Review #1

We thank reviewer #1 for reviewing the manuscript and the thoughts on how to improve it. In order to address all mentioned objections, we reproduce the original statements in blue, and we reply in black; additional text for the revised manuscript is given in red.

General evaluation

This study represents vertical profiles of CO_2 and CH_4 concentration measurements from the ZOTTO tall tower site in Central Siberia. An attempt is made to estimate ecosystem fluxes on intermediate scales (10^4 km^2) applying the modified Bowen Ratio method, which assumes equal eddy diffusivities for sensible heat, carbon dioxide and methan referring to similarity theory. Additionally it is explored how much information on local carbon fluxes can be extracted from the CO_2 and CH_4 concentration profile at ZOTTO.

Considering the remoteness of the site and the obviously excellent data quality, the paper, lacks in originality. In fact, at the end it presents averaged diurnal fluxes during summer-months, but simultaneously relativized the quality of the results. (MBR method, "our approach has certain limitations", "advection can alter the signal especially during sunrise or sunset", "measurement uncertainty is another restriction for our turbulent flux estimates", "in summary, the MBR method can give only limited information about the turbulent fluxes", and many more). At the end the reader wonders what the in the title mentioned "inferences" are.

The title underlines that the setup was not designed on the first place to measure fluxes. Instead of naming it simply flux calculations, we have chosen the wording "inferences from the gas profiles" since it is not a description of a flux measurement setup. Instead, we exploit all available data sets on the ZOTTO tall tower to come up with a time series of ecosystem fluxes, which otherwise would remain unknown. We openly present the limitations of our method, which is the reason why the text is written with so much care. We wish we could make use of a richer data set with additional parameters. In the future, the presented method will only provide a complementary data set for comparison purposes; much better flux measurements will be provided by the newly established eddy covariance sites.

We hope this clarifies the purpose of the paper a bit, we never meant to present an originally new measurement technique (then we would also not match this journal's scope). We make use of methods, which are well established e.g. in the FLUXNET community, to study the ecosystem – based on the ZOTTO dataset, which is quite poor when comparing to a typical eddy covariance site, but has its uniqueness in the tallness of the tower and the remoteness of the site.

MBR requires a) simultaneous measurements of T and the scalar of interest at identical levels and b) that measured H is representative for the same source area. Further on, no horizontal transports are considered. Regarding the large footprint of the top level, sources/sinks of heat and CO_2/CH_4 are not very likely to be the same. Most MBR studies show differences between EC fluxes and MBR derived fluxes which are attributed to different source areas and/or advection. This fact should be addressed more in detail, also regarding the large footprint.

From our perspective, we meet both stated prerequisites for MBR as close as possible. We mentioned the shortcoming about missing horizontal transport in the text (p6/L22), but cannot compensate due to missing well-comparable measurements around the ZOTTO tower. Indeed, the footprint is different for EC and MBR derived fluxes, which might be inferred from our calculations in chapter 2.3. However, we will add the following text to clarify the difference in the paper on p15347/L17:

"Therefore, the two towers represent well their surrounding local ecosystems, while the footprint of the tall tower averages all flux contributions from a much larger area, and cannot be attributed to a specific ecosystem."

Despite the fact that our focus is on the fluxes averaged over the large footprint area, the wind rose plots in the paper give an idea about the flux heterogeneity in the region, which becomes of particular interest for the CH_4 data.

To conclude this topic, please, also have a look at our reply regarding the comments on the advection below.

I agree that the recently installed eddy covariance (EC) system can help to extend the flux estimates back in time. However, since EC data in 2012 was obviously influenced by the great Siberian forest fires, the presented comparison relies on a poor data base, again regarding the different footprints. The statement that "the derived CO_2 fluxes exhibit reasonable diurnal shape and magnitude" is rather vague. A comparison with data from 1996 may be possible, but the time lag of 15 (!) years has to be addressed.

The strong fire influence is the reason for the vague statement. Unfortunately, we do not have other data available, leaving us no other possibility to compare. Regarding the data reference from 1996, we did not intent to compare to the amplitude of the old data directly; we wanted to have a guideline for the eyes. It is very likely, that the monthly averaged diurnal pattern remained unchanged.

We add a clarifying sentence on p15349/L11:

"To use this dataset as a reference is backed by other datasets in the boreal zone (Wang et al., 2007; Davis et al., 2003), which reveal the same diurnal patterns, but changing amplitudes driven by varying meteorology."

There is no information about stratification. Nothing is said about stability nor the height of the boundary layer. Since the most reliable fluxes refer to nighttime, it would be of highest interest to have an estimate of the height of the nocturnal boundary layer, i.e. if the top level is above the NBL. This is essential when comparing with the local fluxes from EC towers.

Thanks for bringing up this topic. We worked on it for a long time prior to this publication. However, neither meteorological measurements (e.g. low frictional velocity u*, stable potential temperature profiles), nor concentration data (e.g. identical night-time CO_2 data on 227 m and 301 m level, or undisturbed night-time CO_2 data at 301 m may stand for a boundary layer height below 227 m/301 m) turned out to be a reliable predictor for the stability state or the height of the atmospheric stratification (see p.15349/L25f). The main reason is the tremendous variation of daily patterns driven by short-term interruption e.g. by changing wind directions etc. Finally, we decided to monthly average the data to get rid of the short-term variations.

Moreover, we do not have additional measurement equipment available to estimate the boundary layer height. A ceilometer or something similar to detect at least the height of the cloud base was in discussion; however, high costs and strict regulations on importation (esp. for remote sensing techniques) hampered the installation so far.

We agree that this is a further limitation for the comparison to the EC towers, apart from the disturbing fires.

There is an ongoing discussion in the FLUXNET community about the correct form of the mass conservation equation and (storage) flux calculation (see Finnigan (2006), comment by Kowalski (2008) and response by Finnigan (2008) in Agr. For. Meteorol., also Kowalski JAS 2012), regarding the physical conservation principles. This issue should be addressed at least in the introduction in the context of tall tower measurements and the sampling times of the six level tubing system.

We thank for making us aware of this discussion and the references, we will add the following text to the introduction, since it is valuable knowledge for interpreting our data:

From our understanding, the reference by (Finnegan, 2006) http://dx.doi.org/10.1016/j.agrformet.2004.12.010 can be summarized as follows:

- The largest loss in the storage flux term due to averaging happens during turbulent conditions.
- Even during stable conditions, time averaging of concentration profiles still does not allow for capturing more than 60 % of the real signal.

Unfortunately, we have neither space averages nor higher temporally resolved data available to compensate for this problem. In contrast, we may use it as an additional argument to increase the height of the control volume to increase the eddy integration time to reduce this error.

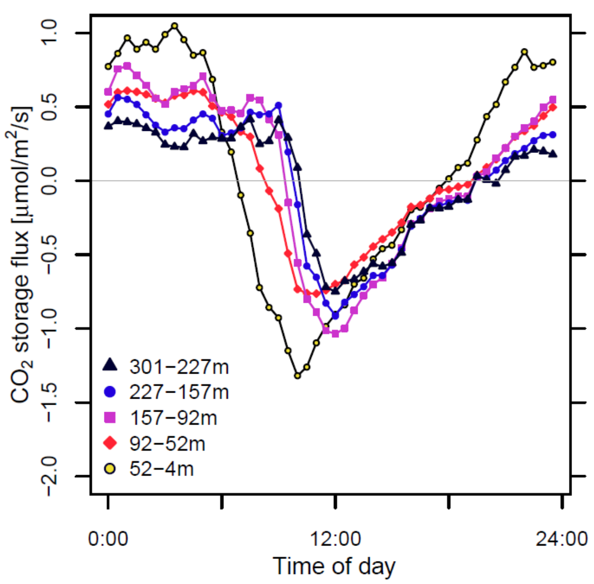
We will add the following text on p15349/L28:

"Recent studies indicate that our way of a temporally averaged storage flux measurement may inherently miss high frequent flux structures, especially under turbulent conditions (Finnigan, 2006)."

As we do not measure mass density, but dry mixing ratio of CO_2 – to our knowledge – the subsequent discussions by Kowalski e.g. about the WBL correction are of minor importance for our manuscript.

As the paper heavily relies on storage flux calculations between different levels I wonder why the authors do not present these values. In my opinion this could significantly improve the originality of the paper.

Here we give a figure, which demonstrates the diurnal cycle of the storage flux from different heights in average over the summer months in the years 2009-2011.



We performed all these tests before, and presented the final, most reliable data set in the paper only. Since, this seems not clear from our current manuscript, we modify the following text in the manuscript on p15346/L1ff:

“In summary, the modified Bowen ratio method can give only limited information about the turbulent fluxes; hence, the storage flux is our most reliable flux component. With the onset of mixing in the morning hours, the flux signal from the ground reaches higher tower levels (see Figures S2 and S3 in the supplementary material). The 301m height of the ZOTTO tower is sufficient to capture most of the NEE as storage flux already, at least during night, leaving the eddy flux data as a small correction term. We use the sum of the storage flux and the eddy flux component at the highest level as the best and the most robust flux estimate we can get with the available data streams.”

We will add illustrating figures in the new supplement (see also the discussion below).

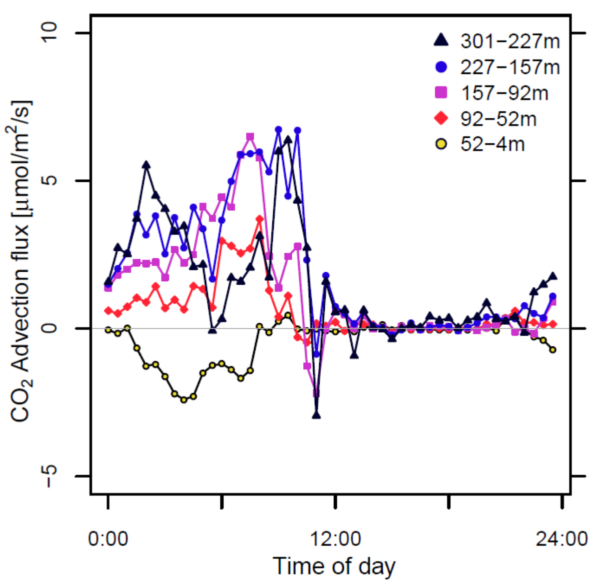
I agree that it is difficult or even impossible to “judge on the contribution of horizontal advection to the measurement signal”. Referring to Finnigan (1999) the authors do not present estimates of vertical advection. However, since there are sonic anemometers installed at all six levels, it would be of highest interest to see estimates of total vertical advection at the top of the tower and between these levels since vertical advection may account for a significant portion of total advection. Further on, as the authors apply the modified Bowen ratio method, it could be of interest to see the propagation of the sensible heat flux and the exchange coefficients with height with regard to the height of a “constant flux layer”.

We try to avoid the advection for several reasons (some are mentioned in our manuscript). We also got feedback by other scientists not including it. On purpose, we tried to circumvent these topics, because of our incomplete knowledge of the advection terms. We cannot compete with much more comprehensive studies which recorded all advection flux components (e.g. Aubinet et al.:, Agr. For. Meteorol, 2010, doi:10.1016/j.agrformet.2010.01.016). Therefore, it is unrealistic, that our data set can contribute to this expert discussion e.g. of the FLUXNET community.

However, we will add a new reference on p15343/L1:.

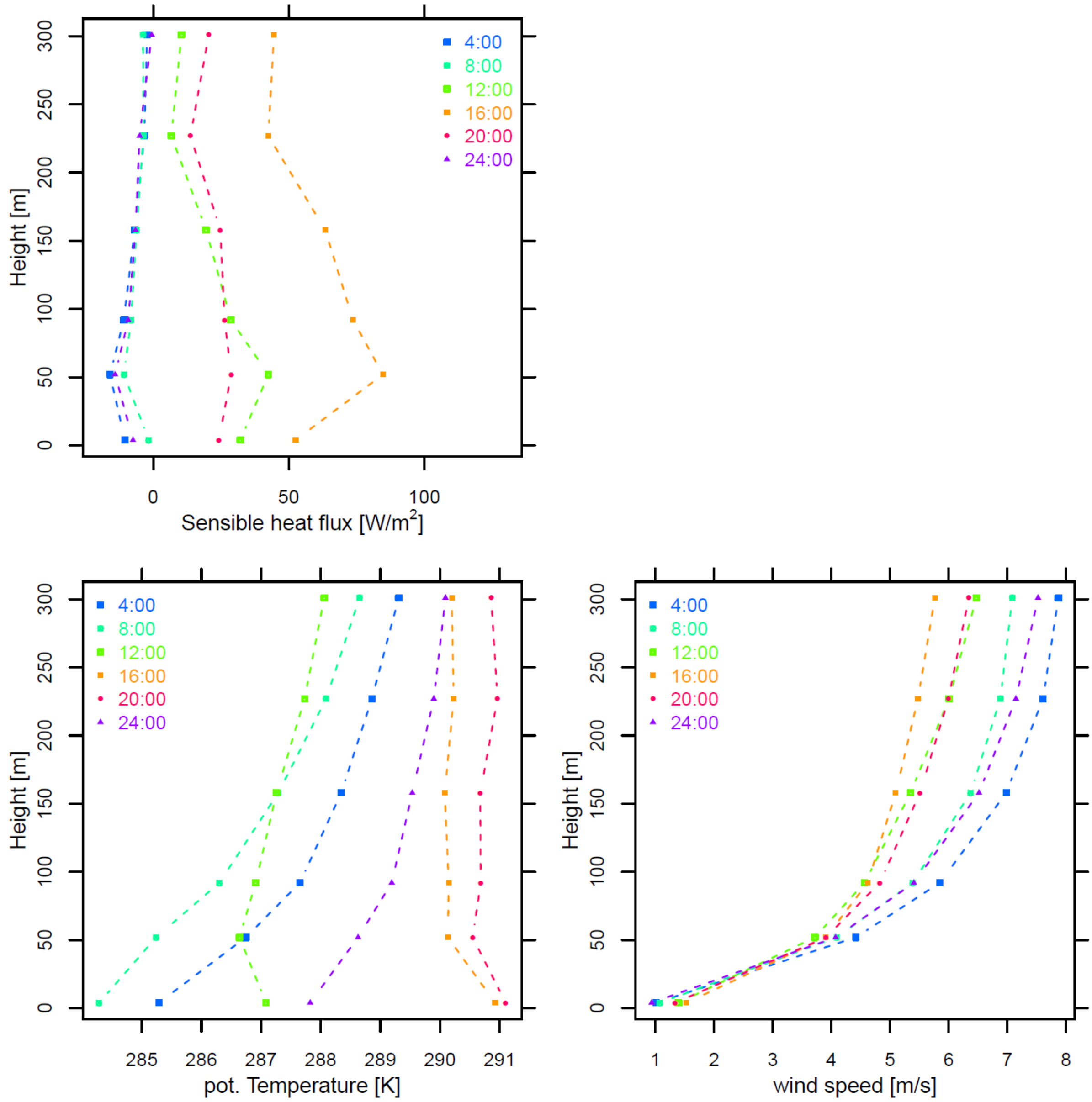
“Since including only one term in the total flux estimate would make it even worse than using none (Finnigan, 1999), we finally omit contributions from advection in our flux estimates (see chapter D3.3 in [Winderlich, 2012], and Figure S5 and S6 in the supplementary material).”

Nevertheless, we generated the figure, which demonstrates the diurnal cycle of the vertical advection flux from different heights in average over the summer months in the years 2009-2011.

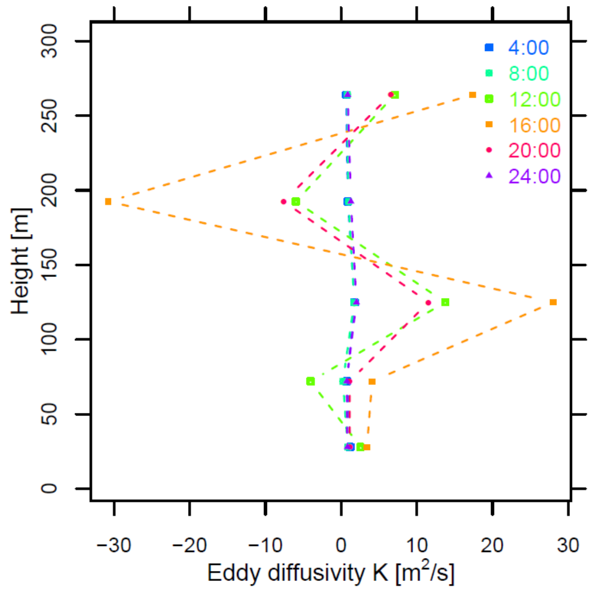


Despite averaging, the signal is quite noisy and the order of magnitude implies a compensating horizontal flux. For this reason, we would like to keep the advection topic out of the revised manuscript, since additional formulas would lengthen the manuscript, and cannot substantially contribute to our results.

For general interest, we will give the height profiles of heat flux, potential temperature, and wind speed in the supplement (Figure S1).



Given the sensible heat flux and the temperature gradients, we also plotted the profiles of the exchange coef. K_T.



While the heat flux has a well-known profile with a maximum flux in the afternoon hours at the 52 m level, the concept of a “constant flux layer” cannot be shown in the eddy diffusivity coefficient. The changing direction of the temperature profile results in unrealistic (negative) values of K_T at the second-highest tower level. The data quality is not textbook-like enough to allow reliable deductions. We investigated the reason for the highly variable pattern, and found the small temperature differences to be the main reason. To use all tower levels for the analysis, an intense inter-calibration between the temperature sensors of all heights would be required.

We will add a link of the ZOTTO project homepage to the figures in the supplementary material to get contacts and the data for further analysis, which are beyond the scope of our presented manuscript.

The paper would generally profit from presenting derived data for the different height levels.

We add this information as a supplement to the manuscript to make our arguments better traceable. To link the figures to the text, we add a reference to the supplements on p15348/L6:

“Additional illustrations of the diurnal evolution of the measured parameters along the tall tower profile are shown in the supplement of this article (e.g., Figure S1).”

Footprint: this is an essential topic when trying to attribute signals from tall towers to local ecosystems. As this is a central part of the paper I would expect much more details about the differences of concentration and flux footprints and how the tall tower signal is interpreted in terms of local ecosystem fluxes. The authors state that “it is explored how much information on local carbon fluxes can be extracted from the CO_2 and CH_4 concentration profile at ZOTTO”. I cannot find the section in the text that really addresses this topic. I further miss the relation of footprint and land use/land cover. I think there is much more to say than “the fluxes of the surrounding boreal forests … have the largest impact on the measurement signal”, and, for the EC towers, “the two towers represent well their surrounding local ecosystems”. Where is the link?

We realize that there is some confusion about the wording of local and regional fluxes. We change the wording in the whole manuscript for a clear division between local fluxes (with eddy covariance footprint) and regional fluxes (with tall tower footprint):

We will change the wording on p15341L18: “it is explored how much information on regional carbon fluxes can be extracted from the CO_2 and CH_4 concentration profile at ZOTTO”.

change in the title: “on regional summer-time ecosystem fluxes”

abstract: 15338L9: “which dominates the regional fluxes, especially during night”

15339L15 “1.2 Regional flux estimation techniques”

15347L4 “The area that contributes to the regional storage flux signal”

We hope, this helps clarifying the link between the local ecosystem and the boreal region.

The different size of the footprints and the reason for their differences are already stated in the manuscript. The link between the different flux results – as close as the reviewer requests – is limited by the coarse time resolution of the reliable flux estimates. The monthly averaged fluxes do not allow a finer localization than the average footprint shown in Fig. 2. Since the land cover in the footprint region is relatively homogenous and without anthropogenic distortions, the regional flux estimates represent an average of the boreal region including forests and bogs (we will add to p15347/L6). In contrast, the Eddy covariance towers represent the ecosystems either forest or bog exclusively on a much smaller scale. To link the tall tower fluxes to a smaller region, we separated our flux information according to the prevailing wind direction in Figure 6 and Figure 11. The implications are already discussed in the manuscript. From our perspective, a more detailed analysis cannot be done with the presented data.

Boundary layer budget methods (e.g. Denmead, 1996; Eugster & Siegrist, 2000) were obviously applied earlier at the site (Lloyd et al., 2001), though with large uncertainties. Nevertheless, this method would be an easy to apply additional control for comparison with the presented fluxes.

Unfortunately, we do not have boundary layer measurements available any more, since the airborne data sampling was stopped more than 10 years ago. Our presented data is an attempt to reduce this cap to earlier flux data sets.

Considering this general evaluation I recommend rejecting the paper.

We hope that our argumentation above and the associated improvements in the revised manuscript may persuade the reviewer to refrain from the original decision.

minor remarks

P..40L21: please provide an approximate mean height of the taiga forest in the surrounding of the towers

We added this information in p15340 L22: “The approximate tree height around the tall tower is 20 m.”

P..40L28 ff.: mixing time of 37 min., frequency 0.0004 Hz (P..44L19). According to Winderlich et al. (2010) one cycle for the 6 levels is 18 min. How are these measurement used in the 30 min. framework (all calculations are done with a temporal resolution of 30 min.)?

The data of each level is received every 18 min, but represents a data set, which is smoothed by the 37 min mixing in the air buffers. To align the gas measurements with the other data streams, we binned (averaged) the all data streams into 30 min periods.

For clarification, we add to our manuscript on p15343L3:

"All calculations are based on 30-minute time steps. All CO_2 and CH_4 measurements (recorded every 18 min for every height) are averaged within a specific 30 min interval, which is determined by the time stamp of the meteorological data set (temperature, heat flux, etc.). "

P..41L21: "…we make use of … and vertical wind measurements"! Where?

This is an artifact of an old manuscript version, before we skipped the advection part. We will remove this words in the revised manuscript. Thanks, for the careful reading!

P..43L3: time step 30 min.

We changed the wording accordingly.

P..43L19: photosynthesis reduces the CO_2 concentration at all heights?

Yes, it can be seen in Figure 1. However, we see, that there is a time shift to the highest tower levels. Therefore, we change the wording from "At noon," to "In the course of the day,".

P..44L11: please add chapter reference in the reference section

Done.

P..45L12: please provide references for "models"

We cited (Huang et al., 2009), we add ???.

P..45L15: abstract Huang et al. : "…eddy diffusivities differ among the three scalars, by up to 10–12%, in the surface layer".

We agree, that is the reason why we cited this reference. To make the section more clear, we modified to:

Models show dissimilarities between heat and CO2 fluxes (Huang et al., 2009). While the CO2 flux stays approximately constant with height, the heat flux linearly decreases up to the boundary layer height. However, the Eddy diffusivities of heat and CO2 were found to be the same within about 10-12 % (Huang et al., 2009).

P..45L55: It would be of interest how many data points were omitted.

We add the amount of omitted data in brackets to the text p15345L25: "(< 2 % of all data)".

P..47L8: please add chapter reference in the reference section

Done.

P..49L8 ff.: I am sceptic about these comparisons considering the completely different footprints. "The general shape of the datasets compare well" is not an argument.

We agree that the footprints are different. However, the CO_2 fluxes in this undisturbed boreal region that surrounds the site are dominated by the forest's photosynthesis. Because the driver is the same in both cases, we think that the diurnal pattern should also be similar. The mismatch between our flux estimate and the old reference dataset is a strong indication for a flux component, which is not yet completely captured by our ZOTTO measurement – however, it is not a proof.

We point this out in more detail on p15349/L25: "The main shortcoming of our method becomes visible especially in the well-mixed afternoon hours, when the turbulent flux component dominates the total flux. While the amplitude of the flux may alter with the meteorological conditions, the different shape between our dataset and the reference suggests a missing flux component in the most turbulent part of the day. Given the homogenous countryside, there is no evidence why the diurnal flux cycle should have changed its pattern. We performed”

P..55L11: please correctly cite chapters 5 and 8 of this book

Done in the revised manuscript.

Attached is the new supplement for the revised paper.

Average height-resolved diurnal cycles of ZOTTO summer data (June to Sept., 2009-2011)

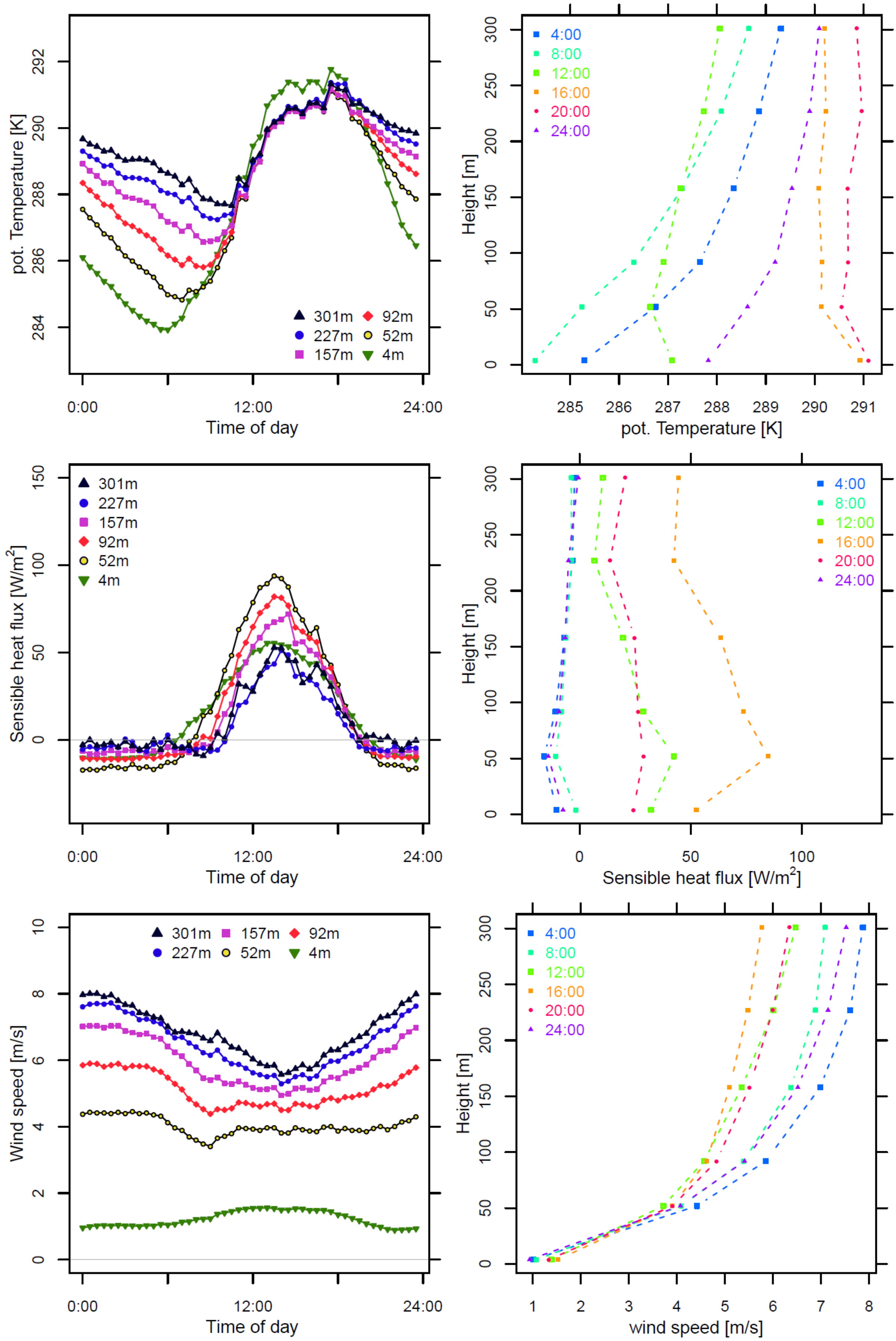


Figure S1 ***left:*** **Average diurnal cycle of potential temperature, sensible heat, and wind speed of all tower heights;** ***right:*** **average profile throughout the day**

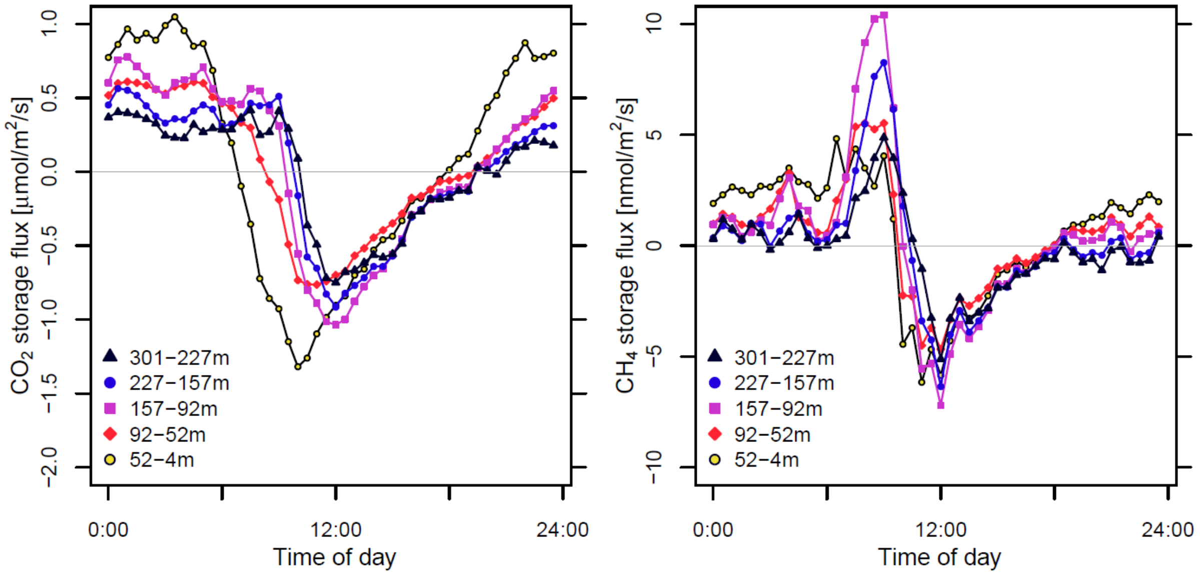


Figure S2 Average diurnal cycle of the storage flux term between all tower levels for CO_2 (left) and CH_4 (right)

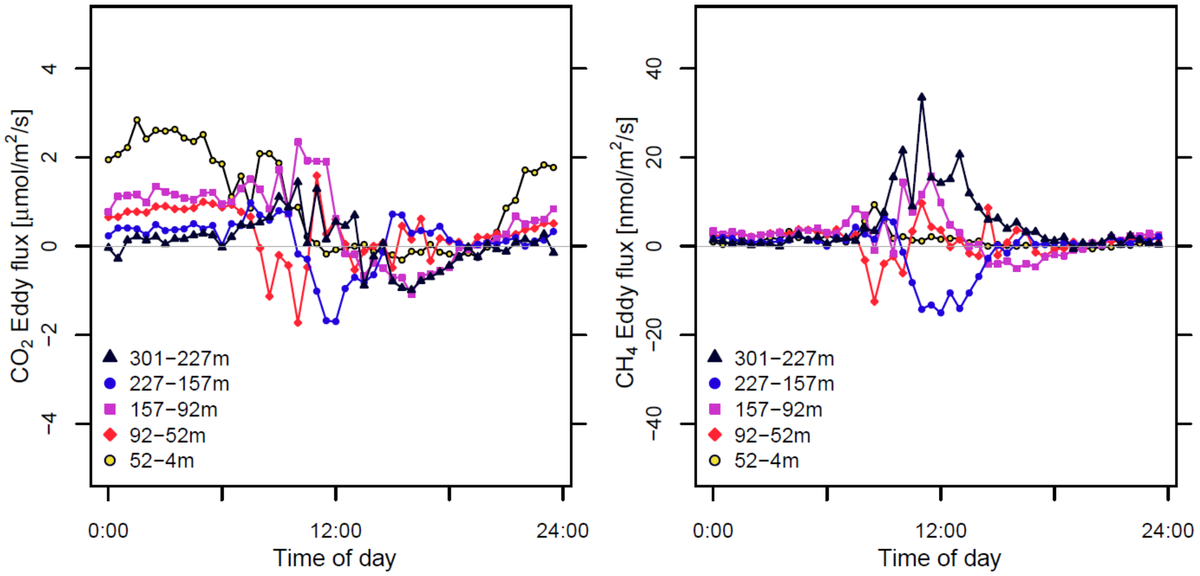


Figure S3 Average diurnal cycle of the eddy flux term between all tower levels for CO_2 (left) and CH_4 (right)

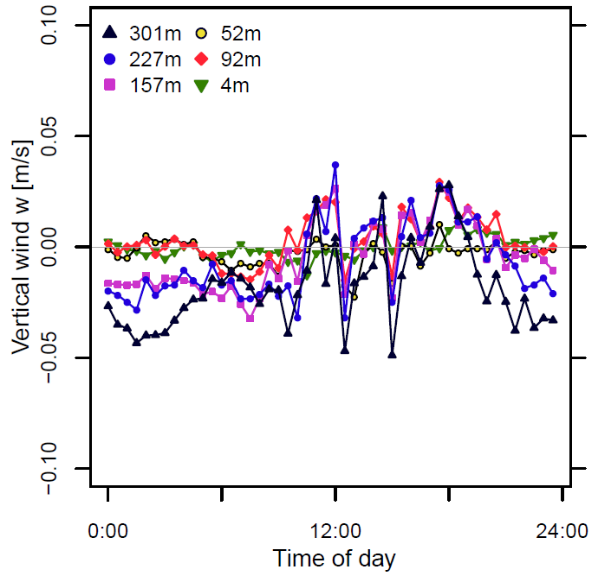


Figure S4 Average diurnal cycle of the vertical wind on all tower levels

Formula for vertical advection flux (Winderlich, 2012):

$$F_{vAdv} = \overline{w}(z_r)\left(\overline{c}(z_r) - \frac{1}{z_r}\int_0^{z_r}\overline{c}(z)dz\right) = \overline{w}_r\left(c_r - \langle c\rangle\right)$$

$\langle c\rangle$ … average gas concentration within the observed air volume below height z_r

c_r …concentration of overlaying air in height z_r

$\overline{w}_r$ … mean vertical wind velocity

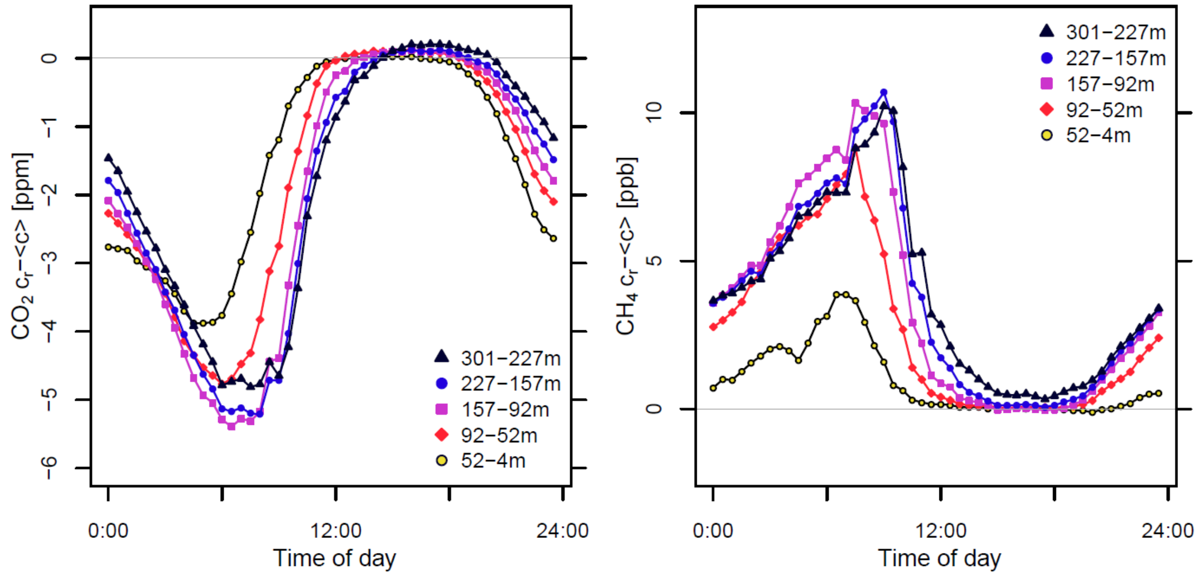


Figure S5 Average diurnal cycle of the advection term (c_r - <c>) between all tower levels for CO_2 (left) and CH_4 (right)

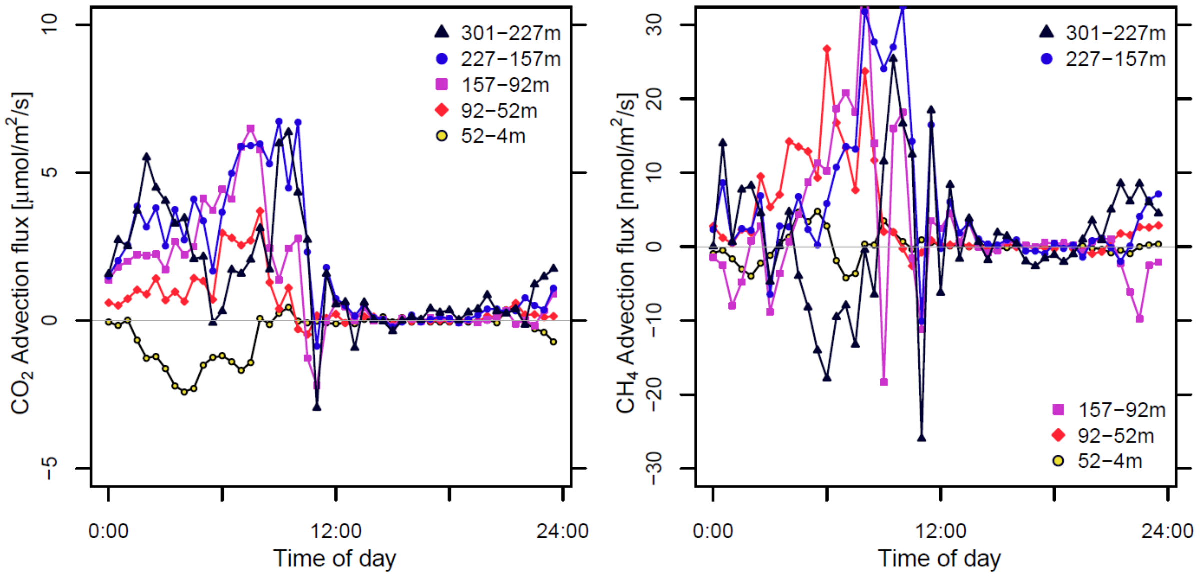


Figure S6 Average diurnal cycle of the advection flux between all tower levels for CO_2 (left) and CH_4 (right)

The ZOTTO data set is available through the ZOTTO consortium.
Please, find the up-to-date contacts on www.zottoproject.org.