Atmos. Meas. Tech. Discuss.,
doi:10.5194/amt-2017-454-RC1, 2018


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.

**Anonymous Referee #1**

Received and published: 22 February 2018

[11pt]article

# Review: “The Polar 5 airborne measurement of turbulence and methane fluxes during the AirMeth campaigns:” Jörg Hartmann, Martin Gehrmann, Torsten Sachs, Katrin Kohnert, and Stefan Metzger

2018 February 21

## 1 General Comments

This paper presents a potentially valuable approach to in-flight calibration and accuracy assessment for an airborne system that measures air-surface gas exchange from low altitude. This calibration and assessment procedure does not require the usual dedicated calibration flights, which consume at least a hour of flight time for each campaign flown. Instead multiple (10 or more) special dual-purpose flights are made both measuring the flux and providing calibration information. These consist of double passes, each covering the same ground track, but in opposite directions. Additional flights can also be flown suitable to other purposes and drawing on the calibration results from the dual-purpose flights. These calibration flights and procedures would seem to be appropriate to low-altitude flux fights. They would not directly generalize, for example, to flights measuring mesoscale divergence (Lenschow et al., 2007), which may be required in the same campaign if significant mesoscale structure is present.

The language of the manuscript is excellent, apart from a number of minor editorial slips. Those that were caught are identified among the Technical Comments. The instrumentation and the flight tracks, including vertical profiles, are quite adequate for airborne flux measurement. With appropriate answers to several questions raised in the Specific Comments section, this paper is well suited to publication in *Atmospheric Measurement Techniques*.

## 2 Specific Comments

### 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."

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 $\chi_1$ the wind direction, the track length, the magnitudes of $v_{||}$ and $v_{\perp}$ and possibly others.

Is the $\Delta t$ 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.

### 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.

### 2.0.3 Calibration procedures

### 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 $v_{gi}$, $\chi_i$, and $\psi_i, i = 1, 2$ 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:





Printer-friendly version

Discussion paper

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 $\gamma_i = \chi_i - \psi_i$ between ground-track direction and aircraft heading for both legs.

Evaluating the "wind triangle" $\mathbf{V} = \mathbf{V_g} - \mathbf{V_{TAS}}$ (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 ($\mathbf{V} = \mathbf{V_1} = \mathbf{V_2}$) 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 $V_{TAS}, i = 1, 2$. 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.

Regarding Equation (5) (Page 6, lines 24, 25), is it appropriate to assume that the total pressure (static plus dynamic) is measured without error by the Rosemount probe as this statement appears to imply?

Using repeat instances (15 in this case) of reverse-track pairs to characterize the uncertainty in the assumptions (constant wind and TAS over the whole round trip) used to compute the correction factor for the dynamic pressure appears reasonable, and beneficial.

#### 2.0.5 Angle of attack

These are promising procedures for determining the offset and slope of the "true" attack angle with respect to the ratio $q_\alpha/q_i$. First, a dedicated flight similar to that used by Crawford et al. (1996) but analyzed differently, provided what appears to be a clean calibration. Then the whole set of flights in the expedition was compounded to provide another estimate of the calibration parameters. With this large sample a restriction to those measurements reporting the same narrow range of vertical aircraft speed, vertical wind speed, and roll angle used with the earlier dedicated flights yielded a sample large enough to provide very nearly the same values for the calibration parameters $\alpha_0$ and $c_\alpha$.

#### 2.0.6 Angle of sideslip and Static Pressure Precision

As with the angle of attack, these are straightforward and promising approaches.

#### 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.

#### 2.0.8 Methane Analyzer

No comments: method looks appropriate.

#### 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. It'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?

#### 2.0.10 Spectral analysis

No comments: looks good





Printer-friendly version

Discussion paper

### 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 $\overline{(w\rho_a)'\mathrm{CH}'_{4d}}$, where $\rho_g$ 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 $\mathrm{CH}'_{4d}$). If $\rho'_{CH4d}$ is intended to be defined as $\rho'_a\mathrm{CH}'_{4d}$ 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.

## 3 Technical Corrections

Mention is made of "precision" on several occasions, *e.g.*, page 4 and especially page 11 and following. Is "accuracy" a better term for some of these? Is the instrument or approach to be considered accurate at least to that stated precision (although its display may resolve greater precision)?

Page 6 Line 29: mispelled word: *tested* also page 11, Line 16.

Page 8 Line 6: "a plane with a fixed aerofoil" appears better as "an aircraft with a fixed aerofoil"

Page 12 line 7 to 8: "Rotating the wind components *into* an along-track..."

Page 13 lines 24,25: heat fluxes labeled in W $m^{-2}$ $s^{-1}$ instead of W $m^{-2}$

Page 14, Figure 6: caption line 3: "deviation has *been* calculated"

Page 15, Line 15: sentence fragment: needs a verb. Could say "Again, more scatter *is seen* for the trace gases than...."

Page 16, Line 4: consider recasting the sentence, e.g., "...the latter need to be taken into account in computing a mass flux from the measured (wet) mole fractions (Webb et al., 1980)."

## 4 Reference Cited Above

Lenschow, D.H., V. Savic-Jovcic, and B. Stevens, 2007: Divergence and vorticity from aircraft air motion measurements. *Journal of Atmospheric and Oceanic Technology*, **24(12)**, pp.2062–2072. Others cited above are listed in the manuscript itself.