Response to Anonymous Referee #2 (amtd-8-C5173-2016-1)

Our responses are written in italic.

We thank the referee for the constructive comments on the manuscript.

General comments:

This manuscript describes the set-up, first applications and comparisons of a new mass spectrometer for aircraft measurement of water vapour with high sensitivity and in flight calibration. Key feature is a new spark discharge ion source generating hydronium ion clusters in air. The paper fits well in the scope of AMT, presents a novel method, and is well-written. Some aspects of the paper deserve clarification especially regarding the specification of the instrument performance in the lower mixing ratio range, the calibration method, and comparison with other instruments. Hence, I recommend publication after minor revisions as listed below. In flight comparison with established hygrometers like FISH or CLH should be sought in order to validate the AIMS-H2O capabilities to obtain reliable water vapour data for mixing ratios below 10 ppm.

We agree that the AIMS-H2O measurements would benefit from an intercomparison with other airborne hygrometers. A comprehensive intercomparison of AIMS-H2O with other water vapor instruments (including FISH) is out of the scope of this paper. In fact it is a matter of ongoing work and it is planned to be published soon.

Specific comments:

Page 13526 line 24: State which accuracy corresponds to which water mixing ratio.

A paragraph discussing that topic is added to section 6.2., also see comment below.

Page 13527 line 2: Give the concentration range and degree of agreement for this comparison.

Sentence is rewritten to be more precise.

Page 13527 line 14-15: In part 2 (Jurkat et al., 2015), setup of the CIMS techniques with SF6-chemistry for measurement of the set of trace gases HCL, HNO3, HNO2, SO2, and ClONO2 are presented.

We use an SF_5^- chemistry indeed by splitting SCF_8 molecules in a gas discharge ion source into CF_3 and SF_5^-.

Page 13527 line 21-22: Formulate the second part of the sentence more clearly.

Sentence is rewritten.

Page 13527 line 25-26: Either give absolute concentrations or write mixing ratios.

The term is now changed to mixing ratios.

Page 13529 line 11: Add a reference for SHARC.

Unfortunately, there is no reference for the SHARC instrument yet. However, there is a publication on the intercomparison of FISH and SHARC where both instruments agree very well:

Meyer, J., Rolf, C., Schiller, C., Rohs, S., Spelten, N., Afchine, A., Zöger, M., Sitnikov, N., Thornberry, T. D., Rollins, A. W., Bozóki, Z., Tátrai, D., Ebert, V., Kühnreich, B., Mackrodt, P., Möhler, O., Saathoff, H., Rosenlof, K. H., and Krämer, M.: Two decades of water vapor measurements with the FISH fluorescence hygrometer: a review, Atmos. Chem. Phys., 15, 8521-8538, doi:10.5194/acp-15-8521-2015, 2015.

The citation is added to the manuscript.

Page 13529 line 16: Figure 1 shows little information. You should replace it by a better picture and include arrows pointing to and identifying the different parts of the instrument.

It is difficult to get a better picture of the instrument in the aircraft since space is very limited. Moreover, the vacuum chamber which is the core part of the instrument is located directly behind the panel computer. A picture where all important parts are visible would mean, that the instrument would be partly disintegrated. Since ewe want to give an impression of the flight setup of AIMS-H2O, we decided to stay with this picture.

Page 13531 line 10: Give the limits of the pressure regulation.

We did not intend to push the pressure regulation to its limit since we would like to prevent damage for the mass spectrometer. However, tests at our climate chamber have shown that the regulation can easily compensate for pressure gradients twice as high compared to regular ascend and descend maneuvers.

Page 13532 line 23: Give in this section the typical in flight calibration interval required to achieve the stated accuracy.

This is indeed an important point, we added a short section on this topic.

Page 13533 line 16-19: Formulate this sentence unambiguously regarding the: “The temperature is chosen such that the CE is becoming independent of temperature”.

Part is slightly rewritten to make the statement clearer.

Page 13534 line 6-9: Give the flow dependence and uncertainty of the CE e.g. in a plot.

The CE decreases linearly with the flow, which is added to the manuscript. The CE contributes the major part (~4%) to the overall accuracy of the inflight calibration of around 6%.

Page 13534 line 10-12: Give the uncertainty of the reference instrument (MBW 373-LX) in comparable units and state the time intervals for characterisation measurements required to achieve the accuracy stated for the AIMS. Is the reference instrument traceable to national standards and hence the AIMS-H2O too?

The accuracy in frost point cannot be directly translated into an accuracy of the measurement of the mixing ratio since it depends on the actual mixing ratio and pressure. At 1013 hPa, the accuracy of 0.1 K (the 0.5 K in the manuscript are incorrect and are now corrected) translate to roughly 1% accuracy in mixing ratio.

Page 13534 line 15: State the precision and accuracy of the water mixing ratios (0.5_?) – (150_?) ppm that can be generated.

Uncertainty is added to the numbers.

Page 13534 line 24-26: State the precision and accuracy of the water mixing ratios 0.5_? - 150_? ppm that can be generated. A table with the individual contributions to the uncertainties like MFC calibrations, reference, concentration and flow dependencies of the CE would be useful to show the major and minor contributors.

Contribution of the individual components is now discussed in more detail in the text.

Page 13535 line 1: It should read Fig. 4 and not 4a.

changed

Page 13538 line 2-3: Water vapour has only a small impact on NO2+ and an insignificant influence on NO+.

Sentence is rewritten to make it clear.

Page 13538 line 25-26: State the contributions of larger clusters for water mixing ratios below 500 ppm.

For mixing ratios 150 ppmv, the signal strength of $H_3O^+(H_2O)_2$ *is constant at around 4% of the* $H_3O^+(H_2O)$ *signal while* $H_3O^+(H_2O)_3$ *exhibits no significant signal at all. At higher mixing ratios, the signal of* $H_3O^+(H_2O)_2$ *increases to above 10% relative to* $H_3O^+(H_2O)$*. The signal on* $H_3O^+(H_2O)_3$ *still remains more than two orders of magnitude (<1%) below the* $H_3O^+(H_2O)$ *signal. A sentence is added to the manuscript.*

Page 13539 line 10: Label Figure 6 with a, b, c corresponding to the text. Why don't you plot m/z=37 and the ion ratio over the logarithm of the water mixing ratio? It would of course be interesting to see a calibration curve covering the whole measurement range from 0.5 to 500 ppm.

Labels are added. The best way to define and explain the features of the calibration curve is to plot in with linear scale for H_2O*. A logarithmic scale plot does not give more insights. The maximum measurement range up to 500 ppmv is realized via dilution of the ambient air. Thus, the directly measured* H_2O *concentrations are usually around 120 ppmv and below. Higher ambient* H_2O *concentrations are recalculated by the dilution correction. Thus, there is no calibration curve extending up to 500 ppmv.*

Page 13539 line 25: Define the parameters in equation 1 and give typical values. Did you test to normalise the m/z=37 to the total ion count or NO+ and did this improve the sensitivity?

The function is an asymmetric S-shaped curve with an initial value A_1 *at x=0, a final value* A_2 *for x-> ∞, a center at* x_0 *and a power parameter p. The fit parameters are added to Figure 6. The evaluation method 2 using the ion ratio is such a normalization method which indeed increases sensitivity in the major part of the calibration range.*

Page 13540 line 20: Please make clear which sensitivity or accuracy value belongs to which mixing ratio in Table 1. You could also table the data for below 15 ppm and above separately.

Text is changed to make clear, that the precision using the ir is higher at low mixing ratios compared to the direct evaluation of $H_3O^+(H_2O)$. This is what is stated in Table 1.

Page 13542 line 6-8: The detection limit can of course be a useful parameter to characterize a hygrometer. You should add information on how the instrument limit of detection and the practical limit of quantification compare for the AIMS-H2O.

Since the detection limit of the instrument is at least on order of magnitude lower than the lowest mixing ratios found in the stratosphere, that value does not seem to be of practical importance for the authors.

Page 13543 line 7: Could you complement Figure 7 with a plot of accuracy over water mixing ratio for the complete measurement range of the instrument (0.5 to 500 ppm)?

The accuracy of the water vapor measurement strongly depends on the quality of the inflight calibration for each flight. That makes the plot accuracy vs. mixing ratio very specific for each flight. However, we agree that the dependence of accuracy on the actual mixing ratio should be made clearer. We therefore added a paragraph in the section on instrumental uncertainties to address this topic.

In the caption of Figure 7 you should replace Eq.3 by Eq.4.

changed

Page 13543 line 16: It would be useful to have one table listing all factors contributing to the instruments accuracy including their relative contributions.

The factors are discussed in detail within the next sections. Since e.g. the quality of the inflight calibration may change between the flights, it is not possible to state global numbers for each factor of uncertainty.

Page 13545 line 7: Explain the data gap for 41000-41300 s. Mention the role of dilution correction for the period 33500-35600 s. Explain when the calibration was done.

The data gap is in fact from 40500-41300 s where a short three-step calibration was performed. The dilution is now mentioned in the figure caption. Another, more extensive calibration was done right before the flight sequence shown in the figure.

Page 13546 line 11: A short description of the SHARK and WARAN instruments including references to both instruments should be added to the experimental section. Explain briefly how SHARC and WARAN are calibrated in comparison to the AIMS-H2O.

A reference with the working principle of WARAN is added and we included references for WARAN (Kaufmann et al., 2014 and Voigt et al., 2014). As stated above, there is no reference for SHARC yet. Comments on calibration of both instruments are added.

Page 13546 line 18-20: Discuss the accuracy of RHi values derived for both instruments and identify the role of the uncertainty of the air temperature.

The accuracy of RHi measurements is indeed an important point when trying to understand the life cycle of ice clouds. For RHi, the accuracy of the measurement of static air temperature increases the uncertainty. We added a sentence to discuss the RHi accuracy shortly.

Page 13546 line 27-28: Be more precise with this comparison.

Since the focus of this paper is a description of the AIMS instrument rather than an instrument intercomparison, the comparison is held more general. A paper on a detailed instrument intercomparison with the different hygrometers used on HALO is in preparation.

Page 13547 line 11-12: Is 8-15% really a high accuracy? Why do you state here 8-15% and not 7-15% as before?

The 8% are an older value with only one evaluation method considered. We changed it to the newer value of 7% considering two evaluation methods. Regarding past discrepancies between different in-situ water vapor measurements, a reliable accuracy of 7-15% is indeed high.

Page 13547 line 24: DLR research aircraft .

corrected

Page 13548 line 1-2: This sentence should be formulated more clearly.

We rewrote this part to be more specific.