Response to Bryan A. Baum

The authors are thankful to the referee for his thorough review of the paper.

Our responses are detailed below. The manuscript has been revised accordingly, and is clearly improved.

In the following, the reviewer's comments are in black, and our answer to each comment is in red.

A glossary of parameters/subscripts/acronyms would have really helped me.

We recognize that a lot parameters with many subscripts are used in this paper. We followed the reviewer suggestion and included a new Appendix C with a glossary for the most important parameters used in the manuscript. Appendix C will read:

Appendix C: Glossary

Notation	Description
$\alpha_{abs,eq}(k)$	IIR equivalent absorption coefficient in channel k
α_{part}	CALIOP particulate extinction coefficient
BTDoc	Difference between observed and computed brightness temperatures in clear sky conditions, channel not specified
BTDoc(12)	Difference between observed and computed brightness temperatures in clear sky conditions in channel 12.05 µm
BTDoc(08-12)	08-12 inter-channel BTDoc difference: BTDoc(08) - BTDoc(12)
BTDoc(10-12)	10-12 inter-channel BTDoc difference: BTDoc(10) - BTDoc(12)
$\beta_{eff}12/k$	Effective microphysical index for the pair of channels 12 and k: $\tau_{a,12}/\tau_{a,k}$
$dT_{k,BB}$	Systematic error in blackbody brightness temperature in channel k
$dT_{k,BG}$	Systematic error in background brightness temperature in channel k
D_e	Effective diameter retrieved by the IIR algorithm
D_e12/k	Effective diameter derived from $\beta_{eff}12/k$
$\Delta\varepsilon_{eff}12\text{-}k$	Inter-channel effective emissivity difference: $\varepsilon_{eff,12} - \varepsilon_{eff,k}$
ΔT_{BB}	Random error in $T_{k,BB}$ (all channels)
ΔT_{BG}	Random error in background brightness temperature (all channels)
ΔZ	Geometric thickness
ΔZ_{eq}	IIR equivalent geometric thickness
$\varepsilon_{eff,k}$	Effective emissivity in IIR channel k
η	Multiple scattering correction factor
IAB	Integrated Attenuated Backscatter at 532 nm
IWC	IIR layer equivalent ice water content
IWP	Ice water path
IWVP	Column integrated water vapor path
k	Used to designate an IIR channel Channel 08.65 µm: k = 08 Channel 10.65 µm: k = 10 Channel 12.05 µm: k = 12
LWC	IIR layer equivalent liquid water content
LWP	Liquid water path

N_d	Liquid droplets concentration
N_i	Ice crystals concentration
$R_{k,BB}$	Blackbody radiance in channel k
$R_{k,BG}$	Background radiance in channel k
$R_{k,m}$	Measured radiance in channel k
T_{base}	Temperature at cloud base
T_c	Centroid temperature, i.e. thermodynamic temperature at centroid altitude Z_c
$T_{k,BB}$	Blackbody brightness temperature in channel k
$T_{k,BG}$	Background brightness temperature in channel k
$T_{k,m}$	Measured brightness temperature in channel k
T_r (k)	Radiative temperature in channel k
T_{top}	Temperature at cloud top
$\tau_{a,k}$	Effective absorption optical depth in channel k
τ_{vis}	Visible optical depth
WF_{IIR}	IIR weighting function
Z_c	Centroid altitude of the 532-nm attenuated backscatter

Line 20: the authors discuss reducing biases found at very small emissivities in V3 of their products, both here and in Section 3.2.1 beginning at line 190. My interpretation of this is that there is a significant low biases in the ice cloud microphysical indices at very low values of the cloud emissivity, which is the same thing as stating that there is a bias at very low ice cloud optical depths.
Yes, we agree.

On lines 26/27, the authors state that V4 improved retrievals in ice clouds having large optical depths. My point is to be consistent in the use of cloud emissivity or cloud optical depth. In fact, lines 569-570 say this very clearly: "The IIR Level 2 algorithm has been modified in the V4 data release to improve the accuracy of the microphysical indices in clouds of very small (close to 0) and very large (close to 1) effective emissivities." Perhaps this sentence should also be in the Abstract.
We added this sentence in the abstract as suggested. The sentence is now inserted on line 20.

And on line 26, we replaced
"We have also aimed at improving retrievals in ice clouds having large optical depths by refining the determination of the radiative temperature needed for emissivity computation."

with (changes in italic)

"We have also *improved* retrievals in ice clouds having large *emissivity* by refining the determination of the radiative temperature needed for emissivity computation."

Line 25: why is the IIR channel at 8.65 microns written as 08.65 here and throughout the manuscript? Is there a reason for including a leading zero on this wavelength?
We wrote 08.65 µm for this wavelength because we chose the short notation '08' to designate this channel, which itself was chosen to have the same number of digits as in '10' and '12' channels. We recognize that we could have used a different approach.

Line 26: suggest changing "aimed at improving" to "improved"
Done

Line 31: define what is meant by "dense ice clouds" here and on lines 112, 122, 296, and 587.
On lines 31 and 587, the sentences were confusing, and we deleted "dense ice clouds".

On line 31, the new sentence reads:
"As shown in Part II, this improvement reduces the low biases at large optical depths that were seen in V3 and increases the number of retrievals."

And on line 587, the new sentence reads (changes in italic):
*"*This correction is expected to *both* increase the number of valid retrievals of crystal sizes *and reduce biases for ice clouds of* large optical depth*."*

On line 112, we are not using the term "dense" anymore and the sentence now starts as (changes in italic):
"The rationale is that unless these low layers are dust (or volcanic ash) layers *of sufficient optical depth*, …"

On line 122, we clarified by changing the sentence to (changes in italic):
"However, clouds detected at single shot resolution have large signal-to-noise ratios (SNR), indicating that *their optical depth is likely large and that they* actually should not be ignored."

Finally, on line 296, the end of the sentence now reads (changes in italic):
"…., and a marked negative tail down to about -8 K is observed, because *these cleared clouds have a fairly large optical depth* and are often colder than the surface".

Line 33: mostly a comment: this is the first of 24 references to "ice crystal models" or something similar in the text. The term "crystal" generally suggests a pristine shape such as a column or plate. The term "particle" includes all habits, pristine or very complex. Naturally occurring ice particles mostly defy description. This article more properly describes the adoption of two "ice habit models" composed of either single hexagonal columns (first found on line 33) or aggregates of columns (line 34).
Thank you.
We changed "ice crystal model" to "ice habit model".

Line 41: add a sentence to provide background and a reference for the A-Train for those readers who may not be familiar with it.
The sentence now reads (changes in italic):
"The A-Train *international constellation of satellites (Stephens et al., 2002)* has delivered a broad range….."

Line 41: define spectrum of wavelengths meant by visible and infrared
We now write:
"…operating in the *visible/near infrared (0.4 – 8 µm) and infrared (8-15 µm)*…."

Line 42: suggest changing "combination of infrared" to "combination of passive infrared"
Done

Lines 127-128: provide a description of the new types of scenes that have been introduced when at least one cleared cloud is present in the column
These new scene types are meant to identify the scenes that are cloud-free according to the 5-km layer products, but have at least one cleared cloud in the column. No IIR retrievals are attempted for these new scene types.
We tried to clarify the text, which now reads:

"Cloud-free scenes in V4 are pristine and have no single shot cleared clouds, while new types have been introduced *to identify scenes that are cloud-free according to the 5-km layer products, but have at least one cleared cloud in the column. No IIR retrievals are attempted for these new scene types*."

Lines 185 and 186: define what is meant specifically by optically very thin and very thick cloud here.
We revised the sentence, and these terms are not used anymore. It now reads (changes in italic):
"Because the sensitivity of the split-window technique decreases *as effective emissivity approaches 0 and 1*, $\Delta\varepsilon_{eff}$12-k is supposed to tend towards zero on average when $\varepsilon_{eff,12}$ tends towards 0 and towards 1."

Line 218: suggest changing "Earth Surface" to "surface"
Done

Line 218: interpolated atmospheric profiles: how many layers/levels are in the interpolated profiles? Do these profiles include trace gases? Are these augmented at very high altitudes by a climatology, e.g., for ozone if this is part of the profile?
We meant to say that the profiles are interpolated horizontally and temporally.
The atmospheric profiles are from the 72 levels of the MERRA-2 model. These profiles are temperature, specific humidity and ozone profiles.
The beginning of Sect. 3.3.1 now reads (changes in italic):

"The background radiance from the *surface* is computed using the FASRAD model fed by *horizontally and temporally* interpolated *temperature, water vapor, and ozone* profiles and skin temperatures. *These ancillary data are from the MERRA-2 reanalysis products in V4.*

Line 222: suggest changing "thanks to the advances" to "to take advantage of recent advances"
Done

Section 3.4.1, lines 313-317: the discussion on calculating a centroid altitude and temperature for multi-layered cloud cases is a bit confusing to me. If a vertical column contains optically thin ice cloud overlying a low-level water cloud, can the resulting centroid be in the mid-troposphere where there is no cloud layer? If this is a possibility, there should be a flag provided to indicate that multilayered clouds are present for that retrieval so that these cases can be filtered out if so desired. More specifically, the flag should be provided with the cloud properties such as the centroid altitude and temperature so that a user does not have to look at potentially multiple products (e.g., cloud mask or cloud phase) to find this detail. The availability of a flag would certainly be of help when comparing your cloud product to a simulated cloud field based on, for example, large eddy simulations.
Thank you for this question.
You are correct that if a vertical column contains optically thin ice cloud overlying a low-level semi-transparent water cloud, the resulting centroid can be in the mid-troposphere where there is no cloud layer.

A lot of CALIOP parameters describing the cloudy scenes are reported in the IIR product. For instance, we report an Ice_Water_Flag, which tells the user if the column includes only ice clouds or only water clouds, etc..., and we also report the CALIOP confidence in the feature type and phase assignments. A case with a thin ice clouds overlying a low-level semi-transparent cloud is flagged as mixed. There is also a flag (i.e., the Multi_Layer_Flag) specifying the number of layers selected by the IIR algorithm in the column. The full list of parameters reported in the IIR Level 2 products is available at:
https://www-calipso.larc.nasa.gov/resources/calipso_users_guide/data_summaries/iir/cal_iir_l2_track_v4-20_desc.php

We added the following text at the end of Sect. 2 about the scene classification:

"A lot of other parameters characterizing the scenes are reported in the V4 IIR product. Among them are the number of layers in the cloud system, as well as an "Ice Water Flag" which informs the user about the phase of the cloud layers included in the system, as assigned by the V4 CALIOP Ice/Water phase algorithm (Avery et al., 2020). A companion "Quality Assessment" flag reports the mean confidence in the feature type (i.e., cloud or aerosol) classification (Liu et al., 2019) and in the phase assignment for these cloud layers. The product also includes the number of tropospheric dust layers and of stratospheric aerosols layers in the column and the mean confidence in the feature type classification. All the suitable scenes are processed regardless of the confidence in the classifications and phase assignments reported in the CALIOP products, so that the user can define customized filtering criteria adapted to specific research objectives."

In Section 4 somewhere, it would be quite interesting to know the range of the effective diameter (De) values for ice clouds inferred from both V3 and V4. Does the range change between V3 and V4? Additionally, does the range ever approach the boundaries of the LUT, either very low or very high values? How often does this happen?

These questions are addressed in details in Sect. 3 of the companion "Part II" paper available at amt.copernicus.org/preprints/amt-2020-388/, preprint accepted for publication in the AMT journal.

As a result of the improved accuracy of β_{eff}12/10 and β_{eff}12/08, the consistency between D_e12/10 and D_e12/08 is drastically improved in V4 at $\varepsilon_{eff,12}$ smaller than 0.5 when the background radiance is computed using the radiative transfer model and cannot be derived from neighboring observations, which represents about 70 % of the cases.

In V4, both β_{eff}12/10 and β_{eff}12/08 are in the range of expected values (according to the respective LUTs) more than 80 % of the time for $\varepsilon_{eff,12}$ between 0.05 and 0.80. In contrast, the $\varepsilon_{eff,12}$ 80 % range in V3 was only 0.15 – 0.7 for the 12/10 pair and only 0.25 – 0.7 for the 12/08 pair.

Most of the time, failed retrievals are due β_{eff} found smaller than the lower boundary of the LUT.

The β_{eff}12/10 and β_{eff}12/08 indices are typically larger in V4 than in V3, which decreases D_e in V4 for a given LUT, but the V4 LUTs tend to provide a larger D_e than in V3 for a given value of β_{eff}.

As a result, we find that D_e12/10 is not significantly changed in V4 compared to V3. However, D_e12/08 is smaller in V4 by up to 15 µm at $\varepsilon_{eff,12} < 0.2$, and larger by up to 10 µm at $\varepsilon_{eff,12}$ between 0.2 and 0.9. D_e is therefore smaller in V4 by up to 7.5 µm at $\varepsilon_{eff,12} < 0.2$ and larger by up to 5 µm at $\varepsilon_{eff,12}$ between 0.2 and 0.9.