

Climate change attribution

An explainer

In the third of an occasional series of explainers on the statistics and data underpinning our understanding of climate change, **Dario Domingo, Andrew Parnell** and **David B. Stephenson** give an overview of the study of the links between climate change and extreme weather events

What is meant by climate change attribution?

Climate change attribution is the scientific process of determining the extent to which human activities have influenced past weather events and climate trends. Attribution seeks to determine whether, and to what extent, human influence has increased the likelihood or intensity of a particular event or trend, compared to a scenario without human-induced climate change.

A combination of statistical and climate models is used to separate out the causal effects of human actions (greenhouse gas emissions, land use changes, etc.) from natural drivers of climate (El Niño-Southern Oscillation, solar activity, volcanoes, etc.).

How is extreme weather event attribution done?

Extreme event attribution aims to determine human influences on specific historical extreme weather events such as floods, heatwaves and storms. Climate scientists use

observational data as well as information from climate model simulations to assess how much human-induced climate change might have affected an observed extreme event.

- *Statistical analysis.* Historical observations are analysed to determine if and how the frequency or intensity of such extreme events has changed over time. Statistical modelling is then used to quantify how the distribution of extremes of a hazard variable such as precipitation, temperature, or wind speed in a region depends on key indicator variables such as global mean temperature.
- *Climate modelling.* Scientists run climate models with and without human-caused greenhouse gas emissions to compare the likelihood or intensity of an extreme event occurring in each scenario.

As an illustration, consider attribution of the annual maximum daily temperature of 35°C that was observed in 2018 at Heathrow

airport (see Figure 1(a); data described in our explainer on extreme weather¹). In Figure 1(a), it can be seen that 35°C was only exceeded once during the earlier period 1960–1991, whereas it was exceeded six times in 1992–2024. If we assume that the difference between the two periods is only caused by human factors, we can attribute the increasing frequency of these exceedances (from 1/32 to 6/33) to human influence on the climate.

Figure 1(b) shows a positive relationship between the annual maximum temperatures at Heathrow and the global mean warming trend in each of the years. Annual maximum temperatures at Heathrow are increasing at about 5°C for every increase of 1°C in global mean warming. Statistical modelling of this relationship – performed using extreme value distributions, a statistical tool for analysing the probability of rare events – allows quantitative estimates to be made of how the probability of exceeding 35°C depends on global mean warming. For example, running simulations with random variations around



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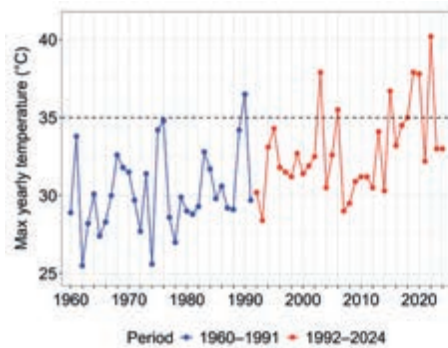
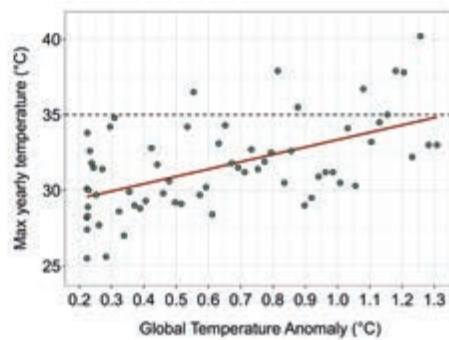


Figure 1: (a) Time evolution of the annual maximum daily temperature at London Heathrow, shown over two periods of 32 and 33 years, respectively: 1960–1991 (blue) and 1992–2024 (red). (b) Annual maximum daily temperature at Heathrow versus the global mean warming since global pre-industrial times (1850–1900). The red straight line, fitted using linear regression, indicates the way that annual maxima increase with global mean warming. In both panels, the horizontal dashed line marks a 35°C threshold.



An extreme event that is exceedingly rare can still be exceedingly rare even though it has become twice as likely

the large uncertainty is that extreme events are, by definition, rare. It can therefore be difficult to estimate how often such events occur with a limited data history. Uncertainty ranges are typically provided as part of research efforts, as shown in Figure 2, but are often omitted for simplicity from headline findings in news stories.

How is climate trend attribution done?

Climate trend attribution is assessed through a combination of climate and statistical modelling techniques:

- **Detection of trends.** Statistical models are used to test whether trends in time series indices (e.g., global mean temperature) are beyond what would be expected by chance from natural variability of climate.
- **Attribution of trends.** Statistical models are used to quantify how trends in climate time series indices are related to those obtained from sets of climate model simulations made with and without human-induced drivers (e.g., greenhouse emissions) but always including natural drivers (e.g., solar activity, volcanoes).
- **Identification of optimal indices.** To better understand how much of the observed climate change is caused by human activities, scientists sometimes create special indicators, known as optimal indices. These are designed to highlight the effects of climate change as clearly as possible. To do this, researchers compare real-world climate data with patterns expected from computer models that simulate what might happen under different levels of greenhouse gas emissions. By focusing on the parts of the data that match these expected patterns, they can more confidently detect the influence of human-driven climate change.

- the trend in Figure 1(b) gives estimates that the probability of exceeding 35°C was 4.5% in 1975 but is now 41.5% in 2025.

More information and examples on attribution of extreme events can be found at worldweatherattribution.org.

What does it mean to say that an extreme event was made more likely because of climate change?

A recent BBC article ([tinyurl.com/5dew56eu](https://www.bbc.com/news/health-55656565)) stated that “the heatwave that hit France in 2015 killing more than 3,000 people ... was made twice as likely because of climate change”. Similar statements have been made about the floods in Valencia, and Storm Boris in Central Europe. Of course, an extreme event

that is exceedingly rare can still be exceedingly rare even though it has become twice as likely.

In the French heatwave case, the researchers used the statistical methods outlined in the previous section. They fitted a statistical model to the data that determined how often extreme events occur under various levels of climate change. Even under no climate change, it is possible for these events to occur, and we can estimate how often. Under the climate change scenario, though, the researchers found that these events occurred twice as often, and that is how they arrived at their figure.

It is important to note that estimates of the change in rate of extreme events invariably have a large uncertainty range. One cause of

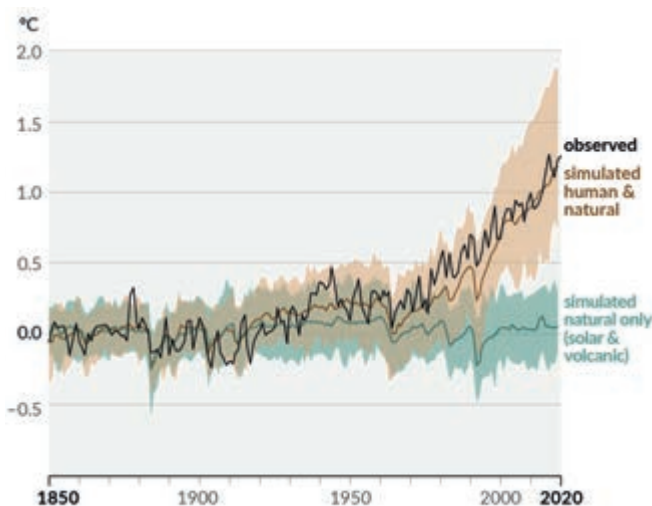


Figure 2: Time evolution of global mean surface temperature (black line), simulated temperature using natural drivers only (green line) and simulated temperature using human and natural drivers (brown line). The shaded bands quantify the uncertainty in the simulated temperature estimates. Source: Intergovernmental Panel on Climate Change.²



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Figure 2 shows global mean temperature (relative to the 1850–1900 pre-industrial average) based on observations and climate-model simulations with and without human drivers. All three solid lines are close to one another up until around 1930, but then after that the observed temperature and simulated temperature made using natural and human drivers start to diverge from the simulated temperature made using only natural drivers.

Hence, the more recent trend in observed temperatures can be attributed to the effect of human drivers.

Where can I find out more about climate change attribution?

There has been much published research on the topic of detection and attribution. Here are some key publications on the detection and attribution of trends:

- The summary for policymakers in the IPCC Climate Change 2021 report.²
- The review of detection and attribution in climate science in the IPCC Climate Change 2013 report.³
- The research article by Hegerl *et al.*⁴ explaining the optimal fingerprinting method.
- More than 90 attribution studies on heatwaves, extreme rainfall, drought, floods, wildfires and cold spells around the world have been produced by an international team of climate scientists – see worldweatherattribution.org.
- For an explanation of how the UK Met Office carries out attribution studies of extreme weather events, see tinyurl.com/4rbuj3br.
- Jonathan D. Haskett's 2023 report to the US Congress on the science behind extreme event attribution can be found at tinyurl.com/yd4x6y75.

Note

This explainer is the result of work carried out by the RSS Climate Change and Net Zero Task Force: Paul Allin, Marian Scott, Etienne Roesch, Claire Miller, Adrian Raftery, Alec Erskine, Amanda Penistone, Andrew Parnell and Dario Domingo (tinyurl.com/u2r9n8zh).

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