Urban heat island effects over Torino

M. Milelli [1]

[1] ARPA Piemonte

1 Introduction

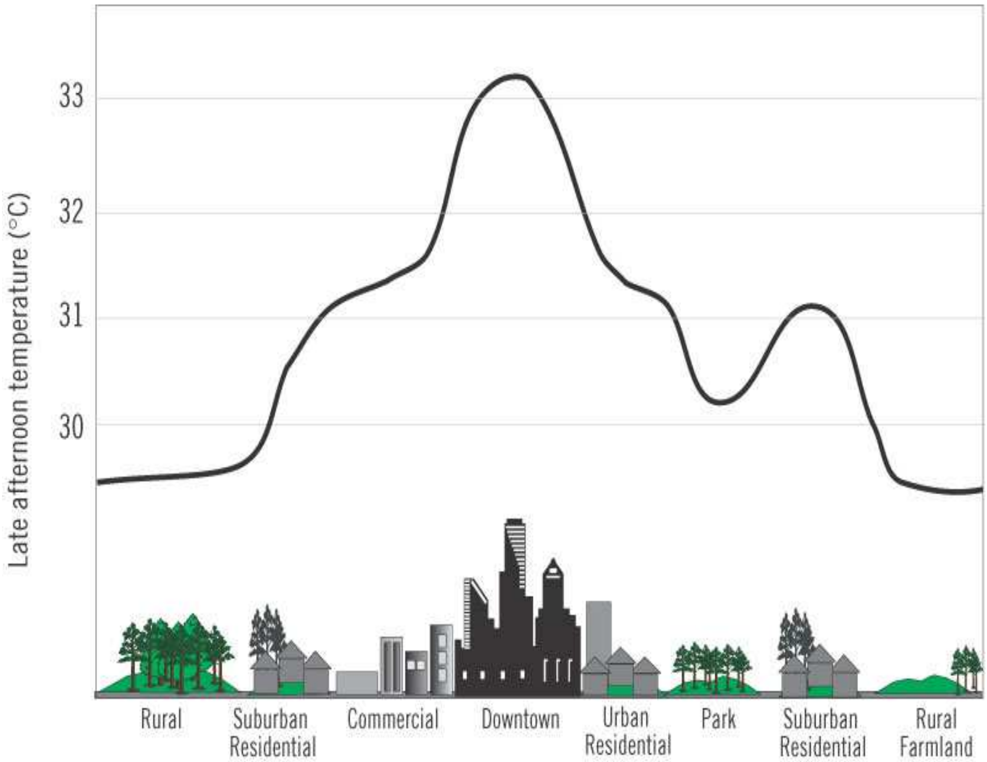

Figure 1: Urban heat island generalized scheme (source: EPA).

The increase of built surfaces (with consequent reduction of natural surfaces) constitutes the main reason for the formation of UHIs. While natural soil with vegetation uses most of the absorbed radiation in evapo-transpiration processes with release of water vapor cooling the surrounding air, paved terrains and buildings tend to absorb a lot of the incident radiation which is then released as heat. The presence of parks in the city has a beneficial effect because of horizontal air circulation due to the formation of temperature gradients. Instead, urban canyons block the release of the reflected radiation. So the main characteristics of UHIs are the following:

- during the warmest hours of the day there are small differences between urban and suburban areas, in fact in urban areas there are often more shadows due to the presence of (usually) tall buildings
- at sunset the thermal inertia of the city is higher then elsewhere, so there the temperature decreases much less then in rural areas leading to the maximum temperature difference during the night

The main contribution to the formation of UHI is therefore the missing night-cooling of horizontal surfaces, together with cloudless sky and light winds. Of course there is also a contribution from indoor heating (during winter), vehicles presence, waste heat from air conditioning and refrigeration systems (anthropogenic effects) but it has been found that they have a minor impact (Taha, 1997).

The usual profile of temperature in the cities is represented in Fig. 1 and the difference between the peak value and the background rural temperature defines the "UHI intensity". The balance among the different components of water fluxes as a function of different landscapes is represented in Fig. 2.

The reduced evapotranspiration observed in a urban landscape (with respect to a rural one) contributes to reduce the cooling of the surrounding air (and increases the fragility of the area in case of floods, but this is another story...). For a more comprehensive analysis of the UHI it is possible to read (among many others) the EPA report (2008) or Shahmohamadi et al., 2011.

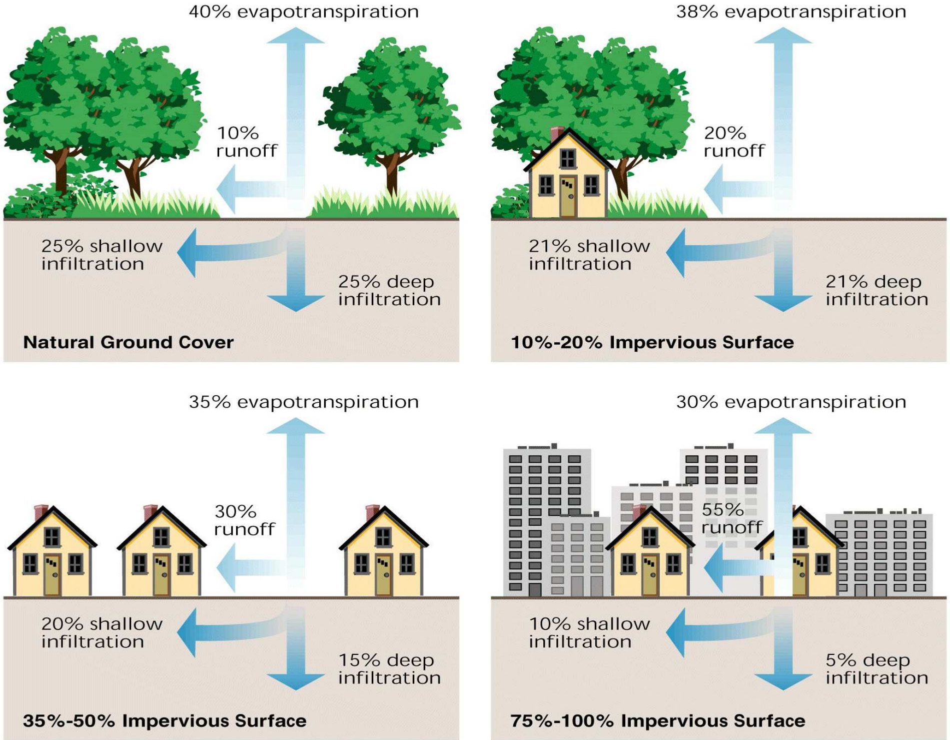

Figure 2: The urban watershed problem (source: the Federal Interagency Stream Restoration Working Group)

2 Methodology

The analysis has been carried out for the years 2009-2010, using data from the ARPA Piemonte ground network (see Fig. 3 for T2m and Rh2m). Since the extension of the UHI is not known, different stations have been considered, some of them far enough from the city center to be considered safely in the rural area.

Values of T2m and Rh2m have been taken and compared during the different months of the year in order to build an average diurnal cycle. All the stations are more or less at the same height (about 250 m asl) for sake of uniformity. This is the reason why the data of Pino Torinese (about 600 m asl) has not been taken into consideration.

Moreover the vertical temperature profiles have been checked using the data of two radiometers (R_1 and R_3 in Fig. 3 above).

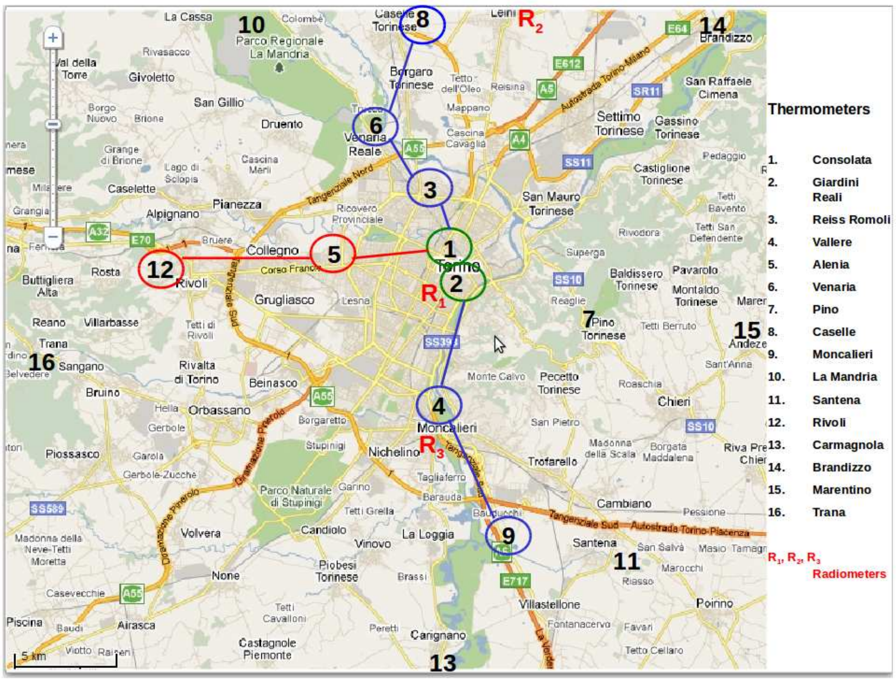

Figure 3: Distribution of the considered thermometers (above) and hygrometers (below) in the Torino area.

3 Results

The results (averaged over 2009 and 2010) are shown according to the two main axis of the city, W-E and N-S, considering the following stations (the correspondence between station number and name is on Fig. 3):

×	W-E	N-S
T2m	12-5-1-2	8-6-3-1-2-4-9
Rh2m	5-1-2	7-3-1-2-4-8

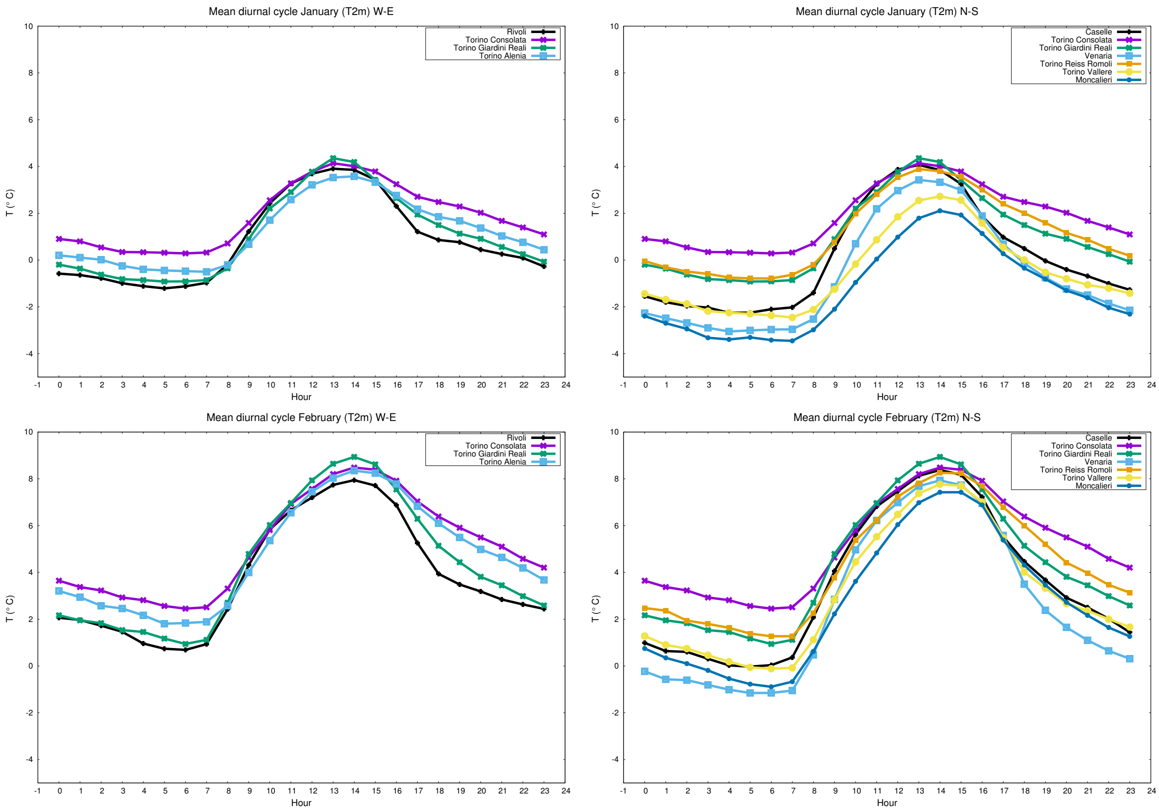

Figure 4: Mean diurnal cycle of T2m in January (above) and February (below), for W-E and N-S sections (left and right respectively)

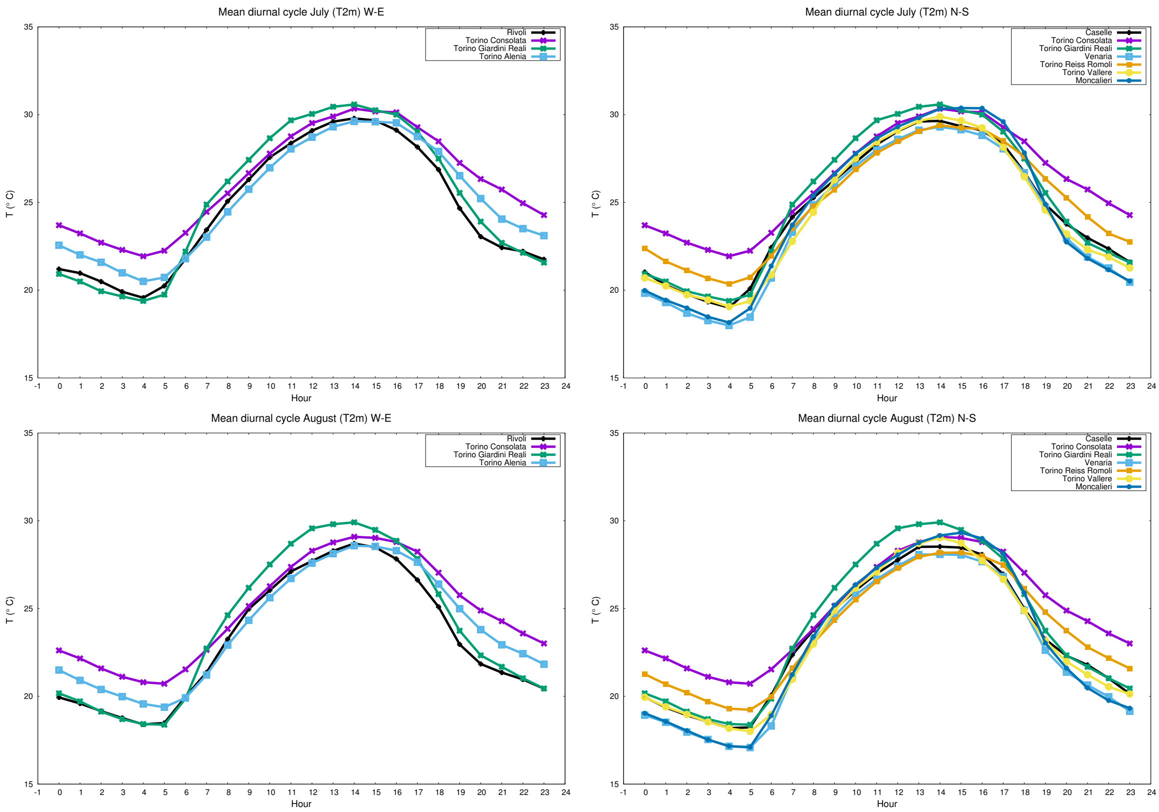

Figure 5: Mean diurnal cycle of T2m in July (above) and August (below), for W-E and N-S sections (left and right respectively).

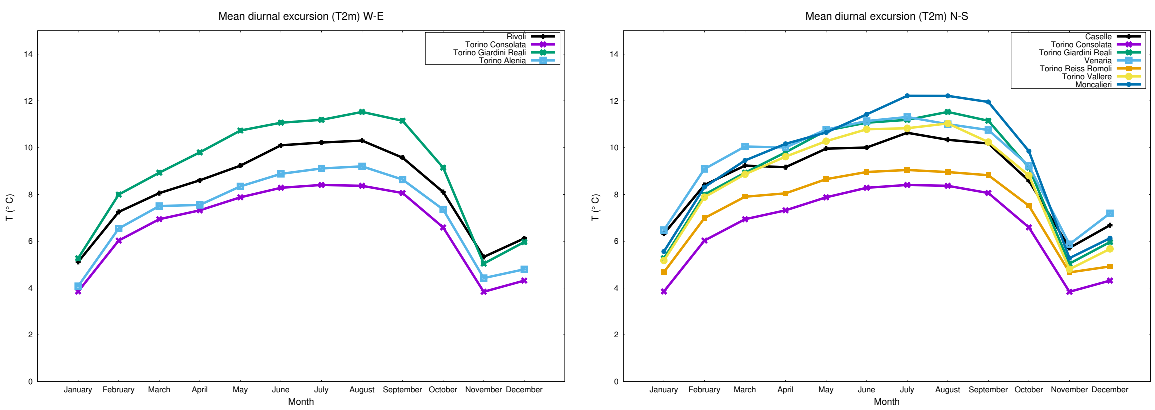

Figure 6: Mean diurnal excursion of T2m as a function of the month, for W-E and N-S sections (left and right respectively).

Looking at the T2m profiles some considerations can be drawn up:

- T2m maxima do not change significantly (the difference ranges from 1 to 2 ℃, Figs. 4 and 5) meaning that the incoming solar radiation is the (main) parameter to influence the temperature. There is only the exception of January in Vallere and Moncalieri, but they probably get the morning shadow of the hills that block the insolation, considering that the sun is quite low above the horizon. The effect (which starts in December but it is not shown here) starts to diminish in February and disappears in March (not shown), which seems to confirm the hypothesis
- the differences among the minima is evident and is between 2 and 4 ℃, value in agreement with other studies (Bonan, 2001). The reason, as stated before, is that urban areas do not permit the evapotranspiration and the natural nocturnal cooling (Figs. 4 and 5)
- Rh2m variations are quite small during the day and larger during the night but the parameter does not seem to be related to UHI (not shown)

In order to better clarify the presence of the UHI effect, the mean daily excursion (the difference between the mean maxima and the mean minima) has been plotted for each month (Fig. 6). It is evident that the stations of Torino Consolata, Torino Reiss Romoli and Torino Alenia are in the UHI because (especially) during summer the daily excursion is limited, due to the non-sufficient cooling in the night. Torino Giardini Reali deserves a special attention because although it is in the center of the city, it is located in a urban park and therefore it is not correlated to the neighborhood. For the same reason, on the southern side of the city, also Torino Vallere can be considered outside the UHI.

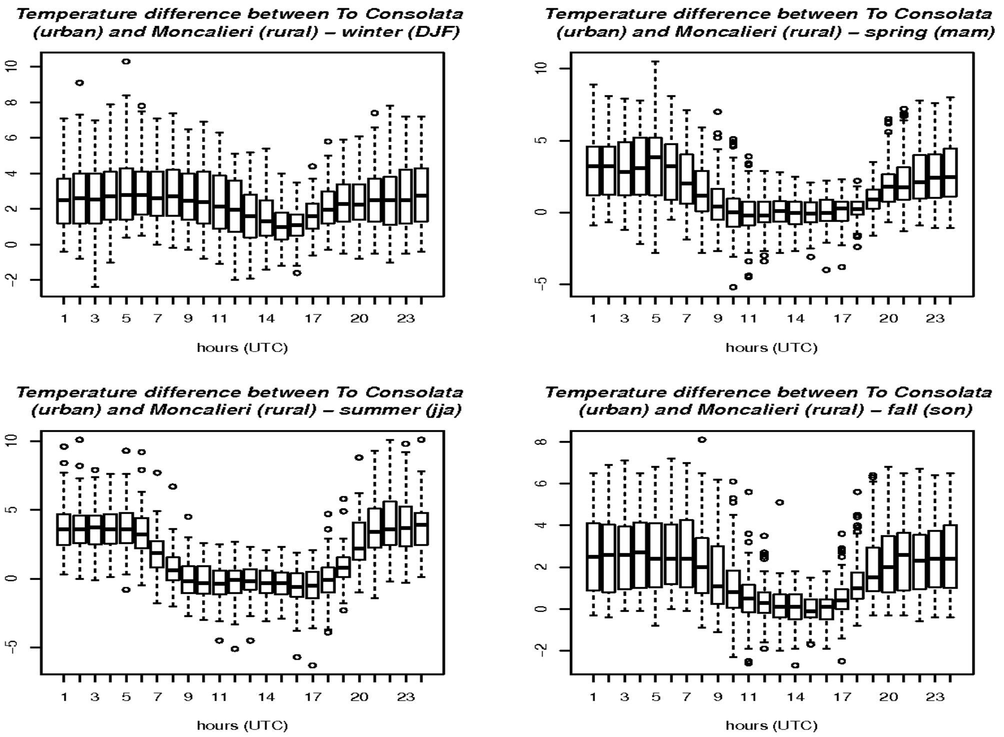

Figure 7: Daily T2m difference between Torino Consolata (urban) and Moncalieri (rural) for different seasons (years 2009-2010).

According to the obtained results, the stations of Torino Consolata (urban, inside UHI) and Moncalieri (rural, outside UHI) have been compared. In Fig. 7 the difference of T2m between the two sites is plotted. It can be seen that the UHI effect is more evident during the night in spring and summer ($\Delta \approx 4$ ℃ but almost 0 from 9AM to 6PM). During fall the effect is reduced but still present during the night ($\Delta \approx 2$ ℃ but almost 0 from 10AM to 5PM), while in winter it is more extended all along the day ($\Delta \approx 2$ ℃).

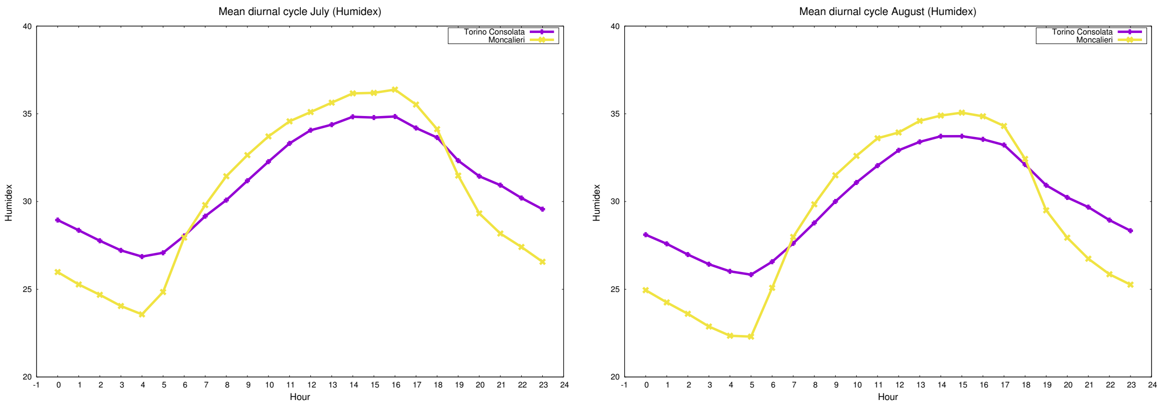

Figure 8: Daily cycle of Humidex index in Torino Consolata (urban) and Moncalieri (rural) in July (left) and August (right) (years 2009-2010).

The same conclusion can be addressed examining Fig. 8 which shows the Humidex index for the same two stations. The Humidex (humidity index) is an index used to describe how hot the weather feels to the average person, by combining the effect of heat and humidity.

It has been developed in Canada (Masterton and Richardson, 1979) and it is a dimensionless quantity based on the dew point according to eq. (1) where T_{air} is the air temperature in ℃ and T_{dew} is the dewpoint in K:

$$H = T_{air} + 0.5555[6.11e^{5417.753(\frac{1}{273.16}-\frac{1}{T_{dew}})} - 10] \quad (1)$$

The adopted convention says that:

- less than 29: no discomfort
- 30 to 39: some discomfort
- 40 to 45: great discomfort; avoid exertion
- above 45: dangerous; heat stroke possible

4 COSMO model evaluation

The same analysis has been performed using the forecast of COSMO-I2 (operational Italian setup). In detail, it has been used the data of 2010 only, 00UTC and 12UTC runs, for the first and the second day (00-24 and 24-48).

Since the data are six-hourly, for sake of comparison, Fig. 9 has been reproduced using only those hours (and only 2010 data of course). The result is shown in Fig. 9.

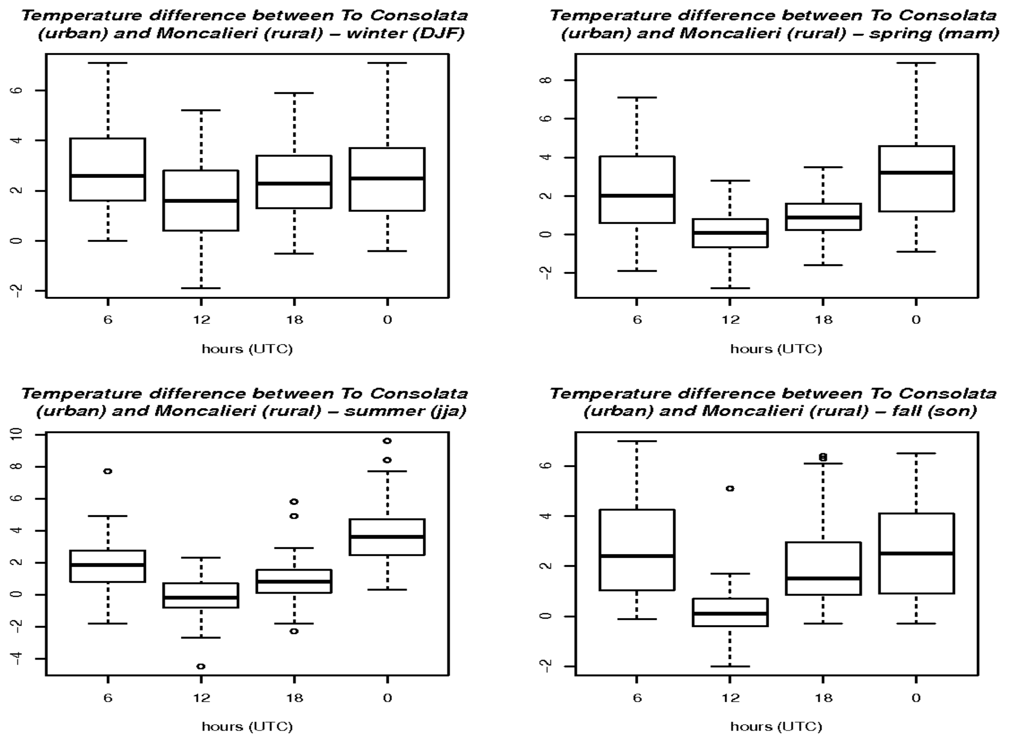

Figure 9: T2m difference between Torino Consolata (urban) and Moncalieri (rural) for different seasons (year 2010), every six hours.

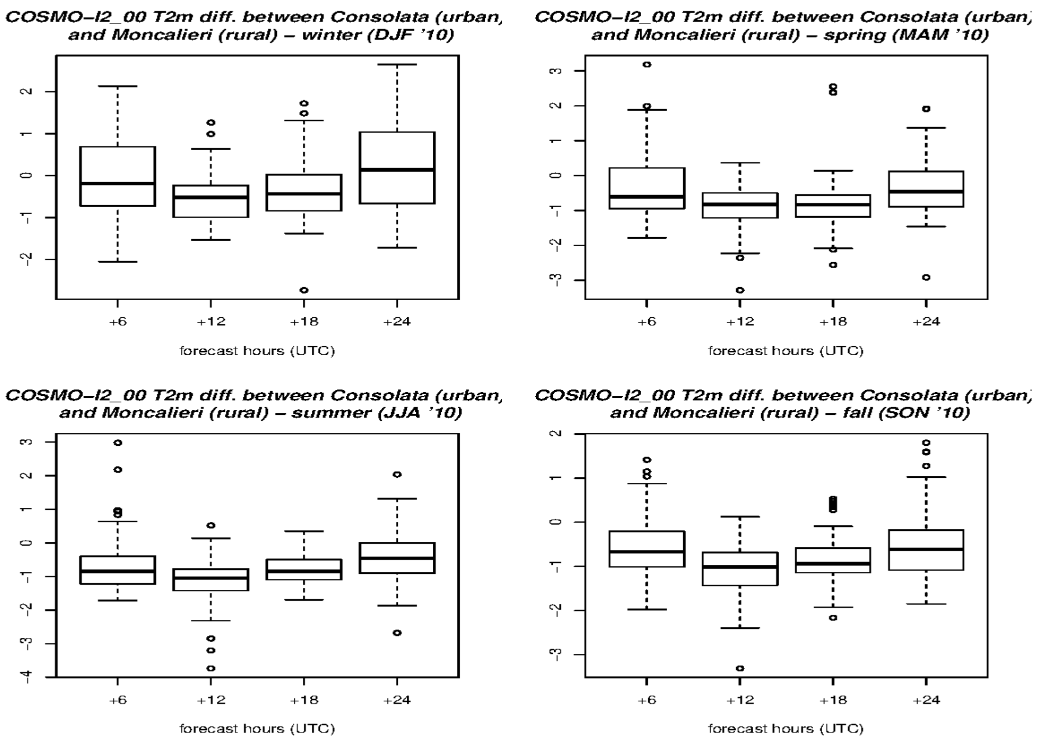

Figure 10: COSMO-I2 (00UTC) T2m difference between Torino Consolata (urban) and Moncalieri (rural) for different seasons (year 2010), from +6 to +24.

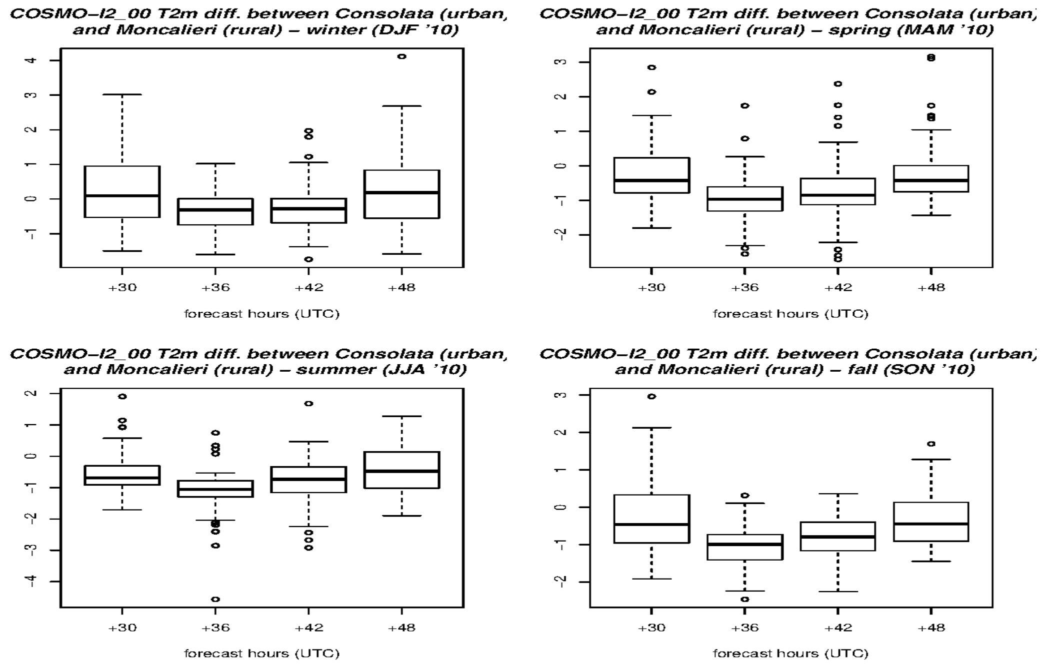

Figure 11: COSMO-I2 (00UTC) T2m difference between Torino Consolata (urban) and Moncalieri (rural) for different seasons (year 2010), from +30 to +48.

It can be pointed out that there is a similar behavior in 00UTC and 12UTC runs (not shown here), in first and second day of forecast, and that there is a considerable difference in the T2m values. In fact in the model the difference amplitude is much less pronounced, that is the two stations (actually the two associated grid points) are too similar and are not able to distinguish the real complexity. This is reflected also in the minor excursion between day and night, which means that the UHI effect is not fully captured, although there is a correct trend in accordance with the observations.

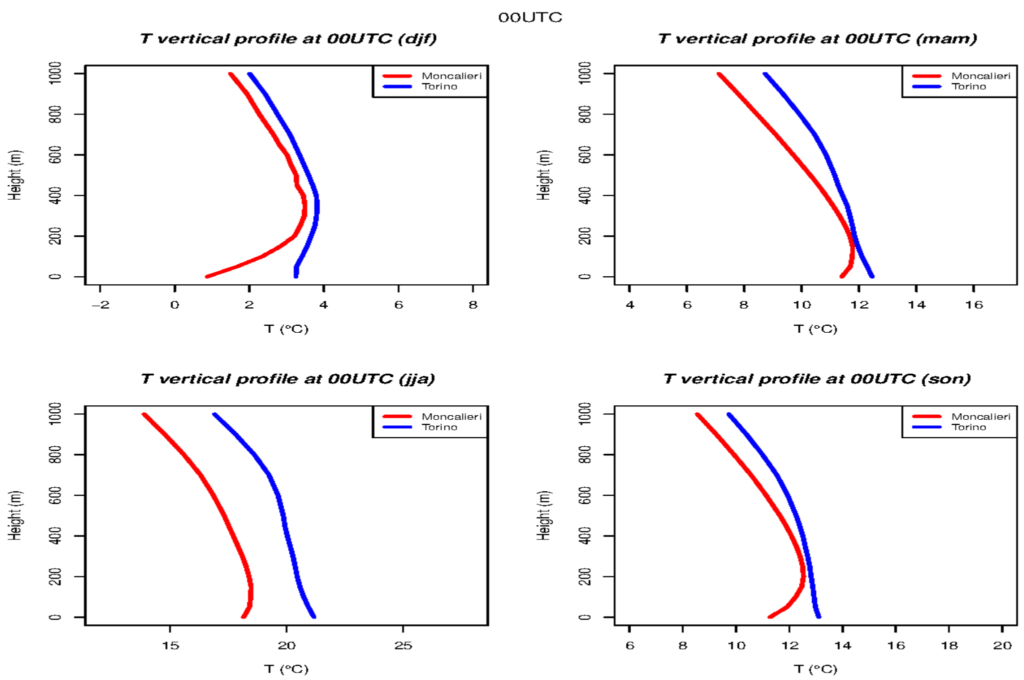

Figure 12: Vertical T2m profile in Torino Consolata (urban) and Moncalieri (rural) for different seasons at 00UTC.

Eventually, the vertical profiles of the radiometers has been examined (see Fig. 3 above). In particular only R_1 and R_3 have been used since they are close to Torino Consolata and Moncalieri respectively. The data have been taken in periods where both radiometers were functioning, that is:

- djf 08/09/12
- mam 08/09
- jja 08/11
- son 08/11

Fig. 12 shows the mean profiles at 00UTC during the different seasons and it is clear that the urban area tends to be warmer than the rural area up to 1000 m. The difference is higher in summer when the nightly boundary layer receives the heat absorbed by the buildings during the day. On the contrary, in winter the difference is concentrated in the lower layers and above 250 m the profiles almost coincide.

5 Conclusions and perspectives

This preliminary work, through the analysis of T2m and Rh2m of different ground stations and two radiometers, clearly highlighted the presence of a UHI effect over Torino. This analysis has to be extended using more recent data. On the other hand it can be seen that the forecast model with a horizontal resolution of about 2 km (COSMO-I2) is not able to represent this peculiar effect. It has to be pointed out that this effect is not parameterized in COSMO (yet) and it probably would need to be studied more in detail. There are examples that go into this direction (for instance Mussetti, 2016), so in the near future it should be possible to test COSMO with this specific parameterization.

References

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