2.5 URBAN IMPACT ON THE AIRFLOW: A FACTOR SEPARATION ANALYSIS OF THERMAL AND MECHANICAL CONTRIBUTIONS WITH A NUMERICAL MODEL

Alberto Martilli*
University of British Columbia, B. C., Canada.

1. INTRODUCTION

A city can strongly modify the boundary layer structure. The two most important causes are mechanical (drag and turbulence induced by buildings), and thermal (shadowing and trapping of radiation in urban canyons as well as thermal properties of the urban materials). A correct parameterization of these effects in mesoscale models is crucial for a good reproduction of pollutant dispersion.
Aim of this contribution is, firstly, to show that a detailed urban parameterization implemented in a mesoscale model is able to reproduce the observed nocturnal structure of the urban boundary layer, and, then, to use the model as a tool to understand the importance of different parameters (wind speed, urban morphology, rural soil moisture) and the mutual interactions between mechanical and thermal factors, using the technique of Stein and Alpert (1993).

2. MODEL DESCRIPTION

The urban exchange parameterization used (Martilli et al. 2002), takes into account the impact of the vertical (walls), and horizontal (streets and roofs) surfaces on momentum and turbulent kinetic energy equations (mechanical factors), as well as on temperature equation (thermal factors). For the mechanical part, a porous approach is used in analogy with the techniques used for vegetation canopy flows. For the thermal part, the heat fluxes from the vertical and horizontal surfaces are computed with an energy budget at the surface. The radiations needed for this budget take into account the shadowing, the reflections and trapping in the urban street canyons.
The mesoscale model used (Martilli et al. 2002) is anelastic non-hydrostatic and boussinesq. The turbulence closure is k-l.

3. TEST CASE

The modeling domain is flat and 2D. In the horizontal, there are 100 numerical grid points with a resolution of 1 km. Vertical resolution is 10 m for the firsts five points near the ground, then it is stretched (with a ratio 1.1) up to 6000 m (top of the domain). The city is located at the center of the domain and is 10 km large. The characteristics of the urban area are the same for all the points. For the base case the mean building height and street width is 15 m, the initial wind speed is 3 m/s and the atmospheric stability is 3.5 K/Km. In rural areas the soil moisture content is 0.25 (volume of water per volume of soil).

4. VALIDATION

Several field experiments have shown a nocturnal elevated inversion layer above a city (New York, Bornstein, 1968, St Louis, Godowitch et al. 1985, Sapporo, Uno et al. 1988). The inversion base altitude Z_h (height where the vertical temperature gradient become positive) ranges between 40-60 m (Sapporo) and 150 m (St. Louis).

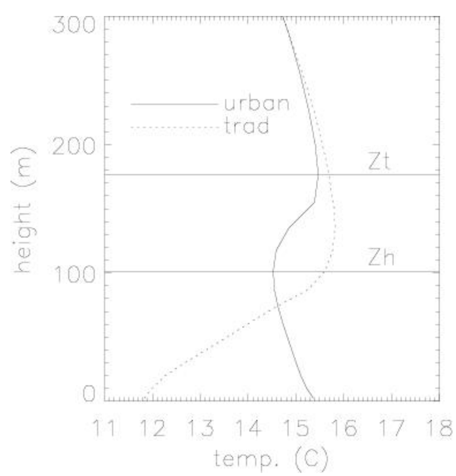

Fig. 1 *Comparison between new (solid line) and traditional (dashed line) approach for vertical profiles of temperature at the center of the urban area at 0300 LST.*

As it is shown in Fig. 1, the parameterization described in section 2 is able to reproduce this elevated inversion layer (inversion base altitude at about 80 m), while a traditional approach (roughness length of 1.5 m and thermal soil characteristics of concrete) is not. These comparisons give us confidence that the model is able to capture the most important features of the nocturnal Urban Boundary Layer.

* *Corresponding author address*: Alberto Martilli, The University of British Columbia, Dept. of Earth and Ocean Sciences, Vancouver, BC, Canada, V6T 1Z4, e-mail:amartilli@eos.ubc.ca

5. SENSITIVITY TO DIFFERENT PARAMETERS

The model has, then, been used as a tool to investigate the sensitivity of nocturnal urban boundary layer structure to different parameters.

5.1 Wind speed

Two other simulations have been done with the same set up described in section 3, but with weaker (1 m/s) and stronger (5 m/s) initial wind speed. Results show that an increase of wind speed increases the inversion base height, as well as the depth of the inversion (defined as the layer between Z_h and Z_t, with Z_t height where the vertical temperature gradient become negative above Z_h). Moreover, the inversion strength ($d\theta/dz$ in the inversion layer) increases with the wind speed.

5.2 Urban morphology

The sensitivity to urban morphology has been investigated by comparing the base case simulation to other two simulations with lower (7.5 m) and higher (30 m) mean building height. Results show that an increase in mean building height increases $Z_{h,}$ but decreases the inversion depth and inversion strength.

5.3 Rural soil moisture

Finally the impact of a modification in rural soil moisture is analyzed by comparing the base case with a simulation with drier soil (0.21 soil moisture content). Since a reduction in soil moisture content induces a stronger cooling of the surface, the stability of the approaching flow increases as the soil moisture decreases. As a consequence the simulation with drier soil show lower values for $Z_{h,}$ and a stronger inversion.

6. FACTOR ANALYSIS

To investigate the relative importance of mechanical and thermal factors on nocturnal urban boundary layer structure three other simulations are carried out for the base case (section 3) analyzed above: with only mechanical factors, with only thermal factors and without the city. Combining the results of these simulations, following the technique described by Stein and Alpert (1993), the thermal and mechanical factors and their interactions can be identified. In a layer near the ground (below 40 m, roughly twice the urban canopy layer), positive effects (meaning an increase of temperature as compared to the rural case) are computed for mechanical (*Sm*) and thermal (*St*) factors and a negative effect for interactions (*Stm*) (Fig. 2). In this layer, and in particular at ground level, *St* is greater than *Sm*, meaning that thermal factors are more important than mechanical in the formation of the urban heat island in the lower boundary layer. Above that height there is a second layer (50 m deep) where *Sm* and, to less extent, *St* are negative and *Stm* is positive. Mechanical factors are, then, more important than thermal ones in cooling (due to vertical mixing) the upper UBL. Both layers are below Z_h. Aloft, in the inversion layer, *St*, *Sm* and *Stm* are negative, all acting to increase the strength of the inversion, but, again, thermal factors are less important, while mechanical are dominant in the lower part of the layer and interactions in the central part of the inversion layer.

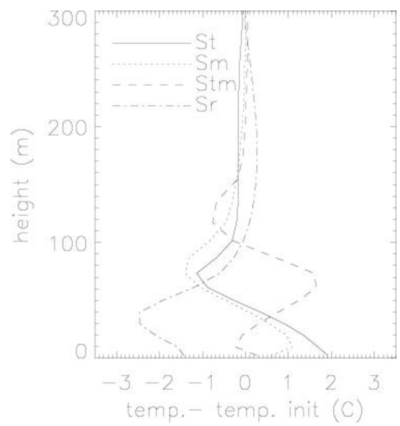

Fig. 2 *Vertical profiles of thermal (St), mechanical (Sm), interactions between thermal and mechanical (Stm) and rural (Sr) factors for difference between temperature and initial temperature*

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