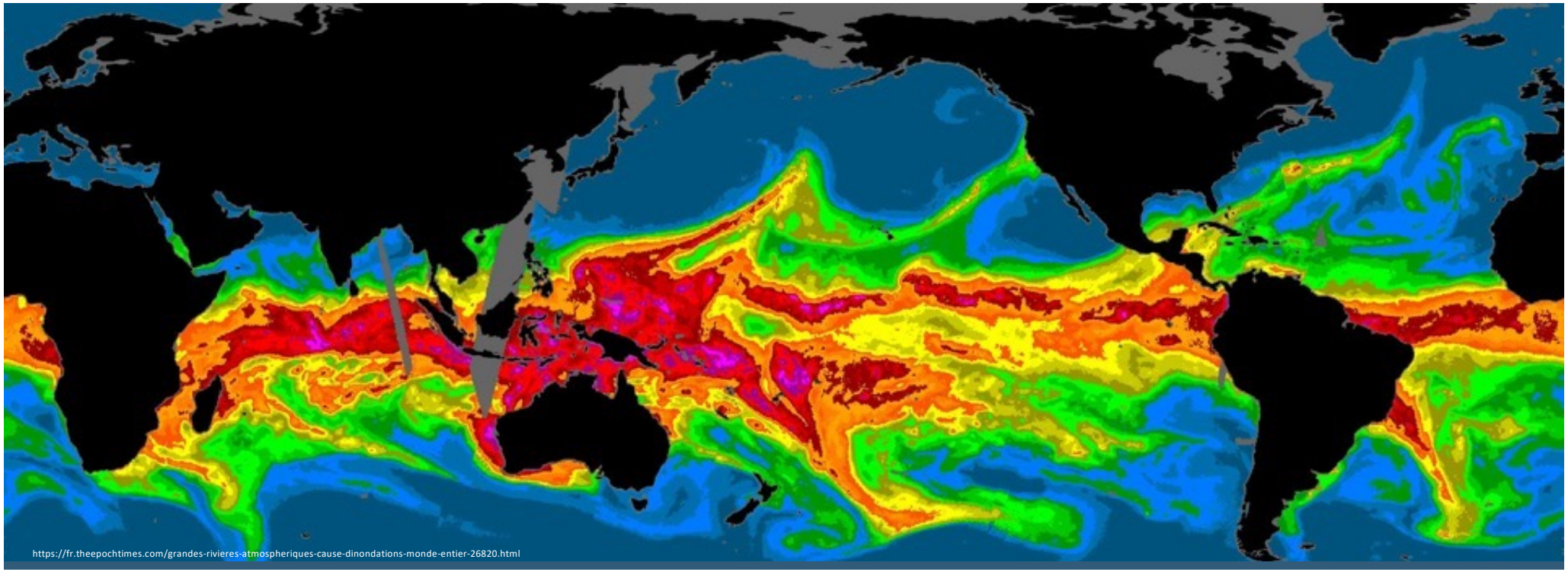


Fingerprinting the Climate System

Ben Santer

Woods Hole Oceanographic Institution
and UCLA

University of Utah
Oct. 4, 2023

My background

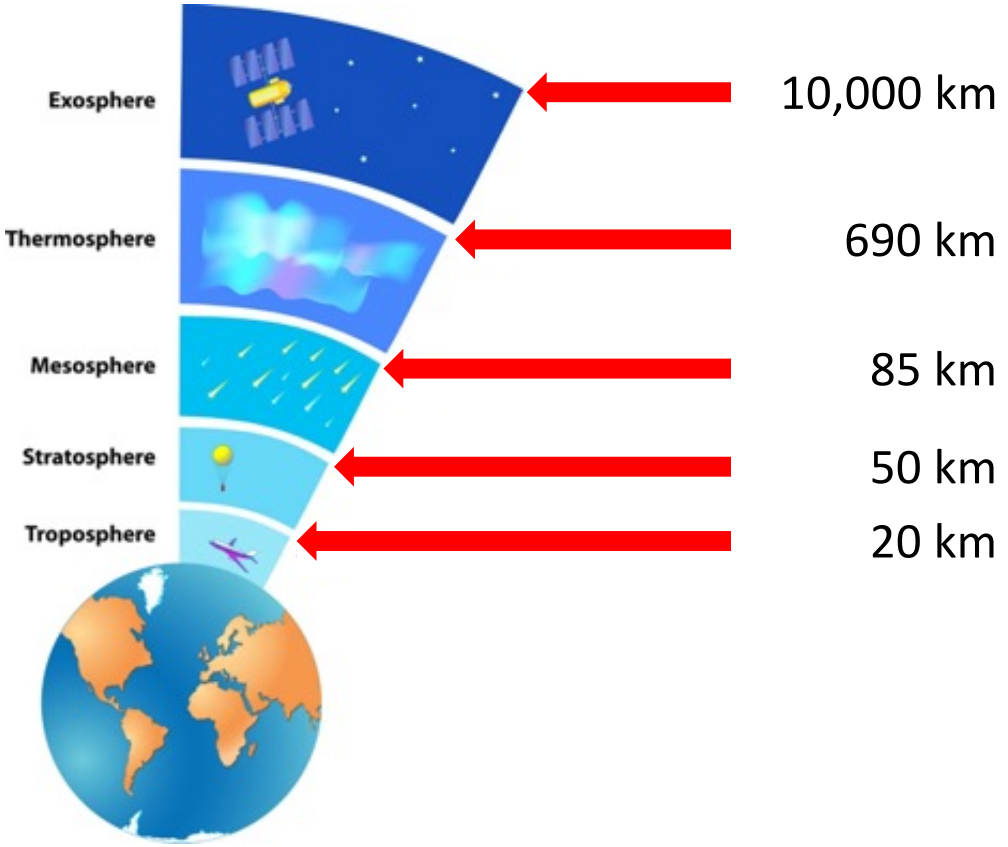
- My job: Atmospheric scientist
- My education: U.K. and Germany
- My research: Climate fingerprinting
- My hobby: Rock-climbing

Photo: Ben Santer

Basics

- Climate is influenced by:
  - Natural factors (the Sun, volcanoes, internal variability)
  - Human factors (greenhouse gases, particulate pollution, land surface changes)
- Climate fingerprinting seeks to disentangle natural and human factors

Basics: Different layers of Earth's atmosphere



Structure

- Climate fingerprinting 101
- Fingerprinting and the 2021 Nobel Physics Prize
- Fingerprinting example
- Looking at the causes of changes in extreme events
- Lessons learned

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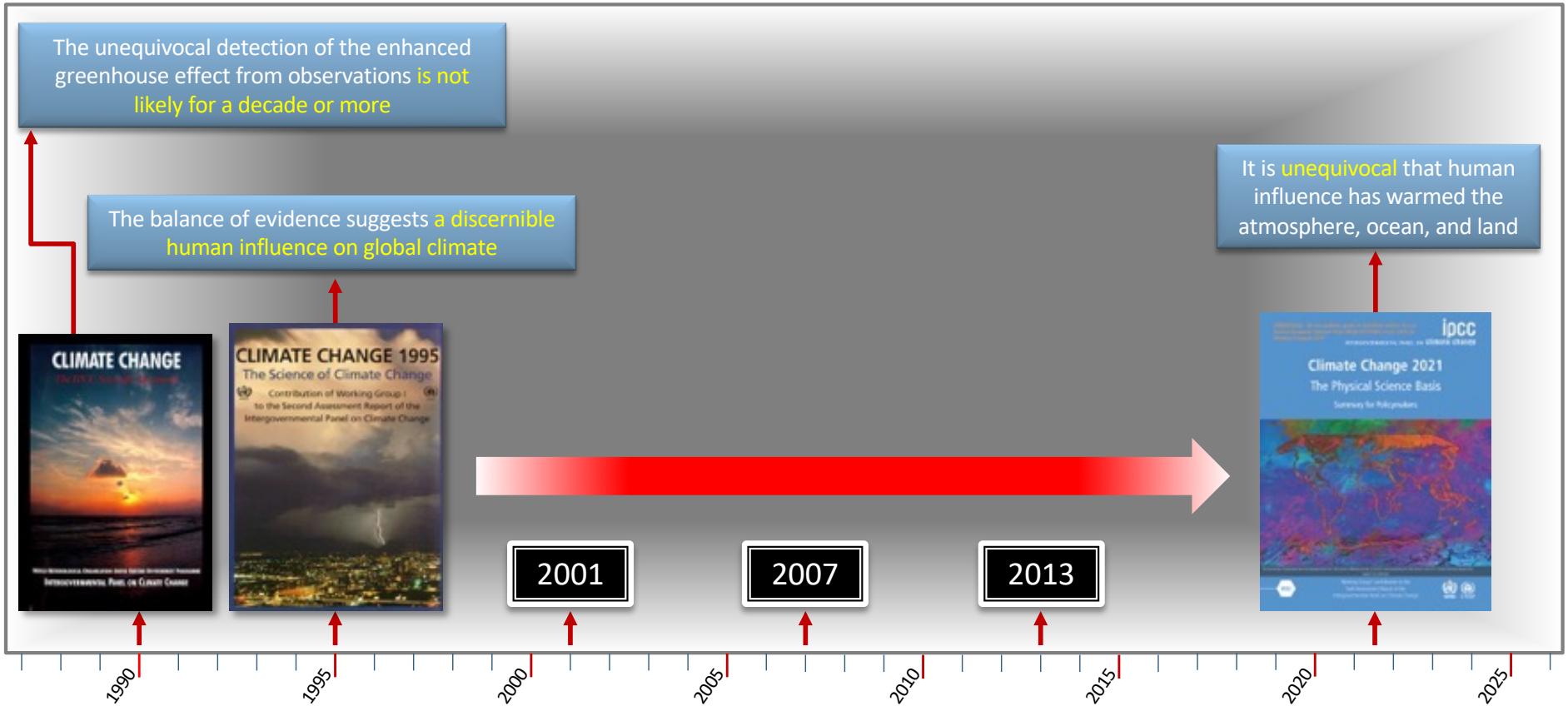
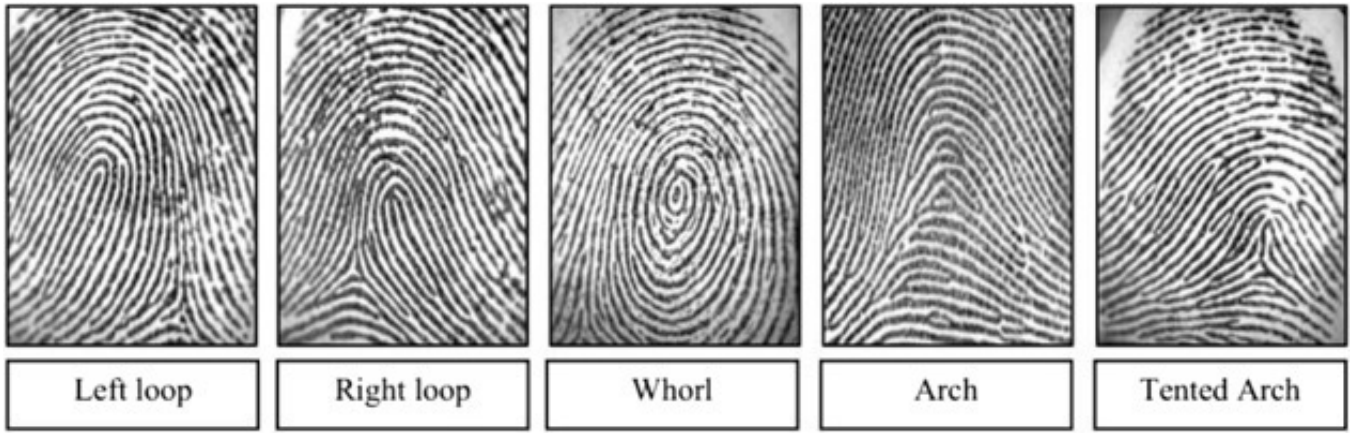
The arc of history

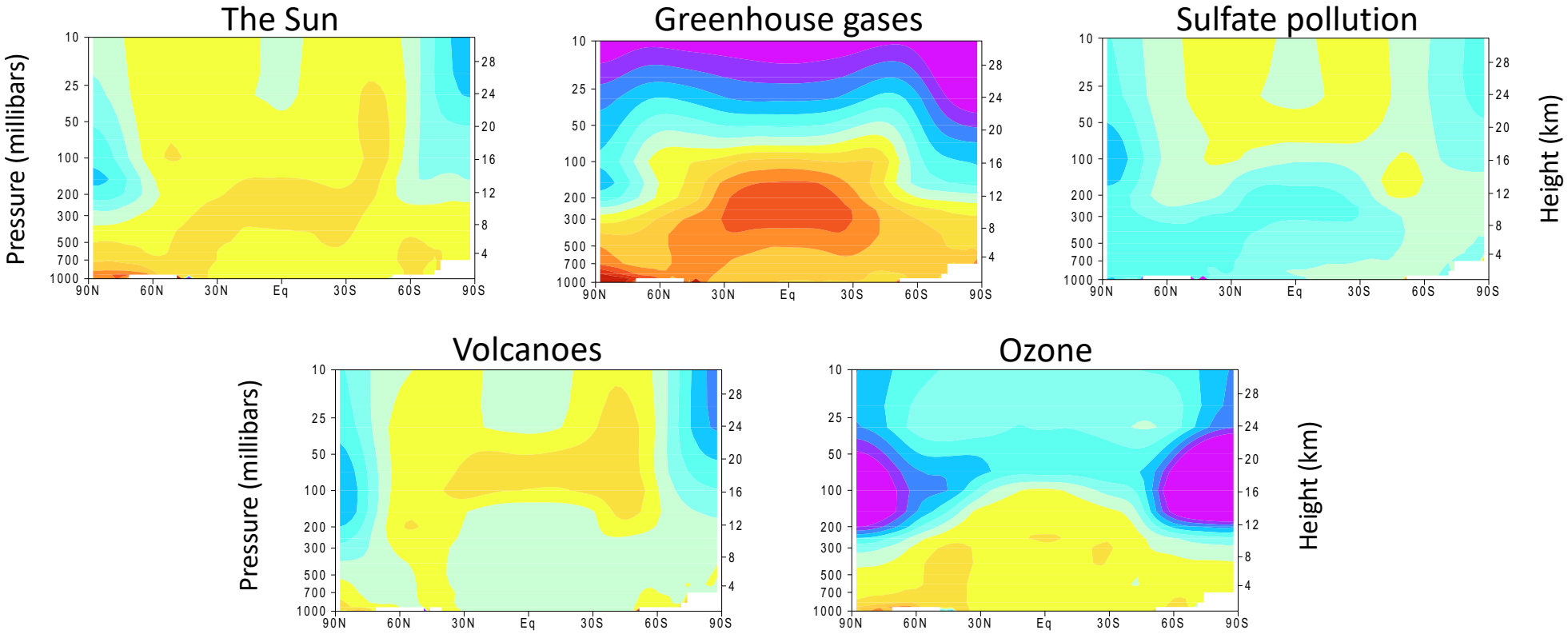


“Climate fingerprinting” contributed to this arc of history

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



Natural and human fingerprints on climate



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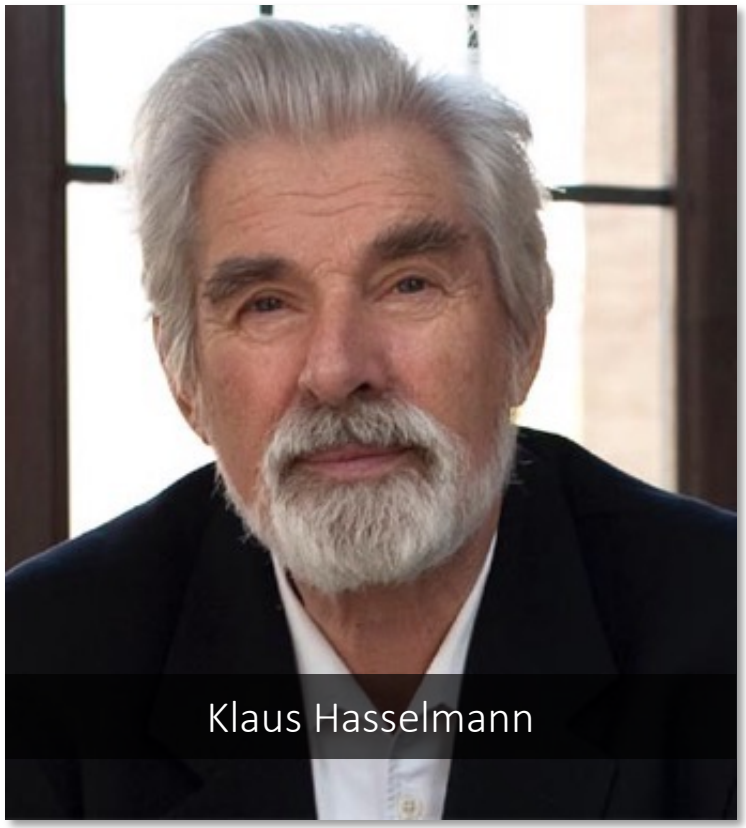
Hasselmann: The power of patterns

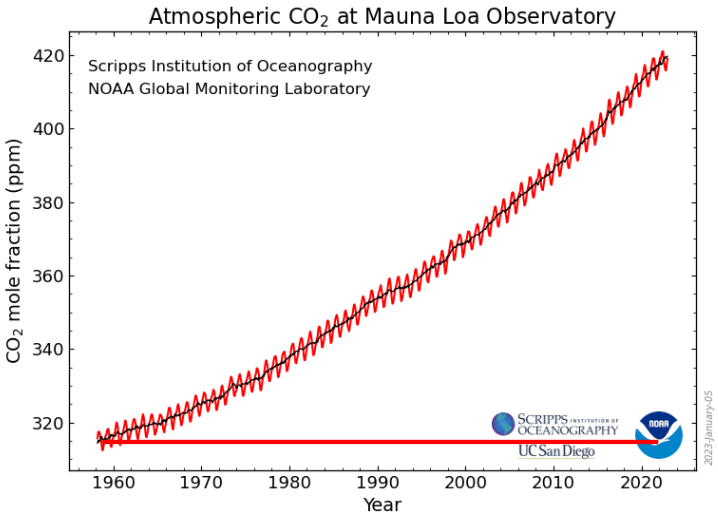

Klaus Hasselmann

2021 Nobel Physics Prize

Awarded for developing:

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

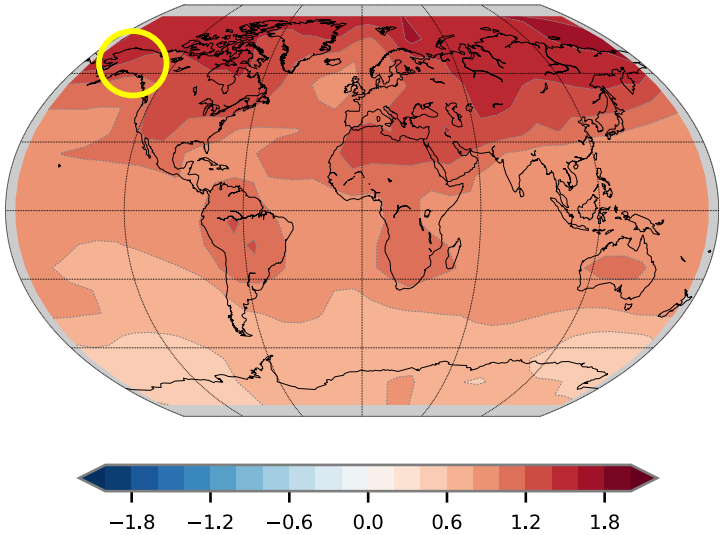
Hasselmann: The power of patterns



Mauna Loa CO_2 figure is from https://gml.noaa.gov/webdata/ccgg/trends/co2_data_mlo.png

What was Hasselmann's key insight?

Human fingerprint



Size of temperature change
(dimensionless)

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"

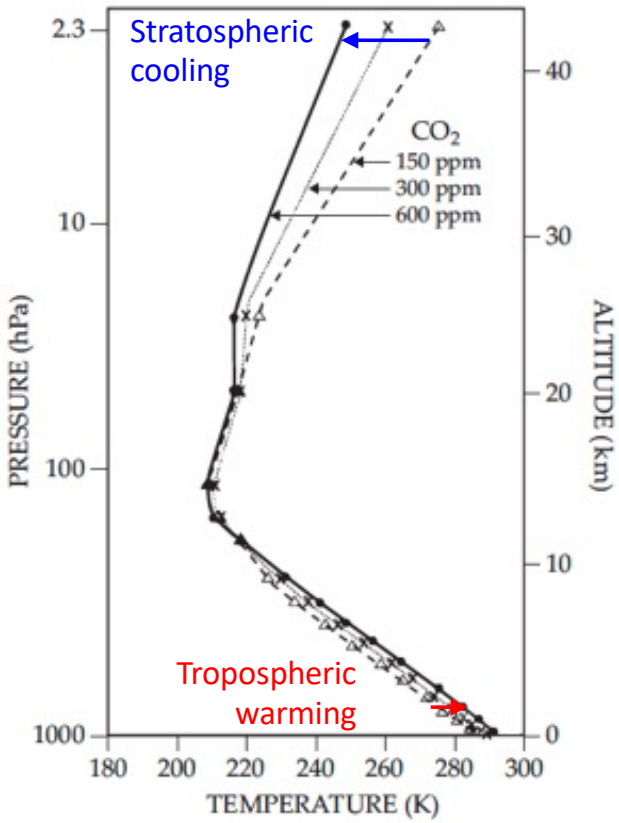
Manabe and Wetherald, 1967

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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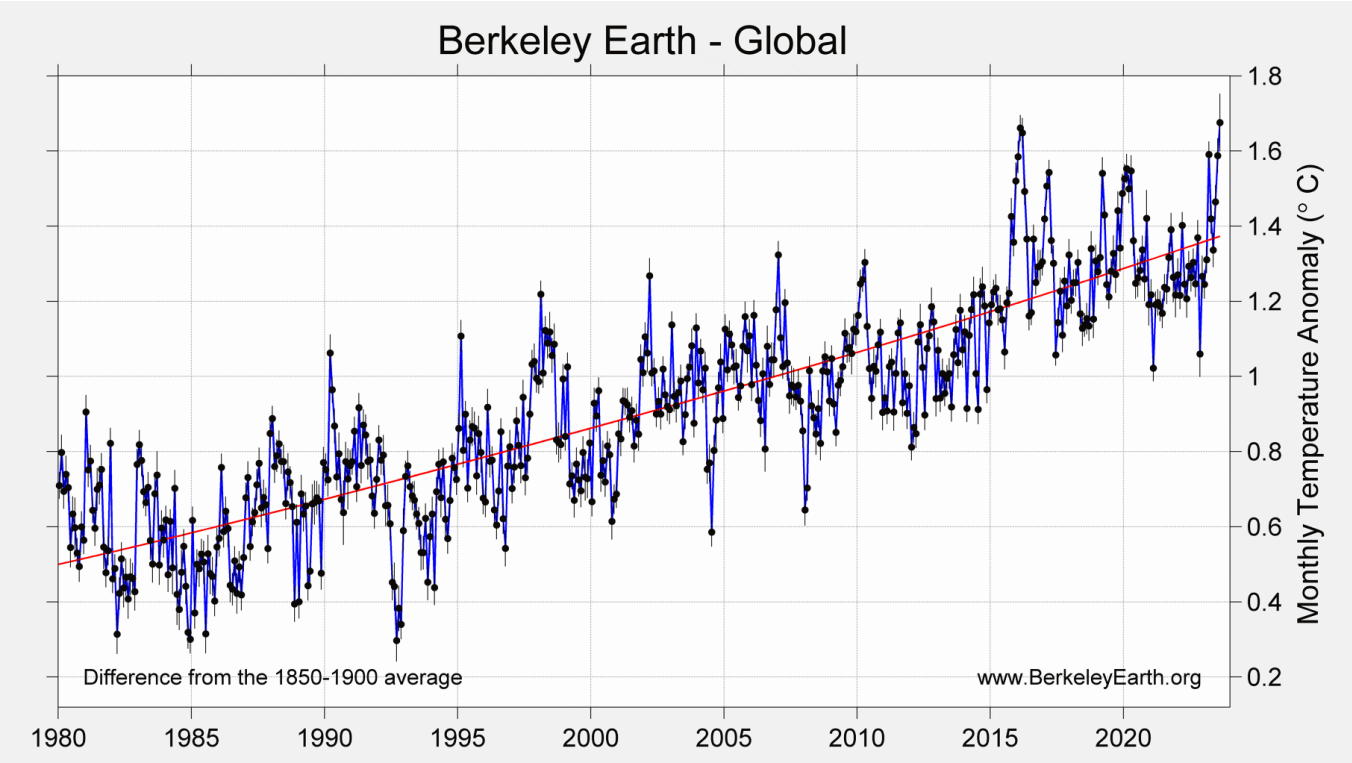
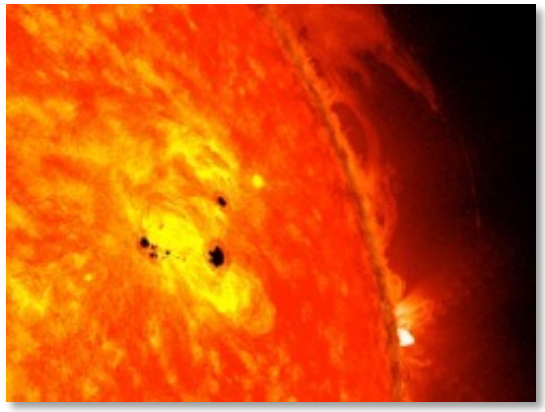
Could all surface warming be due to the Sun?

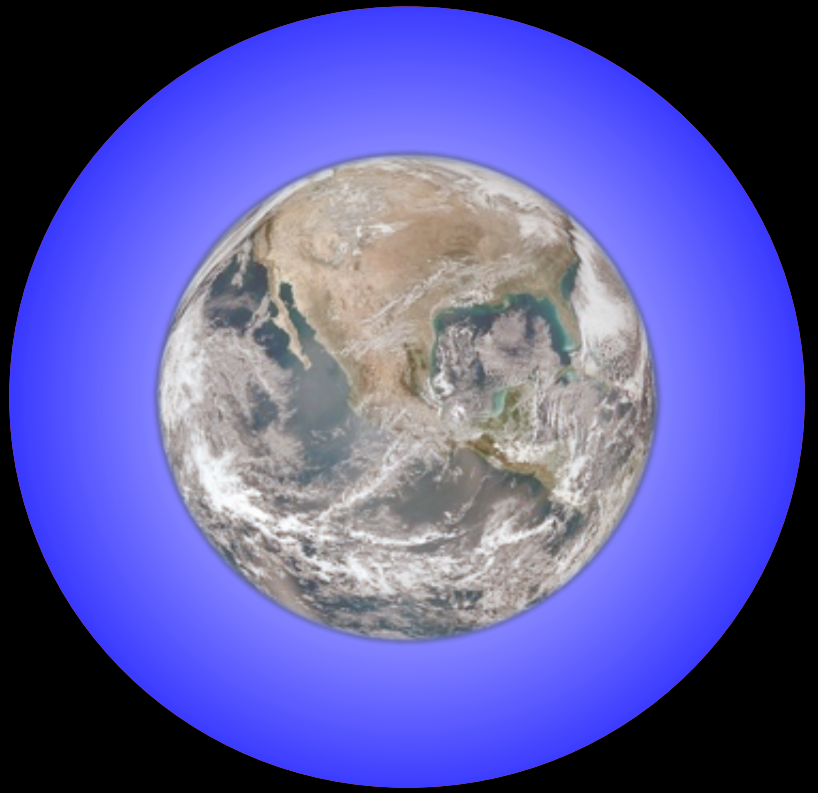




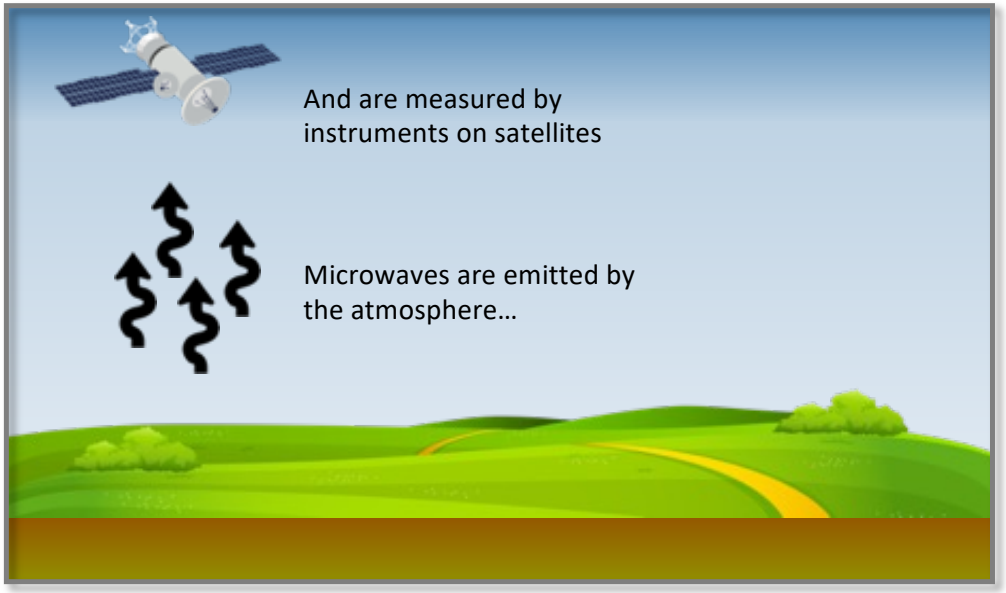
"It's all the Sun"

https://berkeleyearth.org/wp-content/uploads/2023/09/Monthly_time_series_combined_1980.png
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 170+ years is all due to changes in the Sun



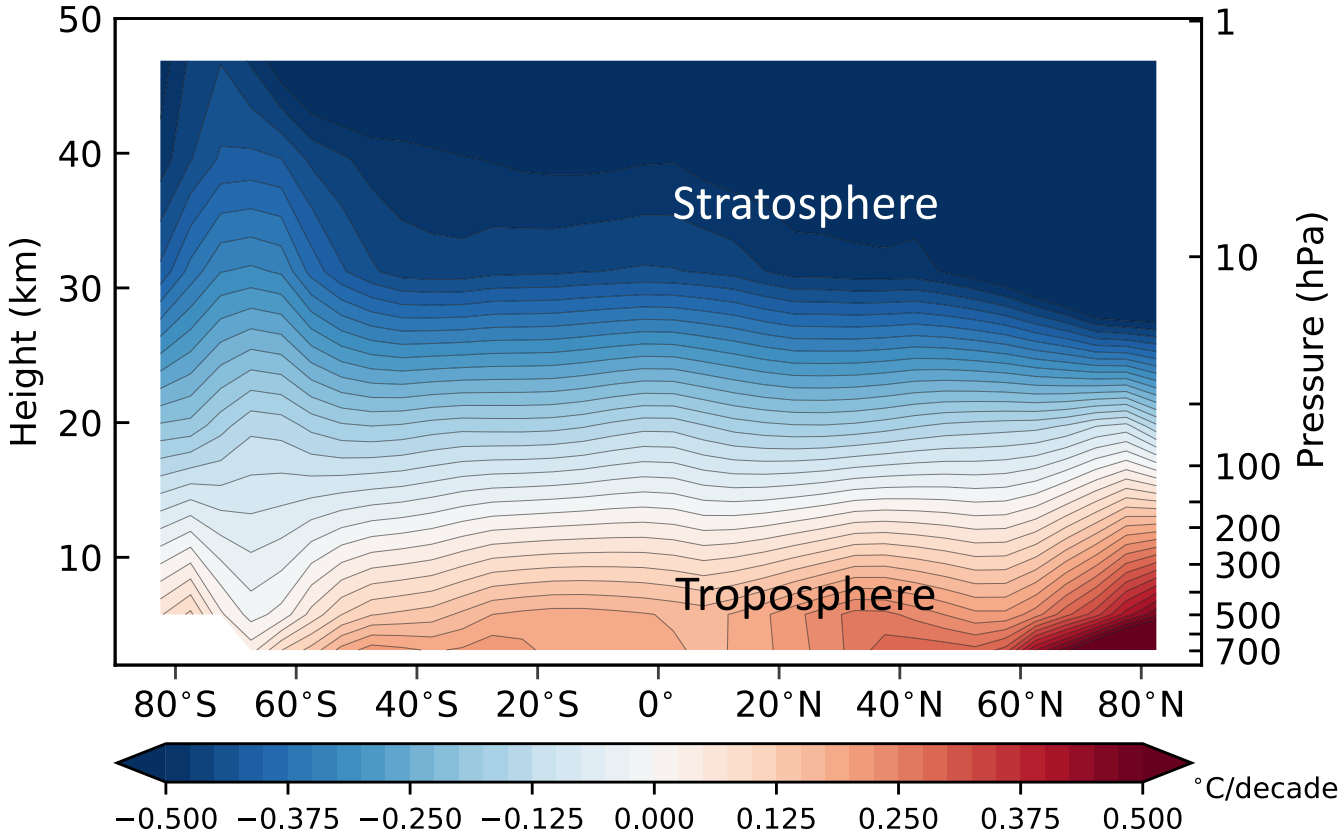
Measuring atmospheric temperature from space



- 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

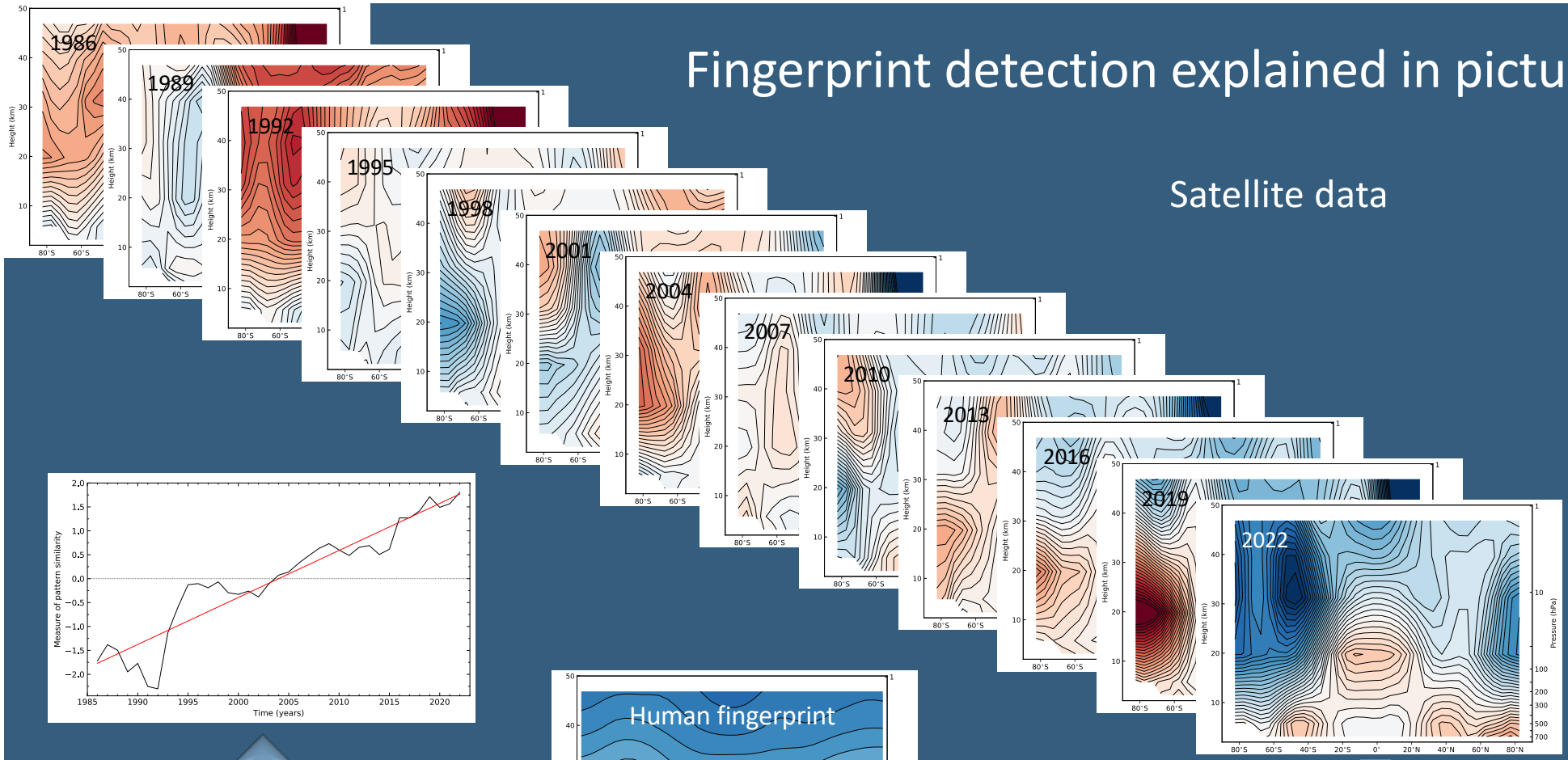
Satellite temperature data show the atmospheric temperature fingerprint predicted by Manabe



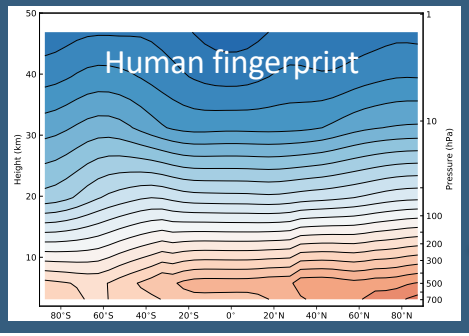
Temperature trend over 1986 to 2021

Source: Santer et al., PNAS (2023)

Fingerprint detection explained in pictures



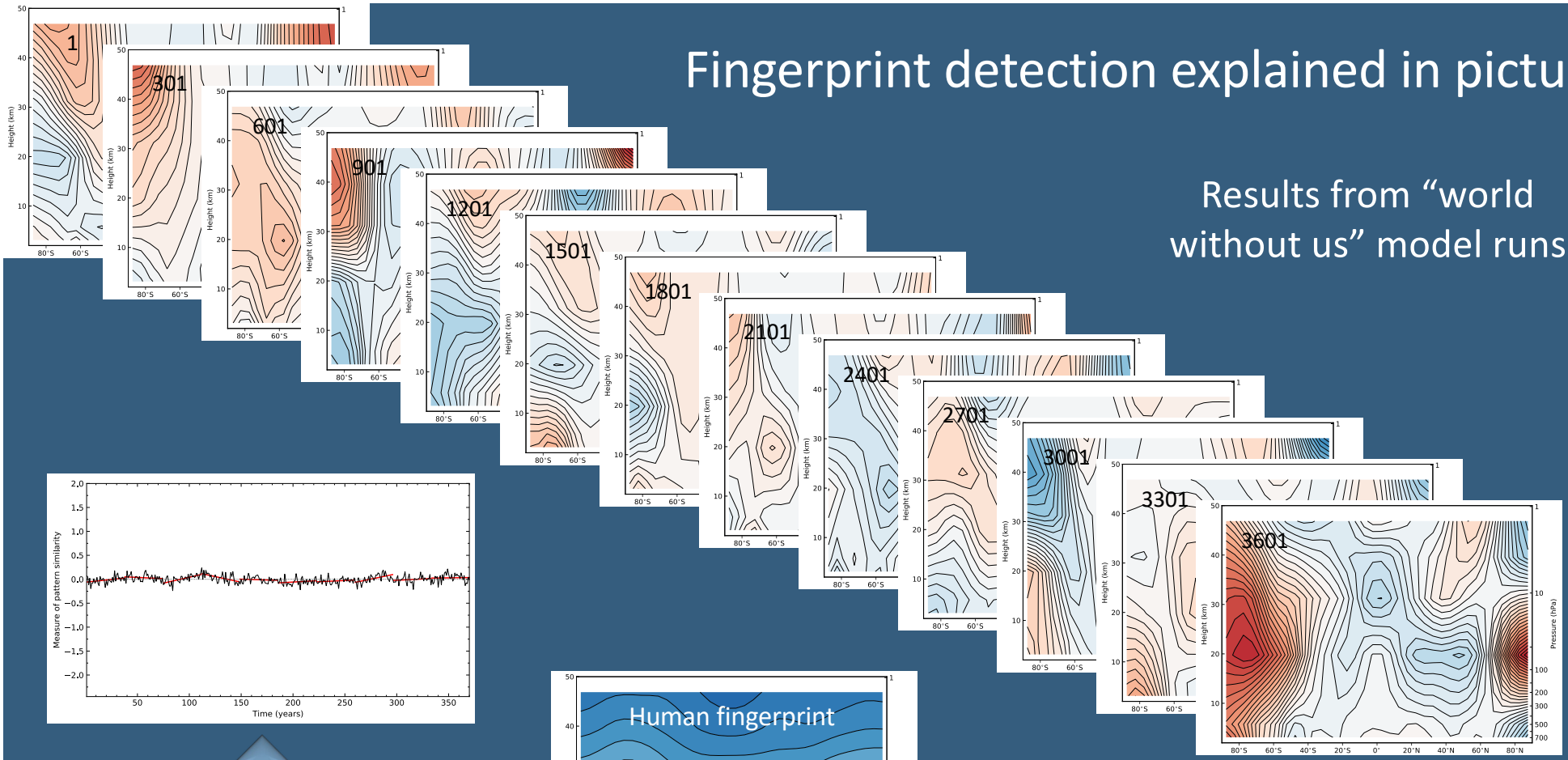
Generate pattern similarity time series



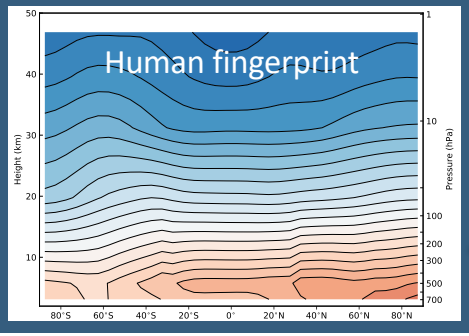
Compare with fingerprint

Fingerprint detection explained in pictures

Results from “world without us” model runs

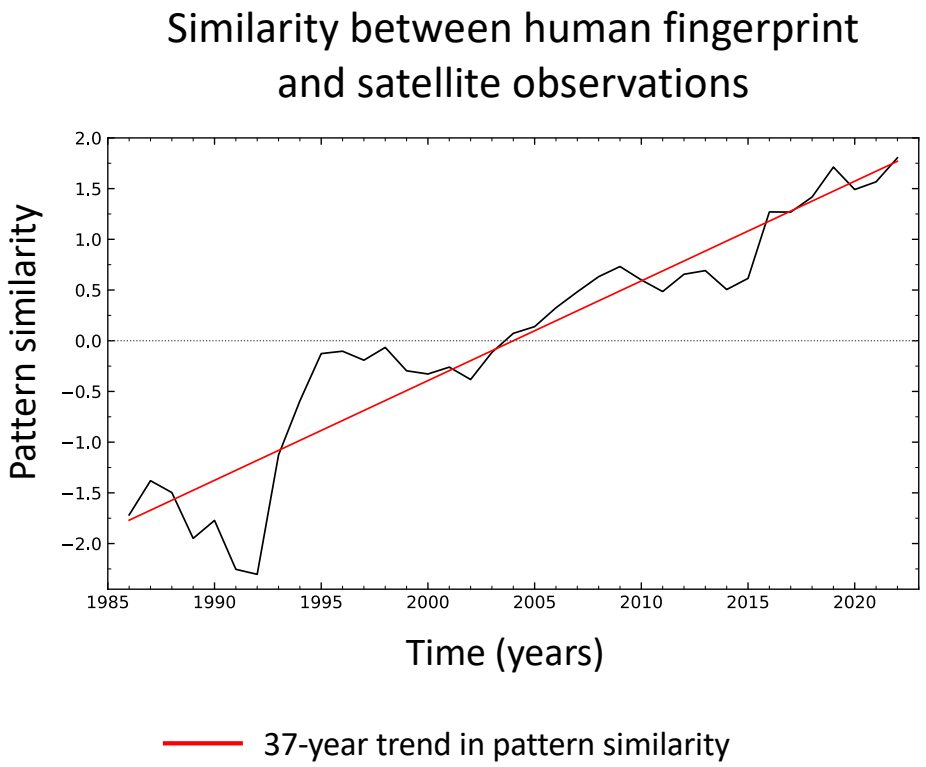


Generate pattern similarity time series



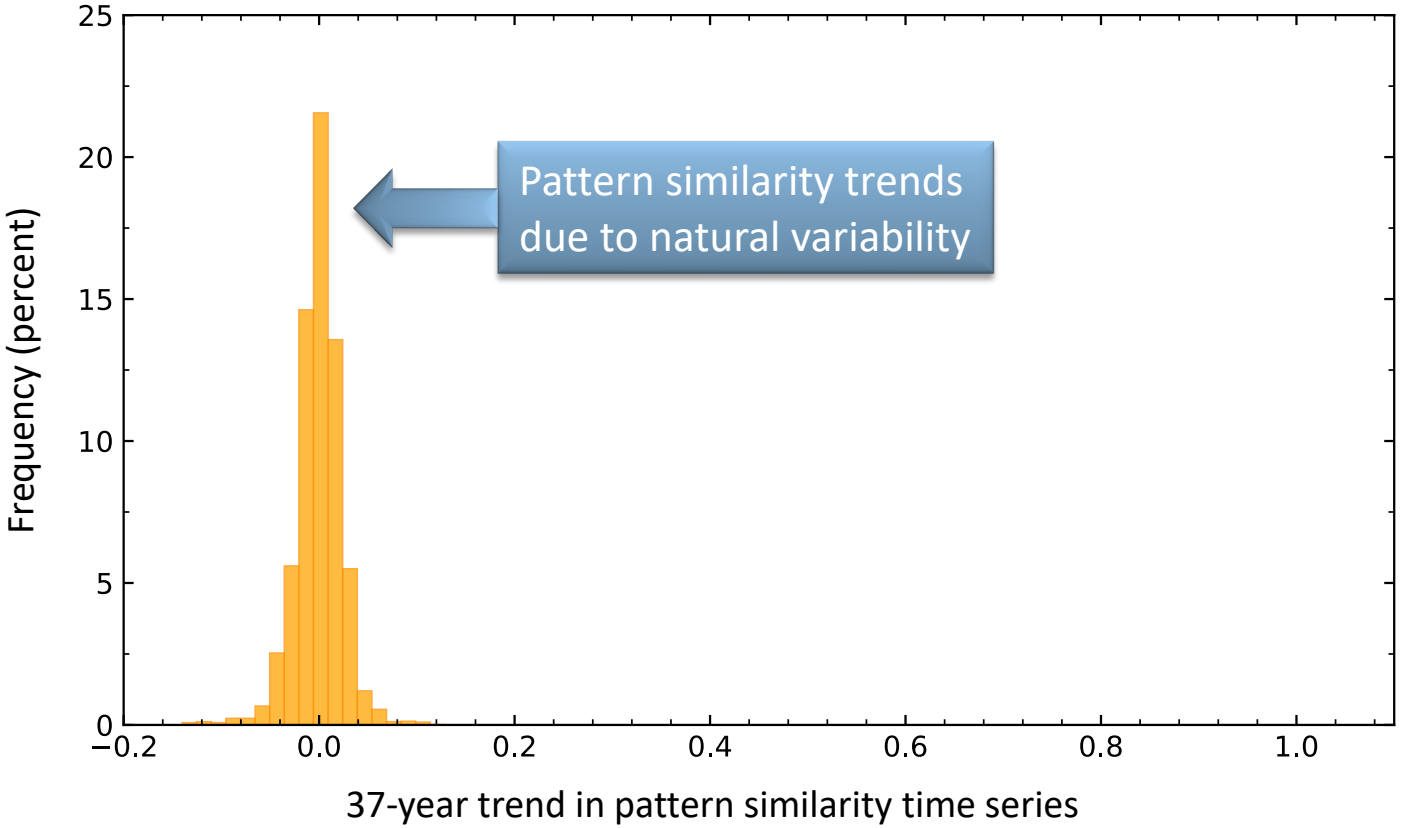
Compare with fingerprint

Fingerprinting explained



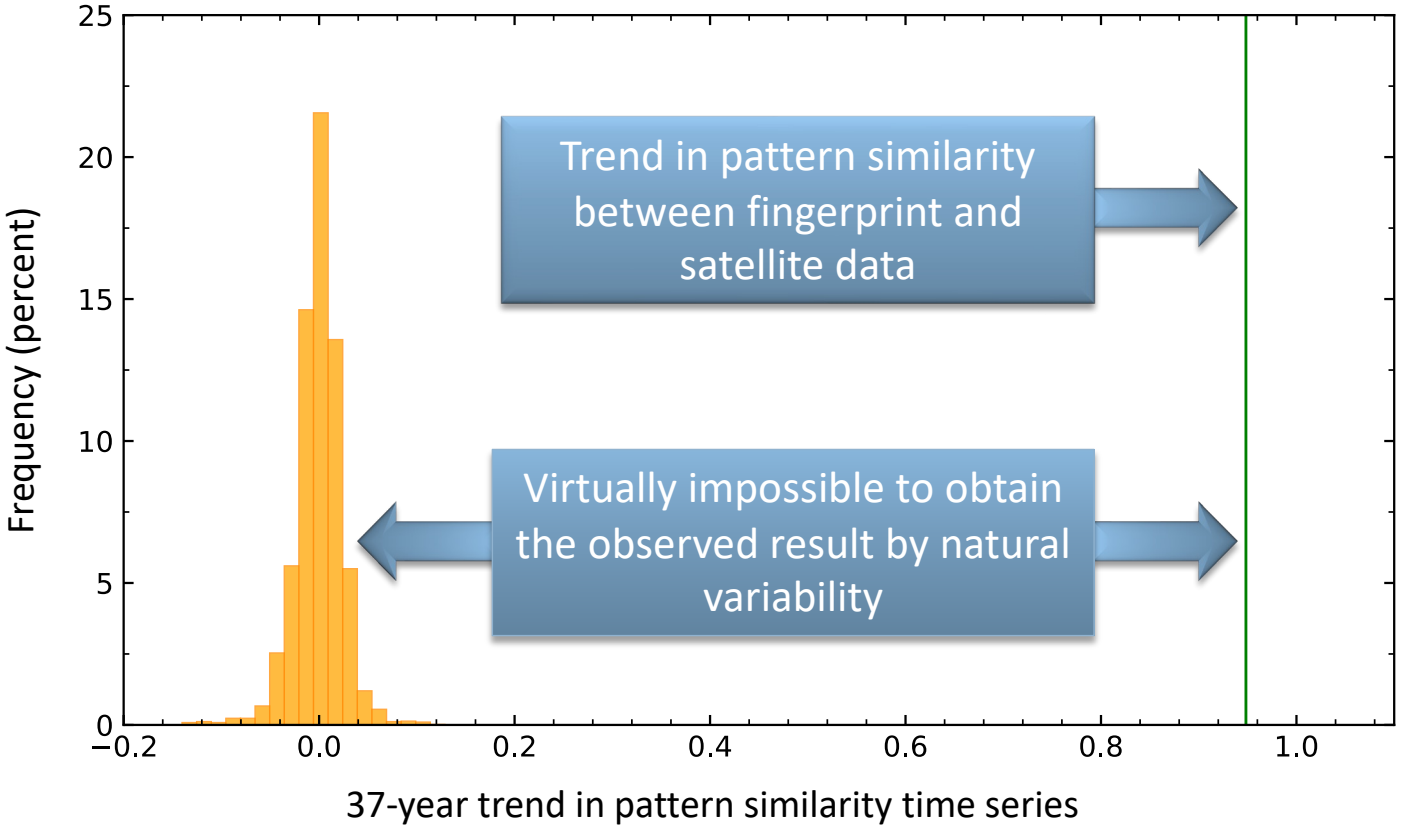
Source: Santer et al., PNAS (2023)

Fingerprinting explained



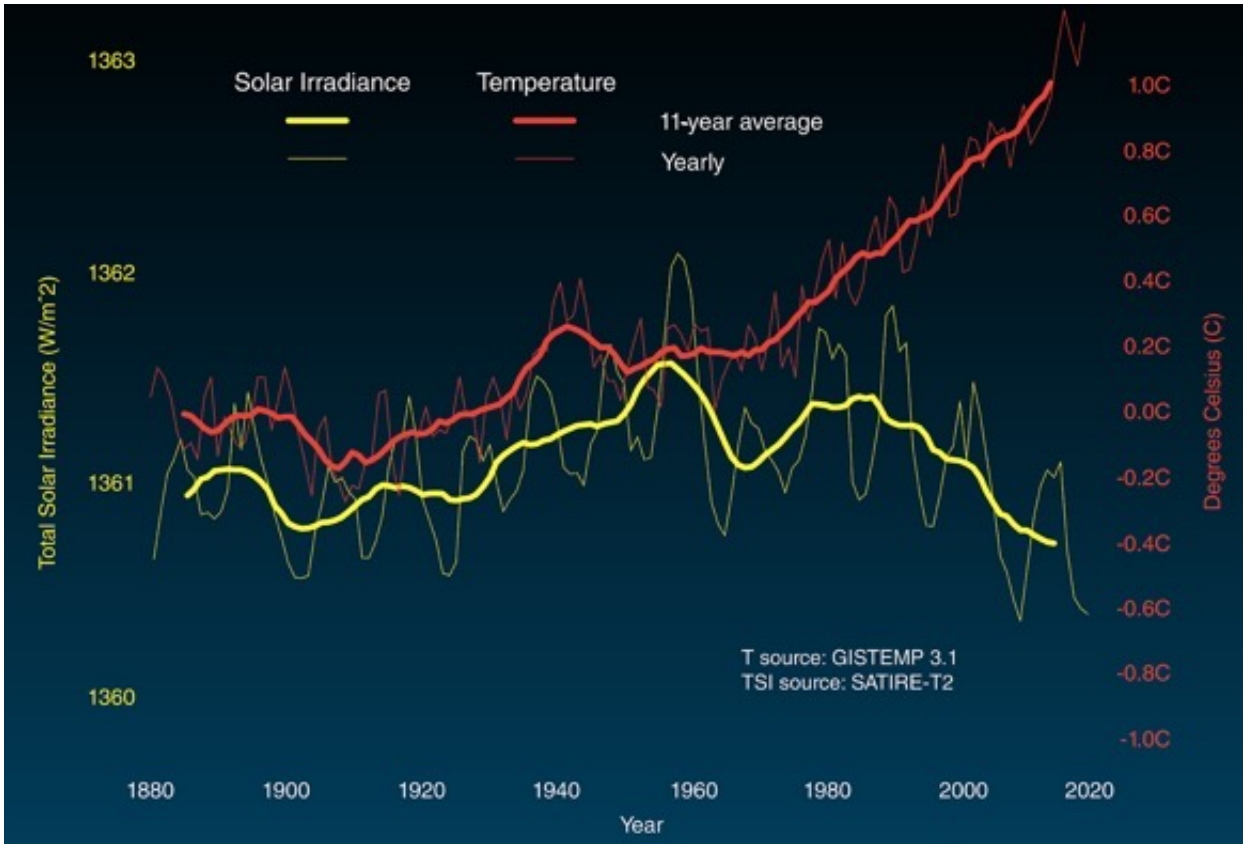
Source: Santer et al., PNAS (2023)

Fingerprinting explained



Source: Santer et al., PNAS (2023)

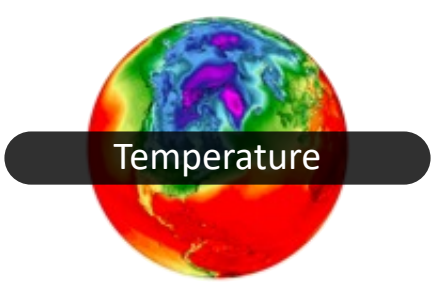
Other evidence against “the Sun explains all surface warming” hypothesis

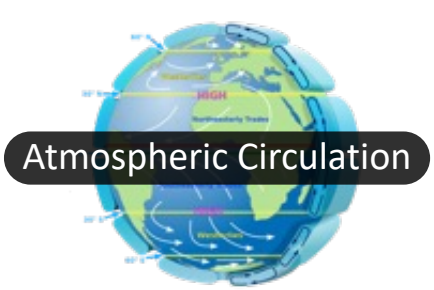


https://climate.nasa.gov/internal_resources/2166

Fingerprinting is performed with many “observables”

- 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 range of instruments

Ubiquitous and unequivocal human fingerprints

Identification of human-induced changes in atmospheric moisture content

B. D. Santer[a,b], C. Mears[c], F. J. Wentz[c], K. E. Taylor[a], P. J. Gleckler[a], T. M. L. Wigley[d], T. P. Barnett[e], J. S. Boyle[a], W. Brüggemann[f], N. P. Gillett[g], S. A. Klein[a], G. A. Meehl[d], T. Nozawa[h], D. W. Pierce[e], P. A. Stott[i], W. M. Washington[d], and M. F. Wehner[j]

[a]Program for Climate Model Diagnosis and Intercomparison, Lawrence Livermore National Laboratory, Livermore, CA 94550; [b]Remote Sensing Systems, Santa Rosa, CA 95401; [c]National Center for Atmospheric Research, Boulder, CO 80307; [d]Scripps Institution of Oceanography, La Jolla, CA 92037; [e]Institut für Unternehmensforschung, Universität Hamburg, 20146 Hamburg, Germany; [f]Climatic Research Unit, School of Environmental Sciences, University of East Anglia, Norwich NR4 7TJ, United Kingdom; [g]National Institute for Environmental Studies, Tsukuba 305-8506, Japan; [h]Hadley Centre for Climate Prediction and Research, United Kingdom Meteorological Office, Exeter EX1 3PB, United Kingdom; and [i]Lawrence Berkeley National Laboratory, Berkeley, CA 94720

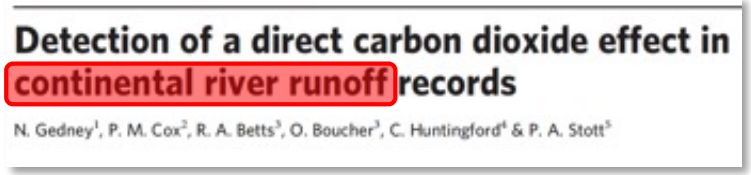
Identifying external influences on global precipitation

Kate Marvel[1] and Céline Bonfils

Program for Climate Model Diagnosis and Intercomparison, Lawrence Livermore National Laboratory, Livermore, CA 94551

Attribution of observed surface humidity changes to human influence

Katharine M. Willett[1,2], Nathan P. Gillett[1], Philip D. Jones[1] & Peter W. Thorne[2]

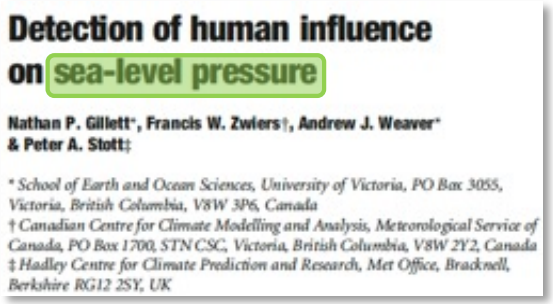


Detection of a direct carbon dioxide effect in continental river runoff records

N. Gedney[1], P. M. Cox[2], R. A. Betts[3], O. Boucher[3], C. Huntingford[4] & P. A. Stott[5]

Human contribution to more-intense precipitation extremes

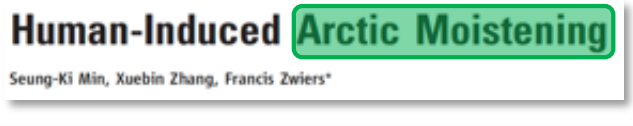
Seung-Ki Min[1], Xuebin Zhang[1], Francis W. Zwiers[1]† & Gabriele C. Hegerl[2]



Detection of human influence on sea-level pressure

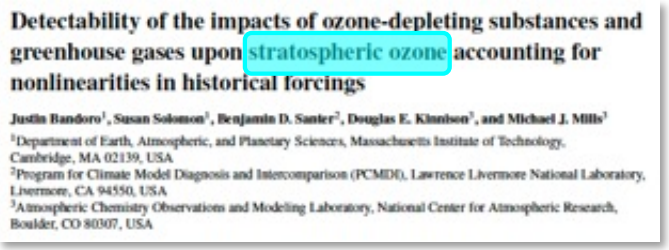
Nathan P. Gillett*, Francis W. Zwiers†, Andrew J. Weaver* & Peter A. Stott‡

* School of Earth and Ocean Sciences, University of Victoria, PO Box 3055, Victoria, British Columbia, V8W 3P6, Canada
† Canadian Centre for Climate Modelling and Analysis, Meteorological Service of Canada, PO Box 1700, STN CSC, Victoria, British Columbia, V8W 2Y2, Canada
‡ Hadley Centre for Climate Prediction and Research, Met Office, Bracknell, Berkshire RG12 2SY, UK



Human-Induced Arctic Moistening

Seung-Ki Min, Xuebin Zhang, Francis Zwiers*



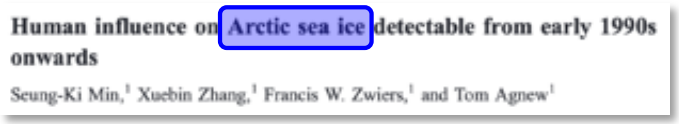
Detectability of the impacts of ozone-depleting substances and greenhouse gases upon stratospheric ozone accounting for nonlinearities in historical forcings

Justin Bandoro[1], Susan Solomon[1], Benjamin D. Santer[2], Douglas E. Kinnison[3], and Michael J. Mills[3]

[1]Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139, USA
[2]Program for Climate Model Diagnosis and Intercomparison (PCMDI), Lawrence Livermore National Laboratory, Livermore, CA 94550, USA
[3]Atmospheric Chemistry Observations and Modeling Laboratory, National Center for Atmospheric Research, Boulder, CO 80307, USA

The fingerprint of human-induced changes in the ocean's salinity and temperature fields

David W. Pierce,[1] Peter J. Gleckler,[2] Tim P. Barnett,[1] Benjamin D. Santer,[2] and Paul J. Durack[2]



Human influence on Arctic sea ice detectable from early 1990s onwards

Seung-Ki Min,[1] Xuebin Zhang,[1] Francis W. Zwiers,[1] and Tom Agnew[1]

Changes in the geopotential height at 500 hPa under the influence of external climatic forcings

Nikolaos Christidis[1] and Peter A. Stott[1]

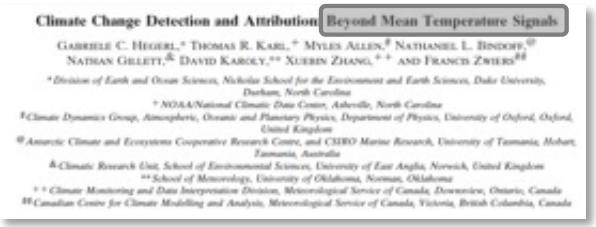
[1]Met Office Hadley Centre, Exeter, UK

Detection of human influence on twentieth-century precipitation trends

Xuebin Zhang[1], Francis W. Zwiers[1], Gabriele C. Hegerl[2], F. Hugo Lambert[2], Nathan P. Gillett[3], Susan Solomon[3], Peter A. Stott[3] & Toru Nozawa[4]

Human influence on joint changes in temperature, rainfall and continental aridity

Céline J. W. Bonfils[1,2], Benjamin D. Santer[1], John C. Fyfe[3], Kate Marvel[1,4], Thomas J. Phillips[1] and Susan R. H. Zimmerman[5]



Climate Change Detection and Attribution: Beyond Mean Temperature Signals

Gabriele C. Hegerl,* Thomas R. Karl,+ Myles Allen,# Nathaniel L. Bindoff,@ Nathan Gillett,& David Karoly,** Xuebin Zhang,++ and Francis Zwiers##

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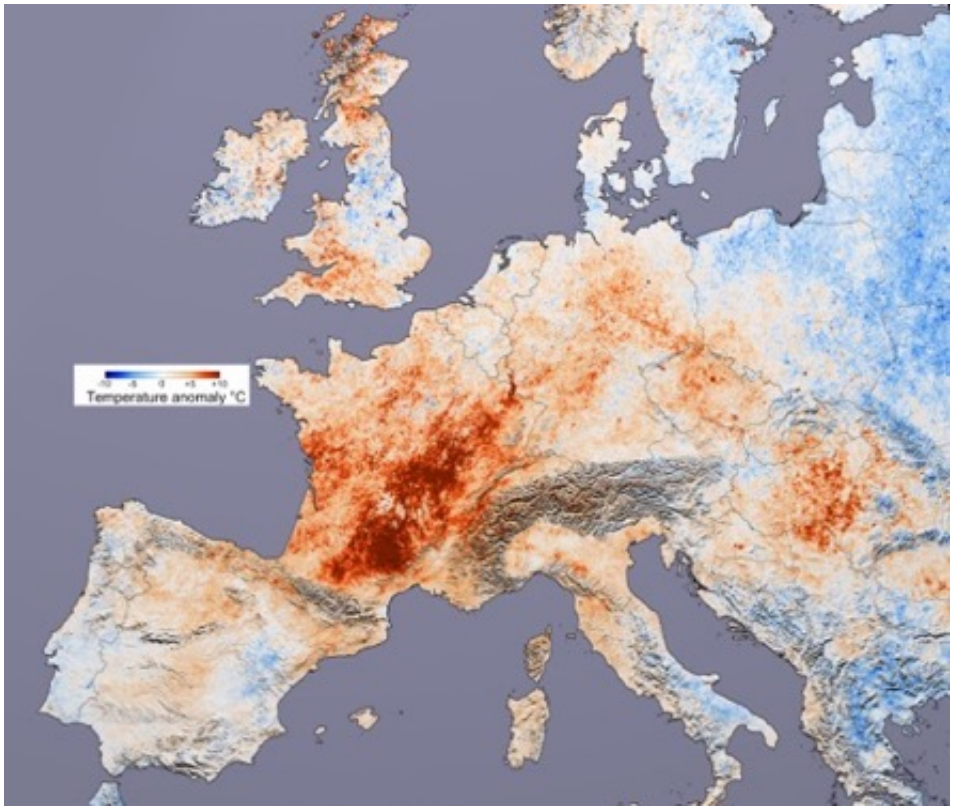
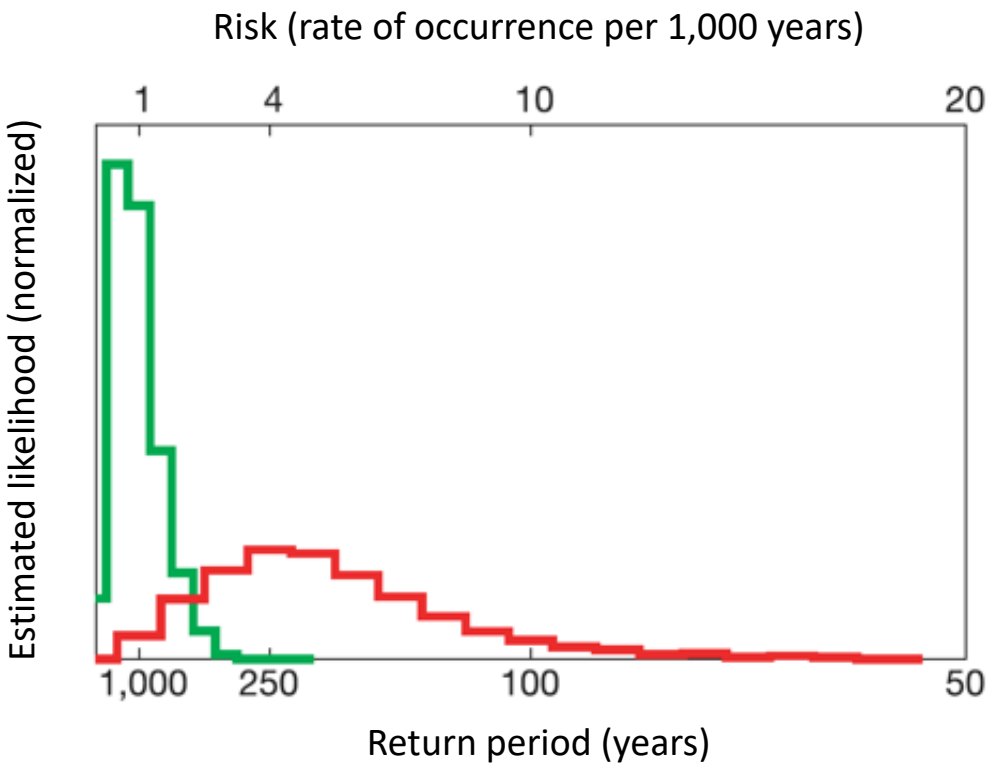
The 2003 European summer heatwave



- 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)

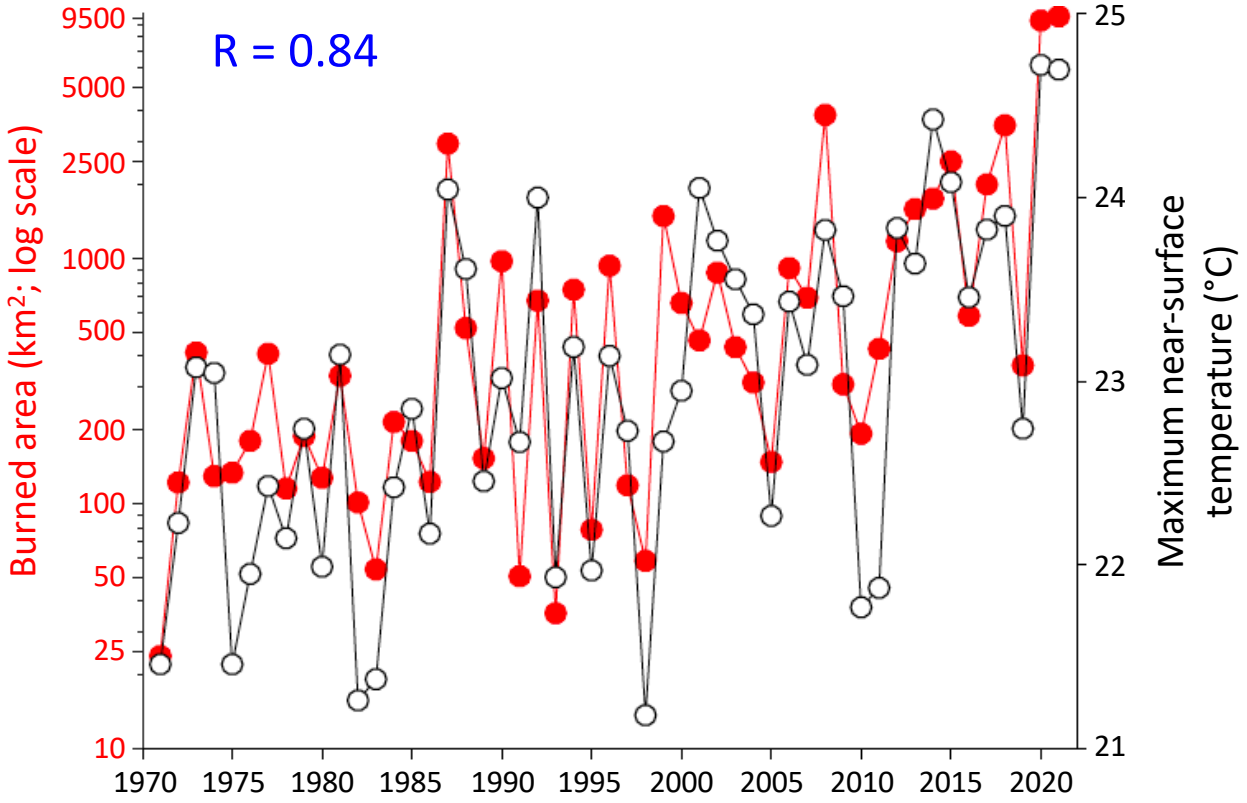
Hurricane Harvey (2017)

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

"…anthropogenic climate change likely increased Hurricane Harvey's total rainfall by at least 19% with a best estimate of 38%" (Risser and Wehner, 2017)

*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

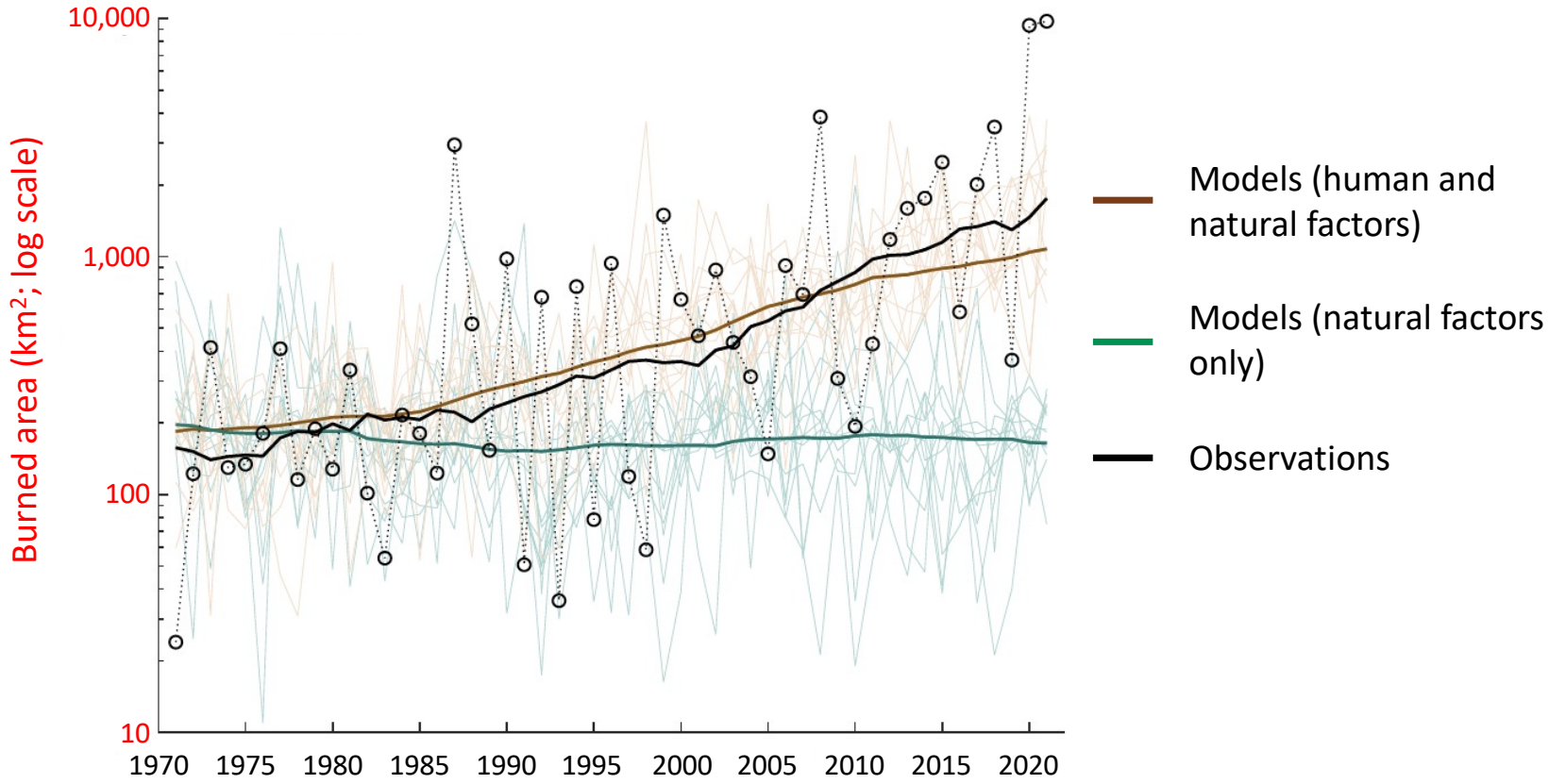
Wildfires in California



"…nearly all of the increase in burned area over the past half-century is attributable to anthropogenic climate change"

Source: Turco et al., PNAS (2023)

Wildfires in California

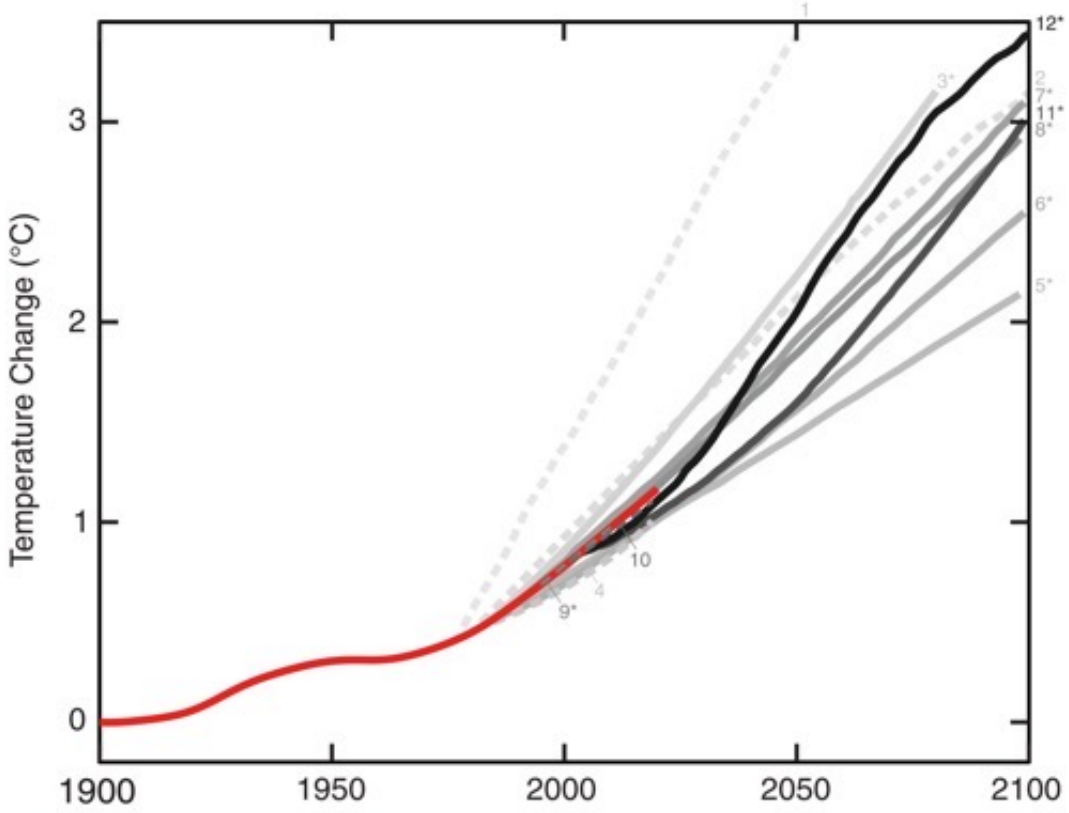


Source: Turco et al., PNAS (2023)

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?

Event attribution: Legal issues and questions



Observed temperature change

Exxon's temperature change projections

Figure is from Supran et al., *Science* (2023)

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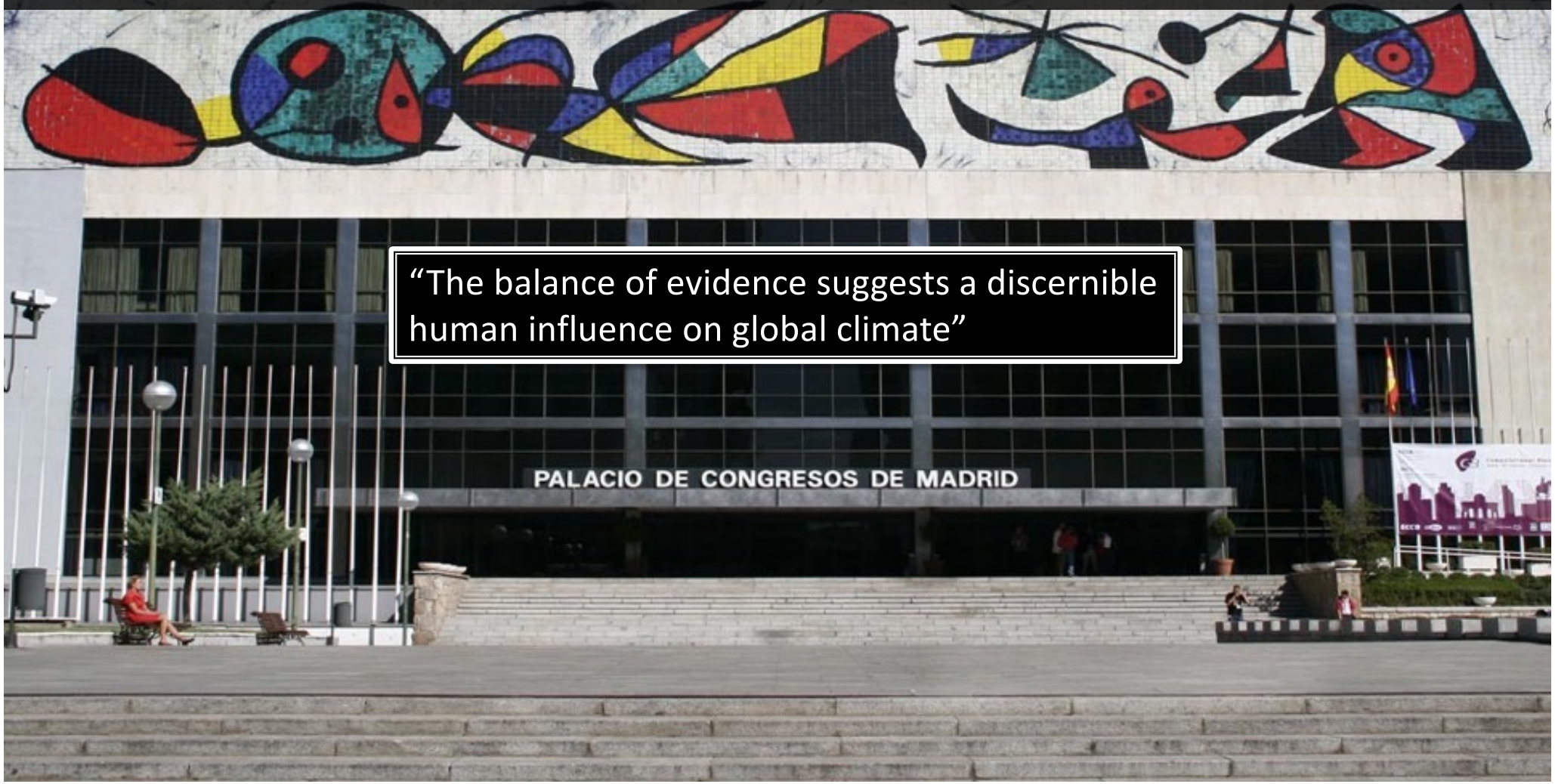
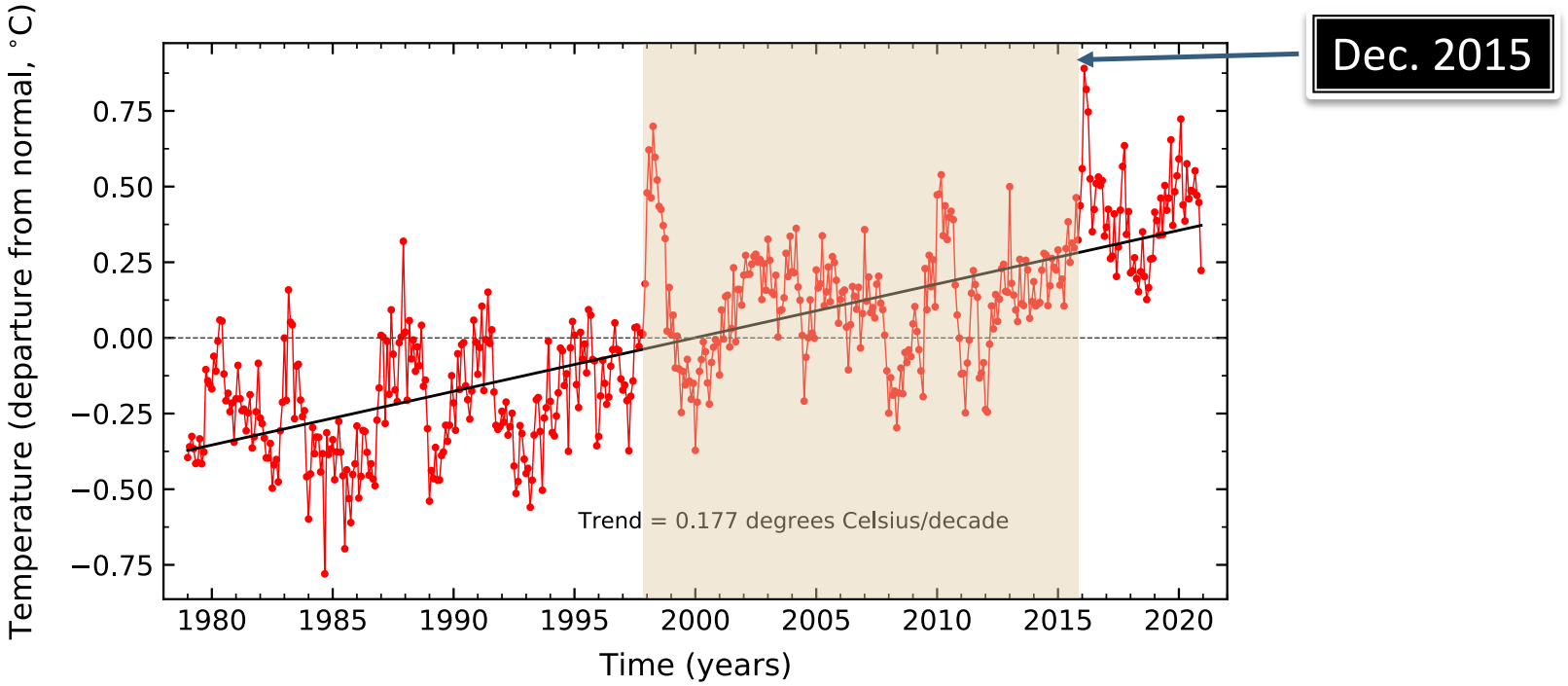
A life-changing event: Madrid, 1995



Four lessons learned

1. Defend scientific understanding
2. Never engage in science by eminence of position
3. Don’t just preach to the choir
4. Declare your values

1. Defend scientific understanding



Senator Ted Cruz, Dec. 8, 2015: “No significant global warming for the past 18 years”

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

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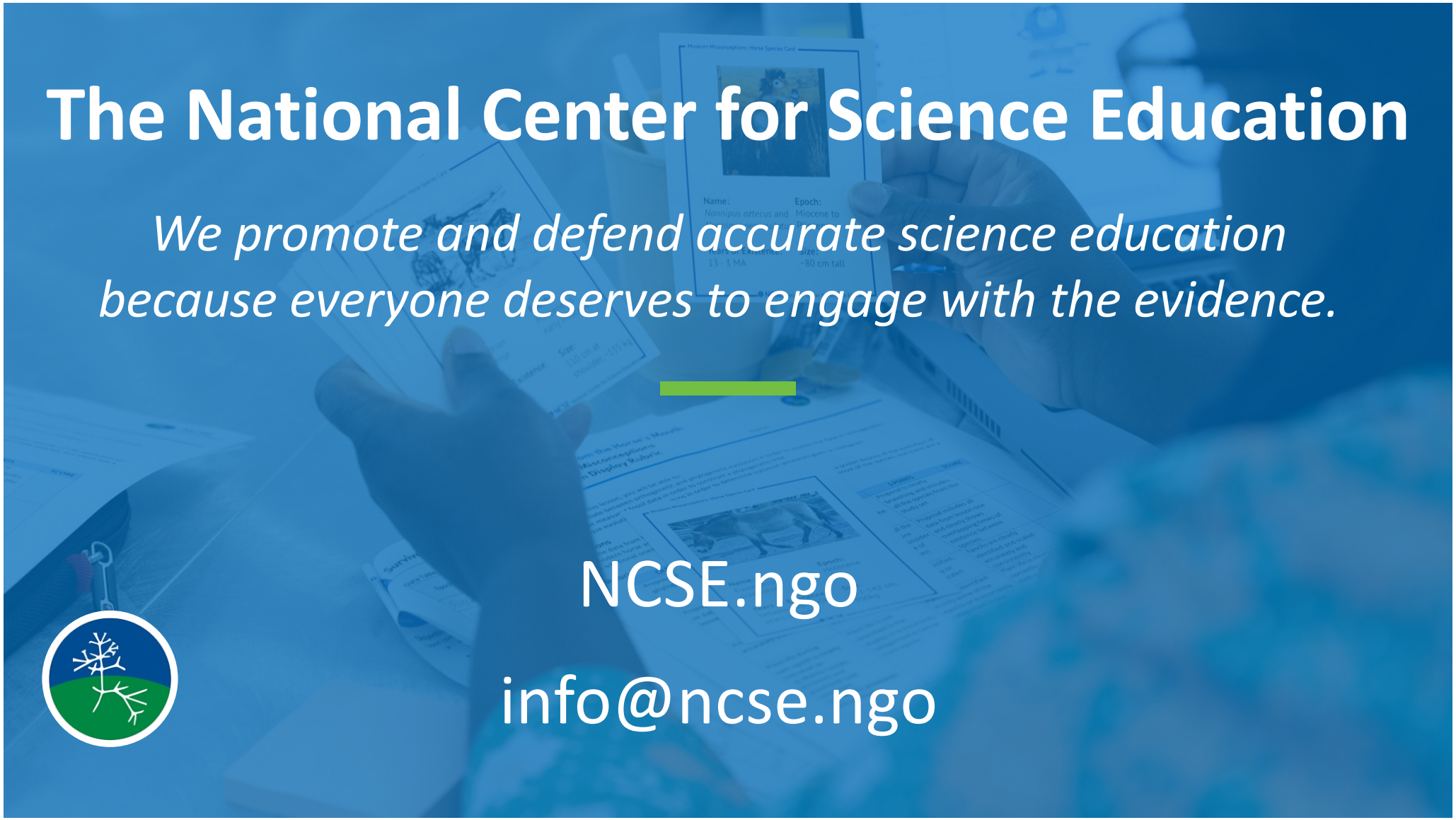
Take-home messages

- “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

Additional resources

- https://nap.nationalacademies.org/catalog/25733/climate-change-evidence-and-causes-update-2020
- https://report.ipcc.ch/ar6syr/pdf/IPCC_AR6_SYR_SPM.pdf
- https://www.science.org/doi/10.1126/science.abk0063 (Assessing ExxonMobil's global warming projections)
- https://www.sigmaxi.org/news/keyed-in/post/keyed-in/2019/11/11/how-do-we-know-that-human-activities-have-affected-global-climate
- https://www.pnas.org/doi/10.1073/pnas.2213815120 (Anthropogenic climate change impacts exacerbate summer forest fires in California)
- https://blog.ucsusa.org/carly-phillips/what-is-vapor-pressure-deficit-vpd-and-what-is-its-connection-to-wildfires



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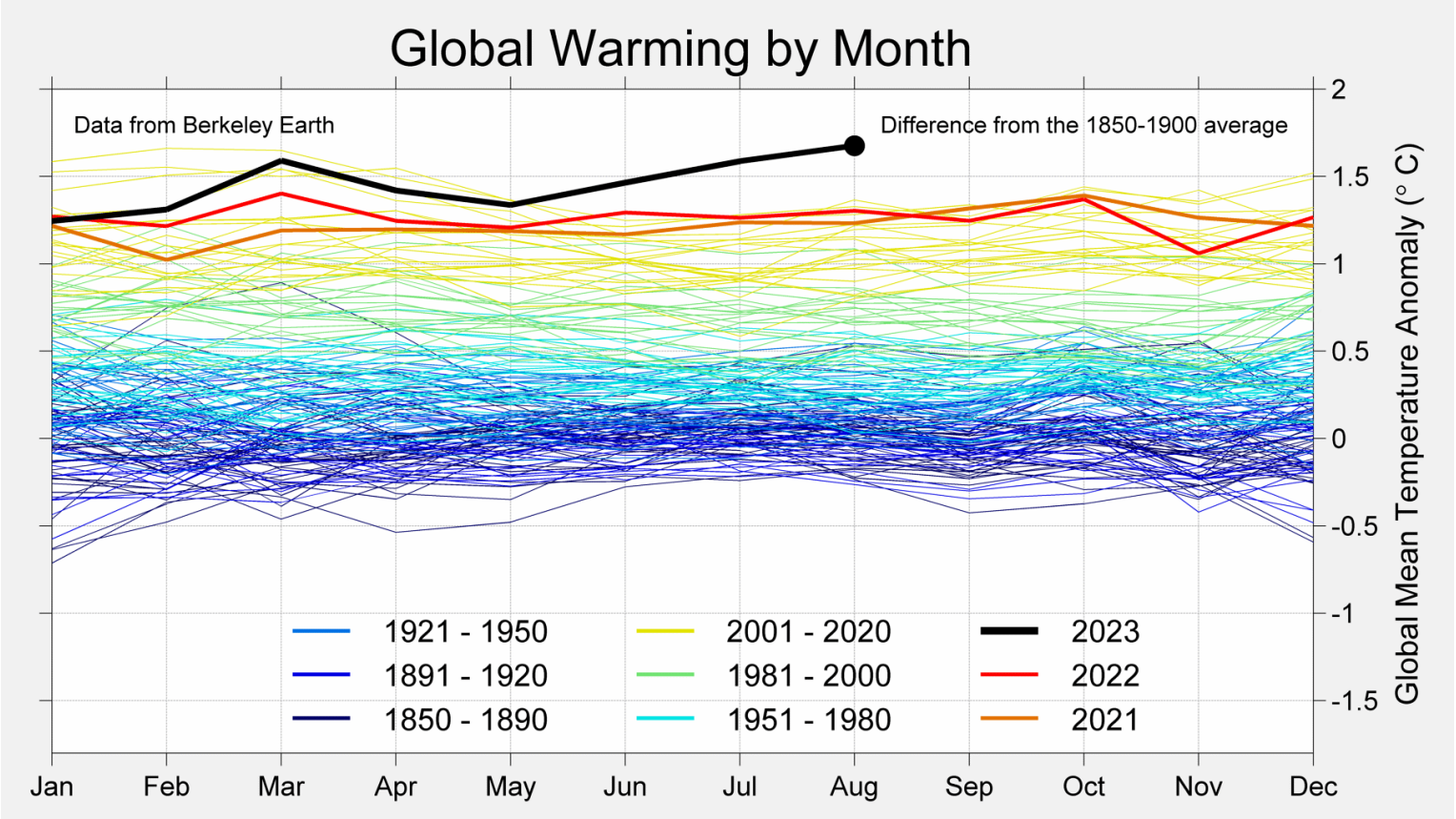
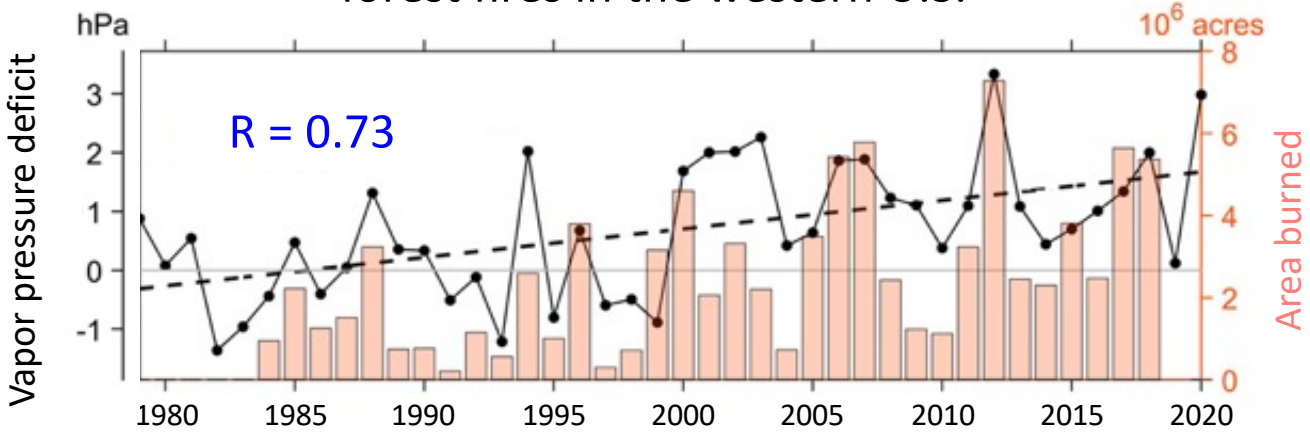
Another way of looking at the observed warming of Earth's surface



https://berkeleyearth.org/wp-content/uploads/2023/09/SeasonalAnomalies-August2023.png

Wildfires in the western U.S.

Vapor pressure deficit and area burned by forest fires in the western U.S.



"…anthropogenic warming is the main cause for increasing fire weather…"

Source: Zhuang et al., PNAS (2021)