Author reply: Eddy covariance measurements of the net turbulent methane flux in the city centre – results of 2 year campaign in Łódź, Poland by W. Pawlak and K. Fortuniak

Referee comments in bold

We would like to thank referee for his thorough reading of the manuscript and for very detailed, constructive and useful comments, which show his dedication to improving this manuscript.

This is a new and important study, in which a long time-series (2 years) of methane fluxes is presented and analysed. The dataset represents the first of its kind in terms of duration, enabling annual total methane flux to be estimated for an urban area, as well as some consideration of inter-annual variability. The analysis focuses on the temporal patterns in the methane flux at various timescales (daily, weekly, monthly, seasonally and annually) and spatial patterns are explored too. In some places deeper analysis may offer additional insight.
The article is generally well written and thorough, but very repetitive in places. Sometimes use of unnecessary words obscures the meaning. I have made some specific suggestions below but **the article as a whole would benefit from being more concise. Shorter (more) paragraphs would also improve readability. Overall the quality of the work is high and I recommend this paper for publication in ACP following minor revisions.**

Specific comments:

1. Introduction: The introduction would be easier to read if it was more concise and less repetitive. Breaking the text up into smaller paragraphs would also help. I have made some suggestions below.
According to referee comments this section has been rewritten and divide to smaller paragraphs

Introduction:
"The temporal and spatial variability of greenhouse gas fluxes in the atmosphere is at present one of the most widely discussed climatological problems. Methane, despite its trace presence in the air (ca 1.8 ppm, Hartman et al., 2013), plays an important role in the environment. It participates in the global carbon cycle and is considered one of the greenhouse gases whose concentration in the atmosphere affects the radiation balance of the Earth's surface. An increase in the concentration of methane contributes to an enhancement of the greenhouse effect; therefore, the emissions of this gas to the atmosphere should be carefully monitored.
Methane is produced during the process of methanogenesis under anaerobic conditions, from the decay of organic plant debris in water. The most important source of methane in the world is wetlands (Shurpali et al., 1998; Rinne et al., 2007; Baldocchi et al., 2012; Hatalaa eta al., 2012), but also paddy fields (Miyata et al., 2000), cattle farming (Laubach and Kelliher, 2005; Dengel et al., 2011; Hartmann et al., 2013; Nicollini et al., 2013), as well as emissions from the soil (Smeets et al., 2009; Denmead et al., 2010; Wang et al., 2013). Moreover, emissions of methane accompany forest fires and grass vegetation. The effect of the combustion of natural gas (which contains at least 80% methane) is mainly water vapour and carbon dioxide. The combustion of fossil fuels is, however, predominantly incomplete, and therefore it is an important factor causing anthropogenic methane emissions. This happens in the case of combustion of both natural gas and hydrocarbons contained in petrol and other fuels (Nam, 2004; Nakagawa et al., 2005; Wennberg et al., 2012). Another important source of methane in urbanized areas is leakage from urban gas pipelines (Lowry, et al., 2001; Gioli et al., 2012; Wennberg et al., 2012; Phillips et al., 2013). Methane may also be emitted during the anaerobic respiration of bacteria in urban soils (Bogner and Matthews, 2003) and in the course of decomposition of solid waste and wastewater in sewage systems and at landfill sites (Bogner and

Matthews, 2003; Laurila et al., 2005; Lohila etal., 2007; Wennberg et al., 2012; Jha etal., 2014). On the other hand, certain soil bacteria consume methane, which is one of the processes of its removal from the air (Goldman et al., 1995; Kaye et al., 2004; Groffman et al., 2006; Groffman and Pouyat, 2009). Methane is involved in some of the reactions leading to photochemical smog formation (Seinfeld and Pandis, 2006). The disintegration of methane also results from its reacting with the hydroxyl group in the atmosphere (Whalen, 2005). Annual global emission of methane to the atmosphere has been estimated as ~5000 Tg of CH4, and emission from landfills and waste (87-94 TG of CH4) or fossil fuels (85-105 Tg of CH4) are 2-3 times lower than estimated emission form wetlands (177-284 Tg of CH4) (Ciais et al, 2013).

Research on the methane content in the air is now a priority because, as it follows from the literature on the problem, the city may be a significant source of this gas (Elliot et al., 2000; Gioli et al. 2012; O'Shea et al., 2012; Nicolini et al., 2013; Phillips et al., 2013; Christen, 2014; Kumar and Sharma, 2014). The measurements of changes in CH4 concentrations have been carried out for decades (Ciais et al., 2013; Hartmann et al., 2013), while the analyses of its flux, especially in urban areas, are extremely rare. In recent years, there have been approximately 500 stations measuring the fluxes of CO2 around the world, of which only ca 20 are located in cities and only a few were able to measure methane flux (Nordbo et al., 2012; Oliphant, 2012; Christen, 2014). It can be concluded that the measurements of methane fluxes in the cities are in the early stage and there are still some challenges like long term measurements (much longer than a few weeks or months) and relationship between methane fluxes and land use.

Basics of theory and measurement techniques of turbulent exchange of mass, energy and momentum fluxes have been developed for decades (Stull, 1988; Lee et al., 2005; Foken, 2008; Aubinet et al., 2013). The measurements of the fluxes of methane were severely limited due to the lack of suitable sensors which to have appeared a few years ago (Pattey et al. 2006; Hendricks et al., 2008; Eugster and Pluss, 2010; Dengel et al., 2011; Detto et al., 2011; Sakabe et al., 2012). At present, the most widely used instrument is in all probability the LI7700 Open Path CH4 Analyzer (Burba and Anderson, 2010; McDermitt et al., 2011) and eddy-covariance as a measurement technique (Aubinet et al., 2012). All over the globe, there are only a few long-term, continuous measurement series of turbulent fluxes of water vapour and carbon dioxide recorded in urban areas (Christen, 2014). In the case of methane flux, such series are probably at the implementation phase, since previous studies focused on areas which are the largest source of methane, i.e. natural wetlands (Shurpali et al., 1998; Rinne et al., 2007; Baldocchi eta al., 2012; Hatalaa eta al., 2012; Aubinet et al., 2013), agricultural land (paddy fields, Miyata et al., 2000) or over forests (Smeets et al., 2009; Wang et al., 2013). The chamber method, widely used in rural areas, has only a limited relevance in the city: it makes it possible to take measurements of methane emissions from the specific areas like urban lawns (Baciu et al., 2008), however, it cannot be used in the case of larger urban areas. A variety of techniques have recently been applied to provide independent estimates of urban CH4 emissions like airborne observations (O'Shea et al., 2014; Mays et al., 2009), Fourier Transform Spectrometry (Wunch et al., 2009) or isotopic source apportionment studies (Lowry et al., 2001). Morizumi (1996), in turn, suggested the occurrence of covariability of radon Rn-222 and the methane flux concentrations, which, based on this, he estimated to be 20 mg·m-2·day-1. In Poland, the issue of exchange of greenhouse gases in an urban area is studied, besides Łódź, in Cracow where, based on the measurements of CH4 concentrations and the height of the atmospheric boundary layer, the average monthly nocturnal flux of methane has been estimated to be 0.8 do 3 mg·m-2·h-1 (Kuc et al., 2003; Zimnoch et al., 2010).

The aim of this study is to analyze the temporal variability of the turbulent flux of methane (FCH4) based on a long-term series of measurements recorded for over two years in the centre of Łódź between July 2013 and August 2015. The diurnal variability of FCH4 was analysed and monthly values of the flux were determined and an attempt was undertaken to assess the cumulative annual exchange of methane between an urban area and the troposphere in order to determine whether the centre of Łódź was an equally efficient source of methane to the troposphere as of carbon dioxide. The measurement results were compared to the variability of selected meteorological elements. As *the methane emissions in the city are determined mainly by anthropogenic factors, the values of fluxes on weekdays and at weekends were compared. Due to the impossibility to obtain relevant data, there was no comparison made with the values of fluxes using specific inventory methods. "*

P2 L15-18: To improve readability delete unnecessary words: 'In the first place', 'furthermore', 'the formation of'
Done

P2 L27-8: Delete ', and methane is also the main component of natural gas' as it is unnecessary given L28-9.
Done

P3 L24 – P4 L8: This part is quite hard to follow, a bit repetitive and could benefit from rewording.
According to reviewer comments this section has been rewritten.and now reads:
*"*Unfortunately, the lack of precise fast response instruments resulted in the fact that initially it was only possible to use indirect methods for fluxes measurements, such as the gradient method or the chamber method (Nicolini et al., 2013). The instruments to measure the turbulent fluxes of greenhouse gases such as water vapour and carbon dioxide became more widely available several years ago and since that time (the first half of the 1990s) research are significantly intense (Aubinet et al. 2012). The measurements of the turbulent exchange of methane were severely limited due to the lack of suitable sensors which to have appeared a few years ago (Pattey et al. 2006; Hendricks et al., 2008; Eugster and Pluss, 2010; Dengel et al., 2011; Detto et al., 2011; Sakabe et al., 2012). At present, the most widely used instrument is in all probability the LI7700 Open Path CH_4 Analyzer (Burba and Anderson, 2010; McDermitt et al., 2011). The number of publications describing the results of measurements of the turbulent flux of methane is therefore relatively small, in contrast to the turbulent process of carbon dioxide exchange, although it should be noted that this kind of research in urbanized areas is still relatively rare (Nordbo et al., 2012; Oliphant, 2012). In recent years, there have been approximately 500 stations measuring the turbulent exchange of CO_2 around the world, of which only ca 20 are located in cities (Nordbo et al., 2012; Oliphant, 2012; Christen, 2014)."

P4 L20-22: This sentence is not clear, please rephrase.
This sentence has been rewritten: "The chamber method, widely used in rural areas, has only a limited relevance in the city: it makes it possible to take measurements of methane emissions from the specific areas like urban lawns (Baciu et al., 2008), however, it cannot be used in the case of larger urban areas."

P5 L18: Delete 'Furthermore'
Done

P5 L19: Delete 'in the following months'
Done

2.1 Study area and site location: This section is long and quite hard to follow, in particular there are many details given about various parts of the city and it does not convey a clear message to the reader. It may be easier to follow if the section was restructured, so that after the description of the city (P5 L30 – P6 L8) comes the description of the measurement location (P6 L28 – P7 L9) starting with 'The measurements of

methane: : : persons per km2' (P7 L8-10) and then the land cover description (P6 L10 – L27). This should make it easier to identify exactly which areas are being discussed in relation to the city as a whole, as opposed to the measurement location and source area. Please also reduce repetition and unnecessary text.

According the reviewer comment this section has been reconstructed. Moreover we agree that some details are not necessary and has been removed from the text:

"Łódź is one of the largest cities in Poland. The area of the city is about 295 km2, and its population is estimated at about 706 thousand residents. The city is located in central Poland, on relatively flat terrain sloping south-westwards (its altitude varying from ~280 to ~160 m.a.s.l.). The most densely built-up city centre covers an area of 80 km2 and the altitude differences in this part of town do not exceed 60 m. In the immediate vicinity of Łódź, there are no large bodies of water, rivers or orographic obstacles, which facilitates investigating the climate of the city. Another factor making it easier to take measurements of turbulent fluxes of mass and energy in Łódź is that the city, unlike other large cities in Poland, does not have a standard central sector of tall buildings, clearly towering over the urban canopy layer.

The measurements of turbulent fluxes of methane are conducted in the western part of the city centre (51°47'N, 19°28'E, Fig. 1), in an area with the highest population density, reaching 17.2 thousand persons per km2. The station for measurements of fluxes of mass, energy and momentum has been operating in the western part of Łódź since 2000 (Offerle et al., 2006a; 2006b, Pawlak et al., 2011; Fortuniak et al., 2013, Fortuniak and Pawlak, 2014), but methane fluxes have been studied since July 2013. The measurement set is mounted on top of a mast at a height of z = 37 m (Fig. 2, left), which, given the average height of buildings of 11 m, enables the assumption that the measurements are taken above the blending height in the inertial sub-layer (Fig. 2). The source area of turbulent fluxes was estimated (Fig. 1) for data collected during unstable stratification ((z-zd)/L < -0.05) around midday (10.00 – 14.00) following the method of Schmid (1994) and ranged from 250 to 750 m away from the measurement station (Fig. 1).

The percentage of artificial surfaces (buildings, sidewalks, streets, squares, etc.) in this part of town is 62%, the remaining part being covered with vegetation, of which only 10% are trees (Kłysik, 1998). The vegetation is distributed unevenly in the form of lawns and trees growing along the street canyons. In the immediate vicinity of the measurement point, 3-5 storey 15-20 m high buildings dominate, built mostly in the 20th century. Most of them are characterized by flat roofs covered with black tar paper or sheet metal. The trees growing in the area are mostly deciduous and their height usually does not exceed the height of the buildings, which results in a well-formed roof surface with an average height of 11 m. The density of built-up areas north and east of the measurement point as compared to the southern and western sectors is 10-20% greater (Fig. 1). The displacement height zd is estimated at 7.7 m. According to the classification by Stewart and Oke (2012), the local climate zone can be described as compact low rise. The roughness coefficient z0m estimated for the neutral stratification surrounding the measurement point was on average ~2.5 m. More information on the city's structure and the local climate conditions can be found, e.g. in Kłysik (1996), Kłysik and Fortuniak (1999), Fortuniak et al. (2006, 2013), Offerle, (2006a, 2006b), Pawlak et al. (2011) and Zieliński et al. (2013). The gas distribution network and sewerage system around the flux tower are shown in Fig. 1."

P6 L4: Delete 'definitely'

Done

P6 L8: Start a new paragraph at 'The measurements: : :'

Done

P6 L10-11: It is not clear what is being 'averaged' here. May be best to omit 'average' and change 'reaches' to 'is' or provide further details (e.g. mention wind sectors used).

Done

Now this sentence reads:
"The percentage of artificial surfaces (buildings, sidewalks, streets, squares, etc.) in this part of town is 62%, the remaining part being covered with vegetation, of which only 10% are trees (Kłysik, 1998)."

P6 L18-20: May be best to switch these two sentences describing the general study area with the previous one which talks about differences between sectors.
Done

P6 L14, L20, L22: There are several different heights given here, presumably for different areas of the city. However, it is not clear to the reader which are the relevant heights, i.e. those that are considered to be within the measurement footprint and used to estimate the roughness and displacement height. Are the '10-12 storey buildings' within the footprint? Have they been included in the calculation of z0, but not zd?
No, these buildings are quite far away (3-4 km from the site location) and definitely outside the footprint. They haven't been included in the calculation both z0 and zd. It was just an information about the other districts of the city but we agree that this is not necessary. The sentence "The centre is surrounded by industrial and residential areas with tall 10-12 storey buildings or loosely built-up with single-family houses." has been removed from the manuscript.

The values given here seem to match those given in Pawlak et al. (2011), so it may be worth directing the reader to that reference in particular. However, different values are given in Offerle et al. (2006a). Please explain.
After Offerle's and ours research in the years 2000-2003 we were able to obtain a more accurate database of buildings height. Urban canopy layer height has been recalculated and final values of zH and zd are a little bit different than in Offerle (2006a).

It would also be useful to give the site name so that readers can relate this work easily to previous work carried out at the same location.
We are not sure if the giving a name of station would be appropriate. In some of the publications listed in the lines P6 L26-27 concerning the center of Lodz " Lipowa station" is used but not in others.

P6 L31-33: To avoid repetition delete this part ('when : : : air') as it effectively says the same as the first half of the sentence and this point has already been made earlier in the paper as well.
Done

P7 L3-7: Suggest rephrasing as, 'The source area of turbulent fluxes was estimated (Fig. 1) for data collected during unstable stratification ((z-zd)/L < -0.05) around midday (10.00 – 14.00) following the method of Schmid (1994).'
Done

P7 L7-9: Could rephrase as, 'The source area ranged from 250 to 750 m away from the measurement station.'
Done, the sentence now reads:
"The source area of turbulent fluxes was estimated (Fig. 1) for data collected during unstable stratification ($(z-z_d)/L < -0.05$) around midday (10.00 – 14.00) following the method of Schmid (1994) and ranged from 250 to 750 m away from the measurement station (Fig. 1)."

P7 L9-17: This part does not really belong in the site description – it would fit better in the results. Suggest simply saying 'The gas distribution network and sewerage system around the flux tower are shown in Fig. 1' here, and saving the methane discussion for the results. (Note Fig. 2 in L17 should be Fig. 1.)

Done

2.2 Instrumentation and data processing: This section is generally clear but splitting into smaller paragraphs would help improve readability. One or two sentences may need to be moved around so that each paragraph deals with a particular topic before moving on to the next. P7 L20-30: Suggest rewriting more concisely.

Regarding to referee comment this section has been divided on smaller paragraphs but without giving them separate titles. The initial part of the section (P7 L20-30) has been rewritten and now reads: "The measurements of the turbulent fluxes of methane were carried out using a standard measurement set consisting of an ultrasonic anemometer RMYoung model 81000 (RMYoung, Traverse City, Michigan, USA) and a methane fluctuation sensor with an open measurement path LI7700 (Li-cor, Lincoln, Nebraska, USA). Due to the fact that the final calculation of methane flux also requires the values of sensible heat and water vapour fluxes in the place of observation (LI 7700 instruction manual), the measurement set also included a sensor of the fluctuations of water vapour and carbon dioxide LI7500 Infra Red CO2/H2O open path analyzer (Li-cor, Lincoln, Nebraska, USA)."

P8 L21: Delete 'during the measurements'

Done

P8 L23, L26: Better to use 'RSSI' throughout this sentence, as opposed to switching between RSSI and signal strength of the instrument/signal strength value.

Done

P8 L21-26 and Fig. 2: Mention that Fig. 2 indicates the cleaned dataset (RSSI > 20%), e.g. in the figure caption.

Done, now caption reads:

"Figure 2. FCH4 measurement site in Łódź (left) and instrumentation (middle). Right figure show frequency of measured 1-hour blocks of raw data in relation with RSSI (Received Signal Strength Indicator) of Li7700 methane open path analyzer. Data recorded only in the case RSSI>20% were taken into account."

This should also be made clearer for the percentages discussed in the text, e.g. ': : :RSSI > 20% were chosen. Of these, RSSI exceeded 70% in only about 8% of cases: : :'

Done

P9 L10: Delete 'In the calculations'

Done

P10 L2: Delete 'earlier'

Done

3. Results: Suggest new paragraphs at P10 L28 (stability), P11 L8 (fluxes).

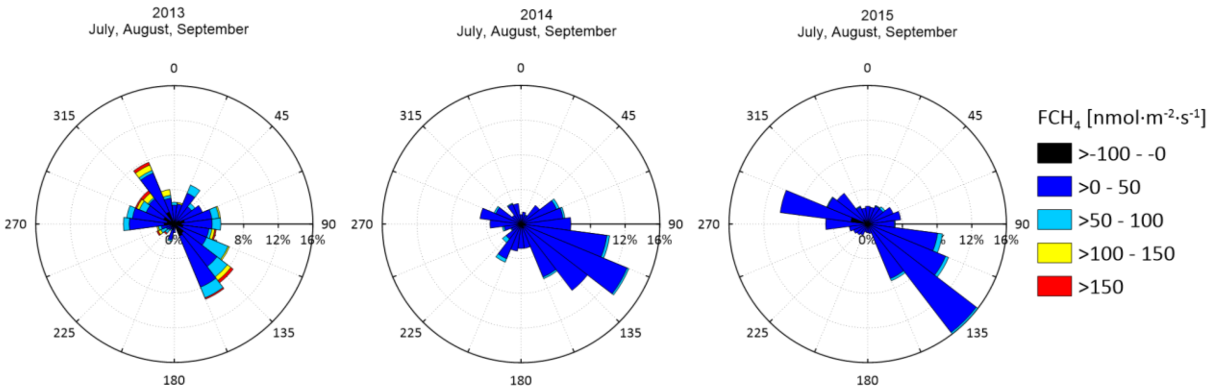
Done

P11 L32: New paragraph before 'It seems: : :'

Done

P11 L31-32, P12 L25: Could the authors suggest an explanation for the exception in July and August 2013? A little more discussion would be helpful (e.g. compare bottom two panels in Fig 3 and the statistics in Table 2 – the variability seems to be possibly more of an exception than the average values)

Indeed July, August and September 2013 are a surprising exception in the series. On the basis of the statistics in the Table 2 it can be concluded that the differences are very significant in the case of averages (vs. 2014 and 2015), but the median differ are significantly less. It may suggest some "incidents" with increased emission of methane in the surroundings of site in summer 2013. Unfortunately it is very difficult for us to give the reasons for this phenomenon. In the period July-September 2013, 2014 and 2015 no difference in the directions of airflow has been found and E-SE and W-NW dominates (see attached figure). In 2013, however, there were significantly higher values, which could affect the averages. Elevated FCH4 fluxes in the E-SE may be associated with the renovation of which at the time was implemented (construction of a tunnel for one of the main streets in the city - main E-W oriented street on the FIG. 1). During the implementation of the investment deep excavations were made and it is possible that some leakage or unsealing of gas pipelines could appear. Unfortunately, we do not have any data to prove it, so this is just our hypothesis (investment has been finished in autumn 2013). In turn, we don't have any ideas about the reasons of elevated FCH4 fluxes from NW sector in 2013.



Information about it has been added to the text and reads:
"The exception was the summer of 2013 when in July and August the recorded values of FCH4 were close to winter values. However, only average values were elevated, while the median values are similar to those of July and August 2014 and 2015. It can be assumed that in the summer of 2013 additional sources of methane occurred, which could be the result of damages of the gas network on SE form the station where the deep excavations associated with the construction of a tunnel for one of the main streets of the city center has been done (see main EW oriented street from the Fig. 2)."

In Fig 4 months in different years have been grouped together to create the daily cycles. Are the patterns significantly different if the years are considered separately (in general and particularly for summer 2013)?
There are no significant differences except summer 2013 months

P12 L4: Is there any evidence for increased discharge from motor vehicles in winter? Is this related to combustion conditions or the traffic load?
No we don't have such evidence. This issue raises our doubts and we regret that we cannot explain it on the basis of actual data. As we mentioned this in the manuscript, unfortunately, we do not have access to any inventory data Including traffic load. On the basis of years of observation can be noted, however, that in the winter, traffic is in Lodz less organised and regular. Definitely higher than during other seasons is the number of traffic jams in which the cars are standing or very slowly moving and fossil fuels combustion is then much more extremely intense than normal motion when the cars go smoothly at a speed of 50-70 km/h.

P12 L30: Suggest deleting 'Most importantly' – unless the annual variability presented in Section 3.2 is in doubt.

Done

The description of time needs to be more precise so that the reader understands exactly what is meant. Examples include P13 L4: 19.00-20.00 is probably too late to call 'afternoon', 'evening' is better. P13 L6: Change 'during the noon hours' to 'around noon', 'around midday' or 'during the middle of the day'. P13 L9: Does 'before noon' refer to the morning maximum (7.00-8.00)? Might be better to say 'in the morning'. P13 L11: Talks about the increased distribution 'during the day' but FCH4 is lowest during the day and peaks in the morning and evening.
Description of time in this section has been clarified.

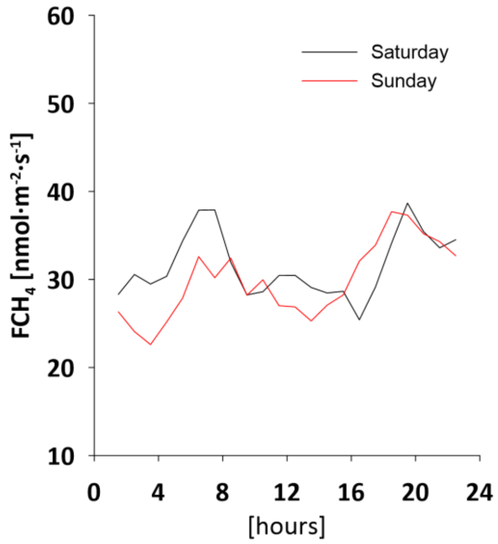
Fig. 5 and Fig. 6 are excellent. The discussion accompanying Fig. 6 is very clear.

P15 L24-26: As the partitioning of the sources of the observed methane flux is unknown, it is not possible to say that it is the anthropogenic sources that are less active at weekends. Rather, the weekday/weekend comparison suggests that the sources are likely to be anthropogenic because the observations show weekday/weekend differences.
We agree with referee's opinion. The sentence has been rewritten and now reads:
"These results suggest that, on average, in the study the period anthropogenic sources of methane are likely to be less active at weekends as compared with working days."

P15 L26-P16 L4: These differences are small and the inconsistency between summer/ winter and spring/autumn makes it hard to draw clear conclusions (as indicated by the authors). Further analysis and discussion may be informative. If the data are examined by month do the same seasonal differences emerge, or is this behaviour due to particular months skewing the results?
We have decided to analyse the differences in working days / weekends for the whole period and for seasons only. The reason is that after the data quality control, dataset has been shortened (Table 1) and we were worried that calculations for shorter time periods may introduce inaccuracy and unnecessarily complicate analysis.

Are the findings any clearer if holidays are taken into account as well as Monday-Friday and Saturday-Sunday differences?
No there are no significant differences

Are there significantly different fluxes on Saturday compared to Sunday, reflective of people's behaviour?
Regarding to referee comment we have compared Saturday and Sunday fluxes and there are some differences. Both on Saturday and Sunday, there are two peaks in the diurnal course (morning and evening) and the overall fluxes are lower in comparison with the working days. On Saturday, the average flux is, however, lower by 6.9%, while on Sunday by 12% thus almost doubled. The difference is a result of significantly lower peak on Sunday morning (see attached figure), which can be attributed to a typical human activity on Sunday- people sleep longer, later use natural gas for cooking, traffic load is also much less than at the same time of day on Saturday.



Information about this has been added to the text and reads:
"These results suggest that, on average, in the study the period anthropogenic sources of methane are likely to be less active at weekends as compared with working days. It should be emphasized that on Saturday, the average flux was lower by 6.9% in comparison with working days one, while on Sunday by 12%. The difference is a result of significantly lower peak on Sunday morning, which can be attributed to a typical not intensive human behaviour on Sunday morning and lower traffic load in comparison with the same time of day on Saturday."

Are there temperature differences between weekdays and weekends which may explain some of the trends seen?
No, there are no temperature differences

The wind direction analysis is interesting but would benefit from deeper examination and discussion. The large vegetated area to the west of the flux tower should be mentioned. Observed FCH4 also appears to be lower for southerly wind directions, potentially coinciding with the undeveloped area and scarcity of gas and sewerage pipes (Fig. 1). Is the large intersection to the south-west likely to have heavier traffic loads compared to other roads in the area?
Done, information about FCH4 from the different sectors has been added to the text: "As mentioned in Section 2.1, building density in the centre of Łódź is the most densely built-up area of the city. The measurement point is located in an area of uniform similar building density parameters, while, as mentioned in section 2.1, this density is slightly greater to the east and north of the station. An analysis of the average value of FCH4 depending on the wind direction confirms, at least in part, the impact of building density on the value of methane turbulent exchange (Fig. 8). The fluxes of CH4 recorded during airflow from the north, and especially from the south-east, were by far the largest in the study period and reached 35-45 nmol·m-2·s-1 (Fig. 8, left). However, it is difficult to regard the relationship urban design-FCH4 as certain, due to the increased values of FCH4 coming also from the south-western sector (approximately 40 nmol·m-2·s-1). Of course, such a relationship cannot be ruled out; however, the local point sources of methane may play an important role, but are difficult to identify. In the case of the south-western sector, the LPG station located approximately 800 m from the measurement station may be such a source, like lying about 200 m further to the west large intersection where traffic load is usually larger than in the surrounding streets. Significantly lower values of FCH4 (less than 20 nmol·m-2·s-1) observed during the airflow from the south and west may be due to the presence of large urban parks (Fig. 1). Through these areas, first of all, do not run the

streets with car traffic, and on the other hand, the density of the gas network and sewage system is also significantly smaller in comparison with other sectors (Fig. 1)."

The discussion needs to explore further than building density – i.e. the results should be related to the networks shown in Fig. 1. More could be made of the temporal differences in the spatial patterns (i.e. the similarity in the magnitude of FCH4 observed during both warm and cold seasons to the west, versus major changes in other wind sectors). If sufficient data are available, the authors may want to consider generating seasonal diurnal cycles for different wind sectors (or groups of wind sectors) to explore whether temporal signatures typical of anthropogenic behaviour (rush hours, weekday/weekend differences, seasonal heating demand) offer additional insight into the various CH4 sources.
As it was written in section 2 detailed quality control and rejection of the data recorded during precipitation has led to a substantial reduction in the number of data suitable for analysis. Such attitude aimed to provide assurance that the analysis of FCH4 fluxes will be carried for only the correct high quality data, but, on the other hand, significantly reduced the data series. For this reason, we have decided to reduce analysis of FCH4/wind direction relation to the basic information.

P16 L18: Could the LPG station be responsible for the increased FCH4 observed over the broad range of south-westerly wind directions? Does it coincide with the 230-240_ wind sector during the warm period? It may be helpful to mark the LPG station (and any other identifiable point sources) on Fig. 1. What about the high fluxes seen between 70-80_ in the cold period?
Identification of methane emission sources without the inventory data is very difficult. Moreover there were also no possibility to perform additional concentration of methane measurements in places with, probably, increased emissions (e.g. local sources like mentioned gas station). LPG station, as previously mentioned area of road tunnel construction are our suspicions about potential sources of methane in the vicinity of the measuring station. On Figure 1 both places has been marked.

Findings from the earlier analysis should be used to develop work towards the end of Section 3. Anthropogenic controls, spatial differences and relation to CO2 are considered almost independently in Sections 3.5, 3.6 and 3.7. But the spatial differences suggest different processes or source strengths are important in different wind sectors, so these findings should be considered in weekday/weekend differences and the relation to CO2.
Although we don't have an opportunity to carry out a more detailed analysis of the relationship between FCH4 and the wind direction and the differences between week days and weekends (see our earlier explanations), we decided not to put such summary at the end of section 3. The summary section contains all our main conclusions.

Building heating and traffic are important in winter, but less so in summer when photosynthesis also occurs, and less so for the vegetated sectors. The relation between FCO2 and FCH4 should include a deeper discussion of the underlying processes – and when and where one might expect FCO2 and FCH4 to be correlated or not.
Section 3.7 has been extended. One figure (no. 10) as well as appropriate paragraph has been added:

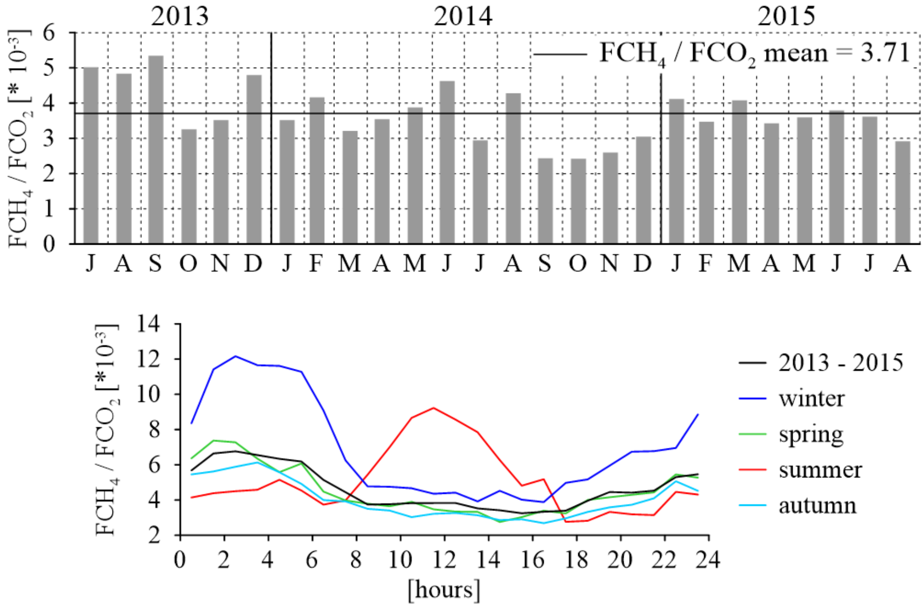


Fig. 10. Monthly FCH4 to FCO2 ratio (up) and mean diurnal courses of FCH$ to FCO2 ratio in the period July 2013 – August 2015 and for seasons.

*"Comparison of FCH4 and FCO2 fluxes allows also the analysis of the relative contribution of each of the fluxes in the total emissions into the atmosphere. The average value of FCH4/FCO2 ratio in 2013-2015 was 3.71*10-3 (Fig. 10, top). Rather stable values of the ratio in months (minimum 2.41*10-3, maximum 5.3*10-3) and the lack of a clear annual course suggest rather comparable magnitude of both fluxes. However, clear diurnal course of the ratio has been observed (Fig. 10, bottom) with reduced values in the day and elevated during night. On average, over the study period and in the transitional seasons, the daily variation of FCH4/FCO2 was rather similar. Between the hours of 9:00 and 17:00, its value was approximately constant of the order 2.5 to 3.5*10-3. At night, these values grow to about 5-7*10-3, which can be explained by a relatively constant methane emissions related to leaks from pipelines, and reduced emission of carbon dioxide which is the result of minimum of traffic load. In winter, the average daily variability of FCH4/FCO2 ratio has been characterized by slightly higher values during the day (about 4.4*10-3) and significantly higher at night reaching 12*10-3 between the hours of 2.00 and 6.00 (Fig. 10, bottom). The cause again can be a minimum of traffic load giving reduced fluxes of FCO2 but also increased methane leaks from pipelines associated with a higher gas consumption for heating of the surrounding buildings. The exception was the daily course FCH4/FCO2 in the summer, which can be described as reverse - the minimum (of the order of 3-5*10-3) was observed at night when maximum (more than 8*10-3) around noon (Fig. 10, bottom). Elevated values of the ratio during the day are the result photosynthesis reducing FCO2 flux."*

The conclusion is strong and provides a good synthesis, setting this work in context.
The comparisons with other sites and other cities is well-written and useful.

P18 L25-7: Can the authors suggest a reason for this?
In our opinion two maximums are reflection of inhabitants diurnal activity - increased consumption of natural gas and traffic rush hours.

Minor comments:

Title: 'results of a 2-year campaign' reads better.
Done

P1 L17-23: In my view this is too much detail for the abstract and 'the measurement

station : : : approximately 1 kilometre' should be omitted.
Done

P1 L30: CH4 and FCH4 are introduced here; to improve readability it may be more helpful to introduce them earlier (or not at all in the abstract), as currently several different ways of referring to the methane flux are used.
Done – FCH4 is now introduced in the end of introduction

P2 L1-2: To improve readability, delete 'The studied area of the centre of Łód´z is also characterised by a cycle of methane exchange – the'
Done

P2 L4: Change 'was characteristic of' to 'occurred in'
Done

P5 L8: Change 'at the same time hinder' to 'do not allow'
Done

P10 L13: Either 'The climate of central Poland is' or 'The climate of Łód´z is' (the reader already knows that Łód´z is in central Poland from P5 L31).
Done

P10 L28: Delete 'Generally, it can be noted that'. (You could say 'generally' before 'prevailed' if it is important.)
Done

P10 L29: Change 'could rarely be' to 'was rarely'
Done

P13 L9: Is 'or' the best word here?
Done

P13 L13: New paragraph after 'hypothetical'
Done

P13 L13: The meaning of this sentence is unclear, suggest deleting.
Done

P14 L4: Suggest deleting 'when they were up to 2.0 g m-2 month-1' as this sounds as though it contradicts the Jan/Feb values. Alternatively change 'up to' to 'around'.
Done

P14 L26: Intended meaning of 'supplementing' is unclear; 'observing' may be more suitable.
Done

P14 L30: Although additional data may be useful for more advanced gap-filling algorithms, simplifications are often used, as is the case in this study. Therefore suggest changing 'are required' to 'may be useful', or similar.
Done

P15 L28: Delete 'mg m-2 day-1'?

Done

P16 L7: Suggest starting this section with ‘As mentioned in Section 2.1, building density is: : :’
Done

P16 L23: Missing value.
Done (it shoul be 55-70 nmols/m2s)

P17 L2-7: Delete as this point has been made already in the Introduction.
Done

P17 L9: Change ‘should be asked’ to ‘can be addressed’
Done

P17 L18-20: This sentence is not very precise. Suggest rephrasing to say something like, ‘We therefore conclude that FCO2 data cannot be used to facilitate gap-filling of FCH4 data in the centre of Łód´z.’
Done

P17 L32: Change ‘in the case’ to ‘for’
Done

P18 L25: Meaning of ‘at the same time’ is unclear. Suggest deleting or changing to ‘for the same period’ if that is the intended meaning.
Done

P18 L25: ‘before and after noon’ is not very precise and potentially misleading: ‘morning and evening’ or giving the times would be better.
Done

P19 L1-3: Hinting at the discrepancy between CH4 observations and inventory estimates at this stage leaves the reader suddenly doubting the measurements they have just read about! Therefore this sentence might be more appropriate earlier on (either where the Florence results are discussed or when inventory data are mentioned).
Done (the last sentence has been moved where Florence results are discussed)

P28 Add percentage units to the table or caption.
Done

P31 L2: Delete ‘set’ Figure captions: ‘in the Łód´z centre’ can be deleted from most figure captions as it seems unnecessary.
Done

P35 L3: Suggest ‘light blue’ and ‘dark blue’ lines.
Done

Technical corrections:

P2 L26: Delete ‘the’
Done

P4 L11: Change ‘hang’ to ‘mount’
Done

P4 L13: Change ‘poorly’ to ‘not’ or ‘poorly widespread’ to ‘rare’
Done

P5 L16: Change ‘a turbulent’ to ‘the turbulent’
Done

P6 L1: Delete ‘a’
Done

P12 L25, Pg14 L5: Change ‘twice’ to ‘two times’
Done

P28 L2, P29 L2: Change to ‘July 2013’
Done

P30 L3 Change to ’10.00 to 14.00’
Done

P32 Fig 3: Change y-axis label to ‘air’ (not ‘ait’)
Done