

Science of Attribution

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Setting the stage.



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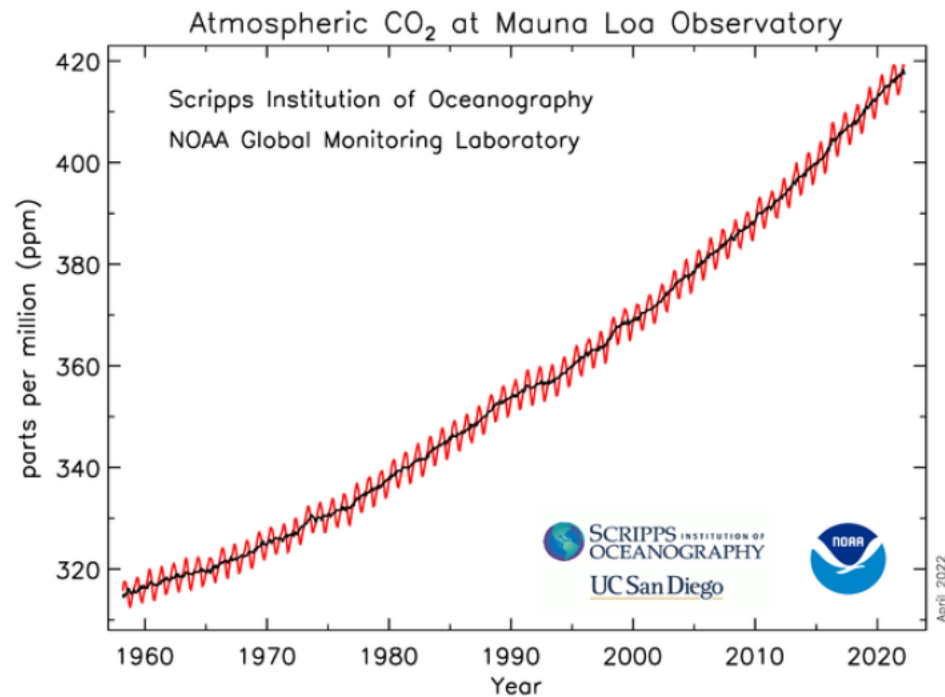
Assumptions for this Presentation

- The scientific foundation of our understanding of the Earth's climate is based on **fundamental principles of the conservation of energy, momentum, and mass.**
- The scientific foundation of our understanding of the Earth's climate is based on an **enormous and diverse** number of observations.

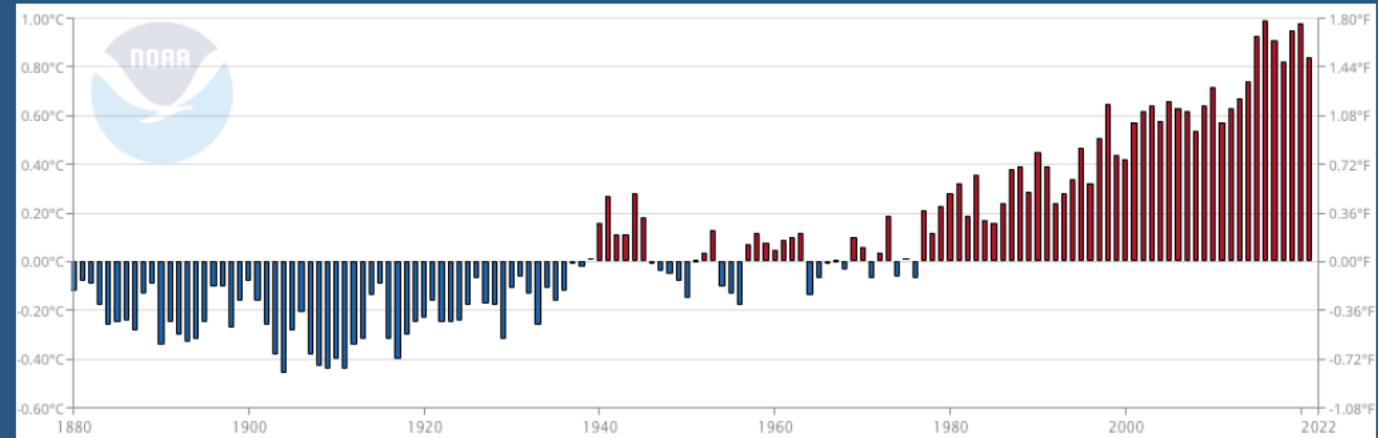


Observed Change

Increasing Carbon Dioxide Concentrations



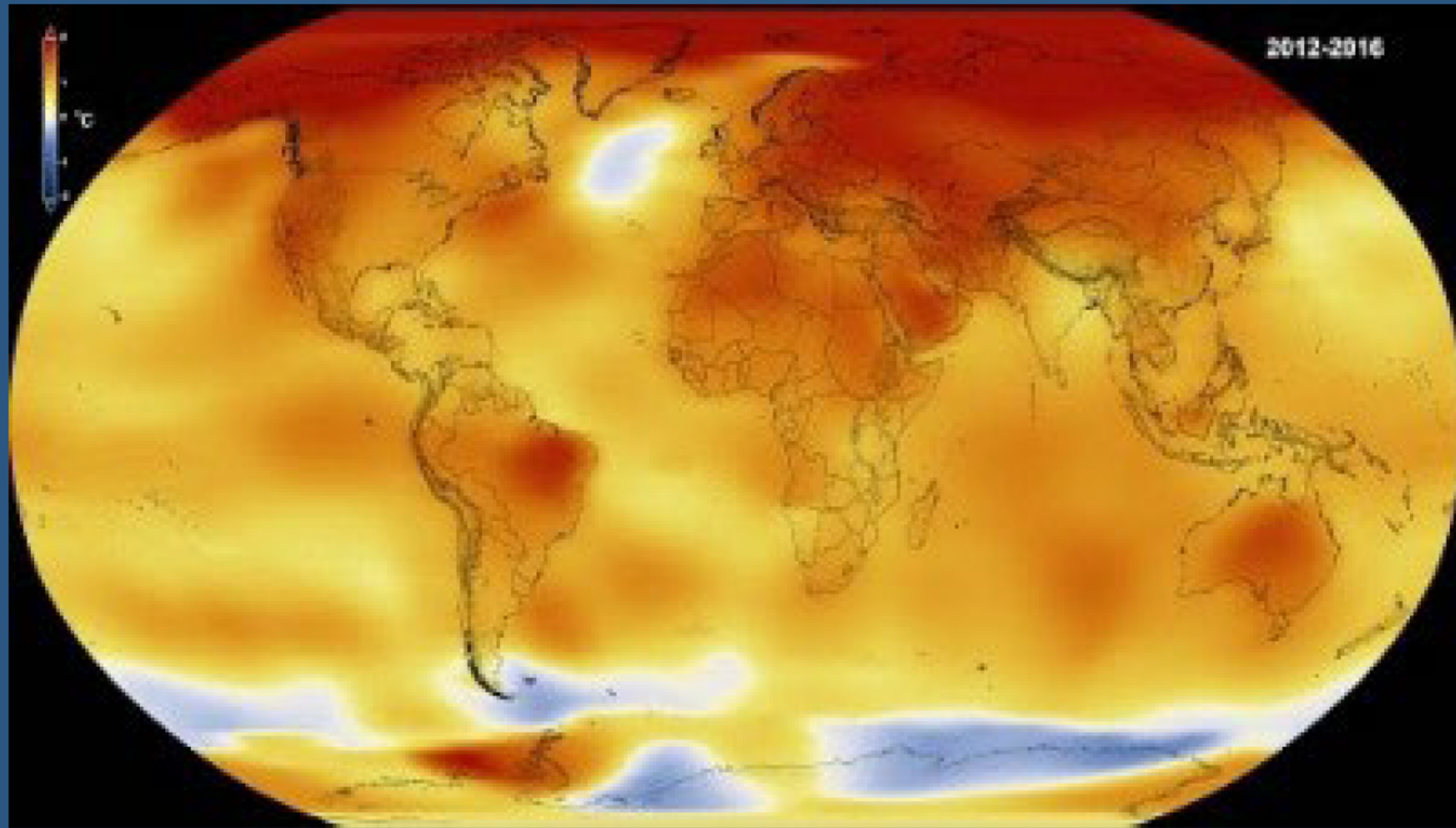
Increasing Global Surface Temperature



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Observed Change



NASA

https://youtu.be/Ni0lppUr_BQ

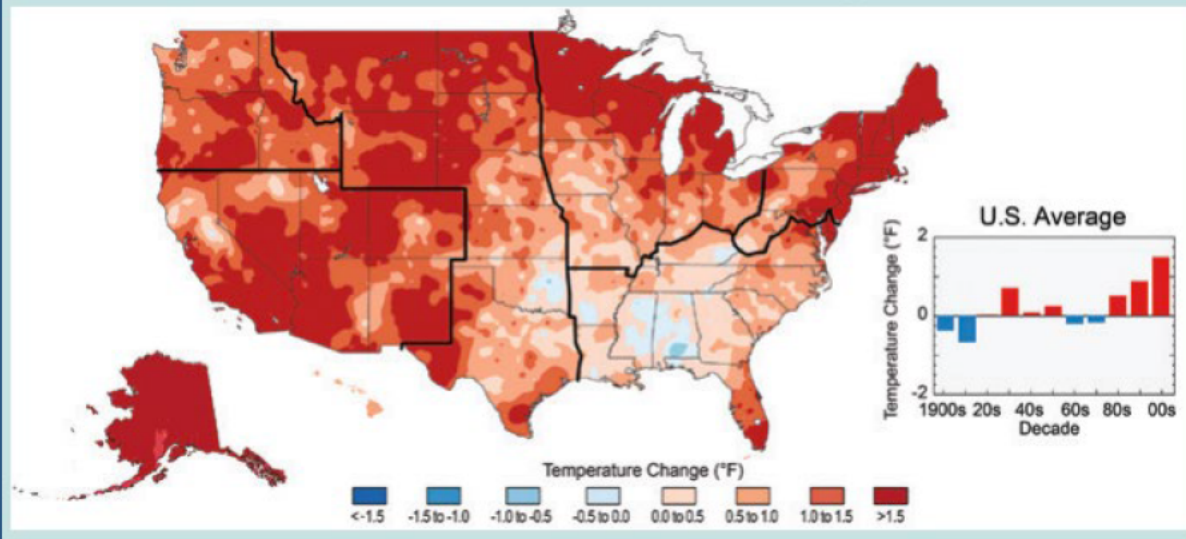


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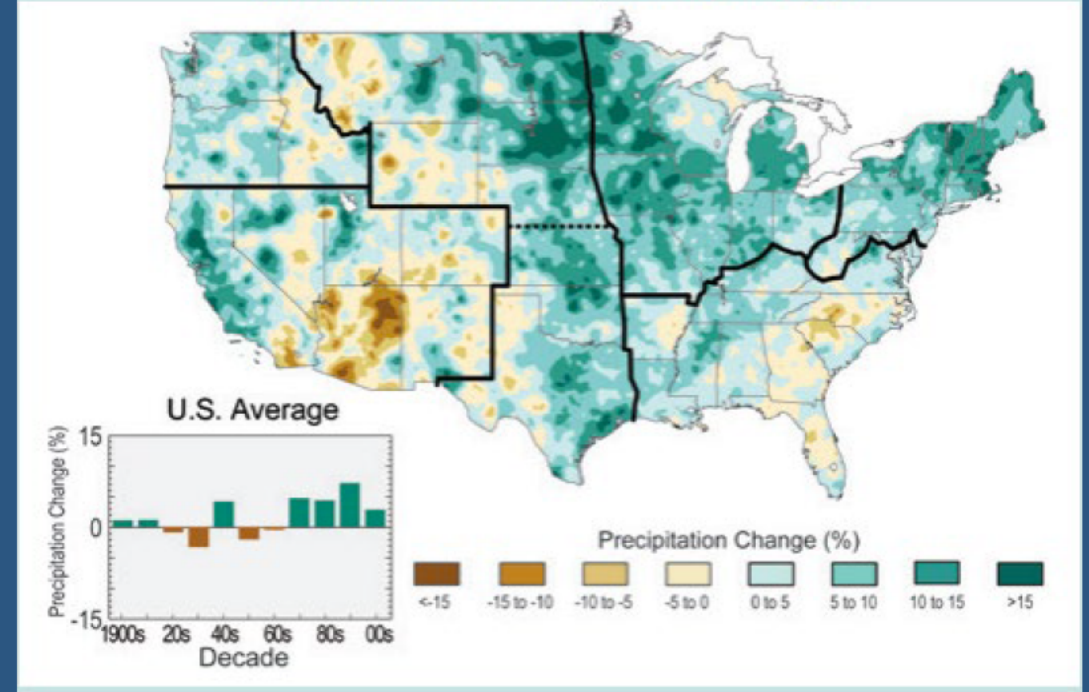
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U.S. National Climate Assessment

Observed U.S. Temperature Change



Observed U.S. Precipitation Change



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Quick Definitions

- What is Weather?

The state of the atmosphere at a given time and place. This state is defined with respect to variables such as temperature, moisture, wind velocity, and barometric pressure.

- What is Climate?

The meteorological conditions (i.e., temperature, precipitation, wind, etc.) that characteristically prevail in a particular region. Generalized weather variation for a given place. Can be thought of as “average weather.”



Recap: Some of What We Know

- The average global temperature of the Earth's surface will continue to rise because of the continued increase of human-caused addition into the atmosphere of gases that hold heat close to the surface.
- Historically stable masses of ice on land will melt.
- Sea level will rise.
- **The weather will change.**



Extreme events shape our experiences.



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A Range of Events



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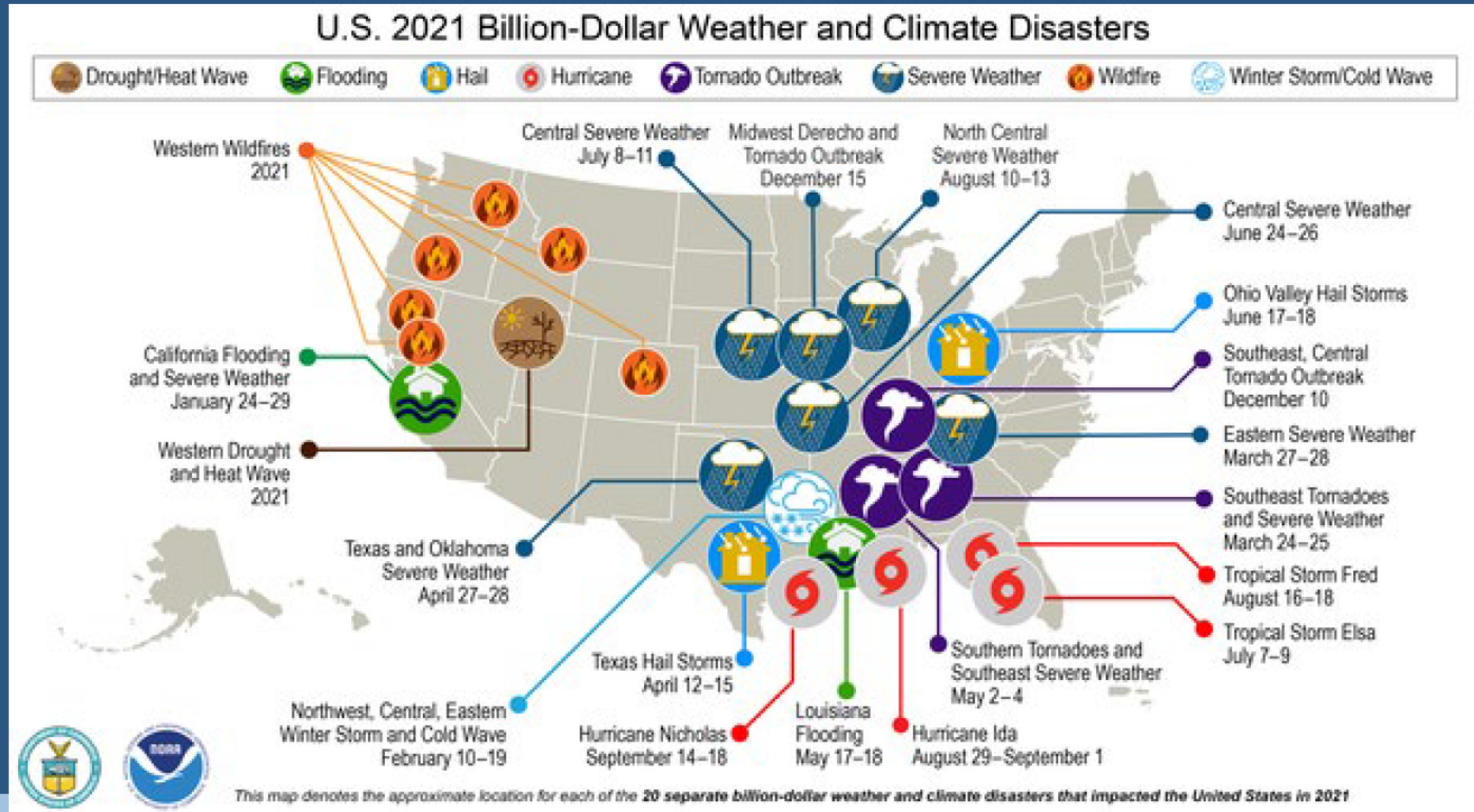
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Hurricane Sandy (2012)



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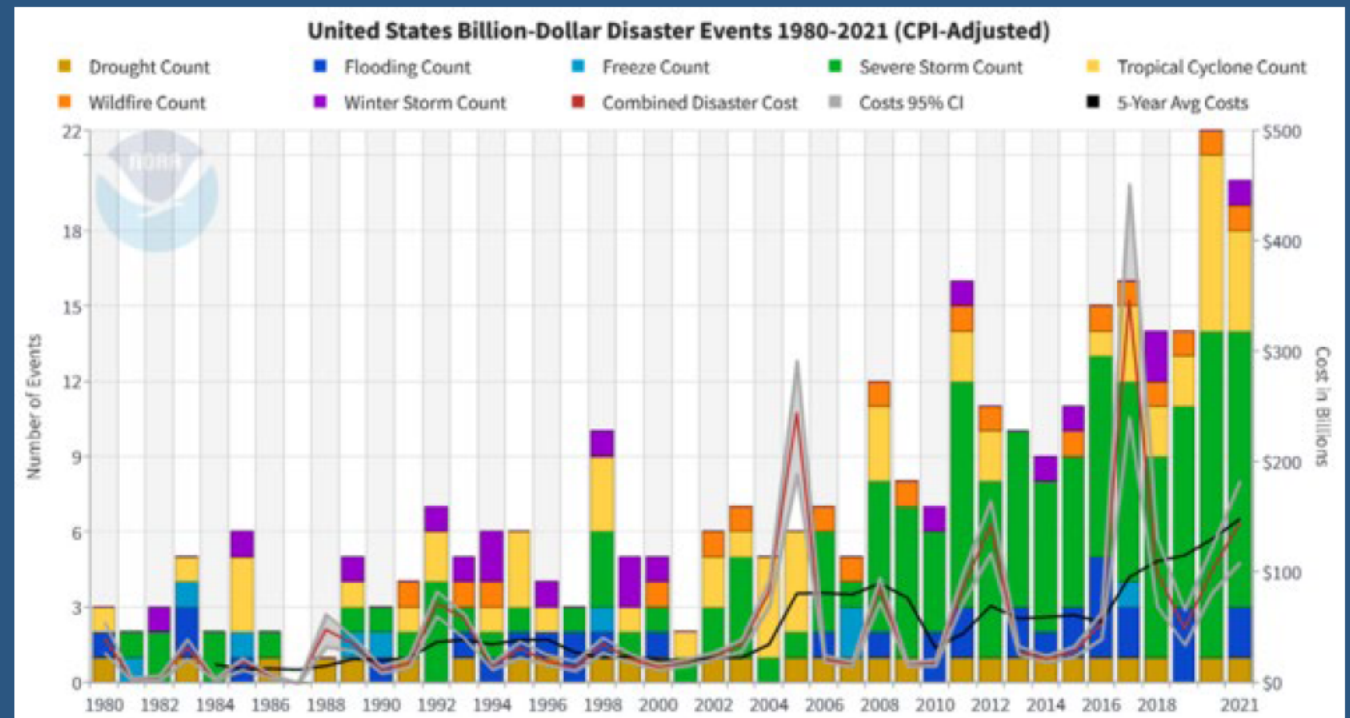
Impacts of Extreme Events



Extreme Events and Climate Change

U.S. National Climate Assessment:

*“Changes in **extreme weather events** are the primary way that most people experience climate change. Human-induced climate change has already increased the number and strength of some of these extreme events.”*



Harvey (2017)



PHOTOGRAPH BY MICHAEL GOODMAN FOR CNN

CNN



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Florence (2018)

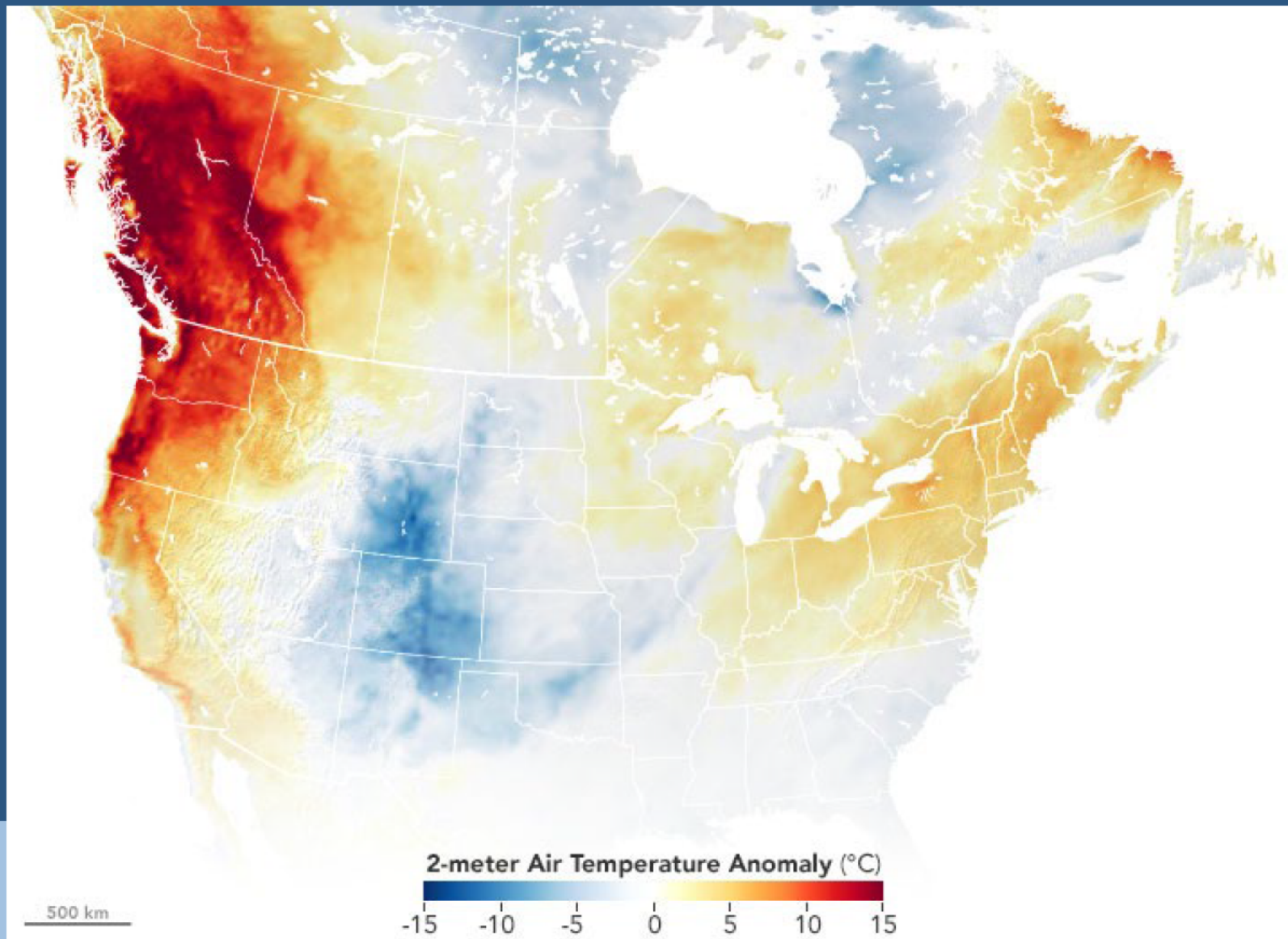


Vox



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Pacific Northwest Heatwave (2021)



NASA



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European Flooding (2021)



Science



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US and Greek Wildfires (2021)



Vox



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Pakistan Floods (2022)



CNN



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Did climate change
change
events like these?



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Really it is Two Questions:

How has the risk of a weather event changed because of climate change?

Or

How did climate change affect the magnitude of that event?



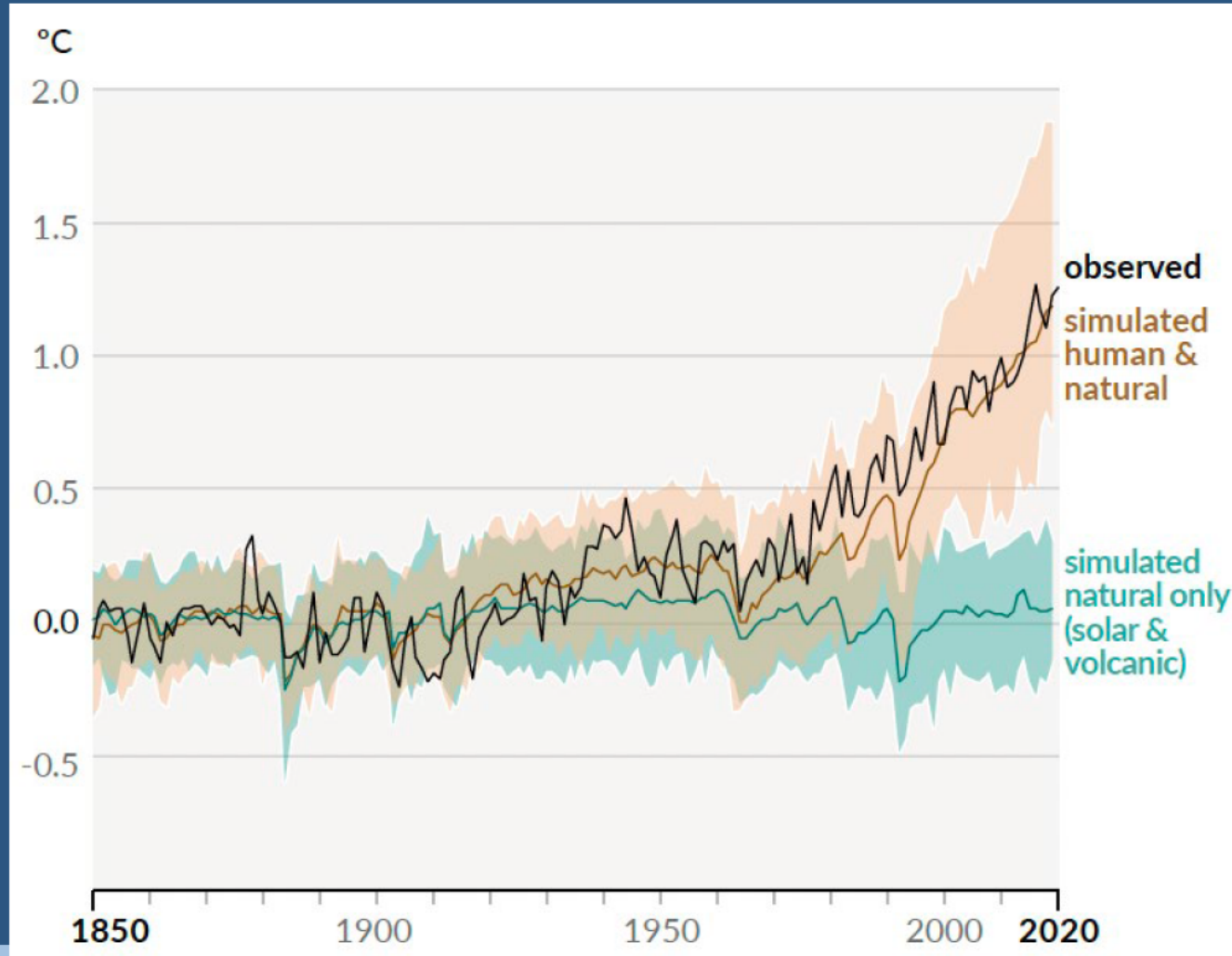
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Back to fingerprinting.



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Formal Detection and Attribution



Actual

Counterfactual

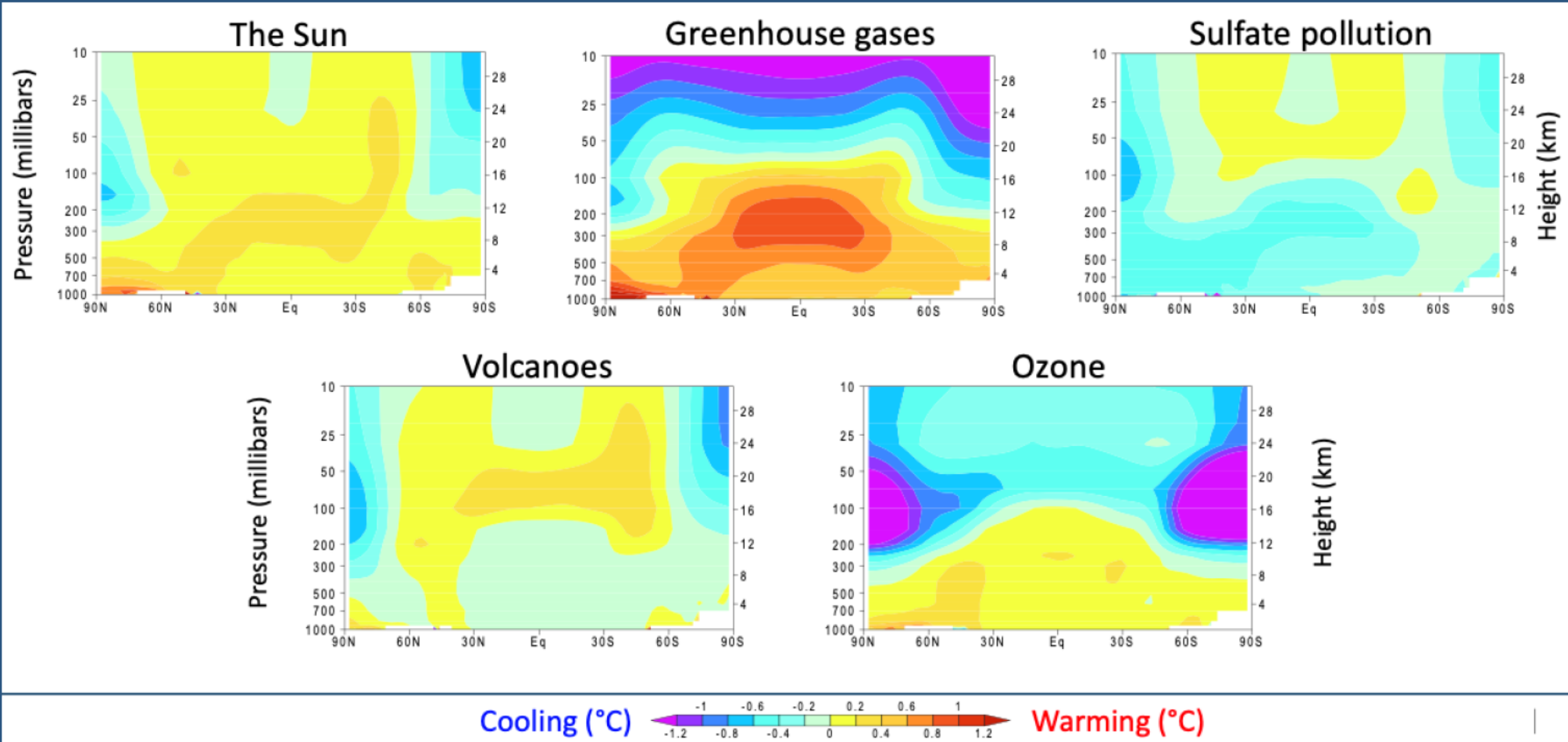
B. Santer

Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S. L., Péan, C., Berger, S., ... & Zhou, B. (2021). Climate change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.



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Natural and Human Fingerprints



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Formal Detection and Attribution

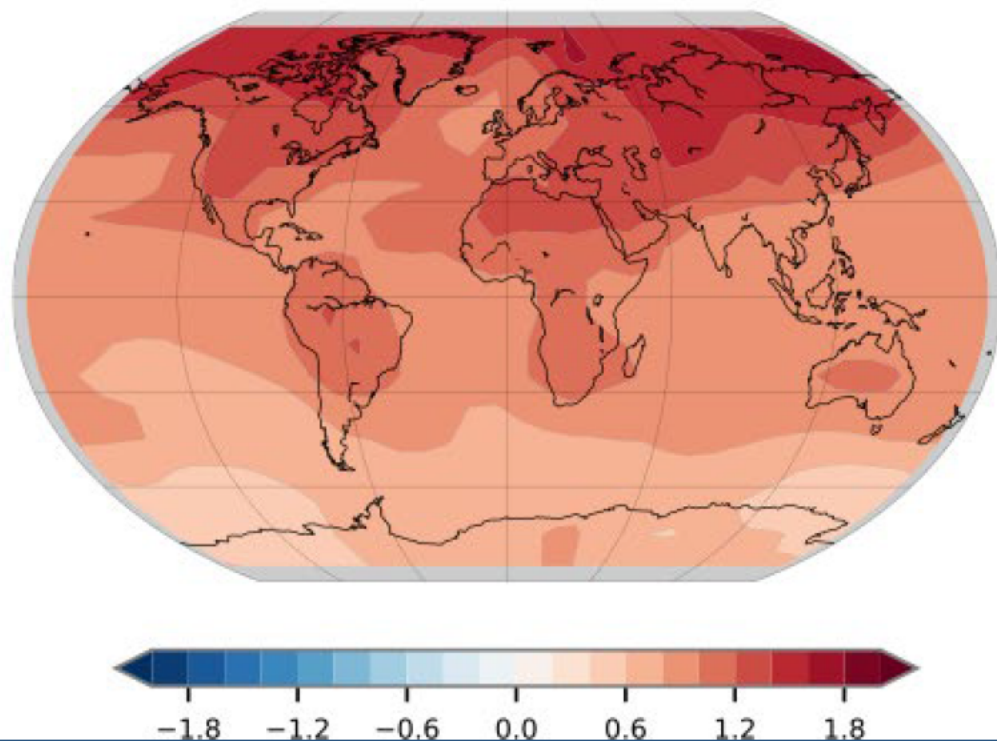
Step 1: Examine some observed variable.

- Air temperature, moisture, ocean temperature, snow cover, sea ice, etc.
- Identify the magnitude and pattern of the change over time.
- A signal to noise problem.
 - Signal is the change.
 - Noise is the natural variability of the climate system (e.g., El Nino).
 - Is the signal distinguishable from the noise in a statistically significant sense?
 - If no, there is no change in this variable, or
 - the observations might not be high quality, or long enough to detect change.
 - If yes, this is “detection” of climate change.

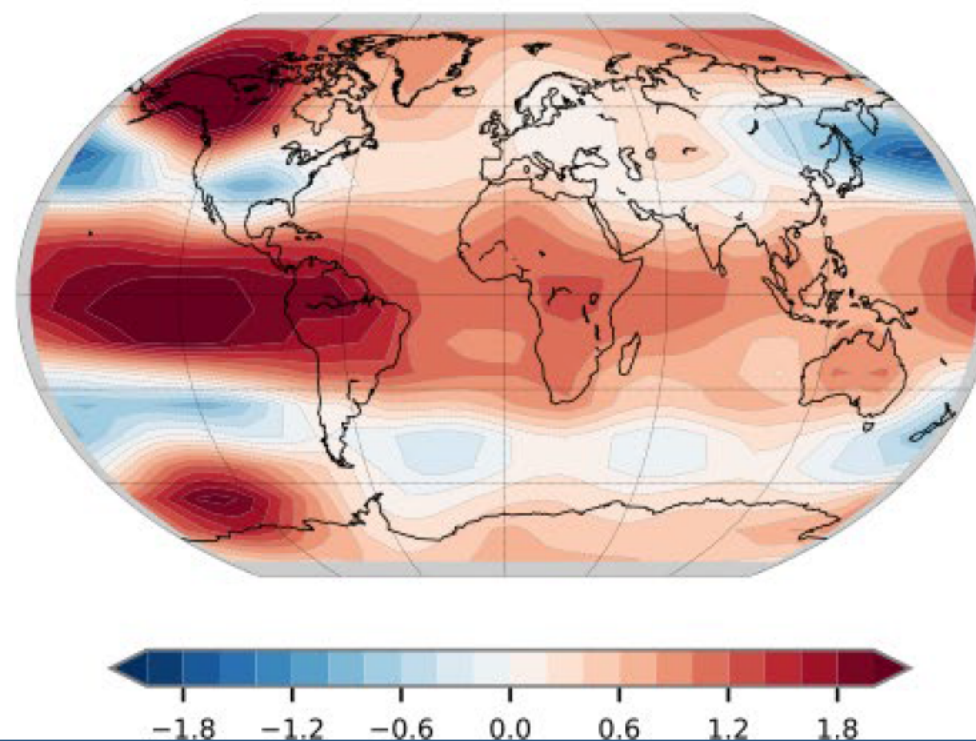


Formal Detection and Attribution

Human fingerprint



Natural climate variability



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Formal Detection and Attribution

Step 2: Examine climate model simulations configured to replicate the actual world as realistically as possible.

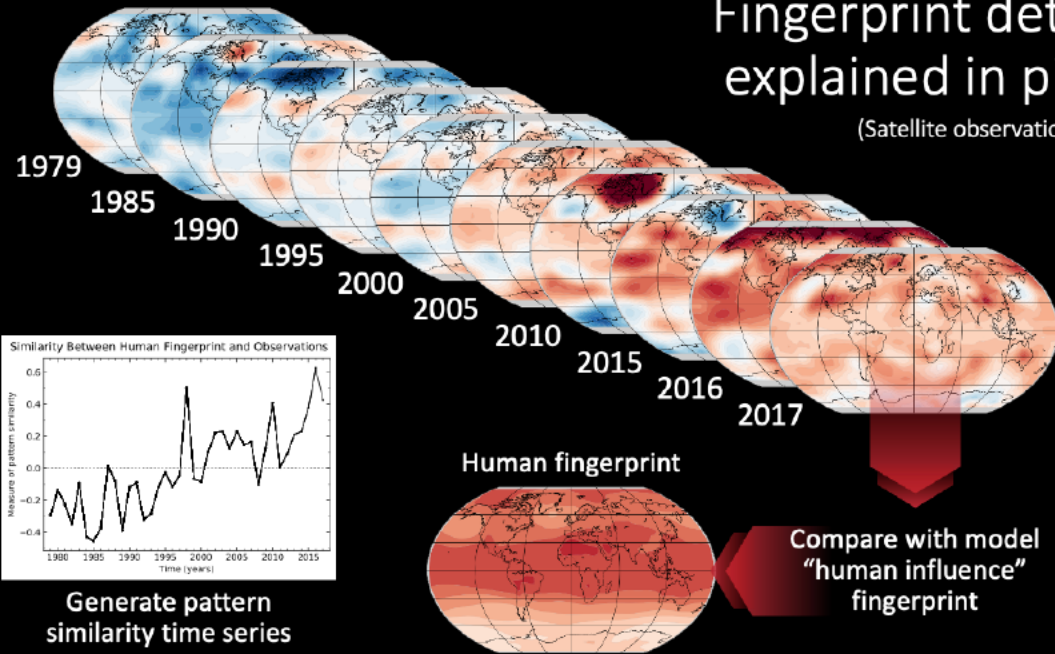
- Use best estimates of observed atmospheric composition, land cover, solar variability and volcanic activity in a climate model simulation.
- Search these simulations to find if the patterns and magnitude of the detected observed changes were produced by the model of the actual world.
- If not, the model is not good enough to simulate the change or,
 - It could be a natural multi-decadal mode of variability.
- **We reject the hypothesis that the humans caused the detected change.**



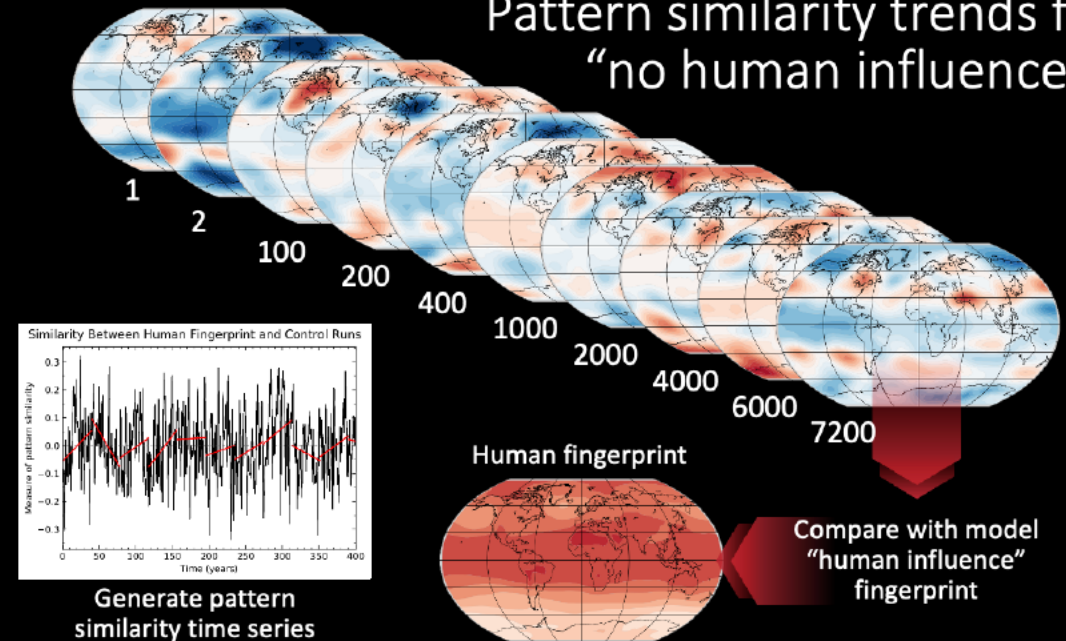
Formal Detection and Attribution

Fingerprint detection explained in pictures

(Satellite observations)



Pattern similarity trends for the "no human influence" case



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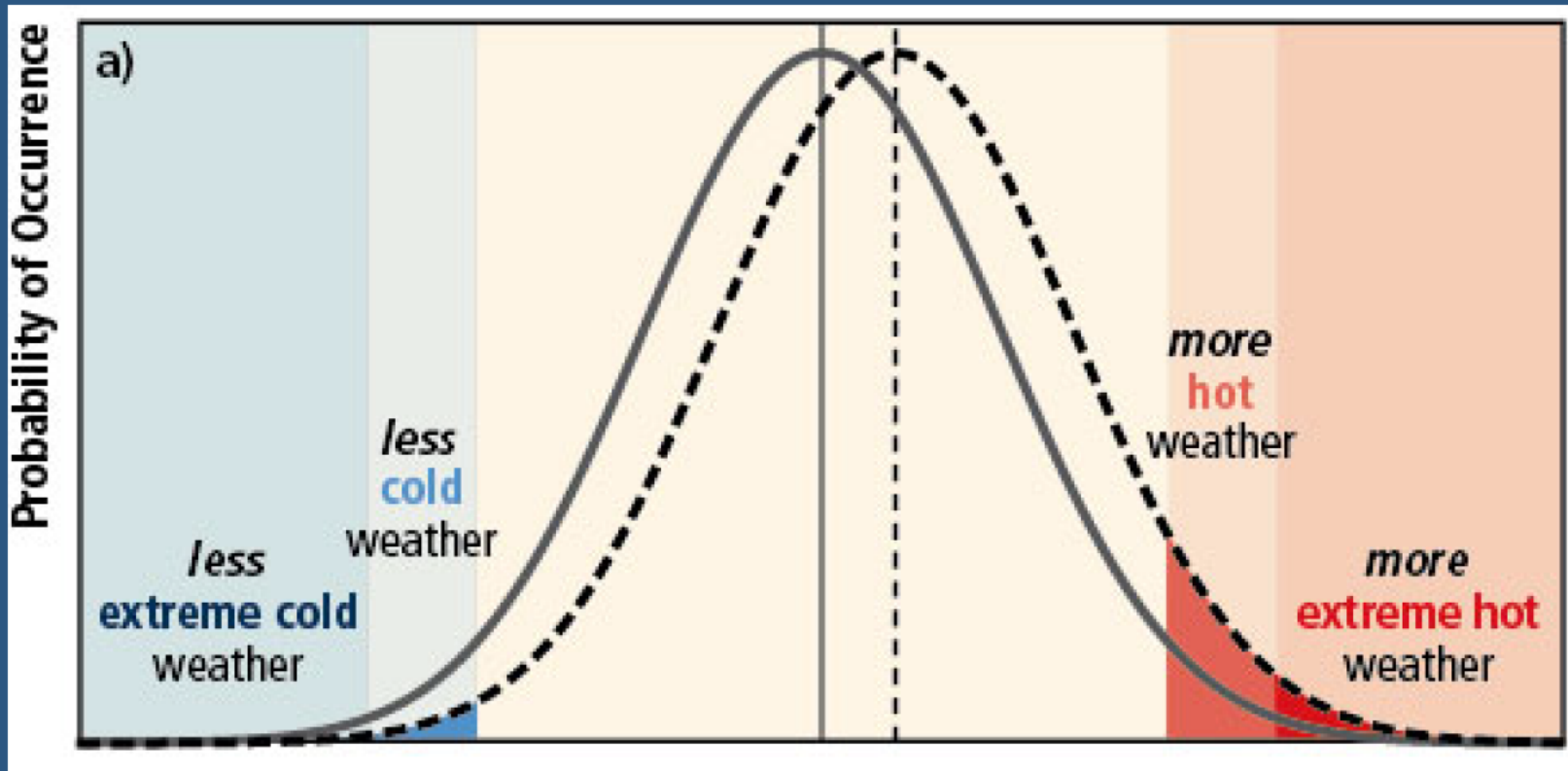
Formal Detection and Attribution

Step 3: Examine similar climate model simulations, except the human changes to the atmosphere and land are removed.

- Typically pre-industrial or counterfactual simulations with out human forcings.
- Search these simulations to find if the patterns and magnitude of the detected observed changes were produced by the model of the actual world.
- If these changes **are** in these counterfactual simulations, the change is NOT attributable to humans.
 - It could be a natural multi-decadal mode of variability or response to other forcings.
- If these changes are not in these counterfactual simulations,
 - but are in the realistic simulations,
 - and are statistically significant, then:
 - **The detected change is attributable to humans.**



Formal Detection and Attribution



B. Santer

Field, C. B., Barros, V., Stocker, T. F., & Dahe, Q. (Eds.). (2012). Managing the risks of extreme events and disasters to advance climate change adaptation: special report of the intergovernmental panel on climate change. Cambridge University Press.



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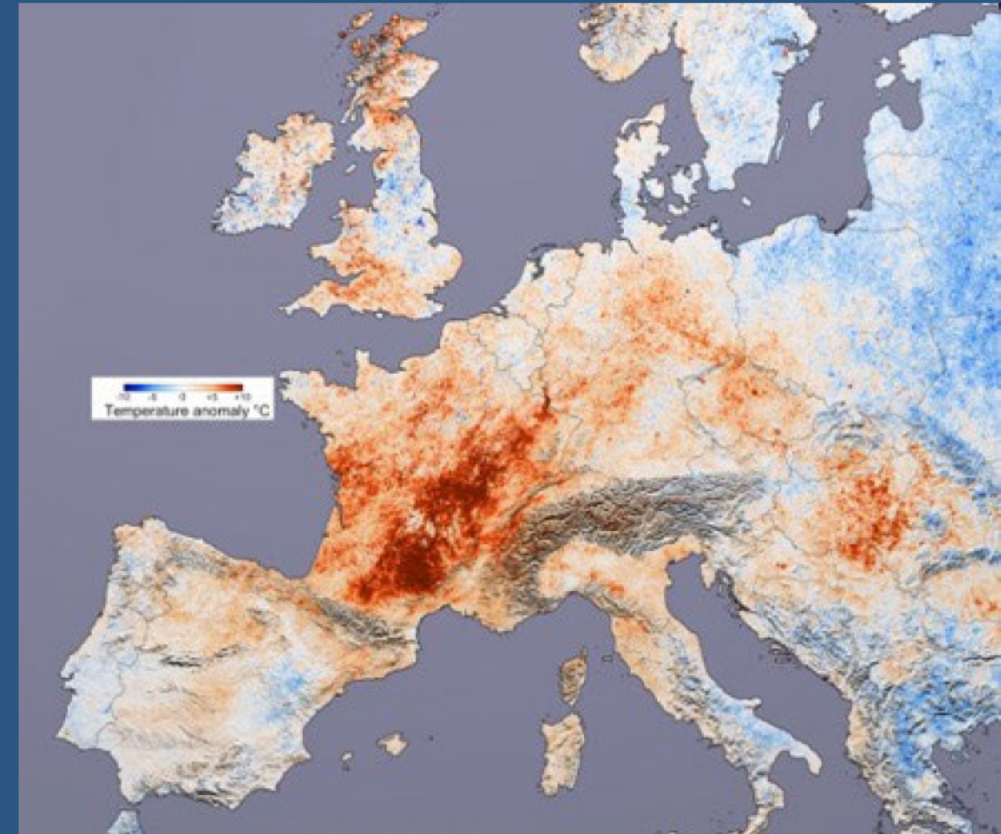
Focusing on event attribution.



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Extreme Event Attribution

- Invented in 2003 after the deadly European heatwave.
- Quantifies the human influence, if any, on extreme weather events that have already occurred.
- Borrows statistical methods from Epidemiology.
- Chances of the 2003 European heat wave were found to be doubled
- But warming has continued.



Stott, P. A., Stone, D. A., & Allen, M. R. (2004). Human contribution to the European heatwave of 2003. *Nature*, 432(7017), 610-614.



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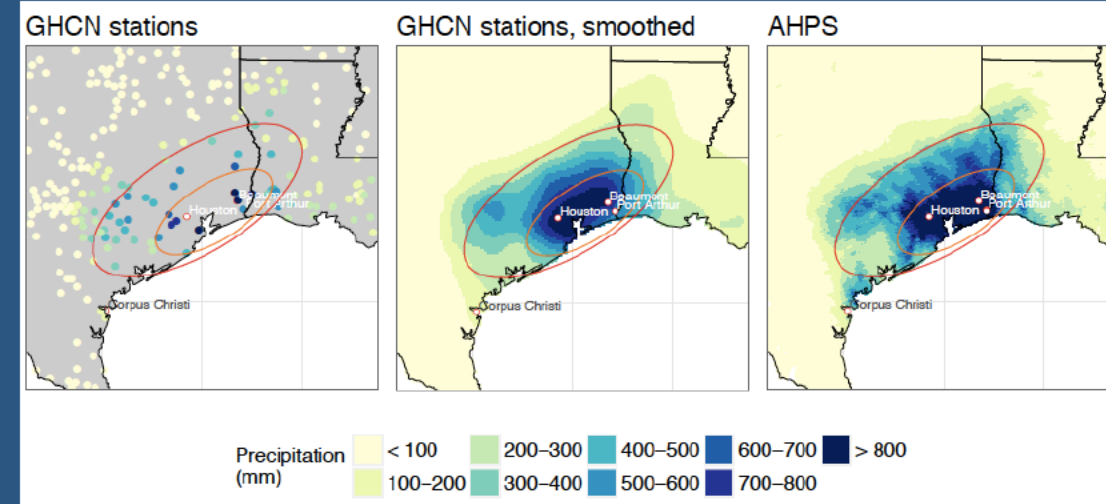
Casual Inference: Two Approaches

1. Design ensembles of climate model simulations tailored to event attribution.
 - Actual world vs counterfactual world without human changes to the atmosphere. A direct interference.
 - **Pearl** causal inference.
2. Analyze observed trends with a statistical model.
 - Postulate a plausible cause but beware of hidden covariates.
 - **Granger** causal inference.



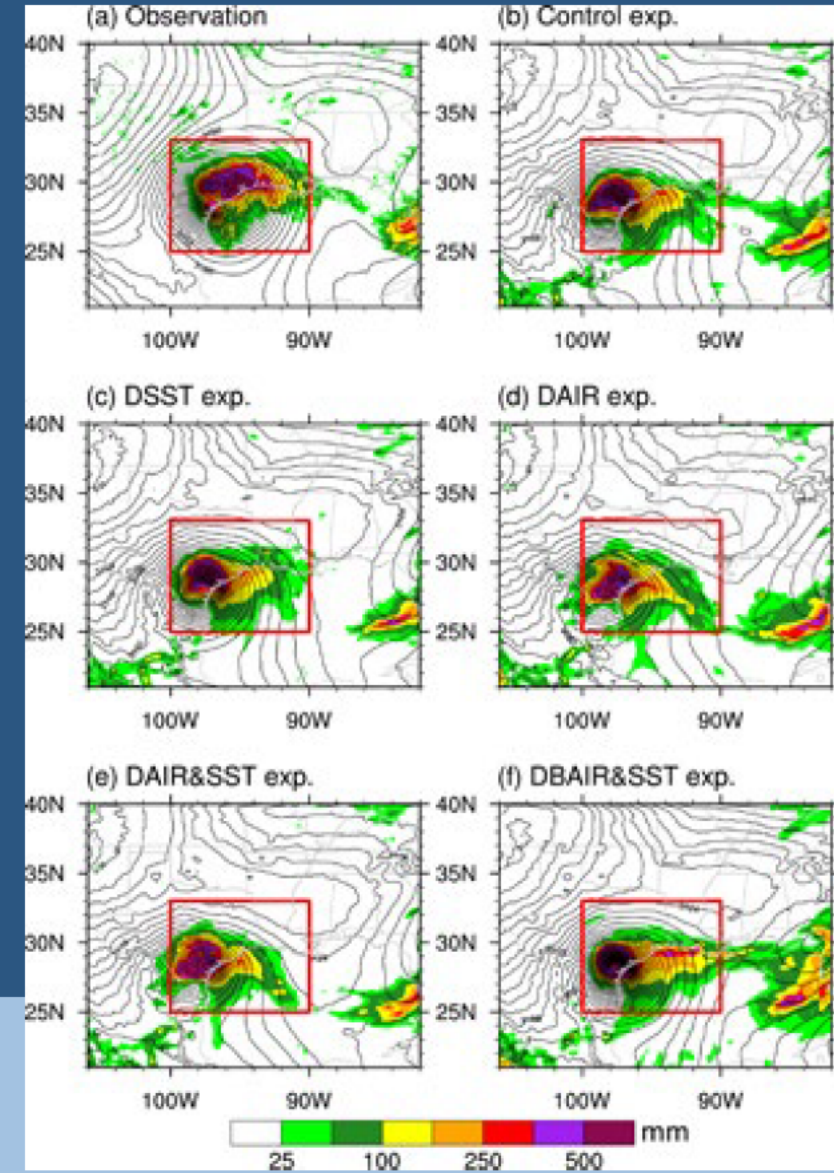
Hurricane Harvey - Granger

- Constructed a non-stationary generalized extreme value statistical model of observed extreme precipitation (Y) in coastal Texas with two “covariates”:
 - X_1 =Atmospheric carbon dioxide: The human influence
 - X_2 =El Nino index: The natural influence
- Three observational datasets (no models)
- Two regions
- **Finding:** Climate change increased
 - chances by 10X (*likely* lower bound of 3.5X)
 - Precipitation by 38% (*likely* lower bound of 19%)



Hurricane Harvey - Pearl

- Constructed control (actual) and counterfactual simulations with climate change trends in SST and atmospheric variables removed.
- **Finding:** Climate change increased
 - Precipitation by 20% (*likely* range=13-37%)



Modeling Approaches - Pearl

- As there is a hierarchy of climate modeling techniques, there is also a hierarchy of attribution methods.
- Every attribution study makes a number of assumptions that should be disclosed.
 1. Long multidecadal simulations of the actual and counterfactual worlds
 2. Short hindcast simulations of the actual event and a plausible counterfactual event.
 - Well suited for extreme storms, as attention is focused on the actual event.
 - But there is an additional condition that the large-scale circulation is unaffected by climate change.
 - Attribution statements are conditional on this (and other assumptions) and are incomplete.
 - Hindcast attribution method (also known as: pseudo-global cooling).



Being Used for a Range of Events



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Quickly evolving and growing science.



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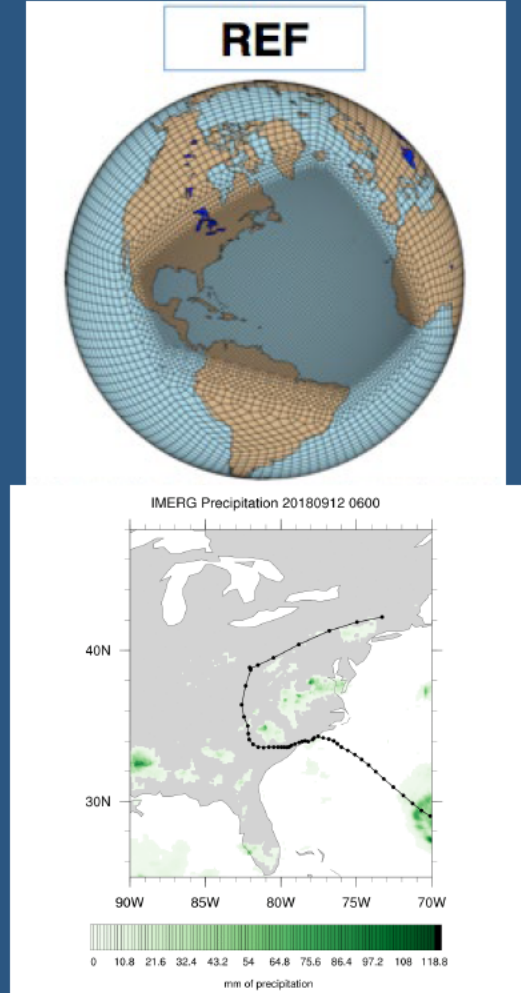
My Scientific Motivation

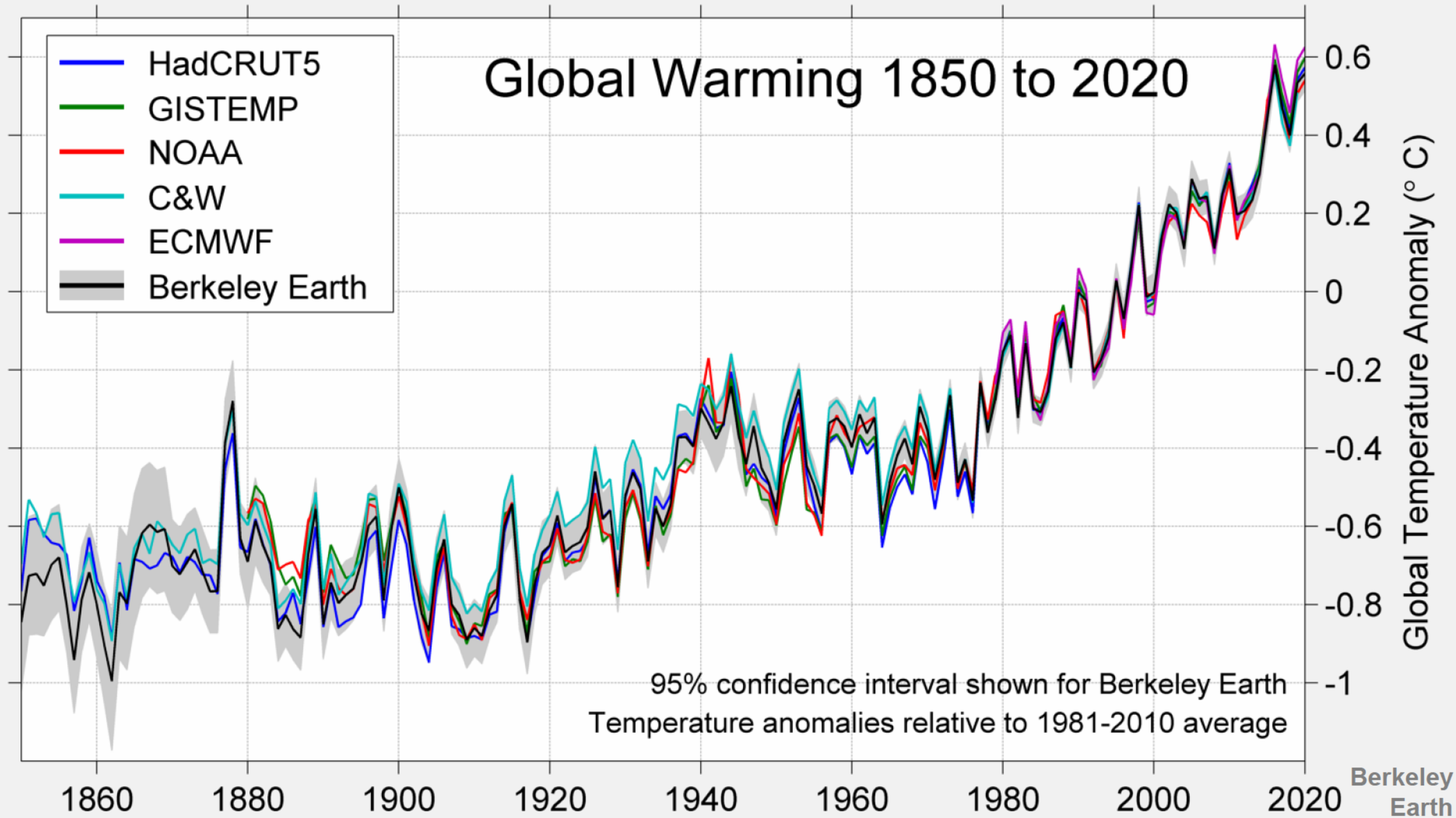
- We are entering an era where the numerical tools typically used to assess long-term climate change are approaching those now used for short-term weather prediction.
- Can the impact of climate change on the rainfall associated with individual hurricanes and full hurricane seasons be quantified?
- How can these event attribution frameworks be utilized to help translate the impacts of climate change to the public and decision-makers?



Modeling Technique - Pearl

- National Center for Atmospheric Research's (NCAR) Community Atmosphere Model version 5 (CAM 5).
- Variable resolution is used over region of interest with 30 vertical levels is used at the local horizontal resolution of:
 $\sim 100 > \sim 25$ km
- **Actual:** Similar to full physics AMIP simulation, but initialized at specific times in advance of hurricane landfall. Initial conditions taken from operational **NOAA GFS**.
- **Counterfactual:** Temperature, specific humidity, and SST from the observed initial conditions are modified to remove effects of climate change (using CAM5 C20C+ or the CESM Large Ensemble).
- Prescribed observed SSTs, ozone, CO_2 , solar forcing.







Actual

Actual



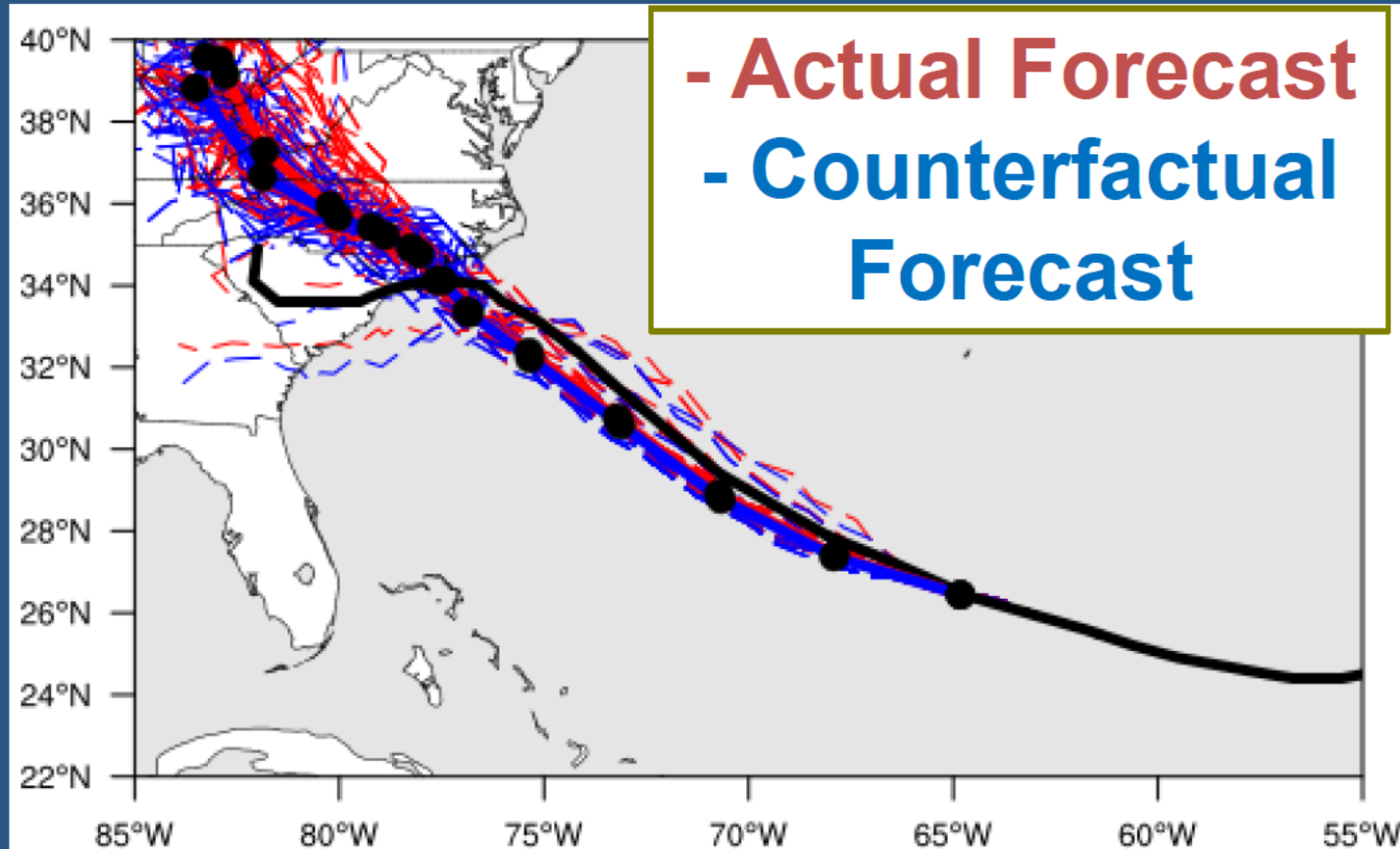


Actual



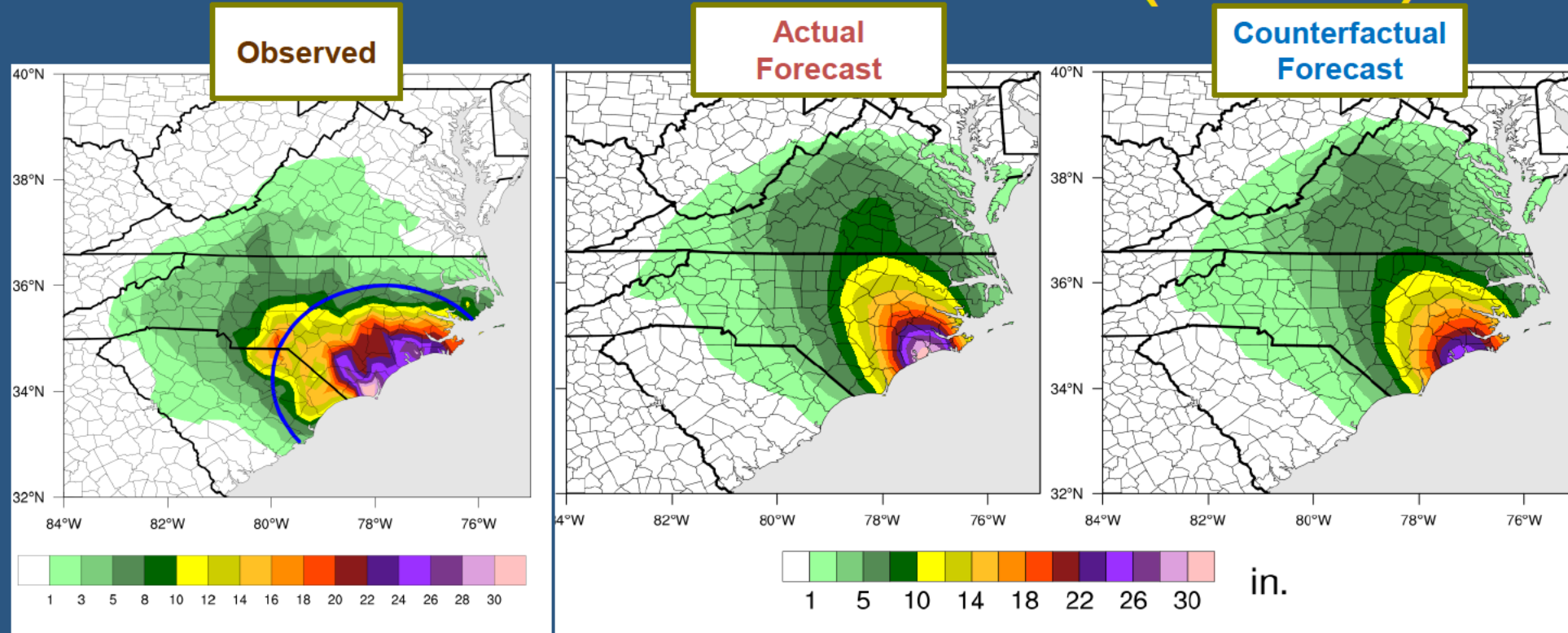
Counterfactual

Hurricane Florence (2018)



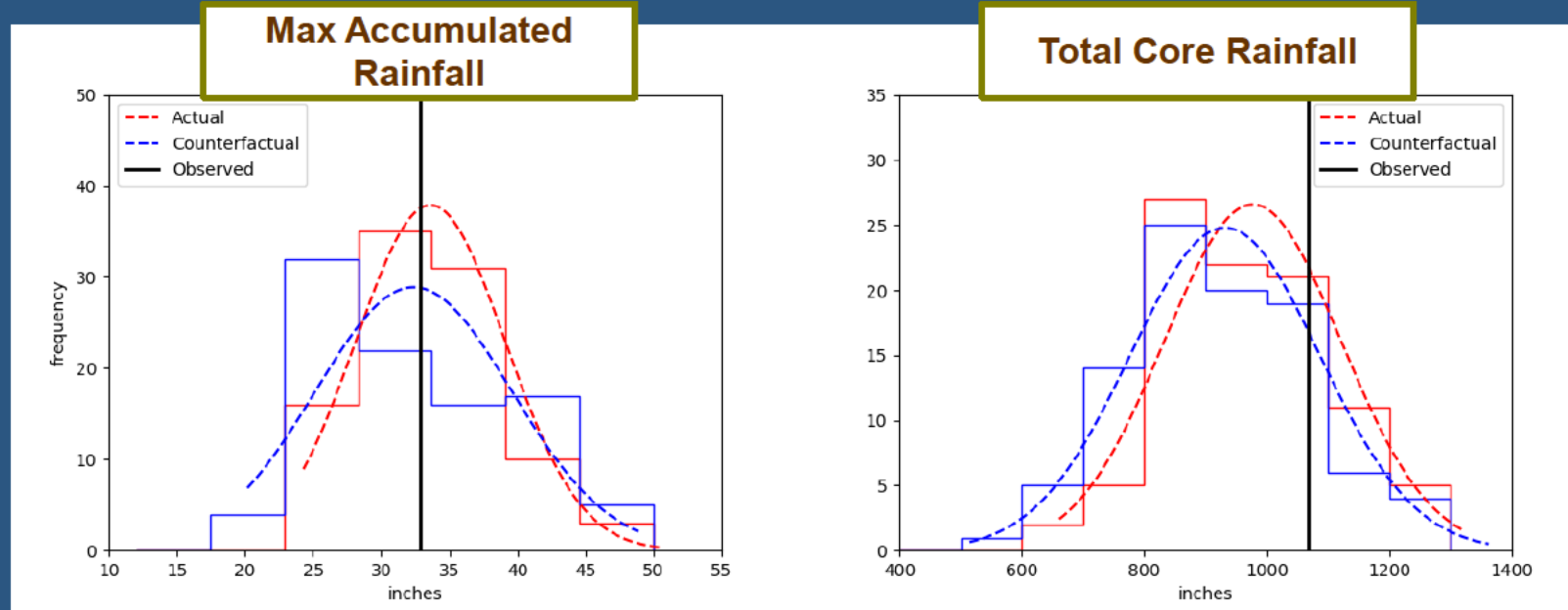
- Model reproduces Hurricane Florence track and landfall location in both landfalls.
- Suggests that the model is **fit-for-purpose**.

Hurricane Florence (2018)



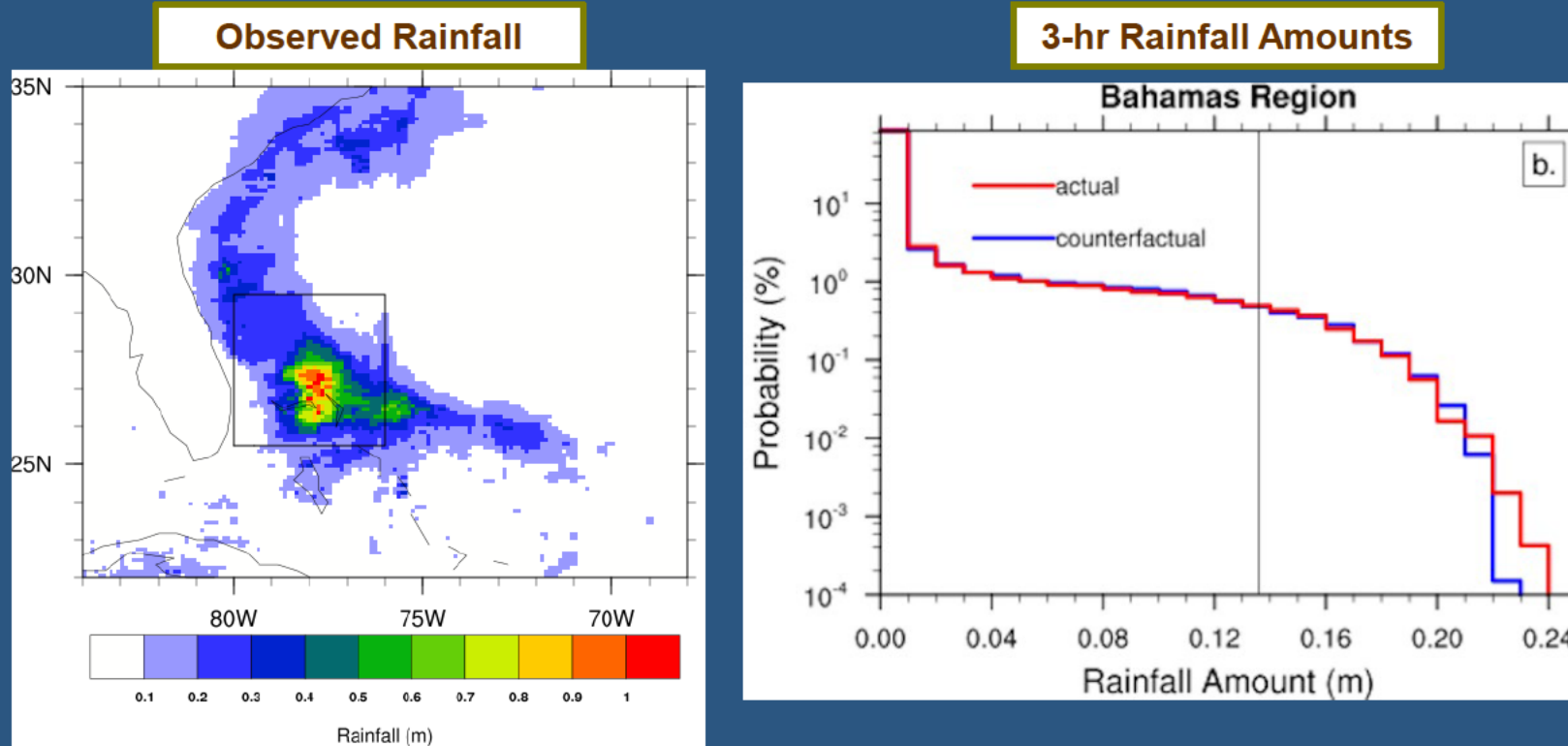
- Actual forecast reproduces Florence rainfall amounts well.
- Rainfall is **increased** due to observed warming.

Hurricane Florence (2018)



- Clear shift of $\sim 4 \pm 5.5\%$ in most extreme rainfall amounts due to climate change in Florence forecasts.
- Increase of $\sim 5 \pm 4.5\%$ in overland land rainfall associated with core of storm (with 200 km of center).

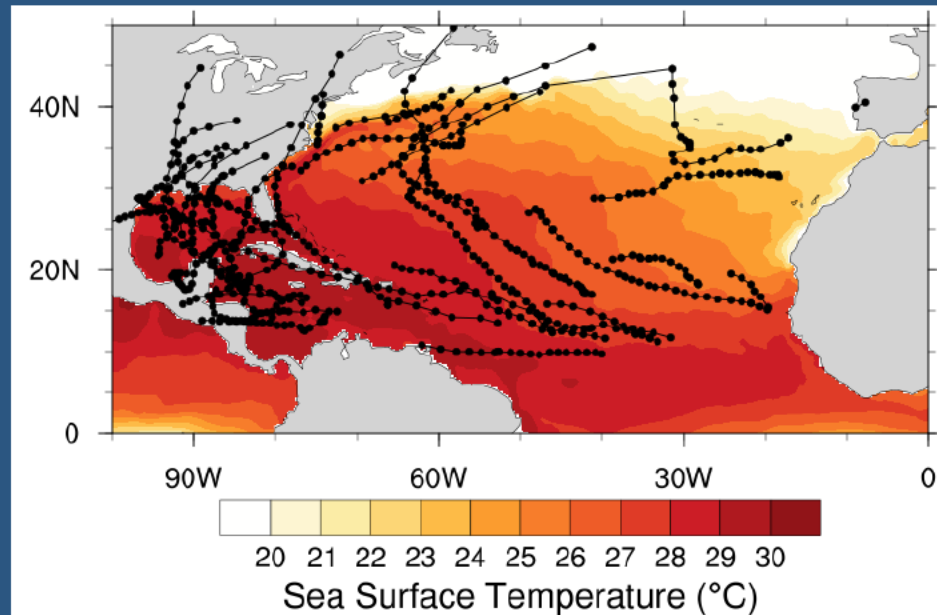
Hurricane Dorian (2019)



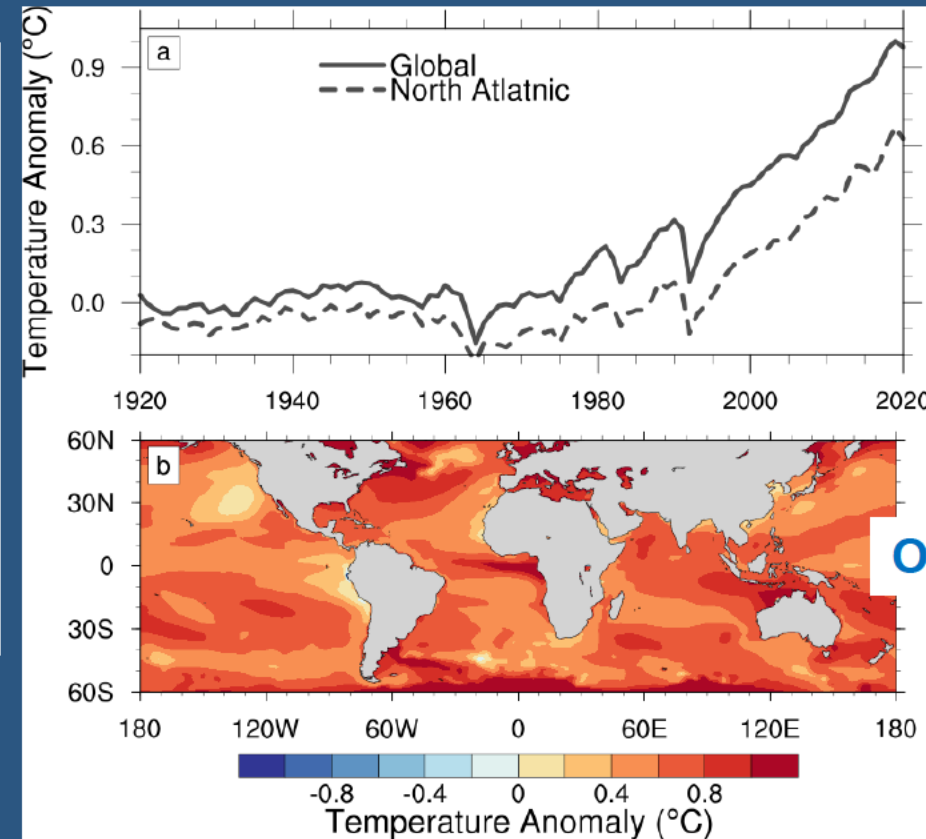
- Increase of $\sim 16 \pm 2\%$ in likelihood of maximum IMERG estimated rainfall amount.

2020 Hurricane Season

Actual Hindcasts



Counterfactual Hindcasts



Our Fingerprint

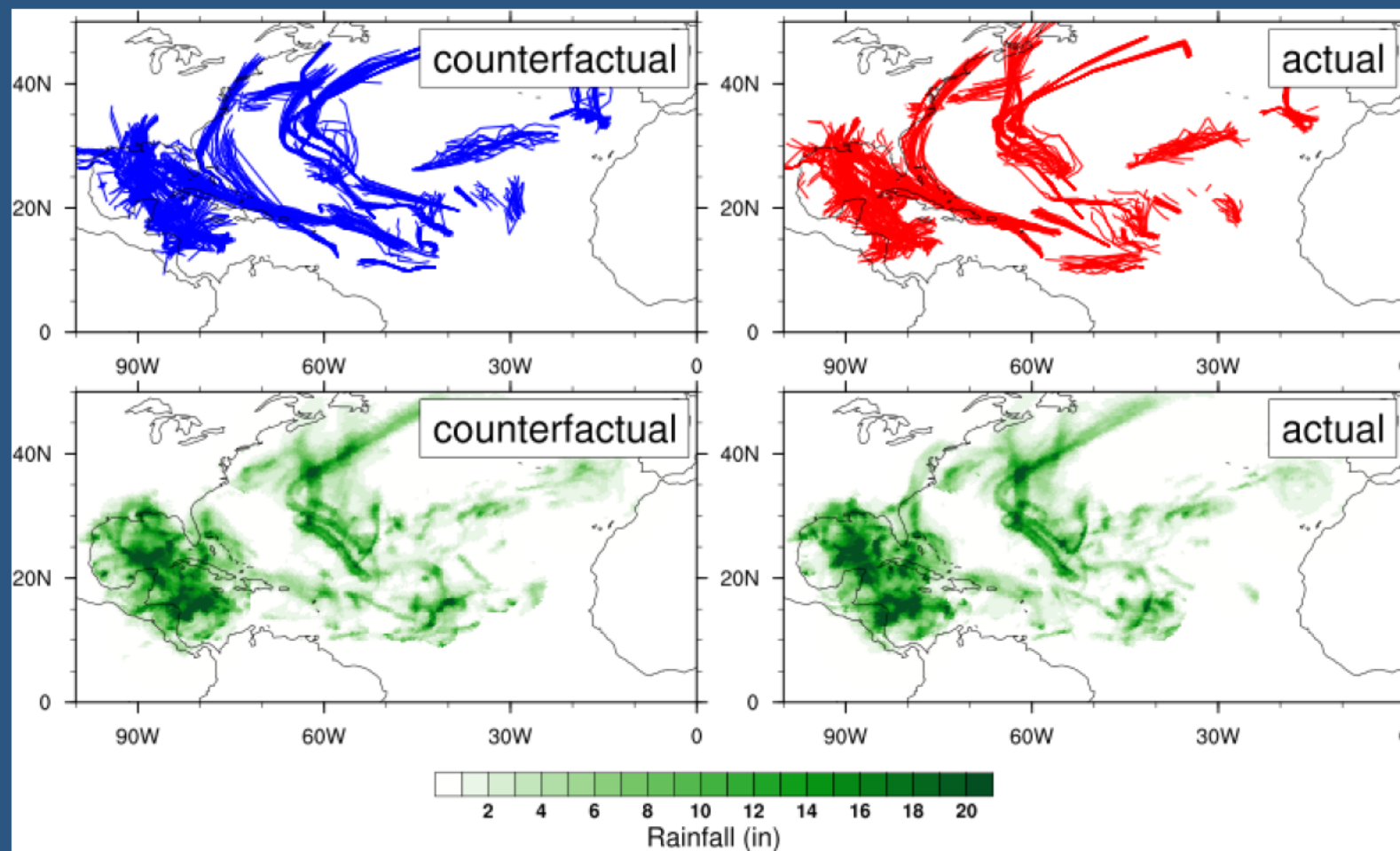
Reed, K. A., Wehner, M. F., & Zarzycki, C. M. (2022). Attribution of 2020 hurricane season extreme rainfall to human-induced climate change. *Nature communications*, 13(1), 1-6.



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2020 Hurricane Season



Reed, K. A., Wehner, M. F., & Zarzycki, C. M. (2022). Attribution of 2020 hurricane season extreme rainfall to human-induced climate change. *Nature communications*, 13(1), 1-6.

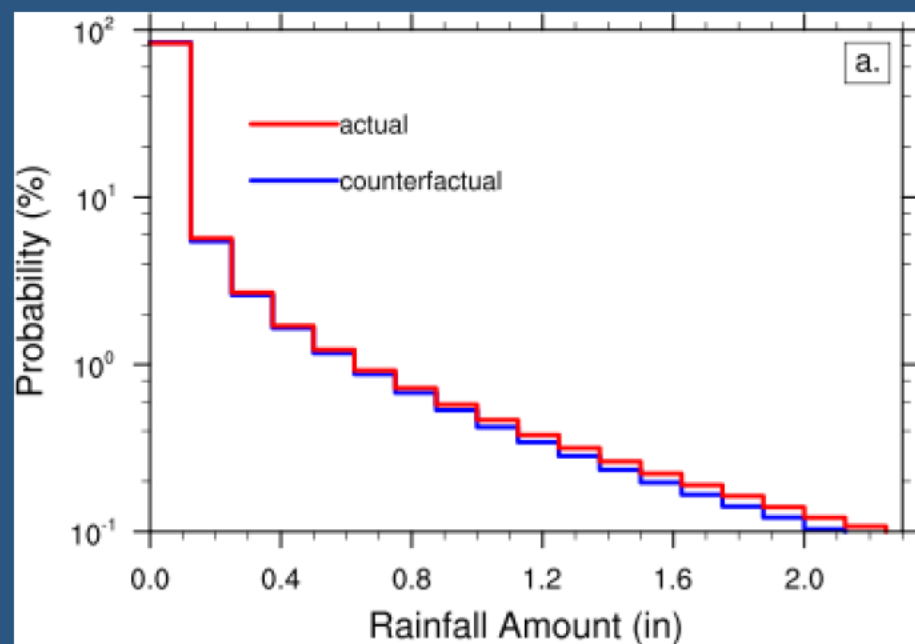


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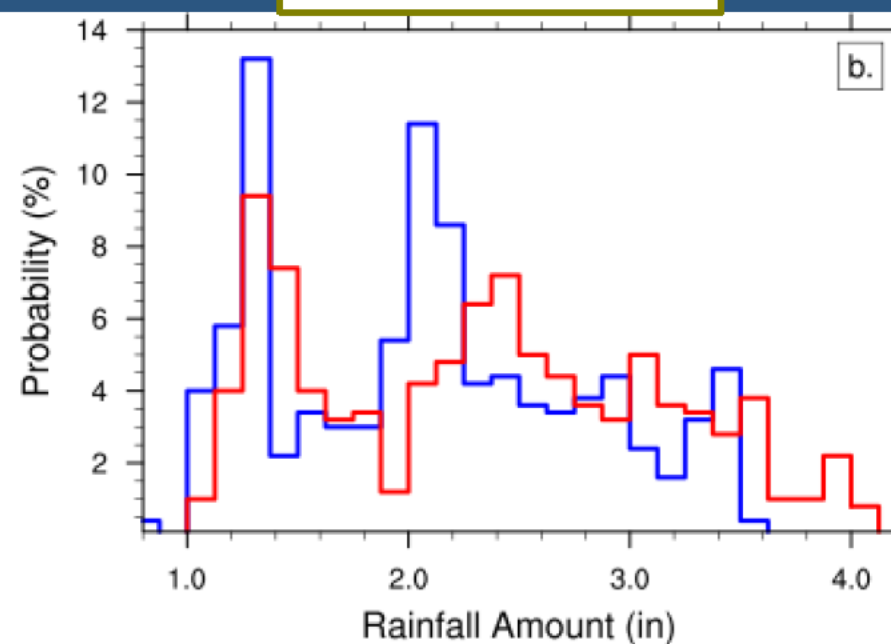
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2020 Hurricane Season

3-hr Rainfall Amounts



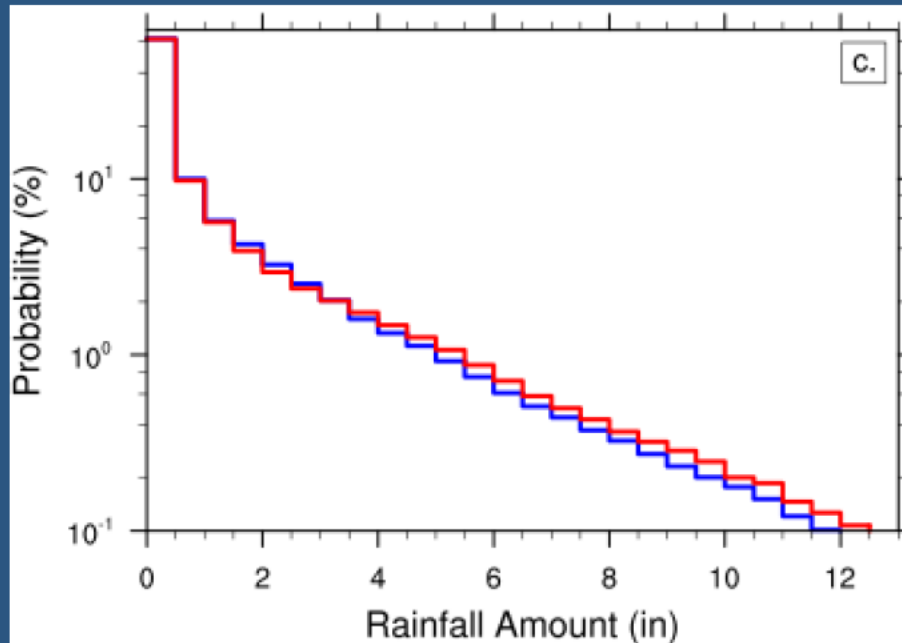
99 percentile
3-hr Rainfall Amounts



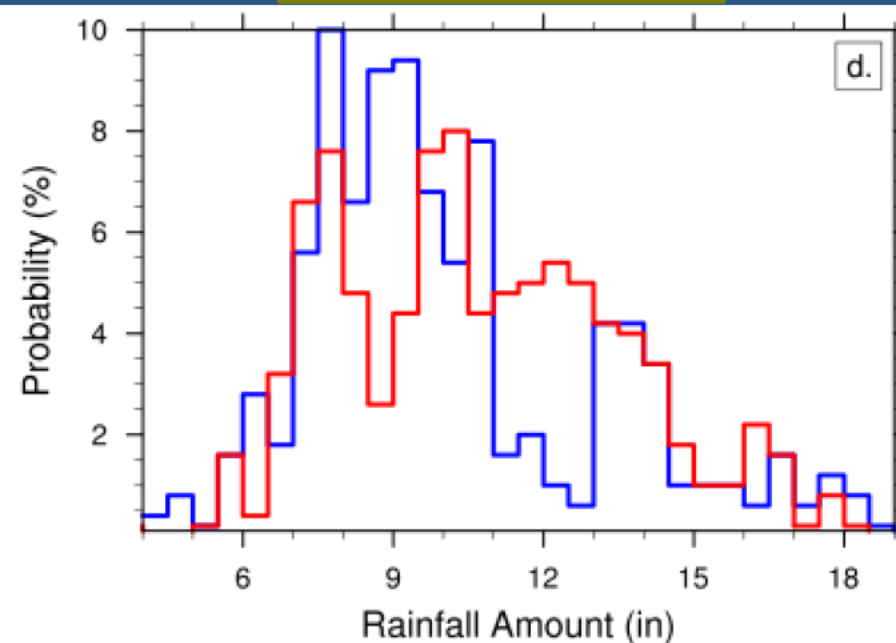
- A shift of $\sim 10 \pm 5\%$ in most extreme rainfall rates.

2020 Hurricane Season

Accumulated Rainfall



99 percentile
Accumulated Rainfall



- Clear shift of $\sim 5 \pm 5\%$ in extreme rainfall accumulation.

Steps forward.



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First, Thanks to...

- Dr. Michael Wehner for help in putting together some of this material.
- Dr. Benjamin Santer for his previous lecture on some of this material (which I used to make connections).
- Research colleagues for collaboration on the studies I have led.
- You for listening!



Takeaways

- The science of attribution has **expanded beyond** patterns of temperature and trends in temperature.
- This expansion includes **a focus on extreme events**, particularly heat waves and hurricanes.
- My work (as well as others) demonstrates that **human-induced climate change increased the extreme precipitation rates and accumulations in hurricanes**.
- These studies are becoming more and more **rapid** with results within weeks of an impactful event.



Discussion

- Suggests there is a pathway toward **operational forecast attribution frameworks** in the future.
- These tools can be applied to applications, such as financial risk models, **to quantify losses and damages**.
- Most (but not all) event attribution studies have focused on events in the developed world. There are reasons for this, but is this equitable?
- Is there a conflict of interest in **who funds** these event-specific studies?



Links

Assessments:

- IPCC - <https://www.ipcc.ch/>
- NCA - <https://www.globalchange.gov/>

