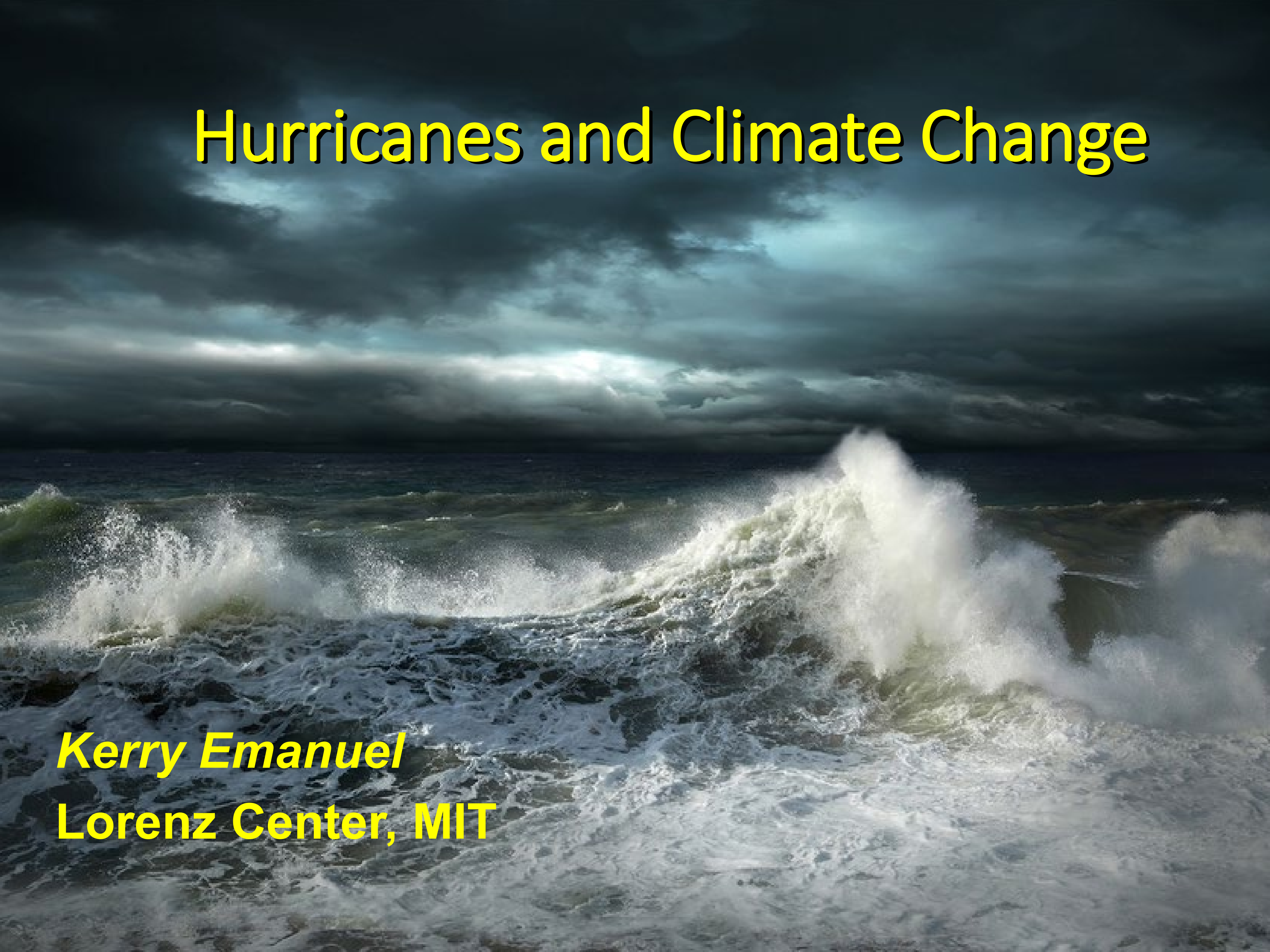


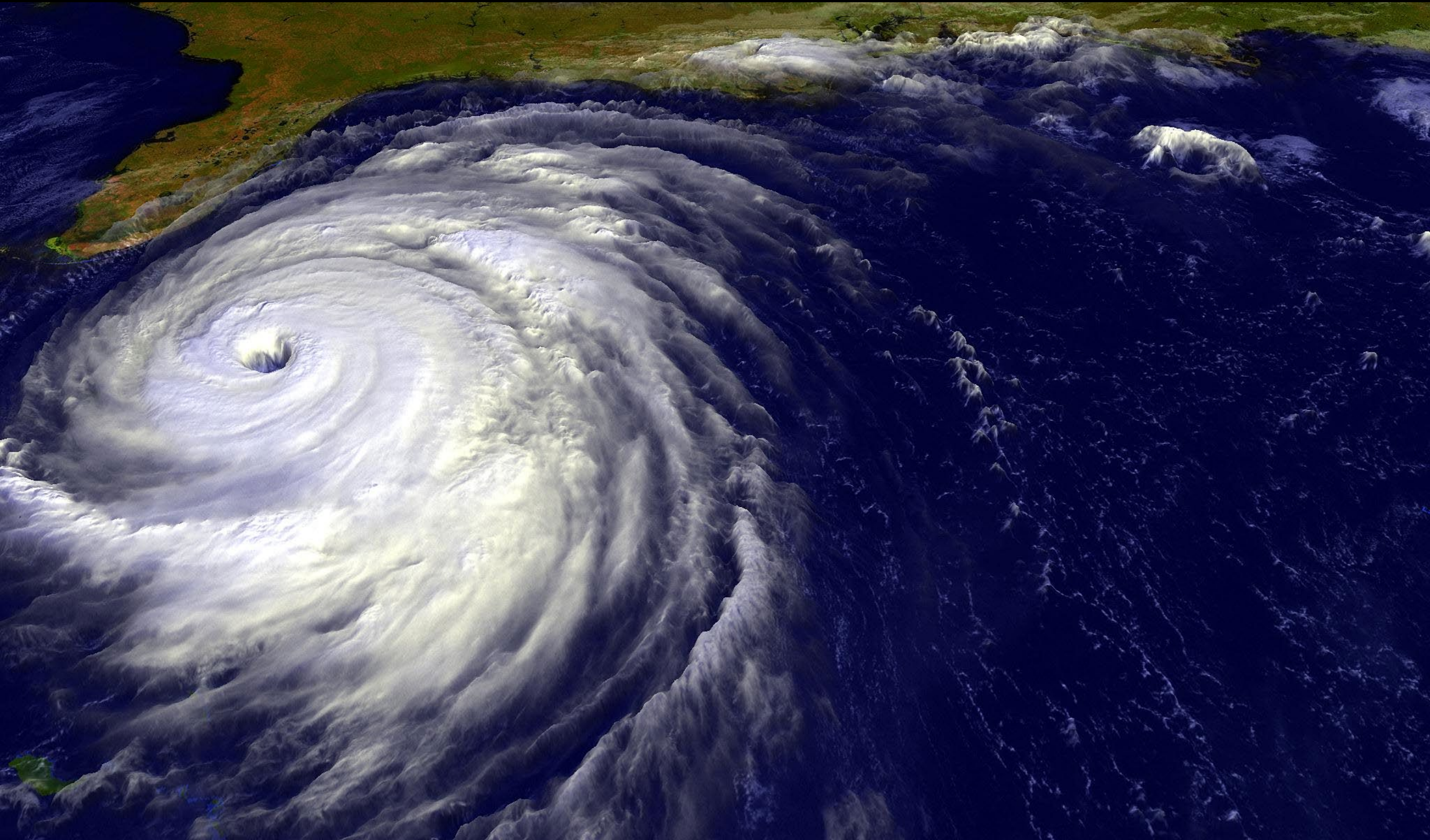
Hurricanes and Climate Change

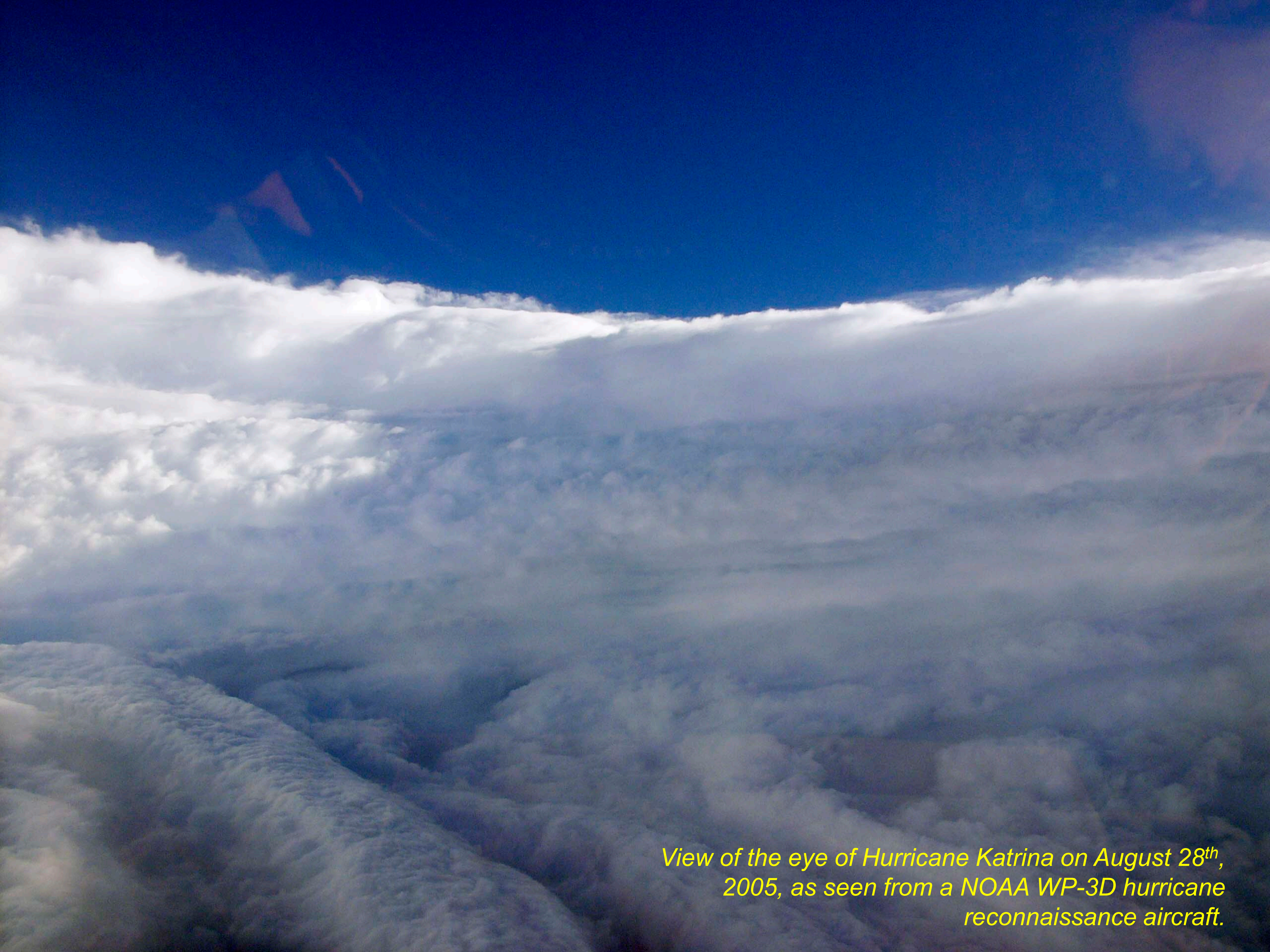
Kerry Emanuel
Lorenz Center, MIT

Program

- Overview of hurricanes
- Overview of climate change
- How climate change might affect hurricanes
- Quantifying hurricane risk in a changing climate

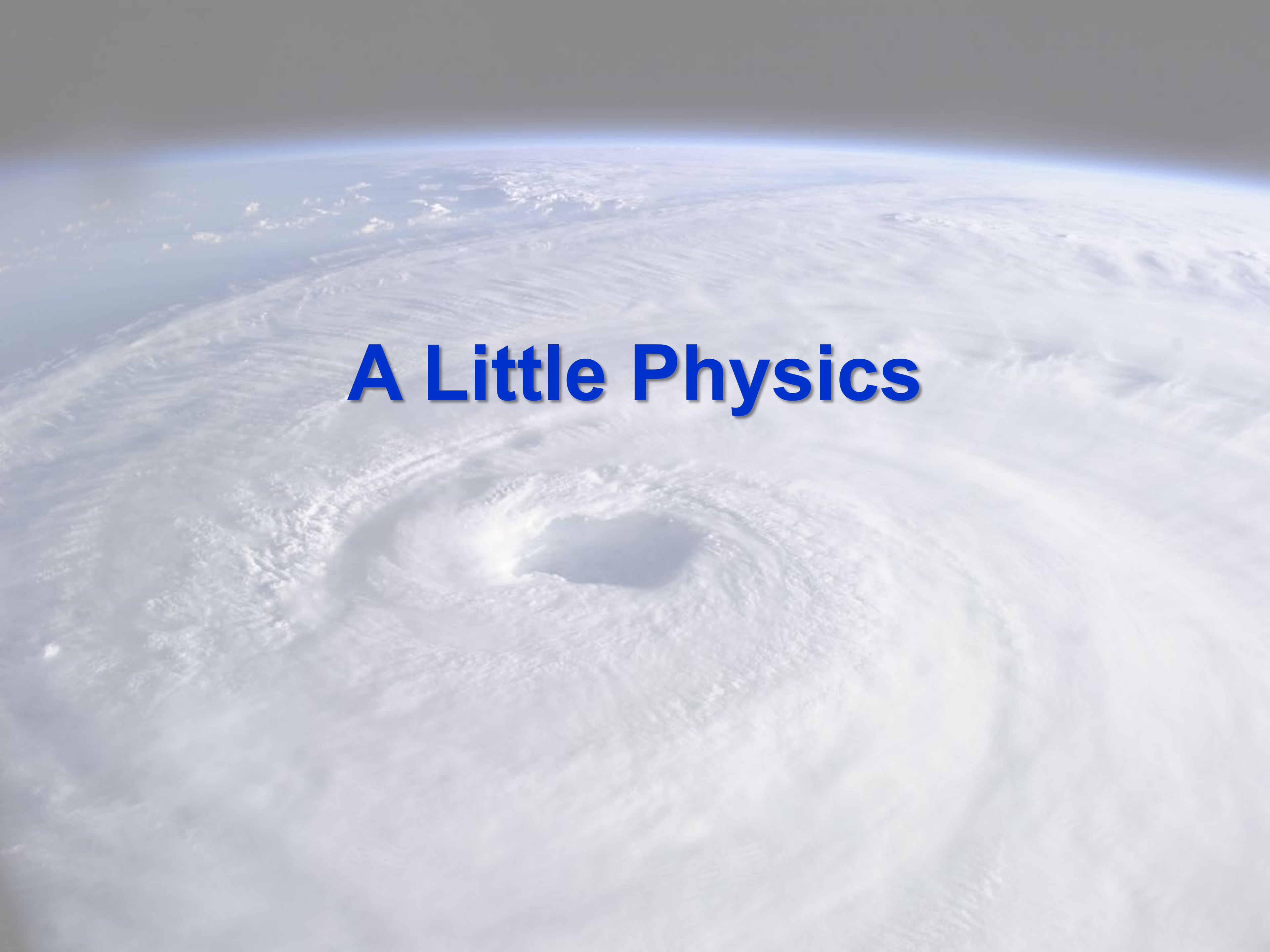
The View from Space



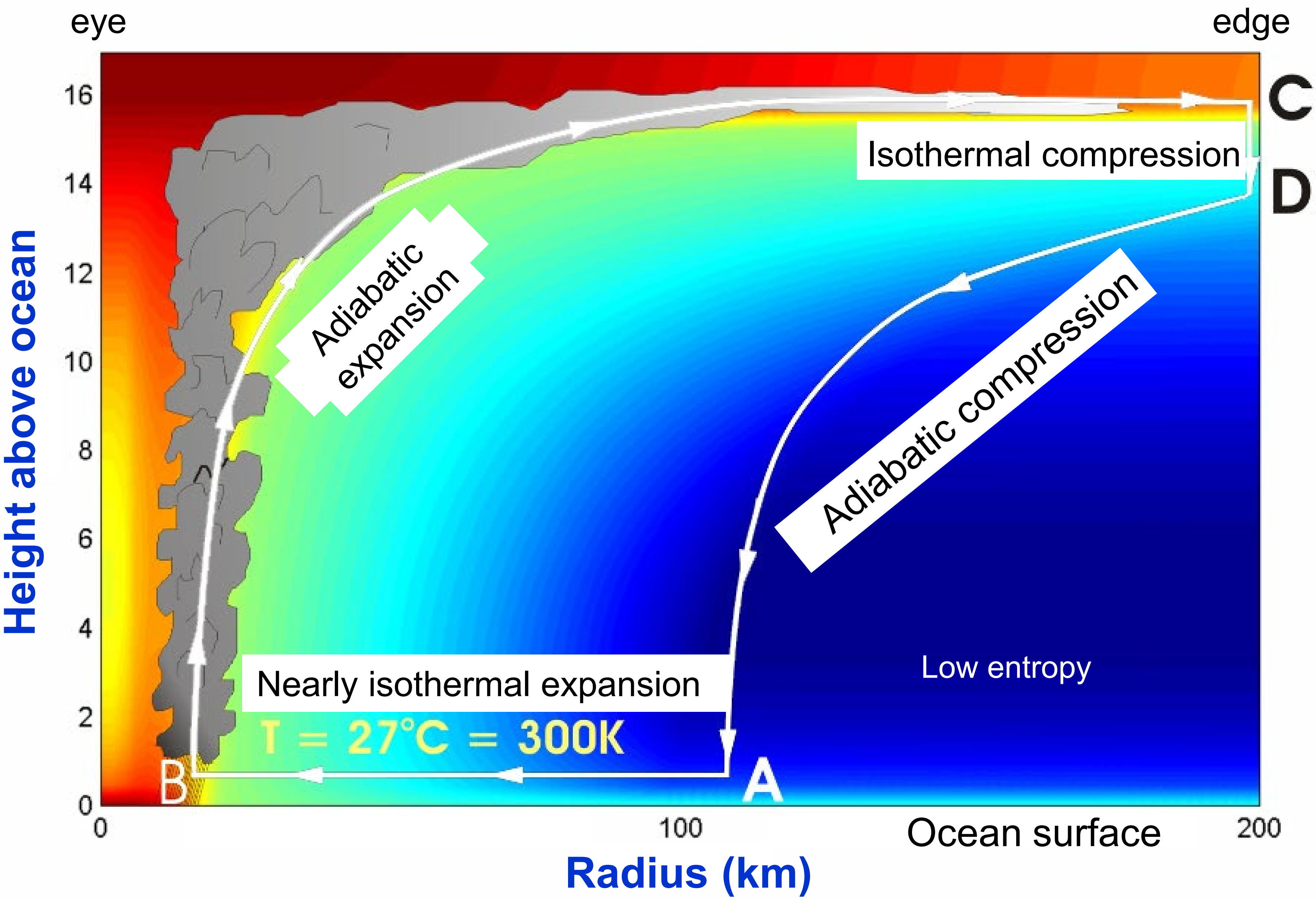


View of the eye of Hurricane Katrina on August 28th, 2005, as seen from a NOAA WP-3D hurricane reconnaissance aircraft.

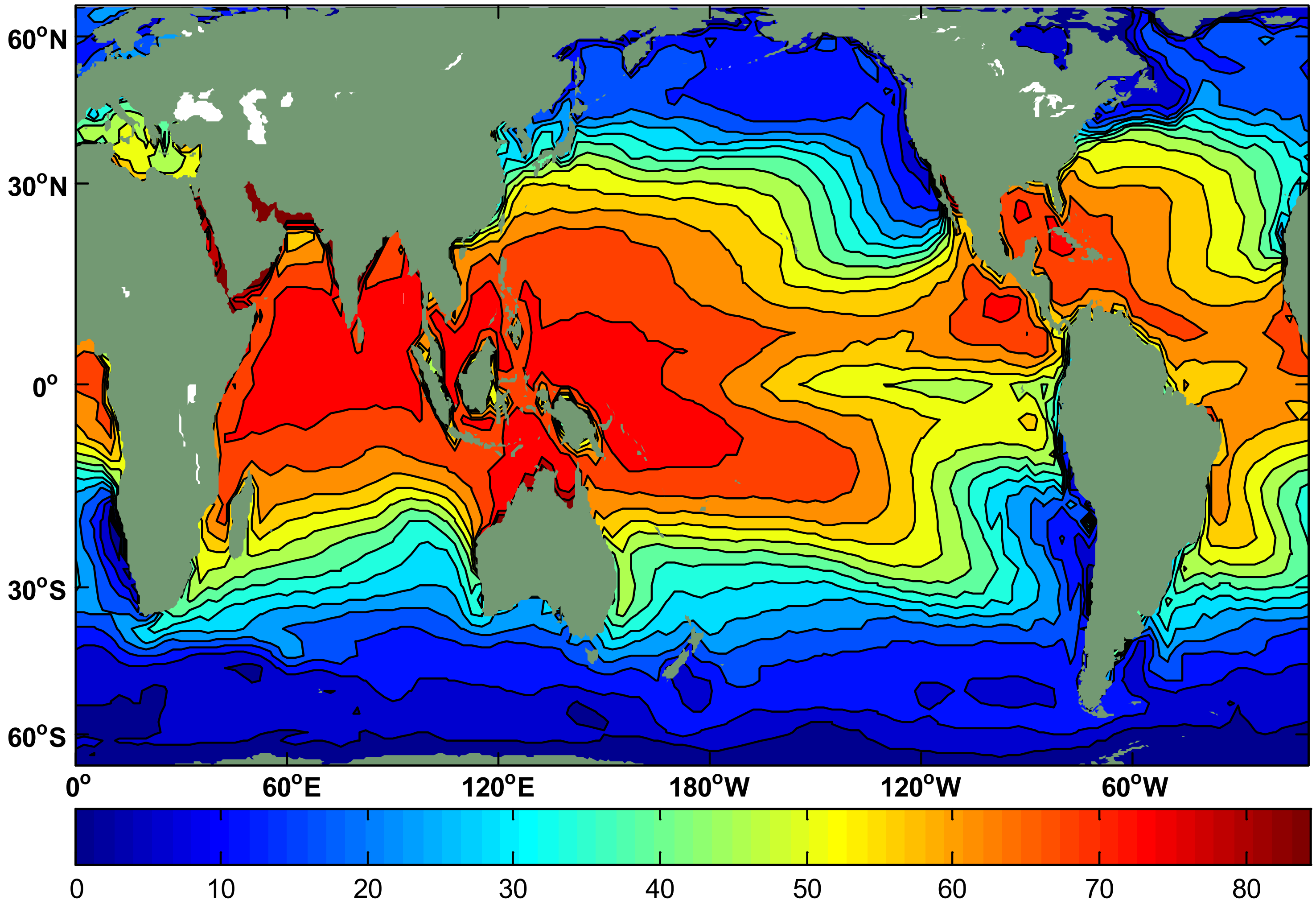
A Little Physics



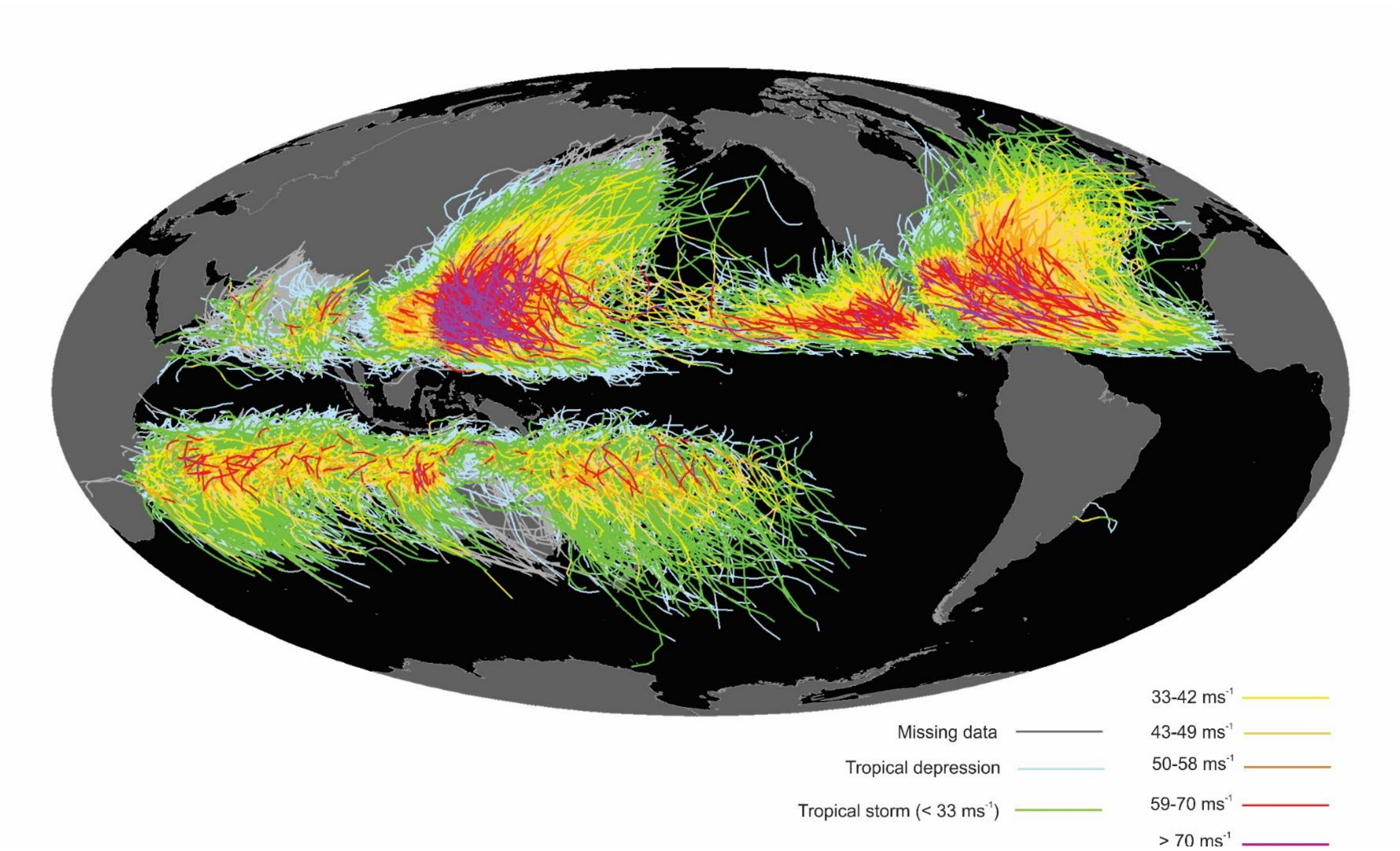
Cross-section through a Hurricane & Energy Production



Annual Maximum Potential Intensity (m/s)



Global Climatology



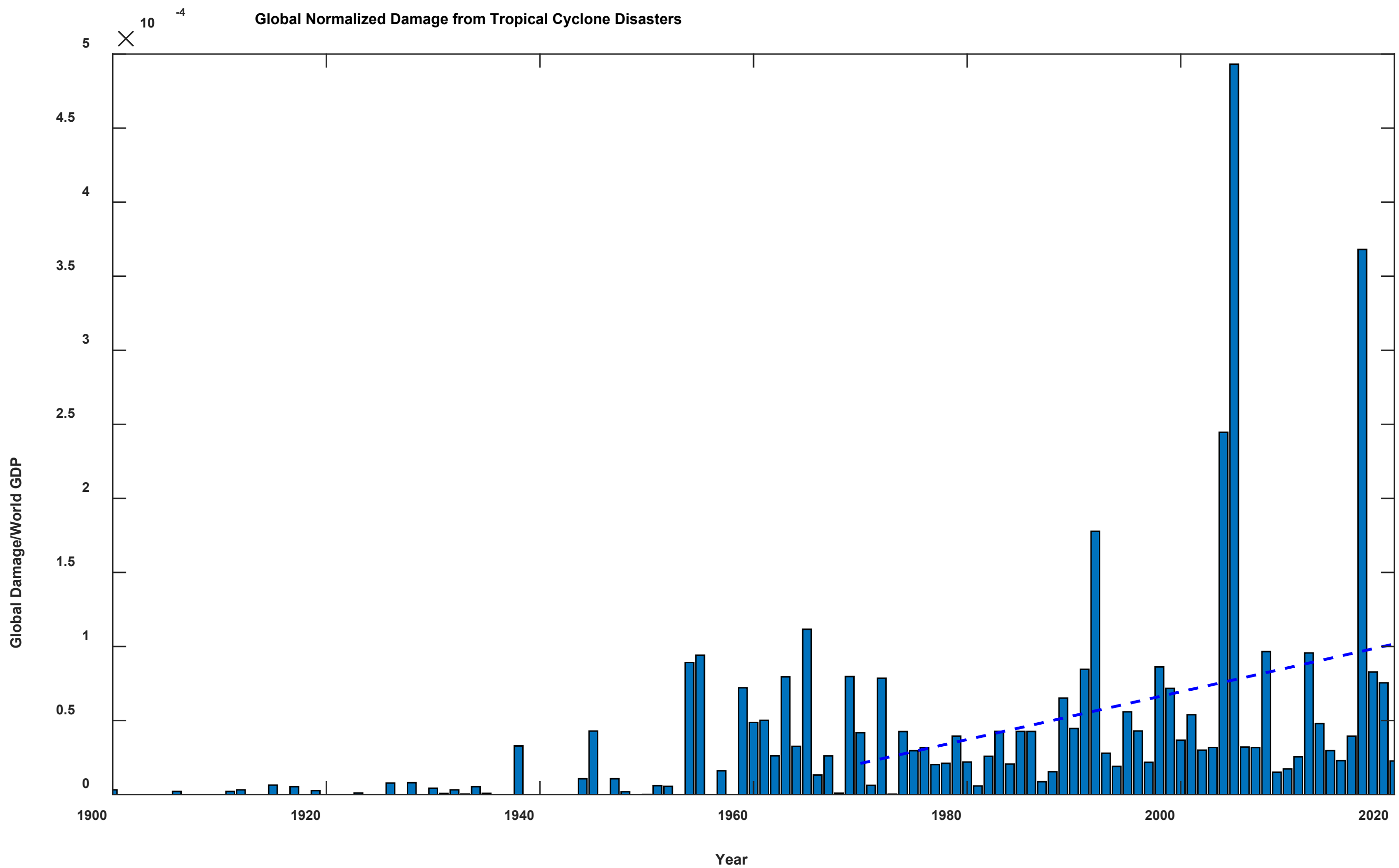
Tracks of all tropical cyclones in the historical record from 1851 to 2010. The tracks are colored according to the maximum wind at 10 m altitude, on the scale at lower right.

The Global Hurricane Hazard

- About 15,000 deaths per year since 1971
- $ 1.1 trillion 2015 U.S. dollars in damages ($21 billion/yr) since 1971
- Global population exposed to hurricane hazards has tripled since 1970

EM-DAT, 2020: The OFDA/CRED International Disaster Database
http://www.emdat.be/.

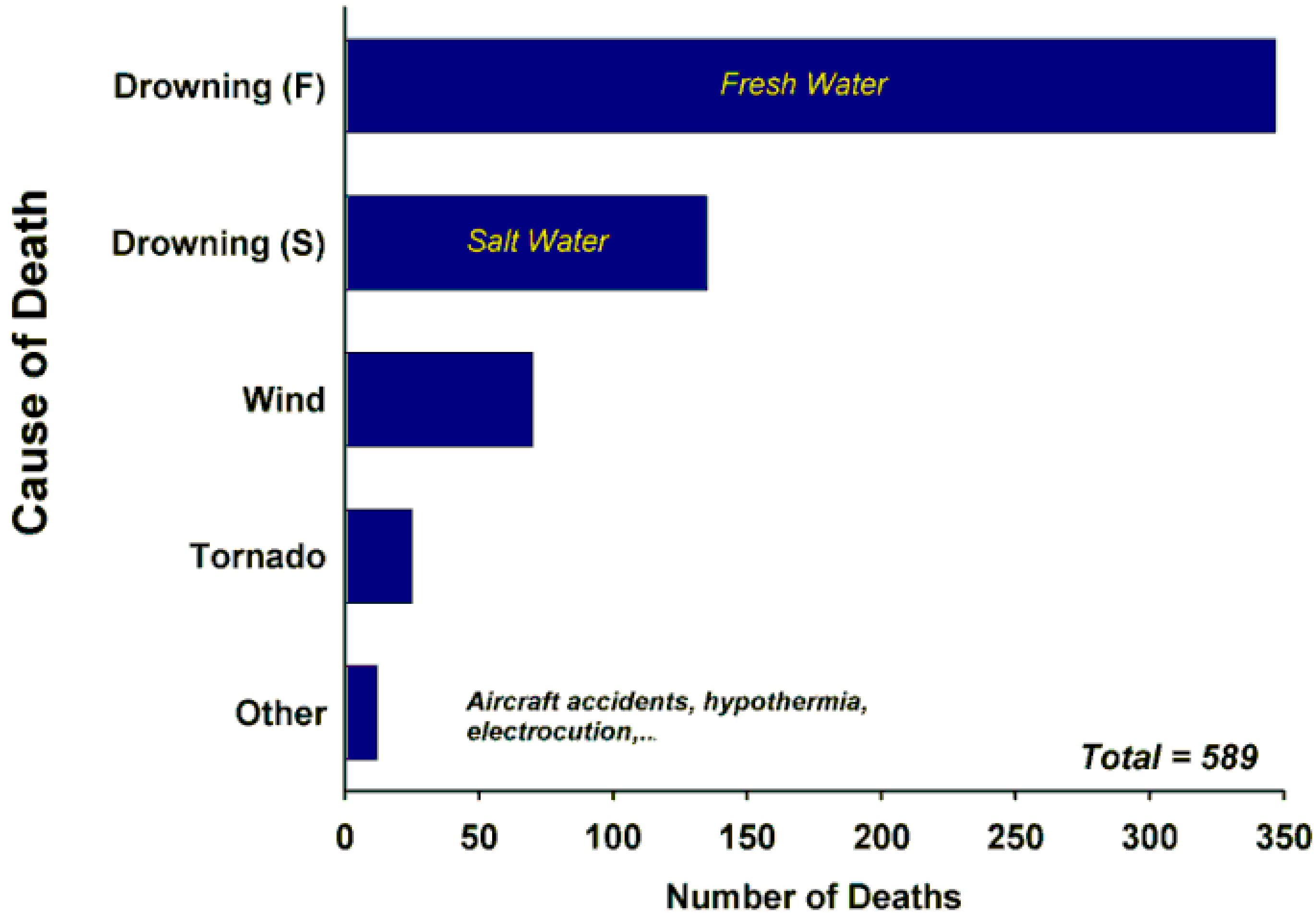
Global Tropical Cyclone Damage Normalized by Gross World Product



- 380% increase since 1970
- Population of TC-prone regions increased by ~200%
- Suggests that climate change has contributed to increasing damage

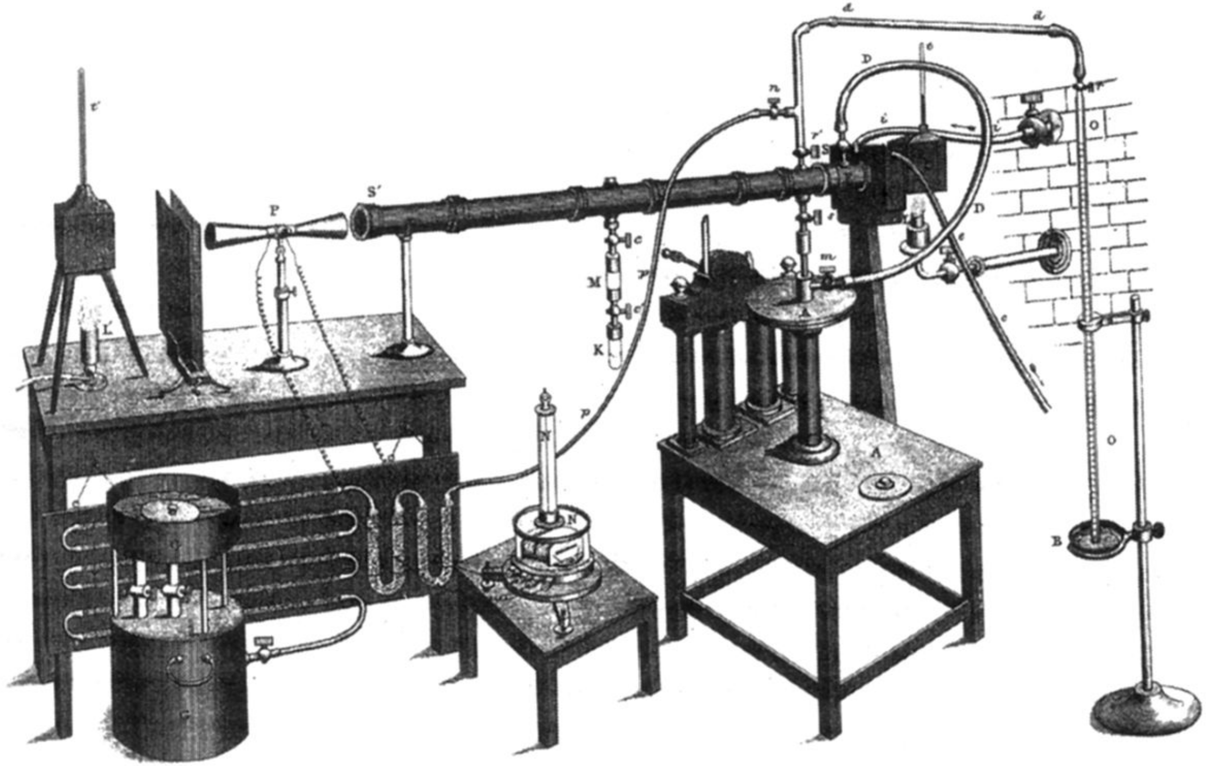
EM-DAT, 2020: The OFDA/CRED International Disaster Database http://www.emdat.be/.

U. S. Hurricane Mortality (1970-1999)



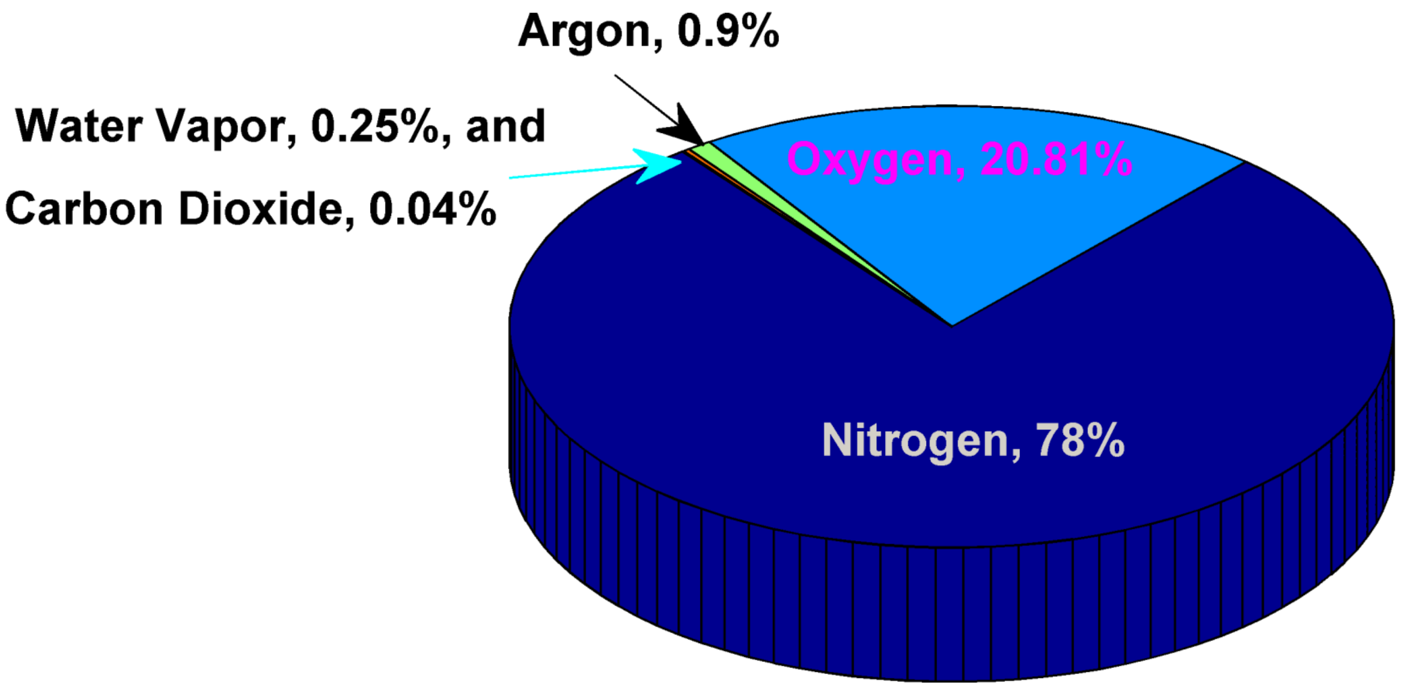
Source: Rappaport, E. N., 1999:
The threat to life in inland areas of the United States from Atlantic tropical cyclones.
Prepreints 23rd Conferenceon Hurricanes and Tropical Meteorology,
American Meteorological Society (10-15 Jan 1999, Dallas Tx), 339-342.

Overview of Greenhouse Gas-Induced Climate Change

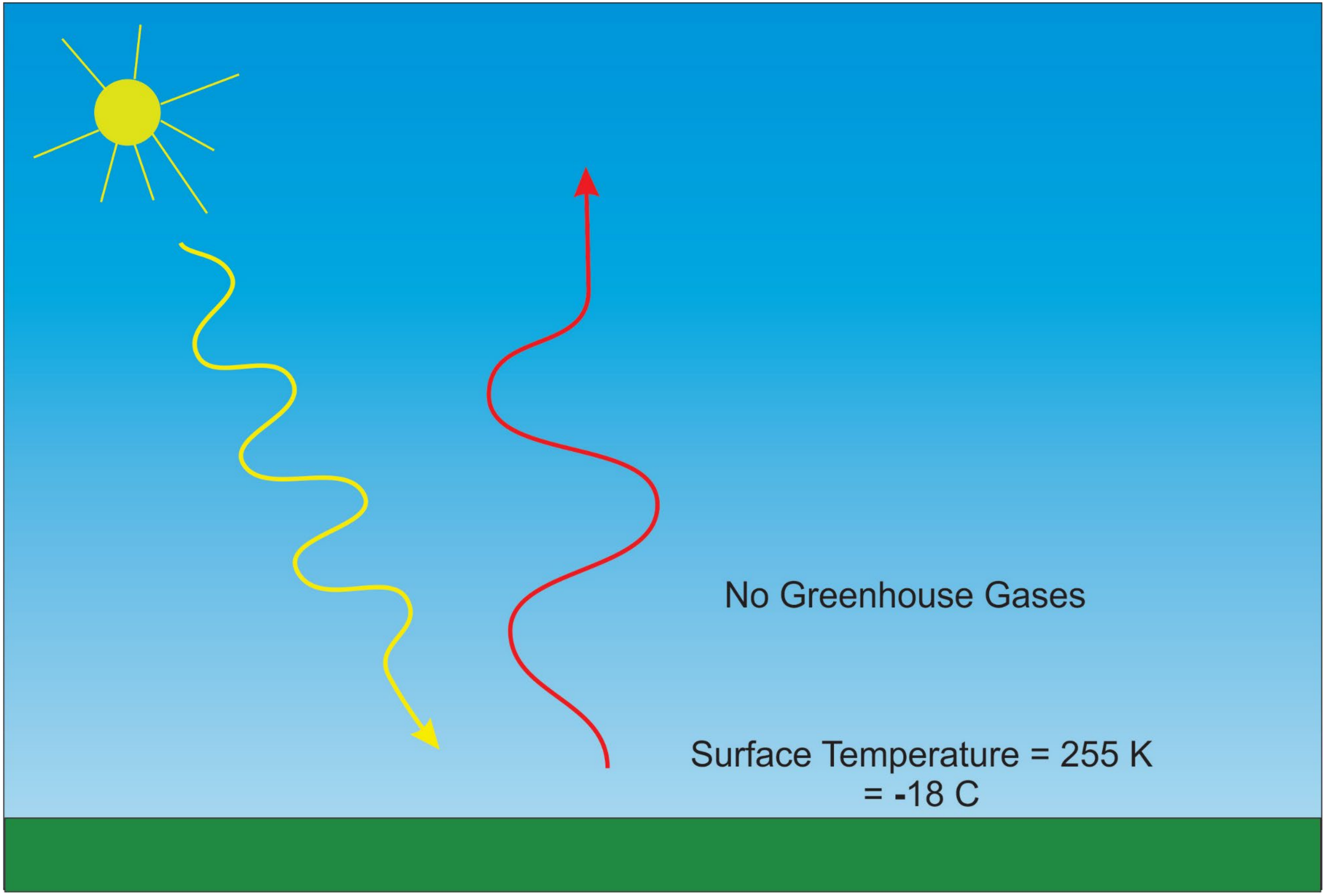


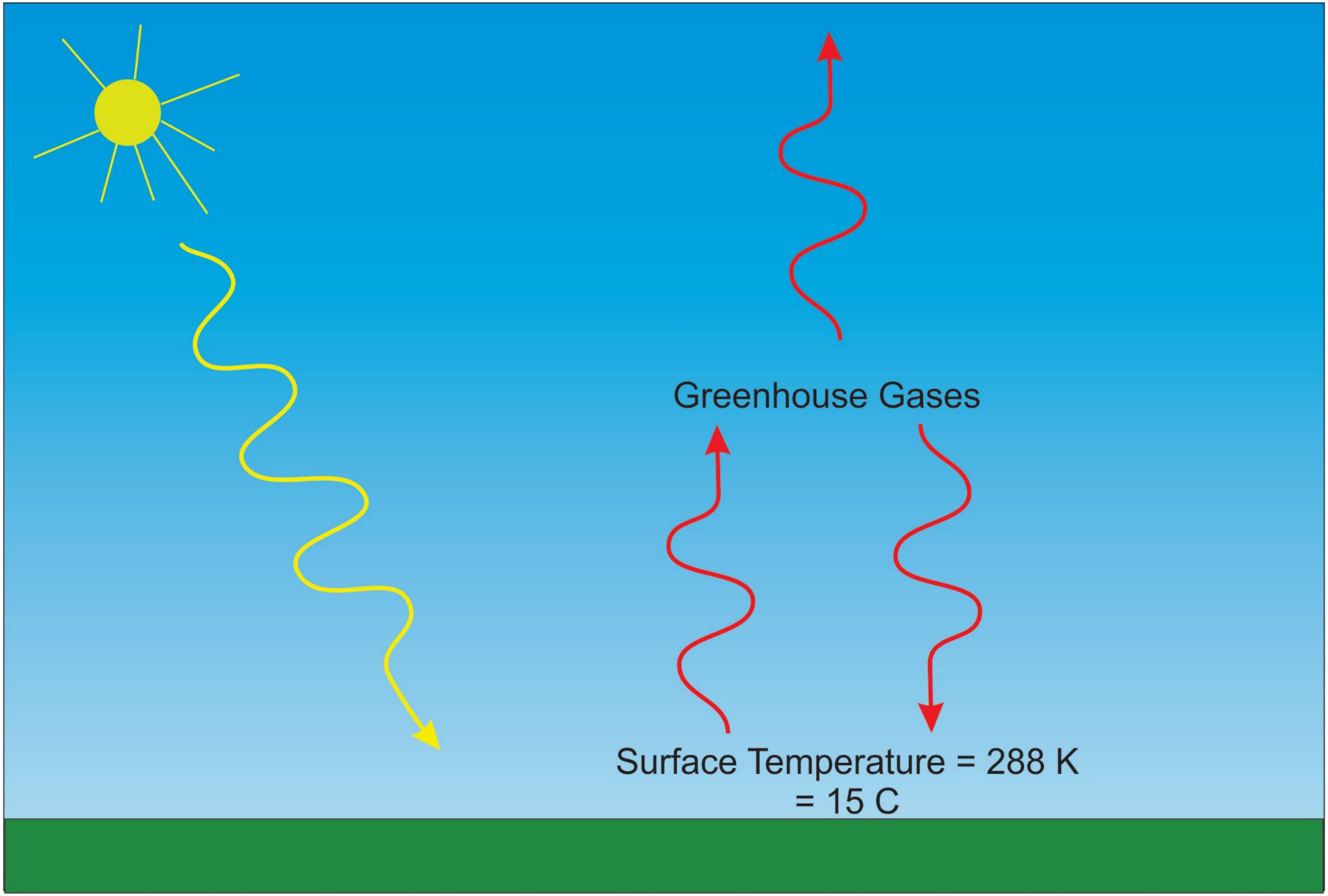
John Tyndall
(1820-1893)

Atmospheric Composition



The orange sliver makes the difference between a mean surface temperature of 0^oF and of 60^oF.


No Greenhouse Gases
Surface Temperature = 255 K
= -18 C

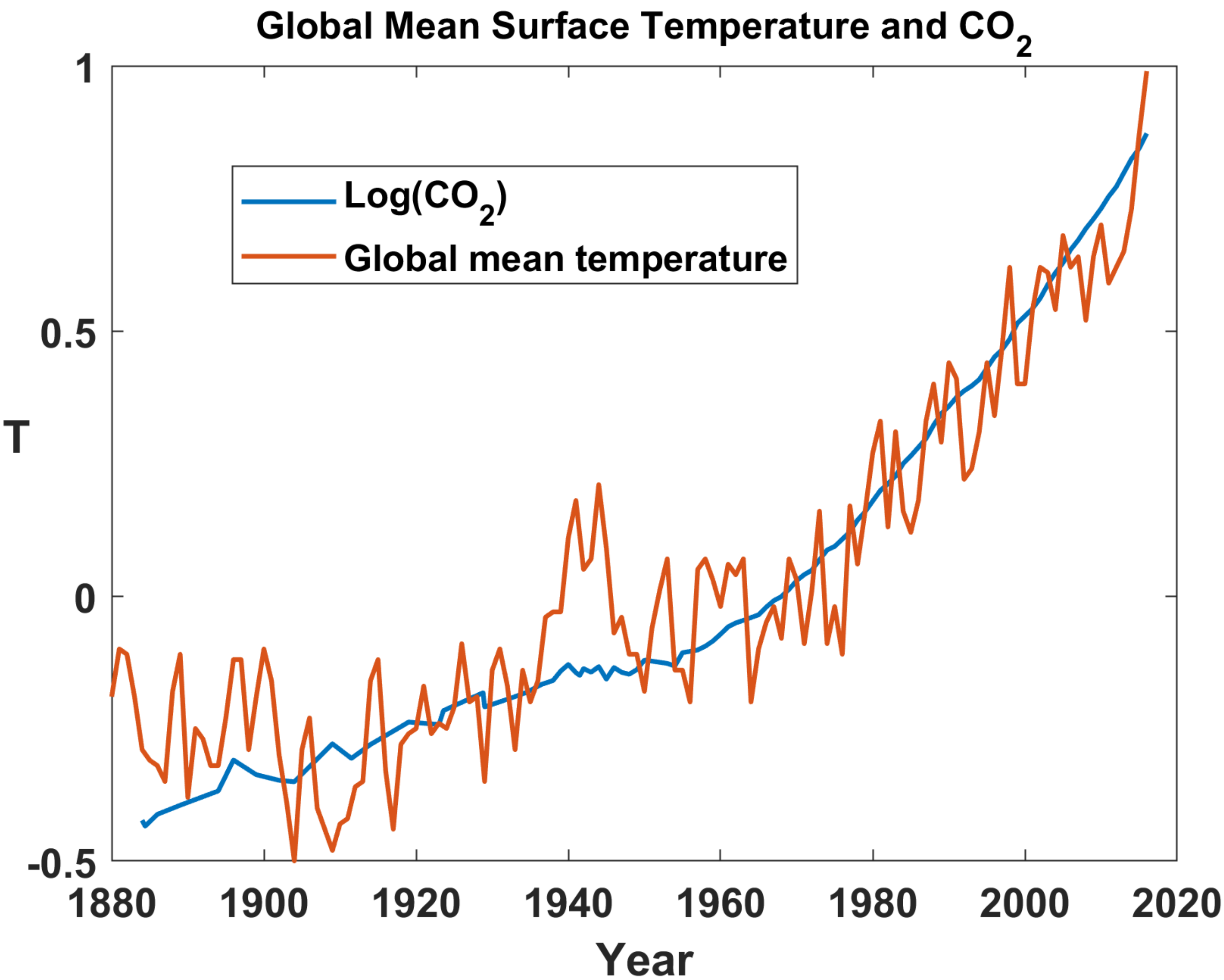


Greenhouse Gases
Surface Temperature = 288 K
= 15 C

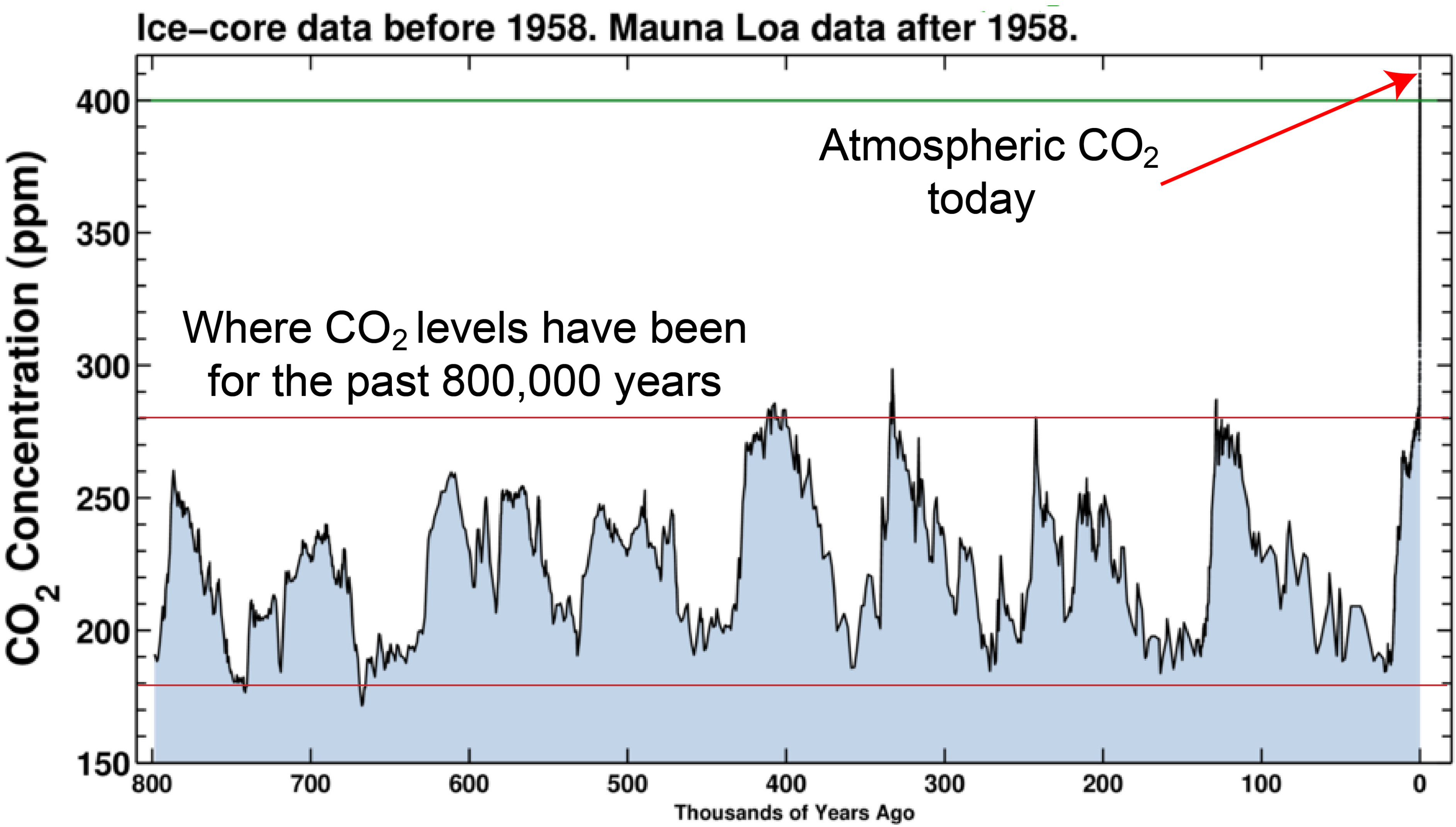
Our Influence on Greenhouse Gases

Svante Arrhenius, 1859-1927

"Any doubling of the percentage of carbon dioxide in the air would raise the temperature of the earth's surface by 4°; and if the carbon dioxide were increased fourfold, the temperature would rise by 8°." – *Världarnas utveckling (*Worlds in the Making), 1906



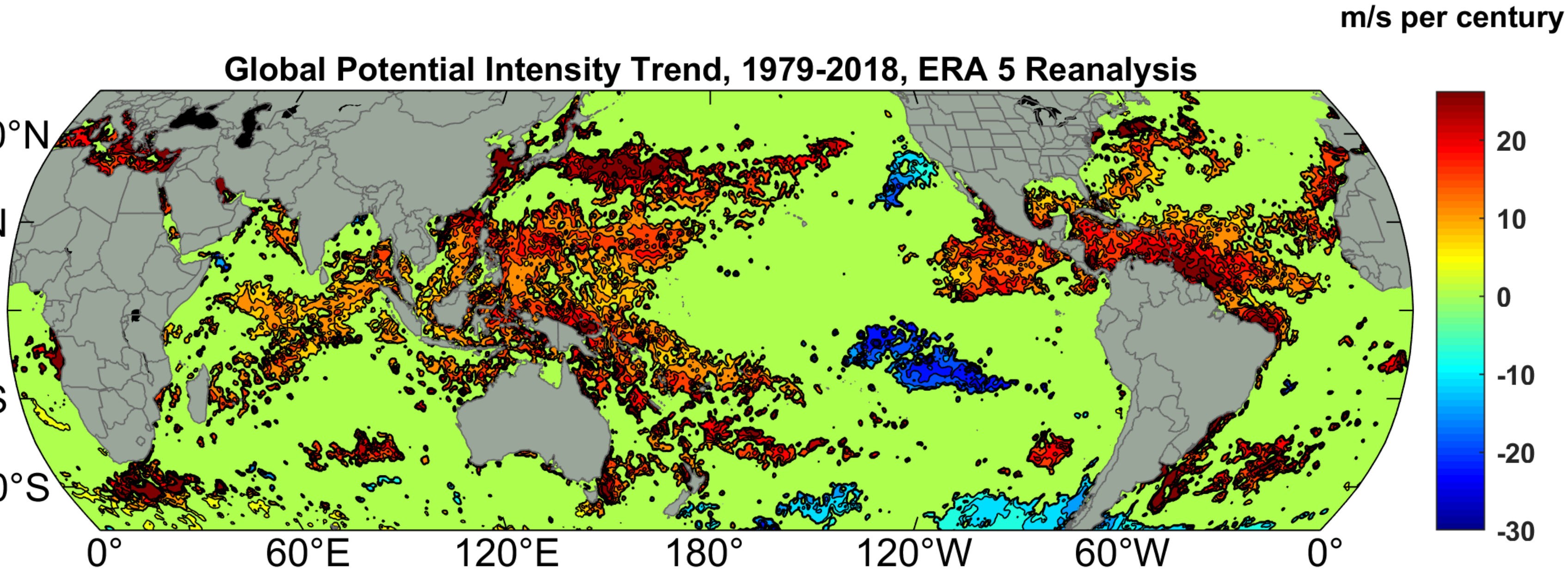
Global Mean Surface Temperature and CO2
Log(CO2)
Global mean temperature
T
1
0.5
0
-0.5
1880
1900
1920
1940
1960
1980
2000
2020
Year


Ice–core data before 1958. Mauna Loa data after 1958.
Atmospheric CO_2 today
Where CO_2 levels have been for the past 800,000 years
CO_2 Concentration (ppm)
400
350
300
250
200
150
800
700
600
500
400
300
200
100
0
Thousands of Years Ago

Climate Change Effects on Hurricanes

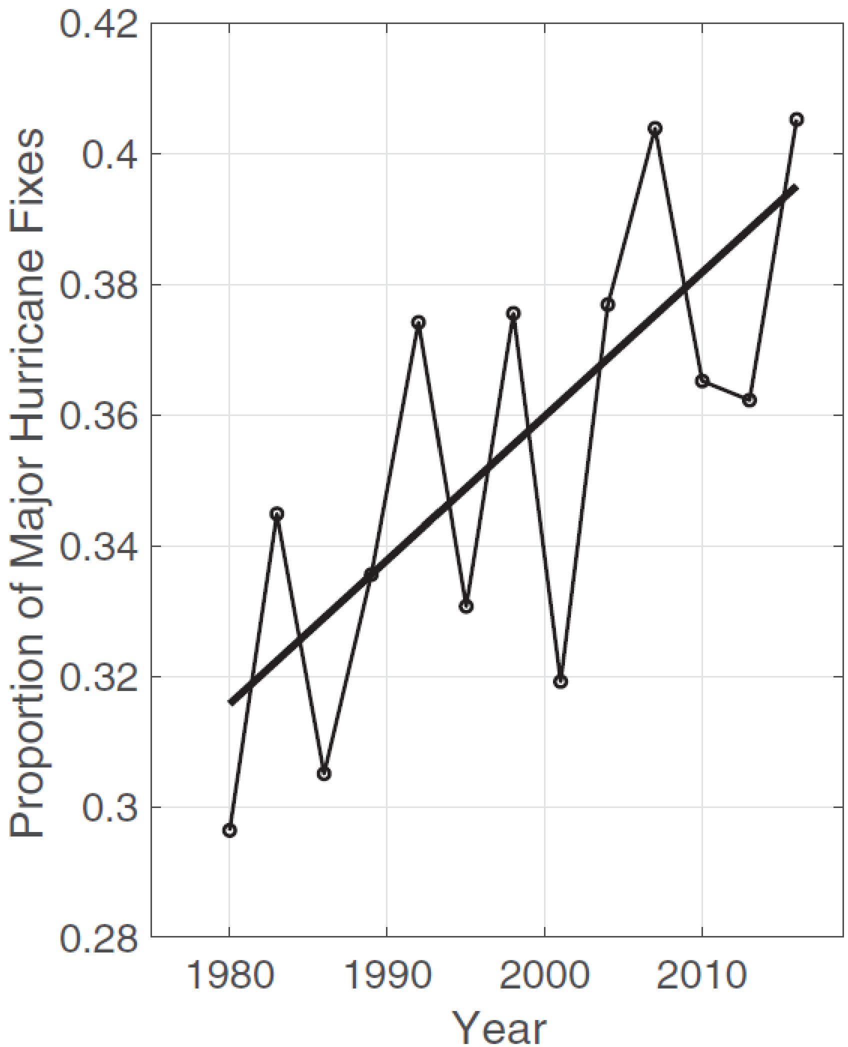
“*Potential Intensity*” **is the theoretical upper bound on maximum surface winds, based on the Carnot-like energy cycle of hurricanes**

Potential Intensity Trend, 1979-2018, ERA 5 Reanalysis



(Trend shown only where p value < 0.05)

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

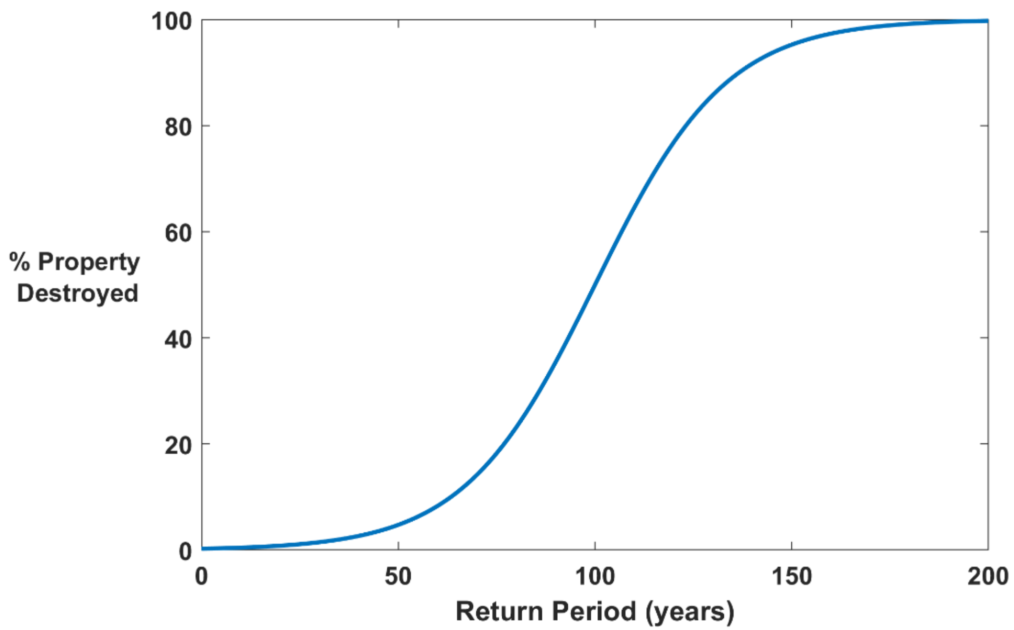

How do we quantify hurricane risks, accounting for climate change?

Flawed Basis of Current Risk Modeling

- Almost all current risk assessments are based on historical statistics
- Historical records are flawed and short
- Moreover, the past 50-150 years is a poor guide to the present owing to climate change that *has already occurred*
- Risk modelers have been slow to migrate to a physics-based approach

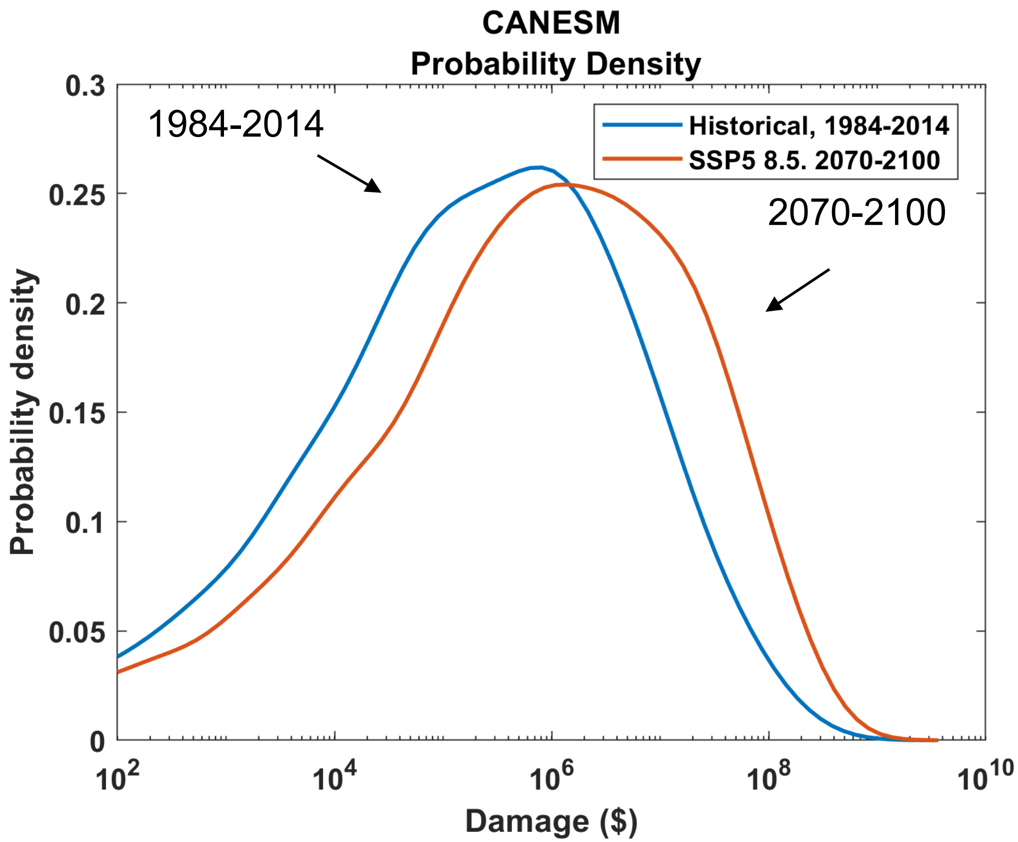
The Heart of the Natural Disaster Problem:

- Societies are usually well adapted to frequent events (> 1/100 yr)
- Societies are often poorly adapted to rare events (< 1/100 yr)
- Large cost increases result when > 100-yr events become < 100-yr events



Example:
Tropical Cyclone Risk Arises Largely from High Intensity Events

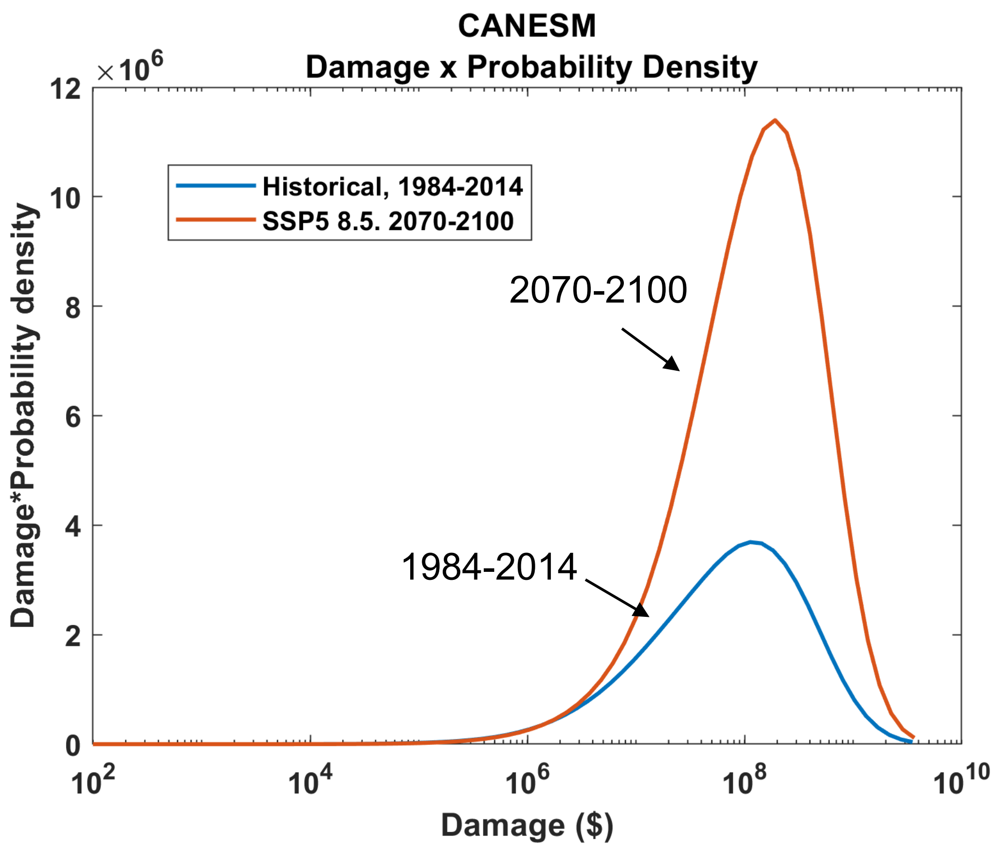
Probability



Probability density of annual damage to a portfolio of insured property in the U.S.

Tropical Cyclone Risk Arises Largely from High Intensity Events

Risk



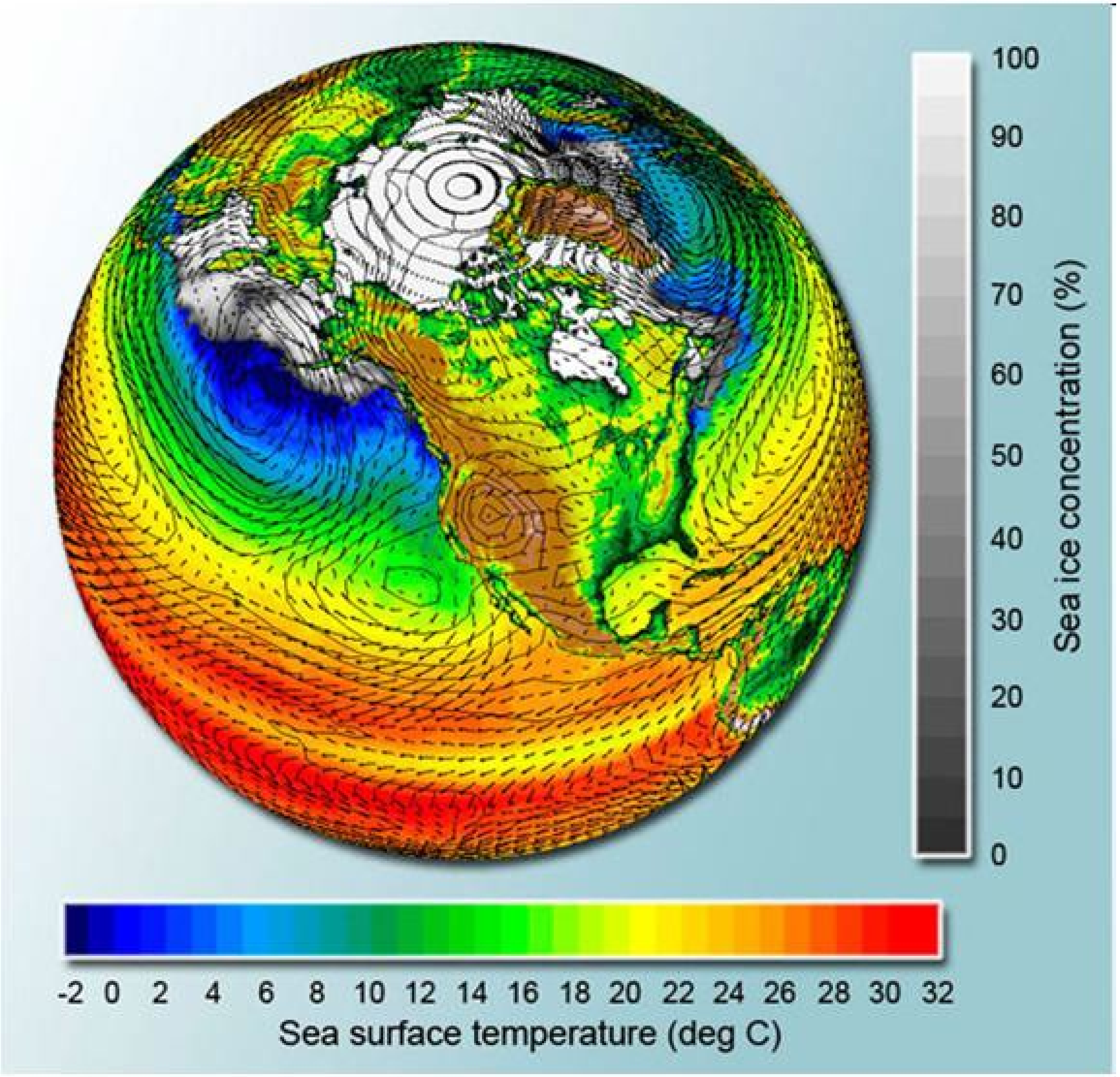
Total expected damage proportional to area under curves

Damage times probability density of annual damage to a portfolio of insured property in the U.S.

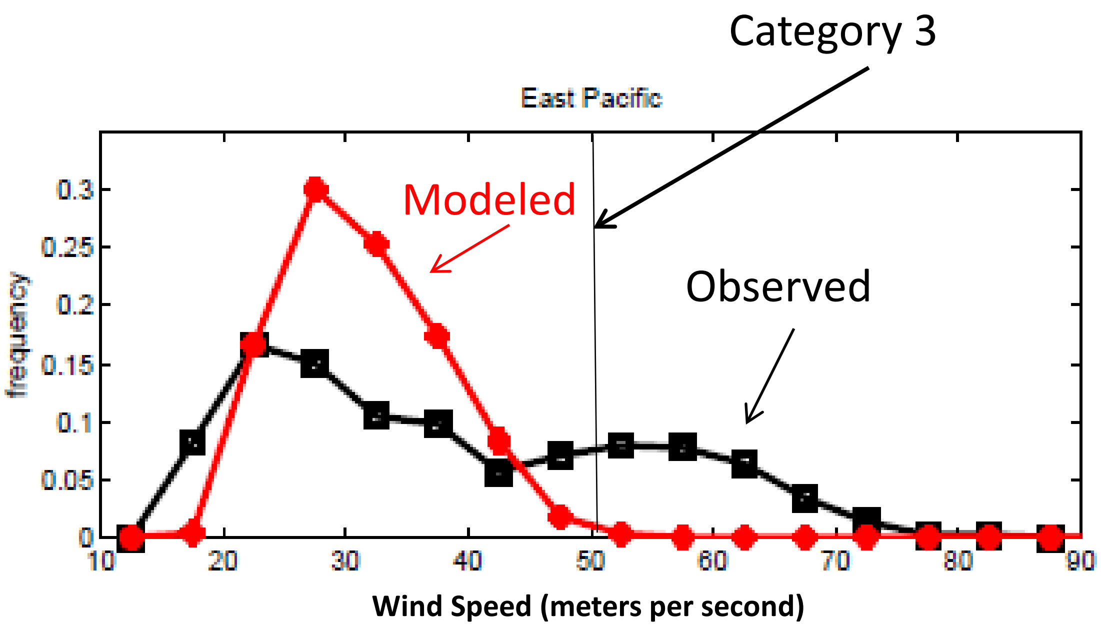
Historical Records

- Hurricane records: ~70 years of good records (U.S.)
- Even if we had 200 years of great records, the past is no longer a good guide to the present
- We need to turn to physical models to get better estimates of current (and future) weather risks

Why Not use Climate Models to Simulate Future Hurricanes?



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



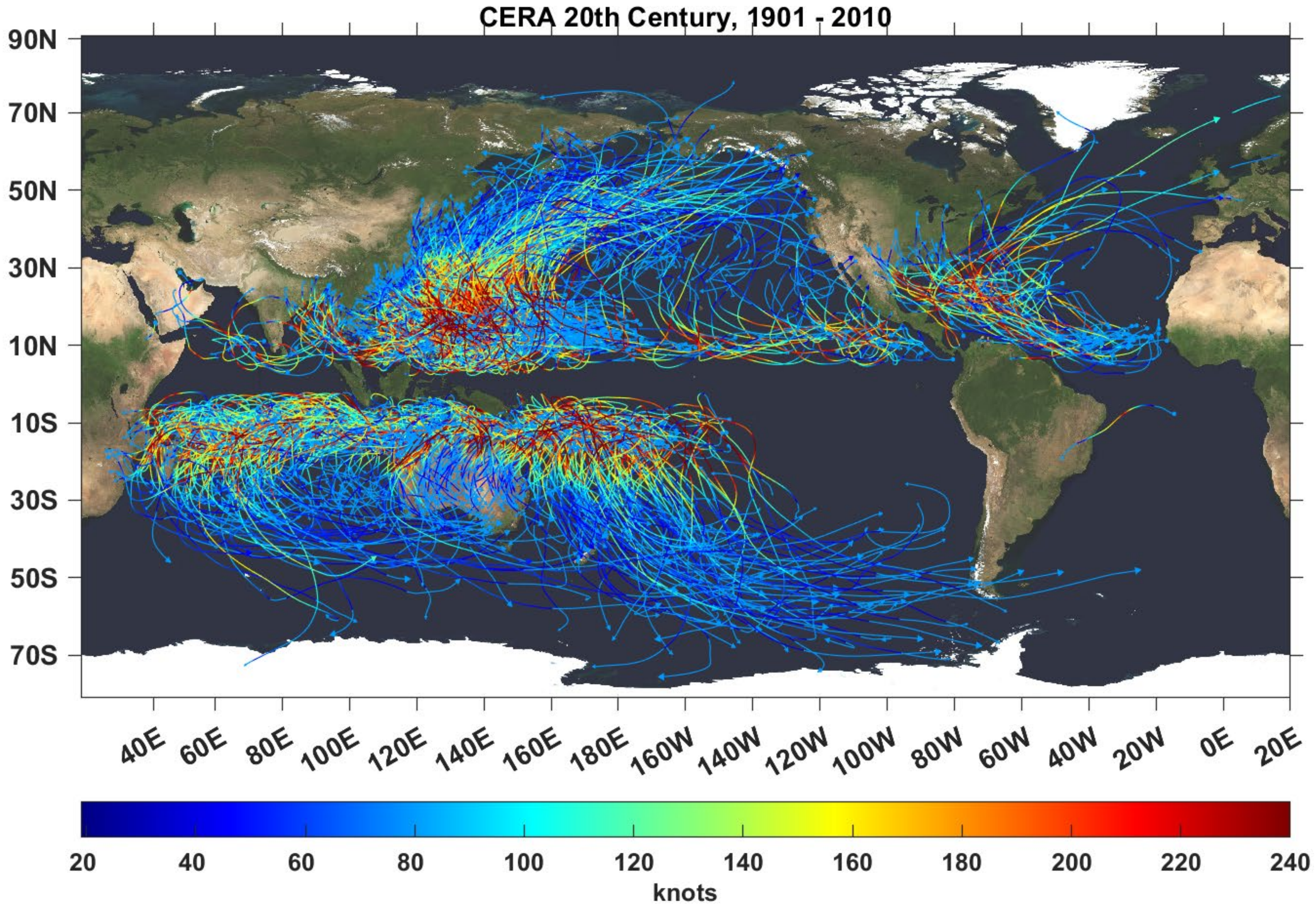
Histograms of Tropical Cyclone Intensity as Simulated by a Global Model with 30 mile grid point spacing. (Courtesy Isaac Held, GFDL)

Global models do not simulate the storms that cause destruction

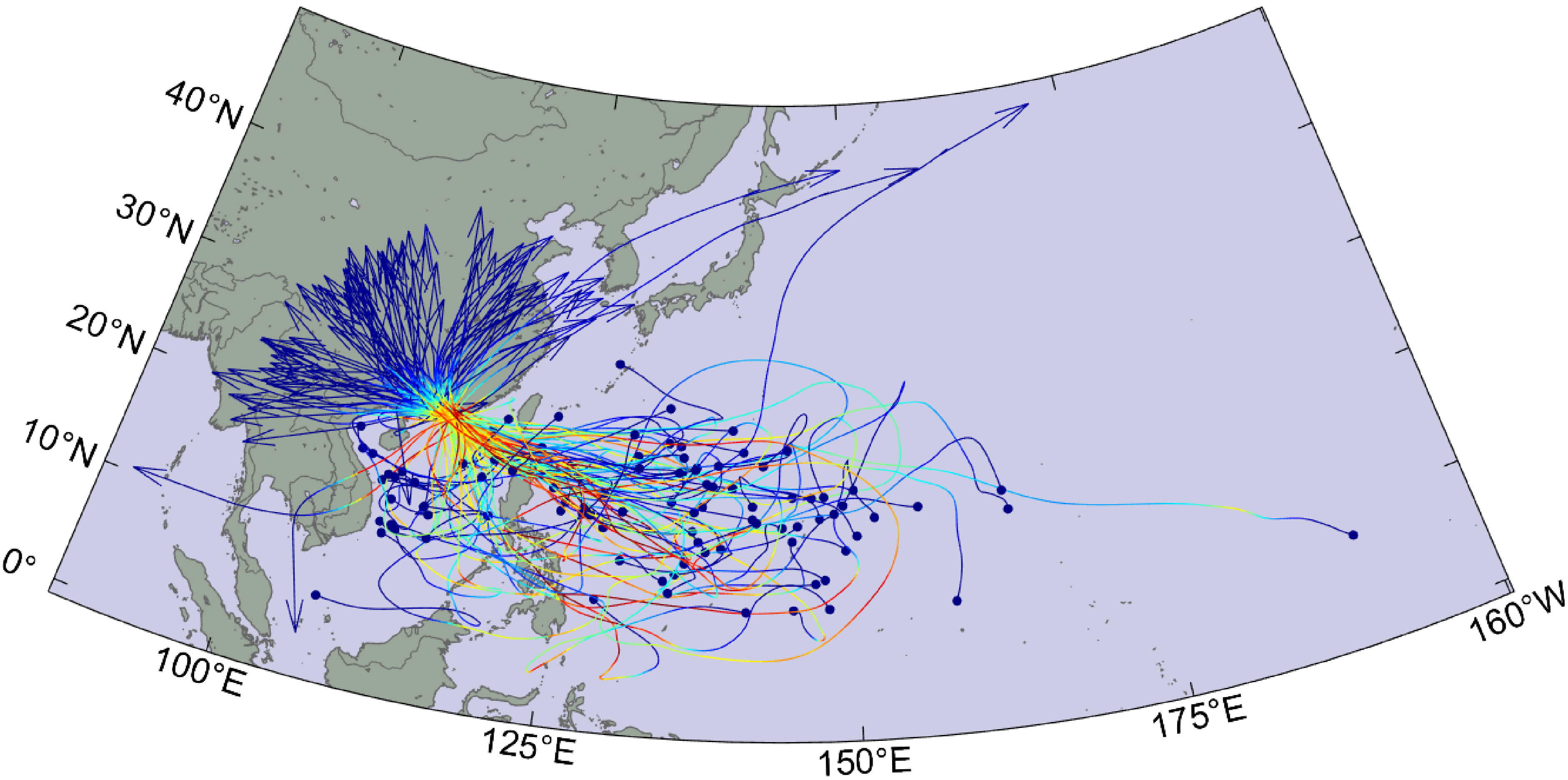
Using Physics to Assess Hurricane Risk

- 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 a specialized, very high resolution physical hurricane model coupled to the ocean
- Extensively validate the results against historical hurricane data
- Exact same method can be applied to output of climate models

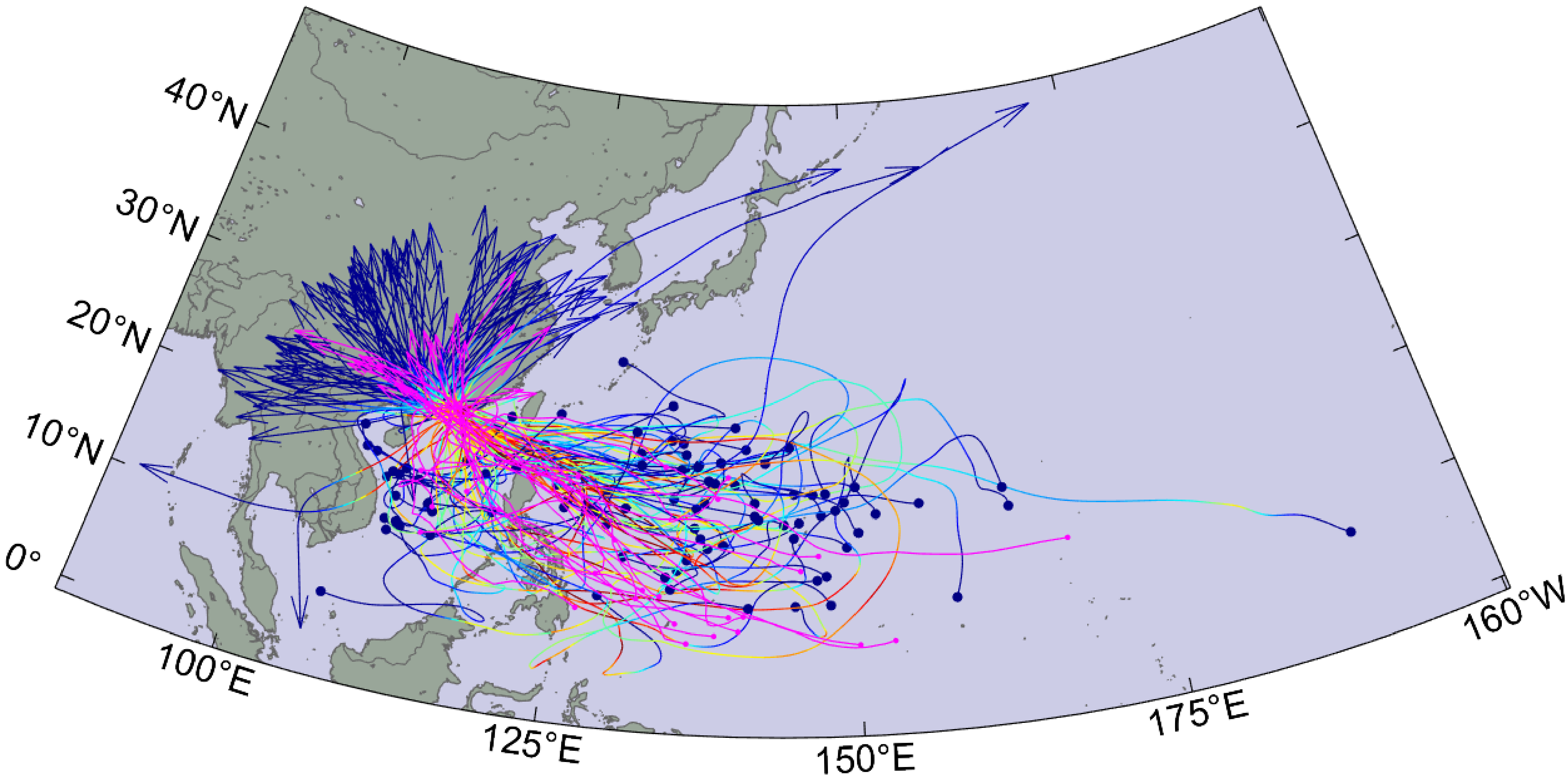
Top 1,000 storms Downscaled from CERA 29th Century Reanalysis



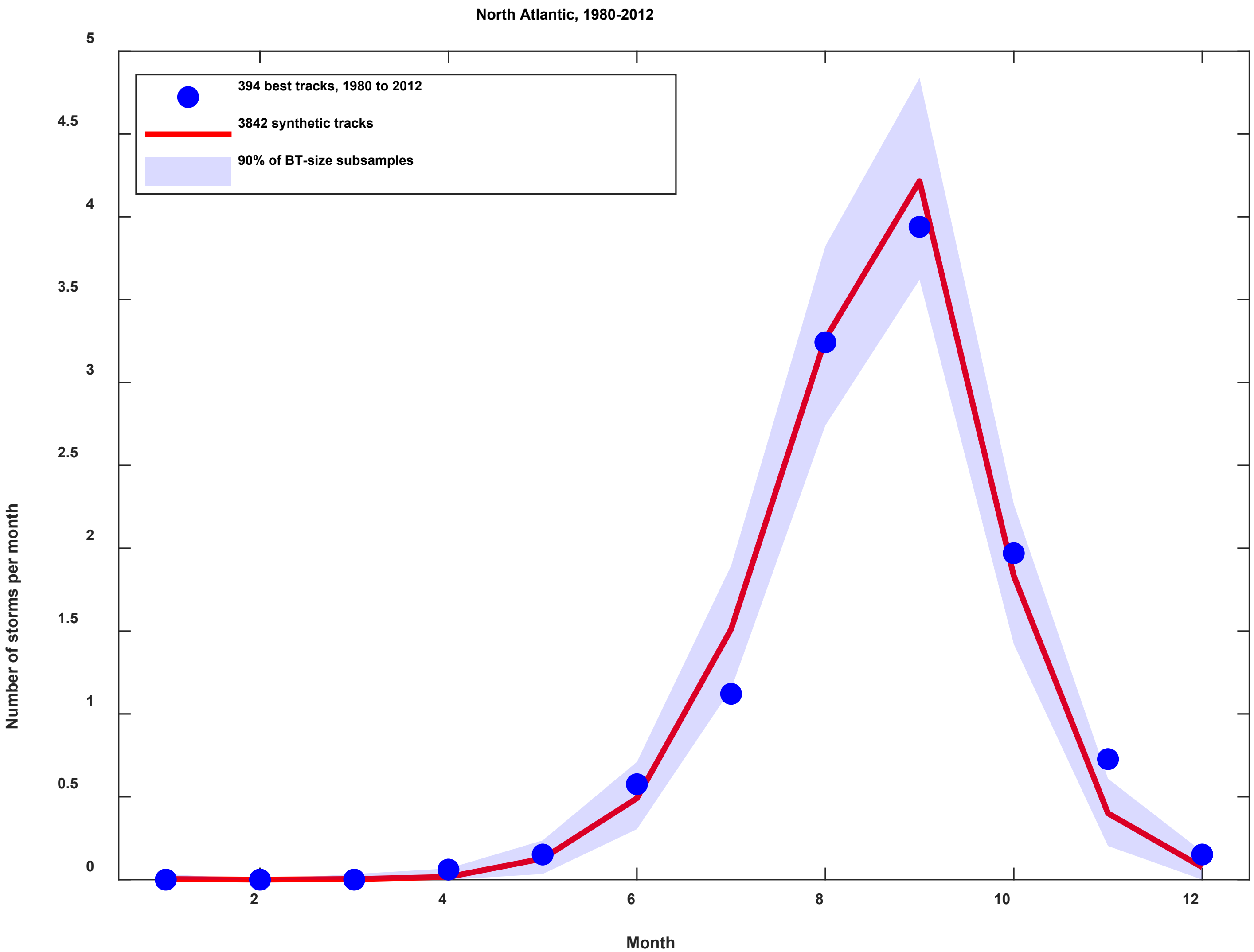
Top 100 of 4,500 tropical cyclones affecting Hong Kong, downscaled from UKMO CMIP6, 20th Century



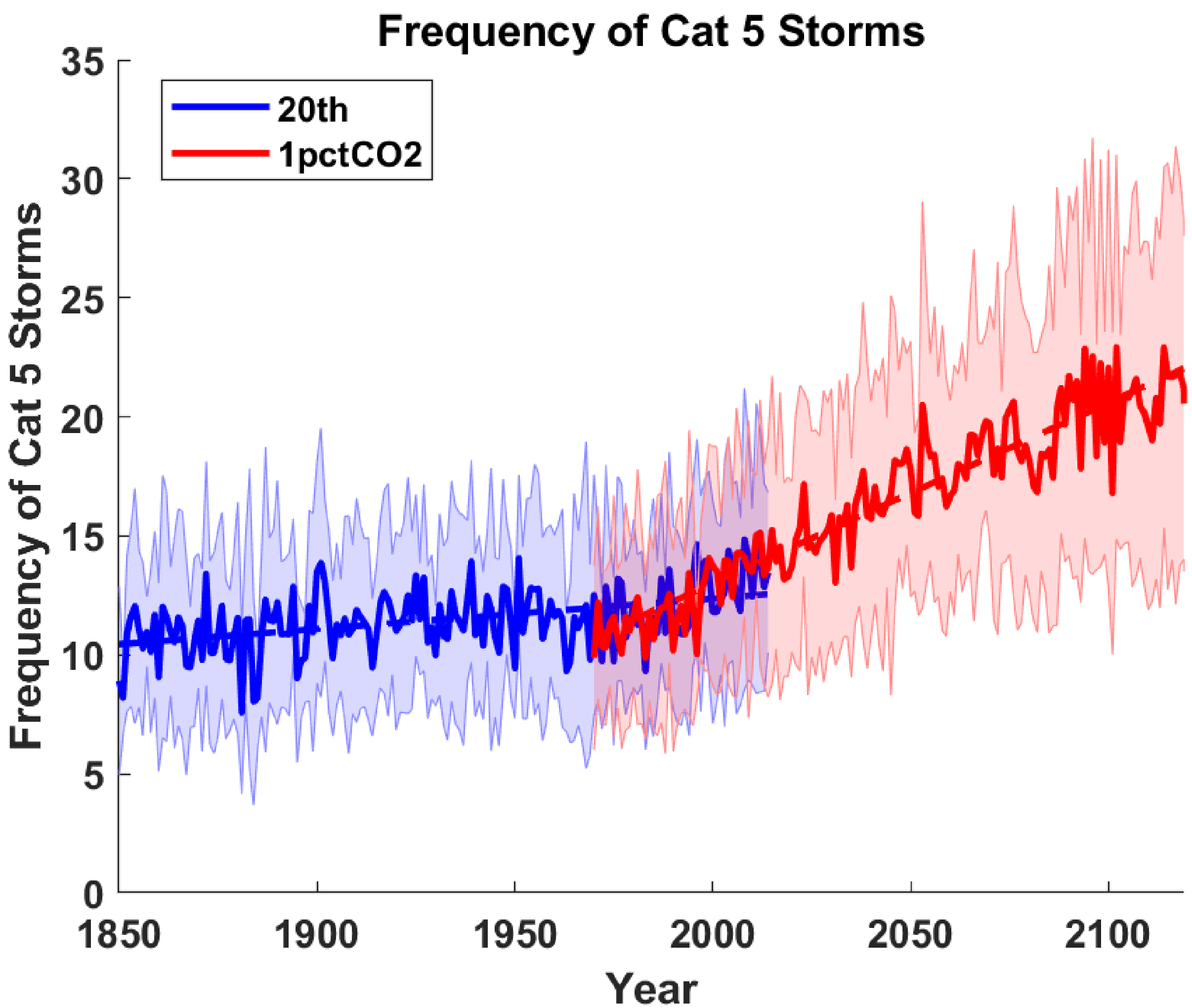
With historical tracks superimposed



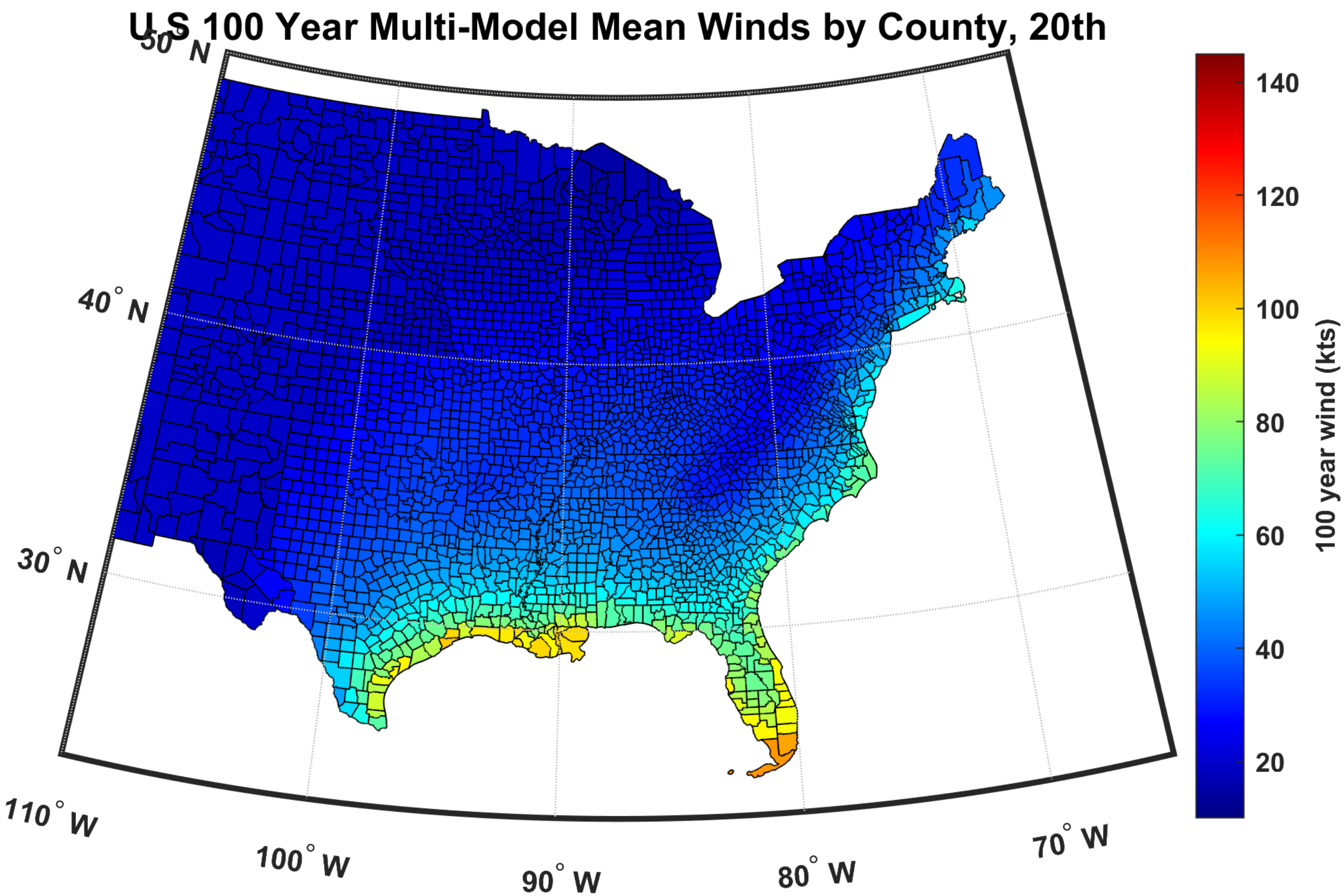
Atlantic Annual Cycle



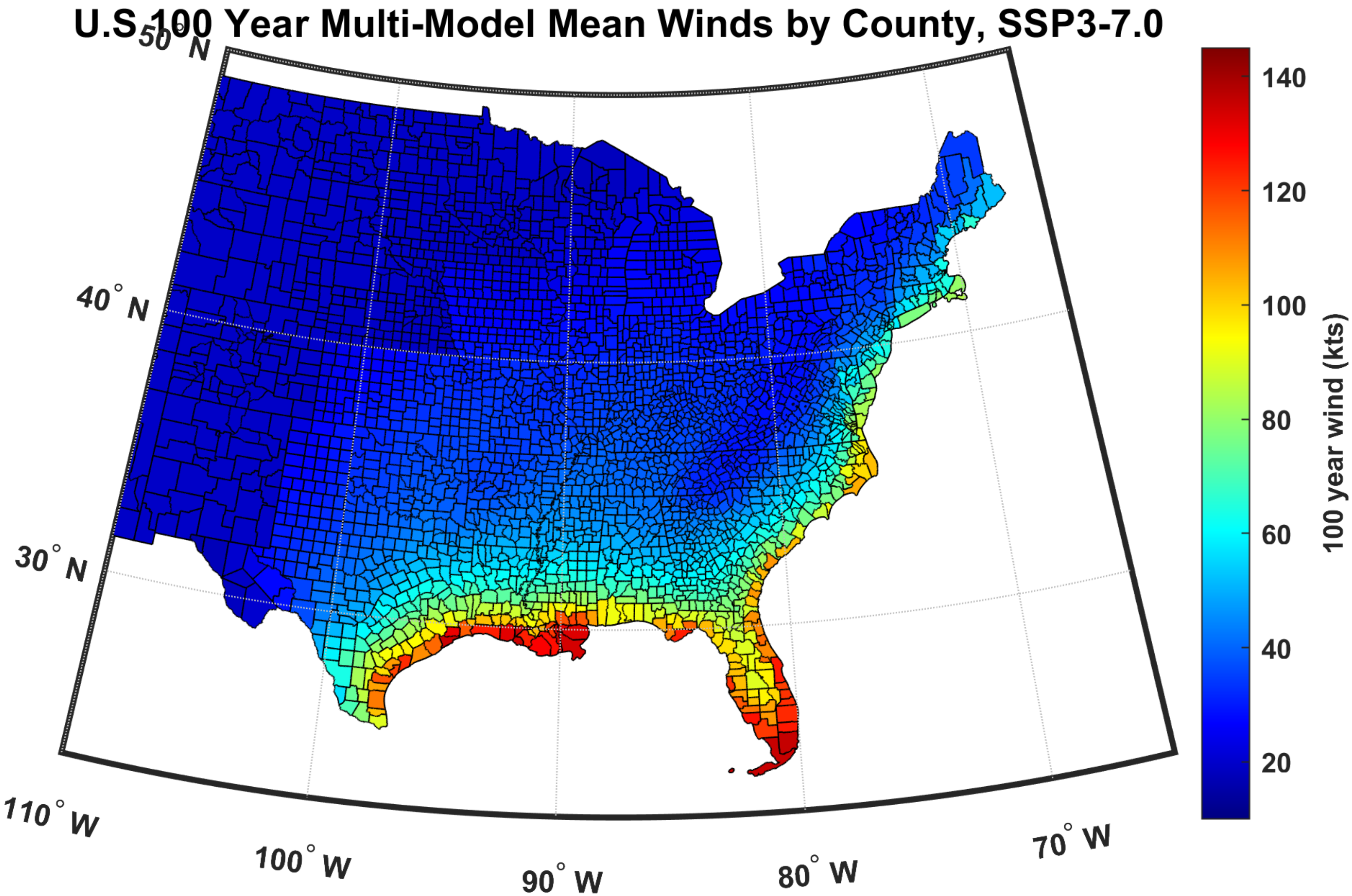
Global Tropical Cyclone Frequency from 9 Current Generation (CMIP6) Climate Models



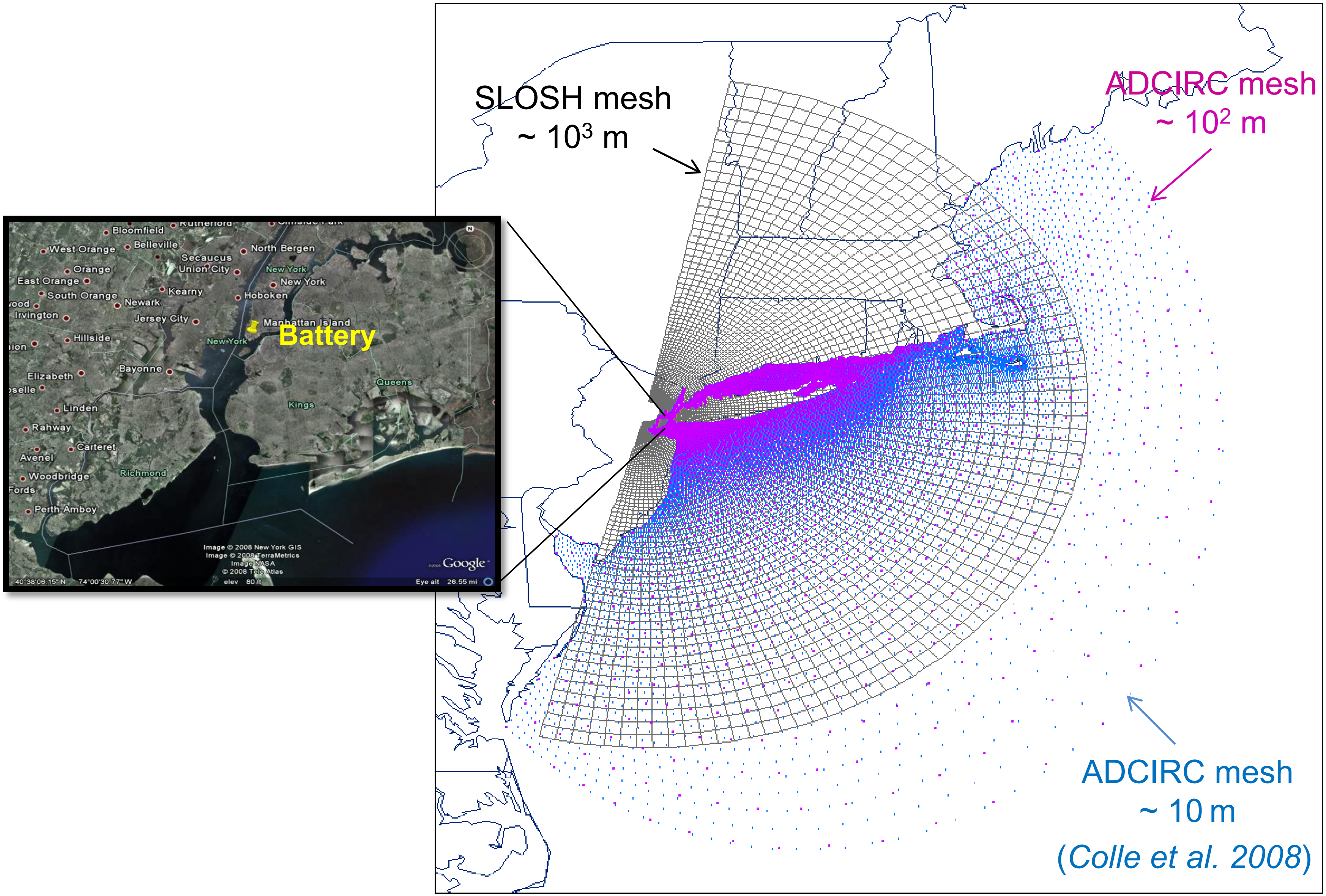
100-year hurricane peak wind based on downscaling 8 climate models, 1984-2014



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

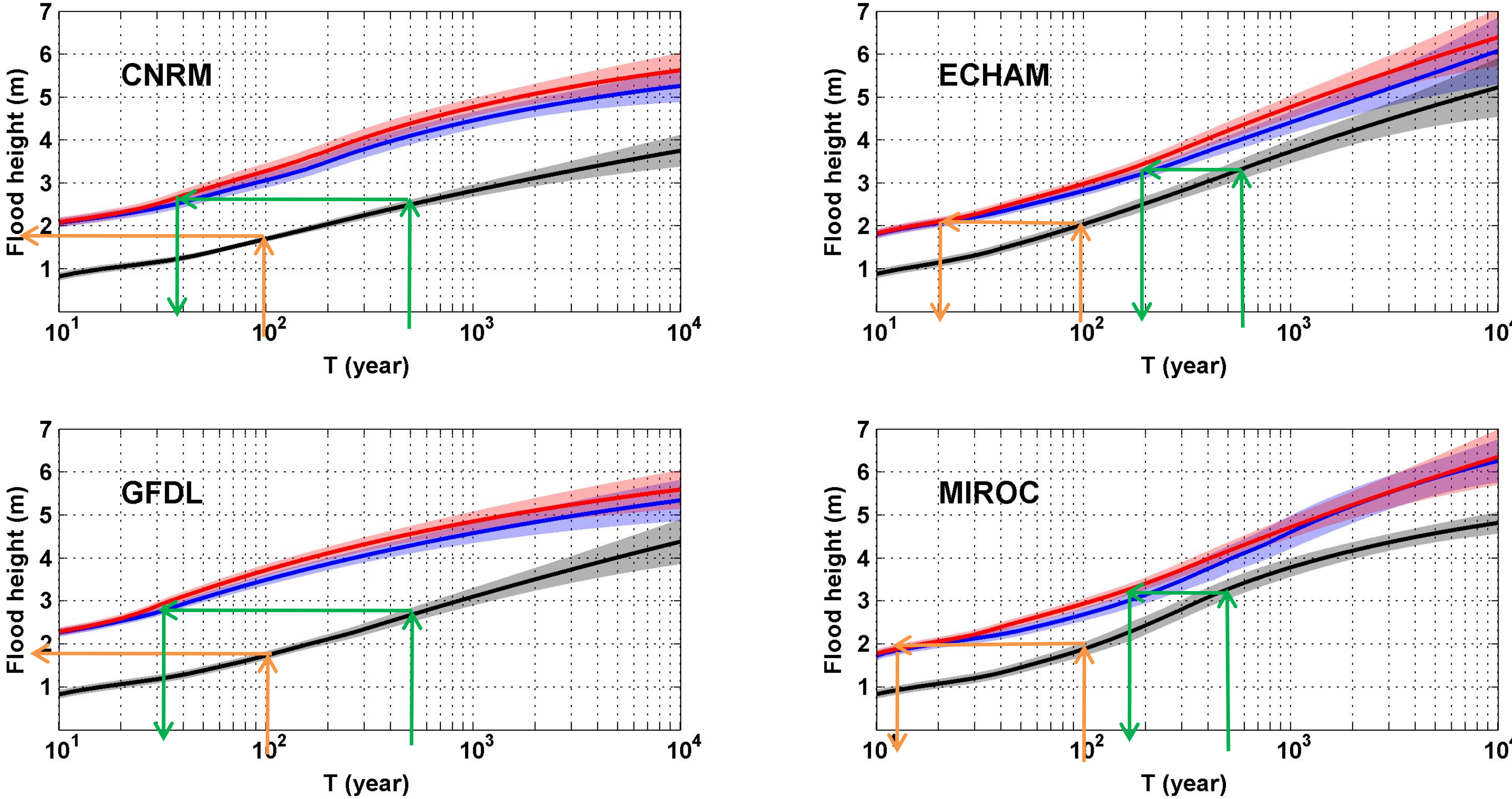


Storm Surge Simulation (Ning Lin)



GCM flood height return level, Battery, Manhattan

(assuming SLR of 1 m for the future climate)



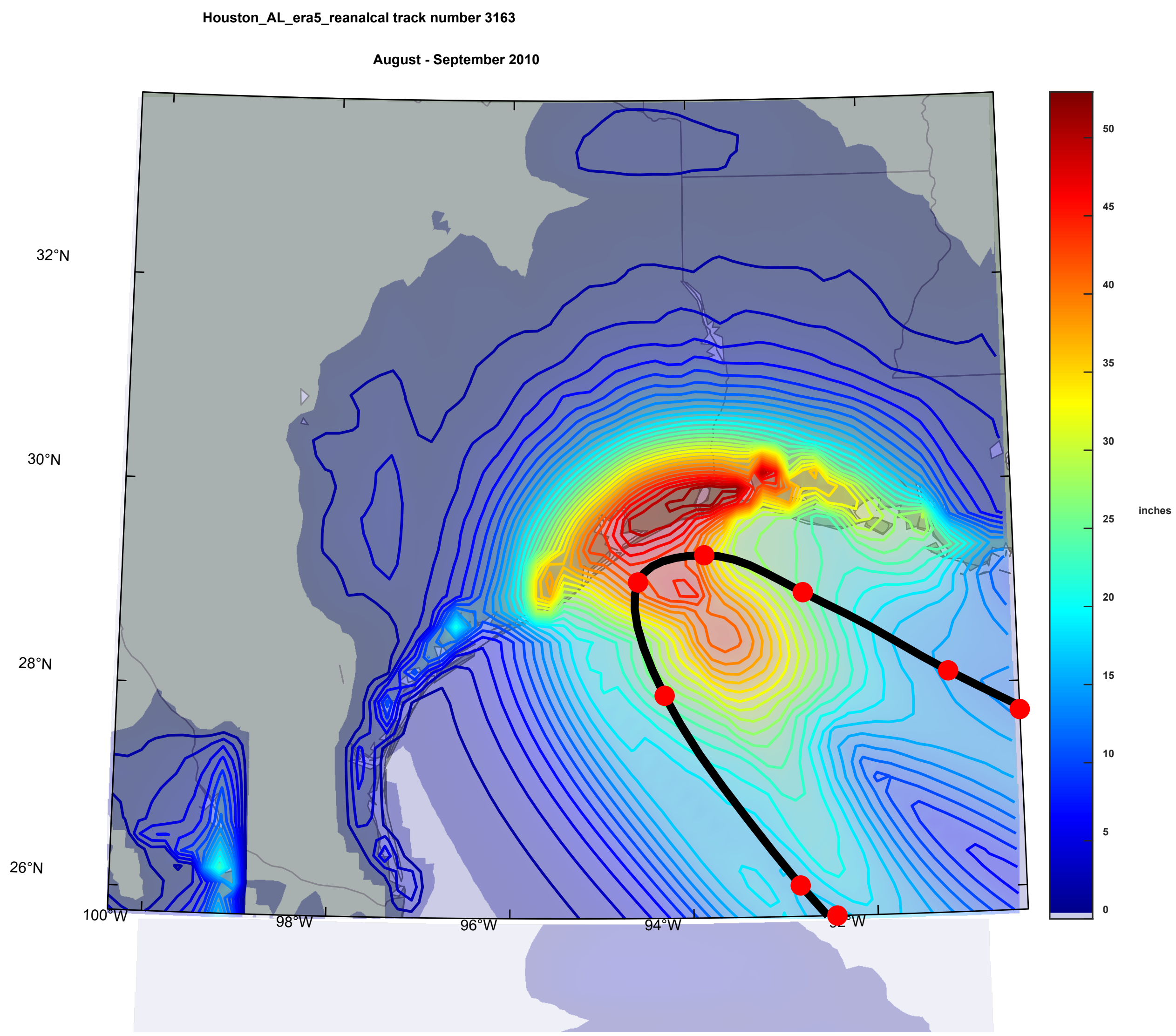
Black: Current climate (1981-2000)

Blue: A1B future climate (2081-2100)

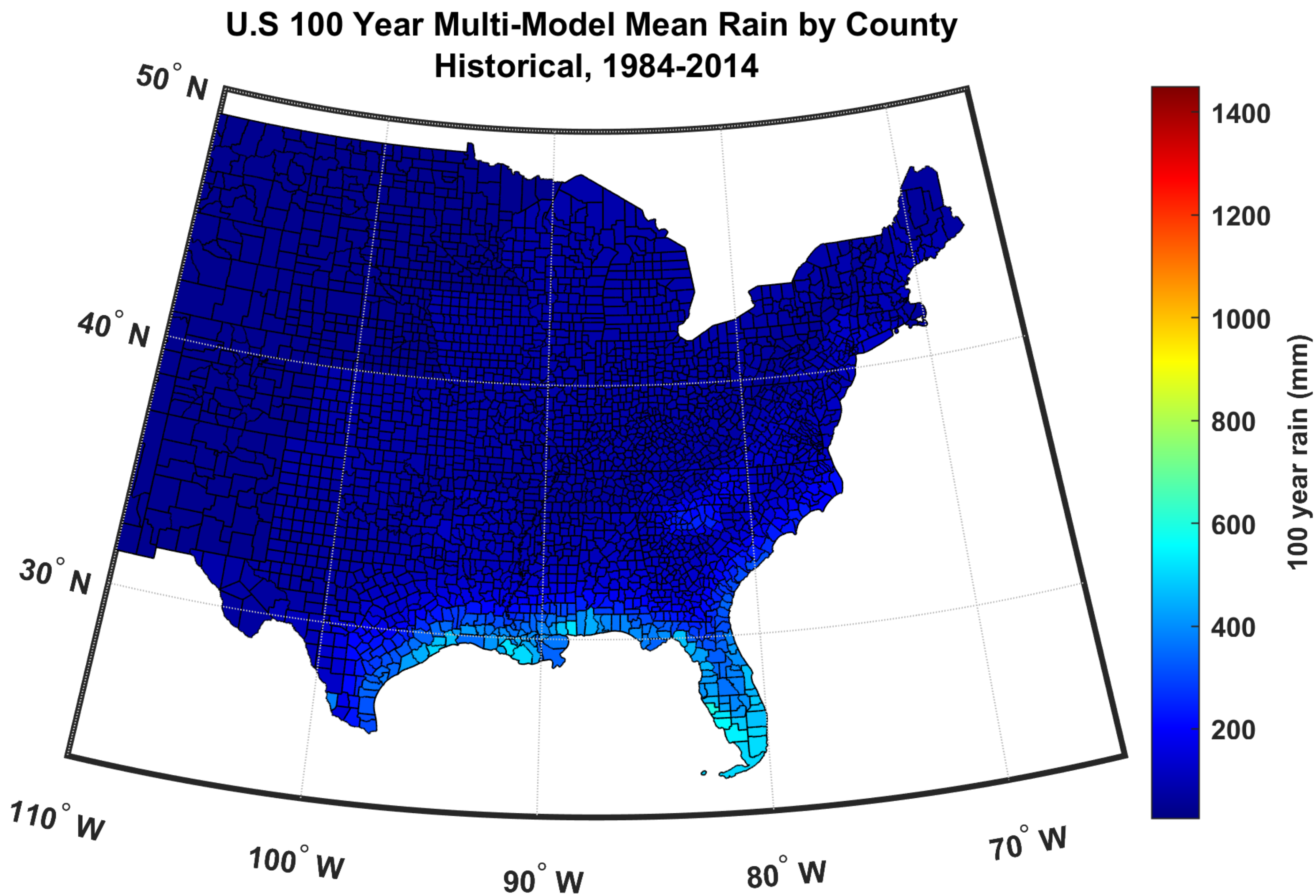
Red: A1B future climate (2081-2100) with R_0 increased by 10% and R_m increased by 21%

Lin et al. (2012)

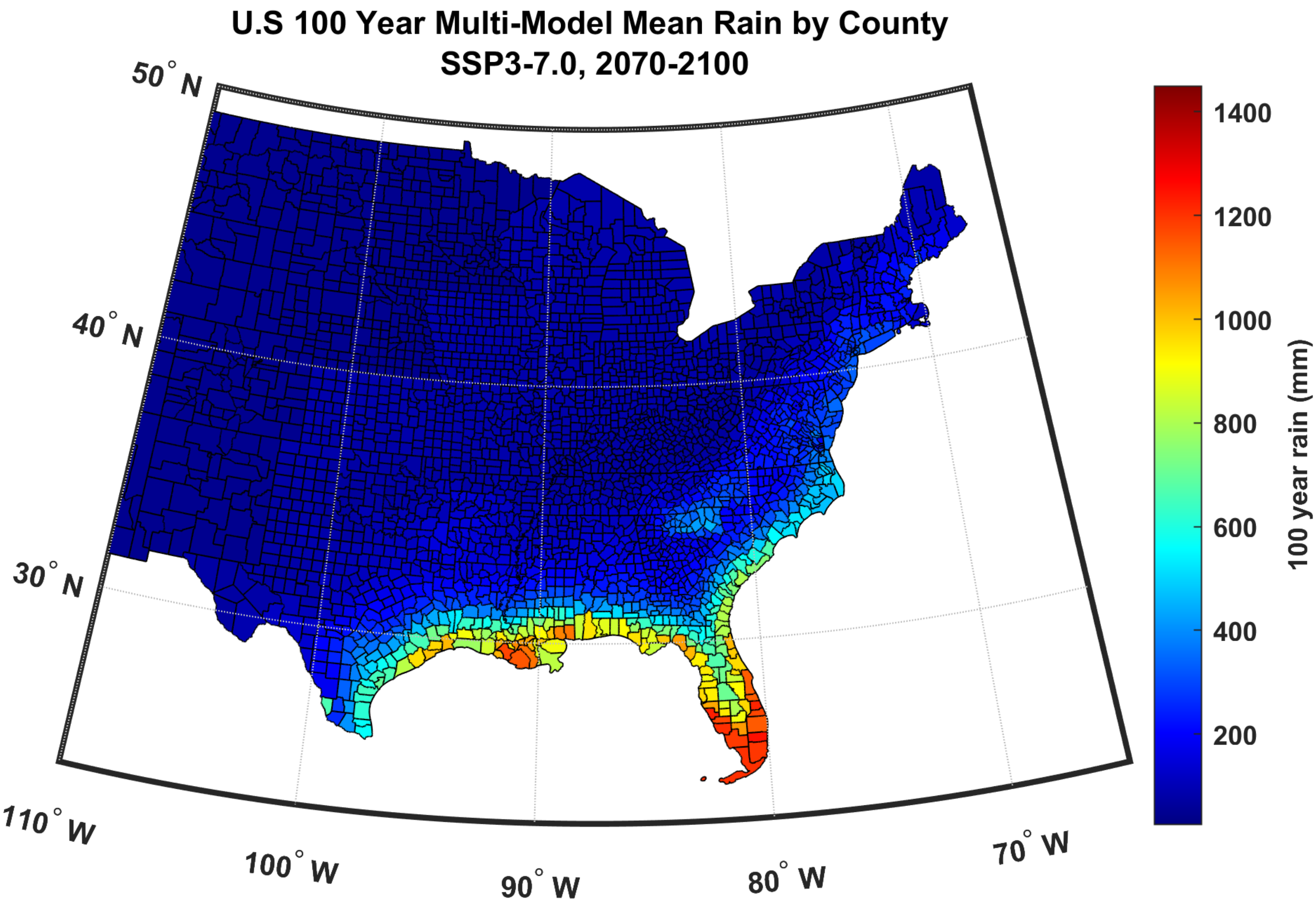
2,000 year rain event for Houston



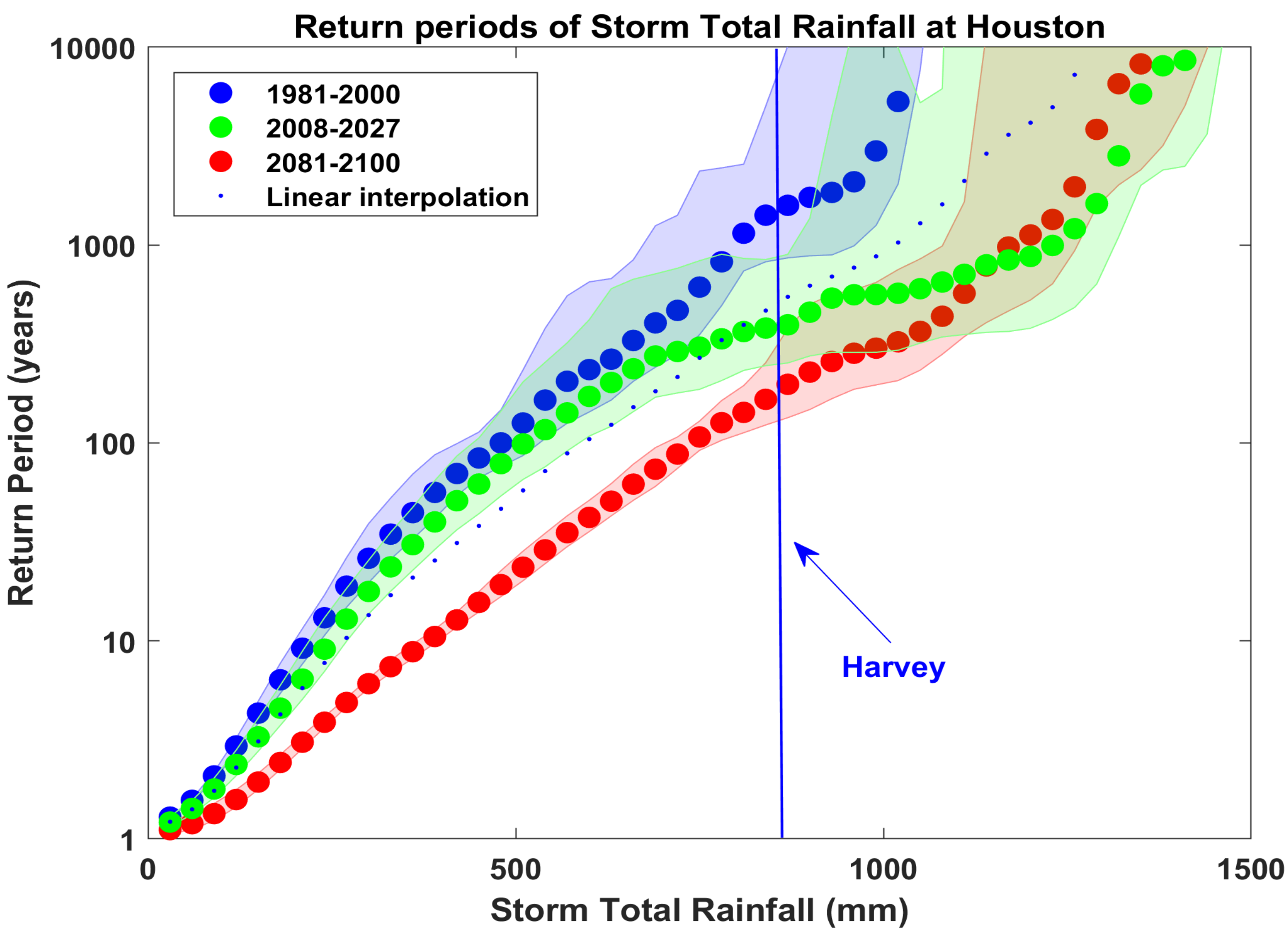
100-year hurricane storm total rain based on downscaling 8 climate models, 1984-2014



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

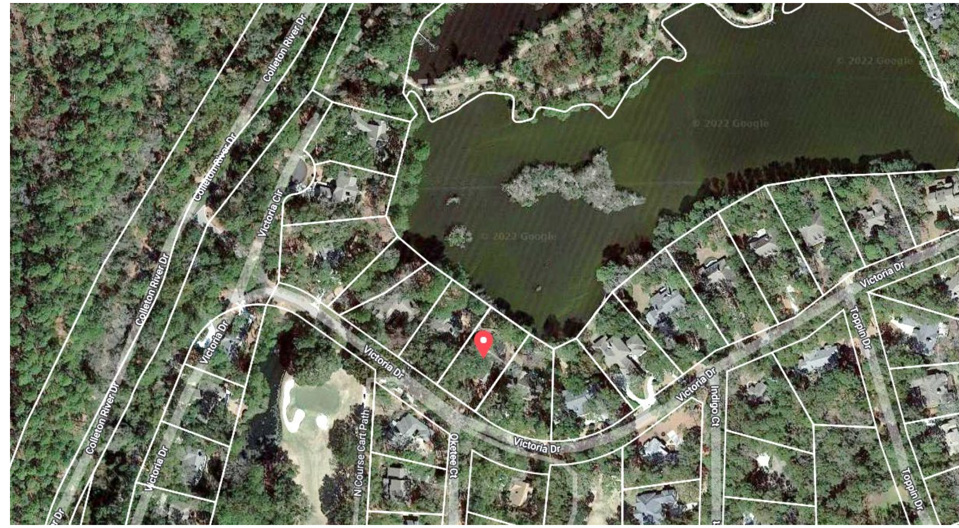


Probability of Storm Accumulated Rainfall in Harris County, from 6 Climate models, 1981-2000, 2008-2027, and 2081-2100, Based on 2000 Events Each, and Using RCP 8.5. Shading Shows Spread Among the Models.



Making it Personal

Property currently for sale in Hilton Head, SC
Realtor.com



For Sale

$750,000 Est. $3,558/mo

3 bed **3** bath **2,521** sqft **0.46** acre lot

133 Victoria Dr, Hilton Head Island, SC 29926

Single Family
Property Type

1 Day
Time on realtor.com

$298
Price per sqft

2 cars
Garage

1988
Year Built

Open Houses

Property Details

Property History

Monthly Payment

Neighborhood

Environmental Risk Flood

Schools

6 /10 MAJOR Flood Factor™

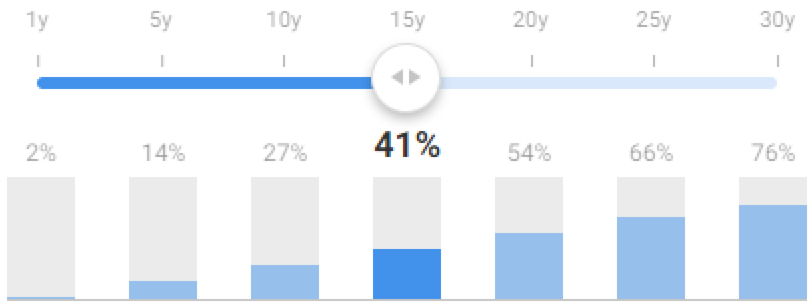
133 Victoria Dr, Beaufort County, South Carolina

FEMA Zone (est.): A9 Flood insurance: required

Work of First Street Foundation

This property has a **Major Flood Factor®**. Because the environment is changing, the annual damage to this building from all flood scenarios could increase by 212% in 30 years.

Likelihood of 6 in flood water to this building within **15 years**



Within the next 15 years, this property has a 41% chance of 6 inches of flood water reaching the building at least once.

Flooding could damage this home

Based on this home's first floor elevation of 1ft, projected flooding will damage this house's interior or foundation.

Annual Flood Damage	Expected loss to building structure over 15y
$4,004 this year $12,490 in 30y (+212%)	$90,800

Adjust building details

Summary

- Hurricanes are examples of organized structures arising from conditions of thermodynamic disequilibrium between tropical oceans and atmosphere.
- This disequilibrium is caused and maintained by the greenhouse effect. Adding greenhouse gases to the atmosphere increases the degree of disequilibrium
- Hurricanes are significant societal hazards

Other Take-Away Points

- We need to move away from sole dependence on flawed historical data in assessing climate- and weather-related natural hazard risk and embrace advanced modeling techniques
- We can no longer regard climate change as a problem for the future; it has already tangibly affected important risks, e.g. Hurricane Harvey's rainfall was ~3 times more likely in 2017 than in 1970
- Hurricane-induced flooding is probably the most serious potential effect of climate change on hurricane-related risks