Extreme Weather Impact Attribution, Environmental Justice and Loss & Damages.

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US DOE Policy 411.2A

SUBJECT: SCIENTIFIC INTEGRITY

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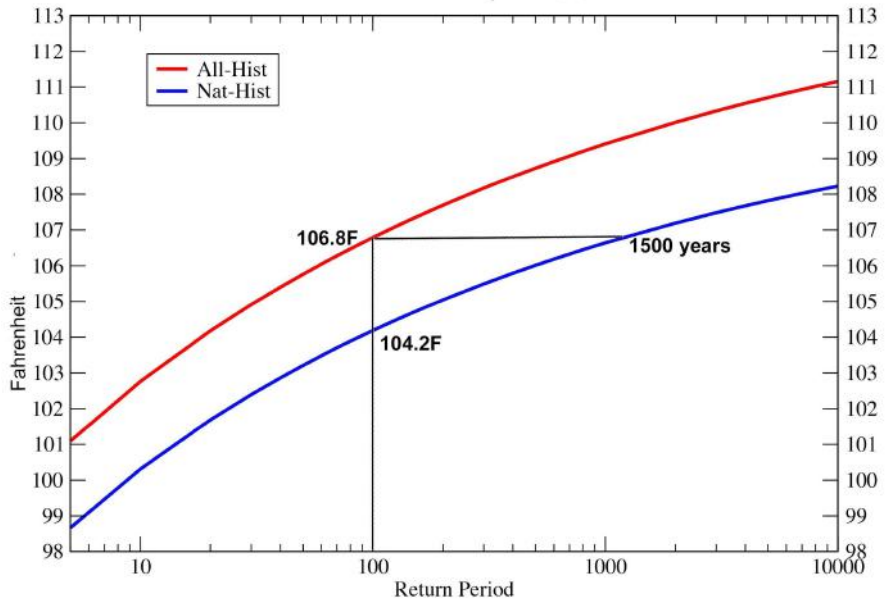
What is extreme weather event attribution?

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.

Public attention often focuses on the first question.

15 times more likely sounds bigger than a 2º increase.

Extreme weather Impact questions are a bit different

- How much did climate change cost in this event?
- How many people died because of climate change?

Or more personally,

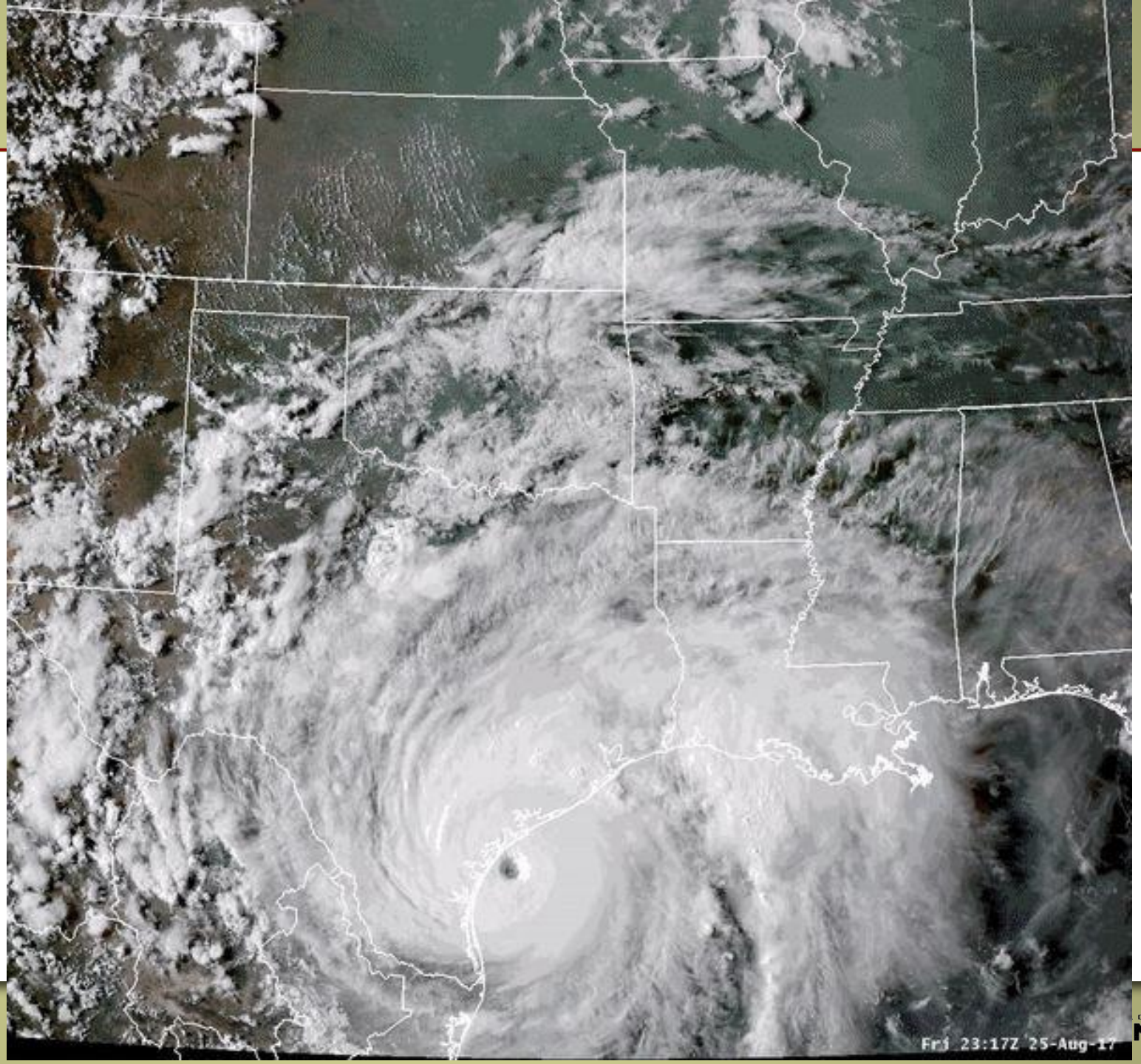
- Did climate change flood my house?
- Did climate change kill my loved one?

These may or may not be tractable questions.

Fundamentally, they are linked to the change in magnitude question. (*Mostly*).

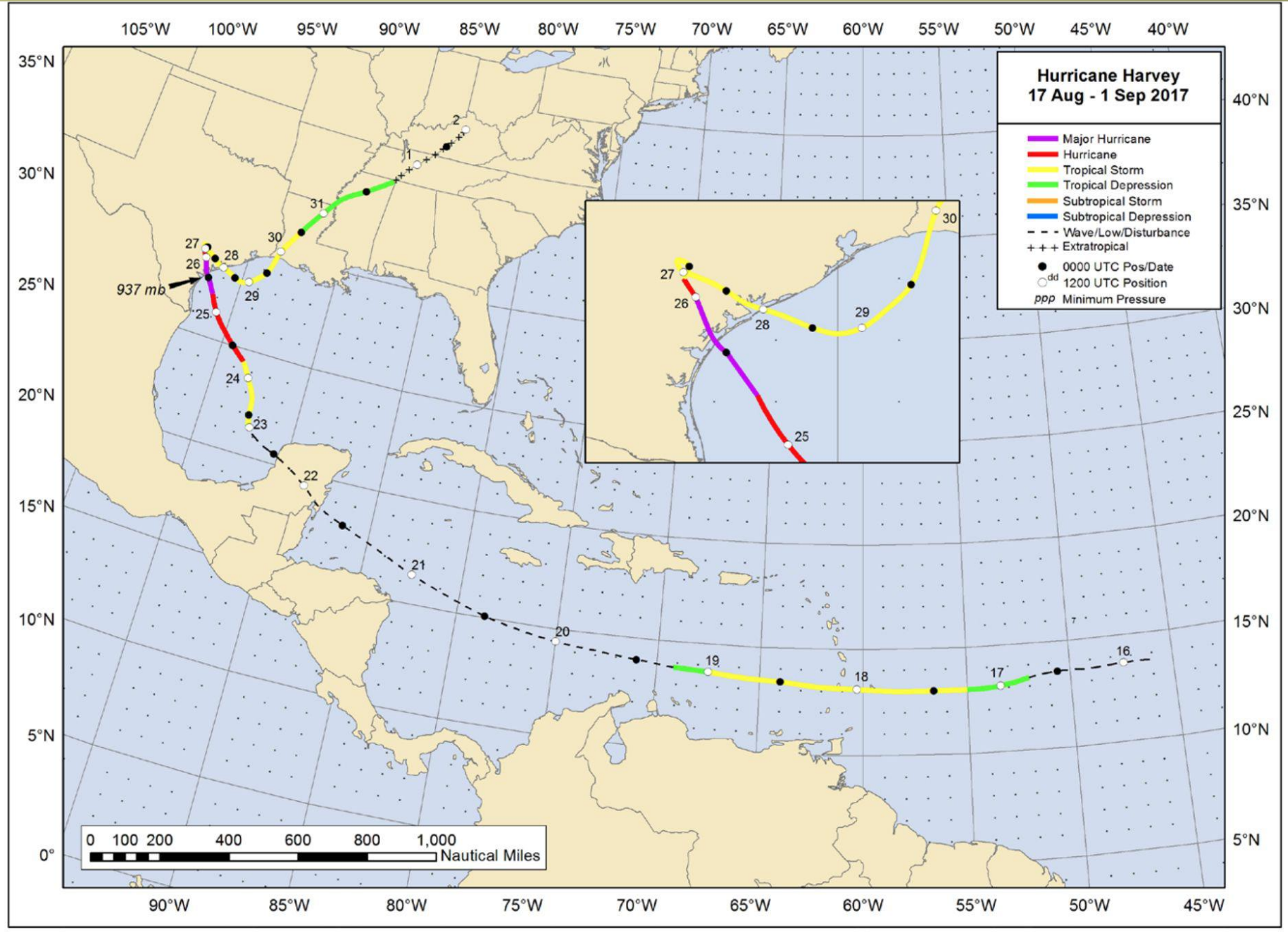
Harvey

August 2017



NOAA

Harvey



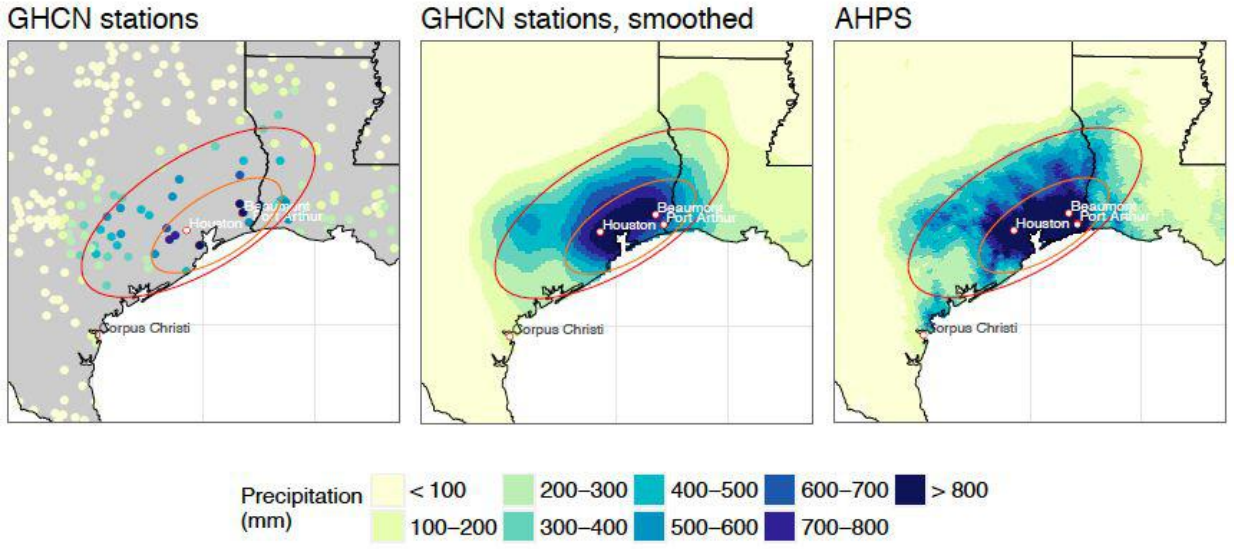
National Hurricane Center

Global warming to rain

- Hurricane Harvey produced copious amounts of precipitation
- 3 independent groups analyzed the attributable precipitation increase due to anthropogenic global warming.
- **All made best estimates exceeding that expected by Clausius-Clapeyron scaling (~7% from 1C of warming in the Gulf).**
  - 3 different modeling methods
  - 3 different observational data sets

Risser & Wehner: 24%
van Oldenborg et al: 16%
Wang et al: 20%

Average ~19%
Upper bound 38%
Lower bound 7%



An aside: Extreme Event Attribution is causal inference.

Two complementary philosophies

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.

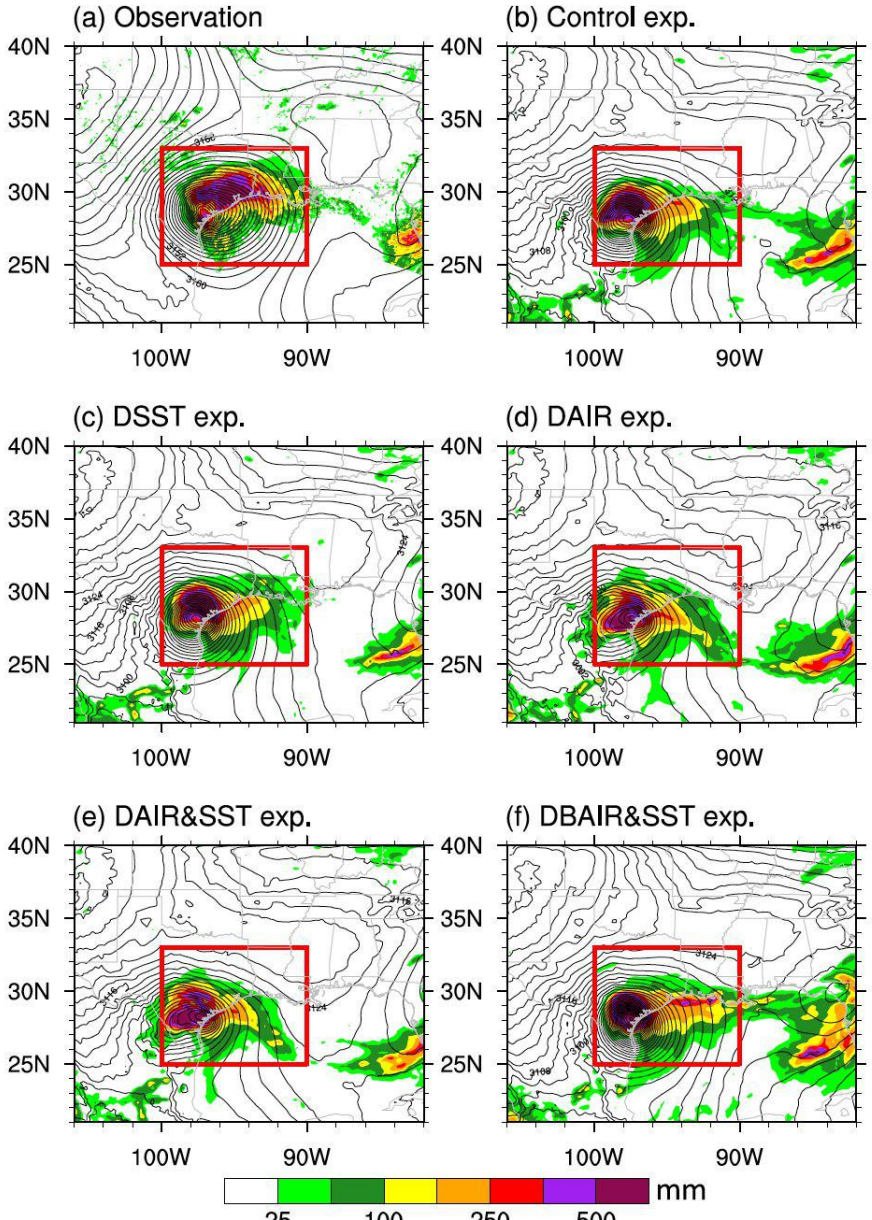
Prof. Judea Pearl, UCLA

2. Analyze observed trends with a statistical model.
   - Postulate a plausible cause but beware of hidden covariates.
   - Granger causal inference.

Sir Clive Granger (1934-2009)

Pearl Causal inference via a storyline

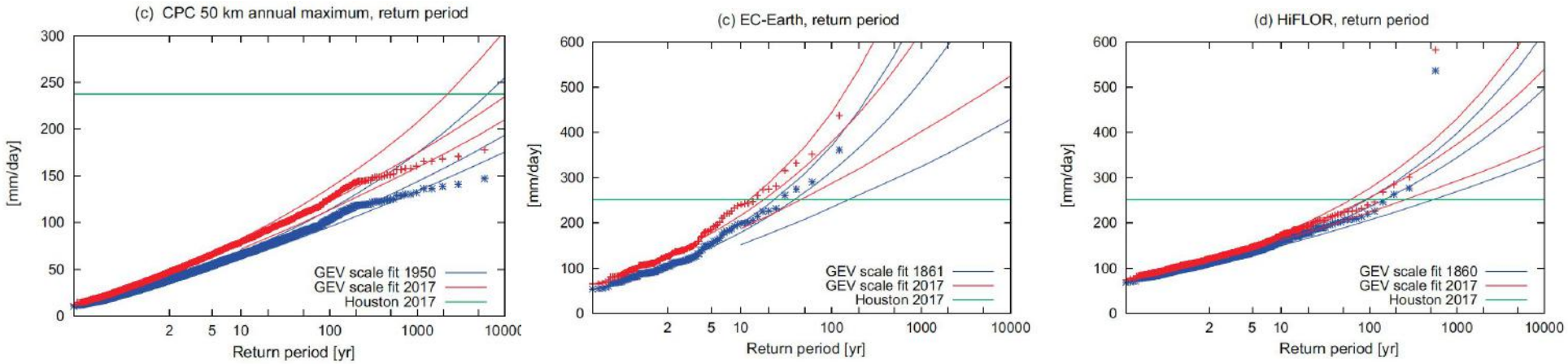
- Wang et al (2018)
  - The storm that was
    - WRF downscaling of the GFS initial condition data
  - The storm that might have been.
    - Same but perturbed by the CESM LE (about 1C attributable warming in the Gulf of Mexico)
  - **Climate change increased Harvey's precipitation by 20%**



Wang et al. (2018) "Quantitative Attribution of Climate Effects on Hurricane Harvey's Extreme Rainfall in Texas." *Environmental Research Letters* 13:054014.

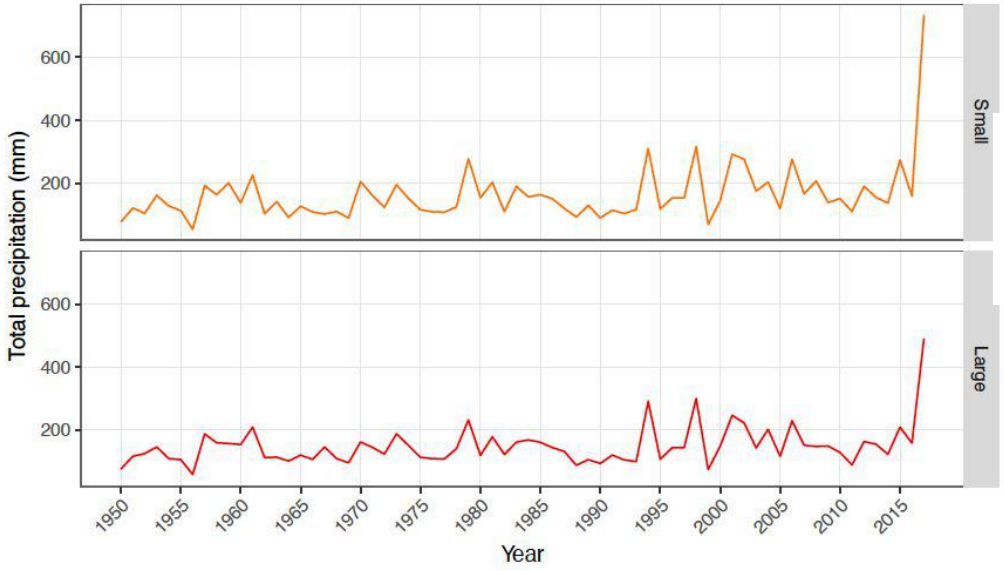
Pearl Causal inference without a storyline ("Traditional")

- van Oldenborg et al 2017
- 3 climate models. EC-Earth, GFDL HiFlor, HadRM3p
  - Ensembles of longer runs of varying length.
  - Harvey was not wired in by initial conditions.
- Plus a GEV statistical model to estimate rarity from CPC observations.
  - Combined this information.
  - *Likely* range of precipitation increase of 8-19%



van Oldenborg et al. (2017). "Attribution of Extreme Rainfall from Hurricane Harvey, August 2017." *Environmental Research Letters* 12:124009.

Hurricane Harvey (Risser & Wehner 2017)



$$G_t(z) \equiv \mathbb{P}(Z_t \le z) = \exp\left\{-\left[1+\xi_t\left(\frac{z-\mu_t}{\sigma_t}\right)\right]^{-1/\xi_t}\right\},$$

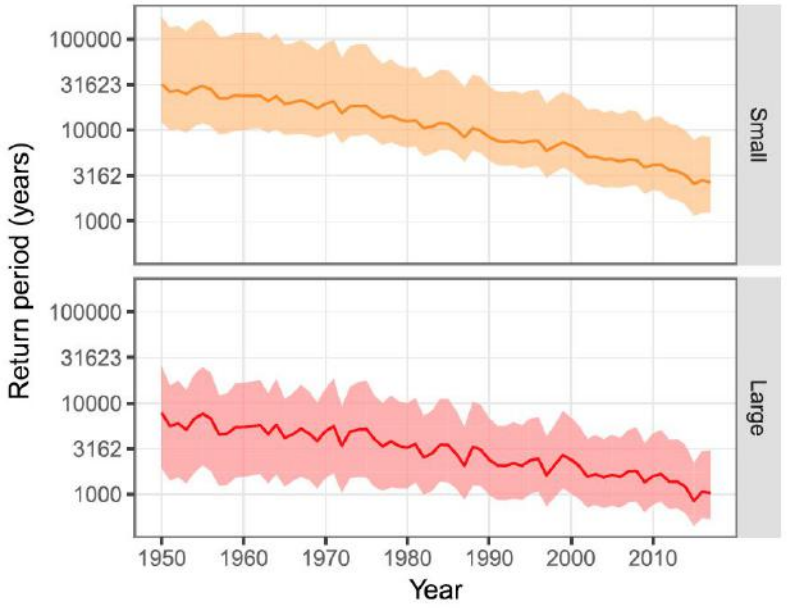
$$\mu_t = \beta_0 + \beta_1 x_{1t} + \beta_2 x_{2t}, \log \sigma_t = \phi_0 + \phi_1 x_{1t}, \xi_t \equiv \xi$$

1=ln(CO_2)$_t$
2=NINO3.2$_t$
Best fit, AIC

Harvey seven day total precipitation

Data source	Small region Pr (mm)	Large region Pr (mm)
GHCN stations (raw values)	735.0	491.6
GHCN stations (smoothed)	700.2	481.6
NOAA AHPS	829.3	552.4

Harvey precipitation return periods in 2017 (best estimates of the actual storm)
Small region: 3000 years
Large region: 1100 years



Hurricane Harvey (Risser & Wehner 2017)

Consider this Granger attribution statement on the change in magnitude of total Hurricane Harvey precipitation, altering the co-variates in the statistical model: A “statistical counterfactual”

By fixing the probability at actual 2017 levels (1/3000 or 1/1100), we can estimate precipitation storm total amounts at that rarity with 2017 values of Niño3.4 but 1950 values of CO_2 and compare to actual 2017 storm totals.

Small region: 38% increase (likely at least 19%
Large region: 24% increase (*likely* at least 7%)

Mark D. Risser and Michael F. Wehner (2017) Attributable human-induced changes in the likelihood and magnitude of the observed extreme precipitation in the Houston, Texas region during Hurricane Harvey. *Geophysical Review Letters*. 44, 12,457–12,464. https://doi.org/10.1002/2017GL075888

Global warming to rain

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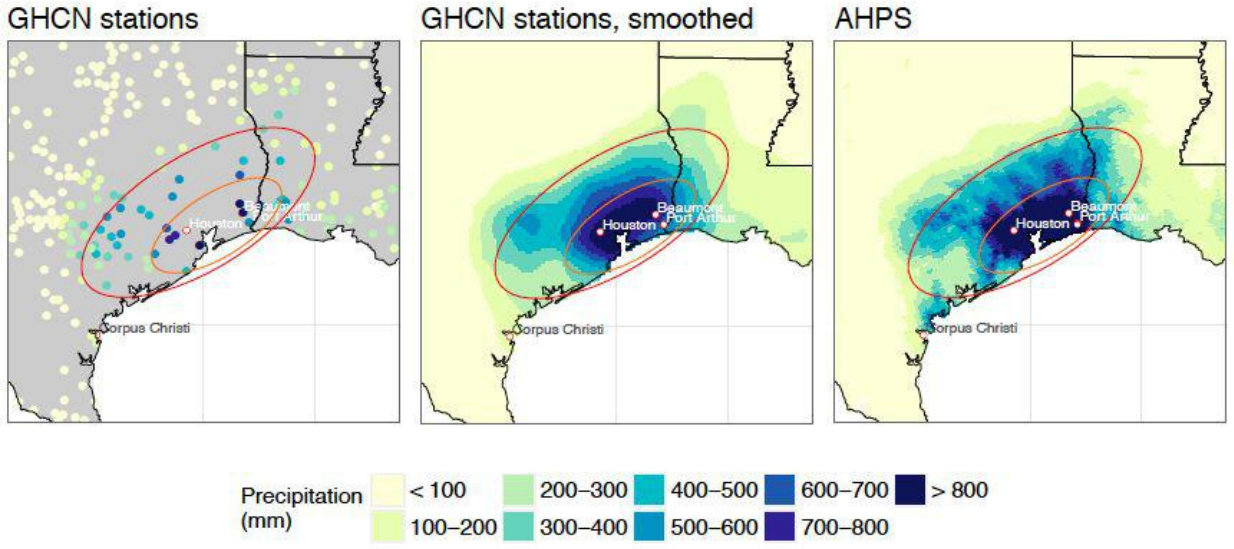


Rain to flood

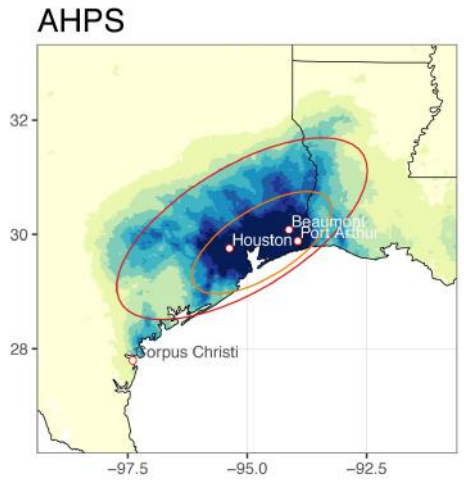
- How did this attributable increase in precipitation affect the flood?
- Design a storyline attribution analysis of the flood. (Pearl causality)

The “flood that was”.

- Fathom 30m hydraulic model driven by precipitation from the NOAA National Weather Service Advanced Hydrologic Prediction Service (AHPS)

The “flood(s) that might have been”.

- Alter the rainfall uniformly by the published attribution statements.
- Published ranges are 7-38% increases
- e.g. Risser & Wehner’s 24% statement
  - Decrease observed precipitation by 1/1.24=0.81



Michael Wehner and Christopher Sampson (2021) Attributable human-induced changes in the magnitude of flooding in the Houston, Texas region during Hurricane Harvey. *Climatic Change.* 166, 20 https://doi.org/10.1007/s10584-021-03114-z

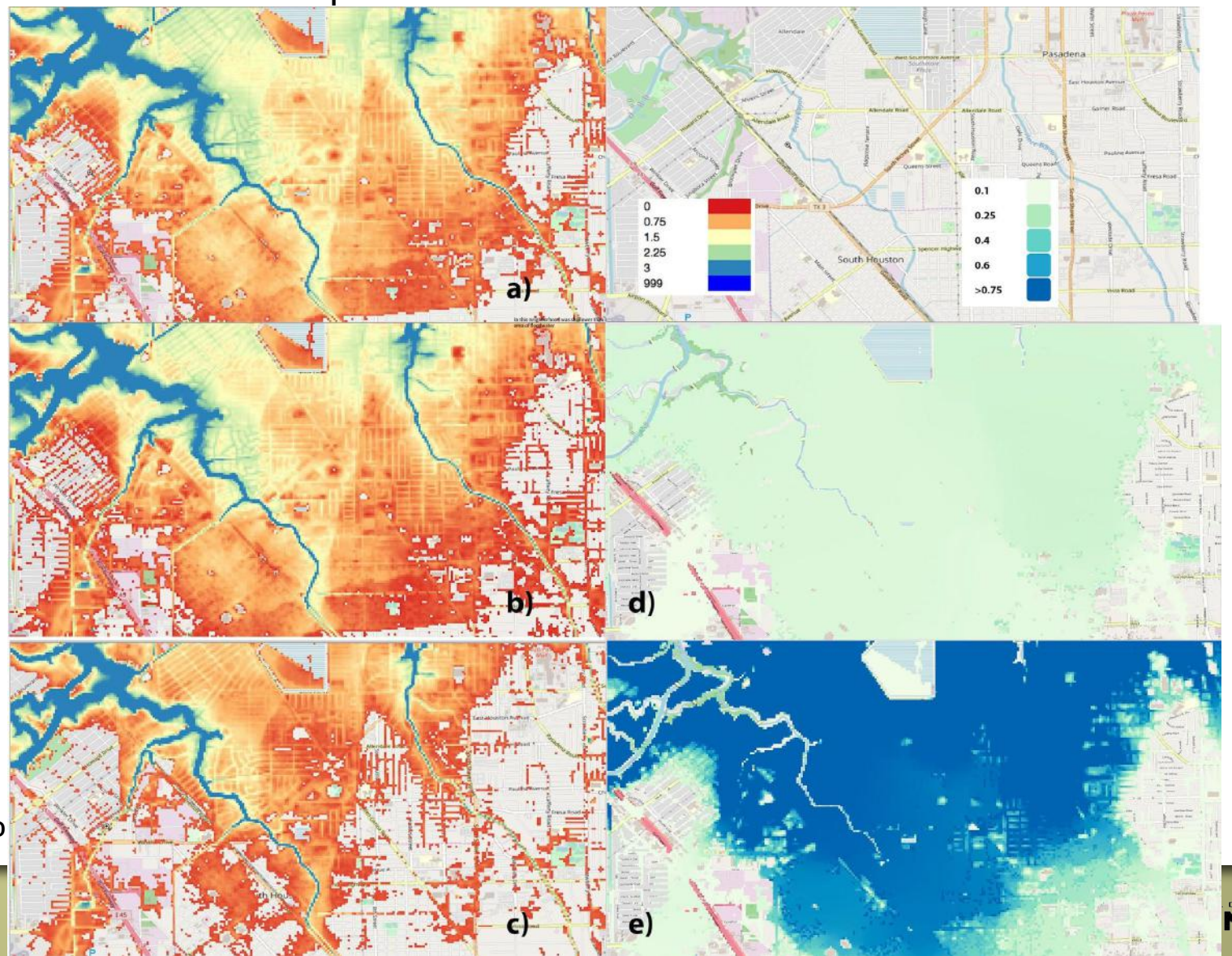
Did climate change flood my South Houston house?

Flood depth | Difference

actual flood that was

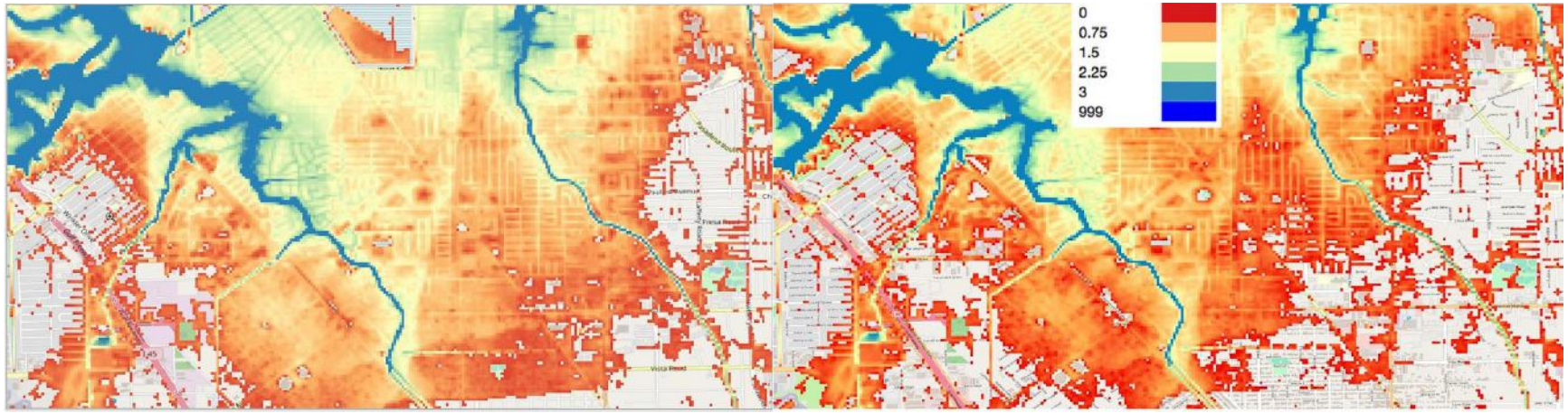
Flood that might have been if precipitation was increased by 7%

Flood that might have been if precipitation was increased by 38%



Did climate change flood my South Houston house?

Flood that was | Flood that might have been

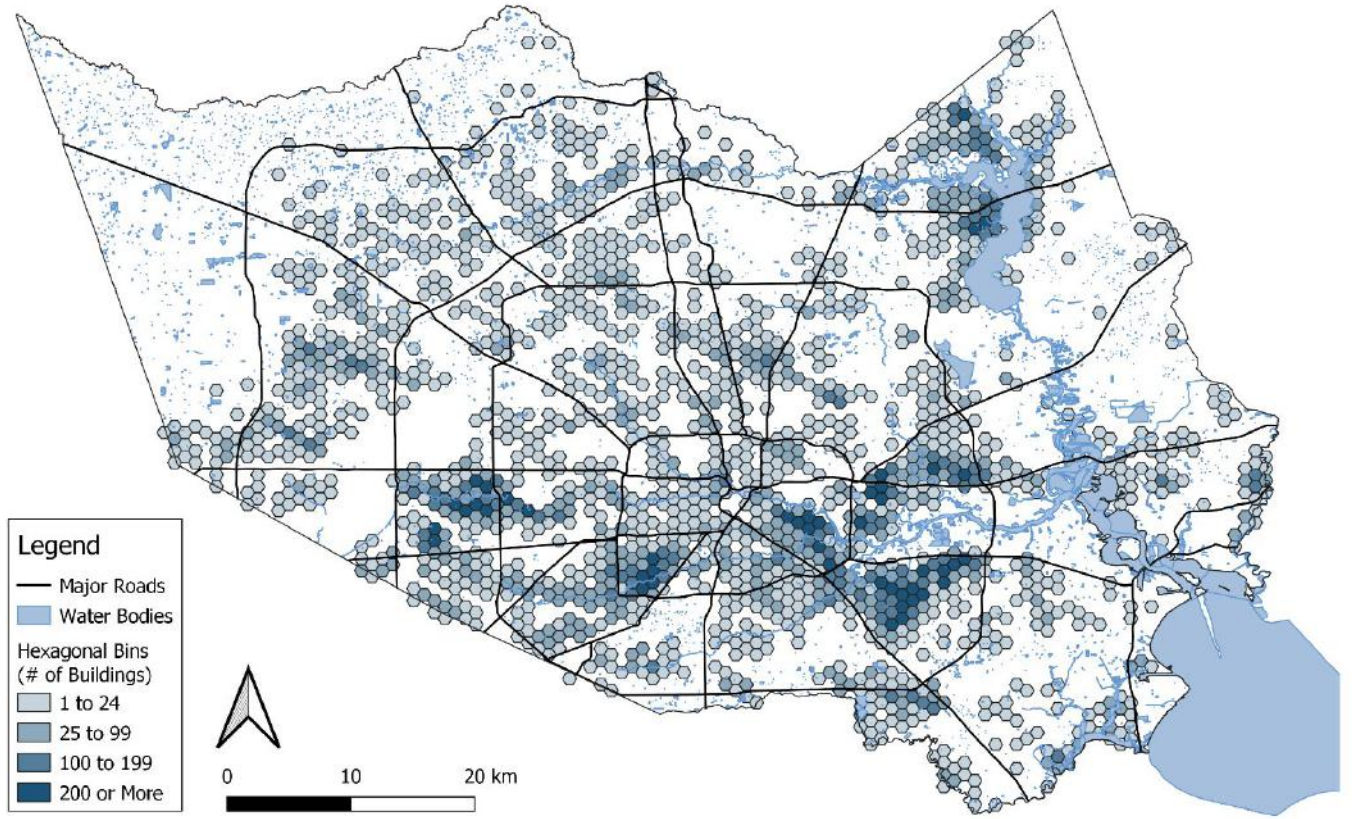


Best estimate rain increase	Best estimate flood area increase	Crude estimate attributable cost	RR
19%	14%	US$13Bn	4

- A best estimate of the insured losses from Hurricane Harvey is US$90Bn.
- "Our best estimate is that climate change increased the ***insured*** cost of Hurricane Harvey by about 14% or US$13Bn".
- "The probability of an ***insured*** US$90Bn hurricane loss in Texas was quadrupled due to climate change."

Flood to impacts

Combine the flood maps of Wehner & Sampson with real estate maps



Each hexagonal bin symbolizes the number of residential buildings that would not have flooded without the added impact of climate change in Harris County, Texas during Hurricane Harvey (38% precipitation increase).

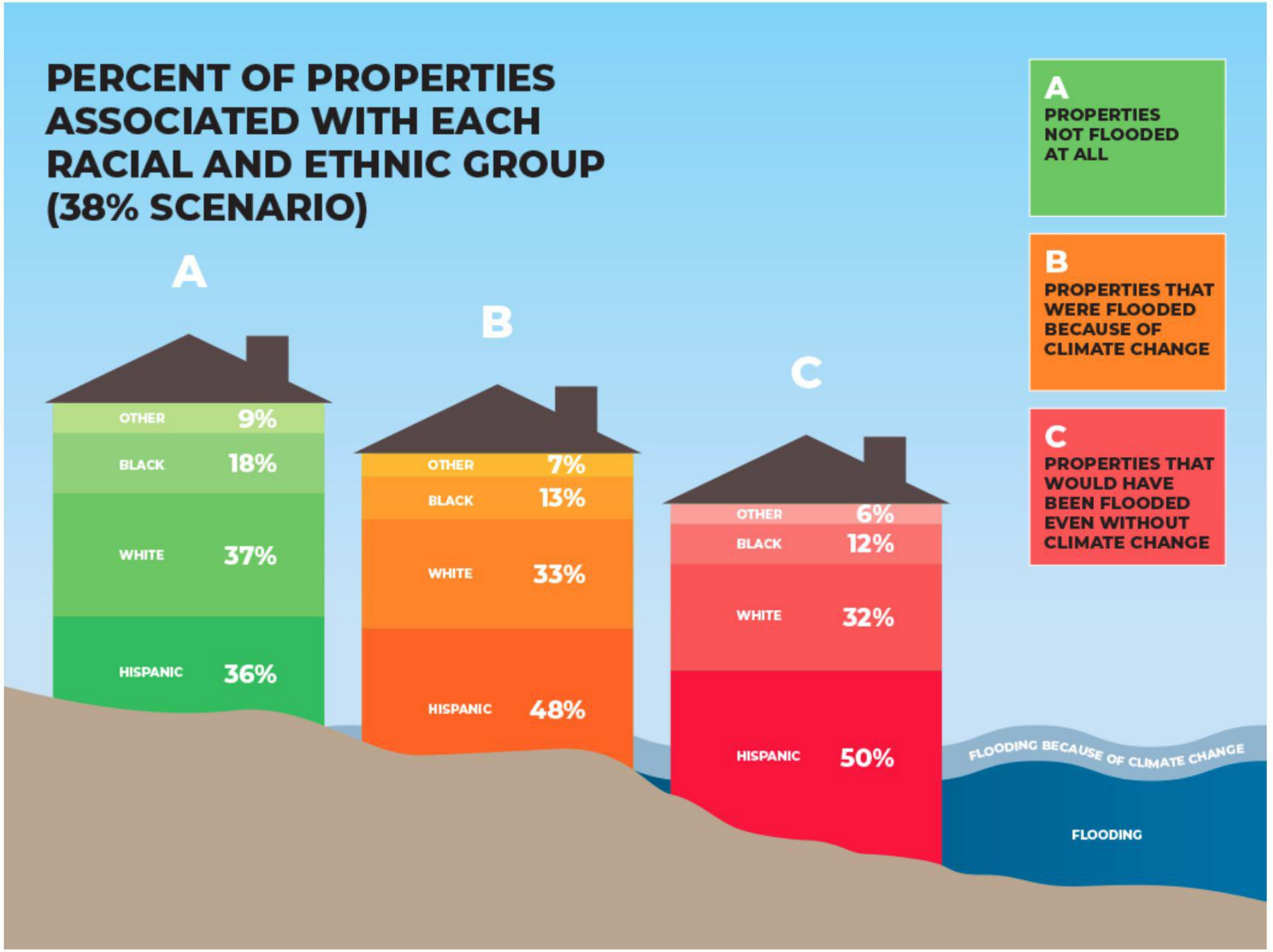
Kevin T. Smiley, Ilan Noy, Michael Wehner, Dave Frame, Christopher Sampson and Oliver E.Wing (2022) Social Inequalities in Climate Change-Attributed Impacts of Hurricane Harvey. *Nature Communications* **13**, 3418 https://doi.org/10.1038/s41467-022-31056-2

Flood to impacts

- From real estate data:
  - 32% of flooded homes in Harris County would not have been flooded without climate change (best estimate, 20% precipitation increase).
  - 75% of the flooded homes were outside the Federal 100 year flood plain and thus uninsured.
  - NOAA estimated loss=$155Bn
    - Global warming caused 1/3 of this damage. $50Bn

- Using census data permits further socioeconomic analysis
  - Income & Race
  - Single/multi-family residence
  - Mobile homes

PERCENT OF PROPERTIES ASSOCIATED WITH EACH RACIAL AND ETHNIC GROUP (38% SCENARIO)



Socio-economic disparity

- Harvey flood damages were not distributed equally across socio-economic groups.
  - Regardless of precipitation change estimate, low-income Hispanic communities were disproportionately affected.
  - In high income (white) neighborhoods, the richer you were the greater the financial damage.
  - In low income, Hispanic neighborhoods, the poorer you were, the greater the financial damage.
  - No statistical significance of income trends in non-white, non-Hispanic neighborhoods.

End to end attribution:

Hurricane Harvey:

- Global warming □ more rain □ more flooding □ more impacts
- 1ºC □ 20% □ 14% □ 32% □ US$40Bn

- Environmental injustice:
  - Low income Hispanic population was disproportionately affected
    - ~50% of the flooded homes but only 36% of the population (even without climate change)
- The Harvey flood data is publicly available at https://portal.nersc.gov/cascade/Harvey/

Michael Wehner and Christopher Sampson (2021) Attributable human-induced changes in the magnitude of flooding in the Houston, Texas region during Hurricane Harvey. *Climatic Change.* 166**,** 20 https://doi.org/10.1007/s10584-021-03114-z

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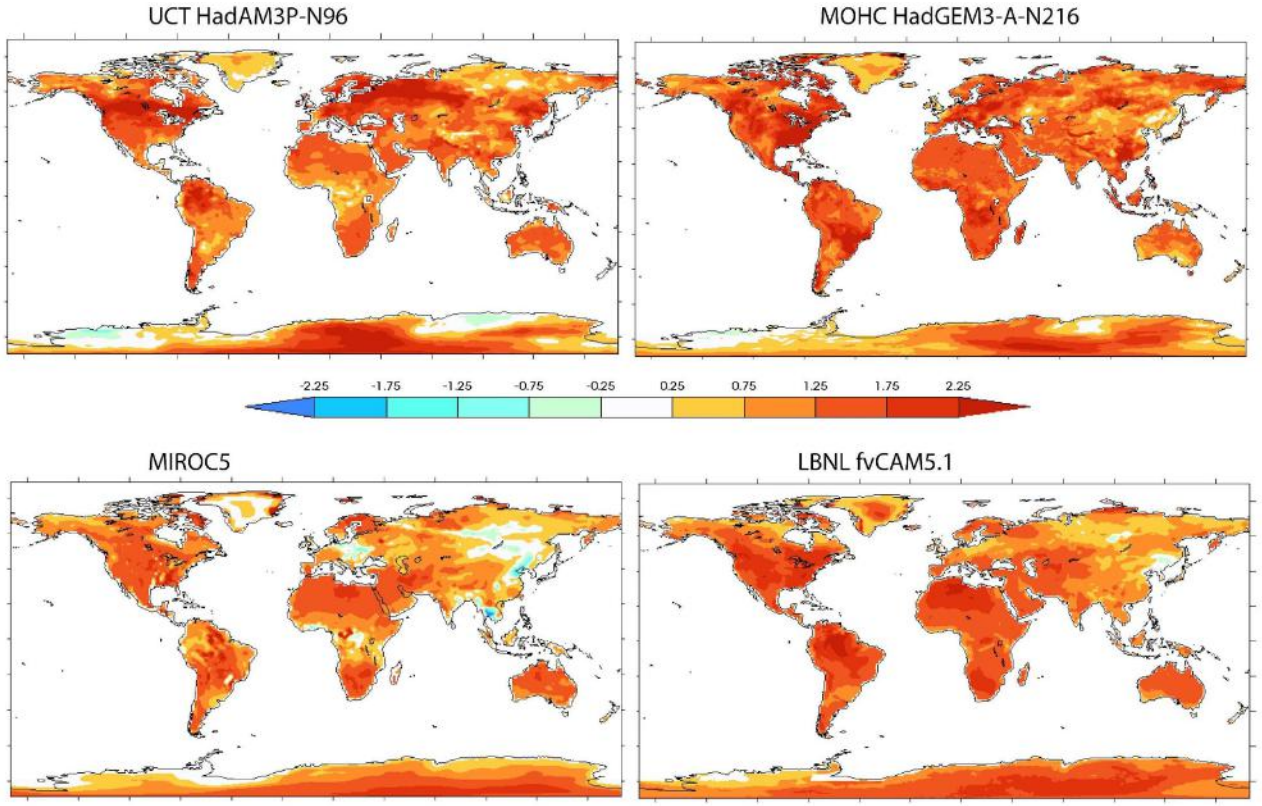
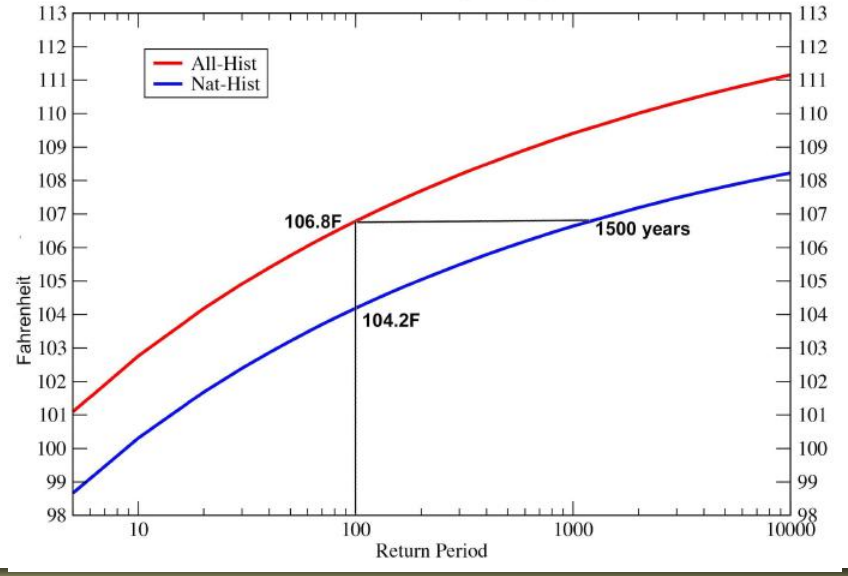
Attributable temperature change



Attributable change in 20 year return value of the annual maximum daily maximum surface air temperature (TXx)

Attributable change in magnitude is weakly dependent on heatwave rarity.

Attributable change in probability is not!



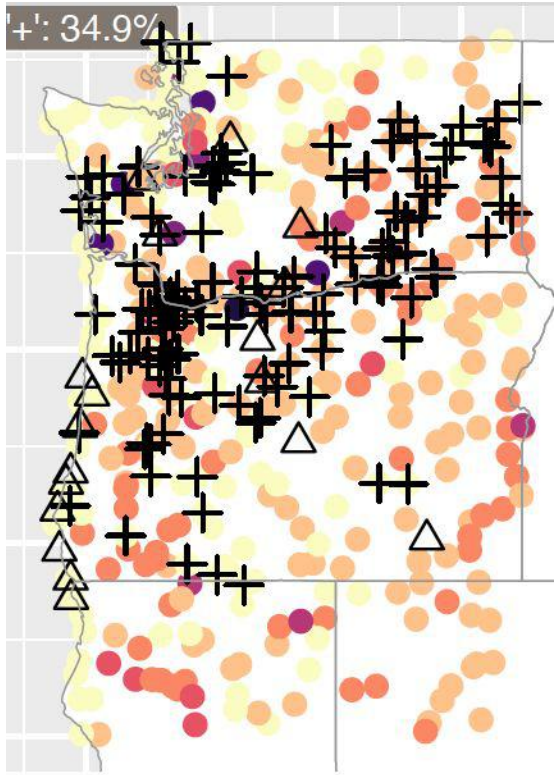
More on statistical counterfactuals…

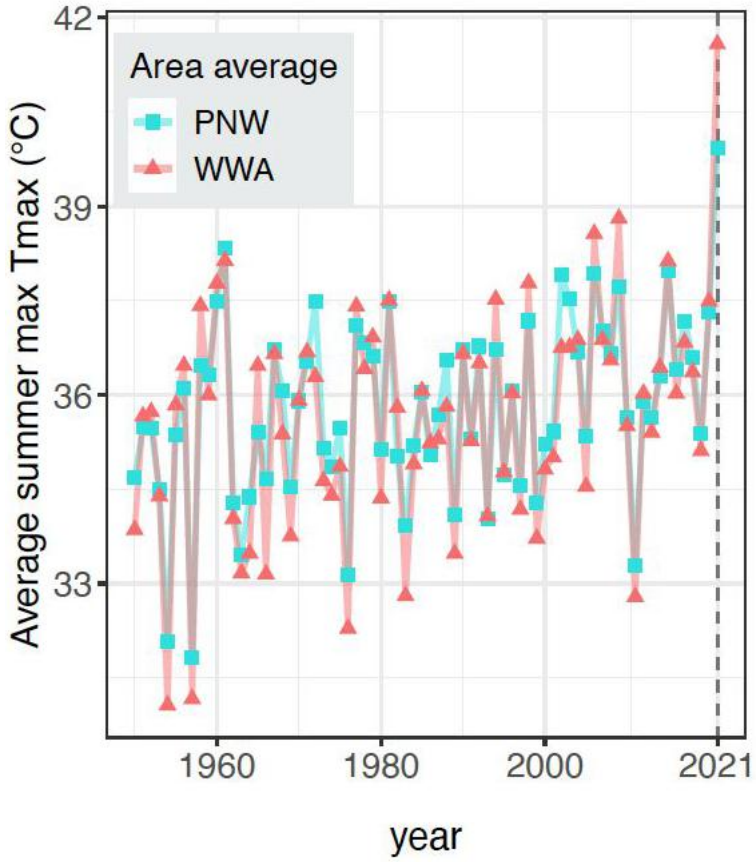
The 2021 PNW heatwave was a very complicated event

- An omega block in a unique location
- A rare summer AR brought latent heat energy
- Pre-existing drought in OR/WA
- Climate change

A 4.5σ event

- Breaks the standard non-stationary extreme value statistical models





The statistical problem

- "Simple" out of sample analysis using 1950-2020 temperatures
  - If you only use greenhouse gas as a nonstationary covariate:
  - Many observations exceed the statistical upper bound.
  - Even exceeding the upper bound of the upper bound.
    - (i.e. 95% confidence interval)
  - **Statistically impossible even with climate change !?**
- OK, how about an in-sample fit using 1950-2021 data?
  - Goodness of fit is so bad that results are not believable.

Likun Zhang, Mark D. Risser, Michael F. Wehner, Travis A. O'Brien (2023) Explaining the unexplainable: leveraging extremal dependence to characterize the 2021 Pacific Northwest heatwave, submitted to *Journal of Agricultural, Biological, and Environmental Statistics.* Preprint available at https://arxiv.org/abs/2307.03688

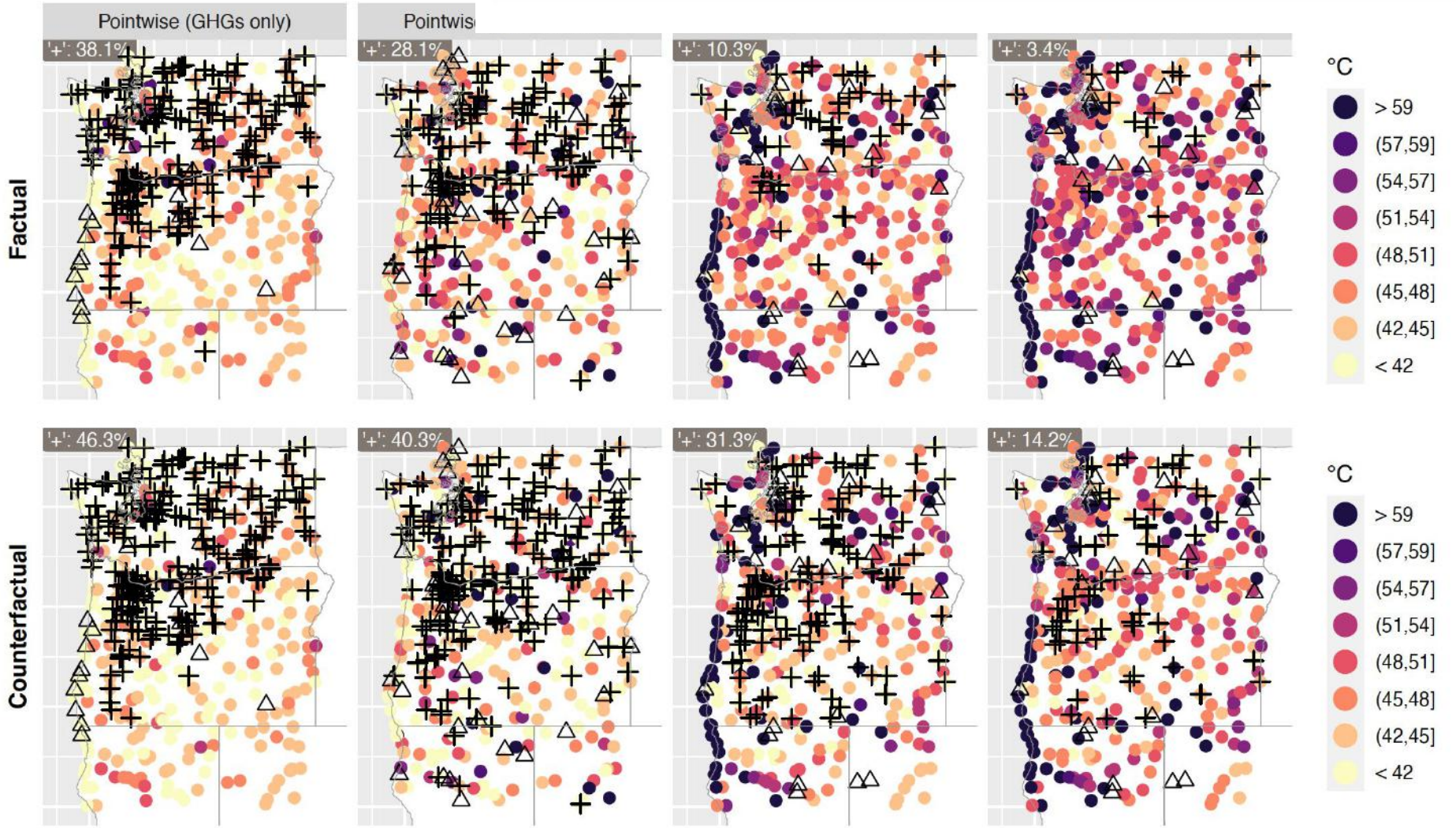
The solution. Add more physics. Add spatial statistics

- Temporal dependence
  - Greenhouse gases, El Nino (ELI)
- Spatio-temporal dependence.
  - Drought, urbanization
- Spatial dependence
  - Mean precipitation climatology, topography (elevation, slope, direction), distance from coast
- Data dependence
  - Impose a copula as stationary Gaussian process with standard Pareto margins.

		Include GHGs?	Include ELI/ PDSI/Urban?	Account for clim. dep.?	Account for data-level dep.?
M1	Pointwise, GHG only	✓			
M2	Pointwise, all covts.	✓	✓		
M3	Clim. dep., all covts.	✓	✓	✓	
M4	All spatial, all covts.	✓	✓	✓	✓

Results

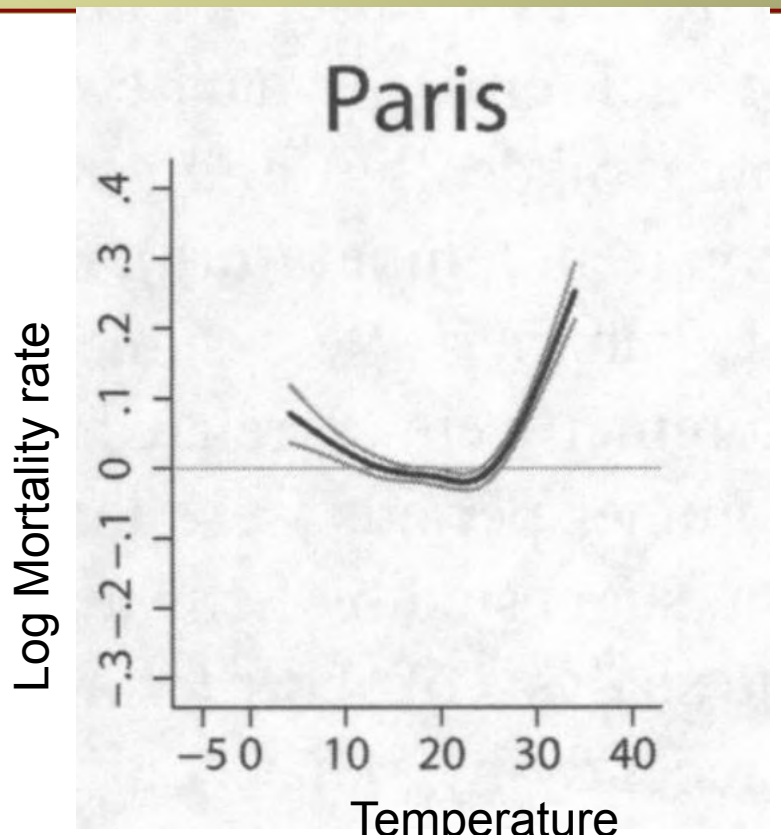
		Include GHGs?	Include ELI/ PDSI/Urban?	Account for clim. dep.?	Account for data-level dep.?
M1	Pointwise, GHG only	✓			
M2	Pointwise, all covts.	✓	✓		
M3	Clim. dep., all covts.	✓	✓	✓	
M4	All spatial, all covts.	✓	✓	✓	✓



Mortality and heat: How many people died?

- The effect of extreme heat increases dramatically with temperature.

mortality risk vs temperature



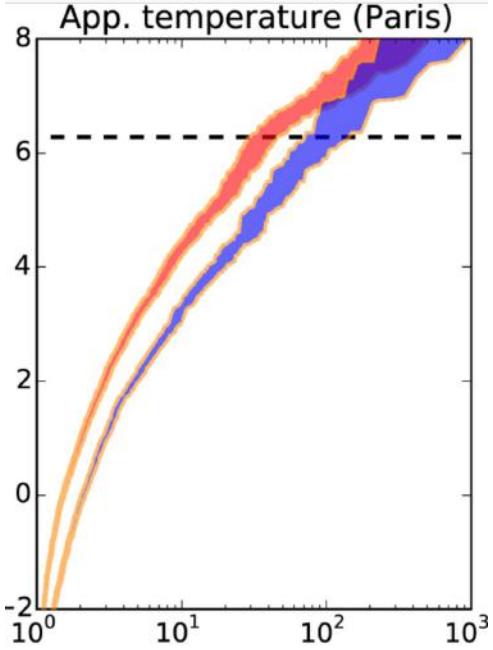
Baccini et al

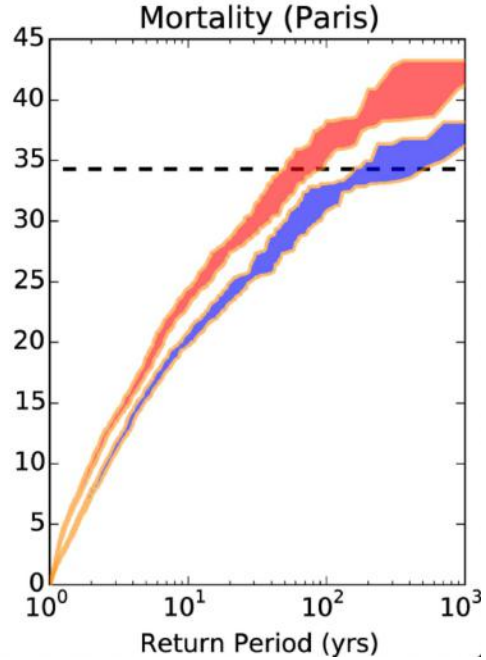
A simple mechanistic approach

1. Attribute the temperature change.
2. Subtract from the observed temperature.
3. Compare mortality rate that was to the mortality rate than ”might have been”

A more traditional approach (Mitchell et al.)

- Use the mortality rate curve to transform temperature to death.
- Pearl causality, but not a storyline.





- The chances of the actual level of mortality due to heat was tripled because of climate change.
- 510 people died in Paris during the 2003 heat wave because of climate change.
- As the 2003 heat wave affected 100s of millions of people across Europe, the total increase in mortality was orders of magnitude more.

Mitchell *et al* (2016) Attributing human mortality during extreme heat waves to anthropogenic climate change *Environ. Res. Lett.* **11** 074006

Impact attribution options

- Mechanistic:
  - Climate change flooded 32% more houses
- Probabilistic (or Risk based)
  - The chances of a US$155Bn Harvey event were quadrupled.
- Binary
  - My house was/wasn't flooded because of climate change (if climate change increased precipitation by 20%)
  - This is the question for the disaster in Libya.
    - Would the dams broke with a less severe storm without climate change?

Actually, Event Attribution is Ready to Inform Loss and Damage Negotiations

Michael F. Wehner
Lawrence Berkeley National Laboratory

Are we really ready?

Comment | Published: 17 April 2023

Event attribution is not ready for a major role in loss and damage

Andrew D. King, Michael R. Grose, Joyce Kimutai, Izidine Pinto & Luke J. Harrington

Nature Climate Change (2023) | Cite this article

Rebuttal :

Event Attribution is Ready to Inform Loss and Damage Negotiations. Ilan Noy, Michael Wehner, Dáithí Stone, Suzanne Rosier, Dave Frame, Kamoru Abiodun Lawal, Rebecca Newman. To appear Nature Climate Change

UNFCCC COP27 decision -/CP.27 –/CMA.4

Decisions 2/CP.27 and 2/CMA.4 established new funding arrangements for assisting developing countries that are particularly vulnerable to the adverse effects of climate change

Supply

What events are important in developing nations?

- World Meteorological Organization:
  - top 10 deadly and expensive weather disasters from 1970-2019
    1. Agricultural droughts->famine: 650,000 deaths
    2. Tropical storms: 577,232 deaths
    3. Non-tropical-storm floods: 58,700 deaths
    4. Heatwaves: 55,736 deaths

These are all classes of events that attribution does well!

Demand

- A demand for information is clearly there.
- The establishment of the UNFCCC COP27 Loss & Damage fund increases the urgency
  - We fear that King et al. could undermine that urgency.
- What could be used instead of event attribution?
  - DICE/Nordhaus macroeconomics models
  - Damage Function=0.003467 * GMT^2 (units = % of GDP)
    - =US$80Bn for the US in 2017 = 2X Harvey.
    - Why would one expect the constant 0.003467 be equally valid for the US and Burkina Faso?

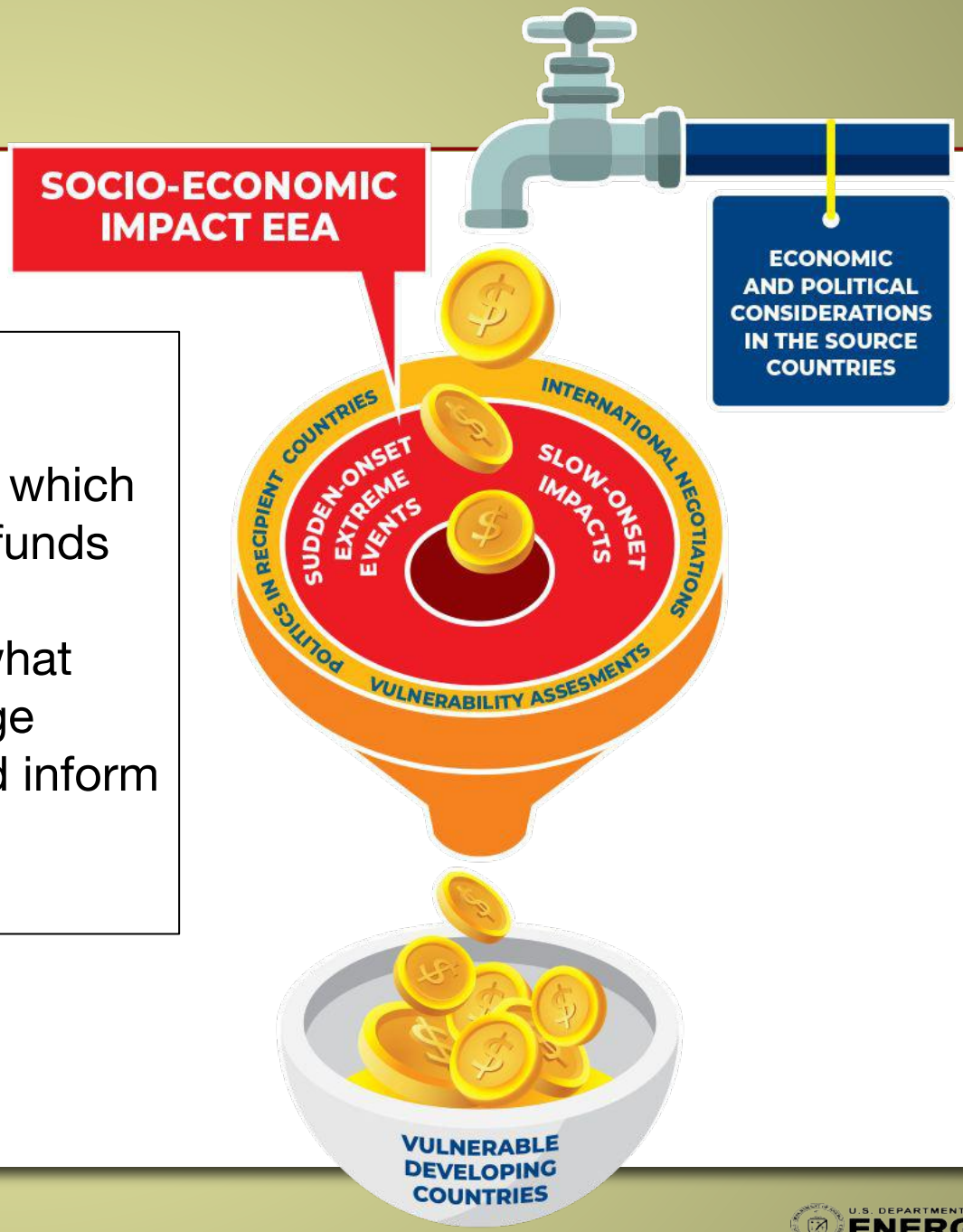
Perspective on the Loss and Damage fund

Politics: Let's not be naïve. "…the IPCC is to provide governments at all levels with scientific information that they can use to develop climate policies." Loss & damage claims will be settled by a political process not by scientists.

- We need to engage physical and social scientists from "particularly vulnerable" nations!

Strawman L&D process

1. Political negotiations about how much money developed nations will contribute
2. An internationally negotiated determination of which particularly vulnerable nations are eligible for funds (outer yellow funnel).
3. Further international negotiations determine what losses have been influenced by climate change (inner red funnel). Information from EAA would inform part of that negotiation.
4. Funds are disbursed.



Conclusions: Statistics, climate science, environmental justice

- There is much room for advanced statistical methods in our field
  - Cross disciplinary research can be challenging.
    - Language, institutional barriers.

Some interesting examples:

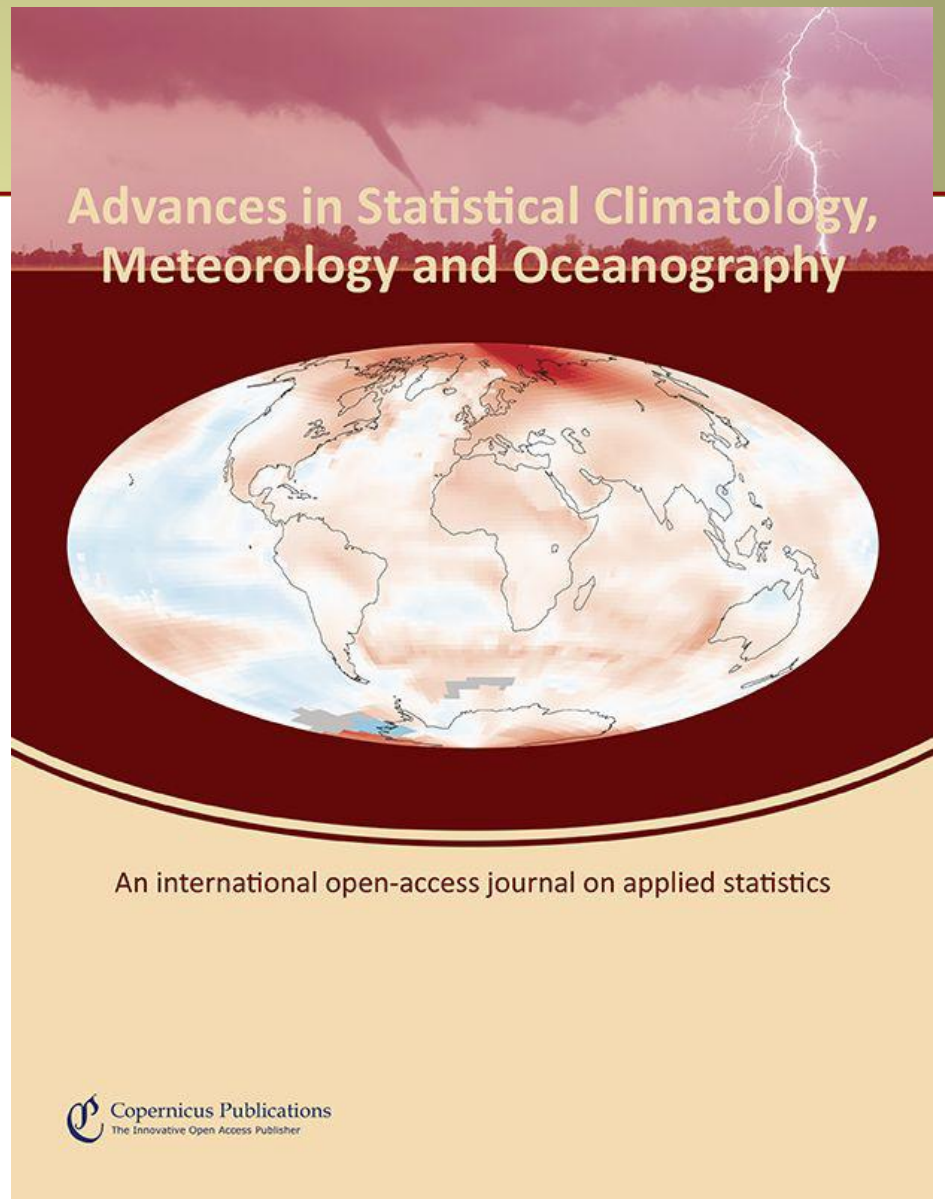
- Spatial statistics.
  - Computationally expensive but can reveal insights about spatial scales.
- Multivariate statistics & compound events.
  - Rare combinations of variables that are not all extreme by themselves
    - Hot, dry, windy vs. Hot, moist, stagnant heatwaves.
    - Available copulas may be overly prescriptive. (Dan Cooley et al)
- Causal inference (including graph networks)
- Machine learning
  - Diagnostic: Supervised feature detection (unsupervised?)
  - Prognostic: Much interest in actual climate modeling, i.e. Nvidia's FourCastNet (promising, but tricky)

Cross disciplinary journals

ASCMO Executive editors:
Michael Wehner & Francis Zwiers

Intended as a bridge between the Statistics and climate/weather/ocean communities

We welcome your submissions.



http://advances-statistical-climatology-meteorology-oceanography.net/index.html

BERKELEY LAB

Thank you!

mfwehner@lbl.gov