Climate Change
Prof. Ryan Sriver

Associate Professor of Atmospheric Sciences at UIUC, 2012 - current

PhD in Earth and Atmospheric Sciences, Purdue University.

Before 2012: Research associate in Penn State's Department of Geosciences and as a NOAA Climate and Global Change postdoctoral fellow in Penn State's Department of Meteorology.

Professor Sriver's research seeks to develop a deeper understanding about the physical processes influencing variability within Earth's climate system and to quantify relevant uncertainties surrounding future climate projections. His work combines observational products, statistical methods and tools, and numerical models spanning a wide range of complexities and scales to understand how extreme weather and climate events are changing with global warming, what are the physical drivers, and what are the implications for natural and human systems.

Climate Dynamics |Earth System Modeling | Ocean-Atmosphere Interactions | Uncertainty and Risk | Weather and Climate Extremes | Tropical Cyclones | Sea-Level Rise | Seasonal Prediction | Multi-Sector Dynamics

Earth's Changing Climate: Observations, Impacts, Models and Uncertainty

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UIUC Seminar in Energy and Sustainability Engineering
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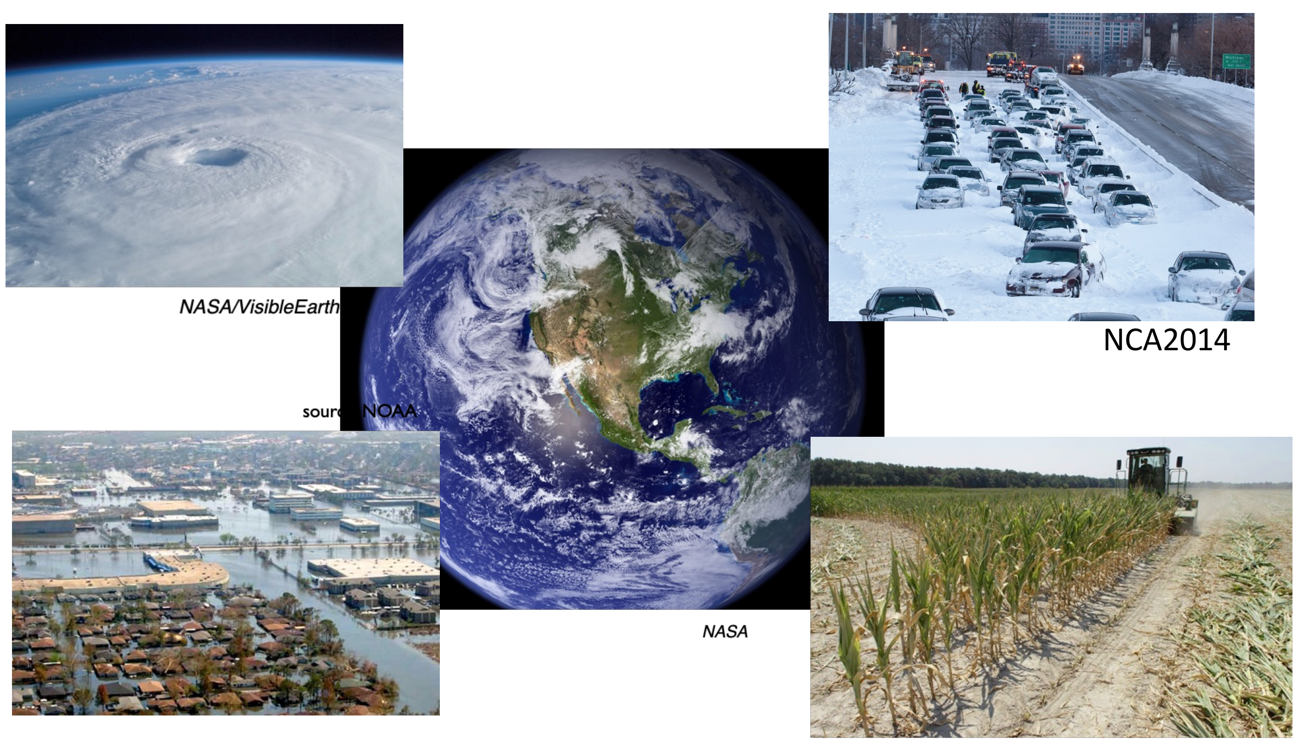
We combine observations, numerical models and statistical tools to understand how climate and weather are changing, what are the physical drivers, and what are the regional impacts across a wide range of time scales.

Research Areas

- Large-Scale Climate Dynamics
- Earth System Modeling
- Extreme Climate/Weather Events
- Uncertainty and Risk

Current Projects

- Extreme temperature and precipitation stats and variability
- Regional climate/weather impacts: Wildfires, Agriculture, Soil Moisture, Drought
- Machine learning and risk-based seasonal/climate prediction: ENSO, Wildfire
- Climate risk and insurance applications: Tropical Cyclones, Severe Convective Storms



NASA/VisibleEarth

NCA2014

source: NOAA

NASA

source: AP/Seth Perlman

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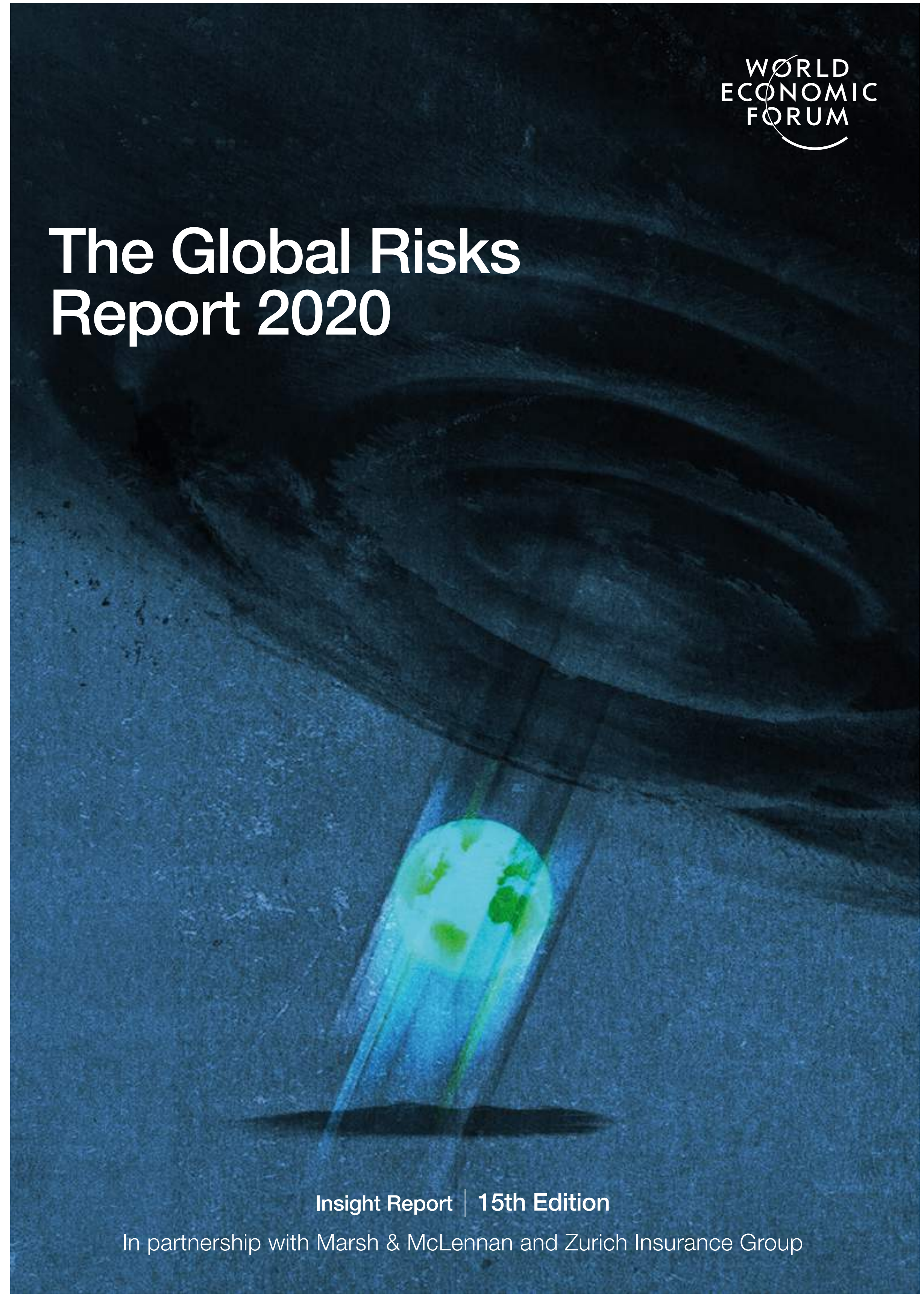
NSF

U.S. DEPARTMENT OF ENERGY

NCSA

ILLINOIS
College of Liberal Arts & Sciences

The Global Risks Report 2020
15th Edition



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Wharton Risk Management and Decision Processes Center, University of Pennsylvania

Figure I: The Evolving Risks Landscape, 2007–2020

Top 5 Global Risks in Terms of Likelihood

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
1st	Infrastructure breakdown	Blow up in asset prices	Asset price collapse	Asset price collapse	Storms and cyclones	Income disparity	Income disparity	Income disparity	Interstate conflict	Involuntary migration	Extreme weather	Extreme weather	Extreme weather	Extreme weather
2nd	Chronic diseases	Middle East instability	China economic slowdown	China economic slowdown	Flooding	Fiscal imbalances	Fiscal imbalances	Extreme weather	Extreme weather	Extreme weather	Involuntary migration	Natural disasters	Climate action failure	Climate action failure
3rd	Oil price shock	Failed and failing states	Chronic diseases	Chronic disease	Corruption	Greenhouse gas emissions	Greenhouse gas emissions	Unemployment	Failure of national governance	Climate action failure	Natural disasters	Cyberattacks	Natural disasters	Natural disasters
4th	China hard landing	Oil price shock	Global governance gaps	Fiscal crises	Biodiversity loss	Cyberattacks	Water crises	Climate action failure	State collapse or crisis	Interstate conflict	Terrorist attacks	Data fraud or theft	Data fraud or theft	Biodiversity loss
5th	Blow up in asset prices	Chronic diseases	Deglobalization (emerging)	Global governance gaps	Climate change	Water crises	Population ageing	Cyberattacks	Unemployment	Natural catastrophes	Data fraud or theft	Climate action failure	Cyberattacks	Human-made environmental disasters

Top 5 Global Risks in Terms of Impact

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
1st	Blow up in asset prices	Blow up in asset prices	Asset price collapse	Asset price collapse	Fiscal crises	Financial failure	Financial failure	Fiscal crises	Water crises	Climate action failure	Weapons of mass destruction	Weapons of mass destruction	Weapons of mass destruction	Climate action failure
2nd	Deglobalization	Deglobalization (developed)	Deglobalization (developed)	Deglobalization (developed)	Climate change	Water crises	Water crises	Climate action failure	Infectious diseases	Weapons of mass destruction	Extreme weather	Extreme weather	Climate action failure	Weapons of mass destruction
3rd	Interstate and civil wars	China hard landing	Oil and gas price spike	Oil price spikes	Geopolitical conflict	Food crises	Fiscal imbalances	Water crises	Weapons of mass destruction	Water crises	Water crises	Natural disasters	Extreme weather	Biodiversity loss
4th	Pandemics	Oil price shock	Chronic diseases	Chronic disease	Asset price collapse	Fiscal imbalances	Weapons of mass destruction	Unemployment	Interstate conflict	Involuntary migration	Natural disasters	Climate action failure	Water crises	Extreme weather
5th	Oil price shock	Pandemics	Fiscal crises	Fiscal crises	Energy price volatility	Energy price volatility	Climate action failure	Infrastructure breakdown	Climate action failure	Energy price shock	Climate action failure	Water crises	Natural disasters	Water crises

Economic Environmental Geopolitical Societal Technological

Source: World Economic Forum 2007-2020, *Global Risks Reports*.
Note: Global risks may not be strictly comparable across years, as definitions and the set of global risks have evolved with new issues emerging on the 10-year horizon. For example, cyberattacks, income disparity and unemployment entered the set of global risks in 2012. Some global risks have been reclassified: water crises and income disparity were recategorized as societal risks in the 2015 and 2014 *Global Risks Reports*, respectively.

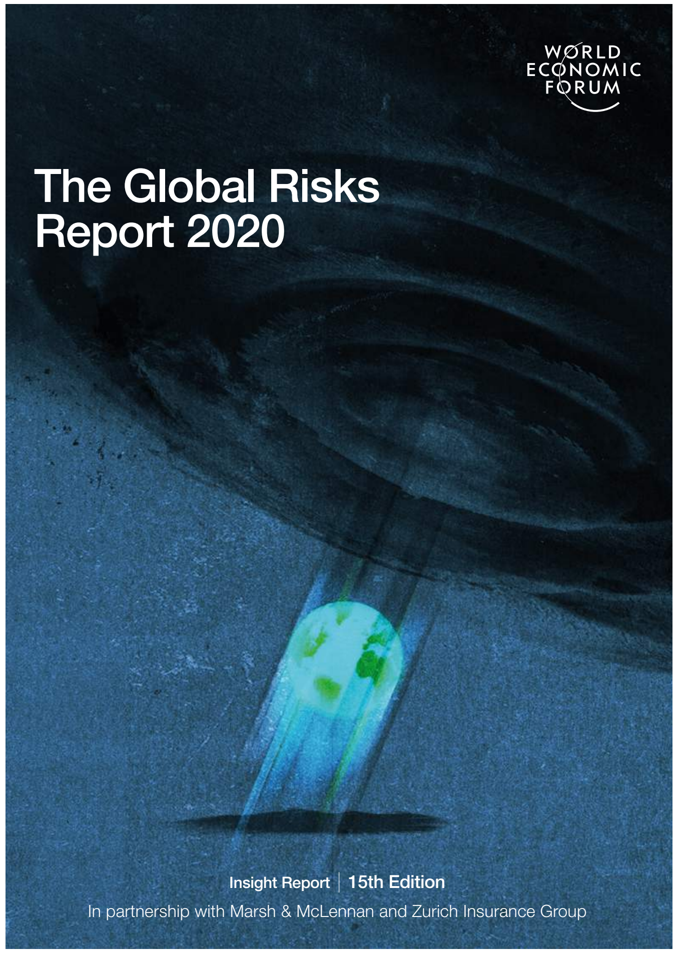
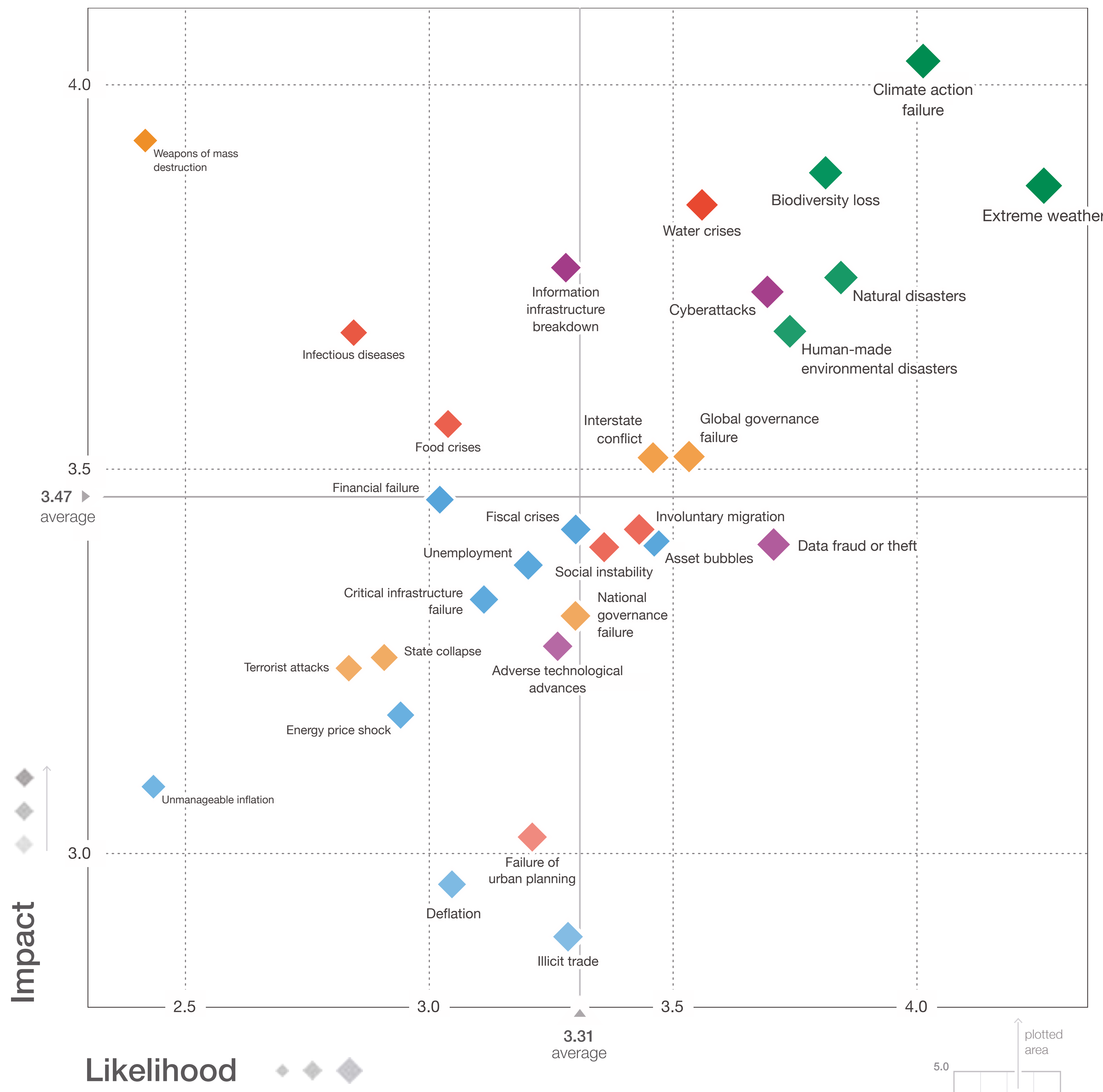
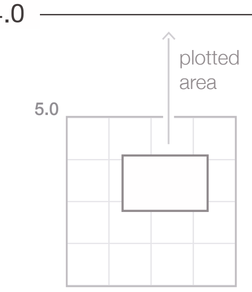


Figure II: The Global Risks Landscape 2020



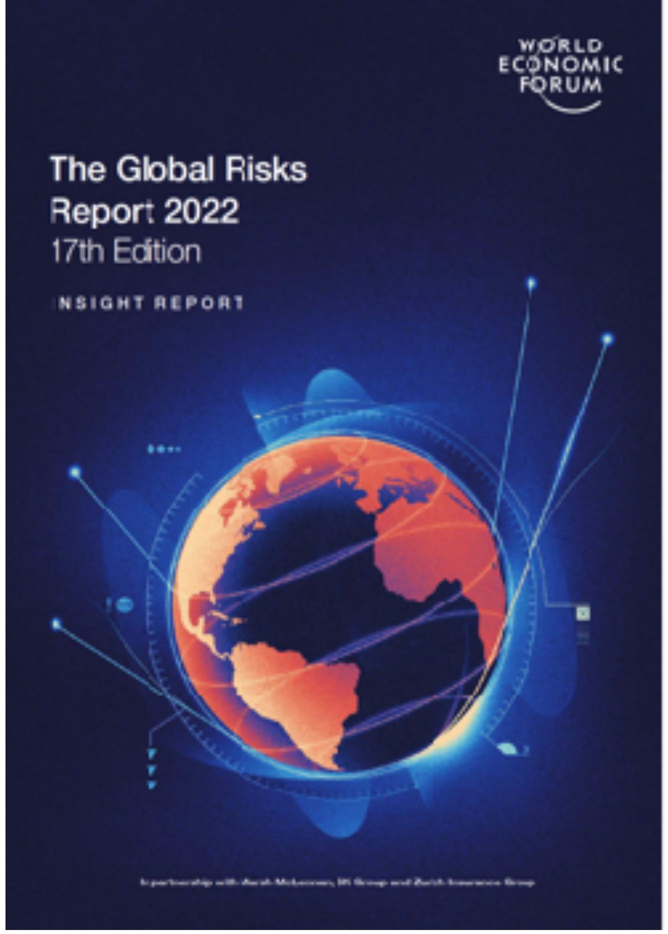


Categories

- Economic
- Environmental
- Geopolitical
- Societal
- Technological

Top 10 risks in terms of

Top 10 risks in terms of



The Global Risks Report 2022
17th Edition

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FIGURE 1.3

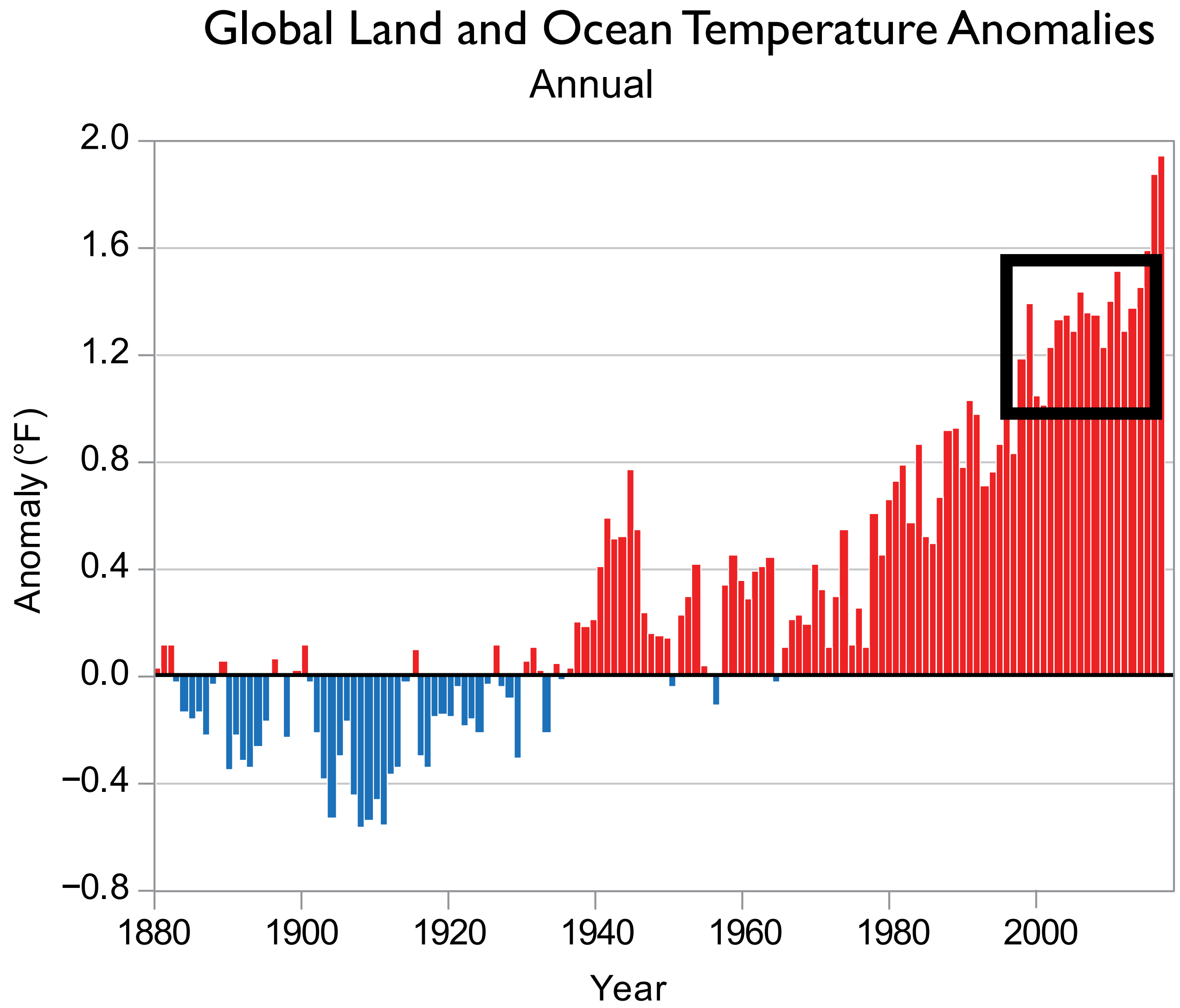
"Identify the most severe risks on a global scale over the next 10 years"

Economic | Environmental | Geopolitical | Societal | Technological

1st	Climate action failure	6th	Infectious diseases
2nd	Extreme weather	7th	Human environmental damage
3rd	Biodiversity loss	8th	Natural resource crises
4th	Social cohesion erosion	9th	Debt crises
5th	Livelihood crises	10th	Geoeconomic confrontation

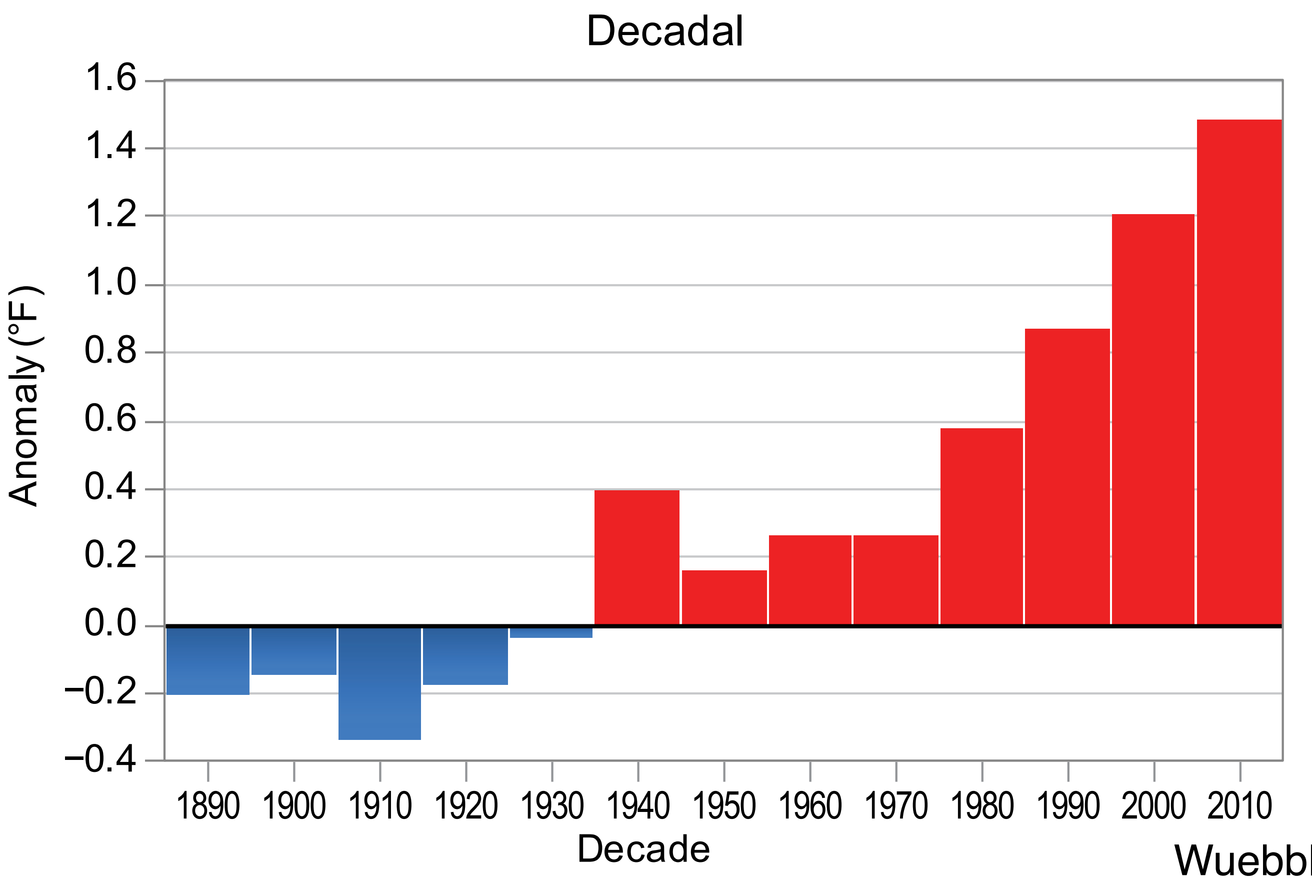
Source: World Economic Forum Global Risks Perception Survey 2021-2022

Earth's Changing Climate: Observations, Impacts, Models and Uncertainty



Earth is warming

Focusing on year to year variability can be misleading (Global warming hiatus or pause)

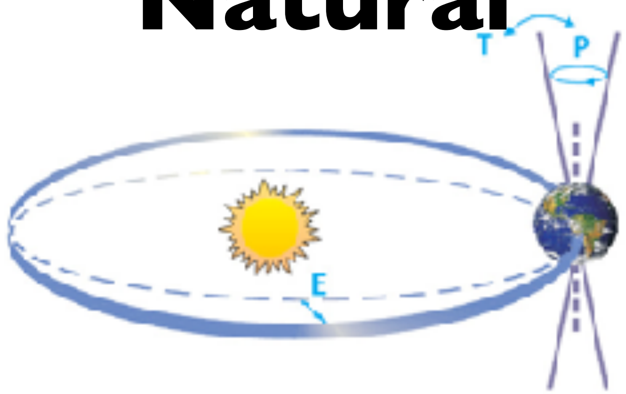


Decadal averages show a smoother upward trend

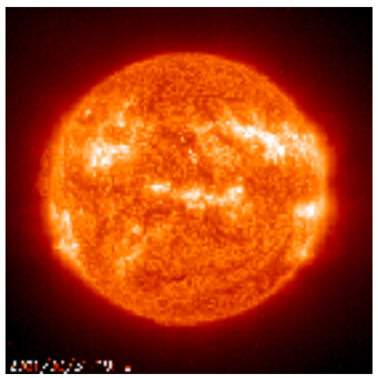
Wuebbles et al., 2017 — NCA 4th Assessment

What are the factors influencing climate change?

Natural



Orbital Changes

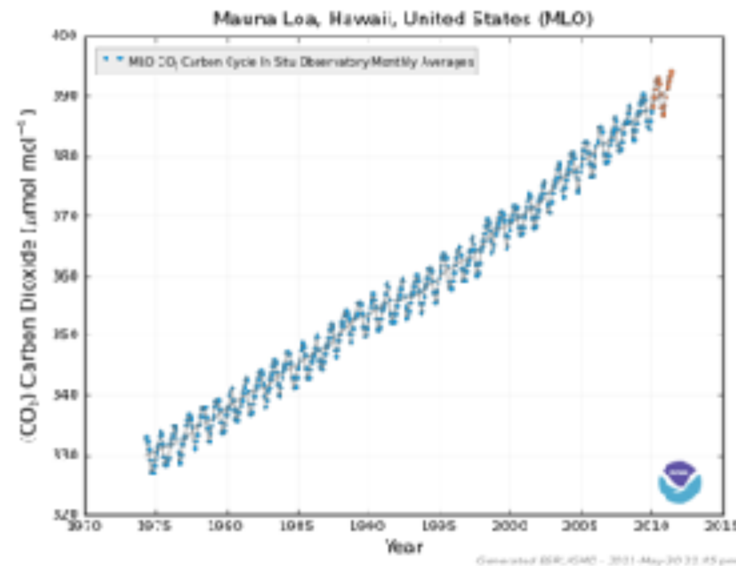


Solar Variability
- Changes in incoming radiation

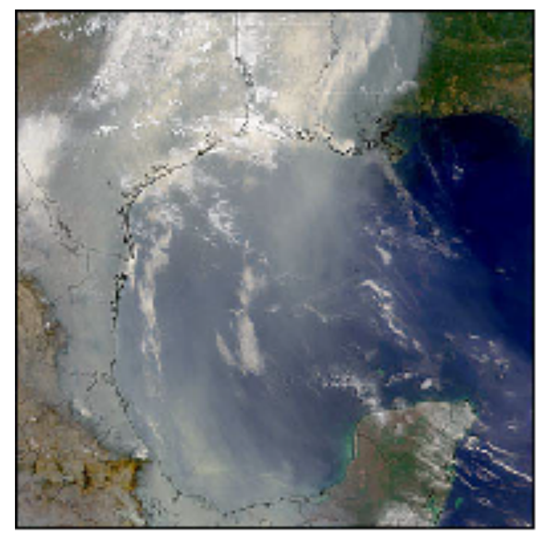
Volcanic eruptions
- **Emits CO2 as well as sulfate aerosols**

Rock Weathering Removes CO2 from atmosphere

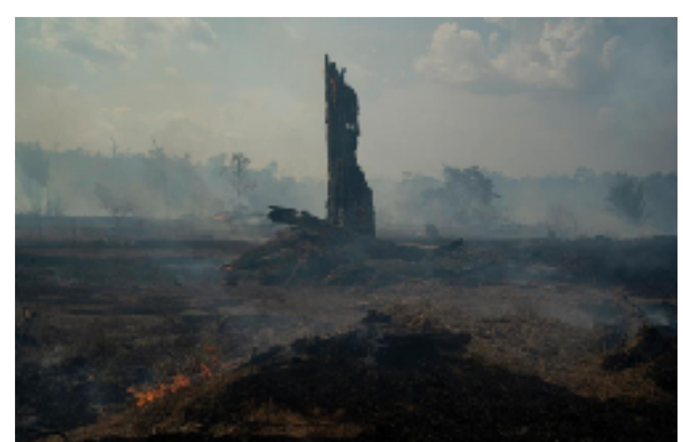
Human Influences



Changes in atmospheric concentrations of greenhouse gases



Aerosols from fossil fuel burning and biomass burning

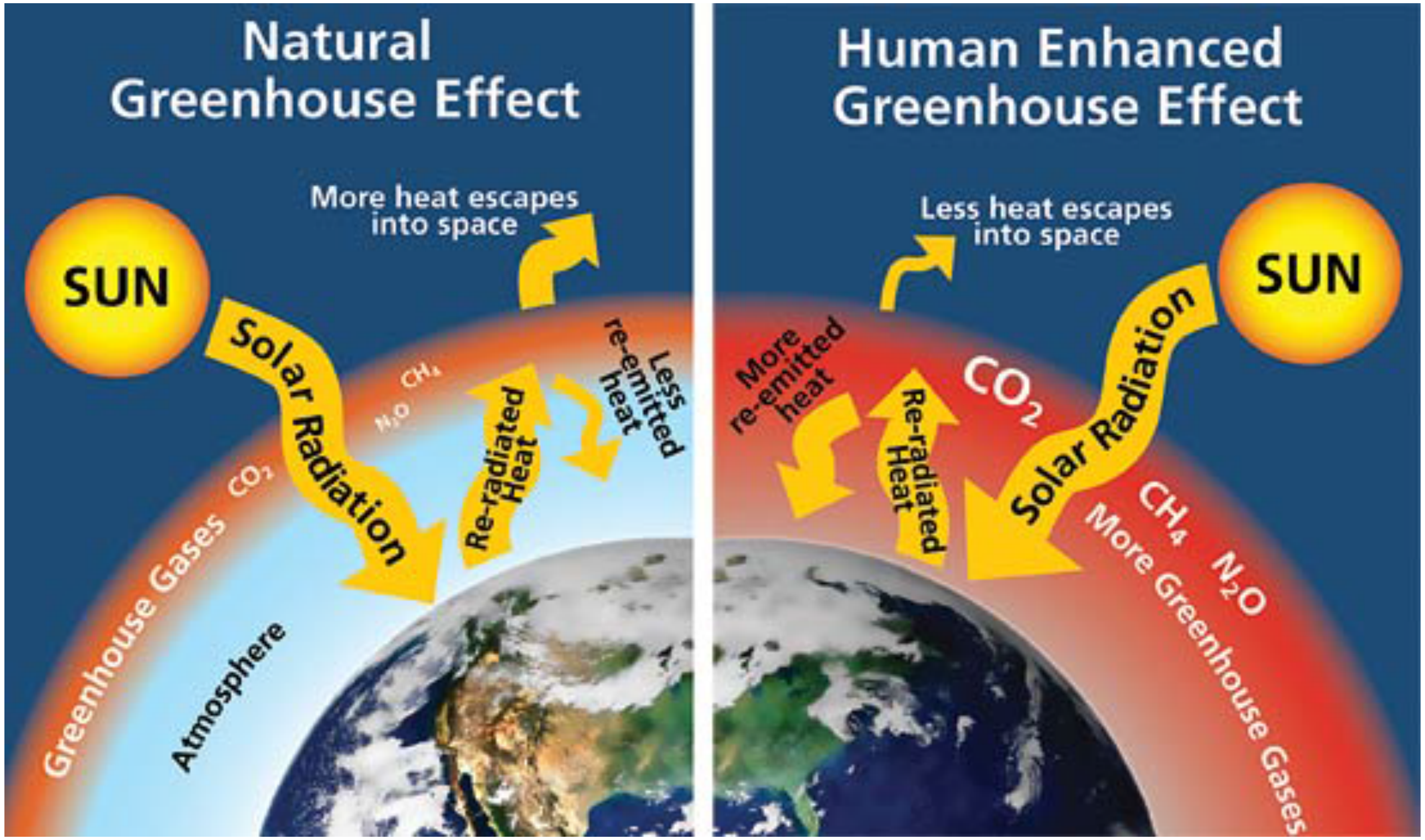


Leo Correa, The Associated Press

Land Use and Land Cover Change (Deforestation)

Figures Adapted from Don Wuebbles

The greenhouse effect

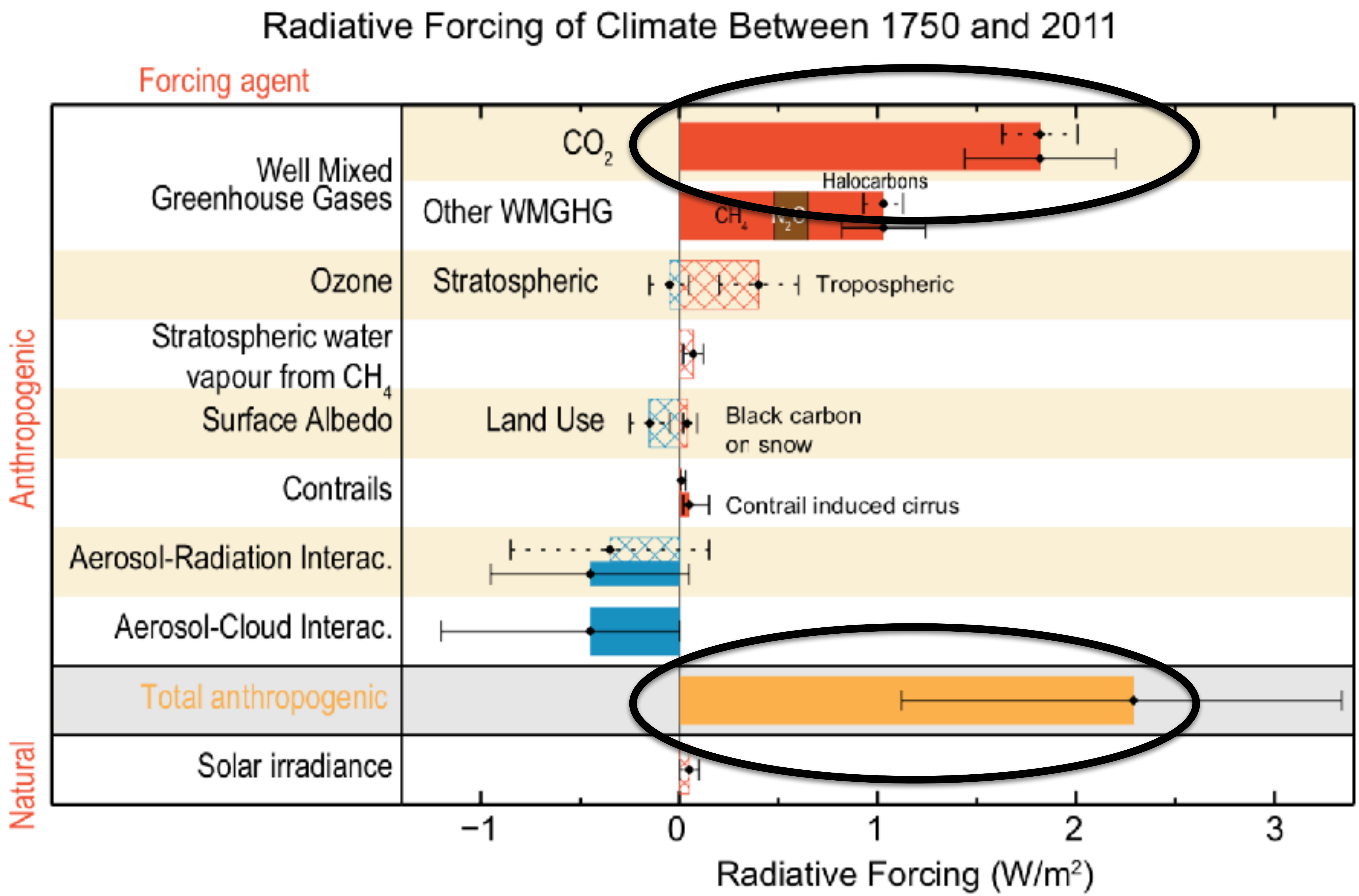


- Earth's atmosphere is largely transparent to solar wavelengths
  - Strong absorber of outgoing radiation (longer wavelengths)

- Result is a warmer surface due to re-emitted heat by the atmosphere back to surface

- Increased greenhouse gases amplify this insulating effect

Figure Courtesy of Don Wuebbles

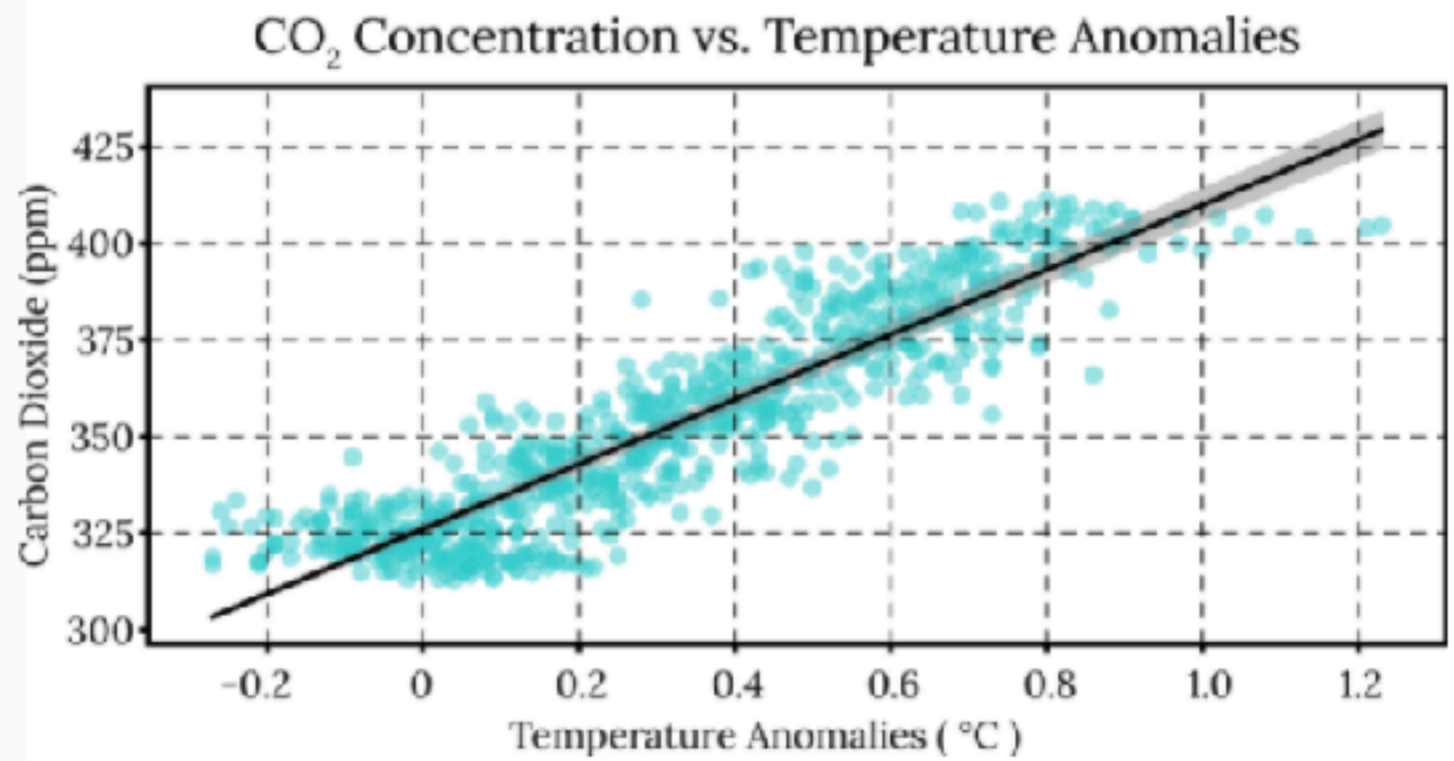


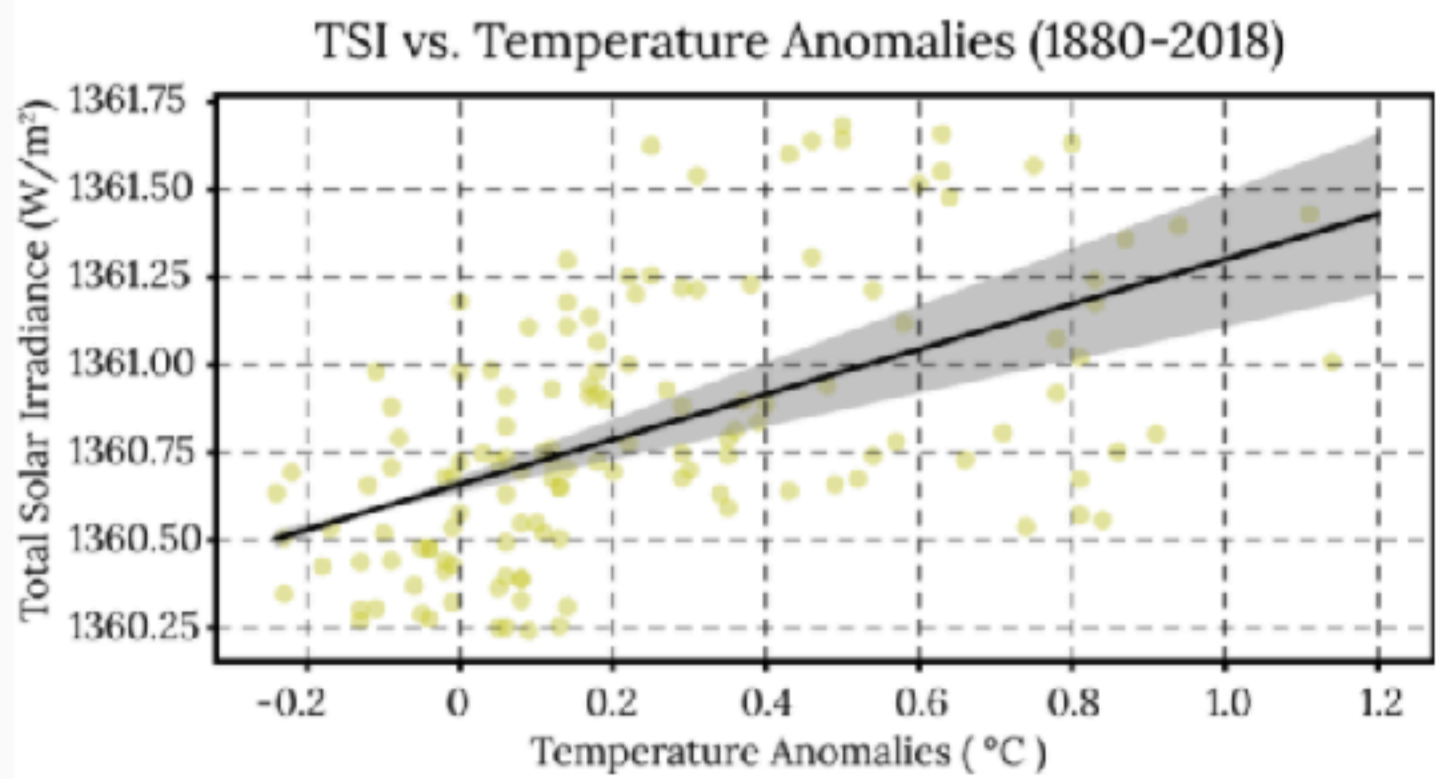
Myhre et al., Chapter 8, AR5, 2013

What matters more for global climate: CO2 or solar variability?

Atmospheric CO2

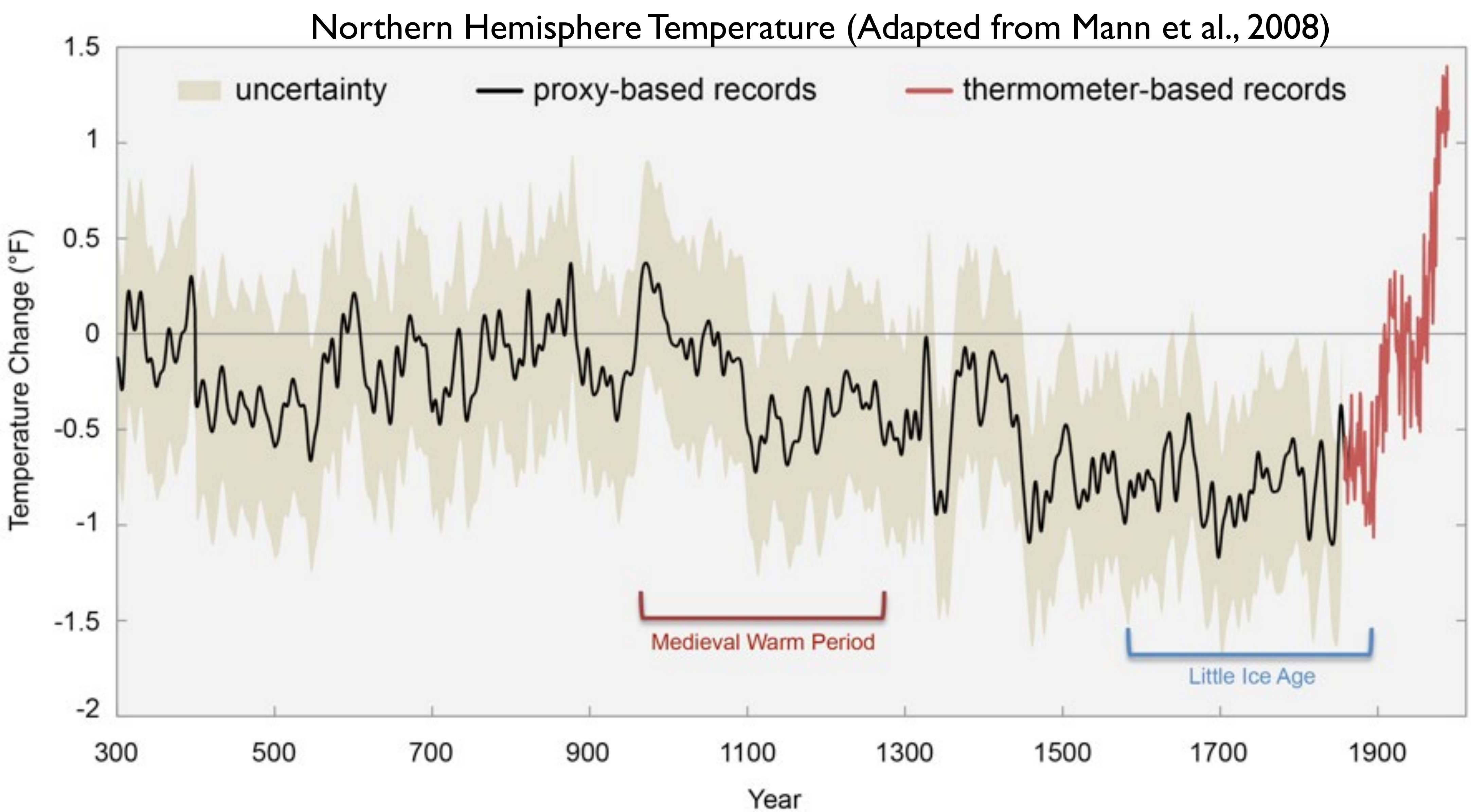
Incoming Solar Radiation





Atmospheric CO2 shows much better agreement with temperature than solar variability

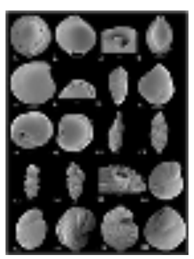
Current Conditions are warmest in last 2000 years

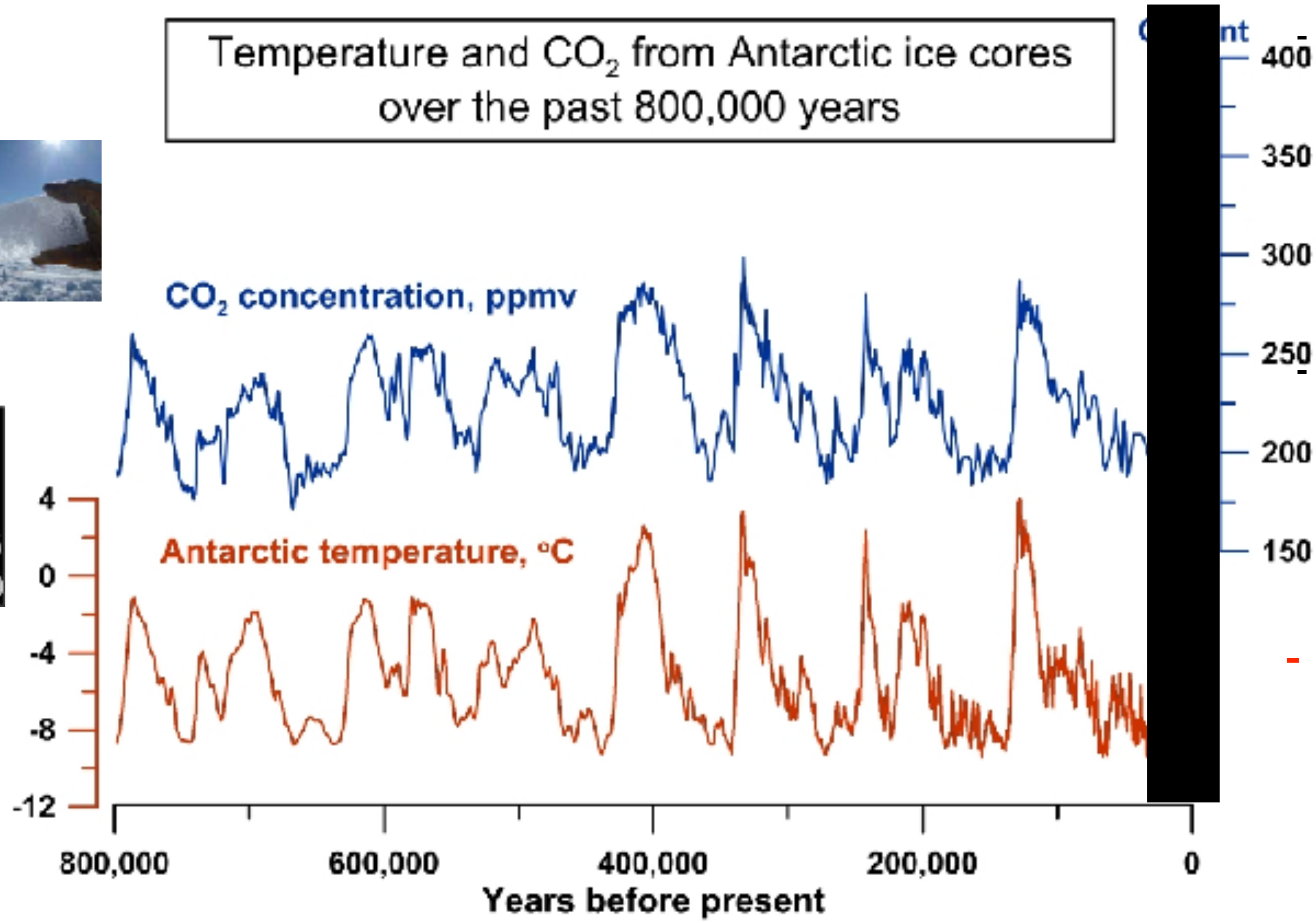


Climate over the last 2 thousand years

Proxy-based records primarily from tree ring data

What are the observable connections between CO2 and temperature?

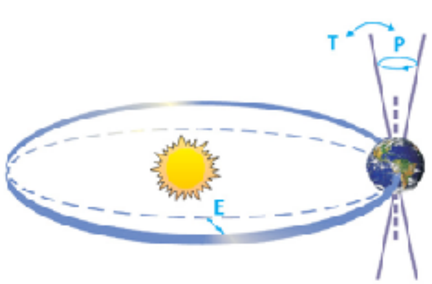




- Temperature and CO2 tend to vary together
  - Neither one moves far without the other
- CO2 lags Temp by several centuries in glacial record
  - Why?

- Current CO2 levels are higher than any other time during at least last 800,000 years
- How will the Earth respond?

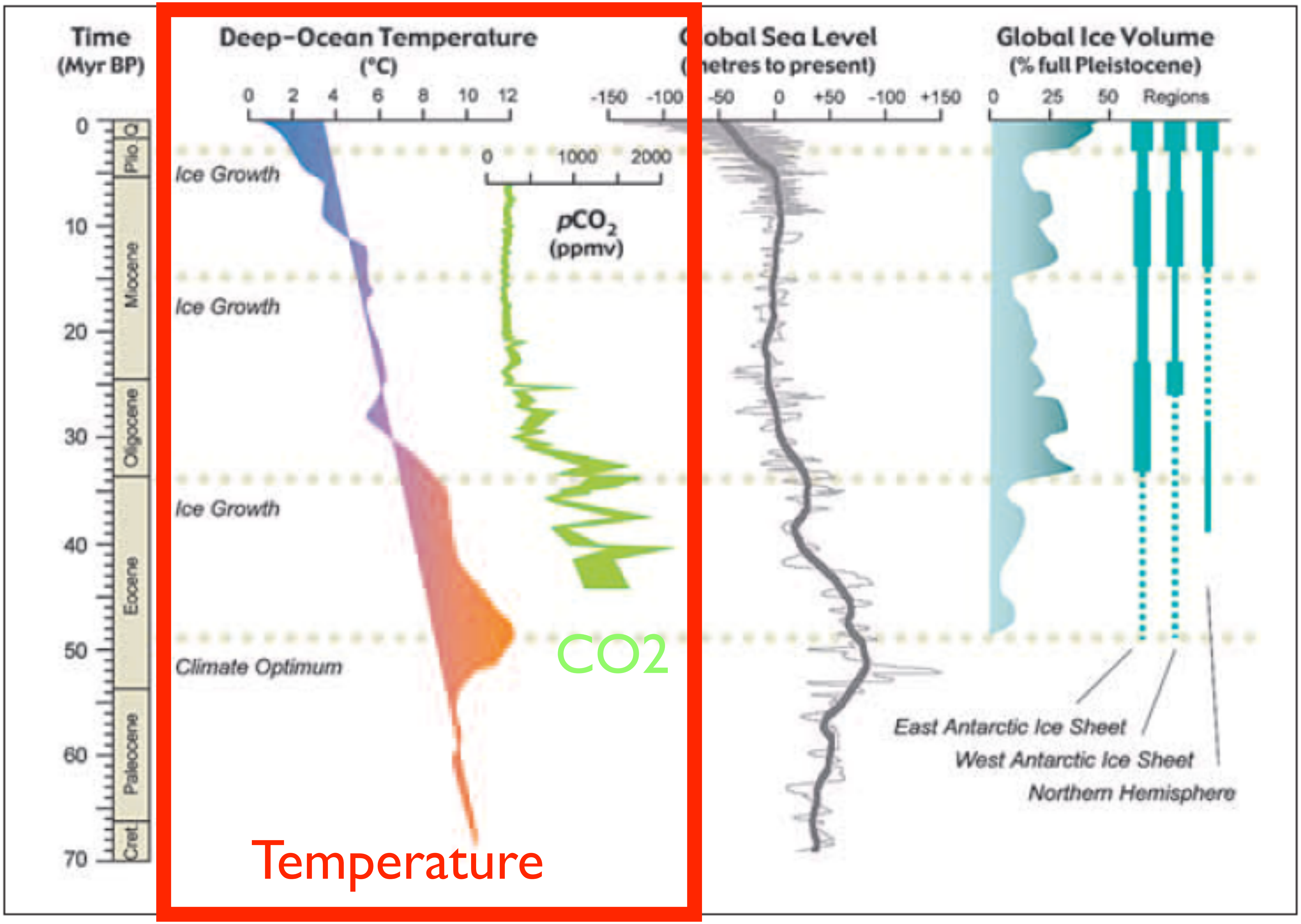
Climate over the past 1 million years



- Changes in orbit lead to warming
  - Warming leads to CO2 increases
    - CO2 leads to more warming

We can't explain observed interglacial temperature variations with orbital changes alone

—> CO2 plays an important part on these timescales



Climate over the last 100 million years

Grobe et al., 2009

What are the impacts of climate change?

source: AP/Seth Perlman

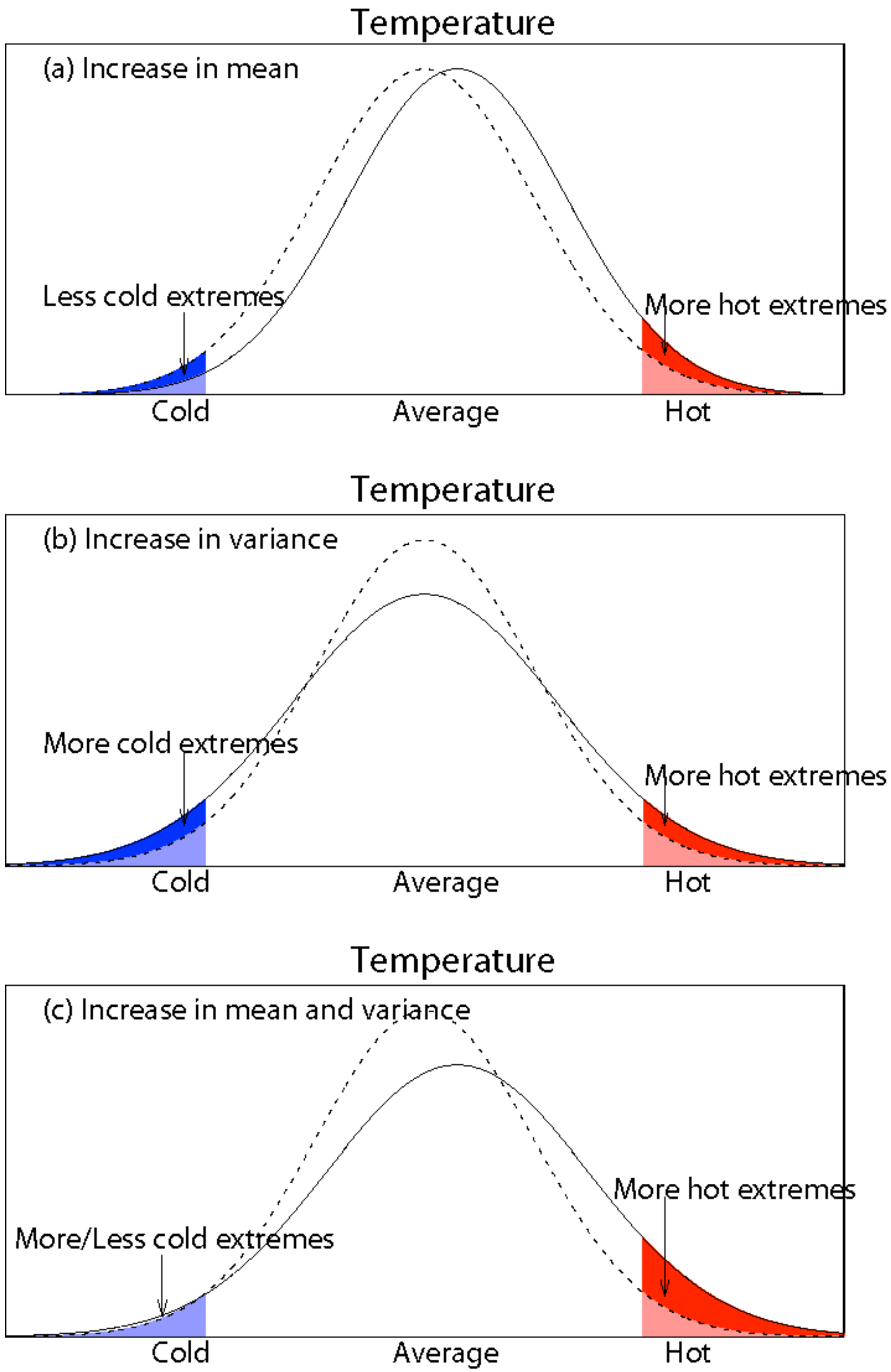
National Climate Assessment, 2014

National Climate Assessment, 2014

source: NOAA

Climate impacts/damages closely linked to extreme (low probability) events

Understanding how extremes may be changing is a major challenge



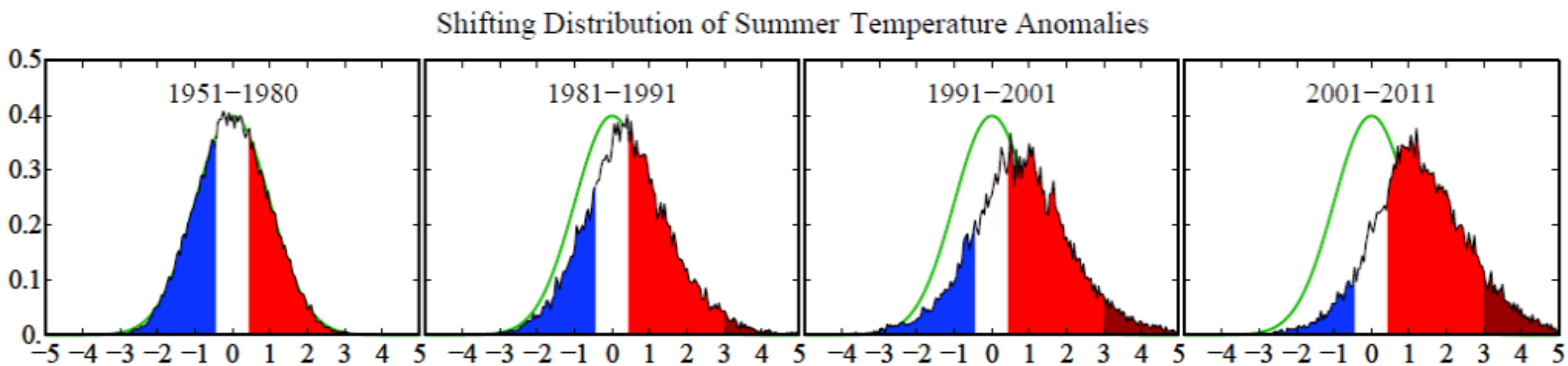
Extreme Temperature

Increase in the Mean

Increase in the Variance

Increase in the Mean and Variance

Observed change in Extreme Temperatures

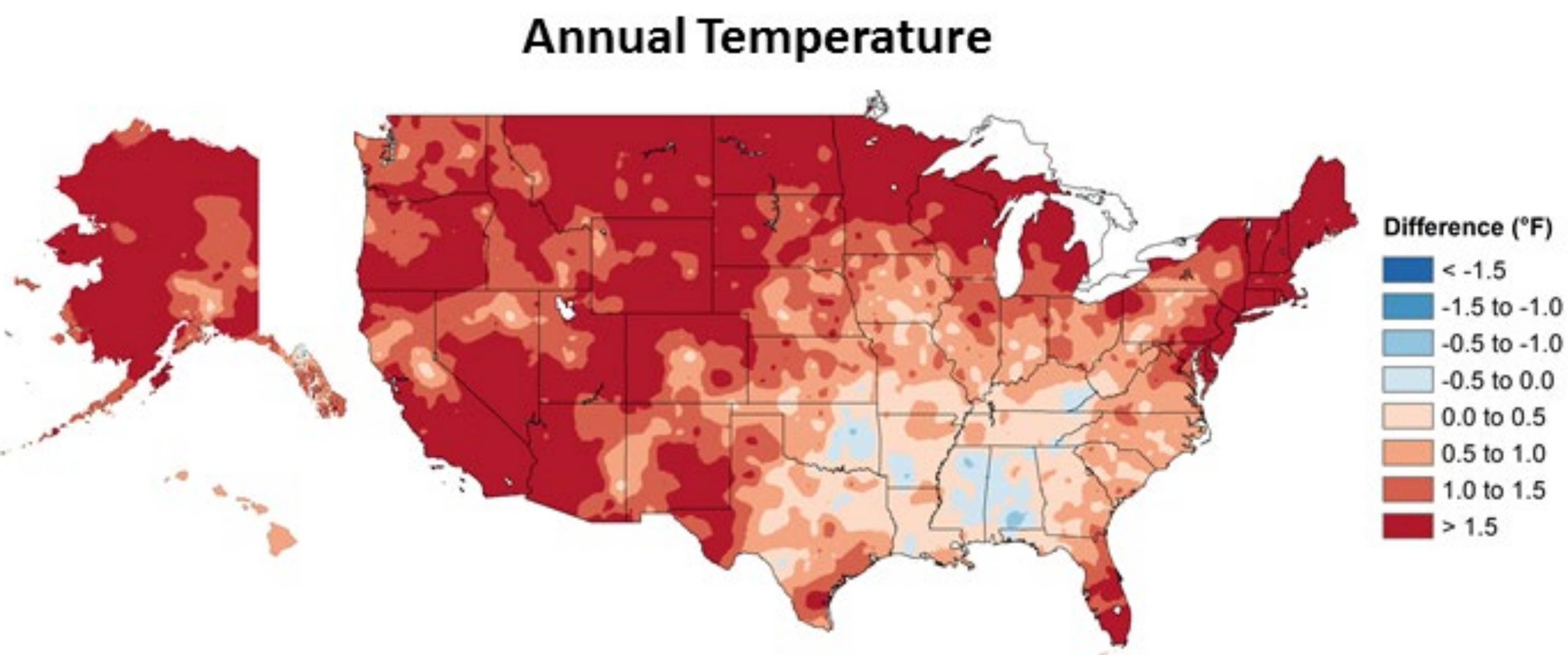


Frequency of occurrence (vertical axis) of local June-July-August temperature anomalies (relative to 1951-1980 mean) for Northern Hemisphere land in units of local standard deviation (horizontal axis).

Source: Hansen, J., Sato, M., and Ruedy, R., Proc. Natl. Acad. Sci., 2012.

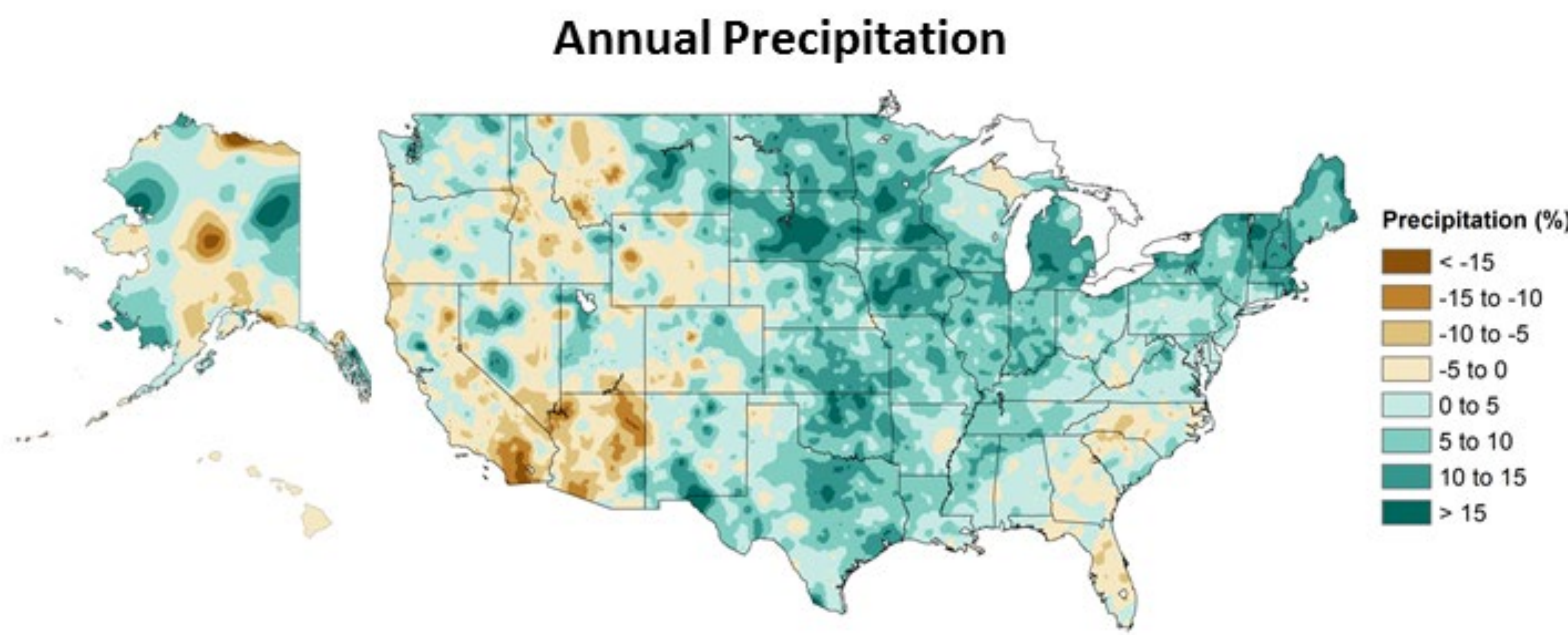
Strong observational evidence of changes in temperature climatologies

What are the observed changes in the US?



Widespread decadal-scale warming

- **Note the spatial patterns**



Increased precipitation across many regions

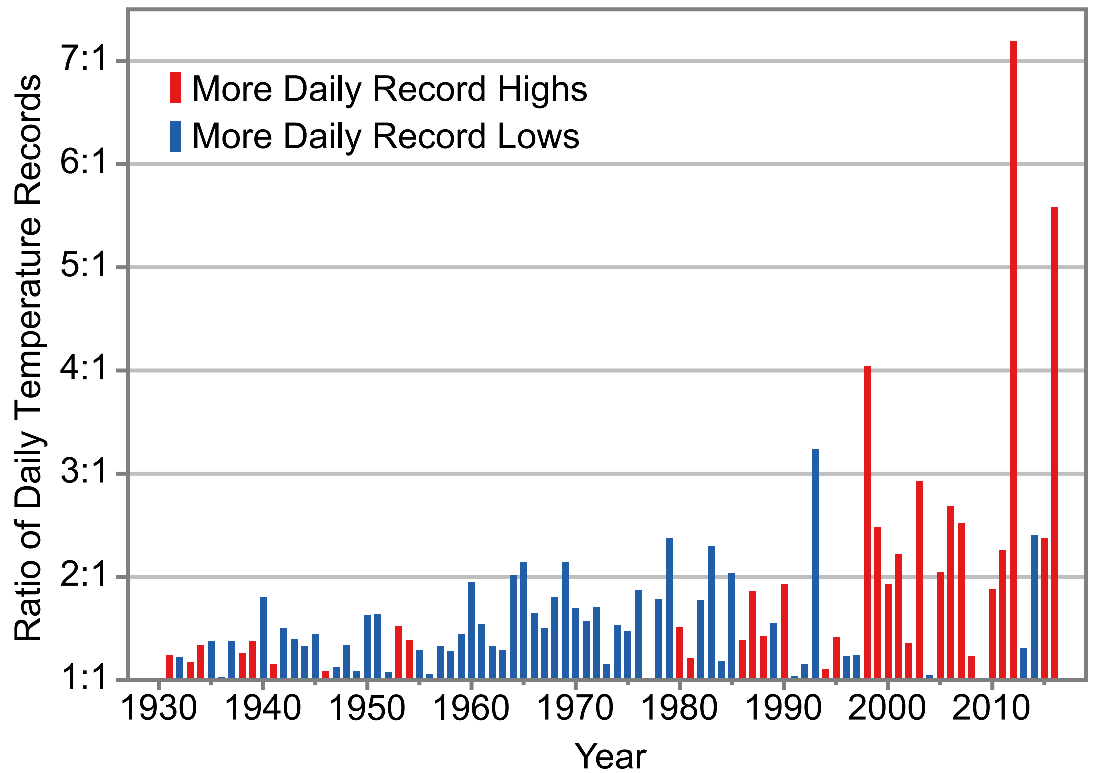
- **Note drying in desert regions**

How do these changes affect natural/human systems?

National Climate Assessment, 2017

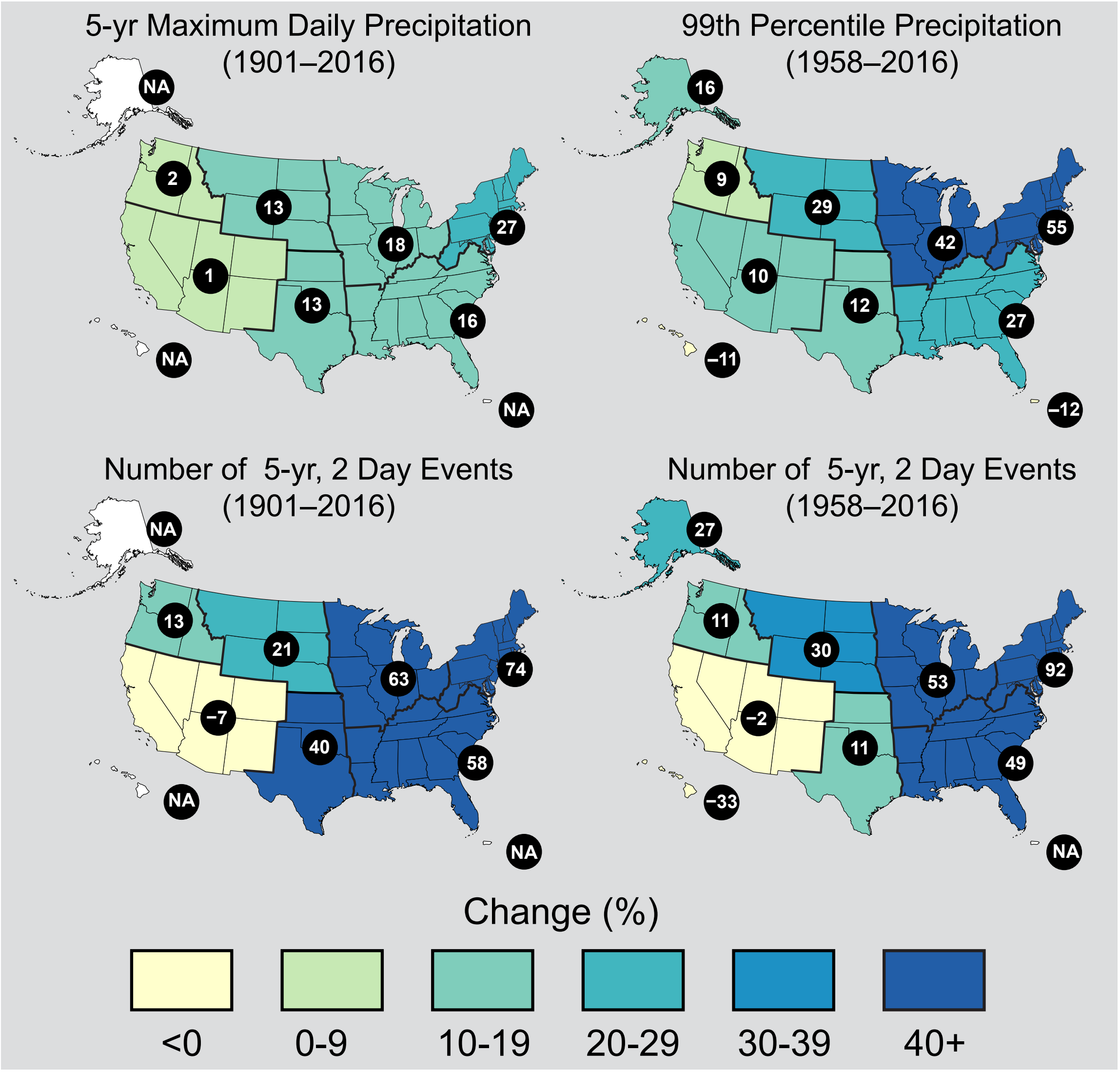
How are the extremes changing?

Record Warm Daily Temperatures Are Occurring More Often



Record warm temperatures occur more often than record cold temperatures

Extreme Precipitation Has Increased Across Much of the United States



Extreme Precipitation is increasing across much of the US
- **Note desert regions**

National Climate Assessment, 2017

Tropical cyclones (e.g. hurricanes) pose serious risks

Katrina, 2005

Harvey, 2017

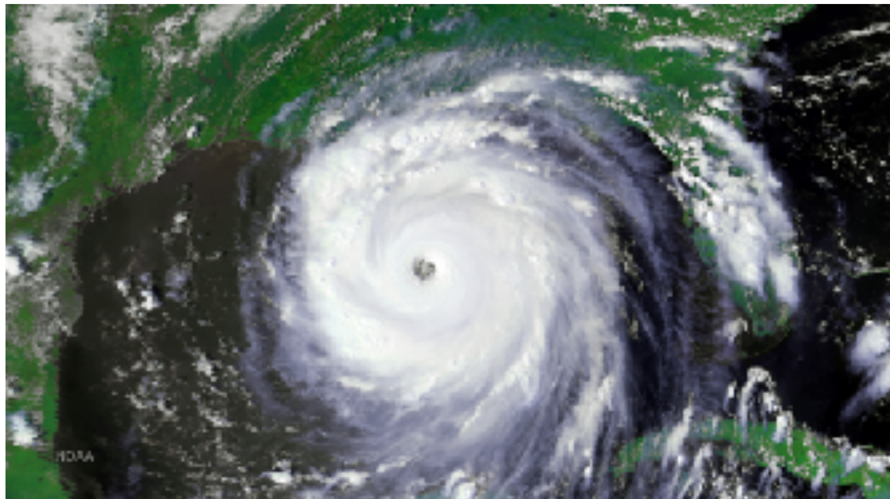
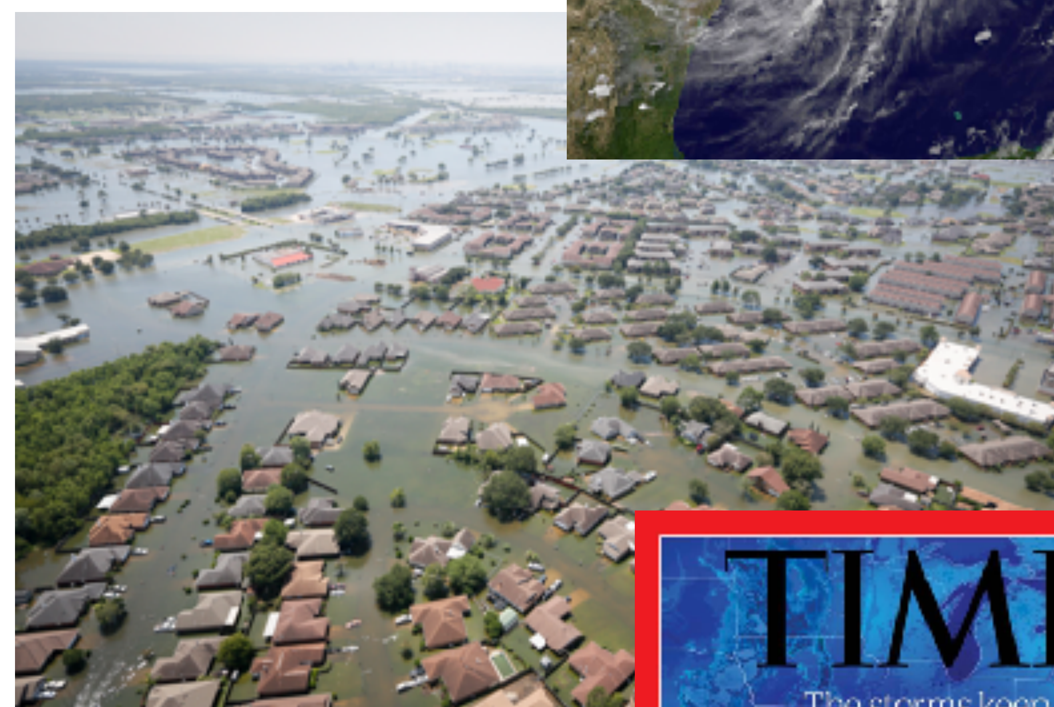


Photo: PBS/NOAA

Tied for costliest hurricanes on record
$125 Billion each (2017 USD)



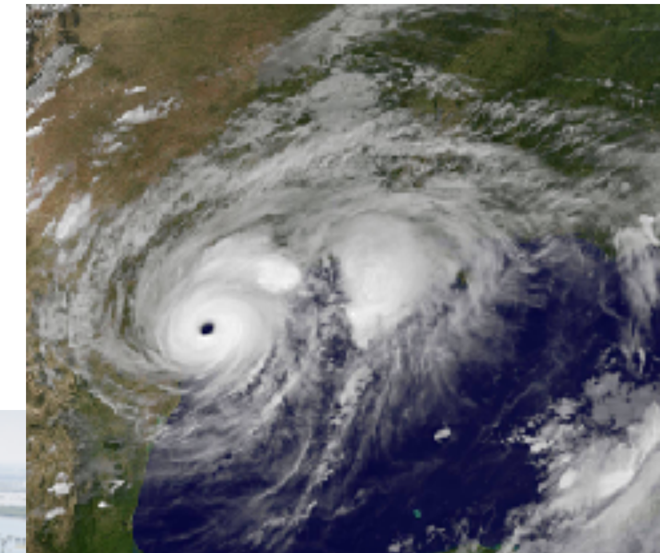
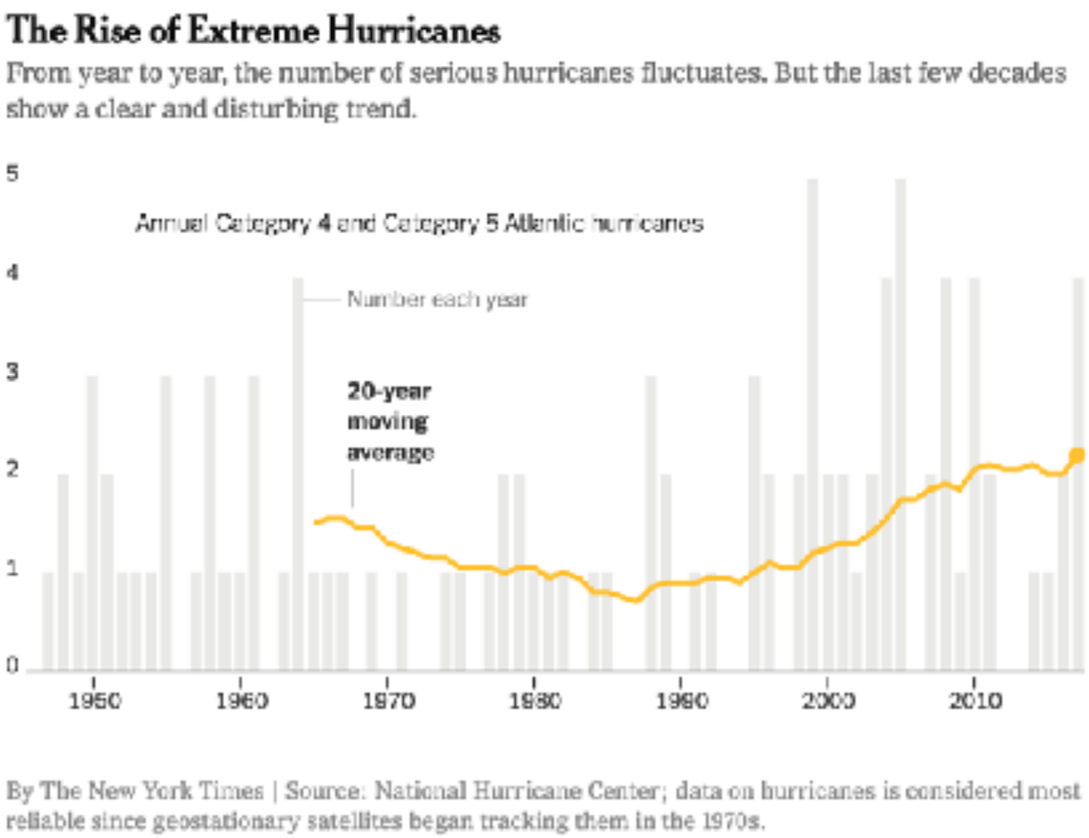


Photo: Wikipedia Commons

Understanding connections between tropical cyclones and climate is critical for coastal planning and flood risk assessments

Are storms becoming more powerful?

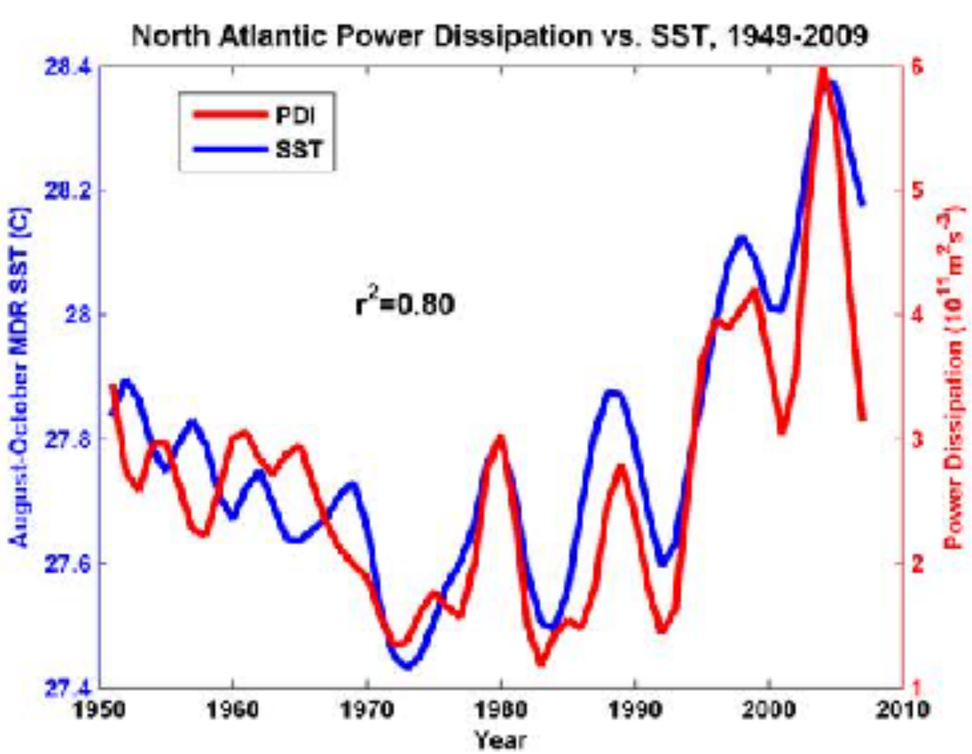


Hurricane Dorian
Sept. 2, 2019

Source:
NOAA/RAMMB

The number of extreme hurricanes per year is increasing over the last several decades

- Is it due to climate change, natural variability, and/or combination of both?



Power dissipation is an integrated measure of storm intensity

- more useful for analyzing climate signals than individual storms
- accounts for intensity, size and duration
- aggregated annually

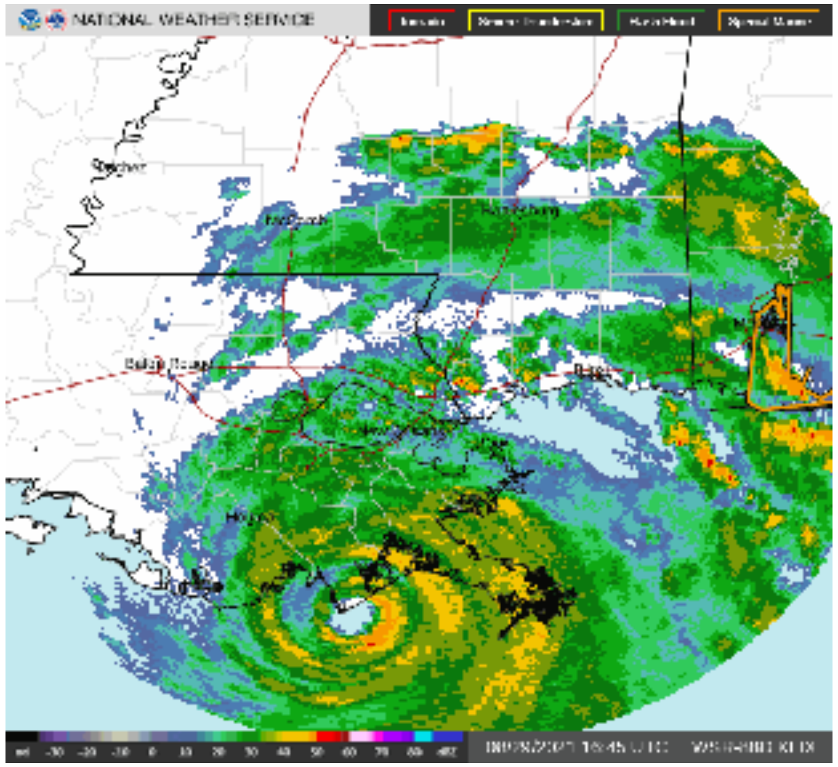
Power Dissipation strongly correlated with tropical ocean temperatures

warmer temps —> more TC activity

What if tropical temps continue to increase?

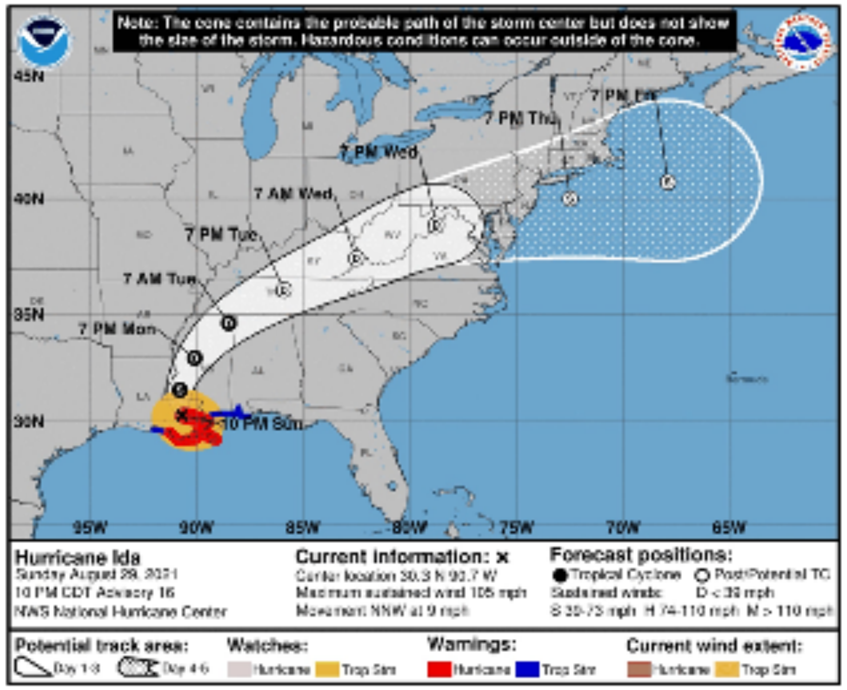
https://emanuel.mit.edu/papers-data-and-graphics-pertaining-tropical-cyclone-trends-and-variability

Hurricane Ida (2021)



- 2nd strongest TC to make LA landfall on record
- Category 4 hurricane with 150 mph winds

- Remnants of Hurricane Ida are now causing historic flooding and tornadoes in the northeast

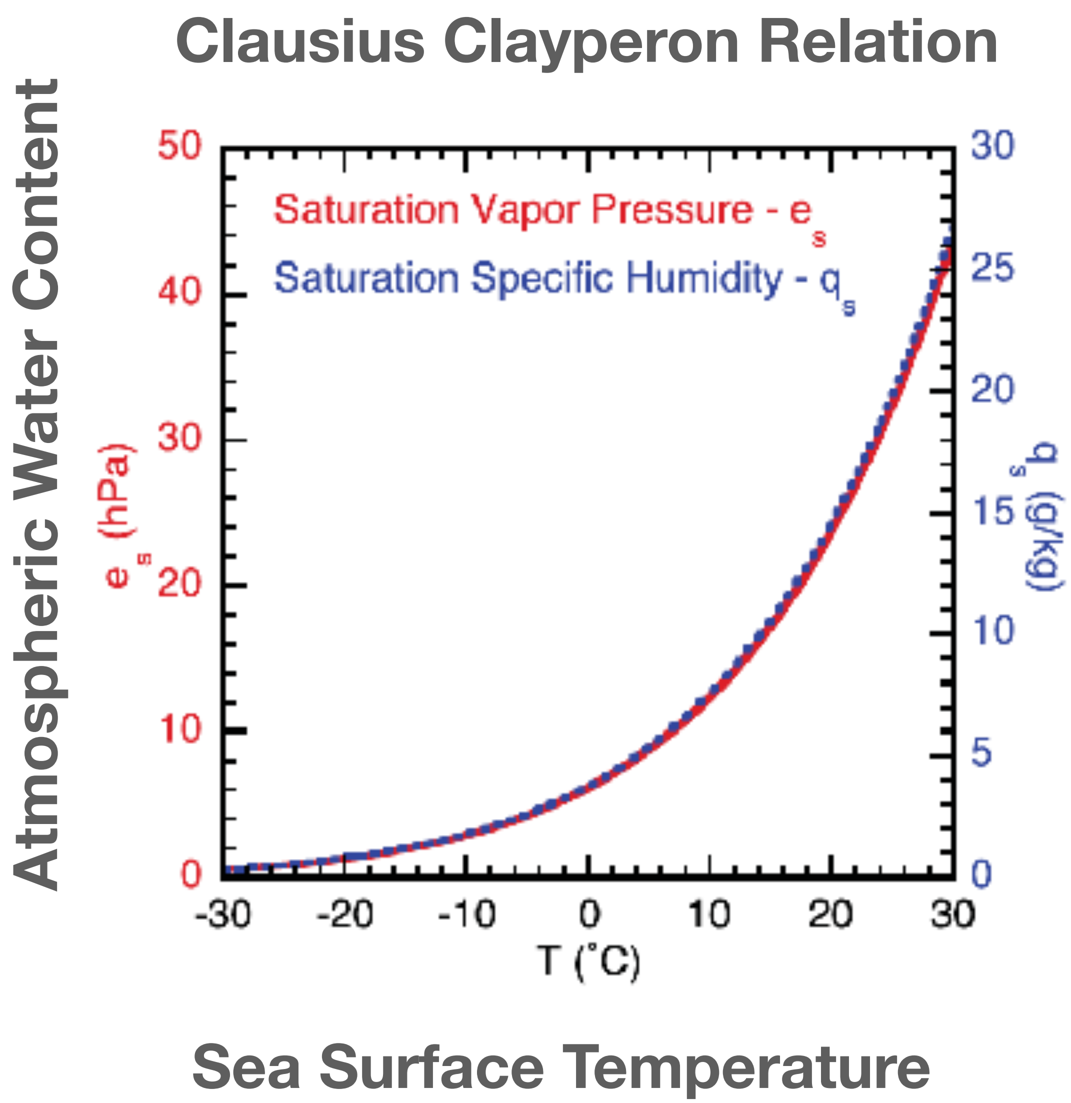


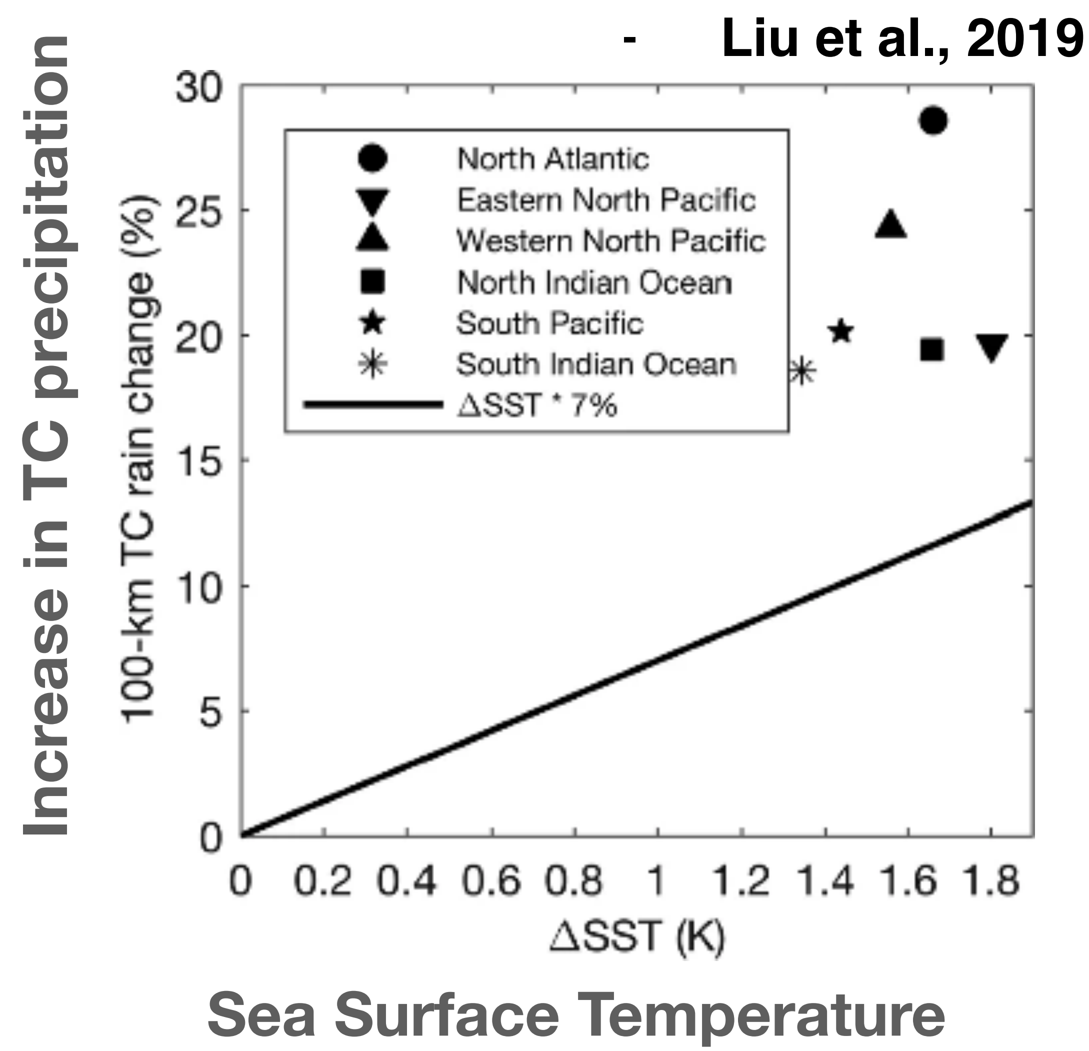
- Boston Herald

- Billy Penn

- What are the connections to climate change?

- **Tropical cyclone precipitation is increasing with global warming!**
- **More precipitation leads to more rain inland and more floods!**
- **Why is TC rain increasing?**

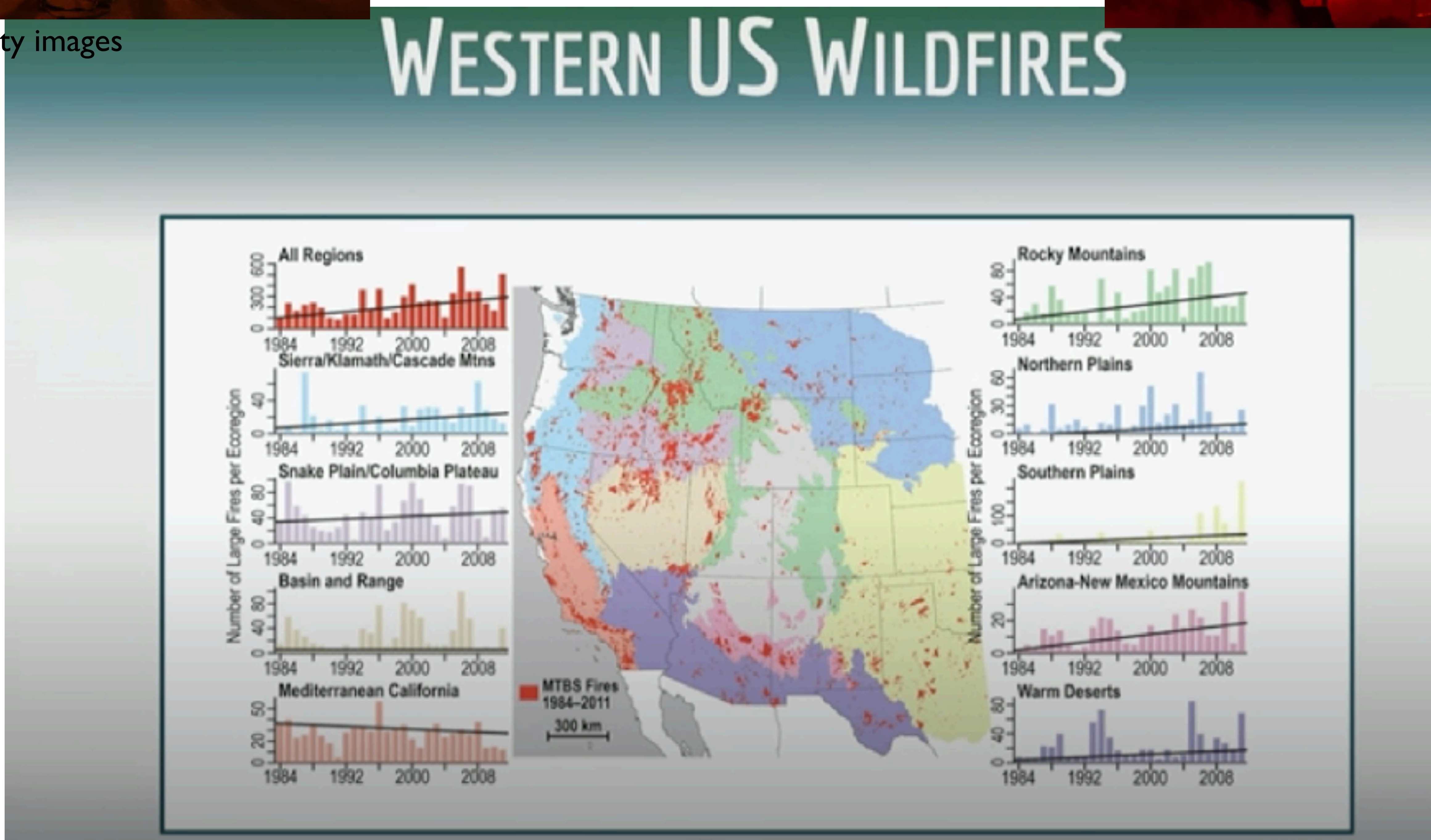




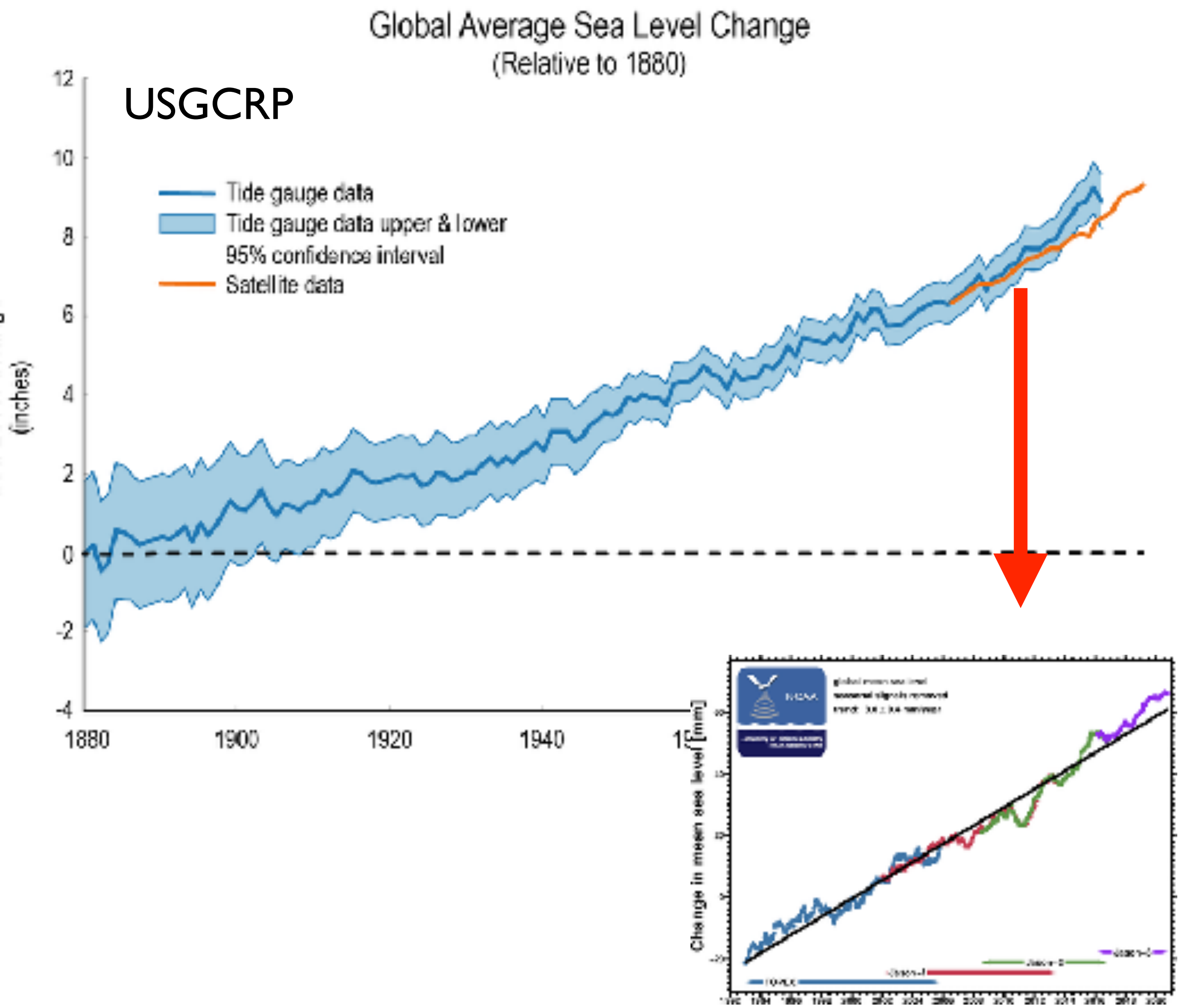
- **Warmer ocean —> Wetter atmosphere —> More rain!**

Wildfires — The number, duration, and area burned are increasing with time

Getty images



Sea-Levels are Rising



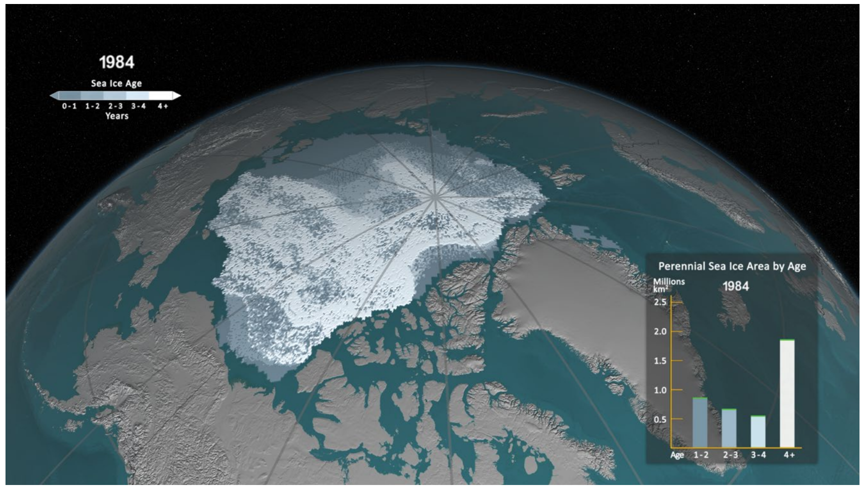
Delfzijl Netherlands, 1994 Photo by Rijkswaterstaat

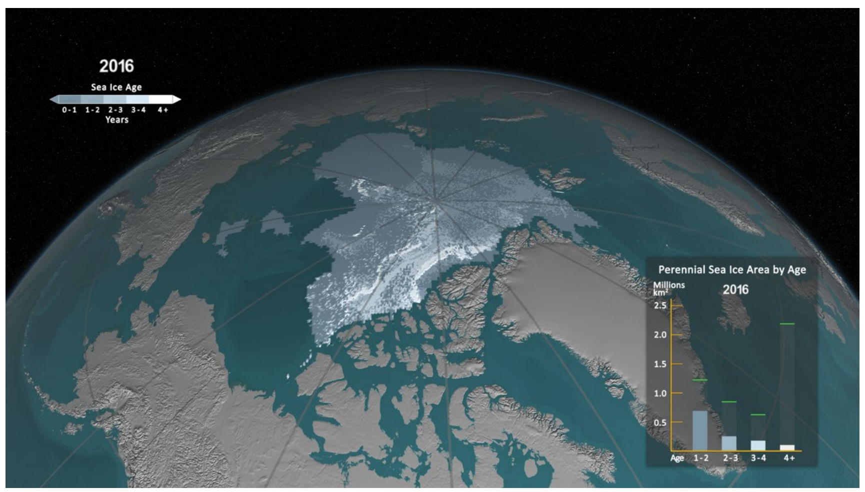
- Coastal systems are at risk of increased flooding

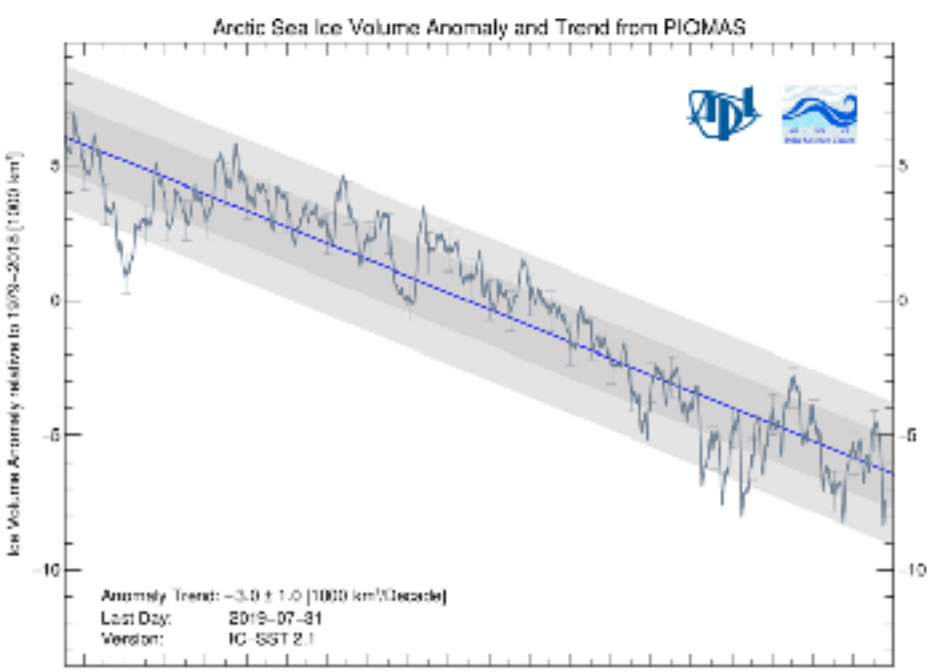
Global Warming and Retreating Polar Ice

National Climate Assessment, 2017

Multiyear Sea Ice Has Declined Dramatically



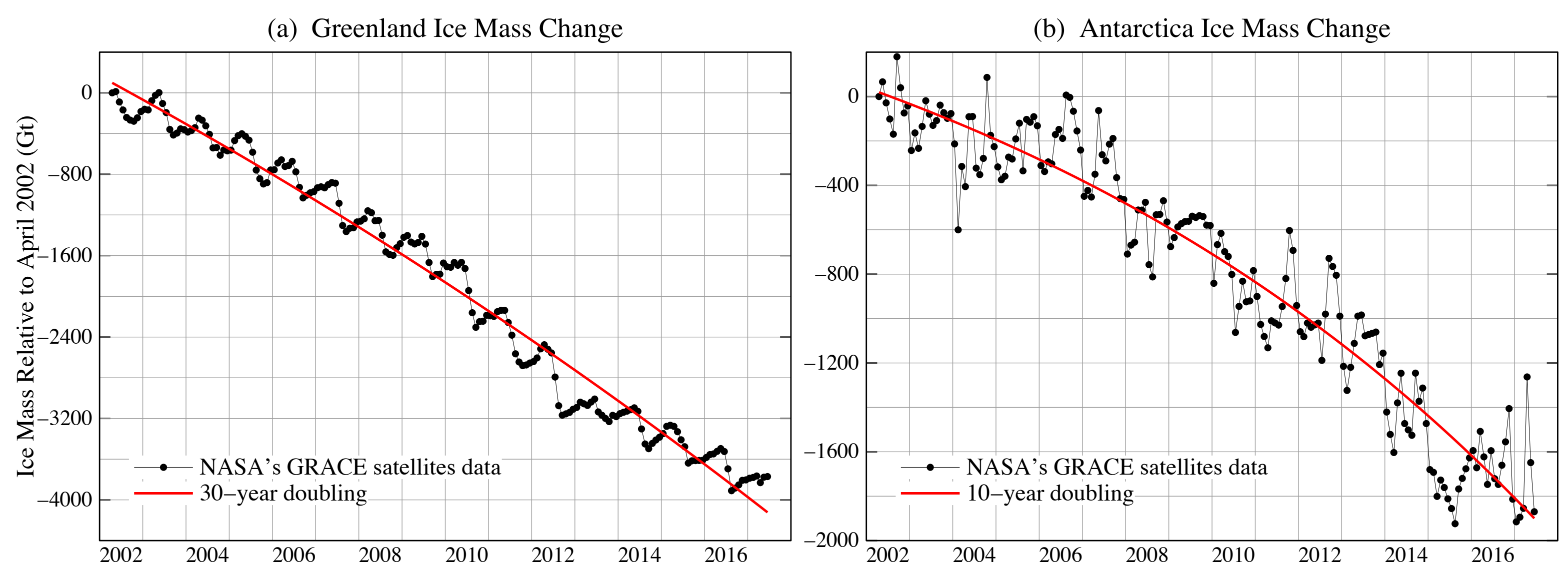




PIOMAS Arctic Sea Ice Volume Reanalysis

http://psc.apl.uw.edu/research/projects/arctic-sea-ice-volume-anomaly/

Ocean/Ice properties useful for analyzing climate change
- large thermal inertia, relatively small variability (large signal to noise)

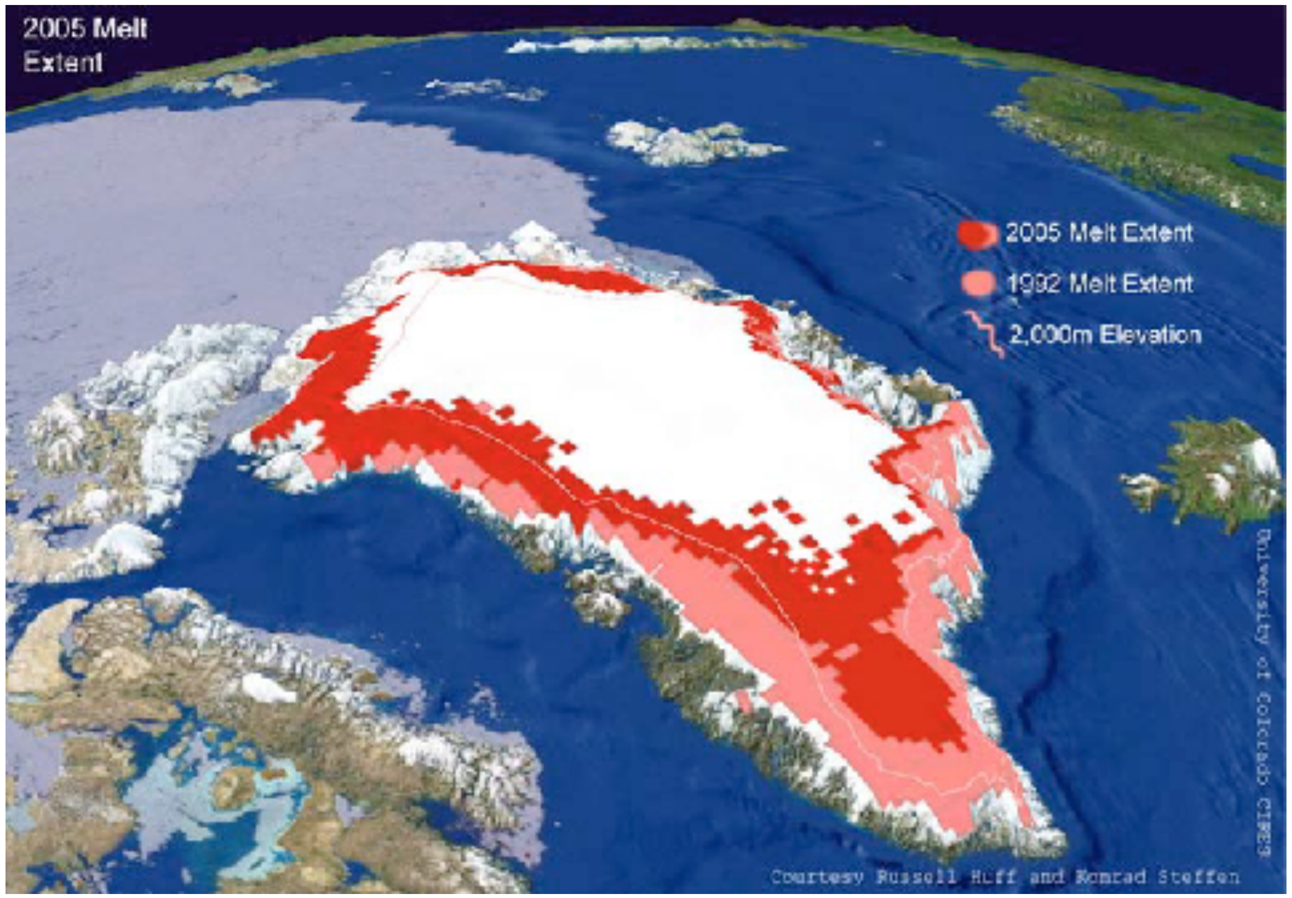


http://www.columbia.edu/~mhs119/IceSheet/

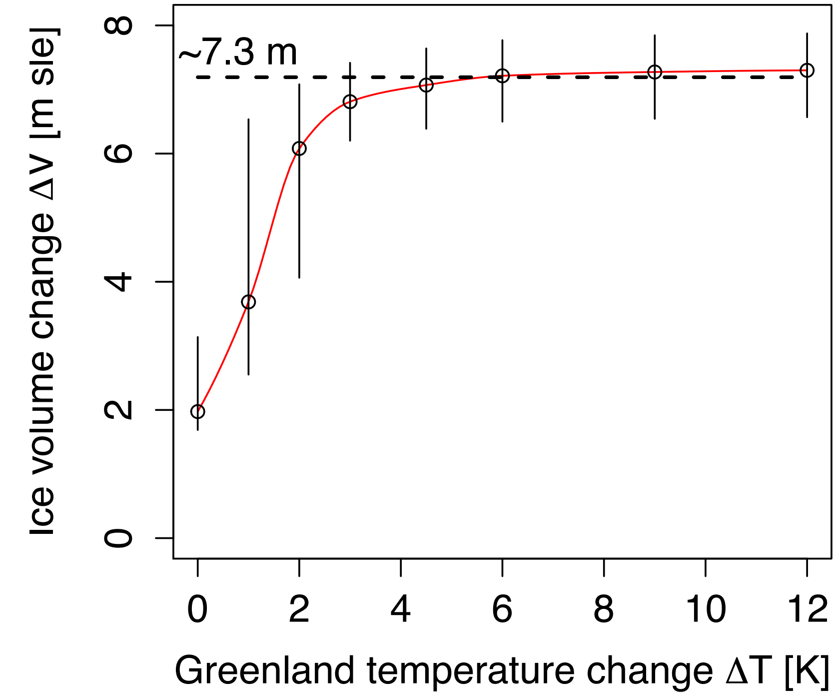
Robust decreases in polar sea/land ice on decadal timescales

Ice Melt and Sea-Level Rise

Changes in melt extent of Greenland Ice Sheet



Modeled relationship between Greenland temp and ice volume

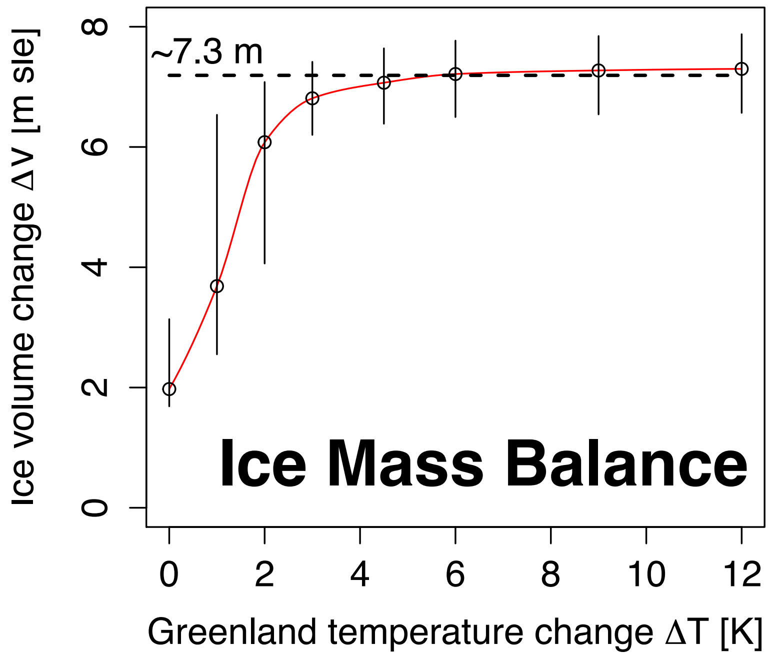


Relatively small increases in Greenland temperature can lead to large changes in sea-level on long (100-1000 year) time scales

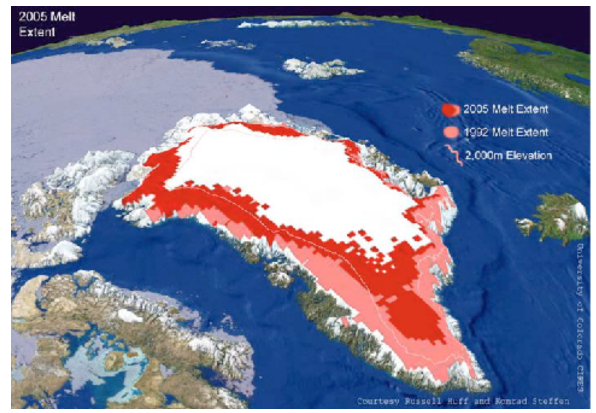
Courtesy Patrick Applegate and Klaus Keller

Parkinson et al., 2015

What about possibility of thresholds and tipping points?

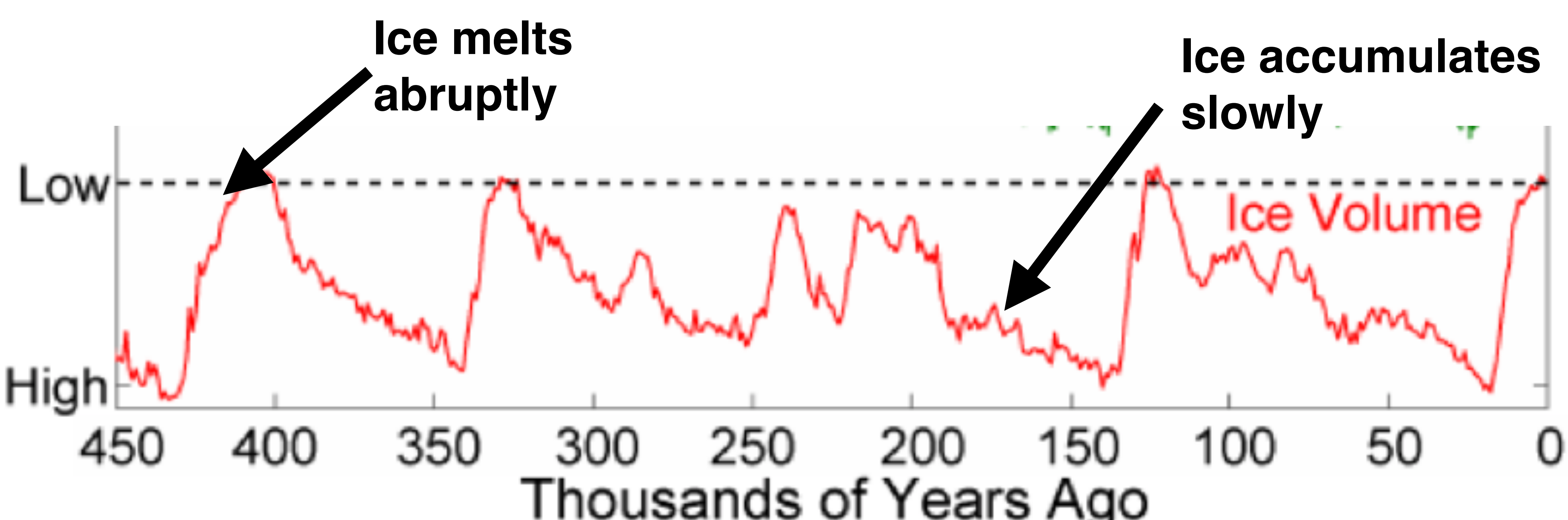


Greenland Ice Sheet



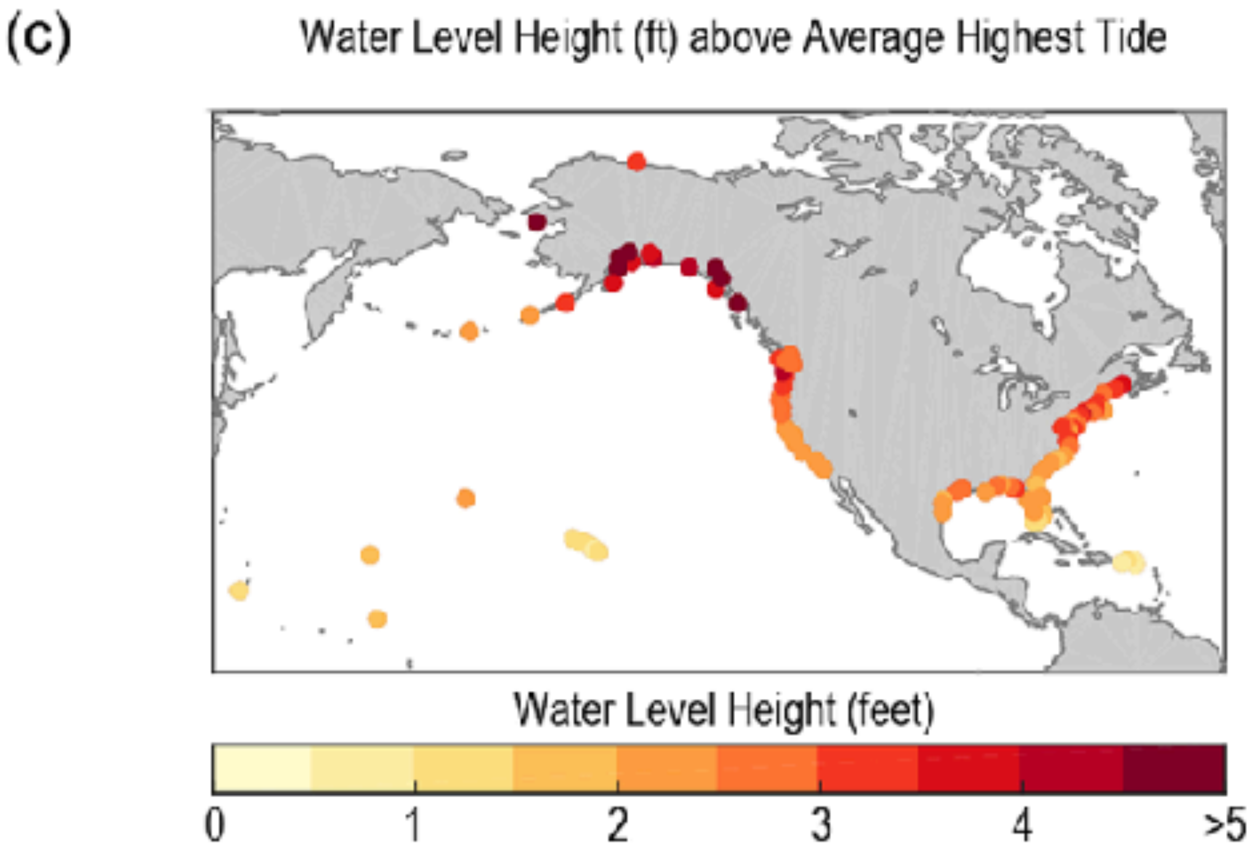
Parkinson et al., 2015

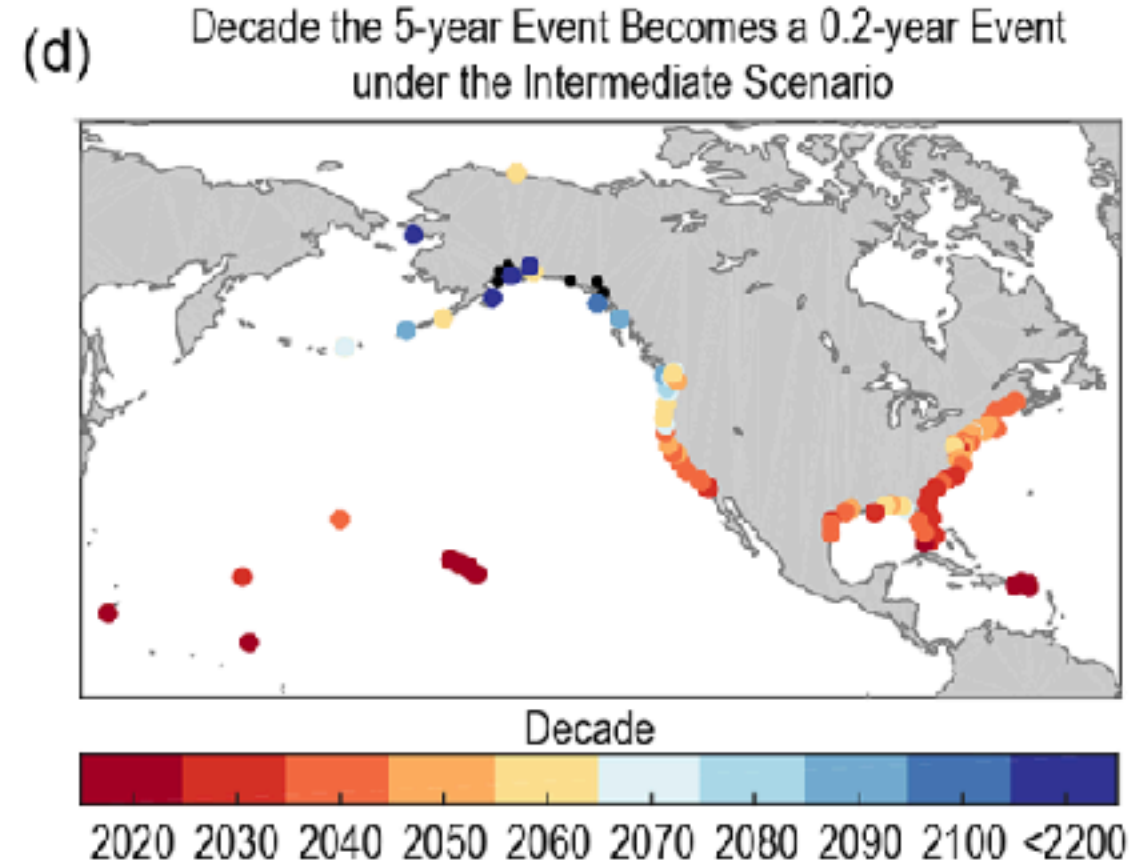
Polar land ice shows strong evidence for threshold responses and hysteresis

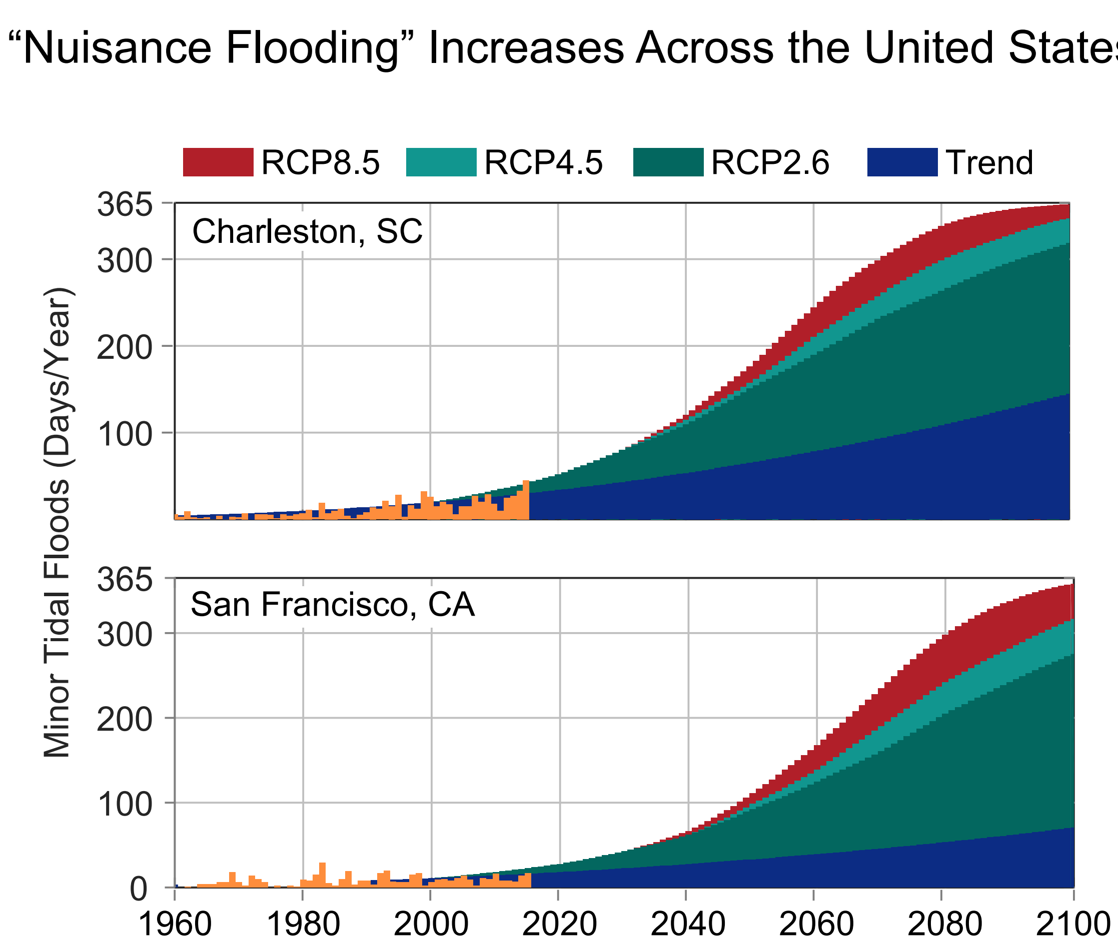


What are the implications for future projections? (No historical analogue)

Occurrences of sunny-day (nuissance) flooding are increasing

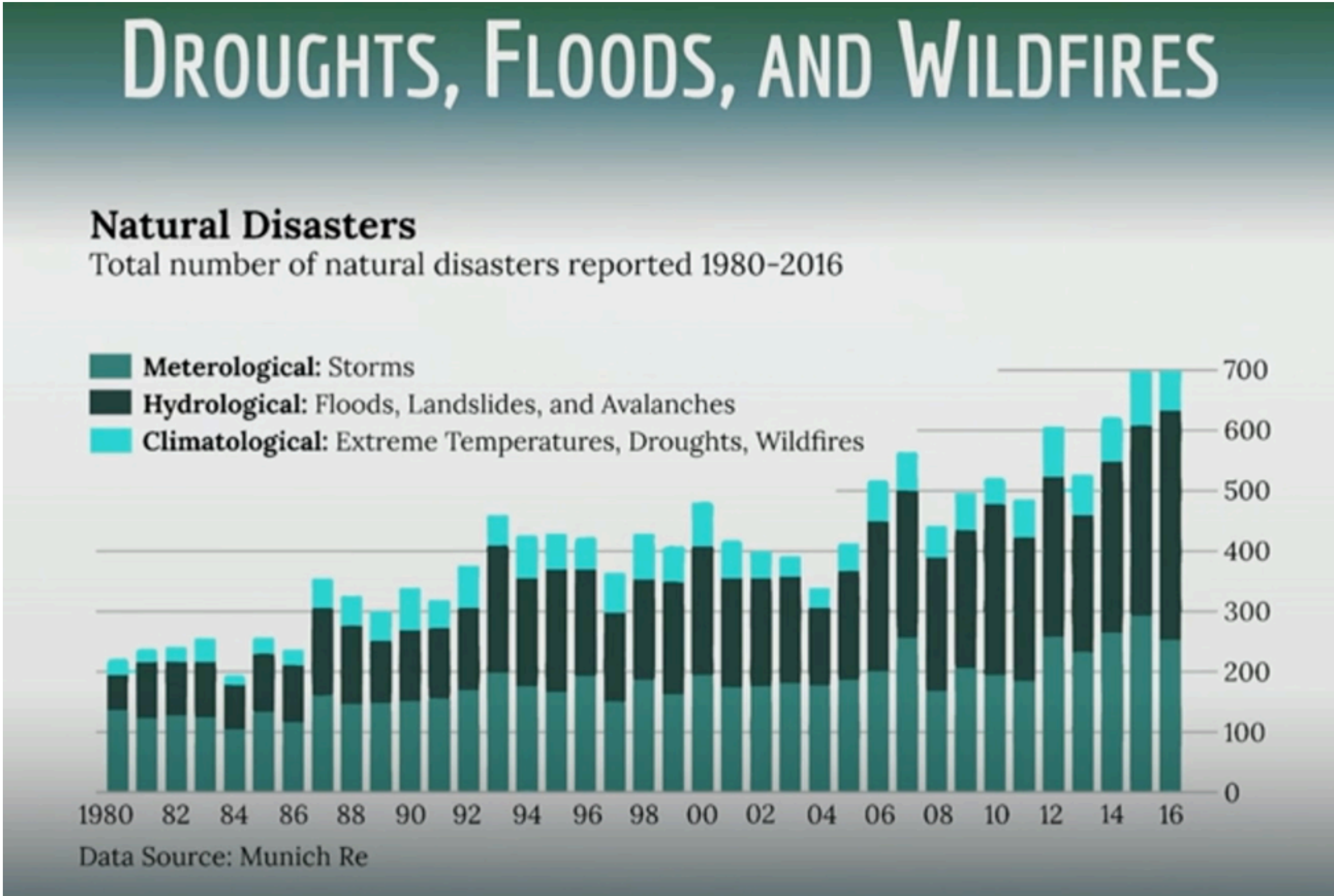






National Climate Assessment, 2018

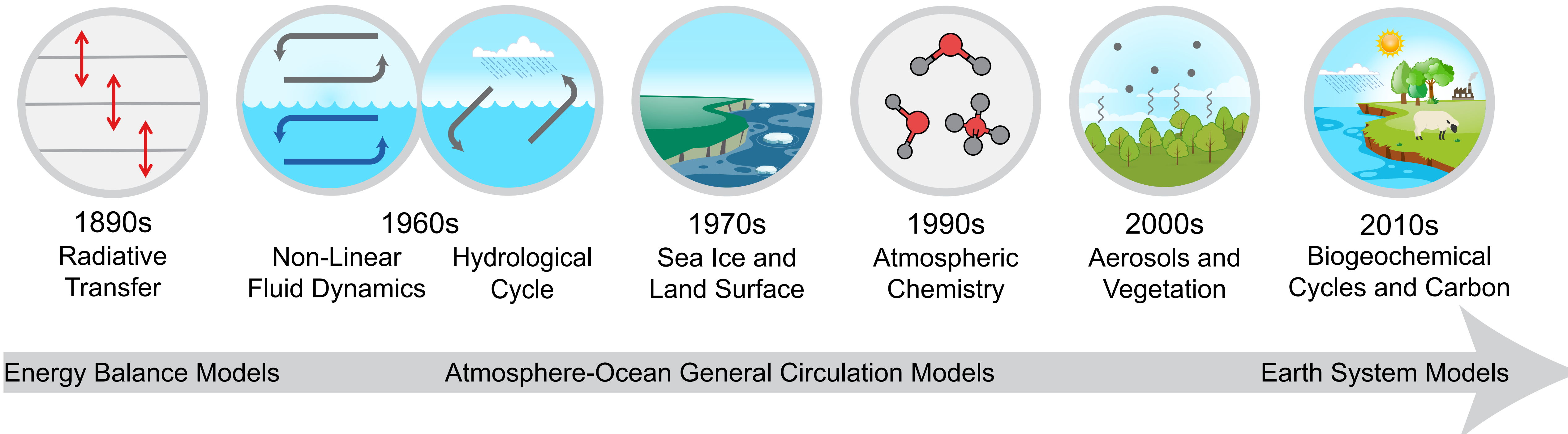
Joe Raedle/Getty Images



On a global scale, extreme events are becoming more frequent and severe, leading to major impacts on human life, environmental sustainability and economic damages

Earth's Changing Climate: Observations, Impacts, Models and Uncertainty

A Climate Modeling Timeline
(When Various Components Became Commonly Used)



Model Complexity

1 CPU
No Dynamics

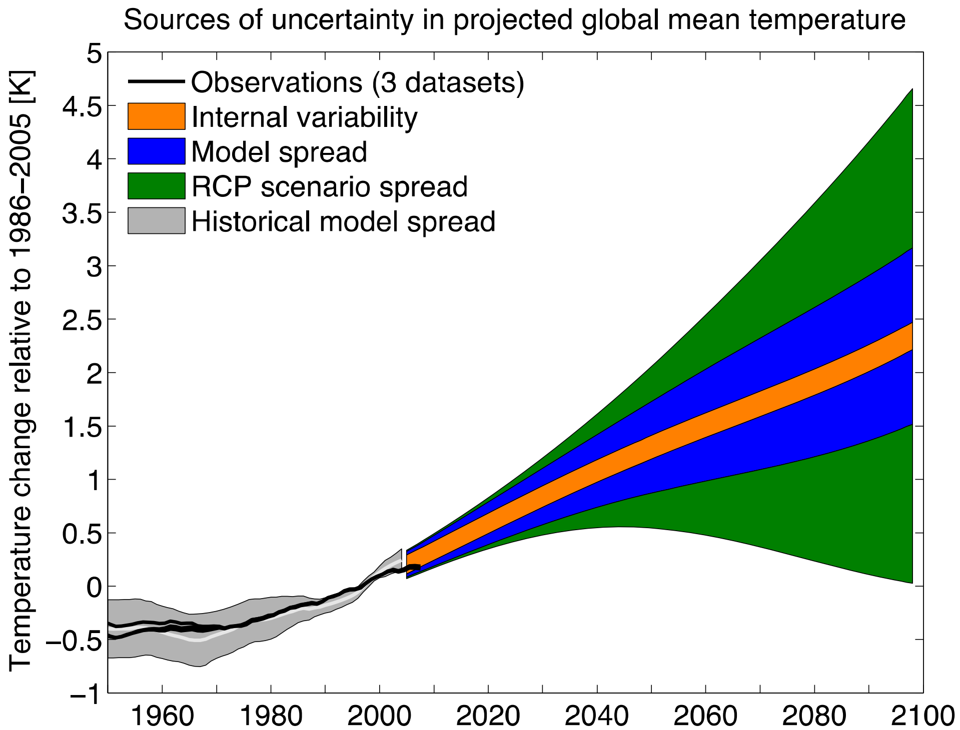
CPUS ~ 100s
Dynamics
Res: 1-2 Deg

CPUs ~ 1000s
Dynamics + Chemistry
Res: < 1 Deg

Computationally
Cheap

Computationally
Expensive

Sources of climate uncertainty



Internal Variability

- natural (unforced) variability of the system

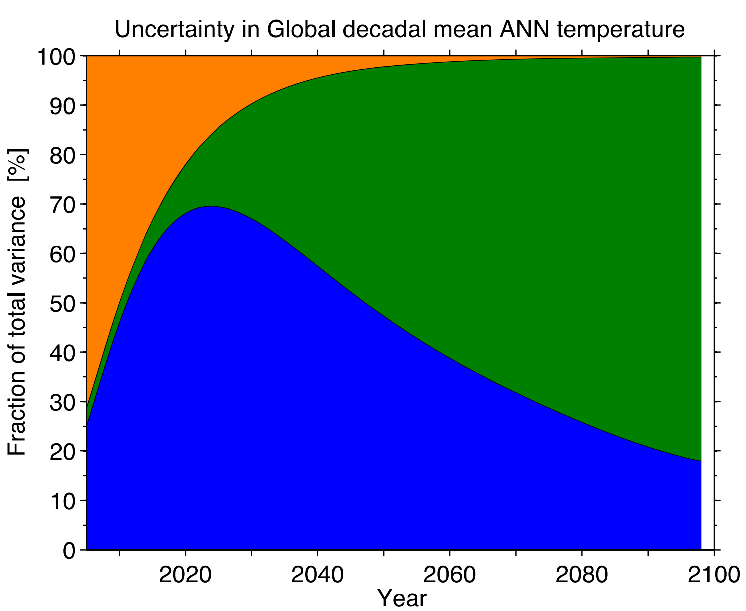
Model (structural) uncertainty

- different physics and numerical formulations lead to different responses to a given forcing

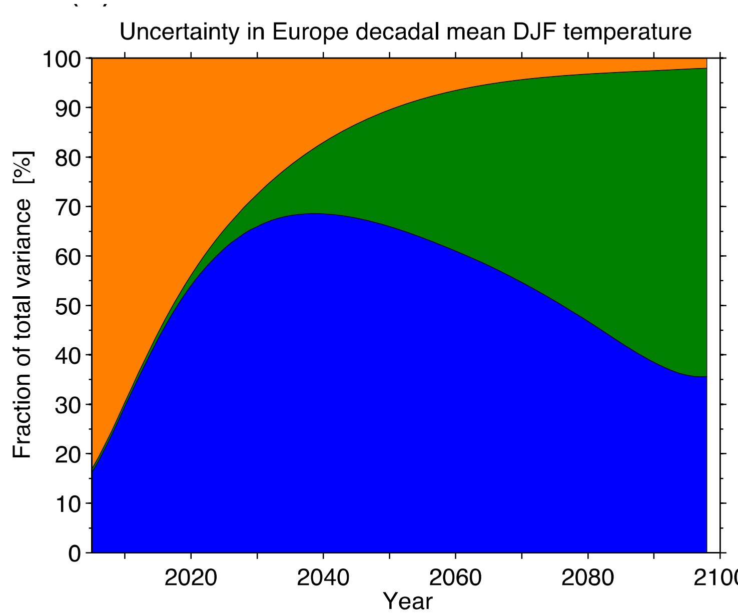
Forcing uncertainty

- incomplete knowledge about future emissions

Partitioning of uncertainties



Global



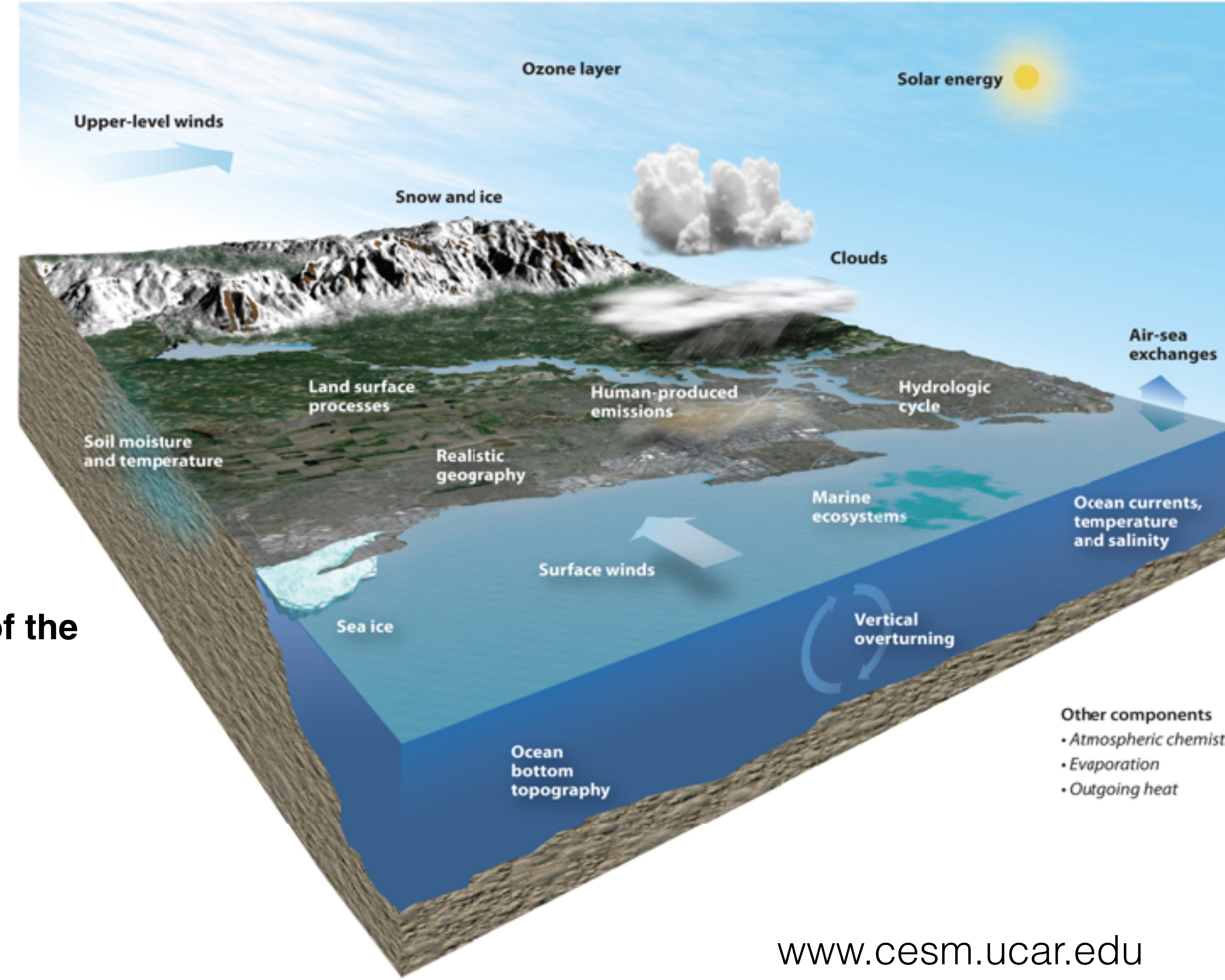
Regional

- Internal variability dominates on short timescales
  - Magnitude increases with decreasing spatial scale

- Forcing uncertainty increases with projection timescale (divergence in future scenarios)

Kirtman et al., 2013 (IPCC AR5, Ch 11)

Modeling Earth's coupled system and interactions



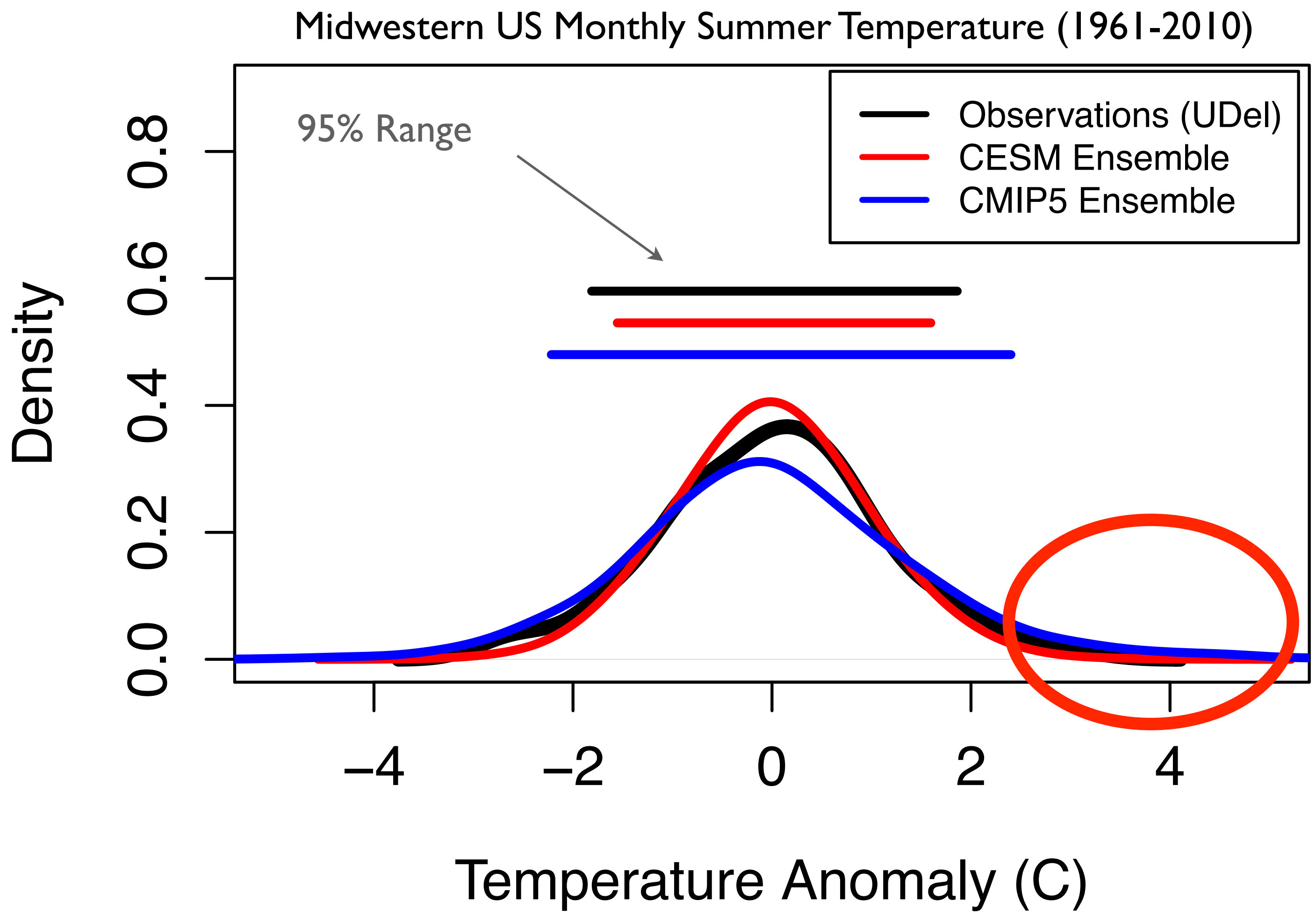
Earth system model: numerical integrations of the physics, dynamics, and interactions between:

- **atmosphere**
- **ocean**
- **land surface**
- **glaciers**
- **polar land ice**

www.cesm.ucar.edu

Earth system models are computationally expensive
- Small numbers of simulations (sample around the median)

Can ESMs capture decision-relevant climate variables?

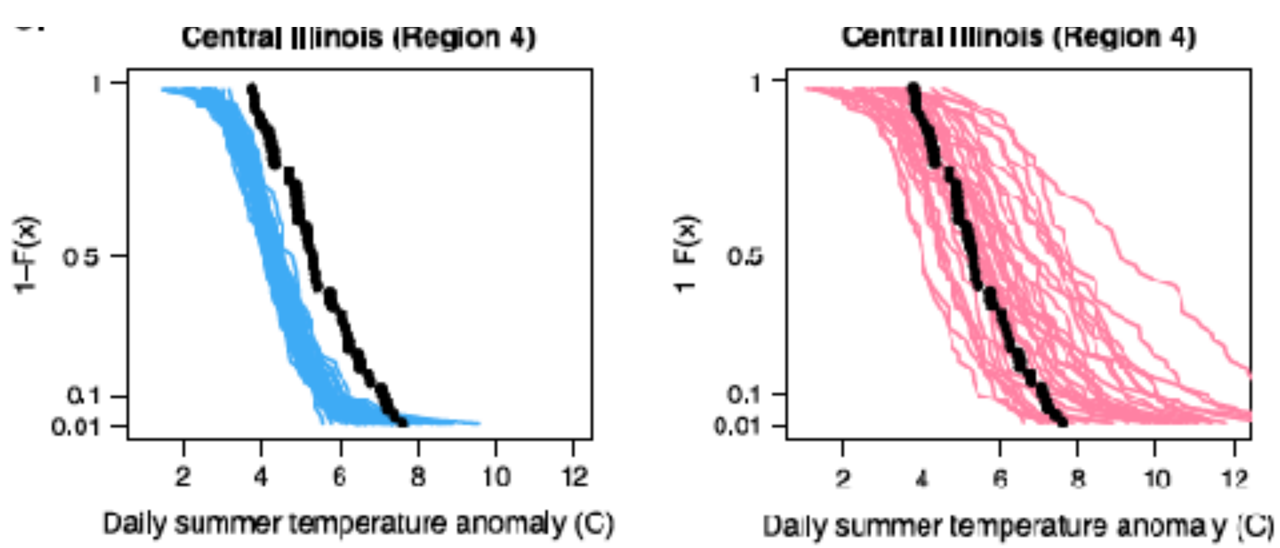


Collectively, ESMs can simulate mean-state regional climate reasonably well

What about the tails?

CESM

CMIP5



Internal Variability

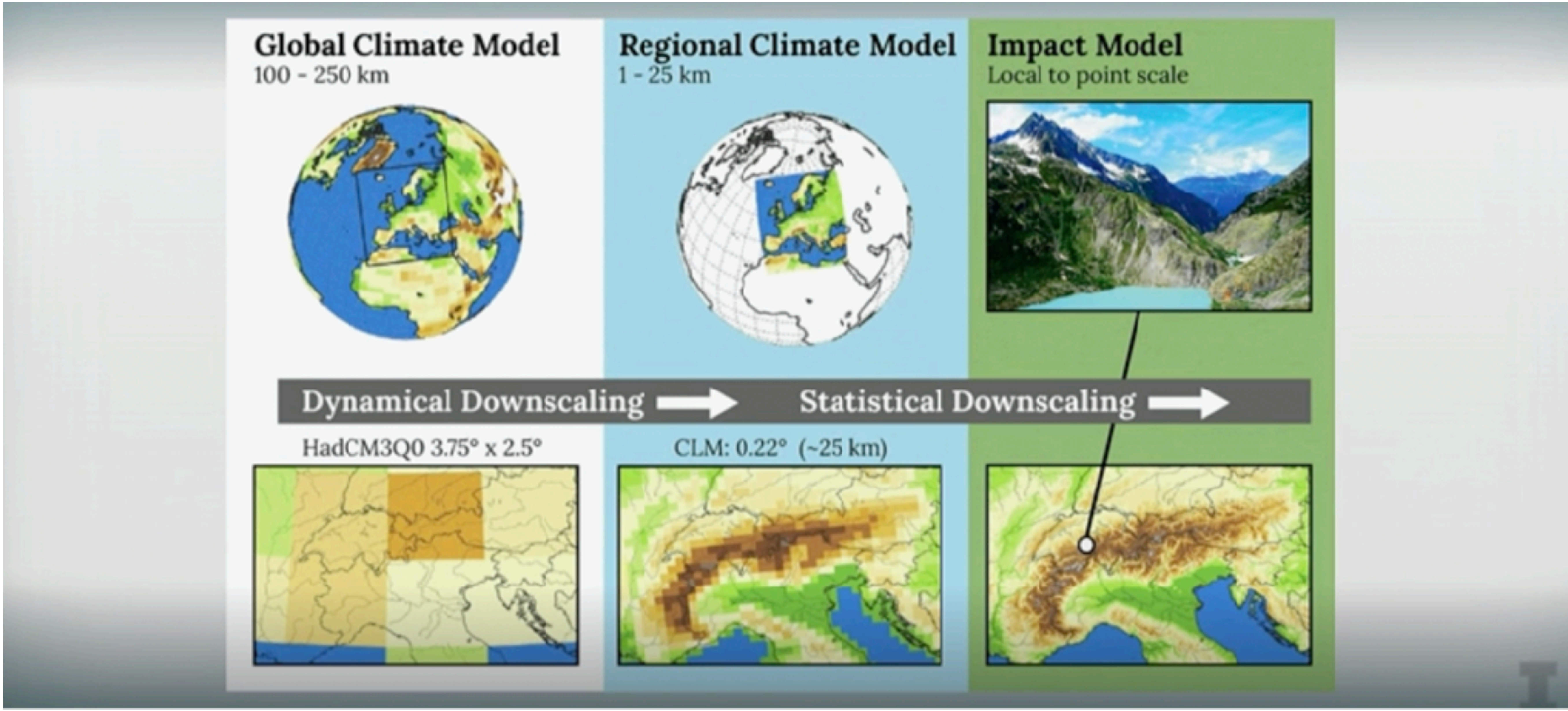
Structural

50-year annual block maxima daily temperature

Ensembles exhibit significant uncertainties and biases in simulating temperature tails on regional scales

Sriver, Forest, and Keller, 2015 (Geophysical Research Letters)

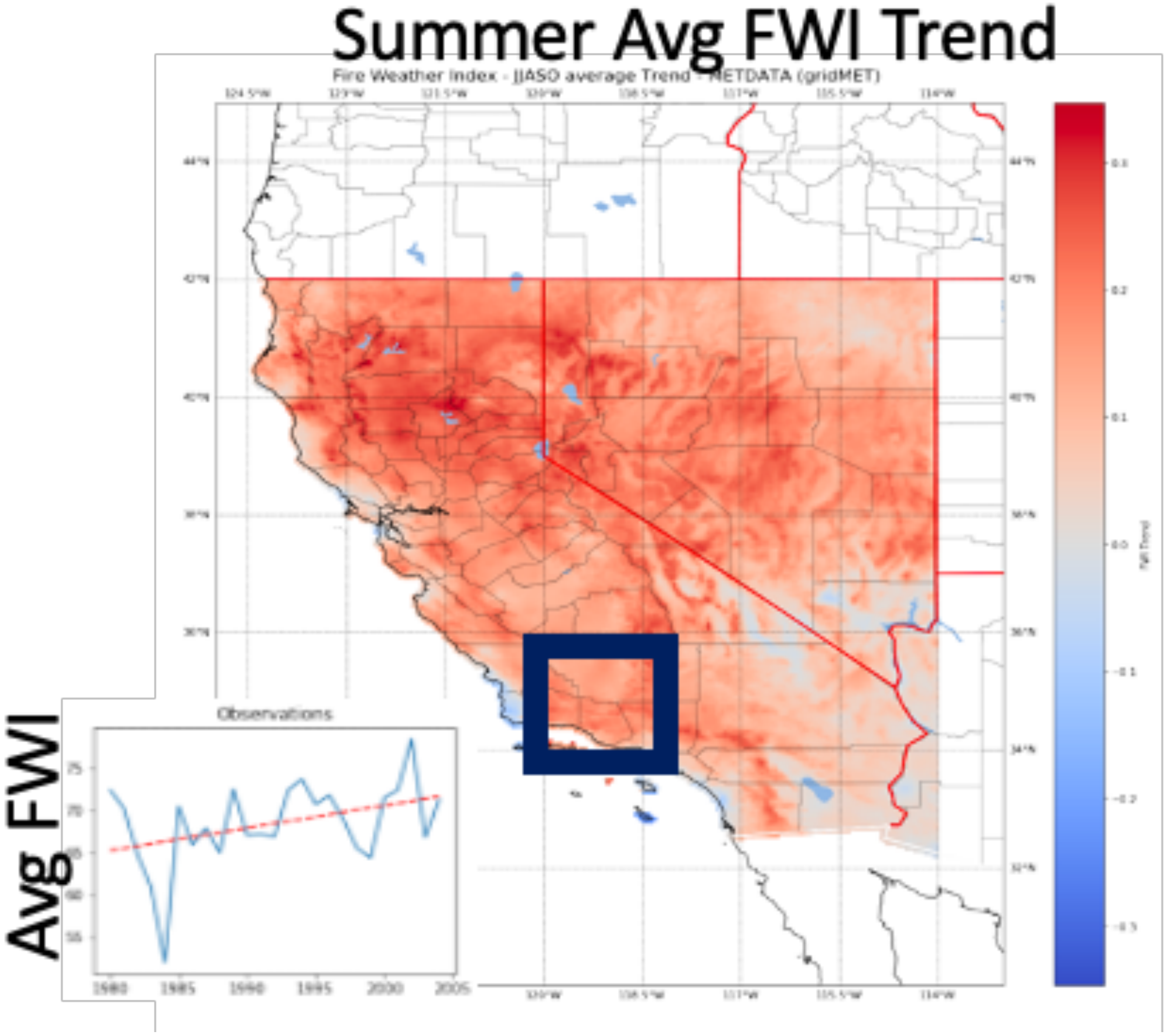
Dynamical/Statistical downscaling is useful for analyzing regional climate extremes and impacts

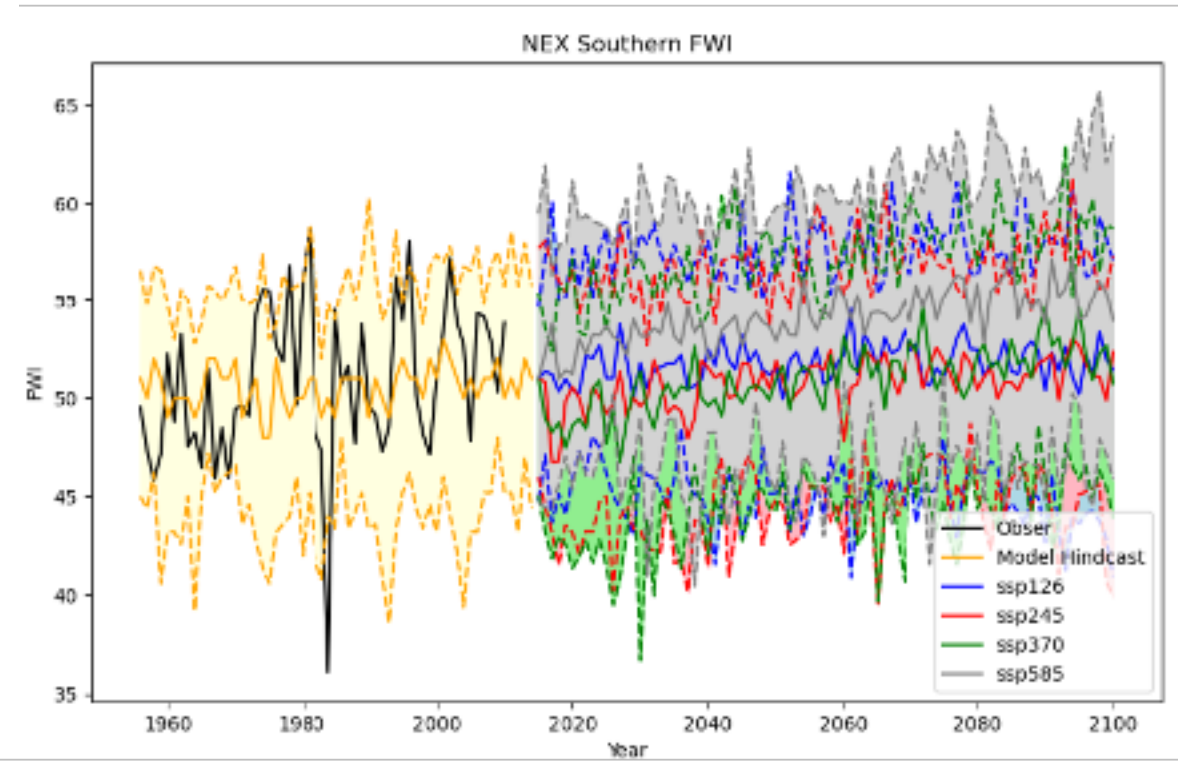


Dynamical and statistical downscaling can help reduce model biases and improve applicability of climate models at fine scales

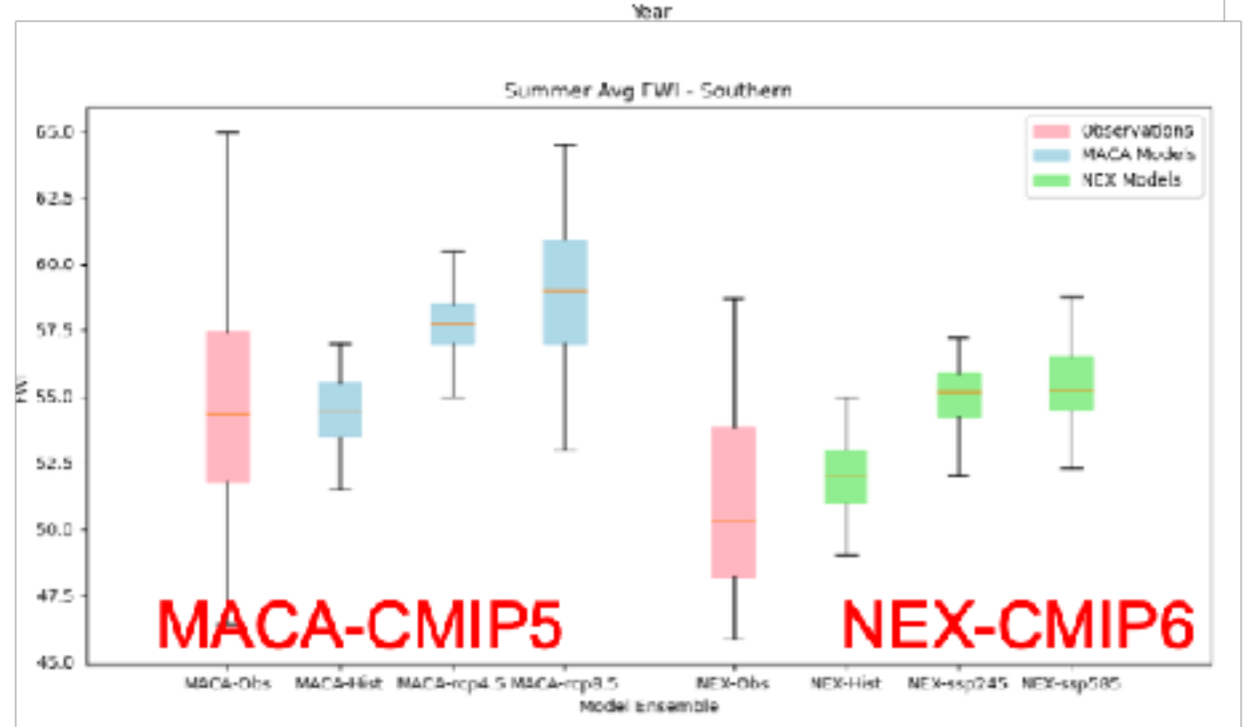
Some Applications

Physical Wild Fire Risk has been increasing in recent decades





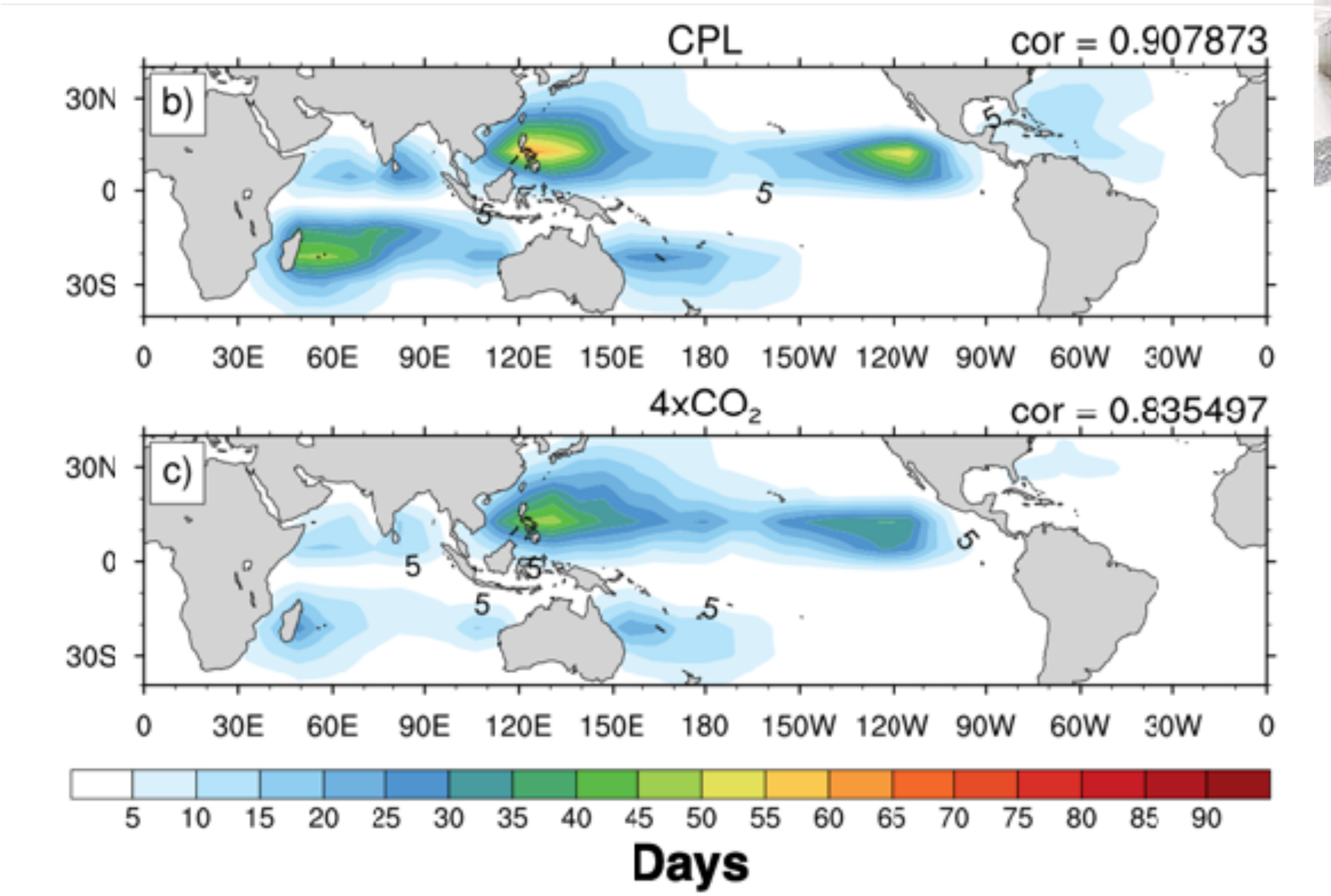
Downscaled climate model ensembles under-estimate seasonal physical fire risk, which may bias future projections.



Charu Samantula

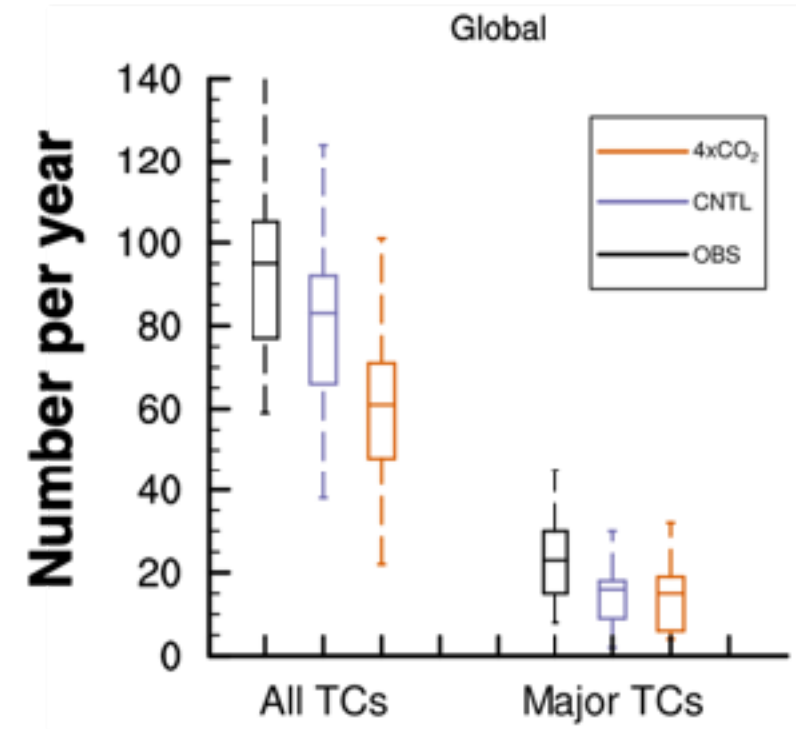
Response in TC activity to increased CO2 in CESM

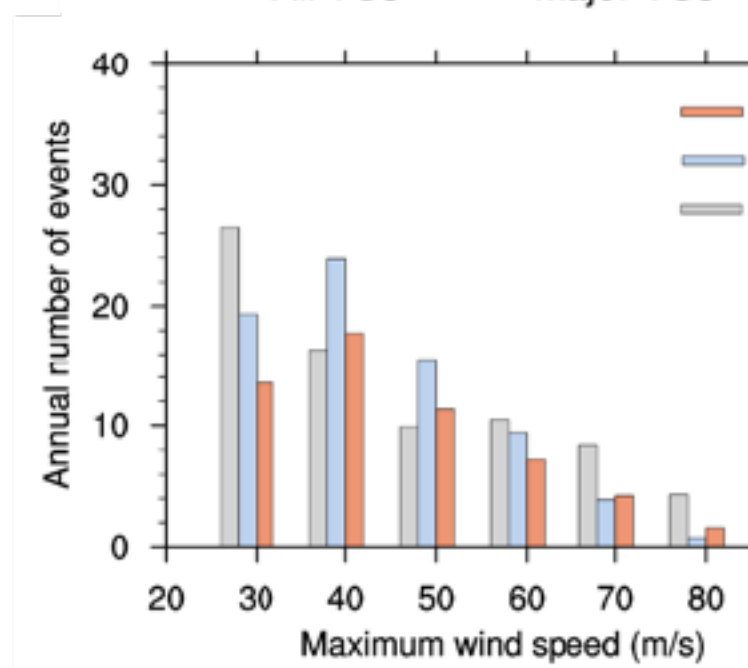
TC Track Density



Storms per year

	4xCO2	Control
AT	4	8
EP	13	16
NWP	19	25
SH	15	30





Under 4xCO2 conditions:

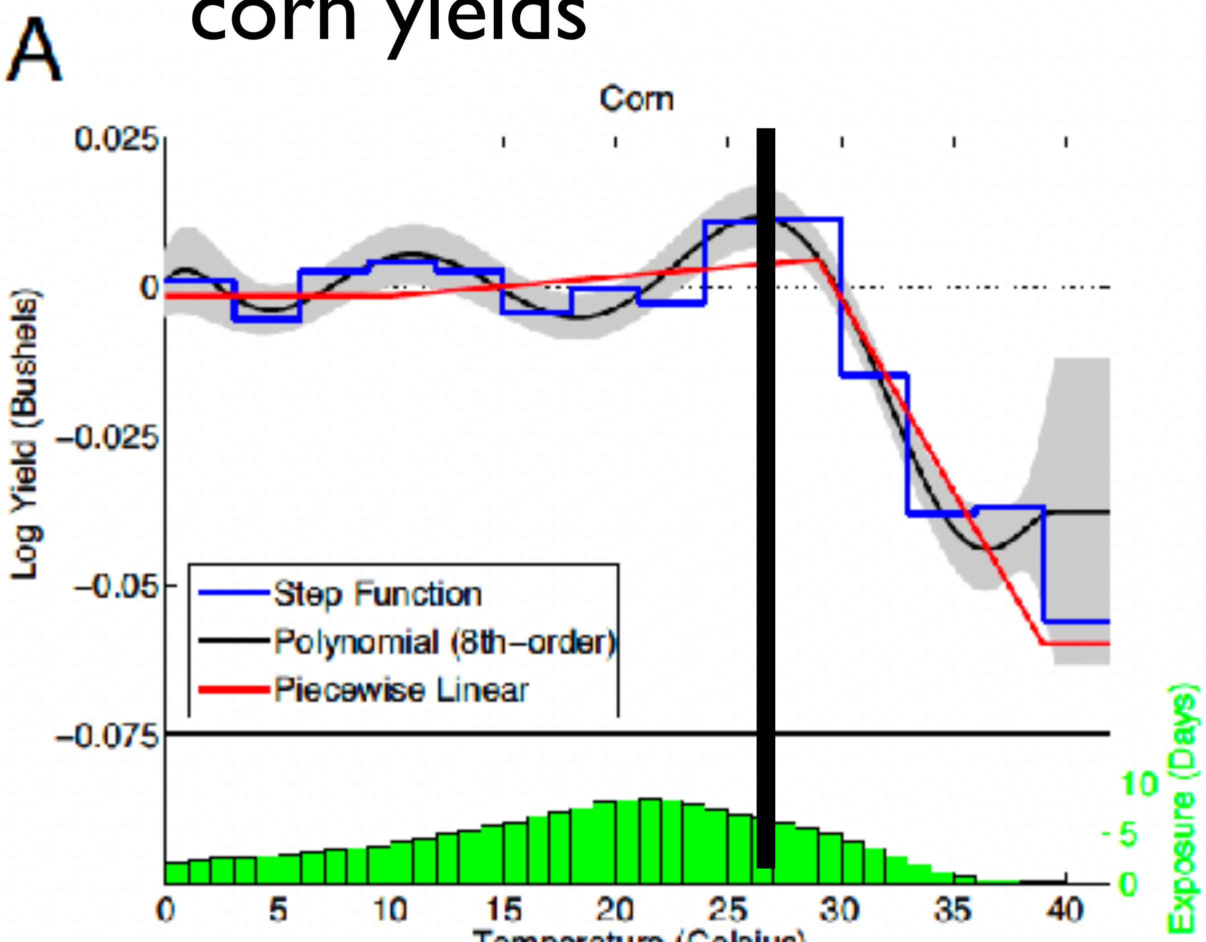
- Decrease in storm counts across all basins
- Increase in storm intensity

Why?

- Tradeoffs between enhanced vertical wind shear and increased SST

Hu Li, NCAR

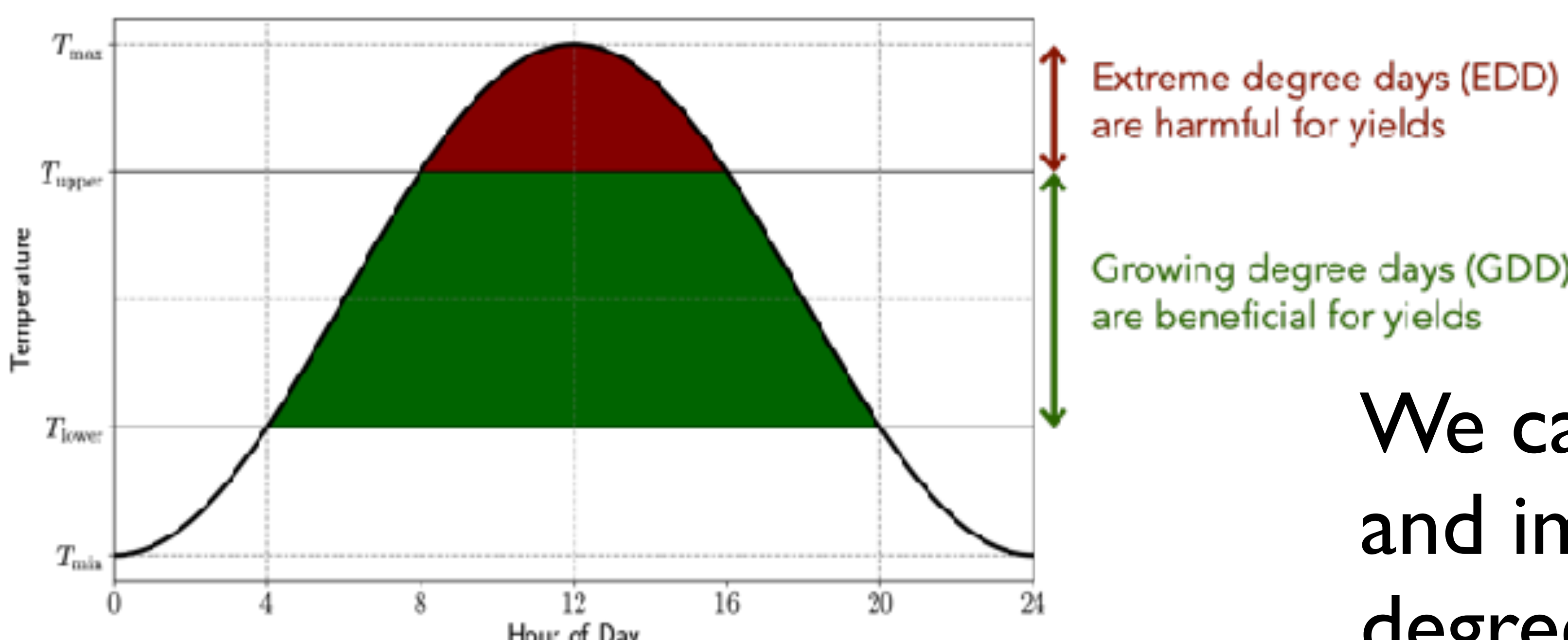
Extreme temperatures negatively affect corn yields



Schlenker and Roberts, 2009

source: AP/Seth Perlman

Corn yields drop sharply with extreme temperature



We can estimate exposure and impacts using growing degree days

One Example of a Statistical (Regression) Yield Model

$$\log Y_{i,t} = f_i(t) + \alpha_i \, GDD_{i,t} + \beta_i \, EDD_{i,t} + \gamma_i P_{i,t} + \delta_i P_{i,t}^2 + c_i$$

USDA recorded yield

Technological time trend

climate/weather influence

'county-fixed effects'
(soil quality, management, etc)

- Detailed enough to be realistic but simple enough to be interpretable
- Climate ingredients: Growing Degree Days (GDD), Extreme Degree Days (EDD), Precipitation (P).
- Historical corn yields are from USDA National Agricultural Statistics Service
- Least-squares regression on quadratically de-trended yields at the county level (n=2756)
- Train on 1960-2005; validate on 2006-2016

Lafferty, Sriver, Haqiqi, Hertel, Nicholas, and Keller (2021)

Statistical yield model reproduces observed year-to-year US corn variability

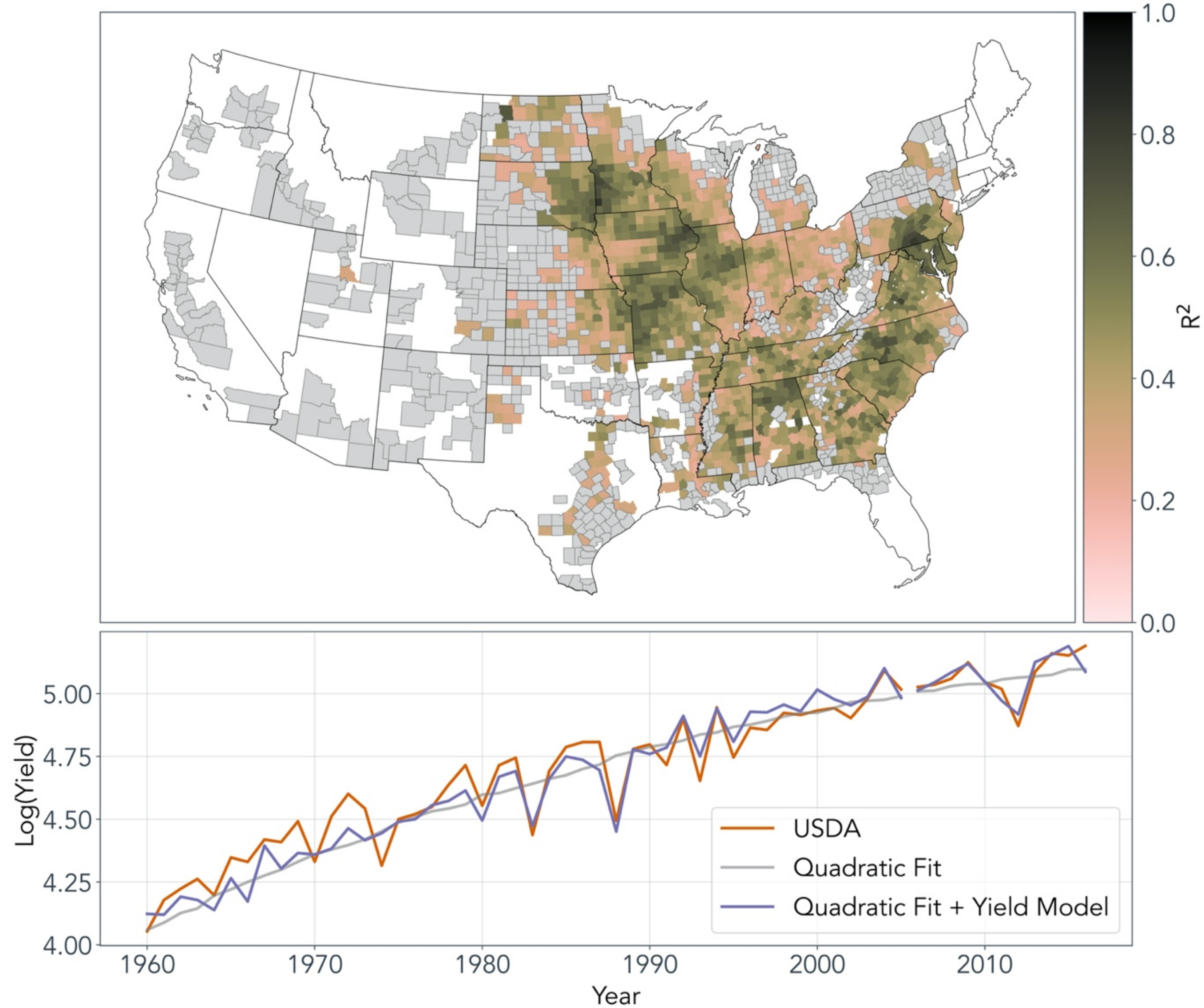


Figure 1: (top) Yield model coefficient of determination measured against USDA records over the historical time period (1960-2005). Counties for which the inclusion of weather variables gave no statistically significant improvement o the time trend are denoted in gray. Counties in white are those that exhibited less than 50% data coverage in the USDA record. (bottom) Annual national-level yield time series, constructed by summing county-level yields with weights equal to yearly historical production shares. The USDA record is shown in orange, the full yield model is shown in blue, and the time trend is shown in gray.

Lafferty, Sriver, Haqiqi, Hertel, Nicholas, and Keller (2021)

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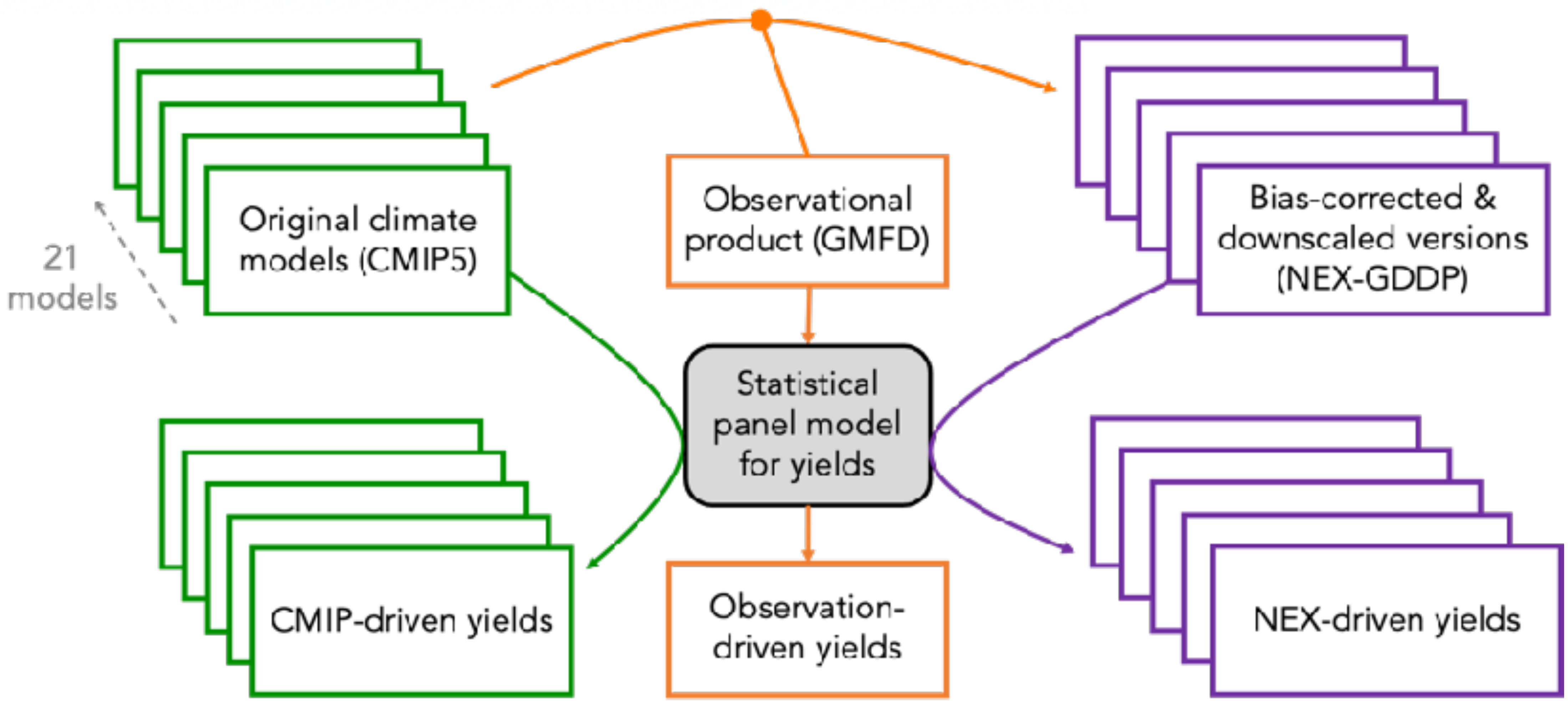
ARTICLE

https://doi.org/10.1038/s43247-021-00266-9 OPEN

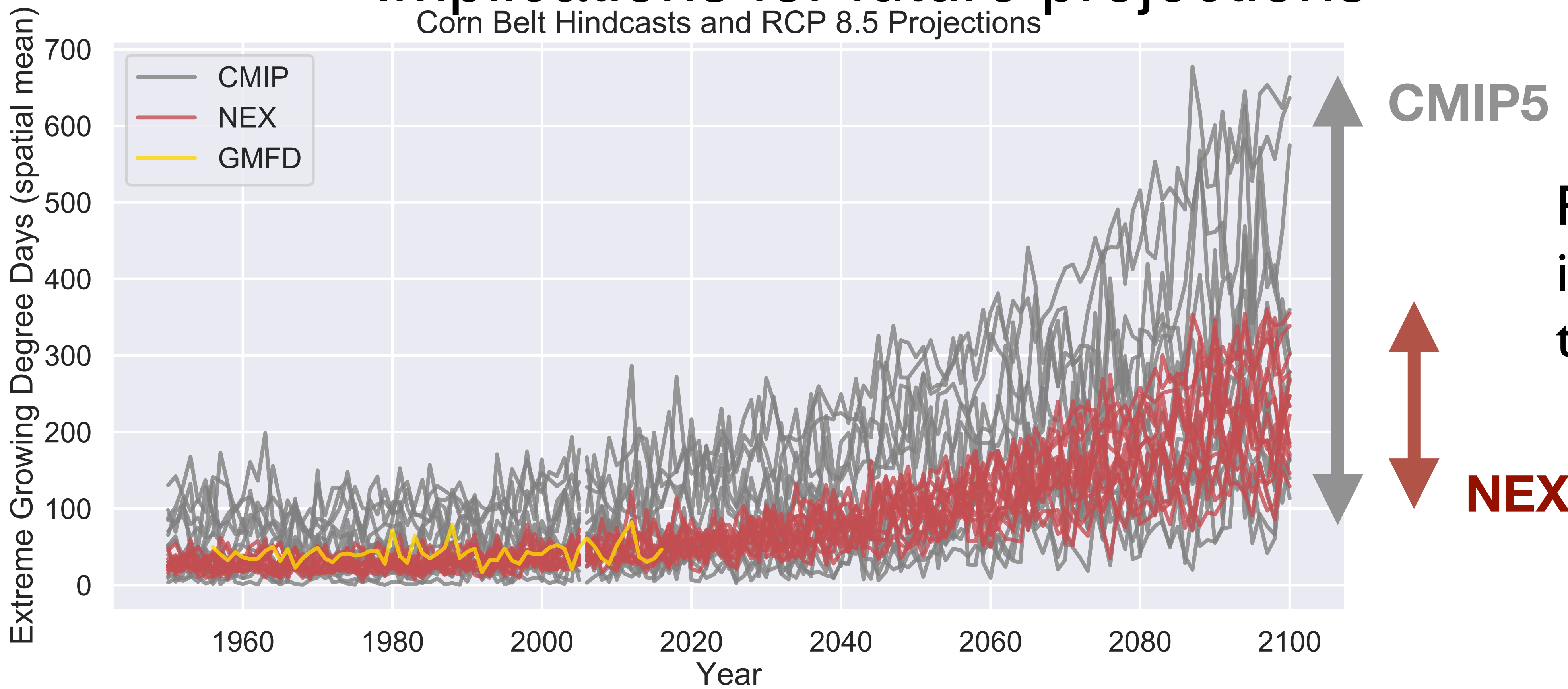
Statistically bias-corrected and downscaled climate models underestimate the adverse effects of extreme heat on U.S. maize yields

David C. Lafferty[1✉], Ryan L. Sriver[1], Iman Haqiqi[2], Thomas W. Hertel[2], Klaus Keller[3,4] & Robert E. Nicholas[4]

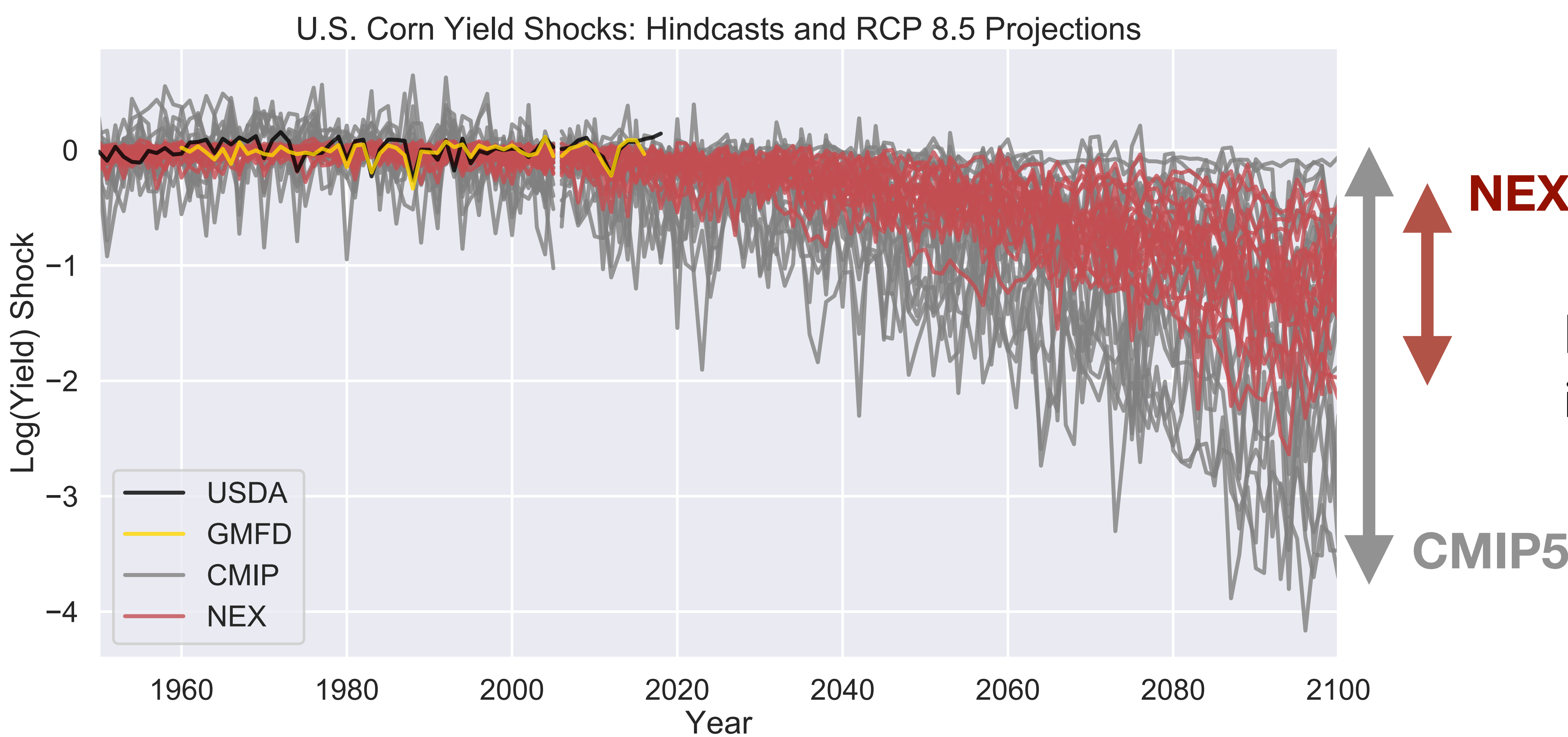


Combine climate model outputs with statistical downscaling to examine the effect of temperature extremes on future corn yield variability (shocks)

Implications for future projections



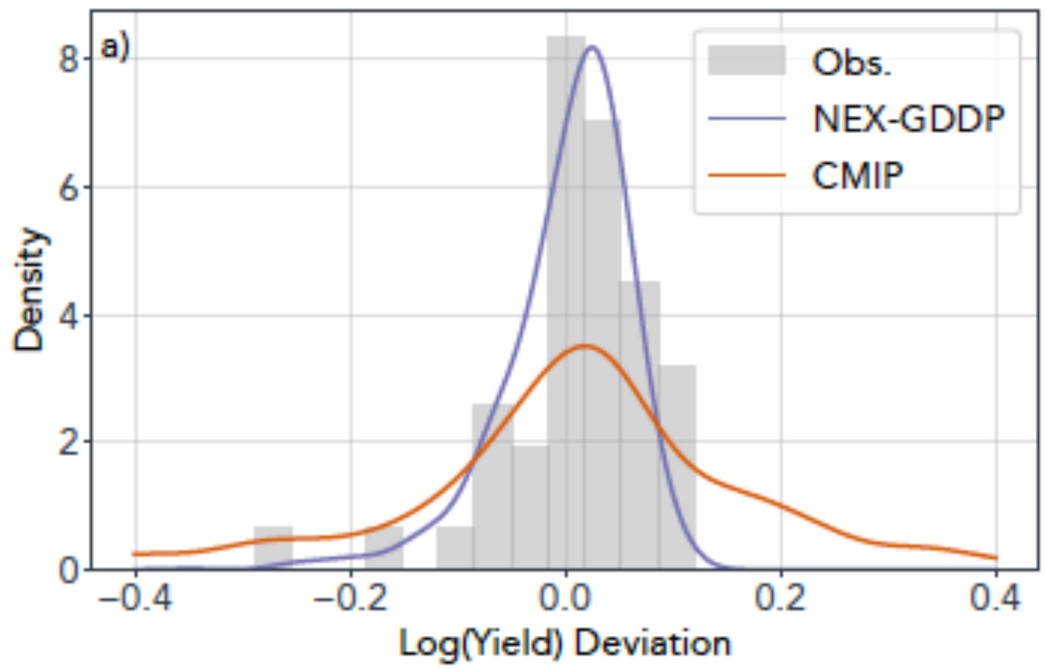
Projected changes in US extreme temperature



Projected changes in US corn yields

Historical versus future yield variability

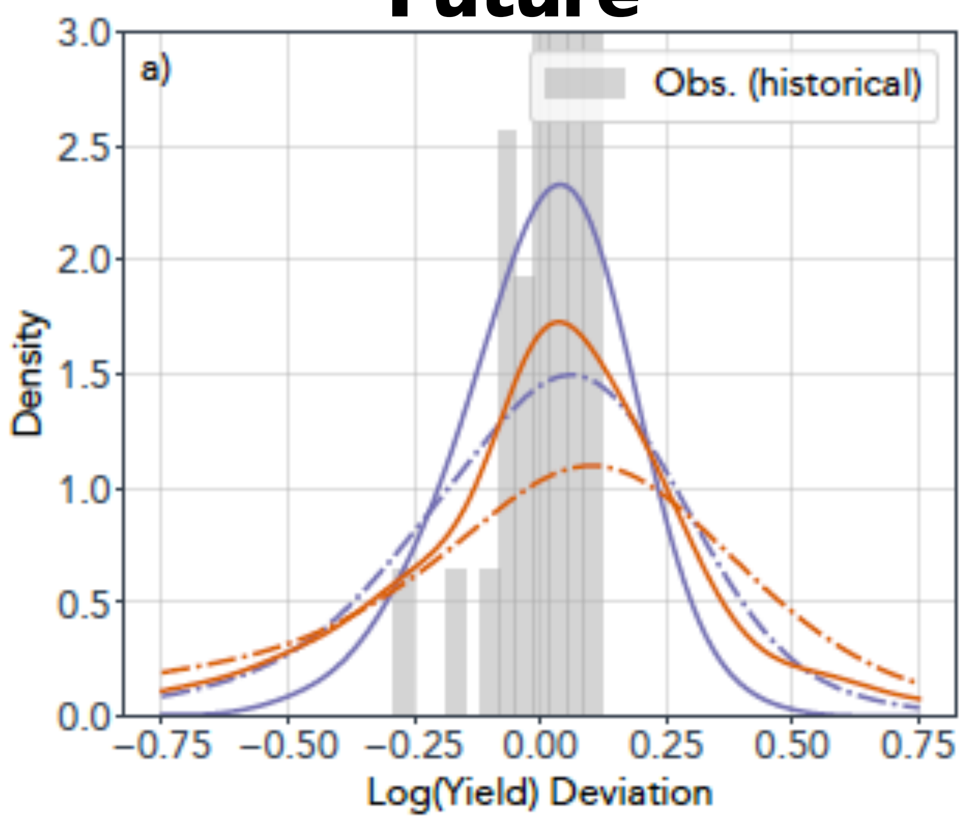
Historical



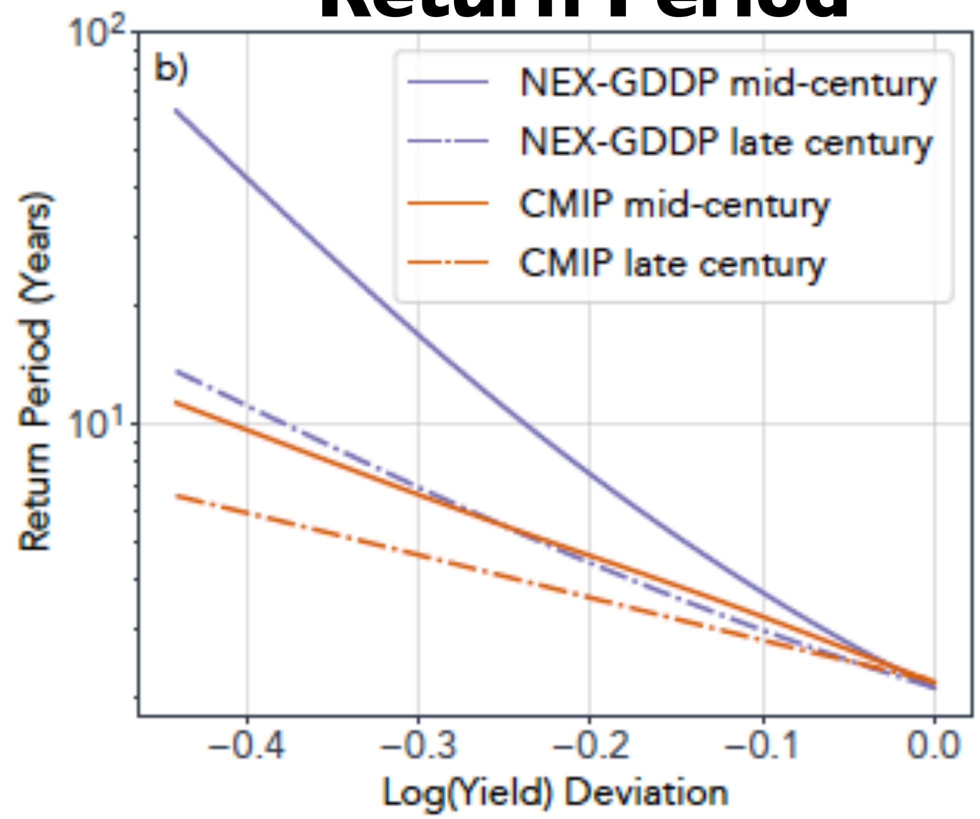
Temp extremes lead to significant yield loss and variability, and large differences in projected return periods of extreme yield loss events.

Return periods in CMIP/NEX differ by more than an order of magnitude for the largest shocks.

Future



Return Period



Key result: There are substantial uncertainties in the temperature tails that can lead to underestimation in projected crop damages and risk

Next steps: Connect climate/yield uncertainties to economics and decision making

Lafferty, Sriver, Haqiqi, Hertel, Nicholas, and Keller (2021)

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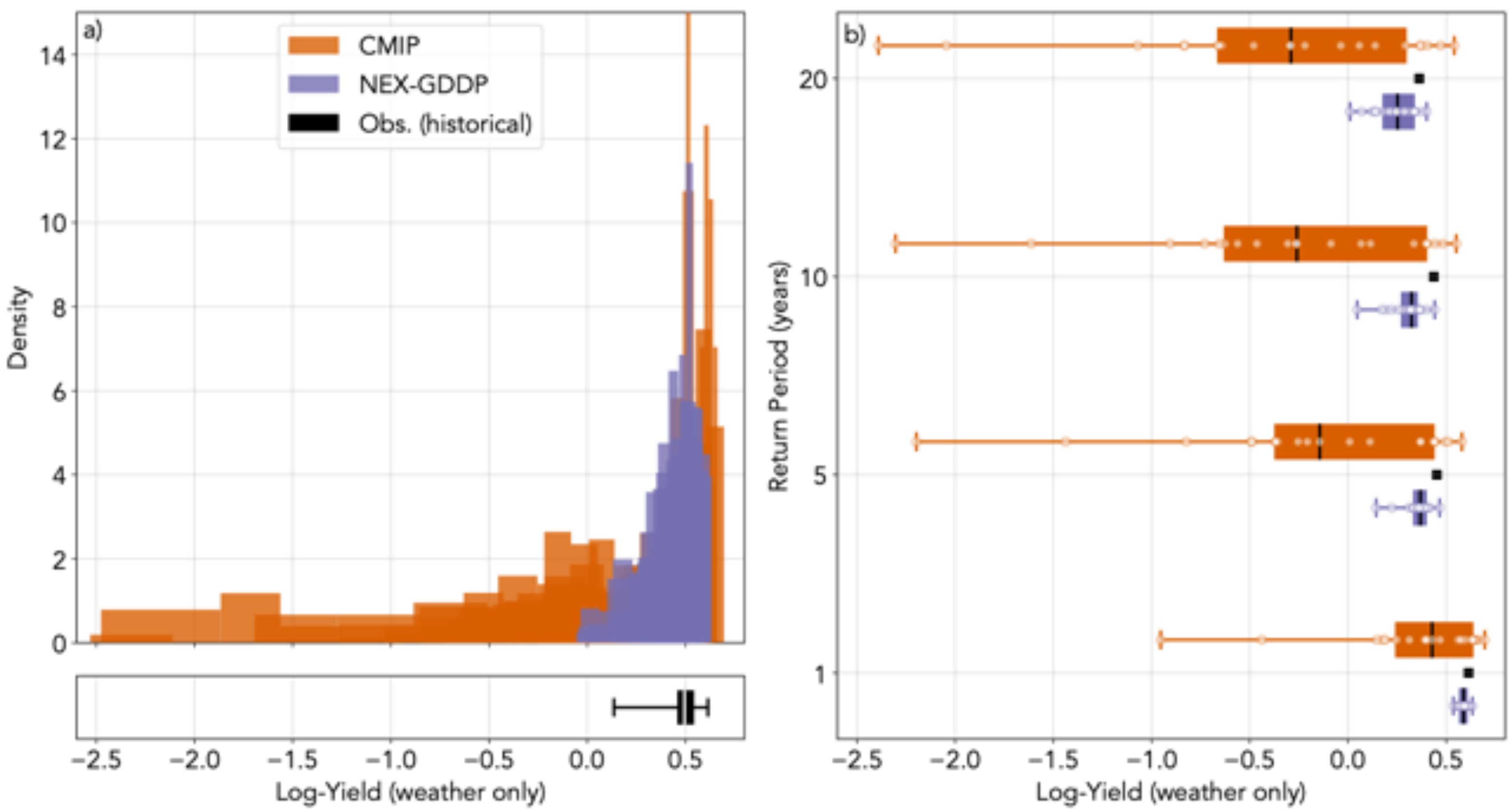
Large projection differences exist between the ensembles throughout this century



- Mid-century (2030-2059) national—level yield distributions and associated return periods under RCP 8.5
- Aggregate to national level using mean 1980-2020 production shares

Conclusions

- Climate-related damages closely linked to extremes

- Understanding how climate and extremes are changing is a major challenge, due to computational tradeoffs and lack of understanding about physical processes

- These challenges require careful treatment of the uncertainties (both known and unknown) for assessing climate-related risks

- We outlined multiple traceable examples combining observations, models, and statistics to address decision-relevant climate impacts

- Results provide useful avenues for connecting science with stake holders and decision-makers