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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Validation of cloud property retrievals with simulated satellite radiances: a case study for SEVIRI" *by* L. Bugliaro et al.

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We thank Phil Watts for his constructive criticism that has been considered by the authors to produce an improved version of the manuscript. Main changes in this new manuscript version are listed here:

- a more exhaustive discussion of the method's limitations has been added
- cloud particle effective radius has been evaluated more thoroughly for the APICS retrieval
- cloud water path has been extracted from cloud optical thickness and cloud effec-

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tive radius for APICS and it has been evaluated together with the corresponding CMSAF variables

- histograms of cloud top temperatures are discussed in addition to the plots already contained in the original manuscript version
- CMSAF data was processed again because of a small bug that affected mainly cloud optical thickness. Cloud effective radius is not a standard output variable for CMSAF and is not considered any longer.

More details can be found below, where we review and answer all *reviewer comments (italic)* regarding our manuscript.

p21933 Abstract l. 24*: » ..algorithms are not always able to..*

Done.

p21934 Introduction*: Include reference to A-Train possibilities*

Done.

p21934 Introduction*: Include discussion on limitations of method*

A discussion of the method has been included in the Conclusions that has been partly rewritten. We felt that the reader would not be able to understand a detailed potential–limitation discussion at the beginning of the paper. However, a reference to this discussion in the conclusions has been added to the introduction.

The new conclusions read like this:

Based on three-dimensional cloud distributions from the COSMO-EU model and a downscaling procedure, a cloud dataset has been produced with a resolution of 2.33 km appropriate for the simulation of SEVIRI radiometer observations aboard the geostationary european MET-8 satellite (MSG-1). These clouds were input to detailed bias-free one-dimensional radiative transfer calculations to produce a realistic synthetic

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MET-8/SEVIRI satellite scene. In this exercise, the channels were assumed to be perfectly calibrated and instrumental noise was not considered.

The outcome of this study is a unique data set for the validation of retrieval algorithms of atmospheric, cloud, and surface properties from Meteosat Second Generation. Using the known cloud properties as a reference (i.e. as reality), we could quantitatively validate the outcome of two cloud retrieval algorithms in a closed-loop test where both input and output data sets are known.

The APICS and CMSAF cloud retrieval algorithms applied here for illustration purposes both proved to be able to satisfactorily reproduce the cloud distribution and its properties although some of them could be better retrieved than other. As far as cloud detection is concerned, APICS' largest inaccuracy consisted in a misclassified (i.e. inexistent) cirrus cloud field while the CMSAF algorithm had difficulties when dealing with cloud edges.

Cloud top temperatures could also be retrieved in a correct way throughout but a large variability was shown. For instance, APICS overestimated some cirrus cloud edges while it underestimated some other cirrus field. CMSAF instead underestimated the same cirrus cloud edges and also some water clouds.

For cloud optical thickness one has to differentiate between water and ice clouds. For water clouds, where the underlying optical properties were parameterised with Mie theory, a good agreement between reality and retrieval was observed, although CMSAF's scattering was slightly larger than APICS'. For ice clouds, where a-priori assumptions about shape and composition are required, the agreement between reality and model was slightly worse for CMSAF. APICS, which used the same ice optical properties parameterisation "as the real clouds", had a strong advantage and reproduced ice optical thicknesses fairly well but with a tendency to underestimation. CMSAF used a different parameterisation for ice crystal optical properties and nevertheless it could derive ice cloud optical thickness in a good way but with some scattering. As expected, pixels

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containing both water and ice clouds caused the largest inaccuracies and the largest scattering of results for both retrievals.

Cloud particle effective radius is difficult to evaluate since it changes with height inside real clouds while retrieval algorithms obtain a single value representative of some distance from cloud top. Thus, we used a weighting of the vertical profiles of effective radii to first extract one quantity to be used in the comparison with the APICS cloud scheme. It shows that the distribution of effective droplet radii larger than 5 µm could be reproduced correctly only. Occurrences of ice cloud and mixed-phase cloud effective particle radii were also derived accurately.

The cloud water path APICS retrieval proved to be quite reliable, especially for water and ice clouds. Although CMSAF derived quite accurate cloud optical thicknesses, cloud water paths were less reliable probably because of the accuracy of the effective radius retrieval and because of the larger scattering observed in CMSAF optical thickness with respect to reality.

The proposed validation technique is thus a powerful tool for detailed investigations of the performance of satellite retrievals because objective information about clouds is available. Since it is based on accurate radiative transfer calculations its basis is sound. However, the underlying cloud model plays an important role: although large scale cloud structures are realistic and consistent with the ambient conditions thanks to the COSMO-EU weather model, the small scale cloud variability is underestimated as the horizontal resolution is limited to 2.33 km. Furthermore, ice cloud properties, in particular shape and size distribution, are probably the most arbitrary factor of the entire simulation since ice crystal habit is unknown. In this study we selected hexagonal columns in all ice cloud boxes. Of course, retrievals that are consistent with this choice have a clear advantage in retrieving ice crystal effective radius. The determination of ice cloud optical thickness, however, is only slightly affected by this choice. In contrast, the representation of water cloud optical and microphysical properties is not arbitrary and is based on the exact Mie theory for spherical water droplets. The optical properties are then determined by the effective droplet radius while the details of the droplet size distribution function inside each box are of minor importance. Another issue is surface albedo: we used data from spaceborne measurements, and if a retrieval assumes the same a-priori surface albedo it certainly has an advantage compared to a completely independent retrieval. This, however, is only true in the case of thin (mainly ice) clouds.

Finally we did not consider real-world issues like inaccurate calibration, noise, incorrect geolocation, channel cross-talk, imprecise interchannel registration, or sensor saturation. All these effects have been excluded from the simulation since we intended to study the performance of the retrievals and assess deficiencies inherent to them which are not produced by external, instrument-related factors. On the other side, every cloud retrieval algorithm has eventually to deal with real data and is designed to cope with all these aspects. This means that the performance of the investigated retrievals when applied to real satellite measurements may slightly differ from the one that is obtained in this study. Instrument-related effects could be quantified in a separate study. It has to be noted that – since retrieval algorithms are often tuned by the actual satellite observations including for instance their calibration biases – their performance when applied to real data could be better than when applied to the bias-free simulations produced in this study.

All these things considered, the proposed validation method for space-borne retrievals is a powerful tool. Since all parameters used in the simulation are realistic and typical for the selected day and time, all retrievals should be able to produce meaningful results. Of course, “free” parameters like ice crystal shape will lead to some uncertainty in the retrieval output and schemes that are fully consistent with the simulation apparatus will have an advantage.

In summary, we have shown the potential of this method for the evaluation of space-borne algorithms and recommend its usage to the scientific retrieval community as one possible effective way to test and tune algorithms. Conceivable applications of this

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approach are manifold: a) the quantitative evaluation of further satellite algorithms as shown here; b) investigations about the impact of different NWP models (for the extraction of the ancillary data needed by the retrieval schemes) on the retrieved quantities, in particular cloud top temperatures; c) studies about the uncertainty of calibration accuracy on the retrieved (cloud) properties; d) implications of point spread functions for space-borne retrievals; e) effect of solar geometry on retrievals; f) impact of ice cloud particle shape on retrieved cloud optical properties. In future, we will also include the effect of the one-dimensional radiative transport approximation usually made in the retrievals. Furthermore, by simulating the same scene from the point of view of a polar orbiting and a geostationary satellite, synergistic effects could be examined in a detailed quantitative way.

p21934 Introduction l. 25*: remove and the accuracy..not known. (redundant part of sentence).*

Yes, somehow it is redundant, but we think that this repetition at the beginning of the manuscript is useful for the reader to understand the target and the spririt of this paper.

p21935 Introduction l. 9+*: There appears to be no mention of instrument noise added to the simulated radiances? There is a good case that realistic noise should be added if the aim is a realistic simulation of retrieval accuracy and sensitivity.*

Please refer to the new introduction where noise and other aspects are discussed.

p21936 2 l.6 *become»became*

Done.

p21936 3.1.1 l.16 *» properties,*

Done.

Fig 1. *Caption labelling wrong ((b) (c))? Why is the spectrum shifted to overall higher energies E(k) in the modified fields?*

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Labelling corrected. Figures corrected (not the spectrum was shifted, but the -5/3 line for orientation).

p21939 3.1.2 l.25 *add resolution of high resolution COSMO-DE for interest?*

Added.

p21939 3.1.2 l.26 *delete to that*

Done.

p21939 3.1.2 l.27 *..size would have had..*

Done.

p21939 3.1.2 *No reference to Fig 2. anywhere?*

Inserted reference into last paragraph of the section.

p21940 3.1.3 l.18 *equation broken*

Corrected.

p21941 3.2 l.3 *»(forward) (or delete)*

Deleted.

p21941 3.2 l.4 *since>for*

Done.

p21941 3.2 l.5 *bit of a personalised and non-standard reference!*

You are right. We reduced the general libRadtran description and mentioned only relevant aspects.

p21941 3.2 l.17 *must not » can not*

Done.

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p21941 3.2 l.17 *Sentence meaning is not clear although can be guessed at. Presumably: ice crystals and not spherical in shape and since no comprehensive theory, as Mie for spheres, can be employed with crystals, the conversion... ?*

We modified the sentence according to your suggestion.

p21941 3.2 l.24 *Parameterisation referes to scattering model? Some hints as to what it is would be nice.*

Done.

p21941 3.2 l.28 *»deserve*

Done.

p21944 4 l.5 *This is linked to the attribution of model snow to ice water perhaps?*

Yes, we think that too much ice is classified as snow and too few as cloud.

p21945 5.1.2 l.15 *How is an opaque cloud identified and how could the opaque cloud method possibly fail if it is simply an assignment of the 10.8 TB to the temperature profile?*

Rather than identifying an opaque cloud we identify a thin cirrus cloud by considering the results of the thin cirrus tests (EBBT10.8-EBBT12.0 for instance) contained in our cirrus detection algorithm MeCiDA (Krebs et al., 2007). In this case, the CO_2 slicing method is applied. A posteriori we check whether the resulting effective emissivity (cloud cover times cloud emmissivity) is small enough. If yes, the CO_2 result is retained, if not the result of the EBBT10.8 matching technique is used. The EBBT10.8 matching technique can "fail" in two ways: 1) the assumed temperature vertical profile is different from the real vertical profile encountered in nature; 2) the correction due to water vapour absorption above the cloud is inaccurate.

p21945 5.1.2 l.20 *Then they » These are*

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Done.

p21945 5.1.3 l.25 *observed » assumed and delete ,i.e. .. detected*

Done.

p21946 5.1.4 l.3 *delete respectively ?*

Yes.

p21946 5.1.4 l.5 *Does the Nakajima King method not work on two solar channels also? If not, perhaps for clarity list the three classical channels .*

The application of the **?** method illustrated in Nakajima and Nakajima (1995) uses the 3.7 μm channel of the AVHRR instrument. Since both solar and thermal radiation is sensed in this spectral interval, the AVHRR window channel centred at 11 μm is used to separate the two contributions. The third channel is of course AVHRR channel 1 centred around 0.6 μm.

p21946 5.1.4 l.9 *»reflectivities calculated by libRadtran are tabulated ...*

Done.

p21946 5.1.4 *Would be clear here to state that the ice treatment here is entirely consistant with the simulations.*

Done.

p21947 5.2.1 l.11 *Too vague to understand what is meant. Also maybe use hand istead of side .*

The sentence has been rephrased:

The second step consists of two tasks: on one hand, a consistency check is performed where pixels having a class type different from their neighbours are reclassified. On the other hand, an opacity and a complete overcast cloud flag is extracted for all cloud contaminated pixels.

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p21948 5.2.3 l.28 *Optical depth 8 seems rather high to be giving up on the retrieved value of Reff? Wiould it also not depend on the viewing angle as oblique views would retain information for thinner (nadir defined) clouds.*

This value is justified by the fact that absorption at 1.6 μm is low. As a consequence, a distinction among different radii is difficult for optically thin clouds. It does not depend on viewing angle conditions.

p21950 6 *Section introduction is rather repetitive of the paper opening. Maybe it is OK to repeat.*

This section introduction has been skipped but the introduction section at the beginning of the paper has become more exhaustive (see above).

p21950 6 l.24 *Would rather emphasise that retrieval intercomparisons highlight (and are intended to highlight) potential algorithmic defects rather than clues to real properties.*

Done.

p21951 6 l.3 *Stress again that it is a validation of the schemes on simulated data, not real.*

Done.

p21952 6.1 l.7 *imediately noticed » seen*

Done.

p21952 6.1 l.9 *prove their » show*

Done.

p21952 6.1 l.9 *anyway » however/nevertheless? (dennoch?) The meaning of the sentence is anyhow a little unclear.*

The sentence has been rephrased:

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In fact, both cloud detection schemes show their capability to reproduce the input cloud distribution. Nevertheless, a pure comparison of the retrievals' output, without knowledge about the real cloud distribution in the observed domain, could lead to erroneous conclusions. For instance, one can see in the South-Western part of the picture that neither scheme is able to detect the edges of the cloud field (the coincident red colour in the cloud mask difference plots). On the contrary, some pixels are retrieved as overcast by both retrievals while in reality they are not (the turquoise colour).

p21952 6.1 1.12 *no retrieval » neither scheme*

Done.

p21953 6.1 l.17 *amounts to » equals or is*

Is.

p21954 6.2 l.1 *more cloud phases » mixed phase* ***p21954 6.2 l.2*** *every MET » a MET and label every » label the*

We made this sentence more explicit:

Since both water and ice clouds could be present inside a MET-8/SEVIRI pixel after re-projection, we decided to label the pixel according to the cloud top phase that appears most frequently in that pixel.

p21954 6.2 l.14 *Should it not be stated as a simple case of miss-classification? Is there an APICS classification of cirrus overlying water cloud?*

Our explanation was too unclear. Yes, it is a mis-classification, and no, we don't have any classification of cirrus overlying a water cloud. APICS simply detected a cirrus cloud. Since some pixels of this cirrus clouds in reality contain a water cloud, our evaluation comes up with the result that the pixels of the real water cloud are correctly classified as cloud but with a wrong thermodynamic phase. The sentence has be re-written:

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The large difference for water clouds (see Fig. 7a and c) is produced by the wrong classification of the cloud field in the North-Eastern corner. Here, APICS erroneously detects an extended cirrus (ice) cloud. Since a subset of these pixels contains a real water cloud, we obtain as a result a wrong cloud top phase for these pixels.

p21955 6.3 l.9 *These relative measures are misleading as dividing by the mean absolute temperature of the cloud is rather meaningless. One could divide the mean error by the range of temperatures in the dataset (80 K) to get 0.04; for the standard deviation presumably the relevant normalisation is by the standard deviation of the real clouds CTT i.e. something like 6.4K (Table 2). This would give a ratio rather larger than 1. This sounds rather alarming but is probably due to a few very large errors on thin clouds, i.e. outliers, dominating. I think I would recommend strongly putting in histograms as you have for the optical depth to clarify the error characteristics of the CTT.*

Again, our text was not clear enough. We computed mean relative differences and did not divide absolute cloud top temperature differences by the mean absolute temperature of the cloud. We only additionally indicated how large the mean cloud top temperature is, to give an idea about absolute numbers. Because of this mis-leading description, we decided to abandon mean differences and inserted histograms instead, following the reviewer's suggestion. Thus, a new picture with histograms of cloud top temperatures for reality, APICS and CMSAF has been inserted and described.

p21955 6.3 l.14 *further down » lower*

Done.

p21956 6.4 l.7-15 *poorly written; I think it should read (note extra ,s):*

In this last pixel class, called multi-phase, the following various cloud situations are collected: vertically extended clouds like cumulonimbus that are made up of liquid water droplets at their base and of ice crystals at their top, 10 pixels where a water cloud

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and a contiguous cirrus cloud coexist and clouds containing mixed phase layers with both liquid water droplets and ice particles or cirrus clouds on top of liquid water clouds. These kinds of clouds are outlined (distinguished?) since they do not correspond to any of the cloud classes considered (pure water or pure ice) in the retrievals and therefore larger inaccuracies are expected in cloud optical thickness and effective radius.

Adopted.

p21956 6.4 l.27 *show retrieval histograms » show histograms of retrieved optical thickess*

Done.

p21957 6.4 l.19 *Description of two peaks should occur early as the two peak feature is mentioned under APICS line 4.*

We do not really understand this issue. The two peaks are mentioned at the very beginning of the paragraph devoted to CMSAF starting at page 21957 line 16.

p21957 6.4 l.24 *data point » pixels*

Done.

p21957 6.4 l.25 *Fig.9d mislabelled; further mis-labelling later in section.*

Mis-labelling has been corrected here and in the following.

p21958 6.5 *I find the treatment, or rather lack of treatment, of the effective radius validation somewhat puzzling. Firstly the point that Reff is really a profile quantity (vertically variable) and the retrieval values are a single value should not preclude comparisons; the retrieved value is often assumed to be the cloud top value and this could be compared to the available reality. Some differences might be attributable to the penetration depth, but then the CTT retrieval is similarly affected as the authors explain (section 6.3 line 13+) and yet this comparison is happily made. The statement (l.11) that there is no real truth to compare with is rather a contradiction of the entire*

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premise of the paper, that simulated model based retrievals provide a truth!

*The discussion (**p21959 l.1>10**) on the sensitivity of the 1.6 channel is also not helpful. For example, the Nakajima King algorithm s entire purpose is to solve for the relative contributions of the optical depth and Reff on the two (0.6, 1.6) channel reflectances and extract the two parameter values. The authors further refute their own arguments on not validating Reff by subsequently validating a LWP that is based entirely on the Reff. In summary, the paper really should include a validation of Reff against the true values along with the other parameters.*

A more detailed investigation of cloud particle radius has been added to the text. However, we implemented a vertical weighting function for cloud particle effective radii inspired by Platnick (2000). The reason is that the effective radius determined by a satellite retrieval does not correspond to the effective radius at cloud top but to a weighted mean of the effective radii in the "upper cloud layers". However, our weighting function, as well as those proposed by Platnick (2000), only represent approximations to what happens in real world and are thus not the "truth".

Furthermore, there is a difference between effective radius, derived from two solar channels, and cloud top height or temperature, derived from thermal measurements. In the thermal spectral range the signal comes from the upper $\tau = 1$ part of the cloud and this represents the uncertainty of the CTT determination. In the solar spectral range, at 0.6 but also at 1.6 μm, radiation is able to penetrate the cloud more easily and we have a reflectivity contribution also from layers much below $\tau = 1$.

Nevertheless, this additional investigation is an interesting contribution to the paper. Section 6.5 has been thus rewritten and can be read in the new version of the manuscript.

***p21960 6.5 l.5** the cloud == the real/true cloud ? Values greater than 12 micron will be expected from pure statistical effects, I m not sure that one should comment specifically on this.*

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Done.

p21960 6.5 l.12 *remind»remember*

Done.

p21960 6.5 1.13 *all clouds » the entire cloud (?) This sentence hangs - it does not obviously follow from the previous nor have a suitable follow-up conclusion?*

This sentence is no longer present due to the rewriting of Section 6.5.

p21960 6.6 *The LWP from the CMSAF seems to be only 2/3 Reff.COT - how difficult woulf it be to generate this quantity for the APICS retrievals and complete the validation more satisfactorily?*

We added a new output variable for the APICS retrieval and evaluated both retrievals with respect to cloud water path. To this end, it was necessary to insert a new short subsection for the description of this APICS retrieval quantity and the validation section related to CWP had to be re-written. Now a new figure similar to the one for cloud optical thickness is present and discussed. It contains histograms and scatter plots for both APICS and CMSAF.

p21958 6.6 l.16 *It is quite surprising that the CMSAF IWP validates so well considering the very high optical depths retrieved (Fig 9h) although the hint of a low Reff (Fig 11b) might compensate. This is worth investigation or at least a comment? Especially as the LWP validates badly (about 2x) Fig 13, while the water optical depths are reasonable. (The conclusion section seems to imply everything is consistent though..)*

Please read the new Section 6.6.

p21961 7 l.26 *Add: albeit noise-free before satellite scene.*

Done.

p21963 7 l.2 *while the largest.. fit reality. What does this mean?*

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The paragraph about effective radii has been modified.

p21963 7 l.10 *can be explained.. Maybe I missed something then, comment above (**p21958 6.6 l.16**) may be invalid.*

A new evaluation of cloud water path has been performed and this paragraph has been accordingly modified.

p21963 7 l.12+ *Either better substituted for worse (typo, but then the sentence doesn t make alot of sense) or I cannot agree! I thought the algorithms were run without real world bias corrections applied (certainly CMSAF). The only things that could make real world retrievals better are happy accidental things like CMSAF ice parameterisation being nearer to real world. Nevertheless, APICS used exactly the right ice properties, how could real world conditions improve the results? Surely the most likely result of going away from internally consistant simulations to real world situations would be a loss of accuracy.*

Algorithms are run without re-calibration of the solar channels, but otherwise the algorithms are unchanged. In the case of retrievals of cloud optical thickness and effective radius the reviewer is right, simulated radiances should produce better results than measured radiances. For cloud detection the situation might be different. In this paper, both retrievals work with threshold tests that are often tuned using observations and have not been modified for the application to simulated values. If for some reason measured radiances behave differently than simulated radiances, this could have a (negative) effect on the retrieval performance. As an example we mention thin cirrus detection with the split window technique (EBBT10.8-EBBT12.0) or (EBBT10.8-EBBT08.7). If these channel differences had a small bias of ± 0.1 K (inside the thermal calibration requirements), this could have an impact on thin cirrus detection because simulated radiances are not biased.

p21963 7 *Another nice use would be the effect of solar geometry on retrievals from the same scene.*

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This has been added to the conclusions.

Krebs, W., Mannstein, H., Bugliaro, L., and Mayer, B.: Technical note: A new day- and night-time Meteosat Second Generation Cirrus Detection Algorithm MeCiDA, Atmos. Chem. Phys., 7, 6145–6159, doi:10.5194/acp-7-6145-2007, 2007.

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Platnick, S.: Vertical photon transport in cloud remote sensing problems, J. Geophys. Res., 105, 22919–22935, 2000.

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