5.1 CHARACTERISTICS OF THE URBAN THERMODYNAMIC ISLAND AND THE ENERGY BALANCE ON TOULOUSE (FRANCE) DURING WINTER AND SPRING PERIODS OF THE CAPITOUL EXPERIMENT

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1. INTRODUCTION

The CAPITOUL field experiment takes place in Toulouse from February 2004 to February 2005 (see Masson et al, 2004). Here we present the first analyses of the:

- energy balance fluxes at a urban site,
- urban temperature and moisture fields.

A residual approach is used to evaluate the anthropogenic heat flux in winter time over the urban old core.

2. MEASUREMENTS

In the old core of Toulouse, a 30 m tower is set up on a terrace roof and instrumented with a 3D sonic anemometer, a Licor 7500 (moisture) and a CNR1 (net radiation Q*). Turbulent fluxes of sensible heat (Q_H) and latent heat (Q_{LE}) are computed by the eddy-correlation technique. Temperature and moisture fields are assessed for the whole agglomeration with 26 stations placed in different Urban Climate Zones (UCZ) according to recommendations of Oke (2004).

3. ENERGY BALANCE DURING A CLOUDY WINTER DAY

Figure 1 presents the measurements of Q*, Q_H and Q_{LE} collected on a cloudy winter day (18 February 2004) as well as the residual term of the energy balance calculated as $R=Q^*-(Q_H+Q_{LE})$. The mean value of R calculated for the whole day is –42 W m^{-2}. In section 5, the evolution of this term from February to June will be discussed. During the diurnal cycle, air temperature varies between 4.0 and 8.7°C in the city centre. During the night, the sensible heat flux remains upward with a value of around 50 W m^{-2}. Because this day is cloudy, the sensible heat flux at night will be mainly due to anthropogenic fluxes (Q_F), so the results from this day suggest that Q_F cannot be neglected under these conditions in order to close the energy balance.

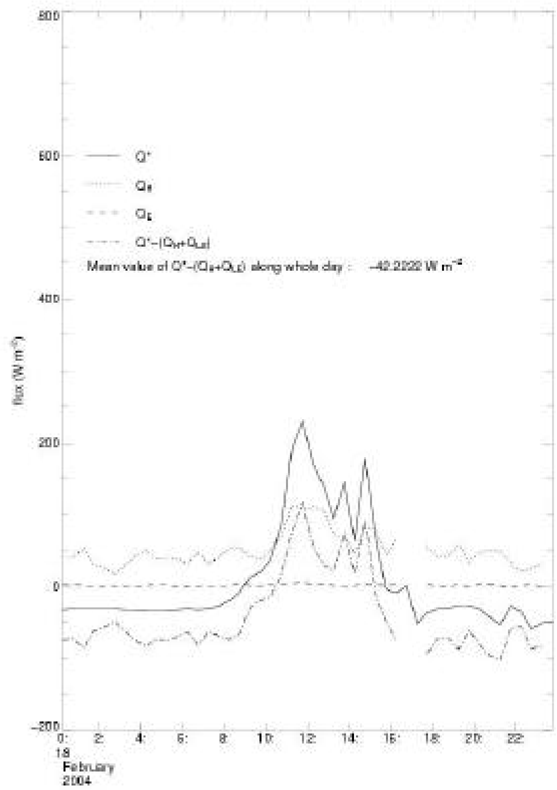

Figure 1: Energy balance components for 18 February 2004

4. ENERGY BALANCE DURING A SPRING DAY WITH RAIN

Data collected from 12 April 2004 are presented in Fig. 2. 0.2 mm of rain fell this day between 1340 and 1405 UTC. During this event, the latent heat flux increases up to 150 W m^{-2} (1345) and then decreases. The energy required to evaporate the rainfall event is 495 kJ m^{-2}. The integral of the latent flux for the period it increases gives 572 kJ m^{-2} which is higher than the preceding value but of the same order. So for a small rain event, evaporation of fallen water is immediate and complete.

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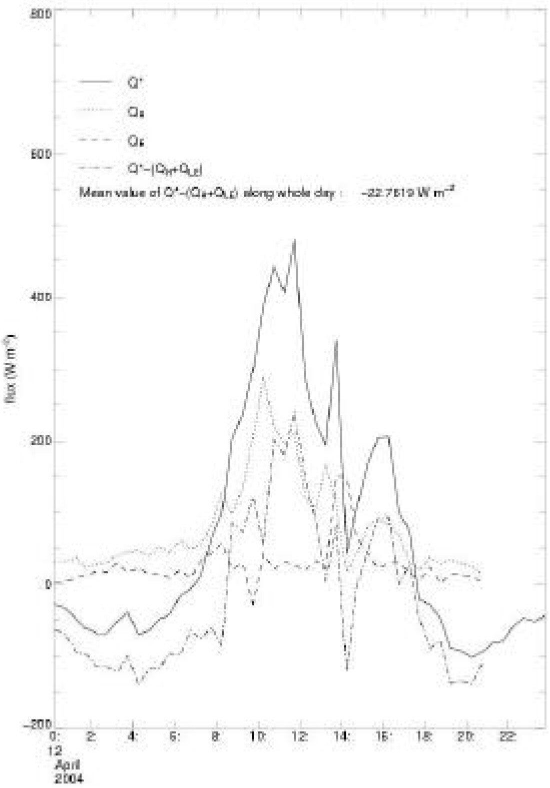

Figure 2: Energy balance components for 12 April 2004

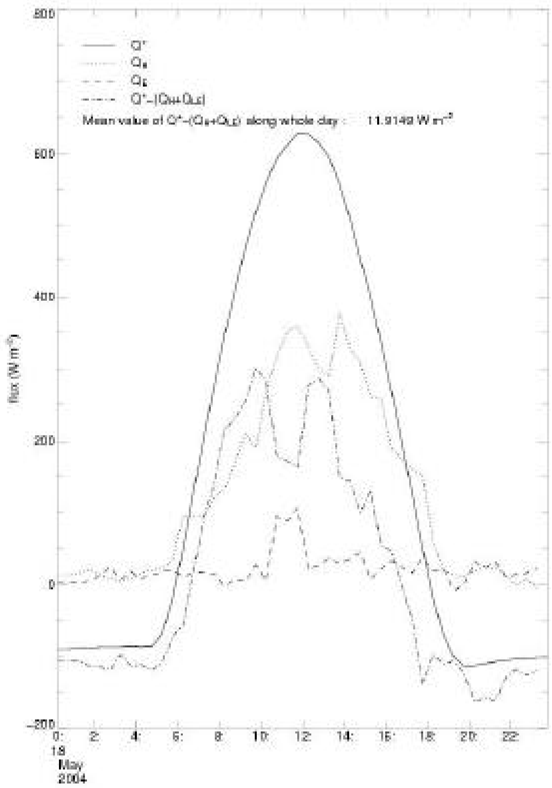

Figure 3: Energy balance components for 18 May 2004

5. ENERGY BALANCE DURING A SUNNY SPRING DAY

Data collected during 18 May 2004 are presented in Fig. 3. We see that the latent heat flux is weak most of the day except between 1030 and 1200 UTC. The sensible heat flux almost reaches 400 W m^{-2}. The residual flux reaches the same order of value but earlier in the morning. During the night, the sensible heat flux is very weak and does not reach the winter values of 18 February. In May, home heating has ended and the contribution of anthropogenic flux is lower. The mean value of the residual over the day is now positive with 12 W m^{-2}.

We will now discuss the significance of the mean daily residual and its evolution during the measurement period.

6. EVOLUTION OF RESIDUAL FROM WINTER TO END OF SPRING

In an urban landscape, the urban energy balance at the top of the street canyon is written (Oke, 1988) as:

$$Q^*+Q_F=Q_H+Q_{LE}+\Delta Q_S+\Delta Q_A \quad (1)$$

where ΔQ_S for storage, and ΔQ_A for advection. We are measuring Q^*, Q_H and Q_{LE}. Rearranging (1) and yields

$$R= \Delta Q_S+\Delta Q_A - Q_F. \quad (2)$$

As shown by Pigeon et al. (2003), ΔQ_A could become significant if the horizontal gradients of temperature and/or moisture are considerable. Initial results show that canopy layer temperature and moisture fields are concentric around the city center (see section 7), and that the horizontal gradient of both parameters is weak in the city centre (where the flux measurement station is located, see Fig. 5 and 8). Therefore, irrespective of the wind direction and speed, the advection term ($u.\partial T/\partial x$) will be very weak in the city center and R will evaluate the term ΔQ_S - Q_F. We will now integrate this term over a day :

$$\int \Delta Q_S dt - \int Q_F dt$$

We assume that integration of the storage term over the day gives a small value. At a seasonal time scale, the storage heat flux necessary to warm a 1 m layer of concrete from 10 K (representative of temperature increase from March to June in Toulouse) during 100 days is 2.4 W m^{-2}. As a consequence, the integration of R over the day will give the amount of energy released by human activities and it should give a negative value as anthropogenic heat flux will always be a positive value (heat source).

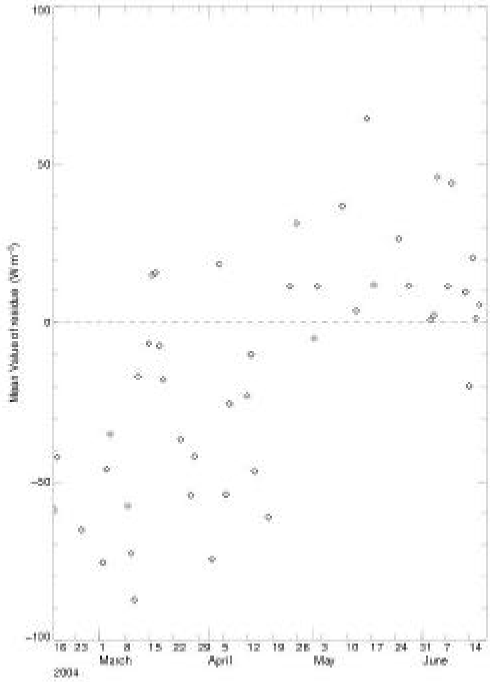

Figure 4: Evolution of the mean daily residual term from February to June.

In Figure 4, the daily residual is plotted for various days from mid February to mid June. This term increases during the period from negative values around –70 W m^{-2} in winter time to positive values around +30 W m^{-2} at the end of spring. Negative values from winter agree with the previous analysis that the residual term should be negative and represents the anthropogenic heat flux. It also quite agrees with former studies on anthropogenic term (Sailor and Lu, 2004). The increase of the term during spring indicates the decrease of anthropogenic heat source. However, positive values can not be explained. Some hypotheses for this effect can be evoked and will be studied in more details in the future:

- net radiation could be overestimated because of the decrease of the upward long wave radiation between the roof level and the measurement level: such a decrease could become considerable for high superadiabatism conditions,
- there may be an underestimation of the sensible and latent heat flux as observed in some other field observational programs (Oncley et al, 2000);
- advection needs to be studied more precisely with help of numerical modelling (Pigeon et al, 2003).

7. URBAN THERMODYNAMIC ISLAND

Data collected with the temperature and humidity network are studied with EOF methods. On the first EOF applied on each parameter, a specific normalization is applied so that the time series of EOF represents difference of temperature or moisture between the two most opposite stations of .the spatial structure of the EOF.

Station	Urban Climate Zone
1	5
2	7
3	5
4	3
5	3
6	4
7	1
8	5
9	3
10	3
11	5
12	2
13	5
14	2
15	5
16	6
17	5
18	4
20	5
21	3
22	6
23	6
24	6
25	6
26	7

Tableau 1: Description of the stations according to the WMO classification (Oke, 2004)

Figures 5 to 7 present the first EOF computed on θ (we use θ rather than T to remove the effect of altitude of the station) of April 2004. The spatial structure (Fig. 5) is almost concentric around the city center (station 7) so the general city arrangement seems to be the major factor (51% of global variance) to explain θ field. We can also see that some stations located close together can present different behaviours because of the urbanization around them. For example, station 15 and 18 are separated by only 1 km but station 15 behaves like a rural station whereas the behaviour of station 18 is the same as suburban stations closer to the city center. Station 18 is located at a large shopping mall (UCZ 4) whereas station 15 is in a suburban area with separated houses and private gardens (UCZ 5). So variations in urban landscape have consequences on θ on short distances. Representation of the EOF spatial component with interpolation gives a good idea of the field structure but interpolation also leads to errors (see Fig. 5 near station 18). On Fig. 6, representation of the same results but according to classification of the stations (Tab. 1) does not lead to such errors. From this figure we could see the general evolution of the EOF according to the classification: there is a general evolution from a warm station in UCZ typical of the city core to a colder station in UCZ typical of outskirts of city (the difference of temperature can be assessed by Fig. 7). Some UCZ presents a wide range of behaviour like UCZ 5 for example. We need to separate these zones on the basis of other factors to understand the controls of θ spatial variation. From Fig. 7, we can follow the evolution of UHI intensity computed from all the stations. Figure 7 represents difference of θ between station that has value 1 in Fig. 5 or 6 and station that has value 0. One advantage of the EOF method is that the intensity of the UHI is computed with data collected by all the stations, so it depends on the complete network and not only of the choice of two stations in this network. Typical value of θ differences between the city center and rural or suburban areas are around 1.5°C during the day or in conditions not favourable to UHI formation. At night and when conditions are favourable, θ differences reach 4°C.

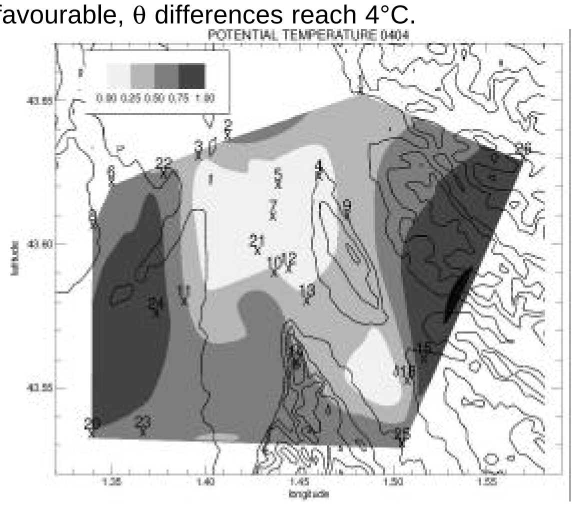

Figure 5: Field of first EOF for θ in April 2004 and terrain elevation

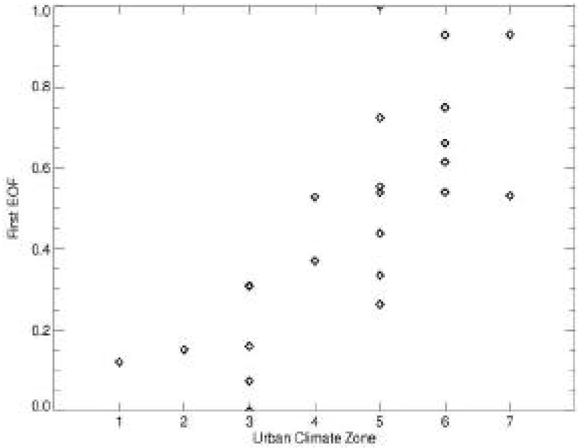

Figure 6: Representation of first EOF spatial component for θ according to classification of the stations

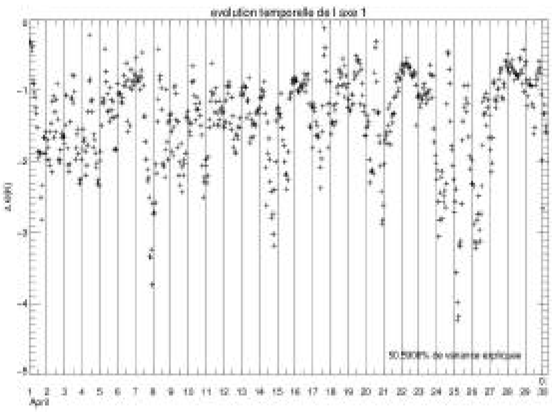

Figure 7: Time series of first EOF for θ in April 2004

Figures 8 to 10 present the first EOF applied on q in April 2004. The shape of the field (Fig. 8) is also concentric around the city but one station in the city seems to have a behaviour like suburban stations. The same results plotted in Fig. 9 according to UCZ of stations show less variability inside the UCZ than for θ except for UCZ 6. But for UCZ6, the nature of the natural soil and presence of vegetation may play a role on moisture and stations in that UCZ may be separated with these elements in future works. Time series of the first EOF (Fig. 10) show a constant difference of q of around 0.7 g kg^{-1} between station 23 and city. The difference is highest at day (up to 2 g kg^{-1}) when evaporation is maximum in areas with permeable soils and it is reduced at night when some dew can appear in colder areas.

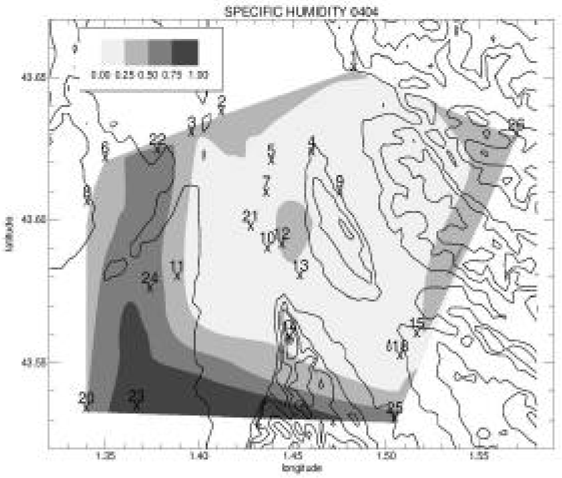

Figure 8: Field of first EOF for q in April 2004 and terrain elevation

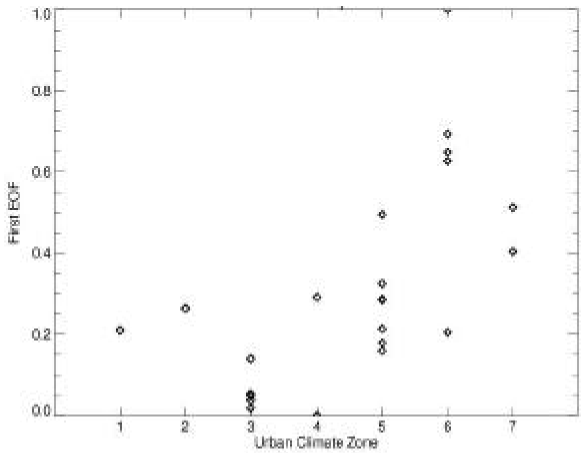

Figure 9: Representation of first EOF spatial component for q according to classification of the stations

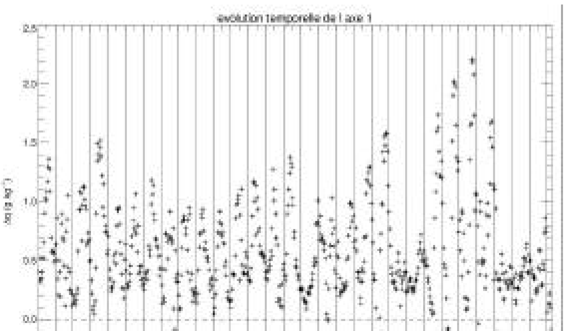

Figure 10: Time series of the first EOF on q in April 2004

8. CONCLUSION

During the winter period, the anthropogenic heat flux forms a potentially important component of the surface energy balance. Here we have evaluated the anthropogenic heat flux from an integration of the energy balance residual component. Results show that Q_F may reach 70 W m^{-2} in Toulouse old city core. During spring, the rain that falls during short and small events is quickly and completely evaporated. At the end of spring, integration of the energy balance residual term over an entire day highlights the problem of energy balance closure. Potential temperature and moisture fields are mainly governed by the urban structure of the city.

9. REFERENCES

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