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Department of Meteorology

Attributing extreme weather events in Africa to climate change: Science, policy and practice

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Declaration

I confirm that this is my own work and the use of all material from other sources has been properly and fully acknowledged.

Hannah Ruth Young

Abstract

Extreme weather and climate-related events can have devastating impacts on people's lives and livelihoods in developing countries, particularly in Africa. Understanding the influence of anthropogenic climate change on extremes is key when addressing the impacts of events now and in the future. Probabilistic event attribution aims to quantify the effect on individual events by analysing changes in probabilities of their occurrences. This thesis investigates this technique and its applications in an African context.

It first assesses whether robust attribution results can be produced for events in West Africa. A case study of high precipitation in 2012 concludes that the probability of such an event was likely decreased due to anthropogenic climate change. The different climate model ensembles analysed produce complementary results, but the study highlights the importance of correctly modelling the anthropogenic climate change impact on sea surface temperatures if results are to be robust in regions such as this with strong teleconnections.

The application of event attribution is then studied in two key contexts relevant to addressing the impacts of extreme weather events in Africa: national adaptation policy, focussing on addressing urban flooding in Senegal, and international loss and damage policy. In both cases there were suggestions for roles these scientific results could play, but there are barriers to their inclusion at present. In Senegal little climate information is currently used in decision-making, and loss and damage policy lacks clarity around what it will address and therefore how scientific information can support this. In both cases stakeholders demonstrated limited awareness of event attribution, highlighting the need to enhance understanding to encourage further dialogue about its relevance. To this end a participatory game focussing on event attribution was developed and is shown here to be a useful tool for stakeholders to consider how results could be relevant for their decisions.

Authorship of papers

The following papers have been included in this thesis. Here, the components carried out by the candidate and the estimated percentage contribution are given. The majority of these have been published under the candidate's previous name of Hannah Parker.

Parker, H. R., Boyd, E., Cornforth, R. J., James, R., Otto, F. E. L. and Allen, M. R. (2016a) Stakeholder perceptions of event attribution in the loss and damage debate. *Clim. Pol.*, **17**, 533–550. doi:10.1080/14693062.2015.1124750

> *Contribution: 75%*
> *H.R.P. designed the study with the assistance of E.B. and R.J.C. H.R.P. carried out the majority of the interviews (two by R.J.), carried out the analysis and led the writing of the paper, with input from all other coauthors.*

Parker, H. R., Cornforth, R. J., Suarez, P., Allen, M. R., Boyd, E., James, R., Jones, R. G., Otto, F. E. L. and Walton, P. (2016b) Using a game to engage stakeholders in extreme event attribution science. *Int. J. Disaster Risk Sci.*, **7**, 353–365. doi:10.1007/s13753-016-0105-6

> *Contribution: 80%*
> *The CAULDRON game was designed by all the authors. H.R.P. collected the data from the sessions, analysed this and wrote the paper, with contributions from all coauthors.*

Parker, H. R., Lott, F. C., Cornforth, R. J., Mitchell, D. M., Sparrow, S. and Wallom, D. (2017) A comparison of model ensembles for attributing 2012 West African rainfall. *Environ. Res. Lett.*, **12**, 014019. doi:10.1088/1748-9326/aa5386

> *Contribution: 70%*
> *H.R.P. designed the study with F.C.L. and input from R.J.C. H.R.P. carried out the analysis, adapting code from F.C.L., and led the writing of the paper, with contributions from F.C.L., R.J.C. and D.M.M. S.S. and D.W. provided data.*

Young, H. R., Cornforth, R. J. and Boyd, E. (2017) Event attribution science in adaptation decision-making: the context of extreme rainfall in urban Senegal. *Global Environ. Change*, in review.

Contribution: 80%
H.R.Y. designed the study with E.B. and input from R.J.C. H.R.Y. collected the data and carried out the analysis. H.R.Y. led the writing of the paper with input from E.B. and R.J.C.

Other papers the candidate contributed to during the course of the PhD referenced in this thesis are:

James, R., Otto, F., **Parker, H.**, Boyd, E., Cornforth, R., Mitchell, D. and Allen, M. (2014) Characterizing loss and damage from climate change. *Nat. Clim. Change*, **4**, 938–939. doi:10.1038/nclimate2411

Otto, F. E. L., Boyd, E., Jones, R. G., Cornforth, R. J., James, R., **Parker, H. R.** and Allen, M. R. (2015) Attribution of extreme weather events in Africa: a preliminary exploration of the science and policy implications. *Clim. Change*, **132**, 531–543. doi:10.1007/s10584-015-1432-0

Bellprat, O., Lott, F. C., Gulizia, C., **Parker, H. R.**, Pampuch, L. A., Pinto, I., Ciavarella, A. and Stott, P. A. (2015) Unusual past dry and wet rainy seasons over southern Africa and south America from a climate perspective. *Weather Clim. Extremes*, **9**, 36–46. doi:10.1016/j.wace.2015.07.001

Parker, H., Cornforth, R. J., Boyd, E., James, R., Otto, F. E. L. and Allen, M. R. (2015) Implications of event attribution for loss and damage policy. *Weather*, **70**, 268–273. doi:10.1002/wea.2542

Boyd, E., James, R. A., Jones, R., **Parker, H.** and Otto, F. (2016) A typology of loss and damage perspectives. *Nat. Clim. Change*, in review.

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Thank you to all those I have had the pleasure of sharing an office with or living with, and to those who provided the many tea breaks needed to get through a PhD and have fun along the way! Finally, thank you to my family and friends for your support throughout the last few years, particularly my parents for your unwavering love, and Matthew for your encouragement, for filling my PhD years with joy, and for marrying me in the middle of it all!

For from him and through him and to him are all things. To him be glory forever. (Romans 11:36)

Contents

1. Introduction

1.1 Extreme events

Extreme weather and climate events, such as heatwaves, droughts and floods, can have large consequences for the environment, and subsequently people's lives and livelihoods. In developed countries this can result in high economic losses, but in developing countries the impacts are often more devastating, with much greater economic losses proportional to gross domestic product (GDP) and higher fatality rates (Handmer et al., 2012). Africa is one such region that is particularly vulnerable to extreme events. Between 1970 and 2012, nearly 700,000 lives were lost in Africa due to weather, climate and water-related disasters, along with US$26.6 billion in economic damages. Of these events, floods and storms led to the highest economic losses and droughts caused the majority of deaths (World Meteorological Organization, 2014).

When an extreme event occurs and produces large impacts, the media and the public often ask whether the event could be 'blamed' in some sense on climate change (Stott et al., 2016). While it is not possible to claim that a particular event was caused by climate change, techniques have been developed to assess how anthropogenic influences affected the probability of such an event occurring. Understanding the links between events and climate change can help build understanding of the impacts of climate change and how these might be expected to change in the future.

1.1.1 Attributing extreme events

The role of anthropogenic greenhouse gas emissions in global mean temperature rise has been clearly demonstrated, however assessing the impact on individual extreme events is much more challenging (Bindoff et al., 2013). This is because extreme events are caused by a number of factors, and in most cases could also have occurred in an unchanged climate (Seneviratne et al., 2012). Individual events therefore can rarely be attributed in a deterministic sense. However, it was first suggested by Allen (2003) that it might be possible to attribute an event probabilistically. This would involve estimating the proportion of the probability of the event occurring that could be attributed to anthropogenic climate change.

The first study of this type investigated the 2003 European heatwave and found that climate change had at least doubled the risk of a heatwave of that magnitude (Stott et al., 2004). There have since been studies looking at different types of events across the world, including both temperature and precipitation extremes and even individual storms (Stott et al., 2016). The methodologies used have been developing, with the majority of studies now employing large ensembles of climate model simulations to assess the change in event probability, while others use observational or reanalysis data (National Academies of Sciences, Engineering, and Medicine (hereafter National Academies), 2016). The numbers of studies has also been increasing, as highlighted in the special reports on extreme events from the Bulletin of the American Meteorological Society (BAMS) since their inception in 2012. These provide a platform for the study of events of the previous year in the context of climate change (Herring et al., 2014; 2015; 2016; Peterson et al., 2012; 2013). The growing interest is also highlighted by recent review papers being commissioned on the state of the science, by Stott et al. (2016) and the National Academies (2016).

1.2 Thesis motivation

Despite the impacts of extreme events often being most devastating in developing countries, relatively few event attribution studies have focussed on these regions. This is clear in a map from Stott et al. (2016) of events studied across three years of the BAMS special reports (figure 1.1). The majority of studies investigated events in Europe and the US, whereas in Africa there were just two studies, both of East African drought. Africa is one of the most vulnerable regions of the world to climate change impacts due to its high exposure and low adaptive capacity, with current impacts on ecosystems, water security, agriculture and health expected to greatly increase in the future (Niang et al., 2014). Many impacts are experienced through extreme events, and in the year 2015 alone there were record high temperatures in South Africa and across northern Africa, heavy rain and flooding across northern Africa, West Africa and Tanzania, Malawi, Mozambique and Zimbabwe, and droughts in Morocco and South Africa (World Meteorological Organization, 2016). Therefore this thesis will focus on event attribution science in an African context, to understand whether knowledge of the link between events and climate change could be useful in this region. Understanding the robustness of event

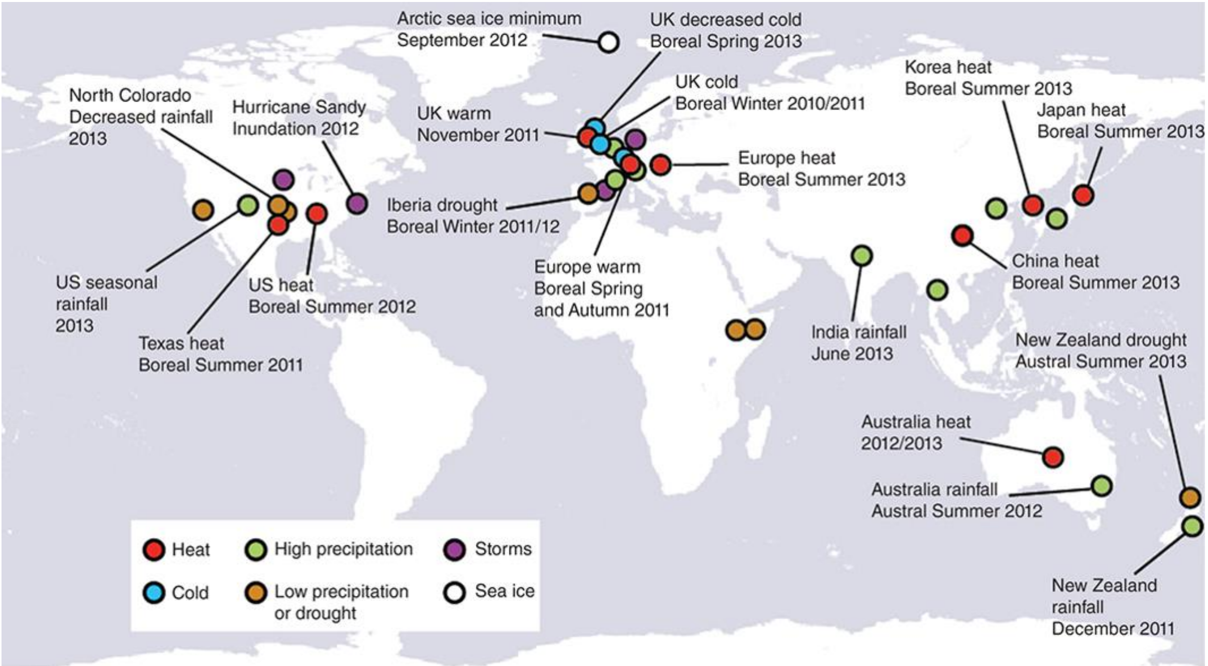

Figure 1.1. Map of events studied in the BAMS reports on extremes of 2011, 2012 and 2013. From Stott et al. (2016).

attribution studies in Africa will be important to increase knowledge of the impacts of climate change in this region, further develop event attribution science in this context, and investigate how results might be useful for stakeholders.

While the science of event attribution has been developing over the past decade, there has been relatively little research into how the results produced might be useful to guide decision-making to address the impacts of extreme events within policy processes. Here, decision-making is defined as "a process or sequence of activities involving stages of problem recognition, search for information, definition of alternatives, and the selection by an actor(s) of one from two or more alternatives consistent with the ranked preferences identified in the first three stages that will maximise or 'satisfice' the actor's goal" (Wasby, 1970, p.131). Decision-making is a key part of both formulating and applying policy, which is taken to broadly mean "a principle or course of action adopted or proposed as desirable, advantageous, or expedient; especially one formally advocated by a government, political party, etc." (OED Online, 2017).

The majority of potential uses for event attribution that have been suggested and debated in the literature have been promoted by the climate scientists carrying out the studies. Engagement between scientists and stakeholders who may be interested in the results has been limited (efforts include a workshop reported on by Stott and Walton, 2013), with only one known study specifically investigating users' perceptions of the relevance of event attribution (Sippel et al., 2015). However, involving stakeholders in identifying the important questions to investigate regarding event attribution is vital in the context of climate policy, to ensure research is relevant and can support decision-making. Therefore this thesis aims to complement and further the preliminary work by Sippel et al. (2015) by investigating potential uses for this area of climate science in specific policy contexts, through engagement with the relevant stakeholders. Furthering understanding of the relevance of results could help guide the scientific development of event attribution in the future to meet user needs.

Meeting user needs also requires a better understanding of how to communicate the science of event attribution among stakeholders. Communication of complex scientific ideas can be challenging, and traditional passive presentation methods can lack interest and engagement from audiences (Suarez, 2015). Novel communication mechanisms such as participatory gaming, where participants become active learners who may more readily retain new understanding and tools (Harteveld and Suarez, 2015), provide a potential means to explore complex understandings of event attribution with stakeholders.

1.3 Thesis aims

This thesis aims to investigate both the science of event attribution and its potential applications in climate policy within an African context, and also to develop how event attribution can be communicated to stakeholders. The research questions to be addressed are:

Q1. Do event attribution studies produce robust results in West Africa?

Q2. Can event attribution play a role in specific national and international policy contexts relevant to Africa through engagement with policy stakeholders?

Q3. Can a participatory game be used to share event attribution science with stakeholders?

In order to address these aims an interdisciplinary approach is taken. This is the first study to bring together the interdisciplinary dimensions of event attribution, using both climate and social science research methods to study both event attribution science and its applications in climate policy. This can lead to a better understanding of the relevance of communicating this scientific method, to develop appropriate communication techniques. More specifically, this is also the first study to develop this understanding of event attribution in an African context – a broader understanding than would be possible to formulate with just one discipline.

Applying findings from event attribution studies in an African context would require understanding of whether the results are robust. In particular there have been a lack of studies carried out on events in West Africa to date, so this thesis will address Q1 by investigating whether it is possible to analyse the anthropogenic climate change influence on a high precipitation season in this region in 2012. Many attribution techniques have been developed over the past few years, but there have been few studies comparing different methodologies for the same event. Therefore, this study will compare results from a selection of the common climate model ensembles used in event attribution to assess whether they are consistent.

Alongside investigating the science, this thesis will look at what stakeholders understand about the attribution of extreme events, and whether they think event attribution could provide relevant information for their decisions (Q2). To address this, two key policy contexts are investigated, each of which are relevant to addressing the impacts of extreme weather events in Africa: national adaptation policy and international loss and damage policy. These are both areas in which the relevance of event attribution has been debated in scientific literature, but not investigated empirically before. The national and international levels are both relevant in terms of understanding the value of event attribution information within policy contexts at different scales. Adaptation by human systems is defined by the Intergovernmental Panel on Climate Change (IPCC) as "The process of adjustment to actual or expected climate and its effects… to moderate or avoid harm or exploit beneficial opportunities". To investigate the relevance of event attribution to adaptation, a case study of national adaptation policy to address flooding in urban Senegal is used. This links to the event attribution study of high precipitation in West Africa in 2012 as this caused flooding across Senegal. The context is investigated using a range of qualitative methods including semi-structured interviews, questionnaires, a workshop and document analysis. The second policy context investigated is that of international negotiations under the United Nations Framework Convention on Climate Change (UNFCCC) to address loss and damage associated with climate change impacts, including slow-onset and extreme events, in vulnerable developing countries (UNFCCC, 2013). This is relevant to the African context as many of the developing countries this policy aims to assist are located in this region and it could help provide support to those vulnerable to the impacts of climate change across Africa. Current understandings of event attribution science and perceptions of its relevance are assessed here using semi-structured interviews and a literature review.

Finally this thesis will also explore how a participatory game can be used to enable the communication of event attribution science to stakeholders (Q3). This will focus on a game developed to both share the scientific concepts of event attribution with stakeholders and provide space to discuss the potential relevance of results in addressing the impacts of extreme weather events. The game focusses on loss and damage policy applications, which are relevant to developing countries in Africa, and can also be used to consider adaptation policy in these countries.

Figure 1.2 depicts how these scientific and policy areas fit together, along with the research questions. Q1 is investigated by applying the event attribution technique to a rainfall event in West Africa. National adaptation policy and international loss and damage policy are both looking to address the impacts of similar types of events at different policy levels, and Q2 investigates whether event attribution science could play a role in these contexts. Q3 looks at the communication space between the scientific community and the policy contexts, through the use of a participatory game.

1.4 Structure

The remainder of the thesis will be structured as follows: Chapter 2 provides a summary of event attribution science techniques and the potential uses for results which have been discussed in the literature to date, along with perceptions of the science, reflecting on the role of communication. This is followed by a background to the links between climate science and policy. This review will highlight the research gaps to be addressed in the thesis. Chapter 3 describes the methodology applied to this thesis, reflecting on the choice of interdisciplinary approach and the research methods selected. Chapter 4 presents the study of the attribution of 2012 West African precipitation (Q1). The Senegal case study of national adaptation policy is presented in Chapter 5, and the loss and damage policy study in Chapter 6 (Q2). Chapter 7 describes the process of developing the participatory game around event attribution (Q3). Finally, Chapter 8 reflects on the conclusions from the working chapters and the answers to the research questions and discusses the implications of this work, along with future research directions.

Each of the working chapters have been written as papers, which are published (Chapters 4, 6 and 7) or submitted (Chapter 5).

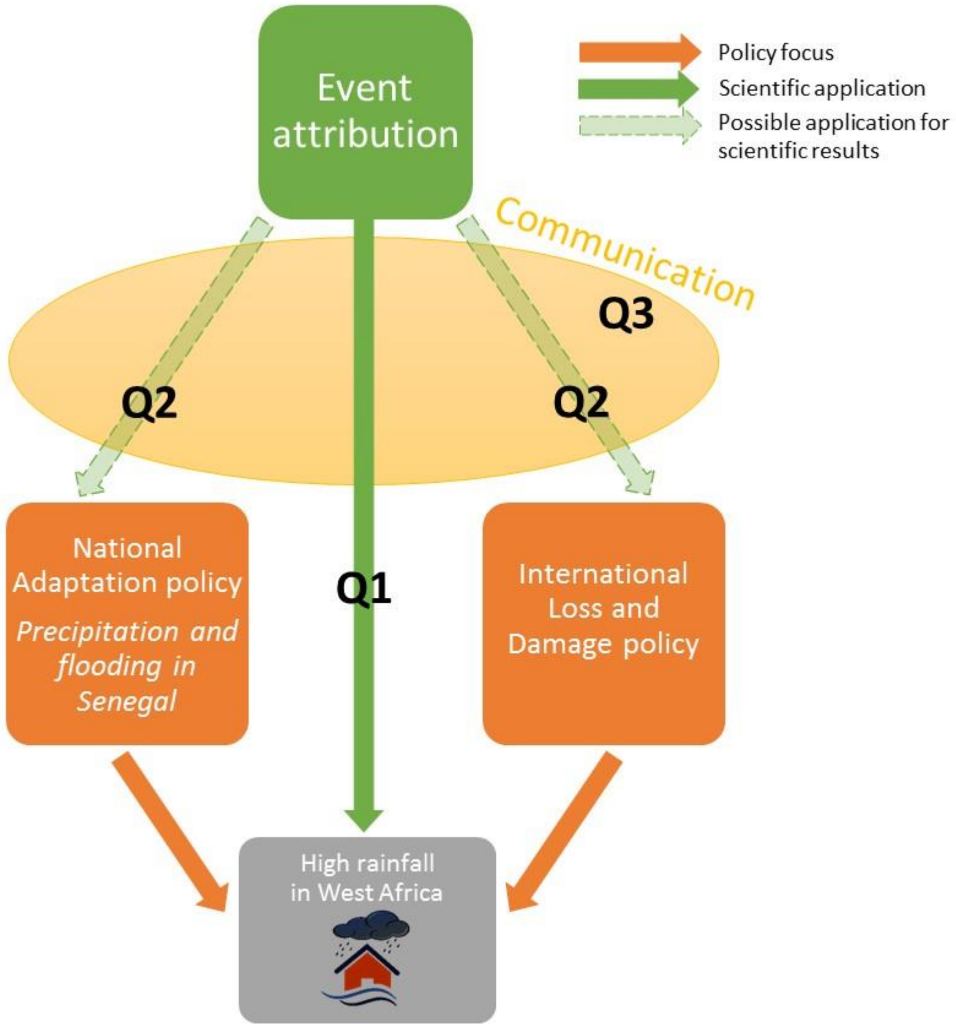

Figure 1.2. How the research questions fit together in the science and policy contexts.

2. Background

This chapter provides a background to the research questions to be addressed in this thesis. As the focus is on the relevance of event attribution for climate policy, it begins with a detailed summary of the development of event attribution science and the methodologies used, along with application of the techniques to African extreme events. This is followed by a description of the key ways in which it has been suggested that event attribution results could be applied. Finally, this chapter discusses more broadly the use of climate science in policy and the challenges associated with this, highlighting how the thesis focus on event attribution in policy has not been addressed before now.

2.1 Event Attribution Science

2.1.1 Attributing individual events

Assessing the role of climate change on individual events is challenging. Extreme weather and climate events occurred before the impact of anthropogenic emissions (Seneviratne et al., 2012), but all events are now occurring in a world that has been affected by climate change (Trenberth, 2012). Attribution is defined as the 'process of evaluating the relative contributions of multiple causal factors to a change or event with an assignment of statistical confidence' (Hegerl et al., 2010, p.2). While a particular event cannot usually be attributed to climate change in a deterministic sense due to the role of natural variability (National Academies, 2016), how it has been affected probabilistically can be assessed in some cases. This was first suggested by Allen (2003), considering who would be liable for damages due to climate change.

The following sections provide a background on the state of event attribution science, discussing the most common techniques applied and the reliability of the results from such studies. This will be followed by a description of the attribution studies that have been carried out on African events to date, as this is the region this thesis focusses on. Finally, considerations for the use of event attribution results and possible applications are discussed.

2.1.2 Event attribution methodologies

This section introduces some of the main methods used in the attribution of specific events. It begins with a description of the general methodology, considering changes in probabilities of an event. It then describes the method used for the first event attribution study followed by those using coupled and atmosphere-only models, and reanalysis and observational data. Considering events in a more conditional way is then discussed and, finally, how comparisons are made between the different methods.

2.1.2.1 General methodology

Event attribution studies generally consider the probability of a class of event above or below a particular threshold. The threshold that is used is often either the magnitude of an actual event that occurred or a percentile from the climatology (National Academies, 2016). The probability of exceeding the threshold is compared in the actual world to a world without a climate driver, such as anthropogenic emissions. These probabilities can be estimated using model simulations or observations, and then compared with a function such as the risk ratio (RR) or Fraction Attributable Risk (FAR; Allen, 2003). These are defined as

$$RR = \frac{P_1}{P_0}$$

$$FAR = 1 - \frac{P_0}{P_1}$$

with P_1 the probability of exceeding the threshold in the world containing all climate forcings, and P_0 the probability in the world with a forcing removed. These probabilities are illustrated in figure 2.1. The RR simply gives the ratio between the two probabilities, while the FAR gives the proportion of the probability that is attributable to the forcing considered. While the majority of studies have removed anthropogenic emissions to compare the probabilities, therefore comparing the actual world to a more natural world, some studies have also looked at the attribution of events to other climate drivers, such as La Niña (e.g. Lewis and Karoly, 2015).

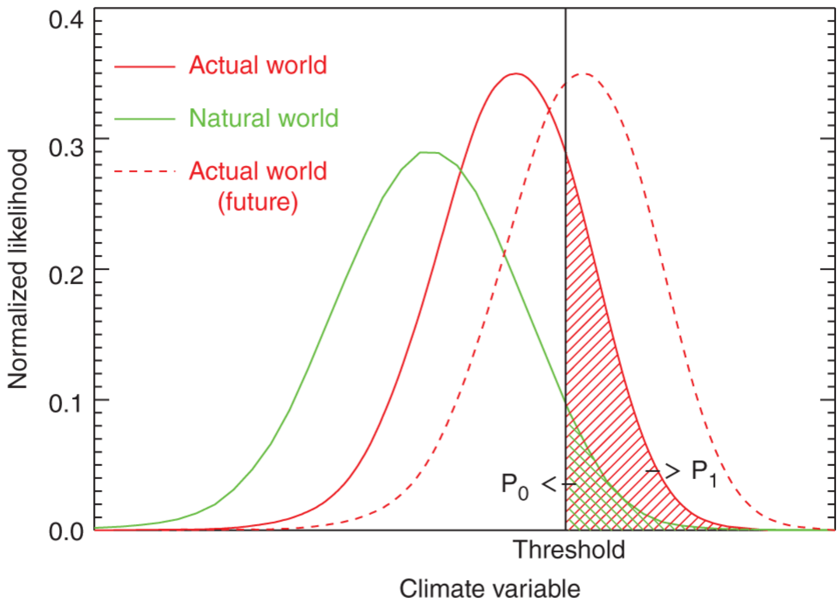

Figure 2.1. An example of likelihood distributions of a particular climate variable for the world with all climate forcings (red) and without a particular forcing such as anthropogenic emissions (green). The red hashed area marks the probability of exceeding a threshold in the actual world with all forcings (P_1) and the green hashed area marks that with the forcing removed (P_0). The red dashed line indicates how the likelihood distribution might change in the future. From Stott et al. (2016).

2.1.2.1 The first event attribution study

The first event attribution study was carried out by Stott et al. (2004) and looked at the 2003 European heatwave. This used the Hadley Centre Coupled Model version 3 (HadCM3), with four simulations including all climate forcings and one simulation including just natural forcings (solar and volcanic). The first step looked at whether a warming signal was detectable using optimal detection analysis. Regressions between observations and model simulations over 1920-1999 were analysed. For the simulations including anthropogenic forcings the likelihood distribution of the scaling factor (factor by which the amplitudes of the model simulations could be scaled while remaining consistent with observations) was found to be inconsistent with 0 and there was a detectable anthropogenic influence on the summertime warming.

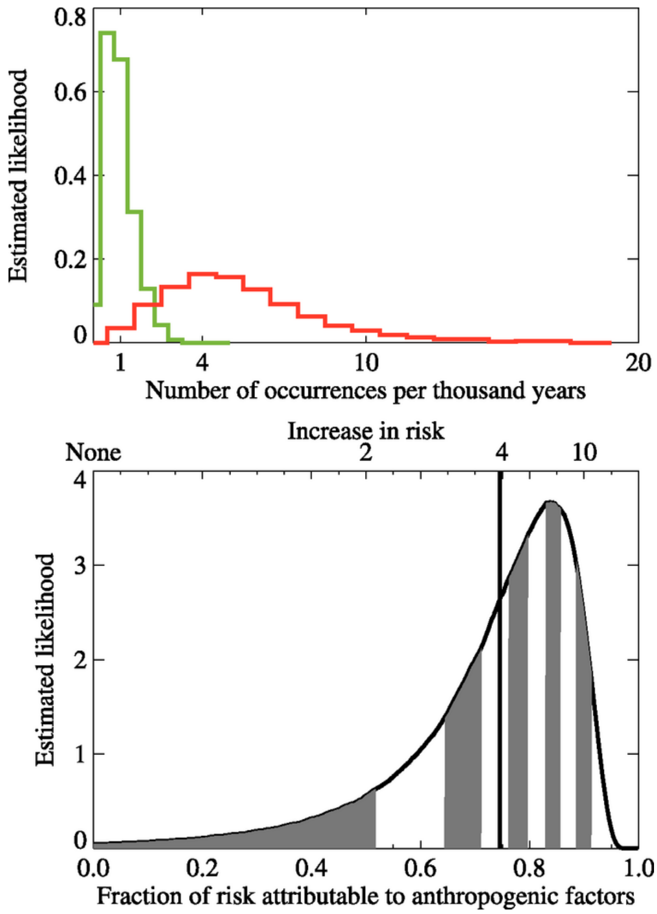

Figure 2.2. (Top) Histograms of the return periods of exceeding 1.6K in the late twentieth century in the world with all forcings (red) and without anthropogenic climate change (green). (Bottom) The distribution of the FAR with the mean value (vertical line). From Stott et al. (2004), in Hegerl et al. (2007).

The change in risk of hot summers was then analysed. The 2003 temperature was 2.3K above the 1961-1990 mean temperature. A threshold of 1.6K was used for the analysis, which was above the previous record high. This helped to reduce any selection bias from studying the exact event that occurred. Also, because the 2003 event was particularly extreme in the climatology, using a lower threshold helped reduce additional uncertainty from extrapolating extreme value distributions. Additionally, this particularly high event may have been amplified by soil-moisture feedbacks, unlike a lower magnitude 1.6K event, which may be under-estimated in the model. Generalised Pareto Distributions (GPDs) were fitted to control run variability around 1990s decadal mean temperatures for the anthropogenic simulations, and to temperatures adjusted to remove anthropogenic influences for the natural distribution. The distributions were bootstrap resampled to estimate the uncertainty, which then enabled the probabilities of exceeding the 1.6K threshold, and thus the FAR, to be calculated (figure 2.2).

This showed that there was a greater than 90% chance that over half of the risk of exceeding 1.6K above the mean temperature was attributable to anthropogenic forcings.

This methodology was repeated in a study by Christidis et al. (2015a), who looked at how the risk of the same event had changed since 2003, this time using seven models from the Coupled Model Intercomparison Project Phase 5 (CMIP5). The 1.6K threshold used in the first study was shown to have a ten-fold increase in probability of being exceeded due to anthropogenic influences – much greater than the estimate of doubled risk from the first study. This may have been due to the use of multiple models and therefore a decrease in uncertainty in the scaling factors, and therefore the attributed warming. This would lead to narrower temperature distributions being used in the calculation of the probabilities. Using the 2.3K threshold reached in 2003, the likelihood of exceedance was shown to have increased with return times down from thousands of years to hundreds of years, since the time of the event.

2.1.2.2 Atmosphere-only model studies

Following Stott et al. (2004), Pall et al. (2011) carried out the next most notable event attribution study, of the flood risk in England and Wales in autumn 2000. They used several thousand climate model simulations of autumn 2000 both under real-world conditions and how a natural world might have been without anthropogenic emissions. This study used the Hadley Centre Atmospheric Model version 3 at N144 resolution (HadAM3-N144, 1.25° longitude by 0.83° latitude). This is an atmosphere-only global climate model, at a higher resolution than was used by Stott et al. (2004), and also with a much higher number of simulations, enabling probability distributions to be constructed without the optimal detection step. This is important in this context where the event is much smaller in both space and time, and the resolution can better simulate features such as extratropical jets. For the natural simulations, greenhouse gases were reduced to 1900 levels and the warming effect on sea surface temperatures (SSTs) and sea ice removed. Estimates of SST warming attributable to greenhouse gas emissions were made based on simulations from four coupled climate models (HadCM3, GFDLR30, NCARPCM1 and MIROC3.2) and an empirical SST-sea ice relationship used to estimate effects on sea ice. This information was then fed into a precipitation-runoff model to look at daily river run-off. The authors found that it was very likely that anthropogenic greenhouse gas emissions had increased the risk of flood, by more than 20% in 9 out of 10 cases, and more than 90% in 2 out of 3 cases.

Other studies using similar methodologies have included, for example, the study by Shiogama et al. (2013) of the 2010 drought in South Amazon using the MIROC5 atmospheric general circulation model. Some studies use a regional climate model nested within a global atmospheric model for events in relatively small regions and on short timescales (e.g. Black et al., 2015; Schaller et al., 2014). Black et al. (2015) used HadRM3P within HadAM3P over an Australasian domain to consider the anthropogenic contribution to the Adelaide and Melbourne heatwaves of January 2014. Schaller et al. (2014) used HadRM3P over Europe within HadAM3P to study heavy precipitation in May and June 2012 in the upper Danube and Elbe basins. In general, atmosphere-only model studies are most relevant for events where feedbacks between the atmosphere and the ocean can be neglected. These studies generally tend to use very large ensembles of simulations (in the hundreds or thousands) that are short (from less than a year to a decade), from usually just one model (National Academies, 2016).

The simulations used by Pall et al. (2011) were run on a distributed computing network using members of the public's computers as part of the weather@home modelling system (Massey et al., 2015). This can generate many thousands of simulations and has also been used for other event attribution studies (e.g. Black et al., 2015; Otto et al., 2015; Schaller et al., 2014; 2016). Christidis et al. (2013) also developed a system for event attribution using atmosphere-only simulations based on HadGEM3-A simulations, run on a more conventional supercomputer system. In the first instance, this was applied to events that occurred in 2010, using 100 simulations of the actual climate and three 100 member ensembles of the natural world, using estimates of the anthropogenic influence on SSTs from three coupled GCMs: HadGEM1, HadCM3 and HadGEM2-ES. The simulations showed that the probability of a winter colder than 2009/10 in the UK had been decreased by 7-10 times by anthropogenic emissions, and emissions had increased the probability of a heatwave in Moscow 2010. Model evaluation showed that it was not able to provide reliable results for an attribution of high precipitation in Pakistan in 2010 which led to flooding, as model variability was too low.

Observations of SSTs and sea ice are used for the simulations with all climate forcings. However one source of uncertainty in these studies is how the anthropogenic greenhouse gas impact on SSTs is estimated, in order to be removed from the SST patterns for the natural model simulations (National Academies, 2016; Christidis and Stott, 2014). Studies such as Christidis et al. (2013) use a model estimate of the anthropogenic effect on SSTs for the natural forcings simulations, and an empirical relationship for the effect on sea ice. For example, this study used estimates from HadGEM1, HadCM3 and HadGEM2-ES, and Pall et al. (2011) used four coupled climate models: HadCM3, GFDLR30, NCARPCM1 and MIROC3.2. Attribution results have been shown to be sensitive to the warming pattern that is removed from the SSTs and so it has been suggested that studies should use more than one counterfactual SST pattern (Stott et al., 2015).

An alternative way that has been suggested is to use SST patterns based on observations, removing the long-term trend in observed SSTs to estimate what they would have been in a natural world. This was introduced by Christidis and Stott (2014) in an effort to reduce uncertainty in model estimates. However this does not separate out natural forcings, but these are likely to be minimal as they are short-lived compared to the long trends used. It also assumes a linear trend in the impact of anthropogenic forcing which, although reasonable for greenhouse gases (GHGs), may not be the case for other aerosols which may have non-monotonic effects (Christidis and Stott, 2014). There is also the problem of observations effectively only being a single realisation of the system, such that the probability of the observed evolution of the climate system (and therefore the representativeness of its trend) cannot be perfectly known.

Because atmosphere-only model simulations are run with prescribed SSTs, they can also be run with forecast SSTs, over periods of days, or months in seasonal forecasts (National Academies, 2016). Examples using weather-type forecasts are often run at much higher resolution, for example the Meredith et al. (2015) study of precipitation in a town in Russia in 2012, who used the Weather Research and Forecasting model down to 0.6km resolution and initialised every 6 hours.

2.1.2.3 Coupled model studies

The other main modelling event attribution technique uses coupled climate models, which include the influence of the oceans. Model simulations are often used from the CMIP5 archive which have already been run, vastly reducing the computational power required to carry out studies. For example, CMIP5 simulations have been used in studies by Lewis and Karoly

(2013) and King et al. (2013) to investigate the anthropogenic contribution on extreme events in Australia, and by Knutson et al. (2014) in their study of 2013 US precipitation. These models can simulate feedbacks between the atmosphere and the ocean which are vital for the development of some events, particularly in the tropics (Stone et al., 2009). While these simulations incorporate all climate variability, some studies have also conditioned on those which can represent teleconnections and are in the correct phase for the particular event, for example for ENSO (Bellprat et al., 2015; Lewis and Karoly, 2013).

2.1.2.4 Empirical approaches

Empirical approaches use observations rather than climate model simulations to estimate how climate change has affected the probability of particular types of events. This is valuable as a check for model results, and to study events not yet represented well enough in models (Stott et al., 2015). Analysis of changing probabilities of events in observations requires long-term high quality data. This method compares the probability of exceeding a threshold in current conditions with an earlier period with less effect of anthropogenic forcings. It therefore does not separate out the anthropogenic climate change component but looks at the total climate change effect (Stott et al., 2015). Attribution using observations is best for temperature or variables closely related to temperature, as there are results quantifying the anthropogenic influence on long-term temperature change (National Academies, 2016). For example, the King et al. (2015) study of Central England temperatures makes use of earlier work attributing at least part of the warming trend in temperatures in that region to human influences (Karoly and Stott, 2006). Other examples of studies using observations include those by van Oldenborgh et al. (2012), looking at 2011 Thailand floods, and by Siswanto et al. (2015), looking at flooding in Jakarta in 2014.

2.1.2.5 Analogue methods

Analogue methods are used to estimate climatic conditions in the past as they would have been under the same large-scale circulation as today. This method commonly uses flow analogues in reanalysis data. Days around the event in question in different years with similar circulation patterns are selected and sampled. Samples are taken from two different time periods and the probability of a particular event calculated in each, under broadly the same circulation. This is therefore an attribution conditional on the circulation pattern. This does not model the world as it might have been without anthropogenic climate change so, like the empirical approach, the event attribution is to overall climate change over the period of study, rather than with the anthropogenic influence separated out. However, the time periods used are assumed to be long enough that low-frequency natural climate variability is cancelled out (Stott et al., 2015). Examples using this method include the Xoplaki et al. (2005) study of European spring and autumn temperature extremes, and the Cattiaux et al. (2010) investigation into the particularly cold winter in Europe in 2010.

2.1.2.6 Conditional model approach

The dynamic effects of climate change are much less certain than the thermodynamic (Shepherd, 2014), and less well represented in models, with smaller signal-to-noise ratios (Trenberth et al., 2015). Therefore, Shepherd (2016) argued that while events caused mainly by thermodynamic processes may be reliably attributed using the standard risk-based approach, for an event that is in part caused by particular extreme dynamic conditions, simulated changes in these conditions would need to be reliable. Shepherd argues for a 'storyline' approach, where each factor's role in an event is assessed conditionally. This follows the (somewhat controversial) suggestion by Trenberth et al. (2015) that for extremes driven by particular dynamic conditions, the thermodynamic effect of climate change on the event should be considered conditional on the unchanged circulation. In separating out the dynamic and thermodynamic components of the event, this does not address the change in likelihood of the dynamical situation leading to the event, and instead conditions on this (Shepherd, 2016). This means that if the probability of the dynamical state changes, the probability of the event could also change. Also, just considering the thermodynamic effects could overemphasise the role of anthropogenic climate change if these are small compared to the natural variability leading to the dynamic state (Stott et al., 2015). Otto et al. (2016) also discussed how looking at the thermodynamic effects on an event, given the particular circulation pattern that occurred, would not give an overall picture of how an event had been affected by climate change. This is because circulation changes due to greenhouse gases could act to either increase or decrease the thermodynamic effects at the local scale. Therefore, for information on the overall climate change influence, which might be more relevant for those addressing the impacts of events, studies should look at both the thermodynamic and the dynamic effects on an event. Although climate models are generally not as good at looking at circulation changes as thermodynamic influences, this can be possible for some types of events (Otto et al., 2016).

There are some examples of studies that have conditioned on the dynamic state. These include a study of hurricane Sandy (Lackmann, 2015) and another of the 2011 Texas drought and heatwave (Hoerling et al., 2013). Hoerling et al. (2013) showed that the precipitation deficit was mainly due to natural variation, but some of the heatwave magnitude was attributable to anthropogenic climate change.

2.1.2.7 Comparing methods

Some studies have begun to compare different methods for the same event. This helps to develop understanding about how robust the attribution statement is for that event. For example, King et al. (2015) looked at high Central England annual temperature in 2014 using both empirical methods and CMIP5 coupled model simulations. This showed that anthropogenic climate change greatly increased the probability of record high temperatures. In another study, coupled and atmosphere-only model ensembles were compared in a study of high precipitation in 2010-2012 in Australia (Lewis and Karoly, 2015). The attribution of heavy rainfall was uncertain using an ensemble of CMIP5 simulations but clearer using two different atmosphere-only model simulation ensembles. There was an increase in probability of extreme rainfall using these models, but there were still differences in the results between models and also between estimates of anthropogenic SST warming. Uhe et al. (2016) studied European 2014 temperatures using an empirical methodology, CMIP5 data and atmosphere-only simulations from the weather@home project. They found anthropogenic influences greatly increased the risk of high temperatures across all of the methods.

The special issues in BAMS attributing events in the previous year sometimes have studies of the same events using different methodologies. For example, there were multiple analyses of the 2013 Californian drought (Funk et al., 2014; Swain et al., 2014; Wang and Schubert, 2014). Funk et al. (2014) showed that long-term SST warming trends did not have a substantial contribution to the droughts of 2012/13 or 2013/14. Swain et al. (2014) showed that the atmospheric conditions contributing to the drought of 2013/14 were more likely due to human emissions. Wang and Schubert (2014) said the warming trend both increased the probability of blocking highs in the northeast Pacific, increasing drought risk in early 2013, but also increased atmospheric humidity over the same region which would increase wet events over California.

They concluded that these two effects seemed to counteract each other. The three papers show that the effects of climate change on drought in the region remain uncertain.

Angélil et al. (2017) carried out the first large-scale assessment of the sensitivity of results to the methodology used by re-analysing a range of events that had been studied in BAMS reports with one method using atmosphere-only model simulations. Results were found to be similar to those in the reports for temperature extremes but disagreed for many precipitation extremes, although without systematic bias. They therefore recommended the use of multiple models in event attribution and highlighted the importance of uncertainty analysis.

In general, through prescribing SSTs in simulations, model biases are reduced and simulations are cheaper to run. This means there are often more ensemble members for analysis, which may lead to better representations of extremes and improved signal-to-noise ratios. However, as the atmosphere and ocean are not coupled, extremes that are strongly affected by coupling may not be well represented (Stott et al., 2015). As the dynamic responses of the atmosphere to climate change are uncertain, it has therefore been suggested that studies should use more than one model (National Academies, 2016). However, to date, there have been relatively few studies comparing the different methodologies and model ensembles. Yet understanding whether results are robust across the different methodologies will be important if such results are to be used in decision-making.

2.1.3 Reliability and confidence in studies

Event attribution results have been shown to be most reliable when they are based on sound physical principles, consistent with evidence from observations, and the models can replicate the event in question (National Academies, 2016). This means that some events are more robustly attributable than others. Also, before using models for event attribution, their ability to produce the type of event being studied should first be evaluated.

2.1.3.1 Model evaluation

As models are often used in event attribution studies, in order for the results to be reliable the models must be able to accurately represent the events they are being used to study. In particular, attribution can be overestimated by unreliable climate simulations (Bellprat and

Doblas-Reyes, 2016). The models need to be able to reproduce similar extremes to that studied along with the statistics of such events, as well as the circulation patterns necessary for the extreme event to develop, the physical processes and mechanisms involved, and internal variability modes which drive regional extremes and local feedbacks (Stott et al., 2015; National Academies, 2016).

Uncertainties in model analyses of event probabilities and magnitudes come from boundary condition uncertainty, model uncertainty, parametric uncertainty, counterfactual boundary condition uncertainty and conditioning uncertainty (Hawkins and Sutton, 2009). Characterising parametric uncertainty can be done by using perturbed physics ensembles to sample from the parameter distributions, as in Christidis et al. (2013). Model uncertainty can be characterised by using ensembles from a range of models, such as from CMIP5 as in King et al. (2013). Using different estimates of SST patterns in a natural world in atmosphere-only model studies (e.g. Christidis et al., 2014) can characterise this part of the uncertainty. Considering changes in events due to circulation changes can be challenging and unreliable at times as models often have difficulties representing circulation changes under climate change (Trenberth et al., 2015). Therefore models can be more reliable for attributing events experiencing thermodynamic changes rather than dynamic, but disentangling the two can be challenging (National Academies, 2016).

Bias corrections can be made to model distributions, usually in terms of the mean or the variance, but this can strongly influence the attribution statement (Sippel and Otto, 2014). Also, bias corrections rely on observations that can have their own uncertainties. Observational uncertainty from measurement error can be an issue for both evaluating models and for empirical approaches (National Academies, 2016).

It has been suggested that a way of evaluating models and therefore the estimated FAR is to use reliability diagrams, which are correlated to the calculation of FAR, or to use two reliability diagrams, from an early and late period of the study. The earlier observational period can then be used as a proxy for observations of the natural world, as this would have less anthropogenic forcing (Lott and Stott, 2016). Some progress has been made using this information to further quantify and correct errors in FAR (Bellprat and Doblas-Reyes, 2016, supplementary material) but this remains in the early stages of development.

2.1.3.2 Different types of events

Different types of events can be attributed with different levels of confidence, as shown in figure 2.3. In general, there is more evidence for the attribution of temperature extremes than precipitation extremes. Over the five years of BAMS reports, all except one heat event studied were made more likely or intense due to climate change, whereas for most high precipitation events no human influence was found (Herring et al., 2016). For heat events the direct thermodynamic effects are generally more straightforward than for events such as extreme precipitation. While extreme precipitation events are expected to increase in frequency and intensity on average due to thermodynamic effects, they are also governed by atmospheric circulation and dynamical changes, for which climate change influences are less well understood (National Academies, 2016).

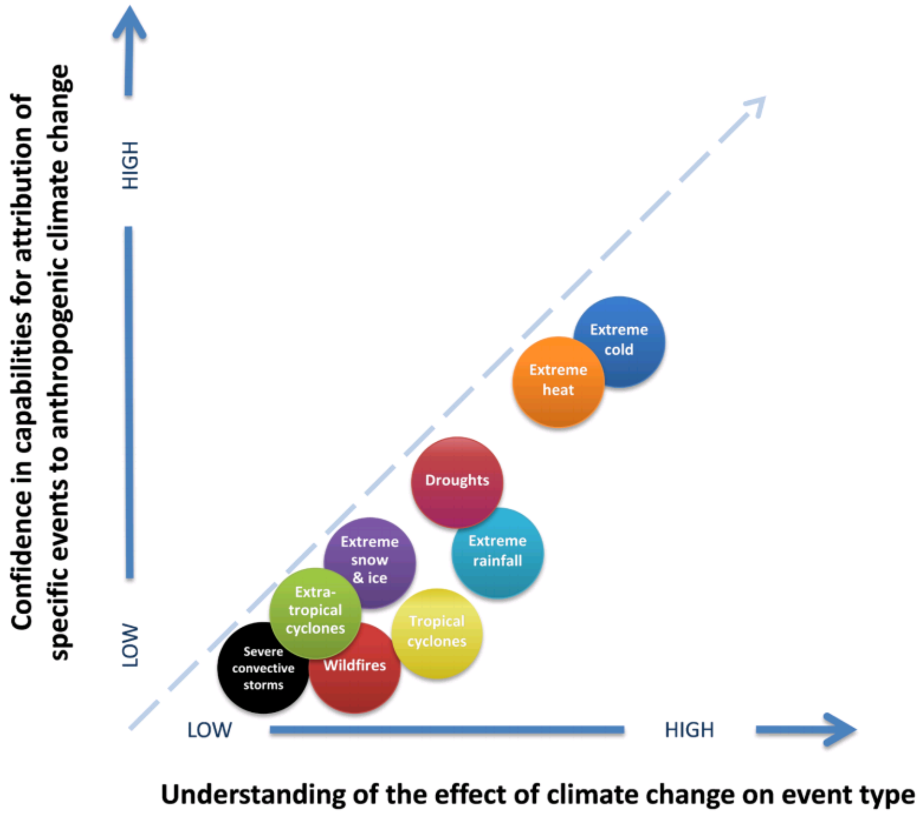

Figure 2.3 Schematic of the state of event attribution science for different types of events. From National Academies (2016)

Challenges in attributing precipitation events include that while there are robust temperature observations across much of the globe, precipitation observations are inadequate in many regions. Good quality observations are required to both define the extreme events to be studied and to validate the climate models used (Otto et al., 2015). Also, models have limited representation of cloud processes which are vital for reliably modelling precipitation events (Stott et al., 2015). Small time and space scales are required for the modelling of extreme precipitation events and the majority of models are not of high enough resolution to parameterise convection, therefore caution is needed in such studies. Another challenge for attributing floods and droughts compared to just the precipitation is that land-use decisions affect the natural hydrology including run-off and therefore also the risks of extremes. There is little or no confidence in the attribution of severe convective storms and extratropical cyclones due to both model ability to represent the dynamics of such events and the high resolution level, and therefore amounts of computing power, which would be required to model them (National Academies 2016).

2.1.4 Africa-specific studies

As discussed in Chapter 1, there have been relatively few event attribution studies on African events. However, understanding the causes of extreme events and how they are likely to change in the future is particularly relevant in developing regions such as this, and so this thesis focusses on event attribution in Africa. As a background, this section summarises the event attribution studies which have been carried out in the region to date. There are challenges to carrying out studies on African events, including limited observations with which to define events and validate models, high interannual variability in precipitation strongly influenced by teleconnections which can make it difficult to distinguish a signal from the noise, and also the uncertain role of aerosols in influencing the climate (Otto et al., 2015).

The first African study was carried out in 2013 by Lott et al. and looked at the East African drought of 2011. This study used an atmosphere-only model and therefore required the anthropogenic warming influence to be removed from the SSTs for the natural forcings simulations. Three different estimates of this influence from coupled models were used. Results showed that the failure of the 2010 short rains was due to La Niña, but human influence had increased the probability of long rains at least as dry as those in 2011. The magnitude of the increase in the probability of dry long rains was shown to depend on which estimate of natural SSTs was used. This highlights a paradox, as climate models project increasing trends in East African rainfall (Rowell et al., 2015), whereas this study found an increased risk of dry conditions in the year studied. This may be due to the strong influence of SST changes on rainfall in the region, which can be both anthropogenic and natural, but further work is needed to understand these mechanisms.

Funk et al. (2013) also studied rainfall deficits in eastern Kenya and southern Somalia, using a similar method to Lott et al. (2013), but considered the influence of ENSO rather than GHGs. Their atmosphere-only simulations were therefore driven by full-ocean and ENSO-only SSTs. This showed that the non-ENSO SST variations increased the risk of a dry event in 2012 and over the 2003-2012 period. However, they note that this does not account for all the drying, and other factors such as a warming Western Pacific are also important.

Another study using atmosphere-only models was carried out by Otto et al. (2013) on Congo basin rainfall, using simulations run by the weather@home system. Comparing simulations of the actual world with those of a world without anthropogenic greenhouse gas emissions showed that return times of extreme high and low Congo dry season precipitation were not significantly changed. The study highlighted that with tropical precipitation having higher interannual variability than in the extratropics, disentangling natural SST variability from anthropogenic drivers is more challenging. However, precipitation in such regions is more predictable from given SSTs than in the extratropics (Otto et al., 2013).

Wolski et al. (2014) studied the flood in the Okavango basin in Botswana in 2009-2011. They used atmosphere-only climate model simulations following the methods of Pall et al. (2011), and estimated the natural SSTs using one coupled model. Wolski et al. used fewer ensemble members than studies such as that by Pall et al. (2011), as the event being studied was over a longer time period and not as rare, so fewer members were needed to represent the statistics of such events. The climate model information was used to drive a hydrological model, which showed that the probability of high floods was lower than it would have been in a climate without GHG emissions. This was found to be due to increased evaporation and minor precipitation changes. This study also highlights an attribution paradox (as the Lott et al. (2013) study did): a trend towards more frequent high floods was observed, but the probability of such events was shown to have decreased. There is some evidence that interannual variability in anomalous SSTs is more important than overall warming for flood risk in the region, which could explain this (Wolski et al., 2014).

Angélil et al. (2014b) used model simulations from the experiments carried out for the study by Pall et al. (2011). Studying daily extremes across South Africa, they found that while attributable changes in hot and cold days were consistent across larger areas, attributable changes in heavy precipitation days had large variations at grid resolution level. This highlighted that attribution results for heavy precipitation events could be sensitive to how the event is defined spatially.

A study by Bellprat et al. (2015) looked at precipitation in southern Africa. This used coupled simulations from the CMIP5 archive to study the anthropogenic climate change influence on the probability of a dry austral summer in 2002/2003 and a wet summer in 1999/2000. This showed that the probability of the dry event had been increased but of the wet had been decreased. However, when using an extreme index of maximum 5-day precipitation totals, the probability of this index being high appeared to have increased for the 1999/2000 event, again highlighting the importance of clearly defining the event being studied. This study also conditioned on simulations being in the correct ENSO phase for the event, as this is a strong teleconnection in the region, however this mainly acted to increase uncertainty in the attributable risk.

Finally, in the most recent BAMS annual reports, studying events from 2014 and 2015, the number of studies focussing on African events has increased. Three studies were carried out in the report on events from 2015: on the late onset of the wet season in Nigeria, where no evidence of a probability increase due to anthropogenic influences or anomalous SSTs was found (Lawal et al., 2016); on drought in Ethiopia and southern Africa, which was influenced by increasing El Niño SSTs and air temperatures caused by anthropogenic warming (Funk et al., 2016); and on the Egyptian heatwave, where the wet bulb globe temperature, a proxy for human discomfort, was found to have been increased by anthropogenic climate change (Mitchell, 2016).

2.1.5 Event attribution science in this thesis

From this review it is clear that there have been only a limited number of event attribution studies focussing on African events, with only one study in West Africa to date. This continent poses challenges for such studies particularly when considering precipitation due to limited observations, high interannual variability and strong teleconnection influences (Otto et al., 2015). It is therefore worth further investigating the application of event attribution techniques here. As has also been shown, there have been a range of techniques developed, but very few studies directly comparing these for the same event, and none for African events to date. Therefore this thesis will address this research gap, investigating whether event attribution results are robust across coupled and atmosphere-only model ensembles for events in West Africa, using a precipitation event in 2012 as a case study.

2.2 Applications of event attribution studies

While scientists have been developing the science of event attribution, there has also been some consideration of uses for the results. This has included suggestions of uses from both scientists themselves and from different stakeholders for whom results could be relevant. The following section discusses a key consideration if results are to be interpreted for use: the importance of defining the question to be studied. This is followed by a discussion of current developments in event attribution, aiming to make results more relevant for applications. Specifically this covers the development of event attribution on an operational basis, and moving from attributing events to anthropogenic climate change, to attributing the impacts they cause. Finally, some of the main ways it has been suggested that results could be useful are presented, including those to be investigated further in this thesis.

2.2.1 Framing the attribution question

The framing of event attribution questions is important to define and communicate clearly so that results can be interpreted accordingly, as discussed by Otto et al. (2015). Stone et al. (2009) describe knowing what output is required by users to be one of the main challenges in event attribution, including what effects and forcings should be considered and what baseline is used. For example, the effect of anthropogenic climate change on temperatures in a particular year may differ from those across a decade (which could be defined as a longer period event). These two scenarios ask different questions: the first how a particular event was affected, given all other factors being the same (such as SSTs, assuming forced SST experiments), while the second considers anthropogenic impact given equal long-term variability and therefore analyses a climatological shift (Otto et al., 2015). The way a question is framed can determine the answer given for the effect of climate change. For example, the thermodynamic and the dynamic responses to greenhouse gases may act in the same way or oppositely for an event, and which response is studied will affect the answer that is found (Otto et al., 2016).

Studying events over larger areas and longer time scales reduces natural variability, which can make it easier to disentangle the anthropogenic contribution to events. This often results in larger FARs reported than for smaller scale extremes. However, the smaller scales often more closely relate to the actual impacts of the event (Stott et al., 2015). Results of attributable risk are particularly sensitive to temporal scales, but are also sensitive to spatial scales (Angélil et al., 2014a). In their study of 2014 European temperatures, Uhe et al. (2016) found the attribution result of an increased risk was sensitive to the spatial and temporal definition of the event, with the increase in risk declining as the spatial scale decreased. Results from studies of temperature events are often valid within smaller domains to that studied, and also in nearby areas, but heavy daily precipitation events are much more sensitive to event definition (Angélil et al., 2014b), and so the results cannot be generalised as well.

When considering the Russian heatwave of 2010, results from Dole et al. (2011) that it was mainly natural, and from Rahmstorf and Coumou (2011) that anthropogenic climate change greatly increased the probability of the heat record, appeared contradictory. These were reconciled by Otto et al. (2012), who showed that while the magnitude of the event was mainly natural, the probability of it occurring was increased by external forcing. This highlights the importance of clarifying the question being considered so that the results can be interpreted accordingly.

It is also important to define the event to be studied. The National Academies (2016) report discusses this using the example of definitions of drought: studies of Californian drought have found no anthropogenic influence when considering just precipitation (Seager et al., 2015), but when considering precipitation alongside high temperatures an anthropogenic influence has been found (Diffenbaugh et al., 2015; Williams et al., 2015). Attributable risks of exceeding different thresholds can also be very different and so understanding what thresholds are most relevant for stakeholders will be vital to ensure that results can be used in decision-making (Otto et al., 2015).

There may be biases in the selection of events that are studied and the impacts of climate change this portrays if events are mainly chosen based on the fact that climate change may have had a role to play. While this could be an issue when looking at the effects of climate change on events globally, it may not be if studies are to be used for adaptation and planning, which require information about specific contexts (National Academies, 2016). A way of removing selection bias is to look at annual extremes across large areas and the contribution of climate change (e.g. Min et al., 2011; Zwiers et al., 2011; Zhang et al., 2013), which would therefore not choose events on the basis of their impacts.

2.2.2 Operational event attribution

Event attribution studies have predominantly been carried out on a case-by-case basis in the aftermath of events that caused particularly severe impacts. Work is now developing the implementation of event attribution on an operational basis, where events could be attributed as soon as they have occurred. An operational system could help provide assessments of events in a more timely manner and remove current selection effects due to scientists choosing the events to study, to build a more general picture of climate change effects on events around the world (Stott et al., 2015). In order for events to be studied quickly a system would require either empirical methods, atmosphere-only models run with forecast SSTs, or precomputed coupled simulations (Christidis et al., 2014).

There are some examples of groups working on these more real-time studies. These include the EUropean CLimate and weather Events: Interpretation and Attribution (EUCLEIA) project, which is working on an operational system based on HadGEM3-A. This will run on a seasonal cycle producing assessments for each season (National Academies, 2016). As part of this project, Christidis et al. (2015b) have pre-computed the changing frequencies of warm extremes across the world using coupled simulations from seven CMIP5 models, so the information is available when a new event occurs.

World Weather Attribution from Climate Central is using observational approaches, CMIP5 and weather@home simulations run with seasonal forecast SSTs to predict the probability of extremes a month ahead (Haustein et al., 2016). World Weather Attribution produced a rapid attribution assessment of the August 2016 Louisiana precipitation which led to flooding in the region. Using both empirical techniques and climate model simulations that were already available, they submitted an analysis in the same month as the event occurred, showing that the probability of the event was increased by anthropogenic climate change (van der Wiel et al., 2017). Another example is the Weather Risk Attribution Forecast, from the University of Cape Town, the Lawrence Berkeley National Laboratory and the University of Botswana. Using atmosphere-only models, preliminary attribution forecasts are made one month ahead using forecast SSTs, and final versions follow 2-3 months later with observed SSTs (National Academies, 2016).

2.2.3 Attributing impacts to climate change

A next step on from attributing particular events is to attribute the impacts of those events to anthropogenic climate change. Some studies (e.g. Pall et al., 2011; Wolski et al., 2014) investigating flood events have used the meteorological information from climate models to drive hydrological models to look at the flood risk. Schaller et al. (2016) go one step further in their study of the 2014 southern England winter floods. Starting with attributing the meteorological event, climate data are fed into a hydrological model to analyse the river flows, and this information is then combined with flood risk information for properties to estimate the change in the number of properties at risk. They found that around 1000 more properties were at risk of flooding in the present climate compared to a natural one when considering an event with a return period of around 100 years, although this has wide uncertainty.

Focussing on health impacts, Mitchell et al. (2016b) looked again the European heatwave of 2003, but examined the risk of deaths in London and Paris. They used a high resolution (25km) regional model and land surface scheme within the weather@home framework, along with a formula for estimating the number of deaths attributable to heat. Results showed that anthropogenic climate change resulted in around 64 deaths in London and 506 in Paris out of approximately 315 and 735 deaths in total during the heatwave, respectively. A study of the 2015 Egyptian heatwave analysed the wet bulb globe temperature during the event. This is a function of temperature and relative humidity and is a measure of human discomfort, and was found to have been increased by anthropogenic climate change (Mitchell, 2016).

2.2.4 Stakeholder relevance

The following discusses some of the key areas in which event attribution results could be applied that have been suggested and debated to date. As event attribution techniques have been developing there have been suggestions made, predominantly by scientists involved, of ways in which results could be applied. There has been limited engagement with stakeholders to establish how results could be useful. For example, there was a workshop held in 2012 with stakeholders from various sectors and attribution scientists to identify the needs of stakeholders and how attribution could fit with these (Stott and Walton, 2013). However, there are still significant gaps in the understanding of stakeholders' views on the role of event attribution for policy making.

2.2.4.1 Adaptation policy

Both scientists and stakeholders have discussed the relevance of event attribution results for adaptation planning to address the impacts of extreme events. Many event attribution studies mention that their results could be useful in this way (e.g. Pall et al., 2011) and this could be useful information for governments and charities (Stott and Walton, 2013). Knowing how the risk of an event has been affected by anthropogenic emissions could help to inform about the future, as changes in risk caused by emissions are expected to continue in the future (Otto et al., 2015; Stott et al., 2011; Stott et al., 2013). However, the applicability of event attribution has also been criticised, as it could suggest that adaptation funding should be awarded where risks are attributable to climate change, instead of building adaptive capacity through considering the vulnerability and exposure of affected populations (Hulme et al., 2011). Considering only the meteorological hazard, rather than the overall risk, could lead to considerations of ethical complexity and political sensitivity not being taken into account (Hulme et al., 2011). Therefore Hulme (2014) argues that the complex social, political and economic structures around hazards should also be considered, and particularly whether damages are due to the meteorological hazard or exposure. Hulme et al. (2011) also suggest that, rather than providing objective scientific analysis, attribution results are subjective. As climate models have uncertainties, results depend on the models selected and judgements on uncertainty, which could lead to political contestation. Nevertheless, it may be that attribution information could be useful alongside knowledge of exposure and vulnerability, as suggested by stakeholders in a study by Sippel et al. (2015). Although these perspectives have been discussed in the literature, they have not yet been investigated empirically in specific policy contexts.

2.2.4.2 Loss and damage policy

The UNFCCC loss and damage agenda aims to address the negative impacts of climate change, including those from extreme events (UNFCCC, 2013). Although this does not make any distinction between events that are attributable to human influence and those that are not, it has been suggested that event attribution could be relevant here if this distinction was to be necessary to determine which losses and damages are to be addressed by this area of policy (James et al., 2014; Parker et al., 2015). It could be useful if a compensation component was to exist (Huggel et al., 2015) or for the recognition of losses and damages attributable to anthropogenic climate change to achieve restorative justice (Thompson and Otto, 2015), but may detract from the need to look at all the components of disaster risk (Surminski and Lopez, 2014).

Determining whether evidence of causality of events will be necessary for loss and damage, and what types of information would be required, will require dialogue between scientists and the policymakers involved (Parker et al., 2015). While there has been much debate around the relevance of event attribution in this area of international climate policy in literature, it has not been examined empirically to develop understanding of the perspectives of those stakeholders directly and indirectly involved in the negotiations.

2.2.4.3 Liability

At the first suggestion of event attribution, Allen (2003) considered its relevance in assigning responsibility and liability for climate change impacts. Liability has been considered as part of the loss and damage negotiations. Knowing the extent to which an event can in some way be blamed on anthropogenic climate change could be relevant for those seeking some form of compensation for harm from emissions (Stott et al., 2013). Liability cases for specific climate-related damages are already being considered in courts, and courts are familiar with dealing with uncertainty in information, such as is inherent in event attribution results (Stott and

Walton, 2013). Studies could also be relevant in cases where geoengineering has taken place, to inform about negative impacts for which people may want compensating (Stott et al., 2013; Stott and Walton, 2013), as an extension to work being carried out by Lo et al. (2016) detecting geoengineering influences in a hypothetical world. However, using results in this way would be complex. For compensation, it is likely that not only would the event need attributing but also the impacts, and complex decisions would need to be made around who is responsible for payment (Mera et al., 2015). There are also questions of whether the risk due to different types of emissions, and other anthropogenic factors such as land-use change, would need to be separated (Hulme, 2014). Furthermore, allocating climate funds will likely remain a political issue not informed by specific scientific studies such as these (Sippel et al., 2015).

2.2.4.4 Awareness raising

It has also been suggested that event attribution results could help to communicate the impacts of climate change and links between climate change and extremes with the public (Stott and Walton, 2013). This could help to raise awareness of the impacts of climate change (Sippel et al., 2015) and improve public understanding of whether events are signs of climate change or if more are expected in the future (Stott et al., 2013). Charities have also said this information could help communicate the need to prepare for climate change effects in the present (Stott and Walton, 2013). It may be that information about the climate change influence on specific events which have affected people at the local level can more clearly convey what is known about global climate change than other information such as long-term climate projections.

2.2.4.5 Improving climate change understanding

Event attribution studies can help improve understanding of the climate more generally, including how and why events change over time (National Academies, 2016). This can be by improving understanding of the causes of extremes and their links to anthropogenic climate change, improving understanding of climate signals, and improving prediction of extremes (Stott et al., 2013). This could be particularly useful for regions where there is a lack of detailed climate information to date, to improve understanding of the current climate (Sippel et al., 2015).

2.2.4.6 Insurance

Results could be relevant for insurance, to provide information on how risks of events are changing so that premiums can be priced accordingly (Stott et al., 2013). However, stakeholders themselves are uncertain as to whether this would be relevant: while it could determine the extra element of risk from climate change (Sippel et al., 2015), it may be more important to consider patterns of events over a period of time than to just study one event (Stott and Walton, 2013).

2.2.4.7 Perceptions of event attribution and communication with stakeholders

Along with gaps in the empirical understanding of the relevance of event attribution for policymaking, there are also gaps in understanding perceptions of event attribution and the role of communication. There is very little literature on perceptions and understanding of event attribution science. Work that has been done by Sippel et al. (2015) involved interviewing a small sample of climate policy and adaptation stakeholders. Interviewees were first presented with results from an attribution study of summer heatwaves in southeast Europe, showing increasing probabilities (Sippel and Otto, 2014). Interview questions then focussed on how the stakeholders used climate science, how probabilistic event attribution results might be useful or not, and how such information could be made more useful. All the stakeholders thought results could potentially be relevant to their work, including in areas of insurance to determine additional risk from climate change, to raise awareness of climate change impacts, and to highlight the relevance of addressing public health-related risks from climate change now. There was also debate around whether results could be relevant to allocating adaptation funds and attributing loss and damage, or whether these questions would remain within political processes. Interviewees highlighted that if event attribution results were to be applied, this would be alongside other climate information already used. Also, the results would need to have high credibility, uncertainties would need to be clearly illustrated, and results would have to be precisely communicated in understandable ways.

This preliminary work was carried out with just 14 stakeholders mostly working in Europe. However, international loss and damage policy is progressing focussing on addressing impacts in developing countries (UNFCCC, 2013). It is these countries, such as those in Africa, that are at particular risk from the impacts of extreme events and climate change, due to high exposure and vulnerability (Niang et al., 2014). Understanding perceptions of event attribution in national and international policy contexts focussing on these countries will be important to understand how results could be applied here. However there has not been any work to date empirically investigating event attribution perceptions in these countries and contexts.

In order to frame event attribution questions relevantly for stakeholders, and to provide results which can be applied to their decision-making if it is deemed relevant, it will be important to understand perceptions of the science and to have communication between the different stakeholders involved. Communication between scientists and policy stakeholders could help develop improved understandings of what information event attribution can provide and whether and how this could fit with a range of policy contexts. The complexity of communicating probabilities and climate risks requires engagement to determine whether and how information could contribute to decision-making (Dow and Carbone, 2007), rather than scientists simply presenting results to stakeholders. Therefore exploring the use of novel methodologies and approaches could be relevant here. Techniques such as participatory gaming could be particularly applicable. Games provide the opportunity to share information in engaging yet rigorous ways, with participants learning through making decisions and experiencing the consequences, and discussing together to reflect on implications for real life (Harteveld and Suarez, 2015; Malaby, 2007; Mendler de Suarez et al., 2012).

2.2.5 Applications in this thesis

While there have been a number of applications for the results of event attribution studies discussed in the literature, these have yet to be investigated empirically in specific contexts. This thesis will address this research gap by focussing on two applications relevant to addressing the impacts of extreme events across Africa: national adaptation policy and international loss and damage policy. This will help develop understanding of whether results can feed into these complex political spaces, and, if deemed relevant by stakeholders, could then lead to research into how results could best be taken into consideration and how the science should develop accordingly to support these applications.

2.3 Climate science and policy

Climate change is having impacts around the world on physical, biological and human systems

(Cramer et al., 2014). In order to produce well-informed policy to respond to these impacts, it is important to understand the drivers of current climate events and impacts and how these might change in the future. For this purpose, the IPCC has been producing reports since 1990 to assess climate change and its impacts in order to guide responses, particularly to inform the United Nations Framework Convention on Climate Change (UNFCCC) (Griggs and Noguer, 2002). The UNFCCC uses this information to inform negotiations between countries on how to both mitigate anthropogenic climate change and adapt to its adverse effects (UNFCCC, 2006).

Other bodies have also recognised the need to focus on the impacts of climate change in order to reduce the risks facing vulnerable people around the world. For example, the United Nations International Strategy for Disaster Reduction (UNISDR) recognised in the Sendai Framework for Disaster Risk Reduction (2015-2030) a need to focus on climate change and variability. This can be a key driver of disaster risk and exacerbate many disasters (UNISDR, 2015). The UK government's Humanitarian Emergency Response Review in 2011 also recommended that climate change impacts should be integrated into disaster risk reduction programmes in order to build resilience (Ashdown, 2011). Climate risk information can also be useful for adaptation planning, in areas including the design of new infrastructure, the management of natural resources, and the change of behaviour, for instance modifying when activities such as crop planting are carried out (Wilby et al., 2009).

As well as at international and national level, climate information is also vital to address the impacts of climate variability and change at local levels. There has been much research on the relevance of seasonal forecasts to planning, such as El Niño–Southern Oscillation (ENSO) forecasts informing emergency managers in the Pacific Islands and farmers in southern Africa (Cash et al., 2006) and seasonal forecasts for north eastern Brazil assisting policymakers in mitigating impacts of drought (Lemos et al., 2002). Following a forecast of above normal rainfall in West Africa in 2012, the Red Cross was able to reduce the associated impacts by requesting funds ahead of the event, putting disaster relief items in place, updating flood contingency plans and warning vulnerable communities and decision-makers (Tall et al., 2012). Near real-time precipitation monitoring in sub-Saharan Africa through the Rainwatch platform can guide decision-makers, such as the Niger government who were able to respond to a developing food shortage in 2011 (Boyd et al., 2013). Climate information on annual timescales, such as seasonal forecast data, is used to some extent in agricultural adaptation strategies in Africa (Ziervogel and Zermoglio, 2009). However seasonal forecast use in Europe has been found to be limited by its low reliability and skill and a lack of awareness and perceived relevance of the information in organisations (Bruno Soares and Dessai, 2016). Information on longer timescales, from interannual to multidecadal, also has the potential to be used by decision-makers for guidance on long-term development (Jones et al., 2015a). Decadal predictions could be relevant for agricultural decision-making, water management and understanding marine ecosystem impacts and disease vector propagation (Vera et al., 2010). However this type of information is often not incorporated in national and sub-national development planning and adaptation decision-making in countries in sub-Saharan Africa, due to political and socioeconomic factors, funding constraints, limited accessibility of quality data, lack of capacity to interpret and apply information, and risk averseness (Jones et al., 2015a; Singh et al., 2017).

2.3.1 How climate science is used in policy

For the benefits of using climate information to be realised, links need to be made between the science and the decision-making contexts. Academics can play an important part in policymaking as policymakers often look to researchers for information relevant to policy they are already focussed on, or if a disaster brings to attention a particular problem (Kingdon, 2003). Scientists can also choose how they associate themselves with policy applications. Pielke (2007) defined four possible positions: pure scientists who research without considering the use of their work or being interested in decision-making; science arbiters who focus their research on the questions asked by decision-makers; issue advocates who focus their research on political agendas to argue their case; and honest brokers of policy alternatives who associate science with all the policy options and let decision-makers choose the course of action.

These positions also reflect the ways in which science can be produced and driven: by the pursuit of knowledge, by demand for a particular problem, or coproduced. In coproduction, the research agenda is defined by both the users and producers of the information in an iterative fashion. This iteration can help increase the usability of the research produced: instead of producers assuming the information is useful, their understanding of the decision-making context is improved, so the research can better fit the specific needs. It can also reveal new uses for climate information, as users may not previously have been aware of how the information produced could fit with the decisions they have to make (Dilling and Lemos, 2011; Lemos et al., 2012).

While this coproduction may be the ideal to ensure that scientific information produced is relevant to decisions and can be used, it can be hindered by disconnects between the producers and users of climate information. These can result in challenges for communication between producers and users, and ultimately for the incorporation of information in decisions (Jones et al., 2016).

2.3.2 Challenges of producing research to inform climate policy

One of the key challenges to developing scientific information that can be used in decision-making is the policy context in which the information is to be applied. This can be complex and involve considerations alongside science (Morss et al., 2005). Scientific information often has to interact with competing priorities, such as economic interests or environmental justice issues (Rose, 2014), and may be seen as less important or not fit the policy priorities (Dilling and Lemos, 2011; Kirchhoff et al., 2013b). Its use will depend on factors such as available resources, capacity and expertise (Bruno Soares and Dessai, 2016).

The usability of scientific information can also be affected by institutional barriers including rules defining the information that can be used, organisational culture, whether the information is viewed as reliable, levels of risk averseness, and whether alternative courses of action based on the scientific information are available (Dilling and Lemos, 2011; Jones et al., 2016; Kirchhoff et al., 2013b; Lemos and Rood, 2010). As decision-makers are a diverse group who have to interact to make decisions, the use of scientific information can be constrained by their ability and motivation to use new information, which can depend on other decision-makers, time, resources, and the balancing of different needs. Therefore scientists need to develop information that clearly applies to specific decision-making contexts, and interact with decision-makers to build trust and credibility (Morss et al., 2005).

One of the key factors in climate information playing a role in policymaking is that the information provided is accessible and in relevant and useable formats. Lemos and Rood (2010) described a disconnect between the perceived usefulness of climate projection information and its lack of use in policymaking. They claim that users may perceive the usability of the information differently to producers. Usability can depend on users' perceptions of how the information fits with their decisions, how the information fits with other information already being used, and the level and quality of interaction between the producers and users of the information (Lemos et al., 2012). The information that is produced therefore needs to be at relevant spatial and temporal scales and skill levels, and accessible in terms of its language, format, representation of the information and availability at the right time for the users (Dilling and Lemos, 2011; Jones et al., 2016; Lemos and Rood, 2010). Both the data and its uncertainties need to be communicated to the relevant decision-makers in appropriate languages, phrases and contexts (Goddard et al., 2010). Furthermore, stakeholders need to perceive the information to be credible (scientifically adequate in its evidence and arguments), salient (relevant to the decision-makers' needs) and legitimate (produced in an unbiased, fair and respectful way, considering stakeholders' opposing views and interests) (Cash et al., 2003). In the case of UK climate projections and their application in adaptation decision-making, saliency in particular was found to depend on the different users and their levels of scientific competence and experience of using climate information (Tang and Dessai, 2012).

Challenges in creating useable information can come from the characteristics of the science itself, such as spatio-temporal resolutions available and uncertainties. These can be limited by the financial resources available for observations and modelling, or scientific and technical capacity (Jones et al., 2016). Spatial and temporal scales are particularly important to match between the scientific analysis and what is needed to inform decisions. Climate information can often be provided at large gridscales which regional and local decision-makers do not see as credible for their decisions (Cash and Moser, 2000). There can also be a mismatch between the long-term impacts of climate change and much shorter political time frames (Jones et al., 2015b). In terms of uncertainty, scientists and decision-makers often have different perspectives: while scientists try to assess, quantify and reduce uncertainty in the information they produce, decision-makers see uncertainty as an unavoidable factor (Morss et al., 2005). Therefore just reducing uncertainty in information does not necessarily mean the science will be more useable (Rose, 2014), and so scientists need to work with decision-makers to establish how information can be relevant.

2.3.3 What is needed going forward

Despite the challenges mentioned, there are ways of ensuring climate information is used in decision-making. For the science that is produced to be useable, the decision-makers' requirements need to be incorporated into the research process (Morss et al., 2005) with the information tailored to particular contexts to increase the perceived salience (Tang and Dessai, 2012). Information should match users' timescales, be compatible with the policy-making processes and be accessible to ensure policymakers are receptive to research results (Jones et al., 1999). Collaborative engagement between the producers and users of information can continue to innovate how understanding of climate variability and change can contribute to decision-making (Dow and Carbone, 2007; Vera et al., 2010). Lessons from how the information is used by decision-makers can be used to guide both model development and how the information is disseminated (Daron et al., 2015), as the application of any information will have to fit into the social and institutional setting (Goddard et al., 2010).

Boundary organisations can work between scientists and policymakers to promote the dissemination, use and understanding of data. They can help ensure that the information produced matches decision-maker needs in terms of level of technicality and answering the right question, and translate and mediate between the different stakeholders (Jones et al., 2015b). Sustained interaction with an effective boundary organisation may help to improve the use of climate information, as this can help address individuals' risk perceptions and scepticism of information (Kirchhoff et al., 2013b).

Alongside collaboration, there is a need for enhanced technical capacity to ensure information is accessible and useable and stakeholders have the means to produce and use the information. Improvements in the science itself, such as the production of more high resolution data and information at spatio-temporal scales which match those relevant for decision-making can ensure information is used (Jones et al., 2016; Vera et al., 2010). In particular, there is a need to strengthen technical skills to enable downscaled model results, relevant at local and regional scales (Ziervogel and Zermoglio, 2009). Information also needs to be provided for relevant variables (Vera et al., 2010). For example, instead of rainfall totals, the number of rainy days, rainy season onset date or length may be more useful, or, considering impacts, the expected crop yield or mosquito distributions (Goddard et al., 2010). In Africa specifically, improved climate observations and the building of capacity and technical resources at African scientific institutions will help produce quality data (Jones et al., 2015b). When communicating their results, scientists need to be precise and transparent in describing their techniques and findings, specify uncertainty, and be audience relevant (Keohane et al., 2014). It is important to know the levels of uncertainty appropriate to the policy context, as different decisions can tolerate different levels of uncertainty in the information (Lemos and Rood, 2010).

In policy, immediate development challenges are often on relatively short timescales and so long term perspectives such as climate change can be side-lined. However, more effective communication of the economic benefits of acting on medium to long term climate information could enhance uptake by more influential stakeholders, including government ministries (Jones et al., 2015b). Improving the understanding and communication of climate scenarios could assist in the use of this information to develop robust, locally-relevant adaptation strategies (Ziervogel and Zermoglio, 2009). Decision support tools are needed to improve access to climate model products and convert awareness of climate impacts into adaptation strategies with technical guidance where appropriate (Wilby et al., 2009). Participatory approaches involving all the relevant actors can help to share information and perspectives, address the issues of uncertain information, and work towards integrating the available information (Singh et al., 2017; van den Hove, 2000). In order to encourage this type of activity, efforts have included the production of handbooks to help both practitioners (Duncan et al., 2014) and scientists (Jacobs, 2002) understand how science can be integrated into decision-making by working together. Institutional reform can help overcome constraints on the use of new information, as can making use of trigger events as windows of opportunity for the perceived relevance of the science, and building trust in the information can all help ensure its use in policymaking (Jones et al., 2016).

2.3.4 Science and policy in this thesis

It is on the basis of this need for collaboration between scientists and policymakers to ensure that climate information is relevant and can be used in decision-making that this thesis investigates event attribution science. The research to date on the usefulness of climate science for policy has looked at information on timescales from seasonal forecasts (e.g. Bruno Soares and Dessai, 2016; Goddard et al., 2010) to decadal (e.g. Vera et al., 2010) and longer term projections (e.g. Daron et al., 2015; Tang and Dessai, 2012) but has not focussed on event attribution. Understanding how extreme events are associated with climate change may be relevant for a range of policy contexts. Therefore in this thesis research on the science itself will improve understanding of the robustness of studies of West African events which will be important to communicate to users. The critical empirical examination of stakeholders' perceptions of the role of event attribution science will develop understandings of stakeholder needs regarding information on links between extreme events and climate change. This is key as creating useable climate information to guide policy decisions relies on engagement with decision-makers to understand their needs, ultimately to ensure the ways in which research questions are formulated and addressed are informed by these (Lemos and Morehouse, 2005). The development of a participatory game will provide a tool to both share information with policymakers about the science, and provide an environment for dialogue between scientists and policymakers around the uses for results. Such dialogue will be vital if scientists are to understand policy contexts and develop event attribution appropriately for these, and for policymakers to understand more about what information can be provided and consider its application in their decision-making processes.

2.4 Summary

Event attribution science has been developing rapidly over the past decade, with different methodologies using observations, climate model simulations, and reanalysis datasets being applied. The number of studies comparing different methodologies has been minimal though, as has the number of studies investigating events in Africa. Therefore, this thesis will include a study comparing some of the common climate model ensembles used in event attribution for a precipitation event in West Africa, to develop understanding of these types of events in this region (addressing Q1). This has not been done before for an event in Africa.

Scientists and stakeholders have debated a range of applications for event attribution since its inception. However, there has been limited consideration of these in specific real-world contexts. This thesis will therefore engage with stakeholders involved in two of the key policy contexts discussed to understand the policy background, use of climate information, understanding of event attribution and relevance of results: national adaptation policy in Senegal and international loss and damage policy (addressing Q2). This will be important to assess whether event attribution information could inform decisions in real-world contexts.

This chapter also provided a background to the main issues around the use of climate science in policy. Key to successfully producing scientific results that are useable for policy is collaboration between the producers and users of climate information, to develop understanding of the science and of the relevant policy contexts. It is therefore important to consider how to facilitate engagement around event attribution between scientists and different stakeholder groups. This thesis will investigate a novel way of sharing and discussing event attribution science and its uses through the development of a participatory game (addressing Q3).

3. Methodology

In order to investigate event attribution science, potential policy applications and how the science can be communicated, this thesis employs an interdisciplinary approach. A quantitative event attribution study was used alongside qualitative research methods from the social sciences. In this chapter, the theoretical background to the approaches used is described, along with why particular methods were chosen for this study.

3.1 Methodology

3.1.1 Ontology and epistemology

Ontology and epistemology are concerned with the nature of reality and ways of learning about the world (Ormston et al., 2014). This thesis takes what can broadly be defined as a realist approach, viewing reality as a concept that exists independently of our beliefs or understanding. This external reality is complex and there can be different perceptions and levels of interpretation – in particular the social world can often be open to more subjective interpretation than the natural world (Ormston et al., 2014). This realist view is influenced by a natural science perspective, seeking understanding of the changes in the climate system, specifically changes in extreme events due to anthropogenic forcings. From a social science perspective, however, understanding is sought of the different perceptions regarding the attribution of extreme events.

From a background in natural sciences and objective knowledge, and from a focus on research questions with definitive answers such as whether or not event attribution science has a role, more nuanced questions have been developed in this thesis. These are around how the science is understood by relevant stakeholders, how it could fit with policies and practices at national and international levels, and its limitations. Answering these questions will produce much more subjective data which will require some degree of interpretation. Therefore from an epistemological point of view, both inductive and deductive approaches are applied here. Inductive logic builds knowledge bottom-up, taking observations of the world to develop theories, whereas deductive logic builds top-down, from theory to a hypothesis which can be applied to observations (Ormston et al., 2014). In this thesis, deductive reasoning has been used in the application of existing event attribution science theory and techniques to an event in West Africa, looking quantitatively at the effect of anthropogenic climate change. Considering applications for such results in policy has taken an inductive approach, investigating specific policy cases, in order to build theory around the relevance of event attribution for stakeholders through their perceptions. An inductive approach was chosen for this part of the thesis as the rich empirical data collected can enable insight into the complex policy processes in order to explain and begin to theory build from these cases (Eisenhardt and Graebner, 2007). A case study, qualitative semi-structured interviews and textual analysis were used to better understand the perspectives that exist around event attribution in the context of national adaptation policy and international loss and damage policy.

3.1.2 Mixed approach

The two approaches, deductive quantitative and inductive qualitative research, are used in partnership in this thesis. This allows the research topic of event attribution science in Africa to be approached from multiple angles, both natural and social science, in order to tackle multiple gaps in our current understanding of both the scientific technique and its application to climate policy in national and international contexts. Ultimately these areas of research can come together to start to build a bigger picture of the application of the science in an African context.

In order to develop this big picture, a pragmatic approach was taken, using the approach and research tools that best fit each specific question (Seale et al., 2007) and avoiding a 'methodological straitjacket' due to commitment to a particular research tradition (Ormston et al., 2014; p.19). In this way, qualitative and quantitative research approaches are able to address the different types of questions and provide complementary insights (Silverman, 2011). These approaches also span more than one discipline.

3.1.3 Interdisciplinarity

Many research problems are not confined to a single discipline (Roper and Brooks, 1999; National Academies, 2005), and this is particularly the case when considering environmental issues such as climate change (Nicolson et al., 2002). Event attribution is one such area. While analysing the effect of anthropogenic climate change on a particular event is inherently a meteorological question, researching how this information could be relevant to addressing the impacts of extreme events requires a social science approach, to understand the types of decisions being made, the information required for these, and the background decision-making contexts. In this way social science can help guide the use of natural science in answering policy questions (Meadow et al., 2015). Therefore in combining the perspectives of different disciplines, greater understanding of such a problem can be generated, which can lead to more relevant and useful lessons for environmental decision-making (Adger et al., 2003). The work in this thesis therefore is situated within the field of climate change science and also the social science subfields of global environmental change (e.g. Adger et al., 2005; Boyd and Ghosh, 2013; Hulme, 2014), considering how the impacts of extreme weather events and climate change are addressed, and climate and society (e.g. Boyd et al., 2013; Kirchhoff et al., 2013a; Lemos et al., 2012), considering the area of communication between scientists and policymakers.

While an interdisciplinary approach is relevant in an event attribution research context, defining interdisciplinary research is not clear-cut (e.g. Lau and Pasquini, 2008; Porter et al., 2007). Here the definition of interdisciplinary research implying an integrated approach between disciplines is used. This is where perspectives from different disciplines are synthesised (Barry et al., 2008; Porter et al., 2007; Roper and Brooks, 1999) and ideas, concepts and methodologies integrated to generate a more complete understanding of the research problem (Lau and Pasquini, 2008; Palmer et al., 2006). Much of the literature on interdisciplinarity has focussed on projects comprising researchers from different disciplines each bringing their own perspectives. However, researchers can also themselves engage in interdisciplinary research (e.g. Carey and Smith, 2007; Lau and Pasquini, 2008), as is the case in this thesis.

Interdisciplinary research can lead to new approaches for studying particular phenomena and even result in higher impact studies than could have been produced using just one discipline (Palmer et al., 2006). It can also help ensure that scientific research is relevant to societal need (Barry et al., 2008; National Academies, 2005). This is relevant in the context of event attribution where the majority of the research has so far been meteorological. Empirical work is needed to see whether this could be relevant to policy and what the appropriate questions to be asking are, by bringing in stakeholder perspectives. This type of research is of course not without its challenges. For example, disciplines each have their own languages and meanings which need to be well-defined to make sure this does not cause problems (Bracken and Oughton, 2006). In the case of event attribution, climate scientists often use the risk of an event to mean the probability of its occurrence (e.g. Stott et al., 2004). On the other hand, social scientists understand risk to incorporate the vulnerability and exposure of the population, alongside the event itself (Lavell et al., 2012). Such definitions therefore need to be used carefully when working with different people. Another challenge is that disciplines are defined by their methodologies to ensure that research is robust (Barry et al., 2008). Working across more than one discipline can result in challenges to reconcile assumptions of what constitutes robust methodologies and evidence, particularly when considering natural and social sciences (Golde and Gallagher, 1999; Heberlein, 1988).

3.1.4 Participatory research

This thesis also engages with participatory research. This is research based on collaborative engagement between researchers and participants, working together to bring about positive change (Kingdon et al., 2007; Ormston et al., 2014) through increasing participants' understandings of situations and abilities to use this information (Wright and Nelson, 1995). This approach has been used within a workshop, held as part of fieldwork investigating the relevance of event attribution for national adaptation policy in Senegal, and through the development of a participatory game and its application in a range of scientific and climate policy contexts. Participatory research is used as this provides the opportunity to share findings with stakeholders and also learn from them about their contexts, decisions and perspectives in order to understand better how event attribution could be applied to policy. In particular, the participatory game can enable stakeholders to better understand the concepts of event attribution techniques, which could lead to more informed discussions and interviews about whether and how it could be relevant to their decision-making.

3.2 Research questions and methods

In order to investigate whether event attribution studies produce robust results in West Africa, an event attribution case study was used. Employing a climate model-based event attribution methodology, the effect of anthropogenic climate change on 2012 West African precipitation was assessed and compared across climate models.

The analysis of potential roles for event attribution results in both national climate adaptation policy and international loss and damage policy uses a range of qualitative methods. Qualitative methods provide the opportunity to understand the contexts being studied, including the processes involved and the relevant influences (Maxwell, 1996). In order to reduce the risk of systematic bias, and to reduce the limitations each method might have on its own, methods were triangulated (Maxwell, 1996).

For the national adaptation policy study, the case of urban Senegal was used. A workshop, questionnaire, interviews and document analysis built an in-depth understanding of the role of climate information in adaptation policy addressing extreme precipitation and flooding. Interviews and a systematic review of peer-reviewed and grey literature were employed to investigate potential roles of event attribution in international loss and damage policy. Finally, a participatory game was developed to communicate the science of event attribution to stakeholders and encourage dialogue about its potential uses.

3.2.1 Event attribution method

As has been demonstrated in Chapter 2, the science of event attribution has been developing over the past decade, with new methodologies being produced and different types of events studied. This study uses a scientific methodology that is well-established in this field, comparing climate model simulations with and without anthropogenic forcings included, to assess the probability of a particular event. This was applied to an event in Africa, which is a region where few attribution studies have been carried out, as shown in Chapters 1 and 2. The region for this study, West Africa, was chosen to correspond with the case study of national adaptation policy in Senegal. Senegal was affected by heavy rainfall in 2012, along with much of the West African region, and so precipitation in this year was chosen for the event attribution study. This study also compares some of the commonly used climate model datasets in event attribution studies to assess whether attribution results are robust across these. To date there have been very few comparative studies carried out. However such information is vital if the information is to be communicated clearly and used in decision-making to address the impacts of events. The results of the event attribution study could then be used to engage with stakeholders in Senegal and to compare with their perceptions of the impact of climate change on precipitation in the region. A full description of the method used in this event attribution study can be found in Chapter 4.

3.2.2 Case study and fieldwork

In order to investigate whether event attribution could be relevant for national adaptation policy addressing the impacts of extreme events a case study was used. While suggestions that event attribution could be relevant in adaptation have been made generally, practically this would likely depend on individual contexts. In this study the case of Senegal was used, a developing country frequently affected by the impacts of extreme rainfall events. This case study provided the opportunity for an in-depth study of this particular context (Yin, 2014), which was researched using multiple methods. While the results from this particular case cannot be generalised (Thomas, 2011) to other national adaptation strategies, it is able to provide an example, along with hypotheses from the empirical evidence that can then be tested in other contexts (Denzin and Lincoln, 2013; Eisenhardt, 1989).

To build an understanding of the adaptation decision-making context regarding extreme precipitation and flooding in Senegal and the role of scientific information, a range of methods were used. Fieldwork was carried out in Dakar, Senegal for two weeks in February-March 2016. During this time a workshop was hosted with other members of the ACE-Africa project team, Cheikh Anta Diop University (UCAD) and the Directorate of Environment and Classified Establishments (DEEC) under the Ministry of Environment and Sustainable Development in Senegal. This was attended by a range of key stakeholders including representatives from government, civil society and research institutes. The aim of the workshop was to discuss whether event attribution results could be relevant for adaptation decision-making regarding extreme precipitation in Senegal, and to collect data from questionnaires and group discussions. The workshop was also vital for meeting relevant stakeholders to follow up with for interviews during and following the fieldwork period. More information about the workshop can be found in Chapter 5.

3.2.3 Interviews

Semi-structured interviews with a range of key informants were used to investigate background policy contexts to both national adaptation and international loss and damage policy, event attribution science understandings, and potential uses for the science. In both contexts, following an initial list of identified key stakeholders, further interviewees were identified by interviewees themselves using a snowball sampling technique (Atkinson and Flint, 2004). This ensured the views of an appropriate range of key people involved with the issues, but with different perspectives, were captured and this could help to limit bias (Eisenhardt and Graebner, 2007).

A list of questions was produced to guide the interview in both contexts. The nature of semi-structured interviews allowed for flexibility during interviews, where interesting leads brought up by the interviewees could be followed and probed where relevant, whilst broadly the same topics were covered in all interviews for comparison (Gillham, 2005; Kvale, 1996). In each case interviews were carried out with a range of key stakeholders, including government, research and civil society in order to gain a range of perspectives on the issues being investigated. Semi-structured interviews were chosen over a more structured method such as a questionnaire as they allowed for greater flexibility and scope for further questioning interesting points raised by interviewees. This is vital when investigating complex policy contexts such as those considered here. It also meant that in some cases more of a discussion could be had about event attribution science to clarify understandings where necessary.

However, semi-structured interviews also come with challenges and weaknesses. They are time-consuming which limits the number that can be carried out. This means only a subset of all those involved with the issues being investigated was spoken to. Furthermore, the reliability of information provided by interviewees may not be clear. Knowledge is subjective, for example it may be personal opinion or influenced by other factors such as positionality in climate negotiations. For these reasons, in each interview context, stakeholders from across the range of sectors involved were interviewed, as each would be able to provide different perspectives and information. These perspectives, although subjective, could then enable a picture of how the stakeholders viewed event attribution to be constructed and interpreted. In each case the interview findings were also triangulated with other sources to ensure their validity. In the case of loss and damage policy this was with peer-reviewed and civil society grey literature, and in the case of Senegal adaptation policy this was with data from the workshop, a questionnaire, media articles and adaptation policy documents.

A small number of the interviews in Senegal were carried out with two interviewees at the same time. In these cases the interviewer alternated who was asked each question first, in order to get answers from each that were as unbiased by the other as far as possible. Some of the Senegal interviews were carried out in English, but the majority were conducted in French using a translator. The translator was from Senegal and had previously carried out research into flood vulnerability in this country so had some background understanding of the context being investigated. While using a translator was invaluable for being able to carry out interviews with key informants that would not have otherwise been possible due to the language barrier, there were also issues to consider. These included trusting that the questions and responses were being translated accurately. Interviewees were encouraged not to speak for too long without translation, but there were still cases where they would speak for an extended length of time and the translator would have to paraphrase. In these cases there had to be trust that the translation was an accurate representation of the interviewee's response and no important points had been missed out. It was also necessary to trust that translations were not being biased by the translator's own opinions. As the translator had some knowledge of the context, there is a chance the translations could have been biased by this. However, the translator had previous experience of carrying out research interviews and so understood the need for neutrality. The need to be impartial and translate accurately was discussed with the translator, as very occasionally they appeared to be adding their own information or opinion, and not acting impartially. In many cases the interviewee was able to understand some English so could roughly validate the translation or clarify where the translation was not accurate. However, a key challenge noted during this process was discussing event attribution science and its probabilistic nature. Translating a description of the science could be difficult and it was not always completely clear how well the interviewee had understood the concepts being discussed.

3.2.4 Participatory gaming

Communicating complex scientific concepts can be challenging, but it is imperative to do so clearly if the science is to be considered and, furthermore, used in decision-making contexts. Results from event attribution studies can be challenging to communicate simply but accurately, as they deal with changing probabilities of events alongside uncertainties from the model and observational data used. Therefore this thesis has considered an innovative way of engaging with stakeholders to inform them about this science.

Participatory gaming encourages people to engage with complex decision-making contexts by having to make decisions, interact with others, and experience the outcomes (Mendler de Suarez et al., 2012). Addressing issues around climate change, and specifically extreme events, can be complex and science is just one part of this. Therefore, gaming was chosen as an avenue to explore how best to engage with stakeholders on the issues around event attribution, to inform them about the science and provide an opportunity for them to consider its uses. More detail on the rationale behind this and a description of the development process can be found in Chapter 7.

3.2.5 Qualitative data analysis

To analyse the qualitative data collected through interviews, the workshop, documents and game feedback, NVivo software (QSR, 2012; 2015) was used. Using a grounded theory analysis approach (Robson, 2002), data were coded in such a way that themes emerged during the coding process. In an iterative fashion codes were extracted from the data and then categorised and compared across the data sources in an inductive thematic analysis (Braun and Clarke, 2006).

3.3 Ethical considerations

Ethical guidelines were followed for the research carried out involving stakeholders, following university and departmental ethical protocols and going through a screening process. Participants for both the interviews and workshop were informed about the nature of the data to be collected, how it would be used and stored securely, and that they could withdraw from the study at any time. Permission from the participants was gathered by the signing of consent forms for those interviews carried out in person and for the workshop. For Skype interviews participants verbally gave their permission. Participants also had to give their permission for the interview to be recorded. The data were then kept securely and in the written up work all quotes used were anonymised.

3.4 Researcher positionality

A researcher’s biography can affect their research by both their personal characteristics and the response of those being researched to the presence of the researcher (England, 1994). Characteristics of the researcher, such as their beliefs, gender, race, educational and cultural background, may affect the research process. These biases of researchers shape the research process (Bourke, 2014). It is therefore necessary to reflect on how my research and results may have been affected as fully as possible, even though it is not possible to completely understand the positionality of a researcher and its impacts (Rose, 1997).

The interviews on loss and damage began at the Conference of the Parties (COP) in Warsaw in November 2013. I was a delegate at the COP along with those I was interviewing and I attended events and meetings about loss and damage, and so developed some understanding of the policy process in this way. This was a mixed environment with delegates from all over the world involved, and different groups represented including governments, civil society organisations, businesses and researchers. Over the past few years researchers have had a fairly prominent role in studying the loss and damage agenda as it develops, which may have meant that key stakeholders involved were used to being interviewed. Although it was challenging at first to identify the key stakeholders, most people I spoke to were happy to be interviewed and to share their views. Also in the case of the Senegal research, each person I interviewed both in person and via Skype was very willing to give their time to fully answer all the questions I had. They generally did not seem to shy away from speaking honestly about the policy situation in the country.

I was an outsider to both of the policy contexts I studied, as I was not a part of these stakeholder groups. This is not necessarily a disadvantage compared to being part of the context and having prior knowledge, as discussed by Herod (1999). While it has been suggested that outsiders will not understand the cultural complexities of a culture other than their own, and there can be difficulties, for example in understanding the different words and phrases used (particularly when using a translator), there are some benefits. An outsider is more likely to constantly question the interviewee and the data and take less for granted than if they already had some understanding. Therefore, more in-depth answers can be retrieved from interviewees instead of making assumptions. Also an outsider can be viewed as more impartial to the group being studied, which can encourage interviewees to be more open with sensitive information (Herod, 1999). For example, this seemed to be the case in Senegal in the way that government interviewees in particular were happy to talk about the difficulties of working with other departments and the challenges they were facing. However, the presence of a translator from Senegal could also have been reassuring for them.

An issue with this research was that while trying to act objectively, and not imply that event attribution science would be relevant in any particular context, I may have been perceived as an advocate for the science. This is partly through introducing myself as working with a group researching event attribution and also, in the case of Senegal, through hosting a workshop focussing on event attribution. While the aim of the workshop was not to advocate the science (rather to present and discuss it, as was described in introducing the day to the participants), I would still have been viewed as a scientist through presenting event attribution results. Interviewees may have been more positive about results being useful, and confident that events could be attributed to climate change, than if this had not been the context.

The final text that is produced from research will be the construct of the researcher as, for example, they will have decided whose voices to include in the analysis and write-up (England, 1994). For this reason I tried to ensure I considered each person’s contributions fully and developed an overall picture based on all of these. For example, I included quotes from a representative cross-section of the interviewees, while taking into account the experience each person interviewed had in the area and therefore the reliability of their responses.

More generally there were some challenges throughout this PhD which stemmed from working as part of a larger project group, especially as many members were event attribution scientists and advocates of the techniques. As such it was important to manage potential biases when carrying out the research into the applicability of results for policy applications, and writing this up, to ensure this was not influenced by the scientists’ own agendas. The aim was to act as objectively as possible during the process of analysing whether event attribution could be relevant for adaptation and loss and damage policy, rather than assuming its applicability as scientists have suggested. I therefore led the research and the write-up for the chapters investigating this, designing the interview protocol carefully so as not to imply the relevance of the science, and carefully considering inputs to the writing from other project members to ensure these did not bias the text. In particular, the chapter on adaptation policy in Senegal was researched and written with very minimal input from the climate science partners on the project (who only attended the workshop) in order to carry out as objective a study as possible.

4. A comparison of model ensembles for attributing 2012 West African rainfall

As described in Chapter 2, the African region provides challenges for event attribution studies, particularly when considering precipitation events, including limited observations, teleconnection influences and large signal-to-noise ratios (Otto et al., 2015). Therefore from a scientific point of view this is an important region in which to investigate the robustness of event attribution results. While there have been a few studies carried out across the continent, these have been particularly limited in West Africa where there has been just one study to date (Lawal et al., 2016). In order to investigate the robustness of results it is necessary to compare results from the different climate model ensembles currently used in event attribution studies, which has not been done for any events in Africa so far. The event chosen to be studied for this chapter is high precipitation across West Africa in 2012, and through the comparison of a range of climate model ensembles, this study is used to address the following research question:

Q1. Do event attribution studies produce robust results in West Africa?

This event had large impacts on the population across the region, and is therefore also relevant for the national adaptation policy study to be carried out in Senegal (Chapter 5).

This chapter has been published in Environmental Research Letters (Parker et al., 2017).

Abstract

In 2012, heavy rainfall resulted in flooding and devastating impacts across West Africa. With many people highly vulnerable to such events in this region, this study investigates whether anthropogenic climate change has influenced such heavy precipitation events. We use a probabilistic event attribution approach to assess the contribution of anthropogenic greenhouse gas emissions, by comparing the probability of such an event occurring in climate model simulations with all known climate forcings to those where natural forcings only are simulated. An ensemble of simulations from 10 models from the Coupled Model Intercomparison Project Phase 5 (CMIP5) is compared to two much larger ensembles of atmosphere-only simulations,

from the Met Office model HadGEM3-A and from weather@home with a regional version of HadAM3P. These are used to assess whether the choice of model ensemble influences the attribution statement that can be made. Results show that anthropogenic greenhouse gas emissions have decreased the probability of high precipitation across most of the model ensembles. However, the magnitude and confidence intervals of the decrease depend on the ensemble used, with more certainty in the magnitude in the atmosphere-only model ensembles due to larger ensemble sizes from single models with more constrained simulations. Certainty is greatly decreased when considering a CMIP5 ensemble that can represent the relevant teleconnections due to a decrease in ensemble members. An increase in probability of high precipitation in HadGEM3-A using the observed trend in sea surface temperatures (SSTs) for natural simulations highlights the need to ensure that estimates of natural SSTs are consistent with observed trends in order for results to be robust. Further work is needed to establish how anthropogenic forcings are affecting the rainfall processes in these simulations in order to better understand the differences in the overall effect.

4.1 Introduction

In 2012, rainfall over 150% above normal for the period from late July to late August was reported across many countries in West Africa (ACMAD, 2012). This year was characterised by an anomalously wet monsoon, with an earlier than normal onset and possible links to the Madden-Julian Oscillation, El Niño Southern Oscillation (ENSO) and strong African Easterly Wave activity (Cornforth, 2013). This led to more than 1.5 million people being affected by floods in countries across West and Central Africa, with deaths in some countries (OCHA, 2012) and hundreds of thousands of people made homeless (IRIN, 2012). When events such as this occur, they can raise questions about how they have been affected by climate change.

Following its proposal by Allen (2003), the science of extreme event attribution assesses the impact of anthropogenic climate change on the probabilities of individual events. This could be relevant for informing adaptation strategies (Otto et al., 2015) and addressing impacts under international climate policy (James et al., 2014), which may be particularly important in regions such as Africa. Since the first event attribution study over a decade ago of the 2003 European heatwave (Stott et al., 2004), there have been many more studies (as reported, for example, in the annual Bulletin of the American Meteorological Society reports, e.g. Herring et al., 2015).

However, relatively few have been on events in Africa in comparison to developed regions of the world (examples in Africa include Bellprat et al., 2015; Lott et al., 2013; Otto et al., 2013; Wolski et al., 2014).

Techniques for assessing how probabilities of extremes have changed due to anthropogenic climate change can be based on observational trends or climate model simulations. Climate model studies compare the probability of a particular extreme in the actual world, simulated with all known external climate forcings, to that in a world with a particular climate forcing removed, such as anthropogenic emissions. These can either use coupled climate models (e.g. Bellprat et al., 2015) or atmosphere-only simulations (e.g. Lott et al., 2013). Coupled simulations assess the change in probability of an event under general climate conditions with all natural variability included, whereas atmosphere-only simulations assess the change in probability of an event given the actual sea surface temperatures (SSTs). When using atmosphere-only models to produce estimates of the world without anthropogenic emissions, the influence of emissions has to be removed from the SSTs as well as the atmosphere. This can provide an additional challenge and level of uncertainty (Christidis and Stott, 2014).

Very few studies have compared the information that coupled and atmosphere-only models can provide about the influence of climate change on an event. Lewis and Karoly (2015) compared a coupled multi-model ensemble of Coupled Model Intercomparison Project Phase 5 (CMIP5) simulations to two different atmosphere-only model ensembles in their study of extreme rainfall in Australia in 2010–2012. They found that anthropogenic contributions to the event depended on the model used, with more robust results using atmosphere-only models than the CMIP5 ensemble. This highlights the need for comparisons of different model ensembles in order to produce robust event attribution results. Here we carry out a similar analysis of the anthropogenic influence on 2012 precipitation in the West Sahel, using a multi-model ensemble of coupled CMIP5 simulations and two ensembles of atmosphere-only simulations from the Hadley Centre Global Environment Model version 3-A (HadGEM3-A) and a regional version of the Hadley Centre Atmospheric general circulation Model version 3P (HadAM3P), to establish if attribution statements about the event are consistent across the ensembles.

The paper is structured as follows: section 4.2 describes the observational and model datasets, model validation methods and event attribution analysis used. In section 4.3 we present the

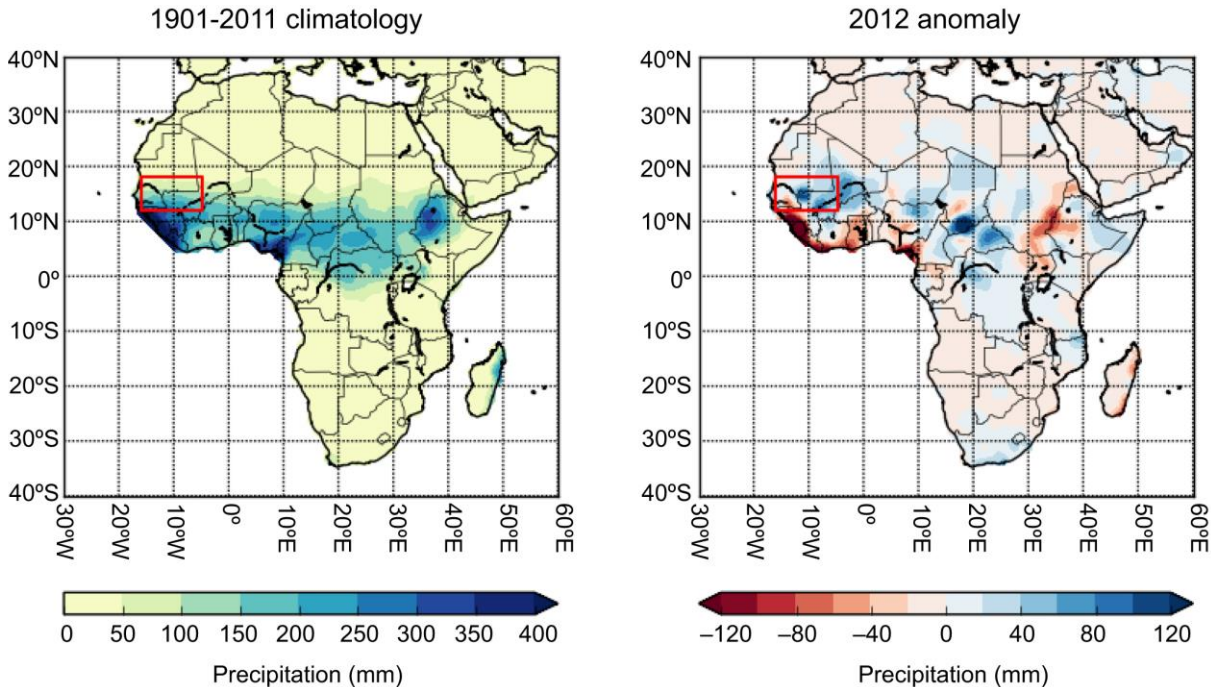

Figure 4.1 Observed JJA monthly mean precipitation from GPCC. The red box outlines the West Sahel region.

results of the model evaluation and anthropogenic influences on 2012 precipitation, and these are compared and discussed in section 4.4. Conclusions can be found in section 4.5.

4.2 Methods

4.2.1 Region and observations

The region considered is the West Sahel, as defined by Rowell et al. (2016), as this encompasses many of the areas that were affected by the rainfall of 2012. This region is shown in figure 4.1 and defined by 16°W to 5°W and 12°N to 18°N. Throughout this study, monthly mean precipitation is averaged over June–July–August (JJA) for each year. Although this period misses the end of the rainy season in the region in September, this standard season definition allows for comparison between all the model datasets (which would not otherwise be possible due to the HadGEM3-A simulations ending in August 2012).

Observations of precipitation are taken from the Global Precipitation Climatology Centre (GPCC, Becker et al., 2013) at 1.0° × 1.0° horizontal resolution. GPCC observations provide a long time-series with which to validate the model simulations, while being consistent with other precipitation datasets in the region over the more recent period. SST observations are from the Hadley Centre Sea Ice and Sea Surface Temperature (HadISST, Rayner et al., 2003) dataset.

4.2.2 Model ensembles

For each model, or multi-model ensemble, two ensembles are required. One comprises simulations with all known external climate forcings included (ALL) and the other with only natural forcings (NAT).

4.2.2.1 CMIP5

From the CMIP5 simulations (Taylor et al., 2012) an ensemble comprising ten models is used, selected on the basis of having monthly precipitation data available for both all forcings and natural forcings simulations including the year 2012. The models and numbers of simulations used are detailed in table 4.1. For the ALL ensemble, historical simulations were extended to include 2012 using extension simulations (historicalExt) where possible, else using RCP8.5 simulations. This emissions scenario was chosen as it is closest to recent emissions observations (Sanford et al., 2014). The NAT ensemble comprises historicalNat simulations. All the models used include greenhouse gas, aerosol, solar and volcanic forcings (for more detail about the forcings see references in table 4.1).

4.2.2.2 HadGEM3-A

An ensemble of simulations is used from HadGEM3-A (Christidis et al., 2013). These are the September 2011–August 2012 experiments from Christidis and Stott (2014). This atmosphere-only model is forced with observed HadISST SSTs and sea ice coverage and run at N96 horizontal resolution. Well-mixed greenhouse gases, aerosols, ozone, land-use changes, volcanic and solar forcings are used (Christidis et al., 2013). Five all forcings runs from 1960–2010 are used for validation. For the year 2012 there are 600 ALL ensemble members and four NAT ensembles with 600 members in each. Each NAT ensemble uses a different estimate of the anthropogenic influence on SSTs, from HadGEM2-ES, CanESM2, CSIRO Mk3.6.0 and using the observed trend. For each model, SST changes are estimated using the difference in temperature averaged over 2003–2012 between the mean of the ALL and NAT simulations. The observed trend is calculated using a linear fit to a time series of HadISST data since 1870.

This change is assumed to be caused by anthropogenic forcings (Christidis and Stott, 2014). These model and observed changes are calculated for each month and gridpoint and subtracted from the HadISST data to approximate the natural boundary conditions to the atmosphere.

Table 4.1 All forcings (ALL) and natural forcings (NAT) simulations from CMIP5 models used. References provide information about forcings used in simulations.

Modelling centre	Model name	Number of ALL simulations	Number of NAT simulations	Reference
Beijing Climate Center, China Meteorological Administration	BCC-CSM1-1	3	1	Xin et al., 2013
Centre National de Recherches Météorologiques / Centre Européen de Recherche et Formation Avancée en Calcul Scientifique	CNRM-CM5	10	6	Voldoire et al., 2013
Commonwealth Scientific and Industrial Research Organization in collaboration with Queensland Climate Change Centre of Excellence	CSIRO-Mk3.6.0	10[a]	5	Rotstayn et al., 2012
Canadian Centre for Climate Modelling and Analysis	CanESM2	5	5	Arora et al., 2011
NASA Goddard Institute for Space Studies	GISS-E2-H	5	5	Miller et al., 2014
	GISS-E2-R	5	5	
Met Office Hadley Centre	HadGEM2-ES	3	4	Jones et al., 2011
Institut Pierre-Simon Laplace	IPSL-CM5A-LR	4[a]	3	Dufresne et al., 2013
	IPSL-CM5A-MR	1[a]	3	
Norwegian Climate Centre	NorESM1-M	1	1	Bentsen et al., 2013
	TOTAL	**47**	**38**	

[a] Denotes where RCP8.5 used to extend simulations rather than historicalExt

4.2.2.3 HadAM3P

The final ensemble used is from the weather@home modelling system (Massey et al., 2015), which allows a very large ensemble of simulations to be produced. The model used for these simulations is a regional version of HadAM3P over Africa, at N96 horizontal resolution. This atmosphere-only model is forced by Operational Sea Surface Temperature and Sea Ice Analysis (OSTIA) SSTs and sea ice coverage (Donlon et al., 2011). The estimated natural world SST patterns are calculated using models in the same way as for HadGEM3-A. All the models listed in table 4.1 are employed leading to NAT ensemble members run with SSTs from the different model estimates. Solar, volcanic, aerosol and greenhouse gas forcings are used in these simulations, which are each run for one year at a time. The ensemble produced has on average 116 members for each ALL ensemble for the years 1987–2011, 2164 members in the ALL ensemble for 2012 and 2313 in the NAT ensemble for 2012.

4.2.3 Model evaluation

4.2.3.1 Variability

All model data are regridded to the observational grid (1.0° × 1.0°). The mean of each ALL ensemble is then bias corrected to that of the observations, over the longest time period shared by the two datasets. This bias correction is also applied to the NAT ensemble. For the CMIP5 ensemble, this is done for each individual model ensemble. The variance is not bias-corrected due to the relatively short data time periods available. The ALL ensembles are evaluated with respect to the observations by analysing the long-term trends, interannual variability and power spectra. Before analysing the interannual variability and power spectra, time series are detrended using a linear least-squares fit, except for the HadAM3P simulations as these are each run for a single year.

4.2.3.2 Teleconnection Analysis

The ability of each ALL ensemble to reproduce significant observed teleconnections is assessed, as these are a key driver of rainfall variability. The SST regions considered are from Rowell (2013) and defined in table 4.2. Teleconnections are first assessed between GPCC precipitation and HadISST SST observations in the six regions, using JJA means of the same year for both. The Pearson correlation coefficient is calculated for each teleconnection and the

Table 4.2 Teleconnection regions

SST region	Definition	Reference
Tropical Atlantic Dipole (TAD)	averages of 5°–25°N, 55°–15°W minus 20°S–0°, 30°W–10°E	Rowell (2013), modified from Enfield et al. (1999)
Equatorial East Atlantic (EqEAtl)	average of 5°S–5°N, 15°W–5°E	Chang et al. (1997) South Atlantic Tropical index in Rowell (2013)
Indian Ocean Dipole (IOD)	averages of 10°S–10°N, 50°–70°E minus 10°S–0°, 90°–110°E	Saji et al. (1999)
Central Indian Ocean index (CIndO)	average of 25°S–10°N, 55°–95°E	Rowell (2013)
Niño 3.4	average of 5°S–5°N, 170°–120°W	Trenberth (1997)
Mediterranean (Med)	Whole basin	Rowell (2013)

significance assessed at a 95% confidence level.

For each model ensemble, teleconnections are assessed for the longest available time period. For the HadGEM3-A and HadAM3P ensembles, these are analysed in the same way as the observations using HadISST and OSTIA SST observations respectively. For the CMIP5 ensemble, the teleconnections are analysed for each model ensemble, using the corresponding SST data, and the analysis used to create a reduced CMIP5 ensemble (CMIP5 tc). Where a model has significant teleconnection of the opposite sign to a significant correlation in the observations, for any of the regions, this model is removed from the analysis. For each remaining model, ensemble members in the incorrect phase for any significant teleconnections in the model years used in the event attribution analysis are removed. In this way, smaller ensembles that represent the relevant teleconnections, ALL_{TC} and NAT_{TC}, are produced in a similar way as by Bellprat et al. (2015).

4.2.4 Event attribution

The ALL and NAT ensembles for 2012 are bootstrapped 1000 times. For the CMIP5 ensemble, which has fewer members, a period of 5 years (2008–2012) is used instead of the single year in order to reduce uncertainty. This is a reasonable compromise as the climate is approximately stationary over this short period and these are coupled simulations so do not represent actual calendar years. The bootstrapped ALL and NAT ensembles have gamma distributions fitted, as this gives a reasonable fit for monthly mean precipitation (Husak et al., 2007). The probability of exceeding the observed 2012 value is then calculated for the ALL distribution (P_{ALL}) and the NAT distribution (P_{NAT}).

The Difference of Binary Logarithms of Probability (DBLP; Lott and Stott, 2016) is calculated to analyse the difference in the probabilities. This is defined as

$$\text{DBLP} = \log_2\left(\frac{P_{ALL}}{P_{NAT}}\right).$$

The more traditional FAR function $\left(\text{FAR}=1-\frac{P_{NAT}}{P_{ALL}}\right)$, while being useful when $P_{ALL} > P_{NAT}$ so FAR is between 0 and 1, is not well-defined when $P_{ALL} < P_{NAT}$ and FAR is negative (Hansen et al., 2014). DBLP has the benefit of being well-defined when positive or negative. It is a symmetrical index tending to positive or negative infinity if either probability is zero, while retaining ease of understanding. For example, DBLP = 1 corresponds to a doubling in probability due to climate change and DBLP = 2 is a 4 times increase. DBLP = −1 corresponds to a halving of probability to climate change and DBLP = −2 a quartering, etc. The bootstrapping enables an estimate of uncertainty in the DBLP distribution to be generated.

4.3 Results

4.3.1 2012 observations

Figure 4.1 shows the observed 2012 precipitation anomaly, which is positive across most of the West Sahel region. The observational times series (figure 4.2(a)) shows that precipitation is at its highest in 2012, at 156 mm month^{-1}, since 1964, at the beginning of the well-documented decreasing precipitation trend and subsequent recovery (e.g. Dai et al., 2004).

4.3.2 Model evaluation

4.3.2.1 Variability

Figure 4.2 compares the model ALL ensembles and observations. The CMIP5 ensemble reasonably simulates the long-term precipitation trend, but fails to capture the drought period and recovery since the 1960s (figure 4.2(a)). However, the ensemble interannual variability captures the spread of the observations well (figure 4.2(b)) and the power spectra of the observations lies within the ensemble spread, except for very short periods (figure 4.2(c)).

The HadGEM3-A and HadAM3P simulations capture the trends in precipitation over recent decades much more reliably (figures 4.2(d) and (g)) and the interannual variability is well-represented (figures 4.2(e) and (h)). This is to be expected from the more constrained

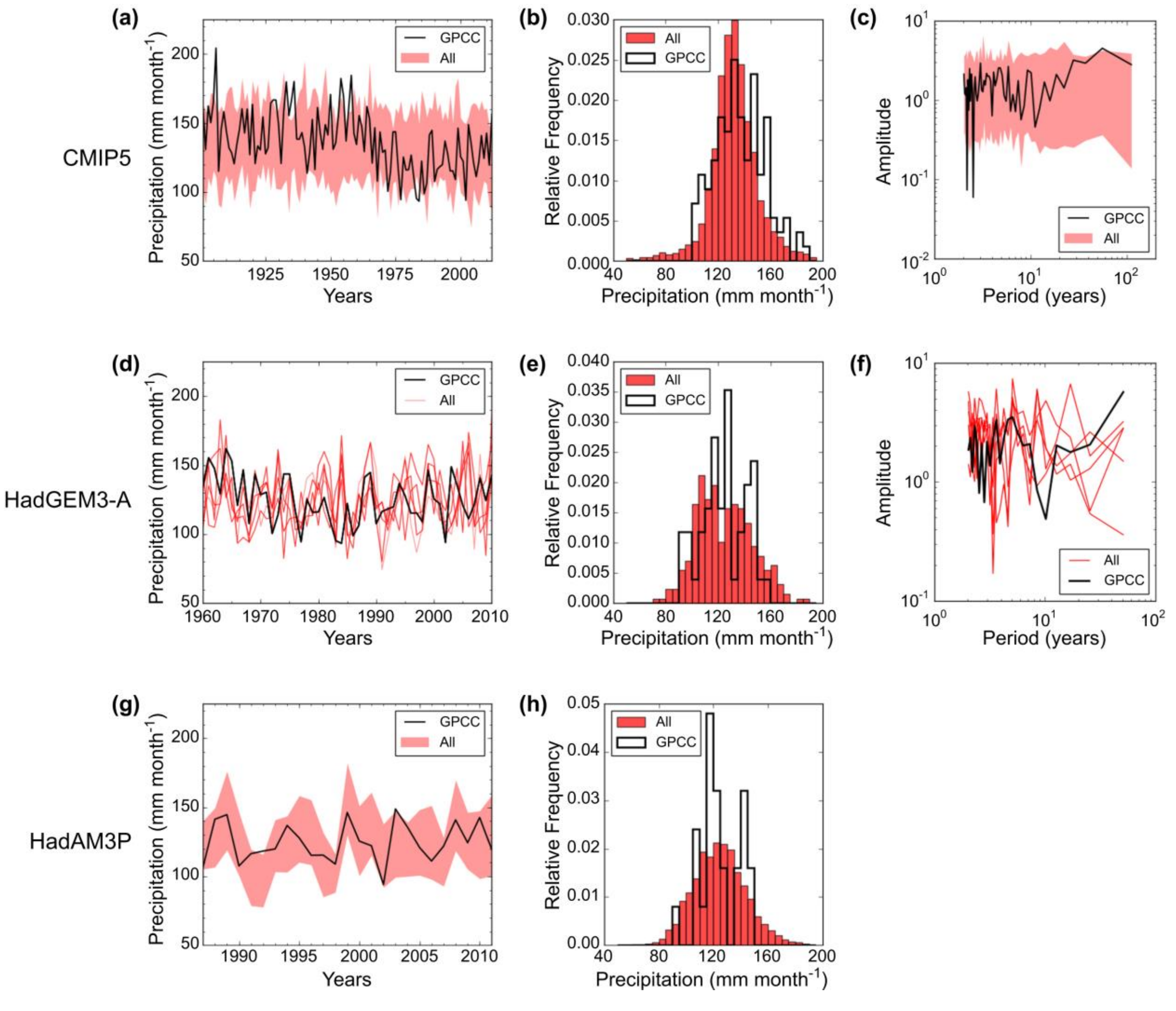

Figure 4.2 Distributions of the ALL ensemble for each model with GPCC observations for the longest available time period covering both the model and observations. For CMIP5 and HadAM3P, shading marks the 5th–95th percentiles of the model ensembles. Model data has been bias-corrected to the observations as described in section 4.1.3.1. Time series for CMIP5 (a), HadGEM3-A (d), and HadAM3P (g). Histograms with detrended model data for CMIP5 (b) and HadGEM3-A (e), and with non-detrended data for HadAM3P (h). Power spectra for CMIP5 (c) and HadGEM3-A (f).

atmosphere-only simulations compared to the coupled simulations. The power spectrum of the observations is also within the spread of the HadGEM3-A spectra ensemble (figure 4.2(f)). This qualitative comparison of the interannual variability and power spectra suggests that the variability in the observations is reasonably well captured by all the model ensembles analysed, which supports only bias-correcting the mean of the model data.

4.3.2.1 Teleconnections

Table 4.3 summarises the correlations between West Sahel precipitation and SSTs in six teleconnection regions. In the observations, the EqEAtl, CIndO, Niño3.4 and IOD regions all exhibit negative correlations with precipitation. The TAD has a positive correlation and the Med correlation is not significant.

Table 4.3 Pearson correlation coefficients (r) between West Sahel precipitation and SSTs in six regions (defined in table 4.2) for JJA monthly means. Where no significant correlation (at 95%) is found the entry is left blank.

Dataset		**EqEAtl**	**CIndO**	**Niño3.4**	**IOD**	**TAD**	**Med**
GPCC		-0.36	-0.52	-0.32	-0.34	0.38	
CMIP5	bcc-csm1-1					0.33	
	CNRM-CM5	-0.12	-0.13	-0.12		0.33	0.11
	CSIRO-Mk3-6-0	-0.09	-0.09		0.12	0.35	0.06
	CanESM2	-0.23	-0.39	-0.11	-0.15	0.23	
	GISS-E2-H	-0.28	-0.30	-0.19	-0.08	0.37	
	GISS-E2-R	-0.17	-0.26	-0.10		0.27	
	HadGEM2-ES	-0.63	-0.13			0.67	
	IPSL-CM5A-LR	-0.36	-0.21			0.32	0.19
	IPSL-CM5A-MR	-0.28	-0.26			0.31	0.17
	NorESM1-M	-0.22				0.37	
HadGEM3-A		0.18		-0.26	-0.14		
HadAM3P		0.26	-0.29	-0.30	-0.12	-0.13	0.24

HadGEM3-A only has three significant teleconnection regions; the Niño3.4 and IOD are of the same sign as the observations but the EqEAtl has a positive correlation which is negative in the observations. HadAM3P has significant correlations for all regions, but these are of opposite sign to the observations for both the EqEAtl and the TAD.

Similar analysis for each of the CMIP5 models shows only one model has a teleconnection that is significant and opposite in sign to the observations: CSIRO Mk3.6.0 with a positive IOD relation. This model was removed from the ensemble and the data from the remaining models removed if in the wrong teleconnection phases for years 2008–2012, as per section 4.2.3.2, to create the ALL_{TC} and NAT_{TC} ensembles. In general, most of the CMIP5 models represent the signs of the EqEAtl and CIndO teleconnections correctly, and all models correctly simulate the positive TAD correlation, most also with very similar magnitudes. However the Niño3.4 and IOD correlations are less well captured and not significant in most of the models.

4.3.3 Distributions of 2012 precipitation and DBLP

The CMIP5 ensemble NAT distribution for 2008–2012 is shifted slightly higher than the ALL distribution, with the observed value in the upper part of the distributions (figure 4.3(a)). With the teleconnection analysis these distributions become narrower (figure 4.3(b)), as expected since some of the SST variability has been removed. The distributions appear much closer together, with the NAT still slightly higher than the ALL. The observed value is situated further towards the tails of the distributions in this case. The DBLP distributions are negative for both of these cases, with the CMIP5 median DBLP at −1.5 (figure 4.4(a)), corresponding to a probability of high precipitation in the all forcings world (P_{ALL}) around one third of that in the natural forcings world (P_{NAT}). The CMIP5 tc DBLP distribution has much greater spread (figure 4.4(b)). The median is lower at −1.8, but distribution ranges from approximately 0 to −4, representing an uncertainty in the change in probability of high precipitation due to climate change varying from no change to a 1/16 reduction.

For the HadAM3P ensemble, the 2012 distributions show a higher NAT distribution than ALL with the observed value in the upper tail of the ALL distribution (figure 4.3(c)). The DBLP distribution is again negative but is much narrower than the CMIP5 distribution (figure 4.4(c)). The median is −2.4, corresponding to a P_{ALL} around 1/5 of P_{NAT}.

In the HadGEM3-A case there are four different NAT ensembles compared with the ALL ensemble (figures 4.3(d)–(g)). In the three model cases, the NAT ensemble is shifted higher than the ALL ensemble. However, using the natural SSTs from the observed trend (figure 4.3(g)) produces the only case where the NAT distribution is lower than the ALL distribution.

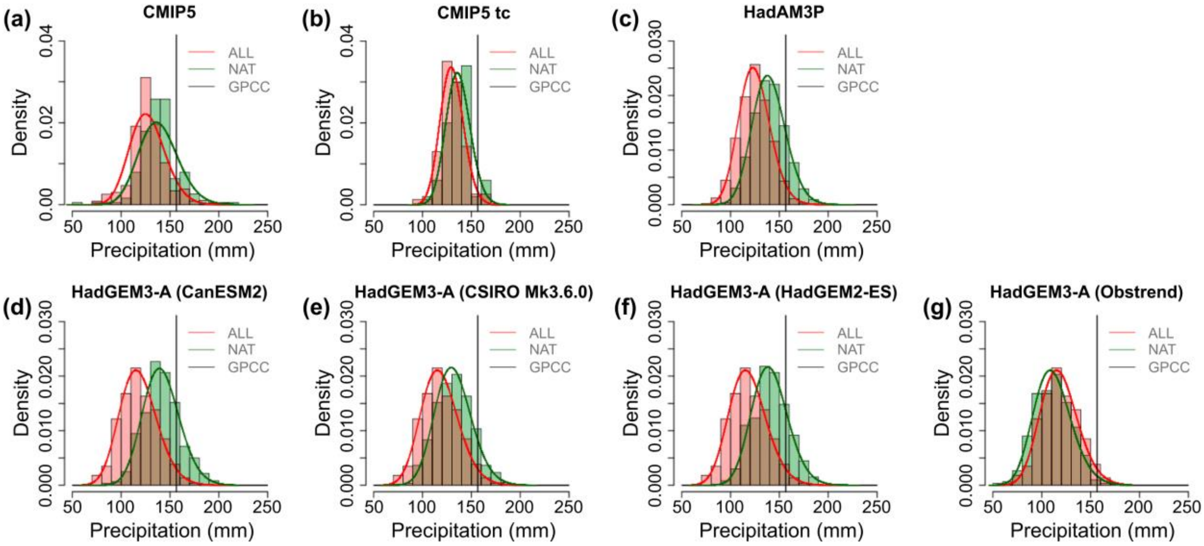

Figure 4.3 Distributions of bias-corrected JJA monthly mean ALL (red) and NAT (green) precipitation for 2012 (2008–2012 for CMIP5) with fitted gamma distributions and 2012 observed precipitation in black. CMIP tc is the CMIP5 ensemble after the teleconnection analysis. These include all ensemble members before bootstrapping.

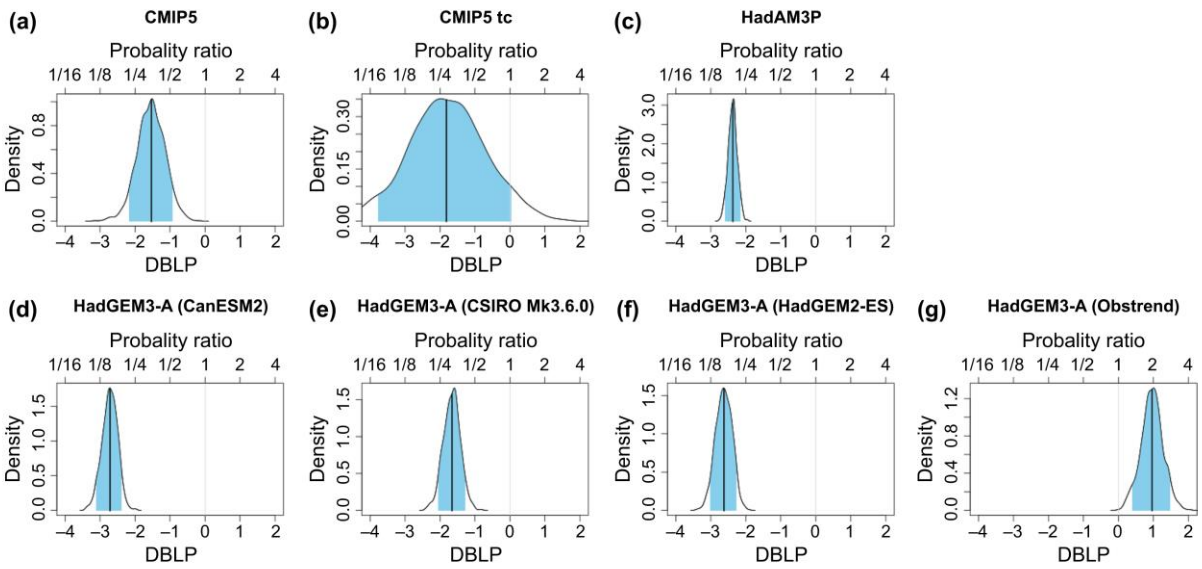

Figure 4.4 DBLP distributions for the different model ensembles. The corresponding probability ratio (PALL/PNAT) is also shown. Blue shading marks the 5th–95th percentiles and the black line the median.

The DBLP distributions are all relatively narrow (figures 4.4(d)–(g)). The three model NAT ensembles all show negative DBLPs, with medians between −2.7 and −1.7. The Obstrend DBLP distribution is positive with a median of 1, corresponding to a doubling of the probability of high precipitation compared to the natural world.

4.4 Discussion

Across most of the model ensembles, climate change decreased the probability of high precipitation in the West Sahel in JJA 2012. However, results from the coupled and atmosphere-only models cannot be directly compared as they ask different questions. While the CMIP5 ensemble assesses the change in probability given all SST variability[1] (with some limitation to this variability by filtering teleconnections), the HadAM3P and HadGEM3-A ensembles assess the change in probability given the actual SSTs at the time of the event (with estimated SSTs for the natural world). This partly explains why the Difference of Binary Logarithms of Probabilities (DBLP) uncertainty distributions are much narrower in the atmosphere-only model cases, as the simulations are much more constrained. It is also due to the greater numbers of ensemble members and use of only one model. The CMIP5 ensemble with teleconnection analysis provides something in between these two cases, by excluding members which incorrectly simulate relevant teleconnections and also those in incorrect SST phases for the event of 2012 (estimated by years 2008–2012). By constraining the distributions we would expect a narrower DBLP distribution than with all the CMIP5 simulations included. However this appears to have been counteracted by the substantial decrease in the number of data points, leading to much greater uncertainty.

Across West Africa and the wider Sahel region there is much uncertainty in climate model

[1] Comment post-publication: As the CMIP5 simulations are coupled they do not represent specific years in the same way as the HadGEM3-A and HadAM3P atmosphere-only simulations which are forced with observed SSTs. This means that a 5-year period of CMIP5 simulations could be used to produce a larger ensemble, but also means the attribution is not of the conditions of a specific year in the same way. Furthermore, while simulations from the atmosphere-only models are anomalously high in the year 2012, as in the observations, the mean of the CMIP5 ALL ensemble is not anomalously wet with respect to the ensemble's climatology, and is in fact slightly drier than the mean. This can be seen from the time series (Figure 4.2(a)). This must be taken as a caveat when interpreting the results from the CMIP5 ensemble, particularly as the ensemble does not capture the long term trend in the observations. However this ensemble can still be used to compare the simulations from the ALL and NAT simulations to understand the influence of anthropogenic emissions on precipitation over the recent period, even if this is not specific to a particular real-life year, and can provide complementary information to the other ensembles analysed.

projections of precipitation (e.g. Biasutti et al., 2008; Druyan 2011) and disagreement about the role of anthropogenic forcings in altering the climate. The direct effect of carbon dioxide in the atmosphere could increase precipitation by enhancing monsoon flow (Biasutti, 2013; Skinner et al., 2012). Dong and Sutton (2015) found greenhouse gases to be the main cause of the recovery of Sahel July-August-September rainfall using HadGEM3-A, explained by the increase in land-sea temperature contrast. This would be consistent with a positive DBLP. However, warming SSTs in different regions have been shown to decrease precipitation in the Sahel (e.g. Bader and Latif, 2003; Biasutti, 2013; Rodríguez-Fonseca et al., 2015) by weakening monsoon flow (Giannini et al., 2003), which would be consistent with a negative DBLP. Tropical ocean warming could also lead to increased precipitation if sufficient moisture is available to reach an increased convection threshold (Giannini et al., 2013). Other anthropogenic emissions may also have an impact on precipitation, for example sulphur dioxide emissions may cause a decrease in precipitation in the Sahel (Dong et al., 2014), and aerosols were shown to producing drying around 1940-1980 (Ackerley et al., 2011), which would act to decrease the DBLP.

When interpreting these attribution results it must be noted that the HadGEM3-A ensemble does not represent the EqEAtl teleconnection correctly, and misses the CIndO and TAD correlations (table 4.3). HadAM3P also has the EqEAtl and TAD correlations in the opposite direction, which will affect the precipitation processes in the model. The CMIP5 ensemble fails to capture the long-term trends in precipitation in the region. Further analysis could consider how well the models represent the relevant dynamical phenomena associated with extreme rainfall in the region, to ensure they are suitable for an attribution study (Mitchell et al., 2016a). Future work is also needed to establish how anthropogenic forcings are affecting the rainfall processes in the simulations. This will help us to further understand the differences in the overall effect on precipitation, so we can be confident that events such as those of 2012 are genuinely less likely to happen in the future, as the majority of the models show.

The HadGEM3-A ensemble with natural SSTs from the observed trend was the only ensemble to produce a positive DBLP distribution. Figure 4.5 shows JJA mean SST time series for each model and the observations used to calculate the SST changes used in the HadGEM3-A simulation, averaged over each teleconnection region which is significant in HadGEM3-A (table 4.2). Considering the trend in HadISST and the difference between ALL and NAT model

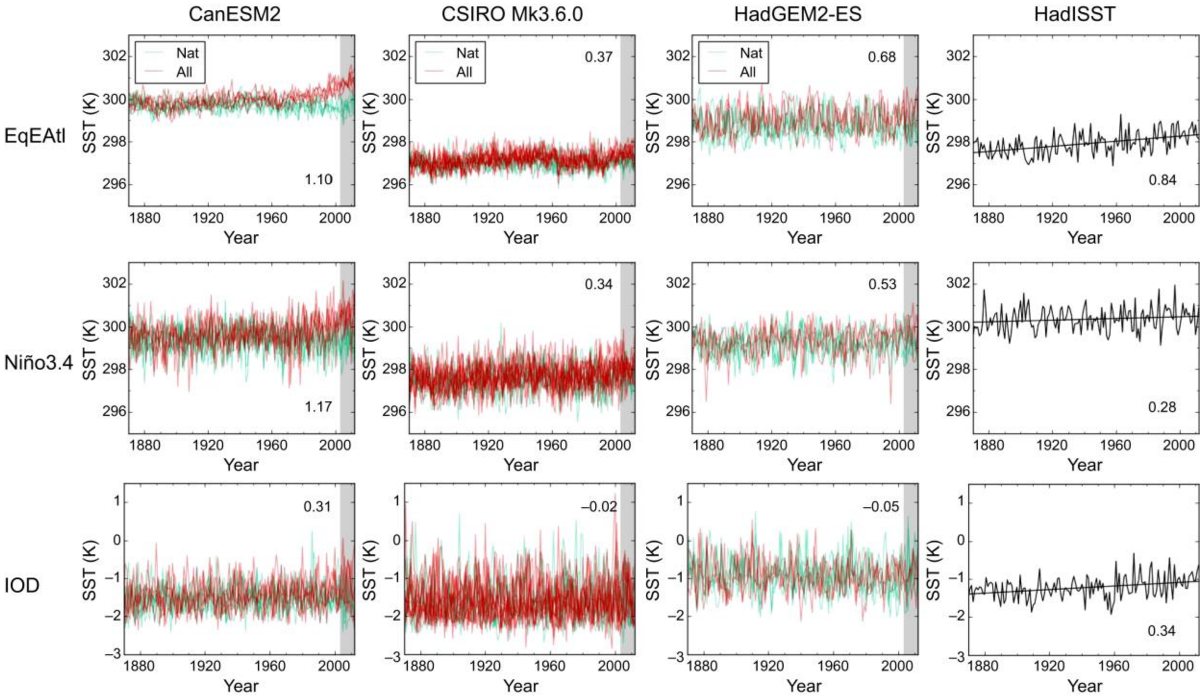

Figure 4.5 Time series of JJA mean SSTs averaged over the EqEAtl, Niño3.4 and IOD regions from 1870–2012 from all forcings (red) and natural forcings simulations (green) for CanESM2, CSIRO Mk3.6.0 and HadGEM2-ES, and from HadISST observations. For the models, the grey region marks the 2003–2012 period over which the difference between the mean of the all forcings and natural forcings simulations are calculated, with the numbers showing this difference. For the observations a linear regression is calculated for 1870–2012 and the slope of this line shown.

simulations over recent years, the EqEAtl region shows a positive difference between the ALL and NAT simulations in all the models which is consistent with the increasing trend in HadISST. In the Niño 3.4 region, ALL simulations are warmer than NAT simulations over recent years in all the models, but with greater magnitudes than the observed trend. In the HadGEM3-A simulations, a greater anthropogenic SST contribution would be subtracted from the HadISST observations in the model cases compared to the Obstrend case. This would lead to higher NAT precipitation because of the positive correlation. This is consistent with the 2012 distributions (figures 4.3(d)–(g)), with the highest NAT distributions corresponding to the models with greatest differences in ALL and NAT Niño3.4 SSTs. The IOD region has a positive HadISST trend with a similar SST difference magnitude in CanESM2. However, CSIRO Mk 3.6.0 and HadGEM2-ES both show the NAT SSTs to be slightly higher than the ALL SSTs. We would expect this to lead to higher precipitation in the Obstrend NAT distribution than in these two models. This is not the case (figures 4.3(e)–(g)), but this effect may be counteracted by the Niño3.4 influence where the teleconnection is of a greater magnitude (table 4.3). The NAT SSTs in the HAM3P simulations were also estimated using CMIP5 simulations and produce a similar DBLP distribution (figure 4.4(c)) to the HadGEM3-A distributions using model estimates of NAT SSTs.

This shows the importance of model SST changes being consistent with observations if results are to be robust. Assessing whether model simulations of SST changes due to anthropogenic climate change are consistent with observed SST trends is one way of validating natural forcings simulations. However it also needs to be considered that long-term trends in observed SSTs may not only be due to anthropogenic forcings. Being able to evaluate natural simulations is obviously a difficulty, as observations do not exist for a world without anthropogenic climate change, and also often do not exist for the world prior to when anthropogenic forcings began to have an influence.

4.5 Conclusions

There is much disagreement between climate model projections about the magnitude and sign of future changes in precipitation in the West Sahel. This study contributes to climate change understanding in this region by analysing the change in probability due to anthropogenic emissions of high precipitation in June-July-August 2012 using three model ensembles. This is one of only a few studies to have analysed results from both coupled and atmosphere-only model simulations, but this is important to generate greater understanding of changes in the event due to anthropogenic forcings. Results show a decrease in the probability of high precipitation across the majority of the model ensembles: the CMIP5 coupled multi-model ensemble, the weather@home HadAM3P atmosphere-only ensemble, and the HadGEM3-A ensembles when natural SSTs are estimated using models. The decreases are between a factor of 0 and 16, and signify a decrease in probability under both general climate conditions and those specific for 2012. The uncertainty in the effect of climate change clearly depends on the model ensemble used, with greater certainty in atmosphere-only models. These models, however, do not completely represent all the observed SST-precipitation teleconnections and so results must be caveated by this. Creating reduced ensembles of CMIP5 simulations where teleconnections were well-represented greatly reduced the number of ensemble members and therefore the certainty in the result.

However, when the observed SST trend is used to estimate the natural world SSTs to force the HadGEM3-A model, climate change increases the probability of high precipitation by a factor of 2. This appears to be due to differing trends in SSTs between the models and observations in the Niño 3.4 region. It is difficult to determine whether this divergence is a product of model errors or natural variability in the observations. This emphasises the need to ensure that modelled climate processes are consistent with observed changes.

Further work is needed to understand how anthropogenic forcings are affecting the rainfall processes in the different models, in order to understand why and how the different model ensembles produce different estimates of the change in probability of high precipitation. This study demonstrates the need for comparisons of model ensembles in event attribution studies, in order to gain understanding of the robustness of results, and to make use of evaluation techniques to ensure that natural simulations are consistent with observations.

4.6 Results in the context of the thesis

These results have shown that for the high precipitation in 2012 in West Africa climate model simulations provide reasonably robust results for the anthropogenic influence, showing a decrease in probability across the majority of the ensembles. This case study demonstrates that it is possible to produce robust results in West Africa, answering the research question:

Q1. Do event attribution studies produce robust results in West Africa?

The study highlighted the challenges that event attribution studies can present due to the strong influence of teleconnections in the region, showing that changes in natural SST estimates can affect the magnitude, and even the sign, of the anthropogenic influence on precipitation. This is similar to the East African rains study by Lott et al. (2013) where the magnitude of the increase in probability of dry long rains depended on which model estimate of natural SSTs was used. The results also highlight a paradox, as other African event attribution studies have (Lott et al., 2013; Wolski et al., 2014). While the precipitation trend since the 1970s has been positive, results show the probability of high precipitation in 2012 was decreased due to climate change. This is likely to be due to the large interannual variability in precipitation and strong teleconnection influences in the region, but could prove a challenge for the application of results.

5. Event attribution science in adaptation decision-making: the context of extreme rainfall in urban Senegal

One of the main areas in which it has been suggested in the scientific literature that event attribution results could be applied is in adaptation policy. Therefore this thesis next investigates how stakeholders involved in a particular national adaptation context in Africa perceive the science and its relevance. Building an empirical understanding of the relevance of event attribution for adaptation is important but has not been done before. For this study the case of Senegal is investigated through engagement with stakeholders associated with national adaptation policy to address urban flooding from extreme rainfall. Senegal is chosen as it is a country frequently exposed to the impacts of urban flooding, which are events with a climate component that may be affected by climate change. It is also a country where there were already links with relevant key people in order to be able to carry out the research, and furthermore there had been some interest in event attribution from the Meteorological Service following flood events. This study follows on from the event attribution study in Chapter 4 investigating the high precipitation in 2012 across West Africa, as this led to large impacts in Senegal. It is used to address the national level component of the following research question:

> Q2. Can event attribution play a role in specific national and international policy contexts relevant to Africa through engagement with policy stakeholders?

This chapter has been submitted to Global Environmental Change (Young et al., 2017).

Abstract

Weather, climate and water-related disasters caused the loss of 1.94 million lives and US$2.4 trillion in economic losses globally between 1970 and 2012. Such events can be particularly devastating for vulnerable communities in developing countries. For policymakers managing the associated risks, understanding the impact of climate change is a key challenge. Event attribution science assesses how climate change affected the probability of individual extreme events. Although this is a science in development, it has been suggested that results could be relevant for climate risk and adaptation policy. However, this has not yet been considered for a specific national adaptation context. Taking the case of Senegal, a developing country frequently exposed to the impacts of flooding, we investigate the national adaptation policy context regarding extreme precipitation and flooding in urban areas, and the scientific information needed to support this policy. We triangulated three sources of information: 23 semi-structured key informant interviews, a workshop and document analysis. We found that flooding in Senegal was viewed primarily as an urban planning concern due to settlements in flood-prone areas lacking drainage infrastructure, rather than as a climate change issue. Actions to address the impacts of floods, such as improved infrastructure and relocation of residents, are focussed on the current vulnerability of urban communities without consideration of changing climate risks. Stakeholders did believe event attribution might be useful to inform about climate change impacts and future risks of extreme events, along with other uses. Still it is unclear whether there would be opportunity for this science to play a role in adaptation decision-making at present, due to the limited role climate information has in this. The complexity of adaptation decision-making, particularly in countries where policy is still developing, means that event attribution may not be incorporable or relevant in many cases at present. While addressing vulnerability to extreme events such as flooding is necessary whether or not the risk is climate change related, if long-term planning is to be resilient then knowledge about future changes in the risks of extremes will need to be considered, even if individual events are not attributed to climate change.

5.1 Introduction

Between 1970 and 2012, weather, climate and water-related disasters caused economic losses of US$2.4 trillion and 1.94 million deaths globally (World Meteorological Organization, 2014). In developing countries, people’s lives and livelihoods are particularly vulnerable to such events (Cardona et al., 2012). Many factors increase the risk of a weather event becoming a disaster including climate change, alongside poorly planned development, poverty and environmental degradation (World Bank, 2013). Understanding the influence of anthropogenic climate change on extreme events is vital for the management of climate risks (Lavell et al., 2012). Extremes may help motivate adaptation to climate change (Berrang-Ford et al., 2010), however such events will only be a useful guide if they signal the underlying climate trend (Travis, 2014). Otherwise decisions could be made leading to maladaptation and greater vulnerability in the future (Barnett and O’Neill, 2010) if, for example, adaptation plans erroneously assumed an event would increase in frequency or intensity.

Alongside considering long-term trends in extremes, establishing the impact of climate change on individual events which have occurred may also be relevant for adaptation decision-making. It has been suggested that much adaptation in developing countries will depend on past experiences of dealing with climate-related risks (Adger et al., 2005) and events, particularly floods, can help the issues associated with them rise up the political agenda and accelerate policy implementation (Johnson et al., 2005; Kingdon, 2003).

In general, establishing what information is relevant for decision-making requires interaction and iteration between information producers and users (Dilling and Lemos, 2011; Lemos et al., 2012; Lemos and Rood, 2010). This can help increase the usability of information (Kirchhoff et al., 2013a), informing the production of the knowledge, the context for its use and its format (Dilling and Lemos, 2011) and ensuring research questions and outputs are relevant (Shanley and López, 2009). This is particularly relevant for countries in the earlier stages of adaptation planning which may not have well-defined information needs, a well-developed science-policy interface, or understanding of how to handle uncertainty (Hanger et al., 2012).

This paper contributes to this process of interaction by exploring the scientific information relevant for national adaptation decision-making addressing flooding in urban Senegal. While climate information may inform decisions, there are many other considerations including resource management, involvement of different stakeholders, and long-term economic development (Dilling and Lemos, 2011; Pegasys, 2015). Therefore this paper also looks to understand the adaptation policy context, including the structures in place and stakeholders involved, and how these factors determine decisions. In particular, we consider whether event attribution science could play a role by providing information about the impact of climate change on individual extreme events. Although it has been suggested that event attribution could be relevant for adaptation policy, this is the first time it has been critically examined for a specific national context.

5.1.1 Event attribution and adaptation policy

Extreme event attribution aims to quantify the impact of drivers such as anthropogenic climate change on individual extreme events. Probabilistic event attribution (Allen, 2003) assesses how the probability of an event has been affected by climate change. This can be done using climate model simulations to compare the probability of the event occurring in models of the actual world and a world without anthropogenic greenhouse gas emissions (e.g. Bellprat et al., 2015;

King et al., 2013; Stott et al., 2004). Any change in probability can be attributed to emissions, helping generate understanding of how climate change is currently influencing extremes.

Scientists developing event attribution methodologies have suggested that results could be relevant for adaptation policy, along with stakeholders associated with negotiations around loss and damage from climate change (Parker et al., 2016a). Specifically, results could inform about whether events are likely to increase or decrease in frequency in the future (Otto et al., 2015). This could help reduce the risk of maladaptation by guarding against adapting to events where anthropogenic climate change has decreased their probability and which are therefore likely to decrease in occurrence in the future (e.g. Otto et al., 2013; Stott and Trenberth, 2009; Stott and Walton, 2013; Stott et al., 2013). Climate policy stakeholders have also suggested results could be relevant for adaptation in highlighting the impacts of climate change on current risks as well as in the future (Sippel et al., 2015). Furthermore, it has been proposed that results could help guide and prioritise resource allocation for adaptation actions (Hoegh-Guldberg et al., 2011; Huggel et al., 2015).

In contrast, Hulme et al. (2011) argue that event attribution would not be relevant for adaptation policy. They claim it may lead to a focus on global climate funds being allocated as compensation for attributable events, considering only the climate change aspect, rather than the overall risk including the vulnerability of those affected. Other scientists support this view, along with stakeholders addressing the impacts of extremes, who argue that addressing drivers of vulnerability is more important than establishing causes of events (Parker et al., 2016a; Surminski and Lopez, 2014). Thompson and Otto (2015) emphasise that event attribution studies consider the impact of climate change on the probability of the event only at the time it occurred, so may not be appropriate for decision-making on longer timescales.

As with any climate model studies, event attribution results are complex and have uncertainties (National Academies of Sciences, Engineering, and Medicine, 2016). In general it is more challenging to attribute precipitation extremes than temperature extremes and so there is less evidence for these types of events (Herring et al., 2015). This is due to the lack of robust observations in some regions and model limitations representing the processes causing precipitation events (Stott et al., 2016). Low confidence in the effect of climate change on a particular event could make applying this information more challenging. However, practitioners are often experienced in making decisions about the future with uncertain information (Morss et al., 2005). Dialogue between scientists and policymakers can communicate the many dimensions to uncertainty (Patt, 2009) and considering these could help decisions makers to better understand potential climate impacts and how to adapt (Mechler et al., 2010).

5.1.2 A case study of Senegal

Senegal is one of the UNFCCC's 48 least developed countries (UNFCCC, 2014b). Along with many other countries in sub-Saharan Africa it is vulnerable to climate change due to its weak state capacity, financial constraints and reliance on agriculture (Castells-Quintana et al., 2015). Senegal's climate is characterised by a rainy season driven by the West African monsoon bringing the majority of the country's rainfall during the months of June to September (Fall et al., 2006; Funk et al., 2012; Rust et al., 2013). Senegal experienced a decrease in precipitation in the 1960s and 1970s, followed by a slight increase (Fall et al., 2006; Funk et al., 2012). New et al. (2006) suggest that rainfall intensity has also increased across West Africa in recent decades. However there is much uncertainty around how rainfall will change in this region in the future, with little model agreement in terms of both mean precipitation (Christensen et al., 2013) and extreme events (Seneviratne et al., 2012). There have been few event attribution studies focussing on African events and this region presents challenges for studies through observational and modelling uncertainties (Otto et al., 2015). However a study has investigated seasonal rainfall over West Africa in 2012, showing that the probability of high precipitation was likely decreased due to anthropogenic climate change (Parker et al., 2017).

Extreme rainfall in Senegal often results in flooding, which particularly impacts low-lying urban areas and can occur frequently during the rainy season. Senegal's National Adaptation Programme of Action highlights this risk. It can result in damage to infrastructure and homes, health problems, and people relocating (Ministère de l'environnement et de la protection de la nature, 2006). From 1980 to 2009, floods in Senegal impacted more than 900,000 people, caused 45 deaths and led to property damage estimated at more than US$142 million (Ministère de l'Environnement et du Developpement Durable, 2015). In 2012, heavy rainfall led to flooding across the country affecting more than 280,000 people, with 19 deaths reported, over 10,000 houses destroyed or damaged, 5000 families displaced, and drinking water sources contaminated, and the national emergency plan, ORSEC (d'Organisation des Secours, Organisation of Relief), was launched (OCHA, 2012).

While rainfall and topography are key drivers of flooding, complex human factors also have roles in Senegal and many other sub-Saharan cities. These include rapid urbanisation, in part increased by decreasing rainfall trends, leading to reduced infiltration, uncontrolled settlements in flood-prone areas which obstruct natural drainage channels, and inadequate and poorly maintained rainwater drainage infrastructure in suburbs (Barrios et al., 2006; Diagne, 2007; Government of Senegal et al., 2010; Government of Senegal and World Bank, 2013; Mbow et al., 2008; UNISDR, 2013; World Bank and GFDRR, 2011). These areas make up around 30-40% of the cities (Government of Senegal, 2014). Residents are often poor and particularly vulnerable as flooding can have large impacts on their housing, economic activities which are often low-income, education and health (Government of Senegal et al., 2010; Sané et al., 2015).

In Senegal, while land use remains the responsibility of the government, urban development governance has been decentralised (Mbow et al., 2008). Vedeld et al. (2015) found a lack of support from higher to lower-level government for climate adaptation, a lack of political guidance from the national level and a shortage of financial resources. Despite lacking national support for addressing flooding there is adaptive capacity among local groups however, as has also been found in Mumbai, India (Boyd and Ghosh, 2013). However Schaer (2015) described how local adaptation strategies employed in urban Senegal can often be maladaptive, and do not compensate for a lack of infrastructure.

5.1.3 Research questions

This paper considers whether event attribution could inform national adaptation decision-making regarding extreme precipitation and flooding in urban Senegal. The following sub-questions will be addressed:

Q1. What are the perceptions of the drivers of vulnerability to flooding events?

Q2. How are flooding events perceived in the context of climate change?

Q3. Who are the important and influential stakeholders working on adaptation and related issues?

Q4. What information is relevant to these stakeholders regarding extreme precipitation and flooding?

Q5. What are the barriers and opportunities to event attribution informing adaptation decisions?

5.2 Methods

Three research methods (interviews, a participatory workshop and document analysis) were selected to elicit specific information and triangulate findings. As the case study focusses on national adaptation policy, key informants included national-level decision-makers, researchers and civil society representatives.

5.2.1 Interviews

Interviews were carried out with stakeholders involved in, and associated with, national adaptation decision-making, and relevant researchers. Interviews investigated how stakeholders perceived the 2012 floods, including both the drivers of vulnerability and the event in the context of climate change (Q1 and Q2). They were also used to map out the important stakeholders (Q3), to gain in-depth understandings of national adaptation policies and the scientific information used and required for these (Q4), and to investigate whether event attribution could play a role in future decision-making in this context (Q5) (see Appendix A for interview protocol).

Interviews were semi-structured, providing the freedom to follow relevant leads as they arose (Gillham, 2005; Kvale, 1996). Key interviewees were identified through existing contacts and a snowball-sampling technique (Atkinson & Flint, 2004) used to identify additional relevant stakeholders. Interviews were carried out between February and August 2016 with a total of 23 people interviewed. Three of the interviews included two stakeholders. Stakeholders included representatives from government ministries (n=10), government research organisations (n=4), non-governmental research organisations (n=6) and civil society (n=3). Interviews were carried out in person (n=14), else by Skype (n=5) or email (n=4), either in French with a research assistant as translator, or in English. Spoken interviews were recorded and transcribed and lasted one hour on average. Transcripts were coded using NVivo version 11 software (QSR, 2015), with a thematic analysis (Braun and Clarke, 2006) used to identify key themes.

5.2.2 Stakeholder workshop

To complement the interviews, a workshop was held in Dakar, Senegal on 24 February 2016 on the theme of event attribution science and its relevance for national adaptation policy in Senegal (see Appendix B for workshop agenda). It brought together 40 participants from government ministries, non-governmental organisations (NGOs) and research institutes in Senegal alongside researchers from the UK. Senegalese participants were identified by gatekeepers hosting the workshop and included 11 representatives from the Direction of Environment and Classified Establishments (DEEC; including 6 from the Department of Climate Change) and 8 from other government ministries responsible for water and flood management and urban development. There were also 13 climate researchers present and 3 NGO participants working specifically on climate change issues and 2 on development.

The workshop was designed to be participatory, involving the sharing and co-production of knowledge to enhance engagement (Jones et al., 2014). At the start, delegates filled in a short questionnaire about their understanding of the links between climate change and extreme events (n=23, questionnaire in Appendix C). Next, results from the event attribution study of 2012 West African rainfall (Parker et al., 2017) were presented to participants and discussed. CAULDRON, a participatory game designed to communicate the science of event attribution, was then played (see Parker et al., 2016b for more details of this game). This aimed to give participants an experience of making decisions under changing probabilities of events, and lead to more in-depth discussions about how the science might be relevant for policy through reflections on the game. Group discussions followed. Groups were assigned randomly and each group added their responses to large pieces of paper (see Appendix D for photos). This gave each group, and each member, a chance to provide their answers in an attempt to include the concerns of all voices (Barbour, 2007) and also helped engage all members of the group (Krueger and Casey, 2009). Groups identified key actors involved in putting adaptation policies in place and using scientific information (Q3) and discussed whether and how extreme events and attribution results could be integrated into adaptation policy (Q5).

5.2.3 Document analysis

Finally, policy documents, reports and media articles were analysed. Government and NGO documents on national adaptation strategies provided information on the adaptation decision-making background in Senegal and on particular policies and projects. Online news articles from five of the major Senegalese online news sites (Agence de Presse Sénégalaise, Le Quotidien, Le Soleil, Sud Quotidien and Wal Fadjri) were also analysed. These were used to further investigate narratives around how extreme rainfall events were related to climate (Q2) and the adaptation strategies regarding flood events reported on. Articles were selected by searching, in French, ‘climate’ AND ‘rain OR precipitation OR flood’ or ‘flood management’, narrowed down to ‘climate change’ AND ‘flood risk management plan’ where necessary. The articles were translated into English and irrelevant ones discarded, leaving 91 articles for analysis. These were coded using NVivo software (QSR, 2015) and a thematic analysis (Braun and Clarke, 2006).

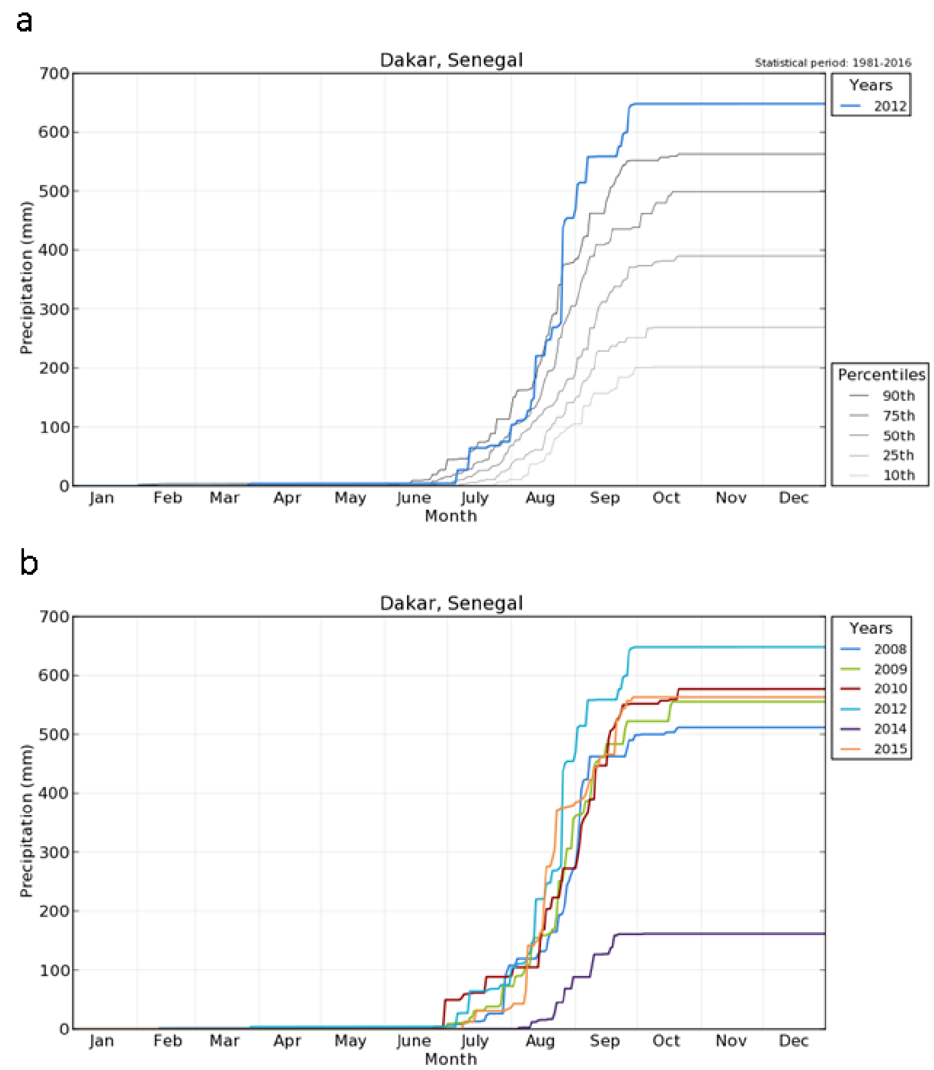

Figure 5.1 Cumulative precipitation in Dakar, Senegal in 2012 compared to (a) percentiles from 1981-2016 period and (b) other recent years for which all data was available. From RAINWATCH (Tarhule et al., 2009), operational across West Africa (http://www.rainwatch-africa.org/rainwatch/, accessed 9 January 2017)

5.3 Results

5.3.1 How extreme rainfall events are perceived in Senegal (Q1, Q2)

From the workshop questionnaire, the majority of participants (91%) thought climate change was affecting precipitation in Senegal. Many effects were mentioned in both the questionnaires and interviews, including more or less precipitation, more heavy rain and floods, more droughts, more variability in rainfall within and between seasons, and changes in the timing of the rainy season. The questionnaire also revealed that many stakeholders thought 2012's rainfall was more intense than normal for Senegal's climate. Others commented that this type of event was 'becoming normal' over the past few years. Interviewees also said flooding is now occurring nearly every year in urban areas in Senegal. Precipitation data for Dakar (figure 5.1) shows that cumulatively 2012 was above the 90th percentile following a particularly heavy event in mid-August. The rainfall total was highest in 2012 compared to other recent years, although others also reached levels around the 90th percentile.

The questionnaire also revealed that 78% of participants thought the 2012 rainfall event was, at least in part, affected by climate change due to there being more, or more intense, rainfall than normal. The majority also thought that, in general, it might be possible to attribute specific extreme events to climate change. Examples of why included being due to their 'greater abundance than normal' and 'intensity and unusual character', caused by 'the influence of temperature observed in the oceans' and 'changes to monsoon phenomena'. The majority of these workshop participants had not heard of probabilistic event attribution previously.

In interviews, stakeholders were more uncertain about whether the 2012 rainfall and other extreme events could be attributed to climate change. While many thought events could be attributed, including because they did not have other explanations for them, others were unsure or did not think it possible. They highlighted the need for more studies and that climate change is not always the cause, despite reporting a general view in Senegal that all extremes are attributable to climate change.

Stakeholders emphasised in both the questionnaires and interviews that human actions can have substantial contributions to the impacts of flooding events. They particularly highlighted the building of houses in flood-prone areas. In Senegal some areas are considered at high risk of flooding and building is not allowed there (Ministère de l'Urbanisme, de l'Habitat, de la Construction et de l'Hydraulique, 2009). However this has previously not been enforced, as an interviewee explained, 'the most vulnerable areas are the zones of very low-lying areas [… in] the drought years in the previous decades the people went to relocate in these areas and when the heavy rains returned these people are the most affected' (Government representative, 4/3/16, Dakar). Another key factor is infrastructure, and the 'drainage problem, with the city [Dakar] growing and with burgeoning settlement and no real network for run-off' (Researcher, 3/3/16, Dakar). It was noted that even a relatively small amount of rain can lead to flooding in parts of Dakar.

Media articles did not widely report on links between floods and climate change, with a few comments on climate change possibly leading to more floods, or natural climate variation causing such events. Other factors affecting flooding impacts were reported on much more, including uncontrolled building in low-lying areas due to a lack of governance, rapid urbanisation, and lacking or outdated rainwater drainage infrastructure.

Senegal's Intended Nationally Determined Contribution (INDC) discusses flooding as an impact of climate change, noted to justify the need to contribute to climate change mitigation and adaptation (Ministère de l'Environnement et du Developpement Durable, 2015). The National Adaptation Programme of Action (NAPA) states that the main causes of floods are climate events. The NAPA and the Senegal Emergence Plan (PSE) note that impacts have highlighted and been aggravated by urbanisation reducing infiltration, a lack of urban planning and management leading to unplanned settlements with inadequate drainage in areas which should not have been built in, and weak sanitation networks leading to problems in removing rainwater (Government of Senegal, 2014; Ministère de l'Environnement et de la Protection de la Nature, 2006). The PSE describes the development of events including flooding as highlighting the new challenge of adapting to climate change (Government of Senegal, 2014). However the World Bank and GFDRR (2011) claim that while there has been unusually high rainfall over recent years, there is no consistent trend and projections for precipitation are uncertain.

5.3.2 Adaptation stakeholders (Q3)

Figure 5.2 highlights key stakeholders involved in adaptation decision-making regarding extreme precipitation and flooding in urban Senegal. The Ministry of the Environment and Sustainable Development is 'the focal point for adaptation strategies for the whole country…. which coordinates all the activities relating to the climate change issues' (government representative, 3/3/16, Dakar). Although some interviewees thought this ministry was involved with addressing flooding, they do not currently have any mechanisms addressing this, and are limited by a relatively small budget (Pegasys, 2015).

The Ministry of Urban Renewal, Housing and Living Environment (MRUHCV) are in charge of flood management policies. The Ministry for Water and Sanitation also has a role through

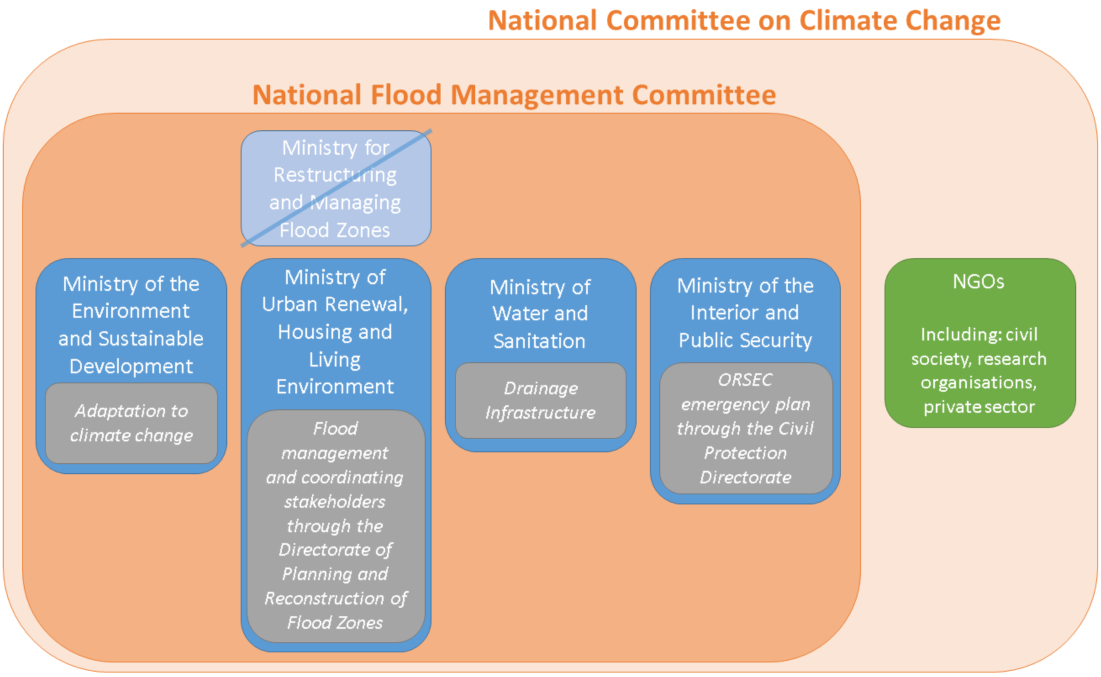

Figure 5.2 Stakeholders involved in climate change and the management of flooding events in urban Senegal. Blue boxes represent the key government ministries (pale blue no longer exist) and grey their primary roles.

responsibility for drainage infrastructure in urban areas. In 2012, a Ministry for Restructuring and Managing Flood Zones (MRAZI) was put in place (GFDRR, 2014). However in 2014 this was dissolved when the government changed, and responsibility for flood areas transferred to the MRUHCV. Within the MRUHCV, the Directorate of Planning and Reconstruction of Flood Zones (DARZI) office is in place to 'coordinate all the activities about flood issues' (government representative, 29/2/16, Dakar).

When an extreme event occurs, the Civil Protection Directorate within the Ministry of the Interior and Public Security are responsible for coordinating emergency actions. Specifically, the ORSEC emergency plan was first established in 1993 and updated in 1999 (Government of Senegal, 1999). It is the 'Minister of the Interior which governs many state agencies and stakeholders…. to say it is time to act' (researcher, 29/2/16, Dakar).

In order to coordinate the actions of different ministries addressing flooding there is a National Flood Management Committee, established in 2009 (GFDRR, 2014) and currently chaired by the MRUHCV. There are also numerous regional and local committees, with local level representatives on the national committee. Interviewees explained that managing flooding is a decentralised process and that ‘decisions come from the ministry, through the technicians, and it is shared with the local government and NGOs to give information and the local stakeholders are those in charge to appropriate this decision and make action’ (Government representative, 3/3/16, Dakar). However there was concern that local governments do not have the competency or financial means to carry out projects themselves (Government of Senegal et al., 2010) and so, for example, civil society organisations can assist. There is also a National Committee on Climate Change (COMNACC), comprising directors of all the ministries, and NGOs including civil society, research and the private sector, which advises ministries on climate change.

Some interviewees indicated that NGOs, including civil society and the private sector, were well-represented on committees addressing precipitation and flood management and in developing national adaptation plans (NAPs). However others disagreed. A governmental organisation representative explained that NGOs are not directly on the National Flood Management Committee (although their services could be requested) and may not have significant influence. Instead, ‘those from the civil servants from the administration are the most represented, instead of having NGOs or civil society or other actors on the committee’ (governmental organisation representative, 3/3/16, Dakar). A civil society representative explained when trying to influence government decisions around managing precipitation, ‘it’s not very easy to deal with the government because they have a lot of political issues’ (13/6/16, Skype). Interviewees from both government and civil society suggested that the main roles for civil society were at local levels, to take action on government decisions and implement projects. However, civil society actions even at local levels may not be significant, as ‘rainwater needs very heavy investment and those organisations don't have the economical means to support all the costs related to rainwater management’ (Government representative, 3/3/16, Dakar).

Many interviewees and media articles commented on a lack of communication and coordination between stakeholders involved in addressing the impacts of flooding: ‘Policies are here in the national plan, everything is there- the problem is coordination and knowing where the priorities are’ (Government research representative, 2/3/16, Dakar). Different stakeholders sometimes intervene in the same issues and so ‘if we don’t have coherence and harmonisation we will have duplication in giving responses’ (Civil society representative, 2/3/16, Dakar). There can be a lack of coordination between the MRUHCV, Ministry of Water and Sanitation and Ministry of the Interior, all playing roles in managing flood events.

Coordination has also been lacking, although may now be improving, between ONAS (National Sanitation Office of Senegal), part of the Ministry of Water and Sanitation, and the ADM (Municipal Development Agency), under the Ministry of Local Governance, Development and Spatial Planning. Both are responsible for installing rainwater drainage infrastructure. Interviewees also noted that ministries do not always ask others for advice before acting. For example, the MRUHCV may not consult the Ministry of the Environment and Sustainable Development when planning settlements and this ‘day-by-day collaboration is missing’ (Researcher, 4/7/16, Skype).

The most influential stakeholders working on flooding therefore are the MRUHCV coordinating actions, along with the Ministry of Water and Sanitation putting in place infrastructure, and the Civil Protection Directorate acting in cases of emergency. NGOs do not have a pivotal role at the national level, and the Ministry of the Environment and Sustainable development may advise on climate change adaptation but is not directly involved with flood management. While these are the key stakeholders identified by interviewees, other government ministries and NGOs are also involved in urban flood management in Senegal, such as the Ministry of Health and United Nations organisations (Schaer et al., 2017).

5.3.3 Addressing flooding impacts in Senegal: Mechanisms and climate information used and needed (Q4)

5.3.3.1 Mechanisms to address flooding

Detail about the actions in place in Senegal to react to and anticipate flood events are given in table 5.1. As mentioned in section 3.2, the ORSEC emergency plan can be launched to react to an extreme flood event. Two principal actions were discussed in interviews and documents to anticipate future flooding. Firstly the improvement of drainage infrastructure, as ‘there is a lack of channels in some areas and there is also a lack of monitoring of these channels and there is also an increase in people, in population.’ (Government representative, 29/2/16, Dakar). Secondly, the relocation of residents from flood-prone areas, and regulation of those zones. A government interviewee (29/2/16, Dakar) explained that ‘the main challenge here in Dakar is to not let people occupy the areas which are supposed to be flooded. Because previously the government don’t take care about where the people are settling, the mode of settlement.’

It was also noted that relocating people would require their participation and incentives to move, and government should work with local populations to encourage awareness and ownership of adaptation strategies. The PROGEP (table 5.1) project's aims do include involving local communities in management and educating them to increase resilience to flood events (Agence de Developpement Municipal, 2015). The Vivre avec l'eau project also involves community workshops to increase public participation in flood prevention aspects such as waste management (BRACED, 2014).

Some interviewees were critical about actions to address flooding, commenting that nothing, or not enough, was being done to address flooding in the long term. For example, only 4 of the 19 new urban centres planned to be put in place between 1995 and 2000 have been developed so far (Government representative, 3/3/16, Dakar). Media articles also reported that drainage infrastructure work had not been completed.

5.3.3.2 Weather and climate information used

Interviewees mostly reported that climate information was not considered in policies to address flooding. However, some of the policy documents supporting these actions do include climate information, such as observed rainfall trends and projections, including the INDC (Ministère de l'Environnement et du Developpement Durable, 2015) and the NAPA (Ministère de l'environnement et de la protection de la nature, 2006). There is also some evidence of historical time series being used in planning drainage infrastructure. A civil society interviewee thought the government was not using information such as seasonal forecasts though. They explained that 'the Senegalese government do not use this information as a planning tool or information tools to manage the floods and this is the main problem for me because this information is essential' (13/6/16, Skype). Reports describe how it is not possible to determine future changes in extreme precipitation due to modelling limitations (Government of Senegal and World Bank, 2013) and actions are taken without carrying out environmental impact or hydrological studies (Government of Senegal et al., 2010).

On shorter timescales, weather forecasts can inform the preparation of the ORSEC plan. ANACIM (National Agency of Civil Aviation and Meteorology) provide these on daily to seasonal scales. The OMVS (Senegal River Basin Development Organisation) also provides information to the government if their monitoring predicts flooding, and the CSE (Ecological Monitoring Centre) can provide information on areas flooded or prone to flooding, if requested.

Mechanisms to address the impacts of flooding

	Emergency plan (ORSEC)	Drainage infrastructure (e.g. channels, basins, pumps)	Regulation of building areas and relocation of residents
Policy document background		• INDC: Strengthen sanitation infrastructure and storm water drainage systems in cities • PSE: Restructure flood-prone areas, put in place infrastructure including water drainage systems	• PSE: Relocate people living in low-lying areas and make sure no building takes place in these areas • NAPA: Define which areas should not be occupied and regulate these • INDC: Plan urban ecosystems including watersheds
Stakeholders involved	• National ORSEC plan led by the Civil Protection Directorate (under the Ministry of the Interior) • Involves all government ministries, civil society and the private sector	• ONAS, Ministry of Water and Sanitation • Ministry of Local Governance, Development and Spatial Planning • ADM	• Ministry of Urban Renewal, Housing and Living Environment (MRUHCV) • ONAS, Ministry of Water and Sanitation • Minister of Local Governance, Development and Spatial Planning

Actions taken	• This is a contingency plan to react when particularly bad flood events occur
	• Actions include
	  ○ Pumping water
	  ○ Temporarily relocating residents (e.g. to school buildings)
	  ○ Providing food and other social assistance.
		• Ten-Year Flood Management Programme, 2012-2022
		  ○ identify potentially flooded areas and build infrastructure
		• PROGEP (Stormwater Management and Climate Change Adaptation Project), 2012-2022
		  ○ put in place infrastructure in Dakar suburbs including drainage systems
		• “Jaxaay” plan (2006-2012)
		  ○ put in place water drainage systems using emergency pumps
		• UK aid BRACED project Vivre avec l’eau (Live with water) also working on infrastructure
		• ONAS constructing drainage systems
			• “Jaxaay” plan (2006-2012)
			  ○ Built >3000 houses in Dakar and other regions for flood victims
			• Ten-Year Flood Management Programme, 2012-2022
			  ○ Relocate populations from flood zones
			  ○ improve land-use planning policy and develop new urban centres
			• Put in place new urban centres with infrastructure

Weather/ climate information used	• Weather forecasts from ANACIM (government may give flood warning)	• Historical precipitation data used in PROGEP and by ONAS	
Sources	Government of Senegal, 1999; Direction de la Protection Civile, 2008; Interviews	Agence de Developpement Municipal, 2011; 2015; BRACED, 2014; GFDRR, 2014; Government of Senegal, 2014; Ministère de l'Environnement et du Developpement Durable, 2015; Interviews	GFDRR, 2014; Ministère de l'environnement et de la protection de la nature, 2006; Ministère de l'Environnement et du Developpement Durable, 2015; Interviews
Policy needs suggested by interviewees	• Early Warning System for floods	• Restructure areas	• Stop settlements being built in flood-prone areas and relocate people from these • Urbanisation plan
Research needs suggested by interviewees	• More accurate forecasts, earlier warnings of extremes • Improved understanding of the causes of extreme events, improved modelling techniques and observations of precipitation	• Map areas prone to flooding • Map the geography of the landscape, including the water table • Understand how extreme events affect the environment • Population data	

Table 5.1 Mechanisms to address the impacts of flooding in urban Senegal

Following a forecast, it is the government's responsibility to provide any necessary warnings, but while an early warning system for flooding has been planned (Ministère de l'Intérieur, 2015), implementation has been stalled by a lack of funds. A government representative explained that if heavy rain is forecast they calculate their resources and inform local governors to prepare. As sometimes an extreme event is forecast but does not occur, the Civil Protection Direction does not actively prepare.

5.3.4 The relevance of event attribution (Q5)

At the workshop, stakeholders thought event attribution could be useful for national adaptation policy, by helping create inventories of events and guiding adaptation through evaluating the drivers of events which have occurred. However it was also noted that such tools may need to be adapted for use in specific contexts. In interviews all the stakeholders thought event attribution results could have some use. The main application mentioned was to understand whether climate change had influenced the likelihood of an event in order to anticipate future events and inform policy decisions. As one interviewee said, 'for long-term planning you have to take into account all the parameters, including climate change' (Civil society representative, 1/3/16, Dakar). Others thought results could be useful to distinguish and communicate impacts of climate change, to ensure all events were not assumed attributable, and to encourage mitigation of greenhouse gases. A use was also suggested at international level for policymakers in negotiations, to 'know the causes, if it is related to climate change how we can have support from developed countries' (Government representative, 7/6/16, Skype). While stakeholders thought such information could be useful to advise policymakers, one interviewee also commented that knowing whether climate change had influenced an event or not might not be relevant for those affected by the impacts (Researcher, 4/7/16, Skype).

5.4 Discussion

5.4.1 Perceptions of drivers of flood vulnerability in the context of climate change

In general, although stakeholders, national adaptation documents and media articles recognised climate as a driver of urban flooding in Senegal, the impacts were perceived to be caused by issues around urban planning. These include a lack of governance of settlements leading to known flood-prone areas being occupied, and lacking and outdated drainage infrastructure.

These findings correspond with work by Mbow et al. (2008), who discussed the impact of rapid urbanisation and informal settlements on flood risk in Dakar and by Diagne (2007), who highlighted the need for improved rainwater drainage in Saint Louis. Interviewees described how many people moved to informal settlements in urban suburbs during the drought period around the 1970s. Along with a failure of the government to control building in these areas, this may also highlight a failure to support people where they previously lived so they did not feel they had to relocate.

The perception of flooding as an urban planning issue is somewhat reflected in the government ministries responsible for managing the impacts. This task is predominantly shared between the MRUHCV and the Ministry for Water and Sanitation, who are responsible for policy and infrastructure, and the Civil Protection Directorate in charge of emergency actions. Although the Ministry of the Environment and Sustainable Development is responsible for climate change adaptation, with the COMNACC also responsible for coordination of such issues, they have very little to do with addressing flooding in practice.

As flooding is primarily addressed by ministries associated with urban planning rather than the environment and climate change this may indicate that climate variability and change are not a prominent or well-communicated consideration when addressing flooding impacts. Rather, the focus on flooding as an urban planning issue is also shown through the transfer of responsibility for flood management to the MRUHCV after the MRAZI was dissolved. There is some effort to involve all the ministries in the management of flood events through the National Flood Management Committee. This may be in recognition that flooding is a multisectoral issue and cannot be addressed by individual ministries alone. However, there is still a lack of coordination and communication between ministries when, for example, planning infrastructure and new settlements, and NGOs lack representation and influence at the national level.

Despite stakeholders mainly attributing the impacts of flooding to ineffective urban planning, the majority of the workshop participants did think specific events leading to flooding, such as the heavy rainfall in 2012, could be attributed to climate change. Their opinions may however have been sensitised due to the focus of the workshop on event attribution. Interviewees showed more uncertainty about the possibility of attributing individual extremes to climate change. Some interviewees also attended the workshop, however as the interviews provided more opportunity for them to consider and explain their answers, this may explain the general reduced confidence in the possibility of attributing events. The range of perceptions regarding attributing extremes are consistent with findings with other climate policy stakeholders (Parker et al., 2016a). If the majority of stakeholders do tend to attribute extreme events and floods to climate change this could lead to maladaptation if decisions are made based on the assumption that flood events will increase in frequency in the future, as Parker et al. (2017) show the probability of high precipitation events may actually have decreased in West Africa.

5.4.2 Addressing flooding and the information required

In urban Senegal, the main actions to anticipate future floods at the national level are the relocation of residents from flood-prone areas to new settlements, and the installation of drainage infrastructure. Correspondingly, stakeholders identified the main information required as population data and maps of flood-prone areas, rather than information about the future climate. This implies that decisions are constructed around understanding current flood risks rather than anticipating future changes and the capacity to plan ahead. Although such decisions can help address immediate issues, actions may not necessarily be resilient in the long-term.

However, this reflects that in sub-Saharan African countries, urban development challenges are often more immediate than require longer term climate projections for decades ahead. In particular, addressing urbanisation often focusses on information about current rather than future climate variability, as the immediacy of the issues can side-line long-term perspectives (Jones et al., 2015b). As interviewees reported that even low levels of rainfall could lead to urban flooding, this could well be the case here that climate information, particularly for the future, may not be the most relevant. This may also be applicable in other developing country urban areas experiencing flooding due to poor drainage, such as Maputo, Mozambique (Broto et al., 2015). While such challenges may be addressed without considering how climate risks may change in the future, this is important to consider if interventions are to be resilient to future changes.

The necessity of planning appropriate infrastructure for new settlements is highlighted by the fact that a new location people were relocated to from Dakar (city Jaxaay) experienced flooding itself due to inadequate rainwater drainage (Schaer et al., 2017). While relocating residents to areas with reduced flood risk may be perceived to be an adaptation measure from a technical perspective, these actions may not necessarily be culturally-informed, and this reflects the need for more holistic adaptation approaches considering community needs (Boyd, 2017). Along with moving away, other local actions to prepare for floods in Dakar currently include improving housing or filling in the lower levels and building up, saving money for lost income during flood periods and digging temporary channels (Schaer, 2015).

On shorter timescales, stakeholders suggested more accurate and earlier forecasts of extreme events would be useful to be able to react accordingly when they occur, and correspondingly the need for an early warning system for urban flood events to disseminate alerts to vulnerable communities (Government of Senegal et al., 2010; World Bank and GFDRR). These needs are reflected in the plans for Senegal's National Framework for Climate Services (Ministère du Tourisme et des Transport Aériens, 2016). The national level experts explained that currently if heavy precipitation is forecast there are very few actions to prepare in advance, with government lacking trust in the forecasts. Local actions during floods are limited to using sand bags, elevating belongings above the water levels, evacuating water where possible and sending children to live with relatives (Schaer, 2015). It is suggested that in order for improved forecasts to be beneficial from the national perspective, dialogue between the scientists and government stakeholders, and also local level stakeholders, would be required in order to build trust in this information. Also the development of an early warning system with appropriate related actions, coordinating the relevant stakeholders and affected communities could help reduce impacts, as has been planned (Ministère de l'Intérieur, 2015).

5.4.3 The relevance of event attribution

The main relevance for event attribution according to stakeholders would be to understand the influence of climate change on events to guide adaptation to future similar events. However, it is important to note that the influence of climate change on a particular event, especially when estimated using climate simulations forced by observed sea surface temperatures, may not be the same on a similar event at a different time. Therefore, using event attribution to inform adaptation to future events may have limitations as studies do not consider the probability of events in the future (Thompson and Otto, 2015). Although this may limit the application individual studies could have to long-term planning, they can help build understanding of climate change impacts in the region, and could be used alongside other climate information such as projections and local knowledge of precipitation events to improve understanding of climate risks (Parker et al., 2016a). This may be particularly helpful in a region such as West Africa where climate projections for precipitation are uncertain.

Event attribution studies provide information to help with the creation of inventories of events, as was suggested in the workshop. Inventories could help develop understanding of the climate risks facing Senegal, which could be fed into adaptation planning. Another use for event attribution studies suggested in interviews was for building awareness and communicating the impacts of climate change. This could both encourage mitigation and ensure that policymakers do not assume all events are caused by climate change, which could lead to potential maladaptation (Travis, 2014). This could also be relevant at local levels where people can have good memory of specific extreme rainfall events (Tschakert et al., 2010), and putting these in the context of climate change could help inform about changing risks.

Event attribution can provide information about meteorological hazards, but not overall risk, which also needs be considered when adapting to events (Hulme et al., 2011). Stakeholders generally viewed flooding as an urbanisation issue, as well as a climate impact, showing awareness that multiple drivers of flood risk need to be addressed. One interviewee commented that attributing events would not be relevant for those affected by the impacts. As relatively little rain can lead to flooding in urban Senegal, it can be argued that the impacts on communities need addressing regardless of whether or not they are climate change-related. This fits with Hulme et al.'s argument that 'climate adaptation investment is most needed where vulnerability to meteorological hazard is high, not where meteorological hazards are most attributable to human influence' (2011, p.765). Current adaptation actions are tackling the vulnerability of urban communities through relocation and infrastructure. Contrary to the concerns of Hulme et al. (2011), it is the knowledge of the hydrometeorological events themselves that needs incorporating into scenario planning and decision-making to buffer future shocks in a more anticipatory manner, as this does not appear to be happening. Further interdisciplinary research will be required if vulnerability is to be addressed alongside the climate hazards successfully (e.g. Daron et al., 2015; Morss et al., 2005).

Other stakeholders thought event attribution results would be more relevant for international policymaking. For example, evidence of the impact of climate change on specific events could be used in negotiations to encourage support from developed countries. This has also been discussed by stakeholders associated with loss and damage negotiations (Parker et al., 2016a), although reference to attribution in this context is contentious due to its association with compensation (James et al., 2014). Still, event attribution can serve as a mechanism to generate questions about how adaptation policy can better link global climate risk to local stakeholders affected by shock events, and merits further research.

5.4.4 Incorporating event attribution: current barriers and future needs

Stakeholders were optimistic in interviews that event attribution studies could have some application in adaptation decision-making over long and short-term time frames. However, this could be challenging due to the current lack of climate change information used in planning. This may be partly be due to urbanisation decisions not requiring climate information in the immediate term, and the climate information that is available may not be perceived as useable (Lemos et al., 2012). However, information about future changes in climate will be required if plans are to be resilient. An interviewee emphasised this by saying there are ‘Too short, urgent plans. There are floods so let’s see how we could respond but we do not plan by saying this is the scenario of five years or ten years or being informed by the science’ (Civil society representative, 2/3/16, Dakar). How to use information about future scenarios will require collaboration between producers of the information and policymakers as one interviewee explained, ‘The integration of climate change in the documents for development policies is quite complex. We have not yet settled the question of how [to integrate climate change information]’ (Government research representative, 10/6/16, email).

If event attribution studies showed that particular events had become less likely due to climate change, this could lead to challenges for policy if this assumed increasing probabilities of events. For example, in Mozambique, narratives in climate policy in the early 2000s were supported by the available climate science that risks of floods were increasing, leading to adaptation strategies and international financial support based on this. Since then, higher spatial resolution results have shown there is very little change in flood risk likely, but the narratives in policy have not changed (Patt, 2012). If in Senegal flood risks were decreasing from a climatological perspective, it is likely their impacts would still need addressing, particularly as a small amount of rain can lead to devastating impacts in urban areas. However it could affect how events are viewed generally, with even greater emphasis on urbanisation issues. As stakeholders already view urbanisation as one of the main causes of flooding impacts, whether or not events are related to climate change does not appear to affect decisions currently or be necessary to reduce impacts in the short-term.

Alongside incorporating climate information, there are more general governance challenges for addressing flooding from extreme precipitation events in Senegal. These will need to be addressed in order to address the policy needs identified by stakeholders, including strategies to react to forecasts, improve infrastructure, and have more effective land use management. Issues around communication and coordination between government ministries, and between the government and NGOs, are key. At present there are duplicated efforts and a lack of sharing of environmental, climate and urban planning information and expertise, with no lead agency responsible for consistently managing flood issues (Government of Senegal et al., 2010). Schaer et al. (2017) also found limited integration between flooding policies and plans developed between the different sectors involved, and overlaps between ministries in charge of coordinating efforts in urban Senegal. In particular, weather and climate information from ANACIM does not appear to play a prominent role in government adaptation planning. If this is to be incorporated in the future, users will need to perceive it to be salient, credible, and legitimate (Cash et al., 2003) and accessible to them (Boyd et al., 2013; Southgate et al., 2013).

Another challenge is the financial resources required to manage the impacts of flooding. Media articles reported that the effect of spending for flood management had not been seen. An interviewee explained that 'there are all these anticipatory plans in the documents but the state don't have the means to put in place infrastructure for the anticipatory aspect.' (Government representative, 3/3/16, Dakar). In Senegal the Ministry of Economy and Finance controls budgets and allocates international climate finance and has significant power in policymaking, being responsible for national development strategies (Pegasys, 2015). Flood management is also a political issue, with the government taking action on flooding before key elections to show commitment to the issues, such as plans to create the city Jaxaay and the MRAZI. Furthermore, suspicion exists around where international funding is directed, with limited coordination and documentation, and funding provided for short-term rather than longer-term projects (Schaer et al., 2017). Financial resources do not appear available at local levels, and Schaer et al. (2017) describe how it is made available according to political affiliations. Local governments lack funding for infrastructure, technical capacity and skills to address complex climate risks, so local institutional capacity requires strengthening, alongside the involvement of local communities (Wang et al., 2009).

The perceptions of whether events can be attributed to climate change and uses for this science found here clearly highlight the need to share what event attribution can provide with the relevant stakeholders. This could help policymakers consider whether results could be relevant for their decisions, understand the uncertainties, and ensure they do not assume all events are attributable to climate change, which could lead to maladaptation and other drivers of risk being neglected. Furthermore, such dialogue could inform the application of the science, so that the events studied are relevant to policymakers and research questions are framed appropriately (Otto et al., 2015).

As there have been very few event attribution studies in Africa to date, it may not be surprising that there was limited knowledge of these techniques among stakeholders in Senegal. This also means that currently there is very little understanding of how climate change has influenced individual events in this region. The study of rainfall in West Africa in 2012 (Parker et al., 2017) only focussed on the high seasonal rainfall so may not be directly relevant when considering floods, which are caused by shorter-term heavy rain events. This will require studies such as that by Bellprat et al. (2015) on southern African rainy seasons which considered both seasonal and extreme rainfall risks, particularly as influences can differ over timescales of events. There is still much uncertainty around how heavy rainfall in West Africa is being affected by climate change and may change in the future (Seneviratne et al., 2012), providing a challenge for policymakers to produce adaptation strategies that will be resilient into the future.

5.5 Conclusions

There is a scientific debate about whether event attribution science could inform adaptation policy, but before now this has not been considered in a specific context. In this paper we have investigated its relevance at national decision-making level using a case study of policy to address extreme precipitation and flooding in urban Senegal. We have shown that national adaptation decision-makers recognise climate as a driver of increasing flood occurrence, but perceive the impacts to be primarily caused by issues around urban planning, including settlements in flood-prone areas and a lack of drainage infrastructure. The key stakeholders addressing these issues are the government ministries responsible for urban planning and water and sanitation.

Stakeholders thought event attribution results could be relevant in order to plan for similar events in the future, understand which events are impacts of climate change, and to encourage support in international climate negotiations. However there are many barriers to integrating this science into planning in Senegal at this stage. These include the limited climate information currently incorporated into planning and decision-making and a lack of coordination between the stakeholders addressing flooding. These barriers will need to be critically examined in line with current understanding and communication of science-policy in adaptation. There is a focus on addressing current rather than future risks, as the impacts of flooding in urban Senegal need to be addressed in order to protect the most vulnerable communities now. Decisions are prioritising addressing current urbanisation issues and do not focus on considering integration of longer-term climate information. Understanding whether events and impacts are caused by climate change may not be directly relevant for this. However if such short-term planning is to be resilient in the long-term and protect vulnerable communities from flooding impacts in the decades ahead, decisions on urban planning, drainage infrastructure and other adaptation actions will need to incorporate relevant and accessible knowledge about how the risks of extreme events are likely to change in the future.

5.6 Results in the context of the thesis

This study has shown that in Senegal while stakeholders were optimistic about potential roles for event attribution results, there currently does not seem to be a place for results to play a role in adaptation decision-making. This is due, among other factors, to a lack of coordination between government ministries and a lack of climate information used in adaptation planning. This is likely to also be the case in other developing country governments, and so it may be that more generally event attribution is currently unlikely to be able to play a role in adaptation policy in those countries which are most vulnerable to the impacts of climate change. Therefore the answer to the question:

> Q2. Can event attribution play a role in specific national and international policy contexts relevant to Africa through engagement with policy stakeholders?

when considering the national level specifically in Senegal seems to be that there is no clear role for event attribution at present. This is an interesting finding in light of the many comments by climate scientists that results could be useful in such contexts. While Hulme et al. (2011) have argued that event attribution would take the focus away from addressing the exposure and vulnerability components of risk, in this case it seems that while actions are aiming to address vulnerability it is the climate change component which is not being considered.

While there may not be a role for event attribution in policymaking in Senegal, one of the other ways stakeholders suggested results could be useful for was raising awareness of climate change and its impacts. It may be that this an area in which results can more readily be applied, to inform both policymakers and local communities, rather than in adaptation policy.

6. Stakeholder perceptions of event attribution in the loss and damage debate

The application of event attribution science is next considered in the context of international climate policy under the United Nations Framework Convention on Climate Change (UNFCCC) to address loss and damage associated with the impacts of climate change. The loss and damage work programme aims to address impacts in developing countries which are particularly vulnerable to the effects climate change. Many of these countries are situated in Africa and so investigating this policy area is relevant in order to consider roles for event attribution at different policy levels addressing the impacts of extreme events. Along with adaptation this is one of the key areas where the relevance of event attribution has been debated among scientists (e.g. Hulme, 2014; James et al., 2014) and so warrants empirical investigation through engagement with key stakeholders. This study addresses the international component of the following research question:

> Q2. Can event attribution play a role in specific national and international policy contexts relevant to Africa through engagement with policy stakeholders?

This chapter has been published in Climate Policy (Parker et al., 2016a).

Abstract

In 2013 the Warsaw International Mechanism (WIM) for loss and damage (L&D) associated with climate change impacts was established under the United Nations Framework Convention on Climate Change (UNFCCC). For scientists, L&D raises questions around the extent that such impacts can be attributed to anthropogenic climate change, which may generate complex results and be controversial in the policy arena. This is particularly true in the case of probabilistic event attribution (PEA) science, a new and rapidly evolving field that assesses whether changes in the probabilities of extreme events are attributable to GHG emissions. If the potential applications of PEA are to be considered responsibly, dialogue between scientists and policy makers is fundamental.

Two key questions are considered here through a literature review and key stakeholder interviews with representatives from the science and policy sectors underpinning L&D. These

provided the opportunity for in-depth insights into stakeholders' views on firstly, how much is known and understood about PEA by those associated with the L&D debate? Secondly, how might PEA inform L&D and wider climate policy? Results show debate within the climate science community, and limited understanding among other stakeholders, around the sense in which extreme events can be attributed to climate change. However, stakeholders do identify and discuss potential uses for PEA in the WIM and wider policy, but it remains difficult to explore precise applications given the ambiguity surrounding L&D. This implies a need for stakeholders to develop greater understandings of alternative conceptions of L&D and the role of science, and also identify how PEA can best be used to support policy, and address associated challenges.

Policy relevance

The WIM was established to address the negative impacts of climate change, but whether attribution evidence will be required to link impacts to climate change is yet to be determined, and also controversial. Stakeholders show little awareness of PEA and agreement on its role, which raises important questions for policy. Dialogue between policymakers, practitioners and scientists could help to build a broader understanding of PEA, to determine whether it is relevant, and facilitate both its development and WIM high level decision-making processes.

6.1 Introduction

In 2013 the UNFCCC established the WIM to address L&D associated with climate change[2] impacts from both slow-onset and extreme weather events in vulnerable developing countries. L&D does not have an official definition under the UNFCCC (Surminski and Lopez, 2014) and there are many aspects of the WIM yet to be determined. L&D has typically been perceived as residual climate change impacts beyond mitigation and adaptation (Huggel et al., 2015), and calls to address L&D have often been interpreted as demands for compensation. However, currently the WIM sits within the Cancun Adaptation Framework, has no mention of compensation, and places more emphasis on risk management strategies. One issue that has

[2] Throughout this article 'climate change' is used as per the UNFCCC definition to mean that which is caused by human activity.

gained attention among climate scientists (e.g. Huggel et al., 2015; Hulme, 2014; James et al., 2014) is whether the WIM will refer exclusively to L&D that is attributable to climate change or more generally to any climate-related impacts (e.g. as in Warner and van der Geest, 2013). Attribution is controversial as it is associated with blame and liability (James et al., 2014). Nonetheless, biophysical and social factors influencing L&D, including climate change, need to be recognised to address the associated risks (Huggel et al., 2013), and consideration of attribution evidence may be useful to inform and facilitate policy discussions (Huggel et al., 2015).

Substantial evidence exists relating slow-onset events, such as sea-level rise and glacial retreat, to climate change (Bindoff et al., 2013). Links between climate change and specific extreme weather events, such as heatwaves, and particularly floods and droughts, are more uncertain due to the greater role of natural variability. It is not possible to prove whether an event would have occurred in an unchanged climate. However, the emerging science of PEA can, for some events, assess the change in probability of occurrence due to anthropogenic GHG emissions. PEA may be less well-understood by policy makers than trend attribution due to its recent development, probabilistic nature and associated uncertainties. Nevertheless, event probability constitutes a vital part of the associated risk (Lavell et al., 2012), so needs to be understood.

Discussion among climate scientists about the relevance of PEA for L&D has been recognised in UNFCCC literature (UNFCCC, 2012), so there is an onus to explore how science could inform L&D. However, attributing changes in the probabilities of events to GHG emissions will require scientists to be sensitive to the political connotations of their findings, especially as it is associated with liability (James et al., 2014). A vital first step in this direction is a better understanding of the existing perceptions of attribution. A shared understanding of the science between stakeholders (those who can influence, or be influenced by, decisions (as in Freeman, 2010)) should be encouraged to lead to informed discussions about potential uses. This is particularly relevant as those developing PEA are actively seeking to incorporate stakeholder needs in the formation of scientific questions (Sippel et al., 2015; Stott and Walton, 2013). This has prompted our study, which investigates understandings of PEA and its usefulness for L&D. Views are investigated via a review of the relevant literatures underpinning PEA and L&D and 31 in-depth key stakeholder interviews with climate scientists, social scientists, non-governmental organisations (NGOs), governmental and intergovernmental organisations, and the private sector.

Firstly, the study aims to investigate stakeholder understandings of whether extreme events can be attributed to climate change. For policymakers to make valuable use of scientific findings, scientists need to communicate probabilities and uncertainties (Patt, 2000) and policy makers need to be able to understand and apply this information (Pidgeon and Fischoff, 2011). Therefore establishing what is currently understood is important to develop further understandings between scientists and policy stakeholders.

The second aim is to examine whether stakeholders perceive roles for PEA in L&D. Academic literature can influence policy changes (Kingdon, 2003), but this requires interaction between scientists and policy stakeholders to ensure research questions and outputs are relevant to the decisions being considered (Cash and Moser, 2000; Jones et al., 1999; Shanley and Lopez, 2009) and results have appropriate levels of uncertainty (Jacobs, 2002). Kingdon (2003) found that policy makers were most inclined to listen to academic research when it directly related to problems they were already considering. It is therefore incredibly timely to be carrying out this research as policy makers begin to formalize how to address L&D.

This article is divided in six sections. The second section describes the background of L&D and PEA. The third outlines the research methodologies used here. Section four includes an in-depth analysis from the literature review and interviews. In section five there is a discussion of the understandings of PEA and potential roles in policy making. The article concludes by reflecting on the implications for PEA and L&D.

6.2 Background: loss and damage policy and probabilistic event attribution

6.2.1 Loss and damage in international climate policy

The concept of L&D associated with climate change was originally proposed by the Alliance of Small Island States (AOSIS) in the early 1990s, seeking compensation for the impacts of sea-level rise (Wilford, 1993). Although this proposal was rejected, a process was established to address L&D in adaptation policy, and incorporated into the Bali Action Plan in 2007. Through the Work Programme on L&D set up at the sixteenth session of the Conference of the Parties (COP 16) in Cancun, reconvened at COP 18 in Doha, the decision was made to put in place institutional arrangements to address L&D by 2013 (Huq et al., 2013). At COP 19 in November 2013, the Warsaw International Mechanism (WIM) was established under the

Cancun Adaptation Framework (UNFCCC, 2013) with a two-year workplan agreed at COP 20 (UNFCCC, 2014a). The WIM aims to address L&D from the adverse effects of climate change, including impacts of both slow-onset and extreme events. The text has no mention of compensation, but focuses on improving knowledge and understanding of risk management strategies, strengthening dialogue among stakeholders, and enhancing finance, technology and capacity building to address L&D (UNFCCC, 2013).

6.2.2 Probabilistic event attribution

Attribution, in the context of L&D, might refer to any of the links in a ‘causal chain’ from anthropogenic emissions, to climate and weather, to local-scale impacts (Hansen et al., 2016). This study focuses on the attribution of weather events to anthropogenic emissions, which can be controversial and so requires careful consideration. While links have been made between anthropogenic emissions and trends in some extremes (Bindoff et al., 2013), PEA (Allen, 2003), a relatively new area of attribution science, looks at the influence on specific events.

Instead of claiming an event would, or would not, have occurred without anthropogenic influences, PEA aims to assess the change in the probability of it occurring. This field includes the empirical analysis of observational data (e.g. van Oldenborgh, 2007) and studies using climate models (e.g. Pall et al., 2011). Climate model studies use simulations of the current climate compared to simulations of the climate as it might have been without anthropogenic emissions. These simulations are used to estimate changes in the event probability attributable to human emissions. Large ensembles of model simulations are required to represent the range of climate uncertainties and the statistics of extreme events (e.g. Stone and Allen, 2005).

Increasing numbers of event attribution studies are being carried out (e.g. Herring et al., 2014; Peterson et al., 2013; Peterson et al., 2012), but PEA has mainly been applied on an ad hoc basis in the aftermath of particularly extreme events, rather than systematically. While the focus of L&D is largely developing countries, there have been very few PEA studies concentrating on these regions (examples include Bellprat et al., 2015; Lott et al., 2013). PEA results have included cases where climate change increased the probability of the event occurring (e.g. the autumn 2000 flood risk in England and Wales; Pall et al., 2011), decreased the probability (e.g. the autumn/winter 2000 snow-melt-induced flood risk in England; Kay et al., 2011), or did not play a role (e.g. the 2011 Thailand flooding; van Oldenborgh et al., 2012). PEA studies can also address different questions about the same event (e.g. the 2010 Russian heatwave discussed in Otto et al., 2012).

A PEA statement consists of a change in the event's probability and a model-based confidence level of that change. Confidence can be limited by a lack of observations with which to evaluate models (e.g. Otto et al., 2013) and model difficulties in realistically simulating the processes driving the events (Trenberth and Fasullo, 2012). In some cases it is therefore not possible to make an attribution statement (e.g. Christidis et al., 2013). There is generally greater confidence in attribution of temperature extremes (e.g. Stott et al., 2004) than precipitation extremes. Modelling the influence of climate change on tropical cyclones would require large ensembles of simulations at higher resolutions, increasing the computing power needed to obtain robust results by orders of magnitude.

6.3 Methodology

To understand the perceptions of PEA and potential roles in L&D, this study triangulated data from three sources: peer-reviewed climate and social science and legal literature, policy documents and grey material, and key informant interviews. Using multiple qualitative methods provided a thorough analysis (Bryman, 2004) and using documents alongside interviews enhanced understanding, as observers' interpretations were compared with published material (May, 2011).

For the systematic literature review, we identified climate science, L&D policy, and environmental law as the relevant research areas. Law was included due to the discussion of compensation and liability surrounding the L&D debate. The review was carried out between January 2014 and July 2015 using keyword searches (combinations of probability, extreme, event, attribution, loss, damage, UNFCCC, weather, climate), manually checking reference lists of relevant articles and collecting policy documents at COP 19 and then using content analysis (Krippendorff, 2013).

We carried out qualitative semi-structured interviews (n = 31) at COP 19 in November 2013 and thereafter until July 2014 with representatives from the science and policy sectors underpinning L&D. These provided the opportunity for in-depth insights into stakeholders' views. The semi-structured format ensured the same topics were covered in each interview (see Appendix E), for comparison, but provided the opportunity to follow different leads as they arose (Gillham, 2005; Kvale, 1996). We interviewed UNFCCC delegates as they were deemed to be especially knowledgeable due to direct involvement in the negotiations. They provided a rich source of first-hand information, however may have been wary of the political implications of their answers (Gillham, 2005). Therefore we also interviewed representatives of NGOs involved with L&D issues, who may have been able to answer more freely. Interviewees were selected by invitation at COP 19 from those attending the Development and Climate Days event and from delegates present at L&D side events. We used snowball sampling techniques (Atkinson and Flint, 2004) to identify other relevant stakeholders. Climate scientists working on PEA, as well as more generally at the science–policy interface, were also important informants for learning about the interplay between PEA and policy. The overall representation was NGOs (n = 14), social scientists (n = 7), governmental and intergovernmental organisations (n = 6), climate scientists (n = 3) and the private sector (n = 1). Interviews lasted around 30 minutes and were carried out in person when possible (n = 22), or else via Skype (n = 8) or e-mail (n = 1). We recorded interviews on a digital sound recorder and later transcribed them (n = 23), or else took notes during the interview (n = 7). We analysed the interviews qualitatively using a grounded theory analysis approach, where themes emerged during the coding process (Robson, 2002), using the software tool NVivo version 10 (QSR, 2012).

6.4 How is probabilistic event attribution perceived by stakeholders?

6.4.1 Literature

6.4.1.1 Scientific literature

The science of attributing extreme events to anthropogenic causes has emerged since Allen (2003) and was included in the latest IPCC Assessment Report (Bindoff et al., 2013) and recognized as a Grand Challenge by the World Climate Research Programme (WCRP). Annual special issues of the *Bulletin of the American Meteorological Society (BAMS)* on extreme event attribution since 2012 (e.g. Herring et al., 2014) demonstrate the growing number of research groups applying different and new methodologies. Often independent methodologies are applied to the same event, thus increasing confidence in results. There is some debate about the robustness of PEA itself within the wider scientific community. Some scientists claim that climate models cannot represent the dynamics of extreme events well enough to attribute them (Trenberth and Fasullo, 2012; Trenberth et al., 2015), or that studies are subjective as they rely on judgements of climate model uncertainties (e.g. Hulme et al., 2011).

Within PEA literature there is consideration of the applications. The importance of communication between producers and users of results to establish how PEA could be applied is recognised (e.g. Stone et al., 2009; Stott and Walton, 2013). This involves establishing what questions different potential user sectors (e.g. government, legal, insurance) are asking, and what levels of certainty in assessments are required (e.g. Otto et al., 2012; Stone et al., 2009; Stott and Walton, 2013; Stott et al., 2013).

In adaptation policy, Hoegh-Guldberg et al. (2011) claim PEA would be useful for allocating resources, as changes in extremes due to GHG emissions are likely to continue in the future. Others agree that PEA may help guard against inappropriate adaptation to events that are expected to become less likely (Otto et al., 2013; Stott et al., 2013; Stott and Trenberth, 2009; Stott and Walton, 2013). Pall et al. (2011) say PEA may be useful for adaptation policy if this is focused on climate change and Huggel et al. (2015) agree it could help prioritise adaptation. It could also highlight current adaptation needs (Sippel et al., 2015).

In contrast, Hulme et al. (2011) argue that adaptation funding should build capacity, rather than be allocated as if it were compensation dependent on events being attributable to climate change. They highlight that PEA studies only consider the meteorological hazard, rather than the overall risk that might be more important for prioritising adaptation. Surminski and Lopez (2014) say that focusing on complex and possibly unsolvable event attribution issues may slow efforts to further adaptation policy, and establishing causation for specific events is less important for adaptation policy than for compensation claims. Thompson and Otto (2015) agree that PEA would be primarily relevant for L&D but not adaptation, as studies do not consider future probabilities of events.

Considering L&D specifically, Hulme (2014) notes that L&D policy currently makes no distinction between events caused by anthropogenic and natural causes, so there will be no place for PEA. Thompson and Otto (2015) disagree, claiming that L&D will need to be linked to climate change. Huggel et al. (2013) note that when attributing L&D, the influence of anthropogenic emissions is only part of the associated risk and vulnerability and exposure also need to be considered. In the analysis of Sippel et al. (2015) some stakeholders thought PEA could be used for L&D or allocating adaptation funding, whereas others thought decisions would be determined by politics and not scientific evidence. It was also suggested that PEA could help clarify an overall picture of climate risk, rather than directly influence decisions.

Huggel et al. (2015) highlight that the need for attribution information in L&D might depend on what the WIM will look like. They think attribution information could lead to a more constructive L&D policy discussion by providing guidance on hazards, rather than being necessary for policy.

Other PEA applications considered include providing evidence of the anthropogenic influence on an event for a liability assessment (e.g. Allen, 2003; Allen et al., 2007; Stone et al., 2009). PEA could also help the media communicate climate change impacts to the public and help aid agencies to encourage preparation for extreme events (Stott and Walton, 2013). The insurance industry is interested in how probabilities of extreme events will change in the future, and what the additional risk from climate change is, to price premiums accordingly (Changnon et al., 1997; Phelan, 2011; Sippel et al., 2015; Stott et al., 2013). Links between losses from weather events and climate change could also encourage mitigation policy (Bouwer, 2011).

Stott et al. (2013) highlight that assessing events soon after their occurrence as part of an operational system, as is currently being trialled by climateprediction.net, could help address possible applications. This would remove selection biases (Stott et al., 2013), which would be especially important in a legal context (Allen et al., 2007). It could also assist climate model development by improving understanding of model processes (Stott et al., 2013).

6.4.1.2 Loss and damage related literature

NGO literature on L&D policy tends to focus on understanding and addressing L&D with little mention of assessing the role of climate change. There are exceptions: ActionAid, Care and WWF (2013) note changing trends in extreme weather events in their report on addressing L&D and a briefing from Christian Aid (2013) in the aftermath of Typhoon Haiyan and Kreft et al. (2012) mention the challenge of attributing individual events (and their associated L&D) to climate change. Other policy literature contains some awareness of PEA, and that GHGs can contribute to the occurrence of specific events, but not cause them entirely (e.g. Hirsch, 2012).

Due to the background of L&D, there is some discussion of compensation and liability in NGO literature that refers more frequently to the influence of anthropogenic emissions on extreme events. Craeynest (2010) discusses the difficulties associated with compensation payments following events when it cannot be proven what damage would have occurred without climate change. The feasibility of compensation claims in courts is also questioned by Wrathall et al.

(2013), due to the complexity of climate impacts and the production of GHGs by a variety of sources. There is also concern that developing countries would not be able to provide causation evidence for the events affecting them (Verheyen and Roderick, 2008).

In terms of legal evidence, Verheyen and Roderick (2008) highlight that current environmental damage and other comparable liability and compensation regimes could imply that similar claims may be possible for climate change damage. However, a compensation claim for sea-level rise impacts in Kivalina was deemed a political rather than a legal issue and dismissed (Breakfield, 2011). If such claims were to be made possible, evidence that GHG emissions had caused harm would be required (e.g. Farber, 2008; Voigt, 2008). In legal contexts, causation is defined as necessary causation: GHG emissions would need to be shown necessary for the event to have occurred, although there could also be other factors required (Hannart et al., 2016). The scientific uncertainty in event attribution and number of factors contributing to each event make establishing such causation difficult (Farris, 2009; Faure and Nollkaemper, 2007; Grossman, 2003), but if L&D from extreme events can be attributed to GHG emissions lawyers may become interested (Adam, 2011). While similar cases have been considered in courts in epidemiology, drawing on statistical evidence and computer simulations, these forms of evidence remain contentious (Allen and Lord, 2004; Farber, 2007; Grossman, 2003; Kosolapova, 2013).

6.4.2 Expert interviews

Interviews with 31 key informants were held covering the two thematic areas: (1) prior knowledge of PEA, and (2) whether PEA could support L&D and wider climate policy.

6.4.2.1 Prior understanding of probabilistic event attribution

Interviewees demonstrated very limited awareness of PEA, with only seven interviewees having heard of it. Three of these were climate scientists, who also commented on challenges such as lack of observational data, model limitations and understandings of probabilities and risk by users of results.

More broadly, there were differing understandings of whether a link can be made between an extreme event and climate change. When asked whether a single event could be attributed to climate change, nine interviewees did not think this possible, with one commenting:

> No, science cannot tell you that. Climate science is generally more credible when you look into the long term on a number of events rather than a single. (Government organization)

Many interviewees commented on attributing changes in frequency or intensity in the long-term trends of events to climate change, rather than individual events. Some thought attributing these changes to be possible, as illustrated here:

> Although it is not possible to attribute the actual occurrence of an individual event, it may be possible to attribute the increase in intensity or frequency of an extreme event. (Social scientist)

The comments on trends in extremes rather than specific events may imply a lack of awareness or understanding of the recent development of PEA, instead reflecting the more traditional scientific perspective.

Two interviewees thought some events could be completely attributable to climate change. Two others thought all extreme or unusual events were the result of increased GHGs. This is similar to the view of Trenberth (2012), that all events are affected as they are occurring in a changed environment. On attributing extreme events to climate change, one interviewee said:

> I think it is not a question of saying ‘can we’, the reports that are coming through are confirming what has already been told to us, that the greenhouse gas emissions are going to cause these extreme weather events. (Private sector)

Extremes have occurred throughout history, so although there is evidence that some may become more intense with climate change (e.g. Meehl and Tebaldi, 2004), their occurrence is not in itself evidence of a climate change impact.

Three interviewees said climate change could contribute to an extreme event, rather than be the sole cause, and other factors could contribute to L&D, such as poor infrastructure. As an example and considering two meteorological factors, one interviewee said:

> If you're looking at taking a particular disaster like a drought, both factors will come into play – both rising temperatures and variable rainfall – and if you attribute one of those factors, with a reasonable degree of certainty to climate change, then you can at least, if not attribute the entire disaster to climate change, but you can say it is a significant contributing factor. (NGO)

Those with direct involvement in the L&D negotiations were asked whether they thought other policy makers were aware of PEA. While two thought they were not aware of the latest science, four thought they had some awareness but would choose what they knew for the negotiations and misuse limitations of the science. As one said:

> There's conflation of politics and science so people choose what they know. (Government organization)

6.4.2.2 Potential uses of probabilistic event attribution

Having had the concept of PEA explained to them if they were previously unaware, interviewees were asked about roles it could play in both L&D and their own area of work. The majority were positive that PEA could be useful in some way.

Some interviewees thought PEA might be useful to encourage support from developed countries for L&D:

> If science can really make a lot of progress in attributing climate losses to global warming then I think the polluting countries will also be more forthcoming in supporting countries either to increase their resilience or to avoid future losses. (NGO)

Some raised concerns that a lack of scientific certainty in event attribution may slow down efforts to address L&D. Speaking of scientific uncertainty and L&D, one interviewee said:

> The push for a loss and damage mechanism was born out of a recognition on a political level that the science wasn't going to be delivered quickly enough – we […] couldn't wait around for the science to confirm the attribution question. (NGO)

Another explained that research into L&D is important to do, whether or not it is due to climate change:

> We cannot wait for them [climatologists] to determine to what extent this is about climate change or not. […] whether it's climate change or not, people are experiencing severe consequences of climatic stressors. (Social scientist)

Another commented that if the science does not catch up with the policy, developed countries may hide behind the lack of evidence linking them to damages.

Eight interviewees thought PEA could be useful for supporting compensation claims as part of addressing L&D. Most of these thought it would add evidence, as this interviewee said:

> We want to know if changes in climate are occurring due to human impact – greenhouse gas emissions. If you can answer that by providing higher levels of probability that's fine, that's all part of the mix of science. We realise it can't give us a complete attribution certainty. (Social scientist)

Two thought it might be possible to use PEA in a compensation mechanism in the future, once the science has advanced:

> Yes if the science is there it's possible – that's kind of one thing that's lagging, […] we can't attribute so this is kind of a pipe dream. (Social scientist)

Others disagreed that PEA could be helpful for compensation claims. One governmental interviewee said that developed countries are already aware of their responsibility for L&D and do not require more evidence.

Another area where it was suggested PEA could play a role was adaptation. It was suggested it could help further understanding of future risks to help with disaster preparedness:

> It [PEA] can also help people to be prepared and to prepare their adaptation plan for disasters and climate change. (NGO)

A social scientist commented that provision for dealing with the uncertainties in PEA results would be needed. Other interviewees claimed using PEA in adaptation would be irrelevant, unproductive or unnecessary, as illustrated by the following comment:

> I don't think it [attribution] matters because to me what matters is why people are vulnerable and how we can make them less vulnerable. You're going to have to address extreme events, regardless of whether climate change is a driver. (Social scientist)

Four interviewees thought PEA could be useful in encouraging mitigation, as illustrated here:

> If attribution can link events to greenhouse gases then the solution is mitigation, and this can work with adaptation to solve the problems (Climate scientist)

However another climate scientist thought that using PEA to enforce payments for L&D attributable to climate change could make a mitigation agreement less likely.

Another suggested role for PEA was in climate model development to help improve predictions of the future. Some interviewees thought a more systematic approach to PEA studies would be useful. A climate scientist suggested this would help reduce bias when choosing events to study, while a social scientist thought this would help accumulate evidence of the effects of climate change.

A common theme in the interviews was the importance of communicating possibly complex results to communities experiencing L&D. One climate scientist did not think local communities would be able to use PEA results due to not understanding how to use probabilities in practice. However a social scientist commented that people deal with risk in everyday life and make relevant assessments. Some interviewees thought PEA results could be used at the national level, for example for preparing for extreme events that may increase in frequency (Social scientist). However, in order to address different purposes, different results may be required:

> If you provide information at the regional level it might only concern the regional organizations […], but if you come to the national level it will convince the national level politicians […] the communities need separate data to the politicians. (NGO member)

6.5 Discussion

This study provides an important initial scoping of stakeholder perceptions on the new research area of PEA in L&D. The interviews, although not generalisable, demonstrate a range of unconsolidated views of PEA from stakeholders from different sectors and provide a useful comparison with the literature.

Both the literature and interviews reveal a variety of understandings of event attribution. Little reference to PEA in L&D literature may partly be a sign that it is not considered relevant, but could also suggest limited understanding outside the scientific community. This was reflected in the interviews, which demonstrated varied perceptions of whether and in what sense extreme events could be attributed to climate change, along with little awareness of PEA.

The reasons for the contrast in understandings can only be speculated on here, but may partly be due to PEA being a new field that is subject to some scientific debate about its robustness. Also, for political reasons, some stakeholders may, as one interviewee put it, ‘choose what they know’ about the influence of GHG emissions on extreme events. The different perceptions represent a challenge for the scientific community to share understanding with policy stakeholders. This also raises questions about the extent to which debates around understandings need to be resolved before PEA is applied to policy.

PEA scientists have discussed many applications for PEA themselves in the literature. In L&D literature, reference to event attribution is mainly confined to discussions of compensation and liability. During interviews, stakeholders identified a variety of applications including mitigation and adaptation policies and compensation claims, along with challenges for applying PEA.

Huggel et al. (2015) categorise L&D into three dimensions: disaster aid, adaptation, and liability and compensation, and argue that the scientific evidence required will depend on the focus of the WIM. Many stakeholders thought PEA could be useful for adaptation, for example by improving understanding of future risks, encouraging adaptation to events that are likely to become more frequent, and guiding adaptation resource allocation and policy if this is to be prioritised by anthropogenic contribution. However others thought studies too uncertain to be used, with limited application for long-term planning because of the focus on current rather than future risk. There was also concern about the lack of consideration of vulnerability and exposure, the focus on compensation rather than capacity-building, and that policy development could be slowed due to the controversy around attribution. It may be that for adaptation and risk management PEA could produce complementary, rather than essential, results for policy and other climate information would be more useful for long-term planning, such as forecasts of trends in extremes.

In terms of liability and compensation, the range of opinions includes those who thought PEA would be essential, and those who thought it could add to evidence once developed further. In L&D literature, Wrathall et al. (2013) questioned whether PEA could be used in compensation claims and others thought that PEA would be too uncertain, that evidence would be too contentious, and it would be difficult to prove the impact of climate change among other factors. There was also concern that developing countries may not be able to provide sufficient evidence to access compensation funding. Legal experts were more confident that compensation claims could be possible and some interviewees were positive that PEA could add to causation evidence and provide guidance. Those advocating compensation mechanisms to address L&D will need to be aware of the evidence that would be available to support cases, and its limitations. Other interviewees thought PEA could encourage support for L&D informally by adding evidence of the impacts of climate change. Information such as the attribution of trends in extreme events could also be relevant to add to PEA evidence.

One of the challenges identified for the application of PEA in policy was uncertainties in results. Levels of certainty required will vary for different applications, and remain subject to debate. However, many of the issues in quantifying and communicating uncertainty are also faced in the application of future climate projections to adaptation policy, so there may be opportunities to learn from this field. There has been much research into taking climate uncertainty into account in adaptation policy (e.g. Dessai and Hulme, 2007; Hallegatte, 2009; Refsgaard et al., 2013). Uncertainties must be clearly expressed (e.g. Schneider and Kuntz-Duriseti, 2002) and this can strengthen communication of risk and lead to more successful adaptation policy (Cardona et al., 2012), using risk-based approaches (Klein et al., 2014) and flexible and adaptive systems (Lal et al., 2012). Instead of directly informing decisions, PEA results could add to the wider pool of evidence of climate change impacts, where levels of uncertainty may be less important.

Another common concern was that emphasis on PEA would shift attention away from addressing social vulnerability. This highlights the importance of interdisciplinary research to investigate all drivers of L&D, both meteorological and social. Also mentioned was that developing countries may not be able to provide attribution evidence. PEA studies in these regions are challenging in part due to the lack of observations available.

In spite of these challenges, there is evidence of sufficient interest in PEA to warrant further investigation of possible applications. L&D is an area where it is perceived that the policy is driving the science (Vincent and Cull, 2014), as was also noted in interviews. This may give PEA the opportunity to develop in a manner that is useful for supporting policy. Imperative for this is a deeper understanding of the differences in stakeholder understandings of PEA, which this study has begun to map out.

How this knowledge feeds into L&D in ways that are debated and constructive is another matter, which also can only be speculated on here. Disagreements over uses for PEA may be because of a lack of in-depth understanding of the science, and varying perceptions of how uncertain information can be used. This highlights the need for dialogue between scientists and policy makers so they are aware of each other's work and requirements for information (Thomalla et al., 2006). Participatory knowledge generation and sharing could be a useful tool (e.g. van den Hove, 2000). L&D has been reported to be opening opportunities for communication between climate and disaster management experts (IIED, 2013). However, the lack of discussion in L&D literature of PEA in connection with adaptation and risk management suggests that this science may not have been given attention to date. Sustained and focused collaboration between stakeholders will help to share understandings of what information PEA can provide and what is required for decisions. For example, case studies could explore the potential to integrate PEA into risk management. Collaboration could also address some of the challenges in applying PEA, notably integrating this with social drivers of risk.

The ambiguity surrounding the WIM, and L&D not being formally defined, may somewhat inhibit further consideration of uses of PEA in this context. Some of the arguments around using PEA clearly depend on how L&D and the WIM are perceived, including whether L&D will need to be attributed to climate change. Where stakeholders have different, and not always clearly articulated, perceptions of L&D, it is challenging to investigate applications. Understanding typologies of L&D could help facilitate more detailed discussions about the scientific evidence that might be appropriate, and the challenges of either incorporating it or not, and could be promoted by the new Executive Committee of the WIM.

6.6 Concluding remarks

This study has found differing understandings of event attribution, along with debate within the scientific community and other relevant sectors about the usefulness of PEA for L&D policy. However, with limited awareness of PEA in interviews, there is little evidence that discussion about uses for PEA is actually currently occurring beyond the scientific community. While the debate demonstrates that PEA could have roles in addressing L&D, the possibility of PEA having greater value relies on it being more effectively communicated in ways that are relevant to policymakers. This demonstrates a clear need for improved dialogue between scientists, practitioners and policymakers. Scientists need to clearly communicate what PEA can provide, policy makers need to determine whether it could support their decisions and, if so, both groups need to discuss how PEA can best be applied.

The limited, but polarised, stakeholder views that were identified could prove a challenge if PEA is to be debated further and fed into L&D. The WIM is at an early stage of development, so this is an ideal time for engagement between the relevant sectors to begin this debate. A potential obstacle is the ambiguity surrounding the WIM; the relevance of PEA will depend on what this will look like, so further work to understand alternative L&D typologies is important. Whether or not PEA is incorporated, policy established in association with the WIM could then be made with full understanding of, and access to, the latest attribution science. If potential roles for PEA in L&D are to be discussed successfully, responsibility for dialogue lies with all relevant science and policy stakeholders.

6.7 Results in the context of the thesis

This research has shown that there are a range of understandings among stakeholders regarding whether extreme events can be attributed to climate change. If results were to be used in this policy context it would be necessary for stakeholders to understand what types of results could be provided and with what levels of certainty. Communicating complex results and probabilities requires engagement with the decision-makers to determine whether the information could inform their decisions (Dow and Carbone, 2007), and so these results reiterate the need to consider novel communication approaches as mentioned in section 2.2.47.

The results also show much debate around potential uses for event attribution science in both the literature and between stakeholders interviewed. As this is a relatively new area of climate policy it appears that event attribution would not be able to play a key role at present, as the focus of this policy area is still undefined along with how scientific evidence will be able to best support this. In answer to the research question:

> Q2. Can event attribution play a role in specific national and international policy contexts relevant to Africa through engagement with policy stakeholders?

these results therefore suggest that event attribution would not be relevant in this international policy context at present. However, it may be that as the policy area continues to develop, there can be further, more informed, consideration of the relevance of event attribution.

7. Using a game to engage stakeholders in extreme event attribution science

From the chapters investigating the relevance of event attribution science for national adaptation and international loss and damage policy, it is clear that stakeholders in these policy contexts are not all aware of the development of this area of science. As mentioned in Chapter 2, novel approaches such as participatory gaming can be useful tools to share the complexities of scientific research with a range of stakeholders. A game could be useful in an event attribution context, particularly for considering its relevance in the policy areas investigated in this thesis: adaptation and loss and damage. This chapter describes the development and use of a participatory games designed to share event attribution with non-scientists, and is used to address the following research question:

Q3. How can a participatory game be used to share event attribution science with stakeholders?

This chapter has been published in the International Journal of Disaster Risk Science (Parker et al., 2016b).

Abstract

The impacts of weather and climate-related disasters are increasing, and climate change can exacerbate many disasters. Effectively communicating climate risk and integrating science into policy requires scientists and stakeholders to work together. But dialogue between scientists and policymakers can be challenging given the inherently multidimensional nature of the issues at stake when managing climate risks. Building on the growing use of serious games to create dialogue between stakeholders, we present a new game for policymakers called Climate Attribution Under Loss and Damage: Risking, Observing, Negotiating (CAULDRON). CAULDRON aims to communicate understanding of the science attributing extreme events to climate change in a memorable and compelling way, and create space for dialogue around policy decisions addressing changing risks and loss and damage from climate change. We describe the process of developing CAULDRON, and draw on observations of players and their feedback to demonstrate its potential to facilitate the interpretation of probabilistic climate

information and the understanding of its relevance to informing policy. Scientists looking to engage with stakeholders can learn valuable lessons in adopting similar innovative approaches. The suitability of games depends on the policy context but, if used appropriately, experiential learning can drive coproduced understanding and meaningful dialogue.

7.1 Introduction

The impacts of weather and climate-related disasters are increasing (Handmer et al., 2012). Addressing the additional risk from climate change on the impacts of disasters will require collaboration between the governmental stakeholders involved to create policies grounded in scientific knowledge (UNISDR, 2015). Effectively integrating science into policy to support such decision-making processes requires synergistic interaction between scientists and policymakers. Both groups must understand what information is needed and can be provided for decisions, along with the barriers to understanding and using that information (Ambani and Percy, 2014; Duncan et al., 2014). This requires scientific research to be made more accessible to nonscientists (Ashdown, 2011; Duncan et al., 2014).

Common ways of sharing complex information, such as slideshow presentations, are often passive and involve unidirectional learning and engagement (Greenblat, 1988; Suarez, 2015) and may be boring and dry. In contrast, interactive games can communicate complex concepts in an emotional and engaging, yet rigorous and effective, way. They have the potential to transform passive consumers of information into active players who absorb and retain new understanding, data, and tools more readily (Harteveld and Suarez, 2015). This can lead to deeper learning (Suarez and Bachofen, 2013) where ideas can be assimilated and applied. Games may therefore be a valuable addition to the ensemble of techniques for sharing scientific information.

This article investigates the relevance of using an interactive game to raise the visibility of probabilistic event attribution (PEA; Allen, 2003), an area of climate science that has been developing rapidly over the last decade. PEA can be used to understand the effects of different climate drivers on extreme events. We assess how the game triggers reflection on the potential relevance of PEA for managing the changing risks of events, and consider specifically the United Nations Framework Convention on Climate Change (UNFCCC) loss and damage (L&D) negotiations. In doing this we aim to encourage other scientists to consider the benefits of, and engage with, different ways of communicating and working with stakeholders.

In section 2 we describe the development of serious games for learning. This is followed by an introduction to the L&D policy context this work focuses on, PEA, and a discussion of why this science could be relevant for L&D. Section 3 describes the initial game development process and the game itself, and section 4 discusses what players learned and how their insights informed further development. In section 5 we reflect on using a game to encourage engagement with PEA in a L&D context, and conclusions are elaborated in section 6.

7.2 Serious games and loss and damage policy

This section provides a brief introduction to the use of serious games to share information and experiences when dealing with complex problems. The game in this article was developed to share and discuss the science of PEA in the context of the UNFCCC L&D negotiations, so a discussion of the backgrounds of these science and policy contexts, and the potential links between them, is then provided.

7.2.1 Serious games

Serious games are designed not just for fun but with an educational purpose (Mendler de Suarez et al., 2012) and are useful tools to simplify and clearly represent complex problems (Greenblat, 1988; Juhola et al., 2013). Players make decisions, pay the consequences, and interact (Greenblat, 1988), generating meaning and interpretation (Malaby, 2007). Players can explore a range of scenarios and outcomes to better understanding processes and decisions (Mendler de Suarez et al., 2012). They share the learning experience with others and have the opportunity to see issues from different perspectives (Mendler de Suarez et al., 2012; Suarez and Bachofen, 2013).

Games are successfully being used by nongovernmental organisations such as the Red Cross Red Crescent Climate Centre in communities and with donors, to convey changing risks and discuss disaster preparedness and humanitarian relief, among other topics (Mendler de Suarez et al., 2012; Suarez and Bachofen, 2013; Suarez et al., 2014). For example, “Paying for Predictions” was designed for humanitarian workers, to encourage reflection on the value of forecasts of extreme events (Mendler de Suarez et al., 2012). There is also a growing body of academic literature on interactive climate games, including for farmers to learn about changing risks of drought (Patt, 2001) and index insurance (Patt et al., 2009), to investigate river management under climate change (Valkering et al., 2012), and to focus on other climate policy contexts (Haug et al., 2011; Juhola et al., 2013).

7.2.2 Loss and damage policy and science

The UNFCCC Warsaw International Mechanism (WIM) was established to address L&D associated with impacts of climate change (UNFCCC, 2013). This includes both extreme events and slow onset events, and is focussed on developing countries that are particularly vulnerable to the adverse effects of climate change. One of its key themes in addressing L&D is "enhancing knowledge and understanding of comprehensive risk management approaches" (UNFCCC, 2013, p. 6), which requires dealing with current and future climate risk changes (James et al., 2014).

There are many issues yet to be determined under the WIM. However, one that has received attention from climate scientists is whether establishing L&D from changes in climate risk will require attribution to anthropogenic climate change (Hulme, 2014; James et al., 2014; Huggel et al., 2015) or whether L&D should refer to impacts from any climate-related events (as in, for example, Warner and van der Geest, 2013). Links between events and climate change may be necessary if it needed demonstrating that impacts were specifically due to climate change to be considered under the WIM (James et al., 2014). Such information could also be relevant for addressing L&D in the future, by considering how events are likely to change in frequency or intensity due to anthropogenic influences in order to inform adaptation (Otto et al., 2015).

While attribution information is potentially relevant for L&D, assessing how an individual extreme event may have been influenced by anthropogenic climate change is challenging (National Academies of Sciences, Engineering, and Medicine, 2016). Nonetheless, scientists are developing methodologies to robustly quantify the role of climate change, as is illustrated in the annual Bulletin of the American Meteorological Society (BAMS) supplements, which puts recent extreme events into a climate change context (for example, events of 2014, Herring et al., 2015).

A key methodology used to attribute extreme events is PEA, which estimates the change in the likelihood of an event occurring that is due to specific drivers of climate variability or change, such as anthropogenic emissions. Using large ensembles of climate model simulations, PEA has been used to establish that anthropogenic climate change likely increased the probability of events such as the 2003 European heatwave (Stott et al., 2004) and the 2013 US precipitation extremes (Knutson et al., 2014). Other studies include a demonstration of the decreased probability of snowmelt-induced flooding in Autumn/Winter 2000 in England (Kay et al., 2011), and an analysis that shows there was little evidence of any climate change influence on the 2012 low precipitation in the central United States (Rupp et al., 2013).

Attribution is controversial in the context of L&D, raising questions about blame and liability (James et al., 2014). Science-policy dialogue is therefore important to foster shared understandings and to determine whether and how PEA might be relevant for L&D (Otto et al., 2015). This is not straightforward as there are limited but conflicting perceptions of the ability to attribute extremes among L&D stakeholders (Parker et al., 2016a). These perceptions include the beliefs that no link can be made between extreme events and climate change, that there are increased risks of events, and that all extremes are attributable to climate change. Climate scientists on the other hand have reached a consensus that event attribution is possible, most confidently for temperature extremes followed by precipitation extremes, subject to observational and modelling uncertainties (National Academies of Sciences, Engineering, and Medicine, 2016). Uses for PEA in L&D and adaptation have also been debated by stakeholders and in the literature (Parker et al., 2016a). It has been suggested attribution could help guard against inappropriate adaptation and guide resource allocation (Hoegh-Guldberg et al., 2011; Stott et al., 2013), but that it could lead to prioritising compensation over capacity building (Hulme et al., 2011) or slow adaptation efforts (Surminski and Lopez, 2014).

Given the rapid development of PEA and its controversial nature, but potential relevance, in policy contexts, there is a challenge for scientists to engage with policymakers to ensure that the research is understood and used responsibly. Scientists have a responsibility to share scientific developments so policymakers have the opportunity for informed discussions around potential uses. As multiple stakeholders across sectors are associated with addressing the impacts of extremes, we hypothesised that a game could be a good way to begin to encourage further dialogue and understanding, if facilitated skilfully so all could participate fully (Suarez et al., 2014). This article describes the process of developing that tool.

7.3 Towards innovative learning and dialogue: the CAULDRON game

This section describes the creation of the CAULDRON game, from the underlying concepts to the phases of the game itself: farming, science, negotiation, and reflection.

7.3.1 Creating the CAULDRON game

The Climate Attribution Under Loss and Damage: Risking, Observing, Negotiating (CAULDRON) game[3] (also described in Suarez et al., 2015) was developed to encourage understanding of the basic concept of PEA, that of changing probabilities of extremes under climate change, and consideration of whether this could play a role in international climate policy. The aim was to bridge the gap between climate science researchers and the users of results. It was designed to be played by policymakers, ideally with some understanding of climate science and an interest in attribution. The impact of climate change to alter the probabilities of extreme events can be challenging to communicate and understand, and so the game focuses on this concept, using drought as an example. The game also illustrates the role of climate models in assessing these changes and the difficulties of estimating probabilities with limited data. It should also encourage dialogue between players about whether PEA is relevant to addressing L&D.

Translating these scientific concepts into an easily understandable game was a challenge that took many iterations. It had to balance being:

- A realistic representation of important scientific concepts.
- Simple to understand and be played in a short space of time.
- Able to be led by facilitators who would not need specialist training.
- An enjoyable and memorable experience.

The game is based on concepts from other climate games designed by the Red Cross Red Crescent Climate Centre, including using rolls of dice to generate rainfall amounts and beans as currency. This simple equipment is readily available across the world, which makes the game easy to replicate in many different countries and contexts.

Players work in pairs, assigned to either a developed or developing country, and groups of pairs make up a region. There are three game phases: farming, science, and negotiation; each is followed by a period of reflection. These are illustrated in figure 7.1, along with the questions players have to consider in each phase. Drought risks change and players have to consider the

[3] The instructions and materials required to play the CAULDRON game are available at http://www.walker.ac.uk/projects/the-cauldron-game under a Creative Commons license.

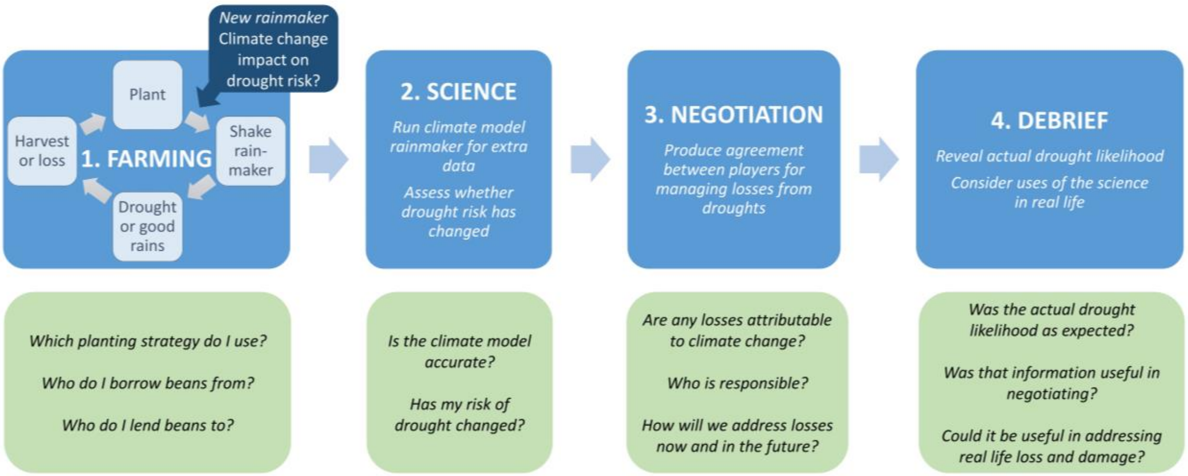

Figure 7.1 Schematic of the phases of the CAULDRON game. Blue boxes describe the game phases and green boxes highlight the key questions players have to address in each phase.

role of climate change and work together to develop response strategies. While in this case the event is a drought, the game could easily be adapted and tailored to different stakeholder groups.

Players take on the roles of farmers, scientists, and negotiators, with the goal that they can collect information in the first two phases and take this into their negotiations, which is the most important part for considering the uses of science. The first two phases also give policymakers an insight into the types of decisions farmers have to make and the work that scientists do. The game is intended to be engaging and fast-paced, with time limits enforced throughout to reflect real-life pressures on decision making.

7.3.2 Farming phase: planting in a changing climate

To begin, players take on the roles of farmers in their countries and have to make planting decisions, with the aim of accumulating as many beans as possible. They play a succession of rounds (symbolizing years) where they must choose to plant beans under either a high-risk high-yield or a low-risk low-yield strategy. The rains are determined by a specially designed "rainmaker" containing a dice (figure 7.2). These are opaque cylinders with one transparent face which allows players to see only the top face of the single contained dice. One face of the dice represents a drought, with all other outcomes representing good rains.

Each year one member of each country shakes their rainmaker (dice). Players gain beans when there are good rains and lose beans when a drought occurs, with greater losses in developing countries. They must try to avoid crises, where they do not have enough beans to plant, and can negotiate with other players in their region to be given beans in the form of loans or aid. Facilitators for each region help ensure players shake their rainmakers fairly and lose or gain the correct number of beans each year. For the first few rounds, all rainmakers have a 1 in 6 chance of drought (although players do not know this). Then players are informed that the climate has been changing due to greenhouse gas emissions (chiefly from the developed countries), which may impact the probability of drought occurring in their country. Each country receives a new rainmaker and continues playing, uncertain of whether and to what degree climate change has impacted their drought probability. In reality, some of the new rainmakers now contain dice with two faces that represent drought, doubling the probability. This provides a very simplified illustration of an impact that, in real life, would occur gradually.

The analogy of changing probabilities of events being like loading dice towards or away from the chances of rolling a six is one often used in PEA science. It demonstrates that although the probability of getting a six may have been increased by climate change, a six could have been rolled anyway.

7.3.3 Science phase: assessing changes in extremes

For the next phase, players become climate scientists, trying to work out whether climate change increased their country's probability of drought. They can use their rainfall

Figure 7.2 CAULDRON gameplay materials: Country allocation cards (farmer for developing, tractor for developed), farming matrices determining planting gains and losses (blue for developing, red for developed), beans used for planting, and rainmakers.

observations from the farming phase to compare the number of droughts they experienced under normal and climate change conditions. These do not provide a very long time series of observations, reflecting what is often available in reality, especially for developing countries.

Players can also use “climate model” data: they are given a third rainmaker, a model of the conditions under climate change, and they can run this a restricted number of times, reflecting real-life available computing power. In practice the “model” rainmaker is identical to the one used in the farming years under climate change, but participants are informed that it may not be a perfect model, a challenge with which climate scientists also have to deal. Players decide in their pairs whether they think the probability of drought in their country has increased or is unchanged and then report their assessment, as well as how confident they are.

7.3.4 Negotiation phase: addressing loss and damage

The final phase of the game is the negotiation. Players assume the roles of policymakers for their countries and negotiate in their region how to address the losses that have occurred due to droughts, particularly considering where they think there have been increased drought risks due to climate change. They can use or disregard any of the information from the other phases. They decide whether and how to use their beans to assist countries that have suffered losses and are asked to write a plausible agreement signed by all players in the region before the end of a strict countdown, to reflect L&D negotiations under the UNFCCC.

7.3.5 Reflection

During CAULDRON there are reflection times after each phase where players consider and discuss with others what they have experienced. There is also a short final debriefing phase, where players can open their rainmakers to see all the faces of the dice, and therefore reveal the probability of drought. They are encouraged to discuss how this probability relates to the conditions they experienced, and consider whether the observational and model data were useful to understand whether their region experienced a change in probability. They can also reflect on whether their understanding of whether their drought risk had changed was useful in their negotiations.

Table 7.1 Details of sessions where CAULDRON has been played with the number of debrief sheets and questionnaires collected for analysis

Date	**Participants**	**Number of debrief sheets (one per pair)**	**Number of questionnaires (one per player)**
October 2013	Attendees at Africa Climate Conference, Tanzania (mostly climate and social scientists and also government organisations) (Prototype version of game)	-	16
November 2013	Attendees at Development and Climate Days event at UNFCCC COP 19, Warsaw (mostly civil society organisations, with some scientists, negotiators and government representatives (Bachofen et al. 2015))	35	-
December 2013	MSc Environmental Change and Management students at Oxford University	4	15
May 2014	MSc Sustainable Development students at Uppsala University	-	44
April 2014	Climate scientists at Met Office	12	8
September 2014	PhD Meteorology students at University of Reading	7	-
November 2014	MSc Environmental Change and Management students at Oxford University	-	16
February 2015	BSc/MSc Resilience for Sustainable Development students at University of Reading	12	25
February 2016	Workshop in Senegal (government representatives and also civil society and scientists)	-	-
	TOTAL	**70**	**124**

7.4 Codevelopment of the CAULDRON game: dialogue begins

The development of CAULDRON has been guided by feedback from players, used to see whether it was achieving its aims and for suggestions on how to improve the game. The main sessions from which feedback was collected are summarized in table 7.1. An initial prototype version was played as part of the Africa Climate Conference 2013 and the game was then played in Warsaw during COP19. Six additional sessions, with between 14 and 44 participants in each, chiefly with climate scientists and students from a range of backgrounds on courses tailored to enhance learning on complex environmental and development issues, were then carried out (table 7.1). While these were not the key intended players of the game, they were able to provide insightful comments to guide its development. CAULDRON aims to encourage learning and reflection for players regardless of their previous knowledge of probabilities, climate change, and PEA itself. The scientists had some knowledge of PEA and were able to provide informed insights on the presentation of the science in the game. Feedback from students was valuable despite their different levels of prior knowledge compared to policymakers. Information and feedback from all these sessions was accumulated and fed into the game. Following this it was played with policymakers in Senegal as part of a workshop focussing on PEA science and addressing loss and damage, which involved 40 government, civil society, and scientist stakeholders.

Feedback was collected via comments players made on debrief sheets where possible, along with the negotiated texts. In some cases, players completed a questionnaire immediately after the game about their prior understanding of PEA and L&D, their main insights from playing, and whether they thought PEA could be used in L&D. A further short survey was sent to some players in the months following to learn about longer-term influences of playing the game but this had limited response (n=7). Game facilitators also made systematic observations of sessions. After the game in Senegal, players reflected in groups on what they felt were the key learning points. Comments from the feedback sheets and sessions are used here to illustrate some of the key themes that emerged.

7.4.1 Learning about PEA

One of the key aims of CAULDRON was that players would learn about the science of attributing extremes to climate change and the probabilistic nature of this. How players learned will have depended on their previous understanding of probabilities, and also their perceptions of climate change and how this is affecting extremes such as droughts. The goal was that players with any level of scientific understanding would be able to benefit from experiencing changing probabilities and reflect on how easy it was to tell if there had been a change.

Players commented that using dice to highlight climate changes was helpful, as one said, “Even though the knowledge was already there, the concept of ‘chance’ and ‘probability’ that is very important became clearer through the experience gained over playing the game.” How players chose to assess whether they had a change in drought probability was up to them. Players with more scientific backgrounds often worked out how many droughts they would have expected to see with a normal dice. Many players noted the difficulty in assessing the changes in probability with such limited data, with players in Senegal commenting that the short timescales made it difficult to see whether there was a change in drought likelihood or it was just variability. This is also a challenge faced by scientists carrying out PEA studies. Another player commented that such analysis could be especially challenging for developing countries. This is particularly the case for those lacking reliable long-term observations and the scientific capacity for analysis of changes. Reflecting on the link to real-life challenges, players in Senegal recognized how the model results could differ from the observations, and that further work was needed to understand how best to use both model and observational data.

The negotiation phase was also useful for seeing how players viewed the science. The views of players with previous knowledge of the science will of course not just be based on the game, but this still provides an opportunity for them to apply their understanding. For example, one region decided not to use attribution information as they felt it was too uncertain, saying “There is still more work to be done on the attribution science to provide evidence for country-specific climate change impacts.” In the game context data are limited and models may be imperfect. Real-world PEA also faces these challenges, but with additional difficulties including framing scientific questions and defining the event to attribute (Otto et al., 2015). These are not incorporated into CAULDRON as the game would become too complex. There are also different methodological approaches being developed to overcome these difficulties (Stott et al., 2016), which are also left out of the game for simplicity. Another player noted that “distinguishing damages from chance, (climate) change, risk taking is tough,” highlighting that L&D can be affected by vulnerability and exposure, which require consideration alongside the meteorological hazard (Huggel et al., 2013).

Most players began the game with no knowledge of PEA (except the Met Office group). After playing, the majority of players reported in questionnaires that their knowledge of PEA had improved (73% slightly improved, 17% greatly improved). We have not systematically analyzed players' understandings of PEA, but the few responses to the follow-up survey showed very varied understandings. This very small sample included views that the chance of extreme events could be affected by climate change, events could be made more extreme due to climate change, that most extreme events are attributable to climate change, and that it is all random. It would therefore be interesting to analyze more systematically what players understood before and after playing the game, as their own perceptions of how much they learnt may not match whether they have a correct understanding.

7.4.2 Improving learning about PEA in CAULDRON in the future

The Met Office group suggested ways to improve how CAULDRON represents PEA science, including having more consideration of uncertainties in the modelling part. Players often found differences between the observational and model data and were uncertain which to trust. It was suggested that models could also be provided of the unchanged climate to assess the model skill, and that models should not imply that they are perfect representations of the real world.

However there is a careful balance to be drawn between keeping the game relatively simple and easily understandable in many contexts, and incorporating all of the complexities of PEA, which CAULDRON is obviously unable to portray. This requires the game facilitator to have the skill to judge the needs and understandings of the players and lead and tailor the game accordingly. The game documents have been provided so that anyone can learn to run CAULDRON; the skills required for the game to have maximum benefit for participants by encouraging engagement, reflection, and learning between players from different backgrounds (Mendler de Suarez et al., 2012) can be more challenging to develop. However by working with more experienced game facilitators and colleagues with skills in different areas, such as experts in PEA science, others can develop these necessary skills through experience and participation.

It is also necessary to consider how the game can be used alongside other activities so players are able to gain a more complete understanding of the science on which the game is based. For example, before a couple of the sessions players were given a more traditional presentation on PEA as this could provide more detailed background.

Work has begun to compare how well players learn during games compared to more traditional methods such as slideshow presentations (Patt et al., 2010), but more long-term monitoring will be needed for the greater impact of games to be assessed (Mendler de Suarez et al., 2012; Harteveld and Suarez, 2015). This can be challenging and requires systematic assessment. Haug et al. (2011) suggest that to collect large enough samples of robust data, evaluation could be embedded into games so it is not seen as a time-consuming extra for players. This could be incorporated as CAULDRON develops. We have not included surveys before playing as this is time-consuming and may put players off. We have instead tried to ensure that players with any level of previous understanding of probabilities can build on this during play—how they do this and the insights from the decisions they make can then be discussed in the debrief.

Nevertheless it would also be interesting to collect quantitative data on players' understandings. Questioning why players made particular decisions, and short, but in-depth, surveys of players' understandings could improve evaluation. While this area has not been our focus in the development of the game so far, questions that could be investigated, for example focussing on decision making in the farming phase, include: What strategies do players use for planting? What do players do when they experience a drought? Who helps who when drought occurs?

7.4.3 Promotion of dialogue about roles for PEA in L&D

The second key objective of the game was that players would have the opportunity to consider whether PEA has a role in addressing L&D, as this has been debated by academics. An earlier version of CAULDRON had an unstructured negotiation phase where players could discuss however they wished. Players tended mainly to address how they would respond to future losses without considering the science of whether drought risks had changed, and whether losses could be attributed to climate change. While an interesting finding, an aim of CAULDRON was to encourage consideration of uses for PEA, even if it was not then used, so a suggested structure for the negotiations was introduced. Players were encouraged (although they could choose not to do so) to consider how many (if any) of the beans they lost could be attributed to climate change, who was responsible, and then how to address this state of affairs.

Of those who filled in questionnaires following playing, most had no, or very little, knowledge of L&D or UNFCCC negotiations before playing (Development and Climate Days players were likely more knowledgeable). For these players, CAULDRON may have been a useful tool to provide a brief introduction to the L&D negotiations, as well as to provide the opportunity to consider how PEA could be used. This may not be discussed in the real policy world. One player said the negotiation phase helped them improve their "understanding of how the science can be applied" and another "how the understanding of climate risk can be used as a negotiating implement."

In the negotiation phase some groups did consider what losses could be attributed to climate change and produced deals to compensate these. Others decided against using scientific information, instead focussing on addressing past or future losses regardless of their causes. One player commented that attribution would lead to blame so could be useful for forcing an outcome, but was not important if developed countries chose to support developing countries. Some players did not think their drought probability had changed and therefore did not attribute losses to climate change; in other cases losses were attributed to players' planting strategies.

Negotiations could be difficult, and from participant observations this was often one of the main messages players carried away from the game experience. They reported that some countries tried to pressure others into agreements, and it was difficult for countries in different circumstances and with different perspectives to agree. Often a deal depended on developed countries taking responsibility, as they generally held the power in negotiations. Players noted that "negotiations are hard because they are not determined only by science but by other factors as well (political etc.)" and participants also commented on the "difficulty of reaching a negotiated deal within a deadline, when working with incomplete and very uncertain information."

Naturally, many players remarked on the similarities between their own behavior and the patterns that emerge from UNFCCC negotiations. In some circumstances, negotiations could also be unrealistic and often led to simplistic solutions. These exaggerated fair distributions of resources, including common resource pools of beans for the future, redistributions of wealth making countries more equally wealthy, and plans to donate beans in cases of future crises, which are not commonly seen in international negotiations. The negotiated texts from Senegal (table 7.2) were much more detailed and less simplistic than others. But players still reflected that countries were willing to help each other in times of crisis more readily than in reality. CAULDRON could perhaps be improved by introducing greater political bias between countries to encourage less "fairness," as has been suggested by players.

Table 7.2 Key points from negotiated texts from CAULDRON session in Senegal

Region 1	• Science is not robust enough to support an agreement • Provide more financial resources, knowledge sharing, capacity building, and new technologies in regions needing this support. • Emphasise funded collaboration for research into climate change projections, impacts, vulnerability assessments, community development, adaptation, and resilience
Region 2	• Use a new planting strategy- alternate high and low yield • Share experiences between developed countries and reduce greenhouse gas emissions, with finance to developing countries • Share experiences between developing countries and integrate the risk factor from climate change • Share experiences between developing and developed countries to help each other
Region 3	• Engagement of developed countries to reduce emissions, transfer technologies, and put in place a climate fund • Emerging countries to use renewable energy and support developing countries • Developing countries to put in place a low emission development model and adaptation strategies
Region 4	• Models are likely accurate, therefore science should be taken into account to support preparing for events • Developed countries are responsible for climate change and they accept the need to support countries suffering with drought • Need finance, transfer of technologies, capacity building, and access to renewable technologies in developing countries • The developing country that became developed will share resources and experiences with countries suffering from drought

From the questionnaires, the majority of players thought PEA could be used in addressing L&D in real life, despite many not explicitly using it in the game. Reasons for its use were not explained in detail, but included preparing for future events, demonstrating climate change impacts, distinguishing anthropogenic and natural causes of events, and because the effects of climate change are often caused by different actors than those who are affected. Some climate scientists and other players were concerned that PEA should only be used if robust enough, showing awareness of the uncertainties. Others disputed using PEA in L&D for reasons that included difficulties distinguishing if an event is attributable to climate change, limited data, the time needed to calculate results, and because the use of PEA could encourage a focus on blame rather than on reducing losses in developing countries. Other suggested uses for PEA included in more general policy negotiations, risk analysis, insurance sector policies, investment planning, adaptation, and improved regional projections. Senegal stakeholders were interested in how PEA results could be implemented at national and local levels. These views suggest that players had a chance to consider some of the issues surrounding using PEA in policy.

7.5 The interplay between science and policy

Our experiences in developing the CAULDRON game and playing it in a range of contexts have given us the opportunity to reflect on both the key benefits that gameplay can provide for the sharing of information and the challenges that come with such work. These are discussed in this section, followed by a reflection on the policy impact that CAULDRON has had, and could have in the future.

7.5.1 Benefits of using a game

CAULDRON is a tool that promotes experiential learning, as players have to make decisions, such as farming strategies, and address the consequences. One player described how "extreme

Figure 7.3 CAULDRON sessions in action. Clockwise from top left: (a) exchanging beans during farming, (b) a spokesperson reading out his region's negotiated text, (c) discussions during play, (d) the shock of drought during farming, (e) shaking a rainmaker, (f) planting beans during farming, (g) presenting negotiated texts. Photographs (a), (c), (d), (e), (g) courtesy of IISD/ENB, November 2013 (http://www.iisd.ca/climate/cop19/dcd/); (b) by Emily Boyd, February 2015; (f) by Hannah Parker, September 2014

events had 'real' consequences and a political 'reality'." Players learnt first-hand "about careful decision making in cases of high unpredictability," which is vital when considering climate risks. It was observed in a session that players seemed confused when the climate change rainmakers were introduced, but this perplexity was quickly followed by realization that the change had occurred and the discovery sparked animated discussion. One of the benefits of using a game is this rapid learning through experience of how probabilities can be affected by climate change.

Another important part of the game experience is that players have to interact with each other. Discussion is often not possible in a traditional presentation context, or may lack engagement from participants. CAULDRON is designed so discussion between players is vital if they are to succeed, from sharing beans during farming to reaching an agreement to address L&D. Useful parts of the game mentioned by players included "trying to understand other groups' points of view to come to an agreement" in the negotiation phase.

We have observed that CAULDRON is able to create an engaging learning experience for players. Players become animated and engaged during the game sessions (figure 7.3). A report on the Development and Climate Days session said participants "appeared deeply engaged in the game, as they could be seen jumping to their feet and running to the front of the room to get in their mandates on time" (IISD, 2013). This was helped by facilitators encouraging players to stand up and shout "Oh no!" whenever they experienced a drought, and race to get their negotiated texts completed. This, along with the noise from the shaking of the rainmakers, created a stimulating learning environment.

Players were also able to learn about many elements of the game context at once. Whereas a traditional presentation tends to focus on one aspect, such as PEA science, by playing CAULDRON people also reported learning about social and political issues. These included differences in resiliency to extreme events between developed and developing countries, and that "climate change reinforces existing inequalities" between rich and poor.

Games have most learning impact when followed by a debriefing and discussion session about insights and how the game relates to reality (Suarez and Bachofen, 2013; Macklin, 2014). In CAULDRON, the debriefings between phases and at the end give players the opportunity to reflect. Reflection was identified as a vital part of the learning process over a century ago (Dewey, 1910), yet traditional presentations can leave little opportunity for this meditative

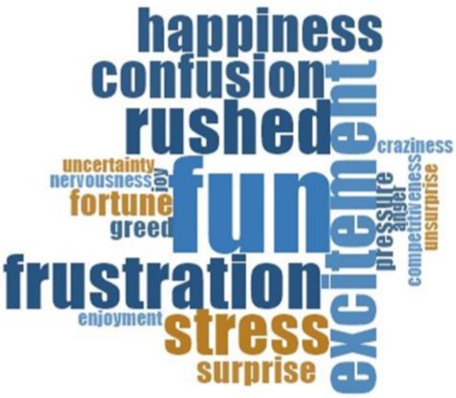

Figure 7.4 Word cloud of the most common words used when describing emotions and feelings during the playing of CAULDRON. The size of the words correspond to their relative frequency (Created using QSR International's NVivo 10 software)

outcome. In the game, players can consider what they have learnt and discuss what they are feeling and thinking. The emotional aspect of a game can also make learning a memorable experience. Players reported a range of emotions (figure 7.4) and it is hoped that they will remember the game and further consider the issues that arose during and after play.

7.5.2 Challenges of using a game

Despite the benefits, we recognise that a game is not capable of presenting all of the complexities of PEA science that would be possible in a more traditional presentation format. CAULDRON is a tool that can be used in conjunction with other methods to share knowledge about PEA science in complementary ways. It is a greatly simplified version of reality and therefore a challenge to include the right level of complexity. If too simplified, understanding may be limited. Yet the game must be simple enough that players do not get too confused and can pick up the rules and aims quickly. Along with the game design, this balancing act during play relies on skilled facilitation. Facilitators need to know their audience to lead the game accordingly and ensure an atmosphere where players feel sufficiently comfortable to engage with the game.

Figure 7.4 shows that players reported feeling both positive and negative emotions during play. Some said they felt rushed. Time pressure is an important part of the game as this reflects reality. We have tried in more recent sessions to ensure players have enough time to understand what is going on so they can fully engage and gain maximum benefit from the game environment. Although a game should not be an entirely negative experience for players, some stresses and frustrations can be important (for example, if the farming phase yields poor results or negotiation is difficult). The disparities between players' experiences are important for discussion in reflection times so players can relate these variations to real-life issues. Providing time for individual and group reflection following play is a key component of CAULDRON. Reflection can provide players with insight into how the game was similar to, yet different from, reality, and how it related to their own experiences. It is at this stage that genuine dialogue between players, particularly those involved in policymaking, may be able to take place.

7.5.3 Policy impact

CAULDRON had a key part in the workshop held in Senegal to engage with national policymakers addressing the impacts of extreme events. The informal discussion atmosphere created by the game, encouraging engagement and working together, was able to filter through the rest of the workshop. This led to meaningful and productive discussions about the relevance of PEA for the decisions they have to make in real life.

Some evidence has been found that games can impact policy by strengthening dialogue (Bachofen et al., 2012). However, more work is needed to establish if and how games can lead to changes in policy, and if they are better than other methods. This will require more thorough baseline studies of knowledge and policy contexts, along with improved evaluation and review following game-play (Bachofen et al., 2012). Nonetheless, one of the key outcomes of CAULDRON is that we as game designers and scientists have begun to better understand some of the complexities of the policy situation surrounding L&D through our engagement with stakeholders in this area. We have become much more aware of the controversial nature of L&D and of the limited role that attribution science can play in these negotiations. While we initially designed the game with the ambition of playing with UN delegates involved in L&D negotiations, except for one session with UNFCCC delegates from one country using an early prototype, we have not played CAULDRON with negotiators as it was deemed too controversial for them to discuss. This may be in part due to scientific evidence not being perceived as the highest priority issue in negotiation bottlenecks. This also may be due to a game being perceived as a nonserious way of learning on which delegates cannot justify spending time, or because they believe they already understand enough about the issues the game addresses.

In other contexts, renaming a game a role-playing activity or simulation has resulted in more engagement from target players (Maenzanize and Braman, 2012), so this repackaging could help attract target audience attention. Also, the format and aims of CAULDRON may not be ideally suited to supporting L&D negotiations. Amending the game so that it is less controversial may make it more appealing to a wider range of audiences. The negotiation phase is the main controversial element due to its reference to L&D negotiations, which themselves have been controversial over the past few years, particularly due to their association with liability and compensation (James et al., 2014). It might be possible to have a more open discussion in the future by playing only the farming and science phases and then prompting stakeholders to reflect on the relevance of the science for their work, without explicit mention of L&D or UNFCCC negotiations.

7.6 Conclusions

In this article we have showcased the development of a participatory game in order to encourage other scientists to see the value in engaging with such tools. We have demonstrated that CAULDRON is able to facilitate both the interpretation of probabilistic climate information and the consideration of its relevance to informing policy in both the game and real life. The experiential nature of the game means players must engage with the concepts, make decisions, interact, and discuss and reflect with other players. Different actors have different learning experiences playing CAULDRON depending on their background, previous knowledge, and how they like to engage with this learning format. CAULDRON could therefore be a useful tool for mutually beneficial science-policy dialogue, as scientists may be able to understand more about the types of decisions being made, and policymakers can gain an introductory, although highly idealised, understanding of PEA to consider whether it could inform decision making. This is vital for the effective consideration and integration of PEA into policy, and could even begin to inform the development of this area of science so research outputs are relevant to policy issues.

CAULDRON also has the potential, with skilled facilitation, to be used with a range of stakeholders at different levels of governance, where there are challenges due to the context and stakeholder power and hierarchy issues (Suarez et al., 2014). Developing participatory games such as CAULDRON could be a way forward that engages multistakeholder groups in discussion around complex issues, such as the management of disaster risks. They may be able to help create a level playing field and lead to more genuine dialogue, as players share the game experience and can use this as a basis for discussing real-life issues. There are many problems that can emerge in game-enabled processes, including inadequate simplification of real-world complexity if not considered carefully, unskilled facilitation, ethical dimensions of authority, and cultural diversity. There are also ways to address these risks to ensure the game-playing experience is beneficial for all involved (Mendler de Suarez et al., 2012).

We are continuing to engage with stakeholders to better understand the decision-making contexts to which PEA could be relevant, including L&D as this policy area develops. Developing and using a game has made us step out of our comfort zones, but has prompted many interesting conversations with players about the scientific and political contexts. We hope this will encourage other scientists to consider innovative ways of engaging with stakeholders, in order for effective dialogue to take place and the links between science and policy to be discussed productively.

7.7 Results in the context of the thesis

This chapter has described how a game has been able to share event attribution with a range of stakeholders, from students to policymakers. It has shared both some of the basic principles of the scientific technique in easy to understand ways and, importantly, provided the opportunity for players to consider the relevance of results for addressing the impacts of extremes, in both the game context and in real life. Therefore in answer to the research question:

Q3. Can a participatory game be used to share event attribution science with stakeholders?

this work has shown that a game can be used to share event attribution science with stakeholders, although more work is needed to establish how much players learn about the details of the science. Importantly, this work has shown that such a tool is able to encourage conversations about the relevance of the science. This is key for this area of climate science where applications have not been empirically investigated before, in order to learn more about where results might be relevant and how they could be applied, to therefore understand more about the usability of such results.

8. Discussion and conclusions

This thesis has considered the development and application of event attribution science in an African context. This chapter discusses the answers to the research questions posed, considering the working chapter results in the broader context of the thesis and the literature, and then highlights how the research fits together and the contributions of this work. Finally, the limitations of the thesis as a whole are discussed and the implications for research and policy are summarised.

8.1 Research questions

8.1.1 Q1. Do event attribution studies produce robust results in West Africa?

As was discussed in Chapters 1 and 2, there have been a limited number of event attribution studies in Africa to date and so one challenge if such results were to be applied in policy contexts would be knowing if the results were robust. This is particularly challenging to know currently as studies in Africa have not compared results from the model ensembles commonly used. Therefore the study in Chapter 4 was used to investigate how results from the different ensembles compare for an event in West Africa. This considered how anthropogenic climate change affected the probability of high precipitation in 2012 using three ensembles of climate model simulations. Results showed that the probability of high precipitation had decreased due to climate change across the majority of the ensembles, although the magnitude and uncertainty of the change depended on the model ensemble used. This highlighted some level of robustness in this result.

The study also highlighted how the estimate of the anthropogenic effect on sea surface temperatures (SSTs) can significantly alter the result, even changing the sign of the climate change effect. This dependence on the SST estimate change is a challenge for studies in regions where teleconnections dominate rainfall variability such as in Africa (Otto et al., 2013). It highlights the need for future studies to compare different estimates in order to understand the robustness of the attribution results.

It is also important to note the difference in the question being investigated between the atmosphere-only simulations forced with observed SSTs from the time of the event, and the coupled model simulations which do not model particular years, as this second set of simulations does not look at the particular year but a more general climatological shift. This is important to communicate to stakeholders if these results were to be used in policymaking as they are different, albeit complementary.

In general, the limited number studies that have been published on events across the African region, including this one, have all been able to provide some form of event attribution result (e.g. Bellprat et al., 2015; Lott et al., 2013; Wolski et al., 2014), despite the challenges this region presents. This is key to know to be able to investigate the applications of such results further.

8.1.2 Q2. Can event attribution play a role in specific national and international policy contexts relevant to Africa through engagement with policy stakeholders?

The thesis moved on to investigate two specific policy contexts where it has previously been discussed in the literature that event attribution results could provide relevant information, to address Q2. The first was in national adaptation policy. A case study approach was taken, focussing on national adaptation policy to address flooding from extreme rainfall events in Senegal. The study concluded that flooding events were viewed primarily as urban planning issues requiring improved infrastructure and land use policy, rather than as events specifically linked to climate change. While current actions to address flooding impacts focus on current risks, policy stakeholders thought event attribution could be relevant to inform about future risks of extremes and to communicate the impacts of climate change. This study highlighted the complexity of adaptation decision-making, and the limited role that climate information can have in this, which will influence the role event attribution results could have. As the relevance of event attribution for adaptation has been suggested in the literature much over the past few years, this study was a key first investigation of relevance in a particular national adaptation context. Although it was not found to be immediately relevant in this particular case, stakeholders still showed interest in results which could be built on further in the future through continued engagement.

The second context investigated was that of international loss and damage negotiations under the UNFCCC. There were a wide range of views among stakeholders around both understanding of, and potential uses for, event attribution science in this area. Applications ranged from compensating for past losses to informing adaptation strategies for the future. There is some controversy in this context around the perceived link between event attribution and compensation. This indicated that further work was needed alongside stakeholders to develop understandings of potential uses for the science in this complex decision-making context. As the negotiations progress and the concept of loss and damage becomes more defined, it may become clearer how science can support this. However, this work provided an important initial investigation into the relevance of event attribution in this area, which had only been considered by scientific literature before, rather than studied empirically.

From investigating these two key policy contexts, the potential for applying event attribution results appears limited. While in both cases some stakeholders were optimistic about the relevance of the scientific results for informing policy, both contexts had distinct barriers to this being possible at present. In the case of Senegal this is primarily the lack of climate information used in decision-making to inform adaptation and siloed nature of government ministries. These results therefore do not support the suggestions in scientific literature that event attribution would be useful for adaptation policy (e.g. Otto et al., 2015; Pall et al., 2011; Stott et al., 2013) for the context investigated here. However they also do not support the main argument against the use of results in adaptation, that vulnerability and exposure would not be considered (Hulme, 2014; Hulme et al., 2011), as it is these drivers of risk which are currently being addressed in the case of Senegal rather than the climate change component.

In the loss and damage negotiations, there are barriers to the inclusion of such scientific results due to the lack of clarity over how loss and damage is defined and how it will therefore be addressed, and therefore the type of scientific evidence that will be required to support this. This therefore leaves open the possibility of results being applicable in ways which have been suggested in the literature such as to distinguish impacts attributable to anthropogenic climate change (James et al., 2014) and to achieve restorative justice (Thompson and Otto, 2015) to be considered further in the future. Roles for the science in compensation claims (Huggel et al., 2015) would likely not be considered further in this context though as liability and compensation were ruled out of loss and damage in the Paris Agreement (UNFCCC, 2016).

A key area which emerged where results could however be useful was in raising awareness of the impacts climate change is already having. This could inform stakeholders from local to international levels to encourage both commitment to mitigation targets and consideration of how to make adaptation strategies resilient to climate change long-term. This is an application which has been mentioned in previous literature (Sippel et al., 2015; Stott and Walton, 2013; Stott et al., 2013). It may therefore be that a key application for event attribution lies in promoting awareness of climate change rather than directly informing policy.

However, this application in awareness raising does come with its own challenges, particularly when studies such as that of West African precipitation presented here find that the probability of an extreme event which had large impacts was in fact reduced by anthropogenic climate change. This could be confusing for those addressing the impacts of such events, as they are observing them with higher frequency, and could potentially discourage mitigation. It is important to remember, and communicate, in such cases that this study looked at one event and the results are specific to the event of that year. Particularly in regions such as Africa where precipitation variability is high and teleconnections have a strong influence, the attribution result could be very different for a similar magnitude event in a different year. This highlights a difficulty of using single event studies for the purpose of building awareness of climate change, and a communication challenge which would need to be addressed.

8.1.3 Q3. Can a participatory game be used to share event attribution science with stakeholders?

Literature has promoted the use of participatory games to share complex information about climate risks and impacts (e.g. Harteveld and Suarez, 2015; Mendler de Suarez, 2012). Both of the policy contexts investigated highlighted a lack of awareness of event attribution science among the policy stakeholders. This sparked the development of the CAULDRON (Climate Attribution Under Loss and Damage: Risking, Observing, Negotiating) game. In Chapter 7 the process of developing and using the CAULDRON game was described. It was created in order to engage with stakeholders addressing the impacts of extreme events, such as those interviewed in the previous chapters, to inform them about event attribution science and allow time for reflective conversations about its uses. While games are becoming an increasingly popular way of discussing climate change issues, this is the first to be produced for event attribution and loss and damage policy. A rigorous analysis of player learning about the science during the game is yet to be carried out. However it was observed that play encouraged dialogue about the issues facing those addressing the impacts of events and led to discussions about whether event attribution information could be relevant.

The game therefore appeared to be a success in the various contexts it was played in, including at an event alongside the UNFCCC Conference of the Parties in 2013 and at the workshop held in Senegal as part of the case study for Chapter 5, by the fact that it provided this opportunity for different stakeholders to come together and discuss event attribution science and addressing the impacts of extremes. This is something that games are able to do through players sharing a learning experience together, leading to the breaking down of barriers between them to promote dialogue (Suarez and Bachofen, 2013) in ways that more traditional presentation methods are not. This was particularly clear in the case of the Senegal workshop, where the game was observed to open up conversation between players having shared the experience of the game, to begin to discuss some of the issues being faced more broadly. It is noted however that games cannot portray all of the complexities of a scientific technique such as event attribution, but by working alongside other communication techniques such as more traditional presentations that could share these details, a game has been shown in this case to be a valuable tool.

8.2 Building a bigger picture of event attribution in Africa

The results from Chapters 4 to 7 all play an important role in developing an interdisciplinary understanding of event attribution science in an African context. By bringing together each of the areas investigated, a broader understanding of the potential roles for event attribution can be developed by approaching the topic from multiple angles, as was described in 3.1.2.

The event attribution study (Chapter 4) provided information about the impact of climate change on the precipitation in a specific year in West Africa, which could be relevant for decision-makers in the region addressing such events. These results were presented as part of the stakeholder workshop held in Senegal (Chapter 5), providing an example of event attribution results to inform the stakeholders' consideration of its relevance. The study also illustrated some of the types of uncertainties in results, both within each model ensemble and also between them. Such information is important for the effective application of results in policy (Bradshaw and Borchers, 2000). It is key to understanding how best to communicate this uncertainty information alongside results, which is vital to ensure information is used appropriately in decision-making (Keohane et al., 2014), if it was deemed appropriate.

For the relevance of event attribution science to be considered appropriately, understandings of the relevant policy contexts are required to understand the other priorities involved in decision-making (Morss et al., 2005; Rose 2014). Chapters 5 and 6 on adaptation in Senegal and loss and damage policy investigate two specific contexts to understand their backgrounds, along with what key stakeholders understand about the links between extreme events and climate change, and whether event attribution could play a role in decision-making. Knowledge of these contexts and the barriers to the inclusion of scientific information, and in particular event attribution, is important if its relevance is to be considered and investigated further. Understanding the types of decisions being made can also be useful to feed into the development of event attribution science, in order to make it as useful as possible if it were to be incorporated. This could mean that relevant events, regions, timescales and methodologies are used in studies, results with useable levels of certainty produced, and these results then disseminated in appropriate ways for the different contexts (Cash and Moser, 2000; Dilling and Lemos, 2011; Lemos and Rood, 2010).

Both policy contexts investigated highlighted the need to share with decision-makers what information climate science can now provide regarding individual events and their relation to climate change. The CAULDRON game is a tool developed to provide an engaging way of sharing information between scientists and stakeholders. Through this engagement, scientists can share information about the science and learn about the policy contexts to be able to tailor scientific research accordingly. Decision-makers can consider whether the information is relevant to their decisions. Using relatively new techniques such as gaming, alongside more traditional techniques such as presentations, can help share complex information in engaging ways (Harteveld and Suarez, 2015; Juhola et al., 2013). This game became a vital tool in engaging with the stakeholders for the other parts of this research into loss and damage and adaptation policy. It was played at an event held during the UNFCCC 19th session of the Conference of the Parties in Warsaw, where the loss and damage policy research was carried out. It was also played at the workshop hosted in Senegal as part of the research into national adaptation policy. In Senegal in particular, it was able to stimulate useful conversations about the role of event attribution through learning about the science, experiencing decision-making in the game, and through the building of relationships between participants through play leading to conversations. The conversations this helped foster were important both for the stakeholders who discussed the relevance of the science for their decision-making, and for the gathering of data for the case study.

8.3 Contributions of this thesis

Through an approach crossing disciplines, this thesis has been able to make contributions to climate science, to areas of social science and to the interface between. To climate science, this has provided the first event attribution study in West Africa and shown that, for the high precipitation of 2012, the majority of climate model ensembles used showed a consistent decrease in probability of this event due to climate change. This is particularly interesting for a region where future projections of precipitation are uncertain (e.g. Biasutti et al. 2008, Druyan 2011), and demonstrates that event attribution might be able to help improve understanding of climate change impacts in this region. However there are uncertainties in this result in both the magnitude of the change and the direction, highlighting the importance of considering different models to establish the robustness of the attribution result, and in particular how the estimate of anthropogenic influence on sea surface temperatures can have an impact. This will be important for other event attribution studies in the future, particularly for events where teleconnections play a key role.

This research has contributed empirically and analytically to the subfields of global environmental change and climate and society. It has developed an empirical understanding of the roles event attribution may be able to play in the science-policy interface introduced in sections 2.2.4 and 2.3.4, through a focus on national adaptation and international loss and damage policy contexts. In this way the aim has been to act as an honest broker (Pielke, 2007), associating the science of event attribution with particular climate policy contexts to then investigate whether results could play a role, through engagement with decision-makers in those contexts. As was discussed in section 3.4, there were challenges to ensure the usability of the science was not biased when considering these applications, due to the project partners this research was associated with. However through awareness of these challenges and concerted efforts to ensure the analysis and particularly the write-up were as unbiased as possible, this research provides a relatively objective investigation into the potential roles for event attribution science, and in this way has tried to act as the honest broker Pielke (2007) describes.

Detailed investigation of the relevance of event attribution to specific policy contexts has not been carried out before. However, it is through researching specific policy contexts rather than more general applications that an improved understanding of applications for results can be developed. This work has been able to provide more general knowledge on the national adaptation policy context in Senegal and on international loss and damage policy at the early stages of its development, which provide key preliminary backgrounds from which further work could investigate the role of climate science to support these areas.

In the subfield of global environmental change, potential roles for event attribution in adaptation policy have been criticised for drawing attention to risks attributable to anthropogenic climate change which could then take focus away from addressing vulnerability and exposure (Hulme, 2014; Hulme et al., 2011). The study here into the application of event attribution in national adaptation policy to address flooding in Senegal (Chapter 5) also exposes this tension – while there is some interest among policymakers in the impacts of climate change, more prominent are the urgent needs to address vulnerability and exposure to flooding events through improved urban planning and management, regardless of whether there is a climate change component to these.

This work has found that although event attribution science may be able to provide interesting information to policymakers about the causes of extreme events, this may currently have limited application in informing decision-making. This is the case both at national levels, where addressing vulnerability to extreme events, regardless of their meteorological cause, may take priority and also at international levels, where attribution is commonly associated with the controversial issues of liability and compensation (as also found by Vanhala and Hestbaek, 2016). Stakeholders also suggested in both policy contexts that event attribution results may be relevant for communicating the impacts of climate change in order to encourage mitigation. This supports findings from Stott and Walton (2013) and Sippel et al. (2015) that results could help communicate the impacts of climate change, and the suggestion from Bouwer (2011) that such links could encourage mitigation policy. This application requires further investigation into whether studies could have such impact, from international to local levels, but it may be that results could be applicable in this area, where there is less association with compensation.

Contributing to climate and society, the development of the CAULDRON game (Chapter 7) has furthered understanding of the communication of climate risks to non-scientists. This follows work by Lemos and Rood (2010) describing the disconnect between the perceived usefulness of information by producers and users, and by Mendler de Suarez et al. (2012) on the development of participatory games to share complex information about climate risks, encouraging engagement between players. While games are frequently used by humanitarian organisations in this way, they are still a relatively new tool in science and academia. The development of the CAULDRON game has provided an example of using gameplay to engage with a range of stakeholder groups, and shown its benefits in sharing scientific information about changing risks and providing an environment for discussions about the role of science in policy. This approach has been seen to be useful for helping stakeholders to make links between the areas of science and policy and also then to interrogate these, and it contributes to better understanding of participation in the context of addressing the impacts of extreme events.

This research has not only contributed to each discipline individually but also to the interface between them. Developing the science is vital if it is to be applied in policy contexts, and understanding those potential contexts can ultimately inform the development and sharing of results so they are most useful for supporting policy decisions addressing the impacts of extreme events under climate change. Developing the science in regions where extreme events often have the most devastating impacts through understanding whether results are robust is vital. This information could then be used alongside socioeconomic understandings of vulnerability to support those affected by events. The creation and development of the CAULDRON game helped bring together scientific knowledge and policy needs, to encourage greater engagement with what this science can provide and further development of this interface in the future.

8.4 Limitations

Each area of work in this thesis has specific limitations which have been discussed in the relevant chapters. However this thesis as a whole also has some limitations due to its efforts to carry out research across disciplines. Investigating both the science of event attribution and also its applications has involved using a range of quantitative and qualitative research methods, comprising analysis of climate model data, interview transcripts, questionnaires and literature.

Studying more than one discipline can be a challenge, because rather than looking at one particular area in great depth, the research is much broader. In this case, instead of focussing on one specific topic, such as event attribution science in Africa, or its relevance for loss and damage negotiations, the thesis has instead investigated the science, possible applications, and how to communicate about the science with stakeholders. This therefore means each of these areas has not been studied in as much detail as could have been possible in a thesis looking at one individually. However, the research was able to evolve throughout the time available to allow for a richer set of findings than might have been possible with a predetermined single hypothesis, and make use of a pragmatic approach through a range of research tools.

Also, such interdisciplinary research is vital in the area of event attribution. There has been limited research to date on its application in developing regions, such as in Africa, and also its policy relevance. As greater understanding of environmental issues can be generated through combining perspectives from different disciplines (Adger et al., 2003), this work has endeavoured to bring together these science and policy areas. This requires understanding the possible applications of results in order for the information to be shared with the relevant decision-makers and tailored to best fit their needs. On the other hand, in order to investigate applications of the science, it is necessary to understand its capabilities in the regions being considered. As there has been very little application of event attribution in African regions, carrying out a study of an event here was a key part of this research. This provided an example of a result that could then be shared with stakeholders in Senegal when discussing the relevance of the science at the workshop.

Investigating the link between science and policy is therefore important if results are to be relevant for decision-makers, but this can be difficult, especially in areas where it is contentious. Event attribution is an area of climate science that has been relatively controversial in the past, due to many scientists considering it very difficult or even impossible to attribute individual events (Hegerl et al., 2007). Investigating this science in the context of loss and damage is particularly contentious due to the historical association of this area of policy with calls for compensation, and the suggestions that event attribution could provide information to support such claims (James et al., 2014; Surminski and Lopez, 2014; Vanhala and Hestbaek, 2016). Such controversy can make it challenging to research these policy areas as stakeholders may be uncomfortable discussing the details, which could potentially limit the information that could be gathered from interviews. Establishing stakeholders' views on the science is nonetheless an important research task, and can be used to gather insights into the range of opinions expressed, which can be reflected on in light of what is already known about the controversies.

Carrying out this interdisciplinary research as a single researcher has brought challenges. As I have a background in meteorology, not only have I had to further my quantitative data analysis skills for the event attribution case study, but have also had to learn how to collect and analyse social qualitative data, which is a very different way of approaching a research question. Furthermore, I have had to manage the different areas of the research project to ensure each question was addressed as thoroughly as possible within the confines of the project. A particular challenge was ensuring I was as objective as possible during the social research, given my experience from the physical science part. Despite these challenges, working across disciplines has brought benefits that would not have been possible from working from a single discipline. It has allowed me to develop a much wider understanding of event attribution science and its applicability, and in particular to better appreciate the need for work at the science-policy interface to ensure decisions are supported by available evidence where appropriate.

8.5 Implications for research and policy

Despite the limitations discussed, this thesis has implications for science, policy and the science-policy interface. From the event attribution case study, it was shown that high precipitation in West Africa in 2012 was likely decreased in probability due to climate change. This result could have implications for policy addressing this type of event, as it could be expected that such events will occur less frequently in the future. However, this also has implications for climate science itself, highlighting a climate change impact in this region. This information can be combined with other studies looking, for example, at longer term trends in such events, to build a greater understanding of the impacts of climate change and the mechanisms behind these. Future work could also investigate the processes in the models analysed causing the differences in the attribution statements to better understand current and future precipitation changes in West Africa. The work highlighted that differences in estimates of anthropogenic influences on sea surface temperatures could have a large influence on the attribution result. This has also since been found in an attribution study of 2014 southern England precipitation and flooding, where estimates of the change in the risk of a 1-in-100-year precipitation event varied from no change to an increase of 164%, depending on which of the 11 anthropogenic SST patterns from coupled models was used (Schaller et al., 2016). Therefore future event attribution studies should consider ranges of estimates of anthropogenic SST changes in order to better understand the robustness of results, while ensuring the related natural world simulations are consistent with observations. How this science develops in the future should also be based on information about the policy contexts it is to be applied in, if it is deemed appropriate. Decision-makers could guide the development so it is relevant to the decisions they have to make and require evidence for.

In terms of policy, this thesis has highlighted the need for improved engagement with stakeholders in order to share understandings of how science can assess the impact of climate change on individual events, as so far this knowledge has been shown to be very limited. This is not entirely surprising as scientists spent many years claiming nothing could be said about the influence of climate change on one particular event. However, now the science has developed to a point where this is possible for some types of events (National Academies, 2016), scientists could improve their sharing about what information can be provided. There is also a need for more attribution studies of African events to build understanding of climate change impacts on specific events in this region. This is particularly relevant as this thesis has highlighted policy areas where results could be relevant for addressing the impacts of extremes. However, as has been described, there have been very few studies in this region to date and also challenges with assessing climate change impacts due to observational and model limitations.

This work has also shown that although event attribution could be relevant in both of the contexts studied, national adaptation in Senegal and international loss and damage policy, both areas have other issues alongside the science which need to be addressed. So while the science could be relevant, it would need to work alongside many other drivers of decision-making, and therefore may not play a key role in negotiations or policy. As there is potential for results to inform decisions though, future work should continue to further investigate these issues. In Senegal, this could build on the work presented here and that by Schaer et al. (2017) and comprise a full political economy analysis, to better understand the decision-making contexts and key stakeholders and their influences. Research could also consider the possibility for application in other national adaptation policy contexts, including those with more developed adaptation policy. This work has also highlighted the need to better understand other drivers of vulnerability as well as the additional risk from climate change. This will require research from a number of different disciplines to work together to better understand how to address the risks of extreme events in vulnerable countries.

The loss and damage work showed event attribution could have a role here but this is a controversial issue due to links to compensation, and there are mixed understandings of links between extremes and climate change among this community. While probabilistic attribution might be able to provide evidence within a legal framework (Verheyen, 2015), the recent Paris Agreement made it explicit that loss and damage does not form a basis for any liability or compensation (UNFCCC, 2016), illustrating just how contentious this issue is. Huggel et al. (2016) have also suggested that while there is low confidence in the attribution of specific impacts on human systems to climate change, general causation evidence (that climate change would be capable of causing particular damage) may be sufficient for the recognition of responsibilities for climate change impacts as part of UNFCCC processes. Loss and damage policy is still developing and so it is unclear whether evidence of causation will be relevant, and whether event attribution could play a role. One of the key points this work highlighted was the lack of agreement over the meaning of loss and damage as a concept. Therefore there is a need to define what loss and damage actually is to different stakeholders, and then to assess what scientific information would be needed to support these different concepts. This may or may not include event attribution. In order to address this, work has been carried out by Boyd et al. (2016) and Vanhala and Hestbaek (2016) to investigate the different ways in which loss and damage is being defined. Boyd et al. (2016) identified four typologies of loss and damage: adaptation and mitigation, risk management, limits to adaptation, and existential, with different research needs for each. In particular, stakeholders had varying opinions about the relevance of attribution for loss and damage policy, with concern that uncertainty in attributing specific losses and controversy around this should not hinder action to assist those being affected by climate events. As this policy area continues to develop, research could further investigate how it can best be supported by scientific understanding. Currently stakeholders have a wide range of views on what would be most relevant, including information on climate change impacts on existing risks, empirical evidence of the limits to adaptation and further understanding of non-economic losses and damages, such as loss of homeland and mental health impacts (Boyd et al., 2016).

This work also has implications for the science-policy interface. It has highlighted that there are potential applications for event attribution in both loss and damage and adaptation policy. However, it has also highlighted the need for further interaction between the scientists carrying out event attribution studies and policymakers who could be interested in using it. This would help ensure that policymakers understand what the science can provide, and scientists can consider developing the science in ways that are relevant to policy decisions. To assist in this,

this thesis has shown that innovative ways of engaging with policymakers, such as games, can be useful tools. The CAULDRON game engaged policymakers and other stakeholders with the issues around event attribution science in an interesting and fun way, helping to break down barriers between the different players involved and provide space for dialogue about the issues they were facing in both the game and real life. Tools such as this provide novel ways for stakeholders to interact and process information. In the future more work on the ways in which players learn from games could be carried out, and the benefits of using gameplay applied to a wider range of science-policy contexts.

8.5.1 Recommendations for future work

Continuing this interdisciplinary work around event attribution would help develop a deeper understanding of how knowledge about the climate change influence on extreme events can be incorporated into policy decision-making. More attribution studies of African events, including investigating results from different climate models, would lead to a better understanding of climate change impacts across the region. As results are potentially relevant for adaptation and loss and damage policy, this warrants further investigation of these, and other, policy contexts addressing the impacts of extremes. Research will need to establish how climate information is currently incorporated in decision-making and what further information might be most applicable in each context, including whether information on individual events could be useful. This thesis has highlighted the need to share event attribution with policymakers in order for them to consider the relevance of results. The benefits of using participatory gaming for this purpose have been shown here and should be further investigated in science-policy contexts in the future.

8.6 Concluding remarks

This thesis has shown that event attribution could have roles in supporting decisions addressing the impacts of extreme events in Africa in the future, by providing information on the influence of anthropogenic climate change on individual events. Results can estimate the change in the probability of an event due to climate change and this information could help those who are vulnerable to understand more about the current impacts of climate change and adapt to expected changes in similar events in the future. More generally, addressing the impacts of climate change will require policies to be put in place that are well-informed by the latest scientific research. This will require dialogue between scientists and stakeholders to ensure that research is relevant to decisions being made. Critically, addressing the impacts of climate change is reliant on interdisciplinary research to investigate both the science and policy contexts, ensuring a deeper understanding of how these can work together to support the most vulnerable.

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Appendix A: Senegal interview protocol

Impacts of extreme precipitation in Senegal

- What are the impacts of extreme precipitation in Senegal? Who is affected?
- What are the factors that lead to these impacts? (meteorological, social, economic, etc.)

Policymaking

- Are there policies in place to address extreme precipitation? What are these? Are you/is your organisation involved in making decisions to address such events?
- What mechanisms exist to anticipate or take action on events such as extreme precipitation and flooding?
- Is climate information used as evidence in the production of these policies? If so, how and what information? Where does this information come from? Do you think it is well-understood and well-used? What other information is needed to inform these policies?
- What do you think are the main research areas relating to extreme precipitation that need to be addressed in the future are?
- What do you think are the main policy areas relating to extreme precipitation that need to be addressed in the future are?

Governance and decision-making in Senegal

- Who is responsible for adaptation decisions related to extreme precipitation, and flooding?
- What are the key decision-making structures established to manage events related to extreme precipitation?
- Is there responsibility at different levels of decision-making? (e.g. national, local)
- How do the different levels of decision making relate to each other? Where are the links?

- Who are the key actors in making decisions to address extreme precipitation events, and how to they influence key decisions?
- Do you think the governance structures are effective? Please explain your answer.
- What are the key decisions that need to be made in managing events related to extreme precipitation?
- What types of information is required for those decisions?
- Are there other key stakeholders (outside of government) involved? Who? Are there intermediaries between stakeholders?
- Is information shared between stakeholders? How?
- How are decisions communicated across the different levels of responsibility? What are the challenges in communicating decisions about extreme precipitation and adaptation?
- Are there mechanisms to deal with extreme precipitation events? At what level? Are these mechanisms for before, during or after events?
- Who is involved in addressing the impacts of flooding? Who is responsible for addressing the impacts? Who funds this?
- How effective are actions in dealing with flooding?
- What are the main challenges when dealing with extreme precipitation and flooding events?

2012 flooding event in Senegal

- How did the precipitation and flooding in 2012 compare to other years?
- Do you think it was affected by climate change? What do others think?
- Is climate change affecting precipitation in Senegal? How?
- Do you think individual extreme events (e.g. the precipitation in 2012) can be attributed to climate change? What do others think?
- Would having an estimate of how the likelihood of an event due to climate change be useful? If so, how?

Appendix B: Senegal workshop agenda

Workshop on extreme weather, climate change and loss and damage

Date: Wednesday 24th February 2016

Location: Salle de Conférence, Direction Environnement et Etablissements Classés, 106 Rue Carnot, Dakar

Agenda:

Please arrive from 9am for coffee, ready for the workshop to begin at 9.30am. Tea and coffee and lunch will be provided. The workshop will finish by 5pm.

9am Arrival and Registration

9.30am Welcome and Introduction

10am Presentation on event attribution science

10.30am Break

11am CAULDRON game: a participatory game exploring the science of event attribution and how it can be used in adaptation policy

1pm Lunch

2pm Group discussions: Mapping relevant stakeholder networks and key adaptation decisions and necessary scientific information

3pm Break

3.30pm Group discussions: How could event attribution study results be useful for adaptation policy?

4.30pm Conclusions and future directions for work

5pm Finish

Appendix C: Senegal questionnaire

1. Do you think that climate change is affecting precipitation in Senegal? If so, in what way? Please explain your answer.

2. In 2012, heavy rainfall during the rainy season in Senegal led to flooding.

   a) Was this a normal event experienced in Senegal's climate?

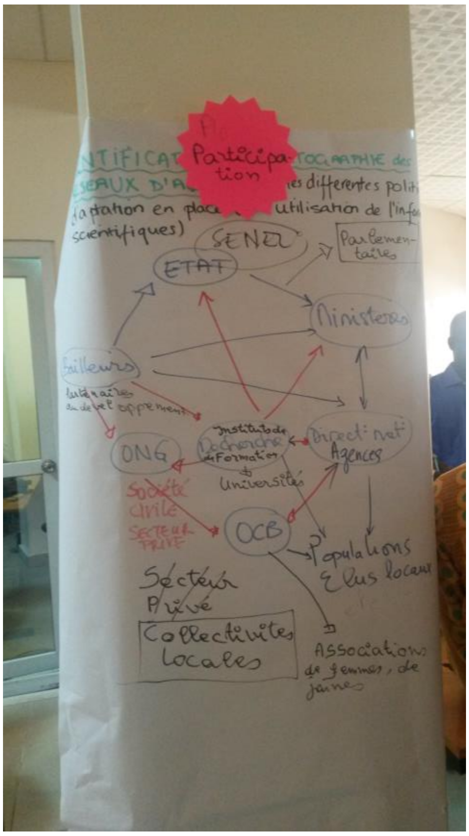
   b) Do you think this heavy precipitation and subsequent flooding was affected by climate change? If so, in what way? Please explain your answer.

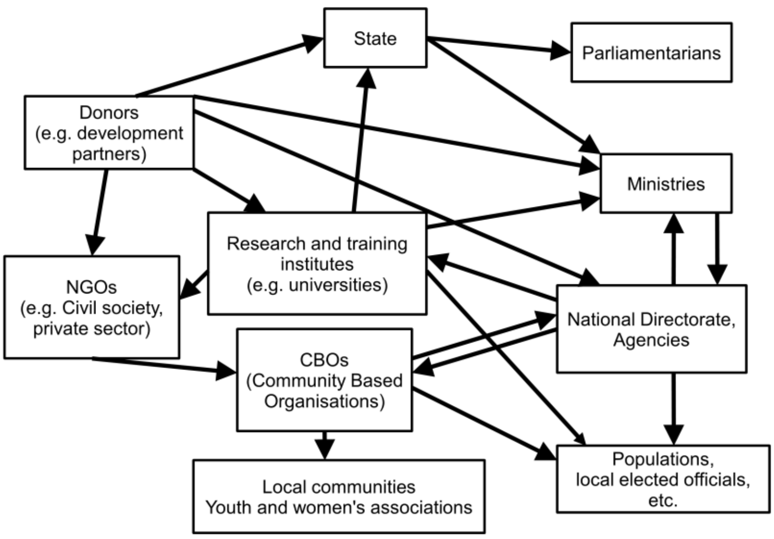
3. In general, do you think specific extreme precipitation events (such as the 2012 rainy season precipitation) can be associated with climate change? In what way?

4. Have you heard of the science of Probabilistic Event Attribution before? If so, where?

Appendix D: Senegal workshop group discussions

Identifying and mapping key actors (including actors involved in adaptation policy and users of scientific information)

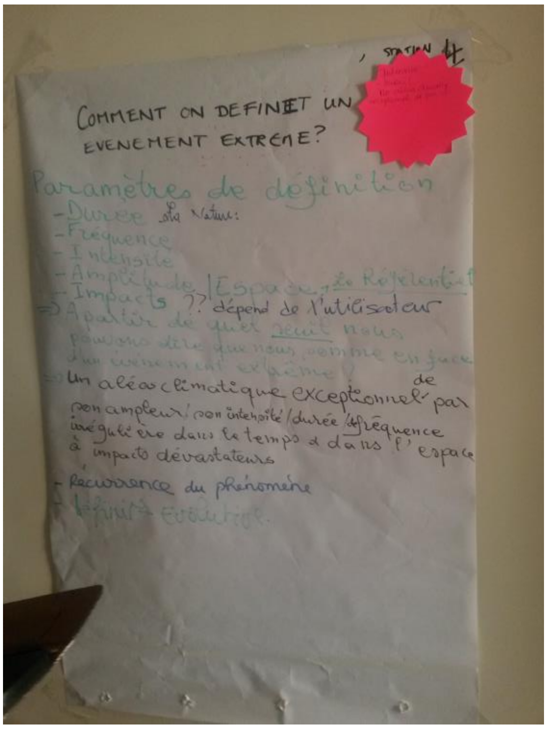




How do we define an extreme event?

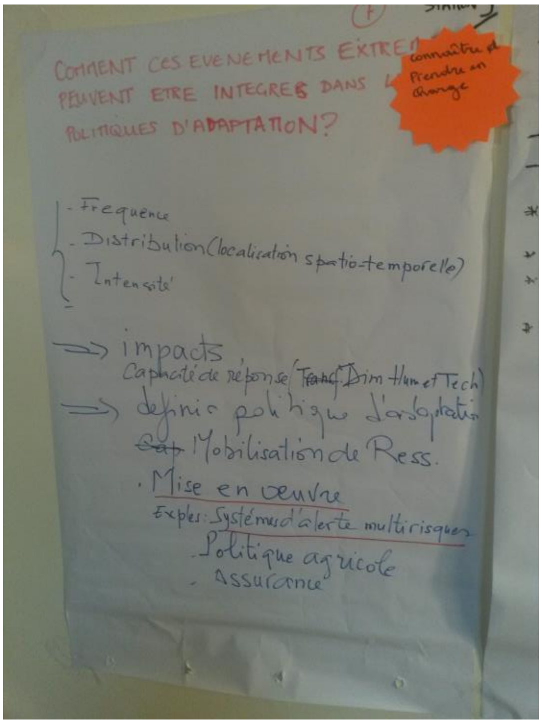
Definition parameters:

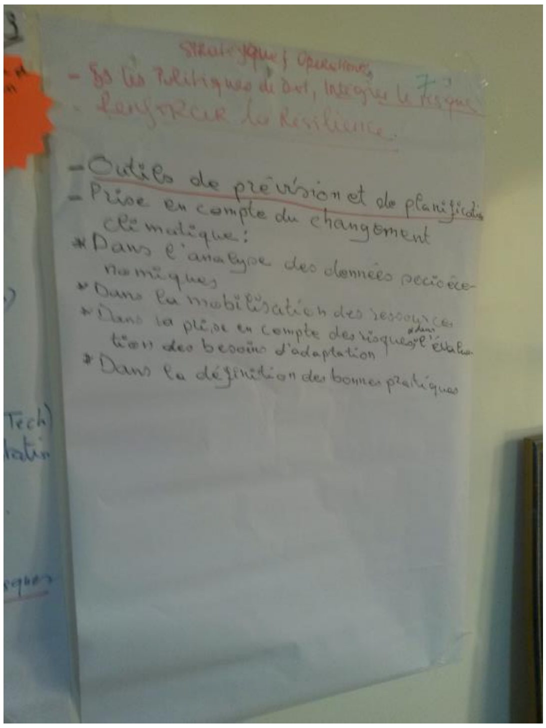
- Duration
- Frequency
- Intensity
- Amplitude/ Space
- Impacts (Depends on the user)



- From what threshold can we say we are facing an extreme event?
- An exceptional climate hazard due to its extent/intensity/duration/irregular frequency in time and area of devastating impacts
- Recurrence of the phenomenon
- Definitions evolve

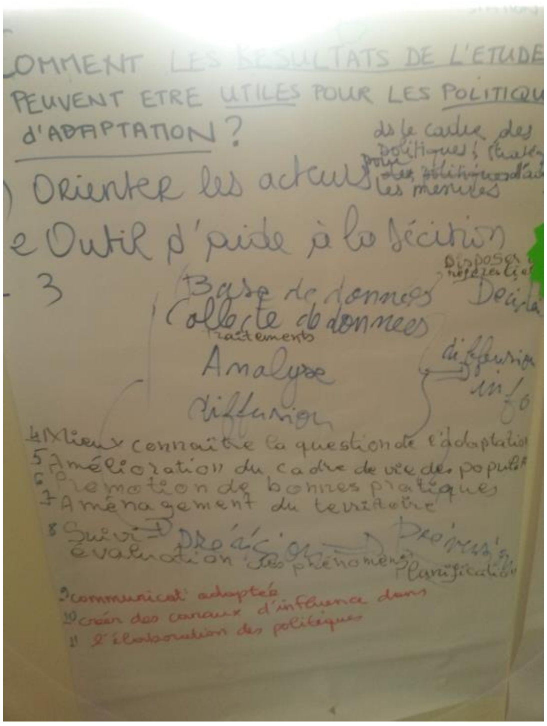
How can extreme events be integrated into adaptation policy?

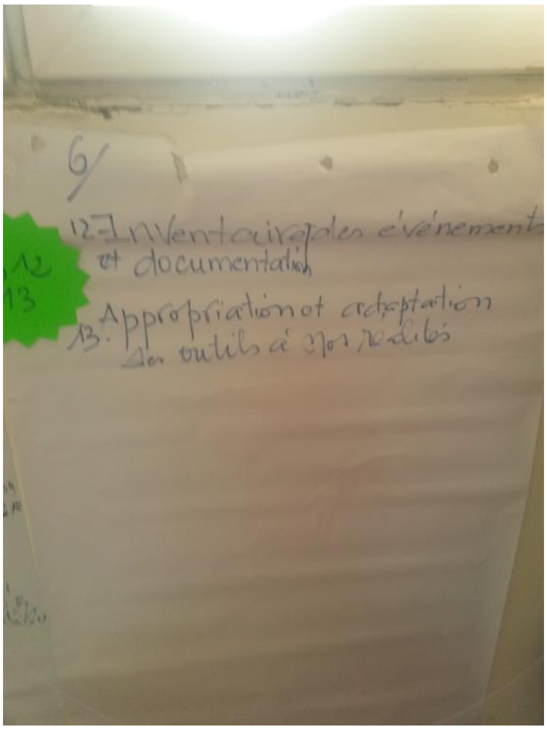




- ownership and take charge
- frequency, distribution (location spatio-temporal), intensity
- impacts, capacity to respond (human and technology)
- define adaptation policy, mobilisation of resources, implementation e.g. multiple-risk warning systems, agricultural policy, insurance
- development policies – integrate risk, strengthen resilience
- tools for forecasting and planning
- take climate change into account
  - in the analysis of socio-economic data
  - in the mobilisation of resources
  - in the consideration of risks and in the evaluation of adaptation needs
  - in the definition of good practices

How could the results of the study be useful for adaptation policies?





- guide actors on the framework, the policies and strategies for adaptation measures
- tool to support decisions
- database to have as reference: collect data, analyse, share information... leading to forecasts?
- know better the adaptation question
- improvement of the population's living environment
- promotion of good practices
- regional planning
- monitoring and evaluation of phenomena for planning
- adapt communication
- create channels of influence
- elaboration of policies
- inventories of events and documentation
- adapting tools and making them appropriate to our contexts

Appendix E: Loss and damage interview question topics

- Prior knowledge of PEA
  - What do you know about extreme event attribution?
  - Is it possible to attribute individual extreme events to GHG emissions? What do people you work with think?
  - Do you know about probabilistic event attribution?
  - Will it ever be possible to wholly attribute an extreme event to climate change?
- Uses for PEA in own work
  - Could extreme event attribution be useful in your work?
  - How confident in attribution statements would we need to be to be useful?
- Loss and damage
  - What is meant by loss and damage associated with the adverse effects of climate change? What does loss and damage encompass?
  - What position do you support in the loss and damage negotiations?
  - Should loss and damage include extreme events as well as slow onset?
  - Who is responsible for addressing loss and damage?
  - What form should a mechanism to address loss and damage take?
- PEA and loss and damage
  - Could extreme event attribution play a part in the loss and damage work programme? How?
  - Is science playing a role in the negotiations?
  - Is it important to distinguish which events are attributable for loss and damage?