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STUDY OF THE STRATIFICATION OF THE URBAN BOUNDARY LAYER OF MARSEILLE UNDER SEA-BREEZE CONDITION

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1. INTRODUCTION

3D numerical simulations, with the Meso-NH atmospheric model including the TEB urban parametrization, are conducted over the south-east of France, in the frameworks of the ESCOMPTE-UBL program. The present work focuses on the 250-m resolution outputs finely describing the vertical structure of the atmosphere above the Marseille area, for the 26 June 2001, characterized by a weak pressure favoring the development of thermal circulations. The numerical results are compared to the data of the Doppler lidar, which presents the interest to spatially document the boundary layer, by providing the radial velocities on a 6-km radius area and on the first 3 km of the troposphere. Thus, it is well adapted to study the complex stratification, which is observed above Marseille under sea-breeze condition. This is followed by an analysis of the modeled back-trajectories to study the origin of the air masses, which produce such structures above Marseille.

2. EXPERIMENTAL CONTEXT

The field ESCOMPTE - Urban Boundary Layer (UBL) program (Mestayer et al., 2004) took place in the Marseille area from June to July 2001. It was specifically aimed to document the thermoradiative budget and the fluxes above the urban canopy layer, and also the 4D structure of the UBL above the city. Marseille is one of the biggest French cities of about 1 million inhabitants and covers a 10 km per 15 km area. Its geographic situation is especially complex because of the proximity of the Mediterranean Sea and the local topography (Fig. 1). In summertime, west and south-west sea breezes frequently take place during the afternoon in Marseille, but also in all the coastal areas of the region.

The present study focuses on the last day of the IOP2 (26 June 2001). A ridge at 500 hPa level is over France, generating a westerly synoptic flow in altitude. The weak surface pressure gradient favors to the development of a sea breeze circulation. The weather is hot (about 35°C inland) and the atmosphere is very sultry.

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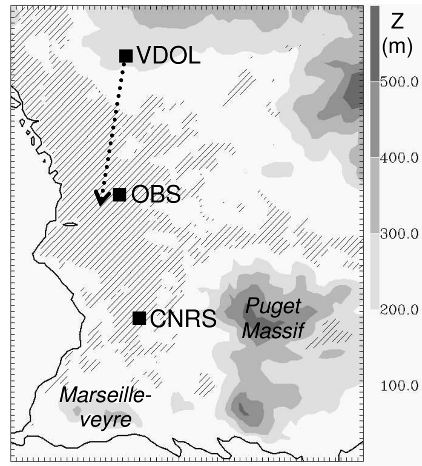

Figure 1 - Marseille area. The shaded part represents the urbanized districts. The arrow corresponds to the LOS of the TWL .

3. DOPPLER LIDAR DESCRIPTION

The Marseille area was largely instrumented for the experimental campaign, at both regional- and city-scales. The urban network, focused on the Marseille area, was composed of meteorological stations, flux stations and wind profilers. This paper presents the measurements of the ground-based Doppler lidar (hereafter called the transportable wind lidar, i.e. TWL) localized at the Vallon Dol (VDOL in Fig. 1) (43.56°N, 5.40°E, z=285 m above sea level (ASL)), in the north districts of the city. It operates at 10.6 µm in the infrared spectral region, where the lidar signals are extremely sensitive to micronic aerosols which are excellent tracers of the dynamics in troposphere, therefore making the TWL a relevant tool for the study of the atmospheric boundary layer dynamics in complex terrain (Bastin et al., 2004). The TWL provides wind radial velocity measurements along the line-of-sight (LOS) of the transmitted laser beam. The TWL radial range resolution and wind velocity accuracy are about 300 m and 0.3 m s^{-1}, respectively. The TWL scanning strategy consisted in vertical-slices (constant azimuth while varying in elevation) for various azimuth angles.

4. NUMERICAL SET-UP

The 3D simulations were realized with the Meso-NH non-hydrostatic atmospheric model (Lafore et al., 1998). The details of the set-up are presented in Lemonsu et al. (2004b). Four grid-nested models are used, the last one (model 4) reaching 250 m of resolution for the

Marseille area (Fig. 1). The vertical grid contains 52 levels, for which 28 levels in the first 1500 m. The turbulence scheme uses a 3D calculation, based on a Large Eddy Simulation parameterization for model 4. The initial conditions of the four models and the model 1 boundary conditions are defined from the European Center Mesoscale Weather Forecasting (ECMWF) analyses. The sea surface temperature, usually defined from the ECMWF analyses, is replaced for models 3 and 4 with a fine data base developed from NOAA AVHRR satellite images (Dousset and Kermadi, 2003). Meso-NH uses two surface schemes: the Interaction Soil Biosphere Atmosphere (ISBA) (Noilhan and Planton, 1989) and the Town Energy Balance (TEB) (Masson, 2000) schemes, to parameterize the surface exchanges for the natural soils and the vegetation, and the urban covers, respectively. The Marseille land cover map is provided by the Regional Center of Geographic Information (CRIGE) at 30 m resolution, based on the CORINE Land Cover Classification (CEC, 1993). Note that an extensive off-line evaluation against energy fluxes of the ISBA-TEB (Lemonsu et al., 2004a) was conducted in the city core.

The IOP 2B (24-26 June 2001) was continuously simulated with an initial spin-up of 12 hours. A complete evaluation at both regional- and city-scales was conducted for the whole period against most of the available observations (Lemonsu et al., 2004b).

5. EVALUATION OF THE MODEL

Vertical sections of radial velocities, from VDOL to the city centre (see Fig. 1), are reconstituted from the TWL measurements. They are compared to the outputs of the highest resolution model. Since the azimuth angle of the investigated LOS is 190^o from the north, a positive (negative) radial velocity indicates that the flow has a northerly (southerly) component as the flow blows away from (toward) the TWL. A wind direction quasi normal to the LOS induces very weak radial velocities.

At 1030 UTC, the TWL data indicate the super-imposition of 3 layers (Fig. 2), where the radial velocities are negative. The first one reaches 1100 m ASL with radial velocities of about -4 m s^{-1}. However, beyond 4.5 km far from the instrument, the velocities are weaker. Thus, the wind observed by the TWL blows toward the instrument in the northern districts, while above the city core it is either very weak or it blows perpendicular to the LOS. Between 1100 and 1700 m ASL, the radial velocities are really close to zero everywhere. Lastly, above it, a further layer of negative radial velocities is observed, characterizing again a flow oriented toward the TWL. At 1400 UTC, the vertical stratification is very similar to the one observed in the morning (Fig. 3). However, the situation evolved near the surface: the TWL sees now a new layer in its first measurement levels, which was not seen previously. It is composed of positive radial velocities until 4.7 km far from the TWL, but of negative velocities more to the south. This illustrates the converge of one northern and one southern flow above downtown about at the OBS site.

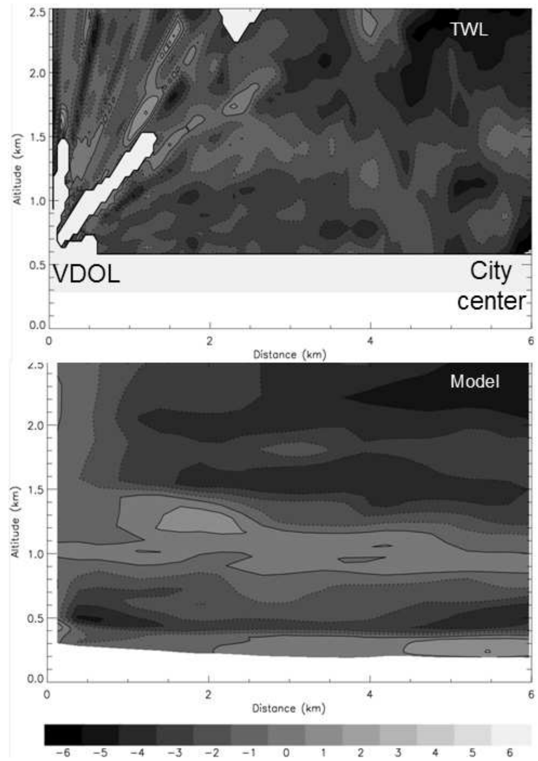

Figure 2 - Observed and modeled vertical sections of radial velocity, from VDOL to the city core, at 1030 UTC.

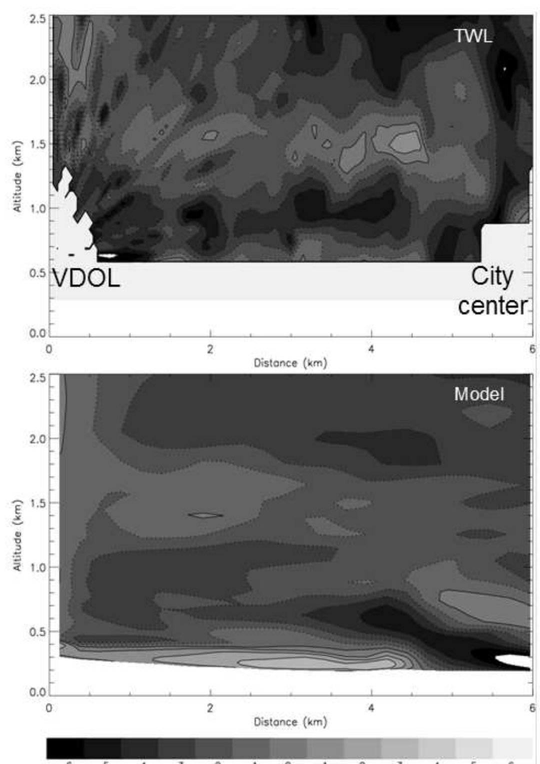

Figure 3 - Observed and modeled vertical sections of radial velocity, from VDOL to the city core, at 1400 UTC.

The model sees also a clear stratification of the atmosphere, with 4 distinct layers. The lowest one, in the first 200 m (above the ground level (AGL)), evolves in the course of the day. There the radial velocities are positive in the morning (Fig. 2). The observations do not show such a layer, probably because it is too low, the TWL data not being good between 300 and 600 m ASL. At 1400 UTC, a core of negative velocities appears beyond 4.7 km from VDOL (Fig. 3), what is really consistent with the observations. Above this latter, the model simulates two layers of negative velocities, one between 400 and 900 m, and the other in altitude. Between both of them, the velocities are very weak, but rather positive in the morning, contrary to the observations. This is connected to a little difference in the wind direction in relation to the LOS, on which depends the sign of the radial velocity. The top of this layer is also shifted of about 200 m according to the altitude. However, at 1400 UTC, all the layers are very similar to the observations, considering their localizations and the associated intensities of radial velocities.

6. INTERPRETATION BY BACK-TRAJECTORIES

The complex stratification of the atmosphere above Marseille, underscored by the TWL for the 26 June 2001, is also confirmed by the other observational systems, especially the UV lidar at VDOL and the UHF radar at the Marseille Observatory (OBS) (Delbarre et al., 2004). In order to understand and to interpret these structures, the modeling is an efficient tool to analyze the involved dynamical processes.

a.

b.

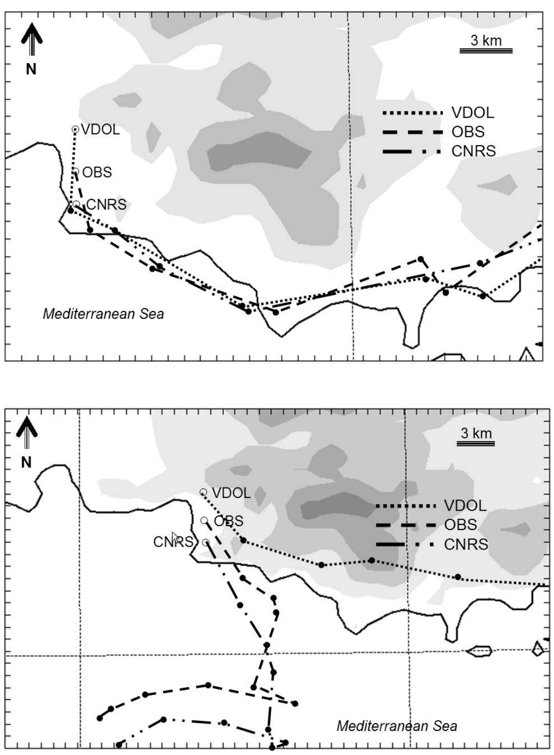

Figure 4 - Back-trajectories at z=50 m (a) and 900 m (b) above the ground level, for VDOL, OBS, and CNRS at 1100 UTC.

The back-trajectories were produced from the 1-hour time step outputs of model 2 (3-km resolution) for the air particles, which would arrive at VDOL, OBS localized downtown and the CNRS Institute (CNRS) in the south of Marseille (all labeled on Fig. 1), at various altitudes from 50 m to 2000 m above the ground level. At the regional scale, the back-trajectories inform us on the origin of the air masses, which arrive above Marseille and constitute the ABL. However, at the urban scale, the spatial and temporal resolutions are too low to precisely describe the flow orientation. They have to be coupled to the analysis of the modeled 250-m wind fields.

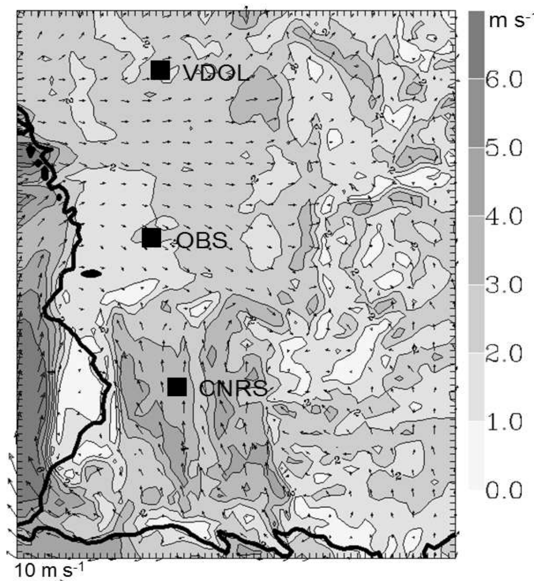

Figure 5 – 250-m horizontal field of the wind at the first atmospheric level at 1100 UTC.

The lowest back-trajectories, between 0 and 700 m AGL (Fig. 4.a), indicate that Marseille is under the influence of a flow, which skirts the Mediterranean coast from the east. Beyond 700 m AGL, the flow turns from the south-west until 900 m above OBS and 1200 m above VDOL. At VDOL this air mass comes initially from the east of the domain (Fig. 4b), while it comes from the west (from the Mediterranean Sea) at OBS and CNRS. According to the humidity of the particles along their back-trajectories, the eastern flow is more humid, what induces a mixing ratio difference of more than 1 g kg^{-1} between VDOL and the rest of the city. Beyond 1200 m, the synoptic flow comes from the Mediterranean Sea, from the south-west above VDOL and from south to south-west above OBS (not shown).

Near the surface, at the urban scale, the flows are disturbed by the local topography and the Mediterranean Sea. According to the 250-m wind fields near the surface (Fig. 5), CNRS receives from 0800 UTC a flow, which skirts the coast from the east and enters in Marseille by the south between Marseilleveyre and the Puget massif. This flow does not reach VDOL and OBS directly, but is diverted on the sea by Marseilleveyre before coming back toward the north districts. Coming from the sea by the west, it turns to west-north-west at OBS and rather to west-south-west at VDOL. While VDOL stays under the influence of this flow until the end of the afternoon, the southern flow penetrates further inland and reaches OBS after 1200 UTC (not shown). This complex organization of the wind, simulated at 250-m resolution, is in good agreement with what is observed by the ground-based stations (Delbarre et al., 2004).

Fig. 6 presents the vertical sections of potential temperature and mixing ratio at 1100 UTC, according to the same direction than for the TWL, but until the southern coastline (while the TWL stops at 6 km of VDOL). The arrows indicate the wind orientation in the section. In the first 200 m, the effect of skirting is observed in the northern part of the city. The flow from west-north-west above Marseille city center corresponds to the layer of positive radial velocities of the vertical section (Fig. 2). At VDOL, the west-south-west orientation of the wind explains that the radial velocities are negative there. The entrance of maritime air by the west clearly appears on Fig. 6, as one homogeneous layer, which is colder and more humid than in the south of the city. This layer is totally disconnected to the one above, which is constituted by the flow arriving from south without skirting effect. This layer, between 200 to 700 m, is characterized by a flow having the same direction everywhere and negative radial velocities (Fig. 2). Note the presence of an updraft just southward of OBS, where the southern flow and the flow diverted by Marseilleveyre converge. It is illustrated by a colder and more humid air mass reaching 600 m ASL. Two drier cores are observed on each side of this updraft and are associated to a downward movement.

CONCLUSION

The comparison between radial velocities collected by the TWL and those simulated by Meso-NH at a comparable resolution presents a consistent agreement, and are also confirmed by the other observations. Both of them indicate a complex stratification of the atmosphere above Marseille, the 26 June 2001 under sea-breeze condition. The back-trajectories are a good indicator of the origin of the synoptic flows, which converge on Marseille. The evolution of the flow orientation according to the altitude explains the presence of distinct layers. However, the lowest layers are directly influenced by local topographic and maritime effects. In this case, the study of the high resolution fields is essential in the analysis of the involved dynamical mechanisms.

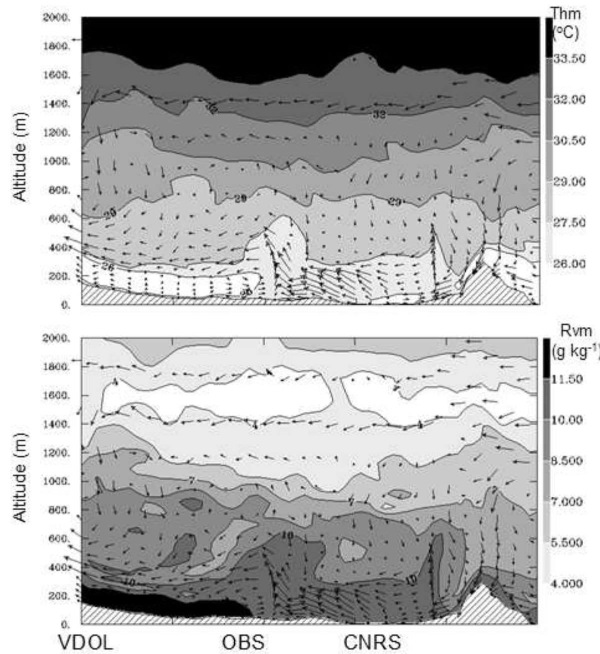

Figure 6 - Vertical sections of potential temperature and mixing ratio at 1100 UTC. The arrows indicate the wind orientation in the section.

References

Bastin S., Drobinski P., Dabas A.M., Delville P., Reitebuch O., Werner C., 2004: Impact of the Rhône and Durance Valleys on sea-breeze circulation in the Marseille area. *Atmos. Res.*, in press.

CEC, 1993: CORINE Land Cover Technical Guide, Addendum 2000 (technical report n°40). *European Environment Agency*. 105 pp.

Delbarre, H., P. Augustin, F. Saïd, B. Campistron, B. Benech, F. Lohou, V. Puygrenier, C. Moppert, F. Cousin, P. Fréville and E. Préjafon, 2004: Ground-based remote sensing observation of the complex behaviour of the Marseille boundary layer during ESCOMPTE. *Atmos. Res.*, in press.

Dousset, B. and S. Kermadi, 2003: Satellites observation over the Marseille-Berre area during the UBL/CLU-ESCOMPTE experiment. *Fifth International Conference on Urban Climate, Łódź, Poland*.

Lafore, J.P., J. Stein, N. Asencio, P. Bougeault, V. Ducroc, C. Fisher, P. Hereil, P. Mascart, V. Masson, J.P. Pinty, J.L. Redelsperger, E. Richard, J. Vila-Guerau de Arellano, 1998: The Meso-NH atmospheric simulation system. Part I: Adiabatic formulation and control simulation. *Ann. Geophys.*, **16**, 90-109.

Lemonsu A., C.S.B. Grimmond and V. Masson, 2004a: Simulation of the Energy Budget of an old mediterranean city core, *J. Appl. Meteorol.*, **43**, 312-327.

Lemonsu, A., G. Pigeon, V. Masson and C. Moppert, 2004b: Sea-town interaction over Marseille: 3D Urban Boundary Layer and thermodynamic fields near the surface. *Theo. Applied Climatology*, in press.

Masson, V., 2000: A physically-based scheme for the urban energy budget in atmospheric models. *Boundary- Layer Meteorol.*, **94**, 357-397.

Mestayer, P., P. Durand et al., 2004: The Urban Boundary Layer field experiment over Marseille. UBL/CLU-ESCOMPTE : experimental set-up and first results, *Boundary-Layer Meteorol.*, in press.

Noilhan, J. and S. Planton, 1989: A simple parameterization of land surface processes for meteorological models. *Mon. Wea. Rev.*, **117**, 536-549