## Reply to interactive comment on Haszpra et al. "How well do tall tower measurements characterize the $CO_2$ mole fraction distribution in the planetary boundary layer?" by Referee#1

First of all, we would like to thank the reviewer for his/her comments and suggestions, which have helped us to improve the manuscript, and for his/her opinion finding our work worthy to be published in AMT. Below you will find our detailed point-by-point response to the comments and suggestions in italic:

• Introduction Page 12252: "We present the trade-off between the height of the tower and the accuracy of the  $CO_2$  mole fraction estimation": I would add ". . .estimation at higher elevation above the tower"

The sentence has been completed as suggested. Revised sentence:

We present the trade-off between the height of the tower and the accuracy of the  $CO_2$  mole fraction estimation at higher elevation above the tower.

• Page 12252: "Is it reasonable to suggest co-located eddy covariance measurements to improve the performance of the tall towers?": ...in terms of representation of the PBL Methodology

The sentence has been rephrased as follows:

Is it reasonable to suggest co-located eddy covariance measurements to improve the representation of  $CO_2$  distribution in the PBL by tall towers?

• Page 12254: "The comparability of the tall tower based and the airborne measurements": I understand that the compatibility of the two dataset is described in details in other papers, but I think you should give the order of magnitude of the possible differences. It should illustrate that they are much lower than the biases you are calculating.

We give the required information completing the original sentence as follows:

The comparability of the tall tower based and the airborne measurements is guaranteed by the calibration standards traceable to the same primary ones at WMO CCL the uncertainty of which is  $<0.1 \ \mu mol \ mol^{-1}$  (Zhao and Tans, 2006).

• Page 12255: "Estimation height": I don't find this term gives a clear idea of what it is representing. Why not Model height?

The term 'model height' is usually attributed to the transport models and it depends on the resolution of the model. In the case of the hypothetic physical tower the tower-top measurement is simply extrapolated to the 'estimation height'. Although, extrapolation is

also a mathematical model in a certain sense, but the common meaning of 'model' is a more complex mathematical structure. 'Extrapolation height' might be the right term here. In the case of the application of the VTT concept we use a more complex function to 'extrapolate' the measured values to the 'estimation height'. As the common meaning of 'extrapolation' is the linear (or a very simple function based) extrapolation we doubt if 'extrapolation height' would be the right term here. Here we use a function for the estimation of vertical distribution of  $CO_2$  concentration in the PBL, which could be considered as a simple mathematical model, and thus we could define the estimation height as 'model height'. However, for consistency, we would have liked to use the same term in both cases that resulted in the compromised 'estimation height'. It might not be the best term but hopefully it is not misunderstandable on the base of the definition in the paper. Terminology has not been changed in the manuscript.

• Page 12256: "Gradients are function of depth within the PBL, not absolute elevation above ground": Is it true that 50% of a 1000m or 100m m high PBL give the same bias?

No, it is not. The vertical concentration gradient in a shallow PBL may significantly differ from that in a deeper one. During the work behind the present manuscript we tried to separate the measurements according to the actual height of the PBL (PBL height<1000 m; 1000 m<PBL height<2000 m; PBL height>2000 m) but the low number of the available profiles did not make possible any sound evaluation. To call the attention to this limitation of the results an extra sentence has been inserted into the revised manuscript:

The reason for this is the fact that a given absolute elevation can represent rather different relative ones within the PBL depending on the actual PBL depth, and gradients are functions of depth within the PBL, not absolute elevation above ground. It should also be noted that the gradient function may be different in shallow and deep PBLs but the limited number of the available measurements does not make possible the resolution according to PBL height.

• Page 12258: "if the eddy covariance can be considered as representative to the surrounding region": what is your estimate of the footprint of the eddy flux measurement at 82m a.g.l. ?

According to our previous study (Barcza et al., 2009, Agr. Forest Met. 149, 795-807.) the eddy covariance measurements performed at 82 m above the ground are directly representative for about a few km<sup>2</sup> around the tower. However, if the land cover of the wider region is similar to that in the immediate vicinity of the tower, the measured flux can be considered as representative for an extended region. In a plain, dominantly agricultural, more or less homogeneous region like in the region of Hegyhátsál tall tower the measured flux values may be considered as representative up to several thousand km<sup>2</sup>. For the clear distinction between the representativeness of the measurements in technical sense and that of the measured values the original, sloppy sentence referred above has been rephrased:

At a monitoring site, where eddy covariance based  $CO_2$  and sensible heat flux measurements are available, this concept can be used for the estimation of the  $CO_2$  mole

fraction gradient if the *flux measurements* can be considered as representative to the surrounding region.

• Results Page 12264: Specific case of shallow PBL is described for Figure 1 but this case can only be described in Fig.2 with absolute vertical axis.

Unfortunately, we could not identify the critical part of the manuscript as the 'Results' section is on the 12259-12262 pages and shallow PBL is not discussed on page 12264 (already the 'Discussion' section) either. We checked all those parts of the manuscript that referred either to Fig. 1 or Fig. 2 but we could not find any mismatch. If the editor or the reviewer indicated the critical sentences we would be willing to revise them.

- Discussion In the discussion I am missing two points:
- 1. can you say something about the representativeness of the Hungarian tall tower/aircraft site? How well is it representative of a typical tall tower?

There has been no systematic study on the spatial representativeness of the Hungarian tall tower or the aircraft measurements above it. In the CHIOTTO Final Report (Vermeulen et al. 2007 – referred in the paper) the concentration footprint of the tall towers is estimated 500-1000 km<sup>2</sup>, while Gloor et al. (2001 – also referred in the paper) tells "the order of  $10^{6}$  km<sup>2</sup>". In principle, the taller the tower the more extended its representativeness, thus the aircraft measurements might be representative to >10<sup>6</sup> km<sup>2</sup>. There may be significant difference among the spatial representativeness of the towers located in different environment. The second paragraph of the 'Concluding remarks' section emphasizes: "our results are primarily valid for relatively homogeneous, flat regions". It may not be valid, or only with limitations, for towers located in mountainous or coastal regions, or in regions with essentially different climate (e.g. huge deserts, arctic regions). As there is no more information that could be added to the sentence already in the 'Concluding remarks' section the manuscript has not been modified.

• 2. regarding the VTT concept that you are promoting in the conclusions, what is the sensitivity of the results to the elevation of the eddy covariance system ? Your system is set up at more than 80m above ground level which is quite unusual. Most systems are installed at elevation lower than 20m. Since the footprint of an eddy flux measurement installed at 10-20m would be much smaller than yours 82m setup the added value of the VTT concept to extrapolate the CO<sub>2</sub> vertical profile would probably also be decreased. I would be interested to see a discussion on this point.

We tested the application of the VTT concept with another eddy covariance system operated at 3 m elevation above grassland (not typical in the region) at the bottom of the Hegyhátsál tall tower. Although, the overlapping operation times of the two systems (82 m [referred in the manuscript] and 3 m) is too short to draw a sound conclusion we got comparable results. This is most likely caused by the covariance of NEE and sensible heat flux between the low and high elevation eddy covariance systems. Covariance of NEE is the result of the fact that functioning of both the mixed croplands and the grassland is driven by the same environmental factors (e.g. radiation, temperature, precipitation). Due to footprint considerations we recommend to use the highest possible elevation for the eddy covariance measurements. The following paragraph has been added to the end of Section 4.4:

As a test of the theoretical considerations on the height above the ground of the eddy covariance system the calculations were repeated using the available data set of another eddy covariance system located at 3 m above the grass covered ground at the bottom of the Hegyhátsál tall tower (Barcza, 2001; Nagy et al., 2011). Although, the overlapping operation times of the two systems (82 m and 3 m) was too short to draw a sound conclusion we got comparable results. This is most likely caused by the covariance of NEE and sensible heat flux between the low and high elevation eddy covariance systems. Covariance of NEE is the result of the fact that functioning of both the mixed croplands sampled by the high elevation eddy covariance system and the grassland sampled by the low elevation one is driven by the same environmental factors (radiation, temperature, precipitation). Due to footprint considerations we recommend to use the highest possible elevation for the eddy covariance measurements.