MICRO-METEOROLOGICAL SIMULATIONS OVER THE COASTAL AREA OF MARSEILLE DURING THE ESCOMPTE EXPERIMENT

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INTRODUCTION

For coastal cities, the dispersion of pollutants emitted in the area depends on a complex system that combines urban- and sea-breezes with topographic flows. A first sensitivity study had already been conducted on an academic city over a flat terrain (*Leroyer et al,* 2004) with simulations with the atmospheric model SUBMESO, linked to the soil model SM2-U. It appeared that the inland penetration of the sea breeze was overestimated when using urban surface simplified description. Here LES are carried out on Marseille, to produce high-resolution meteorological simulations of the IOP2b of the "Urban Boundary Layer - ESCOMPTE" experiment (*Mestayer et al.*, 2005). This campaign took place in this important agglomeration in the south of France, frequently polluted in summer season, in June-July 2001. It aimed at documenting the thermodynamic behaviour of different urbanised sites, and the interaction sea-city. Three days (June 24th, 25th and 26th) of this period were dominated by sea-breeze regimes. In this paper, we compare simulation results with experimental data and analyse the effect of the city on the flow dynamics.

MATERIALS AND METHOD

Presentation of the models

In this study, Large Eddy Simulations (LES) are performed with the atmospheric model SUBMESO, derived from ARPS (*Xue et al.*, 2000). It is coupled with the soil model SM2-U (*Dupont*, 2001) that calculates aerodynamic and thermodynamic fluxes at the canopy-atmosphere interface, on both rural and urban areas. SM2-U has been successfully validated off-line against measurements on Marseille city centre (*Dupont and Mestayer*, 2004). The turbulent fluxes at the sea-atmosphere interface are calculated using a parameterisation of the aerodynamic roughness length, depending on the Reynolds number and on the friction velocity. This model is based on the LKB theory (*Liu et al.*, 1979), including the improvements of *Fairall et al.* (1996). This model has been validated on the FETCH experiment (*Hauser et al.*, 2003), by comparison with inertio-dissipative flux measurements. To achieve high resolution, the on-line grid nesting method is used, by coupling the AGRIF technical module (*Blayo and Debreu*, 1999) and the atmospheric model (*Pénelon*, 2002). In order to set the lateral boundary conditions of the largest domain with external meteorological data coming from another model, a Davies-type relaxation (on 6 cells inside the domain) is applied to the interpolated meteorological variables so that possible incompatibilities between models are smoothed.

Atmospheric model implementation

Three grids are nested, centred on Marseilles' city core (geographical position: 5.32°E, 43.23°N), following the adjustments given in table 1, as. shown by Figure 1. The topography is interpolated from the IGN database, at the resolutions of 110 m for the grids G2 and G3 and 1 km for G1. The regional conditions for the horizontal wind components, potential temperature, specific humidity and pressure are imposed by the hourly RAMS simulation outputs, at a 3 km resolution, which also provide the initial base state on the whole domain. Vertically, the first level follows the topography, at 15 m above ground level, and the upper levels are stretched so that the vertical coordinate for the 30th level is the same at each point (4000 m). About 18 levels are in the first 1000 m, to document well the boundary layer. A Rayleigh layer is then imposed between 5600 m and 9000 m.

Table 1. Simulation domain and nested grids characteristics

Grid name	Mesh resolution	Horizontal cell number	Time step	Acoustic time step
G1	990 m	41 × 44	0.9 s	0.03 s
G2	330 m	41 × 56	0.3 s	0.03 s
G3	110 m	32 × 32	0.1 s	0.01 s

Marseilles urban fabric

On the G2 grid the surface characteristics are determined by using an urban classification of Marseille, based on the IGN database "BD-Topo" available on this domain. This classification method was developed by *Long et al.*, (2003) with a 200 m resolution. As some small surfaces are missing in the BD-Topo, some corrections based on aerial photos are required to have information on the whole surface. A similar classification procedure has been obtained at the 330 m resolution and the results have been shown to provide a smaller variability coefficient than the 200 m classification, i.e., a better homogeneity inside the classes. It has also been decided to add a class called "Industrial and Commercial" due to the specific materials used for the roofs, a parameter that is not documented in the BD-Topo. Marseille is then composed with 10 urban classes, plus the rural and water classes.On G3, focusing on the city centre, the parameters are the same as on G2 since a 110 m classification does not constitute a real improvement on homogeneous districts. On G1, an average is done for the part of the domain that covers G2 while the other part of the domain is described from the Corinne Land Cover database.

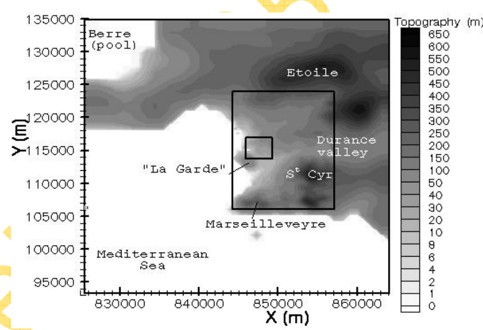

Fig. 1; Simulation domains for the 3 nested grids, in the Lambert III projection system. The topography is represented with the main hills names.

Sea Surface Temperature (SST)

SST is a crucial parameter in the air-sea fluxes calculation. For this simulation, we use the AVHRR-NOAA satellite radiance temperature images to calculate SST from the *Mc Clain et*

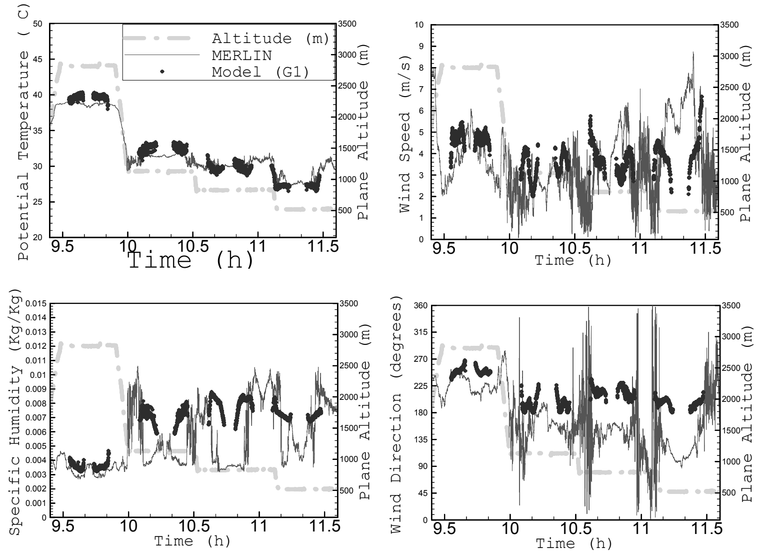

Fig. 2; Time series of flight data measured with the aircraft MERLIN, June, the 26th. Comparison with model outputs on G1, when the trajectory crosses the domain.

al.(1985) algorithm, combining 11 and 12 μm channels. The diurnal amplitude is calculated with those images, and the SST is computed at each time step depending on the solar incoming radiation. When no image is available, as it is the case on June 24th, diurnal amplitude is calculated with the maximum solar radiation and the diurnal averaged wind speed at the first level over the sea, following the *Clayson and Curry* (1996) formulae.

SIMULATIONS RESULTS

Boundary layer aircraft measurements

The first results are confronted against airplane measurements, although the tracks covered a larger domain than the grid G1. We focused especially on the flights of the MERLIN and ARAT aircrafts carried out to document the boundary layer meteorology. An example is given on the Figure 2, for the June 26th MERLIN flight. The model outputs appear, in general, in a good agreement with the measurements, especially for potential temperature. For specific humidity at low levels, the data show rapid variations that are not always well reproduced. The wind intensity is well predicted except at 500 m where the model under-estimate the values. The simulated wind direction matches with data at high levels, but for the two lowest levels the expected south-east flow appears from south-west in the simulation. As a matter of fact, when the flow characteristics are changing too rapidly, the model is reacting slowly.

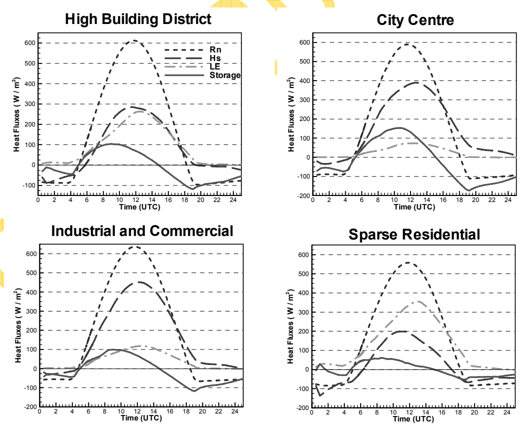

Fig 3; Energy budget on 4 districts on June, the 24th. Simulations on G2.

Energy budgets on Marseille

As shown on Figure 3, the energy budgets of the different districts composing Marseille largely differ. The highest sensible heat fluxes (Hs) occur on the Industrial and Commercial district because of the roof materials, although the city centre stores more energy because of the street morphology, narrow with high buildings. In the High Building District, there are moderate values of sensible and storage heat flux, with a latent heat flux (LE) that is quite important, as the vegetation is quite present between the buildings. The Sparse Residential district has the highest latent heat flux, because this district cover is dominated by vegetation, with spaced individual houses. In this case, few energy is released in the atmosphere in the evening. The Figure 4 represents, on the left, the budget for the "peri-centre" (a district making a crown around the city centre) for two days of the IOP2b, and the comparison is made for sensible and latent heat fluxes with eddy correlation measurements at the "Observatoire" site. Correct agreement is found, with respect to variation between

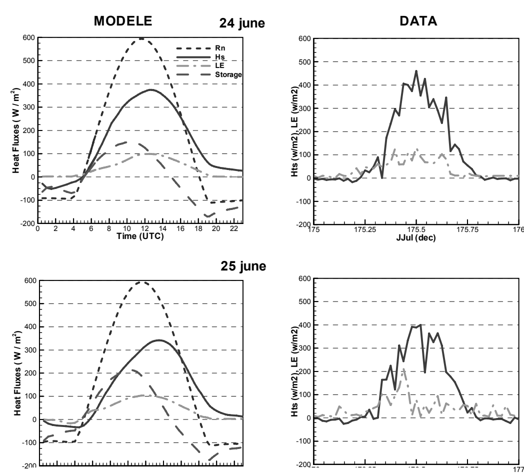

Fig 4; Energy budget on the district "peri-centre", compared with measurements at the site "Observatoire".

different days; Hs is the highest the 24th. On the 25th, the maximum occurs a bit later. However the sensible heat flux peak is slightly under-estimated and data show more fluctuations.

Flow analysis

After a transition day on June 23, anticyclonic conditions took place on the Mediterranean coast, with a north-westerly synoptic flow. These calm and warm conditions let the sea-breeze develop in the low levels during the 3 days composing the IOP2b, bringing cold air on Marseille area and mitigating the urban fabric influence on the flow.

A sequence of simulations on G2 for June 24 is presented on Figure 5. At the beginning of the day, in the boundary layer the flow is from the north-east and is accelerated by the hill “l’Etoile”, and canalised by the Durance valley. Cold air mass is seen to arrive on Marseille from the east, and deviated from this course to the south by the north-east flow and the “La Garde” hill. At 9:00, the early sea-breeze starts with a southerly component, and with a low wind speed over the city centre. At 14:00, the dominating flow is from south-west, and turns clearly from west when arriving on the city; with about 3m/s wind speed. A part of this moderate flow turns around Marseilleveyre to the south, preventing the south-west breeze leg of penetrating inland. At 19:00, the sea-breeze brings again cold air inland, with different direction than at 9:00.

The influence of the city is obvious when looking at Figure 6 showing the result of a similar simulation but without buildings : the differences on Marseille area are increasing during the day. At 14:00 and 19:00, the sea-breeze is more intense and the higher wind speed brings cool air on Marseille more easily, until it reaches the mountain.

The cases of June 25 and 26 are different : the southerly flow separates in two legs, the first

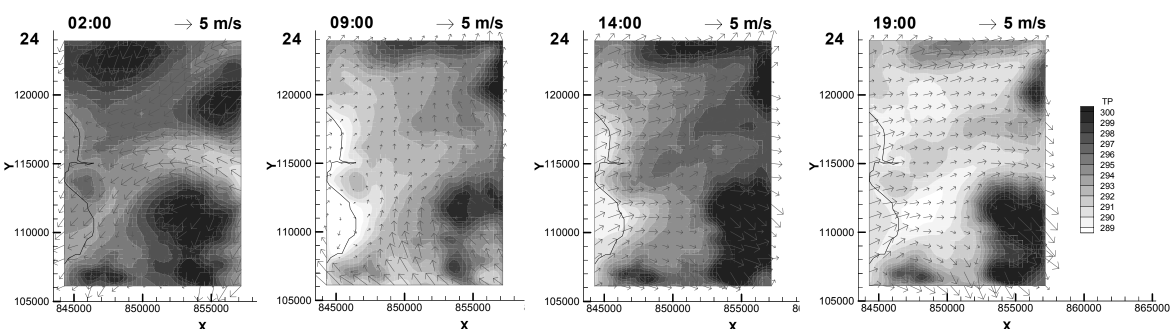

Fig. 5; Horizontal sections of potential temperature at the first scalar level (7.5 m) of the model. Vectors represent horizontal wind speed.

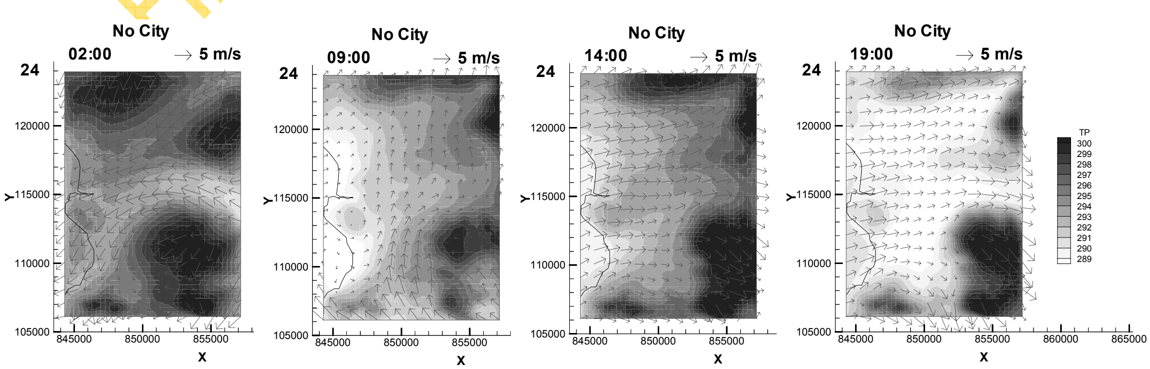

Fig 6 ; The same as Fig. 5, but simulation without city (replaced by Mediterranean vegetation).

one passing over the Marseilleveyre hills, and the second one turning to the west, and returning over Marseille where the topography is lower.

CONCLUSION

An important field campaign took place on Marseille area during summer 2001, in the ESCOMPTE experiment context, to provide diversified dataset to understand dynamical and thermodynamical behaviours of a complex geographical urban site. High resolution simulations performed on this area are confronted against measurements, showing good agreement for scalar and wind variables. The soil model SM2-U is coupled with the dynamical model, and the results show specificities of districts composing Marseille area, with different levels of urbanization or roof material. Dynamical analysis shows a complex interaction between synoptic flow, modified at low levels by topography, and the sea-breeze which is important during the IOP2b, and which develops early in the morning. A sensitivity study, with the same simulation but without buildings, highlights the city influence that limits the spread of cold air inland. This present work constitutes the first validation on a real case of the SUBMESO- SM2-U model couple .

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