**Reply to Anonymous Referee #2**

We also thank Anonymous Referee #2 very much for his/her constructive and critical comments, which hopefully helped to significantly improve the presentation of our paper. In the reply, we hope in particular to convince her/him of the long-term usefulness of this approach, as we do not believe that it will become entirely obsolete with the arrival of MTG.

We have adopted the following convention for our review: citations of the comments are given in italics, followed by our reply. Below each reply, a screen shot of the marked-up text modifications is given, generated with latexdiff. Deletions are shown in red/strike-through style, while insertions are underlined and shown in blue.

Please note that we have also considered several related comments by both reviewers on Sec.4.1 in combination, yielding a more substantial revision which can no longer can be directly associated with a single comment. An identical text listing the revisions including their rationale is included in the replies to both referees at the end.

Specific comments:

*C2.1: Page 2, line 18: Semantics here, but cloud products include more than just the optical properties listed.*
Yes, thanks for pointing this out. We do however wanted to refer here specifically to the properties obtained from Nakajima-King style retrievals. We have tried to clarify this aspect by the following text changes (page 2, line 17ff):

> Currently, the Moderate Resolution Imaging Spectroradiometer (MODIS) flown on the polar-orbiting satellites Terra and Aqua are one of the most widely used satellite instruments for studying the role of clouds in the climate [1]. ~~Based on the~~ A subset of the MODIS cloud products is based on solar reflectances and the bi-spectral method described by Nakajima and King (1990) ~~, cloud products~~ (e.g., estimates of cloud ~~phase,~~ optical depth, effective radius, and ~~cloud~~ water path) ~~are provided~~ at a spatial resolution of $\sim 1 \times 1\,\mathrm{km}^2$ ~~(Platnick et al., 2003).~~ (Platnick et al., 2003, 2017).

*C2.2.: Page 2, line 19: Please also add the more recent MODIS C6 paper.*
Indeed, we unfortunately missed this paper (see also C1.1). We have added this reference in the revised manuscript (this change is included in text changes shown for C2.1).

*C2.3: Page 2, line 20: In addition to biases and uncertainties, such effects can cause increased retrieval failures as well.*
Indeed, we missed to mention this important aspect. The text change to add this point is shown below. Note that this aspect is also now discussed in more detail in our revised version of Sec.4.1 as is described below.

> Despite their wide use, it is ~~well recognized~~ well-recognized that sub-pixel variability and 3D radiative effects can cause retrieval failures (Cho et al., 2015), or introduce substantial biases and uncertainties in these products, which depend on various factors such as solar and viewing geometry (see e.g., Cahalan et al., 1994; Marshak et al., 2006; Zhang et al., 2012; Horváth

*C2.4: Page 2, lines 22-24: This mention of cloud droplet number concentration is unexpected* *here and not tied in to the rest of the paper. In fact, it's only mentioned here and somewhat offhand in the conclusion. It's thus a little irrelevant to this work.*

Cloud droplet number (CDN) is retrieved in various studies based on satellite-retrieved COT and CER (e.g. Quaas et al., 2006). Based on the relation to COT/CER used in that study, it is easy to obtain estimated from the HRV-based COT/CER retrieval, and the accuracy has been discussed in WD20.

As cloud-aerosol interactions are one of the scientific interests of the first author, we have chosen keep the discussion on CDN, but have attempted to better clarify its connection to the present paper (page 2, lines 22ff).

> et al., 2014).While the ~~retrieval of~~ cloud droplet number concentration is of high scientific interest due to its relevance for elucidating the climate impact of aerosol-cloud interactions, ~~it is particularly challenging~~ its estimation from bi-spectral solar reflectances by means of cloud optical depth and effective radius (see e.g. Quaas et al., 2006) is particularly sensitive to such uncertainties (Grosvenor et al., 2018).

*C2.5: Page 4, line 31: I assume the correction factors derived against MODIS account for spectral response differences?*

Instead of an answer, a quote from Meirink et al., 2013 is given here: "Specific attention is paid to correcting for differences in spectral response between instruments." We have revised the manuscript to clarify this aspect:

> et al., 2004). Comparing collocated near-nadir reflectances from the SEVIRI and MODIS instruments and accounting for differences in spectral response between the instruments, Meirink et al. (2013) confirm the temporal stability of this calibration, but find relatively large systematic differences of up to 8 % ~~for collocated near-nadir reflectances from the SEVIRI and MODIS instruments~~. Channel-specific correction factors to account for these differences have been derived and are applied by the

*C2.6: Page 6, lines 21-22: Some more details on the phase algorithm would be nice here (e.g., how you get from the cloud types to thermodynamic phase), but it apparently doesn't play much role later in the paper so I'll leave it to the authors.*

We have added a more detailed description of the cloud phase algorithm to Sec.3.2, which is shown here:

> Retrievals are performed ~~for~~ assuming either a liquid or an ice cloud, based on a determination of the cloud thermodynamic phase by a modified version of the Pavolonis et al. (2005) algorithm. Several spectral tests are performed based on observed SEVIRI brightness temperatures at 6.2, 8.7, ~~which is described in more detail in~~ 10.8, 12.0 and 13.4 $\mu$m, as well as clear and cloudy sky IR brightness temperature simulations with RTTOV. The algorithm initially yields 5 cloud types, which are further condensed into a classification of liquid and ice phase. More details are given in Benas et al. (2017).

*C2.7: Page 6, lines 24-25: Since you're comparing retrievals to MODIS later on, the reader is left to assume that the single-scattering properties used here are consistent with the MODIS products. This of course is highly relevant to understanding the comparison. Please clarify.*

This is an interesting point, however we do think this point is out of scope/cannot be covered comprehensively within the current paper (there is a whole sub-group of the CREW/ICWG initiative dedicated to this aspect). For water clouds, the single-scattering properties of cloud droplets should be rather consistent, but the assumed width of the droplet size distribution does introduce some differences (see Benas et al. 2019). However, this is only expected to matter for geometries close to the cloud bow. Assumptions about ice cloud properties are however a much less consistent, which will impact a direct comparison, but we are not considering ice clouds here for this reason.We have decided to carry out

CPP retrievals based on MODIS data in WD20 to avoid this point. Within the scope of the present paper, we have decided to make the following two changes:

- Add information on the assumed droplet size distribution/width used by the CPP retrieval in Sec.3.2, see below.
- Mention the width used by MODIS C6 retrievals, and its potential impact on the comparison as part of the revisions to Sec.4.1 described separately.

> CPP employs precalculated lookup tables (LUTs) of TOA cloud-top reflectances in a Rayleigh atmosphere, which have been simulated by the Doubling-Adding KNMI (DAK) radiative transfer model (Stammes, 2001). ~~Details~~ For water clouds, the droplet size distribution is assumed to follow a two-parameter Gamma function with an effective variance of 0.15, while randomly oriented monodisperse imperfect hexagonal crystals are assumed for ice clouds. More details on the underlying single-scattering properties of ~~liquid and ice~~ the cloud particles can be found in Benas et al. (2017). The measured reflectances

*C2.8: Page 6, lines 28-29: Only radiometric uncertainty is accounted for? What about other error sources, such as ancillary data, forward models, etc.?*

Yes, this is a limitation of the current implementation of the error estimates by the CPP algorithm. While a more comprehensive uncertainty estimate is obviously desirable, this is beyond the scope of the current study and left for future work.

*C2.9: Page 7, line 32: I assume the second mention of CAMS in this sentence should actually refer to ECMWF, as in the previous sentence?*

No, CAMS is indeed correctly named as source. We are using the ECMWF forecast for atmospheric profiles&surface temperature, but ECMWF does not provide any aerosol forecasts. Hence, aerosol properties are obtained from the CAMS forecast for near-real time application. Re-reading this section, we have found the following text to be misleading / incorrect, likely prompting above comment, and have thus changed it as follows:

> transfer model. As input data streams, either the CAMS (Copernicus Atmospheric Monitoring Service) reanalysis (Inness et al., 2019) or the operational ECMWF forecast together with aerosol properties from the CAMS forecast can be used alternatively with 3-hourly resolution, the latter allowing for near-real time processing, while the former is only available with some time delay. In addition, the NWCSAF software uses the OSTIA dataset as input for sea surface temperature (Donlon et al., 2012).

*C2.10: Fig. 5 and text on page 10, lines 21-29: Some sort of RGB would be useful to help interpret these optical thickness images. Also, do you mean nearest-neighbor sampling rather than interpolation? If interpolation, why is that necessary if you're only showing side-by-side image comparisons and scene statistics (histograms in Fig. 6) rather than pixel-to-pixel comparisons? You might be smoothing the optical thickness field by interpolating, which may be a factor in the HRV retrievals seemingly being lower than MODIS (confirmed by the histograms in Fig. 6).*

We believe that your term "nearest-neighbor sampling" actually is identical in meaning to what we call "nearest-neighbor interpolation". After reviewing e.g. image processing literature, we do think that our terminology is consistent with other use, thus have decided to not change the text. Nevertheless, NN interpolation does not smooth the field and thus can be ruled out as reason for differences in these histograms. We have also decided to add an RGB to Fig.5, see our revisions to Sec.4.1.

*C2.11: Page 10, lines 31-32: This is hard to tell from the color scheme in the histogram plot in Fig. 6, but it looks like the issue is only with too few optically thick clouds rather than too few optically thin.*

We have changed the visualization of the histogram to use 3 separate panels, see revisions to Sec.4.1. Indeed, after re-viewing the text, we agree that the “too few optically thin clouds” was an erroneous interpretation, and is interpretation has been removed as part of our revisions to Sec.4.1.

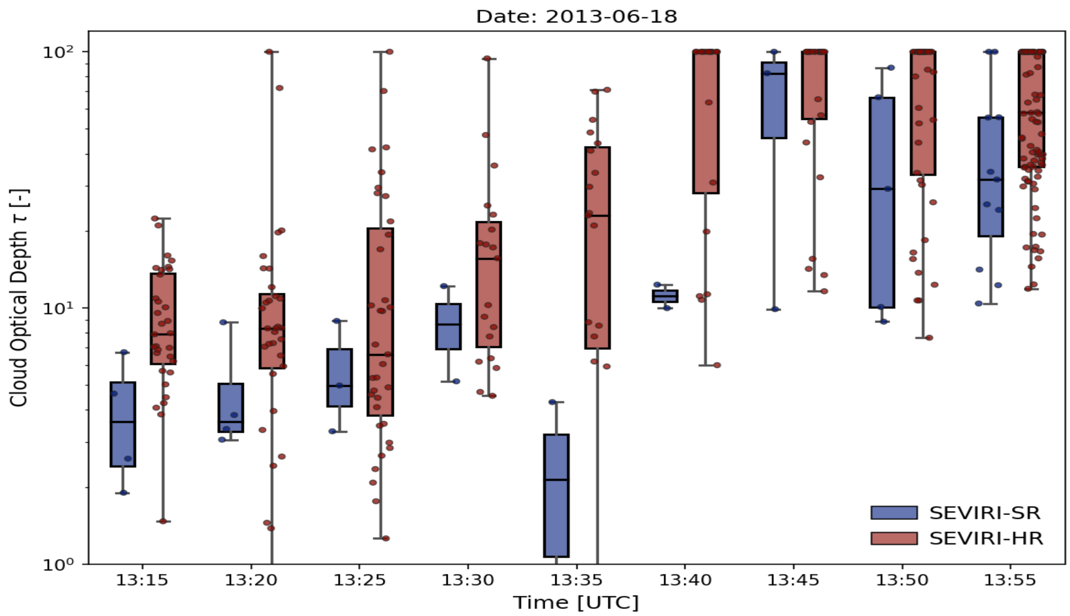
*C2.12: Page 11, lines 3-8: The pixel sizes between MODIS and SEVIRI likely are different in this scene, though maybe not as different as you might think depending on where in the MODIS swath this region is – MODIS pixels grow to about 2x5km at the edge of swath. Also, you mention possible differences in algorithms, sensor calibration, and view geometry. Can you define what algorithm differences might cause retrieval differences? Sensor calibration differences are possible, though you mention earlier that SEVIRI observations have had correction factors applied that were derived against MODIS. Also, the angular differences may indeed be playing a role given the angular dependence of cloud reflection – what part of the scattering angle space are MODIS and SEVIRI sampling in this scene?*
We did select this scene to be close to nadir-viewing (~ 3° in this case at center) to mitigate the mentioned effect. This translates to 1007m and 1006m pixel size in across/along-track direction. MODIS is viewing the scene at ~ 154° scattering angle (180° is backward scattering), SEVIRI around ~150°, far enough away from the cloud bow at 141°. We have now revised Sec.4.1 to give more information on these details, see description of the revisions.

*C2.13: Page 11, lines 8-10: Could these differences in coverage be linked to differences in cloud mask results, with MODIS finding less clouds? A cloud mask plot would be illuminating. If not the cloud mask, then retrieval failures in MODIS are likely playing a role. You can verify this by looking at the Retrieval Failure Metric in the MOD06 files, which would also give you an estimate of what look-up table grid point optical thickness is closest to the out-of-solution space observation.*
Actually, a common pixel mask based on the requirement of COT>0.1 has been used to rule out such an effect, but this was unfortunately not mentioned in the discussion paper. This omission has now been corrected. MODIS does indeed “see” less clouds (83% cloud coverage vs. ~ 98% for both standard-and HRV resolution retrievals), likely due to the effect of the oblique satellite viewing angle of SEVIRI in combination with the larger pixel size.
We have now revised Sec.4.1 to give more information on these details, see description of the revisions. In particular, we have imposed common selection criteria to avoid any influence of cloud mask/retrieval failures on these results. A corresponding description has been added to the revised Sub-Section 4.1, to make it clearer that these reasons can be ruled out.

*C2.14: Page 11, line 18: I guess it isn’t a surprise that effective radius retrievals do not improve, since, if I understand correctly, the only improvement would be due to the higher resolution VIS/NIR reflectance changes aliasing into the effective radius retrievals due to the non-orthogonal solution space.*
It is interesting to note that this comment is based on a rather different expectation than the comment C1.5 by referee #1. We have commented on this aspect in our revisions to Sec.4.1, which are shown separately.

*C2.15: Page 12, lines 28-29: Why do you need to interpolate the standard retrievals to the HRV grid for Fig. 8? This isn’t a pixel-to-pixel comparison, so why not leave the retrievals at their native resolution for the statistics?*
The challenge arises due to the small size of the convective cell. Our intention is to get a better/fairer comparison both visually and statistically, as simple interpolation approaches such as bilinear or bicubic interpolation are readily available. Leaving the retrievals at native resolution, there is a much smaller number of pixels due to the small size of the developing convective cell (just 2-3 pixels up to

13:45Z). Note that we have also used infrared brightness temperature field interpolated to the HRV grid to define the cloud objects, because at standard-resolution, large gradients in this field complicate the separation of cloud objects from cloud-free background, yieldingsignificantly worse separation for the HRV retrieval results. We attach here the same plot just using the native resolution retrievals, which we hope supports our choice visually (alternatively, if there are any convincing arguments otherwise which we have missed, this could be used as replacement).




*C2.16: Page 12, lines 33-34: While the cloud optical thickness signature does appear earlier in the HRV retrievals, it's not clear in this discussion whether or not optical thickness is actually used in CI detection schemes. So it's hard to tell how relevant this improvement is.*

While we are not aware how common the use of cloud properties is versus the use of radiances in operational satellite-based CI schemes, we do believe that the use of cloud properties has advantages for physical understanding, and has been discussed in the literature. To support this aspect, we have made the following revision to the manuscript:

channels, and are thus limited to the standard spatial resolution of SEVIRI (e.g. Mecikalski et al., 2010). Some previous studies already point out ~~some~~ benefits arising from the use of the HRV channel (e.g. Carbajal Henken et al., 2011; Mecikalski et al., 2013a; Merk and Zinner, 2013). ~~Its~~ While the first satellite-based CI detection schemes have been based on observed radiance fields (Mecikalski and Bedka, 2006), the use cloud properties instead of radiances seem promising, as it should remove co-variability with environmental influences and viewing geometry, and aid a more physical interpretation of cloud growth (e.g. Senf and Deneke, 2017). It has thus been considered in several more recent scientific studies (e.g. Mecikalski et al., 2011, 201 . The combination of cloud products and higher spatial resolution offered by the HRV channel could thus be one way to improve the lead time for the detection of convective initiation in current MSG-based CI detection schemes. In particular, developing

*C2.17: Page 16, lines 3-5; lines 26-27: I don't think you would need this type of sophisticated approach for the GOES-R series, MTG FCI, or MODIS and VIIRS, since the highest resolution VIS/NIR channels can be used directly to retrieve cloud optical thickness, a different approach I think than that taken here.*

There are two important parts of our algorithm for carrying out the HRV-resolution cloud property retrievals in the current MSG-based scheme:

- The first part is the use of a linear relation for linking HRV, 0.6 and 0.8um reflectance variations to overcome the challenge posed by the large spectral width of the HRV channel (and consistency with 0.6um-based retrievals), which is indeed MSG-specific and will become obsolete with MTG. This part was already covered in-depth in Deneke and Roebeling (2010), so this is not really the new aspect covered by our paper and WD20.
- The use of multi-resolution satellite images for Nakajima-King retrievals, specifically with a VIS channel at higher spatial resolution than the SWIR channel, including its use for cloud masking (here based on the approach described previously by Bley and Deneke, 2013). This part is also applicable to current-generation sensors (MODIS: 0.6um channel at 0.25km, 1.6um at 0.5km, and 2.2um at 1km), GOES-R ABI (0.6um channel at 0.5km, 1.6um at 1km, and 2.2um at 2km) and will be applicable to MTG (0.6 and 0.8um channels at 500m, 1.6um and 2.2um at 1.0km). (VIIRS is rather an exception, which offers all required channels for such retrievals at 375m resolution. We erroneously included it in the list and have removed it in our revision). Thus, Nakajima-King-style retrievals can be carried out with the same or similar constraints used for handling small-scale variability in the SWIR channel in the retrieval at the spatial resolution of the highest-resolution VIS channel, and this aspect has to our knowledge not been covered before in the scientific literature. And one central message of our studies (both WD20 and this paper) is that care must be taken to not degrade the accuracy of the CER retrievals (see also reply to referee #1, C1.6, as well as the results of WD20).

To clarify this aspect, we have made the following revisions to the conclusion:

> ~~Similar approaches could also be adopted~~ The method described here and in Werner and Deneke (2020) can also be adapted to other meteorological multi-resolution imagers such as the Advanced Baseline Imager aboard the current generation of geostationary GOES satellites, ~~or the~~ the Flexible Combined Imager on the upcoming Meteosat Third Generation, and the polar-orbiting ~~MODIS and VIIRS sensors, and~~ MODIS instruments. This would allow to increase the spatial resolution of the retrieved cloud and radiation products ~~up to that offered by the highest-spatial resolution channels. It has however~~to ~~be~~ 500 m for GOES-R and MTG, and to 250 m for MODIS. These instruments have in common that they feature a higher-spatial resolution VIS channel, which allows to constrain cloud optical depth (e.g. the 0.6 $\mu$m channel with 250 $m$ and 500 $m$ resolution for MODIS and GOES-R ABI, respectively), and lower-resolution SWIR channels (e.g. 1.6 or 2.2 $\mu$m) used as constraint for the cloud effective radius in bi-spectral retrievals. In fact, the constraint imposed due to the relatively broad spectral width of the HRV channel and formalized by Eq. 3 would no longer be required. Only the constraint on the small-scale variability in SWIR reflectance and expressed by Eq. 5 would be needed, thus allowing a simplified implementation. It should be noted, however, that based on the findings presented here and in Werner and Deneke (2020), a too simplistic constraint as e.g. realized by simple interpolation of the absorbing-channel reflectance will lead to a reduced accuracy for cloud effective radius, which might in fact be worse than that of a retrieval done at the lowest common spatial resolution. It also has to be cautioned that a higher spatial resolution does not necessarily imply a higher product accuracy. Specifically, the findings of Zinner and Mayer

*C2.18: Page 16, lines 27-30: This mention of climate applications makes the best case for the ongoing relevance of this sharpening approach, since I think it becomes obsolete with the new MTG FCI. The authors only showed operational applications that are undertaken in real time, rather than retrospective, so how useful this approach is in the future is unclear.*

See our response to C2.17, we do not think the approach described here will become obsolete. We are aware that the reference to potential climate applications is somewhat speculative, and that we do not provide any examples of climate-relevant applications. Nevertheless, we hope this statement might raise interest in using our method for climate applications, and might lead to future collaboration on such an application. Hence, we have decided to leave this statement here in unmodified form.

**Revision of Sec.4.1:** Based on comments C1.5 , C1.7, C1.8 by referee #1, as well as comments C2.3, C2.7, C2.10, C2.11 by referee #2, we have decided to substantially revise the presentation of Sec.4.1, with the following objectives:

- Add a description of the observing and sun geometries, including the true MODIS spatial resolution
- Discuss discrepancies in retrieval assumptions/conditions by MODIS/CPP, in particular including the width of the cloud drop size distribution and its relevance close to the cloud bow
- Mention the frequency of retrieval failures in both MODIS and CPP retrievals
- More detailed discussion of the accuracy of CER, which is known to be limited for such types of cloud fields, and point out the limitations of a comparison based on a single scene.
- Added an RGB image as 4$^{th}$ panel of the scene to Fig.5
- Revised Fig.6 to use separate panels/also show MODIS partially cloud retrievals
- Remove the erroneous interpretation of Fig.6 that SEVIRI retrieves too few optically thin clouds

The revised sub-section 4.1 is appended to this reply.

### 4.1 Shallow Convective Clouds

[Figure 5 about here.]

[Figure 6 about here.]

The main motivation for the development of the HRV-based cloud retrieval scheme has been the expectation that the increase in spatial resolution will lead to more accurate cloud retrievals, and will bring the instrumental capabilities of SEVIRI closer to those of MODIS. Improvements are expected to be significant in particular for shallow convective clouds due to their comparatively small size and their large spatio-temporal variability.

To verify this aspect, a shallow convective cloud field is considered here, and retrieval results are contrasted to those obtained from collocated MODIS observations. A scene viewed by the MODIS instrument flown aboard the Terra Earth observing satellite on 2 June 2013 at 10:50Z over North-Eastern France has been selected for this purpose. The choice of observations from Terra allows the consistent use of MODIS retrievals based on the 1.6 $\mu\mathrm{m}$ channel for comparison with SEVIRI, as this channel of the MODIS instrument is affected by defective detectors on Aqua. While the satellite zenith angle of SEVIRI is about 55.6°, the MODIS zenith angle is close to the nadir direction (2.7°), which implies that the true pixel size is also close to the nominal spatial resolution of MODIS ($1006 \times 1007\,\mathrm{m}^2$). The scattering angles have values of about 155° and 150° for MODIS and SEVIRI, respectively.

The MOD06 cloud properties from the collection 6.1 release are used here ~~, and retrieval results for fully overcast and partially cloudy pixels have been combined. It should be realized that in contrast to the results~~ for comparison (Platnick et al., 2017) . It has to be pointed out that this comparison differs from that presented in Werner and Deneke (2020), ~~products from two inependent~~ where MODIS reflectances have been re-projected to the SEVIRI standard- and HRV-resolution grids first, and then used as input to the CPP retrieval. In contrast, cloud products obtained from two independent retrievals and two different instruments are compared ~~, thus~~ here. Hence, besides differences caused by the spatial resolution, the comparison is also affected by temporal changes due to the mismatch in observation times about one minute, by the different observation geometries, and differences in the assumptions underlying both retrievals. Such assumptions include the width of the cloud droplet size distribution, which have values of 0.15 and 0.1 in the CPP and MODIS retrievals, respectively (Benas et al., 2019). A scene with scattering angles outside the cloud bow and cloud glory has been selected to minimize this sensitivity. The reflectances observed by SEVIRI will also include a significant contribution from cloud sides due to the large satellite viewing angle, while the nadir view of MODIS implies that reflected radiation mainly originates from the cloud tops. Retrieval results will also depend on the assumed values of surface reflectance. Thus, deviations are expected to be substantially larger than the ~~results presented in that study.~~ differences reported in Werner and Deneke (2020).

Fig. 5 shows the fields of $\tau$ obtained for the example scene provided by MODIS, and both the standard and improved HRV-based SEVIRI retrievals together with the day-natural color RGB rendering of the MODIS reflectances (Lensky and Rosenfeld, 2008) . SEVIRI data has been re-projected to the MODIS grid using nearest-neighbour interpolation, and a translation has been applied to account for parallax shift and cloud motion in combination with ~~a~~ the mismatch in observation time~~of about one minute~~. This translation has been determined by maximizing the cross-correlation of both $\tau$-fields, and results in a shift of the

SEVIRI data by about 2.6 km and 0.4 km in North and East directions, respectively. While 83.8 % of the pixels are classified as probably or likely cloudy by the MODIS cloud mask, $\tau$-retrievals are reported for 72.4 % of the pixels (43.6 and 28.8 % in the Cloud_Optical_Thickness_16 and Cloud_Optical_Thickness_16_PCL datasets, respectively), with a remaining 11.3 % of pixels without a valid retrievals. In case of the SEVIRI-based CPP retrievals, the quality flags showed that for 44.8 % and 33.3 % of the pixels for standard- and high-resolution retrievals, convergence could only be achieved for the 0.6 $\mu$m reflectance, and the observed 1.6 $\mu$m reflectance exceeded the range of values of the LUT, indicating in particular that the use of the HRV channel improves the fraction of pixels with high-quality retrievals.

It is clearly ~~evident~~ visible that the increased spatial resolution obtained by using the HRV channel in the retrieval helps to better resolve the small-scale structure of this cloud field. This visual impression is confirmed quantitatively by a significantly higher correlation coefficient of about 0.78 found for the HRV-based $\tau$~~field~~ -field and the corresponding MODIS C6.1 product, compared to a value of 0.47 obtained for the standard-resolution retrieval results.

Both fully overcast and partially cloudy retrieval results have been included in the calculation. Fig. 6 shows the corresponding histograms of the derived $\tau$ using logarithmic bin spacing for this scene. The standard-resolution SEVIRI retrieval exhibits the narrowest distribution of values, with too few optically thin and thick clouds compared to the MODIS product. While the HRV-based SEVIRI retrieval still yields fewer optically thick clouds than MODIS, it reports a similar amount of optically thin clouds, and is able to better reproduce the dynamic range of the MODIS product than the standard-resolution retrieval scheme. For the standard retrieval, the maximum value of retrieved $\tau$ is only 16.5, while values of 40.3 and 61.8 are observed for the SEVIRI HRV-based and MODIS products, respectively. A likely explanation for the remaining underestimation of cloud optical depth is the oblique viewing angle of Meteosat over Europe, which increases the pixel size in North-South direction by a factor of about ~~2, in combination with the lower~~ 2. Combined with the optical resolution of SEVIRI, ~~and limits the maximum $\tau$ for the HRV-based retrieval below that of MODIS. The HRV-based retrieval also reports a significantly larger number of optically thin clouds compared to MODIS~~which is lower than the sample resolution by a factor of 1.6, this results in a 5-fold larger pixel area despite a nominally equal nadir sampling resolution. While it is beyond the scope of ~~this~~ the present article to fully resolve and explain the remaining discrepancies, they are likely due to the combined effects of differences in retrieval algorithms, sensor calibration, pixel resolution and/or viewing geometry. ~~In particular, the MODIS processing scheme has a rather strict quality control, which might be responsible for the fact that no values are being reported for these rather optically thin clouds, despite our choice to also include MODIS results for partially cloudy pixels.~~

It should be noted that for solar energy applications, the correct representation of $\tau$-values at and below a value of 5 is highly relevant, as such values will result in non-zero direct irradiance. While rejecting such retrieval results in the cloud retrieval scheme due to their large uncertainties will most likely improve the $\tau$-retrieval accuracy itself, it will cause a subsequent overestimate of SSI if these pixels are assumed to be cloud-free. Both global and direct irradiance components will be affected, but errors will be most pronounced for the direct irradiance and the direct-diffuse ratio, parameters which are critical for the calculation of the tilted irradiance, e.g., on the plane of a photovoltaic module or the focal plane of a concentrating solar power plant.

~~For the effective radius~~Broken and inhomogeneous cloud fields such as the considered scene are known to be particularly problematic for the accuracy of the retrieved effective radius (Marshak et al., 2006; Wolters et al., 2010), and the following results should be interpreted with caution. For a meaningful comparison, only pixels with $\tau > 8$ in all compared datasets and high-quality retrieval results have been considered (full convergence of CPP retrievals, no partially cloudy retrievals from MODIS). These criteria are fulfilled for only 21.5 % of the pixels. Mean values of 8.2, ~~no significant improvement is found resulting from the use of the HRV channel in the retrieval , and correlations between SEVIRI and MODISresults are relatively low for this scene. Restricting the comparison to pixelswith $\tau$ exceeding a limit of 6 for both MODIS and SEVIRI to ensure reliable effective radius retrievals,~~ 7.7 and 7.3 $\mu$m are found for MODIS and the standard- and high-resolution effective radii retrievals, respectively. The correlations between MODIS- and SEVIRI-based effective radii are much lower than those for optical depth, and only a slight improvement is found from the use of the HRV channel for the retrieval, with Pearson correlation coefficients of 0.43 and ~~0.42 are found~~ 0.39 for the HRV and standard-resolution effective radius results, respectively. The reader is reminded ~~here~~ that a similar magnitude of the correlation is expected, as the retrieval constraint for the 1.6 $\mu$m channel ensures that the effective radius is close to that of the standard-resolution retrieval~~in the iterative algorithm. In consequence,~~. This is confirmed by a comparatively high correlation coefficient of ~~0.85 is found between the two SEVIRI retrievals~~ 0.88 between the SEVIRI results at the different spatial resolutions. A modification of the retrieval to only use ~~the~~ a smoothly interpolated value of the 1.6 $\mu$m reflectance instead results in a ~~sharp reduction of~~ slightly negative value of -0.04 for the correlation of the high-resolution ~~retrieval results with the~~ effective radius retrieval with MODIS $r_e$~~to a negative value of -0.05~~. This finding emphasizes that despite the seemingly low values of correlation for $r_e$ ~~found~~ reported above, the choice of the retrieval constraint is important to ensure that the accuracy of the standard-resolution $r_e$ is not degraded by use of the HRV channel.

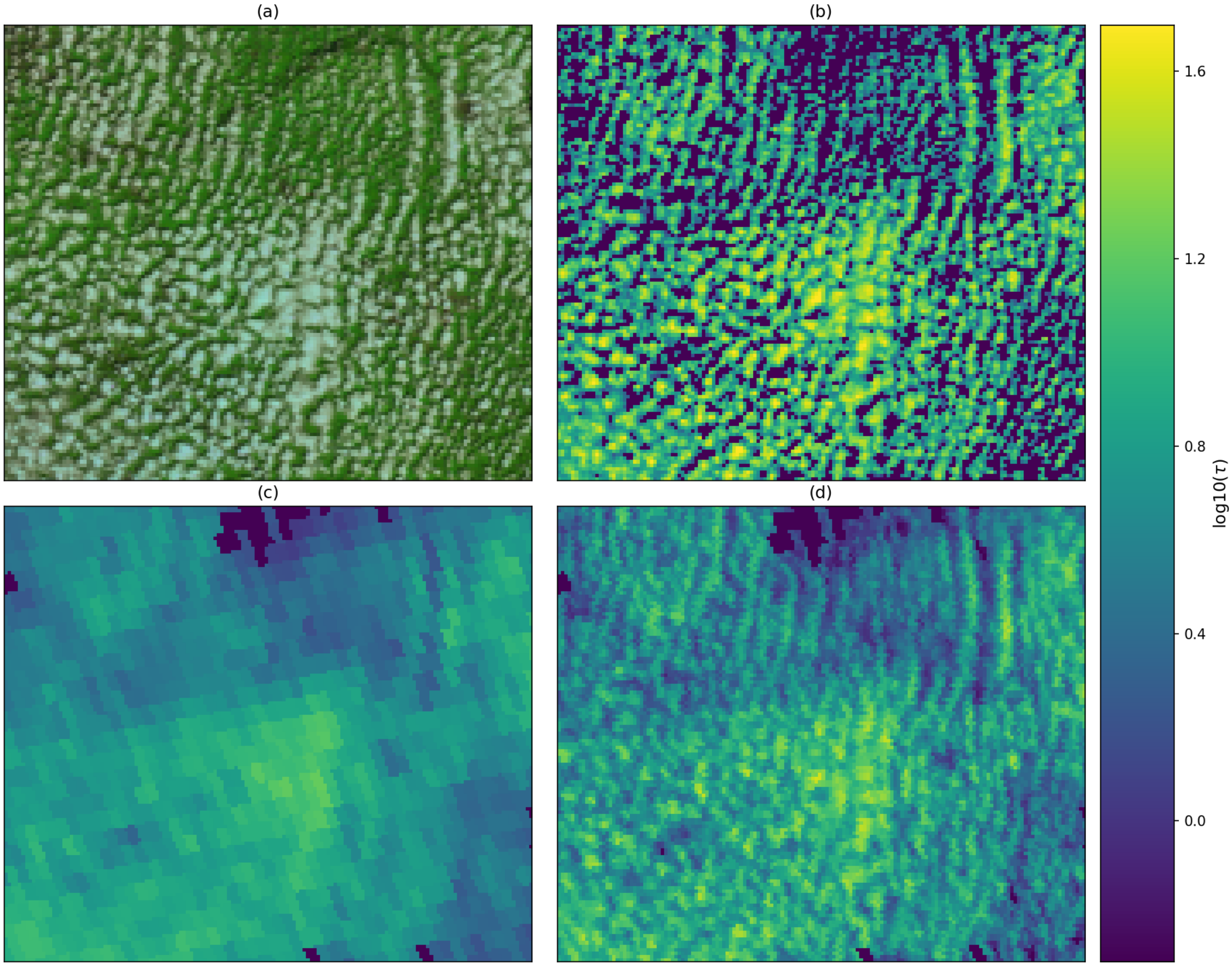



**Figure 5.** ~~Cloud optical depth ($\tau$) of a shallow~~ Shallow convective cloud field observed over North-Eastern France at $3^{\circ}25'$ E and $48^{\circ}7'$ N ~~,~~ on 2 June 2013 at 10:50Z. ~~A logarithmic~~ MODIS reflectances are displayed as day-natural color ~~scale is used. Values~~ RGB composite in (a), and retrieved values of cloud optical depth ($\tau$) are shown for the operational Terra MODIS C6.1 retrieval (~~a~~b), the improved Meteosat SEVIRI retrieval (~~b~~c), and the standard-resolution Meteosat SEVIRI retrieval (~~c~~d) using a logarithmic color scale.

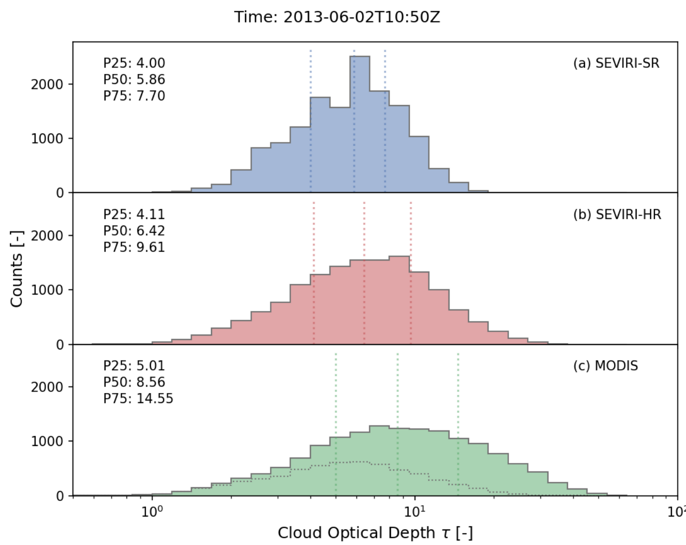



**Figure 6.** ~~Histogram~~ Histograms of cloud optical depth ($\tau$) using logarithmic bin spacing, for the cloud field displayed in Fig. 5. Values are shown for the ~~Terra MODIS C6.1 retrievals~~ standard-resolution SEVIRI retrieval (~~MODIS~~a, ~~green color~~blue), the improved HRV-resolution Meteosat SEVIRI retrieval (~~SEVIRI-HR~~b, red~~color~~), and for the ~~standard-resolution SEVIRI retrieval~~ Terra MODIS C6.1 retrievals (~~SEVIRI-SR~~c, ~~blue color~~red). The contribution of partially cloudy pixels to the MODIS histogram is indicated by a dotted line. Also, for each histogram, the values of the 25th, 50th and 75th percentile are shown as dotted line listed numerically.