Spatial variability, horizontal anisotropy and diurnal evolution of measured infra-red fluxes in a city neighborhood of Toulouse

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1. Introduction

In flat and uniform terrain, the infra-red (IR) fluxes are horizontally homogeneous and isotropic, depending only on the vertical direction. The diurnal evolution, with ground cooling at night and heating during the day is very uniform. This can be modeled with the “plane-parallel” approximation where the fluxes depend only locally on the vertical coordinate and that is the basis of a number of radiative models.

In urban area, however, local variations of the urban fabric, such as big buildings, little houses, parks …, lead to both a horizontal variation of the upward IR fluxes and to an anisotropy of their horizontal component. For example in a northern hemisphere mid-latitude city, a southward facing wall receiving the sunlight will radiate more than its north facing counter part and this will evolve throughout the day and will depend on the local building layout. At night this will tend to equilibrate with the neighboring buildings. To take these effects into account the radiative model needs to be three dimensional. This has long been recognized as a problem for remote sensing the urban climate (Voogt & Oke, 2003) for which remote sensing of urban temperature vary with zenith angle.

2. Methodology

In order to document and quantify these effects experimentally and in the framework of the EUREQUA project (Environmental improvement of neighborhood, sponsored by French ANR, (Haoues-Jouve et al. 2015)), we have deployed an IR imager accompanying a mobile meteorological measurement system and sound recordings. These mobile systems were walked in the neighborhood of Toulouse (Fig.1) approximately every three hours during three days. At each of 9 stop point for each hourly walk, we took one ground picture and eight horizontal pictures one for each direction.

Fig. 1 Path of the mobile meteorological with stop points where the IR images were taken. Here we will discuss in particular Points 1 and 8 in section 3

The imager records simultaneously a visible picture, an IR picture and a text file containing the IR measurements that can be later reprocessed (Fig. 2). The images then needs to be manually tagged to each stop point and direction. These two parts have been the most labor intensive of the data collection. For image processing, we have then developed python scripts to plot histograms, group images and compute simple statistics, such as the min max, mean for each image.

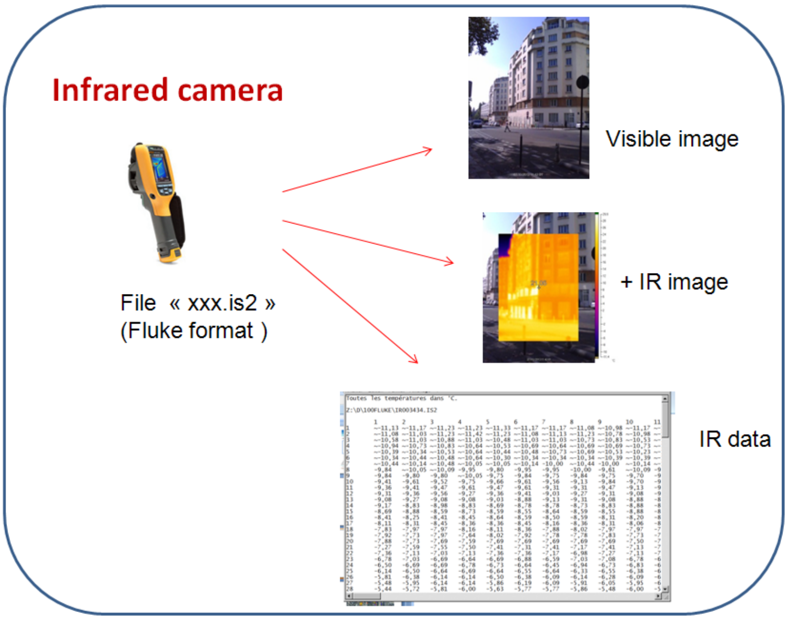

Fig. 2 Schematics of the thermal imaging processing.

3. Results

3.1 Diurnal cycle of IR fluxes at each stop point

Figure 3 represents the time evolution during the June IOP of the average IR flux at each of the stop point of the mobile station path. This average is constructed as follows. For each image, the brightness temperature for each pixel is converted back to flux values which are then averaged over the image. The values for ground average brightness temperature images are plotted in fig.3.

On this figure it is clearly seen that all values for the late night (6am) are very comparable for all stop points, indicating that the IR fluxes tend to homogenize at night in the neighborhood. Once the sun rises, the differences between area start to show. For example Point 1 and is within square with abundance of trees. As a consequence the diurnal cycle of this point is less pronounced than the others. Point 8 has by contrast a much more pronounced diurnal cycle due to the near absence of vegetation (visible pictures surrounding points 1 and 8 are shown in fig. 4).

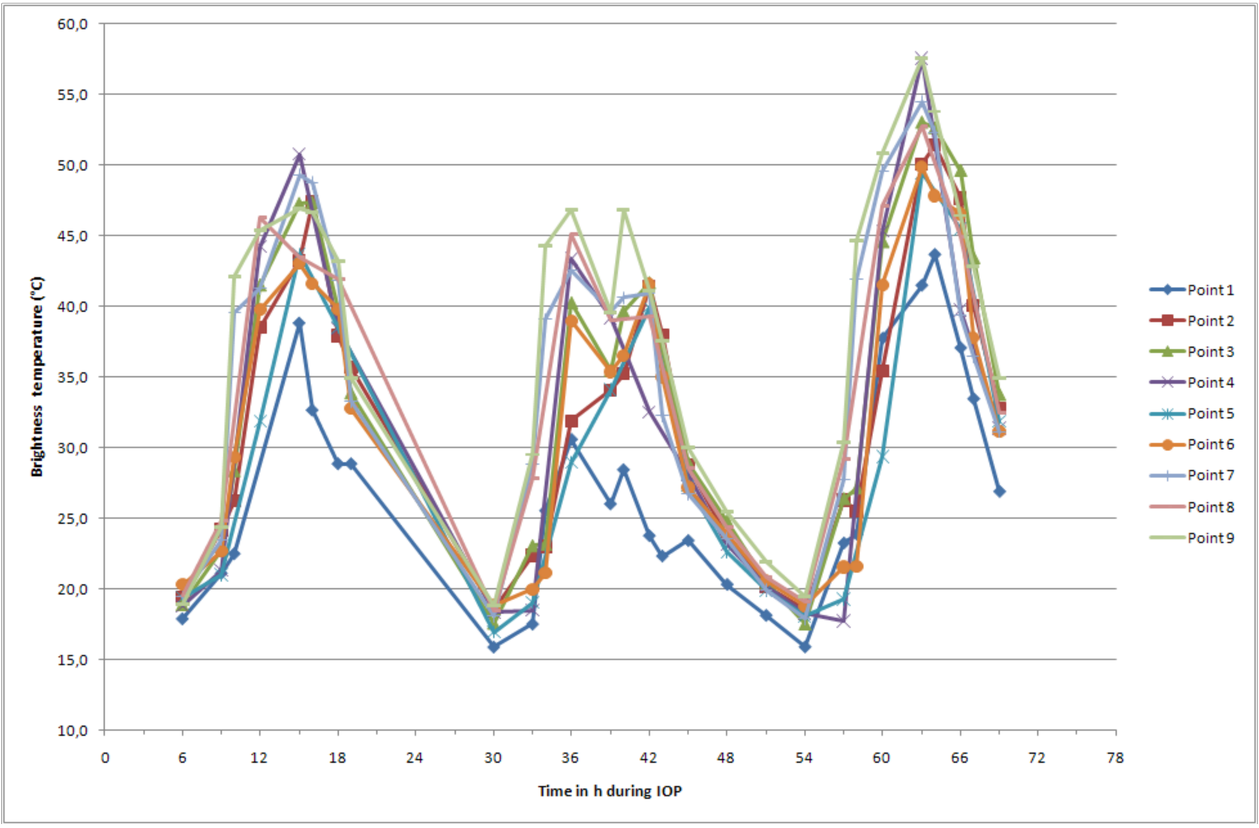

Fig. 3 Time evolution during the June IOP in Toulouse for the brightness temperature at the ground for each of the 9 stop points. Point 1 is located in a square with vegetation. Points 8 has nearly no vegetation

3.2 Diurnal cycle and directional anisotropy of IR fluxes at stop point 1 and 8

From the previous time evolution analysis we have selected the central day at two very different stop points. For the two points, Fig. 4 shows a visible image of the view in each direction. For Point 1, in almost all directions we can see the presence of trees that gave the effect mentioned in Fig. 3. For Point 8, by contrast, the vegetation is very limited with very small gardens and a large proportion of artificial surfaces.

Fig. 4 Visible images of the surroundings of stop point 1 (left) and 8 (right).
a N (resp. S) indicates a Northward (resp. Southward) direction.

For these two points we have sorted, grouped and scaled all images for an easy comparison. Figure 5 present these grouped images as a function of time (every 3h for one day) and the direction starting from Northward and turning according to the meteorological convention (N, NE, E, …).

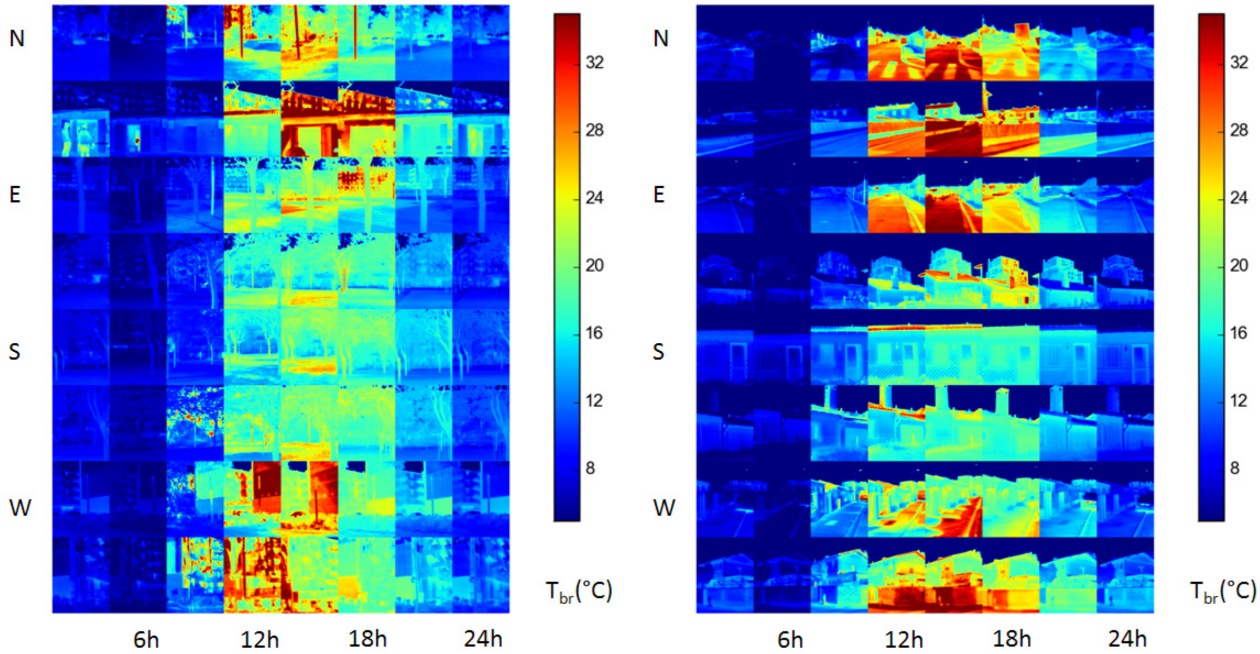

Fig. 5 Selected IR images for point 1 and 8. The horizontal axis present the time evolution of the second day of the June IOP. The vertical axis represent the azimuthal direction : Northward to Westward going from top to bottom . The brightness temperature scale is indicated on the right.

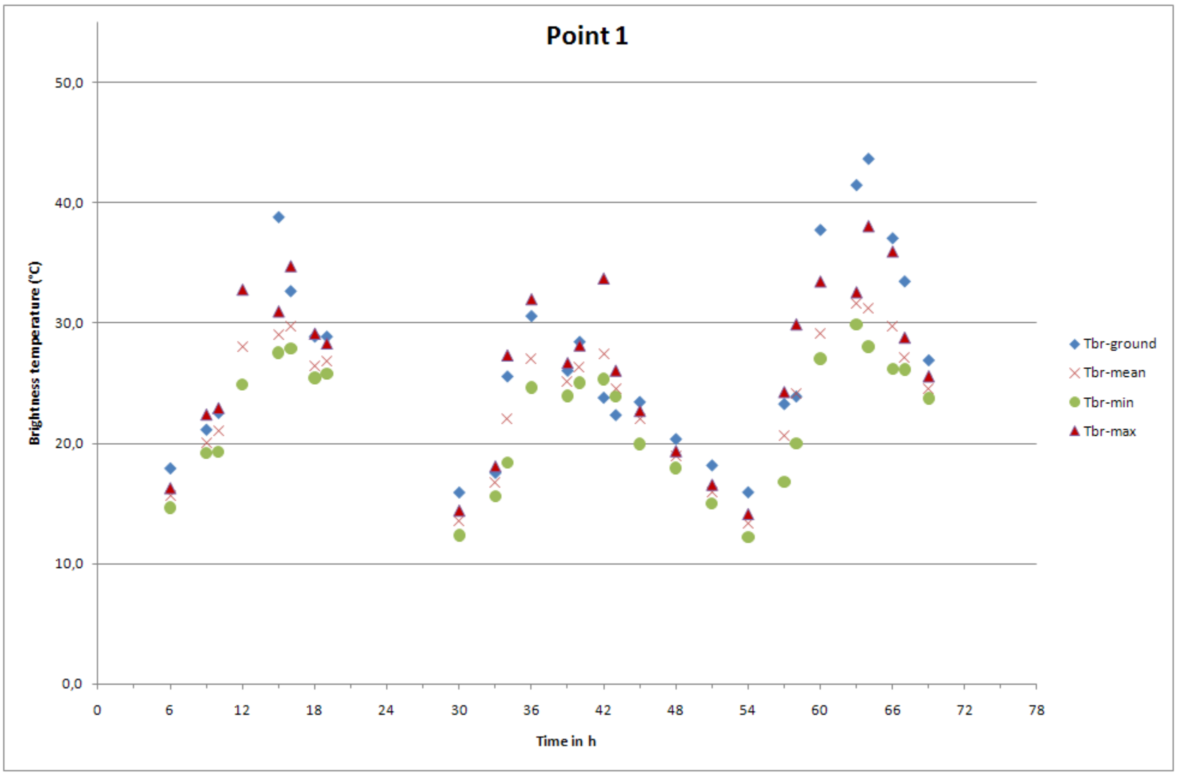

Fig. 6 For point 1, time evolution of brightness temperature throughout the June IOP: for the ground (blue diamond), the horizontal average (cross), the horizontal min (green circle) and the horizontal max (red triangle).

To characterize the horizontal and vertical anisotropy, we have plotted in Fig 6 and 7 the brightness temperature of the ground and the minimum, maximum and average brightness temperature in the horizontal direction. For point 1 (fig. 6) the anisotropy is rather limited (around 5°C) due again to the large presence of trees at this location. The extreme values are above 10°C and below 45°C. However for point 8, with very limited vegetation (fig. 7), the anisotropy is very pronounced with extremes above 50°C and below 5°C.

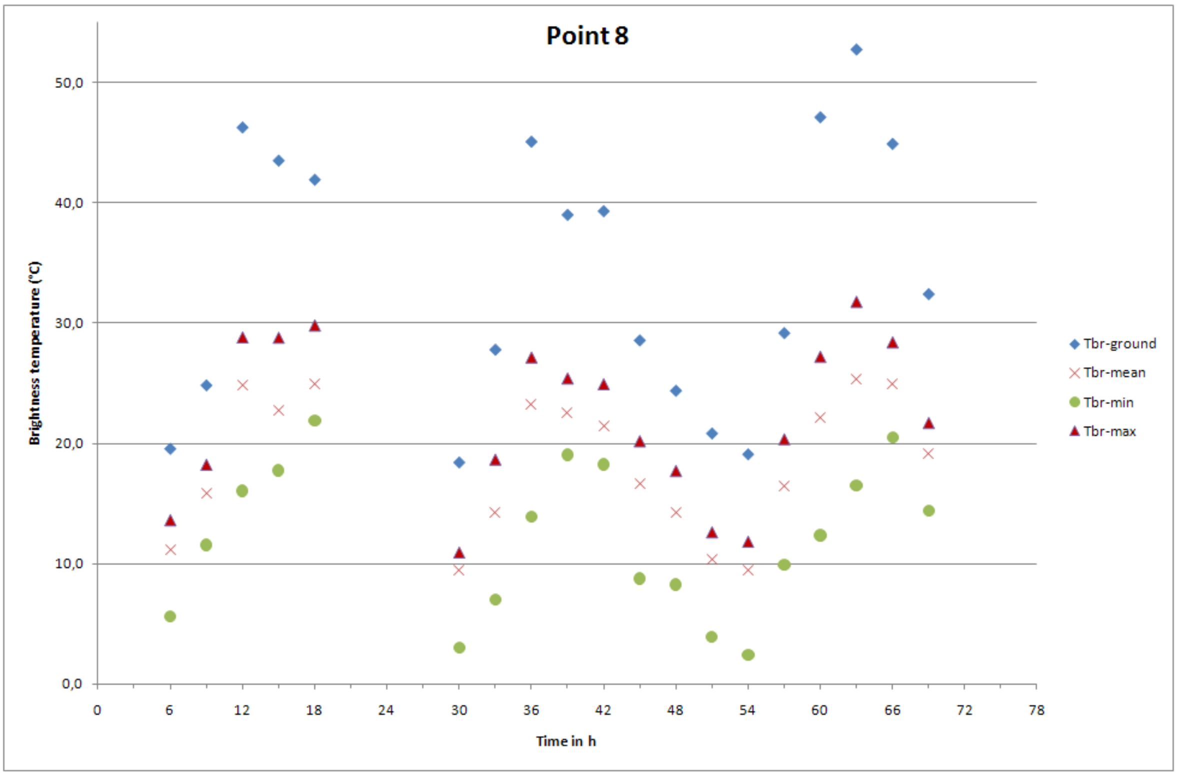

Fig. 7 Same as figure 6 but for point 8.

4. Conclusion and further work

So far we have started to dive into this very rich database of more than 12000 IR images (and simultaneous visible images). First the variations within the neighborhood are small in late night but become much more pronounced during the day, depending on location where the effect of important vegetation is clearly visible. The anisotropy found is also very pronounced, above 20°C in some area but is also strongly dependant on location. There are finer analyses possible before using it for model comparison with 3D IR schemes capable of reproducing the radiation budget in complex urban geometries.

Acknowledgment

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