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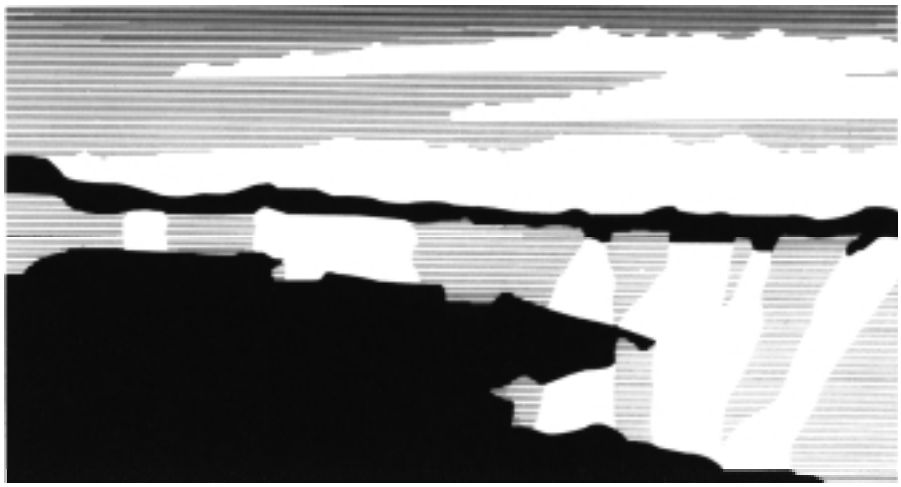

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2.4 TRACER MODELING IN AN URBAN ENVIRONMENT

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1. INTRODUCTION

The accurate simulation of the transport of a tracer released into an urban area requires sufficiently high model resolution (1-10 m grid cells) to resolve buildings and urban street canyons. Within our group a modeling effort has been underway to develop a model — termed HIGRAD — capable of simulating flow at the high spatial resolution required within the urban environment. HIGRAD uses state-of-the-art numerical techniques to accurately simulate the regions of strong shear found near edges of buildings (Smolarkiewicz and Grabowski, 1990; Smolarkiewicz and Margolin, 1993; Smolarkiewicz and Margolin, 1994). HIGRAD also employs a newly developed radiation package which in addition to standard shortwave and longwave heating/cooling effects can account for the shadowing effects of building complexes on the urban flow field. Idealized simulations have been conducted which clearly illustrate the role radiation plays in transport and dispersion in an urban setting. For instance, idealized two-dimensional simulations reveal fewer boundary-layer eddies within cooler shaded regions and rather persistent eddies on the tops of buildings. We have also modeled the flow of an inert tracer in a realistic, complex urban environment. Complex flow/building interactions were produced during the simulation and these interactions had a significant impact on the transport of the tracer. These simulations also show the impact of radiative heating on the overall tracer flow. We show the results of several simulations that illustrate the effect of radiative heating and building complexes on the overall atmospheric flow. Two basic experiments are shown. The first shows the comparison of a tracer release at the southern boundary of the model domain, with southerly ambient winds of about 2ms^{-1}. Temperature and moisture profiles characteristic of an early afternoon boundary layer were used to initialize the model. The second experiment consists of idealized 2-D runs that show the effect of two buildings on the overall boundary-layer flow. In this experiment, we examine the effect of winds, radiative heating, and the buildings themselves on the flow field. Each of these experiments is summarized below.

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2. RADIATIVE HEATING

The effects of radiative heating in the model are illustrated in Figures 1a-1c. Figure 1a shows the near surface net radiative heating pattern at 0700 LST for a

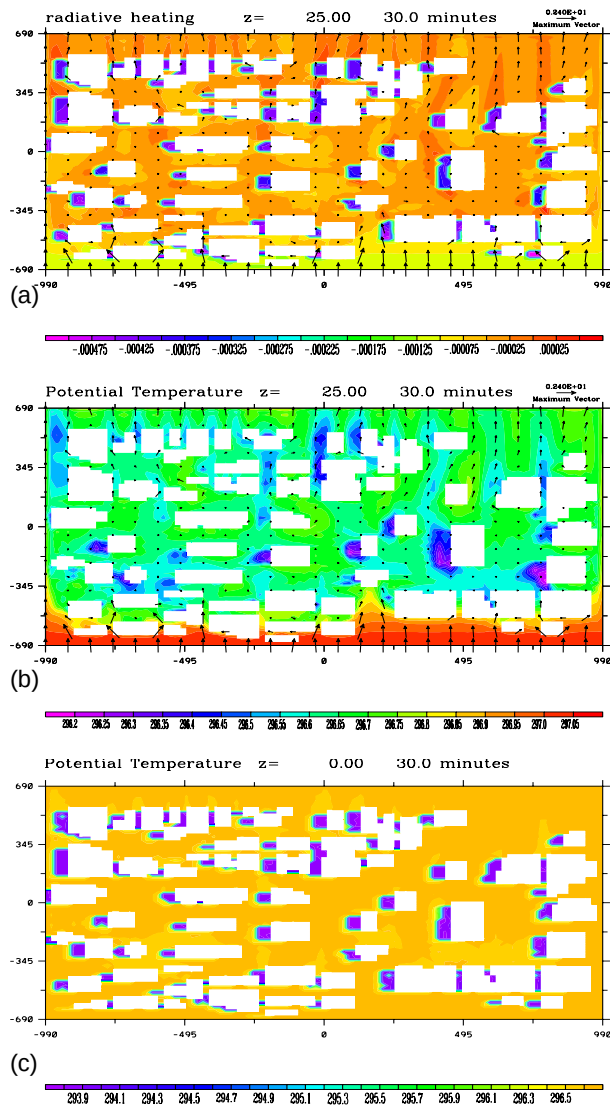

Figure 1. 0700 LST (a) net radiative heating (K-s^{-1})at sigma coordinate z=25m (10m vertical height). (b) Potential temperature (K) at same height. (c) Surface potential temperature. White spaces are buildings.

model simulation begun at 0630 LST with ambient southerly winds of 2 m-s^{-1}. Wind vectors at a vertical-height of 10 m are superimposed in Figs 1a and 1b to

illustrate the overall horzontal flow field. The impact of shadowing is evident on the overall heating pattern. Net radiative cooling occurs primarily in the shaded regions, induced by the proximity to the cool, shaded surface (shown in Figure 1c). Figure 1b shows the slight cooling of the atmosphere in the model layer just above the shaded surface areas. This cooling is primarily associated with heat exchange between the air and the cool shaded surface areas.

3. 3-D TRACER RELEASE

Figures 2 and 3 show the results of a 1230 LST tracer release without radiative heating in the southern portion of the model domain. The time integrated tracer pattern 30 minutes after the release is shown. The near surface wind field is superimposed in Figure 2. Figures 4

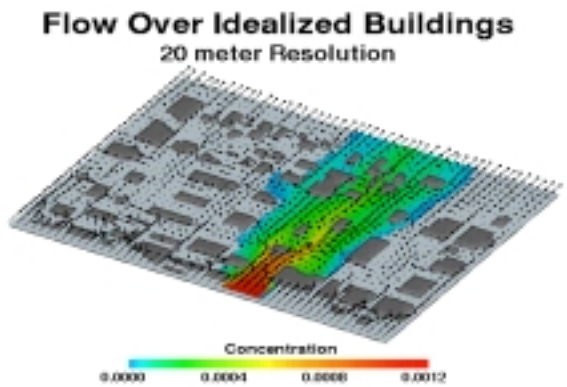

Figure 2. 1300 LST near surface time integrated tracer flow pattern, no radiative heating. Wind vectors are superimposed. Tracer flows in a fairly homogenous plume downwind of the release.

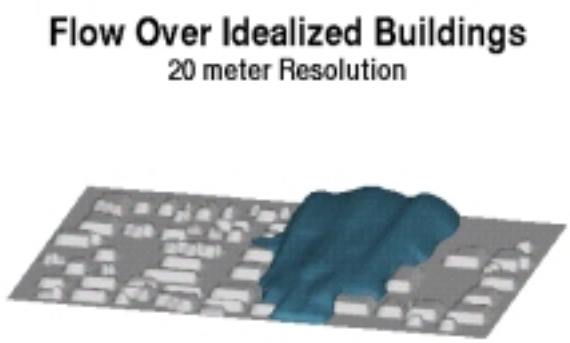

Figure 3. 1300 LST integrated tracer flow pattern without radiative heating. Tracer stays low in the boundary-layer and flows downwind of release.

and 5 are the same as Figures 2 and 3, except that radiative heating is included. The differences in the flow induced by radiative heating are quite dramatic. When it is included in the simulation, thermals sweep the tracer up into all levels of the boundary layer. In the figures shown, this results in divergent motion downwind of the tracer release that inhibits the development of thermals, and divides the tracer into two distinct plumes. Without

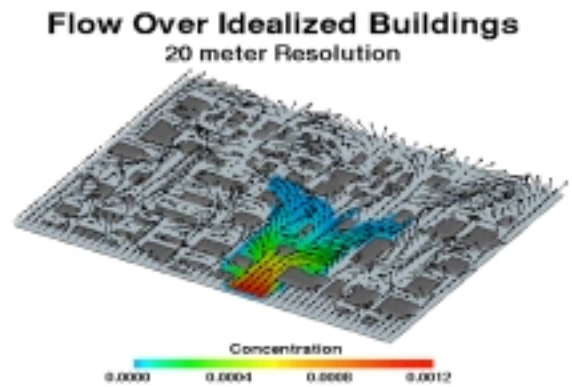

Figure 4. 1300 LST near surface time integrated tracer flow pattern affected by radiative heating. Wind vectors are superimposed. Tracer flow tends to separate in two plumes downwind of the release.

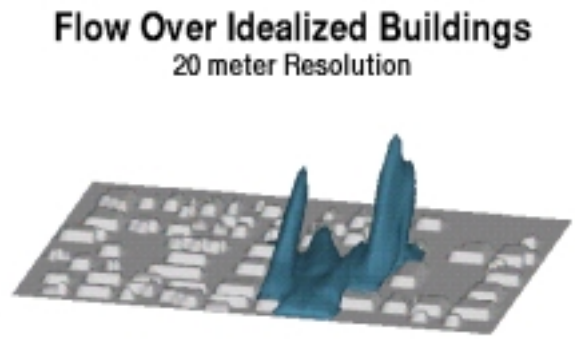

Figure 5. 1300 LST integrated tracer flow pattern with radiative heating. Tracer is separated into two distinct plumes rising throughout the boundary-layer.

radiative heating, the tracer spreads downwind of the release in a fairly homogenous plume. Figures 6a and 6b show horizontal crossections of the potential temperature field at sigma coordinates z=125 (about 60 m vertical height) and z=25 (10 m vertical height), respectively. Eddies rising above buildings and moving downwind are evident in Fig. 6a. The divergent flow downstream of the tracer release, and the convergent motion in the vicinity of the thermals is evident in both Figs. 6a and 6b. Crossections of the vertical profiles of potential temperature are shown in Figures 7a and 7b. In 7a, development of rising thermals is inhibited by overall downward divergent motion, while well developed thermals are seen in 7b.

4. IDEALIZED 2-D RUNS

These runs are initialized at 0630 LST using a stable morning profile for temperature and moisture. The potential temperature field after 2 hours of simulation is shown. Wind vectors are superimposed to illustrate the flow field. Figures 8a and 8b show the potential temperature field for runs initialized with ambient winds of 2 ms^{-1}, without radiative heating (a), and with radiative heating

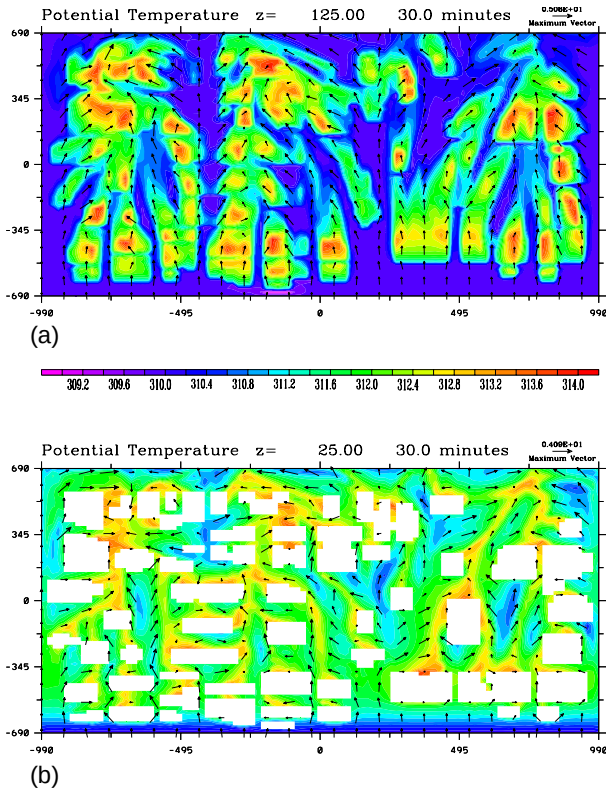

Figure 6. Potential temperature at 1300 LST for (a) sigma coordinate z=125 (approximately 60 m vertical height), (b)and sigma=25 (10m vertical height). Both runs begin at 1230 LST. Plumes evolving from building tops are most evident in (a)

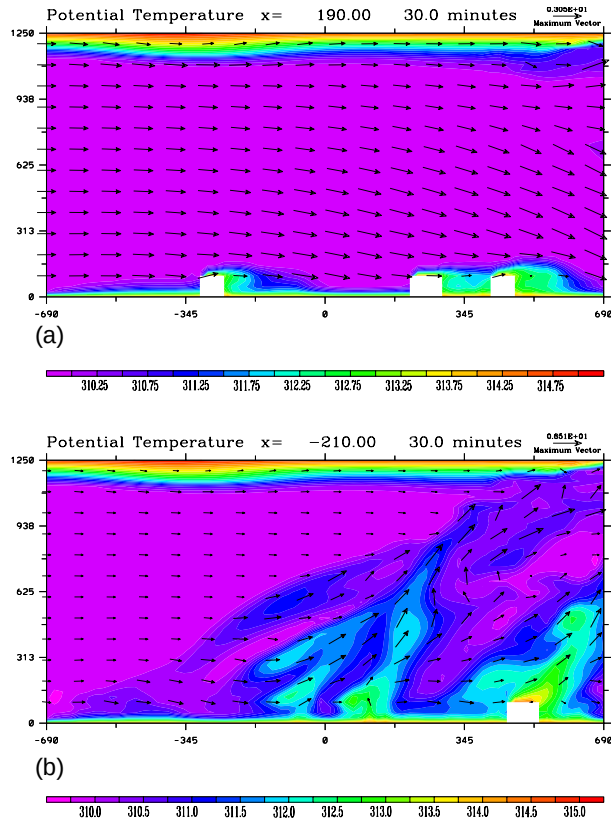

Figure 7. 1300 LST vertical potential temperature profiles for (a) crossection at x=190 m and (b) crossection at x=-210 m. Well developed thermals rising in the boundary-layer are evident in (b) while overall downward motion prevents thermals from forming in (a).

(b). The run shown in Figure 8c is initialized with no ambient wind, and includes radiative heating. In Figure 8a, turbulence in the boundary layer is generated by wind shear only, while 8b shows rising thermals due to radiative heating, and enhanced entrainment of the free atmosphere into the boundary layer. The effect of buildings on the location and size of thermals in the absence of ambient winds is illustrated in 8c. In the cases with radiative heating, there tends to be less turbulence in shaded regions. The tops of the buildings are also characterized by warmer temperature than the surrounding environment. This feature of the model simulation is probably due to recirculation at the building tops that results in reduced transport of heat to the environment.

5. CONCLUSIONS

HIGRAD was used to perform 2-D idealized simulations, and more realistic 3-D simulations of an inert tracer release in an urban setting. These simulations were used to study the effect of radiative heating, as well as buildings and urban complexes, on the overall atmospheric flow. The 3-D tracer release experiments shown reveal the interesting effects of radiative heating on the transport of the tracer in the modeled urban setting. In our experiment, radiative heating creates thermal plumes that sweep the tracer up into all levels of the boundary layer. These plumes cause a region of divergent flow in the center of the modeled urban setting. Without radiative heating, the tracer tends to flow downstream of the release point in a fairly homogenous plume.

The 2-D idealized experiments shown illustrate the respective roles of wind shear and buoyancy driven by radiative heating on the overall tubulent structure of the boundary layer. These experiments also suggest that buildings may act as anchors for the formation of turbulent eddies in the boundary layer. These experiments also clearly show fewer boundary-layer eddies within cooler shaded regions and rather persistent eddies on the tops of buildings.

Currently, work is underway to validate the HIGRAD model at various resolutions and scales against avialable wind tunnel data for single buildings. This work focuses on documenting the performance of HIGRAD in simulating well known features of the building induced flow such as the horseshoe vortex, cavity zone, stagnation points separation and reattachment points, recirculation patterns, and overall turbulence features. Future work will include a budget study of the interesting heating effect produced at the tops of buildings (Figures 6, 7, and 8) and more detailed simulations of multi-building urban settings.

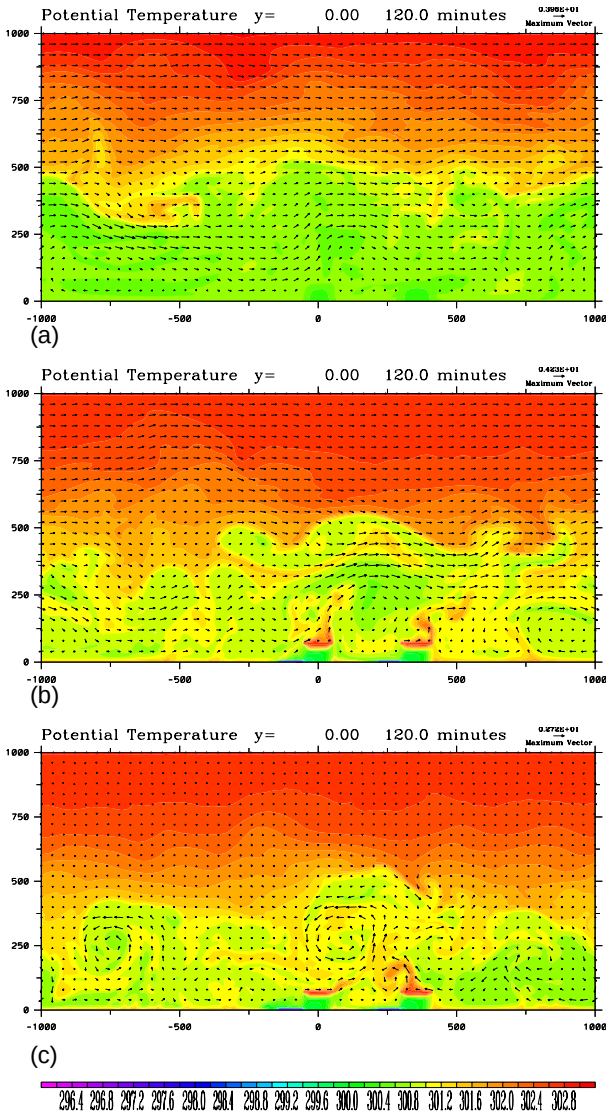

Figure 8: 0830 LST potential temperature (K) field for idealized 2-D experiment (a) with 2 ms^{-1} ambient winds and without radiative heating, (b) with 2 ms^{-1} ambient winds and radiative heating. (c) No ambient wind, but radiative heating included. Run begins at 0630 LST. Effect of buildings, radiative heating and shading on the boundary layer is clearly evident.

6. REFERENCES

Smolarkiewicz, P. K., and W. H. Grabowski, 1990: The multidimensional positive definite advection transport algorithm: nonoscillatory option. *J. Comp. Phys.*, **2**, 355-375.

—, and L. G. Margolin, 1993: On forward-in-time differencing for fluids: extension to a curvilinear framework. *Mon. Wea. Rev.*, **121**, 1847-1859.

—, and —, 1994: Variational solver for elliptic problems in atmospheric flows. *Appl. Math. and Comp. Sci.*, **4**, 527-551.