

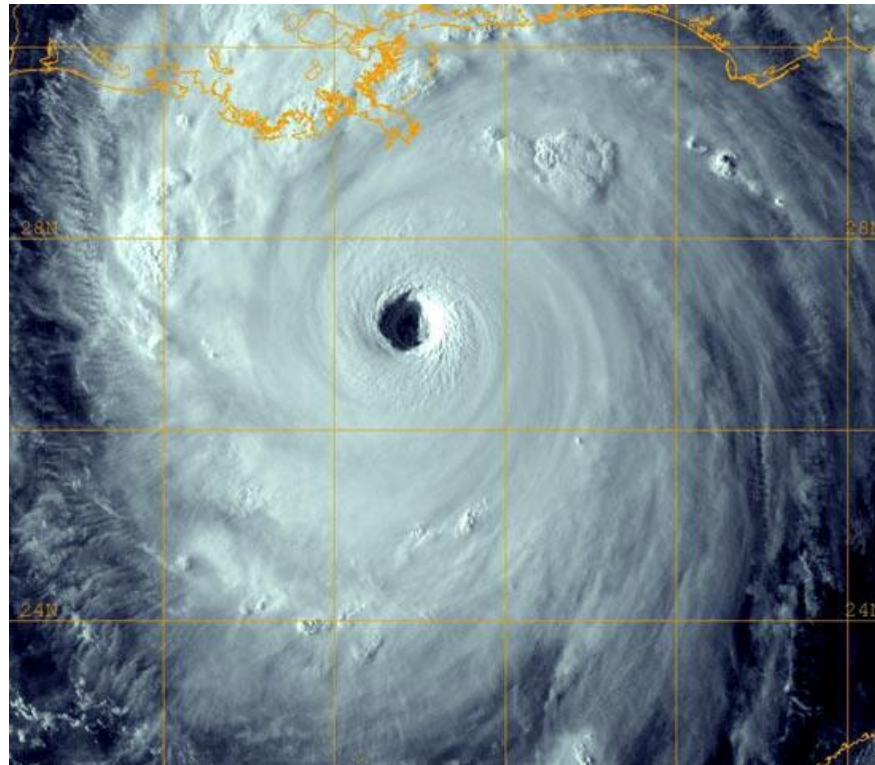
***Climate Change and Extreme Weather:
The latest science from the NCA, IPCC
(and my own interpretations)***

Philip B Duffy

US Global Change Research Program

Scope

- Focus primarily but not exclusively on the U.S.
- Sources: 3rd NCA recent IPCC reports, and some newer stuff.



Extreme weather and climate change: science summary

Event type	Trend Observed?	What's expected in the future?
Extreme heat	Very likely	Increases virtually certain
Extreme precipitation	Likely	More in many areas, including some that will be drier overall
River flood	Regional trends of mixed sign	Tendency for increases in some regions
Coastal Flood	Likely	Very likely to increase
Drought	In some locations	Increased frequency/severity probable in many regions
Severe hurricanes	Virtually certain in N. Atlantic. Insufficient data elsewhere	Likely increase in # of severe storms and in max. wind speed and precip rates (in most basins)
Tornadoes	Unknown	Unknown

“Attribution:” Determination of the cause(s) of observed climate trends

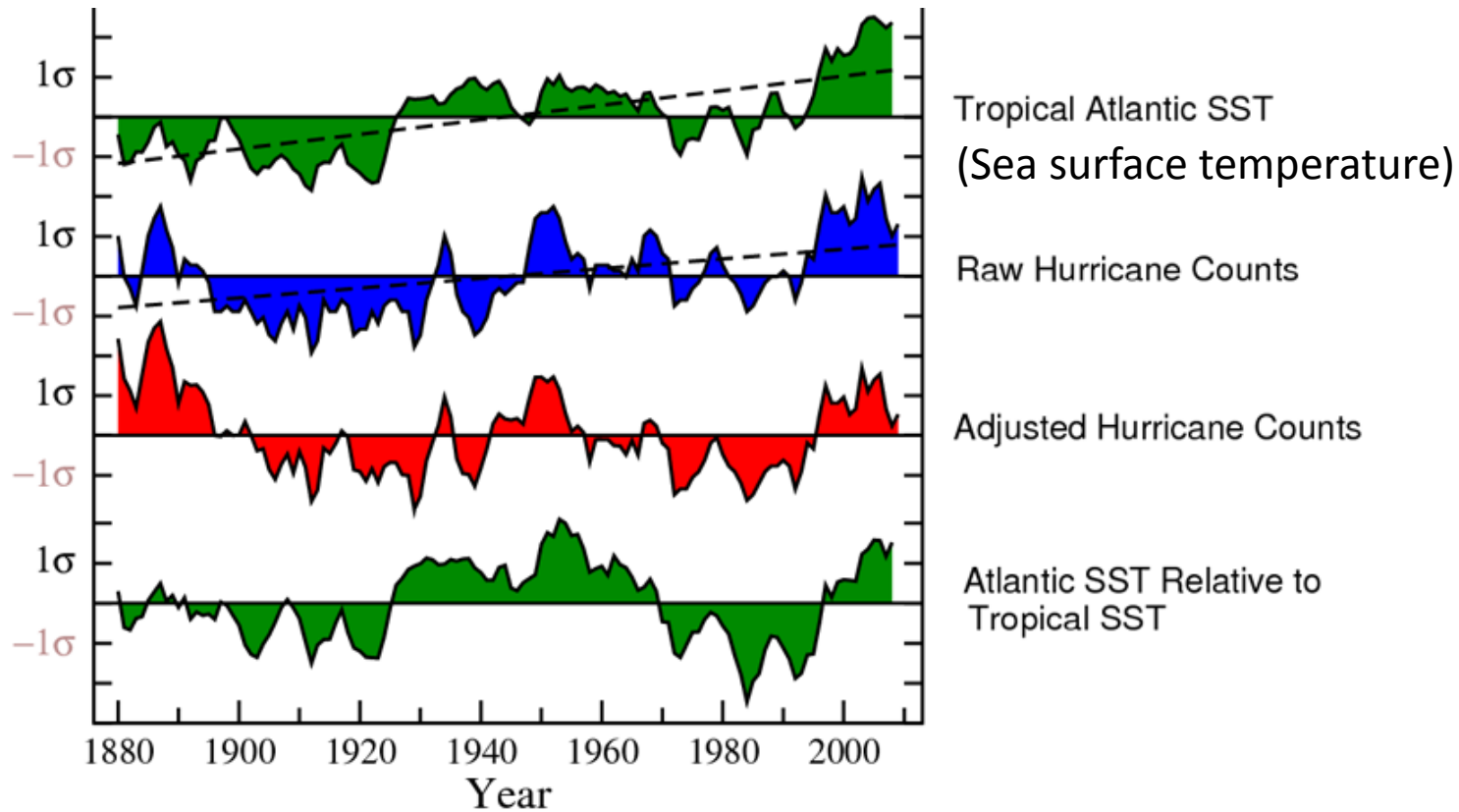
- Typically, this means quantifying the human contribution.
- Consistency between observed and expected changes is not sufficient.
- Natural causes must be ruled out.
- Inability to attribute does not mean no connection exists, only that one cannot now be proven to exist.
(“absence of evidence” vs. “evidence of absence”)

Tornadoes: “We don’t know.”

- Trends not detectable because of inhomogeneities in the data record.
- Climate models too coarse to show tornadoes.
- Theory suggests either increases or decreases possible as a result of climate change.

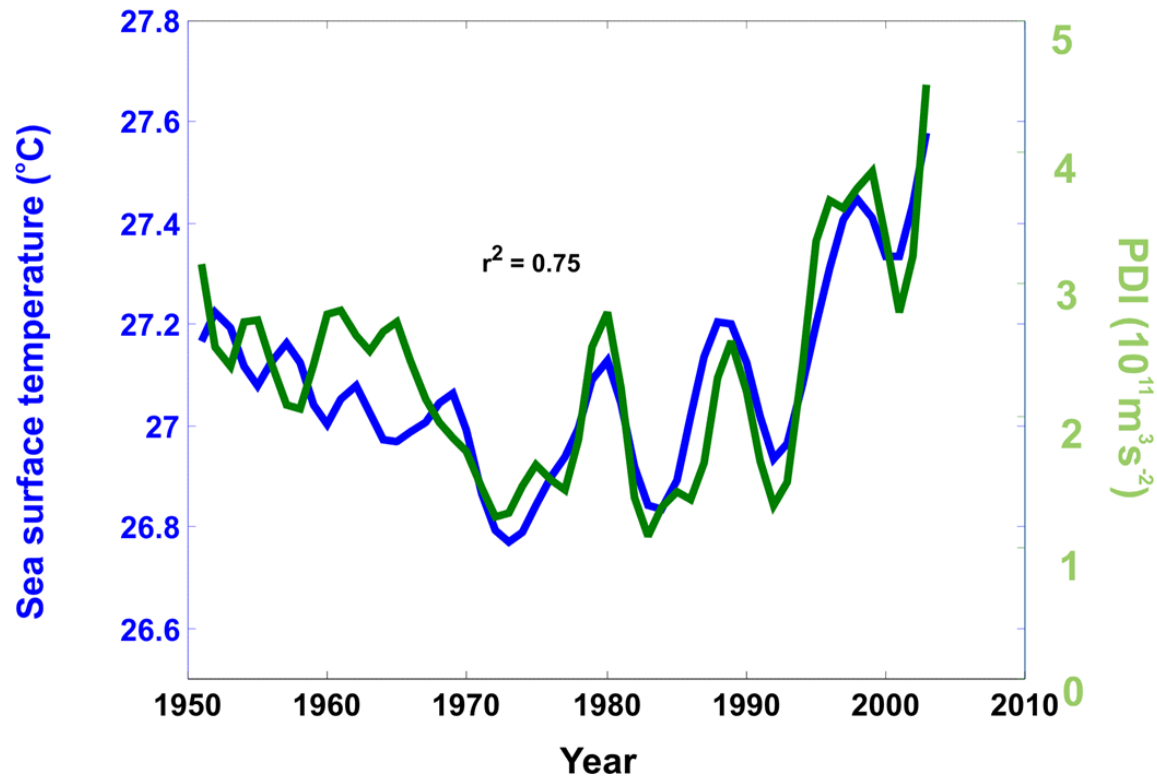


North Atlantic hurricanes: Observations



North Atlantic Hurricanes: Attribution

Hurricane activity is related to sea-surface temperatures (SSTs), but it's not that simple.



Power dissipation index (PDI) = "the sum of the maximum one-minute sustained wind speed cubed, at six-hourly intervals... when the cyclone is at least tropical storm strength"

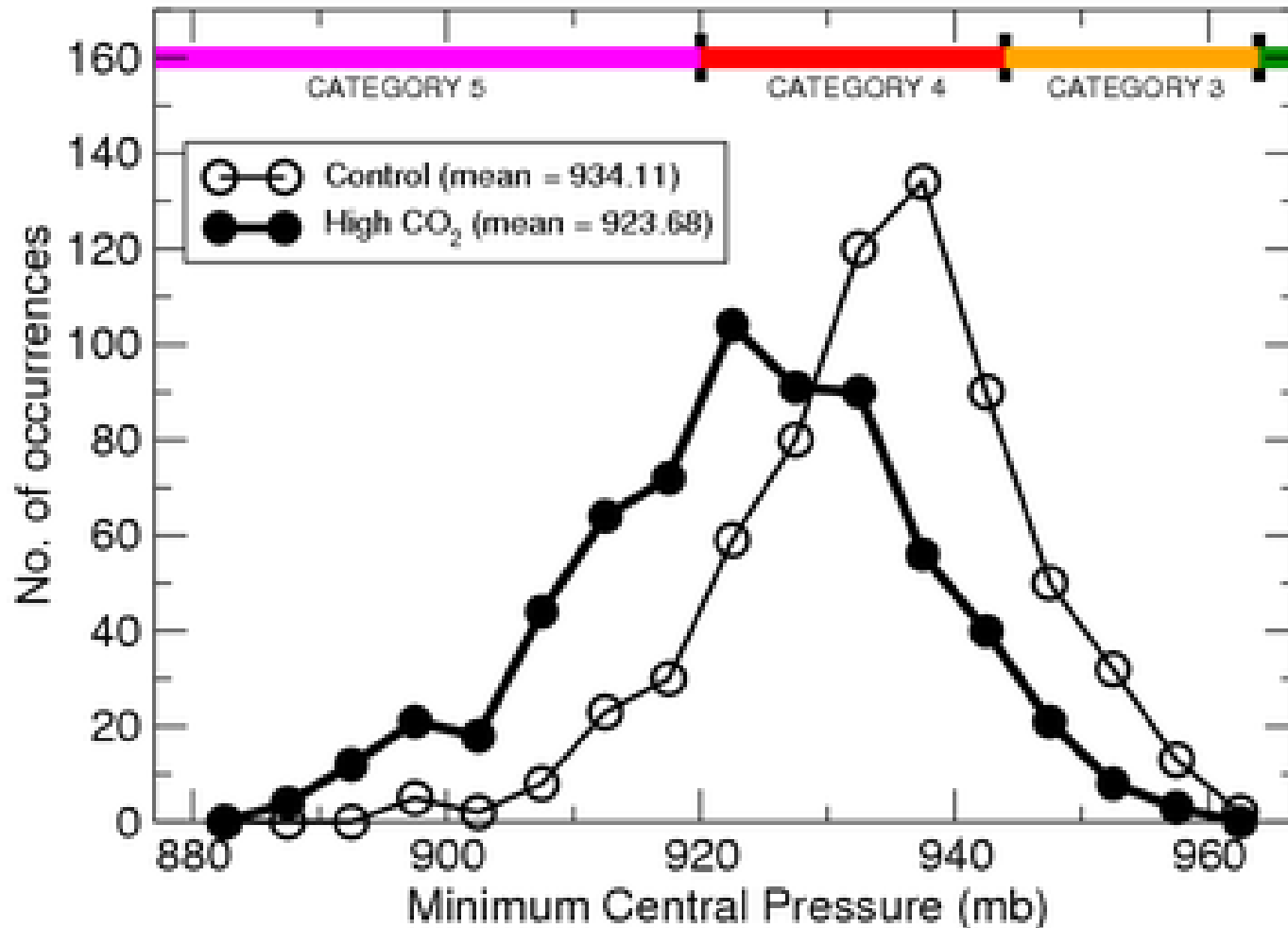
North Atlantic Hurricanes: Detection and Attribution

- Increase in # of hurricanes since 1970 is *virtually certain* (IPCC), but not unique in the record. [“Detection”]
- # of hurricanes and their destructive power are clearly related to sea-surface temperatures.
- It is premature to attribute the recent observed increase to human activities. [No “attribution”]
 - Inability to attribute does not imply no connection exists (“absence of evidence” vs. “evidence of absence”)

Hurricanes: Future trends

Idealized hurricane simulations

Aggregate results: 9 GCMs, 3 basins, 4 parameterizations, 6-member ensembles



← More intense storms

Weaker storms →

North Atlantic Hurricanes: Conclusions

- Observations, models, and basic theory all point to more intense storms in a warmer world.
- IPCC considers this “more likely than not” (>50% odds)
- Sea level rise worsens inundation.
- More exposure tends to increase losses.

Drought



Drought: more than low precipitation.

Drought is defined relative to local and seasonal normals:

- “**Meteorological** drought:” below-average **precip.**
- “**Agricultural** drought:” below-average **soil moisture.**
- “**Hydrological** drought:” below-average **river flow.**

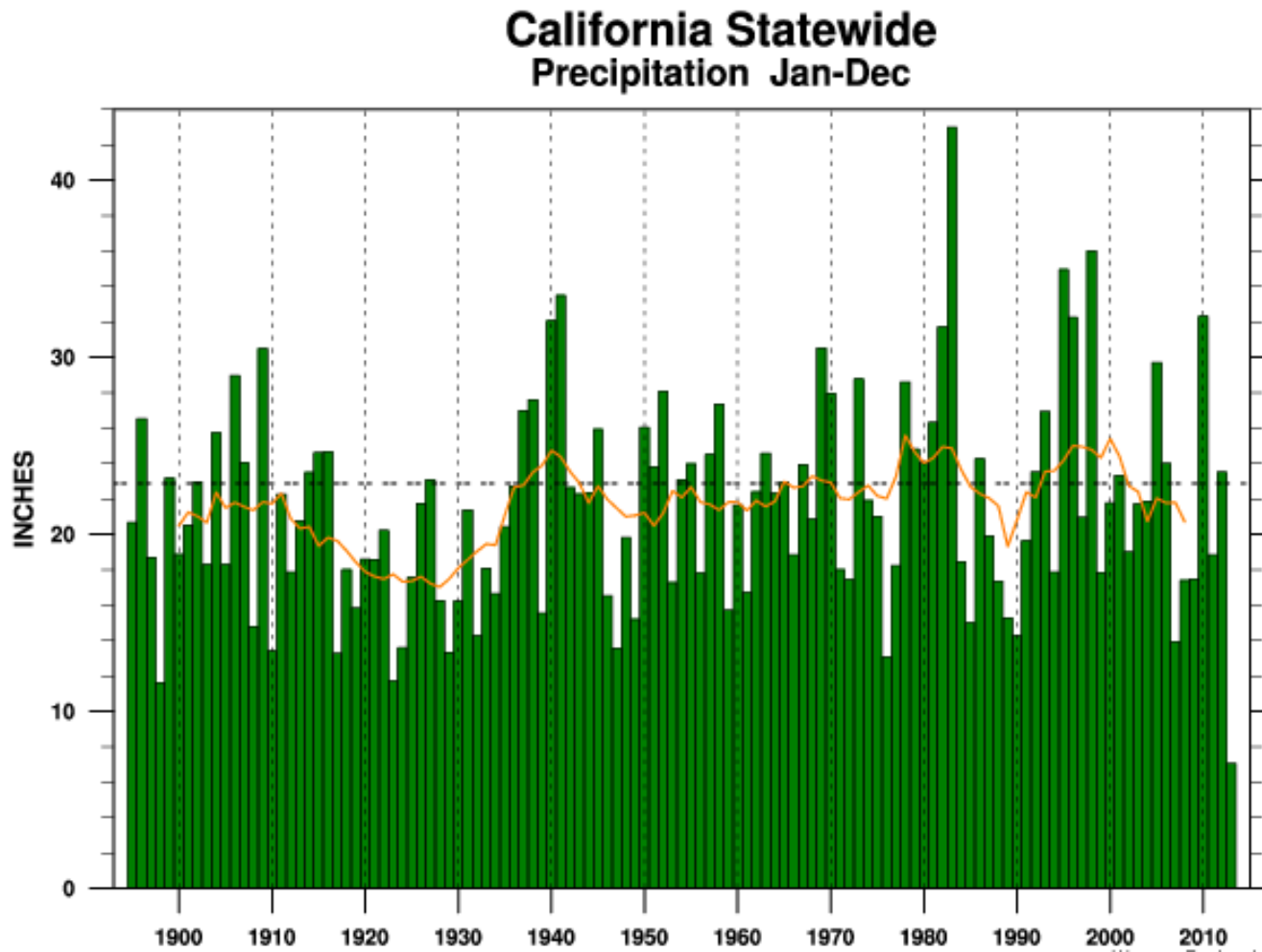
Water scarcity can result from any of these.

Warming worsens agricultural and hydrological drought.

Warming worsens water scarcity, absent changes in precipitation.

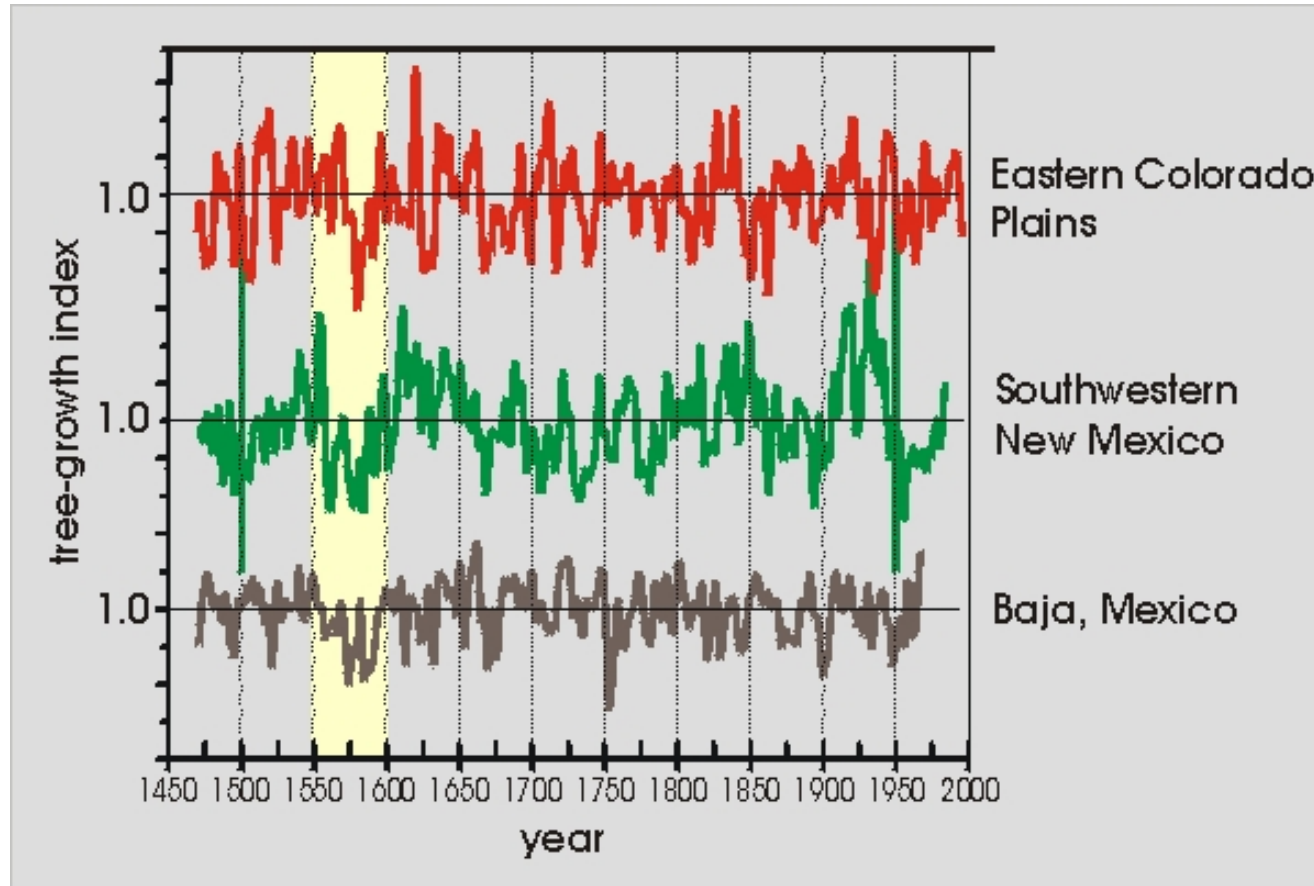
Drought: Observations

Local/regional trends in precipitation usually obscured by “noise” of natural variability.



Drought: Observations

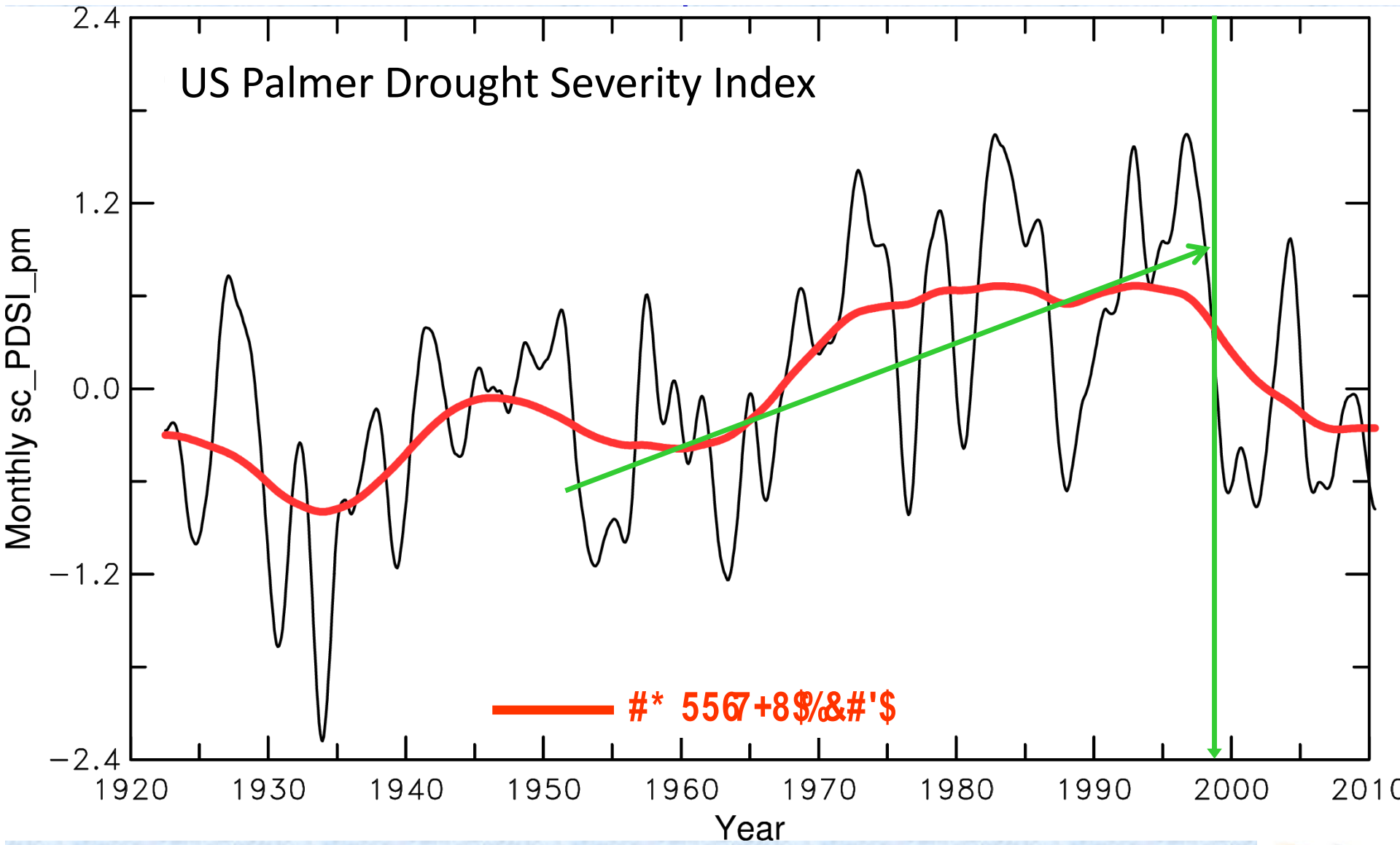
Tree ring data indicate prolonged, severe droughts in the western US.



Were these caused by some external factor, or do they represent a better sampling of today's climate???

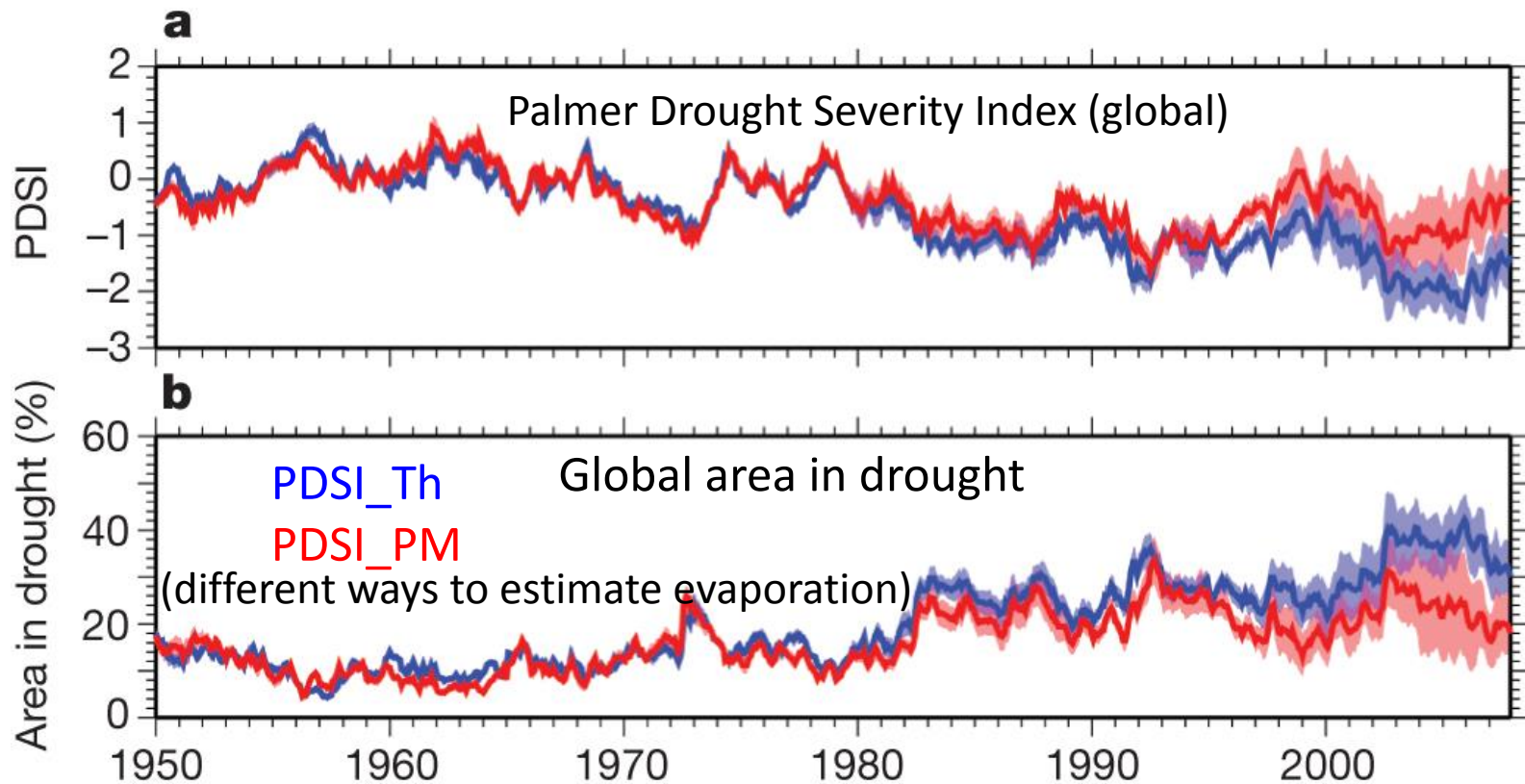
Drought: Observations

The “instrumental record” shows no clear trend



Drought: Observations

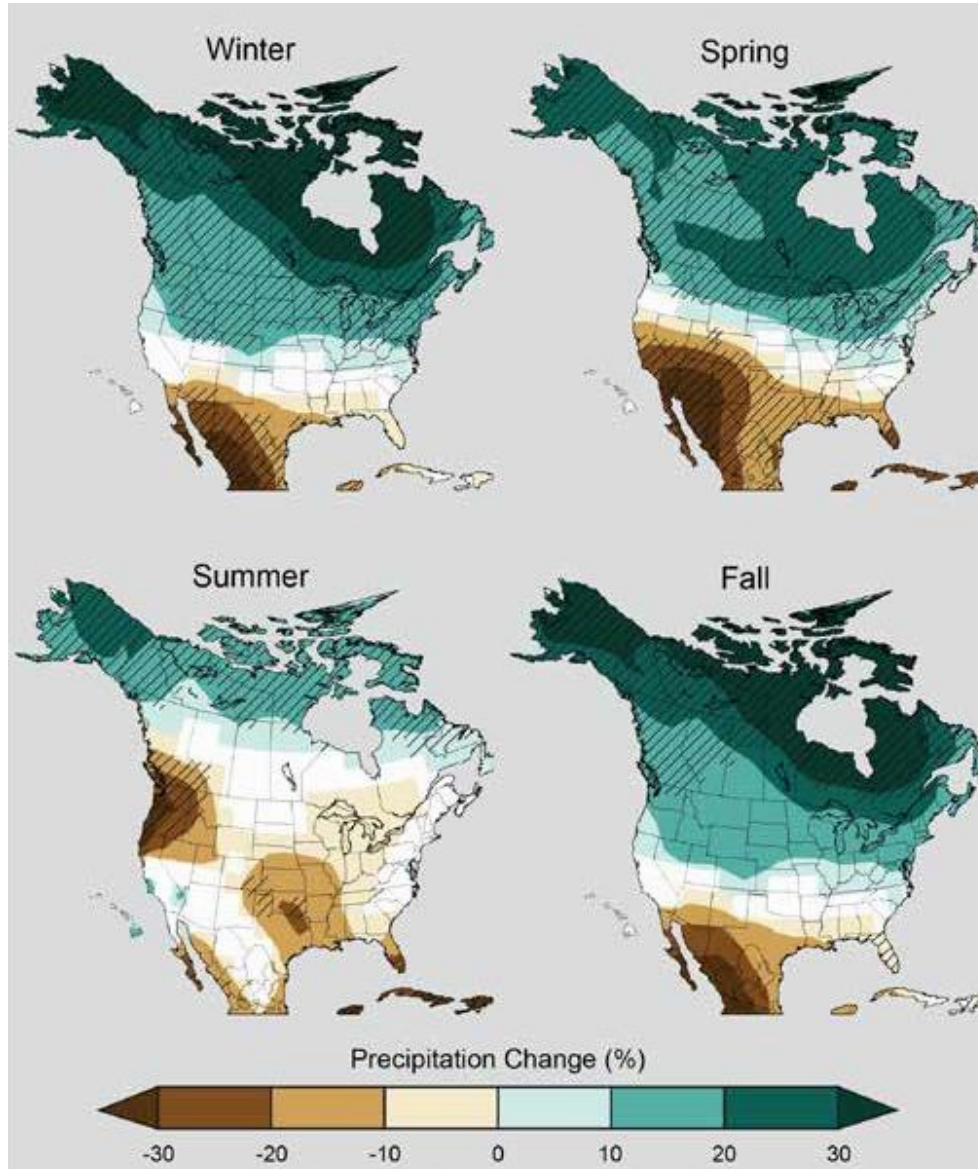
Trends in soil-moisture-based drought indices have to be estimated from models because observations lacking.



Drought: Detection & Attribution

- NCA cites “regional trends in droughts.”
- NCA cites human influence now on drought *severity* but not drought *frequency*.
 - Because of higher temperatures
- IPCC: “low confidence” in attribution of changes in drought intensity or duration (globally).

Projected large-scale patterns of precipitation change are robust

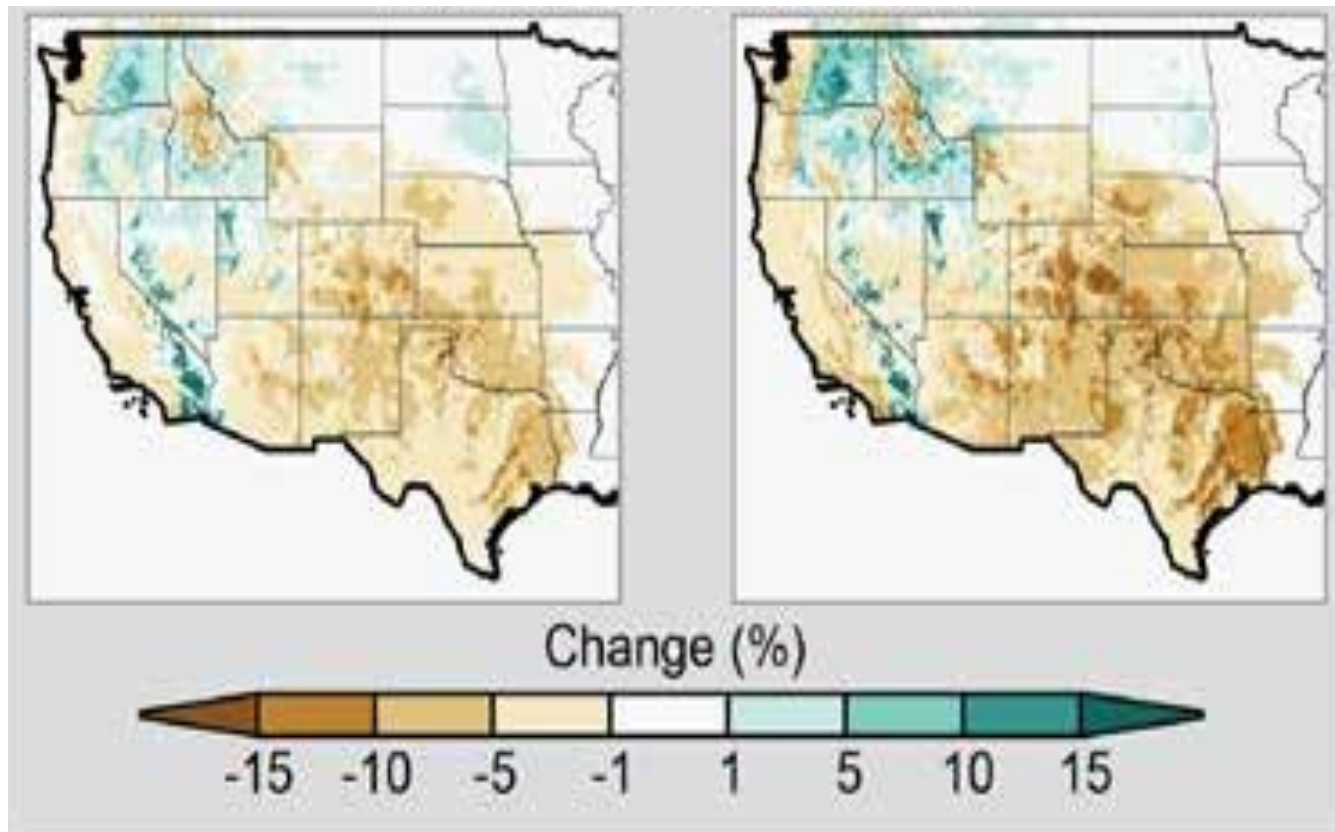


2071-2100 vs.
1970-2000
(assuming rapid
buildup of
greenhouse gases)

Source: NCA

Lower soil moisture is projected even in some regions where precip. expected to increase

Projected change in soil moisture, 2070-2099 vs 1971-2000



Source: NCA

Drought: Summary

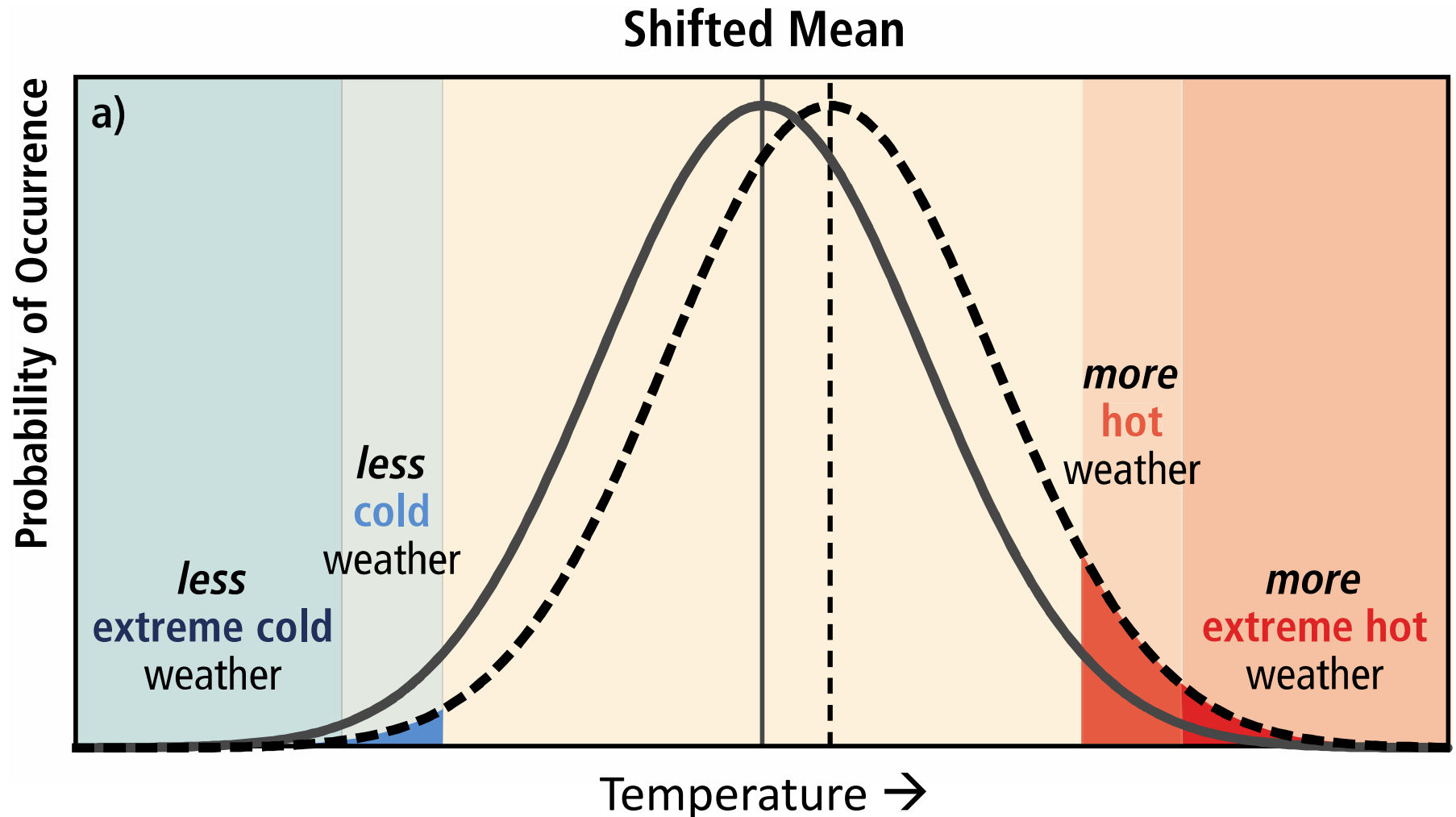
- Trends in precip. difficult to detect amidst “noise” of natural variability
- Large-scale patterns of projected precipitation change are robust.
- Trend towards reduced soil moisture is robust.
- Warming leads to
 - greater risk of water scarcity, through
 - loss of snowpack
 - soil drying
 - increased demand for water

Water suppliers recognize climate change as a threat

“Climate change is having a profound impact on California water resources, as evidenced by changes in snowpack, sea level, and river flows” (California Dept of Water Resources <http://www.water.ca.gov/climatechange/>)

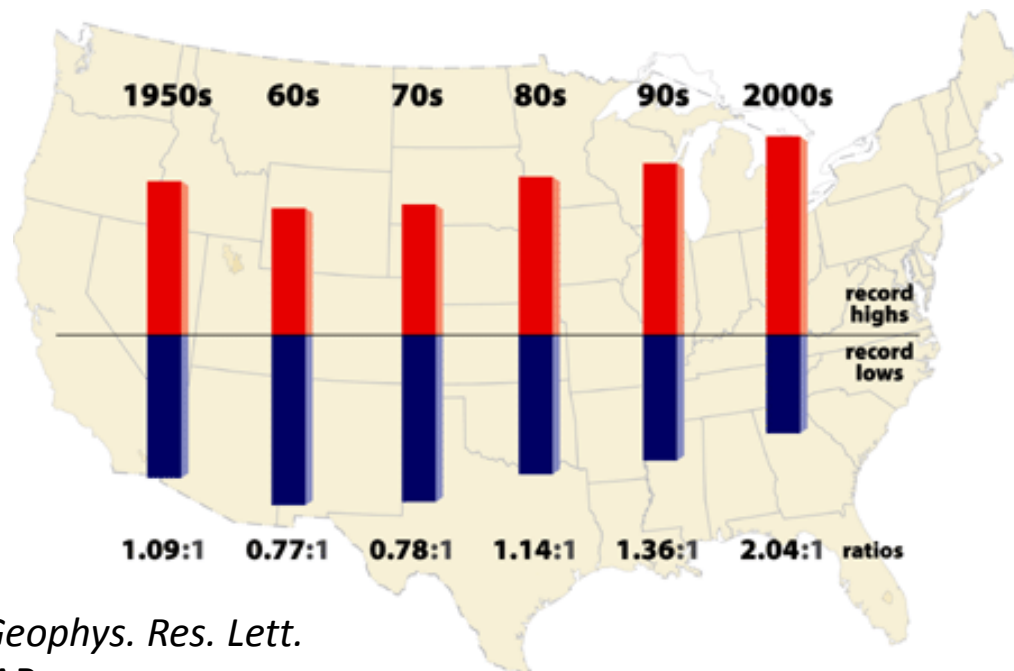
“Temperature increases alone, without any change in precipitation patterns, could dramatically decrease water supply and increase water use.... A 5-degree Fahrenheit temperature increase could decrease supply 22 percent and increase water use by 20 percent.” Denver Water <http://www.denverwater.org/SupplyPlanning/DroughtInformation/ClimateChange/>)

Extreme heat: Warming greatly increases likelihood of exceedances



Extreme heat: Observations

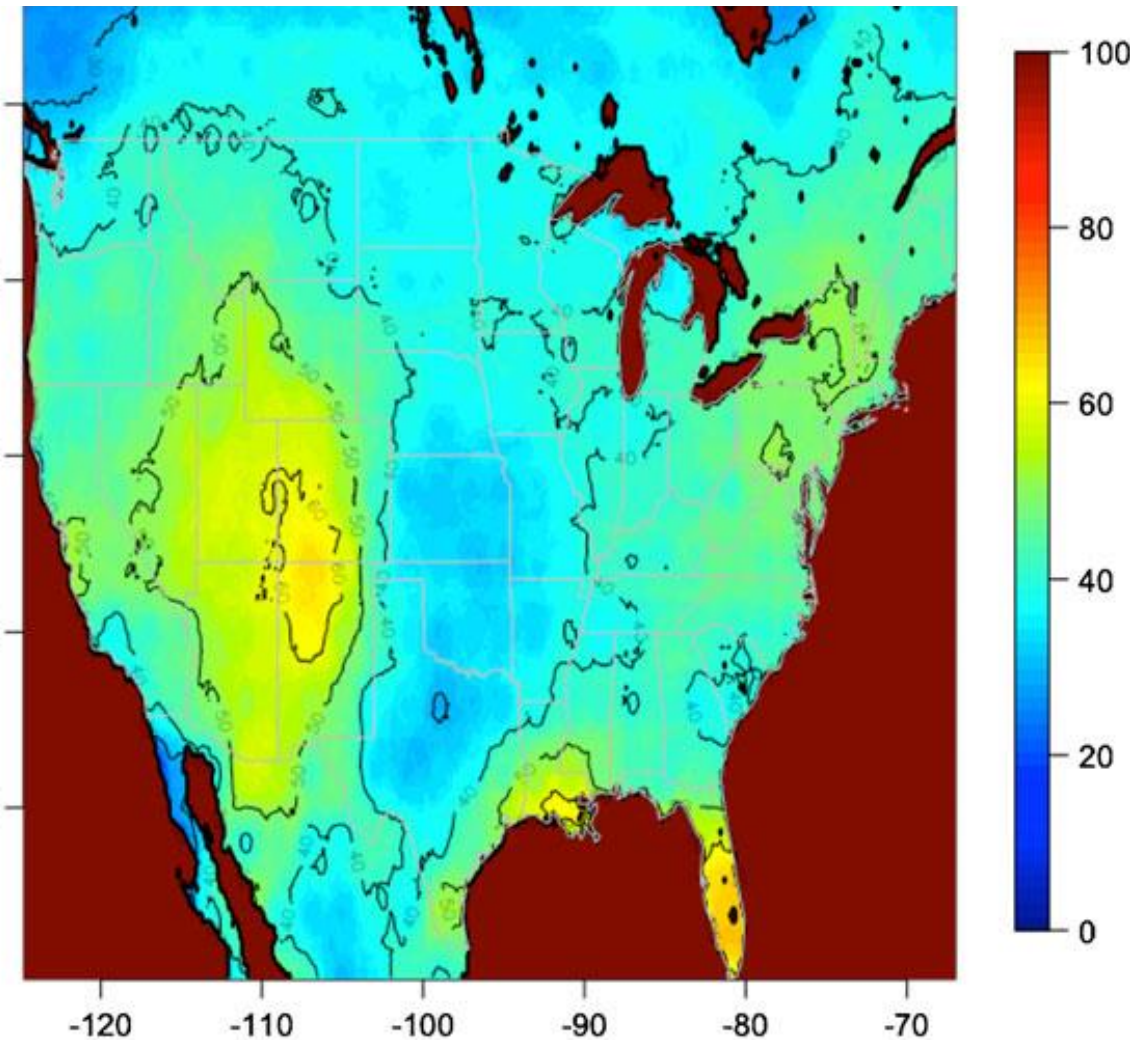
- IPCC and NCA attribute observed increases in extreme heat to human GHG emissions.
 - NCA: “Most of the increases of heat wave severity over the U.S. are likely due to human activity.”



Data: Meehl et al, 2009. *Geophys. Res. Lett.*

Graphic: Mike Shibao, NCAR

Already, previously rare summer temperatures are happening more often

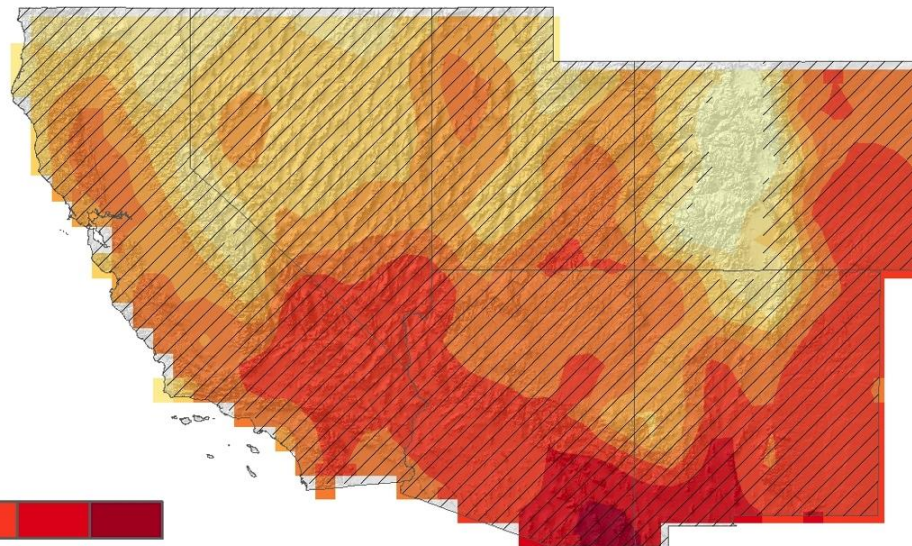


Summer temperatures that used to occur 5% of the time now occur how often?

Extreme heat: late 21st century

- “Warmer and/or more frequent hot days and nights” *virtually certain* (IPCC).
- “More frequent and or longer warm spells and heat waves” *very likely* (IPCC).

NARCCAP, SRES A2, ANNUAL NUMBER OF DAYS TMAX > 95F
Multi-Model Mean Simulated Difference (2041-2070 minus 1980-2000)



Number of Days per Year



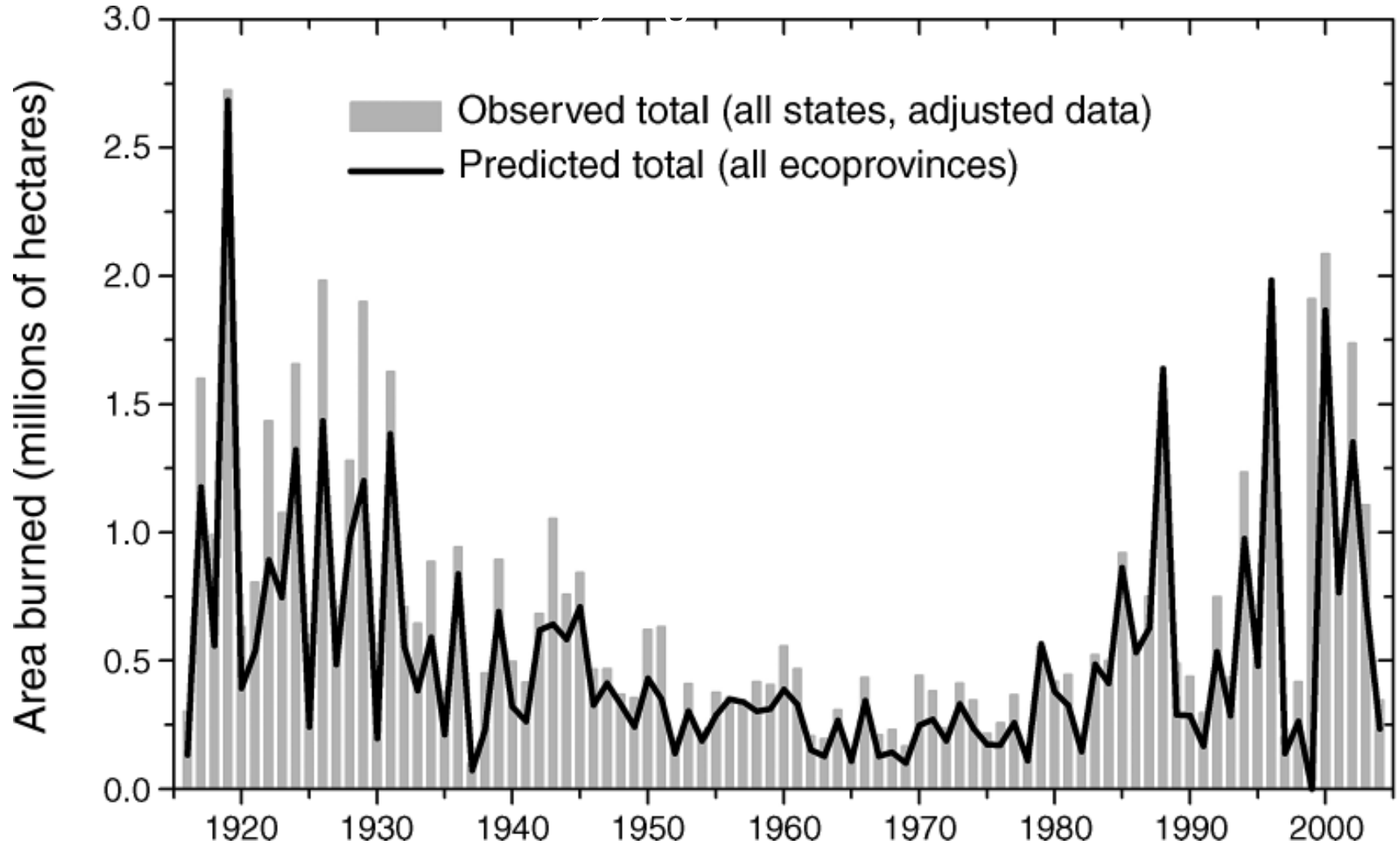
Source: NCA



Wildfire: An impact of climate change that's happening now



Variations in wildfire activity are strongly controlled by climate



Source: Jeremy Littell, University of Washington/USGS

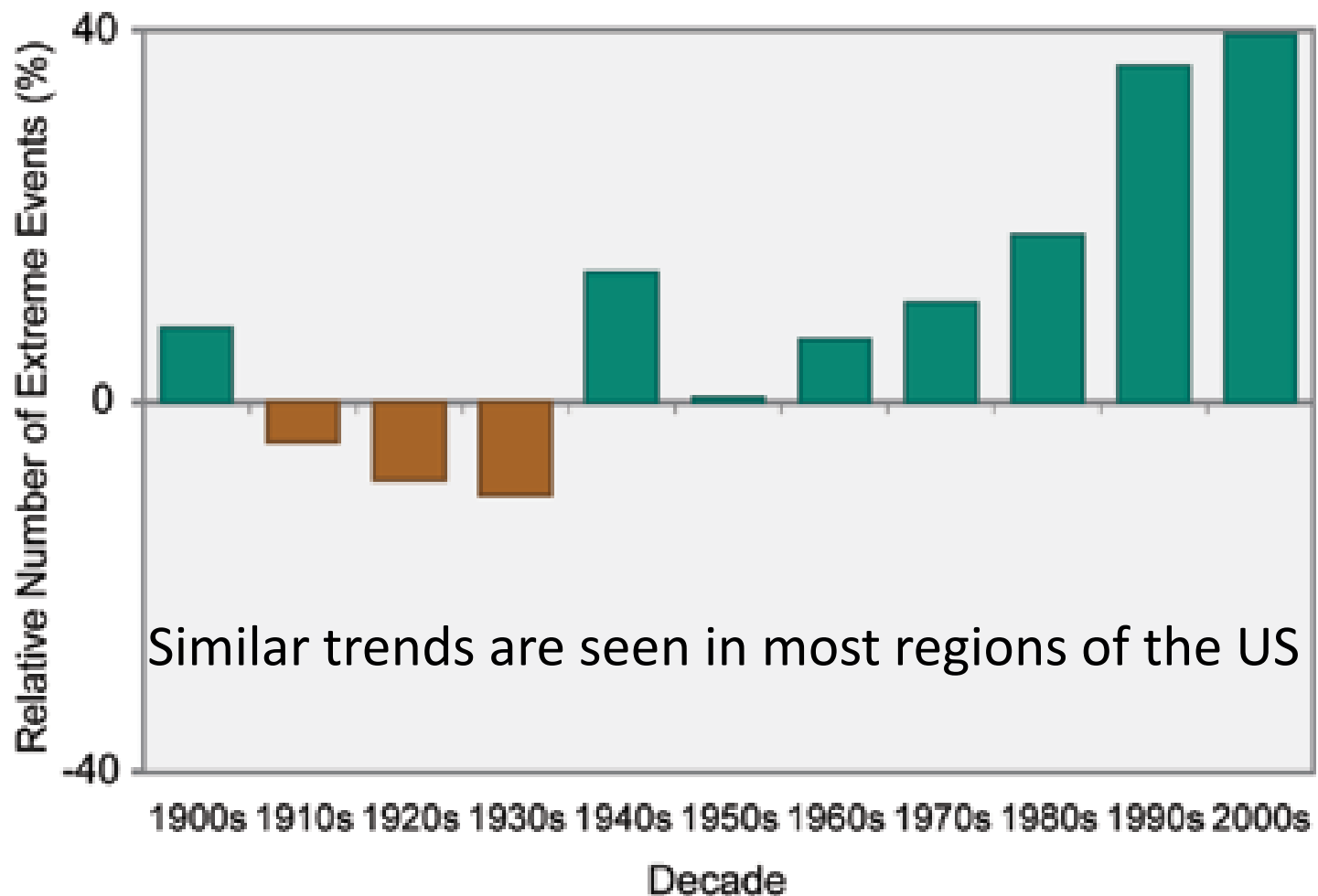
Climate and wildfire: Summary

- Specific relationships between wildfire activity and climate depend on ecosystem type.
- Warming results in drier fuel and a longer fire season, increasing the likelihood of large fires.
- Effects of changes in forest management practices over-hyped.
- NCA attributes more fire weather, but not more fire, to climate change.
- Expect more fire.



Extreme precipitation: Observations

Observed U.S. Trends in Heavy Precipitation

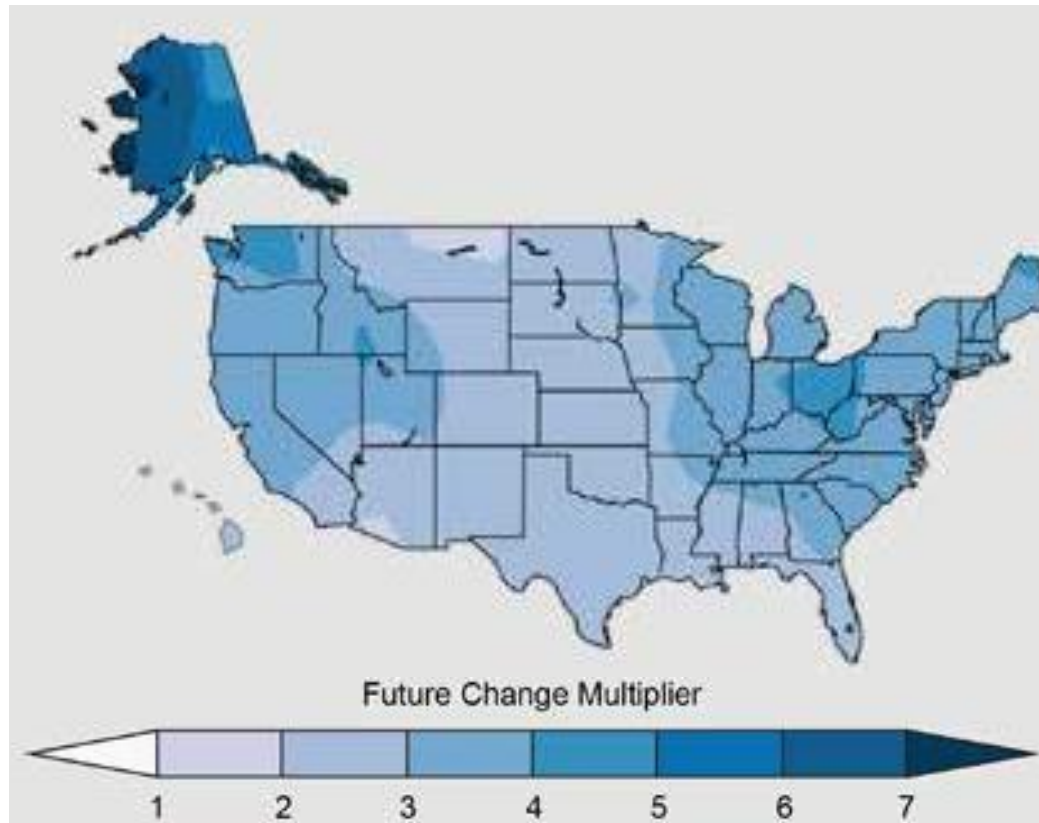


Extreme precipitation: Attribution

- IPCC assigns *medium confidence* globally. (Higher confidence in increased atmospheric moisture content.)
- NCA does not discuss attribution, but cites theoretical support.
- Papers published too late for these assessments do claim attribution (N. hemisphere land areas).

Extreme precipitation: Projections

Formerly once-in-20-years daily precip amount projected to occur more often throughout the US.



Source: NCA

Extreme precipitation: Summary

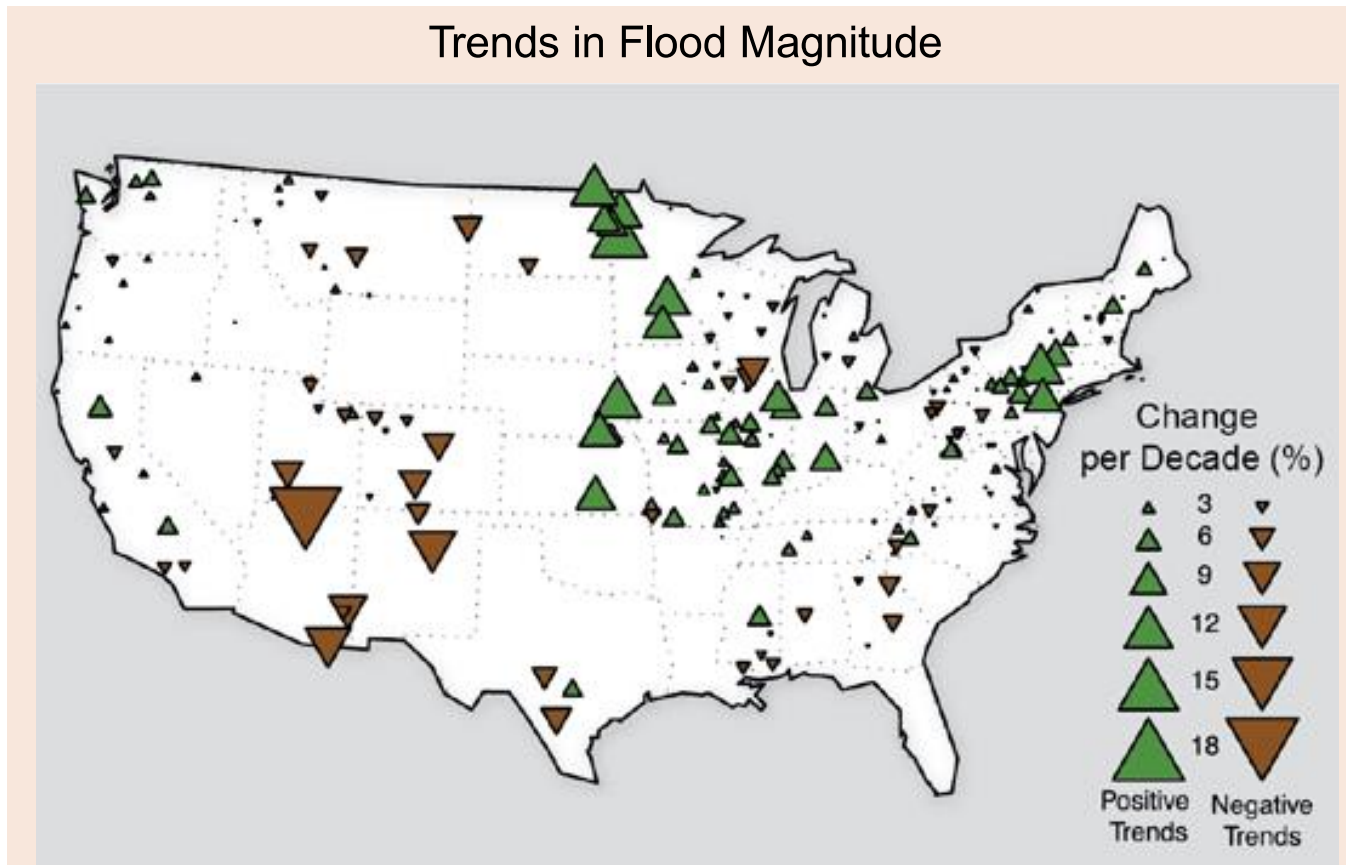
- Increases are robustly predicted by theory and models, and are seen in observations.
- Increases in extreme precipitation expected even in some locations where overall precipitation will decrease.



River floods (NCA)

Regional trends in flood magnitude exist.

Observed regional trends in flood are qualitatively consistent with expectations from climate change.



River floods: Attribution

IPCC (SREX):

- “There is limited to medium evidence available to assess climate-driven observed changes in the magnitude and frequency of floods at regional scales...”
- “Furthermore, there is ... overall low confidence at the global scale regarding even the sign of these changes.”

Climate change and flood risk: Summary

- Very difficult to attribute changes in flood occurrence to specific causes
- Extreme precipitation will continue to increase in many locations; increase in flood risk seems likely.



River floods: If climate change has increased extreme precipitation, why are we not sure it has increased flooding as well?

It may have, but this is difficult to prove, because humans go to great lengths to prevent floods.

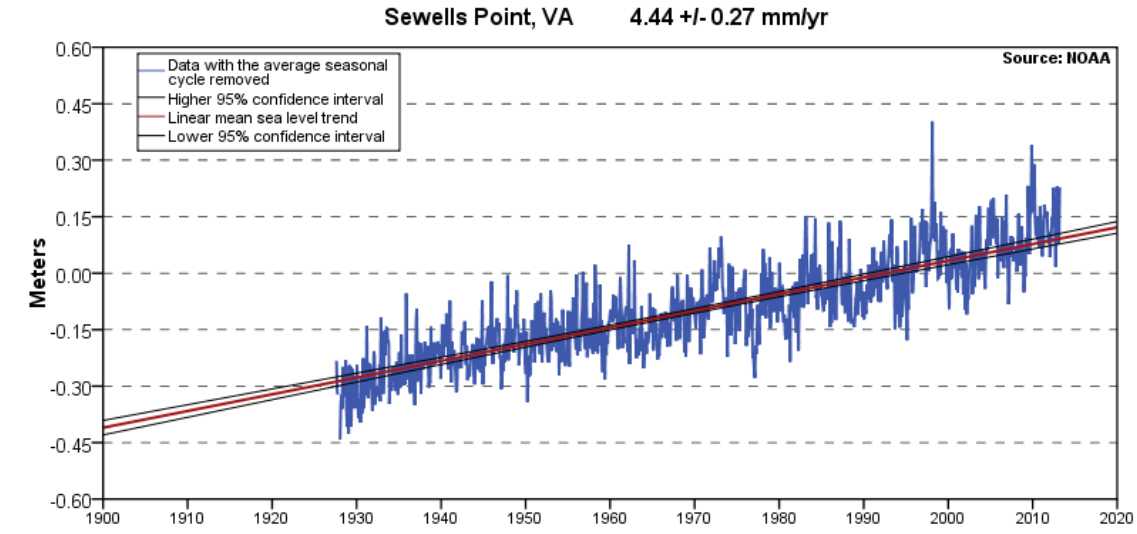


Folsom Lake

Coastal Inundation

IPCC:

- Trend detection *likely*¹.
- Trend attribution *likely*
- End-of-century increase *very likely*²
- Regional trends can vary greatly



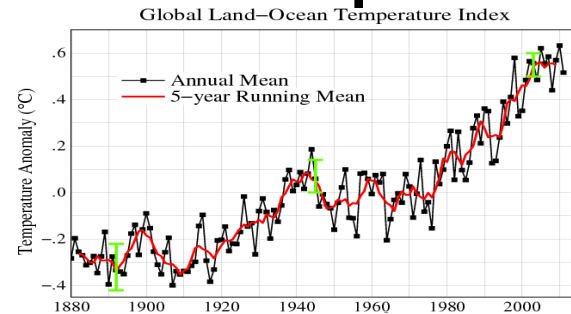
¹ > 66% probability

² > 90% probability

Extreme weather and climate change: science summary

Event type	Trend Observed?	What's expected in the future?
Extreme heat	Very likely	Increases virtually certain
Extreme precipitation	Likely	More in many areas, including some that will be drier overall
River flood	Regional trends of mixed sign	Tendency for increases in some regions
Coastal Flood	Likely	Very likely to increase
Drought	In some locations	Increased frequency/severity probable in many regions
Severe hurricanes	Virtually certain in N. Atlantic. Insufficient data elsewhere	Likely increase in # of severe storms and in max. wind speed and precip rates (in most basins)
Tornadoes	Unknown	Unknown

Attribution example: Changes in near-surface temperature



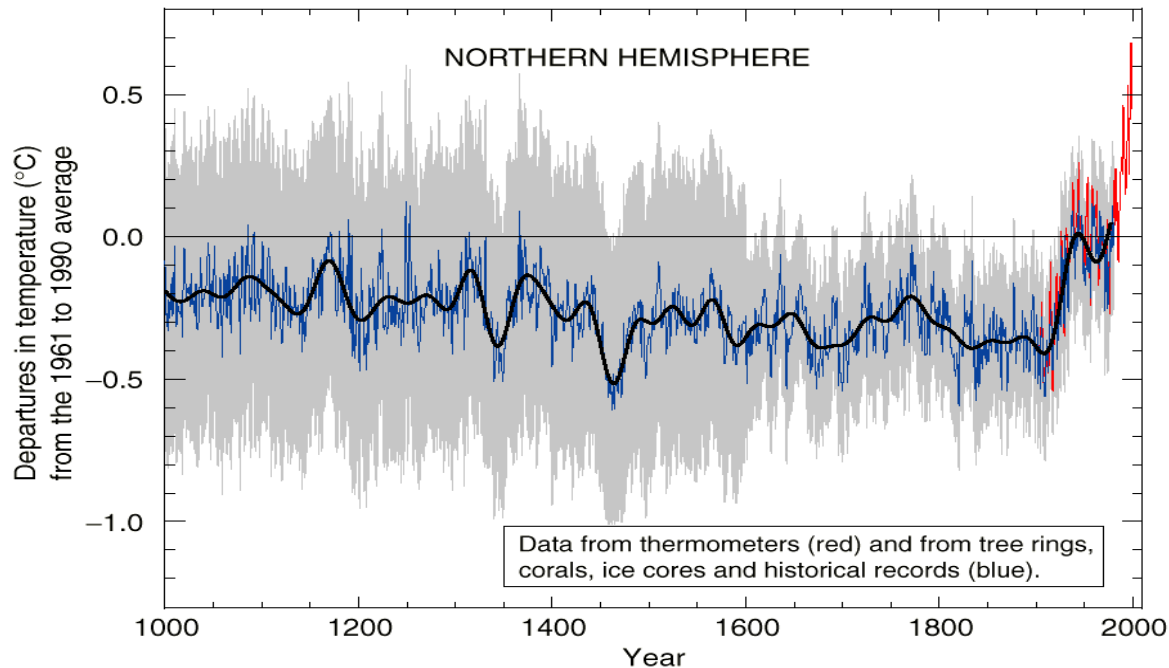
Multiple lines of evidence:

- Basic physics: greenhouse gases cause warming.
- Observations: recent warming is unique over at least the last 1,000 years.
- Climate models cannot replicate observed warming unless human greenhouse gas emissions are included.
- Natural forces alone (such as solar and volcanic activity) cannot explain the observed warming.
- The 3-d spatial pattern of observed temperature change agrees with the predicted pattern better as the years progress.

Attribution example: Changes in near-surface temperature

Attribution is based on multiple lines of evidence:

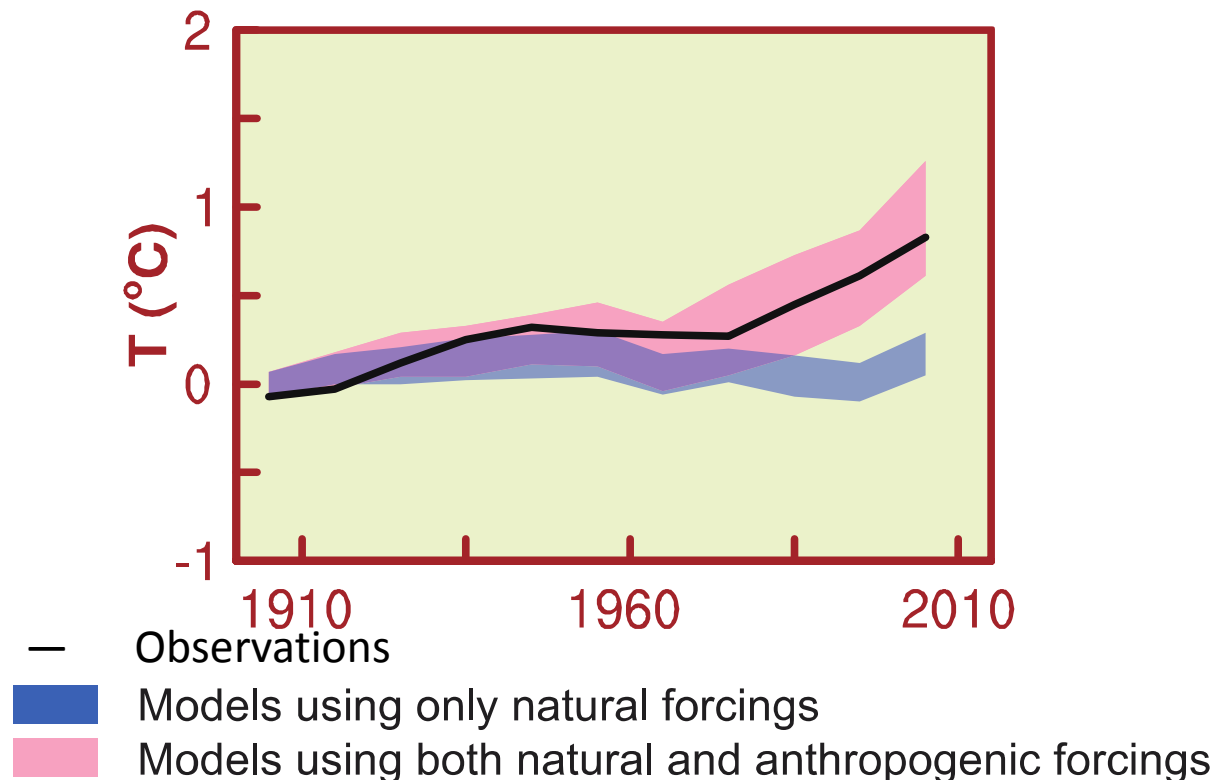
- Basic physics: greenhouse gases cause warming.
- Observations: recent changes in temperature are unique in the context of the last ~1000 years.



Attribution example: Changes in near-surface temperature

Multiple lines of evidence...

- Climate models cannot replicate observed warming unless human greenhouse gas emissions are included.



Attribution example:

Changes in near-surface temperature

Multiple lines of evidence...

- Natural forces alone (such as solar and volcanic activity) cannot explain the observed warming.
- The 3-d spatial pattern of observed temperature change agrees with the predicted pattern better as the years progress.

Hurricanes: Future trends (global)

- Total # of storms expected to remain the same or decrease.
- # of most intense storms projected to increase substantially.
- Maximum wind speeds expected to increase.
- Maximum precip rates expected to increase.