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Simulating Urban Effects Within a Diagnostic Wind Field Model

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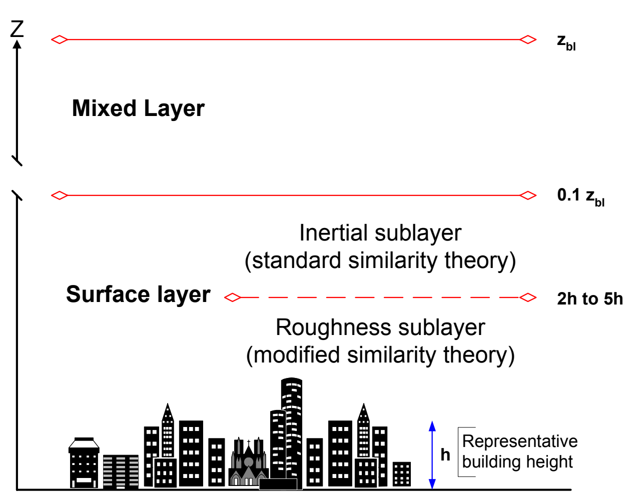
The atmospheric dispersion of hazardous materials within the urban environment is a topic of great current interest. Urban structures have been shown/are known to cause overall slowing of the winds, channeling through street canyons, heat island phenomena, wake vortices and enhanced turbulence. Simulations that explicitly resolve individual buildings are limited by computational requirements to domains of a few kilometers. For models that simulate regions covering tens of kilometers with resolutions on the order of a kilometer, the effects of individual buildings must be parameterized by incorporating area-averaged canopy effects.

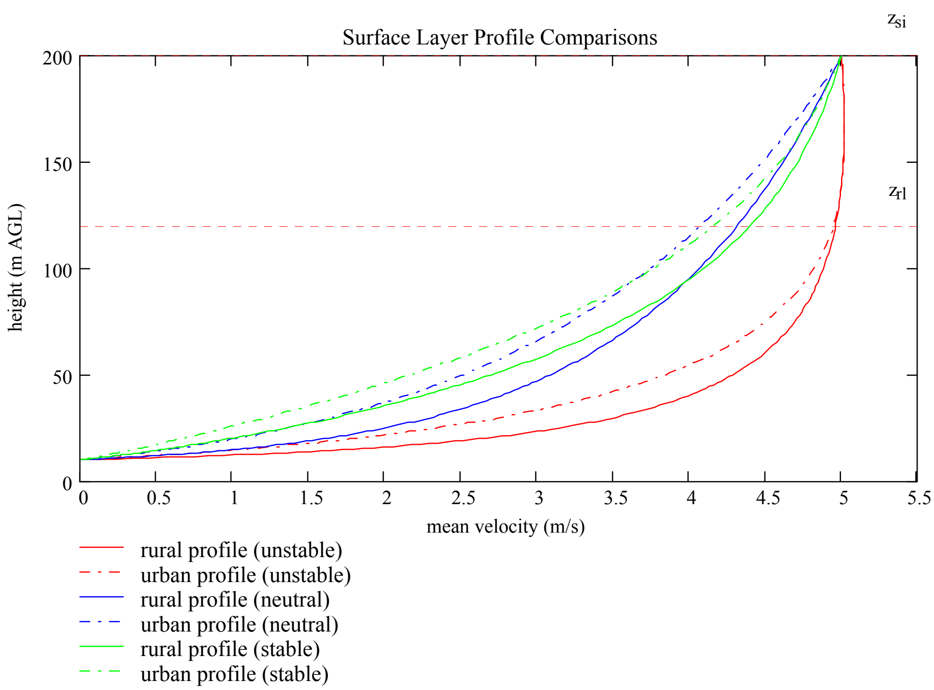
For emergency response applications, results must be provided significantly faster than real time. ADAPT (Sugiyama and Chin, 1998) is a diagnostic model used by the Department of Energy's National Atmospheric Release Advisory Capability (NARAC) at Lawrence Livermore National Laboratory. It produces non-divergent wind, turbulence, and other meteorological fields required by the NARAC dispersion model LODI (Nasstrom et al., 2000). We have incorporated an urban parameterization into ADAPT for simulations with resolutions on the order of a kilometer. We have concentrated upon parameterizing what we believe are the most significant impacts of the urban canopy - the reduction of the mean velocity and the increased turbulence. The parameterization we have implemented is a modification of standard similarity theory based on the definition of an urban roughness layer, which is completely contained in the surface layer. Within this layer, the similarity parameters such as friction velocity and Monin-Obukhov length are taken to be functions of height rather than constant. The resultant vertical profiles evidence a slowing of the wind and an increase in turbulence compared with the standard similarity profile.

The urban parameterization chosen is based upon the work of Rotach, 1997. In this parameterization, the boundary layer is broken into a mixed layer and a surface layer. The surface layer is further divided into a roughness sublayer wherein a modified similarity theory is used and an inertial sublayer in which standard similarity theory is used. The height of the urban roughness layer is a function of building height, building density, and stability. The speed profile for neutral flow in the surface layer is calculated via:



$$u(z) = \begin{cases} \frac{u_*}{k} \int_{d+z_0}^{z} \left(1 - e^{-c_2(z-d)}\right)^{1/2} \left(\frac{1}{(z-d)}\right) \text{for } z \le z_{rl} \\ u_{rl} + \frac{u_*}{k}\left(\ln\left[\frac{z-d}{z_{rl}-d}\right]\right) \text{for } z > z_{rl} \end{cases}$$

where u_* is the friction velocity, z_0 is the surface roughness length, k is the von Karman constant, d is the displacement height and z_{rl} is the height of the roughness layer. (Non-neutral conditions require the addition of ψ stability functions.) U_* is determined by matching the profile to the velocity of the wind at the top of the surface layer, which is derived by the ADAPT from the available observations. The above formulation leads to a slowing of the winds within the surface layer. Typical examples are plotted below for a 200 meter surface layer and a 120 meter roughness layer.



In order to apply the Rotach urban parameterization, the height of the roughness layer must be specified. For an operational capability, data and utilities must be provided, which allow rapid specification of the surface characteristics. We have implemented two different databases of surface characteristics over the United States. The first is the USGS Land Use Land Cover (LULC) database, which has a resolution of ~200 meters with 37 land use categories, including seven urban classes. The second is the NLCD Regional Land Cover (NLCD) database with a resolution of ~30 meters and 21 land use categories, three of which are urban. It should be noted however, that the urban categories in both databases are not ideal for our purposes as they are not directly related to building height but rather usage.

We have applied this system to the Salt Lake City basin in Utah, the site of the Department of Energy's nested Vertical Transport and Mixing (VTMX) and URBAN (Allwine et al., 2001) atmospheric field experiments in October, 2000. The figures below show the modal land use characteristics for this region as derived from sampling the two databases on a 50x50 grid with Δ=1 km. We also calculate the fraction of a grid box that is covered by each land use category.

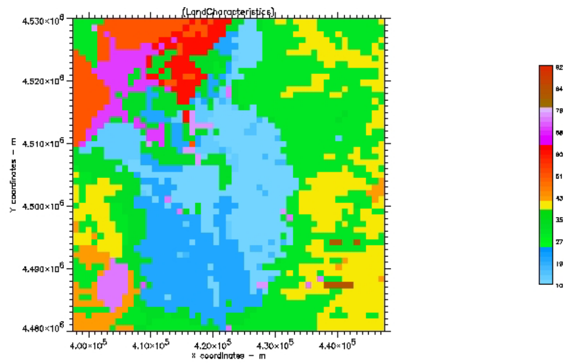


Figure 1. LULC land use categories

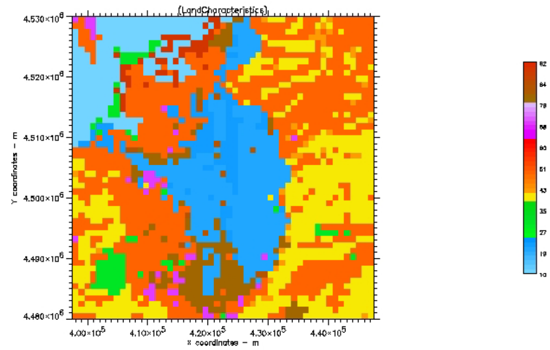


Figure 2. NLCD land use categories

We have developed an initial estimate of the correspondence between the urban categories and the area-averaged building heights based on fractional land-use categories contributions at each grid point.

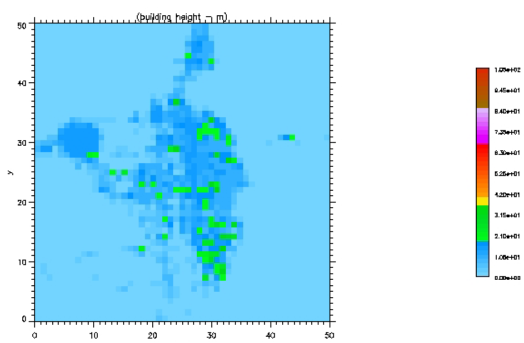


Figure 3. Building heights from LULC

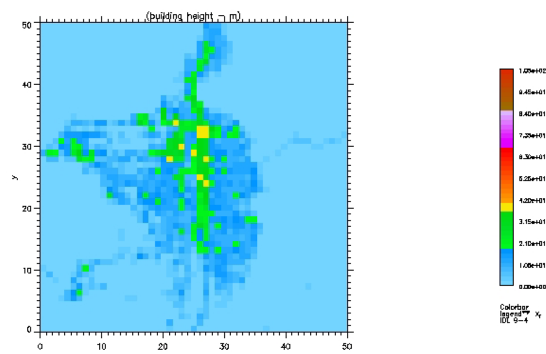


Figure 4. Building heights from NLCD

We also developed a modified estimate of average building heights from visual examination of Digital Orthoquad maps (DOQ's) of the Salt Lake City region.

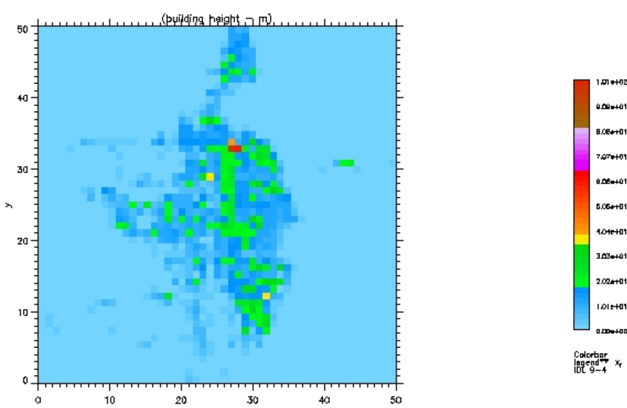


Figure 5. Building heights from DOQ's

These results from the DOQ's are similar to those derived from the NLCD data although the city center buildings are not as high. However, there are significant differences between this and the LULC derived data. There is also an urban region in the left center of the grid in both the NLCD and LULC data that is not apparent in the DOQ derived data. This is a region marked light industrial in the databases and is tailing ponds and salt evaporation ponds.

We calculated the wind fields for the Salt Lake City region for Intensive Observation Period (IOP) 10 of the VTMX/URBAN experiment. This was a nighttime experiment, which included the release of SF_6 in the downtown. The figure below shows the derived velocity field for 00 MST on October 26, 2000 at approximately six meters above ground level, together with the available observations from the MesoWest mesonet. The circles outline the observation locations, with the red vectors showing the observations. This wind field was derived without using the urban parameterization. (The center of Salt Lake City, ($4.26\text{x}10^5$, $4.512\text{x}10^6$), is southeast of the three overlapping circles just above and to the right of the center of the plot).

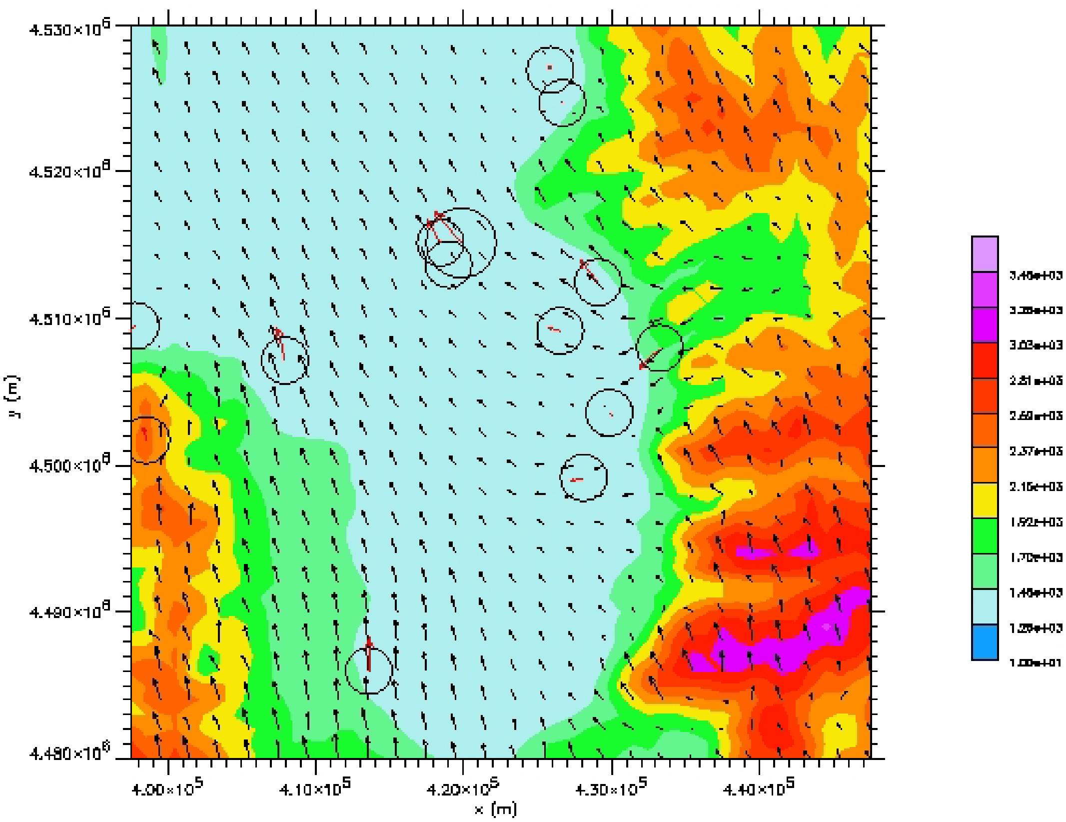


Figure 6. Non-urban velocity field (every third vector) at 6 meters AGL with observations. Maximum velocity = 5 m/s (color contours are terrain)

We then applied the urban parameterizations, using both the LULC and the NLCD average building height fields, to examine the effects of the urban parameterization on the flow. For these tests, we calculated the height of the urban roughness layer as simply three times the average building height.

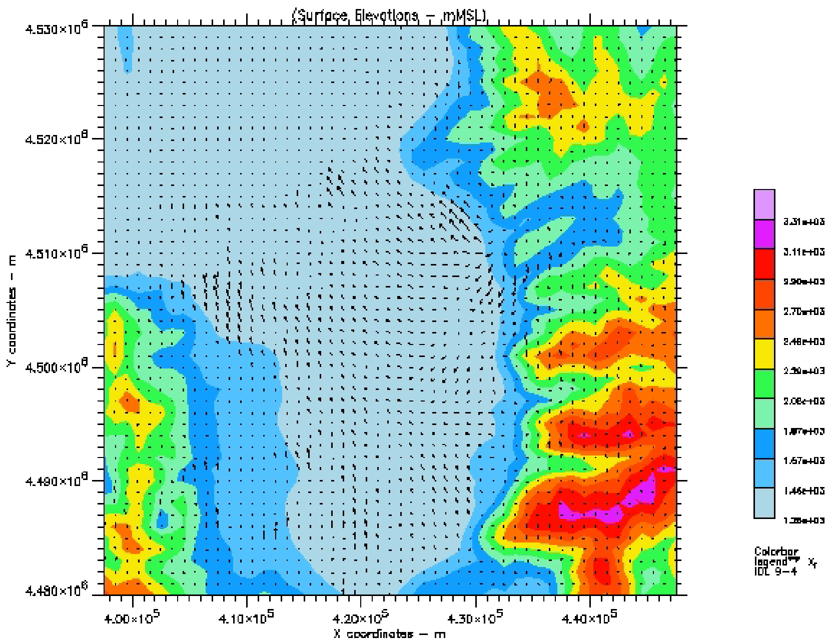


Figure 7. 6 m AGL velocity differences (non-urban result minus the urban result) using LULC building height data. (Maximum velocity = 3 m/s.)

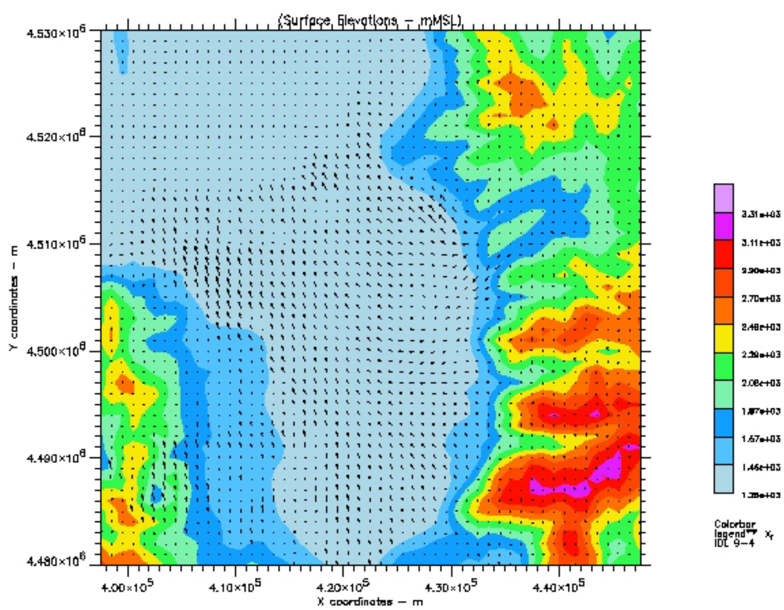


Figure 8. 6 meter AGL velocity difference (the non-urban result minus the urban result) using NLCD building height data. (Maximum velocity = 2.5 m/s)

It is apparent from the figures that the urban parameterization slows the winds by over two meters per second at the lower levels. Examination of the average building height data shows that there is a very high correlation between the reduction and the regions with significant urban structures in the Salt Lake City region and at the base of the mountain at the left center of the grid, also a region of urban development.. The slowing effect decreases rapidly above the surface layer. It is noteworthy that although different in detail, the LULC and NLCD data produce qualitatively similar patterns. In fact, some of the largest differences are in the lower left corner of the grid where the NLCD data has urban development not seen in the LULC data.

Direct evaluation of the ADAPT urban parameterization wind fields is difficult as the model produces area-averaged winds, while point observations within the urban area are very sensitive to local influences. One of the best ways to verify the wind field is via a tracer experiment. During IOP 10 of the URBAN experiment, SF6 was released in the downtown in three one-hour pulses from 00-01, 02-03, and 04-05 MST on Oct 26, 2000. Sampling sites were located in arcs out to 6 kilometers. Data from these arcs is just now becoming available and we are currently conducting ADAPT/LODI dispersion simulations to compare with this data. Below is a sample of the simulated plume which compares qualitatively with the initial data in the mean direction of the plume. Detailed comparisons should provide a test of the urban parameterization.

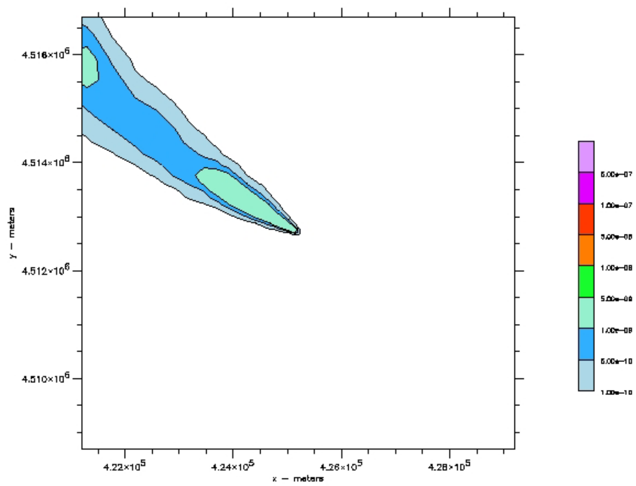


Figure 9. 1 hour average surface concentrations at 06 MST using the non-urban wind fields.

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