Attributing Human Induced Changes to Extreme Weather

8th GEWEX Open Conference

Michael F. Wehner, Christina Patricola, Mark Risser
Lawrence Berkeley National Laboratory
mfwehner@lbl.gov

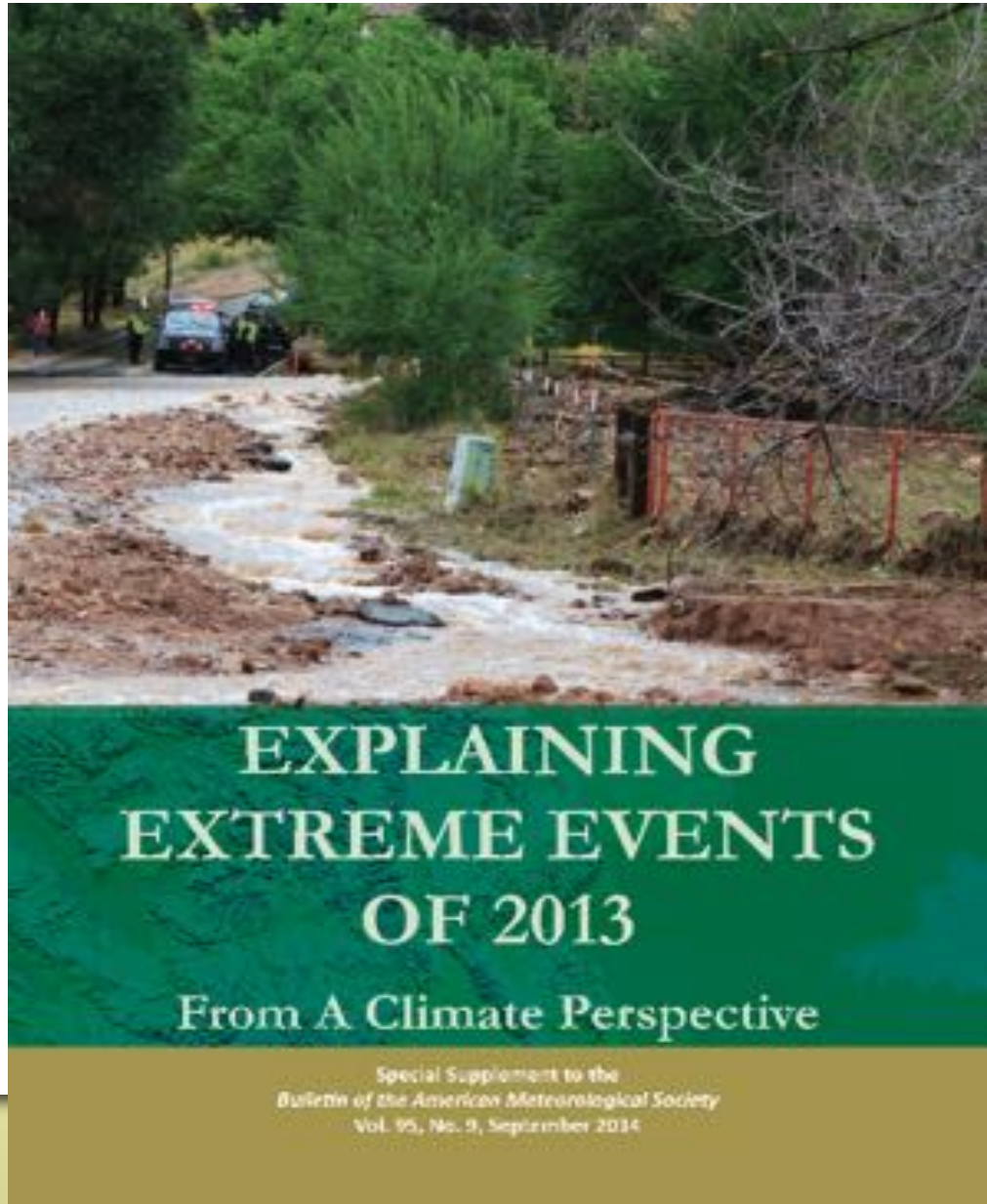
US DOE Policy 411.2A

SUBJECT: SCIENTIFIC INTEGRITY

When expressing opinions on policy matters to the public and media, research personnel must make it clear when they are expressing their personal views, rather than those of the Department, the U.S. Government, or their respective institutions. Public representation of Government or DOE positions or policies must be cleared through their program management to include DOE headquarters.

Extreme Event Attribution

- A rapidly developing science.
- 6 supplements to the annual BAMS State of the Climate reports
- A burgeoning literature.
- Much media and public interest.



What is Extreme Event Attribution?

- Extreme event attribution is an exploration of causality.
- Extreme weather has multiple causes. Always.
  - Large scale meteorological patterns (LSMP).
    - Blocks, large moisture transport fluxes, etc.
  - The state of the ocean.
    - ENSO, AMO, PDO, other modes of variability can affect the statistics of LSMPs.
  - Global warming.

Can we isolate the extent of these influences?

- Causality theory provides a probabilistic framework to partition this variety of natural and human influences on any extreme weather event.

  - This is not as deep as it sounds.
  - In fact, we have been doing it all along without calling it as such.
  - Two branches of causality theory are useful to us here.

Pearl Causality

- This should sound familiar.
- Pearl Causality is based on experiments with an "intervention".
- Judea Pearl (UCLA):

- *Causal Inference in Statistics: A Primer*, (with Madelyn Glymour and Nicholas Jewell), Wiley, 2016. ISBN 978-1119186847

Pearl Causality

Medicine	Climate
Recruit two groups of identically distributed volunteers. 1. One group gets the medicine. 2. The other group gets a placebo.	Perform two ensembles of climate model simulations 1. Realistic simulation of the recent past. (The world that was). 2. Hypothetical simulation without human influences. (The world that might have been).
What fraction of group 1 gets better? What fraction of group 2 gets better?	What are the chances of a particular extreme weather event in experiment 1? What are the chances of a particular extreme weather event in experiment 2?

Quantifying the results of a Pearl experiment

The so-called Risk Ratio tells us how much more likely an extreme event of a fixed magnitude is to occur due to human influences.

The Oxford school.

$$Risk\_ratio = \frac{P_{real}}{P_{Not\_real}}$$

Equivalently, we can ask how much did the human influence change the magnitude of extreme events at a fixed probability.

The Boulder school.

$$\Delta = M_{real} - M_{not\_real}$$

Pearl attribution statements are highly conditional

Medicine	Climate

How diverse are the patients?
• Ages
• Gender
• Weight, etc.
	How prescribed are the simulations?
	• Coupled atmosphere ocean models
	  • Conditional on GHG, ozone, aerosols, land usage. Stott, Stone, Allen (2004)
	• Prescribed SST models (AMIP)
	  • Also conditional on the imposed pattern of ocean and sea ice and their changes. Pall et al. (2011)
	• Short term hindcast experiments.
	  • Also conditional on imposed LSMP. Pall et al. (2017)

The key to Pearl attribution is that the factors that are changed are tightly controlled.

A systematic evaluation of recent extreme events

The many authors of the BAMS supplements use many methods and data sets. It is difficult to compare different events.

Would the conclusions change if a uniform analysis was applied?

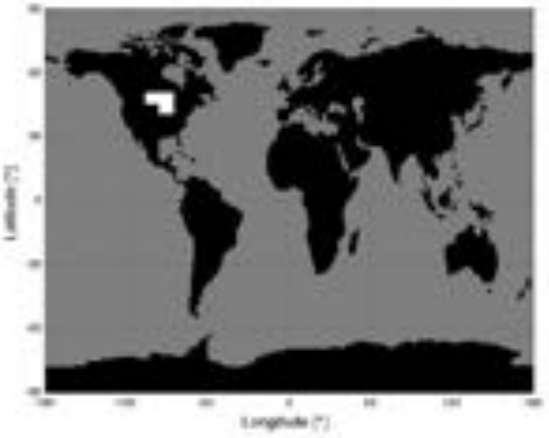
We used two 400 member AMIP-like ensembles to analyze 35 of the 63 extreme seasonal events during 2011-2013 as reported in the BAMS supplements

Is the model “fit for purpose” for attributing the change in risk of each of the events?

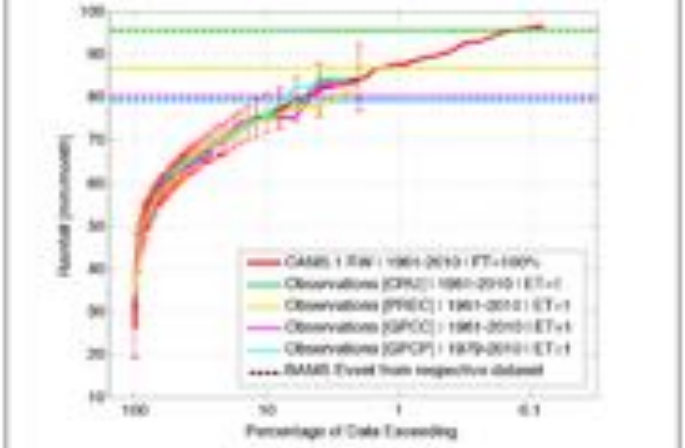
All seasonal heat waves have a risk ratio greater than 1. (Some a lot greater).

Precipitation and drought is mixed.

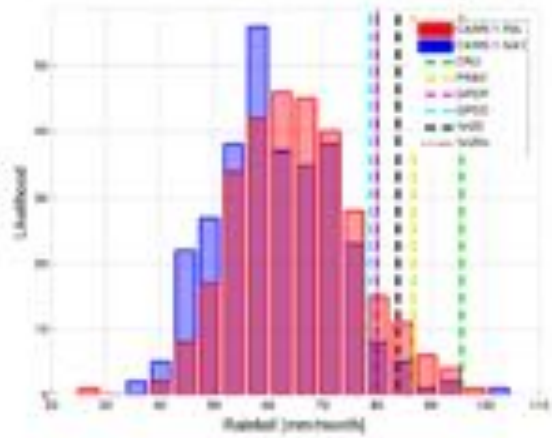
Angelil et al.(2017) An independent assessment of anthropogenic attribution statements for recent extreme weather events. *Journal of Climate 30,* 5-16, DOI: 10.1175/JCLI-D-16-0077.1



(cd) Item 39 | U.S. Upper Midwest



(ce) Item 39 | High MAM Rainfall



(cf) Item 39 | High MAM Rainfall

The deadly combination of heat and humidity in India and Pakistan in summer 2015

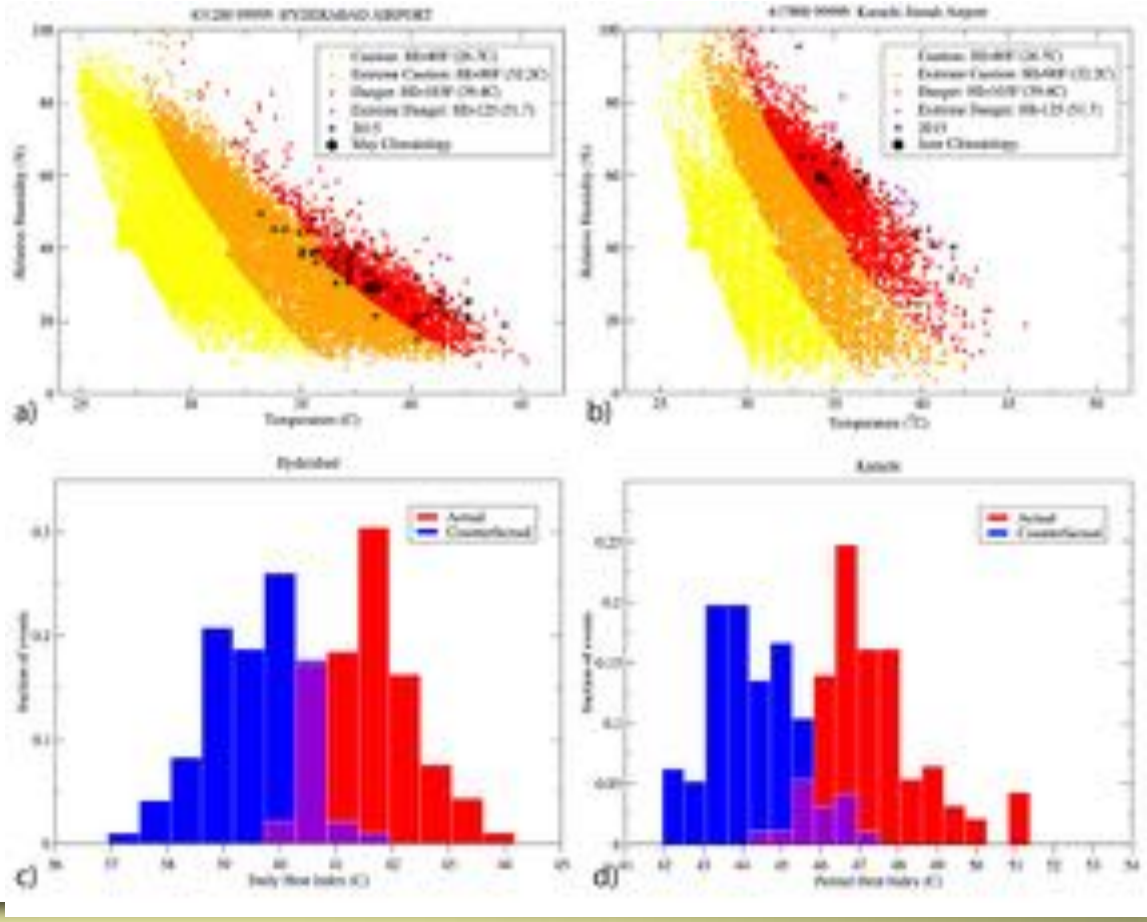
- There were two unrelated but deadly heat waves in India and Pakistan during 2015
  - India (late May), hot & dry
  - Pakistan (mid June) hot & humid

We find a strong human influence on these two events

Heat Index: Risk Ratio

India = 30

Pakistan >1000



Wehner, et al. (2016) The deadly combination of heat and humidity in India and Pakistan in summer 2015 [in "Explaining Extremes of 2015 from a Climate Perspective"]. Bull. Amer. Meteor. Soc., 97 (12), S81 –S86, doi: 10.1175/BAMS-D-16-0145.1.

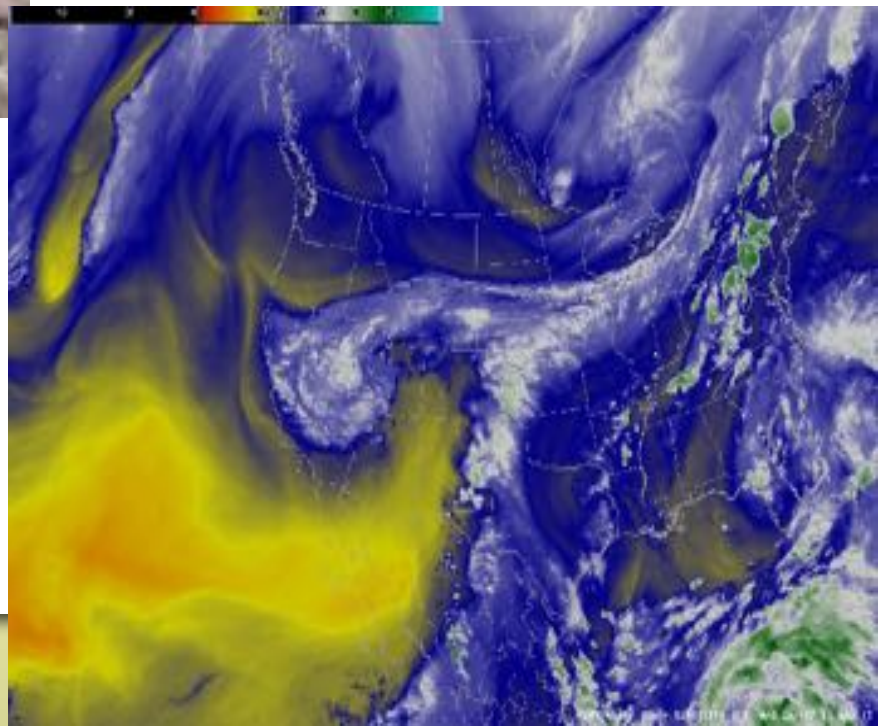
U.S. DEPARTMENT OF ENERGY | Office of Science

The 2013 Colorado Floods

P Pall, C Patricola, M Wehner, D Stone, C Paciorek, W Collins

South Platte River, CO
nytimes.com

Severe floods occurred along the Colorado Front Range during the second week of September 2013, impacting several thousands of people and many homes, roads, and businesses.



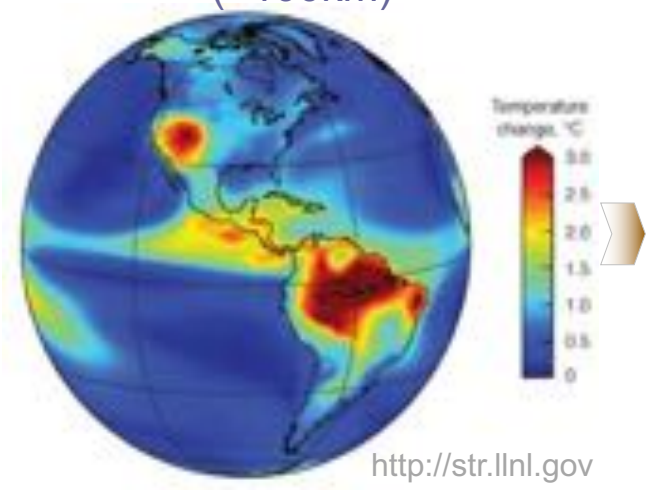
- At least 10 deaths; 11,000 evacuated, 19,000 homes damaged, over 1,500 destroyed, damages > US$3 bn

- CMIP5 models cannot replicate this event. Too intense. Too rare.

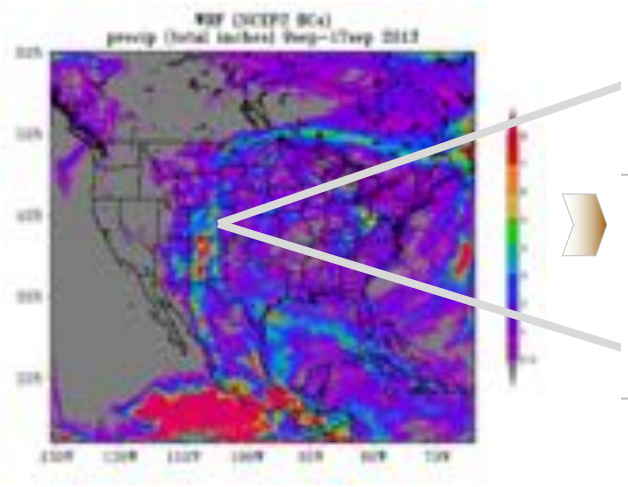
Pall et al. (2017) Diagnosing Anthropogenic Contributions to Heavy Colorado Rainfall in September 2013. *Weather and Climate Extremes* 17, 1-6. 10.1016/j.wace.2017.03.004

Colorado Sep 2013 floods: experiment design

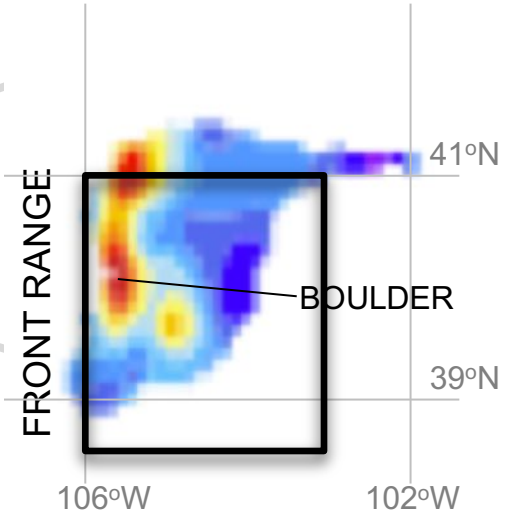
NCEP RE-ANALYSIS (~100km)



WRF MODEL (12km)



SOUTH PLATTE BASIN (CO)



1. Take Sep 2013 weather from re-analysis, under both actual anthropogenic conditions and 'adjusted' non-ant conditions

Adjusted SST, T, u,v, pr, and q based on changes from CAM5.1 historical forcing simulations with and without anthropogenic climate drivers

2. Feed into a regional weather model over North America

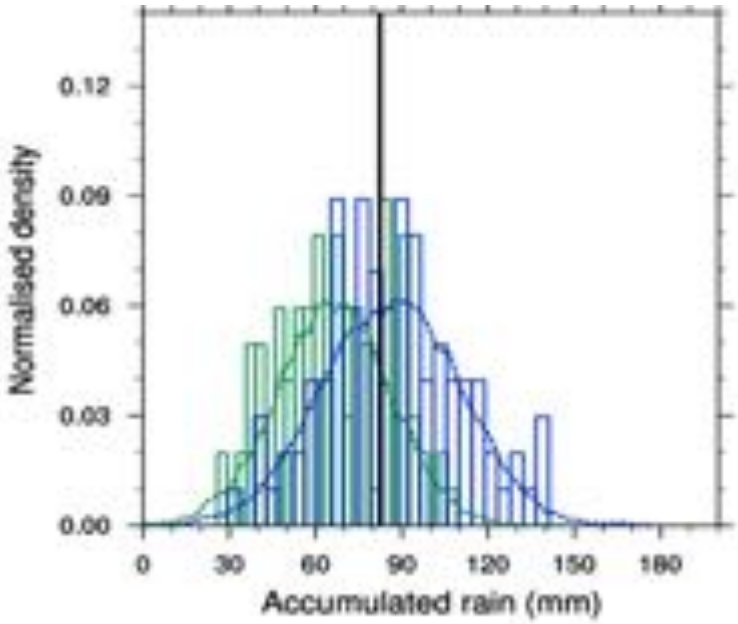
Generate 'time slice' simulations; 101-member i.c. ensembles per anthro / non-anthro conditions

3. Extract rain over South Platte basin

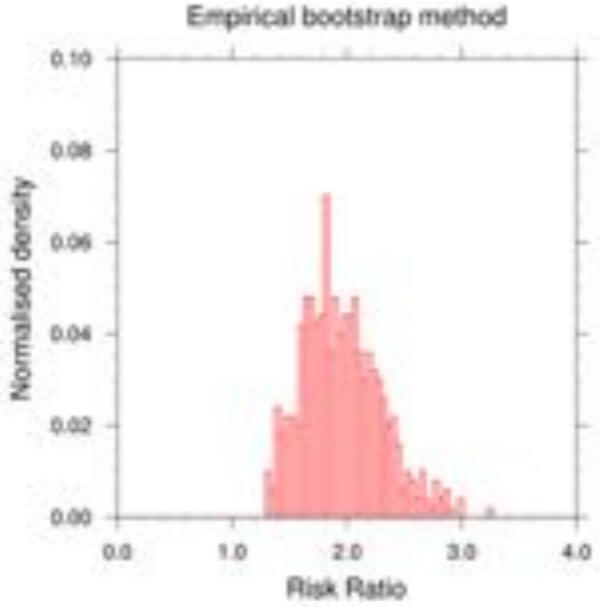
Examine 7-day totals (09-15 Sep 2013)

Colorado Sep 2013 floods: Probabilistic approach

7-DAY RAINFALL



CHANGE IN ODDS OF HEAVY RAIN

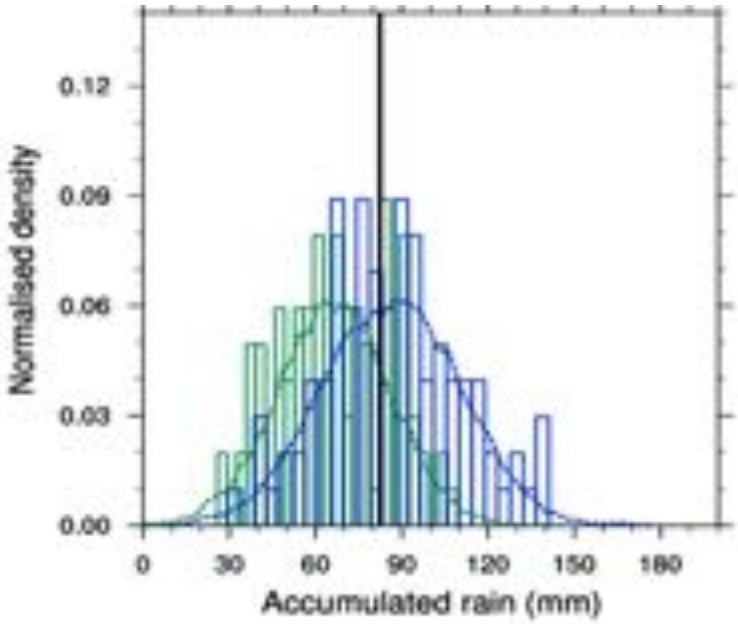


- Probability of exceeding the observed heavy 7-day rainfall total (black line), in both our anthro (P1) and non-anthro (P0) model ensembles
- A "best" estimate of a about a doubling in odds of a heavy rainfall occurrence. I.e. Median of 'Conditional Probability Ratio', CPR = P1/P0, is ~2
  - Median estimate of CPR is sensitive to the observational rainfall estimate.
  - The lower bound of the 95% confidence interval (~1.3) is not.

The conditional chance is *very likely* increased by 30% by human influences.

Colorado Sep 2013 floods: Mechanistic approach

7-DAY RAINFALL



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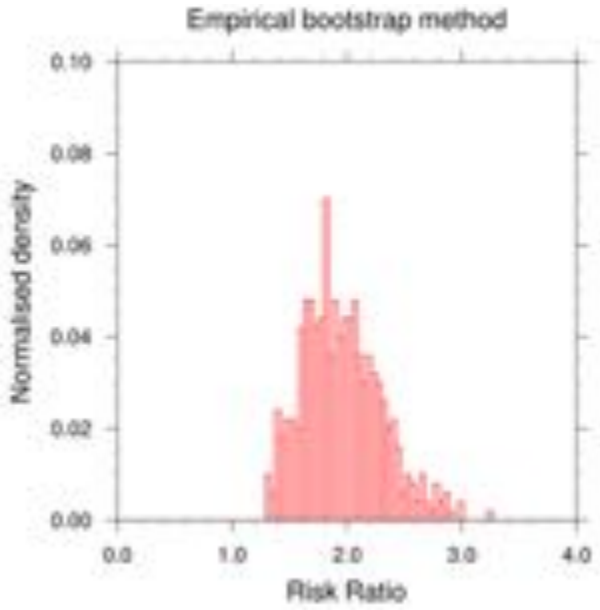


- **We find a substantial shift in our rainfall distributions over the South Platte basin (increase in mean of ~30%)**
  -> beyond a thermodynamic (~7-14%/K) induced increase, given ΔT = ~1.5-2K
- But increase in precipitable water (~15%) appears broadly consistent with C-C
- The 30% increase is a result of increased cumulus convective energy
  - Not a result of changes in larger scale dynamics or uplifting.
  - The “storm that was” was more violent than the “storm that might have been”

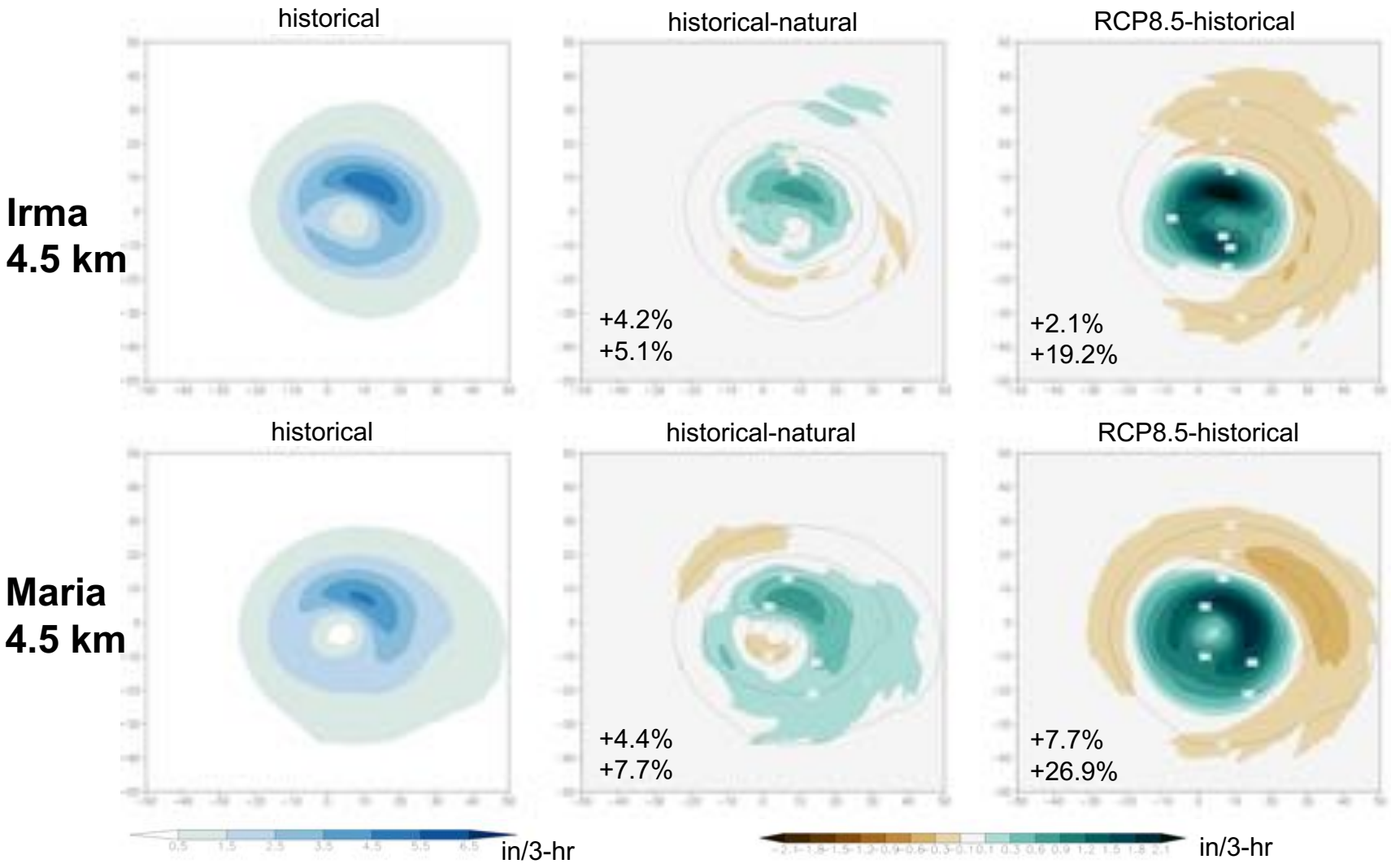
Attribution of the human influence on Hurricanes

Christina Patricola will present our research here:

Tuesday, session S19 at 11:30.

- Key caveat: Are the models and experimental design "fit for purpose"?
  - Convection permitting models often are.
  - But some storms resist analysis.
- Key findings:
  - The human influence on maximum wind speeds of intense tropical cyclones is small so far, but becomes large if the climate continues to warm.
  - The human influence on intense tropical cyclone precipitation is already substantial and gets larger.

Hindcast attribution: Precipitation (composite storms)



5°x5° box
2°x2° box

Granger Causality

Q. Can we make an attribution statement from observations alone without climate models?
A. Yes, but it is a weaker type of causality statement.

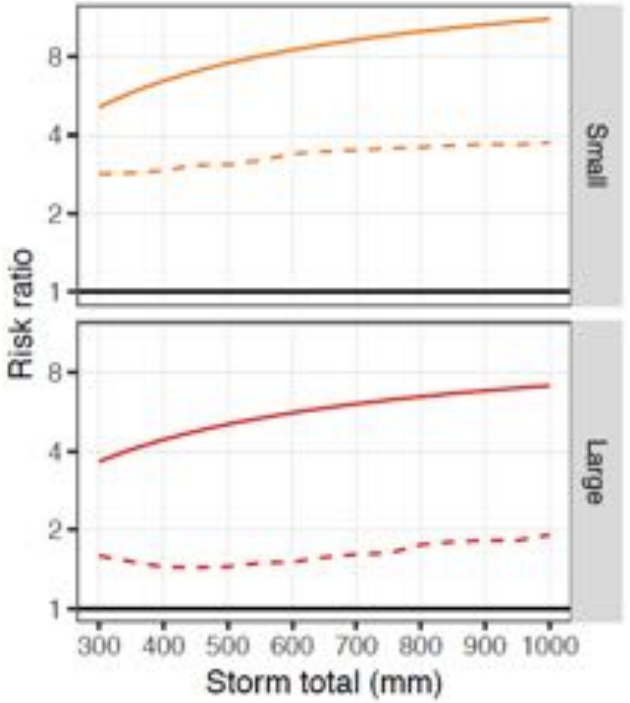
Finance	Climate
How much do tax cuts affect economic growth?	Did global warming enhance precipitation during Hurricane Harvey?
• Analyze the statistics of the stock market before and after the tax cut.	• Model the observed precipitation extremes with non-stationary statistical models.

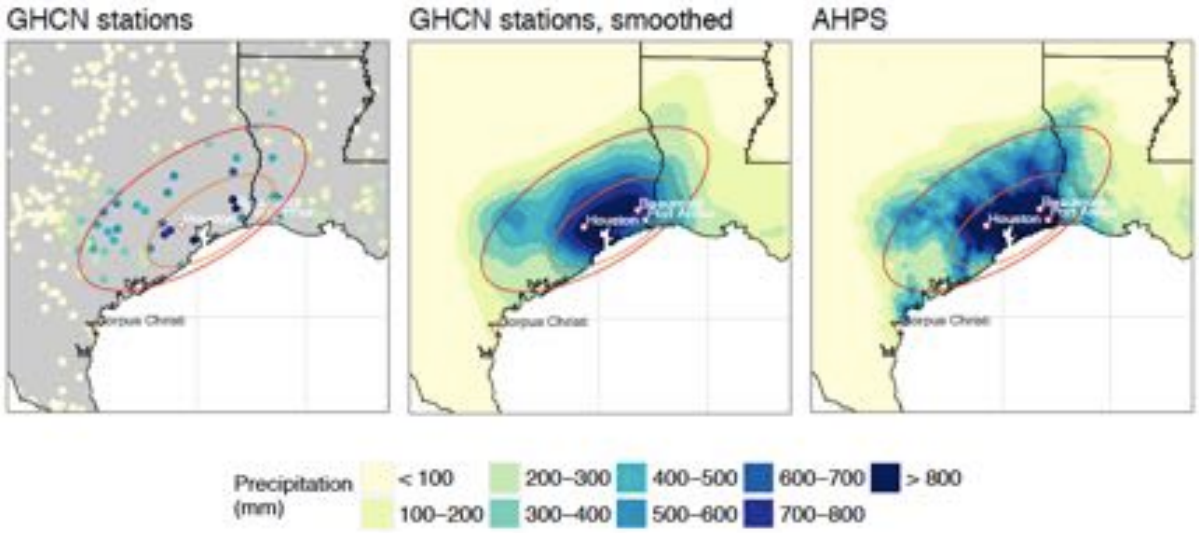
$$G_t(x) \equiv \mathbb{P}(Z_t \leq x) = \exp\left\{-\left[1+\xi_t\left(\frac{x-\mu_t}{\sigma_t}\right)\right]^{-1/\xi_t}\right\},$$

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

Hurricane Harvey precipitation

- We used a non-stationary generalized extreme value distribution with two covariates to model extreme Houston area precipitation.
  - Covariates: $ln(CO_2)$ and Niño3.4
  - 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

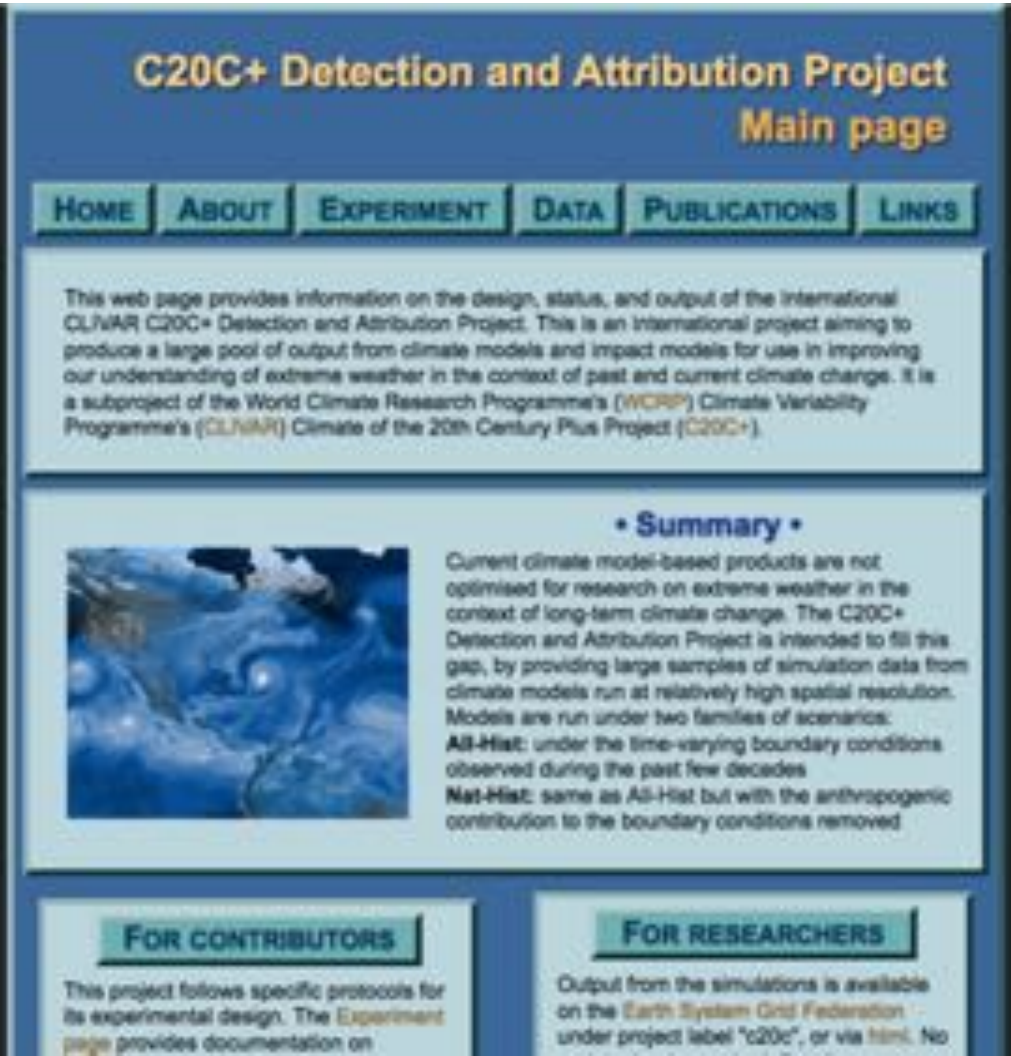
Hurricane Harvey attribution statement

- 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.
- Harvey was a very extreme outlier but our analysis is "out of sample" and stable to storm total precipitation.
- But Granger causality statements do not account for "hidden covariates". We only looked at CO_2 and ENSO.

C20C+ detection and attribution subproject

Model simulations of the factual and counterfactual world are freely available

http://portal.nersc.gov/c20c/



Conclusions

- Extreme event attribution is based on rigorous statistical theory and established climate modeling techniques.
  - Many extreme weather events have had a clear attributable human influence.
    - Lower bound of risk ratio "*likely*" greater than 1.
    - It is possible to partition the attributable risk between natural variations (i.e. ENSO) and human forcings
    - Large body of literature (BAMS, etc.)
- Nonetheless, we have a responsibility to clearly state the conditions, caveats and uncertainties.
  - As this work captivates the public, we must be careful.
  - Are models "fit for purpose"?
  - Are the lower bounds of attribution statements definitive?

BERKELEY LAB

Thank you!

mfwehner@lbl.gov