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Changes in drought frequency, severity and duration for the British Isles projected by the PRUDENCE regional climate models

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Summary Using multiple climate models for impact assessment allows the examination of uncertainty in projections of change, thus providing improved tools for the adaptation and mitigation of the impacts of future change. Here, the performance of integrations from six regional climate models (RCMs) driven by four different general circulation models (GCMs) have been assessed for British Isles mean precipitation and drought statistics for the 1961–1990 period, using two drought severity indices based on monthly precipitation anomalies. Spatially averaged statistics are examined in addition to spatial variations in model performance over water resource regions and compared with observations. Estimates of the range and sources of uncertainty in future changes are examined for the SRES A2 2071–2100 emissions scenario.

Results indicate that the RCMs are able to reproduce the spatially averaged annual precipitation cycle over the British Isles but the spatial anomalies suggest that they may have difficulty in capturing important physical processes responsible for precipitation. The RCMs are unable to simulate the observed frequency of drought events in their control climate, particularly for severe events, possibly due to a failure to simulate persistent low precipitation. Future projections suggest an increase in mean precipitation in winter and decrease in summer months. Short-term summer drought is projected to increase in most water resource regions except Scotland and Northern Ireland, although the uncertainty associated with such changes is large. Projected changes in longer droughts are influenced by the driving GCM and are highly uncertain, particularly for the south of England, although the longest droughts are projected to become shorter and less severe by most models. This suggests that many water supply companies may need to plan for more

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intense short-term droughts but may experience fewer longer duration events under future climate change.

Introduction

Climate models incorporate the effects of small-scale physics through the parameterization of unresolved processes. Consequently, a range of uncertainty exists in the value of such parameters. Models also contain uncertainties in the structures used to represent large-scale climate processes. Consequently, any one model simulation of future climate may represent only one of many possible future climate states. Improved parameterization of climate models is one way in which such uncertainty ranges may be narrowed. Alternatively, a large number of model simulations may be used to assess the uncertainty and estimate the most likely future climate. In practical terms this may be undertaken by running simulations in which parameters are varied within their range of uncertainty (e.g. Murphy et al., 2004), or using different models which may be compared in their ability to model historical climate and so their possible skill in predicting future climate. Methods using multi-model ensembles to provide probabilistic projections of future climate change have recently been developed (Allen et al., 2000; Palmer et al., 2005). However, this effort has been concentrated on assessing uncertainties in future temperature change and defining ''dangerous'' change (e.g. Mastrandrea and Schneider, 2004) at the global scale and there has been little analysis of other variables. Probabilistic methods have not been widely used in climate change impact studies, although they have been used for short- and long-term climate, weather and hydrological forecasting (e.g. Räisänen and Palmer, 2001; Grantz et al., 2005). However, in recent advances, some studies have begun to apply probabilistic methods to hydrological impacts projections (e.g. Wilby and Harris, 2006; Fowler et al., in press).

AquaTerra is a EU FP6 project which aims to address some of the deficiencies in impacts research by developing a framework for the construction of probabilistic climate change scenarios to assess climate change impacts at the regional (~100,000–250,000 km^2), river basin (~10,000 to ~100,000 km^2) and catchment (~1000 to 5000 km^2) scale. The project aims to produce probability density functions (pdfs) of future change by weighting the projections from each of a multi-model ensemble in a way that reflects their ability to reproduce observed climate statistics for the control integration (1961–1990), not only for the mean, but also for higher order statistics such as variability and extremes. These weightings will be derived from the ability of models to produce a range of climate statistics that are relevant to the desired impact application.

A potentially significant impact of climate change over many regions will be changes in the frequency and characteristics of droughts. Although historical drought events in the UK have been much studied (e.g. Bryant et al., 1992, 1994; Mawdsley et al., 1994; Jones et al., 1997; Goldsmith et al., 1997; Phillips and McGregor, 1998; Fowler and Kilsby, 2002, 2004), studies have tended to be based on either single drought events or single regions within the UK. Hisdal et al. (2001) indicated that for the UK there has been a mixed pattern of change in low river flows since the 1960s. A decrease in non-winter precipitation has resulted in an increase in drought severity in areas with limited groundwater storage capacity such as Wales, Scotland and southwest England. Hannaford and Marsh (2006) detected some spatial consistency in recent low-flow trends, with catchments in Wales and western England showing a decreasing frequency but increasing magnitude of low-flows. However, Jones and Lister (1998) indicated that low flows in the 1990s were not historically unusual as more severe events could be identified in the early 20th century.

During the late 1980s and early 1990s, summer droughts were a recurrent outcome of increased hydrologic seasonality (Marsh and Monkhouse, 1993). This culminated in the severe drought of 1995 which affected mainly the north and west of the country (Marsh, 1996). GCMs predict a prominent change in rainfall over the high latitudes of the Northern Hemisphere (Giorgi et al., 2001a,b), with wetter winters and drier summers over the UK (Hulme and Jenkins, 1998; Hulme et al., 2002). This, along with recent patterns of rainfall, evaporative losses and water demands, suggests that the type of water supply stress experienced in 1995–96 may now occur with greater frequency. An extension of these climatic variations and trends will have serious implications for the future management of water resource systems.

In this paper, a multi-model approach is adopted using six Regional Climate Model (RCM) simulations provided by the PRUDENCE project and previously examined on a European scale (Christensen et al., 2007). Here a regional impacts assessment is undertaken for the British Isles by firstly assessing the mean precipitation statistics from the control integration (1961–1990) of each model by comparison with an observed dataset for the same time period. Secondly, estimates of the range of uncertainty in future changes in the mean climate are examined for the SRES A2 emissions scenario for the period 2071–2100 and the role of RCM and GCM selection in that uncertainty discussed. Thirdly, two drought severity measures constructed from monthly precipitation anomalies are used to assess RCM ability to reproduce observed drought frequencies. Future changes in drought frequency, severity and duration are obtained and examined on a model grid cell and regional basis using regions defined by the UK water supply institutions that are responsible for managing water resources. Inter-model comparisons provide the means of assessing model uncertainties in projections of future drought that are essential in the provision of the best tools for policy-makers seeking to make long-term planning decisions.