Response to Reviewers

Referee #1: R.LANG

Thank you very much for your review! All specific comments were regarded in the paper. In the following you see comments to your general remarks:

C1) Even though the consideration of slightly different energy regions may at this point in time not be realistic anymore on the program side (due to the maturity of the program developmental stages especially for FCI and OLCI), I am missing a motivation in the paper why the focus is solely on the NIR above 800 nm. From the above considerations and from the introduction of the paper the next obvious step leading to a more integrated and improved knowledge of WV total columns from a single instrument would be to add more (spectrally targeted) information from the visible, like from the 4nu and4nu+delta bands around 730 and 640 nm. This will very likely significantly increase the sensitivity to the lower troposphere in general and may even make high quality day-time retrievals of total columns over clear-sky oceans or dark land surfaces feasible. Since the contrast between the cloud and clear-sky case is lower in the visible the sensitivity of the retrieved column to residual cloud or scattering aerosol is also lower in the visible. The latter sensitivity is also decreased by a generally larger sensitivity to the lower troposphere. Also saturation effects play a less significant role and the dynamic range of a single channel in the visible can potentially be much larger than in the NIR providing improved calibration and sensitivity of the detector.

A1) The motivation for the focus of the NIR above 800 nm has been improved:
"Although there are many absorption features of water vapour over the whole electromagnetic spectrum, just a few of them are suited for the retrieval of water vapour columns. Some existing water vapour retrieval schemes use radiation measurements in the VIS (Noël et al., 2004) and IR (Susskind et al., 2003). This work focuses on concepts of retrievals which analyse measured radiation in the NIR between 800 nm and 1000 nm. There are several reasons for that, e.g the influence of Rayleigh scattering and scattering on atmospheric particles, and the spectral dependency of the surface reflectance are comparably low. Above this range saturation effects are too dominant to retrieve high water vapour columns. Below that range the absorption lines are too narrow and the sensitivity of the transmittance with respect to water vapour is too low. Although well known above the ocean, the emissivities of land surfaces in the microwave and IR spectrum are highly heterogeneous and mostly unknown. Alternatively, in the visible (VIS) and near-infrared (NIR) wavelength range one can estimate the characteristics of the lower boundary (surface reflectance) from TOA measurements. Consequently, this work only considers the wavelength range of NIR."

C2)
The list of parameters to which the total column retrieval will be sensitive to, surface albedo, aerosol load, and column concentration, is overall well chosen, little is however said about the sensitivity to the profile shape (water vapour in particular but also aerosol scattering layer height and cloud top height). Section four states that in addition to the 27 cases varying the targeted parameter set and for which results are presented, additionally the temperature profile has been shifted by 10K, and also the aerosol scaling height has been altered (leading not only to a higher optical thickness but also to an on average higher layer-height). But later on it is not clear to me where these results are discussed. Is the model assuming a fixed coupling between water vapour and temperature (i.e. Clausius–Clapeyron's relation) such that the changing WV total columns imply a change in profile? This close coupling is however only true for the tropics but not necessarily, or even not at all, in the extra tropics (sees e.g. Wagner et al., 2006).
It is clear that the simulation of a realistic amount of different profile shapes (both for aerosol and water vapour) will probably largely exceed the scope of the paper. Nevertheless it would for the overall scope of the paper be beneficial to provide some results on the vertical information-content

distribution for the various sensors and channel combinations, predominantly concerning the peak altitude of the information content per channel setting. The Bayesian approach used for the derivation of uncertainties is well suited for such an analysis, providing additional input (and effort) of climatological background profile information and their adjacent uncertainties (e.g. from re-analysis). At the end of section 3.2.1 it is stated that no background information and errors are used from which averaging kernels could be derived. But then the next section (3.2.2) on information content does make use of such uncertainties (sigma_a) but is, however, using a completely different concept for the derivation of information content. Even though I acknowledge that this concept is useful for the subsequent discussion of the results (and probably straight forward and robust for implementation), it seems to be not well suited to link information content to altitude or this information, if available at all, has not been exploited. In contrast the averaging kernel concept making use of the Bayesian approach of the previous section would provide such information. From the vertical information-content distribution for the clear-sky case the potential impact on the derived total column under varying WV profile of aerosol load profile conditions can be more easily inferred even though this work might be then left to the reader or to subsequent detailed studies.

A2)The parameters were considered to account for the error influences on the water vapour column. The sensitivity to cirrus clouds was considered to include the influence of subpixel cloud contamination and because todays cloud detection algorithms are not accurate enough to detect thin clouds. The height of the aerosol layer (see below) and the natural change in the temperature profile are significant error influences. Hence, they were included as parameter uncertainties and kept constant for each of the 27 cases.
Furthermore, in this study no influences of profile shapes of water vapour, aerosol or temperature were considered. The US-Standard profile was used. The calculated uncer tainties refer only to the whole vertical column of the atmosphere. Nevertheless, the profile shape plays an important role when interpreting the influences of the albedo and aerosol optical thickness. The peak altitude of the sensitivity for the water vapour column at the TOA can be understood from Figure 1. Here the sensitivities of the apparent transmittance R (window channel at 885 nm, absorption channel at 900 nm) is shown as a function of height for five different surface reflectances. The sensitivities for each layer were derived from the difference between the reference ratio and the ratio simulated with an increased water vapour content (+0.1mm) in that layer divided by the change in water vapour. For reference the US standard water vapour profile was chosen and a homogeneous continental aerosol layer at 700hPa (3000+/-250 m) with an optical thickness at 900 nm of 0.1 was predefined. As the figure clearly shows, the peak altitude of the sensitivity is governed by the surface reflectance and the aerosol layer height. The lower the surface reflectance, the more information originates from the layers above the aerosol layer. The influence of the aerosol layer is even higher with higher optical thickness (not shown here). This is a significant error influence for surface reflectances below 0.2. Nevertheless we only accounted for that in the parameter uncertainties."

The water vapour column content can be changed in the RTM (MOMO) with a scaling parameter. The change on water vapour cloumn content does not imply a change in the temperatur (-profile).
Although you can change profile shapes, to derive the sensitivity to the temperature the profile was modified equally by 10K in every layer.
Indeed, the simulation of a realistic amount of different profile shapes to provide some results on the vertical information-content distribution for the various sensors and channel combinations would be much appreciated but exceeds the scope of this paper. Figure 1 gives an idea of the behaviour of the peak altitude of the information content, althought it is just a comparison of sensitivities for different surface reflectances.
Overall, we concentrated on the uncertainties of water vapour for the whole atmospheric column. This is why the special concept for derivation of information content (see section 3.2) was chosen.

C3)For the reader not necessarily familiar with the future operational mission framework within this study is placed, the introduction should state why only imager data is considered here and why existing operational products from the visible (GOME/SCIAMACHY/GOME-2) and the IR (AIRS / IASI) using high-resolution spectral measurement and capable to detect WV columns and profiles over both land and ocean for cloud-free cases are neglected here. For the informed reader the reason is clear, since the target instruments are of the same (similar) measurement category or principle. This however might not be so obvious to the "uninformed" reader.

A3) This was added in the Text:
“We selected only concepts of imager-sensors who are planned to have water vapour absorption channels in the NIR.”

C4) Section 5.1., p. 6335, l. 2ff: and paragraph thereafter (l.6ff): “Above dark surfaces, most of the photons get scattered and thus do not travel through the whole vertical column...”. Overall this is a confusing statement since in Figure 4 it looks like the variation of the changes with AOT is often stronger for the medium and high albedo case than for the low except maybe for MTG in the low TCWV case. Though the statement on the contribution of the scattering layers and the adjacent uncertainties is in principle correct at first order the results seem not to support this conclusion. This is then stated in the next paragraph. This also points to the fact that the relation of the retrieval uncertainties to the “assumed” profile shapes are not that “simple”.

A4) This part was not phrased well and now improved in the paper:
Above dark surfaces, a large number relative to the total amount of photons get scattered back and consequently does not travel through the whole vertical column of water vapour (Lindstrot et al., 2012) (see also Figure 1). Hence, the uncertainty is higher for dark than for bright surfaces.

This behaviour involves the reduction of uncertainties over dark surfaces and high AOT. Here, a part of the photons get scattered back at the aerosol layer and dont get absorbed by the surface . Consequently, the uncertainty decreases with higher AOT over dark surfaces.
Of course, the dependency to the profile shape of the aerosol and its properties is significant. This would be a good subject for a future study.

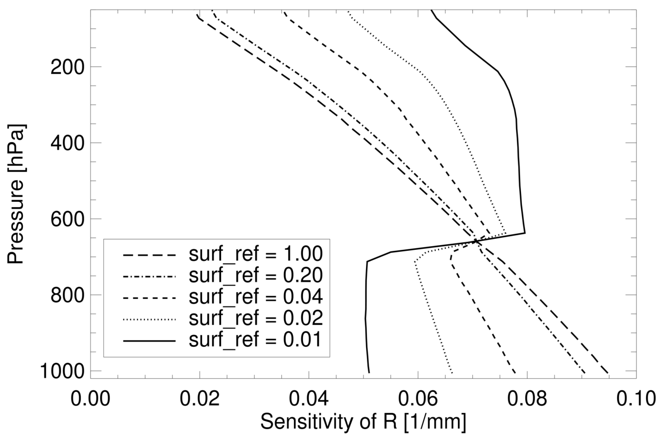

Figure 1: Sensitivity in 1/mm of the apparent transmittance R to the water vapour column content as a function of pressure (height levels) for five different surface reflectances (surf_ref). A constant aerosol layer at 700hPa is present.

Referee #2:

Thank you very much for your review! The second general point of concern and the specific remarks 2, 4, 7, 8, 11, 13, 14 were regarded in the paper. Additionally the Figures were improved (recommendation 15-18).
Detailed answers and comments to the other remarks you can see below

General points of concern:
The potential influence of clouds is mentioned somewhere in the text. But while aerosol optical depth has been explicitly included in the analysis, the potential influence of subvisible cirrus or of low level clouds or of subpixel cloud contamination is not discussed.

A) The follwing paragraph was included in the paper:
"The theory of optimal estimation requires the knowledge of the uncertainties of the model parameters. The assumed accuracies are given in Table 2 as standard deviations. These parameters were considered to account for the error influences on the water vapour column. The sensitivity to cirrus clouds was considered to include the influence of subpixel cloud contamination and because todays cloud detection algorithms are not acurate enough to detect thin clouds. The height of the aerosol layer (see below) and the natural change in the temperature profile are significant error influences. Hence, they were included as parameter uncertainties and kept constant for each of the 27 cases."

C1)How would instruments on two satellites in the same orbit height and with the same local time of descending nodes provide a better temporal resolution?

A1) This is really what we aimed for: To provide a better temporal resolution it is planned to operate two identical platforms which orbit the earth on sun-synchronous tracks in about 815 km height with a delay of 180 degrees.

C3) The first sentence addresses measurement uncertainties, that contain generally bias and statistical errors. Does the following discussion and methodical consideration include both errors?

A3) No, no absolute calibration uncertainties or systematic measurement errors were assumed.

C5) How is the "apparent transmittance" defined?

A5) The apparent transmittance is definded es the ratio of TOA radiances from a absorption and a window channel ($R=T_{abs}/T_{win}$)

C6)According to Table 2 the accuracies are generally assumed the same for the low, medium, and high cases. Only for surface albedo different values are given in each case – why? The legend of Table 2 should refer to Table 1 for the meaning of the three properties Low, Medium, and High! Replace "Porperty" by "Property" in Table 2.

A6) The selection of the parameter uncertainties is arbitrary. Nevertheless, this does not influence the general outcommings of this study.

C9) Why is the other relative maximum at 950 nm not mentioned? Are the maxima in any way significant when looking at the wide range of standard deviation?

A9) Yes. We interprated not only the mean information content but also the minimum, maximum and standard deviation. Then, only the 900 nm and 915 nm are the best choices.

C10) Why is 900 nm selected? The reason is obviously only mentioned at the very end of the paper (p. 6341, l. 4+5) but would be of interest already here. To me it would be much more convincing to clearly show that no other spectral interval (e.g. 915 nm) would give better results.

A10) For comparison, the information content for retrieval with a fixed first absorption channel at 915 nm and a variable second absorption channel is shown in Figure 2. In comparison to the information content using 900 nm as the fist absorption channel, Figure 2 shows lower information content values.

C12) Would not the combination of 915 and 935 nm have been even better?

A12) No, See Figure 2.

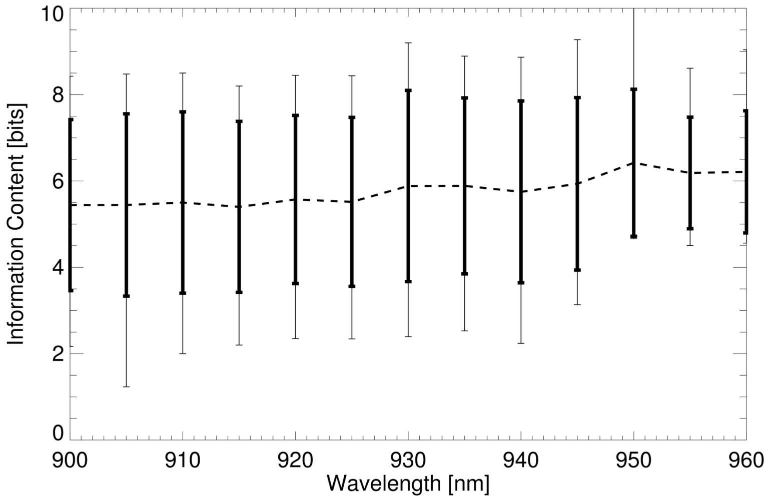

Figure 2: Mean information content in 27 cases of different atmospheric circumstances concerning water vapour of a retrieval usingtwo window channels (865, 1020 nm), a fixed first absorption channel at 915 nm and a second absorptionchannel (width 10 nm) [broad bars account for the standard deviation].