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The effect of climate policy on the impacts of climate change on river flows in the UK

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SUMMARY

This paper compares the effects of two indicative climate mitigation policies on river flows in six catchments in the UK with two scenarios representing un-mitigated emissions. It considers the consequences of uncertainty in both the pattern of catchment climate change as represented by different climate models and hydrological model parameterisation on the effects of mitigation policy. Mitigation policy has little effect on estimated flow magnitudes in 2030. By 2050 a mitigation policy which achieves a 2 °C temperature rise target reduces impacts on low flows by 20–25% compared to a business-as-usual emissions scenario which increases temperatures by 4 °C by the end of the 21st century, but this is small compared to the range in impacts between different climate model scenarios. However, the analysis also demonstrates that an early peak in emissions would reduce impacts by 40–60% by 2080 (compared with the 4 °C pathway), easing the adaptation challenge over the long term, and can delay by several decades the impacts that would be experienced from around 2050 in the absence of policy. The estimated proportion of impacts avoided varies between climate model patterns and, to a lesser extent, hydrological model parameterisations, due to variations in the projected shape of the relationship between climate forcing and hydrological response.

1. Introduction

There have been many studies into the potential impacts of climate change on river flows and water resources in many catchments and countries (see Bates et al. (2008) for examples). Few, however, have explicitly assessed the potential effect of policies to curb the emission of greenhouse gases on these impacts. Several studies have used different IPCC SRES (IPCC, 2000) emissions pathways as surrogates for emissions policies (e.g. Hayhoe et al., 2004), but the only analyses so far which have considered explicit emissions targets or policies have been at the global scale (Fischer et al., 2007; Arnell et al., 2011, 2013). The aim of this paper is to assess the effects of climate mitigation policy on impacts on hydrological regimes at the catchment scale, and discuss implications for adaptation to climate change.

Water resources managers are increasingly seeking information on the potential changes in hydrological regimes which may occur over the next few decades in order to plan adaptation measures. Uncertainty in projected changes to catchment-scale precipitation and temperature due to climate model uncertainty is well recognised, and addressed through the use of scenarios derived from several climate models or, indeed, many thousand scenarios in a probabilistic context (New et al., 2007). Uncertainty due to future emissions is often addressed through the use of 'low', 'medium' and 'high' emissions scenarios representing different assumptions about future economic and demographic change, but 'low' emissions scenarios still assume no explicit climate mitigation policy. A key question therefore is the extent to which climate mitigation policy either reduces impacts or buys time to allow adaptation.

The study compares two indicative climate mitigation policies with two 'business-as-usual' emissions pathways, and focuses on six catchments in the UK representing a diversity of catchment and climatic conditions. One of the indicative mitigation policies assumes that global emissions of greenhouse gases peak in 2016 and decline at 5% per year after, and the other assumes emisssions peak in 2030 and decline at 2% per year (Gohar and Lowe, 2009). The pathway with the 2016 peak produces a 50% probability that the increase in global mean surface temperature by 2100 would be below 2 °C (above pre-industrial; Gohar and Lowe, 2009), and is thus consistent with the aspirations of the Copenhagen Accord which underpins current global climate policy; the 2030 peak pathway produces a median temperature increase of 2.8 °C. The two 'business-as-usual' emissions pathways (SRES A1b and A1FI) result in median estimates of increases in global mean temperature by 2100 of 4 and 5.6 °C respectively; the difference between the

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two represents uncertainty in the effects of future economic development on emissions. Projected changes in hydrological regimes are known to be sensitive to the spatial and seasonal pattern of change in climate as represented by different climate models and, to a lesser extent, hydrological model uncertainty. It is also possible that the effects of climate mitigation policy on these impacts may vary with climate model pattern and representation of hydrological processes. This is assessed here by constructing climate scenarios from 21 global climate models, and by considering the effect of hydrological model parameter uncertainty on the impacts avoided by climate policy.

The potential impacts of climate change in the same catchments but with different climate scenarios have previously been presented in a series of papers (Arnell, 2003, 2004, 2011; Arnell and Reynard, 1996). A number of other studies have estimated impacts in other UK catchments using a range of hydrological models, climate scenarios and methods of constructing scenarios at the catchment scale (e.g. Chun et al. (2009), Cloke et al. (2010), Fowler et al. (2007), New et al. (2007), Wilby (2005), Wilby and Harris (2006), Prudhomme and Davies (2009) and Christierson et al. (2012)): together, these show that projected impacts vary with climate scenario and between catchments.

2. Methods

2.1. Emissions scenarios and climate mitigation policies

Fig. 1 shows annual emissions (in carbon-equivalent terms, with the equivalence calculated using 100-year global warming potentials) under the four emissions pathways considered here, together with change in global mean surface temperature relative to pre-industrial levels. The global temperature under each emissions pathway was calculated using a version (Lowe et al., 2009) of the MAGICC simple climate model (Meinshausen et al., 2011), and the trajectory shown in Fig. 1 represents the median across an ensemble of MAGICC simulations with different sets of feasible parameters (Lowe et al., 2009).

Two of the pathways (A1b and A1FI) represent unmitigated emissions, and differ only in their assumed use of energy. They provide two alternative 'business-as-usual' baselines against which emissions policies are compared. A1FI produces the highest change in global average temperature of all the SRES emissions scenarios, but some of the other SRES emissions scenarios produce smaller increases in temperature than A1b. The two policy scenarios considered differ in the year at which global emissions peak and the subsequent rate of decline. The most aggressive of the two pathways assumes emissions peak in 2016 and subsequently decline at 5% per year to a low 'emissions floor' of around 3 GtCe/year. This pathway has a 50% chance of limiting the temperature increase by the end of the century to around 2 °C above pre-industrial temperatures. This is broadly consistent with the aspirations of the Copenhagen Accord and the emissions pathway recommended by the UK's Committee on Climate Change, which informs the UK's emissions reduction strategy (CCC, 2008). The other illustrative emissions policy has global emissions peaking in 2030 and reducing at 2% per year thereafter, giving a 50% chance of limiting the global temperature increase to 2.8 °C.

2.2. Climate change scenarios

Climate scenarios describing change in mean monthly precipitation, temperature, vapour pressure and net radiation (from which potential evaporation was calculated) under each emissions scenario were constructed by pattern-scaling the output from 21 global climate models to match the change in global mean temperatures shown in Fig. 1, and applying the scenarios to observed 30-year catchment weather records. Pattern-scaling involves scaling the spatial and seasonal patterns of changes in climate variables to define change per degree of global average temperature change, and then rescaling these patterns to specific changes in global average temperature (Mitchell et al., 1999; Mitchell, 2003; Cabre et al., 2010). It is used in this study to construct scenarios for changes in mean monthly climate because global climate models have not been run forced with the policy emissions pathways considered here (note that this paper reports results from part of a larger programme (Warren et al., 2013) which considered a wider range of emissions policies). A major advantage of the approach – unlike one which uses scenarios constructed from global climate models forced with different emissions assumptions – is that the changes in climate over time and between emissions pathways differ only in the underlying signal of climate change (i.e. global mean temperature), and not because of year-to-year unforced climatic variability. However, pattern-scaling assumes that change in local weather variables is linear (after transformation) with global mean temperature, and whilst this has been demonstrated to be a good approximation with continually increasing climate forcing (Mitchell, 2003), it may not hold so well where forcing stabilises or increases then declines. Both these types of pathway can alter the relationship between precipitation and global near-surface warming (Wu et al., 2010). It could be expected, for example, that land would respond more rapidly to the slowdown in forcing than the ocean. Also, it is possible that a low emissions pathway might mean that non-linear or step-change climate responses possible with high forcings would be avoided. The pattern-scaled climate scenarios used here should therefore be interpreted as being indicative only.

Different climate models produce different spatial and seasonal patterns of change, particularly for precipitation, and may produce not only different hydrological responses but also give different indications of the effects of climate mitigation policy. Climate

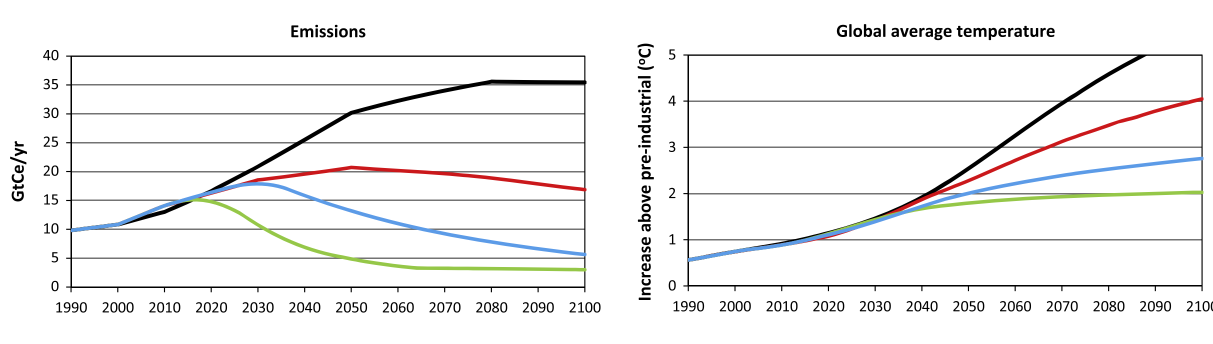

Fig. 1. Emissions pathways and changes in global mean temperature.