Reviewers comments are in black text; *our replies are in blue italics*.

Anonymous Referee #2

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The manuscript addresses the critical problem of remotely sensing thermodynamic profiles within the planetary boundary layer and focuses on analyzing the synergies between passive and active ground-based instrument technologies. These include passive infrared and microwave profilers, as well as state-of-the-art differential absorption lidar (DIAL) systems that will soon be commercially available. The authors implement a combined retrieval algorithm that ingests previously retrieved water vapor profiles from the DIAL systems, and leverages these to improve optimal-estimation-based retrievals for the passive infrared and microwave systems. Two different DIAL instruments are analyzed, one from the company Vaisala and one from NCAR, using data from different measurement campaigns/locations (ARM SGP and the Perdigao campaign in Portugal) with very different a priori profile distributions. The authors account for these important differences by assessing the impact of DIAL observations relative to the AERI instrument only retrievals, thus reducing the impact of the different climatologies in the different measurement locations. Impressive improvements in retrieval precision are reported for the passive systems, with reductions of up to 50%, and it is shown that the majority of the thermodynamic information in the PBL comes from the AERI and DIAL instruments. Furthermore, the authors demonstrate a meaningful reduction in temperature uncertainty that comes from including the DIAL observations of water vapor only.

In general the paper is very well written with sufficient mathematical detail and reasoning to support the main conclusions. I have a few important comments that I would ask the authors to address that I think will benefit the manuscript, as well as some minor comments.

Major comment #1:

I echo the other reviewer’s comment that the manuscript lacks a discussion of accuracy in addition to the extensive precision discussions. How does combining the passive and active observations impact the accuracy of the retrievals (e.g. as compared with radiosonde profiles) in an ensemble/statistical sense (I recognize that there is one radiosonde profile plotted in figs 1 and 2)?

This is a good point. We have added a new section and a new figure that shows the bias profiles compared to 169 radiosondes.

Major comment #2:

It is unclear how fundamentally “synergistic” these observations are. Specifically, I ask the authors to explore the difference between the combined retrieval implemented in this work, and the results that you would get if you simply fused the individual observations after performing passive-only and active-only retrievals (e.g. a weighted average of humidity profiles). In performing such a weighted average, of course one needs to be careful to incorporate the entire passive retrieval covariance matrix. I think showing a marked improvement from implementing a combined retrieval vs. simply fusing the observations will be clear evidence of synergy. I will note that one example of synergy in this work is the reduction in temperature uncertainty from including active observations of water vapor only. However, as mentioned in Major Comment #1 the impact on accuracy is still an open question since there is not an analysis comparing retrievals vs. radiosondes.

The optimal estimation method allows the observations from the various instruments and the data from the prior to be blended in a well described manner to provide the solution that satisfies all of the observations within their uncertainties. We have referenced several papers that shows this, and in particular the seminal work by Clive Rodgers (2000). We believe that this method is indeed "synergistically" retrieving the best profile, assuming that the systematic errors in the observations is negligible.

Major comment #3:

The main thrusts of the paper seem to depend on the viewpoint from which you discuss the synergy. i.e. if you look at the problem as "how does adding DIAL observations improve the passive retrievals?" you may see a huge improvement in resolution and precision. However, if you look at it as "How much better do the DIAL retrievals become when adding passive observations?" the gains may be less substantial. I think this should be addressed in the paper.

The water vapor profiles from both of the DIALs were already characterized against radiosondes and other remote sensing observations in Weckwerth et al. (2016) and Newsom et al. (2020), both of which were discussed in this paper (around lines 180 for the nDIAL and lines 216 for the vDIAL). Thus, we did not feel it was necessary to reperform that type of characterization in this paper.

Minor comments:

1. Line 273: These are not necessarily the only two options for using DIAL observations. Of course, modeling the backscattered energy is not realistically feasible, because you do not know the aerosol distribution. However, one could view the fundamental measurement of a DIAL as the differential optical depth between range bins. I wonder why you do not use this quantity as your DIAL element of the observation vector? If so, the simultaneous retrieval of temperature and inferred pressure allow for the absorption cross sections to be computed as part of the retrieval, and thus the retrieved DIAL water vapor concentration profile would be consistent with the temperature profile retrieved by AERI.

This is true, and have modified the paper to indicate we could have used the differential optical depth as the observed variable from the DIALs. However, as the data product provided by both lidars is the water vapor concentration, we would have had to backwards derive the differential optical depth; so we just used the provided variable as the observation for this study.

2. Line 341-344: I agree that the second question listed here is of considerable value. However, for the first question posed I raise my same point from above. This seems to assume that the necessary way to view the observational problem is from the perspective of DIAL improving AERI vs. MW retrievals. But what about the other way around? How do AERI and MW improve the DIAL retrievals if at all?

Both DIALs only provide a partial profile of water vapor. The useful nDIAL range starts at 500 m above ground level, and the vDIAL observations seldom reach above 1 km. These shortcomings were *included in sections 2.3 and 2.4 that describes these lidars. Thus, the use of the passive remote sensors with the DIAL data allows these shortcomings to be overcome, while still providing retrievals that are consistent with the DIAL profiles within the DIAL's errors.*

3. Figs 3: I think the DIAL-only average uncertainty profiles should be included on this plot.

Excellent suggestion – the mean DIAL uncertainty was added to Fig 3.

4. Lines 438-442: This is an impressive improvement to the passive-only retrievals. It would be helpful to also state what the uncertainty reduction is compared to DIAL-only retrievals.

Good idea – we have added the lidar's water vapor uncertainty to Fig 3 and added a sentence to the end of section 4.2 to point this out.

Very minor comments:

1. Tables 2 and 3: Are uncertainty values reported in the hundredths of a degree C and g/kg water vapor significant? My suggestion would be to use 2 significant digits.

Good idea: we updated the two tables accordingly

2. Line 166: "were" should be "where".

Updated

3. Line 597: Should it be "virtual temperature profile observations" instead of "virtual temperature profiles observations"?

Updated