A large, weathered tree stump in the foreground of a dry, open landscape with hills in the background.

# Heat waves & cold snaps in a warmer world: What are we missing?

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# US DOE Policy 411.2A

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[Credit: Yoda Adaman | Unsplash]

It is indisputable that human activities are causing climate change, making extreme climate events, including heat waves, heavy rainfall, and droughts, more frequent and severe.





# Projected changes in extreme temperatures are larger in frequency and intensity with every additional increment of global warming

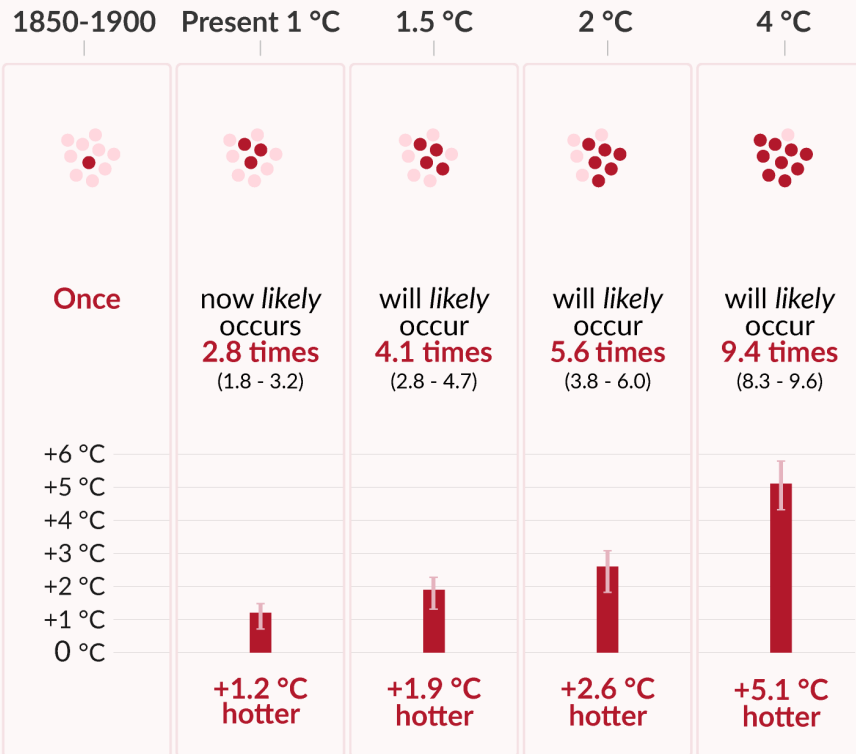
IPCC WG1 AR6 Figure SPM.6

## Hot temperature extremes over land

### 10-year event

Frequency and increase in intensity of extreme temperature event that occurred **once in 10 years** on average in a climate without human influence

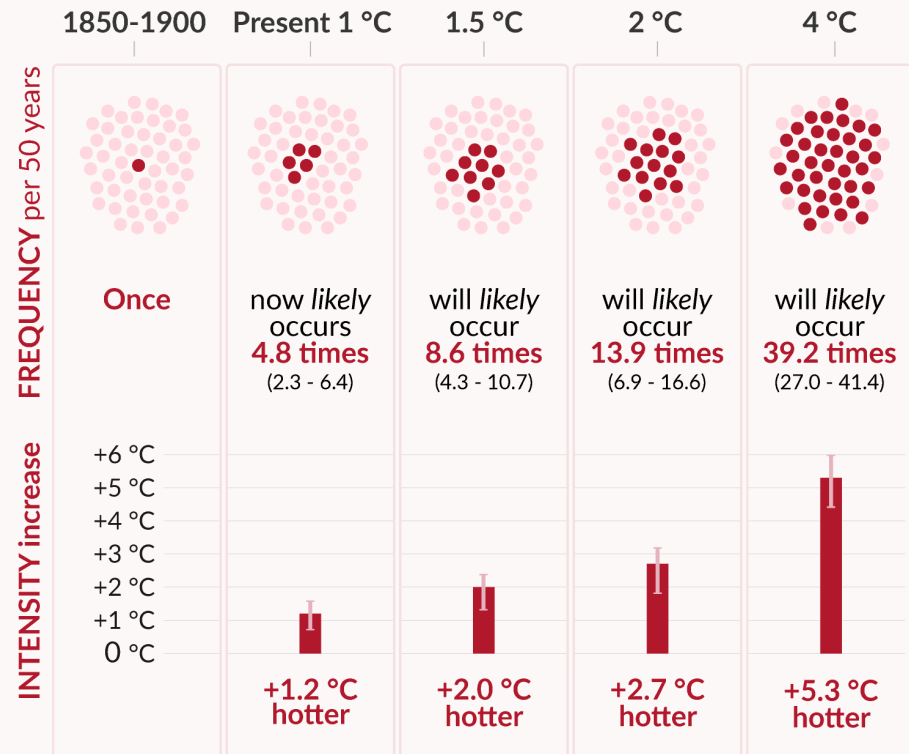
Future global warming levels



### 50-year event

Frequency and increase in intensity of extreme temperature event that occurred **once in 50 years** on average in a climate without human influence

Future global warming levels

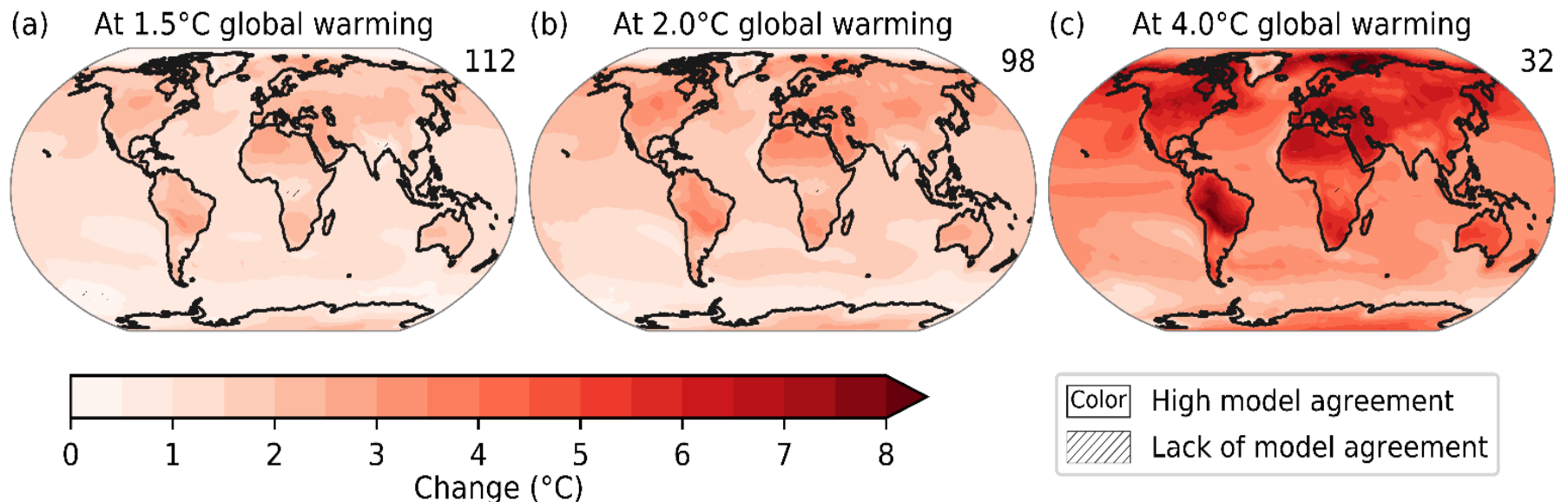




# Extreme heat waves are and will be warmer

- Current US heat waves are 3-5°F warmer than they would be without climate change (Wehner et al. 2018)
- By mid-century, expect another 4-6°F regardless of how we limit emissions. (IPCC AR6 WG1).

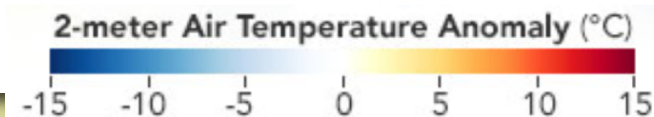
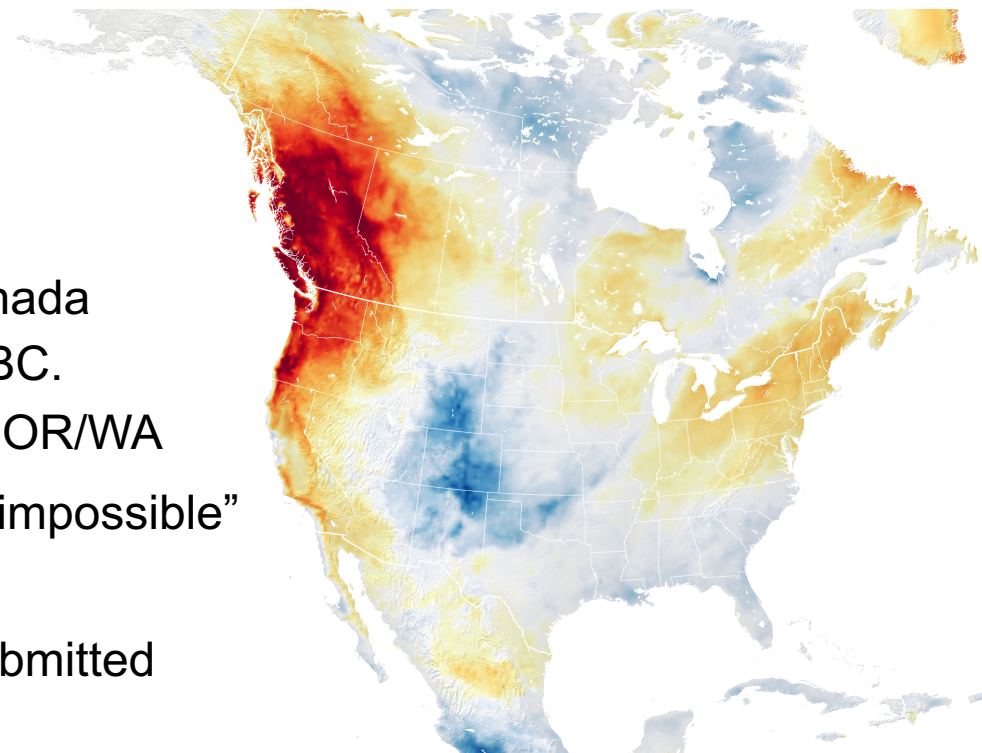
Annual maximum temperature (TXx) - median





# The Pacific Northwest heatwave of 2021

- The World Weather Attribution (WWA) project published a widely circulated “rapid attribution” statement.
  - 30+ scientists across the world.
  - Climate change made the event:
    - At least 150 times more likely
    - $\sim 2^{\circ}\text{C}$  ( $\sim 4^{\circ}\text{F}$ ) warmer
- Temperatures reached  $120^{\circ}\text{F}$  in Canada
  - Resulting fires destroyed Lytton, BC.
  - Temperatures exceeded  $115^{\circ}\text{F}$  in OR/WA
- WWA: Such temperatures “virtually impossible” without climate change.
- Peer review article is about to be submitted



June 27, 2021 Figure credit: NASA



# Extreme Weather Event Attribution

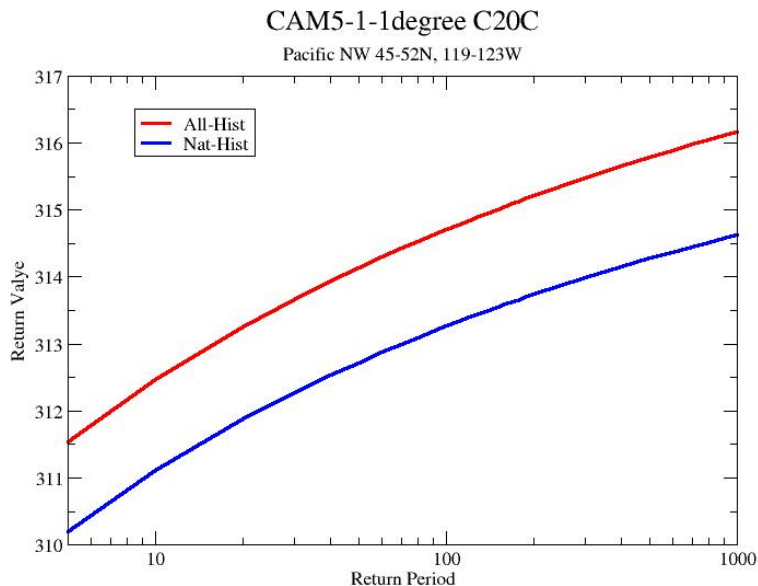
How much has global warming already changed specific individual extreme weather events today?

– To understand the human effects, we borrow from epidemiology to ask:

1. “How has the probability of this event changed because of climate change?”

Or

2. “How did climate change affect the magnitude of this event?”



These are two sides of the same question.

← 2021 Pacific Northwest heatwave.

Red: World with climate change

Blue: World without climate change

1) Fix the magnitude

2) Fix the probability.



# PNW heat wave attribution

- Prior to the 2021 PNW event, I thought attributing the human influence on heat waves is easy. (Geert Jan von Oldenburg thought the opposite!)
- It usually is!
- Hottest day of the year is generally well described by a nonstationary but bounded Generalized Extreme Value (GEV) distribution.
- Fitting PNW data up to and including 2020 but not 2021:
  - PNW temperatures impossible without climate change.

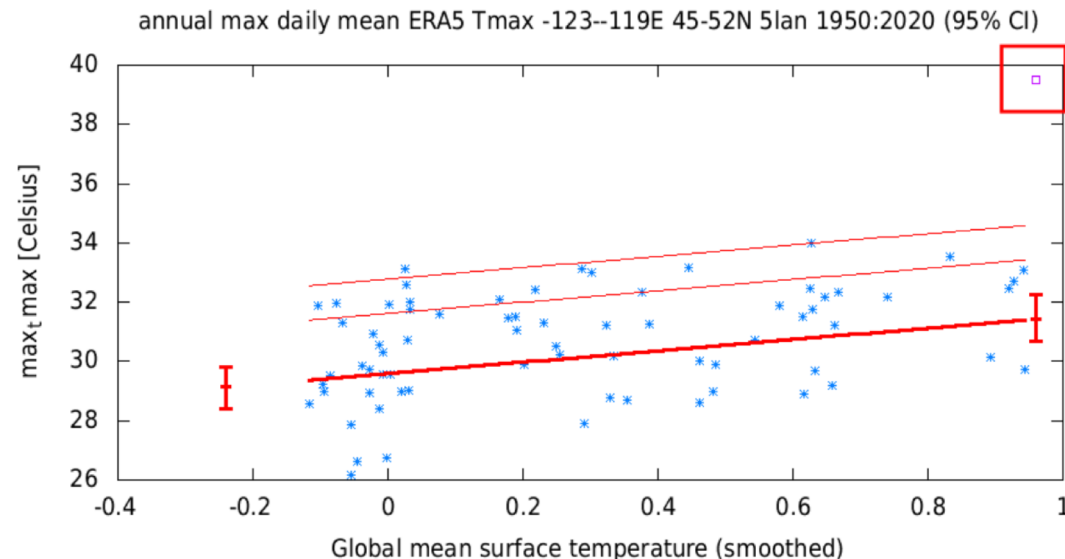


Figure 6: WWA PNW report 2021

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- Fitting PNW data up to and including 2020 but not 2021:
  - PNW temperatures impossible without climate change.
  - But also impossible with climate change!
- Something is obviously wrong!
- So GJ included 2021.
- 1 in 1000 year (or rarer) event now.
- 1 in 150,000 year event w/o global warming

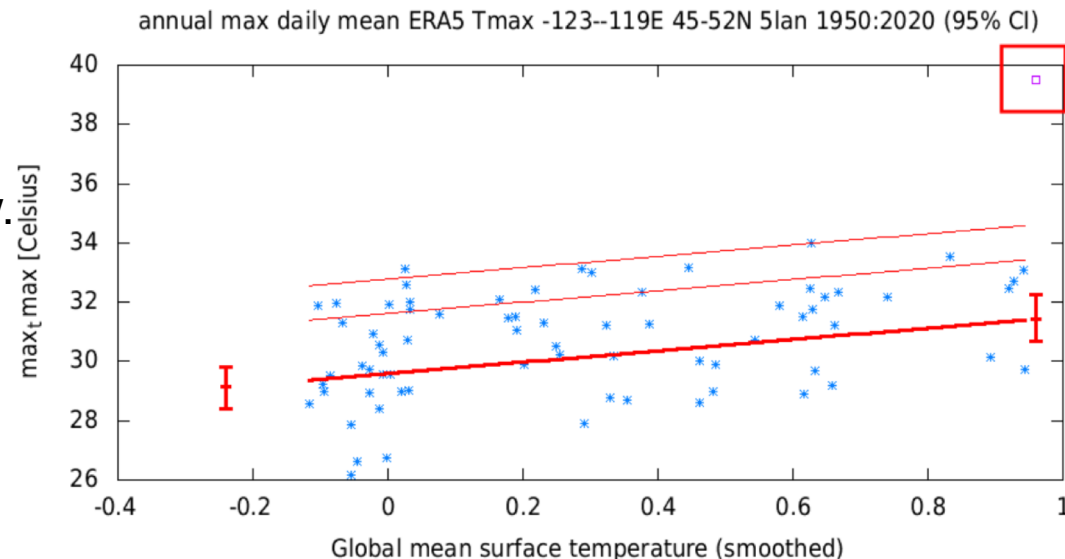


Figure 6: WWA PNW report 2021



## What makes the PNW event so difficult?

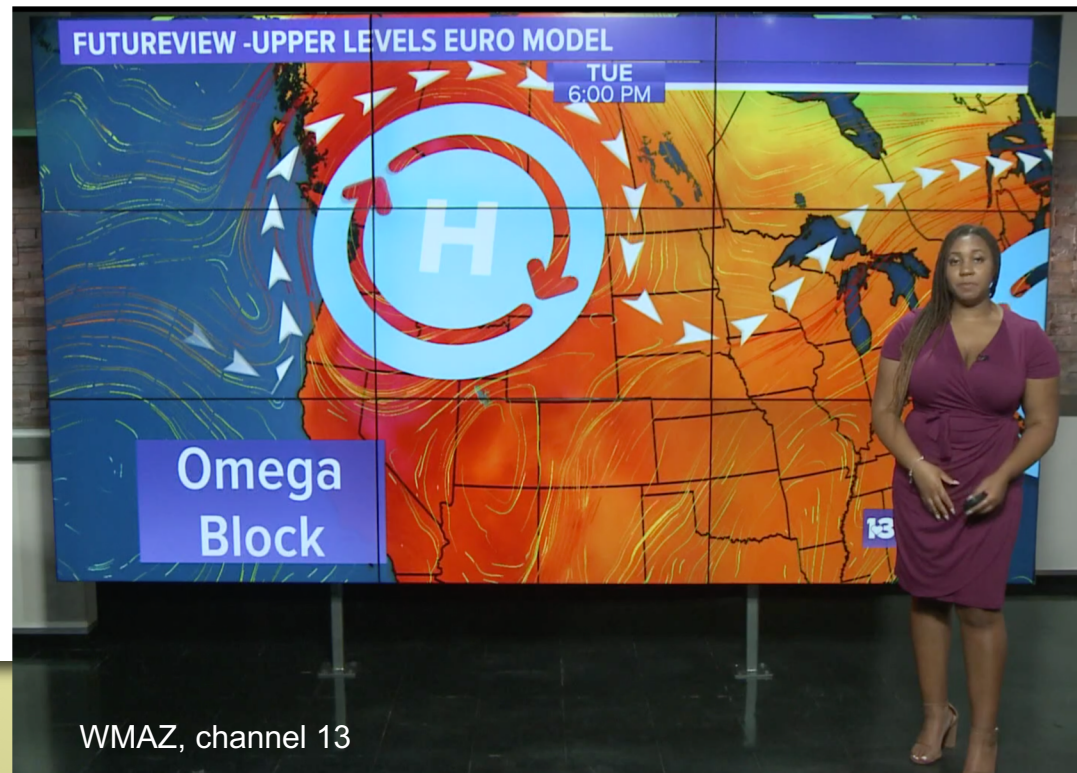
- PNW heat wave breaks the statistical model.
- 2021 values are well above the 95<sup>th</sup> percentile estimate of the "up to 2020" GEV
  - Including the outlier 2021 renders the goodness of the GEV fit to be very poor.
    - (private communication: Likun Zhang and Mark Risser, LBNL).
- Why? The GEV theorems require that data be independent and identically distributed (i.i.d.)
  - In plain language, is the physical phenomena behind by the data uniform?
  - In this case, no!
    - 2021 is (perhaps obviously) the result of some very different weather pattern than other years.

# Heat dome

- The PNW heat wave was directly caused by an “omega block”.
- An omega block is characteristic of the waviness of the jet stream.
- A stagnant high pressure region. Winds go around it. Not through.
  - In summer, it gets very hot. (heat dome)
  - In winter, it gets very cold.
- It was well forecasted.
- An omega block at this location is very rare and likely unprecedented.

(private communication:

Paul Ullrich UC Davis)



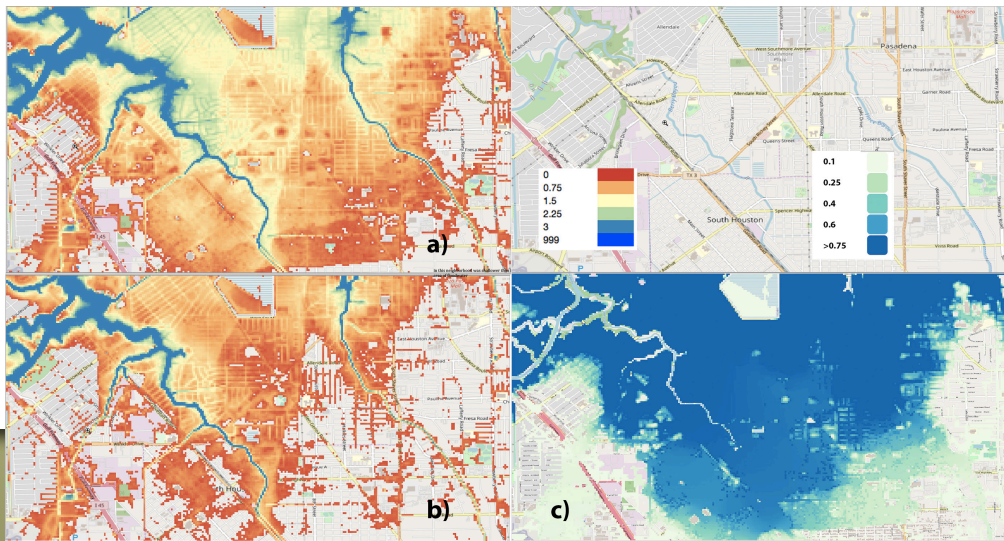


## The PNW heat wave is scientifically interesting.

- PNW heat wave breaks our statistical models (not i.i.d.)
- PNW heat wave breaks our climate models.
  - It may be too rare for our sizable but still limited datasets.
  - Or are we missing some important processes?
- The Francis & Vavrus conjecture:
  - A warmer atmosphere is more stable. (yes)
  - A more stable atmosphere has a slower jet stream (yes).
  - A slower jet stream is wavier (maybe).
  - A wavier jet stream results in more blocking events
    - More heat domes
    - More Siberian Express cross polar flows (i.e. Texas deep freeze 2021).

# And then there is wind...

- IPCC AR6 WG1:
  - Hurricanes
    - The fraction of storms that reach cat 3,4,5 will increase
    - The strongest storms get stronger.
    - Heavier rain and flooding
  - Extra-tropical storms
    - Windier extremes
  - Severe convective storms (tornadoes, hail, etc.)
    - Longer season.



←Attributable Harvey flood



## So now what?

- Changes in garden variety extreme heat waves and cold snaps (1 in 50 year events) are pretty well understood.
- But very rare events are scientifically interesting.
- Is the Francis & Vavrus conjecture true?
  - If so, such very rare events could become more common than suggested by IPCC projections.
- Many groups are analyzing these events.
  - including our group at Berkeley Lab (Emily Bercos-Hickey, Travis O'Brien et al.)
  - Such rare events, tragic as they are, drive progress both in climate and statistical modeling of the effects of global warming.



**Thank you!**  
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