Reply to Referee #2 on the Earth System Science Datasets manuscript

” CLARA-A3: The third edition of the AVHRR-based CM SAF climate data record on clouds, radiation and surface albedo covering the period 1979 to 2023”

by
Karlsson et al, 2023

Repeating general comment:

The authors describe an updated AVHRR-based cloud, radiation, and albedo record CLARA-A3. The AVHRR instruments have made observations from low Earth orbit since the late 1970s and provide a valuable cloud-climate record for the scientific community. However, there are many problems with this instrument: poor calibration, changing instrument characteristics over time (SRFs, channel choices, etc.), challenges with orbital drift, and sparse coverage of the solar and thermal plank functions, to name a few. The authors have been working on this observational record for a long time and should be commended for getting the most out of it. CLARA-A3 has several additional variables compared to the previous version, and the variables common across earlier CLARA versions have shown improvement with respect to other passive and active satellite records. My comments and suggestions regarding the manuscript are fairly minor but should be considered in a revision by the authors.

Reply:

The authors are grateful to the referee for these encouraging words. We have addressed comments and suggestions below and proposed relevant changes to the manuscript where needed.

Detailed comments:

1. Throughout the manuscript: At times the use of English can be fairly colloquial and could be tightened up.

   Author reply: OK, we will try revising the text where we find such parts (e.g., partly guided by some or your specific recommendations below).

2. L44: extra parenthesis **Author reply:** OK, will be deleted.

3. L46: probably should distinguish between individual VIIRS and MODIS records, and the VIIRS+MODIS continuity product, there should be more recent references for the latter

   Author reply: Good point. We propose adding the following at line 46:

   "In addition, measurements from the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument is now capable of providing decadal scale observations suitable for CDR generation and they will also be used to extend the MODIS CDR through a specific VIIRS+MODIS continuity product (Platnick et al., 2021)."

   Added reference:

   Platnick, S.; Meyer, K.; Wind, G.; Holz, R.E.; Amarasinghe, N.; Hubanks, P.A.; Marchant, B.; Dutcher, S.; Veglio, P. The NASA MODIS-VIIRS Continuity Cloud Optical Properties Products. Remote Sens. 2021, 13, 2. https://dx.doi.org/10.3390/rs13010002

4. L79-83: The authors do point out that the reader could go to a validation report for more information. But it would be helpful to explicitly describe the comparisons against CERES fluxes. Since CERES has broadband channels, there are very few photons missed, whereas AVHRR has discrete SRFs and does not measure all frequencies. Also, AVHRR shows really nice spatial structure. It would be worth detailing why one would want to do this with AVHRR data in the first place.

   Author reply: In the lines L79-83 there is no reference to the validation report, and we are not sure which of the CLARA-A3 products the reviewer is talking about (surface fluxes? TOA fluxes?). For the TOA fluxes, the comparison against CERES fluxes is performed and described

(Figures 9, 10, 11 + accompanying text). About added value of this data record: see further, remark on Figure 10.

5. L91: period at start of sentence **Author reply:** Will be deleted.

6. L91: 'has been measuring' should be e.g. 'has been making measurements'

   Author reply: OK, will be changed.

7. L131: period and comma next to each other **Author reply:** Period to be deleted.

8. L160: it should be made clearer that CLARA-A3 is Level 3, but what is Level 2b? Or is CLARA-A3 also Level 2b? This needs clarification.

   Author reply: In fact, for some products (i.e., exclusively cloud property products) also Level 2b representations are provided in addition to L3 products. This is clearly stated on lines 158-160 and in the following lines 161-163 the Level 2b concept is introduced and explained. We think it would be enough to just clarify that these products are not only useful and needed for L3 calculations but they are also available to external users. Consequently, the text "All level-2b products are also available for external users." is added at line 164 (after "products.").

   The motivation for making also Level 2b products available for users has to do with the fact that the CLARA-A3 simulator package (mentioned on lines 197-198) produces results from NWP/Climate models in the form of Level 2b products. Thus, results simulated from models can be compared both to instantaneous observations (Level 2b) and to aggregated results (Level 3).

9. L173-174: prepared separately from the rest of the globe? It would be better to simply say "This latitude band is prepared with gridding strategy A, while that latitude band is prepared with another gridding strategy B." or similar.

   Author reply: Well, we would prefer the following slightly changed formulation:

   "CFC and CTO products are prepared for two additional areas which cover and zoom in on the polar regions. This is motivated since the standard latitude-longitude grid is not appropriate for studies focused on the polar regions because of the variable geometric grid resolution near

the poles in the standard grid. The two polar regions (named South Pole and North Pole) have constant 25 km grid resolution and are used exclusively for the mentioned cloud products and for the surface albedo products (discussed in Sect. 3.3)."

10. L175: why does the sentence end with 'here'? **Author reply:** Deleted because of the reformulation proposed in the previous point.

11. L188: also, clause after comma starts with 'here', not sure what is meant

    Author reply: "Here" refers to the definition of COT in CLARA-A3, which is at a wavelength of 0.64 µm. However, this information is not really necessary, so the part "here with a wavelength of 0.64 µm" will be omitted in the revised version.

12. L189: this begs the question as to why are some variables considered "products" while other variables are considered "extra data layers"? What is the difference? Why not report everything as "products"?

    Author reply: The products as described in Table 2 are the main variables that are provided, each in separate files. In most cases the files contain additional variables, which we call "data layers" here, that are related to the main variables. For example, in the CFC file, also low-, medium- and high-level cloud fractions are provided. Similarly, in the LWP file, COT of liquid clouds is provided. Since the term "data layer" may be confusing, we will skip it, so the sentence becomes: "Both COT and CRE are available in the product files for LWP and IWP."

13. L191: by implication, a CGT implies a cloud base height (CBH). When researchers use this product, they may very well use it to infer a CBH. Have you examined CGH/CBH?

    Author reply: This is in principle true. In addition, with the respective error estimates of CTH and CGT, one could also derive an error estimate of CBH. However, we have not done any validation of CBH derived in this way. It would be an interesting topic, which we may analyze in the future or which a user of the data could investigate.

14. L194: probably should clarify with '…separately for both liquid and ice clouds'. Is this correct?

    Author reply: Yes, the word "separately" will be added in the revised version.

15. Same paragraph: May want to cite documentation or papers for MODIS L3 gridded products that provide similar histograms

Author reply: The sentence "Similar Joint Cloud Histograms are provided in the ISCCP and MODIS data sets (Platnick et al. 2015)." will be added at the end of this paragraph.

Added reference:

Platnick, S., King, M. D., Meyer, K. G., Wind, G., Amarasinghe, N., Marchant, B., Arnold, G. T., Zhang, Z., Hubanks, P. A., Ridgway, B., and Riédi, J.: MODIS Cloud Optical Properties: User Guide for the Collection 6 Level-2 MOD06/MYD06 Product and Associated Level-3 Datasets, Version 1.0, available at: https://modis-images.gsfc.nasa.gov/_docs/C6MOD06OPUserGuide.pdf (last access: 7 July 2023), 2015.

16. L220: what is the definition of 'moisture content'? Vapor only? In the column? Or does it include the sum of vapor, cloud water content, and precipitation?

Author reply: We suggest the following reformulation:

" …total atmospheric moisture content (i.e., column-integrated water vapour excluding cloud water and precipitation),…."

17. L232: 'instead' rather than 'in its stead' **Author reply:** To be changed.

18. L238: Why 231K (-42C) instead of 233K (-40C)? Why 265K (-7C) rather than some other threshold? Can you add a reference(s) to justify these choices?

Author reply: Selection of these thresholds was motivated based on the temperature limits where liquid droplets and ice crystals occur in supercooled clouds, which are included in the extended cloud phase retrieval. These numbers do not match exactly respective limits given in the literature: -40C (e.g. Tabazadeh et al. 2003) and -6C (e.g. Hobbs and Rangno, 1985). For the CPP retrieval algorithm, the specific limits were selected empirically based on comparisons with observations from Cloudsat and CALIPSO.

Added references:

Hobbs, P. V. and Rangno, A. L.: Ice Particle Concentrations in Clouds, J. Atmos. Sci., 42, 2523–2549, 1985.

Tabazadeh, A., Djikaev, Y. S., and Reiss, H.: Surface crystallization of supercooled water in clouds, P. Natl. Acad. Sci. USA, 99, 15 873–15 878, 2003.

19. L253: I did not see any presentation or discussion of uncertainty estimates in this paper. Are we talking about uncertainties in the ancillary data that are somehow utilized to produce the products in Table 2? Or are these uncertainties on the products themselves reported in Table 2? In either case, these should be described, cited, shown in a figure, their methodological approach described and cited, and summarized in some way that demonstrates their use.

Author reply: The approach for estimating uncertainties depends on the product, and including figures to show or validate the uncertainties would make the paper too long. However, we agree that more information on the derivation of the uncertainty estimates should be provided, especially since such estimates have been added to several of the products which lacked such information in the predecessor CLARA-A2. Thus, we can say the following:

- The CFC product is derived from cloud probability products (CMAPROB) where uncertainties are implicitly embedded in the product itself (i.e., maximum reliability at 0% cloud probability and at 100% cloud probability but with maximum uncertainty at 50% cloud probability). These cloud probabilities are available in the Level 2b products so that any user could define their own confidence levels depending on applications. For the L3 product, a simple measure is calculated which is based on the averaging of the 'distance' to the 50% cloud probability level for all pixels within the 0.25 degree grid box. We propose to add the following sentences after line 226:

  "CFC uncertainties for the Level 2b product can be interpreted directly from the CMAPROB product which is provided together with the binary cloud mask. Maximum uncertainty is found at the 50% cloud probability level. For the level-3 product, a simple estimation based on the averaging of the probability distance from the 50% threshold for clear and cloudy pixels is provided."

- The CTO product (Level 2) has an uncertainty estimate based on Quantile Regression Neural Networks. This has already been described

on lines 232-233. The estimated 16th and 84th percentiles correspond to one sigma level. For the L3 product, The CTO 1-sigma uncertainties from Level-2b files are propagated into Level-3 following Stengel et al. (2017) as summarized in the cloud products ATBD (available via the doi link in Sect. 5) in Section 4.4.8. We propose the following sentences after line 233:

"For estimating the CTO uncertainty in the level-2b product, the average of the absolute CTO difference from the 16th and the 84th percentile is provided. These CTO 1-sigma uncertainties from Level-2b files are then propagated into level-3 products, following Stengel et al. (2017)".

Reference added:

"Stengel, M., Stapelberg, S., Sus, O., Schlundt, C., Poulsen, C., Thomas, G., Christensen, M., Carbajal Henken, C., Preusker, R., Fischer, J., Devasthale, A., Willén, U., Karlsson, K.-G., McGarragh, G. R., Proud, S., Povey, A. C., Grainger, R. G., Meirink, J. F., Feofilov, A., Bennartz, R., Bojanowski, J. S., and Hollmann, R.: Cloud property datasets retrieved from AVHRR, MODIS, AATSR and MERIS in the framework of the Cloud_cci project, Earth Syst. Sci. Data, 9, 881-904, https://doi.org/10.5194/essd-9-881-2017, 2017."

- For the LWP, IWP, CDNC and CGT products, we will add a brief description in the relevant section (3.1.1), and the reader will be referred to the ATBDs for more details. Specifically, we will add the following at L250: "Estimated uncertainties in reflectance measurements and various input variables (e.g., surface albedo, total ozone column) are propagated to yield uncertainty estimates in retrieved COT and CRE. These are, in turn, propagated to uncertainty estimates in LWP, IWP, CDNC and CGT. Further details are given by Stengel et al. (2017) and in NWC SAF (2021)."

  Added reference:

  NWC SAF: Algorithm Theoretical Basis Document for Cloud Micro Physics of the NWC/PPS, Satellite Application Facility on Nowcasting and Very Short Range Forecasting, NWC/CDOP3/PPS/SMHI/SCI/ATBD/CMIC, Issue 3.0, 12 October 2021.

- For the TOA products (OLR and RSF), no uncertainties were a priori calculated. Instead, the uncertainty in a given grid box is estimated a posteriori, by validating the data against the state-of-the-art CERES data record (considered as the "golden standard" among the TOA radiative flux data records). It provides the user a good idea of the performance, expressed as Mean Absolute Bias on daily and monthly time scale. It may vary in time and space, and all this information is available to the user in the Validation Report. We can meet the reviewer's request by introducing a table containing the MAB w.r.t. CERES on both daily and monthly timescales, for both OLR and RSF.

- For the surface albedo product we can add the following paragraph after line 506:

  "The albedo data do not contain uncertainty estimates per grid cell. However, a wide variety of parameters describing the statistical distribution and sampling density of the retrieved albedos are provided in the data files, e.g. skewness, kurtosis, and number of valid observations per grid cell."

  For the remaining CLARA-A3 products, no specific uncertainty parameters are provided with the Level 3 product but any user has access to extensive information in the validation reports describing the overall product quality.

- For the surface radiation products there are no uncertainty estimations per grid cell. However, the extensive comparisons with measurements at BRSN stations (detailed in the referenced validation report) should give a good view of the uncertainties of this product. In our opinion, the description in the text is sufficient.

20. L264: do not need 'in addition' at the end of the sentence **Author reply:** Yes, will be removed.

21. L279: the phrasing is a bit awkward. Is this supposed to mean 'more thin cloud with a COT < 0.3 is detected' or 'more thin cloud with a COT > 0.3 is detected'?

    Author reply: We suggest the following revised formulation at line 278 that hopefully can be clearer:

    "…CALIPSO-Passive results. This indicates that a substantial fraction of all clouds with an optical thickness less than 0.3 are now detected in

CLARA-A3. This clearly differs from the performance of the predecessor CLARA-A2 where less thin clouds were detected."

22. L292: 'significant trends' implies that a formal significance test in the trends was performed. Do the authors mean that there are no trends with 95% significance? How did you do this test or conclude this result?

Author reply: It is clear that one has to be careful when using the word "significant" in a manuscript, knowing about the strict statistical meaning of this word. We will change the word "significant" here to the more general and descriptive term "clear" in the text. However, true significance tests have actually been made and published recently (https://www.preprints.org/manuscript/202306.1668/v1). Such studies should preferably be based on de-seasonalized data which was also done in the referenced paper. Thus, we will emphasize in the text that results from more detailed trend studies can be found in the referenced paper.

23. Figure 4: Why does MODIS Aqua show a decrease in liquid cloud? Is this a calibration issue or a physical change in cloud properties?

Author reply: This was not investigated further. The same decrease does not appear in CLARA-A3 and ESA-CCI.

24. L330: Why specifically should we care to read the report? It would help to explain what is in it at a very high level. It is not useful to tell the reader that they need to read another report or series of papers to get the gist of the current paper. The information should be self-contained in some manner.

Author reply: We have reported our most important results from validation studies for all products but there are a lot more details to find in the referenced validation reports. To really go into details describing all validation results for all CLARA-A3 products in the current manuscript would totally explode the size of it. At the same time, we think it is fair to the reader to inform about the more extensive validation reports as well as already published separate studies of the CLARA-A3 products. So, we think we have a reasonable balance between the two objectives to describe the CDR content and to briefly describe product quality. After all, the goal of the ESSD journal is to present new science datasets, not to analyze each of them in depth. The latter should be done in separate publications.

In conclusion, the reader does not need to read the validation reports to get the gist of the paper. But the reports contain additional, more detailed information on the validation of CLARA-A3. We will rephrase as follows: "Additional details on validation results are provided in the dedicated CLARA-A3 Cloud Products validation report available through the link given in Sect. 5.".

25. Same part of manuscript: What about trends in IWP, LWP, and effective radius for liquid and ice clouds? Have these been examined?

Author reply: They have been examined in terms of the stability of their bias with the reference data sets. Although time series are mostly stable over the full CLARA time range, there are signatures of satellite switches and orbital drift. Extensive results are given in the validation report (CM SAF, 2023).

26. L340: spell out Table **Author reply:** OK.

27. L361: look-up table should be spelled out on first use. Also, need to add space between 'LUT' and 'that' **Author reply:** Yes, we will change this.

28. L363: add Hersbach reference for ERA5. Also, define ERA5T. Is this surface temperature? Or something else?

Author reply: OK, we will add this reference also here (even if it was introduced already on line 221). Then, we realize that we started using the term ERA5T before it was properly explained (which is done on lines 660-662). The easiest way to solve it is to just state "(i.e., a preliminary version of ERA5, see Sect. 3.5 for further explanation)".

29. Paragraph starting on line 380: It is unclear what we should take home from the use of a monthly climatology for aerosol averaged over many years. How does this impact the interpretation of the solar products in CLARA-A3 on a daily, instantaneous basis? Relative to the total magnitude of the value of the products, how large is the contribution from aerosol? Less than a few %? Greater than that by a little, or a lot?

Author reply: The exact contribution of the aerosol is difficult to determine (and not part of the current study). The uncertainty of the daily (and instantaneous, even though not provided) surface solar radiation data is impacted by many contributions, incl. the use of monthly aerosol information, but also e.g. the limited number of available satellite observations to estimate the daily average. Since the main determining

factor of daily surface solar radiation is cloudiness, we expect the impact of using a monthly aerosol climatology on the daily surface irradiance to be less than a few %. There surely, however, are situations, when the impact is larger, e.g., very high dust loadings under clear sky conditions. This limitation on the use of monthly aerosol information for the analysis of daily surface radiation data will be mentioned in the revised version of the manuscript.

30. L391: end of sentence, also should be noted that it does not contain day-to-day variability, which conceivably can be significant

    Author reply: We agree with the reviewer that (possibly significant) day-to-day aerosol variability is not included in the clear-sky surface irradiance; this will be stated in the revised version of the manuscript.

31. L406: 'The grid boxes…' **Author reply:** Yes, we will change.

32. L407: end of sentence repetitive **Author reply:** This comment is not clear, we do not see any repetitive statement here. However, we will move the remark on the difficulty for using the CLARA-A3 data record to estimate global averages (line 404 to line 407) at the end of this paragraph, since it also applies to the surface net solar radiation.

33. L419 and L422: Is ERA5T the same as ERA5(T)? **Author reply:** Yes. We will change so we use ERA5T everywhere.

34. L530: 'was very good' is not entirely useful or quantitative

    Author reply: We propose removing the qualitative part "we note that the CDR performance was very good regarding mean bias and stability (the temporal trend in bias)." and reformulate in order that the quantitative part is highlighted first: "As a summary of the results, the mean relative bias was…".

35. L562: how many ADMs are used?

    Author reply: In total, there are 600 scene types, so that is the amount of ADM's that were potentially used. Evidently, their relative importance depends on the occurrence of the scene types.

36. Figure 10: The fact that ERA5 and CLARA-A3 track so closely at short and long temporal scales could be interpreted in a way that suggests CLARA-A3 depends heavily on ERA5 ancillary inputs, and that you are

basically making another version of ERA5. Is this fair to say or is there a clear advantage to using AVHRR data for the solar and thermal flux and irradiance products? This gets back to the earlier comment about why are these products being generated in the first place? What is the added value over other climate records?

Author reply: What you see in Figure 10 is only the global mean RSF, which gives an indication of the record's stability as mentioned in L615. However, that's only one aspect of a data record's performance: also important is the regional uncertainty, which gives an indication of the bias on a particular time in a particular grid box: this is much worse for ERA5 reanalysis since it is basically a climate model constrained with observations (but not with TOA radiative flux observations). But more in general, about the added value of the climate records: we agree with the reviewer that this issue deserves some more attention. We therefore add the following paragraph which addresses the remark of the reviewer:

“A full global coverage of broadband observations is provided by the Clouds and the Earth’s Radiant Energy System (CERES) instruments and derived products (Loeb et al., 2018), which are acknowledged to be the golden standard w.r.t. radiative flux data records. However, there has been an increasing need for long-term, high-resolution TOA albedo products in monitoring the climate impacts of regional-scale events such as air pollution, urbanization, forest fires, and other small-scale land cover changes (Song et al., 2018), which can hardly be detected from data sets with coarse spatial resolution (Wang et al., 2016), and small-scale atmospheric processes e.g. valley fog (Clerbaux et al., 2009). Furthermore, in absence of a global long-term CERES-like CDR, many studies focusing on long term model validation or trend detection fall back to “surrogate datasets” such as reanalysis (e.g. ERA-Interim) or radiative transfer computations (e.g. ISSCP), but would otherwise have preferred a more observation-based alternative. Concerning CERES, two limitations can thus be identified: (1) the products are relatively recent, e.g. starting in year 2000 for the EBAF product, and (2) the products have a relatively coarse spatial resolution of 1°x1° (Fig. 9a). The currently developed TOA flux products in CLARA-A3 resolve those two drawbacks, respectively by (1) a prolongation back in time to the late 70’s and (2) by increasing the spatial resolution to 0.25°x0.25° (Fig. 9b). A third advantage of the new CDR’s lies in their synergy and compatibility with the other CDR’s from the CM SAF CLARA product family (cloud mask and other cloud parameters, surface radiation, surface albedo, etc.) sharing common algorithms and processing chains."

The mentioned references above will be added to the manuscript.

37. L619: did not see Canty et al in reference list

Author reply: Indeed, it is missing in the reference list. The following reference will be added to the list:

Canty, T., Mascioli, N. R., Smarte, M. D., & Salawitch, R. J. (2013). An empirical model of global climate–Part 1: A critical evaluation of volcanic cooling. Atmospheric Chemistry and Physics, 13(8), 3997-4031.

38. Figure 11: Why show MAB instead of actual values of OLR? It would be useful to consider showing OLR in the same way as you did with fluxes of RSF in Figure 10.

Author reply: The conclusions of global mean OLR validation are shortly described in the text (L625-627), just like also has been done for the RSF MAB (L635-637). Figures 10 and 11 should be understood as non-exhaustive (illustrative) examples of the TOA flux validation. As mentioned in L607-608, it is not the intention to include the complete validation for the TOA fluxes in this article because it would go beyond its scope and there are of course limitations on article length and figure count (which is the same approach as for the other products). We simply wanted to show what kind of validation methods were used, i.e. bias and temporal evolution of bias (for stability) and Mean Absolute Bias (for regional uncertainty). There are a number of other validation aspects that we could show as well (e.g. daily mean analysis, monthly mean diurnal cycle, etc..) which are, however, not shown here for the same reasons. So instead, we refer to the TOA flux validation report (119 pages) which is publicly available on the DOI landing page of the product and contains the full validation on all aspects and with all details.

39. L707: 'It is worth…' **Author reply:** Yes, we will change.

40. L711: rogue letter 't' **Author reply:** Yes, we will remove it.

41. L733: If the effective radius is not shown in the paper, at least point to this result in the validation report or elsewhere. This is interesting but the microphysics haven't been shown in the paper.

Author reply: As mentioned before, the validation report (CM SAF, 2023) contains extensive comparisons of time series of cloud products with other datasets, including CLARA-A2. Specifically, Figure 5-36 in

the validation report shows that the cloud droplet effective radius time series is much more stable than in CLARA-A2. We have added “(see Figure 5-36 in the CLARA-A3 Cloud Products validation report, available through the link given in Sect. 5).” at the end of the paragraph.