EGUsphere, author comment AC1
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# Reply on RC1

Bert G. Heusinkveld et al.

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Author comment on "A new accurate low-cost instrument for fast synchronized spatial measurements of light spectra" by Bert G. Heusinkveld et al., EGUsphere, https://doi.org/10.5194/egusphere-2022-726-AC1, 2022

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- **RC1**: 'Comment on egusphere-2022-726', Anonymous Referee #1, 05 Oct 2022 reply

*Our replies to the reviewer are presented below in italic font*

**General comments**

The article is correctly structrured. The scientific rationale is well defined as well as the methodological approach to answer to it.

The Discussion section should be more comprehensive; in particular it should include at least a qualitative assessement of the error budget components affecting the measured PAR with the FROST system.

*We agree that the Discussion section should be more comprehensive and will elaborate this section based on the specific comments from both reviewers. PAR measurements: The main error is the lack of spectral information between the 11 PAR wavebands. However, the information of 11 wavebands is also an advantage (compared to a single band) as it does provide spectral information of the PAR region.*

The interpretation of some results could greatly benefit with the inclusion of mathematical formulae. The radiometrically correct weighting of the wavebands spectral shape should be part of the FROST spectral calibration and digital filter calculations.

*The radiometrically correct weighting of the wavebands spectral shape was part of our calibration procedures; see L339-356. We provided all waveband response data as digital data in supplementary material S1. We will include mathematical formulae.*

**Specific comments**

**Abstract**

- line 12: Doesn't the autor mean "... global horizontal irradiance (GHI)..." ?

*correct*

- line 19: is "... zero offsets ..." a synonim for dark current? If yes, please replace by it.

It is the most used term in the radiometry field.

*Yes, we agree that the term dark current is actually describing well the mechanism that causes offsets in silicon light sensors, but we felt that "zero offsets" is more commonly used for GHI sensors. It can be changed into "dark current".*

- line 23: 2% with respect to which reference temperature?

*It is indeed not clear if the jump happens in the cooling or heating direction around 21°C We will clarify this.*

**1 Introduction**

- line 55: specify that the temperature sensitivity of semiconductors is generally temperature dependent

*In line 55 we state: "..., and temperature sensitivity".*

- line 70: give value of relative (in percentage) rms error as well.

*We will do so.*

- lines 55 and 59: non-linear/nonlinear or non-flat?

*We agree that "non-flat" response would be more appropriate.*

- lines 66 to 69: A figure with both response curves would be more suitable to understand the differences highlighted in this sentence.

*We prefer inserting a reference containing such a Figure. See Fig. 1 of Alados-Arboleda et al., 1995.*

- lines 71 and 72: it is not clear why their similar performance is "surprinsingly accurate". Please develop.

*This was developed in lines 73-79.*

**2.1 Light Sensor**

- line 132: Spectrometer is not the good definition for this instrument as it implies the existance of a scanning mechanism. AMS AS7265x would be better referred as a 18-channel filter radiometer or equivalent. Apply same correction throughtout the text.

*The more specific term for our sensor would be a "filter-based spectrometer", but it still qualifies as a spectrometer. We will clarify this in line 132. The filters are already described in line 136.*

- line 134: It says that there are 3 bands, RGB with 6 Si photodiodes with all the associated optics and electronics but then in line 146, it says that there is a challenge to couple everything to the same sensing area. This seems contradicting as there are 18 sensing areas (from line 134). Clarify this.

*No, there are no 3 bands, no RGB bands. The Red, Green and Blue are used to identify each of the 3 light detection chips. Each chip detects 6 light wavebands. The manufacturer (AMS) also identifies the 3 chips using the same color coding. We understand that this may sound confusing. Line 135 should clarify this, but based on the reviewer's comment,* *more info is needed.*

- line 143: If it is a specification "+/-" shouldn't appear before 10nm FWHM, instead a tolerance, if existing, could be specified either in percentage or absolute.

*It was meant to indicate the width of each waveband (FWHM), therefore "...20 nm FWHM specifications" would be better.*

- line 143: "AMS states that their filter stability (in time and against temperature) is not detectible but does not provide further specifications." While this is an honest statement from the author, this question might be of non-negligible importance: UV exposition is known to generally degrade materials over time with a possible impact on the measurement performance in this particular case. Mentioning this issue, even from a qualitiative perspective with bibliographical support, would be of great value to the article.

*Agree, we will add that the manufacturer warns against strong UV exposure as this could affect long term optical performance. The UV exposure is greatly reduced by the diffusers. We will add recommendations to select acrylic glass as a diffuser material for a new FROST version. Another advantage of Acrylic glass is that is does not exhibit the transmission jump with rising temperatures at 21°C.*

**2.1 Diffuser material**

- line 155: missing %; give more insight on the 1% to 4% transmission changes. Is this between the 3 diffusers, with/without spectral dependence?

*Yes, between the 3 PTFE diffusers tested by Yliantilla and Schreden, 2004. They did not find such a sharp increase in transmittance as we did. However, it is expected to be a sharp increase since the crystallization happens at one temperature. We therefore think that our experiment was more accurate because of the very slow increase in temperature during the experiment. They also found some spectral dependence, especially at temperatures above 29°C (0.7% point difference between 420 nm 580 nm from 29°C to 45°C). We will check our data to see how much this would affect our diffuser.*

- line 157: clarify what the author means by "without jump"

*Smooth linear dependency on temperature, without the sudden transmission jump as found in the PTFE diffusers.*

**3.1 Spectral response and temperature sensitivity**

- general comment: the reader is not necessarily familiar with a Cary spectrophotometer. Please give some detail on the measurement setup (with references when possible) as the spectrophotometer is used for three different types of measurements: wavelength scale, filter transmission and cross-talk.

*We will improve the description of the Cary spectrometer setup. It was not used for cross-talk measurements. At the DWD the Cary was capable of producing the relevant wavelengths, but it was impossible to place the FROST inside the Cary light excitation chamber. They also did not manage to measure the transmission of the PFTE diffuser inside the chamber, but only the transmission of the crosstalk test filter could be tested (Fig. 4).*

*The cross-talk was determined by placing an optical LP filter (Fig. 4) in front of the FROST. Any signal that would be measured by the FROST was interpretated as near infrared cross-*

*talk (see L257-271).*

*At Wageningen, the Cary photo spectrometer was limited to about 800 nm, and thus it was only used to test center waveband positions of the first 12 channels. We will specify this in the text. We therefore could not test near infrared cross-talk. In this case the Cary was used as a monochromatic light source only.*

- general comment: was the FWHM also measured with the Cary spectrophotometer or otherwise?

*Yes, but only for a few channels. These measurements confirmed for these channels the correct FWHM and therefore we trusted the manufacturer-supplied response curves (Fig. 6, left panels). The test with the optical LP filter (Fig. 5) confirmed that the near infrared crosstalk was not understated by the manufacturer (these response curves were provided upon personal request, it would have been nicer to find them in the manufacturer published datasheets).*

- lines 247 and 248: Does this wavelength accuracy refer to the position of the bandpass central wavelengths? If yes the measured wavelength could be shown, for instance in table 2, against the nominal wavelength.

*Yes, this is where we will explain that not all channels were tested, see previous comment.*

- lin 249: Sentence starting by "Comparison" is inconsequent. Rephrase it, putting it in relation with the follow-up sentences.

*Yes, changed to: Linearity was tested by comparing the FROST measurements against a reference thermopile pyranometer CM21 (Kipp and Zoonen, The Netherlands) and a stabilized halogen light source.*

- line 252 and 253: It would be intersting to have a brief summary of the details on how this non-linearity was obtained.

*We will provide an xy Figure to show the quality of the comparison (supplementary materials)?*

- line 253: to which quantity does the calibration refer?

*Good point, it refers the light intensity response.*

- line 272: the paragraph starting here should be rearranged: first mention how the data in Fig.5 were obtained then proceed to compare and then to try to explain the differences observed.

*Lines 257-259 seem too limited to explain how the data was obtained. It was a test to find the intensity of cross-talk resulting from a FROST excited by a light source that only emits light >1000 nm.*

- line 272: if you know the Sun spectrum and the Xe lamp spectrum would not it be possible to correct for this?

*Yes, certainly. For clear sky conditions, measuring incoming solar radiation could work. But as soon as clouds appear it would deviate. Additionally, it does not work for the applications mentioned in Chapter 3 such as measuring reflected solar radiation or surface albedo measurements, or NDVI measurements or PAR within a canopy (unknown spectral properties of leaves, surfaces).*

- line 306: why would the below crosstalk be increased? Additionally it could be intersting to point the origins of the below crosstalk earlier in the text.

*Agreed, additional explanation was lacking. We need to correct a mistake in the Figure reference; 6 should be 8.*

*Some further explanation: See Figure 6 lower right panel, cross-talk below waveband is significant. A correction filter would also greatly affect the response of the 900 and 940 nm bands and therefore increases the cross-talk of the lower wavelengths. This can be seen very clearly in Fig. 10 lower panel (circles).*

- figure 8: it would be more consistent to mantain the strucutre of figure 6: spectral responses in left column and crosstalk on right column

*Yes, we agree.*

- figure 8: from the colors of crosstalk the reader might understand that the bars represent only "above" crosstalk. While this is probably the case, should be indicated in the legend.

*Yes, and "below" crosstalk is a very low fraction of total crosstalk. We will specify this.*

- line 318 and 322: Repeated phrase. Keep one instance and develop the sentence.

*Yes, the sentence "Note that it enhances infrared crosstalk can be omitted".*

- line 342: I understand the principle procedure of calibrating the FROST sensors with the solar spectrum, however some details are missing. For instance the weighing of the solar spectrum by the respective channel response function is not mentioned. This particular paragraph should include an equation detailing the calibration procedure.

*Details regarding the calibration method considering the weighting of the solar spectrum by each respective channel are not missing: Line 340 explains that the reference spectra (either from the sun or a reference spectrophotometer) should be multiplied by the PDF band responses of the FROST. We will add a reference to the Supplementary data (S1) of the PDF of the FROST response. Unfortunately, S1 only contains the PDF for the sensor only, without the transmission data of the correction filter or diffuser. This will be added to S1.*

- Table 2: Counts is usually untiless, but it is indicated has having $nW^{-1}$ Please clarify the quantity.

*These are calibration constants, and the units are [Counts nW-1], dividing the sensor signal by these values gives the output in nW for each waveband (Counts are not in nW-1).*

- Table 2 legend: How is the 35%<crosstalk<40% category handled?

*If waveband accuracy is important, reject the channels with Flags>0.*

### 3.3 Cosine response and GHI

- general comment: As this is used often during this paragraph, how to decouple GHI and diffuse radiation?

*The FROST cannot decouple diffuse radiation from GHI.*

- 13, 14 and 15: It is always more tangible if the error is expressed in relative units. Please show the the error in percentage. Additionally mention the content of each panel.

*Agreed, we will add relative units also and improve Figure 13, 14 and 15 captions.*

- 13, 14 and 15: The caption and the legend do not agree. What are each of the 3 curves in the top panel? What error is shown in the bottom panel?

*We will expand the Figure captions (for example diffuse radiation (Qd) in Figure caption is missing). Figures 14 and 15 captions will also contain the information provided in Figure caption 13.*

- 15: Why are there only binary rain values, 0.00 or ~0.25 mm/min? The visualization of the bottom panel is confuse, please simplify.

*The rain gauge produces a much better resolution than 0.2 mm and outputs the data each minute (Ott Pluvio2s). We will correct this error and add rain gauge specifications and update the Figure.*

- line 407: Do you refer to figure 15 or 16? Does this information provide an additional insight on the data interpretation? If yes, please state which.

*We will change the reference; it should refer to both Figures 15 and 16. We will discuss the possible impact of water droplets on light transmission of the diffuser.*

- line 408: The paragraph starting here needs a mathematical expression to better support the text and the interpretation of Fig. 16.

*To improve Fig. 16, we will change the y axis legend. It should read "Normalized spectral cloud modification factor", see Durand et al., 2021.*

### 3.4 Spatial measurements and synchronization

- 18: There are only nine data points in this plot. Why not a table or a plot with improved readbility? The offset effect of the zeros values worsens the understanding.

*This Figure is a true time series of raw data output of 3 FROSTS responding to a step change in light intensity. There are no offset effects we can think of. The caption may need to reflect this in a better way, so we will add that the first 6 and last 2 samples are zero (no offsets). Of course, we could provide a table of these data also but it would just contain zeros at times 12:00:45.0, 12:00:45.1, 12:00:45.2, 12:00:45.3, 12:00:45.4, 12:00:45.5, 12:00:45.9, 12:00:46.0.*

*We think it is nice to show this as a Figure since it directly visualizes the perfect synchronization, the fast response speed and no zero offset (or dark current).*

### 3.5 Photosynthetic Active Radiation

- 1st paragraph: there seems to be a confusion between solar spectrum ($W.m^2.nm^1$), the number of photons of this spectrum per wavelength and the detector sensitivity. Please clarify the paragraph and taking into account the following remarks:
  - line 480: **measurements**refer to what?

*Measurements of PPFD intensity*

- lines 481 and 482: the number of photons at a given wavelength is unitless, while $W.m^2.nW^{-1}$are the usual units of spectral solar irradiance.

*Removing (per W m-2 nm-1) solves this confusion.*

- lines 482: the wavelength sensitivity or the spectral dependence of the solar spectrum/number of photons?

*The number of photons as a function of wavelength (at constant W m-2 nm-1).*

- line 486: wavelength ($\lambda_n$)

*Accepted*

- second paragraph: the expressions and consequent calculations seem to not take into account the non-finite character of each of the FROST channels spectral reponse. All these quantities must be properly weighted by each of the wavebands spectral response. This paragraph should be rewritten taking into account the above commentaries and be accompanied by a more rigorous mathematical formalism and notation.

*No, we do consider the spectral weighting (assuming a calibrated FROST, see calibration L339-356). What cannot be considered is the lack of spectral information in between the spectral bands.*

- 20: Offset term should be shown and, if zero, mentioned.

*Accepted*

**4 Discussion**

- An overview of the factors contributing to the PAR measurement uncertainty should be expanded.

*Agree, the major factor would be the limited coverage of the PAR band due to narrow band response of the 11 bands.*

**Technical corrections**

- line 14: delete "very"

*The FROST covers the whole PAR range, but not the whole solar spectrum. We think it is unique for a low-cost PAR sensor to be able to quantify the light spectra within the PAR range for 11 wave bands.*

- line 69: their main uncertainty **is**related

*Accepted*

- Numbering of subsections: 2.1 is repeated

*2.1 should be 2.2 and 2.2 should be 2.3 (2.3 was missing)*

- line 100: verify autor name. Probably Lopes Pereira.

*Accepted*

- line 180: 5 m

*Accepted*

- line 252: a t => at

*Accepted*

- line 238: missing )

*Accepted*

- line 341: spectra is the plural form of spectrum.

*Accepted*

- line 352: check English

*Accepted, "recommend to" was missing*

- figure 10: correct formatting of units: nm-1 => $nm^{-1}$for example. Correct the many instances thoughout the text.

*Accepted, subscripts somehow got lost during the submission process.*

- line 595: double check authors surnames: probably Peireira => Pereira, Goncalves => Gonçalves, Vazao => Vazão

*Accepted*

- sections 3.1 and 3.2: Temperature sensitivity is repeated

*Accepted: "3.1 Spectral response"*