

## Short comment on the manuscript bg-2013-293

### Title: “Eddy-covariance flux errors due to biases in gas concentration measurements: origins, quantification and correction”

by G. Fratini et al.

#### General

I want to express my appreciation to the authors for providing such a thoroughly researched and crafted paper manuscript. Only recently the issues associated with dirt contaminations of infrared gas analysers become known more widely, and already the authors provide a very fundamental, theory-based correction procedure. With below comments it is my intention to further motivate the authors to expand upon and clarify several aspects.

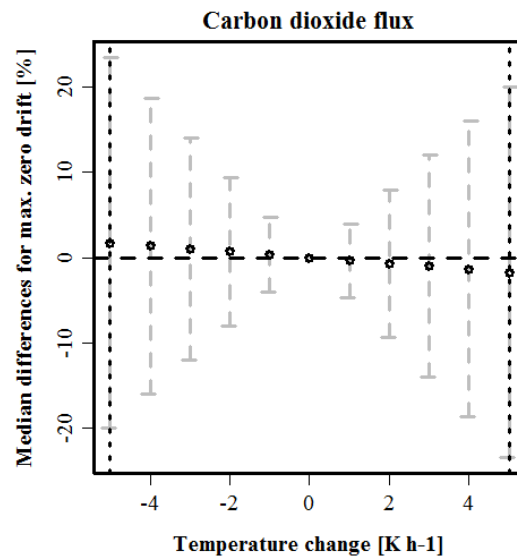
#### Drift of infrared gas analyser with temperature

The authors mention a potential “temperature location bias” of LI-7200 measured concentrations as a result of different temperature levels during laboratory calibration and field validation (p. 13701 l. 7. ff.). I agree with the authors that such mean difference cancels out when calculating the eddy-covariance, as long as drift is restricted to instrument zero and does not significantly affect the instrument gain. In addition, an LI-7200 is typically subjected to the environment, and shorter-term temperature variations resulting from the diurnal radiation and temperature cycles can be superimposed over the temperature location bias. The authors state that “*Such variations are slow enough not to directly affect the estimation of turbulent fluctuations*” (p. 13701, l 11 f.). However, e.g. for 12 months of LI-7200 data from the Niwot Ridge Ameriflux tower, a body temperature change rate of  $3.6 \text{ K h}^{-1}$  is found at the 95<sup>th</sup> percentile.

The authors also state that “*The magnitude and even the sign of (a resulting) deviation are largely unpredictable for each given unit, but it is expected to be within the manufacturer’s specifications.*” (p. 13701, l 18 f.) For example for  $\text{CO}_2$ , the manufacturer specifies maximum drifts of  $\pm 0.3 \text{ ppm K}^{-1}$  (instrument zero) and  $\pm 0.1\% \text{ K}^{-1}$  (instrument gain) for a population of LI-7200 instruments (LI-COR Inc., 2013). However, for an individual LI-7200, Bertelmann et al. (2013) were able to determine the sign and magnitude of the combined effects of zero and gain drifts to  $+0.19 \pm 0.02 \text{ ppm K}^{-1}$  ( $R^2=0.97$ ). This suggests that the thorough characterization of each individual LI-7200 in a climate chamber could better constrain instrument drift by one order of magnitude. Where available, the fast LI-7200 data could also

be based on simultaneously measured slow, though high-precision, high-accuracy gas analyser readings, e.g. through complementary filtering approaches (e.g., Metzger et al., 2012).

If left untreated, as suggested by the authors, the encountered drift (worst case  $0.3 \text{ ppm CO}_2 \text{ K}^{-1} \times 3.6 \text{ K} = 1.1 \text{ ppm}$ ) can reach the same order as noontime  $\text{CO}_2$  fluctuations. In the following, such drift is numerically propagated for 168 h of eddy-covariance data. For simplicity reasons a linear trend corresponding to the instrument drift over 1 h was superimposed over the original concentration time series. In reality however, body temperature likely changes non-linearly. For both, the original and the treated  $\text{CO}_2$  time series the covariance with the vertical wind is calculated over 1 h periods, and the difference between the treatments is shown in below figure. The open round symbols are the median differences (measure of location), and the error bars are the median absolute deviations (measure of dispersion). The results show that the longer-term bias of the observed flux is practically negligible (open round symbols). However, the flux magnitude of individual 1-hourly  $\text{CO}_2$  flux observations is attenuated/amplified by up to  $\approx 20\%$  ( $1 \sigma$  error bars, up to 30% for  $\text{H}_2\text{O}$ ). To my knowledge, this error has thus far not been accounted in uncertainty budgets. Also, it depreciates the value of flux observations for data assimilation approaches at a nominal time step (e.g., 30 min or 60 min).



### Other comments

Bias vs. drift: From my perspective, using the terminology of “drift” instead of “bias” might even better reflect the phenomenon treated in this manuscript. For example, the International Organization for Standardization defines:

- Drift: Slow change of a metrological characteristic of a measuring instrument.
- Systematic error/bias: Mean that would result from an infinite number of measurements of the same measurand carried out under repeatability conditions minus a true value of the measurand.

p. 13681 l. 13 f.: *Precision here means that the instrument is able to accurately discriminate small variations of gas concentration.*

Using the “accuracy” terminology for defining “precision” is ambiguous. Maybe “accurately” could simply be omitted?

p. 13684 l. 25 ff.: *In the following we will refer to either mole fraction or number density, with the understanding that air density fluctuations are duly taken into account when changing between the two.*

How specifically are these taken into account? For example, by fast ideal gas law transformations, WPL formulations (Webb et al., 1980), or the WPL formulations plus the pressure covariance term (e.g., Nakai et al., 2011)?

p. 13685 l. 9 ff.: *Thus, for water vapour, mixing ratio is not proportional to number density or partial pressure, making it an unsuitable unit for gas analyser calibrations.*

Dry mole fraction (mixing ratio) can be expressed as  $p_{\text{H}_2\text{O}} / (p_{\text{air}} - p_{\text{H}_2\text{O}})$ , with  $p_{\text{H}_2\text{O}}$  being the partial pressure of water vapour and  $p_{\text{H}_2\text{O}}$  the pressure of ambient (moist) air, which is a proportionality.

p. 13686 l. 8 ff.: *First, because the slope of the calibration curve increases with CO<sub>2</sub> /H<sub>2</sub>O concentration, any zero offset will have a larger effect at ambient concentrations (Fig. 2) and adjusting zero will remove most or all of apparent drifts.*

While I agree with this statement, Figs. 3 and 7 show the opposite behaviour, i.e. the errors resulting from a given zero absorbance drift are smaller at higher baseline concentrations. This might suggest that the calibration polynomial becomes more linear (less curved) at higher concentrations?

p. 13693 l. 15 f.: *...the eddy-covariance method involves several computation steps, where mean concentrations and variances of different gases interact in a complex manner.*

As well as the correlation of gas concentrations with the vertical wind. Applies also to p. 13705 l. 11 ff.

p. 13693 l. 25 f.: *For example, positive biases in CO<sub>2</sub> and H<sub>2</sub>O concentrations, leading to increased covariances with  $w$ , partially compensate each other in the WPL term for  $F_c$ .*

Only as long as CO<sub>2</sub> and H<sub>2</sub>O flux are of opposite sign.

p. 13699 l. 12 f.: *The experimental data and numerical simulation results follow the same pattern suggesting that, to a large extent, the concentration bias explains the observed flux differences.*

While the analytical derivation of the correction procedure and its simulation is very thorough, it would be interesting to also see how they compare quantitatively to experimental data. This also holds for Fig. 8, where it might be interesting to evaluate the significance of the correction in the light of statistical sampling errors.

p. 13700 l. 22: In comparison to Fig. 6, the improvement is 3.7% and not 39%.

p. 13711 Fig. 2: I think it might be more intuitive for the reader if the effect of the same zero absorbance bias  $\delta a$  would be shown at both, high and low concentrations.

## References

Bertelmann, M., Bozem, H., Krause, J., Waleska, P., and Hoor, P.: Aufbau und Charakterisierung eines neuen Messsystems für flugzeuggetragene CO<sub>2</sub> Messungen, DACH conference of German, Austrian and Swiss meteorologists, Innsbruck, Austria, 2 - 6 September, 2013.

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Metzger, S., Junkermann, W., Mauder, M., Beyrich, F., Butterbach-Bahl, K., Schmid, H. P., and Foken, T.: Eddy-covariance flux measurements with a weight-shift microlight aircraft, *Atmos. Meas. Tech.*, 5, 1699-1717, doi:10.5194/amt-5-1699-2012, 2012.

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