5.18 A SENSITIVITY ANALYSIS OF URBAN BOUNDARY LAYER ON CANOPY DESCRIPTION

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INTRODUCTION

The air quality in an urban area depends on meteorological processes involved in the dispersion of pollutants emitted in the region. A city is commonly admitted to induce a local circulation by its morphological and thermal properties. Indeed, changes in aerodynamic roughness due to the presence of different types and arrangement of buildings, modifies the urban boundary layer flow dynamics. Materials used in buildings have different heat capacities and different albedo that modify energy budget. In numerical simulations, cities are most of the time represented by a rural area with poor soil water content, and with a high aerodynamic roughness. However, this may not be sufficient for meso- to local-scale simulations. An improvement of city characterisation is an effort admitted by the scientific community.

For moderate wind condition, simulations performed with the SUBMESO atmospheric model coupled with the SM2-U soil model (*Dupont, S. et al.,* 2003), demonstrated the urban boundary layer flow dependence on the city representation. Three simulations were performed, with first, as a reference, a detailed city composed of specific districts. Results were compared with a mean city, to evaluate city aerodynamic effect, and with a classical "rural" city, to assess its thermal effects. Differences are significant: particularly, the development of an urban heat island is observed, occurring only above the detailed city, showing the importance of considering urban heterogeneity.

A study of sensitivity to synoptic forcing is presented here, aiming at determining if the same conclusions can be drawn under different meteorological conditions. New simulations with the same urban characteristics, but with a lower synoptic wind forcing are analysed here and compared with previous results.

PRESENTATION OF THE MODELS

The atmospheric model SUBMESO

SUBMESO is a compressible non hydrostatic model developed at the *Ecole Centrale de Nantes*, derived from the Advanced Regional Prediction System (*ARPS)* model. Navier-Stokes equations are solved using Large Eddy Simulation method (*Anquetin et al*., 1999). The subgrid-scale fluxes are modelled by solving an equation for the turbulent kinetic energy. It allows simulating atmospheric flows with a range of mesh resolution from a few meters to several kilometres. The equations are written in the 'terrain-following' coordinate system. An option for stretching grid vertically is available while the mesh is homogeneous in the horizontal direction. The solution is advanced in time using a time-splitting method. The heat, moisture and momentum fluxes based on the Monin-Obukhov Similarity Theory are used as boundary condition in the first cell layer at the ground, to model canopy influence on the boundary layer flow.

The soil model SM2-U

SM2-U is the urban extension of the force-restore model of *Noilhan, J. and S. Planton* (1989). It is composed with 3 soil layers and a canopy layer. In each computational cell at the ground, 7 types of covers are defined by their characteristics and surface density: bare soil without vegetation (denoted "*bare*"), bare soil located between sparse vegetation elements (*nat*), vegetation over bare soil (*vegn*), vegetation over paved surfaces (e.g., trees on the road side: *vega*), paved surfaces located between the sparse vegetation elements (*pav*), building roofs (*roof*), and water surfaces (*wat*). The horizontal exchanges inside the urban canopy are not considered except radiation reflections and water runoff from saturated surfaces. The deep soil temperature and water content remain constant during the day. For buildings and water surfaces temperature evolution, a simple conduction equation is used, without force-restore process. Important processes like radiative trapping inside the street canyon is parameterised by an effective albedo of the street. The surface dynamical influence is represented through roughness lengths and displacement heights. Energy and water budgets are performed for each type of surface in order to deduce heat and moisture fluxes to be set at the interface between canopy and atmosphere (*Dupont, S.*, 2001).

SIMULATIONS SETUP

Atmospheric model implementation

Large eddy simulations have been performed with SUBMESO. The grid size is 100 km west-east and 50 km south-north and the horizontal mesh resolution is one square kilometre. The first vertical level is at 20 meters, and the last is at 4600 m, at the top of a Rayleigh layer. Zero gradient condition is set on lateral boundaries, except for the Eastern one (downstream) where a radiative condition is imposed to avoid wave reflections. A synoptic wind forcing at 1 m/s blows eastward all the time, and the atmosphere is assumed hydrostatic and stably stratified at the initial time (midnight UTC, the June, 22nd), at the geographical position of (47°N, 5°E).

Surface parameters

Surface characteristics are summarised in Table 1. Taking the four districts detailed city ($S1_{ref}$) and the mean city ($S2_{ref}$) simulations with moderate wind (3 m/s) as references, the same urban surface characteristics are used in the $S1_{lw}$ and $S2_{lw}$ cases, but with wind of 1 m/s. The urban area is 21 km × 26 km for all cases. H/W is the mean street aspect ratio.

Table1. Values of districts, urban, and rural areas parameters used in SM2-U.

Parameter	*Unit*	*City-centre (CC)*	*Residential district (RD)*	*High building districts (HBD)*	*Industrial & commercial district (ICD)*	*Urban Area (UA)*	*Rural area (RA)*
Simulation concerned		$S1_{ref}$, $S1_{lw}$	$S1_{ref}$, $S1_{lw}$	$S1_{ref}$, $S1_{lw}$	$S1_{ref}$, $S1_{lw}$	$S2_{ref}$, $S2_{lw}$	*All*
f_{vega}	-	0.10	0.00	0.025	0.00	0.013	0.00
f_{vegn}	-	0.00	0.30	0.225	0.00	0.190	0.90
f_{nat}	-	0.00	0.20	0.05	0.00	0.080	1.00
f_{bare}	-	0.00	0.00	0.00	0.10	0.040	0.00
f_{roof}	-	0.50	0.20	0.30	0.40	0.300	0.00
f_{pav}	-	0.40	0.30	0.40	0.50	0.277	0.00
f_{wat}	-	0.00	0.00	0.00	0.00	0.000	0.00
salinity	‰	-	-	-	-	-	-
Z_{0m}	*m*	1.00	0.40	1.20	0.80	0.75	0.15
H/W	-	2.8	0.7	3.0	0.4	1.26	-

All the simulations are performed by imposing a constant ratio of 10 between momentum and scalar roughness lengths.

IMPACT OF THE SYNOPTIC FORCING

Energy budget analysis

Figure 1 represents urban area (UA) averaged energy budgets of $S1_{ref}$, $S1_{lw}$, $S2_{ref}$ et $S2_{lw}$. It appears that the energy budget is more dependant on the surface characteristics than on the synoptic forcing; the same behaviour is observed between $S1_{ref}$ and $S1_{lw}$, when districts are well described, and between $S2_{ref}$ and $S2_{lw}$ when the urban area is averaged. Nevertheless, sensible and latent heat fluxes are more homogeneous in low wind cases than in moderate wind cases. Particularly, the storage heat flux reaches a maximum (190 $w.m^{-2}$) at 10:30 in $S1_{ref}$ case, while it is only 158 $w.m^{-2}$ in $S1_{lw}$ at the same hour. Consequently, less energy is released in the evening in $S1_{lw}$ (103 $w.m^{-2}$ compared to 153 $w.m^{-2}$ at 19:30 at the maximum), reducing the urban heat island effect. $S1_{lw}$ surface energy budget behaviour can be seen closer to that of the mean city $S2_{ref}$. This is explained by the fact that in both simulations the districts do not interact with each other; in $S2_{ref}$ because the heterogeneity of the city is not considered, and in $S1_{lw}$ because the convective cells generated above the warmest districts are not advected over the other ones. An illustration is given in Figure 2 by looking at the energy budget for one of the “warmest” district (the City Centre) for simulations $S1_{ref}$ and $S1_{lw}$. The main differences appear on the sensible and storage heat fluxes where the influence of the advection of air from other districts is generated by fluctuations of the fluxes up to 100 $w.m^{-2}$ in the moderate wind case $S1_{ref}$.

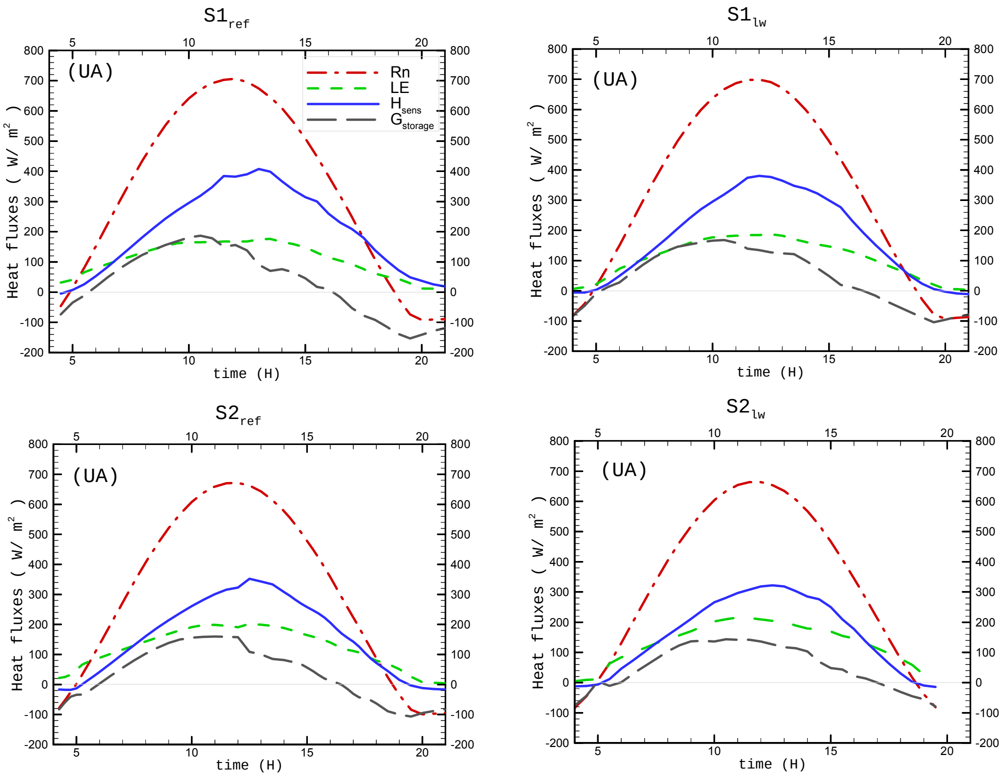

Figure 1. Energy budgets in the whole urban area for the four simulation cases $S1_{ref}$, $S1_{lw}$, $S2_{ref}$ and $S2_{lw}$. The net radiation flux (Rn), the latent heat flux (LE) , the sensible heat flux (H_{sens}) and the storage heat flux ($G_{storage}$) are represented. Time is in hour UTC.

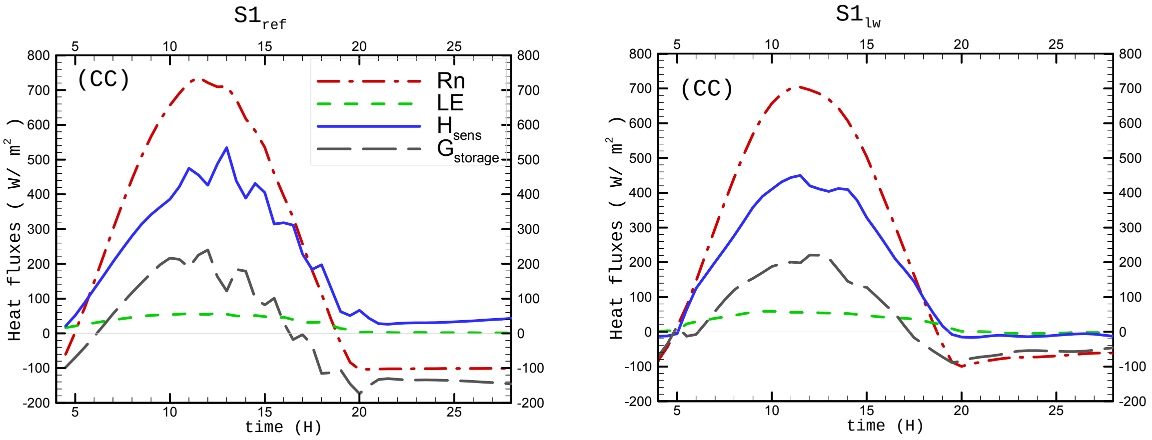

Figure 2. Energy budgets in the city centre (CC) for the simulation cases $S1_{ref}$ and $S1_{lw}$. Fluxes representation is the same as in figure 1.

Urban boundary layer analysis

During the day, convective cells due to urban surface warming are more intense in the low wind forcing case $S1_{lw}$ than in the $S1_{ref}$ case, because of the absence of strong horizontal advection affecting the moderate wind case. As can be seen in Figure 3, where potential temperature and wind at 12:00 are represented in the vertical central cross section (in the middle of the city), this situation leads to a more efficient air mixing between urban and rural areas in $S1_{lw}$ case. Indeed, even if the mean flow is weaker in $S1_{lw}$, the wind around the city

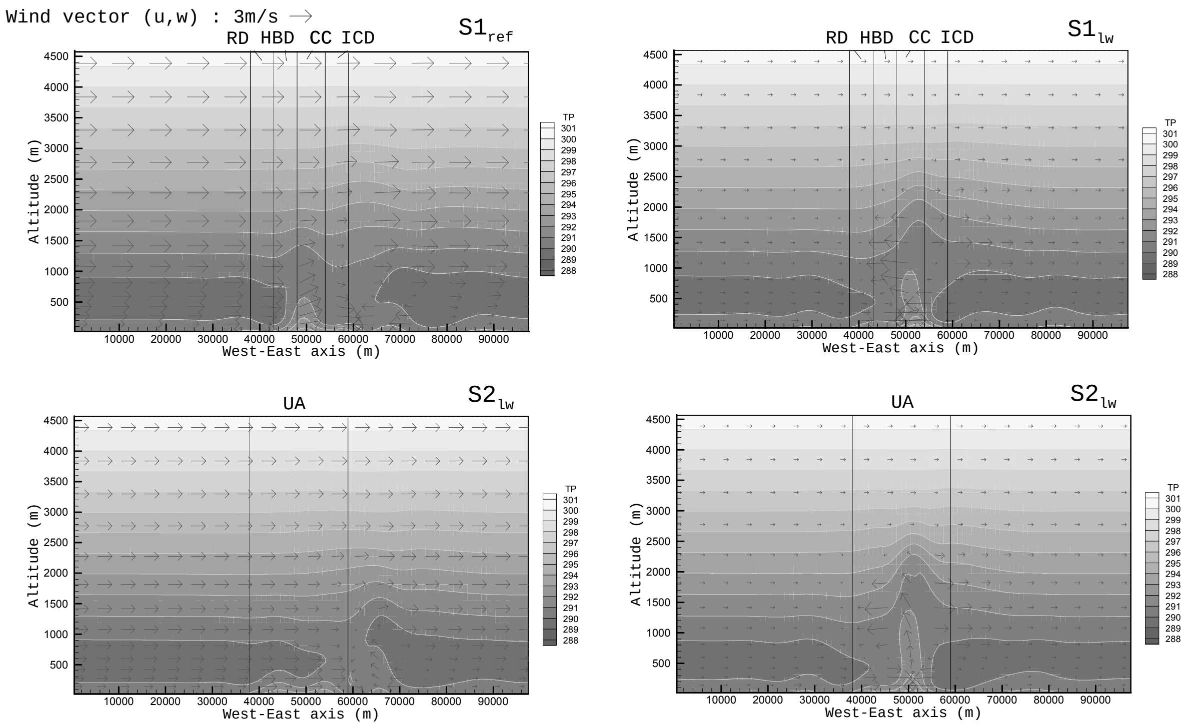

Figure 3. Potential temperature (K) vertical section at j=25 (middle of the domain S-N) at 12:00 UTC. Wind is represented by arrows and districts position is reported by black lines.

becomes much larger than the initial forcing, showing the city breeze phenomenon earlier and more intense than in the $S1_{ref}$ case. Warm air is easily convected in $S1_{lw}$ above the city, lifting up air masses layers until 2500m height. As a consequence, colder air masses from rural areas converges towards warmest districts, of the city centre (CC) and the industrial and commercial district (ICD). The same conclusions can be drawn by comparing mean city cases $S2_{ref}$ and $S2_{lw}$, but the effect of averaging is less pronounced in $S2_{lw}$ than in $S2_{ref}$. As there is no south-north forcing wind, urban breeze is also visible on transverse sections (not shown), where air masses convergence at surface and divergence at the mixing layer top, take place with a wind transversal component of 5-6 m/s for example in $S1_{lw}$.

CONCLUSION

Previous simulations carried out with SM2-U coupled with SUBMESO have demonstrated the benefit of detailing urban fabric in moderate wind forcing meso-scale atmospheric simulations. It is not so obvious in light wind conditions; in this case, the simulations presented here show that the urban canopy stores, and releases at night, less heat, reducing the urban heat island. The energy budget for the detailed city with weak wind is then closer to that of the city with averaged surface characteristics at moderate wind condition. Moreover, in the urban boundary layer, the mixing effect is more important for light wind in the two city representation cases, leading to urban surface coldness. The impact of averaging surface characteristics is then less pronounced. Horizontal advection is shown to play a very significant role in the dilution of the urban heat effects at higher levels, and the choice of city representation in meso-scale modelling may depend on the synoptic case study.

However, it should be pointed out that the parameterisation of the scalar roughness for heat and humidity depend on the friction velocity and on the wind speed; they may be over-estimated in our simulations. The influence of the roughness length values has to be tested. Another simulation will be performed with the presence of the sea, because an additional circulation modifies the development and the propagation of the urban breeze. After analysing the sea effects, this sensitivity study will allow us to determine the correct methodology to describe cities and simulate the real case of Marseille, where a detailed description of the urban land cover modes has been generated (*Long N.*, 2003), and where an important urban experiment took place in 2001 (*Mestayer, P.G. and P. Durand,* 2003).

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