

**Heavy Weather**

Tracking the fingerprints of climate change, two years after the Paris summit

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# Executive Summary

Since the United Nations climate summit in Paris two years ago, scientists have published at least 41 studies concluding that climate change has increased the risk of extreme weather events around the world.

The events analysed in these studies encompass episodes of extreme heat, drought, flooding and wildfire outbreaks, and concern every continent except Antarctica. They include heatwaves in Europe, China and Japan; droughts in Syria and Tibet; elevated wildfire risk in the US and Canada; and Storm Desmond, which hit Cumbria and other parts of the UK, coincidentally, during the Paris summit. The studies span 32 individual events for which the risks have increased due to climate change, with other studies focusing on the long-term trend for increasing risks.

We searched through English-language scientific journals with the aim of finding all research papers published since the Paris summit on the attribution of specific events to climate change. We found 59. Of these, 41 conclude that climate change has increased the risks of a given type of extreme event. Some detect an increase in frequency, others an increase in intensity or duration, or link a particular impact to climate change – or a combination of these effects. Only four concluded that climate change has decreased the risk of particular extreme events. The proportional increase in risk generated by climate change across the various events ranges from single-digit percentages to 330-fold.

A small proportion of the individual extreme weather events analysed in these studies have a quantified cost in terms of lives lost or economic damage. In these few events, we can deduce that climate change caused about 4,000 deaths and about $8bn in economic damage.

These figures cannot and must not be taken as estimates of the overall cost of climate change for this period, which will be far higher. Additionally, for any extreme event, the scale of human and economic impact is related to location and to society’s preparedness, not just to the weather itself. So, the importance of these numbers must not be over-stated; nevertheless, they provide an indication of costs tied up in the increasing risks of extreme weather.

Climate science forecasts that rising greenhouse gas concentrations will increase the frequency and/or intensity of extreme weather events in many parts of the world. But that does not imply a blanket increase in risks of all events; the odds of some may go down, others stay the same. The developing science of climate event attribution means that scientists are increasingly able to track these changes, whatever they are, as they occur, to provide near-real time monitoring of the extent to which climate change is loading the dice of extreme events, and what additional costs that is likely to bring.

# The Paris Agreement

At the annual summit of the United Nations climate change convention (UNFCCC) in Paris in December 2015, governments concluded a new global deal, the Paris Agreement[[1]](#footnote-1). It saw every country pledge to constrain its greenhouse gas emissions with a view to keeping climate change within limits conventionally regarded as “safe”, thus fulfilling the aim of the 1992 UN convention[[2]](#footnote-2) to “prevent dangerous anthropogenic interference with the climate system”.

Anecdotally, one of the main reasons why governments concluded the Paris Agreement was because of rising concern about impacts of climate change, including its potential to exacerbate extreme weather events.

In advance of the summit, the Papal Encyclical *Laudato Si* said[[3]](#footnote-3) that the rising average global temperature “has been accompanied by a constant rise in the sea level and, it would appear, by an increase of extreme weather events…”. The NATO Parliamentary Assembly warned[[4]](#footnote-4) that “climate change-related risks will affect international security through increased natural disasters”. The World Health Organisation predicted[[5]](#footnote-5) that climate change “will cause some 250,000 additional deaths per year by the 2030s”, one of the main reasons why being “more intense heatwaves and fires”.

Scientists have long warned that climate change is expected to increase the frequency and intensity of some extreme weather events. The view of precisely which events in which parts of the world has evolved over time as scientific knowledge has progressed. The most recent report from the Intergovernmental Panel on Climate Change (IPCC)[[6]](#footnote-6) summarises the evidence thus:

“Climate-change-related risks from extreme events, such as heat waves, extreme precipitation, and coastal flooding, are already moderate (*high confidence*) and high with 1°C additional warming (*medium confidence*). Risks associated with some types of extreme events (e.g., extreme heat) increase further at higher temperatures (*high confidence*).”

More specifically, the IPCC concludes[[7]](#footnote-7) that heatwaves are very likely to occur more frequently and with longer duration as climate change progresses, and that extreme rainfall events are very likely to become more frequent and more intense over most of mid-latitude and tropical land during this century.

A few days into the Paris summit Storm Desmond landed on UK shores, centred on Cumbria. Within days scientists had performed and released an initial analysis[[8]](#footnote-8) concluding that climate change had increased the odds of an event such as Storm Desmond, by about 40% - a conclusion that was later confirmed in the peer-reviewed literature[[9]](#footnote-9).

In the Paris Agreement, governments pledged to hold global warming since pre-industrial times “well below” 2 degrees Celsius, and to “pursue efforts” to keep it below 1.5ºC, recognising that this would significantly reduce the risks and impacts of climate change. Article 8 of the Agreement specifically addresses extreme weather: “Parties recognise the importance of averting, minimising and addressing loss and damage associated with the adverse effects of climate change, including extreme weather events…”

The global average surface temperature is already about 1ºC above pre-industrial times[[10]](#footnote-10). Therefore, the question arises of to what extent climate change is already affecting extreme weather events around the world.

# Event attribution science

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Extreme weather events such as hurricanes, floods and droughts occur naturally, and would continue to do so even in the absence of climate change. The questions that the science of climate event attribution asks are: “Did the presence of climate change make a specific event more or less likely, or more or less intense? If so, by how much?”

Scientists use a variety of methods to answer these questions, but they fall into two broad categories:

* Analysis of historical data to see whether an unequivocal change in frequency or intensity can be identified
* Use of computer models to assess any effect of climate change in terms of changing occurrence rate, intensity or duration – and sometimes to link that to a change in a specific outcome

Scientists use a number of different ways of expressing a link between climate change and the observed event. They may use the form “climate change made event X 40% more (or less) likely to occur”; or talk about a change in the expected time interval between events, for example “what would be expected once every 100 years is now expected every 50 years” (climate change has “halved the expected return time”); or they may discuss a specific impact, eg “climate change explains half of the observed increase in hospital admissions”.

Some studies focus on individual events in a specific place, for example the 2015 heatwave in Japan. Others look for a trend in a specific type of extreme weather event over time. Studies also use different regional scales in asking the attribution question, with some focusing on global impacts, some regional, and others more localised.

The title of “first scientific study on event attribution” is usually bestowed on a 2004 paper by Peter Stott of the UK Met Office and colleagues[[11]](#footnote-11), which concluded that climate change had at least doubled the risk of the 2003 heatwave in northern Europe. Since then, scientists have published about 170 papers on event attribution[[12]](#footnote-12). The number seen in the last two years – 59 – therefore shows that this is an accelerating field of work. In addition to formal scientific papers, researchers now regularly produce quick-turnaround initial analyses[[13]](#footnote-13) of whether a specific weather event has a climate change signal within a few days of the event happening.

# Findings

To compile the list of studies, ECIU used, verified and sifted a pre-existing partial database[[14]](#footnote-14), conducted a fresh search of scientific literature, and asked climate attribution scientists for input. Through this process we identified 59 research papers on attribution of extreme weather events published in peer-reviewed English language scientific journals between December 2015, the month of the UN climate summit, and November 2017.

We cannot be certain that this list is exhaustive, but we think it is unlikely to have missed major papers. The question of papers published in other languages has not been addressed. All of the papers included address weather phenomena; we excluded, for example, those detecting a climate change signal in shrinkage of Arctic sea ice, as this would fit outside a conventional definition of “weather”.

Of the 59 papers identified, 41 found a positive link (ie, climate change made the extreme event more frequent, longer-lasting, more intense, or that it contributed to a particular type of impact). Of these, 32 focus on a recent individual event or a specific recent season; the remainder find a long-term increasing trend in a particular type of extreme event, locally, regionally or globally.

By contrast, only four studies identified a negative link (ie, climate change made the type of event less likely to occur or less severe). Seven concluded that there was no link to climate change, while the remaining seven were inconclusive. A summary of results is given below (Table one), while the full list is available for download [here](https://drive.google.com/file/d/1Dhz2QxHzci_r6HsNZXUZxnhTisSYkMFL/view?usp=sharing).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Event type** | **Positive link** | **No link** | **Negative link** | **Inconclusive** |
| Heat | 15 | 0 | 0 | 0 |
| Drought | 9 | 2 | 1 | 4 |
| Rainfall/flooding | 9 | 2 | 0 | 3 |
| Storms | 3 | 2 | 2 | 0 |
| Wildfires | 4 | 0 | 0 | 0 |
| Cold, snow, ice | 1 | 1 | 1 | 0 |
| **Total** | **41** | **7** | **4** | **7** |

***Table one:*** *Summary of results*

***Figure one:*** *Summary of results*

We then looked for estimates of specific consequences of these extreme events, on human mortality or economic cost. Combining the costs of an event with the increase in risk driven by climate change allows a simple calculation of a climate change cost from that event. For example, if an event is 50% more likely to have occurred as a result of climate change, one can say that 1/3 of the risk (50/150) is attributable to climate change. The costs can be attributed accordingly. So if the event carries an estimated cost of $3bn, the cost of climate change’s involvement in it would be $1bn. Similarly, an eightfold increase in frequency of an event – ie, that climate change makes it 700% more likely – means that 7/8th of the risk and the cost could be attributed to climate change.

It might be argued that this is an overly simplistic assessment method, and that a sophisticated calculation would compare the cost of an event augmented by climate change with one occurring in the absence of climate change, because the relationship between the scale of an extreme event (the amount of rain falling, the length of drought, etc) and its impact is non-linear. However, in practice there is unlikely to be a set of data from which this counterfactual could be calculated; and so the simple assignment used here, we argue, is a reasonable and feasible way of arriving at a ballpark estimate.

A crucial caveat is that the cost of an event in lives lost or economic damage is not only determined by the scale of the event, but by where it occurs and by society’s preparedness. The damage from a hurricane, for example, is far greater if it makes landfall on a densely-populated urban area, if evacuation and sheltering plans are inadequate, and if buildings are poorly-built and easily swept away. However, in some cases event attribution studies are able to circumvent this issue by focussing on a specific locality; then, unless one assumes major changes in population size or level of development, it may be reasonable to assume that the costs of a similar event several years hence will be comparable.

# Lives Lost

The majority of documented lives lost across this set of extreme weather events stem from two events in the same year – the 2015 heatwaves in France and in South Asia.

The French heatwave carried an estimated mortality of 3,275[[15]](#footnote-15). An attribution analysis[[16]](#footnote-16) concluded that about half of the temperature elevation in the heatwave could be laid at the door of climate change, with natural variability accounting for the remainder. Therefore, an estimate of the number of deaths in this event attributable to climate change is approximately 1,000.

Another analysis[[17]](#footnote-17) looked at heatwaves in India and Pakistan in 2015 – separate events, though occurring close together in time and space. Temperatures remained above 45ºC for several days at a time; humidity was also unusually high, contributing to a “heat index” (the temperature felt on the body) 7-12ºC above normal for the time of year in Karachi. The two heatwaves together caused an estimated 3,200 additional deaths. This study calculates that climate change made these conditions 8-10 times more likely. Thus, a simple calculation would lay at least 2,800 of these deaths at the door of climate change.

The study database contains several other studies of deaths during climate change-enhanced heatwaves – in Egypt, Japan and Argentina – and flooding in the US. However, the studies put the combined number of deaths in these events at 243. Therefore, a combined analysis of climate change-linked mortality across these studies will be dominated by the results from France and India/Pakistan.

As a rough estimate, then, climate change caused about 4,000 deaths through exacerbating these extreme weather events.

As well as the caveat above on the simplicity of this calculation method, it is worth noting that these are only “first-order” deaths. The surveys producing the mortality figures cannot capture deaths occurring later through exacerbating long-term medical conditions – still less impacts of the lower productivity possible at these elevated temperatures, which could for example constrain food availability, certainly in areas of subsistence farming.

# Economic Damage

A small subset of extreme weather events contained in this database of studies come with cost estimates. This time the subset is dominated by rainfall and flooding. The main events are listed below; a few others also come with cost estimates, but are negligible besides these.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Event** | **Country** | **Year occurred** | **Attribution** | **Cost** | **Approx climate cost** |
| Floods | Louisiana, US | 2016 | 40% more likely | $10.4bn | $3bn |
| Floods | Southern China | 2015 | 40% more likely | $5.6bn | $1.6bn |
| Floods | Colorado, US | 2013 | 30% more likely | $1.6bn | $0.4bn |
| Extreme rain | Cumbria, UK | 2015 | 60% more likely | $2bn (£1.5bn) | $0.8bn |
| Wildfires | Alberta, US | 2016 | 50% more likely | $6.9bn | $2.3bn |
| **Total** |  |  |  |  | **$8.1bn** |

***Table two:*** *Economic damage from extreme events*

Thus using this simple methodology, the cost of climate change manifested in increased risks of this small subset of extreme weather events amounts to $8.1bn.

It must be stressed that this cannot be summarised as “the cost of climate change”. An across-the-board cost calculation would also include the impacts of all other manifestations of climate change, not just exacerbation of extreme weather events. It is not even a cost of the enhancement by climate change of extreme weather events in the years covered by this report; most of the studies we identified do not have a cost estimate alongside, and for the majority of extreme weather events, no attribution studies exist. It is merely a figure that can be calculated from the data available – in this case, for five extreme events.

# Conclusions

The science of climate attribution is advancing rapidly. Only a couple of years ago, when discussing an event such as a drought or a hurricane, many scientists were reluctant to say any more than that an increase in the frequency or intensity “is consistent with what we would expect”. Increasingly, however, science is asking more precise questions about extreme weather events, and providing answers.

As this report shows, within just two years researchers have produced at least 59 scientific papers on the attribution of extreme weather events to climate change – events of many kinds, in all regions of the world. And 41 of them conclude that climate change has made the events investigated more likely, more intense, more long-lived, or contributed measurably to harm – or a combination of these effects.

Extreme weather events would continue to occur even in the absence of climate change. However, the real-world evidence presented here indicates that climate change is already increasing the odds of extreme weather events and doing so regularly, with attendant costs in terms of lives lost and economic damage.

The pledges that governments made under the Paris Agreement, both to adapt societies to impacts of climate change and to cut carbon emissions, are not yet ambitious enough to meet the goals of the Agreement itself, nor yet of the 1992 UN climate change convention[[18]](#footnote-18).

Next year, governments are due to begin a process within the UN negotiations (the Talanoa Dialogue[[19]](#footnote-19)) aimed at increasing their commitment, with the aim of making those commitments more compatible with the goals they agreed at the Paris summit. With concern over climate change impacts being a factor behind the Paris Agreement, the extent to which scientists are identifying detectable increases in extreme weather events should serve as an important input to the Dialogue, and to governments’ own planning for climate change adaptation and mitigation.

1. <http://unfccc.int/paris_agreement/items/9485.php> [↑](#footnote-ref-1)
2. <http://unfccc.int/key_documents/the_convention/items/2853.php> [↑](#footnote-ref-2)
3. <http://w2.vatican.va/content/francesco/en/encyclicals/documents/papa-francesco_20150524_enciclica-laudato-si.html> [↑](#footnote-ref-3)
4. <https://www.actu-environnement.com/media/pdf/news-25462-resolution-otan-2015.pdf> [↑](#footnote-ref-4)
5. <http://www.who.int/globalchange/mediacentre/events/cop21-key-messages/en/> [↑](#footnote-ref-5)
6. <http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/ar5_wgII_spm_en.pdf> [↑](#footnote-ref-6)
7. <http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SPM_FINAL.pdf> [↑](#footnote-ref-7)
8. <https://www.ft.com/content/e1466920-9f81-11e5-8613-08e211ea5317> [↑](#footnote-ref-8)
9. <http://iopscience.iop.org/article/10.1088/1748-9326/aa9663/pdf> [↑](#footnote-ref-9)
10. <https://public.wmo.int/en/media/press-release/2017-set-be-top-three-hottest-years-record-breaking-extreme-weather> [↑](#footnote-ref-10)
11. <https://www.nature.com/articles/nature03089> [↑](#footnote-ref-11)
12. <https://www.carbonbrief.org/mapped-how-climate-change-affects-extreme-weather-around-the-world> + ECIU calculation [↑](#footnote-ref-12)
13. <https://wwa.climatecentral.org> [↑](#footnote-ref-13)
14. <https://www.carbonbrief.org/mapped-how-climate-change-affects-extreme-weather-around-the-world> [↑](#footnote-ref-14)
15. <https://reliefweb.int/sites/reliefweb.int/files/resources/CredCrunch41.pdf> [↑](#footnote-ref-15)
16. <http://www.ametsoc.net/eee/2015/12_europe_heat.pdf> [↑](#footnote-ref-16)
17. <http://www.ametsoc.net/eee/2015/16_india_pakistain.pdf> [↑](#footnote-ref-17)
18. <https://www.unenvironment.org/resources/emissions-gap-report> [↑](#footnote-ref-18)
19. <http://unfccc.int/items/10265.php> [↑](#footnote-ref-19)