CO₂ flux measurements in Łódź, Poland

Introduction

Łódź (51°46'N, 19°27'E) is the third largest city in Poland, with a population of approximately 750,000. In the old centre of the city, buildings constructed in this period are mainly 15-20 m high and make up an extensive, fairly homogenous and compact settlement of great density. The old centre is surrounded by new districts of blocks of flats, industrial and residential areas. Łódź is situated in central Poland, on relatively flat terrain (altitudes range from 180 m to 235 m a.s.l.).

Measurements of turbulent mass and energy exchange have been carried out in Łódź since November, 2000. The first part of this research, during the years 2000-2004, started under cooperation between the Department of Meteorology and Climatology, the University of Łódź and the the Department of Geography of the University of Indiana (Fortuniak, 2003, 2010; Offerle, 2003; Offerle et al., 2003, Offerle et al., 2005, Offerle et al., 2006a, 2006b; Pawlak et al., 2004). Originally a measurement point was located at the Lipowa Street site in the city centre (Figs. 1-2), but because of insufficient instrumentation, FCO₂ flux measurements were not registered. Another eddy covariance measurement set, equipped with an Li7500 CO₂/H₂O IRGA analyzer, enabled implementation of a few short-term experiments (of a few days to a few weeks) in other parts of Łódź, outside the city centre (Fig. 1), including residential, post-industrial, and suburban areas (Offerle, 2003; Pawlak et al., 2007). Regular investigations of CO₂ exchange and other fluxes started in July 2006 when the measurement point at Lipowa Street was equipped with a new system including a CO₂ gas analyser (Fortuniak et al., 2006; 2008; 2010). Results registered until today cover almost 5 years and are the first and only long-term FCO₂ measurements from an urban area in Poland and one of a very few Polish FCO₂ data sets obtained with the eddy-covariance technique (Pawlak, 2010; Pawlak et al., 2009; 2010; 2011).
Site descriptions

The Lipowa Street eddy covariance measurement point for FCO\textsubscript{2} (Fig. 1) is located in the western part of the densely built-up city centre (51°45'45"N, 19°26'43"E, 204 m a.s.l.). The nearest surroundings of the measurement point are characterised by compact building development. Artificial surfaces (buildings, roads, pavements, etc.) cover ~50–70% of the surface in this part of the city (Kłysik, 1998). Vegetation is interspersed with buildings; it consists mainly of many small lawns and covers 38% of all surfaces. The measurement height is 37 m above ground level, which is more than twice the canopy height, so it is possible to make the assumption that measurements are carried out above the roughness layer. The high elevation of the sensors results in a large source area for turbulent fluxes, which for unstable conditions has been evaluated as a circular shape up to 1 km in diameter (Fig. 1, right).

The other sites, where short-term experiments were carried out in the years 2002-2003, are located outside the city centre, on terrain characterised by less dense building development and a bigger portion of areas covered by vegetation (Fig. 1). In the post-industrial district, ~40% of the measurement site’s surroundings are covered by artificial surfaces, while for the residential area with small houses the artificial cover is ~30% and for the suburban site (grass surface on the Łódź Władysław Reymont Airport) it is ~5%. Thus the green area coverage in these parts of Łódź is ~60%, ~70% and ~95% respectively.

Figure 2. Urban canopy around the Lipowa measurement site (top), and measurement tower at Lipowa Street (bottom, with sensor maintenance shown at middle and right). Photo: K. Fortuniak.
Long term FCO$_2$ measurements registered at the Lipowa site (Fig. 3, top) show that regardless of the season, the centre of Łódź is a significant source of carbon dioxide. FCO$_2$ during the analysed period is characterised by an annual course that is the reverse of the air temperature course (Fig. 3, top and bottom left). Mean daily fluxes observed during the winter season often exceed 40 g m$^{-2}$ day$^{-1}$. Such high FCO$_2$ in wintertime is caused by increased emissions of anthropogenic CO$_2$ in the cold season from domestic heating sources (Kłysik, 1996; Offerle et al., 2005) and increased traffic densities observed in urban areas especially during the day. Summertime FCO$_2$ does not exceed values on the order of 30 g m$^{-2}$ day$^{-1}$. This can be explained by a decrease in anthropogenic CO$_2$ emissions (lack of domestic heating and reduced private car traffic) and CO$_2$ absorption by vegetation.

An extremely high FCO$_2$, when mean daily fluxes exceed 50-60 g m$^{-2}$ day$^{-1}$, can be observed during the cold season but only when air temperature is adequately low, as was observed in January 2010 (mean daily air temperature ~ -10°C). In comparison, a relatively warm January the next year (with mean air temperature of about 0°C) caused much less intensive carbon dioxide exchange, on the order of only 30 g m$^{-2}$ day$^{-1}$. Mean annual FCO$_2$ exchange in the centre of Łódź in the analysed period has been estimated as ~11 kg m$^{-2}$.

FCO$_2$ variability is also characterized by a clear diurnal rhythm (Fig. 3 bottom middle and right). As the factors determining this rhythm change seasonally (anthropogenic emission, vegetation age, length of the day etc.), variability changes by season. Maximal mean winter values of FCO$_2$, observed between 9 am and 6 pm, are significantly higher than in summer, primarily because of the high emission of anthropogenic CO$_2$ all day long. In summer, anthropogenic CO$_2$ fluxes are much lower and exchange is related to the increase in biological processes. As a consequence, instead of the FCO$_2$ maximum occurring at noon and in the afternoon, minimum FCO$_2$ occurs at those times. As CO$_2$ emitted by car traffic is suspected to be a significant anthropogenic source, diurnal courses were recalculated separately for working days and for weekends (Fig. 3, bottom middle and right). Diurnal courses show lower FCO$_2$ values on weekends. Summer weekends are the only occasion when, on average, minimal FCO$_2$ is close to 0 which indicates that CO$_2$ uptake during photosynthesis almost compensates for its anthropogenic emission. In the winter, the mean diurnal weekend course
also reaches lower values as a result of less intensive car traffic.

As mentioned, a few short-term experiments were also carried out in the years 2002-2003 (Fig. 4). Because FCO$_2$ wasn’t measured in the centre of Łódź during these years, results have been compared with averaged data obtained at Lipowa Street after July 2006. Only FCO$_2$ measured above the post-industrial area seems to reach similarly high values, as in the city centre mean daily exchange measured in autumn 2002 is about 10 g m$^{-2}$ day$^{-1}$ lower than that registered in the centre in the period 2006-2011 (31 g m$^{-2}$ day$^{-1}$). CO$_2$ exchange measured above residential and suburban areas was clearly different in comparison with the city center. In both cases the daytime minimum was negative, which indicates a prevalence of CO$_2$ biological uptake over the anthropogenic emission. Especially fluxes observed above the grassy suburban area were high and negative. Mean daily FCO$_2$ measured in the residential area in summer 2002 was 12 g m$^{-2}$ day$^{-1}$ lower than at Lipowa Street (19.3 g m$^{-2}$ day$^{-1}$). CO$_2$ exchange measured above residential and suburban areas was clearly different in comparison with the city center. In both cases the daytime minimum was negative, which indicates a prevalence of CO$_2$ biological uptake over the anthropogenic emission. Especially fluxes observed above the grassy suburban area were high and negative. Mean daily FCO$_2$ measured in the residential area in summer 2002 was 12 g m$^{-2}$ day$^{-1}$ lower than at Lipowa Street (19.3 g m$^{-2}$ day$^{-1}$). As expected, mean FCO$_2$ registered in summer 2003 above the suburban area was negative and reached -2.9 g m$^{-2}$ day$^{-1}$ (mean summer FCO$_2$ at Lipowa Street was 20.5 g m$^{-2}$ day$^{-1}$).

Measurements obtained from Łódź are similar to those obtained for sites established in city centres like Tokyo, Edinburgh and Helsinki. Results confirm that one of the factors determining CO$_2$ exchange intensity is land use. As a next step, we plan more detailed measurement outside the Łódź centre.

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**References**


