Extreme weather in a changing climate

Building Efficiency for a Sustainable Tomorrow
University of California, Berkeley
December

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Outline of my talk

- Brief introduction to climate change
  - Current climate change
  - Projected future change
- Extreme weather in a changing climate
  - Hurricanes
  - Extreme event risk attribution
- Some closing thoughts.

Climate is what you expect

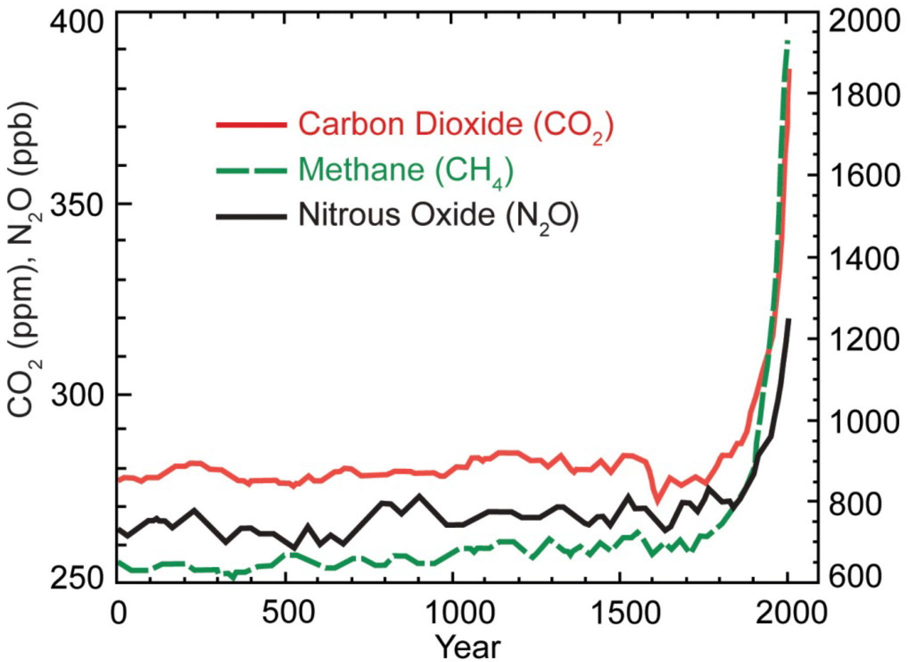
weather is what you get!

Robert Heinlein

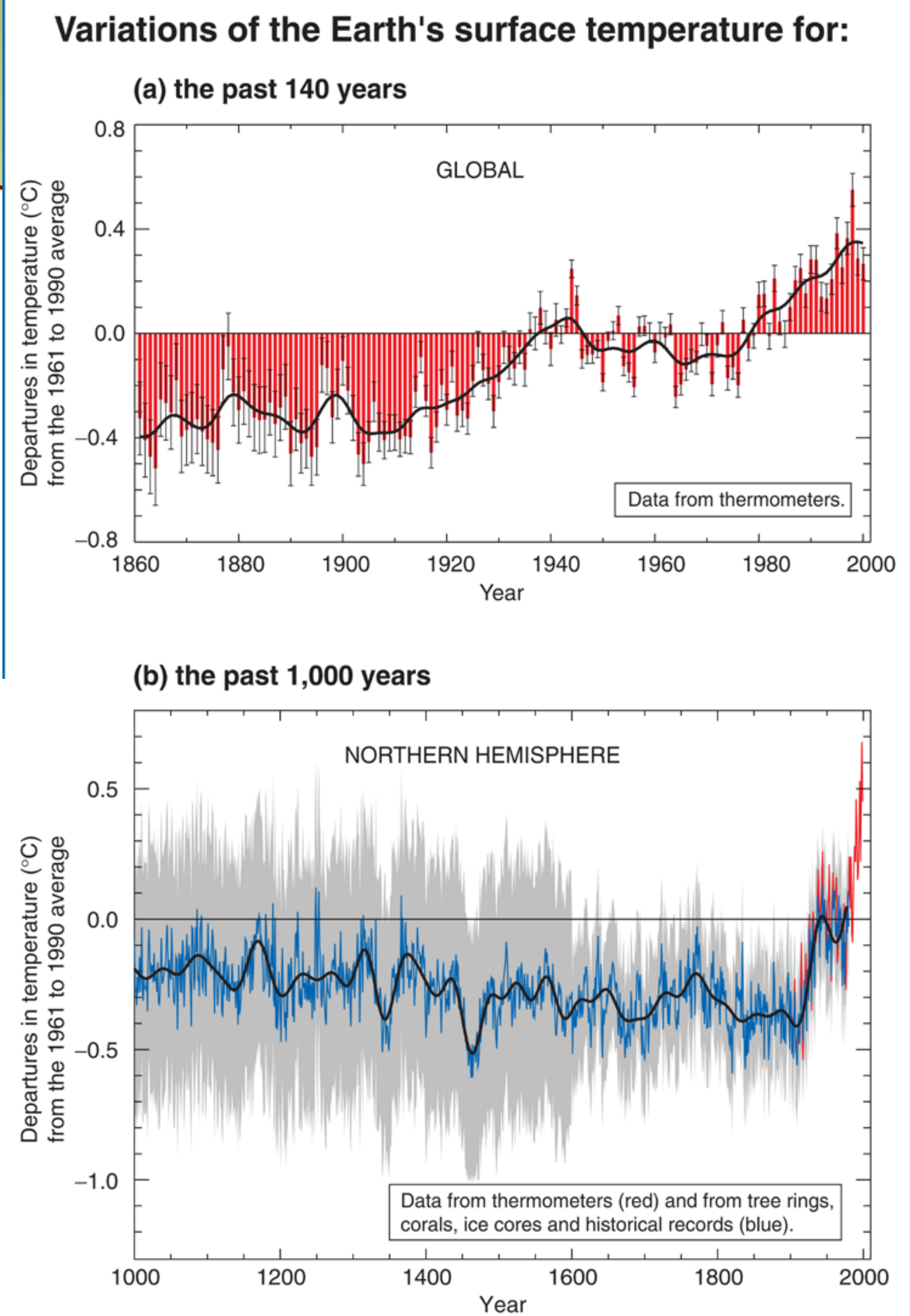
No fooling: Warming is “unequivocal”

Global mean surface air temperature is rapidly increasing.

CO_2 is increasing due to humans.



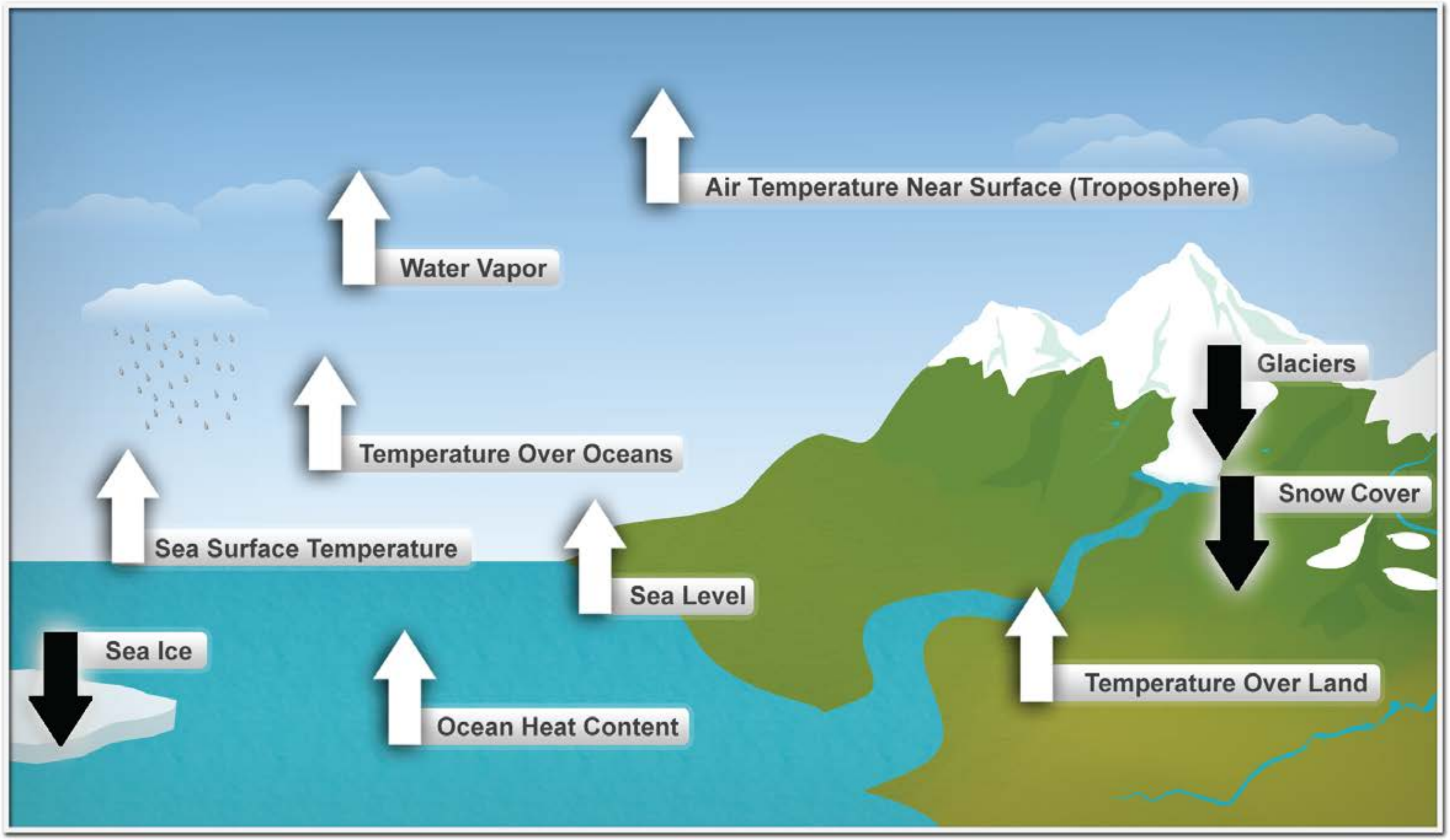
Forster *et al.*[3];Blasing[7]



The evidence for recent climate change is multivariate.

- Consistency across multiple aspects of the climate system.

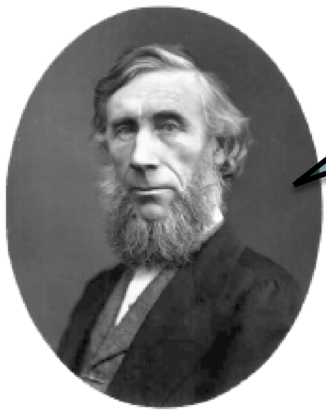
Ten Indicators of a Warming World



3rd US National Climate Assessment (draft)

This is not rocket science

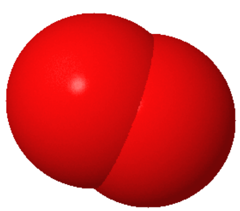
We have known about the greenhouse effect for more than 150 years.
It is steam engine science.



"The atmosphere admits of the entrance of the solar heat, but checks its exit; and the result is a tendency to accumulate heat at the surface of the planet."

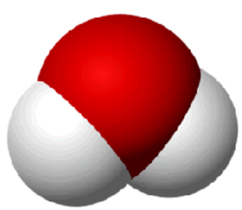
-- John Tyndall, 1859

Tyndal measured the radiative absorbtive properties of many gases.



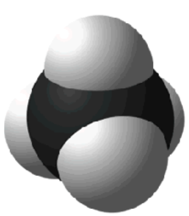
O_2, N_2

Low



H_2O, $CO_{2,}$ N_2O

,Medium

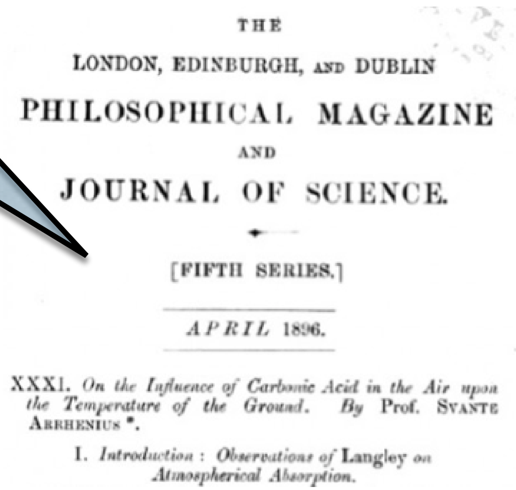


CH_4

High

Quantum mechanics

"Doubling of CO_2 would raise surface temperature by 5-6 °C, or 9-11 °F, above pre-industrial temperatures."
-- Svante Arrhenius,1896



THE

LONDON, EDINBURGH, AND DUBLIN

PHILOSOPHICAL MAGAZINE

AND

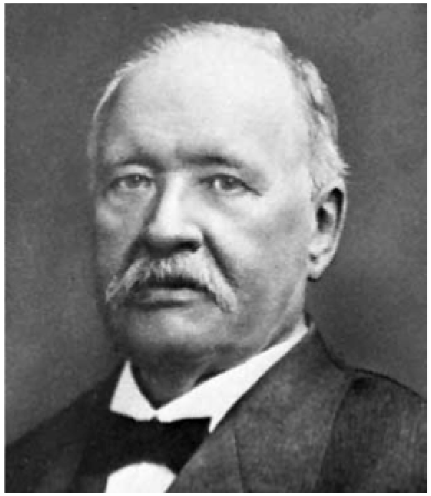
JOURNAL OF SCIENCE.

[FIFTH SERIES.]

APRIL 1896.

XXXI. *On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground.* By Prof. SVANTE ARRHENIUS *.

I. *Introduction: Observations of* Langley *on Atmospherical Absorption.*



We now call the climate system's response to doubling CO2
"The equilibrium climate sensitivity".

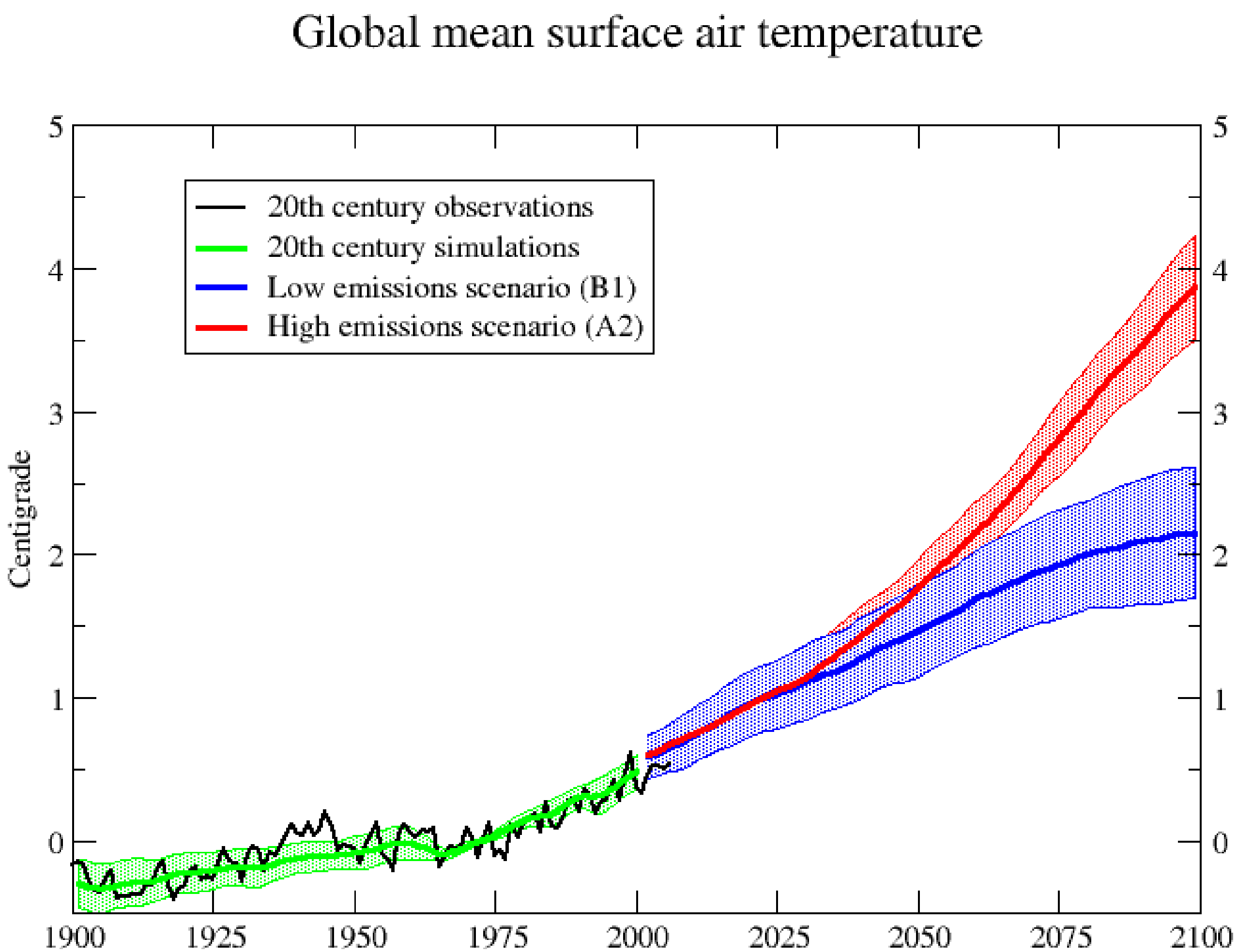
1896: 5-6 ^{o}C (Arrhenius)
2013: 2-6 ^{o}C (Intergovernmental Panel on Climate Change)

Projections indicate it will get a lot warmer.

- How much depends on how much greenhouse gas we put in the atmosphere

- Key uncertainties
  - Human activities
  - "Climate sensitivity"
  - Natural variability

The relative importance of these factors varies with projection lead time



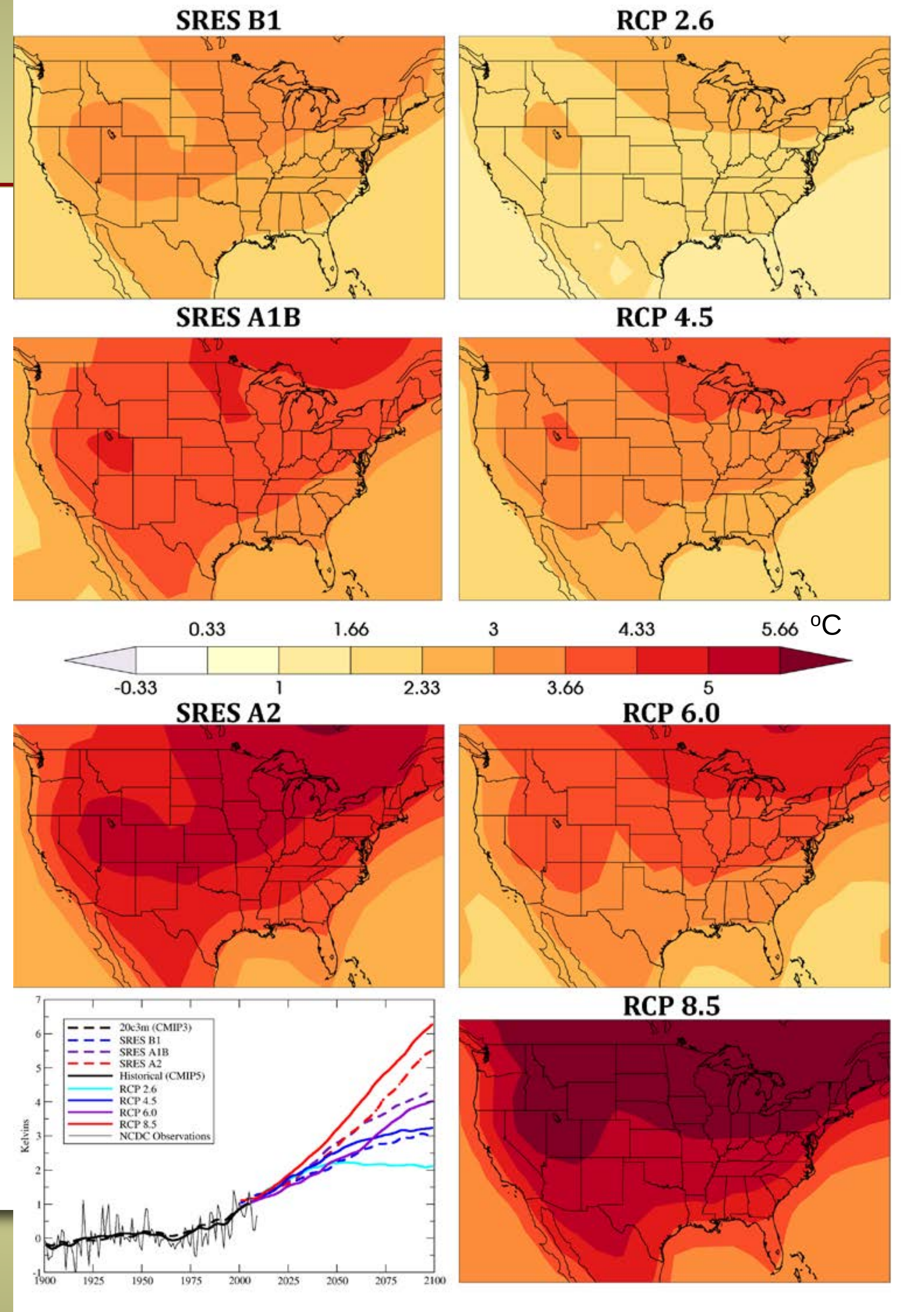
US temperature change

- Projected annual mean change
- end of 21st century relative to now

- Our behavior matters
- Scenarios range from aggressive mitigation to “no policy”
  - 2 to 6+ °C

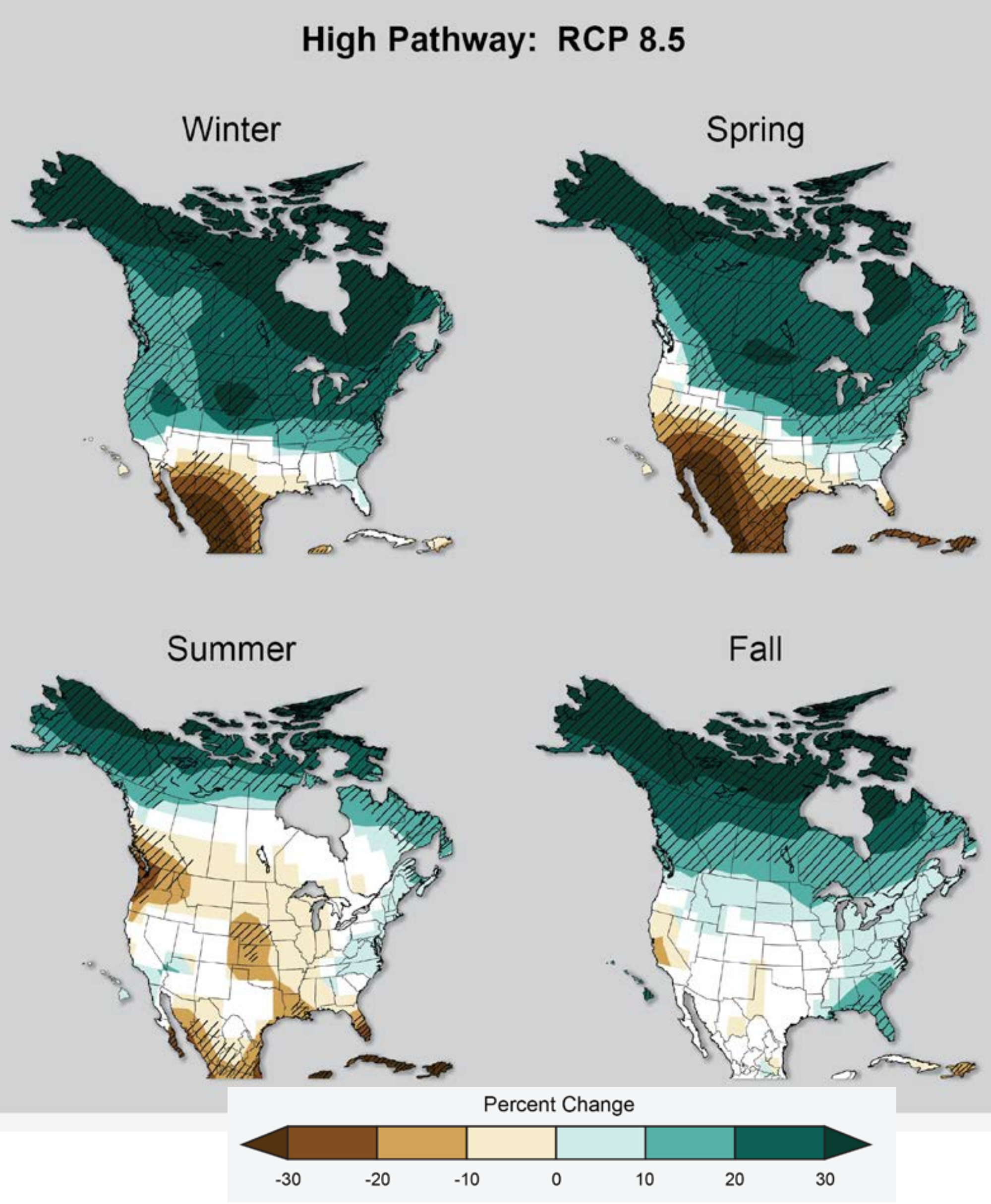
- Varies by season
  - Winter > summer

- Any of these futures will come with significant impacts



Precipitation change

- Percent change at end of this century relative to now
- Warmest scenario “No policy”
- Green = wetter; brown = drier
- Hatched regions = high confidence that change will be large
- White regions = high confidence that change will be small
- Strong seasonal dependence
  - Will affect impacts
    - Agriculture
    - Flooding
- Confidence is enhanced when physical mechanisms of change are understood.



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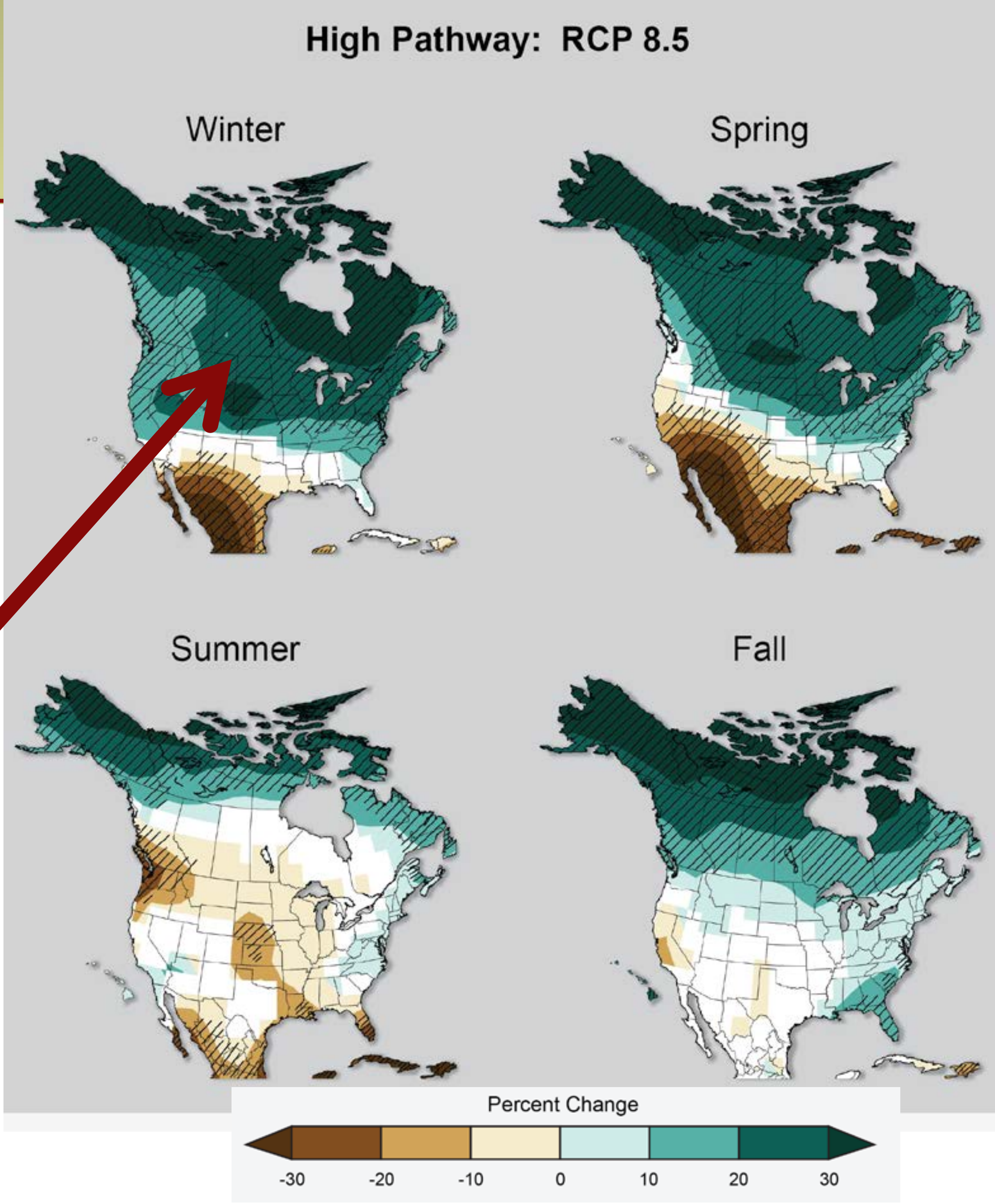

Warmer air holds more water

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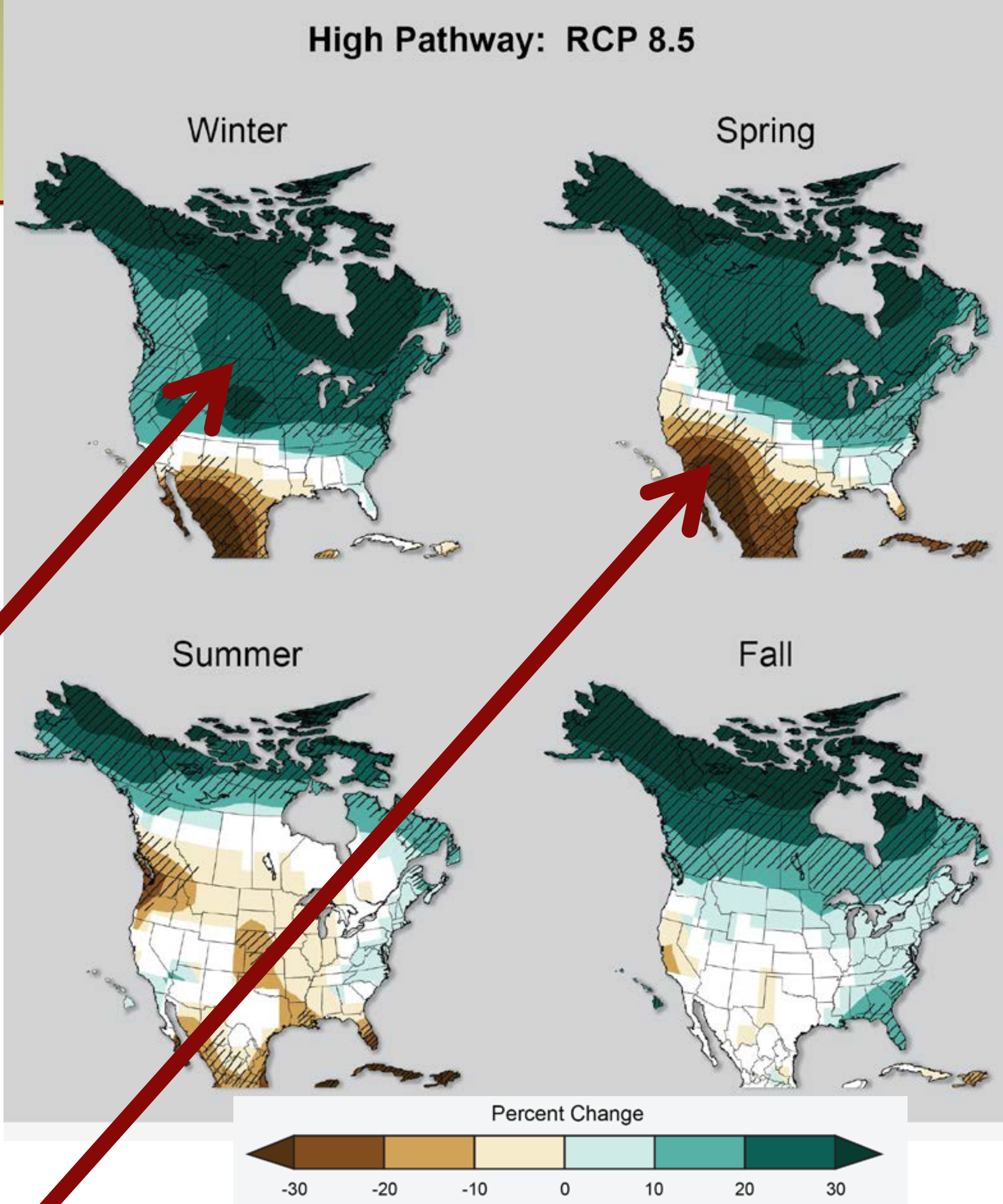
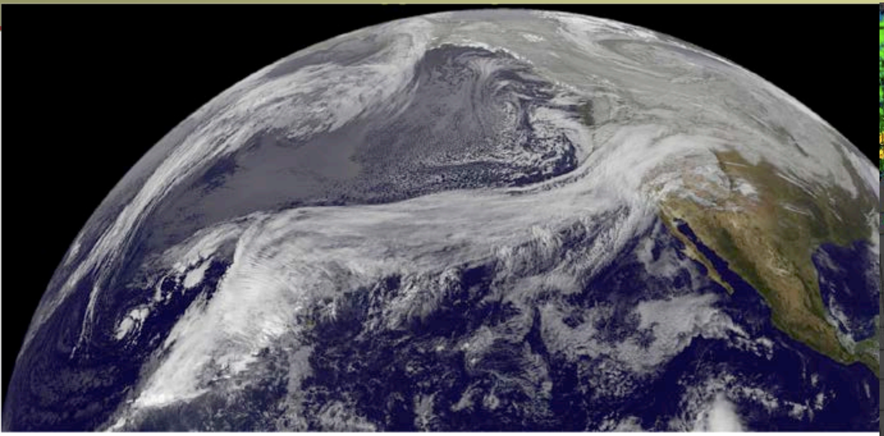
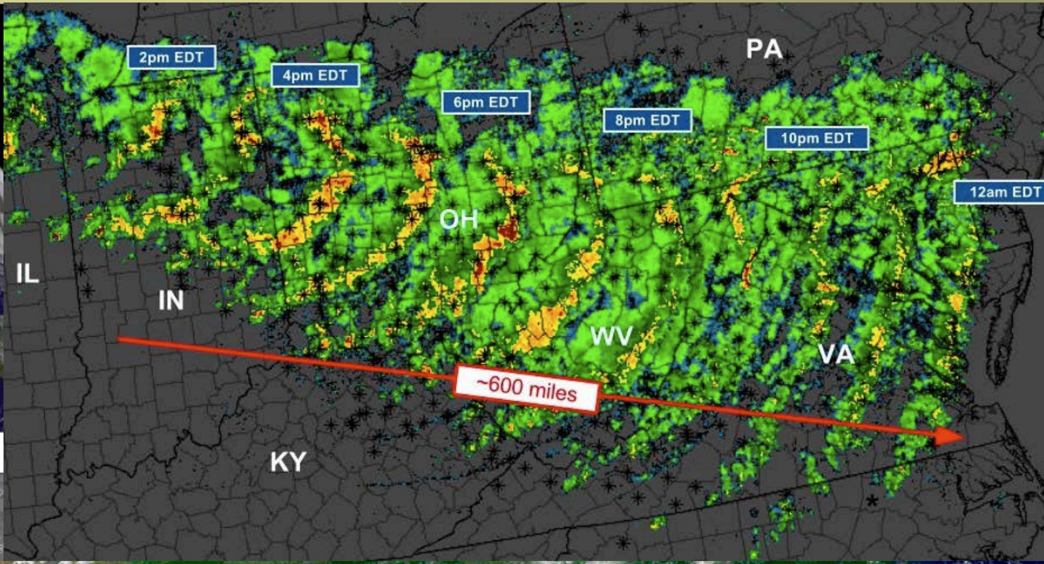


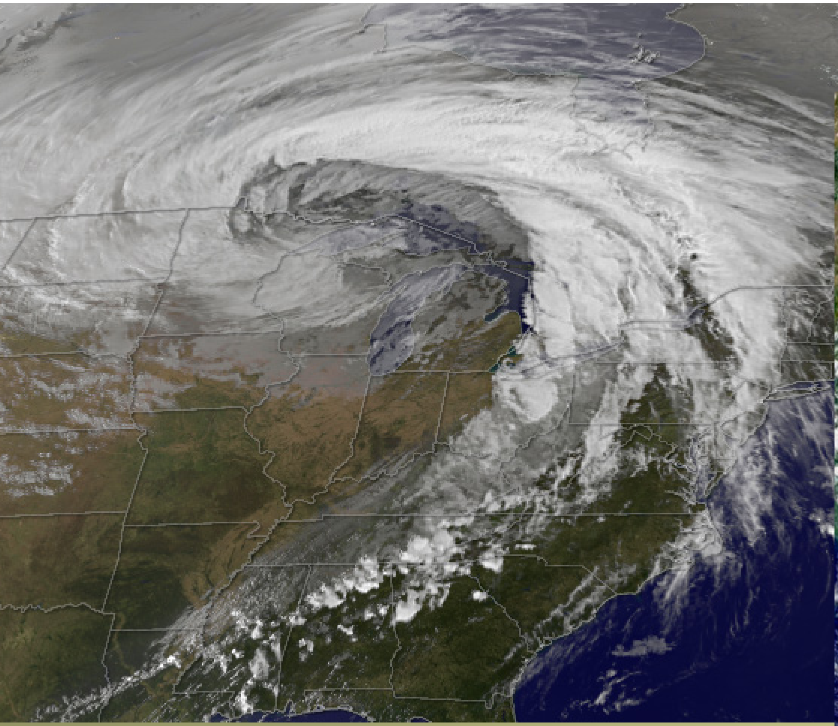
Warmer air holds more water

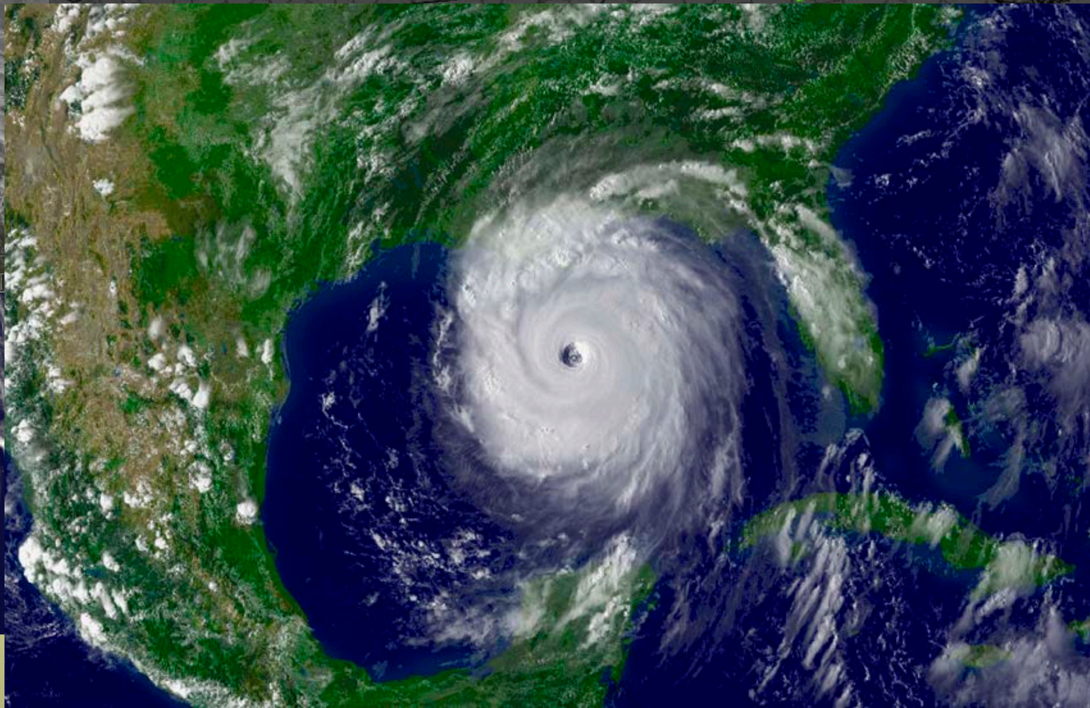
Expansion of the tropics induces a circulation change

Extreme Weather in a changing climate







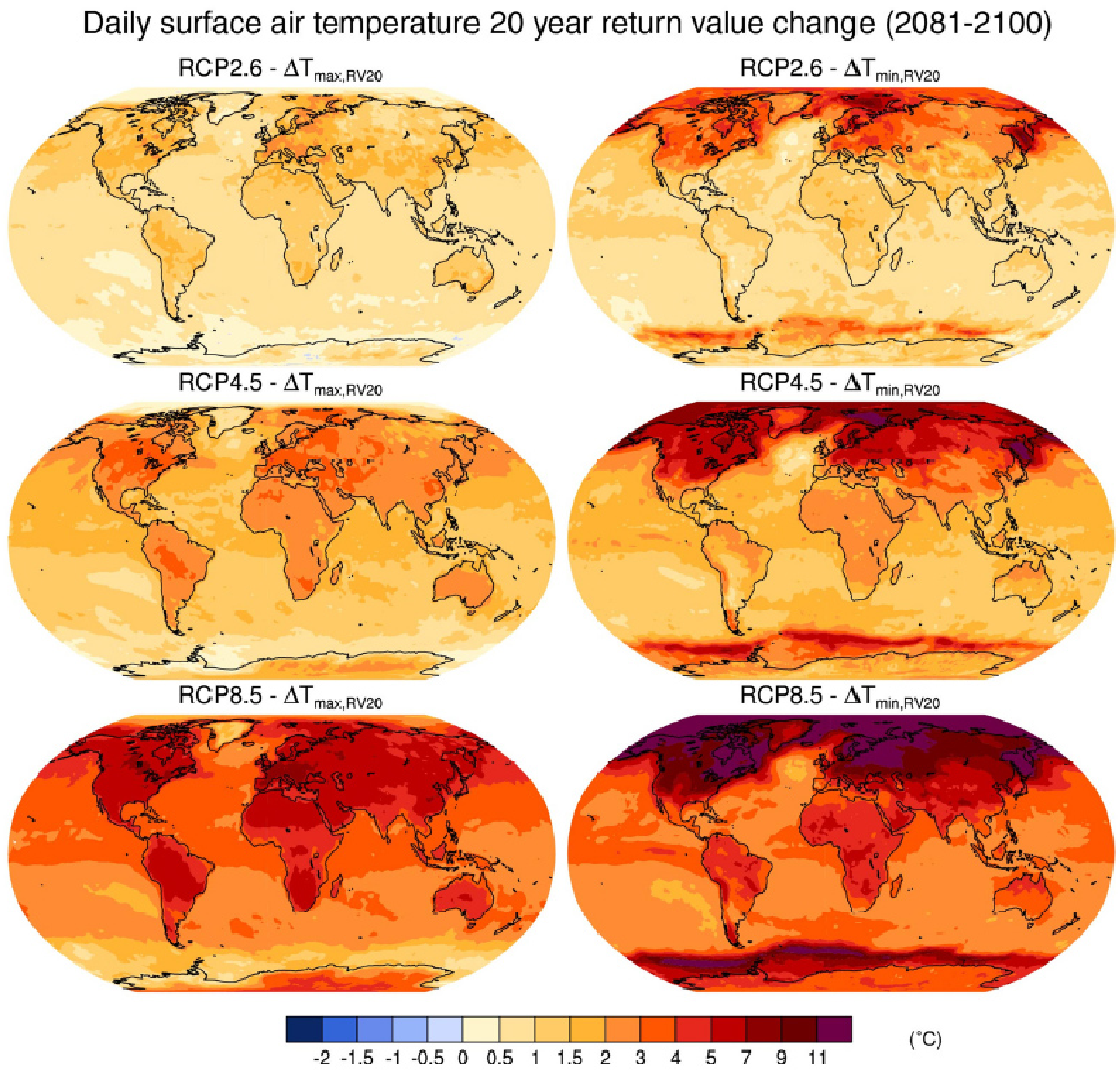


What does the IPCC have to say about temperature extremes?

- AR5 ES:
  - It is *virtually certain* that, in most places, there will be more hot and fewer cold temperature extremes as global mean temperatures increase
  - Under RCP8.5 it is *likely* that, in most land regions, a current 20-year high temperature event will occur more frequently by the end of the 21st century (at least doubling its frequency, but in many regions becoming an annual or two-year event) and a current 20-year low temperature event will become exceedingly rare.

IPCC AR5 Figure 12.14

- Changes in 20 year return values of the annual hottest and coldest day.
- “Today’s rare hot events become commonplace”
- Cold extremes increase more than hot extremes.



What does the IPCC have to say about precipitation extremes?

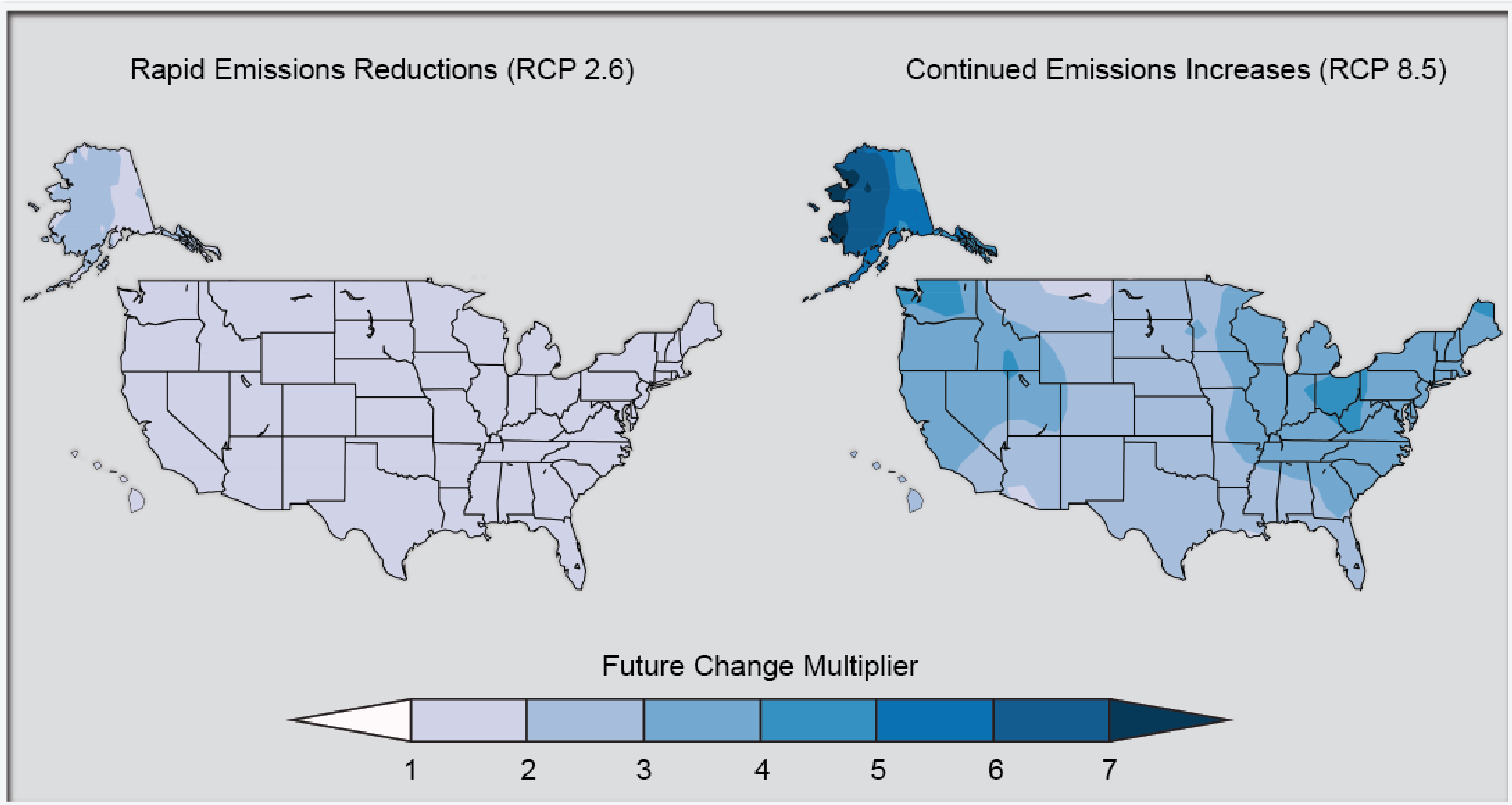
- AR5 ES:
  - Globally, for short-duration precipitation events, a shift to more intense individual storms and fewer weak storms is *likely* as temperatures increase.
  - Regional to global-scale projected decreases in soil moisture and increased risk of agricultural drought are *likely* in presently dry regions and are projected with *medium confidence* by the end of this century under the RCP8.5 scenario.

3rd US National Climate Assessment

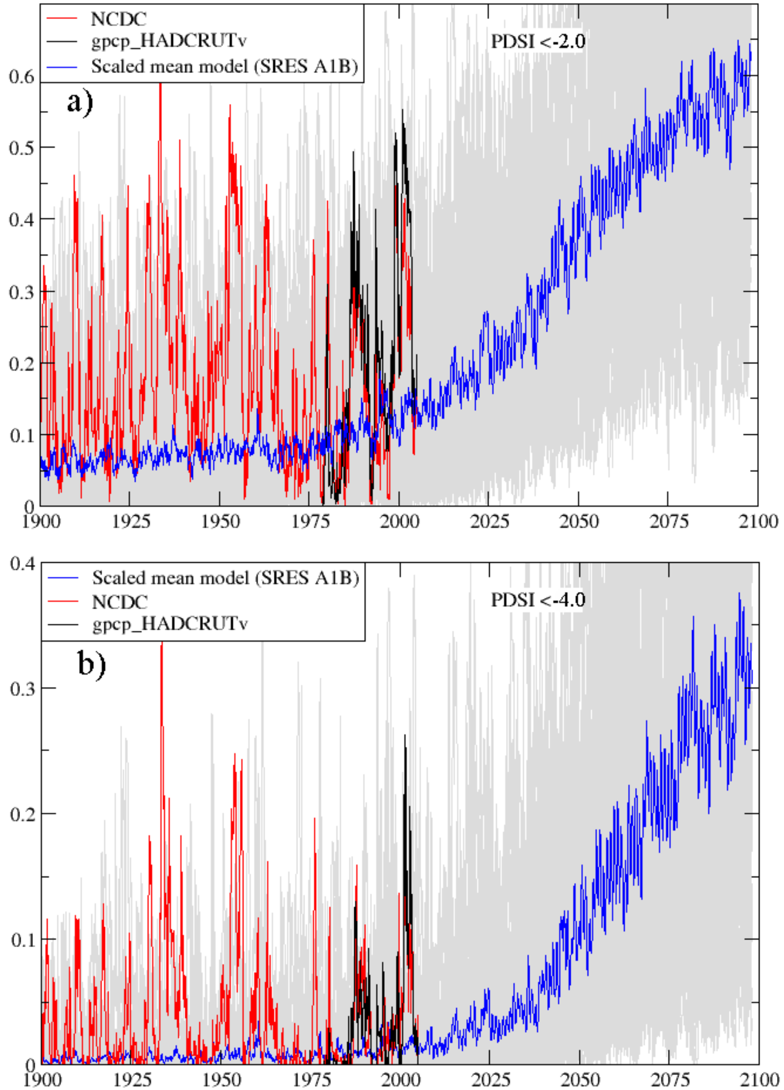
- "Frequency change multiplier"

$$= RP_{2000} / RP_{2100}$$

Projected Change in Heavy Precipitation Events

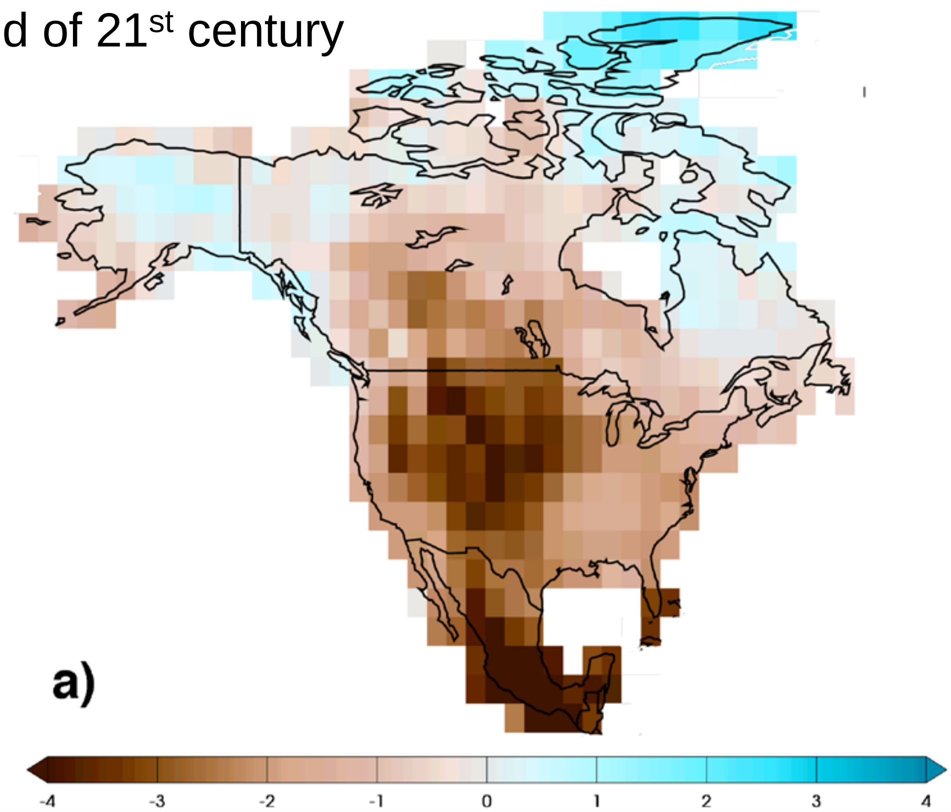


Palmer Drought Severity Index



Projections indicate that soil moisture will decrease

End of 21st century



High resolution global climate modeling

- High resolution is required to accurately simulate intense storms.
  - Our aim is to simulate the statistics of extreme weather not forecast actual storms
  - Extremely computationally expensive.

- ~25km global Community Atmospheric Model (CAM5.1)
  - Able to simulate hurricanes up to Category 5.
  - Far superior extreme precipitation statistics.
  - Thanks to the large US DOE investment in high performance computing.

  - Our current research focuses on describing the model's ability to simulate extreme weather statistics, assess the changing risk and to project future changes in extreme weather.

High resolution global climate modeling

CAM5 hi-resolution simulations (0.25°, prescribed aerosols)

Michael Wehner, Prabhat, Chris Algieri, Fuyu Li, Bill Collins
Lawrence Berkeley National Laboratory

Kevin Reed, University of Michigan

Andrew Gettelman, Julio Bacmeister, Richard Neale
National Center for Atmospheric Research

June 1, 2011

The Pineapple Express

Tropical Storm

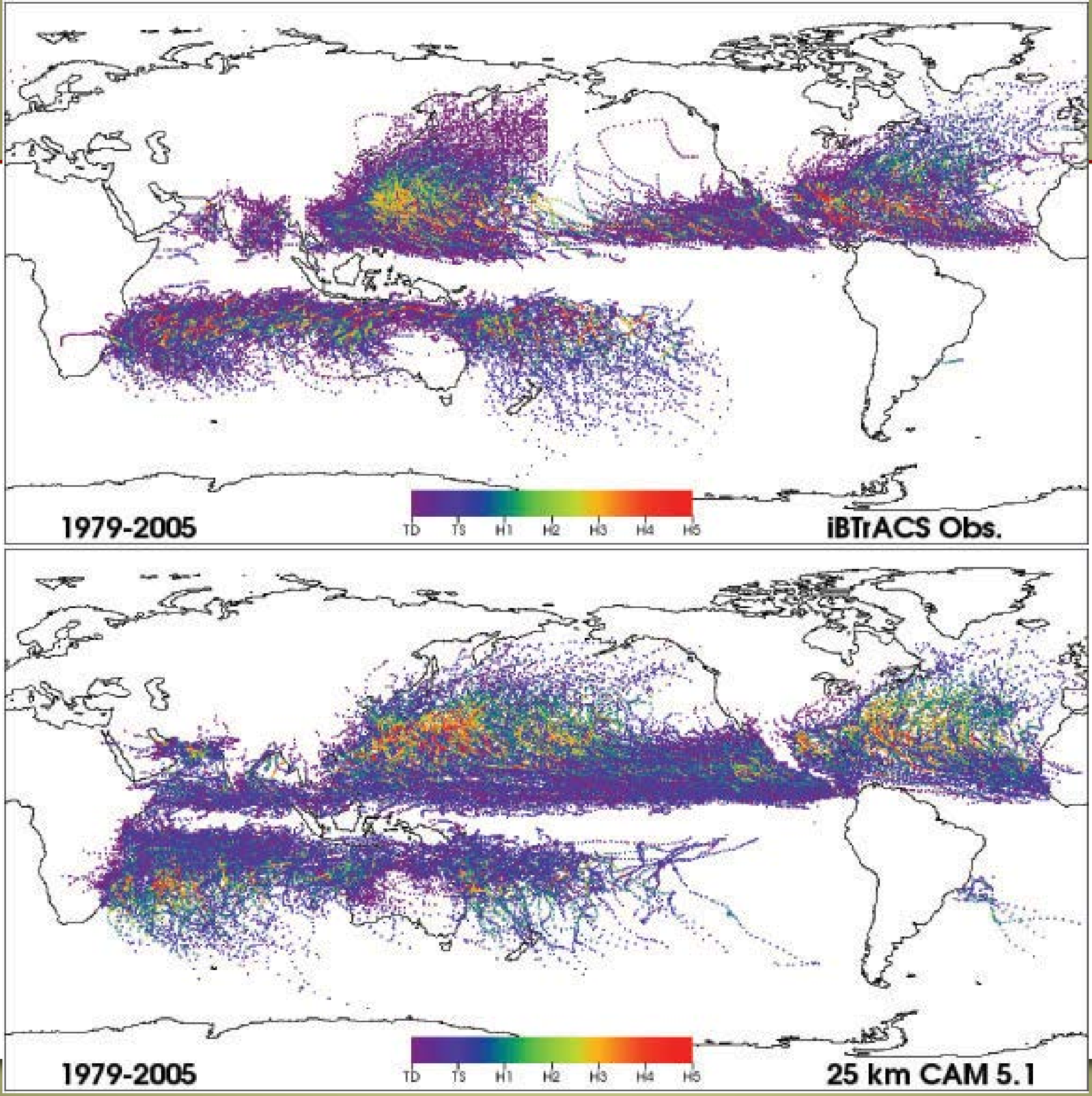
Cat1

Cat2

Cat3

Cat4

Cat5



Figures by Prabhat

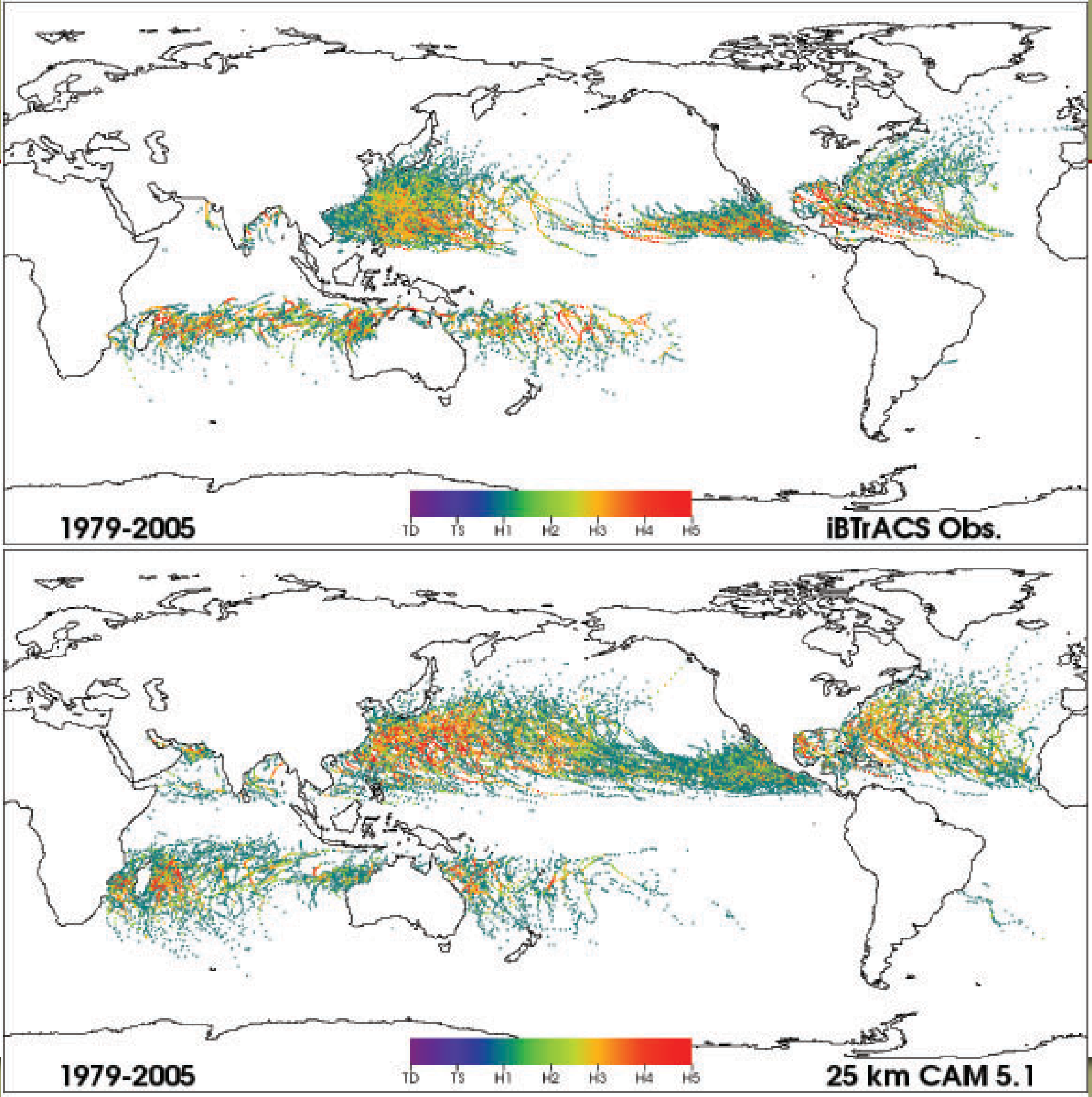
Cat1

Cat2

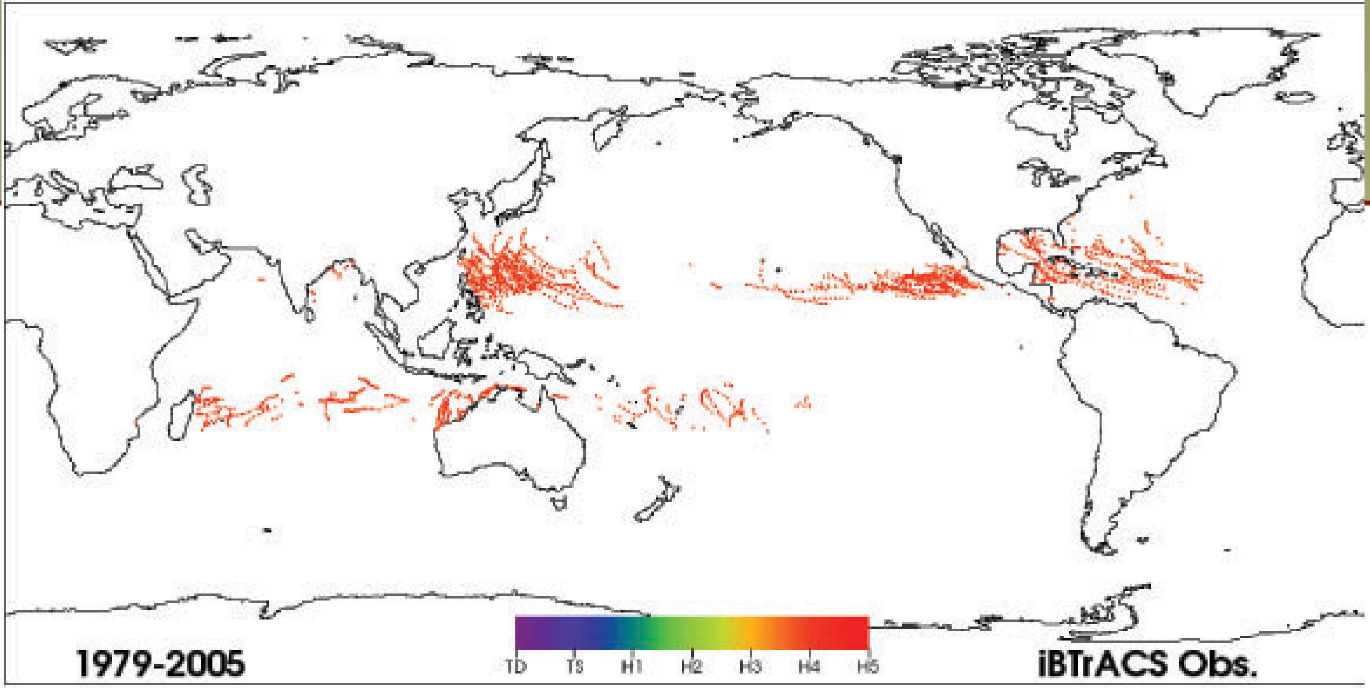
Cat3

Cat4

Cat5

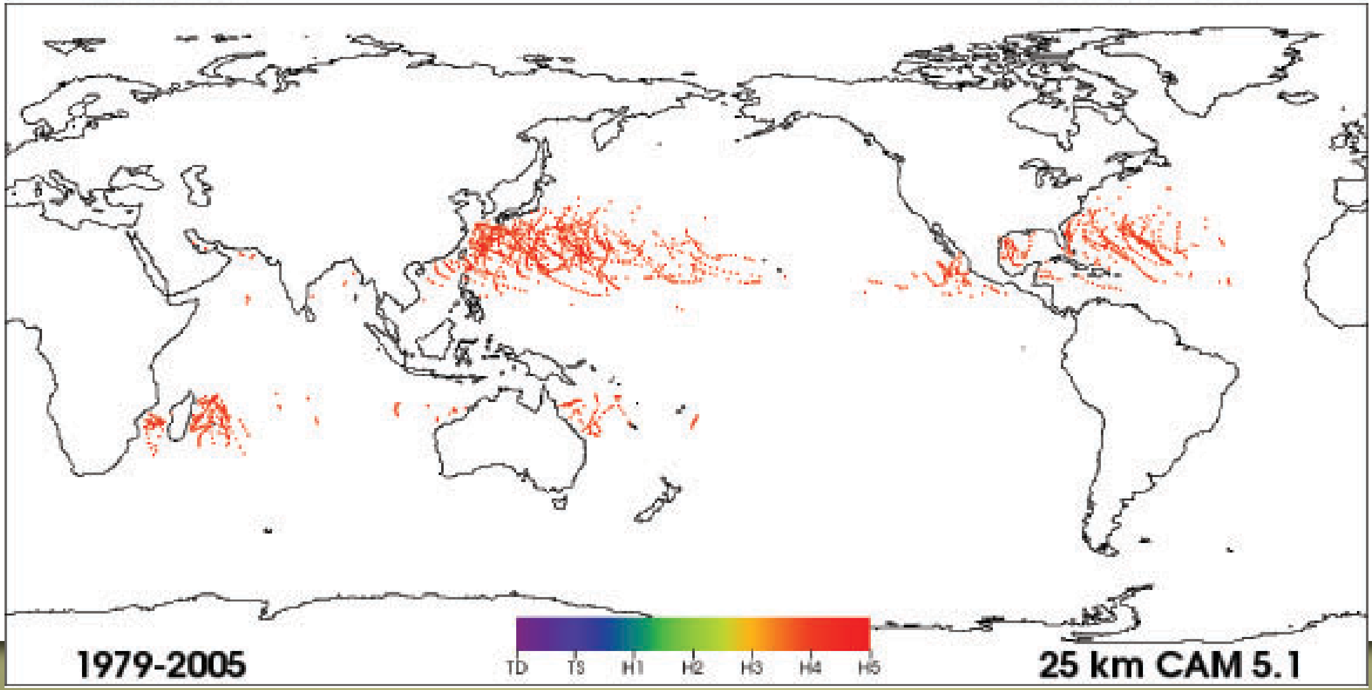


Figures by Prabhat



Cat4

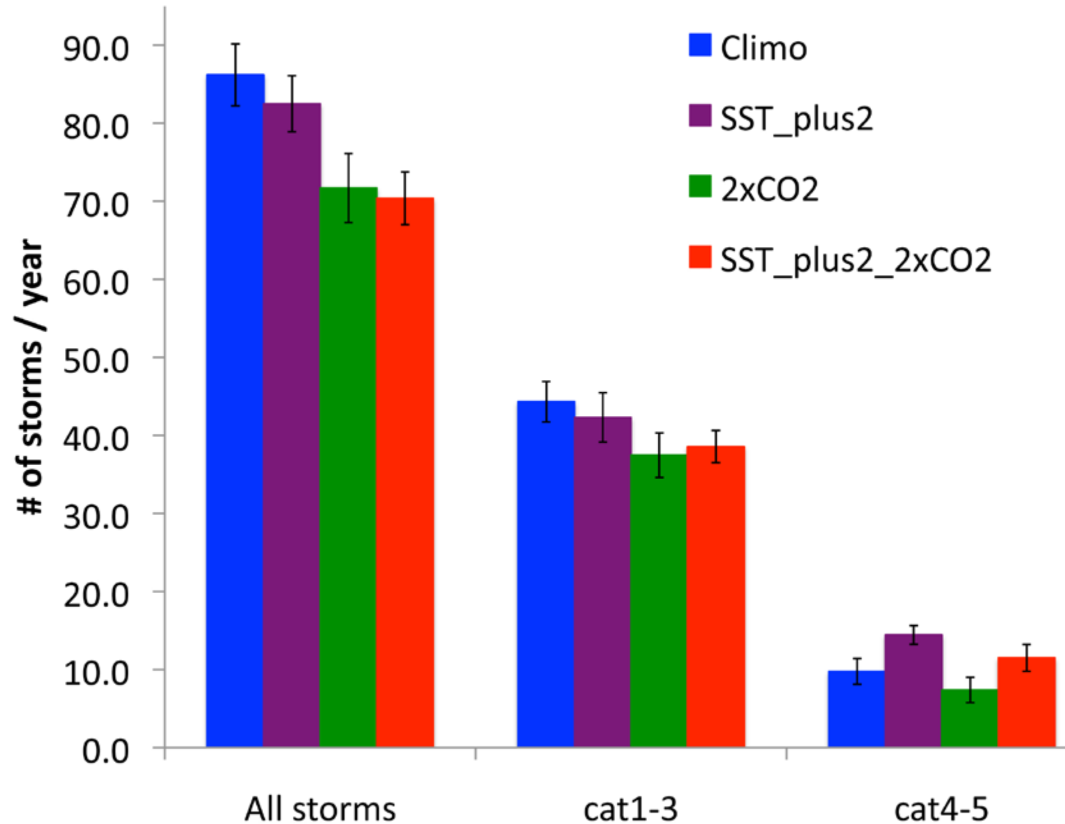
Cat5



Figures by Prabhat

Future global tropical cyclone activity

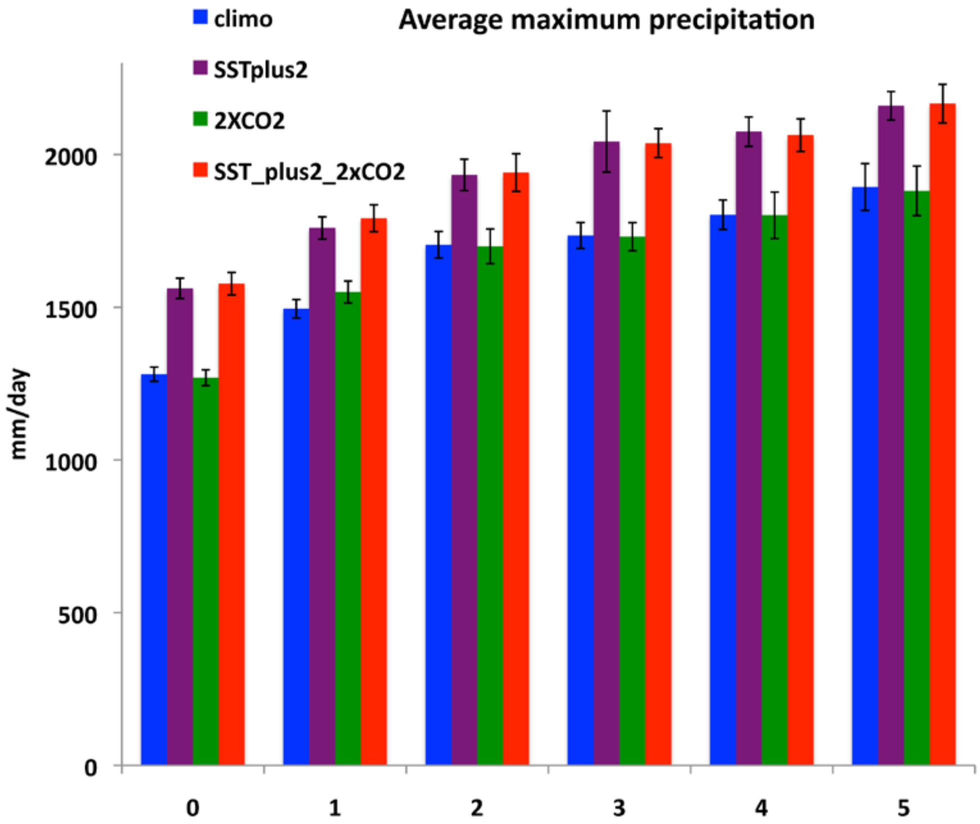
- Blue = idealized now
- Red = idealized 2º warmer future (aggressive mitigation)

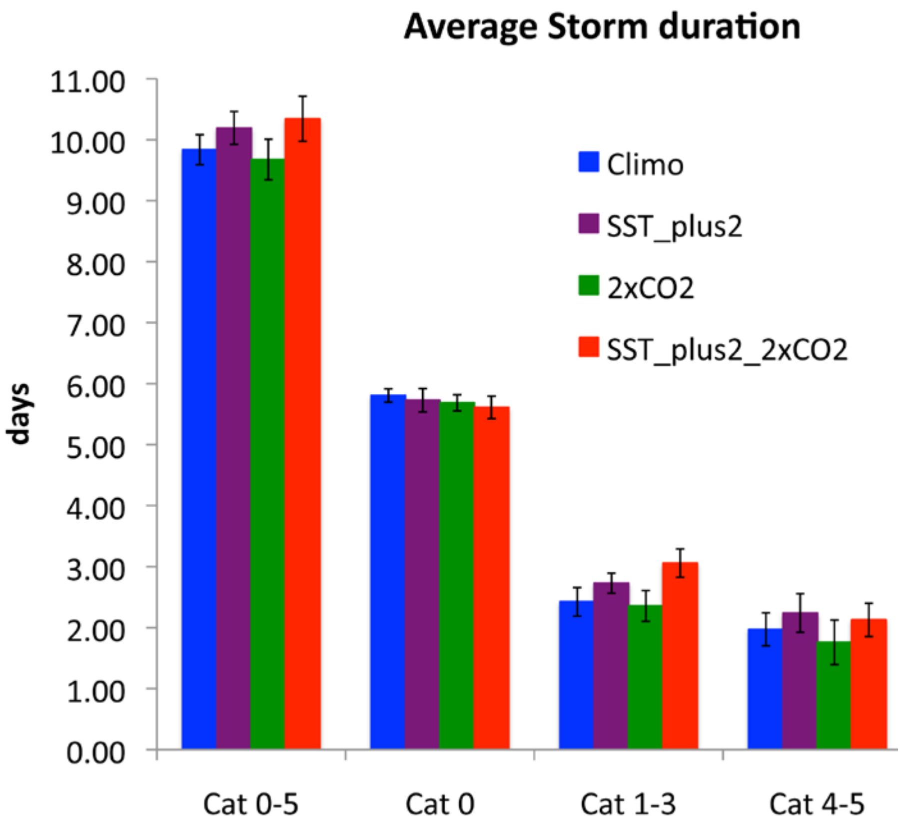


- Fewer total # of tropical cyclones
  - Fewer weak storms
  - More intense storms

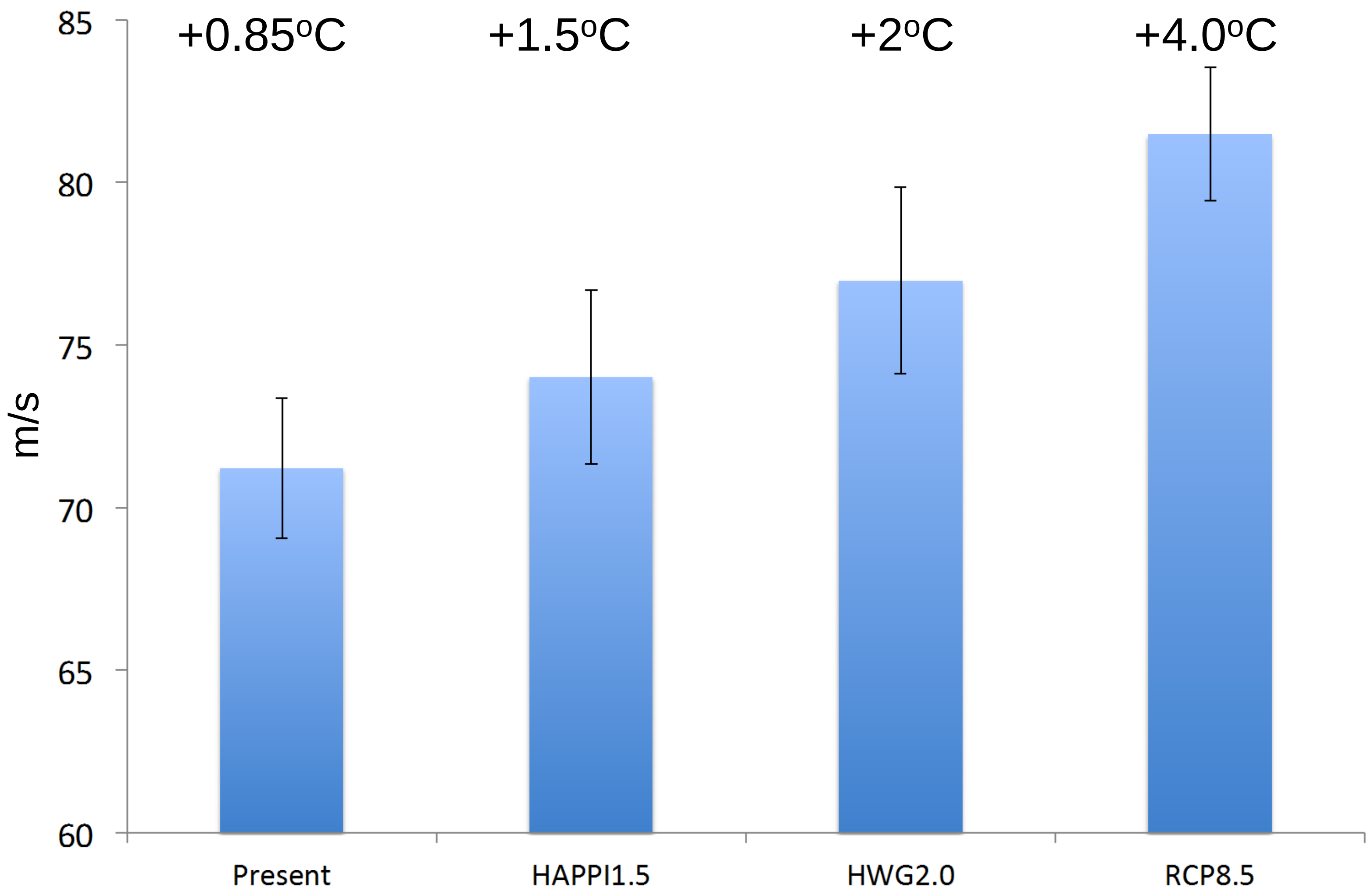
- Impacts
  - More damage from intense storms
  - Less drought relief
    - Southeast US
    - Taiwan
    - Elsewhere?

Hurricanes will last longer and rain harder in a warmer world





The strongest hurricanes get more intense.



Average annual most intense tropical cyclone wind speed (m/s)

Extreme Event Attribution

- When extreme weather happens, the public wants to know
  - "Is this climate change?"

- Not quite the correct question, better to ask:
  - "How has the risk of this event changed because of climate change?"

  Or

  - "How did climate change affect the magnitude of this event?"

- We approach these questions in two different ways.

1. Use extreme value statistics and the existing CMIP5 "ensemble of opportunity".
2. Design our own ensembles of climate model simulations tailored to event attribution.
   - Climate of the 20th Century C20C (~50 ensemble members)
   - climateprediction.net (~1000+ ensemble members)
   - Not talking about this now, but this is a major effort for us.

Extreme event attribution: CMIP statistical analysis

- CMIP (Coupled Model Intercomparison Project) is a public database of output from the worlds' leading climate model.
  - Common numerical experiment and data formats, etc.

- Consider three different summer heat wave events
  - Europe 2003 (~70,000 excess deaths)
  - Russia 2010 (~50,000 excess deaths, massive fires)
  - Texas 2011 (lots of dead cows, massive drought)

- These are very rare events. We are interested in how the rarity of these events has changed.

- We calculated the change in risk by comparing the extreme value statistics in these regions from realistic historical simulations to those in the pre-industrial simulations and the observations.
  - (Skipping the statistical mumbo jumbo, including normalization)

Fractional attributable risk (FAR)

- Real World: with industrialized humans
- Not Real World: without industrialized humans

$$Risk\_ratio = \frac{P_{real}}{P_{Not\_real}}$$

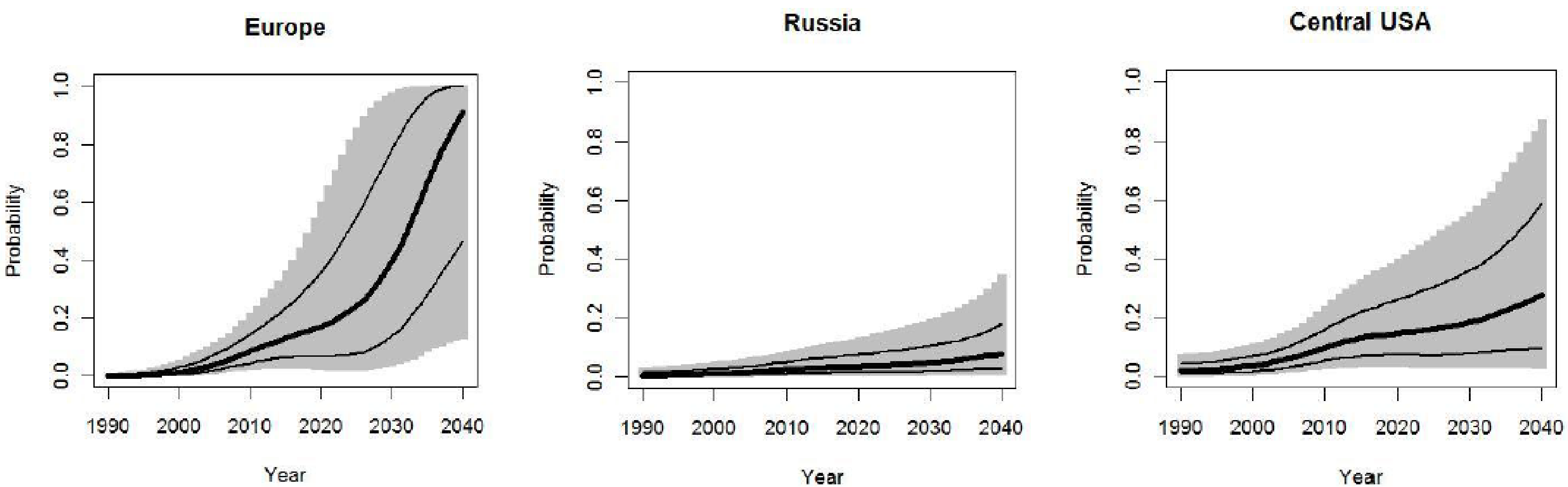
$$FAR = 1 - \frac{P_{Not\_real}}{P_{real}}$$

- Fractional attributable risk is often used to determine liability.

Extreme event attribution: CMIP statistical analysis

The risk of each of these events has least doubled since the preindustrial era

Event	Risk Change at time of event	Change in risk 2023	Change in risk 2040
Europe 2003	~2X	35X	154X
Russia 2010	2-3 X	2.5-4 X	5-8 X
Texas 2011	1.5-4 X	2-5 X	4-10 X
Midwest US 2012	?	?	



Extreme Event Attribution

- It is hard to find a recent severe heat wave without a human increase in risk.
- What about the "Polar Vortex"?
  - Probably not a cold as it would have been without a human intervention to the climate system.
  - Cold extreme will continue to occur, but less frequently.
    - (unless there is a significant change to the atmospheric circulation…)
- What about precipitation extremes and intense storms?
  - They are far harder to analyze.
  - 2000 UK floods were about 25% more likely.
  - 2013 Colorado floods?
  - Hurricane Sandy?
  - Other intense hurricanes?
  - Tornadoes (nothing to say at this point in time.)
  - This is still a developing science.

Multivariate extremes

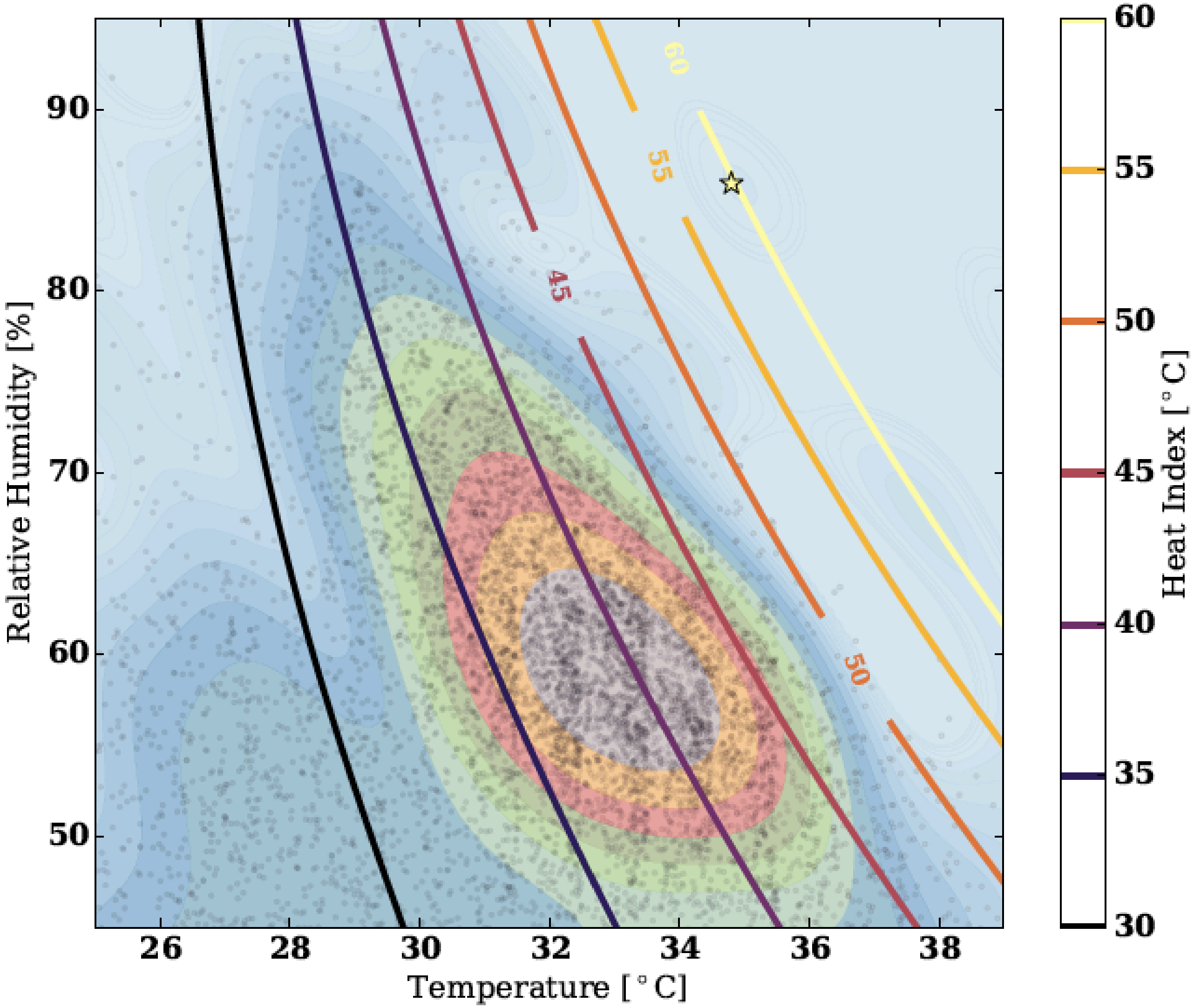
- Real world systems are multivariate.

- Impacts can depend on the combinations
  - Hot, dry, windy → wildfires
  - Hot, moist, stagnant → human health

- Past and future statistics also depends on the combinations.
  - Mechanisms of changes vary.

- Our upcoming project brings climate analysts, impacts scientists and statisticians together
  - Impacts scientists help us define what is “extreme”.
  - Statisticians are developing non-asymptotic methods.
  - Climate analysts design targeted numerical experiments

Temperature & Relative Humidity in Karachi, Pakistan



2015 Pakistan Heat wave

Not so hot, but very humid

"Heat Index"
Risk Ratio >1000

Figure courtesy of Travis O'Brien, LBNL

Conclusions

- Claims of current and future climate change are well founded.
- The risk of extreme weather is changing and attributable to humans.
- The change in risk of an individual extreme event due to humans can be estimated.
  - Increasing:
    - Heat waves
    - Extreme precipitation
    - Intense hurricanes
    - Drought
    - Certain types of floods
  - Decreasing:
    - Cold snaps
    - Certain types of floods
- Scale is critical. Global models are fast approaching scales relevant to impacts.

Thank you!

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