2.3 COUPLING BETWEEN THE URBAN ENERGY BALANCE AND BOUNDARY LAYER

Ian N. Harman[1]*, Martin J. Best[2], Stephen E. Belcher[1].
[1]University of Reading, Reading, UK. [2]Met Office, Bracknell, U.K.

1. INTRODUCTION

Urban areas represent a complex challenge for the surface energy balance and boundary layer schemes of numerical weather prediction models. Accurate forecasting of surface and near-surface air temperatures has a large number of practical applications. Although parameterisations schemes for the surface energy balance of urban areas exist, there is little understanding of the importance in the coupling between the surface energy balance and boundary layer over urban areas.

This coupling is known to be important for the evolution of the boundary layer and hence such features as the near-surface urban heat island. We need to understand this coupling and the underlying mechanisms responsible in order to develop parameterisation schemes for urban areas.

2. MODEL COUPLING

A dry energy balance model of an urban street canyon has been developed of a type which has been shown to have skill in simulating surface temperatures when forced by observed winds and air temperatures (Kusaka et al., 2001). This energy balance model has been coupled to the first-order, one-dimensional boundary layer model of Busch et al. (1976). The coupling implies that the sensible heat fluxes and surface temperatures of the facets of the canyon are dependent on the boundary layer wind and potential temperature. In turn, the eddy diffusivities and surface boundary conditions for the boundary layer model depend on the surface temperatures and area-averaged sensible heat flux. This coupling removes the tight control on the energy balance that is exerted by forcing with observations.

Results from day two of a mid-latitude spring case with clear skies and low winds are shown. Care has been taken in the choice of the run as the boundary layer model is representative of the case of full adjustment to the surface. The case shown here is therefore representative of the boundary layer over a large city in light winds.

3. RESULTS

Figure 1 shows temperature profiles for three cases at midnight, six hours after sunset. The three cases are a flat surface with small roughness (smooth case), a flat surface with high roughness (rough case) and the urban street canyon down to the road surface (urban case). The urban case shows a significantly less stable profile than either the smooth or rough cases. Differences in the temperature of the residual layer are due to the accumulated sensible heat flux from the previous day. A near-surface heat island of over 2K is reached together with a doubling in the height of the nocturnal boundary layer.

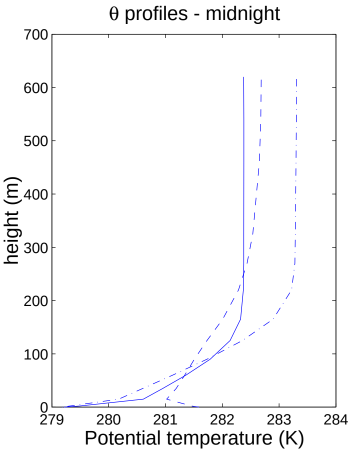

Figure 1. Potential temperature profiles six hours after sunset. Solid line - smooth case, dash-dotted line - rough case, dashed line - urban case.

The decrease in the stability of the profile is caused by two processes. Firstly, increased roughness leads to increased wind shear and enhanced mixing. This results in the loss of heat over a deeper layer and is the mechanism responsible for the differences between the smooth and rough cases. Secondly, the canyon energy balance, primarily the

---

[*] *Corresponding author address:* Ian Harman, PO Box 243, Department of Meteorology, University of Reading, Reading RG6 6BB. United Kingdom

reduction in longwave radiative loss due to canyon geometry, inhibits surface cooling. This surface and near-surface warming reduces the stability of the air column and allows enhanced mixing over a deeper column air when compared to the rough case. Observations of the energy balance of urban areas (Oke, 1987) show positive or small negative night time sensible heat fluxes and hence neutral boundary layers through the night. Although this work has been unable to reproduce these features there is clear progress towards doing so.

The near-surface profile of potential temperature over the urban area shows a discontinuity in the lowest levels. This is due to the differing surface temperatures of the canyon facets. The roof is cold due to longwave radiation loss and extracts sensible heat from the atmosphere stabilising the profile. The road and walls remain warm and release sensible heat into the atmosphere. The boundary layer adjusts to minimise this conflict of forcing. This points to a complexity of the system that could not be simulated by simple slab models if this energy balance model is correct.

The adjustment of the boundary layer to the surface forcing highlights the importance of coupling the energy balance to a boundary layer model. Increasing the fraction of the horizontal surface area occupied by the street canyon (the canyon fraction) while maintaining the canyon geometry in an uncoupled model would increase the night time area-averaged sensible heat flux. For the case shown in figure 1, positive night time heat fluxes could be maintained if the canyon fraction was large enough.

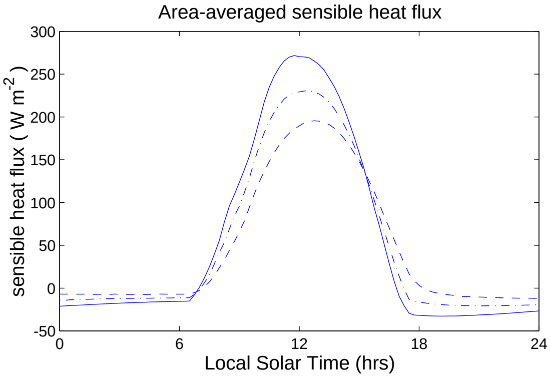

Figure 2. Sensible heat flux profiles from the coupled urban canyon model. Solid line - 5% canyon fraction, dash-dotted line - 50% canyon fraction, dashed line - 95% canyon fraction

Figure 2 shows the diurnal profile of the area-averaged sensible heat flux from coupled urban runs with varying canyon fractions. Although increasing the canyon fraction does increase the night time area-averaged sensible heat flux, it does not become positive. The process responsible for this is the adjustment of the boundary layer. A coupled surface energy balance and boundary layer model may give qualitatively different results to the uncoupled energy balance model.

4. CONCLUSIONS

Coupling an urban energy balance model to a one dimensional boundary layer model has allowed investigation into the causes of near-surface urban heat islands. Both increased roughness and surface warming play a role in bringing stable potential temperature profiles back towards the observed neutral nocturnal profiles. Coupling the energy balance of an urban area to a boundary layer model is crucial in determining how the system as a whole evolves. The urban canyon energy balance model shows promise in being able to simulate near-surface heat islands when coupled to a boundary layer model.

Acknowledgements: This work forms part of the UWERN Urban Meteorology Programme (www.met.reading.ac.uk/Research/urb_met/). This work is funded by the Natural Environmental Research Council and the Met Office (NER/S/A/2000/03555).

5. REFERENCES

Busch, N., Chang, S., and Anthes, R. (1976). A multi-level model of the planetary boundary layer suitable for use with mesoscale dynamic models. *J. Appl. Met.*, **15**(9), 909–919.

Kusaka, H., Kondo, H., Kikegawa, Y., and Kimura, F., (2001). A simple single-layer urban canopy model for atmospheric models: Comparison with multi-layer and slab models. *Bound.-Layer Meteor.*, **101**, 329–358.

Oke, T. (1987). *Boundary Layer Climates.* Routledge, 2nd Edition, pp.262–303.