Manuscript AMT-2022-288

Reply to Anonymous Referee #2

In the following, referee comments are written in italics, our replies in normal font. Sections describing changes in the manuscript are indicated in blue. Figure and Table numbers refer to the original manuscript and supplement.

The authors determined the angular response of optical inlets for measuring actinic flux densities and provided corresponding correction functions for ground-based and airborne applications and a wide range of atmospheric conditions. Their approach is based on detailed laboratory measurements combined with extensive radiative transfer calculations. Overall, the manuscript is well suited for publication in AMT. However, some comments might be considered before.

Reply: We thank the referee for the positive feedback and helpful comments.

General Comments
The authors give a lot of details to demonstrate what they did. The supplement material even extends their efforts to show everything that was made. This brings me to the main general comment. The reader might be overloaded by the number of plots and information specific to author's optics and applications. Therefore, the authors should consider limiting their plots to those that show significant differences. For example, it is not necessary to show the results for the four selected wavelengths for all investigations.

Reply: We agree that a lot of material is presented. We tried to make each step as plausible and reproducible as possible with the help of the figures. The wavelength dependence in the measurement range is an important aspect of the study. The only figure (with extra panels) in the manuscript that shows rather small differences between different wavelengths is Fig. 17 (HALO measurement example, 400, 500 and 600 nm). However, it would be inconsequential to omit the wavelength dependence in this last plot showing the finally corrected data. We agree that in other figures in the Supplement the differences are small. To reduce the figure load, we removed Figs. S26, S27, S29 and S30 from the Supplement. The corresponding references were removed from the text in L379, L409, and the captions of Fig. 12 and Fig. 13.

Specific Comments
P2L46: "the accuracy of measurements in the UV-B range" – I think it is rather a question of sensitivity what is meant here. Technically, the accuracy includes also the uncertainty due to a non-perfect angular response.

Reply: What we mean is explained in the paragraph (i) below (L48-L54): it's a combination of enough UV sensitivity and a correct treatment of stray light which both affect the accuracy. We replaced "accuracy" by "specificity" in L46.

P2L52: Maybe also refer to Jäkel et al. (2007) (https://doi.org/10.1175/JTECH1979.1) who discussed the stray light correction for a similar instrument.

Reply: We were too much focussed on introducing our own accompanying paper. We changed the sentence to: "In previous studies suitable approaches were described for a widely used type of spectroradiometer (Jäkel et al., 2007; Bohn and Lohse, 2017)". The corresponding reference was added.

P3L64: "…, owing to the greater importance of upward radiation, …" Why is it of greater importance?

Reply: We extended the sentence: "…, owing to the greater importance of upward radiation, reflected by underlying air columns and clouds, …"

P4L96: "of typically high spectral radiances in both hemispheres." This is not necessarily valid, e.g., flights performed over land or open water under cloud-less conditions show a low contribution of upward radiances.

Reply: We discuss these cases in the succeeding sections. We changed "typically" to "commonly" which is certainly true for most airborne measurements.

P7 Fig3: I'm wondering if this could be combined with the cross-section plots shown in Fig.4.

Reply: Although the figures somehow belong to each other, they have different formats which makes it difficult to combine them without creating empty space in the resulting figure (which in addition would have to be downsized significantly). The figure sizes were chosen to fit in one column of the final two-column format of the journal. We are confident that the figures can finally be positioned next to each other.

P8L172: "Because of the rotational symmetry of the receivers, dependencies on azimuth angles are minor." From the contour plot (Fig.3b), I would estimate a distinct variation of the angular sensitivity in azimuth direction (for 60° polar angle). Is this considered as minor dependence?

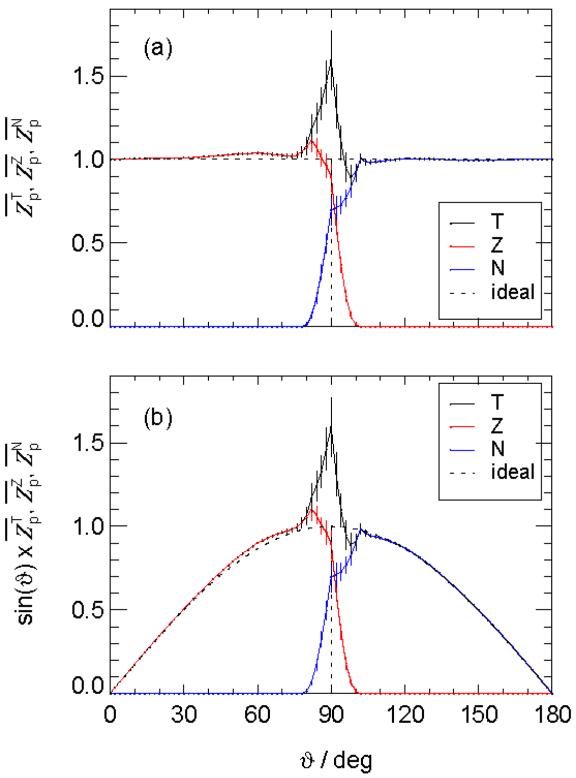
Reply: Each receiver is different. As the example shows, there were some variations in a 5% range. These can still be considered as minor because they do not translate to a 5% variability of the measurements unless radiation is received from a single direction. We changed from "minor" to "typically minor (<5%)" to specify.

P8L176: "The dependencies on polar angle and the wavelength Zp dependence are slightly different for the different receivers." Please give the range.

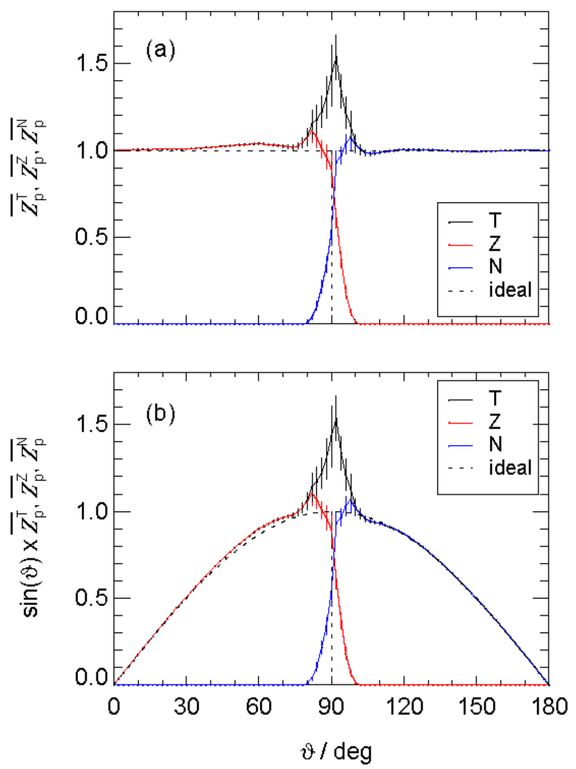
Reply: We extended the sentence "… for different receivers but can differ by up to 15% at greater polar angles."

P11 Fig5: Here, azimuthal averages are plotted. Think about to show also the corresponding standard deviation as in Fig. 4.

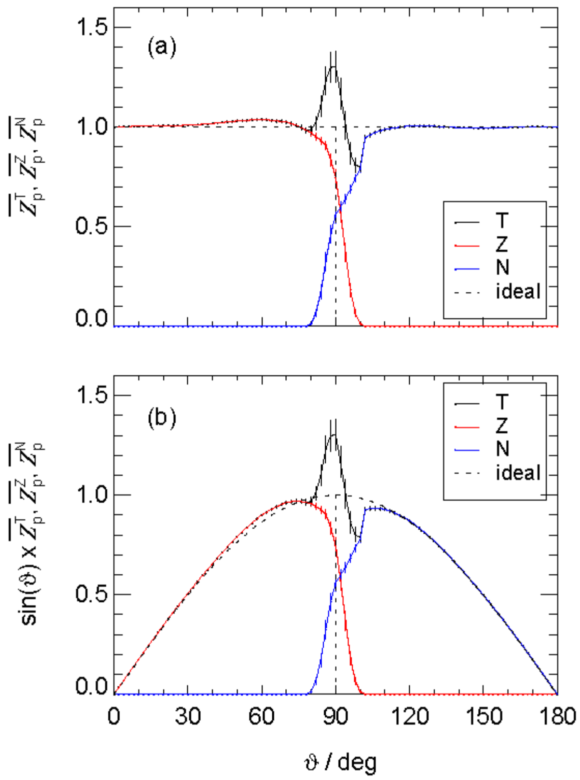
Reply: The referee probably means Fig. 6. The standard deviations would be misleading here because the field-of-view effects can introduce strong azimuthal dependencies close to the horizon as shown in Fig. 3. Instead, we added the estimated uncertainties for the mean values and noted this in the caption of Fig. 4 and the corresponding Figs. S9, S11 and S13, see below. As mentioned in L195-199, Fig. 5 merely serves to visualize the (average) contributions of the top and bottom receivers. These mean data are not used to calculate corrections except for the hypothetical case of an isotropic radiance distribution as discussed in the paragraph L200-204. In this case the use of the mean values is justified. The final corrections are calculated based on the data shown in Fig. 5 (exemplarily for 400 nm). To clarify we extended the sentences in L204-206: "In order to obtain more realistic corrections, sensitivity distributions as shown in Fig. 5, as well as wavelength dependent direct sun contributions and diffuse spectral radiance distributions are required. The latter information is usually not available under measurement conditions."



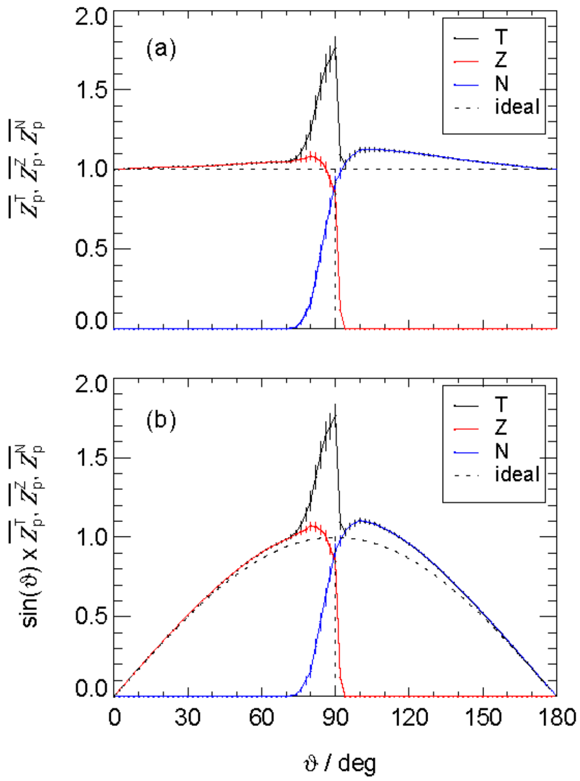
Revised Fig. 6.: (a) Azimuthal averages of total relative angular sensitivities Z_p^T (T) of HALO shown in Fig. 5 with contributions Z_p^Z (Z) and Z_p^N (N) of top and bottom receivers, respectively, for a wavelength of 400 nm (2°-interpolations). Error bars represent estimated mean uncertainties not covering azimuthal variabilities. The sensitivities of ideal 2π and 4π-receivers are shown for comparison (dashed lines). (b) The same data as in (a) but multiplied with sin(ϑ) to account for the ϑ-dependence of solid angle contributions.



Revised Fig. S9.



Revised Fig. S11.



Revised Fig. S13.

P12L200: "In panel (b) of Fig. 6 relative sensitivities were multiplied with sin(θ) to account for the solid angle contributions consistent with the θ-dependent areas in the projections of Figs. 3 and 5." I'm not sure if this step is obvious for the reader.

Reply: The projections are introduced in L170. We extended the sentence to explain more clearly: "An azimuthal equal-area projection was chosen to correctly reproduce the solid angle contributions for different polar angles relevant for actinic flux density measurements, i.e. the areas increase with the sinus of the polar angle consistent with Eq. (2) ($d\omega = \sin(\vartheta)\, d\vartheta\, d\varphi$)."

P13L242: "The applied ground albedos are based on literature data." Please give reference. Same for the cloud settings (L248).

Reply: In L238 we added one sentence and three references related to the cloud microphysical properties: "These data represent typical values adopted from the literature (Miles et al., 2000; Sassen and Comstock, 2001; Krämer et al., 2009)." In L242 three references for the ground albedo were added: "(Bowker et al., 1985; Feister and Grewe, 1995; Wendisch et al., 2004)". The references are the same as already cited in the Supplement.

P14L243: "… considered a normal ground albedo" Maybe it is better to call it a "default albedo" for your study. Same for the aerosol optical depth (L249).

Reply: The term "default" is used several times already for the libRadtran default aerosol. With "normal" we meant to say not too high and not too low. We will replace "normal" by "standard" throughout the text which hopefully reflects the intended meaning.

P14L263-P16L285: The authors present the simulations of the diffuse radiance field for cloud-less conditions. I would rather prefer to see a direct comparison to the more interesting cases that are shown in the supplement.

Reply: As the referee noted, the number of figures in the manuscript is already large and we therefore shifted the other examples to the Supplement. A cloudless case is considered more common as a reference and is suitable to introduce the two representations of the radiance distributions in Figs. 7 and 8. The interested reader will certainly look for the other examples in the Supplement.

P15 Fig.7: Could be combined with Fig.8.

Reply: Here the same arguments hold as for Figs. 3 and 4 which we repeat here: The figures have different formats which makes it difficult to combine them without creating empty space. The figure sizes were chosen to fit in one column of the final two-column format of the journal. We trust that the figures will finally be positioned next to each other.

P16 Fig.8: Is it reasonable to give azimuthal means here, since the distribution for the downward component has such a large azimuthal dependence? Think about a plot showing the principal plane direction instead.

Reply: The azimuthal and polar angle dependencies for 400 nm are shown in the contour plot in Fig. 7 as an example, also for the principal plane. We think that the azimuthal averages in Fig. 8 are more relevant quantities for the integrating measurements examined here because radiation from a specific direction is never received exclusively. Moreover, if the azimuthal dependence of the receiver sensitivities were small, their means could be used directly together with the azimuthal means of the spectral radiances to derive the corrections for diffuse radiation (compare similarities of Figs. 6 and 8).

P20L349: "clear-sky corrections": Does clear-sky corresponds with cloud-less conditions?

Reply: Yes, throughout the text clear-sky refers to cloud-free conditions as is common in meteorology (cloud-cover=0). We stated this in line 234 and clarify here again by extending the sentence: "The greatest AOD in the model led to clear-sky corrections, i.e., corrections in the absence of clouds, like for the Cs cloud case."

P22 Fig.11 / P23L390: "solar azimuthal position": Maybe use the term relative azimuth angle instead.

Reply: We changed the sentence accordingly: "A solar heading angle (γ_o) was defined describing the relative azimuth angle of the aircraft heading with respect to the sun: …"

P25 Fig.12: The number of dots should be 3 x 5 x 3 for this scenario, but it looks like less.

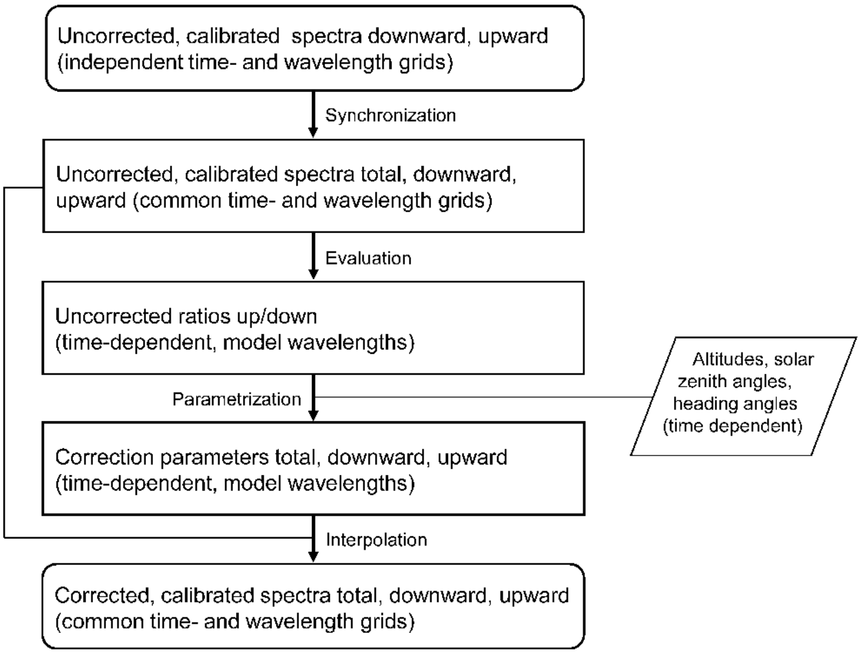
Reply: The scenarios that were used for the analysis are listed in Tab. S1. However, the scenario groups T (3) and A (5) share one scenario (with standard ground albedo and aerosol) which was not explained. We therefore slightly revised the table caption: "The letter T (turbidity) denotes three scenarios with different aerosol optical depth cases at standard ground albedo (A_{470} = 0.04), the letter A (albedo) four additional scenarios with different ground albedo cases at standard aerosol optical depth (AOD_{550} = 0.2)." The total number of scenarios therefore is (3+4) x 3 = 21 for the Zeppelin in Fig. 12 and (3+4) x 3 + 3 (Str) = 24 for HALO in Fig. 13.

P27L474: "altitude-interpolated coefficients": Do the atmospheric profiles of e.g. temperature and pressure have an effect on the altitude dependence?

Reply: In terms of the corrections the effects are expected to be insignificant compared to those resulting for the different atmospheric scenarios. This is confirmed by the test calculations for a ground elevation of 1 km (900 mbar) which produced very small changes. As was mentioned in lines 282-285: "Potential uncertainties of the model results were also not considered. Rather the variability of naturally occurring radiance distributions is assumed to be represented realistically by the different atmospheric scenarios." In line 262, where the model input is described, we will add a statement to clarify: "Atmospheric pressure and temperature profiles were not varied. Their influence is presumed to be insignificant compared to that of the different atmospheric scenarios."

P27L490: "A detailed description of the correction procedure is given in Sect. S7 of the Supplement." Maybe it is useful to provide a schematic that illustrates the correction procedure directly in the main manuscript.

Reply: These technical details were deliberately moved to the Supplement. We produced a schematic (see below) which however cannot include all relevant details given in Sect. S7. We'll put the new figure next to Sect. S7 in the Supplement where the numbering of steps was consistently adapted.



New Figure X: "Schematic of data evaluation steps to derive corrections for airborne measurements. More details are given in Sect. S7. The final step of data selection (dependent on platform-specific selection criteria, e.g., minimum altitudes, shadings etc.), was omitted."

P32L552ff: The paragraph partly contains advices which are obvious (e.g., "if measurements are made on a pavement or artificial platform in an area dominated by vegetated ground, measured upward flux densities can be misleading." In my opinion, it goes beyond the scope of this manuscript to go into the question of how to measure actinic radiation. Here the authors could shorten the text.

Reply: We removed the two sentences following "For example, …" in line 570. Moreover, we removed the two sentences following "A few more practical remarks…." and start the paragraph with "Generally, for measurements of downward spectral actinic flux densities the cross-talk to the lower hemisphere should be minimized…"

P35 Conclusions: I would suggest to give a final quantification of the corrections to illustrate their necessity.

Reply: We included a sentence in L681: "The corrections derived in this work typically ranged well below 10% for total and downward spectral actinic flux densities but became more significant for upward spectral actinic flux densities dependent on the platform and atmospheric conditions."

Technical Comments

P2L32: lifetimes – lifetime

Reply: Was changed as suggested.

P8L173: "are obviously invisible" - not visible ?

Reply: We changed to "not visible".

P9 Fig.4, P11 Fig.6: Please revise the legend. The dashed line is not shown as dashed line there.

Reply: The dashed line appeared as a single, shorter line in the legend which may be confusing. We changed the line-style to make the legend clearer. As the same line-style was used in several figures, all were changed accordingly, i.e. in Figs. 6, S9, S11, S13 shown above and Figs. 4, S5 (not shown).

P9l192: "in panel (a)" - give also figure number

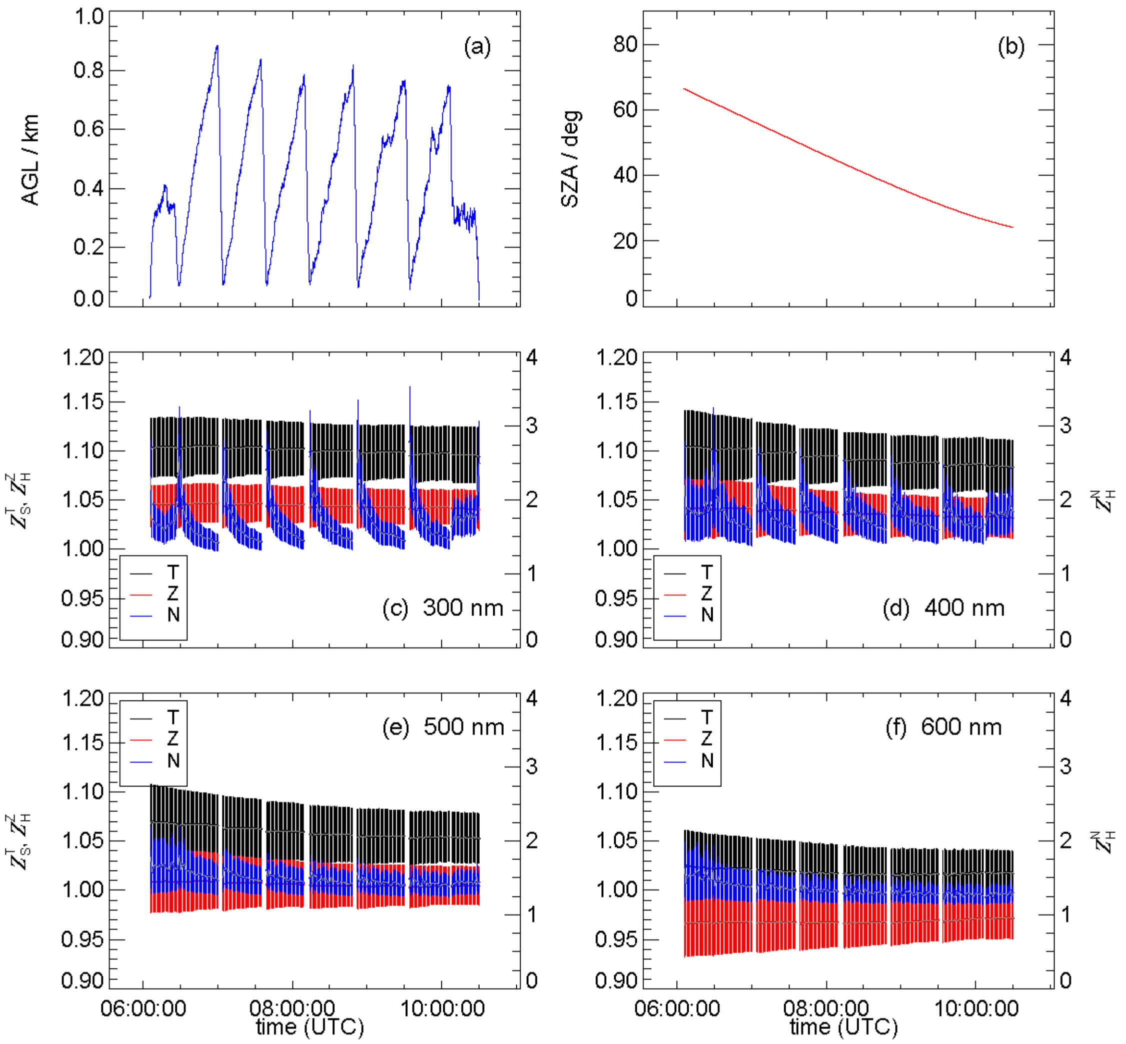
Reply: Was changed.

There are several figures without labeling the four panels.

Reply: We now consistently labelled different panels in all figures with (a), (b)… in Figs. 9-17. (Figs. 14-17 are shown below).

P28 Fig.14: Maybe adjust the range of the x-axis (zoom in, e.g. 06:00 – 10:15 UTC). The date is not required as x-axis label.

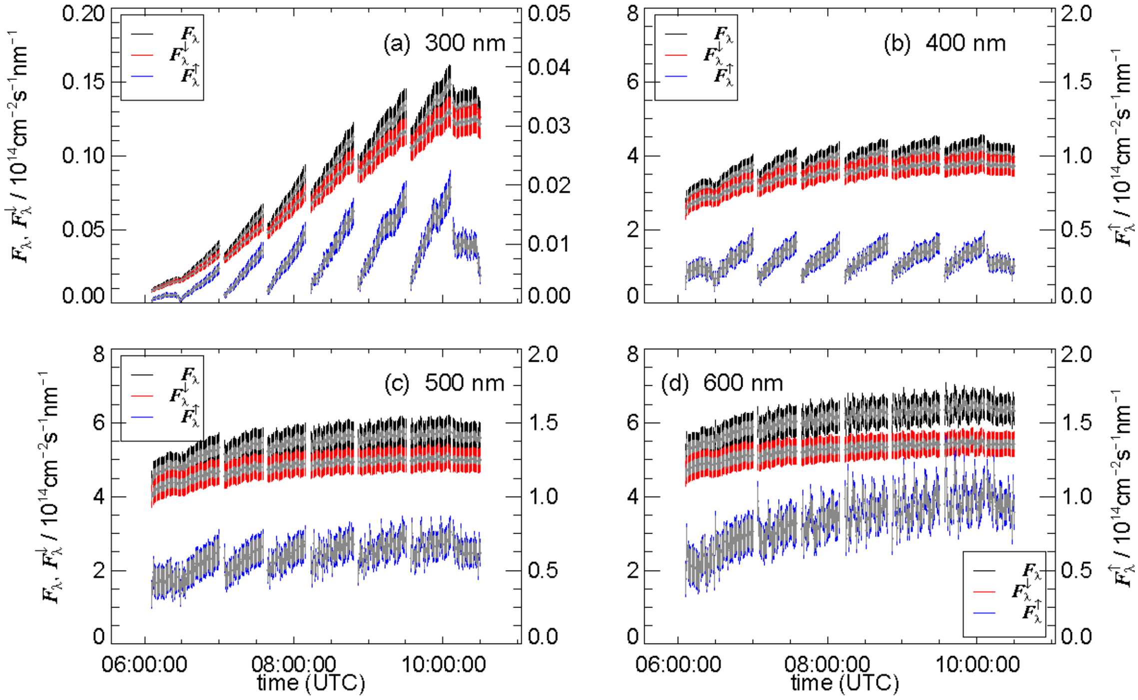
Reply: We changed the range of the x-axis, removed the date from the label and replaced it by "time (UTC)" to create a proper label, and rearranged the legends and labelling. Fig. 16 (HALO) was changed accordingly.



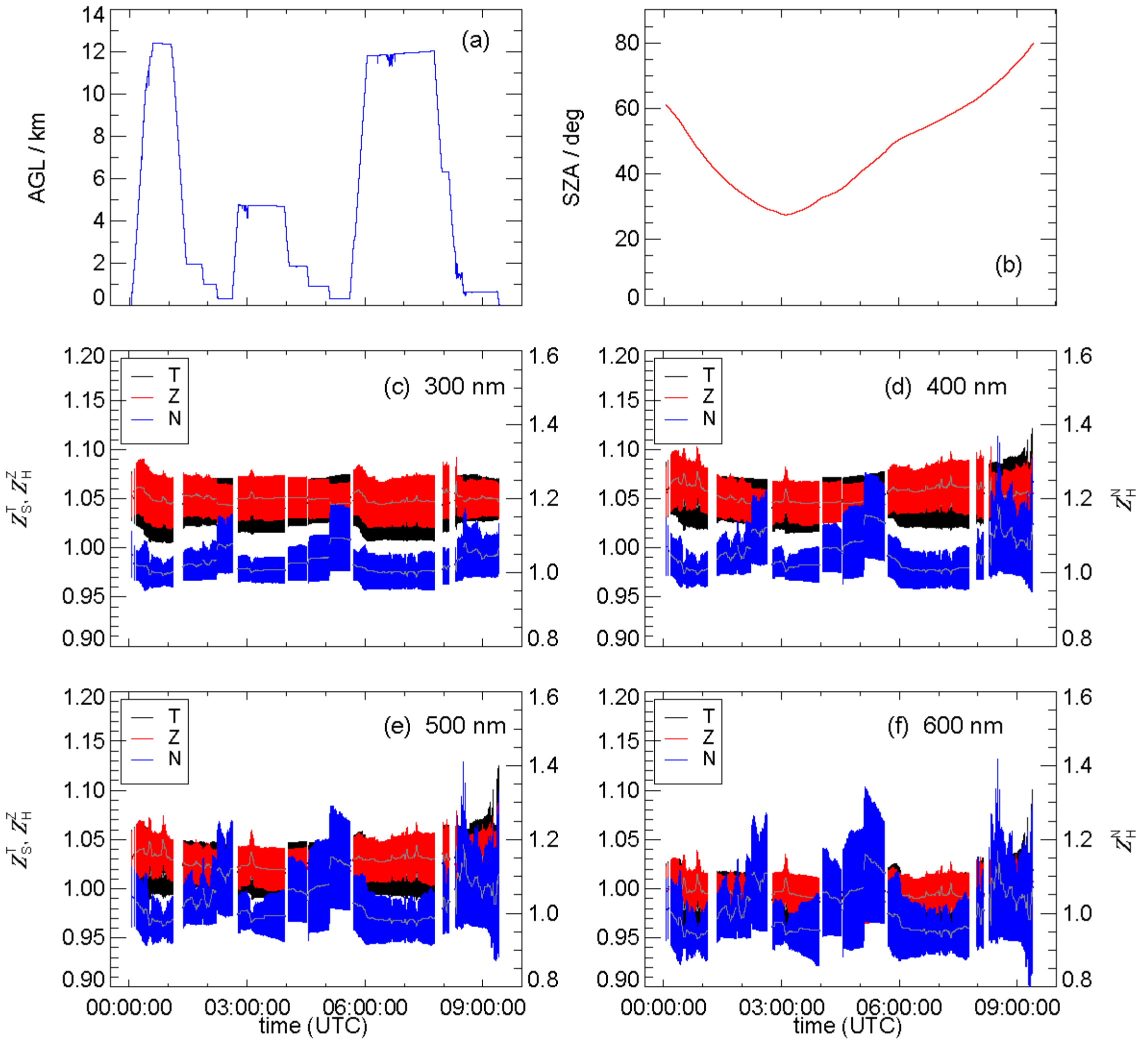
Revised Fig. 14.

P29 Fig. 15: Use the same y-scale if appropriate. It helps to make the plots more comparable.

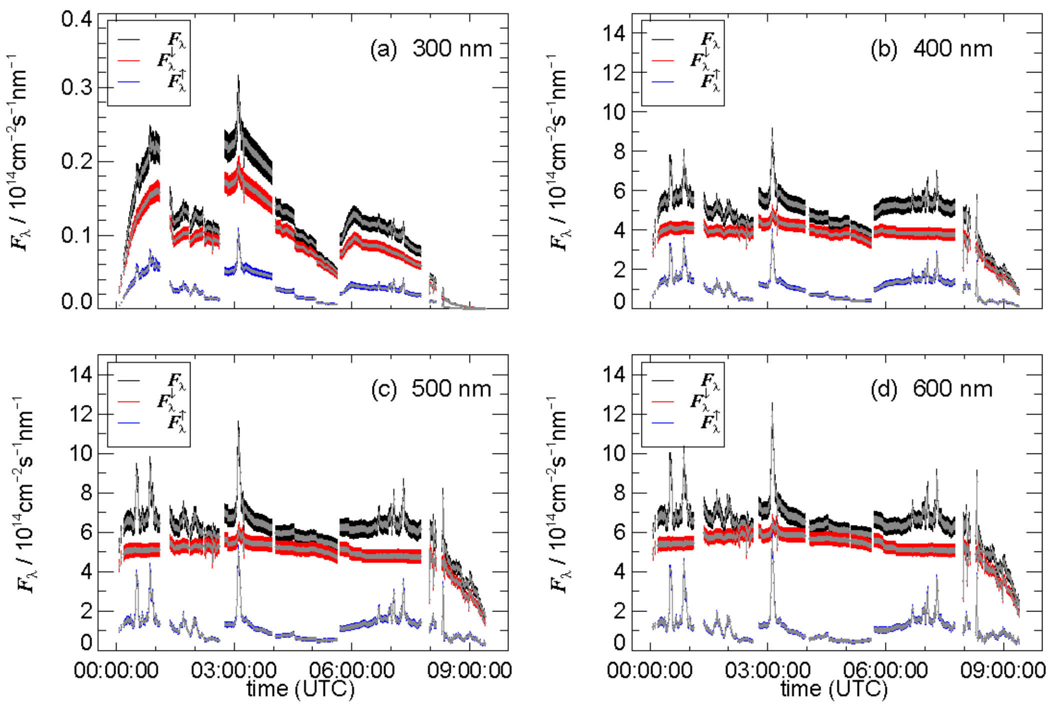
Reply: The y-range of the three VIS-range panels are the same now. Labelling was made as in Fig. 14. Fig. 17 was changed accordingly.



Revised Fig. 15. Error bars from the corrections alone are shown in addition, in response to referee #1.



Revised Fig. 16.



Revised Fig. 17. Error bars from the corrections alone are shown in addition, in response to referee #1.