Reply to Reviewer #2

We thank the reviewer for their careful reading of the manuscript and for their constructive feedback. Their comments have been very helpful in improving the clarity and scientific quality of our manuscript. Below, we address each comment point by point. Reviewer comments are shown in bold while our responses are given in normal font.

General comments:

This work seems very valuable. It should improve the ongoing validation of a valuable services/dataset (CAMS McClear clear sky irradiance) by making it more robust, and could be more broadly applicable to researchers in solar energy and meteorology that need to automatically classify measured data as "clear-sky". It's great to see an open-source repository that accompanies the paper.

We sincerely thank the reviewer for this very positive and encouraging feedback. We are pleased that the value and potential applications of our work, as well as the open-source implementation, are appreciated.

Specific comments:

The authors' point that existing clear-sky detection techniques commonly rely on a clear-sky irradiance model, and that this can be problematic if the clear-sky detection processes is intended to be part of validating a clear-sky model (the validation would have a circular dependency).

The emphasis on minimizing false positives is good to see for this type of application.

We thank the reviewer for highlighting these important aspects of our approach, particularly the need to avoid circular dependencies in the validation of clear-sky models and the importance of minimizing false positives in this type of application. Both have been important motivations in the development of MuscaDet.

The comparison with the incumbent method, Lefèvre et al. (2013) (which is also the most recent method reviewed in Bright 2020 that does not require a clear-sky model), is good to see. Not only is there a notable increase in the number of points that can be compared/validated (about 3X at the Palaiseau site, Fig. 13), but there is significantly more validation at lower solar elevation angles (higher zenith) (Fig. 10). This means that resulting validations will be more robust, even at low solar elevation angles, where clear-sky modeling can be more difficult. When it comes to situations where the Lefèvre method flags intervals as clear but the novel method does not, the examples in Fig. 12 appear to be intervals that should not have been flagged to begin with, further making the new method appear superior.

The multi-timescale approach seems to be a good and relatively novel approach.

We sincerely thank the reviewer for this very positive and encouraging assessment. We are particularly pleased that the improvements in the number of detected clear-sky instants, the better coverage at low solar elevations, and the multi-timescale approach are recognized as important contributions of this work.

It would have been helpful to see more analysis or discussion on the impacts of the limitation near sunrise and sunset (requiring 30% minutes in delta_t before a given instant to be "suitable," meaning that the method does not allow periods within approximately 20-30 minutes of sunrise and sunset to be classified as clear).

Similarly, a sensitivity analysis or some other discussion on the selection of the delta_t values could be interesting.

Thank you for these very relevant comments. We agree that the limitations associated with the detection of cloud-free instants near sunrise and sunset, as well as the sensitivity to the choice of temporal scales, deserve further discussion. We have therefore added the following paragraph in the revised manuscript (lines 587–593):

"*A possible limitation of the implementation presented here is the lack of detections near sunrise and sunset, due to the size of the temporal windows and the minimum amount of valid data required for a detection. This is nevertheless consistent with our objective of selecting confidently cloud-free instants, as irradiance measurements at high solar zenith angles are subject to greater uncertainties, owing both to the increased optical air mass and to the higher likelihood of shadows being cast onto the instrument by nearby obstacles. It is worth noting, however, that MuscaDet has been designed to allow users to adjust the temporal scales used by the detector. This makes it possible to increase the number of detected cloud-free instants, at the expense of lower confidence in the cloud-free classification."*

Minor suggestions:

clarifying at the beginning that *E* is sometimes referred to as "global horizontal irradiance (GHI)"

Thanks for this suggestion. The following sentence has been added at lines 29-31:

"Depending on the scientific field and the authors, this quantity is referred to by various names, including surface solar irradiance, downwelling solar irradiance, downwelling surface shortwave irradiance, surface incoming shortwave radiation, and global horizontal irradiance."

mentioning the selected multiscale time windows (e.g., 15-121 minutes) earlier in the paper would help give the reader context.

Thanks for this suggestion. A reference to the selected time windows has been made in the introduction (l. 69-70):

"Besides the use of this parameterization, the innovation lies in the use of a multiscale approach, with time scales ranging from 15 to 121 min, and the accounting for uncertainties arising from both sensor measurements and atmospheric variability."

Plots visualizing some of the equations/concepts in the methodology could be helpful, for example, plotting the tolerance term against zenith angle, and possibly something related to eqs. 2, 3, or 4. This is not necessary, however.

Thank you for this helpful suggestion. We agree that visual illustrations can improve the understanding of the MuscaDet methodology. We have therefore added two appendices: Appendix B illustrates the principle underlying the comparison between E_{meas} and E_{MLB} for cloud-free detection, while Appendix C provides an illustration of the effect of the correlation threshold in situations marked by a low variance of E.

Appendix B: Illustration of the principle of cloud-free detection based on the comparison of E_{meas} and E_{MLB}

The identification of cloud-free conditions relies on comparison of E_{meas}, with the E_{MLB} as illustrated in Fig. B1, which shows E_{MLB}, computed using a 60-min moving window, for four distinct time windows labelled (a) to (d). The red and grey lines represent E_{MLB} and E_{meas}, respectively, using data from the Carpentras station. In case (a), E_{MLB} closely matches E_{meas}, consistent with cloud-free conditions. This agreement is further supported by the scatter plot in the lower panel of Fig. B1-a, where the data points lie close to the identity line, yielding a Pearson correlation coefficient of 0.9992. In case (b), although E_{MLB} appears to follow E_{meas} closely in the upper panel, the corresponding scatter plot (lower panel of Fig. B1-b) reveals a weaker correlation, with a Pearson coefficient of 0.8970. This reduction may be related to changes in irradiance preceding cloud arrival, which could affect the agreement between the two time-series. Cases (c) and (d) illustrate situations with broken cloud cover. The corresponding Pearson correlation coefficients (0.3295 and 0.2266, respectively) indicate poor agreement between E_{meas} and E_{MLB}, consistent with the presence of clouds.

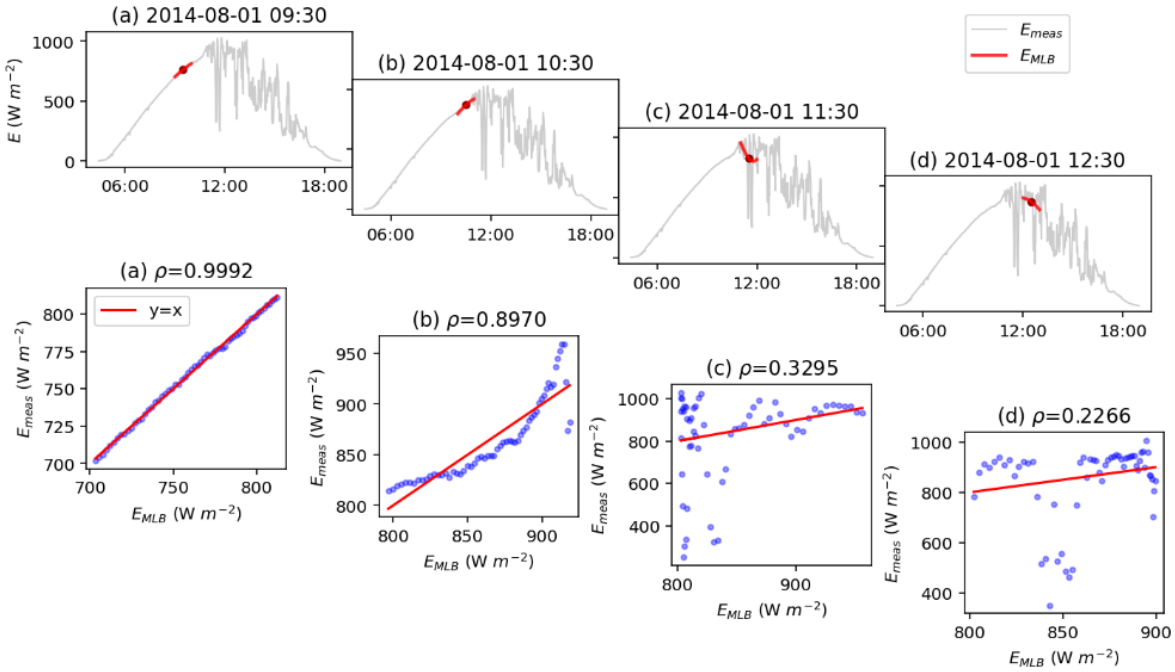


Figure B1: ***E_{MLB}, calculated using a 60-min moving window at four distinct time instants (red lines), overlaid on time series*** *of* ***E_{meas} (grey lines) in the upper panels. The corresponding lower panels show scatter plots of E_{meas}versus $E_{MLB}$for each of the four 60-min*** *intervals.*

Appendix C: Illustration of the effect of the tolerance parameter on the cloud-free detection criterion

A key feature of MuscaDet is the introduction of a tolerance parameter in the detection criterion. Although this tolerance is relevant under all conditions, its effect becomes particularly apparent when the dependence of E on θ_s is weak, i.e., around solar noon or at high latitudes during summer. Indeed, as discussed in Section 4.3, the variance of E becomes very small under these conditions, resulting in lower correlation coefficients between E_{meas} and E_{MLB}.

This effect is illustrated in Fig. C1. The upper panel shows the time series of E_{meas} recorded at the Carpentras station over five consecutive days (black lines), while the lower panel shows the corresponding Pearson correlation coefficients between E_{meas} and E_{MLB}, calculated over a 60-min moving window (blue line). The correlation decreases not only under cloudy conditions (on the first, fourth, and fifth days) but also around solar noon on the cloud-free days (the second and third days). This behaviour is consistent with the reduced variance of E_{MLB} discussed in Section 4.3.

Under these circumstances, the detection threshold must decrease around solar noon on cloud-free days while remaining high under cloudy conditions. This is the purpose of the adjusted correlation threshold defined in Eq. (A-9b) and shown by the red line in Fig. C1. As expected, the threshold decreases around solar noon on cloud-free days while remaining sufficiently high during the days characterised by cloud cover.

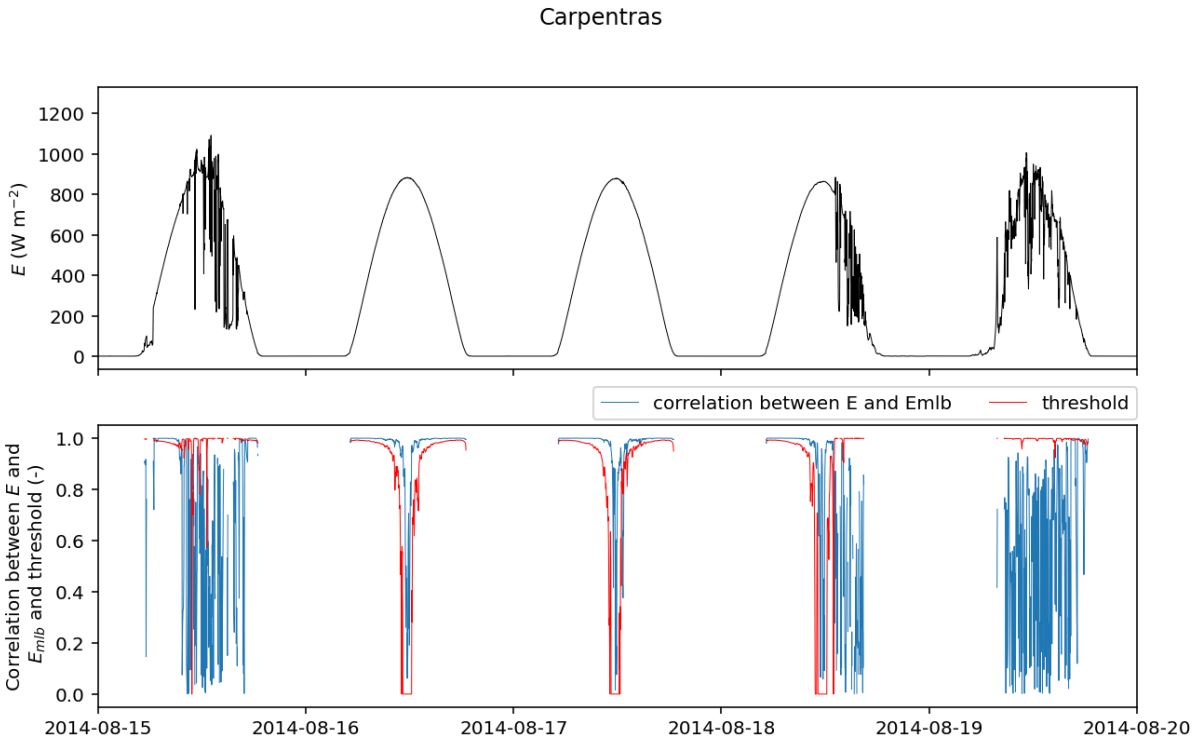


Figure C1: Time series of $\boldsymbol{E_{meas}}$ at Carpentras over five consecutive days (upper panel, black lines). The lower panel shows the Pearson correlation coefficient between $\boldsymbol{E_{meas}}$ and $\boldsymbol{E_{MLB}}$, calculated over a 60-min moving window (blue line), together with the adjusted correlation threshold defined in Eq. (A-9b) (red line).

Use of sky imagers could have been useful for verification and exploration (this is noted already by the authors in section 7). Similarly, perhaps satellite imagery could be explored, for example, to explore the possibility of thin cirrus clouds suggested by the authors in relation to Fig. 4.

Thank you for these suggestions. We agree that sky-imager observations and satellite imagery could provide useful complementary information for the evaluation of MuscaDet and its further development.

The potential use of sky imagers was already mentioned in the original manuscript (lines 578–580), in the discussion on the low-amplitude irradiance variability. In an addition made during the first review, we add a section explaining that satellite data may be used to avoid the use of direct or diffuse measurement for the implementation of MuscaDet (601-606). Finally, we have added a section mentioning the potential of infra-red images for discriminating situations with thin cirrus clouds in the lines 607-610:

"Satellite images and derived products could also be incorporated as additional criteria in future developments of MuscaDet to improve the detection of thin cirrus clouds. These clouds may be difficult to identify using the current approach, which relies solely on time series of E_{meas}, but could be more readily detected using satellite observations in the near-infrared and thermal infrared channels."