Review of “Advances in CALIPSO (IIR) cirrus cloud properties retrievals — Part 1: Method and testing” by Mitchell et al.

The manuscript presents significant improvements to the retrieval method previously described by Mitchell et al. (2018). These include methodological refinements, incorporation of additional in-situ observations to develop new empirical relationships linking retrieval properties with CALIPSO observations, and benefits from recent improvements in the IIR and CALIOP operational products (version 4). The updated retrieval approach appears not only to show more precise results but also notably enhances sensitivity to tropical tropopause layer cirrus and polar stratospheric clouds.

The method presented, following Mitchell et al. (2018), remains unique and built upon robust theoretical considerations. A major advantage over existing retrieval methods is that it does not rely on assumptions regarding the ice particle size distribution. It provides an extensive set of (interconnected) microphysical properties, such as the IWC, effective size De, extinction, and Ni. The latter is particularly valuable to the community, given the limited availability of such retrievals from satellite remote sensing.

The authors provide thorough uncertainty evaluations, including the propagation of retrieval uncertainties and statistical comparisons with in-situ observations. I have no fundamental criticisms of the methodology itself. The study clearly falls within the scope of ACP, although, in my opinion, it could fit more naturally as a technical note.

The retrieval methodology is robust, and the resulting product is highly valuable. While I have few specific concerns regarding the method itself, I do have several major general comments on clarifying the nature of the retrievals, the capabilities and limitations of the method, and aspects of its validation. I recommend publication after addressing the major revisions detailed below.

General comments:

1. The authors have thoroughly discussed uncertainties throughout the manuscript, including uncertainties propagated through operational CALIPSO products (sections 2.2.3 and 2.2.4) and indirect comparisons with in-situ measurements. However, the key conclusions related to these uncertainties are, in my opinion, not sufficiently highlighted in the current conclusions section. I suggest including a more comprehensive summary of this uncertainty analysis and explicitly outlining the method’s limitations. Additionally, clearly defining optimal conditions for the retrieval’s application would help users better understand how to effectively utilize or compare the dataset (e.g., for model evaluations). Specifically, aspects related to land/sea contrasts and impacts from snow and sea ice discussed in section 2, along with clarifications associated with the other points below, should be better highlighted in the conclusions.

2. Operational product uncertainties are adequately discussed, and identified as significant uncertainty sources in section 3.4. However, uncertainties stemming from in-situ-based parameterizations (e.g., regressions in Table 3 and relationships in Table 5) should also be acknowledged and discussed similarly, as they might be even more significant for this method. Section 4 provides climatological comparisons between retrievals and in-situ measurements, mostly confirming that in-situ measurements fall within the retrieval spread, except notably for Ni in tropical regions (Figures 17 and 18). I think the manuscript would greatly benefit from one or two detailed case studies, involving coincident satellite and in-situ observations (covering both tropical and mid-latitude scenarios). Such case studies should be feasible using the campaigns already discussed or the Krämer et al. (2020) dataset used for validation.

3. It would also be beneficial to clarify what exactly the retrieved quantities represent. The IIR measurements inherently reflect vertically integrated quantities, weighted by emissions from various cloud layers. Section 2.2.5 briefly discusses these aspects in terms of equivalent layer thickness, but the implications for interpreting retrievals remain somewhat unclear. Typically, passive sensors retrieve integrated properties (IWP, optical depth), while this method retrieves parcel-scale properties (IWC, Ni, De, extinction). Clarifying whether the retrievals represent the entire cloud vertical extent or a specific altitude associated with the radiative temperature (Tr) is needed for proper user interpretation. Comparative case studies as mentioned in my comment #2 could involve CALIOP or DARDAR vertical profiles to clarify these points.

4. The retrieval method relies primarily on parameterizations derived from tropical campaigns, with only one mid-latitude campaign (SPARTICUS) providing somewhat less robust data due to reliance on 2D-S measurements and subsequent corrections. The question of the global applicability of the method should be addressed more explicitly, particularly in the conclusions, given the global applications discussed in Part 2 of this series. Clarifying whether significant limitations exist, such as for high-latitude regions, and advising users on potential constraints would be valuable.

5. It would be informative to directly compare the performance of this updated retrieval method with Mitchell et al. (2018), perhaps through global maps or temperature-dependent analyses. Such comparisons would more clearly highlight the specific advancements made, aligning directly with the manuscript's title.

Specific comment

1. Given the extensive general comments, I have only one concise specific comment or rather a question: Section 2.2.5 illustrates the utility of the IIR weighting function to reconstruct CALIOP extinction profiles. Could similar reconstructions be feasible for IWC, De, and Ni profiles? While this clearly extends beyond the present study's scope, briefly mentioning this possibility as a potential future improvement in the conclusions would be beneficial.