Attribution of extreme weather events in Africa: A preliminary exploration of the science and policy implications

Friederike E. L. Otto[1*], Emily Boyd[2], Richard G. Jones[3, 1], Rosalind J. Cornforth[2], Rachel James[1], Hannah R. Parker[2], Myles R. Allen[1, 4]

1 Environmental Change Institute, University of Oxford, South Parks Road, Oxford, OX1 3QY, UK.
2 University of Reading, Whiteknights, Reading, RG6 6AB, UK.
3 Met Office Hadley Centre, Fitzroy Road, Exeter, EX1 3PB, UK.
4 Atmospheric, Oceanic and Planetary Physics, University of Oxford, Parks Road, Oxford, OX1 3PU, UK.
* friederike.otto@ouce.ox.ac.uk

Abstract

At the most recent session of the Conference of the Parties (COP19) in Warsaw (November 2013) the Warsaw international mechanism for loss and damage associated with climate change impacts was established under the United Nations Framework Convention on Climate Change (UNFCCC). The mechanism aims at promoting the implementation of approaches to address loss and damage associated with the adverse effects of climate change. Specifically, it aims to enhance understanding of risk management approaches to address loss and damage.

Understanding risks associated with impacts due to highly predictable (slow onset) events like sea-level rise is relatively straightforward whereas assessing the effects of climate change on extreme weather events and their impacts is much more difficult. However, extreme weather events are a significant cause of loss of life and livelihoods, particularly in vulnerable countries and communities in Africa. The emerging science of probabilistic event attribution is relevant as it provides scientific evidence on the contribution of anthropogenic climate change to changes in risk of extreme events. It thus provides the opportunity to explore scientifically-backed assessments of the human influence on such events.
However, different ways of framing attribution questions can lead to very different assessments of change in risk. Here we explain the methods of, and implications of different approaches to attributing extreme weather events with a focus on Africa. Crucially, it demonstrates that defining the most appropriate attribution question to ask is not a science decision but needs to be made in dialogue with those stakeholders who will use the answers.

Key words

Attribution, extreme weather events, risk, stakeholder dialogue, adaptation, loss and damage

1. Introduction

While there are no ambiguous research findings concerning the fact that the world is warming due to anthropogenic greenhouse gas (GHG) emissions (Stocker et al. (eds.) 2013), not all aspects of future climate change or its many potential impacts are understood. This is clearly articulated by the Intergovernmental Panel on Climate Change (IPCC) Working Group 2 (WG2) contribution to the IPCC Assessment Report 5 (AR5) in its chapter on Africa (Chapter 22, Niang et al. 2014). It notes that there is high confidence that changes are occurring in the distribution and dynamics of all types of terrestrial ecosystems in Africa but despite many of these being consistent with a climate change signal as the primary driver of these changes lower confidence is found in attributing them to observed climate changes. In other sectors such as water, agriculture or health, there are insufficient data or research on these to establish clear findings on the impacts of observed climate changes. However, it notes that the further climate changes we have confidence will occur in the future have the potential to exacerbate or multiply existing threats to human security including food, health and economic security.

The IPCC WG2 AR5 Chapter 22 also notes that the impacts of recent extreme events demonstrate development strategies are currently not able to counter current climate risks – but more positively that strengthening links between adaptation and development would help to counter the current adaptation deficit and reduce future mal-adaptation risks. Key to this is being able to assess the extent to which the frequency or intensity of climate extremes are attributable to anthropogenic climate change and so provide solid scientific evidence as to where investment in climate change adaptation would have positive development and climate resilience outcomes. However, the chapter finds that one important research gap is research and improved methodologies to assess and quantify the impact of climate change on different sectors and systems. Finally, it also notes, in a specific headline statement on food production, that processes such as collaborative, participatory research that includes scientists and farmers and strengthening of communication systems for anticipating and responding to climate risks provide potential pathways for strengthening adaptive capacities for climate change.

At the global scale basic physics implies with further increases in GHGs temperatures will continue to rise and, as a result, so will global average precipitation. This can lead to an increase in extreme heavy rain events in general (IPCC 2012 SREX report Field et al. 2012) but is dependent on the feedbacks of the climate system (see e.g., Liu and Allan 2013) which can modulate the response on local and regional scales. In addition, in some regions precipitation is projected to decrease which (especially with increases in temperature and evaporation) can lead to increases in drought (Field et al. 2012). It is extreme weather events like these (for example the recent droughts in the Greater Horn of Africa (Funk et al. 2013)) that cause disproportionately high damages but the detection of changes in them and attribution to external climate drivers is hampered by lack of good data and statistical sampling issues. However, if we are able to understand if anthropogenic climate change has influenced events of this nature when they do occur then we can provide guidance on whether to expect increases or decreases in their intensity or frequency in the future. Such information would be valuable in planning how to reduce the risk of negative consequences from these events in the future. Specifically, it has the potential to help address the loss and damage due to climate-related and extreme weather events as required by the Warsaw international mechanism for loss and damage associated with climate change[1] established by the United Nations Framework Convention on Climate Change (UNFCCC) at the Conference of the Parties (COP) in Warsaw in November 2013 (http://unfccc.int/resource/docs/2013/cop19/eng/10a01.pdf).

Many people are of the impression that it is impossible to attribute extreme and rare weather events to past anthropogenic greenhouse gas emissions. However, the emerging science of probabilistic event attribution (PEA, Allen 2003) increasingly allows for evaluation of the extent to which human-induced climate change is affecting localised weather events (e.g. Stott et al. 2004; Stone and Allen 2005; Pall et al. 2011; Otto et al. 2012). But while it is conceptually straightforward to perform an attribution study of extreme weather events in general, it requires considerable resources employing large sets of climate model simulations. Studies of probabilistic event attribution undertaken so far have concentrated on certain high profile events to demonstrate the method (Stott et al. 2004, Pall et al. 2011, Otto et al. 2012, Peterson et al. 2013), mainly in midlatitude climates, with very few studies attempting to attribute extreme weather events in Africa (Lott et al. 2013, Funk et al. 2013, Otto et al.

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[1] The UNFCCC was founded to act against anthropogenic climate change and defines climate change as " a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.” (Article 1, UNFCCC, 1992)We adopt the same convention for this paper as its focus is the loss and damage agenda under the UNFCCC.

2013). The central concept of probabilistic event attribution is to compare the simulation of a defined extreme weather event including the observed external drivers of the climate system, e.g. greenhouse gas concentrations in the atmosphere, volcanic eruptions, sulphate aerosols, incoming solar radiation, with the simulation of the same type of event in a climate with specific drivers removed, e.g. the anthropogenic fraction of greenhouse gas concentrations. The exact method used to remove a climate driver from the model simulations and the decisions on which drivers to remove will significantly influence the result of an attribution study.

Probabilistic event attribution requires the availability of large climate model ensembles to simulate the statistics of extreme events, which are by definition rare. A particular challenge in Africa is the lack of long-term meteorological observations which are needed on the one hand to identify extreme events and define crucial thresholds, and on the other hand to validate the model data. Event attribution relies on the model's ability to reliably simulate the climate conditions generating the extreme weather event, however the model does not need to have predictive skill, i.e. it needs the ability to predict the correct frequency of events rather than the exact time of occurrence. So far there have been several successful assessments on the human-influence on the probability of occurrence of extreme precipitation events (Pall et al. 2011, Lott et al. 2013, Sparrow et al. 2013). These have focused on specific events but a system could be set up using an existing validated modelling framework to run a seasonal attribution experiments routinely which would mean the resources necessary to attribute single events would be relatively small.

Numerous studies (e.g. Folland et al. 1986, Hoerling et al. 2006) have demonstrated the importance of sea surface temperature (SST) variations in explaining variability in African precipitation. This offers an entry point for reliable attribution studies of extreme precipitation events in Africa despite the considerable gaps in observations. Prescribing SSTs in an atmosphere-only general circulation model (AGCM) allows fundamental processes correlated to SSTs to be well simulated resulting in a good representation of extreme weather events, and improved signal-to-noise ratio. An explorative attribution study of such events in the Congo Basin (Otto et al. 2013) highlighted this potential by analysing the high predictability of rainfall from prescribed SSTs in several African regions. However, this approach also depends on relatively good observations of SSTs and sea ice and of the weather events we are interested in analysing in the model simulations, both for validation of the simulations and possible bias correction. The sparseness of or lack of access to the latter could be a reason for the lack of comprehensive attribution studies in the context of African extreme events. Below, we analyse how the three existing studies on event attribution approached this challenge.

The science outlined above it is very much in its infancy, particularly as applied to Africa despite its vulnerability to climate change. Given that the loss and damage agenda focuses on addressing issues in developing countries there is an emerging need to consider the relevance and value of more comprehensive attribution studies on extreme events in Africa. The relevance of exploring extreme event attribution is that it will expand the science available to address not only the highly predictable events like sea-level rise but extreme weather events as well. In this way the Warsaw Mechanism will have science available relevant to a much wider range of impacts and by including impacts from extreme weather events will avoid excluding many communities, especially in vulnerable regions in Africa.

We have identified two major reasons for the current lack of attribution studies in Africa despite the high losses and damages associated with extreme events on the continent. Firstly, the method is just becoming established scientifically with only test cases and *ad hoc* responses to natural hazards (Stocker et al. 2013, Chapter 10.6) undertaken so far. Reliance on good observational data makes such studies especially challenging in Africa. Secondly, it is not a priori clear how the scientific research question should be framed exactly. While different framings lead to scientifically equally robust results the results will differ in quantifying the risk and it is not clear how attribution studies need to be framed to inform strategies to reduce the risk from or adapt to the impacts of extreme climate events. In addition to the attribution framework the exact definition of an extreme event is crucial with different thresholds relating to very different risks. Section 3 will detail what this exactly means and discuss the implications.

Within this context the dialogue between scientists, technocrats, NGOs, politicians and decision-makers, and local stakeholders is crucial however. While science can determine some of the research questions that attribution help answer, the dialogue is needed to identify those which are most relevant to changes in risk, and how risk is understood by different groups and framed in a broader context, which incorporates both scientific and public understandings of climate change risk. The primary aim of this paper is to discuss the implications of how research questions about attribution are posed by reviewing probabilistic attribution studies on Africa in context of loss and damage, and thus contributing to the emerging dialogue.

In Section 2, the limited literature on event attribution in Africa is reviewed; core challenges identified and potential ways to overcome these are explored. Section 3 presents an example of an attribution analysis on July daily minimum temperatures in East Africa to illustrate how slightly different methodologies can lead to large differences in the quantifiable risk. The implications are discussed in Section 4 and conclusions summarised in Section 5.

2. A changing African climate

As yet, attribution of extreme weather events in Africa to external climate drivers has not been attempted comprehensively. There are, however, a number of examples of event attribution studies and process-oriented attribution studies that can inform event attribution that have been performed for African extreme weather events. For example, in a recent study by Lott et al. (2013) the method of probabilistic event attribution (PEA) was applied to the East African drought in 2011, which followed two consecutive dry rainy seasons in Kenya and Somalia.

The method requires access to a sufficiently large number of simulations of weather events under given climate conditions to enable subtle changes in the probability of occurrence of a rare event to be estimated with confidence. The use of large ensembles (e.g. Pall et al. 2011) allows for analysis of the statistical distribution of meteorological variables to be sampled. Using observed SSTs to drive AGCMs, possible weather given the current climate conditions is simulated, including statistics of rare events. In the approach used by Lott et al. (2013) and most other attribution studies employing PEA, the so-called ACE-method (Attribution of Climate-related Extremes, e.g. Christidis et al. 2012) is used: the ensembles representing present-day weather statistics are contrasted with the simulation of equally large ensembles of a so-called counterfactual world, a “world that might have been”, had anthropogenic greenhouse gas emissions not altered the climate system. These simulations are achieved by running the same climate model but with the anthropogenic forcing removed. Differences in the obtained statistics of extreme weather events can be attributed to anthropogenic greenhouse gas forcing.

Lott et al. (2013) quantified the attributable increase in risk of extreme low precipitation in the two rainy seasons in East Africa preceding the 2011 drought. They found that the failure of the “short rains” (in October-December) could be attributed to a large-scale tele-connection pattern known as the El Niño Southern Oscillation (ENSO) and in particular, to the occurrence of a strong La Niña event earlier in the year. Although human influence was found to have increased the likelihood of an extremely dry “long rains” season (March-June), the magnitude of the increase strongly depended on the exact warming pattern removed from the observations to simulate the “world that might have been”. To account for this uncertainty, Lott et al. (2013) used three different possible SST patterns representing the anthropogenic influence resulting in 3 different ensembles of the year 2011 in a world without human-induced climate change. In addition to observed SSTs to drive the model, observed weather data including the studied event was needed for model validation purposes. In the absence of in-situ measurements, Lott et al. (2013) relied on satellite data to remove model biases from the simulations.

In another recent study of the Congo Basin Otto et al. (2013), applied the method of PEA to the data sparse African region. The authors refrained from applying a bias correction because the model simulations were within the spread of the observed satellite and reanalysis data sets; satellite measurements in such sparsely populated region provide no guide to what extreme events really happened. The aim of this was to investigate the applicability of PEA analysis to a tropical region, in this case the Congo Basin. In view of the unreliability of observed data, the high signal-to noise ratio from using the high-quality SST observations from the surrounding ocean basins to force the model provided some confidence in the model and led to the conclusion that event attribution studies on extreme precipitation events can be robust in spite of poor-quality observational data.

Both studies (Lott et al. 2013; Otto et al. 2013) therefore highlight the importance of representing the major large-scale mechanisms which influence weather events and their frequency of occurrence in Africa. Otto et al. (2013) examined a type of extreme event, rather than a single specific event; in this case, the cumulative water deficit in the June-August dry season. Ensemble simulations of the decade 2000-2010 were compared, using the prescribed SST approach, with simulations of the 1960s, under the assumption that decade-long simulations reduce the influence of specific SST patterns and the difference between the decades therefore represents the predictable anthropogenic influence, largely independent of interannual large scale tele-connection patterns.

The most recent event attribution study for Africa was published in a supplement on "explaining extreme events from a climate perspective" (Peterson et al. 2013). In this context Funk et al. (2013) examined the attribution of rainfall deficits in Kenya and Somalia and the potential link between warmer SSTs in the Indian Ocean and the poor 2012 March–May East African rains. They generated a 30 member-ensemble of simulations with observed SSTs and 30 simulations driven with observed SSTs with all other variability apart from ENSO removed, including trends in ENSO. Although this approach is similar to Lott et al. (2013), Funk et al. (2013) looked at the differences between full-ocean and ENSO-only SST effects. The anthropogenic influence could then be identified by assuming the difference in SSTs between the two ensembles represented, amongst other large-scale teleconnection patterns, the anthropogenic warming. Results showed that the dominant influence causing the drought was non-ENSO SST forcing, which included the anthropogenic warming signal, as well as other SST patterns from either the Indian Ocean (Washington et al., 2013) or the Pacific Ocean (Williams and Funk 2011; Lyon and DeWitt 2012). Their conclusion was that the drought resulted from both anthropogenic and residual natural variability contributions. When the analysis was repeated for the years 2000-2012 and 1993-2012, the influence of non-ENSO forcing became weaker over these longer timescales. This implies that non-ENSO forcing caused the recent drought but that ENSO plays an important role in earlier droughts highlighting that a case-by-case analysis is necessary for the attribution of individual events.

All three event attribution studies focusing on African extreme events above adopt a similar approach. By simulating the observed climate conditions to obtain statistics of the observed extreme weather event, they facilitate attribution and comparison of these statistics with the frequency of occurrence of the same type of event in a climate model ensemble representing a climate without the anthropogenic signal. Lott et al. (2013) simulated the latter climate by removing a warming pattern obtained from coupled general circulation model runs without anthropogenic forcing from the observed temperatures and used this to drive the simulations of the year the extreme event occurred. Funk et al. (2013) only removed the ENSO signal from the observed SSTs. Otto et al. (2013) compared simulations from a whole decade to remove the influence of ENSO events and minimise the influence of other modes of interannual variability. All three approaches are scientifically valid but lead to different estimates of the changes in the risk of an extreme weather event to occur and, crucially, would do so had they investigated the same event. Crucially they provide answers to different questions as will be explained in sections 3 & 4 below.

If these studies are to be useful beyond academic interest, the framing of the questions must be made explicit and below we will show that the difference in using two of the approaches discussed above (Lott et al. 2013; Otto et al. 2013) can be dramatic, and that the change of risk that can be attributed crucially depends on the approach and the threshold analysed. This leads to questions about which risks really matter to those such as African farmers who will be affected by such events and how these stakeholders understand the results of these studies.

3. Asking the right question

By using scientifically meaningful implementations of similar methodological approaches, the attribution studies described above can be used to explore how to address the question regarding whether, and to what extent, a meteorological extreme event is attributable to anthropogenic greenhouse gas emissions. Figure 1 illustrates two of the approaches using model simulations of minimum daily temperatures in July in East Africa (12S, 22E – 18N, 52E). The differences in the four return periods of minimum night temperatures in July demonstrates that the answer to the attribution question depends crucially not only on the modelling framework available but also on how the research question is framed within a modelling approach and the definition of the threshold that constitutes the extreme event.

3.1 Methodology

Figure 1 was generated following a similar methodology to Pall et al. (2011), in which very large ensembles of global climate models (GCMs) were used to assess the change in risk of autumn flooding in the United Kingdom under two different climate scenarios: i) the observed Autumn 2000; and ii) a scenario based on a counterfactual ensemble forced with greenhouse gas concentrations representative of autumn 2000 had the anthropogenic greenhouse gas emissions not been released. We are using the distributed computing framework - weather@home (Allen 1999; Massey et al. 2006; Massey et al. 2014) -where members of the public facilitate multi-thousand-member ensemble weather simulation experiments at 1.25 x 1.875 degrees resolution via the volunteer computing network.

The model, HadAM3P, is an atmosphere only, medium resolution GCM developed by the UK Met Office, based upon the atmospheric component of HadCM3 (Pope et al. 2000; Gordon et al. 2000) with some improvements as described in Massey et al. (2014). The model runs several hundred times with varied initial conditions. In this way, very large ensembles (of the order of thousands) of GCMs can be computed which increases the statistical confidence in rare events.

Two very large ensemble simulations of weather events in the decade 2000-2010 were run and the statistics of extreme weather events analysed. The first ensemble run represents the actual climate conditions of the decade. The second ensemble run is identical except that it excludes anthropogenic greenhouse gas and aerosol emissions. Both ensemble simulations are driven by observed SST patterns, although the warming signal of anthropogenic emissions is removed from the SST forcing in the counterfactual ensemble. The warming signal was obtained from CMIP5 (Taylor et al. 2012) simulations of the Met Office Hadley Centre Model HadGEM2-ES.

The resulting ensembles are simulations of weather as it could have occurred given the observed and counterfactual climate conditions. This allows us to compare the likelihoods of extreme events, in the exemplary case shown in Figure 1 for extreme daily minimum temperatures in July in East Africa (12°S -18°N, 22°E-52°E,).

3.2 Results

Figure 1 shows four ensembles for the daily minimum temperatures in the actual and the counterfactual ensemble for each single year 2005 and the whole decade 2000-2010. The red (b) and the blue (d) curves represent simulations of July minimum temperatures for the whole decade, while the pink (a) and the green (c) curves represent just 2005.

Under the assumption that the differences between the two complementary ensembles ((a) and (c); and (b) and (d)) simulate weather in a world with and without anthropogenic climate change, the differences between magnitude and frequency of occurrence of temperature extremes gives an indication of whether and to what extent the risk for such extremes has changed due to anthropogenic climate change. Assuming there had been a heat wave in July 2005 characterised by high minimum temperatures this figure could used to quantify the changes in risk of such an event to occur. Different assessments of the extent of the change in risk are obtained by comparing either just the simulation of the year 2005 or simulation of the whole decade in both ensembles. In the illustative case shown in Figure 1 we use an arbitrary threshold of 19C min temperature to define the extreme event. If an assessment is made based on the whole decade, the incorporation of anthropogenic forcing increases the probability of a minimum temperature above19C from 1 in every 6-7 years to more than once every year (figure 1, dark grey arrow). If the assessment is based only on 2005, anthropogenic climate forcing increases the probability of the event to occur from 1 in every 40 years, to more than once every year (figure 1, light grey arrow). Making the assessment based on individual years suggests that changes in the risk of an extreme event occuring due to anthropogenic forcing are much larger than if the assessment had been made based on the simulation of decades. Both ways of estimating changes in risk for a given extreme event have been used in previous attribution studies; e.g. Lott et al. (2013) simulated single years while Otto et al.(2013) compared the whole decade.

Furthermore, choosing an equally arbitrary threshold of 18.5°C the changes in the probability of exceeding this threshold are much smaller, as illustrated by the brown arrows in Figure 1. This highlights that the definition of a threshold and its representation in the model are crucial for attribution studies if the aim is to quantify the fraction of changes in the risk of an extreme event to occur attributable to human-influences. This point is comparably trivial but highlights the importance of the definition of an extreme weather event.

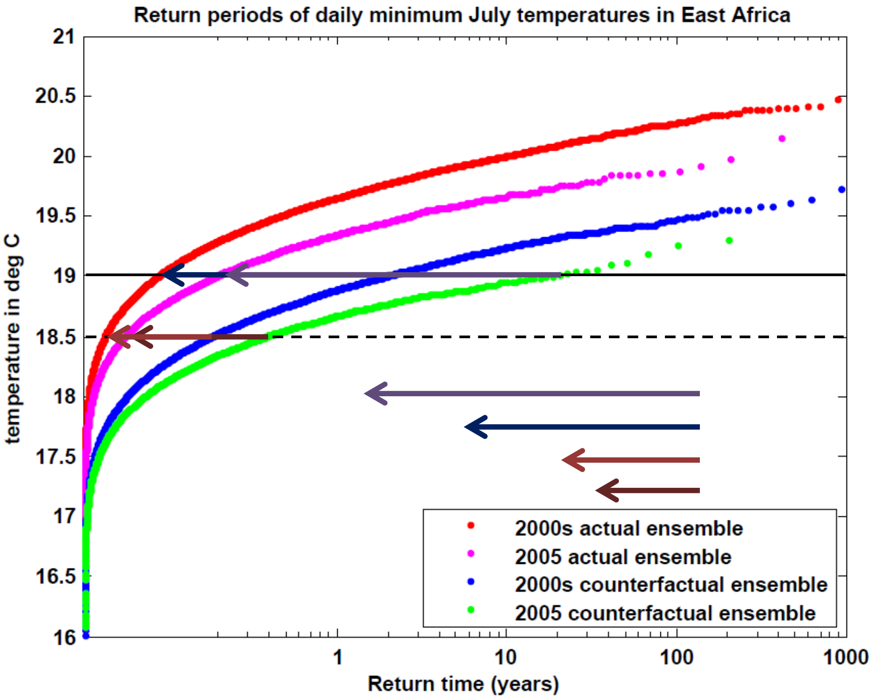

Figure 1 Return periods of daily minimum temperatures in July in East Africa in 4 different ensembles. (a) July minimum temperatures in the actual climate simulations of the year 2005 (pink); (b) July minimum temperatures in the actual climate simulations of the decade 2000-2010 (red); (c) July minimum temperatures in the counterfactual climate simulations of the year 2005 (green); and (d) July minimum temperatures in the counterfactual climate simulations of the decade 2000-2010 (blue). The horizontal black line represents a threshold of 19°C, the dashed line a threshold of 18.5°C. The grey arrows represent the increase in risk of exceeding the threshold of 19°C in the decadal (dark grey) and annual simulation approach (light grey). The brown arrows represent the increase in risk of exceeding the threshold of 18.5°C in the decadal (dark brown) and annual simulation approach (light brown). The arrows have ben copied above the key to allow a comparison of the change in probability inferred from each analysis technique.

4. Discussion

It is estimated that globally 250 million people on average are affected annually by extreme weather events, which is an increase of more than 30 per cent in the past 10 years with direct economic losses averaging $100 billion per year over this time period (in relation to national income, Warner and Ahmed Zakieldeen, 2012). It is within this context that the international community pledged funds to counter the impacts from climate change. The Copenhagen

Accord pledged $30 billion by 2012 with an aim to rise to $100 billion by 2020 (UNFCCC 2009). The UNFCCC established a work programme on loss and damage in Cancun in 2010 (UNFCCC 2010) and the first loss and damage expert meeting, held in Tokyo, Japan in 2012, identified the need for 'holistic' dialogue and methods that are designed to manage the range of loss and damage associated with extreme weather events and slow onset events (Warner and Ahmed Zakieldeen 2012). This lead to the establishment of the Warsaw international mechanism for loss and damage at COP19 in Warsaw 2013.

In this context probabilistic event attribution might potentially play role as it allows identifying whether and to what extent anthropogenic climate change played a role in the magnitude and probability of occurrence of the event.

4.1 The importance of question framing

However, if the results of such attribution studies as described in section 3 above are used to inform the Warsaw mechanism and adaptation planning and decision-making under the UNFCCC it is important to clarify which approach is used in different situations.

Comparing simulations of a single year answers the question "given all other conditions being equal, how has the risk of such an extreme event to occur changed as a result of anthropogenic emissions"? Comparing whole decades instead smoothes the interannual variability of large-scale oscillations in the SSTs, thus answering the question "given all *predictable* (long term) things being equal, how has the risk changed due to the global mean temperature increase and increase in greenhouse gas forcing?". With the former approach addressing the event conditioned on the SSTs and the latter analysing the climatological shift. Another approach to probabilistic event attribution, which has so far not been employed with large enough ensembles to attribute extreme events but is probably the most promising, is to use SSTs from seasonal forecasts instead of observed SSTs for the season of interest. This will provide an answer to the question "given all *predictable* (short term) conditions being equal, how has the risk of such an extreme event to occur changed as a result of anthropogenic emissions"? The latter approach will eleminate the unpredictable noise for the given year from the assessment of changes in risk. It is not a priori clear which estimation of the change in risk is appropriate as all are scientifically valid and all have their advantages and disadvantages.

For an assessment of the anthropogenic influence on African climate overall, the use of decadal or longer simulations has the potential to better quantification the overall changes in risk which is relevant for long term adaptation planning. However to analyse for a given year the risk of a certain threshold to be exceeded in that year, dependent on the observed drivers of events in that year, single year simulations (either with observed or seasonal forecast SSTs) will give a better assessment of how anthropogenic climate change altered the risk of these specific events occurring. This allows us to make use of observed responses to extremes to help plan the adaptation to anthropogenic changes.

Thus from an decision making point of view we are looking at two different problems: the first is assessment of a specific observed event which gives guidance on what to do more or less of given this event and its impacts and responses; the second is assessment of climatological shifts from which we can provide more general guidance on responses. While it is paramount that the scientific community communicates the exact framing of the research question they aim to answer, it is also important to identify the questions decision-makers and stakeholders need answers to.

It is likely that the questions which information is needed to answer will depend on spatial and temporal factors relating to the vulnerability of people, such as where they are located geographically. The answers will also be determined by people's existing experience of extreme events, and by social dimensions, e.g. gender, ethnicity and age (Blaikie et al. 1994).

Another important issue is how decision frameworks are determined by relationships between different actor groups and governments, which are in-turn often influenced by power dynamics and asymmetry of information (i.e. moral hazard). Clearly a blueprint "one fits all" approach might not be desirable. The discussion needs to start now; to find out which questions the scientific community should aim to answer if scientific evidence is to play a role in the loss and damage agenda.

4.2 The importance of dialogue

The interaction between hazards and evolving vulnerability, including how vulnerability may change as stakeholders respond to new information, is critical in determining overall risk. Scientists are acutely aware that simply providing information may have unpredictable consequences, including diverting attention away from building resilience towards a “search for the guilty” (Hulme et al. 2011). The appropriate response is for dialogue between scientists and societal and policymaking stakeholders to learn together how new information and existing indigenous knowledge is being interpreted and used. Co-production of knowledge is vital. Co-production of knowledge occurs when scientists and stakeholders come together to generate new knowledge and technologies jointly through processes of learning. Co-production works when there are clearly defined boundaries and the means to overcome asymmetric power dynamics (Jasanoff 2006). To initiate this process it is important to build on existing mechanisms (e.g. participatory action and scenario development planning), engage with novel approaches (e.g. serious gaming, Suarez et al. 2012) and to develop new platforms such as Rainwatch-AfClix. Rainwatch-AfClix is operating in a growing number of countries in the African Sahel and consists of a real-time rainfall monitoring system (Rainwatch) coupled to a boundary organization (AfClix) for facilitating stakeholder engagement (Boyd et al. 2013). Each of these different “mechanisms” presents opportunities to discuss probabilistic event attribution in an African context and initiate a dialogue.

Scientists believe that scientific event attribution studies could play a key role in the science-policy dialogue, but to make it useful, attribution studies need to bring in multi-stakeholder groups comprising scientists and decision-makers. This need for broadening sectoral engagement is demonstrated by the SREX report (Field et al. 2012), which calls for “new balance…to be struck between taking measures to reduce risk, transfer risk (e.g. through insurance) and effectively prepare for and manage the impacts of disasters in a changing climate. This balance will require a stronger emphasis on anticipation and risk reduction” (Mitchell and van Aalst 2011). It might be that many stakeholders will take the view that simulated evidence, with current relatively low-resolution climate models, is not robust enough in the context of tools and information relevant to adaptation and loss and damage. This need to be clearly communicated as it means that attribution results of extreme weather events would not be usable to address damages from events other than the so-called slow-onset events such as sea-level rise for at least another decade when high resolution models may be available to be used for running large ensembles. Although such slow-onset events in context of the loss and damage agenda are highly predictable events, they cannot include other comparable but unpredictable slowly evolving events like multi-month droughts. While concentrating on predictable slow-onset events in developing countries for consideration under "loss and damage" might be good news for the Maldives, this outcome is likely to raise serious problems for land-locked African countries assuming that impacts of human-induced climate change are addressed.

4.3 Policy and practical implications of loss and damage

From a human rights and climate justice perspective the implications of an international loss and damage mechanism such as the Warsaw international mechanism are critical, especially since those most at risk from anthropogenic climate change contribute minimally to global greenhouse gas emissions (CARE International 2012). Nevertheless, there are outstanding matters to be resolved on the ground. Firstly, if scarce resources are allocated to the wrong actions today based on a poor understanding of climate-related adverse impacts (e.g. devoting resources 'only' to climatological hazard as opposed to investing in development, e.g., education, health etc.), then that could leave future generations worse off (UNFCCC 2012). Secondly, currently climate mechanisms are bureaucratically cumbersome and woefully inadequate to achieve their aims (Boyd and Tompkins 2010). Thirdly, strategies to address loss and damage need to improve at the country level to coherently address loss and damage globally (UNFCCC 2012). In this case, locally appropriate adaptation strategies require more user-friendly and accessible information for timely and informed actions by decision makers and practitioners (Cornforth et al. 2013), better understanding of community knowledge and technologies and of their role in systematic disaster risk management, enhanced integration of social protection measures with risk reduction, risk transfer, risk governance and climate change adaptation, more effective conditional cash-transfer through innovative civil society, government and stakeholder partnerships, and finally, greater detailed national policy regarding actor roles and responsibilities in development sectors and local governments (UNFCCC 2012).

5. Conclusions

Attribution studies have the potential to provide scientific evidence relevant to loss and damage occurring from anthropogenic climate change and could thus play a key role in the science-policy dialogue. In particular, probabilistic event attribution studies are currently the only source of scientific evidence with respect to observed extreme events. Omitting these events in a loss and damage framework by concentrating on slow-onset events alone would exclude addressing their effects on the many vulnerable communities in developing countries such as those in Africa which are exposed to them. However, to make the science useful, attribution studies need to address the appropriate attribution questions identified by multi-stakeholder groups comprising scientists and decision-makers. Extensive validation of the models and clear communication regarding the limitations of event attribution is paramount. Poor adaptation decisions taken now could leave future generations worse off if the increased risk of an event is attributed wrongly to anthropogenic warming rather than the natural and internal variability of the climate system (Stott et al. 2013). However, not using available information from attribution studies could lead to equally ill-planning if crucial changes in the magnitude and frequency of extreme events are not taken into account. Co-production of knowledge between scientists, users and decision-makers is vital to avoid pre-defined event definitions that do not take account of the perspectives and priority needs of users of event attribution studies (Stott et al. 2013).

Looking forwards, regular assessment of extreme events in relation to their probable triggers will lead to improved understanding of extreme events in the near term, and improved projections in the longer term. Policy expectations and needs on the ground will need to be better aligned however with the evolution of the scientific understandings of extreme events.

Experience has shown that communicating science between scientists and those who can use it to meet societal needs can be challenging but also rewarding to all involved. In this case, the reward could be the inclusion of unpredictable extreme events into a scientifically based approach to address loss and damage under the UNFCCC framework and thus of specific benefit to many of the most vulnerable communities adversely affected by anthropogenic climate change. Finally, any clear messages on the effects of climate change on the magnitude or frequency of extreme events would be of significant use in both understanding the need for and designing climate change adaptations.

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