# Intention to submit: Probabilistic attribution of the UK Autumn 2000 floods

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**The United Kingdom floods of October and November 2000 occurred during the wettest autumn on record[1] causing widespread damage and an estimated insured loss of £1.3 bn[2]. While it has been noted that this type of event might become more likely under climate change[3], it is impossible to prove beyond doubt that this particular event could not have occurred in the absence of human influence on climate[4,5]. It is, however, possible to attribute the contribution of increasing greenhouse gas levels to the risk of such an event[6,7]. This study will determine, using the method of probabilistic attribution, the extent to which past anthropogenic emissions of greenhouse gases contributed to the risk of a flooding event as serious as that of Autumn 2000 occurring at that time. Here we use a high-resolution global atmospheric climate model (HadAM3-N144[8,9]) to make this assessment by comparing large ensembles of simulations of Autumn 2000 conditions before and after removing an objectively-determined range of estimates of the signal of attributable greenhouse warming.**

# 1 Introduction

The United Kingdom floods of October and November 2000 occurred during the wettest autumn in England & Wales since records began in 1766, with a total of 503mm of rain, exceeding the previous maximum by almost 50mm[10], and resulting in almost double the average (1961-1990) seasonal precipitation[1]. The national picture was of persistent widespread heavy rain rather than very strong localised events, although these did also occur. Synoptic data for the period showed that the October-November period was dominated by persistent and repeated frontal depressions, with broad bands of rain enclosing notable high-intensity rain cells across the British Isles. The resultant flooding was hydrologically complex with large local and regional variations in its severity and was the cumulative effect of the series of exceptional rainfalls affecting different parts of the country at different times and in many cases more than once. Some areas flooded two or three times in the autumn and some even five times during 2000[11]. The estimated insured loss was £1.3 bn[2] with just under 10,000 properties being flooded at over 700 locations as well as widespread disruption to road and rail services.

The severity of these floods prompted public and political debate about how unusual such an event is and, in particular, whether it was due in any part to anthropogenic climate change. By the very nature of a chaotic climate system, however, it is impossible to prove beyond doubt that this particular event could not have occurred in the absence of emissions of greenhouse gasses[4,5]. It is, however, possible to attribute the change in risk of such an event occurring, that is to say the change in climate, provided that climate has been rigorously defined to encompass all the properties of the 'attractor' of weather[6,7]. We use this latter 'probabilistic attribution' approach to determine the extent to which past anthropogenic emissions of greenhouse gases contributed to the risk of a flooding event as serious as that of Autumn 2000 occurring at that time.

The rigorous definition of the impact of external factors on weather risk is then made via large ensemble simulations with a high-resolution version of a global atmospheric climate model, namely the Third Hadley Centre Atmospheric Model (HadAM3-N144)[8,9]. This explicit modelling of the system with and without the influence of greenhouse gasses is in contrast to otherwise similar attribution studies such as ref[12] focussing on the European heatwave of 2003. That study essentially scaled the output of a relatively coarse-resolution climate model up and down to assess the range of possible changes in heat-wave risk resulting from anthropogenic influence to date, and assumed the statistics of variability about the externally driven change in mean summer temperatures remain unchanged. That appeared valid for the large area seasonal mean temperatures under consideration in that study. It is not, however, appropriate for our higher resolution, smaller spatio-temporal scale, study and not for a variable such as precipitation which we would expect to respond in a more non-linear fashion[3].

## 2 Method

The probabilistic attribution method is applied as illustrated schematically in figure 1. The 'Autumn 2000' distribution of precipitation is estimated from an initial condition ensemble of model simulations of the UK climate for twelve months (April 2000 - March 2001) leading up to and around the Autumn 2000 floods, with prescribed greenhouse gas levels, sulphate aerosols and sea surface temperatures (SSTs) for that time. April 2000 is chosen as the start date because antecedent weather conditions are considered to be an important factor in maintaining soil moisture, aquifer and river flow at relatively high levels through the summer leading up to Autumn 2000[10].

Similarly, the 'Non-industrial Autumn 2000' distribution is an initial condition ensemble with greenhouse gas levels and SSTs prescribed to represent the same twelve month period in 2000 had anthropogenic emissions of greenhouse gases since 1870 not occurred. We then analyse available observations to determine the rainfall anomaly that caused the Autumn 2000 floods and derive the analogous event in the model, shown by the vertical line. It then follows that the fraction of risk attributable to anthropogenic greenhouse gasses is given by, $R = 1 - P_0/P_1$. Values of $R$ close to 1 (or 0) would suggest that all (or none of the) risk of the floods occurring during Autumn 2000 was attributable to anthropogenic greenhouse gas warming since 1870.

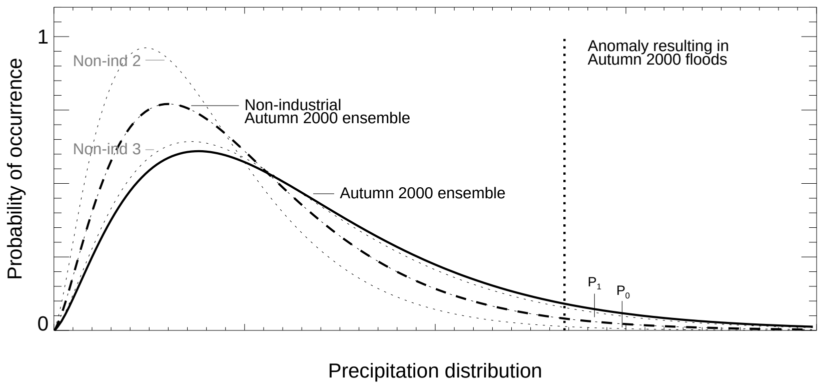


Figure 1: Schematic of the probabilistic attribution experiment for the Autumn 2000 UK floods. The risk under 'Autumn 2000' and 'Non-industrial Autumn 2000' like climates of the flood event, represented here in terms of precipitation, occurring is quantified via ensemble integrations with HadAM3-N144. See text for details.

The SSTs prescribed in the Autumn 2000 ensemble are weekly-means from the observational based NOAA Optimum Interpolation dataset, version 2 (OI.v2)[13]. We then estimate the SSTs for the Non-industrial Autumn 2000 by removing, from the weekly Autumn 2000 SSTs, the patterns of temperature change attributable to greenhouse gases estimated from a range of climate models using a conventional detection and attribution method[14,15]; hence allowing for model response uncertainty in the warming pattern removed. These response patterns have

1870 as their reference point, dictated by the reliability of observations for that method, so that this is also our reference point for the Non-industrial ensemble as was stated above. They are also only available at seasonal resolution and so will have to be interpolated to weekly resolution. Moreover, since this warming signal is inherently uncertain we must repeat our attribution experiment a number of times (of order 10) by subtracting a range of greenhouse induced changes in SSTs which span this range of uncertainty. This is represented schematically for the first few repetitions, by the 'Non-ind 2' and 'Non-ind 3' distributions in figure 1, and allows us to build-up a distribution on $R$.

## 3 Proposed analysis

Precipitation is shown as the variable of interest in figure 1 and, in the first instance, we intend to produce that analyses using season-mean UK precipitation totals from our simulations of Autumn (September-November) 2000, as it was this entire period which was the wettest on record. In addition to computing output precipitation statistics, we need to establish that any change is taking place for the right reasons. Hence the model must also be able to capture the large scale synoptic patterns that were present during this time, such as the suggested 'Scandinavia pattern' which resulted in persistence of low pressure over, and displacement of the Atlantic jetstream toward, the UK – bringing with it the associated persistent wet weather [16]. Thus we also intend to search for this pattern in the ensembles.

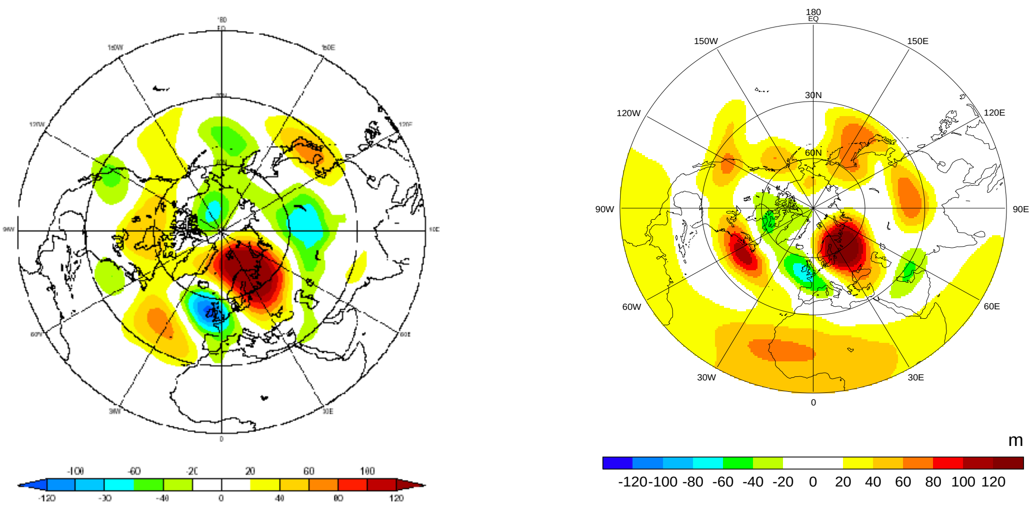


Figure 2: Comparison between Autumn 2000 northern hemisphere geopotential height anomalies as found from observations and preliminary simulation. The left panel shows (in metres) the observed Autumn 2000 300hPa anomaly relative to climatology found by ref[16] using ECMWF analyses data. The right panel shows the simulated 'Autumn 2000' 250hPa anomaly, for a 5-member ensemble-mean, relative to the corresponding 'Non-industrial Autumn 2000' climatology found from preliminary simulations with HadAM3-N144 (the discrepancy between the pressure levels used was due to availability of data).

Results from our first few preliminary integrations show some promise in being able to simulate the Scandinavia pattern, as demonstrated in figure 2. Notably, the characteristic train of observed geopotential height anomalies extending from the mid-Atlantic over Eurasia, with a cyclone over the UK and strong anticyclone over Scandinavia are simulated reasonably well. They are thought to be primarily due to the influence of tropical SSTs on anomalous deep convection and subsequent teleconnection patterns, and this will also be investigated.

It must be stressed, of course, that the simulation in figure 2 is from a relatively very small ensemble of integrations and it can be seen that other regions do not reproduce so well. Furthermore, the exact metric for capturing the flood event may be more complex. A multivariate distribution of hydrological parameters, for example, precipitation, pressure and soil moisture may be looked at, and over varying spatio-temporal scales. Moreover, much larger ensembles sizes are needed before one can hope to have rigorously defined the Autumn 2000 and Non-industrial Autumn 2000 climates, and we also expect to appeal to extreme value theory to improve the reliability of estimates of extreme features in the model.

In fact, anticipating that the Autumn 2000 events were relatively unlikely, even given the SST and greenhouse gas levels prevailing at that time, each of the initial condition ensembles for both the Autumn 2000 and Non-industrial Autumn 2000 will need to be quite large (we estimate of order 50-100 members for each), so the total number of model-years required would be in the region of 600-1100 with this high-resolution model. This would represent a very significant resource requirement for conventional computing facilities, necessitating the use of distributed computing[17].

Such assessments of attributable risk under climate change of the meteorological conditions associated with extreme flood events would be of value to hydrological modellers and environment agencies, as well as insurers[18]. This study will also help in understanding the intrinsic predictability of the Autumn 2000 extreme event. Further, the robustness and simplicity of the probabilistic attribution method lends itself to assessing risk for similar iconic floods and future extreme events.

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