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Atmospheric Measurement Techniques Discussions

Interactive comment on "Using digital image processing to characterize the Campbell–Stokes sunshine recorder and to derive high-temporal resolution direct solar irradiance" *by* A. Sanchez-Romero et al.

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GENERAL COMMENTS

The authors present a semi-automatic method of processing CS recorder cards using an image scanner, describe a method of inferring direct solar insolation information from the scanned images and then compare those data with a reference pyrheliometer. The work is generally well written and the author's arguments are well presented. However, the sections describing the image capture method is for the most part not

original and has already be described elsewhere. The scientific value of this work is in the analysis of, and comparison between, sunshine data from co-located instruments of differing types and a pyrheliometer. The testing of a "transfer function" for obtaining values of direct solar insolation from CS recorder data is of particular value.

We really appreciate the referee's comments about the scientific value of our work. We also appreciate his/her comment about the presentation of our arguments. The reviewer is right regarding a study published by Horseman et al. (2013) using a similar method, and it is something we have mentioned certain times in different sections of the manuscript. Nevertheless, it is worth noting that our method is very effective in detecting the burn areas of the CSSR cards. In addition, it presents certain differences as, for example, that the automated steps (the image processing and the measurement of burn width) are developed in Matlab (a program of common use in the scientific community that ensures the spread of the method) or that it uses a different image positioning technique (i.e., it can be used for different types of cards). The Specific and Technical comments raised by the referee are addressed below.

SPECIFIC COMMENTS

Throughout the manuscript the authors describe their method being semi-automatic despite it needing considerable manual intervention (feature location). This manual component means that the method would not be practical for the extraction of long time series that they propose in the conclusions. The image capture and processing described is a subset of that already published in Wood and Harrison (2011), and Horseman et al. (2013). The manuscript would benefit from the authors reworking section 3 to simply reference this previous work and state where their method differs i.e. the manual location of key features and omission of the rectification step. They could then expand the description of their solar insolation data extraction "thresholding" which is new. Including a figure showing the Im1 and Im2 stages and their combination would aid clarity. Similarly the conclusions should be refocused on the thresholding method, data analysis and comparisons.

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We appreciate the reviewer's comment. It is true that our method has a manual component that, obviously, somewhat slows down the process. Nevertheless, it is worth noting that the method of Wood and Harrison (2011) is completely manual. In addition, we do not consider that our method is much less automatic than the previous work of Horseman et al. (2013), as the process of scanning is the most time consuming, and this is common in both methods. In our case, the process of scanning and further manual intervention (i.e., image positioning) can last only 1.5 - 2 minutes for card, i.e. it is possible to process a year of burnt cards in about 12 hours of work. In addition, this manual image positioning is important as it is a way to check the process (i.e., the scan and the image treatment) and it allows using our method for any type of card. Equally, we agree with the referee that a part of the method is similar to the work published by Horseman et al. (2013), which we have tried to reference more often in Section 3 when both methods coincide, while putting more effort to explain the parts that both methods differ. In that direction, we have changed Fig. 3 by adding an example of Im1 and Im2 in order to clarify the digital treatment of the image (threshold values). Finally, we have introduced the topic of the image threshold values, and its importance in our results, in the section of "conclusion and future research". The abbreviation DSI (direct solar insolation) throughout the manuscript values obtained from pyrheliometer measurement, derived from CSSR burn width and indirectly from CSSR sunshine duration - this can be confusing. The authors should take care to clearly indicate the origin of the DSI each time it is used, maybe using a suitable suffix. We agree with the referee. DSIW and DSISD are introduced in the manuscript to distinguish the DSI estimated by burn width and estimated by SD, respectively, in order to avoid confusions on the origin of the DSI.

P9542 L8 the method used by Jaenicke and Helmes also needed cloud cover data. It would be useful to mention this here.

Done.

L20 see p9543:l24-27.

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See our answer to your comment in p9543:L24-27.

L21 mentioning a high temporal resolution of 1h is not consistent with the resolution of 1min mentioned elsewhere - this needs clarification.

We have removed this sentence from the introduction. We now talk about the resolution of the method (1-min) in section 3 and about the relationship with DSI at 1-hour resolution in section 4.2.

P9543 L4-5 as CSSRs are affected by environmental conditions it would be useful to very briefly describe the climate of the location.

Done. We have briefly explained the climate of Girona.

L6-11 the WMO recommend that the horizon for sunshine detectors be clear above 3 degrees above horizontal which is not true for the site used. The authors state that this is not a problem, it would be useful to explain why.

The obstacles in the eastern horizon mean that both CSSR records and DSI measurements are affected during the early morning, but we assume that this issue does not affect the relationship between both variables during the rest of the day. If we were interested in the correct measure of daily SD that would indeed be a problem. We have reworded the sentence in order to clarify this point.

L24-27 the time period of 2 years (January 2012 to January 2014) is mentioned, but only 239 cards were analyzed. It would be useful to state why only ∼33% of the available cards were used e.g. lack of any discernible burn or cards were too damaged etc. This kind of information is important for building complete time series.

We are not interested in building a long SD cards series, only to prove that CSSR records may become a proxy measurement of direct solar radiation. Thus, the number of cards is relatively small because we don't put cards every day (e.g., holidays, weekends...). We also removed the cards that were too damaged due to the rain, or with no trace of burnt (i.e., totally overcast days). We have added this information in

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the manuscript.

P9545 L7-24 this is the core of the thresholding process and would benefit from expansion, perhaps a step-by-step explanation referencing a figure.

We agree with the referee. We have expanded the description of the thresholding process, as well as changed Fig. 3 by adding images of Im1 and Im2 in order to clarify this step.

P9546 L7 the cards are described as symmetric, but Fig 2 suggests they do have a little asymmetry. Do the authors mean that the markings are symmetric about the midday marker even if the card edges are not?

The referee is right as all cards are symmetric about the midday marker, even if, in the case of equinoctial card of Thies Clima, the card edges are not. We have reworded this sentence in the manuscript in order to clarify this point.

L15 explain why the geometry of the Thies Clima cards is difficult.

We have explained in the caption of Fig. 2 why the geometry of the Thies Clima equinoctial cards is more difficult than the other. In addition, we have removed the sentence from the main text in order to simplify the explanation of the method.

P9548 L1-5 non-solar environmental effects will also affect the SD series from CSSRs.

We agree with the referee, but in this point we only want to remark the importance of the errors directly associated with the instrument, as summarized by Brázdil et al. (1994). Further on we talk about the non-solar environmental effects. Anyway, we have reworded the sentence in order to clarify this point.

L15 the term "SDpyr method" needs explanation here.

We have now explained the meaning of SDpyr. The sentence now reads as “We define here the SDpyr method as considering a threshold of 120 Wm-2 in DSI in order to calculate SD, that is, counting the minutes when DSI is higher than 120 Wm-2. By

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doing so, the mean value found for our database is 7.16 h, which can be taken as the reference (correct value) for other estimations."

L27 see P9549:l1.

See our answer to your comment in P9549:L1.

P9549 L1 it is not clear if the "latter values" means both 55W/m2 and 110W/m2 or just 110W/m2. The correspondence between SDI and the CSSR threshold here and on p9548 needs further explanation. Have the authors considered whether the apparent difference in sensitivity between the CSSR instruments is influenced by the different "time to distance across the card" scaling mentioned at p9547:l9.

It refers to both 55 Wm-2 and 110 Wm-2. We have reworded these sentences in order to clarify the meaning. Moreover, we do not think that the different time to distance ratio across the card may explain the different values of threshold, as this distance is related to the instrument geometry (focal distance), while the threshold seems more related to the type of card.

P9550 L2-7 was the installation and alignment of the instruments checked? The differences between instruments could also be due to simple manufacturing variation.

The alignment of CSSRs was accurately checked several times along the analyzed period and, in addition, a visual check of the alignment of both instruments was done every time that the cards were changed. So it is not a problem of misalignment or installation. As almost all SDaut values from CSSR1 are higher than SDaut values from CSSR2, it is obvious to think that this fact is related to the instrument and/or the cards. The ageing of the glass sphere is difficult to be taken into account, but we explain how to deal with the different quality and color of the recording cards.

L7-12 it would be better to mention revised thresholds in the section regarding further work.

We agree with the referee. We have added the discussion about revised thresholds in

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the section “conclusions and further research”. We have also kept this discussion at the end of section 4.1 because it matches with the discussion of the SD differences between the two CSSRs.

P9551 L3 could the lag between the CSSR and DSI simply due to the inherent lag in getting the card up to charring temperature, which is also influenced by moisture and temperature.

As we state in the response to P9950, L2-7 comment, we consider that the CSSR alignment is correct. We checked that, in average, burn appears almost immediately (less than one minute) when the sun is bright enough. However, when installing a particular card, some small (but random) misalignments can be introduced: the shift between the burning in each card and the DSI data can be positive or negative (we misused the word ‘lag’ here, it has been corrected in the manuscript). That’s why we have related this shift to a random misalignment of the CSSR cards respect the DSI data.

L21-24 the meaning of this sentence is unclear, please reword.

We have reworded the sentence in order to clarify this meaning.

P9553 L1 the logistic curve fitting shown in Fig 6 has clear "tails". Could the authors expand upon the physical reasons for these i.e. the saturation at the upper end most likely due to their threshold method not weighting burn-through, and the sensitivity of the onset of burn to environmental factors like moisture and temperature?

Thank you for this comment. For high values of DSI (800-1000 Wm-2), the effect of DSI on burn width decreases, and other factors have a role in the measure of burn width. It is possible that the atmospheric conditions in those moments (for example, moisture and temperature) could explain this behavior, but further research is needed. We agree with the referee about the fact that considering the perforated part of the burn could give some light to explain the reason of this tail, so we have added this

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suggestion in the section of Conclusions and Future Research.

L27-29 would this still be true if "burn through" could be correctly accounted for?

We are not exactly sure what the referee refers to. If the referee considers “burn through” as the perforated part of the burn, we would continue to be unable to distinguish values of DSI ranging from, for example, 500 (instead of 200) to 1000 Wm-2, i.e. this range could be reduced, but still so wide to estimate DSI as accurately as the method based on burn width.

P9555 L10-14 this is confusing and should be reworded.

We have tried to reword these sentences for further clarity: “Future research may consider taking into account the perforated part of the burn (Roberts, 2012) besides the burn width (perforated plus scorched parts); a priori, this would help in the estimation of DSI.”.

L17-24 this repeats the conclusions of Helmes, Jaenicke, Kasten, Horseman etc. and doesn’t relate to the detail of the manuscript - it should be removed or reworded.

We reworded this paragraph in order to relate our results with the works of Helmes, Jaenicke, Kasten, Horseman, etc.: “Once this method is implemented, other magnitudes can be introduced. Since DSI is affected by atmospheric turbidity, especially at times near sunrise and sunset because of the longer optical path, having an estimation of DSI from the burn width may be used to estimate turbidity, i.e. CSSR records can become a proxy measurement for turbidity and atmospheric aerosol loading. This possibility has been proposed before by Jaenicke and Kasten (1978), Helmes and Jaenicke (1984, 1985, 1986), and more recently, by Horseman et al. (2008, 2013), as reviewed by Sanchez-Romero et al. (2014)”.

L25-29 it would be fairer to say that work validates the idea of constructing a long time series of DSI data from CSSR proposed by previous authors.

We agree with the referee. We have introduced in the manuscript the previous literature

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that proposed the same idea. P9556 L1-5 these useful references could be moved to the introduction (around p9540:l10) and given as motivation for examining the CSSR record.

We agree with the referee and we now mention these references in the introduction. However, we have decided to maintain this comment at the end of the conclusions to remark the possibility of applying our method, as it some long-term records of SD cards exist.

P9569-70 Fig 6 and 7, the geometry of the cards is different for the winter, equinoctial, and summer periods, as is the environmental conditions the instruments experience. It would be useful to differentiate between results from each period, perhaps by color coding the points or even providing separate plots for each period. This may offer insights into the reasons for the 'tails' of the fitted functions. Although the latter option may require too much additional work for incorporation in this manuscript.

In Figure 1 and 2, the referee can find the proposed scatterplots, but only for CSSR1. The different colors distinguish the type of card (green for winter cards, red for equinoctial cards, and blue for summer cards). As the referee can observe, there is a mix of colors, not only in the tail, but also in the rest of the plot. Thus, the tails of the data are also visible for high DSI for all type of cards. The same homogeneous distribution of points corresponding to the three types of card is found in Fig. 2. Consequently, we have decided not to include these new figures in the revised manuscript.

P9565 Figure 2, identify each model of instrument and cards shown in the image.

We agree with the referee. We have put tags for each model of instrument and card.

TECHNICAL CORRECTIONS

P9538 L5 remove ". Contrarily, " and run sentences together with ", but". Done L7 remove semi-automatic and follow method with "of analysis is used,". Done L14 re "unbiased" it is difficult to see how all bias can be removed, better to say improve

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estimation. Done L15 preface results with "experimental". Done

P9539 L13 replace "involve" with "are". Done L14 replace "plate" with "frame". Done L15 replace "metallic spherical" with "metal frame". Done L17-20 mention that different designs of card are used. Done L23 replace "During" with "Over". Done L25 remove "methods". Done

P9540 L1 replace "in" with "during". Done L8 the meaning of "filling" is not clear in this context, do the authors mean "recording". Done L29 remove "by". Done

P9541 L1 remove "Concretely,". Done L7 insert "apparently" before "lasting". Done L28 replace "of" with "to the". Done

P9542 L13 insert "analysis" after "new". Done

P9543 L1 replace "Burnt" with "Exposed". Done

P9544 L7 explain the abbreviation TST. Done

P9547 L20-25 I don't think this paragraph is needed. It is true that this paragraph does not give new information, but we think that it is interesting to guide the reader through the various applications of the burn width measurements before explaining them one by one. Nevertheless, we have shortened the paragraph.

P9548 L9 either "after the 1960s" or "after 1960". Done L19 replace "accounted" with "counted". Done L26 insert "by" before "searching". Done

P9549 L11 remove the 's' from "advices". Done

P9550 L15 remove "both". Done L23 replace "null" with "nil". Done

P9551 L17 insert "with" before "respect". Done L21 replace "among" with "between". Done L26 remove "their". Done L27 remove "basically". Done L28 remove "basically". Done

P9552 L3 replace "us to propose a certain" with "a". Done L5 remove "too". Done

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P9553 L6 replace "proven" with "shown". Done L12 replace "of" with "about". Done L13 remove "on". Done L14 insert "as to" before "whether". Done

P9554 L6-7 reword "threshold in DSI" to "DSI threshold". Done L8 remove "several". Done L9 remove the 's' from "advices". Done

P9558 L30 page reference missing. Done

P9559 L23 the pages for this reference are 327-331. Done

P9560 L23 "Abridged Final Report of the Third Season". Done

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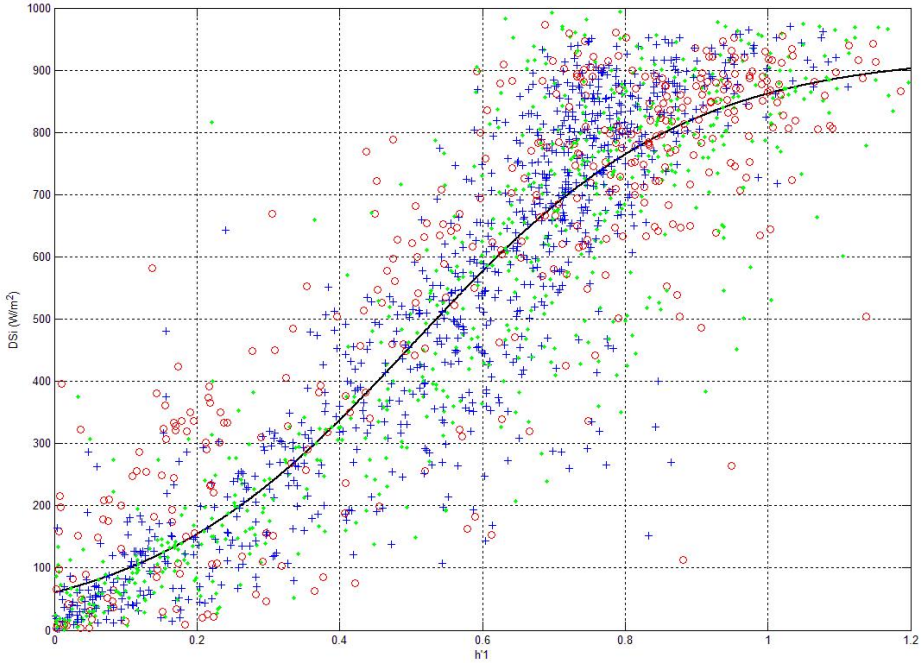

Fig. 1.

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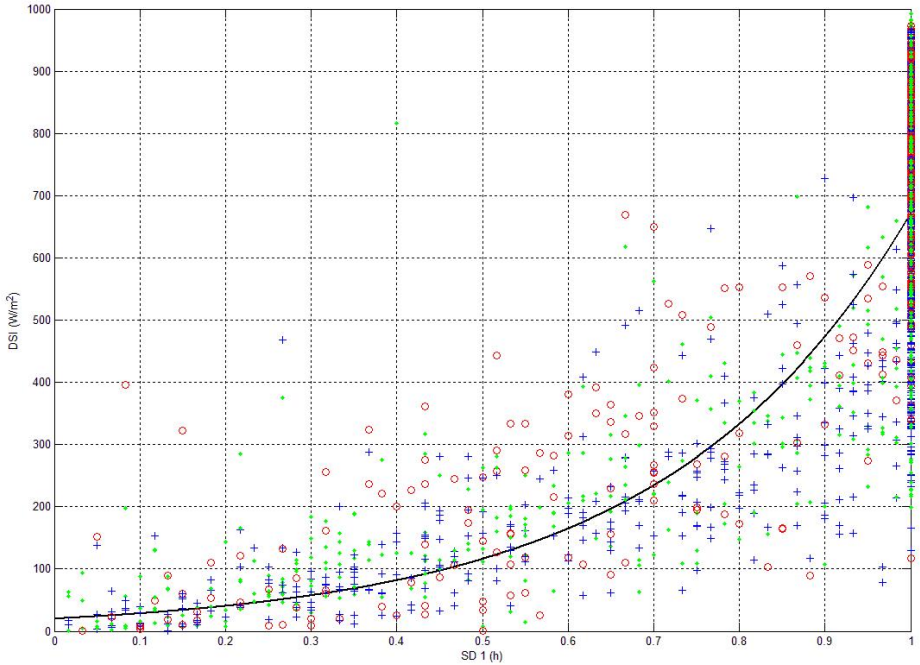

Fig. 2.

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