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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Sensitivity of mesoscale model urban boundary layer meteorology to urban morphology" *by* D. D. Flagg and P. A. Taylor

D. D. Flagg and P. A. Taylor

david.flagg@zmaw.de

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Reviewer #3:

Point 1: In response to this concern, an amended title "Sensitivity of mesoscale model urban boundary layer meteorology to the scale of urban representation" is proposed.

Point 2 (Introduction): Some discussion of the nature of the urban RSL is retained to provide a more balanced description of the impact of the urban surface on the overlying atmosphere. Further discussion on the role of vegetation and its coverage in urban areas has been added.

P 25911 L 9-10: The terminology in this area is not entirely clear. Barlow and Coceal (2009) write "the urban RSL can be further subdivided into an urban canopy layer

(UCL) up to mean building height" while Rotach (1999) while both Rotach (1999) and Arnfield (2003) utilize a variation of the phrase "roughly mean building height" to define the depth of the UCL. This paragraph is substantially re-written for improved clarity.

P 25911 L 14: This line has been clarified.

P 25911 L 16-19: This line has been removed.

P 25911 L 19: This word has been removed.

P 25911 L 5-18: The paragraph is re-organized to enhance clarity.

P 25911 L 15, L28: The word morphology is intended to describe building layout and geometry. The references at L28 is re-written and re-organized to retain this definition. Additional references to this word are also clarified (Abstract, P25917 L19, Section 4.1, P25932 L7, Section 5)

P 25911 L 29: Additional discussion of latent heat flux with respect to urban surfaces has been added to this section.

P 25912 L 1-15: This paragraph briefly summarizes the methods available for modeling the urban surface in order to provide important context for the approach applied here (NWP model with coupled single layer urban canopy model (UCM)). WRFv2.2 offered two options for treating the urban surface: the 'sandbox' approach (physical and thermodynamic parameters assigned to one or more surface cover classes) and the single layer urban canopy model of Kusaka et al. (2001). A summary of the new functionality appearing in current WRF versions is added. A brief summary regarding the selection of the single layer UCM approach is added. A more thorough discussion of the UCM parameterizations exists in Section 2.1.

P 25912 L 16-21: The proposed change to the manuscript title and subsequent editing and clarification on the use of the word 'morphology' (outlined above) should now allow a better fit for this paragraph.

P 25912 L 20 (1 & 2): These concerns are addressed through changes outlined above. Section 2.1: Further discussion is added to describe the process of grid cell surface class assignment and how this differs from a flux aggregation technique using sub-grid class fractions.

P 25914 L 6: This word has been changed.

P 25914 L 8-10: A typographical error has been resolved to improve the clarity of this sentence.

P 25914 L 12: The wording of this sentence is modified to improve clarity.

P 25914 L 21-22: The interior building temperature estimate is derived from observations of mid-latitude interior building temperature during the summer (Walker, 2006; reference added to the text). The surface temperature data is acquired from the National Weather Service forecasting office Detroit/Pontiac, MI on-line climate records (National Weather Service-Detroit/Pontiac, 2010; reference added to the text).

P 25915 L 17: The midpoint of the lowest model vertical level is situated approximately 27-28 m above the ground. This has been added to the text.

P 25916 L 23-24: A typographical error was identified and the sentence has been re-written to improve clarity.

P 25917 L 6-7: This sentence has been removed.

P 25917 L 20: The model grid size in d04 is held constant throughout the study (Δx=0.3 km) to distinguish the effect of change in surface representation from model resolution. A clarification has been added to the preceding paragraph. All scales of surface representation (including 10 s) are sufficiently coarse to avoid resolution of individual buildings.

P 25921 L 15-19: Will assume the Reviewer is referring to P 25920 L 15-19. This is a tri-linear interpolation in time (16 pts) drawing from discrete model estimates. As such, there are unfortunately no analytical functions available from which to derive a proper estimate of the absolute error of interpolation (which, for a linear interpolation, requires a second derivative evaluation). In general, we know that linear interpolation scales according to square of the distance between the known points while the error of more complex polynomial fits would be proportional to higher powers of this distance. One alternative approach to error estimation of a linear fit would be to compare the results of a linear fit with a spline fit (e.g., cubic), assuming that a spline interpolation would provide a better approximation to the model estimates, which are discrete quantities themselves. This test was not conducted in part because error introduced by interpolation was assumed to be very limited with respect to the calculated model biases (see response to Section 3.3 below) and because it does not provide a definitive quantification of the error introduced by the linear interpolation, only the relative error versus another interpolation which, itself, may contain error.

Section 3.3: It is assumed that by “model uncertainty range for the parameters that are compared with measurements”, the Reviewer is referring to the range resulting from the error of interpolation of model gridded estimates to a point, as discussed in the preceding question. The observations used here for model verification fall within the ABL (and within a few hundred meters of the ground) where vertical resolution is very high ($\Delta z < 100$m). Most also fall within the d03 grid (Δx=1.5 km), so the horizontal resolution is comparatively coarse. However, on the basis of the substantial model biases found for moisture, temperature, wind and the relatively horizontally homogeneous nature of the model estimates during these verification periods (both aircraft flights were nocturnal), it was assumed that model bias versus measurement was likely significantly higher than error introduced by the local interpolation of the gridded model estimates. This interpretation has been incorporated into the text.

P 25921 L 13: Here, the word ‘significant’ is used only in a qualitative context. The word has been replaced with ‘large’ to define the bias as large relative to the measured quantity.

P 25921 L 17: This section has been rewritten to improve clarity.

P 25927 L 1-4: These are some interesting points. From some rough comparison, the authors did compare the results of flux from the urban canopy in Figure 8 versus the energy balance time series presented from the BUBBLE (Rotach et al., 2005) and ESCOMPTE (Mestayer et al. 2005) field campaigns, which both examined mid-latitude heavily built-up sites under generally clear skies, light ambient winds and near the time of the summer solstice, similar to the experiment presented here. The magnitude and shape of the sensible and latent turbulent heat fluxes from the urban canopy agree reasonably well with the published field campaign results; the net radiation is slightly higher here. Model estimated daytime heat uptake by the urban ground heat flux (storage term) appears to underestimate the measurements shown by BUBBLE and ESCOMPTE (closer to -200 Wm-2 rather than -100 Wm-2 shown here) with additional underestimation of the ground heat flux nocturnal emission strength (typically peaking over 100 W m-2 for BUBBLE and ESCOMPTE). It should be noted that the ground heat flux is computed as a residual term in BUBBLE and ESCOMPTE. It's agreed that the urban environment should have a larger thermal inertia than a rural setting and this is manifested through the ground heat flux term, driven by a thermal conductivity parameter, the difference between the skin surface temperature (roof/wall/road) and the mid-point of the highest 'soil' level (i.e., of the four sub-surface layers at all canyon facets, the layer closest to the surface) and the distance between these two points. In this example shown, the nocturnal ambient horizontal wind speeds are low (at 27-28 m AGL, dropping from around 4 ms-1 during the day to 2 ms-1 at night and within the canopy, dropping from around 1.5 ms-1 during the day to less than 1 ms-1 at night). This, coupled with a much reduced difference between lowest-model layer air temperature and grid-averaged urban skin surface temperature (see Figure R3) significantly reduces the magnitude of the turbulent heat fluxes (SH, LE). As a result, given that urban skin surface temperature is calculated as a result of energy balance along each canopy facet (SW rad, LW rad., SH, LE, G), at night when the SW radiation disappears and SH and LE drop substantially, the LW radiation and ground heat flux are

constrained to balance. As anticipated, the downwelling LW rad. from above exceeds the outgoing LW from the urban canopy, giving a positive Rn (thus, a negative –Rn, as depicted on the graph). The SH from the urban canopy does remain positive at night, though just above 0 Wm-2. Regarding the role of the phase shift in natural and urban SH curves with respect to the response of model temperature estimates across case studies, this phase shift can foreshadow near surface air temperature response given a shift in fURB, and therefore can foreshadow the timing of maximum temperature difference, such as that seen between case 10s and case 20s peaking around 18:00 UTC (Fig. 11). This is added to the text.

Section 4.3: The discussion of skin surface temperature was originally placed here because urban skin surface temperature computation is coupled with the urban energy balance in the UCM. The brief discussion of change to skin surface temperature in case 20s vs. case 20s has been shifted to Section 4.4. Second 4.3 (2nd sentence): The shift in grid-averaged fURB from case 10s to case 20s is a subtle increase, likely not easily detected by eye, though one of the more conspicuous changes is the loss of scattered, limited area natural surface class grid cells over Windsor (south of the river) to urban classes in Fig 7b vs. Fig. 7a. This has been clarified in the text and a reference to Fig. 7 has been added.

P 25927 L 16-21: This paragraph was meant to describe the competing influences on the turbulent heat fluxes as a result of the increase in fURB from case 10s to case 20s, to be followed by a more detailed analysis of the net effect of the individual components of the surface energy balance later in this section. This has been clarified in the text.

P 25929 L 19-22: Building density does increase in case 20s versus case 10s. This was mentioned on P25927 L14. This note is now repeated on P25929 for added clarity.

Figure 1: This figure has been re-created with a discrete colorbar to distinguish individual surface cover classes.

Figure 7: This figure has been re-created with a discrete colorbar to distinguish indi-

vidual surface cover classes.

Figure 8: This figure has been re-created with markers to indicate time of local sunrise and sunset.

Technical corrections: Any use of the term “urban canyon layer” is now no longer present in the text. During the course of this study, and following references in the literature, it became necessary to distinguish between processes within or characteristics of the open space between buildings and the overall “urban surface” (combined buildings and street canyons). Thus, for example, there is urban canyon heat flux (flux from canyon space to the overlying atmosphere), urban roof heat flux and urban canopy heat flux (heat flux from the combined rooftop and canyon area: e.g., Hurban). It is agreed that “urban canopy layer” is the accepted description of this layer in the context of the vertical atmospheric structure.

P 25911 L 16: This sentence has been deleted per the suggestion “P25911 L 16-19.”

P 25914 L 24: There was an editing change here. The expression has been changed to “(2m above ground level)”

Works Cited

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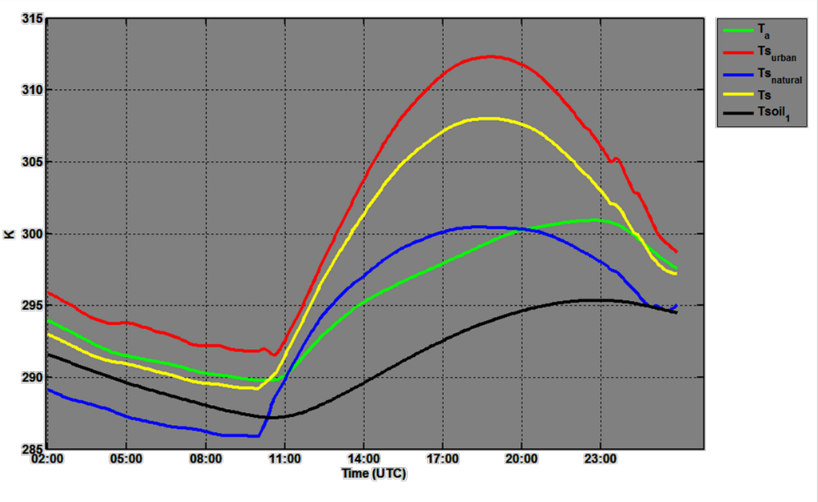

Figure R3: Change of temperature in time (UTC) for case 10s for the period 02Z 24 June – 01Z 25 June 2007 in units of K, including the lowest model layer temperature (T_a; ~ 28 m AGL here, green), the skin surface temperature over the urban canopy (Ts_{urban}, red), the skin surface temperature over the natural surface ($Ts_{natural}$, blue), the total skin surface temperature (Ts, yellow) and the soil temperature of the upper-moist layer ($Tsoil_1$, black). Temperatures are averaged over all points in the fourth model grid except Ts_{urban}, which exists only in cells where f_{URB}>0.