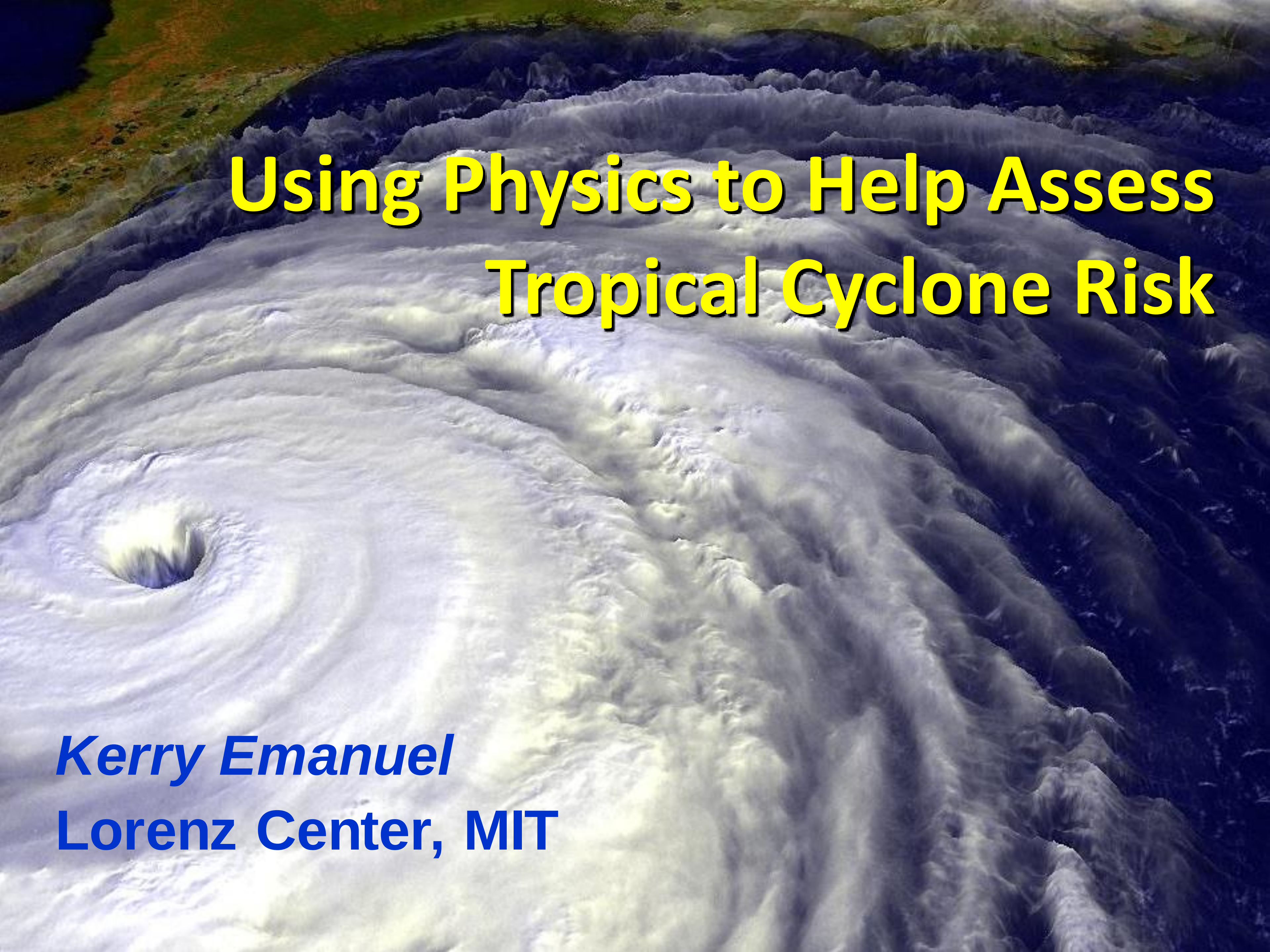
Using Physics to Help Assess Tropical Cyclone Risk



Kerry Emanuel
Lorenz Center, MIT

Program

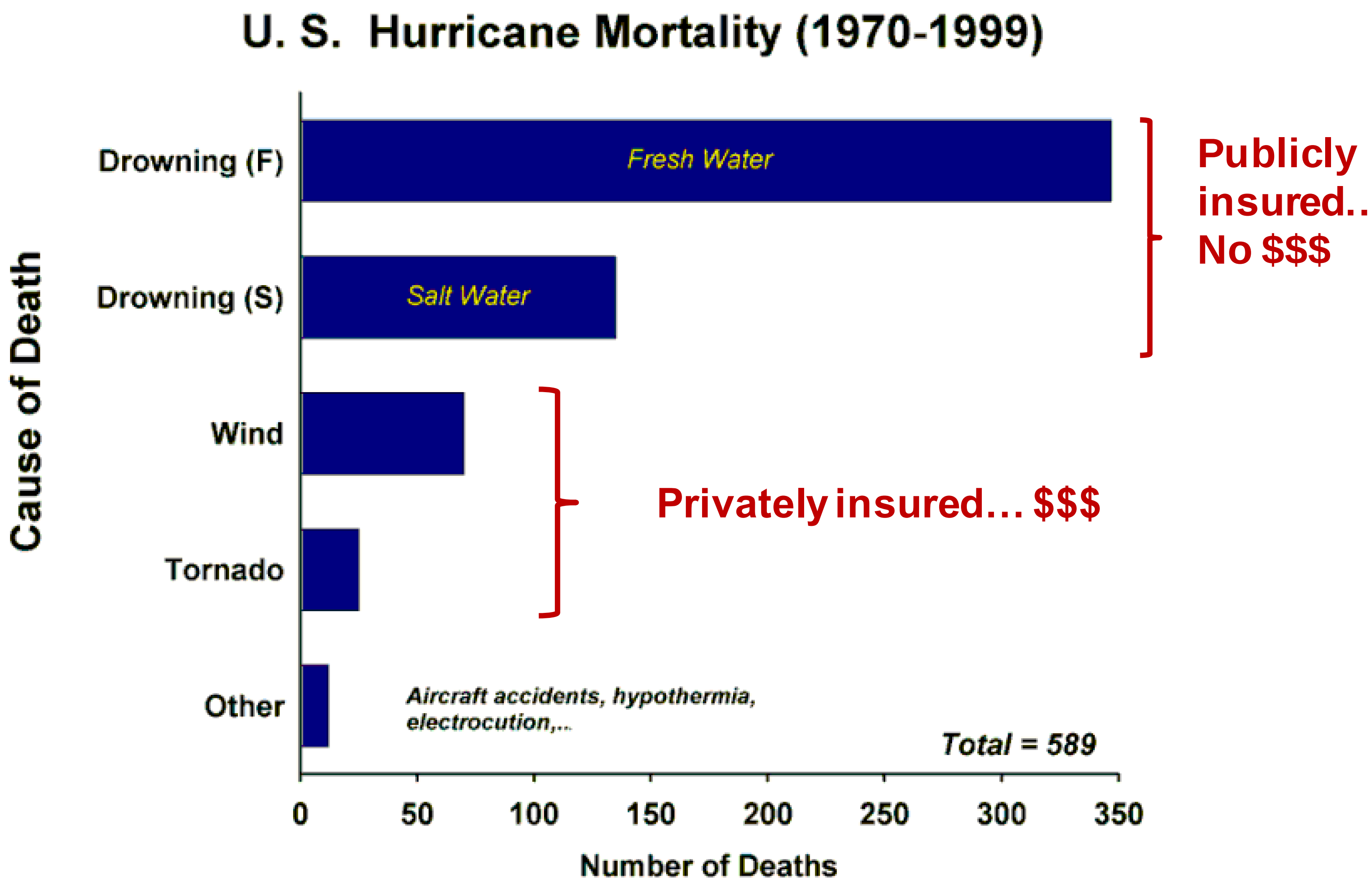
- **Limitations of the actuarial approach**
- **A physics-based approach**
- **Coupling to ADCIRC to assess surge risk**

Hurricane Risks:

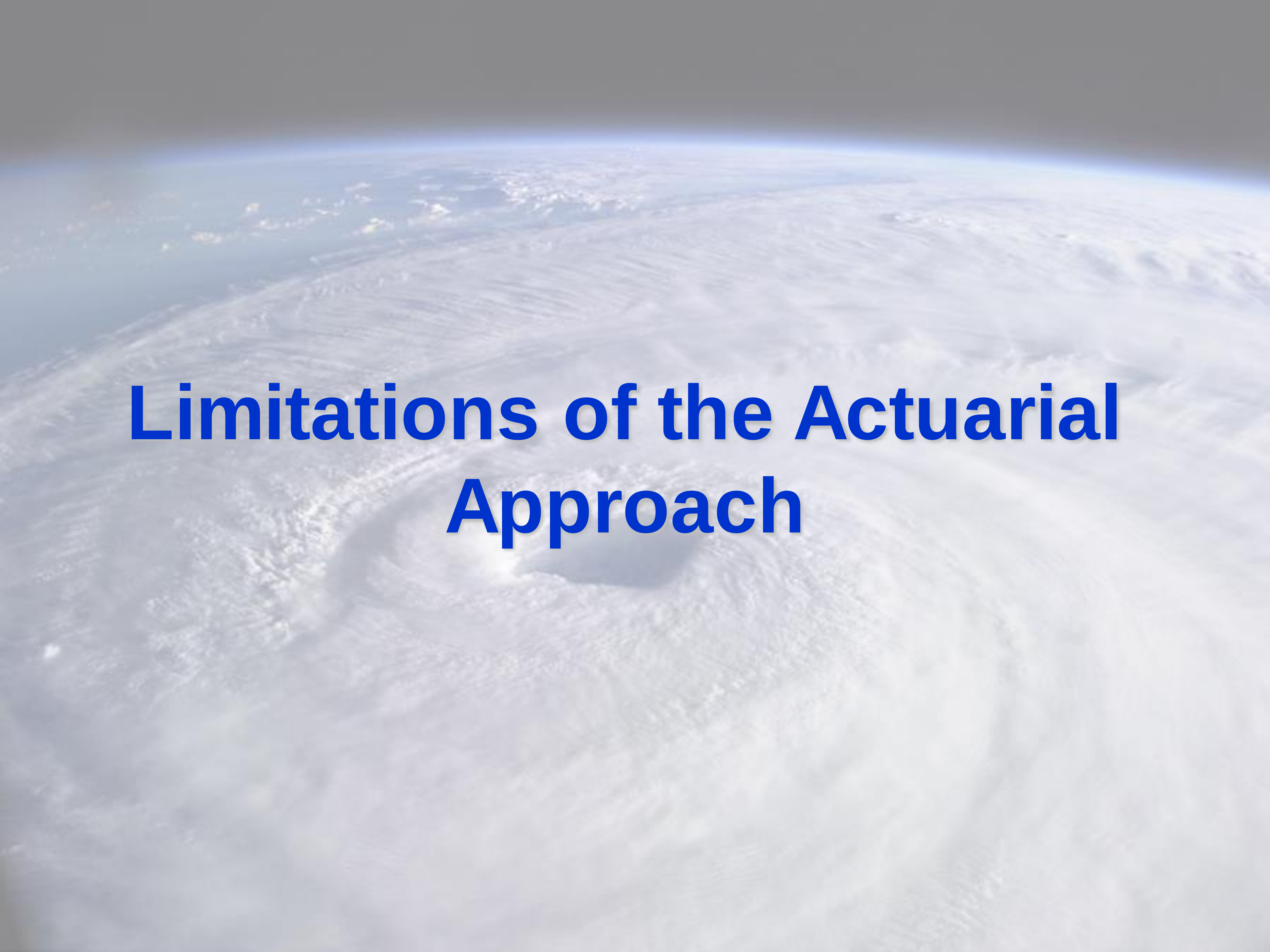
- Wind

- Rain

- Storm Surge

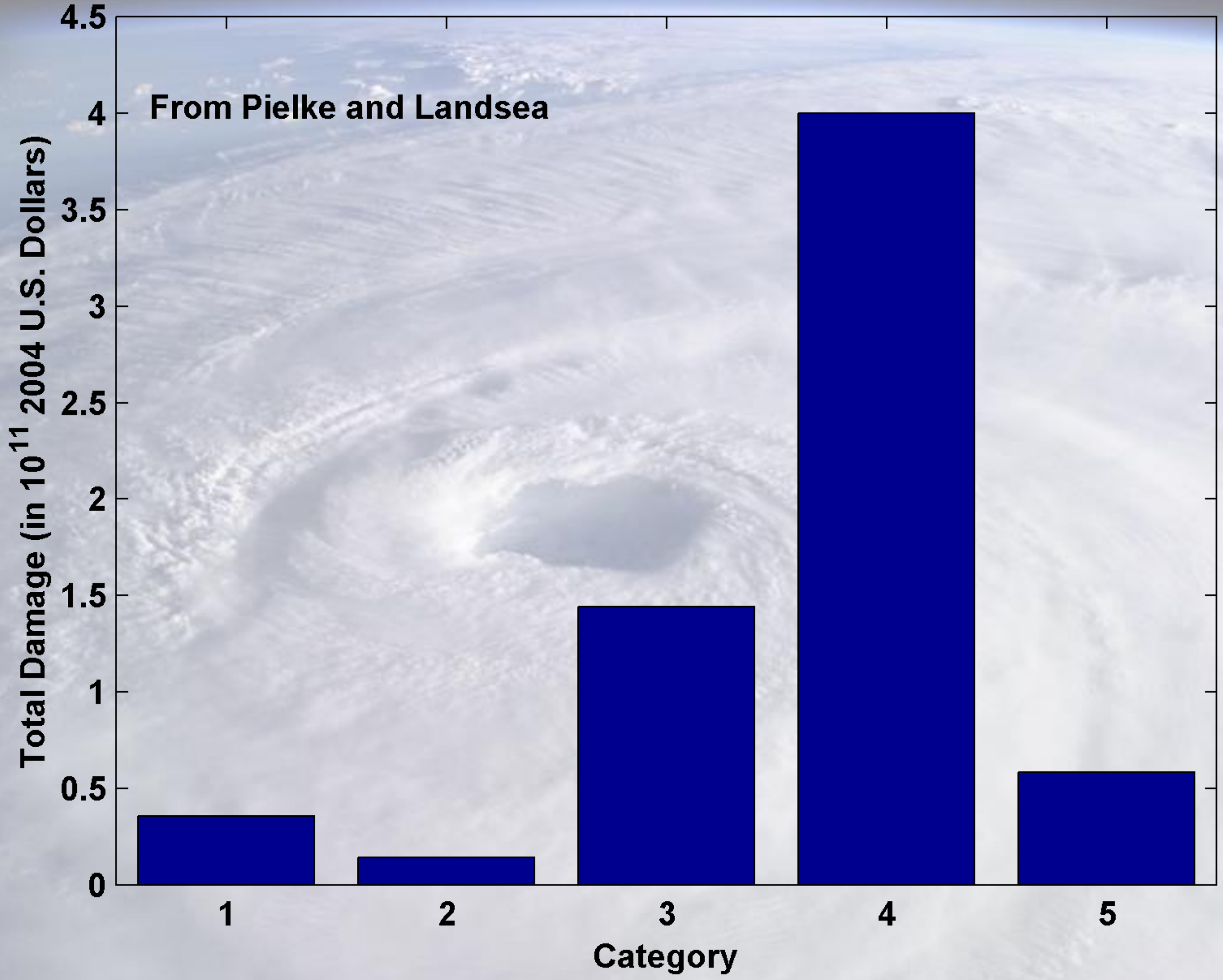


Source: Rappaport, E. N., 1999:
The threat to life in inland areas of the United States from Atlantic tropical cyclones.
Prepreints 23rd Conferenceon Hurricanes and Tropical Meteorology ,
American Meteorological Society (10-15 Jan 1999, Dallas Tx), 339-342.

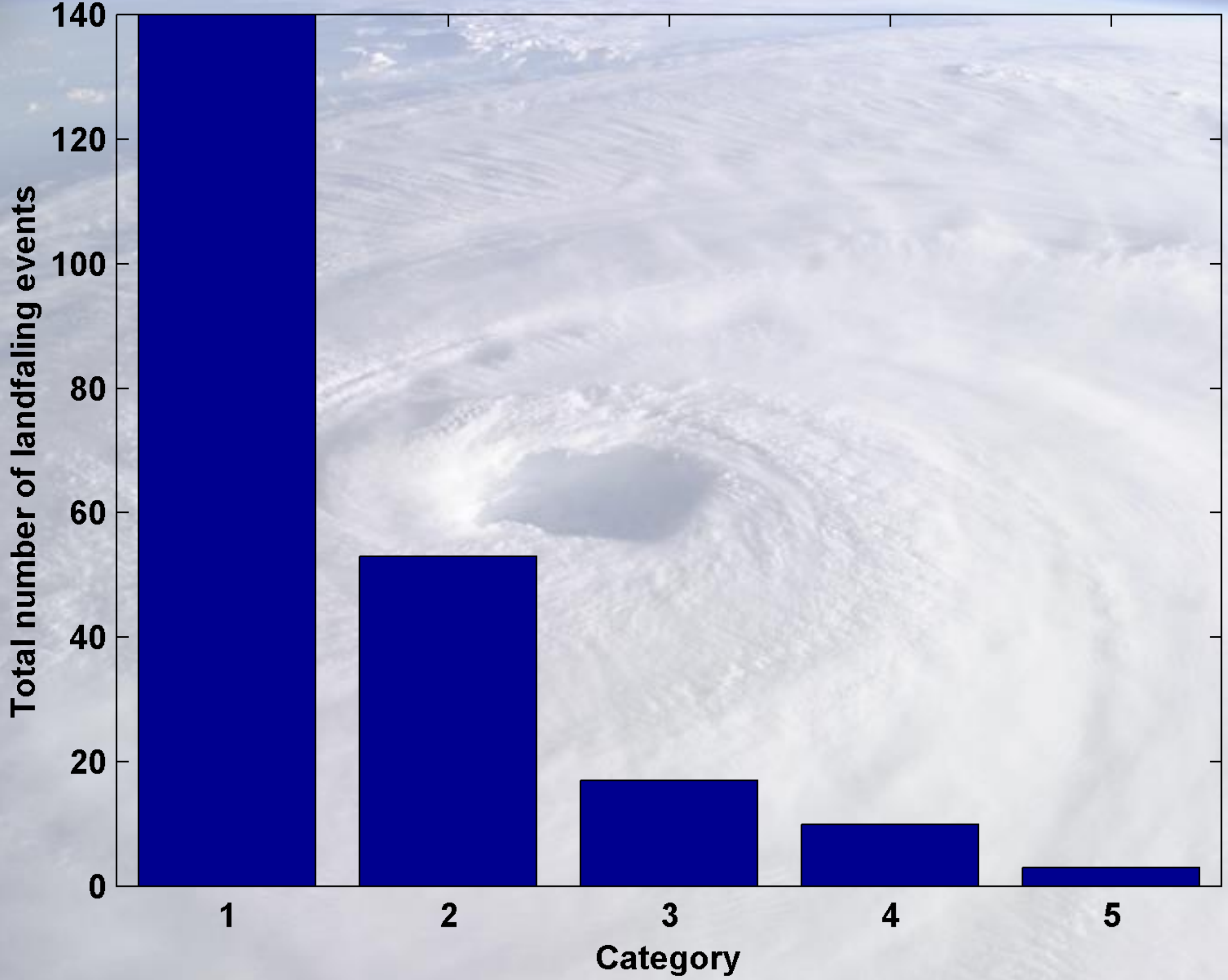


Limitations of the Actuarial Approach

U.S. Hurricane Damage, 1900-2004,Adjusted for Inflation, Wealth, and Population



Total Number of Landfall Events, by Category, 1870-2004

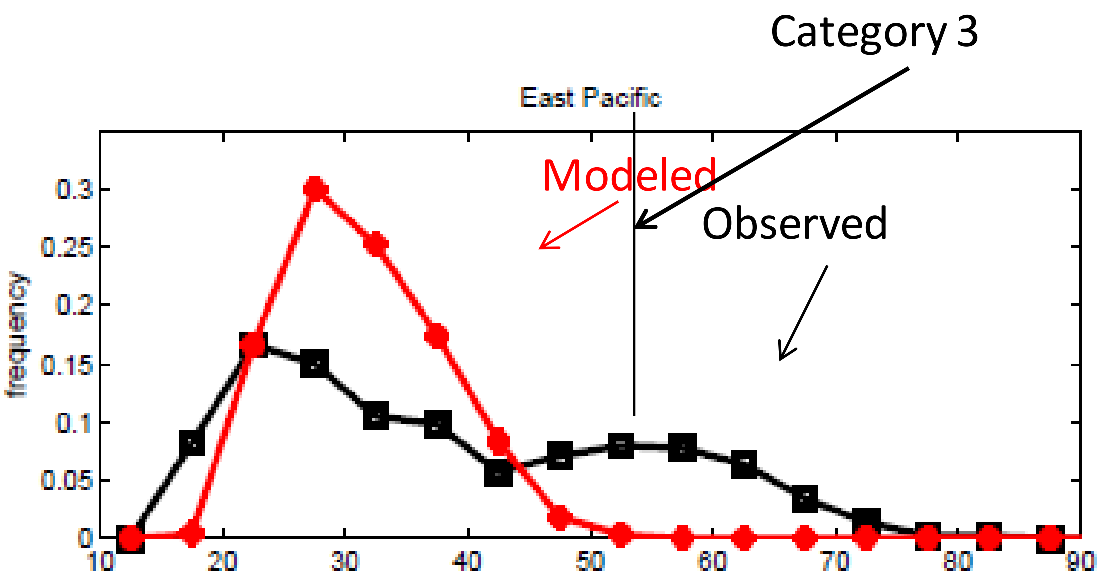


Limitations of a strictly statistical approach to hurricane risk assessment

- >50% of all normalized U.S. hurricane damage caused by **top 8 events**, all category 3, 4 and 5
- >90% of all damage caused by storms of category 3 and greater
- Category 3,4 and 5 events are only 13% of total landfalling events; only 30 since 1870
- ∴ ***Landfalling storm statistics are inadequate for assessing hurricane risk***

Risk Assessment by Direct Numerical Simulation of Hurricanes:
The Problem

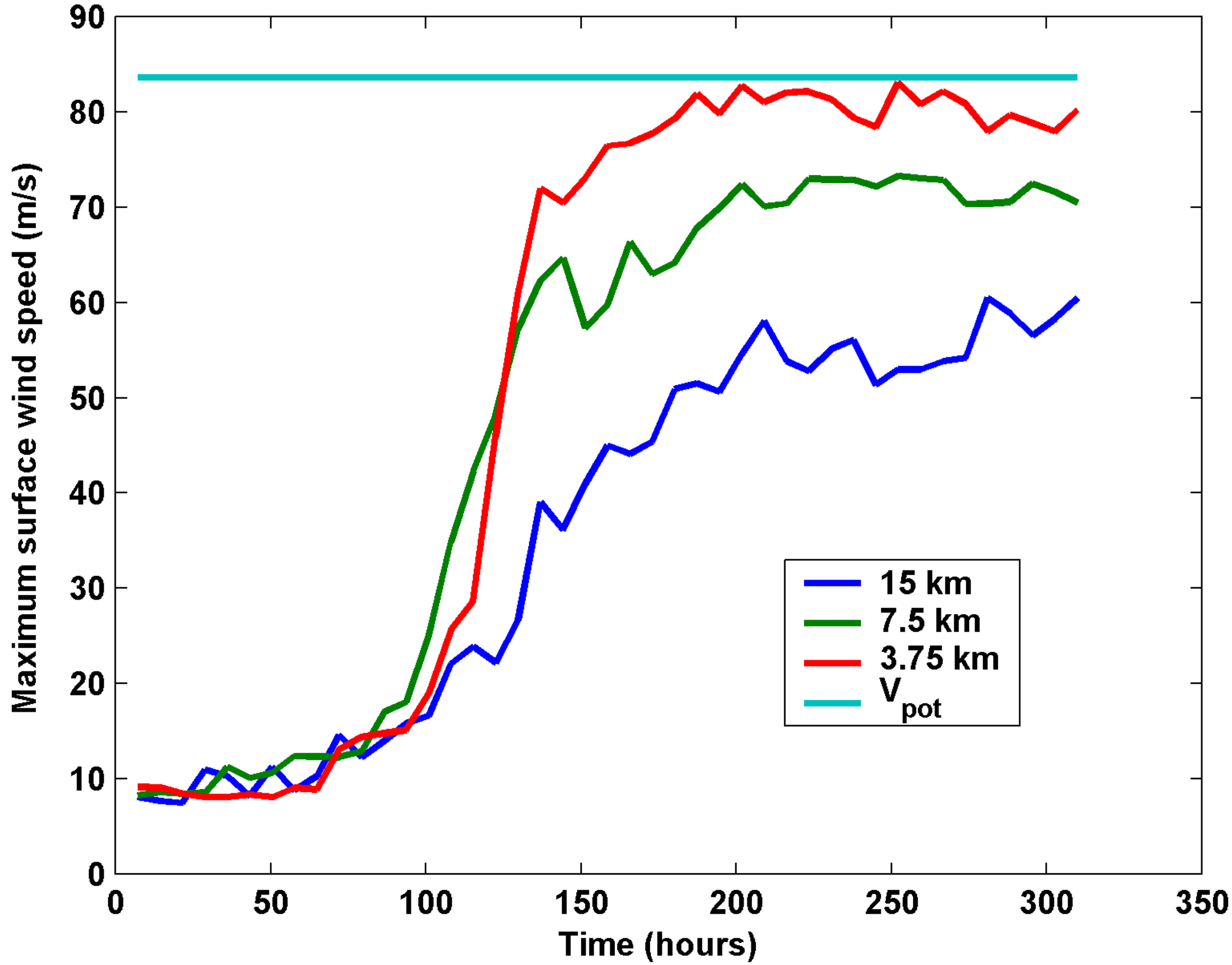
- **The hurricane eyewall is a front, attaining scales of ~ 1 km or less**
- **At the same time, the storm's circulation extends to ~1000 km and is embedded in much larger scale flows**
- **The computational nodes of global models are typically spaced 100 km apart**



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

Numerical convergence in an axisymmetric, nonhydrostatic model (Rotunno and Emanuel, 1987)



How to deal with this?

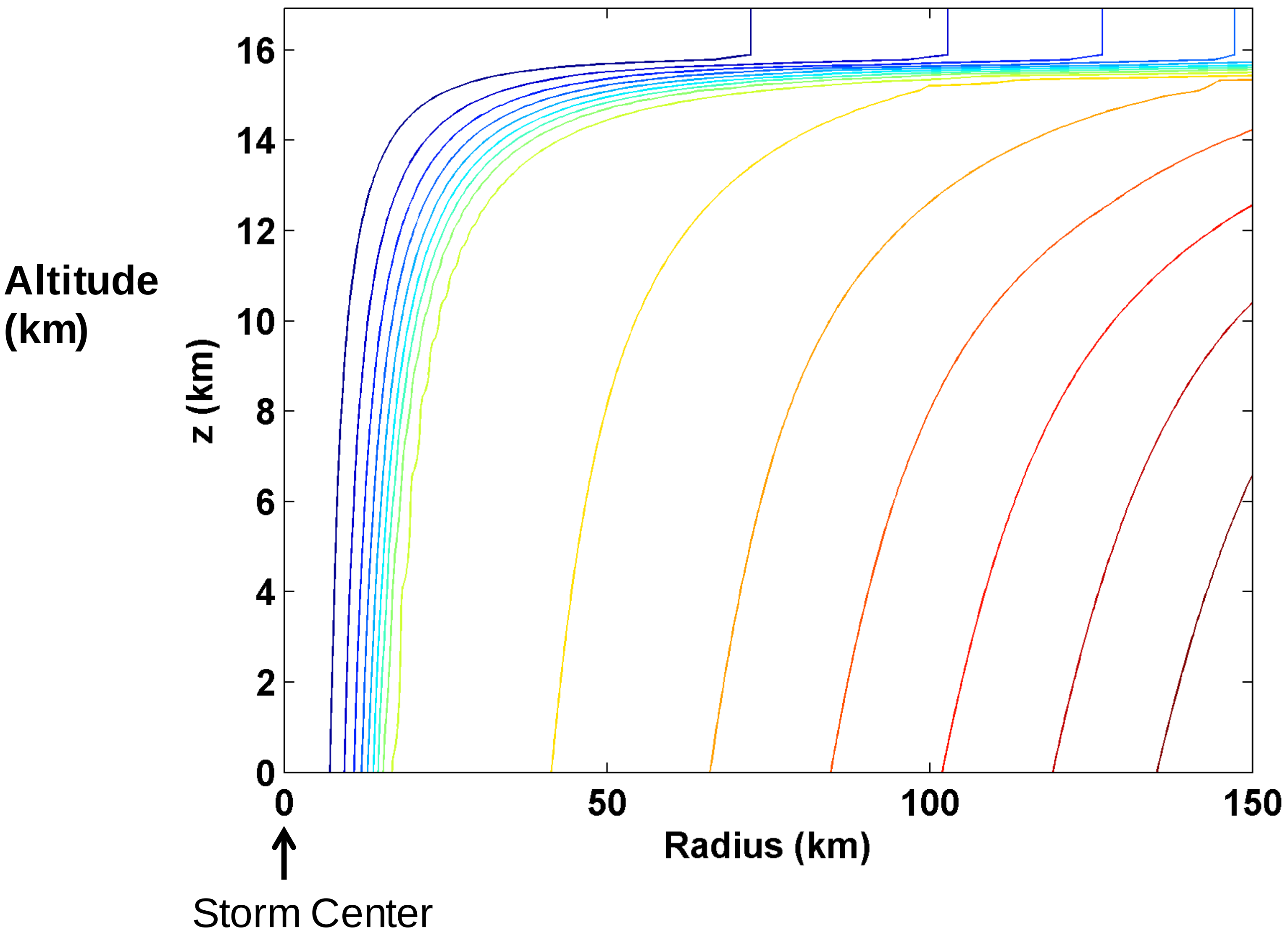
- **Embed high-resolution, fast coupled ocean-atmosphere hurricane model in GCM or reanalysis data**

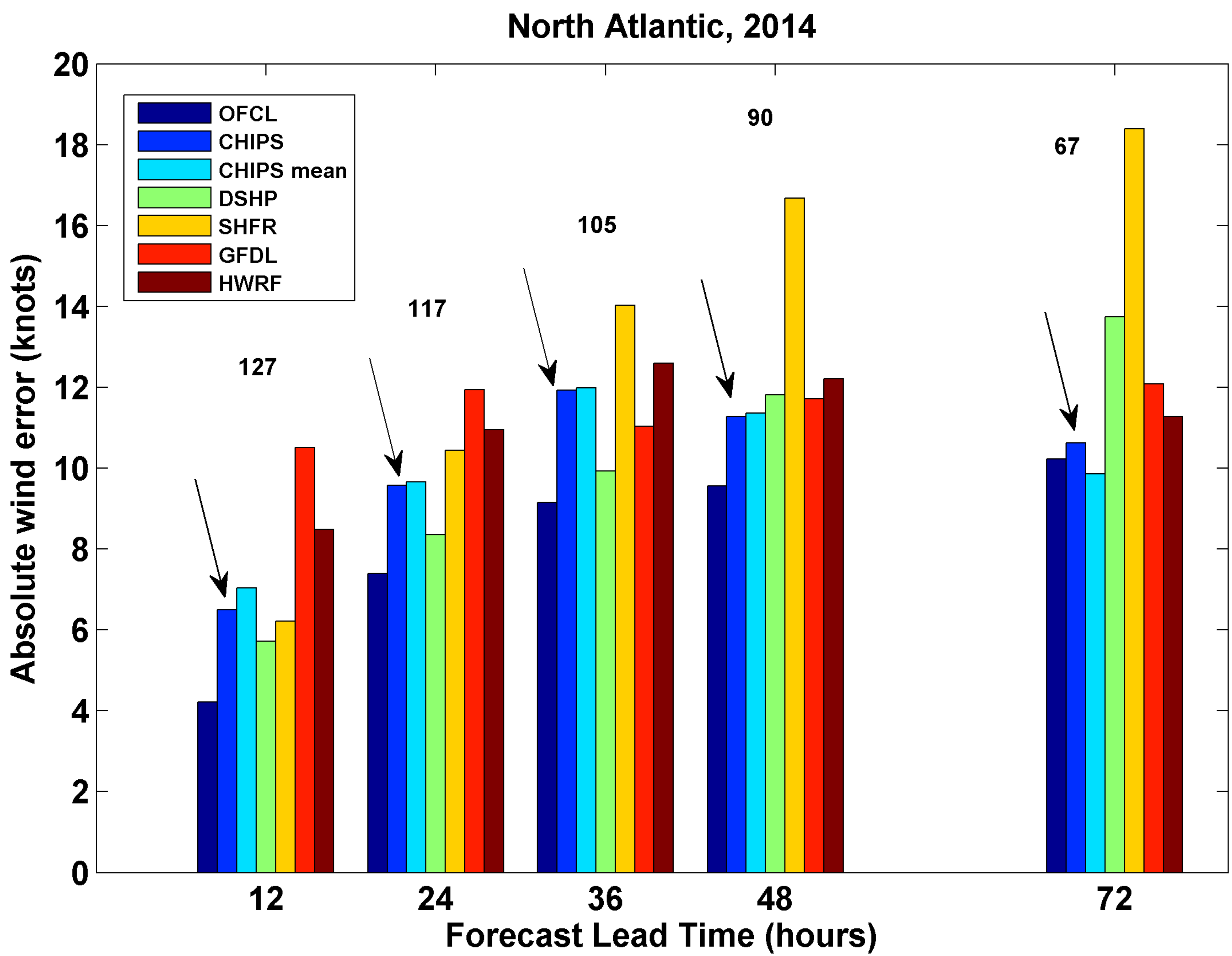
Time-dependent, axisymmetric model phrased in R space

$$M = rV + \frac{1}{2} fr^2 \qquad \frac{1}{2} fR^2 \equiv M \qquad f \equiv 2\Omega \sin\theta$$

- **Hydrostatic and gradient balance above PBL**
- **Moist adiabatic lapse rates on M surfaces above PBL**
- **Boundary layer quasi-equilibrium convection**
- **Deformation-based radial diffusion**
- **Coupled to simple 1-D ocean model**
- **Environmental wind shear effects parameterized**

Angular Momentum Distribution





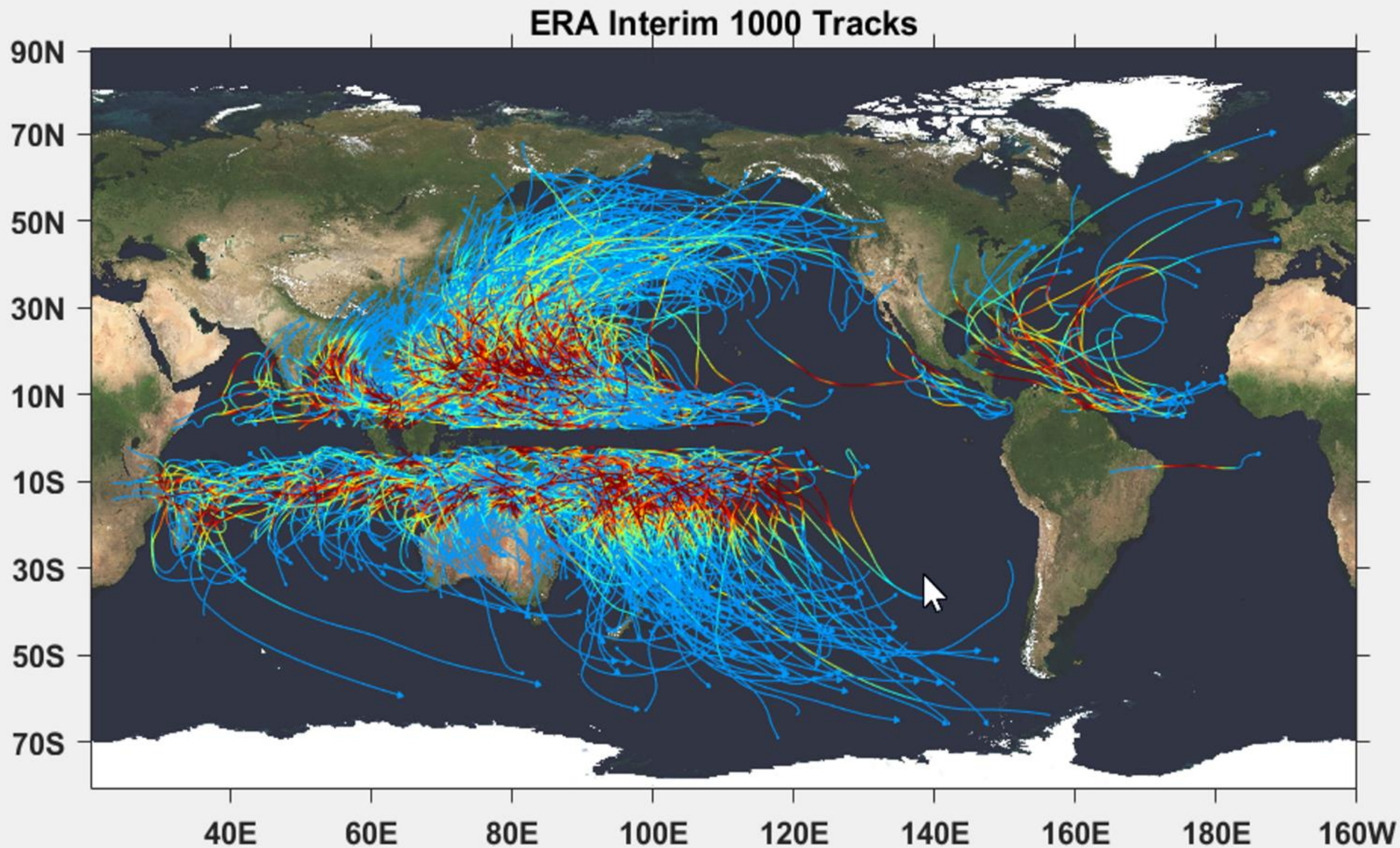
North Atlantic, 2014
Absolute wind error (knots)
Forecast Lead Time (hours)
0
2
4
6
8
10
12
14
16
18
20
12
24
36
48
72
OFCL
CHIPS
CHIPS mean
DSHP
SHFR
GFDL
HWRF
127
117
105
90
67

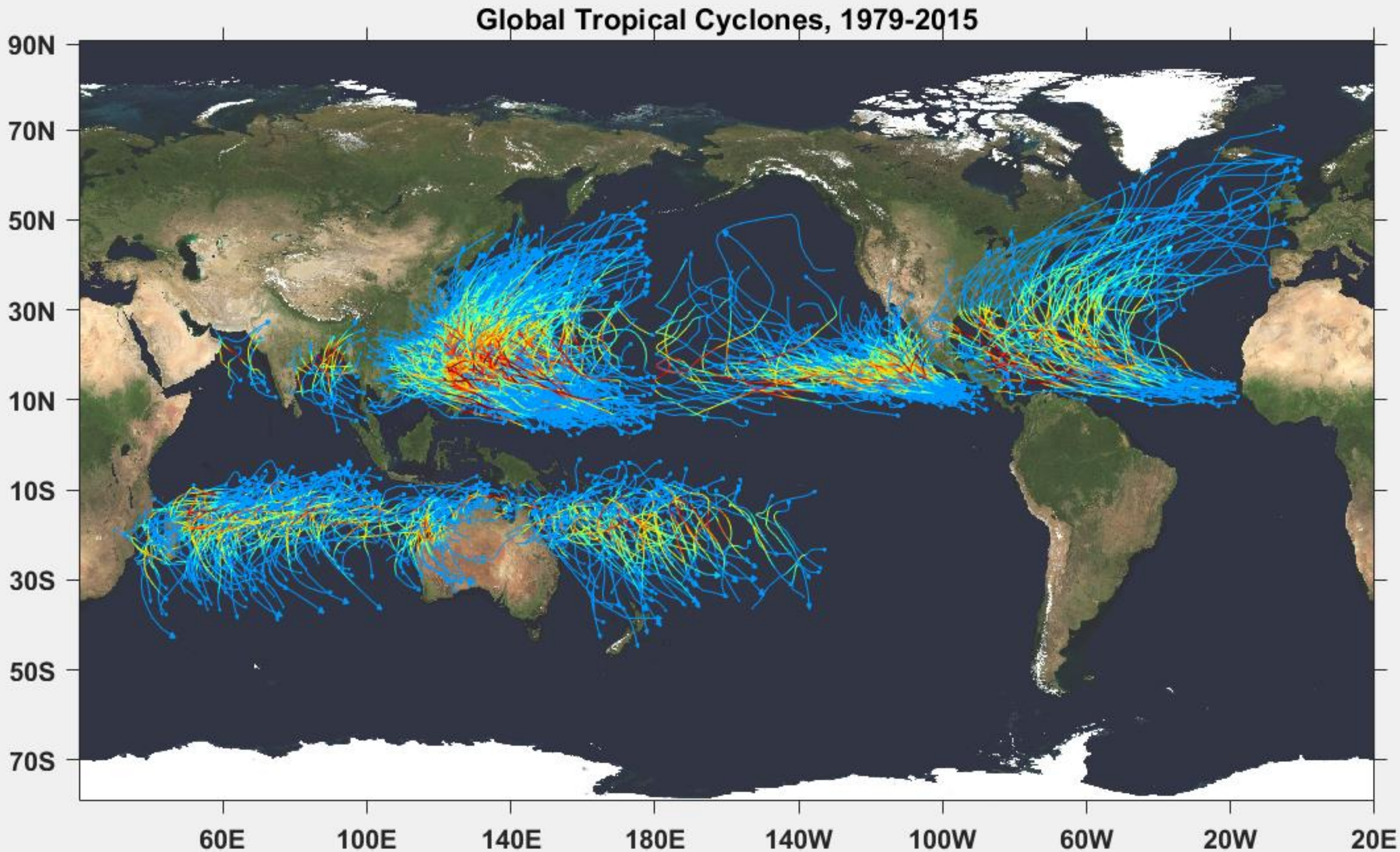
How Can We Use This Model to Help Assess Hurricane Risk in Current and Future Climates?

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

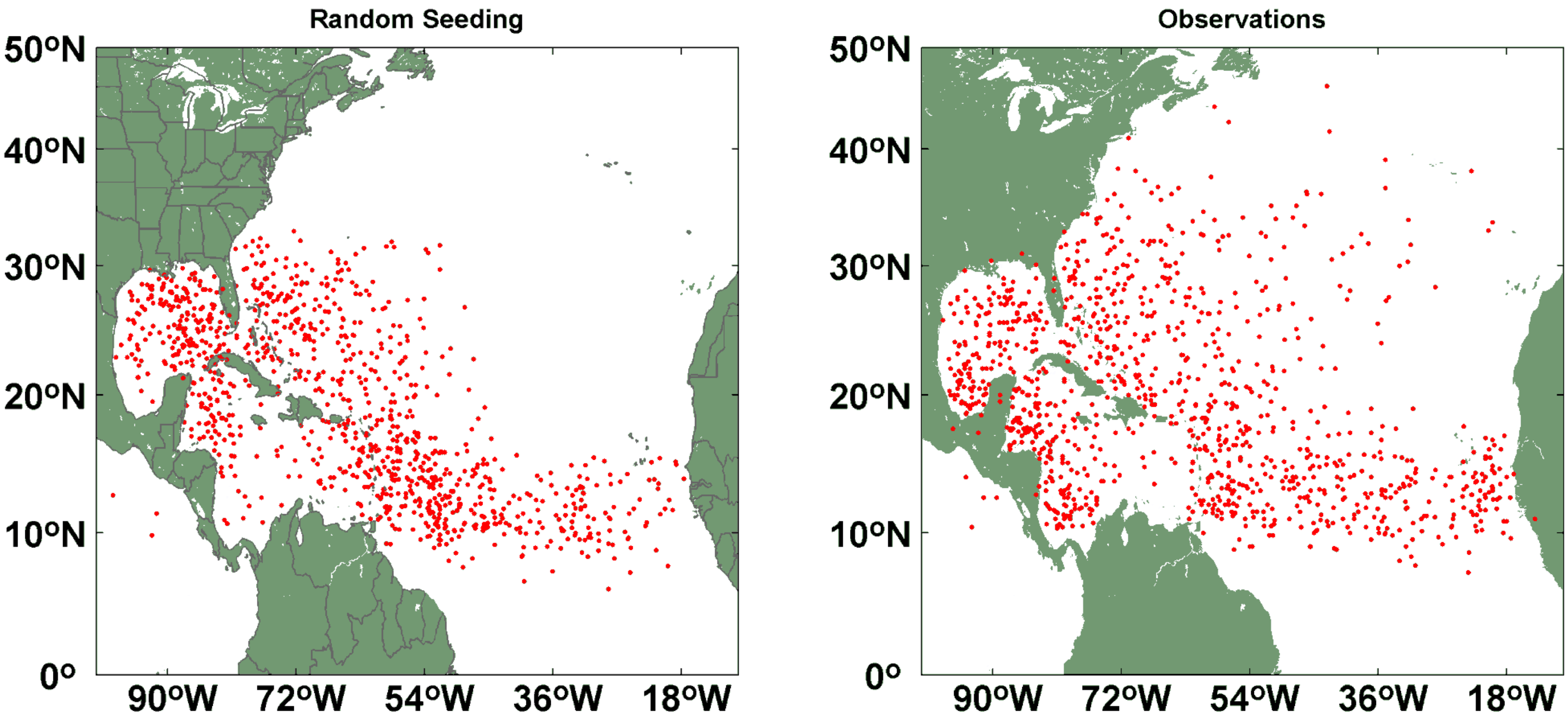
Details: Emanuel et al., *Bull. Amer. Meteor. Soc*, 2008


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

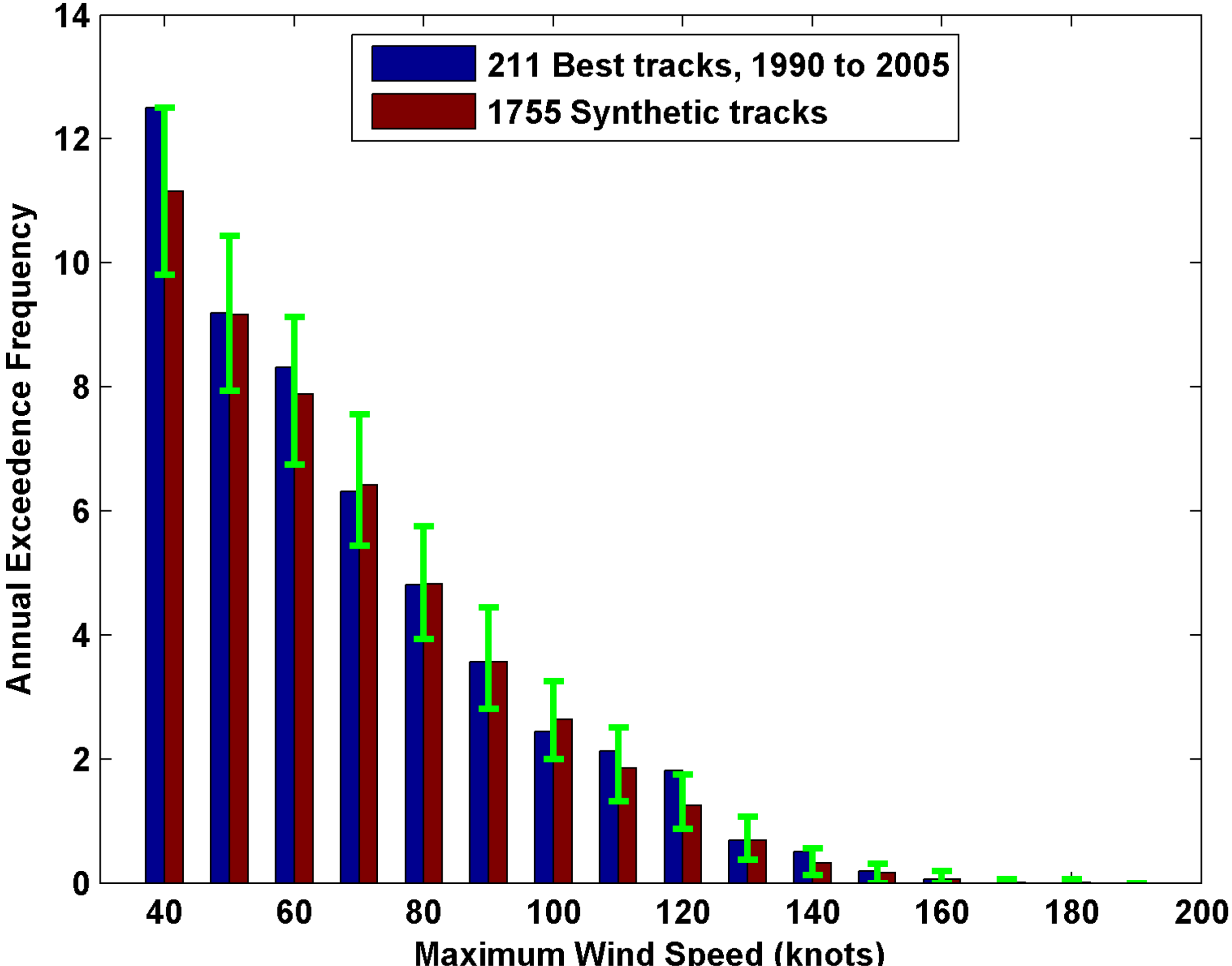


Global Tropical Cyclones, 1979-2015
90N
70N
50N
30N
10N
10S
30S
50S
70S
60E
100E
140E
180E
140W
100W
60W
20W
20E

Comparison of Random Seeding Genesis Locations with Observations

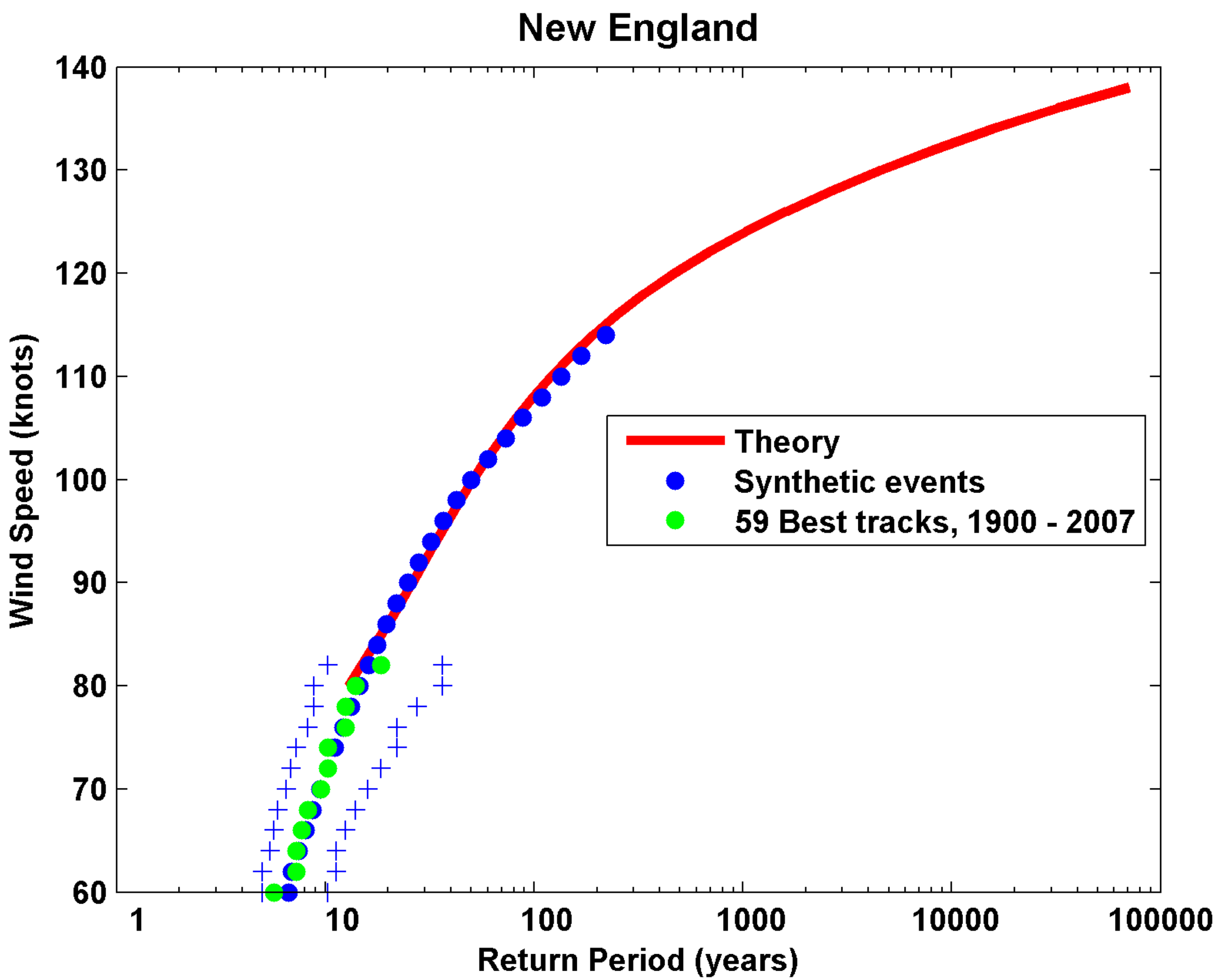


Cumulative Distribution of Storm Lifetime Peak Wind Speed, with Sample of 1755 Synthetic Tracks

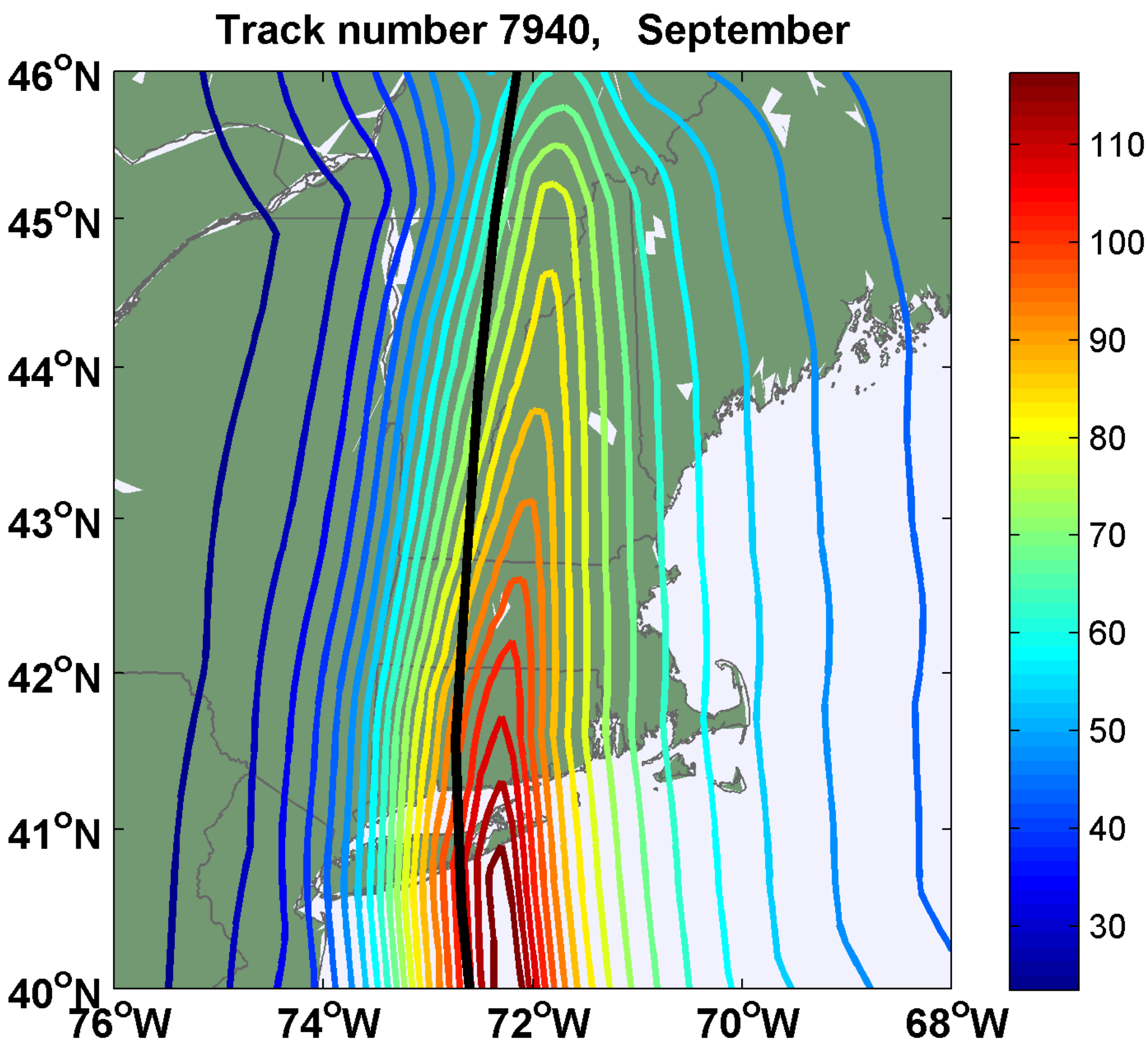


90% confidence bounds

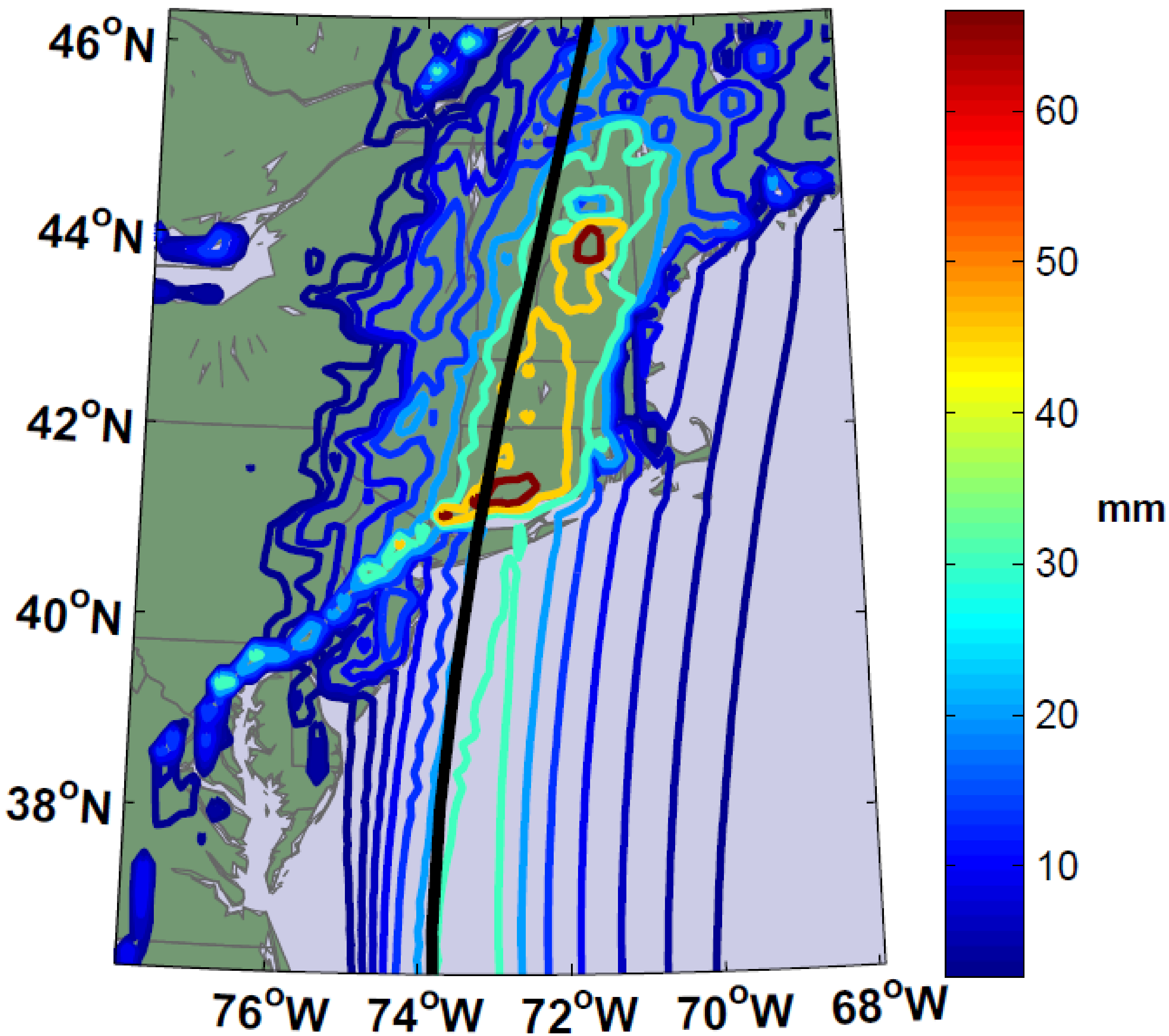
Return Periods



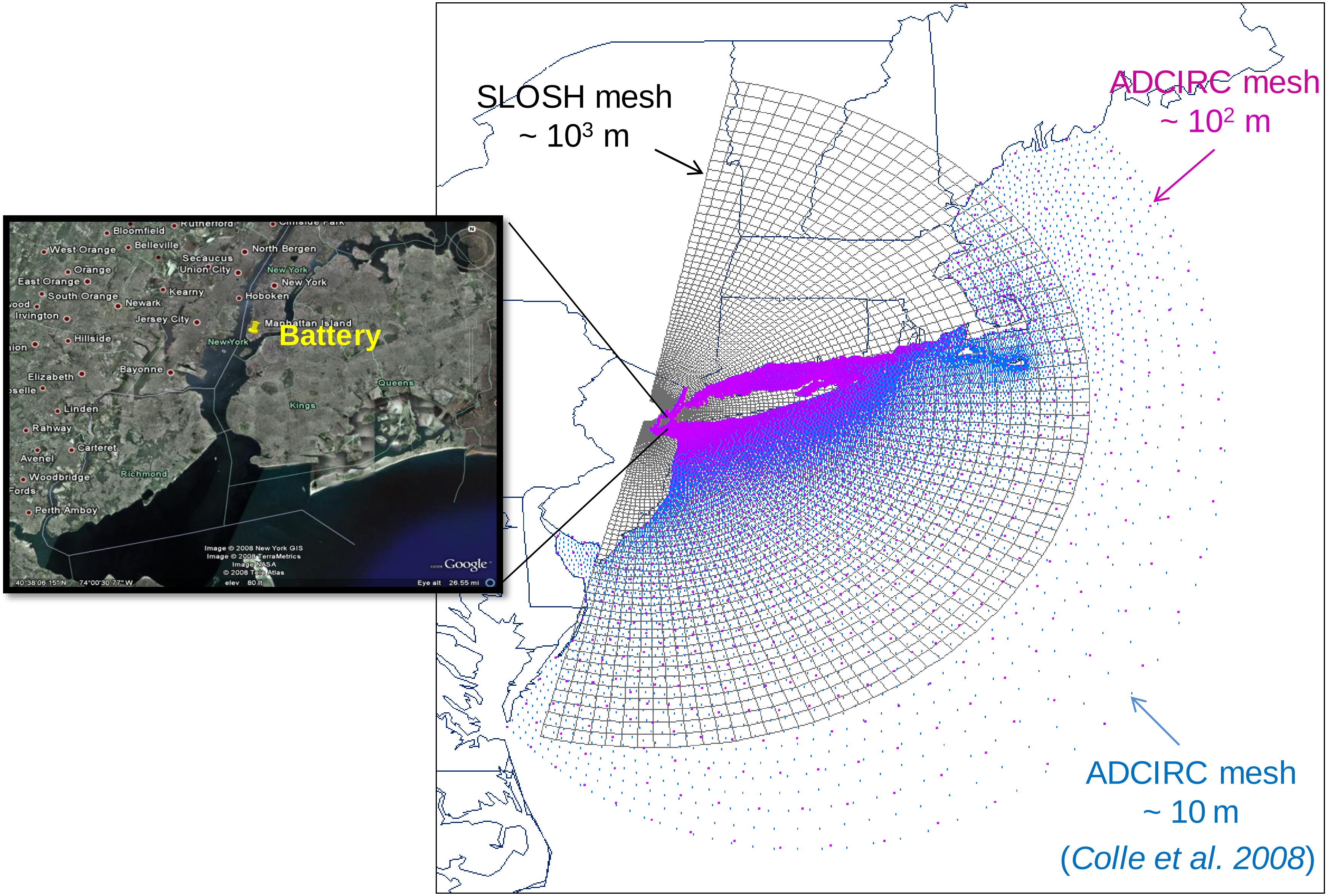
Sample Storm Wind Swath

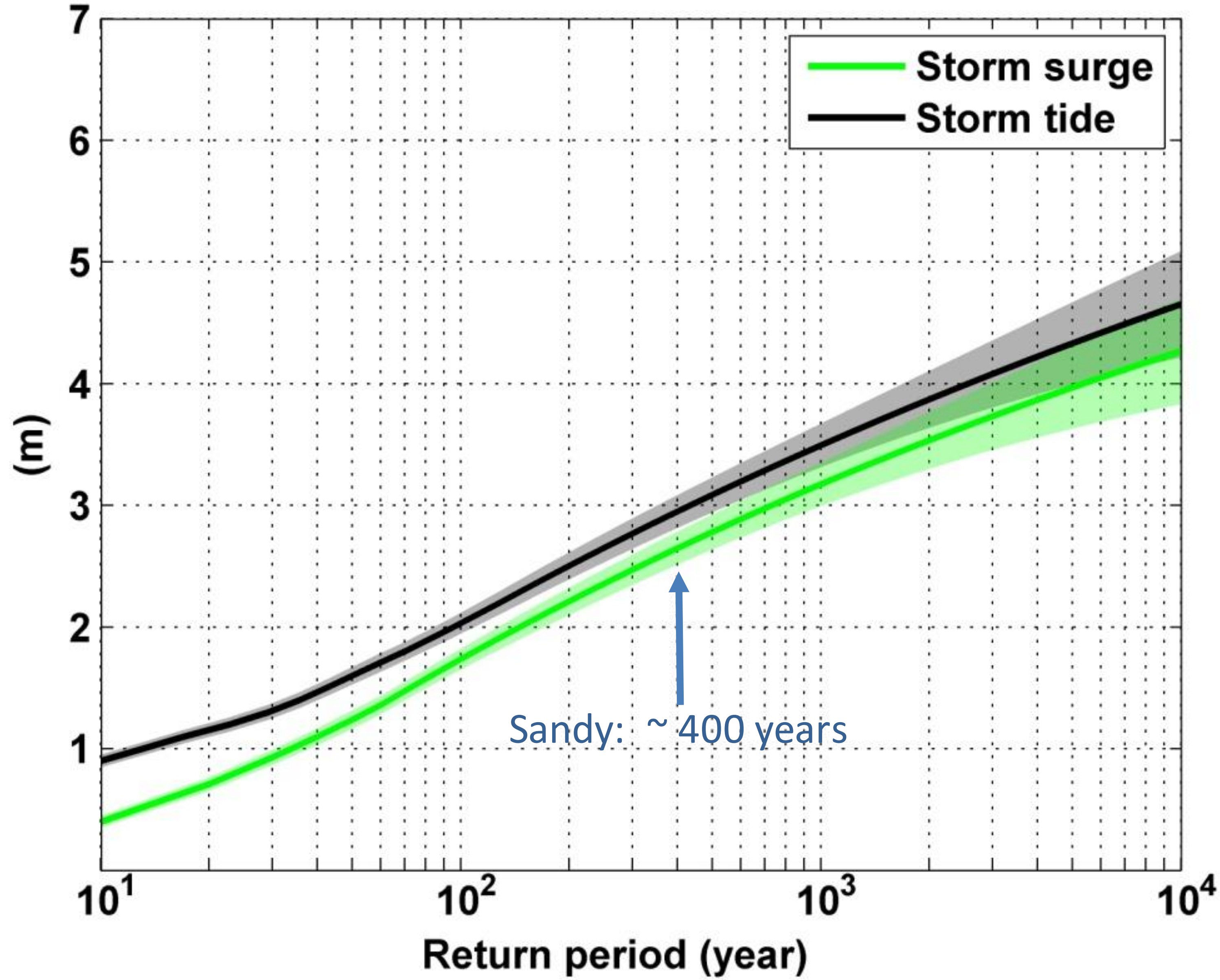


Accumulated Rainfall (mm)



Storm Surge Simulation

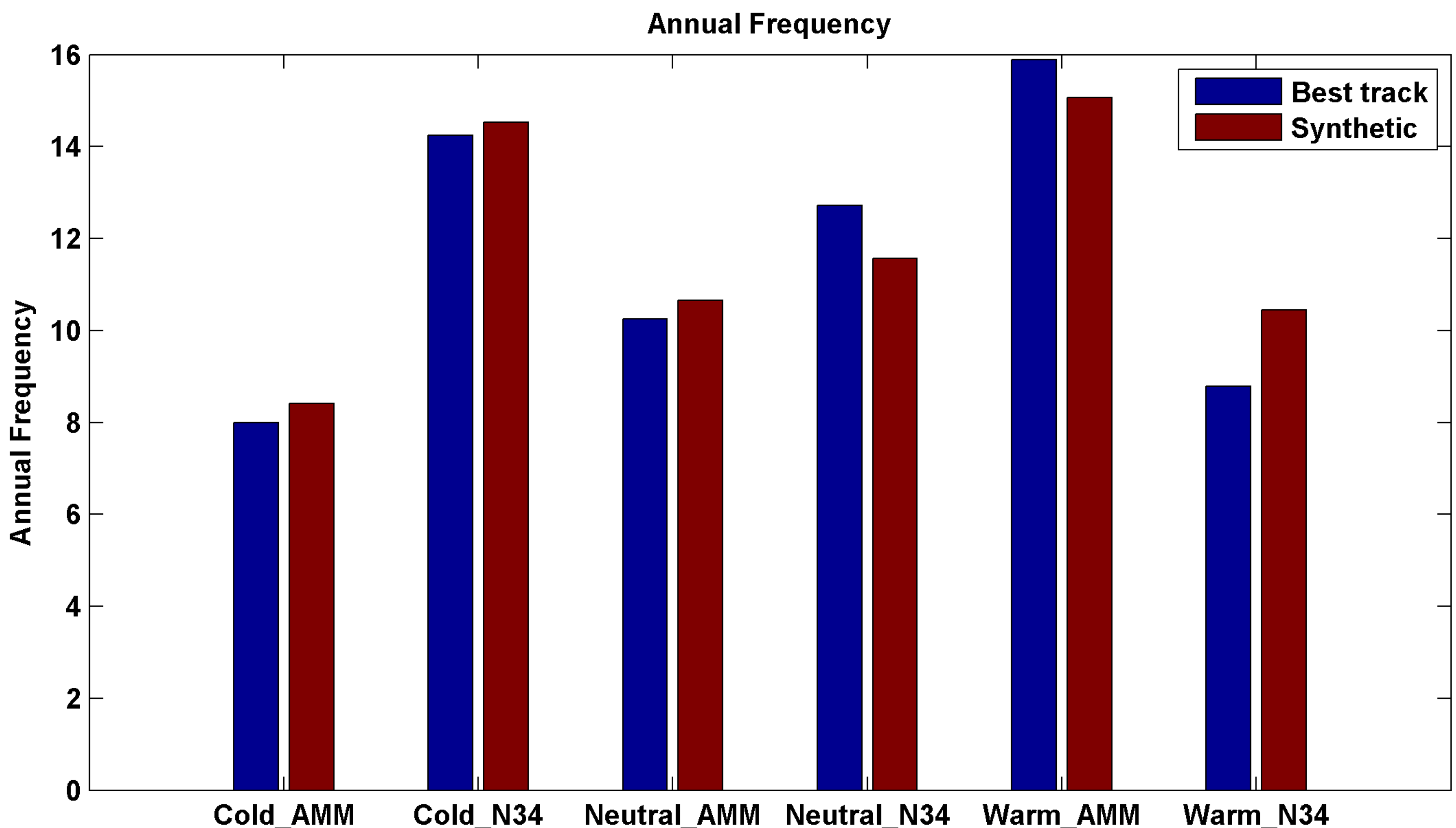




7
6
5
4
3
2
1
(m)
Storm surge
Storm tide
Sandy: ~ 400 years
10^1
10^2
10^3
10^4
Return period (year)

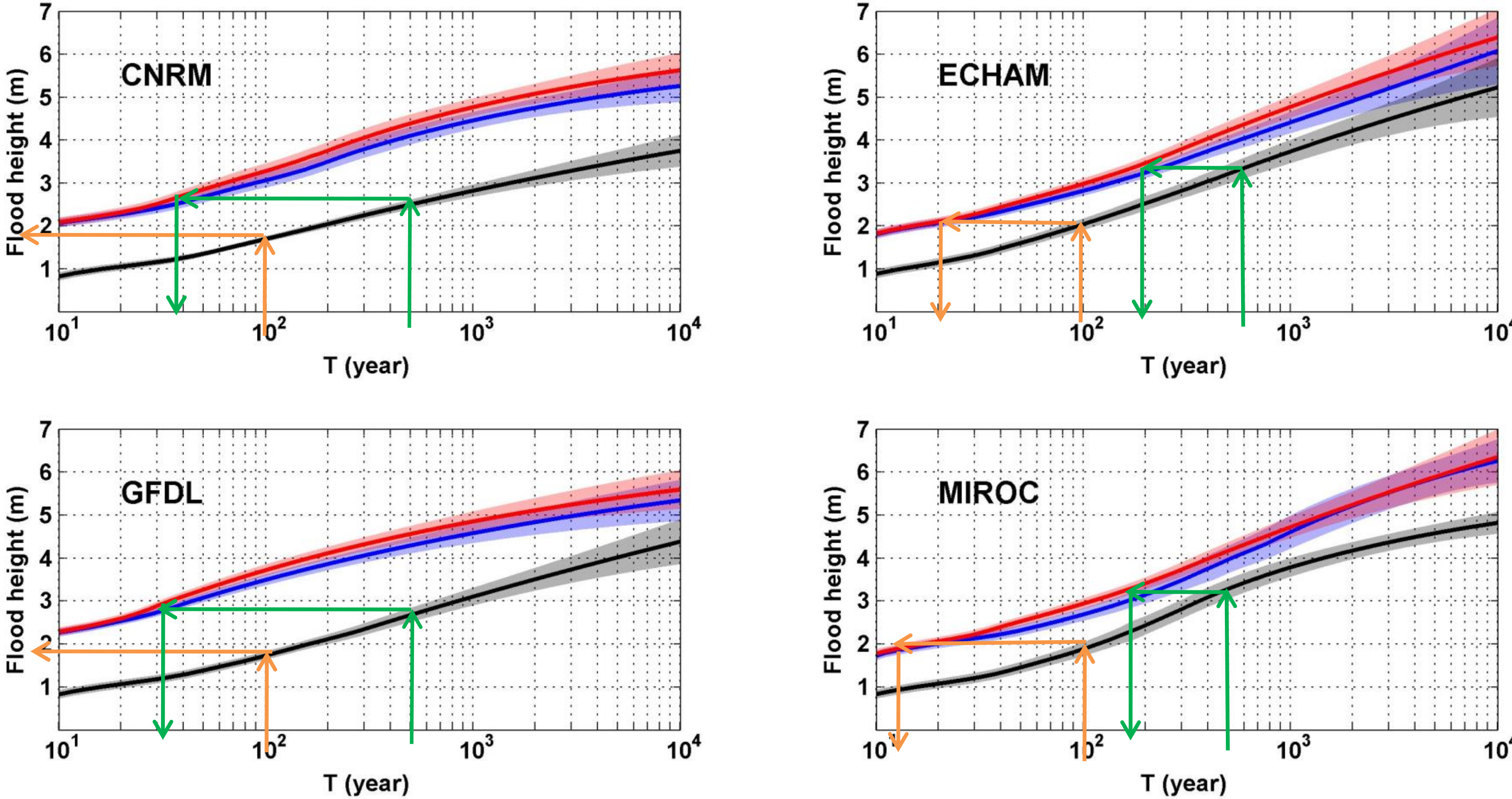
Taking Climate Change Into Account

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



GCM flood height return level, Battery, Manhattan

(assuming SLR of 1 m for the future climate)



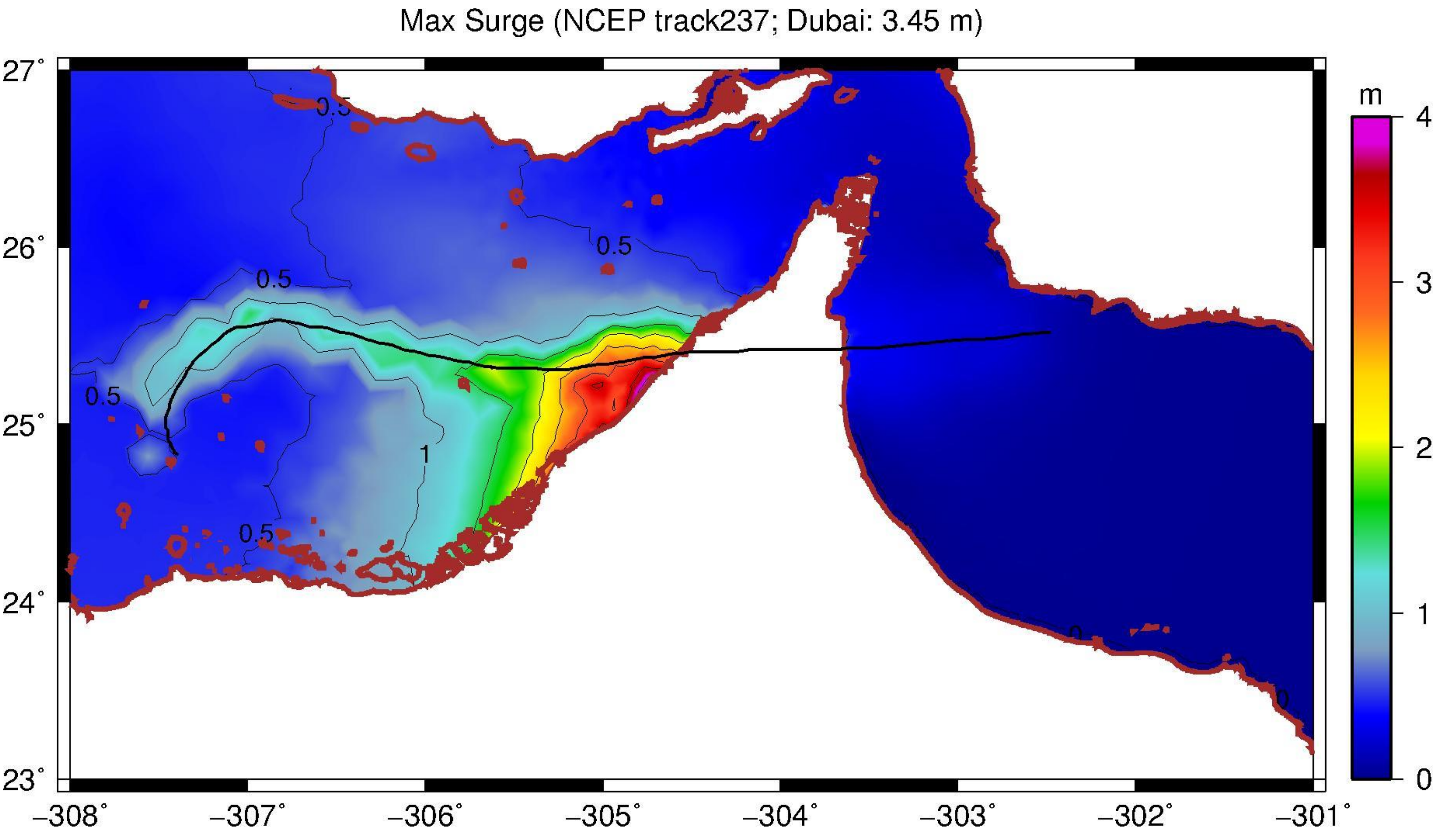
Black: Current climate (1981-2000)

Blue: A1B future climate (2081-2100)

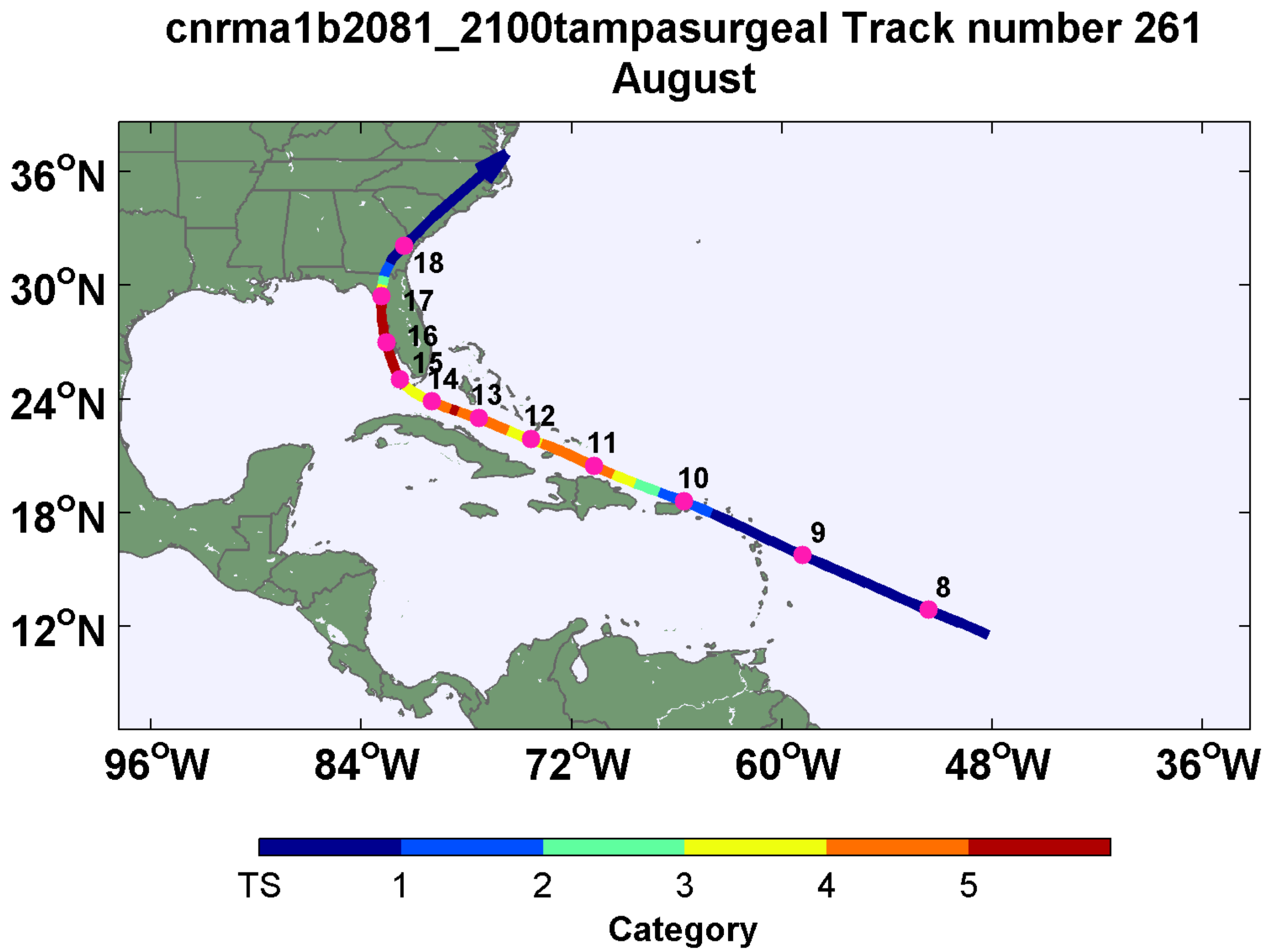
Red: A1B future climate (2081-2100) with R_0 increased by 10% and R_m increased by 21%

Lin et al. (2012)

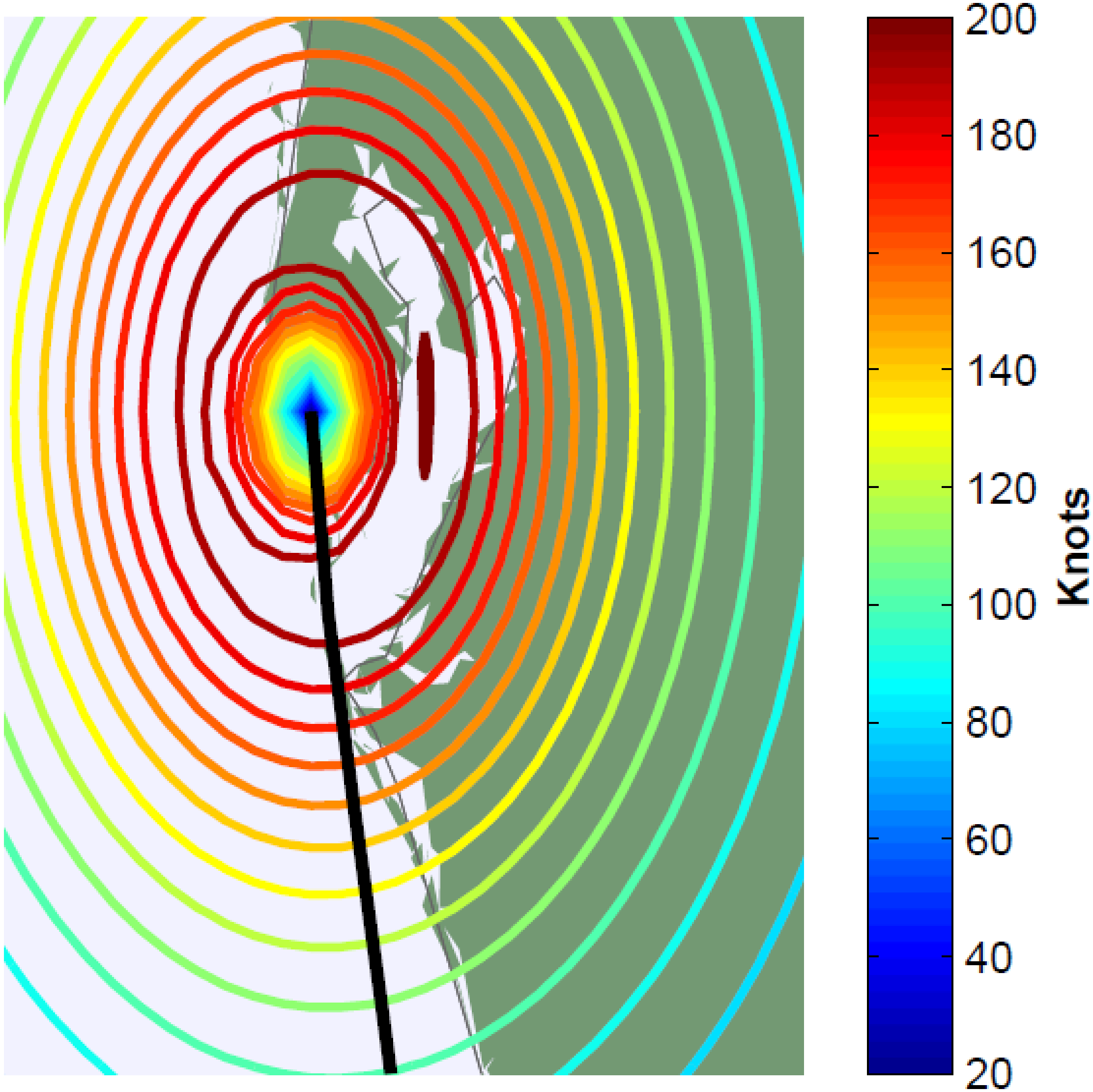
A Black Swan: Dubai



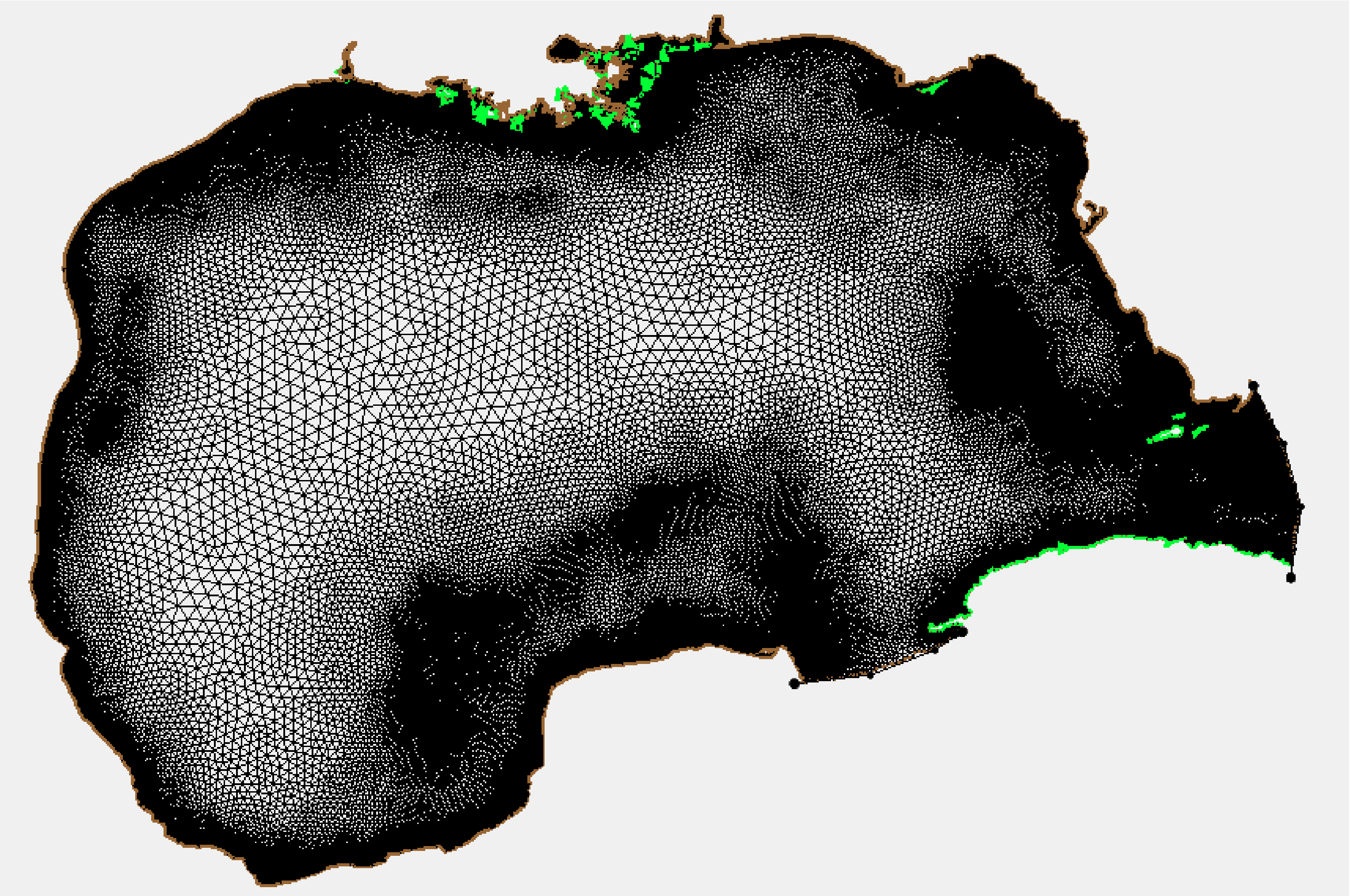
Black Swan Affecting Tampa



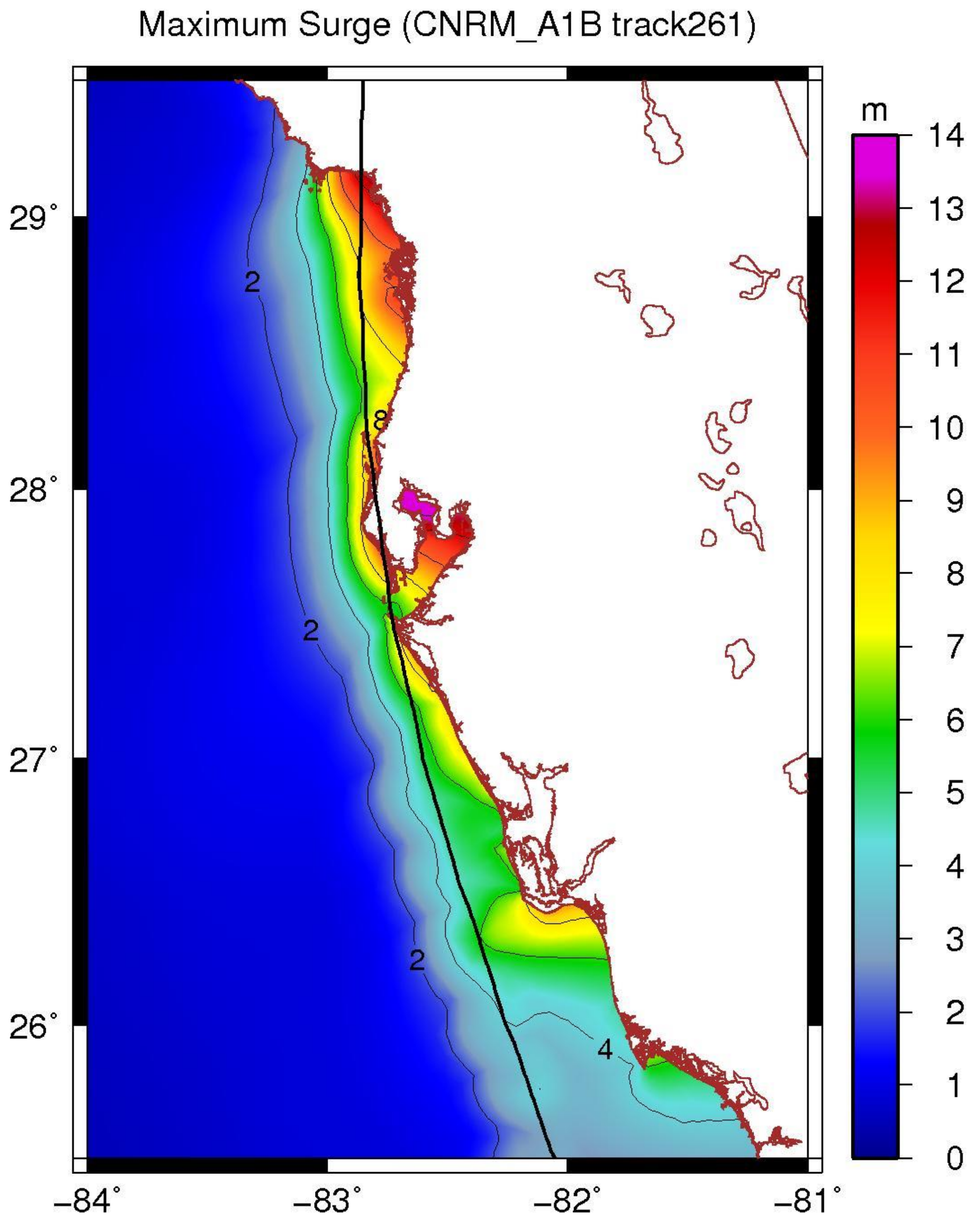
cnrma1b2081_2100tampasurgeal
Track number 261, August 16, 08:00 GMT



ADCIRC Mesh



Peak Surge at each point along Florida west coast



Summary

- History is too short and imperfect to estimate hurricane risk
- Better estimates can be made from downscaling hurricane activity from climatological or global model output
- Hurricanes clearly vary with climate and there is a risk that hurricane threats will increase over this century