UBL/CLU-ESCOMPTE : the urban boundary layer field experiment over Marseille and the database

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ABSTRACT

The UBL/CLU experiment is a side project of the regional photochemistry experiment ESCOMPTE over the Berre-Marseille area. It took advantage of the large experimental set-up, with chemistry and dynamics, ground-based and airborne instrumentations, including a large array of vertical and 3D sounders. With additional specific instrumentation in the lower urban atmosphere, the UBL/CLU project aimed at documenting the dynamics and thermodynamics of the urban boundary layer (UBL) of the Marseille area during sunny periods.

To date the initial data analyses include (a) the quality control inter-comparison of energy flux instrumentations, (b) the quality evaluation of the measurements at the urban stations, (c) the comparison of the Town Energy Balance model with the data obtained over the city center, (d) the evaluation of heat flux measurements with the scintillometers, (e) the temperature and moisture variability at the canopy level, (f) the 3D structure of the UBL during sea breeze episodes, (g) the visible and thermal infrared signatures of the urban canopy, (h) the numerical urban data base and satellite data analysis to generate high resolution land use and aerodynamic roughness maps.

1. INTRODUCTION

The ESCOMPTE field campaign took place over an area of 120 km x 120 km, from June 4 to July 16, 2001. The set-up involved 20 stations, equipped for gas (ozone, nitrogen oxides, VOCs, ...) and/or particle measurements, among which two on ships, and two in trucks. The surface energy budget was measured at 9 sites. The meteorological basic parameters were also measured at 5 complementary sites. Wind profile was continuously measured at 12 sites by 7 sodars, 4 UHF and 4 VHF radars. Three Lidars were also operated, as well as 4 radiosonde systems, and 7 aircrafts. Finally 33 constant-volume balloons were launched and tracked during the Intense Observing Periods (IOPs).

The UBL/CLU experiment aimed at documenting the four-dimensional structure of the urban boundary layer in connection with the urban canopy energy exchanges with the atmosphere during a summer period of low wind and breeze conditions. The objectives were (1) to compare urban and rural atmospheric boundary layers (ABL), explore the influence of sea breeze on the UBL, and document the UBL turbulent fields, and (2) to construct a data base allowing to test urban energy exchange schemes, surface temperature remote sensing from satellites, and high resolution meteorological and chemistry-transport models.

During the campaign, two types of intensive observation periods were more densely documented :

- the 5 ESCOMPTE IOPs (called 1, 2a, 2b, 3 and 4, for a total of 15 days) during situations of land-sea breeze and high insulation, mixed with a light Mistral during the IOPs 2a and 4. During these periods one airplane flew over Marseille to document the urban boundary layer, measuring the atmospheric composition and the wind and turbulence within or at the top of the boundary layer.
- the 4 Infrared IOPs when a light airplane equipped with a thermal infrared mapping camera scanned the urban canopy at different times in the day. The influence of spatial resolution and sensor orientation on the surface temperature measurements were documented by flying successively in 8 different directions with respect to the sun over the same sites : 3 typical city quarters including the city center around the CAA site monitored by the array of IR radio-thermometers. Radio-sondes were launched from the Observatoire site during these IOPs, and air temperature was also monitored at the 2 m level with a car driven under the flight paths.

After data qualification/validation, most of the data have been delivered to the ESCOMPTE structured data base (http://medias.obs-mip.fr/escompte) which will be freely accessible after April 2003 for model validation.

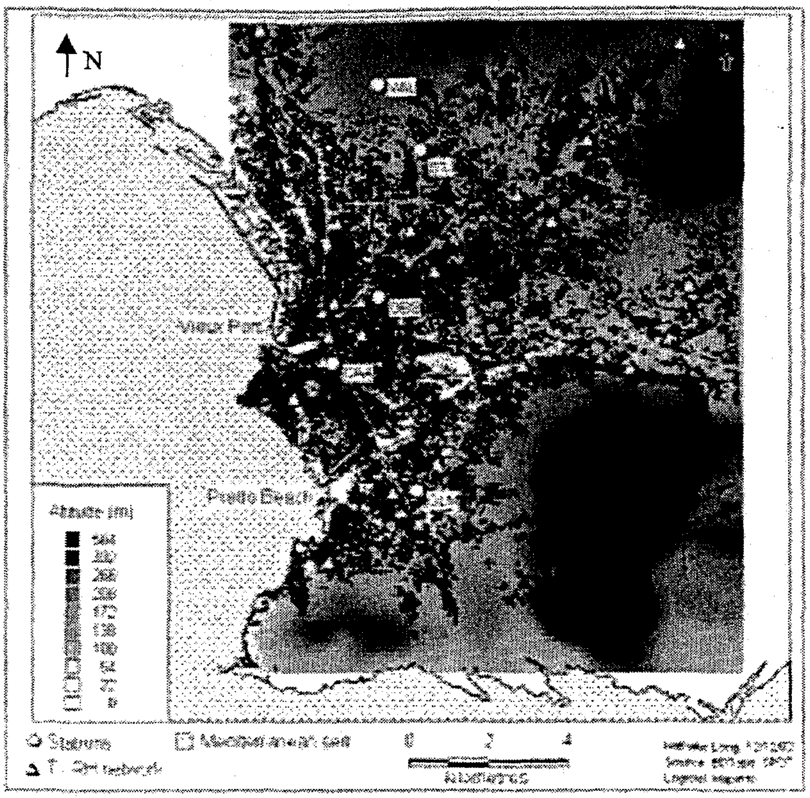


Figure 1. Map of the Marseille area. The shaded rectangle shows the area covered by the IGN data base BDTopo. The grey levels indicate the terrain altitude. The poly-lines are the building contours. From North to South the hill lines are called l'Etoile, Garlaban St Cyr, Carpiagne, Les Calanques, Marseilleveyre

2. THE EXPERIMENTAL SET-UP AND THE FIRST RESULTS

Some specific features of Marseille must be noted (Figure 1). It is located within an arena of hills, 400-650 m high, separated by small valleys converging towards the city center ancient harbor (Vieux Port) and the Prado beach, which are themselves separated by two steep hills about 250 m high. The city faces the sea on the west, in the southern part of a large bay, while at a scale of ~100km the coast is facing the Mediterranean Sea to the SSW. This combination of orientations requires special attention during the breeze episodes as well as when the weather is dominated by a low Mistral, the northern wind exiting from the Rhone valley. The population of the urban area is slightly less than one million inhabitants. Except in the city center, the harbor area and the outskirts, the urban fabric is most often composed of an irregular admixture of small individual or collective houses and small ensembles of 4-10 levels collective dwellings.

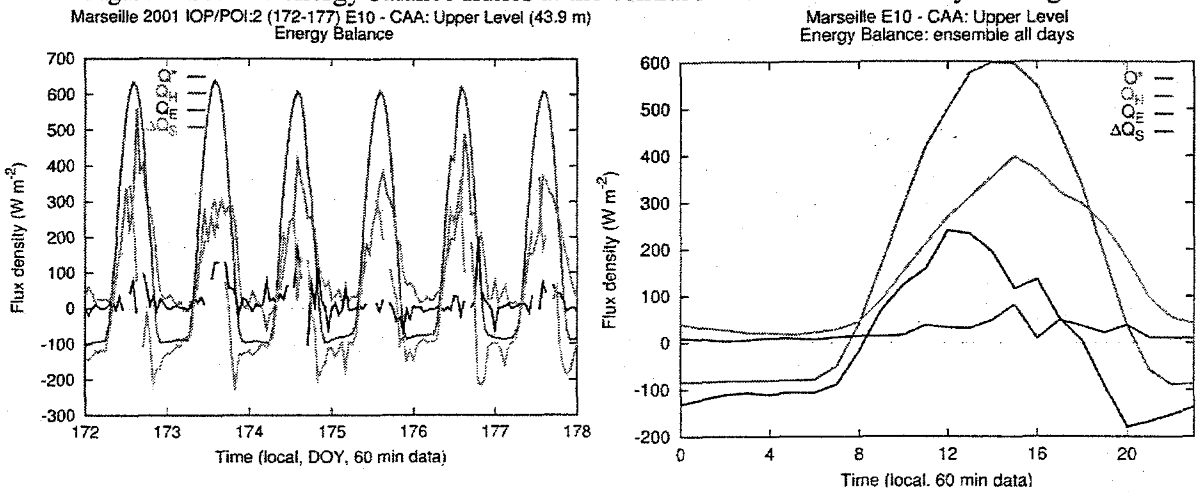
In the city center, roughly a circle 2 km in radius around the Vieux Port, the streets are relatively regular and the constructions form a dense canopy averaging 15 m in height, with sparse, higher, isolated buildings. The harbor area is a strip of low storage constructions and surfaces, about half a kilometer wide, all along the Northern coast. The outskirts are mainly composed of individual houses with gardens, rarely over very large surfaces without any collective building ; they spread over the hill slopes. The city contains quite few high rise towers, always isolated.

In the urban area, the permanent instrumentation was mainly deployed at five sites along the North-South axis of the city, roughly parallel to the shoreline (Figure 1). Three urban/suburban stations (GLM, CAA, STJ) were equipped with micro-meteorological masts where the turbulent and radiation fluxes necessary to monitor the canopy surface energy budget were continuously measured : the masts raised some 12 to 20 m above the urban canopy level and the turbulent fluxes were measured at 2 levels. The other two sites (OBS, VAL) also included turbulence instrumentation on 12 and 10 m masts, respectively, as a ground reference of vertical profilers (see below).

The central site (CAA) was located in the rather uniform, 18-19th Century, dense part of the city center. Surface energy balance fluxes were measured using eddy covariance instruments and radiometers, mounted on a pneumatic tower on the roof of the Cour d'Appel Administrative, 20.7 m above roof level. Two scintillometers were also deployed to evaluate the integrated heat flux over the city center, with 2 km optical paths oriented N-S and E-W respectively. In addition the site was also equipped with an array of up to 19 IR radio-thermometers, either fixed to monitor the surface temperature of selected elementary surfaces, or hand-held to evaluate surface temperature distributions during periods of intense observation (two IR radio-thermometers were also operated at the suburban site STJ to monitor the composite surface temperatures of the ensembles immediately North and South of the site). In this urban fragment thermometers also monitored the heat exchanges between building inside and outside during some periods.

Figure 2 shows examples of diurnal cycles of the energy balance components over the IOP 2, used to test the urban energy schemes LUMPS and TEB. The TEB model was evaluated using air-temperature from within urban canyons, surface temperatures for roads, roofs and walls, and flux measurements from the tower and scintillometers. All the energy fluxes were simulated well and the model succeeded in producing a positive sensible heat flux at night, and the correct daily cycle of heat storage.

Figure 2. Surface energy balance fluxes at the central station CAA for six days during IOP 2



An array of 20 T-RH sensors with continuous recorders, at a 6 m height above the ground allowed to monitor the dependency of the urban heat island on the meteorological conditions. In addition some transect T-RH measurements were occasionally obtained with a car equipped with T-RH ventilated sensors at z = 2 m.

The set-up included an array of four vertical sounders : two Sodars at the sub-urban sites GLM and STJ, sounding the atmospheric surface layer, a wind profiler UHF Radar and a tethered balloon occasionally measuring thermodynamic and ozone profiles from 20 to 300 m, at the OBS site, close to the city center, and a RASS-sodar temperature and wind vertical sounder at the VAL site. At this site, located at the border of the city and overlooking most of the urban area two Lidars were scanning the atmosphere horizontally and vertically up to a distance of about 10km : a UV Lidar measuring the O3 concentration, and a 10 µm Doppler Lidar (called TWL, transportable wind Lidar) measuring the radial wind ; both instruments were operated in parallel to generate tomographic observations of the aerosol content and the UBL structure in the scanned volume (Figure 4) . These sounders were also part of a larger array of vertical sounders within the ESCOMPTE experimental set-up allowing to monitor the 3-D structure of the ABL over the regional domain. The data from the sounders are composed with those obtained during the airplane flights over Marseille (Figure 3) to provide complete understanding of the UBL/ABL structure.

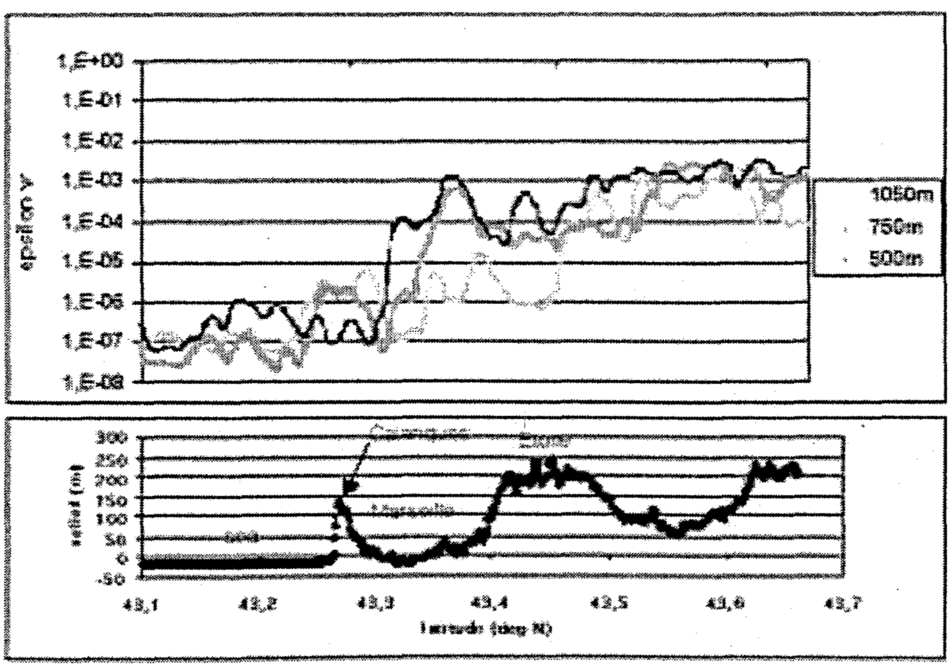
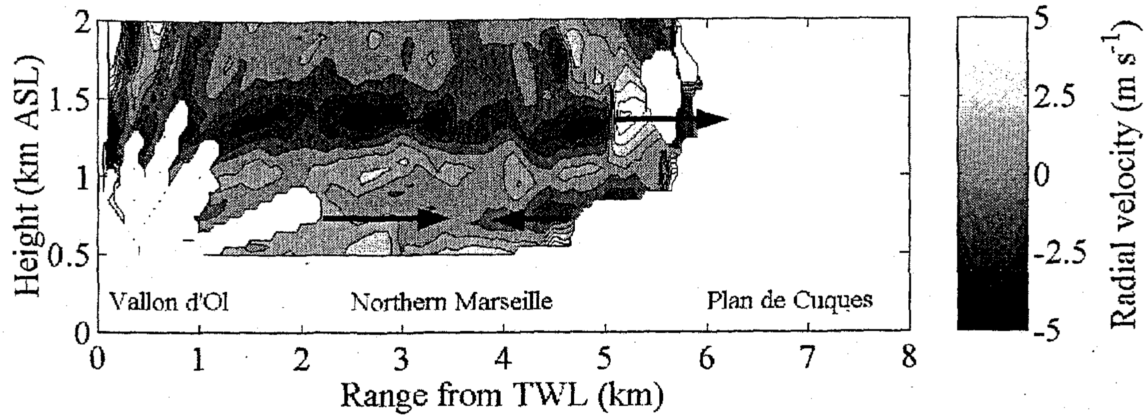


Figure 3. Dissipation rate of turbulent kinetic energy (m^2s^{-3}) measured with the Merlin IV (MeteoFrance) along the south-north legs at levels 1050, 750 and 500 m. The overflown relief is also represented with the sea on the left (south). The duration of the flight over the town, between the Calanques ridge to the south and the Etoile massif to the north, is 3 minutes. The energy spectrum high frequency tail is a relevant indicator of turbulence intensity in such inhomogeneous conditions.

Figure 4 : Vertical cross section of radial velocities with TWL pointing eastward towards land (azimuth 110°). The arrows indicate the flow circulation in the section.



Satellite images were collected during the experiment, from a variety of sensors and platforms. About 150 useable images from the Advanced Very High Resolution Radiometer (AVHRR) on board satellites NOAA-12, NOAA-14 and NOAA-16, collected at the University of Modena by F. Parmigiani, were contributed to the project, an average of 4 images/day for the period 4 June to 13 July 2001. Sixty-six images from MODIS on board the TERRA satellite were also obtained from the NASA/EOSDIS data center. Finally, a single high resolution ASTER image was obtained from NASA/JPL and NASDA on 27 May 2001; this was complemented by an additional image on 2 August 2002. The thermal data set also includes airborne measurements using a PRT5 Barnes radiometer (8-14 µm spectral band) aboard the Merlin IV aircraft providing nadir surface temperature, and a thermal infrared (TIR) camera (INFRAMETRICS model 760, 7.5-13 µm spectral window) equipped with 80° wide-angle lenses and placed aboard a PA28 aircraft, inclined about 20° backward. Flying several axis crossing above the city allowed to obtain TIR measurements in a -60° to +60° range of zenith view angles and in all azimuth directions, and to characterize TIR directional effects as the difference between oblique and nadir measurements of radiative surface temperature. As an example, Figure 5 shows the AVHRR (channel 4 not corrected for atmosphere), Inframetrics camera, and SC500 FLIR scanner thermal infrared images of July 10 2001 at 13:18 UTC. Differences in brightness temperature of up to 5 and 8 C are observed between rural areas, and the urban-industrial areas of Marseille. In the city, surface temperatures (LST) reach 31 °C in the densely built areas, with small parks generating cool islands of 1.5 to 3.5 °C. LST are somewhat lower in residential areas (29 °C), probably due to larger proportions of vegetation.

Multi-spectral and panchromatic SPOT images were also analyzed to obtain with a very high resolution the types of surface coverages. Specific statistical analysis of the 3-D data base BDTopo of IGN (the French national geographic institute), describing such urban objects as buildings, constructions, vegetation, etc., have been combined with satellite data to generate high resolution maps of the surface energy model input parameters such as urban land uses, roughness length, albedo, etc.

ACKNOWLEDGEMENTS

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Figure 5. Example of multi-scale approach of the TIR over Marseille city with NOAA-AVHRR channel 4 (a), airborne Inframetrics 760 camera (b), SC500 FLIR scanner from roof level (c) (brightness temperatures without atmospheric correction, scales of 17.5-32.5, 29.0-43.0 and 20.0-50.0 °C respectively)