Review of Shao et al.: Characterizing the tropospheric water vapor spatial variation and trend using 2007-2018 COSMIC radio occultation and reanalysis data

We thank the reviewers for the helpful comments and suggestions. We have revised the manuscript and addressed the reviewer's comments. The manuscript has been largely improved. In the following, we summarize our reply to the reviewer.

Editor's Comment:

1. Check the spatial resolution of ERA5. Is it 0.2 or 0.25?
We checked the spatial resolution of the ERA5 reanalysis data we downloaded. It is 0.25 degree. Thank the reviewer for pointing this out. The texts at L131 and L171 have been revised.

2. How the sampling error in COSMIC can affects trend estimation, but not bias?
The relative water vapor biases are estimated from the collocated COSMIC and ERA5 data. The sampling error correction is a correction factor derived from the difference between mean of ERA5 data collocated with COSMIC and the mean of all ERA5 data in the Region of Interest (RoI). The trend estimation needs to keep the time-dependent sampling error correction in the time series of COSMIC and ERA5 data in order to separately estimate the trends.

3. "About the discussion on monsoon climate and water vapour trend"
Precipitation is generally known as a sink rather than a source of water vapour. The monsoon climate influences water vapour variability and trends through the moisture transport. Please modify the discussion to include a link between the water vapour trend and moisture transport, not precipitation.
We have revised the paragraph as "This region is affected by the monsoon climate over the south of the Himalayas. The monsoon climate influences water vapor variability and trends through moisture transport (An et al., 2015; Turner and Annamalai, 2012). The variability in water vapor trends in a region experiencing a monsoon climate is closely tied to the alternating wet and dry phases. Factors such as the strength and duration of the monsoon, the temperature of the ocean waters, and atmospheric circulation patterns all play a role in determining the extent of moisture transport and its impact on water vapor levels. Changes in sea surface temperatures due to global warming can affect the intensity and timing of monsoon patterns, leading to shifts in moisture transport and potentially altering the variability of water vapor content in affected regions. Indian Ocean is an essential part of the coupled Indian monsoon system because it feeds the moist convection over both land and ocean."

4. "Representative months January and July for winter and summer in northern hemisphere, respectively"
I understand that these months can be representative of the seasons, but any significant changes in winter and summer cannot be directly linked to these months; as they could occur in other months of the respective seasons as well. In other words, any changes in these two months, such as trends and bias, may not represent the seasonal change. It should be specified in Methods.

Yes, we agree with the reviewer. Only in Fig. 1, we chose January and July months for the scatter plots of collocated COSMIC water vapor retrieval versus ERA5 and ERA-Interim water vapor data comparison. We also studied the scatter plots for other months (not shown in the

paper), the conclusion that COSMIC water vapor is more consistent with ERA-5 than ERA-Interim holds for these other months as well. We added this note in the paper.

In the later part of paper, the study of the seasonal variability of the of COSMIC and ERA5 water vapor distribution in Section A.1 was performed over 12 months.

5. Reanalysis data can be used as reference for the validation of satellite measurements? To support this argument, cite some references on the validation of ERA5 (to check the consistency of ERA5) and write about the errors, if any.
We added one paragraph in Section 2.1 to address this "Many studies have been conducted to validate the ERA5 atmospheric products using satellite measurements (Chen and Liu, 2016; Lei et al., 2020; Tang et al., 2021; Campos et al., 2022). Overall, the results of these studies show that ERA5 is in good agreement with satellite measurements (or retrieved products). For example, Tang et al. (2021) compared the Atmospheric downward longwave radiation (DLR) from Clouds and Earth's Radiant Energy System (CERES) satellite retrievals and ERA5 data with observations at Baseline Surface Radiation Network (BSRN) stations over land surfaces. The ERA5 atmospheric reanalysis performed better than satellite retrievals in estimating DLR over the land surface. According to Chen and Liu (2016), the global water vapor trend over 1992–2014 from the data of the ECMWF reanalysis model agrees well with the microwave satellite data. These studies provide confidence in the accuracy of the ERA5 products for comparison with COSMIC retrievals."

6. In reply to my previous comment "Why COSMIC water vapour overestimates ERA5 in the upper troposphere?" authors state that there is large uncertainty in retrieving water vapour in the reanalysis model in the upper troposphere. It should be clearly mentioned in the methodology, why there is a bias in ERA5 and how much, because ERA5 is used as the reference data for the validation of COSMIC here. It is better to check the consistency of ERA5 in other pressure levels also.
The main cause that at 300 hPa, water vapor from COSMIC is higher than from ERA5 stems from the distinctive cloud-penetration capability of the RO signal, whereas the water vapor from the reanalysis data is assumed from the cloud-free scenes. COSMIC RO water vapor is retrieved over both cloudy and cloud-free scene, while water vapor from the ERA5 reanalysis model is from cloud-free scene water vapor profile. It is expected that the water vapor concentration derived from COSMIC will be higher than ERA5 at 300 hPa when cloudy scene is accounted in the RO retrieval. Our evaluation of the bias of ERA5 at 300 hPa indicates that the ERA5 may underestimate the global water vapor by about 5.67% when assuming cloud-free in the ERA5. Such assessment is consistent with the water vapor biases between COSMIC-2 and ERA5 presented in Johnston et al., 2021. Figure 1 below shows the height-dependent COSMIC versus ERA5 water vapor biases. The biases between COSMIC and ERA5 grows from nearly 0% at 450 hPa to about 8% at 260 hPa (10 km) in the upper troposphere.

We note that there are large uncertainties in estimating the upper troposphere water vapor by the reanalysis model, which are due to the combined effects of complex atmospheric dynamics (jet streams, convection, and mixing) at high altitudes, sparse observations and difficulties in validation, errors in extrapolating from lower altitude measurements, and accurate accounting of radiative effects at high altitudes. There are ongoing efforts to quantify the ERA5 biases in the upper troposphere through comparison with other measurements such as using multi-campaign data set on research aircraft (Krüger et al., 2022). But, the results are not conclusive due to limited regional, height and temporal coverage of the comparison. In this regard, the comparisons presented in this paper help assess the biases in the reanalysis model. Further

comparisons with collocated radiosonde measurements can also help assess the biases in ERA5 in the upper troposphere.
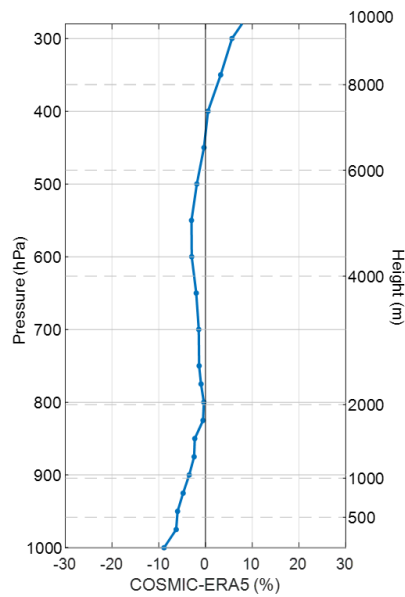

Figure 1: COSMIC vs. ERA5 water vapor biases (%) as a function of pressure or height.

Reviewer #1's Comments:

The manuscript has significantly improved, but still lacks in the quality of the language and a clear writing. There are lot of small errors. It would have been good if the authors would have spent more effort in a careful check of the manuscripts before submission. To list all this small errors is for me as referee really time consuming and distracts me from really focusing on the contents of your study.

We thank the reviewer for the helpful comments and have substantially revised the manuscript.

General comments:

The abstract is a bit too long and detailed on the results. I would suggest to skip the explicit numbers of the trend and rather qualitatively state if the trend is positive or negative (and give the order, i.e a few percent). Further, it should be more clearly stated which comparisons have been made instead of writing in detail which differences where derived in which area. I also think mentioning that the El Nino water vapor increases are visible in the data is rather obsolete in the abstract. Write down some key points and make out of these a clear structured abstract.

Following the reviewer's suggestion, we have revised and significantly shortened the abstract. The sentence on the El Nino-related water vapor increases has been removed.

I don't understand the difference between slope and trend. Isn't the slope of the linear fit the

trend?

Yes. the slope is the linear fit of the trend. We went through the paper to limit the use of term "slope" only for fitting.

The result session is still too descriptive and lacks explanations.

We made improvements to the manuscript to address this. Details can also be found in our replies to the specific comments.
1. Added detailed motivations of choosing three pressure layers in this study, their characteristics, and uncertainties, and past studies.
2. Revised and expanded the explanation inter-hemispheric water vapor differences.
3. Added the explanation of the connection between higher temperatures and higher levels of water vapor in the atmosphere
4. Added explanations of Niño3.4 3.4 and Niño4 indices, and the identification of El Niño event.
5. Added the motivations and methods for selecting the regional sites presented in this paper.
6. Expand the discussion on the Monsoon climate effects on regional water vapor trends,

The term trending should be replaced by trend, wetter should be replaced by moister, heights by altitudes.

We went through the manuscript and made corresponding corrections.

There is still too much data analyses shown in the result section. It is not clearly motivated what the intention is of picking all these sites and looking at them.

The representative regional sites selected in Section 5 help quantitatively understand the regional variability, consistency and differences between COSMIC and ERA5 water vapor trends. Section 5.3 in previous draft has been moved to Appendix A.4. Sections 5.2, 5.3 and Section A.4 provide quantitative information of the water vapor trends over the selected sites and complements the color map of Fig. 7 shown in Section 5.1. We added the explanation of the motivations and selection processes for these regional sites.

The first set of sites (Sites #1-3 in Fig. 8) discussed in Section 5.2 is over stratocumulus cloud-rich regions. Section 5.1 helps to answer the question if there are differences between COSMIC and ERA5 water vapor trends over these stratocumulus cloud-rich regions and quantify the difference. The selection of these stratocumulus cloud-rich sites follows the study of Wood 2012 (see the figure below).
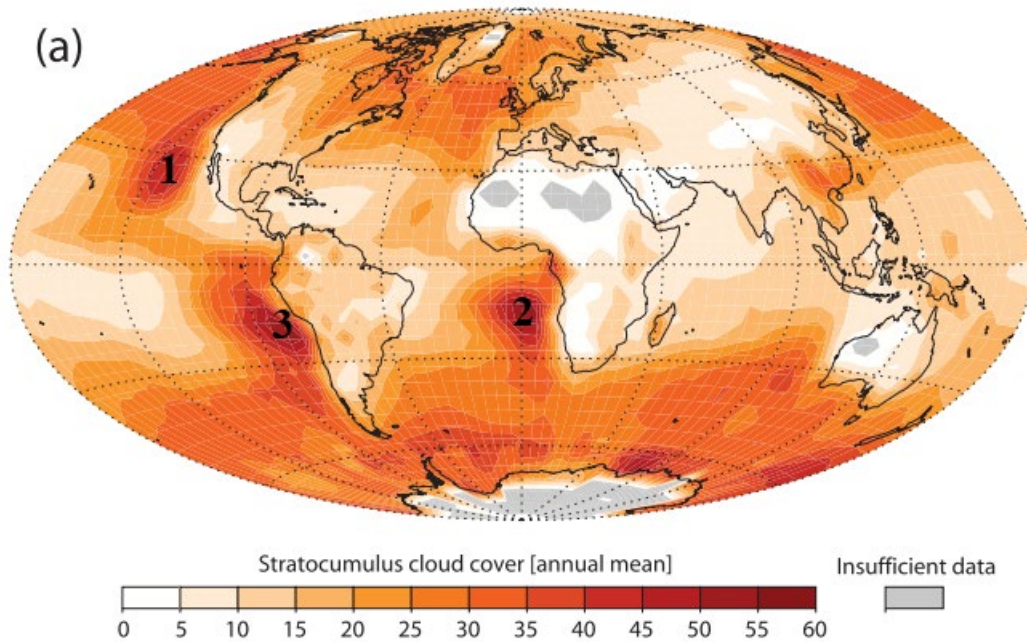
Figure 2: Selected stratocumulus cloud-rich regions (Site #1-3 in our paper) overlaid on the annual mean coverage of stratocumulus cloud map from Wood, 2012.

The sites studied in Section 5.3 (Section 5.4 in previous draft) all have substantial water vapor trend differences between COSMIC and ERA5. We added the explanation of the motivation and process for selecting these sites "Comparing regional water vapor trends between COSMIC and ERA5 data and quantifying their differences contribute to validating both datasets. In particular, it can identify regions where the reanalysis model could exhibit constraints. In this section, we select a few sites with a notable trend difference between COSMIC and ERA5 to quantitatively understand the magnitude of the differences and the distribution of these sites. To identify these sites, we first searched the 10°×10° global map of the water vapor trend difference between COSMIC and ERA5 (Fig. 7e and 7f shown in Section 5.1). We identified the regions with the largest positive or negative water vapor trend difference between COSMIC and ERA5. Within these regions, we selected one representative 10°×10° grid in each region as the site of interest. The estimated water vapor trends for COSMIC and ERA5 over these sites, with notable trend differences are listed and compared in Table 4.".

We have moved Section 5.3 in previous draft to Appendix A.4. The motivation and details of the selection process for sites with strong increasing and decreasing water vapor trends are explained in the first paragraph in Section A.4. The explanation can also be found in our response to the question that immediately follows the next one.

since you have trouble expressing yourself it makes following the discussion really difficult. In this case a shorter more concise study would be more beneficial. Section 5 should either significantly improved or omitted. At the moment it makes only the paper longer, but does not provide any knowledge gain.

Section 5 has been improved with our revision. We have shortened Section 5 by moving Section 5.3 to Appendix A.4 "Comparison of COSMIC and ERA5 over sites with notable increasing and decreasing water vapor trends".

We also revised Section 5 following both reviewers' specific comments. For example, we expand the discussion on the Monsoon climate effects on regional water vapor trends, added the explanation of the connection between higher temperatures and higher levels of water vapor in the atmosphere, and added the motivations and methods for selecting the regional sites presented in this paper. Section 5 is a critical part of this paper which complements previous sections on the global and latitudinal water vapor trend comparisons between COSMIC and ERA5. In Section 5, the emphasis on evaluating the consistency and differences of regional water vapor trends between COSMIC and ERA5, and provide quantitative information of the water vapor trends over the selected sites.

For example Section 5.3. Why is this studied? It's just a listing of trend estimates without explaining or discussing the cause or consequence of these increasing trends.

Following the reviewer's suggestion, we have revised and moved Section 5.3 to Appendix A.4 "Comparison of COSMIC and ERA5 over sites with notable increasing and decreasing water vapor trends".

In Section A.4, we added the motivation and the selection process of these regional sites "Although the global and latitudinal water vapor trends presented in Section 4 exhibit an overall upward trend, Figures 7a-d in Section 5.1 highlight that within tropical and subtropical regions, the regional distribution of water vapor trends displays significant local variations with a blend of pronounced increases and decreases in trends. Such variations in regional water vapor trends in general agree with the past studies, e.g., Ross and Elliott, 2001; Dai, 2006; Mieruch et al., 2008, 2014; Zhang et al., 2018. In this section, we quantitatively evaluate the regional variability of water vapor trends by selecting a few sites with notable increasing (Sites #8-#12 in Fig. 8) and decreasing (Sites #13-#17 in Fig. 8) water vapor trends and compare with past studies. To identify these sites, we first searched the $10^o \times 10^o$ global grids and identified the regions with the largest increasing and decreasing water vapor trends. Within these regions, we selected one representative $10^o \times 10^o$ grid in each region as the site of interest, and the water vapor trends of these sites estimated from COSMIC and ERA5 data are listed and compared in Table A.1 and A.2. ".

Section 5.4 is quite confusing. Here you refer to Figure 7, but this Figure has already been described in Section 5.1. Are you using this figure for both sections? Is the reference really correct? You should more clearly state here what is shown in this figure and refer to Section 5.1.

We agree with the reviewer and have moved the paragraph on Figure 7e-7f (map of trend difference between COSMIC and ERA5) to Section 5.1 to avoid confusion about the discussion of Fig. 7e and f.

Further, I am not satisfied with your answer why you selected the altitudes 500 and 300 hPa. You should provide a motivation with respect to atmospheric processes or a certain atmospheric region, e.g. stating that you with these levels cover the entire troposphere (lower, middle, higher troposphere) would be fine with me. However, how can you know what differences and uncertainties to expect? Isn't that what you derive from this study? I think you should improve this paragraph (Sect. 2). Further, you should provide an explanation why you expect this differences.

We have revised Section 2 on the motivation of choosing the three pressure levels studied in the paper to address this.

"The pressure level at 850 hPa studied in this paper is close to the surface and within the boundary layer. Its water vapor can vary based on factors such as humidity levels near the surface, regional water vapor sources, and weather patterns. From previous studies (Ho et al., 2009, 2020a; Shao et al., 2021a; Johnston et al., 2021) of comparing RO water vapor data with collocated reanalysis model data or radiosonde measurements, it was found that RO water vapor retrievals have a negative bias in the lower troposphere. The COSMIC water vapor retrieval is strongly affected by super-refraction at this pressure level in the moisture-rich regions (Ho et al., 2010). It is worth evaluating the relative biases and consistency in the trends on various spatial scales between COSMIC and ERA5 water vapor datasets at this 850 hPa pressure level.

The water vapor at 500 hPa can vary widely depending on local weather conditions and atmospheric patterns. Water vapor at 500 hPa is crucial for understanding the development of weather patterns, including mid-latitude cyclones, ridges, and troughs. This pressure level also contributes to the upper-level atmospheric circulation patterns through convection, which carries moist air upward from the lower troposphere and plays a role in redistributing heat and moisture. It was learned from the earlier comparison of RO data with radiosonde measurements that starting from the pressure level at 500 hPa, the RO-water vapor retrieval uncertainty increases as altitude decreases. Therefore, we chose 500 hPa as the representative middle troposphere of interest to study in this paper.

The 300 hPa pressure level represents the water vapor layer with fewer horizontal variations at higher altitudes. Water vapor in the upper troposphere plays a critical role in the Earth's radiative balance and climate system. It affects the absorption and emission of radiation, contributing to warming (absorbing and trapping infrared radiation, i.e., greenhouse effect) and cooling (emitting heat energy) effects. Johnston et al. (2021) showed large discrepancies in the ERA5 and MERRA2 reanalysis model water vapor profiles compared to COSMIC-2 in the upper troposphere. There are large uncertainties for the reanalysis model to estimate the upper troposphere water vapor due to the combined effects of complex atmospheric dynamics (jet streams, convection, and mixing) at high altitudes, sparse observations and difficulties in validation, errors in extrapolating from lower altitude measurements, and accurate accounting of radiative effects at high altitudes. Therefore, we chose 300 hPa as the representative upper troposphere level to compare spatial and temporal variabilities of water vapor between COSMIC and ERA5."

I think also the conclusion and discussion should be improved. You just squeezed in there some answers to my comments, which however feel there rather lost and out of context.
We have revised and improved conclusion and discussion section by incorporating the reviewer's specific comments.

I have listed my specific and technical comments below.
We have addressed the specific and technical comments one by one. See our replies below.

Specific and technical comments:

P2, L25: qualities -> quality
Corrected.

P2, L59: skip "and" before microwave
Corrected.

P2, L63: skip "and others". I would say that this is obsolete since you already write in the beginning of the sentence "mainly"
Corrected.

P3, L65: in -> for, so that it reads "for long-term……."
Corrected.

P3, L66: I would not use the term "monitoring" for reanalysis data. This is a term that should be rather used with measurements. Thus, I would suggest to write: These atmospheric reanalysis data have been used for understanding (or investigating) long-term atmospheric water vapor variability and trends (or more general changes).
Rephrased the sentence to "These atmospheric reanalysis data have been used for investigating long-term atmospheric water vapor variability and trends".

P3, L82:the rise -> the increase
Corrected.

P3, L88: data -> datasets
Corrected.

P3, L90: add "ERA" before Interim
Corrected.

P3, L90: better than reanalysis from -> better than the reanalysis data (add "the" and "data")
Corrected.

P3, L92: What exactly do you mean with "other sensor data"? Please clarify and rephrase.
We have rephrased the sentence as "The ERA-interim overestimates the PWV over the ocean for the period before 1992 compared to microwave satellite data."

P3, L94: assure the climate community with -> provide to the climate community (replace assure by provide to and delete with)
Corrected.

P4, L101: microwaves -> microwave
Corrected.

P4, L102: Add "Further," before "RO-derived".
Corrected.

P4, L108: skip comma and add "for" and "and", so that it reads "for climate and meteorological research"
Corrected.

P4, L110: distribution -> distributions
Corrected.

P4, L111: from 2007 to 2018 -> for the time period from 2007 to 2018
Corrected.

P4, L121: replace "As supplementary" by "Additionally"
Corrected.

P4, L122: add "the" -> in the Appendix
Corrected.

P4, L122: ……with introduction to estimating the water vapor trend -> you mean with introducing (or rather describing) the estimation of the water vapor trend? Please check and rephrase (correct English grammar)
Rephrased the sentence to "Appendix A.2 and A.3 describe the estimation of the water vapor trend with sampling error removal and its associated uncertainties for a given region of interest (RoI)."

P5, L138: occulted by the Earth's atmosphere -> not correct, please rephrase.
The sentence has been revised to "bent by atmospheric refraction".

P5, L140: Start the sentence with "From" replace "data" by observations and write "are derived", thus "From the retrievals …… first the bending angle……are derived"
Corrected.

P5, L144: profile -> profiles
Corrected.

P5, L146: 2007 to 1028 _> 2007 to 2018
Corrected.

P6, L166: before the study? Please rephrase? Do you mean before the analyses has been performed?
Corrected.

P6, L169: add "the" -> For the RO
Corrected.

P6, L173: could -> may
Corrected.

P8, L231: troposphere -> tropospheric
Corrected.

P8, L233: small -> low
Corrected.

P8, L233: skip "also" and rephrase the next sentence as follows: "The main cause that at 300 hPa higher water vapor from ERA5 than from COSMIC is derived is due….. estimating water vapor….." You can retrieve data, but from a model the data is simulated or estimated.
Corrected.

P9, L247: delete "model"
Corrected.

P9, L248: in consistently -> is consistently
Corrected.

P9, L249: not the "retrieval", but the "retrieval data", thus change "retrieval" -to "retrieval data" P10, L262: 20-degree-latitude-bin-averaged -> please rephrase and write averaged over 20 degree bins, thus you could write "averaged over 20 degree latitude bins at the three selected pressure levels (300, 500 and 850 hPa).
Corrected.

P10, L266: in Fig. 3 -> shown in Fig. 3 or just write Fig. 3 in parentheses -> (Fig. 3)
Corrected.

P10, L272: a wetter what? A wetter atmosphere? Skip? Rephrase?
We have removed "wetter".

P10, L278: wetter -> moister
Corrected.

P10, L279: Sentence not clear. Please rephrase.
The sentence has been rephrased to "Feulner et al. (2013) examined climatological data, Earth's energy budget, and model simulations for factors that could lead to interhemispheric temperature differences.".

P10, L281: Which factors? Clearly state what you are referring to.
We revised the sentence as "The study of Feulner et al. (2013) compared various factors, including seasonal differences in solar radiation, the tropical land area difference, the difference in albedo and temperature between Antarctic and Arctic polar regions, as well as cross-equatorial ocean heat transport from the southern hemisphere to the northern hemisphere." to make it clear.

P11, L282-283: What do you mean with "warmer NH" and "colder SH"? The winter and summer hemispheres?
We should remove "warmer" and "colder" here. The sentence has been revised to "cross-equatorial ocean heat transport from the southern hemisphere to the northern hemisphere".
The warmer NH and colder SH refer to the air temperature in the northern hemisphere being 1–2°C warmer than in the southern hemisphere according to the annual values for hemispheric average of surface air temperature listed in Table 1 of Feulner et al. (2013).

P11, L286: grow -> increase
Corrected.

P11, L286-287: Sentence is not clear. Something is missing here.

We rephrased the sentence as "As greenhouse gas emissions continued to rise throughout the industrial era, interhemispheric temperature disparities became larger. This is attributed to the intensified warming of land areas compared to oceans and the significant reduction of Arctic sea ice and snow cover in the northern hemisphere.".

P11, L289: These factors? Do you mean these conditions? Not clear what you exactly mean.
We revised the sentence as "These factors, e.g., cross-equatorial ocean heat transport, albedo difference in polar regions, intensified warming of land areas, and reduction of Arctic ice/snow cover, affecting interhemispheric temperature difference, can affect the interhemispheric water vapor difference.".

P11, L289: How or why? How can temperature differences affect water vapor? You just described temperature differences. How is temperature connected to water vapor?
We added explanation "The close relationship between temperature and the capacity of the atmosphere to hold water vapor is governed by the Clausius-Clapeyron equation (Held and Soden, 2006). The equation states that for every 1-degree Celsius increase in temperature, the saturation vapor pressure increases by about 7%. As temperature increases, this will lead to the potential for more water vapor to be held in the air. In other words, warmer air has a higher capacity to hold water vapor. This relationship is crucial for understanding how temperature changes can impact atmospheric humidity. The observed and modeled evidences presented by Wentz and Schabel (2000), Trenberth et al. (2005), Held and Soden (2006), and Allan et al. (2014), supports the notion that higher atmospheric water vapor contents are, in general, associated with higher temperatures."

P11, Figure 3 caption: skip "20-degree-latitudinal……" Just write in the first sentence what is compared and then in the second sentence how the data has been treated.
Corrected.

P11, L291: retrieval -> observation or retrieved data
Corrected.

P11, L295: over all months in 12 years -> for all months of the considered 12 year period
Corrected.

P12, L297: add "shown" before "in the middle……."
Corrected.

P12, L310: put Fig 3h and 3f in parenthesis
Corrected.

P12, L311: Fig 3h shows -> From Fig 3h it can be seen…..
Corrected.

P12, L314: Same here: From Fig 3j it can be seen….. P12, L316: add "differences" before being
Corrected.

P12, L3198-319: Skip "after sampling……". You don't need this in the section title. It is enough to mention this in the text part.
Corrected.

P12, L323: Sampling removed water vapor -> rephrase. Rather write COSMIC water vapor data where sampling errors have been removed.
Corrected.

P12, L323: in the rest of this paper -> in the remainder of this paper, but better would be to write in the following.
Corrected.

P12, L325: This section compares. Not the section is doing the comparison, but you. Correctly it should read "In this section………are compared".
Corrected.

P13, L335: Change "It is noted" to "It becomes visible" or "It can be seen"
Corrected.

P13, L341. What is NINO3.4 and NIN4? An explanation should be given in the text.
The sentence has been revised as "The recent 2015-2016 El Niño event broke warming records in the central Pacific according to Niño3.4 (sea surface temperature (SST) anomalies averaged over the equatorial region (Latitude: -5° to 5°; Longitude: -150° to 160°) of the Pacific Ocean) and Niño4 indices (SST anomalies over the region (Latitude: -5° to 5°; Longitude: -150° to 160°))." to explain the two indices.

P13, L342: add "the" before April
Corrected.

P13, L346: Add "the" before
seasonal
Corrected.

P13, L346: change "as seen" to "as visible" or even better skip this and put Fig 4a in parenthesis at the end of the sentence.
Corrected.

P14, Figure 4 caption: Needs to be improved. Too much repetition. First sentence obsolete? Trending should be replaced by trend (throughout the manuscript).
Corrected.

P14, L366: trending -> trend and put Fig 4a in
parenthesis P15, L366: Add time period after water
vapor concentration.
Corrected.

P15, L369: with -> using, delete of ECMWF data or write ECMWF ERA-40 data
Corrected.

P15, L369, 370 and 371: delete "in" and put references in parenthesis.
Corrected.

P15, L373: were trended -> were used to derive the
trend P15,
Corrected.

L378: move the time period behind paper
Corrected.

P15, L379: at three -> at the three and replace from by considered in
Corrected.

P15, L384: add "the" -> the three
Corrected.

P15, L386: trends -> trend, with -> for the and move the time period
data
Corrected.

P15, L387: is -> are
Corrected

P15, L388: overlapped -> overlapping
Corrected.

P15, L390: Just write "a positive water vapor trend of " or " a positive water vapor trend of
1.44%". If you write positive or negative you do not need to give a number. Vice versa, If you
give the number then you do not need to write positive or negative.
Corrected.

P16, L404: trending -> trend
Corrected.

P16, L408 and 411: What do you mean with trending slope? Is not the trend the slope of the
linear fit?
Corrected.

P16, L409: in -> at and delete "latitude range" at the end of the sentence.
Corrected.

P16, L416: in should be replaced by at or for
Corrected.

P17, L426: "mixed with" should rather read "composed of" or "consisting of".
Corrected.

P17, Figure 5 caption: Comparing -> Comparison of (two
occasions)
Corrected.

P17, Figure 5 caption L437: skip retrieval.
Corrected.

P17-18: Figure 5: The sentence starting with "The bar ….." is not clear and needs to be
rephrased.
Corrected.

P18, L445ff: In most occasions you can skip writing northern and southern. IF you provide the coordinates with plus and minus signs this is enough.
Corrected.

P18, $49: within -> of
Corrected.

P18, L453: Put Fig 5f in parenthesis and delete "in"
Corrected.

P18, L454: Why -60 to 80? Is that correct? Or should it be -60 to -80?
Corrected.

P19, L457: Put "Figure 5g and Table 2" in parenthesis and delete "show that"
Corrected.

P19, L460: high -> higher
Corrected.

P19, L461: estimations -> estimated
Corrected.

P19, 463: with latitude bins needs to be rephrased.
Corrected.

P19, L460ff: I thought you made a separation into 20 degree bins, Why are in this section larger bins discussed?
Certain latitude bins exhibit similar or closely aligned trends. As a result, the characteristics of these latitude bins are collectively discussed within combined latitude ranges.

P19, L466-467: Sentence not clear. Needs to be rephrased.
We have rephrased the sentence as "This indicates that the main reason for the relatively lower global water vapor trends estimated from COSMIC data compared to ERA5 data at the 850 hPa level (as presented in Table 1) is the lower values of COSMIC trends within the middle and low latitude bins."

P19, L475: interval -> period
Corrected.

P19, L476: the period -> this time period
Corrected.

P19, L476: delete distributed and write "mostly fond over the ……"
Corrected.

P19, L477: above -> greater than
Corrected.

P19, L478: Sentence not clear. Please correct.

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We have rephrased the sentence to "Missing COSMIC RO data is prominent over the regions covering the Tibetan Plateau, specifically at pressure levels of 500 and 850 hPa. The absence of RO data in these regions can be attributed to the lower atmospheric pressure prevailing over areas at an average altitude of around 4 km."

P19, L478:trending -> trend
Corrected.

P20, Figure 6 caption: no monthly data missing? What do you mean here? With no data or with missing data? I guess the grids with missing data are shown as white blanks.
Corrected. Figure 6 caption has been revised as "The percentage of missing monthly data over the 2007 to 2018 interval on the global 10°×10° grids. The percentage of missing data is shown as color-coded. Grids with complete monthly data and without gaps, i.e., covering all months, are represented as white blank spaces."

P20: I do not understand what you mean here with interface.
Corrected.

P21, Figure 7 caption: In two occasions trending should be replaced by trend.
Corrected.

P22, General: Move the latitudes und longitudes behind the respective region, e.g Laccadive Sea
Corrected.

P22, L533: Here you write this region, but two different latitude and longitudes are given. Do you mean "these regions"? And which regions are you talking here about? The text would be much easier to read if you would put the coordinates at the end and not always after "region".
Corrected.

P22, L544: "These established sites are in 10 by 10 longitude/latitude grids". Not clear what you mean since sentence not grammatically correct. What do you mean with established?
We have merged this sentence and the previous sentence to make it clearer. It is revised as "The center locations of these selected 10°×10° grids are shown in Fig. 8.".

P23, L550 and 552_ heights -> altitudes
Corrected.

P23, L550: delete "being driven
by"
Corrected.

P23, L553: cloud -> cloud layer
Corrected.

P23, L564: show -> show that
Corrected.

P23, L565: Increasing with what? With time? With space?
Corrected.

P24, L574: heights I -> altitudes from
Corrected.

P24, L575: cloud -> clouds
Corrected.

P24, L576: water trends -> water vapor trends
Corrected.

P24, L580 and 581: add "located" -> are located in the ocean, are located on the land
Corrected.

P24, L580: Delete "In" and move Table 4 in parenthesis at the end of the sentence and start sentence with "Both".
Corrected.

P24, L581-582: What do you mean with substantial water vapor? High concentrations?
Corrected.

P24, L590: Still the connection between water vapor and temperature has not been explained. Why should or does higher temperature cause higher water vapor?
We added the explanation in Appendix A.4 "Many previous studies have explored the trends in surface temperature (e.g., Gu and Adler, 2022 and references therein). Global surface keeps warming up, though with rich spatial structures of temperature change. Higher surface temperatures are closely linked to higher levels of water vapor in the atmosphere through the relationship governed by the Clausius-Clapeyron equation. The saturation vapor pressure of water vapor increases with temperature. The close relations between higher temperature and higher water vapor have been shown in observations and models (Wentz and Schabel, 2000; Trenberth et al., 2005; Held and Soden, 2006; Allan et al., 2014). From the study by Gu and Adler, 2022, ocean surface warming can readily be seen in the Indian and tropical Pacific oceans, roughly corresponding to the strong increasing tropospheric water vapor trends for Sites #8, #9, and #12 we observed."

P26, L623: add located (twice) before over the ocean and over land, respectively.
Corrected.

P28, L630: What do you mean with "on the west"? The West Pacific?
We revised the sentence to "There are no 850 hPa RO data over the Andes Mountains (over 6 km in altitude) area. The RO water vapor trend data mainly come from the Pacific Ocean in the 10°×10° grid of Site #7."

P26; L631: from 2007 to 2018 -> for the timer period 2007 to 2018
Corrected.

P26, L632: Change to "From the linear trend study of global……"
Corrected.

P26; L634 to 635: singular or plural? A nearby cloud or nearby clouds? Why nearby? How do you know that a cloud was nearby?

We have revised the sentence as "Site #7 is situated in close proximity to Site #3 and falls within an area where there is a frequent presence of low-height stratocumulus clouds (Wood, 2012)"

P26, L636: in -> at
Corrected.

P26, L639: delete "area"
Corrected.

P26, L646: paper -> study
Corrected.

P26, L649: move "´better" before "resolve", so that it reads "better resolve……"
Corrected.

P27, L654: The section "Conclusions and Discussions" should be renamed to "Discussion and Conclusion".
Corrected.

P27, L664: I don't agree. Only because the COSMIC data agrees better to ERA5 it does not mean that it is closer to the true state of the atmosphere. The reanalysis is, although data is assimilated, still a model. I also do not understand why the assimilation impacts are negligible. This discussion should not be squeezed to the major conclusion bulltest, but rather discussed beforehand.
We agree with the reviewer and removed the sentence "COSMIC water vapor is closer to the true state of the atmosphere, i.e.," to avoid calling ERA5 as the true state of the atmosphere. We also rephrase the sentence as "). Our study shows that COSMIC water vapor retrievals are more consistent with ERA5 reanalysis data than ERA-Interim. From the data assimilation point of view, this suggests that although UCAR COSMIC 1DVAR retrieval used ERA-Interim as the background model (see Section 2.2), but the impacts from ERA-Interim in the UCAR 1DVAR retrieval processing is minimum.". The impacts of the ERA-Interim on UCAR COSMIC 1DVAR retrieval was discussed in Section 2.2 and referenced here.

P27; L666: Also mentioning here SPARC feels a bit lost. The mentioning of the efforts of the SPARC community would rather fir into the first paragraph of this section to highlight why such intercomparisons are important.
This is a good suggestion. We moved the mentioning of "SPARC" to the beginning of this paragraph. The revised sentence reads "There have been coordinated efforts from Stratosphere–troposphere Processes And their Role in Climate (SPARC) Reanalysis Inter-comparison Project (S-RIP) to compare reanalysis datasets such as ERA5 and ERA-Interim using a variety of key diagnostics. The SPARC S-RIP confirmed the significant improvements of the latest version of reanalyses in ERA5 compared to ERA-interim (Fujiwara et al., 2017)."

P27; L675: this paper -> here
Corrected.

P28; L694: estimating from 2007-2018 -> estimates for the time period from 2007 to 2018
Corrected.

P28; L704: have substantial variabilities -> show substantial variability
Corrected.

P28, L707: slopes?
We have corrected it to "trends".

P29, L711: with -> between
Corrected.

P29, L717: move the latitude/longitude coordinates behind the respective
areas
Corrected.

P29; L729: What can be better characterized?
We revised the sentence to "the height and temporal distribution of water vapor can be better characterized in RO retrievals than ERA5 in the presence of convection, such as deep clouds.".

P29, L737: Not clear, if you mean here in general or in specific areas. Before good quality of RO data mentioned, here now deficiencies discussed, but is not made clear that this is a correction of the data.
Our intention was to discuss the sampling error removal and that the comparison of water vapor trend of COSMIC with ERA5 can be extended to compare with other reanalysis models such as MERRA and NCEP. We have combined the two paragraphs to "In analyzing long-term water vapor trends from RO data, it is important to remove sampling errors to correct the biases due to RO data's limited time and location coverage. ……This paper's overall global water vapor trends are close to the trend results from Allan et al. (2022). We postulate that using other global reanalysis models, such as NCEP and MERRA-2, may have compatible global trends but differ in regional trends from our results, which will need further evaluation.".

P29, L738: Here it could be stated that ERA5 data has significantly improved compared to ERA- interim.
We revised the sentence to "confirms that ERA5 has significantly improved quality than ERA-Interim."

P29, L739: trending -> trend
Corrected.

P30, L746: times of what. Please be more precise.
We revised the sentence as "After applying sampling error removal, our estimations indicate a reduction in uncertainty by approximately 4.8 times at 500 hPa and 3.1 times at 850 hPa." to make it clear.

P38, L921: trending -> trend
Corrected.

P38, L933, Figure A6 caption: Delete distributions
Corrected.