ATTRIBUTION

Weather risks in a warming world

The global atmosphere is warming and human emissions are responsible. Now research shows that an increasing fraction of temperature and precipitation extremes are attributable to that warming.

Peter Stott

Last year was once again a year of extremes[1]. Flooding in Bangladesh, heatwaves in Australia, downpours in Kenya — all occurred during 2014, nominally the warmest on record (albeit by a small margin)[1]. Increasing temperatures, diminishing snow and ice, and rising sea levels contribute to unequivocal evidence for a warming world[2] and research is now starting to examine whether increased greenhouse-gas concentrations and other anthropogenic factors have favoured the occurrence of some specific extreme events[3]. But given that unusual heat and heavy rainstorms were causing mayhem long before the rise of industrial emissions, what is the evidence that climate change has altered the expected occurrence of such extremes worldwide? Writing in *Nature Climate Change*, Erich Fischer and Reto Knutti examine this question[4]. They find that about 18% of moderate daily precipitation extremes, and about 75% of moderate daily hot extremes, that are currently occurring over land are attributable to warming.

As each year goes by, evidence continues to accumulate that our climate is changing[5]and that human influence plays a dominant role in observed warming[2]. The prevalence of extremely hot temperatures is expected to increase with warming and more moisture in the atmosphere leads to a tendency towards more extreme rainfall events, changes that have been detected in the observational record[6,7]. But what has been lacking up to now is a robust calculation of how much more likely extreme temperatures and rainfall have become worldwide.

The extent to which climate change might have changed the odds of extreme events — such as heatwaves, flood and droughts — has been investigated for a number of specific examples using the concept of fraction of attributable risk (FAR, ref. 8). Given the potentially large natural variations in climate, it is hard to envisage most extreme events being impossible in a world that hadn't seen any human-induced climate change. But anthropogenic climate change can significantly increase, or decrease, the chances of certain types of extreme weather event, loading the dice in favour of the European heatwave of 2003[9] and the flooding seen in the UK in Autumn 2000[10].This change in odds can be expressed as a FAR — the fraction of events attributable to human influence — or as a probability ratio (the ratio of current probability to what it would have been without human influence). Studies of events using such concepts are now being extended to others parts of the world in a series of annual reports examining extremes of the year before[3]. The analyses are by their nature ad-hoc, dependent on the capacity of scientific groups to analyse particular events, and their interest in doing so.

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Rickshaw drivers in Dhaka, Bangladesh carry passengers through flood waters after a heavy downpour in June 2014.

Fischer and Knutti[4] apply a similar framework to the globe as a whole. They analyse daily temperatures and daily rainfall totals from climate models and a range of thresholds including those expected to occur once in 1,000 days (about once every 3 years) in an unperturbed climate — referred to as moderate daily extremes. Such an analysis is only possible thanks to a remarkable international coordinated effort from climate modelling groups, the Coupled Model Intercomparison Project Phase 5 (CMIP5; ref. 11). Fischer and Knutti have mined the resultant database of simulations of both climate variability and change to construct their estimates of global FAR. The results are striking.

Today, Fischer and Knutti find, ~75% of the moderate daily hot extremes over land are attributable to warming. This might seem a surprisingly high fraction but is consistent with our understanding of how an upward shift of the temperature distribution rapidly increases the chances of temperatures in the upper tail of the undisturbed distribution. The fraction of moderate daily precipitation extremes is smaller, but at 18% nevertheless shows an appreciable effect that is important to account for in a global risk assessment. Looking into the future, this fraction is forecast to rise to about 40% when warming reaches 2 °C relative to pre-industrial temperatures. The idea that in a two-degree world almost half of heavy rainfall events would not have occurred were it not for climate change is a sobering thought for policymakers seeking to mitigate and adapt to climate change.

The study of Fischer and Knutti[4] does not directly address the attribution question asked by individuals facing the brunt of a specific damaging storm or heatwave. While the authors do provide maps of how probabilities of extreme temperatures and precipitation have changed across the globe, the framework they use means that such probabilities cannot be applied to specific individual extreme weather events. The effects of natural and human-induced climate change can vary from place to place and from year to year, increasing or decreasing the FAR relative to the averaged global numbers calculated in this study[4]. Further work is therefore needed to refine regional estimates and to unpick the effects of anthropogenic influences on climate from natural influences, such as changes in solar output and internal variations in the climate system (the El Niño/Southern Oscillation, for example). But one strength of their approach is that global aggregation of data potentially allows for a more robust estimate of the effects of warming on extreme events overall, which may be less affected by modelling uncertainties than some of the studies applied to individual events.

Global risk assessments are needed to inform mitigation and adaptation decisions. Risk does not just arise from hazard, the meteorological extremes that Fischer and Knutti[4] examine, it also comes from the degree of exposure to that hazard and the vulnerability of citizens and societies. Maps showing the probability of exceeding extreme meteorological thresholds can be combined with maps of vulnerability and exposure to examine where climate risks are greatest. Fischer and Knutti point to the tropics and many island states where internal variability is relatively low[12] and vulnerability can be high. Such work highlights a greater point about climate change research. While human influence on the climate system is clear, much more work is needed across interdisciplinary boundaries to understand how people of the world will be affected, and how best to avoid the worst outcomes. ❒

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CLIMATE POLITICS

Designing energy policy under uncertainty

Countries need to cut greenhouse-gas emissions from the energy sector if the world is to avoid the worst impacts of climate change. But no one is sure of the best path. New research highlights the key uncertainties driving energy policy debate in the UK.

Catherine Mitchell

Policymakers are divided over how best to decarbonize the global energy system. Many studies focus on what we know about current technologies' ability to meet emissions reduction targets. But understanding the impact of future uncertainties around governance, business models, economics, and public attitudes is equally important.

Such uncertainties perpetuate debates about the best policies to transform countries' energy systems. In an article in *Energy Policy,* Jim Watson and colleagues[1] suggest that more time and better data is unlikely to resolve these conflicts, and that decisions must inevitably be based on imperfect knowledge.

They map 14 significant sources of uncertainty, and set out potential actions to mitigate such conditions. In doing so, they give a good impression of the complexity decision-makers face when designing energy policy.

A major debate in the UK's parliament prior to the last election was whether the Conservative-led government would loosen the country's mid-term emissions reduction target, known as the fourth carbon budget. Watson and colleagues carry out an assessment of the feasibility of the budget (covering the years 2023 to 2027), and the implications that sticking to it could have for policymakers and other stakeholders.

Eight instrumental factors that introduce uncertainty into decision-making are highlighted: the availability of finance for low-carbon power generation, commercialization of low-carbon power generation technologies, diversity of heat decarbonization pathways, heat pump performance, district heating investment and business models, energy efficiency improvements and demand reduction, diversity of transport decarbonization pathways, and adoption of electric vehicles. They also identify six systemic uncertainties: fossil fuel availability and price, bioenergy availability and price, material scarcity, ecosystem service impacts, public attitudes to energy system change, and political commitment to a low-carbon transition.

They point out the unexpectedness of change, showing that actual developments often lie outside the range of imagined futures. So, how helpful is this in terms of meeting the fourth carbon budget?

Decision-makers need to understand the complexities of available climate and energy policy choices. The main contribution of Watson and colleagues is to identify a useful framework to assess this.

They set out some basic rules for making decisions in a time of uncertainty: policymakers need to set about 'opening up' the process to get the public involved and connected, need flexibility and diversity of options within energy policy, need to learn from best practice, and need to set about ensuring their country, region or locality uses as little energy as possible.

But while they give a good overview of energy policy uncertainties and what the most rational processes are to deal with this situation, they do not reference cases where rapid change has already occurred. If they had done this, they might have concluded that some decision-making