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Atmospheric Measurement Techniques Discussions

Interactive comment on "The Impact of Neglecting Ice Phase on Cloud Optical Depth Retrievals from AERONET Cloud Mode Observations" *by* Jonathan K. P. Shonk et al.

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We thank both reviewers for their suggestions and comments. Our responses are presented below. A marked-up version of the manuscript has been uploaded with changes highlighted.

Reviewer "B" Summary: This paper reports the results of an algorithm that builds naturally on earlier ones developed by Marshak, Chiu, and others for retrieving cloud optical depth from two-channel (visible and near infrared) downwelling radiance measurements. Here, the goal of the algorithm enhancements is to reduce retrieval error when ice particles, as well as liquid particles, contribute to the downwelling radiances.

The paper is easy to understand and all of the analyses make sense. I recommend its publication in AMT. My comments are minor in nature.

Comments: 1. The algorithm makes use of one-dimensional radiative transfer theory and differential surface reflectivity at the two wavelengths to compensate for it. After reading the Introduction it was not clear how accurate this approach is when applied to different cloud types. In particular, how good is it when applied to fields of horizontally small but vertically developed convective clouds in the tropics as a function of overall cloud fraction? Does significant side illumination and/or cloud side leakage of the convective elements cause problems? If Aeronet is located near a coastal site, do differences in the surface reflectivity of the land and the ocean cause problems? These types of questions are relevant to the paper because the algorithm is applied to tropical convective clouds at sites with mixtures of surface types in their environs. Strengthen the Introduction by making clear, with supporting references, how accurate the retrieval is expected to be for different cloud types and mixtures of different surface types. If this is not known, then say so and caveat your optical depth retrieval accuracies towards the end of the paper.

–> The performance of the method was examined by Marshak et al (2004) and Chiu et al. (2006), who showed that the method works well for both overcast and broken cloud fields. The method will not work well when clouds do not fully cover the field of view (FOV) of the radiometer (the so-called "clear-sky contamination" issue; see Chiu et al., 2006). Therefore, unphysical cloud optical depth can happen near cloud edges. Such contamination is more frequent in small cumulus clouds, although convective clouds have sufficiently large horizontal extents that they can completely cover the narrow 1.2° FOV of the sun-photometers. Note that when a time series of retrievals is available (e.g., cases in Chiu et al., 2006), one can detect unphysical retrievals near cloud edges and remove them. For AERONET cloud mode retrievals which are not made from a complete time series, it is more difficult to detect these unphysical retrievals. For this reason, AERONET reports a "cluster" average (see Chiu et al., 2010), excluding retrievals below the 25th and above the 50th percentile – a similar approach to that of Remer et al (2005), for aerosol retrievals.

–> Differences in surface reflectivity is important to consider for cloud mode retrievals. Surface albedo information is considered over a 4 × 4 km domain surrounding the AERONET site, and a combination of land and ocean surfaces surrounding a site is not ideal. For this reason, the sites included in the AERONET cloud mode dataset have been selected to ensure that the spectral contrast from surrounding vegetated surface is sufficient for the retrieval method (see Chiu et al, 2010).

–> We have added more detail addressing these questions into the fourth paragraph of the Introduction section and divided the paragraph into two (see page 3, lines 3âĂŤ15).

A study that uses three-dimensional radiative transfer theory to pound on these types of uncertainties would be valuable if such a study has yet to be performed. If it has, do reference and discuss it within the Introduction.

–> The reviewer is right; such studies would be valuable. While a lot of studies have focussed on reflected radiance at the top of the atmosphere, there is actually no published paper for zenith radiance at the surface. We looked into 3D radiative effects on cloud mode retrievals a long time ago, but have not found time yet to wrap this up. We incorporate the reviewer's point in the manuscript and, hopefully, this could also motivate others to conduct thorough analyses on 3D radiative transfer.

2. Lines 23-25 on Page 5 and Lines 1-2 on Page 6 indicate that the radiative transfer is always performed with the ice in a top layer and the liquid in a bottom layer. So these calculations are done with ice on top and liquid underneath and not for what are traditionally called mixed-phase clouds. Does it make any difference if the layers are mixed up together to form what is generally called a mixed-phase cloud?

–> Mixing up the ice and liquid will affect the radiance (see Sun and Shine, 1994) – the zenith radiance will be slightly higher if the ice and liquid particles are fully mixed

rather than in two separate layers as in our idealised calculations. More work would be required to understand and quantify the effect of this "mixing" on the correction equation. We have included this question in the future work paragraphs at the end of Section 5 (page 16, lines 1âĂŤ7).

On Page 10, Line 4, the paper refers to mixed-phase cloud in the traditional sense. But on Page 12, Line 12, it is not clear what mixed phase means here. Just be sure to be clear everywhere exactly how the liquid and ice are being dealt with. It may not make any difference for the calculations, but it sure does make a difference for the retrievals: retrieving the properties of liquid only and ice only clouds is not easy but it sure is easier than retrieving the properties of ice and liquid particles all mixed together.

–> We have been quite inconsistent with what we mean by "mixed-phase" clouds in this study, especially in Section 4. We have now tidied it up in various places so that "mixed-phase" is only used to mean mixtures of ice and liquid particles, while general clouds containing both liquid and ice have been described as such. It should now be clearer in both places mentioned in the comment above. We have also cleared it up in Table 2, where the words "mixed-phase cloud" have been replaced with "ice and liquid cloud".

Error estimates for the retrieved liquid and ice particle properties would be more convincing if they were provided in the context of the types of clouds above. These context-based error estimates would be of value if percolated into uncertainties for the retrieved optical paper depths. For example, in convective clouds with mixtures of in-cloud rain, in-cloud ice precipitation, liquid cloud, and ice cloud, not clear at all as to what the actual errors in the retrievals might be.

–> We thank the reviewer for this suggestion. We agree that it would be good to provide errors in the context of cloud types, but we wish to leave it for future work because it requires substantial work and proper ancillary datasets to address this issue properly. Note that AERONET sun-photometers only operate in the absence of precipitation to keep lenses clean and dry. Therefore, we actually do not have many observations for convective clouds described above. If in-cloud rain evaporates before reaching the ground, we have chances to sample such clouds and provide retrieval. However, we have found rain (or drizzle in most cases) do not affect zenith radiance significantly due to its small number of concentrations, based on work in Fielding et al. (2014, 2015). It would be important to tackle the properties of precipitating ice particles, but current retrievals and model simulations for ice microphysical and optical properties are quite uncertain. We are currently working on ice retrieval using polarimetric radar measurements. Hopefully, we can find good collocated datasets to address this.

Minor Details: A marked-up manuscript is being returned to the authors; perhaps some of the mark up may be of value to them.

–> Thank you – this was a helpful inclusion. We have made a number of modifications following your suggestions on the mark-up version (not all of which are mentioned directly in a comment here).

3. First sentence of the abstract: "Cloud optical depth remains a difficult variable to represent in climate models" might be true for a bunch of different reasons not related to "a need for high-quality observations of cloud optical depth from locations around the world". So, the first sentence of the abstract is not compelling.

–> We have reworked the first few sentences of both the Abstract and the Introduction to better link the challenges associated with modelling clouds to the need for cloud optical depth observations. Also, we have reworked and edited the Abstract following the many comments on Reviewer B's marked-up manuscript.

4. The words "could", "could be", "can be",..., are used a lot in the paper. These are weak words in a scientific context and replacing them all with well thought out stronger words would improve the paper.

–> All instances of these words (as highlighted in the reviewer's marked-up document)

have been reviewed and, where appropriate, stronger words have been used.

5. Page 4, Figure 1: The dashed line is really hard to see close to 0.

–> The lines on Figure 1 are now coloured to make the contrast easier. For consistency, the colouring of the lines has been changed in Figure 2 to match.

6. Page 5, Line 13: Wrong units for radiance.

–> The units for radiance both here (now page 6, line 3) and in the y-axis label of Figure 2 should actually be dimensionless, as they correspond to radiances calculated for a unit flux at the top of the atmosphere. This has been corrected, and the normalised nature of the radiances explained in the caption in Figure 2. We have also clarified that the radiances presented here are normalised in the text (page 5, lines 18âĂŤ19).

7. Page 6, Figure 3: Why not squares for the top row of figures with the same x- and y-axis range? A line along the diagonal would help too.

–> The square axes for the top panels of Figure 3 is not practical, as extending the range of true optical depths to 100 would result in the inclusion of many retrievals that exceed 100 (the maximum optical depth in the AERONET look-up tables; this limit has now been mentioned in Section 2). Hence we have only included true optical depths up to 50 as, in this range, none of the retrievals (however high their ice fraction) exceed 100. For clarity, however, we have added the one-to-one line on the top row of panels in Figure 3 as requested. For consistency, we have also added zero lines on the bottom row of Figure 3 and all of Figure 4.

8. Page 8, Lines 23-24: "hence far less of an issue ..." is a subjective statement and would depend upon the application. As such, it is not a correct statement for all situations.

–> Our paper centres on assessing whether the errors affect the long-term cloud optical depth statistics, but we do recognise that there may be instances where accurate retrievals are required at low optical depths. Greater accuracy at low optical depths could be achieved by generating an improved, more complex version of Equation 1. We have highlighted this in Section 3 (page 9, lines 14âĂŤ18) and then again in a little more detail in Section 5 (page 15, lines 28âĂŤ30). This Discussion section is a new addition that brings together the various discussion points from the results sections in one place.

9. Page 10, Lines 14-19: Past tense would probably be better for describing what you did to execute the study.

–> The paragraphs describing the data and how we sampled it is all now in the past.

10. Page 13, Figure 7: Make sure all of the minor tick marks show up in the figure.

–> The grid on Figure 7, which previously was drawn behind the coloured boxes of the 2D histogram, is now replotted on top (but under the blue contours).

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