Hannover, 19.08.2025

Dear Editorial Team,

Dear Reviewer,

Thank you very much for your efforts and for taking the time to read our paper "Case study on the impact of moving broken clouds on spectral radiance". Your comments and suggestions were helpful and will further improve the quality of the paper. We hope we were able to answer your comments satisfactorily. Below are our responses to your comments.

Kind regards

Jens Duffert (lead author)

General comments:

The manuscript presents a case study in which the Advanced MUltiDIrectional Spectralradiometer (AMUDIS) was used to measure spectral radiance in different directions under cloudy and cloud-free conditions on two different days. It was observed that the spectral radiance was by a factor up to 3 higher under cloudy conditions.

The availability of ground-based spectral radiance is – despite of their relevance for cloud-radiation interaction studies – very limited and thus this study is in my opinion highly important to the community and suited for publication in AMT.

The manuscript is in general quite well structured and - with some exceptions - clearly written. The literature has been carefully selected and cited. Graphics and tables are in general clear and the captions self-explanatory (but not always, see minor comments). The physical interpretations of the results could partly be improved. In addition, an outlook on further planned activities and capabilities of AMUDIS should be included in the conclusions. When the substance of the content is improved by giving more thorough physical explanations of the results, and the focus is sharpened towards a more original, better structured and formulated conclusion including an outlook, this study will be an interesting and valuable contribution to the atmospheric science community and is in my opinion suited for publication in AMT.

Specific comments:

Section 2. Devices Materials and Methods.

Comment:
- state the spectral resolution of AMUDIS (e.g. in line 70)

Answer:
AMUDIS can measure between 280 and 1700 nm and is split into three ranges set by the manufacturer. These are:

UV: 280 – 390 nm with a resolution of 0.1 nm per pixel
VIS: 380 – 890 nm with a resolution of 0.5 nm per pixel
NIR: 880 – 1700 nm with a resolution of 1.3 nm per pixel

Comment:
- what about stray light and potential correction? Can you comment on that?

Answer:
Currently, no stray light correction is used. However, for this paper only the visible range was used. In this range we did not observe any significant difference between the dark signal and those ranges with wavelengths where no signal is expected. Therefore we concluded there is no detectable stray light in the VIS range. We operate the measuring device in a light-tight climate box so that no external radiation can reach the spectrometer. We also shade the device from direct sunlight using a shadow band, which minimises overexposure in certain directions.

Comment:
- Why is the FOV different for different fibers? Production and alignment of the fibers?

Answer:
Up to now we have no satisfactory explanation for this feature, although we have asked several specialists for fibre optics. One hypothesis is that it may be caused by the manufacturing process of the input optics. This could possibly also be a fibre property, as these have a very small diameter of approx. 50 µm. A more comprehensive analysis has been presented by (Tobar Foster et al., 2021.

Tobar Foster, M., Weide, E.L., Niedzwiedz, A. Duffert, J., Seckmeyer, G.: Characterization of the angular response of a multi-directional spectroradiometer for measuring spectral radiance. EPJ Techn Instrum 8, 12 (2021). https://doi.org/10.1140/epjti/s40485-021-00069-4, 2021.

Comment:
- calibration: I am confused: the method of Niedzwiedz et al. (2021) was used to calibrate AMUDIS (line 120). This is an absolute calibration method. However, you did not point out the absolute nature of the calibration but highlighted its stability only. Later you used counts for the individual measurements instead of W/m^2/sr/µm what is in principle appropriate because you calculated ratios. Nevertheless, you should clearly state if you have calibrated AMUDIS absolutely, especially since you highlighted in the abstract that AMUDIS can be used for the validation of RTM, which requires an absolute calibration.

Answer:
Sorry for the confusion and thanks for pointing that out. We checked how stable the measuring device is by using the UK-100 mentioned in Niedzwiedz et al. 2021 and limited the noise to a variation of +/- 3.5%. The cited paper is intended to show that the UK-100 itself is stable and it can be used for this investigation and also later for absolut calibration. The count values are then used to calculate the relative changes. The note about the RTM was intended to provide some perspective. We changed the text accordingly to avoid the confusion.

Niedzwiedz A., Duffert J., Tobar-Foster M., Quadflieg E., Seckmeyer G.: Laboratory calibration for multidirectional spectroradiometers, Measurement Science and Technology, https://doi.org/10.1088/1361-6501/abeb93, 2021.

Section 3: Results

Comment:
- why have you chosen the three fibers 4, 28 and 90 for analysis? Is it for these particular cloud scenes? Would different directions may be more suitable for these specific cloudy scenes?

Answer:
We selected these three fibres because they correspond well to the trajectory of the cloud and think this selection is sufficient for a first case study.

Comment:
- you pointed out a potential impact of aerosols in the cloud-free scene (line 224). Is there any aerosol information available (AOD, single scattering albedo...), e.g. from a nearby AERONET site?

Answer:
Unfortunately, no parallel aerosol measurements were taken, so we do not have this data available. However, measurements using various measuring instruments are planned as part of the C3SAR project (Cloud 3D Structure And Radiation, https://c3sar.de).

Comment:
- the physical interpretations of the observed features are sometimes limited, e.g. what is the physical cause of individual readings to be lower than the uncertainty limit of the cloud-free reference (line 350)? Or what is the physical explanation for higher ratios for longer wavelengths (line 400)? Try to give a more concise and physically-based interpretation for such cases

Answer:
A first attempt to explain these results can be seen in the following graphs. It should be noted that this paper only analyses a period of 10 minutes. Therefore, the following statements are initial hypotheses and must be taken with caution.

In the first graphic, this is for the "Broken cloud with low cloud cover case". This case is divided into 4 situations:

1. There is no cloud in the sky. The fluctuations in the measurements are caused by device properties and changes in the atmosphere (in this case, these are smaller than the fluctuations are probably caused by the device properties only.
2. A cloud enters the FOV of the two fibres. The situation is such that the constellation cloud – AMUDIS optics – sun is present (from left to right in the figure). Thus, the cloud does not directly obscure the sun. As can be seen in Figure 6 in the paper, the ratios become greater than 1 for all fibres and wavelengths. This could be the result of the cloud reflecting radiation to the input optics. The wavelength dependence of the results can be caused by the reflection of radiation at the cloud surface and their return path through the atmosphere (Rayleigh scattering). This has already been discussed in Kylling et al., 1997 for the UV range. This would therefore occur on the ‘bright' side of the cloud.
3. The cloud is now directly above the optics and continues to reflect the radiation as in 2.
4. The cloud moves on and is now between the entrance optics and the direct sun beam. This means that they now shade the AMUDIS optics, causing the ratios to decrease again. Since the radiation is “modified” again by scattering on the cloud surface and thus

travels a longer path through the atmosphere. This also changes the radiation because of Rayleigh scattering.

This reflection on the cloud surface can then of course be different on the "white" side or on the dark side of the cloud, as the albedo of the cloud is different.

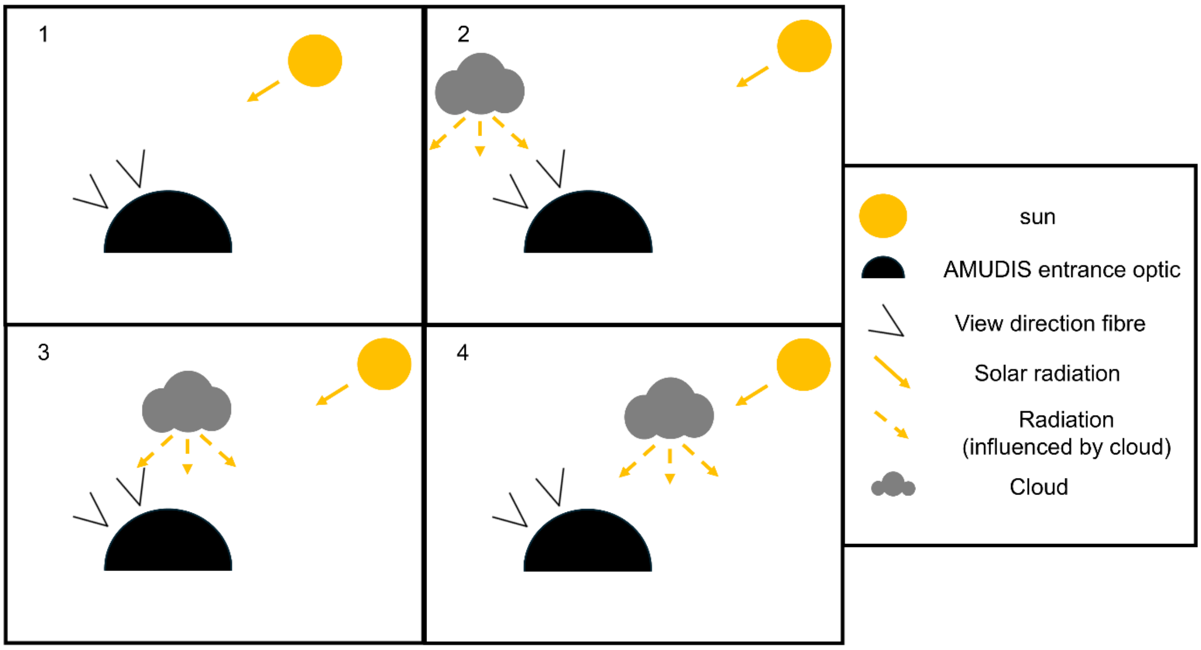

Figure 1: Sketch of the sun cloud interaction in the case with low cloud cover.

This also happens in the second case presented, the 'Broken cloud with higher cloud cover case'. However, it must be noted that the radiation scattered by the individual clouds is further influenced or 'modified' by other clouds. This multiple scattering by different clouds also reduces the directional dependence (case 1 in the lower figure). Also interesting are clouds in front of the direct sun beam (case 2 in the figure below) and clouds in the FOV of the fibres. This is the case presented in the paper between 13:20 and 13:22 UTC.

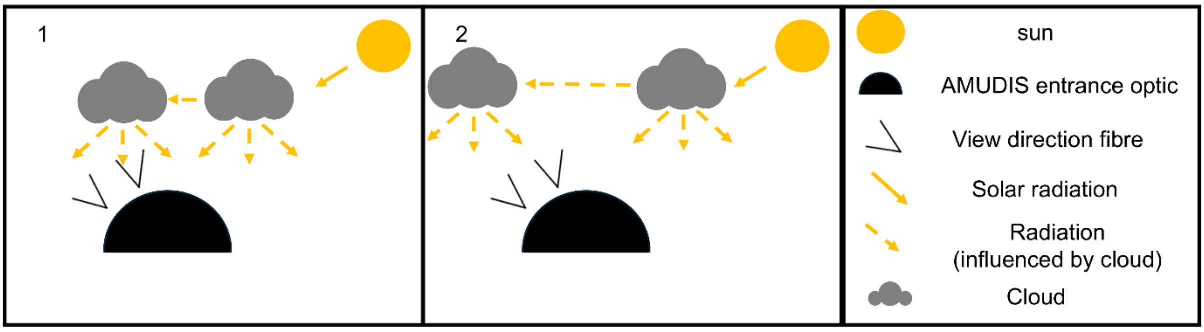

Figure 2: Sketch of the sun cloud interaction in the case with higher cloud cover.

All of the hypotheses mentioned are likely to be influenced by the type of cloud (e.g. due to differences in optical thickness) and the position of the sun. A larger data set is probably required in order to provide more comprehensive interpretations. In some cases, the clouds in the examples are quite transparent, meaning that there is hardly any dark side. In general, it is considered that the light side reflects more and thus causes an increase in the measured radiation, while the dark side causes a decrease (depending on the relative position of the cloud to the measuring device/fibre).

Kylling, A., Albold, A., Seckmeyer G.: Transmittance of a cloud is wavelength-dependent in the UV-range: Physical interpretation, Geophysical Research Letters Volume 24, Issue 4 pp. 397-400, https://doi.org/10.1029/97GL00111, 1997

Section 4: Conclusion and Discussion results

Comment:
I propose to include an outlook: what are your plans for AMUDIS in terms of technical activities and analysis, for instance:

- implementation of a stray-light correction (if necessary)?

- absolute calibration (if not yet conducted, see my comment above)

- are there any plans/possibilities to retrieve some macro-/microphysical aerosol and/or cloud properties from spectral radiance observations of AMUDIS? If yes, which ones?

- quantification of 3D radiative effects?

- validation of RTM

Answer:
In future, it is possible to calculate not only relative changes but also absolute changes using the absolute calibration described in the paper of Niedzwiedz et.al. In addition we intend to compare AMUDIS with other measuring devices. Further radiation effects are to be investigated as part of the C3SAR project (Cloud 3D Structure And Radiation, https://c3sar.de/). AMUDIS will there also be part of the large campaign planned for summer 2026. The calculated absolute radiance will be compare to the results of RTMs, at least in a statistical sense.

Minor comments

Comment:
Line 15: may insert "…the temporal variations of the spectral radiance was calculated…"
Answer:
Thank you for pointing this out. We will change it.

Comment:
Line 19: Validation of RTM: I would rather put this in the outlook. In addition, an absolute calibration of AMUDIS is required (see my comments above)
Answer:
Thank you for pointing this out. We will delete it here and add it to the outlook as described above.

Comment:
Line 23: delete "source"
Answer:
Thank you for pointing this out. We will delete it.

Comment:
Line 27: cloud and radiative properties
Answer:
Thank you for pointing this out. We will change it.

Comment:
Lines 33/34: May rephrase this sentence, e.g.: "Solar radiance at the surface can be observed using various measurement systems, such as:"
Answer:
Thank you for pointing this out. We will change it.

Comment:
Line 38: May rather use "constituents" than "parameters"
Answer:
Thank you for pointing that out. We will edit the sentence in lines 38 and 39

Comment:
Line 39: "…such as clouds, aerosols may not be detected…"
Answer:
Thank you for pointing this out. We will change the sentence with the clouds in and remove the clouds.

Comment:
Lines 46/47: may rephrase this sentence, e.g.: "…(HIS) systems, although they are mainly used to detect clouds, calculate the total cloud cover, classify clouds and study their radiative effects"

Answer:
Thank you for pointing this out. However, we would leave this sentence as it is.

Comment:
Line 51: Due to their automated…
Answer:
Thank you for pointing this out. We will change it.

Comment:
Line 56: May rephrase, e.g.: "Non-scanning multidirectional spectroradiometers such as the multidirectional spectral radiometer (MUDIS) and the advanced multidirectional spectral radiometer (AMUDIS)…"
Answer:
Thank you for the hint, we will change it so that we write in example after the first bracket.

Comment:
Line 60: What does "large-scale device" mean?
Answer:
Thank you for pointing this out. What we mean is that AMUDIS has a larger wavelength measurement range of 280–1700 nm than MUDIS, for example. We will adjust the wording accordingly.

Comment:
Line 60: I would delete the DFG approval
Answer:
Thank you for the hint. We will remove the DFG approval.

Comment:
Line 62: "temporal uncertainties in measurements in different direction of the atmospheric variability" sounds strange to me. You may mean that with AMUDIS you can observe the spatial and temporal variability of the atmospheric constituents and properties or similar, I guess.
Answer:
Thank you for pointing this out. We will change the sentence: "With the AMUDIS, it is possible to reduce the temporal uncertainties in measurements in different directions of atmospheric variability." to "With the AMUDIS, it is possible to reduce the time span between consecutive measurements in different directions of the variability of the radiance."

Comment:
Line 71: "…as described in Seckmeyer et al. (2018 and Tobar Foster et al. (2021), it is based on…"
Answer:
Thank you for pointing this out. We will change it.

Comment:
Line 87: may use "…the light is detected by three CCD image sensors"
Answer:
Thank you for pointing this out. We will change it.

Comment:
Lines 106-110: Caption of Figure 1: Use "upper left, bottom left and right" for the description of the three images. Define IMUK
Answer:

Thank you for pointing that out. We will add it and write out the acronym IMUK (meaning “Institut für Meteorologie und Klimatologie”) in full in the caption.

Comment:
Line 150: May add “Thus, an instrumental uncertainty of 3.5 % is assumed “ or similar
Answer:
Thank you for pointing this out. We will change it.

Comment:
Table 2: Shutter on: Replace “on” by “open”
Answer:
Thank you for pointing this out. We will change it.

Comment:
Line 234: May replace “at” by “for”
Answer:
Thank you for pointing this out. We will change it.

Comment:
Line 253: Isn’t it section 3.1 instead of section 3.2?
Answer:
Thank you for pointing this out. We will take it out.

Comment:
Line 269 and Line 345: Table 4 and Table 5: The minimum of the ratio is not indicated.
Answer:
Thank you for pointing this out. We did not list the minimum ratios in the tables because they are all within the +/- 3.5% limit (except for one point in time in Section 3.3) and therefore do not offer any direct added value.