

Science of Attribution

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Setting the stage.



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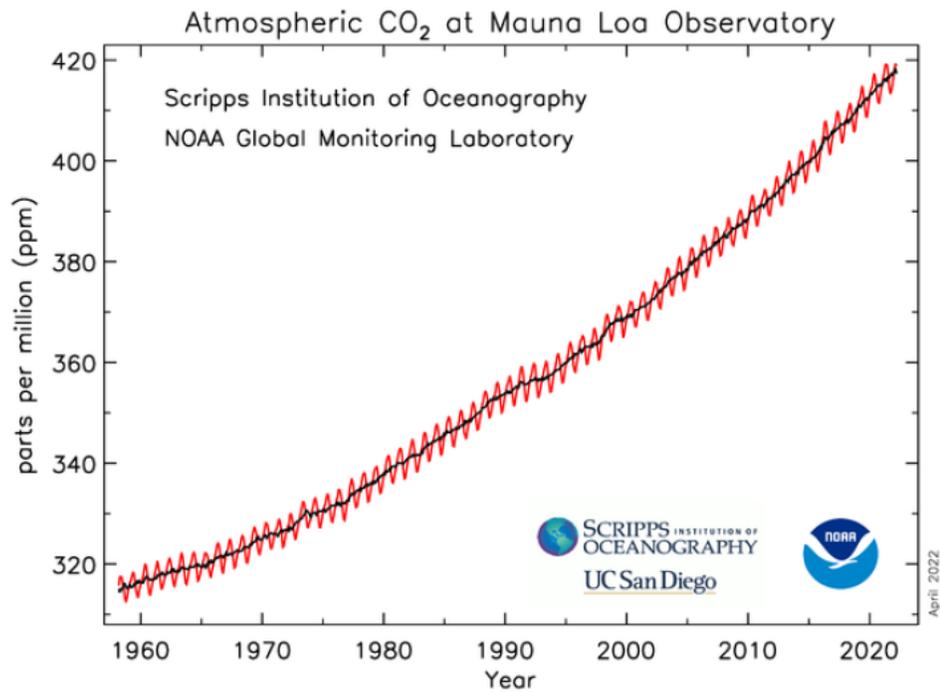
Assumptions for this Presentation

- 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.

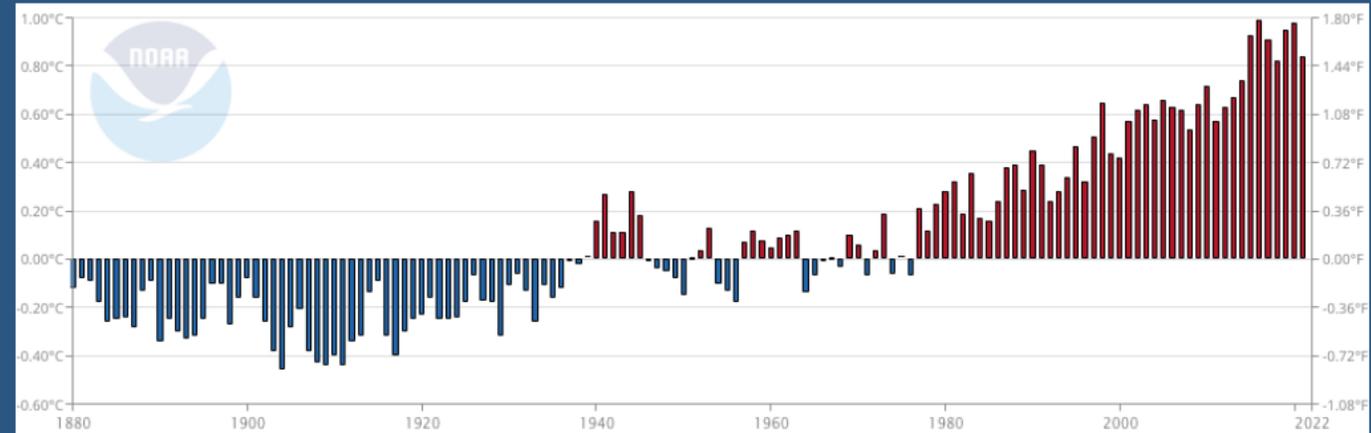


Observed Change

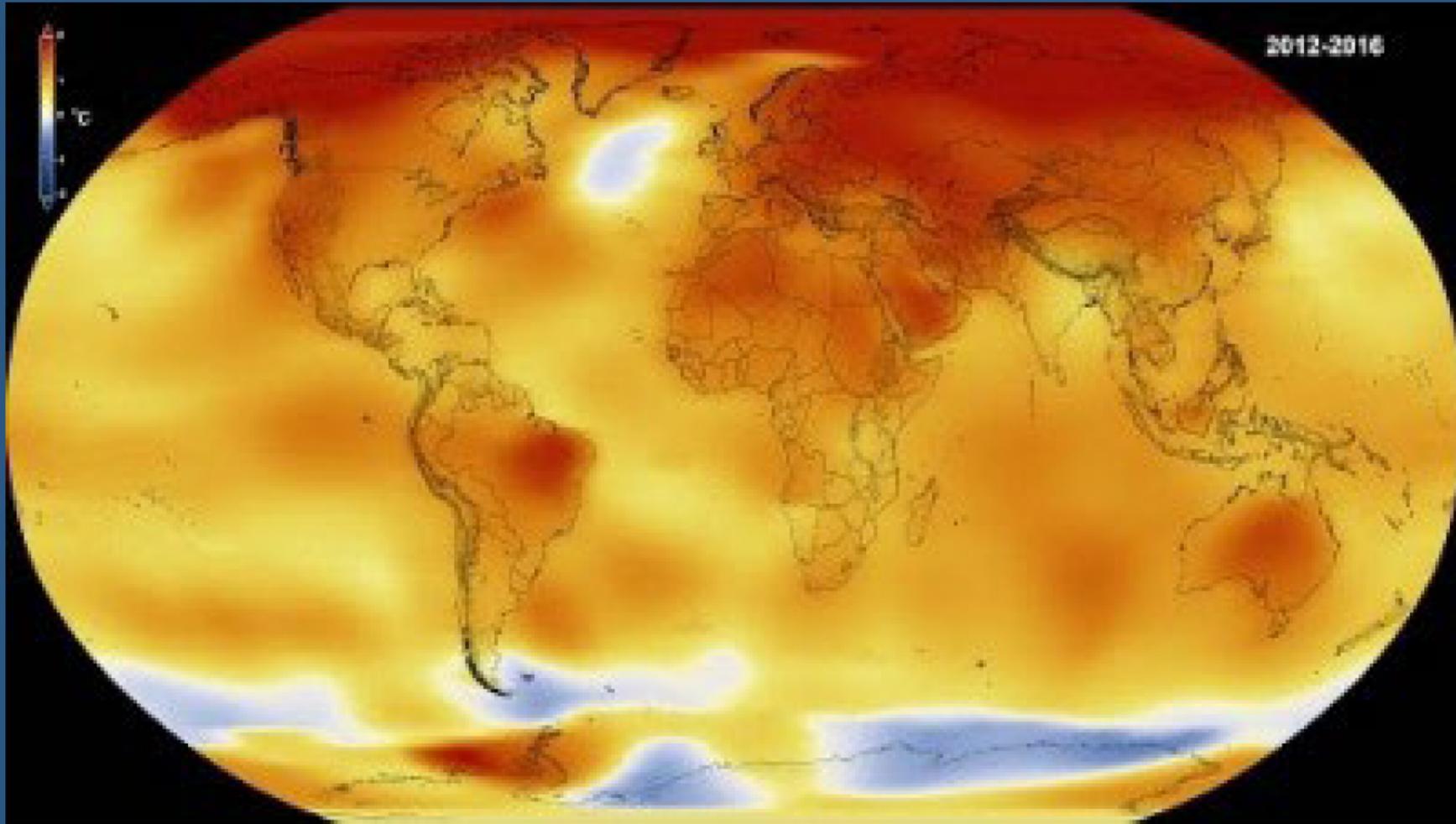
Increasing Carbon Dioxide Concentrations



Increasing Global Surface Temperature



Observed Change



NASA

https://youtu.be/Ni0lppUr_BQ

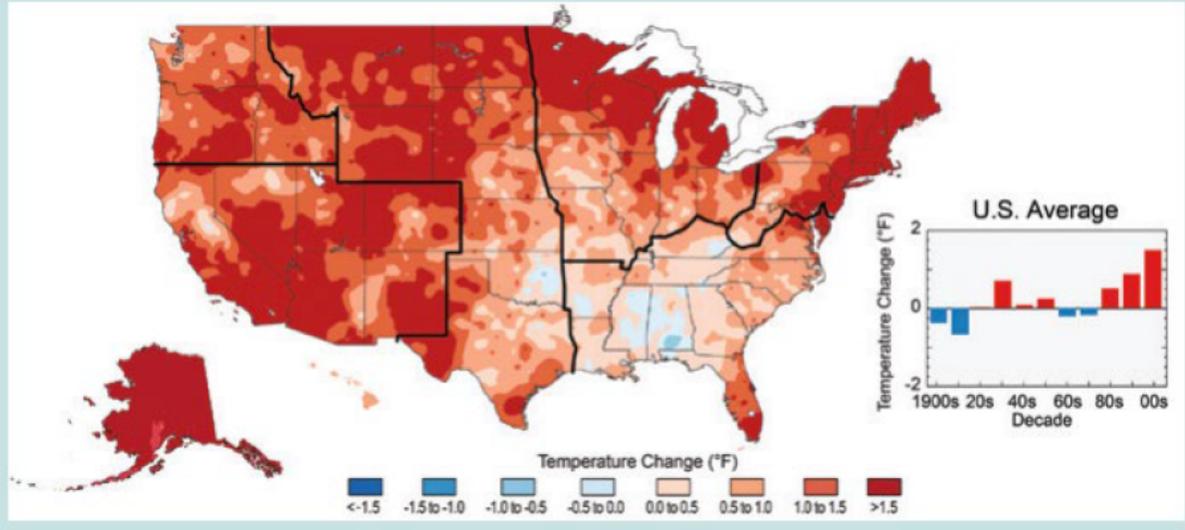


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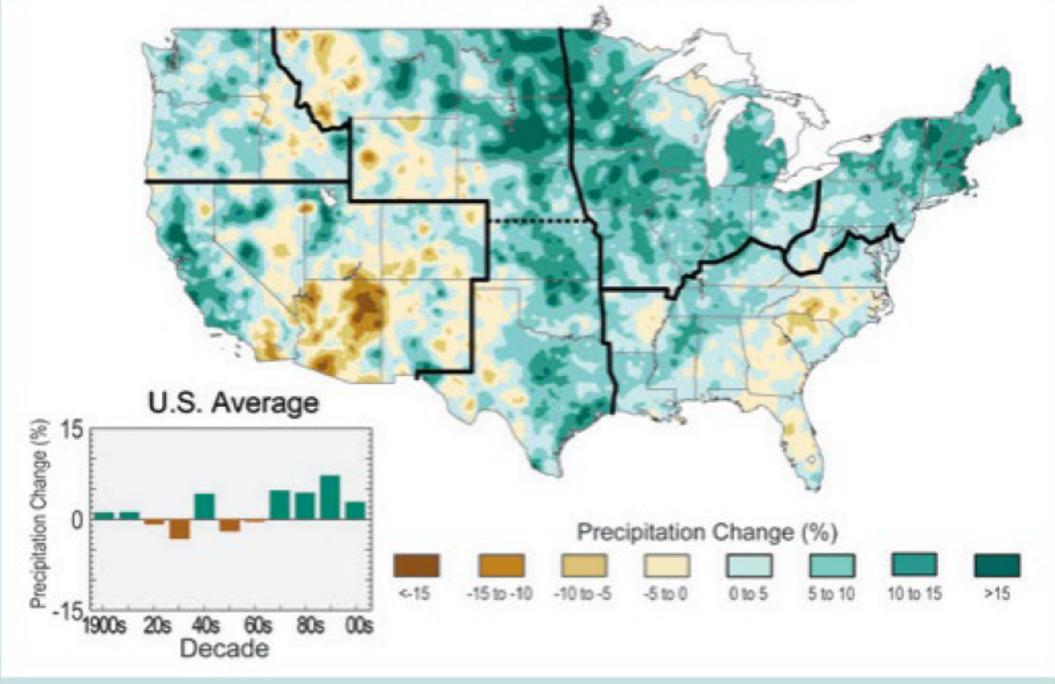
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U.S. National Climate Assessment

Observed U.S. Temperature Change



Observed U.S. Precipitation Change



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

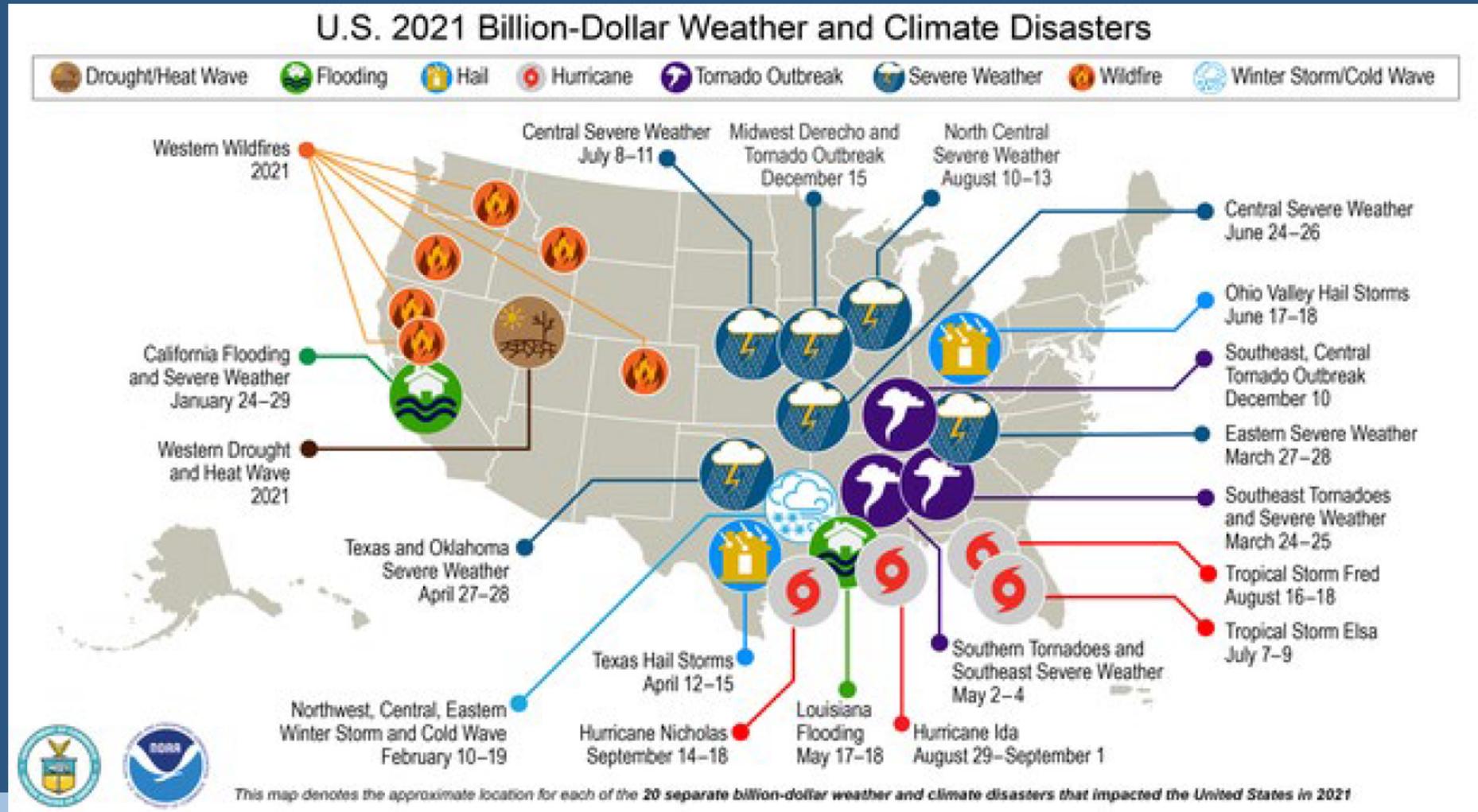


Hurricane Sandy (2012)



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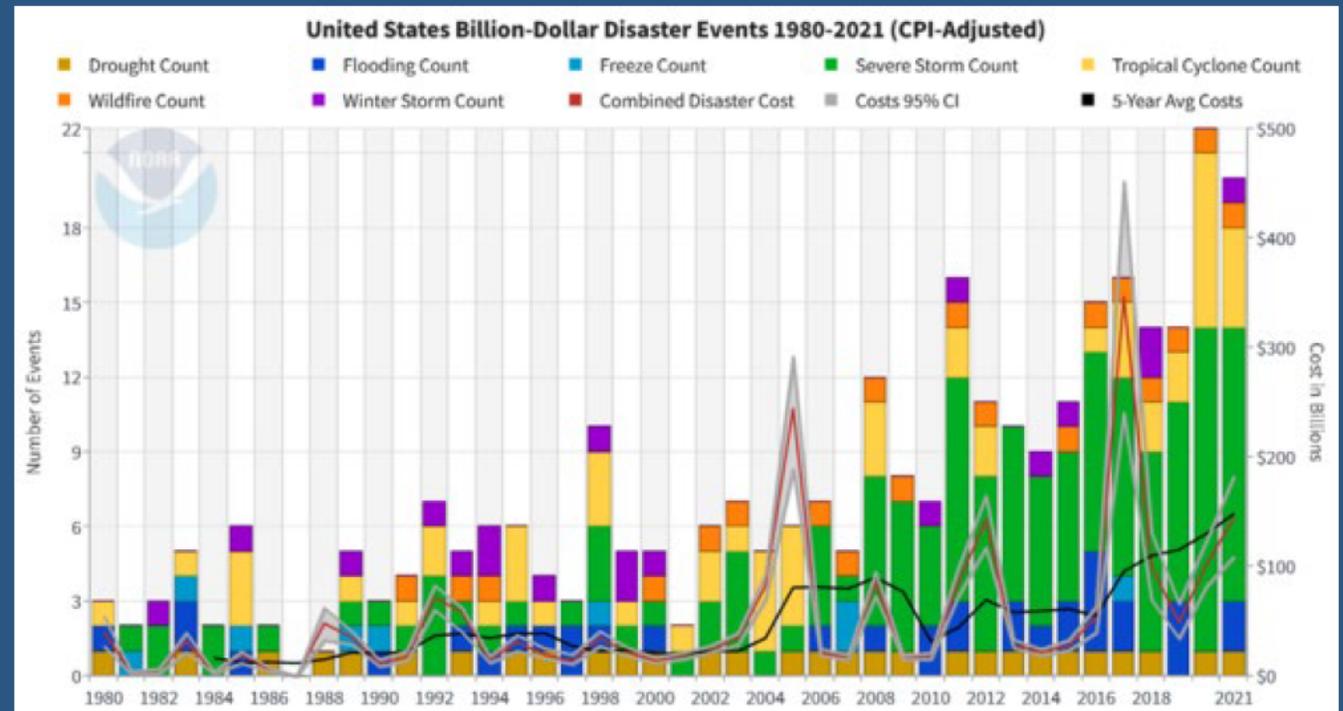
Impacts of Extreme Events



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)



PHOTO COURTESY OF CNN

CNN



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Florence (2018)



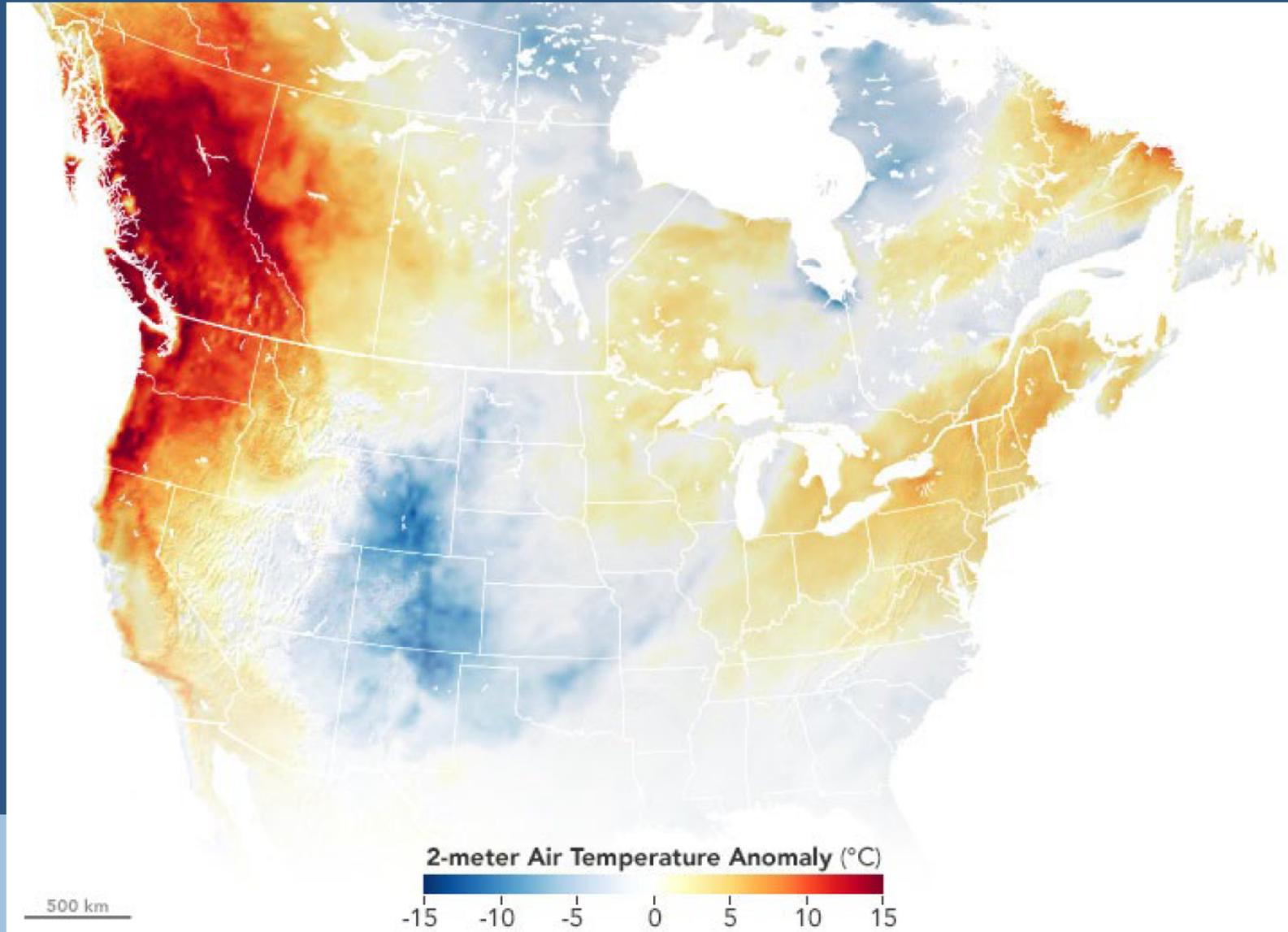
Vox



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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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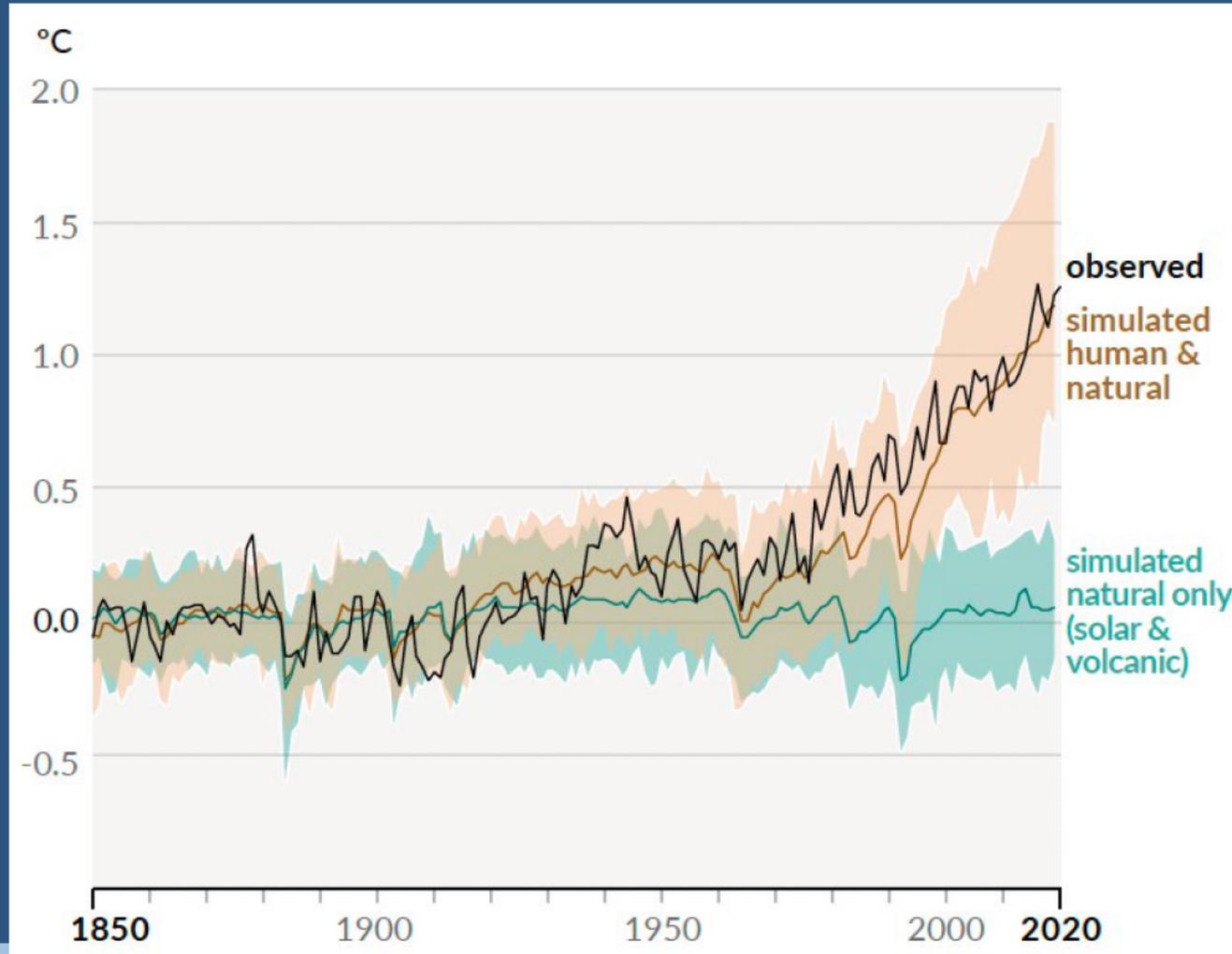
Back to fingerprinting.



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Formal Detection and Attribution



Actual

Counterfactual

B. Santer

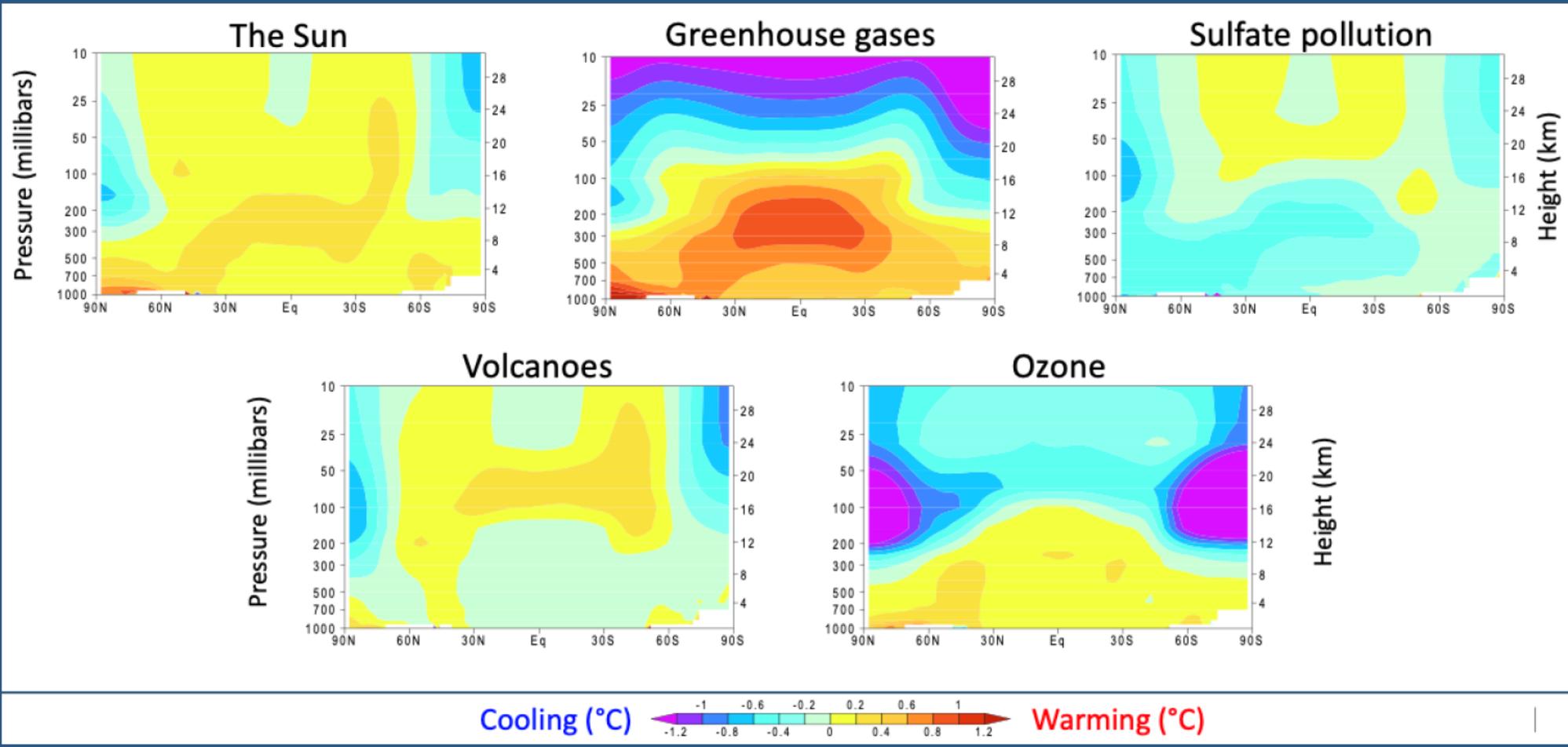
Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S. L., Péan, C., Berger, S., ... & Zhou, B. (2021). Climate change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.



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Natural and Human Fingerprints



B. Santer

Formal Detection and Attribution

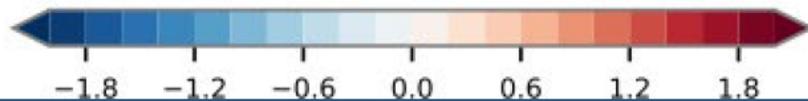
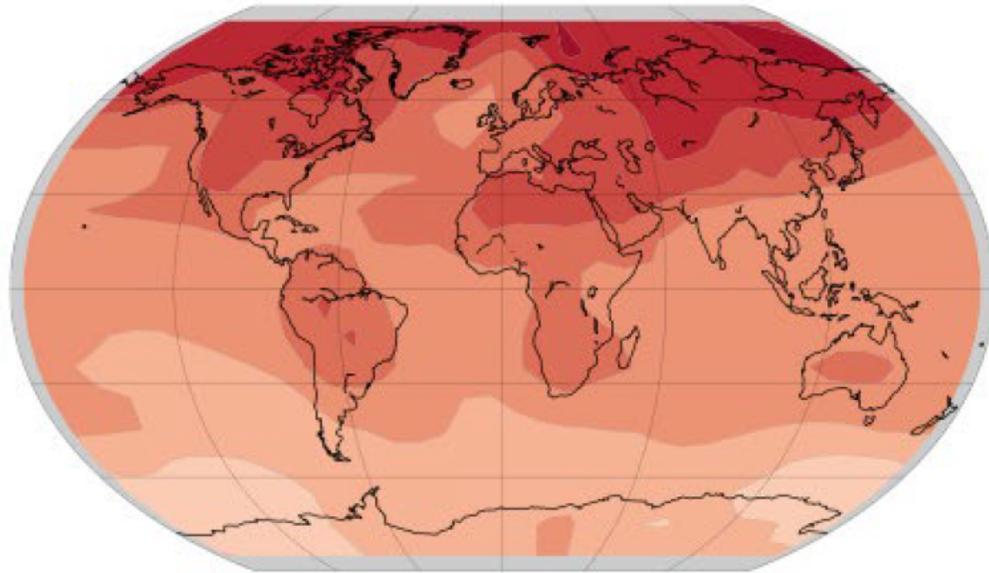
Step 1: Examine some observed variable.

- 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.

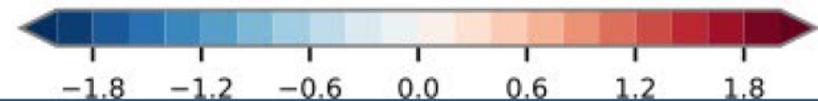
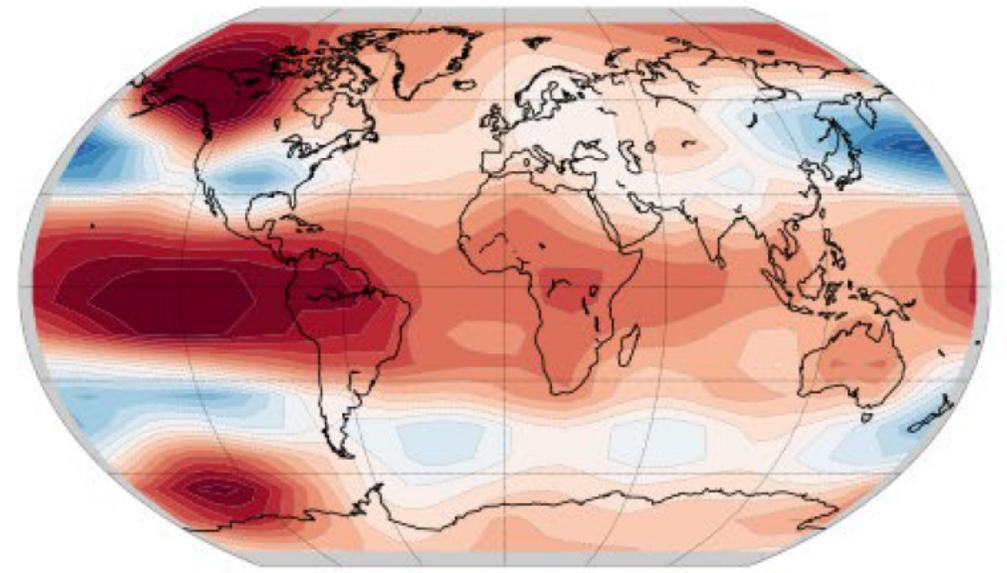


Formal Detection and Attribution

Human fingerprint



Natural climate variability



B. Santer



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Formal Detection and Attribution

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

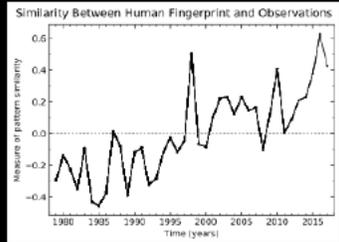
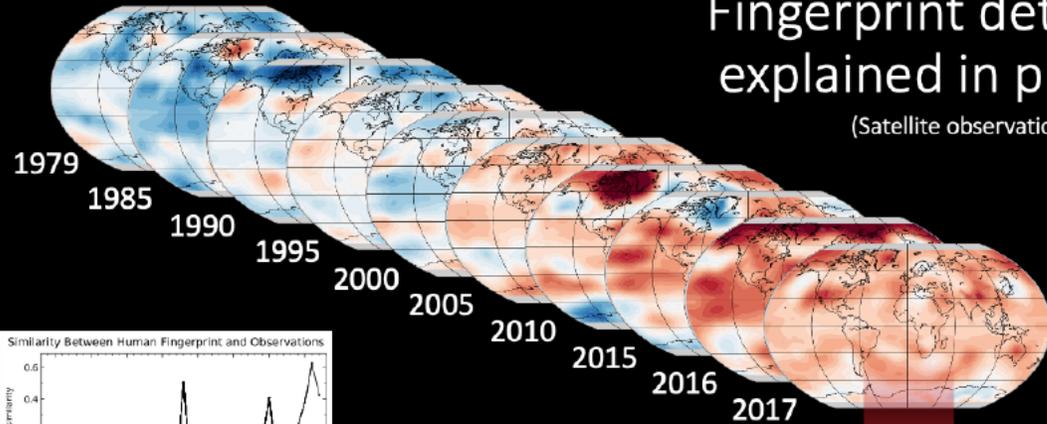
- Use best estimates of observed atmospheric composition, land cover, solar variability and volcanic activity in a climate model simulation.
- Search these simulations to find if the patterns and magnitude of the detected observed changes were produced by the model of the actual world.
- If not, the 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.**



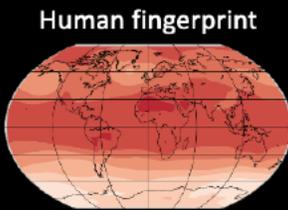
Formal Detection and Attribution

Fingerprint detection explained in pictures

(Satellite observations)

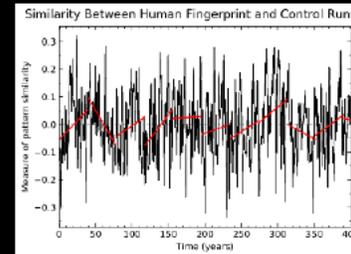
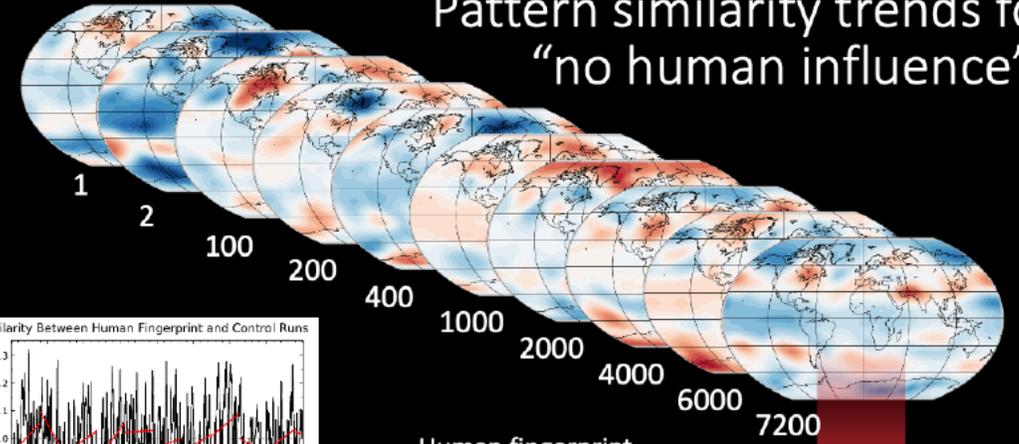


Generate pattern similarity time series

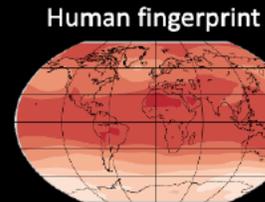


Compare with model "human influence" fingerprint

Pattern similarity trends for the "no human influence" case



Generate pattern similarity time series



Compare with model "human influence" fingerprint

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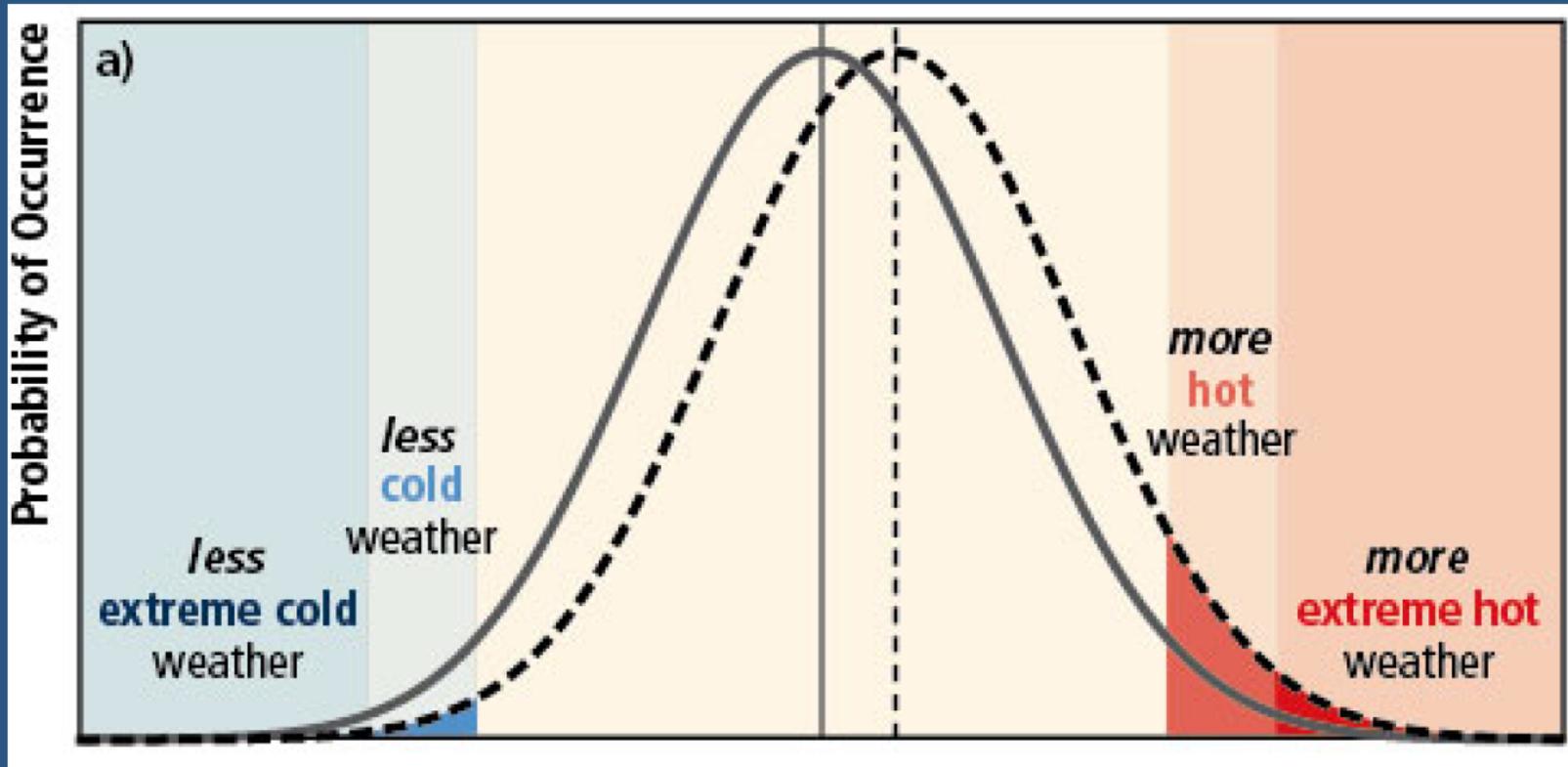
Formal Detection and Attribution

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.



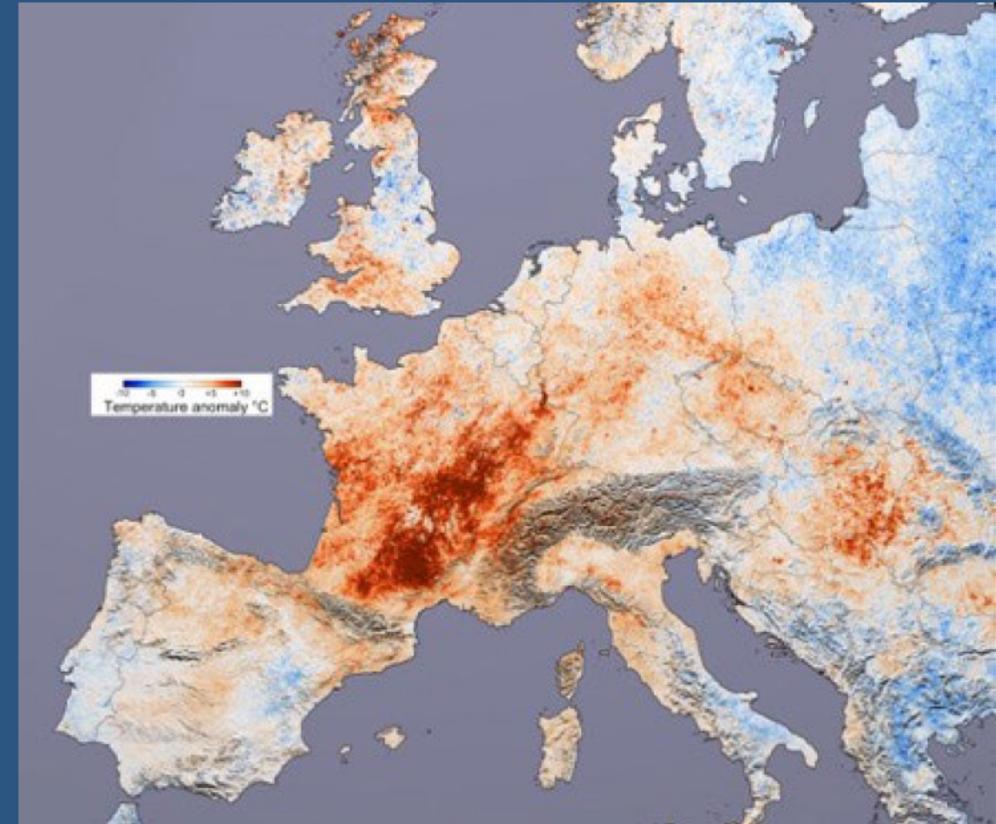
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Focusing on event attribution.

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.



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.



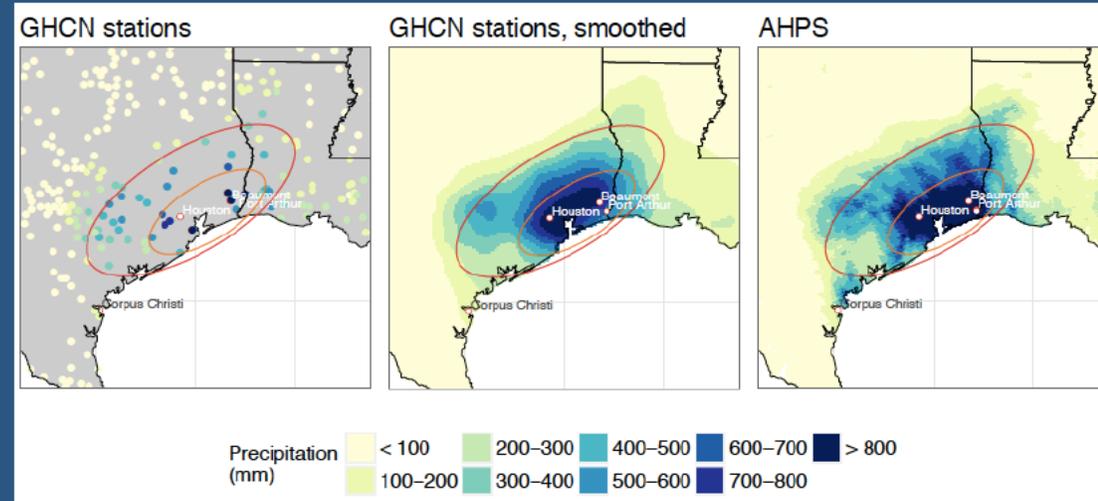
Hurricane Harvey - Granger

- 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

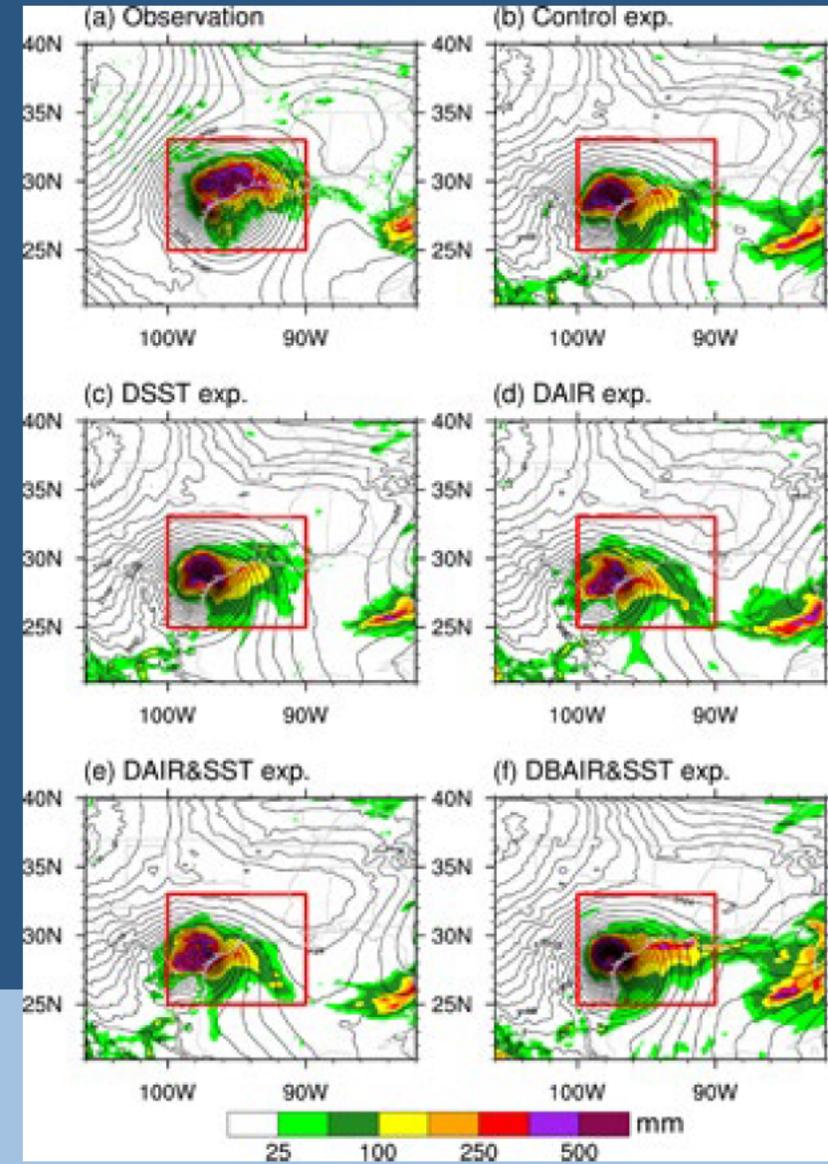
X_2 =El Nino index: The natural influence

- 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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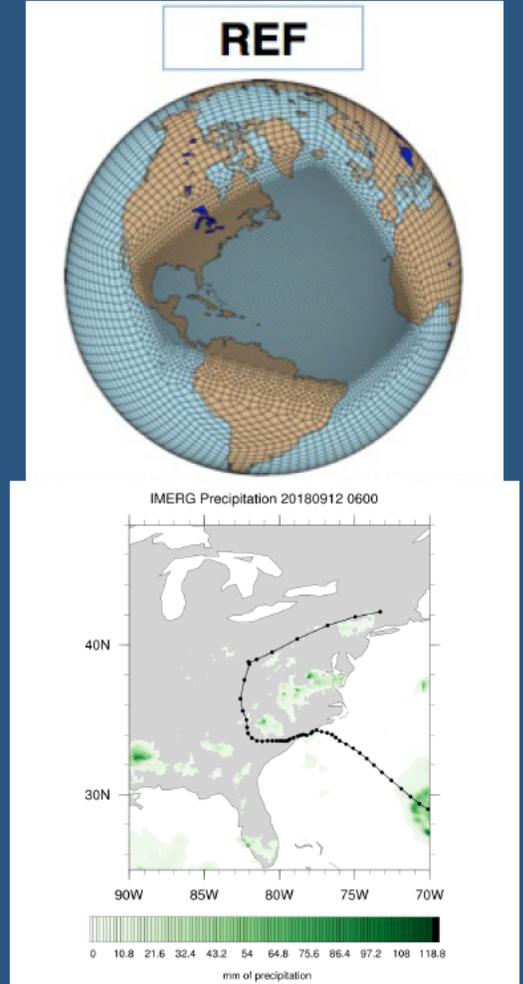
My Scientific Motivation

- 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?



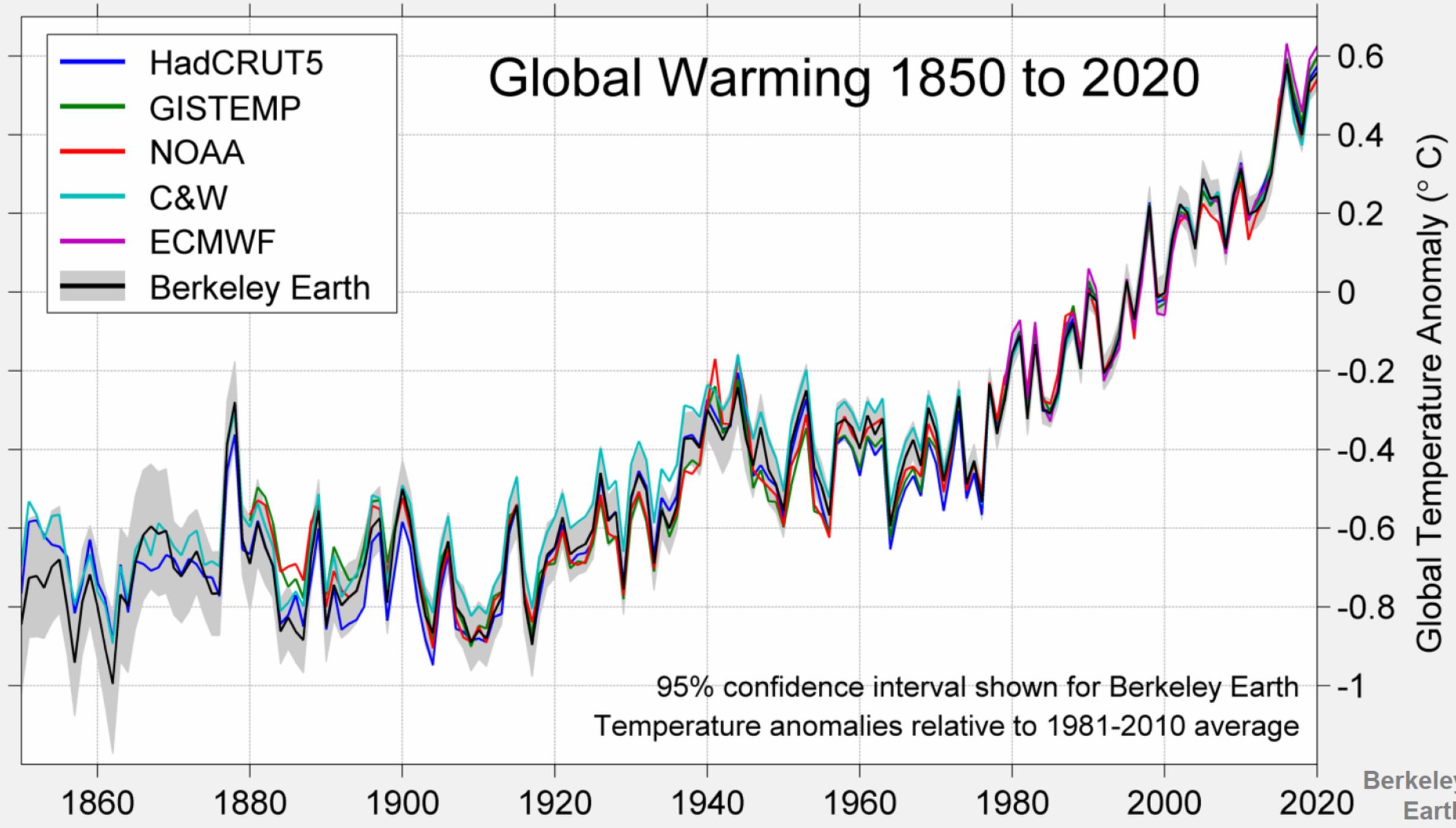
Modeling Technique - Pearl

- 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:
~100 > ~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, CO₂, solar forcing.



Global Warming 1850 to 2020

- HadCRUT5
- GISTEMP
- NOAA
- C&W
- ECMWF
- Berkeley Earth





Actual



Actual



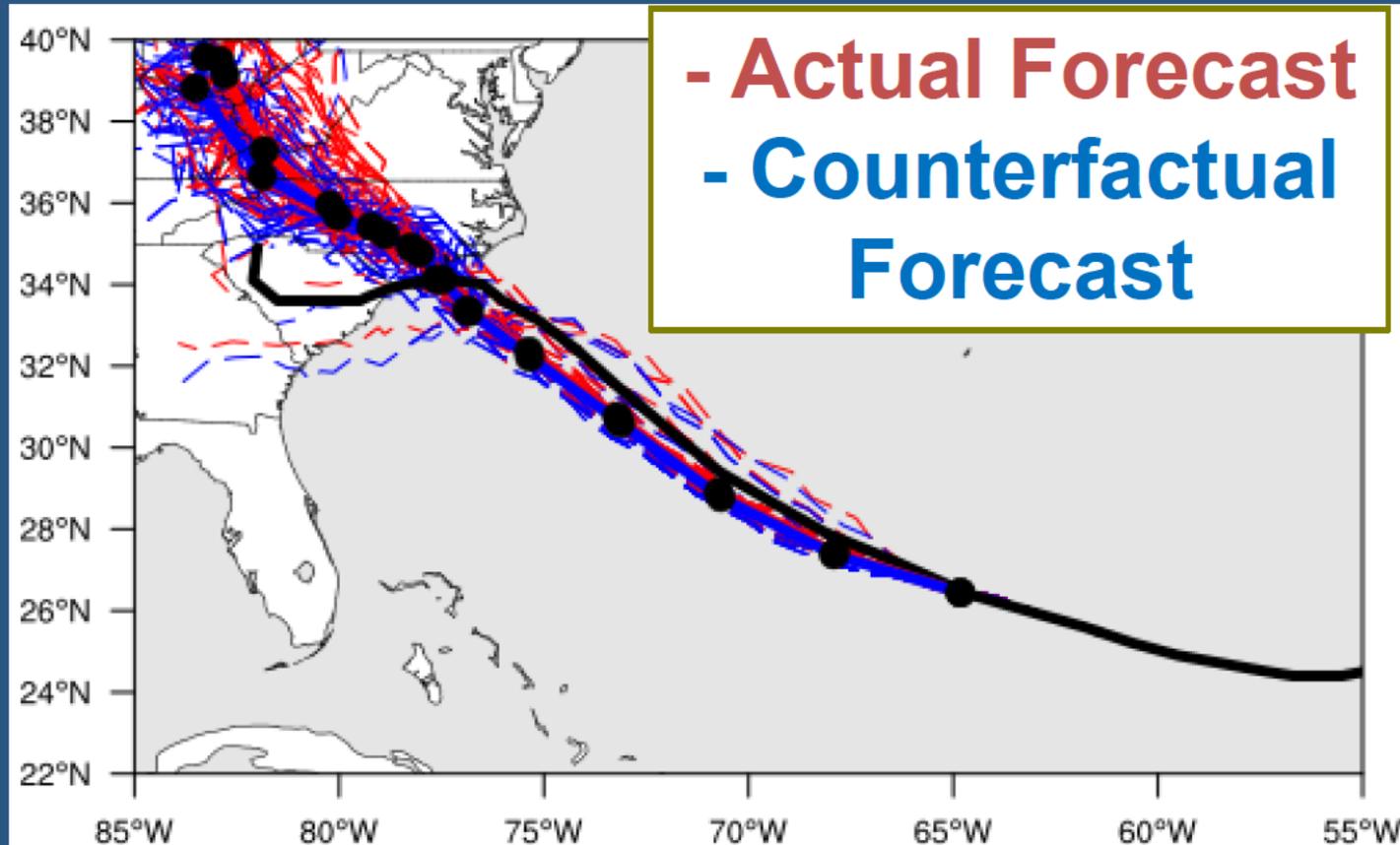


Actual



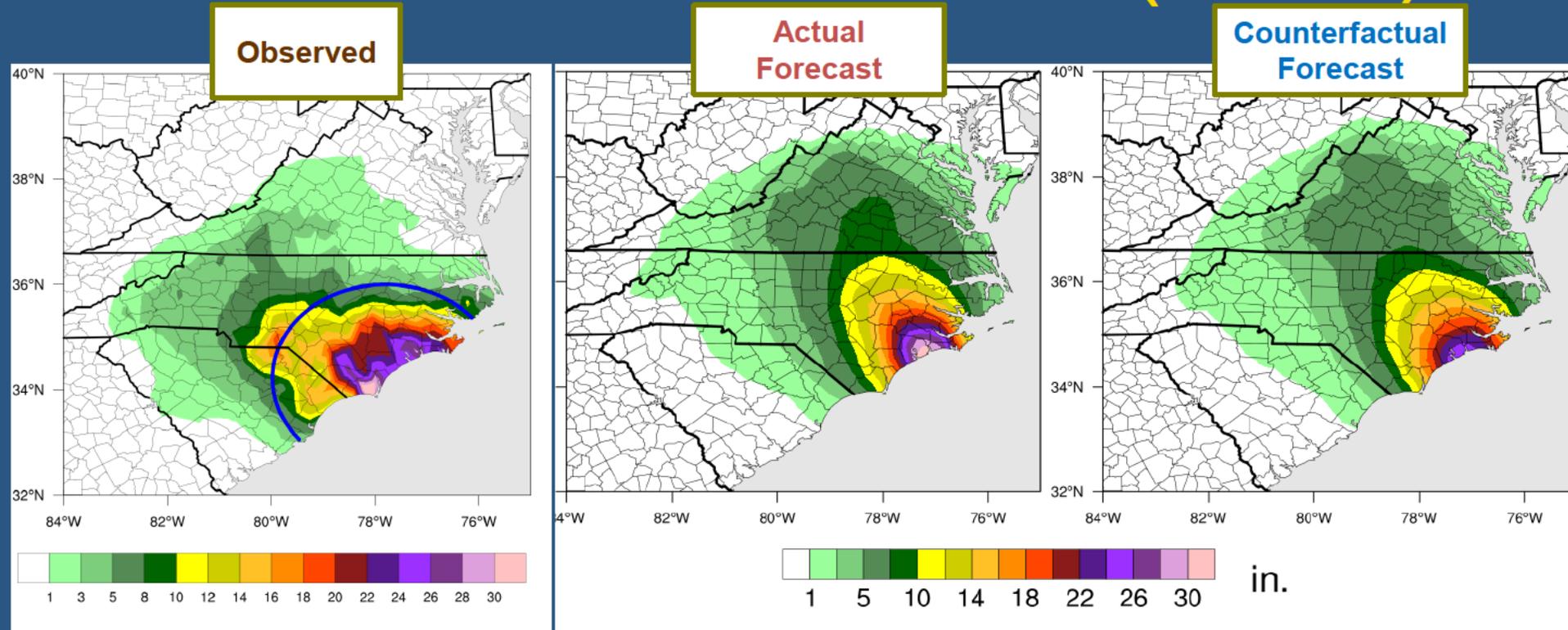
Counterfactual

Hurricane Florence (2018)



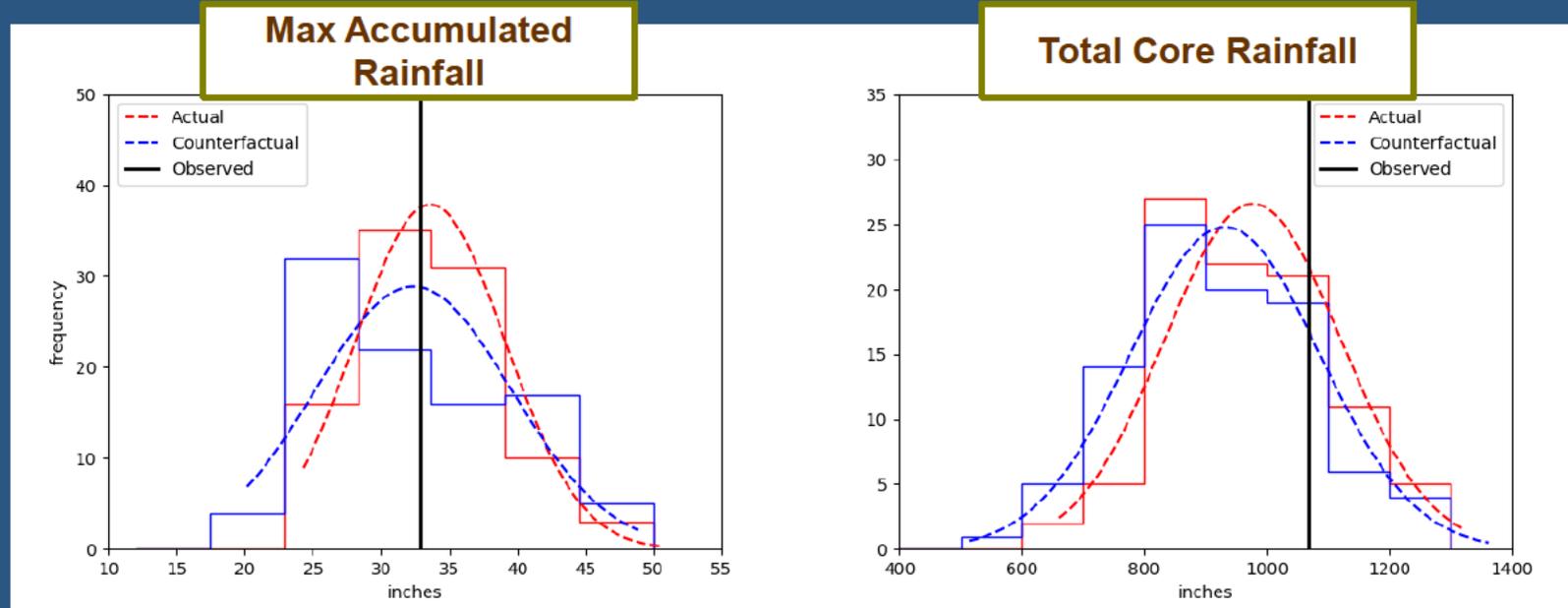
- Model reproduces Hurricane Florence track and landfall location in both landfalls.
- Suggests that the model is **fit-for-purpose**.

Hurricane Florence (2018)



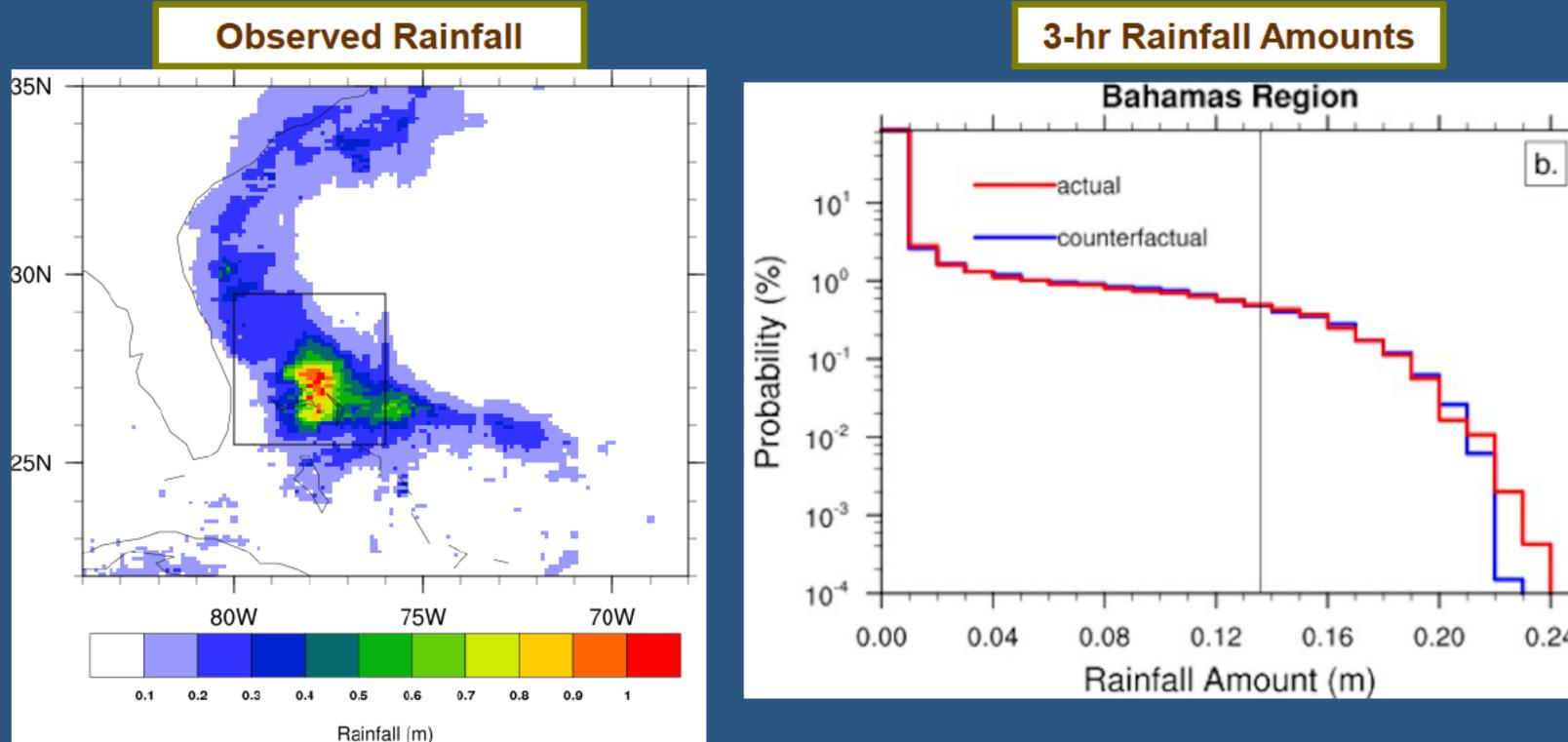
- Actual forecast reproduces Florence rainfall amounts well.
- Rainfall is **increased** due to observed warming.

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).

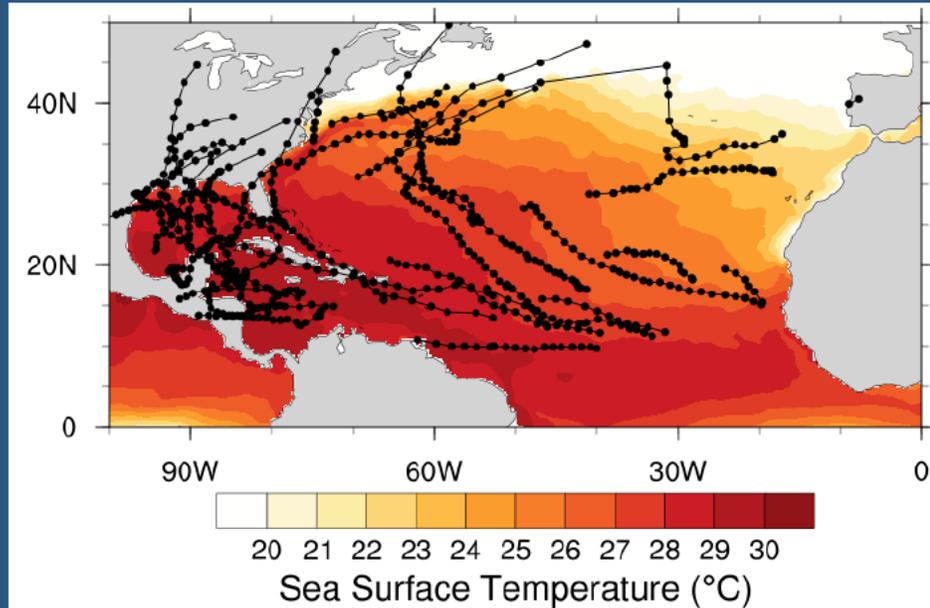
Hurricane Dorian (2019)



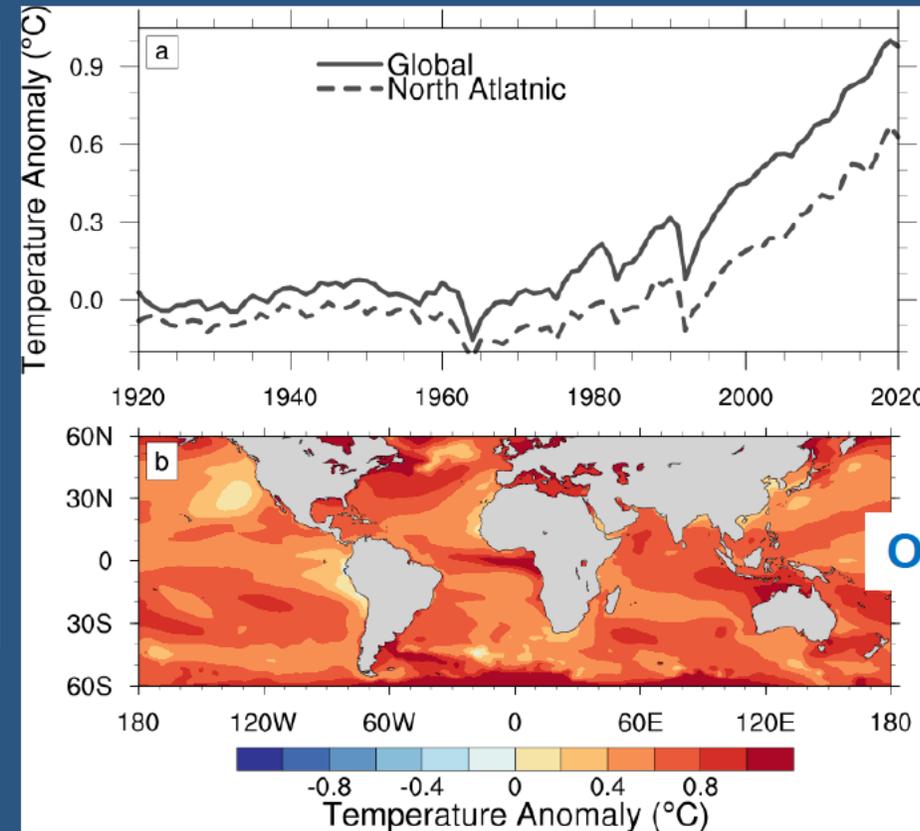
- Increase of $\sim 16 \pm 2\%$ in likelihood of maximum IMERG estimated rainfall amount.

2020 Hurricane Season

Actual Hindcasts



Counterfactual Hindcasts



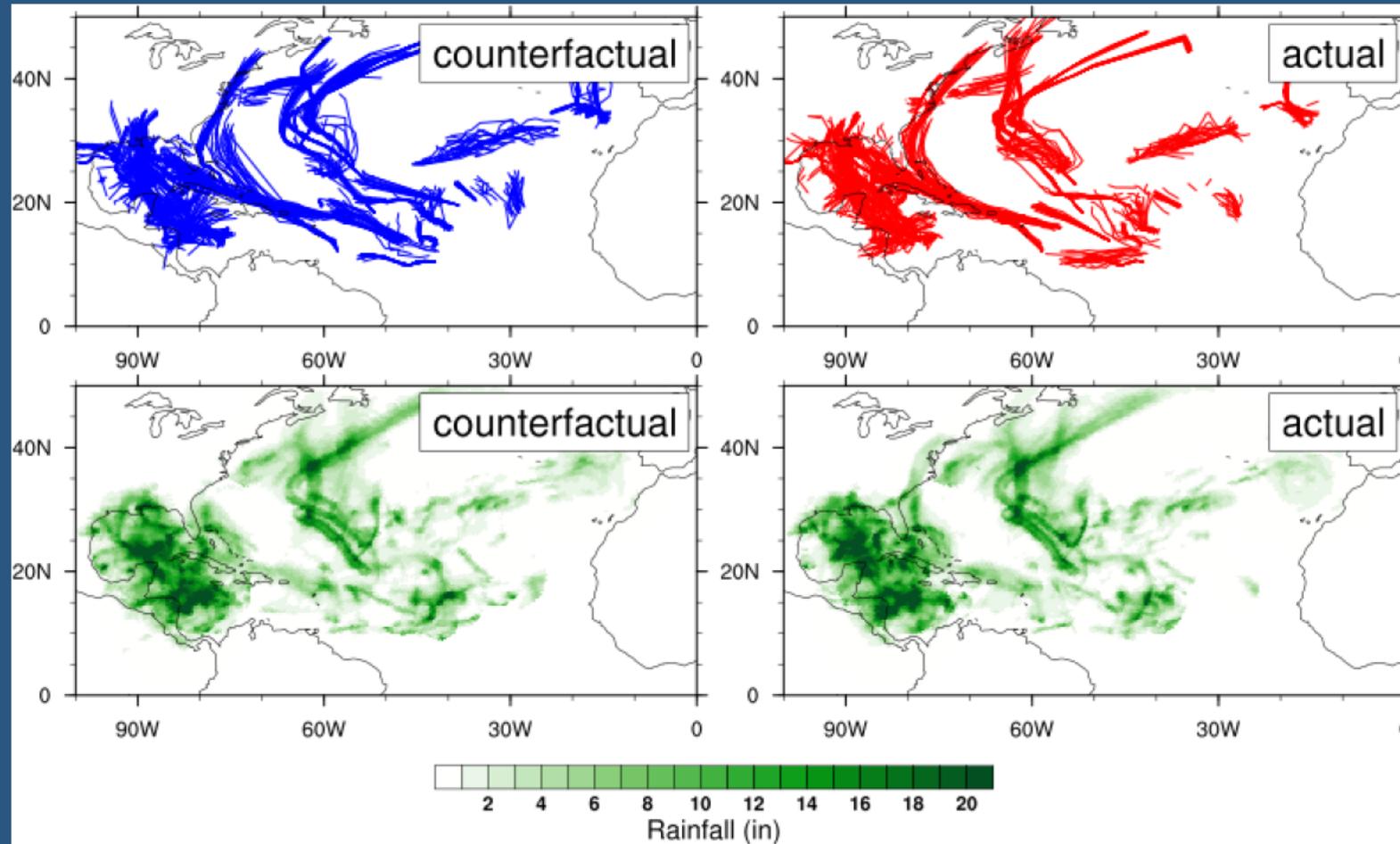
Our Fingerprint

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.

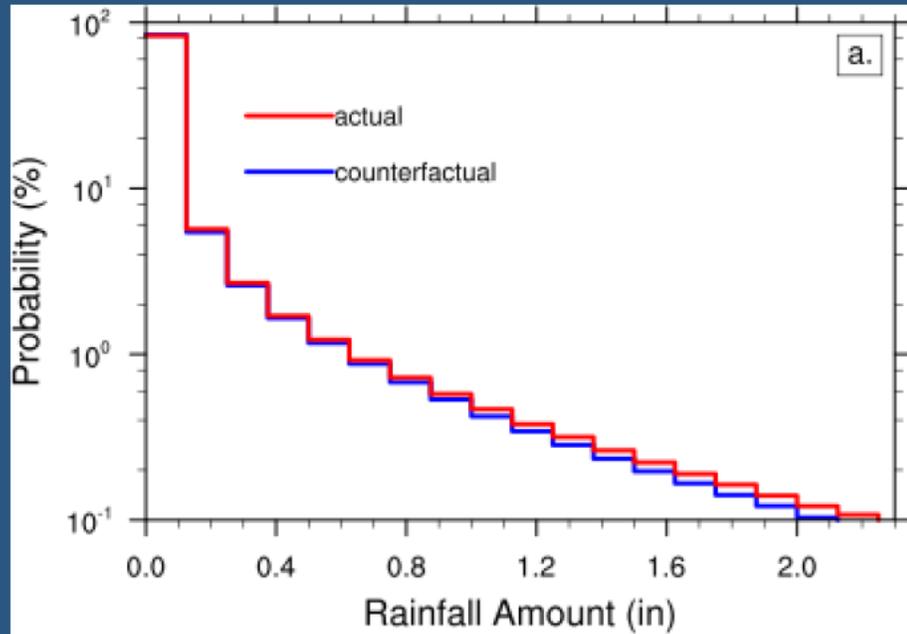


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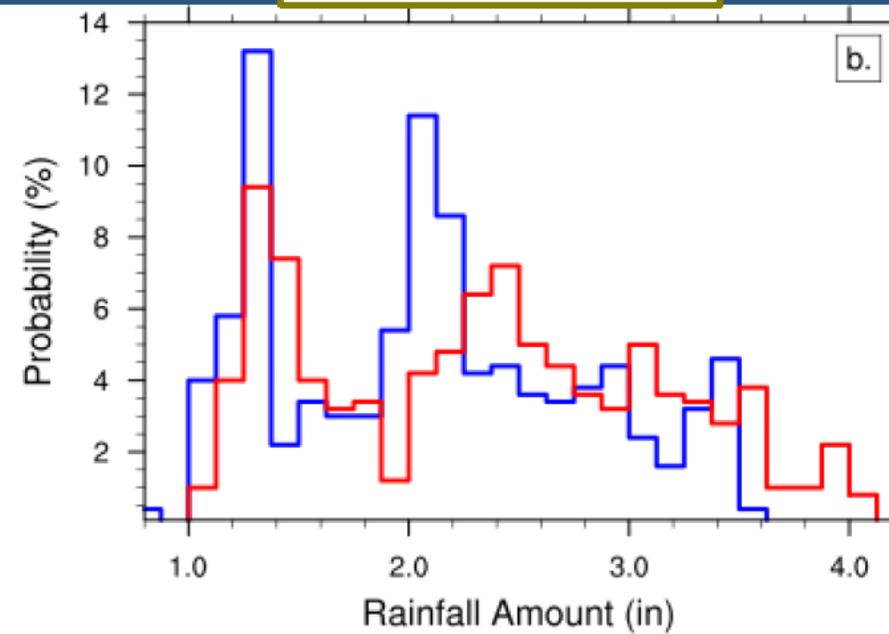
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2020 Hurricane Season

3-hr Rainfall Amounts



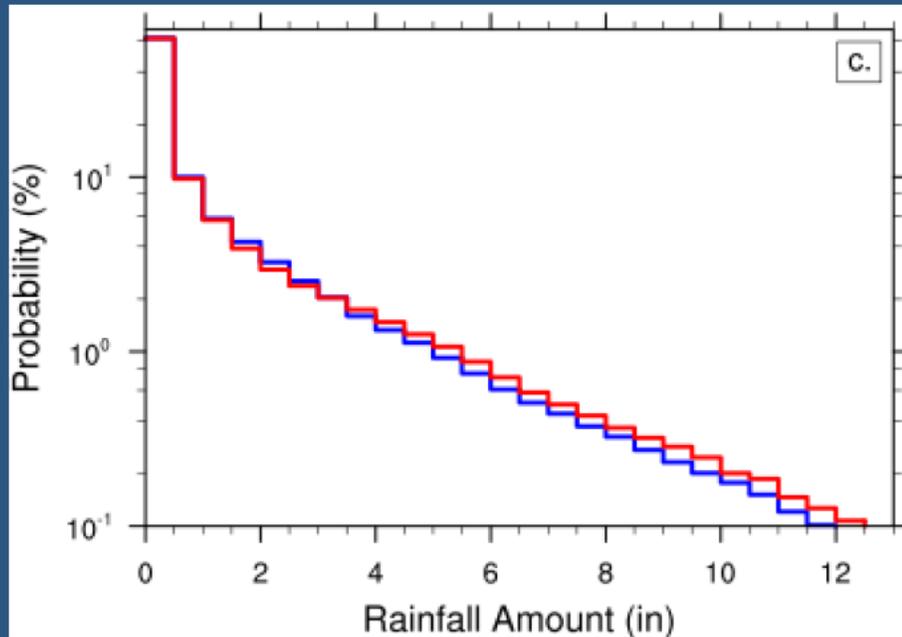
99 percentile
3-hr Rainfall Amounts



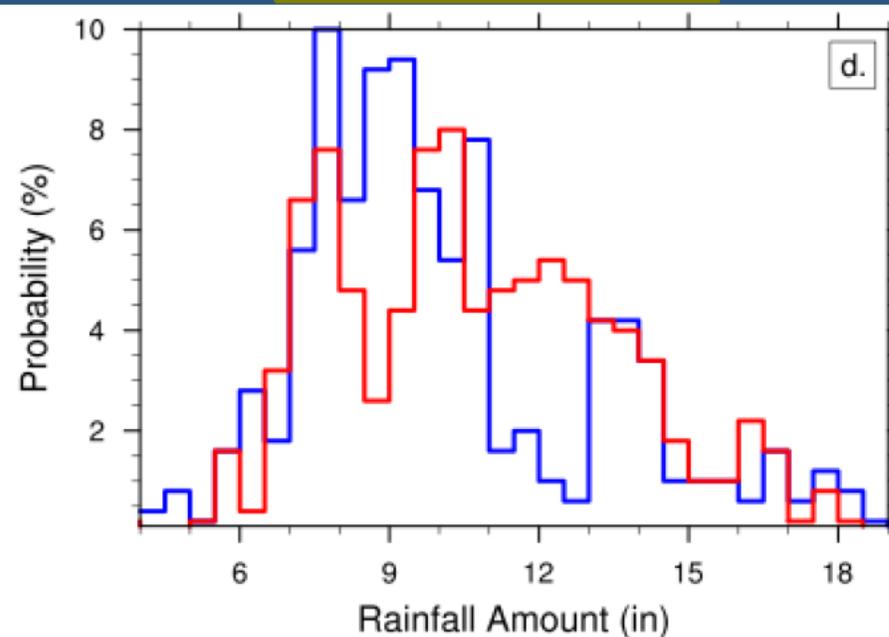
- A shift of $\sim 10 \pm 5\%$ in most extreme rainfall rates.

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 related to this topic.
- Research colleagues for collaboration on the studies I included.

- You for listening!

- Contact information: kevin.reed@stonybrook.edu



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?
- **Who funds** these event-specific attribution studies? Just because an event wasn't formally studied (e.g., in developing countries), doesn't mean it wasn't impacted by climate change.



Links

Assessments:

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