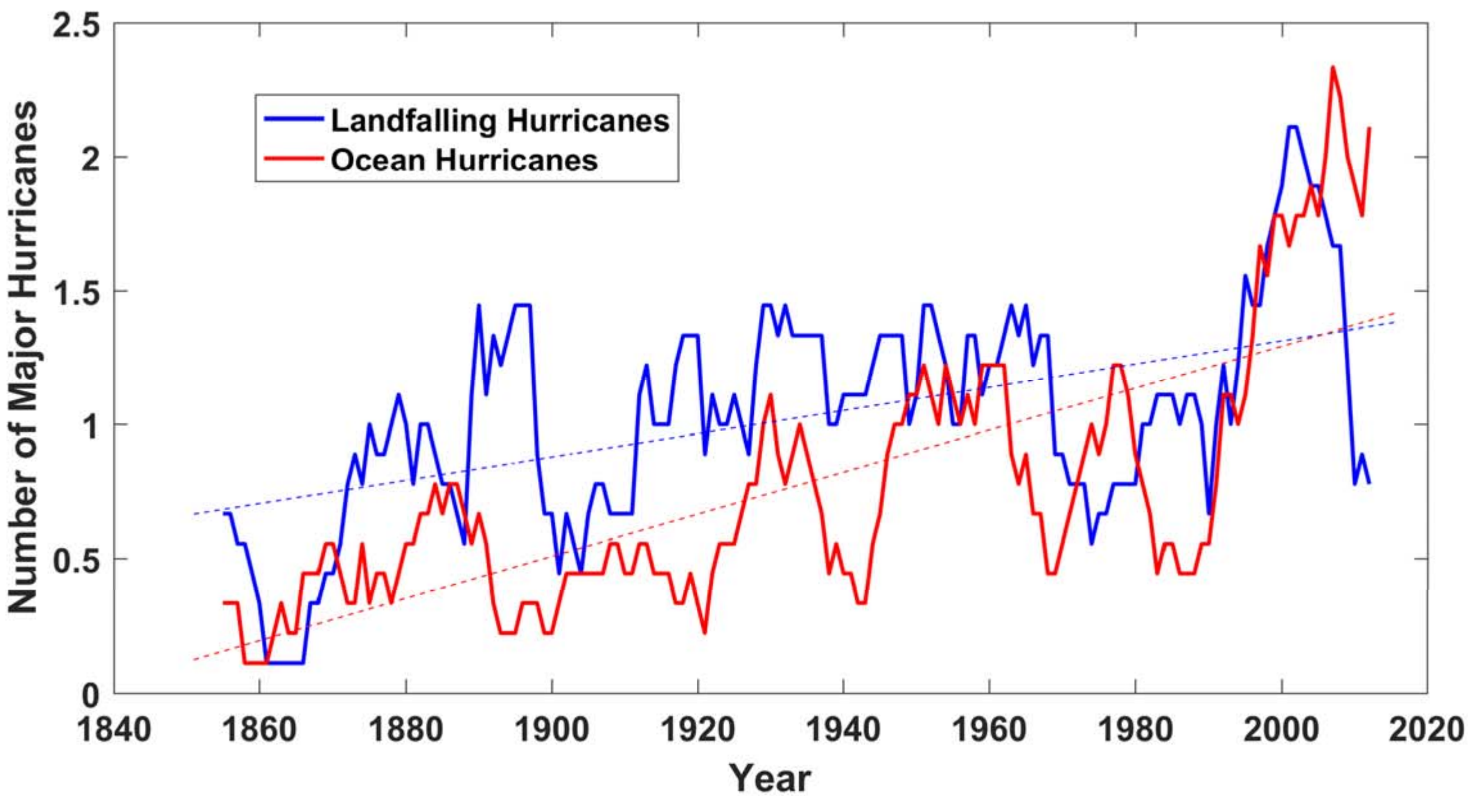
Audio is only available over the phone: dial toll-free (from US or CAN): 1-877-708-1667. Enter code 7028688#

Program

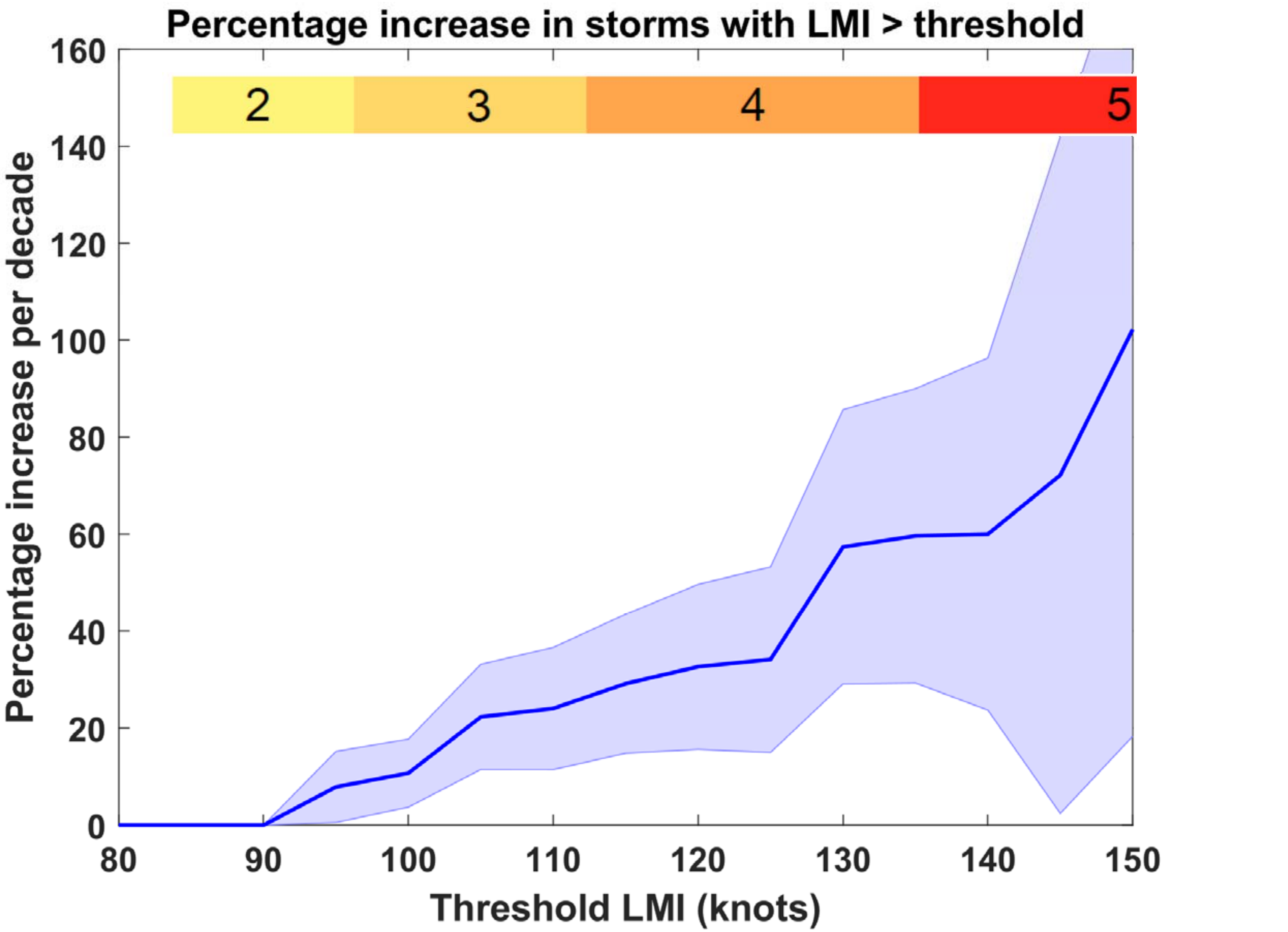
- Inferences from historical records
- Inferences from basic physics
- Using physics to estimate risk

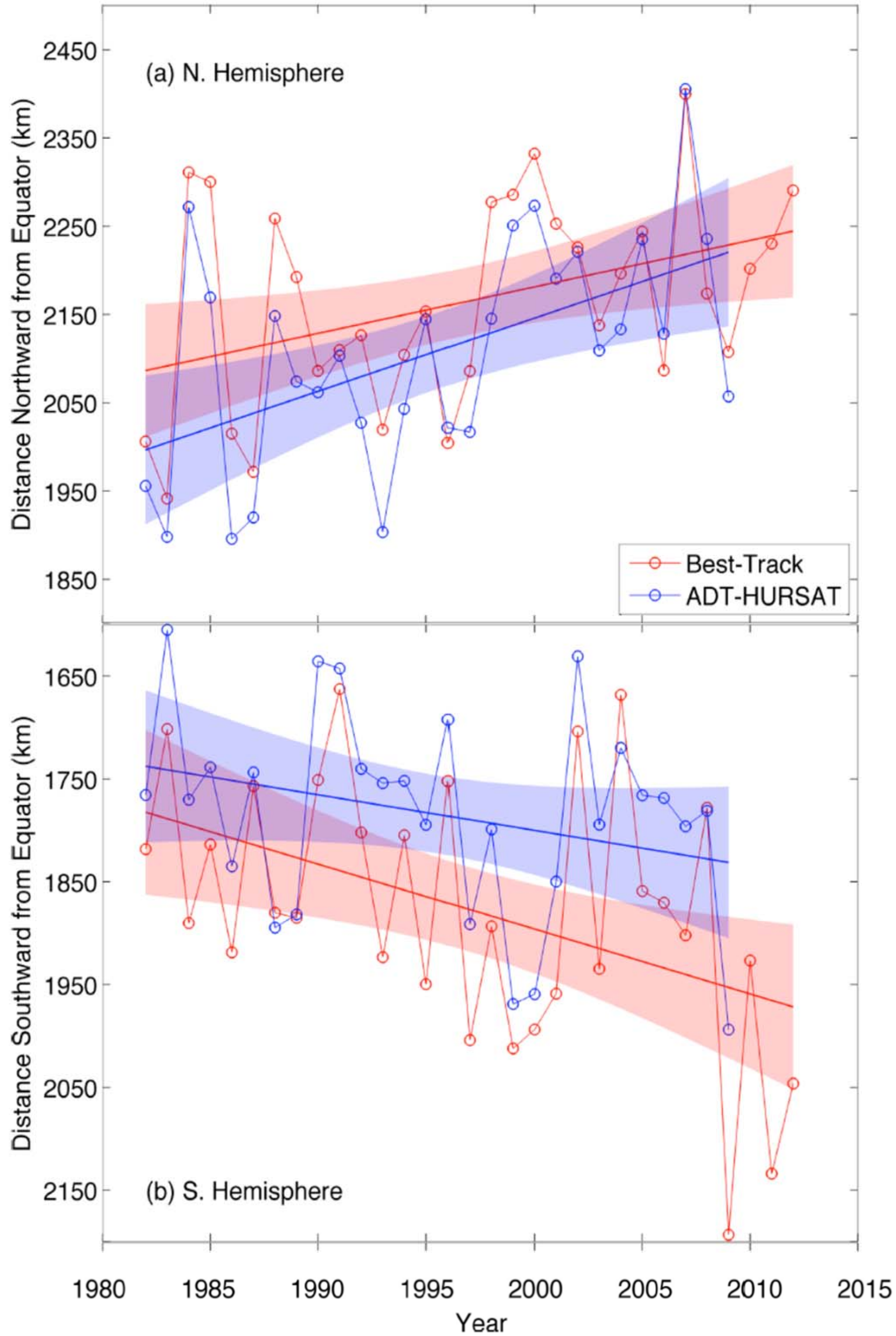
Prior to 1970, Many Storms Were Missed



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.

Trends in Global TC Frequency Over Threshold Intensities, from Historical TC Data, 1980-2016. Trends Shown Only When $p < 0.05$.



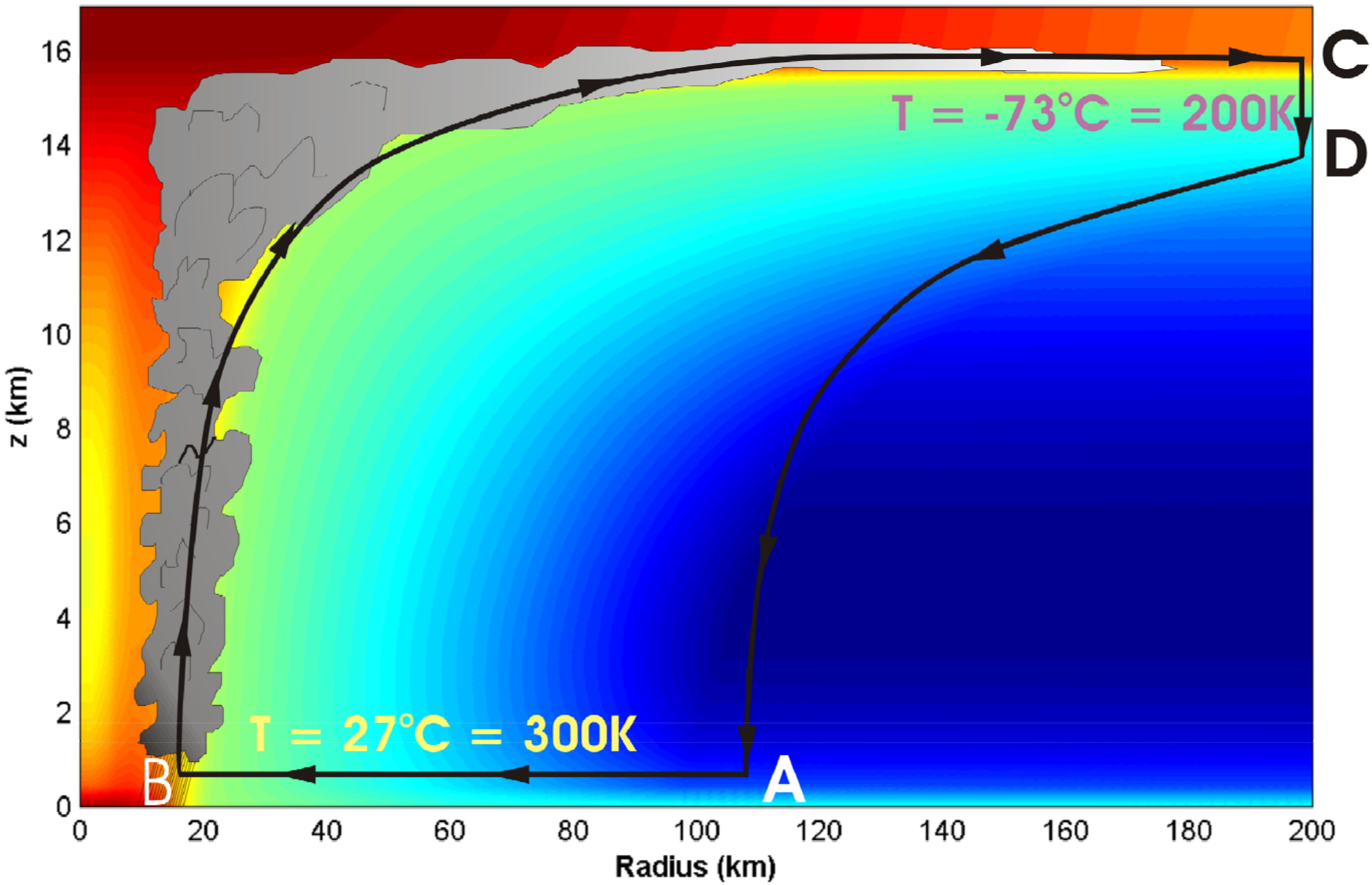


Hurricanes are reaching peak intensity at higher latitudes

Time series of the latitudes at which tropical cyclones reach maximum intensity.

From *Kossin et al. (2014)*

Basic Physics: Energy Production



Theoretical Steady-State Maximum Hurricane Wind Speed:

$$V_{pot}^2 = \boxed{\frac{C_k}{C_D}}\frac{T_s - T_o}{T_0}\left(h_0^* - h_e^*\right)$$

Surface temperature

Saturation static energy of sea surface

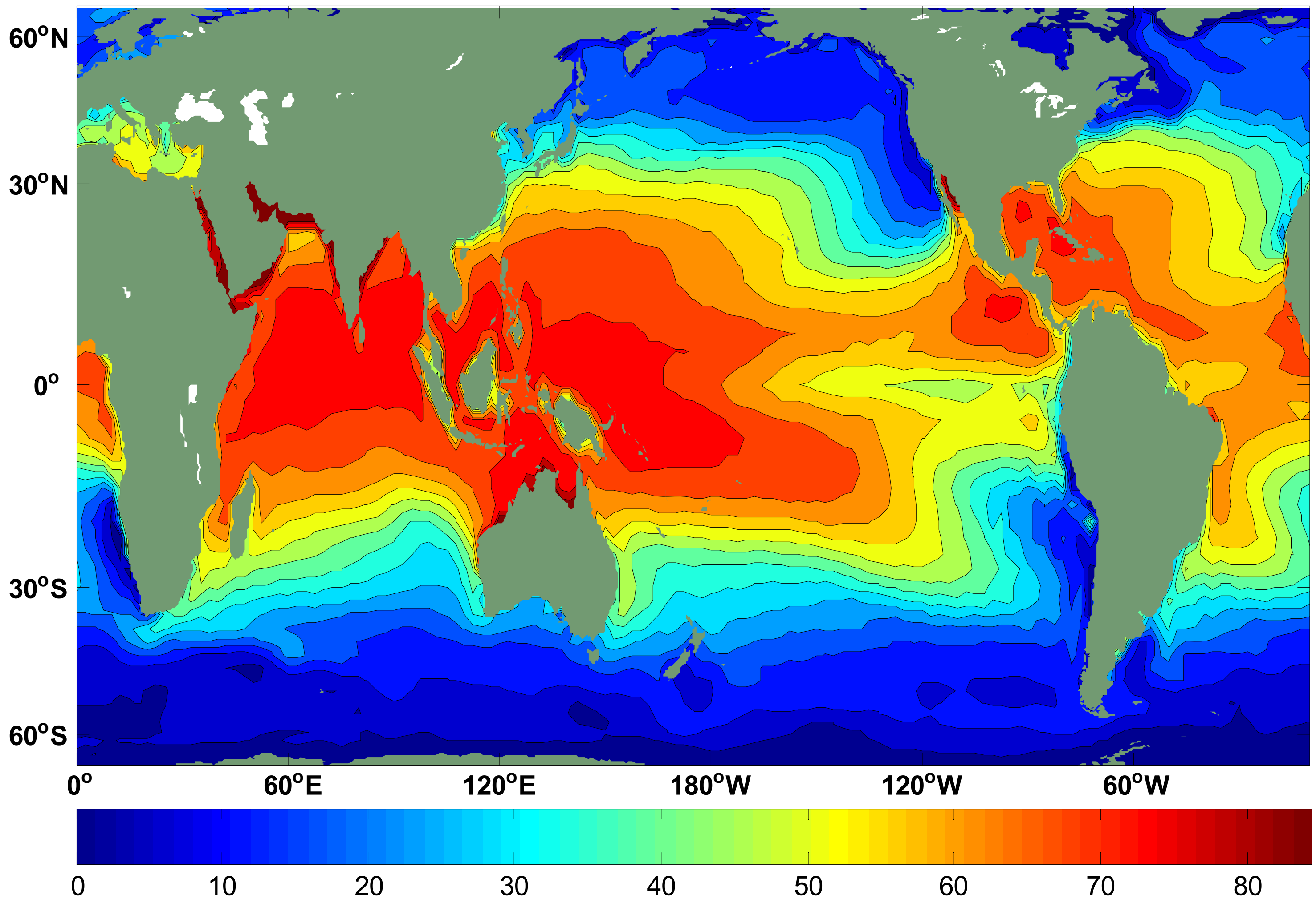
Saturation static energy of troposphere

Ratio of exchange coefficients of enthalpy and momentum

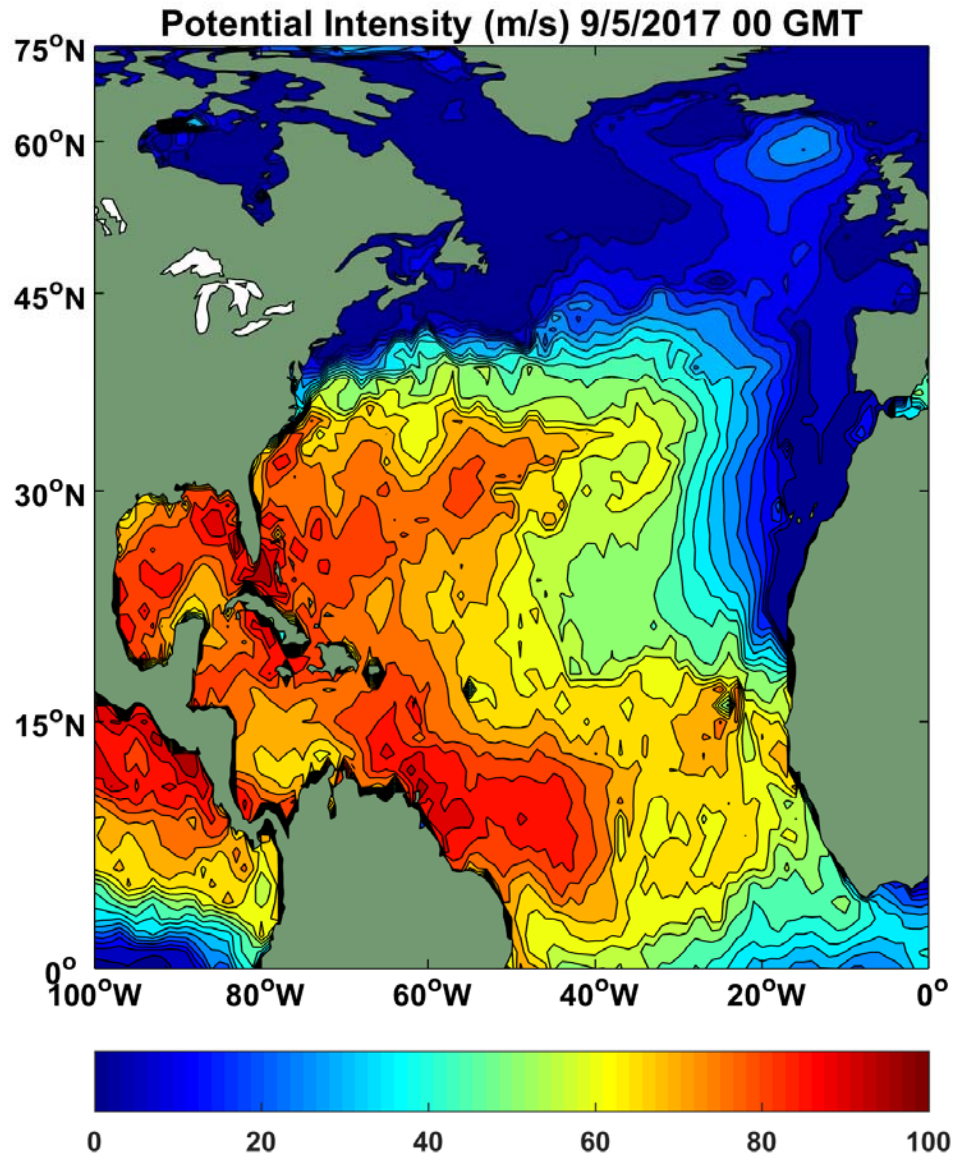
Outflow temperature

Air-sea enthalpy disequilibrium of moist static energy

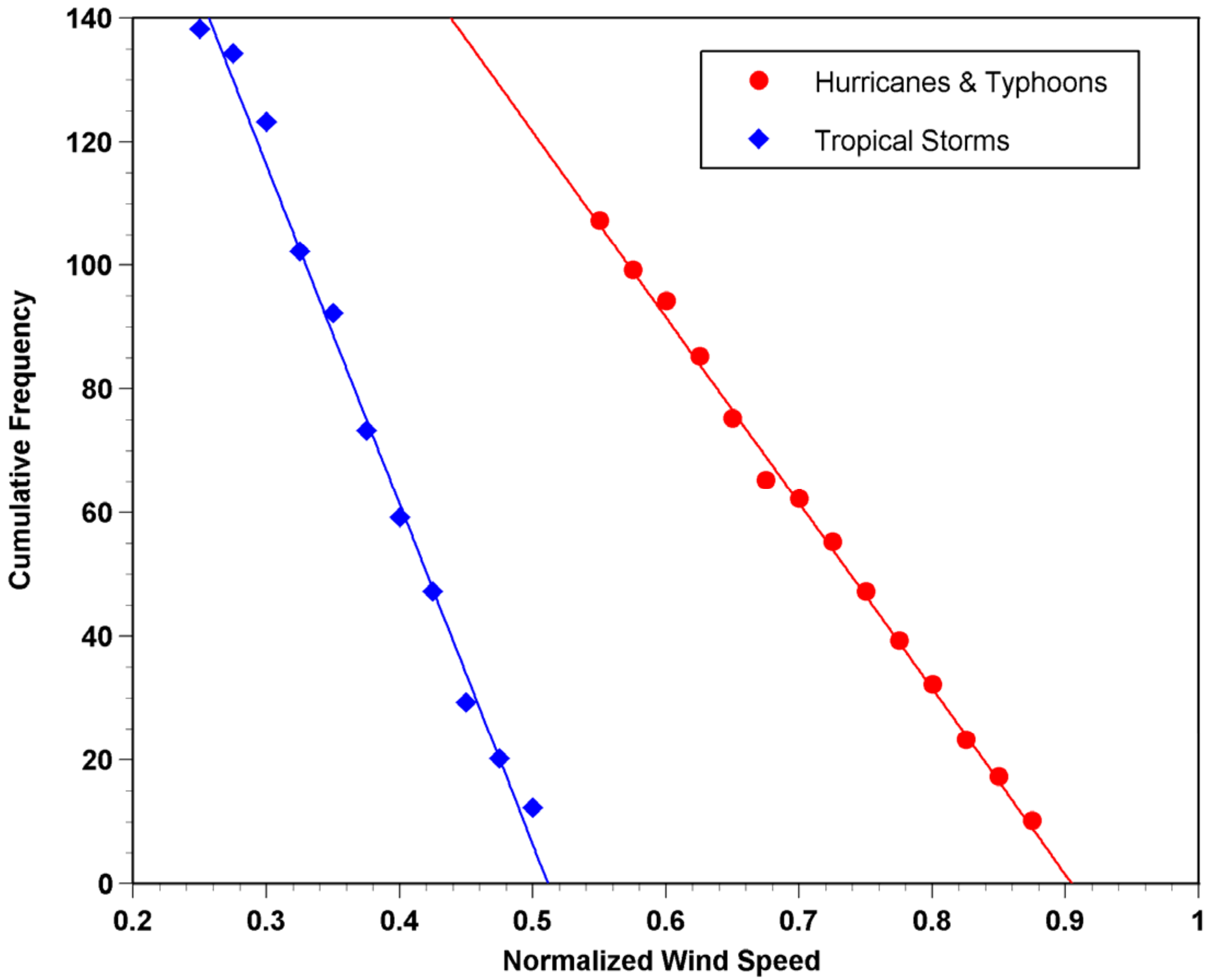
Annual Maximum Potential Intensity (m/s)



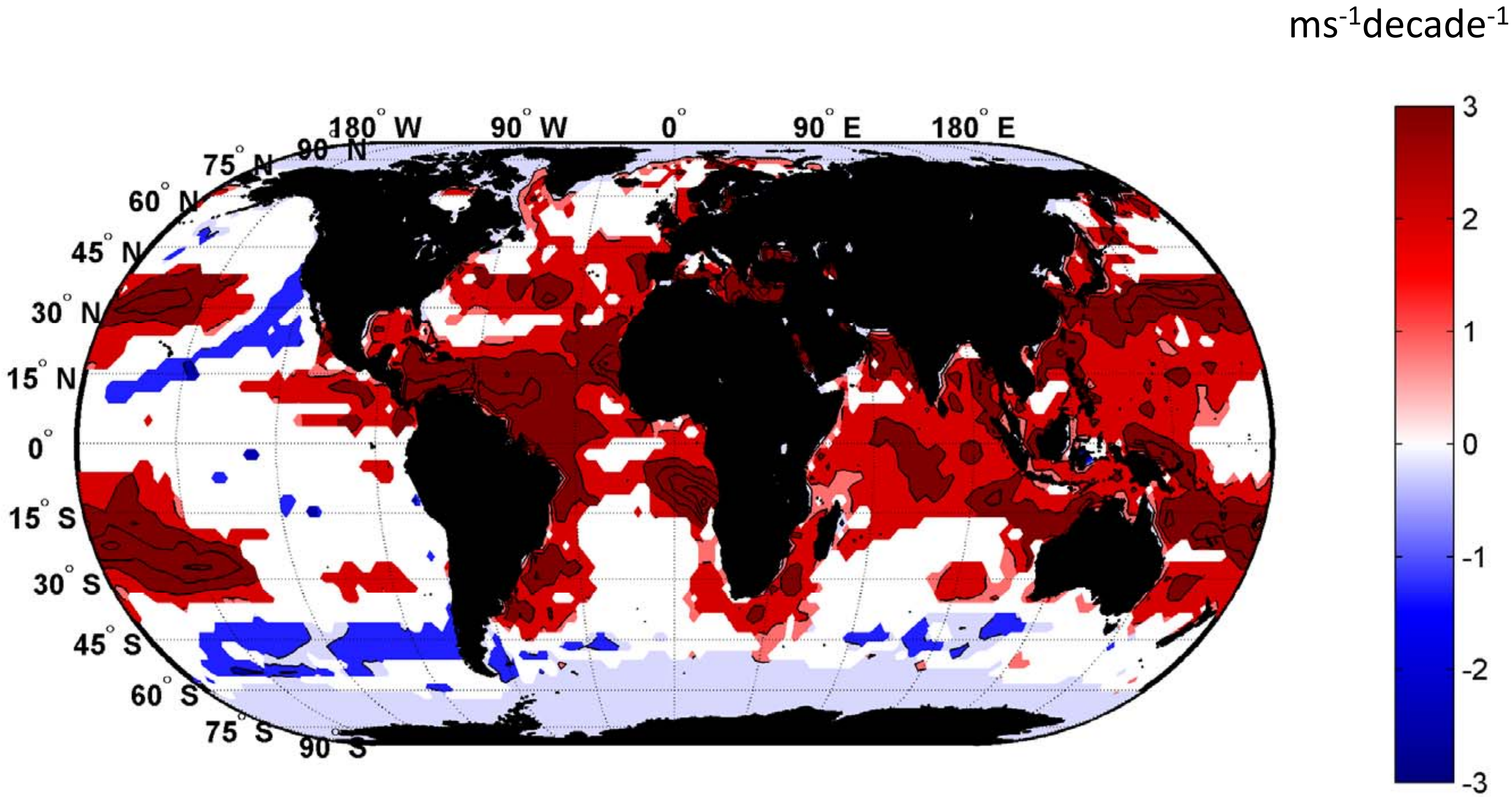
Potential Intensity at Onset of Hurricane Irma



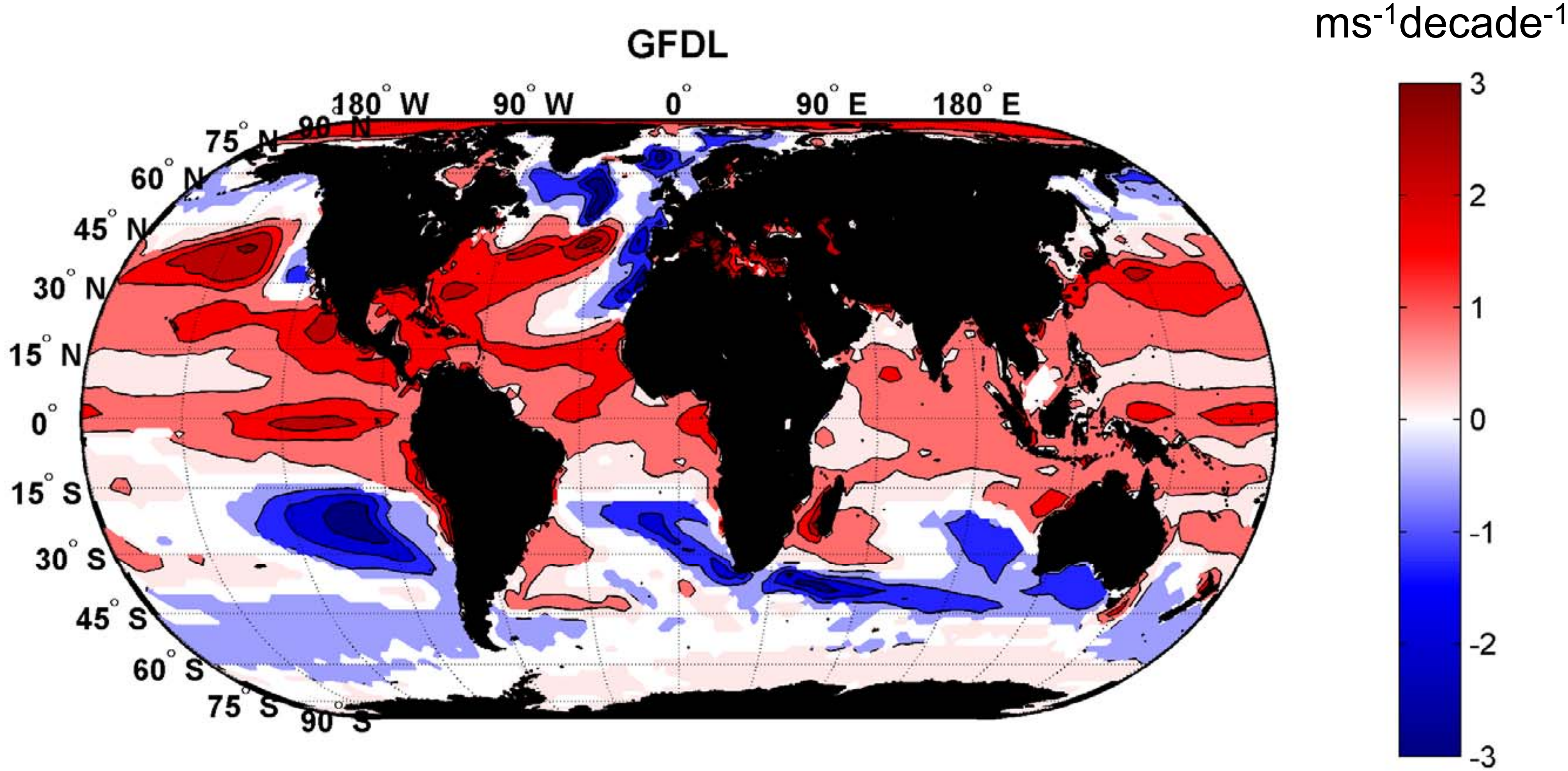
Cumulative Frequency of Storm Lifetime Maximum Intensity Normalized by Potential Intensity



Trends in Thermodynamic Potential for Hurricanes, 1980-2010
(NCAR/NCEP Reanalysis)



Projected Trend Over 21st Century: GFDL model under RCP 8.5



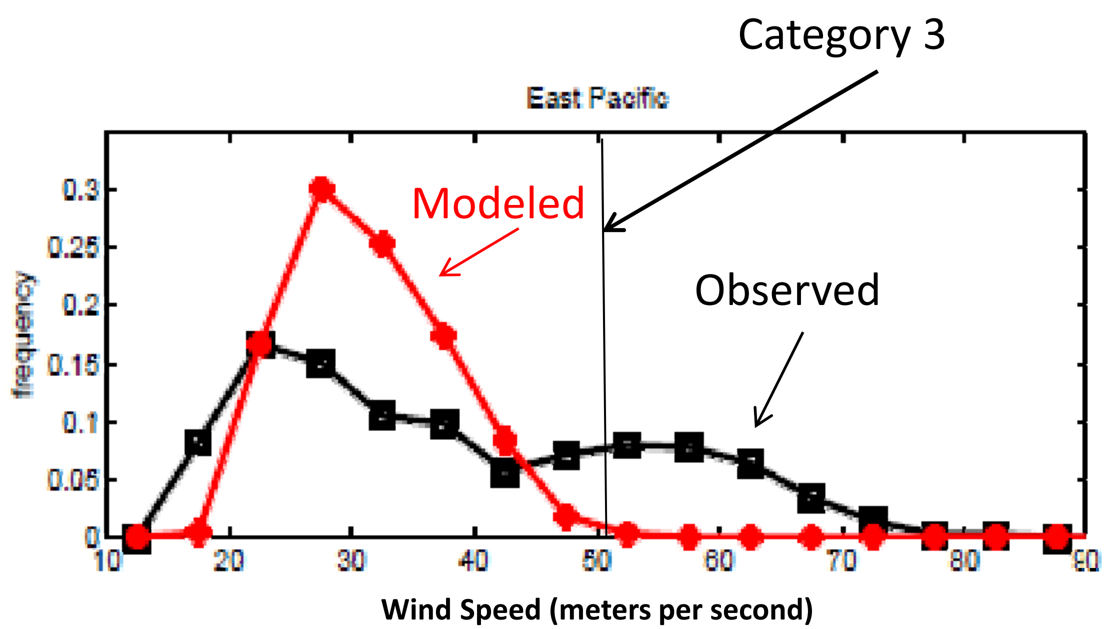
Inferences from Basic Theory:

- Potential intensity increases with global warming
- Incidence of high-intensity hurricanes should increase
- Increases in potential intensity should be faster in sub-tropics
- Hurricanes will produce substantially more rain: Clausius-Clapeyron yields ~7% increase in water vapor per $1^{o}C$ warming

Using Physics to Estimate Hurricane Risk

Why Not Use Global Climate Models to Simulate Hurricanes?

Problem: Today's models are far too coarse to simulate destructive hurricanes



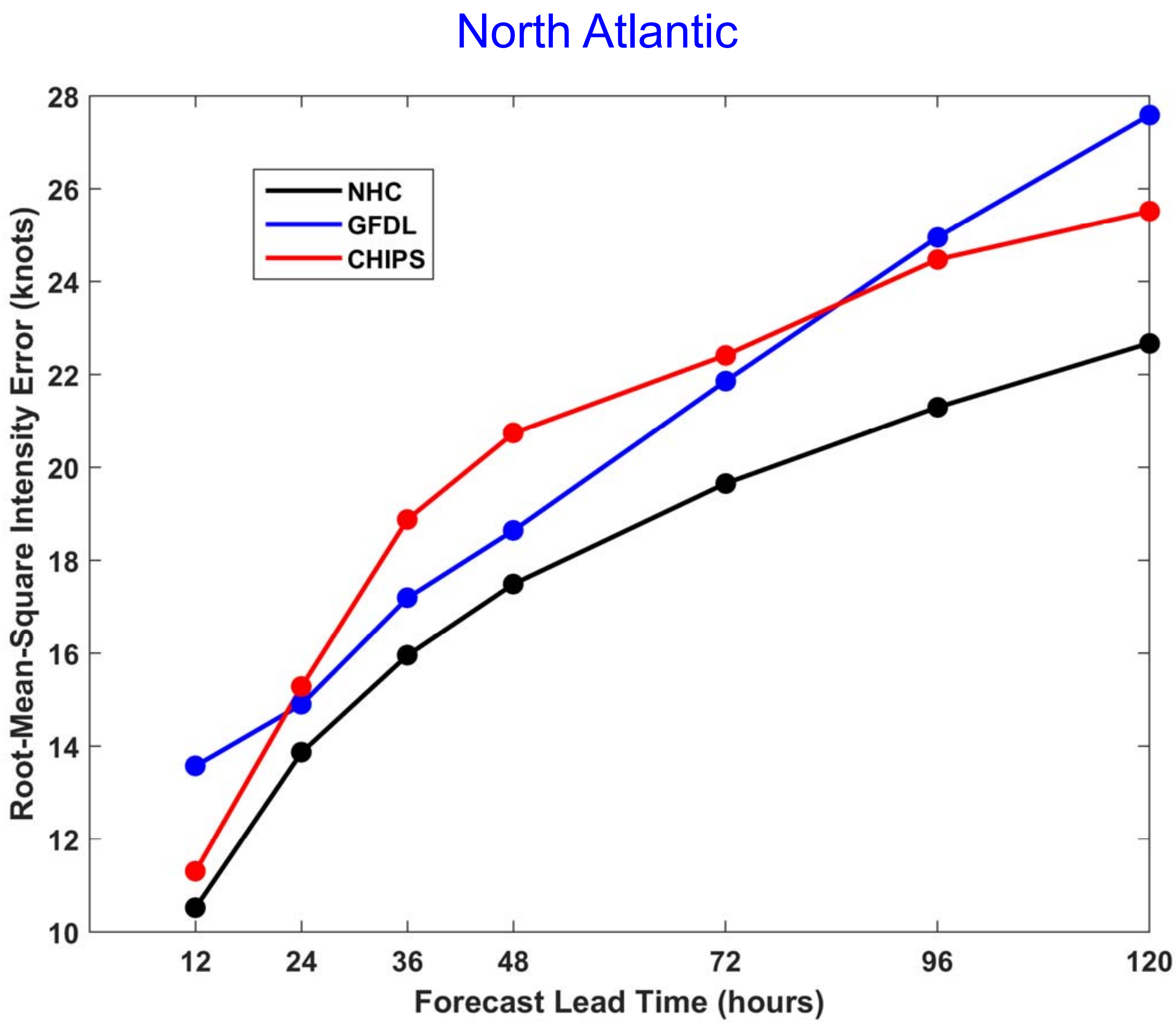
Histograms of Tropical Cyclone Intensity as Simulated by a Global Model with 30 mile grid point spacing. (Courtesy Isaac Held, GFDL)

Global models do not simulate the storms that cause destruction

How to deal with this?

- **Embed high-resolution, fast coupled ocean-atmosphere hurricane model in GCM or reanalysis data**

RMS Intensity Errors, 2009-2015

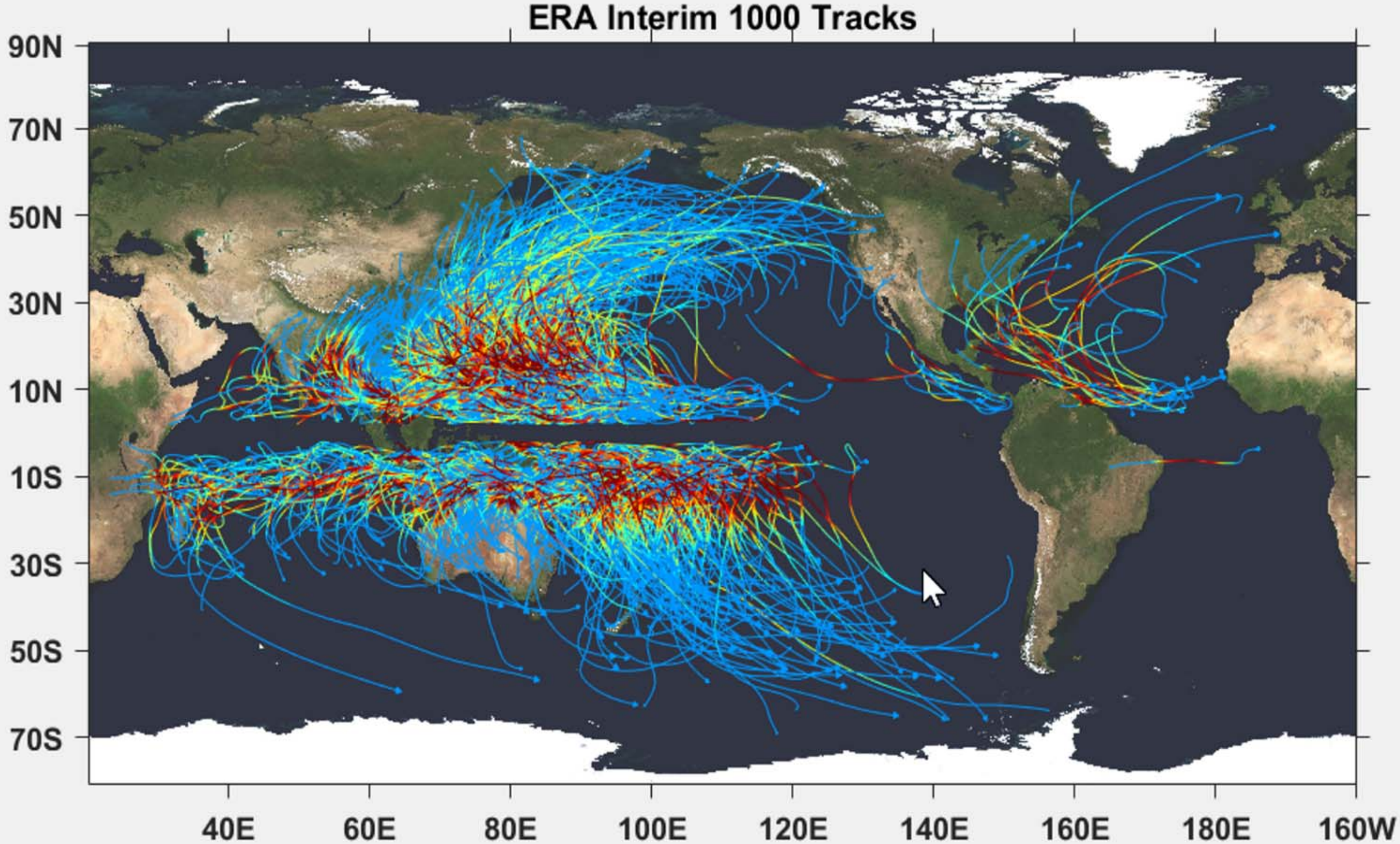


How Can We Use This Model to Help Assess Hurricane Risk in Current and Future Climates?

Risk Assessment Approach:

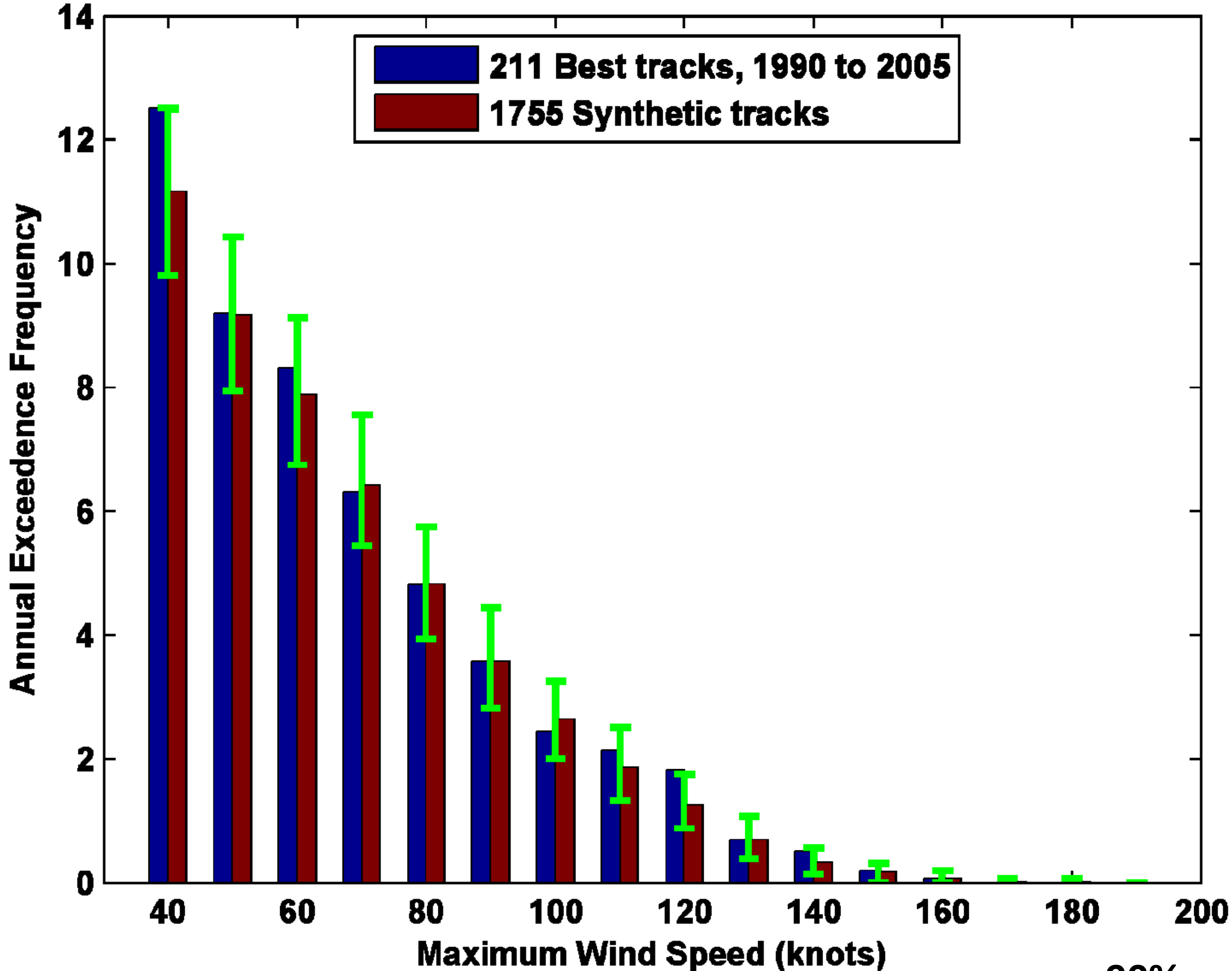
- **Step 1**: Seed each ocean basin with a very large number of weak, randomly located cyclones
- **Step 2**: Cyclones are assumed to move with the large scale atmospheric flow in which they are embedded, plus a correction for the earth's rotation and sphericity
- **Step 3**: Run the CHIPS model for each cyclone, and note how many achieve at least tropical storm strength
- **Step 4:** Using the small fraction of surviving events, determine storm statistics. Can easily generate 100,000 events

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



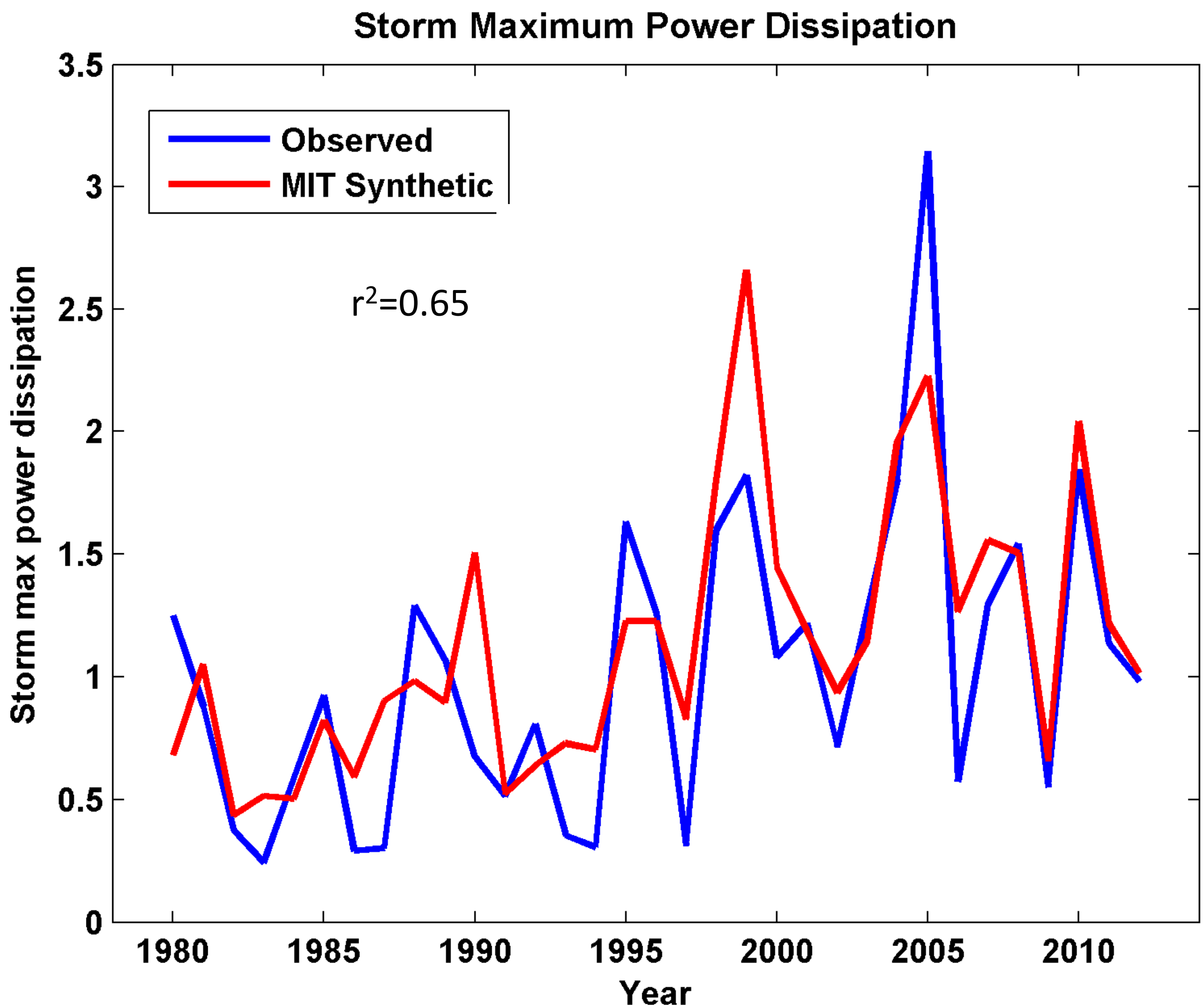
ERA Interim 1000 Tracks
90N
70N
50N
30N
10N
10S
30S
50S
70S
40E
60E
80E
100E
120E
140E
160E
180E
160W

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

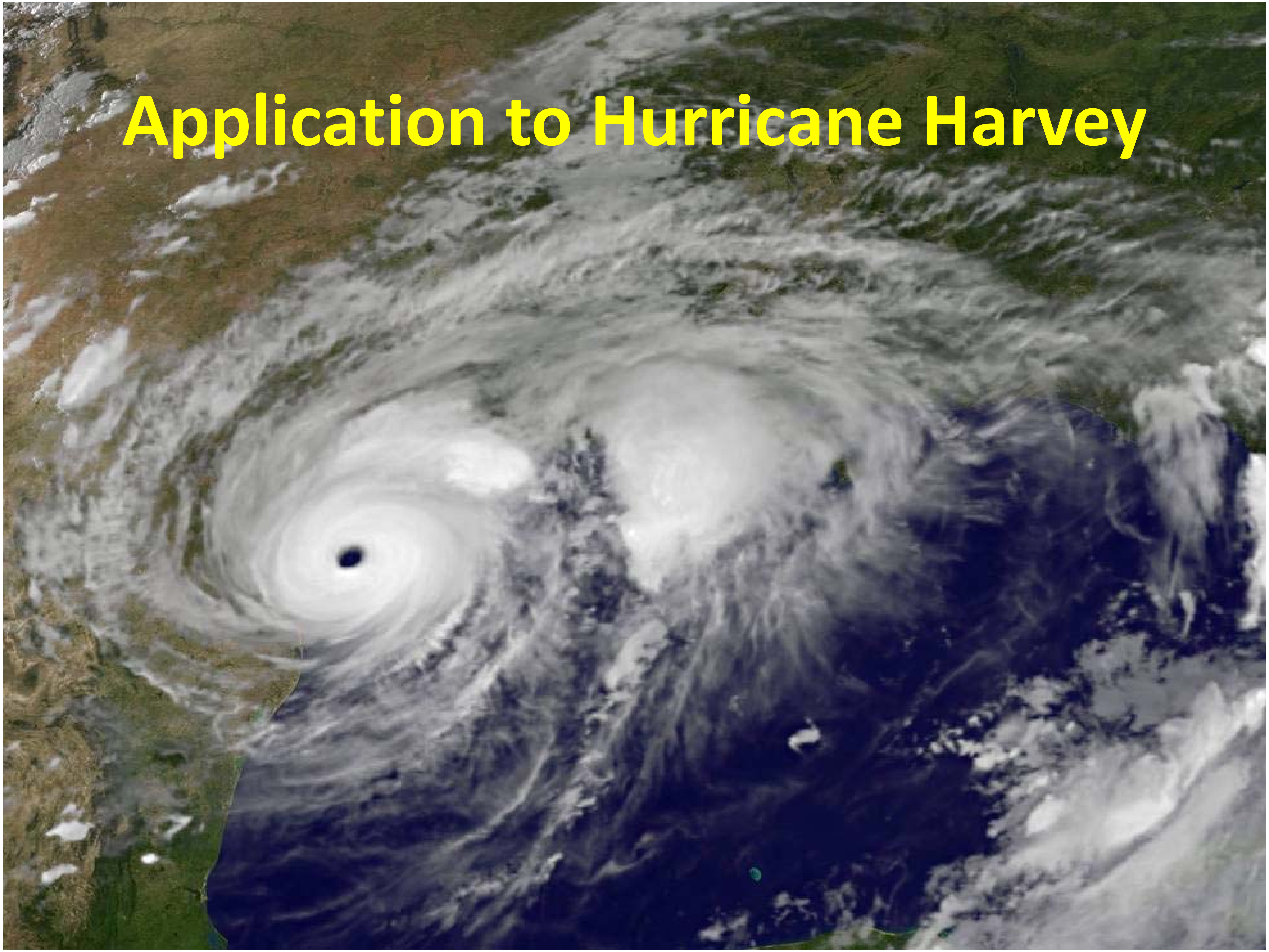


90% confidence bounds

Captures Much of the Observed North Atlantic Interannual Variability



Application to Hurricane Harvey



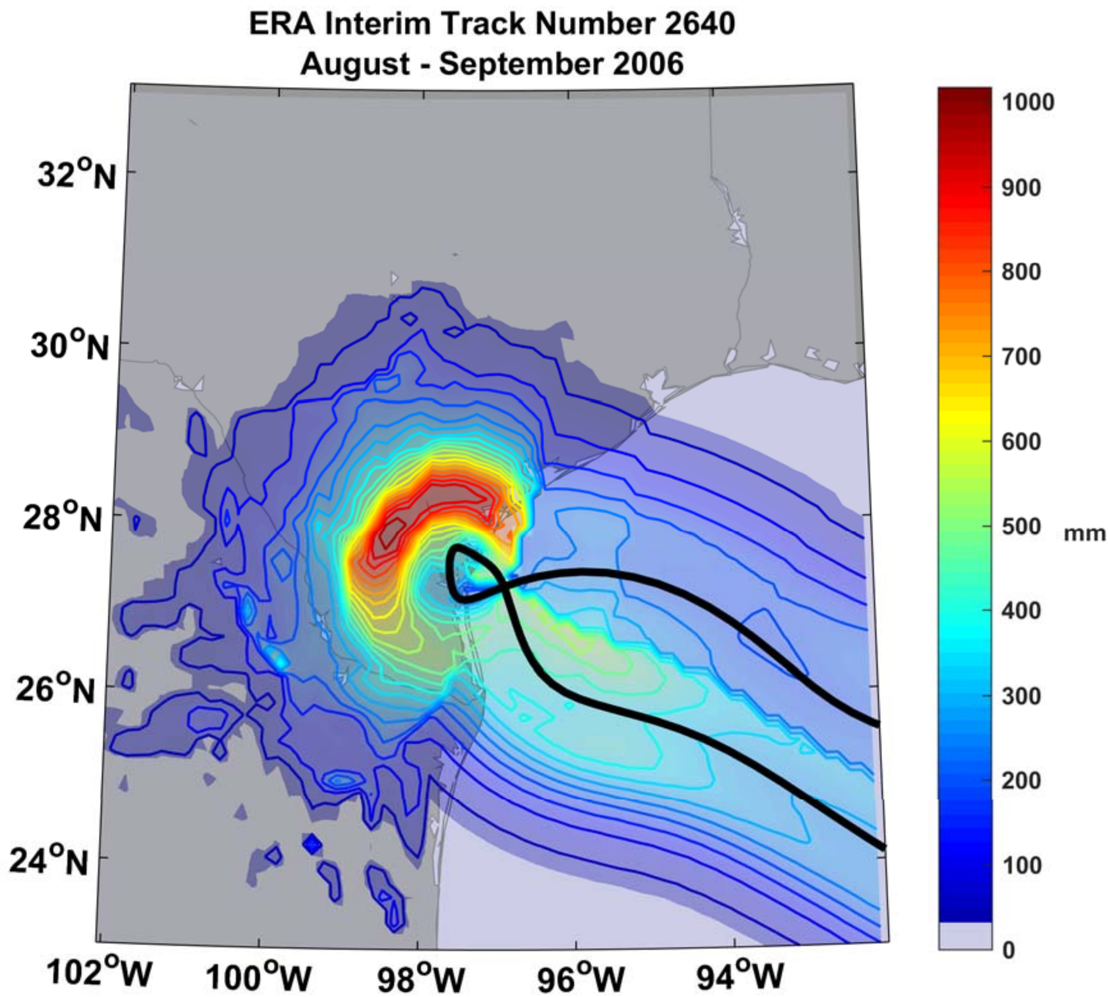
Risk Assessment for Houston and Texas:

- Run 100 events for each year from 1980 to 2016 (3700 events total) passing within 300 km of Houston, downscaled from three climate reanalyses

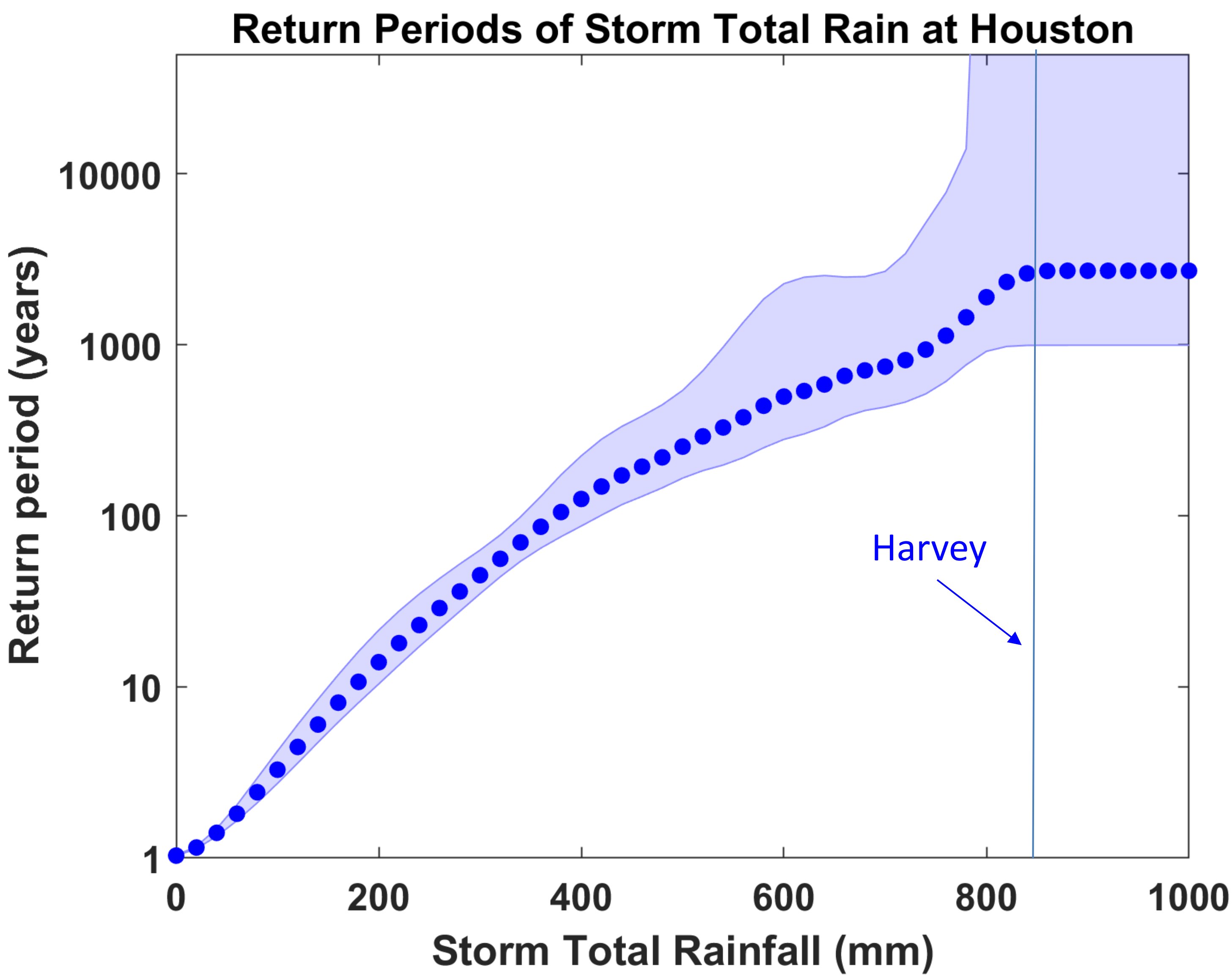
- Run 100 events each year from 1979-2015 passing over the Texas coastline, downscaled from NCAR/NCEP reanalyses. Calculate storm total rainfall for each event at each of 78 points constituting a grid extending from 26° N to 31° N and from 99° W to 94° W, at increments of 0.5°, but excluding points over the Gulf

- Run 100 events each year during two periods: 1981-2000 and 2081-2100, passing within 300 km of Houston, downscaled from six climate models

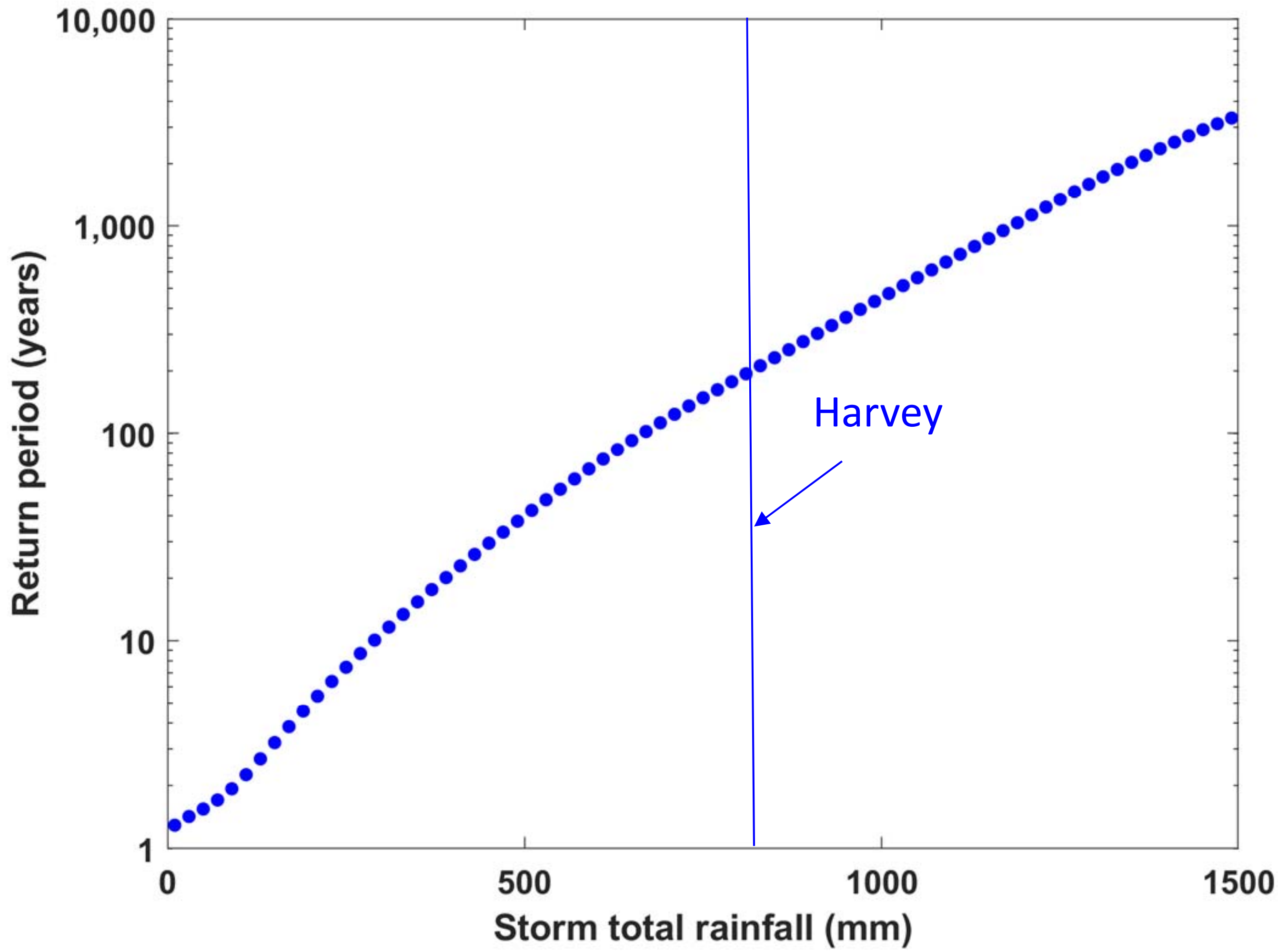
Example of Accumulated Rainfall from a Harvey-like Event Downscaled from ERA Interim Reanalysis



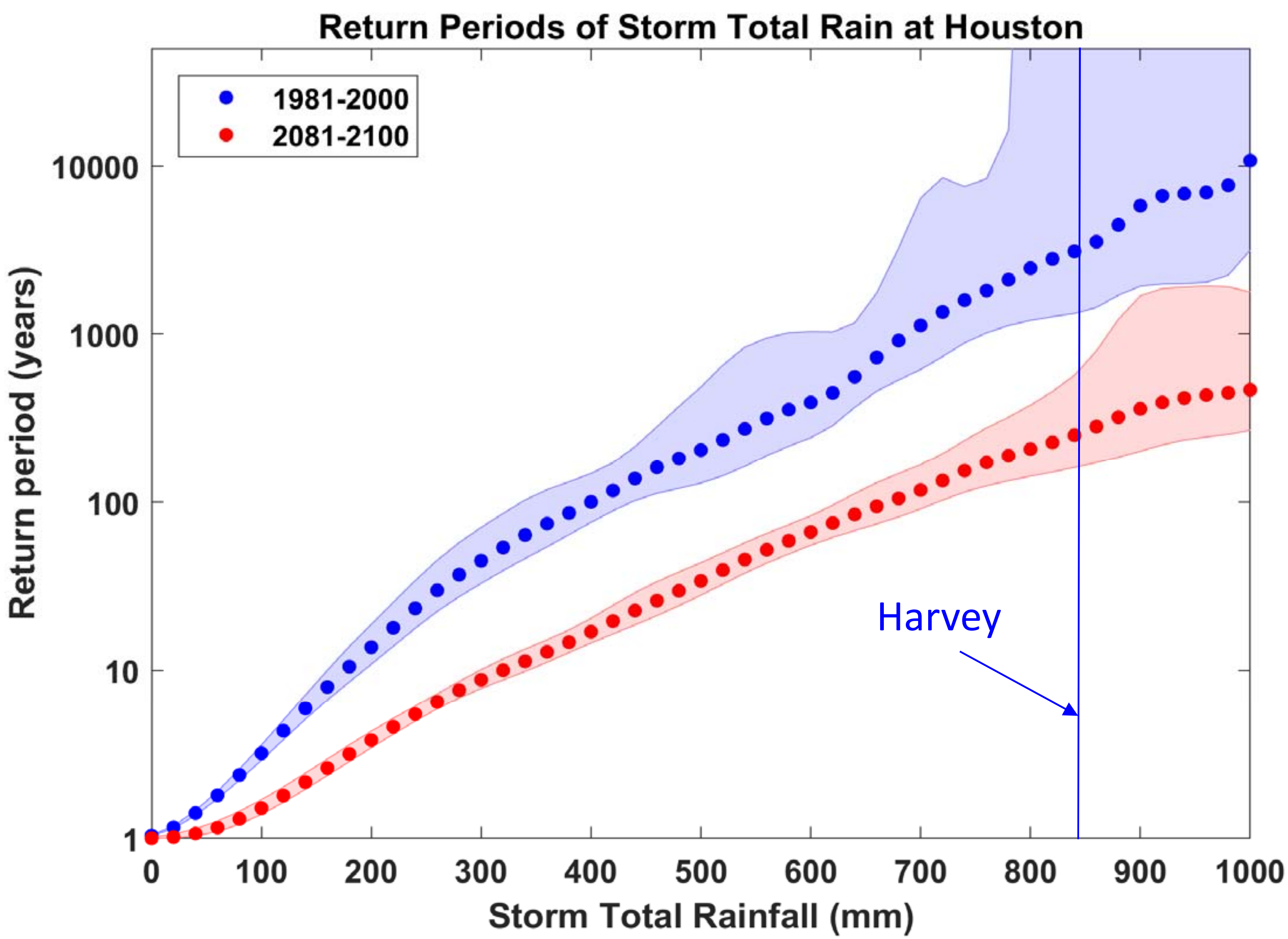
Probability of Storm Accumulated Rainfall at Houston, from 3 Climate Reanalyses, 1980-2016 Based on 3700 Events Each. Shading shows spread among the reanalyses.



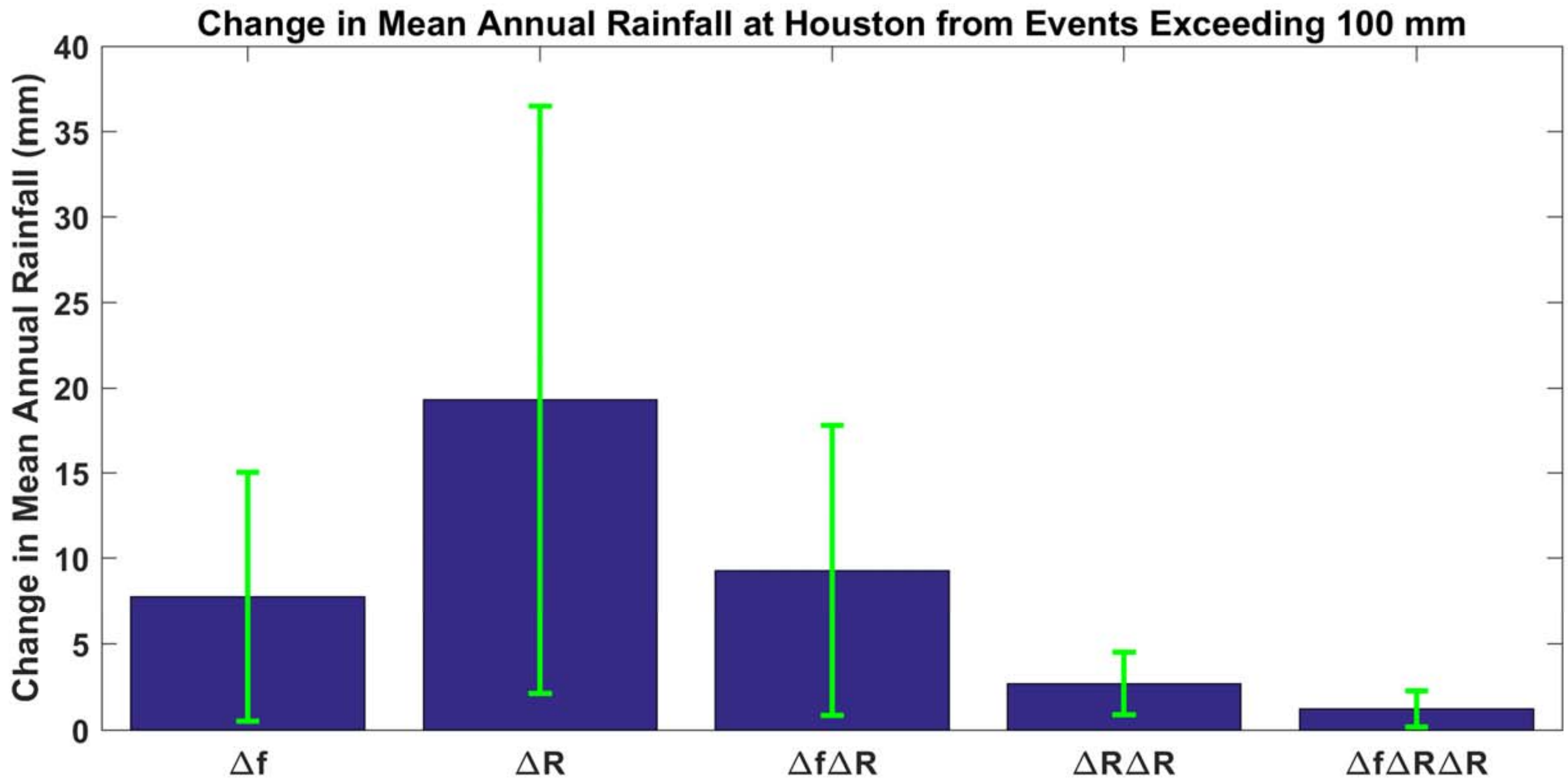
Probability of a Accumulated Hurricane Rain Anywhere in Texas, based on 3700 Events Downscaled from NCAR/NCEP Reanalysis with Rainfall Analyzed at 78 Points



Probability of Storm Accumulated Rainfall at Houston, from 6 Climate models, 1981-2000 and 2081-2100, Based on 2000 Events Each. Shading shows spread among the models.



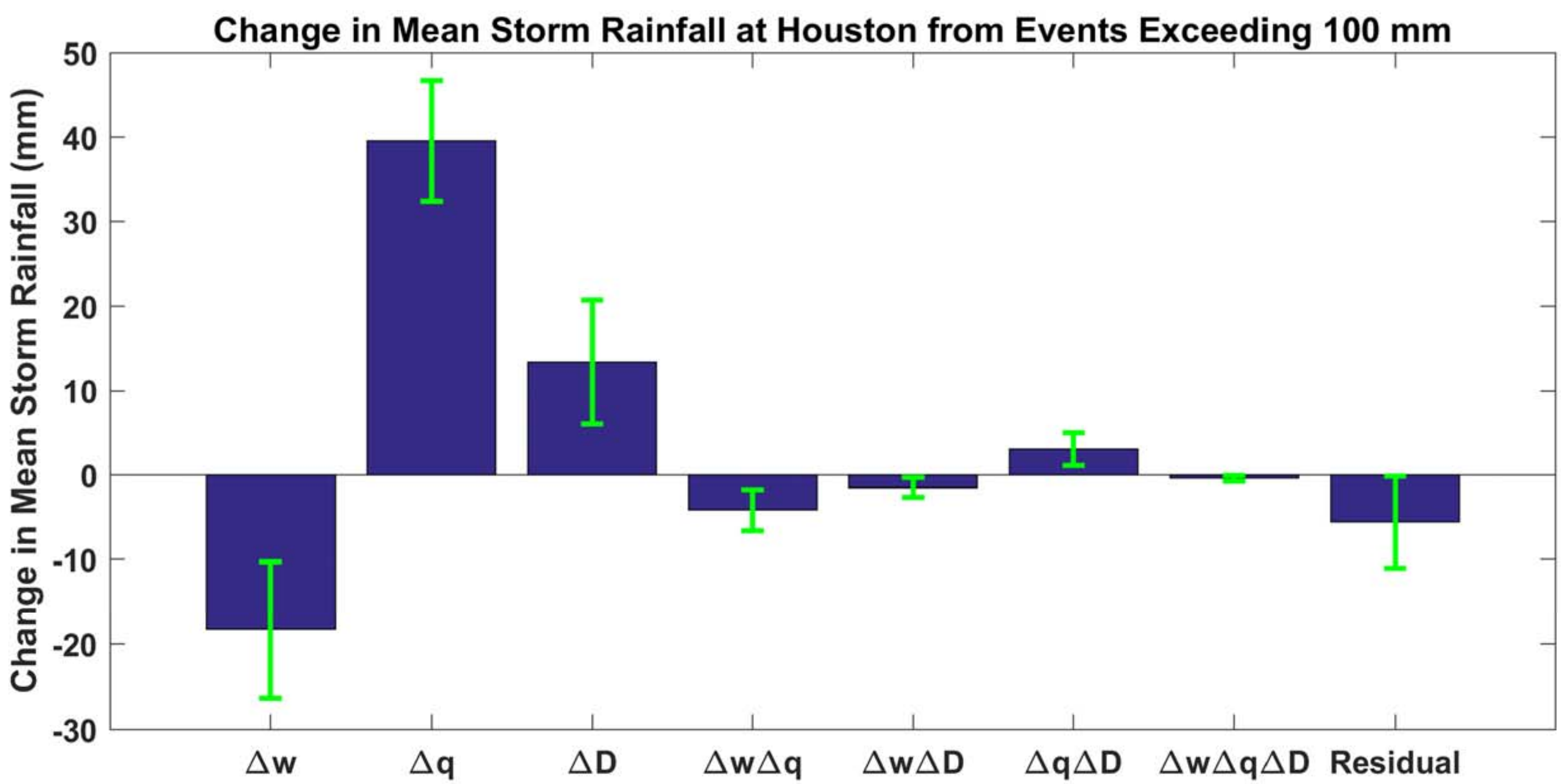
Contributions to Changes in Annual Mean Hurricane Rainfall at Houston from Changes in Overall Event Frequency and in Average Storm Rainfall



Δf = Change in overall hurricane frequency

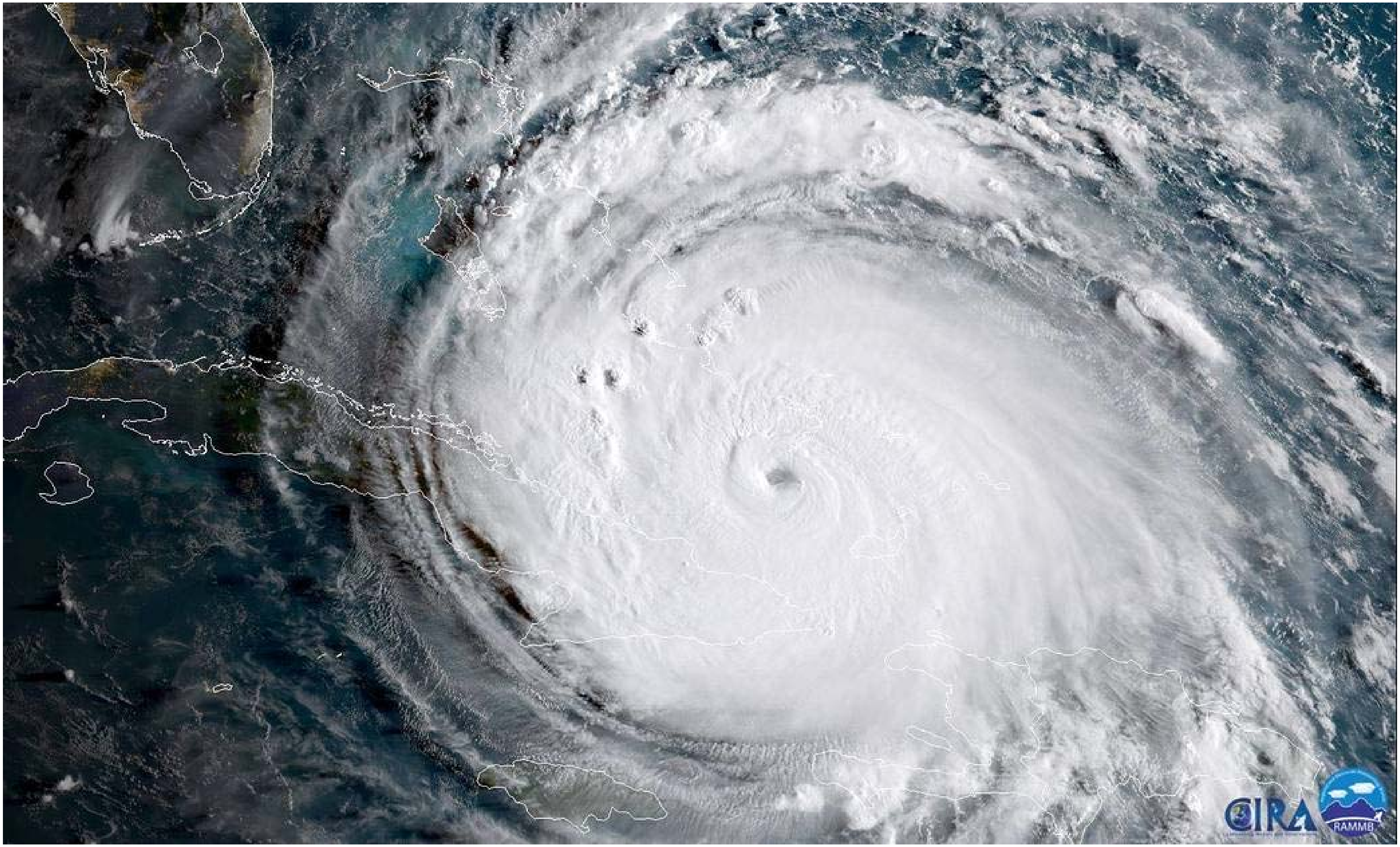
ΔR= Change in Rainfall amounts in excess of 100 mm

Contributions to Changes in Hurricane Rainfall at Houston from Changes in Updraft Speed, Water Vapor Content, and Storm Duration



Δw = Change in updraft speed
Δq = Change in water vapor concentration
ΔD = Change in storm duration

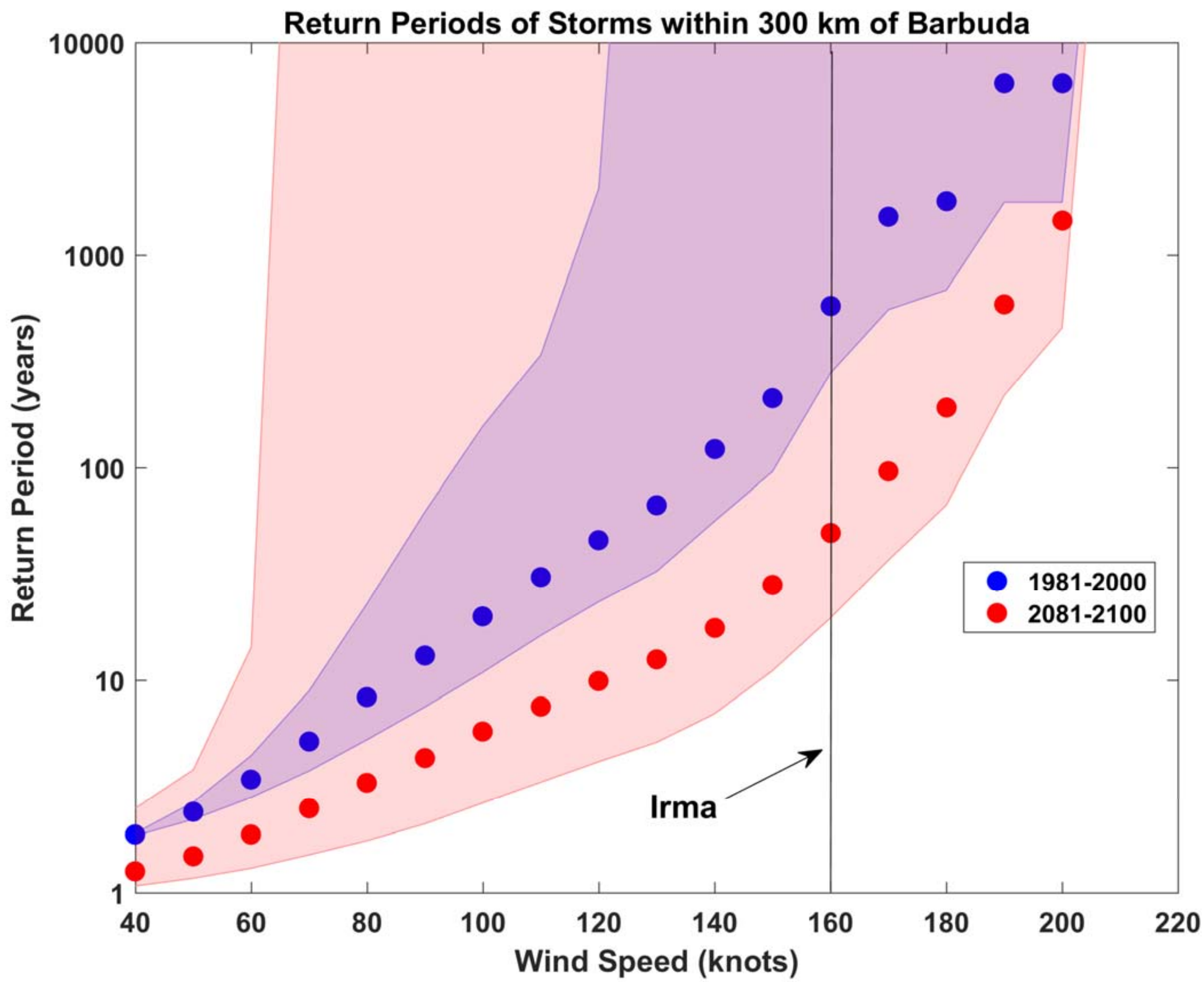
Hurricane Irma



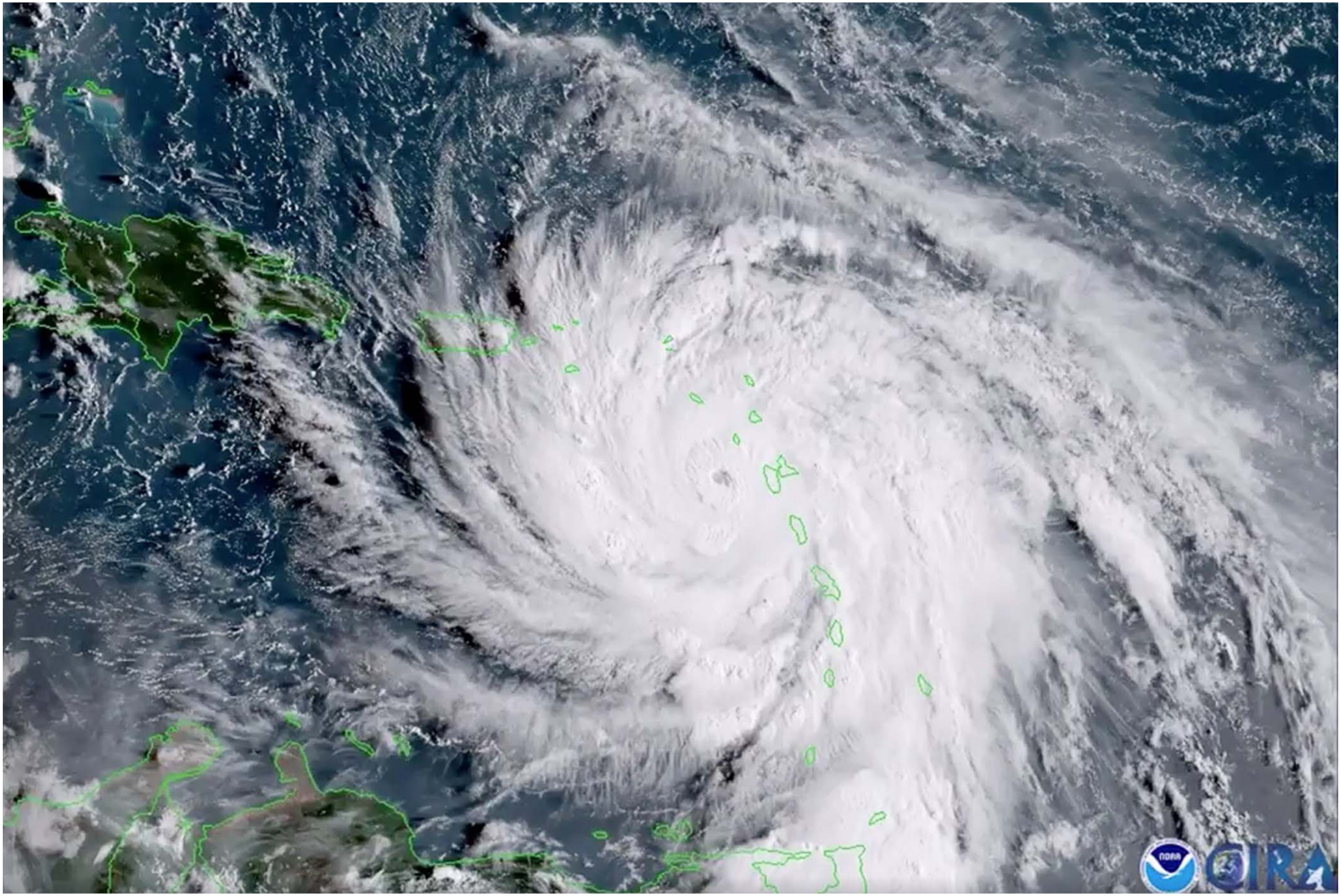
Irma

- Run 100 events each year during two periods: 1981-2000 and 2081-2100, passing within 300 km of Barbuda, downscaled from six climate models

Probabilities of Storms of Irma's Intensity within 300 km of Barbuda, from 6 Climate models, 1981-2000 and 2081-2100, Based on 2000 Events Each. Shading shows spread among the models.

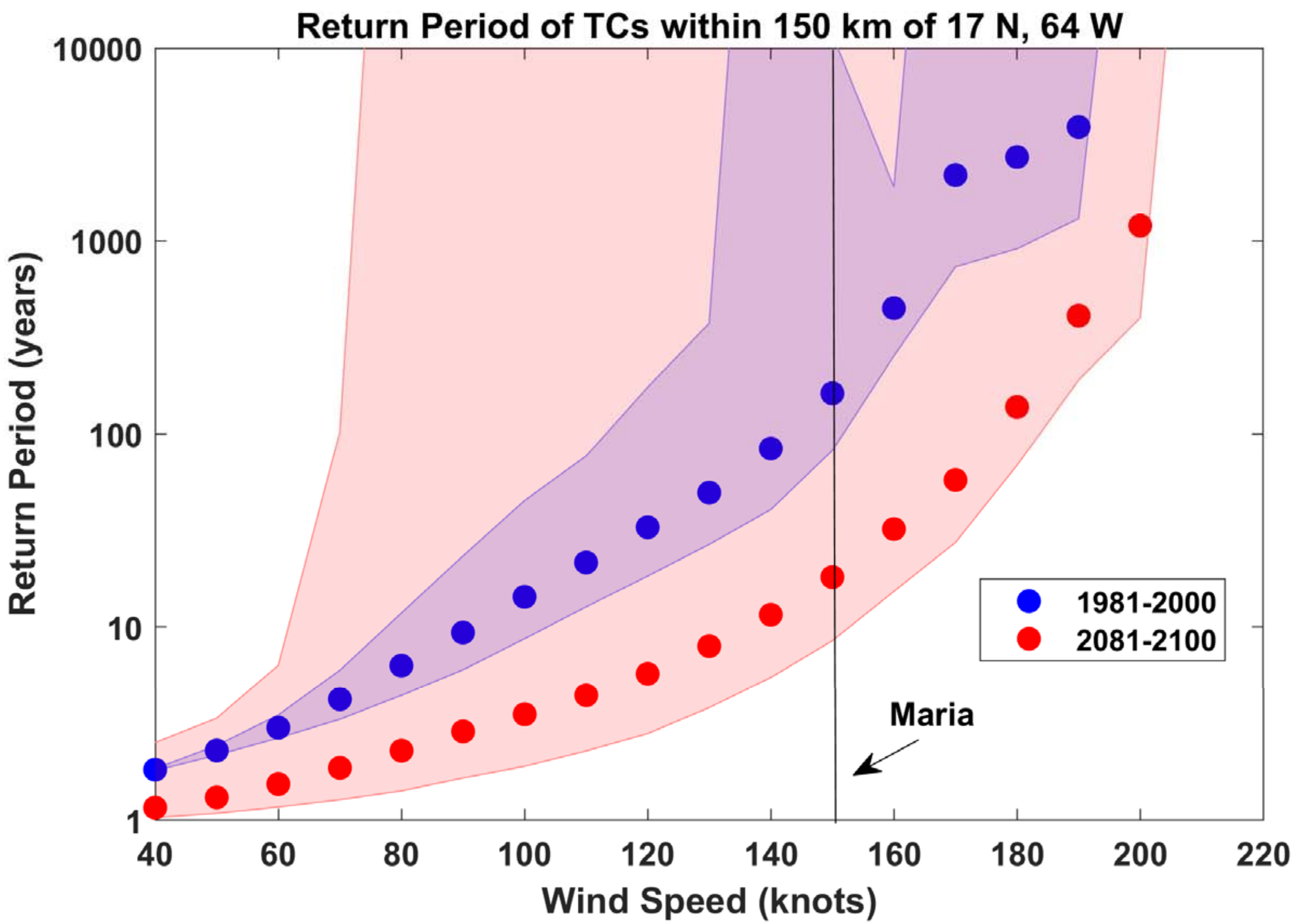


Hurricane Maria



Maria

- Run 100 events each year during two periods: 1981-2000 and 2081-2100, passing within 150 km of 17^{o}N, 64^{o}W, downscaled from four climate models



Return Period of TCs within 150 km of 17 N, 64 W
Return Period (years)
10000
1000
100
10
1
40
60
80
100
120
140
160
180
200
220
Wind Speed (knots)
1981-2000
2081-2100
Maria

Summary

- The observational record of hurricanes is too short and noisy, and of a quality too low to make robust inferences of climate signals
- Satellite data do show a migration of peak intensity toward higher latitudes and some indication of a greater fraction of intense storms

Summary (continued)

- Potential intensity theory demonstrates that the thermodynamic limit on hurricane intensity rises with temperature
- Observations show that this limit is indeed increasing
- Physics can be used to model hurricane risk in current and future climates

Summary (continued)

- Rain of Harvey's magnitude in Texas was a ~ 1% annual probability event in 1990 and is projected to increase to 15% by 2090. A linear increase in frequency yields a 5% probability in 2017. (Observational studies by Risser and Wehner, 2017 and van Oldenborgh et al., 2017, state probability increases of at least 3.5 and 1.5-5, respectively.)
- Irma's peak winds of 160 kts within 300 km of Barbuda are estimated to have had an annual probability of 0.13% in 1990, increasing to 1.3% in 2090
- Maria's peak winds of 150 kts within 150 km of 17 N 64 W are estimated to have had an annual probability of 0.5% in 1990, increasing to 5% by 2090.

Contact Information and Links

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Papers on Harvey's rains:

Emanuel, K., 2017: Assessing the present and future probability of Hurricane Harvey's rainfall. *Proc Net. Acad. Sci*., doi/10.1073/pnas.1716222114.

Risser, M. S., and M. Wehner, 2017: Attributable Human-Induced Changes in the Likelihood and Magnitude of the Observed Extreme Precipitation during Hurricane Harvey. *Geophys. Res. Lett*., DOI: 10.1002/2017GL075888

Van Oldenborgh et al., 2017: Attribution of extreme rainfall from Hurricane Harvey, August 2017. *Environ. Res. Lett*., **12**, doi.org/10.1088/1748-9326/aa9ef2