

## 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”

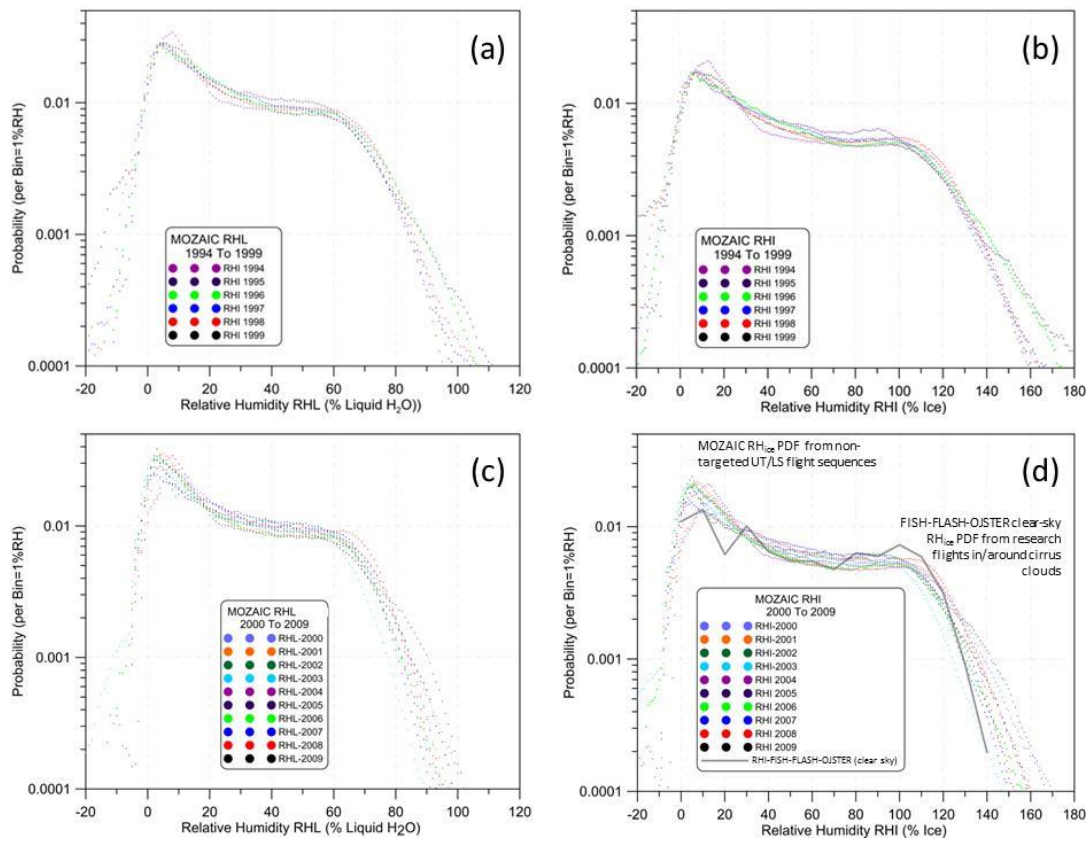
I suggest revising the Abstract starting on p11 as:

“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  $RH_{\text{liquid}}$  and  $RH_{\text{ice}}$  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 RH<sub>liquid</sub> (a, c) and RH<sub>ice</sub> (b, d) for the indicated periods; the solid line in panel (d) represents the average RH<sub>ice</sub> 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<sub>liquid</sub> 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<sub>liquid</sub> 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 (see 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 such 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<sub>ice</sub> values from ODIN (ODIN-SMR is a limb-sounder operating in the 500 GHz region) at 200 hPa with MOZAIC RH<sub>ice</sub> at 200 hPa for the period 2001-2004 over tropical regions. The agreement of the PDF for RH<sub>ice</sub> from ODIN and MOZAIC sensors is better than 5% RH<sub>ice</sub>, 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<sub>ice</sub> 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<sub>ice</sub> would shift by about 10% RH<sub>ice</sub> 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<sub>2</sub>O 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<sub>liquid</sub> 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<sub>liquid</sub> 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<sub>liquid</sub> 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<sub>liquid</sub> such that major impact already had been corrected for. Results and conclusions are appropriate.

### **Smaller points**

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

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

P18906 In 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 In 10 replace 'are' with 'were'. *Reply:* Done.

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

P18907 In 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 In 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 In 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 In 6 'Few. . .' and 'A few. . .' have different meanings in this sentence. I suggest 'A few. . .' *Reply:* Done.

P18911 In 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 In 23 change to 'LAH, respectively;' *Reply:* Done; please note that the paragraph was shifted to the next section, as suggested by Referee #1.

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

P18914 In 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 In 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<sub>ice</sub> 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<sub>ice</sub> 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( $\alpha$ ) 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<sub>ice</sub> is slightly higher and the peak at 10%RH<sub>ice</sub> 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 MOZAIC 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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