

Stony Brook University

# Applications of High-Resolution Modeling

**Kevin A. Reed**

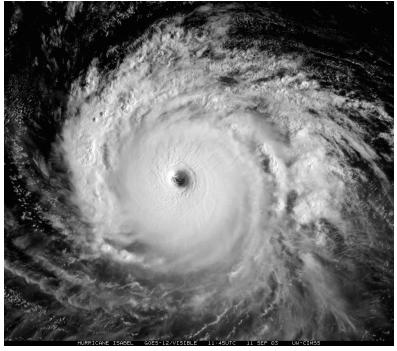
School of Marine and Atmospheric Sciences  
*Stony Brook University, Stony Brook, New York*

***Many Collaborators!***

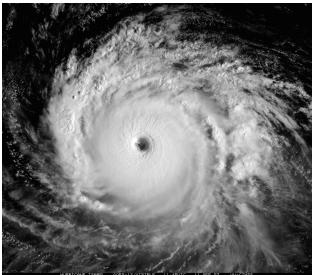


# Initial Points

1. We are entering an era where **climate models** are approaching **weather scales**.
2. High-resolution (< 30 km) global climate modeling will greatly improve our ability to model **multi-scale phenomena** and to project **regional impacts** of climate change.
3. Together, this can (*will?*) have many applications to other **scientific disciplines** and **local communities**.

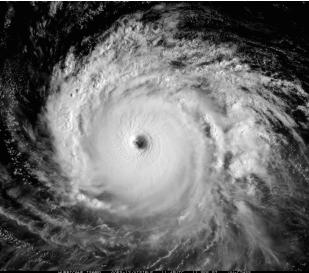


# Introduction/Motivation



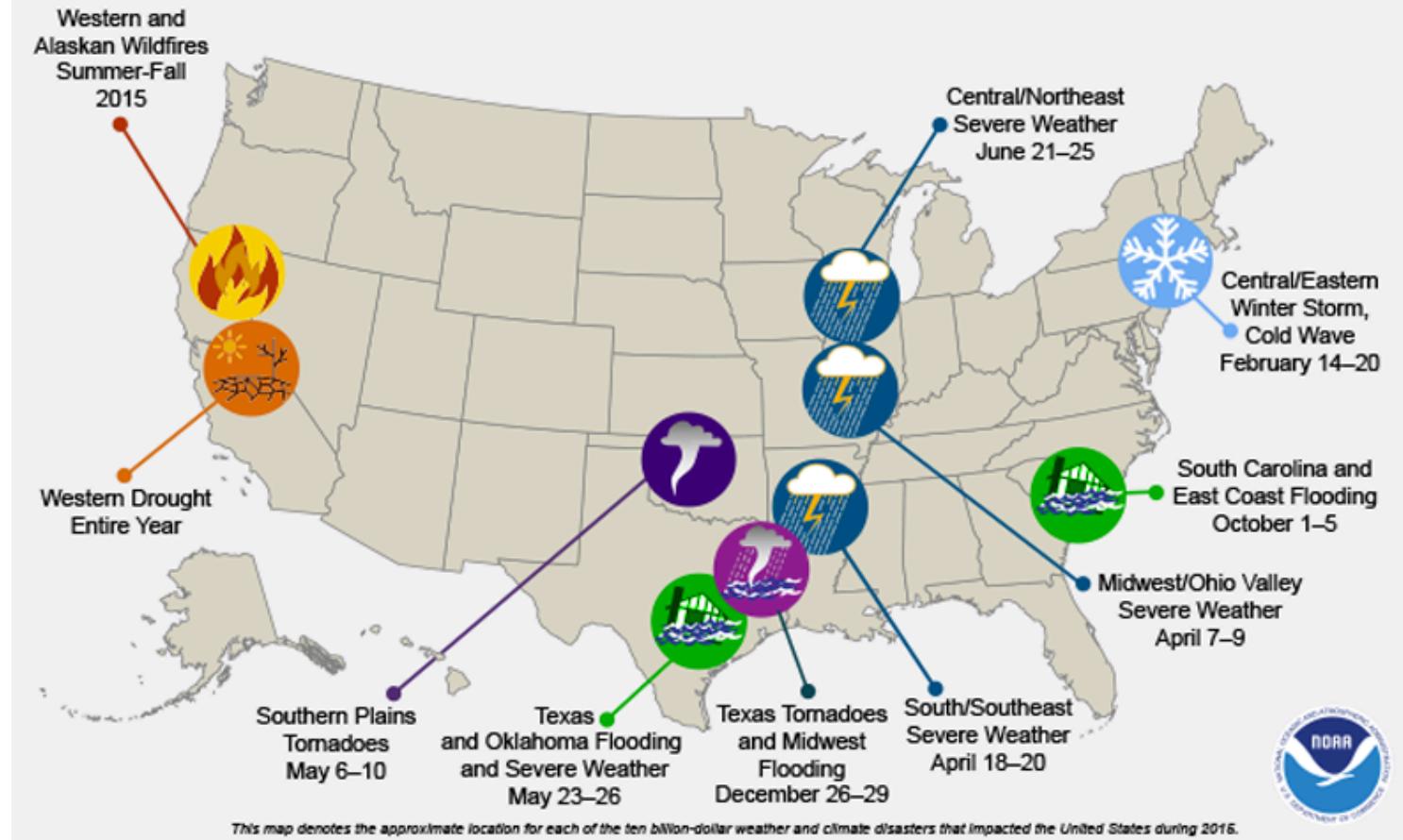
# Extreme Weather

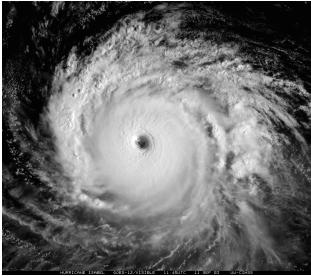




# Extreme Weather Impacts

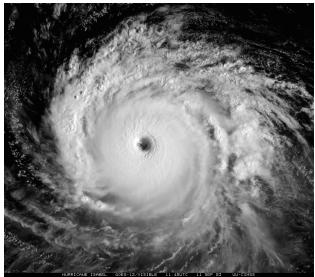
## U.S. 2015 Billion-Dollar Weather and Climate Disasters





# Example: Tropical Cyclones

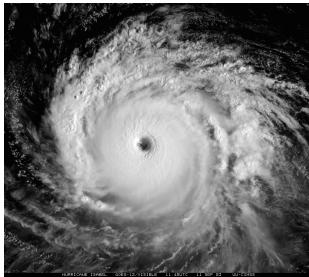
- Tropical Cyclones (TCs) are:
  - extreme atmospheric vortices.
  - develop over the warm tropical oceans.
  - an important component of the Earth system, as they transport large amounts of energy and moisture from the tropics towards the poles.
  - among the most destructive and lethal geophysical phenomena.
- In the United States, hurricanes are the costliest of all natural disasters.
- In 2004 and 2005 hurricane seasons caused over \$150 billion in damages in the U.S. alone.
- Hurricane Sandy in 2012 cost U.S. over \$70 billion alone!



# Numerical Modeling

## U.S. National Climate Assessment:

*“Changes in extreme weather events are the primary way that most people experience climate change. Human-induced climate change has already increased the number and strength of some of these extreme events. Over the last 50 years, much of the United States has seen an increase in prolonged periods of excessively high temperatures, more heavy downpours, and in some regions, more severe droughts.”*

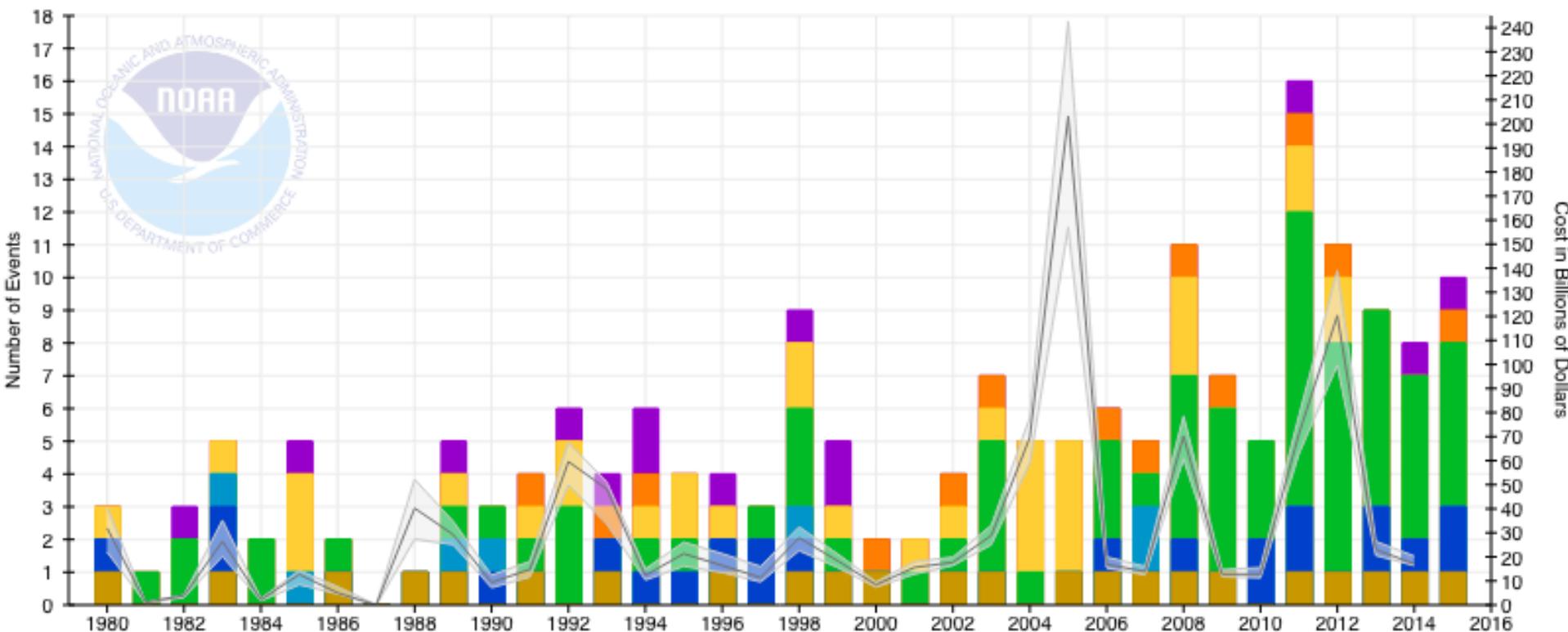


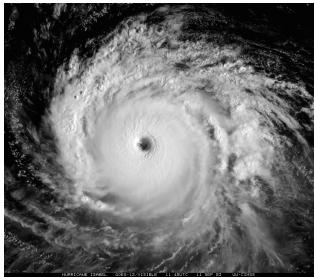
# Changing?

Billion-Dollar Disaster Event Types by Year (CPI-Adjusted)

Legend:

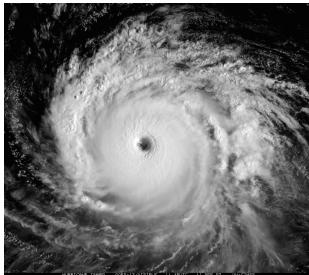
- Winter Storm
- Wildfire
- Trop Cycl
- Severe Storm
- Freeze
- Flooding
- Drought
- Cost w/ 95% CI



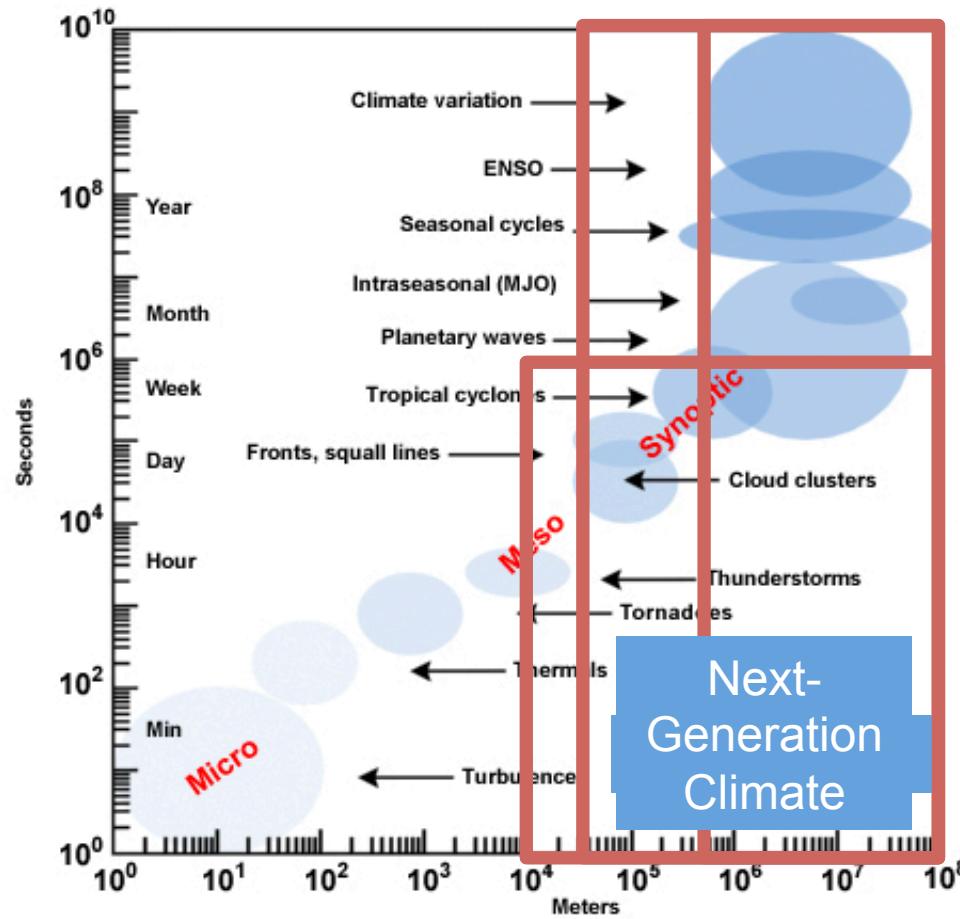


# Numerical Modeling

- Numerical modeling of extreme weather in General Circulation Models (GCMs) presents several challenges:
  - Model resolution
  - Parameterizations (subgrid-scale processes)
- However GCMs are still capable of generating extreme events (e.g., tropical cyclones), but their intensities are generally weaker than observed.



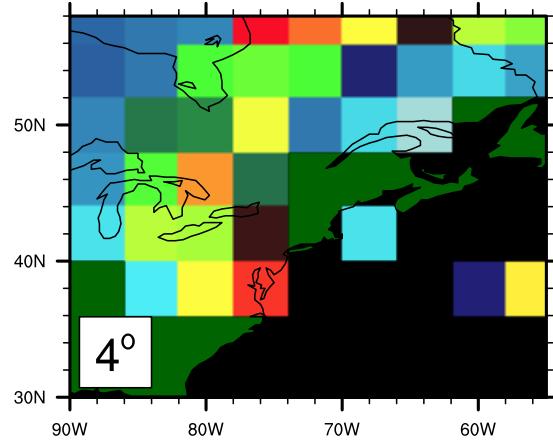
# Numerical Modeling



©The COMET Program



# Spatial Scale of Sandy

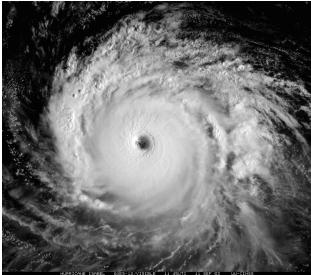


Resolution ↑, better representation of:

- Extreme weather events
- Land-surface processes
- Topography
- Atm/ocn/ice/lnd interfaces
- Chemical emission/transport/reactions/removal

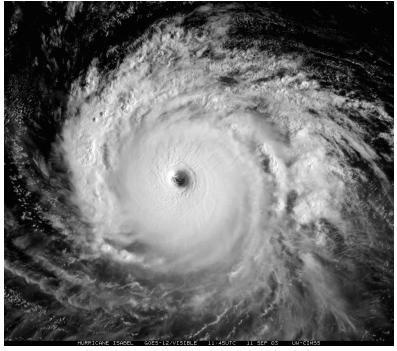
OLR (W/m<sup>2</sup>)

130 137 144 151 158 165 172 179 186 193 200 207 214 221 228 235 242

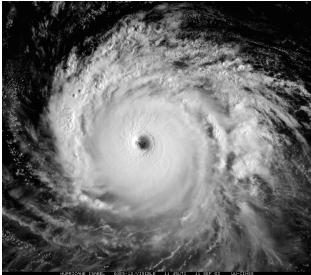


# General Design of Simulations

- National Center for Atmospheric Research's (NCAR) Community Atmosphere Model version 5 (CAM 5).
- General, two dynamical core options, **FV** or **SE** with 30 vertical levels is used at the **horizontal resolutions** of:
  - $\Delta x = 1.0^\circ$ ; ne=30; ~100 km
  - $\Delta x = 0.25^\circ$ ; ne=120; ~25 km
- Full physics with Atmospheric Model Intercomparison Project (**AMIP**) protocols for 1980-2005.
- In addition, **future warming** scenarios for 2070-2009.
- Prescribed observed SSTs, ozone, CO<sub>2</sub>, solar forcing, etc.

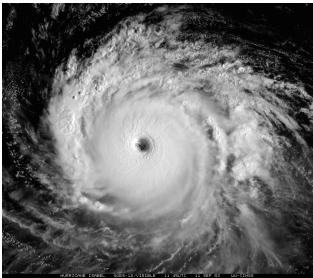


# Recent Climate - Precipitation

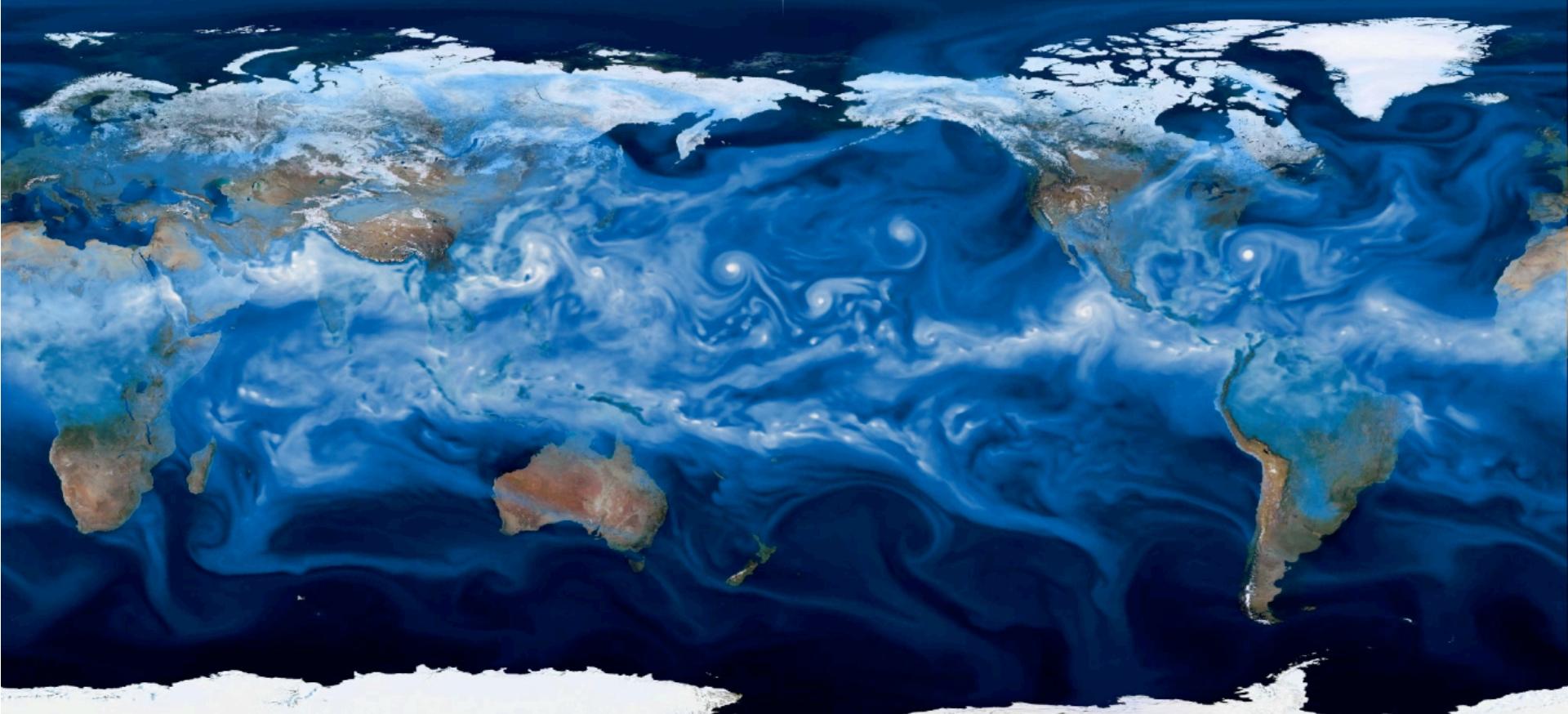


# Design of Decadal Experiments

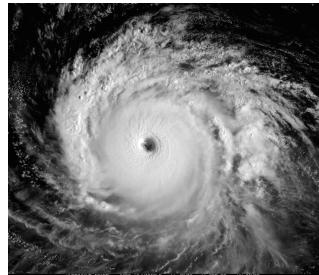
- National Center for Atmospheric Research's (NCAR) Community Atmosphere Model version 5.1 (CAM 5.1).
- The default **FV** dynamical cores with 30 vertical levels is used at the **horizontal resolutions** of:
  - ~200 km
  - ~100 km
  - ~25 km
- Full CAM 5.1 physics with Atmospheric Model Intercomparison Project (**AMIP**) protocols (with prescribed aerosol forcing).
- Observed ozone, CO<sub>2</sub>, solar forcing, etc.



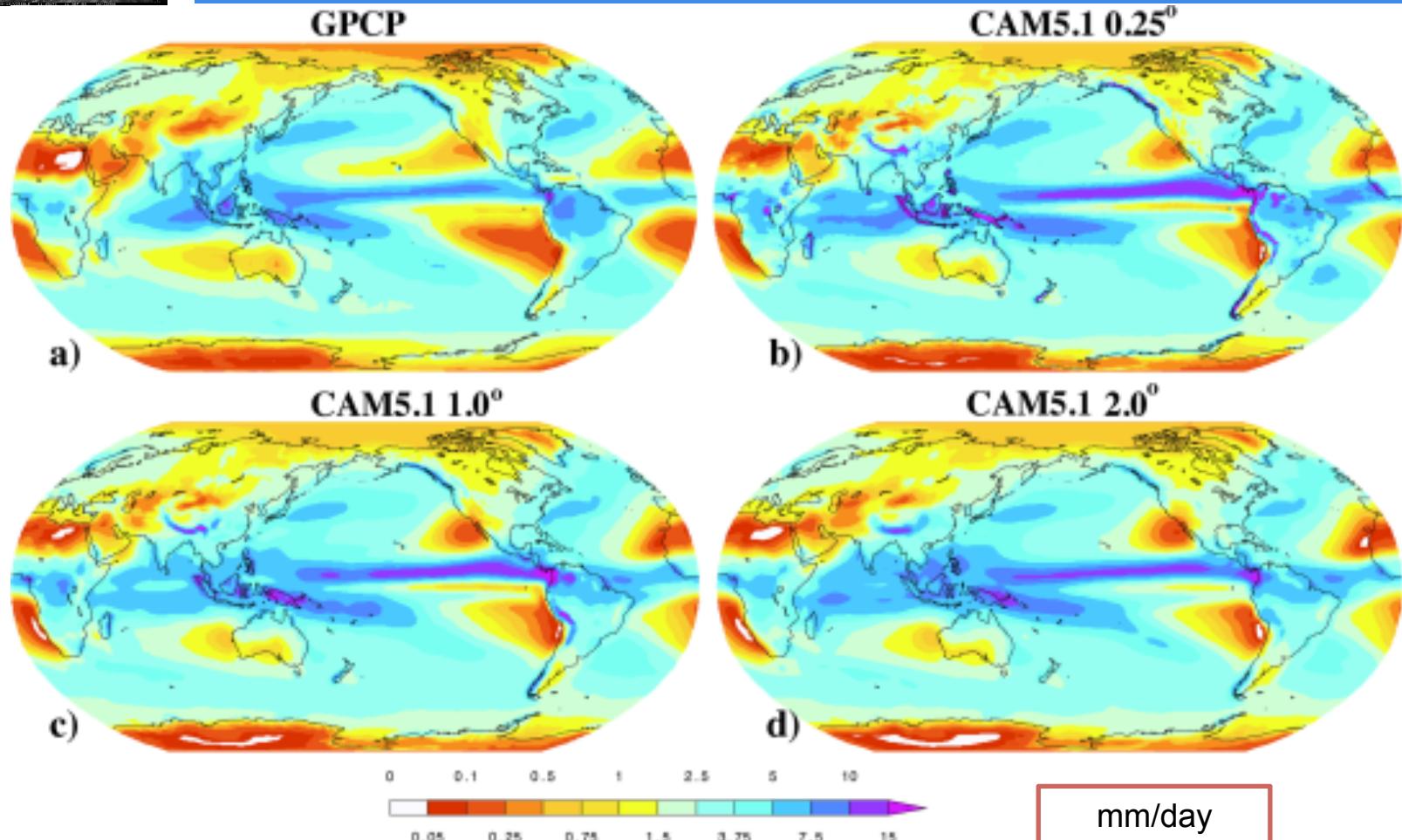
# What Does High-Resolution Provide Us?



<https://www.youtube.com/watch?v=cNyftYdjt-Q>



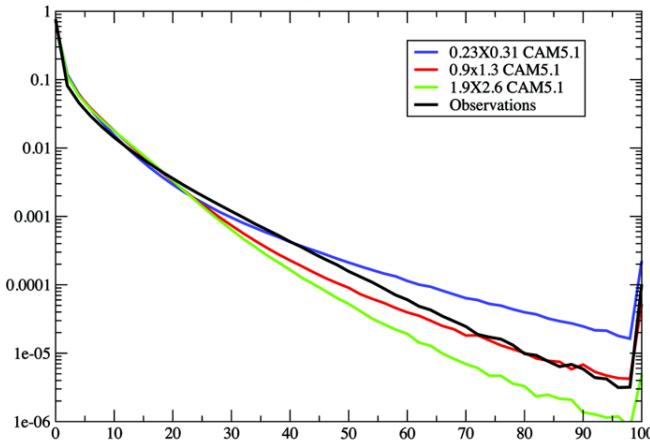
# Annual Mean Precipitation



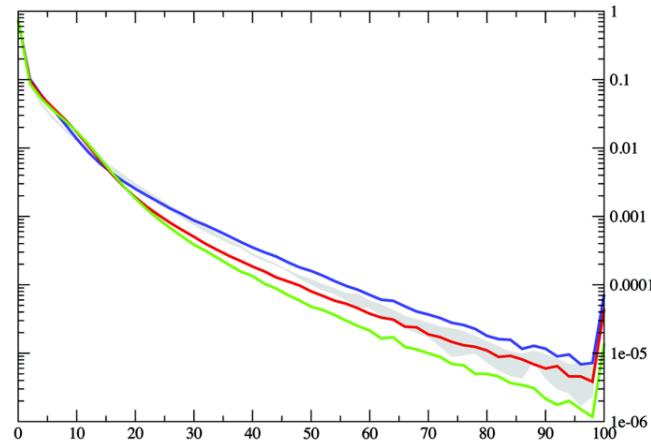


# Precipitation Distribution

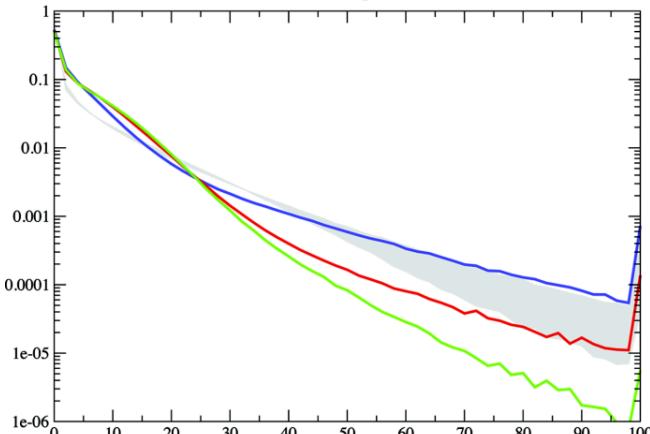
(a) Global



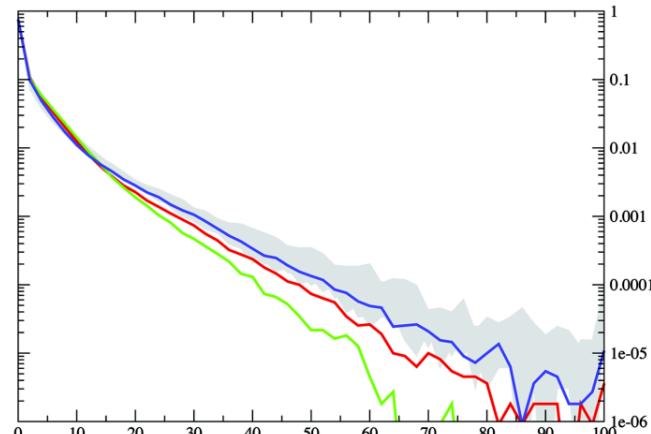
(b) Global Land



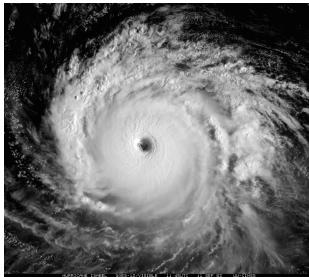
(c) Tropics



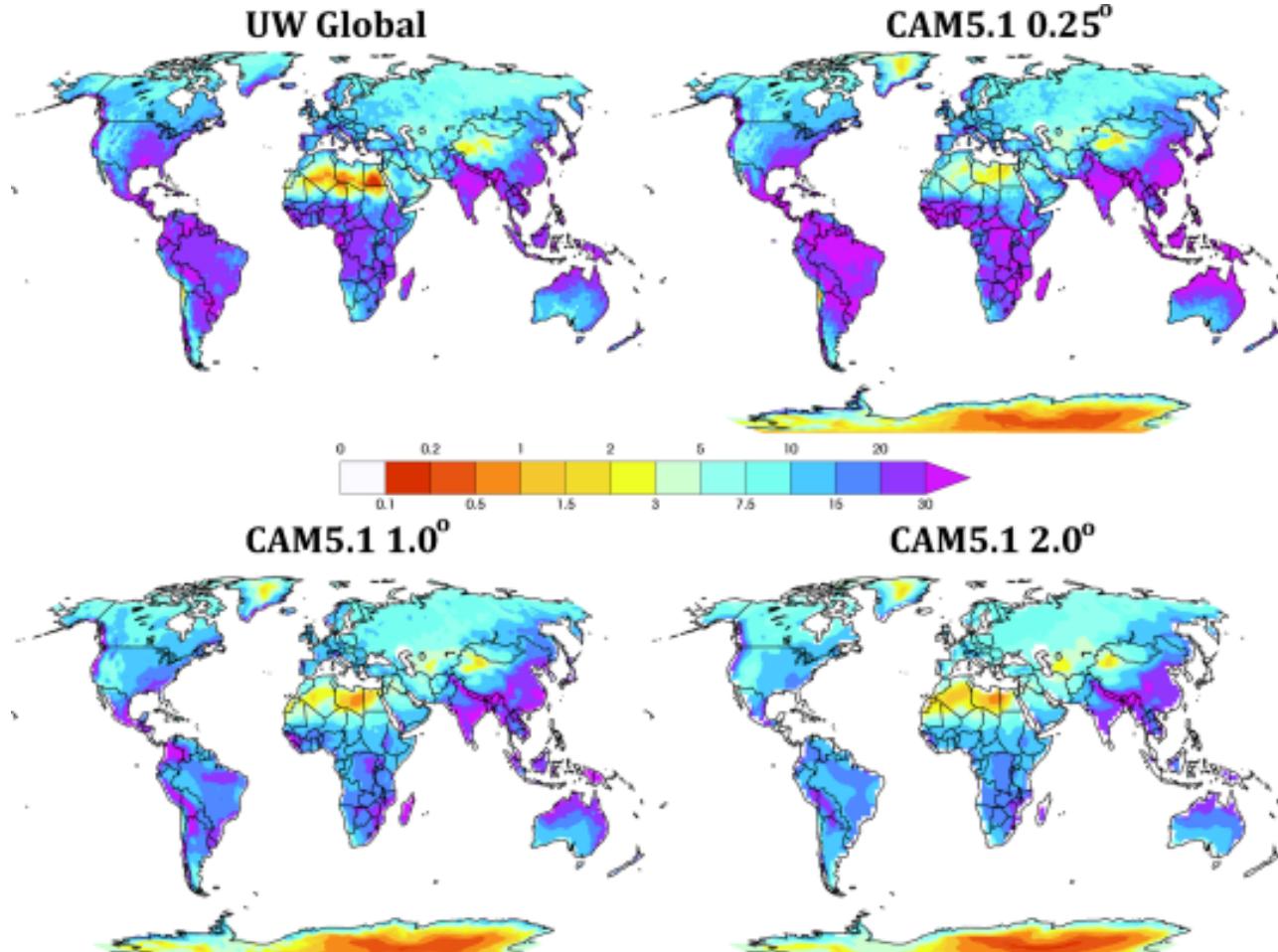
(d) CONUS



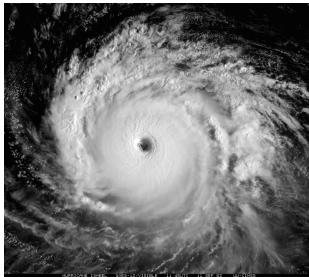
mm/day



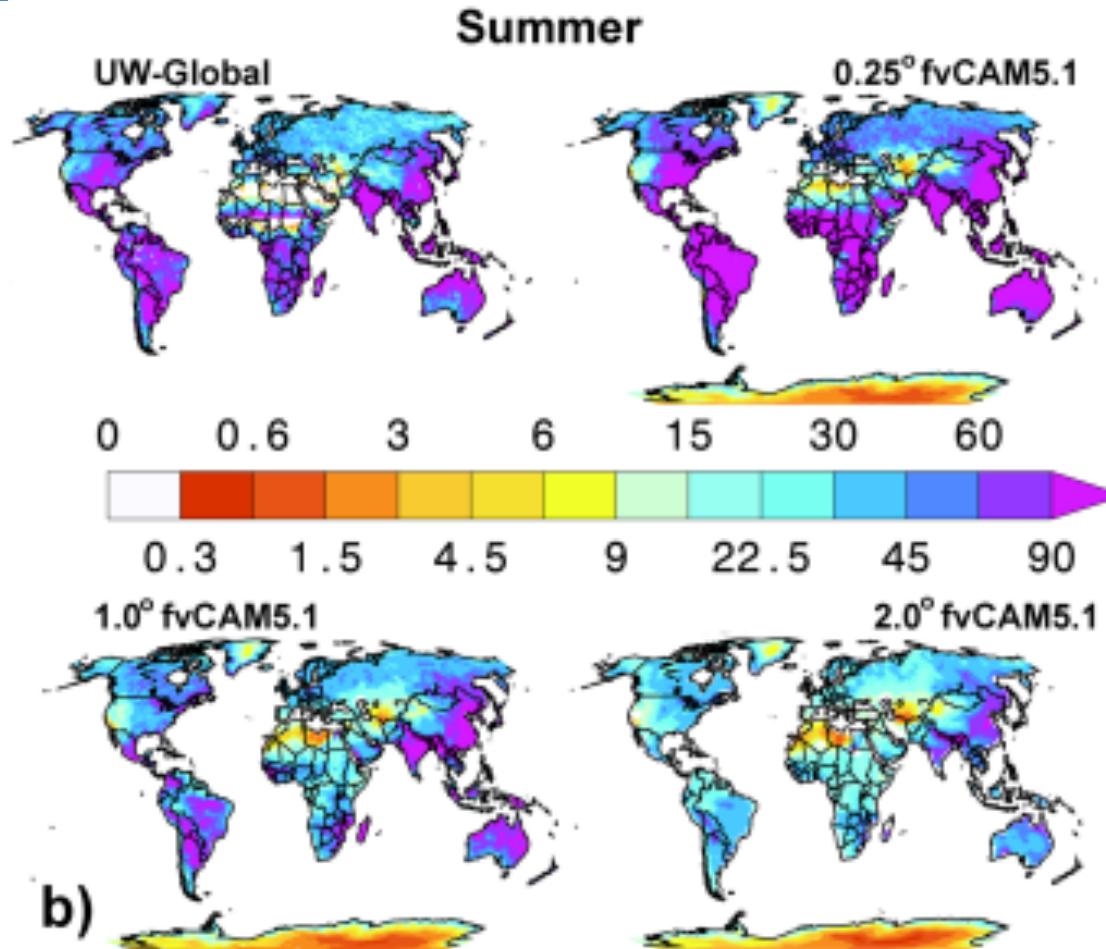
# Annual Maximum 5 day Accumulated Precipitation



mm/day

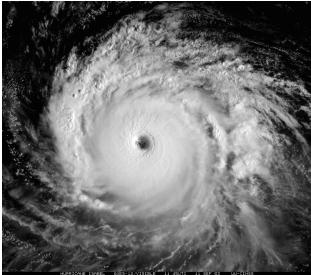


# 20 Year Return Value



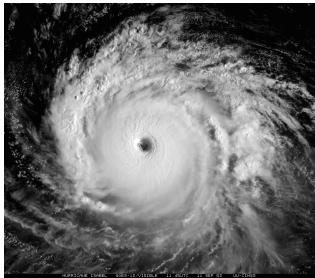


# Recent Climate - Hurricanes

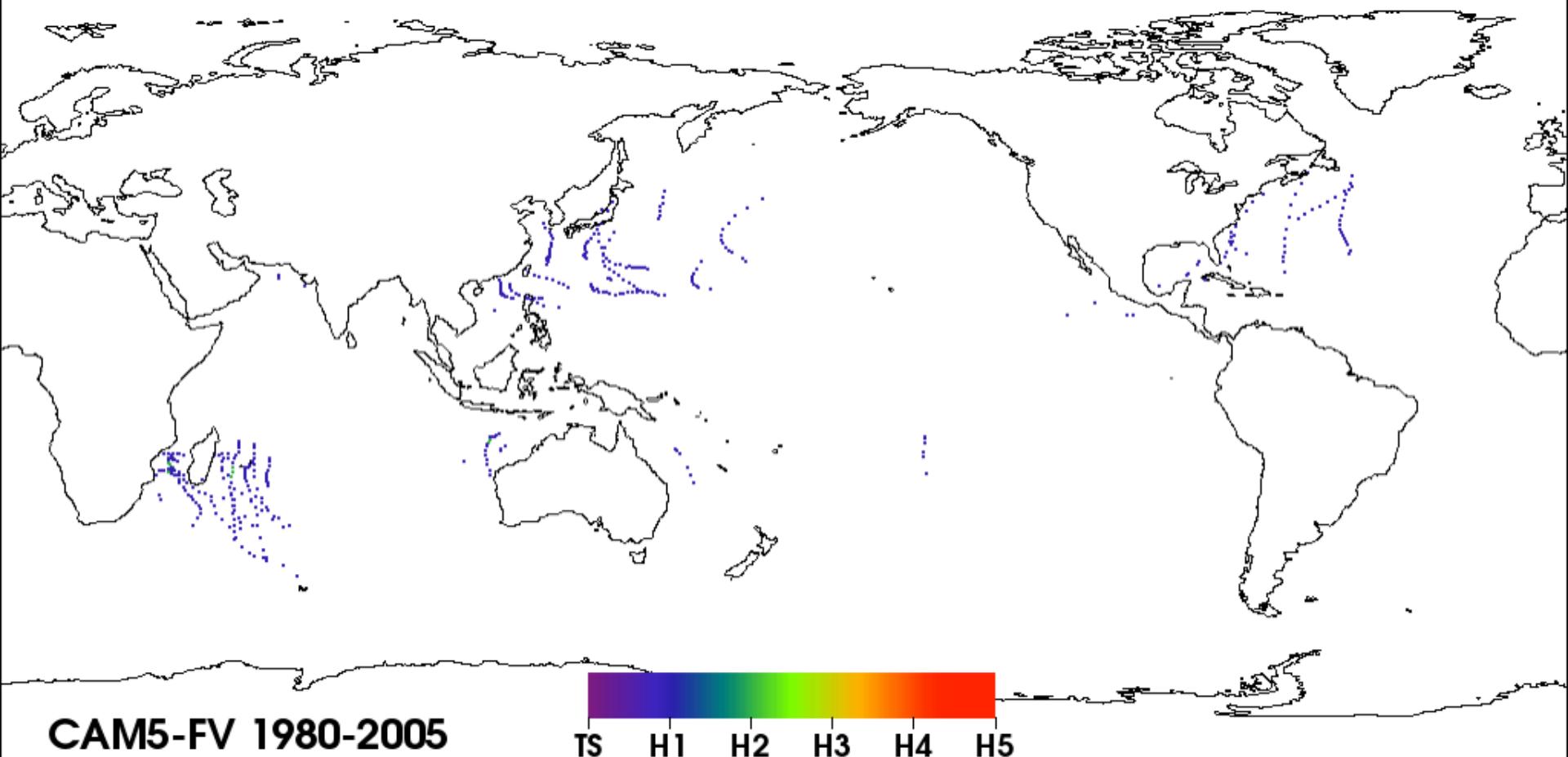


# Design of Decadal Experiments

- National Center for Atmospheric Research's (NCAR) Community Atmosphere Model version 5.1 (CAM 5.1).
- The default **FV** dynamical cores with 30 vertical levels is used at the **horizontal resolutions** of:
  - ~100 km
  - ~25 km
- Full CAM 5.1 physics with Atmospheric Model Intercomparison Project (**AMIP**) protocols (with prescribed aerosol forcing).
- Observed ozone, CO<sub>2</sub>, solar forcing, etc.
- GFDL tracking code.
- **Completed 1979-2005.**

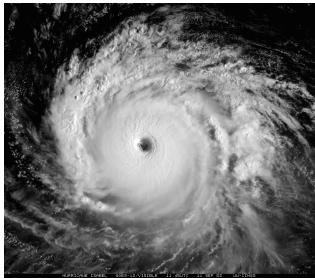


# CAM5-FV 0.9° by 1.25° Storm Tracks - AMIP

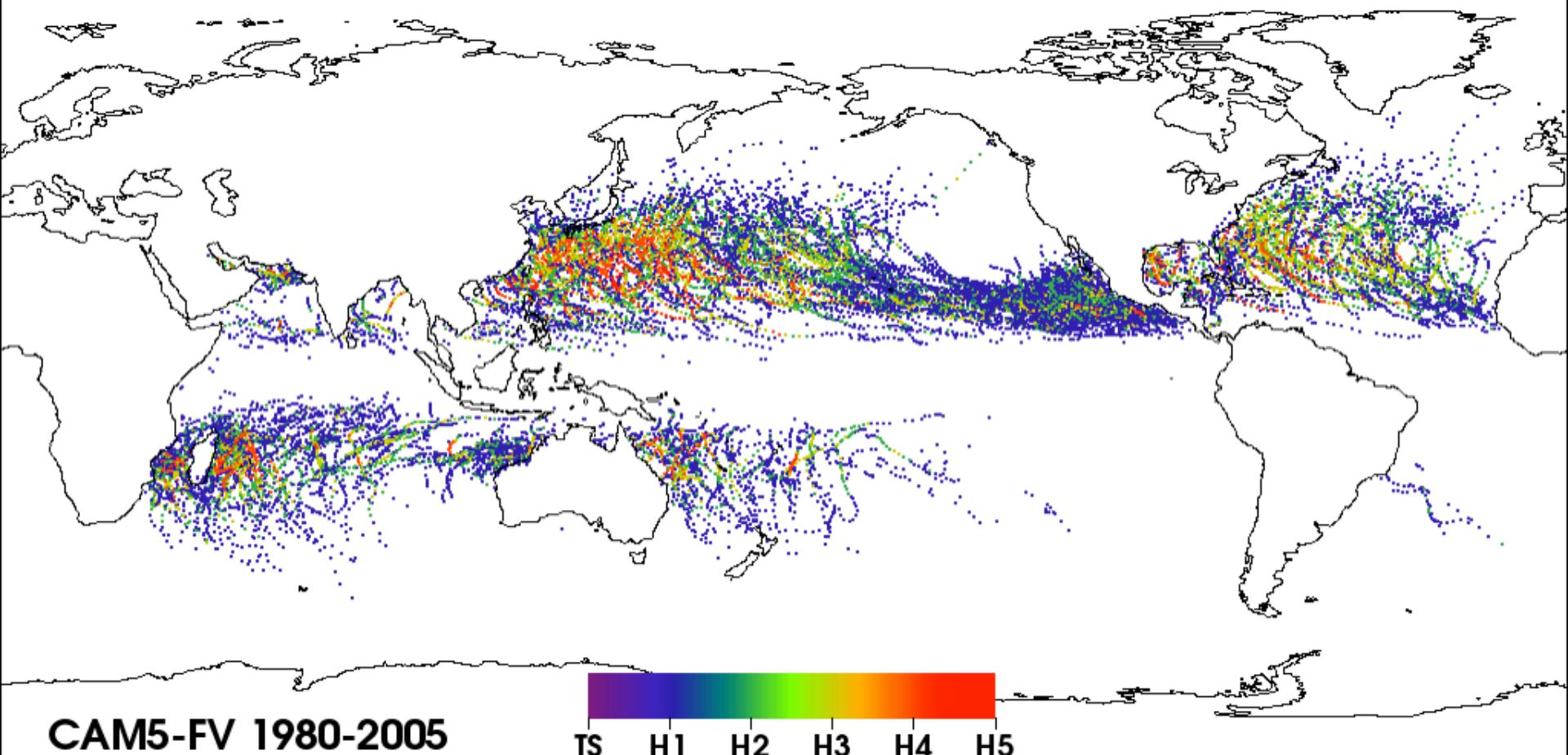


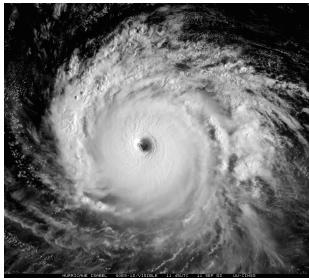
**CAM5-FV 1980-2005**

TS    H1    H2    H3    H4    H5

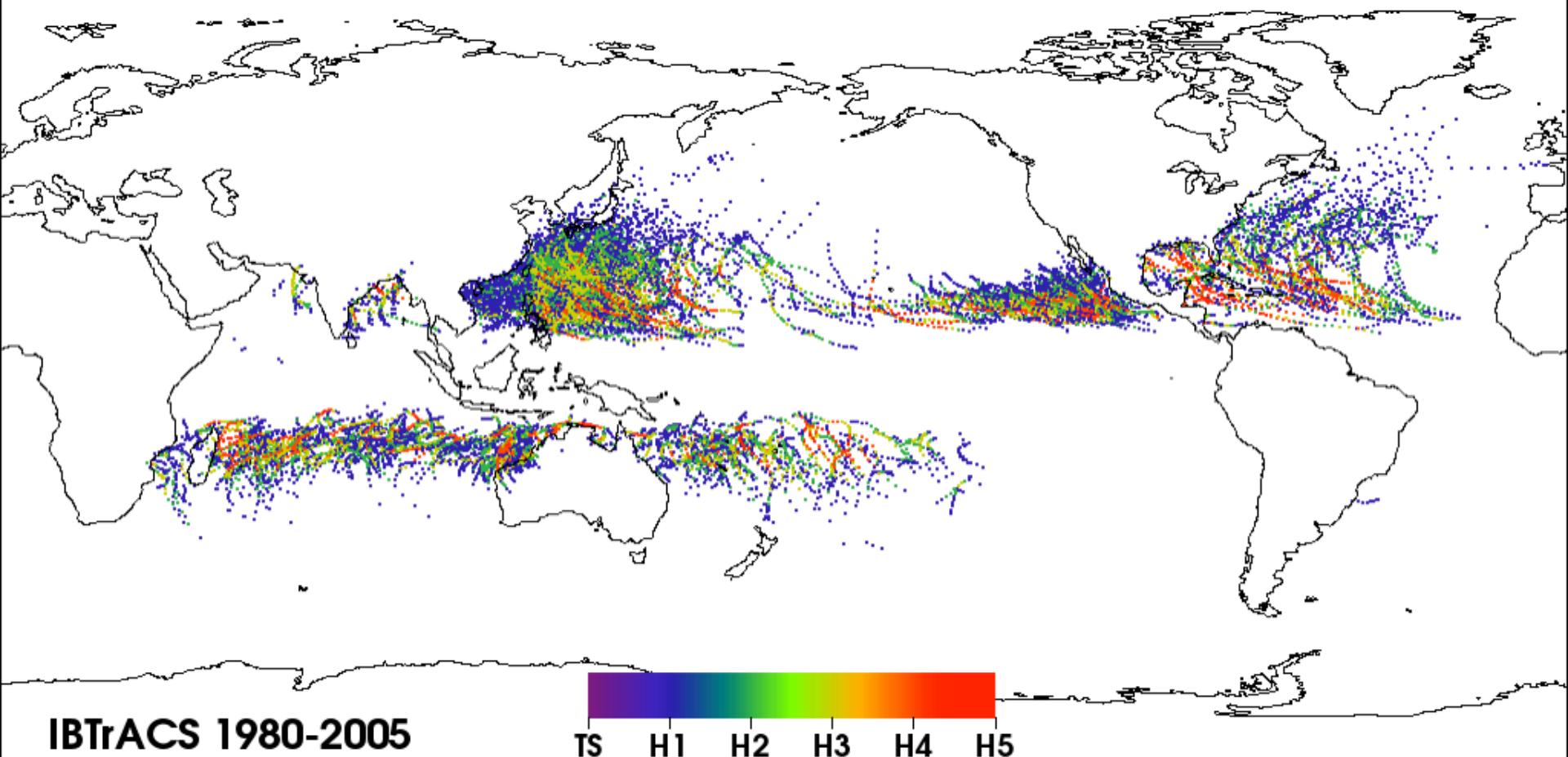


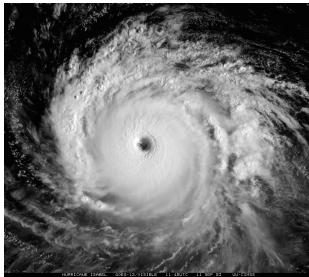
# CAM5-FV 0.23° by 0.31° Storm Tracks - AMIP



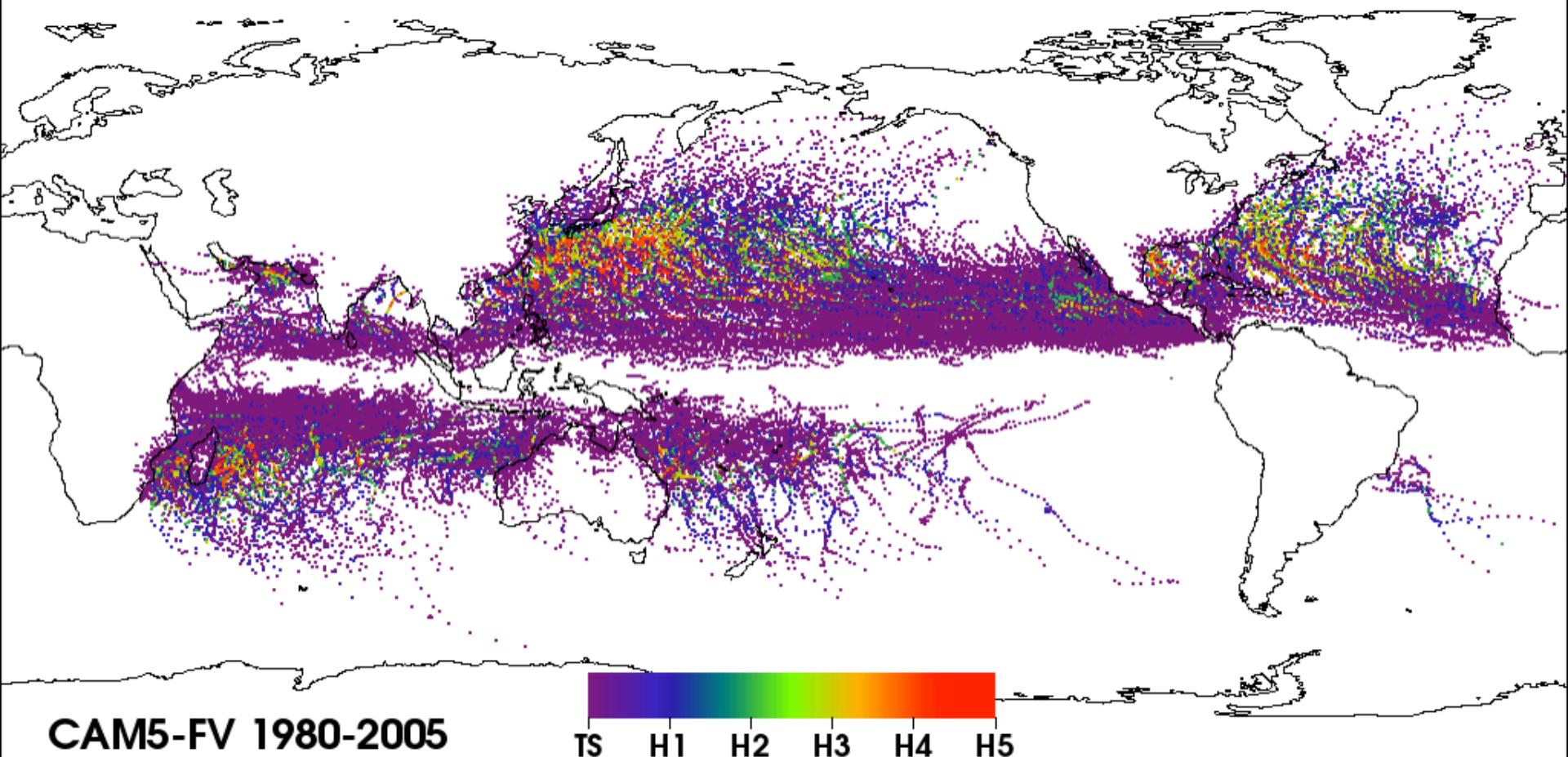


# Observations



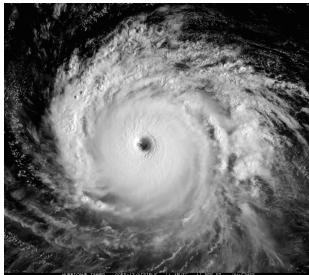


# Categories TS - 5

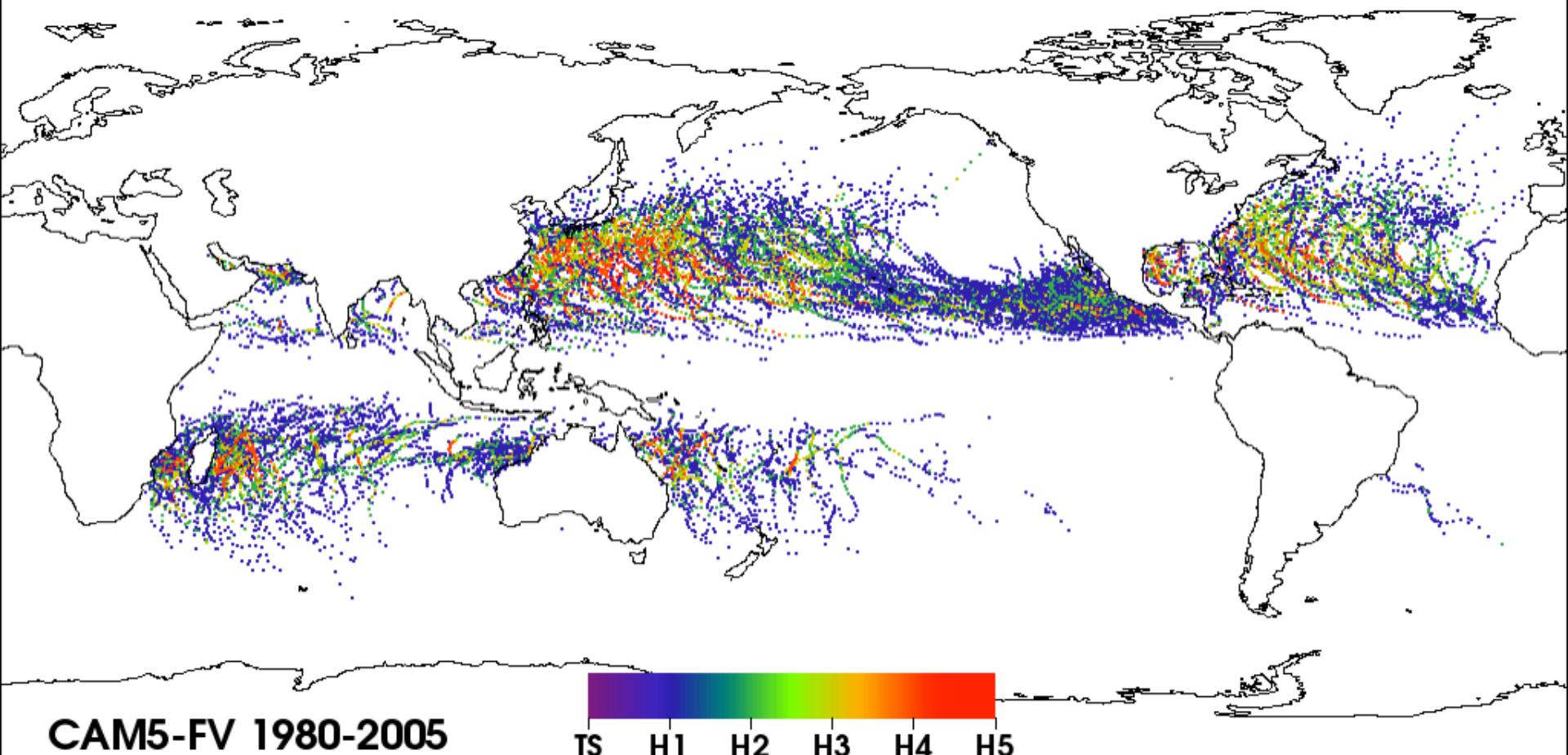


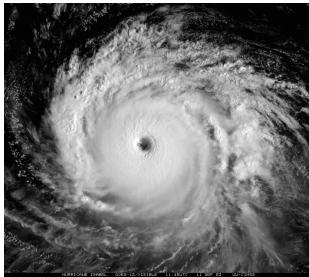
**CAM5-FV 1980-2005**

TS    H1    H2    H3    H4    H5

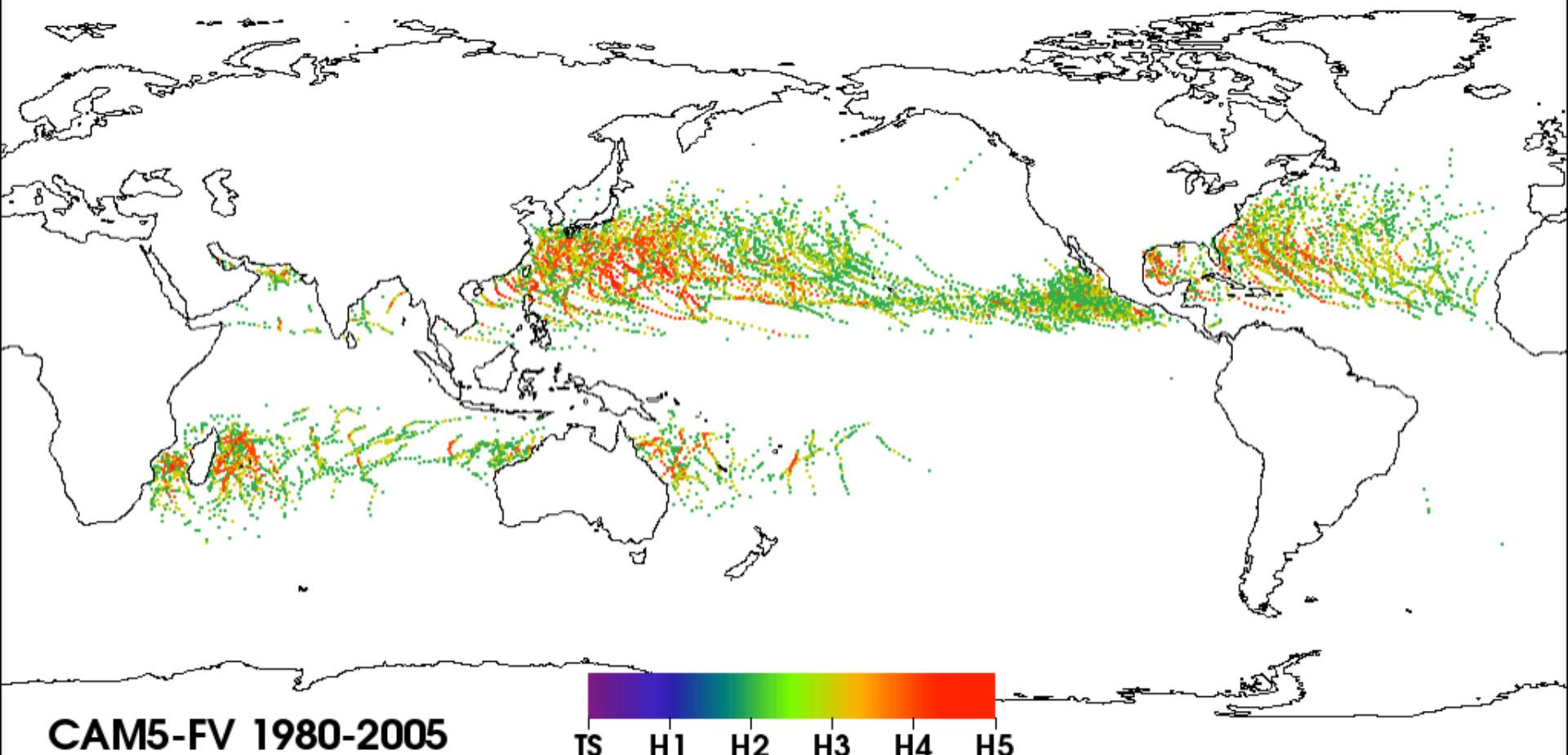


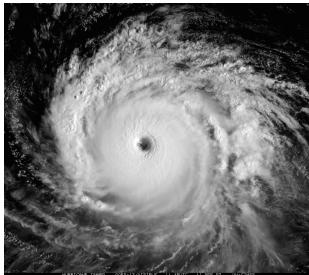
# Categories 1 - 5



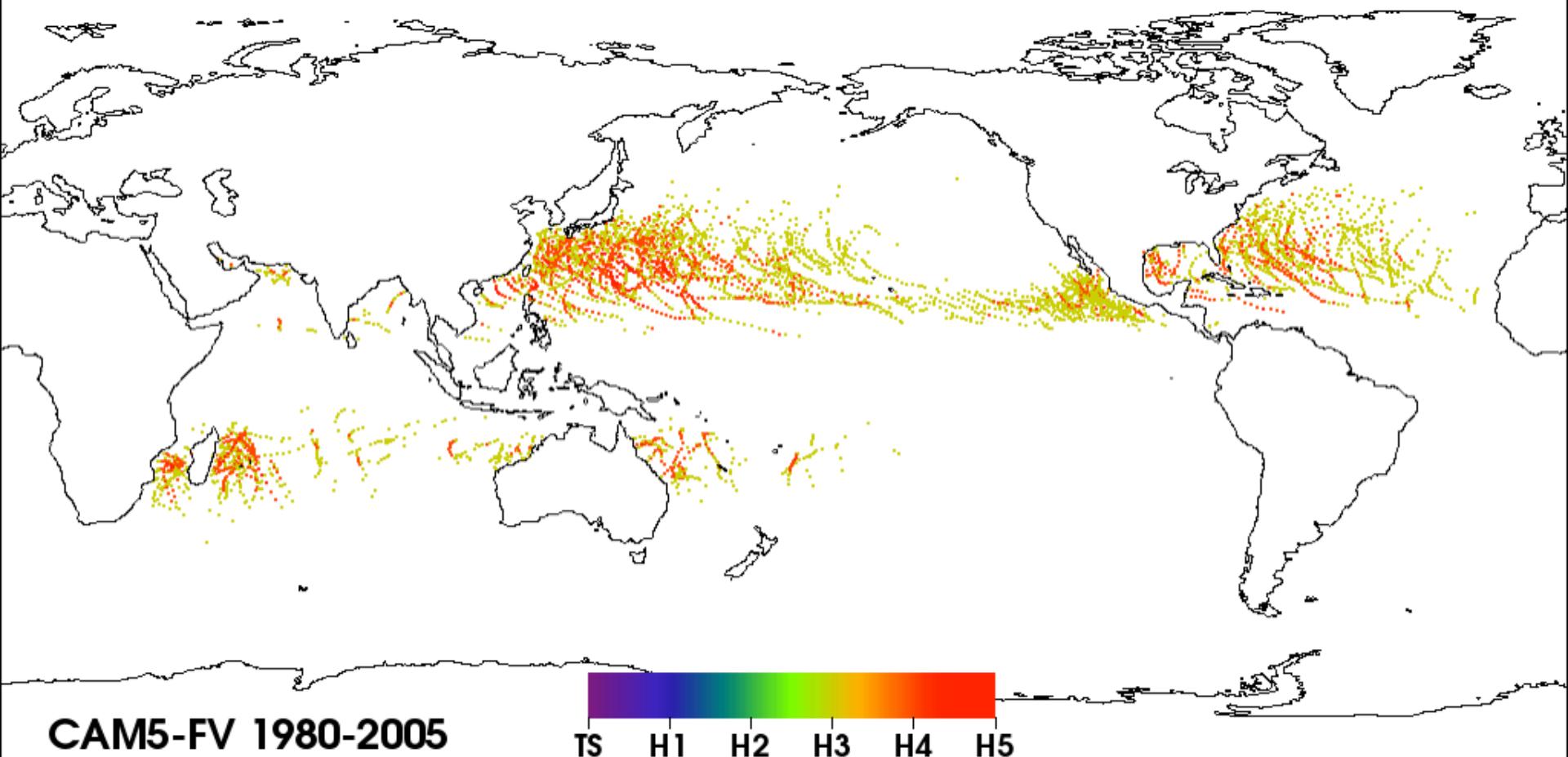


# Categories 2 - 5



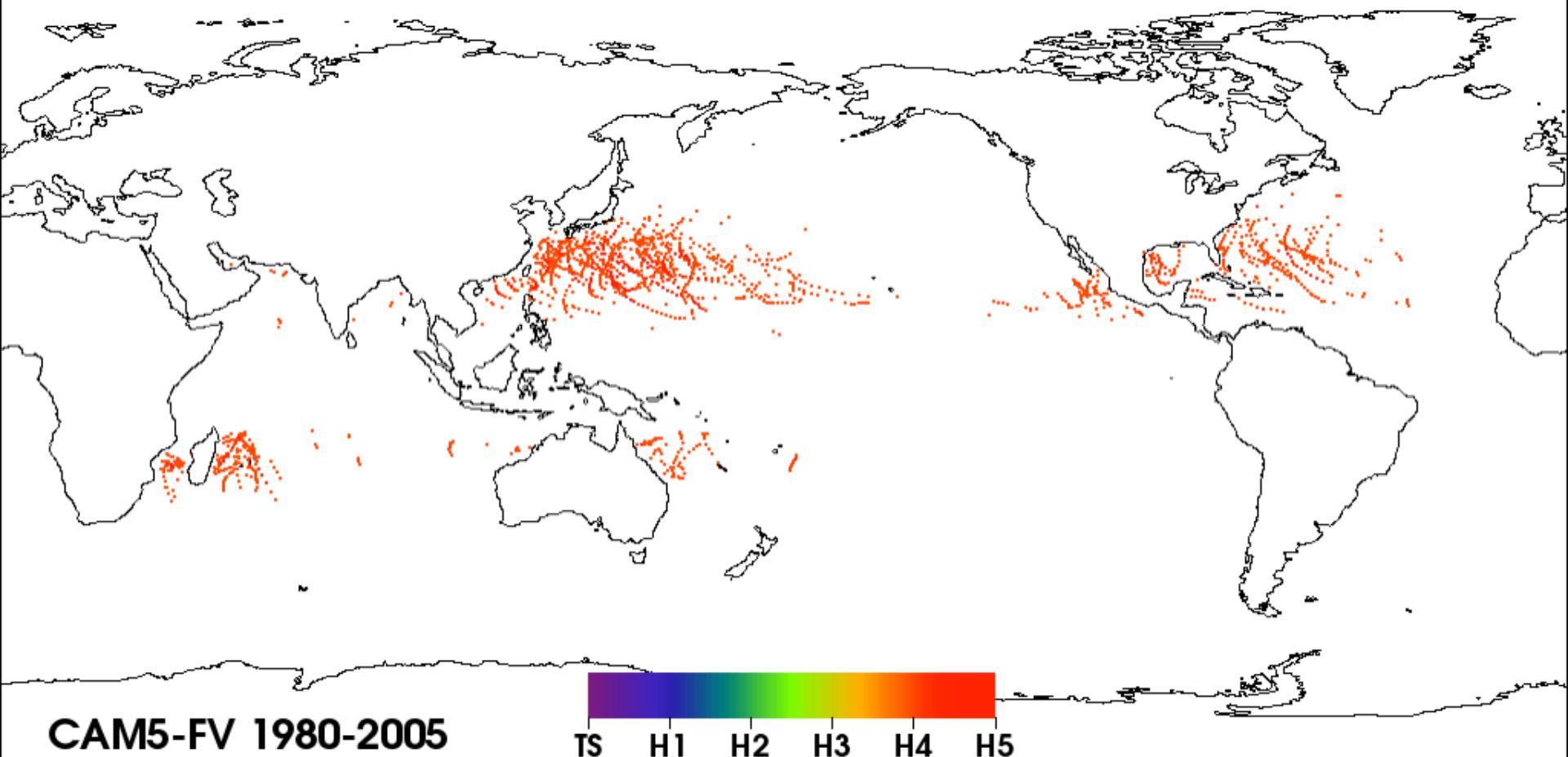


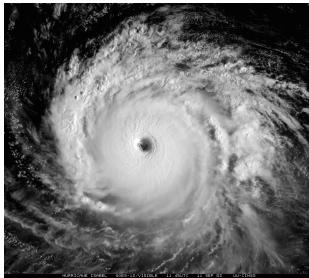
# Categories 3 - 5



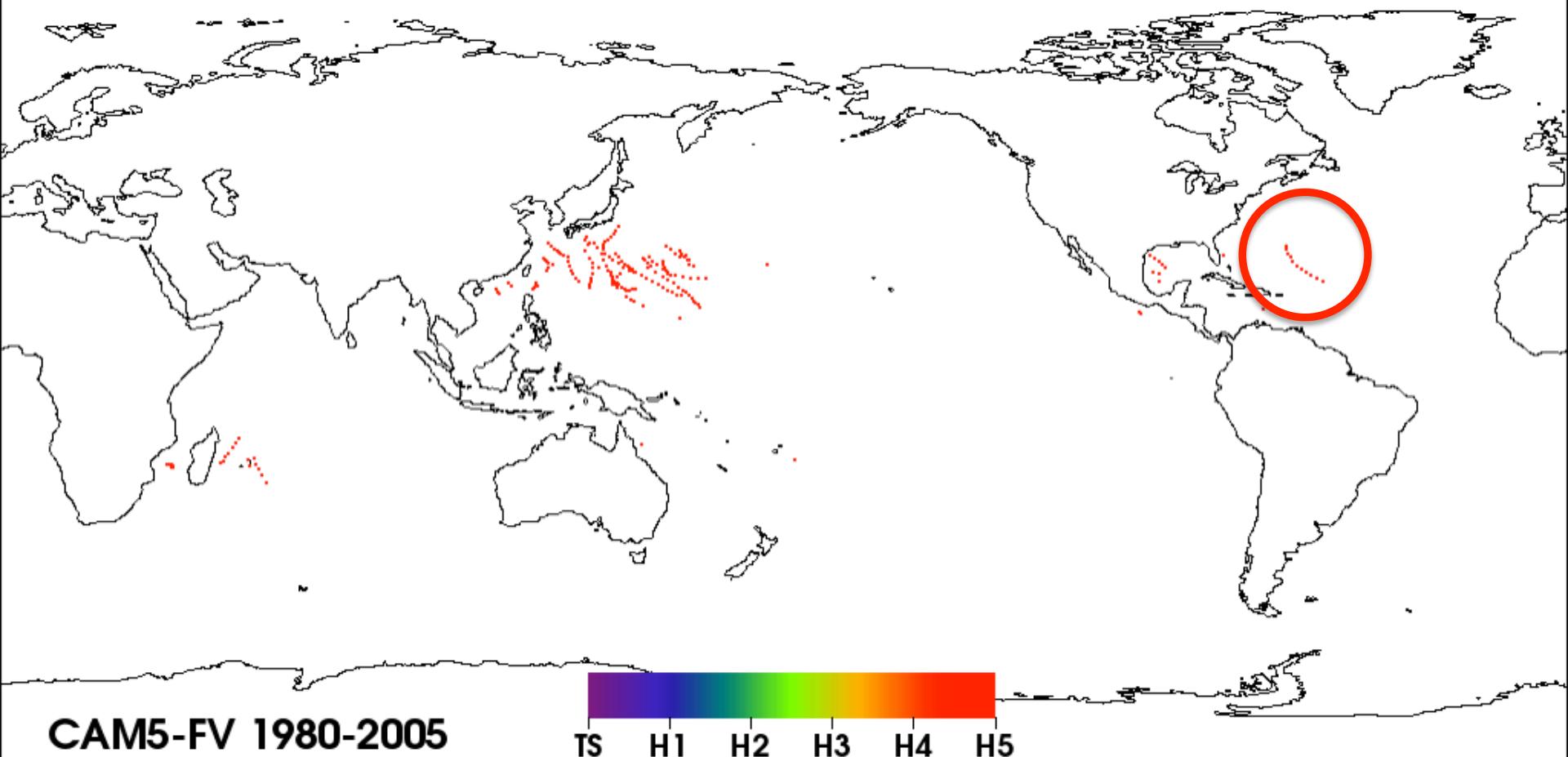


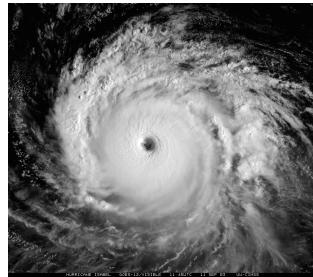
# Categories 4 - 5



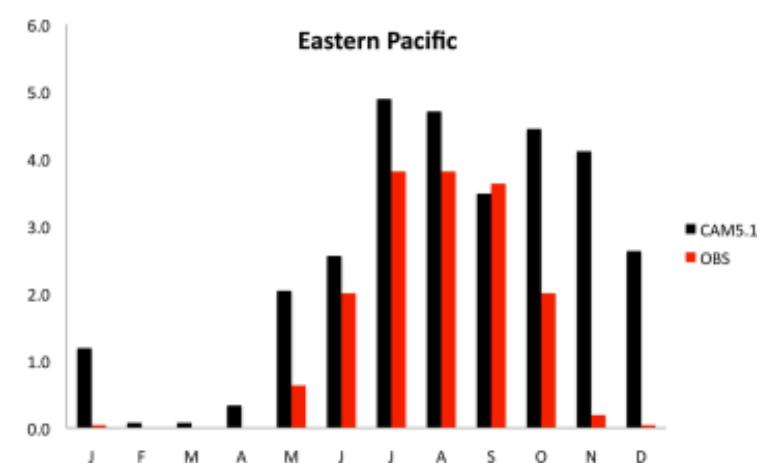
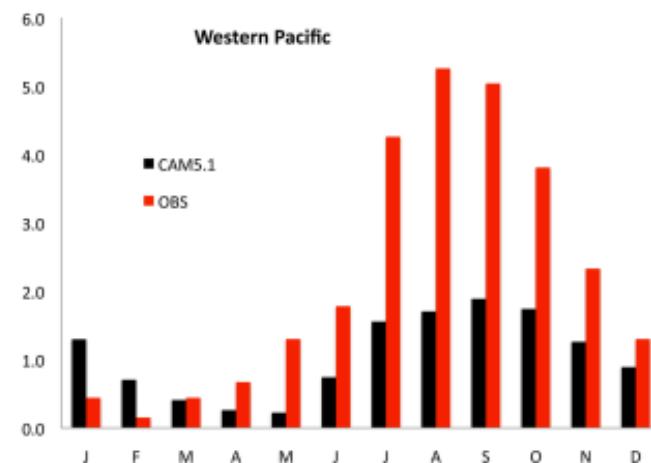
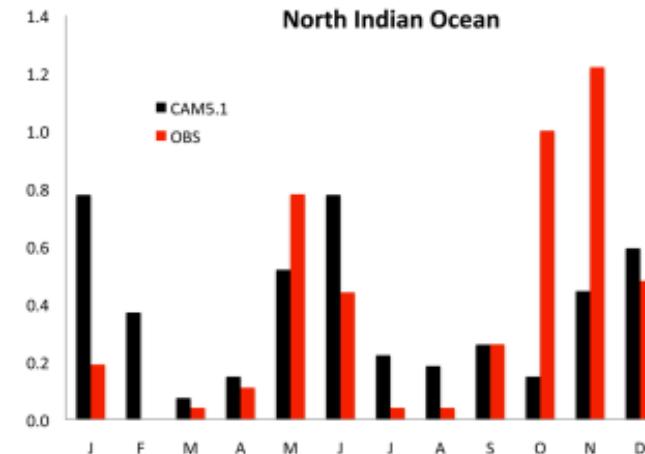
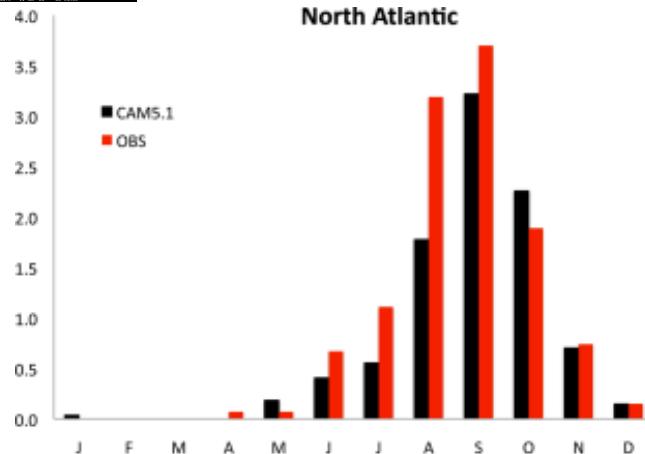


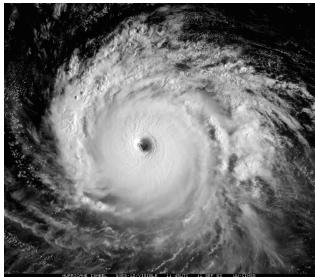
# Category 5





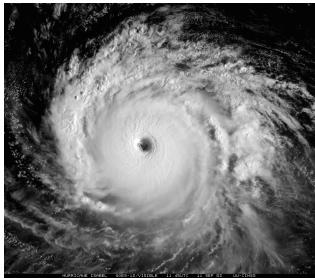
# Seasonal Cycle



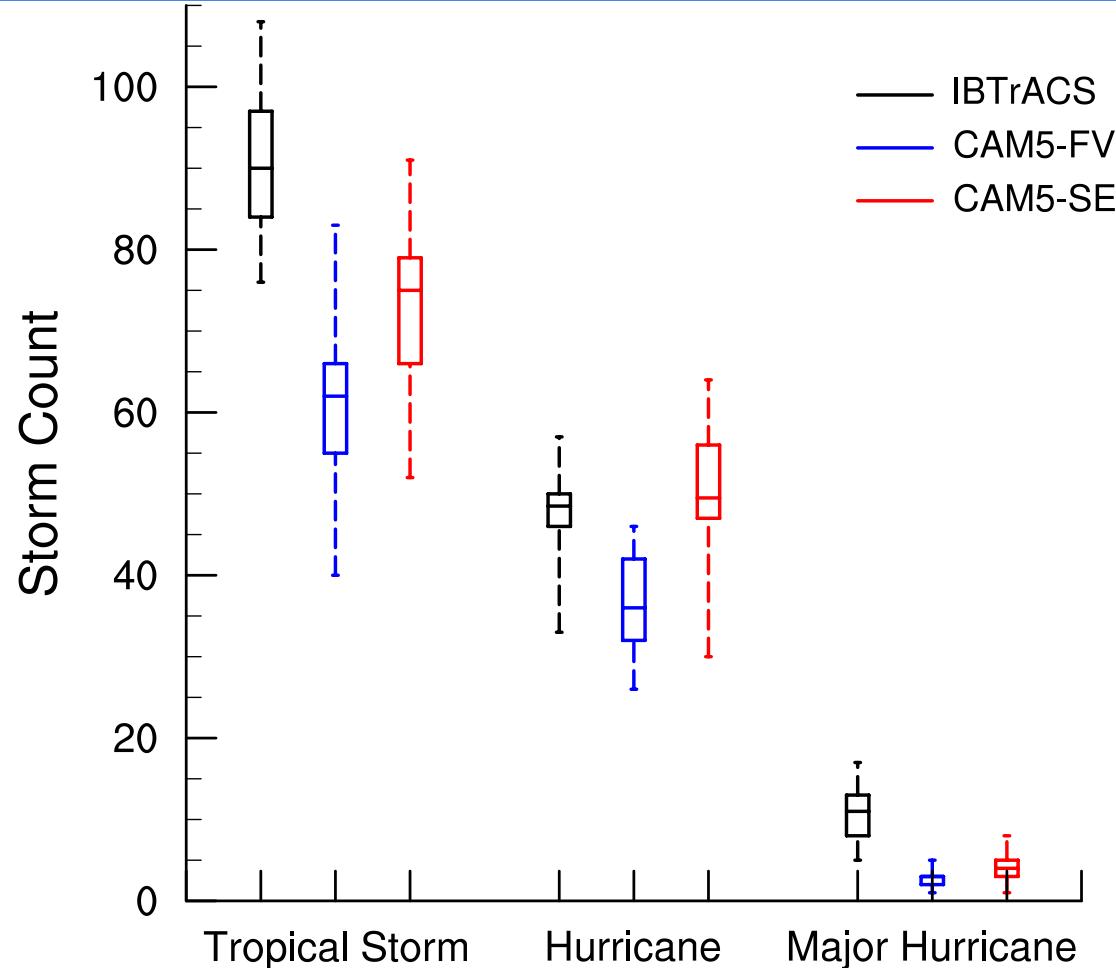


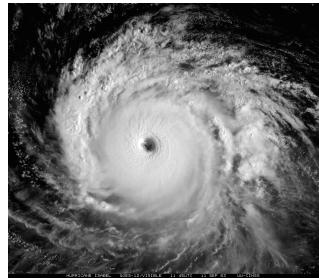
# Design of Experiments

- National Center for Atmospheric Research's (NCAR) Community Atmosphere Model version 5.3 (CAM 5.3).
- The default Spectral Element **SE** dynamical core with 30 vertical levels is used at the **horizontal resolution** of ne120 (~25 km) – comparable to **CAM5-FV 25 km** run.
- Full CAM 5.3 physics with Atmospheric Model Intercomparison Project (**AMIP**) protocols for 1980-2005.
- Prescribed observed SSTs, ozone, CO<sub>2</sub>, solar forcing, etc.
- Both simulations use the same prognostic aerosol schemes.
- GFDL tracking code (C++/mpi) is used for calculating all tracks.



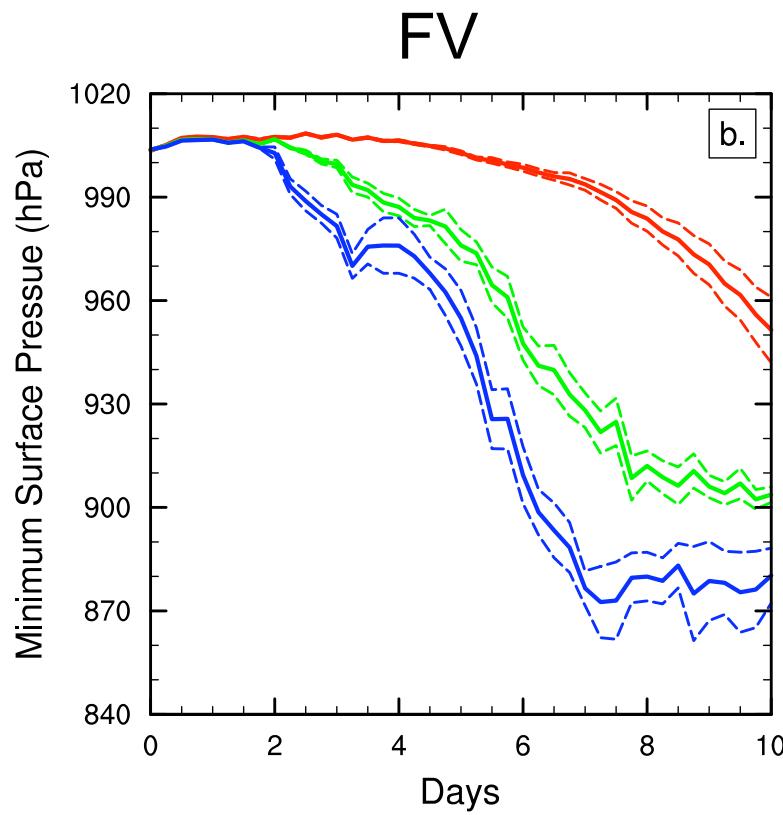
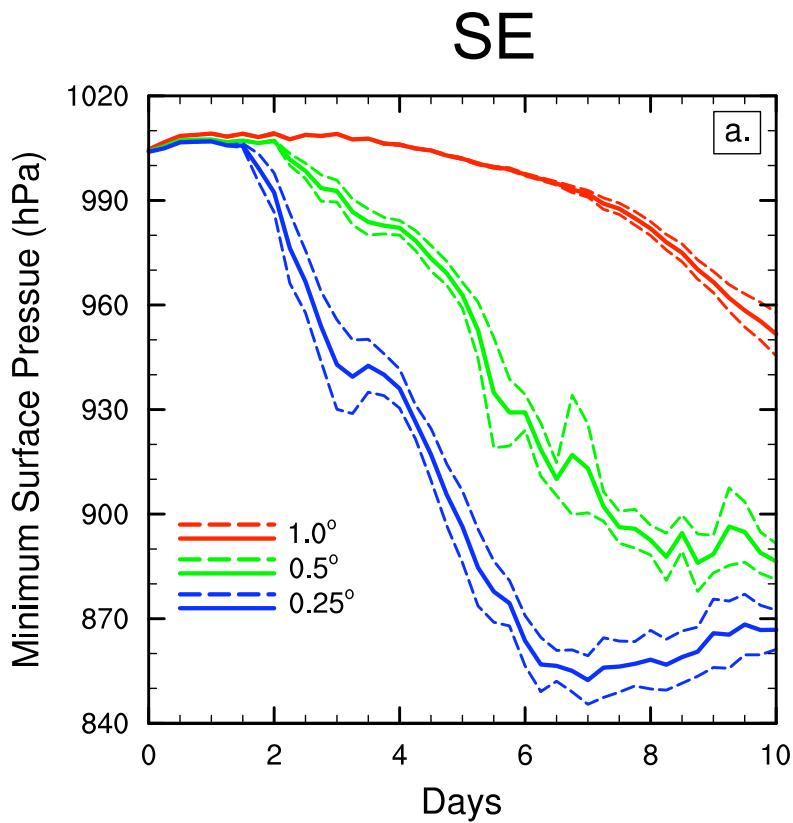
# Impact of Dynamical Core

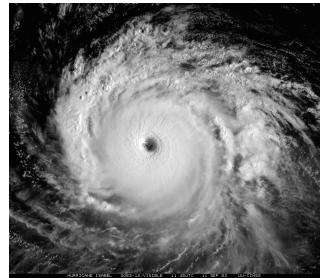




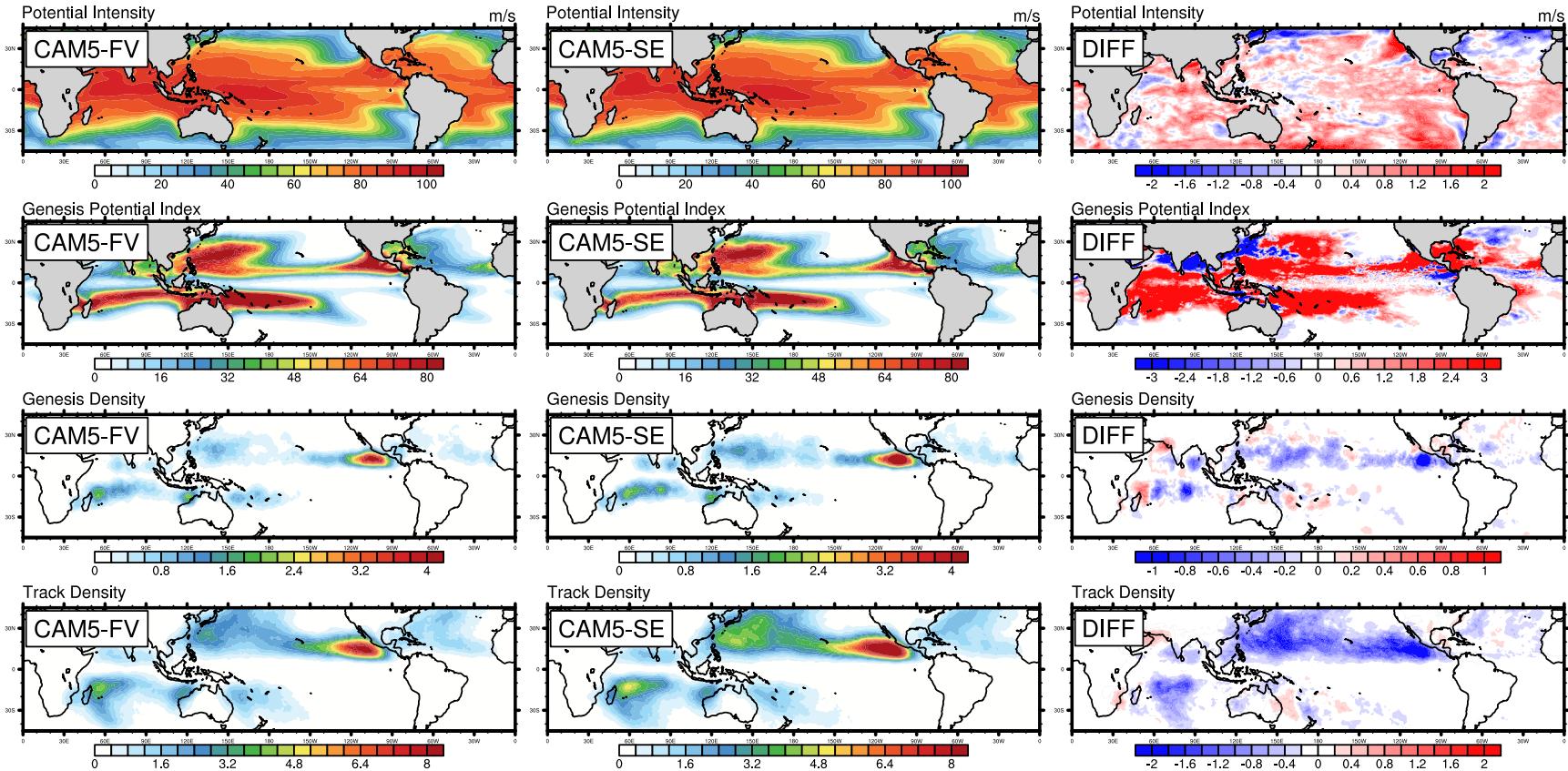
# Bonus: Consistent with Idealized Simulations

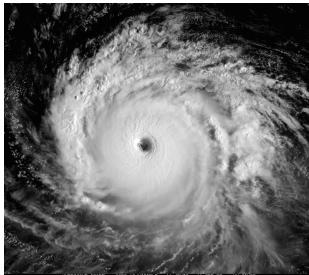
***Similar to the TC test used here at DCMIP!***



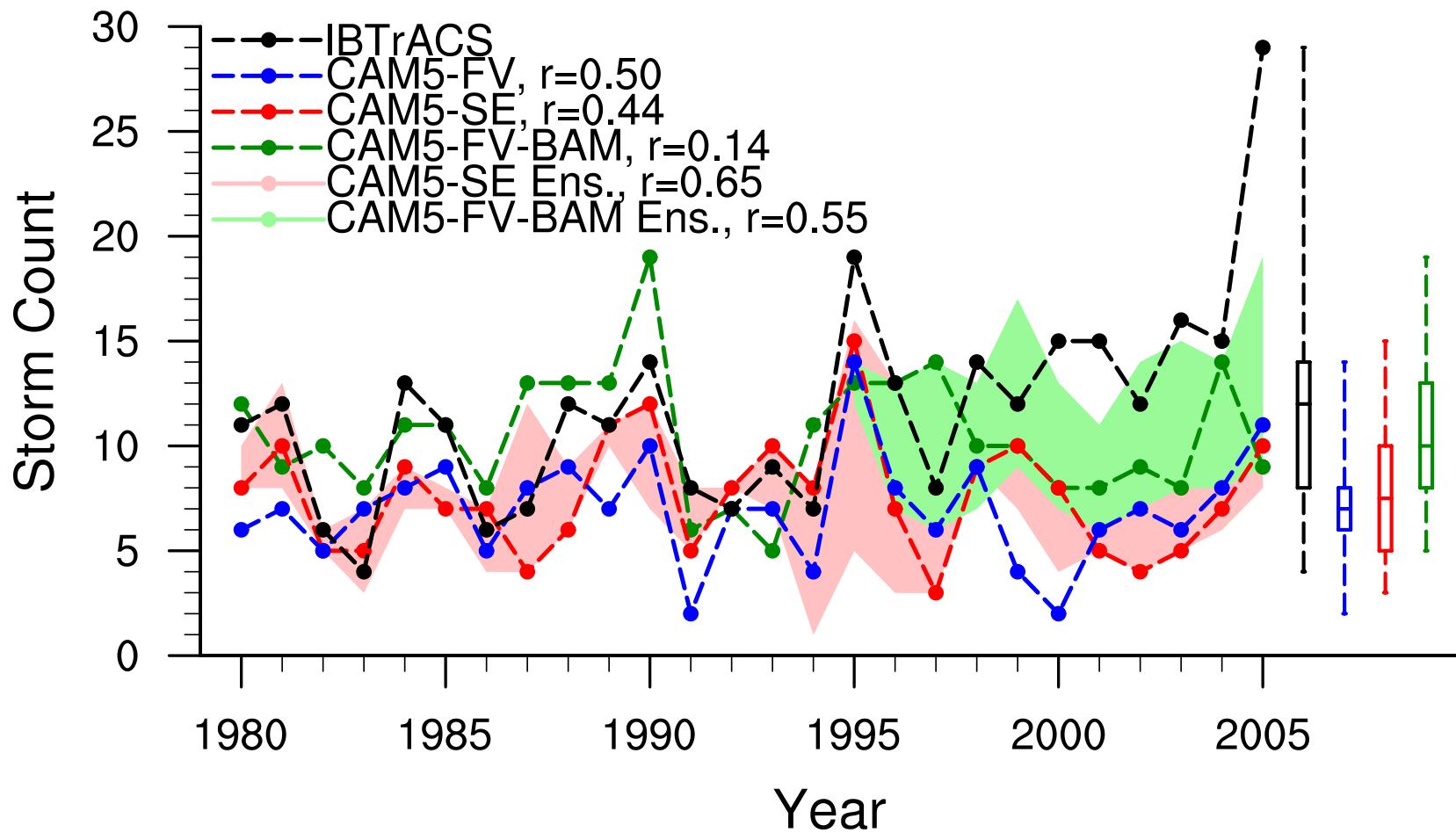


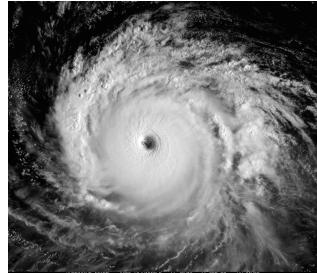
# Impact of Dynamical Core





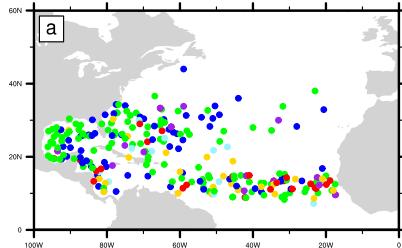
# North Atlantic Basin



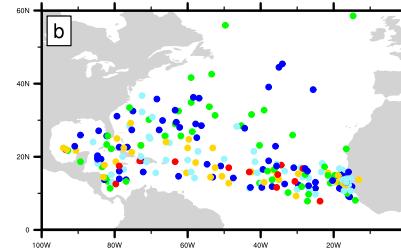


# North Atlantic Basin – Aerosol Impact?

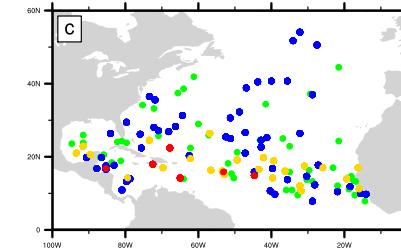
Ibtracs Genesis for NA J-N 1982-2005



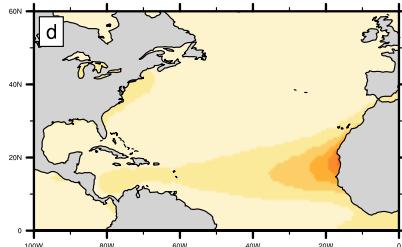
BAM Genesis for NA J-N 1982-2005



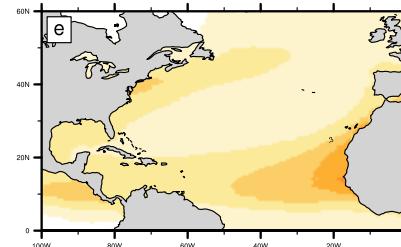
MAM Genesis for NA J-N 1982-2005



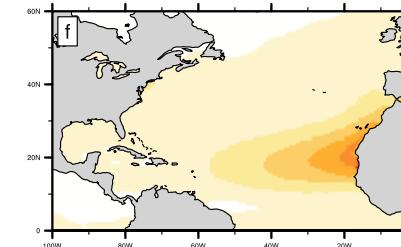
MERRA Average Aerosol NA J-N 1982-2005



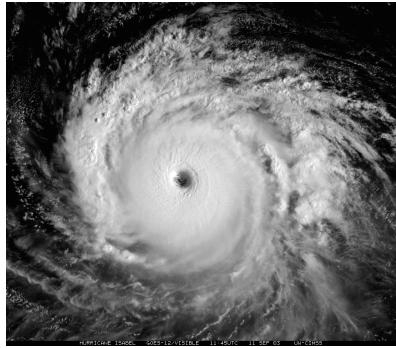
BAM Average Aerosol NA J-N 1982-2005



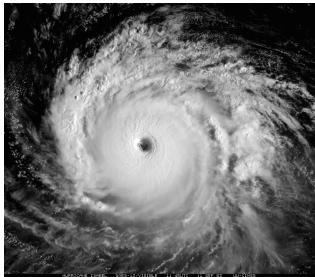
MAM Average Aerosol NA J-N 1982-2005



■ TS ■ Cat1 ■ Cat2 ■ Cat3 ■ Cat4 ■ Cat5

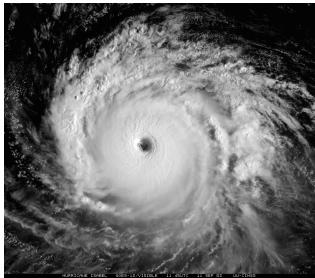


# Future Changes: Tropical Cyclones

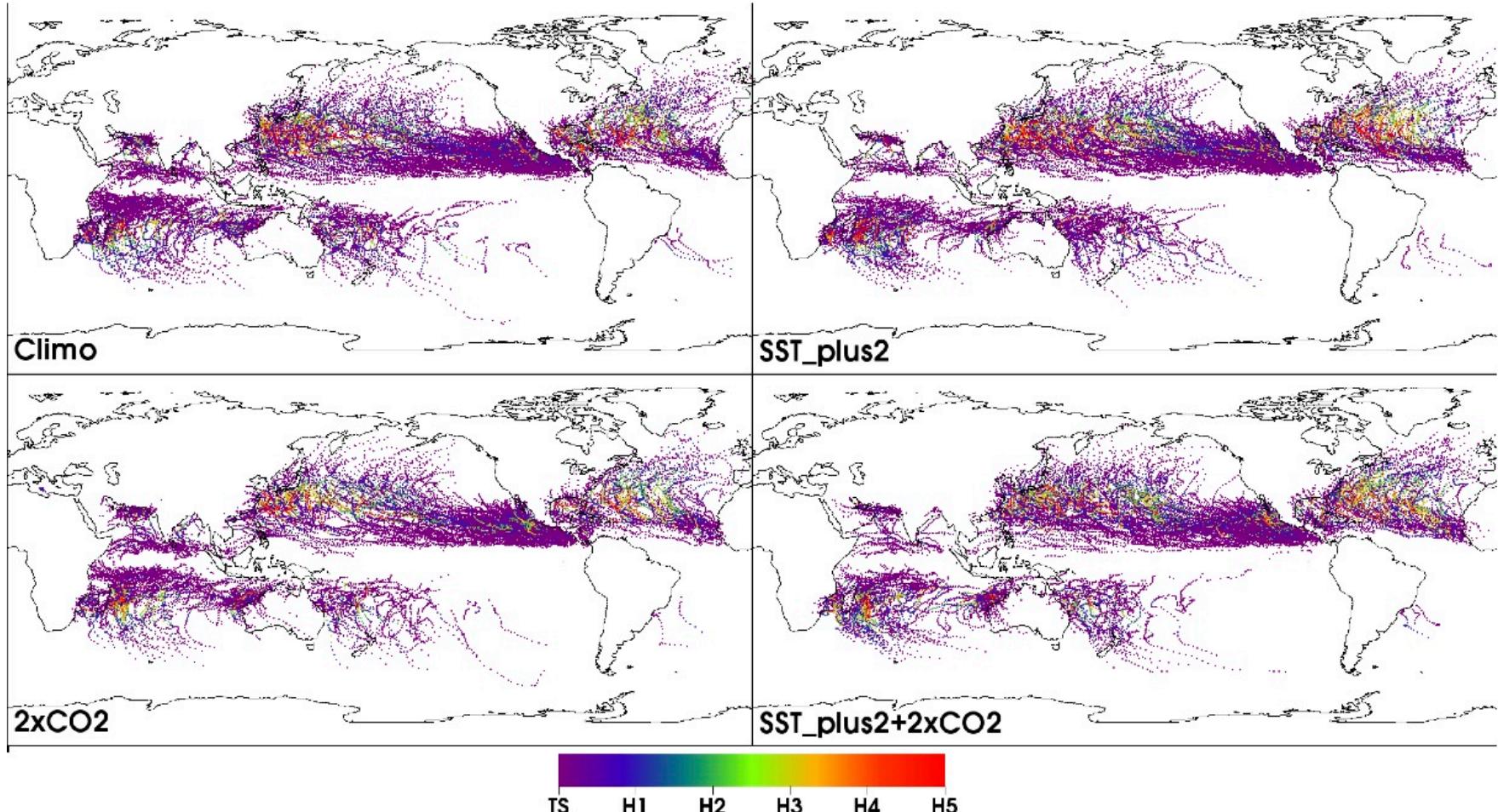


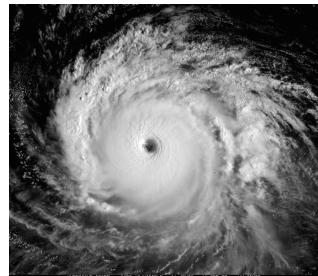
# Design of Experiments

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- The default Spectral Element **SE** dynamical core with 30 vertical levels is used at the **horizontal resolution** of ne120 ( $\sim 25$  km) – comparable to **CAM5-FV**  $0.23^\circ \times 0.31^\circ$  run.
- **RCP 4.5** and **RCP 8.5** scenarios for 2070-2099.
- Or, climatology runs... with uniform changes.
- Prescribed observed SSTs, ozone, CO<sub>2</sub>, solar forcing, etc.
- Both simulations use the same prognostic aerosol schemes.
- GFDL tracking code (C++/mpi) is used for calculating all tracks.



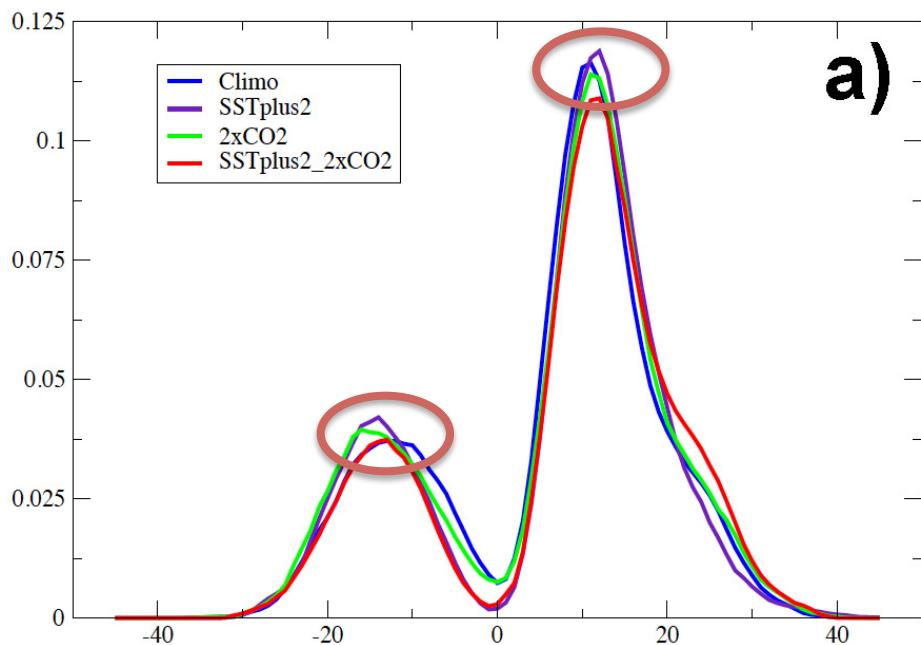
# Idealized Forcings





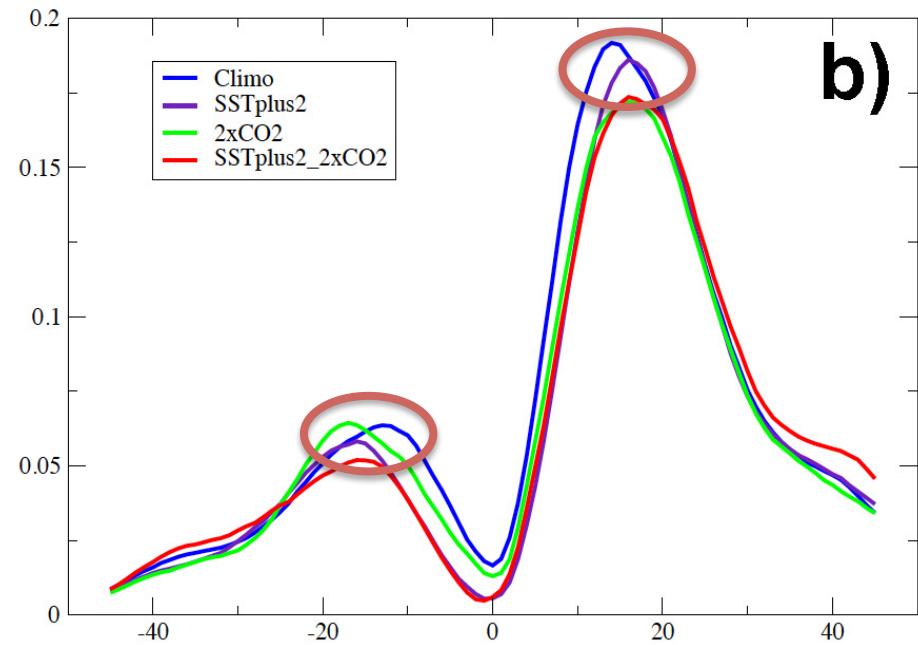
# Idealized Forcings

Genesis density



a)

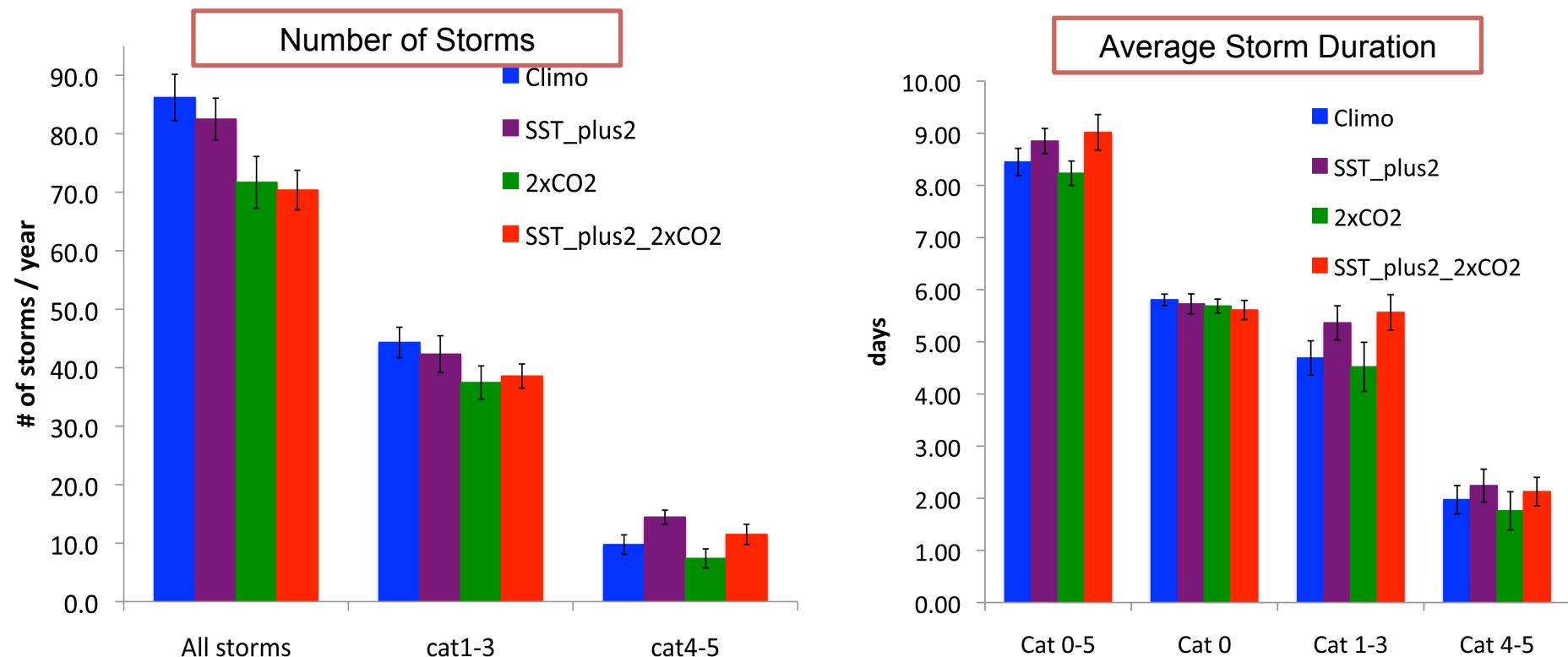
Tropical Storm Track Density

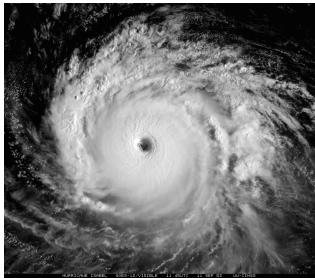


b)

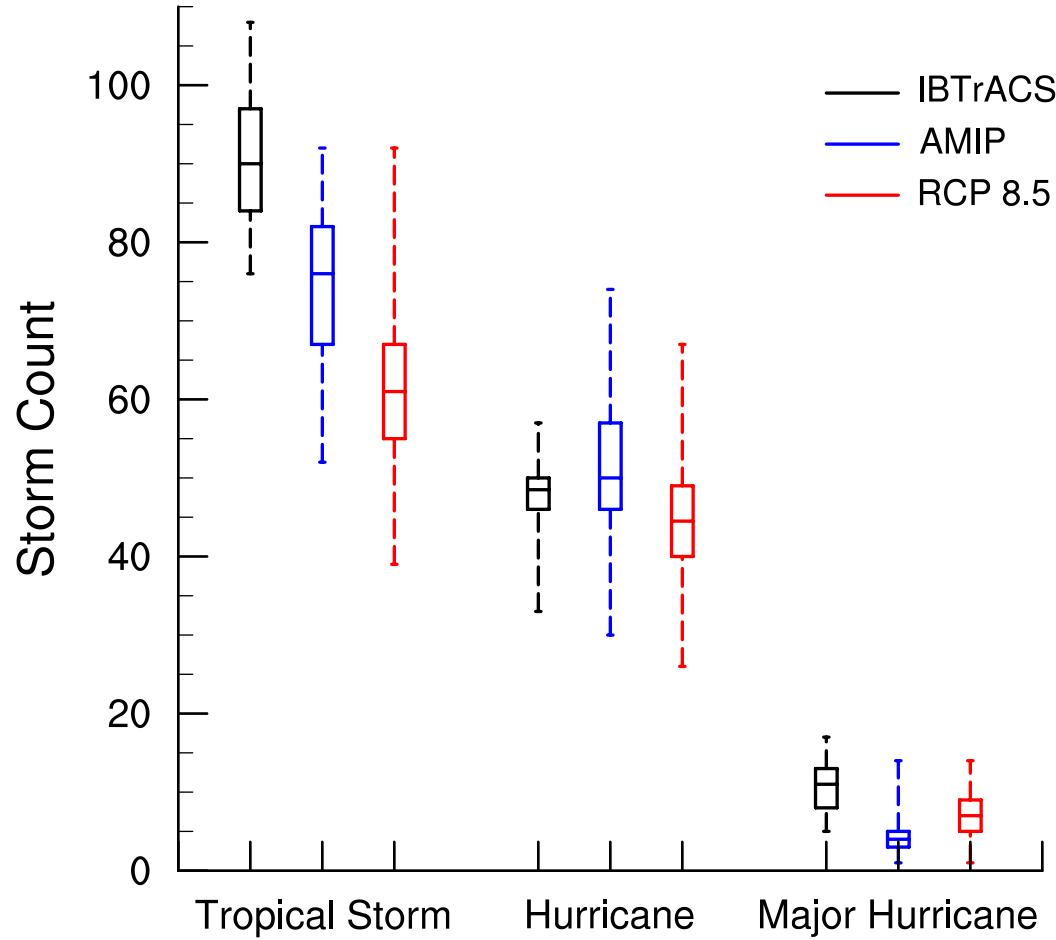


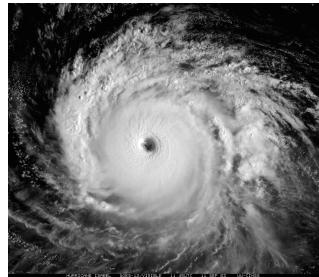
# Idealized Forcings



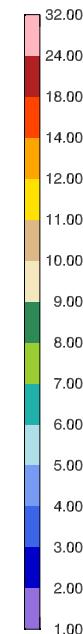
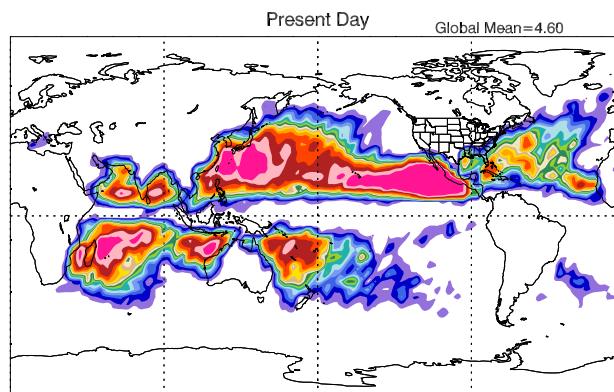
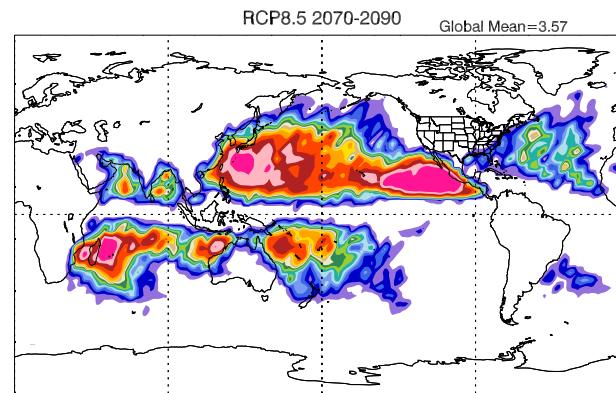
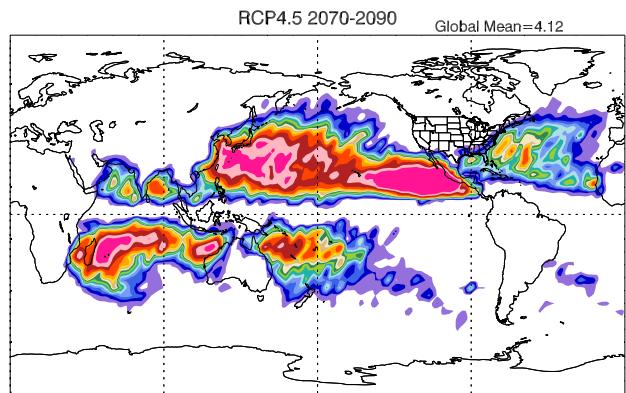


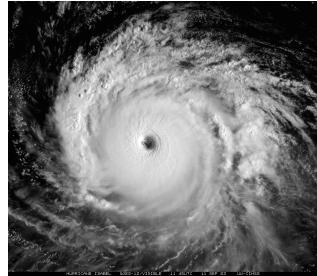
# Future Climate Scenarios: Global Statistics



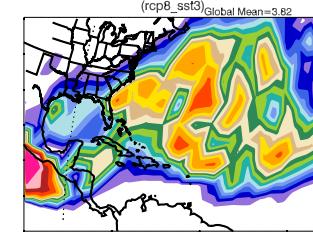
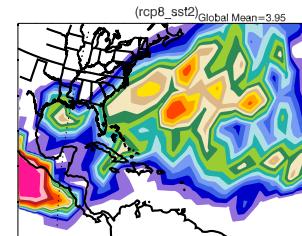
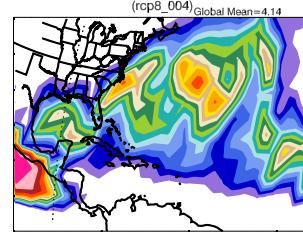
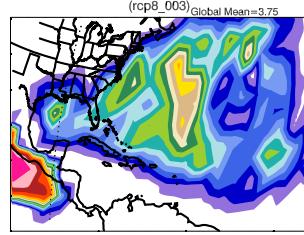
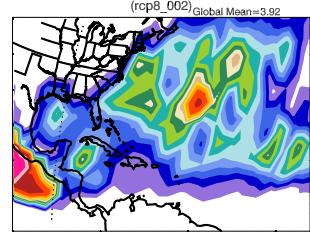
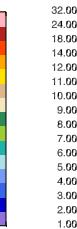
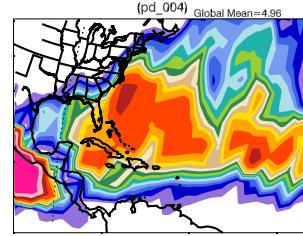
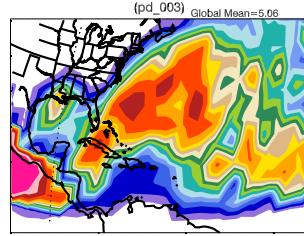
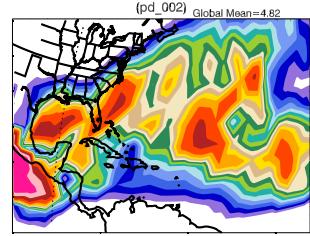


# Global Distributions



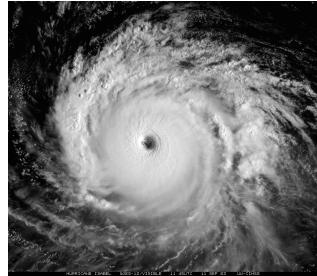


# North Atlantic Distributions

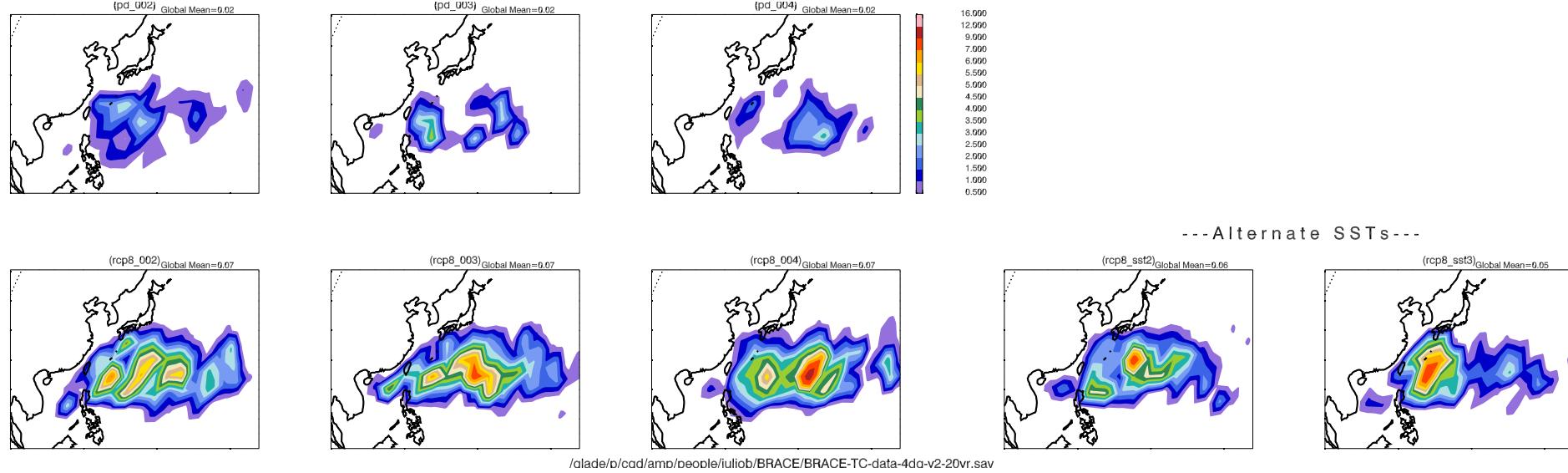


---Alternate SSTs---

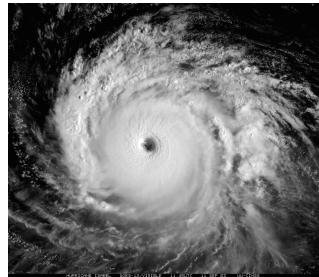
- Appears to be a robust **decrease** in storms in the North Atlantic.
- Though, the **magnitude** of the decrease is dependent on the sea surface temperatures.



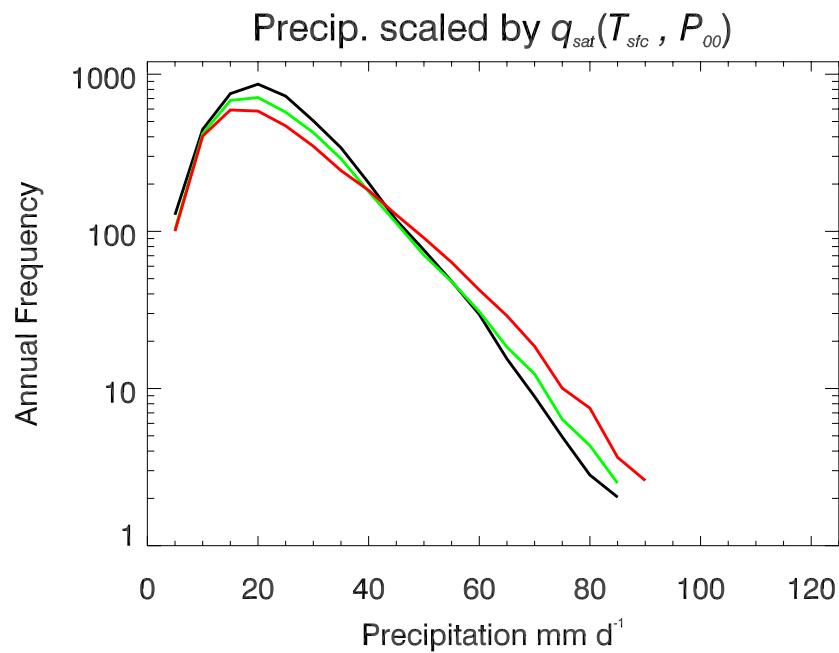
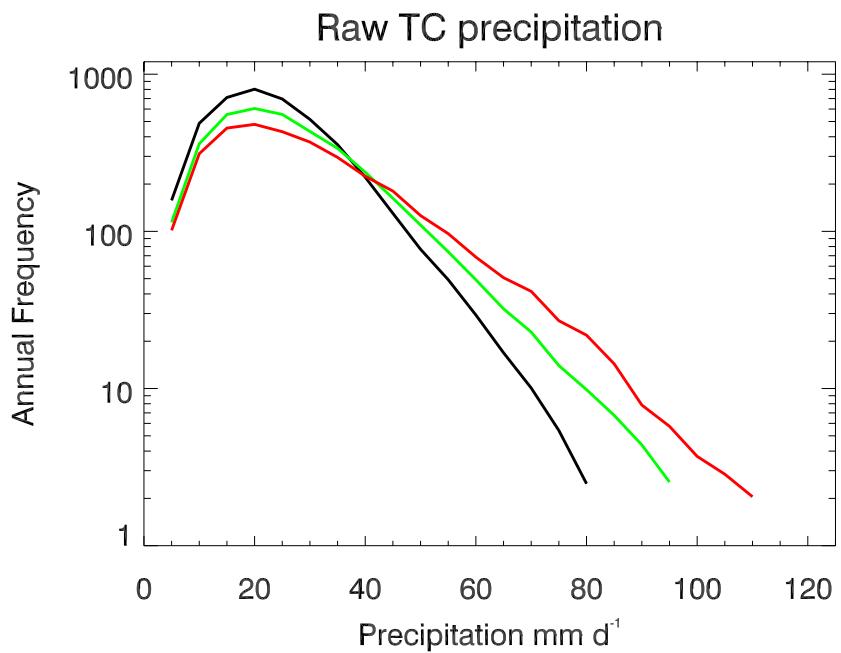
# West Pacific Distributions

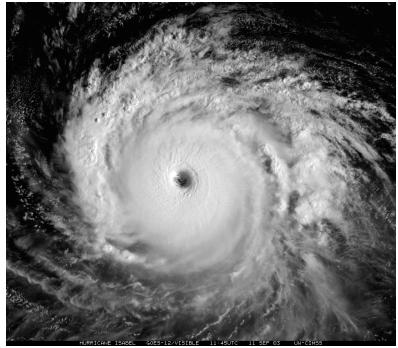


- Appears to be a robust **increase** in intense storms in the West Pacific.
- Though, the **distribution** is dependent on sea surface temperatures.

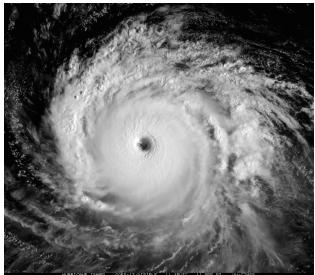


# Precipitation Distributions



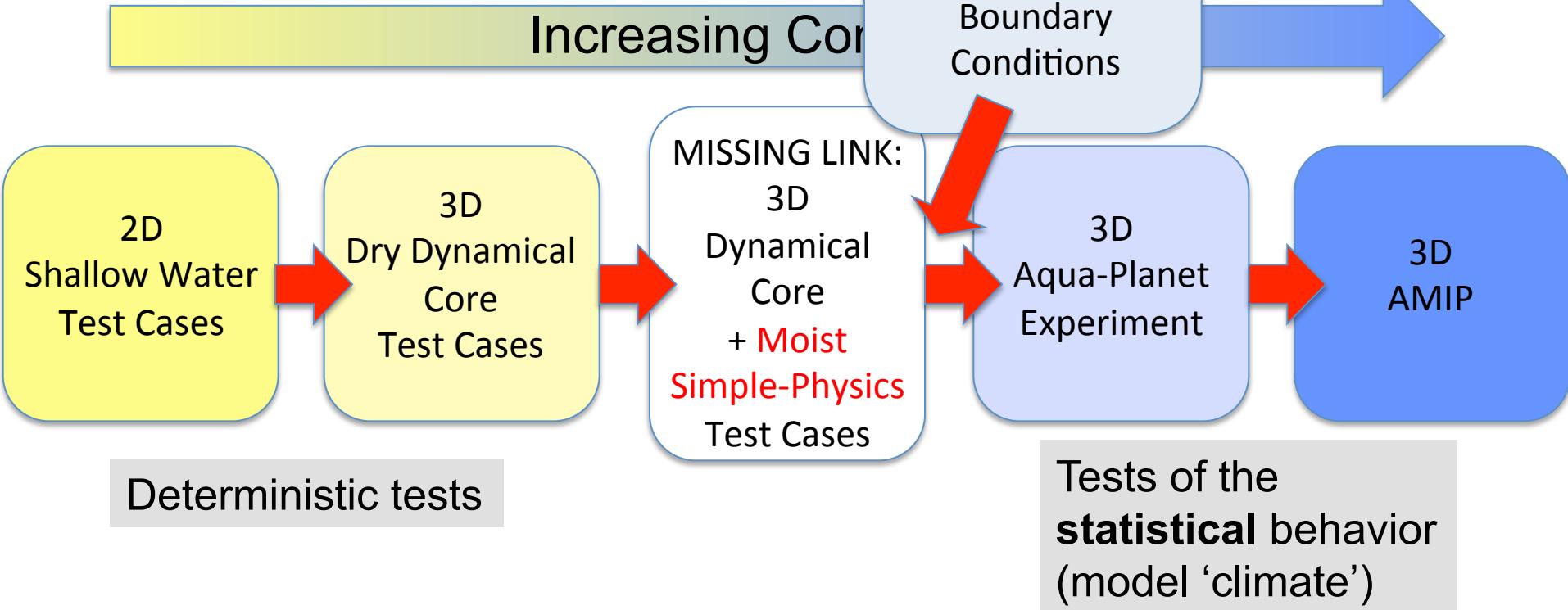


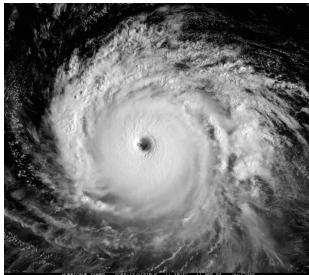
# Reduced-Complexity: Improved Understanding



# How Do we evaluate GCMs?

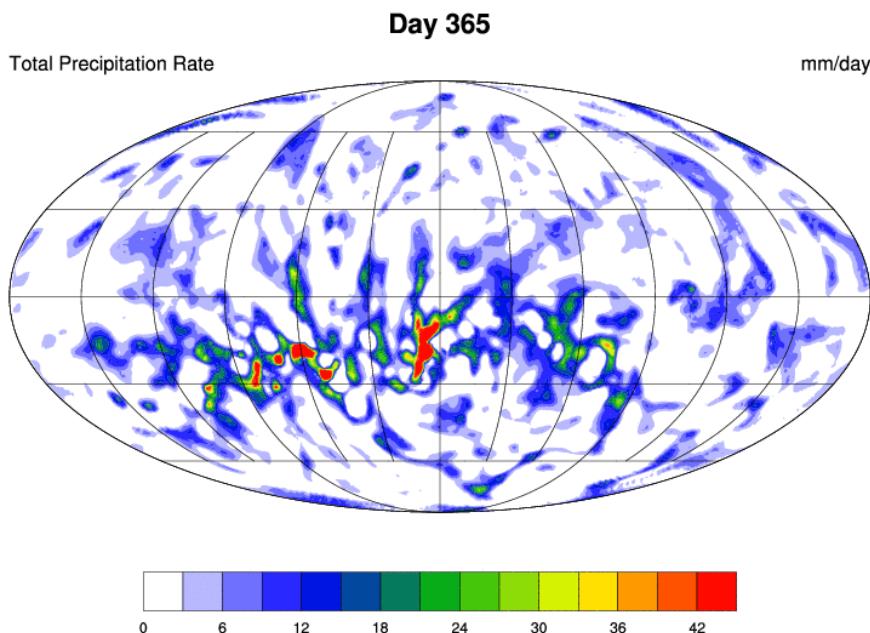
- Utilize a test hierarchy



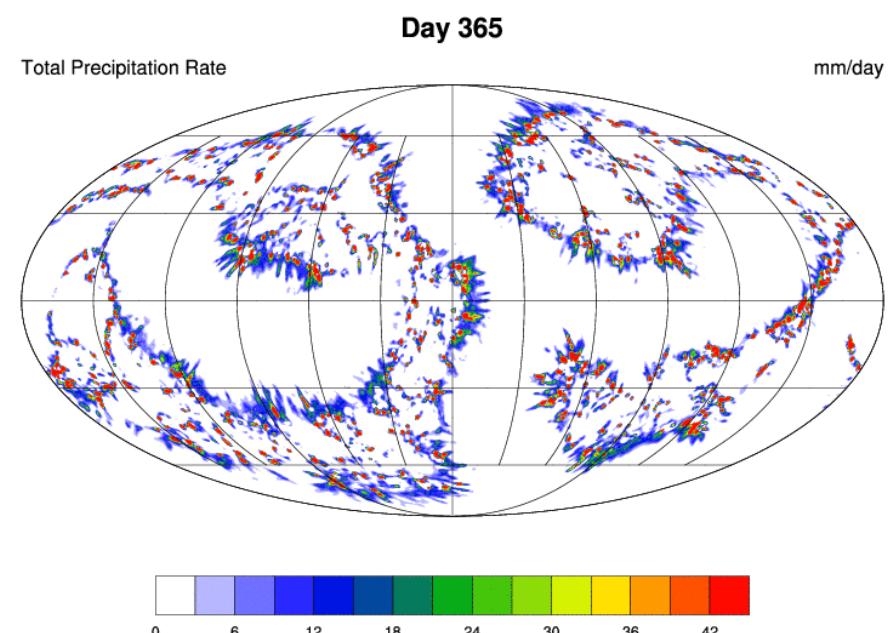


# No Rotation: Resolution Comparison

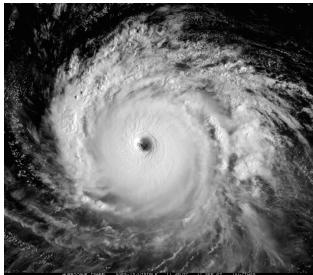
## 6-hr Avg. Precipitation (mm/day)



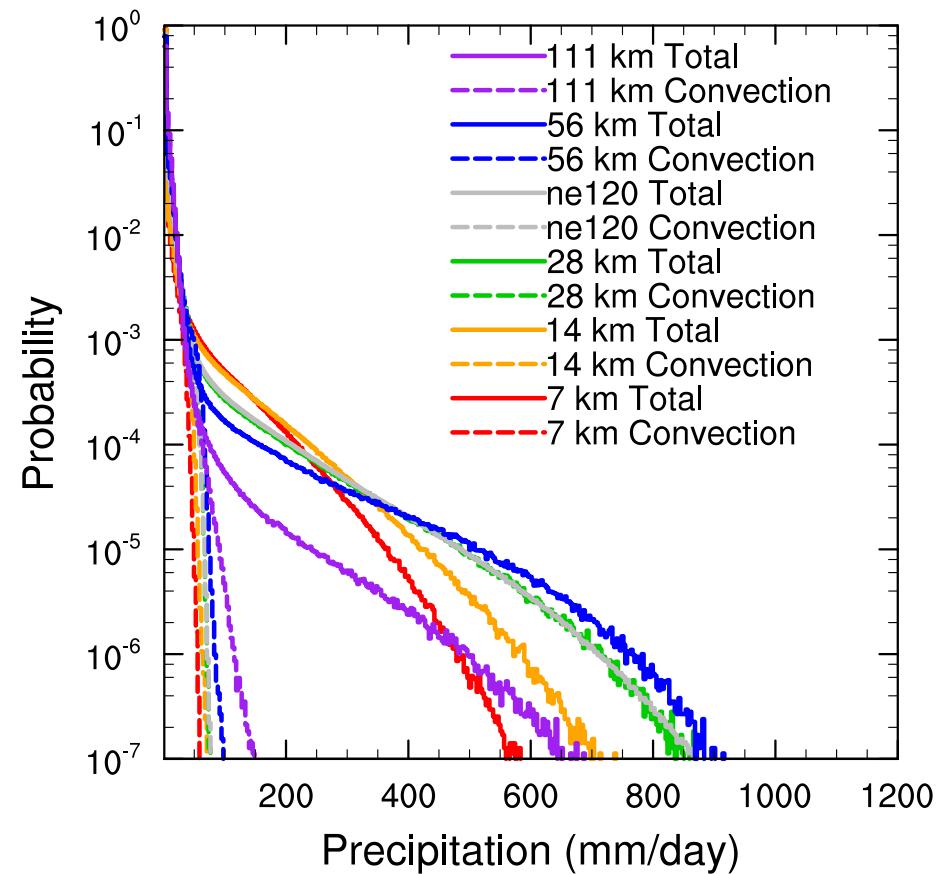
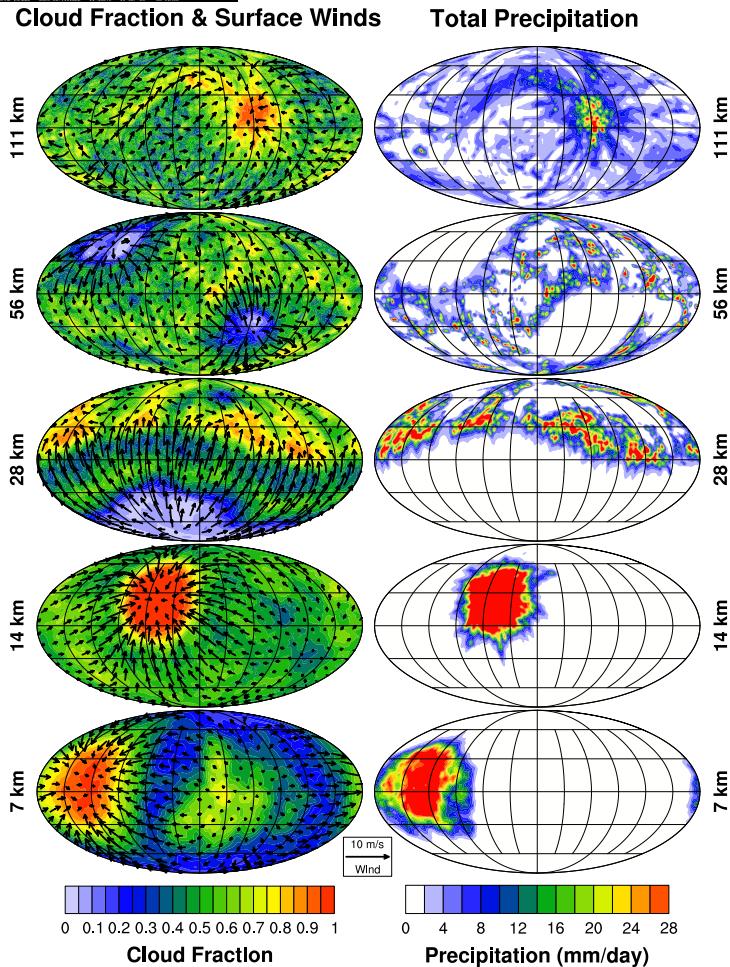
ne30 (~100 km)

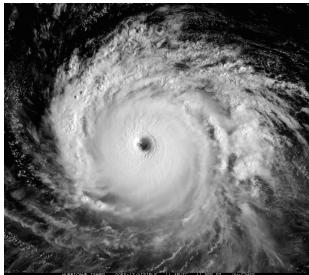


ne120 (~25 km)



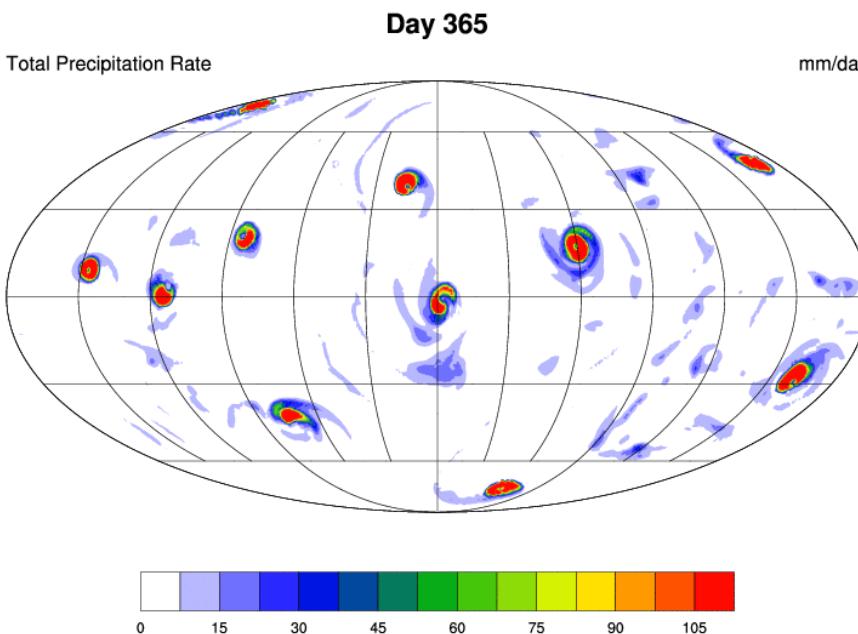
# Reduced Planet RCE



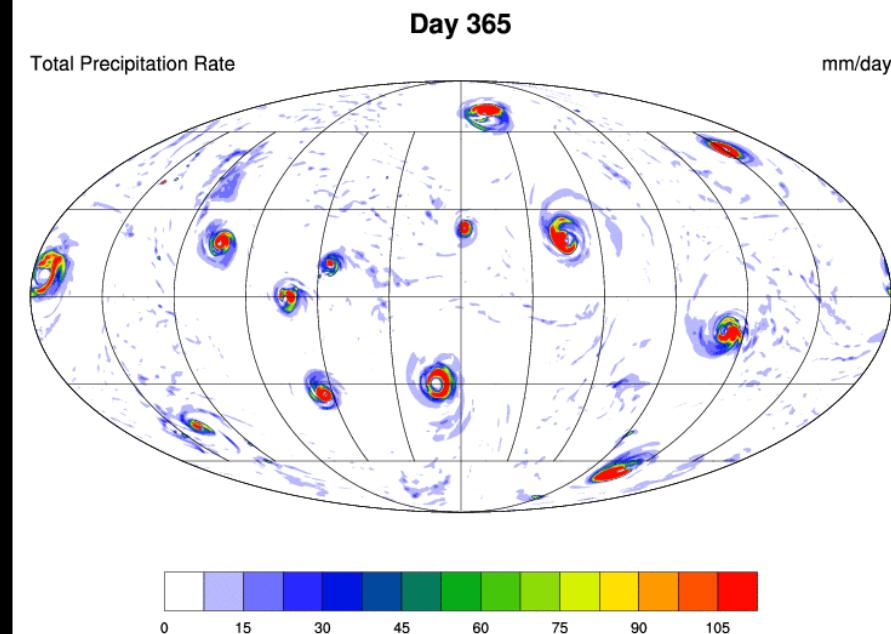


# Resulting TC World

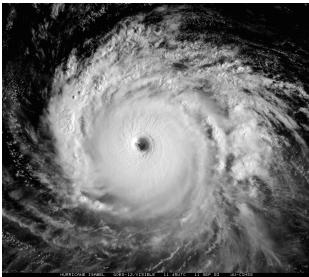
## 6-hr Avg. Precipitation (mm/day)



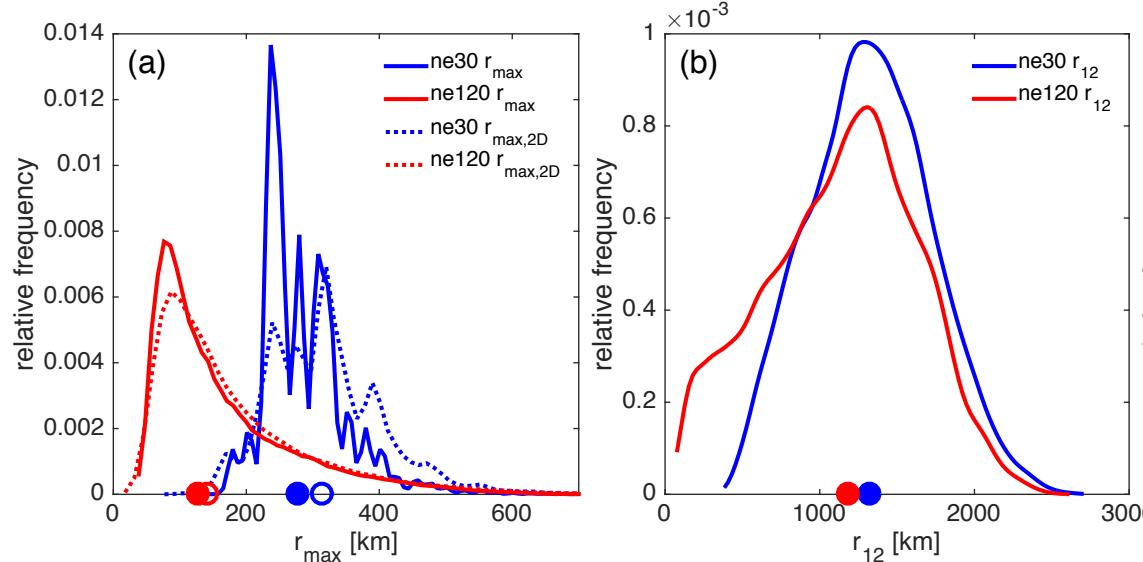
ne30 (~100 km)



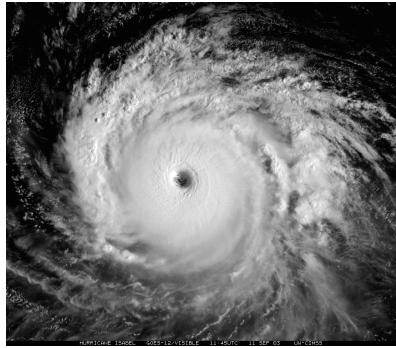
ne120 (~25 km)



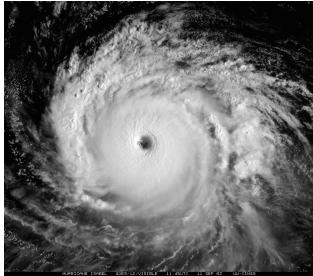
# TC Size Distributions



- The difference in  $r_{max}$  between the two resolutions is large.
- While the difference in the  $r_{12}$  distribution is not as large and with a consistent shape of the distributions.



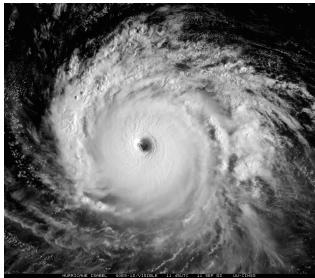
# Conclusions: Final Thoughts



# Final Thoughts

- The decadal simulations compare reasonably well to global hurricane counts. BUT, there are still **biases**.
- As the climate warms the **number** of tropical cyclones **decreases**. However, the **most intense storms become more intense**.
- Decadal **ensemble** simulations start to shed light on **regional** changes in tropical cyclone distributions, but the magnitude of changes is still **uncertain** and depends on the pattern of future sea surface temperatures.
- Others are applying these **high-resolution approaches** to other extreme events!

**[kevin.a.reed@stonybrook.edu](mailto:kevin.a.reed@stonybrook.edu)**



# Thank You

