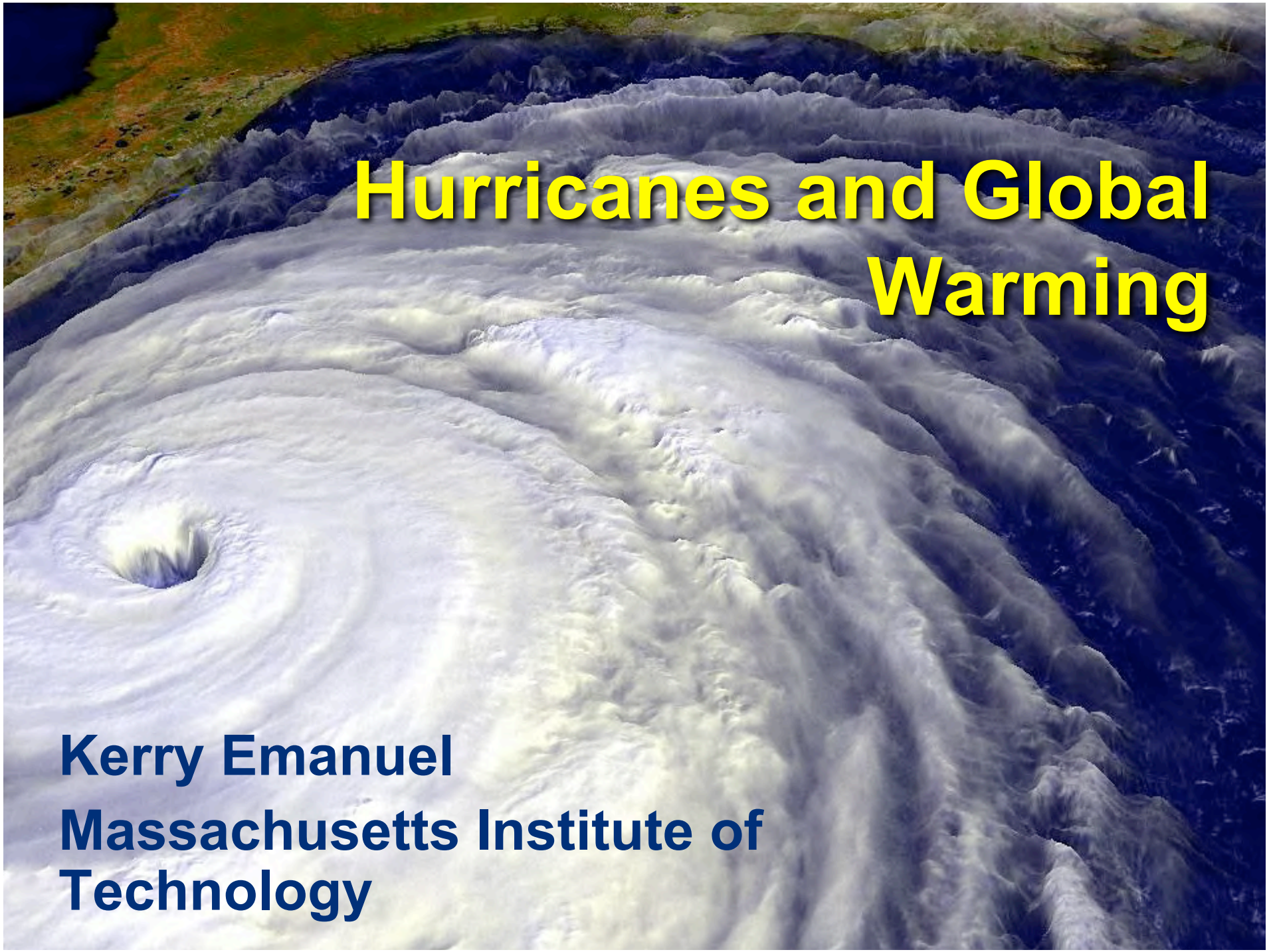


Hurricanes and Global Warming

Kerry Emanuel

Massachusetts Institute of Technology

Issues

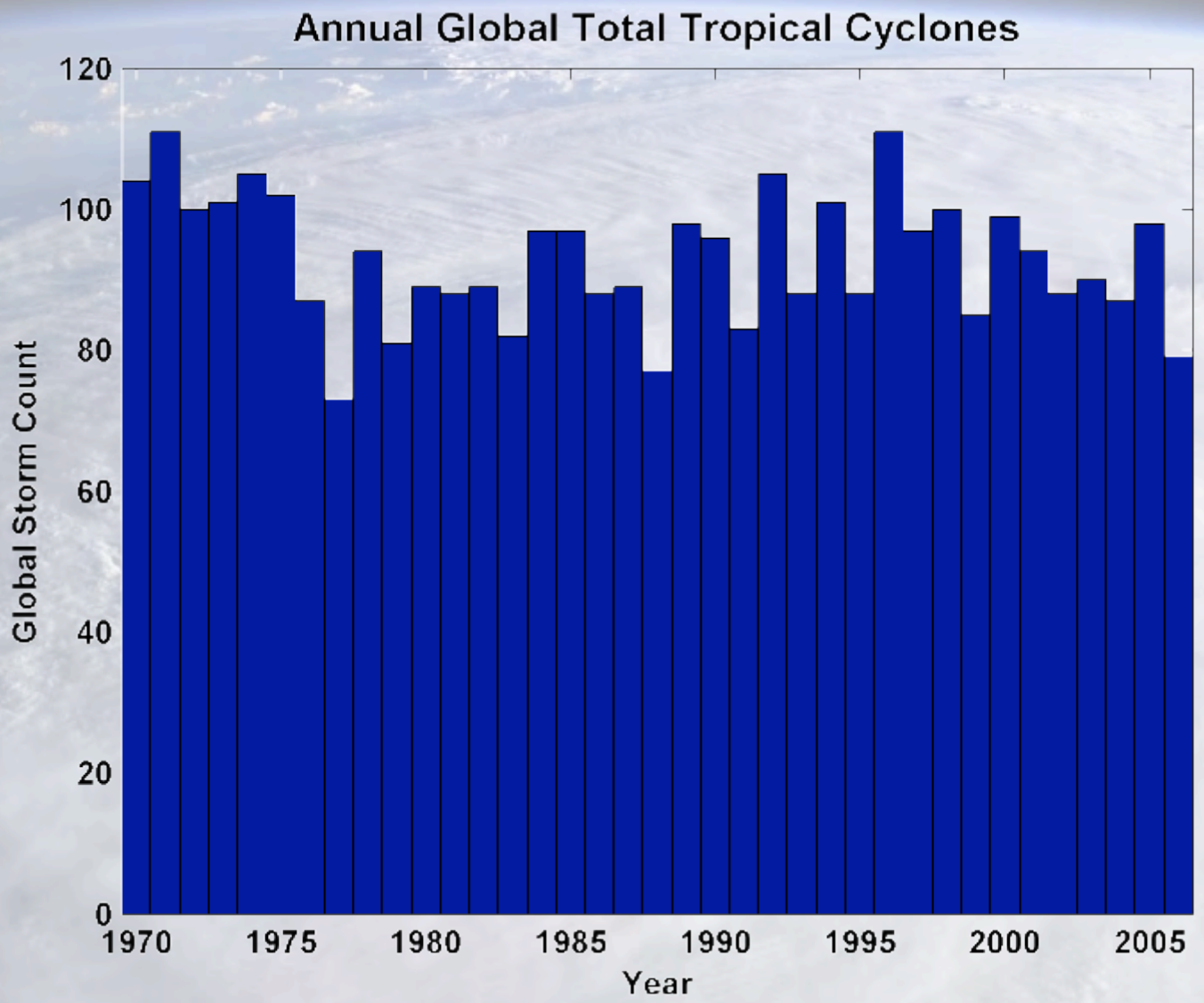
- Effect of climate change on tropical cyclone activity
- Role of tropical cyclones in the climate system

Approaches

- The historical record
- Physics
- Models


The Historical Record

Global TC Frequency, 1970-2006



Data Sources: NOAA/TPC and NAVY/JTWC

Better Intensity Metric:

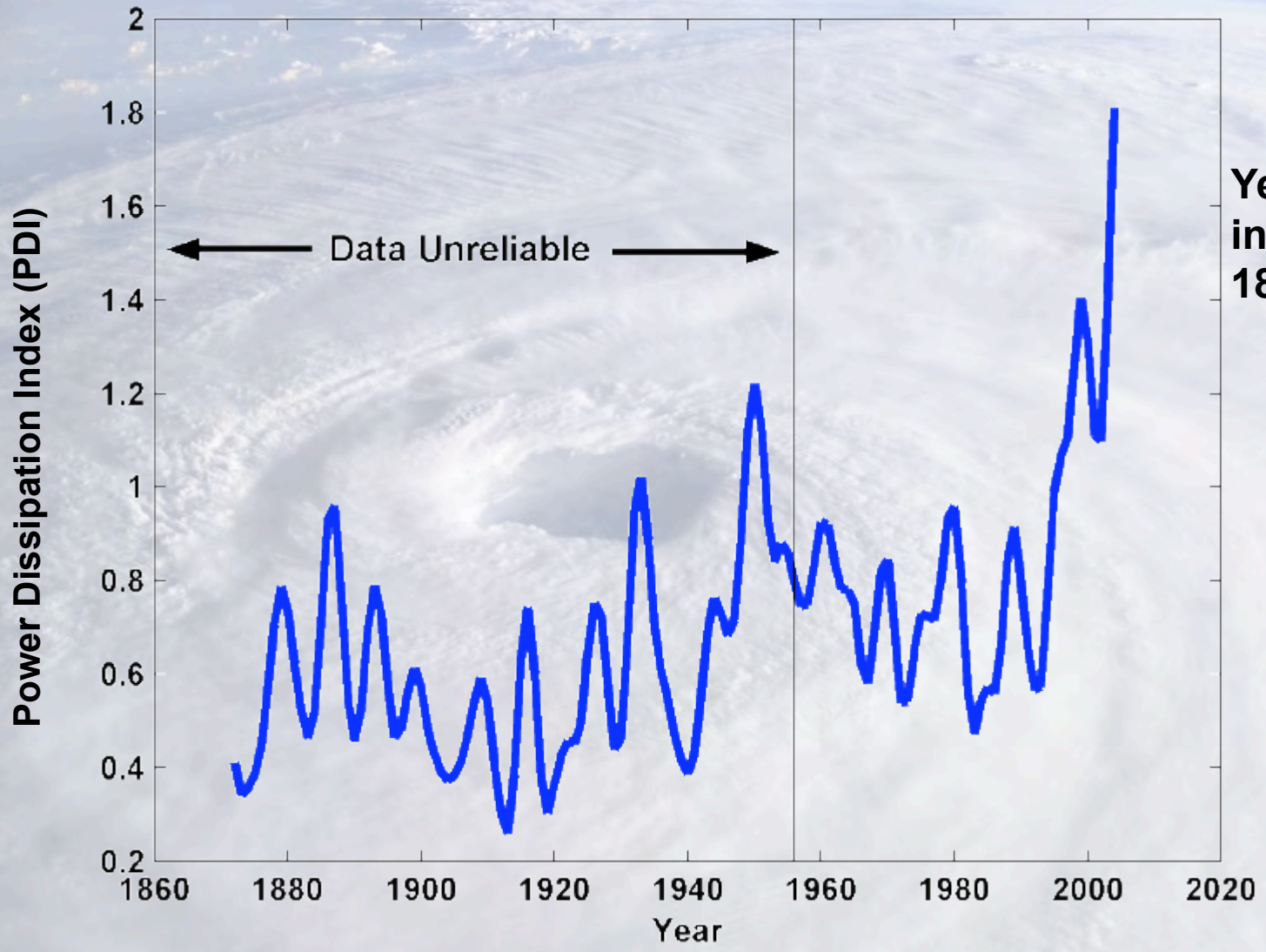
The Power Dissipation Index

$$PDI \equiv \int_0^{\tau} V_{max}^3 \, dt$$

A measure of the total frictional dissipation of kinetic energy in the hurricane boundary layer over the lifetime of the storm

Atlantic Storm Maximum Power Dissipation

(Smoothed with a 1-3-4-3-1 filter)

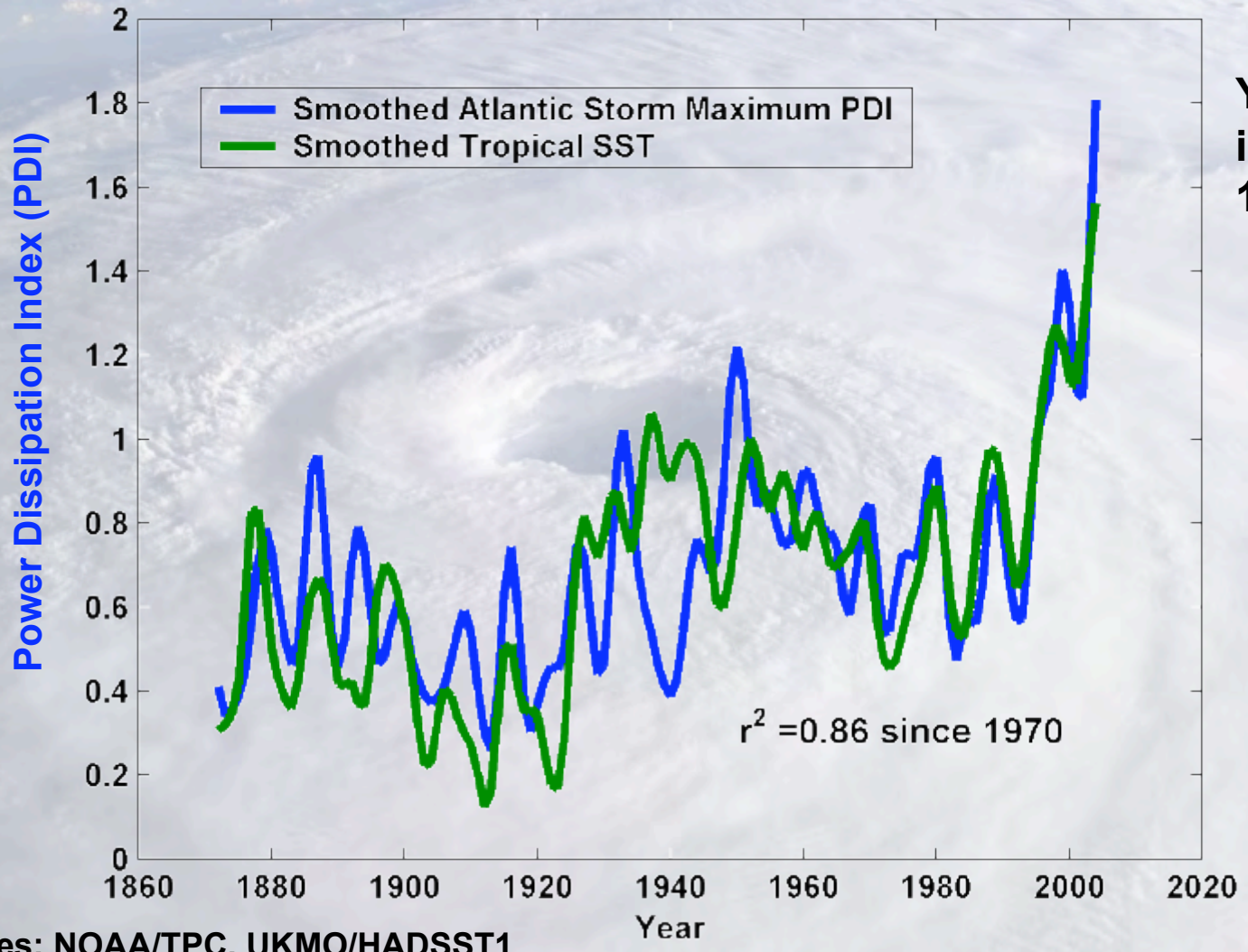


Years included: 1870-2006

Data Source: NOAA/TPC

Atlantic Sea Surface Temperatures and Storm Max Power Dissipation

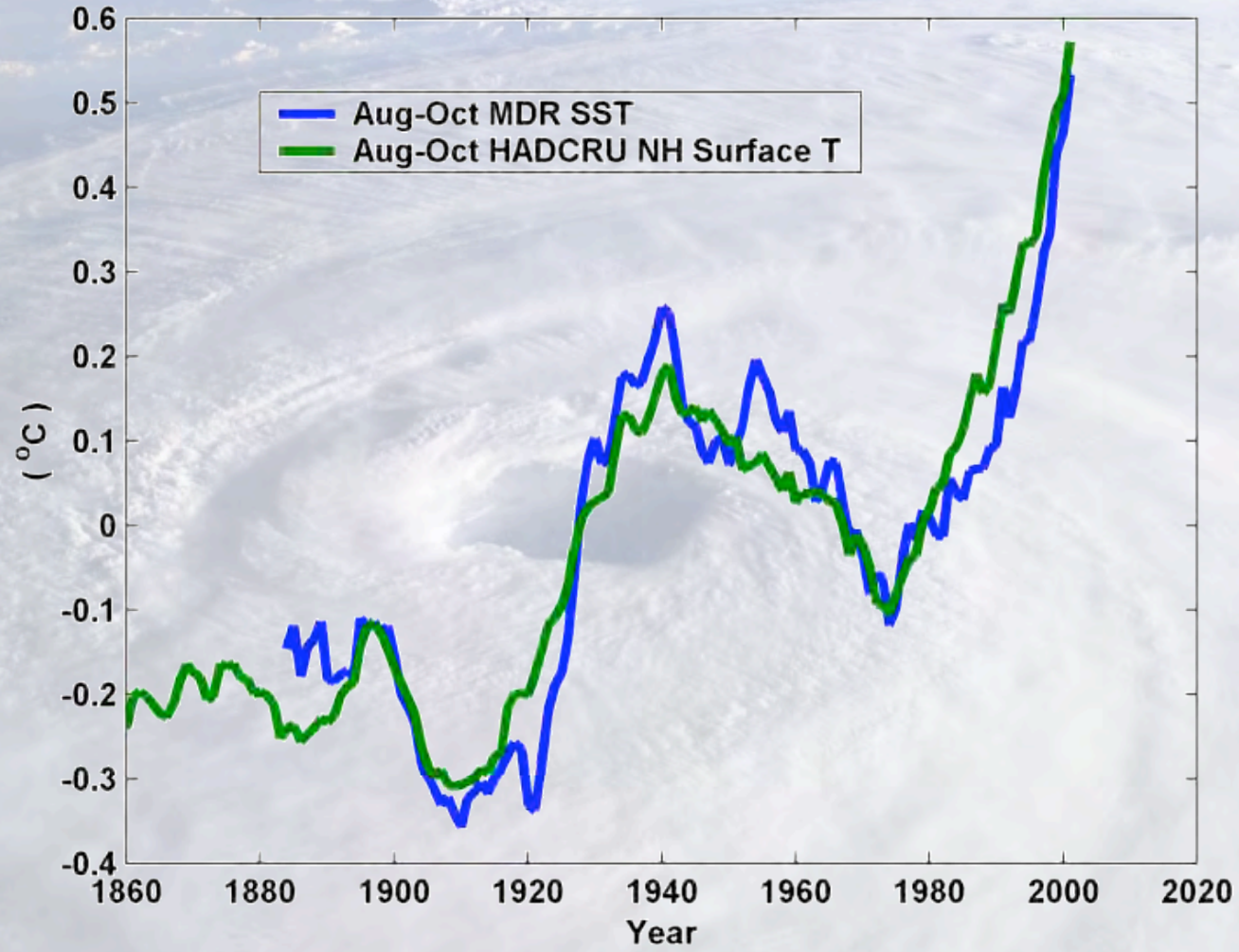
(Smoothed with a 1-3-4-3-1 filter)

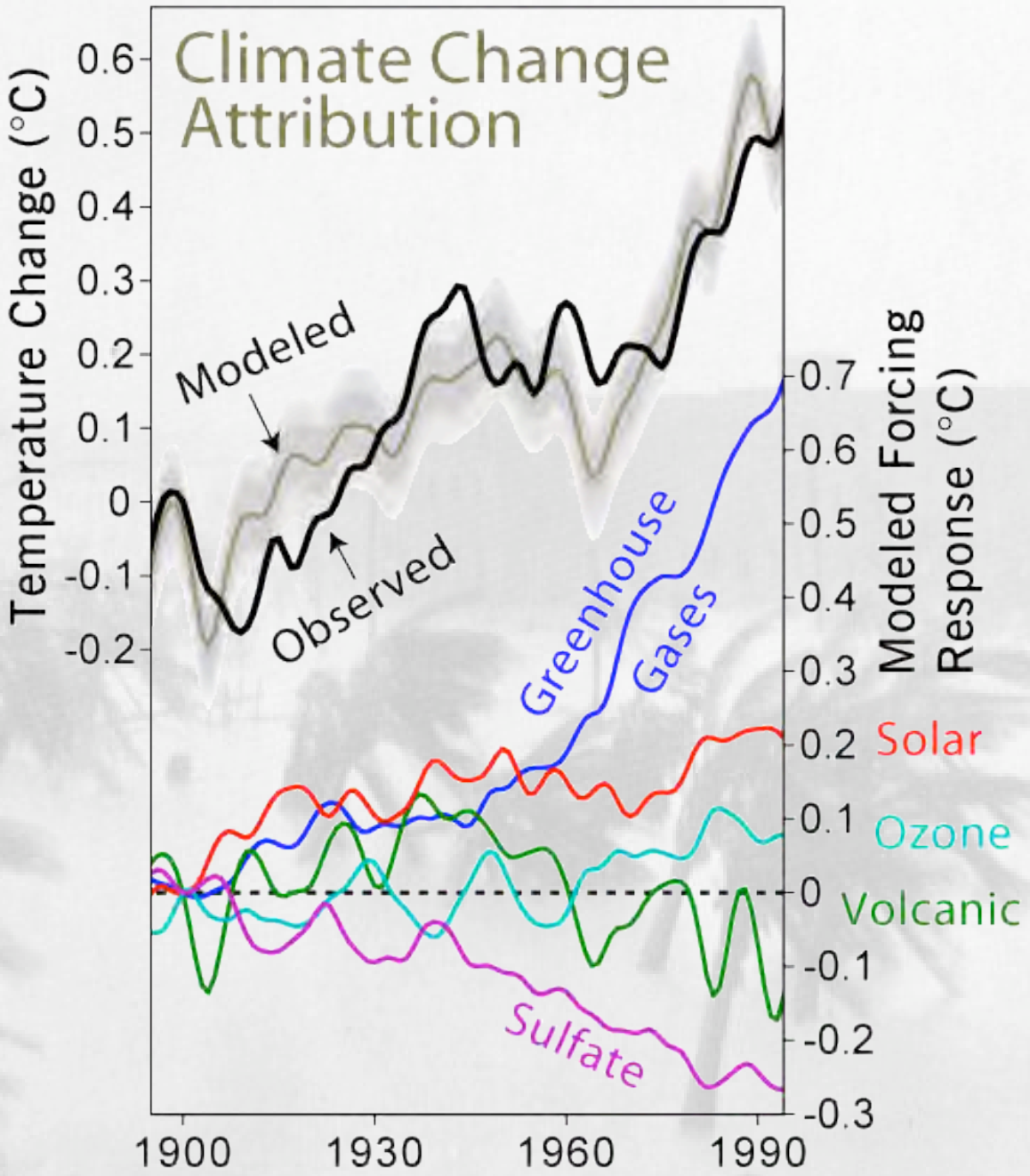


Years included: 1870-2006

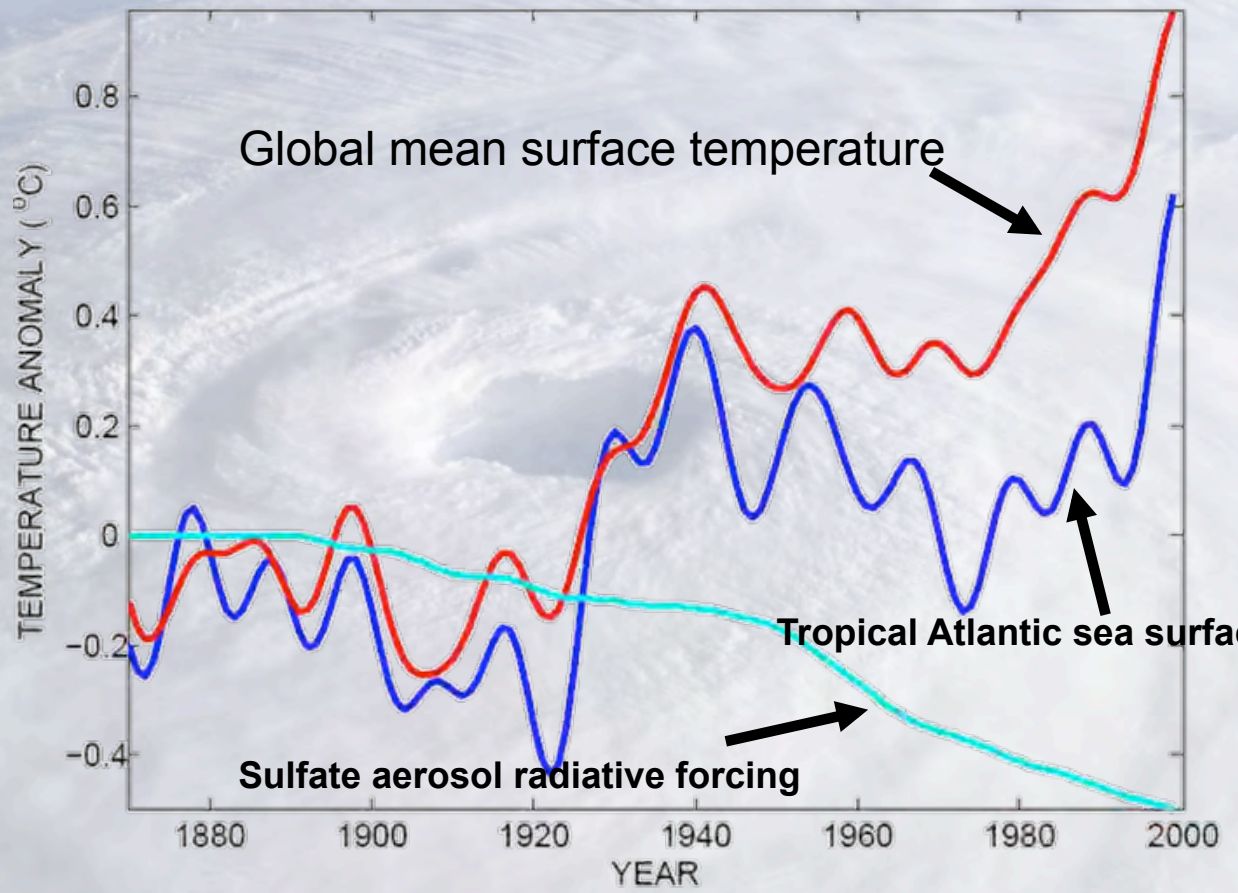
Data Sources: NOAA/TPC, UKMO/HADSST1

10-year Running Average of Aug-Oct NH Surface T and MDR SST



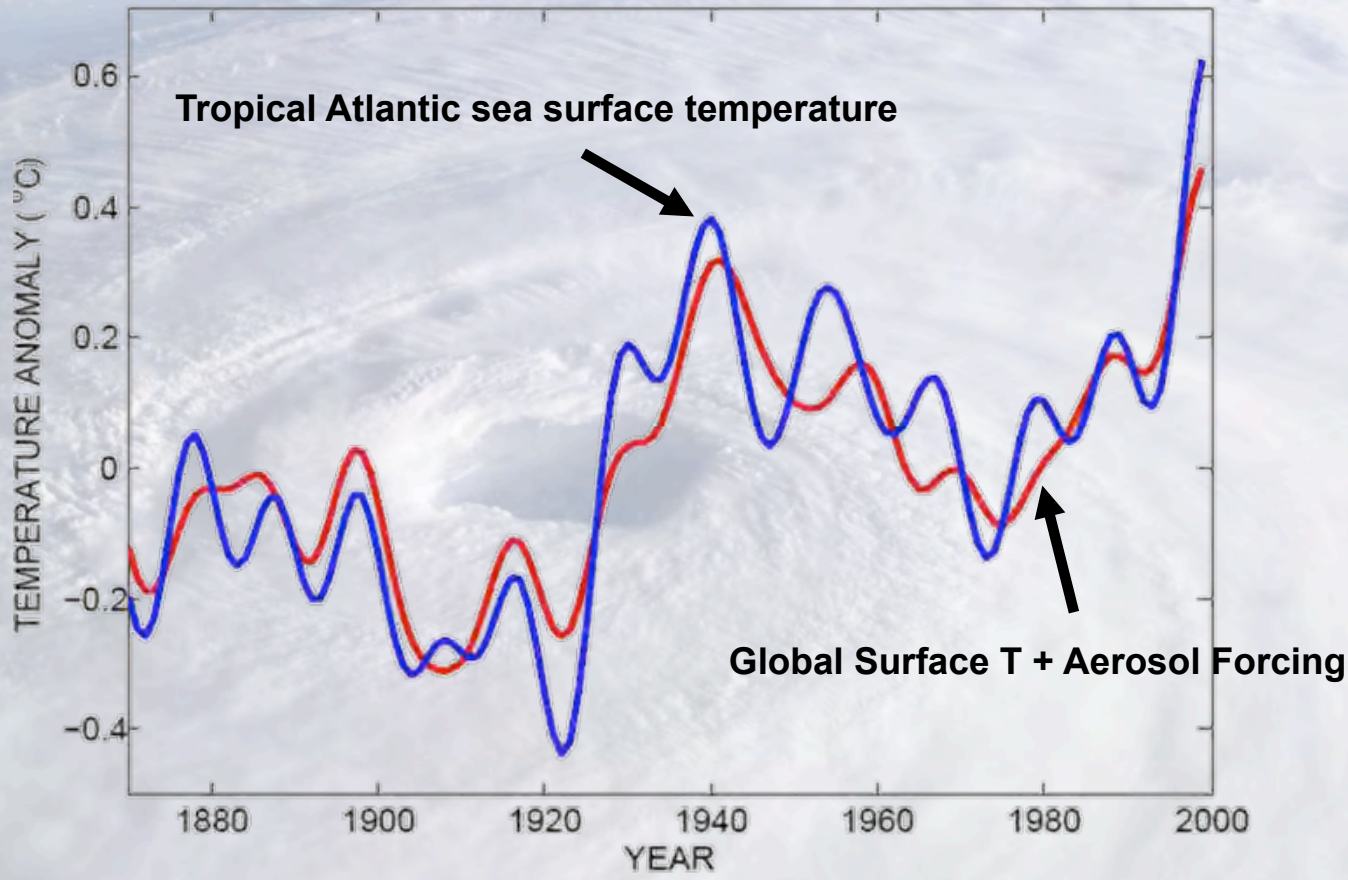

Climate Change
Attribution
Temperature Change (°C)
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
Modeled
Observed
Greenhouse
Gases
Solar
Ozone
Volcanic
Sulfate
Modeled Forcing
Response (°C)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
1900
1930
1960
1990

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

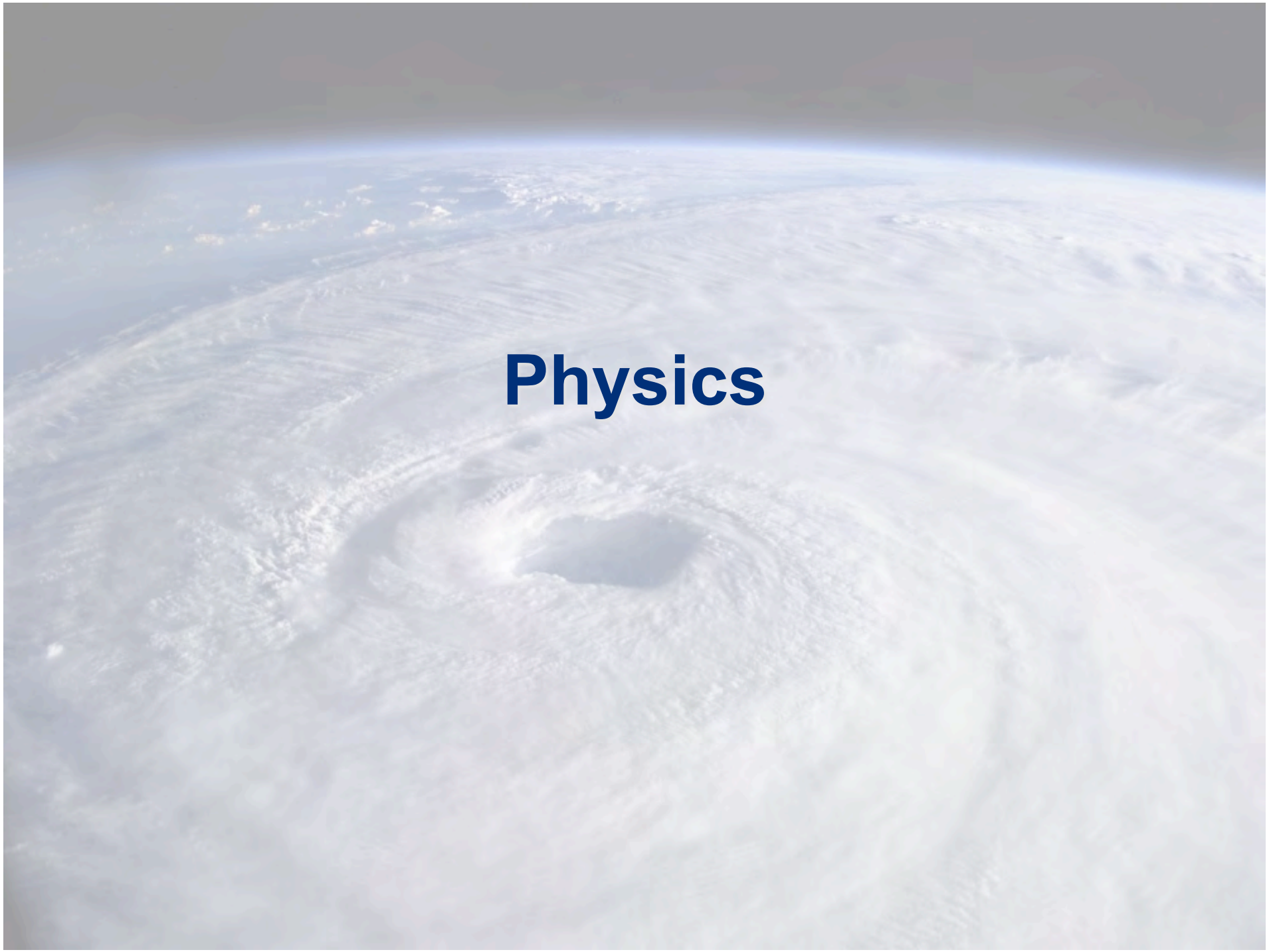


Mann, M. E., and K. A. Emanuel, 2006. Atlantic hurricane trends linked to climate change. EOS, 87, 233-244.

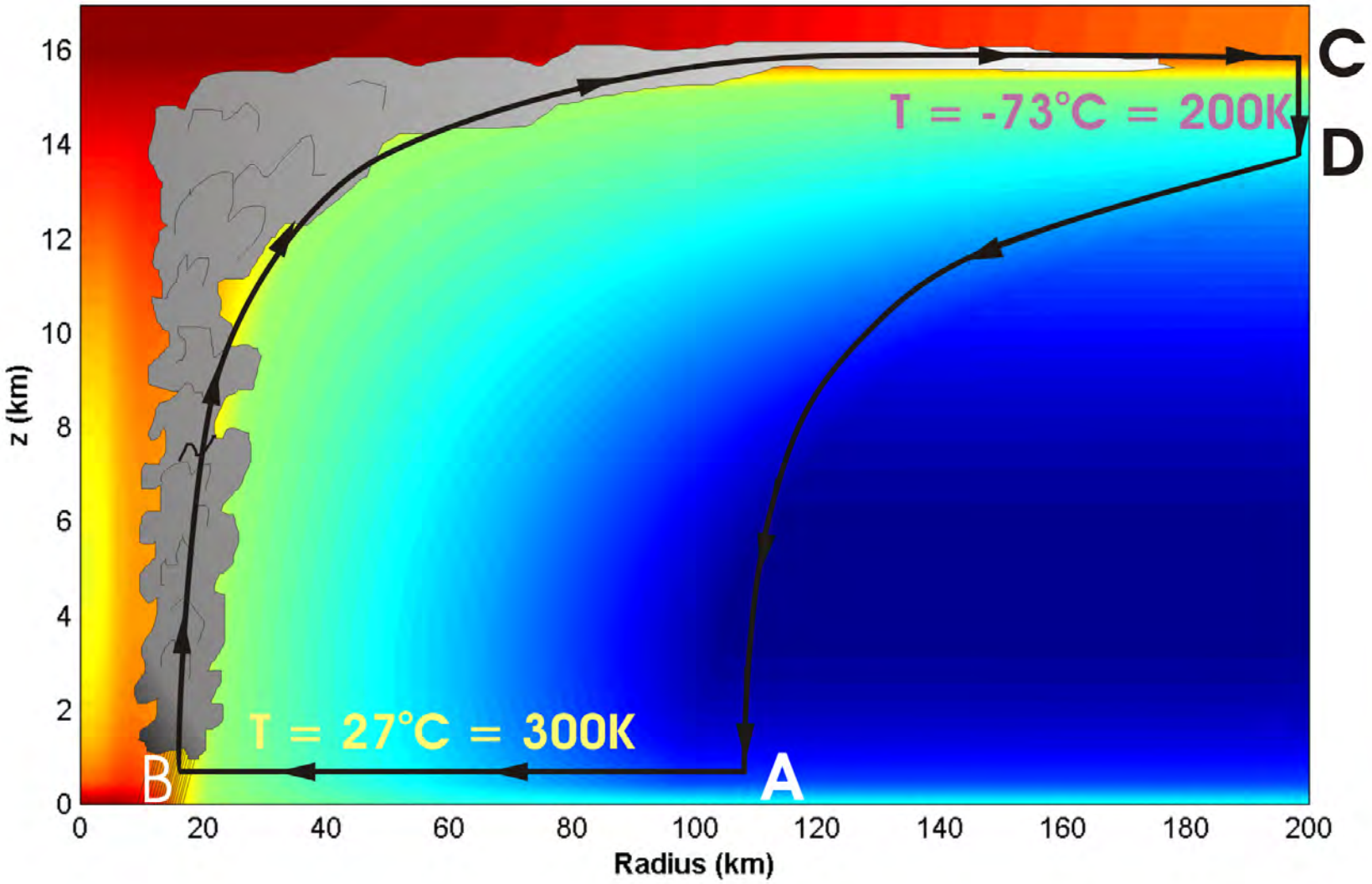
Best Fit Linear Combination of Global Warming and Aerosol Forcing (red) versus Tropical Atlantic SST (blue)



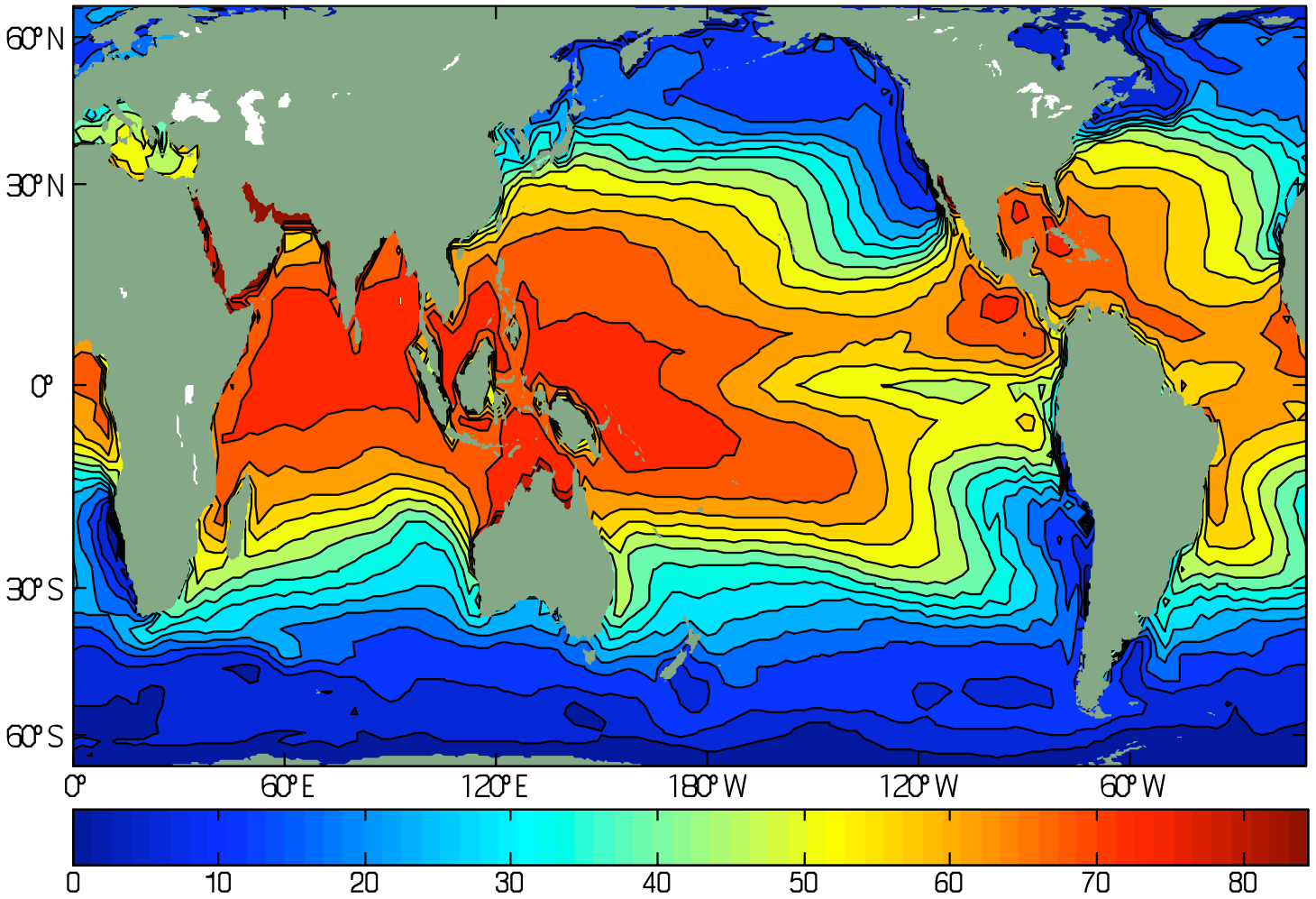
Mann, M. E., and K. A. Emanuel, 2006. Atlantic hurricane trends linked to climate change. EOS, 87, 233-244.


Physics

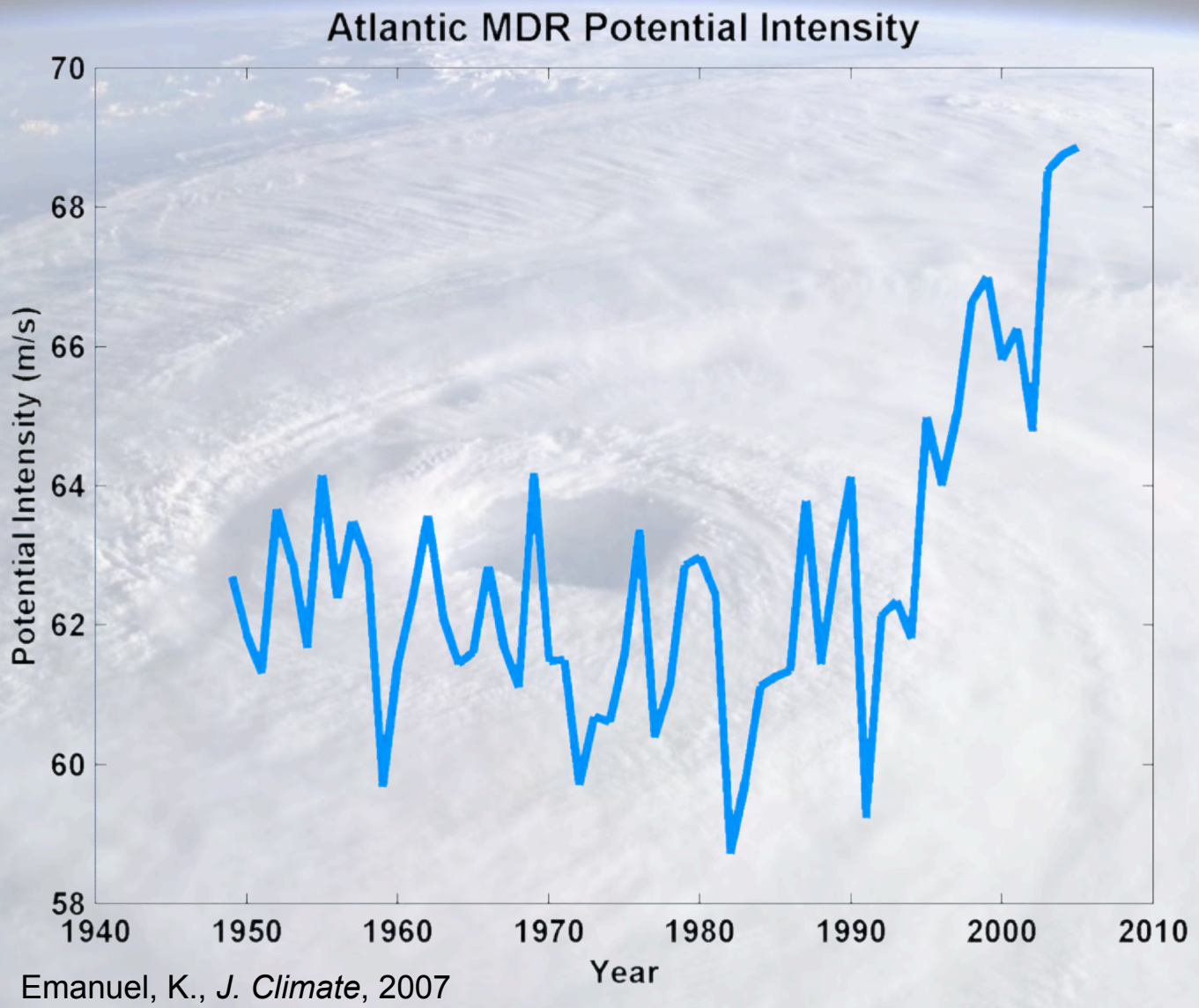
Energy Production: The Hurricane as a Carnot Heat Engine



Annual Maximum Potential Intensity (m/s)



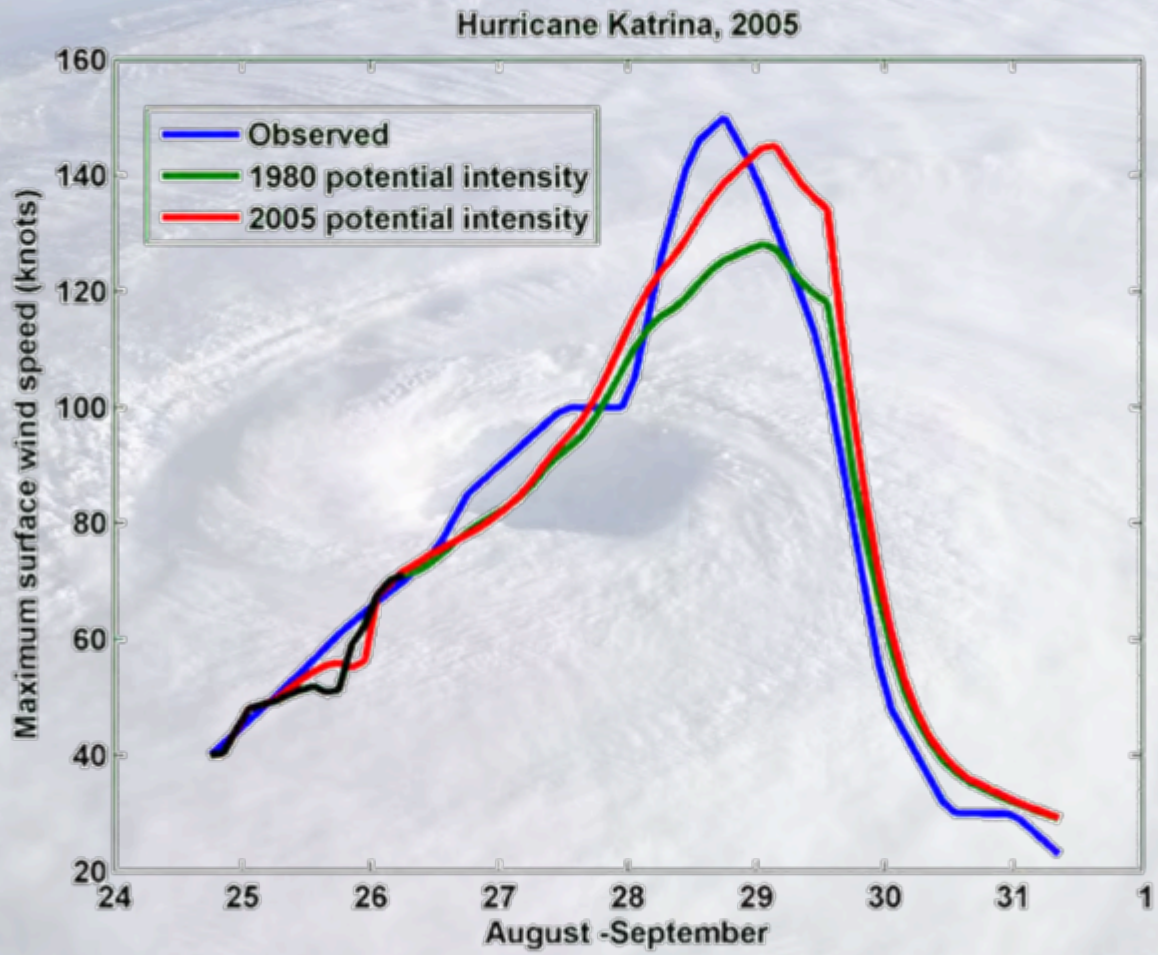
Observed Tropical Atlantic Potential Intensity



Emanuel, K., *J. Climate*, 2007

Data Sources: NCAR/NCEP re-analysis with pre-1979 bias correction, UKMO/HADSST1

Effect of Increased Potential Intensity on Hurricane Katrina



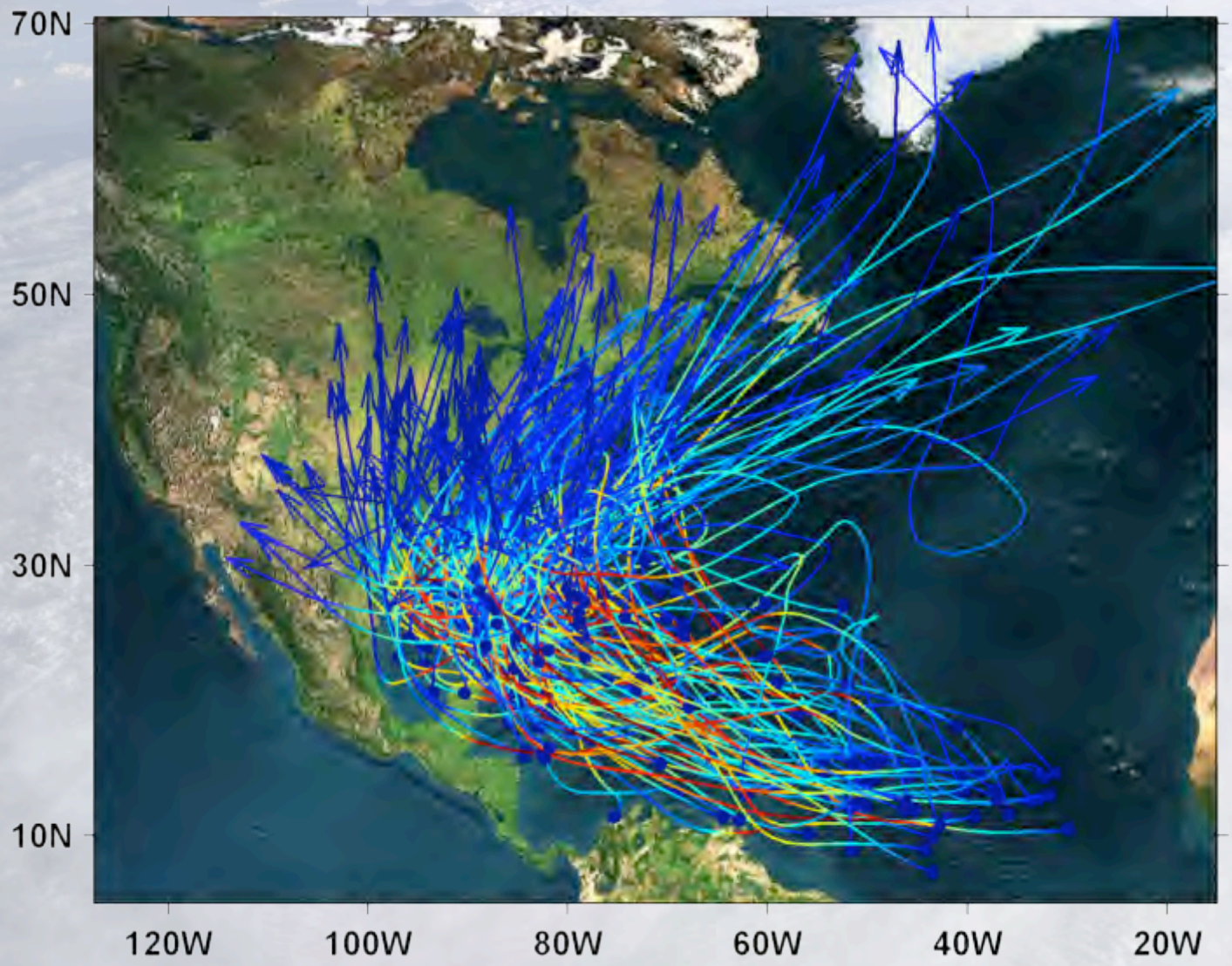
Projecting into the Future: Downscaling from Global Climate Models


Today's global climate
models are far too coarse to
simulate tropical cyclones

Our 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
- **Step 3**: Run a coupled, ocean-atmosphere computer 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.

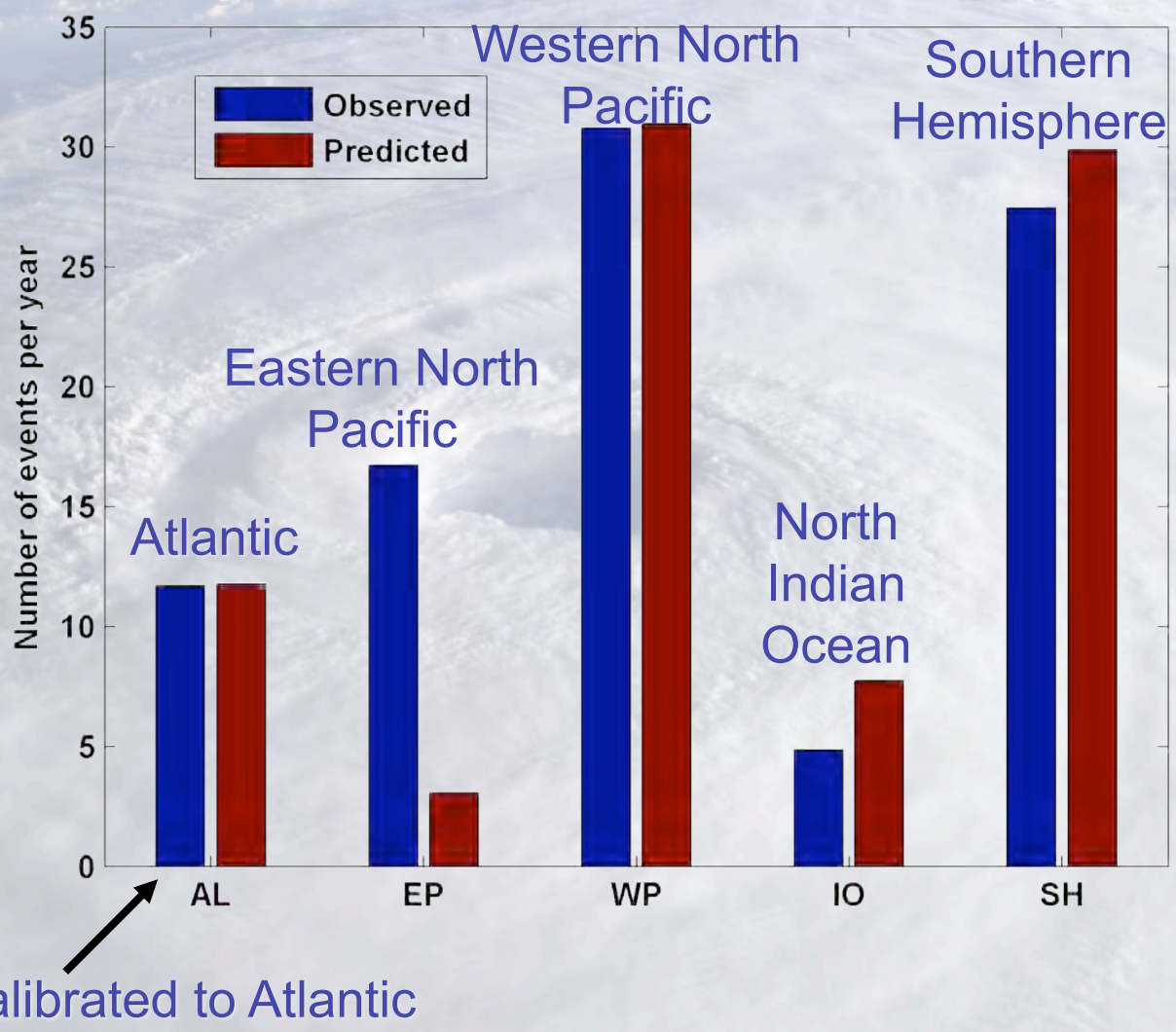
200 Synthetic U.S. Landfalling tracks (color coded by Saffir-Simpson Scale)



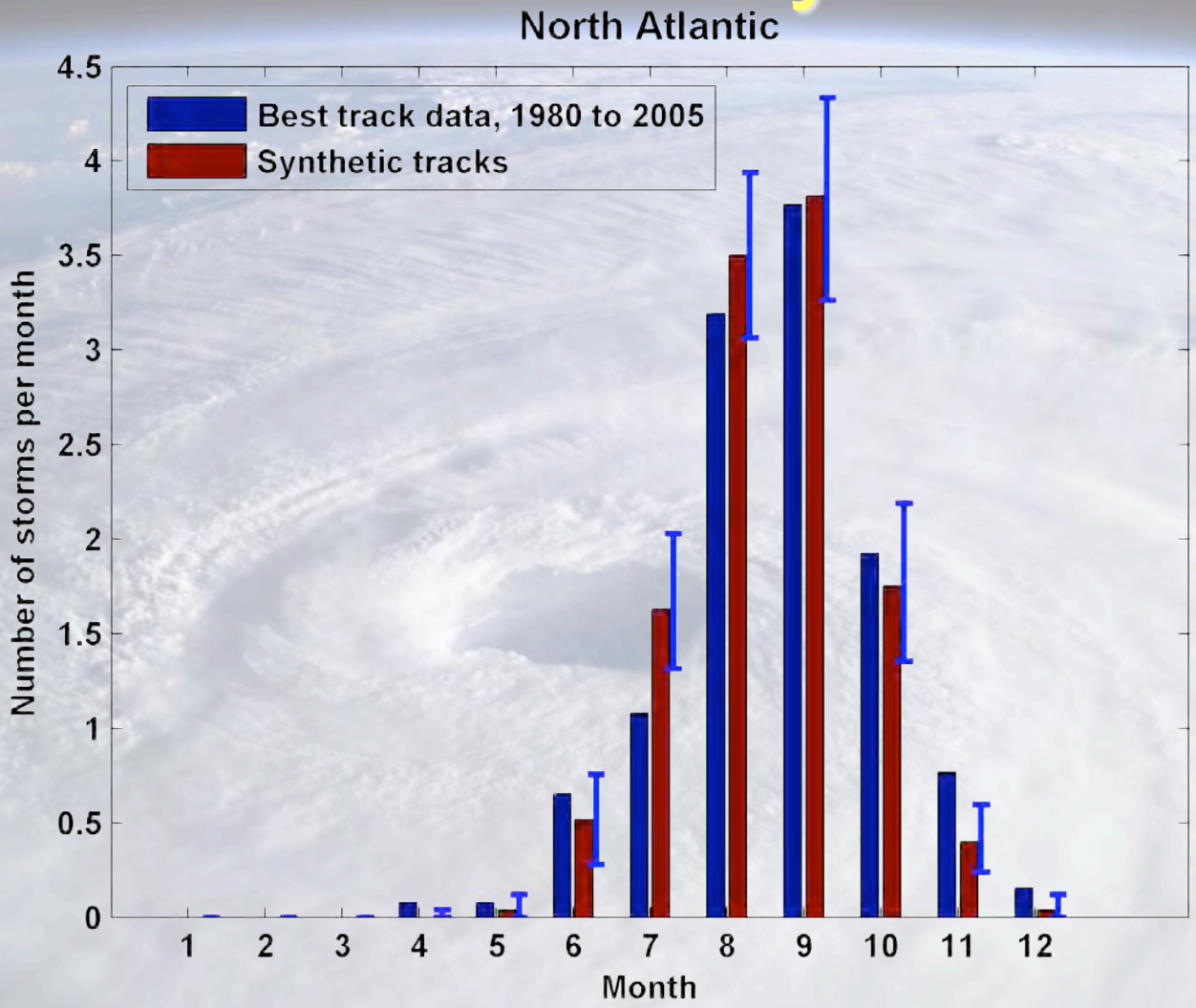
Calibration

- **Absolute genesis frequency calibrated to North Atlantic during the period 1980-2005**

Genesis rates

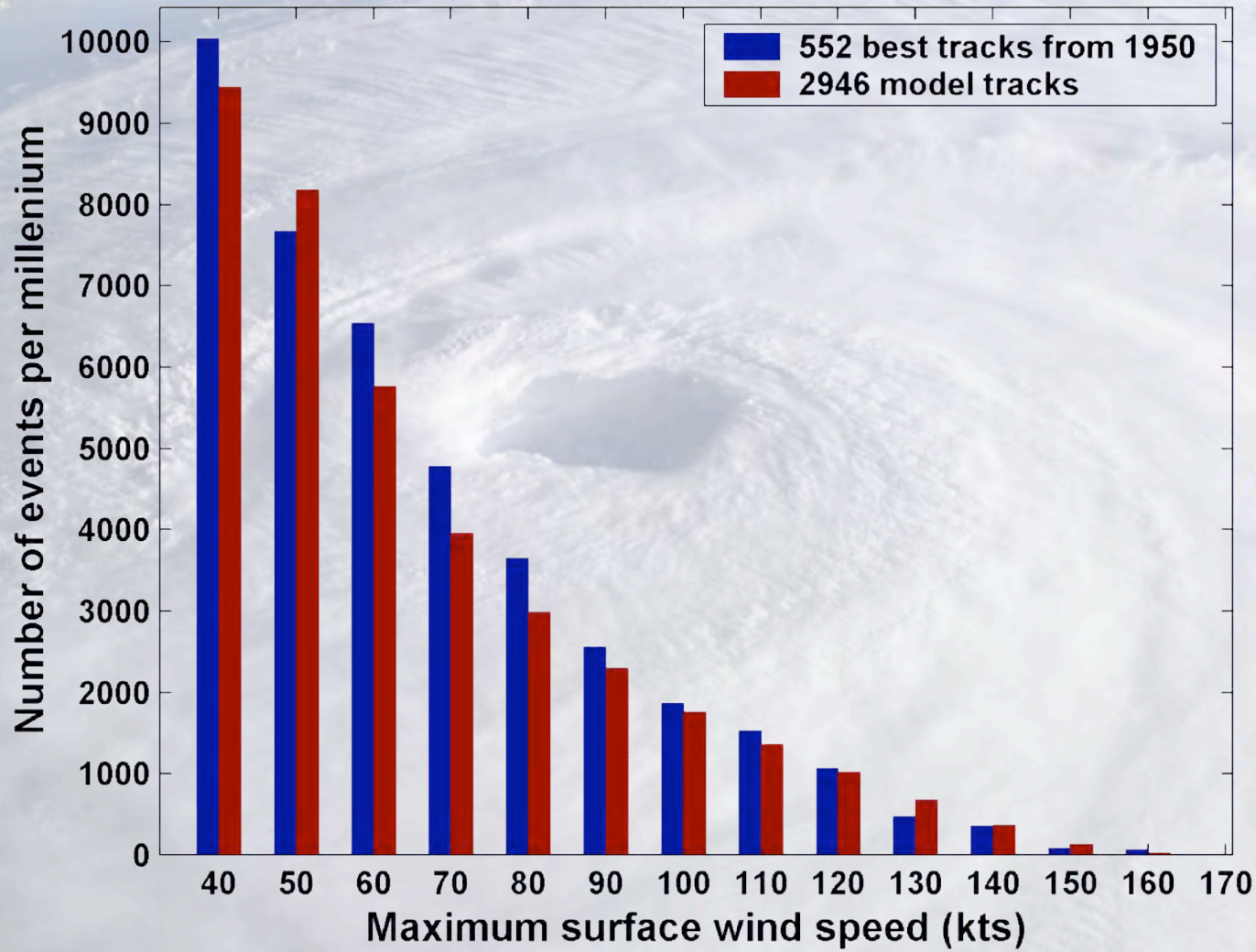


Seasonal Cycles

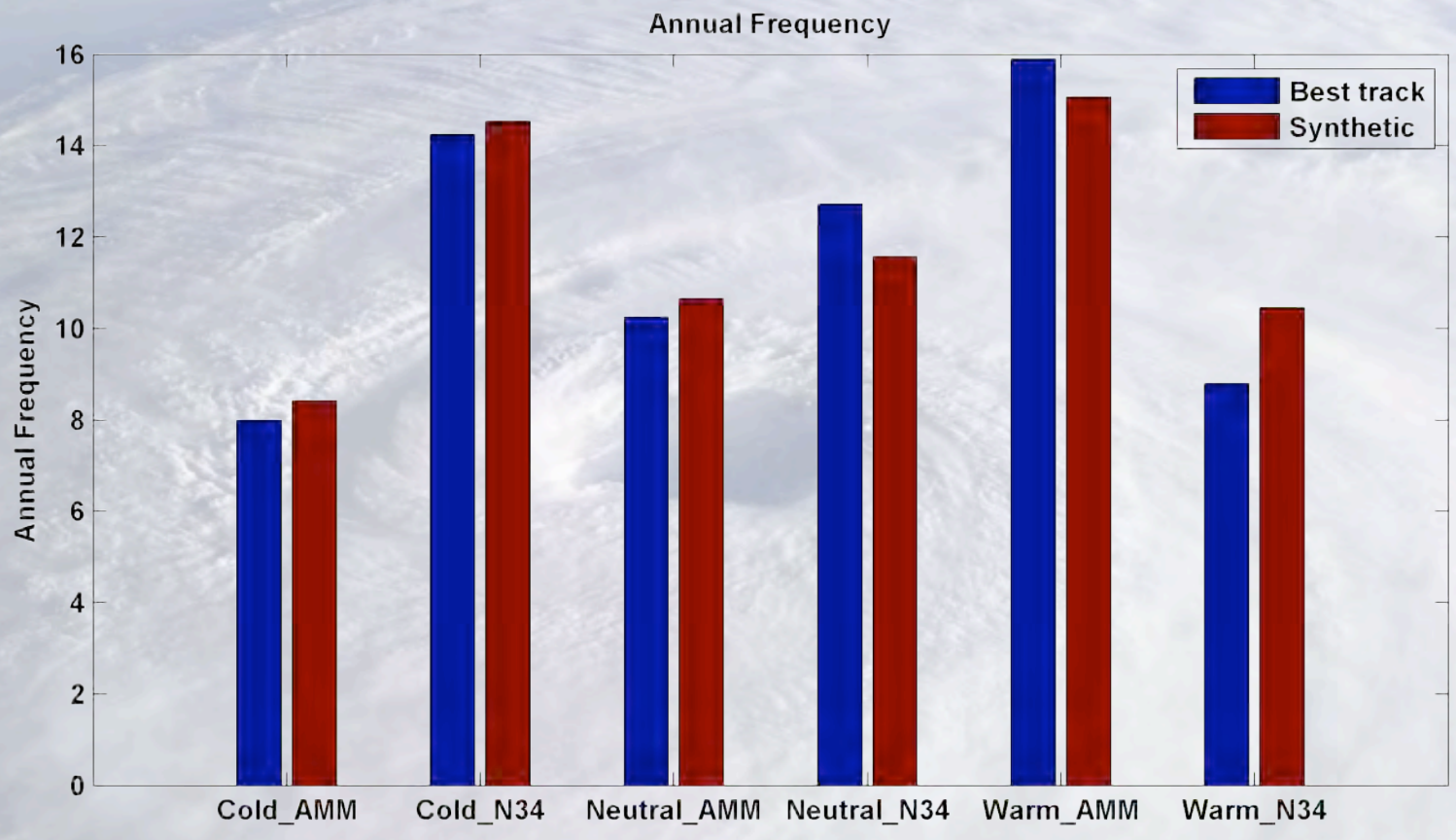


Atlantic

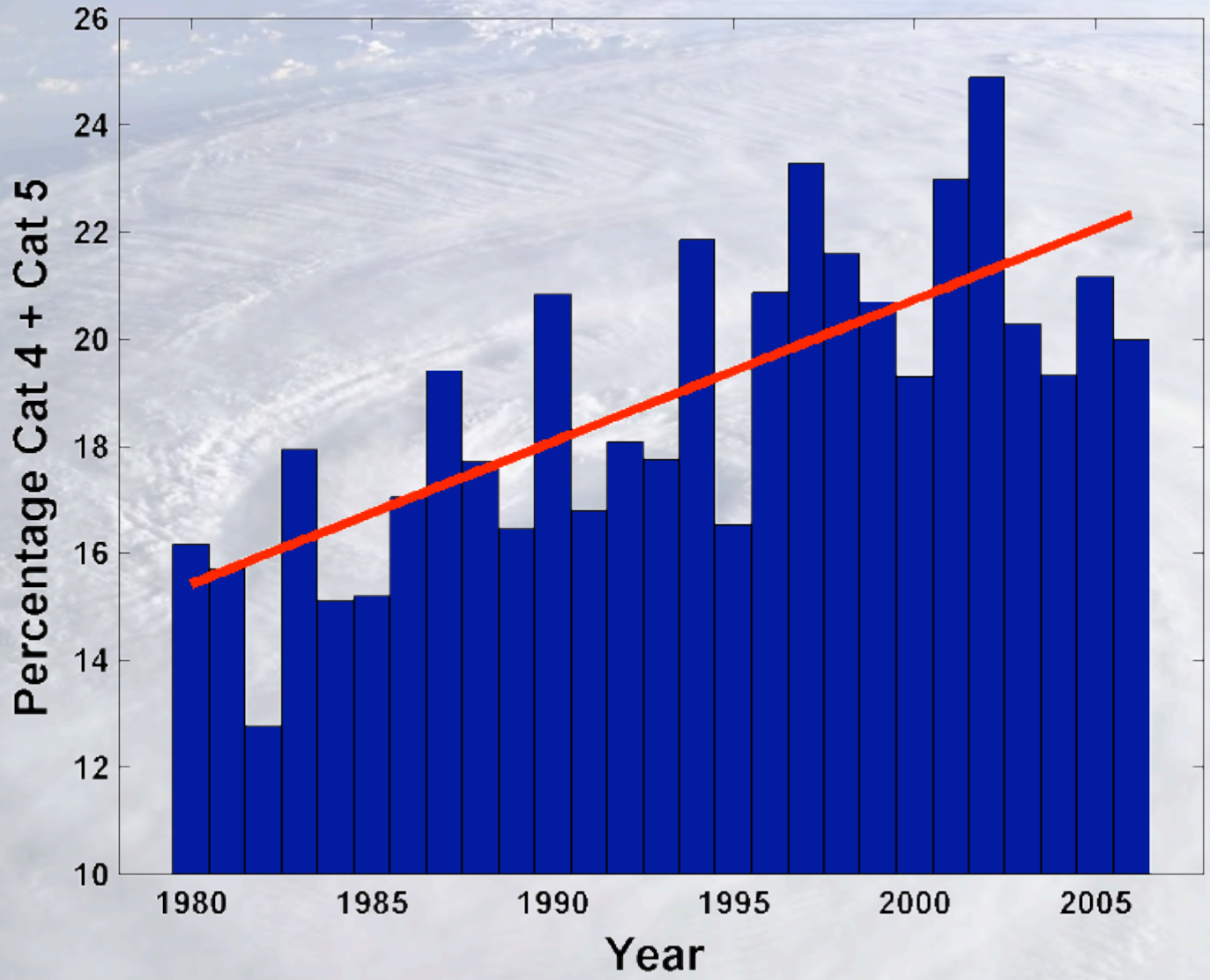
Cumulative Distribution of Storm Lifetime Peak Wind Speed, with Sample of 2946 Synthetic Tracks

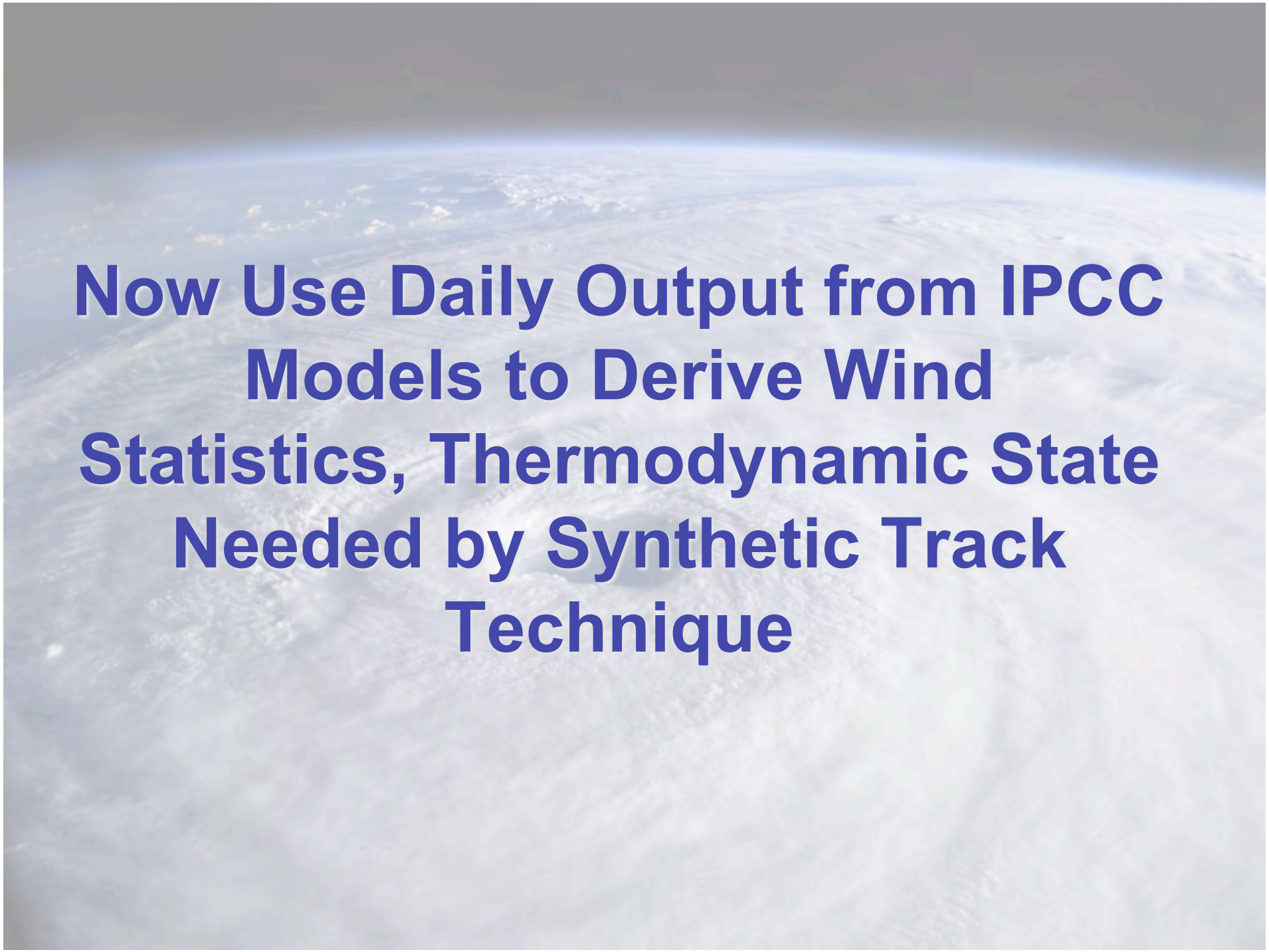


Captures effects of regional climate phenomena (e.g. ENSO, AMM)



Global Percentage of Cat 4 & Cat 5 Storms



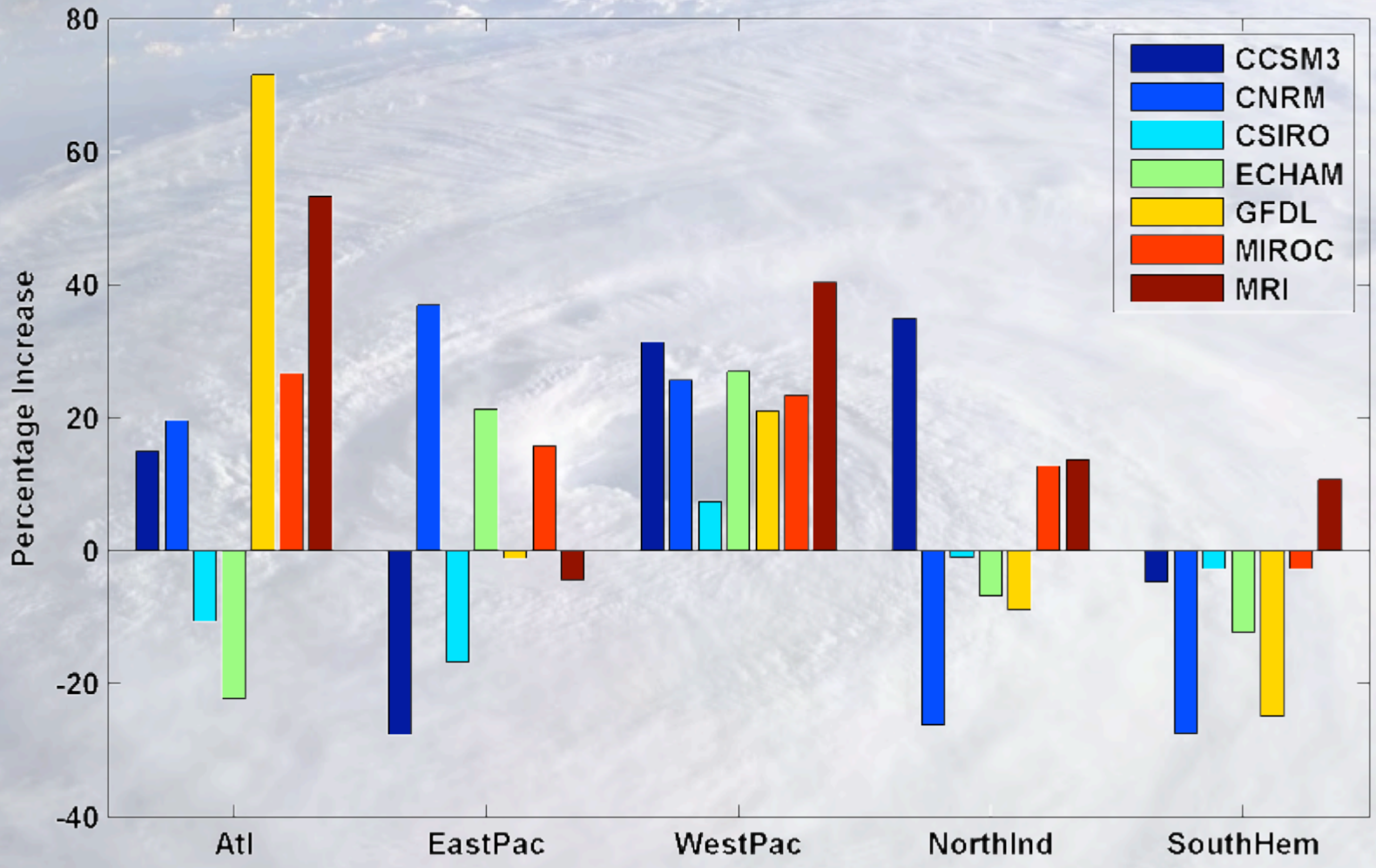

Now Use Daily Output from IPCC Models to Derive Wind Statistics, Thermodynamic State Needed by Synthetic Track Technique

Compare two simulations each from 7 IPCC models:

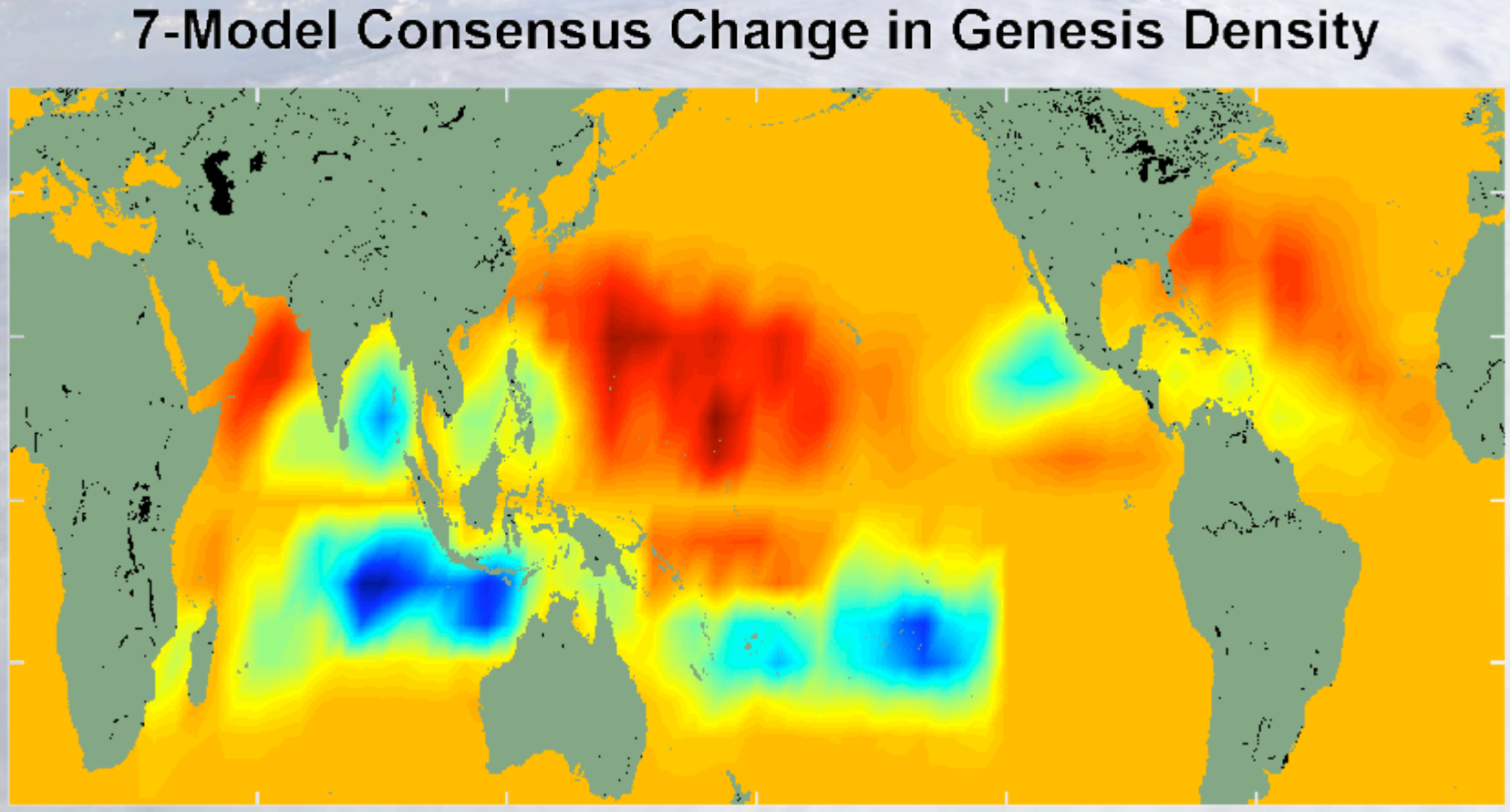
1. Last 20 years of 20th century simulations

2. Years 2180-2200 of IPCC Scenario A1b (CO_2 stabilized at 720 ppm)

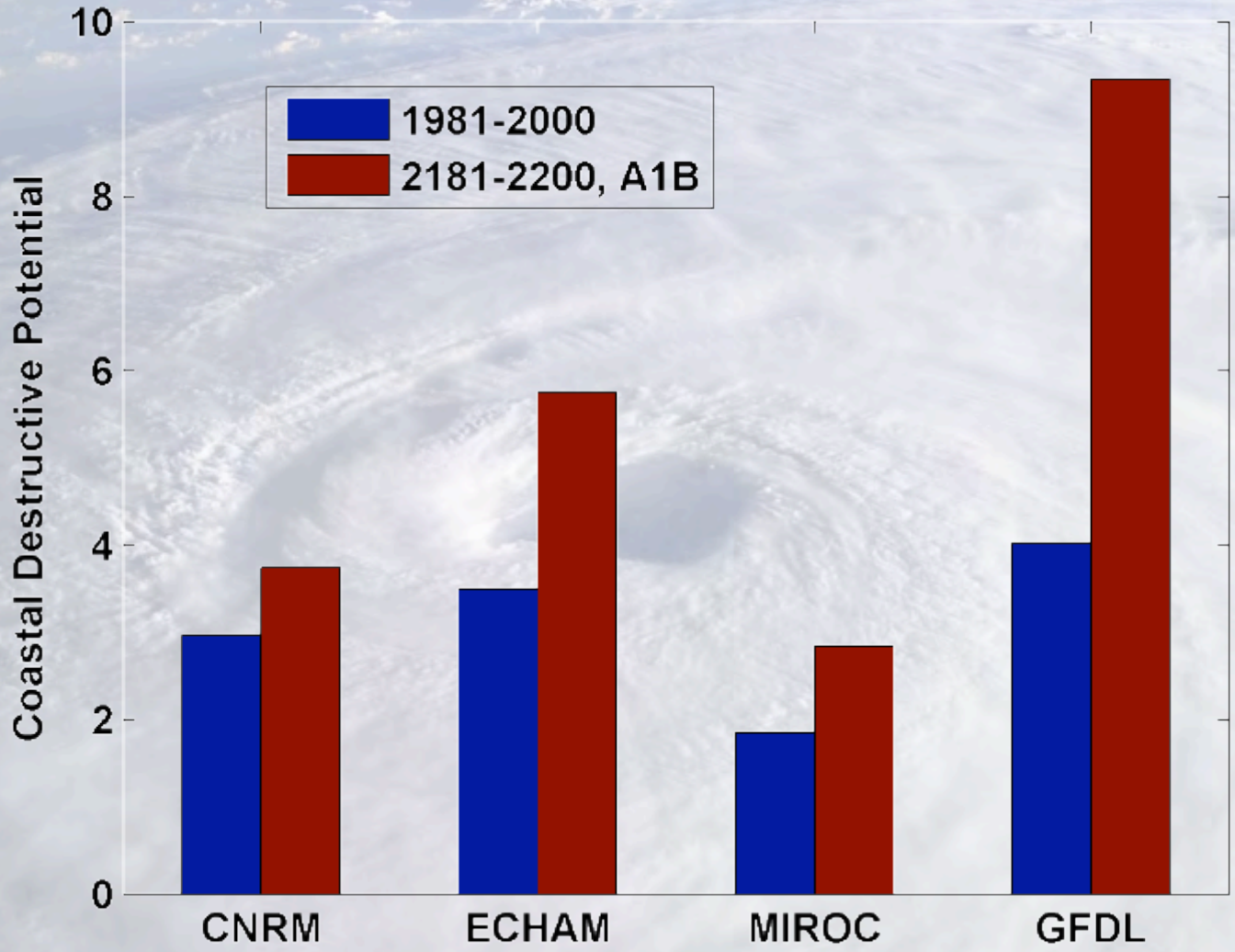
Basin-Wide Percentage Change in Power Dissipation

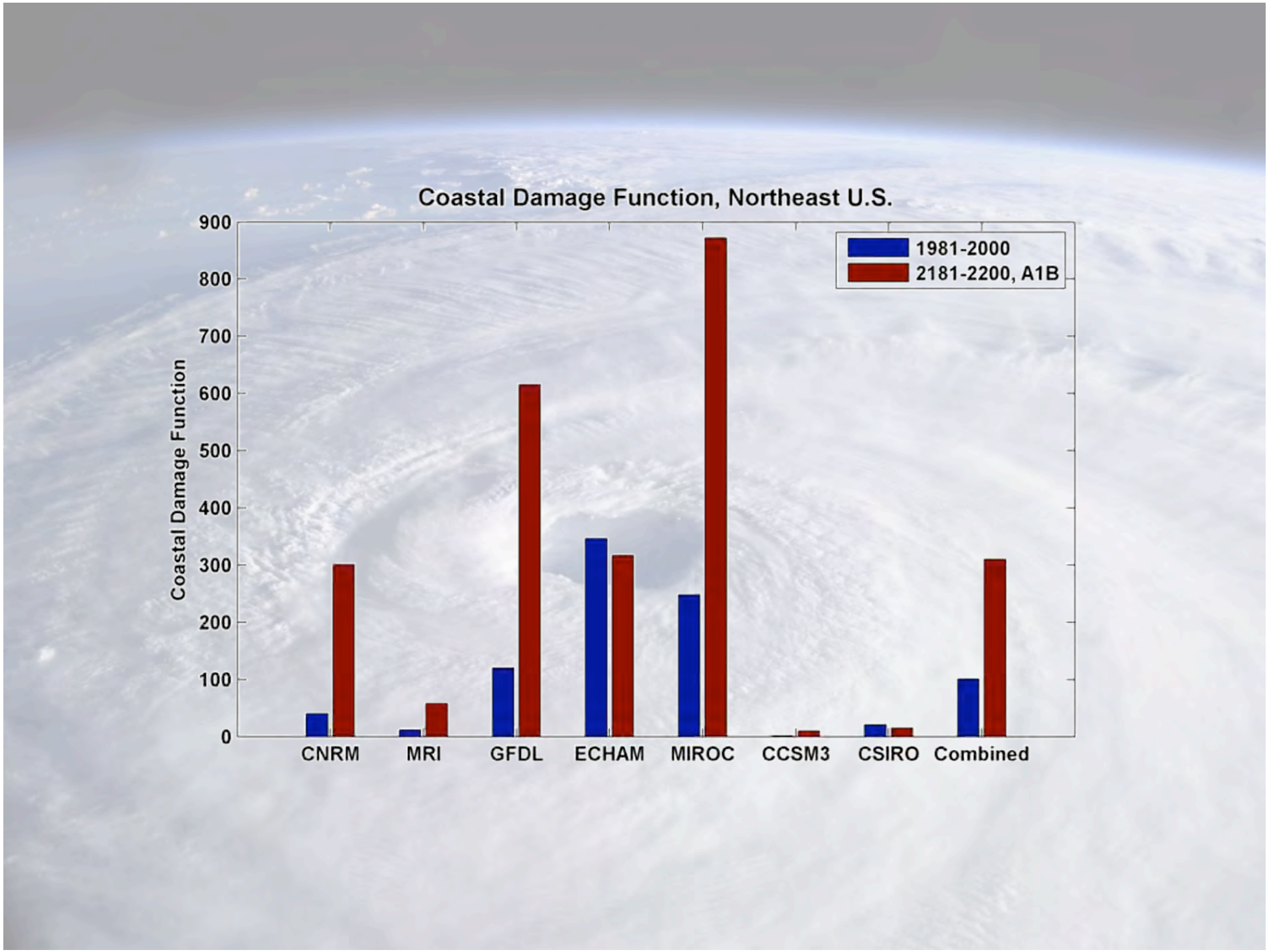


7 Model Consensus Change in Storm Frequency



U.S. Coastal Damage Potential




Coastal Damage Function, Northeast U.S.
Coastal Damage Function
900
800
700
600
500
400
300
200
100
0
1981-2000
2181-2200, A1B
CNRM
MRI
GFDL
ECHAM
MIROC
CCSM3
CSIRO
Combined

Summary:

- Tropical cyclones are sensitive to the climate state, as revealed by historical (and geological) data

- Observations together with detailed modeling suggest that TC power dissipation increases by ~65% for a 10% increase in potential intensity

- New technique for downscaling climate models shows promise for predicting response of global tropical cyclone activity to climate change

- Climate models may have systematic errors that compromise estimates of tropical cyclone response to global warming