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THE IMPACT OF CLIMATE CHANGE ON OUR CITIES.

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1. INTRODUCTION

With the majority of the World's population living in cities, and the number predicted to grow over the coming years, it is important to know how climate change will affect these environments. However, no models before now have attempted to include urban areas in climate change simulations. The most that has been done is to take current urban signals and apply the simulated results from standard climate change experiments that do not model these urban areas.

Mitigation measures and other actions may be based upon these simulations, but is the true impact of climate change on our cities different to these results? The answer to this question is important because is could have implications not only for increasing temperatures leading to heat stress in certain cities, but could also impact on human health and ultimately on the economy of the society that has to deal with the consequences.

This study includes urban areas in climate change simulations in an attempt, not only to answer this question, but to also look at what the impacts of climate change are on our cities. It also attempts to quantify the relative impact of anthropogenic heat sources within urban areas compared to the climate change signal from Global warming, due to the increase of atmospheric CO_2 concentration and the greenhouse effect.

2. MODEL SIMULATIONS

The model used in the simulations presented in this paper is based on the Hadley Centre atmospheric climate model HadAM3 (Pope et al. 2000) with the latest Met Office surface exchange scheme, MOSES 2.2 (Essery et al. 2003). Simulations have been done with current day atmospheric CO_2 concentrations ($1xCO_2$) and double the current day levels ($2xCO_2$). Each model run has a climatology for sea surface temperatures which is in balance with the atmospheric CO_2 concentration, hence minimising model spin up effects. In combination with this, simulations have been completed with and without an urban parametrization to assess the impact of climate change on these urban areas. The urban scheme uses a simple canopy representation for cities, whereby the available energy at the surface from the incoming radiation is divided into sensible and latent heat fluxes and heat storage within the canopy. This canopy is then radiatively coupled to the underlying soil. More details of the scheme and its general characteristics have been presented in Best (1998) and Best (2000).

An anthropogenic heat source has been added to the urban areas for some of the simulations. There are essentially two ways in which an anthopogenic heat source can be added to the canopy scheme. It can be included as an additional source to the surface energy balance equation which is then subsequently partitioned between the turbulent fluxes and the heat storage (representing a heat source from, for instance, buildings), or it can be added directly to the sensible heat flux (representing a heat source from, for instance, vehicles). In this study, the heat source has been added to the energy balance equation. This has been done to maximise the effect in the results, given that the resolution of a climate model means that any direct heat source into the atmosphere will be a small term given the fraction of urban areas in a gridbox.

The size of the anthropogenic heat source has been determined from global energy consumption. During 1996, approximately 8000 million metric tons of oil equivalent was used, which converts to 335 EJ (335 $x10^{18}$ J) of energy. If all of this energy was dissipated in urban areas, then it would give a heat source of ~45 Wm^{-2}. For this study we have assumed that about half of this energy is dissipated in urban areas, hence we have added an anthropogenic heat source of 20 Wm^{-2}. In addition, for one of the $2xCO_2$ simulations we have

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assumed that the fossil fuel energy consumption will increase by a factor of three and have hence set the anthropogenic heat source to 60 Wm^{-2}.

At the typical resolution of climate models there are no urban areas which are explicitly resolved. This is the reason why climate simulations have neglected the effects of urban areas to date. However, with the introduction of tile (or mosaic) surface schemes which can represent the surface exchange from many different surfaces within one atmospheric model gridbox, it is now possible to include the effects of these urban areas and study the impacts. However, there are still only small fractions of urban areas in any of the model gridboxes and for this reason, we will concentrate on the results for the gridbox containing New York, as this has the highest fraction of urban at around 15%. The following results show temperature distributions which have been derived from the daily maximum and minimum temperatures from the last twenty years of 25-year model simulations, i.e. the first five years are discarded to allow for the spin up of the model.

3. RESULTS

The temperature distribution from a $2xCO_2$ run with an interactive urban representation is shown in Figure 1 (labelled as prognostic). Also shown in figure 1 is the result of taking the temperature distribution from a $1xCO_2$ run without an interactive urban area and adding on the mean temperature increase from a standard $2xCO_2$ run, again without interactive urban areas (labelled as diagnostic). Comparing these two temperature distributions for both maximum and minimum daily temperatures shows that whilst the general shape of the two curves are similar the details are different, with the interactive urban giving a wider distribution for both the maximum and more evidently the minimum temperatures. This shows that it is not possible to use current day urban temperature distributions along with standard climate change results to accurately predict the likely temperature distributions under future climates.

To assess the impact of the anthropogenic heat source on the urban temperature distribution, three $2xCO_2$ model simulations with the anthropogenic heat sources of 0 Wm^{-2}, 20 Wm^{-2} and 60 Wm^{-2} are shown in Figure 2. This figure shows the impact of the increasing anthropogenic heat source on daily minimum temperatures for both the urban areas and the surrounding rural areas. There is little impact from introducing the 20 Wm^{-2} anthropogenic heat source, with only a small change in the temperature distributions. However, for the larger 60 Wm^{-2} anthropogenic heat source, there is a significant shift of the distribution to warmer temperatures. This is true for both the urban and the surrounding rural areas, although the signal is larger in the urban areas, as might be expected. This shows that the anthropogenic heat source will have a greater influence on the temperature distribution with increase fossil fuel consumption compared to current day levels.

Figure 1: Impact from including urban areas in simulation

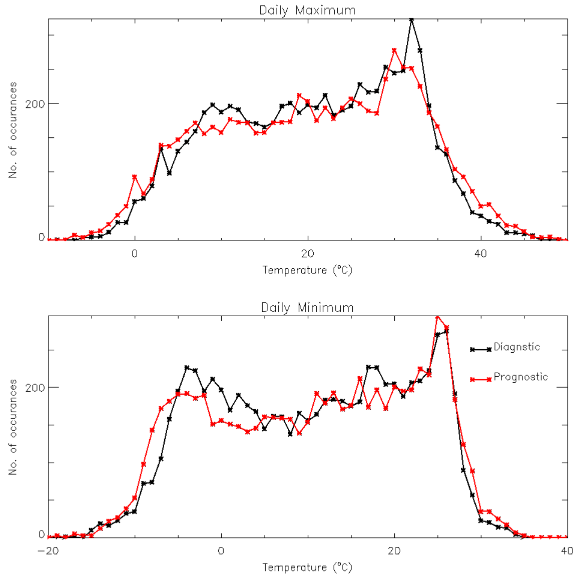
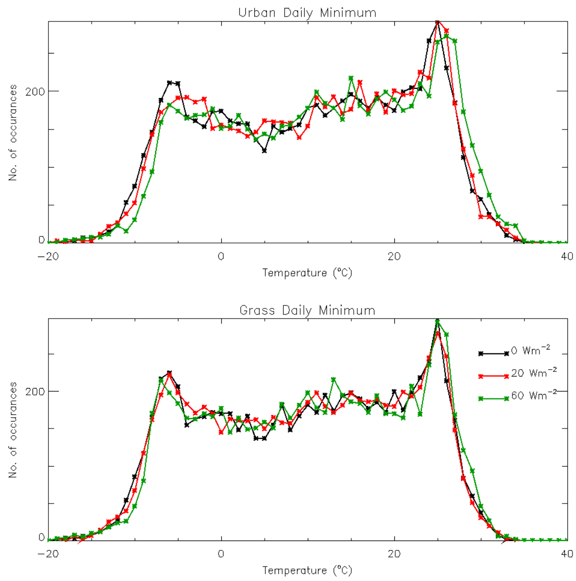


Figure 2: Relative impact of anthropogenic heat sources



To put the size of this shift in the temperature distribution from the increased anthropogenic heat source into context of the overall warming from the increased atmospheric CO_2 concentration of future possible climates, the temperature distribution from a $2xCO_2$ simulation with 60 Wm^{-2} anthropogenic heat source is shown in Figure 3, along with $2xCO_2$ and $1xCO_2$ simulations with a 20 Wm^{-2} anthropogenic heat source. It is clear from Figure 3 that whilst the increased anthropogenic heat source has a significant warming in the distribution for both maximum and minimum temperatures, it is much smaller than the impact of the increased atmospheric CO_2 concentration This shows that whilst a large amount of effort is being concentrated on mitigating the impact of anthropogenic heat sources in urban areas, these mitigation processes will overtaken by climate change.

Figure 3: Impact of anthropogenic source compared to increased CO_2

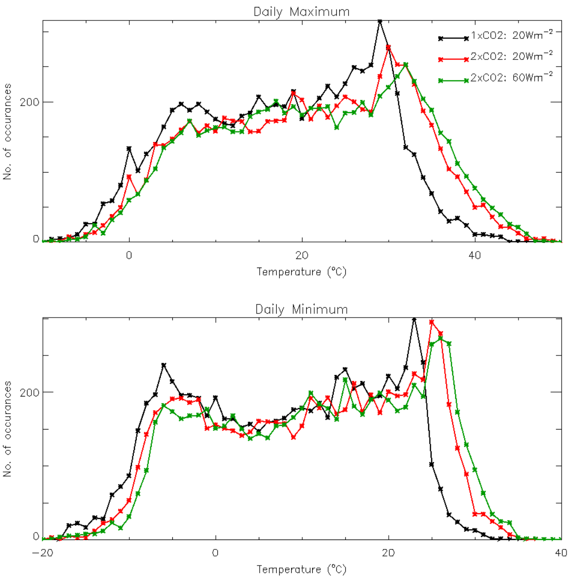
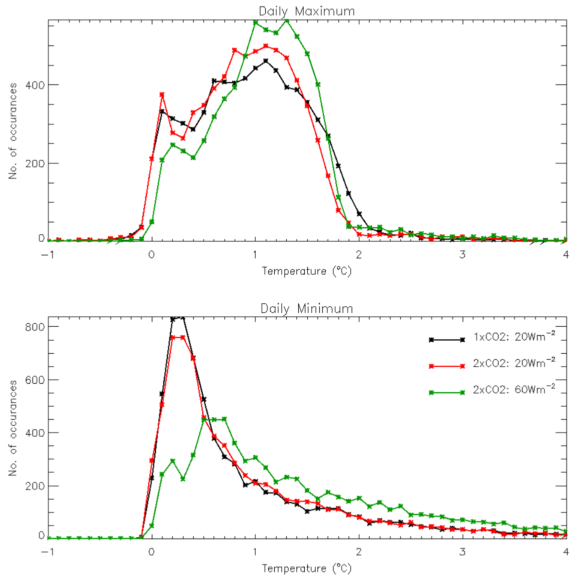


Figure 3 also shows that whilst the maximum temperature in New York does not exceed 40°C very often in the current climate, it is likely to exceed this temperature on a significant number of occasions in the future. It is also likely that the there will be a number of occasions in the future when the minimum temperature will not fall below 30 °C, which also rarely occurs at present. This has implication for heat stress and the subsequent impact on human health.

To understand how the anthopogenic heat source and climate change impact on the urban heat island, the distribution of the heat island at maximum and minimum temperatures are shown in Figure 4. The results shown are for simulations with $1xCO_2$ and 20 Wm^{-2}, $2xCO_2$ and 20 Wm^{-2} and $2xCO_2$ and 60 Wm^{-2}. The increased atmospheric CO_2 concentration does not have a large impact on the shape of the urban heat island distribution. The maximum distribution has fewer occurrences of daytime heat islands of around 2 °C, but the nighttime heat island has an almost identical distribution. This is not the case with the increased anthropogenic heat source. The daytime distribution becomes more peaked with less occurrences of heat island between 0-1 °C and more occurrences between 1-2 °C, although there are still less occurrences of heat islands around 2 °C than under the current climate. The change in the nighttime distribution is the most marked however. The shape of this distribution is significantly changed, with a lower peak in the occurrences of a small heat island and more occurrences in the tail of the distribution at higher heat islands.

Figure 4: Change in urban heat island due to anthropogenic source



4. CONCLUSIONS

This study has been an initial attempt to understand the true impact of climate change on our cities by directly modelling urban areas within the simulations. Whilst more work is required to fully understand the results from these simulations and to improve on the representation of the urban areas, there are a number of important conclusions that can be made:

- Urban areas need to be simulated within climate simulations if we want to build up a true picture of the impact of climate change within the cities themselves.
- If the anthopogenic heat source increases in the future, due to additional fossil fuel emissions, then the relative warming effect will be larger than the impact of the current day anthropogenic heat source. This means that mitigation measures may not be correctly designed.
- The impact of the anthropogenic heat source on warming within urban areas is significant, but not as large as the signal from the increase in the atmospheric CO_2 concentration. This means that whilst we may try to mitigate against the direct warming from anthropogenic heat sources, different measures will be required to address the more significant effects associated with global warming.
- The impact of an increased anthropogenic heat source in the future could significantly change the distribution of the urban heat island. There could be less occurrences of a near neutral heat island and a larger number of greater heat islands, especially during the night.

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