Author reply to referee 2 AMT-2016-123

Dear Reviewer,

thank you for your support and for your suggestions for improving our manuscript.

In general, all reviewers suggest to strengthen the literature review, especially to improve the discussion of earlier publications on imaging ice cloud remote sensing (Schaefer et al. 2013) and the introduction of the visible spectral slope solution for the transmissivity ambiguity (Brueckner el al. 2014 and Le Blanc et al 2015). This is an obvious weakness of our manuscript. The reason for this negligence on our side is partly due to the fact that our manuscript has had a long history already. In our group the spectral slope approach originally goes back to a Master‘s thesis of co-author Petra Hausmann from 2012. We obviously noticed that “our approach“ was published meanwhile in proper journals by others. Even though this is no excuse for gaps in our literature review, it might explain why we do not want to state any direct “use“ or “application“ of ideas introduced by the aforementioned authors. In our revision we do both, we try to strengthen our literature discussion, and at the same time we would like to include the Hausmann Master‘s thesis from 2012 as a reference. Although it is no peer-reviewed publication it is an official university thesis in English language available online.

Point by point reply to all major comments (all minor were considered as suggested, apart from the one mentioned below):

2 Major comments

Existing methods have not been considered

In the manuscript some available studies have not been discussed properly. E.g., the problem discriminating the ambiguity of thin and thick cirrus clouds was already solved by Brückner et al. (2014) who applied a similar retrieval for transmissivity measurements and also used a ratio in visible wavelength for a third coordinate in the retrieval grid separating thin and thick cirrus.

Similarly, in the sensitivity study and in the conclusions shape effects for transmissivity are discussed. Results of the sensitivity study should by compared to Schäfer et al. (2013) who did similar sensitivity studies for the retrieval of optical thickness by transmissivity in case of tropical cirrus. Additionally, Schäfer et al. (2013) present an approach to estimate ice crystal shape. This could be applied to some extend for the measurements of specMACS as well reducing the retrieval uncertainty due to the assumption of ice crystal shape.

=> The section in the introduction now reads:

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Recently Brückner et al. (2014) as well as LeBlanc et al. (2015)
presented similar solutions for unambiguous retrievals of optical
thickness and effective radius for pointing system without
providing imagery. Both suggest the use of spectral slopes in the
visible to separate between the two optical thickness regimes.
We will present a combination of both, a solution for the
transmittance ambiguity using a similar spectral slope (following
ideas of Hausmann, 2012) and results for imaging measurements which
provide context information on the distribution of optical
thickness and effective radius over a large area.
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We also mention Brückner and LeBlanc at the end of section 3 “Retrieval...“ where we presented our version of the idea and in the section 5 “Summary and Discussion“.

We included a comparison to the Schäfer et al results into the discussion section:

Schäfer et al. (2013) also assessed the sensitivity of their ground-based cirrus optical thickness retrieval to variation of certain parameters. The values can not be directly compared to our results, as they only refer to a small number of specific situations regarding observation geometry and cirrus situation and not a large range of combinations as in our sensitivity test. For variation of crystal habit and for small optical thickness up to 1 they showed large relative differences up to 80% with average absolute differences at 0.1. Though such cases are contained in the sensitivity test shown here, average impact over many different situations is smaller. Schäfer et al. (2013) also present large uncertainties for an albedo variation. This is caused by their choice of a test albedo which is extremely different from the measurement situation, while here it was assumed that the general albedo situation can be characterized well and remaining uncertainty has only small impact.

We also extended the final discussion of the possibilities to exploit the spatial distribution of transmissivity similar to Schäfer et al.:

Of course the most important step forward would consist in a reduction of the crystal type uncertainty. The halo regions around 22° and 46° scattering angle were avoided here for our spectral approach. Uncertainties can be expected to be higher in these regions with strong angular gradients of transmittance under single scattering conditions, if no additional information on crystal habits is available. However the imaging capabilities of the specMACS sensor (especially if combined with a scanning platform, see Ewald et al., 2015) do not only allow to successfully avoid these regions for the spectral evaluation, but would allow for the utilization of the spatial distribution of transmittance in these regions to provide the missing information. Use of this spatial distribution could provide important constraints regarding the present average phase function as Schaefer et al. (2013) demonstrated. Especially the presence of optical scattering phenomena like type and intensity of halo displays could be used to identify specific particle shapes and orientation and information on the mixture with less perfect rough ice particles. A combination of the presented method with additional information of this kind will be the next step in our effort to provide better ice cloud property observations.

State of art transmissivity retrievals

I wounder, why the authors do not build their retrieval algorithm on the existing improvements introduced by Brückner et al. (2014), McBRide et al. (2011), LeBlanc et al. (2015) for transmissivity retrievals? These retrieval are based on radiance ratios instead of absolute radiance/transmittance and do improve the retrieval uncertainty. This was even discussed by the authors in the conclusions. Therefore, I wounder why the authors did not apply these new methods despite knowing that they provide more precise results than the "classical" Nakajima-King approach. As all look-up tables seem to be calculated for the full spectral range given by specMACS, switching to ratios should be an easy task.

=> In part the answer was given in the beginning of our response. That means development of the described techniques was work going on in parallel to the above mentioned not afterwards. The development of a retrieval purely based on ratios would be a totally new effort not within the scope of the project that lead to our manuscript. Apart from this general organizational problem, lookup tables were only generated for the parts of the spectrum needed for our retrieval. This would therefore be related to extensive reprocessing of simulations.

Case study 2. October

The choice of the second case study presented in the manuscript was rather unfortunate. As discussed in detail by the authors, the comparison between satellite and ground-based measurements suffers due to low level clouds contaminating the cloud retrieval of the satellite instruments. Therefore, the data sets are in general not comparable in my point of view. Presenting this comparison is not meaningful and does not add any value to the manuscript. At least not for the main subject, cirrus transmittance retrieval using imaging spectrometers. So I would suggest to choose another case or at least remove the satellite comparison. Instead it might be worth to compare and discuss the differences in cloud properties and retrieval uncertainties between both cases.

=> We think the second test case should stay in the manuscript.

(1) We do not only want to show a single perfect example, but also show an example where the quality is not so good for good reasons (“quality“ was renamed “significance“ following a comment from another reviewer).

(2) This second example is also interesting because it demonstrates the possible advantages of a ground-based method. Looking upward, clouds below the mountain top do not directly affect the retrieval, except that they increase the albedo (in contrast to the satellite retrievals which obviously are affected). Very likely our results are the best possibility to provide a “ground truth“ for cirrus satellite retrievals in such situations. The possible implications of albedo changes by the underlying cloud patches around the sensor position are also discussed in an additional “spectral albedo“ test case in the sensitivity tests and mentioned for this example. We discuss that in the end of this section:

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An interesting aspect of this complex example is the demonstration
of the potential of a ground-based method to provide accurate cloud
properties compared to satellite methods, especially for thin
cirrus. The same quantities are retrieved by both methods,
utilising similar wavelength bands, but the ground-based method
benefits from its much higher spatial resolution which allows to
separate different parts (or layers) of the observed cloudiness. In
the ground-based data there might still be an impact of increased
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albedo (low level cumulus below the instrument). The low levels of significance of our results at larger sensor zenith angles might be a sign of it (see Fig. 12d). Nonetheless the ground-based method is less affected by this problem and generally most likely much better at retrieving thin ice cloud properties than the satellite methods.

3 Minor comments

P6, Section 3.2: Section 3.2. somehow does not fit in the outline of the manuscript. It should be placed at 2.2 where already model, surface albedo and ice crystal scattering properties are introduced.

=> In section 2 we describe all tools that were available to us when we started and which everybody else could use. Section 3 describes the new method. I'm not sure whether it is useful to renumber section 3.1/3.2/3.3 to 2.3.1/2.3.2/2.3.3 ?

Fig 8,9,12: Increase font size of axes and labels.

=> I increased font size of Fig 8. For Figure 9 and 12 I would prefer a larger image size which also will depend on the later layout.

Reference:

- Hausmann, P.: Ground-based remote sensing of optically thin ice clouds, 89 pages, Master's thesis, Ludwig-Maximilians-Universität, Munich, http://www.meteo.physik.uni-muenchen.de/DokuWiki/lib/exe/fetch.php?media=intern:abschlussarbeiten:2012:ma2012_hausmann_petra.pdf, 2012.