We thank the reviewer #1 and the editor for the constructive feedbacks and valuable suggestions. The followings are our responds to each reviewer #1's comment (underlined).

## General Comments:

A nice manuscript/study, fusing two satellite observation techniques to derive an improved temperature, water vapour profile information in the lower troposphere. A few suggestions for improved readability are below.

[Authors] Thank you for the positive feedbacks, which help improve this article.

## Specific Comments:

L10: "…characterize the complex thermodynamic structures in the lower troposphere" seems to imply this is presented in this study, but the study just proposes a way to improve the characterisation. Please re-phrase.

[Authors] We agree the vocabulary used here should be more accurate. This sentence has been modified to:

"In this study we combine these two measurement techniques in an optimal estimation approach, 1D Variation method (1DVar), to **improve the characterization of the complex thermodynamic structures** in the lower troposphere."

L53: Metop-A is no longer flying (or better, providing data), but Metop-B, -C does. So maybe just state all Metops?

[Authors] Good suggestion. We've changed it to:

"…NOAA-18, NOAA-19, **Metop series**, Advanced Microwave Scanning Radiometer…"

L68: "…they remain challenging to apply in practice" I think one major issue here is that SI traceability is lost when applying such an ad-hoc correction. Maybe that should be pointed out here too.

[Authors] We agree this is an appropriate statement to add:

"While several bias-correction methods for RO within PBL have been proposed (Xie et al , 2006; Wang et al , 2020), they remain challenging to apply in practice **and the corresponding SI traceability for refractivity could potentially be lost**."

L121: Maybe I missed it, but was the symbol e formally introduced?

[Authors] The introduction of the vapor pressure "e" is missing. It has been added back to the statement:

"p is the pressure in mbar, **e is the water vapor pressure in mbar**, and T is the temperature in Kelvin"

L164: "… state vector spanned from 0 to 10 km altitude" Suggest to add that you are ignoring the upper atmosphere in your setup, as the focus is on the lower few km and the contribution of the upper atmosphere decreases exponentially. Maybe even add an uncertainty estimate here.

[Authors] We agree that the suggested description can be added here to make the statement more convincing:

"**The vertical range of the state vector spanned from 0 to 10 km altitude. We focus on estimating the lower atmosphere because: 1) the contribution of the upper atmosphere to the lower troposphere is small due to exponentially decreases of atmospheric refractivity (with <0.4% standard deviation above 10 km), and 2) most of the vapor is distributed in the bottom 10 km of the atmosphere**."

L171: Are you using 12 or 22 channels in your MWR BT? At L154 it appears the 22 were reduced.

[Authors] In this article all 22 channels from ATMS are used. The discussion in L154 was given for possible future work plan. We make this statement clearer that 12 channels are not for current setting:

"**This process can be improved in the future** by using only the channels that are most sensitive to the tropospheric temperature and water vapor structure and discarding the rest."

"The trade-off between the number of channels used and the corresponding retrieval accuracy needs to **be further investigated in the future studies.**"

L194: Just to note that ROPP includes this differentiation, thus no need for time consuming numerical one (but of course does not have the bending angle ducting modifications included).

[Authors] Thank you for the great information! We numerically implemented the equation for all the results shown in this article, and with this ROPP precomputed Jacobian term the 1DVar will take much less time for non-ducting cases. The following sentence is added:

"**Alternatively one can use the Jacobian term calculated by ROPP software to lower the time consumption for numerical differentiation computation**."

L229: "…to the a-priori T error with < 1 K difference to the truth" Suggest to state "… error at maximum not even 1K difference…"

[Authors] We agree this is a better statement. The sentence has been modified:

"On the other hand, the MWR-only solutions (purple dotted-dashed) appear to be less sensitive to the a-priori T **error with not even 1K difference at maximum** compared to the truth."

L234: Please add the figure you are talking about (2e?)

[Authors] In fact the figure we refer to in L234 is the Figure 1 (all panels). To better clarify this sentence has been modified:

“Combining RO bending and MWR $T_b$ in the 1DVar framework discussed above, we observe that the retrieved $T$ (red solid line) **in Fig. 1(a) and (b)** are close to truth despite the $-2$ K bias that was added to the a-priori**,** and generate detailed water vapor retrieval **(red solid line)** in Fig. 1(c) and (d) that is more accurate than either MWR **(purple dotted-dashed)** or RO **(green dotted-dashed)** alone.”

L236: “…the 1DVar solution for MWR-only tends to follow the shape of the given a-priori” Suggest to add figure being discussed. And I am unsure if the “tends to follow” really captures what the MWR is showing. Seems to more show the same structure.

[Authors] Agreed. We have addressed these comments as follows:

“In the RICO case **(Fig. 2 )**, the water vapor retrieval from the MWR-only scenario (purple dotted-dashed) shows a large error of 2 hPa at two kilometers.”

“As a result, the 1DVar solution for MWR-only **shares nearly identical structure with** the given a-priori profile (orange dotted), which was heavily smoothed with small structure removed, and correct only the bias from the T measurements.”

Figure 1: Left plot does not show apriori, likely covered by the green curve. And maybe add a full title, and also the figure letters a, b, c, d? As the caption talks about these, but they show nowhere on the plots. And this title point is general for all figures.

[Authors] The figures have been modified accordingly.

L265: What is this “(magsondewnpnM1.b1.20121104.120900)” exactly? A profile identifier? A file name? If name, maybe better point to where it is available.

[Authors] Thank you for the suggestion, this is the file name (.cdf) for a specific profile retrieved from the balloon-born radiosonde in MAGIC campaign. A reference is added for the data access:

**Keeler, E., & Burk, K. Balloon-Borne Sounding System (SONDEWNPN). Atmospheric Radiation Measurement (ARM) User Facility. https://doi.org/10.5439/1595321**

And the term is clarified:

“To investigate the sensitivity of the 1DVar solution to the a-priori and the measurement covariances, we perform a number of simulations using a radiosonde profile from the MAGIC campaign (**file name**: magsondewnpnM1.b1.20121104.120900)(**Keeler and Burk , 2012**)(Lewis , 2016).”

L287: “In all cases, the added observation have a positive impact…” Add weight after observation? There are no new observations added.

[Authors] To avoid confusion we changed the sentence to the following:

“In all cases, **the combination of RO and MWR observations** have a positive impact on the solution causing the RMSE to reduce.”

L320: “(2020-04-01-03:10c2f4_gps58)” As above.

[Authors] This is a file name from the JPL processed COSMIC2 RO database. This case is published with the following URL:

https://genesis.jpl.nasa.gov/data/ftp/publication_data/Wang_et_al_AMT

The url of the data has also been added in the “Code and data availability” section.

Figure 6: c,d x labels not really readable.

[Authors] We changed the units of x axis from “rad” to “mrad” to make it readable.

Figure 8: The BT shown here at 31.4GHz appear not related to the channels proposed for use here (see Section 2.2: For ATMS, we can focus on channels 4 to 9 (51.76 GHz - 55.5 GHz) that are most sensitive to the tropospheric temperature, and channels 17 to 22 (165.5 GHz to 183.31 GHz) that are most sensitive to water vapor (Shao et al, 2021).) This channel shown appears to be a window one.

[Authors] We added another sub figure (Fig. 8b) using the 165.5 GHz to better reflects the channel contributes to the water vapor retrieval.

**Editorial:**

L79: “the the”

L259: “, While”

L284: “Overall, The”

[Authors] Thank you very much for catching the errors. They have been corrected.