We thank the reviewers for the helpful comments and suggestions. We have made revision to the manuscript and believe that we have adequately addressed the reviewer's comments. In the following, we summarize our reply to the reviewers.

Reviewers' comments:

In this study COSMIC radio occultation and ECMWF reanalyses data is used to estimate trends in tropospheric water vapour. The trend analyses is performed globally for specific latitude bands, separating the globe into latitude bins of 20° and on three pressure levels, namely 300, 500 and 850 hPa. Before the trends are estimated the data sets are inter-compared.

General comments:

The study itself is worth to be published, however needs major revisions before publication in ACP. Since in this study first a detailed inter-comparison is performed followed by a quite detailed trend analyses, the paper becomes very long and hard to follow. The current version of the manuscript gives the impression that actually two manuscripts have been combined. I would suggest to significantly shorten the paper, especially the inter-comparison part. The most important results of the inter-comparison should, however, be provided in an appendix or supplement to this manuscript because knowing the differences between data sets is important for interpreting the derived trends.

Following the reviewer's suggestion, we have moved several sections (Seasonal variability analysis, Method of removing the COSMIC sampling errors, and Effects of sampling error removal on the uncertainty of the regional water vapor trend analysis) to the Appendix. The sections moved to the Appendix accumulate to about 10 pages. The main text of the manuscript has been substantially shortened.

A motivation for why a separation into 20° latitude bins has been performed. Accordingly, a motivation for why the three pressure levels 300, 500 and 850 hPa have been used is missing. Why do you look at the seasonal cycle before calculating the trends?

We have added the motivation for selecting three pressure levels in this study in Section 2.2 (L173) as "For RO data, the fine vertical resolution COSMIC RO water vapor profiles are interpolated onto three pressure levels, e.g., 300, 500, and 850 hPa, selected to characterize water vapor variations at representative heights around 9 km, 5.5 km, and 1.5 km, respectively. In particular, the pressure level at 850 hPa is close to the surface, and the COSMIC water vapor retrieval is strongly affected by super-refraction in the moisture-rich regions (Ho et al., 2010). The retrieved water vapor at 850 hPa from COSMIC data could differ from ERA5, making it worth evaluating the relative biases and consistency in the trends between these two datasets. Starting from the pressure level at 500 hPa, the RO-water vapor retrieval uncertainty increases as height decreases. The 300 hPa pressure level represents the water vapor with less horizontal variations at higher heights."

We also added the motivation for separating 20° latitude bins in the latitudinal dependence analysis in Section 3.2 (L251) as "The 20-degree wide latitude bins over northern and southern hemispheres are selected to characterize water vapor latitude-dependence in different reprehensive latitudinal

zones such as 0º-20º for tropical, 20º-40º for sub-tropical, 40º-60º for mid-latitude, and 60º-80º for high-latitude regions.”.

We have moved the section on “Seasonal variability of COSMIC and ERA5 water vapor distribution” to Appendix 1 as supplementary information. The seasonal cycles in the monthly-mean water vapor time series need to be removed before calculating the trends (see Appendix 2).

Further, the manuscripts need significant improvements in writing and presentation of the results. Most of the figures and all tables need to be improved. Some figures are not really concise and use to small fonts.

We have made substantial changes to the figures such as replotting with larger fonts, rearranging labels, adding SH/NH separation lines, and rearranging/replotting panels for seasonal variability analysis. The tables (1-6) have all been revised to make them more comprehensible. The quality of the figures (1, 2, 3, 4, 5, 7, A.1, A.2, A.3, A.4) and tables (1-6) have been improved.

Instead of water vapour variation you should clearly state “seasonal cycle and trend”. The time period considered could also be mentioned in the title.

We have revised the paper title to “Characterizing the Tropospheric Water Vapor Spatial Variation and Trend using 2007-2018 COSMIC Radio Occultation and ECMWF Reanalysis Data”.

The reason of adding “spatial variation’ in the title is to emphasize that this paper studies the water vapor variation in different spatial scales such as global, latitudinal and regional, and over three pressure levels.

Since the study of seasonal variabilities of water vapor has been deemphasized in the revised manuscript, we added “Trend” in the title by following the reviewer’s suggestion.

Specific comments:

P2, L38-41: This paragraph is too general and too broad and thus a bit out of the context of the study and thus not useful at all. The whole paragraph should be removed.

This paragraph has been removed.

P2, L46-47: I would suggest to put the references at the end of sentence.

The references have been moved to the end of the sentence.

P2, L58: Please rephrase the sentence. “such as” is not correct here. It should rather read “and”.

‘such as’ has been changed to ‘and’.

P6, L196: Which selected months? Do you mean January and July? Why have these two months been selected?

We modified the phrase to "two selected months (January and July of 2007)" to make it clear. These two months are selected as two reprehensive months (winter and summer of northern hemisphere) to show the relative seasonal consistency in the comparisons of collocated COSMIC water vapor retrieval versus ERA5 and ERA-Interim water vapor data. We also revised L187 to explain the motivation as "**Error! Reference source not found.** depicts the monthly (using January and July of 2007 as representative winter and summer months of the northern hemisphere) scatter plots of the collocated COSMIC global water vapor versus ERA5 and ERA-Interim water vapor data at three pressure levels." to explain the motivation.

P7, Figure 1: Why is the comparison done for ERA-5 and ERA-interim? Why not only ERA-5?

The UCAR's 1DVAR retrieval algorithm for COSMIC WETPrf (water vapor and humidity) uses ERA-Interim background profiles as the *a priori* input (Wee et al., 2022). In addition, the UCAR water vapor/temperature retrieval also enforces a retrieval constraint to the residual refractivity (refractivity computed from the final temperature and moisture minus the observed refractivity). Such constraint can determine the influence of ERA-Interim on the final water vapor retrieval at different pressure levels. On the other hand, the ERA5 provides a more comprehensive and reliable reanalysis by using improved weather forecast and data assimilation models with various ground, in-situ, and satellite measurements compared to ERA-Interim. To understand the impacts of ERA-Interim on the UCAR 1DVAR COSMIC water vapor retrieval, we use the comparison of the COSMIC retrieval with ERA5 as the reference. We have added these explanations to the paragraph above Figure 1 (L182 to L188).

P9, Figure 2: Put the labels of the panels at the top left of each panel.

The labels in Figure 2 has been placed on the top left of each panel.

P9, Figure 2: I am surprised by the good agreement between the two data sets and was wondering if COSMIC data is assimilated into ERA-5. If yes, this needs to be considered in the interpretation and discussion of the results.

Yes, COSMIC bending angles are assimilated into ERA5, which especially improve the upper-troposphere and lower-stratosphere temperatures (Hersbach et al. 2020). However, the COSMIC 1DVAR retrieval has more independence from its *a priori* (ERA-Interim) for water vapor within the lower/middle troposphere and major information is retrieved from the RO observations at these altitudes, which our study is focused on. As we can see from the quantitative comparisons in Section 3.1, the mean differences between COSMIC and ERA5 global water vapor are 5.67%, -1.86%, and -2.30% for pressure levels at 300, 500, and 850 hPa, respectively. These global and latitude-dependent (Fig. 3) water vapor bias evaluations between COSMIC and ERA5 help understand the extent and regional dependence of the assimilation of COSMIC RO water vapor data in ERA5. We have noted these points at L221 in the revised manuscript.

Hersbash, H., and Coauthors, 2020: The ERA5 global reanalysis. Quart. J. Roy. Meteor. Soc. 146, 1999-2049, https://doi.org/10/1002/qj.3803.

Figure 1-2 and according text could be moved to an appendix/supplement.

We moved three sections with ~10-page figures and texts to the Appendix (see our reply to general comments No.1). We kept Figure 1 and 2 in the main text since these figures and texts are more relevant in the main texts.

P10, L255ff: Is this shift in the NH/SH due to the ITCZ? If yes, then I assume this figure would look different for other months? Which month actually is shown here?

Fig. 3 shows the mean water vapor over 20-degree latitude bins for the collocated COSMIC and ERA5 data averaged over all months of 12 years (2007-2018). This has been noted in the text.

P11, Figure 3: The time period that has been considered should be added. Has an average over the 2007-2018 period been considered? For which month is shown in this figure? Or is here an average over all months/years shown?

For Figure 3, collocated COSMIC and ERA5 water vapor data over all months in 12 years (2007-2018) have been used to calculate the mean water vapor in the corresponding latitude bins. We have added the note to Figure 3 caption to make this clear.

Figure 4-6: I am not happy with these figures. In my opinion these are two overloaded and hardly readable. I am not yet convinced the figure 4b, 5b, 6b. These could be moved in an appendix/supplement. Or consider rearranging the results presented. See the following comment.

Following the reviewer's suggestion, Section 3.1 on "Seasonal variability of COSMIC and ERA5 water vapor distribution", including Figures 4-7, have been moved to Appendix 1. Also, see the reply to the following comment on the revision of Fig. 4-6 (Fig. A. 1 and A.2 in the revised manuscript).

P12-14, Figure 4-6: My suggestion would be to completely change the way of presenting the results for the seasonal cycle. Wouldn't it be better to show the NH and SH separately and then use one figure for each hemisphere showing the results for the three pressure levels. You then could have additionally one figure showing the differences for the three pressure levels (and as now with differences for both hemispheres).

The section on seasonal variability of water vapor distribution with Figures 4-6 has been moved to Appendix 1. In addition, we followed the reviewer's suggestion and revised the figures by showing seasonal variation in NH and SH separately into two figures (Fig. A.1 and A.2) with panels for the three pressure levels in the same figure. The texts have also been revised.

P15, Figure 7: I am also not happy with this figure. Is it really worth to who three pressure levels? The results are quite similar and thus there is no need to show in all figures all three levels. Also I would suggest to improve the figure so that the hemispheres can be better compared. One way of doing this would be to add a vertical line in the middle of the plot separating the NH and SH bars.

Section 3.1, including Figure 7 (Fig. A.3 in the revised manuscript), has been moved to Appendix 1. Also, following the reviewer's suggestion, we added a vertical line in the middle of each panel to separate the NH and SH bars. The texts in the figure caption has also been revised to reflect this change.

P18, L451: Add references.

Reference has been listed.

P19, L472: Which latitude bin? 0-20°, thus tropics? What trend do you derive for the other regions?

Figure 9 (or Figure 4 in the revised manuscript) and related texts (in Section 4.1) discuss the global water trends at three pressure levels, i.e., "COSMIC and ERA5 water vapor trending data in Fig. 4 show that the global water vapor trends at three pressure levels are all positive, suggesting the increase of global water vapor concentration, i.e., becoming globally wetter, over time at these pressure levels." The latitude-dependent water vapor trends are shown and discussed in Section 4.2.

P22, Figure 10: Add a vertical line at 0° to visually separate NH and SH. You could also write in the plot SH and NH, respectively.

Vertical green lines have been added to panels of Figure 5 in the revised manuscript. We also added in the figure caption "The green line in each panel separates the southern (to its left) and northern (to its right) hemispheres" To make it clear.

P23, Table 2: The table should be improved. In it's current form it is hard to read and thus not really useful.

We have revised and reformatted Table 2 to make it more readable.

P26, Figure 12: I don't understand this figure. What exactly has been done? Why is this kind of analyses useful? I think this analyses does not need to be shown in the main part of the paper and could be moved to the appendix.

Following reviewer's suggestions, the Section on "Effects of sampling error removal on the uncertainty of the regional water vapor trend analysis" (Figure 12 and relevant texts in previous draft) has been moved to Appendix 3. This section is to provide supplemental information on the impacts of the sampling error removal on the uncertainties in the regional water vapor trend estimation.

P28, Figure 13: Why is here only 500 and 850 hPa shown and not 300 hPa?

We noted in the paragraph "The distributions of COSMIC and ERA5 water vapor trends at 300 hPa have smaller regional variations. They are not shown in Fig. 7." at L464 in the revised manuscript.

P29, Figure 14 and corresponding text: It should be motivated how these sites have been selected.

We have added the motivation at L509 in the revised manuscript "In the following sections, we selected a few representative sites, such as stratocumulus cloud-rich sites (section 5.2), sites with notable increasing (wetter) and decreasing (drier) water vapor trends (Section 5.3), and sites with a notable difference between ERA5 and COSMIC trends (Section 5.4) to understand the spatial variability of water vapor trends. Their center locations are shown in Fig. 8. These established sites are in 10^o by 10^o latitude/longitude grids.".

P30-31, Tables 3-5: These tables are hard to read. You should find a way to present the results in a readable way. All additional information could be put into the appendix. E.g. in table 3 columns 2 and 3 could be combined.

Following reviewer's suggestion, we have revised Tables 3-6 by combining columns 2 and 3 into one column. We also removed the brackets in the table cell and reformatted these tables to make them more comprehensible.

P33, L762: ERA-5 is the latest version of reanalyses and has been significantly improved compared to ERA-interim. Thus, it is not astonishing that the agreement between COSMIC and ERA-5 is better than the agreement between COSMIC and ERA-interim. It would be maybe useful to check and discuss the results from the SPARC reananlyses comparison project (https://www.sparc-climate.org/activities/reanalysis-intercomparison/).

We have added in the summary Section "It is noted that the coordinated efforts from Stratosphere–troposphere Processes And their Role in Climate (SPARC) Reanalysis Inter-comparison Project (S-RIP) plays an important role in comparing reanalysis datasets using a variety of key diagnostics and particularly confirmed the significant improvements of the latest version of reanalyses in ERA5 compared to ERA-interim (Fujiwara et al., 2017).".

Technical corrections:

P1, L24: sub-tropics → sub-tropical

The term 'sub-tropics' has been changed to 'sub-tropical'.

P1, L28: are around → "are found around" or "are observed around"

The 'are around' has been changed to 'are found around'.

P1, L28: delete "at sites"

"at sites" has been deleted.

P3, L75: in → of

The term 'in' has been changed to 'of'.

P5, L139: Put "in this study" at the begin of the sentence.

"in this study" has been moved to the begin of the sentence.

P5, L141: delete "for global environment and weather studies".

"for global environment and weather studies" has been deleted.

P7, Figure 1: Write “ECMWF” in the x-label instead of “ERA”.

The term ‘ERA’ has been changed to ‘ECMWF’ in Figure 1.

P8, L220: tropics → tropical

The term ‘tropics’ has been changed to ‘tropical’.

P11, Figure 3: Put labels at the top left of each panel.

Label has been moved to the top left of each panel.

P12, L294-195: same month …..same latitude zones → each month and each latitude zone

‘the same month and in the same latitude zones’ has been changed to ‘each month and each latitude zone’.

P15, L373: “RO” obsolete → delete

The term “RO” has been deleted.

P17, Figure 8: Put labels at the top left of each panel (should be aligned).

Label has been moved to the top left of each panel.

P18, L425: “~ “should be “- “

‘~’ has been changed to ‘-’.

P18, L433: Same here.

‘~’ has been changed to ‘-’.

P19, Figure 9: Put labels at the top left of each panel.

Label has been moved to the top left of each panel.

P22, Figure 10: Put labels at the top left of each panel.

Label has been moved to the top left of each panel.

P22, Figure 10 caption: What do you mean with “zone—mean”? Zonal mean or do you mean the latitude bins?

We have revised Figure 10 caption to “latitude bin-mean”.

P22, L535: add “tropical” after “northern” so that it reads “northern tropical 0° to 20° latitude bins”.

‘tropical’ has been added after ‘northern’.

P24, L69: Write either “no data points” or “missing data points”.

‘no missing monthly data’ has been changed to ‘no data points’.

P24, L584: [2020] → (2021)

‘[2020]’ has been changed to ‘(2020)’.

P25, L589: [2020] → (2021)

‘[2020]’ has been changed to ‘(2020)’.

P25, Figure 11 caption: either “no monthly data” or “ missing data”.

‘no missing monthly data’ has been changed to ‘no data points’ in Figure 11.

P26, Figure 12: Put labels at the top left of each panel.

Label has been moved to the top left of each panel.

P27, Figure 13: Put labels at the top left of each panel.

Labels in Figure 13 have been moved to the top left pf each panel.

P32, L717: low latitude → tropical regions

‘low latitude’ has been changed to ‘tropical regions’.

P32, L720 and L727: trending → trend

We changed “trending → trend”.

P32, L739: tropics → tropical, subtropics → subtropical

‘tropics’ and ‘subtropics’ have been changed to ‘tropical’ and ‘subtropical’, respectively.

P33, L751: trending → trends

‘trending’ has been changed to ‘trends’.

P34, L778: from trending → from estimating the trend for 2007-2018 from

‘from trending of 2007-2018’ has been changed to ‘from estimating the trend for 2007-2018 from’.

P34, L792: tropics and sub-tropics region → tropical and subtropical regions

‘tropics and sub-tropics region’ has been changed to ‘tropical and subtropical regions’.

P35, L803 and 810: degree sign misplaced.

Degree sign has been modified.

P35, L805: difficulty → difficult

‘difficulty’ has been changed to ‘difficult’.

P35, L813: having → have

We didn’t find the word ‘having’ in this line.

P35, L814: trending → trend

We changed “trending → trend”.

P36, L829: trending → trend estimation

‘trending’ has been changed to ‘trend estimation’.

P36, L846: [2021] → (2021)

‘[2020]’ has been changed to ‘(2020)’.

P38, L912: Co-authors are missing.

Co-authors have been listed.