Interactive comment on “Technical Note: Reanalysis of upper troposphere humidity data from the MOZAIC programme for the period 1994 to 2009” by H. Smit et al.

Authors Reply to Anonymous Referee #1

We would like to thank Referee #1 for the useful comments, which help clarifying and improving our paper. Answers to specific issues of broader relevance are addressed below, while detailed suggestions for rephrasing sentences and correcting typos will be considered accordingly in the revision of the manuscript.

General Recommendation

Users of the MOZAIC relative humidity data have long waited for a fix of the problem that appeared after 2000. In this paper Smit et al. now describe the cause of the problem and how it has been solved. Most importantly they state that the corrected data are available to interested researchers, and thus the paper is a very welcome contribution. It is appropriate for publication in ACP. I have only a couple of minor comments which might help to make the paper clearer at some points.

Reply: We appreciate the very positive response to our efforts of fixing the problem which has occurred in the MOAZIC data on relative humidity (RH) since 2000.

Minor Comments

Page 18906, Line 11: "is not possible from thermodynamical principles" is not correct. It does not occur in the atmosphere because there are plenty of condensation nuclei that trigger condensation as soon as liquid saturation is slightly exceeded. Please rephrase.

Reply: We rephrase the sentence to: “As a result, PDF of UTH data show a substantial fraction of observations above 100% RH_{liquid}, which, however, does not occur in the atmosphere because there is always a sufficient number of condensation nuclei available, that trigger condensation as soon as liquid saturation is slightly exceeded.”

L. 22: "large variability of observations" is a bit unclear. Is it the humidity field that has large variability (I think so) or are the observations so imprecise?

Reply: We rephrased the sentence to:”… because of its large natural variability in the troposphere and relatively short records of observations.”

P. 18910, Ll. 1-8, Figure 5: Please define what you mean with "fractional coverage of MOZAIC upper tropospheric humidity data". Explain what it is good for.

Reply: We rephrased the sentence to: “The regional distribution of data coverage by MOZAIC UTH observations is shown in Fig. 5 for the period 1994 to 2009, emphasising that the horizontal coverage by MOZAIC observations is highly inhomogeneous and dominated by the major global flight routes”.

P. 18912, Ll. 20-25, Figure 7: I do not see what you want to say here. Is it good or bad? My impression is that this paragraph should be shifted into the next section, after the first paragraph there. The figures 7 and 8 should be interchanged accordingly.

Reply: We agree, the paragraph was shifted to the next section and the figures were interchanged.

P. 18915, L. 6: "differences of slopes are close to zero", fortunately not the slopes themselves.

Reply: Fully right, changed into: “"differences of slopes .... are close to value zero"

P. 18915, L. 8: The word "reduces" is misleading here. The impression is that the problem gets smaller, but since the offset *a* is often negative, the problem gets worse. You could simply state $a_{post} - a_{pre} -0.2 \cdots - 0.4$.

Reply: We rephrased the sentence to: “On the other hand, the differences of offsets between pre- and post-flight calibrations are significant from -0.2 to -0.4, which however is a consistent finding for the periods 1994 to 1999 and 2000 to 2009.”

P. 18916, L. 23/24: what is the recovery factor?

Reply: We added the following explanation of the recovery factor: “[This factor] expresses the effect that the adiabatic conversion of energy into heat is not exactly 100% such that the temperature measured inside the housing, the total recovery temperature, is about 0-1.0 K lower than TAT, depending on aircraft speed. The housing manufacturer provides an empirical recovery factor to determine the real TAT from the measured recovery temperature.”

L. 28: How small?

Reply: We refer to the values given in Table 2 from the analysis of the statistical distribution of calibration factors. Thus we complemented the sentence: “If these differences are in a similar range as the values listed in Table 2 and shown in Figure 9, …”

P. 18917, L. 12-17: I suggest to state typical values in this paragraph.

Reply: We agree to add typical values to this paragraph. The entire paragraph is rephrased as: “Figure 11 show the variations of uncertainties of the RH measurements in $\%RH_{liquid}$ for the altitude range covered by the observations. Uncertainties are calculated from the mean plus standard deviation of the individual total uncertainties over all MOZAIC data of 1994-1999 and 2000-2009 period. In the middle and upper troposphere the total uncertainties centre at approx. 4.5% RH_{liquid} (2.5 - 6.5 % RH_{liquid}) for both periods. In the lower troposphere the total uncertainties for the first period of approx. 6% RH_{liquid} are slightly higher compared to the value of <5% RH_{liquid} for the second period due to the missing calibrations at temperatures above -20°C. “

P. 18918, L. 27/28: 1) "ppmv". 2) how can the FISH instrument become optically thick?

Reply: The FISH instrument is based on the absorption of Lyman(α) radiation by H_2O molecules. For high VMR values the absorption of Lyman(α) radiation along the light path inside the instrument is so strong, that the detector becomes insensitive to further changes of the VMR, and thus the

instrument is opaque or saturated. We added one sentence for explanation to the text, saying that : "For the sensor intercomparison study, data for H_2O VMR > 1000 ppm were excluded because at these large water vapour abundances the FISH instrument, which is based on the absorption of Lyman(α) radiation by H_2O molecules, becomes optically opaque and thus insensitive to further changes in VMR (Zöger et al., 1999)."

P. 18919, L. 1: "neglect" sounds a bit strange here. What about refuse, reject, dismiss, avoid...

Reply: Agreed, we changed the text to "…avoid…"

Ll. 16-22: To my view the comparison with OJSTER does not look very well, at least not at the higher RH values. Don't overstate.

L. 23: "proof of validity". Please change this. There is no proof of whatever. All that we see is that the pdfs look quite similar and this underpins a good quality of the MHC data in a statistical sense, but it does not prove anything.

Reply: We substantially revised the paragraph related to Fig. 12. The section reads now:

"In a cloud-free atmosphere, MCH and reference instrument FISH agree very well. Linear regression analysis provides a correlation coefficient R^2 = 0.97 and a slope m = 0.96 $\pm$ 0.05 while the y-axis intercept equals zero within the limit of uncertainty (2.2 $\pm$ 2.0 % RH_{liquid}). The data for $RH_{liquid} \geq 75\%$ and $RH_{liquid} \leq 10\%$ suffer from a small number of counts and are not considered for the MCH performance analysis because of limited statistical significance.

At cloud edges and inside cirrus clouds, i.e., RH_{liquid} > approx. 60%, deviations between instruments are larger, with a systematic bias of the reference instrument towards higher RH_{liquid} values than measured by MCH. One potential and likely explanation is related to the fact that both reference instruments FISH and OJSTER report data on a 1 Hz basis while the response time of the MCH is of the order of one minute or longer at these temperatures (Helten et al., 1998). Hence, small scale fluctuations of high RH_{liquid} values are captured by the reference instruments but missed by MCH.

Despite the weaker agreement between MCH and reference instruments near to and inside cirrus clouds, the data shown in Fig. 12 rule out the speculated contamination of MCH data by partial or complete evaporation of hydrometeors via adiabatic heating in the sensor housing; see e.g. Helten et al. (1998). This type of contamination would result in systematically higher RH_{liquid} values measured by MCH inside clouds, compared to the reference instruments. However, the opposite behaviour was found; for details see Neis et al. (2014).

The good quality of the MCH RH_{liquid} data in a statistical sense is shown in Fig. 13. The PDF for RH_{liquid} agree very well between MCH and the reference instrument (FISH or OJSTER, resp.) for the entire CIRRUS-III data set. An in-depth analysis of the MCH performance including implications for the MCH data analysis is provided separately by (Neis et al., 2014)."

We believe that this interpretation is justified and more clear now.

Figure caption of Fig. 7, L. 3: delete "for details" once.

Reply: Done.

Figure 8 (now 7): Although the linearity is very good with respect to RH_{UC}, the relation is not at all linear with respect to T. How do you define calibration coefficients at untested T values? A simple linear interpolation might be insufficient.

Reply: The complete calibration procedure is described in the manuscript and in (Helten et al., 1998). However, for clarity we added one sentence to the figure caption: "Displayed are hygrometer measurements (crosses) together with corresponding linear regression fits. Offset *a* and slope *b* are determined as function of temperature from a functional curve fit through the calibration coefficients obtained at the five different calibration temperature levels; see also Eq. (1)."

Figure caption of Fig. 11: explain meaning of the bars and the central lines.

Reply: The revised figure caption reads now: "Mean uncertainty of MOZAIC relative humidity measurements in % RH_{liquid} as a function of altitude (blue solid line) for periods 1994-1999 (left) and 2000-2009 (right). Horizontal bars represent the standard deviation of the mean uncertainty."

Figure 14: too small, noisy, and hardly readable.

Reply: Agreed, both diagrams will be sized larger by factor 2 and expanded with two similar annual PDFs, but then for period 1994-1999 (Request of Reviewer#2); see figure below:

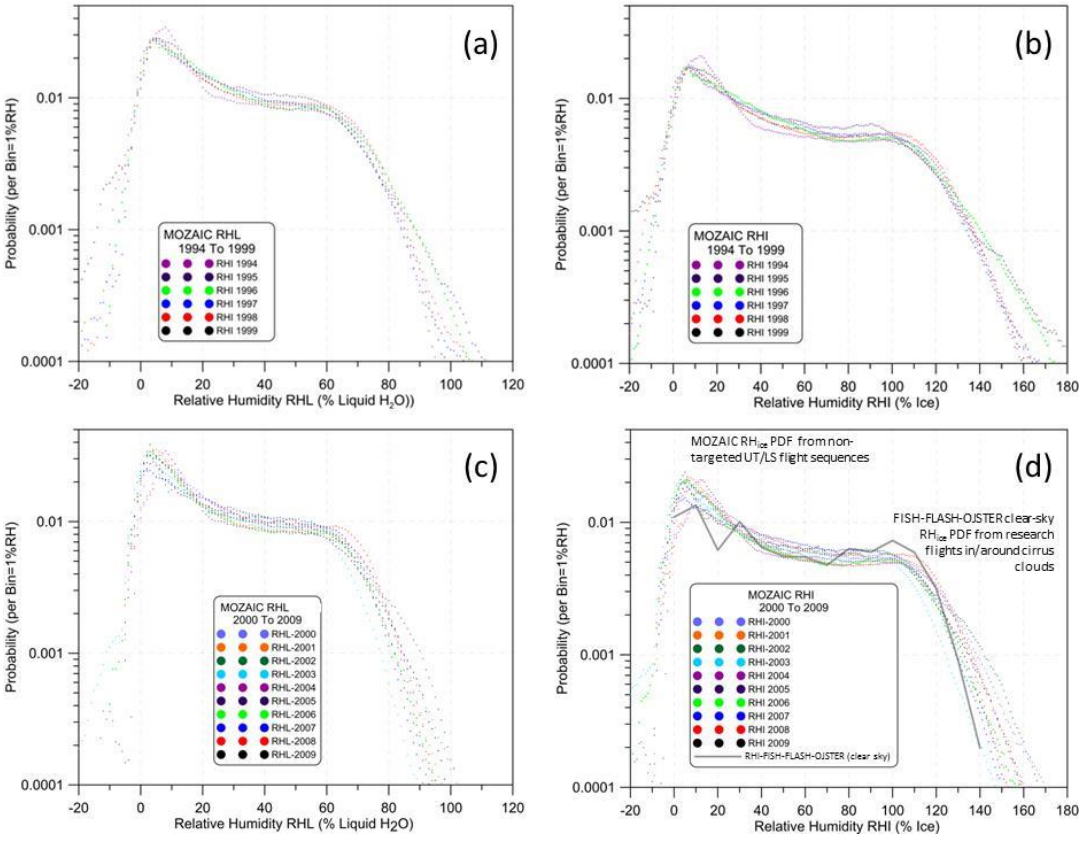

Figure 14. Annually averaged probability distribution of UTH observations from the MOZAIC Capacitive Hygrometer with respect to RH_{liquid} (a, c) and RH_{ice} (b, d) for the indicated periods; the solid line in panel (d) represents the average RH_{ice} PDF for the UTH clear-sky data set reported by Krämer et al. (2009).

Typological errors and other issues

P. 18912, Ll. 23-25: I suggest to avoid the use of "=" in these sentences. *Reply:* All “=” are replaced by “is” or “are”.

Eq. 2 and text thereafter: write pair consistently. *Reply:* Done.

P. 18915, L. 29: I suggest to replace "and co-workers" with "et al.". *Reply:* Done.

P. 18916, Ll. 4-16: Is there a difference between RH and RHD? Both are described as "ambient relative humidity". *Reply:* We clarified the sentence which reads now: “The transformation of RH values measured by the capacitive sensor of the MCH (RH_D; Helten et al. (1998)) to RH values for ambient air temperature and pressure conditions (RH_S; Helten et al. (1998)) requires knowledge of the static air temperature (SAT) of ambient air and of the total air temperature (TAT) at the position of the capacitive device inside the MCH housing.”

Reference Neis et al. This is unpublished material "in preparation". It should not appear in the references list. The text should reflect that it is a planned publication, e.g. "will be provided elsewhere (Neis et al.). The use of two figures from a planned publication is unusual as well. I suggest not to cite Neis et al. in the figure captions. Instead Smit et al. should be quoted in the planned paper once these figures are re-used.

Reply: The reference Neis et al. (2014) is now available in AMTD. Therefore we updated the reference in the manuscript and removed the suffix “in preparation”.

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Interactive comment on "Technical Note: Reanalysis of upper troposphere humidity data from the MOZAIC programme for the period 1994 to 2009" by H. Smit et al.

Authors Reply to Anonymous Referee #2

We would like to thank Referee #2 for the useful comments, which help clarifying and improving our paper. Answers to specific issues of broader relevance are addressed below, while detailed suggestions for rephrasing sentences and correcting typos will be considered accordingly in the revision of the manuscript.

General Comment

The MOZAIC dataset for water vapor is a treasure trove of unique observations of one of the most important greenhouse gases in our atmosphere. The spatial and temporal characteristics of the observations allow evaluation and intercomparison that are essential to further our understanding of dehydration and cloud processes. It is critical that the community has trust in the documented quality of the dataset. This manuscript retroactively improves the quality of a large fraction of the water vapor dataset and hence is an important contribution to the peer reviewed literature. The manuscript is publishable after the authors and editors consider the following points.

Reply: We appreciate the very positive response to our efforts of fixing the problem which has occurred in the MOAZIC data on relative humidity (RH) since 2000 and will consider the points raised in the review carefully.

Abstract and elsewhere:

The word 'artefact' is not appropriate to use in this study. The definition is '..something observed in a scientific investigation of experiment that is not naturally present but occurs as a result of the preparation or investigative procedure. . .' A 'artefact' referred to here is a software coding error that widely and systematically propagated through an extensive dataset. The outgassing of water vapor in the Rosemount probe is an example of an artifact but a software error is not. I suggest removing this word and replacing it with 'error' as was already used in the title of section 3.2.

Reply: We will follow the recommendation and consequently replace "artifact" by "error"

I suggest revising the Abstract starting on p11 as:

"An in-depth reanalysis of the data set identified a coding error in the calibration procedure from year 2000 on. The error did not affect earlier data from 1994 to 1999. The full data set for 2000–2009 was reanalysed applying the corrected calibration procedure."

Reply: We picked up the suggestion to revise the two sentences in the abstract

Figure 14 should really include the the pre-2000 data which is considered unaffected by the calibration error. Please add 2 more panels.

Reply: We included two extra panels of the PDF of RH_{liquid} and RH_{ice} for the years 1995-1999; see Figure below.

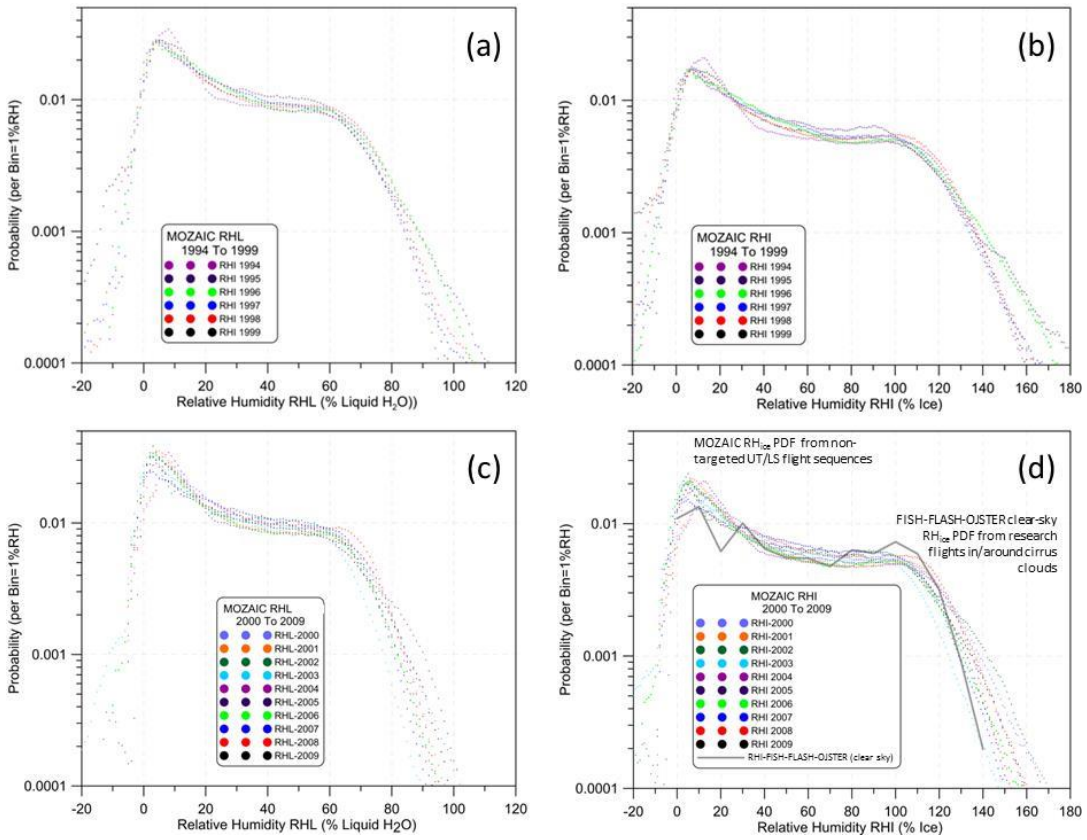

Figure 14. Annually averaged probability distribution of UTH observations from the MOZAIC Capacitive Hygrometer with respect to RHliquid (a, c) and RHice (b, d) for the indicated periods; the solid line in panel (d) represents the average RHice PDF for the UTH clear-sky data set reported by Krämer et al. (2009).

Further, something must be said about how the relative uncertainty between the sensors leads to scatter at the low probabilities for $RH_i > 100\%$, i.e. if the data were shifted within its uncertainty band the PDF would move by an order of magnitude at a given RH_i. Is the PDF spread at a given RH_i between the sensors known to be statistical and not systematic?

Reply: We will include following text in manuscript: "Concerning the scatter of data at high ice-supersaturation ($RH_{liquid} \geq 80\%$ or $RH_{ice} \geq 130\%$, respectively), it has to be noted that the PDF displayed in Fig. 14 represent annual mean distributions with only a small fraction of data in this range of RH values. The mean uncertainty of MCH data is about 4-6% RH_{liquid} for the 1994-1999 period and about 4% for the 2000-2009 period. Due to the fact that the RH uncertainty is of statistical nature and not systematic, the consideration of the RH uncertainty range of approx. 5% in the calculation of the PDF would result in additional data scatter but not in a systematic shift of the PDF"

The change in the apparent frequency of supersaturated air parcels changed significantly as a result of this correction. I suggest adding a brief discussion citing the published studies that used flawed water vapor data and conjecture how important the biased data may have been in influencing these

previous conclusions. Ultimately, the authors of these previous studies will need to revisit their conclusions using the corrected data, but the current authors owe the reader an indication of the importance.

Reply: We have evaluated all previous studies, which have used the flawed MOZAIC water vapor data, addressing in how far the wet bias may have influenced the results and the conclusions made. We will add following discussion on the actual impact of published studies based on 2000-2009 data:

We have evaluated all previous studies, which have potentially used the flawed MOZAIC water vapor data, addressing in how far the wet bias may have influenced the results and the conclusions made:

Studies by Crowther et al. (2002), Offermann et al. (2002), and Spichtinger et al. (2004) have analysed MOZAIC UTH data from the period 1995-1999, whereas Nedoluha et al. (2002) and Kley et al. (2007) have used data from 1995 until February 2000 and April 2000, respectively. Hence, these studies are not affected by the revision of the MCH data set.

Bortz et al. (2006) used MOZAIC UTH data from August 1994 until December 2003 in the tropics, i.e., 4 years of 10% RH_{liquid} enhanced UTH data (2000-2003) contributed to seasonal means derived for values averaged over one decade. Investigations focused on absolute humidity (g/kg) on a logarithmic scale. The 10% RH_{liquid} wet bias of 2000-2003 period has no impact on the results or conclusions drawn in this qualitative study.

(Luo et al., 2007; 2008) analysed 10 years of MOZAIC UTH data from August 1994 to December 2004 over 3 tropical regions (Atlantic Ocean, Tropical Africa, Asian Monsoon) and compared their results to ECMWF products. For the tropical Atlantic Ocean and the Asian Monsoon region there is only little data for the period after 1999. For Tropical Africa, seasonal UTH data show enhanced values for 2000-2004 compared to years before 2000 (sse Figure 5b). Using re-analyzed data would lower these enhanced UTH values to values common to the period before 2000. Conclusions drawn are not influenced. Most of the comparison has been performed on decadal averages of UTH data sucht that the impact of the wet bias is of minor influence on the results because the variability of UTH is very that large in that region.

Ekström et al. (2007); (2008) compared RH_{ice} values from ODIN (ODIN-SMR is a limb-sounder operating in the 500 GHz region) at 200 hPa with MOZAIC RH_{ice} at 200 hPa for the period 2001-2004 over tropical regions. The agreement of the PDF for RH_{ice} from ODIN and MOZAIC sensors is better than 5% RH_{ice}, which is within the retrieval error of ODIN. In consequence, using re-analyzed MOZAIC data for the intercomparison would suggest that ODIN-SMR shows a wet bias of about 10% on relative scale; see the PDF shown in Fig.7 (Ekström et al., 2007). In their consecutive study Ekström et al. (2008) compared PDF of RH_{ice} measured by ODIN, AURA-MLS and UARS-MLS with MOZAIC UTH data optimized at 205 hPa; see Fig. 4 of their paper. They found that MOZAIC UTH data is slightly wetter. Thus, agreement would be getting better if MOZAIC PDF of RH_{ice} would shift by about 10% RH_{ice} to drier values. However, uncertainties in satellite retrievals are large so that conclusions drawn in the paper are not affected at all by the wet bias of the MOZAIC UTH data.

Kunz et al. (2008) used climatological data of MOZAIC UTH from the period August 1994-December 2005 for comparison with SPURT-FISH data on UTH which were collected in the periods November 2001 and July 2003 during dedicated research flights. Applying the performed statistical analysis to reanalyzed MOZAIC data would reduce the reported difference between PDF of H_2O volume mixing ratio of SPURT and MOZAIC. Further statistical studies focused on the analysis of variances. In this

case, the wet bias of MOZAIC UTH data is only of minor influence and the conclusions drawn by Kunz et al. (2008) are not affected.

Heise et al. (2008) used MOZAIC UTH data from March 2001 to Feb.2006 for the comparison of UTH and temperature results from GPS Radio Occultation aboard the CHAMP mini-satellite with MOZAIC measurements. Observed wet bias effects of MOZAIC UTH data compared to ECMWF and CHAMP results can be qualitatively and for part quantitatively explained by the 10% RH_{liquid} wet bias of MOZAIC UTH data; see Fig.3 of Heise et al. (2008). Agreement between CHAMP and MOZAIC increases when using revised MOZAIC UTH data.

(Sahu et al., 2009; 2011) analysed MOZAIC UTH data and RH_{liquid} vertical profiles over Delhi/India for the period 1996 to 2001. Data are lumped together to obtain sufficient statistical relevance for investigating the seasonal variations on a monthly average base. RH(%) and q (g/kg) are analysed only in a qualitative way. Since the period 2000-2001 contributes only 1/3 to the monthly averages, MOZAIC RH_{liquid} data revision is of limited relevance.

Lamquin et al. (2012) have raised the issue of the wet bias and data were corrected by 10%RH_{liquid} such that major impact already had been corrected for. Results and conclusions are appropriate.

Smaller points

P18906 ln 2 'respectively' is not needed. *Reply:* We will omit it.

P18906 ln 9 'the PDF. . .' *Reply:* Done.

P18906 ln 11 'not possible' is not correct. *Reply:* According to Reviewer#1 we have changed the sentence into: "… which, however, does not occur in the atmosphere because there is always a sufficient number of condensation nuclei available, that trigger condensation as soon as liquid saturation is slightly exceeded."

P18907 ln 10 replace 'are' with 'were'. *Reply:* Done.

P18907 ln 15 replace 'data base is' with 'sampling regions are'. *Reply:* Done.

P18907 ln 22 This meaning is not clear in '..as the altitude band from pressure level at potential vorticity 2.0PVU±15 hPa. . .'. *Reply*: We changed the sentence to: "..as the altitude band centered around the pressure level (±15 hPa) at potential vorticity 2.0 PVU . ."

P18909 ln 13 Suggest changing to Specifically, the investigation of seasonal variations of atmospheric chemical composition is meaningful only for those airports being visited continuously over the entire period (see e.g. Zbinden et al. (2013)). *Reply:* Done.

P18910 ln 4 What is the source of PV data? *Reply:* PV data are part of the MOZAIC-data base and are calculated from ECMWF analyses. We added a sentence "PVU values are calculated for each single MOZAIC data point from ECMWF analyses" to the text after the definition of the tropopause.

P18910 ln 6 'Few. . .' and 'A few. . .' have different meanings in this sentence. I suggest 'A few. . .' *Reply:* Done.

P18911 ln 1 'could not be explained by physical reasons' What effort was made? *Reply*: We added a reference to Lamquin et al. (2012) and the discussion therein, where MOAZIC data were compared to RH data from AIRS.

P18912 ln 23 change to 'LAH, respectively;' *Reply:* Done; please note that the paragraph was shifted to the next section, as suggested by Referee #1.

P18913 ln 9 change to 'instrument was used.' *Reply:* Done.

P18914 ln 11 Change to 'Consequently, this bias in the calibration function has had a quantitative impact of equal magnitude on the RH flight data and thus correcting the bias requires: (1) reprocessing. . .' *Reply:* Done.

P18914 ln 25 Change 'will provide' to 'provides' *Reply:* Done.

P18934 legend Change 'new' and 'old' to 'after' and 'before' *Reply:* Done.

P18935 This phrase is not understandable: '(for details see corresponding explanations for details);'

Reply: We changed text into: "(see corresponding explanations for details);"

P18942 The Krämer line beyond 100% RH_{ice} is invalid for comparison to MOZAIC as stated in the text. Either remove it here or show as dashed line and define as upper limit.

Reply: We have modified Fig. 14 and exchanged the Krämer et al. line by RH_{icce} for exclusively gaseous water vapour measurements. The new figure is shown above. We also have rewritten the respective paragraph which reads now: "The validity of the reprocessed MOZAIC UTH data set is further confirmed by the comparison with an extensive data set collected by Krämer et al. (2009) ; see the solid line in Fig. 14 d. This data set is based on 28 research flights in 10 field campaigns in the UT/LS and in/around cirrus clouds using the Lyman(α) Fluorescence Fast In-situ Hygrometers FISH (Zöger et al., 1999) as well as FLASH (Sitnikov et al., 2007) and the open-path tunable diode laser instrument OJSTER (Krämer et al., 2009). The PDF shown in Fig. 14 d refers to clear sky conditions and are based on FISH total water measurements far off cirrus and FLASH or OJSTER gas phase measurements in the vicinity of cirrus. The difference between the MOZAIC and the FISH-FLASH-OJSTER PDFs can be explained by the different underlying flight strategies. While in the MOZAIC programme flights are not targeted to scientific questions, the flights performed by FISH-FLASH-OJSTER are dedicated to research in the UT/LS and in/around cirrus clouds. Hence, the peak around 100% RH_{ice} is slightly higher and the peak at 10%RH_{ice} slightly lower in FISH-FLASH-OJSTER than in the MOZAIC PDF, since regions around cirrus are more frequently present in the research flights than in the regular passenger flights. Further, the larger fraction of data points at high ice-supersaturation in the MOAZIC compared to the FISH-FLASH-OJSTER data set is due to the fact that MOZAIC data include occasional cirrus cloud encounters where ice-supersaturation frequently occurs, whereas the FISH-FLASH-OJSTER data represent cloud-free conditions."

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