# SENSITIVITY STUDY OF THE URBAN HEAT ISLAND INTENSITY TO URBAN CHARACTERISTICS

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**Abstract**

A detailed urban surface exchange parameterization, implemented in a mesoscale atmospheric model, has been used to study the urban heat island intensity during a summer period in the city of Basel, Switzerland. In this urban parameterization, the city is represented as a combination of three urban classes (road, roof, and wall), characterized by the size of the street canyon and the building and is thus able to take into account the momentum sink over the entire height of the building, as well as the shadowing and the radiation trapping effects. A control experiment including all the urban parameters describing the city center of Basel, produced a canyon air temperature that compared well with observations. A series of experiments was then conducted in which successively each of the urban parameters characterizing the city center was changed providing the basis for an assessment of its effect on urban heat island mitigation.

**Key words:** BUBBLE, Martilli's module, Urban heat island

## 1. INTRODUCTION

In response to the numerous limitations of the simple urbanization approaches, recent efforts have focused on incorporation of sophisticated techniques to parameterize urban effects on the thermodynamic and momentum fields in mesoscale and building-scale numerical models. In this study, we use the parameterization of Martilli et al. (2002) which combines the thermal and dynamical effect of the urban canopy, since mesoscale models do not have the spatial resolution to simulate the fluid dynamic and thermodynamic in and around urban structures. This urban module represents the city as a combination of three urban classes (road, roof, and wall), characterized by the size of the street canyon and the building and is thus able to take into account the sink of momentum over the entire height of the building, as well as the shadowing and the radiation trapping effects, which are commonly neglected. The Martilli's urban scheme is one of the most complete parameterization of urban effects, no other urban parameterization, except the one by Masson (2000), explicitly considers the effects of buildings, roads, and other artificial materials on the urban surface energy budget. However, the Martilli's urban scheme did not include vegetation in its original version, and in the literature a lot of numerical simulations and field measurements indicate that increasing vegetation cover in urban area can be effective in reducing the surface and air temperature near the ground (Taha, 1997). Thus, in order to take into account the vegetation effect on urban canopy, we divide the urban grid cell into a non-urban fraction (vegetated fraction) and a urban fraction, and then further subdivide the urban canopy fraction into road, wall, and roof according to Martilli's scheme. This new version is implemented in a mesoscale model TVM (Thunis and Clappier, 2000). In a lot of numerical modeling studies, results suggest that city size has little effect on the UHI intensity. Seaman et al. (1989) found that an increase in urban area of a factor of three resulted in an increase of only 0.1°C in UHI intensity. In the paper of Atkinson (2003), the horizontal dimension of the urban area was varied from 6 to 20 km. Results revealed only a small sensitivity, about 0.2 °C, of the UHI intensity to city size. Energy budget modeling of Oke et al. (1991) strongly suggested that factors other than size were more important in determining the intensity of the UHI: thermal properties of materials, urban geometry, and vegetation cover. Therefore, in order to study the relative contribution of every factor in the genesis and the development of the UHI, our urbanized mesoscale model is run on a 1D-column. The methodology of the study was as follows. A control experiment, including all the urban parameters describing the urban area, produced a canyon air temperature that compared well with observations. Sensitivity experiments, in which successively one of the parameters was changed, allowed identification of the role of that parameter.

## 2. THE 1-D CONFIGURATION

In this study, TVM is run on a vertical column using measurements recorded at tower top (30 m) as forcing. The model calculates the meteorological variables from this level down to the ground (Figure 1). Forcing is applied to wind, temperature, humidity, turbulent kinetic energy, and downward global short- and long-wave radiation. The period of the simulations extends from 17 June to 19 June 2002 (3 clear sky days). The wind speed ranged from 0.61 to 2.85 m $s^{-1}$. As the model is run in a 1-D column, no horizontal advection is considered. In fact, since the temperature gradient around the site of Basel-Sperrstrasse is not as strong as in Pigeon et al. (2007), the horizontal advection is not a significant term. The vertical resolution is set to 5 m.

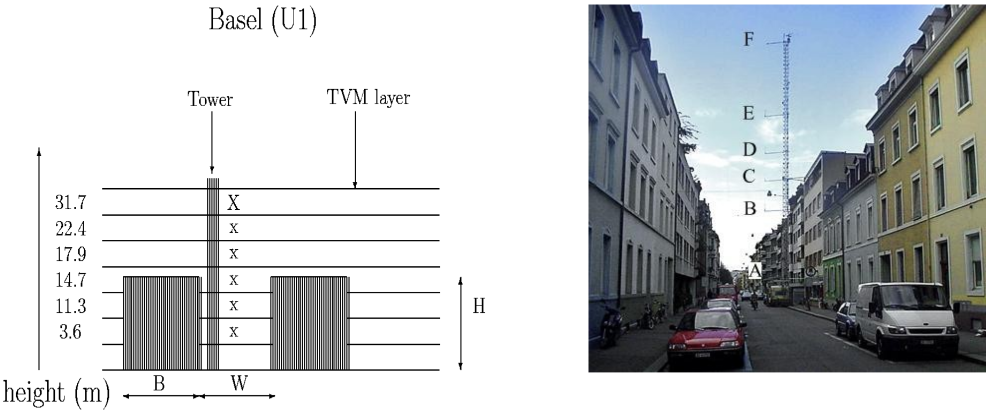

**Fig. 1. Configuration of the 1D configuration, with forcing from the top (*), and calculation down to the ground in the street canyon (x), and schematic representation of the city (street and buildings).**

Two simulations were performed (see Hamdi and Schayes (2008) for more details). The first simulation, denoted "control", uses the urban version of TVM. The second simulation, called "classical", represents the classical approach used in TVM to account for urban surface using the Monin-Obukhov Similarity Theory (city characterized only by a change in roughness length and the surface conditions).

## 3. CANYON AIR TEMPERATURE

Figure 2a shows the time variation, from June 17 to June 19 2002, of the observed temperature, inside the street canyon at 2.5 m for U1 and at 2 m for the rural reference station R (Village Neuf). The computed temperature using the urban version "control" and the classical approach used in the model to account for urban surface "classical" are also represented. Good correlations are found between the urban simulation and the observations measured inside the urban canyon at U1. Cooling during nighttime is less important with the urban simulation than with the classical one. As a result, the classical simulation underestimates the daily minimum by 3 to 5 °C. Taking into account, differential heating/cooling of buildings surfaces, radiation trapping effects in street canyon and heat storage in buildings allow the urban simulation to reproduce the generation of the UHI effect. In Figure 2b the near-surface simulated or observed UHI was defined as the difference, between the simulated or observed urban temperature inside the street canyon at 2.5 m at U1 and the observed rural reference temperature at 2 m, averaged over the 3 days covering the period of simulation. The observed UHI stays positive night and day. The rapid cooling in the rural reference station, combined with a nocturnal release of heat in the city center of Basel (Hamdi and Schayes, 2007), enhances the UHI during the night. At 2300 UTC, the UHI reaches 5 °C. Such a well developed heat island is not surprising for the climatic conditions of the period of simulation (anticyclonic situation and low wind). The UHI is less intense during the day. After sunrise the temperature in the rural reference station increases more rapidly than in the city center of Basel leading to a minimum of the UHI intensity, 0 °C at 0700 UTC. In fact, the incident energy is used by the surfaces to heat the atmosphere, for heat storage, and as an evaporation flux. Since the heat storage in artificial materials is dominant in the morning in urban areas, the atmospheric warming is delayed and limited. In the same way, urban cooling is reduced because of the heat release by the surfaces to the atmosphere (Lemonsu et al., 2004). During the day the UHI reaches its maximum of 2 °C at noon. In the afternoon, the cooling process begins with the decrease of solar radiation, inducing a decrease of the UHI by 1 °C. After 1600 UTC, the heat storage flux gets negative and releases energy to the surface (Hamdi and Schayes, 2007) inducing an increase of the UHI.

The urban simulation, "control", captures all these elements of the diurnal variation of the UHI, but:

1. overestimates slightly the diminution of the UHI in the morning.
2. overestimates the UHI between 1200 and 1600 UTC by 1 °C.

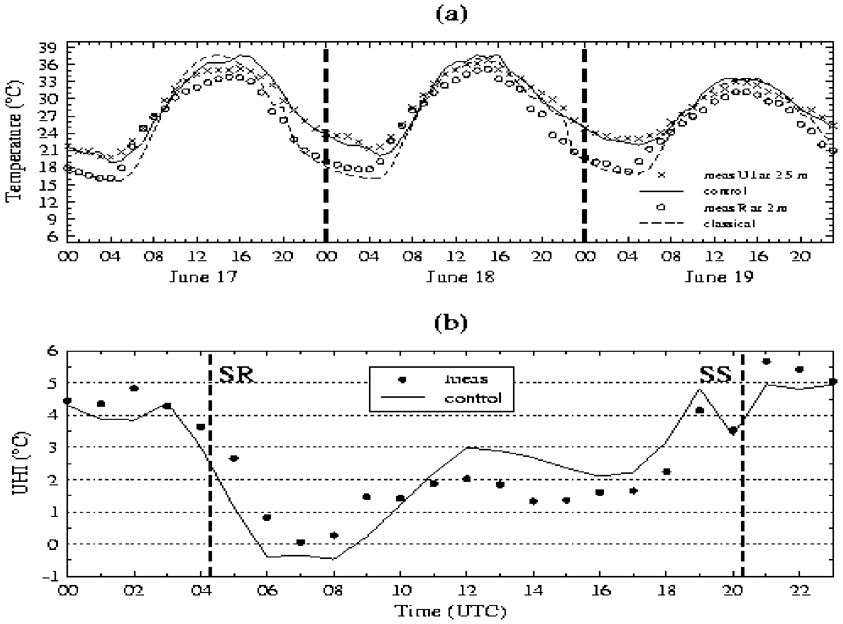

**Figure 2. (a) The time variation, from June 17 to June 19 2002, of the observed temperature, inside the street canyon at 2.5 m for U1 and at 2 m for the rural reference station R, and computed using the urban version of the topographic vorticity-mode mesoscale model "control" and the classical approach used in the model to account for urban surface "classical". (b) The urban heat island defined as the difference between the simulated or observed urban temperature inside the street canyon at 2.5 m at U1 and the observed rural reference temperature at 2 m, averaged over the 3 days covering the period of simulation. SR is sunrise; SS is sunset.**

The surface energy budget and the three surface temperatures (roof, wall, road) were validated by Hamdi and Schayes (2007) for Basel and Marseilles city center. The model represents correctly most of the behavior of the fluxes typical of the city center of Basel, including the large heat uptake by the urban fabric and the positive sensible heat flux at night. Evaluation of the model with wall, road, and roof surface temperatures gave good results with a bias less than 1 °C for the three surface temperatures for Marseilles city center. The agreement between the simulated energetics and intensity of the UHI and observations suggest that further analysis is profitable. In this context, the effects of the surface characteristics on UHI intensity are assessed in the next section.

## 3. SENSITIVITY STUDIES (MORE DETAILS IN HAMDI AND SCHAYES (2008))

The results showed a difference in the causes of daytime and nighttime urban heat islands. It is shown that:

● Increasing thermal diffusivity, heat capacity, surface albedo, and fraction of vegetation, and roof planting decreases summer peak temperature during daytime.

- Increasing thermal diffusivity, heat capacity, and roof planting produces the opposite effect during nighttime.
- At night the effect of street canyon geometry on urban heat island intensity is the most important.
- Surface emissivity have a minimal effect on urban heat island intensity.
- The intensity of the maximum nighttime urban heat island presents a linear relationship with the Sky View Factor.

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