First and foremost, we would like to express our sincere gratitude to Luca Lelli, the anonymous reviewers, the editor, and the editorial support team for taking the time to review our manuscript and provide valuable feedback. The comments we received were extremely helpful in improving our manuscript, and we are very grateful for them. As outlined below, we have revised the manuscript based on the feedback. The reviewers' comments are copied below and shown in *italics*, while our responses and the corresponding text in the manuscript are shown in red and orange, respectively.

Response to the editorial support team

Regarding figures 3, 7: please ensure that the colour schemes used in your maps and charts allow readers with colour vision deficiencies to correctly interpret your findings. Please check your figures using the Coblis – Color Blindness Simulator (https://www.color-blindness.com/coblis-color-blindness-simulator/) and revise the colour schemes accordingly with the next file upload request.

Answer: In response to the comment, we updated the color scheme for Figures 3 and 4 (excluding Figure 3a) to the 'Scientific Color Maps' recommended on the AMT submission page (https://www.atmospheric-measurement-techniques.net/submission.html).We recognize that adjusting the color scheme of the RGB images in Figures 3a and 7 as well would also be preferable. However, since the values of the three channels are directly assigned to R, G, and B, we are unsure how to modify them to make them colorblind-friendly. Instead, we utilized the 'Coblis – Color Blindness Simulator' to confirm that the RGB images in Figures 3 and 7 can be correctly interpreted by readers with anomalous trichromacy.

Response to Anonymous Referee #2

GENERAL COMMENTS

SGLI onboard GCOM-C is a powerful instrument to cover wide spectral range of both solar reflected light and thermal emission. By adding O_2A information, understanding vertical distribution of clouds will be much improved. Authors referred their former studies. However, the description of why several cloud parameters such as base height and thickness can be retrieved from space is essential. How many parameters can be retrieved by assuming how many parameters from how many spectral channels should be described. In addition, the degree of freedom and uncertainties for each retrieved parameter using the optimal estimation method should be presented. I recommend major revision before its AMT publication.

Answer: We would like to thank you very much for carefully reading our manuscript and providing us with valuable comments. We have revised our manuscript, by taking full account of the referee's suggestions. The original comments are copied below and shown in *italics*, while our responses and the corresponding text in the manuscript are shown in red and orange, respectively.

I have the following general questions.

(1) SGLI covers the O_2A band with one spectral channel, of which spectral radiance depends on observation geometry, cloud height and fraction, surface albedo etc. The algorithm cannot use individual lines within the O_2A band. Large airmass causes saturation in strong absorption lines. Do viewing geometry and solar zenith angle affect the quality of retrieval? If uncertainties from retrieved cloud parameters varies with latitude etc., it should be presented.

Answer: In response to this comment, we have included a new figure, Figure S5, in the revised supplemental material, illustrating the angular dependence of cloud properties. Figure S5 presents the zonal means of a) COT, b) CER, c) ICOTF, d) CTH, and e) CBH, calculated for specific ranges of satellite zenith angles. Figure S5 shows that the deviation of zonal means of all these parameters with respect to the satellite zenith angle is relatively small compared to the zonal mean values themselves, indicating that the angular dependence of our algorithm is not significant. However, the zonal mean of CBH shows a moderate variation with the satellite zenith angle, particularly in low-latitude regions. This may be due to the fact that a larger satellite zenith angle causes the sensor to observe the side view of tall clouds, such as deep convective clouds. It remains crucial to continue investigating retrieval uncertainties related to the three-dimensional structure of clouds.

Therefore, the following text have been added to the main text as well:

[Last paragraph of Section 5.2; Lines 687 - 695]

"The supplementary material also presents additional analysis results that may help in examining the issues that remain in our retrieval algorithm. Figure S5 demonstrates that the deviations in the zonal mean for all cloud properties retrieved by our algorithm were relatively minor with respect to the satellite zenith angle, indicating that the angle dependence of the algorithm is not significantly influential. However, the moderate angle-dependent variations in the zonal mean of CBH at low latitudes may require further investigation."

(2) Forward calculation: retrieved parameters must be defined in the forward model. Definition of vertical layers, cloud top and bottom height, optical thickness of high-altitude cirrus cloud and aerosol help readers' understanding. Which cloud-related parameters are retrieved, and which are assumed? Do authors assume a single pixel is fully covered? Do they consider popcorn like clouds?

Answer: In the revision, we have added a new supplemental material containing the details of the forward model used in our retrieval algorithm. The forward model can consider 12 variables listed in Table S1 and surface albedo A_s in Equation (A2). Of these variables, five variables for cloud properties (τ_c, r_e, $ICOTF$, P_c, and P_b) were estimated by the inversion process, three variable for solar-sensor geometry (θ_0, θ_1, and ϕ) were given from the SGLI observations, and four variables for atmospheric condition (P_s, TPW, COL, and DU) were given from using the MERRA-2 products. In addition, A_s for land was estimated from the SGLI land reflectance product and A_s for ocean was estimated from sea surface wind speeds. To include an explanation of the supplemental material, we have added the following texts in Section 2.2.2.

[Section 2.2.2; Lines 245 - 246]

"The technical details of the forward model are provided in the supplemental material (see Text S1)."

In contrast, the use of the MERRA-2 and SGLI land surface products to determine atmospheric and surface conditions is described in Section 2.3 in the original manuscript as follows. Note that the mathematical symbols used in the supplement text S1 are not used to avoid complications in the explanation:

[Section 2.3; Lines 259 - 264]

"The third input was the SGLI land surface reflectance product (referred to as SGLI-RSRF). It provides land surface reflectance for the VNIR-to-SWIR channels of the SGLI, along with the parameters for the bidirectional reflectance distribution function model, which are input into the forward model for land pixels. For ocean pixels, the RSTAR7 subroutine was employed to estimate sea surface reflectivity from sun–satellite geometry and sea surface wind speed, which were then fed into the forward model."

(3) By assuming the signal to noise ratio of SGLI and other uncertainties such as none-linearity of electronics, radiometric calibration error, what is the expected detection limit or uncertainties of these parameters from theoretical optimal estimation method? The values of a prior distribution and ranges are well summarized in Table 1. How about posterior? What are the results using real SGLI data versus posterior? These descriptions will improve readers' understanding of the validation part of this paper.

Answer: In the supplemental material, we have included a section (Text S2) on sensitivity analysis based on error propagation theory and radiative transfer simulation, together with the results shown in Figures S1 and S2. Figure S1 demonstrates how perturbations in SW1, SW4, SW3, TI1, and VN9 propagate to the retrievals of COT, CER, ICOTF, CTH, and CBH. Figure S2 illustrates how uncertainties in the measurement vector induce uncertainties in the retrievals. Figures S2a and S2b compare different combinations of channels used in the retrieval process.

We agree that this sensitivity analysis is useful for understanding the behavior of our algorithm; however, we would prefer to limit it to the supplemental material. This is because the comparison with the ceilometer and other satellites is the main focus of this study, which reveals realistic error factors (such as the vertical inhomogeneity of cloud characteristics and multilayer cloud structure) that are difficult to incorporate into the sensitivity analysis.

Therefore, the following text have been added to the main text as well:

[Last paragraph of Section 4.1; Lines 412 - 425]

"In our algorithm, the uncertainty in CBH retrieval is also entangled with the uncertainty in COT retrieval. We performed a sensitivity analysis based on the error propagation theory to examine how measurement uncertainties propagate to retrieval uncertainties (see Text S2 in the supplemental material). Figure S1 demonstrates how perturbations in individual measurement channels induce retrieval errors. Notably, perturbations in SW1, which is a channel sensitive to COT but located outside the oxygen A-band, can induce errors not only in COT retrieval (Fig. S1(1,1)) but also in CBH retrieval (Fig. S1(5,1)). This indicates that COT errors disturb the separation of COT and CBH from VN9 measurements. Figure S2 further demonstrates how the overall uncertainty in the multi-wavelength measurements incorporated into the inverse estimation propagates to retrieval uncertainties. The comparison of Figs. S2a1 and S2b1 reveals incorporating VN11 alongside SW1 reduce the uncertainty in COT retrieval, which, in turn, contributes to reduce uncertainty in CBH retrieval. As described in Section 2.2.1, our algorithm utilized both SW1 and VN11. The results of these sensitivity analyses emphasize the importance of carefully addressing uncertainties in COT retrieval when deriving CBH from VN9 measurements. The entanglement of COT, CTH, and CBH retrieval errors associated with oxygen A-band measurements has also been reported by Lelli et al. (2014)."

(4) For the last 10 years, line parameters of the O_2 A band have been much improved by innovative laboratory spectroscopy. Which database the authors used? Do authors use line by line calculation for the O_2A band or look up tables in their forward model?

Answer: The RSTAR package used for radiative transfer calculations in this study contains gas absorption tables compiled using the k-distribution method for narrowband channels, provided with a spectral resolution of approximately 0.8 nm in the oxygen A-band region. Radiative transfer calculations are performed for each narrowband channel and subsequently integrated using the spectral response function of the SGLI VN9 channel to simulate TOA radiances. However, the gas absorption line database underpinning this k-distribution table is HITRAN2004. As you have noted, this means that recent updates to oxygen absorption line data are not incorporated. To clarify this point, we have added the following text:

[Section 2.2.2; Lines 234 - 237]

"The RSTAR version 7 (RSTAR7) package includes gas absorption line tables compiled into narrow bands using the k-distribution method. However, the k-distribution table is based on the HITRAN 2004 molecular spectroscopic database (Rothmana et al., 2005) and does not incorporate recent updates to the oxygen absorption lines."

(5) A priori information. How many A priori information such as aerosol type, surface pressure, wind speed over the ocean are included? How much uncertainties are assumed?

Answer: As described in Section 2.3 of the main text, the atmospheric and surface variables other than cloud properties handled by the forward model include temperature profile, water vapor profile, surface pressure, surface temperature, and sea surface wind speed, which are given by the MERRA-2 product. In addition, land surface reflectance is given by the SGLI-RSRF, the operational land surface reflectance product of the GCOM-C/SGLI mission. These atmospheric and surface variables excluding cloud properties, are treated as known, and their uncertainties are not explicitly considered in the inverse estimation. Aerosols are neglected in both the forward model and inverse estimation. To clarify these points, the following text has been added to Section 2.3.

[Section 2.3; Lines 275 - 279]

"It should be noted that the uncertainties in the meteorological variables provided by the MERRA-2 reanalysis data, as well as those in the land surface reflectance data from the SGLI-RSRF, were not explicitly accounted for in the inverse estimation. Furthermore, the impacts of aerosols on the observed radiance were not considered in either the forward model or the inverse estimation."

SPECIFIC COMMENTS

(1) Page 1, lines 21-22

What is the difference between "systematic" bias in line 20 and bias in line 21?

Answer: "systematic" was an inappropriate adjective. In the revised manuscript it has been removed and simply written as 'bias'.

[Abstract; Lines 21 - 22]

"These include the bias of SGLI CTH related to cirrus clouds and the bias of SGLI CBH caused by multi-layer clouds."

(2) Page 11, Line 267

What do authors mean by "negatively affect cloud retrieval"? Generally speaking, by properly considering uncertainties, adding spectral channel for retrieval provide information.

Answer: The phrase included in the original text did not intend to mean "*negatively affect cloud retrieval*" but more precisely intended to mean "*negatively affect cloud <u>phase</u> retrieval*". In our previous study (Nagao and Suzuki, 2021), we developed a retrieval algorithm for cloud properties (COT and CER) and cloud thermodynamic phase (ICOTF) using the SWIR channels. In this study, we extended the algorithm to incorporate the TIR and oxygen A-band channels, enabling the simultaneous estimation of CTH and CBH. The sentence containing the phrase in question indicates that the quality of the original cloud phase retrieval using SWIR channels was not compromised by the functional extension to include the TIR and oxygen A-band channels. To clarify this point, the revised sentence is as follows.

[Section 3.1; Lines 310 - 312]

"In other words, the incorporation of the TIR and oxygen A-band channels in this study did not adversely impact the quality of cloud phase retrieval based on the SWIR channels."

(3) Page 19, Line 433,

What are the definitions of mid- and high-level clouds? What is the difference from "lower-level" in line 363?

Answer: The sentences that contain the phrases in question are as follows:

- "In contrast, for thin cirrus clouds, CTHs are underestimated by 2–3 km relative to those detected by CALIOP due to factors such as COT and overlap with lower-level clouds (Baum et al., 2012; King et al., 2013)" (Section 4.1)
- "The CBH retrievals using the SGLI oxygen A-band were most effective for mid- and high-level clouds." (Section 4.2)

The former sentence cites discussions from previous studies on CTH retrieval errors in the case of multi-layered clouds. In this context, the term "lower-level clouds" refers to clouds situated below cirrus clouds. On the other hand, the latter sentence describes the results in Figure 6, and the term "mid- and high-level clouds" is defined in the paragraph preceding it as "mid- and high-level clouds, as suggested by the relatively high CBH (> 4 km), and the examples shown in Fig. 7g–i".

TECHNICAL CORRECTIONS

(1) Line 544, "CTT"

It appears first in this paper. It looks typo.

Answer: "CTT" has been replaced by "CTH".

[Section 5.1; Lines 620 - 621]

"Moreover, the challenge in utilizing the 763 nm channel is that it is sensitive not only to CBH and CGT but also to CTH and other cloud properties."