General Replies to comments

We thank both reviewers for their careful assessment of the manuscript and for the constructive comments provided. We have revised the manuscript accordingly and completed a thorough quality check of the data, figures, and text. A brief summary of the key changes is provided below.

Reviewer 1 raised further concerns regarding the AVHRR PATMOS-x collocation at day boundaries. We re-examined all PATMOS-x swaths and confirmed the presence of a small subset of swaths that spanned across calendar days and were incorrectly assigned to the following day. These initially accounted for approximately 5% of the dataset. To ensure the issue is fully resolved, we expanded the exclusion window to remove swaths occurring within the first and last two hours of each UTC Day. This increases the proportion of excluded PATMOS-x swaths to approximately 12.8%. Importantly, this extended exclusion does not materially change any of the scientific results or conclusions. All affected swaths have now been removed, and all relevant figures and tables have been updated.

No changes were required to the case study used in the current version, as it is unaffected by the AVHRR day-boundary issue.

A detailed point-by-point response to all reviewer comments is provided below.
In the general section, reviewers' comments are included in *italics* with the original sentence in *'italics'* and changes in blue. The "Line #" is for the track change document for the modified manuscript.

Reply to individual comments from Reviewer 1

I believe the manuscript is much improved. I have a handful of comments. Most are small but one or two may require effort to address.

Thank you for your valuable comments. We appreciate the reviewer's insightful feedback and constructive suggestions.

Comment 1: *Collocation case study:*
I appreciate the author's finding a new case study that does not suffer from the previous day issue described in the first review. It is worth noting that this issue can impact both the beginning and ending of a day, so the authors would need to exclude swaths for the first and last couple of hours of each day to be sure they removed the issue. The updated text starting at line 273 suggests they only excluded data after 22:00 UTC.

We agree with the reviewer's point and have clarified accordingly. In the revised analysis, we extended the exclusion window to cover both the first two hours and the last two hours of each UTC Day (i.e., 22:00–24:00 and 00:00–02:00). This adjustment increased the proportion of excluded AVHRR PATMOS-x swaths from ~5% to ~12% of the dataset. All affected swaths have now been removed. Importantly, this change did not materially alter the collocation statistics or the overall conclusions, confirming that the method remains robust.

"Hence, all case studies after 22:00 UTC were discarded from the whole year's analyses."
changed to
'Hence, all case studies within the first two hours and last two hours of each UTC day (00:00–02:00 and 22:00–24:00) were discarded from the whole year's analyses.' (Line 273)

Subsequently, the figures and tables and text were adjusted to reflect the changes as shown below.
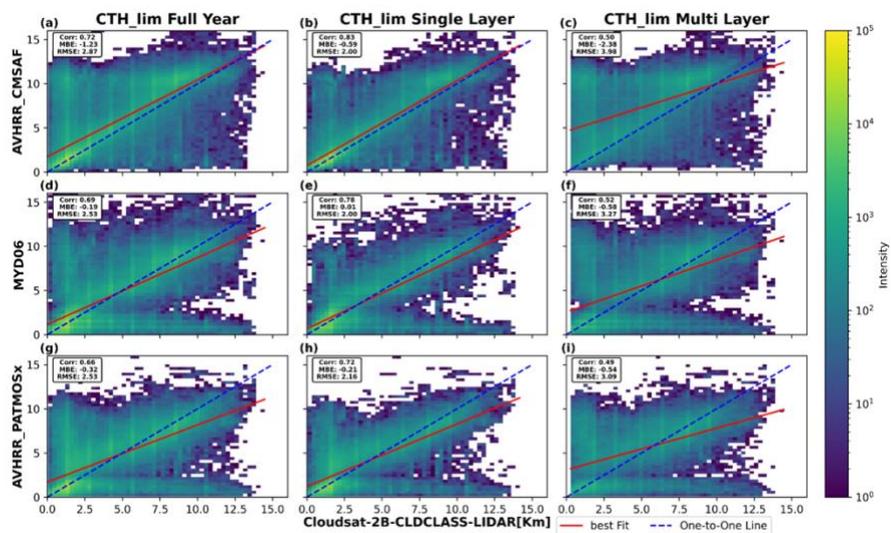
Figure 8 changed from

Figure 8. Collocated Level 2 AVHRR CMSAF (top), MODIS (middle), AVHRR PATMOS-x (bottom) and CLOUDSAT-CALIOP merged data analysed for Cloud Top Height (CTH), over the Southern Ocean, for 2015 (left) shows the Joint 2D Histogram for CTHs, the 2D histograms for multilayer (right) and single-layer (centre) masked collocated data.
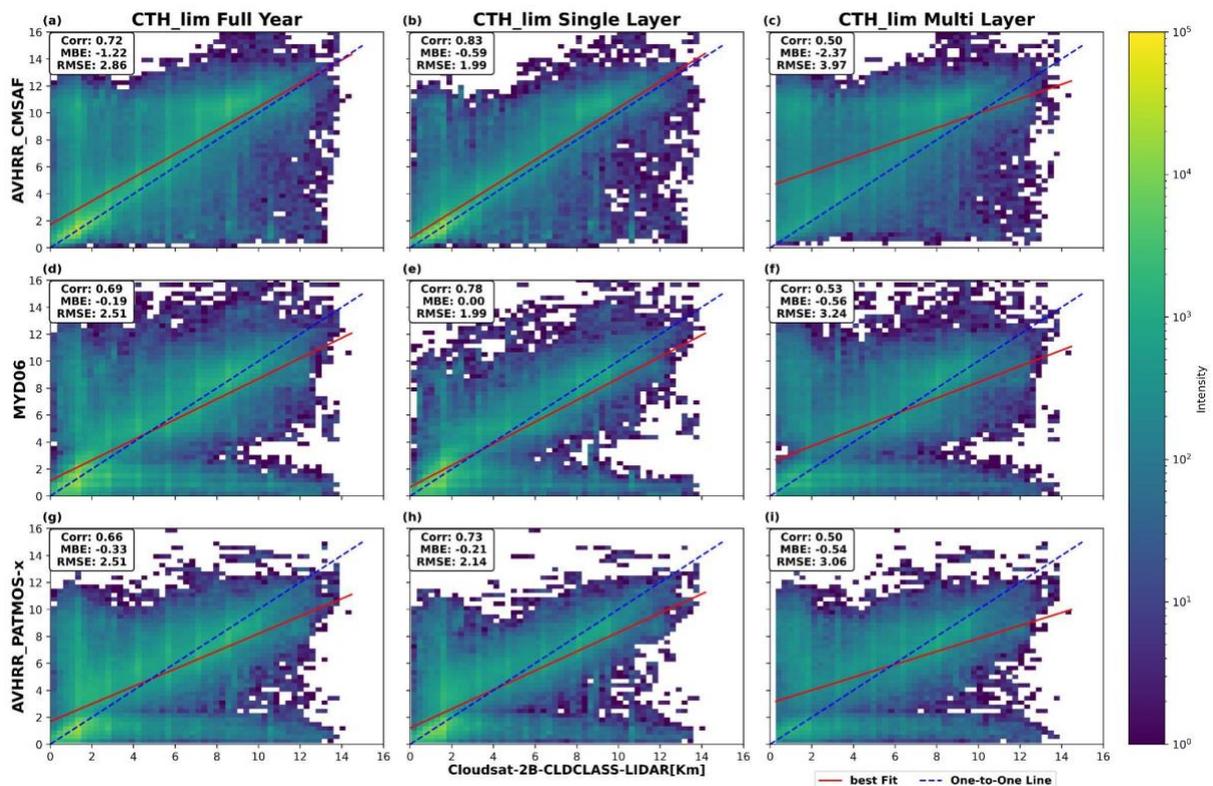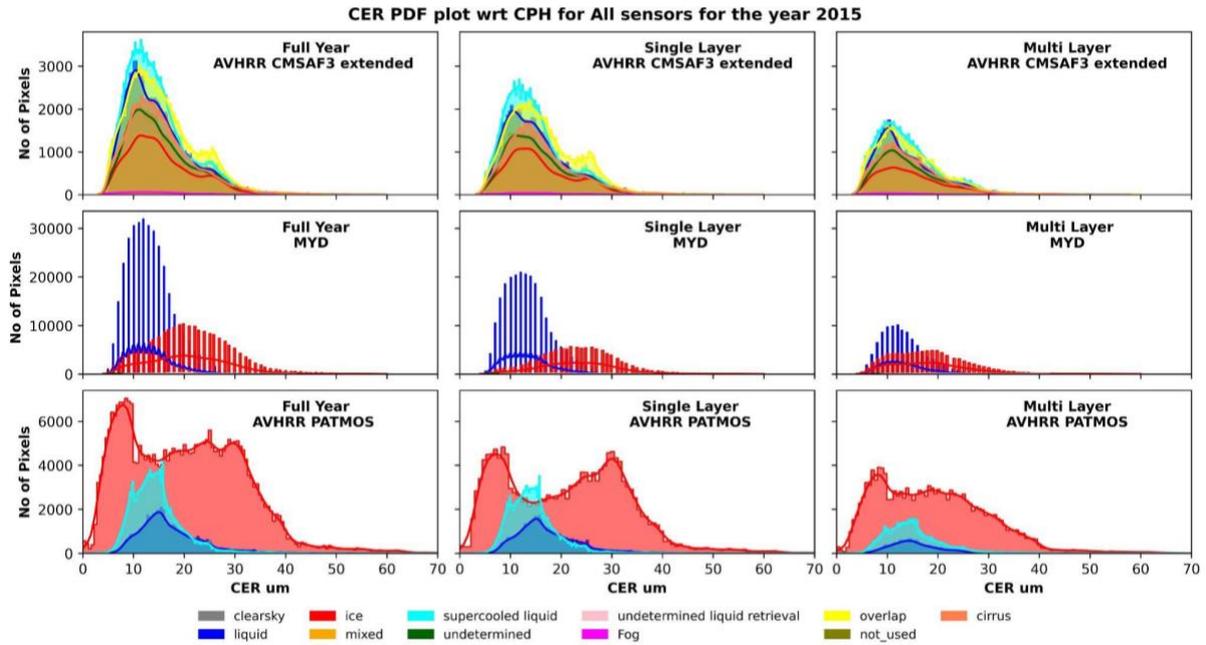
Figure 9 changed from

Figure 9 Cloud Effective Radius (CER) distribution according to the cloud phase for the collocated data
for the year 2015, over the Southern Ocean, for all passive sensors.

To

Figure 9: Cloud Effective Radius (CER) distribution according to the cloud phase for the collocated data
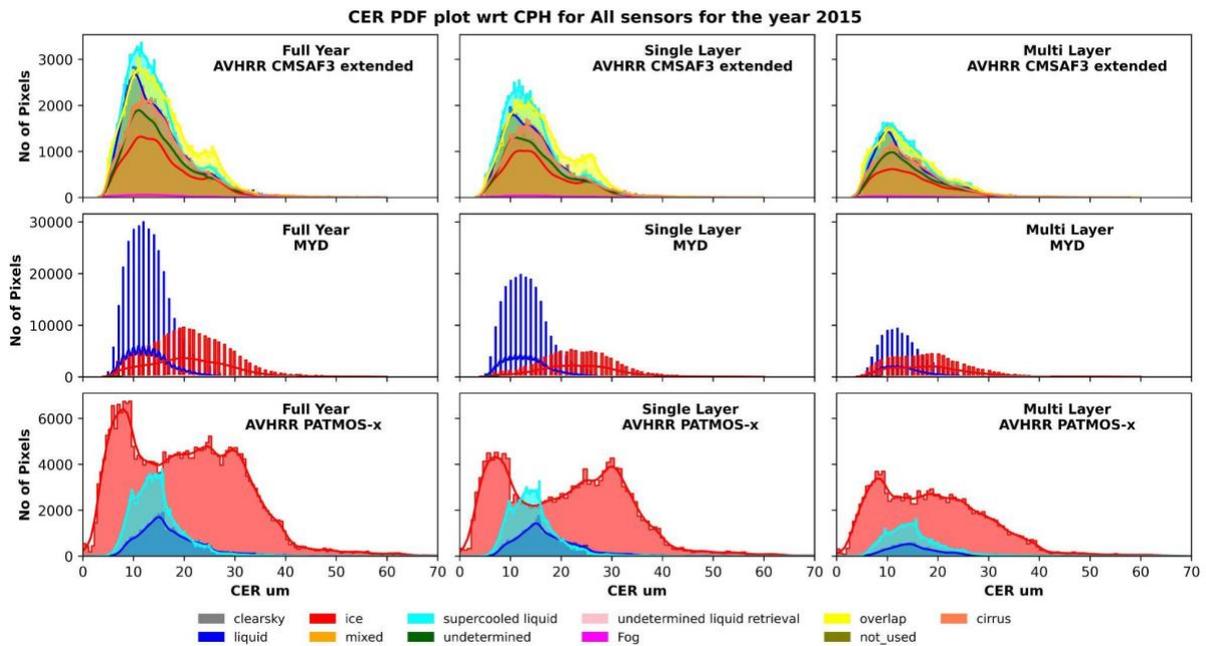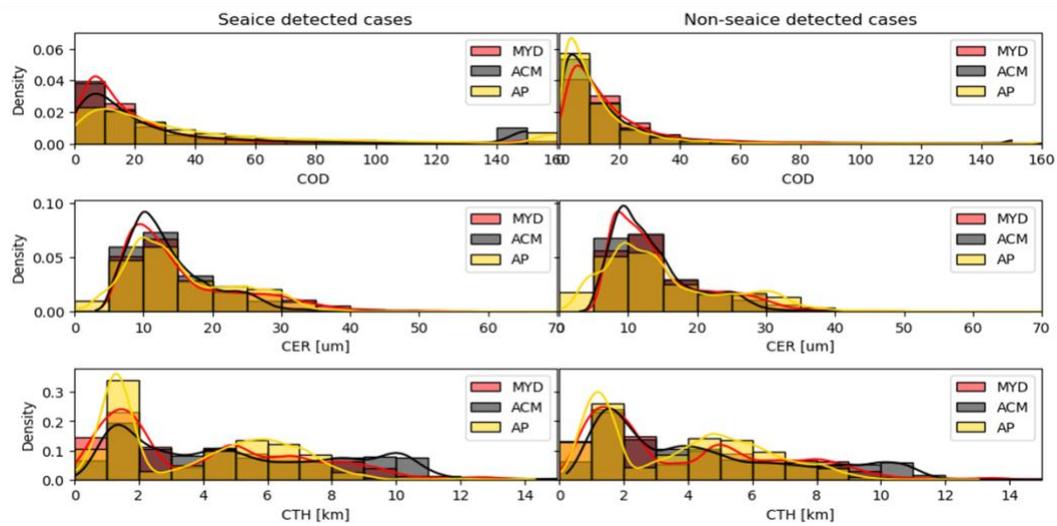for the year 2015, over the Southern Ocean, for all passive sensors.

Figure 10 changed from

To

Figure 10: Cloud Optical Depth (COD), Cloud Effective Radius (CER) and Cloud Top Height (CTH) as a function of Sea ice Flag from AVHRR PATMOS-x for all passive sensors, over the Southern Ocean. MODIS (MYD) is shown in red, AVHRR CMSAF (AC) is shown in black, and AVHRR PATMOS-x (AP) is shown in yellow.
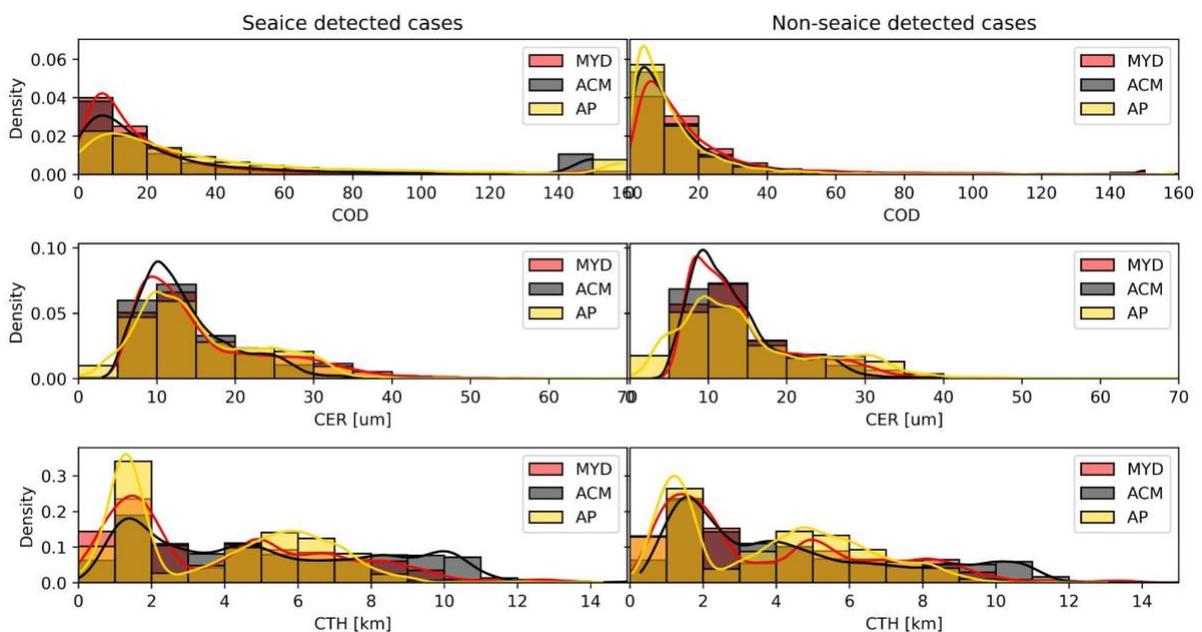
Tables are changed as below

Table 6 From

Mean Values of CTHs					
	CloudSat_CALIOP (km) > 0.5 COD	CloudSat_CALIOP (km) without COD limit	AVHRR CMSAF	MODIS	AVHRR PATMOS-x (km)
2015	3.92	5.48	5.15	4.12	4.25
Single-layer cases	3.43	3.86	4.00	3.42	3.63
Multilayer Cases	4.82	8.41	7.20	5.40	5.37

(a)

Statistics	CC vs AVHRR CMSAF				CC vs MODIS				CC vs AVHRR PATMOS-x			
	RMSE (km)	MAE (km)	MBE (km)	Correlation	RMSE (km)	MAE (km)	MBE (km)	Correlation	RMSE (km)	MAE (km)	MBE (km)	Correlation
2015	2.87	1.77	-1.23	0.72	2.53	1.55	-0.19	0.69	2.53	1.65	-0.32	0.66
SL Cases	2.00	1.13	-0.59	0.83	2.00	1.18	0.01	0.78	2.16	1.35	-0.21	0.72
ML cases	3.98	2.94	-2.38	0.50	3.27	2.21	-0.58	0.52	3.09	2.19	-0.54	0.49

(b)

Statistics	CC vs AVHRR CMSAF				CC vs MODIS				CC vs AVHRR PATMOS-x			
	RMSE (km)	MAE (km)	MBE (km)	Correlation	RMSE (km)	MAE (km)	MBE (km)	Correlation	RMSE (km)	MAE (km)	MBE (km)	Correlation
2015	2.00	1.08	0.33	0.86	2.90	1.81	1.36	0.75	3.01	2.00	1.23	0.70
SL cases	1.27	0.65	-0.16	0.93	1.67	1.02	0.44	0.88	1.97	1.28	0.22	0.81
ML Cases	2.88	1.85	1.21	0.64	4.31	3.23	3.01	0.54	4.29	3.30	3.05	0.45

(c)

Table 6. a) Mean Cloud top height (CTH) values for 2015 over the SO for Level 2 CTHs data MODIS (MYD), CloudSat-CALIOP (CC), AVHRR CMSAF (AC) and AVHRR PATMOS-x (AP). Statistics of the comparison of CC CTH with the COD limit > 0.5 is shown in b) and c) is for CC CTH without the COD limit.

To

Mean Values of CTHs					
	CloudSat_CALIOP (km) > 0.5 COD	CloudSat_CALIOP (km) without COD limit	AVHRR CMSAF	MODIS	AVHRR PATMOS-x (km)
2015	3.91	5.47	5.14	4.11	4.24
Single-layer cases	3.41	3.84	4.01	3.41	3.62
Multilayer Cases	4.81	8.40	7.18	5.37	5.35

(a)

Statistics	CC vs AVHRR CMSAF				CC vs MODIS				CC vs AVHRR PATMOS-x			
	RMSE (km)	MAE (km)	MBE (km)	Correlation	RMSE (km)	MAE (km)	MBE (km)	Correlation	RMSE (km)	MAE (km)	MBE (km)	Correlation
2015	2.86	1.77	-1.22	0.72	2.51	1.54	-0.19	0.69	2.51	1.63	-0.33	0.66
SL Cases	1.99	1.12	-0.59	0.83	1.99	1.17	0.01	0.78	2.14	1.34	-0.21	0.73
ML cases	3.97	2.93	-2.37	0.50	3.24	2.19	-0.56	0.53	3.06	2.17	-0.54	0.50

(b)

Statistics	CC vs AVHRR CMSAF				CC vs MODIS				CC vs AVHRR PATMOS-x			
	RMSE (km)	MAE (km)	MBE (km)	Correlation	RMSE (km)	MAE (km)	MBE (km)	Correlation	RMSE (km)	MAE (km)	MBE (km)	Correlation
2015	2.01	1.08	0.33	0.86	2.90	1.82	1.36	0.75	3.00	1.99	1.23	0.70
SL cases	1.27	0.65	-0.16	0.93	1.67	1.03	0.43	0.88	1.96	1.27	0.22	0.81
ML Cases	2.90	1.87	1.22	0.64	4.31	3.25	3.03	0.54	4.29	3.30	3.05	0.45

(c)

Table 6. a) Mean Cloud top height (CTH) values for 2015 over the SO for Level 2 CTHs data MODIS (MYD), CloudSat-CALIOP (CC), AVHRR CMSAF (AC) and AVHRR PATMOS-x (AP). Statistics of the comparison of CC CTH with the COD limit > 0.5 is shown in b) and c) is for CC CTH without the COD limit.

Table 8 From

Cloud Effective Radius [μm]								
Phase	Sensors	Full year		single-layer		Multi Layer	
		Mean	Median	Mean	Median	Mean	Median
Liquid	AC	14.75	13.36	14.81	13.45	14.16	12.59
	MYD	13.28	13.00	13.38	13.00	13.07	12.00
	AP	17.20	15.51	17.35	15.95	16.61	15.03
Ice	AC	15.57	14.24	16.20	14.84	14.53	13.15
	MYD	20.90	21.00	23.36	23.00	18.33	18.00
	AP	20.40	19.67	21.39	21.74	19.26	18.09
Supercooled Liquid	AC	14.65	13.31	14.91	13.59	14.18	12.78
	MYD	nan	nan	nan	nan	nan	nan
	AP	14.70	13.97	14.54	13.88	15.21	14.33

Table 8. Mean and Median Cloud Effective Radius (CER) comparison for 2015 over the Southern Ocean, for water, ice and supercooled liquid phases from Level 2 AVHRR CMSAF (AC), AVHRR PATMOS-x (AP), MODIS (MYD) and CloudSat-CALIOP (CC).

To

Cloud Effective Radius [μm]								
Phase	Sensors	Full year		single-layer		Multi Layer	
		Mean	Median	Mean	Median	Mean	Median
Liquid	AC	14.62	13.26	14.73	13.37	14.11	12.55
	MYD	13.20	13.00	13.30	13.00	13.01	12.00
	AP	17.12	15.75	17.30	15.90	16.37	14.99
Ice	AC	15.58	14.22	16.20	14.84	14.55	13.09
	MYD	21.02	21.00	23.35	23.00	18.41	18.00
	AP	20.26	19.48	21.19	21.37	19.18	18.01
Supercooled Liquid	AC	14.53	13.21	14.72	13.45	14.17	12.72
	MYD	nan	nan	nan	nan	nan	nan
	AP	14.71	13.97	14.54	13.87	15.23	14.34

Table 8. Mean and Median Cloud Effective Radius (CER) comparison for 2015 over the Southern Ocean, for water, ice and supercooled liquid phases from Level 2 AVHRR CMSAF (AC), AVHRR PATMOS-x (AP), MODIS (MYD) and CloudSat-CALIOP (CC).

Table 9 From

	COD				CER [μm]				CTH [km]			
	Sea ice		Non Seaice		Sea ice		Non Seaice		Sea ice		Non Seaice	
Sensors	Mean	Median	Mean	median	Mean	Median	Mean	median	Mean	Median	Mean	median
MYD	24.08	13.00	18.55	12.00	15.92	13.00	14.46	12.00	4.02	3.30	3.93	2.80
ACM	33.89	14.38	14.44	9.17	14.02	12.25	13.01	11.91	5.07	4.52	4.40	3.60
AP	41.71	24.28	12.70	8.37	15.64	13.37	15.54	12.94	3.74	3.62	3.75	3.85

Table 9. Mean and Median values of Cloud Optical Depth (COD), Cloud Effective Radius (CER) and Cloud Top Height (CTH) over sea and over sea ice for Level 2 AVHRR CMSAF, AVHRR PATMOS-x and MODIS pixels at latitudes (> 60◦ S).

To

	COD				CER [μm]				CTH [km]			
	Sea ice		Non Seaice		Sea ice		Non Seaice		Sea ice		Non Seaice	
Sensors	Mean	Median	Mean	median	Mean	Median	Mean	median	Mean	Median	Mean	median
MYD	24.39	13.00	18.68	12.00	16.06	13.00	14.32	12.00	4.01	3.35	3.92	2.80
ACM	34.62	14.72	14.51	9.22	14.07	12.31	13.46	11.84	5.11	4.59	4.40	3.56
AP	42.55	24.85	12.77	8.37	15.68	13.44	15.49	12.91	3.77	3.74	3.75	3.85

Table 9. Mean and Median values of Cloud Optical Depth (COD), Cloud Effective Radius (CER) and Cloud Top Height (CTH) over sea and over sea ice for Level 2 AVHRR CMSAF, AVHRR PATMOS-x and MODIS pixels at latitudes (> 60°S).

Table 9. Mean and Median values of Cloud Optical Depth (COD), Cloud Effective Radius (CER) and Cloud Top Height (CTH) over sea and over sea ice for Level 2 AVHRR CMSAF, AVHRR PATMOS-x and MODIS pixels at latitudes (> 60◦ S).

Comment 2: *Section 3.2*
I have concerns about the Level 2 collocated data. Typically a comparison of an imager and lidar would best be done for simultaneous nadir overpasses (SNO), the 'nadir' being an important part of that. In this case there is no mention of sensor zenith angle criteria being applied for the collocations. I don't believe they could be, because to get collocations close to nadir they would need to be farther poleward than the Southern Ocean. This creates a challenge, as imagers viewing clouds at oblique angles can impact cloud height, fraction, and optical depth retrievals, when compared to nadir observations of the same clouds. I think a section describing this challenge and how it could impact the results is warranted.

We thank the reviewer for highlighting this important point. We agree that simultaneous nadir overpasses (SNO) represent the optimal configuration for passive–active sensor comparisons. However, as the reviewer notes, achieving SNO geometry for MODIS, CMSAF AVHRR, or PATMOS-x with CALIOP is not feasible over the Southern Ocean due to orbital constraints. Consequently, our collocations necessarily include a range of sensor zenith angles for the passive imagers.

To address this, we have added a dedicated paragraph in Section 3.2 (line 250) describing the potential impact of off-nadir viewing geometry on retrieved cloud properties. This addition ensures that the limitation is clearly acknowledged and its implications for the results are transparent.

Line 255-"An additional limitation of the collocation approach is that true nadir overpasses between passive imagers and CALIOP cannot be achieved over the SO due to orbital geometry. Consequently, many scenes are viewed at oblique angles, which can introduce uncertainties in retrieved cloud top height, optical depth, and cloud fraction relative to nadir CALIOP observations. While this effect is inherent to all three passive satellite data sets, it represents a source of uncertainty that should be considered when interpreting the results, as imagers viewing clouds at oblique angles can impact cloud height, fraction, and optical depth retrievals, when compared to nadir observations of the same clouds.

Comment 3: *Figures 7 and 9:*
Labels still reads PATMOS instead of PATMOS-x

The labels for the figures have been changed and updated. Please see the attached figure 7 and Figure 9 for references.

Figure 7 Vertical profiles for cloud properties Cloud Top Height (CTH; Top panel), Cloud Optical Depth (COD; Second Panel), Cloud Effective Radius (CER) ; third panel) and Cloud Phase (CPH; Bottom Panel) retrieved from collocated data of AVHRR CMSAF (AC), AVHRR PATMOS-x (AP), MODIS (MYD) and merged CloudSat-CALIOP (CC) for Case study on 19-10-2015 at 08:37 UTC.
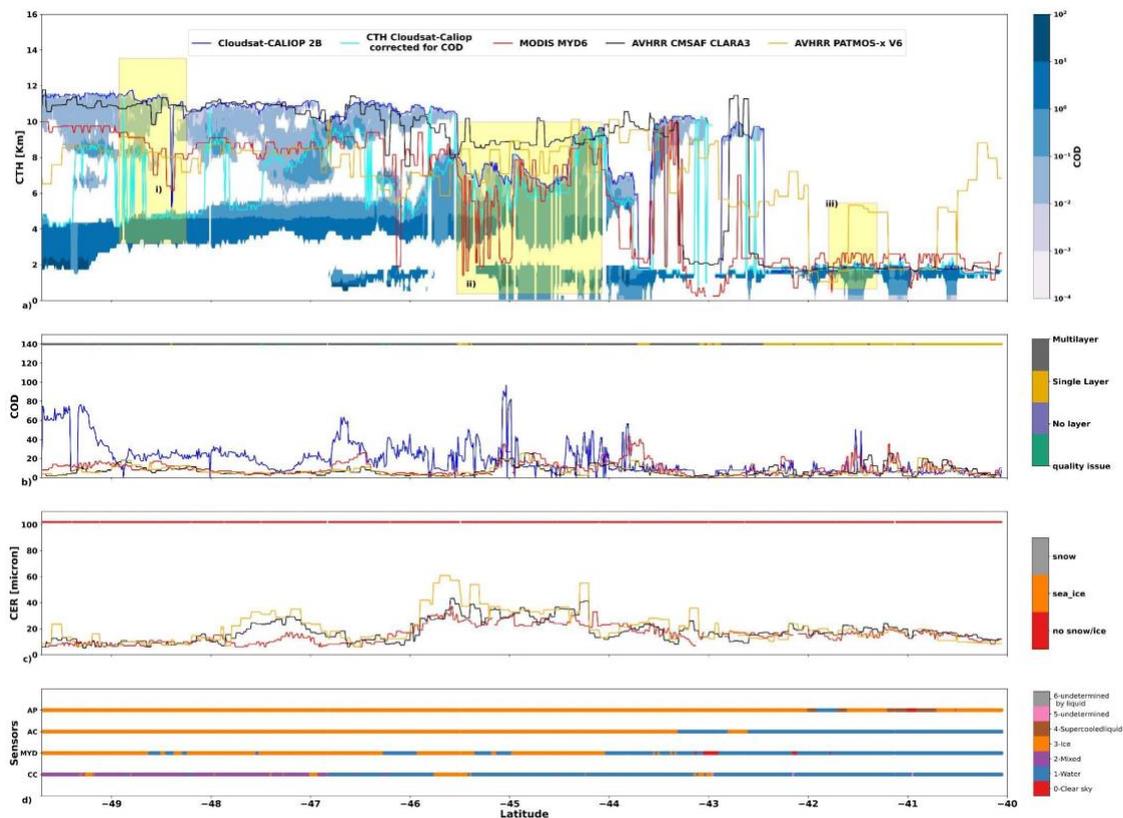
Comment 4: *Figure 8:*

The caption says MODIS is the top row and CMSAF is the middle row. I think this should be switched. I'm also having trouble reconciling numbers in Figure 8 and Table 6 with the conclusions and abstract of the article:

"In the case of the CTH analysis, a mean absolute bias of 0.65 km (AVHRR CMSAF), 1.02 km (MODIS), and 1.28 km (AVHRR PATMOS-x) was observed for single-layer cloud scenes cases. This mean bias increased to 1.85 km (AVHRR CMSAF), 3.23 km (MODIS), and 3.30 km (AVHRR PATMOS-x) for multilayered cloud scenes. Hence, we can conclude that the passive sensor MAE against the active sensor for multilayer cases is 3 to 4 times the corresponding MAE for single-layer cases and 2 times MAE for the overall year. The bias can also be attributed to the retrieval algorithm differences, COD of the layers, and sensitivity of sensors to the cloud."

This (and text beginning at line 737) suggests CMSAF performed significantly better for single- and multi-layer cases than PATMOS-x or MODIS, but the stats in Figure 8 show CMSAF has noticeably larger MBE and RMSE than the other two for multi-layer cases. Rereading the description, it seems the conclusions are based on comparisons with no COD threshold, but Figure 8 applies a COD threshold of 0.5. This makes more sense, but I am curious why the threshold of 0.5 was chosen, and why are the conclusions based on no threshold? Looking at Figure 8, one could reasonably conclude that MODIS performed best for single-layer clouds and PATMOS-x performed best for multi-layered clouds. I've seen similar comparisons where a COD threshold of 0.1 was chosen to filter out sub-visible cloud that a lidar may detect but an imager would not. Using 0.5 would filter out some pretty thick clouds. Is this based on a previous study?

We have corrected the caption so that CMSAF is identified as the top row and MODIS as the middle row.

Table 6 reports statistics for both with and without applying a COD threshold, whereas Figure 8 illustrates only the COD ≥ 0.5 case. The conclusions in the abstract and Section 5 are based on the full dataset (no COD threshold), which explains why CMSAF appears to perform better overall. When the COD ≥ 0.5 filter is applied, the relative performance shifts, as the reviewer notes, with MODIS and PATMOS-x showing smaller biases for certain multilayer cases.

We chose a COD threshold of 0.5 to exclude optically thin clouds that are often detected by CALIOP but missed or poorly retrieved by passive sensors, consistent with previous studies (Karlsson et al., 2017; Marchant et al., 2020; Yost et al., 2023). A lower threshold of 0.2 was considered, but this would still include many tenuous clouds that are effectively invisible to imagers, leading to inflated differences. The 0.5 threshold provides a balance by removing sub-visible and very thin clouds while retaining the majority of optically thick cases relevant for passive–active comparisons.

We have clarified this distinction in the revised text to ensure readers understand that Table 6 presents both COD-filtered and unfiltered statistics, while Figure 8 illustrates the effect of applying the COD ≥ 0.5 filter.

Added the sentence "We chose a COD threshold of 0.5 to exclude optically thin clouds that are often detected by CALIOP but missed or poorly retrieved by passive sensors, consistent with previous studies (Karlsson et al., 2017; Marchant et al., 2020; Yost et al., 2023)." (Line 472-474)

Also, in the summary section we have included the wording "without the 0.5 COD limit", (Line 607) after the "In the case of the CTH analysis," to clarify that the conclusion is for without COD limit.

Reply to individual comments from Reviewer 2

The paper has been well revised according to the reviewers' comments and each point has been well discussed. The authors have done a great job revising the manuscript and updating the entire case study. I recommend that the paper be accepted pending minor revisions, detailed below.

General comments:

Many of the figures have writing that is too small for the reader.

We thank the reviewer for their valuable comments and corrections.

The figures have been resized for the readability and the modified figures are shown below.

Figure 7 Vertical profiles for cloud properties Cloud Top Height (CTH; Top panel), Cloud Optical Depth (COD; Second Panel), Cloud Effective Radius (CER) ; third panel) and Cloud Phase (CPH; Bottom Panel) retrieved from collocated data of AVHRR CMSAF (AC), AVHRR PATMOS-x (AP), MODIS (MYD) and merged CloudSat-CALIOP (CC) for Case study on 19-10-2015 at 08:37 UTC.
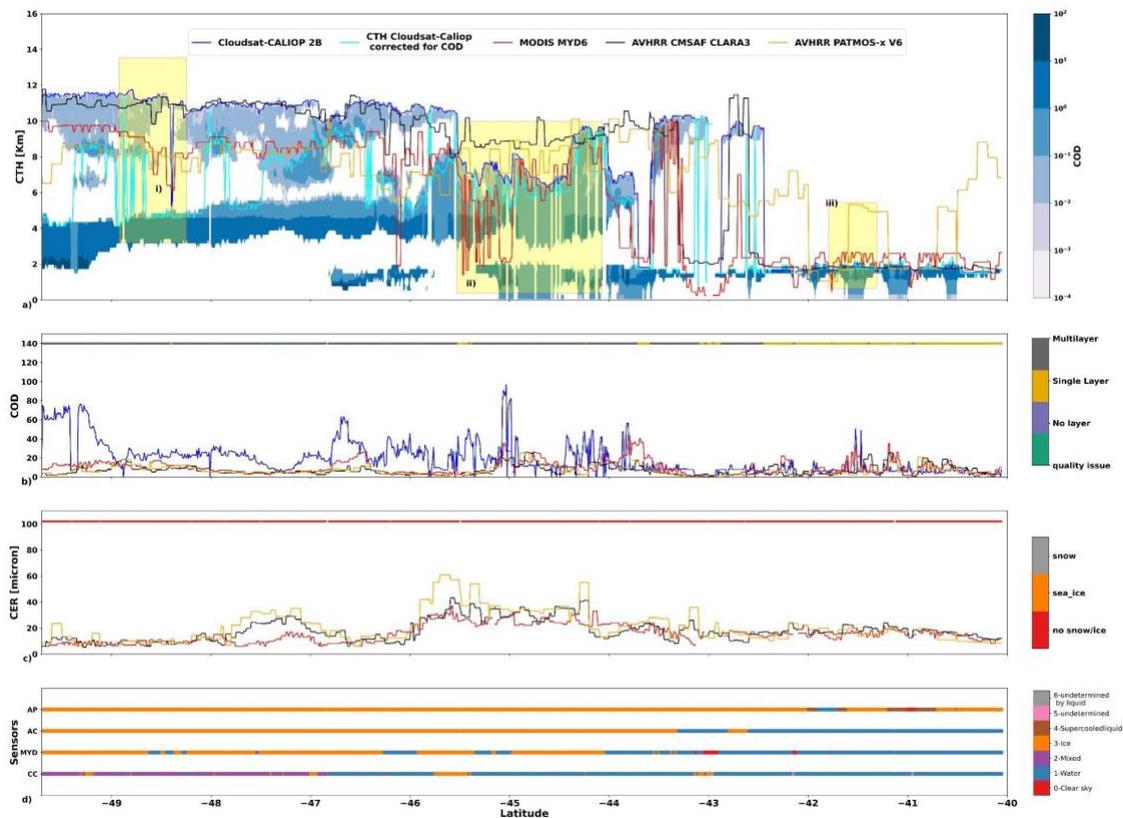
Figure 8. Collocated Level 2 AVHRR CMSAF (top), MODIS (middle), AVHRR PATMOS-x (bottom) and CLOUDSAT-CALIOP merged data analysed for Cloud Top Height (CTH), over the Southern Ocean, for 2015 (left) shows the Joint 2D Histogram for CTHs, the 2D histograms for multilayer (right) and single-layer (centre) masked collocated data.
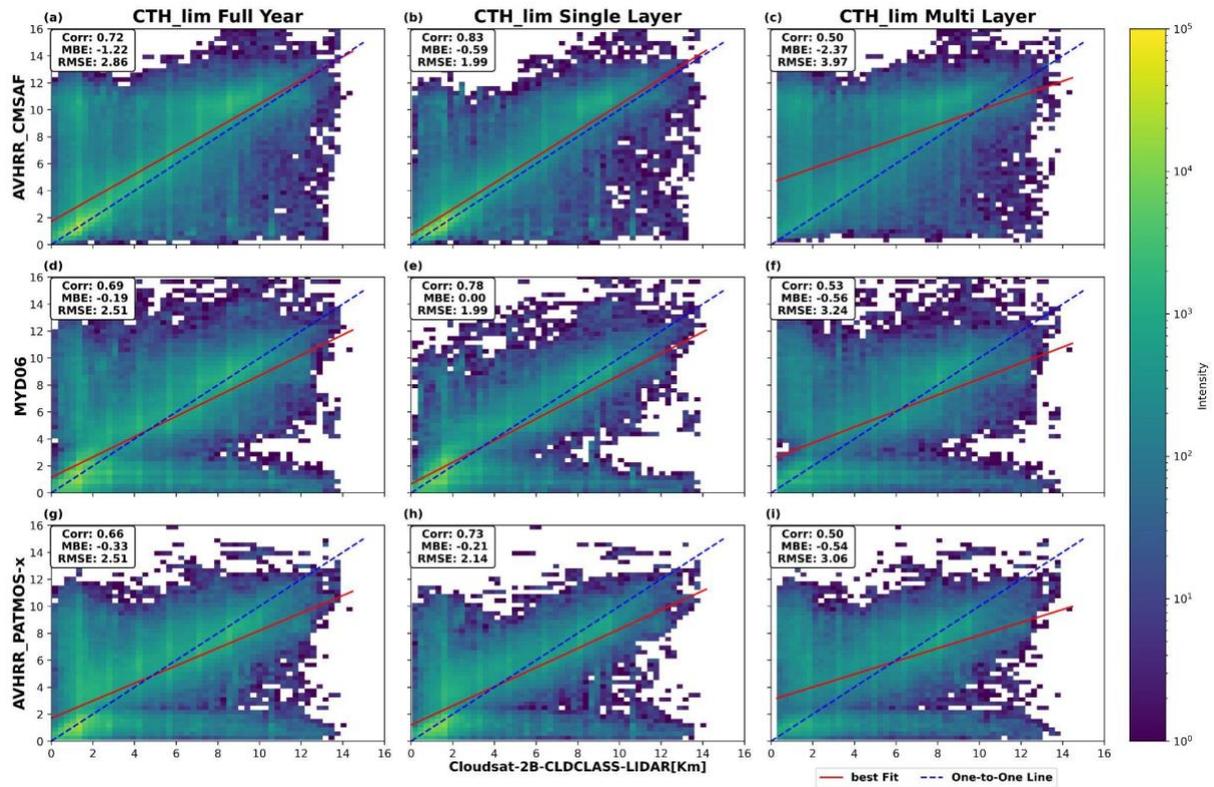

Figure 9. Cloud Effective Radius (CER) distribution according to the cloud phase for the collocated data for the year 2015, over the Southern Ocean, for all passive sensors.
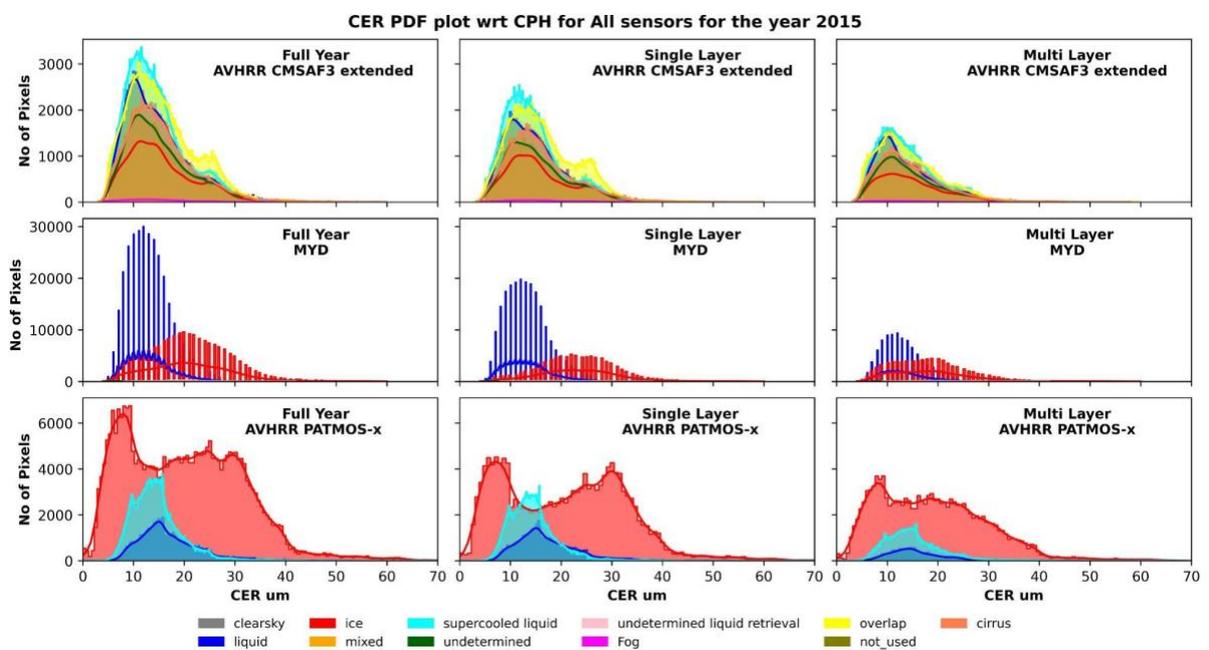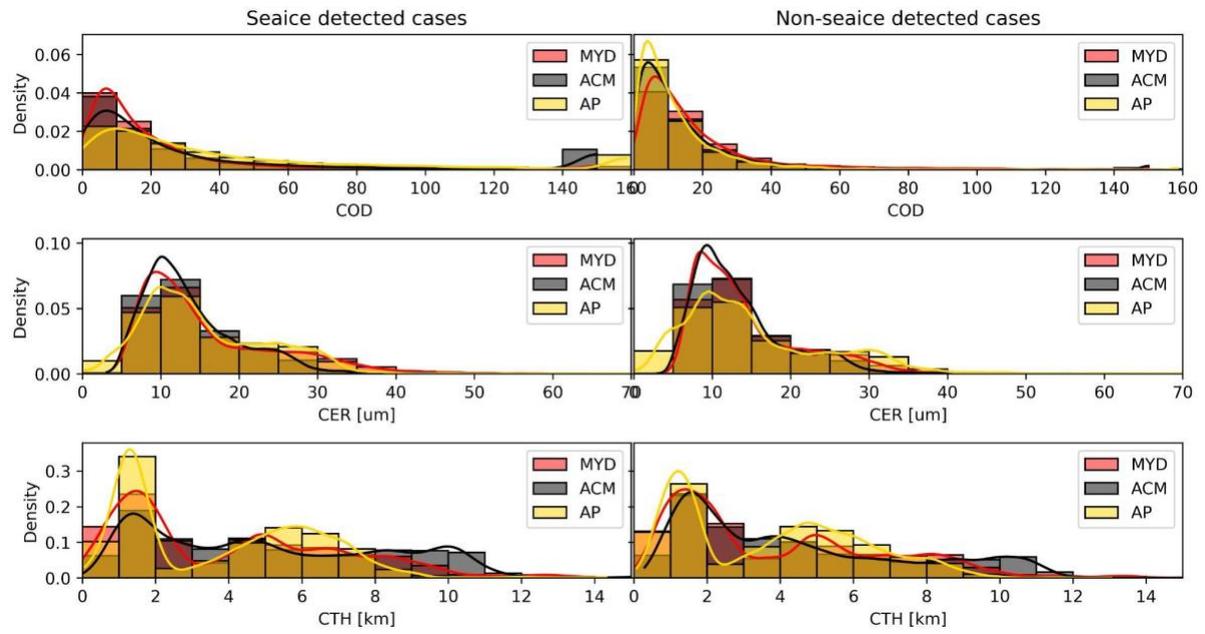
Figure 10. Cloud Optical Depth (COD), Cloud Effective Radius (CER) and Cloud Top Height (CTH) as a function of Sea ice Flag from AVHRR PATMOS-x for all passive sensors, over the Southern Ocean. MODIS (MYD) is shown in red, AVHRR CMSAF (AC) is shown in black and AVHRR PATMOS-x (AP) is shown in yellow.

Comment 1: *Lines 8 : "... AVHRR CMSAF showed higher cloud cover over mid-latitudes and lower cloud cover over land ..."*

"... while AVHRR CMSAF had higher cloud cover over mid-latitudes and lower over land ..." has been replaced to '... AVHRR CMSAF showed higher cloud cover over mid-latitudes and lower cloud cover over land …' (Line 8)

Comment 2: *Ligne 9-10 : suggestion "... against CALIOP indicates that AVHRR CMSAF tends to overestimate, whereas MODIS tends to underestimate the liquid cloud fraction. The magnitude of the difference varies with the latitude and season."*

"..against CALIOP indicated that AVHRR CMSAF tends to overestimate and MODIS tends to underestimate liquid cloud fraction the difference varied with latitude and season." has been changed to '.. against CALIOP indicates that AVHRR CMSAF tends to overestimate, whereas MODIS tends to underestimate the liquid cloud fraction. The magnitude of the difference varies with the latitude and season.' (Line 10)

Comment 3: *Lines 32-33: I don't really understand the sentence, suggestion "The new finding that contradicts previous studies may result from the difficulty of retrieving cloud optical depth over ice using the retrieval algorithms."*

"This is different from previous studies, and we hypothesise that this difference is likely due the difficulty in retrieval algorithms in retrieving cloud optical depth over ice." changed to 'The new finding that contradicts previous studies may result from the difficulty of retrieving cloud optical depth over ice using the retrieval algorithms.' (Line 25-27)

Comment 4: *Line 72: "They observed a bias of -10 W/m2 in LWCRE and concluded that the factors contributing to this bias include ..."*

"They observed that there exists a bias of -10 W/m^2 in LW CRE and concluded that the factors contributing to this bias, includes ..." changed to 'They observed a bias of -10 W/m2 in LWCRE and concluded that the factors contributing to this bias includes …' (Line 67)

Comment 5: *Line 74 -75: "... were evaluated AGAINST CALIOP observations by Yost et al. (2023) and the reevaluation showed that multilayer clouds are one of the main contributors to errors in cloud top height retrieval."*

"....were evaluated with CALIOP observations by Yost et al. (2023) reevaling that multilayer clouds are one of the main contributors to errors in the retrieval of cloud top height." changed to '..were evaluated against CALIOP observations by Yost et al. (2023) and the re-evaluation showed that multilayer clouds are one of the main contributors to errors in cloud top height retrieval.' (Line 70-72)

Comment 6: *Line 86: "... are found that mixed-phase clouds..."*

In the line added 'clouds' after "found that mixed-phase…" (Line 82)

Comment 7: *Line 91: add a "," after "instruments"*

In line added ',' after 'instruments'. (Line 86)

Comment 8: *Line 93: add a "," after "which".*

In line added ',' after 'which'. (Line 89)

Comment 9: *Lines 97-102: You could perhaps specify the chapter number for each step described in this paragraph, if possible.*

The paragraph was modified to include the section numbers as suggested by the reviewer. "We validate the cloud top height in Section 4.2.3 and the cloud mask in Section 4.2.2 with merged CloudSat CALIOP data. The cloud phase and effective radius were compared in

Section 4.2.4. We perform the analysis at the monthly level (L3) in Section 4.1, followed by an in-depth analysis into instantaneous observations (L2) in Section 4.2. The results are analysed separately for single and multilayer clouds, and a case study illustrates the main findings in Section 4.2.1." (Line 95-99)

Comment 10: *line 127-128: "LIDAR and RADAR for understanding cloud vertical profileS, cloud classification and cloud properties, such as cloud top height (CTH)..." (remove cloud layer top).*
Removed *'cloud layer top'* from the line 125

Comment 11: *Line 129: Remove the "," after "product".*

In line removed ',' after 'which' (Line 126)

Comment 12: *Line 138: If "the data" is plural --> remove the "s" at the end of includes ("the data include"). In the previous sentence data is plural.*

In line removed 's' in 'includes'(Line 135)

Comment 13: *Line 140: "The L2 data consist of..." without "s".*

In line removed 's' in 'consists'(Line 137)

Comment 14: *Line 149-150: "The latest AVHRR has six channels, out of which only five can be transmitted at any given time." is already mentioned in line 146. You could modify your first sentence to include all information about the channels.*

"The AVHRR instrument is a broadband radiometer with five or six spectral channels in the visible, near IR and IR." modified to 'The AVHRR instrument is a broadband radiometer with six spectral channels spanning the visible, near-infrared, and infrared regions, of which only five can be transmitted at any given time.' and removed the sentence *"The latest AVHRR has six channels, out of which only five can be transmitted at any given time."* (Line 143)

Comment 15: *Line 154: add provided --> "AVHRR instrument, providing clouds, suface albedo...". I don't understand what you mean with provided cloud? what from clouds? cloud properties?*

To clarify the sentence *"clouds"* was changed to 'cloud properties'. (Line 150)

Comment 16: *Line 156: "...and the time-period available.."*

In line added 'time-period' to change the line to '...*and the time- period available*' (Line 153)

Comment 17: *Line 158: Suggestion "The data used in the analysis have a spatial resolution of 5 km."*

"The resolution of the data used in the analysis is 5 km data." changed to 'The data used in the analysis have a spatial resolution of 5 km.' (Line 154)

Comment 18: *Line 166:"The climate data record covers a period of 44 years..."*

"The climate data record includes 44 years of data…" changed to 'The climate data record covers a period of 44 years…' (Line 163)

Comment 19: *Line 170:"In this study, the ACHA CTH algorithm uses 11..."*

"The ACHA CTH algorithm in this study uses 11.." changed to 'In this study, the ACHA CTH algorithm uses 11..' (Line 166)

Comment 20: *Line 176: "Validation of the cloud products over the SO has been mostly performed using monthly data."*

"The validation of cloud products over the SO has been mostly performed using monthly products." changed to 'Validation of the cloud products over the SO has been mostly performed using monthly data.' (Line 171)

Comment 21: *Line 178: "... compared against CALIOP..."*

In the line changed 'with' to 'against' (Line 173)

Comment 21: *Lines 178-180: Separate the sentence in 2 sentences --> "...1km CALIPO product. In the case of..."*

In the line removed *", and"* and made a new sentence "1 km CALIPO product. In the case of…" (Line 174)

Comment 22: *Line 183: "They observed that the smallest mean CTH differences ..."*

"They observed the minimum mean CTH differences.." changed to 'They observed that the smallest mean CTH differences ..' (Line 178)

Comment 23: *Line 188: "... with biases increasing as COD decreasing..."*

"..biases increasing with COD decreasing…" changed to '... with biases increasing as COD decreases...' (Line 183)

Comment 24: *Line 190: ".... during the polar winter."*
In the line added 'the' before 'polar winter' (Line 185)

Comment 25: *Line 192: Which polar region? polar regions or southern/northern polar region.*

Both the southern and northern polar regions.
To clarify the sentence *"around"* changed to 'across'. (Line 187)

Comment 26: *Line 206: Multilayer clouds detection? or detection of what?*

Heading changed from *"Multilayer clouds and detection"* to 'Multilayer clouds and detection algorithms'(Line 201)

Comment 27: *Line 209: Chen et al is written 3 times.*

The references are corrected in the revised manuscript. There are some typos in the track change document. In this case it shows three different references as the same one "Chen et al".

2.5 Multilayer clouds and detection

Mace et al. (2009) used the CloudSat-CALIPSO product to show that mid- and low-level multilayer clouds are present in more than half of the scenes over the SO (along the ocean polar front), which is more often than their Arctic counterparts.

200 Similar studies, have found that ignoring the multilayer structure of clouds can lead to errors in the retrieval of cloud properties such as cloud top pressure, cloud optical depth, and cloud fraction (Chen et al., 2000; Heidinger and Pavolonis, 2005; Joiner et al., 2010). L'Ecuyer et al. (2019) found that the multilayer clouds contribute to enhancing LW radiation by 10.4 W/m^2 and reducing SW radiation by 22.3 W/m^2, and they are often misclassified as single-layer thick mid-clouds leading to global CRE of -17.1 W/m^2. The study also confirmed that the discrepancy in radiative fluxes, indicates that clouds with similar top of the

205 atmosphere radiative signatures can have varying impacts at the surface and on atmospheric heating.

Comment 28: *Line 216: Remove the "," after "instruments".*

In line removed ',' after 'instruments'(Line 210)

Comment 29: *Line 224: Li et al. is written 3 times.*

The references are corrected in the revised manuscript. There are some typos in the track change document. In this case it shows three different references as the same one "Li et al".

atmosphere radiative signatures can have varying impacts at the surface and on atmospheric heating.

Several multilayer cloud detection algorithms for global satellite instruments, using visible to infrared bands have been developed (Baum et al., 1994; Joiner et al., 2010; Kawamoto et al., 2002). In general, the multilayer detection algorithms are limited to thin-cirrus over low clouds, ocean areas or two-layer retrieval systems (Joiner et al., 2010; Sun-Mack et al., 2006). MODIS, AVHRR, CERES have used CALIOP datasets to train decision tree algorithms to refine the multilayer cloud detection algorithms (Li et al., 2011; Marchant et al., 2020; Sun-Mack et al., 2006; Simpsom et al., 2001).

In the multilayer detection flag for MODIS MYD (Level-2 data; Marchant et al., 2020), the multilayer classification agreement with CloudSat-CALIOP merged product is only 34% (Wang et al., 2016). New Artificial intelligence (AI) methods have brought the accuracy for multilayer detection to around 60% for geostationary satellites such as Himawari (Li et al., 2022; Tan et al., 2022; Ritman et al., 2022). In this analysis we use the multilayer detection algorithm described in Ritman et al. (2022).

Comment 30: *Line 251: replace "contained" with "contains"*

In line replaced 'contained' with 'contains' (Line 244)

Comment 31: *Line 252: add a "," before "such as".*

In line added ',' after 'such as' (Line 244)

Comment 32: *Line 268: In the literature, ML is also used to designate the melting layer, which could be misleading or confusing for the reader.*

We agree with the reviewer's concern. To avoid ambiguity, we have added a note in the manuscript clarifying that ML refers exclusively to multilayer clouds. The revised sentence now reads, '..multilayer (hereby abbreviated as ML, referring exclusively to multilayer clouds)..' (Line 266)

Comment 33: *Lines 289-290: I don't understand the sentence --> Is cloudy used twice in the classification?*

The MODIS cloud mask has four categories: cloudy (00), uncertain (01), confidently clear (11), and probably clear (10). In our analysis, we unified uncertain and cloudy as cloudy, and confidently clear and probably clear as clear. To avoid confusion, the sentence has been revised from
"Similarly, MYD cloud masks were classified as cloudy (0), uncertain (01) and cloudy (00) and as clear (1), confidently clear (11) and probably clear (10)."
to

'Similarly, MYD cloud masks were classified as cloudy (0) for uncertain (01) and cloudy (00) categories and as clear (1) for confidently clear (11) and probably clear (10).' (Line 286-287)

Comment 34: *Line 313: add a "," after "factors" --> "factors, such as..."*

In line added ',' after ' factors' (Line 308)

Comment 35: *Lines 313-314: You could combine sensitivity and resolution --> "differences in sensor sensitivity and resolution,..."*

The line was changed accordingly from *"differences in sensor sensitivity, differences in sensor resolution,"* to 'differences in sensor sensitivity and resolution' (Line 309)

Comment 36: *Line 317: Replace "and" with "to" "ranging from 0.36 ... TO 0.32 ...".*

Replaced *"and"* with **"to"** in Line 312

Comment 37: *Line 319: The sentence concerning the MBE is unclear*

The sentence has been modified for clarity from

"The MBE for passive with the active sensor is 0.46 km for C-A and 1.12 km for C-M."

To

'The MBE is 0.46 km for C-A and 1.12 km for C-M, showing a larger offset for MODIS'.
(Line 315)

Comment 38: *Line 326-328: Add MBE before ">" --> "with MBE>1 km", "MBE± 0.5 km", MBE>1km" and "MBE>1.5km" so that the reader understands what you mean. I would suggest applying this throughout your manuscript wherever you use the >, <, or ± symbols.*

The sentence has been revised to include "MBE" before the symbols as suggested, and this notation has been applied consistently throughout the manuscript.

From

"Meanwhile, the inverse is true for the austral summer (DJF) with a correlation of 0.36 and MBE of 1.05 km with > 1 km, positive bias over the mid-latitudes, and smaller bias (± 0.5 km) over the high-latitudes. Another intriguing observation is that in austral winter (JJA),MODIS overestimates (> 1 km) the CTHs in the high-latitude and underestimates (> 1.5 km) in the mid-latitudes with an MBE of 1.25 km."

to

'Meanwhile, the inverse is true for the austral summer (DJF) with a correlation of 0.36 and MBE of 1.05 km with MBE > 1 km, positive bias over the mid-latitudes, and smaller bias (MBE ± 0.5 km) over the high-latitudes. Another intriguing observation is that in austral winter (JJA), MODIS overestimates the CTHs in the high-latitude (MBE > 1 km) and underestimates in the mid-latitudes (MBE > 1.5 km), with an overall season MBE of 1.20 km.' (Line 320-325)

Comment 39: *Lines 337: This contradicts what you state in lines 304–308; could you please explain why?*

The difference arises because lines 304–308 refer specifically to the ocean latitude band between 62°S and 70°S and to polar land areas, while lines 328–340 summarise domain-wide seasonal tendencies across the Southern Ocean and Antarctica. In the ocean band, both passive sensors generally overestimate CTHs compared with CALIOP, except in winter when only MODIS does so, and over Antarctic land AVHRR CMSAF underestimates CTH while MODIS overestimates CTH. When aggregated across the full domain and seasons, however, AVHRR CMSAF shows an overall tendency to overestimate and MODIS to underestimate. We have revised the text to clarify that the latter statement refers to domain-wide averages, while the earlier section highlights subregional and seasonal exceptions.

"The results indicate that the AVHRR CMSAF generally overestimates the CTHs compared to CALIOP. Conversely, MODIS tends to underestimate the CTHs."

Changed to

'The results indicate that the AVHRR CMSAF generally shows a tendency to overestimate the CTHs compared to CALIOP, although in some subregions (e.g. Antarctic land) it underestimates. Conversely, MODIS tends to underestimate the CTHs overall, but can overestimate in specific latitude bands such as 62° S to 70° S.' (Line 333-334)

Comment 40: *Line 339: "for the active and passive sensor data"*

The line was changed from *"for the active sensor and passive sensor data overall"* to 'for the active and passive sensor data' (Line 337)

Comment 41: *Line 399: You could write the date in the title. Suggestion: "case study on the 19.10.2015 at 08:37 UTC". It could help the reader.*

The section heading changed from *"Case study"* to 'Case study on the 19.10.2015 at 08:37 UTC' (Line 394)

Comment 42: *Line 400: A brief sentence describing the case study and what it was used to observe before introducing the Figure 6 would be appreciated.*
We have added a brief introductory sentence before Figure 6 was added for providing the purpose of the case study.
The sentence was added
'To illustrate these differences in retrieval behaviour, we present a case study over the SO on 19 October 2015, which was used to examine how passive and active sensors capture cloud properties under varying cloud structures.' (Line 395)

Comment 43: *Line 406: Change "see" in "observe".*

Replaced *"see"* with "observe" in Line 402

Comment 44: *Lines 406-408: I don't understand the sentence. Suggestion: "Although all three sensors observed a similar high cloud pattern around 50°S: AC retrieves the CTH at around 11km height, while MYD and AP retrieve the CTH at around 9 km height. Finally, AP has a significant region of cloud with CTHs at around 5 km Height located at 40°S and 80°E, while AC and MYD observed low clouds with CTHs at around 2 Km height for the same region."*
The line was changed from *"Although the general pattern of CTH is similar between the three passive sensors, there are some significant differences. Although all three sensors see a similar high cloud pattern around 50◦ S, AC retrieves the CTH around 11 km, while MYD and AP are around 9 km. AP has a significant"* to 'Although all three sensors observed a similar high cloud pattern around 50°S: AC retrieves the CTH at around 11km height, while MYD and AP retrieve the CTH at around 9 km height. Finally, AP has a significant region of cloud with CTHs at around 5 km height located at 40°S and 80°E, while AC and MYD observed low clouds with CTHs at around 2 km height for the same region' (Line 402-405)

Comment 45: <mark>*Line 423: suggestion "...over thick lower-level clouds"*</mark>

The line was changed from *"thick low-level clouds"* to 'thick lower-level clouds'. (Line 414)

Comment 46: <mark>*Line 425: You can add "height" after "km" if you speak about altitude of clouds.*</mark>

In the line added the word 'height' after '12 km'. (Line 416)

Comment 47: <mark>*Line 431: "lower-level cloud" or "lower layer cloud"?*</mark>

In this case "lower layer cloud" is correct, as the description refers to the vertical layering of clouds rather than their altitude classification. No change was required.

Comment 48: <mark>*Line 444-447: Please reorganize the sentence which is not very clear. You could rephrase it in 2 sentences. Suggestion: "...temperature profiles. Indeed, the CTH can vary substantially, particularly at high altitude and altitude, and depends on the difficulty in identifying the inversion at the tropopause..."*</mark>

The line was changed from *"for temperature profiles, which can vary substantially, particularly at high altitudes and high latitudes, and the difficulty in identifying the inversion at the tropopause"* to 'temperature profiles. Indeed, the CTH can vary substantially, particularly at high altitude and depends on the difficulty in identifying the inversion at the tropopause' (Line 423-425)

Comment 49: <mark>*Lines 448+451: "Figure 7aiii shows a region of boudary layer clouds around 41.5°S"*</mark>
We have rephrased the sentence for clarity and conciseness.
"The section Figure 7aiii around 41.5\degree S shows a region of boundary layer clouds"
was changed to 'Figure 7aiii shows a region of boundary layer clouds around 41.5°S' (Line 426)

Comment 50: <mark>*Line 457: The second panel of which Figure do you mean? 7b?*</mark>

We have added the figure details to ring clarity to the sentence

Added '(Figure 7b)' after 'The second panel'. (Line 430)

Comment 51: <mark>*Line 461: "active sensors" --> Is there only one active sensor (CALIOP) or several?*</mark>
Typo *"active sensors"* changed to 'active sensor'(Line 435)

Comment 52: *Line 472: You can move ",particularly where ice clouds detected are quite different" (remove the first "are") to the end of the sentence after "in general". Add "of" before AP CER" --> "the vaues OF AP CER".*

The sentence has been rearranged as suggested, with "of" added before AP CER and the phrase concerning ice clouds moved to the end for improved clarity.
"While the general pattern of the CER from the passive sensors is in agreement, the values, particularly where ice clouds are detected are quite different, AP CER are higher than MYD and AC CER retrievals in general." was rearranged to 'While the general pattern of the CER from the passive sensors is in agreement, the values of AP CER are higher than MYD and AC CER retrievals in general, particularly where ice clouds detected are quite different.' (Line 425)

Comment 53: *Line 485: "in Sect. 4.2.4"?*

Typo *"in Sect. 4.2.4"* changed to ' in Table 7'(Line 447)

Comment 54: *Lines 576-577: You can remove this part of the sentence "for example, MYD has five phase categories, while AC has eight, including a supercooled water class" because it is already shown with the Table 7.*

 Line 503-505 *"The passive sensors categorise thermodynamic phase into various classifications according to their retrieval algorithms; for example, MYD has five phase categories, while AC has eight, including a supercooled water class. The categories used by each dataset are presented in Table 7."* The sentence has been revised to include the suggested clarification. The revised sentence now reads 'The passive sensors categorise thermodynamic phase into various classifications according to their retrieval algorithms and the categories used by each dataset are presented in Table 7.' (Line 522)

Comment 55: *Lines 650-673: The paragraph appears twice: you can delete the text from lines 662 to 673.*

The paragraph was only repeated in the track change document. It is not repeated in the final pdf. The repeated paragraph was removed from the track change document also

Comment 56: *Line 706: Change "biases" in "bias".*
"biases" changed to 'bias' (Line 601)

Comment 57: *Line 741-742: "..the cloud thermodynamic phase...", remove the "s" at the end of thermodynamic.*

"Thermodynamics" changed to 'thermodynamic' (Line 630)

References

1. Karlsson, K.-G., and E. Johansson, 2013: On the optimal method for evaluating cloud products from passive satellite imagery using CALIPSO-CALIOP data: example investigating the CM SAF CLARA-A1 dataset. Atmos. Meas. Tech., 6, 1271–1286.

2. Marchant, B., S. Platnick, K. Meyer, and G. Wind, 2020: Evaluation of the MODIS Collection 6 multilayer cloud detection algorithm through comparisons with CloudSat CPR and CALIPSO CALIOP products. Atmos. Meas. Tech., 13, 3263–3275.

3. Yost, C. R., P. Minnis, S. Sun-Mack, W. L. Smith Jr., and Q. Z. Trepte, 2023: VIIRS Edition 1 Cloud Properties for CERES, Part 2: Evaluation with CALIPSO. Remote Sens., 15, 1349.