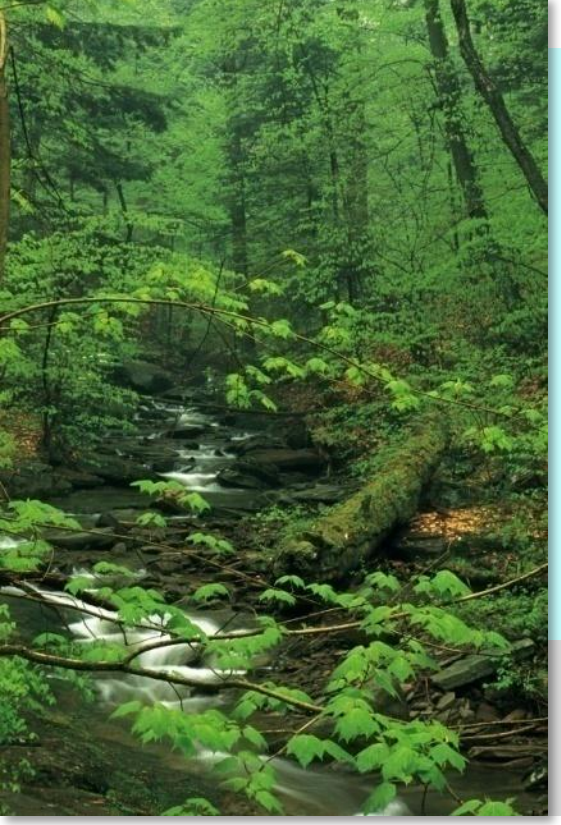


Climate Change Research: Recent Findings and New Directions

Don Wuebbles

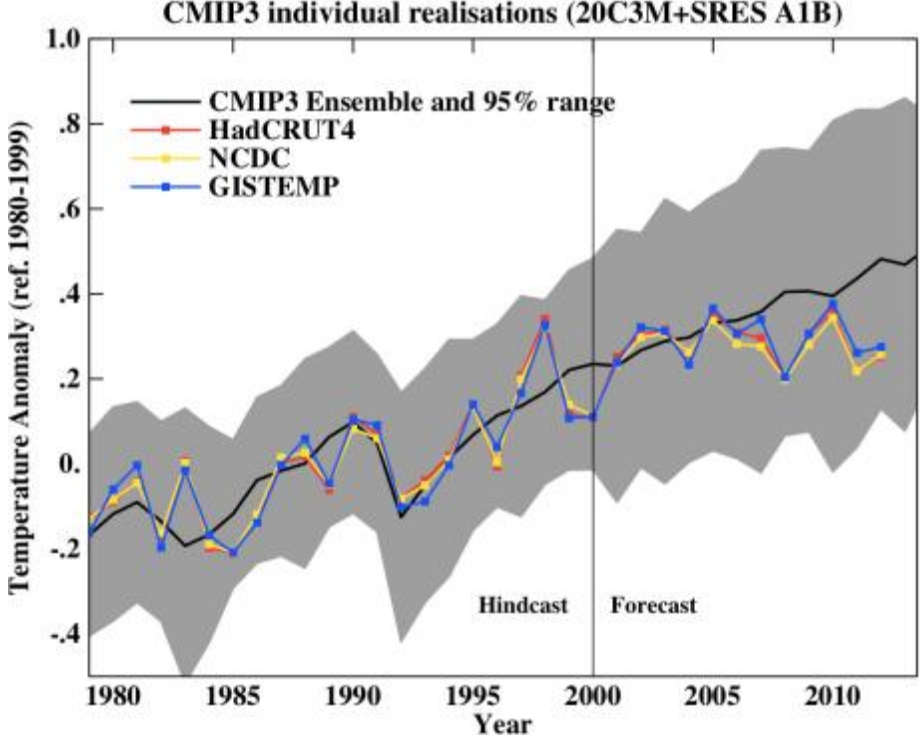
Department of Atmospheric Sciences

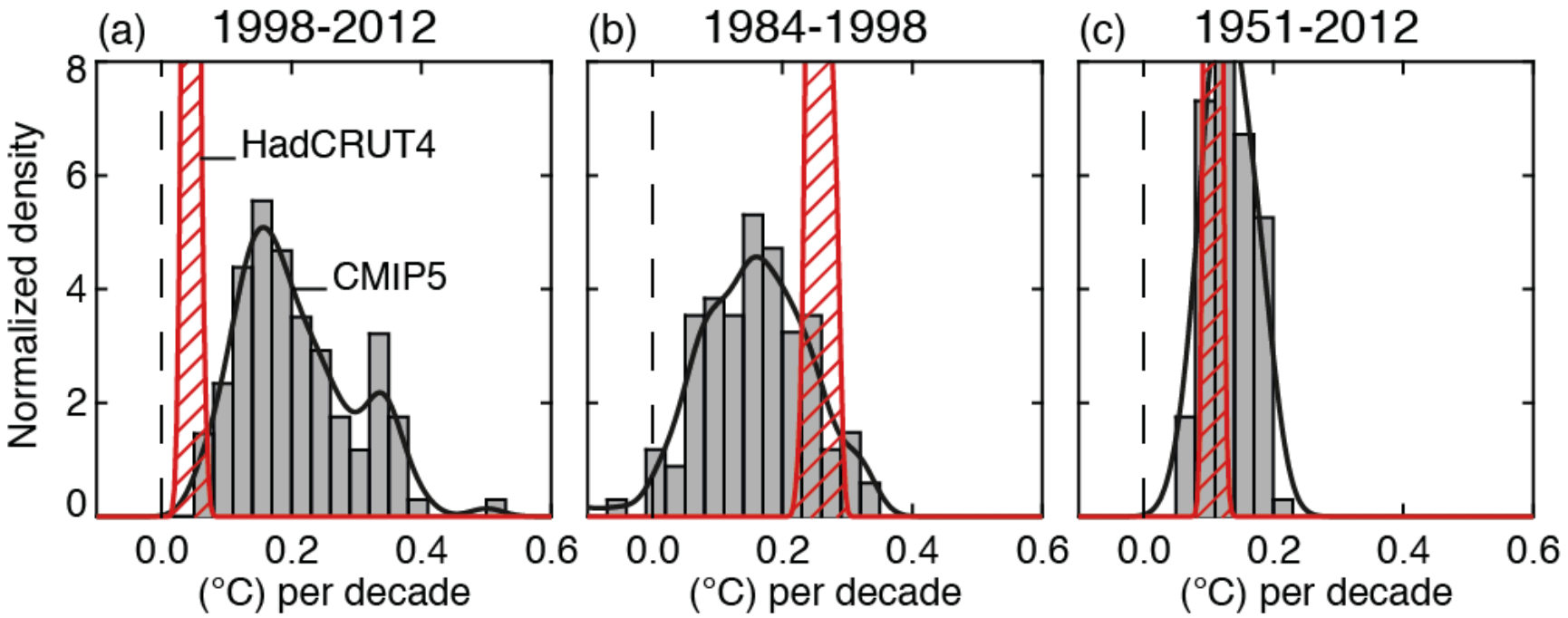
University of Illinois, Urbana

The Next 5 Years: Some Key Issues in Climate Science

- Will we understand the hiatus in temperature?
- Where will modeling of the Earth's Climate System be at?
- What is the climate sensitivity?
- Will we have a better understanding of sea level rise during this century? Contribution from Greenland and Antarctica?
- How rapidly will the Arctic Sea ice melt and how does this affect us?
- How will severe weather events affect us? (Ken)

The Hiatus in Temperature Change



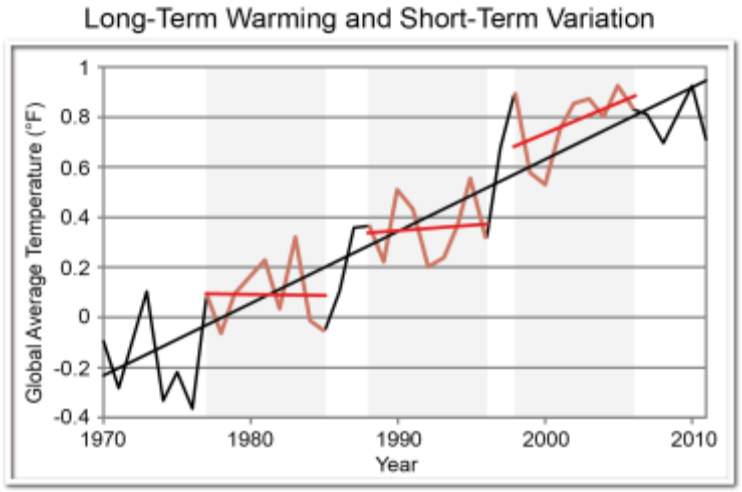


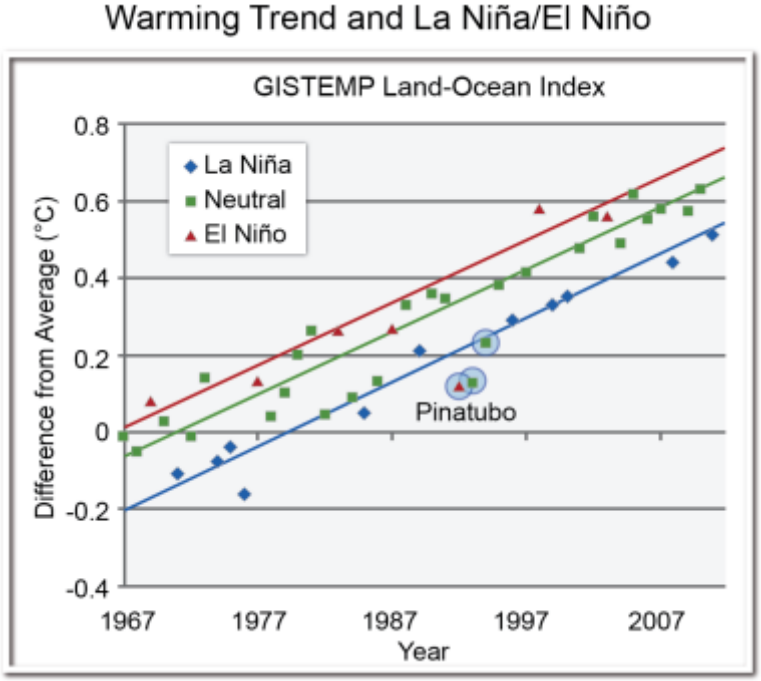
Why the Hiatus?

- Seen before; part of natural variability
- More energy during this period going to deep ocean

Models do not consider:

- Timing of El Niños / La Niñas
- Decrease in solar flux
- Recent smaller volcanic eruptions
- Different timing for longer natural ocean cycles

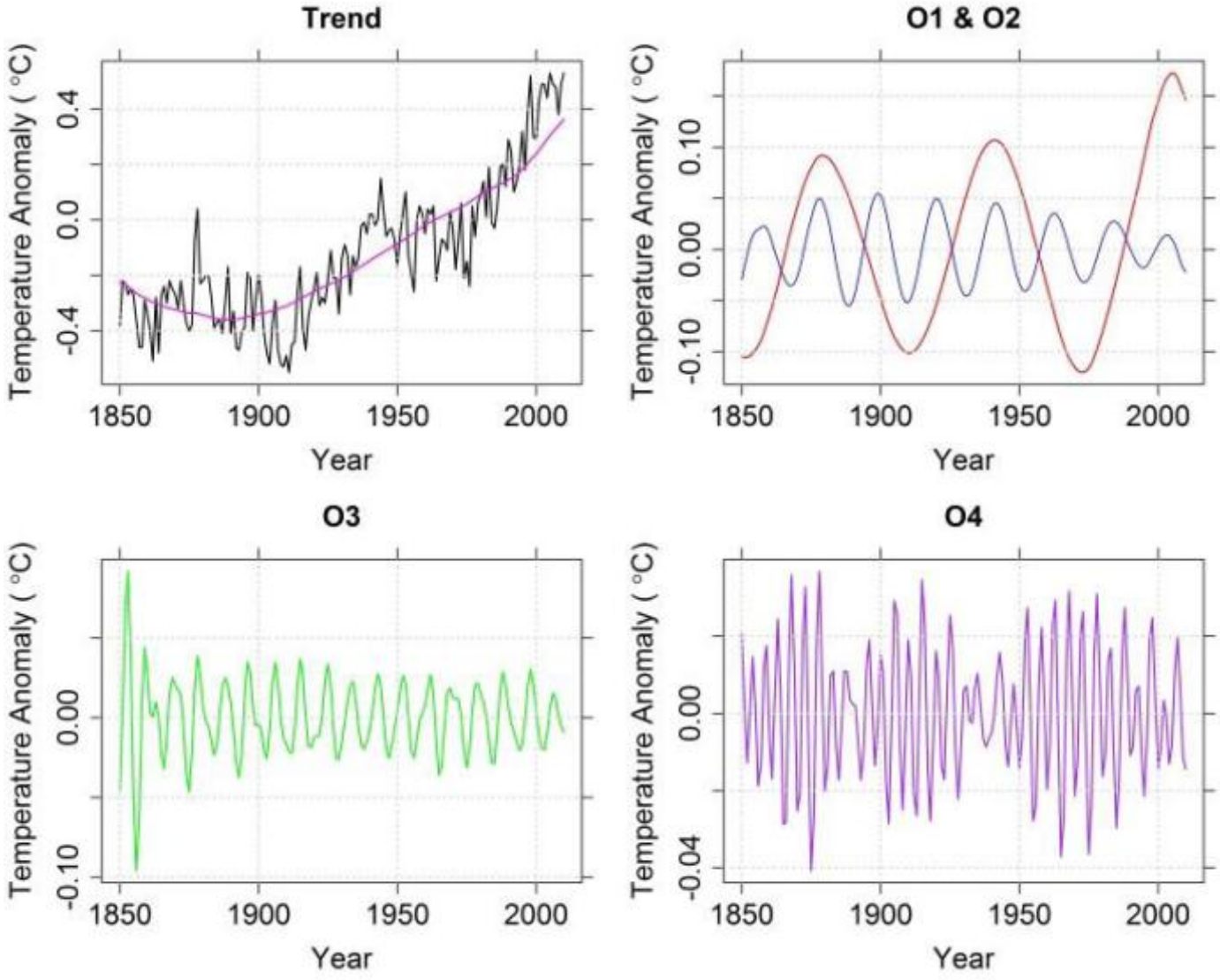




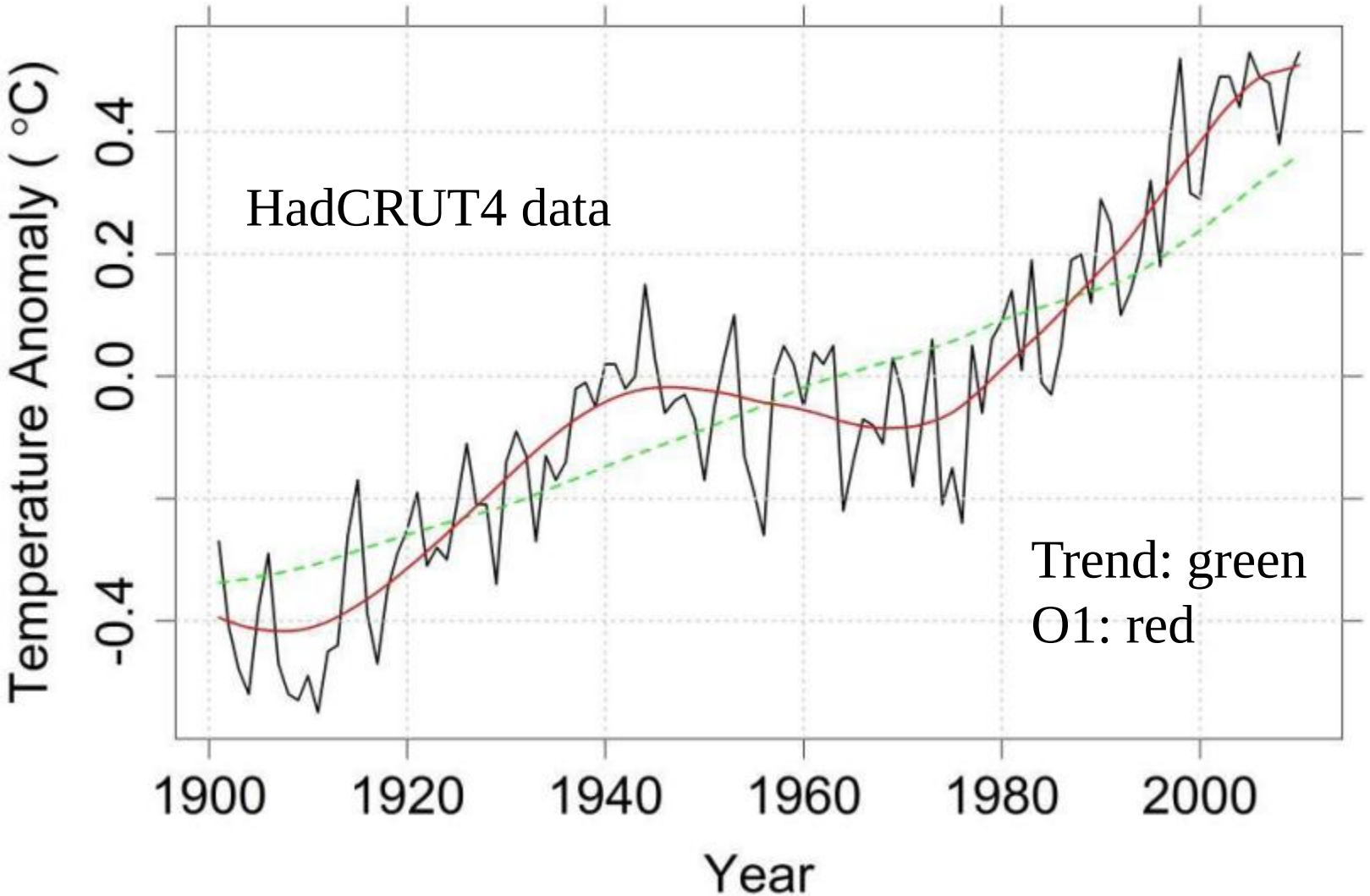
Lindner (2013): Quasi-Periodic Oscillations in HadCrut4

Periodicity
O1: 61 yrs;
O2: 21 yrs;
O3: 9 yrs;
O4: 5 yrs
O5: 4 yrs

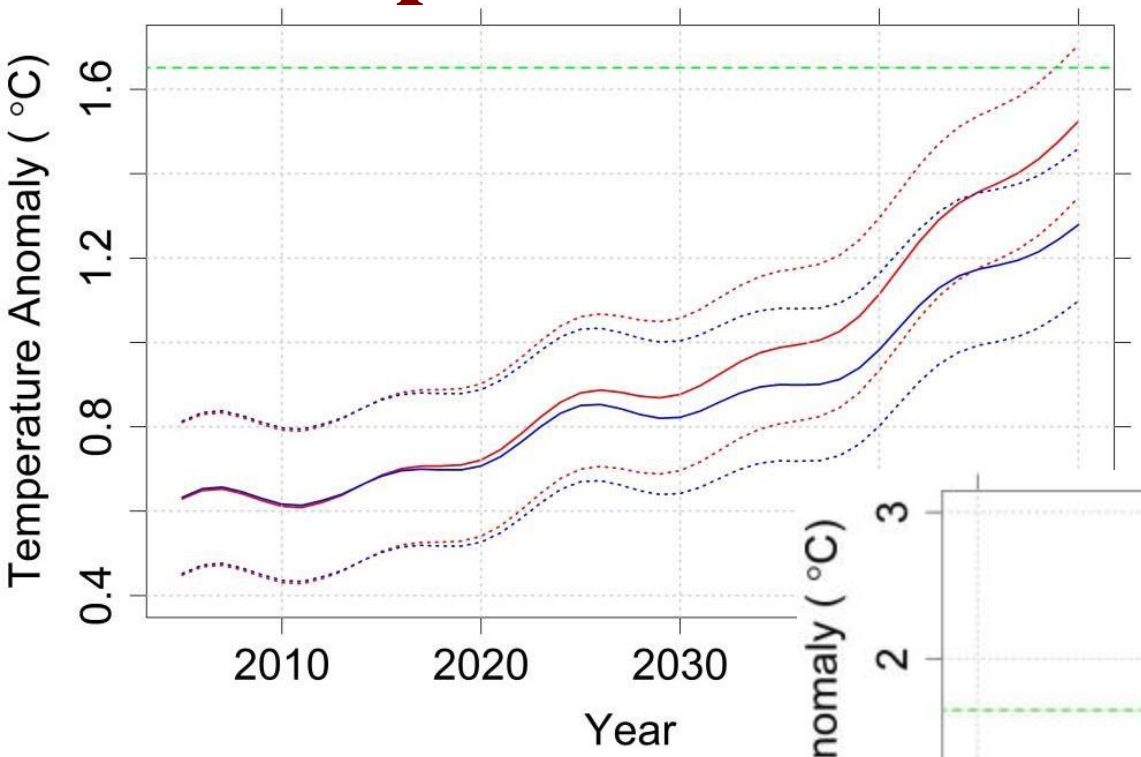
Uses Singular Spectrum Analysis



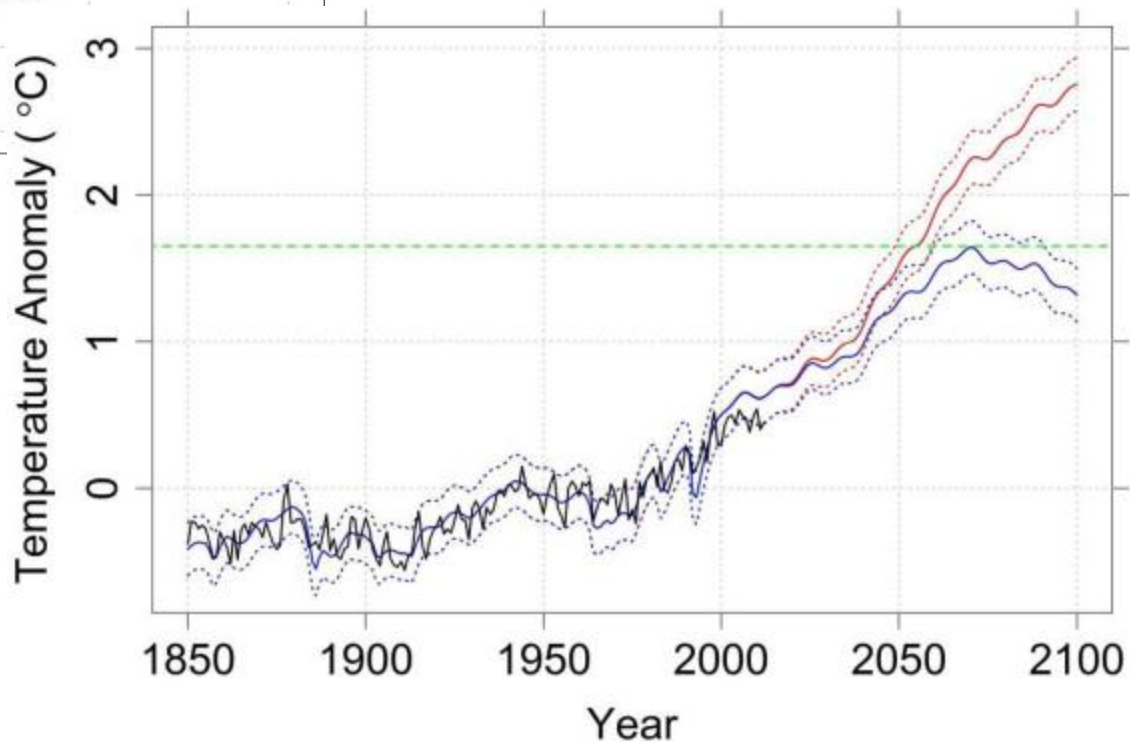
Lindner (2013): QPO Can Largely Explain the Hiatus



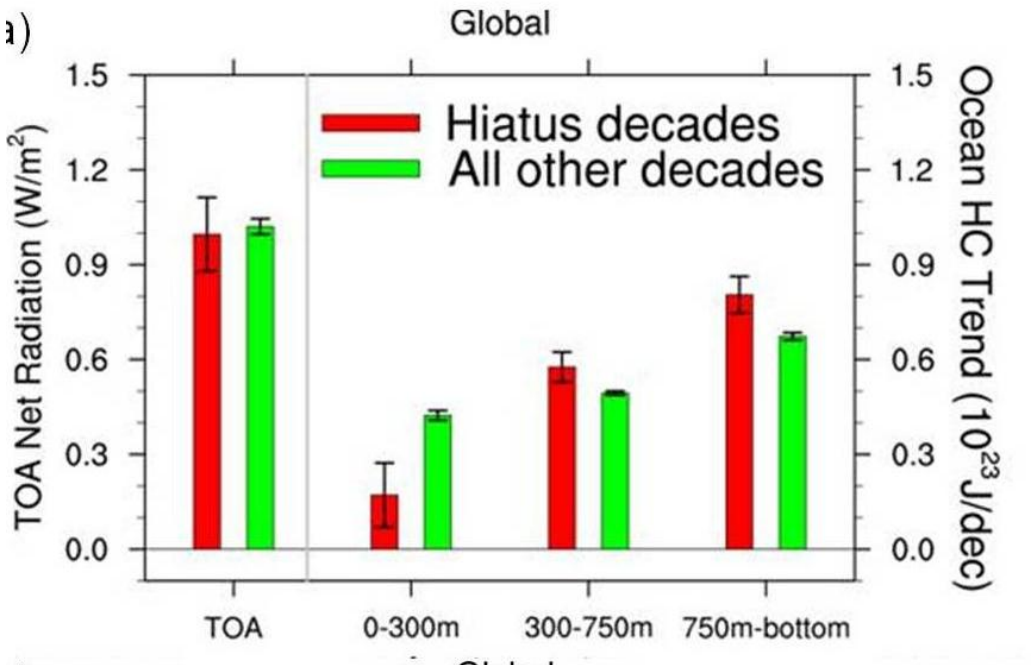
QPO: Hiatus to ~2020, then Temperature Increases Rapidly

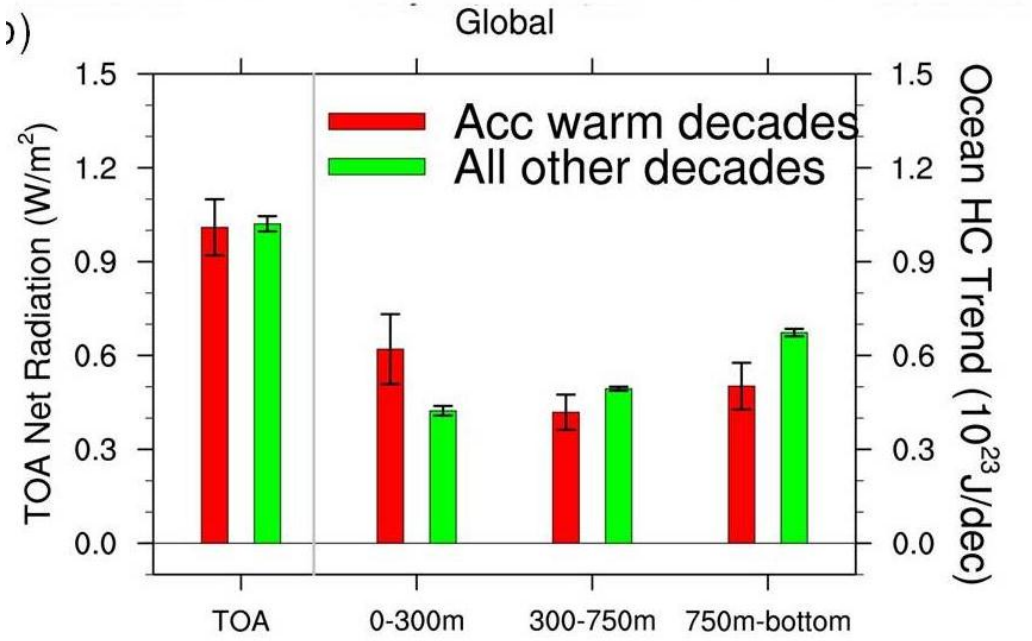


Two Scenarios:
Red: RCP8.5
Blue: FP2 Mitigation
(Schesinger et al, 2013)



Results from Lindner (2013) PhD thesis





Decadal "hiatus" periods in CESM

In hiatus decades, heat content trend is largest in the deeper ocean (negative IPO with stronger Pacific subtropical cells, weakened Antarctic Bottom Water formation and AMOC)

In accelerated warming decades, heat content trend is largest in upper ocean

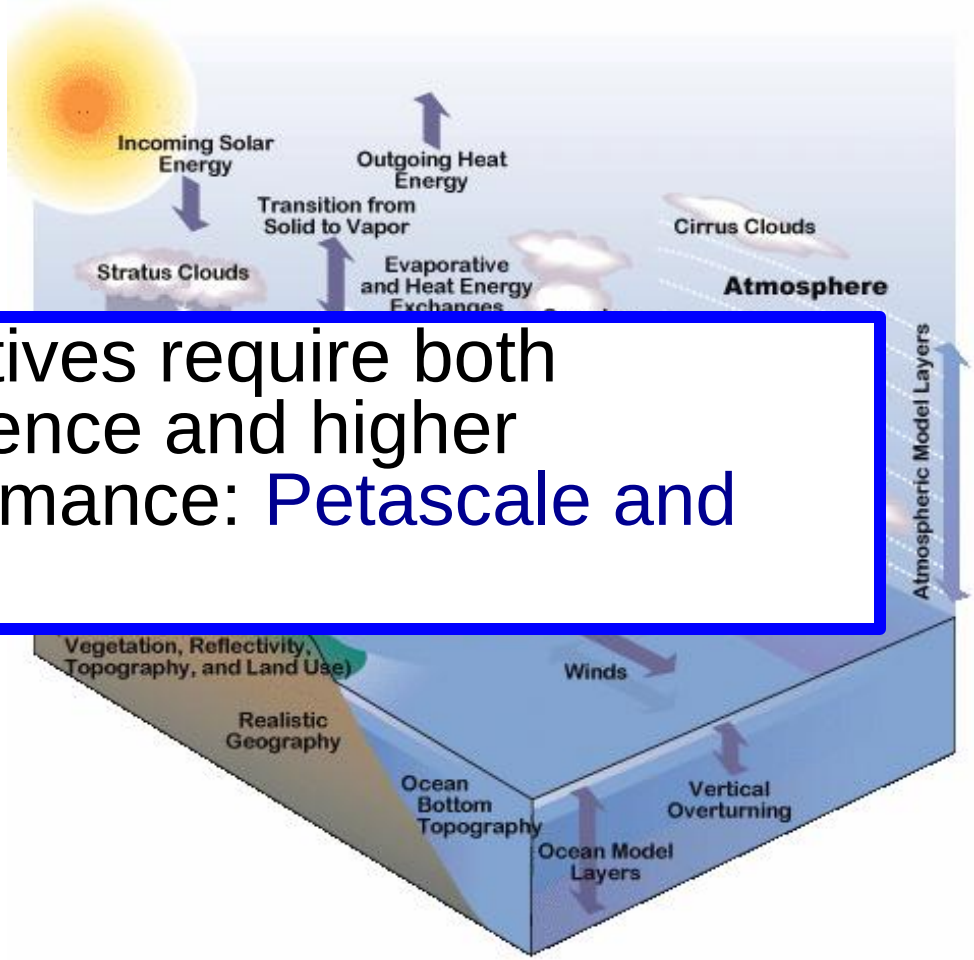
(positive IPO with weaker Pacific subtropical cells, strengthened Antarctic Bottom Water formation and AMOC)

(Meehl et al., 2011; Meehl et al., 2013, J. Climate)

Modeling the Earth's Climate

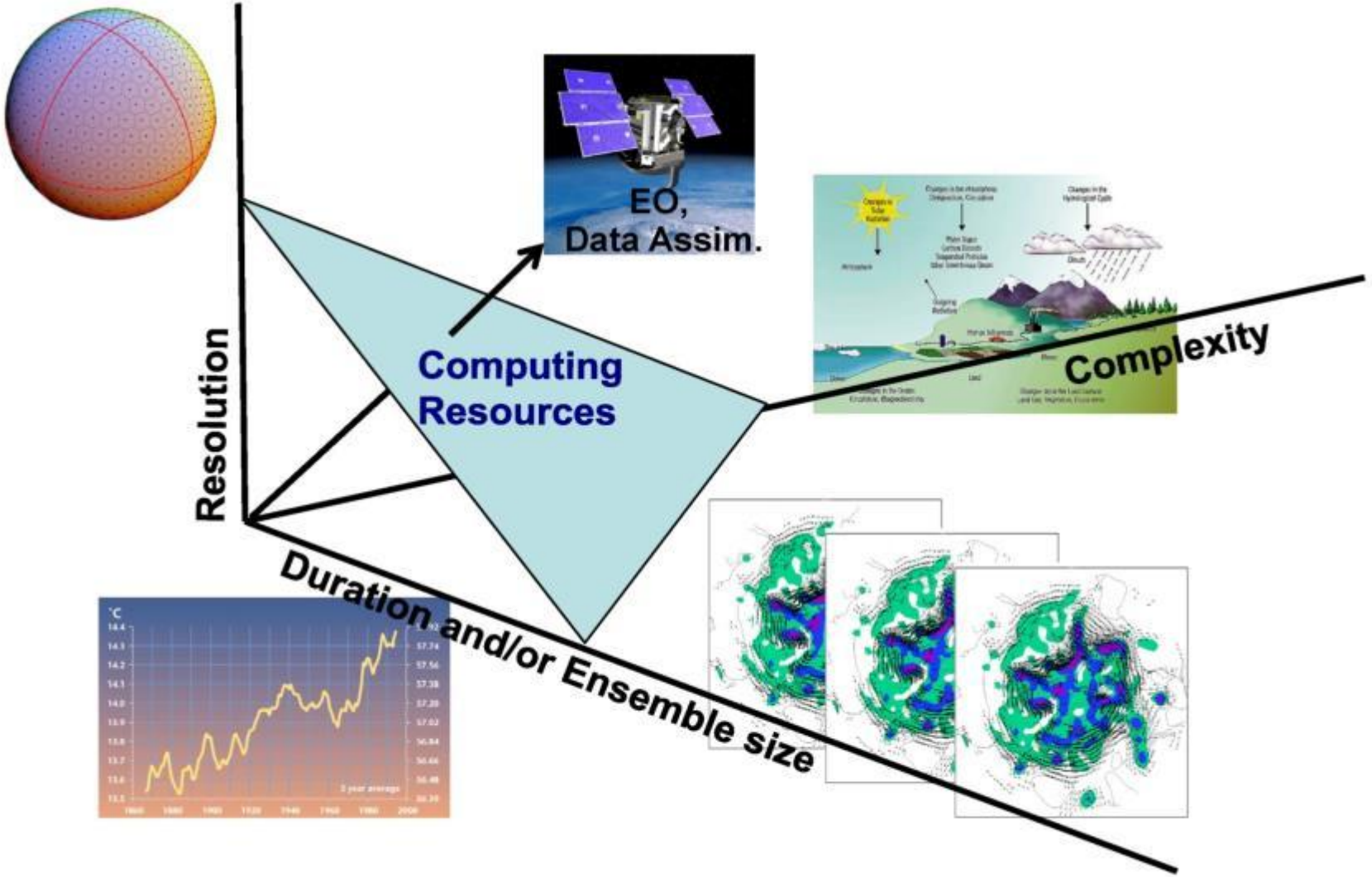
- Our environment is subject to long term changes like increases in land and ocean temperatures
- Our changing climate is responsible for an increased likelihood for severe events that can have dramatic societal and economical impact
- The ob… to und… evoluti…
- And to establish models that can effectively project future changes in our our climate
- To be more accurate and reduce uncertainties, climate models need higher resolution and more/better components that influence climate.

Earth System Models



Meeting these objectives require both enhanced model science and higher computational performance: Petascale and Beyond

Petascale and Beyond: Substantial computing resources required for multi-decadal climate studies

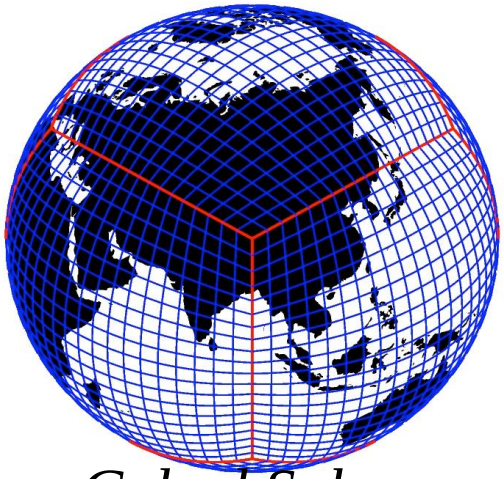


New Dynamical Cores for High Resolution

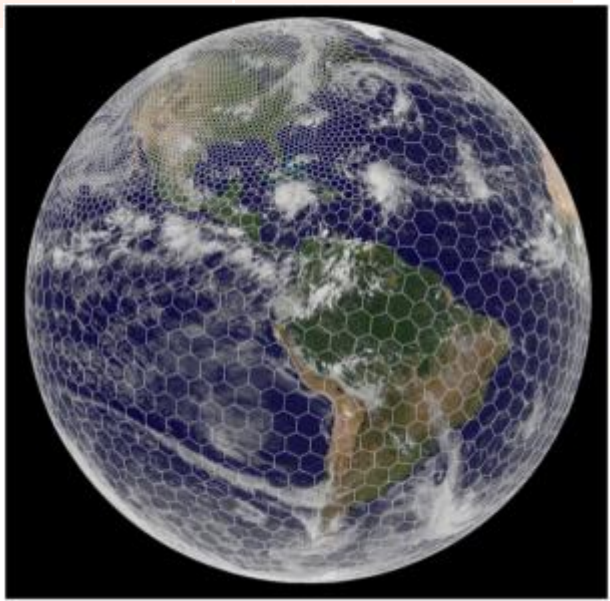
Near-term CAM dynamical-core developments
Strategy: separate dynamics and physics/tracer transport grids

CAM GRIDS	Low (3°)	Medium (2°)	High (1°)	Higher (1/4°)	Highest (1/8° and better
Spectral (w/CSLAM)	**X (T31x3)**	**X (T42x1)**			
FV (Finite Volume)		X	X		
SE (Spectral Element / HOMME)			X	X	X
MPAS non-hydrostatic			X	X	X

Regular lat-lon

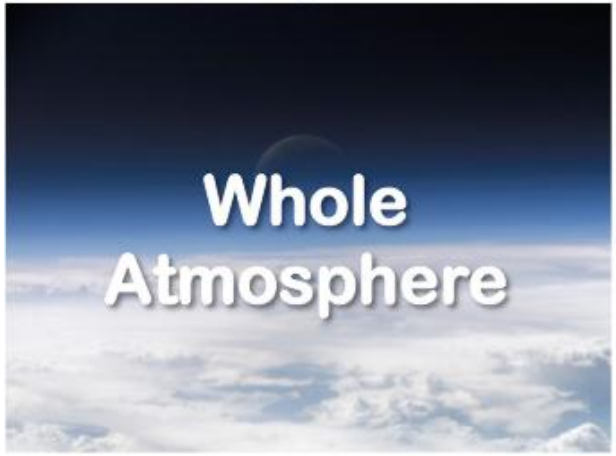


Cubed Sphere



Enhanced Treatment of All Climate Processes is a High Priority

Community Earth System Model



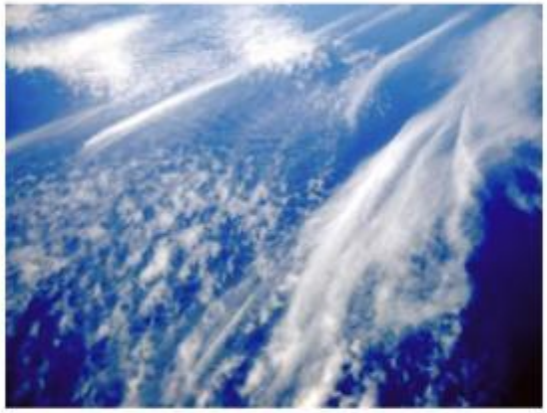
From Hurrell et al., 2013, BAMS

Defining Climate Science Issues Needing Petascale and Beyond

- **Want 10 km or finer; Need regional scale for impacts / adaptation analyses**
  - Enhanced understanding of effects on human and natural systems
  - Existing results suggest increased accuracy w/ high resolution
  - Large number of ensembles needed to detect signal from natural variability
  - Next generation models will improve treatment of surface hydrology, agriculture, and urban environs

Global Cloud System Resolving Climate Modeling

Direct simulation of cloud systems replacing statistical parameterization.



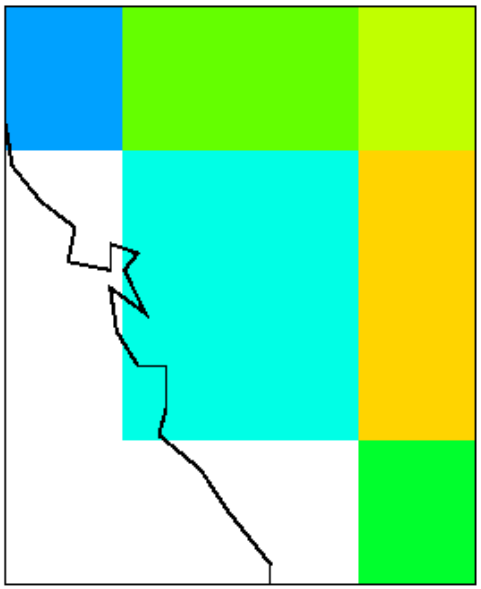
Individual cloud physics fairly well understood

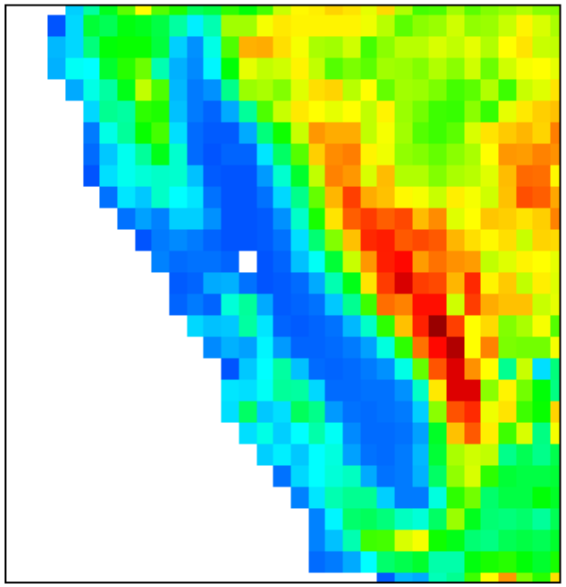
Parameterization of mesoscale cloud statistics performs poorly.

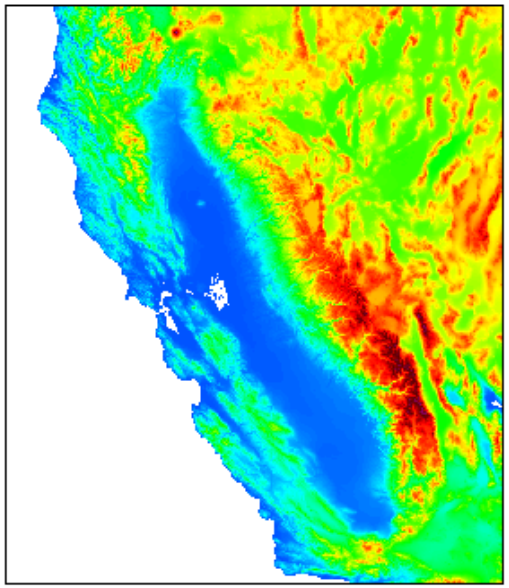
Direct simulation of cloud systems in global models requires exascale!

Global Cloud System Resolving Models are a Transformational Change

Surface Altitude (feet)







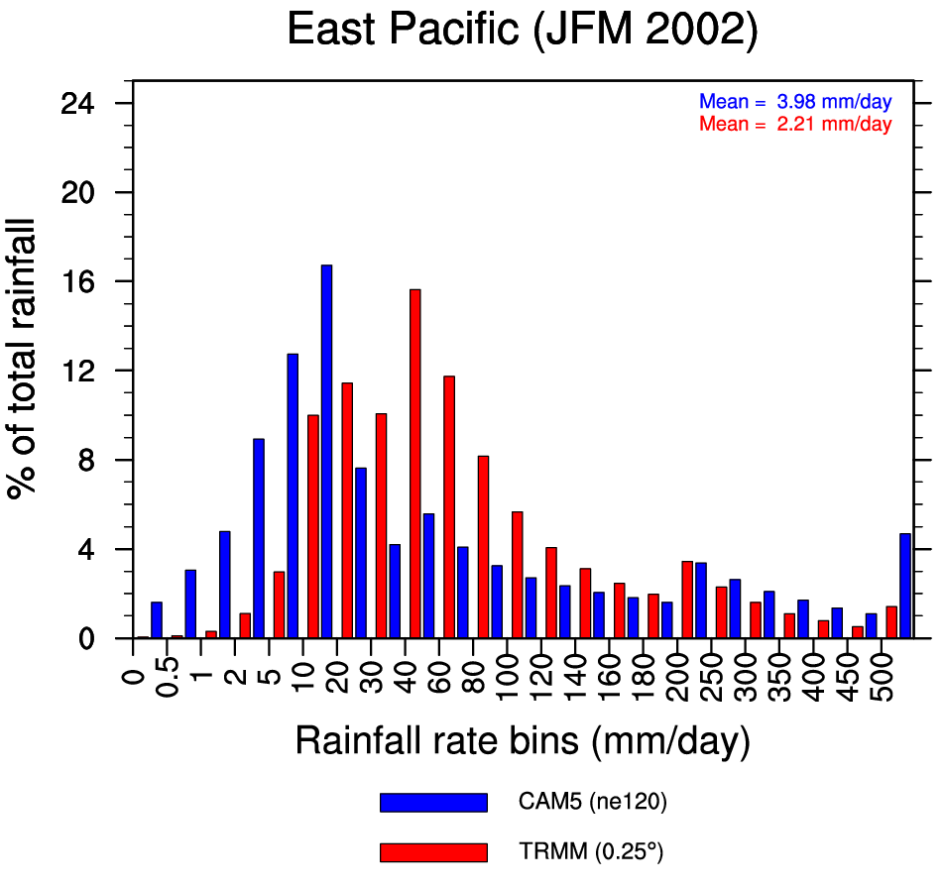
200 km
Typical resolution of IPCC AR4 models

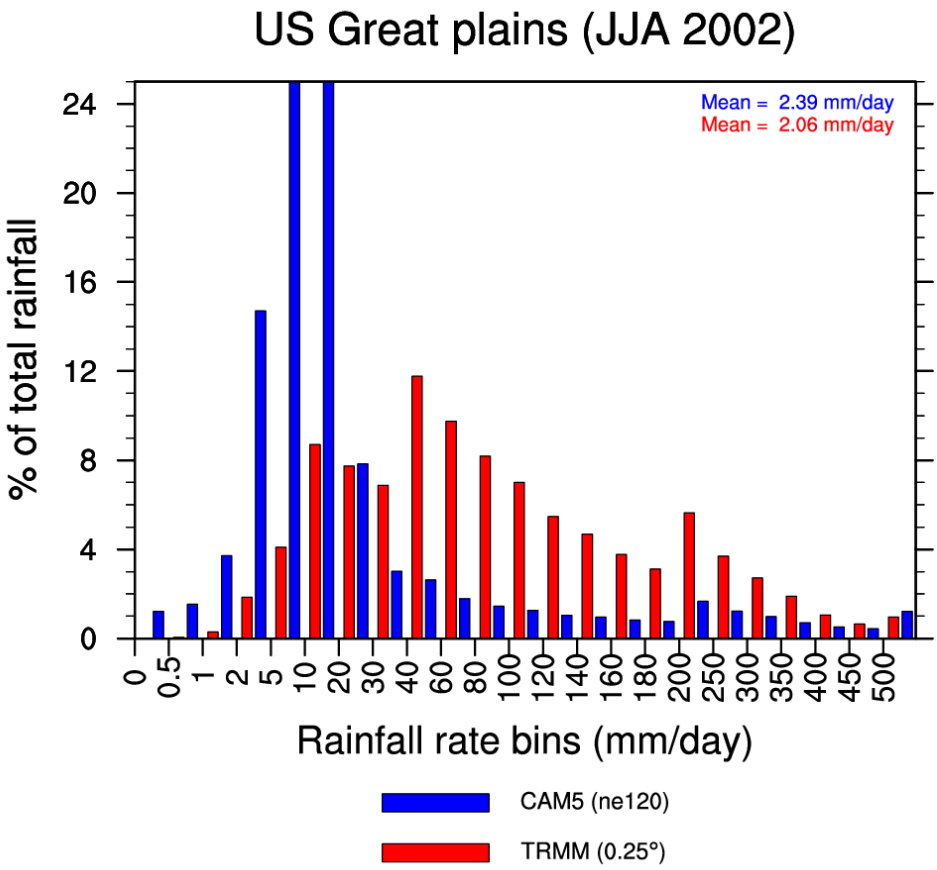
25 km
Upper limit of climate models with cloud parameterizations

1-2 km
Cloud system resolving models

CESM1 Bias in Rainfall Frequency

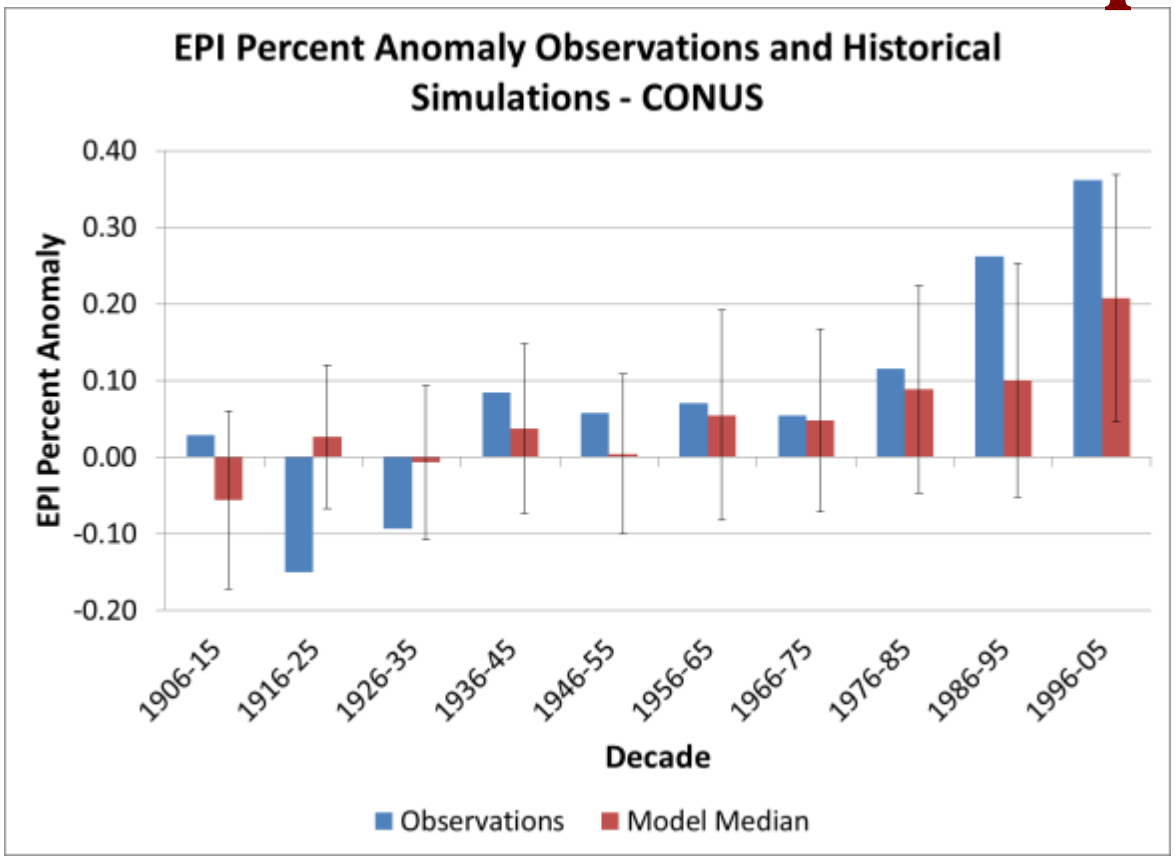
Common bias for many regions and most/all models: Too much light rainfall, not enough heavy





Courtesy of Rich Neale

CMIP5 Models: Underestimate Trends in Severe Precipitation



- Positive trend in observed EPI anomalies over the past 4 decades
- Multi-model median of CMIP5 simulations shows an increasing trend in EPI anomalies over last 4 decades
  - Smaller than observed
  - Standard deviation between models large

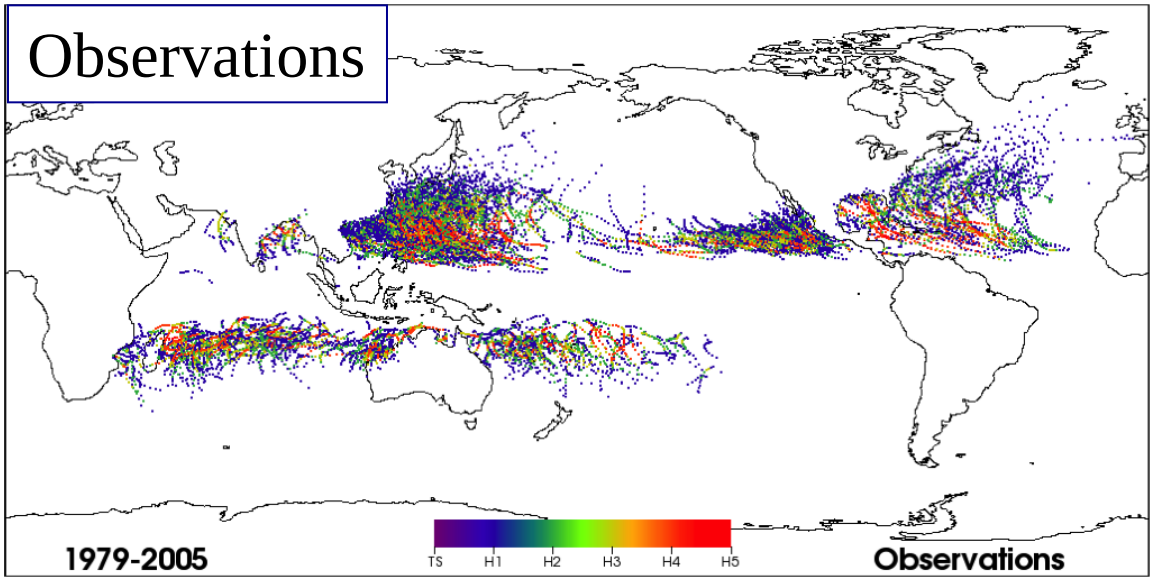
- 2day duration 5year return
  - EPI calculated annually for 1901-2005,
  - Decadal averages calculated for 1906-2005

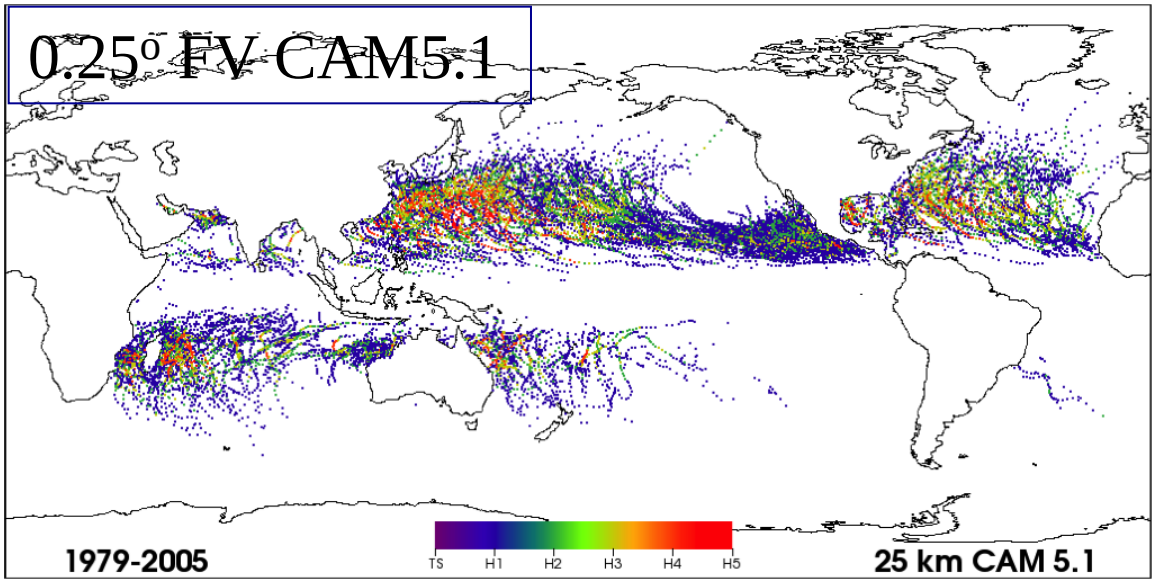
CESM On Blue Waters

Using NCSA Blue Waters (Petascale)

- **UIUC/NCAR project with NSF to run CESM1 at 0.25° (~25 km) resolution**
- **100 years in past and 100 years future**
- **Multiple realizations (ensembles)**
- **Also will be doing uncertainty analyses to enhance understanding of radiative-cloud-aerosol interactions**

Projected Changes in Tropical Cyclones

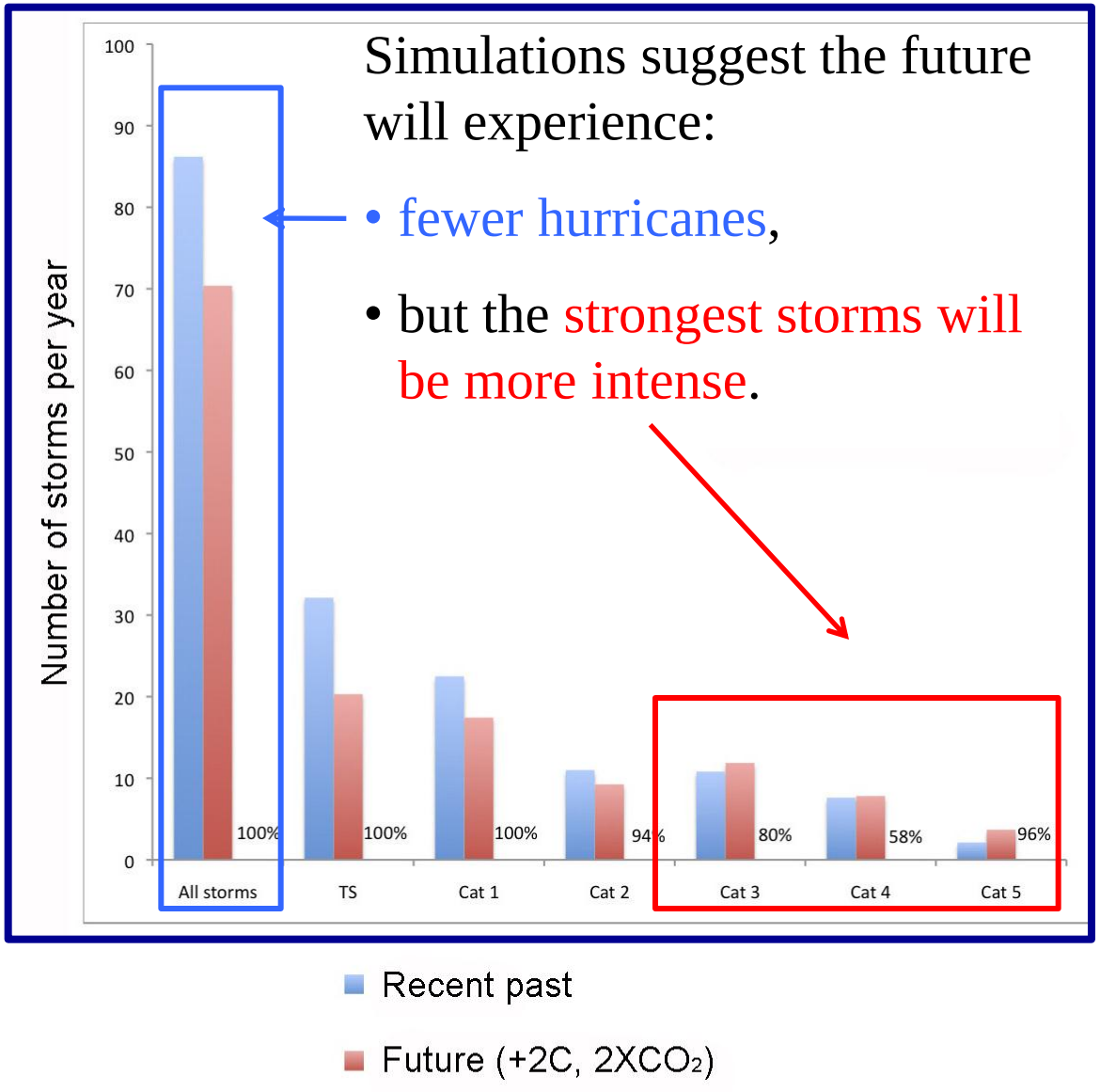




High resolution (0.25º) atmosphere simulations produce an excellent global hurricane climatology

Courtesy of
Michael Wehner, LBNL

Projected Changes in Tropical Cyclones



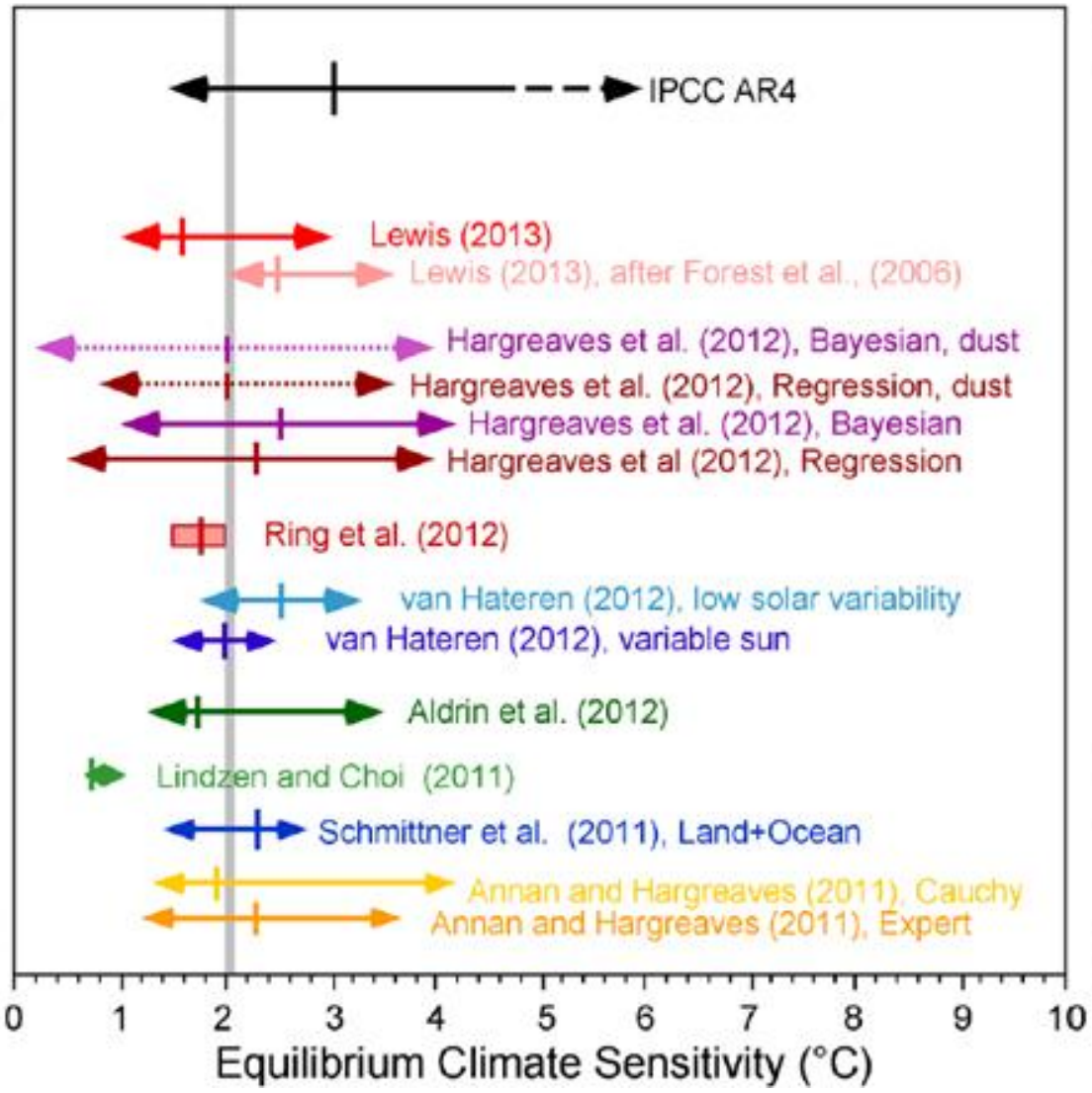
High resolution (0.25º) atmosphere simulations produce an excellent global hurricane climatology

Courtesy of
Michael Wehner, LBNL

Is Climate Sensitivity Overestimated?

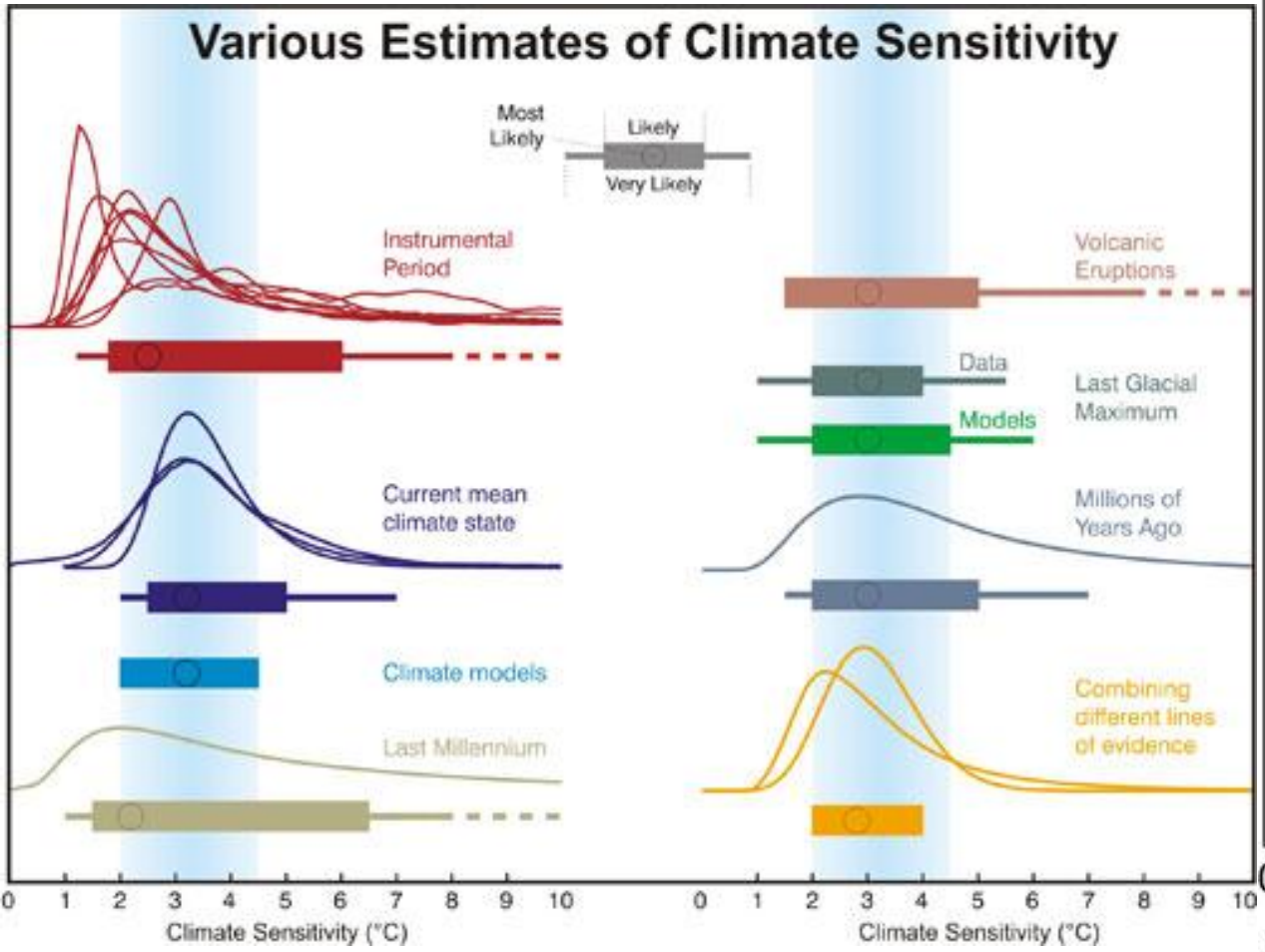
The Claim in the Blogs: “The IPCC’s "best estimate" (3.0° C) is 50% greater than the mean of recent estimates (2.0° C).”

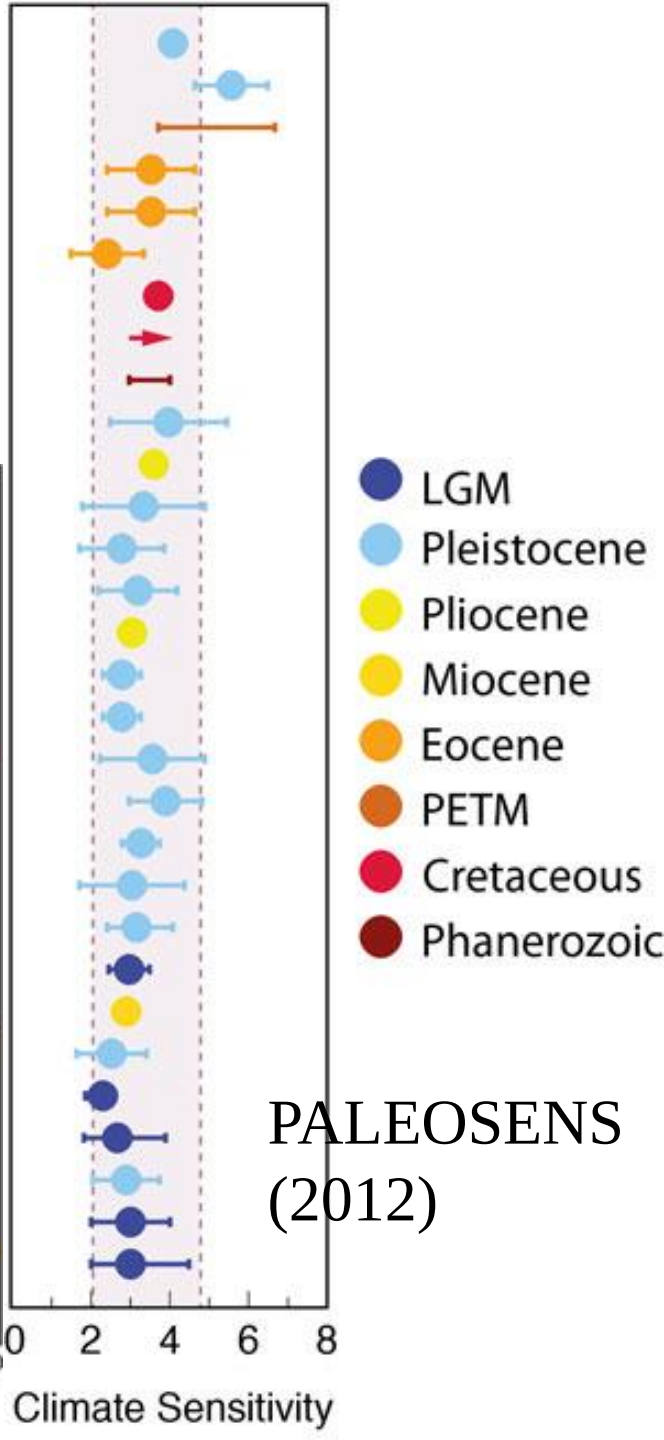
Started with paper by Lewis (2013): 1.6 K (1.0-3.0) using Bayesian analysis with MIT 2D model



Best Evidence: No Change in Climate Sensitivity

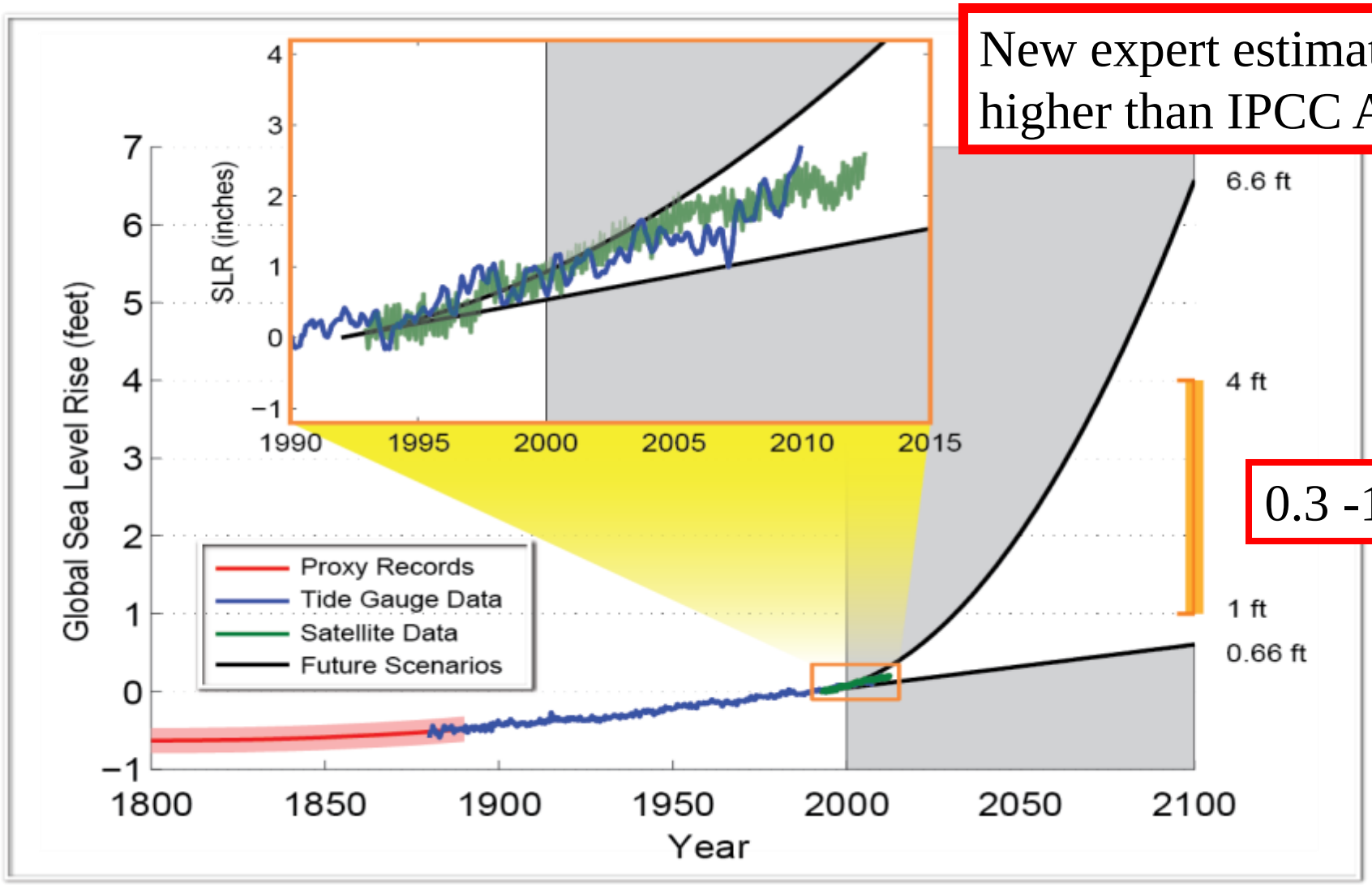
Knutti and Hegerl (2008)





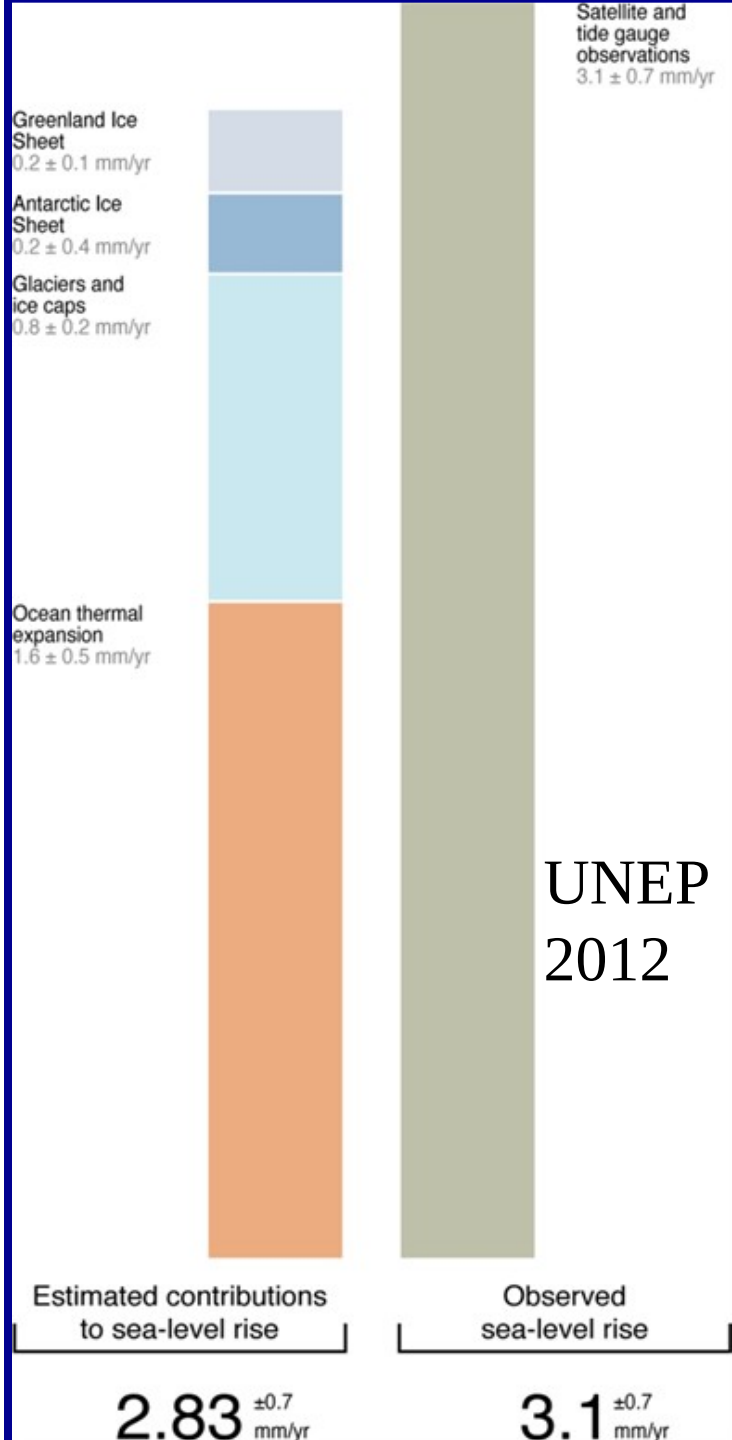
PALEOSENS (2012)

Sea Level Rise is Occurring Globally and is Likely to Continue to Rise



Sea Level Rise

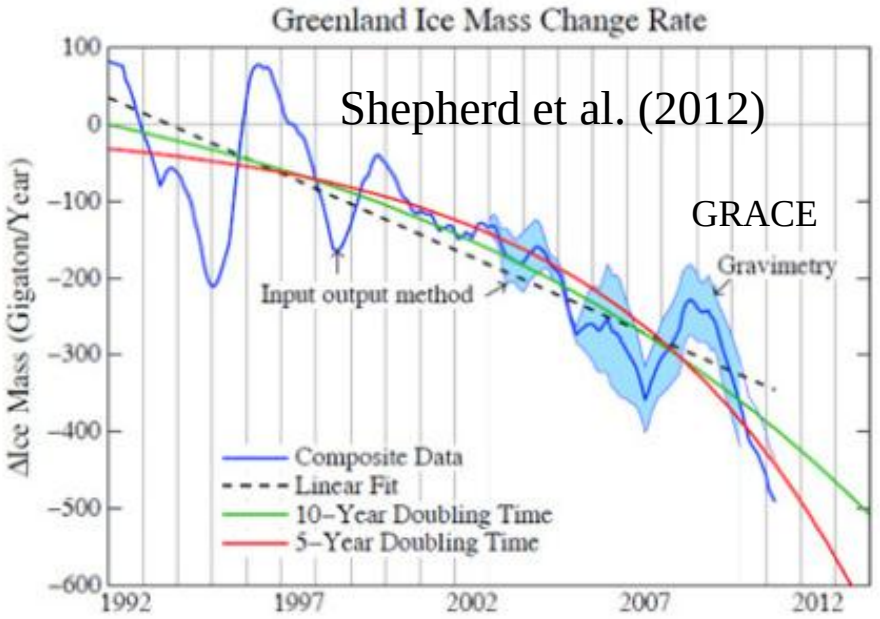
- To this point, thermal expansion and glaciers have been the largest contributors.
- The key to better projections will be understanding the role of the Greenland and Antarctic Ice Sheets



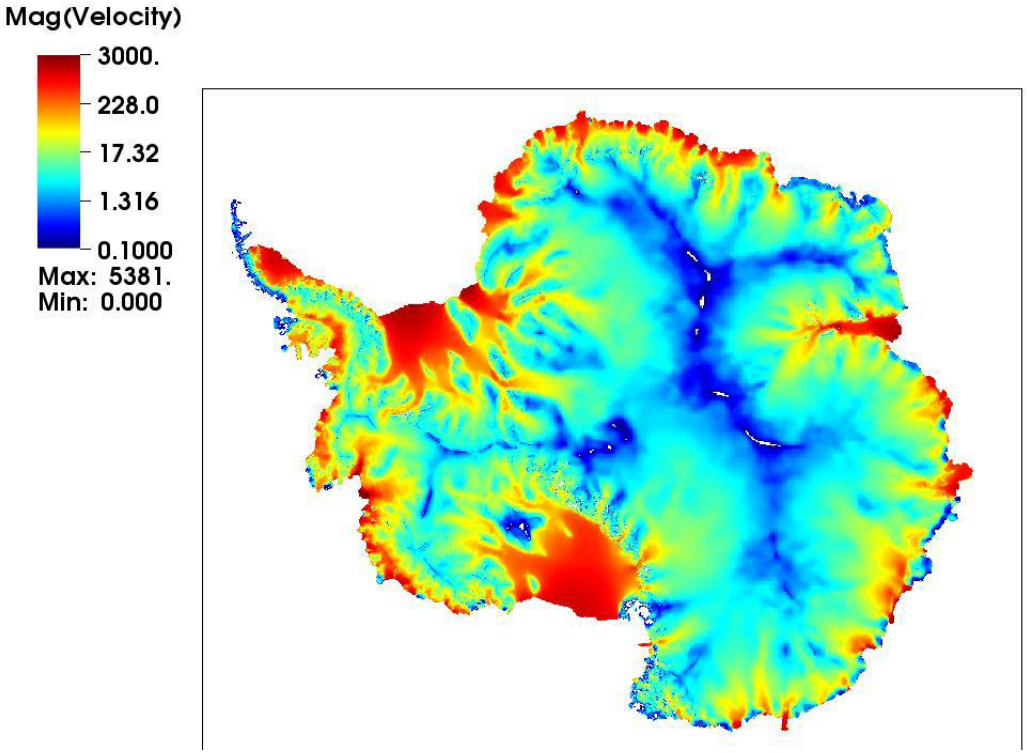
UNEP 2012

Projecting Changes in the Greenland and Antarctica Ice Sheets

- **Greenland**
  - Mass is being loss, but questionable as to how much can be loss during the 21st century
  - "Bumpiness" of terrain is an issue
- **Antarctica**
  - Major questions about potential large losses this century in West Antarctica
  - Depends on melting of the "flying buttresses"



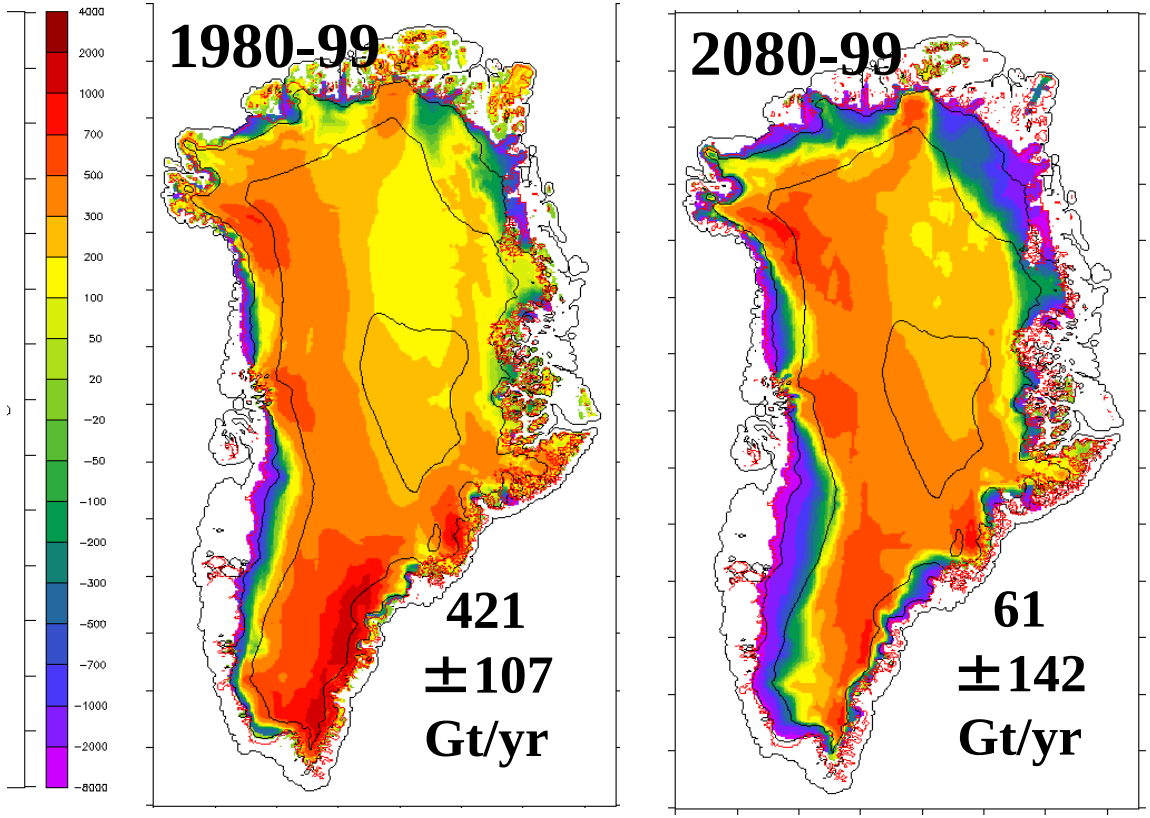
Next Generation in Climate Modeling: Community Ice Sheet Model (CISM)



Antarctic ice speed, BISICLES model (red = fast flow)

- NCAR testing scalable dynamical cores with higher-order ice flow
  - SEACISM dycore with Trilinos solvers
  - BISICLES dycore with adaptive mesh refinement
  - To be included in CISM 2.0, CESM 1.1

Slide courtesy of Bill Lipscomb



CESM1-CISM

Changing Ice Sheet Conditions

Community Ice Sheet Model (CISM)

Simulated Greenland surface mass balance (red = net growth, purple = net melting)

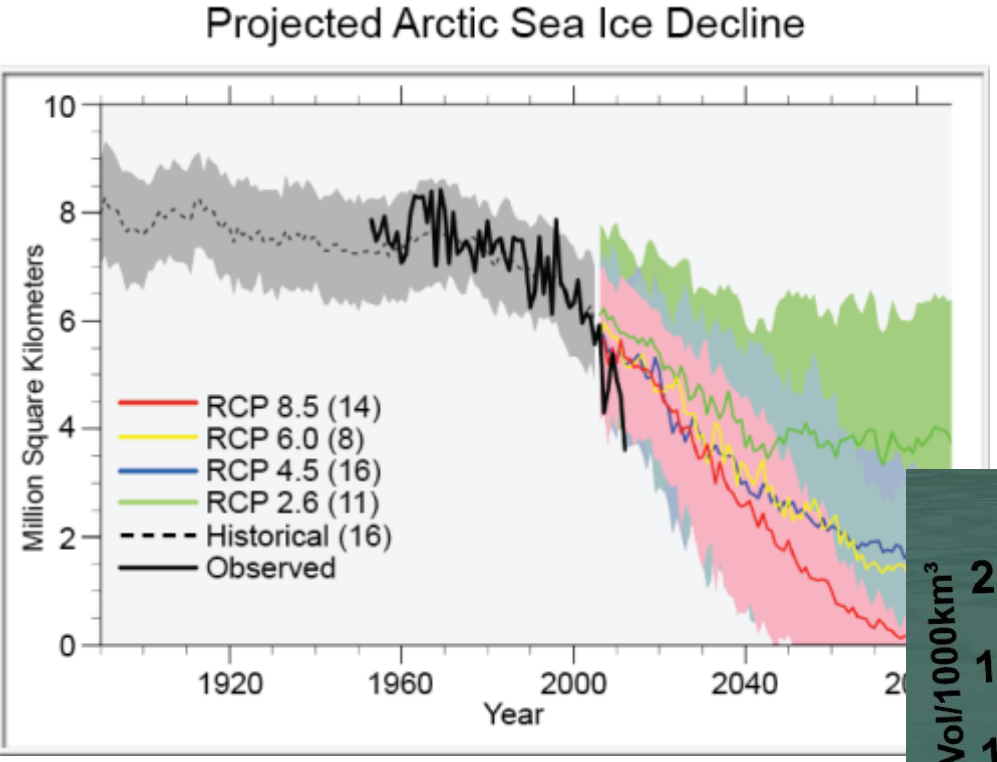
- Fully coupled CMIP5 simulations (preindustrial, 20th century, RCP8.5) with Greenland ice sheet model are completed
  - 20th century surface mass balance (SMB) agrees well with regional models
  - SMB approaches zero by late 21st century, implying long-term instability
- Ran 100-member spin-up ensemble to optimize Greenland ice sheet parameters for modern climate

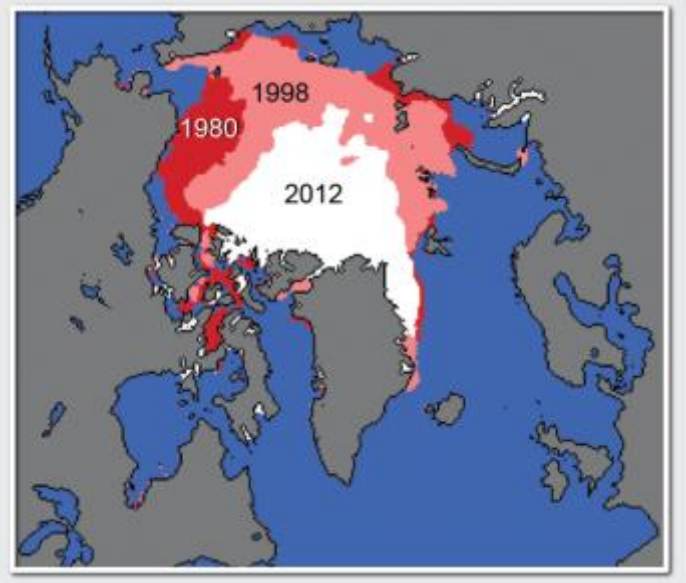
Slide courtesy of Bill Lipscomb

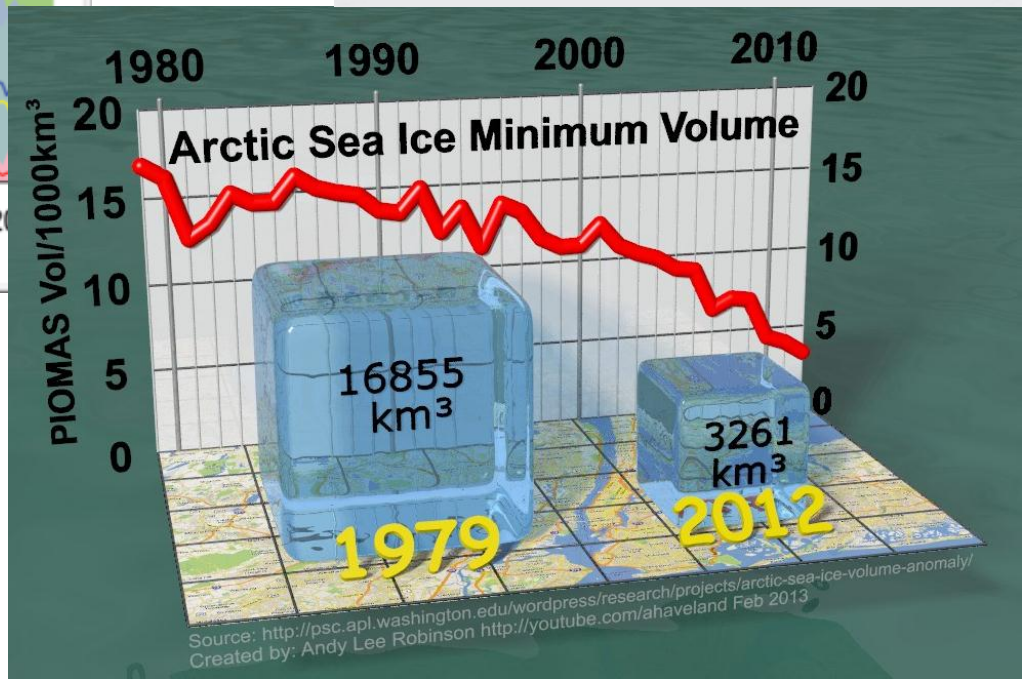
NAS Polar Research Board: Key issues for the Arctic

1. What are the relative roles of the ocean and the atmosphere in sea ice loss? Related: Why is there a difference between Arctic and Antarctic sea ice trends?
2. Will (and if so, how) will the loss of sea ice loss affect the large-scale atmospheric circulation and middle latitudes?
3. How rapidly will Greenland loss mass over the coming decades and centuries? (E.g., Impacts of the surrounding oceans on the outlet glaciers). Also Antarctica!
4. Will the Arctic's changing ice cover and ocean properties (e.g., salinity cap) impact the overturning circulation of the global ocean?
5. How will thawing permafrost (terrestrial and subsea) affect the releases of greenhouse gases (CO2 and methane)?

Models Tend to Underestimate Arctic Ice Loss



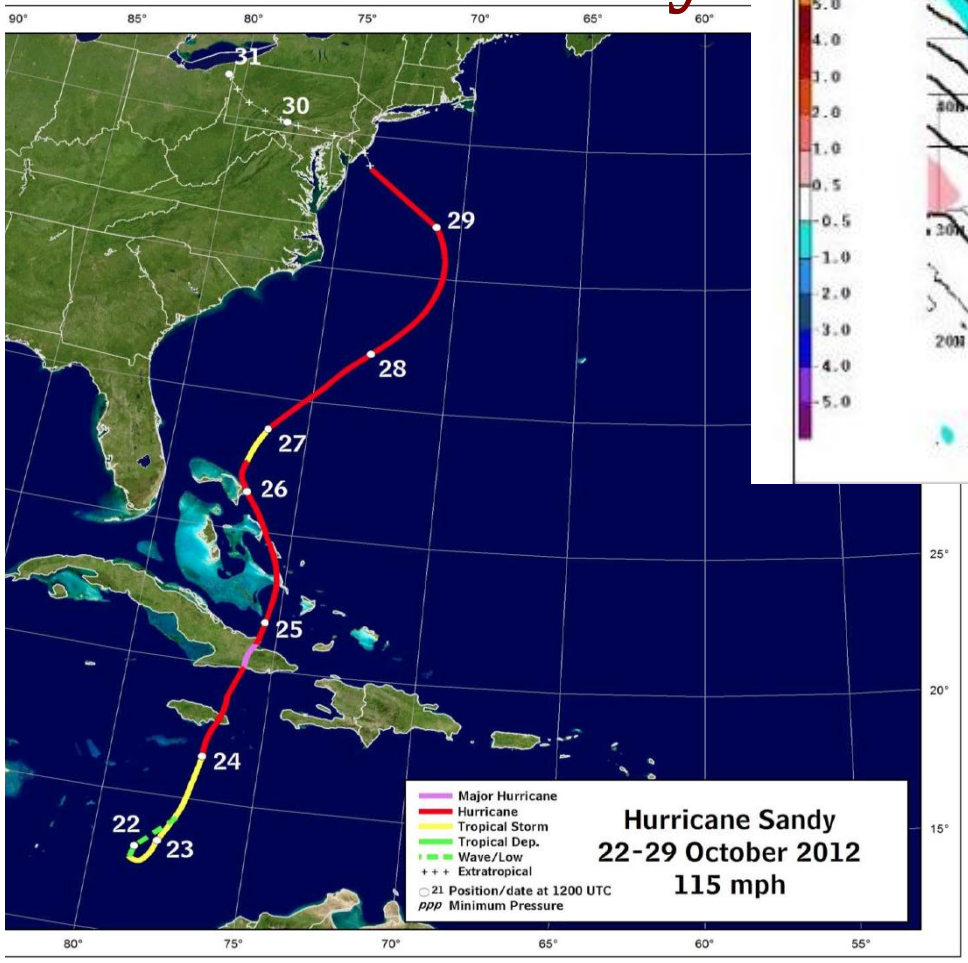


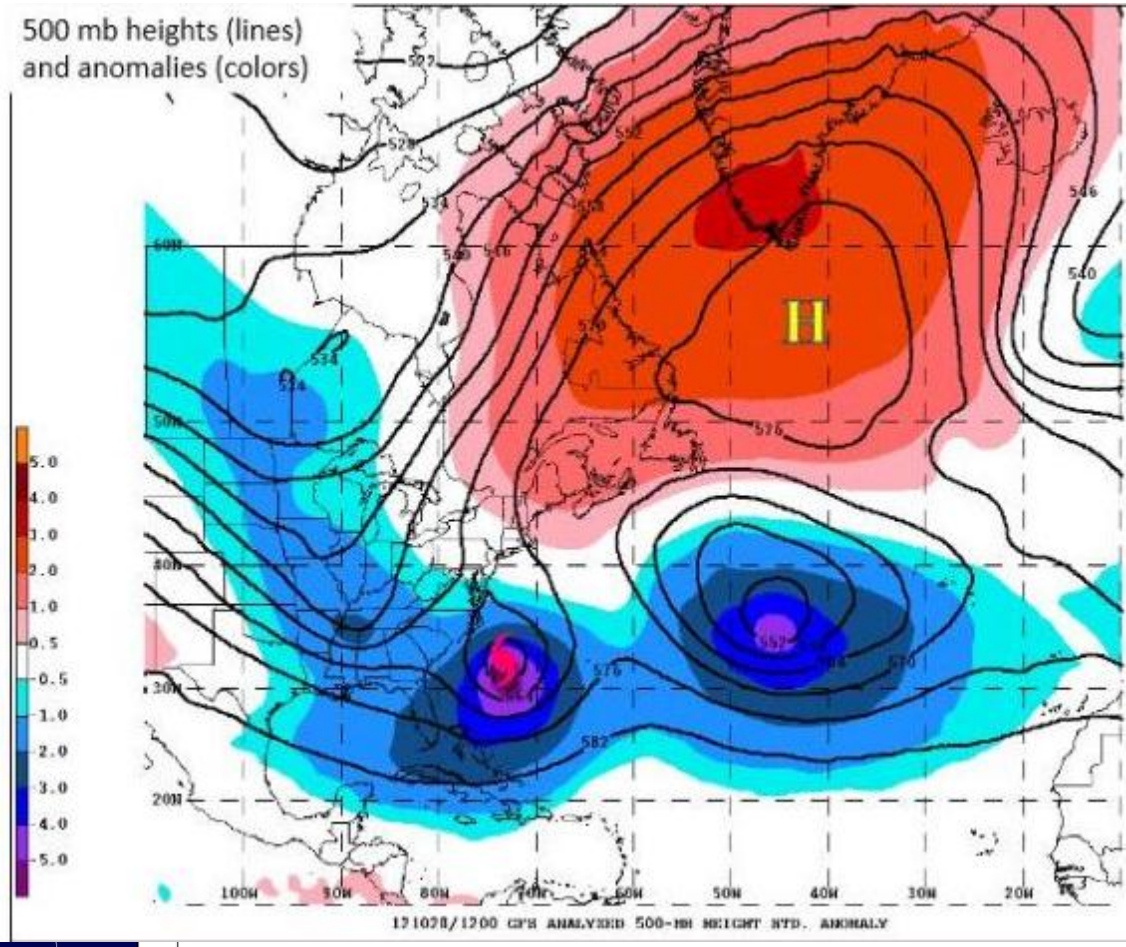


Arctic Warming Effects on Midlatitudes: The Jury is Still Out

- Jennifer Francis (Rutgers)
  - Loss of summer Arctic sea ice has led to the weakening of the polar vortex leading to more extreme weather elsewhere.
  - Jet stream has stronger North-South variations
  - More persistent weather patterns
- Others have added caution to this interpretation – exchange of heat in tropics far more than Arctic to midlatitudes
- The science is still not settled

Did Climate Change Contribute to Hurricane Sandy?





Generally we would say no, but is the persistent High in the Arctic that is likely related to the warming and melting ice a factor? We don't know yet.

Thank You