Urban-rural differences in longwave radiation – Łódź case study

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1. Introduction

The influence of the city on shortwave radiation is well established. It is well accepted that the solar radiation is reduced about 10% in the case of annual totals, about 20% for monthly totals and more than 30% for selected days. In contrary, the city role in modification of longwave radiation is poorly documented, even if general processes leading to alternation of this radiation by a city are well understood. The pollution in urban atmosphere increases downward longwave radiation, L↓, about 6-10%, but this estimations based on a few available publications only. The aim of this work is to estimate urban-rural differences of longwave radiation components in Łódź, central Poland

2. Data, sites locations and instrumentation

The analysis based on 3 years (2011.11.01 – 2014.10.31) of continuous measurements at two sites. The urban site is located in Łódź, in the west site of the city core (51°45'52'' N, 19°26'42'' E, 208 m a.s.l.). The city population is ca 700 thousand. The CNR1 net radiometer is fixed at the height 37m above the ground at the top of thin mast (10 cm in diameter). The mast (20 m) is placed at the roof of the 17 m in height building. Buildings in the nearest surrounding are mostly lower with the average height about 11 m. Street trees are deciduous, 8□15m tall but generally below building height. Within 500m of the tower, buildings with flat, tarred roofs, asphalt streets and pavements dominate the surface cover (see Offerle et al. 2005, Offerle et al. 2006a,b, Pawlak et al. 2011, Fortuniak et al. 2013, Fortuniak and Pawlak 2014 for details). The rural site is located about 50 km east from Łódź (51°45'1'' N, 20°25'3'' E) close to Annosław village, in the typical Polish agricultural landscape (Pawlak et al. 2012). The CNR4 net radiometer is fixed at the typical tripod at height of 3 m. The wheat, rye, potatoes, strawberry or other plants are cultivated at podzolic soil at the patched fields in the nearest surrounding of the site. At both sites the data are governed by Campbell Sci. dataloggeres. The slow respond data (the eddy covariance systems work at both sites) include all typical meteorological parameters are stored every 1 min. In the present study the we analyze data of downward, L↓, and upward, L↑, longwave radiation components as well as net longwave radiation, L* = L↑ – L↓, chosen for 5 min intervals.

3. Methodology

Because of the distance between two sites a simple calculation of the differences may be misleading. A random distribution of convective clouds can lead to large differences which are not a result of the urban influence on the atmospheric boundary layer. To overcome the problem, the results can be analyzed either in statistical characteristics of both sites or in selected cases of cloudless or overcast situations. In the statistical approach we have first calculated mean daily courses for each month for each site as well as daily courses of 2^{nd}, 10^{th}, 90^{th}, and 98^{th} percentiles. The statistic have been calculated for each hour on the base on all available data for selected hour for selected month in all 3 years period. Next we have analyzed differences between urban and rural site for these statistics. In selected cases approach we have chosen cases of clear sky on the base on 90th and 10th percentiles of L*. Cases when L* had been greater than 90^{th} percentile have been chosen as a cloudless situations and the cases when L* had been lower than its 10^{th} percentile have been chosen as an cloudy ones. Then for the selected cases we had first calculated urban-rural differences and next an average daily course for cloudless and cloudy days.

4. Results and discussion

Figure 1 presents the daily courses of downward longwave radiation for each month at Lipowa and Annosław. The simple overview of the data presented at Fig. 1 shows evident exceed of L↓ on urba areas over rural one. The highest values of L↓, which occur in the presence of thick low clouds, are in summer (July and August) on the level of 470-480 Wm^{-2} at Lipowa and 420-430 Wm^{-2} at Annosław. In winter the highest values are at urban site slightly higher and at rural site slightly lower tha 350 Wm^{-2}. The lowes values of L↓ occure under clear sky conditions. In February the recorded values are on the level of 180 Wm^{-2} at urban and 160 Wm^{-2} at rural areas. In summer a daily course of Ld in cloudless situations is clear. At night in July L↓ is about 330 Wm^{-2} at Lipowa and 290 Wm^{-2} at Annosław whereas in the afternoon it is 380 Wm^{-2} and 350 Wm^{-2} respectively.

The upward longwave radiation at urban site ranges from 250 Wm^{-2} in winter nights to almost 600 Wm^{-2} in summer afternoons (Fig. 2). The respective values at rural site are 200 Wm^{-2} and Wm^{-2}. Upper values exhibits high daily variability in summer when it is representative for a clear sky conditions.

The values of net radiation, L*, at both stations (Fig. 3) also support the thesis on the city influence on longwave radiation. The most streaking feature is drop of highes values at rural station in May and June related to growing vegetation and relative decrease of Lu. In July after crops cutting the longwave emission from bare soil increase and in consequence increases L*.

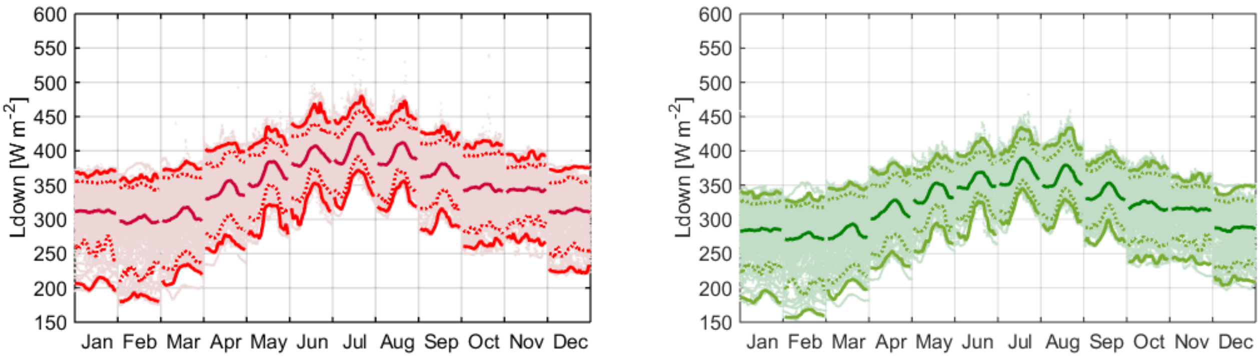

Fig. 1 Daily courses in months of downward longwave radiation at Lipowa (urban site – left plot) and Annosław (rural site – right plot) for the period 2011.11.01 – 2014.10.31. Dots represent raw data. Lines from the bottom to top represent the 2nd, 10th percentiles, mean, 90th and 98th percentiles calculate for each hour for each month on the base on 3 years of measurements.

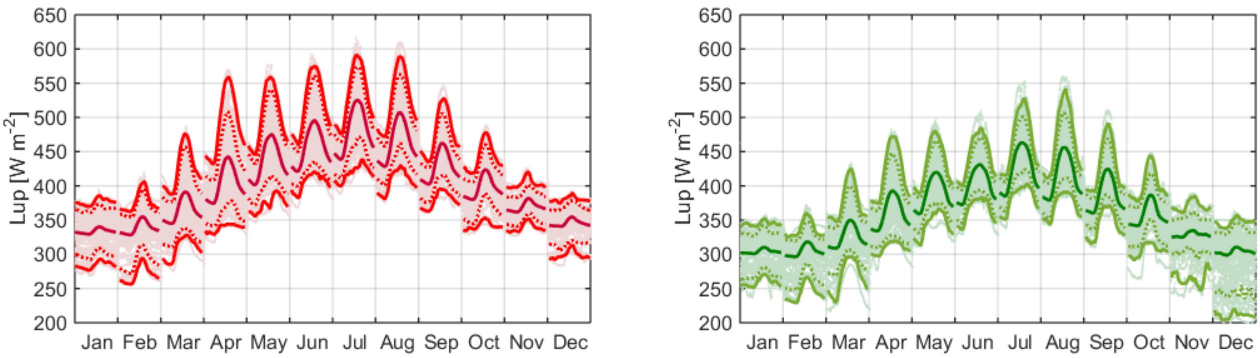

Fig. 2 The same as Fig.1, but for the upward longwave radiation.

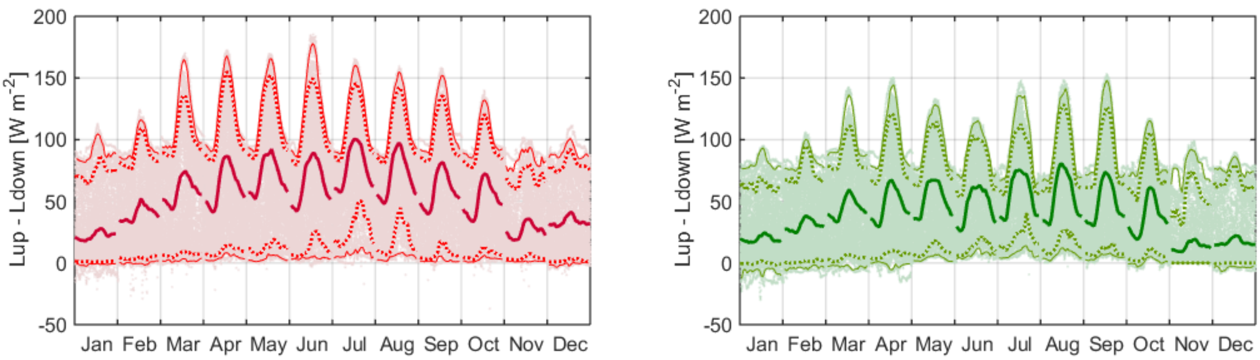

Fig. 3 The same as Fig.1, but for the net longwave radiation.

The differences between 2nd percentiles are on the level of 20-30 Wm^{-2} with lower values in winter and higher in summer which gives 6-10% of L↓ at urban site except the February and November, when it rises to around 12% (Fig. 4). Analyzing differences in sunny days selected on the base on high values of net radiations it is easy to mention that they are on similar level except July-September, when they are higher, reaching 35 Wm^{-2} in July. Differences in 98th percentiles are general higher with clear annual course reaching 30 Wm^{-2} site in winter and above 40 Wm^{-2} in summer. In relation to L↓ at urban site it gives 8-10%. The differences in selected cloudy days are in general on the level of 25-35 Wm^{-2} with slightly pronounced seasonality (highest values in summer).

Because of low albedo (in Łódź it is 8-10%) the urban surface warms intensively during sunny days. In result the difference in L↑ are highest in sunny days – above 90 Wm^{-2} in June afternoon (Fig. 5). The drop of differences in July can be attributed to changes in a rural surface related to agricultural activity. This thesis is supported by an increase of L* in July at rural site (Fig. 6). Mean daily values of L↑ in cloudless days undergo clear annual course with highest values in summer (up 70 Wm^{-2}) and lowest in winter (around 30 Wm^{-2}).

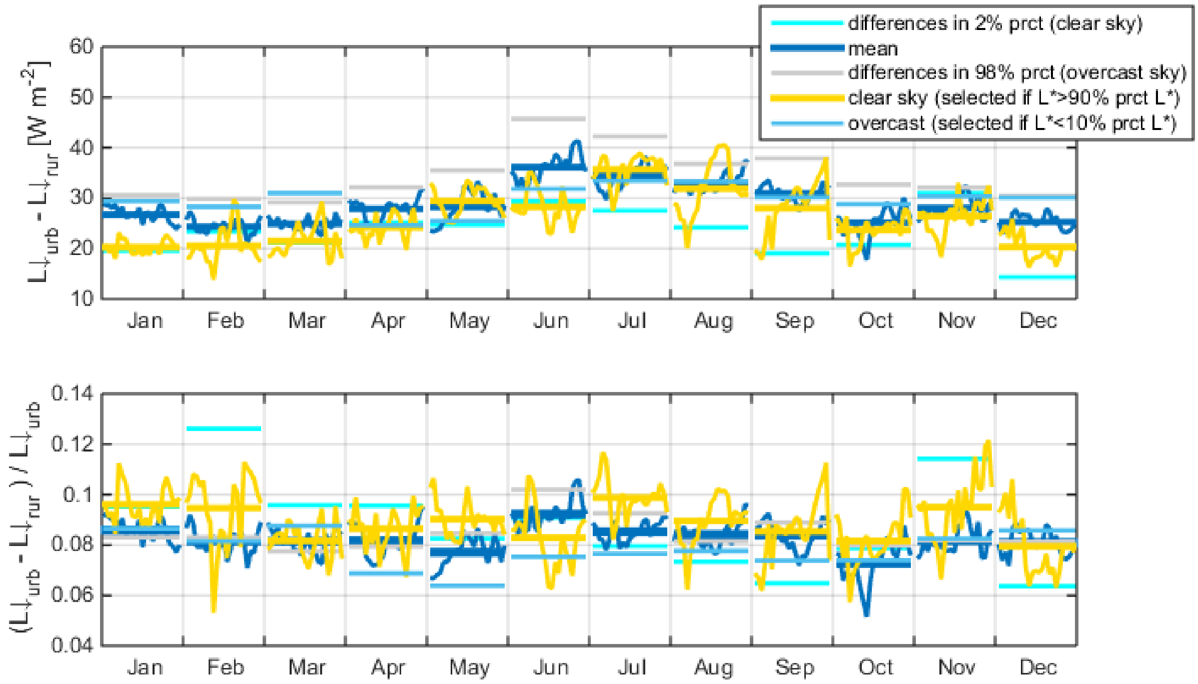

Fig. 4 Urban-rural differences in downward longwave radiation in months (mean values and daily course) calculated with different methods: differences between 2nd percentiles at Lipowa (urban site) and Annosław (rural site); differences between mean daily plots on both sites; differences between 10nd percentiles; mean daily course of urban-rural differences for selected case of cloudless situations (L > 90th percentile of L*); mean daily course of urban-rural differences for selected case of overcast situations (L* < 10th percentile of L*).*

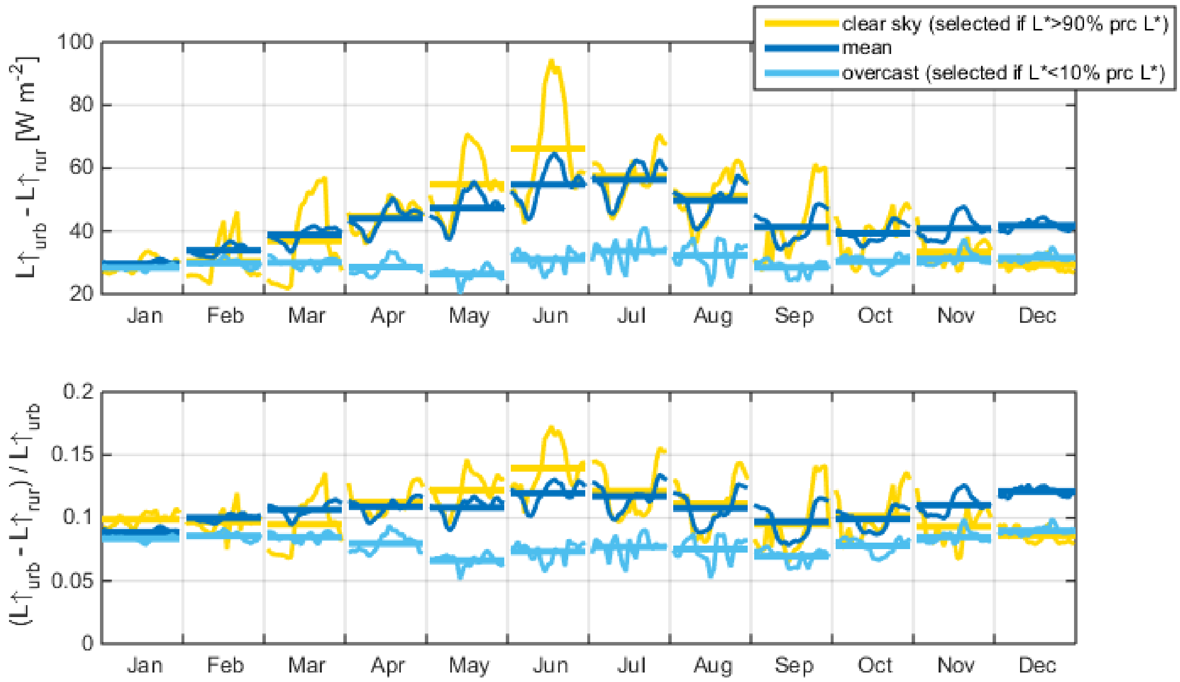

Fig. 5 Urban-rural differences in upward longwave radiation in months (mean values and daily course) calculated with different methods. Color labeling as at Fig. 4.

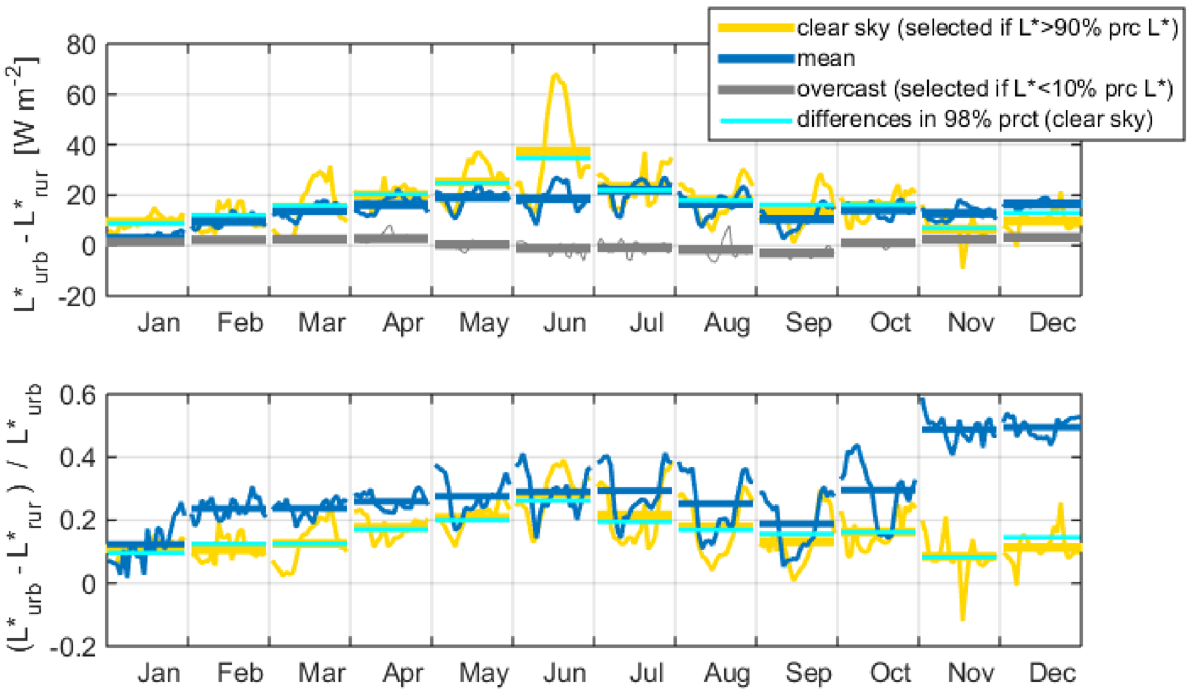

Fig. 6 Urban-rural differences in net longwave radiation in months (mean values and daily course) calculated with different methods. Color labeling as at Fig. 4.

5. Conclusions

The downward longwave radiation is about 20-30 Wm^{-2} higher in the city with slightly pronounced maximum in summer. The differences in relation to L↓ at urban areas are at the level of 8-10% all over the year. In cloudless situations the differences in upward and in net longwave radiation exhibits a clear annual cycle with a summer maximum. The mean daily L↑ varies from 30 Wm^{-2} in winter to almost 70 Wm^{-2} in summer, whereas L* from 10 Wm^{-2} to almost 40 Wm^{-2} respectively. In cloudy situations L↑ differences remains at the constant level about 30 Wm^{-2} all over the year.

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