Referee: R. Lang

We thank the referee R. Lang for the very helpful and constructive comments. We have incorporated them in the revised version of the manuscript.
Below we give answers to all comments in blue. In black is the text of the original referee report.

The detailed evaluation of truly independent water vapour climatologies from satellite observations is an important prerequisite towards the establishment of a global, longterm 3D data-set of water vapour available for the evaluation of climate models and the studying of climate feedback related to the hydrological cycle. The work presented here provides important insights in the usage of two existing, and potentially valuable, data-sets from SCIAMACHY using AMC-DOAS (here SCIAMACHY-ESA WVC) with vis/NIR data, and SCHIAMACHY-IMLM using SWIR data. The establishment of such a future 3D data-set is challenging with respect to the complex nature of the water vapour profile, being highly variable in time, not well mixed, and decreasing by three orders of magnitude until the tropopause, i.e. with a significantly larger scaling height than oxygen. The paper by du Piesanie et al. is generally well written and presented. It provides an evaluation of the two retrieval techniques for total column water vapour (WVC) by comparing to in-situ radiosonde data over a period of one year (AMC-DOAS) and two individual years (IMLM).

General comment:
While the paper presents a detailed analysis of the individual sets it is short in detailing and evaluating the pros and cons of both retrievals with respect to each other. For the latter task only one day for comparison and a very brief analysis is provided in Section 5.
Given the fact that a detailed evaluation of the AMC-DOAS algorithm has already been provided in Mieruch et. al. along the same lines of reasoning (evaluating the biases due to the AMF CF approach) and using similar measures, and considering that there are currently a large amount of water vapour retrievals available (which in itself is not a bad thing), I believe the paper should put more attention the description of the advantages and disadvantages of both data-sets, by taking into account their underlying fundamental limitations due to observation geometry, surface type, presence of clouds, cloud height, etc, and with respect to the fundamental limitations of their specific energy region. Since no single retrieval of water vapour, profile and columns, can cover all aspects concerning the much needed 3D monitoring of the WV field, the remaining task lies in an evaluation of the potential synergies between data-sets, in order to arrive at such a 3D global data-set.
So I propose to expand more on these synergies for the given sets both in the introduction and, if possible, by reducing or focusing the section on the AMC-DOAS evaluation to those aspects, which are relevant with respect to such potential synergies (and otherwise refer to the paper by Mieruch et al.), while expanding the section on the comparison between the two sets.

The discussion at the end of Section 3 on the cause of SCIAMACHY-ESA WVC mean bias together with the results found by Mieruch et al. (2010) has been somewhat shortened (page 9 in revised manuscript).
Section 5 has been expanded to include comparisons between SCIAMACHY-ESA and SCIAMACHY-IMLM WVC for a one month period. A further comparison between SCIAMACHY-ESA and SCIAMACHY-IMLM WVC data is performed by comparing both these data sets with their collocated radiosonde WVC amounts for the same one month period.
Results (described in Section 5 in the revised manuscript) indicate that SCIAMACHY-ESA WVC amounts are consistently higher than that of SCIAMACHY-IMLM over land and during cloud free conditions. The comparison of the three water vapour data sets (SCIAMACY-ESA, SCIAMACHY-IMLM and Radiosonde) highlights the influence that the choice of cloud product can have when using certain cloud cover criteria to select the SCIAMACHY water vapour column data.
The last section (Section 6) in the paper has been changed to "Discussion and Conclusions" (page 15-17 in revised manuscript). In this section the advantages and disadvantages of both SCIAMACHY water vapour data sets are discussed, including possible synergetic use together with the best selection criteria of the two data products.

Specific comments:

1. In the evaluation of biases and standard deviations from AMCDOAS there is one conceptual issue which I am not sure I have fully understood. From my point of view the AMC-DOAS formulation, as presented in Eq. 1, introduces two systematic biases in the case of an atmospheric light-path, which is different from the pure geometrical (the introduction of biases of some sort in this case is of course true for basically all remote sensing retrievals): One is from the assumption that a scaling of the observed WV along the path, and after the geometrical AMF c has been applied, to a "true" total vertical water vapour column, which is based on a scaling of the oxygen profile. This bias can be evaluated quite well, as done in Figure 6, based on climatological profile (-differences) of both O2 and WV with respect to RT calculations. The other bias is however introduced by the difference between these climatological WV profiles (neglecting the small error in O2 w.r.t. its true profile) and the real WV profile below the fraction of the pixel which is shielded by a cloud at a certain height. The latter can be quite different from the assumed climatalogical one, as to why the above mentioned 3D knowledge of it is so much needed. It occurs to me that the observed differences to validation sources (here radiosonde data), as presented in Fig. 4 and 5, and with respect to the impact of cloud shielding, are always referred to the former error not to the latter. Can it be that the latter error (the difference between the climatological assumption of the WV profile to the real shielded profile), is indeed negligible in comparison to the O2/WV profile-difference error in the scaling? And can this be shown somehow (or has this been shown somewhere)? To this respect it might be beneficial to look at the partial columns from AMC-DOAS with respect to radiosonde data, as has been done for IMLM, and which at the same time may help the discussion on synergies, as suggested in my general comment.
   In the case of a cloudy scene the true water vapour profile shape (under the cloud) may indeed be different from the one assumed in the radiative transfer calculations (and thus have a systematic effect on the results). But in the majority of cases, if the oxygen profile shape is the same as the water vapour profile shape, this should be handled and corrected for by the AMF correction. It is more likely that the larger differences found during cloudy conditions are mainly caused by the different O2 and water vapour profile shapes.

2. In the comparison section 4 (p. 678) it would be helpful if Table 2 would state explicitly which retrieval settings are making use of which type of cloud retrieval (FRESCO+ or other).
   Table 2 (as it originally appeared in the manuscript) has been removed from the revised manuscript (see answer to comment 3 below).

3. I don't quite understand the conclusion of Section 4 (p.678, l. 22f). Table 2 shows that the mean bias will increase when including some cloudy scenes (as expected). So, either one has to increase the acceptance/accuracy limit for a total column product, which is fine, as long as one defines what this limit should be. Or one derives a partial water-vapour column data-set which is evaluated with respect to partial columns from radiosonde profiles, which however is something different than a total-column data-set. I think one should not mix them both and then call it an extension.
   We agree with the reviewer that the partial water vapour column obtained from radiosonde and SCIAMACHY-IMLM above the cloud is a different WVC product.
   One of the reasons for including this section in the manuscript was to investigate if it is possible (and if so, under what conditions) for water vapour column data from SCIAMACHY-IMLM to be used during cloudy conditions. For comparisons over ocean surfaces good results are found during cloudy conditions because of the high cloud reflectance compared to the low ocean surface reflectance.
   In order to avoid confusion, the second half of Section 4 has been modified to only include results from comparisons of partial water vapour column data over ocean surfaces during cloudy conditions, while the first half of Section 4 remains the same and still focusses on results from comparing SCIAMACHY-IMLM with radiosonde water vapour column data over land surfaces during cloud free conditions (as was suggested by Schrijver et al., 2009). The second half of Section 4 has been moved to a sub-section (Section 4.1 in revised manuscript), entitled "*Partial*

water vapour columns above cloud over ocean surfaces“ and includes the results from comparisons over the ocean during cloudy conditions between partial water vapour column data from radiosonde and SCIAMACHY-IMLM.

In addition to these modifications a supplementary comparison has been performed in Section 4.1 for the partial water vapour column comparisons. In the original manuscript, cloud top height obtained from FRESCO+ was used to calculate the partial radiosonde water vapour column. In addition to this, the methane total column (which is retrieved simultaneously with SCIAMACHY-IMLM water vapour) is also used to derive the cloud top height and to calculate the partial radiosonde water vapour column. The results of both approaches are summarized in the new Table 2.

Following the above modifications in Section 4, the original Table 2 has been removed from the revised manuscript.

Referee: Anonymous Referee #2

We thank the Anonymous Referee for the careful reading of the manuscript and the helpful and constructive comments. We have incorporated them in the revised version of the manuscript. Below we give answers to all comments in blue. In black is the text of the original referee report.

In this paper the authors present two independent SCIAMACHY total water vapour column (WVC) products retrieved using two different algorithms applied in the visible and short wave infrared spectral regions: the SCIAMACHY-ESA WVC (using AMC-DOAS) and the SCIAMACHY-IMLM WVC (using the Iterative Maximum Likelihood method). The two products are compared with integrated water vapour data obtained from radiosonde relative humidity measurements and with each other. Substantial conclusions are reached regarding the dependence of the bias on cloud parameters and selection criteria. The results are sufficient to support the interpretations and the conclusions. The manuscript is well written and the whole procedures and set of assumptions are clearly stated. Moreover, the knowledge of the global distribution of water vapour is fundamental for global atmospheric models aiming to predict weather and monitor climate. I therefore recommend this manuscript for publication in the AMT Journal after some minor corrections and clarifications addressed below.

1. In the Abstract, the authors describe clearly the aim and results of their work, however the time period used for the two validations are not clearly stated. Also in Section 1, 17 I find the sentence "respectively covering an 18 month and 2 yr period" confusing, and I would suggest to add a short comment on the choice of these two time frames.

   At the time this study was started the latest available data of the SCIAMACHY-ESA water vapour product was used for the comparisons. The separate years of 2004 and 2009 were initially chosen for the SCIAMACHY-IMLM product to investigate if the increase in the measurement noise error from the year 2004 to 2009 (due to detector degradation) had any influence on the product.
   The sentences in the Abstract and in Section 1 in the revised manuscript have been changed to more clearly reflect which time periods are used in the comparisons for which SCIAMACHY water vapour product.
   In the revised manuscript (page 1) the last sentence of the abstract has been changed to:
   "The SCIAMACHY-ESA WVC product is compared with radiosonde derived WVC amounts for an 18-month period from February 2010 to mid August 2011, and the SCIAMACHY-IMLM WVC amounts are compared with radiosonde WVC amounts for the two individual years of 2004 and 2009. The WVC amounts from SCIAMACHY-ESA and SCIAMACHY-IMLM are compared with each other for a 1 month period of June 2009."

   The sentence in Section 1 (page 3 in revised manuscript) has been modified:
   "A comparison with the total water vapour columns from the SCIAMACHY water vapour product retrieved by the AMC-DOAS method is performed for an 18 month period (February 2010 to mid-August 2011), and the comparison between the SCIAMACHY water vapour columns derived using the IMLM method is performed for a two year period for the years of 2004 and 2009. Furthermore, the two SCIAMACHY water vapour data sets are compared with each other and with radiosonde water vapour data for a one month period."

   The two time periods chosen for the comparisons were also added to the beginning of each of the two sections describing the results of the SCIAMACHY-ESA and SCIAMACHY-IMLM comparisons (beginning of Section 3 and Section 4).

2. In Section 3, the comparison between SCIAMACHY-ESA WVC and radiosonde is discussed. Following the work of Mieruch et al. (2010), the authors study the bias as a function of cloud parameters and show the differences for all individual collocated cases as a function of the AMF CF. The original result is that the bias increases rapidly with cloud top heights, and therefore

depends on cloud water path. However, I would like to see in the paper a qualitative (and if applicable quantitative) comparison with previous findings, with a clear statement about the best selection criteria to use in the datasets, since the limitations of the AMC-DOAS where already studied extensively in the literature. Also, it would be interesting to investigate the bias using radiosonde profiles integrated from the top of the clouds, like was done for SCIAMACHY-IMLM.

We agree with the reviewer that a qualitative assessment between our results and that of Mieruch et al. (2010) can be given in Section 3 in order to distinguish more clearly our findings from that of Mieruch et al. (2010). This part of the text in Section 3 has been modified and rephrased (page 9 in revised manuscript).

The study done by Mieruch et al. (2010) focuses mainly on measurements performed over the ocean and uses version 1.0 of the AMC-DOAS algorithm, whereas in our study we validate SCIAMACHY WVC over both land and ocean surfaces and make use of the operational SCIAMACHY version 5.01 water vapour column product.
Mieruch et al. (2010) suggests that the mean bias over ocean is caused by the cloud water path (CWP). The results of this comparison do not disagree with those of Mieruch et al. (2010), but suggests that the cloud height is in fact the determining parameter for the mean bias. We further suggest that there is a relation between cloud water path and cloud top pressure which can explain why the results from Mieruch et al. (2010) indicate that the mean bias is dependent on the CWP. The results showing that the WVC mean bias depends strongly on cloud top height is useful for the selection of WVC data, because the cloud top height product is included in the SCIAMACHY-ESA dataset (whereas CWP is not). Therefore it can directly be used as a selection criterion for the WVC data.

The "best" selection criteria depend on the intended use of the data. From Table 1 we suggest that for most cases it is best to use either one of the "AMF CF ≥ 0.95" or “cloud height smaller than 2km” selection criteria. The user should however be aware that the data selection according to the cloud height criterion could be affected by errors originating from the cloud algorithm. Selecting according to the AMF CF criterion the number of points decreases with only 30%, while the bias, scatter, and correlation all improve.
A description of the best selection criteria has also been added to the end of Section 3 (bottom of page 9 in revised manuscript) and are further discussed in the revised manuscript in Section 6 (”*Discussion and Conclusions*”).
Regarding the last part of the reviewer’s comment: The AMC-DOAS method used is also applied to cloudy scenes and implicitly corrects for water vapour below clouds via the fitted AMF correction factor. Thus the partial water vapour columns from radiosonde measurements above clouds should not be compared in a similar way to what was done with WVC from SCIAMACHY-IMLM.

3. The validation between SCIAMACHY-IMLM WVC data with radiosondes is presented in Section 4. The bias is computed using a number of selection criteria as suggested by Schrijver at al. (2009), and the measurement noise error shows a clear dependence on the signal strength. Both the SPICI and the FRESCO+ clouds product are used to determine cloud properties. Finally the authors suggest to select cloudy conditions with low cloud height or to use partially integrated radiosonde water vapour profile for the comparison in order to extend the data sample. However, in the first case the bias increases, and maybe other datasets could be more promising for the validation, while in the second case the selection would not be useful to retrieve the global distribution of total column water vapour. I would suggest to clearly distinguish the two different comparisons in the text of Section 4 (P 678), not to generate confusion in the reader.

   We agree with the referee that the comparisons in the last part of Section 4 (whereby the water vapour column comparisons are expanded to included cases over the ocean and during cloudy conditions) might generate confusion in the reader. In light of this, the second part of Section 4 has been modified and now includes a sub-section.

The first part of Section 4 remains unchanged and still focusses on results from comparing SCIAMACHY-IMLM with radiosonde WVC over land surfaces for cloud free conditions. The second half of Section 4 has been modified (Section 4.1, *Partial water vapour columns above cloud over ocean surfaces*) and now only includes the results from the partial water vapour column comparisons over the ocean during cloudy conditions.
In addition to these modifications a supplementary comparison has been performed in Section 4.1 for the partial water vapour column comparisons. In the original manuscript, cloud top height obtained from FRESCO+ was used to calculate the partial radiosonde water vapour column. In addition to this, the CH_4 total column (which is retrieved simultaneously with SCIAMACHY-IMLM water vapour) is now also used to derive the cloud top height and to calculate the partial radiosonde water vapour column. The two approaches are also compared in the text and in Table 2 in the revised manuscript.

4. The comparison between the retrieved SCIAMACHY-ESA and SCIAMACHY-IMLM datasets is performed for only one day and the authors infer a good correlation between the products with SCIAMACHY-ESA WVC generally higher than the SCIAMACHYIMLM measurements over land for cloud free conditions.
However, this result is in apparent contradiction with the validations results, since the authors state that the SCIAMACHY-ESA present a negative bias with respect to radiosonde measurements, while a mean difference of 0.08 g cm-2 is found for the SCIAMACHY-IMLM data.
Even though the two validation are performed within different time frames and over land the bias is positive for SCIAMACHY-ESA, in my view the authors should extend the Section 5, and possibly also the time period of the inter-comparison between the two water vapour datasets and clarify the discrepancies between them. The quality of the paper would strongly benefit from a brief analysis on the advantages and disadvantages of the two datasets, and a statement about potential synergies of both methods aiming to establish a reference water vapour product.

Section 5 has been extended and the comparison between SCIAMACHY-ESA and SCIAMACHY-IMLM WVC data sets has been expanded to include a longer time period of 30 days. Furthermore, the two SCIAMACHY WVC data sets are collocated with matching radiosonde values for this same one month period in order to perform a simultaneous comparison between the three datasets.
The comparison between the SCIAMACHY water vapour products in Section 5 are performed for measurements where both SCIAMACHY-ESA and SCIAMACHY-IMLM are cloud free and over land only. For cloud free conditions over land SCIAMACHY-ESA water vapour has a positive mean bias of 0.09 g/cm^2 (a negative bias is found when comparing all SCIAMACHY-ESA measurement cases for both land and ocean surfaces and all cloud conditions, see Figure 3 in manuscript), and a mean bias of 0.08 g/cm^2 is found for the SCIAMACHY-IMLM water vapour over land and for cloud free conditions.
The last section (Section 6) in the manuscript has been changed to "Discussion and Conclusions". In this section the advantages and disadvantages of both SCIAMACHY water vapour data sets are discussed, including possible synergetic use together with the best selection criteria of the two data products.