

The human influence on recent extreme storms.

Probabilistic Flood Hazard Assessment (PFHA) Research Workshop
US Nuclear Regulatory Commission
February 19, 2020

Michael F. Wehner
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Houston, Texas after Harvey



The human influence on recent extreme storms. Or Did global warming flood my house?

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US DOE Policy 411.2A

SUBJECT: SCIENTIFIC INTEGRITY

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What is the “safe” amount of climate change?

- United Nations Framework Convention on Climate Change”
 - “to achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic [human] interference with the climate system.”
- 2009 Copenhagen Accord:
 - This level is such that the global average temperature should be stabilized at two degrees Celsius (3.6 degrees Fahrenheit) above its preindustrial level.
- 2015 Paris Agreement (COP21):
 - “Invites the Intergovernmental Panel on Climate Change to provide a special report in 2018 on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways”
- 2020: We are already over 1°C above pre-industrial levels.
 - I will argue that this is not safe.
 - Dangerous climate change is here now.

What have we done to extreme weather?

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

Or

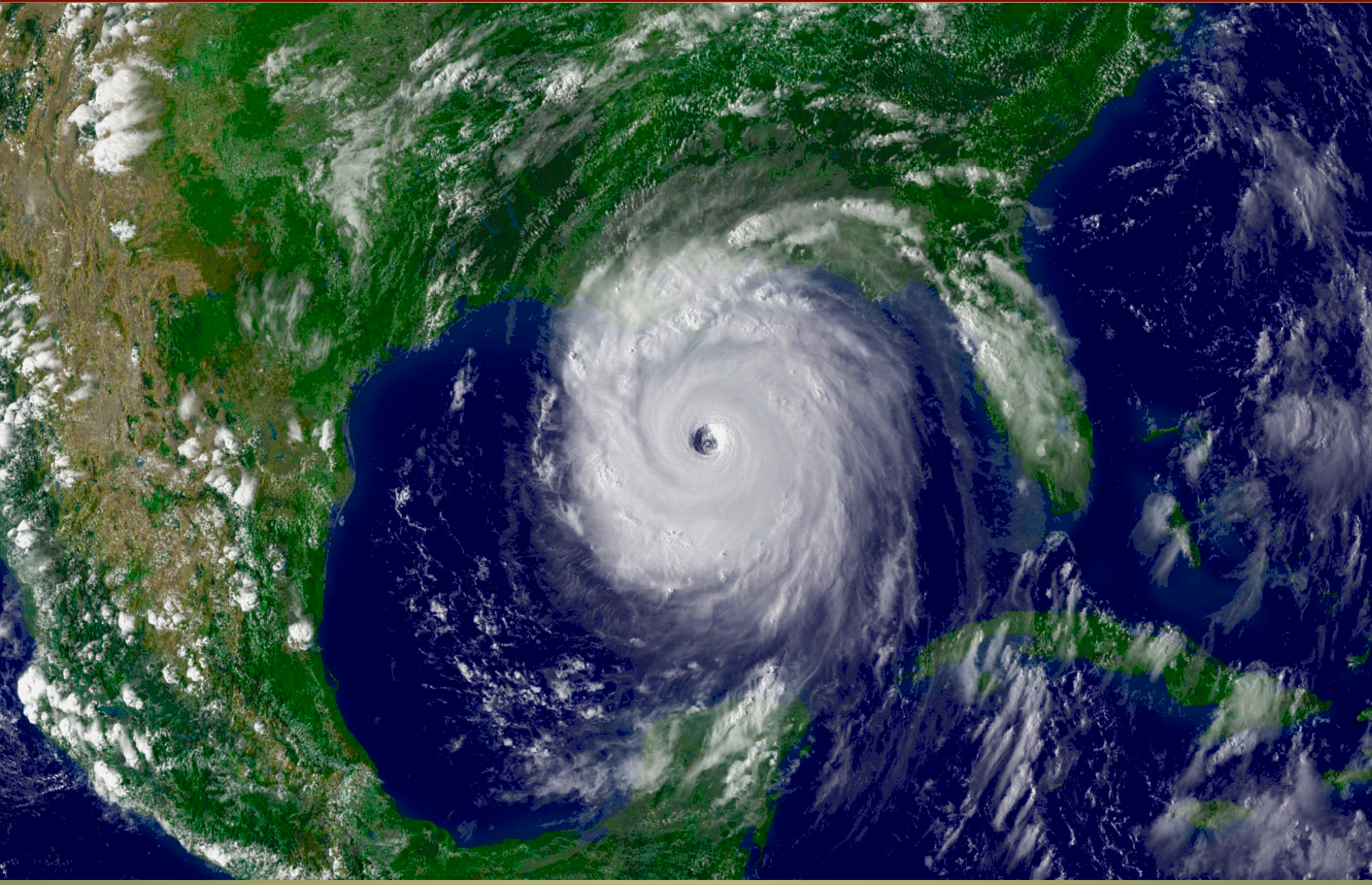
- “How did climate change affect the magnitude of that event?”

- This new science is called “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.
 - Fundamentally an exercise in Causal Inference.
 - A rapidly evolving science.
 - New technologies.
 - It is still getting warmer...

Extreme event attribution examples

- The chances of the 2003 European heat wave were found to be doubled.
 - Now, those chances have been increased by 10x.
- Global warming increased the chances of the 2015 hot and humid heat wave in Pakistan by a factor of at least 1000.
- Some seasonal flooding has been made more severe.
 - E.g. Spring 2013 Midwestern US
- As have some droughts.
 - E.g. 2011 East Africa

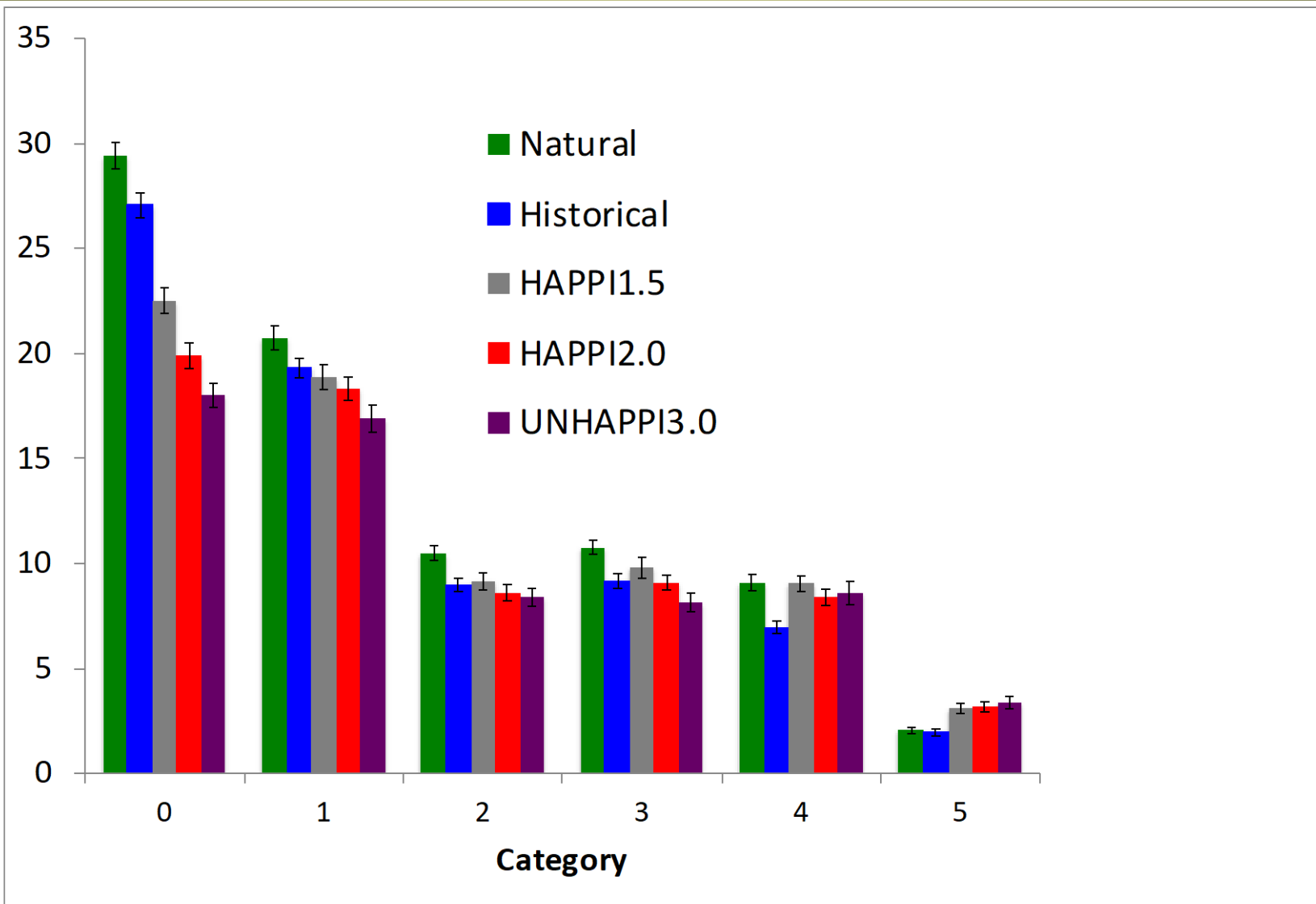
A significant human influence has been found in hundreds of similar large scale events.



Expectations about global warming and hurricanes.

- Tropical cyclones are the most intense storms on the planet.
- They require warm ocean temperatures, high humidity and low wind shear to get really large.
- Climate change increases temperature and humidity, but has only small effects on wind shear.
 - The general consensus is that global warming causes the most intense hurricanes to become more intense.
 - No real consensus on changes in the total TC number.
 - Either no change or a decrease.
 - Number of intense (cat 4 or 5) will either increase or decrease depending on the magnitude of this change.
 - Precipitation will increase. Available water increases according to Clausius-Clapeyron relationship
 - $\Delta Q = \sim 6\%$ per $^{\circ}\text{C}$ warming

Global TC # (25km CAM5.1)



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

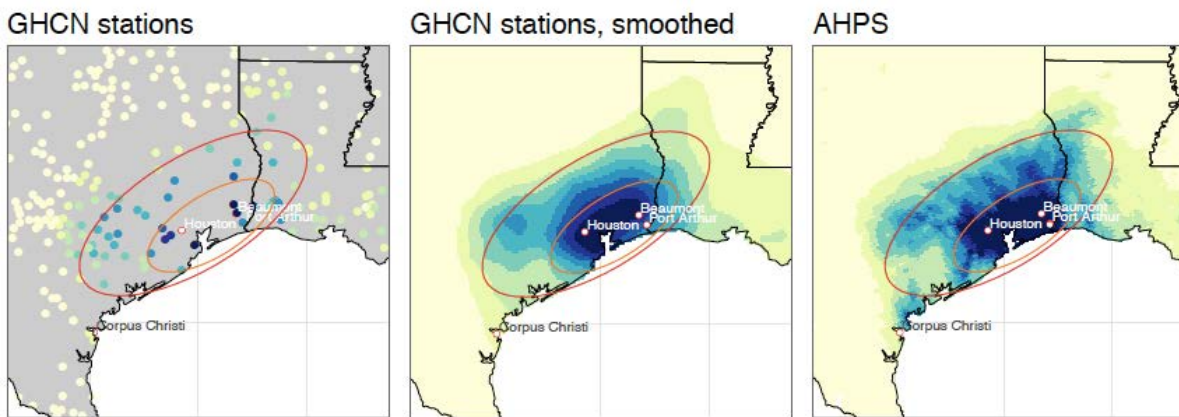
2. Analyze observed trends with a statistical model.
 - Postulate a plausible cause but beware of hidden covariates.
 - Granger causal inference.

Sir Clive Granger (1934-2009)



Granger causality statement for Hurricane Harvey

- We 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
- Two regions
- Three observational datasets
- No climate models.



Risser & 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>

Hurricane Harvey attribution statement (small region)

- Anthropogenic climate change *likely* increased Hurricane Harvey's total rain fall by at least 19% with a best estimate of 38%.
- This is substantially larger than the 6-7% expected from thermodynamical arguments and C-C scaling.
- Anthropogenic climate change *likely* increased the chances of the observed rainfall by a factor of at least 3.5 with a best estimate of 9.6.

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

→ defined for $\{x : 1 + \xi_t(x - \mu_t)/\sigma_t > 0\}$

Granger causality

- Risser & Wehner 2017 (small region)
 - Chances increased by 10X (*likely* lower bound of 3.5X)
 - Precipitation increased by 38% (*likely* lower bound of 19%)
- Risser & Wehner 2017 (large region)
 - Chances increased by 5x (*likely* lower bound of 1.4X)
 - Precipitation increased by 24% (*likely* lower bound of 7%)

Pearl causality:

- Van Oldenborgh, van der Wiel et al. 2017
 - Chances increased by 3x (range =1.5 to 5)
 - Precipitation increased by 15% (*very likely* range= 8-19%)
- Wang et al. 2018
 - Precipitation increased by 20% (interquartile range 13-37%)

The statements are all within each other stated uncertainties.



Pearl Causal modeling analyses

- 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 AKA pseudo-global cooling.

- Ensemble hindcast technique aka “Pseudo-global warming”
 - Factual: The storm that was.
 - Counterfactual: The storm that might have been.

The counterfactual storm is constructed by perturbing the initial and boundary conditions of the hindcast model.

- We used WRF as the hindcast model.
- We used the CAM5.1 ensemble of C20C+ simulations to construct the perturbation.
 - This removes the human influence.
- We also used the CESM1.0 RCP8.5 simulations to make a projection of the “storm that might be”.

3 km resolution regional climate model simulation of Hurricane Katrina (2005)

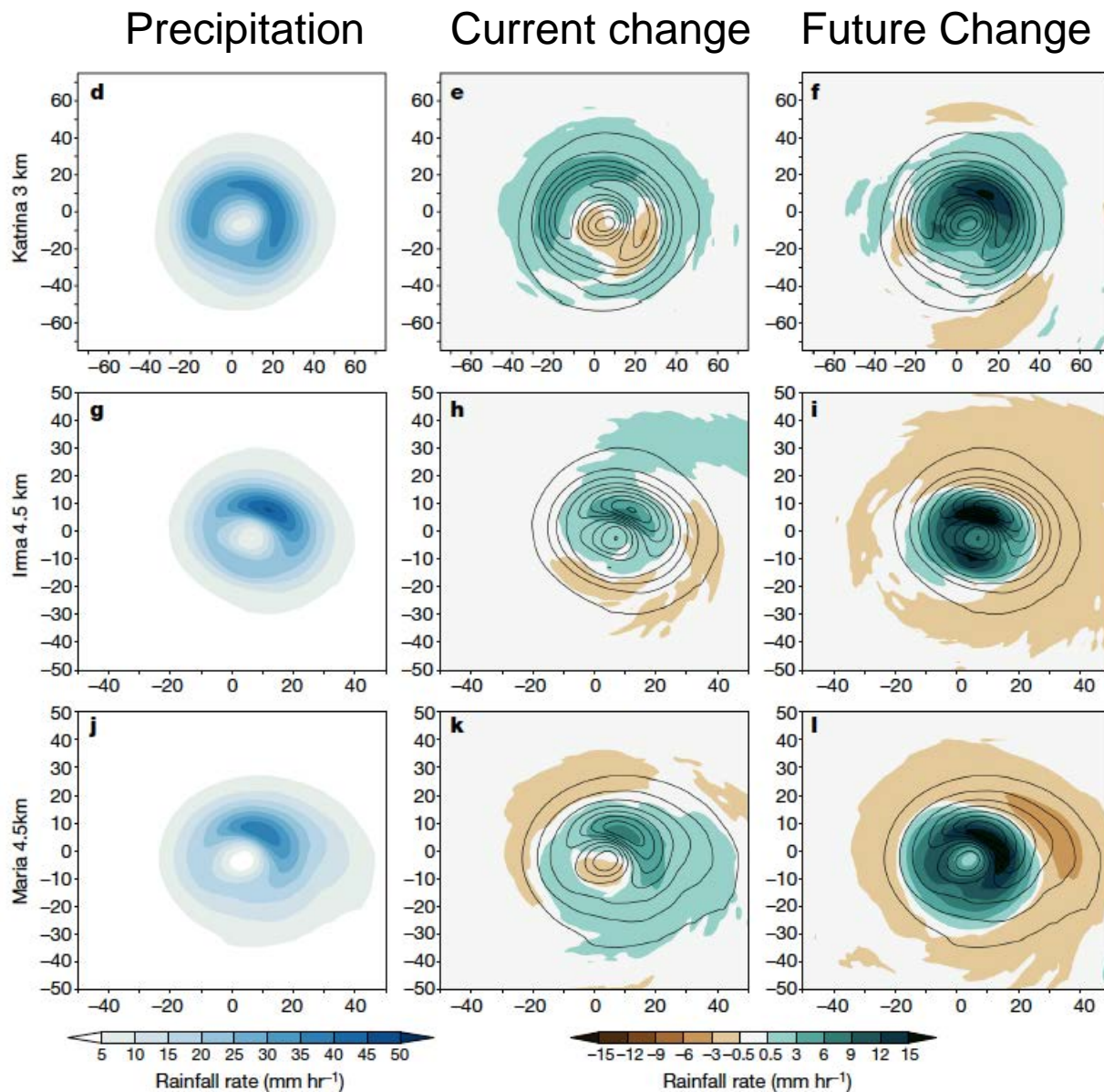
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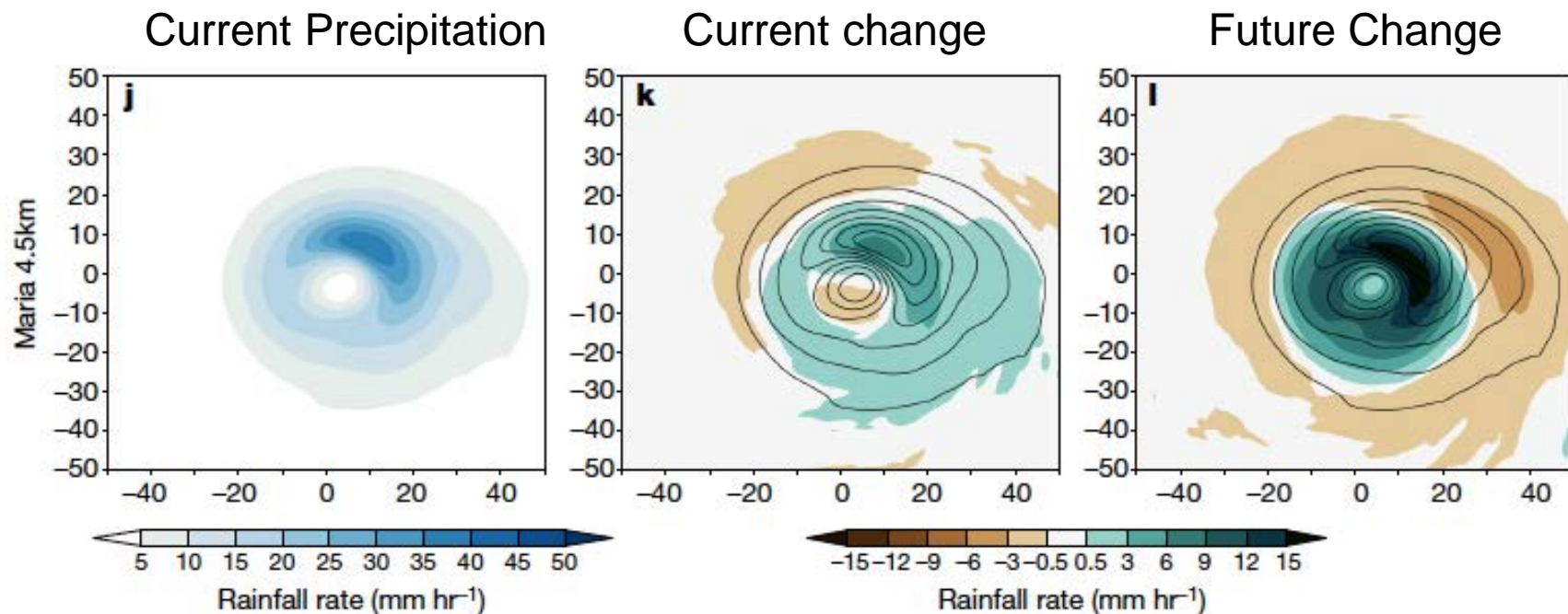
Human induced increases in hurricane precipitation totals are already large and can exceed Clausius-Clapeyron scaling.

- Global warming induces a structural change in the storm

Storm composites →



C-C scaling case Study: A closer look at Maria



- Clausius-Clapeyron constraint on specific humidity = $\sim 7\%/^{\circ}\text{C}$
- Actual is 0.6C warmer than counterfactual.
 - C-C scaling = $\sim 4\%$
 - At peak = >6 mm/hour (20%)
- RCP8.5 is 2C warmer than actual.
 - C-C scaling = $\sim 14\%$
 - At peak = >12 mm/hour (40%)

Flooding of Houston

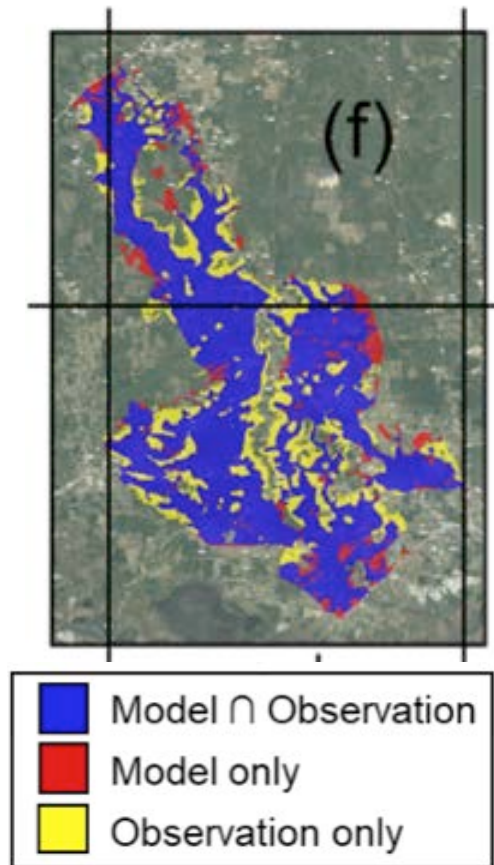
- How did this attributable increase in precipitation affect the Harvey flood?
- Design a storyline attribution analysis of the flood. (Pearl causality)
- Fathom-US, a continental-scale hydraulic model
 - 30 meter resolution
 - Demonstrated to be “fit for purpose”
 - “flood that was”
 - Most of the errors are at the periphery of the flood.

The “flood that was”.

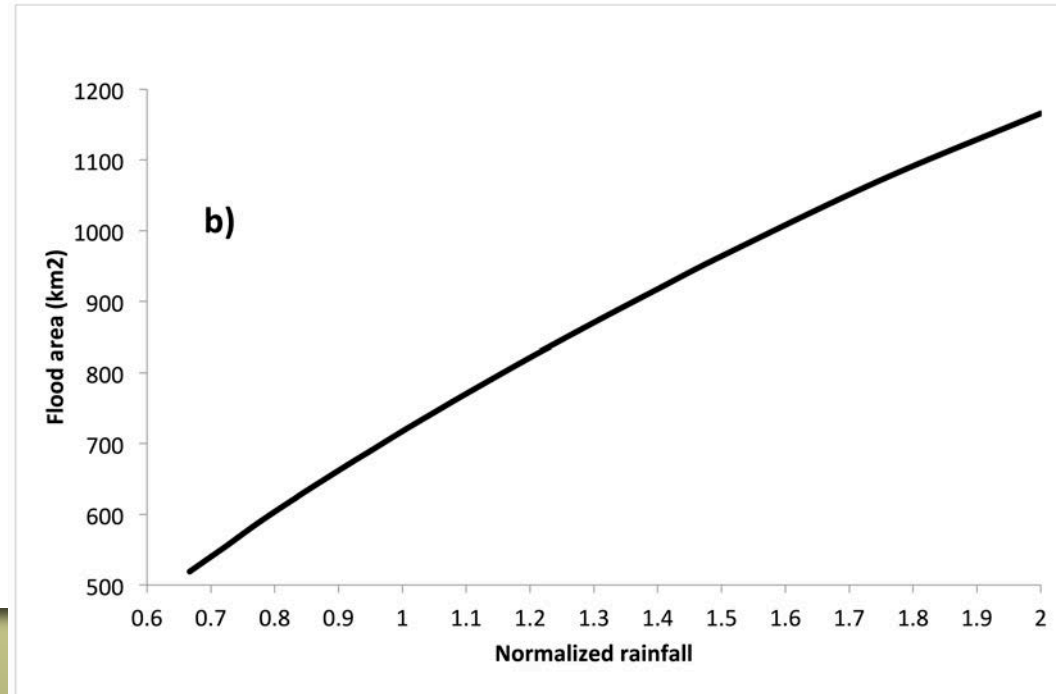
- Driven by observed rainfall.

The “flood(s) that might have been”.

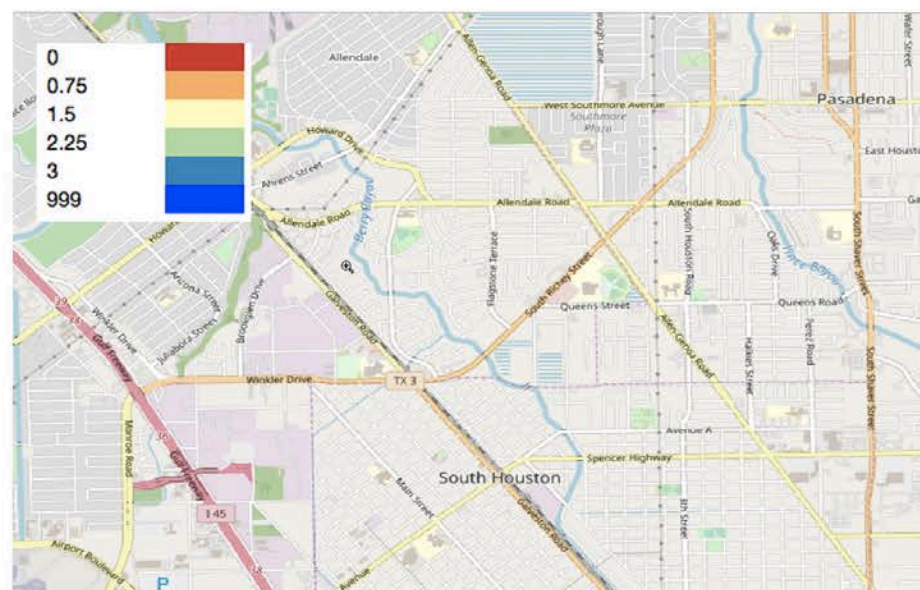
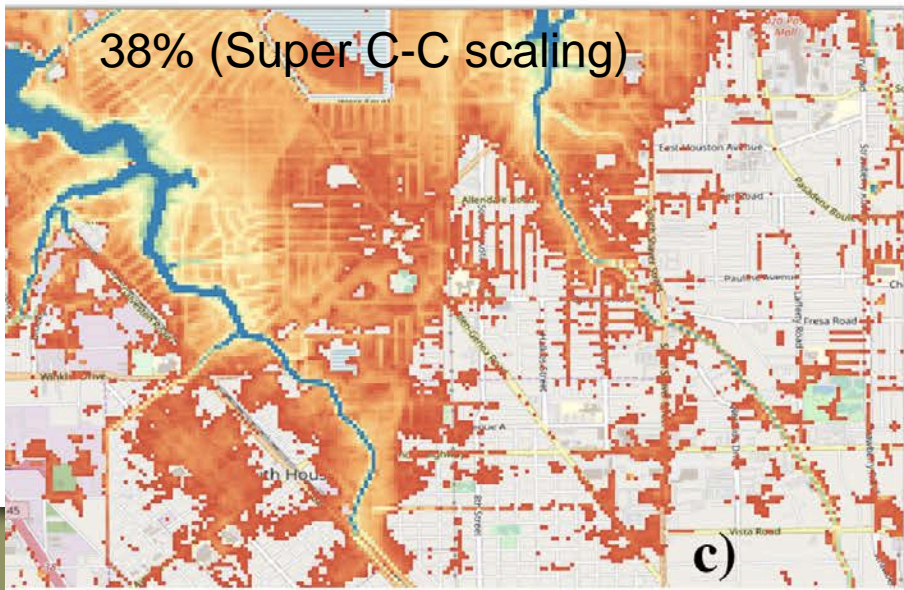
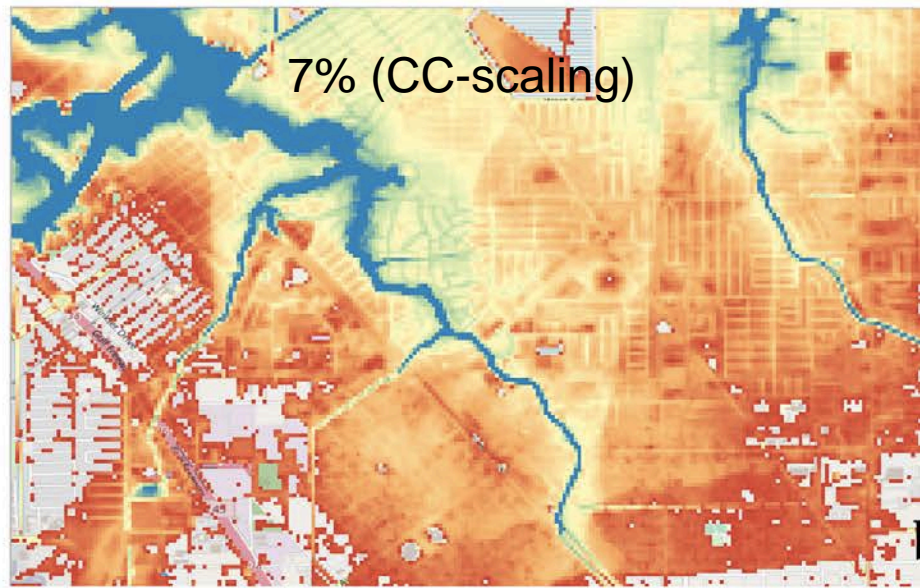
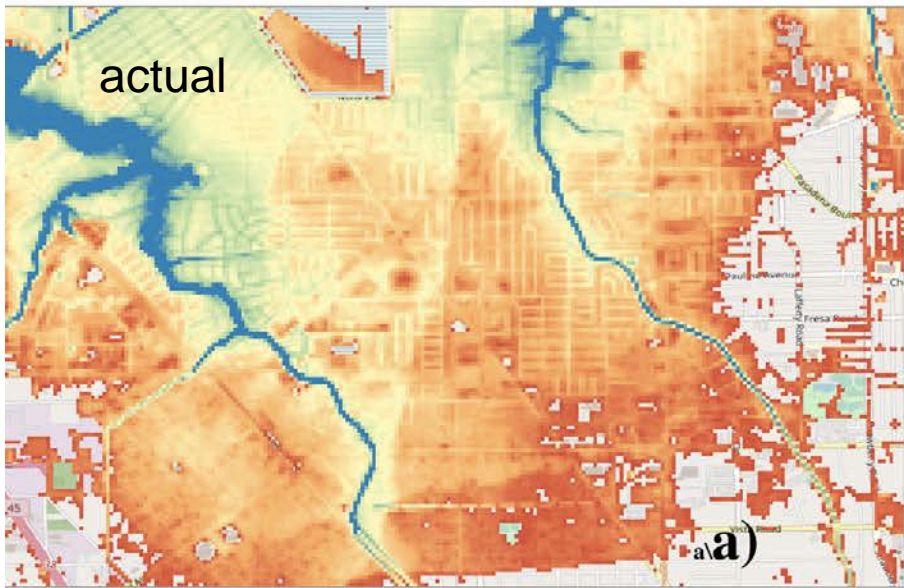
- Alter the rainfall uniformly by the published attribution statements.
 - e.g. Risser & Wehner’s 24% statement
 - Decrease precipitation by $1/1.24=0.81$



- Attributable flood water volume is essentially the same as the attributable precipitation.
- Drainage to the Gulf is slow compared to rainfall rates
- Attributable flood water area is less than the attributable precipitation.
 - Weakly sublinear
 - But not small...
 - Highly non-uniform.



South Houston / Pasadena flooding after 5 days



- Super C-C scaling of tropical cyclone precipitation is a real thing.
- Changes in *local* dynamics are responsible.
- But we should not expect different extreme storms types to behave in the same way.
 - Tropical cyclones
 - Extra-tropical cyclones
 - Atmospheric Rivers
 - Mesoscale convective systems.
 - Frontal systems
- Multiple routes to super C-C.
 - But all are probably dynamical in nature.
 - What is the relative role of changes in local vs. large scale dynamics?



Did global warming flood my house?

- This question needs to be interpreted in the probabilistic sense of extreme event attribution.
- It depends a lot on which range of attribution statements you are willing to accept.
- It also depends a lot on where your house is.
 - Many homes would have been flooded even without the human increase in precipitation.
 - But some homes would not have been.

Data and software available at

<https://portal.nersc.gov/cascade/Harvey/>



Thank you!
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