Brief overview of event attribution in climate science

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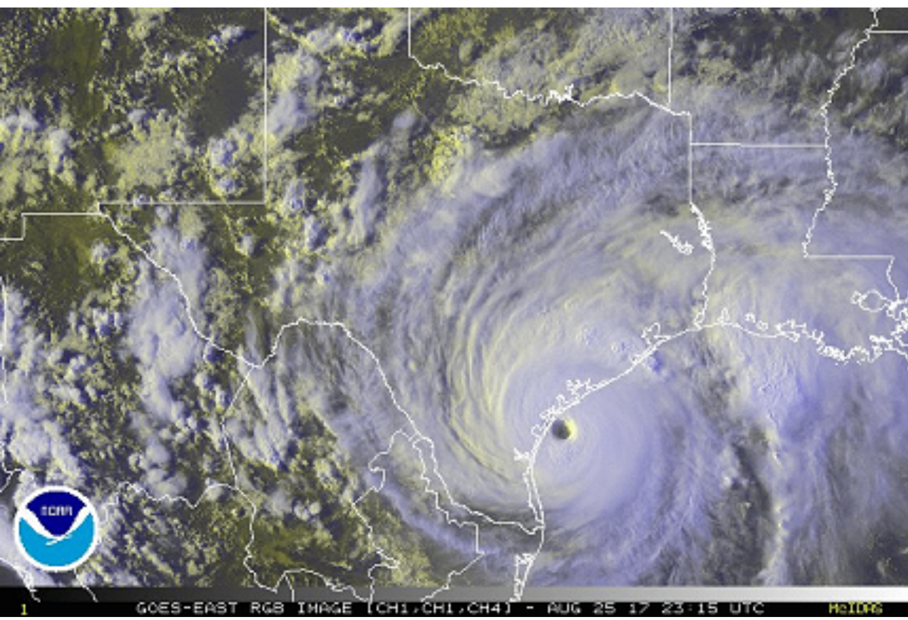

Hurricane Harvey in August 2017 led to $125 billion of damages

What caused extreme weather?

Liability for climate change

Will it ever be possible to sue anyone for damaging the climate?

Myles Allen

As I write this article in January 2003, the flood waters of the River Thames are about 30 centimetres from my kitchen door and slowly rising. On the radio, a representative of the UK Met Office has just explained that although this is the kind of phenomenon that global warming might make more frequent, it is impossible to attribute this particular event (floods in southern England) to past emissions of greenhouse gases. What is less clear is whether the attribution of specific weather events to external drivers of climate change will always be impossible in principle, or whether it is simply impossible at present, given our current state of understanding of the climate system. The issue is important as it touches on a question that is far closer to many of

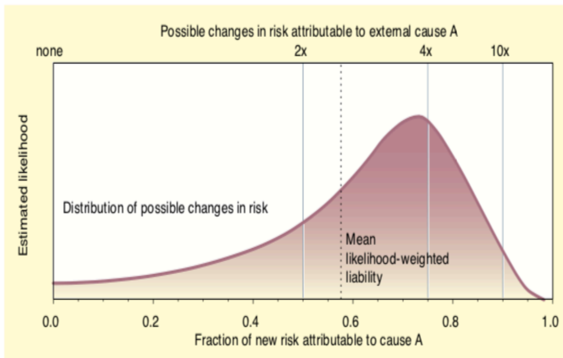

Figure 1 **How we might be able to calculate liability for climate change. We will never know exactly how external drivers of this change, such as greenhouse-gas emissions, alter the risk of undesirable events, such as floods, but this does not prevent us working out a 'mean likelihood-weighted liability' by averaging over all possibilities consistent with currently available information.**

Attribution of extreme rainfall from Hurricane Harvey, August 2017

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Supplementary material for this article is available online

Abstract

During August 25–30, 2017, Hurricane Harvey stalled over Texas and caused extreme precipitation, particularly over Houston and the surrounding area on August 26–28. This resulted in extensive flooding with over 80 fatalities and large economic costs. It was an extremely rare event: the return period of the highest observed three-day precipitation amount, 1043.4 mm $3dy^{-1}$ at Baytown, is more than 9000 years (97.5% one-sided confidence interval) and return periods exceeded 1000 yr (750 mm $3dy^{-1}$) over a large area in the current climate. Observations since 1880 over the region show a clear positive trend in the intensity of extreme precipitation of between 12% and 22%, roughly two times the increase of the moisture holding capacity of the atmosphere expected for 1 °C warming according to the Clausius–Clapeyron (CC) relation. This would indicate that the moisture flux was increased by both the moisture content and stronger winds or updrafts driven by the heat of condensation of the moisture. We also analysed extreme rainfall in the Houston area in three ensembles of 25 km resolution models. The first also shows 2 × CC scaling, the second 1 × CC scaling and the third did not have a realistic representation of extreme rainfall on the Gulf Coast. Extrapolating these results to the 2017 event, we conclude that global warming made the precipitation about 15% (8%–19%) more intense, or equivalently made such an event three (1.5–5) times more likely. This analysis makes clear that extreme rainfall events along the Gulf Coast are on the rise. And

The procedure

- Which historical event is of interest? e.g. Hurricane Harvey flooding in Aug 2017

- How can we best measure its intensity? Construct a suitable intensity index for such events that can be reliably observed and simulated e.g. 3-day mean or max of area average precipitation (*possible future parametric trigger variable?*).

- How much does global warming change the probability of extremes in this index?

  - **Observational approach**: Estimate the trend by fitting an extreme value distribution to past observations that includes global mean temperature as a covariate e.g. GEV fit with temperature-dependent location and scale parameters. Quantify the trend by calculating a **Probability Ratio (PR)** equal to the probability of exceedance in the year of interest to that of the probability of exceedance in the the pre-industrial period. **(detection)**

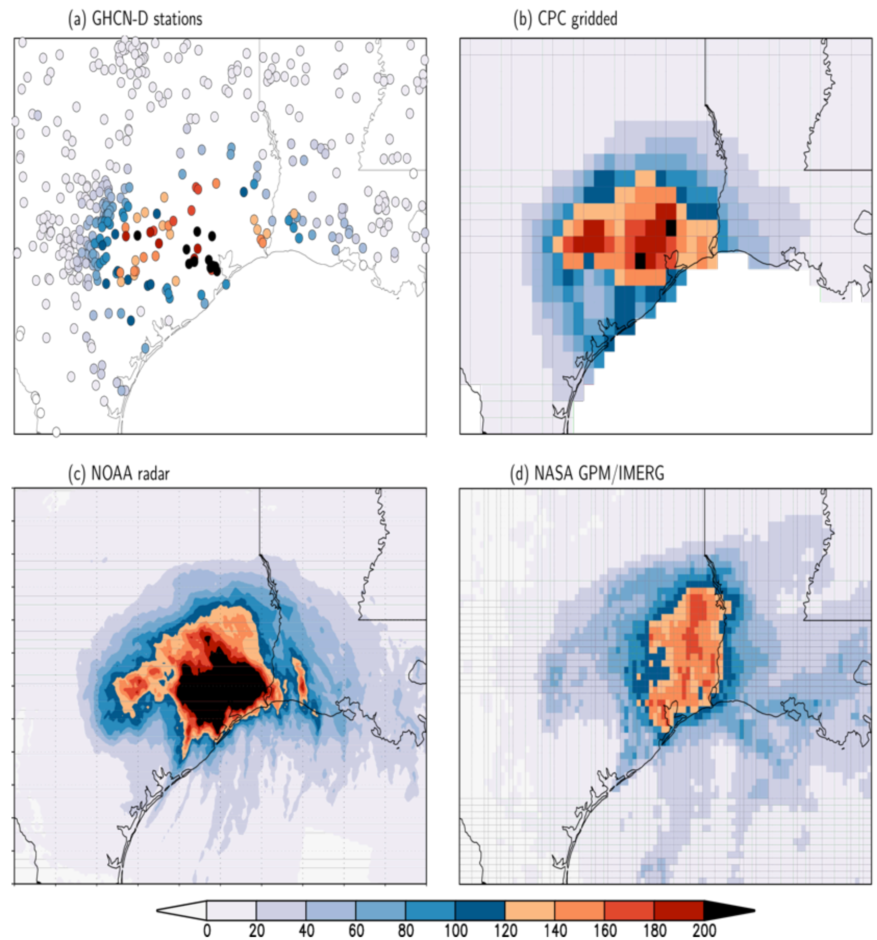
  - **Climate model approach**. Select climate models that can realistically simulate such events and then after some bias correction estimate Probability Ratios from experiments made with these models. **(attribution)**

- Compare and and combine the different Probability Ratio estimates to make a robust detection and attribution statement. **(synthesis)**

Example: Hurricane Harvey flooding

Figuring out what happened is non-trivial.

Here they chose the spatial and annual maximum of 3-day station precipitation on the Gulf Coast.



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Extreme Value fits to the observations

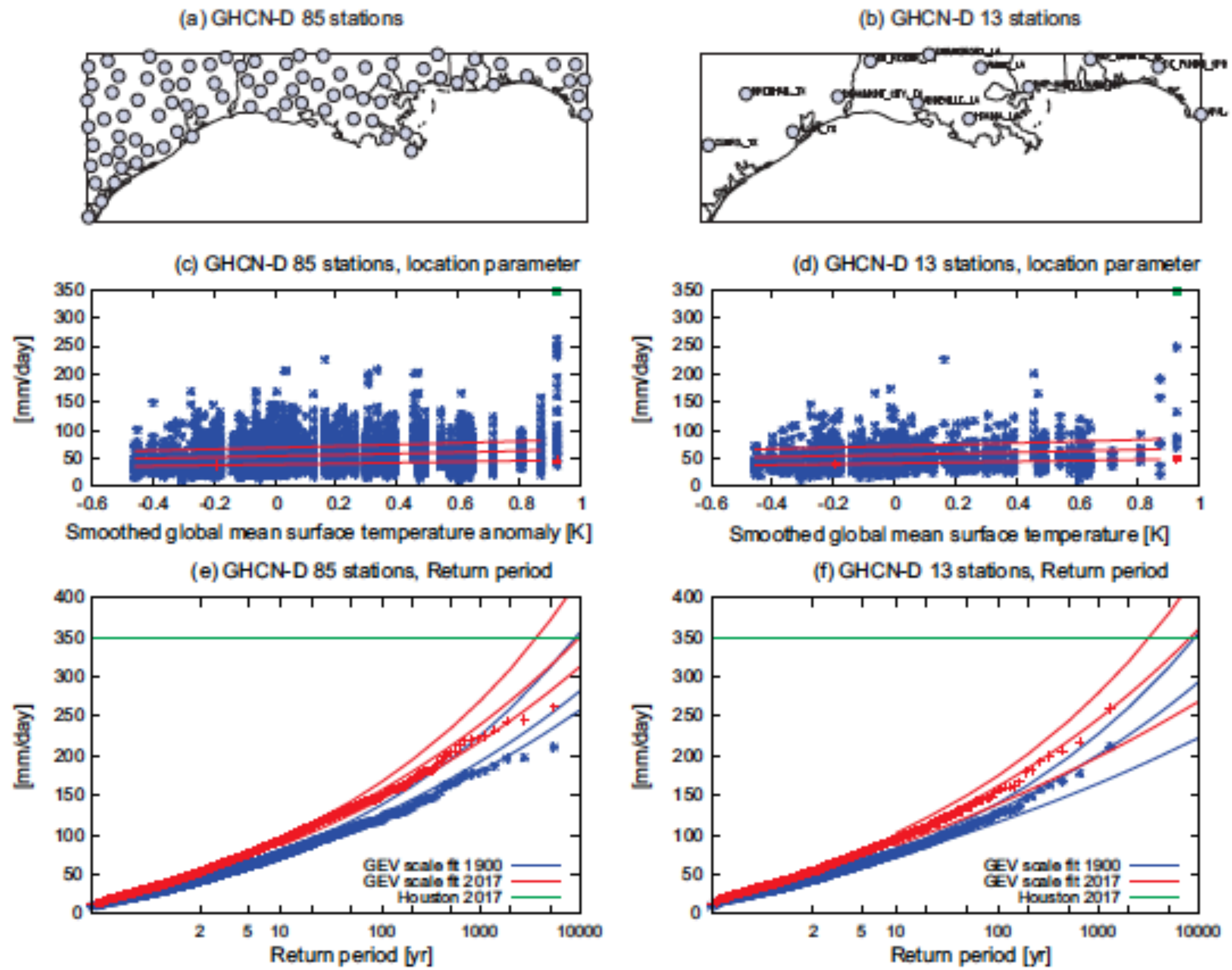


Figure 4. Fit of the annual maximum three-day average GHCN-D station precipitation on the US Gulf Coast to a GEV that scales with smoothed global mean surface temperature. (*a*) Location of 85 GHCN-D stations with minimum 30 years of data and 0.1° apart, (*c*) observations (blue marks), location parameter μ (thick red line), $\mu + \sigma$ and $\mu + 2\sigma$ (thin red lines) versus global mean temperature anomalies, relative to 1951–1980; the two vertical red lines show μ and its 95% CI for the two climates in (*e*). (*e*) Gumbel plot of the GEV fit in 2017 (red line, with 95% uncertainty estimates) and 1900 (blue line); marks show data points drawn twice: scaled up with the fitted trend to 2017 and scaled down to 1900. The green square (line) denotes the intensity of the observed event at Baytown, TX. Panels (*b*, *d*, *f*) are the same as (*a*, *c*, *e*), but for 13 GHCN-D stations with a minimum 80 years of data and minimum spatial separation of 1.0°.

Attribution measures

Probability Ratio	$\mathrm{PR}=\dfrac{\Pr(X>x\mid \mathrm{GW})}{\Pr(X>x\mid \mathrm{no\ GW})}=\dfrac{1-F_{GW}(x)}{1-F_{NGW}(x)}$
Fractional Attributed Risk	$\mathrm{FAR}=1-\dfrac{1}{PR}$
Intensity Change	$\Delta I = x - F_{NGW}^{-1}(F_{GW}(x))$

where x is the observed value and $F(x)=\Pr(X\le x)$.

The Generalised Extreme Value fit assumes:

$$F(x)=\exp\left[-\left\{1+\xi\left(\frac{x-\mu}{\sigma}\right)\right\}^{-1/\xi}\right]$$

where the parameters can depend on global temperature.

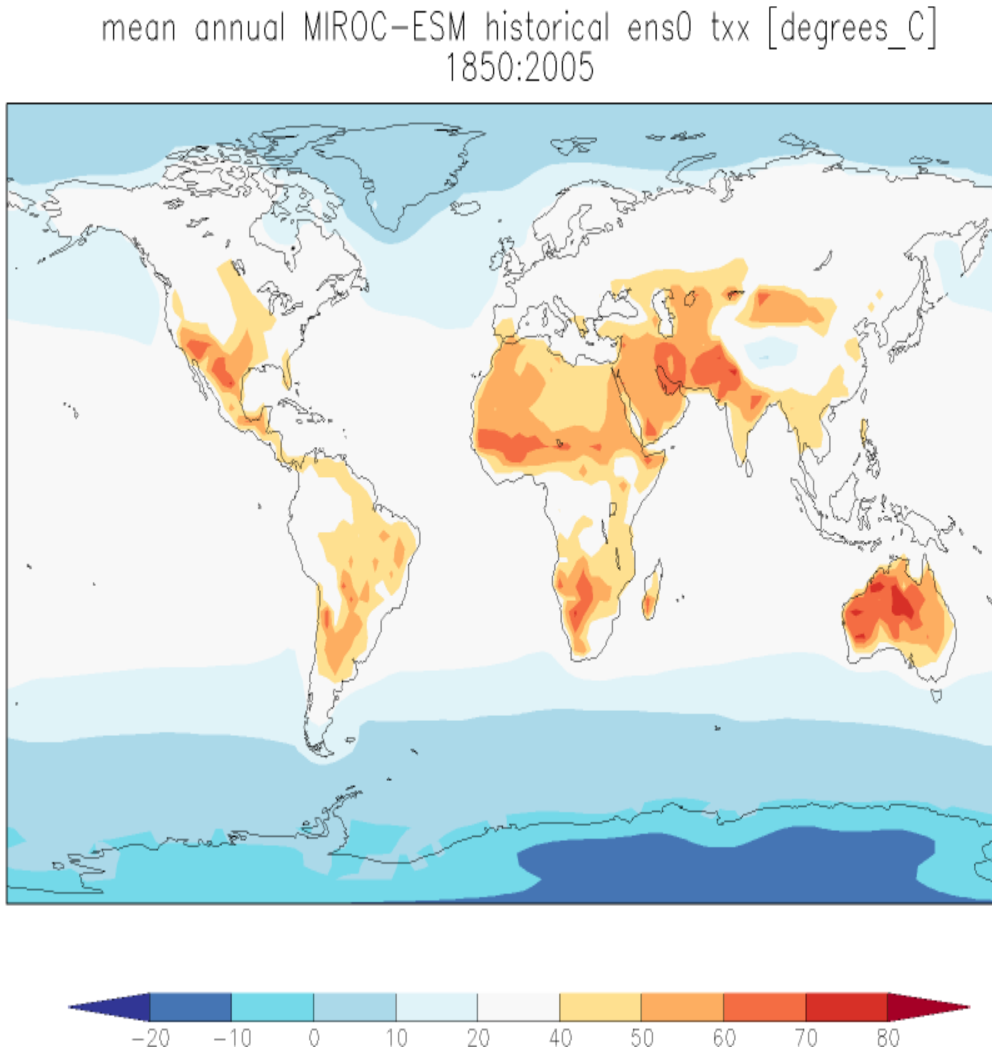
Attribution using climate models

Two ways to obtain the influence of anthropogenic emissions (greenhouse gases, aerosols) on extremes simulated by climate models:

1. Fit an extreme value distribution to a transient run as was done for the observations;
2. Run the model twice, once with current climate conditions, once with no anthropogenic emissions (*counterfactual experiment*). Then either count the number of extreme events above the threshold to compute PR = p1/p0. Or use two fits to extreme value functions to compute the probabilities p0, p1.

The probability ratio PR can be re-expressed as either a Fractional Attributable Risk (FAR=1-1/PR) or the change in intensity ΔI can be calculated.

Example: climate model discrepancy



Maximum daily average air temperature exceeds 70ºC whereas maximum ever reliably observed was 41.9ºC in Australia on 17 Dec 2019
(and 54.4ºC in Death Valley 16 August 2020!)

Synthesis

Sometimes, the models agree with the observations (as demanded in the model evaluation) but not with each other.

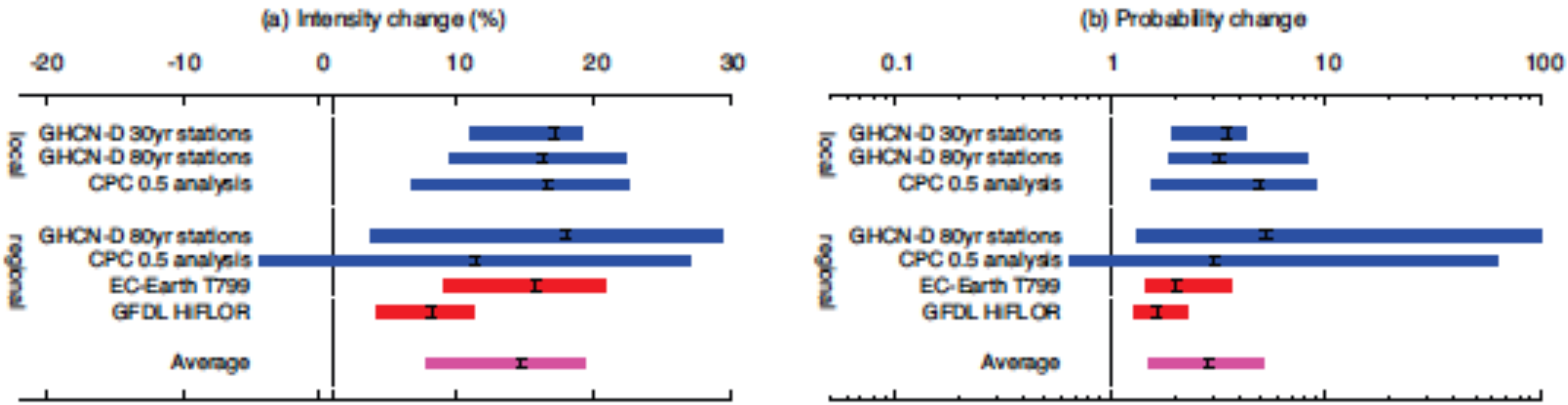


Figure 7. Synthesis of the results. (*a*) Intensity changes 1880–2017 for local and regional extreme three-day precipitation events along the US Gulf Coast (%). Observations are shown in blue, models in red. The magenta line is the average of the three estimates from local observations (with smaller uncertainties) and the two regional model analyses (that can only reproduce these more extreme events reliably). (*b*) Same for the RRs (changes in probability).

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Some reflections

- A high probability ratio does NOT tell you that global warming caused the event of interest - it’s not equal to Pr(due to global warming)/Pr(not due to global warming). [Prosecutor’s fallacy] E.g. *Drinking gin greatly increases my probability of falling over but if I fall over it doesn’t necessarily mean I’ve been drinking gin!*

- It is not surprising that PR>1 for events one suspects might increase with global warming (e.g. heat waves and flooding). [Selection bias]

- There is uncertainty in the observational estimates of PR due to shortness of record, inhomogeneities, natural variability, quality of GEV fit etc.

- PR ratios can be very dependent on which index is used to measure the event.

- Not that obvious how to correct and combine risk ratio estimates from climate models that have discrepancies and dependencies.

- The probability ratio summarises changing probability of hazard not risk − no loss, vulnerability or exposure data is formally used.

Further reading

- https://www.worldweatherattribution.org/

- van Oldenborgh et al. 2017 Attribution of extreme rainfall from Hurricane Harvey, Environ. Res. Lett. 12 124009

- Frame, D.J., Rosier, S.M., Noy, I. et al. Climate change attribution and the economic costs of extreme weather events: a study on damages from extreme rainfall and drought. Climatic Change (2020). https://doi.org/10.1007/s10584-020-02729-y

- Attribution of Extreme Weather Events in the Context of Climate Change, National Academies of Sciences Engineering and Medicine (2016). 186pp.

- Van Oldenborgh, Pathways and pitfalls in extreme event attribution: reflections based on the WWA experience (submitted).

Thank you for your attention

Any questions?

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