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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Comparison of in-situ FISH measurements of water vapor in the UTLS with ECMWF (re)analysis data" *by* A. Kunz et al.

Anonymous Referee #1

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Comment: This is a very interesting study and the authors made large effort to use a comprehensive 10-year water vapor climatology consisting of FISH measurements collected during several research campaigns to evaluate ECMWF's ERA-interim reanalysis. Additionally, the authors compared observations with operational analyses to study a temporal trend resulting from major changes to the forecasting system. The authors use interesting methods to describe differences between reanalysis and observations in different parts of the UTLS. The results are of interest to the modelling community as well as for studies working with ERA-interim data.

This is an interesting paper that is certainly worthy of publication in ACP. The authors do a nice job of presenting the data and the figures are of high quality. However, the paper should be improved by a more precise and structured discussion and I feel that

there are several points that the authors need to address before this manuscript can be accepted. I list these points below.

Abstract:

Page 14400 Explain abbreviations UTLS, ERA. Here and elsewhere: Explain all abbreviations when first mentioned.

Page 14400, line 6-9 – What does the sentence "At the same time. . ." mean? I suggest moving the sentence to last paragraph of the abstract. Explain more carefully why you also use operational analyses. List the key findings.

Page 14400, line 13-15 – you speak of "strong" differences and indicate ranges of your deviation ratio. Are these values minimum and maximum values? Why don't you use mean values?

Page 14400, line 24 – What are the indicated stratospheric processes?

Introduction:

The introduction is sometimes a bit confusing and I miss a clear statement about the main aims as a logical consequence of the state of the art. What is new, what is unique? The information is more or less there but you should better point out what the main open questions are that you want to answer.

Page 14401, line 1 – "number one" in terms of?

Page 14401, line 18 – "additionally" to what?

Page 14401, line 22 and elsewhere – What does "The assimilated (. . .) water vapor fields" mean? For me, assimilated fields would be observational data used in the assimilation process. Do you mean analysis fields?

Page 14401, line 22 – The sentence "deviate [. . .] in-situ measurements" needs a reference. What are the possible reasons for these deviations (see also next comment!)

Page 14401, line 24 to Page 14402, line 6 – This paragraph is confusing and needs to be revised:

- It might help the reader to explain the ECMWF reanalyses and the difference to the operational assimilation system more carefully followed by a discussion of its possible weaknesses. - What do you mean exactly with “less data assimilation problems”? - “the representation of the stratospheric circulation” and “the quality in stratospheric circulation” seems to be the same. - What is the “(...) consistency in time of reanalyzed geophysical fields.”

Page 14402, line 7-15 – this paragraph is not coherent. First you cite ERA-interim applications and then use field campaigns to motivate a quality assessment of ERA-interim data. Please rephrase this paragraph and make clear what the aim of your study is.

Page 14402, line 21 – I wonder how a too shallow boundary layer can be related to an overestimated convective transport. Consider adding “large differences were found”.

Page 14403, line 13 –you might consider adding “the calculation of radiative fluxes . . .”

Page 14403, line 10-16 – this paragraph discusses the moist bias” should be part of the motivation for an ERA-Interim evaluation. As mentioned earlier, please explain the “limitations”.

Page 14403, line 23 – consider using “validation” instead of “assessment”

Page 14403, line 24 – explain the idea of using ERA-interim data and operational analysis fields and move the sentence to Page 14404 where you summarize the main aims of the study.

Page 14403, line 25 to Page 14404, line 2 – I suggest discussing the data set and the different campaigns in section 2.1.2. A summary of the amount of flights and data would be enough in the introduction.

Page 14404, line 11 – the line break should be done after “. . . covering the UTLS”. After this sentence the content of this paper is summarized.

Page 14404, line 13 – as mentioned earlier “assimilated water vapor fields” is unclear.

Page 14404, line 14 – you might want to specify “specified episodes”

2.1.1 Measurement technique of FISH

Page 14405, line 1 – remove “(Fast In-Situ Stratospheric Hygrometer)”

Page 14405, line 11 – the accuracy discussion needs a reference

Page 14405, line 14 – “may” is vague, please specify

Page 14405, line 20 – consider adding “500 pmmv above 400 hPa”

2.1.2 FISH-based water vapor climatology

Page 14406, line 12 – how do you select gasphase-only data?

Page 14427, Table 1 – you should add references to all campaigns if possible

Page 14429, Figure 1 – please add values to the contours of winds and Theta-Surfaces. Consider adding “mean altitude of ERA-Interim” to the caption

2.2 ERA-Interim data

The manuscript discusses the weaknesses in the ERA-interim data set. However, the information is distributed at several points in the manuscript which is confusing. In the introduction you mention the insufficient representation of the stratospheric circulation. Here, several changes to the forecasting system are listed that impacted the quality of the data set. As this is very important for the interpretation of your results, you should take together all the information and discuss this comprehensively. What are the dominant weaknesses causing insufficient reproduction of humidity? Is it the misrepresentation of stratospheric or tropospheric dynamics, missing observations, insufficient horizontal and vertical resolution, or numerical problems to treat the tropopause,

parameterizations?

Page 14406, line 21 – what exactly is the “water vapor product”? – specific humidity?

Page 14406, line 21 to Page 14407, Line 14 – from your description it remains unclear when and where changes are made to the forecasting system and what is different in ERA-Interim. Does “prior” mean during the years before, just before Cycle31r2 or only for the ERA-Interim model version. “Refined for ERA interim” is confusing. The discussion about the influences of the changes ti the model versions your results should be done in the discussion part of the manuscript.

Page 14407, line 16–25 – This paragraph needs some more explanation on the comparison method: - The first sentence is grammatically incorrect. - What does “transforming” mean? Does that mean that the observed air parcel is advected to the temporally closest synoptic times? - “Synoptic observation” is a new terminology. Does that indicate the position of the in-situ observation? - What are the weaknesses or errors of the “temporal interpolation” method? Do you assume that the observed values remain you constant over the integration time? What are the advantages compared to linear temporal interpolation? Why do you use Theta to interpolate in the vertical coordinate? What is the vertical resolution of the ERA-interim data

Page 14408, line 4 – Even though it has been discussed in your previous papers (Kunz et al. 2011a, b) you should consider giving a short summary on the calculation of equivalent latitudes and what the idea is behind that. It is not mentioned in the introduction why you use this specific method and what can be expected.

Page 14408, line 8 – What do you mean with “the measurement location is also placed in relation with the location of the thermal tropopause on altitude levels”?

2.3. Operational analysis

You could merge sections 2.2. and 2.3 in a common ECMWF data section. Please also consider to give some information on how horizontal resolution has changed in

the operational analysis and how this relates to the fixed resolution of ERA-Interim. Page 14408, line 21 – Please comment on the criteria for the 6 time intervals. What are the major changes, e.g. changes in resolution or parameterization that you were taking into account for the separation?

2.4 Ratio of water vapor between reanalysis fields and FISH

Consider to comment the thresholds values of $\triangle$(H2OERA) of 0.1,0.5,0.9,1.1„2 and 10 that are often used throughout the manuscript e.g. as you did in the caption of Figure 3 “double. . . half as high”.

2.5 An example flight

There is some repetition of information when you discuss deviations in Figure 2 and then give the same information from Figure 3. I suggest to put Figure 2 and 3 in one plot and to revise the discussion. It is also a bit confusing that you first introduce the metric $\triangle$(H2OERA) and then explain absolute differences of FISH and ERA-interim. Consider adding some description of Figure 2 (top panel) by commenting the static stability, location of the jet stream, flight altitudes, thermal tropopause and the tracer locations. Adding a map with the flight track would help the reader to more easily orientate and localize the deviations. Additionally I recommend to add the time markers in the top panel.

Page 14409, line 14 – consider adding “Measurements are collected both”

Page 14409, line 20 – add a time window [XX:XX – XX:XX UTC] to make clear where the “poleward side of the jet stream” is.

Page 14409, line 27 –“deeper troposphere” – do you mean upper troposphere?

Page 14409, line 28 – I suggest to put the discussion on the impact of different cycles to the end of the paper manuscript.

Page 14410, line 12 – add some explanation on the mean water vapor mixing ratio per

Δ(H2O) plot and how this can be interpreted. What FISH water vapor mixing ratios are used to calculate the mean values over the different bins (black line)? Don't they differ for ERA-interim and operational analysis for the different bins?

Page 14410, line 16-22 – I suggest moving the discussion on the influence of the measurement uncertainty on the calculation of Δ(H2O) to section 2.4.

3.1 Campaign based analysis

Page 14411, line 16 – consider adding "is varying from"

Page 14412, line 9-10 where do I see this agreement and what is in between 100 and 300 ppmv?

3.2 Tropopause based analysis

The discussion in section 3.2 is confusing and misses a clear structuring. This part of the paper needs to identify the key information from Figures 5 and 6. I suggest to discuss the three domains separately before comparing them. Give more references to the panels.

Some further comments:

Page 14412, line 21-22: remove this sentence as it is a repetition of the first sentence.

Page 14413, line 3 – why "However"?

Page 14413, Line 6 – please add information about the three domain classification and what the author can see in Figure 1. What happens in cases of double detected tropopauses with the aircraft flying in between, e.g. at $\sim$18:30 UTC?

Page 14413, line 7 – What do you mean with "influence of the jet stream"?

Page 14413, line 13 – add e.g. "are found in the"

Page 14413, line 21 – add e.g. "are ranging between"

Page 14413, line 21 – "more strongly over and underestimate" compared to what. Where do you see that?

Page 14413, line 21 – Why "may reach"?

Page 14414, line 1 – I suggest to change "on isentropes" to "at potential temperatures"

Page 14414, line 2 – From the colorbar it is not clear where the transition at 400 ppmv is exactly located. Is there a change in color? Please indicate this threshold in Figure 5.

Page 14414, line 8 – Where can the underestimation by a "factor of up to 3" be identified? Add values to the red dashed vertical lines in Figure 5, as it is done in Figure 6.

Page 14414, line 11-15 – I miss a discussion of the subtropics. Why are the lowest values of FISH and ERA such sharply truncated in the extratropics? Figure 5, caption: where are the "middle panels"? Use maybe column and rows. Here and elsewhere: avoid "water vapor" and instead use water vapor mixing ratio or specific humidity.

3.3 Equivalent latitude-based analysis on isentropes

Page 14414, line 17-26 - the beginning of this section contains information on the applied methods that should be explained in more detail and moved to the methods section 2.2 (see also earlier comments): - Why are you using equivalent latitudes in this context? - What is the difference between using a maximum PV-gradient compared to the 2PVU threshold? - What is done exactly: do you take observed potential temperatures and calculate the distance on nearest isentropic surfaces? - Explain equivalent and relative equivalent latitude.

Page 14414, line 22-26 – "The PV-gradient based tropopause is (located???) in the . . ."

Page 14415, line 4 - Page 14415, line 4 – It is hard to follow the discussion of Figure

7 and 8. Please improve this paragraph e.g. by adding latitude information to the potential temperature values and discuss stratosphere and troposphere separately. Give more references to the panels.

Figure 7, caption – does "Zonal mean zonal wind ..." mean that you just use the u-component of the wind vector in this case? Why?

Page 14416, line 3 – specify "problems"

4 Water vapor evaluation: operational analysis vs. FISH

Page 14416, line 6-9 – confusing sentence that mixes up two things. On the one hand the idea to evaluate the ERA-Interim data by comparing with FISH data to investigate a temporal trend related to changes in the assimilation system, resolution and other changes. On the other hand you want to explain why you analyze the data separately for stratosphere and troposphere. Rephrase and consider to move this to the introduction.

Page 14416, line 10-11 – what means "is done separately for the different IFS cycles"?

Page 14417, line 1-2 – this sentence is a repetition.

Page 14417, line 3-6 – where do I see the overestimations that are related to humidities lower than 5 ppmv. I also see a lot of higher values? Where are the middle panels?

Page 14417, line 12 – what is "the second period of IFS cycles 36r1-37r2"?

Page 14417, line 19 –"The increase...": is this a comparison of the bottom panels of Fig. 9 and 10?

Page 14417, line 21-23 –"This may... ": I do not understand this argument and where this comes from. Consider adding this this to the discussion.

How robust are the findings from Figure 9 and 10? E.g. you identified a region of improvement in the analysis (i.e. the region where the yellow dots do not overlap with the

green dotted area). Is this only data from one case? I would be interested in seeing how the model data of analyses and ERA-interim differ in this case, e.g. by visualizing model cross sections along the flight track. This may show differences in the humidity fields or indicate positional/temporal shifts of the tropopause structure related to differences in the dynamics. This would also be interesting for the case study in Figure 3. Maybe it gives some hints about the processes causing the improvement. Regarding the improvement over time, it would be interesting to calculate an improvement metric for the daily means. You could compare norms of the absolute differences between H2O(ERA) and H2O(FISH) and between H2O(EC AN) and H2O(FISH). The difference of these norms implies either an improvement or deterioration. A time-series would show whether there is a clear signal in improvement or not.

5 Summary and discussion

Please revise this section and clearly elaborate the key findings. The discussion of findings for stratosphere/troposphere and tropics/extratropics/subtropics is mixed up. You should summarize the applied methods (case study, error metric for all flights, direct comparison, errors vs tropopause height, equivalent latitude method, operational analysis vs. ERA-interim), why you used them and what the key findings are. I miss a discussion about the value of the different considerations and what you learned from it. How do these finding relate to literature?

Page 14418, line 12-20 – this paragraph is in large parts a repetition of the introduction. The rest of the information could be moved to the introduction.

Page 14418, line 21-Page 14419, line 2 – this paragraph mixes up a comparison with older studies, the operational analyses, tropical and extratropical regions and method of looking at thermal tropopause height without mentioning any of your results. It is unclear what "short-term evaluations" are.

Page 14419, line 3-12 – this paragraph is the main listing of results. As mentioned above please extend this discussion and give some more values (e.g. mean values

for the different parts of the UTLS that you identified) that support your conclusions. I suggest to use “reproduce” or “represent” instead of “reflect”. A discussion of the subtropics is missing. Is there a difference that may be related to mixing processes?

Page 14419, line 13-21 – as mentioned above, you should extend the discussion on the differences between analysis and reanalysis. You refer to a case study of H2OANA in Figure 3. Where do I find that? What is the possible reason for the improvement (see earlier comments)? What about the results from section 4?

Page 14419, line 22- Page 14420, line 10 – specify how your comparison has shown that tropospheric processes are challenging. Specify “challenging dynamics” and “Problems” and relate e.g. to the wet bias that is described in literature.

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