

Response to Anonymous Referee #2

We greatly thank the reviewer for his/her comments. Below are our responses in blue

General comments:

This paper presents an assessment of boundary layer water vapor from satellite data. The method applied is based on a 16-year dataset of collocated near-infrared and microwave satellite observations.

In general, the paper is well structured, and provides some new interesting results. However, it needs some minor revisions before it can be published.

Specific comments:

p.2, l.4-5: you should mention that the datasets are derived from **satellite** observations

That sentence will be changed to: The aim of this study is to show results from a ~16 year boundary layer column water vapor (BL-CWV) dataset derived from the synergy of microwave and near-infrared **satellite** imagery.

p.2, l.30-31: Other months do not show this inconsistency? What are the reasons for that?

As explained to reviewer 1, the issue was a one-off coding error on the MODIS processing algorithm (per the personal communication with Richard Frey). We will modify the following sentence: Instead, version 6.1 was used for all December months **as recommended by the MODIS team. A full reprocessing of the AMSR-MODIS dataset using MODIS version 6.1 (or the latest MODIS version) is left for a future AMSR-MODIS version.**

p.2, l.34-35: Is this error (between 5 and 10 %) the error of the near infrared channels? Or the error of CWV? What about the error between cloudy and cloud-free cases? Is there a dependency on solar zenith angle?

This is the error of the CWV, the sentence will be changed to: In particular, we use the CWV estimated using near-infrared channels. These CWV values have an estimated random error between 5% and 10% [Gao et al 2013].

There is no literature describing any differences between cloudy and clear-sky cases nor any dependence for solar zenith angle for the near IR CWV product. We will add the following sentence which will follow immediately after the Gao et al 2013 citation: These errors may have a solar zenith angle dependence as found for other MODIS products [i.e., Horvath et al (2013), Grosvenor et al (2014)] and may worsen under cloud conditions, as such, we assume the 10% error through-out.

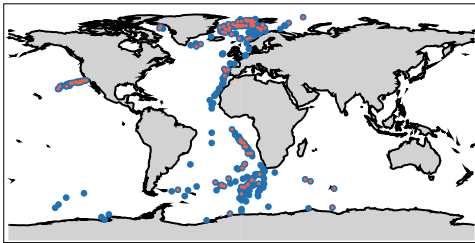
p.3, l.6-7: Do you mean that you use only clouds that have been classified as “only liquid”? It is not clear here how you deal with mixed-phase clouds. The whole sentence should be rephrased for better clarity.

The sentence will be changed to: We only use the clouds which have been classified, by the cloud thermodynamic phase classification algorithm (Plattnick et al 2015), as liquid. This is a completely re-written algorithm which instead of using a linear sequential structure, as in version 5, uses a voting discrimination logic to identify the cloud thermodynamic phase as ice, liquid or undetermined (Marchant et al. 2016).

p.3, l.12-13: The monthly standard deviation of BL-CWV depends strongly on the variability of the boundary layer height (CTH). Have you checked this dependence?

Yes, there is a strong dependence between CTH and the BL-CWV as expected. In a future study we will exploit its dependence to explore different bulk BL-CWV characterization (i.e. Stephens 1990- cropped at the CTH, a well-mixed model, a piecewise model, etc).

p.3, l.31: Did you only use Arctic/Antarctic radiosondes? Which latitude belts did you include?
The following figure will be added:



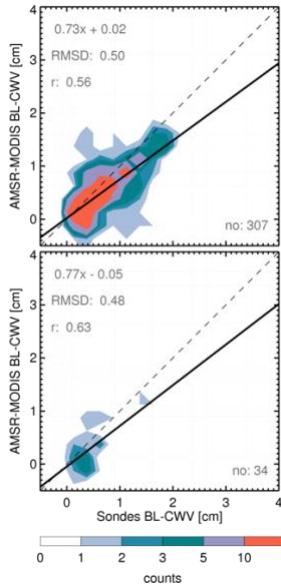
Caption: Map showing the geolocations of the radiosondes used in this study. Blue dots display the radiosondes that fulfill the criteria used in Figure 3-top while red dots display the subset that fulfill the criteria of Figure 3-bottom.

p.4, l. 10ff (and Fig. 2): I think that the variability within 6 hours is much larger than over 10 km. I guess most of the uncertainty reduction in the 1 hour/1km analysis comes from the shorter time range.

Note, that we do not have a 1hour/1km we display a 10km/6hours and a 1km/6hours.

Have you tried to keep 10 km (or even more) and reduce the temporal distance to 1 hour? In addition, 1 km drift of radiosondes is easily reached already within the boundary layer, therefore, I would suggest to neglect this “strong 1km” criterion and rather focus on temporal matching.

Below is a figure similar to figure 2 (in the original draft) keeping the 10km and reducing the temporal distance to 1 hour (bottom panel). As can be seen, these criteria result in only 34 matches and hence we prefer our previous one. Note that increasing the spatial threshold to 20km only results in 43 matches.



p.4, l. 20-23: It is known that GPS-RO data are missing some lower level inversions (especially below 1000 m above ground). How do you deal with this fact? Does it introduce a bias in your comparison? As pointed by the reviewer in his/her next comment, we only use GPS above the inversion (when an inversion can be found) and subtract that estimate from the total CWV from AMSR.

p.5, l.3 (and Fig. 4): It is a bit misleading that you call the algorithms “AMSR-MODIS” and “GPS-RO”. This suggests that the GPS-RO algorithm is independent, however you use GPS-derived CWV above the inversion and then subtract it from AMSR total column. Therefore, you are not comparing independent data here. Please comment on that!

We will change the section name to AMSR - GPSRO to avoid misleading the reader. Also, the first sentence will read: As cross-validation, we use **AMSR - GPSRO** data. The **GPSRO** technique uses phase delays ...

Also, we will add the following sentence: As such, a comparison between AMSR-MODIS and AMSR - GPSRO, is, in essence, a comparison between MODIS water vapor above the clouds and the GPSRO water vapor above the BL inversion layer.

p.5, l.7: Although slope and RMS decrease, the correlation coefficient also decreases. Do you have an explanation for that?

The RMSD depends on the values compared. If normalized, for example, by the mean of the AMSR-GPSRO values. The NRMSD are 0.50 and 0.49 for the sharpness parameter threshold of 2.5 and 3 respectively, that is to say, almost identical. We will update Figure 2 and 4 of the previous draft to use the NRMSD.

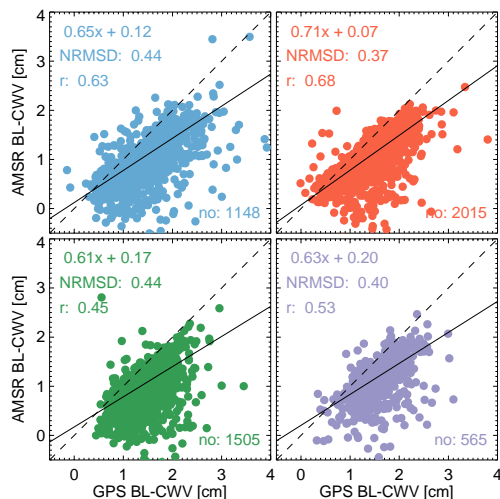
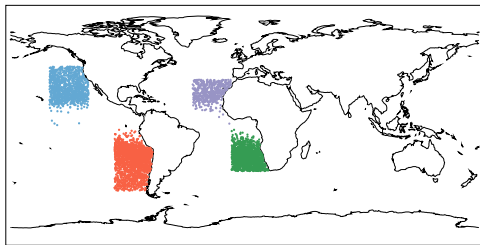
We will change the radiosonde comparison sentences to: The best-fit line has a slope of 0.73, a normalized (by the mean of the sondes values) root mean square deviation (NRMSD) of 0.69, and a correlation coefficient of 0.56 ...

And to: By decreasing the coincidence criteria distance from 10 to 1 km (Figure 3-bottom) it is possible to improve these metrics (the best-fit line slope becomes 0.75, the NRMSD 0.59, and the correlation coefficient 0.71) but the total number of matches decreases from 307 to 124.

We will also change the GPSRO text to: By increasing the sharpness parameter requirement from 2.5 to 3.0 (Figure 5-bottom) the relationship between these two datasets improves with the best-fit line slope becoming 0.71 and the correlation coefficient 0.54. The NRMSD (in this case normalized by the mean of the AMSR-GPSRO values) remains nearly identical at ~0.5. However, the total number of matches decreases from ~23500 to ~750.

p.5, l.10-18: Is it possible that different viewing geometries or high solar zenith angles play a role in the uncertainties? If so, did you make separate analyses for different solar geometries or for different regions of the Earth?

As shown in the figures below (using a sharpness parameter of 2.5), there is some variation in the agreement between the two datasets per region, but not high enough to strongly indicate a viewing geometry/geolocation bias (at least in the stratus regions where most of the AMSR-MODIS observations are located, i.e. Figure 5 of the original draft).



p.6, l. 33-34 (and Fig. 7): What is the reason for the lower LTS in the Canarian region? Is it due to frequent advection of unstable air masses from the Saharan desert?

As discussed by Klein and Hartmann (1993), the SST for the Canarian region are about 3 to 5 degrees warmer than in the California region (this can be seen in figure 8 of the original manuscript) while the 700mb temperatures are really similar which results in a lower LTS.

p.7, l.3: Why did you reverse the order of the regions here (compared to p.7, l.1)? We will change the order to be the same as in p7 l.1.

p.7, l.21-25: What are the model constraints? Vertical temperature structure? CWV? CTH?

The model description will be changed to:

Figure 10 shows the measured annual cycle for BL-CWV, as well as the derived one from a simple well-mixed boundary layer model as the one described by Millan et al (2016), assuming a surface relative humidity of 80% **and using the AMSR SST temperature, the MODIS CTH and ERA-Interim surface pressure as constraints**. These cycles were both normalized by their respective maximum values.

p.7, l.26-27: I cannot see an overestimation since you are plotting normalized values in Figure 9. It would be good to see absolute values from the model! Does the magnitude of the overestimation is in line with the findings in Figures 2 and 4?

The overestimation is not entirely explained by it, another reason is because the well mixed layer model is a oversimplification of the BL water profile, and it normally overestimates the BL-CWV. The following will be added: **and in part because of the simplistic representation of the boundary layer humidity profile by such a model.**

After consideration, we decided to show the figure with the normalized version to highlight that the water vapor observations can be, in general, be interpreted by a simple model as opposed to highlight the deficiencies of the model.

p.8, l.18: You are mentioning only here the restrictions of your method to homogeneous cloud fields during daylight. Does that affect the overall validity of your results? Do you expect a diurnal cycle?

The need of homogeneous cloud fields is mention in p3 l4: That is, we aim to identify homogenous fields of clouds in the MODIS data. Further, it is also mention, in section 4.1: High number of observations means that uniform liquid cloud fields were found consistently in such areas, and can be interpreted as ...

The daylight restriction is implicit in P2 l5,6: Near infrared imagery provides the water vapor above the clouds (by measuring the solar radiation reflected near the 0.94-um water vapor band) while microwave imagery ...

These restrictions do not affect our result because in regions where the boundary layer is well defined, the clouds tend to be homogenous, i.e. stratus clouds.

Although there is a boundary layer diurnal cycle, this does not affect our results, the AMSR-MODIS dataset simply captures the boundary layer state at around 1:30pm. This will need to be considered in

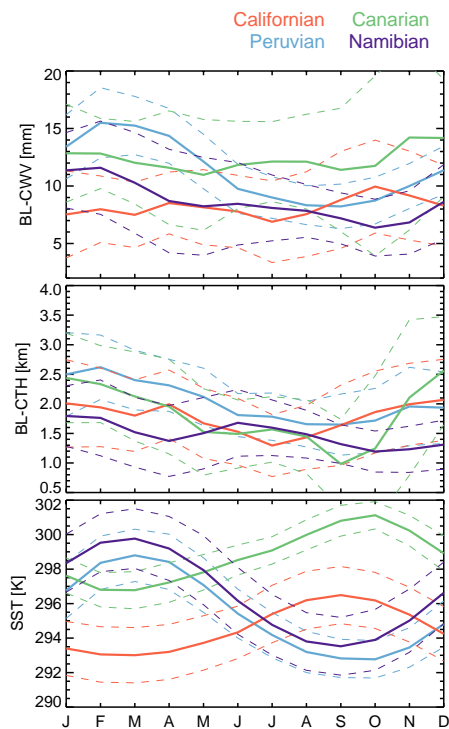
future studies using the AMSR-MODIS dataset as with any other dataset measuring any atmospheric parameter with diurnal cycle.

The AMSR and MODIS equator crossing time will be mention in the following sentence: All these instruments orbit in tandem measuring the same volume of air within minutes of each other, that is, by design, these measurements are collocated; **their equatorial crossing time is ~1:30pm.**

p.8, l.23-25: This sentence (That is version2.0 (...) algorithm) is not necessary in the summary. **The sentence will be deleted from the summary.**

Figure 8: Please provide information on the monthly variation of BL-CWV and BL-CTH, e.g. showing error bars or box-and-whisker plots

Below is the figure showing the standard deviation.



To avoid cluttering, the following figure will be used with the following sentence in the caption: The numbers shown are the average standard deviation per region.

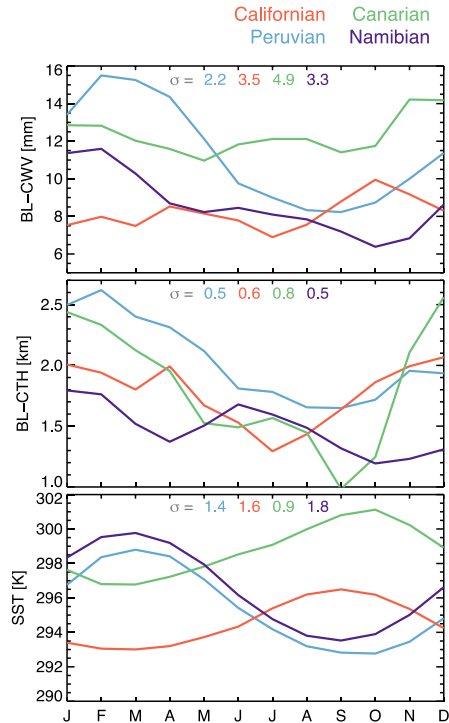


Figure 9: Since you plot normalized values, the unit [mm] is not correct! Thanks for spotting this, it will be changed to mm mm⁻¹.

Technical corrections:

p.1, l.20: replace “are” by “is” Done

p.1, l.24: “processes” Done

p.3, l.22: “criterion”, not criteria We believe that criteria is the right option since we use a temporal condition, a spatial condition, and, in the case of GPS-RO, a sharpness parameter condition.

p.3, l.24: “gridding” Done

p.3, l.25: “represent” (not “represents”) Done

p.5, l.1: “coast” (not “cost”) Done

p.6, l.31, p.7, l.10: “4 K” (without degree sign) Done

p.8, l.14: “remain”, not “remains” Done

p.8, l.32: “over”, not “on” Done

p.8, l.32: “Sc-Cu”: You never introduced these acronyms: we changed to Stratocumulus to Cumulus

Fig. 9 (caption): please correct: Normalized (...) The numbers (...) coefficients (...) Done

References:

Horvath et al (2013) - doi:10.1002/2013JD021355

Grosvenor et al (2014) - doi:10.5194/acp-14-7291-2014

Marchant et al. (2016) – doi:10.5194/amt-9-1587-2016