General comment from the reviewer

“This manuscript describes a retrieval algorithm of integrated water vapor content above cloud form shortwave infrared observations as will be measured with the C3IEL mission. The manuscript is of interest for AMT. However, I recommend some clarifications to be added to the manuscript, related to the questions below. Please address these issues in the revised manuscript.”

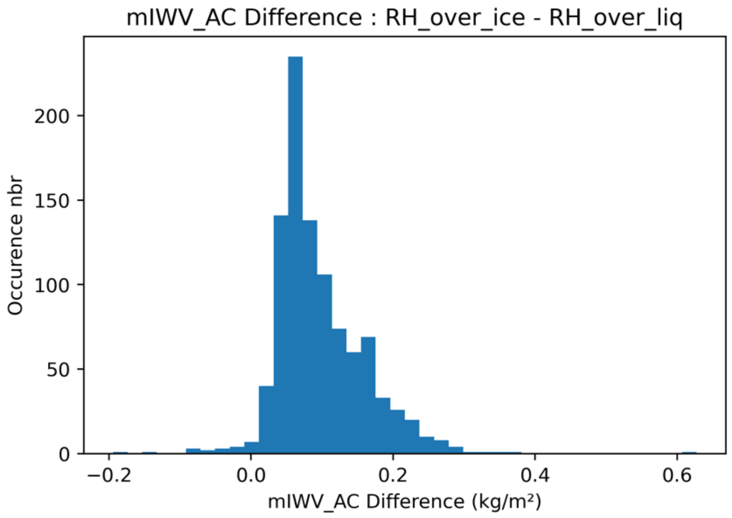
https://doi.org/10.5194/egusphere-2025-787-RC2

Dear reviewer,

Thanks for your comments and your questions. In the revised manuscript all the typos and suggested reformulations are accounted for, and your questions have been addressed. We have listed your questions below (in red), then explained how we have addressed each point in the revised manuscript and provided new sentences (in green).

“The relative humidity is assumed to be 100% in cloud. I assume here the relative humidity is defined with respect to liquid water. This assumption is then true for water clouds, but not necessarily true for ice clouds. What is the impact of this assumption for ice clouds?”

The in-cloud relative humidity was set to 100% with respect to liquid water for all retrievals. This is a valid assumption for liquid-phase clouds, but it does lead to an overestimation of in-cloud humidity for ice clouds (saturation vapor pressure over ice is lower). However, we can expect this assumption to have a limited impact on the results. The cloud optical thickness constrains the depth to which radiation can penetrate. In optically thick clouds (which is the case for deep convective cloud), the radiation reaching the instrument comes primarily from above the cloud top and the uppermost layers of the cloud. So, the absorption occurring deeper within the cloud, and the influence of the in-cloud humidity profile should remain low. However, to make sure that this assumption is correct we have made the test, and the results are very similar. The histogram representing the difference (retrieved mIWV_AC using RH=100% over ICE minus retrieved mIWV_AC using RH=100% over Liquid) is presented below. As expected, the influence is low (mainly less than 0.2 kg/m2) and as there is less in-cloud water vapor using the calculation over ice, the algorithm compensates this by adding water vapor above the cloud (hence the quasi-systematic positive difference).



Though this test confirmed our hypothesis, we acknowledge that RH_ice should be used in the retrieval algorithm for high level clouds, so we have modified the corresponding plots in the paper. We have added a sentence clarifying this point in the manuscript (new file, page.8 lines. 183-185):

"For low- and mid-level liquid clouds (Section 5.2.2), the assumption is applied with respect to liquid water. For high-level mixed-phase clouds (Section 5.2.3), relative humidity is defined as 100% with respect to liquid water below 4 km and with respect to ice above."

"For clouds with tops higher than 4 km, cloud tops are assumed to be ice. Many supercooled liquid clouds extend much higher than 4 km. What is the impact of a wrong cloud top phase assumption to the results?"

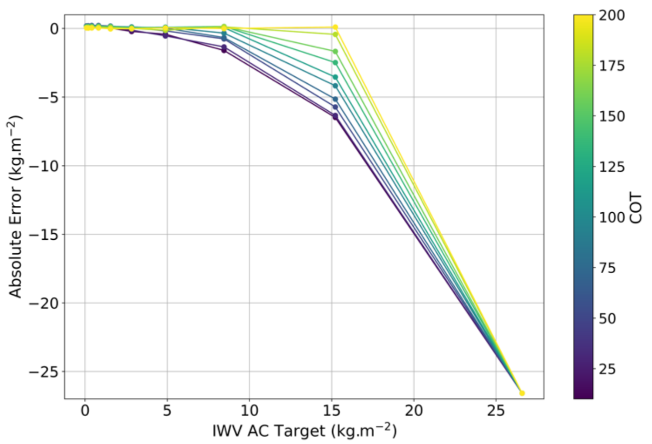
This is a valid concern, and we agree that supercooled liquid clouds can be present well above 4 km altitude, especially in convective systems. However, we have no information to know the exact vertical profile inside the cloud, so we have to make an assumption. The 4 km threshold used in our study is based on the average "0°C isotherm" level from the ECMWF-IFS profiles. An incorrect cloud phase assumption could affect the cloud optical properties, especially the single scattering albedo, asymmetry factor, and extinction coefficient, which could influence the estimation of cloud transmittance and the retrieved integrated water vapor content above cloud. In the future, we plan to improve the cloud model defined in our retrieval algorithm and use a more realistic and complex cloud vertical structure. We have added a sentence in the conclusion and perspective section (new file, page.21 lines. 431-434):

"The cloud model phase used during the retrieval process can also be improved, particularly the assumption of 4 km made for the top of the liquid phase, for tests on mixed-phase clouds, given that supercooled liquid clouds can be present well above 4 km altitude. A better definition of the different cloud phases would allow for a better representation of the cloud's optical properties."

"What is the sensitivity of the results to the assumed base height? The sensitivity is briefly discussed in section 5.2.2., but I think it should be systematically investigated related to the analysis shown in figures 3 and 4."

Thanks to this comment, we realized that there was a mistake in the value of the cloud base used in the idealized cases (section 5.1). We modified this value to its actual value (new file, page.10 line.228): *"0.5 km"*.

Tests were carried out to see the effect of the cloud base altitude on the retrieval in the idealized cases where we increased the error on this fixed parameter from 320m (in the current version) up to 2000m. Results are presented in the figure below (using the three channels for the retrievals), added to the document (new file, page.13 Figure 5.).



Caption (new file, page.13 Figure 5.): *Same as figure 4 for the three spectral bands (1.04, 1.13 and 1.37 µm) configuration but with a large uncertainty of 2000 m for the cloud base altitude identified as a non-retrieved parameter.*

As can be seen, the retrievals for low-level clouds with CTH below 4 km are largely underestimated, especially for optically thin clouds, while retrievals with CBH = 1 km are not possible (no convergence for all considered COTs), whereas for clouds with tops from 4 km, the impact is not significant. The following paragraph has been added to the manuscript (new file, page.12 lines.280-286):

"Note that C^3IEL will not give information about the cloud base altitude, for the idealized case, we use 0.5 km and a standard deviation obtained from the ECMWF-IFS database. In order to test the sensitivity of the proposed algorithm to this fixed parameter, we performed the retrievals by adding a large error on this parameter (2000 m). Figure 5 shows these retrievals. Using the 3-channels approach, for cloud top altitude of 1 km, the algorithm do not converge. For low-level clouds with cloud top altitudes of 2 and 3 km, large absolute errors are observed (around -5 to -2 kg.m-2, respectively for moderate COTs, purple to blue lines). Above these altitudes, for cloud tops from 4 to 10 km, this parameter does not significantly modify the results, and absolute errors are in the same range as previously."

"In line 235 it is stated that "Consequently, less radiation is absorbed within the cloud with the SAS model used for the retrieval than with the AFGL tropical model used to simulate the test measurements." This seems to contradict the statement in line 215 that "different first guess profiles, both in idealized and realistic scenarios, give similar results." What is the real influence of the assumed profile?"

There is indeed confusion, we made a mistake here. Below the correct paragraph with additional information to discuss the influence of the assumed first guess profile:

(new file, page.10 lines.232-236) *"Tests carried out with different first guess profiles, both in idealized and realistic scenarios, show that initial profile has an impact on in-cloud water vapor since we assume that RH=100% between cloud base and cloud top altitudes. So, starting iterations with the smooth SAS profile leads to an underestimation of the in-cloud water vapor absorption as the SAS profile is drier than the tropical profile used to generate the test data."*

(new file, pages.11-12 lines.253-266) *"The absolute error is positive, indicating that the retrieved IWV_AC is overestimated due to less in-cloud water vapor absorption. This occurs because the water vapor profile within the cloud is not adjusted during the retrieval process, and the first-guess profile (AFGL SAS) is drier than the target AFGL tropical profile. Consequently, less radiation is absorbed within the cloud with the AFGL SAS model used for retrieval than with the AFGL tropical model used to simulate the test measurements. To compensate for this lower absorption and minimize the difference between the forward model simulations F(x) and the measurements y, the retrieved integrated water vapor above the cloud is overestimated. For optically thick clouds, the same behavior appears to a lesser extent, since less radiation interacts with the in-cloud water vapor.*

Tests made using the tropical profile as the first guess in order to have the same in-cloud water vapor absorption between the simulated measurements and the retrievals *leads to smaller errors for thin clouds since the COT is well retrieved. Conversely, larger negative errors for low-level and optically thick clouds occur, as the algorithm underestimates the extinction profile. Consequently, there is more in-cloud absorption and the algorithm underestimates water vapor above clouds. Based on these results, the use of the SAS profile as a first guess appears to introduce a compensatory effect that partially mitigates the systematic underestimation of large COT."*