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UNDER THE WEATHER

Tracking the fingerprints of climate change, five years after the Paris Agreement

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Executive Summary

Usually kept away from the front pages by Covid-19, 2020 has been another year of weather extremes around the world. Wildfires across Australia, floods in southern and eastern Africa bringing deaths, displacement and disease, South Asia's unusually heavy monsoon season, drought and extreme heat in at least five South American nations, record temperatures in the Russian Arctic, fires in California, Pacific cyclones including Amphan and Harold, an exceptionally active Atlantic hurricane season...[1] 2020 was a year when the natural world was anything but locked down.

The rise in such damaging weather extremes was a major reason why governments agreed, at the Paris climate summit whose fifth anniversary we mark this weekend, to attempt to keep global warming below 1.5 degrees Celsius.[2] And as we show in this report, the last five years have provided increasing evidence that climate change is already strengthening the impact of weather extremes on every continent and the global ocean that links them. We find that since the conclusion of the Paris summit, researchers have published at least 145 scientific studies looking for links between climate change and extreme weather events. In nearly 80% of those studies, they found that climate change played a role – either making it more likely to occur or making it more damaging when it did occur. By comparison less than 10% found that climate change is making the extreme weather in question less likely or less damaging.

Although fewer than half of the events in this list come with a quantified health or economic price tag, the documented damage amounts to many thousands of deaths, tens of billions of dollars in economic harm, and a threat to the food supply for many millions of people.

This is of course a fraction of the overall damage caused by extreme weather events each year. For comparison, the global insurance company Aon calculated the total cost of natural disasters last year at $232bn – this includes non-weather events, but the majority of the cost did come from extreme weather such as cyclones and flooding.[3] And only a proportion of extreme weather events are scientifically probed for a climate change fingerprint, those affecting more prosperous nations being disproportionately represented; so the true toll is undoubtedly higher, especially in developing nations.[4]

This report calls into question our routine use of the term 'natural' to encompass extreme weather events given the number whose drivers include human-made climate change. And extreme weather is only one of the ways in which emissions of greenhouse gases cause harm, alongside progressive impacts such as the rising temperatures faced by outdoor

1 https://public.wmo.int/en/our-mandate/climate/wmo-statement-state-of-global-climate
2 https://unfccc.int/process/conferences/pastconferences/paris-climate-change-conference-november-2015/paris-agreement
3 https://www.aon.com/global-weather-catastrophe-natural-disasters-costs-climate-change-2019-annual-report/index.html
4 https://journals.ametsoc.org/view/journals/bams/101/10/bamsD190317.xml

workers, loss of mountain glaciers that store drinking water and the acidification of the global ocean.

Events of the last few months – pledges from China, Japan and South Korea to reach net-zero emissions by mid-century, the likelihood of stronger targets from the European Union, the election of Joe Biden in the US – have approximately halved between the trajectory emissions were on, heading for about 2.7 degrees Celsius of global warming by the end of the century, and the Paris Agreement target of 1.5°C.[5] Provided, that is, those countries implement the pledges they have made. In the meantime however, the concentration of greenhouse gases in the atmosphere continues to rise despite a year lived partially under Covid-19 lockdown.[6]

Five years after every nation agreed to constrain rising emissions, this report shows that climate change is increasing the damage caused by extreme weather to individuals, communities and economies, threatening to undo the gains from social and economic developments over recent decades. The effect of climate change is forecast to increase as long as the planet continues warming. The impacts to date, then, illustrate the benefits to be gained by governments meeting the goals they themselves set at the Paris summit, whose fifth anniversary we mark on Saturday 12th December.[7]

Flooding – Kerala, 2018

In August 2018, the Indian state of Kerala received an extended period of very heavy rainfall as a result of a low-pressure system near the beginning of the month being followed several days later by a monsoon depression. The resulting floods killed over 400 people and displaced a million more.

Scientific conclusion: Future global warming will exacerbate the impacts of flooding resulting from similar events, unless there's a 54% increase in dam capacity.

– Hunt & Menon, Climate Dynamics, 54, 2433–2446 (2020)

5 https://climateactiontracker.org/press/global-update-paris-agreement-turning-point/
6 https://public.wmo.int/en/media/press-release/carbon-dioxide-levels-continue-record-levels-despite-covid-19-lockdown
7 https://www.climateambitionsummit2020.org

Introduction

With the Paris climate summit of December 2015 in full swing, a team of scientists published a small piece of research that helped illustrate what the summit was all about. Storm Desmond had just put substantial areas of the UK under water, displacing villagers from their homes, knocking out electrical supplies and compromising healthcare facilities. And one of the factors behind its existence, the scientists calculated, was human-induced climate change, which had made the storm about 40% more likely to happen.[8]

At the time, it was still common to hear scientists and other people who follow the science saying that "you cannot attribute any extreme weather event to climate change" – even though it was already well-established by then that you absolutely could attribute a part of many extreme weather events to climate change. Since 2004, when Peter Stott of the UK Met Office showed that climate change had at least doubled the odds of the 2003 European heatwave,[9] scientists had been using a range of methods to probe both individual extreme events and patterns in how they were changing over time, in an attempt to detect a human fingerprint.

Extreme rainfall and flooding – Louisiana, 2016

Flooding devastated a large area of southern Louisiana resulting in 20 to 30 inches of rainfall over several days. More than 30,000 people were rescued from the floodwaters that damaged or destroyed over 50,000 homes, 100,000 vehicles and 20,000 businesses. It was the most damaging US flood event since Superstorm Sandy impacted Northeast regions in 2012.

Scientific conclusion: '...the regional probability of 3-day extreme precipitation has increased by more than a factor of 1.4 due to anthropogenic climate change'

– van de Wiel et al., Hydrology and Earth System Sciences, 21, 897-921 (2017)

Not all studies produced a 'positive' conclusion – showing that climate change did make the event in question more likely or more intense – but many did. This led the World Health Organization to forecast during the build-up to the Paris summit that climate change "will

8 https://www.theguardian.com/environment/2015/dec/11/storm-desmond-rainfall-flooding-partly-due-to-climate-change-scientists-conclude

9 https://www.nature.com/articles/nature03089

cause some 250,000 additional deaths per year by the 2030s", one of the main reasons being "more intense heatwaves and fires".[10] The NATO Parliamentary Assembly warned that "climate change-related risks will affect international security through increased natural disasters".[11] The Papal Encyclical Laudato Si also spoke of climate change bringing "an increase in extreme weather events".[12]

Heatwave – Northeast Asia, 2018

Throughout much of July 2018, a record-breaking heatwave affected large areas of Japan, the Korean peninsula and China. Many Japanese regions experienced temperatures in excess of 35°C, and Kumagaya recorded a temperature of 41.1 °C – the highest ever observed in the country.

Scientific conclusion: The heatwave was an unlikely event without human forcing; by 2050, these heatwave events will become 1-in-4-year events.

– Qian et al., Bull. Amer. Meteor. Soc., 101, S77-S82 (2020)

Extreme weather events such as hurricanes, floods and droughts occur naturally, and would continue to do so in the absence of climate change. The questions that the science of 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.

10 https://www.who.int/globalchange/mediacentre/events/cop21-key-messages/en/
11 https://www.actu-environnement.com/media/pdf/news-25462-resolution-otan-2015.pdf
12 http://www.vatican.va/content/francesco/en/encyclicals/documents/papa-francesco_20150524_enciclica-laudato-si.html

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.'

By the time of the Paris summit, scientific methods had improved so much that rapid turnaround studies could be performed and published within a week or so of the extreme weather event itself, as with the Storm Desmond study cited above. Often the event would be investigated more thoroughly some time later using more data, and the results formally published in peer-reviewed scientific journals.

And academics, business groups or public authorities would sometimes follow up with assessments of damages, couched in terms of deaths, disease, effect on food supply, consequences for nature or economic impact. Follow-up studies on Storm Desmond showed, for example, that the initial 40% figure was an under-estimate, and put the real figure at 60%[13] - while the economic damage from Desmond and the two following storms, Eva and Frank, has been estimated at £1.5bn ($2bn).[14]

Two years after the Paris summit, in December 2017, we published a short report entitled 'Heavy Weather', collating all the peer-reviewed scientific studies we could find that had been formally published in the intervening period.[15] We identified 59 papers in all, covering events such as heatwaves, drought, rainfall/flooding, storms, wildfires and cold/snow/ice. In 41 of them, scientists found that man-made climate change had made the particular event either more likely or more intense. We repeated the exercise the following year in 'Even Heavier Weather,' with very similar results.[16]

This December, nations are contemplating the first turn of the Paris Agreement's five-yearly 'ratchet mechanism' intended to strengthen their unilateral commitments on cutting carbon, preparing for climate impacts and providing finance to help the poorest to do both. We present a summary of what science has shown us in the intervening five years, and what evidence has been produced to demonstrate the harm these climate change-fuelled events are doing to people, nature and economies.

13 https://www.worldweatherattribution.org/uk-storm-desmond-revisited-december-2017/

14 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/672087/Estimating_the_economic_costs_of_the_winter_floods_2015_to_2016.pdf

15 https://eciu.net/analysis/reports/2017/heavy-weather

16 https://eciu.net/analysis/reports/2018/even-heavier-weather

Methodology and Findings

The method used in this study could not be simpler: we searched through relevant English-language scientific journals with the aim of finding all research papers published since the Paris summit on the attribution of extreme weather events to climate change. The fact that we do not include non-English language journals means that the numbers we find are certainly an underestimate of the total number of studies performed on this issue. And we have been conservative in other ways – for example, we did not include studies whose primary aim was to explore methods of attribution. We have however included a few studies finding a positive signal of climate change in marine heatwaves; though these fall outside a conventional definition of 'weather', they do carry a human impact, not least through their effect on fisheries.

Because it can take several years to move from extreme weather event to analysis to formal scientific publication, our list includes some events dating back to 2013 or so, while there are only a few from 2019 and none from 2020. We could have encompassed those by also including rapid-turnaround analyses that have not gone through peer review and formal scientific publication, but we chose not to do that in order to maintain the gold-standard of peer review associated with academic journals.

Heatwave – Europe, 2019

Western-central Europe experienced the most severe June–July heat on record in 2019, with several heatwaves occurring over the most densely populated regions. Highest 3-day averaged daily mean temperature in June–July averaged over the region exceeds normal by 4.7°C, which is estimated to be a 1-in-283-year event over the 1950–2014 climate.

Scientific conclusion: Anthropogenic forcing has caused a sevenfold increase in the likelihood of extreme heat over the 1950–2014 climate, and a 23-fold increase since the 1980s.

– Ma et al., Geophysical Research Letters, 47, e2020GL087809 (2020)

We then performed a search for estimates of the damages caused by the extreme events identified as bearing a positive fingerprint of man-made climate change, using both the

academic literature and a targeted search of media coverage using the Factiva database. Many such estimates come in the form of reports from governments or (for example) insurance companies, which will not be included in academic publications.

We found 145 academic papers – the majority focussing on one particular extreme weather event, a smaller number looking at a trend in, for example, heavy rainfall or drought events in a given region. Of these, 113 find that man-made climate change has increased the risk: 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. The increase in risk generated by climate change ranges from single-digit percentages to 330-fold.

A far smaller number of studies, 13, conclude there was no detectable association with man-made climate change, while 11 find an inverse relationship, with climate change decreasing the risk. The remaining eight are inconclusive.

In a few cases, multiple studies on the same specific event come to different conclusions. In most cases these studies use different ways to define the event in question. For example, one study might look at three days in Copenhagen during the 2018 heatwave, while another might probe the entire pan-continental heatwave for its entire duration; it is not necessarily a given therefore that all studies on the same event will reach the same conclusion. Sometimes studies are complementary in that one (for example) may look for a change in frequency, the other in severity.

Signal	Heatwave	Drought	Rainfall / Flooding	Storms	Wildfires	Cold, Snow, Ice	Total
Positive	42	20	29	9	8	5	113
Neutral		4	5	2	1	1	13
Negative		1	3	3		4	11
Not enough data		5	3				8
Total	**42**	**30**	**40**	**14**	**9**	**10**	**145**

The relationship to man-made climate change is unsurprisingly strongest for heatwaves, where all 42 studies show a positive link, and weakest for cold, snow and ice. But it holds across all types of extreme weather, and encompasses events affecting every continent and the global ocean that links them. Once again, a caveat is that those extreme weather events investigated by science are not representative of climate-driven extremes overall, given the bias towards researching those affecting developed nations.

Reports assessing the impacts of these extreme events are less comprehensive: for only 49 did we find estimates of their toll on health, infrastructure, nature, the economy, and so on. It

does not of course follow that the other weather extremes had no impact – merely that the impacts were not studied, or we did not find a record.

Forty-nine is obviously far too small a number of estimates from which to draw quantitative conclusions, and we do not attempt to do so, instead highlighting here a few of the most notable examples:

MORTALITY			
France	2015	Heatwave	3275 deaths
Peru	2017	Rain/flooding	100+ deaths
UK	2019	Heatwave	900 deaths

HEALTH & FOOD SUPPLY			
Western Australia	2016	Severe frost	Damaged nearly half WA's grain crop
East Africa	2017	Drought	21 million people food insecure
Northeast Asia	2018	Heatwave	Thousands hospitalised

ECONOMY			
Louisiana, US	2016	Rain/flooding	$10.4bn
Canada	2016	Wildfires	$6.9bn
Peru	2017	Rain/flooding	Cost of reconstruction more than $6bn

Conclusion

In the five years since the Paris Agreement, nearly four out of five scientific studies (78%) of extreme weather events find a positive fingerprint of climate change – 10 times the number that find a negative relationship. The idea that one "cannot link climate change to any particular extreme weather event" is definitively outdated.

The Paris Agreement specifically recognises the risks and indeed the cost of extreme weather events, with Article 8 stating:

"Parties recognise the importance of averting, minimising and addressing loss and damage associated with the adverse effects of climate change, including extreme weather events..."[17]

Since then, the Intergovernmental Panel on Climate Change has confirmed that the increase in damaging extreme events will be reduced if governments succeed in holding global warming to 1.5°C compared with levels expected at 2°C. "Limiting global warming to 1.5°C instead of 2°C could result in around 420 million fewer people being frequently exposed to extreme heatwaves, and about 65 million fewer people being exposed to exceptional heatwaves," it concludes.[18] The lower level of warming would also reduce the added risks from floods, wildfires and drought.

Despite the recent spate of net zero pledges from nations, states and regions, cities and companies, emissions are not yet heading for levels needed to keep global warming below 2°C, never mind the safer guardrail of 1.5°C. However, the United Nations Environment Programme confirmed this week that the 1.5°C target remains within reach.[19]

Whatever governments pledge over the year to COP26, science suggests that climate change will continue stoking the losses and damage caused by extreme weather, and so the costs of dealing with it. But, simply put, the further climate change runs, the greater the risks and the greater the damages.

On the eve of the Paris Agreement's fifth anniversary, this report serves to show that its objectives remain as relevant as ever – that science is unequivocally detecting the fingerprints of climate change on extreme weather of all kinds, in all parts of the world. In so doing, it serves to remind us of why the Agreement and indeed its parent UN climate change convention came into being – and the benefits humanity can expect by delivering on them.

17 https://unfccc.int/files/adaptation/groups_committees/loss_and_damage_executive_committee/application/pdf/ref_8_decision_xcp.21.pdf

18 https://www.ipcc.ch/sr15/chapter/chapter-3/

19 United Nations Environment Programme (2020). Emissions Gap Report 2020. Nairobi

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