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A three years long fieldwork experiment to monitor the role of vegetation on the urban climate of the city of Strasbourg, France

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1. Introduction

The ICube Laboratory (UMR 7357 University of Strasbourg - CNRS), in collaboration with the PIAF Laboratory (UMR 547 INRA) and the local association for atmospheric pollution monitoring (ASPA), has initiated in 2013 a fieldwork experiment to measure and monitor the urban climate of the city of Strasbourg, East of France, with a particular focus on the role of vegetation with respect to micro-climatic conditions suitable for human comfort. This fieldwork experiment is organized around four complementary objectives. At first, a detailed analysis of the spatial and temporal variability of the urban heat island effect is conducted through the deployment of a network of twenty-three weather stations in and around the city, monitoring standard parameters such as air temperature and humidity, as well as wind speed and direction. This network also contributes to the European INTERREG IV project “Atmo-IDEE”. Secondly, to allow for an in-depth analysis of the physical processes controlling the UHI, two sites have been equipped with a set of radiometers and eddy correlation sensors to measure the radiative and energy balance. The first site, located in a densely urbanized area, can be considered as mineral and has a large footprint since the sensors are installed 30 meters above ground. The second site is located in an urban park near the city center, and is equipped with the same set of instruments, here on top of a 20 meters high mast. The later site is used to fulfill the third objective, which is to closely keep track of the contribution of the vegetation to turbulent fluxes measured on top of the urban canopy. To do so, a group of six trees is equipped with sap flow sensors. Simultaneously, other sensors are monitoring the soil temperature and water content at seven levels, as well as the photosynthetically active radiation profile below, inside and on top of a tree. Additionally, the contribution of the soil and grass is measured during intensive observation periods using a closed transpiration chamber. The last objective of this experiment is to measure thermal comfort indices, combining integral radiation measurement methods, black globe thermometers, 38 mm flat globe thermometers and a dense set of twenty weather stations (UBIQUITY auto-communicating network). The entire experimental design is presented together with preliminary results.

2. Experimental design

The measurement network deployed and maintained since 2013 over the city of Strasbourg is composed of 23 stations as of today (Fig. 1). Most of these stations are equipped with air temperature and humidity probes and are spread in various locations showing different land cover, especially in terms of building structure and vegetation density (in blue on Fig. 1). They range from the city center to suburban areas and rural areas, giving a good picture of the air temperature variability and of the Heat Urban Island effect. Part of the stations were designed in-lab and record both parameters with a high quality Sensirion SHT75 probe at a 15' time step. There are usually installed on street lamps at a height ranging from 3 to 4 meters above street level (Fig. 2a).

A second group of stations is intended to capture radiative and energy balance variables (in orange of Fig. 1). One station is equipped with a Kipp & Zonen Solys 2 suntracking system together with a CHP1 pyrheliometer to record direct solar radiation, as well as a pyranometer for the global solar radiation, a pyrgeometer for the incoming infrared radiation, and a sensor measuring the incoming photosynthetically active radiation (Kipp & Zonen CM11, CG4 and PSQ1 PAR Lite respectively), each recording at a 2' frequency. The second and third stations are dedicated to turbulent flux measurements, one in a densely urbanized area north of the city center (Fig. 2b), the second in the urban park of the main University campus, east of the city center (Fig. 2c). The densely urbanized station is located is a mineral area, with very few trees, no grass, and buildings of height ranging from 20 to 30 meters. This site is instrumented with a Campbell Sc. CSAT-3 eddy-correlation system together with a LICOR LI7500 gaz analyzer on top of a mast reaching a height of 30 meters above the street level. The mast is also equipped with two levels of air temperature and humidity probes (Rotronic HC2), one standard anemometer, and a set of CM11 pyranometer and CG4 pyrgeometer pointing downward. The station situated in the urban park of the university characterized by a large area of grass with numerous trees (mainly silver linden), and is surrounded by old 20 meters high university buildings. A 20 meter high mast deployed on the grass, between two alignments of linden trees, is equipped with a second set of CSAT-3 and LI7500, as well as a CM11 pyranometer and a CG4 pyrgeometer looking downward (Fig. 2d).

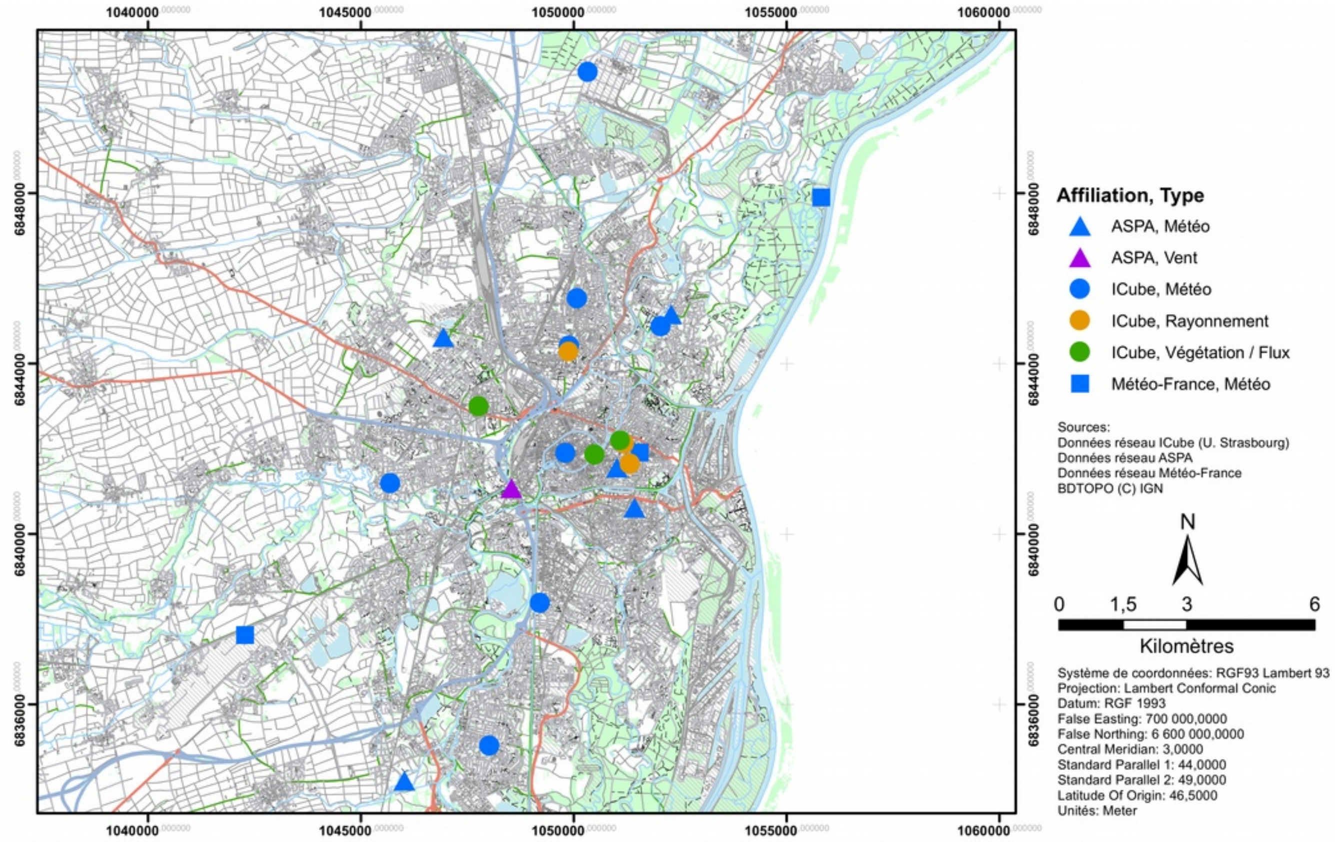


Fig. 1 Map of the existing network (air temperature and humidity stations in blue, radiative and energy flux stations in orange, vegetation monitoring stations in gree).

The urban park of the university campus is central to this experiment, and a dedicated effort was conducted in collaboration of the INRA laboratory PIAF to deploy a large number of complementary instruments. Therefore, beside the already mentioned turbulent flux measurements, a group of six linden trees located around the mast was equipped with sap flow sensors to continuously capture the actual evaporation from these trees since early 2013. Moreover, two transpiration chambers are installed on two slots of grass to measure the contribution of the grass. The later measurement method is sparser than the other since it requires two operators, and is conducted only for some dedicated clear sky days since June 2014 (Fig. 2g). As a complement to these sensible and latent heat flux measures, the soil temperature and water content profiles are monitored at 7 levels from the near surface to 1.2 meters. One of the six linden trees (Fig. 2e) was selected for an in-depth studies of its behavior, and is equipped with :

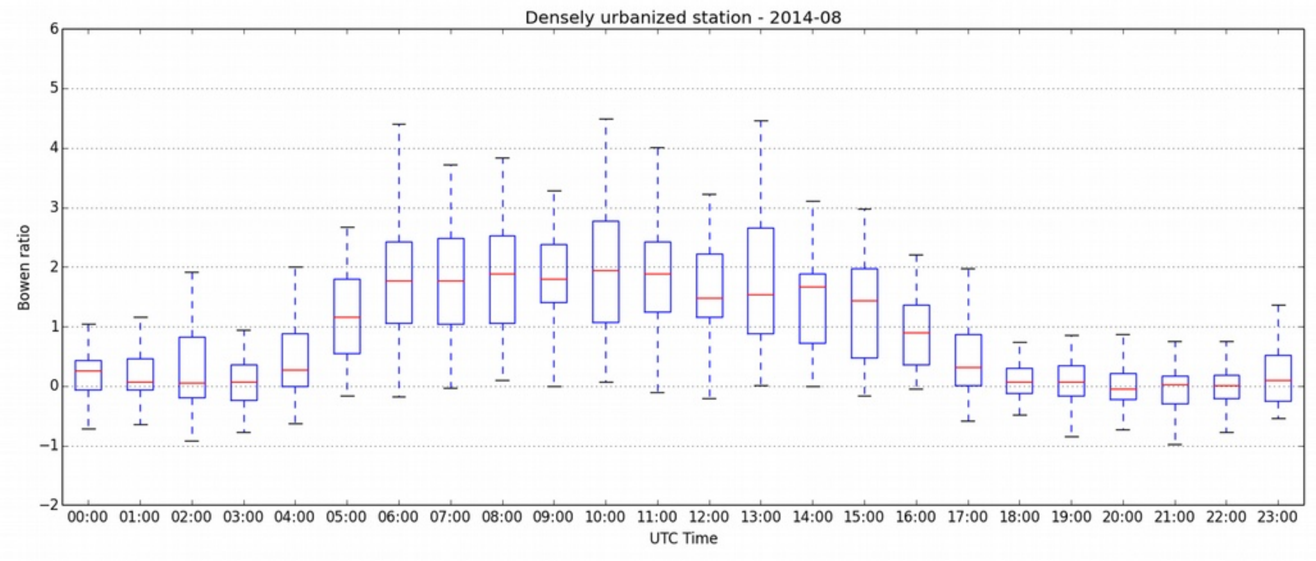
- air temperature and humidity probes at four levels in the canopy;
- incoming PAR profile at four levels in and under the canopy, as well as a measure of the outgoing PAR under the canopy;
- leafs brightness temperature with radiometers pointing eastward and westward, as well as two radiometers capturing the brightness temperature of the surrounding grass and soil;
- branches micro-metric variations of diameters, to monitor daily water stress and yearly growth, using the PepiPIAF sensors designed by the INRA/PIAF laboratory (Fig. 2h);
- the actual 3D structure of the trees from ground LIDAR in winter time (branches alone) and along the phenological season (Fig. 2f. See Landes et al., this poster session).

Additionally, a total of 7 young linden trees are monitored in two other locations to better capture the behavior of the tree specie. To measure thermal comfort indices, a set of 38 mm grey globe thermometers has been build according to Thorsson et al. (2007) and deployed in various stations (Fig. 2i). As compared to the standard 150 mm copper thermometer, the later has very little inertia and comes to equilibrium with the environment in less than five minutes, allowing it to be used on mobile outdoor stations. The two mobile stations include an air temperature and humidity probe, a net radiation sensor, an anemometer and a grey globe sensor. They are used to perform transects along heterogeneous areas of the city, passing by existing fixed stations and stopping for acquisition every 200-300 meters on key spots. As a complement, a new set of twenty wireless auto-communicating sensors is about to be installed in and around the urban park to perform high density monitoring of air temperature. The later sensors, called UBIQUITY, are developed within ICube from a collaboration between climatologists and radio networks experts, and are designed such that each measurement node is also relaying information from other nodes, allowing the network to adapt to a variety of spatial distributions while ensuring real time monitoring and back-up of the data.

Fig. 2 (a) An example of air temperature and humidity station built in-lab, composed of an Arduino module gathering measurements from a Sensirion SHT75 probe and powered by a solar panel ; (b) Aerial view of the densely urbanized area where flux measurements are performed. The mast is set up on top of the building in the center of the picture; (c) Aerial view of the urban park of the university campus. The orange star shows the location of the 20 meters mast. (d) A view of the 20 meters mast in the urban park; (e) The linden tree equipped with a mast for air temperature and humidity profile, a mast for the PAR profile, a sap flow sensor and four infrared radiometers; (f) The same linden tree reconstructed from ground LIDAR point cloud; (g) The transpiration gas chamber to monitor the evaporation from the grass; (h) a PepiPIAF monitoring micro-metric variations of the diameter of the branches; (i) A 38 mm flat grey globe thermometer built in-lab.

3. Preliminary results

Since the experiment is on-going at the time of writing, the following results are mainly intended to illustrate the variety and high potential of the acquired observations. While a detailed footprint analysis of the turbulent flux measurements is still to be performed, sensible and latent heat flux values computed from the two eddy-correlation systems are already of great interest to illustrate the difference of pattern of the flux partitioning between the two areas, especially in summer. As an example, the figure 3 illustrates the Bowen ratio in terms of hourly mean values for the month of August 2014. While this ratio shows median values of nearly 2 in the densely urbanized area, the median Bowen ratio hardly exceed 0.5 in the urban park station.



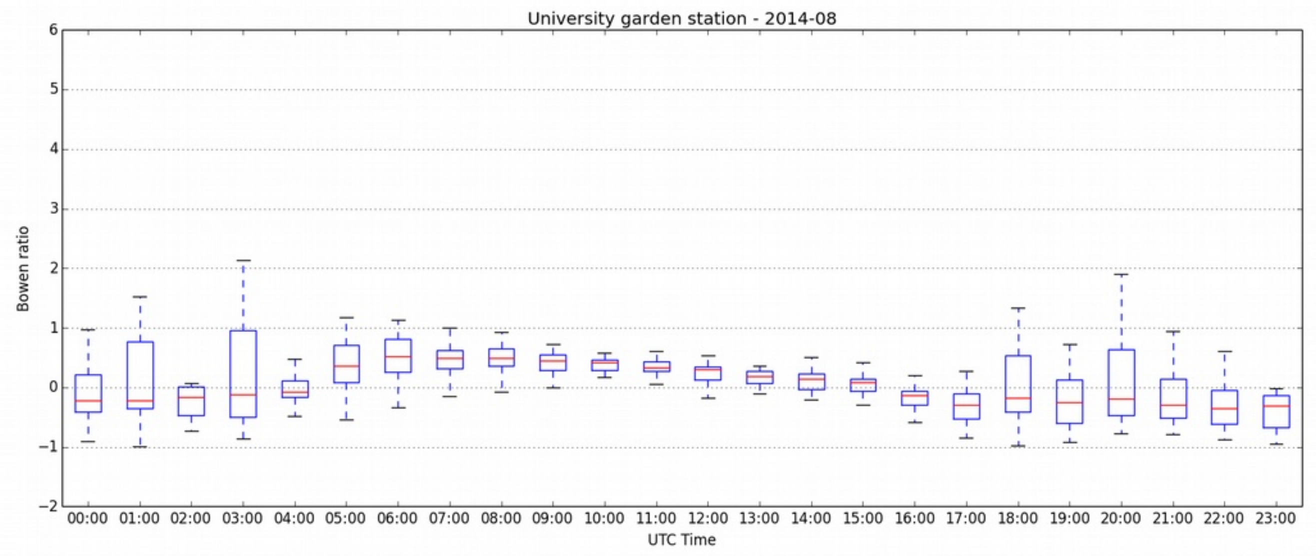


Fig. 3 Values of hourly mean Bowen ratio for the month of August 2014 measured at 30 meters in the densely urbanized area (top) and at 20 meters in the urban park (bottom). Red lines are median values, the blue box expresses the inner-quartile range IQR, the whiskers extend at 1.5 time IQR before and beyond the IQR box.

The evaporation measured over the two grass slots equipped with gas transpiration chamber give interesting results too. While not directly comparable with the latent heat flux on top of the mast, they well illustrate the fast response of the grass to water stress. As shown in figure 4, the latent heat flux ranges from less than 50 W.m^{-2} to more than 100 W.m^{-2} the 19th of June 2014, which is the end of a three weeks dry period, while it exceeds 260 W.m^{-2} the 15th of July, after one full week of rain. For the later day, it is worth mentioning that the exposure of the grass to direct sun directly and significantly affects the evaporation: since this day is partly cloudy, the three large decrease of flux are well linked with the shadowing effects of sparse clouds. Moreover, one can easily see that the slot 1 (in orange) is under the sun earlier than the slot 2, resulting in a difference of latent heat flux of nearly 100 W.m^{-2} at 10am.

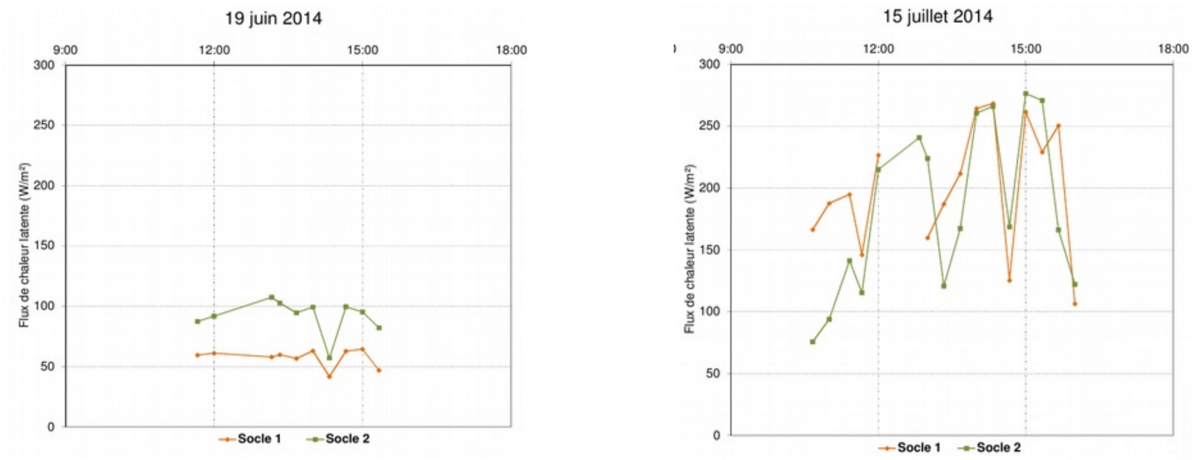


Fig. 4 Evaporation measured on two slots of grass in the urban park during a typically dry period (left, June 19th 2014), and after a week of rain (right, July 15th 2014).

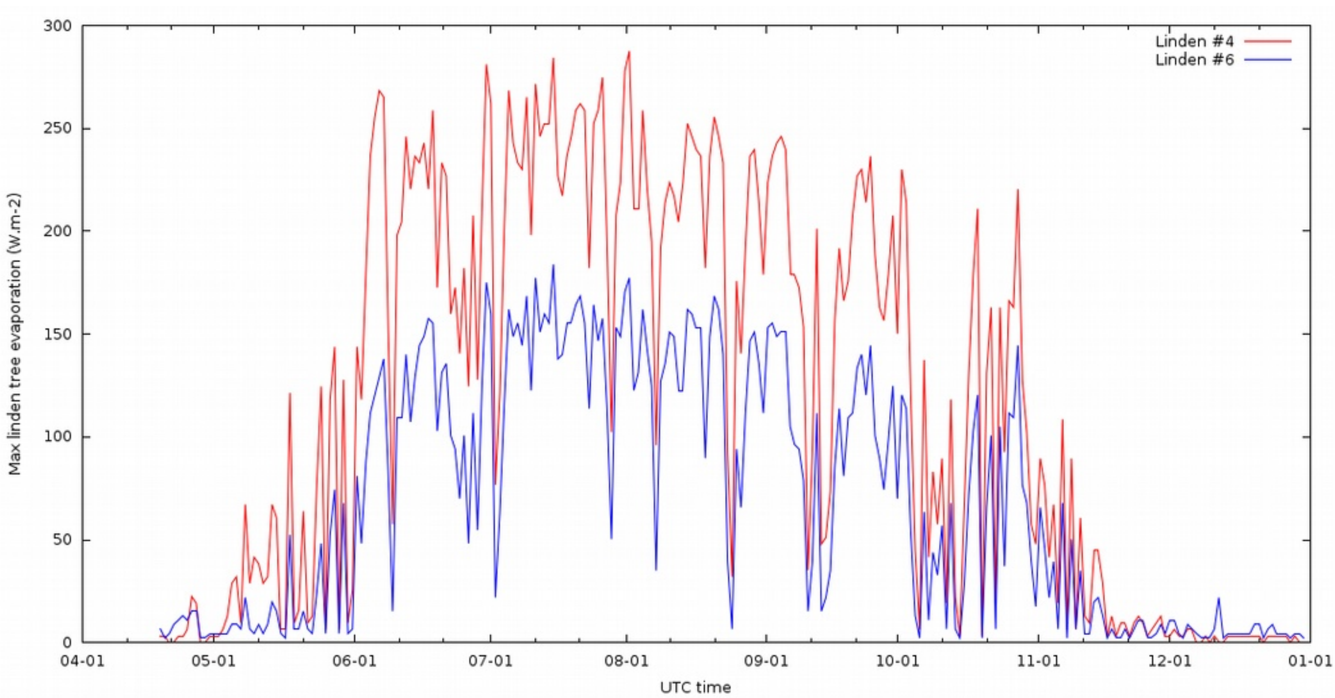


Fig. 5 Evaporation of two linden trees monitored from April to December 2013. The linden tree number 6 shows the lowest evaporation observed from the six tree monitored, while the number 4 shows the highest values.

The evaporation of the linden trees derived from the sap flow sensors also provides an interesting view of the behavior of individual tree and common trends. The figure 5 shows evaporation values of two linden trees, the number 6 (in blue) showing the lowest values as compared to the 5 others, while the number 4 (in red) shows the highest evaporation rate. While being of similar age and comparable size, they show a difference in latent heat flux that can easily exceed 100 W.m^{-2}. On the other hand, one can see that their leafs become active are very comparable dates, and they both show a state of water stress, especially in the second half of June, and in mid-October (for more details, see Ngao et al., this conference).

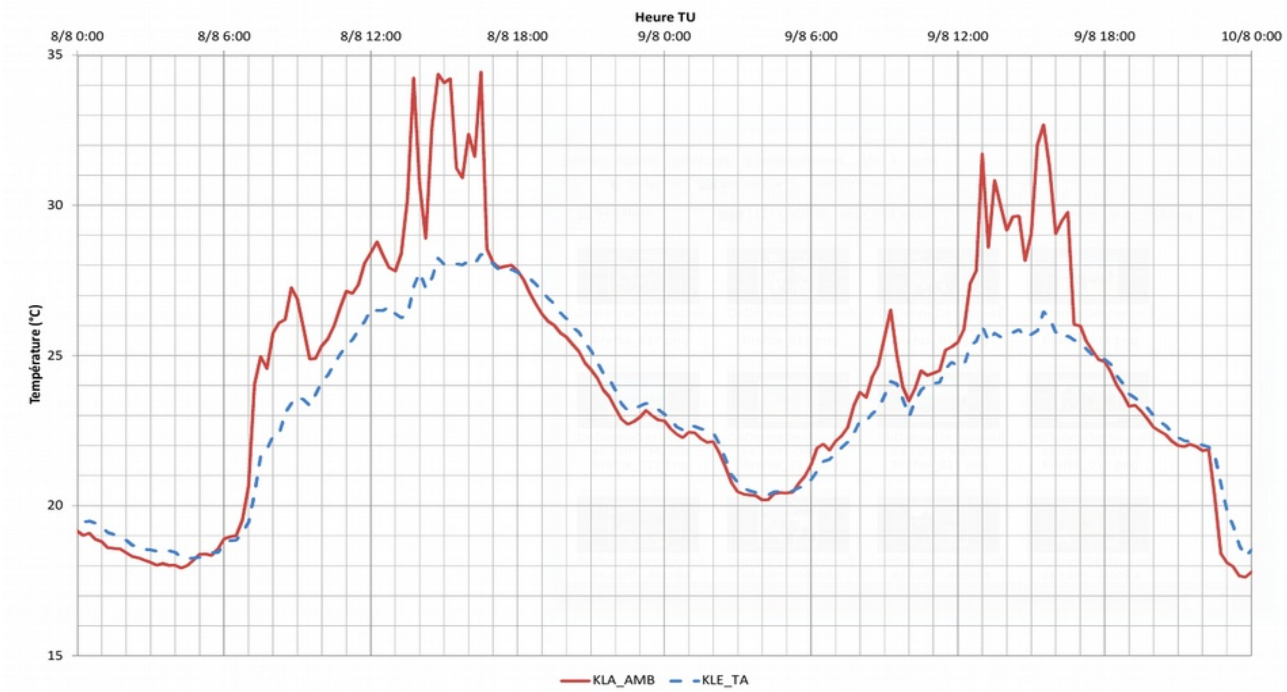


Fig. 6 Measurements of the standard air temperature (dashed blue) and temperature of the grey globe (red) for the 8th and 9th of August 2014, showing a strong increase of ambient temperature when the street comes under direct sun.

Finally, the figure 6 illustrates observations obtained from the flat grey globe thermometer built by the team. While the standard air temperature (in dashed blue) shows a regular pattern for the two selected clear sky days, the shadowing effect of the surrounding buildings is clearly visible from the grey globe temperature (in red). This specific station is situated in the city center, at the crossing of two streets with building reaching 30 meters and a height/width ratio close from 1. While low over the horizon, the sun directly reaches the station from East starting from 7am, and it then hidden by buildings after 8:30am, leading to a difference between the ambient and standard air temperature of nearly 4°C. Then starting from 1:30pm, the direct sun reaches the station from the second street oriented North-South, leading to a maximum temperature difference higher than 6°C.

4. Conclusion

The on-going experiment coordinated by the ICube Laboratory in Strasbourg involves climatologists, eco-physiologist, LIDAR, topography and remote sensing experts, as well as sensor design engineers. The meteorological measurement points counts 23 stations, and will reach a total of 52 fixed and mobile stations during the coming intensive observation period of July 2015. Altogether, 13 linden trees are monitored continuously since 2013, and two radiative and energy balance stations are fully operational since 2014. The results presented here must be considered preliminary though strongly encouraging. This experiment offers new opportunities for an in-depth investigation on the role of vegetation in the urban climate of the city of Strasbourg. The large variety of sensors deployed, the broad range of expertise of the partners involved and the overall duration of the observations (four years in total) will provide high quality data to validate and refine existing models (see Kastendeuch et al., this poster session).

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References

Thorsson S., Lindberg F., Eliasson I., Holmer B., 2007: Different methods for estimating the mean radiant temperature in an outdoor urban setting, *Int. Journ. Climatology*, **27**, 1983-1993