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Editorial: Special issue on CAPITOUL (Canopy and Aerosol Particle Interactions in TOulouse Urban Layer) experiment

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Cities bring together 50% of the world population, and this share exceeds 80% in developed countries. Moreover, urban areas concentrate the vast majority of capital stock (housing, water delivery and transportation infrastructures). Clearly, such population concentrations give rise to social, economic, and environmental concerns. Among these issues, urban areas are subject to specific micro- and meso-climates whose most striking feature is the Urban Heat Island (UHI). This phenomenon, whereby air temperature is often higher downtown in comparison with the outskirts (which are themselves warmer than the surrounding countryside), was first observed by Howard (1820) over the city of London. Nowadays, the temperature difference can reach up to 10° for large agglomerations and can strongly enhance heat stress, especially at night, during heat waves, and lead to serious consequences in terms of public health. This was the case in 2003 when a strong heat wave affected Europe and caused more than 70,000 casualties, with a higher percentage of victims in urban areas (for example, in France). Better understanding of the urban climate is therefore necessary, since climate projections have foreseen an increase in the frequency and intensity of heat waves by the middle of this century (Déqué 2007). However, urban climatic phenomena are not restricted to the UHI, as the city also affects the wind pattern in the boundary layer (both by modifying synoptic-scale flow and inducing urban-related thermal flows), alters near-surface humidity, changes the frequency of fog events and enhances convective clouds, and atmospheric turbulence (Oke 1978, Hidalgo et al. 2008a). More controversially, it may also play a role in changing amounts and types of precipitation over and downwind of cities (Bornstein and Lin 2000).

In order to improve our knowledge of a system (in this case, the urban climate), several tools are at the disposal of the scientific community: theory, laboratory experiments, numerical simulations and *in-situ* observations. While the first three are, in one way or another, representations of the system created by the scientist, the fourth (*in-situ* observations) is, and always will be, crucial, because experimental observation of the real system, when available, is necessary to maximize access to the reality of the state and processes of the system (and can be used to validate the first three conceptual approaches).

While modern scientific observations of the urban climate began to accumulate in the early 20th century, more rigorous, process-oriented studies, such as the work of Tim Oke on the physics of the urban canopy in Canadian cities

(Oke 1973, 1988), were largely initiated in the late 1960s, 1970s and 1980s. Also during this period, METROMEX, the first large-scale observational experiment on the dynamical and thermo-dynamical impacts on the local atmosphere, took place over American Midwestern city of Saint Louis (Changnon 1981). While observational studies on meteorological processes remained at the forefront of urban climatological research thereafter, large-scale collaborative, observationally-intensive studies of the urban atmosphere tended to be focused on air quality and pollution aspects, and not on the physics of the urban boundary layer. Recently, since the turn of the century, urban climate studies within intensive observational programs have again become prominent, as exemplified by ESCOMPTE (Cros 2004) in the coastal city of Marseille, France, and BUBBLE in the urban area of Basel, Switzerland, in a mountainous region (Rotach et al. 2005). In these experiments, due to the geographical locations of the cities, the urban influences were in complex interaction with the sea breeze and mountain flows. The need arose to study a city whose atmosphere is not influenced by such local effects, in order to observe experimentally the role of several purely urban processes on the urban micro- and meso-climate. The topic of the present special issue is to present the results of the Canopy and Aerosol Particle Interactions in TOulouse Urban Layer (CAPITOUL) experiment, that took place over a period of one year over the city of Toulouse, France.

The CAPITOUL experiment is a joint experimental effort in urban climate, including the energetic exchanges between the surface and the atmosphere, the dynamics of the boundary layer over the city, and their interactions with aerosol chemistry. The campaign took place in the city of Toulouse in southwest France, from February 2004 to February 2005. This allowed the study of both the day-to-day and seasonal variability in urban climate processes. The observational network included surface stations (meteorology, energy balance, chemistry), profilers and, during intensive observing periods, aircraft and balloons.

(1) 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 refers to three main aspects of the urban climate:

(2) Urban canopy energetics
- Pigeon et al. (2008) present the modelling of the anthropogenic heat flux by the TEB urban scheme (Masson 2000) and its validation against anthropogenic fluxes estimated by an new method using standard surface energy balance measurements (previously published by Pigeon et al. 2007).
- The first observations of nocturnal thermal anisotropy are presented by Lagouarde and Irvine (2008). No azimuthal anisotropy was found at night, but there is a zenithal dependence. 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) Urban boundary layer flows
- An urban breeze circulation was observed on a warm summer day (Hidalgo et al. 2008b). 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 (convergent winds between 1 and $2\,m\,s^{-1}$), and divergence in the upper boundary layer.
- This episode was successfully simulated by Hidalgo et al. (2008c).
- *In-situ* and aircraft SF_6 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) 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 $4.5\,\mathrm{K\,day^{-1}}$ 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.

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