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Atmospheric Measurement Techniques Discussions

Interactive comment on "The Polar 5 airborne measurement of turbulence and methane fluxes during the AirMeth campaigns" *by* Jörg Hartmann et al.

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We thank reviewer 1 for the review and for the helpful and constructive comments. We took nearly all of them into account in preparing a revised version of our manuscript. The specific comments are answered in the following:

Specific Comments:

RC1: 2.0.1 Title

The title more suggests a description of the turbulence and gas fluxes than a new technique of their calibration and assessment. One might onsider something like: "New calibration procedures not requiring dedicated calibration flights for airborne measurement of air-surface exchange developed using the Polar 5 Aircraft during the AirMeth campaigns."

We agree and changed the title to:

New calibration procedures for airborne turbulence measurements and accuracy of the methane fluxes during the AirMeth campaigns

RC1: Since Table 1 concerns itself primarily with the differences between outbound and inbound legs. It would be helpful to have be a separate table in the same format presenting absolute quantities that define the environment of these flights. Some of these already appear in Table 1, but would better fit in this new table. Such quantities include elapsed time to cover the pair of flight legs, the track direction χ_1 the wind direction, the track length, the magnitudes of $v_{\|}$ and $v_{\perp}$ and possibly others.

We added a further table (Table A1) in the appendix listing all suggested quantities for each individual flight leg.

RC1: Is the Δt column meant to give the difference in travel time between the out and return legs, or is it to give the total elapsed time in traversing both legs: is it $t_{leg2} - t_{leg1}$ or is it $t_{leg2} + t_{leg1}$? Later discussion (static pressure precision) suggests it is the latter, but also presents it as a function of position on the track, not a single number as given in Table 1. This could use some clarification in the table caption and text.

In Table 1 the difference between the mean time of each leg is given. The symbol Δt was misleading, we changed to $\Delta\bar{t}$. This is now clarified in the caption of Table 1. The time duration needed to fly each leg is now also listed in Tabel A1. In the discussion of the static pressure precision the symbol Δt denotes the (position dependent) time difference.

RC1: 2.0.2 Flight altitude

The airspeed of 60 m s^{-1} was given, but there was only one mention of the height above ground. That was 50 m above ground for the discussion of Figure 7. Since the ability to attribute flux measurements to surface characteristics deteriorates with height above ground, this parameter is important and could be included in the recommended (absolute environment) companion to Table 1.

The low level flights for flux measurements were mostly done at a height of 50 m above ground. We included the averaged height now in the new table A1. For the calibration of the turbulence probe, however, the height has little relevance and we therefore included in that section also some flight legs at greater heights. Those were actually flown to calibrate remote sensing instruments that are not subject of this paper. For the flux analysis, as e.g. presented in the papers of Kohnert et al. (2018) and Serafimovic, et al. (2018), many more legs were used that did not have an immediate successor on the return track.

RC1: 2.0.4 True Airspeed

The primary concern is a lack of clarity in the development of Manuscript Equation (2) for the "Reference ground speed." The point of Manuscript Equation (2) appears to provide a determination of the true airspeed from the GPS/INS independent of the gust probe's measurements under conditions of the special dual-purpose flights. Some clarification would be helpful:

Quantities $v_{gi},\ \chi_i, i = 1, 2$ are probably averages of ground speed (magnitude) over their respective tracks (out and back). This should be made explicit. Presumably, the aircraft is on an autopilot rule to maintain airspeed (but not heading) and ground

track (but not groundspeed). If so, however, the origin of Equation (2) is not readily discerned. The following assumptions appear to apply given the description of the reverse-track flights:

1. Wind velocity (magnitude and direction) does not change during the reverse-track maneuver.

2. True airspeed (but not heading) is held as near constant as possible, e.g. 60 m s$^-1$ (by autopilot or by human pilot)

3. Ground-track direction (but not ground-speed magnitude) is defined by a line segment on the surface, which is followed by the aircraft's autopilot (or human pilot) guided by GPS.

4. Averages are taken of airspeed, groundspeed, and the angle $\gamma_i = \chi_i - \Phi_i$ between ground-track direction and aircraft heading for both legs.

Evaluating the "wind triangle" $V = V_g - V_{\mathrm{TAS}}$ (Manuscript Equation 1) for each of the two passes over the ground track is possible using the law of cosines:

$$V_i^2 = V_{gi}^2 + V_{TASi}^2 - 2V_{gi}V_{TASi}\cos\gamma_i \tag{1}$$

where the non-bold characters represent the magnitudes of the bold vectors, and all quantities are understood to be averages over their respective ground tracks (i = 1, 2). Since wind does not change $(V = V_1 = V_2)$ the righthand sides of Equation (1) above for i = 1, 2 can be equated, eliminating windspeed as a variable. All other quantities are known from GPS/INS except for $V_{TAS}i, i = 1, 2.$ But the airspeed was held near constant allowing the assumption $V_{TAS1} = V_{TAS2} = V_{TASr}$ where V_{TASr} is the reference that should be equal to $\overline{v_g}$ of the Manuscript Equation (2). Solving for V_{TASr} one gets (assuming the algebra was correct)

$$V_{TASr} = \frac{V_{g1}^2 - V_{g2}^2}{2(V_{g1}\cos\gamma_1 - V_{g2}\cos\gamma_2)} \tag{2}$$

Equation (2) above bears some resemblance to Manuscript Equation (2), but time did not permit reconciling these two. They appear to have incompatible forms suggesting that the authors used a different development to arrive at the manuscript's Equation (2). Some additional discussion of the assumptions and derivations actually used, in supplementary material if necessary, needs to be given.

We thank the reviewer for pointing out the deficiency of the manuscript in this part. We clarified our assumptions and rephrased the entire derivation of the reference true airspeed. Please refer to the revised manuscript.

Though mathematically correct, Equation (2) of the reviewer leads to problems in the practical use, as a relatively small difference of two larger quantities appears in the denominator. Assymmetries in the measurement inaccuracies then cause large scatter of the result. The ground speed appearing the the square in the numerator is available with a high accuracy by the gps. The true heading direction, however, is less accurate and represents actually the largest uncertainty in the entire wind derivation. Thus, the small difference of the terms involving direction in the denominator leads to large scatter.

RC1: 2.0.5 Angle of attack ...

No action required.

RC1: 2.0.6 Angle of sideslip and Static Pressure Precision ...

No action required.

RC1: 2.0.7 Accuracy of horizontal wind measurement

The $v_{\|}$ is declared on page 12, line 10 to dominate "by far" the vector wind compared to the $V_{\perp}$ component. "By far" should be quantified. Apparently the flight legs were flown

as much as possible parallel to the wind, but if that was clearly stated somewhere, I missed it.

The formulation was misleading, we rephrased that sentence. We meant an error propagation for the along track component only, as in this component the uncertainty of the dynamic pressure is the major contributer. An error assessment for both wind components is given further down in that section.

RC1: 2.0.8 Methane Analyzer

No action required.

RC1: 2.0.9 Accuracy of methane flux measurements

The precision estimates for the methane flux use a technique described by reference to other publications. I had not seen it before. It looks intriguing. It would help the moderately interested reader (who can't justify digging through the references) to have a summary of the method. I's not intuitive how one gets a variance of noise error from a cross covariance input. Nor is it described how one finds the standard deviation over the blue-shaded areas. At the very least, the symbols C_{11} and p could be defined with indication of how to compute them. Perhaps C_{11} is the autocovariance of the methane signal with itself and p is the lag?

We added in the revised manuscript brief summaries of the methods cited and used to assess the instrumental noise and the flux detection limits. Further, we added the missing explanations of the symbols and how to calculate the standard derivation that is now marked in the figure (was Figure 6, now Figure 7).

RC1: 2.0.11 Dry mole fraction flux

Because the methane instrument and the water instrument did not share the same cell in the first two years, it was necessary to use different versions of the WPL terms. The approach looks sound, but the notation suggests some possible problems, hopefully more apparent than real. Page 17, equation (16): The usual expression from WPL in the notation of this manuscript is $\overline{(w\rho_a)' CH'_{4d}}$, *where* ρ_g *is the density of the fraction of "dry" air. This computes the molar flux of* CH_4 *as the average of the product of the following departure quantities: the molar flux of dry air (as departure quantity* $(w\rho_a)'$*) times the dry-air mixing ratio of methane (as departure quantity* CH'_{4d}*). If* ρ'_{CH4d} *is intended to be defined as* $\rho'_a CH'_{4d}$ *then it does not separate out the dry-air mass flux* $(w\rho_a)'$ *which is inconsistent with the method of WPL. Otherwise this section is an informative exploration of the significance of the WPL correction for methane flux in the arctic and an effective demonstration of the effect on the uncertainty when different sensors for water vapor and methane must be used.*

The reviewer pointed to a slight inconsistency in the notation. We intended ρ_{CH4d} to be defined as the density of methane. We now dropped the subscript d in the revised manuscript to be consistent with the following formulas.

The technical corrections have all been applied.

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