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Analysis of the urban heat island from TIR airborne data: first results obtained during the CAPITOUL experiment over the city of Toulouse

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ABSTRACT. The characterization of the urban heat island (UHI) in terms of both spatial extension and intensity is important for various purposes: analysis of urban climate, impact on the atmospheric boundary layer, urban breeze, diffusion of pollutants and air quality… Airborne measurements performed using two thermal infrared cameras have been performed over the city of Toulouse and its surroundings in order to describe the UHI in the framework of the CAPITOUL experiment (http://medias.cnrs.fr/capitoul/). Flights have been performed at different times (daytime and nighttime conditions) during several intensive operation periods (IOP) in 2004 and 2005. The first results of the 2005 winter IOP only are presented in the paper. The protocol of the measurements and the processing of data are briefly described. The variability of surface temperature between the center of the city, peri-urban and rural areas is analysed and compared against the air temperature field obtained from the dense network of meteorological stations installed by Météo France over the study area.

1 INTRODUCTION

Several factors influencing the surface energy balance combine to make cities generally warmer than surrounding areas and to generate the so-called urban heat island (UHI): important absorption of radiation in relation with the urban structure (canyon effect), thermal properties of materials affecting the heat storage, low vegetation ratio contributing to lack of evapotranspiration, anthropogenic sources (domestic heating, air conditioning, traffic), eventual presence of pollutants (Oke, 1982; Arnfield, 2003). In the generic term of UHI, we must distinguish the surface UHI that affects the surface temperature (Ts) performed during different IOP (Intensive Observation Periods) along years 2004-2005. Preliminary results of the winter IOP (February 2005) are presented here.

2 EXPERIMENTAL

2.1 Experimental setup

The TIR (thermal infrared) measurements were performed using 2 airborne TIR cameras placed aboard a small twin-engine aircraft Piper Aztec PA23 flown by SAFIRE group (Service des Avions Français Instrumentés pour la Recherche en Environnement, http://www.safire.fr/).

The setup was designed to perform simultaneous measurements of TIR directional anisotropy. For details, the reader is referred to previous papers (Lagouarde et al., 2000 and 2004). The 2 cameras INFRAMETRICS M740 and FLIR SC2000 (*) were equipped with 80° wide angle and 24° lenses respectively and placed aboard the aircraft with backward inclinations of 10 and 50°, thus resulting in a overlapping area used for in-flight intercalibration (see further). The aircraft speed was 70 ms⁻¹; acquisition rates of images were 1 and 4.3 Hz respectively.

Both cameras had been calibrated at the laboratory before the experiments by aiming at a thermo-
regulated bath. Geometric and radiometric distortions related to the use of the 80° wide angle lenses were also analysed and corrected.

Air temperature was measured over the city and surroundings at 26 points. Urban stations were located inside the canopy layer.

(*) Trade name and company are given for the benefit of the reader and do not imply any endorsement of the product or company by the authors.

2.2 Flight protocol

The urban city centre of Toulouse (about 3 km in diameter) is densely built, with narrow ‘canyon’ streets and no vegetation. Most buildings are old ones, the materials most commonly used being brick for walls and tiles for roofs. The peri-urban area includes residential areas with small houses and gardens in the vicinity of the centre, and recent commercial and industrial areas a little further. The protocol of measurements consists of several short flight lines, 6 to 8 km long, in different directions crossing at the city centre. This was initially designed to investigate the spatial variability of surface temperature within the agglomeration. All of them are flown within ¾ hour, which is short enough to avoid too important natural variations in surface temperature and to provide reliable information of Ts differences between urban and peri-urban areas. Additional measurement were performed over longer transects (20 to 30 km) above rural (an also some peri-urban) areas N and S of Toulouse and flown either W or E of the city depending on air traffic. An example is given in Fig. 1.

<table>
<thead>
<tr>
<th>Flight</th>
<th>Urban and peri-urban</th>
<th>Rural</th>
</tr>
</thead>
<tbody>
<tr>
<td>0509</td>
<td>09:06 – 09:52</td>
<td>09:52 – 10:14</td>
</tr>
</tbody>
</table>

Table I : flights performed in 2005 February (UT time)

2.3 Processing of data

Studying the spatial variabiity of surface temperature to characterize the UHI requires eliminating any possible contamination of the data caused by directional anisotropy effects. We therefore used the radiative M740 temperatures averaged within a ±20° zenith viewing cone only.

Several calibration tests of the cameras had previously been performed at the laboratory by aiming at a water surface in a thermo regulated bath: they revealed that the SC2000 calibration curve was stable with time and consistent with the technical specifications provided by the manufacturer. As the calibration of the M740 camera was less satisfactory (lack of temporal stability over long periods and sensitivity to its internal temperature), this instrument was continuously intercalibrated in flight against the SC2000 camera using the overlapping area between images (Figure 2).
Figure 3: Transects of surface temperature measured over the Toulouse city and surroundings. Nighttime conditions, February 24 and 25 2005: city centre and peri-urban areas (a, c), rural (b, d). Daytime conditions, morning (February 24: e, f), afternoon (February 25: g, h). The arrow approximately indicates the position of the old city centre.
images prior to the extraction of the averaged temperature within the 20° cone around nadir. Particular care was also given to the geometric rectification of M740 images (correction of the deformation related to the use of wide angle lenses particularly) and to the overlap of both cameras.

3 RESULTS

The transects of surface temperature are presented in Figure 3. For a sake of clarity, those over the city have been represented with the origin of the x-axis taken at the Capitole square which corresponds to the point where they were all crossing. For the same reason lines flown in opposite direction have been drawn with opposite abscissas to allow the same points at the ground to be represented together. All transects display rapid fluctuations that can be easily related to features at the surface (water surfaces such as Garonne river or ponds in rural areas, large squares…).

Over urban and peri-urban areas, 0510 and 0512 night flights display quite comparable bell-shape variations characteristic of the UHI, with maximum surface temperature at the city centre. Its ‘intensity’ (maximum difference between urban and rural) reaches 5°C and 4°C for 24 and 25 February nights (table II).

<table>
<thead>
<tr>
<th>Flight</th>
<th>Urban</th>
<th>Rural</th>
<th>UHI</th>
</tr>
</thead>
<tbody>
<tr>
<td>0510</td>
<td>2 – 3</td>
<td>-2</td>
<td>4 – 5</td>
</tr>
<tr>
<td>0512</td>
<td>3 – 4</td>
<td>-1</td>
<td>3 – 4</td>
</tr>
<tr>
<td>0509</td>
<td>6 – 7</td>
<td>6 – 7</td>
<td>0</td>
</tr>
<tr>
<td>0511</td>
<td>16</td>
<td>-13 – 14</td>
<td>2 – 3</td>
</tr>
</tbody>
</table>

Table II : Spatial variations in surface temperature (°C) for 2005 winter IOP

During the night, differences between surface and air temperature are in the opposite direction over urban areas (positive difference) and over rural areas (negative difference). This results in upward sensible heat flux over urban areas and downward flux over rural areas. During this winter period of the year influence of domestic heating should be kept in mind to explain these differences.

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5 CONCLUSIONS AND PERSPECTIVES

Results obtained during the CAPITOUL experiment are consistent with previously reported results. They confirm that the surface temperature is well suited to the characterization of the UHI, and that it displays larger variations than air temperature. These preliminary results are to be completed by the analysis of the other measurements performed during the CAPITOUL experiment, in September and October 2004 for which the anthropogenic contribution to the energy budget is likely to be much lower. (Pigeon et al., 2006). Finally the relation between UHI and land use has to be investigated further using the information from various urban data bases. A comparison of airborne measurements against satellite data (AVHRR, ASTER) will also be done for UHI spatialization purposes.

5 REFERENCES


