Response to Review Comments on

"Validation of OMI Total Column Water Vapour Product"

Thank you very much for your review. We have revised our manuscript accordingly. Please find our response to each comment below. To facilitate reading, we have highlighted your review in blue with Arial font, our response in black with Arial font, and our revised text in black with Times New Roman font.

General comments:

The manuscript "Validation of OMI Total Column Water Vapor Product" Describes the geophysical validation of Aura Validation Data Center (AVDC) Collection 3 OMI Total Column Water Vapour data set against ground-based GPS, AERONET sunphotometer and satellite-based SSM/I data over period from 2005 to 2009. Authors report good agreement against GPS and AERONET data over land and general underestimation against SSM/I over ocean. Manuscript then describes experimental setup for retrieval algorithm to improve retrieval over ocean and presents comparisons between new algorithm and AVDC TCWV data.

Subject matter is well suited to ACP and methods used are sound and explained clearly. Figures shown are meaningful, although their clarity and quality should be improved. Interpretation of the results shown in section 3 is somewhat lacking and results should be contrasted with other published work. More detailed look on effects of the measurement parameters (viewing geometry, surface albedo, seasonal variation etc.) would also improve the article. However, the manuscript is sufficiently sound to be published in ACP after revision.

Detailed Comments:

Section 3.: Does the general quality screening (MDQF=0) include screening for OMI row anomaly?

MDQF = 0 does not check for OMI row anomaly. However, unless specified otherwise, we filter out the pixels affected by row anomaly using the cross-track data quality flag. This has now been clarified.

Towards the end of Section 2.1, we added "The MDQFL criterion checks that the fitting has converged, the retrieved SCD is < 4×10^{23} molecules/cm^2 and the SCD is positive within 2σ fitting uncertainty."

We modified the first paragraph of Section 3.1 to "…The filtering criteria for OMI require that the general quality check is passed (MDQFL = 0), the cross-track quality flag indicates that the retrieval is not affected by OMI's row anomaly, the SCD fitting RMS is < 5×10^{-3}, the cloud fraction is < 10%, the cloud top pressure is > 500 hPa, and the AMF is > 0.75".

Section 3.1: While it is good idea to conduct these comparisons for cloud free cases, it would be good to show the effect of the cloud cover on reliability of the observations. Are cloudy observations still useful?

When we compare Version 1.0 OMI data with RSS's SSMIS data in Section 3.3, we found that cloudy OMI data have a large high bias associated with small AMF estimate. We do not recommend using cloudy OMI data. The following changes are made.

In Section 3.3, when we discuss Figure 8, "There are some positive values in the lower left panel. They are mostly located in areas of missing data in the lower right panel, suggesting that the positive values are associated with significant cloud cover (5% – 25%). This further indicates that the Version 1.0 OMI data tend to have a high bias under cloudy sky condition and a low bias under clear sky condition. The cloudy sky high bias is mainly due to the small AMF estimate, especially for high clouds (not shown)."

In Section 5, "OMI data (with cloud fraction < 25%) are significantly higher than all sky SSMIS data in areas with persistent cloud cover. We therefore do not recommend using OMI data that are affected by clouds".

Section 3.3: Results here should be contrasted to other published work. How does the OMI TCWV compare against other TCWV products (as mentioned in introduction), when they are compared to SSM/I?

Wang et al. (2014) published comparisons between Version 1.0 OMI and GlobVapour's MERIS+SSMI data. In this revision, we have added Section 4.2 (below) that includes comparisons between Version 2.1 OMI and GlobVapour's MERIS+SSMI data (Figure 13 and Figure 14, attached to the interactive comments file). We use GlobVapour since its validation document contains extensive comparisons with other data sets. We have added Section 2.5 to introduce GlobVapour's MERIS+SSMI data.

"**2.5 GlobVapour's SSMI+MERIS Data**

The GlobVapour project sponsored by the European Space Agency (ESA) Data User Element (DUE) program generated a global Level 3 (0.5°×0.5°) TCWV product by combining MERIS land and SSM/I ocean observations from 2003 to 2008 (www.globvapour.info). The MERIS near IR data are collected around 10 AM and derived from the water vapor absorption around 950 nm. The SSM/I microwave data are collected around 6 AM and derived using a 1D-Var method for ice-free non-precipitating ocean. The GlobVapour Level 3 product combines clear sky MERIS land data with all sky SSM/I ocean data. Over the land, GlobVapour is on average about -1.3 mm lower than the GCOS Upper-Air Network (GUAN) radiosonde data and +0.2 mm higher than the AIRS clear sky infrared data. Over the ocean, it is on average about +1.3 mm higher than GUAN and +0.7 mm higher than AIRS. The standard deviation of the difference ranges from 2 mm to 5 mm (Schröder and Bojkov, 2012). Wang et al. (2014) compared the monthly mean GlobVapour data with the monthly mean Version 1.0 OMI data. They found an overall agreement (within 1 mm) over land and an OMI low bias of -3 mm or more over the ocean. In this paper, we sample the daily gridded GlobVapour data to compare with the updated OMI data in Section 4."

"4.2 AMF Update

AMF is used to convert SCD to VCD. Consequently, errors in AMF also affect OMI TCWV. The AMFs in previous sections were derived by convolving the monthly mean water vapor profiles used in the GEOS-Chem model (2°×2.5°) with the scattering weights interpolated from a look-up table (Wang et al., 2014). The look-up table was constructed using the radiative transfer model VLIDORT (Spurr, 2006). The scattering weights in the lookup table depend on surface pressure, surface albedo, Solar Zenith Angle (SZA), View Zenith Angle (VZA), Relative Azimuth Angle (RAA), ozone column amount, cloud fraction, cloud pressure and wavelength.

The following updates have been made to the AMF calculation. (1) Using higher resolution (0.5°×0.5°) a priori water vapor profiles generated by the MERRA-2 project of the Global Modeling and Assimilation Office (GMAO). (2) Using the MERRA-2 surface pressure instead of an estimate based on the surface topography and the 1976 US standard air. (3) Reconstructing the look-up table with more reference points for surface albedo, cloud fraction and cloud pressure, so that the interpolated values are more accurate. (4) Improving scattering weight parameterization with respect to RAA. (5) Using simultaneously fitted ozone amount in scattering weight calculation. We will refer to the algorithm with both these AMF updates and the SCD update described in Section 4.1 as Version 2.1.

We have retrieved TCWV using the Version 2.1 algorithm for July and January 2005. Figure 12 shows the result for July 2005. The OMI data used here correspond to a 5% cloud fraction cutoff. The top left panel shows the monthly mean difference between Version 2.1 and Version 2.0 OMI data. The difference results from the AMF updates described above. Version 2.1 is about 3 – 5 mm higher than Version 2.0 in the tropics, 3 – 5 mm lower over high topography, and almost unchanged in other areas. The bottom left panel shows the monthly mean of (Version 2.1 OMI – "clear" sky SSMIS). It is calculated using the same method as that for the bottom right panel of Figure 11. Comparing the two, we find a further reduction of the low bias over the tropical oceans. In fact, the majority of the Version 2.1 OMI data between 0° and 30°N are now within ±3 mm of the "clear" sky SSMIS data. The bottom right panel shows the histograms of (OMI – "clear" sky SSMIS) for three versions of OMI retrievals. The mode of the distribution shifts from -4.0 mm (Version 1.0) through 0 mm (Version 2.0) to 1.5 mm (Version 2.1). The top right panel of Figure 12 shows the 2D normalized histogram of Version 2.1 OMI versus SSMIS "clear" sky data. The slope is close to 1, but OMI is higher by about 1.5 mm which is consistent with the result shown in the bottom right panel.

In Figure 13 and Figure 14, we compare the Version 2.1 OMI data with the GlobVapour MERIS+SSMI data for July and January 2005, respectively. The top left panel shows the monthly mean of (OMI – GlobVapour). It is calculated as the average of coincident daily gridded Level 3 data within the month. The OMI daily data are gridded with a 5% cloud fraction cutoff to represent "clear" sky condition. Note that GlobVapour's land data (MERIS) are for clear sky condition, but its ocean data (SSMI) are for all sky condition. There are usually about 10 – 20 coincident data points / pixel in the low latitudes (upper right panel). The differences between OMI and GlobVapour are generally within ±6 mm. Among them, large differences are typically located in the areas where few data points exist, such as northern South America, central Africa, eastern US, China and the Pacific rim in July. In areas with good statistics, the differences are largely confined to within ±3 mm. The 2D normalized histograms of OMI versus GlobVapour are shown in the middle row for land (left) and ocean (right). The two data sets follow each other well. Over the ocean, OMI data are slightly higher than GlobVapour's SSMI data by about 1 mm in July and agrees with GlobVapour's SSMI data in January. Over land, OMI data are slightly higher than GlobVapour's MERIS data when TCWV is < 15 mm and slightly lower when TCWV is > 15 mm. The normalized histograms of (OMI – GlobVapour) are shown in the bottom row for land (left) and ocean (right). The distributions show that OMI agrees with GlobVapour within ±1 mm for both land and ocean and for both July and January. The FWHM in July is 6 mm for both land and ocean, and that in January is 6 mm for ocean and 1 mm for land."

Figures 2. and 5.: Is there a change in long-term levels due to the changes in viewing geometry? Due to asymmetrical nature of the row anomaly, any dependencies on viewing geometry (SZA, VZA, local time?) in the product might affect the long term time series even after screening.

We have not noticed any apparent long-term change associated with viewing geometry from 2005 to 2009 in Figures 2 and 5.

Figures 4. and 7.: What is the reason for overestimation over ocean for large total water vapour columns, especially in contrast to general underestimation over ocean? Are there specific situations where OMI TCWV is not reliable?

The large overestimation of OMI TCWV over the ocean is due to cloud contamination, as it is much more apparent with the 25% cloud fraction cutoff than with the 5% cloud fraction cutoff (Figure 8). The SCD fitting uncertainty of the cloudy pixels is not particularly larger than normal, however, clouds lead to an underestimation of AMF and therefore an overestimation of VCD.

In Section 3.3, when we discuss Figure 8, "There are some positive values in the lower left panel. They are mostly located in areas of missing data in the lower right panel, suggesting that the positive values are associated with significant cloud cover (5% – 25%). This further indicates that the Version 1.0 OMI data tend to have a high bias under cloudy sky condition and a low bias under clear sky condition. The cloudy sky high bias is mainly due to the small AMF estimate, especially for clouds at high altitudes (not shown)."

In Section 4.1, when we compare the updated Version 2.0 OMI data with RSS's SSMIS data, we have added "In comparison with the bottom left panel of Figure 8, the Version 2.0 OMI data generally do not show any large low bias. However, large high bias is seen in several places. As a result, the global mean over the ocean change from -1.7 mm (Figure 8) to 2.9 mm (Figure 11). A comparison between the lower left and lower right panel of Figure 11 reveals that these large positive values are consistently located in the vicinity of the missing data of the lower right panel, which indicates that they are affected by significant cloud cover. As discussed before, OMI cloudy data are expected to be less reliable and tend to overestimate TCWV. This will partly compensate for any low bias if the pixel is occasionally cloudy and show up as a high bias if the pixel is persistently cloudy."

In the summary, we have added "Clouds usually lead to large overestimates of OMI TCWV. As a result, the OMI data with cloud fraction < 25% are significantly higher than the all sky SSMIS data in areas with persistent cloud cover. We therefore do not recommend using OMI data that are affected by clouds."

All figures: Please clarify the figures, especially colour scales used.

We have revised our figures (attached to the interactive comments file). We notice that our .ps files have better quality than those shown in the WORD document which was subsequently converted to PDF file. We will upload the figures separately this time.