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# OBSERVATION OF AN URBAN PLUME DURING CAPITOUL EXPERIMENT

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## 1. ABSTRACT

An urban plume has been observed the 9th and 10th March 2004 over the city of Toulouse during the CAPITOUL experiment. The meteorological conditions, light synoptic wind, sunny and cold (between 0 and 5 Celcius degrees), were favorable for the establishment of urban induced circulations in the boundary layer.

Observations were conducted both at or near the surface (surface energy balance in city center and rural area), UHI measurement network, profilers and completed by in-situ measurements in the boundary layer: radiosoundings (upwind rural and in the city center) and aircraft.

The contrast between the rural and urban surface energy budgets is clear. At night the city warms the atmosphere by more than 50 $Wm^{-2}$ continuously through the night. This creates an UHI and over the city an instable boundary layer more than 100m develops during the day, the larger warming from the city surface induces a boundary layer of 1100m deep, compared to 900m in the countryside upwind of the urban area. The urban dome is then approximately of 200m. Aircraft measurements measured a thermodynamical plume, with an increase of air temperature at 300m of height of approximately 1.5 degree when the airplane flew from upwind to above city. This warmer air is advected 50km downwind of the city.

Passive tracer release (SF6) were also conducted during this day by IRSN (Institute for Radiological Protection and Nuclear Safety), with surface measurements at sunrise, and in the afternoon. In the latter case, the SF6 concentrations were measured both at the surface and by the airplane.

## 2. EXPERIMENTAL CONTEXT

The CAPITOUL experiment takes place over the city of Toulouse, France, from February 2004 to March 2005. The objectives are: (i) to study the response of the surface, especially urban energy balance, to a wide range of atmospheric conditions (winter, summer, intermediate seasons, rainfall, showers, cold, extreme winds, etc...) (ii) to quantify the response of the boundary layer to the city surface forcing, eg, urban breeze, urban (thermodynamical) plumes, impact of fog, and of course continuous observation of the urban heat island. (iii) to measure the transformation of the properties (physical, chemical and radiative) of the urban aerosols, from the emission sites (including turbulent fluxes of aerosols) to the near countryside (50km away). (iv) to study the dispersion of SF6 in the atmosphere in suburban environment. (v) to measure the thermal signature of the surfaces roads, walls, roofs) of the city.

The Intensive Observation Period (IOP) number 2 took place the 9th and 10th of March, 2004. The meteorological situation, weak wind from NW (5m/s) and cold air mass (with nocturnal freezing in the countryside), is favorable to the formation of a thermodynamical urban plume.

During this IOP were combined ground measurements and airborne instrumentation and balloons (see paper **1.2** for details).

## 3. SURFACE ENERGY BALANCE

The urban and rural Surface Energy Balance (SEB) are presented in Fig 1a and 1b respectively. The differences between the two underscore the peculiar behavior of the urban canopy compared to the more usual vegetated surface.

During the day, the net radiation is slightly larger for the city, due to the radiative trapping, causing a small albedo. Then, the major part of the energy goes as sensible heat flux in the city, while it goes as latent heat flux in the countryside. This is because water is available for evaporation in the soil at end of winter. What is also usually crucial in the urban SEB is the large storage flux. It is not measured directly, but estimated as a residual. As the anthropogenic heat source to the system is not yet estimated (it will be done using energy consumption data), the residual also contains the (opposite of) the anthropogenic heat. During the IOP, the weather was cold (0°C), and domestic heating was probably large.

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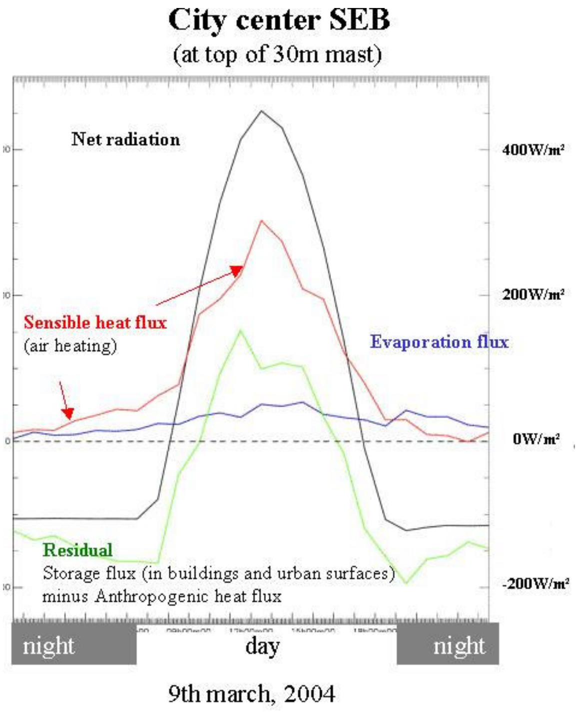


Fig 1a : urban observed SEB

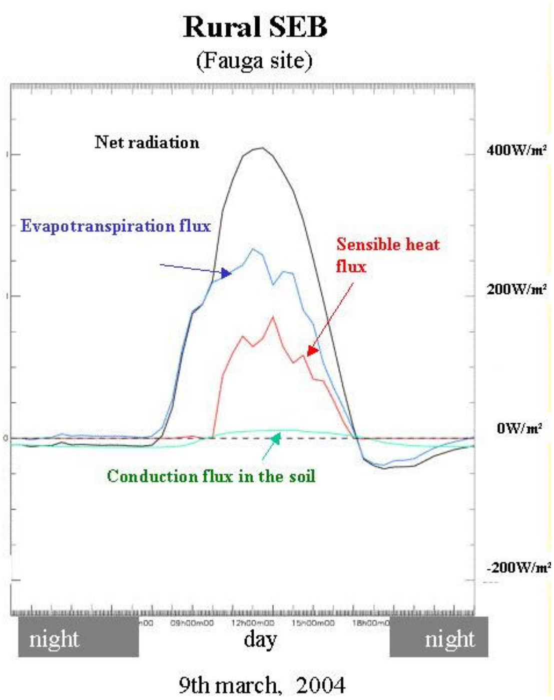


Fig 1b : rural observed SEB

The storage term during the day is then probably larger than the residual drawn here.

During the night, the net radiation is very low, because surfaces are warm compared to the cold atmosphere, leading to a deficit in infra-red radiation. This deficit stays constant during the night. One can note that, while turbulent fluxes at the rural site are very low, these are positive at night in the city. The turbulent heat flux is determined both by the heat stored by the materials during the day and by the anthropogenic heat flux due to domestic heating.

## 4. VERTICAL STRUCTURE OF THE UBL

These differences in SEB between the city and the countryside can lead, if the meteorological conditions are calm, to significant urban effects on the BL. During the IOP, The UHI reached more than 4K, even with a mean wind of 10 to 20kmh$^{-1}$.
Another impact was observed on the vertical structure of the BL, using radiosondes all along the day and night. Fig. 2 shows the vertical profiles of potential temperature and water vapor at end of the day (18UTC). The BL above the countryside, upwind of the city, reaches 900m while, over the city, it is as high as 1100m. This could be a signature of an urban dome.
At night (not shown), the rural site shows a 300m deep stable layer of 8°C, while there is a near neutral layer all night over the city, of approximately 100m. This one is caused by the positive sensible heat flux.

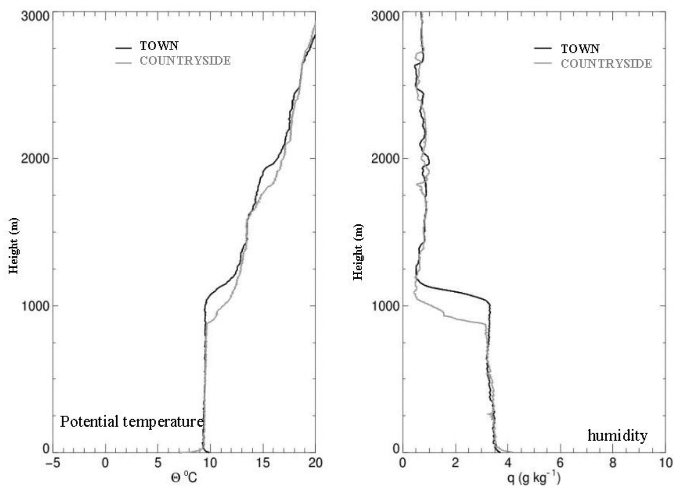


Fig 2 : radiosoundings at 18UTC over the town and 15km upwind in the countryside.

## 5. HORIZONTAL STRUCTURE OF THE UBL

Further exploration of the BL was performed by the instrumented aircraft of Météo-France. The structure of the urban plume observed during IOP2 is shown on Fig 3. At 300m above the ground, the air temperature increases by more than 1°C above the city. This air is advected by the synoptic flow (20kmh$^{-1}$) to the East-south-East.

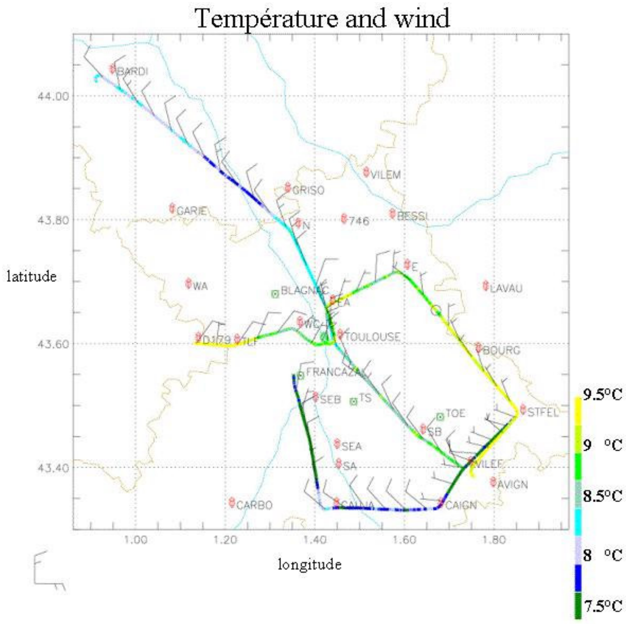


Fig 3: aircraft flight between 12UTC and 15UTC on the 9th of march, 2004. Flight legs are at 300m. Temperature (color) and wind (in knots).

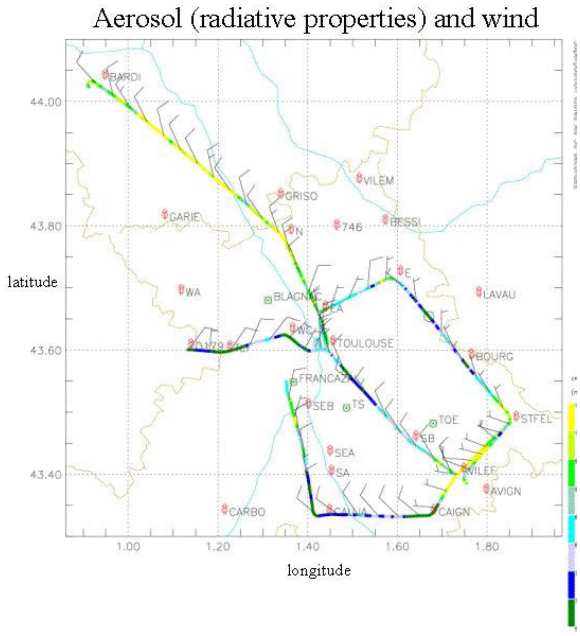


Fig 4: aircraft flight between 12UTC and 15UTC on the 9th of march, 2004. flight legs are at 300m of height. Yellow indicate aerosols with low absorption. Blue and green indicate aerosols with a strong absorption

## 6. HORIZONTAL STRUCTURE OF THE AEROSOLS

The aerosol properties were measured by the aircraft with an aethalometer (fig 4). The radiative properties of the aerosol upwind are typical of continental aerosols. However, above and downwind the city, massive income of urban aerosols modifies these properties. Light absorption by aerosols become stronger which shows the presence of black carbon in the urban layer.


Fig 5: instrumentation in the aircraft

## 7. SF6 DISPERSION EXPERIMENT

Release of SF6 was done during this IOP. The airborne measurements were made every 3 sec. at an height of 100m, when the aircraft flew perpendicularly to the wind direction. The first leg was approximately 2000m from the release point, the second leg 800m. In addition, ground measurements were performed with a lab truck and air samples collected downwind of the discharging point..

During the afternoon, significant values of SF6 were obtained near the wind axis, both in altitude and near the ground (fig 6). Measurements will be used to validate a modeling system used for accidental release in case of emergency.

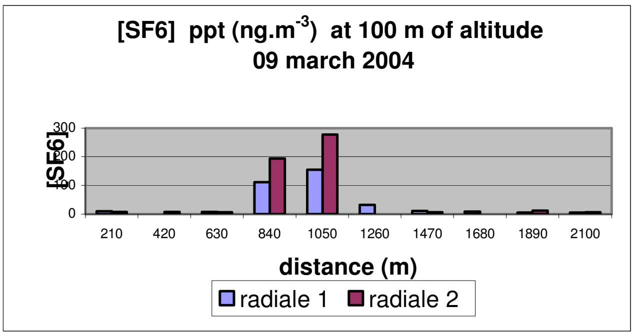


Fig 6: measurement of SF6 by the aircraft.
Left columns: at 2000m from release point.
Right columns: at 800m from release point.

## 8. CONCLUSION

A thermodynamical and chemical urban plume was observed, for moderate wind. Other situations will be observed during CAPITOUL, some with very light synoptic wind, in order to observe urban influence.

3D modeling will then be used both to validate against observation the atmospheric models at urban scale and study in detail the processes in interaction in the UBL.