Thanks for the reviewer's efforts to review this paper. The point-by-point responses are included below with the reviewer's comments in black and our replies in blue.

Reviewer #1
Referee comment on "Evaluation of the hyperspectral radiometer (HSR1) at the ARM SGP site" by Balmes et al.

The study summarizes the results of a comparison of spectroradiometer measurements over a two-month period. Data from an instrument capable of measuring total and diffuse spectral irradiance separately are compared with several other instruments in terms of total and diffuse irradiance, diffuse fraction, and derived AOD.

General Comments

The authors provide a comprehensive overview of statistical measures used to describe the correlations and regressions between the different data sets. Such intercomparisons as part of an instrument study are important to document the suitability of new instruments. However, this work is limited to the mere presentation of statistical comparative figures without deeper discussion and investigation of the causes. For this reason, I cannot recommend the manuscript in its current form for publication in ATM, but would encourage the authors to submit a new manuscript that is less descriptive. Below I give comments and some suggestions to improve and expand the content.

Thanks for the reviewer's efforts to review this paper. See our replies below.

Specific Comments

1. It is not clear what the new technical specifications of the HSR1 are compared to the instrumentation described in Wood et al. (2017) and Nogren et al. (2022)? Is it the same instrument? The instrumental design of the HSR1 is not fully described by the authors. What kind of spectrometers are used?

We have revised the text to include more specific details on the technical specifications of this instrument and what is different from previous prototypes and references (Section 1): "The spectrometer within the HSR1 is a significant improvement over those reported in Wood et al. (2017), which used either an array of low-cost commercial spectrometers, or a fiber switch with a higher specification spectrometer to measure the seven spectral inputs. The current HSR1 uses a custom designed multichannel spectrometer, which images and spectrally disperses the light from the input fibers onto a 2D image sensor, so all channels are measured simultaneously. This significantly improves the measurement resolution, speed and matching between the channels compared with the earlier implementations. An early version of this system was also used by Norgren (2022)."

2. The study lacks a detailed uncertainty analysis. The authors provide little information on calibration issues and only mention the "dome lensing effect" in the discussion section without explaining it. They should definitely expand this section. What are the single

measurement / calibration uncertainties and how do they contribute to the different products?

We have revised the text to include information on the HSR1 uncertainty (Section 2.1.1): "A reference HSR1 is calibrated by removing the shading mask, and exposing the sensors to a 1000W 'FEL' lamp, with an output spectrum calibrated by the UK NPL. This calibration is transferred to other HSR1s during routine calibrations and calibration checks using an integrating sphere. The expected uncertainty in F_{total} measurements is expected to be around 5% between 400 nm and 900 nm."

We also plan to discuss further sources of measurement/calibration uncertainties in Section 5 in a revised version. We also plan to discuss further in a follow-on paper of post-processing modifications and other sources of measurement/calibration uncertainties.

3. The presentation of the different instruments in Section 2 should also include the instrumental uncertainty. The subsubsections (Sec. 2.2) that inform about the other instruments are quite short. Consider summarizing them without subdividing them further and showing a table with the main specifications.

Thank you for the suggestion. We are working on new Table 1 (see draft below) which summarizes the main instrument specifications and uncertainties to Section 2.

Table 1. Instrument specifications including spectral range, spectral resolution, retrieved quantities, and uncertainty estimates.

Instrument	Measurement	Spectral coverage (resolution)	Retrieved quantities	Uncertainty
HSR1	Total and diffuse hyperspectral irradiances	300-1100 nm (3 nm)	AOD at 415, 440, 500, 615, 673, 675, and 870 nm	Total irradiances: 5% AOD: 0.02 (500 nm), 0.05 (415 nm), 0.04 (440 nm), 0.01 (615-870 nm)
CSPHOT	Direct solar irradiance and sky radiance	340, 380, 440, 500, 675, 870, 1020, and 1640 nm	AOD at 440, 500, 675, and 870 nm	AOD: 0.01
MFRSR	Total and diffuse spectral narrowband irradiances	415, 500, 615, 673, 870, and 940 nm	AOD at 415, 500, 615, 673, and 870 nm	Irradiances: 2-3% AOD: 0.01
SASHe	Total and diffuse hyperspectral irradiances	300 to 1100 nm (2.4 nm), 950 to 1700 nm (6 nm)	AOD at 415, 500, 615, 673, and 870 nm	TBD

4. P2L46: "radiometer with no moving parts is now available called the hyperspectral radiometer (HSR1)" – I would leave out the phrase "no moving parts". It would be better to say that no rotating shadow band is required.

We have revised the text to make clear that no rotating shadow band is required (Section 1): "In an attempt to ease the operational difficulties of hyperspectral radiometry, a newly developed hyperspectral radiometer with no moving parts and no requirement for rotating shade rings or motorized solar tracking devices is now available called the hyperspectral radiometer (HSR1) (Wood et al., 2017; Norgren et al., 2022)."
We have kept in the text that no moving part since this is a unique feature for measuring diffuse that provides utility for remote and harsh deployments.

5. P2L53-L59: I had difficulty understanding the brief description of how to separate total and diffuse irradiance. Only the references given made it clearer. Even though it is redundant to the other publications, I would recommend a sketch for better understanding. Since these are instrumental details, I would place this information in Sec. 2.

We have revised the text to provide more details on how the total and diffuse spectral irradiances are measured based on the multiple sensors with equations in the introduction (Section 1): "The HSR1 was designed with seven spectral sensors: six sensors placed on a hexagonal grid, one sensor at the center, under a complex static shading mask (see Figs. 1 in Badosa et al., 2014 and Wood et al., 2017). The shading mask design is to ensure that, at any time, for any location: (1) at least one sensor is always exposed to the full solar beam; (2) at least one sensor is always completely shaded and; (3) the solid angle of the shading mask is equal to π thus corresponding to half of the hemispherical solid angle. With no moving parts or specific azimuthal alignment, the instrument is ideal for deployment on moving platforms such as ships and remote locations where regular maintenance is difficult.

Assuming isotropic diffuse sky radiance, the third property related to the shading mask implies that all sensors receive equal amounts (50%) of $F_{diffuse}$ from the rest of the sky hemisphere. Therefore, at any instant, the minimum signal (F_{min}) measured among the seven sensors is the shaded sensor, which measures half the $F_{diffuse}$, and the maximum signal (F_{max}) from among the seven sensors is fully exposed to the solar beam, and therefore measures the direct irradiance (F_{direct}) plus half the $F_{diffuse}$. From this the following relationships can be formed:

$F_{diffuse} = 2F_{min}$, (1)

$F_{direct} = (F_{max} - F_{min})$, (2)

F_total $= F_{direct} + F_{diffuse} = F_{max} + F_{min}$. (3)

In the HSR1, F_{max} and F_{min} are selected from the integrated spectral measurements from each sensor, and these relationships are applied to the corresponding spectral measurements to calculate the Ftotal and $F_{diffuse}$. Due to the nature of the measurements, the F_{total} and $F_{diffuse}$ are measured simultaneously. This is in contrast to rotating shadowband systems which must make the F_{total} and $F_{diffuse}$ measurements separately and, therefore, at different times."

We have kept this information in the introduction following a suggestion from the editor's initial review.

6. P2L53: "the shadow pattern allows one of the seven sensors to be illuminated unobstructed by the shadow pattern, which measures the total irradiance" – According to Wood et al. (2017) it should be I_max+I_min, which gives the total irradiance. Please clarify.

We have revised the text to clarify how the total irradiance is calculated, including the equations (Section 1). See above reply.

7. P3L79-L83 + Fig. 1: I think that this example plot is not needed at this point. Data coverage is reported at the beginning of this section. All the detailed information about the reasons for the downtime may be less important to the reader. Try to shorten them. Perhaps show a time series of the radiation data along with the cloud cover data.

We have shortened the HSR1 downtime information by removing the paragraph description and only including in the text (Section 2.1): "The HSR1 exhibited excellent uptime and near-autonomous data collection over the two-month test period with an uptime of 97.5%." We are also working on a new figure to a revised version of the manuscript that is a timeseries of the irradiance(500 nm) and AOD(500 nm) with a clear-sky marker.

8. The second part of Sec. 2.1 should contain more technical details of the HSR1 instrument. Here the spectra from Fig. 1 would fit.

We have added in more technical details to the second part of Section 2.1. We have removed the downtime information description and, therefore, the spectra figure has not moved but is now where the text of technical details is.

9. P5L98-L103: The spectral range limitation could be better justified by using radiative transfer simulations that show the low performance at the edges of the spectral range. Is it really stray light that is causing the low performance? Have you done lab tests with edge filters to analyze this?

We have revised the text to include that the straylight issues are known based on lab tests (Section 2.1): "In particular, considerable noise was noted for wavelengths greater than 1000 nm (Fig. 2c) as the measurements were contaminated by second-order stray light as identified in the lab using a monochromator. As with all spectrometers, measurements at the two extremes of the spectrum have low sensitivity, and therefore additional noise is apparent."

10. P5L108: “lensing effect” might be important – Please elaborate. It is referred to Sec. 5, but there is no deeper discussion.

We are working on expanding the discussion of the dome lensing effect in the discussion section (Section 5). We plan to include this in a revised version of the manuscript.

11. Section 2.2: Please give uncertainties for all instruments / products.

Thank you for the suggestion. We have added uncertainty estimates into the text where available as well as summarized in new Table 1.

12. P6L143: What is the wavelength range that is covered by the instrument?

We have added into the text the spectral range that is covered by the SW instruments that are input into Radflux (Section 2.2.4): “The SW broadband radiometer spectral range is 295 to 3000 nm (Andreas et al., 2018).”

Andreas, A., Dooraghi, M., Habte, A., Kutchenreiter, M., Reda, I., and Sangupta, M.: Solar Infrared Radiation Station (SIRS), Sky Radiation (SKYRAD), Ground Radiation (GNDRAD), and Broadband Radiometer Station (BRS) Instrument Handbook. Ed. by Robert Stafford, ARM Climate Research Facility. DOE/SC-ARM-TR-025. https://doi.org/10.2172/1432706, 2018.

13. P6 Sec.2.2.3: Too many details on instrumental failures. It is sufficient to say, that only cloudless conditions could be considered due to instrumental issues.

Thank you for the suggestion. We have revised the text to reduce the detail of the SASHe data reprocessing (Section 2.2.3).

14. P7L150: I am not sure that the comparison of PAR data is really necessary in this study, since it is just another quantity based on spectral integration.

The PAR comparison shows an application of the HSR1 that is possible with hyperspectral information. We have moved the PAR comparison to new section Appendix B.

15. 3: Please discuss the uncertainty of the AOD retrieval.

Thank you for the suggestion. We are working on uncertainty estimates for the HSR1 AOD to include in a revised version of the manuscript.

16. P8L183: How does tau_gas depend on the vertical profile of temperature and pressure? Is ozone the only type of gas that contributes?

The AOD retrieval in this study only considers the contribution of ozone columnar amount. We have updated the text to make this point clear (Section 3): "For τ_{gas}, only the effect of ozone is considered due to the wavelengths considered as other gaseous absorption is considered negligible (Koontz et al., 2013; Ermold et al., 2013). In addition, only the column amount of ozone is considered (i.e., no vertical dependence)."

17. The figures are well presented but include all formula signs in the text. Example Fig. 2: "F_total".

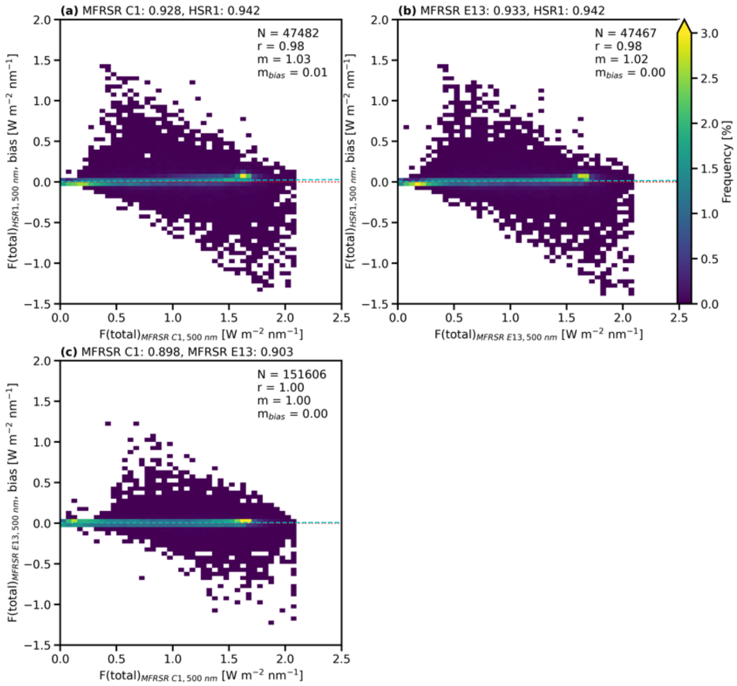
Thank you for the suggestion. We have revised the text to change to formula signs throughout.

18. All frequency histograms give the mean value of the two-month period. I am not sure if this is an appropriate measure since the data are not normally distributed and may have multiple modes.

The frequency histograms along with the regression lines, especially the regression line of the bias in the subplots, provide an evaluation across the distribution beyond the means. We have also added in the root mean square error to all plots for another evaluation metric. See Figures 5-12 and B1. Furthermore, the regression line of the bias helps capture how the bias changes across multiple modes.

19. 2d: Only the regression line is shown here. What does the scatter plot look like?

The frequency plot of the bias is shown below. The regression lines are shown to summarize the bias tendencies. The frequency plot of the bias is not shown in the manuscript as similar information is shown in Figure 5a-c.

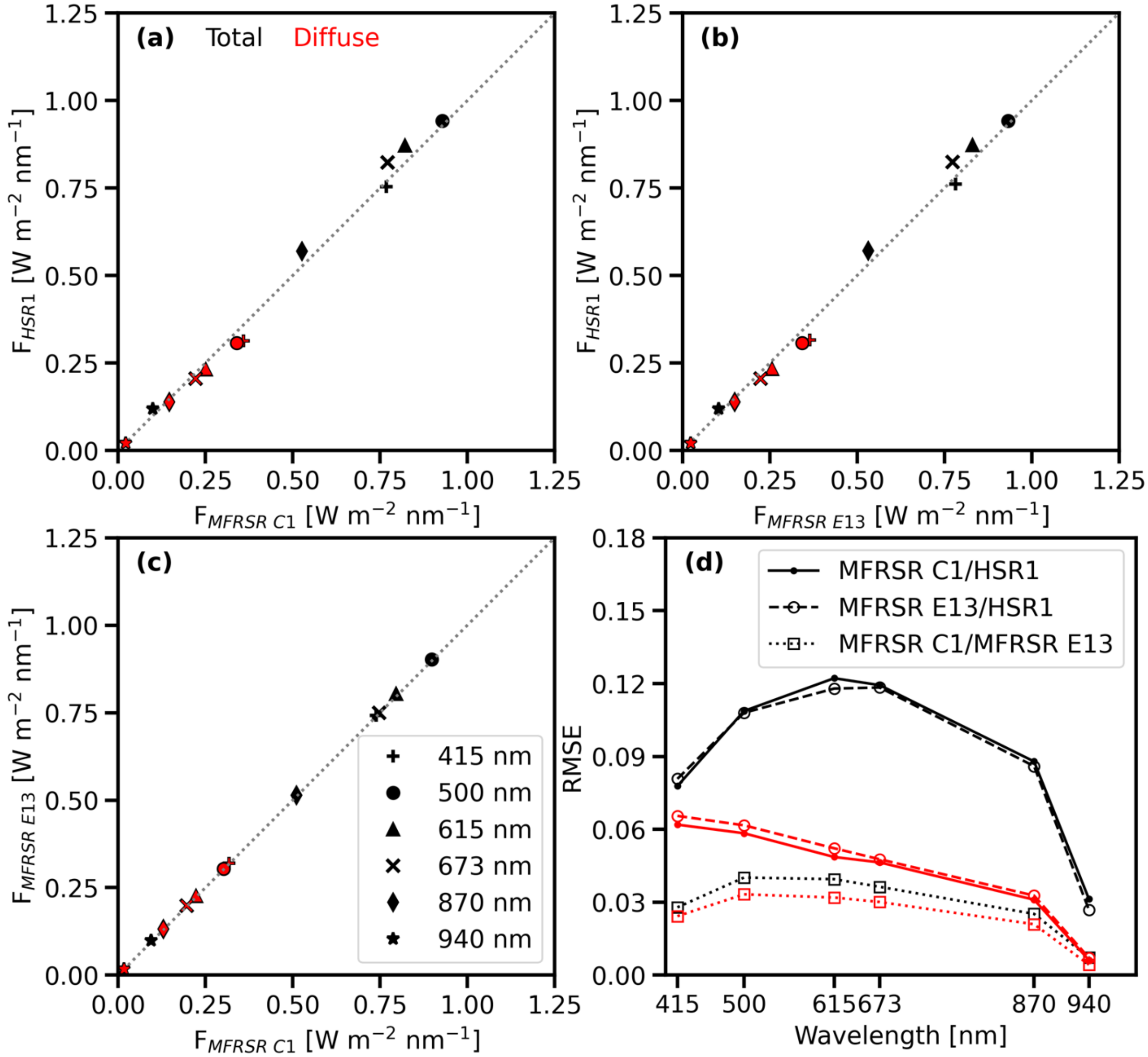


20. All scatter plots / frequency histogram: Is the scatter between the different instruments within the measurement uncertainties?

We plan to include text on the comparison of the instruments in terms of the uncertainties in a revised version.

21. 4: same as Comment#16. To show a possible wavelength dependence, it might be helpful to plot the RMSE as a function of wavelength. Table 1 is sufficient for the interpretation of the sign of the bias.

Thank you for the suggestion. We have added in a plot of the RMSE as a function of wavelength to Figs. 7d (previously Fig. 4). See revised figure below.



22. Table 1: Way too many numbers. I recommend reducing the data to the HSR1 comparison only. The AOD results should be given in a separate table in Sec. 4.2.

We have removed previous Table 1 to improve readability.

23. 4.1.1: I don't see any gain in information when the comparison results between the other instruments are shown. It is a bit monotonous to give all the numbers in the text which can be read from the table. The same holds for the AOD comparison P18L340-L351.

The comparison results between the other instruments provide a reference for the HSR1 comparison. We have revised the text to highlight this point for why the other instruments are compared. For the irradiance, the text is revised to (Section 4.1): "The MFRSR C1 and MFRSR

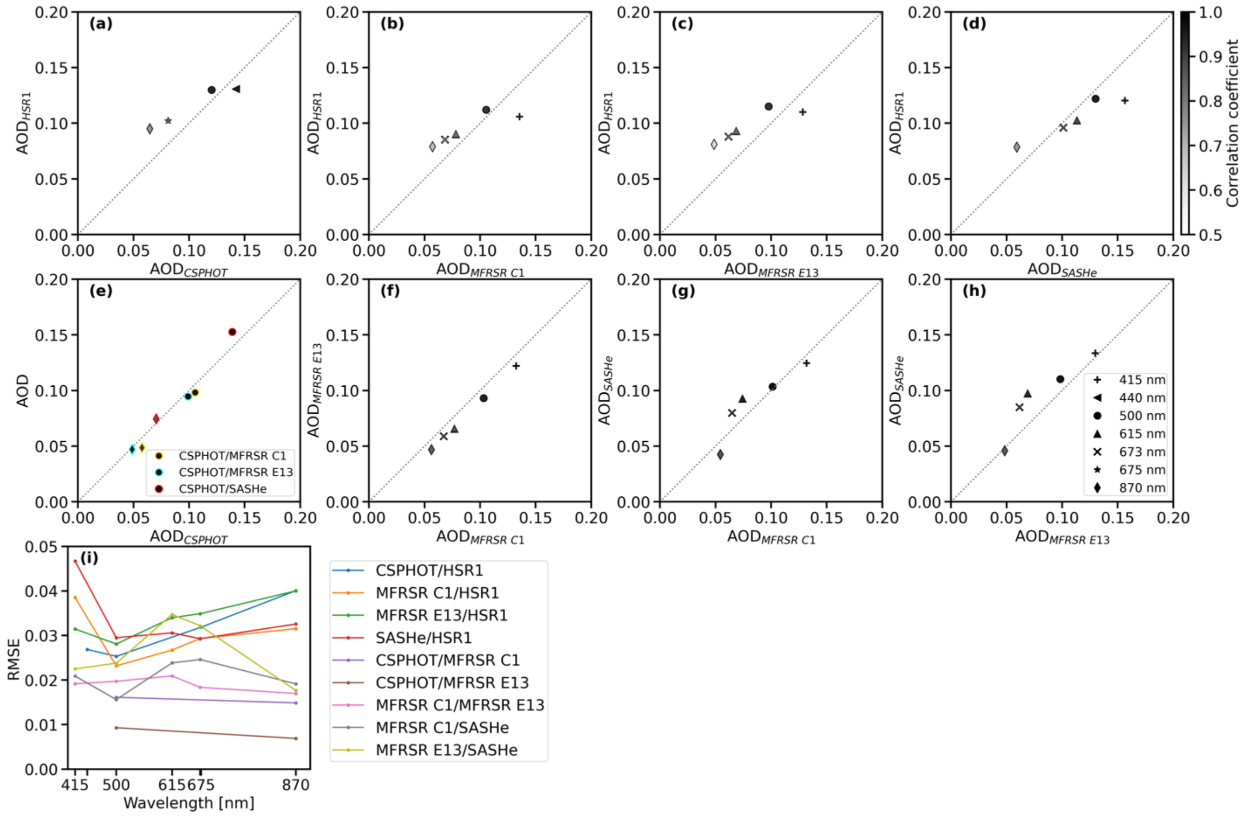
E13 spectral irradiances are also compared to each other in Fig. 5 and Fig. 6 to provide context to the HSR1 comparison by considering the comparison of established instruments that are also the same instrument in nearly the same location." For the AOD comparison, the text is revised to (Section 4.2): "The CSPHOT, MFRSR C1, MFRSR E13, and SASHe AODs were also compared for AOD at 500 nm to provide context to the HSR1 AOD comparison based on the comparison of established instruments and AOD retrievals." We have also removed the tables and reduced the text to clarify the story.

24. P21L363: "The spectral AOD results at all wavelengths are similar to those at 500 nm (Fig. 6)" – rewrite. The absolute numbers are not similar.

We have revised the text to make clear that the relative ordering of the comparison is the same across the wavelengths and not the numbers (Section 4.2): "The relative ordering in the AOD comparison at all wavelengths are similar to those at 500 nm (Fig. 9): the mean HSR1 AOD is larger than those from the CSPHOT and the two MFRSRs except for the mean SASHe AOD, which is larger than the mean HSR1 AOD."

25. 7: same as Comment 21: To show a possible wavelength dependence, it might be helpful to plot the RMSE as a function of wavelength.

Thank you for the suggestion. We have added in a plot of the RMSE as a function of wavelength to Figs. 10i (previously Fig. 7).



26. Maybe swap Sec. 4.3.1 and Sec. 4.3.2. It would make more sense to look at the diffuse spectral components first before showing the integrated values.

Thank you for the suggestion. We have swapped Section 4.3.1 and Section 4.3.2 in order to present the diffuse spectral diffuse ratio comparison before the broadband diffuse ratio comparison.

27. P22L408: "The motivation of this comparison is to understand if the HSR1 integrated diffuse ratio captures the diffuse ratio in the absence of a diffuse broadband irradiance observation (e.g., only total broadband SW measurements) despite measuring only a portion of the solar spectral range." The wording could be improved. Do you mean "broadband" in the sense of solar broadband? The spectral integration of the measured total and diffuse irradiance gives a broadband irradiance but not fully covers the solar spectral range. To identify the missing fraction could be analyzed more deeply by using a radiative transfer model.

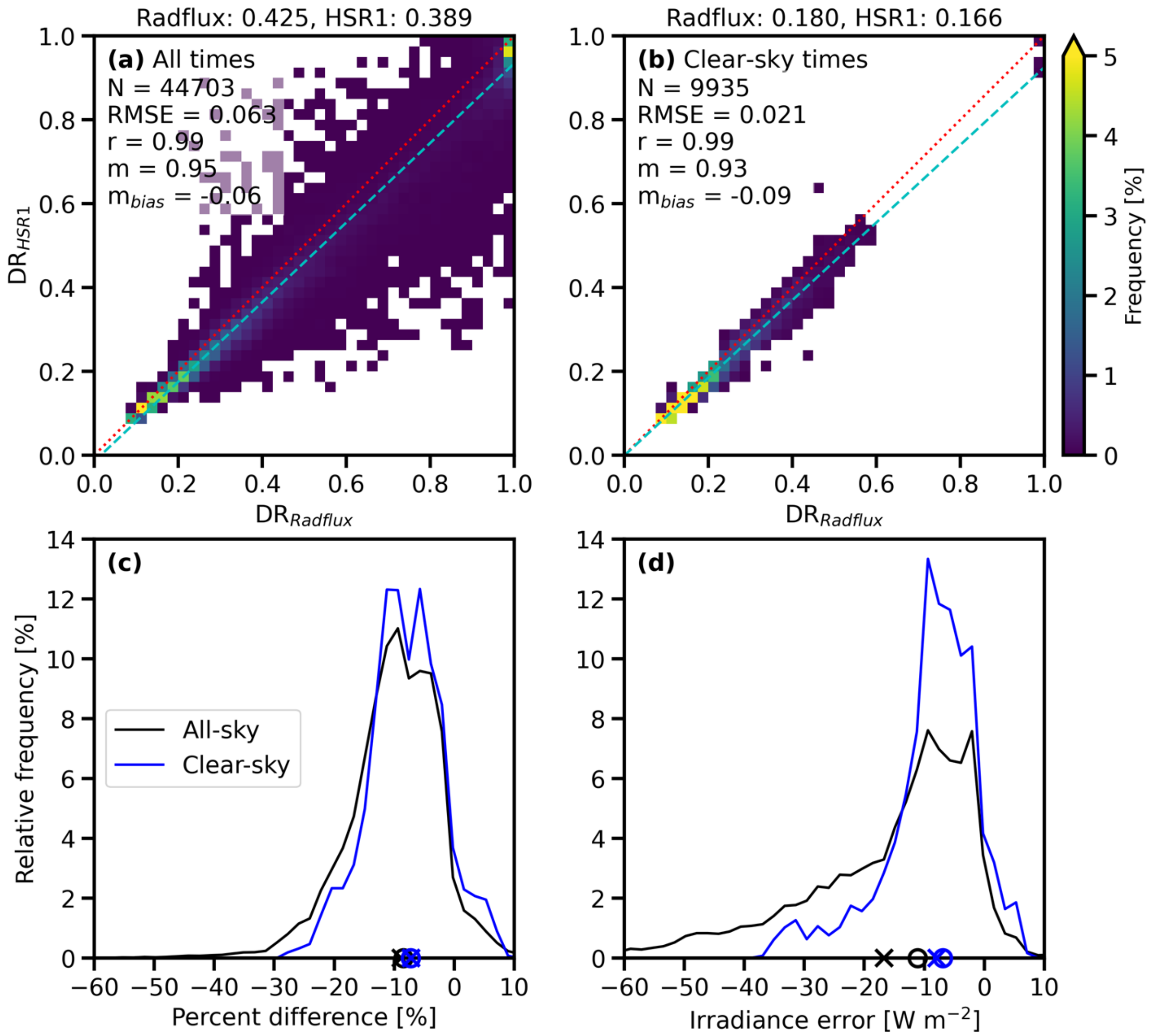
We have revised the text to clarify that it is the solar broadband (Section 4.3.2). We agree that a radiative transfer model could identify the missing fraction. However, our intent is to assess how well the diffuse ratio measured by the HSR1 compares to those that are measured by solar broadband instruments.

28. P23L412: A lower mean diffuse ratio is reported for the HSR1 than derived from the Radflux instrument which covers a broader spectral range. I would expect it to be the other way around, since with increasing wavelength the diffuse ratio decreases strongly, as radiative modeling could show.

Yes, the low bias in the HSR1 diffuse ratio is due to the low bias in the HSR1 diffuse measurement, which is opposite of the high bias induced by the smaller spectral range of the HSR1 compared to Radflux. We have added into the text clarification that the smaller spectral range would introduce the opposite bias observed (Section 4.3.2): "Furthermore, the smaller solar spectral range of the HSR1 would induce a high bias as the diffuse ratio decreases with increasing wavelength. This further suggests that the low bias in the HSR1 diffuse measurements is the dominant feature for the low diffuse ratio bias."

29. P23L422: "The mean diffuse flux error is -16.7 and -7.9 W m-2 for all times and clear-sky times, respectively." Perhaps it would be better to show a distribution of the bias illustrating the different modes.

Thank you for the suggestion. We have revised the figure from a boxplot to relative frequency plots in new Figure 12 c&d (see below).



30. P23L423: "Noting the measurement uncertainty of ±3% in the diffuse flux (Michalsky and Long, 2016), only 16.5% (all times) and 18.3% (clear-sky times) of the diffuse flux errors due to considering the HSR1 diffuse ratio are within measurement uncertainty." I do not understand this sentence. Please rephrase.

We have revised this sentence for clarity (Section 4.3.2): "The measurement uncertainty of the $F_{broadband,diffuse}$ is ±3% (Sect. 2.2.4). If the $F_{broadband,diffuse}$ is determined by the DR_{HSR1}, then the $F_{diffuse,error}$ considering the DR_{HSR1} are within the $F_{broadband,diffuse}$ measurement uncertainty only 16.5% (all times) and 18.3% (clear-sky times) of the time."

31. P25L471: "The SASHe clear-sky spectral diffuse ratios were also compared at 415, 615, 673, and 870 nm. The results are found to be similar to the 500 nm results." – rephrase. The absolute numbers are different.

Thank you for the suggestion. We have revised the text for clarity (Section 4.3.1): "The relative differences at other wavelengths are found to be similar to the 500 nm results."

32. Discussion section: It is not really a discussion of the results. Definitely more content and deeper thinking about the reasons, uncertainties, and relationships between the quantities is needed here. The information on calibration and post- processing is quite vague.

We are working on expanding the discussion section to include further discussion and plan to include in a revised version.

33. Summary section: This section is a way to long. It repeats all the numbers which is kind of exhausting for the reader. Try to reduce it to the main points.

Thank you for the suggestion. We have reduced the summary section to the main points.

34. Conclusion section: I do not find any conclusion here. What can the reader learn from this study?

We are working on expanding the conclusion section and plan to include it in a revised version.

Technical Comments

1. P3L78: "C1 (36.607322 °N, 97.487643 °W) and E13 (36.604937 °N, 97.485561 °W)." – Give the distance.

Thank you for the suggestion. We have added a map of the instruments' locations across the site in new Figure 1 (see below), which indicates that the physical distance is 170 m or less.

2. P7L158: “Ozone satellite”: rephrase

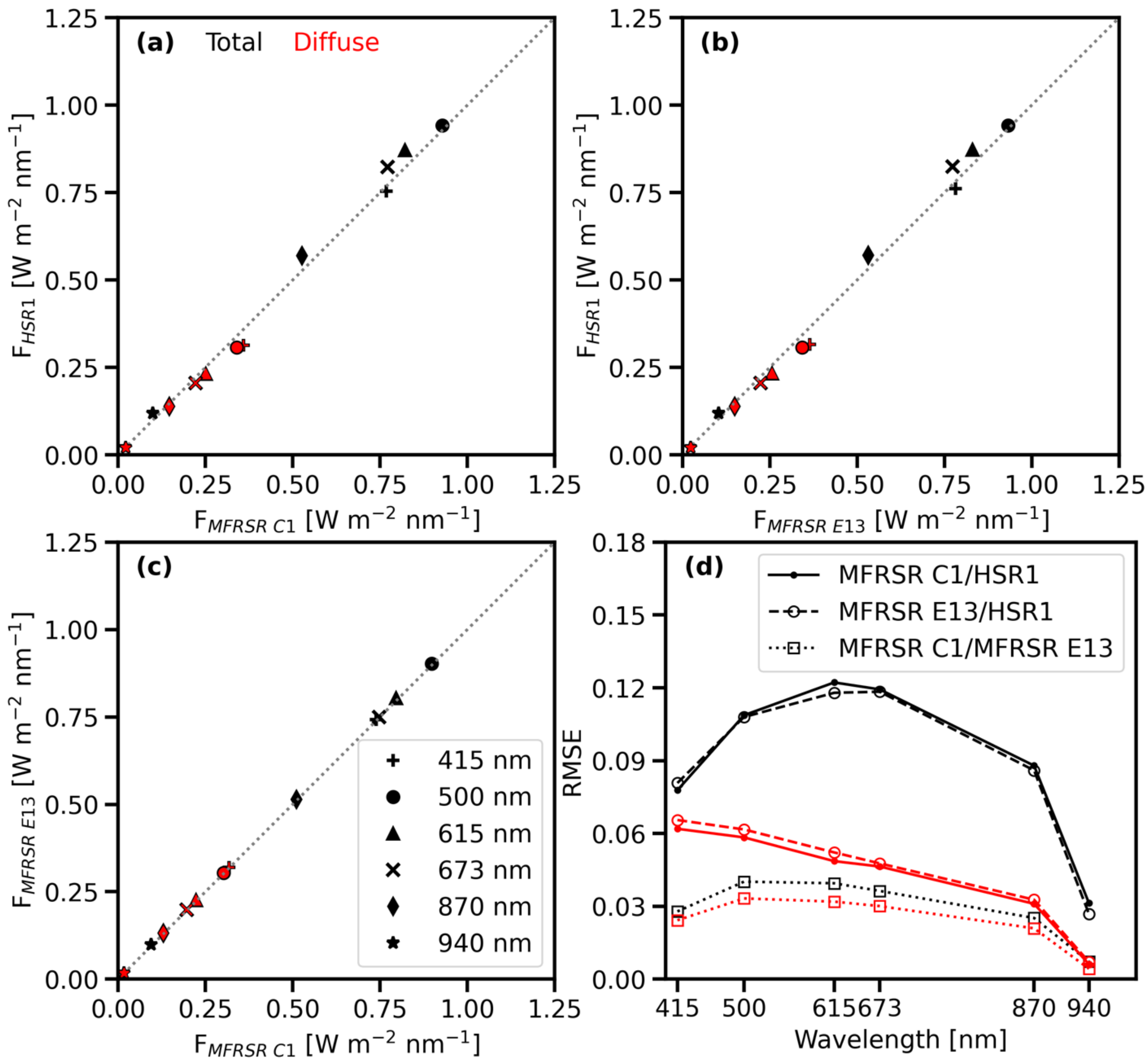
We have rephrased “Ozone satellite” to “OMI” (Section 2.2.6) to follow the styling of the other data sections.

3. P7L151: “PQS1”: What does it mean?

PQS1 is the instrument name, which stands for PAR Quantum Sensor. We have revised the text to include this information (Appendix B).

4. 4: Symbols and labels are too tiny.

We have revised Figure 7 (see below) by increasing the size of the symbols and increasing the font size of the labels.

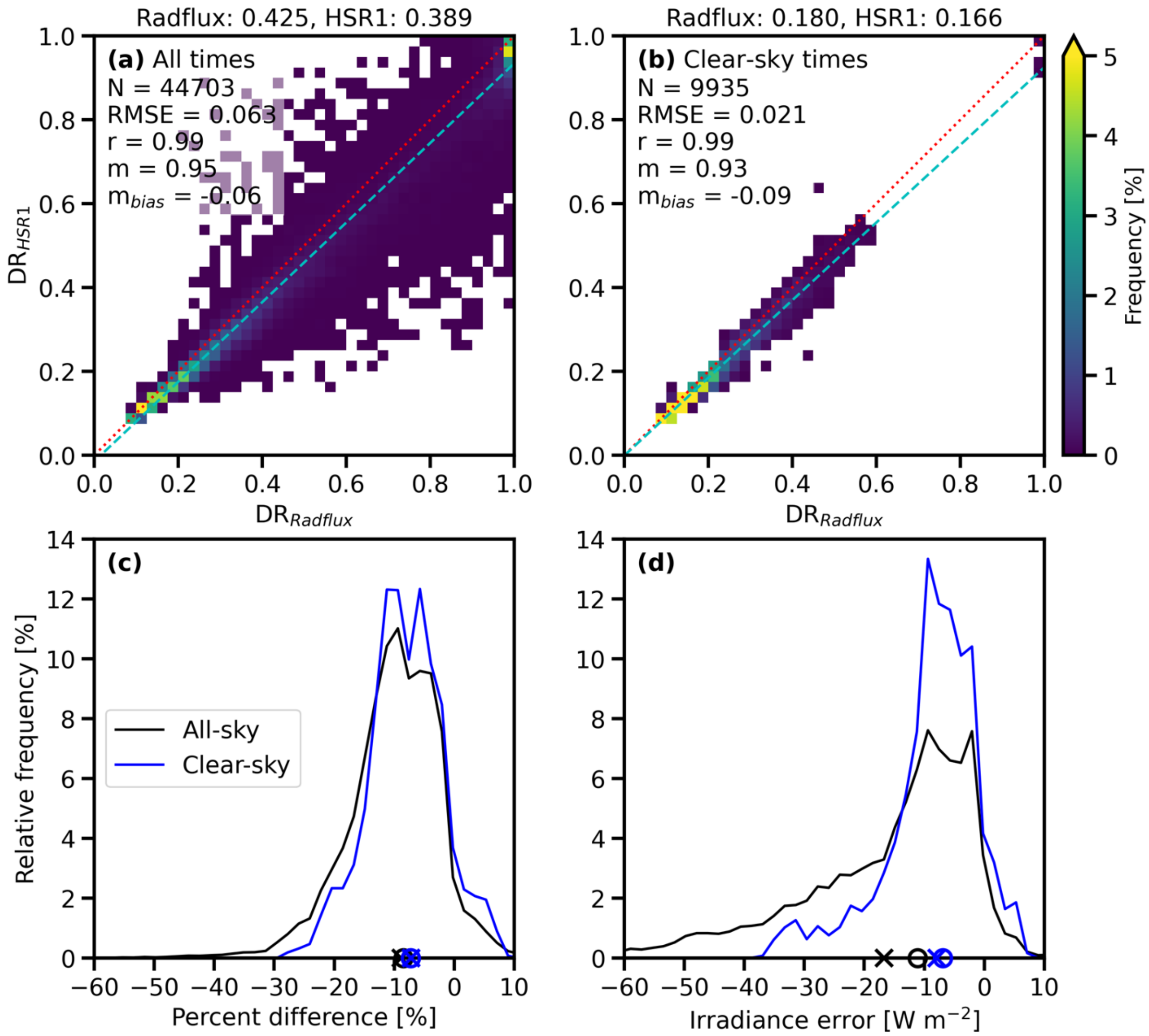


5. P15L247: “MFRSR filter” à MFRSR narrowband filter

Thank you for the suggestion. We have revised the text from “MFRSR filter” to “MFRSR narrowband filter” (Section 2.2.2).

6. 8c: No y-axis label.

We have added in labels for the x-axis and y-axis for new Figure 12 c&d (previously Figure 8c). See revised figure below.



7. P23L418: Here and at other locations the term “flux” is used. Keep using the term irradiance.

Thank you for catching this. We have replaced “flux” with “irradiance” at this point in the text (Section 4.3.2) as well as throughout.

8. P24L437: “F” irradiance in italic

We have revised the text to italicize the “F” (Section 4.3.2): “$F_{\text{diffuse, 500 nm}}/F_{\text{total, 500 nm.}}$”