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Interactive comment on "Deriving Photosynthetically Active Radiation at ground level in cloud-free conditions from Copernicus Atmospheric Monitoring Service (CAMS) products" *by* William Wandji Nyamsi et al.

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First of all, we thank Referee #1 for these constructive remarks on this topic. The authors believe that they have understood the concerns of the referee. All remarks have been taken into account for revising a part of the text following recommendations of the referee.

General comments: The manuscript "Deriving Photosynthetically Active Radiation at ground level in cloud-free conditions from Copernicus Atmospheric Monitoring Service

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Discussion paper

(CAMS) products" describes a method of calculating the photosynthetically active radiation (PAR) during cloud-free conditions from widely available CAMS data using the libRadtran radiative transfer numerical model in combination with a spectral resampling procedure. Since PAR is an important variable to assess the carbon and water cycle of the terrestrial biosphere and is used in most process models and statistical models, this research paper and the research question described within is of high interest for the research community. However, overall the manuscript suffers from a lack of novelty regarding the presented method. The actual new portion of the work is not much. While most of the method such as the spectral resampling has been developed and published already before, and the authors also refer to that appropriately. Yet, the new part is so little that it is in fact summarized in only 4 lines by the authors, in particular lines190 to 193 in the manuscript. The rest is simple interpolation and regression analysis as well as an application of the libRadtran library functions in order to success fully relate PAR to other measurements which is not new at all even though, a specific dataset was used for the predictor variables. The new contribution seems rather minor for a publication in Biogeoscience and for that matter for a research paper. I suggest enhancing your study to non-cloudy conditions as alluded to at the end of the manuscript (lines 281 to 289), for instance. Since the amount of PAR at the surface is clearly related to the total irradiation, cloudiness and atmospheric variables such as aerosol optical depth and other meteorological conditions this seems feasible and would more of an advance in this field of research over previous studies. I therefore suggest a major review/overhaul of the manuscript

Answer: Thank you for this comment. We feel that apparently we were not able to emphasize clearly enough those parts of the method that have been already published from those that are discussed and published first time. We appreciate this comment and we have tried to clarify these issues in the revised manuscript. Moreover, we want to stress that the core objective was to validate this approach (at PAR range) against ground-based measurements. This is done first time in this manuscript and is entirely new contribution.

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Discussion paper

The method we described is a combination of three parts: (1) use of CAMS products to describe the atmospheric state, (2) irradiances of correlated–k approach over only eleven bands covering the PAR wavelengths by the means of libRadtran and (3) the resampling technique for computing PAR estimates. Only the third part has been previously published by ourselves. The goal of this current manuscript is to focus on the entire approach (e.g. also including the other two parts) and to present the ground-based validation.

Since estimation of PAR under cloud-free conditions at any time and place is an important first step in calculating PAR in all-sky conditions, in this paper, we concentrated first on these conditions.

Based on the above referee comment, we have re-written several parts of the text accordingly. For instance, a part of introduction is re-written as follows: "This resampling technique has not been validated in operational conditions, i.e. using available inputs to describe the atmosphere in cloud-free conditions and the properties of the ground, and tested against ground-based measurements. This paper is making this step forward and aims at describing and evaluating the entire method when tested against measured PAR in cloud-free conditions."

It is also important to emphasize that the second part of the method can be obtained by the means of other radiative transfer models using correlated–k approach such as Doubling Adding KNMI (DAK), Rapid Radiative (RAPRAD) transfer, SPECMAGIC. We have also stressed the universality of entire method when correlated–k estimates are available.

Specific comments:

Comment 1. In line 44 to 54 the authors give only few references. Due to the importance of PAR and the sparsity of its measurements similar research has been going on for many years. Please include more studies that also aim to model PAR by using atmospheric measurements as predictor variables. Also, the performance of the approaches presented in those different studies should be compared to your findings to put your results into context of this ongoing research in his field.

Answer: Thank you for this remark. We fully agree with you. We have re-written the relevant part of the paragraph and have added a paragraph in the text as follows:

"Therefore, several authors have developed methods for estimating PAR in cloud-free conditions by using different sources of atmospheric measurements as predictor variables, and the effect of clouds accounted for separately by an appropriate attenuation or modification factor (Oumbe et al., 2014). Su et al. (2007) has proposed such method with Clouds and the Earth's Radiant Energy System (CERES) products providing atmospheric conditions. Their method mostly shows a positive relative bias reaching up to 7% when validated with PAR measurements at seven Surface Radiation Budget Network (SURFRAD) sites in cloud-free conditions. Following the same idea, Bosch et al. (2008) has developed a parametrization for PAR estimates in cloud-free conditions. The relative bias was less than 1% when validated with three of the seven SURFRAD sites. It is important to mention that the authors used mainly ground-based atmospheric conditions. More recently, Sun et al. (2017) has proposed a method using solar radiation in the UV–visible spectral band. They found mostly a negative bias for all the seven SURFRAD sites of less than 4% when using ground-based atmospheric measurements. These last two validations do not show the performance of the models in actual operational conditions."

Comment 2. In the paragraph starting in line 44 the authors also discuss the quality of the PAR measurements and also address the error of the PAR devices. This is a bit too short given the complexity of this issue. The error of the ground measurements, when used a reference, are of outstanding importance for the model presented. There are studies already published that address the errors of PAR measurements in practice at the ground level. Schmidt et al. (2012), for instance, give an average error of 3% for PAR measurements among a large network that is, however, affected by a large standard deviation of errors observed between PAR sensors at different sites and a reference system. A PAR sensor's response to the natural spectrum needs to be addressed briefly. Although the authors describe the quality control of the measurements used, the fact that measurements might always shows some deviance from the real value should be addressed on a certain level in a manuscript that focusses on PAR. The response of the very common PAR sensor (LICOR quantum sensor) that is also used in this study is not perfect for the natural spectrum but adheres to an optimized spectral curve. Please address this issue if the performance of your approach is measured by the correlation with those ground-measurements.

Answer: Thank you for this remark. The comment raises good points involving the uncertainty of PAR measurements. Different plants absorb at varying spectral ranges, so a PAR radiometer that would apply to all plants would be impossible to design. But, the absorption spectra for all plants are most active in the range 400 to 700 nm. That led to a proposal that PAR be given a physical definition of photon flux over 400 to 700 nm (McCree (1972). Based on this definition, an ideal instrument response would be a step function from 400 to 700 nm. The spectral response of PAR sensor used in the SURFRAD network best approximates that ideal response among commonly available PAR sensors. That is, according to the manufacturer, deviations from the ideal response, or actinity errors, based on sunlight as a source for the PAR sensors used in the SURFRAD network, are 0.3% ($\pm$0.7) for most PAR sensor models used, and 0.5% ($\pm$0.3) for the latest model that began to be used in 2017. Actinity errors for other PAR sensors are on the order of 2 to 3%, with one showing an error of nearly 12%. From 1997 to 2012, Schmidt et al. (2012) compared field measurements of PAR at 84 AmeriFlux sites with a traveling, freshly calibrated standard instrument. Through 2006, AmeriFlux used the same PAR instrument as SURFRAD. For those years, the mean relative error for the field PAR instruments was -3%, but with very large standard deviation of nearly 14%. This large variability was attributed to, among other things, "infrequent calibrations, [and] inconsistent and sometimes high rates of degradation." They report that calibration drift for PAR sensors is on the order of "<2% per year although higher values (>10% per year) have been reported." The general practice of SURFRAD operations is to replace PAR sensors each year with freshly calibrated instruments, and within the year calibration drift is monitored on a daily basis by examining the ratio of PAR to total SW broadband. If a systematic drift is detected, that PAR instrument is replaced and data during the period of drift is corrected. These two QA practices of SURFRAD eliminate the large sources of error reported by Schmidt et al. (2012) for AmeriFlux measurements.

Comment 3. The sentence in lines 75 to 78 is not quite clear, neither is the approach described. Although a reference is given, please rephrase and add a brief description about the method. How many narrow bands are used in your case? The authors mention “one or more”. I would expect the model performs better the more band bins are correlated and used. How strong do the correlations have to be? The summary is too simple to understand the process. Later in section 3. 2 the method is explained in more detail, yet the statement “A total of 19 NBi is sufficient” comes out of nowhere. Please give information as to why 19 can be considered sufficient. Please also merge these two sections and explain this part of the method only once but thoroughly. Details about the origin of the function parameters (slope and intercept) are not given although it seems to be the central point of the method. How many comparisons at which stations were used to get these parameters of the affine functions? A statement like “The choice of these NBi has been made on an empirical basis.” As give in lines 188 and 189 is not a sufficient description of the process. Please elaborate.

Answer: Thank you for this remark. We fully agree with you. Firstly, we have re-written this relevant part of the text and have added a brief description about the method as follows:

“The eleven KBs are KB #6 [363, 408] nm up to KB #16 [684, 704] nm. They do not cover exactly the PAR range which is limited to [400, 700] nm. In addition, the bandwidth in several KB is larger than 30 nm and may be considered large for estimating PAR in an accurate manner. A spectral resampling technique has been developed by Wandji Nyamsi et al. (2015) to overcome this difficulty. In brief, the proposed technique gives the irradiance for every 1 nm width within each KB over the PAR range from the irradiance of 30 nm width of each KB in any atmospheric state under cloud–free conditions. The technique is explained in more detail in the section 3.2”.

Then, in section 3.2, we have rewritten this relevant part of the text including all the suggestions. We would like to emphasize that no measurements have been used to develop the affine functions. They have built based on a pure modelling approach by the means of radiative transfer model.

Comment 4. Figure 3 gives the differences between the measured (at the sites) and CAMS data. While the upper panel gives a ratio, the lower panel gives the absolute difference divided by 100. It is not clear why the difference given in the original data units should be divided by 100 (unless one wants to make them appear much small than they are). Also, please provide unit labels on the vertical axes showing the differences of the various variables in the lower panel.

Answer: Thank you for this remark. We have provided figures as requested.

Technical corrections:

The sentence in line 75 starts with a dot. Please correct (delete).

Answer: Thank you. Done as requested.

In line 163 there is a dot missing at the end of the sentence. “. . .any location and any time.”

Answer: Thank you. Done as requested.

Line167: Please spell out AFGL dataset. The acronym appears for the ïňĄrst time here and not any reader might be familiar with that dataset and its origin.

Answer: Thank you. Done as requested.

Line 137 and 138: The sentence reads“:::cloud-free instants instances.” Please correct.

Answer: Thank you. Done as requested.

Reference used in comments:

Schmidt A., C. Hanson, W. S. Chan, B. E. Law (2012): Empirical assessment of uncertainties of meteorological parameters and turbulent fluxes in the AmeriFlux network. Journal of Geophysical Research 117, G04014, doi:10.1029/2012JG002100.

McCree, K. J., (1972): The action spectrum, absorptance and quantum yield of photosynthesis in crop plants. Agricultural and Forest Meteorology, 9, 191-216.

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