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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

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Response to Reviewer #1

1. Concerning the effect of surface cover precision on model simulation, only a limited amount of verification data was available for the Detroit-Windsor domain, including METAR, radiosondes and two Twin Otter aircraft flights. The majority of this data exists at altitudes above the surface layer, where the model would be most sensitive to change in the local land surface cover. Among those limited points of comparison, the finest resolution (10 arc-seconds) leads to model estimates that are closest to the observations, but such limited verification unfortunately prohibits the ability to draw robust conclusions as to which surface cover resolution performs best with the model. In lieu of sufficient verification, the statistical analyses provide a measure of model sen-

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sitivity to surface cover resolution and suggest how the model estimates resulting from progressively coarser surface cover scales deviate from those resulting from the best estimate of the surface cover (10 arc-seconds). Thus, we can begin to understand how overall model performance changes, by variable or parameterized quantity, from these statistical assessments (e.g., Fig. 11). In some cases, the change in model performance is minimal (e.g., for wind speed in the lowest model layer, Fig. 11e) and in others, there is progressively higher deviation at coarser resolutions (e.g. water vapor mixing ratio in the lowest model layer and in the urban canopy in the late morning and early afternoon, Fig. 11c & f). With regard to a recommendation for the scale of urban surface representation, the 10 arc-second scale selected here (dx $\sim$ 308 m) was chosen because it is very near the finest resolution possible for direct application to a mesoscale NWP model (i.e., without a coupled CFD model to simulate the urban environment). This scale can adequately represent a ‘neighborhood’ plan area, consisting of multiple structures of common material types and sizes distributed across sealed and unsealed surfaces (Stewart and Oke 2009). At finer horizontal scales, the surface representation would begin to resolve individual structures and surface covers, disrupting the parameterization approach. A finer resolution could improve the estimation of surface radiative temperature and soil temperature by distinguishing material types (concrete, asphalt, brick, grass, etc.), presuming this information is available. However, the UCM estimate of canyon wind speed requires an estimate of displacement height (zd), which itself requires an understanding of the local area building density and could not be determined for an individual structure or open surface. Other wind speed parameterizations would also likely to require some quantification of building separation, canyon dimension and/or orientation, all properties of a neighborhood scale. The canyon wind speeds are critical not only for flux estimation but also as a lower-boundary condition for the model wind profile. On the other hand, at coarser scales (e.g.,>1 km), such representations would fail to diagnose important local variations in urban intensity, as found in Fig. 7. Such variations can, for example, significantly affect model estimated turbulent heat fluxes. These heat fluxes can affect the development of con-

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vective structures, local stability and moisture content. Thus, for a mesoscale model simulation of the urban environment, an ideal resolution for NWP would capture the local variability in urban intensity while remaining suitably coarse to parameterize the near-surface wind flow. For air quality applications from urban mesoscale modeling, temperature can affect reaction rates and wind direction and speed are of particular importance for advection and diffusion of pollutants (Fisher et al. 2006, Banta et al. 2009). As discussed below in response to question (2), model estimates from a parallel installation for a separate domain reveal consistent wind speed overestimation in the shear layer above the canopy rooftop and considerable RMSE in wind direction within the surface layer, suggesting that the WRF v2.2 and single-layer UCM coupling would likely be inadequate for providing meteorological data to accurately model air quality. In this case, a higher resolution of the surface would be needed to better understand dispersion in and around buildings (Hanna et al., 2007, Robins et al. 2008), but this would be best accomplished with a CFD model (MacDonald et al., 1997; Solazzo and Britter, 2007; Michioka and Sato, 2009) of the urban environment coupled to the mesoscale NWP model.

2. At a 0.333 km resolution, LeMone et al. (2010) appears to show a mixture of (horizontal convective) rolls (HCR) and cellular structures, trending toward cells at higher resolution. Trier et al. (2004) shows a similar tendency at coarser resolutions (3.3 km to 1.1 km) using an earlier version of WRF-ARW with the MYJ PBL without the single layer urban canopy model. Similar HCR structures were found over Beijing (Miao and Chen, 2008) and New York (Gutiérrez et al., 2010), though further observations are needed to verify this behavior. In this study, the non-dimensionalized Obukhov length parameter (-zi/L) was also examined to diagnose stability conducive to HCR development. Figures R1c and d compare the 10 s and 20 s cases in the early afternoon in fair-weather and show -zi/L < 25 ((LeMone, et al. 2010); (Miao and Chen 2008)) for all areas except above the vegetated surfaces in Windsor. The vertical velocity field (Figures R1a, b) suggests HCR presence and this is further supported by boundary layer depth estimates (Figures R1e, f) which show roll width of approximately 2.5 km

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with a local spatial mean hABL $\sim$ 820m, satisfying the observed 3:1 ratio of HCR width to depth (Stull 1988). Examples in both the 10 s and 20 s case are circled in Figures R1e and f. This wavelength (2.5 km) is also among the smallest scale of structures reliably resolvable by the model grid's effective resolution (Skamarock 2004) of $\sim$7dx (2.1 km). A more thorough verification of the model installation (using identical grid scales) was conducted over Oklahoma City using extensive field campaign data collected during Joint Urban 2003 (Allwine et al. 2004), concentrating on temperature and wind performance. In brief, the temperature performance was fairly strong within the urban canopy (1-2 K RMSE) with some slight diurnal bias possibly due to the lack of an explicit parameterization for anthropogenic heat flux. Above the canopy, within the boundary layer, was a slight positive bias ($\sim$ +1 K). Model wind speed and direction performance was fairly strong above the surface layer with minimal RMSE over several days of model-measurement comparison during summer periods of fair weather over the urban area. Greater error in wind speed and direction is found near the surface and appears to be concentrated in the shear layer above the mean canopy rooftop, likely due at least in part to the local heterogeneity of the actual building geometry (Klein et al. 2007) resulting in a general model overestimation of wind speed in this region. Given that the convective structures discussed above are of a scale much greater than those within or adjacent to the urban canopy, it is anticipated that model performance in the bulk of the ABL is similarly strong in the Detroit-Windsor domain.

3. The area of discussion with regard to discrepancy in lake breeze front (LBF) penetration speed between case 10s and case 20s has been highlighted with a dashed circle in Fig. 12. To expand analysis on this example, results from case 60s have been added, with additional figure highlighting and description in the text. This example (23 June 2007) is the sole example available here with a clearly distinguishable Lake Erie LBF. However, as 24 June 2007 shows the development of a thermal internal boundary layer from on-shore flow off Lake St. Clair (Fig. R2), whose position varies between case 10s and case 20s, resulting in locally strong (>1 K) deviations in near-surface air temperature. Further examination of case results in the text was limited here in favor

of discussion of LBFs.

4. This typographical error appears to be an editing error as this was not present in the submitted manuscript. The correct value (‘308’, in place of ‘30’) will again be printed in the revised manuscript.

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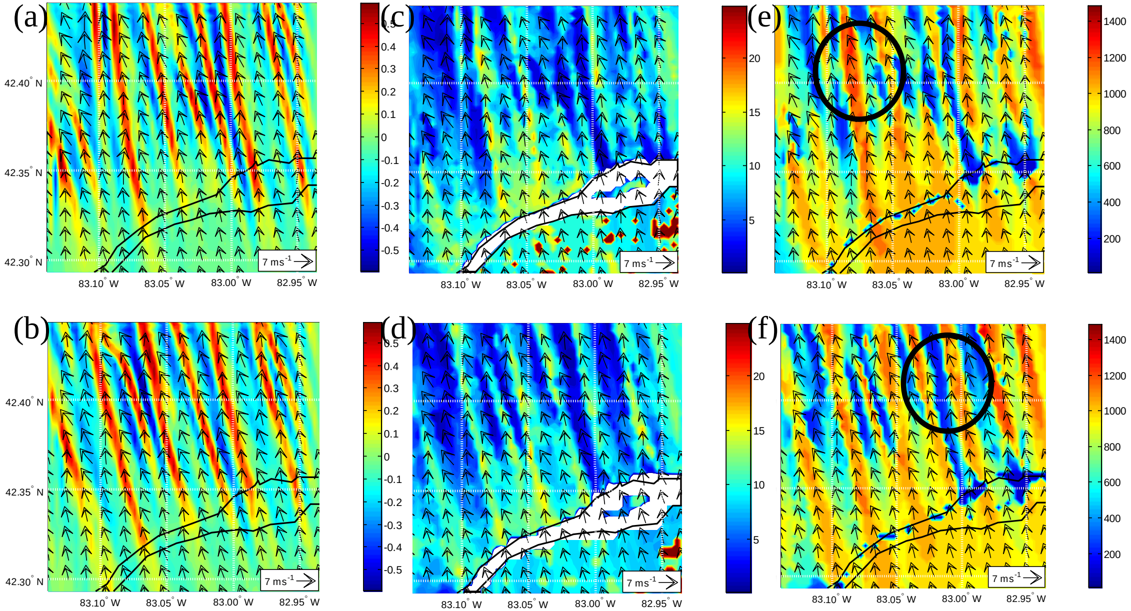

Figure R1: Comparison of the 4th model grid in case 10 s (left) and 20 s (right) at 18:20 UTC 24 June 2007 for vertical velocity (m s^{-1}) at the midpoint of the second lowest model layer (~ 91 m AGL) (a, b), a non-dimensional Obukhov stability parameter ($-z_i/L$) (c,d) and ABL depth (m) (e,f). Examples of HCR signature are circled (e, f). All figures show horizontal wind in black vectors, scaled by the reference vector at the lower right.

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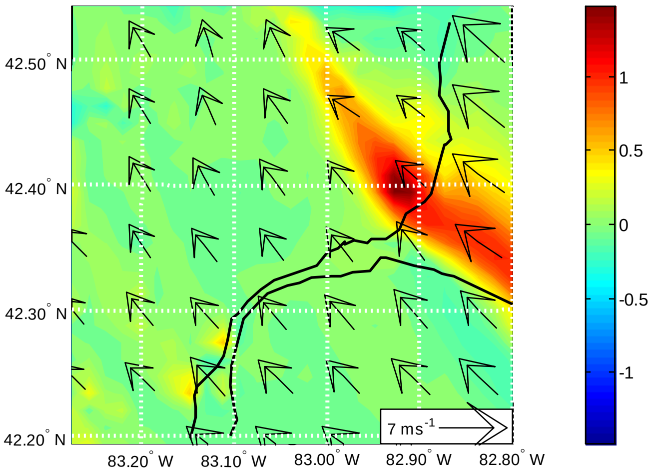

Figure R2: Temperature difference (case 10s – case 20s), (K), at the lowest model layer (~ 28 m AGL) over the third model grid of the domain at 23:20 UTC 24 June 2007. Horizontal wind speed for case 10s at this height is shown in black vectors scaled by the reference vector at the lower right.

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