Transportation System Resilience, Extreme Weather and Climate Change

Extreme Weather and Climate

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Massachusetts Institute of Technology

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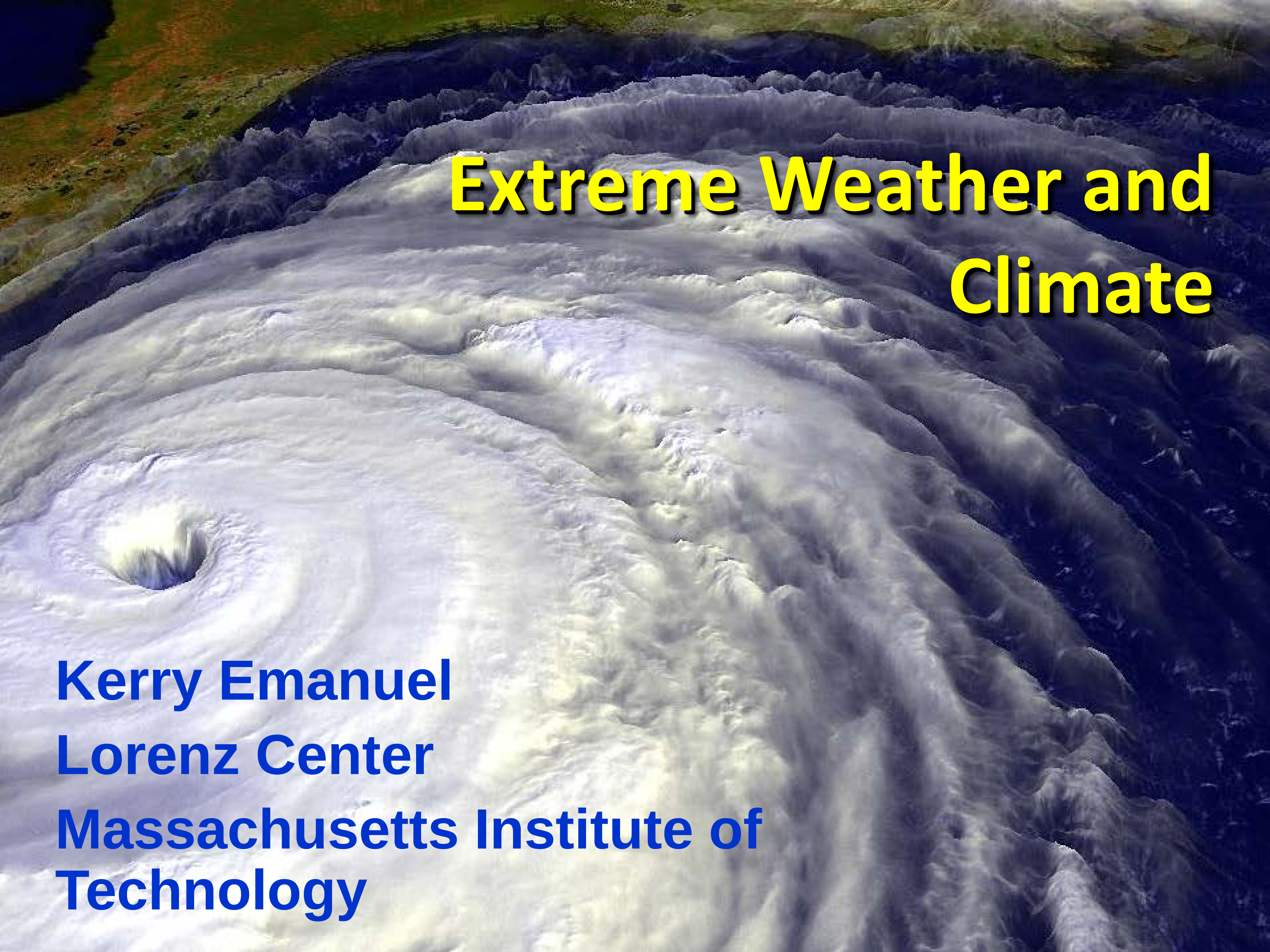
U.S. Department of Transportation

Volpe



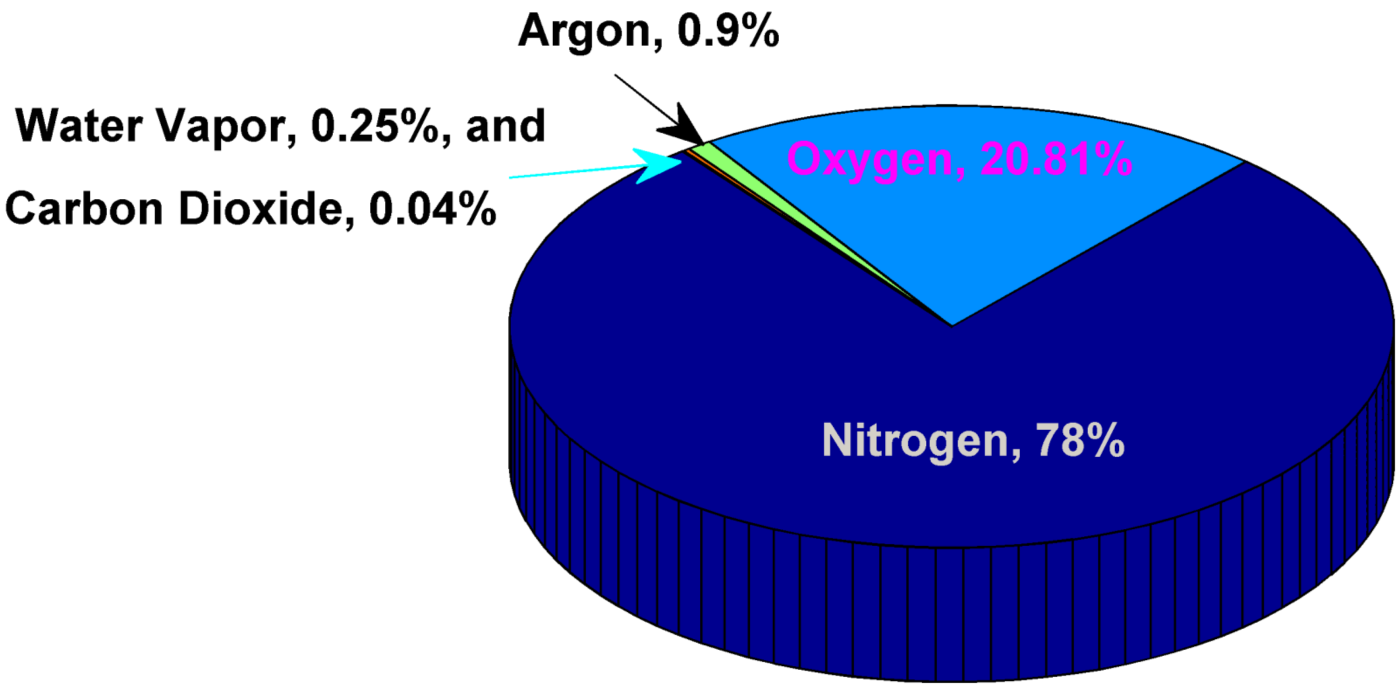
Extreme Weather and Climate

Kerry Emanuel
Lorenz Center
Massachusetts Institute of Technology

Program

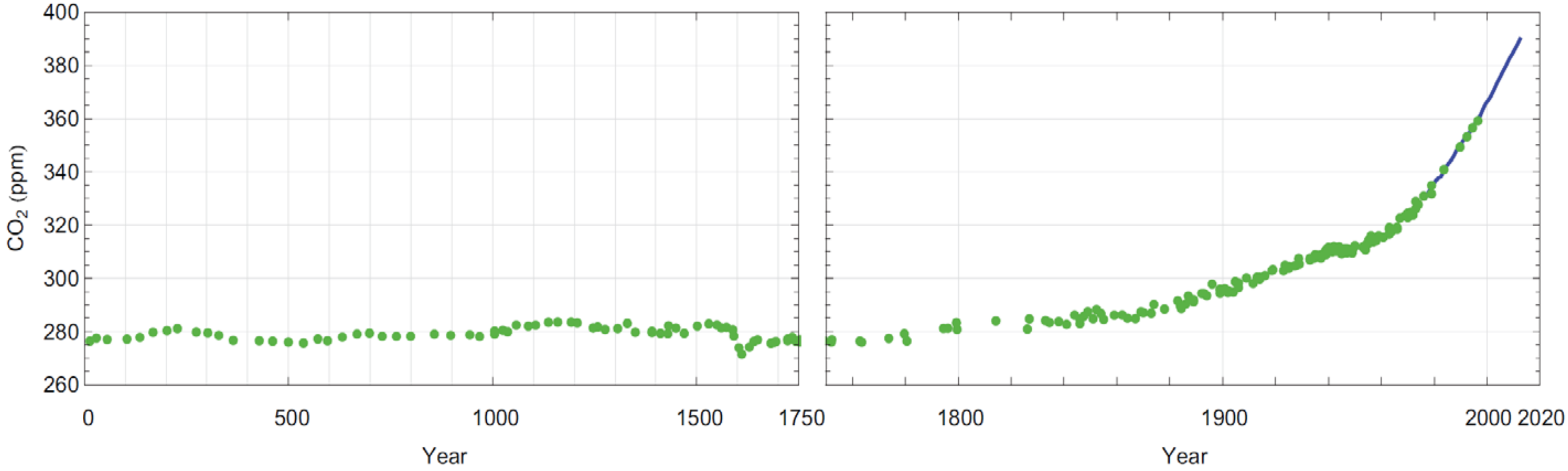
- **Overview of Climate Change**
- **Climate and Extreme Weather**

Greenhouse Gases



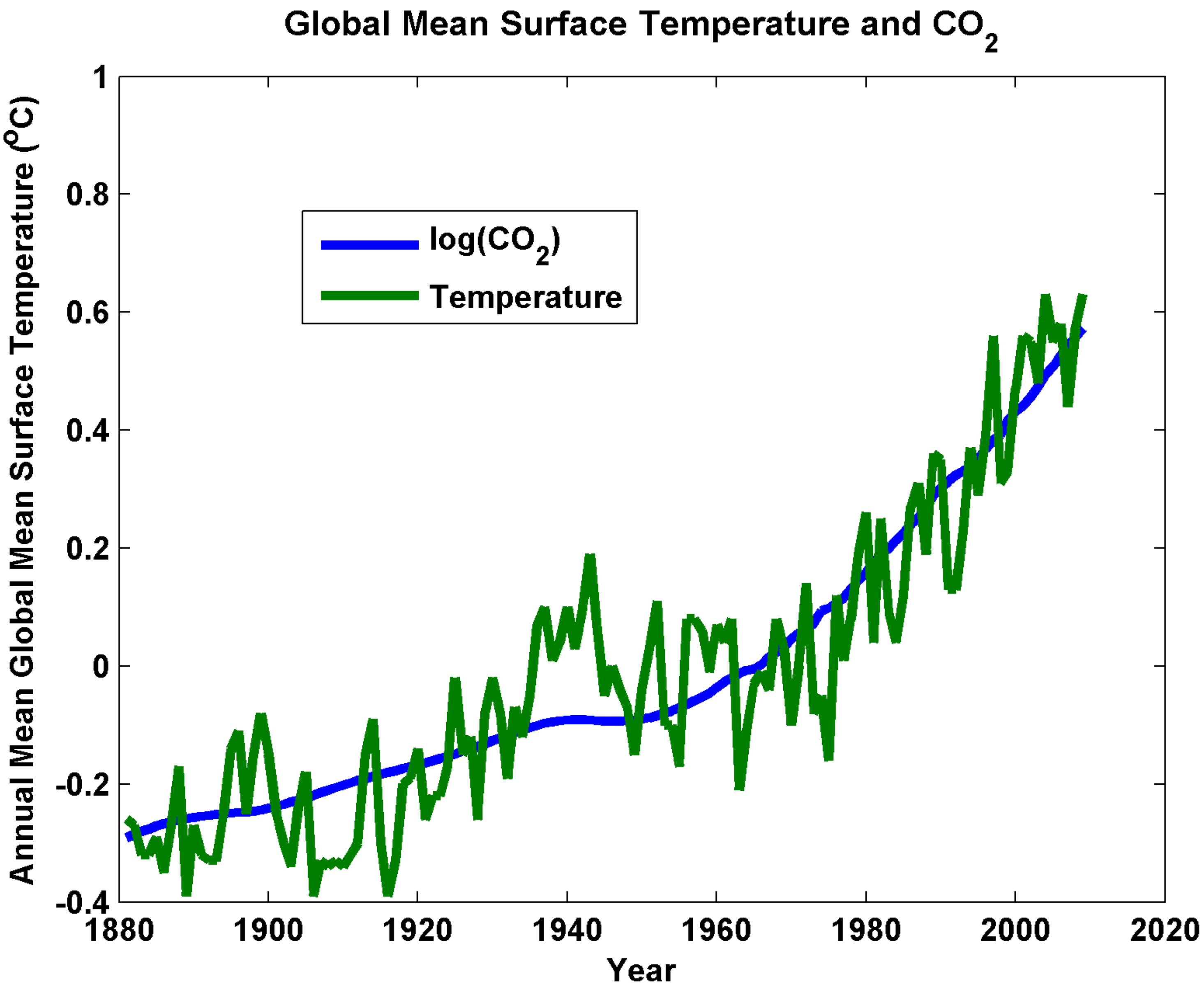
The orange sliver (can you see it?) makes the difference between a mean surface temperature of -18^{o}C and of 15^{o}C.

Carbon Dioxide Content is Increasing

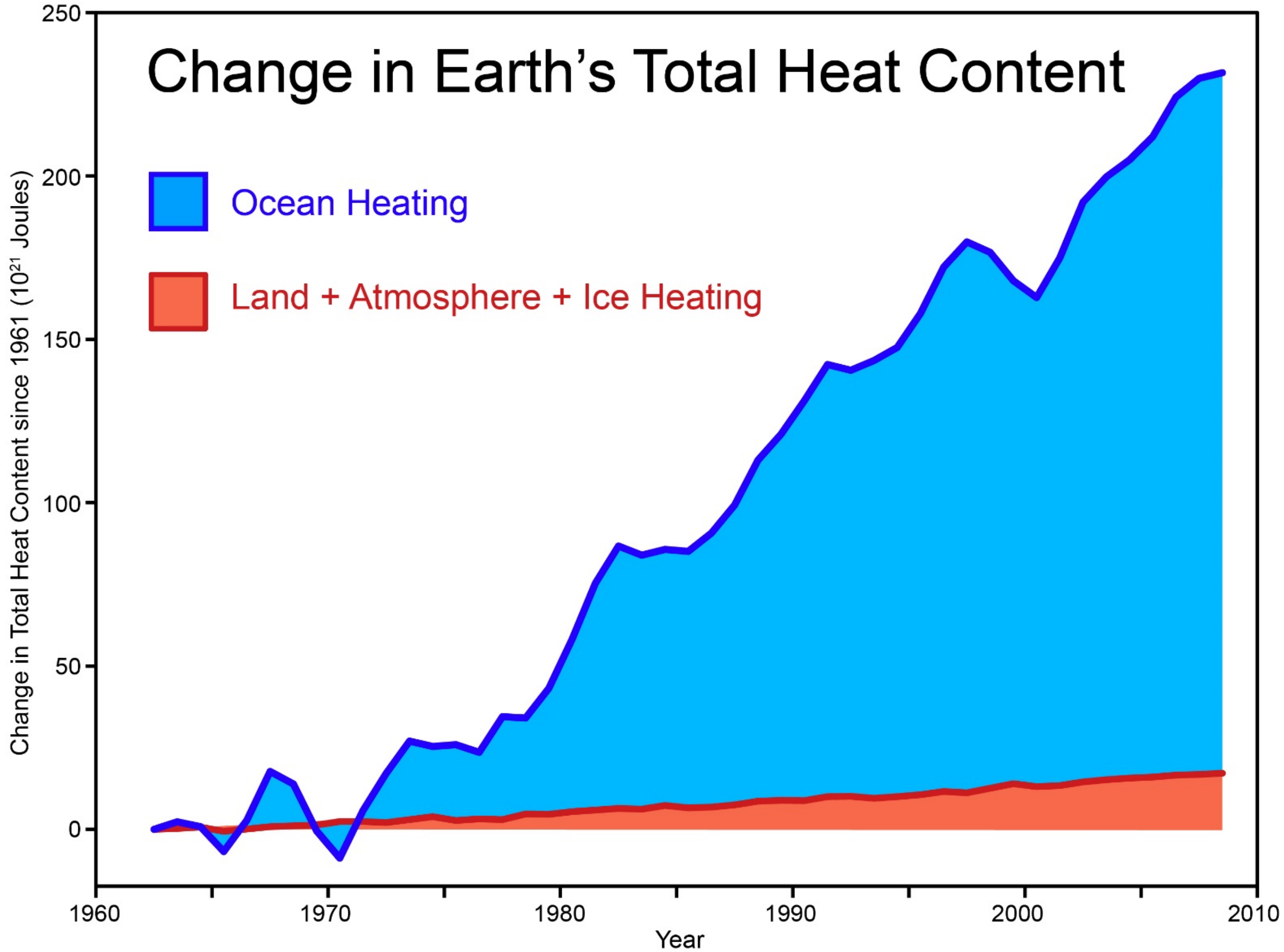


Carbon dioxide concentrations from ice cores (green dots) and direct measurements (blue curve)

Source: *IPCC Assessment Report 5 (Chapter 6)*



Global Mean Surface Temperature and CO_2
Annual Mean Global Mean Surface Temperature (^oC)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
1880
1900
1920
1940
1960
1980
2000
2020
Year
log(CO_2)
Temperature



Total amount of heat from global warming that has accumulated in Earth's climate system since 1961, from Church et al. (2011) (many thanks to Neil White from the CSIRO for sharing their data).

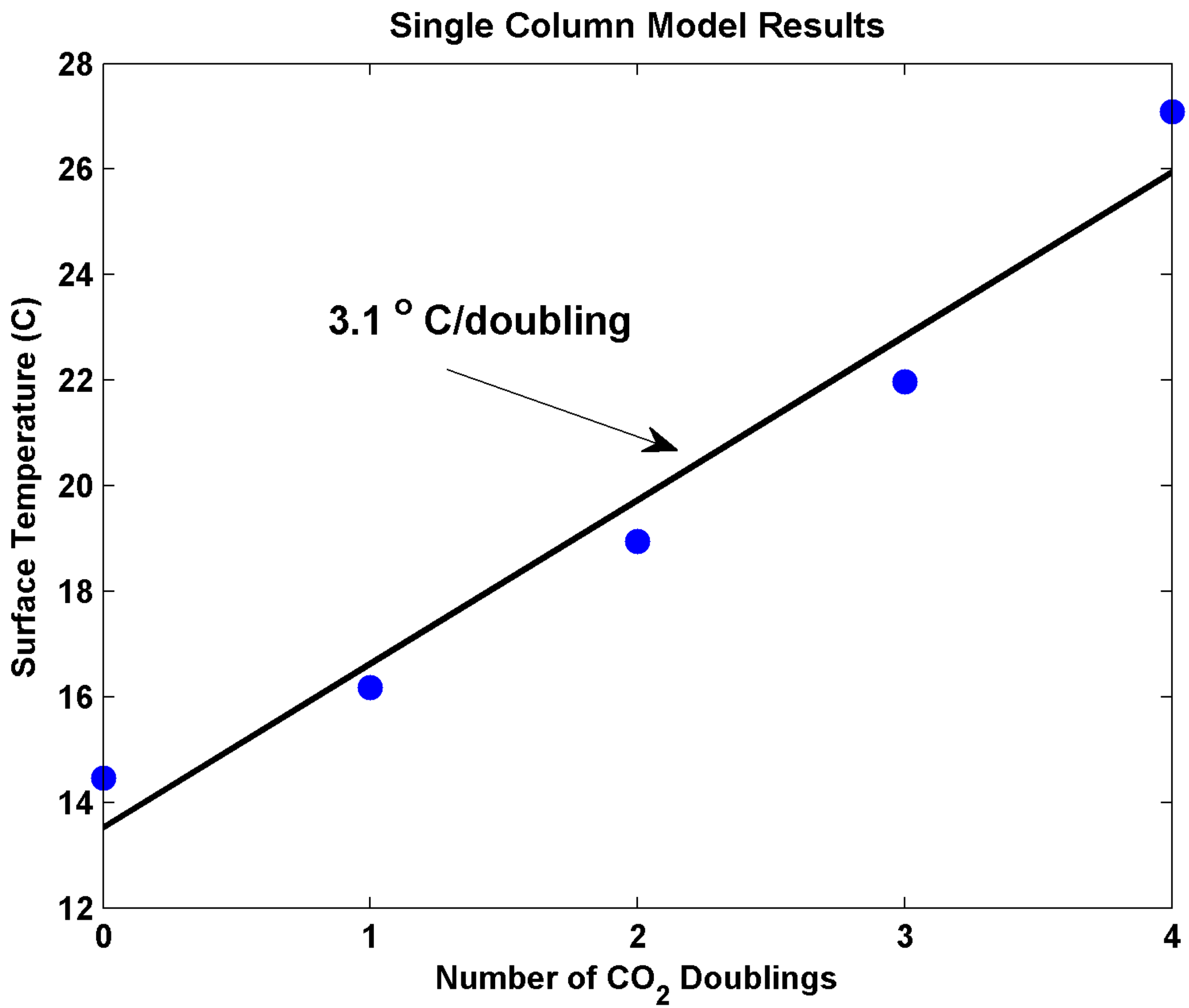
Supercomputers Not Needed to Understand This

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°C; and if the carbon dioxide were increased fourfold, the temperature would rise by 8°C." – *Världarnas utveckling (*Worlds in the Making), 1906

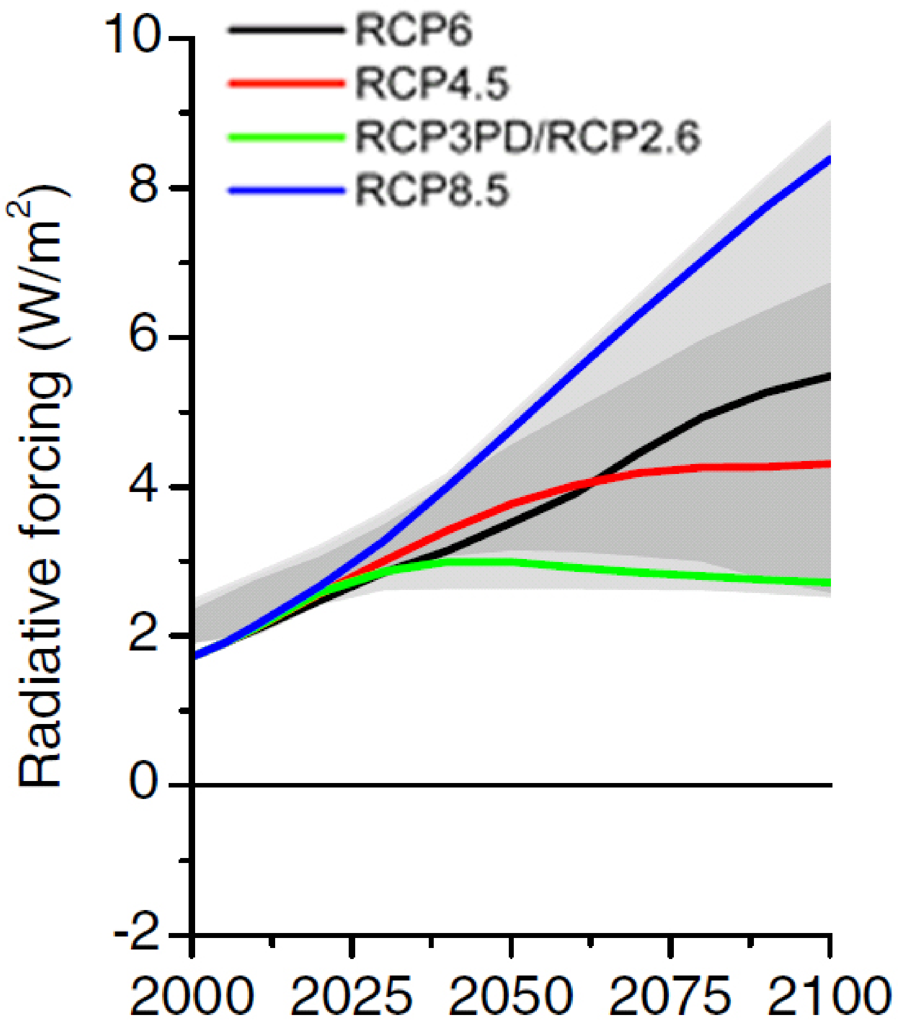
Latest estimate from IPCC (2013): *1.5 – 4.5 °C*

MIT Single Column Model
(Can be run on a laptop)



IPCC Estimate: 1.5-4.5 °C

Projections



Radiative Forcing of the Representative Concentration Pathways (RCPs). The light grey area captures 98% of the range in previous IAM scenarios, and dark grey represents 90% of the range.

Image credit: *IPCC Fifth Assessment Report*

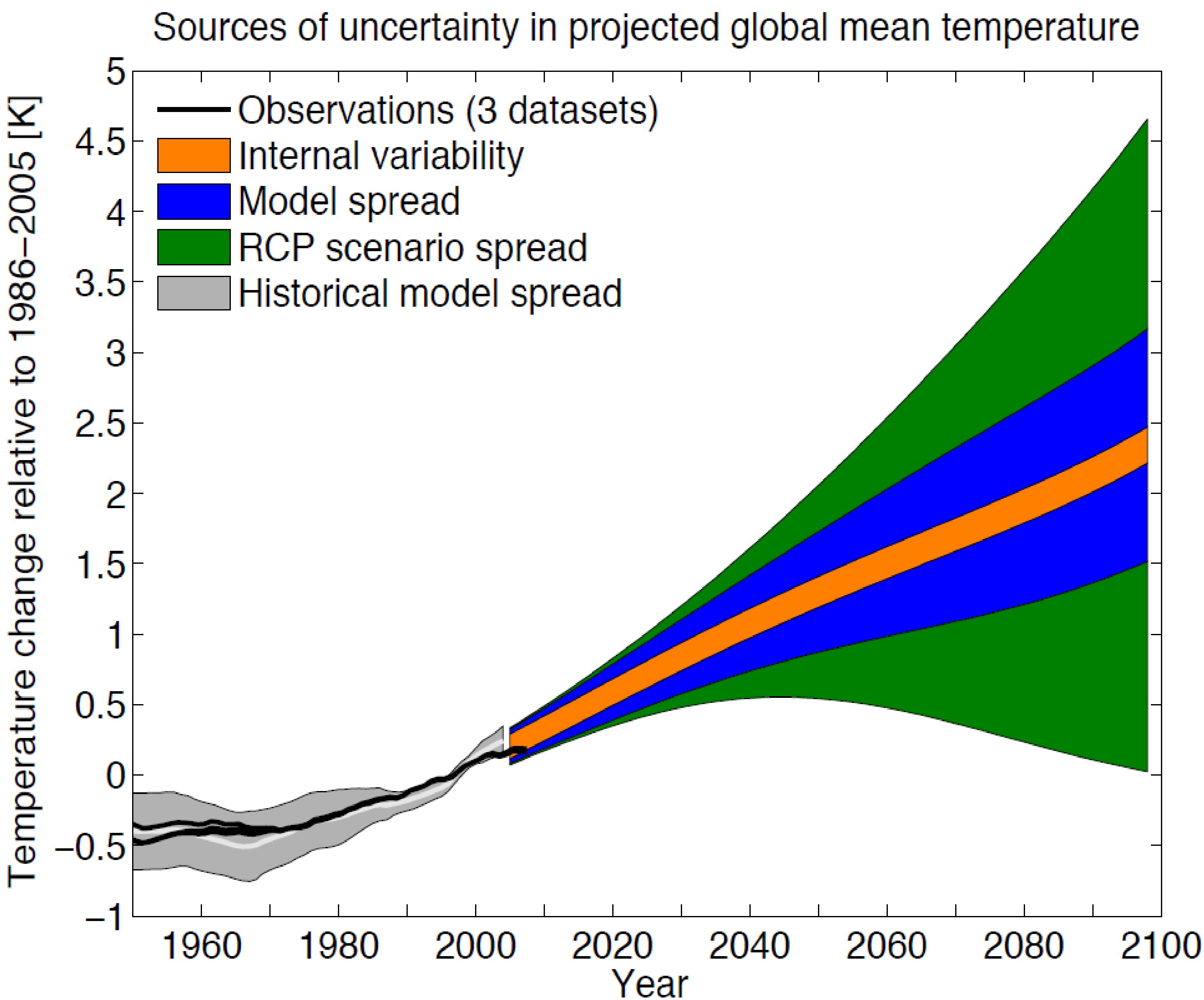
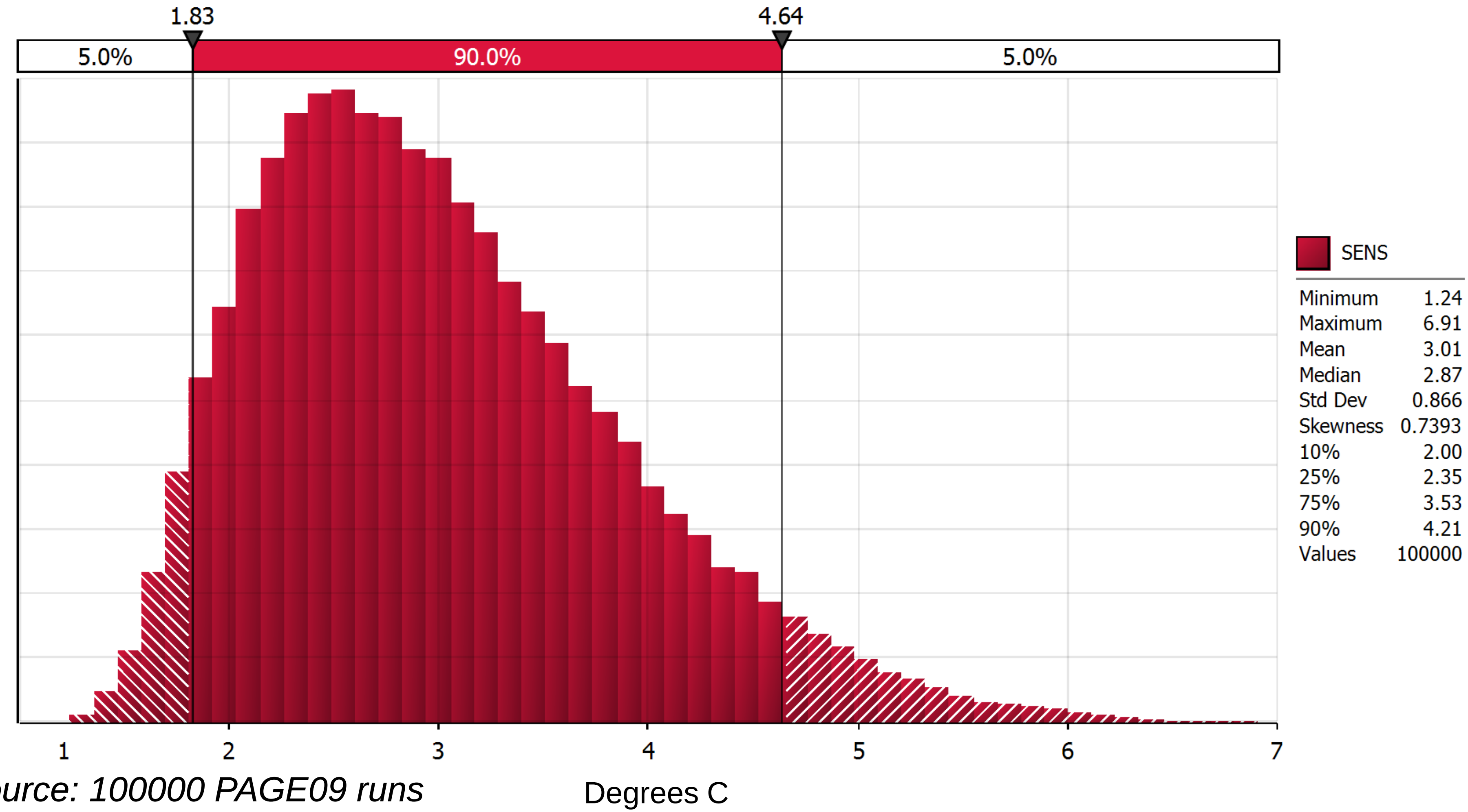


Image credit: *IPCC Fifth Assessment Report*

Estimate of how much global climate will warm as a result of doubling CO_2: a probability distribution



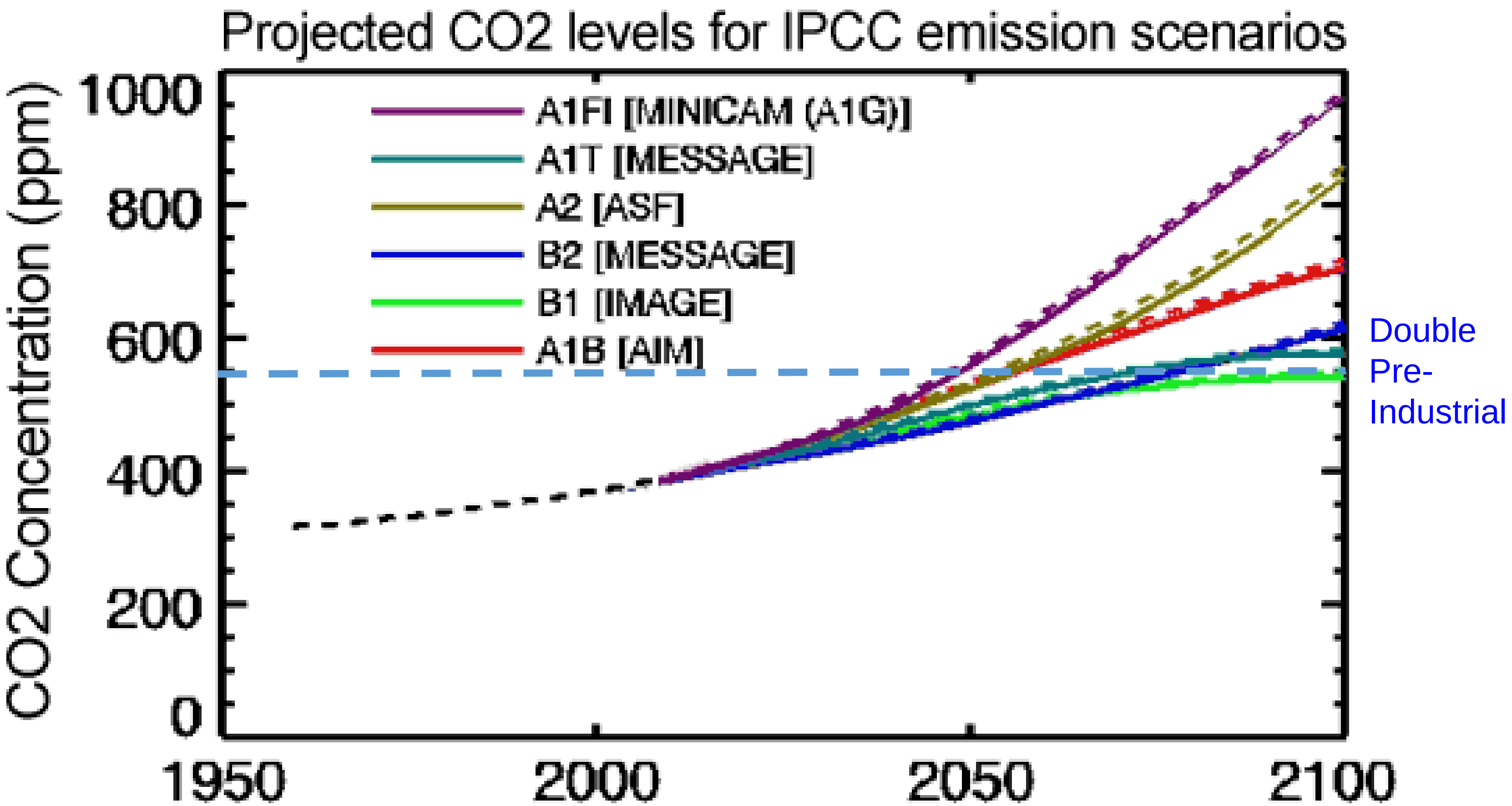
Source: 100000 PAGE09 runs

SEI

ClimateCost

Chris Hope, U. Cambridge
courtesy Tim Palmer

CO_2 Will Likely Go Well Beyond Doubling



IPCC 2007: Doubling CO_2 will lead to an increase in mean global surface temperature of 2 to 4.5 °C.

Atmospheric CO_2 assuming that emissions stop altogether after peak concentrations

Global mean surface temperature corresponding to atmospheric CO_2 above

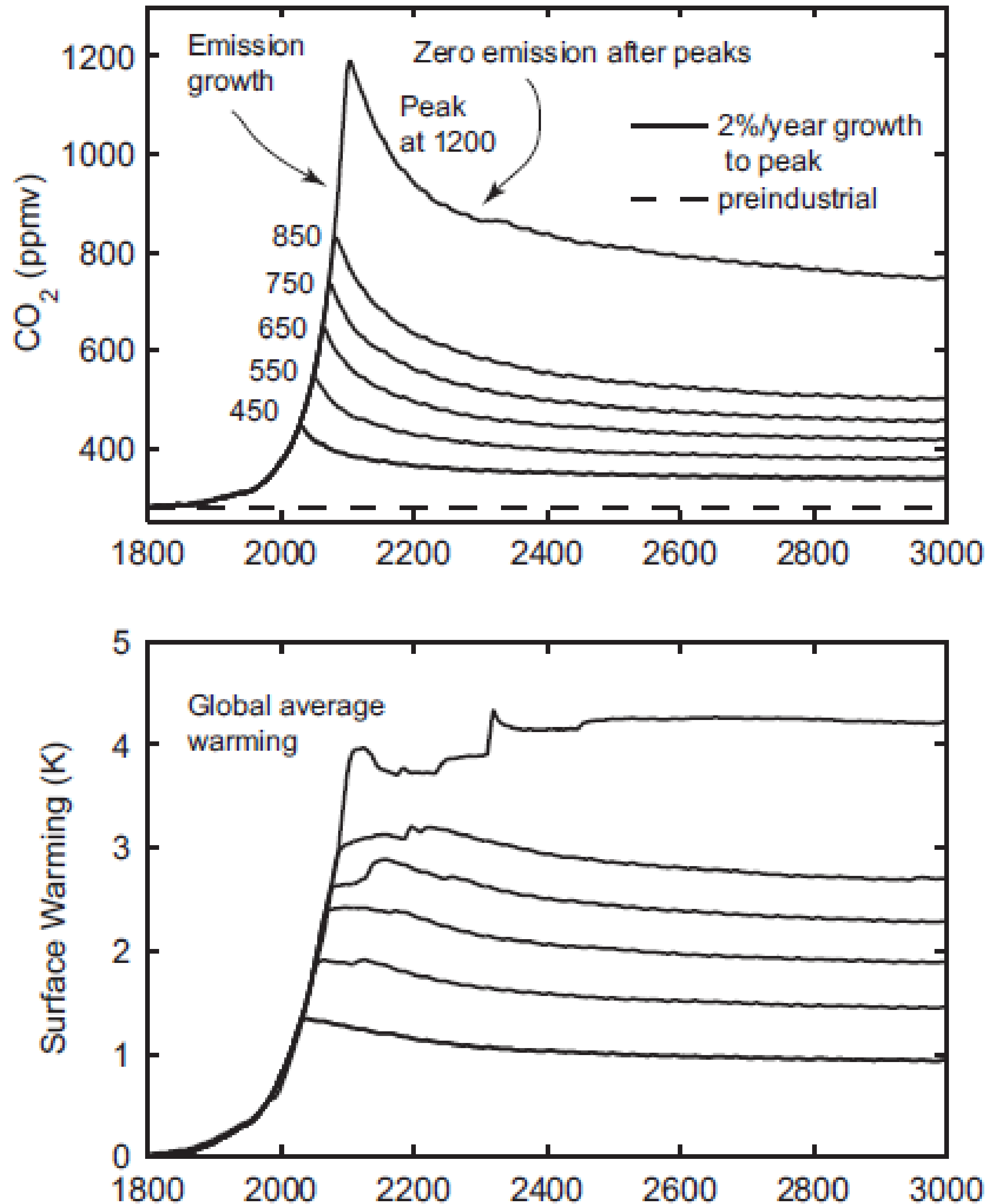
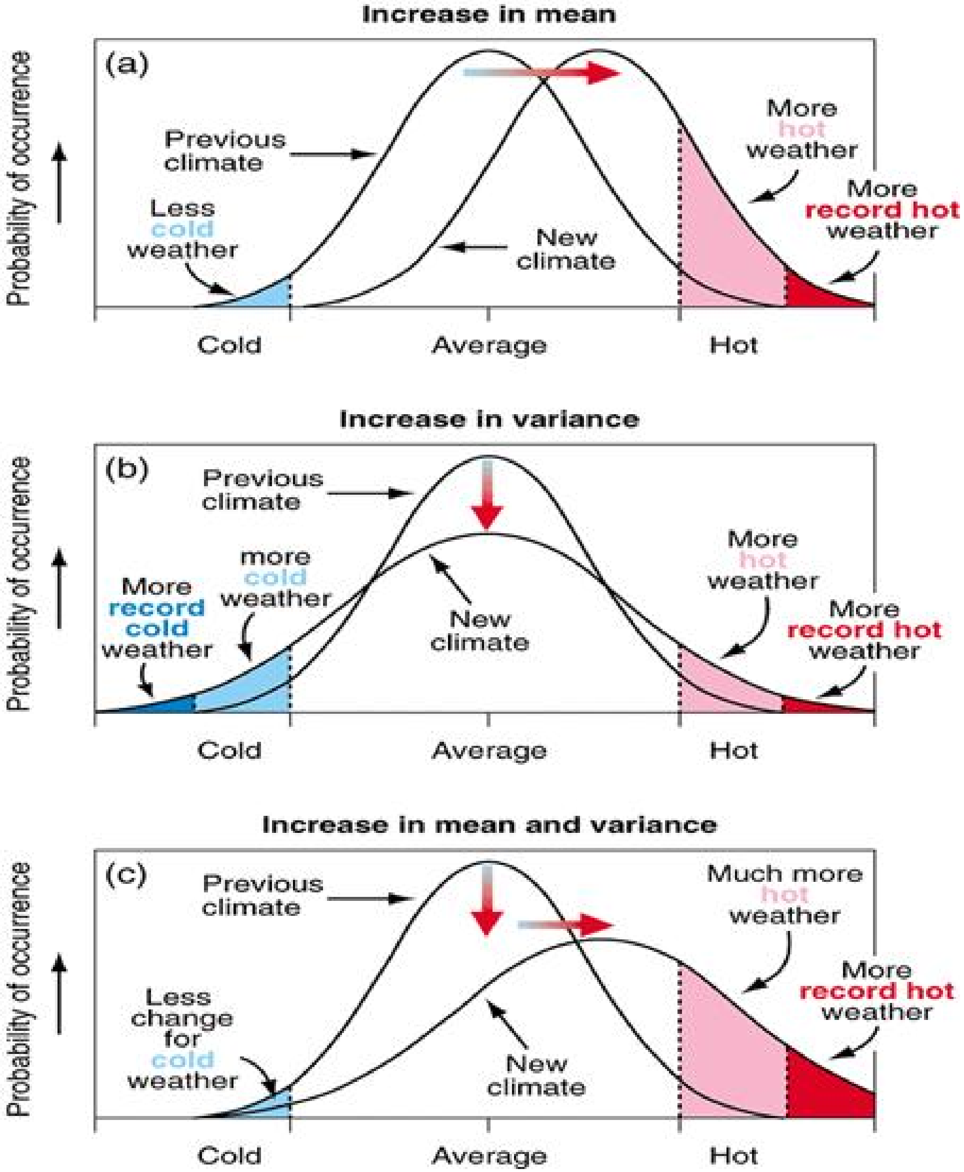
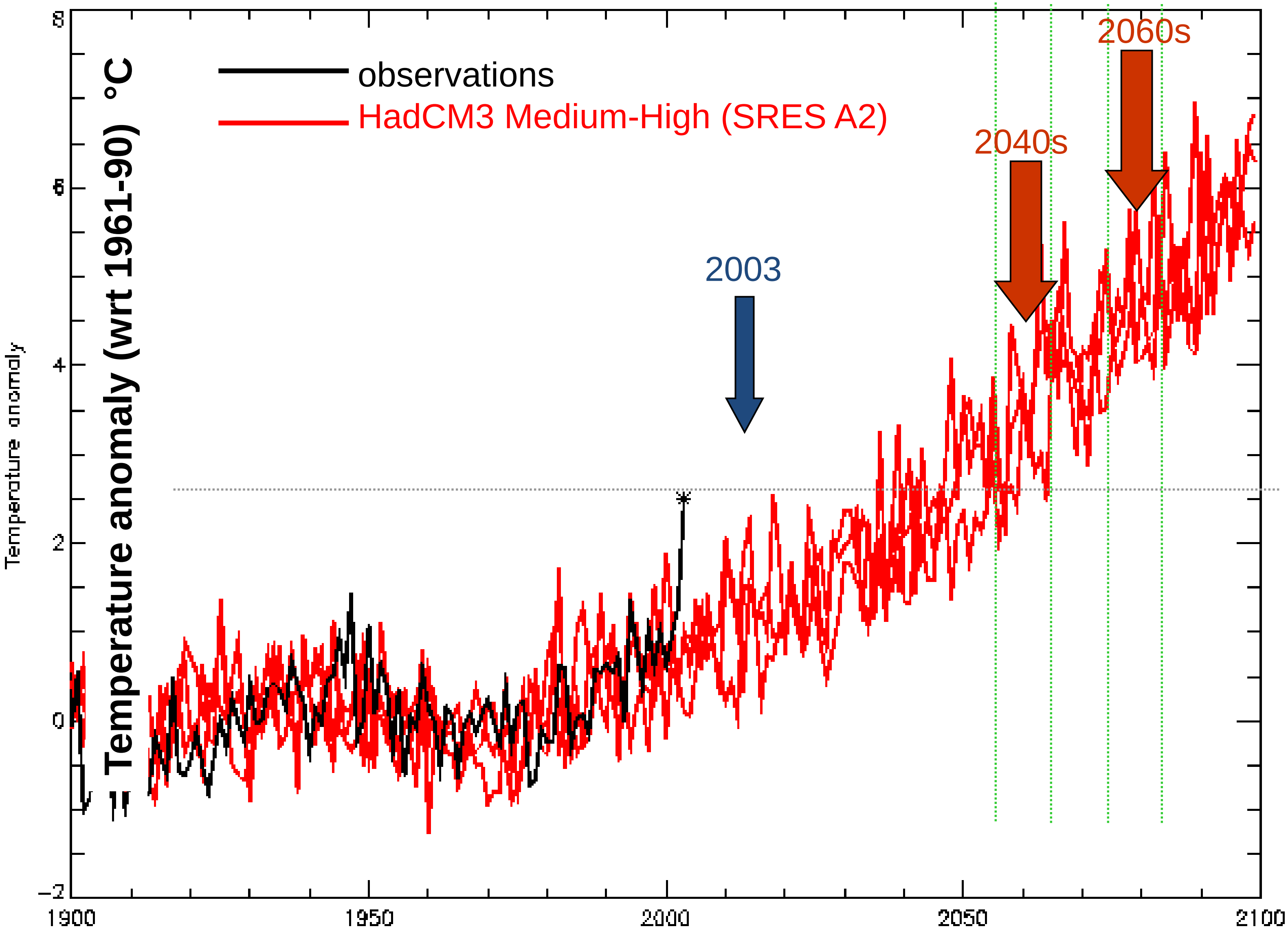


Image source: Solomon, S., G.-K. Plattner, R. Knutti, and P. Friedlingstein, 2009, *PNAS*, **106,** 1704-1709

Large Risks in the Tail of the Distribution



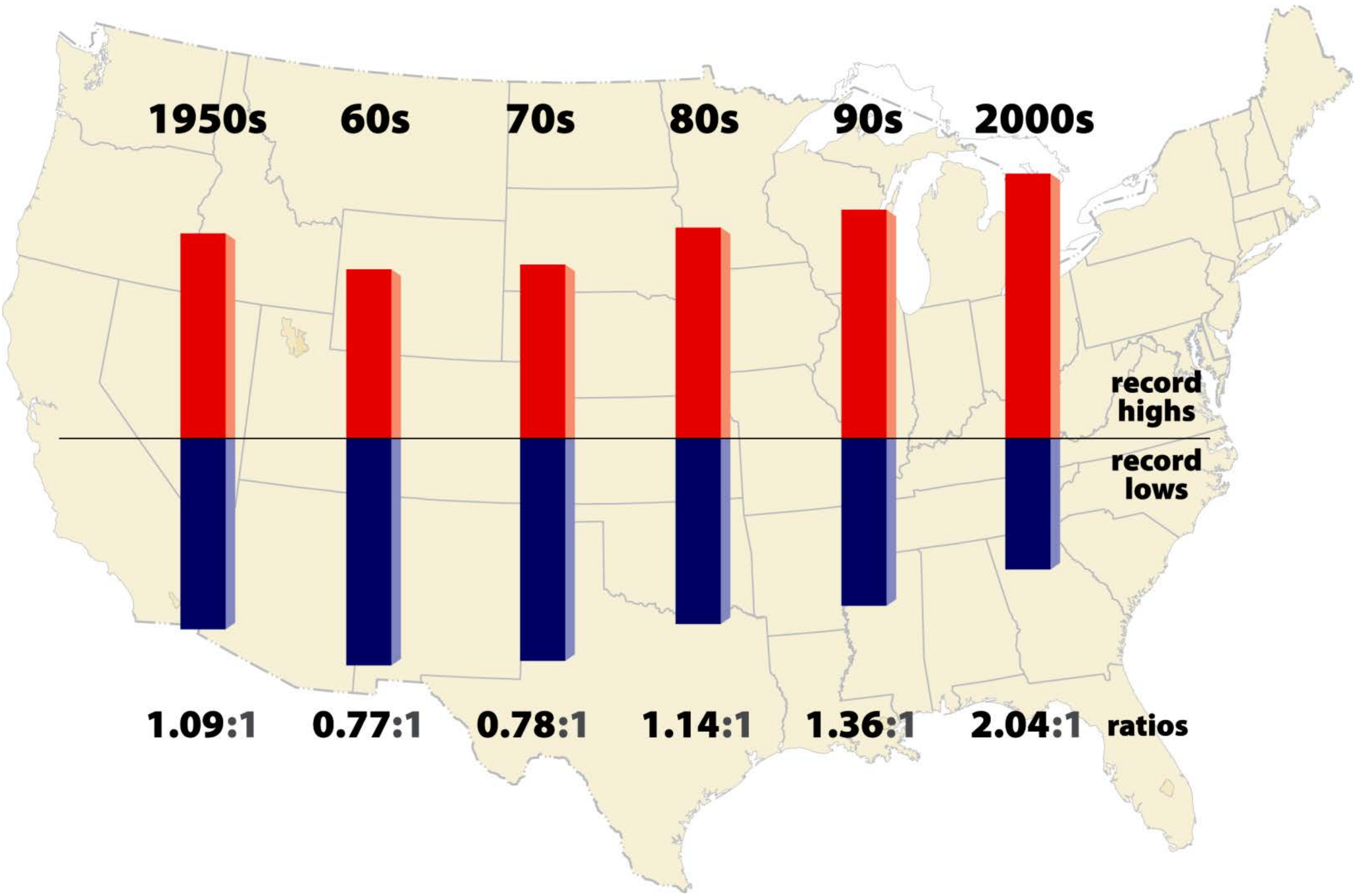
Heat Waves



observations
HadCM3 Medium-High (SRES A2)
2003
2040s
2060s
Temperature anomaly (wrt 1961-90) °C
Temperature anomaly
-2
0
2
4
6
8
1900
1950
2000
2050
2100

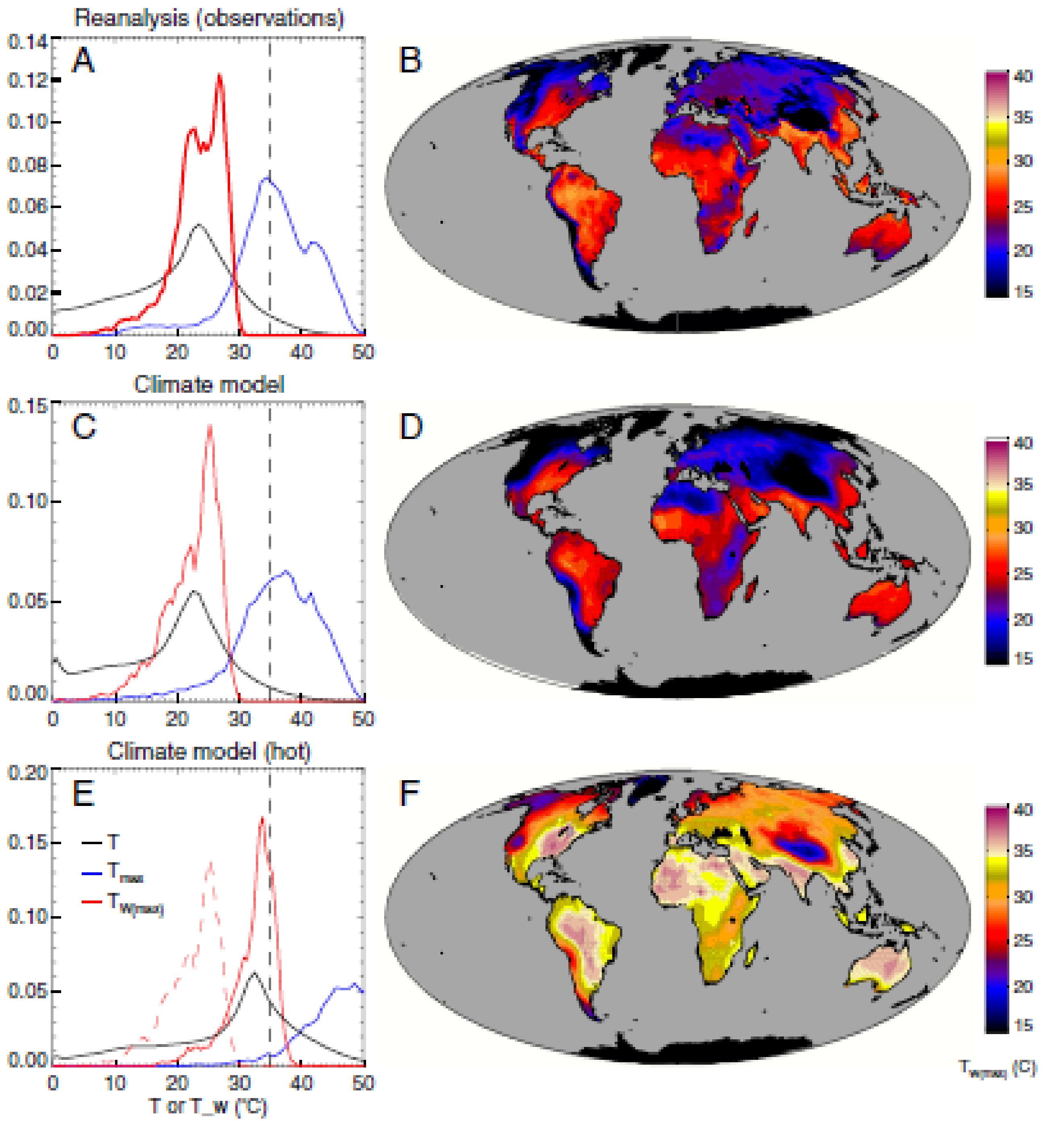
High vs Low Temperature Records

2011- 2.7:1



Sherwood and Huber, PNAS, 2010

Adaptation Limit: Maximum Tolerable Wet Bulb Temperature



12º increase in mean global T

Hydrological Extremes Increase with Temperature

Floods

Blizzards

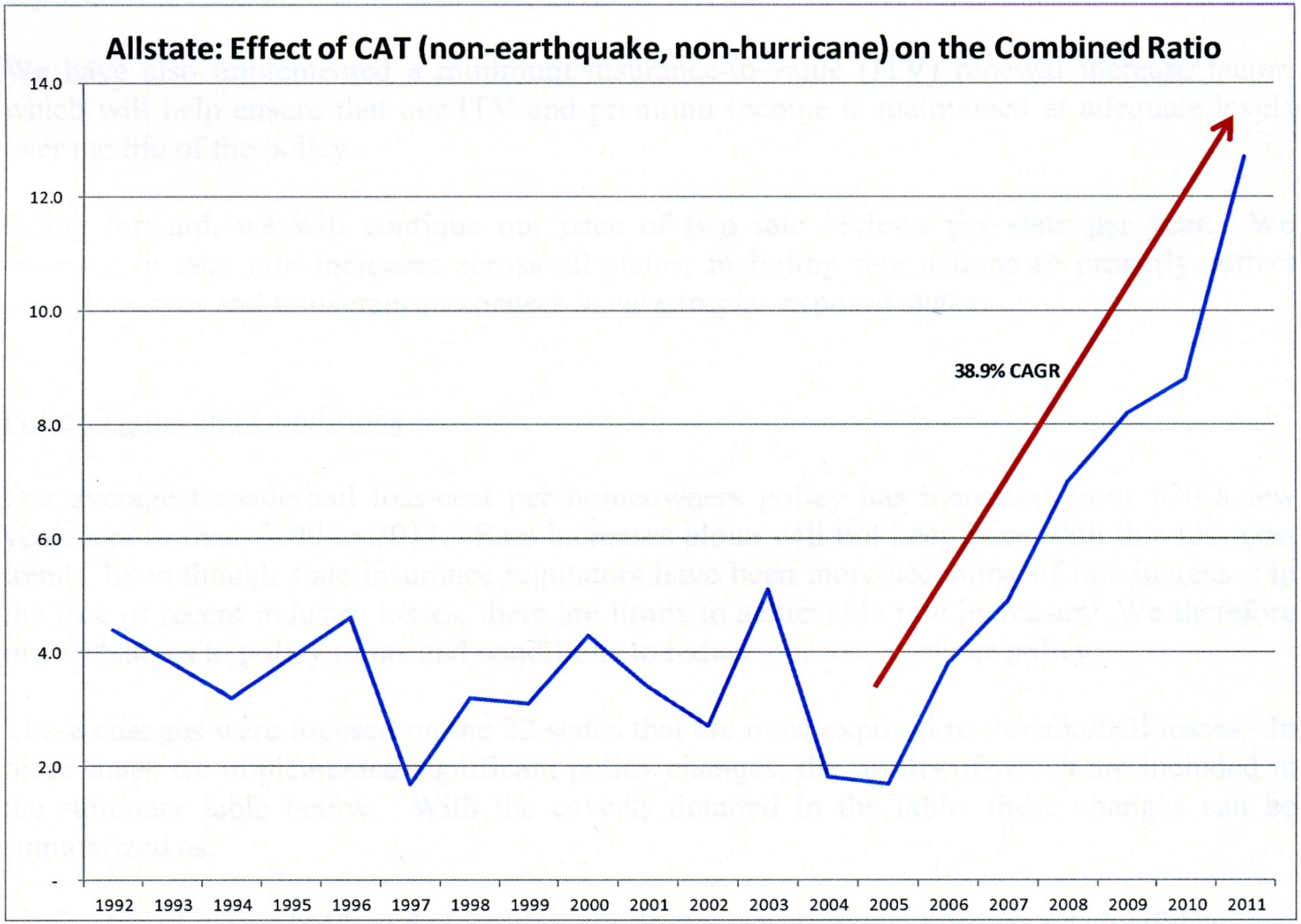
Drought

Severe Thunderstorms

Tornadoes

Hail Storms

Allstate ratio of losses to premiums



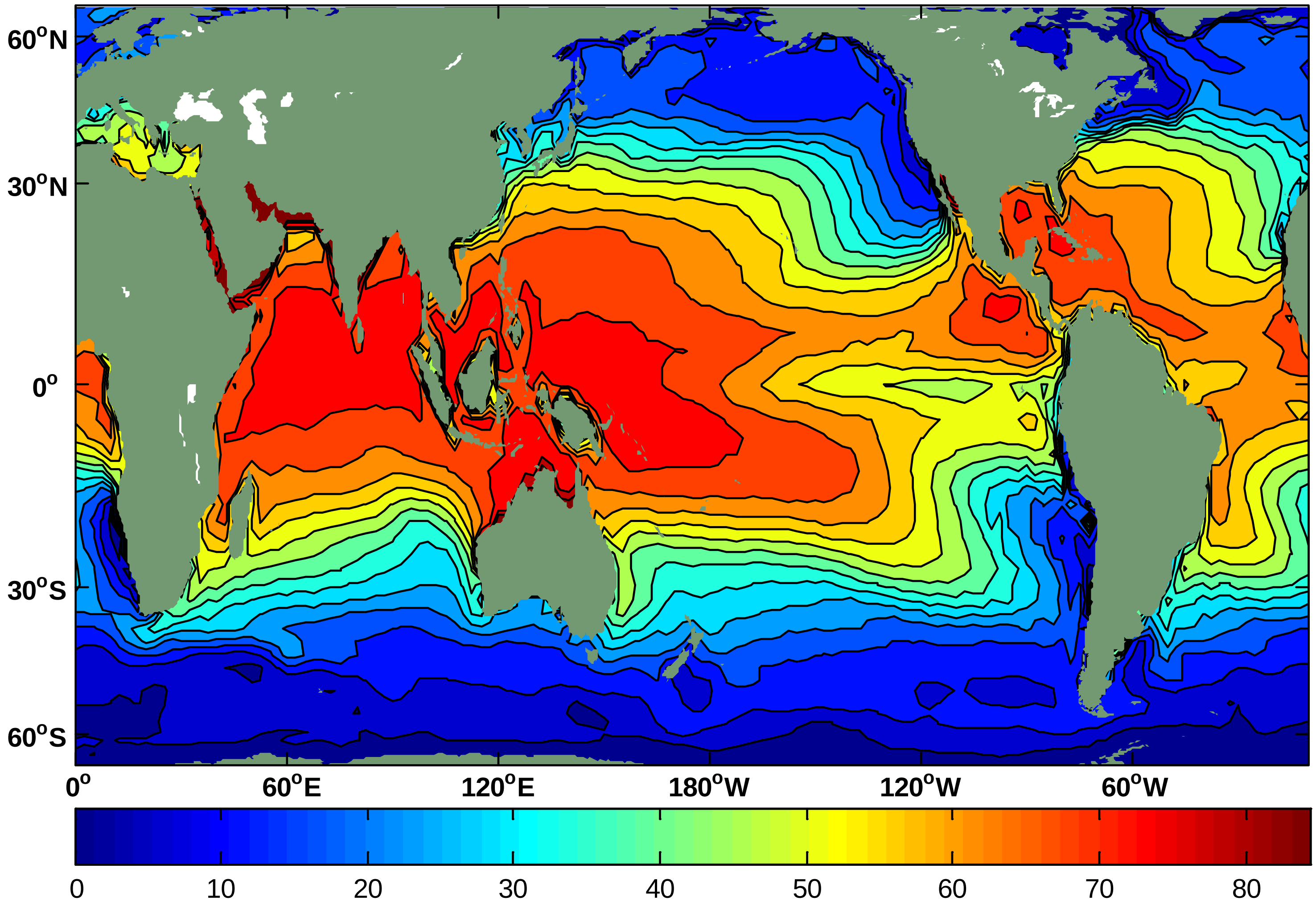
Source: ALL Q4, 2011 Statistical Supplement

Hurricanes

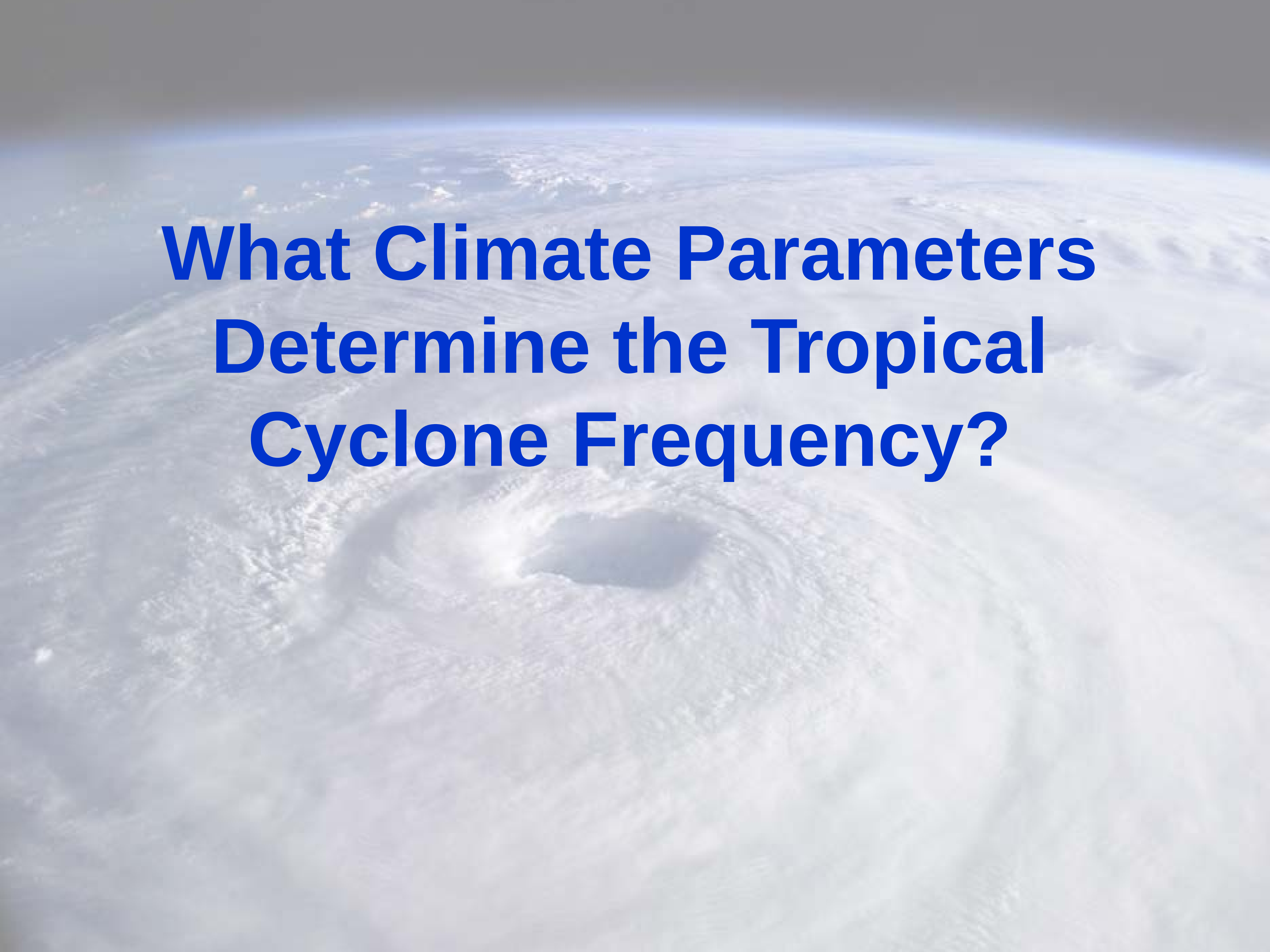
Intensity Theory

Potential Intensity: **Maximum sustainable surface wind speed in a given thermodynamic environment (sea surface temperature and atmospheric temperature profile)**

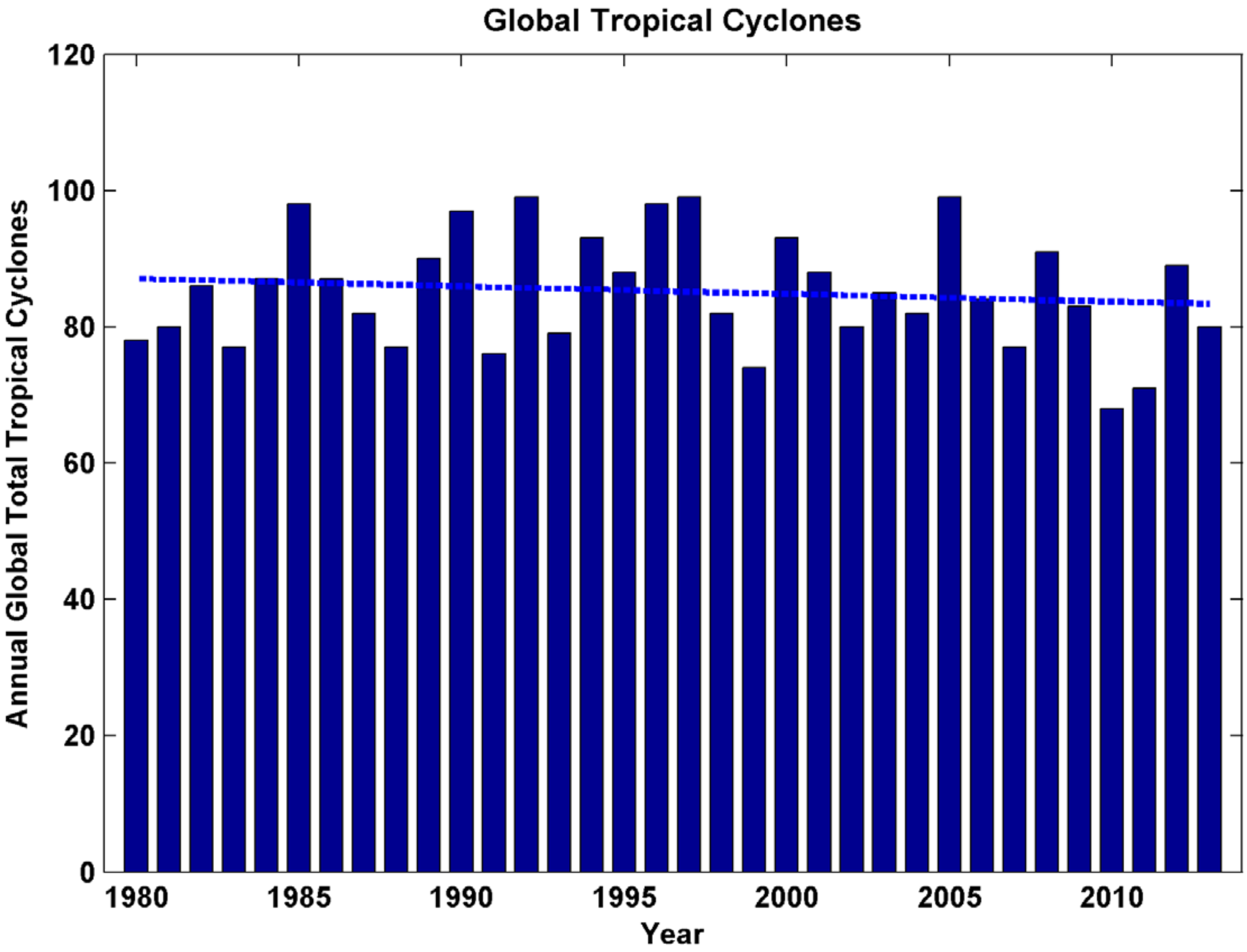
Annual Maximum Potential Intensity (m/s)



What Climate Parameters Determine the Tropical Cyclone Frequency?



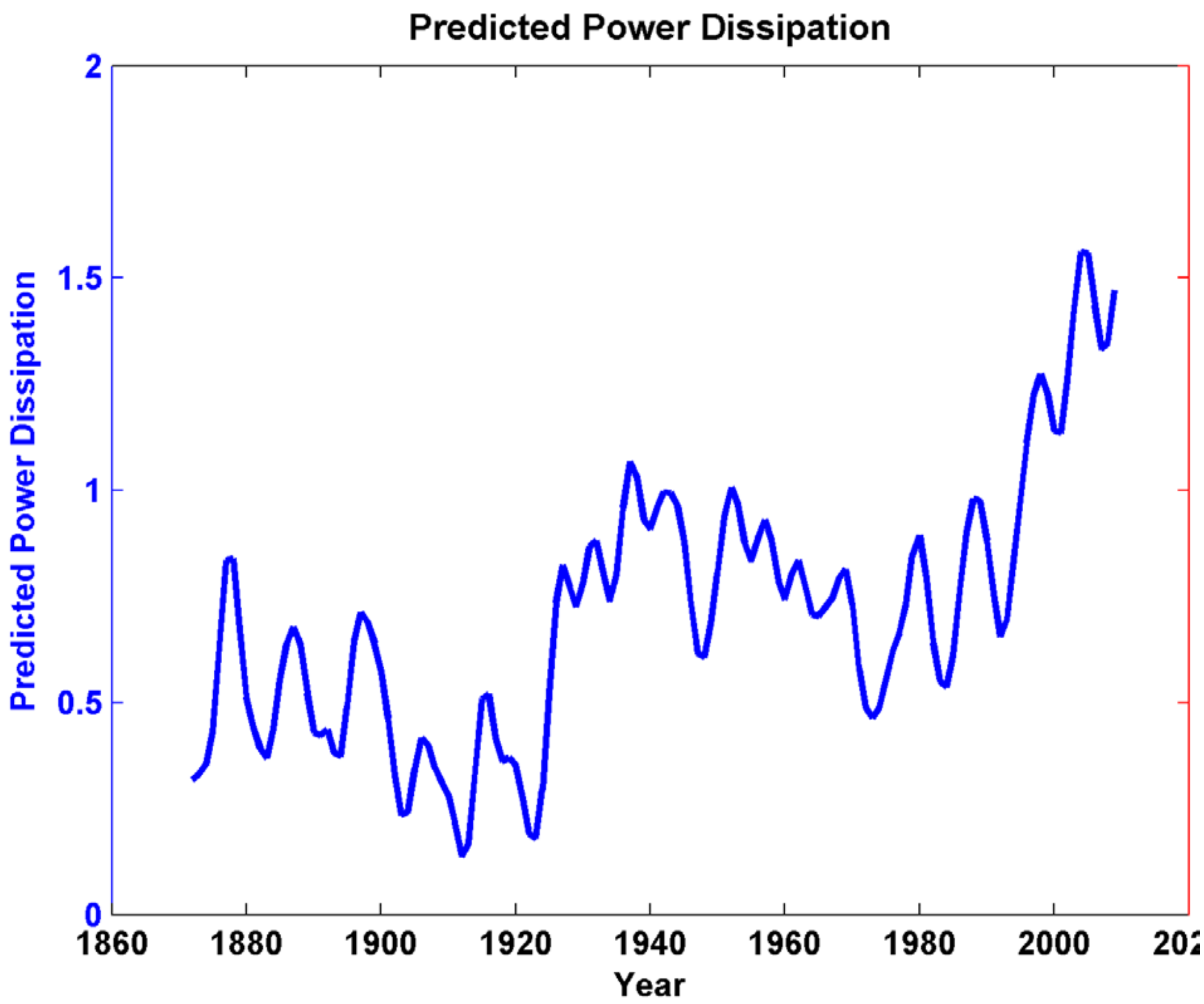
Global Tropical Cyclone Frequency, 1980-2013



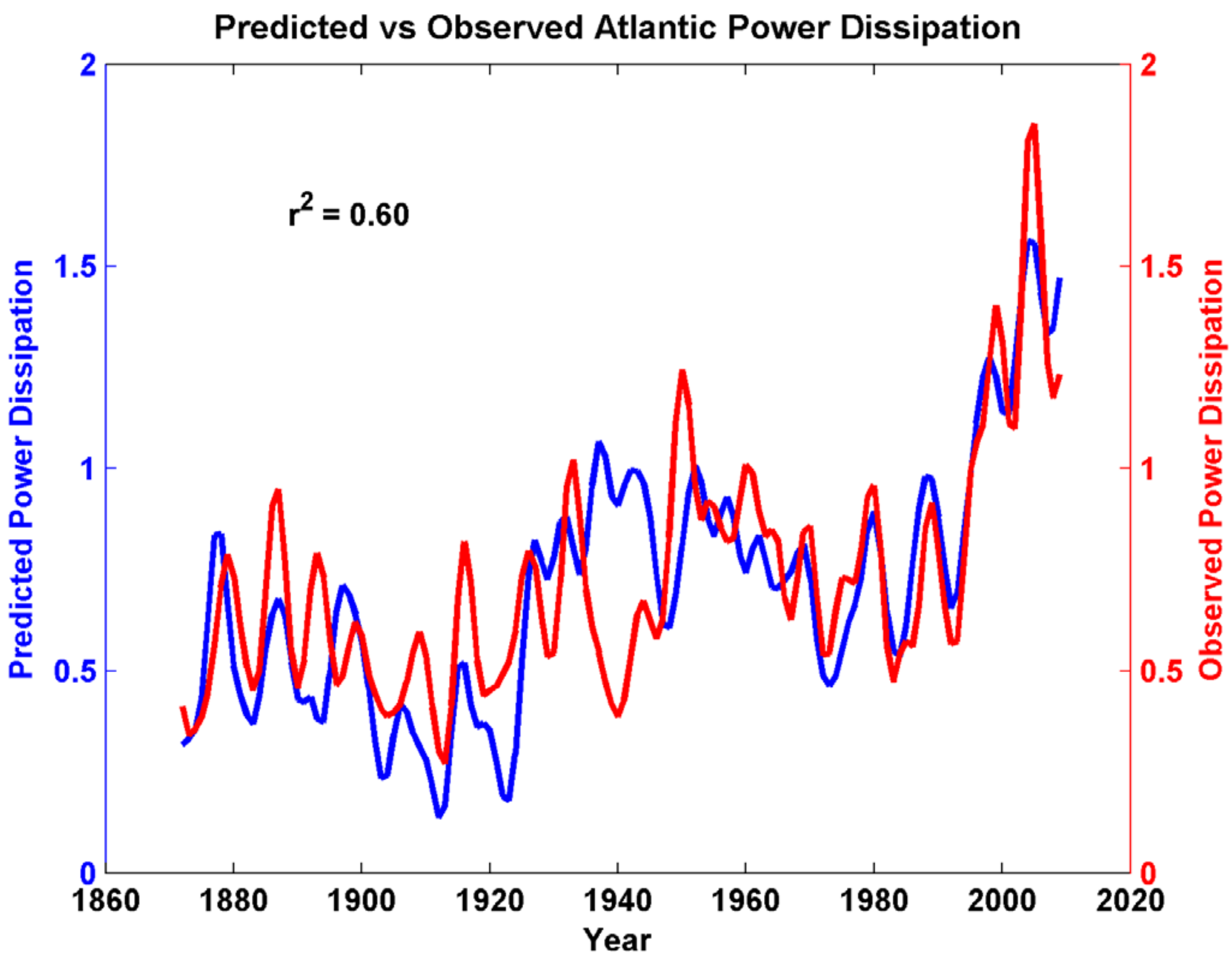
Data Sources: NOAA/TPC and NAVY/JTWC


Some Empirical Findings

Sea Surface Temperature Scaled to Observed Hurricane Power Dissipation, 1980-2011



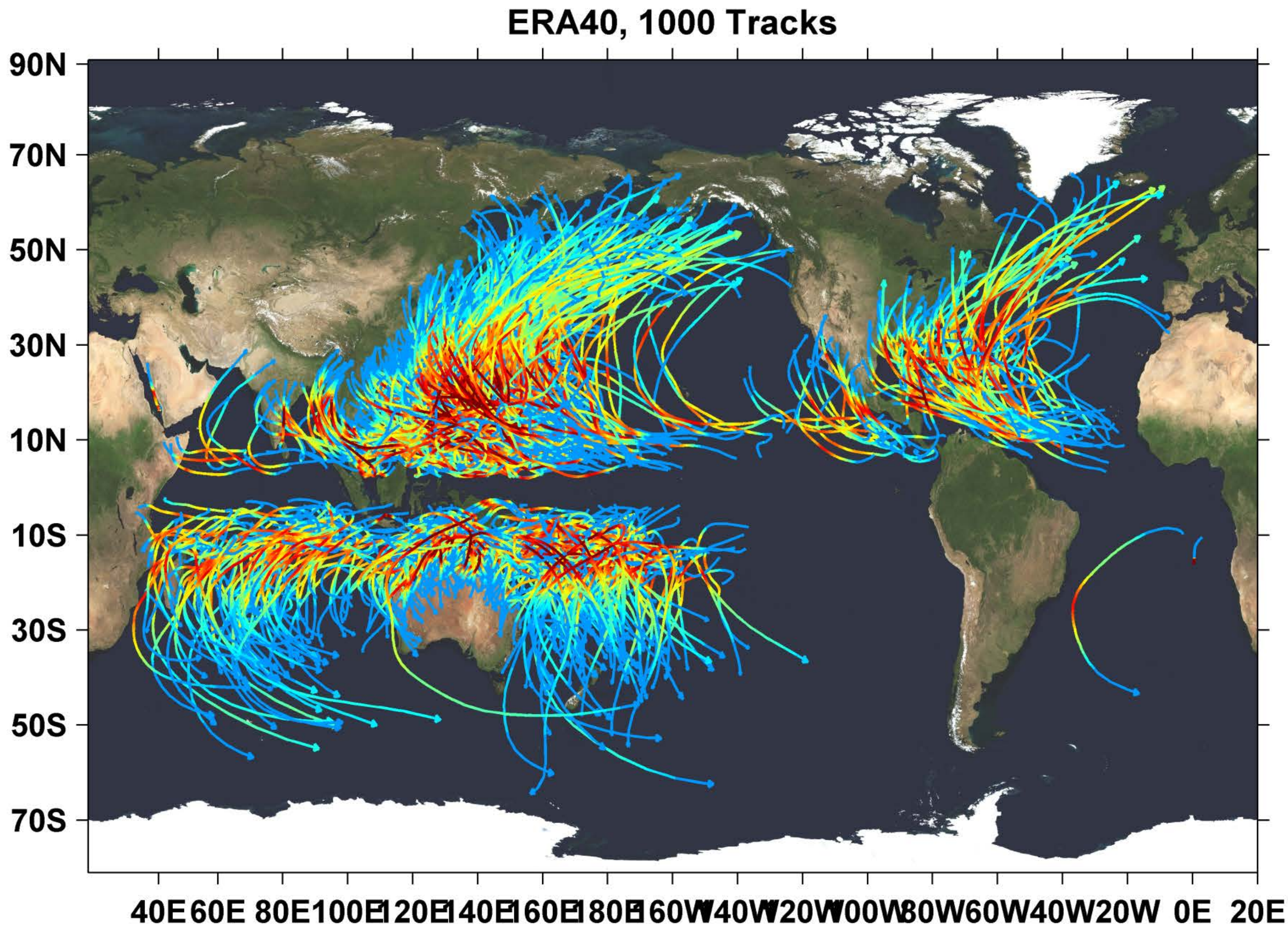
Compare to Observed Storm Maximum Power Dissipation



Looking Ahead:
Using Physics to Assess Hurricane Risk

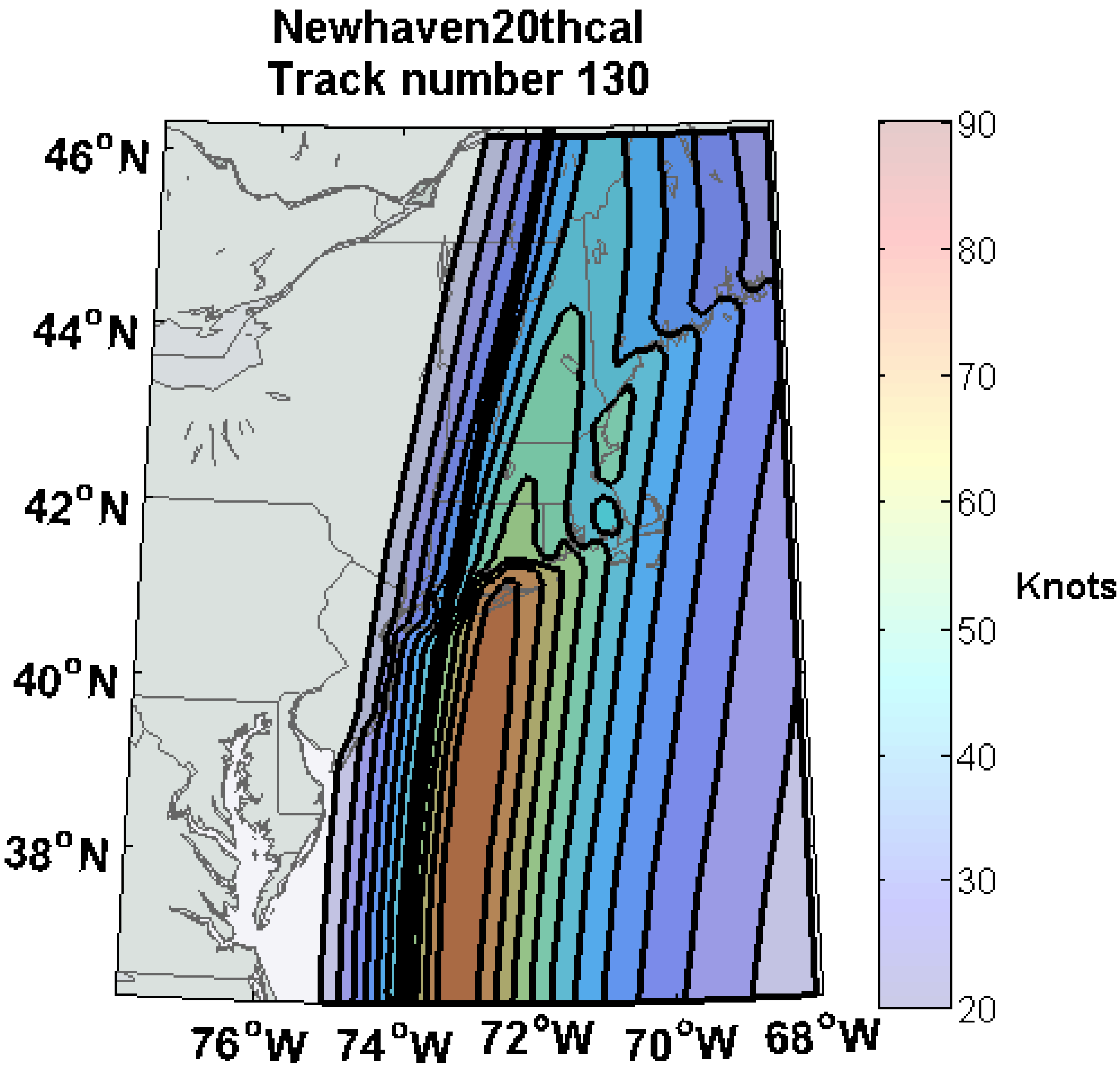
Our Approach to Downscaling Tropical Cyclones from Climate Models

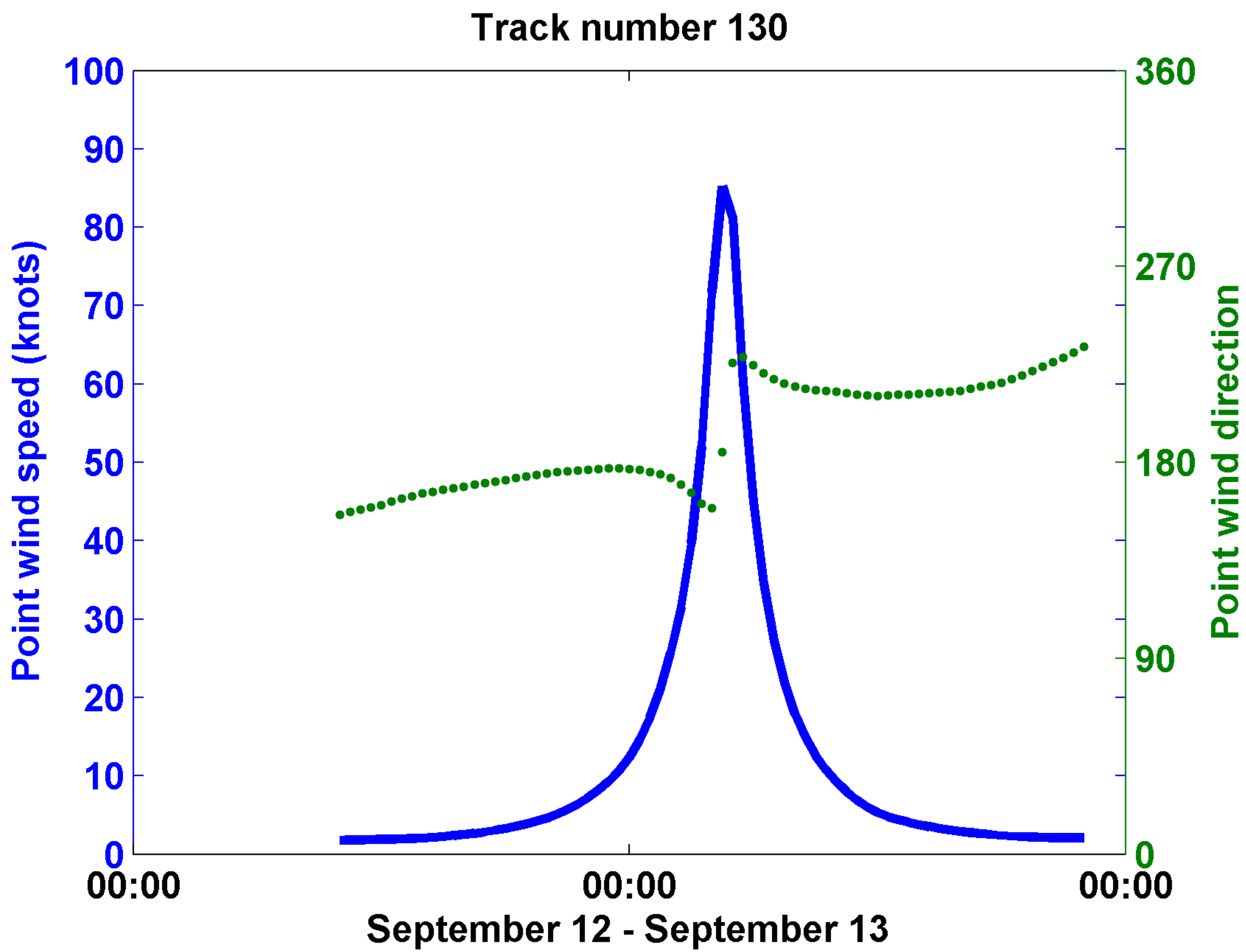
- **Step 1**: Seed each ocean basin with a very large number of weak, randomly located vortices
- **Step 2**: Vortices are assumed to move with the large scale atmospheric flow in which they are embedded
- **Step 3**: Run a coupled, ocean-atmosphere computer model for each vortex, and note how many achieve at least tropical storm strength; discard others
- **Step 4:** Using the small fraction of surviving events, determine storm statistics.


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

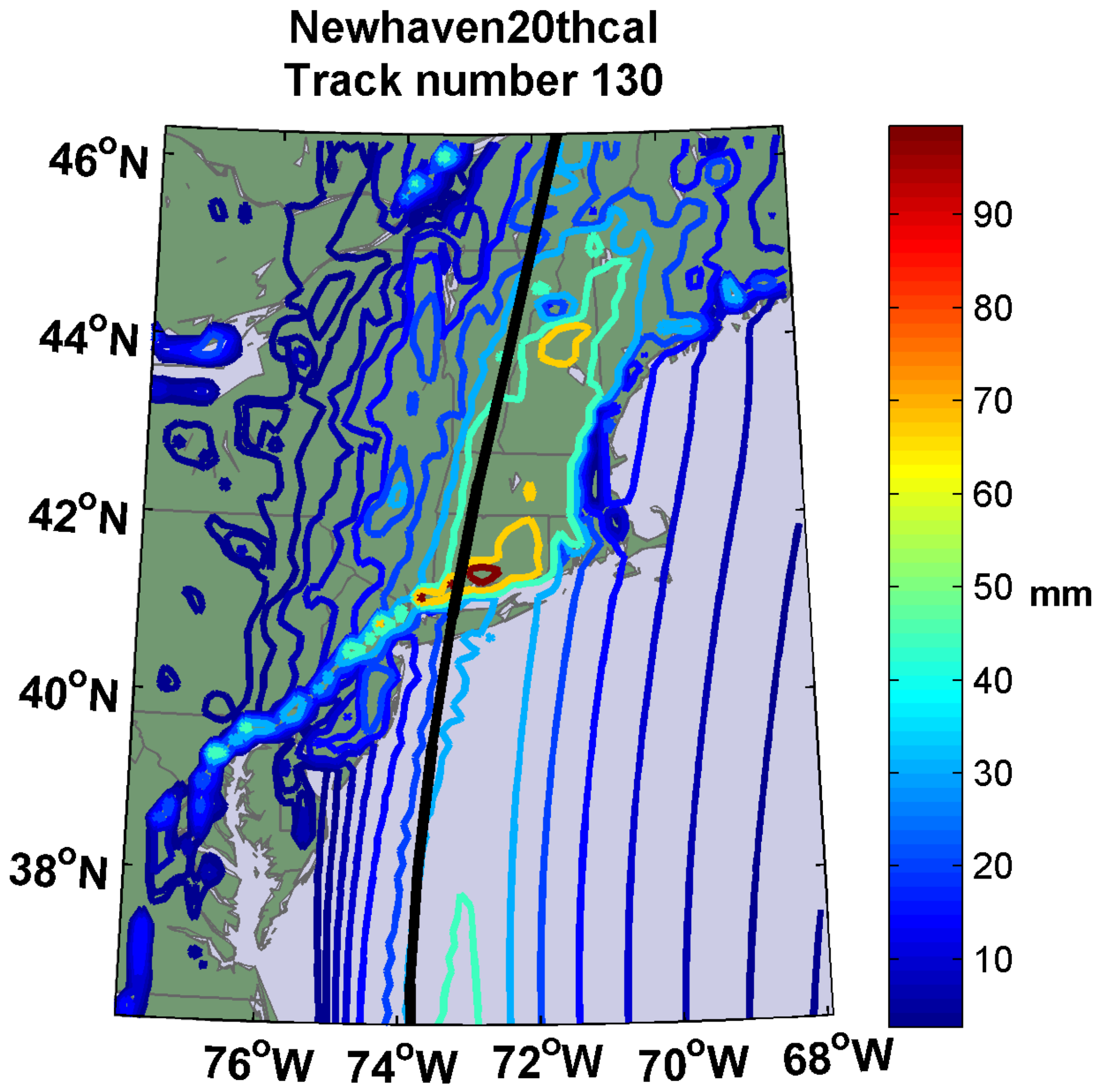
50 MIT Synthetic (various colors) and 8 Historical Hurricanes (lavender) Affecting New Haven, Connecticut

Peak Wind during Event




Track number 130
Point wind speed (knots)
Point wind direction
100
90
80
70
60
50
40
30
20
10
0
360
270
180
90
0
00:00
00:00
00:00
September 12 - September 13

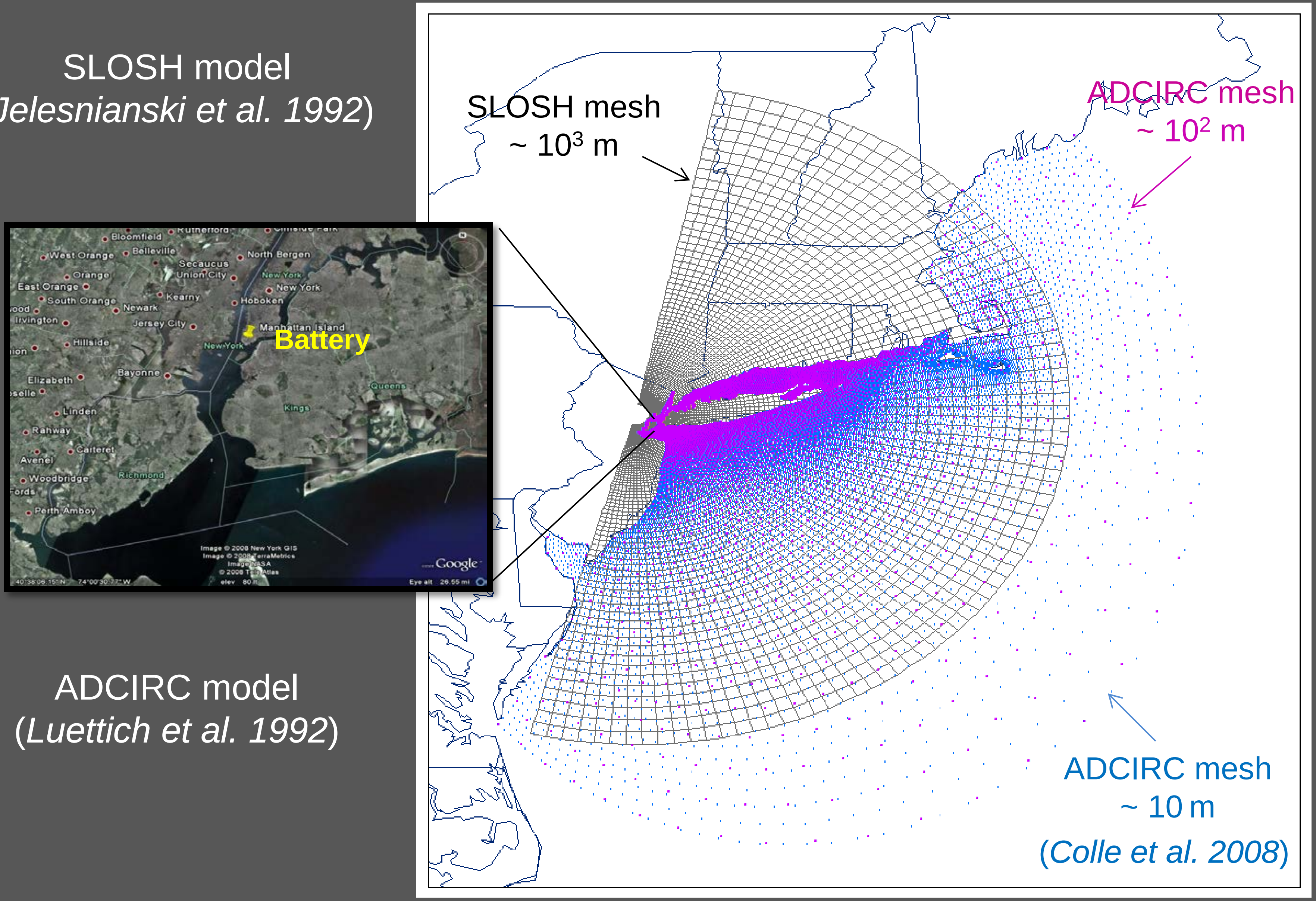
Accumulated Rainfall (mm)

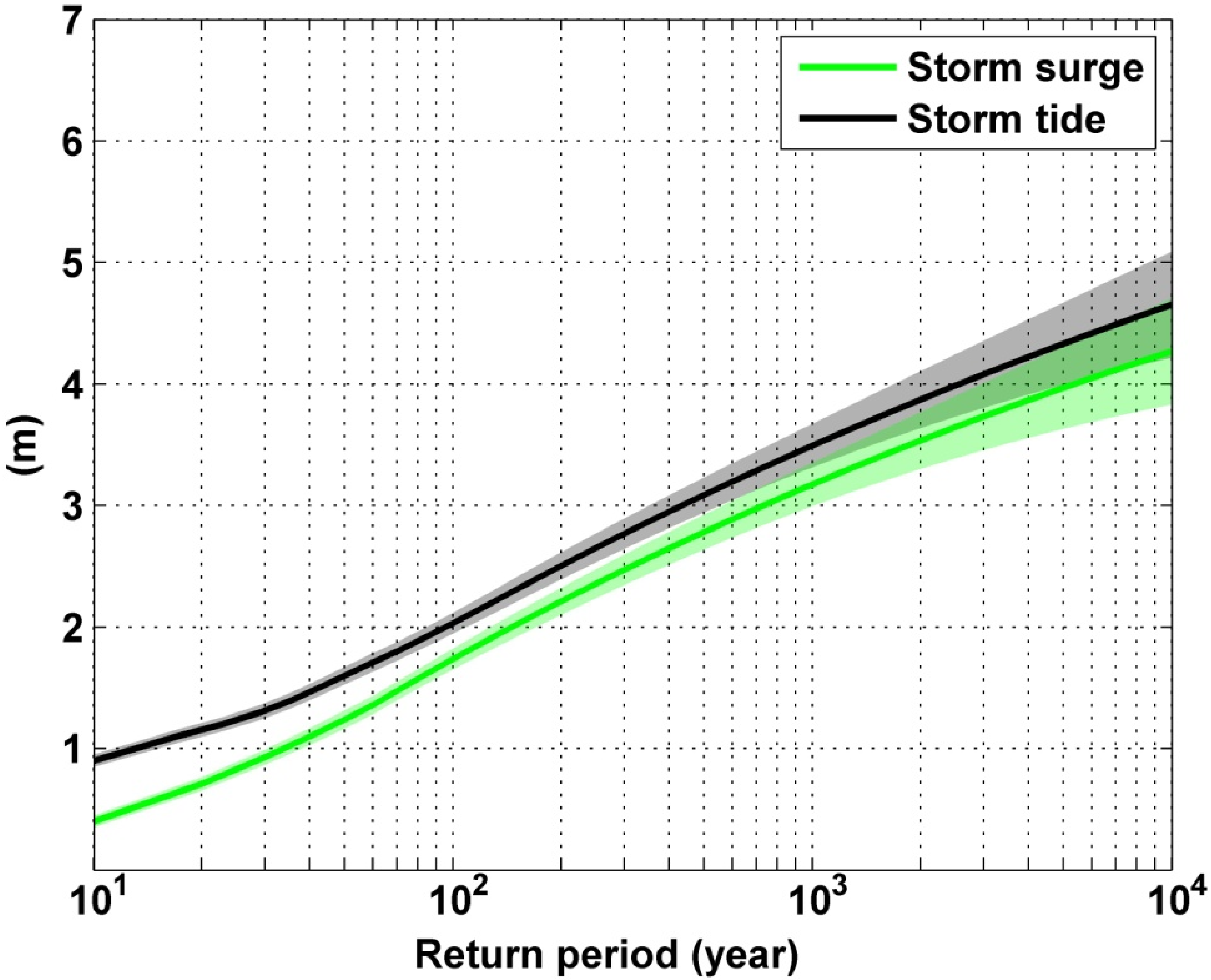


Storm Surge Simulation

SLOSH model
(*Jelesnianski et al. 1992*)

ADCIRC model
(*Luettich et al. 1992*)



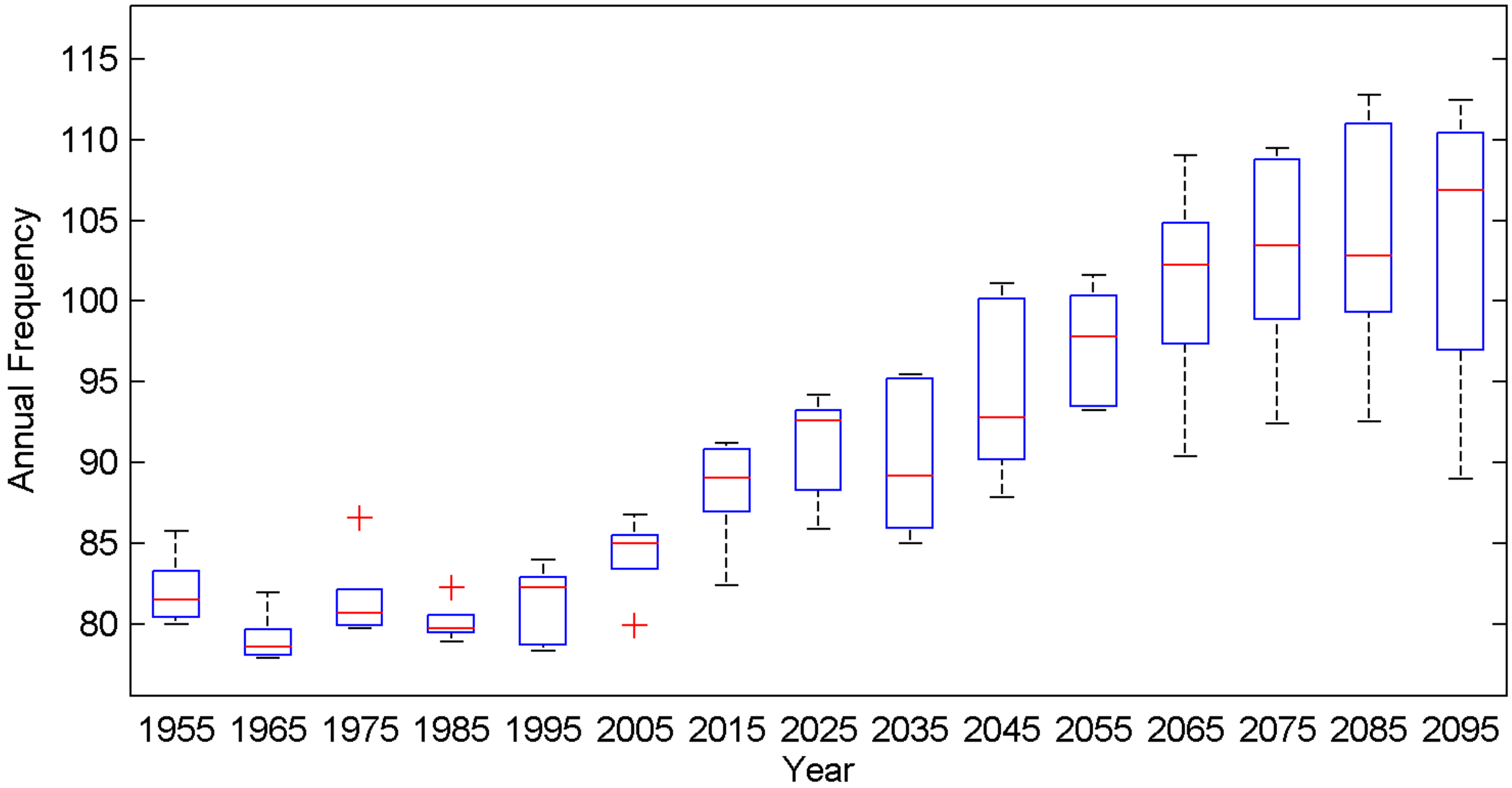


Storm surge
Storm tide
(m)
Return period (year)
7
6
5
4
3
2
1
10^1
10^2
10^3
10^4

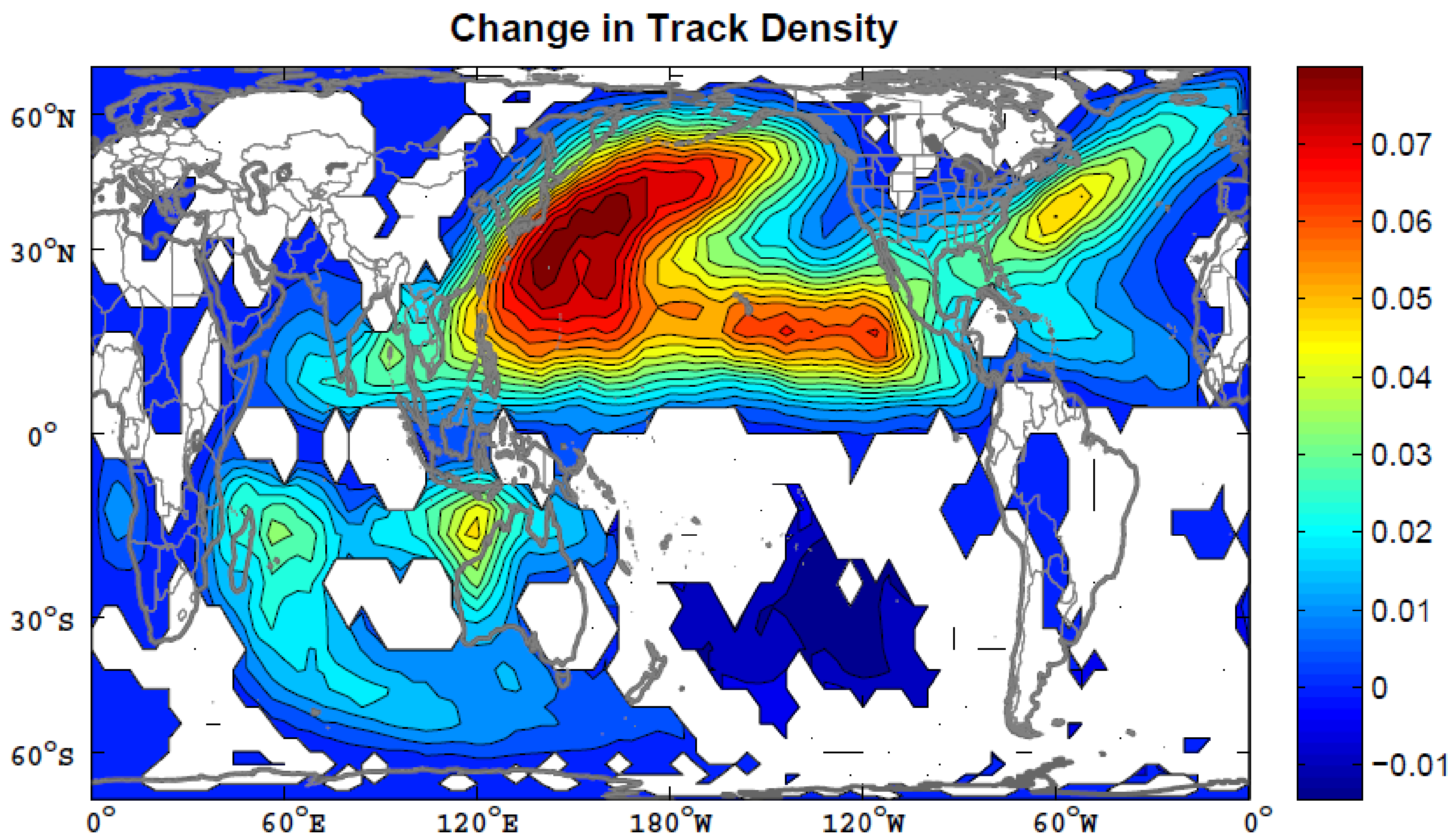
Downscaling of AR5 GCMs

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

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

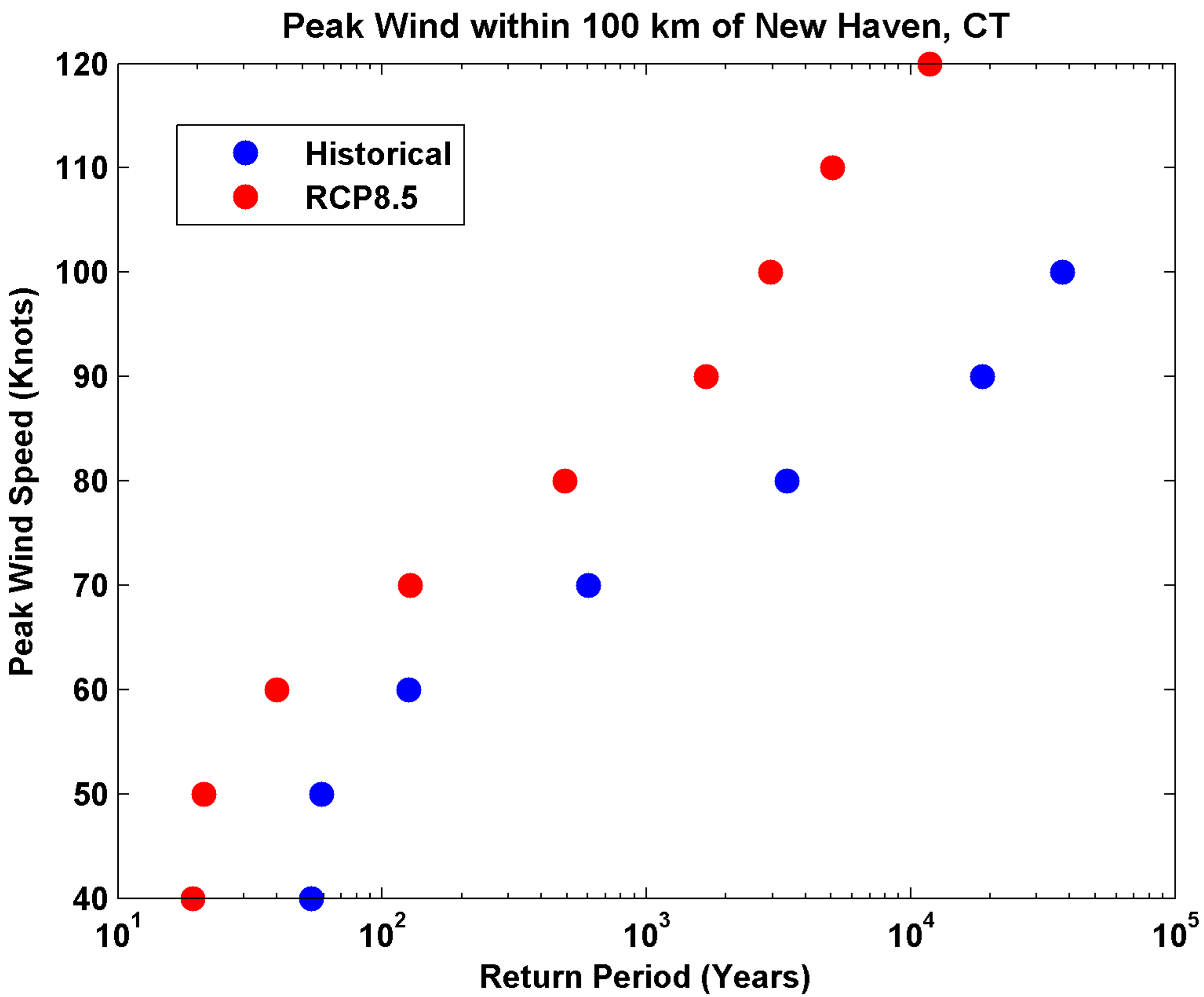


Global annual frequency of tropical cyclones averaged in 10-year blocks for the period 1950-2100, using historical simulations for the period 1950-2005 and the RCP 8.5 scenario for the period 2006-2100. In each box, the red line represents the median among the 5 models, and the bottom and tops of the boxes represent the 25th and 75th 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.



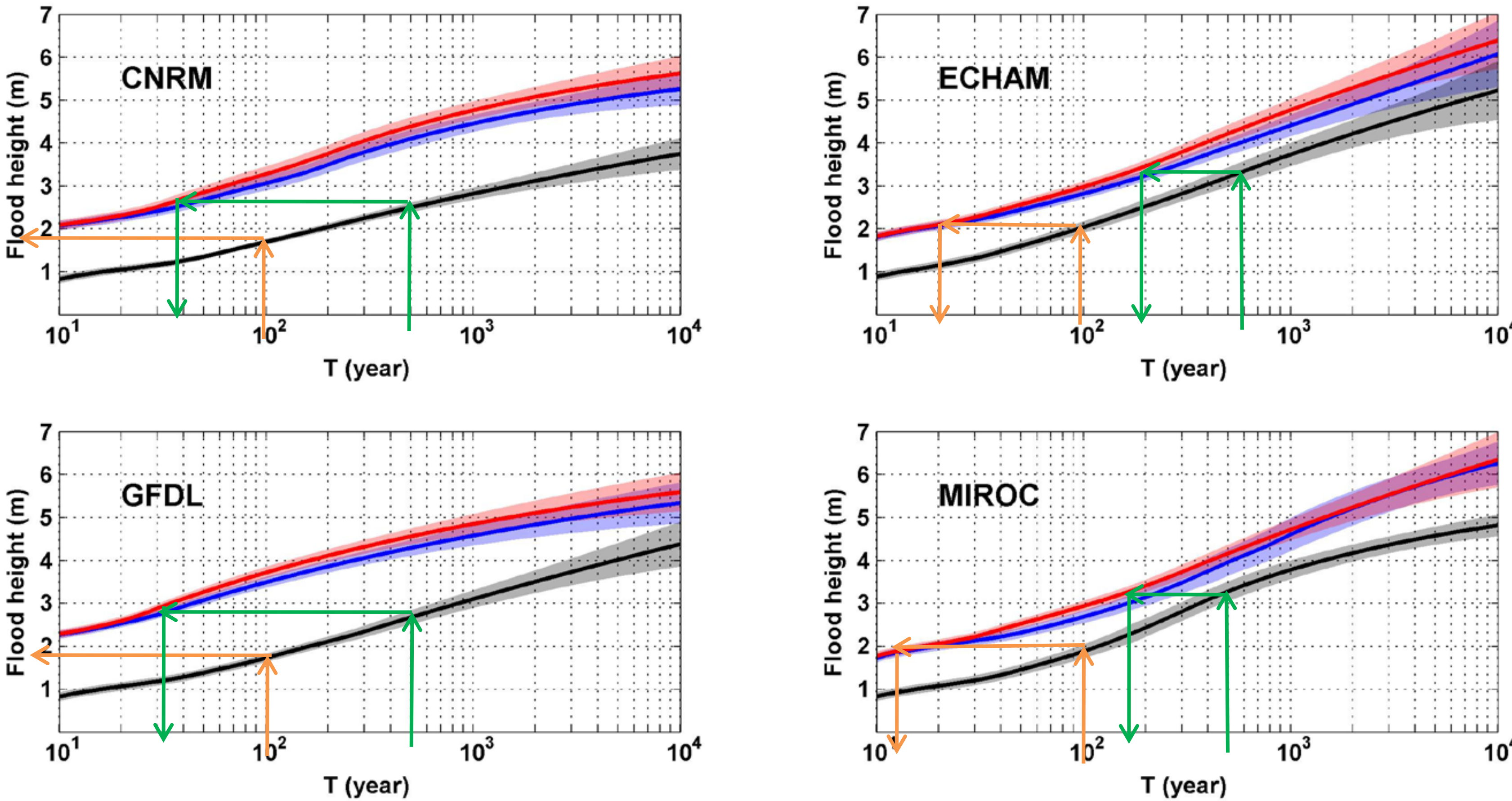
Change in track density, measured in number of events per 4º X 4º square per year, averaged over the five models. The change is simply the average over the period 2006-2100 minus the average over 1950-2005. The white regions are where fewer than 4 of the 5 models agree on the sign of the change.

Return Periods based on 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)

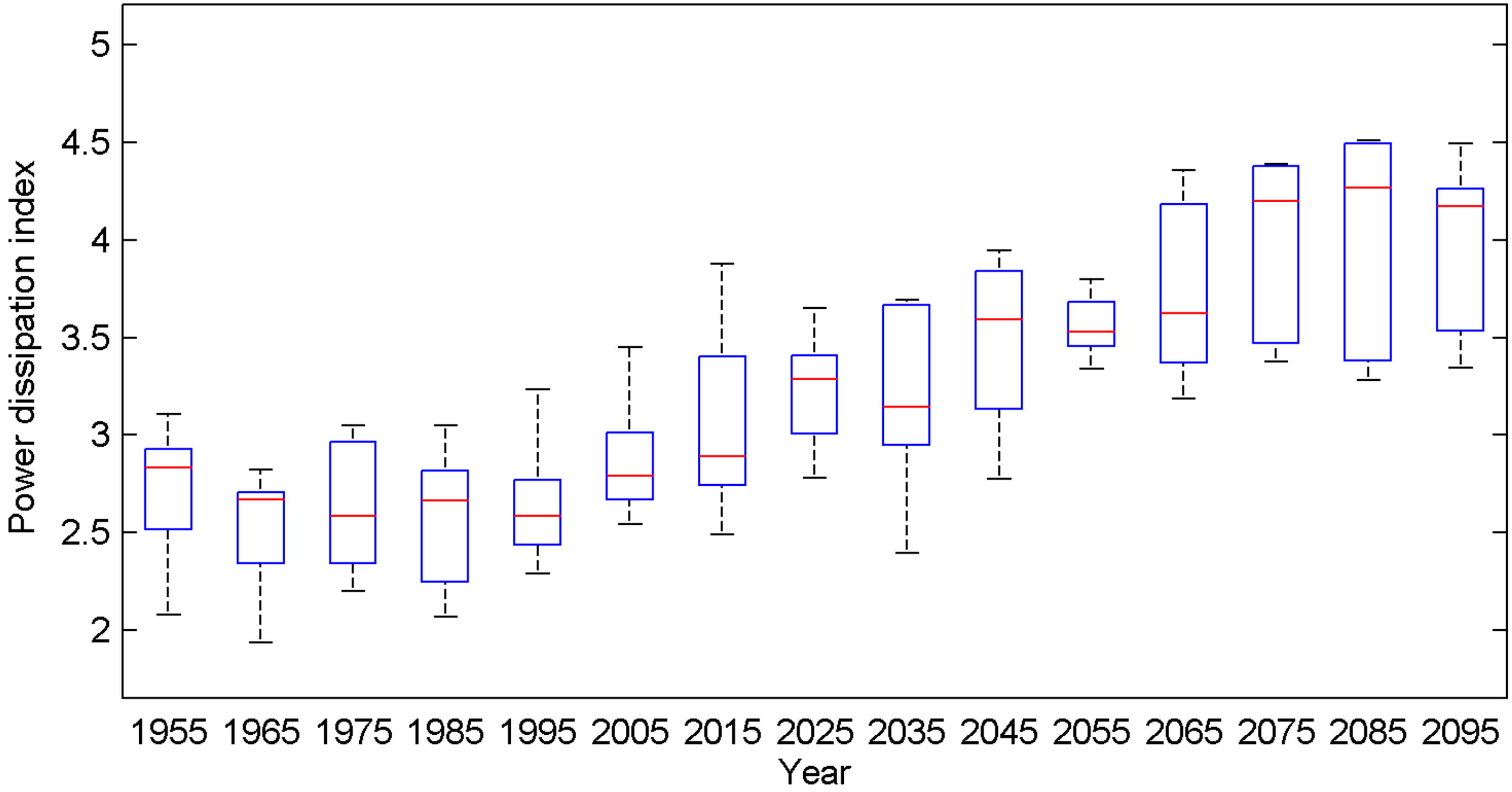
Summary

- **Our climate is generally warming, owing to an increase in greenhouse gas concentrations**
- **Much of the tangible risk of climate change is in changing occurrence of extreme weather events**

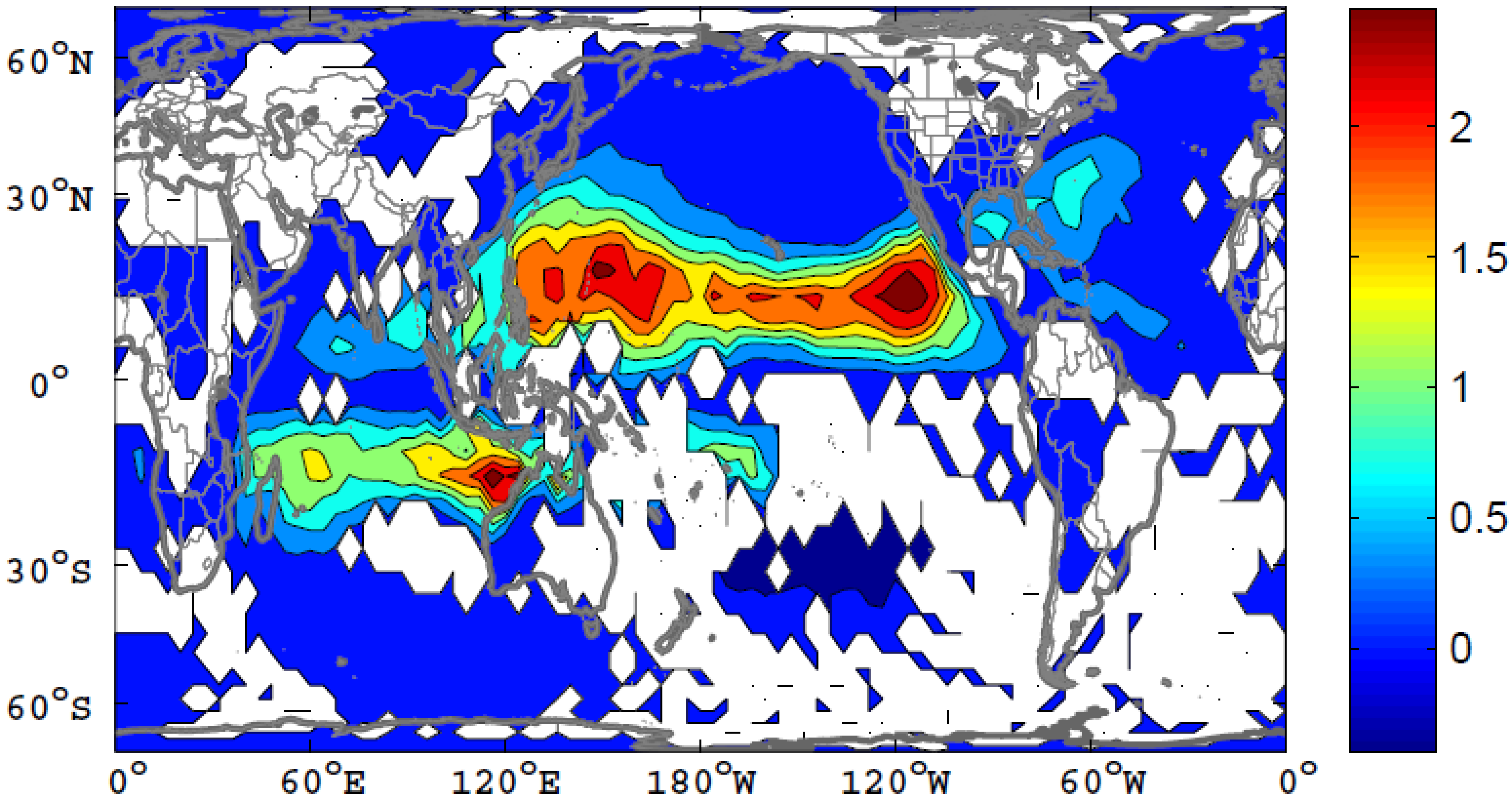
- Projections of climate change effects on weather extremes vary a great deal depending on type of event and model projections
- Heat waves become more frequent, and cold waves less so
- Incidence of floods increases fairly rapidly
- Incidence of drought also increases rapidly

- Very little currently known about response of severe thunderstorms to climate change
- Frequency of intense (destructive) hurricanes projected to increase
- Hurricane-related flooding exacerbated by rising sea level, increased incidence of very strong storms, and enhanced rainfall

Global Tropical Cyclone Power Dissipation



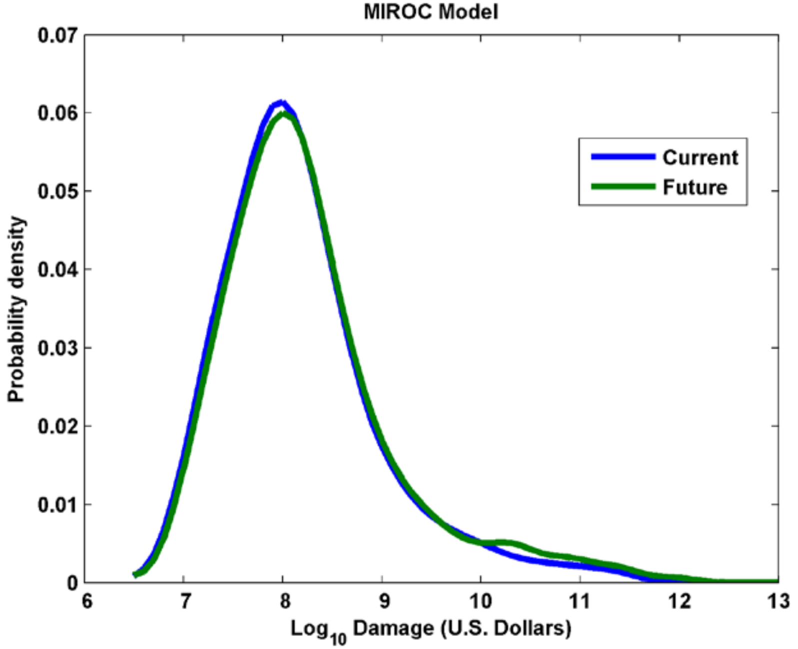
Change in Power Dissipation



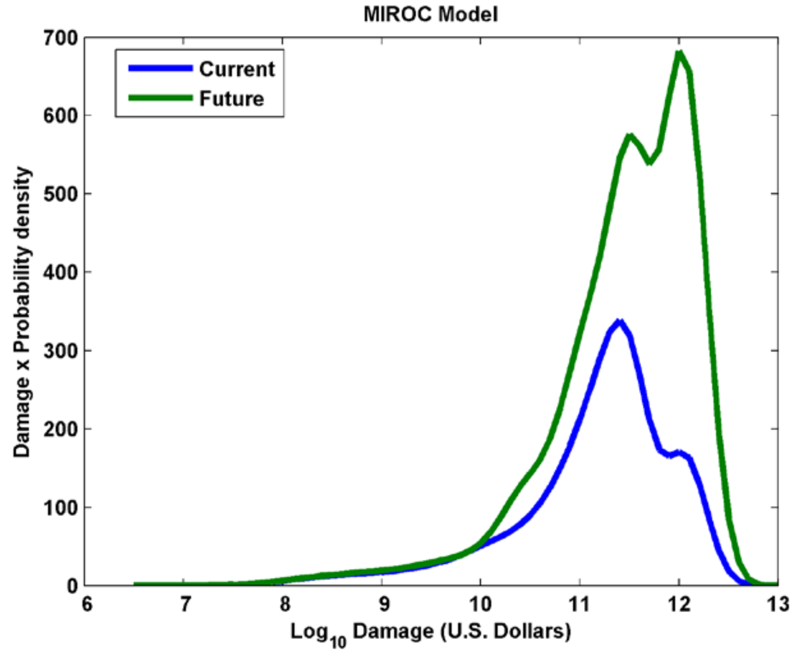
Integrated Assessments

with Robert Mendelsohn, Yale

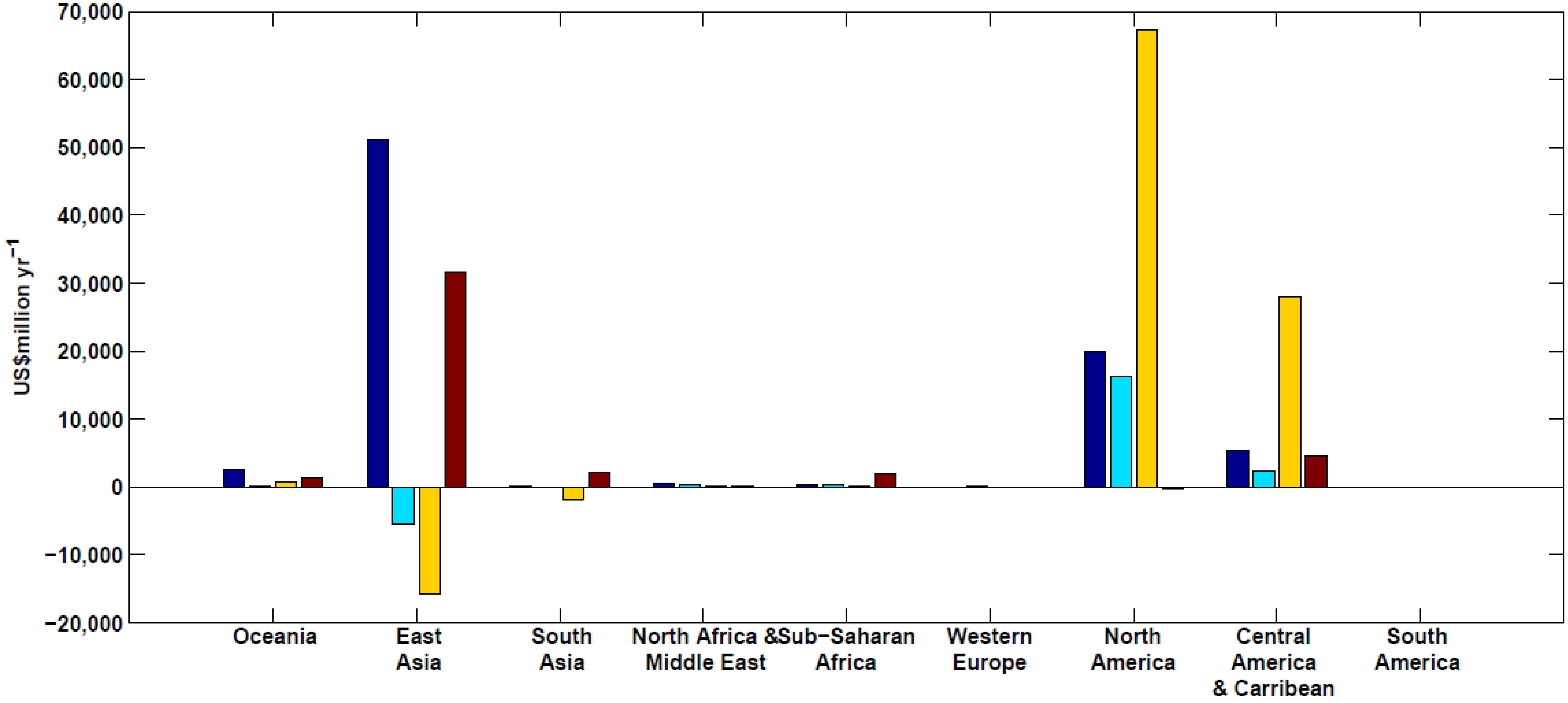
Probability Density of TC Damage, U.S. East Coast



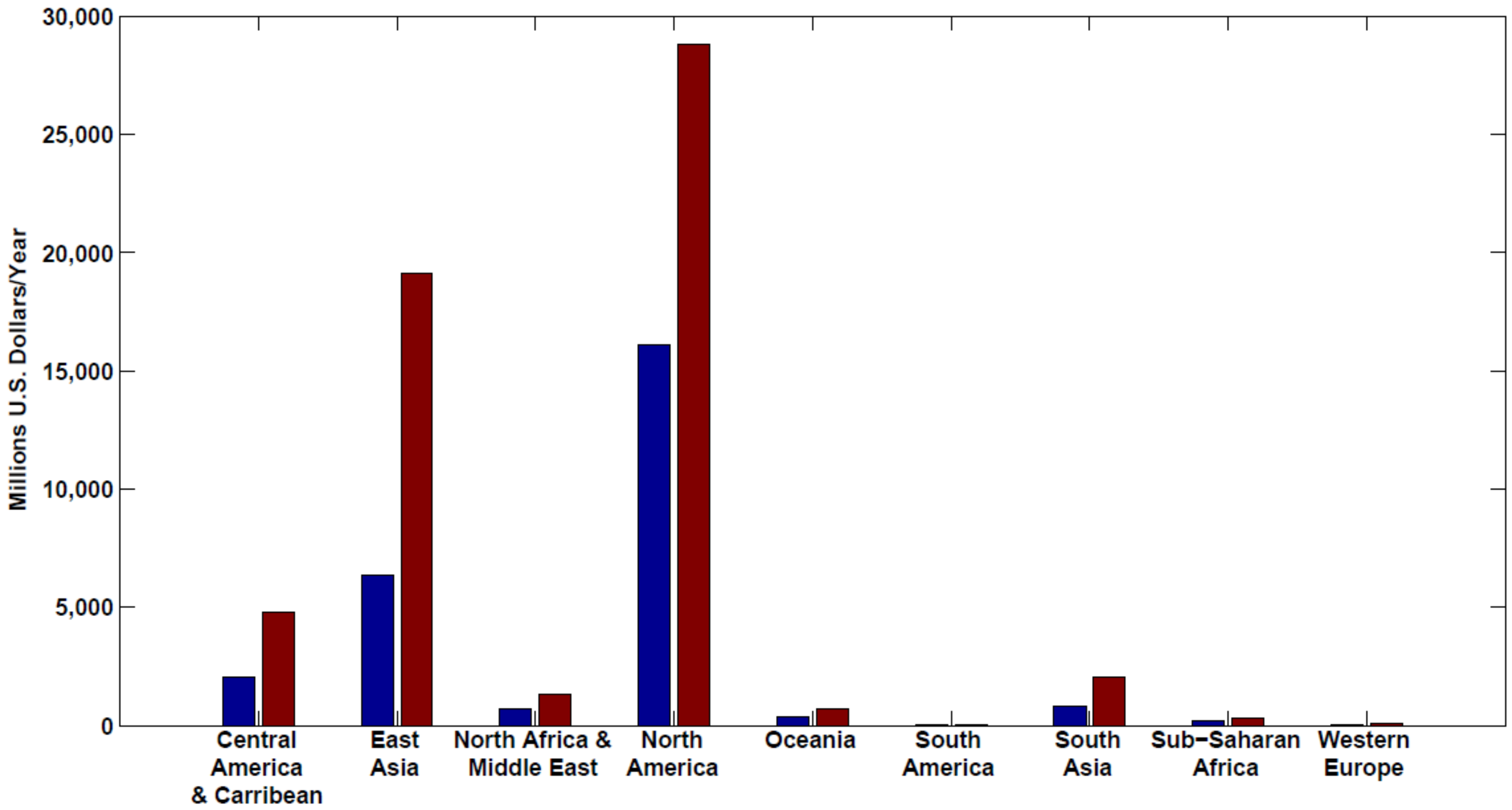
Damage Multiplied by Probability Density of TC Damage, U.S. East Coast



Mendelsohn et al., 2012

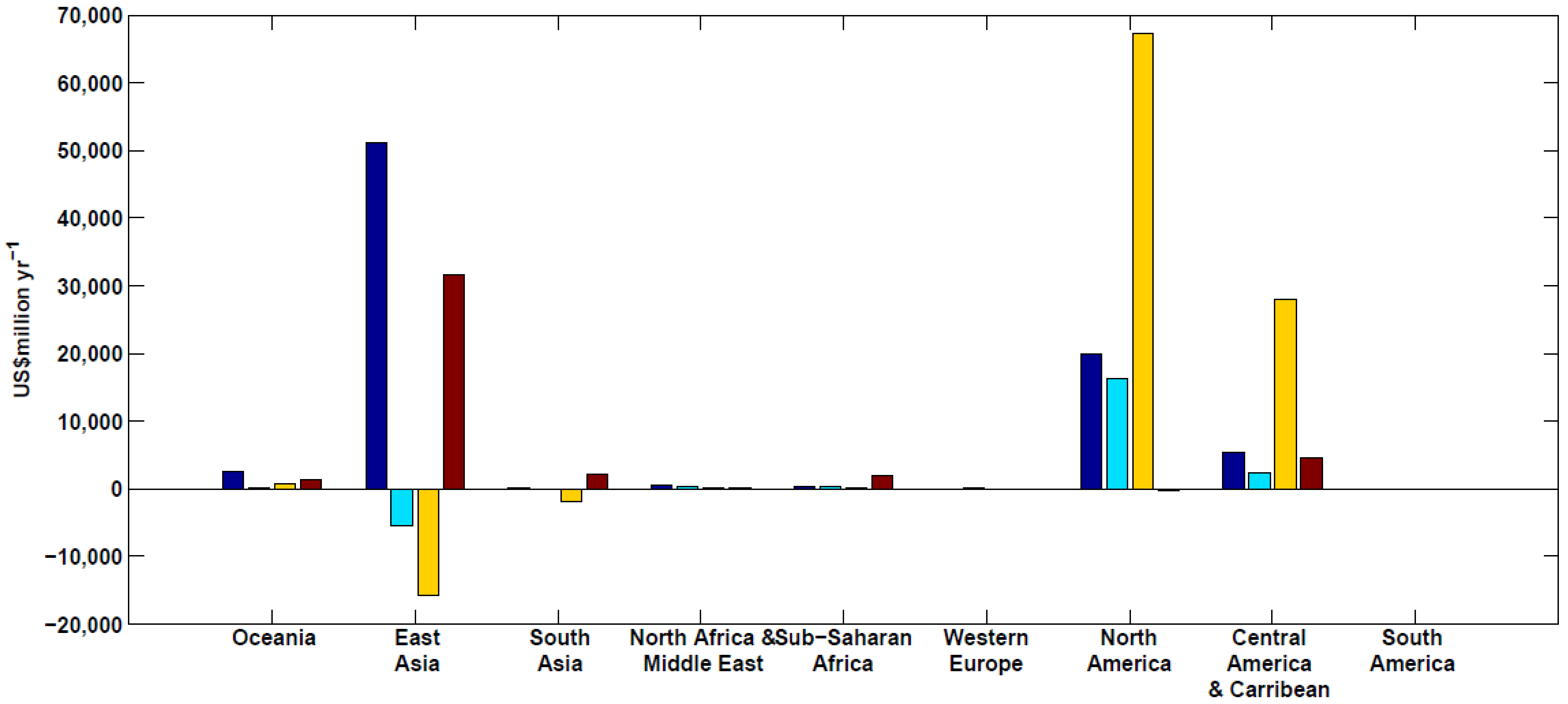


Climate change impacts on tropical cyclone damage by region in 2100. Damage is concentrated in North America, East Asia and Central America–Caribbean. Damage is generally higher in the CNRM and GFDL climate scenarios.

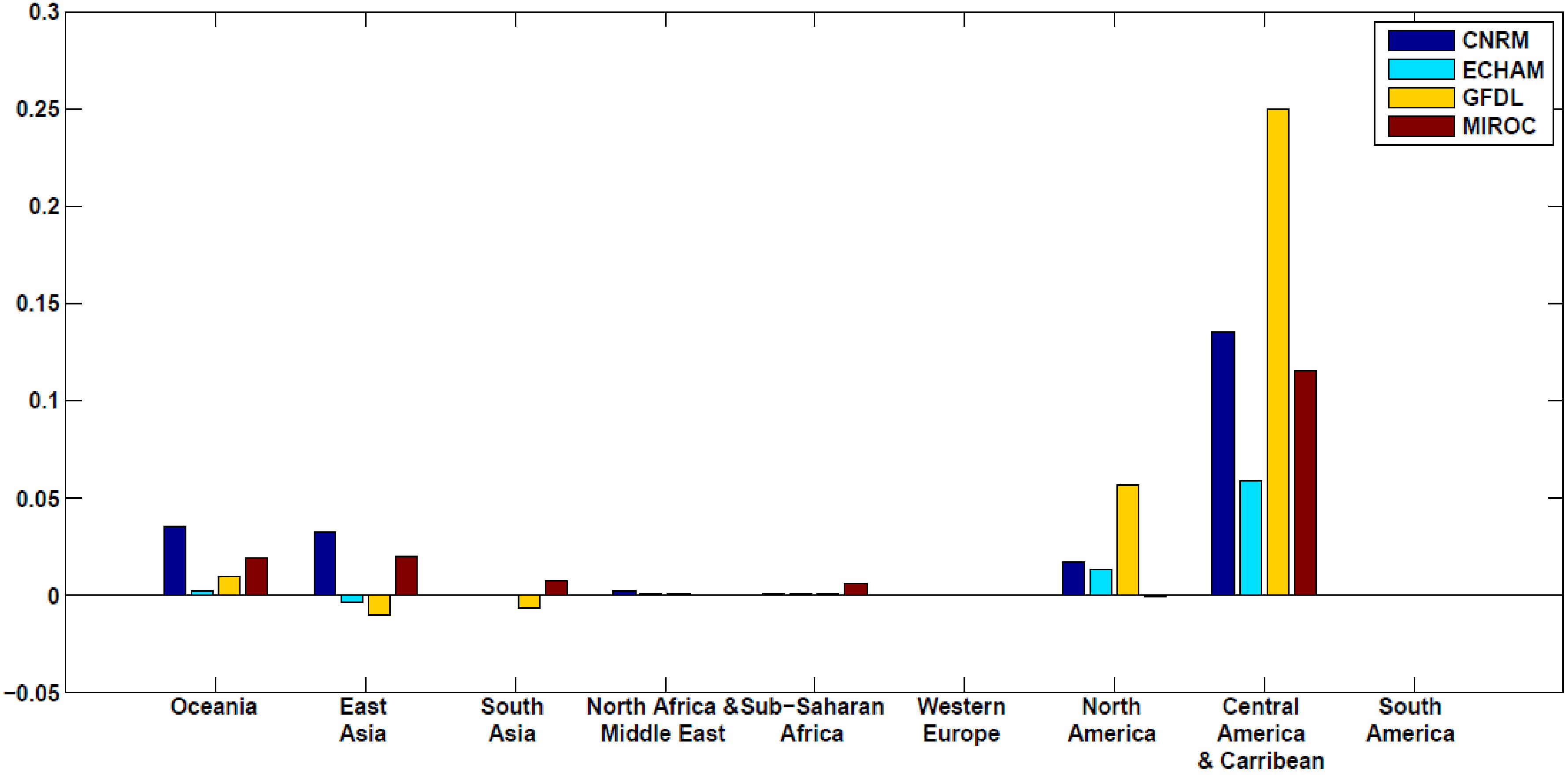


Present and future baseline tropical cyclone damage by region.

Changes in income will increase future tropical cyclone damages in 2100 in every region even if climate does not change. Changes are larger in regions experiencing faster economic growth, such as East Asia and the Central America–Caribbean region.

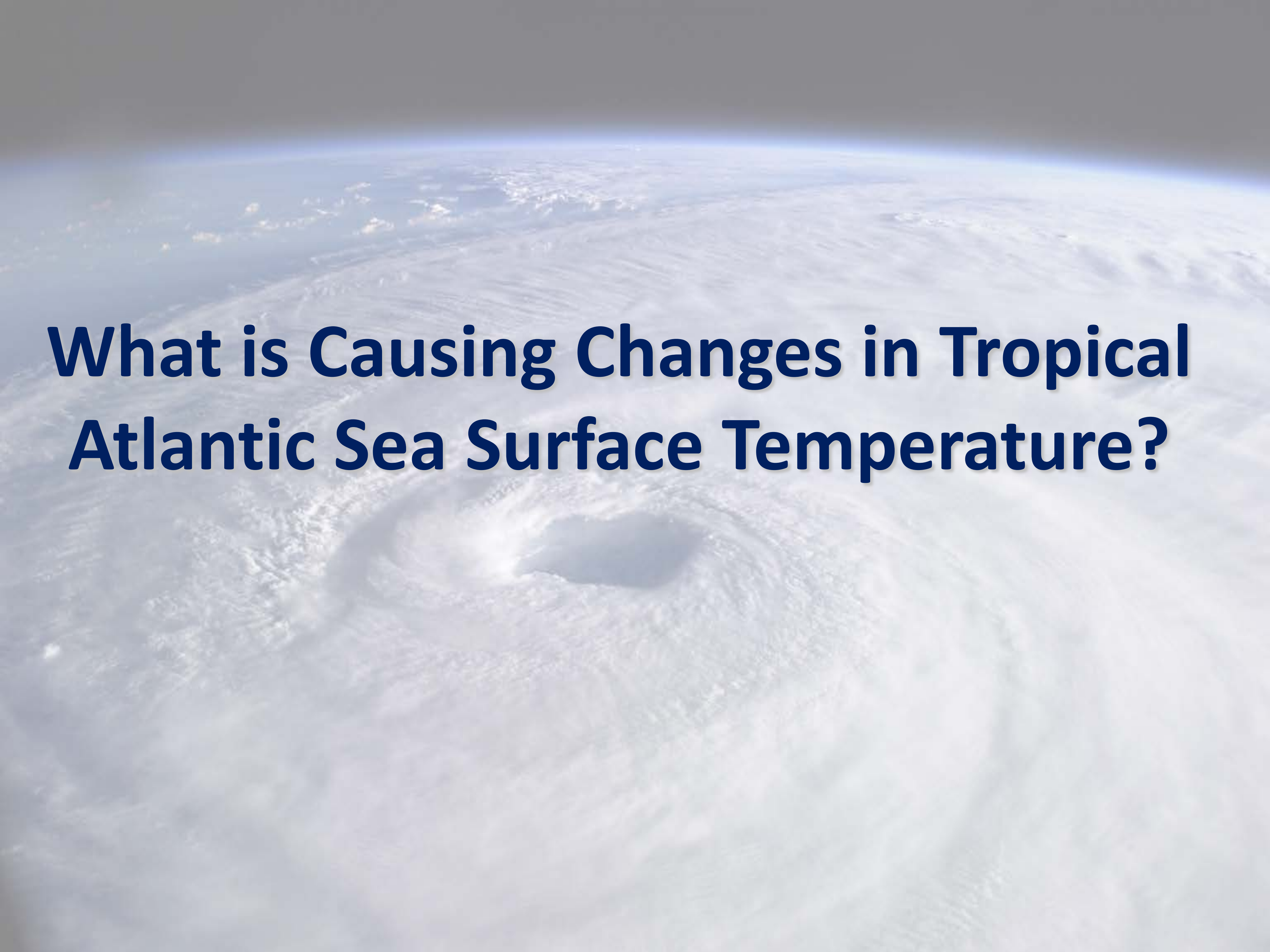


Climate change impacts on tropical cyclone damage by region in 2100. Damage is concentrated in North America, East Asia and Central America–Caribbean. Damage is generally higher in the CNRM and GFDL climate scenarios.

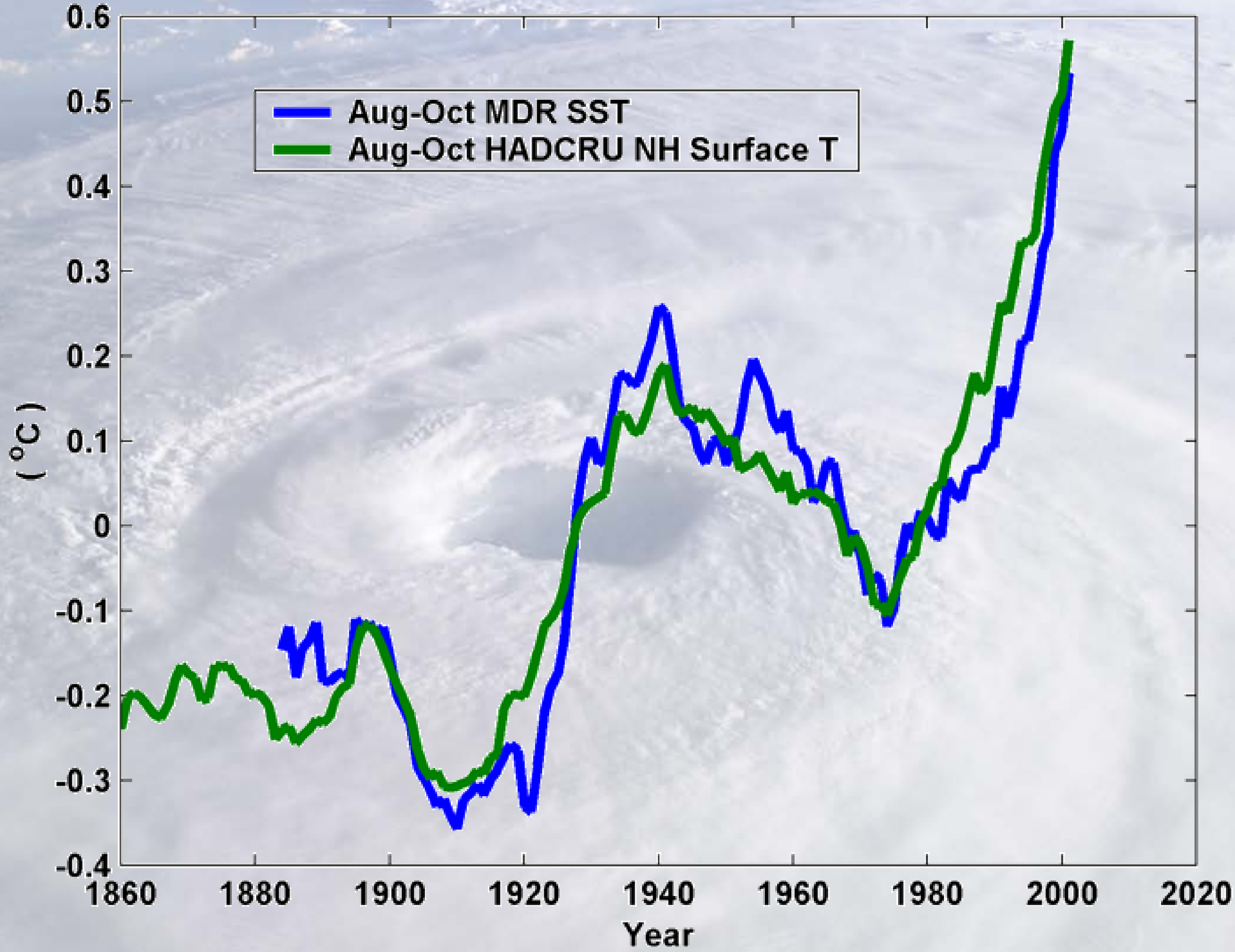


Climate change impacts on tropical cyclone damage divided by GDP by region in 2100. The ratio of damage to GDP is highest in the Caribbean–Central American region but North America, Oceania and East Asia all have above-average ratios.

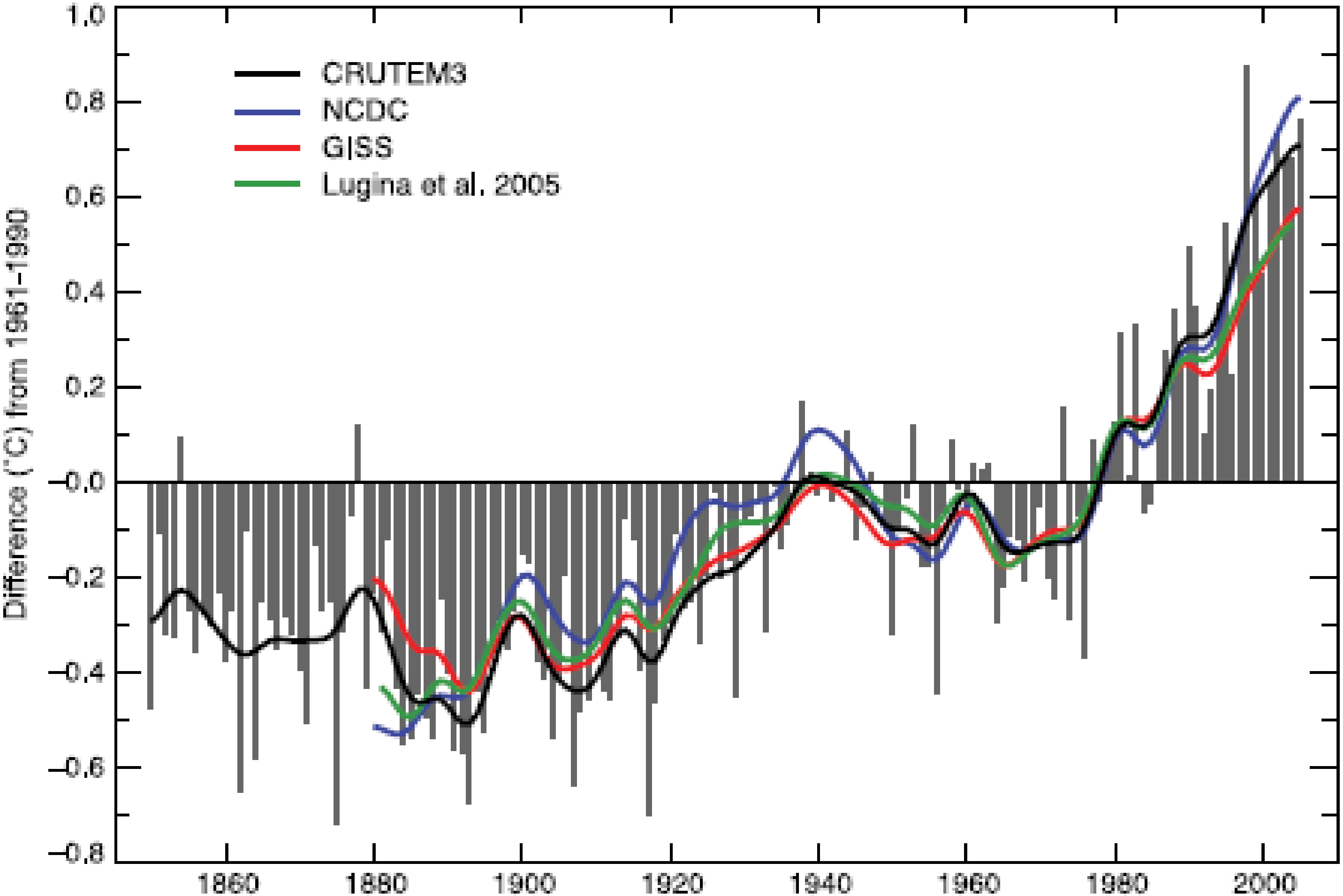
What is Causing Changes in Tropical Atlantic Sea Surface Temperature?

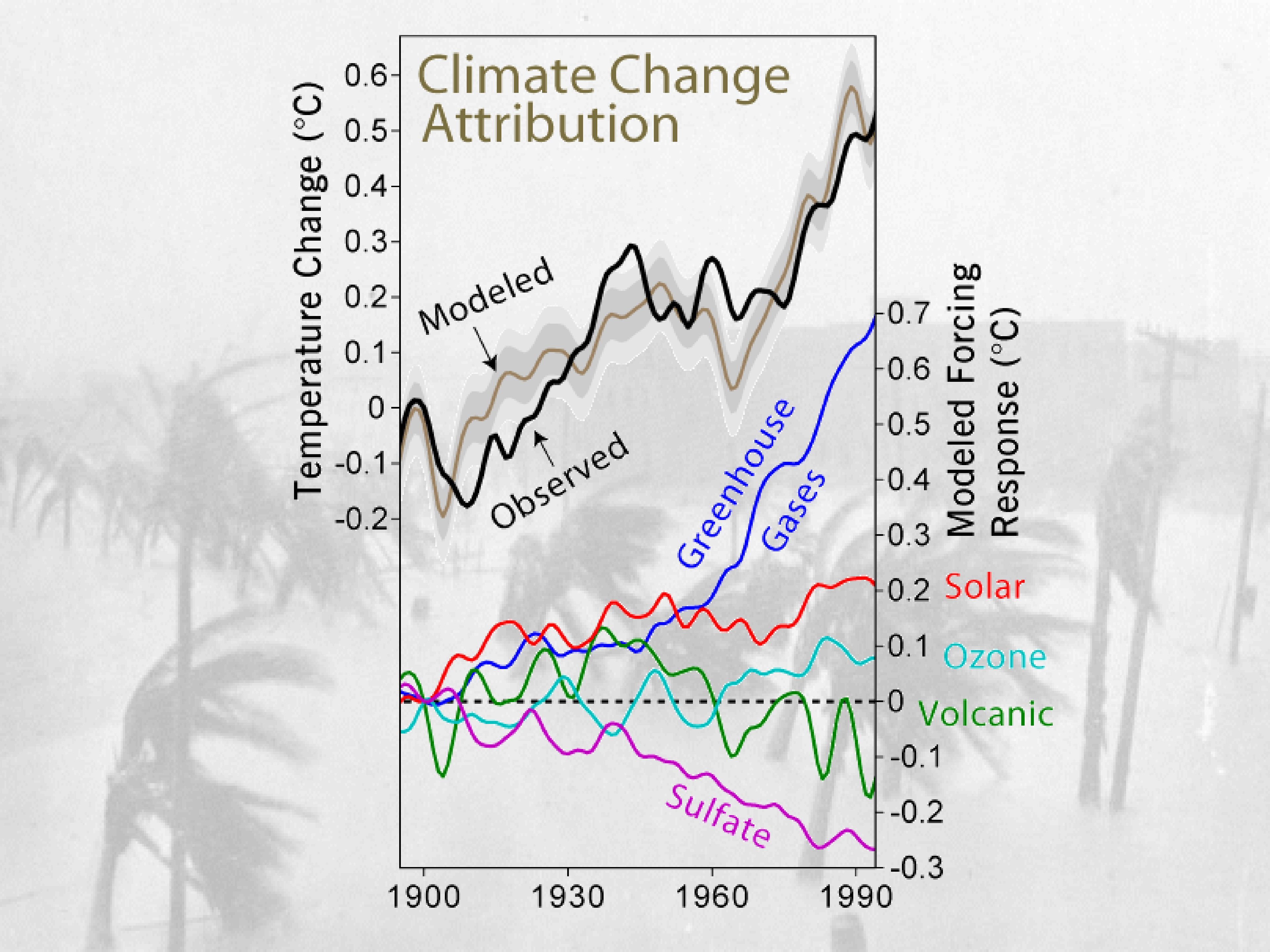


10-year Running Average of Aug-Oct Northern Hemisphere Surface Temp and Hurricane Region Ocean Temp



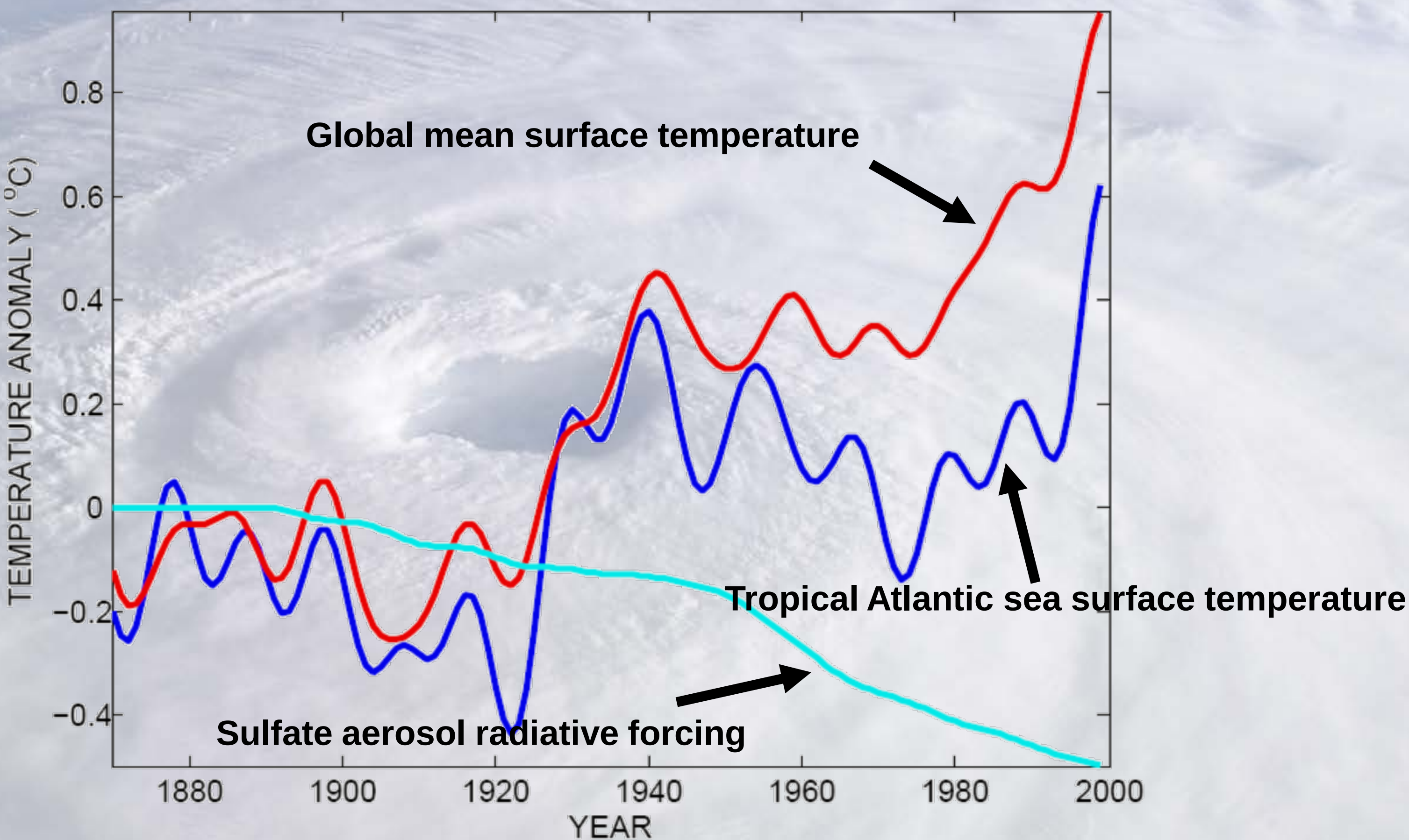
Estimates of Global Mean Surface Temperature from the Instrumental Record





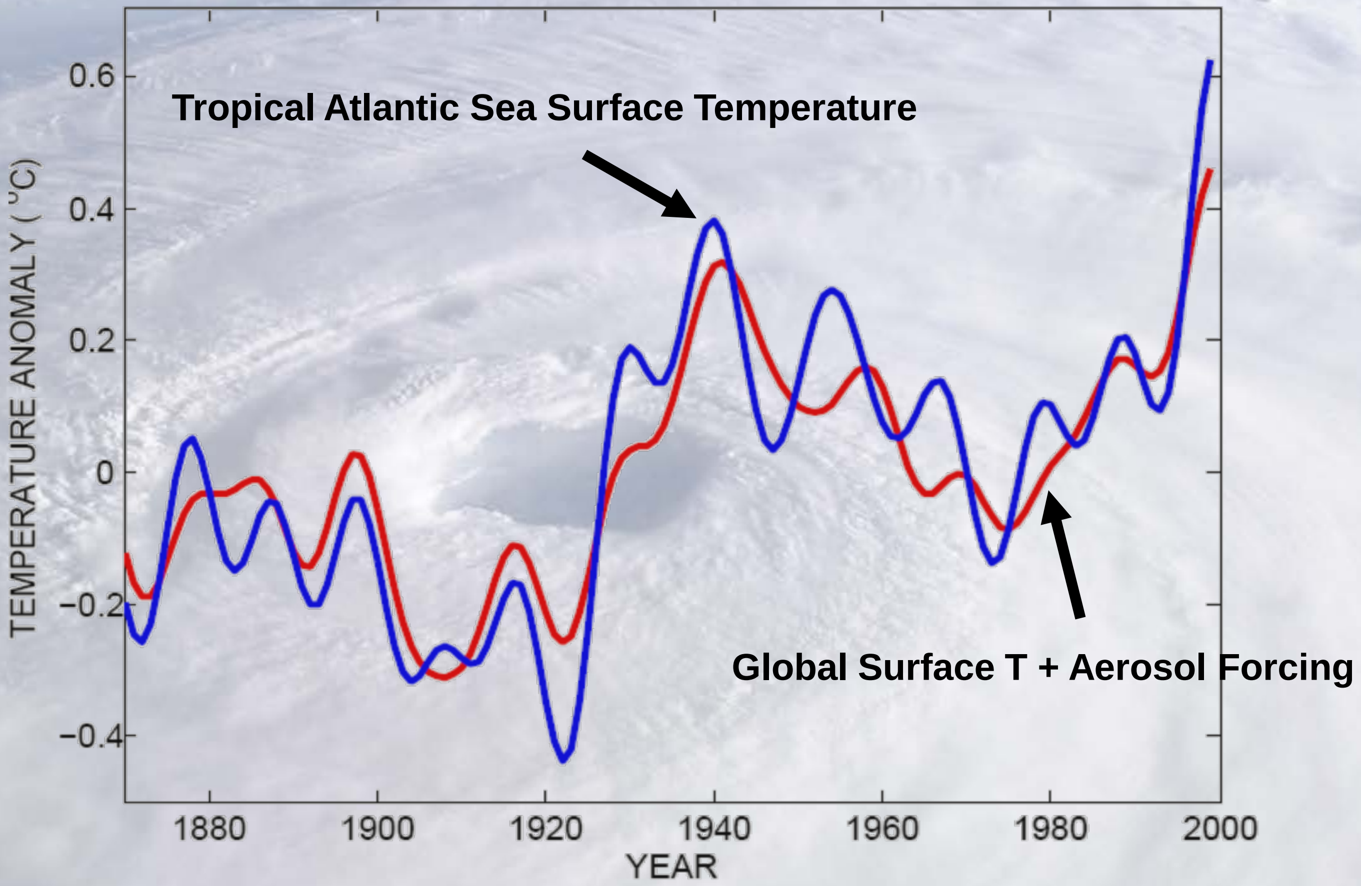
Climate Change Attribution
Temperature Change (°C)
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
Modeled
Observed
Modeled Forcing Response (°C)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
Greenhouse Gases
Solar
Ozone
Volcanic
Sulfate
1900
1930
1960
1990

Tropical Atlantic SST(blue), Global Mean Surface Temperature (red),
Aerosol Forcing (aqua)



Mann, M. E., and K. A. Emanuel, 2006. Atlantic hurricane trends linked to climate change. EOS, 87, 233-244.

Best Fit Linear Combination of Global Warming and Aerosol Forcing (red) versus Tropical Atlantic SST (blue)



Mann, M. E., and K. A. Emanuel, 2006. Atlantic hurricane trends linked to climate change. EOS, 87, 233-244.

Application to the Climate of the Pliocene