Potential Climate Surprises: Compound Extremes and Tipping Elements

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OneNOAA/Climate Science Special Report (CSSR) Seminar Series
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science2017.**globalchange.gov**

The report can be summarized in one sentence:

It's real
It's us
It's serious
.. and the window of time to prevent widespread dangerous impacts is closing fast.

Situating This Talk in the Broader CSSR/NCA Context

About This Report

Guide To This Report

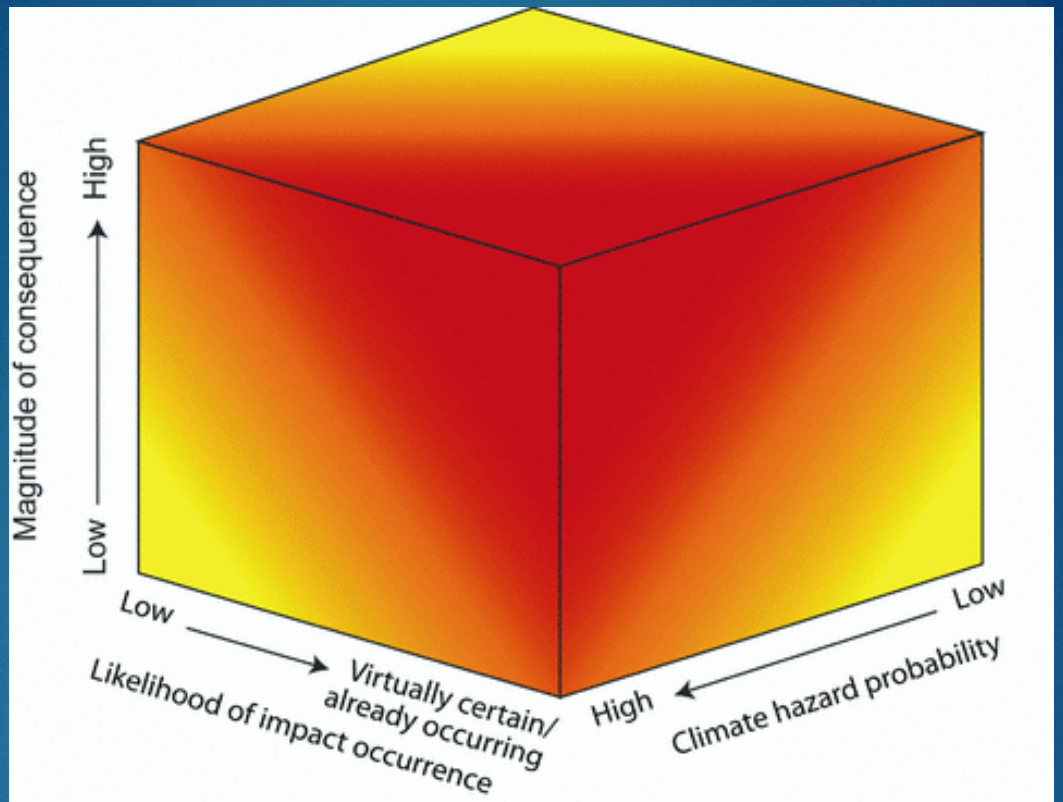
Executive Summary

1. Our globally changing climate
2. Physical drivers of climate change
3. Detection and attribution of climate change
4. Climate models, scenarios, and projections
5. Large-scale circulation and climate variability
6. Temperature changes in the United States
7. Precipitation changes in the United States
8. Droughts, floods, and wildfires
9. Extreme storms
10. Change in land cover and terrestrial biogeochemistry
11. Arctic changes and their effects on Alaska and the rest of the United States
12. Sea level rise
13. Ocean acidification and other ocean changes
14. Perspectives on climate change mitigation
15. Potential surprises: Compound extremes and tipping elements

Plus several Appendices

Kopp, R.E., K. Hayhoe, D.R. Easterling, T. Hall, R. Horton, K.E. Kunkel, and A.N. LeGrande, 2017: Potential surprises – compound extremes and tipping elements. In: Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 411-429, doi: 10.7930/J0GB227J.

Risk Management Framework

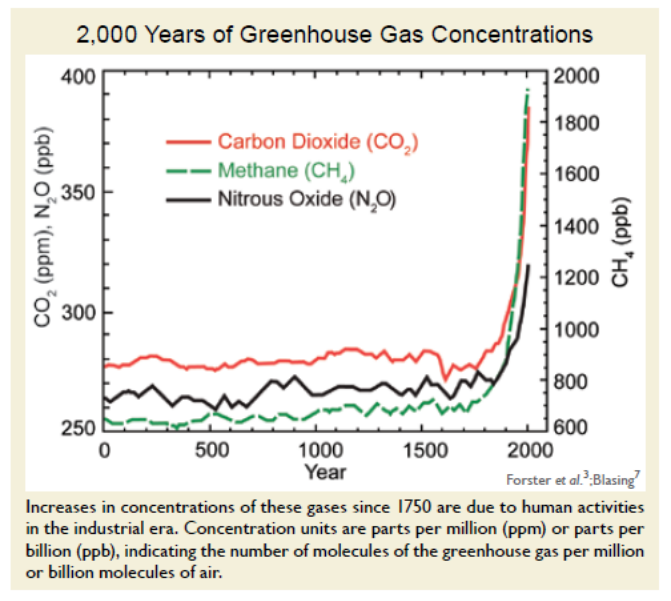


RED	*Risks for which adaptation strategies should be developed.*
ORANGE	*Risks for which adaptation strategies may need to be developed or for which further information is needed.*
YELLOW	*Risks for which impacts should be monitored but which may not need actions at this time.*

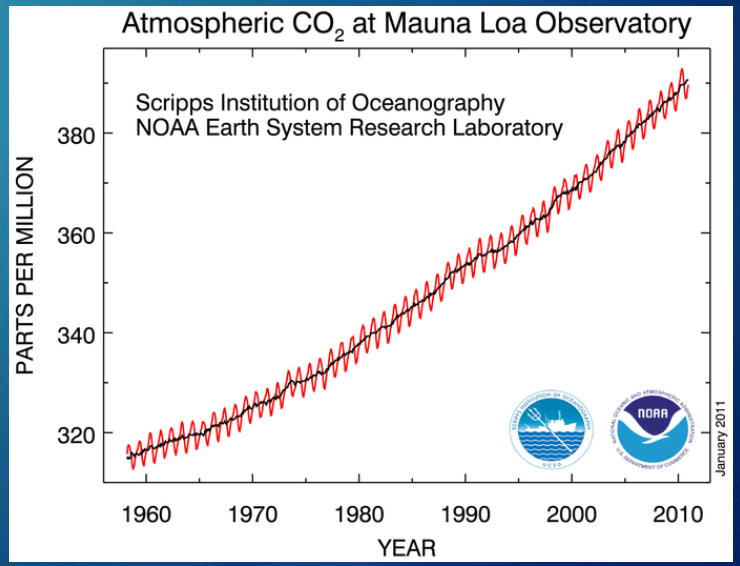
New York City Panel on Climate Change, 2009

Greenhouse Gas Concentrations

- Greenhouse Gases
  - Carbon dioxide (CO2), Methane (CH4, Nitrous Oxide (N2O)
  - Transparent to sunlight, but trap thermal radiation
  - Long residence times
- Recent Measurements
  - Mauna Loa, Hawaii

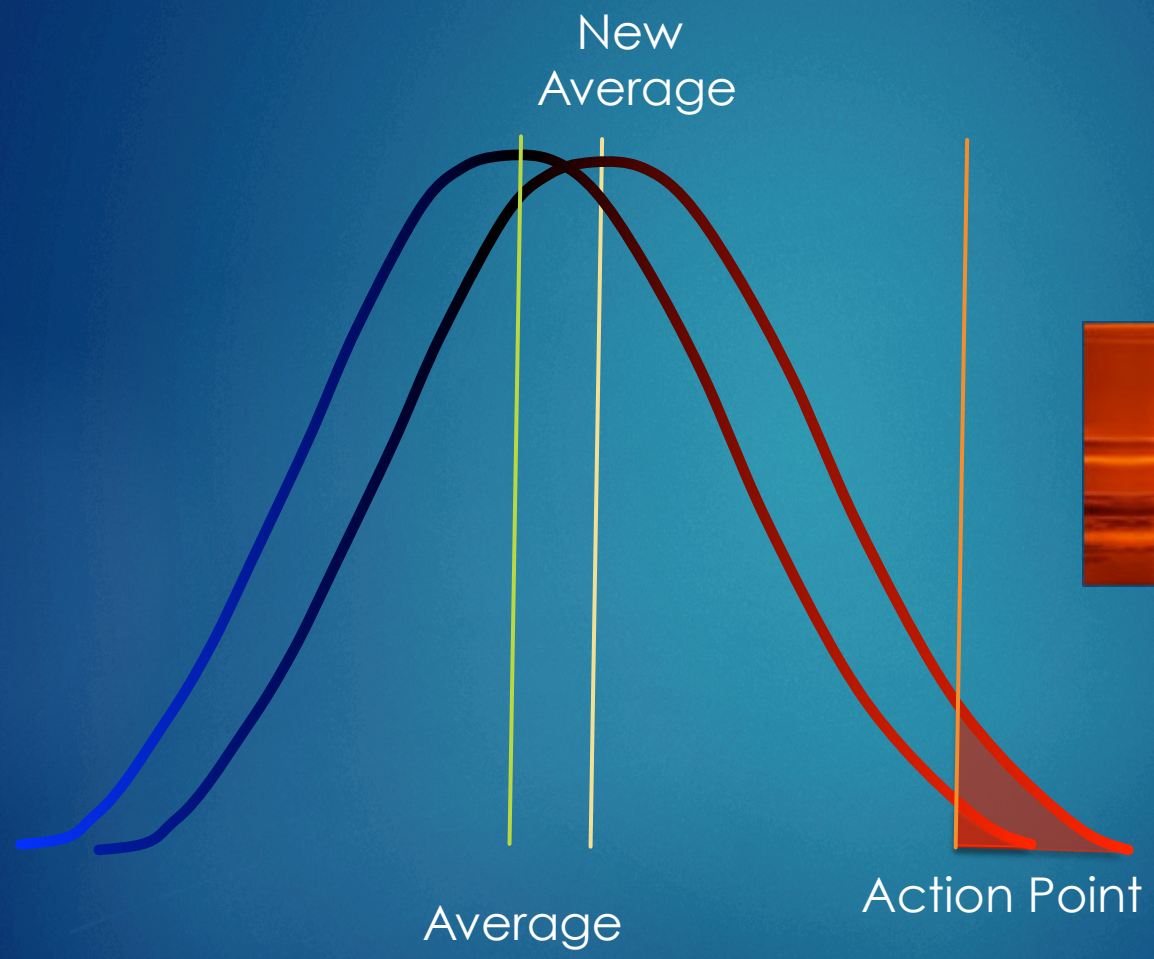


Increases in concentrations of these gases since 1750 are due to human activities in the industrial era. Concentration units are parts per million (ppm) or parts per billion (ppb), indicating the number of molecules of the greenhouse gas per million or billion molecules of air.



Shifting Statistics of Extreme Events

What can a few degrees warmer do?

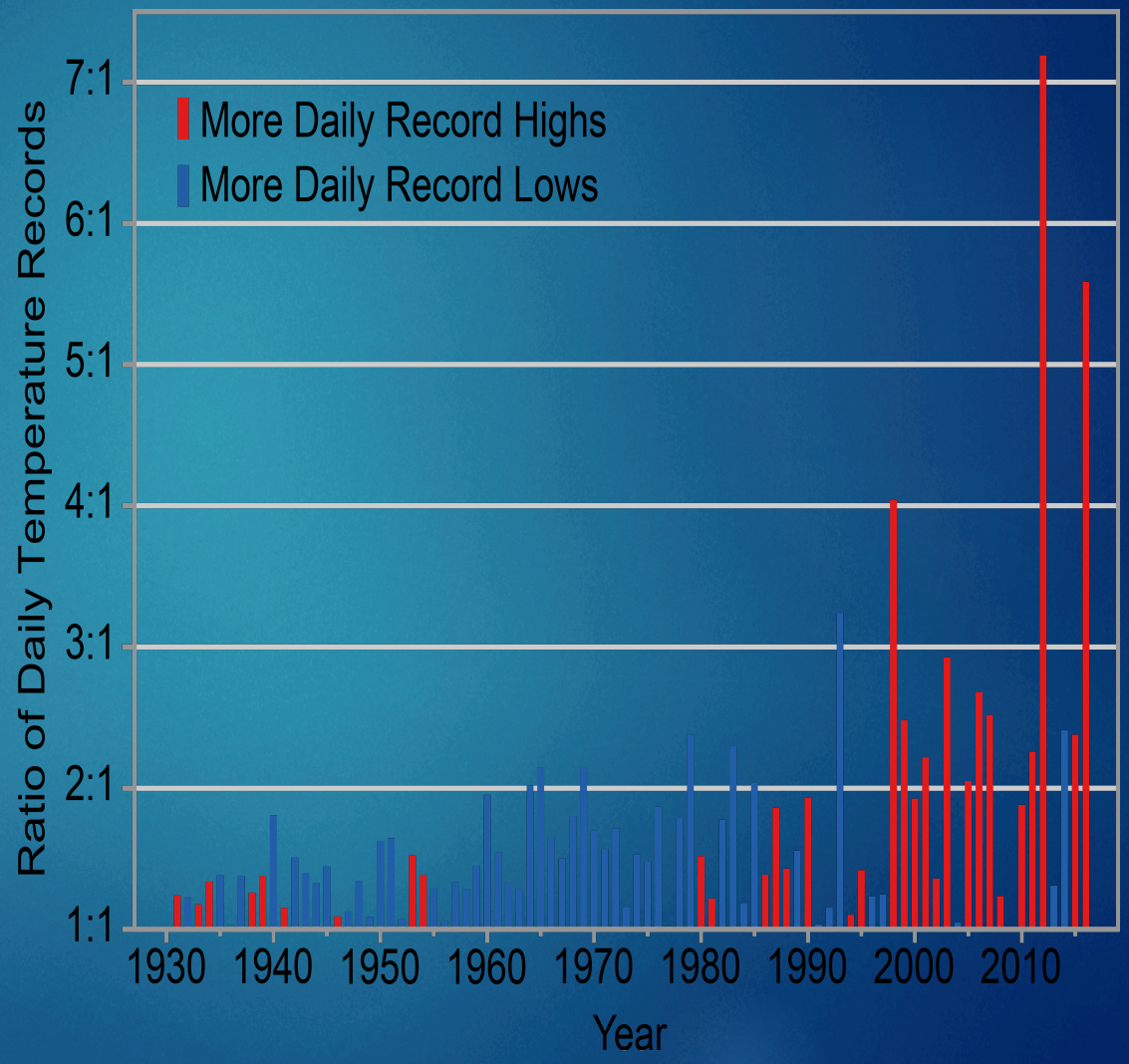


Very Likely Increase:

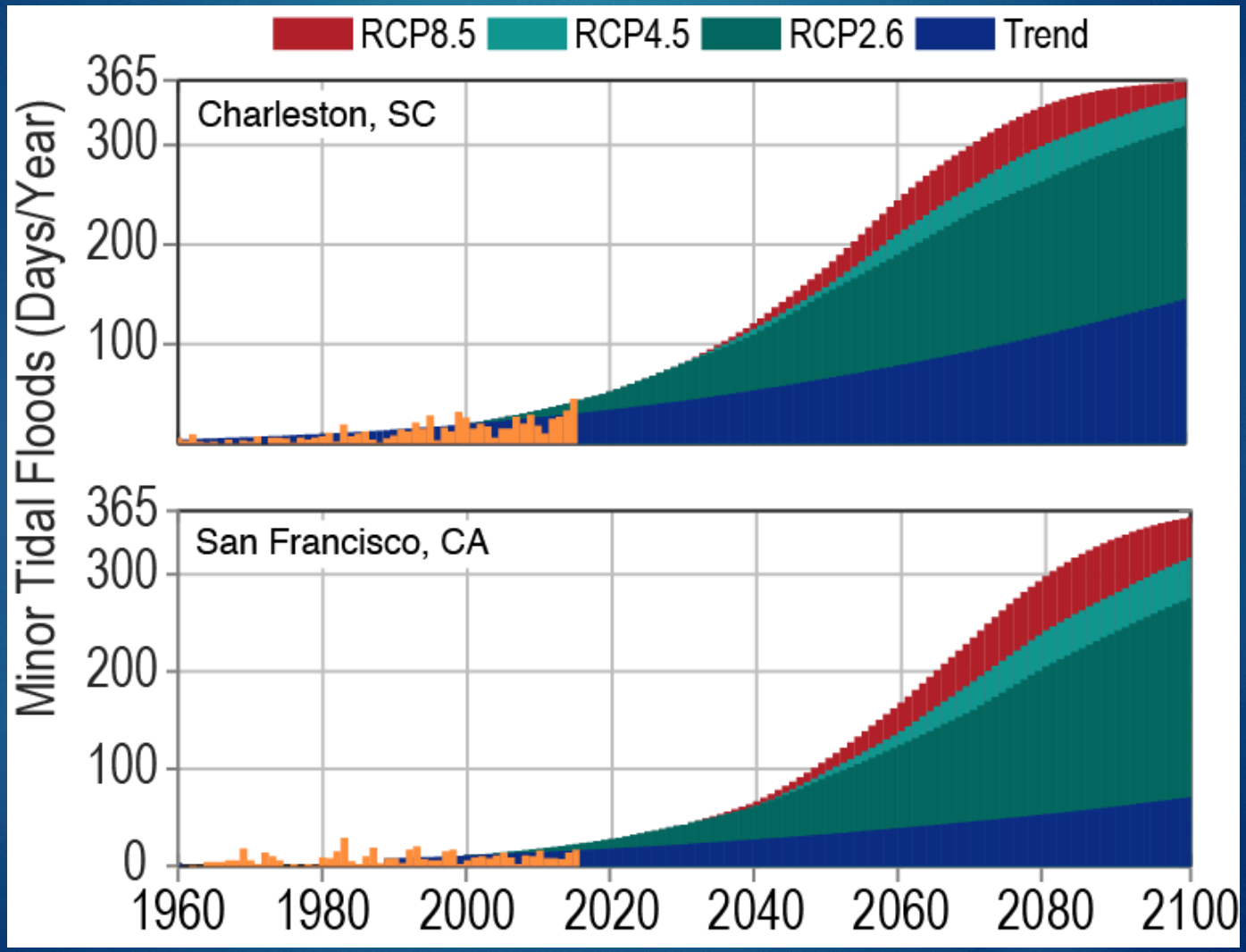
Days with Extreme Heat

A small average change can have large effect on extremes

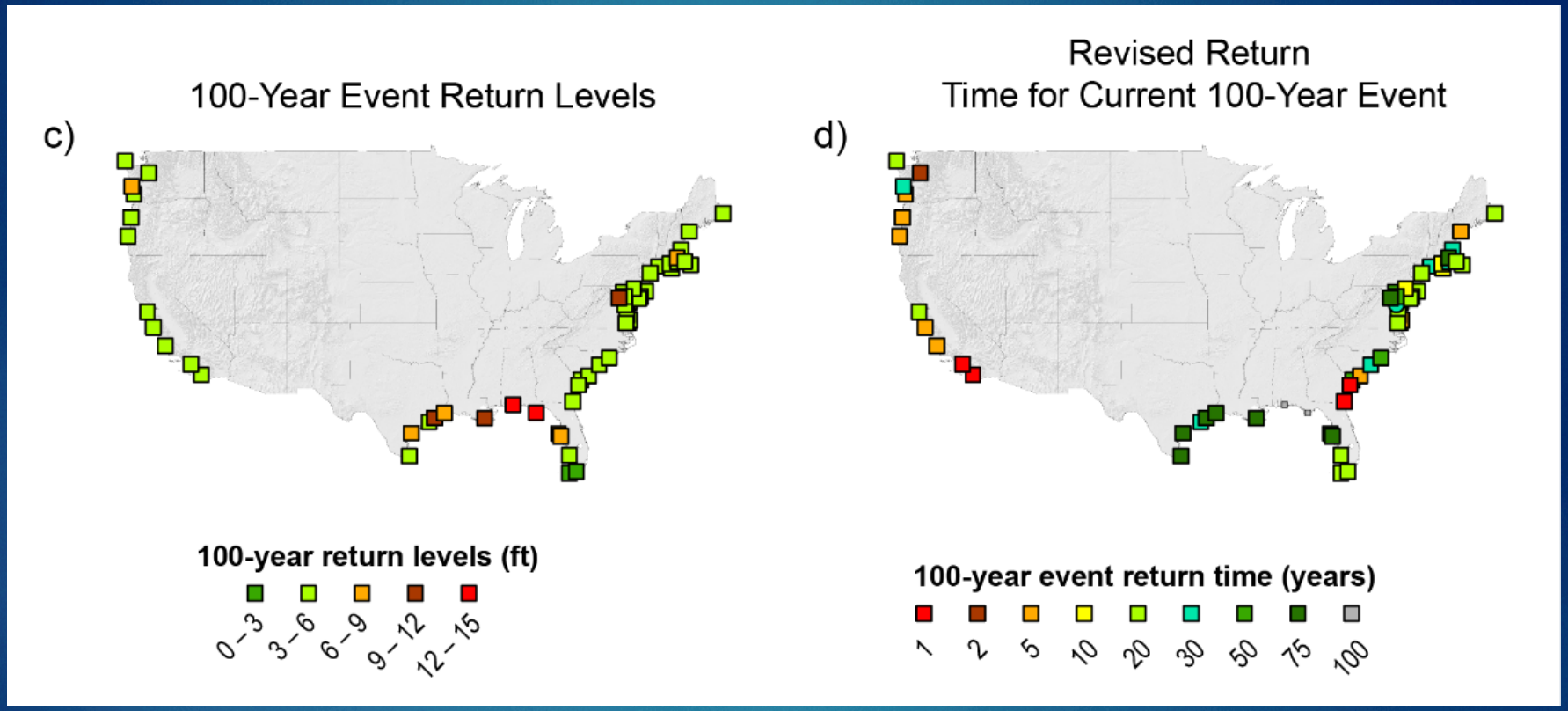
The frequency and intensity of **extreme heat** and **heavy precipitation** events are increasing in most continental regions of the world.



"Nuisance Flooding"—flooding associated with high tides--is Increasing Across the United States



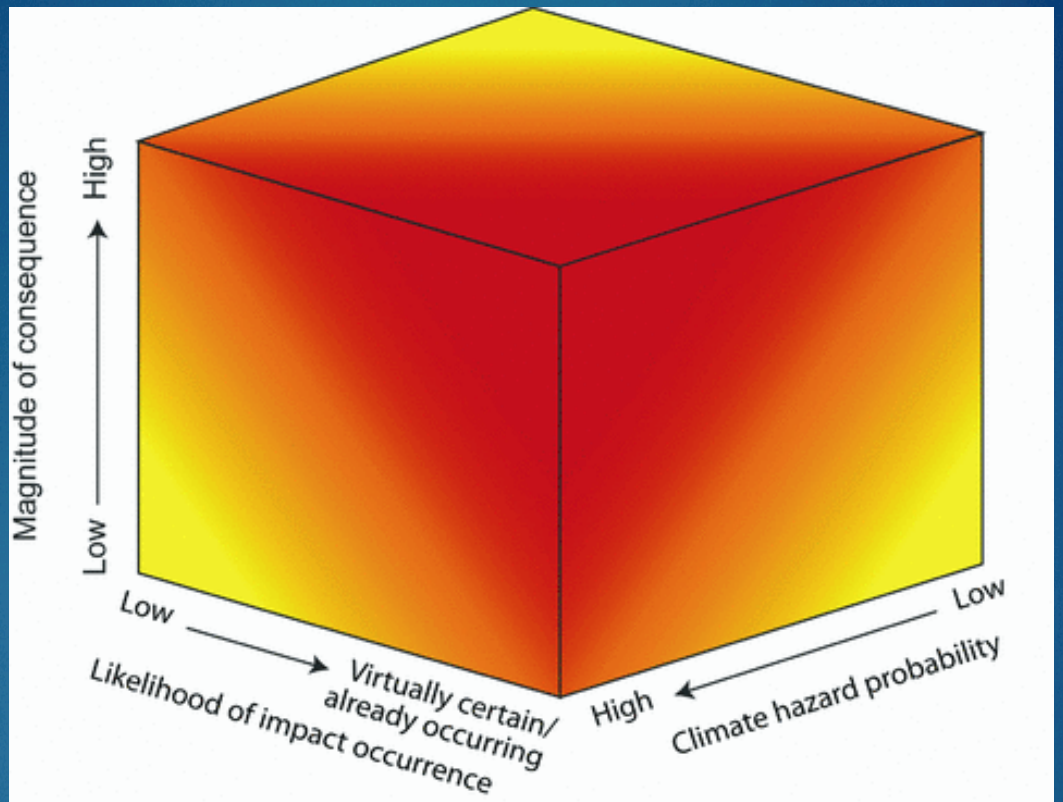
Sea Level Rise = More Frequent Flooding



National Climate Assessment, 2014

Sea level rise of just 2 feet, without any changes in storms, would more than triple the frequency of dangerous coastal flooding along much of the U.S. coast

Risk Management Framework



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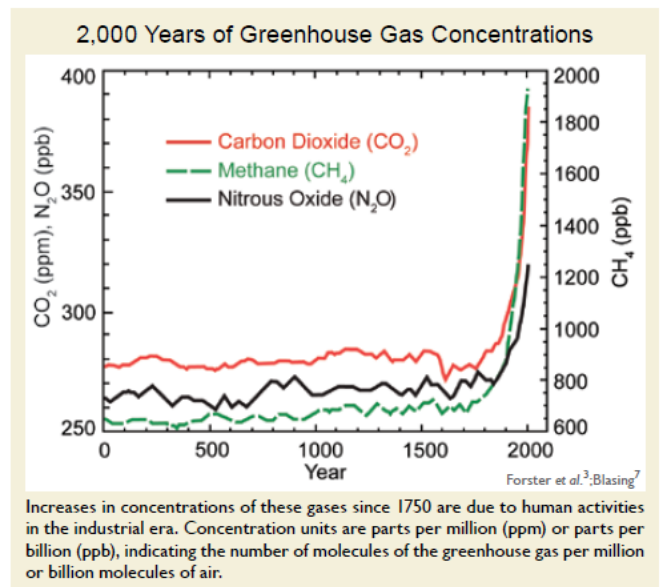

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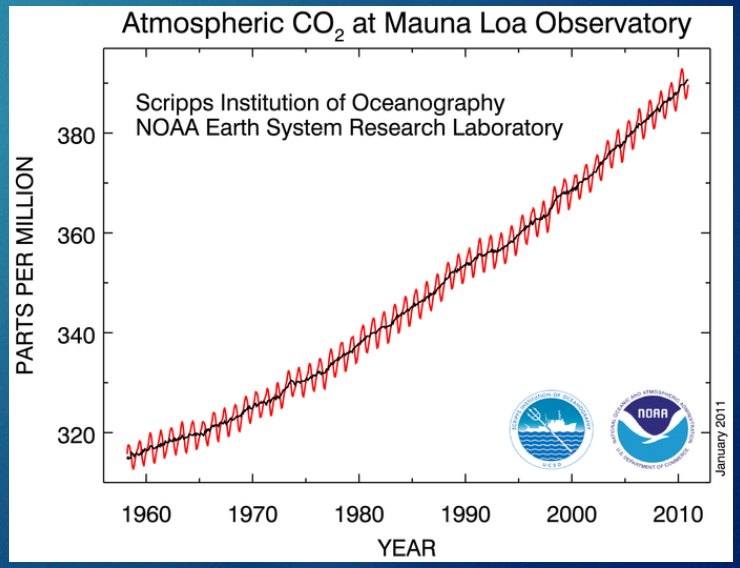


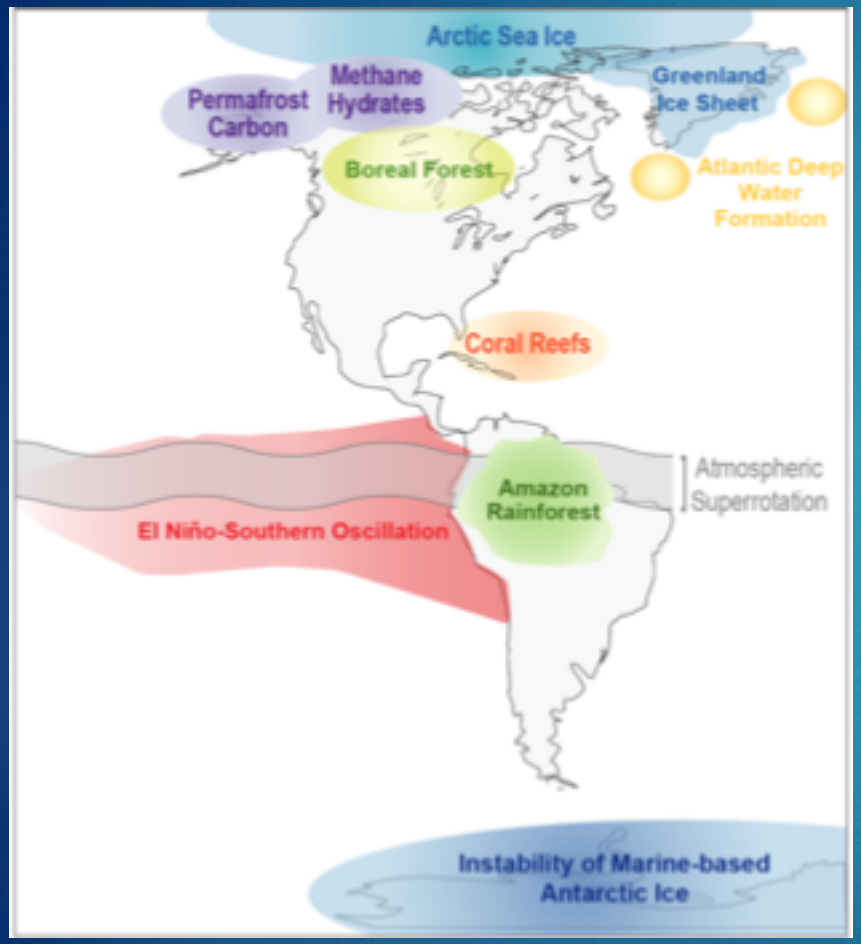
Key Messages

While climate models incorporate important climate processes that can be well quantified, they **do not include all of the processes** that can contribute to feedbacks, compound extreme events, and abrupt and/or irreversible changes.

Future changes outside the range projected by climate models cannot be ruled out.

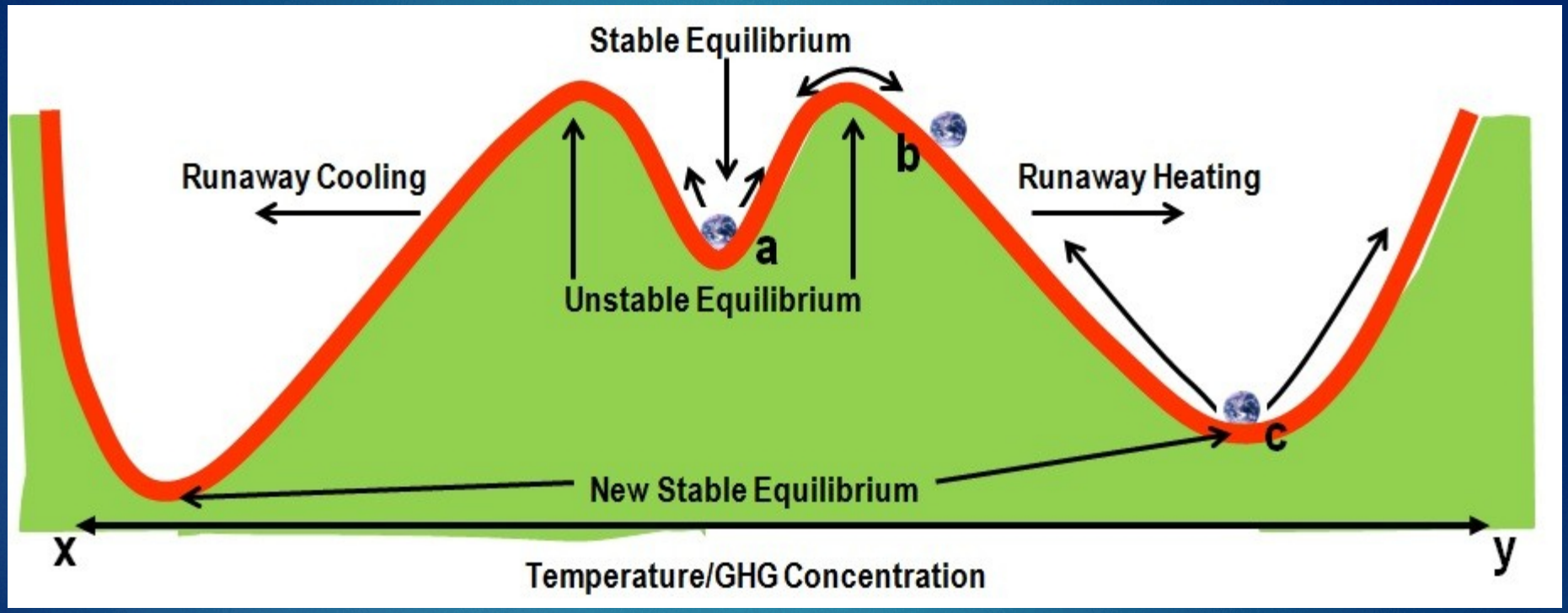
Moreover, the systematic tendency of climate models to underestimate temperature change during warm paleoclimates suggests that climate models are **more likely to underestimate than overestimate** the amount of long-term future change.

Potential Surprises



- Positive feedbacks (self-reinforcing cycles) within the climate system have the potential to accelerate human-induced climate change. Some feedbacks are probably still unknown.
- **The physical and socioeconomic impacts of compound extreme events can be greater than the sum of the parts (*very high confidence*). Few analyses consider the spatial or temporal correlation between extreme events.**
- Future changes outside the range projected by climate models cannot be ruled out (*very high confidence*).

Tipping Elements



K. Harrison, 2013, adapted from from D. Wasdell, 2013

Tipping Element Examples

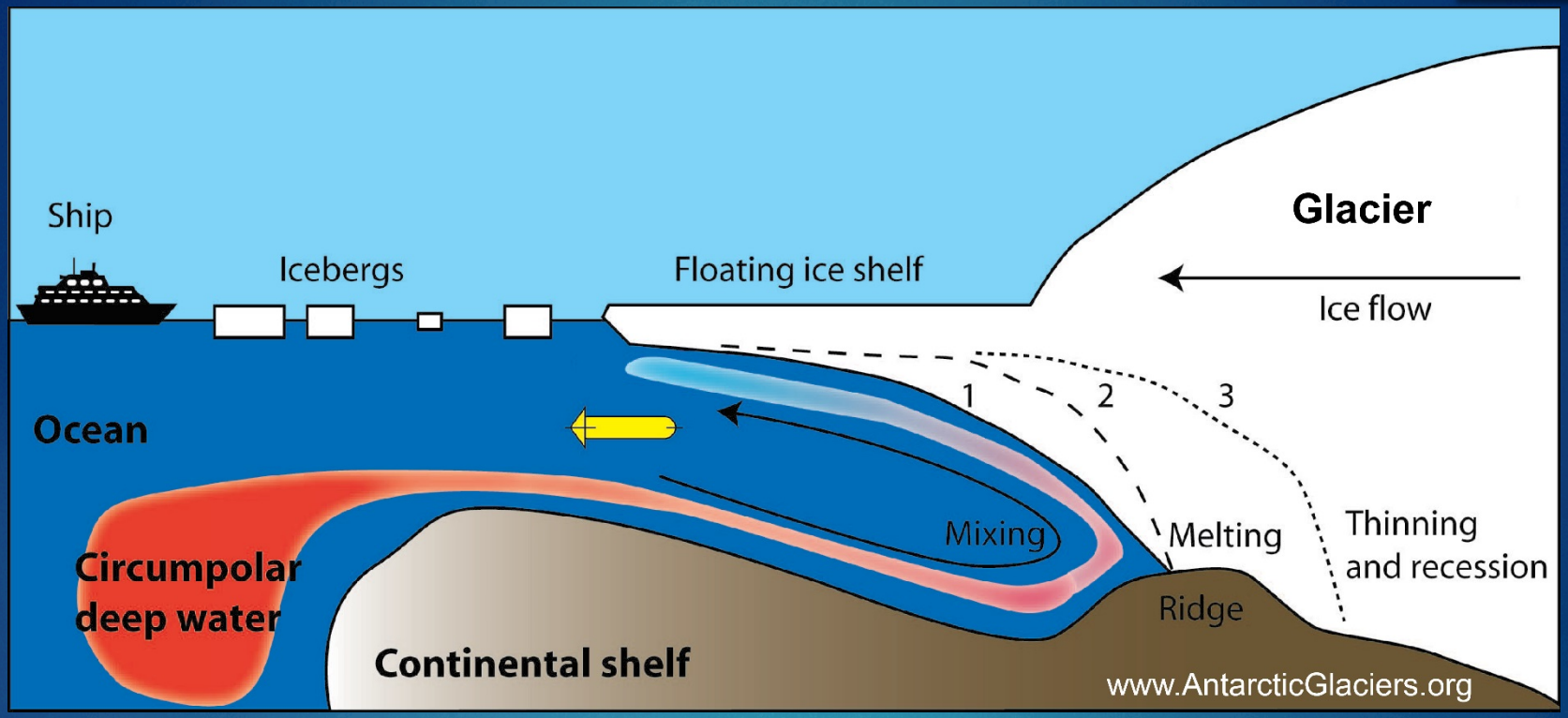
Table 15.1: Potential tipping elements (adapted from Kopp et al. 2016[11]).

Candidate Climatic Tipping Element	State Shift	Main Impact Pathways
Atmosphere–ocean circulation		
Atlantic meridional overturning circulation	Major reduction in strength	Regional temperature and precipitation; global mean temperature; regional sea level
El Niño–Southern Oscillation	Increase in amplitude	Regional temperature and precipitation
Equatorial atmospheric superrotation	Initiation	Cloud cover; climate sensitivity
Regional North Atlantic Ocean convection	Major reduction in strength	Regional temperature and precipitation
Cryosphere		
Antarctic Ice Sheet	Major decrease in ice volume	Sea level; albedo; freshwater forcing on ocean circulation
Arctic sea ice	Major decrease in summertime and/or perennial area	Regional temperature and precipitation; albe-do
Greenland Ice Sheet	Major decrease in ice volume	Sea level; albedo; freshwater forcing on ocean circulation
Carbon cycle		
Methane hydrates	Massive release of carbon	Greenhouse gas emissions
Permafrost carbon	Massive release of carbon	Greenhouse gas emissions
Ecosystem		
Amazon rainforest	Dieback, transition to grasslands	Greenhouse gas emissions; biodiversity
Boreal forest	Dieback, transition to grasslands	Greenhouse gas emissions; albedo; biodiversity
Coral reefs	Die-off	Biodiversity

Global mean sea level has risen by about 7–8 inches (about 16–21 cm) since 1900, about 3 of those inches since1993.

Emerging science on **Antarctic ice sheet stability** suggests that, for high scenarios, global mean sea level rise exceeding 8 feet by 2100 is physically possible, *although the probability of such an extreme outcome cannot currently be assessed.*

Marine Ice Sheet Instability (MISI) on Antarctica



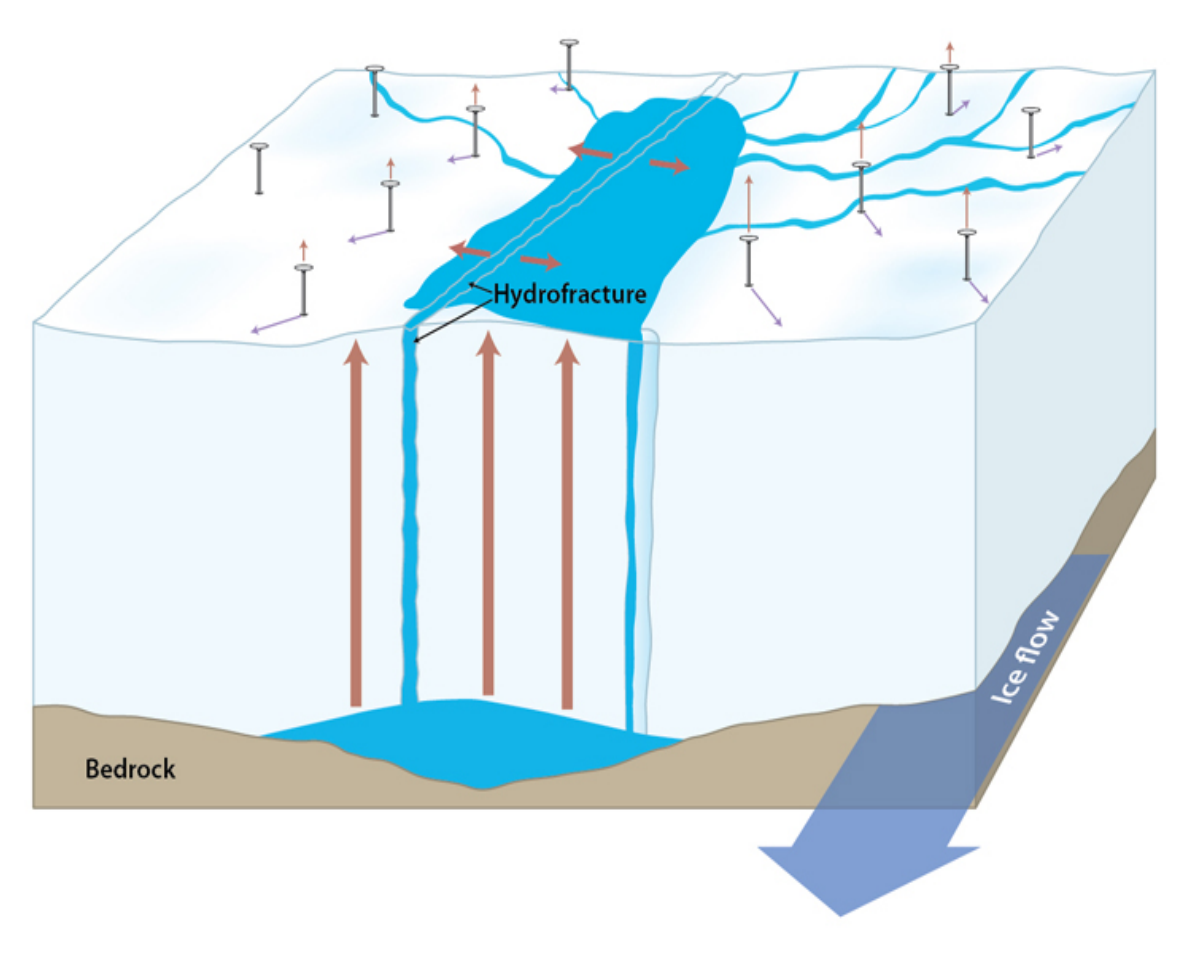
ICE STREAM/GLACIER GROUNDED ON BEDROCK RIDGE; 2) WARM CIRCUMPOLAR DEEP WATER FLOWS INTO CAVITY, THINS ICE SHELF, MELTS GLACIER BASE AT GROUNDING LINE; 3) GROUNDING LINE RETREATS DOWNSLOPE, THINS ICE SHELF MORE, CAUSING GLACIER TO ACCELERATE FORWARD.

MODIFIED FROM BETHAN DAVIES, ANTARCTICGLACIERS.ORG

Ice Cliff Failure – Antarctica

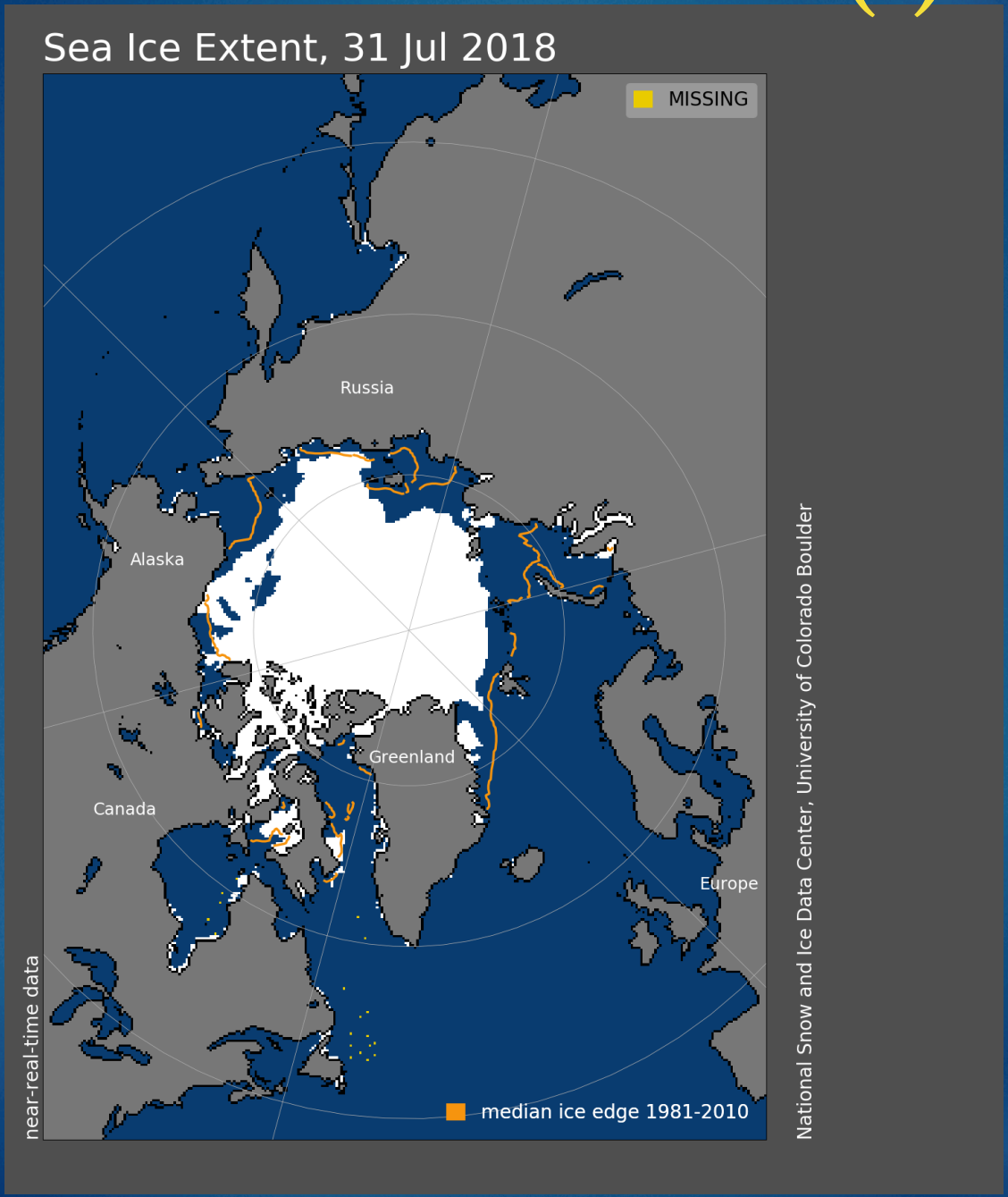
CREDIT: DAVID POLLARD; ROBERT DECONTO

Hydrofracturing on Ice Sheet



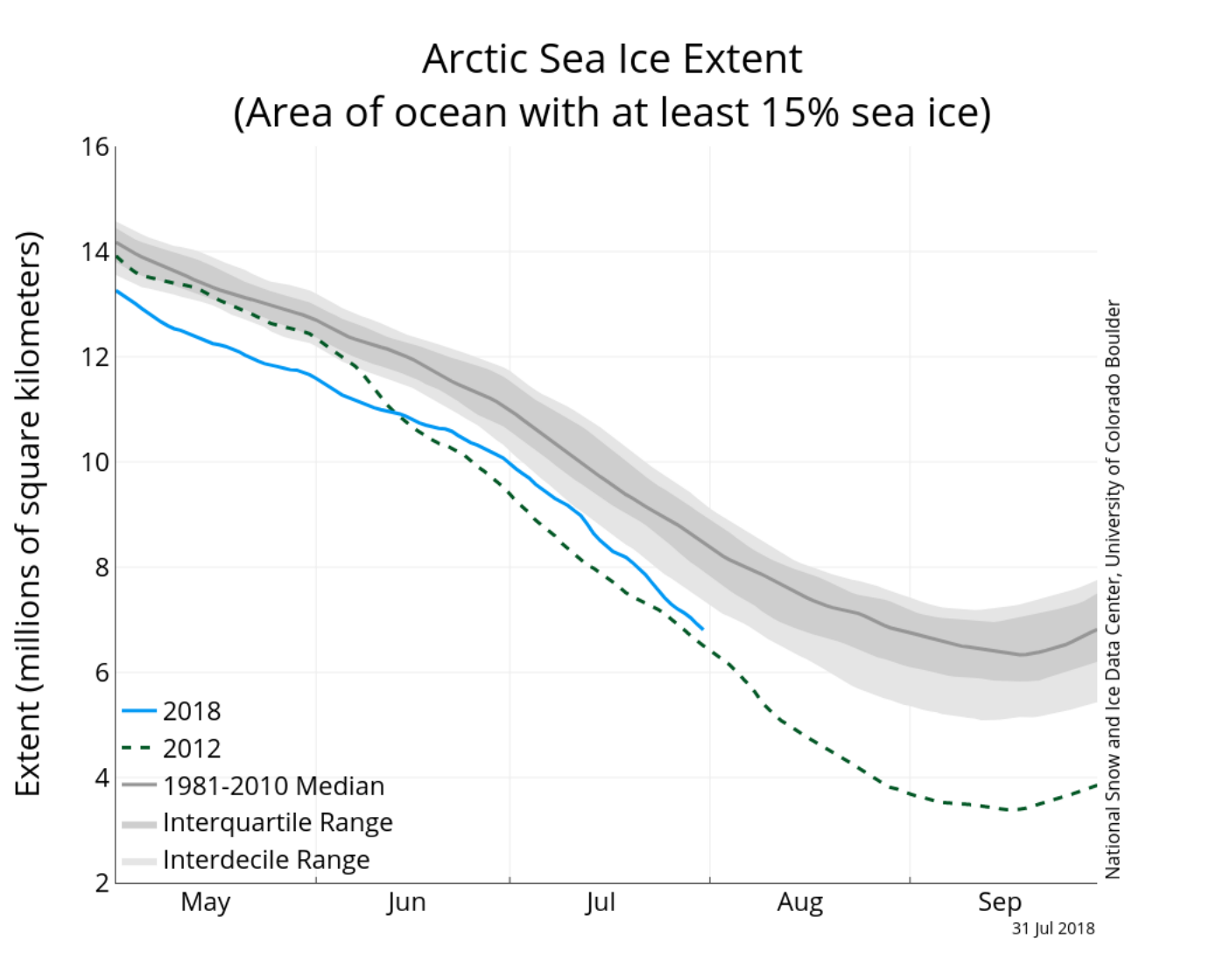
WWW.WHOI.EDU

Arctic Sea Ice (1)



NSIDC

Arctic Sea Ice (2)

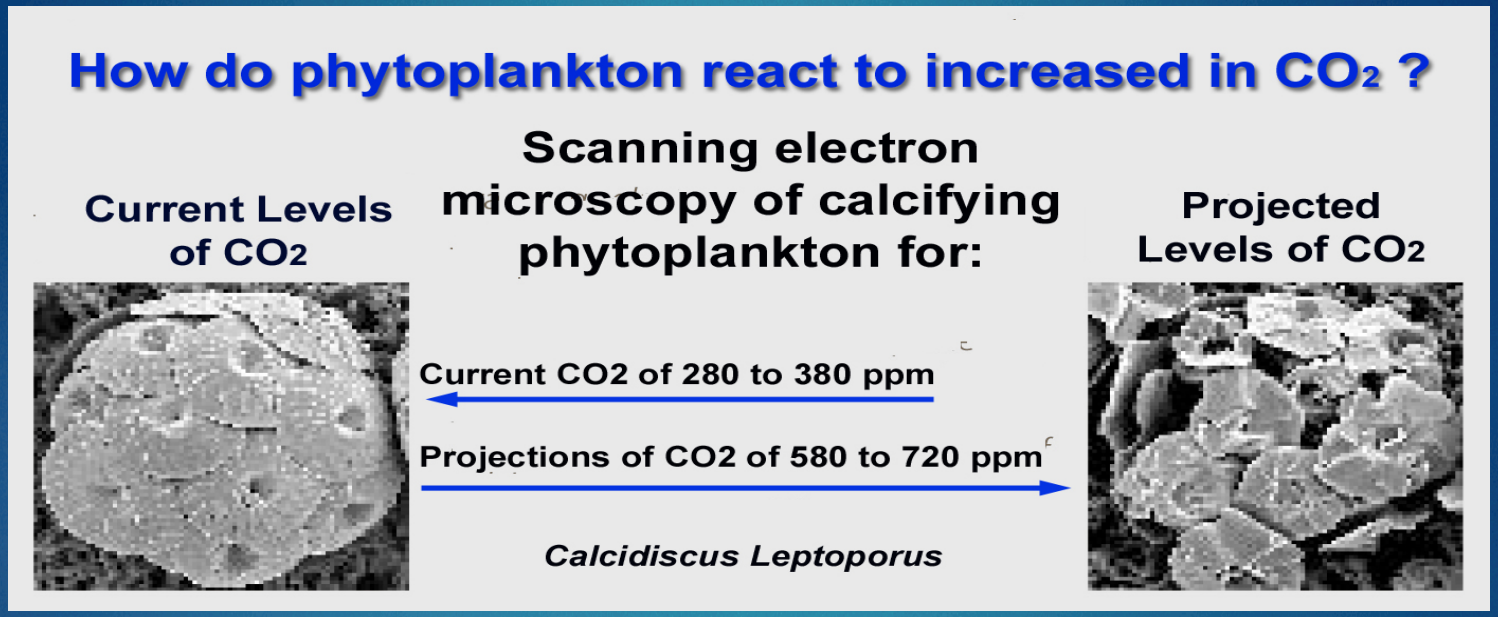


NSIDC

Ocean Ecosystems

Ocean acidification

- Lowered pH will dissolve calcium-based shells and skeletons



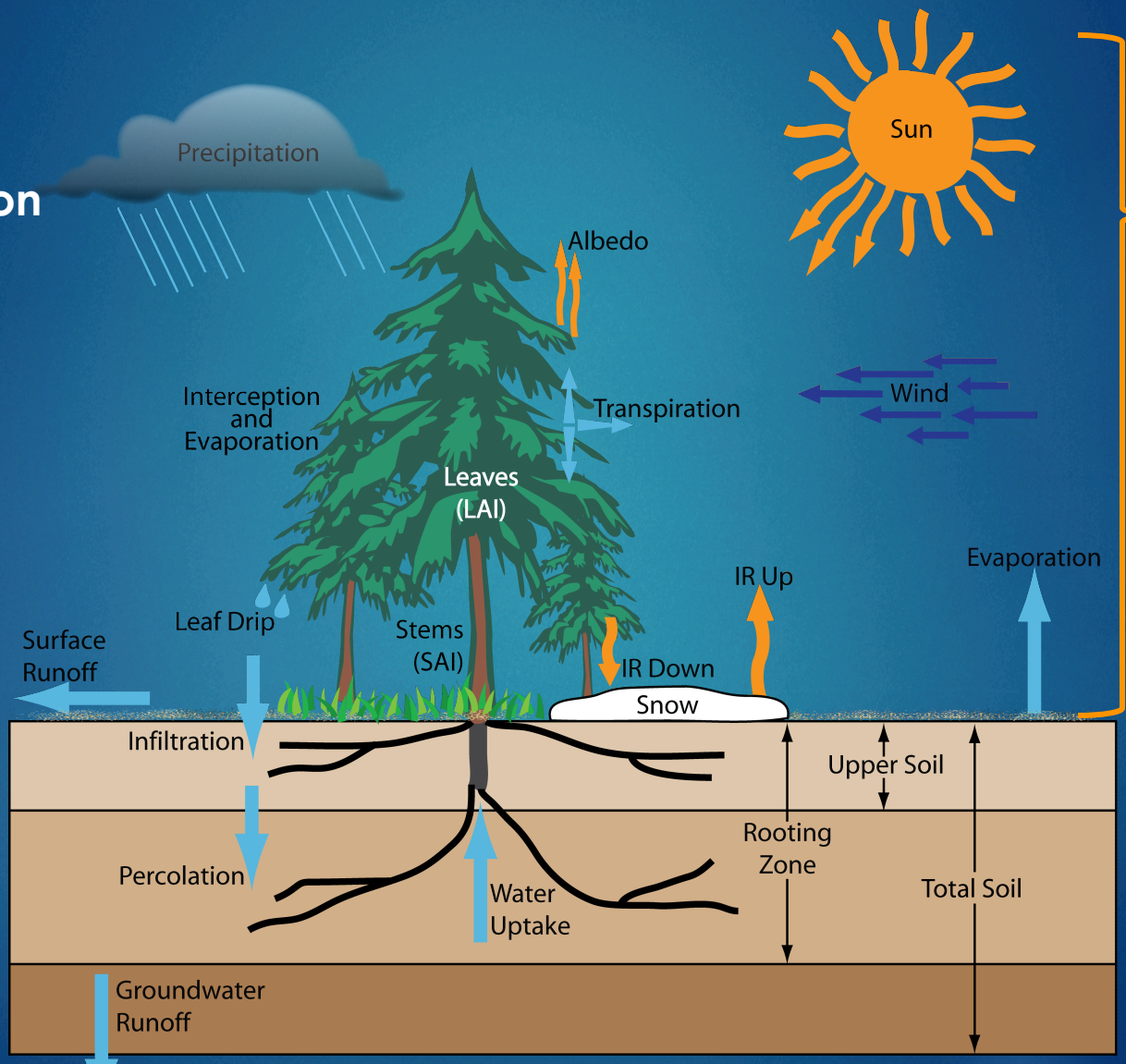
Coral Reefs

- **Require a narrow range of ocean temperatures**
- Require sea level to be at a certain level
- Cannot migrate and grow as fast as temperatures and depths will change

Fire and drought in the western states …

Firefighters monitor flames threatening the Oakmont community along Highway 12 in Santa Rosa. (Genaro Molina / Los Angeles Times)

Supply: Precipitation



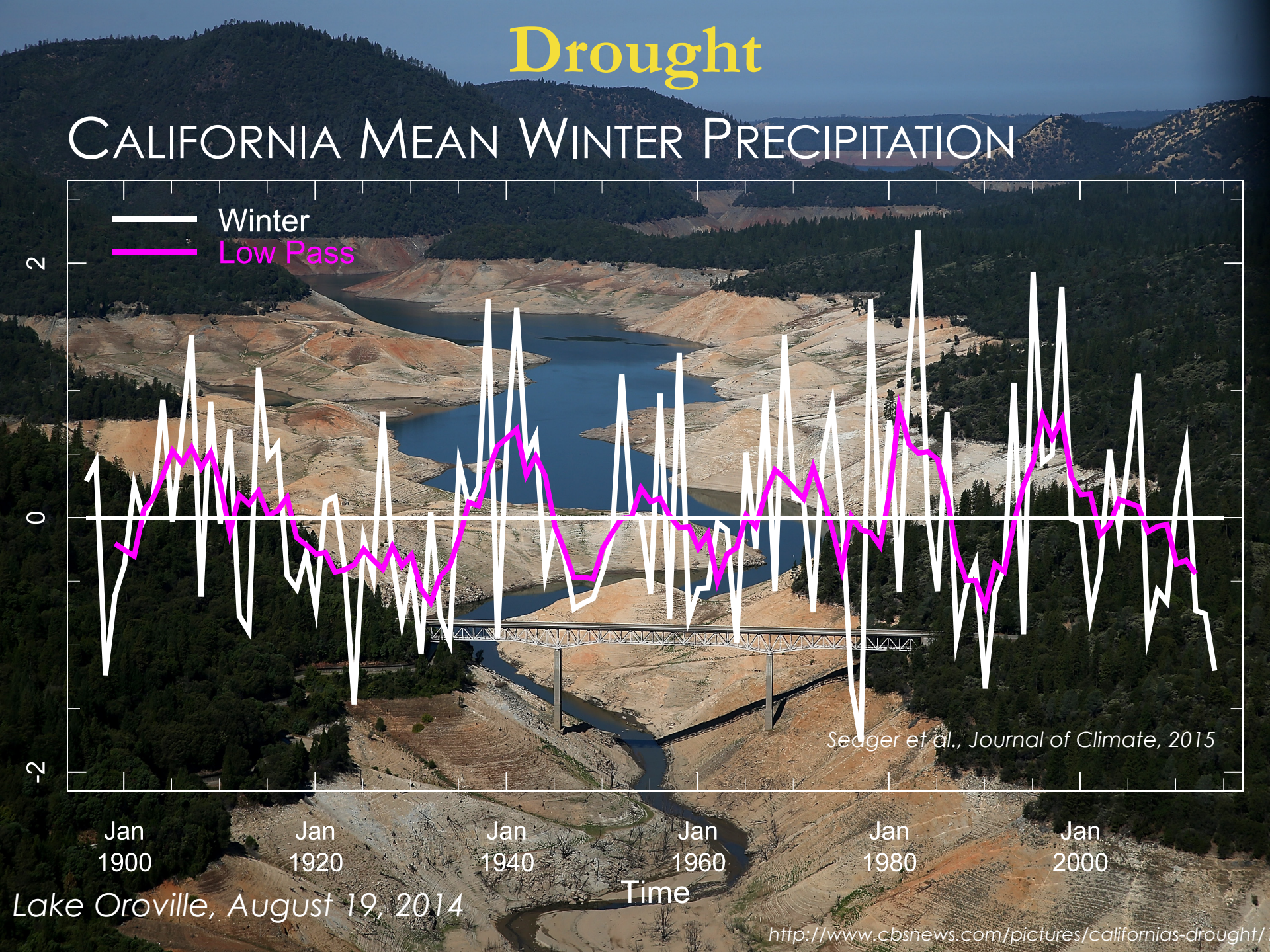
Background

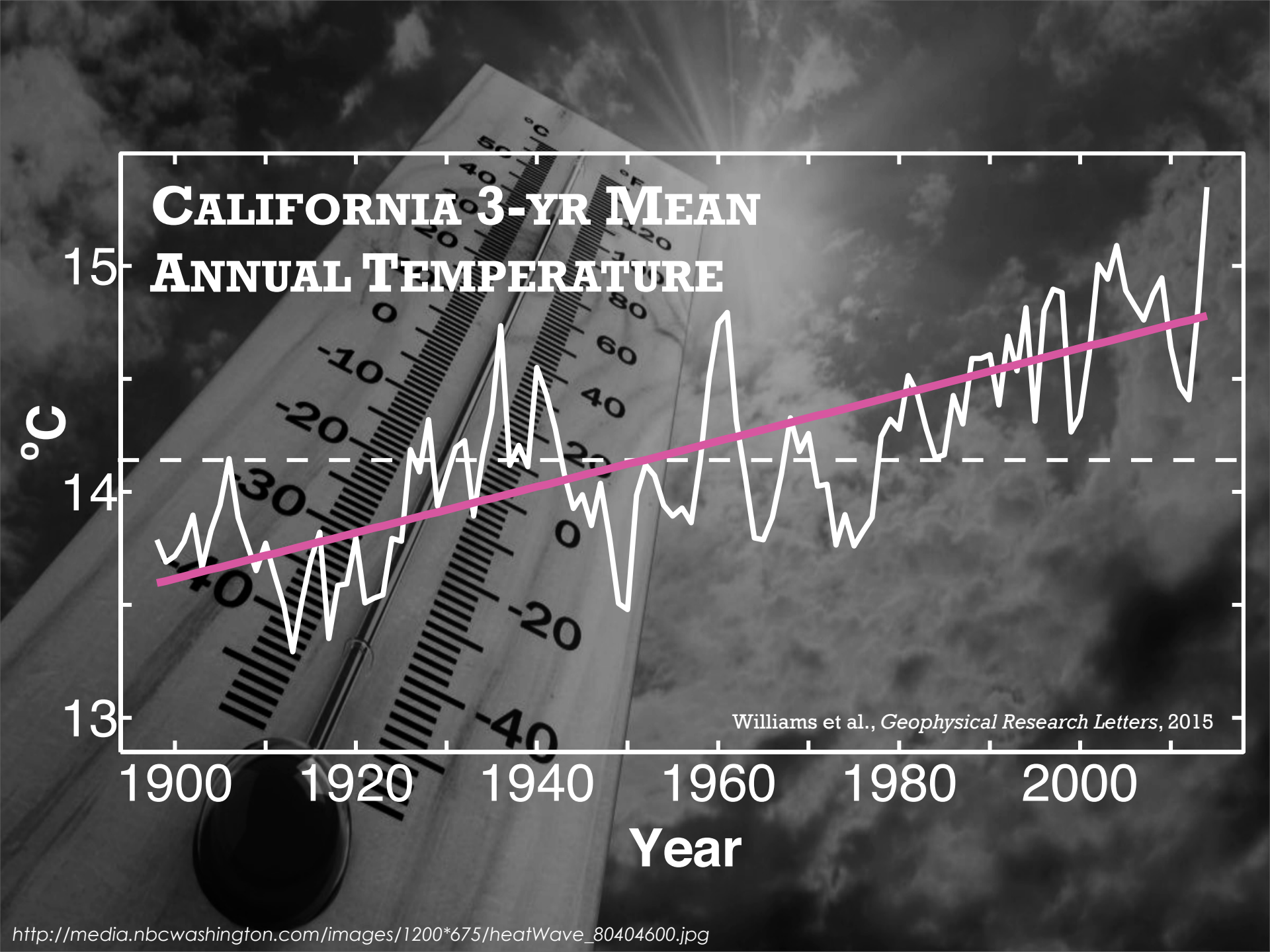
Demand: Temperature + Wind + Radiation + Humidity

http://regclim.coas.oregonstate.edu/wp-content/uploads/BATS_highres1.png

Drought

California Mean Winter Precipitation

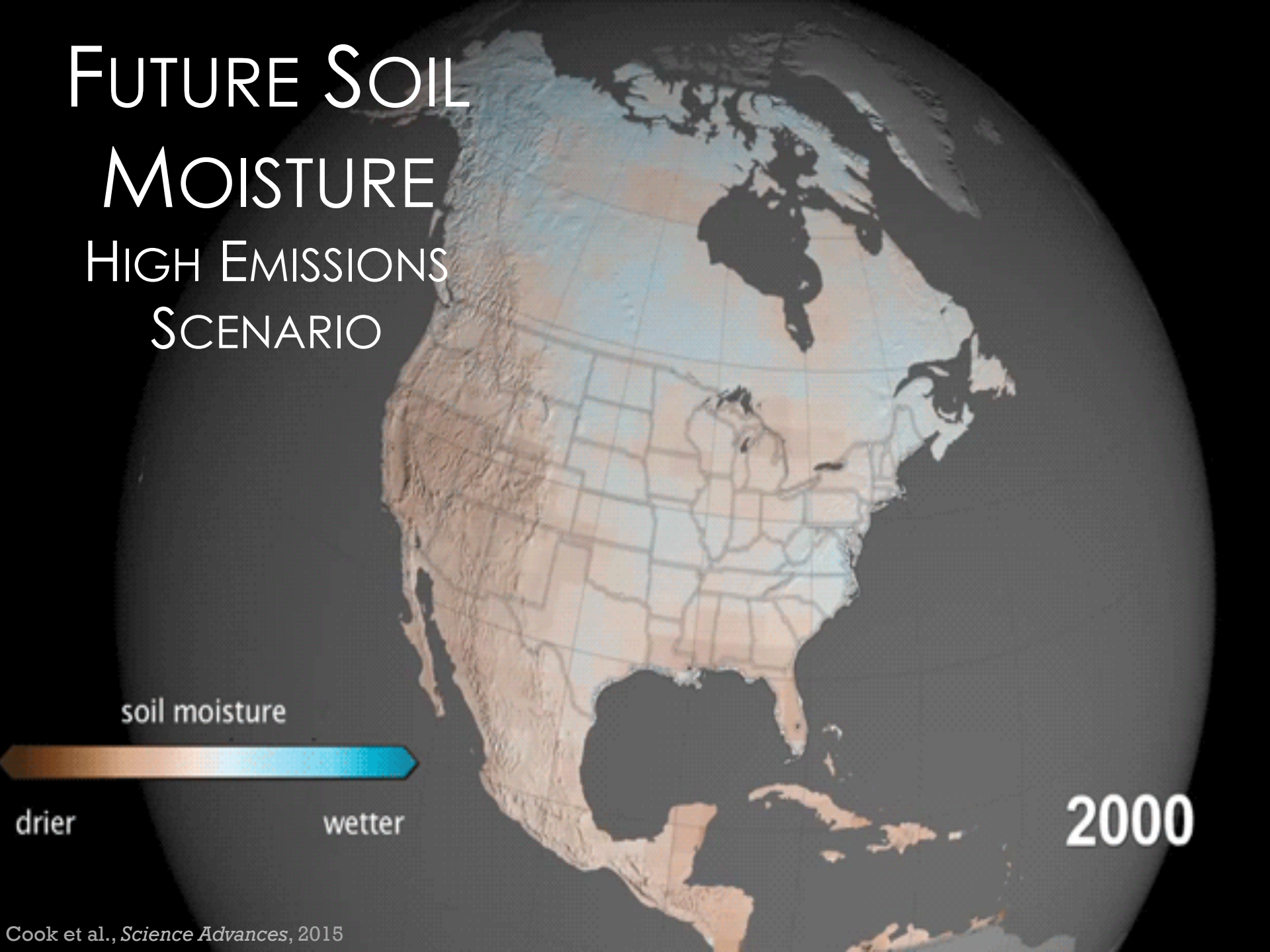




http://media.nbcwashington.com/images/1200*675/heatWave_80404600.jpg

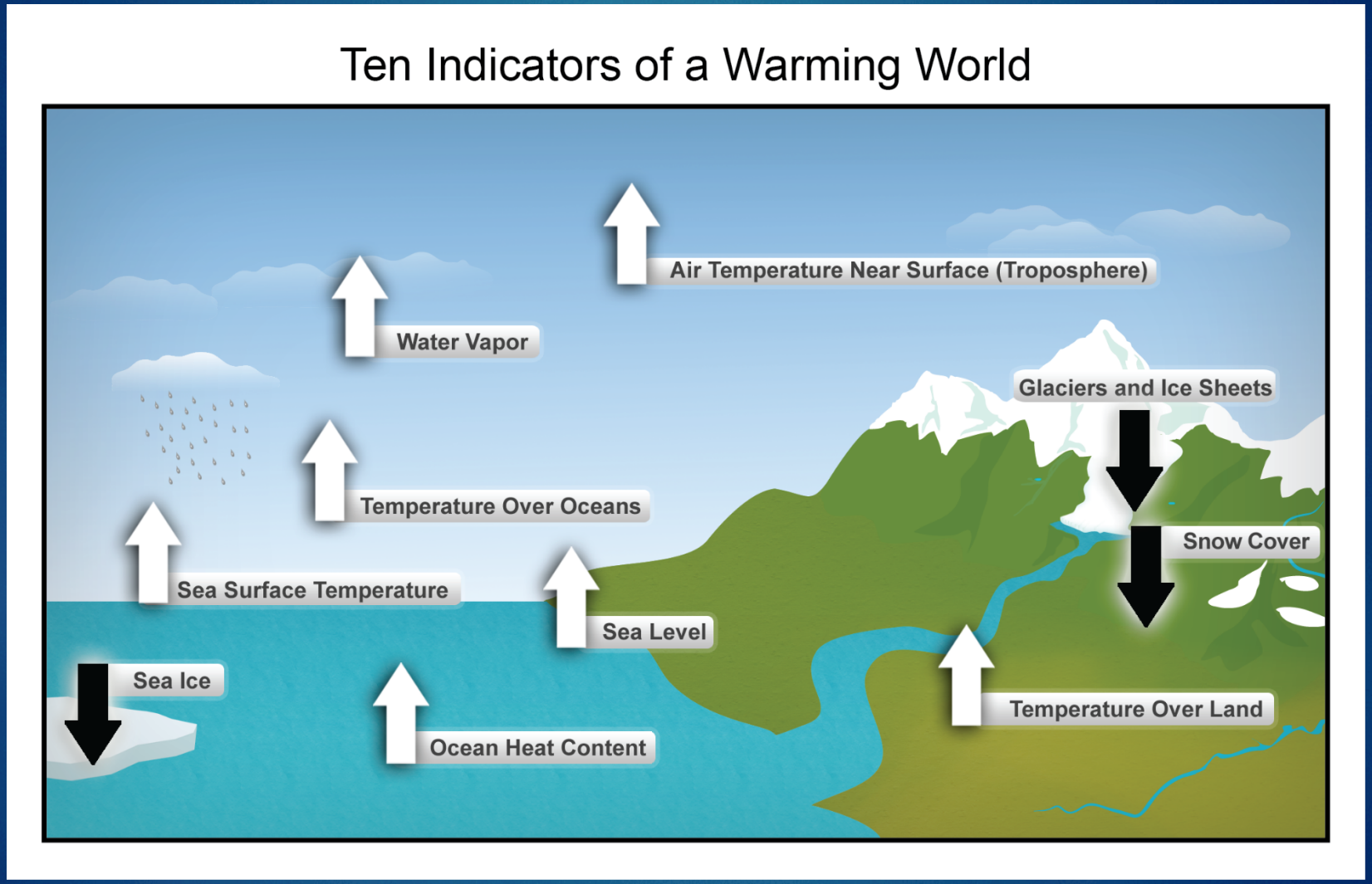
Future Soil Moisture

High Emissions Scenario



Cook et al., *Science Advances*, 2015

System Interactions

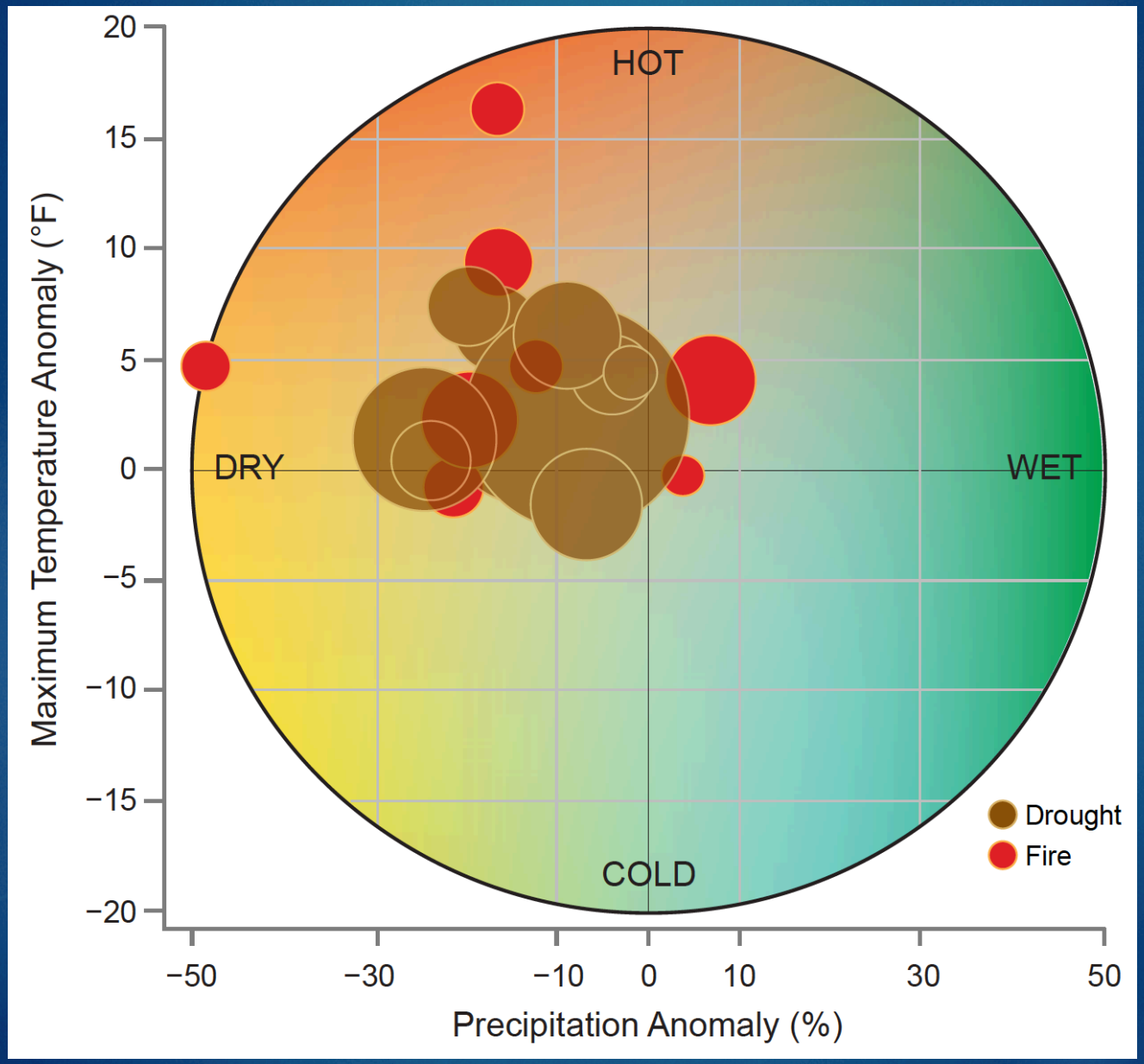


National Climate Assessment, 2014

Compound Extremes

Categories of Compound Extremes

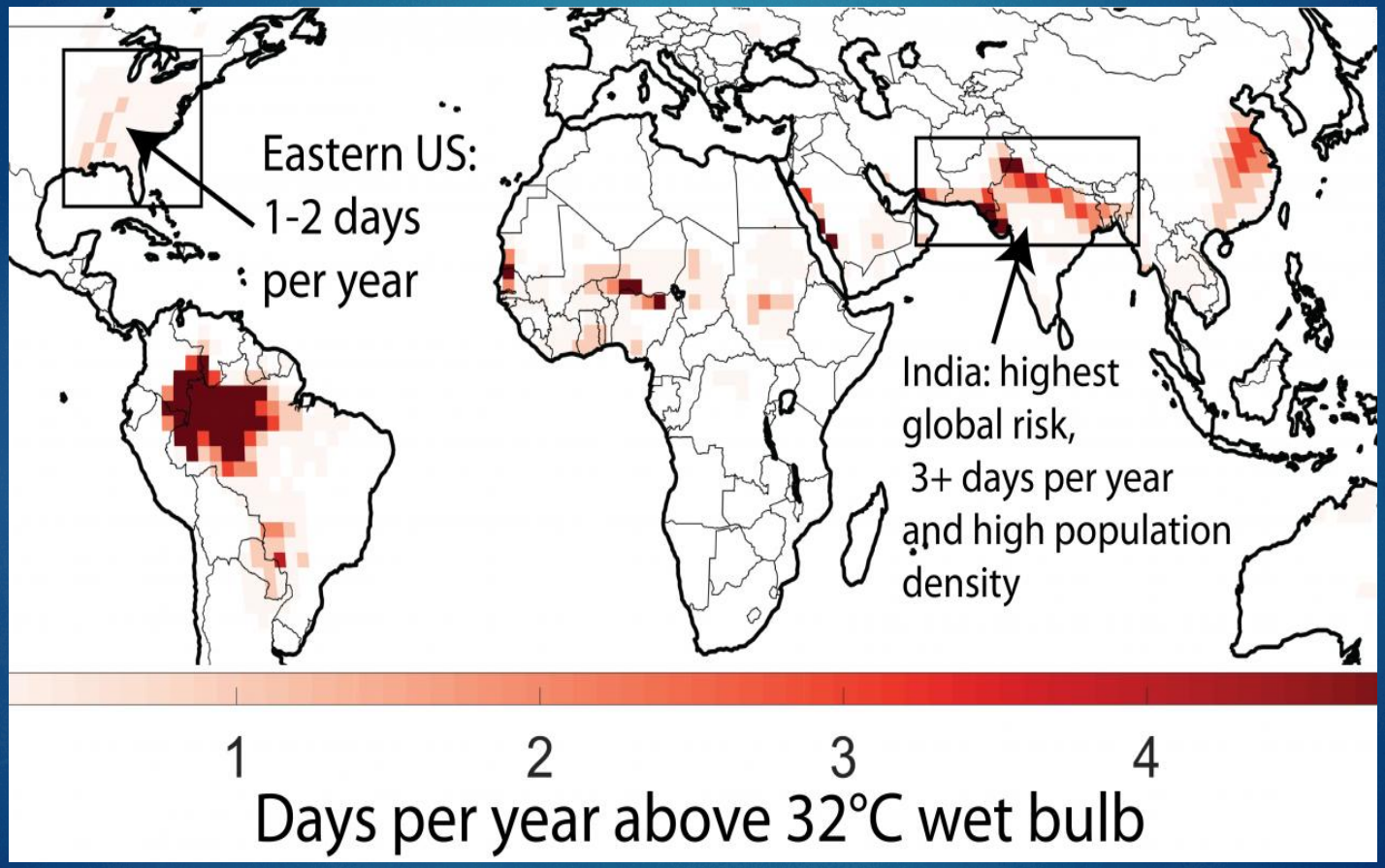
- Multivariate
- Correlated through space
- Correlated through time


HOT
DRY
WET
COLD
Drought
Fire
Maximum Temperature Anomaly (°F)
20
15
10
5
0
−5
−10
−15
−20
−50
−30
−10
0
10
30
50
Precipitation Anomaly (%)

Temperature + Humidity

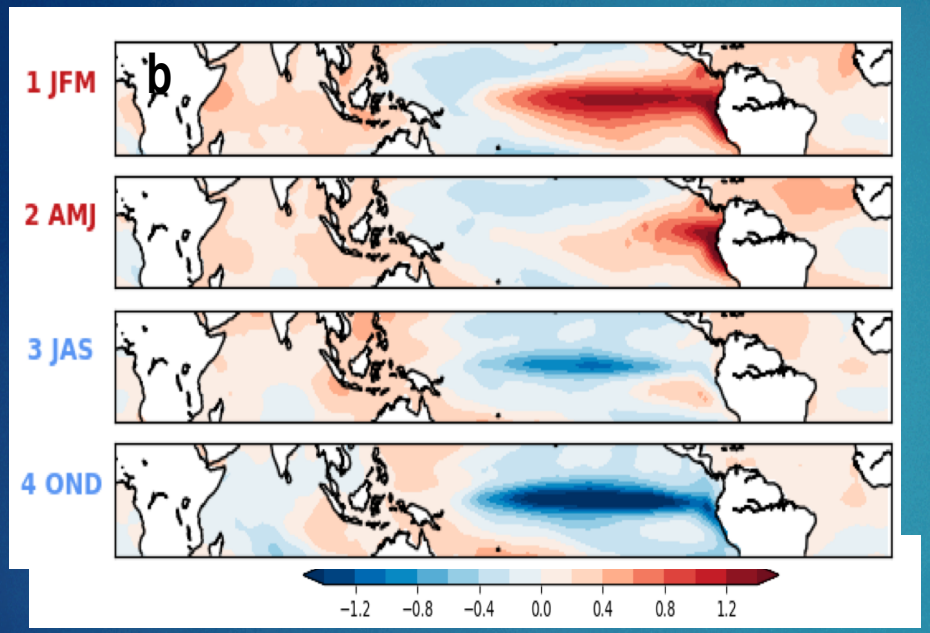
- The lowest temperature that can result from evaporative cooling = wet bulb temperature
- Max in recent heatwaves: 31°C
- Theoretical max for human tolerance: 35°C (Sherwood, Huber, 2010)

Coffel, E., R.M. Horton, and A. De Sherbinin, Population exposure to heat stress in the 21st century (in preparation)

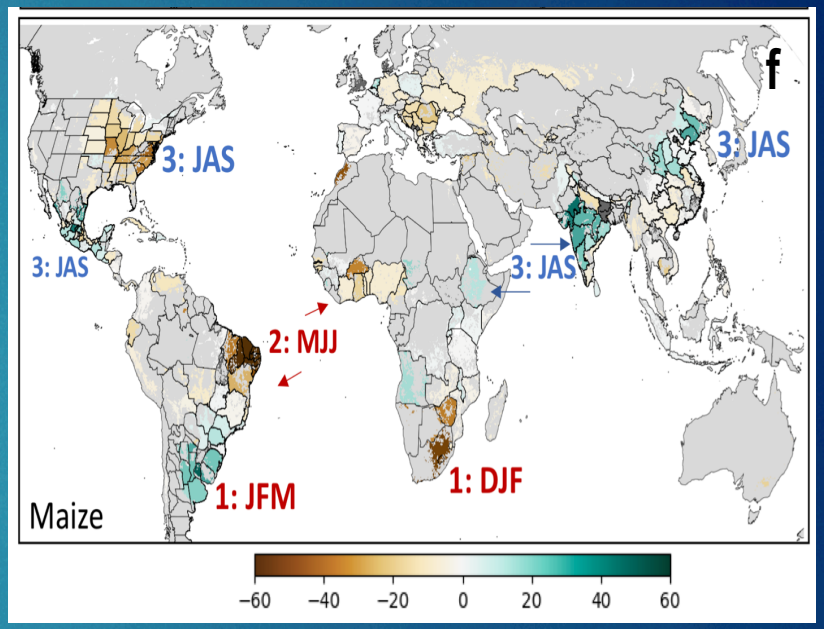

Eastern US:
1-2 days
per year
India: highest
global risk,
3+ days per year
and high population
density
1
2
3
4
Days per year above 32°C wet bulb

ENSO and maize yield variability

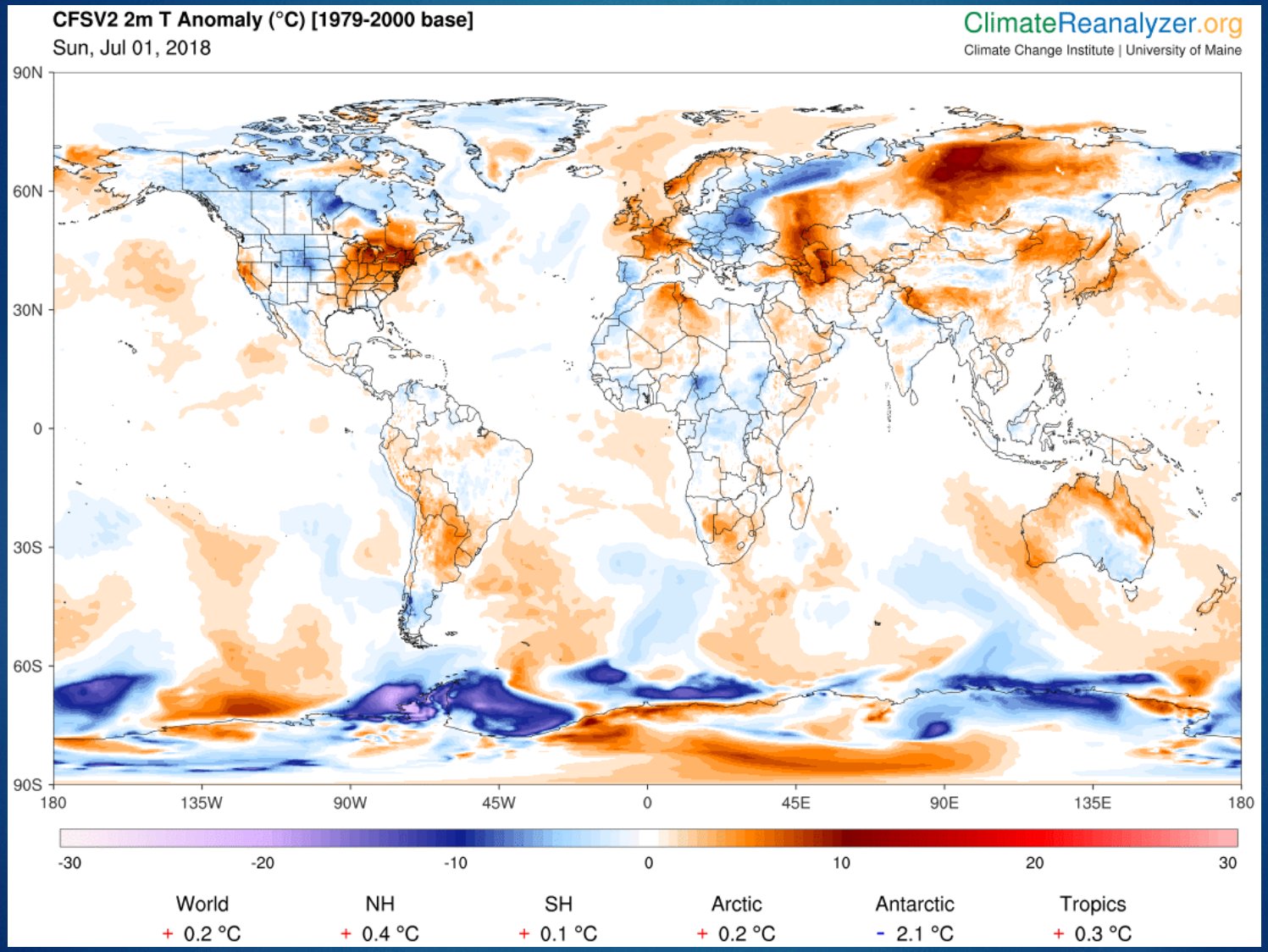
Tropical SST anomalies

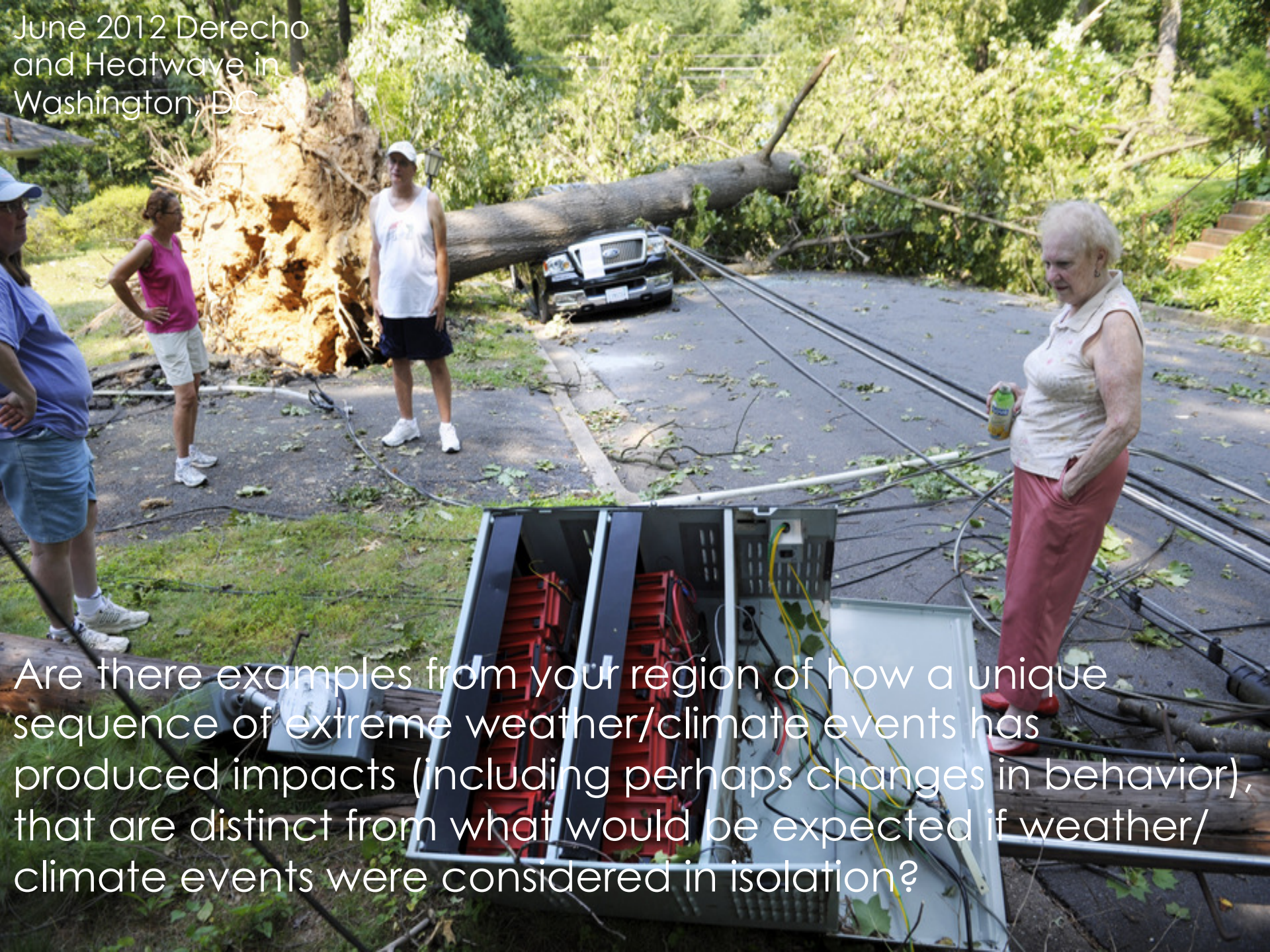


Crop yield anomalies



Weston Anderson, 2018


CFSV2 2m T Anomaly (°C) [1979-2000 base]
Sun, Jul 01, 2018
ClimateReanalyzer.org
Climate Change Institute | University of Maine
90N
60N
30N
0
30S
60S
90S
180
135W
90W
45W
0
45E
90E
135E
180
-30
-20
-10
0
10
20
30
World
+ 0.2 °C
NH
+ 0.4 °C
SH
+ 0.1 °C
Arctic
+ 0.2 °C
Antarctic
- 2.1 °C
Tropics
+ 0.3 °C

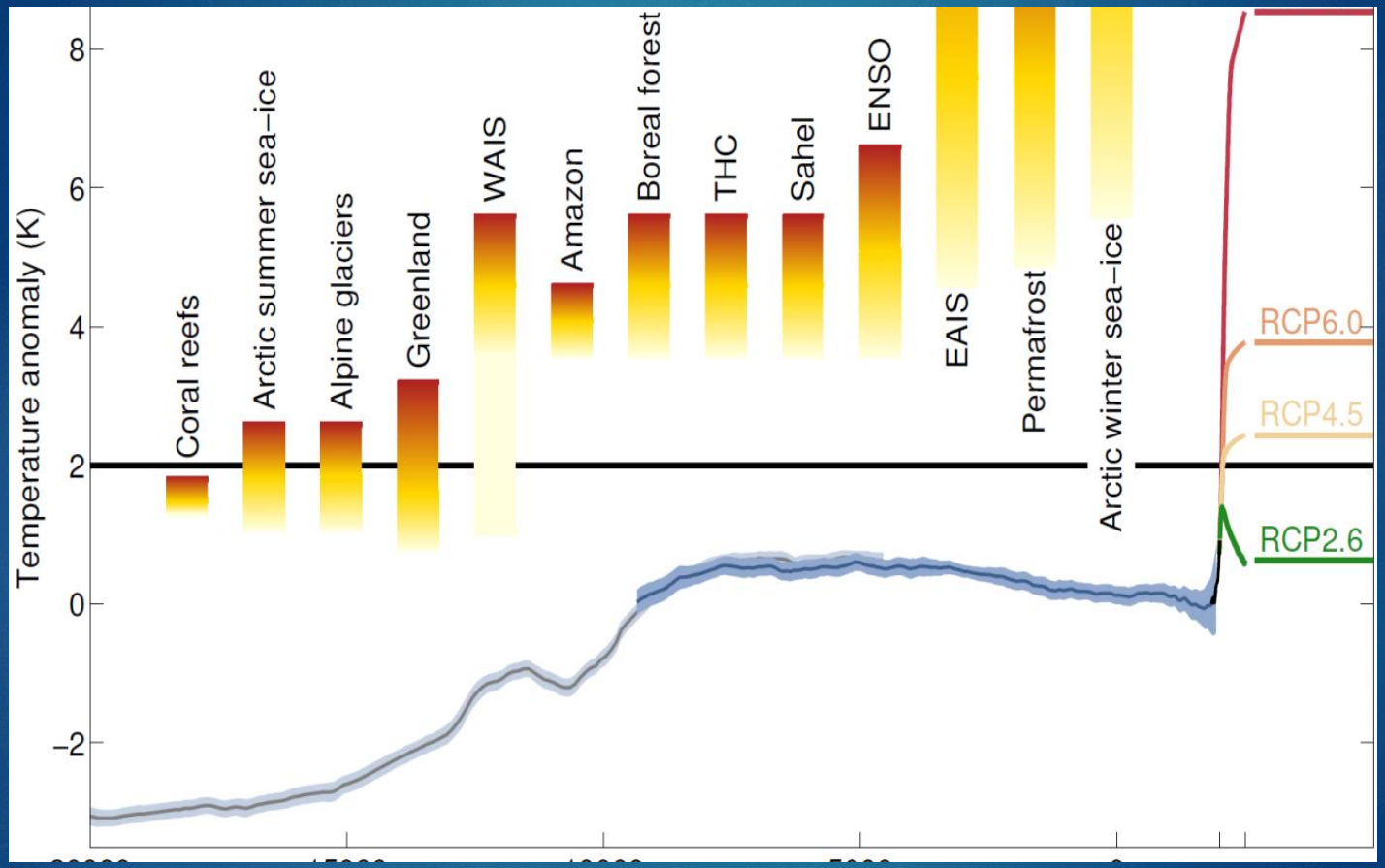


Are there examples from your region of how a unique sequence of extreme weather/climate events has produced impacts (including perhaps changes in behavior), that are distinct from what would be expected if weather/climate events were considered in isolation?

Impact Surprises

Tuvalu - The Guardian – 05/16/2008, photo by Matthieu Paley/Corbis

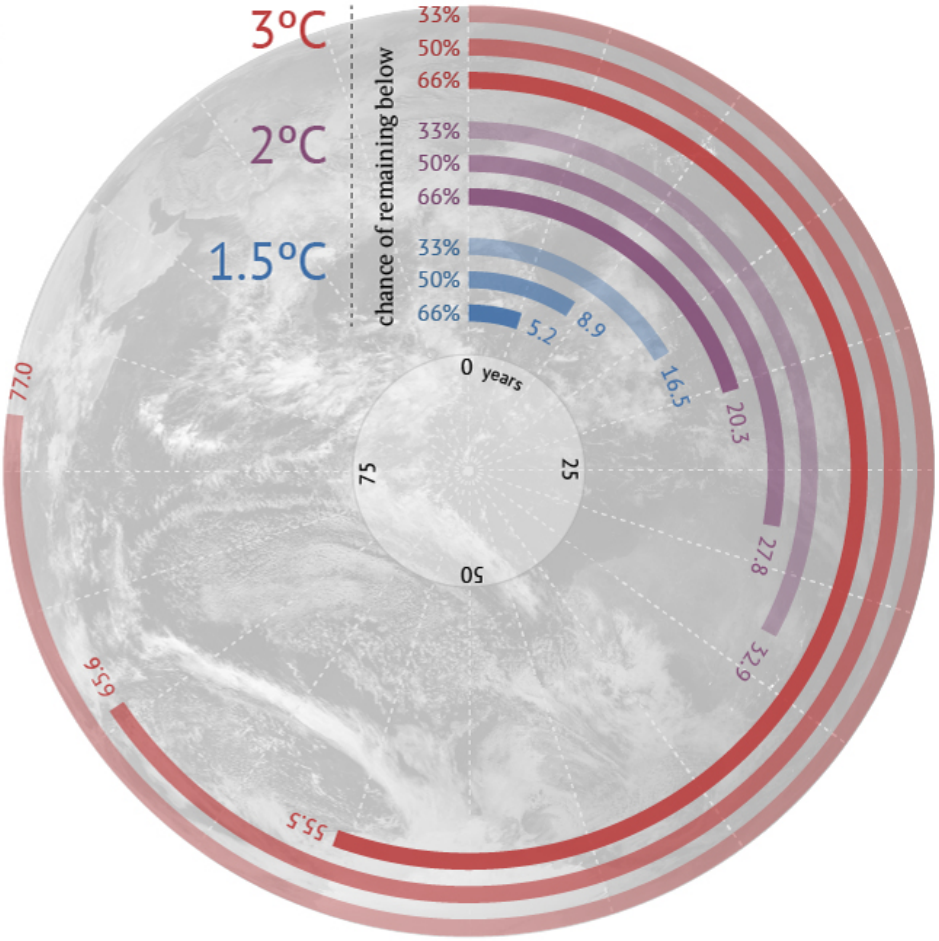
Kennedy Space Center



Schellnhuber, H. J., Rahmstorf, S. & Winkelmann, R. Why the right climate target was agreed in Paris. Nature Climate Change 6, 649-653 (2016).

Carbon Countdown

How many years of current emissions would use up the IPCC's carbon budgets for different levels of warming?



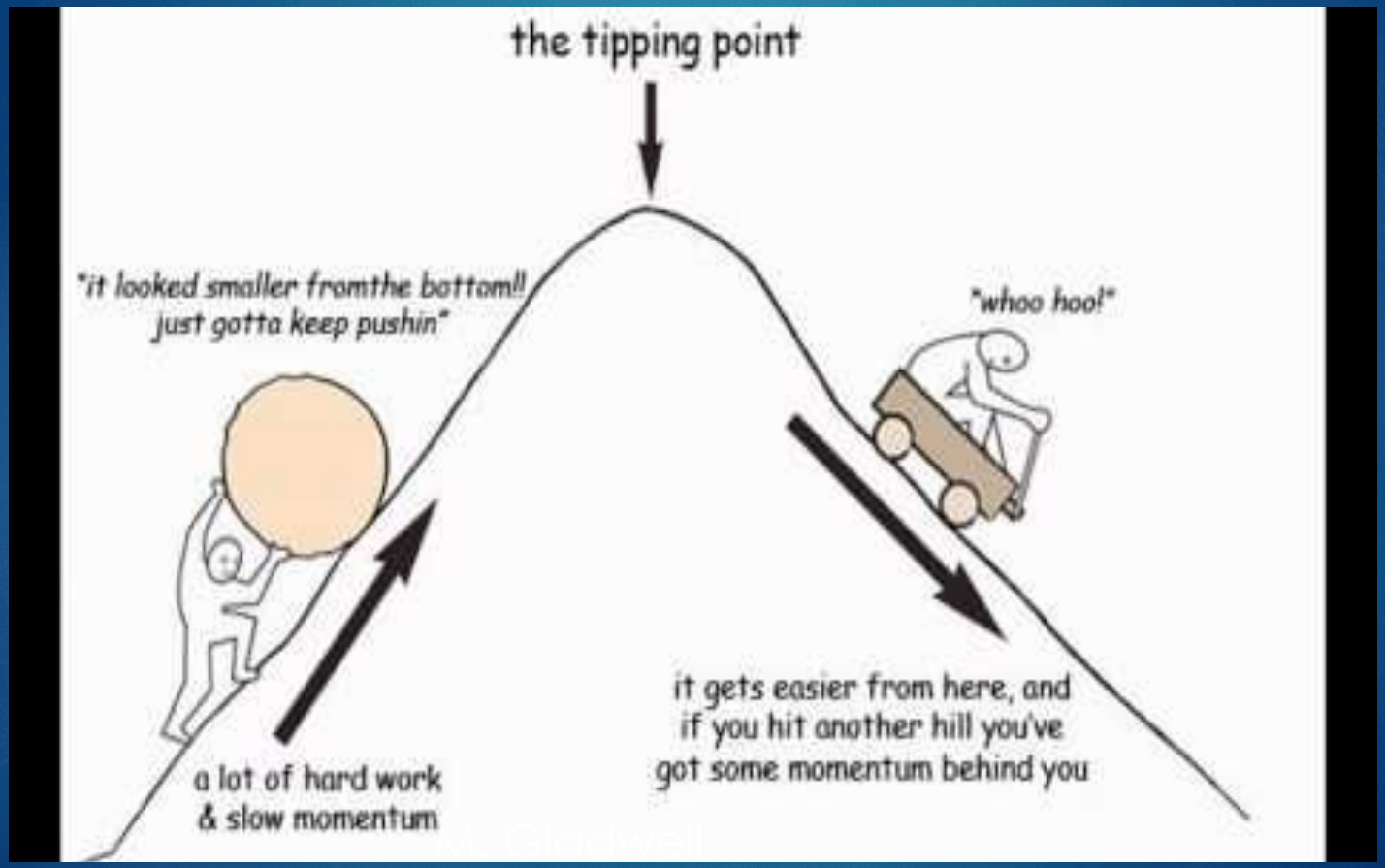
CarbonBrief
CLEAR ON CLIMATE

Photo credit: NASA Goddard Space Flight Center
Stopwatch icon: T-Kot/Shutterstock.com

Key Points

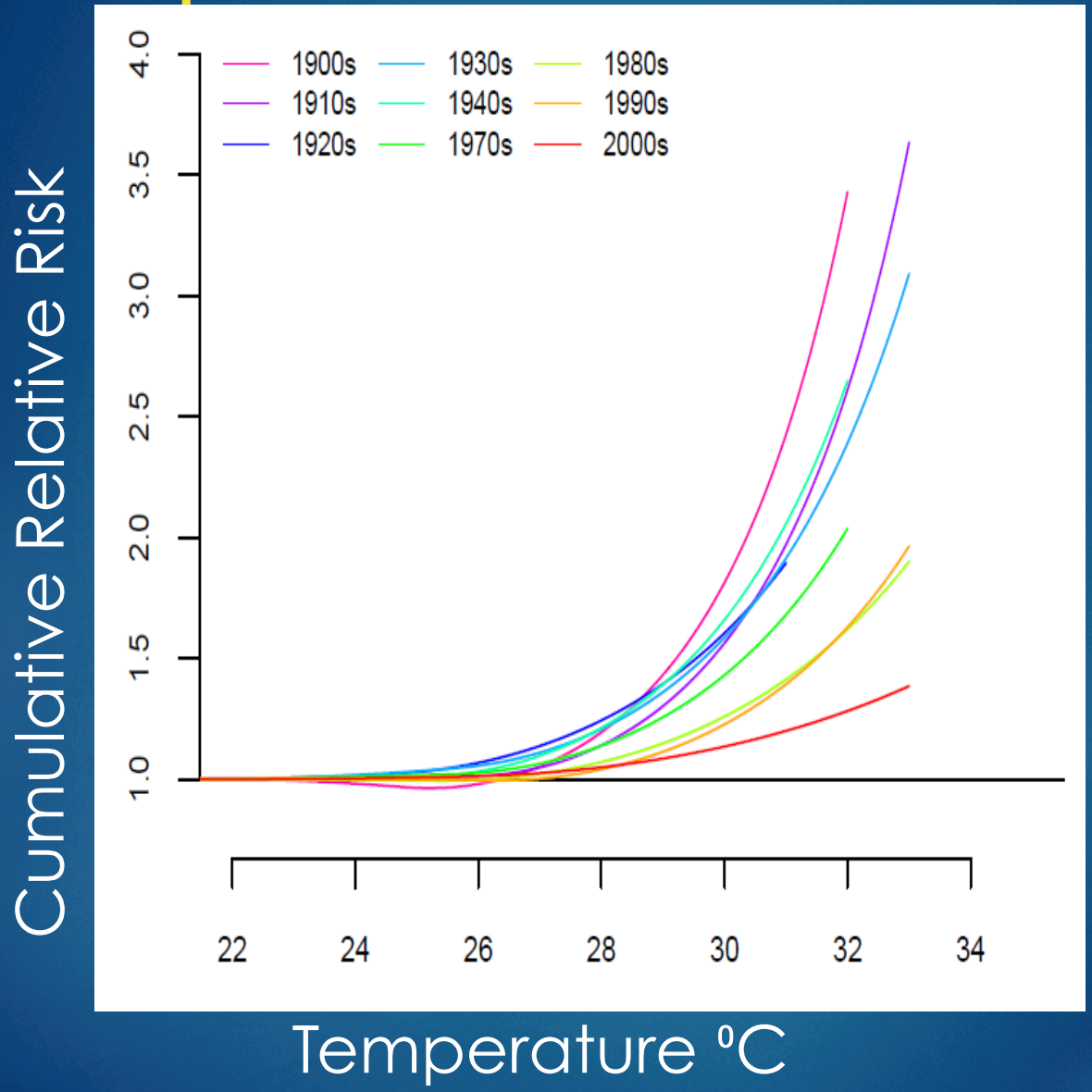
- The statistics of many types of extreme events have already shifted in recent decades
- As long as greenhouse gas concentrations rise, we expect to see an acceleration of many of these changes in extreme event statistics
- The further we push the climate system, the greater the potential for surprises
- Innovations in greenhouse gas mitigation, and adaptation, could also lead to surprises

Solutions can be a tipping point as well



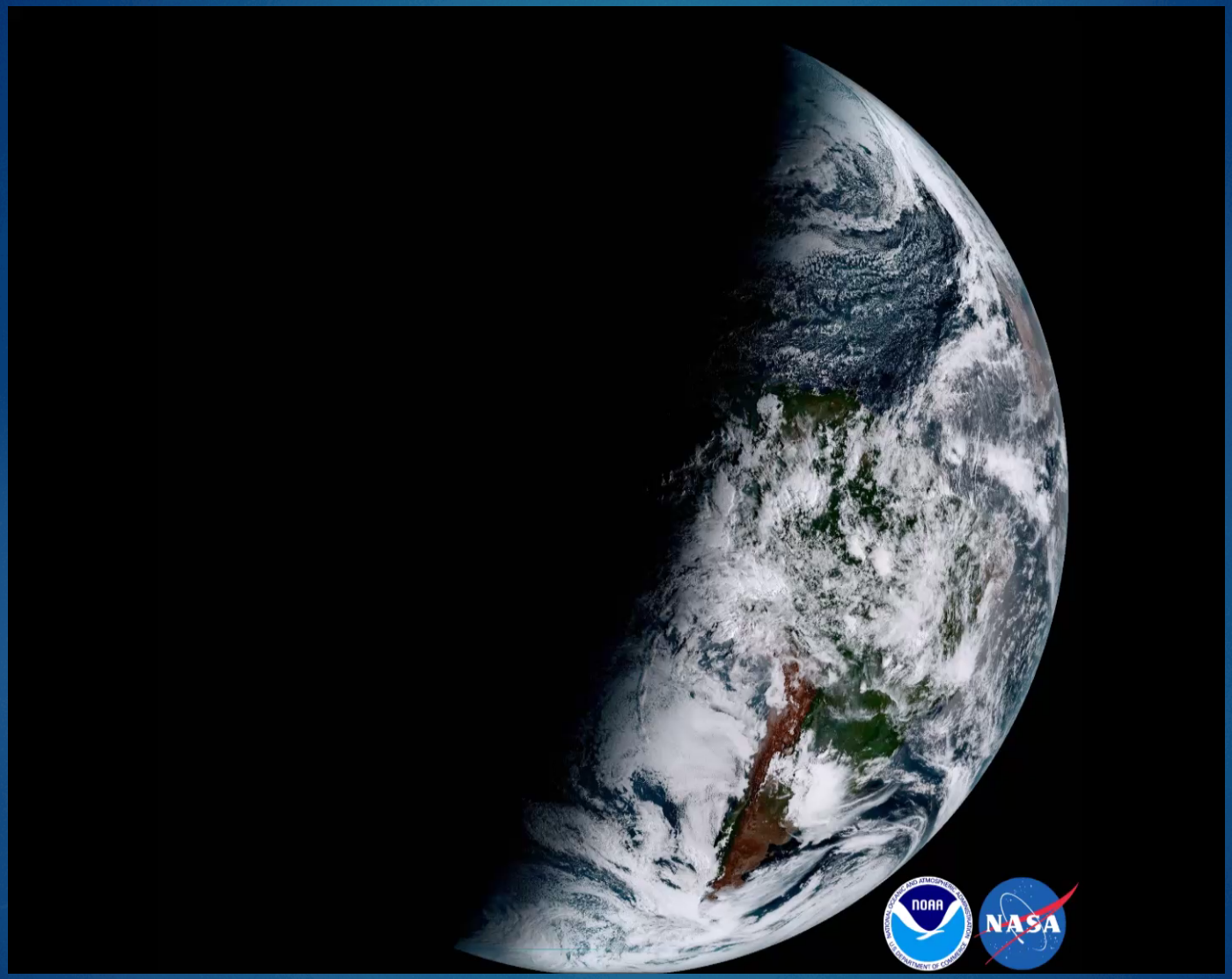
M. Gladwell

Non-linear impact and adaptation relationships: heat and human health



Petkova et al., 2014

Planned Berm and Park, Lower East Side, Manhattan, NY


NOAA
NASA