Reply to Review #3 of the manuscript "Determination of circumsolar radiation from Meteosat Second Generation"

We thank the reviewer for the constructive comments on the paper. In the following reviewer comments are *italic.*

1. In page 5841, lines 22 and 25; please consider changing flat to smooth.

Indeed, "smooth" is more appropriate.

2. Line 6, page 5838: Please rephrase the sentence to be more accurate: cirrus clouds can have (and usually have) COT above 2.0, but the optimal range for CST applications is 0.1-2.0? or just state that the cirrus type relevant for this analysis are thin cirrus clouds (COT<3.0*).*

Cirrus clouds as classified by their morphology ("fibrous appearance and or silky sheen") seldom occur with optical thickness values larger than 3 (Lynch, 2002). However, in satellite remote sensing the distinction is usually made by discriminating ice, water and mixed clouds and not by morphology. Vertically thick clouds with ice tops (e.g. thunderstorm anvils) can certainly occur with $\tau > 100$. Our point is, that we rather focus on ice/cirrus clouds than on water clouds because the latter are usually opaque and do not permit operation of CSTs, although average retrieved optical thickness values for low clouds from satellite remote sensing can be lower than 3 due to partial cloud cover. To eliminate any ambiguity we have rephrased the passage.

Also, please note that many of the polar orbiting satellite platforms encounter difficulties in detecting thin cirrus of below COT of 2.0 (e.g. Zhang et al., 2009 for MODIS and POLDER; see reference below).

The mentioned paper by Zhang et al. (2009) deals with the dependence of the COT retrieval on the utilized ice optical properties. Zhang et al. (2009) found that on average the POLDER COT is some 30% lower than the MODIS COT. They relate this mainly to the asymmetry factor difference between the utilized optical property datasets (0.83 vs. 0.77 in the "0.86 μm band" and at $r_{\text{eff}} = 30\ \mu m$).

The optical property datasets used in our study (HEY and "Baum") exhibit an asymmetry factor between 0.76 and 0.82 at 860 nm and $r_{\text{eff}} = 30\ \mu m$ and should therefore cover a similar uncertainty range. An estimate of the total uncertainty of the method (including the one from APICS) can for example be derived from Fig. 9 in the discussion paper. The optical property datasets “Baum v2” and “Baum v3.5” – for which the obtained results were thoroughly validated – exhibit similar asymmetry factors of 0.80 and 0.81 at 860 nm. The differences in asymmetry factor between “Baum v2” and “Baum v3.5” in the visible and infrared were also shown by Baum et al. (2011). In general they increase with the effective radius.

3. Since the suggested method capitalizes heavily on the retrieved cirrus properties by the APICS algorithm, there is a need for some additional details about the validation and uncertainty of the APICS method itself. So far it seems that the Bugliaro et al. 2011 manuscript is only partially validating the algorithm, especially for thin cirrus clouds. Maybe some details from the present work by Bugliaro et al. [2013, in preparation] should be given.

Bugliaro et al. (2013) validated the APICS optical thickness especially for optically thin cirrus clouds utilizing measurements of an airborne high spectral resolution lidar. In the study of Bugliaro et al. (2013) the Baum and HEY optical properties were used as well. In general APICS seems to overestimate the optical thickness. In a linear regression slopes of 1.26 and 1.54, respectively, were found for “Baum v2” and “Baum v3.5”. The correlation coefficient is close to 0.8 for all optical property datasets. However, only approximately 150 data tuples could be used for the validation and all measurements were taken during the same flight. A scatter plot of this validation for “Baum v2” can also be found in (Bugliaro et al., 2012)

An according paragraph was added to the manuscript.

Also, how does the strong forward scattering due to ice particles is treated with the APICS algorithm?

The APICS lookup tables were generated using the CDISORT radiative transfer solver from libRadtran with 16 streams (Buras et al., 2011). While it can be problematic to calculate the sunshape for cirrus covered skies under certain geometries with CDISORT we do not expect trouble for calculations of radiance for directions out of the forward scattering cone.

And does the algorithm was tested at all with the new ice particle habit that are used in the present work? (the former validation work for APICS seem to be using the Yang ice particle dataset).

Yes. See above.

4. Page 5841: line 10-12: "This in turn influences the modeling of the circumsolar radiation as well as the cloud property retrieval, which in the end is also based on radiative transfer modeling". Isn't it the other way around? First the cirrus properties are determined by the APICS algorithm and then they are used as input to derive CSR? The end of the sentence:", which to modeling" seems un-necessary.

The sentence was not meant to express a sequence of the steps. Maybe we emphasized the obvious: That the cloud property retrieval is based on radiative transfer simulations. The sentence was rephrased and hopefully is better comprehensible now.

5. Page 5841: line 13: "we use a range of cloud bulk optical properties for modeling the circumsolar radiation". The ice particle optical properties used are from various datasets and do not represent a range that is usually attributed to continues variable. Please rephrase.

"a range of" was replaced by "several"

6. Page 5842, line 21-22: "it is especially important in the context of this study that optically thin cirrus clouds are retrieved as well as possible", sentence not clear; please correct English.

Paragraph rephrased: "APICS was originally developed as a multi-purpose cloud property retrieval. However for this study it is of special importance that optically thin cirrus clouds are retrieved with as little error as possible. To account for that we modified APICS as described in the following."

7. Page 5846: line 21: "was assess" change to "was assessed".

Typo corrected.

8. In Table 1, please state the wavelength at which the k values were calculated. Also, clearly state that in the text corresponding the table on page 5849, line 17.

Added following sentence to the text: "For technical reasons the wavelength range considered in the radiative transfer simulations of solar integrated values differs between the "Baum" (430 nm – 2000 nm) and the HEY (300 nm – 2600 nm) optical properties. Due to the strong absorption in the atmosphere in the UV-spectrum, the figures are even higher for the solar irradiance at ground level."

Added following sentence to the table caption: "The listed k values translate a slant path optical thickness at 550 nm into a broad band (430 nm – 2000 nm) apparent optical thickness. "

9. In figures 6 and 7, please color-code the different ice crystal habits for better clarity so that the effect of a specific ice particle habit can be better assessed. Also, please keep x-axis and y-axis similar for both figures, to make the comparison easier for the reader. If possible, please elaborate or suggest explanation for the differences between these figures. It seems that after constraining the total irradiance values (to be above 200) the differences when using different ice particle models are higher (but maybe because clear sky instances were included in figure 7 as well?).

Figure 6 was removed following advice from reviewer #2. However, as you noted the two different histograms had different data as basis. Different measurements contributed to the histograms an also the occurrence was computed relative to different bases.

The color coding for the remaining figure was improved.

10. In the discussion on Figure 9, the authors can relate their results to the particle mixture habit of the Baum 3.5 set, where bullet rosettes, solid columns and aggregates are the major components in the distribution.

We now consider the contribution of rosettes and droxtals to "Baum v3.5" in the discussion of the figure.

11. In section 3.2, some additional elucidation on the differences between the CSR values obtained by the two different datasets can add to the understanding of what are the main drivers that affect this difference; the fact that the two datasets represent smooth versus roughened particles? Or their different ice particle habit mixtures?

The reasons for differences in CSR results between "Baum v3.5" and "Baum v2.0" are difficult to unravel. Baum et al. (2011) stated that the roughening of the particles in general reduces the asymmetry factor. This should lead to a decrease in retrieved optical thickness values and at the same time to increased values of the retrieved effective radii. This was demonstrated by Baum et al. (2011) with an excerpt of a Nakajima-King look-up table for a certain illumination and observation geometry for MODIS.

Even if these generalized statements would always hold true – which for the APICS look-up tables is not the case – the implication for the retrieved CSR are not obvious: Depending on the field of view the CSR at a given optical thickness is maximized for a certain effective radius; the CSR does not increase or decrease monotonically over the whole r_{eff}-range (comp. Fig. 2 in the discussion paper). Therefore a general tendency to larger effective radii cannot be translated into a general tendency in CSR without further ado.

Not only has the change of optical properties influence on the satellite retrieval but also on the modelling of the circumsolar radiation itself. This manifests itself in the different k-tables. For effective radii larger than 10 µm "Baum 3.5" yields by tendency smaller CSR($\alpha = 2.5°$) at fixed r_{eff} and τ combinations than "Baum v2.0".

A further complication is that some of our results were obtained after an additional selection step ($I_{\mathrm{tot},\alpha=2.5°} > 200\,\mathrm{W/m^2}$). The applied criterion also depends once more on the retrieved optical thickness and the forward scattering.

In principle one can use circumsolar radiation measurements to test different modifications in the generation of optical property datasets. If changes from one optical property dataset to another are small one could possibly explain their effects on retrieved CSR. However the changes from "Baum v2.0" to "Baum v3.5" are manifold and include

- 3 new particle shapes in the mixture
- a modification of the size dependent particle mixture including the smooth transition of the shape composition with maximum diameter
- a new method to calculate the single scattering properties of the individual particles
- the roughening of the particle surfaces

With the multitude of changes to the "Baum" parameterization and the multitude of their effects we will probably not be able to provide new insights by entangling in speculations of the individual causalities. However Baum et al. (2011) capitalize on the roughening of the particle surfaces in their discussion of the new optical property dataset so that we assume that the roughening has the biggest impact on the optical properties of the implemented changes.

We improved the description of the differences between "Baum v2.0" and "Baum v3.5" in section "2.3 Optical properties of cirrus clouds".

What was the trend for the specific models? (e.g. does the solid columns were closer in result to the Baum 3.5 version than the bullet rosettes?).

Considering the mean circumsolar irradiance (displayed for "Baum v3.5" and "Baum v2.0" in Fig. 10 of the discussion paper) we found that the HEY aggregates deliver the results closest to "Baum v3.5" which may be due the fact that they are the only roughened particles of HEY. This may also indicate that the roughening accounts indeed for the largest share of the differences between "Baum v2.0" and "Baum v3.5". Solid-columns deliver the results closest to "Baum v2.0". Solid-columns also account for a large share of the medium sized particles in "Baum v2.0". We added an according paragraph to section "3.2 Circumsolar irradiance".

12. It would be insightful to see how the same distribution in Figure 12 looks likes with the manual cumuli filter (although number of data points will be reduced), which claimed to produce better agreement. Maybe the authors would consider this as Figure 12b? or at least comment on this in the text.

The histograms do not change much due to the manual filtering (besides overall amplitude, of course). Therefore they are not shown. The cumulus filter seems to improve especially the agreement of instantaneous values (see r_{rank}, r, MAD and RMSD) but not so much the statistical distribution. As can be followed in the newly added scatter plot, the filter removes an approximately equal amount of points above and below the 1:1 line and has little influence on the bias.

Bibliography

B. A. Baum, P. Yang, Andrew J. Heymsfield, Carl G. Schmitt, Yu Xie, Aaron Bansemer, Yong-Xiang Hu, and Zhibo Zhang. Improvements in shortwave bulk scattering and absorption models for the remote sensing of ice clouds. Journal of Applied Meteorology and Climatology, 50:1037–1056, 2011. doi: 10.1175/2010JAMC2608.1.

Luca Bugliaro, Hermann Mannstein, and Stephan Kox. Ice cloud properties from space. In Ulrich Schumann, editor, Atmospheric Physics, pages 417–432. Springer, 2012.

Luca Bugliaro, Andreas Ostler, Martin Wirth, Claudia Emde, and Ulrich Schumann. Validation of cirrus detection and cirrus optical thickness derived from msg/seviri with an airborne high spectral resolution lidar. to be submitted to ATMD, 2013.

R. Buras, T. Dowling, and C. Emde. New Secondary-Scattering Correction in DISORT with Increased Efficiency for Forward Scattering. J. Quant. Spectrosc. Radiat. Transfer, 112:2028–2034, 2011.

David K. Lynch, editor. Cirrus. Oxford University Press, Oxford, 2002. ISBN 0-19-513072-3. Includes bibliographical references and index.

Z. Zhang, P. Yang, G. Kattawar, J. Riedi, L. C. Labonnote, B. A. Baum, S. Platnick, and H.-L. Huang. Influence of ice particle model on satellite ice cloud retrieval: lessons learned from MODIS and POLDER cloud product comparison. Atmospheric Chemistry and Physics, 9(18):7115–7129, 2009. doi: 10.5194/acp-9-7115-2009. URL `http://www.atmos-chem-phys.net/9/7115/2009`.