12. THE USE OF A VERY LARGE ATMOSPHERIC MODEL ENSEMBLE TO ASSESS POTENTIAL ANTHROPOGENIC INFLUENCE ON THE UK SUMMER 2012 HIGH RAINFALL TOTALS

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Introduction. In 2012, the United Kingdom experienced a drier than average first three months followed by an exceptionally wet period lasting well in to the summer months. Overall, 2012 was the wettest on record since 1910 (CEH 2012), except for 2000 (Met Office 2013). The high rainfall amounts experienced were brought in to focus given the international attention placed on the United Kingdom in the months leading up to the Olympics. The contrasting rainfall features are particularly noteworthy given that towards the end of March 2012, many water utility companies were warning of potential drought conditions ahead, including predictions such as summer hosepipe bans. At the end of March, reservoir levels were becoming exceptionally low in water levels (CEH 2012). However, by the end of year 2012, flooding was causing repeated problems, affecting homes and the ability to travel (JBA Risk Management and Met Office 2012). The aim of this study is to assess whether there was an attributable anthropogenic contribution to the high rainfall totals experienced over the United Kingdom in summer 2012.

Experimental configuration. Existing studies with single simulations by a "nested" version of the Hadley Centre Regional Climate Model (RCM) suggest that for many parts of the United Kingdom and as atmospheric greenhouse gas concentrations rise, extreme rainfall return periods might reduce in the future (Huntingford et al. 2003). Here we use very large ensembles of the atmospheric component of version 3 of the Hadley Centre GCM; (Pope et al. 2000), HadAM3P, combined with the same model in a nested regional configuration over Europe. These simulations have been undertaken by "citizen scientists," through performing calculations by their screensavers and on otherwise idle computers, and in each instance with slightly altered initial conditions (Allen 1999). This system, called ClimatePrediction.Net (CPDN), has already been utilized to analyze the floods of 2000 (Pall et al. 2011).

The advantage of large ensembles is that they can generate well-sampled distributions of predicted quantities of interest (in this case, precipitation) and account for chaotic aspects of the weather system, where predictions can diverge significantly even if initialized with almost identical starting conditions. Such distributions can be derived for present day and simultaneously for an estimate of preindustrial conditions by running the same model setup with two different climate scenarios and associated forcing conditions.

Hence, we make two ensembles, one representing 2012 and the other representing an imagined analogous year in the preindustrial period. This involves the prescription of differences in three sets of driving conditions between these scenarios: (i) changes of atmospheric gas constituents (most notably raised levels of carbon dioxide), (ii) different SSTs, and (iii) different sea ice fractions. SST and sea ice fraction values for 2012 are taken from the Operational Sea Surface Temperature and Sea Ice Analysis (OSTIA) dataset (Stark et al. 2007; Donlon et al. 2012). To estimate preindustrial conditions for SSTs, we calculate SST differences between nonindustrial and present day simulations of the HadGEM2-ES model and subtract them from the OSTIA SST data for 2012. For nonindustrial sea ice, we adopt conditions that correspond to the year of maximum sea ice extent in each hemisphere of the OSTIA record. The ensemble modeling structure then provides two probability distributions of seasonal rainfall for each UK grid box: for 2012 (called "All Forcings" and with prescribed CO_2 concentration of 385 ppm) and for an estimate of nonindustrial conditions (called "Natural," CO_2 concentration of 296 ppm), available from the nested RCM.

Modeling summer 2012 UK precipitation. We present our findings in Fig. 12.1, where we concentrate on the summer period of June, July, and August (JJA). In panel (a), we show the actual seasonal mean

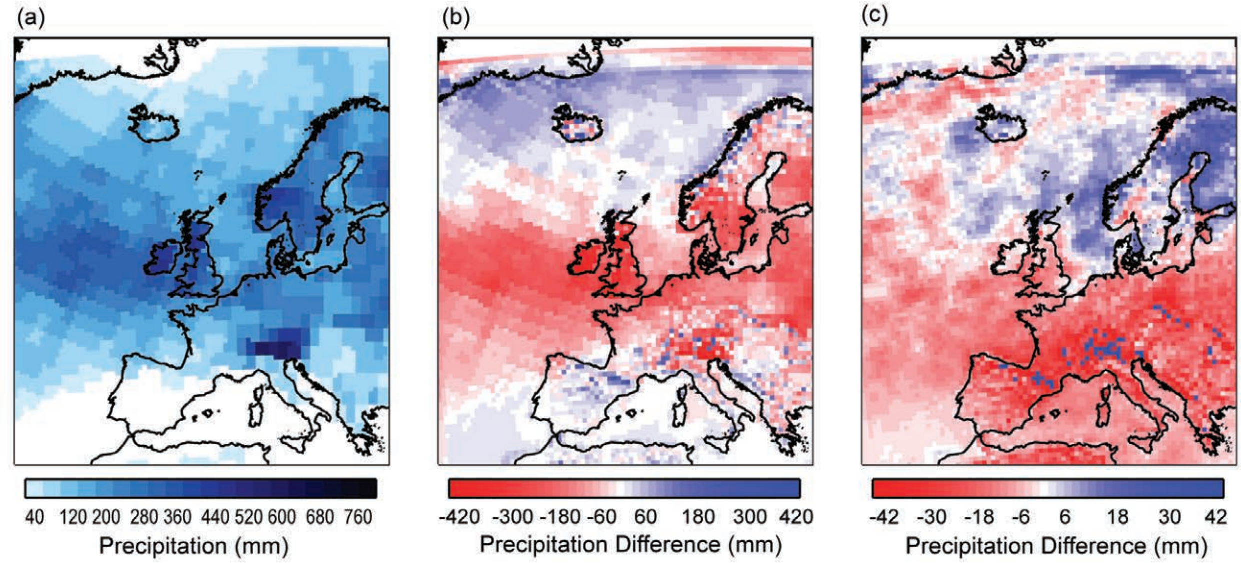

Fig. 12.1. (a) ECMWF ERA-Interim estimates of Jun–Aug 2012 total rainfall (mm) mapped onto part of the nested European RCM grid of the CPDN simulations with HadAM3P. (b) The difference in total seasonal rainfall between the 50th percentile of the All Forcings simulation (representative of 2012) and the ERA-Interim data. (c) The difference at the 50th percentile between the All Forcing and Natural (latter representative of preindustrial conditions).

rainfall amounts based on the European Center for Medium Range Weather Forecasting (ECMWF) Interim reanalysis product (Dee et al. 2011). In panel (b), we show the difference between the ECMWF values of panel (a) and the 50th percentile from the All Forcings ensemble. The differences in this plot are large, especially for the United Kingdom. In fact, the rainfall amounts from the ECMWF reanalysis dataset are greater than the 99th percentile for the All Forcings ensemble distribution for most locations in the United Kingdom. This implies one of two possibilities: either (1) our findings are correct for the prescribed atmospheric CO_2 concentrations, SST, and sea ice fractions appropriate to 2012, then the chances of the observed summer UK rainfall patterns occurring are in fact incredibly small, or (2) there are systematic biases in our atmospheric modeling structure. These biases possibly correspond to raised rainfall amounts falling incorrectly over the seas more to the north of the United Kingdom, rather than over the United Kingdom as seen in the observations. Problems in capturing heavy precipitation with this model have also been noted in "Are Recent Wet North Western European Summers a Response to Sea-Ice Retreat?" in this report. Figure 12.1c shows the precipitation difference between the 50th percentile All Forcings simulation minus that of Natural. There is a distinct geographical feature where, in general, northerly regions experience higher JJA rainfall amounts, whereas for southern Europe the opposite is true. The United Kingdom lies close to the nodal line of this pattern.

In Fig. 12.2a, we present the SST changes prescribed to our modeling system, which are based on HadGEM2-ES GCM. When compared to the differences in the observationally based HadISST dataset (Rayner et al. 2003) of seasonal decadal averages between the 1880s and the 2000s [shown in panel (b) and as 2000s minus 1880s], our model-based changes, although of a similar magnitude on a global scale, show different patterns locally. The largest discrepancies in the SST differences occur in the North Atlantic and North Pacific, the former of which could impact modeled storm tracks and European weather patterns (Brayshaw et al. 2011; Woollings et al. 2012).

How was summer 2012 UK precipitation influenced by climate change? If we regard the rainfall experienced as an extreme event for the given year, 2012, CO_2 concentrations and SST and sea ice conditions (i.e., possibility "i" above), produced by the natural variability of the climate system, then we may still wish to understand how anthropogenic forcings may have altered its probability of occurrence. Our calculations of the FAR statistic (Fractional Attributable Risk; methodology e.g., Otto et al. 2012), not shown but based on comparing the two ensembles' distributions at the known precipitation levels, sug-

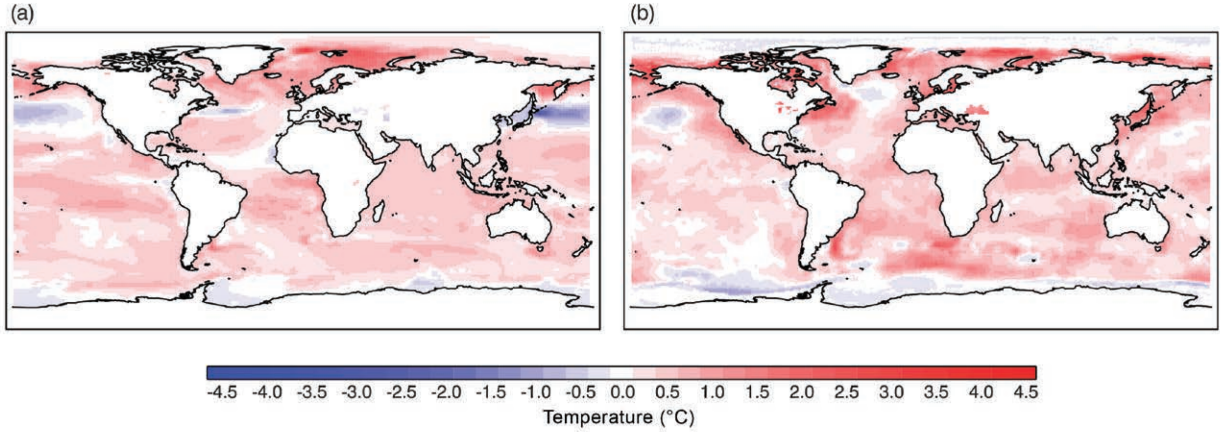

Fig. 12.2. (a) The temperature differences between the HadGEM2ES-based SSTs prescribed to the CPDN simulations, here as All Forcings minus Natural. Panel (b) shows the change in SSTs based directly on the HadISST dataset and presented as the 2000s minus the 1880s.

gests there was almost no anthropogenic influence on the rainfall patterns over the United Kingdom for summer 2012. However, in this instance, we suggest caution in providing this as a headline result. This is because, as noted above, the event occurs beyond the 99th percentile of the All Forcings model ensemble distribution. Instead, we suspect that there remain deficiencies in our atmospheric model that require resolution before making any such definitive statements regarding human influence on changed probabilities of rainfall events. The major differences in modeled and measured forcing SSTs also require consideration. Our initial argument was that until recently (and certainly before satellite retrievals), the number of measurements contributing to SST climatologies is relatively small (Rayner et al. 2003) and model derived differences may be more trustworthy. However, we now plan to make a new set of simulations using both the longer HadISST dataset directly and SST warming patterns based on other GCMs that have contributed to the CMIP5 database. A recently submitted paper (Haynes et al. 2013, manuscript submitted to *PLOS ONE*) using a similar methodology, but an observed pattern of SST warming, shows detectable changes to UK precipitation between the 1960s and 2000s. This study reinforces our conjecture that UK precipitation is sensitive to the pattern of warming in SSTs and not just the magnitude of the changes.

We believe very large ensembles and the associated capability to generate FAR-type statistics is a powerful method to quantify any anthropogenic influence in the event of more extreme weather occurrences. This avoids any polarized views, where statements over extremes can sometimes reduce to either being completely the fault of human-induced climate change or the opposite. However, this study also reiterates that there are likely still issues of model development and refinement of forcing conditions that need to be undertaken simultaneously. This study shows that taking a purely thermodynamic argument, as in Pall et al. 2011 (their supplementary information), can give potentially misleading results; therefore, it is important to continue building physically based ensembles and within these ensembles, explore the implications of uncertainty in boundary conditions and model physics.

Conclusions. Although the summer UK rainfall in 2012 was unusually large, the model distributions studied suggest that any anthropogenic influence on these patterns was minimal. However, a note of caution must be expressed with regard to this result. Firstly, the summer UK rainfall totals fall beyond the 99th-percentile range of our All Forcings distribution. So, whilst the rainfall experienced may simply have been extreme for the given driving conditions, there may also remain deficiencies in the atmospheric model that need to be resolved. Secondly, large differences exist between the pattern and the amount of observed and model derived SST differences under climate change. We feel it is necessary to establish the impact of such differences before making a formal statement on the size of any human influence to 2012 UK precipitation, based on any probability distributions from GCM ensembles. Further experiments are planned to address these issues.