

Challenges to Understanding Extreme Weather Changes in Lower Income Countries

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ABSTRACT: The science of event attribution has emerged to routinely answer the question whether and to what extent human-induced climate change altered the likelihood and intensity of recently observed extreme weather events. In Europe a pilot program to operationalize the method started in November 2019, highlighting the demand for timely information on the role of climate change when it is needed most: in the direct aftermath of an extreme event. Independent of whether studies are provided operationally or as academic studies, the necessity of good observational data and well-verified climate models imply most attributions are currently made for highly developed countries only. Current attribution assessments therefore provide very little information about those events and regions where the largest damages and socio-economic losses are incurred. Arguably, these larger damages signify a much greater need for information on how the likelihood and intensity of such high-impact events have been changing and are likely to change in a warmer world. In short, why do we not focus event attribution research efforts on the whole world, and particularly events in the developing world? The reasons are not just societal and political but also scientific. We simply cannot attribute these events in the same probabilistic framework employed in most studies today. We outline six focus areas to lessen these barriers, but we will not overcome them in the near future.

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The science of event attribution has evolved from a new method very sparsely applied in single model studies (Stott et al. 2004; Pall et al. 2011) to a branch of science that regularly applies multimethod and multimodel approaches (Herring et al. 2018; Philip et al. 2018; van Oldenborgh et al. 2018) to answer the question of whether and to what extent human-induced climate change altered the likelihood and intensity of extreme weather events to occur. The framework of event attribution has been developed and applied primarily for meteorological events with few exceptions (Schaller et al. 2016; Mitchell et al. 2016). A European pilot program to operationalize the method started in November 2019, whereby national Met Services plan to implement event attribution into their operational systems (Schiermeier 2018). This development highlights the demand for timely information on the role of climate change in the occurrence of extreme weather events but also increases that demand through the information being available. Through media, in particular, raising awareness of the potential of attribution, this will also increase demand in areas where attribution is currently unavailable, rendering it even more important to invest in research now.

Both operational services and timely developed academic assessments can provide attribution-driven information when it is needed most: in the direct aftermath of an extreme event. This is when there is a window of opportunity to allow for new and different disaster risk reduction schemes to be implemented and to “build back better” based on changing risks [see, e.g., Kruse and Seidl (2013) on the importance of reactive disaster management]. Of course, the availability of event attribution information is not ultimately required to inform timely adaptation decisions, and whether and to what extent weather turns into disasters is not determined by the availability of scientific information but societal and governance factors (Andrijevic et al. 2020; Dilling et al. 2019). Attribution evidence, in particular, when presented across time scales (Otto et al. 2018) can help to bridge gaps between scientific information and practical implementation (van Aalst et al. 2018). However, to provide robust attribution statements within a time frame, and at scales that are relevant in a decision-making context, demands good observational data and well-evaluated climate models. This constraint implies that most attribution analyses are currently made for highly developed countries only. Thus, most attribution assessments crucially do not provide information about the types of events that incur the largest damages and socio-economic losses and where a factual assessment of the role of climate change is arguably needed most to avoid adapting to yesterday’s problems.

The European heat waves of 2003 and 2010 notwithstanding, the most damaging events with respect to people’s lives did not occur in the developed world. As Fig. 1 illustrates, red circles mark extreme weather events that are attributable in principle (e.g., heat waves, extreme rainfall, droughts and floods but excluding landslides), have occurred since 2003 (when event attribution methods were first developed; Stott et al. 2004), and had associated deaths reported on the Emergency Events Database (EM-DAT). The size of the circle represents the number of reported deaths and is thus a measure of the impact of the event. An alternative would be to use the number of events; however, this metric would not meaningfully distinguish between nuisance floods and a devastating hurricane. The number of affected people

would be another alternative to deaths (see Fig. A1): we chose deaths not to diminish the importance of impacts on infrastructure and property but as an impact-related measure least dependent on different definitions. We further note that, in using this approach, event attribution studies in developing countries for events without reported deaths are not shown in the figure.

The deadliest extreme weather events in Africa since 2003 is the 2010/11 East African drought, followed by floods and tropical cyclones. Heat waves likely had very large impacts but are underreported (Singh et al. 2019; L. Harrington et al. 2020). In Asia, Tropical Cyclone Nargis in 2008 cost by far the most lives, followed by the Indian and Pakistan heat wave of 2015 and a heat wave in Afghanistan in 2008. The list continues with floods, cyclones, and heat waves. For the Americas floods, tropical cyclones, and several cold waves in Peru lead to the highest humanitarian impacts.

The European heat waves aside, very few of these highly damaging events have been studied from an attribution point of view. The black circles in Fig. 1 depict the number of deaths associated with an event for which the influence of anthropogenic climate change on the event has been studied, i.e., where an attribution study exists. The black circles do not represent the deaths attributable to human-induced climate change, as such an assessment would not only require the existence of an attribution study but also a designated assessment of the relationship between the weather event and mortality (Mitchell et al. 2016). This means for places where the circles are entirely or largely red, the role of climate change in recent high-impact events is unknown. A few exceptions of very deadly reported events where studies exist outside of Europe include the 2010/11 East African drought, the 2011 cold wave in Peru (Otto et al. 2018), floods in Nigeria (Lawal et al. 2016), and the India and Pakistan 2015 heat wave (Wehner et al. 2016; van Oldenborgh et al. 2018).

In the Americas, there are attribution studies for Hurricanes Harvey and Sandy (Risser and Wehner 2017; van Oldenborgh et al. 2017; Lackmann 2015), both of which hit the United States. Harvey is the tenth-deadliest tropical cyclone in the Americas this century, if deaths are counted by individual country. However, Sandy had 54 associated deaths in the United States (where the attribution study focused on), but a further 81 deaths in Haiti and Cuba were also associated attributed to the same hurricane, some five days earlier. The only studies on rainfall associated with hurricanes outside the United States include Irma (47 deaths in the Caribbean and 58 in the United States) and Maria (143 in the Caribbean and 4 in the United States; Patricola and Wehner 2018), both following in Harvey's wake in 2017. This alone illustrates the discrepancy between where attribution studies are conducted and where the largest damages associated with extreme weather events are. Arguably, these much larger damages signify a greater need for information on how the likelihood and intensity of such high-impact events have been changing and are likely to change in a warmer world. In short, the question is: why do we not focus research efforts on event attribution on the whole world; explicitly including events in the developing world?

The reason is not just societal and political but also scientific. We simply cannot attribute these events in the same probabilistic framework employed in most studies today.

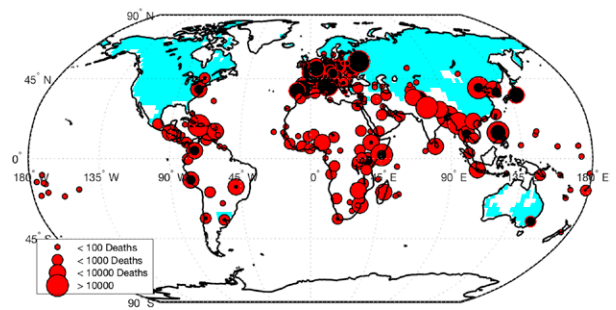


Fig. 1. Number of deaths associated with extreme weather events (heat waves, storms, floods) in different countries from 2003 to 2019 (red circles) according to EM-DAT and the number of deaths associated with events for which an attribution study has been undertaken (black circles). All deaths from events occurring in the time frame are added up and circles are placed on the location of the capital of every country. The grid points in blue show the parts of the world where long records of temperature observations are available in the GHCN-D dataset.

In this perspective we briefly outline why this is the case and discuss what we can do instead to answer the call for more scientifically robust information on the changing risks of extreme weather events (van Aalst et al. 2018).

Why do not we focus event attribution research where extreme weather affects most people?

While the answer to the attribution question (Otto et al. 2016; National Academies of Sciences Engineering and Medicine 2016) is relatively predictable (at least in the sign) for heat waves, this is not the case for the more complex events like droughts, tropical cyclones, and other events that cause major losses. Attribution studies that do exist for some of these most deadly events tend to emphasize the absence of the requisite data needed to quantify the role of climate change satisfactorily. An example of a high-impact event where attribution studies and climate projections alike have not provided a quantitative or qualitative assessment of the role of climate change is the East African drought of 2010/11 (and subsequent droughts in the region). Despite a comparably large effort by the scientific community (Philip et al. 2018; Uhe et al. 2017; Marthews et al. 2015; Funk et al. 2016; Philip et al. 2018; Kew et al. 2019a), we can conclude that the reduction in rainfall is the dominant driver in recent droughts observed in eastern Africa. However, with all available studies today we can only state that climate change is affecting the likelihood of the lack of rainfall by less than a factor of 10. Although there is certainly value added in doing such studies from a scientific point of view, the usefulness for decision-making is limited. Arguably this assessment could have been made without analyzing any data, considering that for all extreme events other than heat and cold waves the highest change in the likelihood of occurrence due to climate change we see is not larger than a factor of 3 (Herring et al. 2014, 2015, 2016, 2018). One reason for this is that eastern Africa is a relatively dry region that exhibits significant interannual variability, and thus a drought that is not very extreme from a statistical perspective can still generate large impacts. This also means that identifying trends on the order of 10% is much more difficult in these regions, as trends would need to be much larger to emerge from the high noise. This means that from a purely meteorological perspective, the attribution of extreme drought events is more difficult in highly vulnerable areas.

Furthermore, we can identify four nonclimate factors that lead to challenging conditions to conduct useful attribution studies. These are highlighted in East Africa but applicable to most high-impact developing country extreme weather events.

First, the lack of historical observations renders it extremely difficult to be able to quantify the severity of the event and in the case of floods also the spatial and temporal extent. Figure 1 illustrates in blue the areas where in the world long-term observations of daily temperatures are readily available using the Global Historical Climate Network–Daily (GHCN-D; Menne et al. 2012) as an example. Other long-term datasets have similar coverage, and variables other than temperature have even less coverage or are only available for shorter periods.

Second, the lack of historical observations hinder thorough model evaluation, making it impossible to assess whether modeling analysis paints a reliable picture of the real world. Additionally, the outcomes of the evaluation process might be conflicting depending on the scale of the analyses and selected variables or processes: evaluation criteria tailored to attribution frameworks have been the focus of development only recently (e.g., Vautard et al. 2019).

Third, climate models currently successfully used in attribution studies over the midlatitudes struggle to represent tropical climates. For example, convective processes are highly relevant for tropical weather but need model resolutions higher than the current state-of-the-art ensemble simulations afford. Furthermore, climate models are currently designed primarily in developed countries and thus tuned to represent the climate of their country of origin best, often to the detriment of the developing world (James et al. 2018). Apart from the

inability of climate models to simulate the driving mechanisms of tropical weather reliably, the way some present-day attribution experiments prescribe SSTs as part of the experiment setup leads to models lacking atmosphere–ocean feedbacks essential for many tropical meteorological phenomena. Fischer et al. (2018) have shown that this fact leads to large biases in attribution statements in tropical climates.

Fourth, there is a significant bias in expertise necessary to conduct and implement attribution studies between the developing and the developed countries with strong consequences for the manpower available to conduct studies as well as the usefulness of the studies. If scientists from the developed world conduct studies about a region they are not experts in, the framing and context of the studies will be less useful as if conducted by scientists with local expertise.

These reasons are in addition to framing questions that apply to all attribution studies and have been discussed in the literature (e.g., Jézéquel et al. 2018), rendering uncertainties in estimating the role of climate change in extreme events in developing country contexts particularly high.

It is important to note that these deficiencies equally hinder the constructions of reliable projections, which are needed to adapt to the unavoidable climate change already emerging. Attribution analyses, with their comparisons against observed statistics and trends of extreme events, are thus very useful to point out problems with projections.

Together these facts result in a systematic (selection) bias in attribution studies toward focusing on places with lower vulnerability. This fact needs to be considered more thoroughly when we think about selection biases and our aggregate understanding of changes to extreme events “worldwide.”

Defining impact-relevant attributable events

Apart from these difficulties particular to data-sparse regions, more thorough research on the definition of weather events is necessary to make attribution relevant. Assessing the changing likelihood of hazards requires as a crucial step the definition of the hazard, and dependent on this definition the ultimate change in risk can be very different (Sippel and Otto 2014). This holds not only in an event attribution context but quantitative risk analysis more generally (Hall and Leng 2019). And while there is no one correct way to define a hazard, there are definitions that can be more closely linked to the impact of an extreme event, thereby better capturing vulnerability and exposure components. For example, if a hurricane led to large damages because of the wind force, a study focusing on rainfall alone only reflects a part of the hazard and potentially a small one. In case of the hurricanes, however, it is the rainfall part of the hazard where climate models are most robust, and thus a quantitative assessment of changes is more reliable (van Oldenborgh et al. 2017).

A different example could be heat waves: these can be defined either based on temperature alone or on heat stress, but it is also crucial what the temporal and spatial scales of the definition matter for the impact and for estimated changes. While a heat wave defined as continent-wide seasonal average (Vogel et al. 2019) will have a huge attributable signal compared to assessments on a city level (Kew et al. 2019b; Mitchell et al. 2016), what actually links to human health impact is probably the heat stress on a city level with the smaller attributable signal. Thus, one method to make attribution results more relevant with respect to the overall risk is to define an event based on the impact, not based on the climate change signal or maximizing the extremeness in the meteorological event (Cattiaux and Ribes 2018). This is not a radical suggestion and many attribution studies attempt to do this; however, implementing an assessment of the impacts formally as part of the attribution framework could render this approach the “standard” and hence exceptions to be more easily recognized as such. The method could profit from the similarity of attribution with seasonal forecasting:

learning from these and even including them in the framework can give an indication of which are the main drivers of impacts (Coughlan de Perez et al. 2019).

Toward better understanding of the role of climate change in extreme events in data-sparse regions

A lot of the issues raised above relate to our inability to define the severity of an observed event, put it in the context of the historic record (i.e., a return period), as well as an inability to evaluate the model against specific observations in the place where an event happened. The following are additional steps we can take:

- 1) Further emphasis needs to be placed on other sources of weather data, like reanalysis products. Satellite analysis often suffer from short time series and disappointing quality for extreme events (e.g., van Oldenborgh et al. 2017), and the same is often true for reanalysis data, in particular with respect to precipitation (Tan et al. 2020); however, this has not been assessed comprehensively for extremes. There needs to be more research efforts into where different reanalysis products agree or disagree on types of extremes that have happened in parts of the world with poor observational networks, and particularly why (following Angélil et al. 2016). There are places with very few observations, but where reanalyses nevertheless agree very well as to what extremes have happened over the satellite era or even earlier for large-scale extremes. Similarly, there might be some global weather forecast products that perform better than others, for parts of the world with few historical observations.
- 2) In cases where it will be impossible to identify a “return period” for an extreme event that happens in a region with few historical observations, that does not mean we do not have confidence in the absolute event threshold for what actually happened there. This will prohibit a probabilistic attribution statement, but instead storyline approaches conditioned on the event could be undertaken to explore the role of the warming alone (Meredith et al. 2015; Shepherd et al. 2018). While answering a different attribution question (Otto et al. 2016) such studies could be useful in allowing decision-makers to identify plausible futures (Shepherd et al. 2018).
- 3) A further way to improve attribution statements in data-poor regions, even when operational services are unlikely to be implementable in the near future, would be a more standardized approach to attribution studies. Similarly, to trend detection and attribution where best-practice guidelines exists (Hegerl et al. 2010), following a protocol would allow for clarity on the event definition, whether it is based on the record, maximizing the signal-to-noise ratio, or trying to attribute the event that most closely maps to impacts. Moreover, some basic tests on the results could be recommended, including a statement on future changes in the same event (Otto et al. 2018) and alternative event definitions (Harrington and Otto 2018) to test the robustness of often highly uncertain results. Such a protocol would also help to avoid overconfident conclusions (Fischer et al. 2018; Bellprat and Doblas-Reyes 2016).
- 4) We need a concerted effort to rescue old data that are often undigitized in archives and attics, and an effort to make historical and current weather data available (Hawkins et al. 2019)—preferably publicly available, but in any case unbureaucratically available to local researchers and scientists working on attribution and projection studies.
- 5) All attribution studies require local meteorological expertise, thus building the capacity of researchers in developing countries to conduct attribution analysis needs to be a priority, for example, by developing north–south knowledge exchange through attribution PhD programs that prioritize applicants from the places where the most impactful extreme events happen. In addition, it will be important to enable developing countries to

- fund their own research programs on attribution to have sustainable capacities but also to develop ownership of the research. These capacities are further necessary to develop research programs that go beyond attributing hazards but incorporate assessments of vulnerability and exposure (see point 6) and link to the local rebuilding and disaster risk reduction context in the country as well as connecting these attributions to projections.
- 6) Finally, a major avenue for making progress in understanding the changing risks of extreme weather to further understands the other aspects of the event that generated severe impacts, specifically, the vulnerability and exposure components of risk, how these have already changed (e.g., due to increasing urbanization, social safety nets, technology etc.), current trends, and how these factors will continue changing in the future. This would thus require a new framing of event attribution methods, giving more equal weight to all three components of risk. Currently, assessments of vulnerability and exposure are done in an ad hoc way by a variety of organizations, on very different geographical and temporal scales, following different schools of thought and disciplinary approaches. While a detailed assessment is outside the scope of this perspective, implementing event attribution firmly within the hazard–vulnerability–exposure risk framework provides an important aim on the international climate research agenda.

Conclusions

The continued focus on how attribution science is rapidly improving, to the point of potential operationalization in a few countries, is only half the story. In reality, there are many parts of the world where these methodological advances in attribution are of little use, by virtue of the fact that there simply are not the observational networks present in many parts of the (often developing) world to be able to complete essential steps of an attribution analysis: event definition, observational analysis to establish the return period and trends, and identifying adequate models for analysis.

While these obstacles are not easily overcome, it would be detrimental, in particular from a climate justice perspective, to concentrate efforts in improving the science on the global north. This paper sought to clarify the specific issues that remain outstanding for these challenging regions of the world that are highly vulnerable and experience the most severe impacts and identify some pragmatic ways to make the most use of limited data but mainly highlights research priorities.

Attribution will not magically achieve what climate assessments in the past have failed to deliver, namely, drive governments, businesses, and communities to act on climate change information. It remains nevertheless crucial, in order to understand how climate change is already affecting extreme events today, but in a slightly different way than has been understood in the past. It remains very useful, in particular as a means of communication and for specific applications (insurance, dike heights) to explicitly quantify how the likelihood and intensity of the type of event that has led to the impact has changed. It is also arguably more useful to instead look at the region/country in question in a climate change context more broadly in addition to the attribution study. With most high-impact events that lead to complex disasters, the answer to the attribution question is not “yes” or “no” and thus even a failed attribution study where a quantitative assessment is not possible can be highly valuable. First, to identify problems with climate models and thus where projections cannot be relied upon for future planning and second even if uncertainties are large, excluding climate change as a game changer is also valuable.

Long-term, the improvement of methods, data availability, and event definitions that more truly reflect what actually causes the impacts (Kew et al. 2019a) will go some way to address some of the issues with the hazard definition; however, in a data-poor region like East Africa this is challenging, as observations about crucial drought indicators like soil moisture are

so sparse that they do not allow for any robust quantitative assessments. Therefore, a comprehensive attribution framework needs to have room for qualitative assessments and large uncertainties, and to integrate the other factors that lead to impacts by including the vulnerability and exposure components. In this way, there is also an opportunity to raise awareness of the need to reduce vulnerability and exposure in places where it is playing (a sometimes overwhelming) role in contributing to disaster impacts.

APPENDIX: Extreme Weather Event Deaths versus Number of People Affected

As discussed in the manuscript, there are several ways to measure impacts of extreme weather events, reported on the emergency events database EM-DAT. Figure A1 shows the difference comparing reported deaths to affected people, highlighting that for most events the number of people affected is much higher, with some notable exceptions. It is important to highlight though that many events in the database have either deaths or the total number of people affected reported and thus the two measures are not directly comparable.

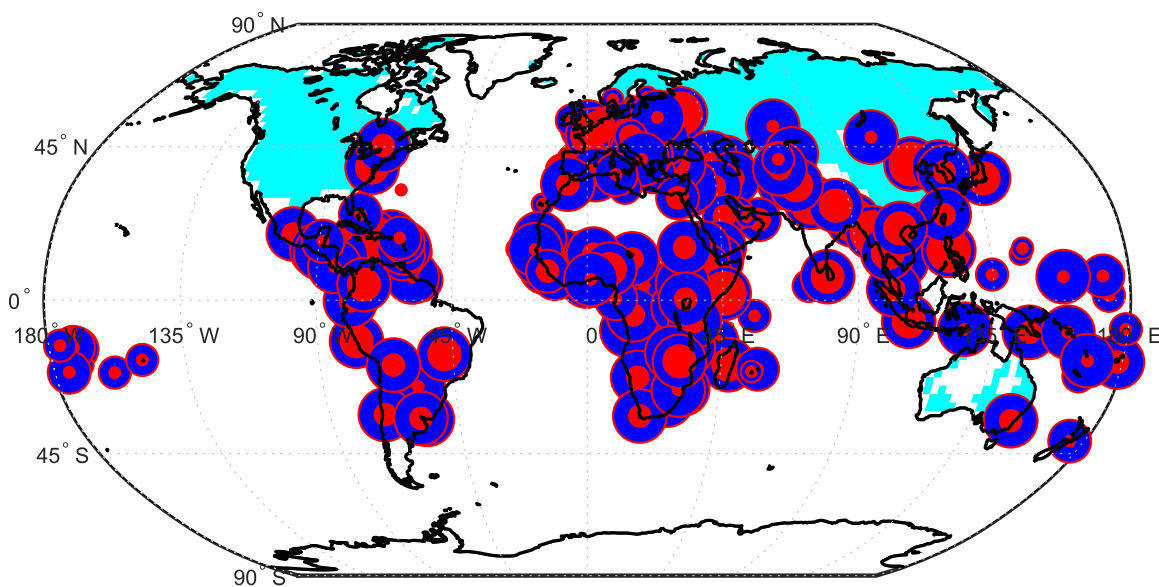


Fig. A1. Number of deaths associated with extreme weather events (heat waves, storms, floods) in different countries from 2003 to 2019 (red circles) and the number of people affected by these events (blue circles). The grid points in blue show the parts of the world where long records of temperature observations are available in the GHCN-D dataset. The size of the circle represents the same number of people as in Fig. 1.

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