



Hurricanes and Global Warming

Kerry Emanuel
Massachusetts Institute of
Technology

Issues

A satellite image of a tropical cyclone, showing a distinct eye and spiral cloud bands over a vast expanse of the ocean. The image is taken from a high altitude, providing a top-down view of the storm's structure.

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

Approaches

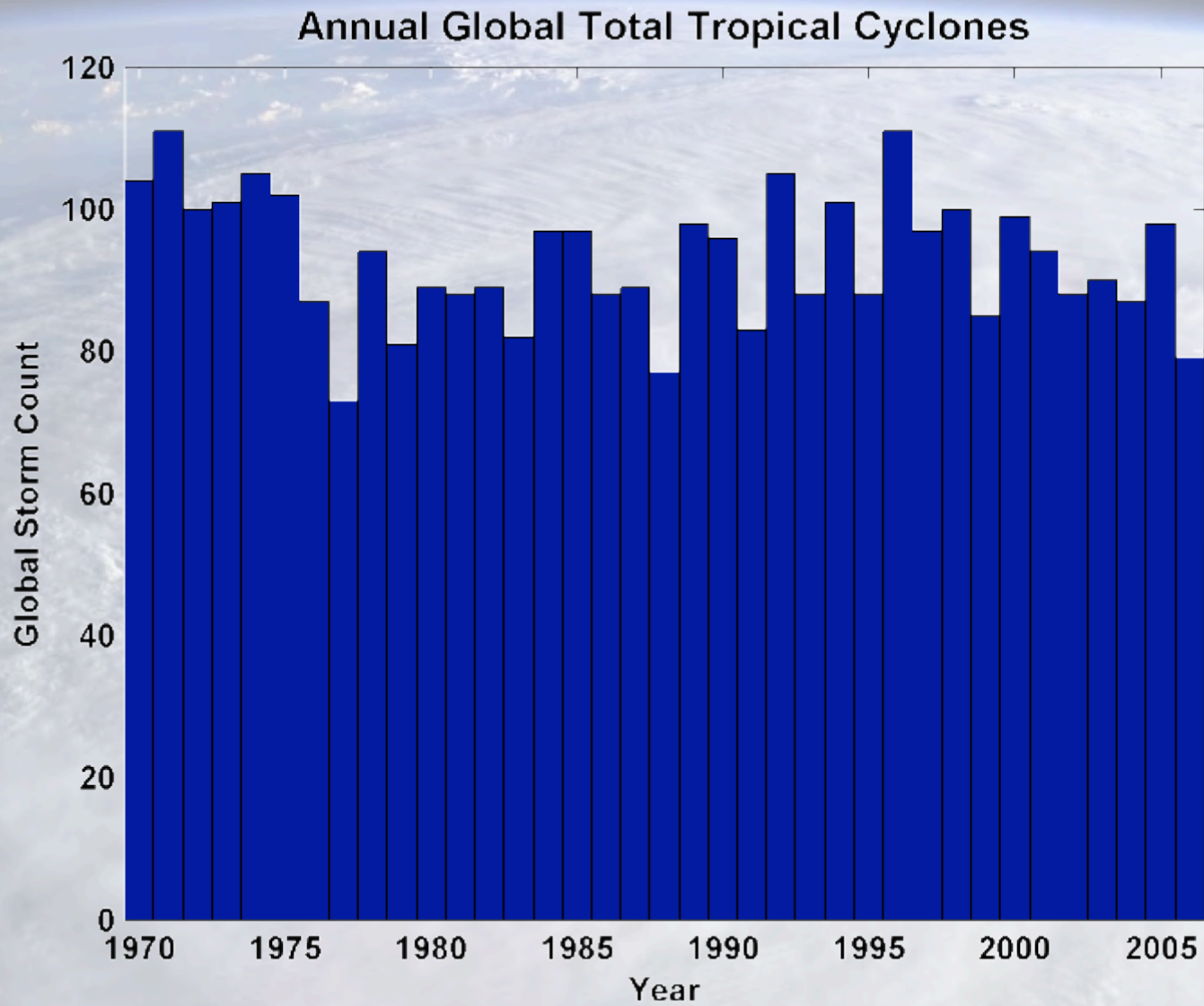
A satellite image of Earth from space, showing a large, well-defined cyclone or hurricane over the ocean. The cyclone's eye is clearly visible in the center, surrounded by dense, swirling cloud bands. The surrounding ocean and parts of the continents are visible in the background.

- **The historical record**
- **Physics**
- **Models**

An aerial photograph of a tropical cyclone, showing a well-defined eye and a dense, swirling cloud structure over the ocean. The eye is a dark, circular center surrounded by a bright, white ring of clouds. The surrounding clouds are thick and spiral outwards, creating a distinct pattern on the sea surface. The horizon is visible in the distance, showing the curvature of the Earth and a thin layer of clouds.

The Historical Record

Global TC Frequency, 1970-2006



Data Sources: NOAA/TPC and NAVY/JTWC

Better Intensity Metric:

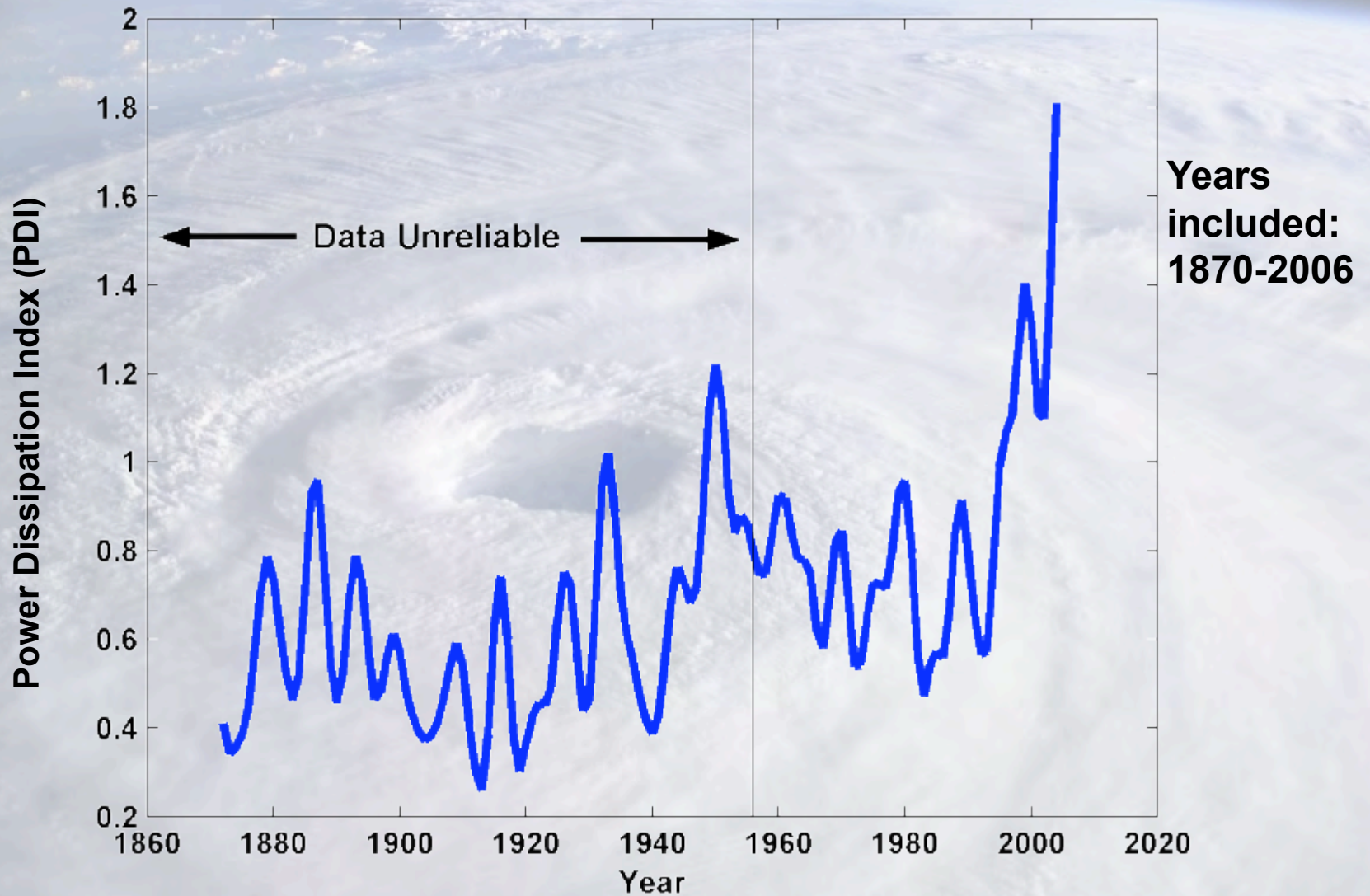
The Power Dissipation Index

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

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

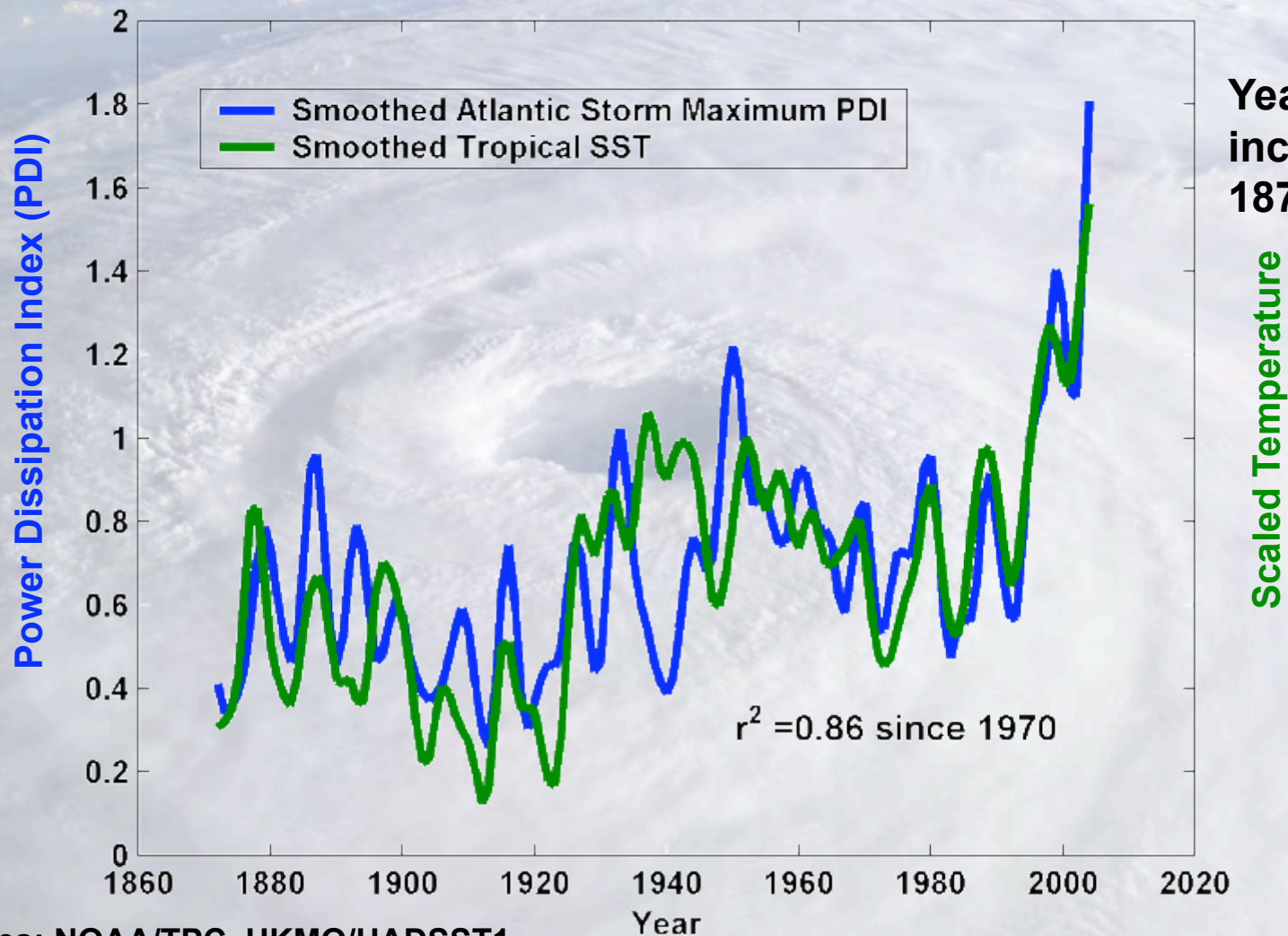
(Smoothed with a 1-3-4-3-1 filter)



Data Source: NOAA/TPC

Atlantic Sea Surface Temperatures and Storm Max Power Dissipation

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

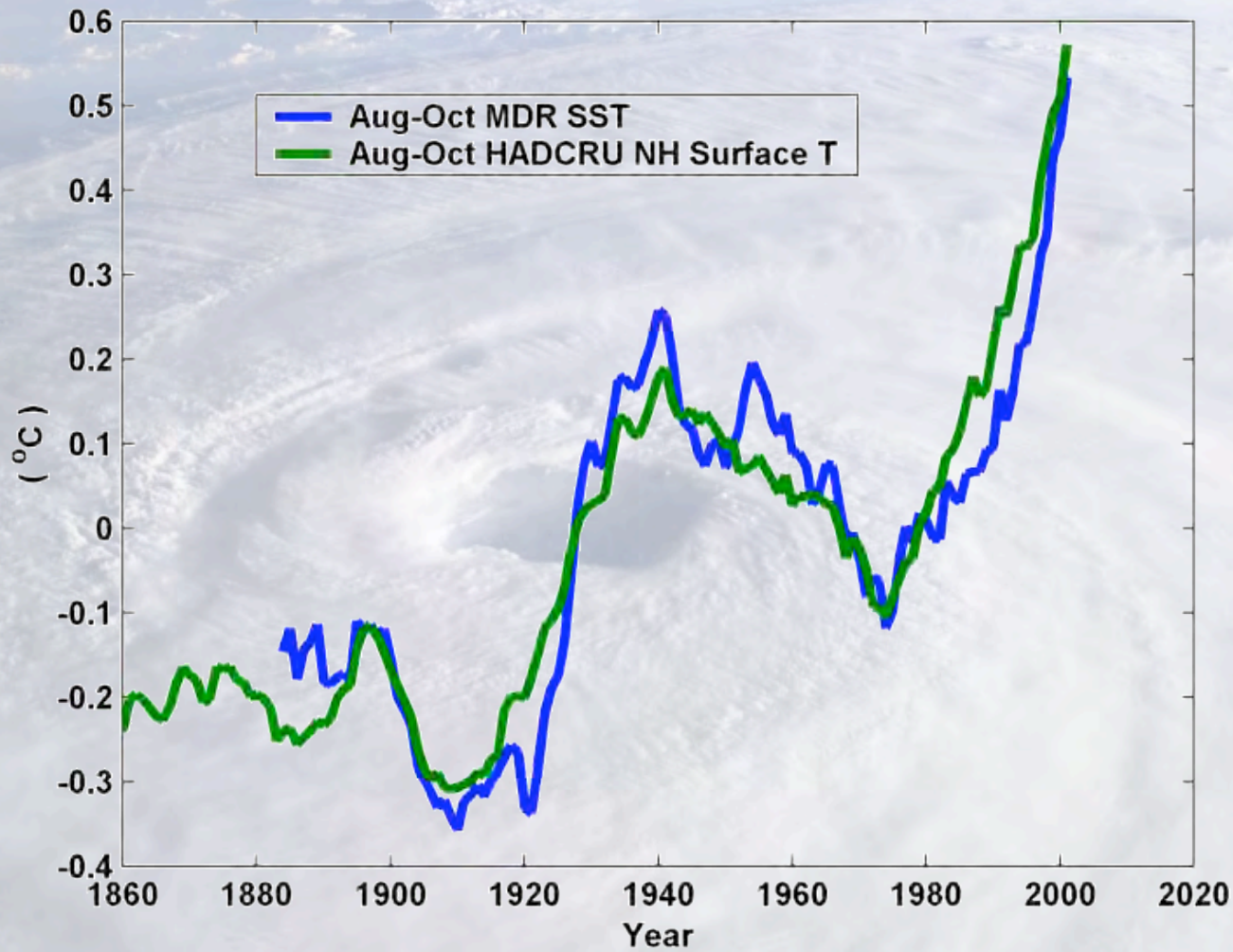


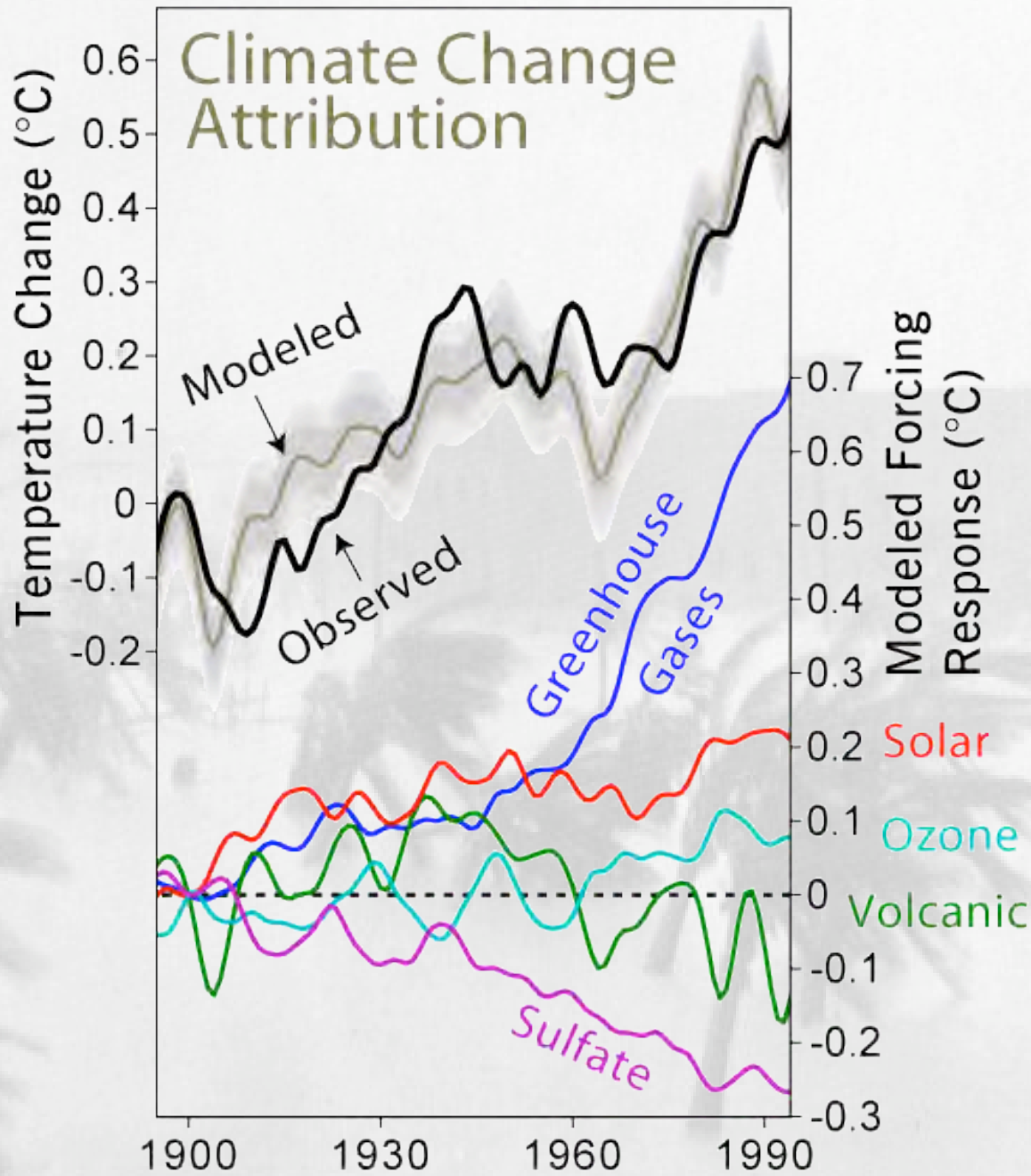
Years included:
1870-2006

Scaled Temperature

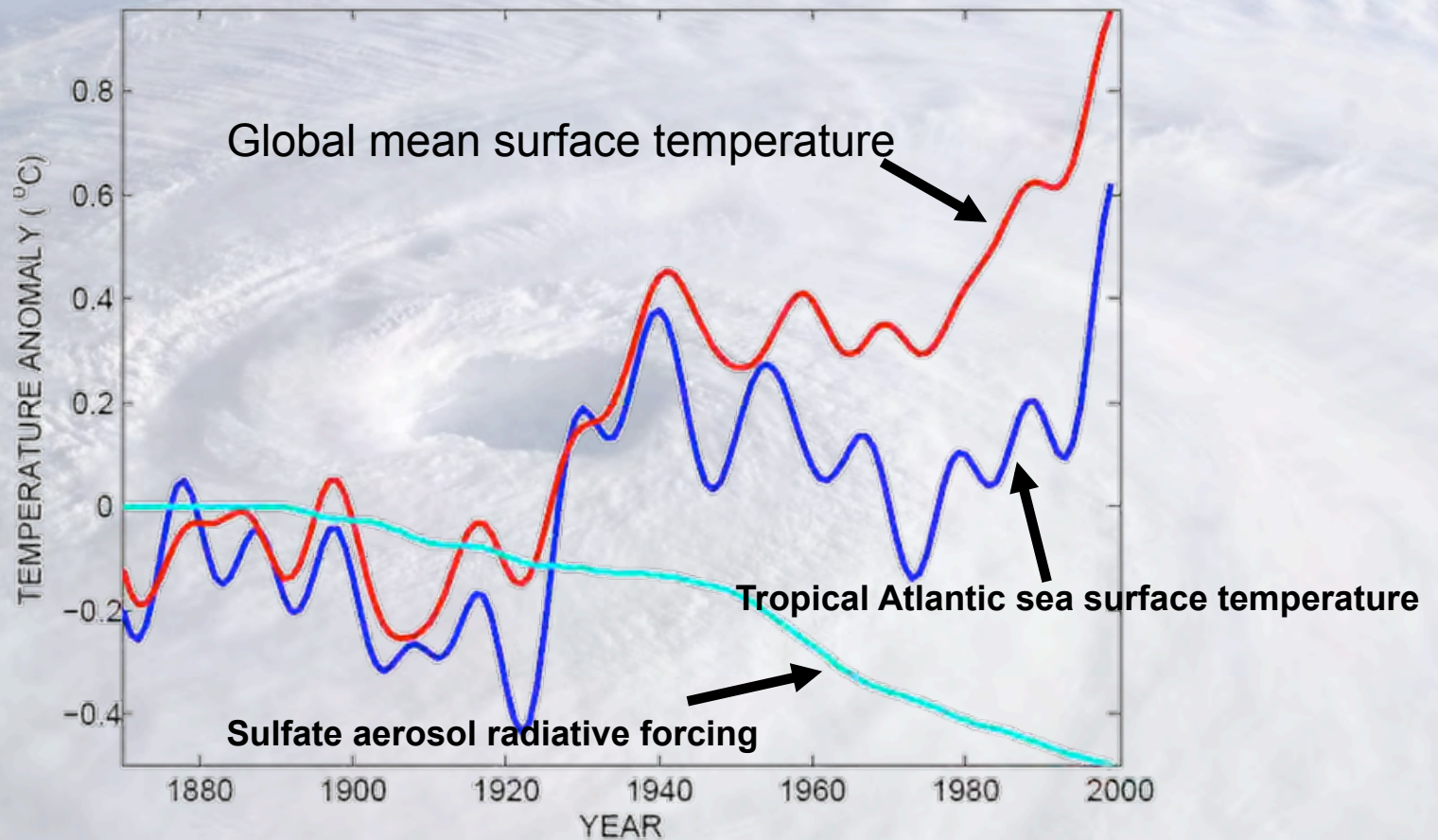
Data Sources: NOAA/TPC, UKMO/HADSST1

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



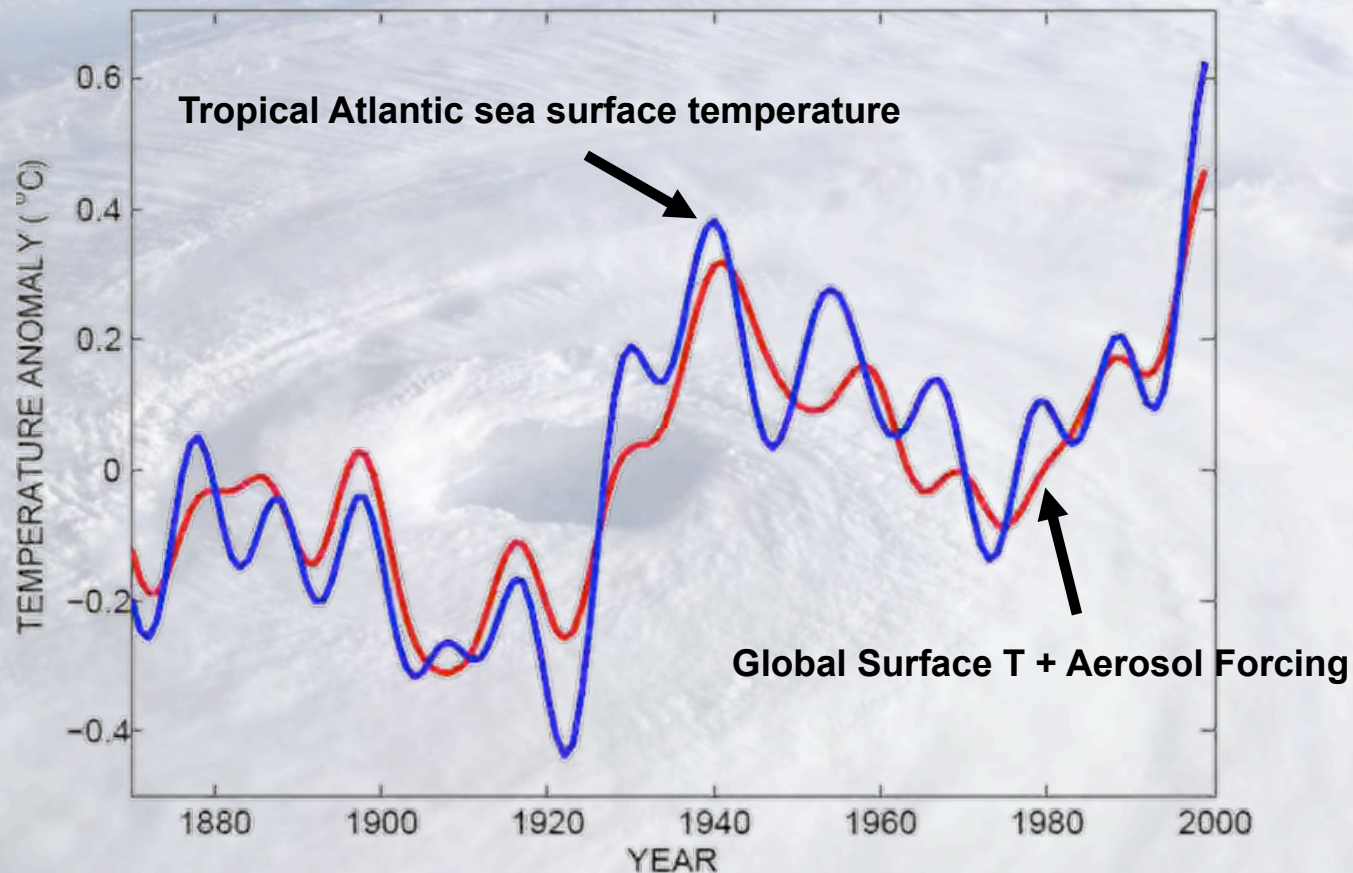


Tropical Atlantic SST(blue), Global Mean Surface Temperature (red), Aerosol Forcing (aqua)



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)

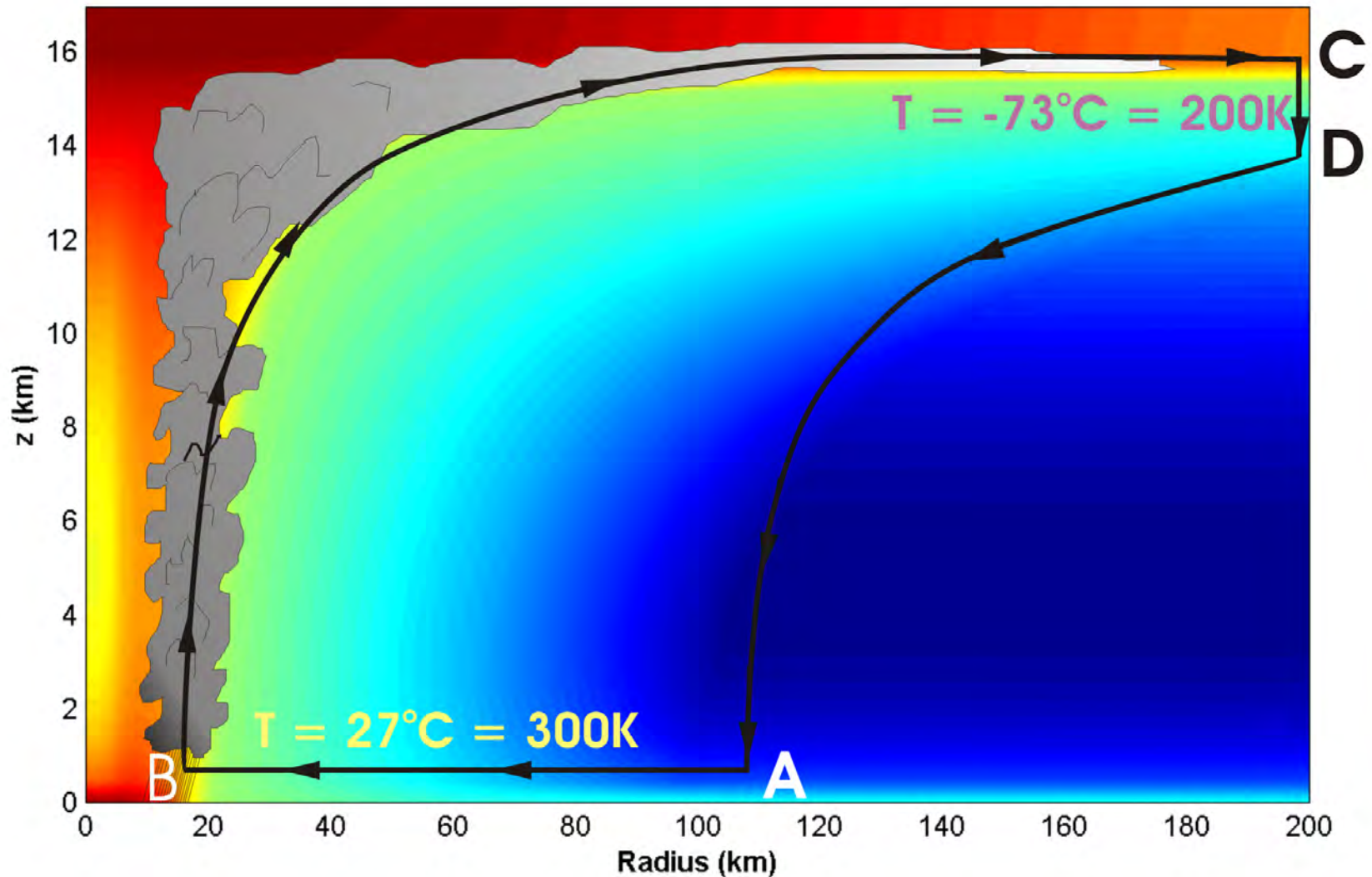


Mann, M. E., and K. A. Emanuel, 2006. Atlantic hurricane trends linked to climate change. EOS, 87, 233-244.

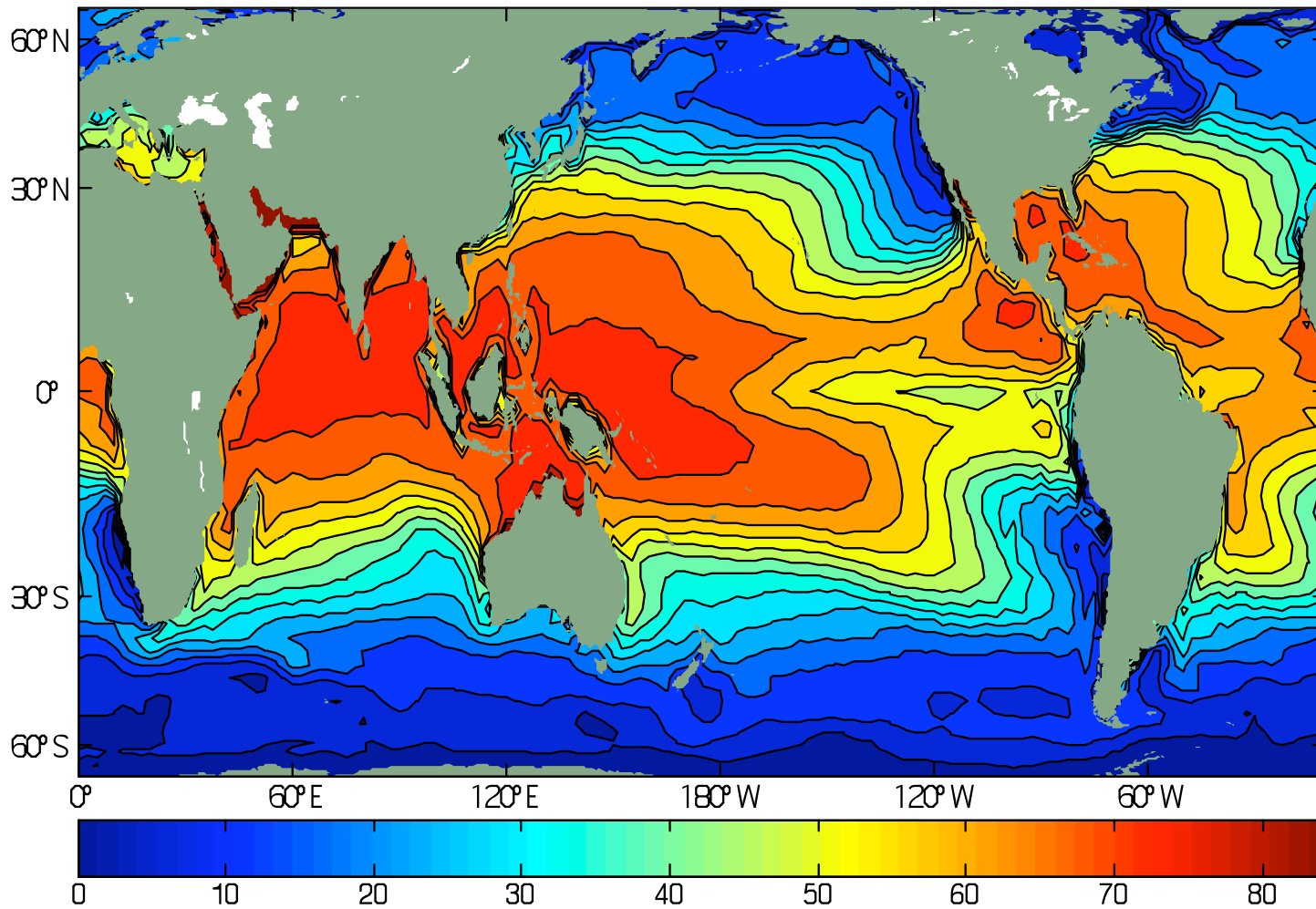
An aerial photograph of a tropical cyclone, showing a well-defined eye and a dense, swirling cloud structure over the ocean. The word "Physics" is overlaid in the center of the image in a bold, blue, sans-serif font. The background shows the curvature of the Earth and the horizon line.

Physics

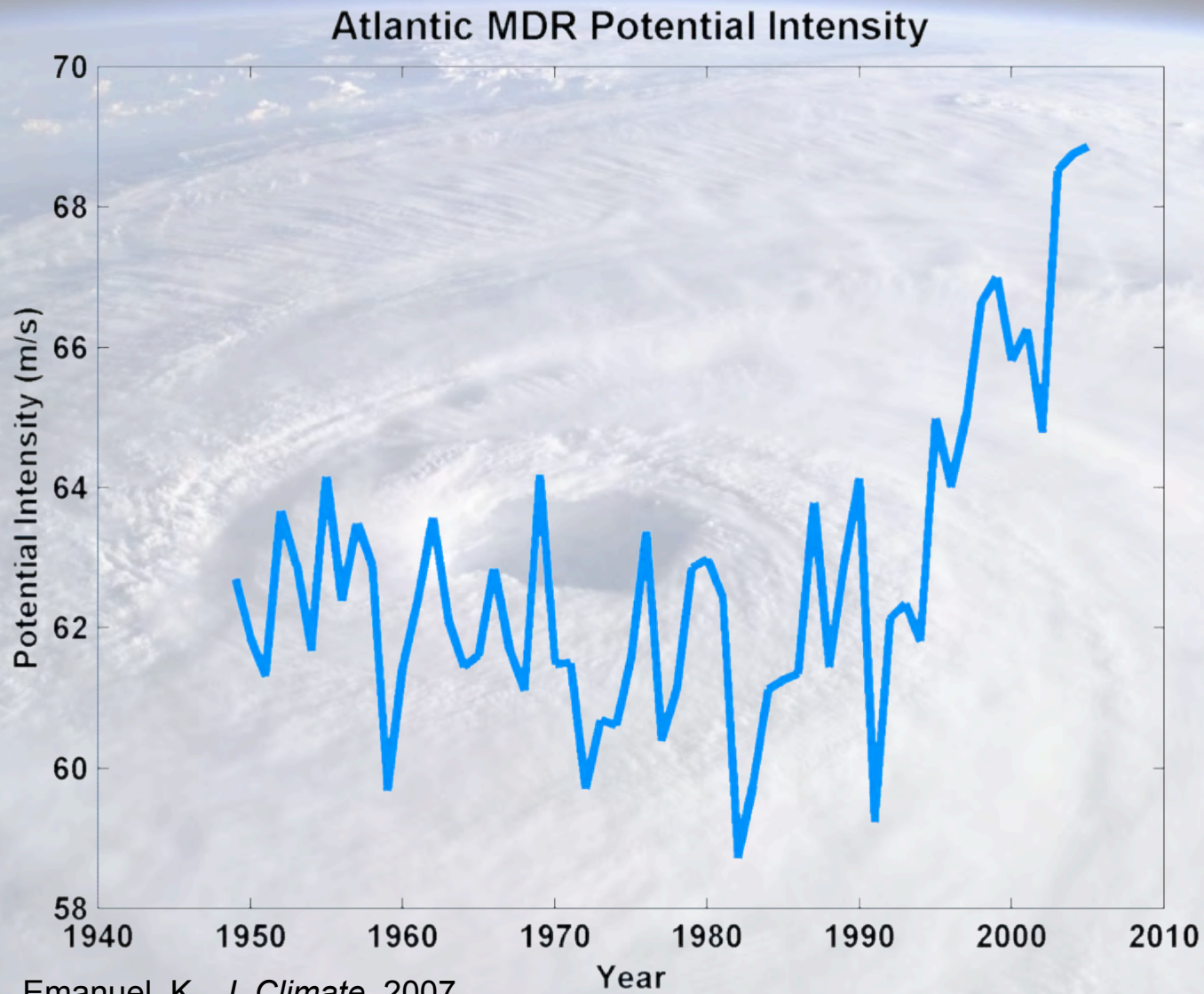
Energy Production: The Hurricane as a Carnot Heat Engine



Annual Maximum Potential Intensity (m/s)



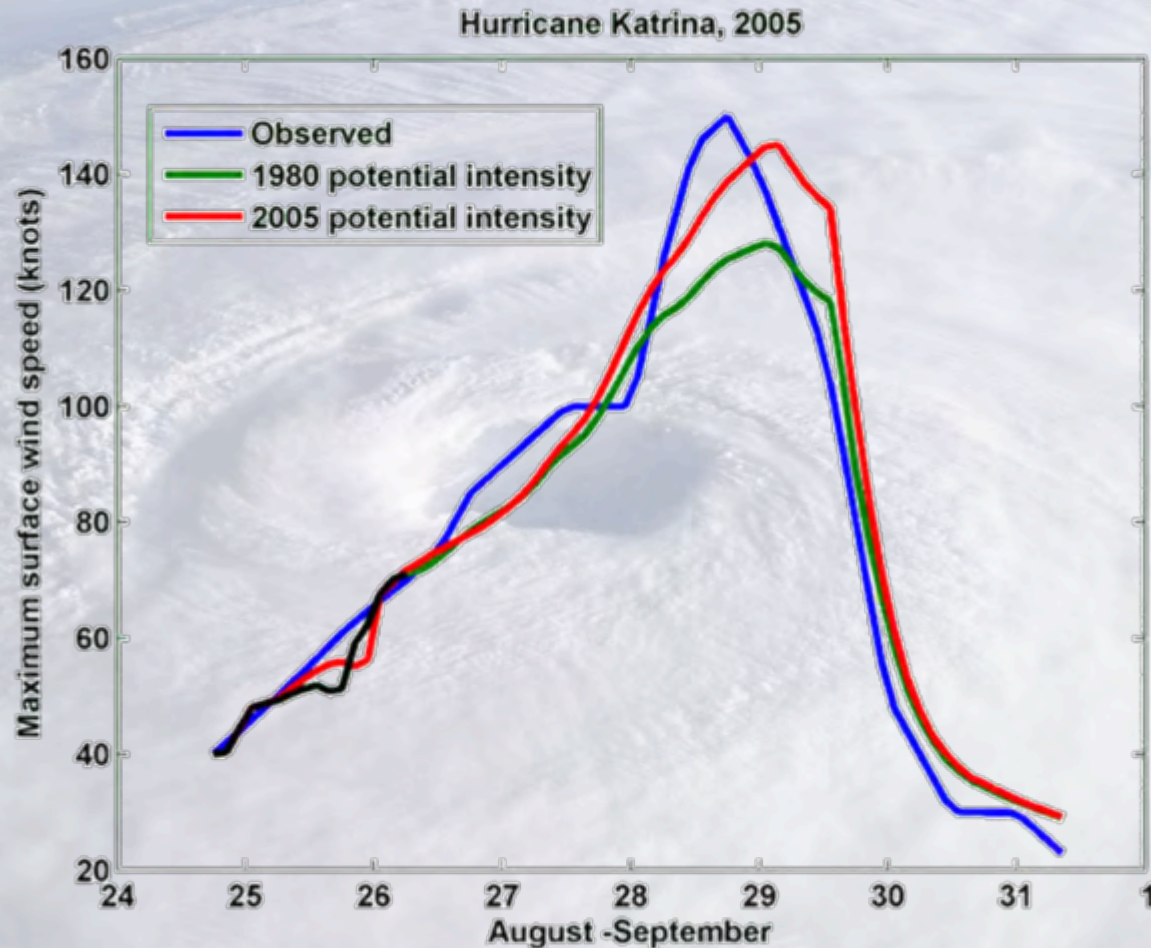
Observed Tropical Atlantic Potential Intensity



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



An aerial photograph of a vast, flat, light-colored landscape, possibly a salt flat or a desert, under a clear sky. The terrain is mostly white and light blue, with some darker patches and textures. The horizon is visible in the distance, and the sky is a pale, clear blue.

Projecting into the Future: Downscaling from Global Climate Models

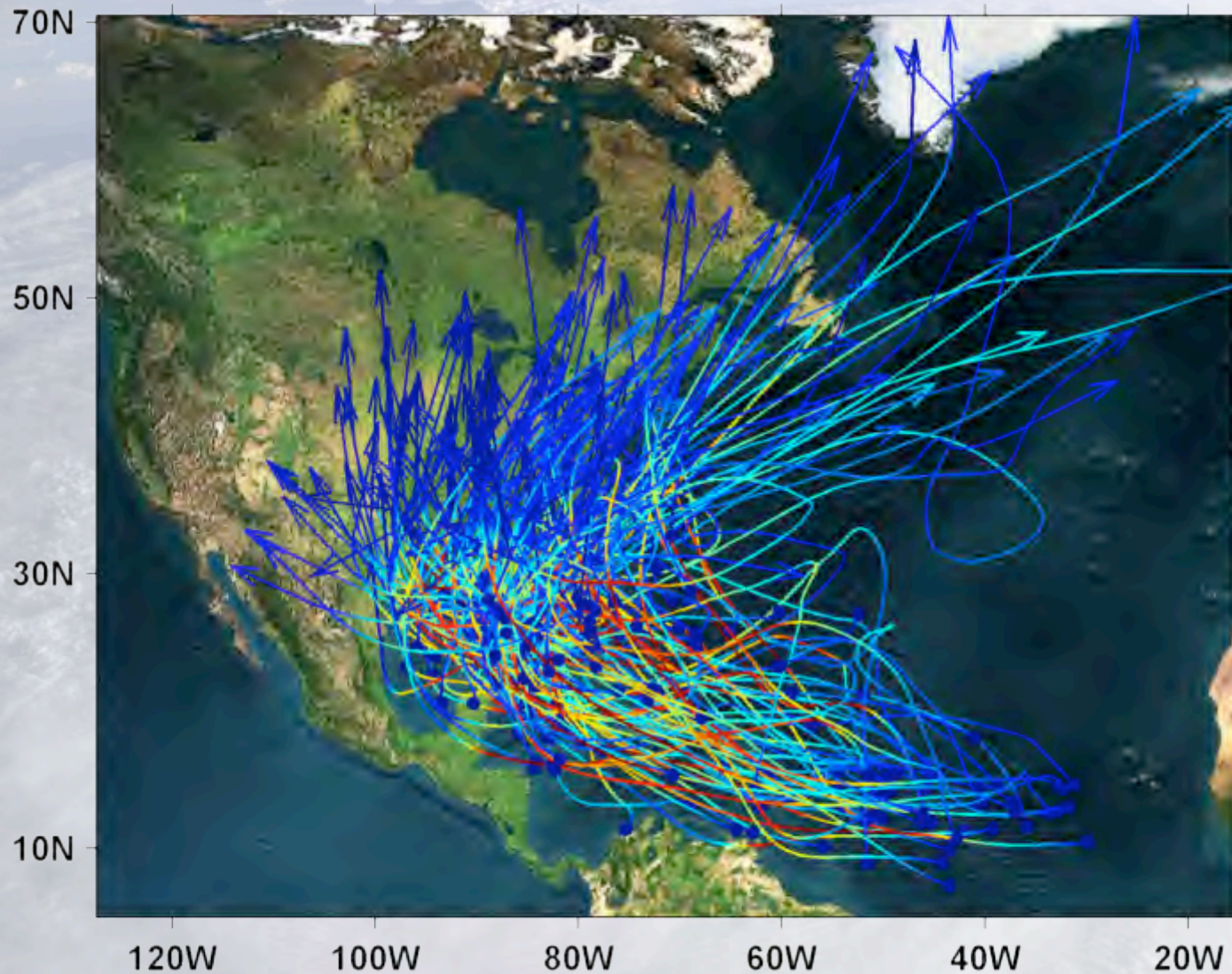
An aerial photograph of a tropical cyclone, showing a well-defined eye and a dense, swirling cloud structure over the ocean. The text is overlaid in the center of the image.

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)

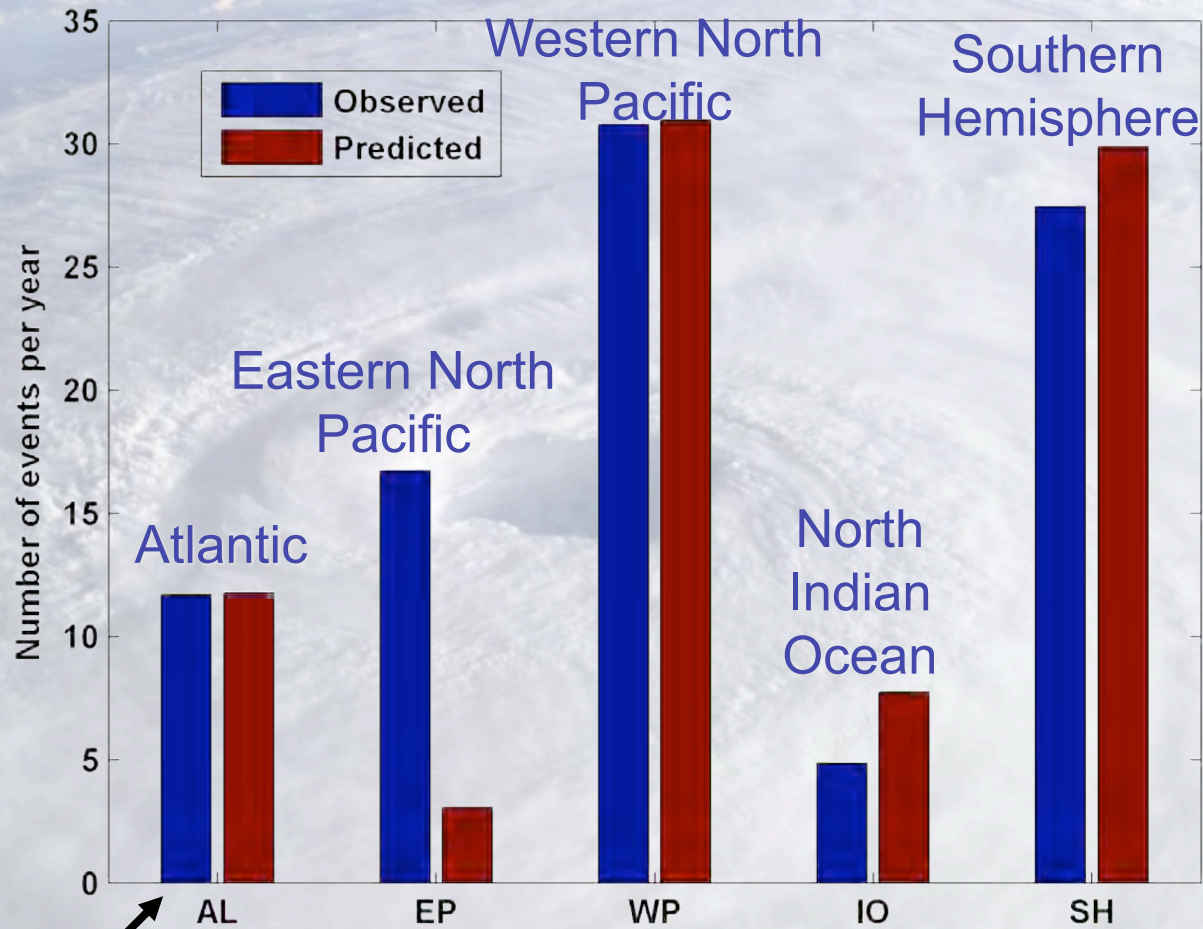


Calibration

A satellite image of the North Atlantic Ocean, showing a large, dark, swirling cyclone in the center. The ocean surface is textured with whitecaps and waves. The horizon of the Earth is visible at the top, with a thin blue line of the atmosphere.

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

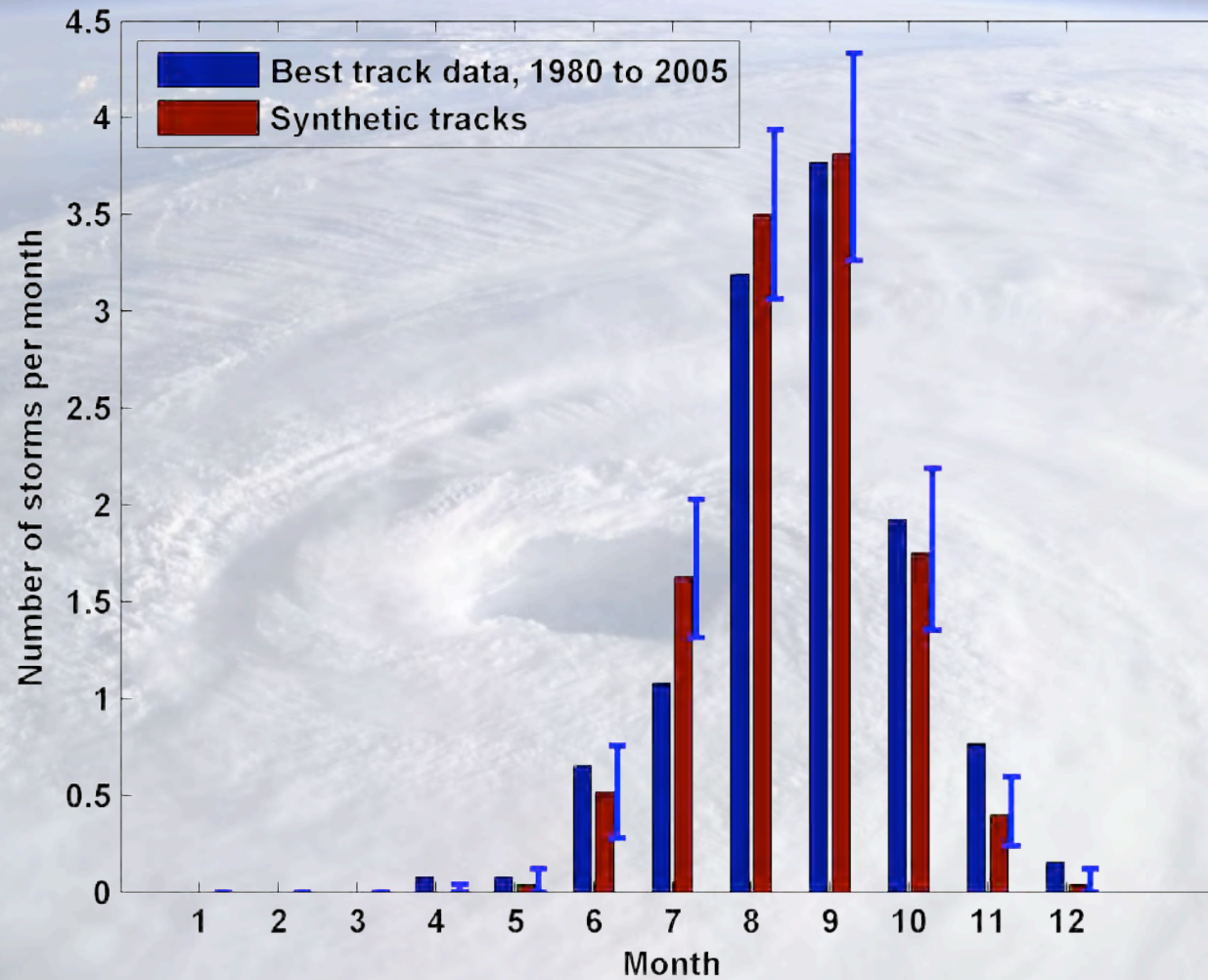
Genesis rates



Calibrated to Atlantic

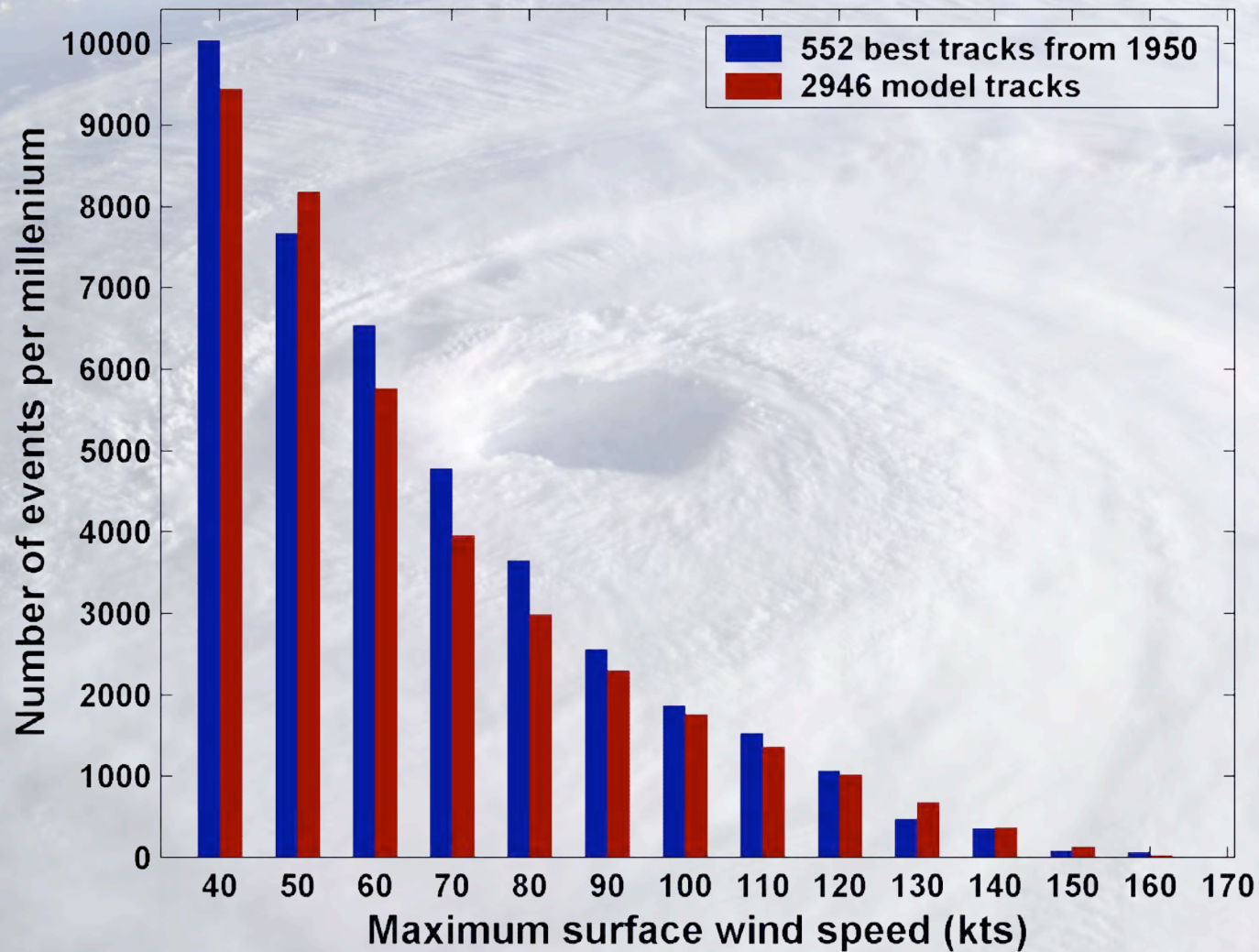
Seasonal Cycles

North Atlantic

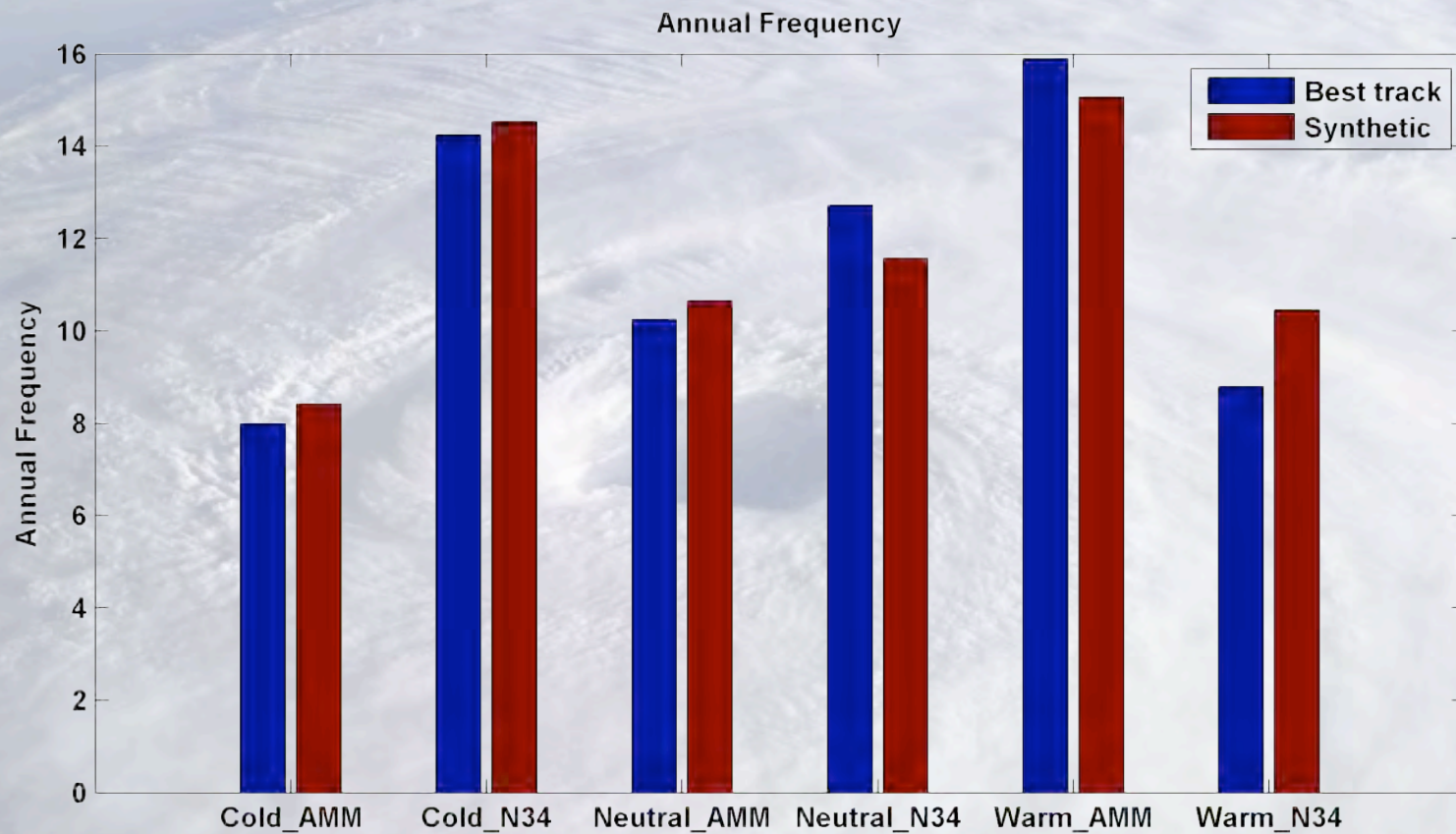


Atlantic

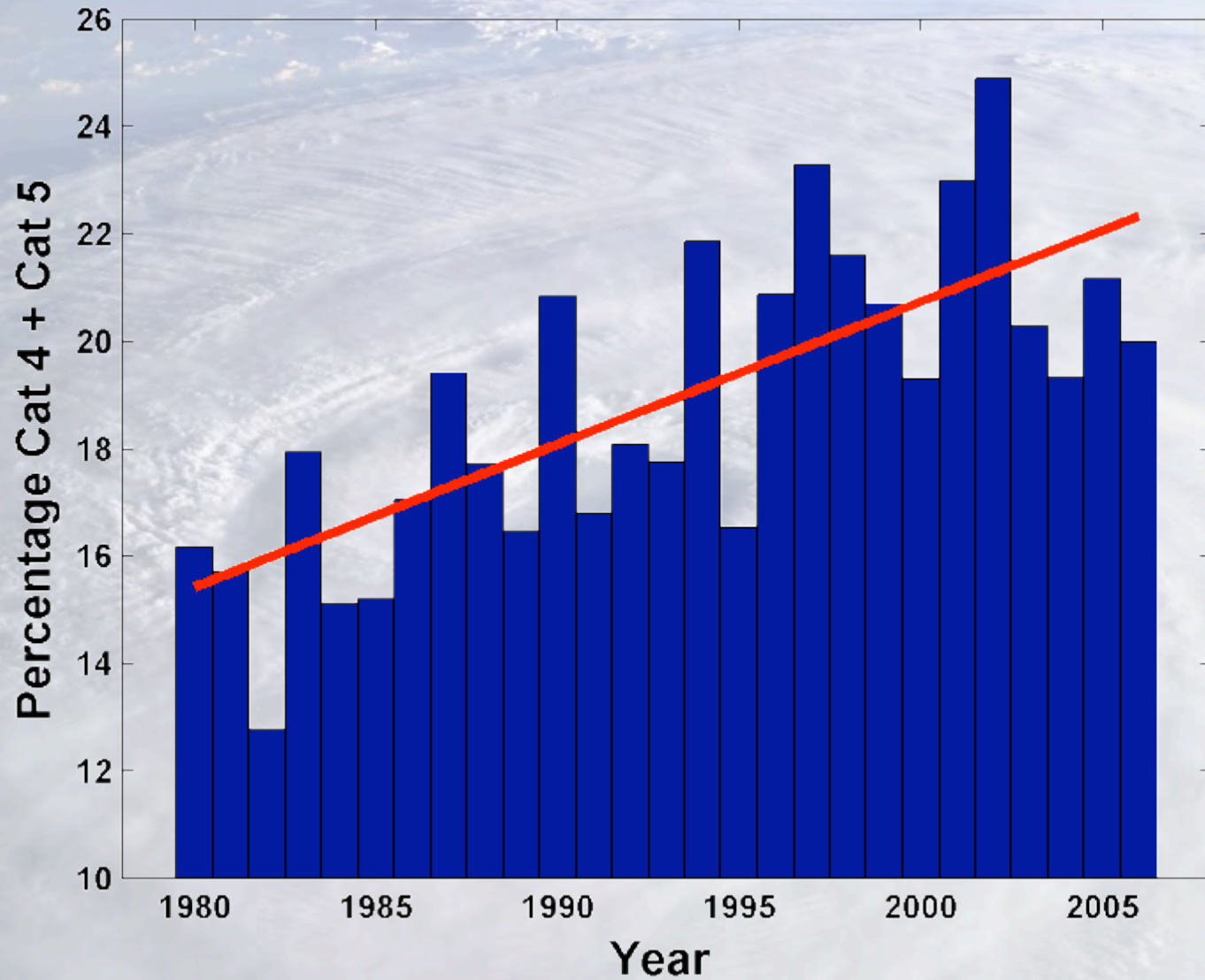
Cumulative Distribution of Storm Lifetime Peak Wind Speed, with Sample of 2946 Synthetic Tracks



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



Global Percentage of Cat 4 & Cat 5 Storms



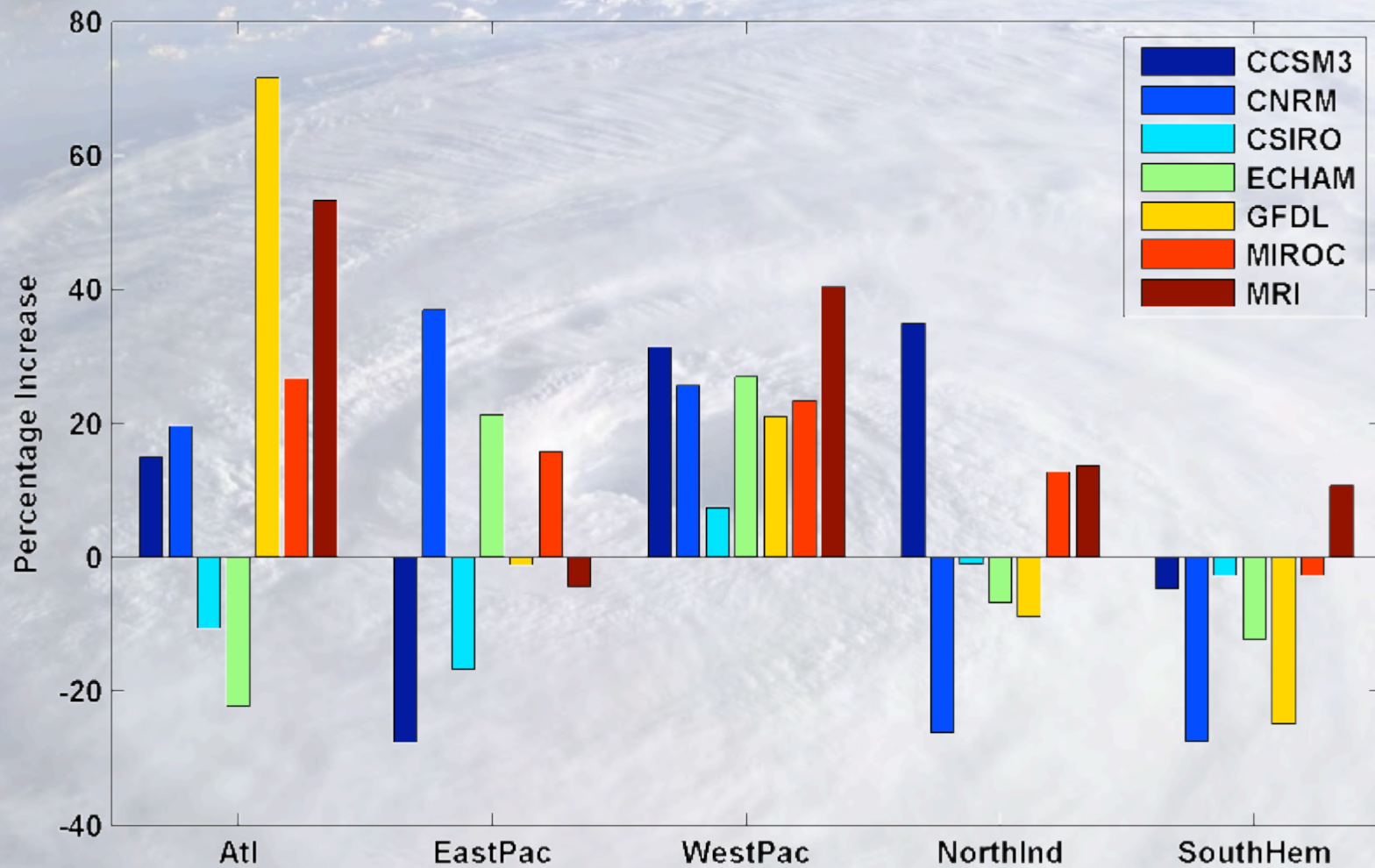
An aerial photograph of a tropical cyclone, showing a well-defined eye and spiral cloud bands over a vast expanse of the ocean. The text is overlaid on the center of the image.

**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:

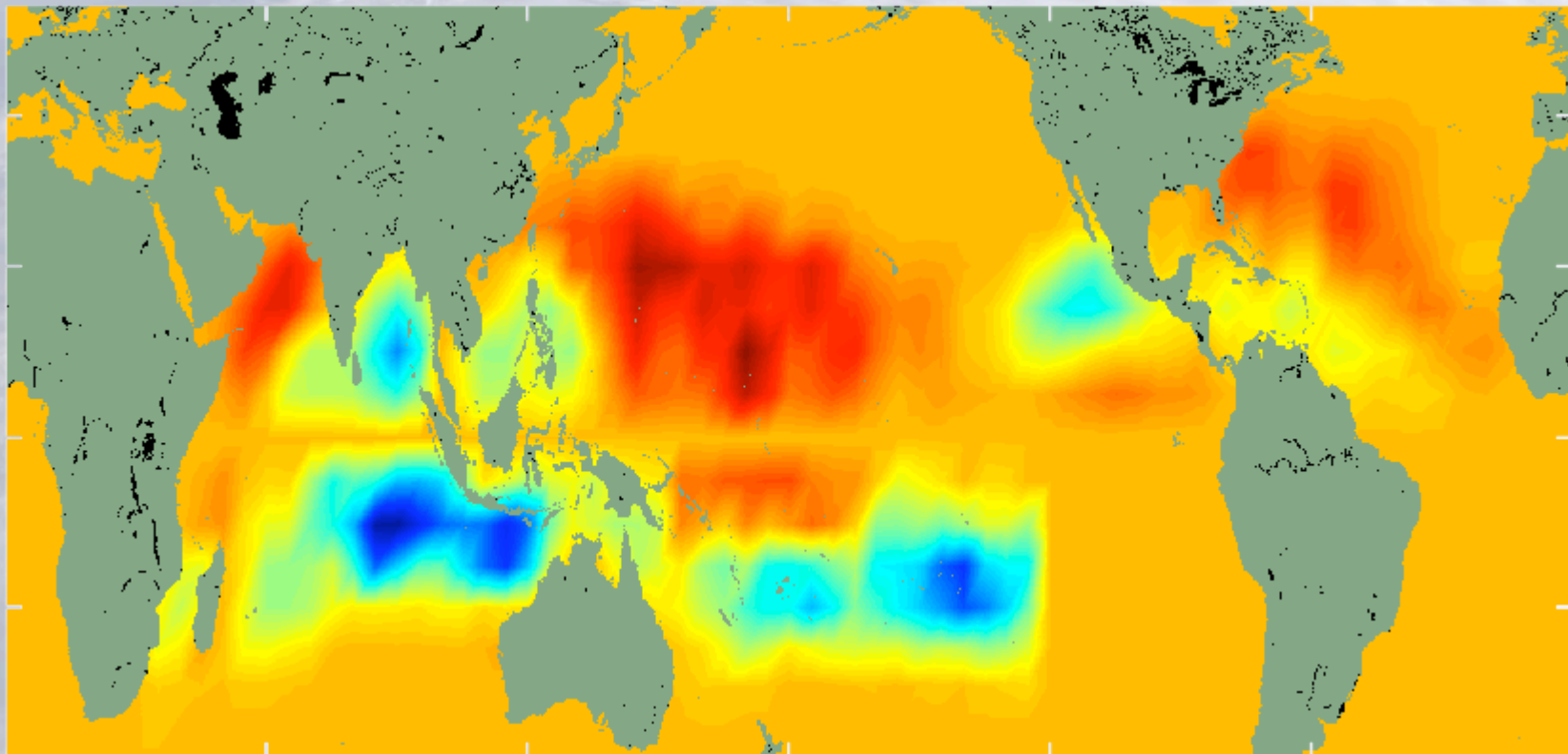
1. Last 20 years of 20th century simulations
2. Years 2180-2200 of IPCC Scenario A1b (CO₂ stabilized at 720 ppm)

Basin-Wide Percentage Change in Power Dissipation

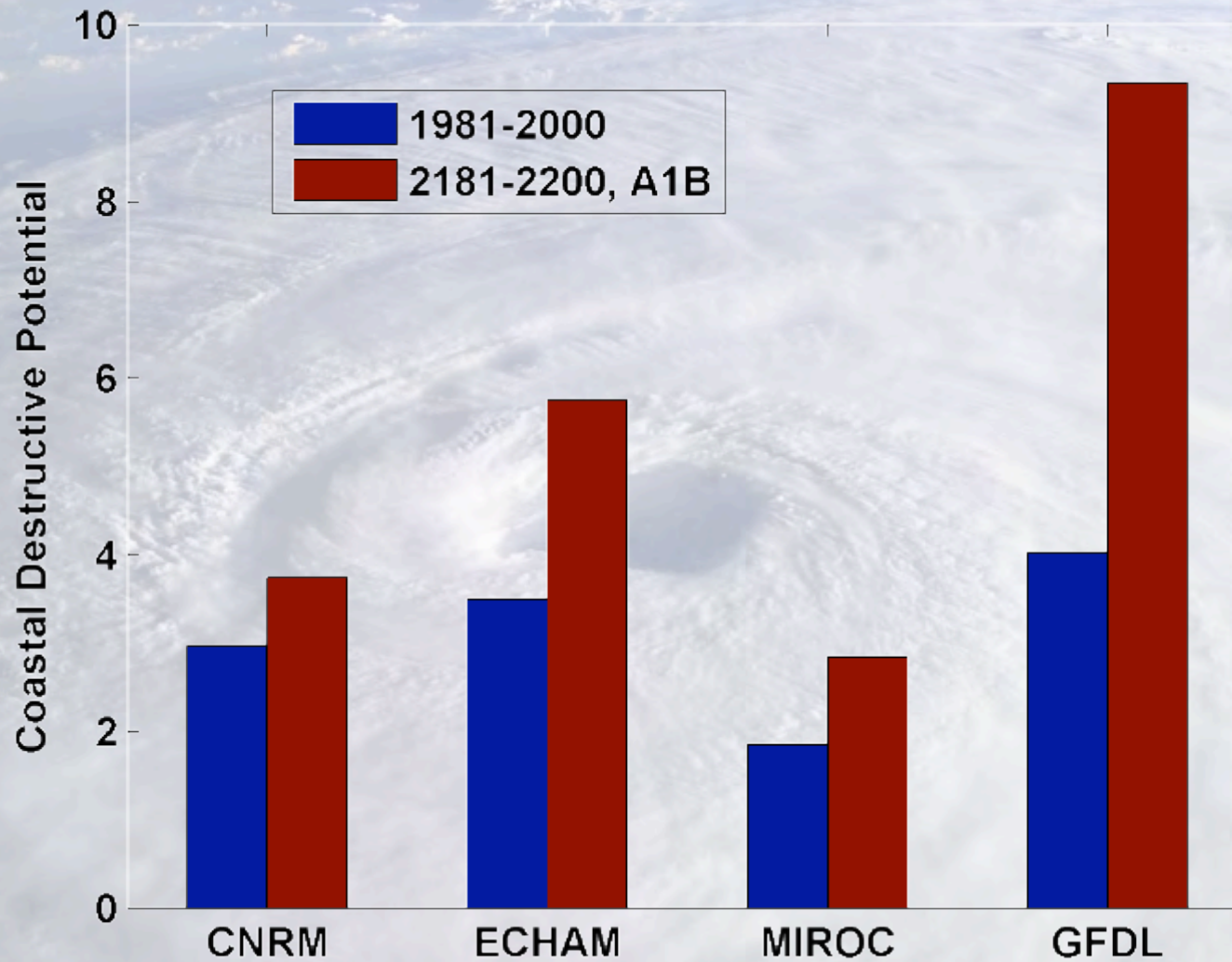


7 Model Consensus Change in Storm Frequency

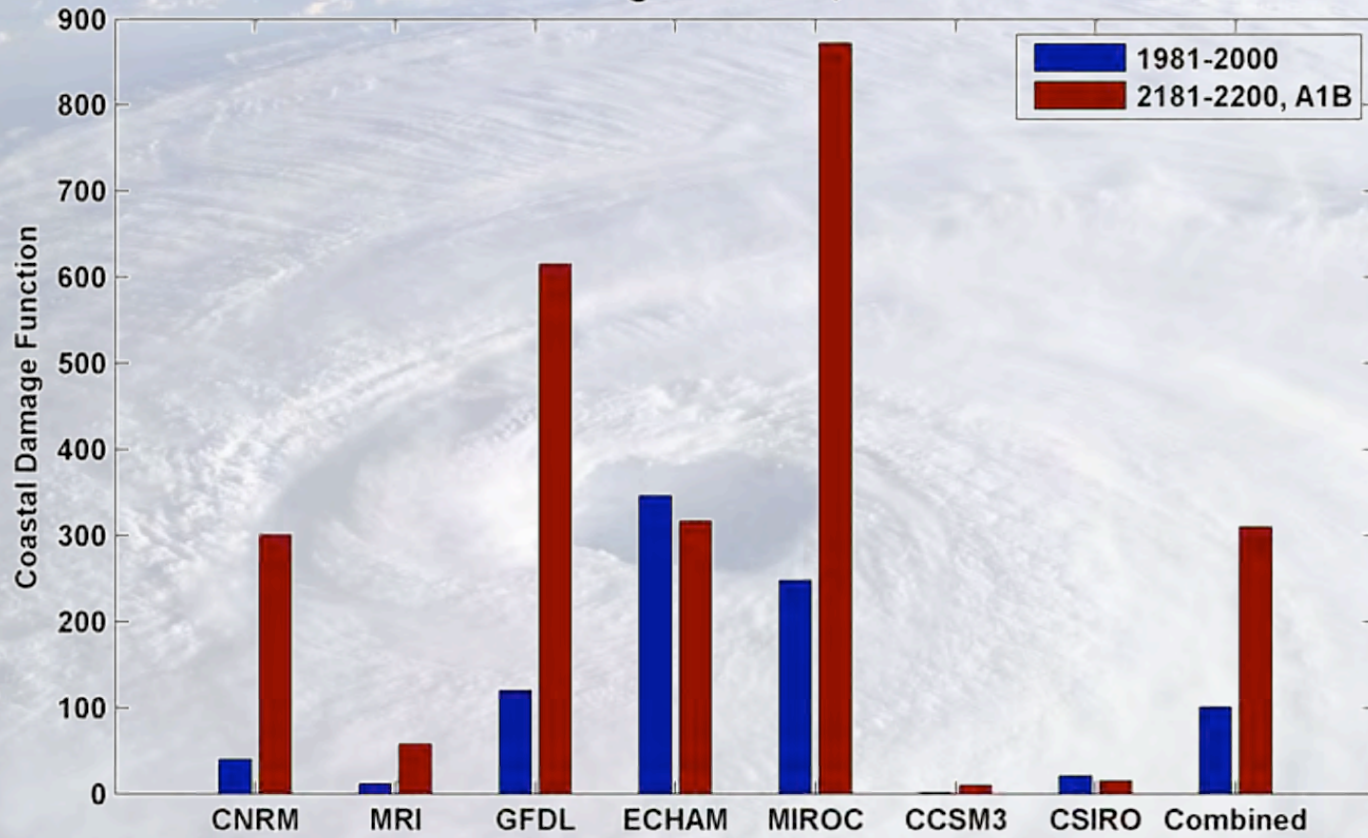
7-Model Consensus Change in Genesis Density



U.S. Coastal Damage Potential

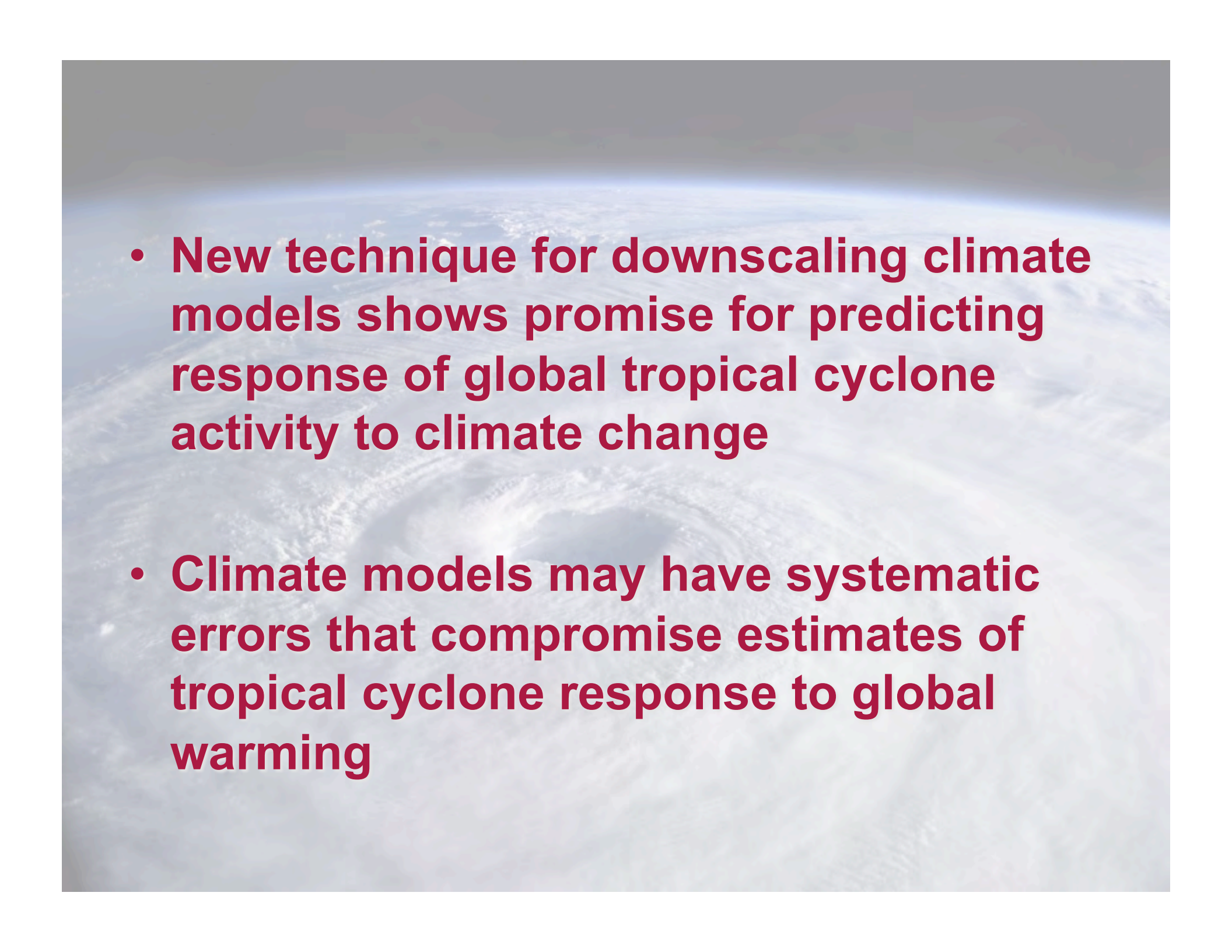


Coastal Damage Function, Northeast U.S.



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**

- 
- A satellite image of a tropical cyclone, showing a distinct eye and spiral cloud bands over the ocean. The image is used as a background for the text.
- **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**