An Initial Estimate of the Uncertainty in UK Predicted Climate Change Resulting from RCM Formulation

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This report has been superseded by the following paper:

Rowell, D.P., 2005: Uncertainty in projections of UK climate change resulting from regional model formulation. Int. J. Climatol., submitted

This contains some additional analysis, minor changes to the conclusions, and improvements to the context in which the work is placed. Please feel free to request a copy.

An Initial Estimate of the Uncertainty in UK Predicted Climate Change Resulting from RCM Formulation

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Introduction

Uncertainties in projected climate change arise from a number of sources: the formulation and accuracy of the general circulation model (GCM); the amplitude of anthropogenic emissions; and the temporal and spatial impact of natural variations in the climate system. Furthermore, in order to provide detailed projections of local climate change to the impacts community and policy makers, a further tier of complexity is required. This is the nesting of high resolution regional climate models (RCMs) within the GCMs. Thus a further source of uncertainty is introduced, which is the robustness with which such models are able to downscale global projections to national and finer scales.

This study aims to provide an initial estimate of the relative importance of uncertainty arising from RCM formulation, and compare it with the other three sources of uncertainty noted above. Our focus is on the UK.

Experimental Approach

To address this issue, data from the EU PRUDENCE project is utilised (PRUDENCE stands for "Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects"). This venture aims to provide scenarios of future climate change over Europe, estimate their uncertainty, provide examples of their use in climate impacts models, and help assess their implications for policy makers.

An aspect of the project that is relevant here is its experimental approach towards evaluating sources of uncertainty. By pooling a coordinated set of model integrations, carried out by those partners with a climate modelling capability (including the Met Office Hadley Centre), a four-dimensional matrix of experimental data has become available. This enables us to evaluate uncertainty due to either RCM formulation alone, GCM formulation alone, scenario uncertainty, or uncertainty due to internal variations of the climate system. The matrix of data used in this study is illustrated in Table 1. Each control integration simulates the period 1960-1990, and each scenario integration simulates the period 2070-2100. Thus, we are able to estimate (a) the uncertainty due RCM formulation by comparing the climate change responses in 9 different RCMs, all forced by a common pair of GCM scenarios (the HadAM3H control and SRES A2 integrations); (b) the uncertainty due GCM formulation by comparing climate change responses in the DMI and SMHI RCMs which have each been forced by 2 differing GCM scenarios; (c) the uncertainty due to projected emissions rates by comparing the response to the A2 and B2 SRES scenarios in 5 different RCMs; and (d) the uncertainty due to internal chaotic climate variations by comparing responses between 3 HadRM3P RCM simulations that were nested within an ensemble of integrations of the Hadley Centre GCM.

Driving GCM RCM	HadAM3H	HadAM3P	ECHAM/ OPYC	ECHAM/ OPYC DMI-Version
DMI	A2			B2 A2
ETH	A2			
GKSS	A2			
ICTP	A2			
KNMI	A2			
MO/HC	A2	B2 A2-1/2/3		
MPI	A2			
SMHI	B2 A2		B2 A2	
UCM	B2 A2			

Table 1. Four-dimensional matrix of the experiments used in this study: (1) each row shows the use of different RCMs; (2) each column shows the use of different driving GCMs; (3) entries formatted along the diagonal of each cell label different scenarios (the existence of corresponding control integrations is implied); and (4) the notation '-1/2/3' indicates the RCM has been driven by different ensemble members of the GCM.

Estimated Uncertainties

Figure 1 illustrates projections of late twenty-first century anomalies in UK seasonal mean surface air temperature (SAT) and precipitation, grouped to demonstrate their sensitivity to each source of uncertainty. Also shown is the standard deviation (SD) of the data within each group. Note however that these SDs enable only an approximate comparison of uncertainties because sample sizes are rather small (due to obvious limitations in computing power), and because the 2 scenarios and 2 GCMs selected under-represent the full range of possibilities.

For SAT, uncertainty in projected climate change over the UK due to RCM formulation alone is relatively small in all four seasons. It is slightly larger than the uncertainty due to large-scale internal variations of the climate system, but somewhat smaller than that arising from the emissions scenarios, and considerably smaller than that arising from the formulation of the driving GCMs. This is because a significant component of the SAT response over the UK is dependent on the temperature response of the lower troposphere at the location of the RCM lateral boundaries (particularly the western boundary) and on the temperature response of the surrounding ocean. Both these factors are identically specified by the driving GCM that is common to all RCMs in the first grouping of Figure 1, and hence there is little spread between the RCM data. Conversely, and for the same reason, sensitivity to

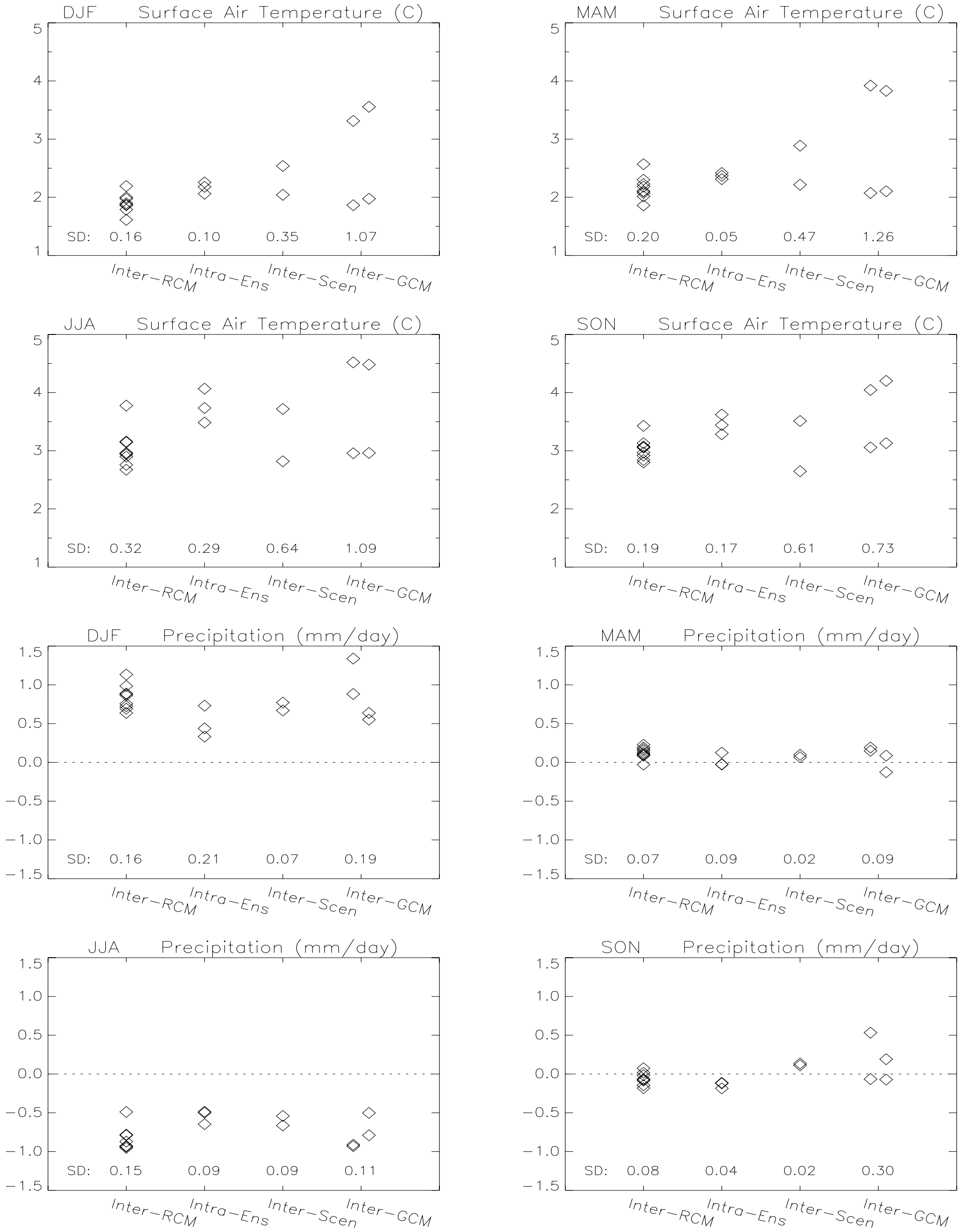

Figure 1. Projected climate change anomalies averaged over the UK, computed as the time-mean difference between 2071-2100 and 1961-1990. Results are shown for each season, and for surface air temperature (^{o}C) and precipitation (mm/day). Within each plot four groups of anomalies are shown: ‘Inter-RCM’ contains anomalies from 9 different RCMs all driven by the same GCM (HadAM3H) and the same control and SRES A2 scenarios; ‘Intra-Ens’ contains anomalies from 3 HadRM3P RCM integrations, driven by different members of a HadCM3/HadAM3P ensemble and the same control and SRES A2 scenarios; ‘Inter-Scen’ contains anomalies using the SRES A2 and B2 scenarios, averaged over 5 RCM/GCM combinations; and ‘Inter-GCM’ contains a pair of anomalies from the SMHI RCM driven by 2 different GCMs and the same control and SRES A2 scenario (located at the same point on the x-axis), and a similar pair of anomalies for the DMI RCM. Also included is the standard deviation (SD) of each group of anomalies, which in the case of ‘Inter-GCM’ is computed as the average of the 2 SDs of each pair.

different formulations of the driving GCM is considerably larger. The source of the (small) RCM uncertainty that is nevertheless apparent lies in the variety of plausible formulations of model parameterizations that govern local feedback mechanisms and the (local) radiative response to greenhouse gases. Note also that these make a greater contribution to uncertainty in summer when the ambient flow is weaker, thus reducing heat advection from the surrounding ocean and lateral boundaries.

For precipitation, the relative contributions of the four sources of uncertainty are more equal. This altered balance (compared to SAT) can be attributed to at least three factors. First, the dependence of rainfall on the driving GCM data at the ocean surface is lower. Second, local rainfall variability is more chaotic than SAT (in both time and space), resulting in greater divergence between RCM realisations. Last, its dependence on the RCM parameterization schemes may be higher due to the greater complexity (and hence increased uncertainty) involved in modelling cloud and convective physics. Despite the uncertainties, from all sources, the seasonal mean changes portrayed by the PRUDENCE experiments consistently predict enhanced winter rainfall and reduced summer rainfall over the UK. This is consistent with the single model realisation provided by UKCIP. During the equinoctial seasons, and in the annual mean (Figure 2), rainfall anomalies are predicted to be much smaller, with consequential uncertainty in their sign.

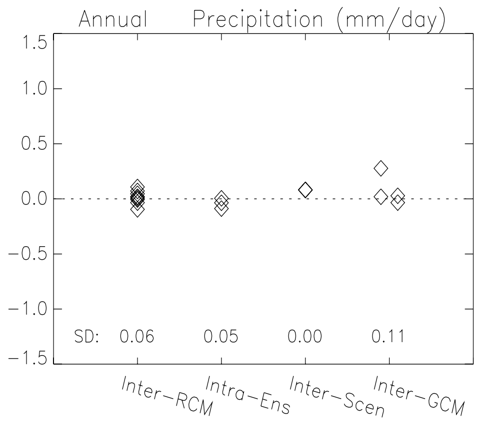

Figure 2. As Figure 1, but for annual mean precipitation.

Finally, Figure 3 shows that uncertainty in RCM formulation also impacts the gradient of precipitation across the UK. This effect is strongest in summer (the example shown here), because again the weaker ambient flow reduces the influence of GCM boundary data. For SAT, however, the impact of RCM uncertainty on sub-national anomaly patterns is negligible in all seasons (not shown).

Conclusions

The initial analysis presented here has shown that uncertainty in the formulation of regional climate models adds further uncertainty to projections of climate change at the national scale. This effect is small for seasonal mean surface air temperature, but more substantial for precipitation. Results have been presented for the UK, but similar conclusions may be drawn for other European regions (not shown). Note, however, that the additional uncertainty found here does not of course negate the benefits of dynamical downscaling, which is to increase the accuracy of climate projections at spatial and temporal scales that are inadequately resolved by GCMs.

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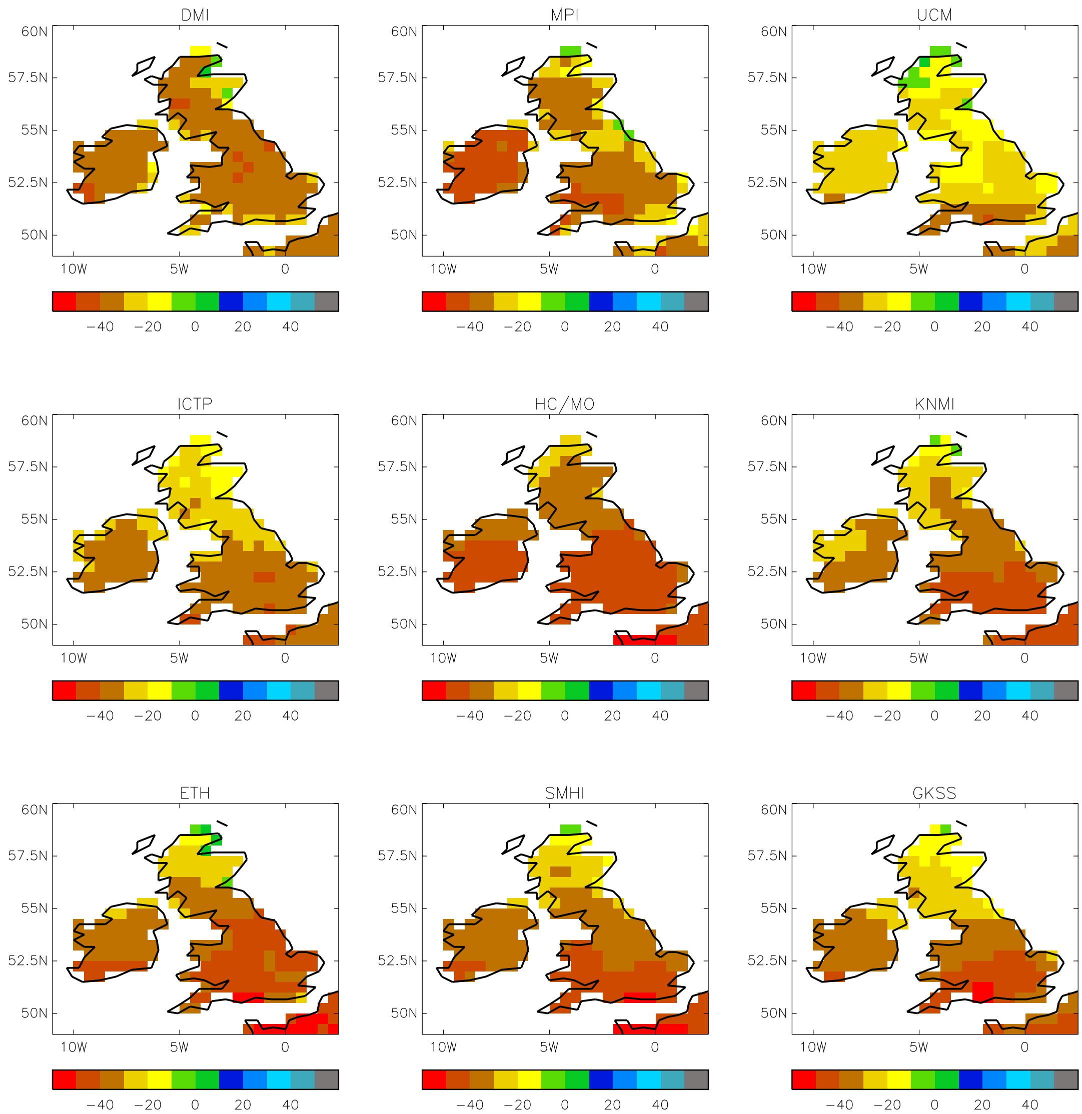

Figure 3. Projected climate change anomalies of JJA mean precipitation over the UK (2071-2100 minus 1961-1990), computed as their percentage of the 1961-1990 mean. All 9 RCMs are driven by the same GCM (HadAM3H), and by the same control and SRES A2 scenarios. The panels are ordered (from left-to-right, then top-to-bottom) according to the gradient of their anomalies between the southern and northern UK.