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CITIES UNDER A CHANGING CLIMATE

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Abstract

Cities occupy less than 1% of the global land surface. Therefore the urban land surface is poorly resolved by climate models, and they have been largely ignored in projections of future climate change. However the highly heterogeneous distribution of the world's population, with approximately 50% residing within cities, dictates a strong need to consider the interaction of climate change at both the global and city scale, if we are to understand and predict the potential climate stresses that populations may be exposed to.

Here we present results from climate model simulations that incorporate a surface exchange scheme that allows for sub-grid scale surface heterogeneity. This scheme allows us to include an explicit model of the urban surface. This model has been used to explore the interactions between radiatively forced climate change resulting from greenhouse gas emissions and local drivers of change that occur within urban areas.

Key words: Climate change, global warming, cities

1. INTRODUCTION

Urban populations are exposed to both urban induced local climate modification and larger scale greenhouse gas forced climate change. Non-linear associations between the urban heat island and climate create a requirement for the inclusion of cities within climate models in order to study potential climate change impacts on our urban populations. The challenge is that even the highest resolution regional climate model tends to be at a scale larger than required to explicitly capture urban heat islands, and such models cannot practically be run for extended periods of time. However urban parametrizations suitable for inclusion in numerical weather prediction and climate models are becoming more widely available (Best 2005, Masson 2006, Oleson et al. 2008).

2. MODEL CONFIGURATION

The Met Office use a "tiled" surface scheme within the operational forecast and climate models. This allows for sub-grid scale variations at the model surface (Essery et al. 2003). Each model grid box is composed of a varying mix of five vegetation types, and four non-vegetation surfaces that includes urban. The transport of heat and water between the atmosphere and surface is calculated for each surface type within the grid cell. Vertical fluxes are then averaged using blending height techniques to give grid-box average values. This is a more appropriate treatment of the surface exchanges than determining effective land surface properties to conduct a single surface exchange (Essery et al. 2003). In addition to the heat and moisture fluxes, the scheme allows for surface and air temperatures to be diagnosed individually for each surface type.

The urban tile within the MOSES2 provides representation of cities at sub-grid resolution. A description of the model formulation can be found in Best (2005) and Best et al. (2006). The urban tile is modelled in a simple way by introducing a canopy that has the thermal properties of urban elements and is radiatively coupled to the underlying soil scheme. It has previously been shown to be effective at reducing forecast temperature error (Best 2005). However, it has received very little attention in the context of the climate model.

The Met Office Hadley Centre regional climate model (RCM) is used to downscale climate change projections from the Hadley Centre Global climate Model (HadCM3). For these RCM experiments a transient projection from the medium emissions (SRES A1B) transient climate change scenario from the HadCM3 model were used as boundary conditions to drive the RCM for a number of time-slice experiments to test urban sensitivity to the climates of 1971-1990 and 2041-2060. The HadCM3 model configuration is described in Collins et al. (2006, version 3.0 in their Table 1) and the RCM is a nested version over the European domain at approximately 25km resolution.

An additional and well documented driver of urban climate is anthropogenic heat released to the environment through human activity in cities such as heating and cooling of buildings, traffic, and even human metabolism (e.g. Ichinose et al. 1999, Sailor and Lu 2004, Pigeon et al. 2007). Energy use statistics for London have been analysed to estimate the heat flux (Greater London Authority, 2006). The results suggest heat fluxes averaged over a 25km grid cell located over the city centre of London to be of order 25Wm^{-2}, and for urban areas not including the core to be of order 15Wm^{-2}. We have used the more conservative value of 15Wm^{-2} as a default heat flux estimate at the RCM resolution, but have conducted a set of sensitivity tests with the heat flux at 0Wm^{-2}, 15Wm^{-2}, and 45Wm^{-2}. This heat flux is included in the model as an additional source to the surface energy balance equation of the urban tile.

3. SIMULATED URBAN CLIMATES

3.1. Simulated urban heat islands

Fig. 1 shows the simulated urban heat island determined as the difference between the urban tile and grid cell mean 1.5m minimum (Tmin) and maximum (Tmax) temperatures for a climatology period 1971-1990. The feedback of the urban heat island to the atmosphere is not included in this particular experiment in order to simplify the definition of the heat island in this case. In other words the results presented here show a simulated urban heat island potential for one configuration of a simple urban surface, at all locations within the model domain, but with zero effective size.

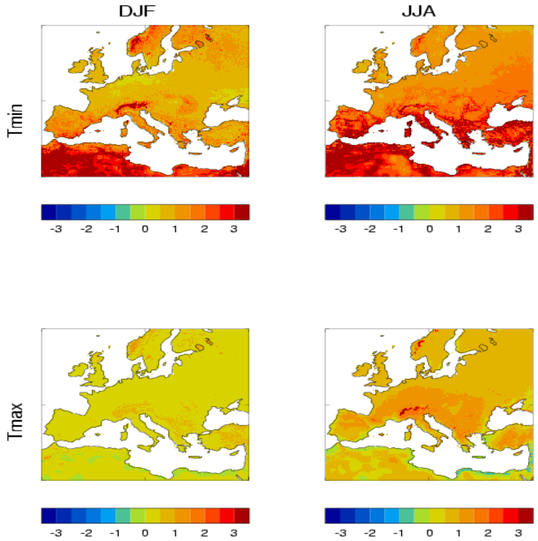

Figure 1: Temperature differences (^oC) between urban tile temperature and grid cell mean temperature for Tmin (upper) and Tmax (lower) in winter (DJF, left) and summer (JJA, right).

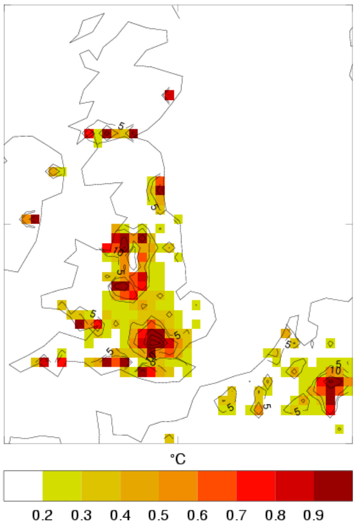

Fig. 2: Impact of the urban model on the regional climate of the UK. The coloured block plot shows the impact on gridcell average Tmin of including the urban model. The contours show the percentage urban coverage within gridcells. Contour lines are shown for 5%, 10%, 30%, 50%, and 70% urban cover.

The simulated heat island is larger for night minimum temperatures (Tmin), and generally much smaller for day time maximum (Tmax), and larger during the summer than winter. Mediterranean regions support the largest potential urban heat islands. Low soil moisture resulting in low heat capacity of soil and vegetation surfaces yield large diurnal temperature ranges in this region. The urban tile reduces the night cooling rate resulting in larger night time urban heat islands for the Mediterranean in the summer.

Fig. 2 shows the urban tile feedback when the urban tile is fully interactive. The UK contains a large urban coverage and is therefore highlighted here. Within this model the urban tile results in a detectable temperature perturbation across most of the South and Central England, including those regions outside of the major urban centres and with less than 5% urban coverage. Therefore urban land-surface feedbacks should not be ignored in downscaling of climate change projections. To that end there remains a requirement for further improvement in our understanding of the meso-scale performance of such numerical urban land-surface schemes at the resolution of climate models.

3.2. Simulated Urban Climate Change

The sensitivity of the simulated urban climate to greenhouse gas (GHG) forced climate change has been tested within both the HadCM3 global climate model (not shown) and the HadRM3 regional climate model (Fig. 3). In the absence of other forcings the rate of warming in response to the GHG radiative forcing is similar for both urban and non-urban surfaces. Exceptions to this occur in certain regions where cloud and soil moisture feedbacks perturb the solar forcing and diurnal temperature range. This can be seen in South West Europe in Fig. 3 with changes in the urban heat island of order a few tenths of a degree on a climate signal of 2-3^{o}C that is reflected in an equivalent and opposite change in the magnitude of the diurnal temperature range for the non-urban surface.

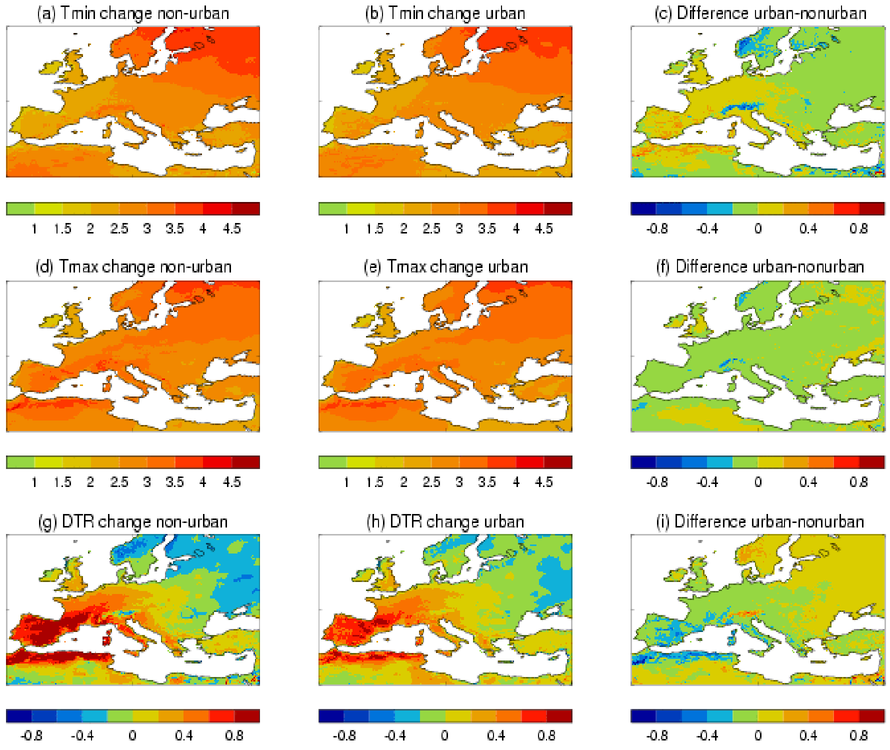

Figure 3: Climate change for nonurban and urban surfaces. These represent the difference in mean climate between 2041-2060 and 1971-1990 (a) Tmin for non-urban surface, (b) Tmin for the urban tile, (c) difference between (b) and (a). (d) to (f) are same as (a) to (c) but for Tmax. (g) to (i) are the same as (a) to (c) but for diurnal temperature range (DTR) defined as Tmax-Tmin.

We have also tested the sensitivity to changes in the local anthropogenic heat release. Fig. 4 shows the urban tile temperature change in response to GHG forced climate change and tripling of the urban anthropogenic heat release from 15Wm^{-2} to 45Wm^{-2}. As mentioned previously and shown in Fig. 1 the urban tile surface exchange is calculated at all grid cells regardless of whether the urban fractional coverage is greater than zero or not. Therefore Fig. 4 does not represent the true regional climate change, but is a measure of the simulated local sensitivity of urban areas to GHG and anthropogenic heat release forced climate change. The greatest sensitivity to increased heat release is found for the large northern European cities, and for areas around the south East of the region. In both cases Tmin increases of 0.5 to 1^{o}C are simulated. Sensitivity of urban climate to anthropogenic heat release is dependent not only on the magnitude of the heating and size of the city, but also on the local climate.

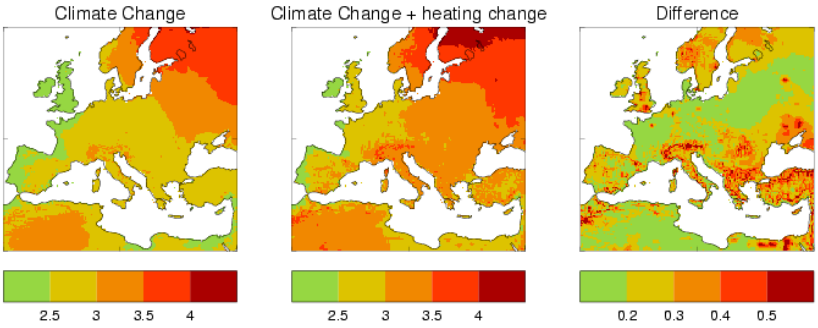

Figure 4: Urban climate change projection. Temperature change between 2041 to 2060 and 1971 to 1990 for urban tile Tmin. Including greenhouse gas (ghg) induced climate change only (left), including ghg climate change and tripled anthropogenic heating term for cities (middle, 15Wm^{-2} in 1971-1990 rising to 45Wm^{-2} by 2041-2060), and the difference, i.e. the contribution from tripled anthropogenic heating (right). It should be noted that these maps are for urban tile temperatures only, and do not represent gridcell mean temperature change.

4. DISCUSSION

There is an ever growing requirement for detailed climate change information at spatial scales smaller than most climate models can achieve. The high proportion of the global population projected to live in urban areas through the 21st Century will be exposed to climate modification from both greenhouse gases and urban factors. However the influence of urban areas on climate has generally been ignored within the climate model community.

We have conducted a first analysis of the impact of a simple urban parameterization within the Hadley Centre climate model. We find significant feedbacks into the regional climate for highly urbanized areas such as the UK. The simulated response to GHG forcing is similar for urban and non-urban surfaces, but the urban heat island in the model does respond to climate feedbacks that change the surface radiation balance (e.g. clouds, soil moisture). We also demonstrate regional variations in the sensitivity to anthropogenic heat release within urban areas that is an additional local climate forcing of some significance to human populations. Future projections of man-made climate change need to give sufficient emphasis to the appropriate inclusion of urban factors, particularly for the analysis of the potential vulnerabilities, impacts, and adaptation options for global cities.

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