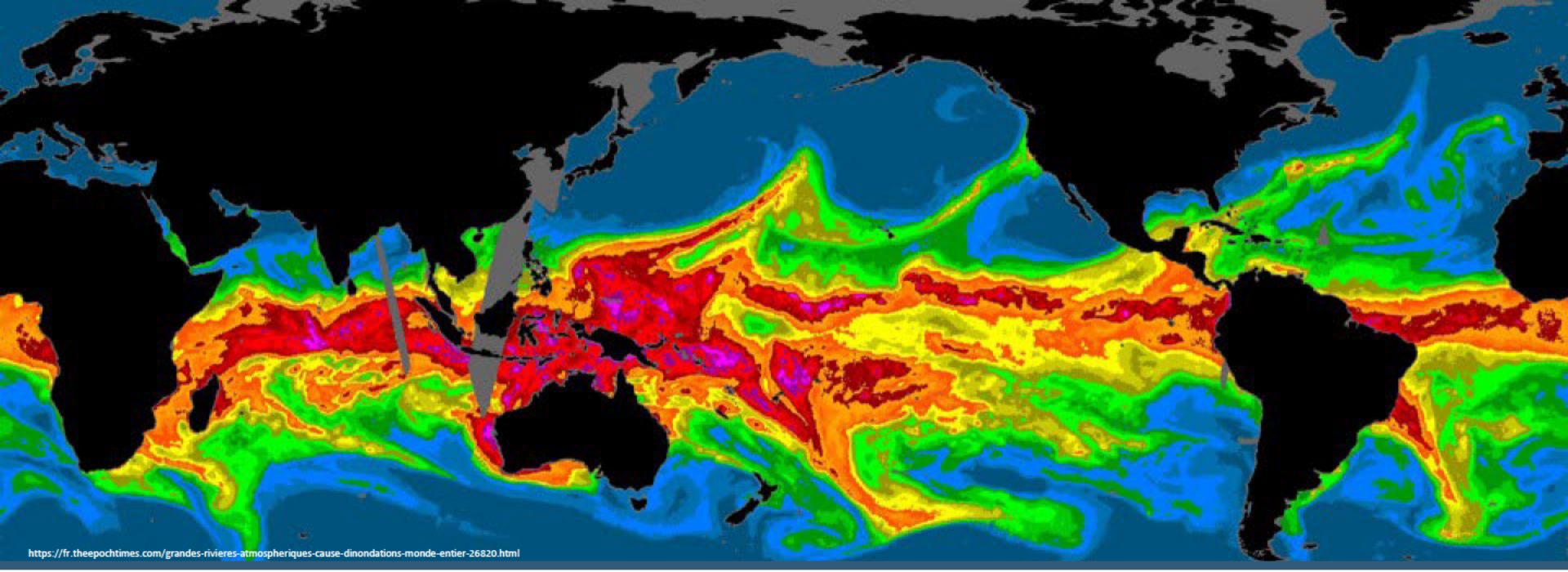

Introduction to Climate Science: Part 2

Ben Santer
Visiting Researcher, UCLA

National Judicial College
March 15, 2022

What Part 2 will cover

- Climate fingerprinting 101
- Fingerprinting and the 2021 Nobel Physics Prize
- Fingerprinting examples
- Looking at the causes of changes in extreme events
- Satellite temperature data
- Conclusions

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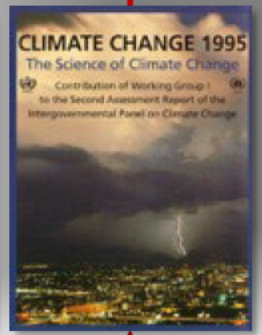
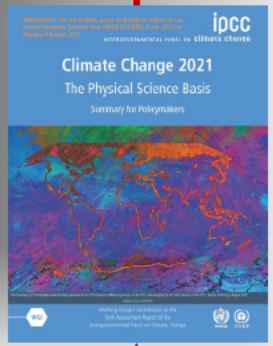
The arc of history…

The unequivocal detection of the enhanced greenhouse effect from observations is not likely for a decade or more

The balance of evidence suggests a discernible human influence on global climate

It is unequivocal that human influence has warmed the atmosphere, ocean, and land





2001

2007

2013

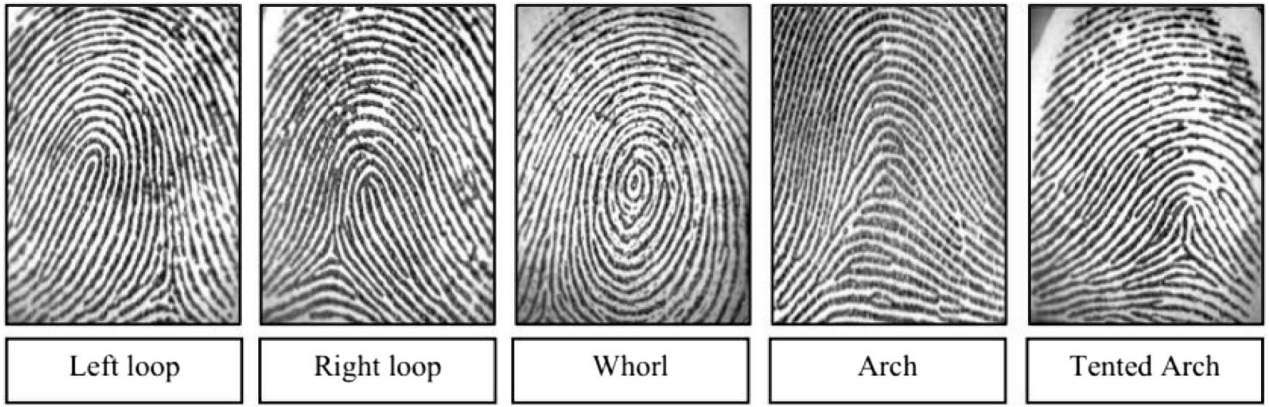
1990 1995 2000 2005 2010 2015 2020 2025

How was scientific progress made?

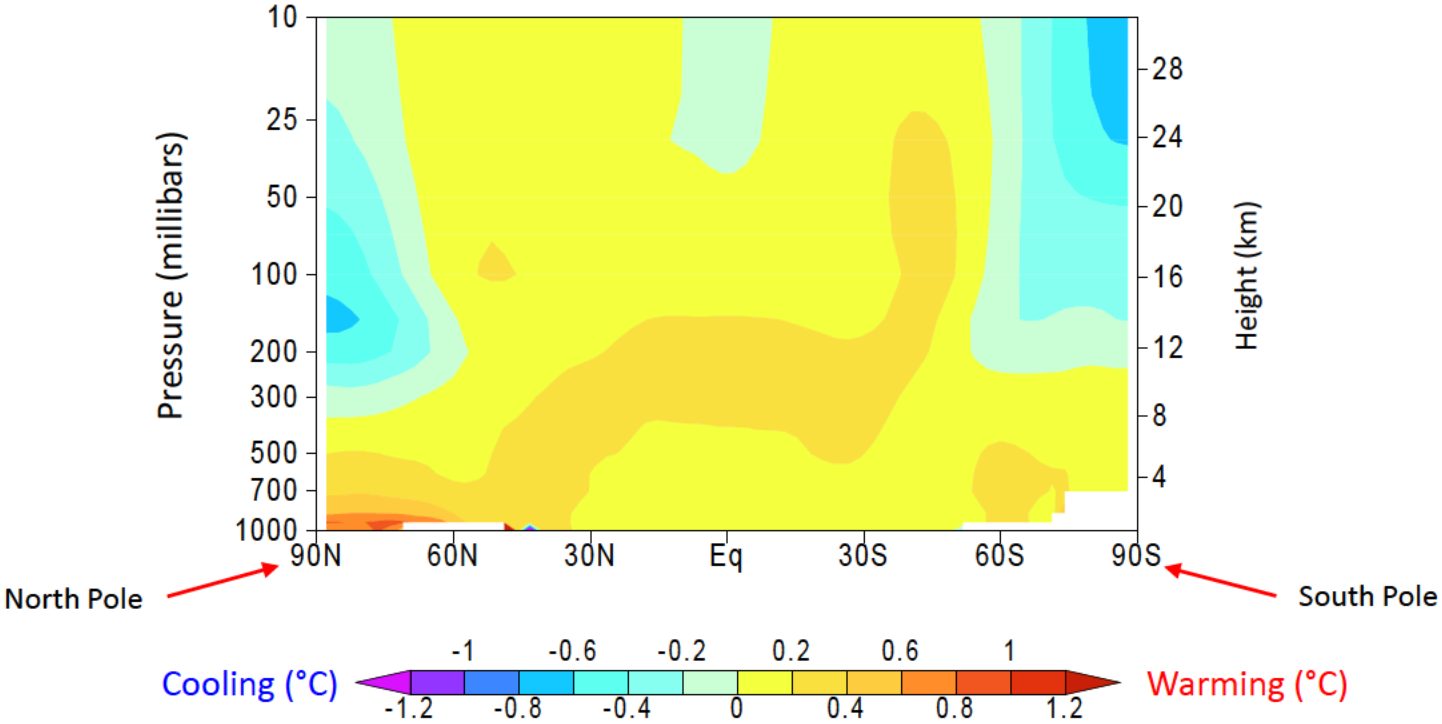
- Improved (and more) climate models
- Better understanding of factors that affect climate
- Improved (and longer) observed climate records
- Community-wide analysis of climate model results
- Infrastructure for sharing climate model output
- “Climate fingerprinting”

What is “climate fingerprinting”?

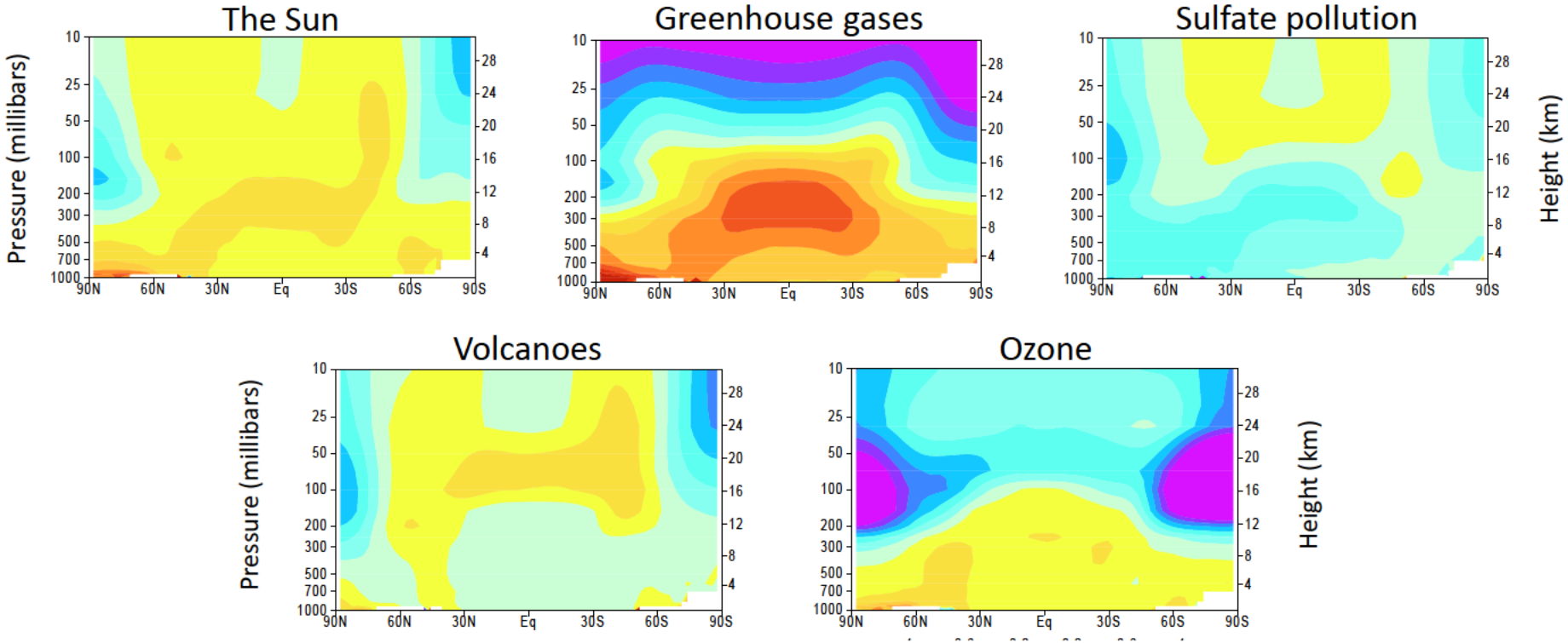
- Basic idea:
  - Different influences on climate have different signatures
  - Signatures are easier to discern in patterns (“fingerprints”)



The fingerprint of changes in the Sun's energy



Natural and human fingerprints on climate



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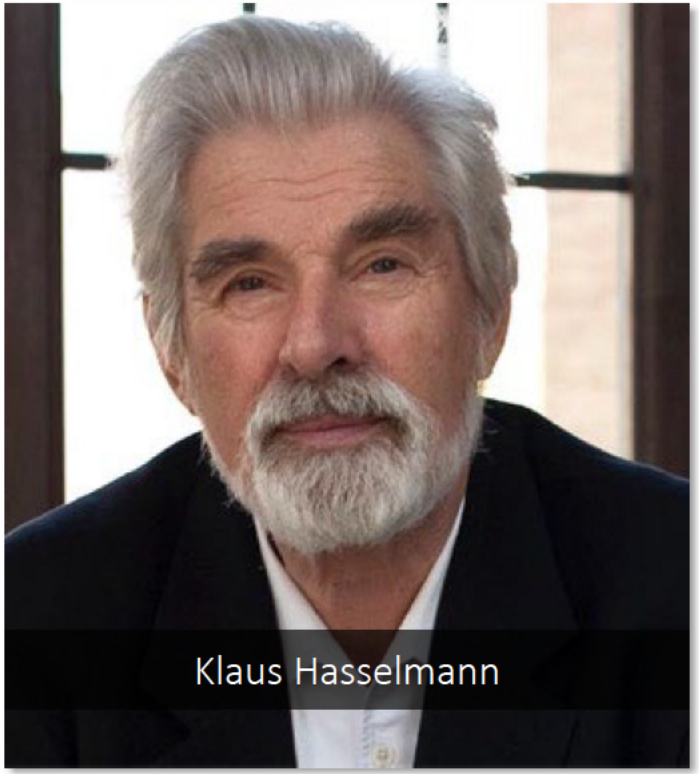
Hasselmann: The power of patterns


Klaus Hasselmann

2021 Nobel Physics Prize

Awarded for developing:

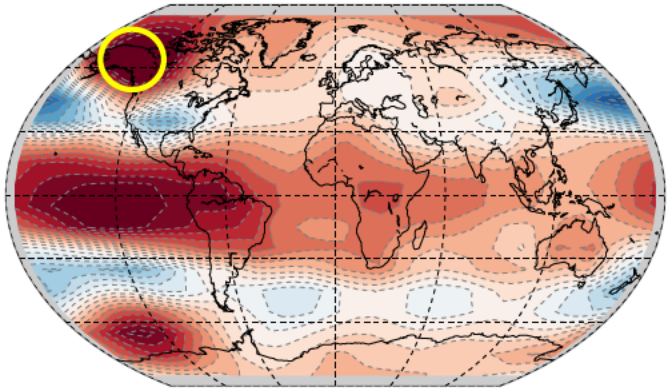
"…methods for identifying specific signals, fingerprints, that both natural phenomena and human activities imprint in the climate"

Using patterns to discriminate between human and natural effects on climate

Human fingerprint

Pattern amplitude

Natural climate variability



Pattern amplitude

Lower tropospheric temperature in CMIP5 models. From Santer et al., *Proceedings of the National Academy of Sciences*, 2019

Manabe: Using models to understand the real-world climate system

2021 Nobel Physics Prize

Awarded for:

"…the physical modelling of Earth's climate, quantifying variability and reliably predicting global warming"

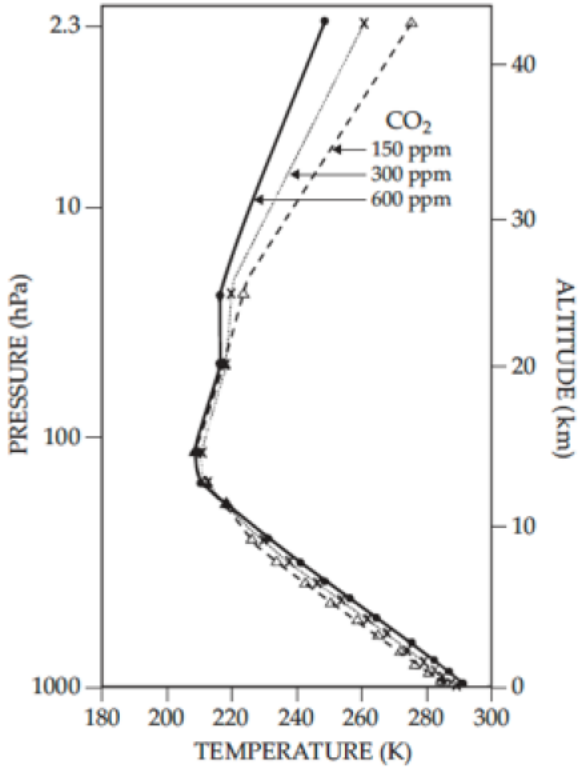
Manabe and Wetherald, 1967

Thermal Equilibrium of the Atmosphere with a Given Distribution of Relative Humidity

SYUKURO MANABE AND RICHARD T. WETHERLAND

Geophysical Fluid Dynamics Laboratory, ESSA, Washington, D.C.

(Manuscript received 2 November1966)



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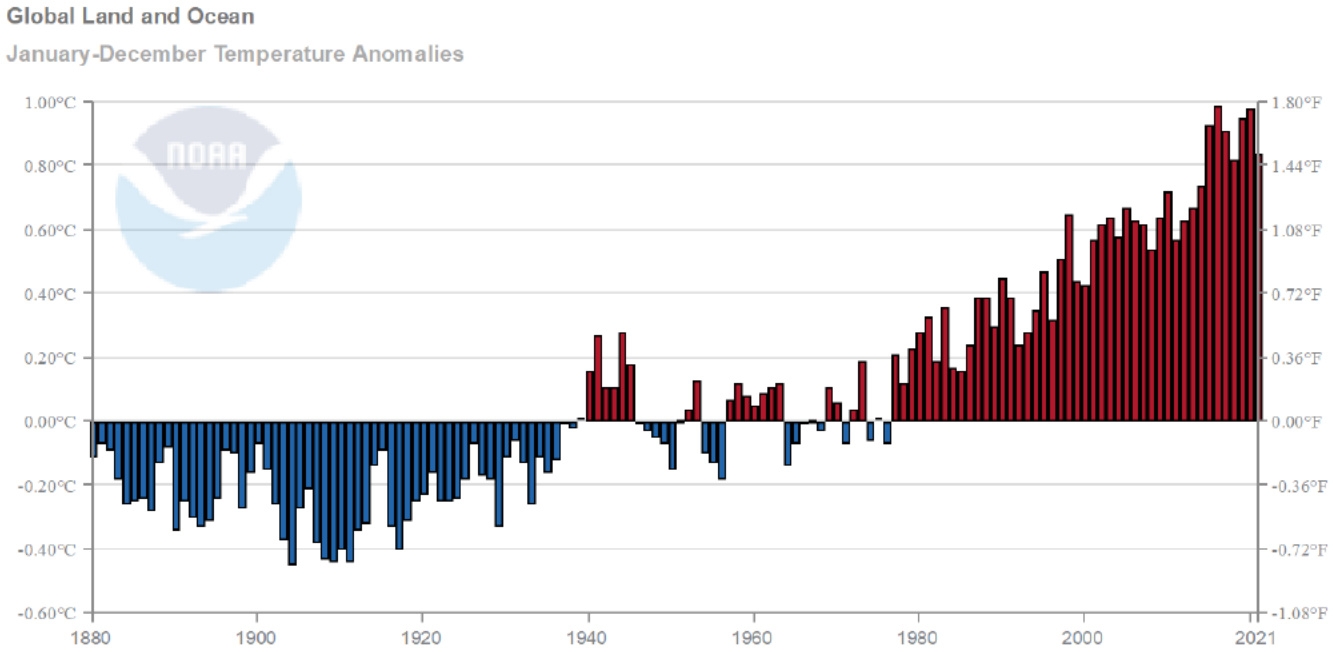
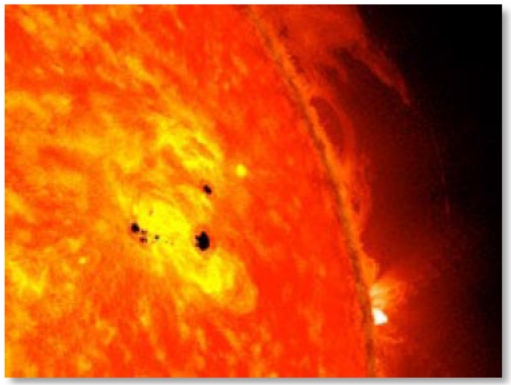
Fingerprinting examples: Temperature

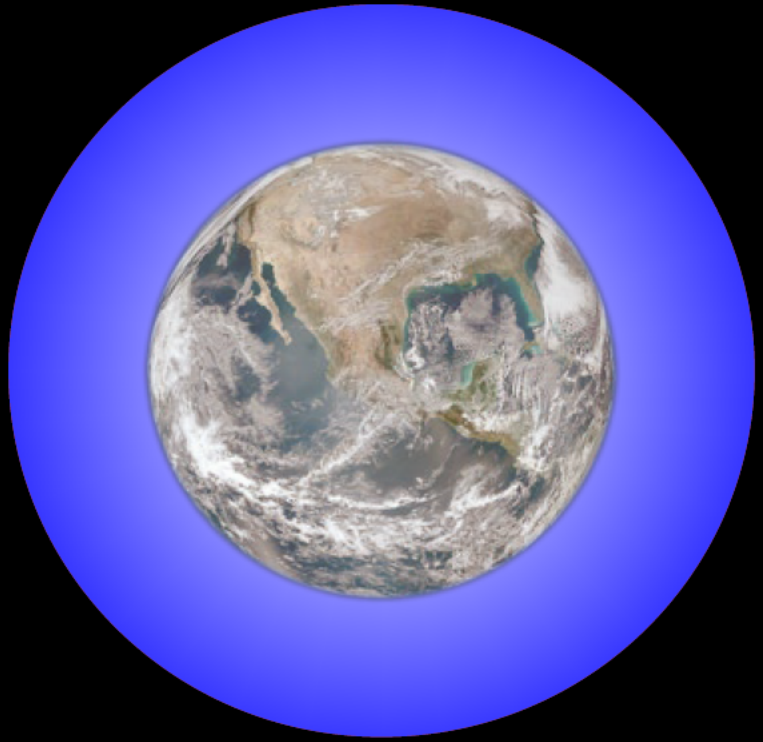




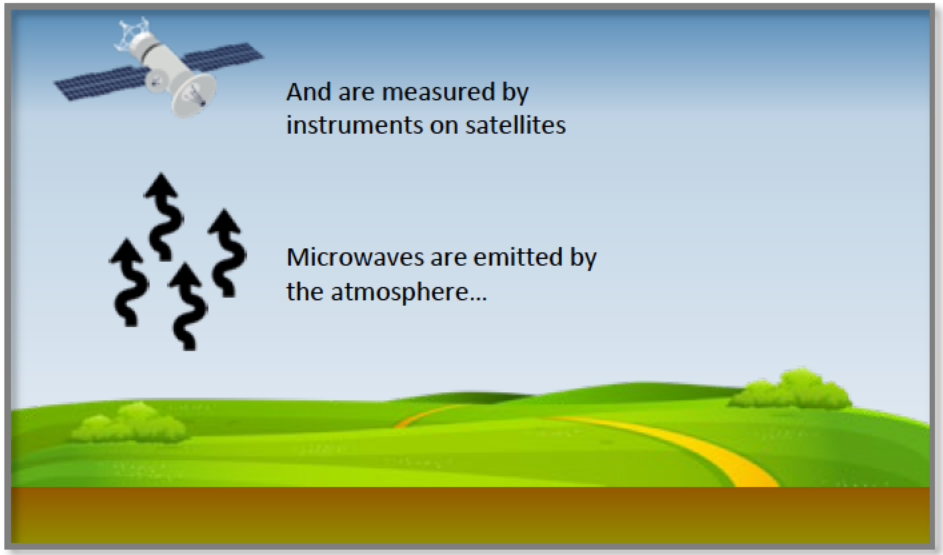
"It's all the Sun"

https://www.ncdc.noaa.gov/cag/global/time-series/globe/land_ocean/ytd/12/1880-2021
Image of sunspots courtesy of http://www.nasa.gov/sites/default/files/728799main_022013-continuum-304_full.jpg

Testing claims that the surface warming of the last 140 years is all due to changes in the Sun



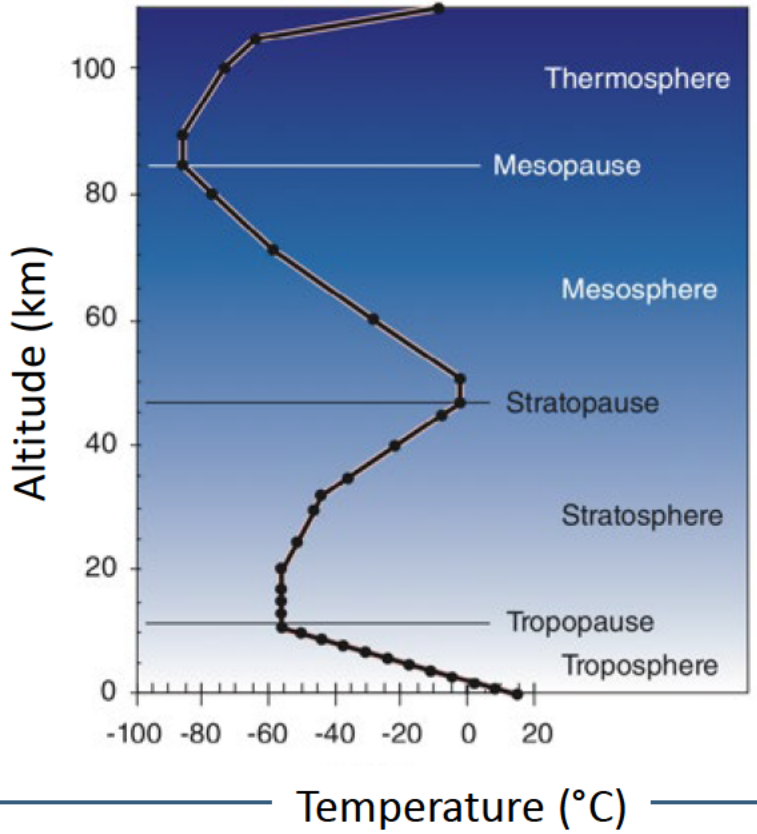
Measuring atmospheric temperature from space



- Higher temperatures = More microwave emissions from oxygen molecules
- By choosing different microwave frequencies, different atmospheric layers can be measured

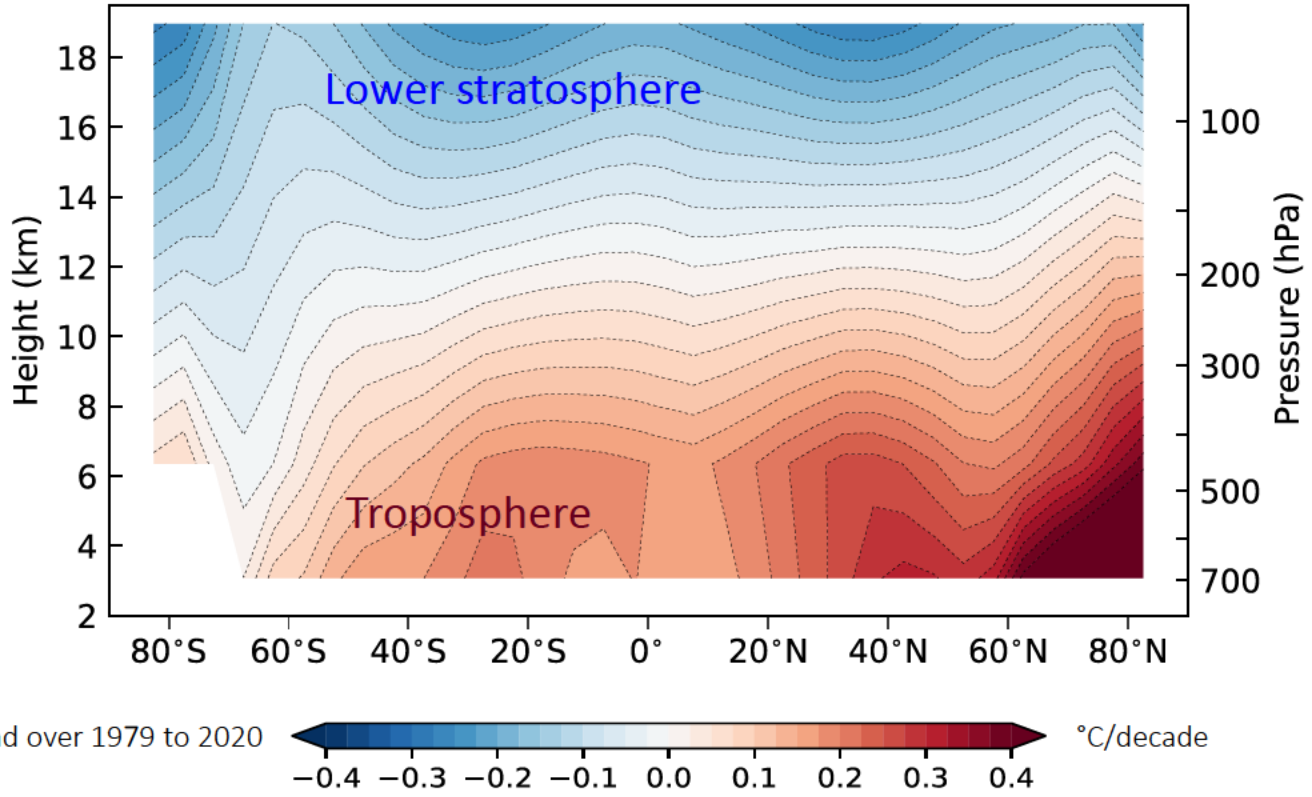
Text courtesy of Carl Mears, Remote Sensing Systems

Different layers of Earth's atmosphere



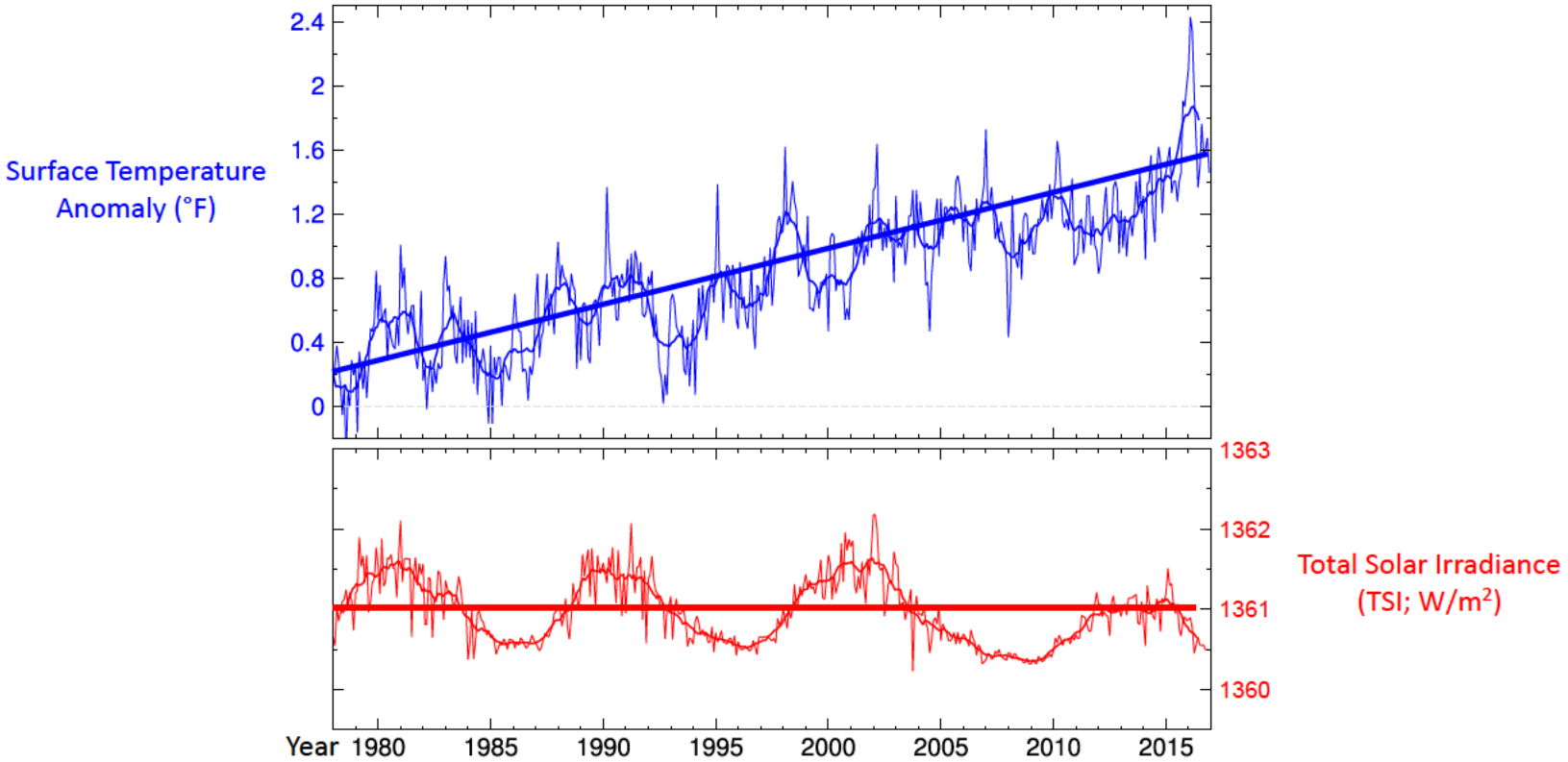
Satellite temperature data show the atmospheric temperature fingerprint predicted by Manabe

Satellite observations (Santa Rosa, CA)



Santer et al., *Proceedings of U.S. National Academy of Sciences*, 2013 (updated)

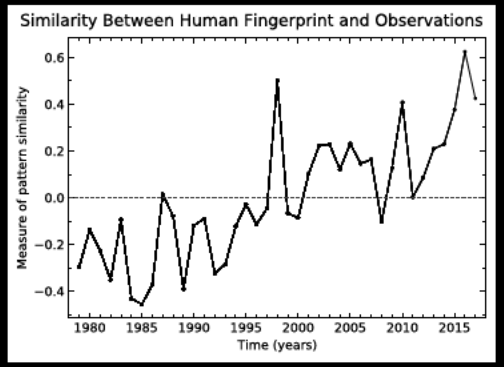
Other evidence against “the Sun explains all surface warming” hypothesis



Fingerprint detection explained in pictures

(Satellite observations)

1979
1985
1990
1995
2000
2005
2010
2015
2016
2017

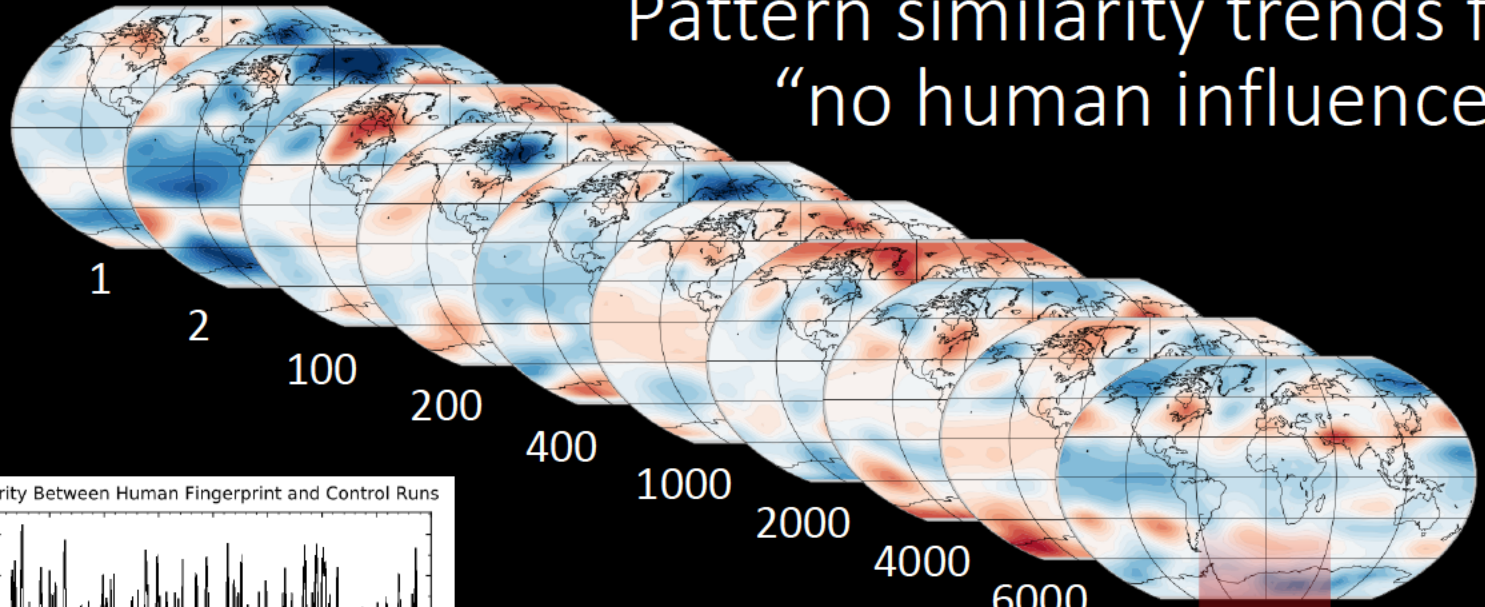


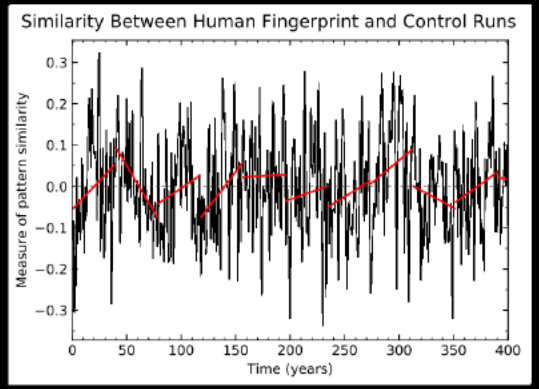
Generate pattern similarity time series

Human fingerprint

Compare with model "human influence" fingerprint

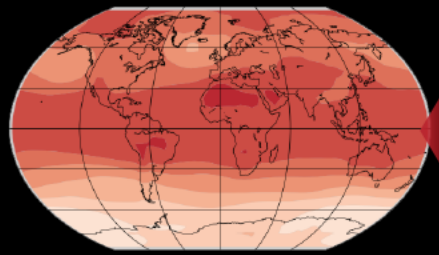
Pattern similarity trends for the "no human influence" case





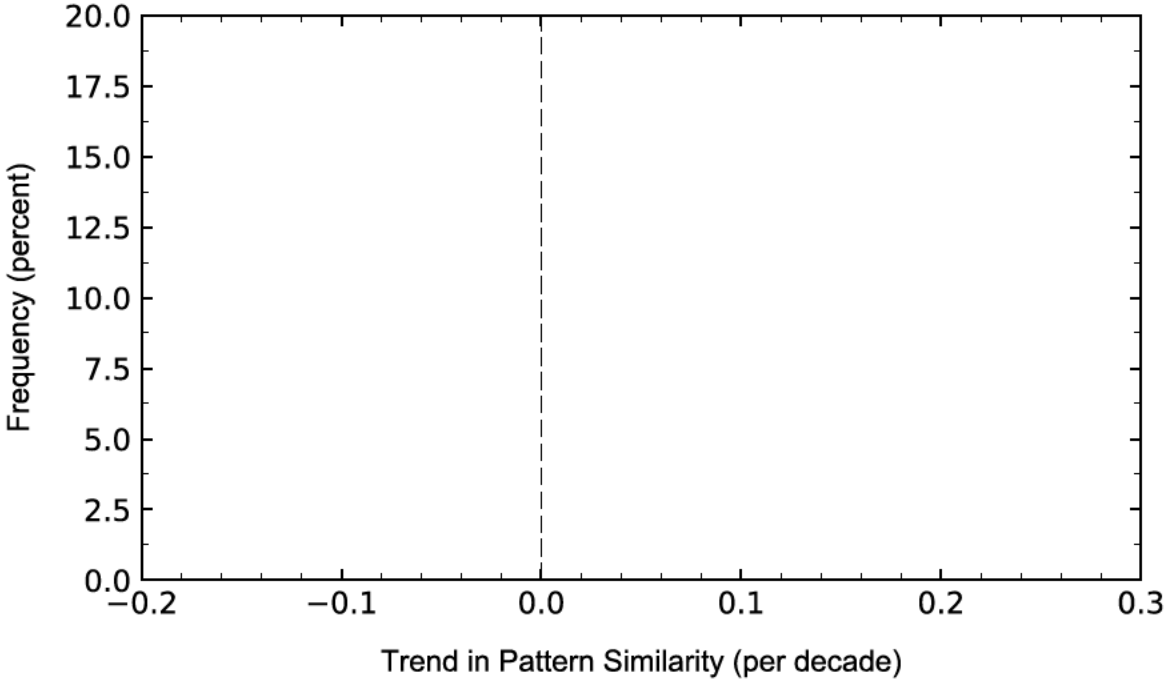
Generate pattern similarity time series

Human fingerprint



Compare with model "human influence" fingerprint

The “match” between the human influence fingerprint and satellite data is unlikely to be due to natural causes



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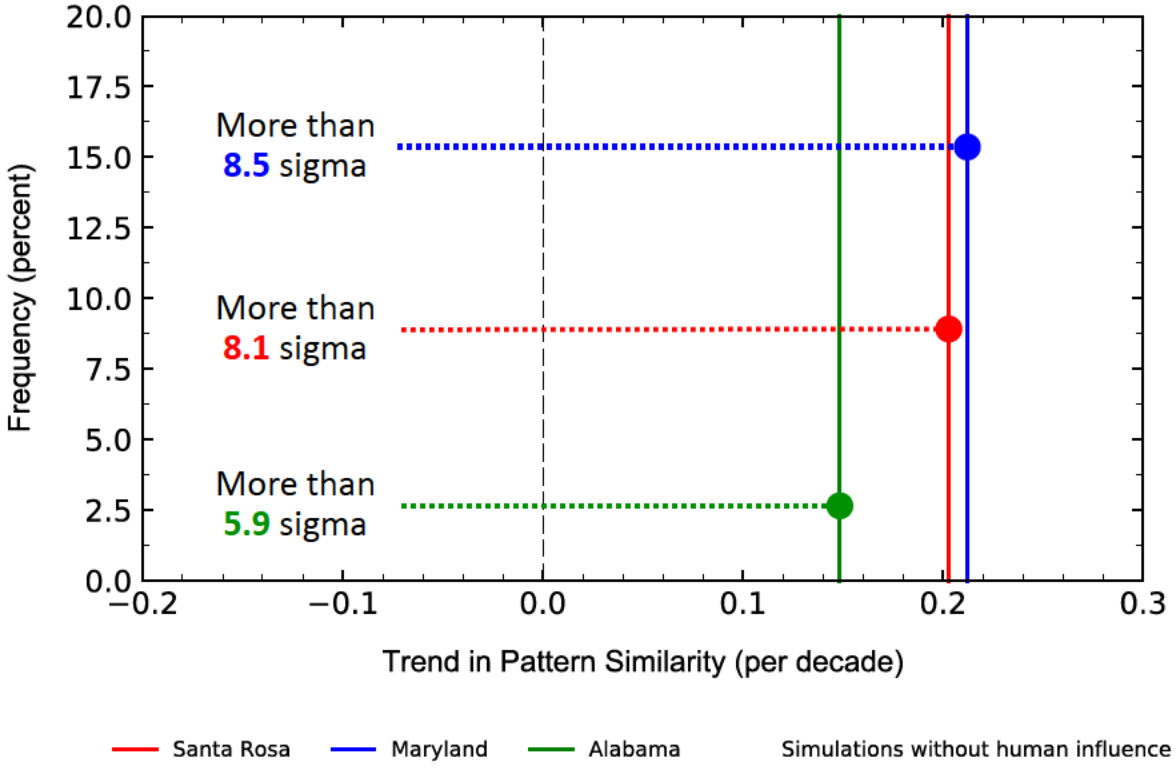

Fingerprinting has moved beyond “temperature only” studies

- Climate scientists have identified human “fingerprints” in many different aspects of the climate system – not just in temperature

- Changes in different climate variables are physically and internally consistent, and are independently monitored with a wide range of instruments

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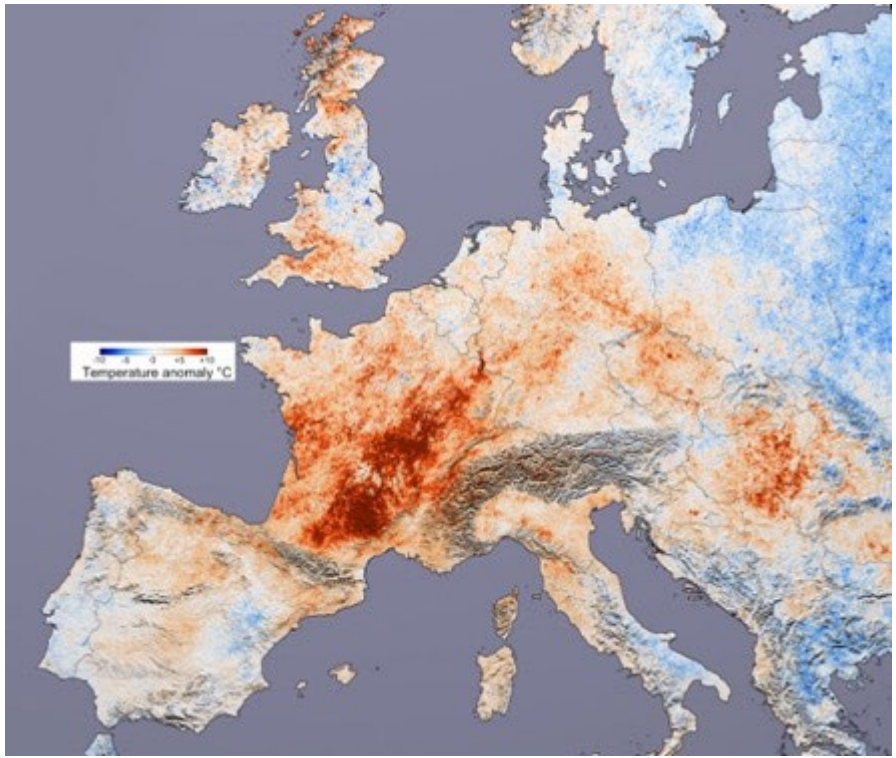
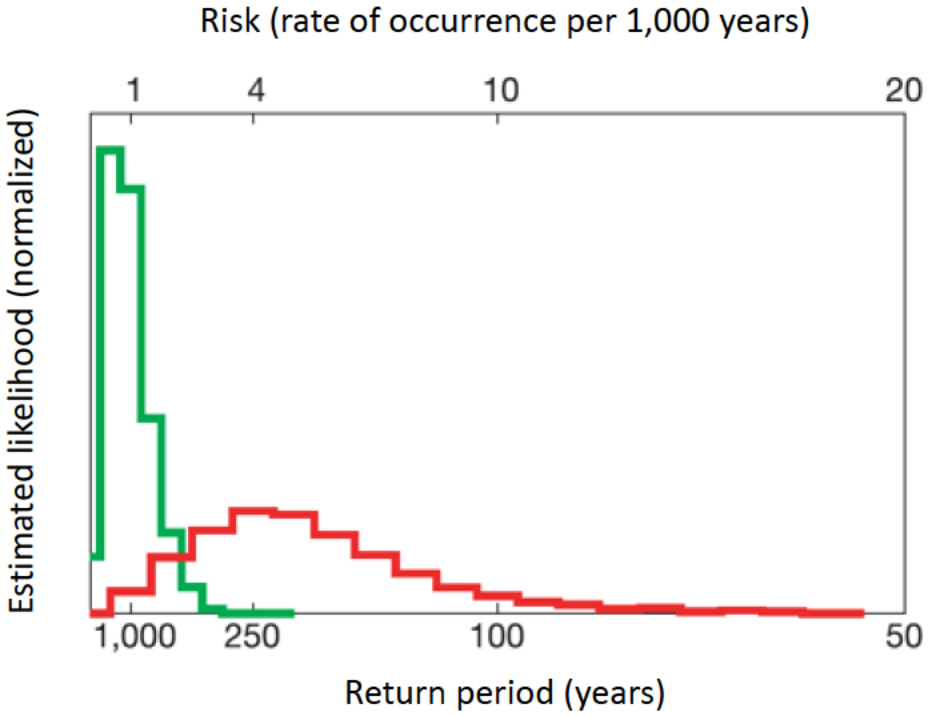
The 2003 European summer heatwave



- July and August 2003
- Health crises in several countries
- Estimated death toll: 72,000*

*U.N. Office for Disaster Risk Reduction
Graphic: https://upload.wikimedia.org/wikipedia/commons/7/7e/Canicule_Europe_2003.jpg

The 2003 European summer heatwave



Histogram of return periods without human-caused climate change

Histogram of return periods with human-caused climate change

> **"We estimate it is very likely (confidence level >90%) that human influence has at least doubled the risk of a heatwave exceeding this threshold magnitude."**

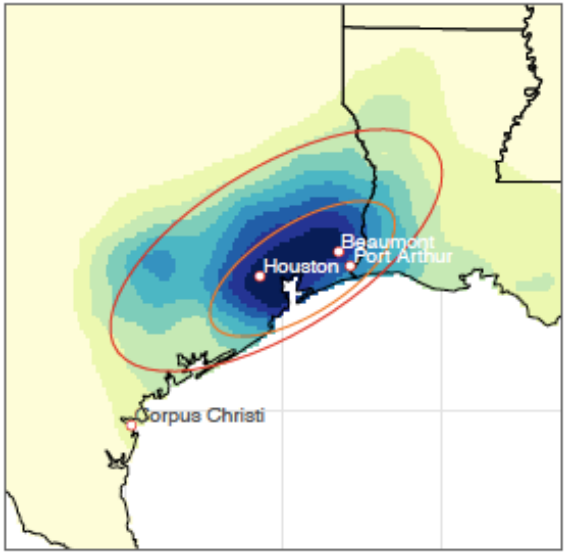
Figure and quote are from Stott et al., *Nature* (2004)

Hurricane Harvey (2017)

- Category 4 hurricane
- Landfall: August 2017
- $125 billion in damages
- More than 100 deaths
- Peak rainfall: > 60 inches in 4 days

*U.N. Office for Disaster Risk Reduction
Graphic: https://upload.wikimedia.org/wikipedia/commons/thumb/0/04/Harvey_2017-08-25_2231Z.png/1280px-Harvey_2017-08-25_2231Z.png

Event attribution: Hurricane Harvey



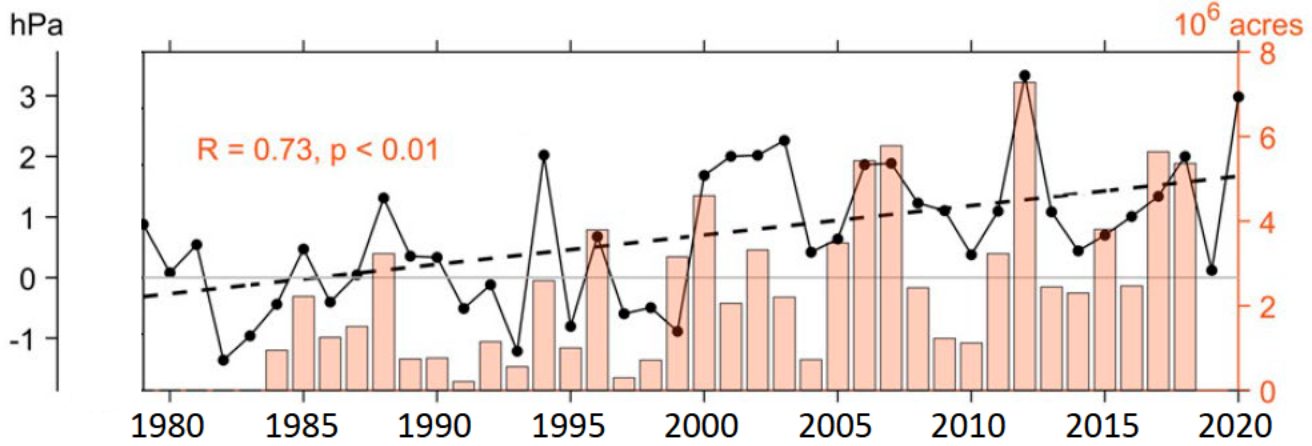
Precipitation total for Houston region from 25 to 31 August (2017)

“…Anthropogenic climate change likely increased Hurricane Harvey’s total rainfall by at least 19% with a best estimate of 38%”

Figure and quote from Risser and Wehner, *Geophysical Research Letters* (2017)

Changes in wildfire weather

Vapor pressure deficit



Burned areas (warm season days)

Fingerprinting with changes in vapor pressure deficit

Event attribution: Legal issues and questions

- Can we reliably estimate the human contribution to the extreme event's likelihood?
- In estimating this contribution, are the key uncertainties well-quantified?
- Are there reliable damage estimates for the extreme event?

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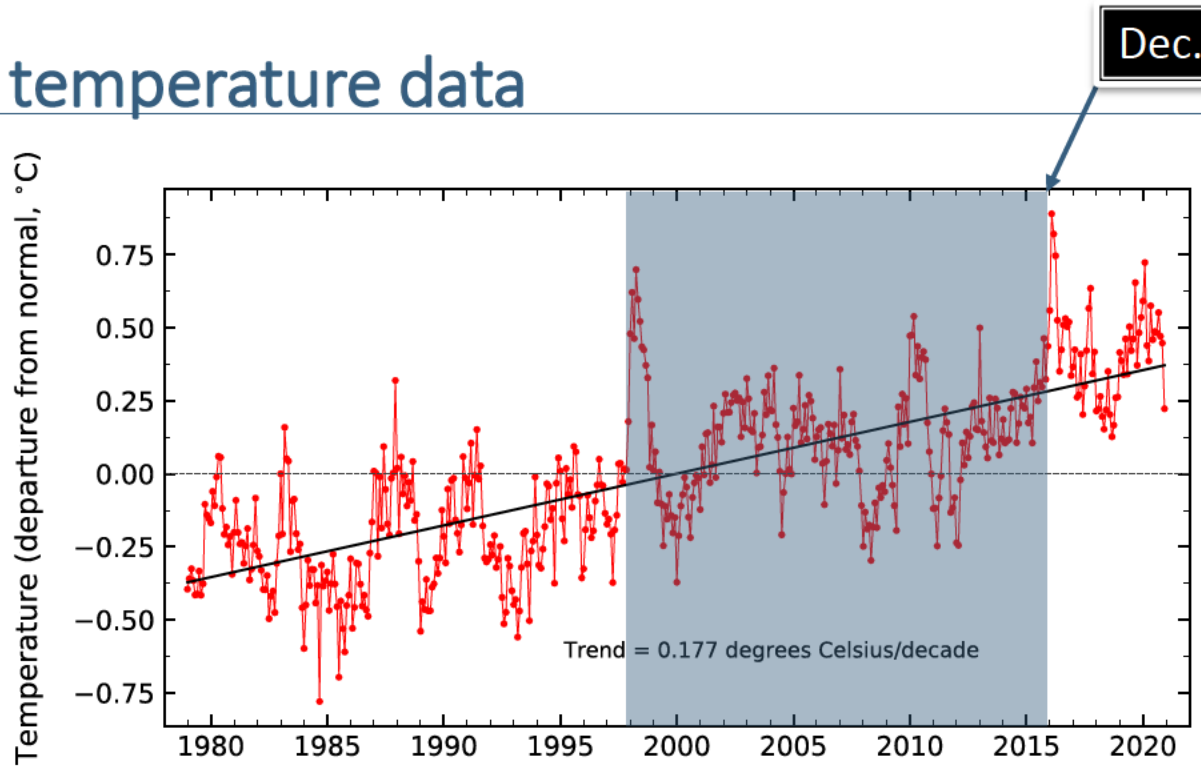
Satellite temperature data: Technical issues

- Satellite orbit drift
- Satellite altitude decay
- Drift in calibration of microwave sounder on the satellite
- Change in type of instrument

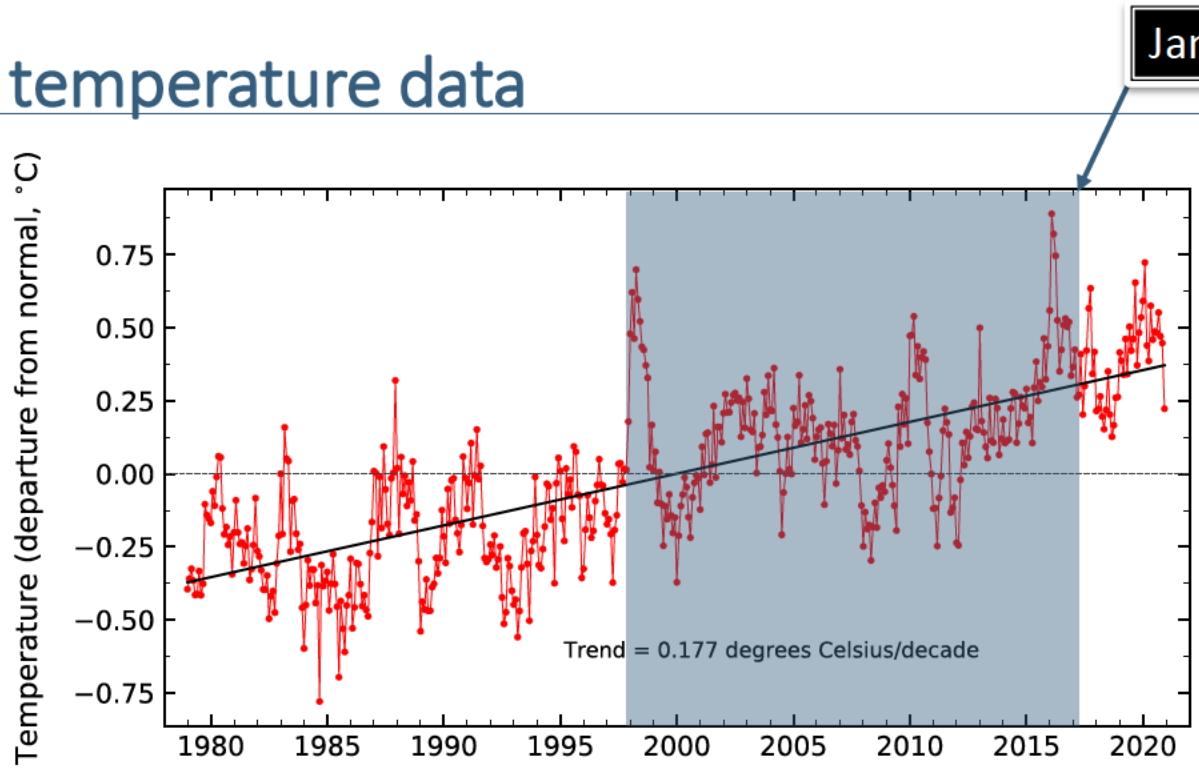
Satellite temperature data



"No significant global warming for the past 18 years" Senator Ted Cruz on Dec. 8, 2015 (see also earlier claim by Senator Cruz on Late Night with Seth Meyers, Mar. 16, 2015)

Graphic: Ben Santer. Source of quote: Senator Ted Cruz, U.S. Senate Committee on Commerce, Science and Transportation, "Data or dogma?" hearing, Dec. 8, 2015. Available online at: https://clio.columbia.edu/catalog/12267036

Satellite temperature data

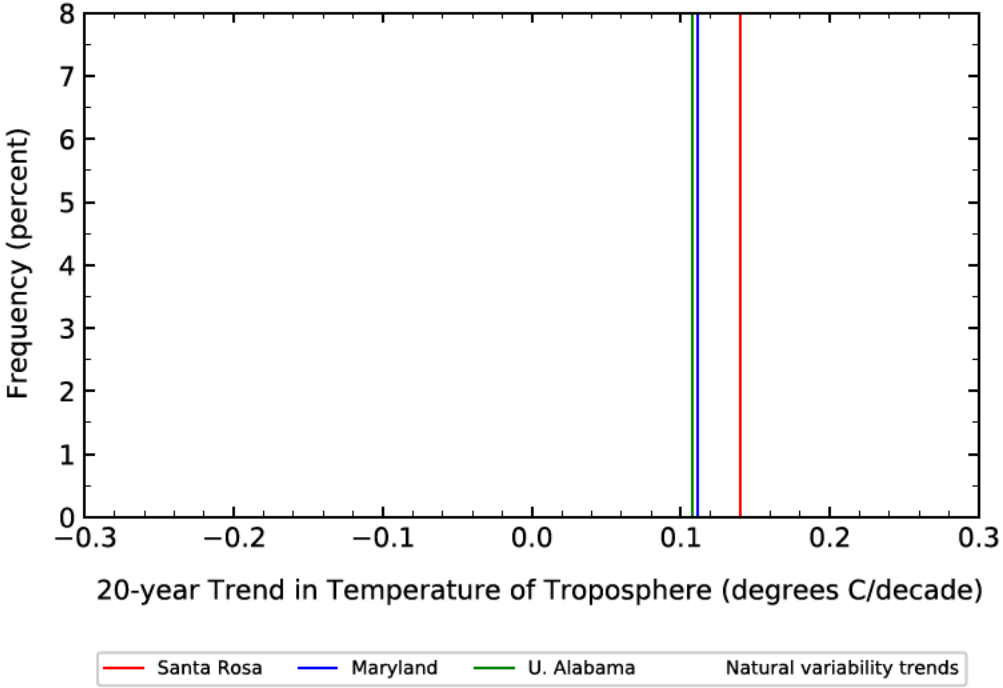


"Satellite data show leveling off of warming over the past two decades"

EPA Administrator Scott Pruitt, Jan. 18, 2017

Graphic: Ben Santer. Source of quote: Former E.P.A. Administrator Scott Pruitt. U.S. Senate Environment and Public Works Committee Hearing, "Nomination of Attorney General Scott Pruitt to be Administrator of the U.S. Environmental Protection Agency", January 18, 2017.

Testing the “leveling off of warming claim”

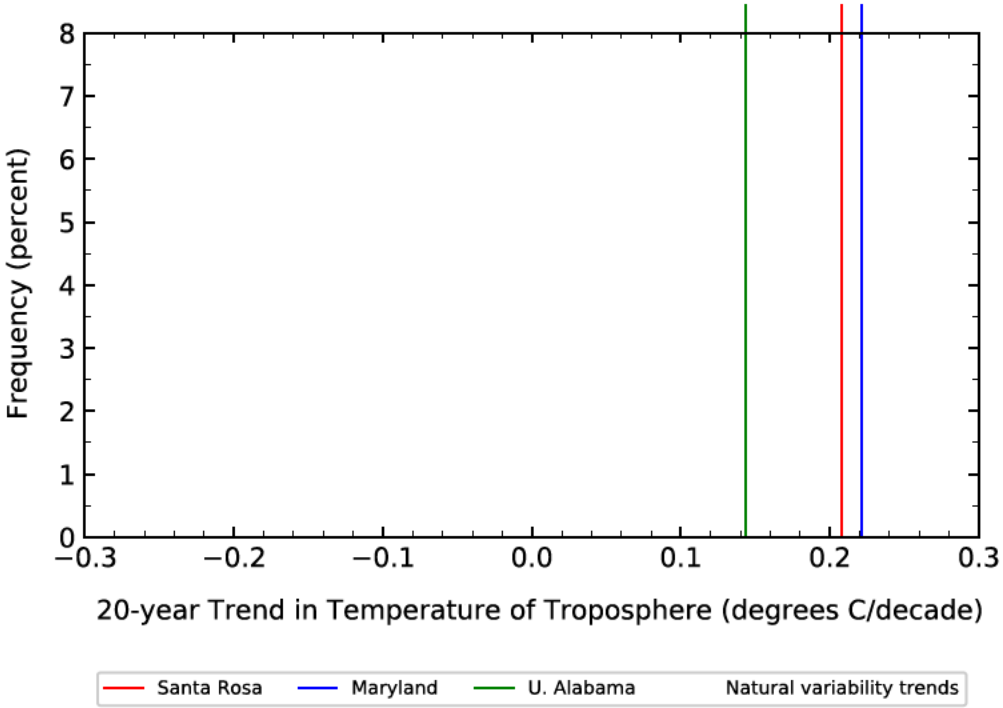


Probability that final 20-year warming trend in satellite data could be natural

Santa Rosa	1.6%
Maryland	3.1%
Alabama	6.3%

Graphic is from Santer et al., *Scientific Reports* (2017)

Testing the “leveling off of warming claim”



Probability that average of all possible 20-year trends in satellite data could be natural

Santa Rosa	0.007%
Maryland	0.006%
Alabama	1.7%

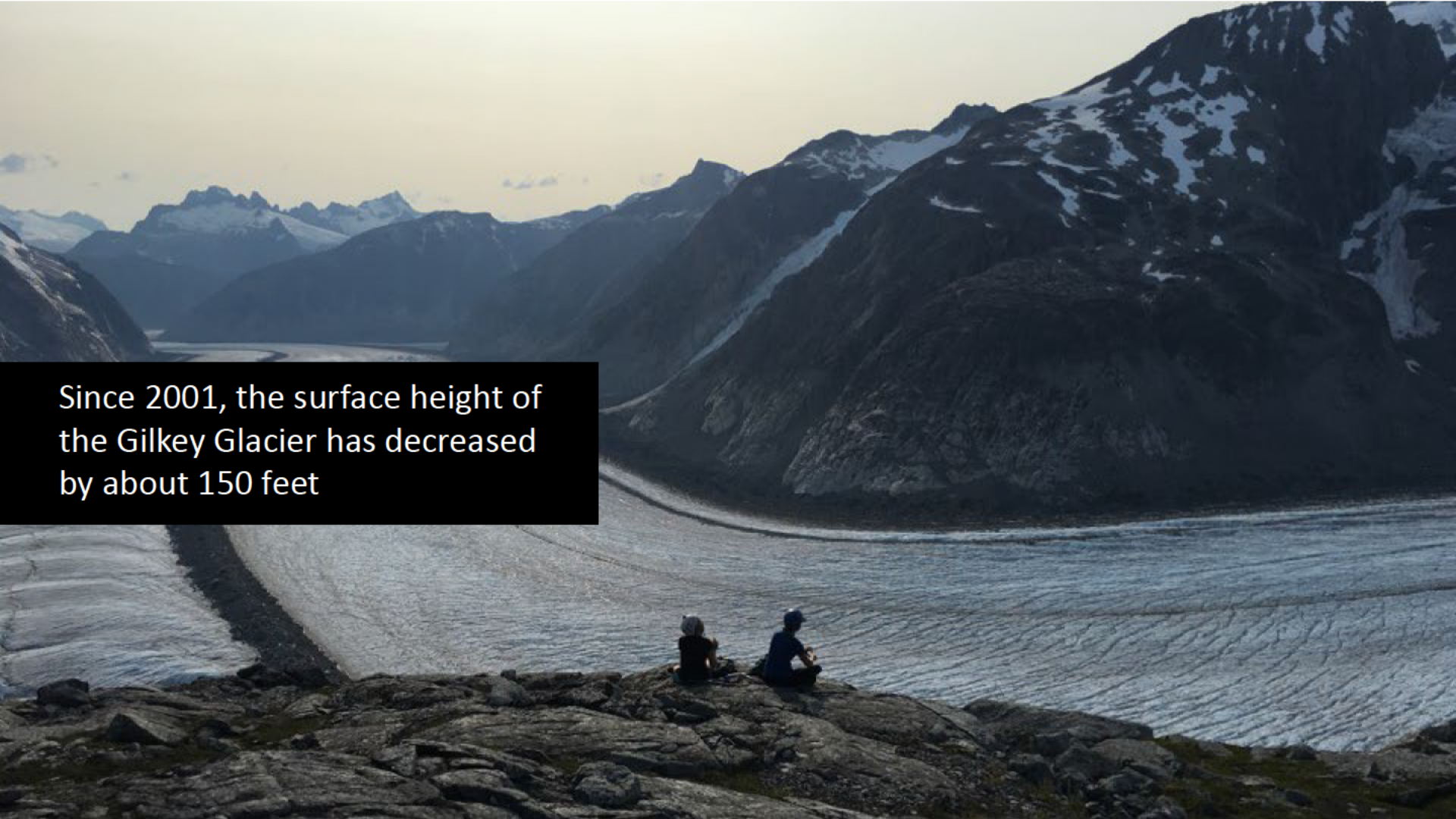
Graphic is from Santer et al., *Scientific Reports* (2017)

Summary

- “Climate fingerprinting” uses pattern information to separate human and natural effects on climate
- It was developed in the late 1970s
- Human fingerprints on climate are unequivocal and ubiquitous
- Today, scientists routinely estimate the impacts of climate change on extreme events
- Satellite temperatures show significant global warming

Declare your values

Photo: Ben Santer


Since 2001, the surface height of the Gilkey Glacier has decreased by about 150 feet

Resources

- https://www.nap.edu/catalog/25733/climate-change-evidence-and-causes-update-2020
- https://www.nap.edu/catalog/21852/attribution-of-extreme-weather-events-in-the-context-of-climate-change
- https://www.nap.edu/catalog/12781/americas-climate-choices
- https://www.nap.edu/catalog/12181/carbon-dioxide-and-climate-a-scientific-assessment