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The Impact of Climate Change: International Evidence and Experience

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The world is warming

Scientists agree that the world's climate is warming. The UN body charged with assessing the state of the climate, the Intergovernmental Panel on Climate Change (IPCC), concluded in its most recent report that “warming of the climate system is unequivocal” (IPCC, 2013). This conclusion is based on a wealth of observational data showing that the atmosphere and oceans are warming, that snow and ice are melting and that sea level is rising. These changes are associated with rising concentrations of greenhouse gases in the atmosphere which have now reached over 400 parts per million in the atmosphere, the highest values in over 800,000 years and which compare to values of about 280 parts per million in pre-industrial times following the end of the last ice age. Carbon dioxide is a greenhouse gas and these additional concentrations resulting from human activities are adding to the natural greenhouse effect, thereby warming the climate. Global temperatures are now about one degree Celsius warmer than they were in pre-industrial times.

The climate is the average weather you can expect over a period of time, often calculated as the thirty-year averages of variables such as temperature or rainfall in a particular place at a particular time of year or during a particular season. Therefore, the average temperatures in Ireland in summer over a period of thirty years would be one measure of the summer climate in Ireland. Of course you do not expect every summer to be the same; some will be warmer and sunnier, others cooler and wetter, thanks to the variability of weather. There is a further important point to bear in mind when we think about weather and climate. No longer is climate generally stable, like it was for many generations before ours. Now that the effects of increasing greenhouse gases in the atmosphere have started to take hold, climate is changing at a rapid rate compared to the natural variations of climate seen before.

Extreme weather

With a changing climate comes a change in the risk of extreme weather. The most recent IPCC assessment concluded that “changes in many extreme weather and climate events have been observed since about 1950” and that “it is likely that the frequency of heat waves has increased in large parts of Europe, Asia and Australia.” The IPCC has also made a careful assessment of the extent to which climate changes can be blamed on human activities. The assessment, based on thousands of peer-reviewed studies by scientists from all around the world, examines whether natural causes, such as changing output from the sun or interactions between the ocean and atmosphere, could have caused the observed warming. It concludes that “human influence on the climate system is clear”. The observed patterns of climate change simply do not agree with the changes expected from natural causes but they do agree with those expected from human activities. As the IPCC concluded, "it is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century.” (IPCC, 2013)

With a warming climate comes a clear expectation of more heat waves and more heavy rainfall events which can lead to flooding. This is because a rise in mean temperatures dramatically increases the chances of what would have been very rare extreme temperatures in a pre-industrial temperature. This is illustrated by the schematic seen in Figure 1. Even with only a small shift in average temperatures (seen as the distribution changes from that shown by the dotted line to that shown by the solid line) the chances of very hot temperatures (the areas under the red shaded parts of the curves) increases substantially. Research has shown that about 75% of daily temperature extremes occurring over land are attributable to human-induced warming (Fischer and Knutti, 2015).

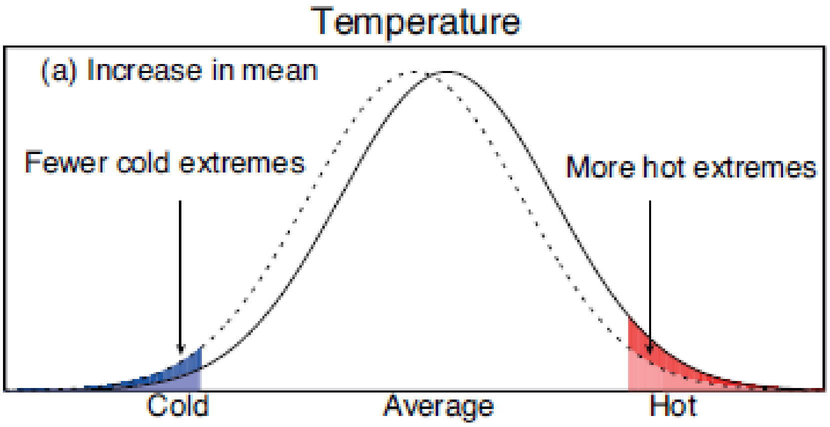

Figure 1: Schematic representation of the probability of daily temperature. The dashed line represents a previous distribution and the solid line a changed distribution. The probability of occurrence, or frequency, of extremes is denoted by the shaded areas. For temperature, changes in the frequencies of extremes are affected by changes in the mean.
(*Source: IPCC AR5 WGI, CH1, Fig 1.8*)

A warmer atmosphere contains more moisture as a result of greater evaporation from the oceans. This increase, which amounts to about 6 to 7% per degree of warming, means that there is more moisture to fuel storms when they form. This adds to their energy making them more powerful and increases the chances that such storms will lead to exceptionally heavy rainfall. Research has shown that about 18% of daily precipitation extremes occurring over land are attributable to human-induced warming. In future, if warming reaches two degrees relative to pre-industrial temperatures, about 40% of the precipitation extremes occurring then could be attributable to human-induced warming (Fischer and Knutti, 2015). The idea that in a world that is only one degree warmer than now almost half of heavy rainfall events would not have occurred were it not for climate change is a sobering thought (Stott, 2015)

However, these findings do not mean that all extreme weather can be attributed to human-induced climate change. Unusual extremes have always happened in our variable climate. It can be all too easy to put the entire blame of catastrophic weather-related disasters onto human-caused climate change but such misattribution can easily lead to bad policymaking around how to adapt to climate change. That is why the science of climate change attribution is now being applied to single events, such as the extremely hot summers in Europe in 2003 and Australia in 2013, and the flooding seen in recent winters in North Western Europe including in 2014 and 2016. The aim of these studies is to calculate how global warming has affected the intensity or likelihood of such events.

To do this, we need to compare what actually happened with what might have happened in a world without man-made climate change. The only way to do this is to use a climate model to simulate the conditions we could have experienced in the absence of human-induced climate change. We can then compare the results of climate model simulations with and without human influence on climate to see how the odds of particular events such as heatwaves, floods and droughts have changed. How this is done is shown schematically in Fig 2 (taken from Stott, 2016). First scientists compare changes in observed temperatures to modelled temperatures with human influence on climate (caused largely by greenhouse gas emissions; red line) or without any human influence (only natural factors such as volcanic eruptions and variations in the sun's energy, blue line). Our current climate (the red spread of temperatures shown in the right hand side of Fig 2) can then be compared with the climate we would have had without human-induced climate change (blue spread of temperatures). It is then possible to calculate the chances of having the observed temperatures (black line and star in the right hand side of Fig 2) in these two climates. In the schematic case shown in figure 2 the chances of experiencing the extreme temperatures shown have increased substantially.

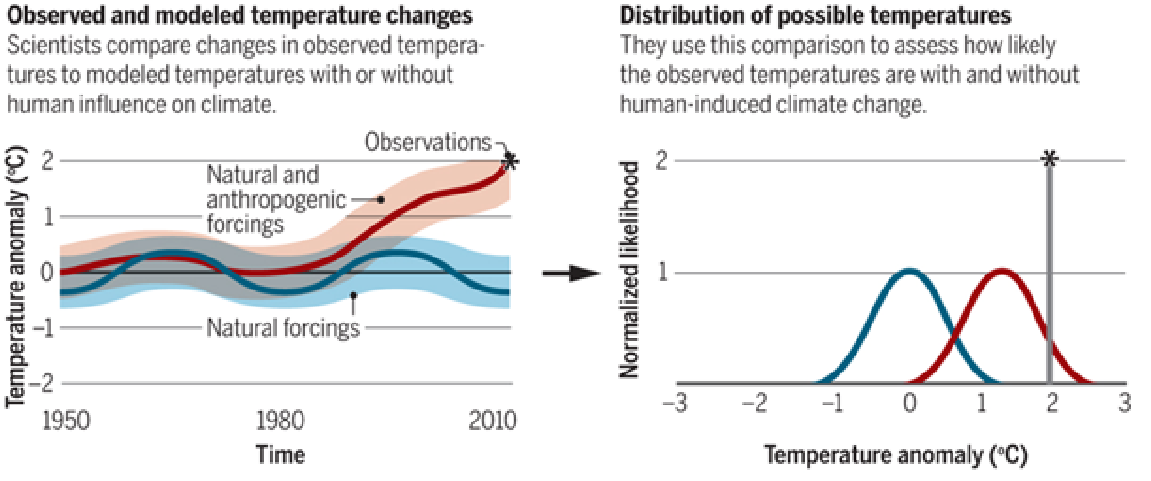

Figure 2: Schematic of the methodology applied in attribution studies.
(Source: Stott, 2016)

This approach has now been adopted by a large number of scientists to investigate extreme climate events around the world. Some studies employ large numbers of climate computer model simulations (ensembles) generated by people making climate models runs on their own home computers (e.g. Pall et al., 2011). Some studies also investigate the role of natural variability in addition to human induced climate change. For example some studies impose the sea surface temperature conditions representative of an El Nino state as we saw in 2015 (a natural variation of conditions in the Pacific Ocean that see the trade winds slacken and ocean temperatures rise in the Eastern Pacific). In this way, it is possible to compare the risk of extreme weather conditions when there is an El Nino compared to when there isn't.

In response to the high demand for attribution information by policy makers, the science of event attribution has developed rapidly in recent years with many research groups around the world publishing peer-reviewed studies. The US National Academy of Sciences recently assessed this new science (NAS, 2016) and concluded that "it is now often possible to make and defend quantitative statements about the extent to which human-induced climate change (or another causal factor such as a specific mode of variability) has influenced either the magnitude or the probability of occurrence of specific types of event".

The journal Bulletin of the American Meteorological Society (BAMS) publishes a well-respected special annual supplement called [Explaining Extreme Events from A Climate Perspective]**.** Each of these special supplements demonstrates an increasing number of analyses that quantitatively assess the effect of possible factors like human influence on the climate to extreme climate events that occurred during the previous year over the globe. Human-induced climate change has increased the intensity or likelihood of almost all the heat-related events examined, and has affected many other events including heavy rainfall, tropical cyclones and forest fires.

Investigations are also continuing in developing an operational attribution service that would provide regular updates on extreme events and their links to climate change. The

UK Met Office is developing such a system (Christidis et al., 2013) in a European project in collaboration with Met Éireann and other European collaborators.

Heatwaves

The first study to link a specific extreme weather event to human-induced climate change analysed the 2003 European heatwave whose record-breaking temperatures had severe impacts in central and Mediterranean Europe, resulting in the heat-related human death toll running into tens of thousands (Stott et al, 2004). The study concluded that 'Human influence has very likely at least doubled the risk of European summer temperatures as hot as 2003'. This study was updated ten years on (Christidis et al 2015) during which time European average summer temperatures had risen substantially. The new study found that the chances in a particular year of breaking the pre-2003 record for European temperatures had increased from about one in fifty then to about one in five now. Under different scenarios of future greenhouse gas (GHG) emissions nearly all computer model simulations suggest that by 2040 a European summer as hot as 2003 will have become very common.

Figure 3 (left hand panel) shows how much warmer temperatures were in 2003 compared to other years. The right hand panel of Figure 3 shows how observed European temperatures have changed year by year and how they have warmed substantially since 1900 (black line) and how these compare with climate model simulations. The observations now lie well outside the range expected from natural climate variability (green spread) but are consistent with climate model predictions of how warming in Europe is rapidly leading to a much higher chance of extreme temperatures (red spread).

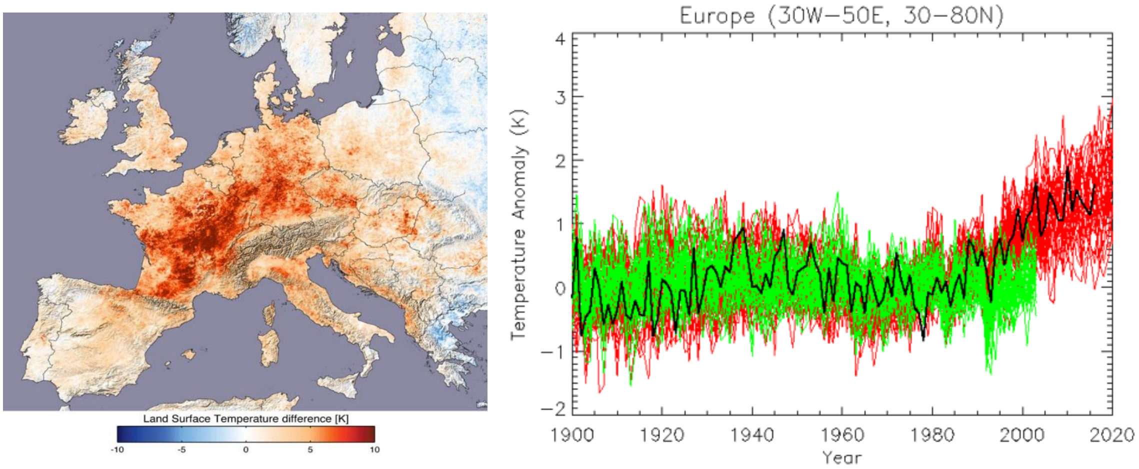

Figure 3: Map showing the average land surface temperature anomalies (degrees centigrade) for the period June July August 2003. Plot shows a time series of the summer mean temperature anomaly relative to 1961-1990 for Europe. The black line shows actual observed temperature, shaded areas show the range of temperature anomalies from seven climate models with (red) and without (green) man made emissions. *(Source: Christidis et al 2015)*

Heavy rainfall and flooding

The British and Irish Isles experienced a winter of exceptionally wet and stormy weather during the winter of 2013/14. The persistent storms and heavy rainfall through the season resulted in this being the wettest winter for the UK in a series from 1910. It was also the wettest winter in the long running England and Wales Precipitation series from

1766 (Met Office review of the 2013-2014 UK winter storms). In Ireland many places saw an exceptionally wet winter, including the observatory at Cloone Lake, Co Kerry which recorded its wettest winter since it opened in 1949 and the Valentia Observatory which recorded its wettest winter since 1866/1867 (MET Eireann Winter Review 2013/2014). Research has been undertaken into this winter which shows both human-induced climate change and natural climate variability played a role in raising the risk of heavy rainfall. The unusually stormy weather patterns played a large part. Figure 4 (left hand panel) compares climate model simulations with the same weather patterns (red bars) and different weather patterns (green bars). It shows that the unusual weather patterns (which are largely natural in occurrence) increased the chances of exceptionally heavy rainfall by about a factor 8. On top of this there is a human factor. Figure 4 (right hand panel) compares climate model simulations under such stormy conditions today (red bars) with that expected without climate change (blue bars). In such stormy weather conditions, human-induced climate change has increased the chances of the exceptionally heavy rainfall observed by about a factor 7. The conclusion from this work is that we can blame the unusual storminess on natural weather processes, though when the storms occurred, their impacts in terms of heavy rainfall and flooding were worse due to climate change (Christidis and Stott, 2015).

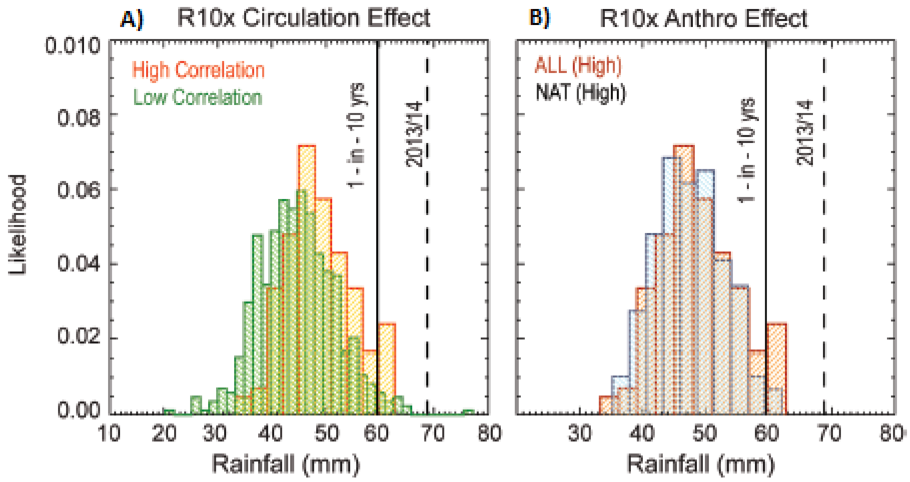

Figure 4: The impact of the 2013/14 winter circulation pattern and manmade GHG emissions on December/January/February (DJF) rainfall. The left hand plot illustrates the rainfall distributions for DJF and stormy weather patterns in the near-present-day climate based on simulated winters with high (orange) and low (green) correlations with flow pattern experienced in the 2013/14 winter. The right hand plot shows the same distributions but for high-correlation cases only from model experiments with (red) and without (blue) manmade GHG emissions. *(Source: Christidis and Stott, 2015)*

As well as heavier rainfall associated with winter storms there is also emerging evidence that climate change is increasing the risk from flash flooding in the summer months. Again this is associated with the increased atmospheric moisture in the warmer atmosphere available to feed storms. Studies have indentified an increase in the risk of extreme convective rainfall seen in the UK (Otto et al, 2015) and China (Burke et al, 2016) and have identified an increase in the magnitude of heavy rainfall impacting New Zealand during summer 2011/2012 (Dean et al, 2013). Because of the challenges of modelling very localised intense rainfall, and the large natural spatial and temporal variations in heavy summer rainfall there is still some remaining scientific uncertainty as to the extent to which human-induced climate change has affected recent heavy summer rainfall events. (National Academies of Sciences, Engineering and

Medicine, 2016). These findings are consistent with the assessment of the IPCC Fifth Assessment Report that “there is medium confidence that anthropogenic forcing has contributed to a global-scale intensification of heavy precipitation” (IPCC, 2013).

Future Impacts of climate change

There is a wealth of scientific evidence showing that limiting the rise in global average surface temperature will help avoid some of the most dangerous impacts of climate change – including limiting flooding from sea level rise, impacts on human health, loss of biodiversity, and many other factors. At the December 2015 United Nations Framework Convention on Climate Change (UNFCCC) Conference of Parties (COP) meeting in Paris in December 2015 the world’s governments signed an historic agreement with the aim to ‘limit global temperature increase to well below 2^{0}C with efforts to limit to 1.5^{0}C’. However even if such aims are achieved countries will still need to adapt to some adverse effects as the world warms.

Figure 5 shows some selected global climate impacts in 2100 under three future scenarios of climate change. It clearly shows that taking action to mitigate climate change through reducing GHG emissions will significantly limit the severity of key impacts on people and society. This includes the number of people exposed to heatwaves, the decline in croplands, the number of people affected by flooding and the numbers of people exposed to increased water stress.

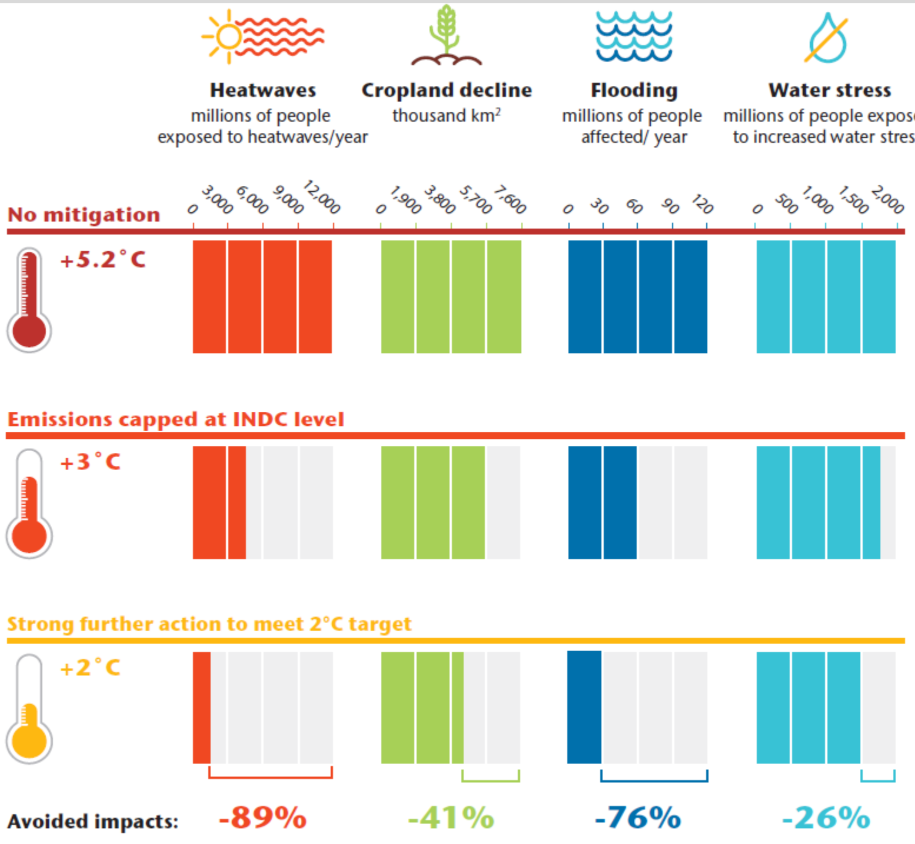

Figure 5: Avoiding the impacts of dangerous climate change *(Source: AVOID2 infographic [mapping the impacts of climate change](), December 2015)*

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AVOID2 infographic mapping the impacts of climate change, December 2015

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