Author's Response

Paper Number: ACP-2021-976
Paper Title: Evaluation of tropical water vapour from CMIP6 GCMs using the ESA CCI "Water Vapour" climate data records

We thank the editor and the anonymous referee for the comments on our manuscript that help to improve the quality of this manuscript. We have carefully addressed all the points raised by the reviewer. Please find below our response and corresponding changes made in the revised paper.

Sincerely,
On behalf of all authors,
Jia He

Anonymous Referee #3

Focusing on the tropical belt, this study compares interannual variability of total column water vapour of global climate models and ERA5 with that inferred from the ESA TCWV-COMBI data set. Large discrepancies between ESA TCWV-COMBI and ERA5/GCMs are found over the land, and the authors attribute the discrepancies over the land to a clear-sky scene selection issue as well as deficiencies in model parameterizations. This is an interesting study, but I think there are some aspects that need to be clarified.

Data sampling issue: I agree with the authors that discrepancies over the tropical land are mainly related to clear-sky scene selection. Figure 1 implies, however, that the discrepancies may also result from incomplete spatial/temporal coverage of satellite observations. For instance, in the bottom left panel of Fig. 1, TCWV values are missing over some land regions (e.g., 20E-30E, diagonal direction from southwest to northeast) because those regions are not covered by satellite observations, rather than due to cloud contamination. In addition, Table 1 indicates a discrepancy in temporal sampling between ESA TCWV-COMBI (day-time only) and ERA5/GCMs. Given this sampling issue, I think monthly-mean data (or weekly-mean) are more appropriate for this intercomparison study than daily-mean data.

Reply: We appreciate this comment. The reason that we conduct this evaluation analysis using daily data instead of monthly mean for several reasons. Firstly, our intention is to evaluate the datasets with the highest temporal resolution, as the temporal averaging will mask out the extremes and the PDFs would have been smoothened. Secondly, since the cloud condition varies significantly over short time scales, quantification at high temporal resolution is required. Last but not least, the spatial resolutions for GCMs are much coarser than the observation data of TCWV-COMBI. To maintain certain amount of data for further evaluation after cloud screening process, it is judicious to use the daily data in our analysis. Moreover, the datasets are decomposed into dynamical regimes to evaluate the evolution of a particular regime, the discrepancy result from the swaths gaps of satellite observations will not affect the model-observation comparison.

Potential mismatch in large-scale atmosphere circulation between daily and monthly time scales: In this study, the mean climatology and interannual variability of daily-mean TCWV are examined as a function of monthly-mean 500-hPa vertical velocity. However, due to large day-to-day variability of vertical motion, descending motion can occur for some days of a given month while large ascending motion is prevalent over that month, and vice versa. This mismatch in vertical velocity between daily and monthly time scales can result in potential errors and inconsistencies. In other words, low values of daily-mean TCWV accompanied by daily-mean descending motion could be assigned into ascending motion bins at monthly time scale. In fact, the distribution of ESA TCWV as a function of monthly-mean 500-hPa vertical velocity shown in Fig. 7d appears to be inconsistent with Fig. 2: while the largest values of ESA TCWV are found over weak subsidence regime in Fig. 7d, Figure 2 suggests a clear linkage of humid regimes with large ascending motion. So I think that the analysis associated with Figs. 7-11 should be conducted at the same time scale using either daily or monthly-mean data.

Reply: Thanks for the comment. The previous study suggests that the ω500 is sensitive to local dynamics and subject to significant biases at the instantaneous scale (Trenberth, K.E., Stepaniak, D.P. and Caron, J.M., 2000. The global monsoon as seen through the divergent atmospheric circulation. Journal of Climate, 13(22), pp.3969-3993). The monthly vertical motion can represent a mixture of ascending and descending atmospheric conditions. By adopting the monthly mean of ω500 in our evaluation, the fluctuations of shorter time scales, where small-scale convection probably dominates, are ignored. However, research show that the ω500 with shorter time scales are unreliable (Höjgård-Olsen, E., Brogniez, H. and Chepfer, H., 2020. Observed evolution of the tropical atmospheric water cycle with sea surface temperature. Journal of Climate, 33(9), pp.3449-3470). Therefore, the daily water vapour data are decomposed by the monthly mean ω500 in our analysis.

Figure 2 shows that the large-scale downward motion is associated with a dry troposphere, and large-scale ascending motion is associated with humid atmosphere, while the in Figure 7d, the results show that the atmosphere remains humid even in the weak subsidence regime, this was because that the evaporation from the ocean is the primary source of water vapour in the atmosphere, the oceanic boundary layer is humid even in weak subsidence regime.

L7: "especially" – Please consider deleting it as the second part of the sentence describes the ocean case.

Reply: We have revised the manuscript as suggested.

L9: El Niño/La Niña

Reply: We have revised the manuscript as suggested.

L35: total water vapour content (TCWV) – total column water vapour (TCWV) according to L65

Reply: We have revised the manuscript as suggested.

L125: It is unclear whether the same method is applied to the ocean case as in the land case.

Reply: The data over land areas are under clear-sky condition, while the data over ocean areas are under all-weather condition except for heavy precipitation. The following sentence has been revised to clarify this problem:

"Over tropical oceans, the percentage of data that remained after removing the pixels under heavy precipitation conditions range from 99.79% to 99.98."

Figure 1: Some values are plotted over some regions in the southeast Pacific (~20S, 100W) and south Atlantic (~20S, 5W). Are these regions big islands?

Reply: The land-sea mask applied for the sampled model in Figure 1 (CanESM5) was defined by the land area fraction product of the model. Here we defined the area as land where the percentage of the grid cell occupied by land larger than 50%. The areas in question are archipelago, for instance, the Isla de Pascua (~30S, 110W) and the Saint Helena (~20S, 5W).

L118： "The land area fraction product is adopted as the land-sea mask for the CanESM5 model. Here we defined the area as land where the percentage of the grid cell occupied by land is larger than 50%."

L171-172: There are differences in the range of daily mean TCWV exists some differences – Please clarify.

Reply: We have revised the manuscript as follows:

"There are differences in the range of daily mean TCWV."

L172: all datasets have the same changing tendency – I failed to understand the meaning of "changing tendency".

Reply: We have revised the manuscript as follows:

"all datasets varied with the seasons"

L177: softer – weaker?

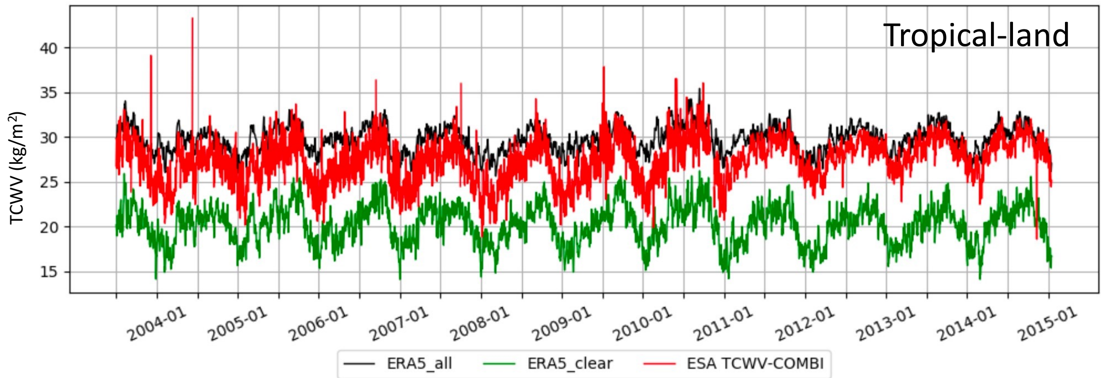
Reply: We have revised the manuscript as suggested.

L178: interannual signal – interannual variability?

Reply: We have revised the manuscript as suggested.

L180: Given that both in situ and satellite observations are used for data assimilation processes in ERA5, it is very surprising to see a large discrepancy (~10 kg/m2) in TCWV between ESA TCWV-COMBI and ERA5. Do the raw ERA5 data without the cloud screening show a similar bias?

Reply: Thanks for the comment. The daily mean data of TCWV over the tropical land areas from raw ERA5 data under all-weather conditions (black), ERA5 under clear-sky conditions (green), and TCWV-COMBI (red) were displayed in the figure below. As the satellite observations are assimilated within the ERA5, the raw ERA5 data are indeed closer to the observations. For the clear-sky ERA5 results, we believe that the large dry bias is due to the fact that the cloudy area, which has been removed as contaminated data, is likely wetter than the nearby clear-sky area for a given location.

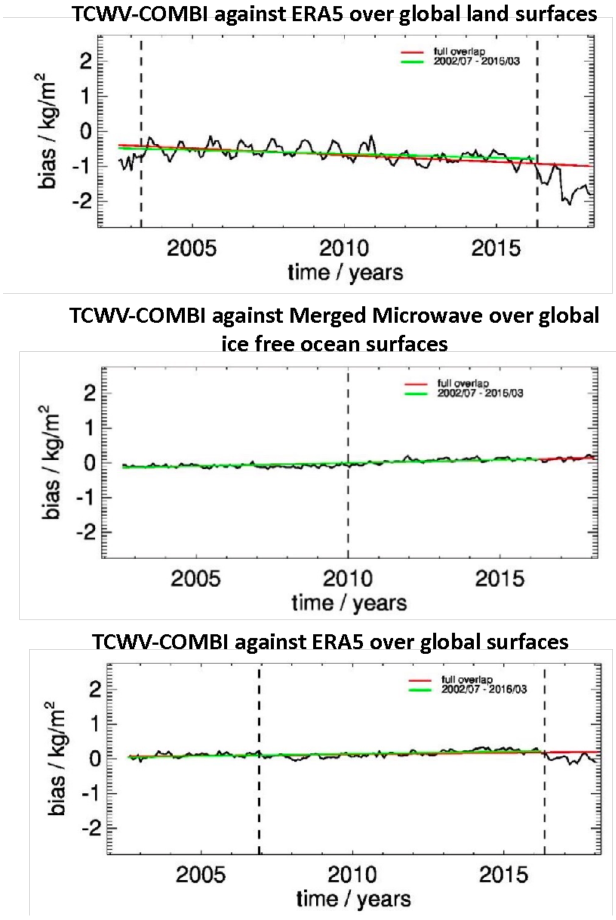


L195-196: This sentence is inconsistent with Fig. 4.

Reply: Thanks for the comment. We have removed this sentence to clarify this problem.

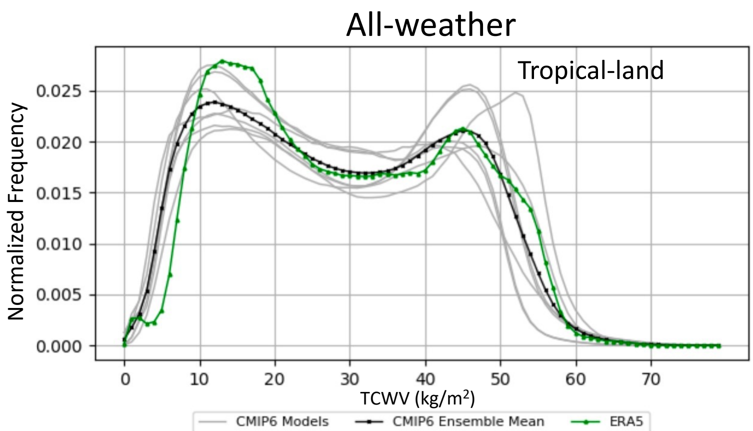
L197-198: Figure 3a shows distinct differences in the long-term mean and associated standard deviation of ESA TCWV between 2003-2011 and 2011-2015, which doesn't appear to support the argument that the ESA TCWV-COMBI dataset is stable and accurate during the whole observations period.

Reply: Thanks for the comment. The ESA TCWV-COMBI dataset is stable and accurate during the evaluation period in this research. The stability of the CCI dataset has been thoroughly evaluated in the "Product Validation and Intercomparison Report", which should be available soon on the ESA CCI Water Vapour web page (https://climate.esa.int/en/projects/water-vapour/key-documents/). As shown in the following figure generated in the report, the ESA TCWV-COMBI data is stable during the observation period in this research (2003 ~ 2014).



Figures 4a/5: Do the resutls based on raw ERA5 and GCMs data (without cloud screening) show a similar distribution?

Reply: We have recalculated the PDFs of ERA5 and GCMs over tropical land under all-weather conditions and the results are displayed in the figure below. This figure has to be compared to Figure 4a. As shown in the figure, the raw datasets are more humid than the data under clear-sky only conditions, with a second peak near 50 kg/m^3 that reaches the about same amplitude than the peak at 10-15 kg/m^3. The cloud screening has removed some of the humid pixels and smoothened the second peak of the raw data.



Figures 5/6: It is difficult to understand why the land case shows large discrepancies between ESA TCWV-COMBI and ERA5 while the distribution is generally similar to each other for the ocean case.

Reply: Thanks for the comment. The TCWV-COMBI dataset merged the NIR water vapour products over land under clear-sky conditions and microwave measurements over the ocean under all-weather conditions. As there is no cloud mask for the models, several parameters on the cloud are adopted in the screening process. Although a series of threshold tests were conducted, there are still differences between the criteria applied in the cloud screening process and the cloud-mask of TCWV-COMBI, therefore, uncertainties are expected for the comparison over land.

L224: El Nino -> El Niño

Reply: We have fixed the problem.

L240: Could you explain the reason why the most humid regimes are over weak subsidence for ERA5?

Reply: As shown in Figure 4a, the ERA5 data over land show a dry bias in the humid area comparing to other datasets, results in a drier ascending area comparing to other models.

L244-245: Please clarify the sentence.

Reply: We have revised the sentence for clarification purpose:

"Besides, as the reference $\omega 500$ for TCWV-COMBI are from ERA5, it is sensible that there are differences observed in the TCWV-COMBI data comparing to other datasets that are decomposed by the corresponding model products."

L261-265: Please clarify the sentence.

Reply: We have revised the sentence for clarification purpose:

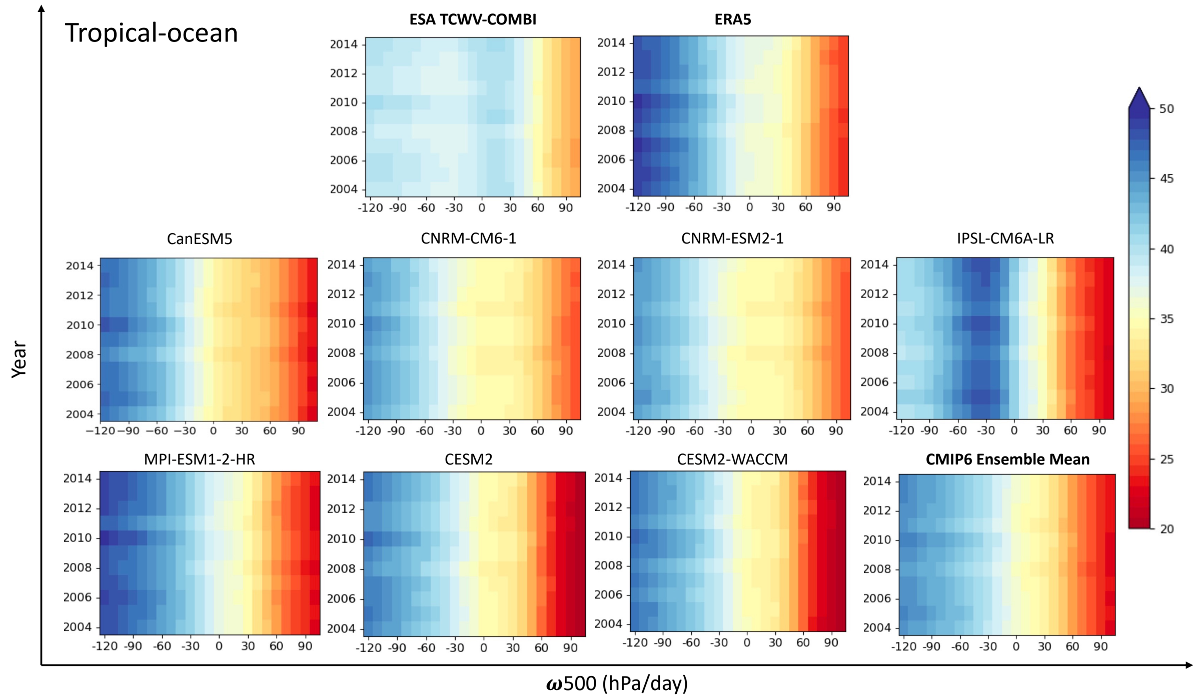
"The discrepancy observed from CanESM5 is partly because of its strong effective climate efficiency compared to other CMIP6 models (Virgin et al., 2021). For the CanESM5, the positive low and non-low shortwave cloud feedbacks, as well as the subtropical and extratropical free troposphere cloud optical depth, particularly with regards to low clouds across the equatorial Pacific, are the dominant contributors to its increased climate sensitivity (Virgin et al., 2021)."

Figure 8: It is very surprising that convectively active regimes have very low TCWV values for ERA5 and CanESM5. In contrast, Figure 1 shows that large TCWV values are observed over those regions, although the analysis time period is different between the figures.

Reply: As shown in Figure 3a, the ERA5 has dry bias comparing to other models and TCWV-COMBI data under the clear-sky conditions over tropical land. This may result from the cloud screening process that has remove some of the humid pixels as contaminated by cloud. It is sensible that the overall value of TCWV at the circulation regimes are drier comparing to other models.

Figure 10: The distribution for CanESM5 appears to be inconsistent with the results shown in Fig. 7. In addition, the TCWV values appears to be too low compared to Fig. 3 where the lowest values of ocean-mean TCWV are much greater than 20-25 kg/m2.

Reply: Thanks for the observation. We have checked the results and revised the figure to fix this problem.



There are some grammatical errors in the manuscript. For instance, "The algorithm for NIR imagers [are] discussed (L82).

Reply: We have checked the manuscript. We hope that this is now improved.