Response to the Reviewer2

This study presents a bispectral retrieval algorithm for determining cloud optical thickness (COT) and cloud effective radius (CER) using data from the Advanced Geostationary Radiation Imager (AGRI) on the FengYun-4A satellite. The algorithm was validated against coincident MODIS cloud products, demonstrating its reliability. Furthermore, ten idealized multi-layer cloud scenarios were employed to investigate the sensitivity of visible and shortwave-infrared (SWIR) reflectance to vertical cloud structure. This study is interesting. I think this paper is publishable after several major revisions before I could recommend it with enthusiasm.

Response: We sincerely thank the reviewer for their constructive comments and valuable suggestions, which have helped us improve the clarity, coherence, and scientific rigor of our manuscript. We have carefully revised the manuscript according to the comments, and detailed point-by-point responses are provided below. All modifications are highlighted in blue in the revised manuscript.

Major comments:

1. This study comprises two primary components: i) the development of a CER and COT retrieval algorithm utilizing AGRI data, and ii) an assessment of the sensitivity of simulated visible/SWIR reflectance to vertical cloud configurations through ten idealized multi-layer cloud scenarios. That said, the linkage between these sections currently lacks immediacy. I suggest that improving the second part to detail how vertical cloud structures influence real-world retrieval outcomes would greatly enhance the paper's coherence and narrative progression.

Response: Response: We sincerely thank the reviewer for this critical insight regarding the linkage between the two primary components of our study. We fully agree that strengthening this connection is essential for the paper's coherence. Since the retrieval results serve as the basis for the sensitivity experiments, we have streamlined the retrieval sections in the revised manuscript by merging Sections 3.1 and 3.2 (**Lines 214–246**). The case study serves both to validate the retrieval model and, more importantly, to provide a basis for the subsequent sensitivity experiments. This connection is explicitly clarified in the revised manuscript (**Lines 230–231, 245–246**).

To further clarify this linkage, we have added a pivotal analysis in the revised manuscript (**Lines 385–411**) and present the key findings here. This new analysis compares the COT–CER relationships from multi-layer cloud simulations against those derived under the single-layer assumption, thereby directly detailing how vertical structures influence retrieval outcomes.

The core results are as follows (and summarized in the new Fig. 12):

The difference between single-layer retrievals and multi-layer simulations strongly depends on CER and vertical configuration (ΔCOT_retrieval, hereafter abbreviated as ΔCOT_R). Overall, when CER < 10 μm, ΔCOT_R changes from negative to positive, indicating that the single-layer assumption systematically underestimates the true COT under small droplet conditions. As CER increases beyond 14 μm, ΔCOT_R gradually becomes positive, with single-layer retrievals exceeding two-layer simulations by approximately 20 units on average. This primarily results from the single-layer assumption's inability to capture the shielding effect of overlying ice clouds on underlying water clouds, as well as the differential contribution of particles at different vertical levels to reflectance in the visible and shortwave infrared channels.

For the "mid-level water cloud and high-level ice cloud" structure, ΔCOT_R remains negative for CER < 22 μm before turning positive (Fig. 12a). For the "low-level water cloud and high-level ice cloud" structure, positive ΔCOT_R appear only when CER > 45 μm (Fig. 12b). Increasing the IWC of the high-level ice cloud maintains negative ΔCOT_R at small CER, with the positive transition also at CER > 45 μm. In the "low-level water and mid-level ice" scenario, ΔCOT_R is near zero for CER < 5 μm, increases gradually with CER, and plateaus beyond 30 μm. The critical CER values where ΔCOT_R changes sign depend on the perturbed layer: ~14 μm for mid-level IWC and ~30 μm for low-level CWC (Fig. 12c), consistent with reflectance sensitivity results.

For the three-layer cloud case, increasing mid-level CWC results in single-layer retrievals being consistently smaller than the simulations when CER < 50 μm, highlighting the limitations of the single-layer assumption under complex vertical structures (Fig. 12d). Together with the preceding COT–CER analyses, these results quantitatively demonstrate that neglecting vertical heterogeneity introduces significant biases in single-layer retrievals, with both the magnitude and sign of ΔCOT_R strongly dependent on CER and the vertical distribution, thickness, and microphysical properties of water and ice layers. Importantly, the trends observed in ΔCOT_R are consistent with the reflectance sensitivity experiments, confirming the direct impact of vertical cloud structure on operational COT retrievals.

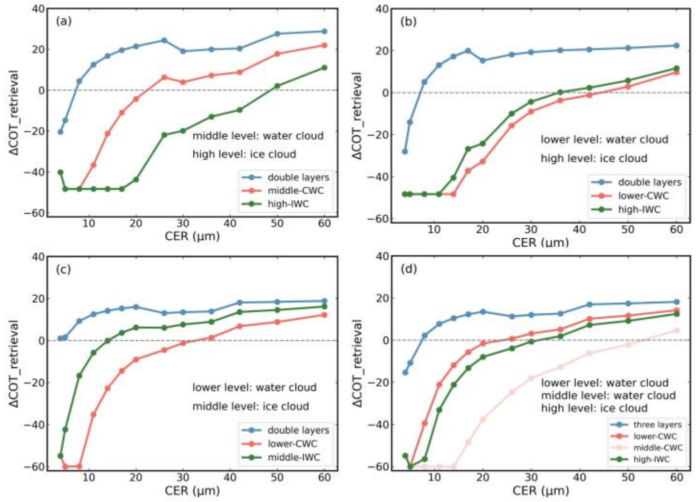

Figure 12. Differences in cloud optical thickness (COT) between multilayer cloud vertical structures and the single-layer assumption as a function of CER. Blue: difference between COT retrieved under the single-layer assumption and COT simulated for double-layer clouds; Red and pink: difference after adding CWC to the mid-level water cloud; Green: difference after adding IWC to the high-level ice cloud.

2. In agreement with Reviewer #1, although Figure 4 demonstrates excellent consistency between AGRI-derived results and MODIS cloud products, the findings presented in Figures 5 and 6 reveal persistent limitations within the current retrieval algorithm. It is advised that the authors conduct a thorough reassessment of their results, ensuring that the representation in Figure 4 provides an unbiased depiction of the algorithm's capabilities.

Response: We sincerely appreciate the reviewer's comment. To further clarify this point, we have plotted the PDFs of COT and CER for MODIS (1 km) and FY-4A/AGRI (4 km) in **Fig. S1**. The results indicate that the overall trends of the two datasets are generally consistent, suggesting that the discrepancies observed in Figs. 4–6 mainly stem from differences in data processing and sensor resolution.

Since the pixel positions and spatial resolution of FY-4A/AGRI differ from those of MODIS, direct pixel-by-pixel comparisons are not possible. Fig. 4 shows a scatterplot based on FY4A/AGRI retrievals and MODIS data resampled to a 4 km grid, providing the overall pixel-wise correlation. Fig. 5 shows the PDFs of COT and CER aggregated on the same 4 km grid, illustrating the pixel-scale statistical characteristics. Fig. 6 displays the spatial distributions of COT and CER in the same region using the original-resolution data, showing consistent spatial patterns while highlighting differences caused by sensor resolution and retrieval methods (**Lines 214~220, Lines 221~225, Lines 230~237, in the revised manuscript**).

Previous studies have shown that cross-resolution data matching may introduce a "partial-filling effect." For example, when higher-resolution visible pixels (~2 km) are matched to coarser radar pixels (~5 km), clear-sky areas may be included, leading to shifts in the PDFs (Chen and Fu, 2017; Chen et al., 2020). Overall, the observed differences are mainly attributable to: (1) spatial resolution differences (MODIS 1 km vs. AGRI 4 km); (2) horizontal inhomogeneity of clouds within AGRI pixels; and (3) visible channel degradation and SWIR fluctuations (Sun et al., 2025). In addition, in the region of 106–107°E and 32–35°N (corresponding to the Dabie and Wuling Mountains), FY-4A/AGRI and MODIS retrievals exhibit noticeable differences (Fig.6), which may be related to the influence of high-elevation terrain on satellite observations. The current retrieval algorithm was primarily tuned for lowland surface types and does not explicitly account for mountainous characteristics. Despite these local discrepancies, the overall distributions of COT and CER remain consistent across the overlapping regions, thereby confirming the robustness and reliability of the retrieval method and providing strong support for the sensitivity experiments in Section 4(**Lines 238~246 in revised manuscript**).

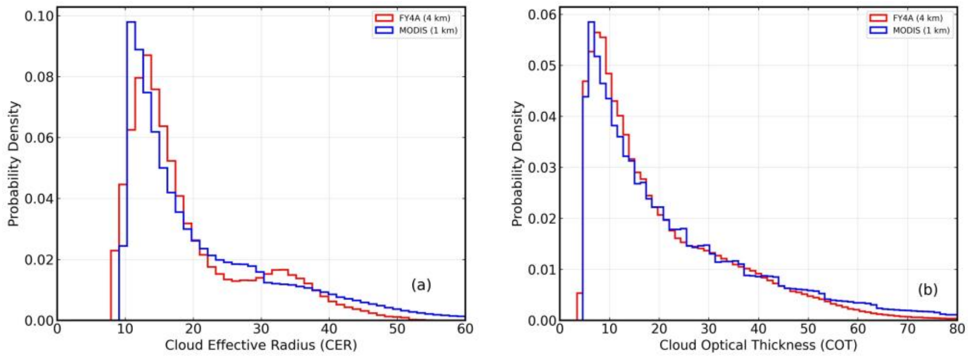

Fig. S1. Probability density function (PDF) of the FY4A/AGRI retrieval results and the MODIS cloud products in the region. The red and blue solid line shows the FY4A/AGRI(4km) results and the MODIS(1km) results, respectively.

References:

[1] Fu, Y.: Cloud parameters retrieved by the bispectral reflectance algorithm and associated applications, J. Meteorol. Res., 28, 965982, https://doi.org/10.1007/s13351-014-3292-3, 2014.

[2] Ackerman, S. A., Holz, R. E., Frey, R., Eloranta, E. W., Maddux, B. C., and Mcgill, M.: Cloud detection with MODIS. Part II: Validation, J. Atmos. Ocean. Tech., 25, 1073–1086, https://doi.org/10.1175/2007JTECHA1053.1, 2008.

[3] Chen, Y., Chen, G., Cui, C., Zhang, A., Wan, R., Zhou, S., Wang, D., and Fu, Y.: Retrieval of the vertical evolution of the cloud effective radius from the Chinese FY-4(Feng Yun 4) next-generation geostationary satellites. Atmos. Chem. Phys. 20,1131-1145, https://doi.org/10.5194/acp-20-1131-2020, 2020.

Minor comments:

1. Line 132: As COT and CER were previously defined, repeating their definitions here is unnecessary.

Response: We appreciate the reviewer's careful reading. The repeated definitions of COT and CER at Line 132 have been removed and the sentence has been revised at **Line 150** to: "aiming to investigate the impacts of cloud layering on reflectance, COT, and CER."

2. Figure 1: Is the logical relationship depicted between "cloud detection" and "cloud" accurate?

Response: We thank the reviewer for pointing this out. The label "cloud" in Fig. 1 has been revised to "Cloud pixel" in the updated manuscript to accurately reflect that the detection is performed at the pixel level.

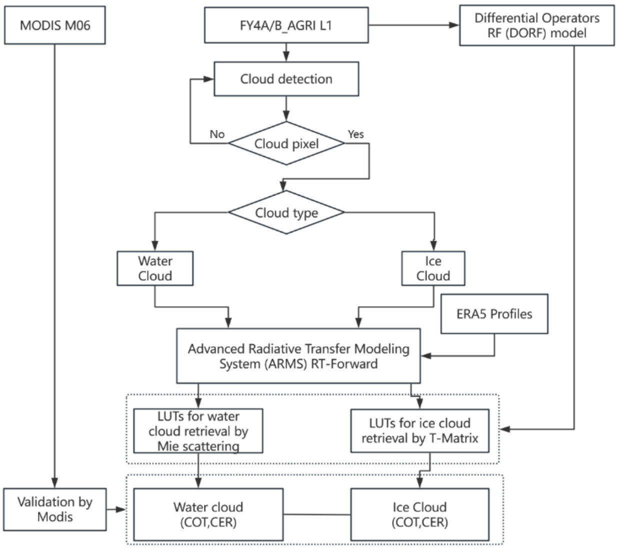

Figure 1. Framework of the COT and CER retrieval algorithm for FY4A_AGRI

3. Section 3.1: How are the 4-km AGRI observations/retrievals spatially matched with the 1-km MODIS cloud products?

Response: We appreciate the reviewer's question regarding the spatial matching of AGRI and MODIS data. To enable a fair pixel-by-pixel comparison, the 1-km MODIS retrievals were resampled to the 4-km AGRI grid using nearest-neighbor interpolation (**Lines 215~216 in the revised manuscript**).

4. Line 349: "10b" should be corrected to "11b".

Response: We thank the reviewer for pointing out this typo. It has been corrected from "10b" to "11b" in the revised manuscript (**Line 372**).

5. Figure 12: Lacks clarity in showing how visible/SWIR reflectance responds to vertical cloud structure.

Response: We thank the reviewer for pointing out the lack of clarity in Fig. 13(note that the original Figure 12 has become Figure 13 in the revised manuscript due to the addition of a new figure). In the revised manuscript, Fig. 13 has been improved to better illustrate the response of visible (channel 2) and SWIR (channel 5) reflectance to cloud vertical structures. In addition, the related conclusions have been updated to better capture the implications of the revised conceptual diagram (**Lines 434~469 in the revised manuscript**).

Conceptual illustration of the response of visible (channel 2) and SWIR (channel 5) reflectance to vertical cloud structure. For single-layer clouds, low-level water clouds yield the strongest enhancement in channel 2 reflectance, while mid-level water clouds show a weaker effect and high-level ice clouds mainly increase channel 2 reflectance with little impact on channel 5. For double-layer clouds, the combination of low-level water clouds and mid-level ice clouds shows contrasting effects: increasing low-level water cloud enhances reflectance in both channels, whereas adding mid-level ice clouds reduces reflectance with increasing CER, especially beyond 30 μm. For triple-layer clouds, increasing low- or mid-level water clouds enhances reflectance, with mid-level contributions being more pronounced. In contrast, increasing high-level ice clouds leads to overall reductions in reflectance, particularly for CER > 30 μm in channel 2 and CER > 14 μm in channel 5, with the latter decreasing by up to 0.15.

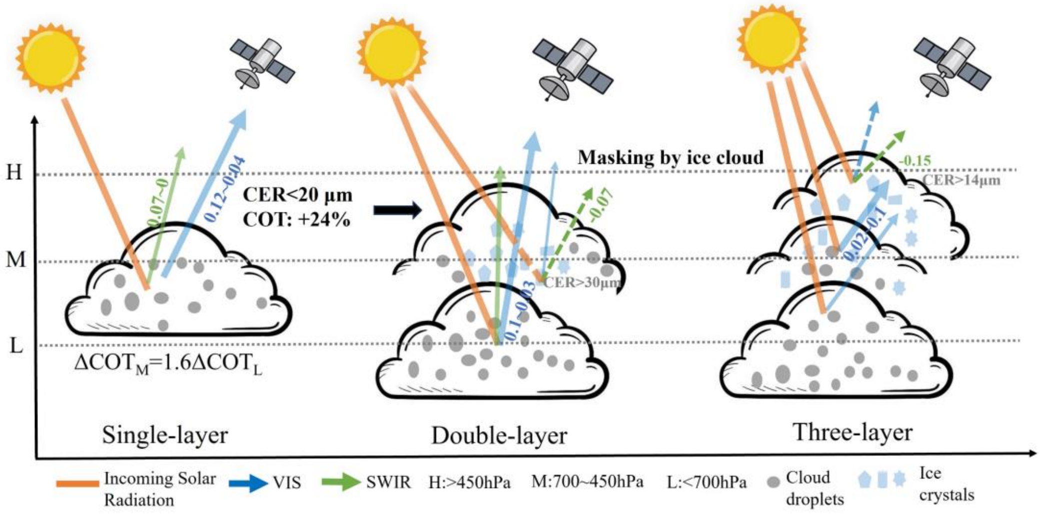

Figure. 13. Conceptual diagram illustrating the radiative characteristics and retrieval implications of COT and CER under different vertical cloud structures. The thickness of arrows represents the relative magnitude of reflectance, while dashed lines indicate negative reflectance gradients with increasing CER. The numerical ranges in the figure denote the changes in reflectance when CWC/IWC increases from lower to high cloud layers.