Climate change and the summer 2007 floods in the U.K.

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Introduction

We have always bemoaned the wetness of the ‘Great British Summer’. The summer of 2007 was, without a doubt, one of the wettest on record. We have had wet summers before, indeed some quite recently. Analysis of the Meteorological Office’s rainfall series for the United Kingdom (Figure 1) shows that in about 20% of years, the U.K.’s summer rainfall is greater than the median winter and autumn rainfalls for the period 1914 to 2007. However, the U.K.’s summer rainfall for 2007 (357.1 mm) was the second highest on record, only marginally less than the wettest (1956, 358.4 mm). But one thing stands out in relation to 2007: the way in which, in many different areas of life, the summer of 2007 has become linked to the belief that our climate is changing. Consider, for instance, Prime Minister’s Question Time on the 25th July 2007, immediately in the aftermath of the Central England flooding (Hansard, Volume 463, Part 130, Column 834):

Sir Menzies Campbell: “The Prime Minister was responsible for the establishment of the Stern review, which he will recall pointed out the severe economic consequences of climate change. Is it not clear from the events of the past few weeks that we cannot afford not to take the necessary steps or indeed, not to spend the necessary money, in order to mitigate the effects of climate change?”

The Prime Minister: “The right hon. and learned Gentleman is right. The Stern report, which the Treasury commissioned, said that global warming is very likely to intensify the water cycle and increase the risk of floods. It is an accepted part of the Stern recommendations that we have to do more…”

In this article, I think through the relationship between climate change and the U.K. floods of 2007 and, in so doing, show that in order to understand the range of scales of climatic variability upon which any kind of climate change signal will be superimposed, we need to take a more historical perspective which a much stronger grounding in the atmospheric and oceanic drivers of the U.K.’s weather and climate.

The weather ‘conveyor belt’

The UK’s ‘weather’ is driven in the main by weather systems originating in the Atlantic. A complex interaction between high and low pressure systems, and the associated ‘conveyor belt’ of the Circumpolar Vortex, or ‘jet stream’, acts to determine whether the UK is influenced by ‘high pressure’, or ‘low pressure’ systems (Figure 2). The jet stream is a current of fast moving air, thousands of km long, hundreds of kms wide and a few kms deep. It is a dynamic feature, spatially and temporally, bounding polar air on the north side and cooler air on the equatorwards side. There are three primary dynamical aspects: (1) strength; (2) position; and (3) sinuosity. The strength of the jet stream is primarily a function of the temperature gradient between the equator and the pole. This gradient is weakest in the summer, and therefore the jet stream is commonly weaker. In the winter, the gradient is strongest and the jet stream is commonly stronger. Its average position migrates northwards during
spring, to lie north of the U.K. in a typical summer. It migrates southwards during autumn to lie south of the U.K. in a typical winter. Its sinuosity varies from weak to strong. When the sinuosity is strong, of particular importance is the position of ridges and troughs (Figure 2a). When a trough is positioned close to the south or south-west of the U.K., there is generally divergent air aloft, leading to rising air and low pressure at the surface. This draws in air which tends to rotate counter clockwise, leading to cyclonic weather systems, called extra-tropical cyclones in the mid-Latitudes (Figure 2b). The development of a cyclone is called cyclogenesis, and this pulls warm tropical air northwards and cool polar air southwards, with the air masses mixing along fronts. As the warm air moves northwards it encounters cooler polar air and is forced to rise upwards, causing condensation and precipitation as it does, along what is called a warm front. This rise is commonly gradual (Figure 2c). Cooler polar air, moving southwards, encounters warmer tropical air along a cold front, forcing the tropical air to rise dramatically, and also leading to precipitation, normally in the form of sharp showers (Figure 2c). The cooler polar air may eventually catch up with itself, completing a complete cycle, with cool air fully below and warm air fully aloft, and called an occluded front (Figure 2b). As the jet stream leads to ridges and troughs, and because the position of the troughs forms low pressure systems, the jet stream exerts a fundamental control upon where cyclones track across northern Europe, the ‘weather conveyor belt’.

‘Normal’ and ‘unusual’ jet stream behaviour

In a ‘normal’ year, during the spring, two key processes should happen. First, as the equator to pole temperature gradient weakens, the jet stream should weaken. Second, the jet stream normally moves northwards across the U.K. and positions itself further north. Associated with this is the building of high pressure from the south and south-west, often labelled the Azores high. The effect of this is to cause a transition from a dominance of cyclonic weather during the winter-spring to more stable weather during the summer. In the autumn, the situation reverses as the jet stream swings south. As late as the beginning of June 2007, we were still expecting a ‘normal’ summer. In its update to its summer seasonal forecast on the 31st May 2007, the U.K.’s Meteorological Office reported “Current rainfall indications suggest that over summer as a whole southern parts of the UK are more likely to experience average or below-average rainfall, while the north is more likely to see average or above average rainfall.”

The summer of 2007 was unusual in that the jet stream did not move north until August, it remained very intense throughout the summer and it remained sinuous, with a trough close to the west/south-west of the U.K. This resulted in three effects: (a) Atlantic weather systems tracked some way further south than normal for the period May to July; (b) as a result of the position of the jet stream trough, these weather systems became very slow moving as they moved over the U.K.; and (c) they tended to carry more moisture as they tracked over relatively warmer sea than would be normal if they tracked further north.

The result of these patterns were severe rainfall anomalies across certain parts of the U.K. (Figure 3). Compared with the 1961 to 1990 average, the U.K.’s Meteorological Office has calculated that the rainfall anomaly for April was 40% of the long-term average, but then 159% for May and 188% in both June and July. However, this hides significant variability within the U.K., with a June anomaly for England of 231% and a northern England anomaly of 270%, its wettest summer on record. In July, the figure was 219% for England, its wettest summer on record, and 237% for southern England. Concurrently, parts of the far north-west of Scotland, which remain influenced by the jet stream in a ‘normal’ summer had one of the driest summers on record.

Was the U.K. summer of 2007 unusual?

There are at least two candidate hypotheses for the events of the summer of 2007: (1) that these were unusual events, associated with human-induced climate change; and (2) that these were unusual events but not entirely unexpected when viewed in the longer term.

**Hypothesis 1: These were unusual events, associated with human-induced climate change**
The immediate and popular interpretation of the summer of 2007 has been that the flooding was a direct consequence of 'climate change'. There is certainly scientific evidence that points to changing rainfall characteristics, and notably an increase in the magnitude of extreme rainfall, which has increased over two-fold for parts of the UK since the 1960s (Fowler, and Kilsby, 2003). Climate change predictions for the future are more ambiguous. Table 1 shows those predicted for Ouse sub-basins, which were impacted upon by the June 2007 event. Under all emissions scenarios, the predictions suggest an annual reduction in precipitation, but with a substantially drier summer and wetter winter. The summer of 2007 does not seem to sit within these predictions. Indeed, the general assumption is that under future climate scenarios, the mid-latitude response to warming will be a stronger Azores high pressure with the jet stream moving further north, possibly for longer, on average. This would lead to more summer drought (Table 1). There could be more summer floods under such a scenario, but these would be associated with movement and/or weakening of high pressure systems, sometimes linked to the incursion of frontal weather, and exacerbated by intensive land surface heating, leading to the kind of convective rainfall events witnessed in Boscaddon (Cornwall, 2003) and Helmsley (North Yorkshire, 2005).

However, these observations should not lead to the rejection of the climate change hypotheses, but leave it unresolved for a number of important reasons. First, the kind of evidence reported in Fowler and Kilsby (2003) does suggest that extreme rainfall events appear to be changing in terms of their characteristics. Second, the data in Table 1 refer to mean changes in seasonal precipitation. It is quite possible that changes in mean seasonal precipitation are accompanied by changes in the between year variability in seasonal precipitation: the same summer reductions in mean precipitation could be associated with many more drier summers plus a smaller number of very much wetter summers. Third, current climate models really struggle to represent precipitation change, especially in the mid-latitudes, where extra-tropical cyclone activity is more weakly correlated with key drivers such as global teleconnections and patterns of sea surface temperature, as compared with tropical cyclone activity. Global climate models are commonly too coarse (e.g. 250 km x 250 km) to represent the extra-tropical cyclones that drove the summer 2007 floods. To generate meaningful U.K.-scale predictions of precipitation change (e.g. Table 1), regional climate models with a finer spatial resolution are used. However, even these can only provide meaningful predictions of monthly to annual changes in precipitation, not the event-scale (daily and sub-daily) predictions needed for the summer 2007. Even seasonal forecasts, based upon a combination of dynamical models with the statistical analysis of historical data (e.g. sea surface temperatures), issued a few months ahead, were not able to predict the summer of 2007. In terms of understanding future climate change impacts, it ought not to be necessary to predict each event. However, we must be able to predict, over the 30 year period used to characterise ‘futures’ (e.g. ‘the 2050s’, ‘the 2080s’), the range of dynamic conditions that will future weather patterns, and it is possible that current modelling methods simply do not do that yet.

**Hypothesis 2: these were unusual events, but not unexpected when viewed in the longer term**

One of the means by which faith in Hypothesis 1, climate change, might be strengthened, is if all other hypotheses for the summer 2007 events are disproven. Thus, it is important to ask a simple question: are the weather conditions which led to the events of 2007 to be entirely expected, given historical information. This may seem like a simple question to ask, but it turns out to be a particularly difficult question to answer. Central to the problem is the specific nature of the summer 2007 events: not only were the rainfall depths great, they were also spatially coherent, something that is only revealed through the spatial signals generated by rainfall radar data, available for the last 10 to 15 years. Point rainfall records, generated by rain gauges, may capture some of this spatial coherence, but they are rarely enough records of sufficient duration to capture this effect. This is illustrated for Figure 4, which shows the U.K.’s rain gauge data held by the Environment Agency, North-East Region, Dales Area, which covers the northern third of the area impacted upon by the June 2007 event. Of the almost 500 gauge records that are still providing data, only about 7% are longer than 46 years. The flat part of the curve reflects a decision to digitise a further 10% of historical records, but only from 1961 onwards. After this, there is an exponential decrease in record length as the number of records increases, with a marked break point around 15 years ago, reflecting a progressive increase in the rate at which new rain gauges have been put in catchments, and coincident with the onset of automatic digital logging. The summer 2007 events were exceptional because they do not fit with the standard assumption that there is an inverse relationship between the spatial scale of a storm event and the associated
maximum rainfall depth (CEH, 2000). As the driver is as much the spatial coherence, as it is the rainfall depths recorded, and given the short duration of digitised point records, assessing how ‘normal’, or otherwise, the summer 2007 events were remains exceptionally difficult using rainfall records.

There are two broad approaches that can address the point rainfall data problem. The first is to look carefully at the very longest records that we have available, such as the record in Oxford that extends back to 1753 and the record in Durham that extends back to the 1850s (Burt and Horton, 2007). These records are important as they allow us to look for longer timescales of rainfall variability than can be detected in the majority of our records, which are available digitally from 1961 onwards. An example of how instructive this can be is shown in Figure 5, for two locations: Oxford and Southampton. These long term records rarely have data that have a resolution that is better than daily or monthly. However, they are suitable for identifying ‘wet’ and ‘dry’ periods in long-term records. Here, we focus on the three month running rainfall totals, which reflects the kind of duration used in typical reporting of seasonal statistics (three months). Whenever the three month running total (TMRT) is in the greatest 2% of TMRTs recorded in the record, we record a wet period. We then cumulate the number of months between recorded wet periods, setting the total back to zero whenever the TMRT is in the top 2%. For both Oxford and Southampton, the results suggest a clear patterning of the rainfall record into wet periods and dry periods. For Oxford, there is a period with few TMRTs between c. 1915 and 1960, including two very long periods of 150 months (equivalent to c. 12.5 and c. 25 years) when the 2% TMRT was not reached. Also shown are the dates before 1950 when there are written reports of floods on the Cherwell obtained from the British Hydrological Society’s archive of extreme events (Black and Law, 2004). Such records need to be interpreted with caution: copyright restrictions mean that there are fewer events recorded from the 1930s onwards; and documentary evidence will inevitably be incomplete. However, the wetter period in the TMRT record (c. 1875 to 1915) seems to coincide with a period of many more documented flood events. This seems to be a ‘flood rich’ period, associated with repeated TMRTs greater than the 2% TMRT threshold. For Southampton, the last half of the 19th Century appears to be biased towards TMRTs greater than the 2% threshold, with the 20th Century having many fewer and with notably fewer 2% TMRTs between the late 1940s and the late 1980s. The key finding of this analysis is that there appear to be notably ‘flood poor’ and ‘flood rich’ periods, commonly extending for multiple decades, in the rainfall data.

Similar kinds of conclusions can be drawn from other sources. Returning to the seasonal rainfall data shown in Figure 1 for the U.K. rainfall series, since 1914 there have been 15 summer rainfalls greater than 300 mm. Before 2007, the most recent was 2004 (314.9 mm), there are then none until 1985 and 1980 and again a gap until the period 1948 to 1956, when there were seven > 300 mm summers. Another wet period seems to be found in the 1920s. Discrepancies between the timings shown in Figure 4 and those found in the seasonal rainfall data are not surprising as the Figure 4 analyses are based upon point records but the seasonal data are based upon the U.K.-wide rainfall series. However, one conclusion stands out in both records. The period since 1960, to which many of our rainfall records are biased, is relatively flood poor as compared with the last 150 years as a whole. These long records cause us to revisit the perception that the late 1990s and early 2000s are exceptionally ‘flood rich’: there appears to be some evidence that there have been ‘flood rich’ periods before. It also leaves us with the very difficult issue that the major expansion in our housing stock (between 1945 and 1976) appears to have occurred during a period that is relatively ‘flood poor’ during which a collective sense and memory of low flood risk may have caused us to occupy parts of the landscape that actually have considerable flood risk when viewed over a longer time period.

The second approach to the point rainfall data problem follows from what can be learned from taking a longer and more historical perspective to rainfall records. If there have been ‘flood rich’ periods in the past, can we identify their causes in terms of atmospheric processes and, if so, assess the extent to which the unusual events of the summer of 2007 have historical precedent? Understanding and measurement of, broad scale weather systems and their influence on rainfall intensity, duration and location, is even less mature as a science. There are long-term series that aim to describe the characteristics weather patterns observed over the U.K., such as Lamb’s ‘weather types’ (Lamb, 1972), and attempts have been made to link these to flood records (e.g. Longfield and Macklin, 1999). The summer 2007 events were characterised by an unusual atmospheric configuration and it is only recently that we have started to explore the hemispheric signatures of data fields like pressure (e.g. Seierstad et al., 2007) that might be diagnostic of such unusual situations. There is good reason for
starting to think through flood events in such a way, especially those linked to extra-tropical cyclonic activity. First, by emphasising the estimation of the return periods of rainfall depths *per se*, rather than the return periods of rainfall depths associated with specific atmospheric conditions, we are failing to capture the fact that the same rainfall depth, occurring twice in the rainfall series from a particular location, may have very different atmospheric origins with very different return periods. Second, at least some of the problems of the summer 2007 events arose from the sequencing or ‘clustering’ of cyclone activity rather than individual events appearing in isolation. For instance, there were at least two major events in the north of England in June 2007. The first appears to have had a localised rainfall depth in some areas that was greater than the second (e.g. in Sheffield), even though it was the second that resulted in the major flooding. Recent work on Atlantic depression storm clusters (Mailier et al., 2006) shows that there can be a prevalence towards clustering of storms in time and we may be just about reaching a position where we can factor the probability of the clustering of meteorological events into understanding the frequency and intensity of resulting rainfall events. Second, we should not forget the critical influence of catchment characteristics in moderating the importance of processes like sequencing. For instance, in relation to the Sheffield event, the effects of water supply reservoirs being filled during the first event may have led to no storage during the second. Finally, the events of July 2007, as well as the evidence provided above, raise difficult questions regarding how we factor spatial scale into the analysis of extreme magnitude rainfall events. The quite severe changes in rainfall anomaly that result from the progressive reduction in the spatial scale considered (from national, through regional, to local and eventually point scales) emphasises that extreme rainfall events can gain their severity from both the associated rainfall depth and the extent of those depths. Our dominant approach to the analysis of this problem has two dimensions: return period and magnitude. It probably needs three: return period, magnitude and spatial scale.

**Conclusion: where next?**

Both the analysis of longer rainfall records and the newly emerging ways of interpreting extra-tropical cyclone activity point to the need to think about longer term oscillations in dominant weather patterns and how these oscillations might respond to greenhouse gas-induced climate change. The bias in our rainfall records to the last 50 years is undermining our ability to identify meaningful scales of variability, and this is where new analyses, based upon the analysis of the drivers of mid-latitude precipitation, offer much scope. As with the climate change hypothesis, the possibility that the summer 2007 events are a normal but unusual happening cannot yet be dismissed.
References


Figures

Figure 1. Distributions of seasonal rainfall taken from the U.K. rainfall series for 1914 to 2007. Data provided by the U.K.’s Meteorological Office:

http://www.metoffice.gov.uk/climate/uk/seriesstatistics/ukrain.txt
Figure 2. Schematic diagram of the jet stream (2a), an example extra-tropical cyclone (2b) and a section through 2b (2c)

in separate file
Figure 3. The Meteorological Office Rainfall Anomalies for May to July 2007 (source: U.K. Meteorological Office)
Figure 4. Cumulative frequency distribution of the lengths of rainfall records available for stations in the Dales area of the U.K. Environment Agency’s North-East region.
Figure 5. Cumulative number of months when the three month running total (TMRT) was less than the 2% largest TMRTs found in the record for: (a) Oxford; and (b) Southampton. Also shown for Oxford (crosses) are the dates of recorded floods on the River Cherwell, before 1950, using data from the British Hydrological Society’s archive of extreme events.

(a)

(b)
Table 1. Summary of UKCIP02 precipitation changes (%) with respect to the 1961-1990 average for different emissions scenarios for the Ouse sub-catchments (from Hulme et al., 2002). NV ‘indicates within natural variability’.

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