

The science of attributing extreme weather events and its potential contribution to assessing loss and damage associated with climate change impacts

Environmental Change Institute



Friederike Otto, Rachel James, and Myles Allen (friederike.otto@ouce.ox.ac.uk)

Environmental Change Institute, School of Geography and the Environment, University of Oxford

www.eci.ox.ac.uk

The Warsaw international mechanism on loss and damage associated with climate change impacts has been established to address the adverse effects of climate change [1]. There is, however, still no clear scientific picture about what the effects of anthropogenic climate change are on a regional or local level. One of the functions of the Warsaw mechanism is to “enhance knowledge and understanding of comprehensive risk management approaches to address loss and damage associated with the adverse effects of climate change” [1]. The importance of “assessing the risk of loss and damage associated with the adverse effects of climate change” [2] has also been recognised.

In order to make a scientific association between anthropogenic climate change and loss and damage, it is necessary to investigate: (a) the link between greenhouse gas (GHG) emissions and meteorological change, and (b) the link between meteorological change and societal impacts. The existing discussion of risk assessment to support the loss and damage agenda [3,4] has focused on (b). This document is intended to outline a body of research, known as Probabilistic Event Attribution (PEA), which deals with (a), examining to what extent extreme weather events can be associated with past anthropogenic emissions. In many countries databases are being built to account for losses from weather events [3]. PEA could be used to augment this information with inventories of which losses can be specifically associated with anthropogenic climate change.

PEA is an emerging science with many uncertainties and it is thus important to give an overview of the key concepts, recent advances, and future developments. These will be presented here, alongside an initial discussion of the potential relevance of the science for the Warsaw mechanism. The aim is to provide a starting point for dialogue between scientists and parties to the UNFCCC about what the science can offer, and how it might contribute to the policy process.

The Science of Attributing Extreme Events

Warming of the climate system is unequivocal, predominantly due to anthropogenic GHG emissions [5], but the implications for regional climates are less clear. Some slow-onset events such as sea level rise are direct consequences of large-scale warming and can therefore be linked directly to past emissions. In many regions, however, extreme weather events, like heatwaves, floods, and droughts, are associated with greater loss and damage.

An increase in average temperatures will lead to an increase in the frequency or magnitude of some extreme events [6]. However, the chaotic nature of weather means that it is generally impossible to say, for any specific event, that it would not have occurred in the absence of human influence on climate. In a simple analogy, a dice may be loaded to come up six, but a six could have come up anyway without the loading.

Many people therefore think that it is impossible to attribute extreme weather events to past GHG emissions, even in principle.

The emerging science of Probabilistic Event Attribution (PEA) [7], however, increasingly allows a quantitative assessment of the extent to which human-induced climate change is affecting local weather events [8-11]. This assessment focuses on “attributable risk”: quantifying whether and how much past emissions have contributed to the probability of an extreme event occurring: how have we loaded the weather dice?



Assessments of attributable risk are based on large numbers of climate model experiments, called “ensembles”. Large ensembles are needed to assess the frequency of extreme events (which are, by definition, rare) and how this frequency may be changing. PEA studies compare how often a particular extreme weather event occurs in model experiments representing the “world as it is” (with human influence on climate) with how often the same type of event occurs in experiments representing the “world that might have been” (with the estimated impact of human influence on climate removed, allowing for uncertainty in this impact).

Probabilistic Event Attribution in practice

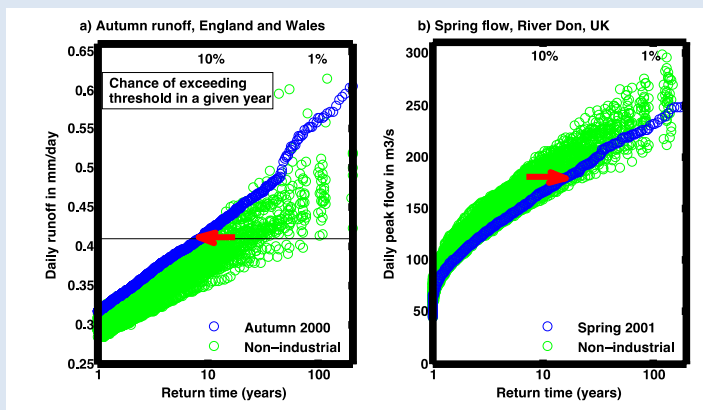


Figure 1 adapted from Figure 10.18 IPCC AR5 WG1 chapter 10.6 [5]. Return times of run-off (an indication of flooding) for simulations of the “world as it is” (blue) compared to the “world that might have been” without anthropogenic GHG emissions (green). Panel (a) is for Autumn 2000 in England and Wales [10] with the black line showing the threshold exceeded in observations and panel (b) is for a different season and catchment [12].

Figure 1 shows results from two recent PEA studies. The data is presented in so-called “return time plots”, used to illustrate small changes

in the probability of rare events. Here river runoff is shown, as a measure of flooding. The magnitude of runoff is shown in the vertical direction, and the frequency of exceeding any given runoff threshold is indicated in the horizontal direction. Each dot on the graph is a model simulation of “possible weather” under the given climate conditions. The blue dots are the “world as it is” under observed conditions, while the green dots represent the “world that might have been” in a climate without the impact of past anthropogenic GHG emissions.

Plot (a) shows that, in this study, in the current climate (the blue dots), the chance of exceeding the critical runoff threshold observed in 2000 of 0.42 mm/day is one-in-ten in any given year. In the “world that might have been”, with various estimates of the impact of pre-2000 GHG emissions removed, it would have been more like one-in-twenty. So, on average, GHG emissions increased the risk of this kind of autumn flood by around a factor of two (the red arrow points to the left), but with a large range of uncertainty.

Plot (b) shows that not all damaging extreme weather events are being made more frequent by human influence on climate. This looks at a spring-time flood triggered by rapid melting of accumulated snow. This kind of event has been made less frequent by past GHG emissions (the red arrow points to the right).

The science of PEA is relatively new, the first studies having been conducted only ten years ago [8], but the field is growing rapidly. Since 2012, an annual report has been published in the Bulletin of the American Meteorological Society to establish the role of anthropogenic emissions on events from the previous year [13,14], and many of the most widely-reported recent events have been investigated, including the 2010 Russian heatwave and 2011 East African drought [11,15]. There are now efforts to develop operational attribution systems.

There are many uncertainties in attribution studies. Particular challenges are the availability of long-term meteorological observations and the reliability of climate model simulations of the climate conditions generating an extreme weather event. Uncertainties are present in all PEA studies, but there is generally higher confidence in studies focusing on heatwaves [8] than those focussing on extreme precipitation [10,15,16]. Investigation of hurricanes and typhoons is currently limited by the ability of global climate models to simulate these events.

There is also variation between regions in the ability to attribute events, due to differences in regional climates, availability of observational data, and modelling capability. The majority of PEA studies to date have focused on events in mid-latitudes [8,10,11], but there is increasing interest in event attribution for tropical regions [15,17]. Promising approaches are being explored to conduct robust attribution studies in parts of the world with sparse observational data [18]. However, in some regions PEA studies have been inconclusive due to model weaknesses [19].

Another important scientific development that is directly relevant to the Warsaw mechanism is extending PEA from hydro-meteorological events (e.g. heatwaves, floods, droughts) to their socio-economic impacts (e.g. crop failure). Attribution studies [20] are currently exploring the use of impact-relevant combinations of climate variables [21,22]. Quantified assessment of the socioeconomic loss and damage due to extreme weather events attributable to human influence on climate is possible in principle, but uncertainties increase due to confounding factors in the impacts of extreme weather events.



Autumn 2000 flooding in England and Wales: model results indicate that twentieth century anthropogenic GHG emissions increased the risk of floods of this magnitude by about a factor of two. [10].



Pakistan floods 2010: a model evaluation study suggests that the model in question cannot provide reliable results for this event. This does not preclude further research but highlights that assessment is more difficult for some events than others. [19]

Potential contributions of attribution science to the implementation of the Warsaw mechanism

If the implementation of the Warsaw international mechanism requires evidence to link loss and damage to anthropogenic climate change, there is potential for scientific research to deliver relevant information. However, there are many uncertainties associated with attribution studies, and these are generally larger for extreme events than for slow-onset events, larger for some extreme events than others, and larger for some regions than others. Intensive research is currently underway to address the scientific challenges outlined above, but some uncertainties will remain, and the concern has been raised that robust assessments may be biased towards countries whose history or meteorological conditions happen to make attribution questions more tractable [23].

The Warsaw international mechanism will, under paragraph 7(c) “convene meetings of relevant experts and stakeholders” [1], and this provides a good opportunity for dialogue about what the science can offer, and in what context the implementation of the mechanism should rely on scientific evidence. If attribution studies are thought to be useful, the mechanism could also “promote the development of...information” (paragraph 7(d), [1]) by discussing the most helpful way to conduct the science. There is more than one scientifically valid way to frame attribution questions [17], and this is an opportune time for the policy community to establish broad principles about how they would like these questions of attribution to be addressed.

- 1 UNFCCC. 2013 Decision 2/CP.19: Warsaw international mechanism for loss and damage associated with climate change impacts. (<http://unfccc.int/resource/docs/2013/cop19/eng/10a01.pdf#page=6>).
- 2 UNFCCC. 2014 Briefing note: Initial meeting of the Executive Committee of the Warsaw international mechanism for loss and damage associated with climate change impacts. (http://unfccc.int/files/adaptation/application/pdf/excom_briefing_note_13_mar.pdf).
- 3 UNFCCC. 2012 Report on the expert meeting on assessing the risk of loss and damage associated with the adverse effects of climate change. (<http://unfccc.int/resource/docs/2012/sbi/eng/inf03.pdf>).
- 4 UNFCCC. 2012 Technical paper: Current knowledge on relevant methodologies and data requirements as well as lessons learned and gaps identified at different levels, in assessing the risk of loss and damage associated with the adverse effects of climate change . (<http://unfccc.int/resource/docs/2012/tp/01.pdf>).
- 5 Stocker et al. (2013) The IPCC Fifth Assessment Report: The Physical Science Basis. Available at: ipcc.ch.
- 6 Liu C, Allan RP. 2013 Observed and simulated precipitation responses in wet and dry regions 1850–2100. *Environmental Research Letters* **8**:034002.
- 7 Allen M. 2003 Liability for climate change. *Nature* **421**:891-2 (DOI:10.1038/421891a).
- 8 Stott PA, Stone DA, Allen MR. 2004 Human contribution to the European heatwave of 2003. *Nature* **432** (DOI:10.1029/2001JB001029).
- 9 Stone DA, Allen MR. 2005 The End-to-End Attribution Problem: From Emissions to Impacts. *Clim Change* **71**:303-318 (DOI:10.1007/s10584-005-6778-2).
- 10 Pall P, Aina T, Stone DA, Stott PA, Nozawa T, Hilberts AGJ, et al. 2011 Anthropogenic greenhouse gas contribution to flood risk in England and Wales in autumn 2000. *Nature* **470**:382-385 (DOI:10.1038/nature09762).
- 11 Otto FEL, Massey N, van Oldenborgh GJ, Jones RG, Allen MR. 2012 Reconciling two approaches to attribution of the 2010 Russian heat wave. *Geophys Res Lett* **39**:1-5 (DOI:10.1029/2011GL050422).
- 12 Kay A, Crooks S, Pall P, Stone D. 2011 Attribution of Autumn/Winter 2000 flood risk in England to anthropogenic climate change: A catchment-based study. *Journal of Hydrology* **406**:97-112.
- 13 Peterson TC. 2012 Explaining Extreme Events of 2011 from a Climate Perspective. *BAMS* :1041-1067 (DOI:10.1175/Bams-D-12-00021.1).
- 14 Peterson TC, Hoerling MP, Stott PA, Herring S. 2013 Explaining extreme events of 2012 from a climate perspective. *BAMS* **94**.
- 15 Lott FC, Christidis N, Stott Pa. 2013 Can the 2011 East African drought be attributed to human-induced climate change? *Geophys Res Lett* **40**:1177-1181 (DOI:10.1002/grl.50235).
- 16 Sparrow S, Huntingford C, Massey N, Allen M. 2013 The use of very large atmospheric model ensembles to assess potential anthropogenic influence on the UK summer 2012 high rainfall totals. In: Peterson TC, Hoerling MP, Stott PA, Herring S, (eds). *Explaining Extreme Events of 2012 from a Climate Perspective* 94 (9): BAMS. p.S36-S38.
- 17 Otto FEL, Boyd E, Cornforth RJ, James R, Parker HR, Allen MR. 2014 Attribution of extreme weather events in Africa: A preliminary exploration of the science and policy implications. *submitted to: Global Environmental Change* .
- 18 Otto FEL, Jones RG, Halladay K, Allen MR. 2013 Attribution of changes in precipitation patterns in African rainforests. *Philosophical Transactions of the Royal Society B* :1-16.
- 19 Christidis N, Stott Pa, Scaife Aa, Arribas A, Jones GS, Copsey D, et al. 2013 A New HadGEM3-A-Based System for Attribution of Weather- and Climate-Related Extreme Events. *J Clim* **26**:2756-2783 (DOI:10.1175/JCLI-D-12-00169.1).
- 20 Sippel S, Otto FEL. 2014 Attribution of changes in the risk of extreme events in South-East Europe using impact-relevant climatic variables. *submitted to: Climatic Change* .
- 21 Beniston M. 2009 Trends in joint quantiles of temperature and precipitation in Europe since 1901 and projected for 2100. *Geophys Res Lett* **36**.
- 22 Fischer E, Knutti R. 2012 Robust projections of combined humidity and temperature extremes. *Nature Climate Change* **3**:126-130.
- 23 Hulme, M, O'Neill, SJ, Dessai, S. 2011 Is weather event attribution necessary for adaptation funding? *Science*, **334**:764-765