Is it global warming or just the weather?

Scientists are getting more confident about attributing heatwaves and droughts to human influence

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EARLY this year, touring a drought-stricken fruit farm in California, Barack Obama cited the state's three-year dry spell, the worst on record, as an example of the harm that climate change can cause. Politicians like this sort of pronouncement. David Cameron, Britain's prime minister, said in 2014 that he very much suspected that climate change was behind floods in parts of the country's south-west. In contrast, climate scientists have been ultra-cautious about attributing specific weather events to global warming. Because the weather is by its nature variable, it is impossible to know whether climate change caused any particular drought or flood. So the scientists have steered away from making firm connections.

Until now. A new branch of climate science is starting to provide answers to the question: was this drought (or heatwave or storm) at least partly attributable to climate change? In some cases, the answer seems to be a cautious yes. As the research progresses, it could change public perceptions and government policy.

For years, the central debate of climate science has focused on how much global mean surface temperatures would rise by 2100. This is so important that a target for mean temperature rises is likely to be embodied in an international treaty to be signed in Paris later this year. The increase in the mean is the simplest way to measure the long-term impact of climate change. But it has drawbacks. It makes global warming seem like something that will happen in 100 years' time. Most people do not think about global temperatures but local ones. And climate change affects ecosystems not just through increases in the mean, but also through changes in the extremes—more intense droughts, say. Extremes also have a profound impact on people: a heatwave in 2003 caused about 70,000 premature deaths in Europe. Focusing on links between climate change and the local weather thus makes sense in terms of both science and public understanding.

In principle, attributing the weather to climate change might seem straightforward. The two are so closely related that the climate can be defined as the average daily weather over a long period (or, as Edward Lorenz, a mathematician and meteorologist, once put it, "climate is what you expect; weather is what you get").

Of butterflies and bad weather

In practice, though, there are so many influences upon the weather—famously expressed by Lorenz's idea of a butterfly's wingbeat in one part of the world causing a hurricane in another—that isolating any individual factor is hard. That remains true. It is not possible to say categorically that climate change has caused any individual storm, flood or heatwave.

But scientific attribution does not require certainty; it deals in probabilities. Even now, doctors cannot be sure that a case of lung cancer has been caused by smoking (the patient might have got the disease anyway). Nevertheless, it is possible to say that smoking increases the risk of cancer by a certain amount and that smoking causes cancer in a general sense. In a similar way, scientists are now able to say that climate change increases the risk of a particular weather pattern by a measurable amount and, in some cases, that a particular episode is almost impossible to imagine without global warming. That is as near as you can get to saying global warming caused a weather event.

The science of weather attribution started in 2003 with an article in *Nature*, "Liability for climate change"by Myles Allen of Oxford University. It showed that human contributions to climate change can be calculated by looking at what the climate would have been like if people had not increased greenhouse-gas emissions. That meant comparing observations of the weather with computer models of what might have happened without climate change. Much climate science depends on such models, which describe the complexities of the climate. By running them using different assumptions (for example, no increase in greenhouse-gas emissions, or more volcanic activity), and comparing the results with reality, it is possible to reveal the probable effects of the emissions. With lung cancer it is possible to compare groups of smokers and non-smokers; with climate change computers have to simulate the equivalent of the non-smokers.

The trouble is that weather observations are limited and climate models imperfect. Dr Allen showed that, by quantifying the uncertainties, you can calculate the probability of a weather pattern occurring. That made it possible to say that man-made climate change made this or that weather event twice as likely, five times more likely, or less likely.

Dr Allen argues that the study of weather attribution followed naturally from the establishment, in the 2000s, of a scientific consensus that humans are largely responsible for climate change. Heidi Cullen of Climate Central, an American research group, points out that there was also a technical contribution. The climate is global and climate models are, too. Weather, on the other hand, is local—and until recently models were not precise enough to describe it. In the past few years, though, it has become possible to impose a finer grid on the global picture. Computers have become powerful enough, and enough data have been collected, to describe what is happening in an area as small as 25km by 25km. The result has been the development of regional climate models.

Turbulence ahead

Most of the episodes that have so far come under the microscope have been large, long-lasting ones, such as Australia's heatwave in 2013, or California's continuing drought. But one study, by Hans von Storch of the Institute of Coastal Research in Germany, looked at a storm that passed through northern Germany and southern Denmark in 2013 and lasted less than a week. (It found no evidence of human influence.) Traditional climate research is a little like epidemiology, the study of disease at the level of the population; Dr von Storch's study was a bit like an autopsy.

The number of such studies is proliferating. Dr Allen's outfit at Oxford has put its regional climate models online so anyone can download them. Hundreds are doing so, running their own studies and making this project, called weather@home, one of the largest examples of "citizen science" in the world. The science of weather attribution now has a network of researchers and a group of institutions which shapes the studies (in addition to Oxford and Climate Central, it includes the University of Melbourne, America's National Oceanic and Atmospheric Administration and the Royal Netherlands Meteorological Institute). There is also an academic journal which publishes most of them: the *Bulletin of the American Meteorological Society*(BAMS).

Though the groups use somewhat different approaches, their conclusions are strikingly similar. The strongest evidence for human influence can be seen in heatwaves, such as Australia's "angry summer" of 2013, when average temperatures were 1.5°C above the norm for 1911-40. In a study in *Geophysical Research Letters*, David Karoly of the University of Melbourne argues that it is possible to say with considerable confidence that human influence increased the risk of such high temperatures fivefold, at least. The heatwave of 2013, he argues, would have been "virtually impossible" without climate change.

The most recent BAMS contained nine studies of heatwaves in 2013, including in Europe, China, Japan and Korea. All showed that man-made climate change had increased the likelihood of exceptional heat. In Korea daily minimum summer temperatures were 2.2°C above the 1971-2000 average; the study found that climate change had boosted the chance of this happening tenfold. Germany is likely to have a summer as hot as that of 2013 about once in seven years now; before industrialisation the odds were one in 80. For Europe, the odds rose even more, by 35 times—the result of changes to ocean currents and the great Arctic melt, and to emissions of greenhouse gases and aerosols (which, like the melting of Arctic ice, are influenced by natural variability, as well as humans).

You would expect more heatwaves with more global warming; they are two sides of the same coin. But climate change also seems to be contributing to droughts, though the evidence here is weaker. The link is intuitively plausible: higher temperatures speed up evaporation, reduce soil moisture and lead to drought. One BAMS study of California also found that atmospheric pressure patterns associated with droughts in the past are becoming more likely than they would be without greenhouse-gas emissions.

On the other hand, another study concluded that global warming increases the risk of drought in California in some ways but decreases it in others, leaving no net change. Forthcoming research on drought in south-east Brazil suggests other sorts of human influence, such as population growth and water consumption, also matter. Of four studies of droughts in the most recent BAMS, two showed that man-made influences were increasing the risk; two found no link or an uncertain one.

The evidence is weaker still when it comes to storms. It is often said that climate change is making hurricanes and other intense storms more frequent. But the BAMS researchers looked at three unusual storms in 2013—the one in northern Germany; a blizzard in South Dakota and autumn snow in the Pyrenees—and found no evidence of human influence in any of them.

In an attempt to give the overall picture, a new study in *Nature Climate Change* by Erich Fischer and Reto Knutti, both of the Federal Institute of Technology in Zurich, moved away from individual events to consider heatwaves and rain storms in general. They took all the heat and precipitation extremes between 1901 and 2005, defining extremes as events likely to occur once every 1,000 days. By running the climate models with and without climate change, they found that 0.85°C of warming (the rise since the industrial era began) has made such heat extremes four or five times more likely, roughly the same as in the Australian study. The authors attribute 75% of the heat extremes, and 18% of the precipitation extremes, to observed global warming. Worryingly, the risk of an extreme event seems to rise exponentially as mean temperatures creep up. The probability of a heat extreme is twice as great at 2°C of warming than at 1.5°C.

That does not mean, alas, that the science of weather attribution will be able to forecast particular droughts or heatwaves, only to say that more of them are likely to happen. That is a useful addition to climate science. People are routinely told about—and routinely ignore—the bad things they are doing to the climate. The attribution studies show that the climate is doing bad things back.