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FluxSAP 2010 EXPERIMENTAL CAMPAIGN OVER AN HETEROGENEOUS URBAN ZONE, PART 1: HEAT AND VAPOUR FLUX ASSESSMENT

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Abstract: The FluxSAP 2010 is the first of two experimental campaigns aiming at quantitatively assessing the contribution of urban vegetation in the sensible heat and water vapour fluxes, over an heterogeneous area including buildings, semi-impervious surfaces, low and high vegetation. The 2010 experiment objective was primarily the feasibility of measurements with five different methods, and their analysis with respect to the surface cover mode variability of their footprints.

***Key words:** Urban vegetation, heat flux, water vapour flux, urban climatology.*

INTRODUCTION

With some fifteen partners, the research institute of urban sciences and techniques (IRSTV) launched a large federative programme of research and assessment of the role of vegetation in the sustainable urban development, VegDUD, a 4 years programme (2010-2013) funded by the French National research agency (ANR). Two campaigns of urban climatology measurements combining a ground-based experimental set-up with airborne remotely-sensed observations are associated to this project in 2010 and 2012. The study area spreads over a part the north-east sector of Nantes, between the Erdre and Loire rivers. The scientific objective of the FluxSAP campaigns is to obtain reference data allowing model validation, as concerns heat and water vapour transfers, over an heterogeneous urban site, identifying their sources and separating the contributions from the bare and covered soils, from the buildings, and from the vegetated areas. The first campaign took place during 4 weeks in May 2010 around the district of the Pin Sec watershed which is instrumented by the IRSTV for monitoring urban hydrology and meteorology since 2006 (Ruban, V. et al., 2011). Mainly oriented towards measurement feasibility and quality assessment, this campaign included the following measurements:

► meteorological variables and aerodynamic turbulent fluxes from 8 instrumented telescopic masts of 10 to 30 m, at some open areas of the district ;
► temperature and water content in the soil and at the surface at 8 points,
► temperature and humidity at 2-3 m above the surface at 14 points,
► integrated heat fluxes by 5 large aperture and one small aperture scintillometers from flat roofs of elevated buildings;
► passive tracer concentrations along a mast and under a small tethered balloon;
► surface temperatures by two airborne thermal infrared (TIR) cameras and two handheld radiometers;
► surface cover modes (materials, vegetation and grounds) by two high spectral and spatial resolution airborne hyper-spectral spectro-imagers and an handheld spectrometer.

The data base will include geographical information and will be freely available

THE OBJECTIVES

The program objectives are twofold, methodological and quantitative. The methodological objective concerns the feasibility of measuring the sensible and latent heat fluxes in an heterogeneous urban area, and assessing the various contributions. The quantitative objective is to obtain over one heterogeneous urban site some heat and water vapour transfers reference data allowing to assess models which take into account the heterogeneity of urban grounds and the presence of networks. For this purpose it is necessary to perform reliable and precise measurements of the fluxes, but also to identify the footprints of these measurements (see Maro, D. et al., 2011). In May 2010 our objective was to implement 5 flux measurement methods over one domain and to compare their results.

• Water table level, water content and temperature measurements in the ground allow to monitor the water and heat transfers through the soil layers. The temperature profiles allow to evaluate the conduction heat flux with the gradient harmonic method based on a Fourier analysis of temperature time series at several depths. These are point measurements and their locations have been chosen to assess the behaviour variability of the open green spaces.

• Temperature and humidity measurements at the surface (T_s, q_s) and at a height z of 2-3 m above the surface (T_z, q_z) may provide fluxes with the method of the mean gradients:

$$H_s = \rho\, C_p\, C_H\, U\, (T_z - T_s)\ ;\ \ LE = L_v\, C_V\, U\, (q_s - q_z) \tag{1}$$

where U is a reference wind speed, and C_H and C_V transfer coefficients whose values are a function of surface characteristics. The analysis at the district scale (i.e. the mapping of the fluxes over the whole domain based on point measurements) requires to compute interpolations based on ground cover modes and sensor environment classification. Remote sensing measurements with airborne TIR cameras will allow to complete ground measurements to determine the spatial distribution of the surface temperatures.
• Sensible heat and water vapour turbulent flux measurements with fast sensors (at least 10 Hz) of turbulent fluctuations of vertical wind speed w', temperature T', water vapour concentration q', at the top of meteorological masts, are analyzed with the aerodynamic “eddy correlation” method:

$$H_s = \rho\, C_p <w'T'>\ ;\ \ LE = L_v <w'q'> \tag{2}$$

where the brackets indicate a time averaging.
Their footprints are of the order of 10 ha depending on wind speed/direction, atmospheric stability and surface roughness.
• The measurements with elevated scintillometers, above the urban canopy, allow to evaluate sensible heat fluxes integrated over their 1–2 km path lengths; their footprints extend over a few km^2.
• Temperature, humidity and wind speed measurements at several levels of the instrumented mast of the permanent observation site allow, in principle, to evaluate the fluxes with the mean vertical profile or gradient method.

The footprint issue is a key of the feasibility objective. The footprint of a flux measurement is the ground area where most of the measured flux is coming from. Its size (length and width) and its distance from the sensor depend on the sensor height, the wind direction and speed, the atmospheric stability, and the transfer characteristics of the area such as C_H and C_V or the roughness lengths (Schmidt, H.P., 2002). The scintillometer footprints have an additional dependency on the ground relief since the height above ground varies along the path when the ground is not flat and/or when the transmitter and receiver are not at the same height. In a urban area where the land use and cover modes present a large heterogeneity the determination of the footprints, at each measurement period, is necessary to evaluate separately the flux contributions of the various classes of surfaces. This requires a precise documentation of the land use/cover modes, with a high spatial resolution, and a pertinent footprint model. Since the available footprint models have not been developed for urban areas, their validation or adaptation may also be necssary.

THE EXPERIMENTAL SET-UP

The measurements were performed in Nantes N-E sector between the Erdre and Loire rivers in a district with heterogeneous land uses (≈ 50 % vegetation) around the small permanently instrumented urban watershed of Pin Sec (Figure 1). The campaign spread over the 4 weeks of May 2010. The meteorology was rather favourable since over the measurement period we observed a range of situations from overcast with showers to very strong insolation.

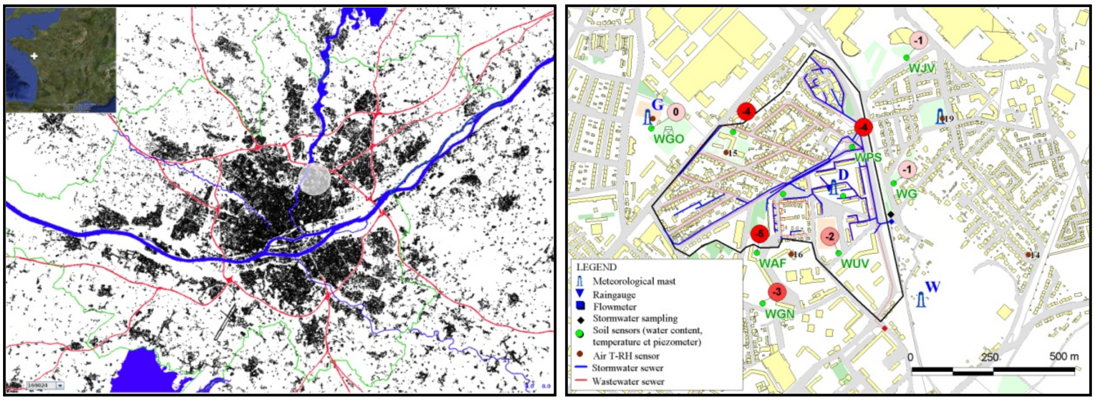

Figure 4; Left: location of the experimental domain (white disc) within the Nantes urban area (blue, water surfaces; red, main roads; black, buildings; green, limits of urban area. Right: Instrumentation of the Pin Sec catchment (long term observation area - the black line delineates the watershed); G et D indicate the permanent meteorological masts at the Goss site (30 m) and on the Dunant building roof; the temperature profiles in the ground were set at the same places than the piezometers; the pink-to-red dots give the measured soil drying at 35 cm during the month of May 2010 (in moisture %).

Height masts or available supports were equipped with ultrasonic anemo-thermometers at heights of 10 to 26 m above ground level (agl), among which two at 2 levels (G and E) and six with H_2O/CO_2 sensors. Five large aperture scintillometers were set to form a triangle and a cross, among which 2 were twinned in parallel to test a method to obtain the friction velocity (Figure 2). A small aperture scintillometer was set between two neighbour buildings at the central site (D), with a 75 m long path. In the measurement domain, the T-RH network included 14 air temperature and humidity sensors at 2-3 m agl with autonomous recorders. The network of ground sensors included 10 piezometers, 8 water content sensors, and 8 co-located temperature profiles between 0 and -50 cm or -1 m (Figure 2). A Sodar was also operated but during only 2 days due to the noise nuisance. Details can be found in Mestayer, P. et al. (2011a and b)

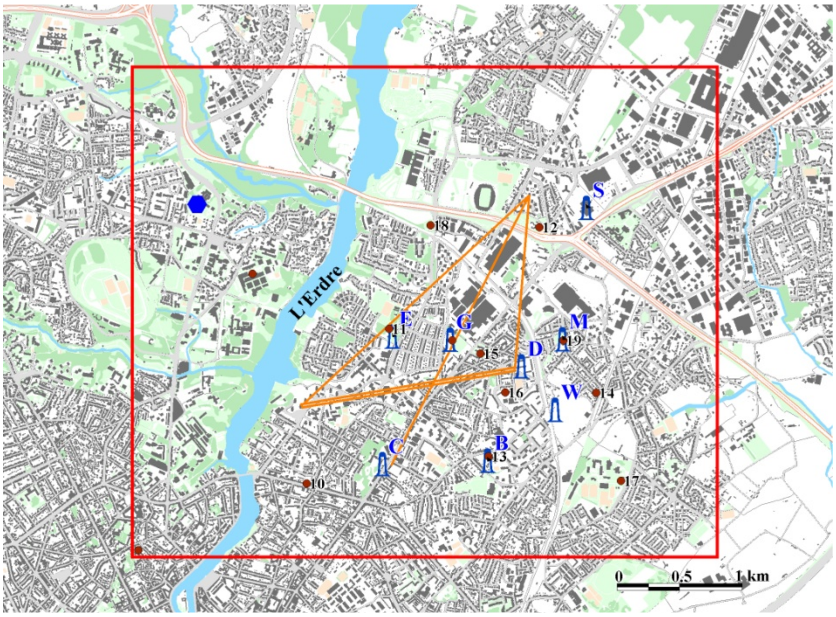

Figure 2. Measurement domain and set-up during the 2010 campaign: red dots, T-RH sensors; blue symbols, turbulent flux sensors on masts; orange lines, scintillometer paths; blue hexagon, Sodar; red frame, limits of the geographical data base.

In addition, the campaign included the following measurements:
- over 3 days, 13 infrared remote sensing flights with two TIR cameras on board of the SAFIRE[1] Piper Aztec 21, coordinated with 140 reference target TIR measurements at the ground, to document the spatial variability of surface temperature at each hour of a sunny day;
- one hyperspectral flight with two push-broom Hyspecs cameras providing 160 images in the VNIR domain (400–1000 nm) and 256 in the SWIR (1000–2500 nm) to document the surface cover modes (materials and vegetation types) with a spatial resolution of 0.6 m;
- 30 tracer gas emissions (SF6) to document the dispersion within the urban canopy in view of testing the footprint models, which are presented elsewhere by Maro, D. et al. (2011).

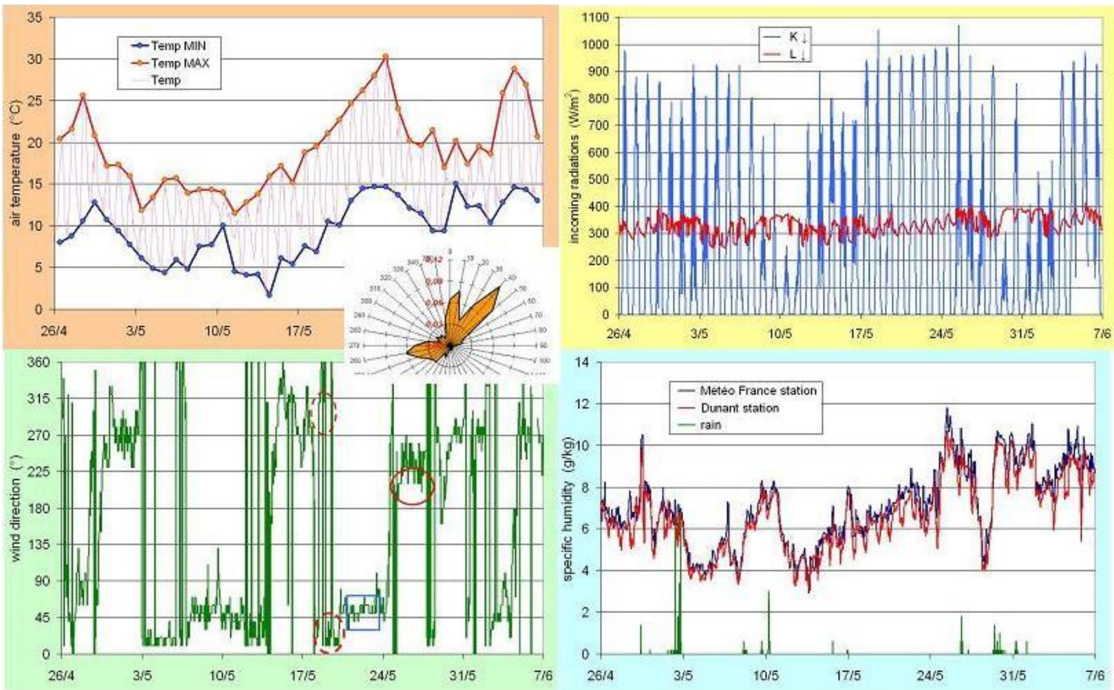

Figure 3. Meteorology during the campaign: temperatures, solar and infrared incoming radiations, wind direction and wind rose, water vapour density and rain.

The recorded meteorological variables (Figure 3) include the measurements at the permanent Pin Sec site and the data from the Météo France station, located on the south of the urban area. The wind rose is rather representative of the dominant wind

[1] Service of the French instrumented airplanes for the environmental researches, joint unit of CNRS, CNES and Météo France.

regimes over the year in Nantes. May 10 and 29 stand out with a strong cloud coverage. The temperatures varied largely, sometimes rapidly, by 2 to 30 °C. The rain showers were numerous and regularly spread, but the precipitation total was about one half of those of May in the preceding years (in the average 41 mm). The ground hydrological sensor network worked well from May 7. The observation period belongs to the decline phase of ground saturation levels, after the winter high water-table period ending by the end of March. The measurements in the ground indicate that the ground water content decreased by 2.4 % in the average, with a noticeable spatial variability between the measurement points, located on various green spaces; this appears in Figure 2 which indicates that the ground drying during the month of May varied from 0 to 5 % of the volumetric soil moisture. The sub-surface flows are indeed influenced by the presence of roots and buried networks, and the morphology of the instrumented green spaces is variable, at the surface as well as in the subsoil.

THE FIRST RESULTS

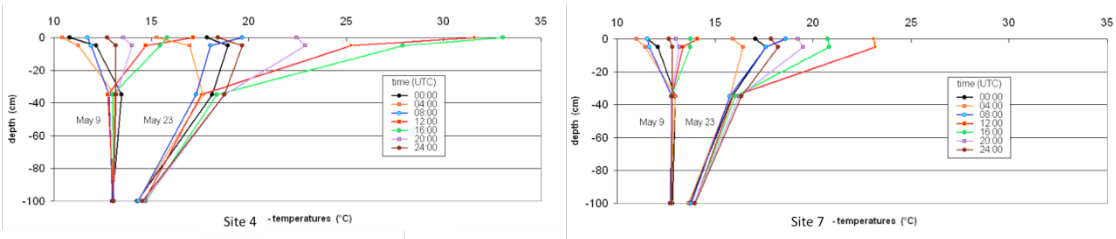

Figure 4. Temperature profiles in the ground at two sites.

The ground temperatures have been measured at 3 or 4 depths. To illustrate the spatial variability of temperatures and storage fluxes in the upper layers Figure 4 displays the profiles obtained during two typical days, May 9 after a relatively cool and humid period and May 23 at the end of the hot period (see Figure 3). The site 7 (close to WAF) is most of the time in the shadow (sunlit from 9h30 to 11h in May), while the site 4 (WPS) is open and the temperature variation amplitude is larger. The phase shift between the surface and the -5 cm depth is about 1 hour for the two sites. At the surface the temperature is directly dependent on the local insolation ; thus the storage flux, associated to the surface gradient, is negative during the night and may stay so during a large part of the day at the masked site 7 while it is largely positive all day long at the open, sunlit site 4 on May 23. This Figure also shows that the temperature variations a 1 m in the ground are nearly null at the day scale and small at the week scale.

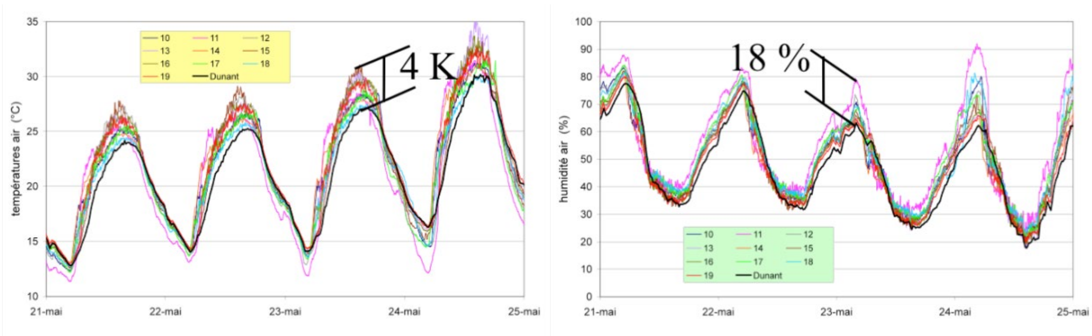

Figure 5. Examples of air temperature (left) and relative humidity (right) at 2-3 m agl from the T-RH network sensors.

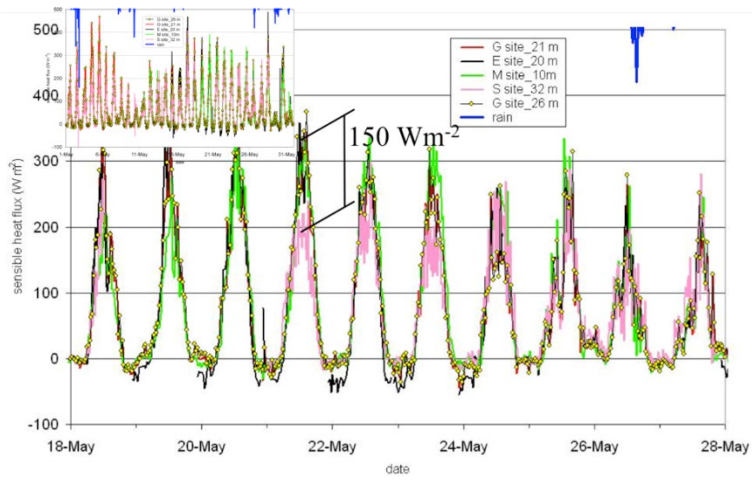

Figure 6. Sensible heat fluxes measured by the eddy covariance method at 4 sites (5 sensor systems); the upper corner vignette shows the whole measurement period and the blue bars the rain intensity.

The main results available to date are the comparative time series of the sensors which allow to evaluate the heat fluxes, with different footprints. Examples are given here for air temperature and relative humidity measurements at 3 m agl (Figure 5), sensible heat fluxes from the eddy-correlation sensors (Figure 6) and from the scintillometers (Figure 7), averaged over 15 minutes. Each data set present a remarkable coherency in the daily variations, but also noticeable differences between the various sensors. We think that the coherency is the indication of the measurement quality and that the differences are the signatures of the differences in land cover compositions of the different footprints. Not all the data are available yet, but we must note that in these preliminary results the scintillometers yield heat fluxes twice as large as the eddy-correlation sensors, which implies that more comparisons and adjustments are necessary before starting the detailed analysis with the footprints, and before the second campaign in June 2012.

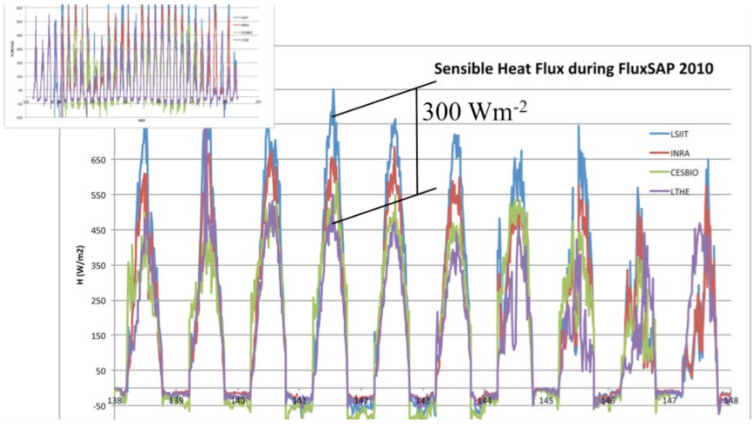

Figure 7. Sensible heat fluxes measured by 4 large aperture scintillometers from May 18 to 28; the upper corner vignette shows the whole measurement period. (Irvine M. et al., 2011)

For the 2012 campaign, we consider to bear some efforts to better document the experimental domain and to better quantify the role and the functioning of vegetation, in the traditional arrangements as well as in the ecologically innovative management zones. With parallel developments of models, we think that this imposes to refine the understanding of the evapotranspiration flux in urban heterogeneous zones, and notably (i) to better document the connections of impervious surfaces to the rainwater network to know better the contribution of the runoff from these surfaces to the water flow at the network outlet, (ii) to evaluate the water storage in the ground by the measurement of at least one vertical profile of soil moisture and suction, (iii) to differentiate more clearly the measurement sites and the use of the scintillometers, with strongly mineral footprints on the one hand, strongly vegetal ones on the other hand, which implies to have at disposal more secured supports and more water vapour sensors. As concerns the experimental set-up of the campaign, it also seems interesting:

- to extend the instrumented zone to the neighbour, recently developed eco-district ;
- to instrument a building with temperature sensors to monitor its energy budget within that of the district ;
- to document the lower atmosphere (0-200 m) wind, temperature and humidity profiles ;
- to document the differences between concentration and flux footprints with a passive tracer flux measurement system ;
- last but not least, to implement one, two (or more ?) water vapour prototype scintillometers, maybe with new partners.

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