Review Wiltink et al. (2026)

General remarks:

This work assesses the uncertainty in satellite-retrieved global horizontal irradiance (GHI) introduced by the independent pixel approximation (IPA) and plane-parallel approximation (PPA) and the corresponding neglect of 3D radiative effects in current retrievals. In particular, the influence of the spatial resolution on the retrieved GHI is analyzed. To this end, a LES cloud field of shallow cumulus clouds is applied. GHI is retrieved from simulated synthetic TOA reflectance and compared to directly simulated GHI for different scenarios (two solar zenith angles, two surface albedos, two cloud fractions) for varying spatial resolutions. The TOA reflectances as well as the simulated reference GHI are computed using both 1D and 3D radiative transfer solvers. Differences between the retrieved and reference GHIs are explained by the relative importance of irradiance enhancements, shading, and clear-cloudy mixing. In addition, the contributions of the IPA and PPA assumptions to the total bias/RMSE is determined and discussed. The findings highlight the importance to account for 3D radiative effects with increasing spatial resolutions of satellite measurements.

The work addresses an important topic, which is very relevant with higher resolution satellite measurements becoming available, and extends previous work on the influence of 3D radiative effects on cloud and radiation retrievals at different spatial resolutions. However, some additional explanations and further discussions as well as language sharpening/improving would be helpful and should be considered before publication. Please see the general and specific comments below.

In general, it would be very helpful to introduce figures properly and define all variables in the text before referencing them. In particular, please add an explanation on how the effective clear-sky, irradiance enhancement, and cloud shadow fractions in Fig. 9 and similar figures were determined and better explain the content of the figures before discussing and analyzing it. This makes it much easier for the reader to follow. More detailed comments are provided below.

It is stated that cloudy and clear-sky GHI in the retrieval is computed based on a cloud mask using the liquid water path. However, there is a second cloud mask applying the optical thickness. Why are two different cloud masks used? It is not clear to me, why two different cloud masks are necessary and which cloud mask is exactly used for what. Different cloud masks between the different simulated GHIs and retrievals can affect the results and analyses.

I am missing a discussion about other potential error sources, such as e.g. aerosols, the influence of the cloud morphology, and potential limitations of the presented study. In the study, shallow cumulus clouds were considered and differences between two fields of shallow cumulus clouds with different cloud fractions were demonstrated. I would be careful with too general conclusions due to the limited number of configurations with two solar zenith angles, two cloud fractions, and two surface albedos for a nadir viewing geometry and an additional case for a large viewing zenith angle of 70 degree. The importance of 3D radiative effects is influenced by the complex interaction of the solar and viewing geometry, surface albedo, and cloud fraction with mutual influence. In addition, it strongly depends on the cloud type and the related 3D cloud geometry and microphysics.

Specific comments:

l. 38-39: Stricly speaking, the PPA assumes horizontal homogeneity, vertical variations are accounted for.

l. 41 and 44: These are very general statements. Maybe add references such as Zinner and Mayer (2006).

l. 79: Passive imagers can provide information about 3D cloud geometry. In particular, they can resolve horizontal variations and 3D cloud geometry can, for example, also be derived using stereographic methods.

l. 95: Could you add at least one or two sentences about the LES simulations giving just a quick summary about the model and data used for the simulations?

l. 112-118: You state that you excluded gases besides ozone in your radiative transfer simulations, but the satellite retrieval includes the effects of water vapor and CO_2. Why did you not include these gases in the simulations as well to avoid inconsistencies? Later in l. 159f you write that the retrieval does not use other gases. Please clarify.

l. 135: How large is the error introduced by using monochromatic simulations instead of directly simulating the satellite channels by performing simulations for a narrow wavelength band and applying the spectral response function of the channels? I guess the retrieval assumes input reflectances for the real satellite channels in contrast to the simulated monochromatic reflectances.

l. 160 + 165: You first mention that you flag pixels as cloudy based on the optical thickness. Besides, you have an additional cloud mask using the liquid water path. Why do you use two different cloud masks and when exactly is which cloud mask applied? Differences between the cloud masks and therefore the classification into cloudy and clear sky affect the GHI estimates and therefore the results and analyses.

l. 245: Why is the uncertainty of the retrieved optical thickness larger for optically thicker clouds and the optical thickness increasingly overestimated? For optically thick clouds, the reflectance saturates at some point, which would, however, lead to an underestimation of the optical thickness. Please add a short explanation and a reference.

l. 250: How did you decide to use a decay scale of 10? The vertical weighting function generally depends on the vertical cloud structure and solar geometry. Did you compute the weighting functions following Platnick (2000)?

l. 251: Related to the previous point: deviations of the assumed vertical weighting function from the actual one are an additional explanation for the observed differences between the retrieved and the model values.

l. 306-308: The probability density functions or the average GHIs become much more similar between the different cases at coarser resolutions, but to be honest the spatial distribution to me looks very different. They all appear kind of noisy but the structures and the absolute values look very different.

Fig. 7 and similar figures: This and similar figures are stated to show the probability density function (PDF), but values up to 400 are observed? Are these then absolute frequency values? Please check and clarify.

Fig. 8: Could you add the standard deviations to this and similar plots to also visualize the variability?

l. 361 / Fig. 9: Please shortly introduce the content of Fig. 9 in the text before using it for the discussion of the results. In particular, please explain how the effective clear-sky fraction, irradiance enhancement fraction and cloud shadow fraction were determined and are defined. These quantities have not been introduced.

l. 370: Where does the clear-sky reflectance threshold of 0.22 come from?

l. 377-385: The solar zenith angle also affects the magnitude of the radiation enhancement not only the number of pixels that are affected. The enhancements are related to radiation escaping through and being reflected on the cloud sides whose orientation relative to the sun matters.

l. 390: Why are irradiance enhancements absent for a surface albedo of 0? Radiation can still be reflected on the cloud sides or escape through them.

Fig. 10/14a: Could you add a horizontal line at 0 to make it easier to distinguish between negative and positive biases?

Fig. 10 /l. 400-408: In the introduction you stated that the validity of the IPA decreases with increasing spatial resolution. So, I would expect that the error due to the IPA also increases with increasing spatial resolution, but the biases related to the IPA in Fig. 10 appear constant and independent of the resolution.

l. 411: The error due to the PPA increases towards coarser resolution, in agreement with Zinner and Mayer (2006). Add this reference there.

l. 423: The impact of 3D radiative effects might be smaller due to the partial compensation, but it is still not irrelevant. Even for the domain averages large biases remain.

l. 430: Is there a simple explanation, why the residual RMSE is less sensitive to the spatial resolution than the other RMSE components?

l. 470: What do the given percentages refer to? How were they computed?

Fig. 13a: Was the behavior of the PDFs for decreasing resolutions similar to scene 1 in Fig. 7?

Sect. 5.1 / Fig. 15: This section was very hard to follow, partly because Fig. 15 and the related methods were not introduced properly. I strongly recommend to rewrite and restructure this section. You could first start with the basic idea: apply the retrieval and average results and compare this to the averaged true values, due to non-linearities you expect differences, and properly explain Fig. 15. To me, it was very unclear at the beginning, what you are explaining and why. The figure caption of Fig. 15 contains new methods and many details which should better be included in the text. Why are geometries close to default used and not the exact default geometries? Please also explain the differences between the different columns and what the dashed lines denote in the figure caption.

l. 593/594: This is a very general statement. Your study is based on a limited number of configurations for a specific cloud type, namely shallow cumulus clouds. For the analyzed small number of cases, the conclusion is justified, but you should be careful with generalizations. For stratiform clouds, current GHI retrievals might still perform sufficiently well at higher spatial resolutions. In addition, the influence of solar and viewing geometry, surface albedo, cloud fraction, cloud geometry etc. is very complex and cannot easily be separated. You provided a valuable first investigation of different influencing factors, but for a complete picture much more cloud cases and different solar and viewing geometries etc. would have to be analyzed. In addition, aerosol and other factors, which were not accounted for in your study, could also influence the retrieved GHI. Please add a more detailed discussion about this and the limitations of your work.

Technical corrections:

l. 96: add "horizontal" to resolution

l. 97: "with a 25 m resolution" -> with a resolution of 25m

l. 127: "create synthetic satellite retrievals" -> create synthetic data for satellite retrievals

l. 152: "which would additional uncertainties" -> which would introduce additional uncertainties

l. 172: "which is the mid-latitude summer value" -> which is a typical value for the mid-latitudes in summer?

l. 202: assuming independent and homogeneous pixels? 1D means both applying the IPA and PPA.

l. 207: In abstract and conclusion the coarsest resolution is 12.4 km, whereas here it is 12.2 km.

l. 238: eliminate the last "resolution".

l. 258: "in 4" -> "in Fig. 4".

l. 285: the top 2 rows of Fig 6 show 1D retrieval and 1D reference but you refer to 3D reference and 1D (reference?) GHI fields.

l. 355: geometry -> solar geometry

l. 386: cross and triangular markers?

l. 502: add: ...between the horizontal, yellow dashed lines in the middle and right columns.

Fig. 17b: These values are again normalized by clear-sky GHI?

l. 540: "retrieval 17b" -> "retrieval in Fig. 17b"

l. 589: Start a new sentence: ...total bias. For...

In general, I can recommend using Grammarly or similar tools for improving punctuation etc.