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THE INFLUENCE OF VEGETATION ON THE URBAN CLIMATE

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1. INTRODUCTION

The traditional view of cities is of hot dry areas compared to their rural surroundings. This view has developed partly because there is little water available for moisture fluxes on buildings or road surfaces. However, there are large areas of urban environments which contain vegetation and hence have access to the store of moisture in the soil. Observational experiments have shown that the moisture fluxes can be a significant term in the energy balance within suburban areas (e.g. Grimmond and Oke 1995). So how important is this vegetation within the cities on the urban heat island, the atmospheric structure of the boundary layer, or on any mesoscale circulations?

This study looks at the effects of changing the fraction of urban areas which make up a gridbox within a numerical model. By changing the ratio of urban to vegetation areas within the model it is possible to assess the impacts on the surface layer heat island and the boundary layer structure over a city.

2. NUMERICAL MODEL

The high resolution mesoscale version of the Met Office Non-Hydrostatic Unified Model has been used in this study. This model has a tile or mosaic scheme for calculating its surface exchange. This means that the surface exchange is calculated for up to 9 different types of surface and the fluxes are then averaged, using blending height techniques, to give gridbox values. One of the surface types is taken to represent the buildings and roads within urban areas and is explicitly represented using the canopy approach which has been shown to represent many of the observed urban phenomenon (Best 1998). So changing the amount of urban within a gridbox is done by changing the fraction of the urban tile which makes up the gridbox average.

The model was multiply one-way nested, in order, global (~60 km), 12km, 4 km and 1 km. The inner domain of the model is 300x300 km, 38 vertical levels, centred on London, U.K.. The bottom temperature level is at 20m. The model was run from 12Z on 10 May 2001 for 24 hours to capture the evening transition. Conditions were clear sky anti-cyclonic, with light but not negligible winds. These are typical conditions for urban heat island formation.

Figure 1 shows the domain of the model and the fraction of urban areas within each 1 km. gridbox. To assess the impact of changing the ratio of urban to vegetation, these urban fractions have been scaled by constant factors of 1.0, 0.67, 0.33 and 0.0, for different model integrations. The remaining 8 landuse types within the model have then been re-scaled so that the total fraction of landuse in each gridbox adds up to 1 for each integration.

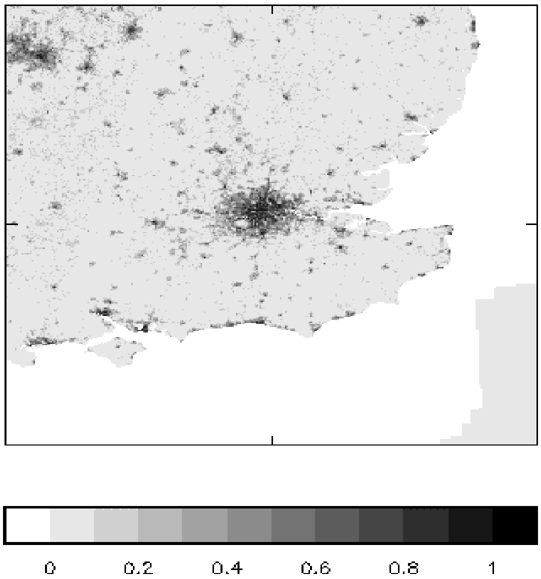

Figure 1: Urban fraction of gridbox

3. RESULTS

To assess the impact of vegetation on the urban heat island, two grid points have been considered. One point is in central London and the other point is in Reading, which is a large town to the west of London. To obtain urban and rural surface layer differences, the runs which have an urban fraction (those with scaling factors of 1.0, 0.67 and 0.33) have been differenced from the run with zero urban fraction (scaling factor of 0.0).

Figure 2 shows the differences in surface layer temperature at 0Z for each of the model runs against the fraction of urban areas at the two grid points. It is clear from this figure that the surface layer urban heat island increases with increasing urban fraction, but this response is not a linear one. The increase in temperature difference at both small and large urban fractions is greater than the increase at medium urban fractions.

Also, the increase in surface layer heat island from a large urban area is greater than from smaller urban areas. This means that the upstream boundary layer evolution has an influence on the urban heat island, but this is a second order effect compared to the fraction of urban areas. The degree of non-linearity in the response of the heat island to increasing urban fraction also depends upon the horizontal extend of the city. This

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suggests that larger urban areas have a response which is more linear than small urban areas.

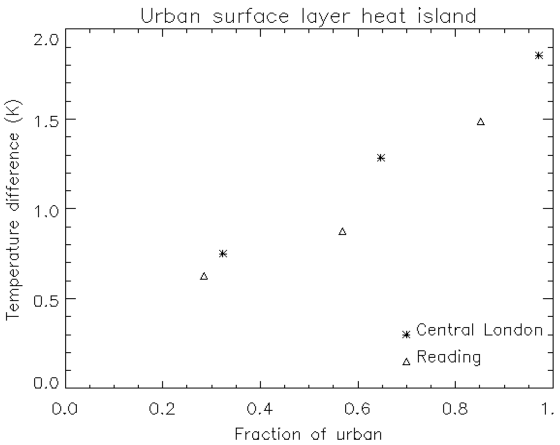

Figure 2: Landuse influence on heat island

Similar results are found for both specific and relative humidity, with increasing urban fractions reducing the humidity and resulting in a dry surface layer island. Again there are two impacts to the changes in urban fraction, the humidity differences increase with both increasing urban fraction and for larger urban areas. Although the response to increasing the urban fraction is still non-linear, the extent of the urban area does not have such a large effect on this non-linearity as it does for the temperature difference.

To investigate the boundary layer behaviour due to changing the urban fractions, vertical profiles have been taken at 4 points roughly along the wind direction through central London. These points are 1: rural upwind site, 2: central London site, 3: downwind suburban London site and 4: downwind rural site. Figure 3 shows the potential temperature profiles at 21Z for these site from each of the model integrations.

The temperature profiles are consistent with a stable boundary layer about 600 m deep advecting in off the North Sea, within which an unstable layer grows during the afternoon. As dusk approaches, the depth of the land driven relatively unstable boundary layer decreases rapidly, and by 21Z has stabilised upwind of London. Over London itself, a neutral, well mixed layer about 200 m deep remains if the urban fraction is present. This layer grows but stabilises from the surface downstream so that the eventual behaviour is complex, with relative cooling aloft (300-600 m) with urban present. This cooling may be a consequence of enhanced upward transport of surface cooling because of the well mixed air aloft, but may also perhaps result from differential horizontal advection because of different wind directions with and without the urban.

There is a strong non-linearity to changing the urban fraction, especially over central London. Even with small fractions of urban landuse, a neutral boundary layer of about 200 m can be sustained into the night. The impact of this non-linearity can also be seen at the downstream points, although the non-linearity is not as large.

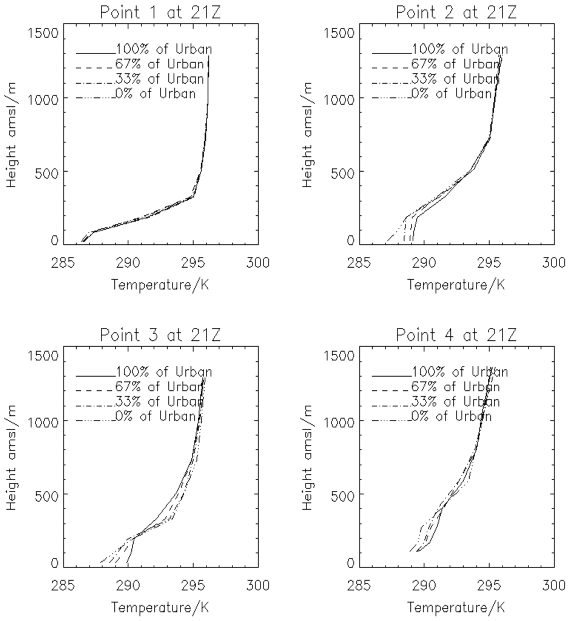

Figure 3: Vertical potential temperature profiles

4. CONCLUSIONS

The ratio of urban fraction to vegetation fraction within a city influences the size of the urban heat and dry islands. The response to increasing the vegetation fraction decreases the urban heat island but this change is not linear. The degree of non-linearity depends upon the size of the urban area.

The boundary layer structure is significantly altered by the presence of an urban fraction. The neutral temperature plume over the city is advected downwind as a lofted plume, with important implications for pollution dispersion. There is also a strong non-linearity in the boundary layer response to an urban fraction. Even small fractions of urban can produce neutral nocturnal boundary layers of a city.

5. REFERENCES

Best, M. J., 1998. Representing urban areas in numerical weather prediction models. *Second Urban Environment Symposium, Albuqueque, 2-6 November 1998.*

Grimmond, C. S. B. and Oke, T. R., 1995. Comparison of heat fluxes from summertime observations in the suburbs of four North American cities. *J. Appl. Meteorol., 34, 873–889.*