Canopy and Aerosol Particle Interactions in the Toulouse Urban Layer

The CAPITOUL Project

The CAPITOUL experiment is a joint experimental effort in urban climate, aiming to study (i) the energetic exchanges between the surface and the atmosphere, (ii) the dynamics of the boundary layer over the city and (iii) the interactions between urban boundary layer and aerosol chemistry. The campaign took place in the city of Toulouse in southwest of France, from February 2004 to February 2005.

Toulouse is relatively isolated from significant relief and coastlines, so that it is not influenced by valley or sea breezes, favoring the apparition of urban effects on the boundary layer. The old city core is very homogeneous in terms of building height and construction materials (red brick walls and tile roofs, Fig. 1). The one-year duration of the field measurements allowed the study of both the day-to-day and seasonal variability in urban climate processes. The observational network included surface stations (meteorology, chemistry , energy balance) with a 30m high tower installed on a 20m high roof (Fig. 2), profilers, and, during intensive observing periods, aircraft and balloons (launched from the countryside and also the city center – Fig. 3). A complete description of the campaign as well as the first results are presented in a special issue in *Meteorology and Atmospheric Physics* (http://www.springerlink.com/content/v9p38ju105q1/?sortorder=asc&p_o=0).

Figure 1. View of Toulouse downtown roofs from the terrace of the central site.

1. General Overview

The first paper of this special issue (Masson *et al* 2008) gives a general view of the experiment, describing the goals, experimental set-up and a summary of the results.

The nine following papers present original scientific advances attributable to CAPITOUL. These papers refer to three main aspects of the urban climate:

2. The urban canopy energetics

- Pigeon *et al* (2008) present the modelling of the anthropogenic heat flux by the TEB urban scheme (Masson 2000) and its evaluation against anthropogenic fluxes estimated by an inventory of energy consumption (Fig. 5). This inventory has been compared before

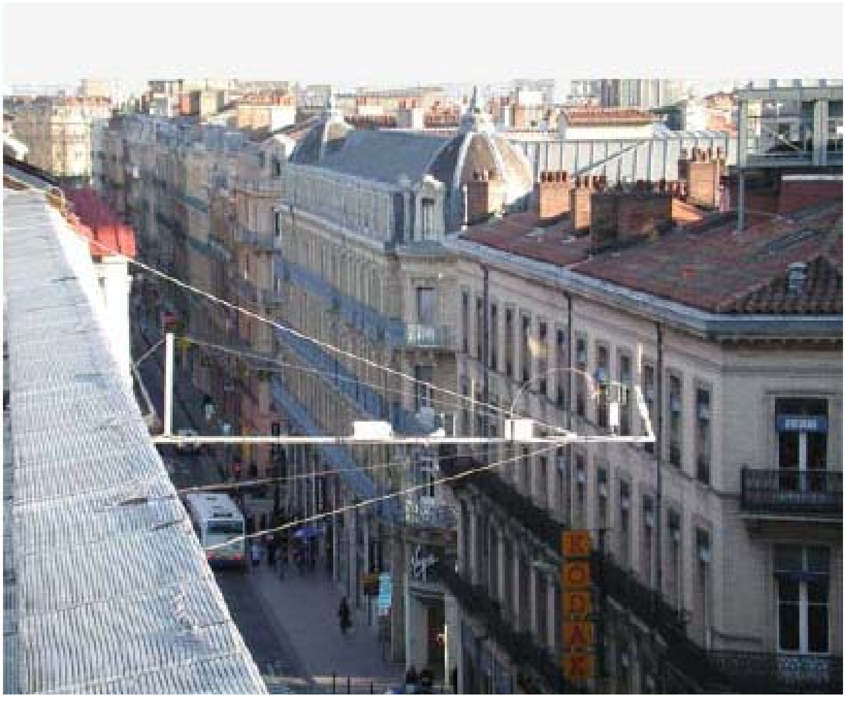

Figure 2: (Left) surface energy balance pneumatic tower; (right) 5 m turbulence-aerosol measurement boom at the top of one street canyon.

Figure 3: Radio-sounding site in city center.

against a new method using standard surface energy balance measurements (Fig. 4, work previously published by Pigeon *et al* 2007).

- The first observations of nocturnal thermal anisotropy (Fig. 6) are presented by Lagouarde and Irvine (2008). No azimuthal anisotropy was found at night, but there is a zenithal dependency. This can be linked to the fraction of roofs viewed and to the vertical gradient of wall surface temperatures.
- These radiative heterogeneities of the urban surface, shown by the thermal infrared data acquired during the campaign, are modelled on a domain of approximately 1 km^2 with the Gastellu-Etchegorry (2008) model.
- With the objective of classifying the ground and roof surfaces over the urban area, Lachérade *et al* (2008) developed and tested on CAPITOUL data the ICARE model to estimate the ground optical properties whatever the irradiated ground conditions (even in shadows).

3. The urban boundary layer flows

- An urban breeze circulation (Fig. 7) was observed on a warm summer day (Hidalgo *et al* 2008a). While the city air is colder than that of the countryside in the morning, the sensible heat flux becomes larger during the afternoon, leading to the urban breeze circulation. Aircraft measurements show that an urban breeze starts in early afternoon, with convergence at low levels (with convergent winds between 1 and 2 m s^{-1}, Fig. 5), and divergence in the upper boundary layer.
- This episode was successfully simulated by Hidalgo *et al* (2008b).
- In-situ and aircraft SF6 tracer measurements in and over a suburban area show the plume to behave differently relative to inhomogeneous thermally-driven turbulence (Lac *et al* 2008). The data were used to validate a coupled meteorology-dispersion model used in emergency response situations.

4. The aerosol-boundary layer interaction

- An increase of the relative abundance of black carbon in the ultra-fine mode causes a decrease of the single scattering albedo of aerosols from 0.9 to 0.5, which can lead to a diurnal average heating value of 4.5 K day^{-1} in the urban boundary layer (UBL) (Gomes *et al* 2008). There is a strong link between the UBL height and aerosol concentration.
- This strong seasonal variability was also observed in the chemical speciation of the aerosol, throwing into relief the influence of various dominant sources (Calvo *et al* 2008).

Data from the CAPITOUL campaign are available to the scientific community on the campaign web site (http://medias.cnrs.fr/capitoul). Interested scientists are encouraged to employ this unique coupled energetics/dynamics/aerosols dataset in order to improve our knowledge of urban climate.

Articles of the CAPITOUL special issue

(Meteorology and Atmospheric Physics, December 2008, Volume **102**, Numbers 3-4):

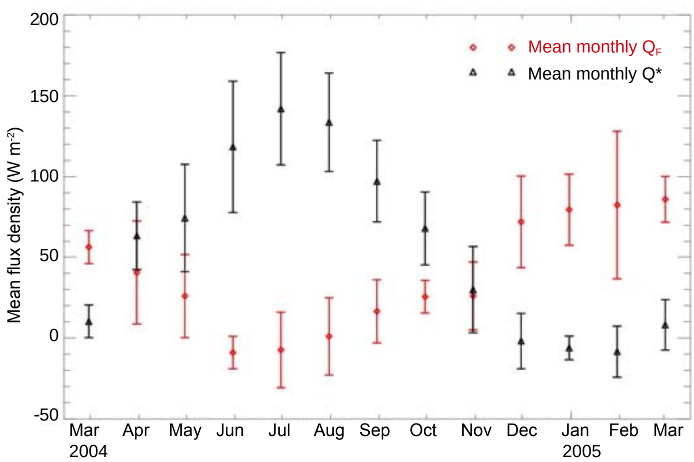

Figure 4: Annual cycle of monthly averaged net radiation (black, measured on the tower) and anthropogenic heat flux (red) estimated from the integrated residual method (Pigeon *et al* 2007).

Masson V., L. Gomes, G. Pigeon, C. Liousse, V. Pont, J.-P. Lagouarde, J. Voogt, J. Salmond, T. Oke, J. Hidalgo, D. Legain, O. Garrouste, C.Lac, O.Connan, X. Briottet, S. Lachérade, 2008: The Canopy and Aerosol Particles Interactions in TOulouse Urban Layer (CAPITOUL) experiment. *Meteorology and Atmospheric Physics*, 102 (3-4), 135-157.

Pigeon G., M. A. Moscicki, J. A. Voogt and V. Masson, 2008: Simulation of Fall and Winter energy balance over a dense urban area using the TEB scheme, *Meteorology and Atmospheric Physics*, 102 (3-4), 159-171.

Lagouarde J.-P., M. Irvine 2008: The directional anisotropy in thermal infrared measurements over Toulouse during CAPITOUL experiment: first results, *Meteorology and Atmospheric Physics*, 102 (3-4), 173-185.

Gastellu-Etchegorry J.P., 2008, 3D modeling of satellite spectral images and radiation budget of urban landscapes, *Meteorology and Atmospheric Physics*, 102 (3-4), 187-207.

Lachérade S., C. Miesch, D. Boldo, X. Briottet, C. Valorge, H. Le Men, 2008: ICARE: A physically-based model to correct atmospheric and geometric effects from high spatial and spectral remote sensing images over 3D urban areas, *Meteorology and Atmospheric Physics*, 102 (3-4), 209-222.

Hidalgo J., G. Pigeon, V. Masson, 2008 (a): Urban-breeze circulation during the CAPITOUL experiment: Experimental data analysis approach, *Meteorology and Atmospheric Physics*, 102 (3-4), 223-241.

Hidalgo J., V. Masson, G. Pigeon, 2008 (b): Urban-breeze circulation during the CAPITOUL experiment: Numerical approach, *Meteorology and Atmospheric Physics*, 102 (3-4), 243-262.

Lac C., F. Bonnardot, C. Camail, O. Connan, D. Maro, D. Hebert and M. Rozet, 2008: Atmospheric dispersion experiment during CAPITOUL to evaluate an operational disper-

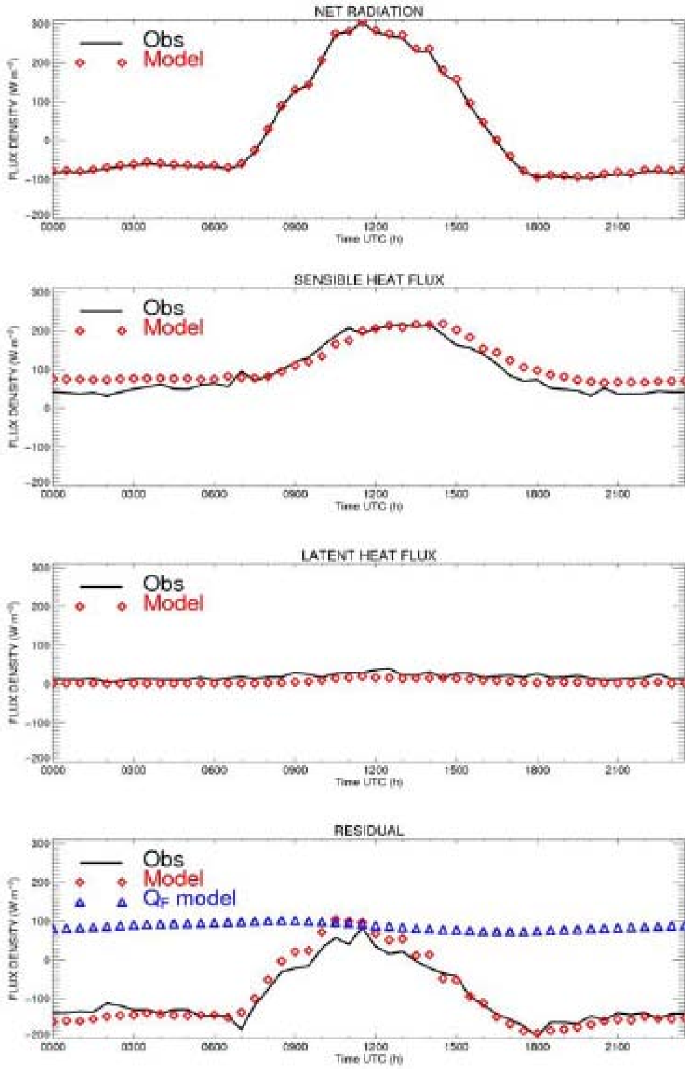

Figure 5: Comparison between simulated (TEB) and observed components of the wintertime Surface Energy Balance (mean diurnal cycle for 20-28 Feb. 2005).

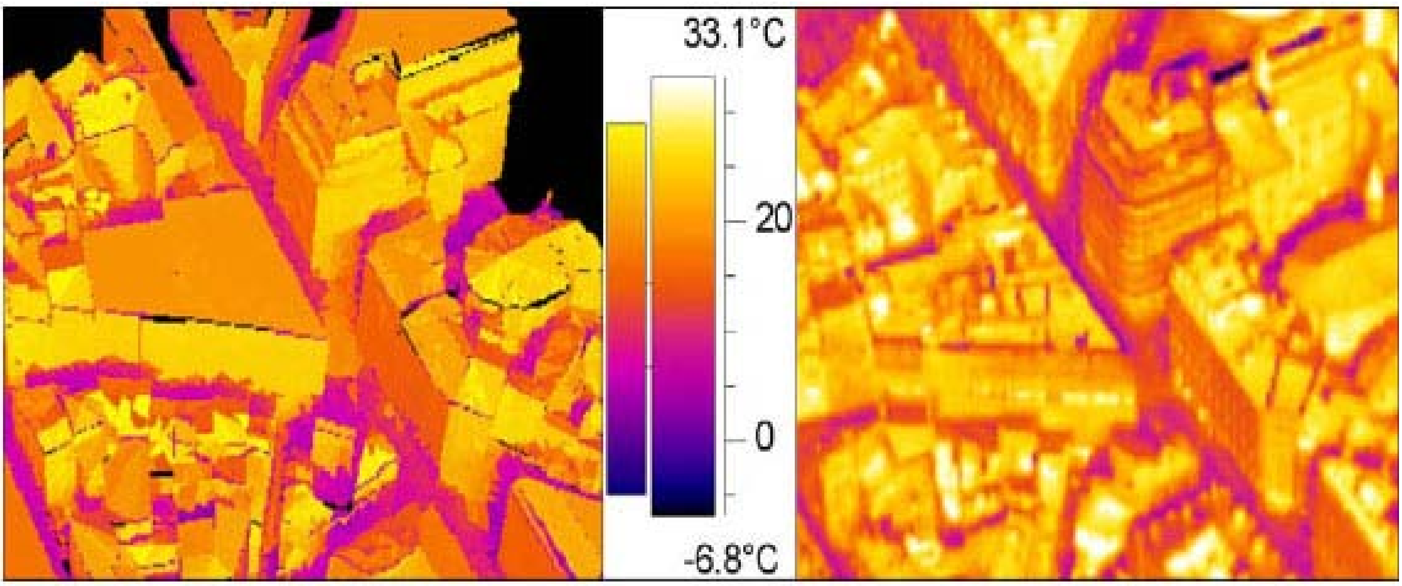

Figure 6: Thermal anisotropy of the urban canopy: simulation with SOLENE model (left) and aircraft observation (right). (courtesy of A. Hénon, ECN, Nantes, France).

sion modelling system: Evaluation of a mesoscale dispersion modelling tool during the CAPITOUL Experiment, *Meteorology and Atmospheric Physics*, 102 (3-4), 263-287.

Gomes L., Z. Veresoglou, S. Rojas, V. Pont, and M. Mallet, 2008: Evolution of the chemical, microphysical and optical properties of aerosol particles in the Toulouse urban layer during CAPITOUL, *Meteorology and Atmospheric Physics*, 102 (3-4), 289-306.

Calvo Ana, Véronique Pont, Catherine Liousse, Bernard Dupré, Armand Mariscal, Cyril Zouiten, Eric Gardrat, Pierre Castera, Corinne-Galy Lacaux, Amaya Castro, Roberto Fraile, 2008: Intra-Annual and monthly trends of the chemical composition of urban aerosols in Toulouse, France (CAPITOUL-Canopy and Aerosol Particles Interaction in TOulouse Urban Layer-experiment), *Meteorology and Atmospheric Physics*, 102 (3-4), 307-323.

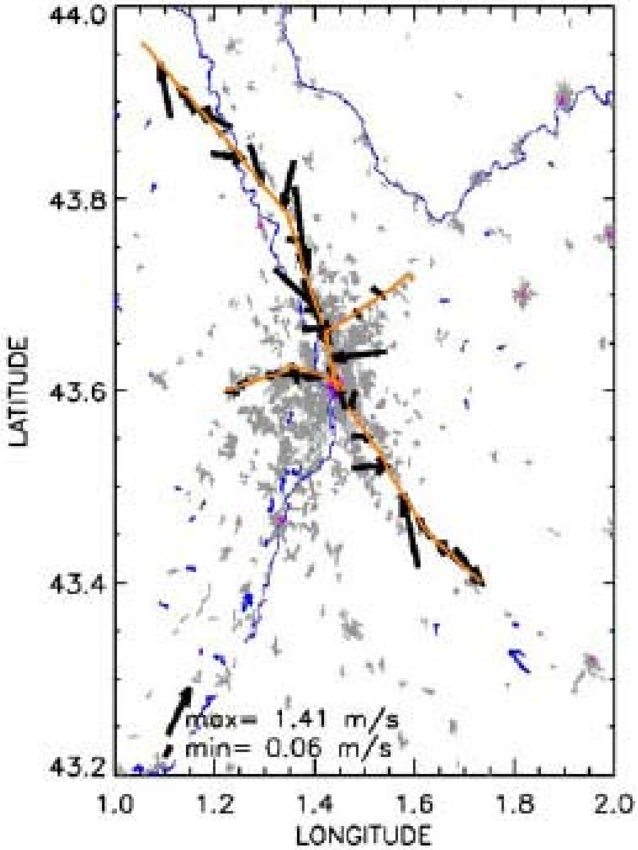

Figure 7: Urban breeze (convergent branch in the lower boundary layer) observed by the aircraft.

Other references on CAPITOUL:

Pigeon G, Legain D, Durand P, Masson V. 2007. "Anthropogenic heat release in an old European city (Toulouse, France)". *International Journal of Climatology*, 27(14), 1969-1981.

Pigeon G., A. Lemonsu, V. Masson and J. Hidalgo, 2008 "From urban climate observation to integrated modelling of the city", *La Météorologie*, 62, I-IX.

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