Author response to referee comments

1. Referee comments (RC3) are in **BLACK**
2. Authors' answers (AC) are in **BLUE**
3. Changes in the manuscript (MC) are in **PURPLE**; the lines refer not to the original, but to the revised version of the manuscript.

Author's response to comments of Referee #3

AC: We thank the anonymous referee for the review and all the comments and remarks you made. We addressed all major and minor comments below, and stated what changes were made to the manuscript based on them.

RC3: This is a review of a revised version of a manuscript titled "Assessment of spectral UV radiation at Marambio Base, Antarctic Peninsula" by Čížková et al. I have also reviewed the response of the authors to the comments of two reviewers pertaining to the original version of the manuscript. I confirm that that the authors have addressed the reviewers' concerns appropriately. Unfortunately, I have found additional major flaws in the revised manuscript, which must be addressed before the manuscript can be accepted for publication. Most importantly, data of the Brewer spectrophotometer and the complementing model calculations should have been reported as "spectral irradiance", not "irradiance". Furthermore, data presented in the manuscript are too low by at least two orders of magnitude. Most data therefore have to be reprocessed. In addition, data presented in Figures 7–9 show large artefacts related to the artificial neural network model. Most notably, Figure 8c indicates that UV irradiance depends on total column ozone at wavelengths larger than 350 nm when in fact (and confirmed by my own calculations) the ozone absorption cross section in this wavelength range is too small to have a noticeable effect on UV irradiance. The dataset is worth publishing, considering that there are only a few sites in Antarctica that provide spectral UV data. However, my "major" and "minor" comments should be addressed first, and the language should be improved also. I have included several pages related to language with suggestions to improve the text and make it more readable.

*****Major comments**

RC3: **Data are not provided in the correct quantity and the magnitude of the results is incorrect

All results are provided as "irradiance" in units of mW m-2. A Brewer MK III measures spectral irradiance, not irradiance, in units of mW m-2 nm-1 (with a spectral resolution (bandwidth) of 0.5 nm according to the authors; although, to my knowledge, the resolution of this instrument is 0.6 nm). If the authors provide results in irradiance instead of spectral irradiance, the wavelength interval over which their spectral data were integrated to get irradiance has to be specified. Furthermore, irradiances presented by the authors seem to be off by several orders of magnitude. For example, for a solar zenith angle (SZA) of 60°, I would expect a spectral irradiance of 335 mW m-2 nm-1 at 363 nm for a spectroradiometer with a 1 nm wide triangular slit function. The "irradiance" data presented by the authors in Figure 4 max out at about 0.8 mW m-2. This is different from the correct result (presuming that irradiance data were integrated over a wavelength interval of 1 nm) by a factor of more than 400. Even if data had only been integrated over 0.5 nm (the resolution and sample-step of the Brewer) instead of 1 nm, as in my calculations, the results would be off by two orders of magnitude. As a result of these errors, all subsequent results presented in absolute terms (irradiance in mW m-2) and model results (which are tied to measurements) in Figure 7–10 are incorrect. All absolute values in the manuscript have to be recalculated to correct for these errors.

AC: Thank you for noting the discrepancies. The Brewer spectrophotometer measures in the sampling interval of 0.5 nm, and the measured wavelength interval (full width half maximum) is 0.6 nm. We will clarify this in the text. The reason of the errors in UV irradiances was that in the original paper, the units were in $W \cdot m^{-2} \cdot nm^{-1}$, not in $mW \cdot m^{-2} \cdot nm^{-1}$.

MC: The units were changed to $mW \cdot m^{-2} \cdot nm^{-1}$ throughout the entire manuscript, of course including all the figures. Also, the wording was changed from "irradiance" to "spectral irradiance" where applicable throughout the manuscript. The clarification of Brewer spectrophotometer sampling interval and FWHM was added in lines 101–102.

RC3: **The artificial neural network (ANN) is not described.

It is stated in line 156 that the ANN model is a "perceptron" model, but no other details are provided. Please provide information on this model, either a reference or a description on how it works. Without any detail, it is just a black box. Journal papers like this require a description that would allow the reader to reproduce these model calculations.

AC: Thank you for the comment. The model was built as follows, using the TIBCO Statistica software (TIBCO, 2023):

First of all, many crossvalidated tests of randomly initialized neural networks with a random division of the whole dataset to training (70 % of data), validation (15 %) and testing (15 %) subsets were carried out (the process is also described in for example Malik et al., 2022). The aim of these tests was to find the best set of predictors and to establish the appropriate complexity of the neural network, corresponding to the complexity of underlying relations between predictors (SZA, TOC, cloud cover, albedo) and predictands (spectral UV irradiance). These tests revealed that about 22 neurons in the hidden layer are (quasi)optimal to avoid both over- and underparametrisation of the relation.

Then, an ensemble of 10 neural networks with logistic activation functions, each with 22 neurons in the hidden layer were trained, again with random division of the dataset to training (70%), validation (15%) and testing (15%) subsets and with random initialization of the networks. The "early stopping" measure against overtraining is already described in the text.

- TIBCO Statistica® User's Guide: Statistica Automated Neural Networks (SANN) - Neural Networks Overview, https://docs.tibco.com/pub/stat/14.0.0/doc/html/UsersGuide/GUID-F60C241F-CD88-4714-A8C8-1F28473C52EE.html, last access: 3 February 2023.

The advantage of the ANN approach is that it derives the appropriate complexity of the neural network directly from even a relatively simple real data, and it is not limited by an a priori assumption about the shape of the regression function. In addition, neural networks are capable of modeling relationships that are difficult to describe analytically and from this point of view, they are more general than the analytical approach (e.g., Barbero et al., 2006; Malik et al., 2022).

Therefore, ANN models are commonly used in atmospheric sciences including UV radiation climatology, for example for purposes like forecasting or reconstructions, and they perform reasonably well. Here you can find the citations of several works that successfully illustrate the use of ANN modeling in UV climatology:

- Barbero, F. J., López, G., and Batlles, F. J.: Determination of daily solar ultraviolet radiation using statistical models and artificial neural networks, Ann. Geophys., 24, 2105–2114, 2006.
- Feister, U., Junk, J., Woldt, M., Bais, A., Helbig, A., Janouch, M., Josefsson, W., Kazantzidis, A., Lindfors, A., den Outer, P. N., and Slaper, H.: Long-term solar UV radiation reconstructed by ANN modelling with emphasis on spatial characteristics of input data, Atmos. Chem. Phys., 8, 3107–3118, 2008.
- Latosińska, J. N., Latosińska, M., and Bielak, J.: Towards analysis and predicting maps of ultraviolet index from experimental astronomical parameters (solar elevation, total ozone level, aerosol index, reflectivity). Artificial neural networks global scale approach, Aerosp. Sci. Technol., 43, 301–313, 2015.
- Raksasat, R., Sri-iesaranusorn, P., Pemcharoen, J., Laiwarin, P., Buntoung, S., Janjai, S., Boontaveeyuwat, E., Asawanonda, P., Sriswasdi, S., and Chuangsuwanich, E.: Accurate surface ultraviolet radiation forecasting for clinical applications with deep neural network, Sci. Rep.-UK, 11 (5031), 1–12, DOI: 1038/s41598-021-84396-2, 2021.

ANNs are also used in various studies concerning solar radiation in general, as shown for example in this review, which even claims ANN can provide better results than conventional methods:

- Yadav, A. K. and Chandel, S. S.: Solar radiation prediction using Artificial Neural Network techniques: A review, Renew. Sust. Energ. Rev., 33, 772–781, 2014.

A more recent review of the use of ANNs in solar radiation climatology shows ANNs are still a widely used method, with the statements confirming that when extrapolation is avoided (which was done in our case), ANNs provide results of similar, or even better quality to conventional methods:

- Malik, P., Geholt, A., Singh, R., Gupta, L. R., and Thakur, A. K.: A Review on ANN Based Model for Solar Radiation and Wind Speed Prediction with Real-Time Data, Arch. Comput. Method. E., 29, 3183–3201, 2022.

MC: The ANN model description was extended (lines 169 – 193), and the reference to the User's Guide of the program we used was added (line 188 and lines 685–686). We also cited the relevant works we mentioned above (lines 176–177 in the text).

RC3: **The spectral UV measurements are insufficiently described.

For example, how many spectra were measured per day? Are these spectra distributed equally throughout the day (otherwise the average and median of daily measurements would be skewed). What is the uncertainty of the measurements? Have the measurements been independently validated, for example, by participating in an intercomparision campaign with a reference spectroradiometer.

AC: Thank you for the comment.

There were between one and 29 spectral measurements taken during each day with observations, the distribution is shown in Fig. 1 below.

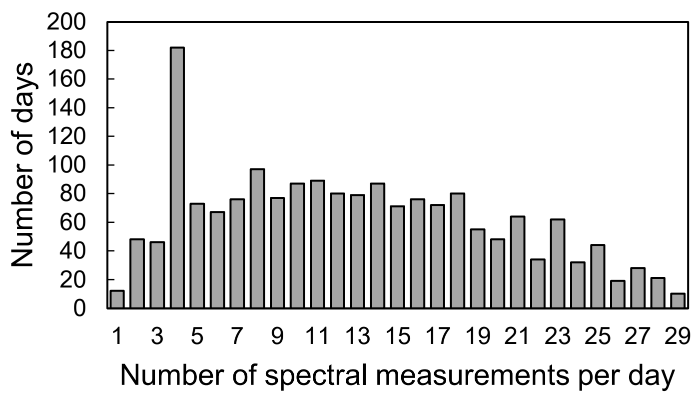


Fig. 1. Number of days with a certain number of spectral UV measurements per day at Marambio Base, 2010–2020.

The temporal distribution of the measurements was more or less even in small-SZA months and centered around noon in large-SZA months, as seen from Fig. 2.

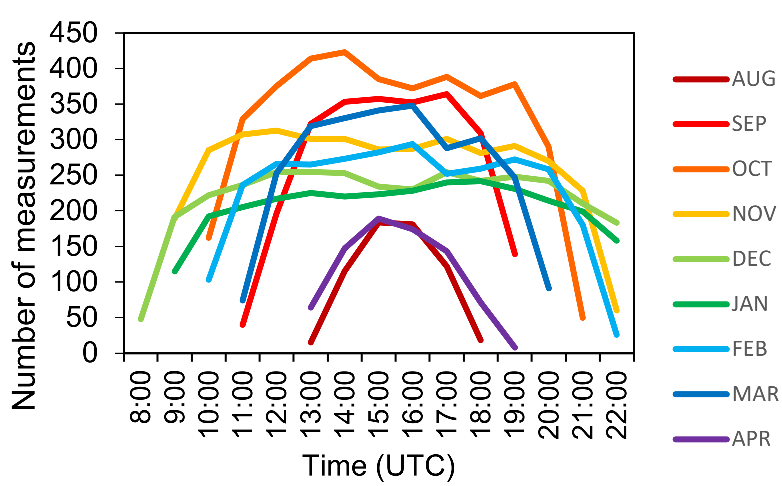
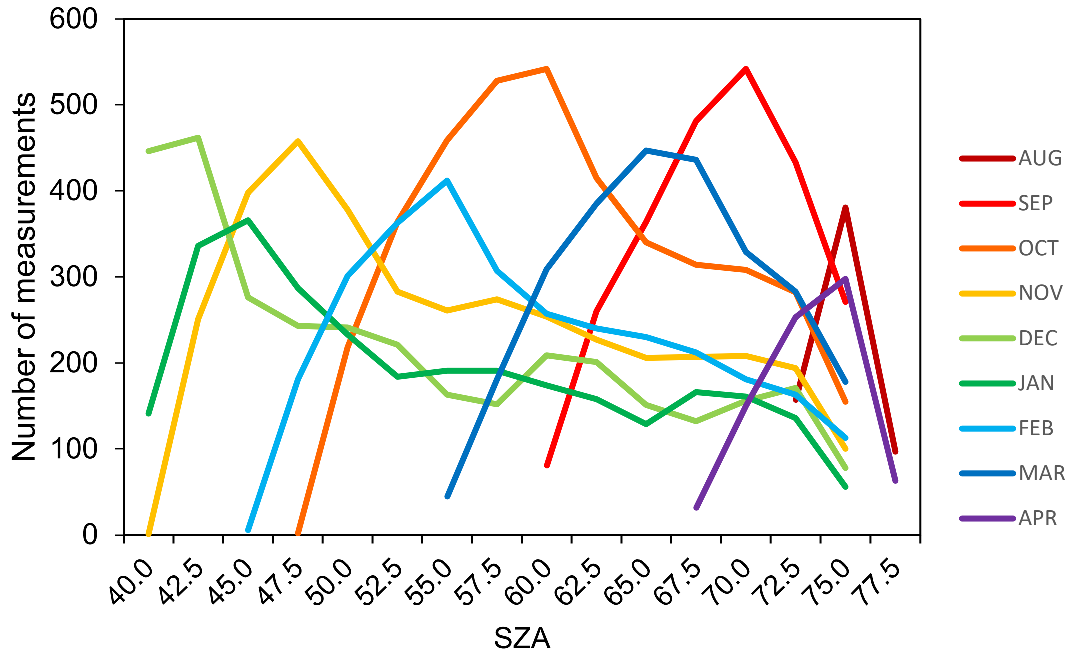


Fig. 2. Temporal distribution of spectral UV measurements in individual months at Marambio Base, 2010–2020.

Therefore, the measurements are centered around low SZAs in summer months, and around mean SZAs in spring and fall. The median SZAs are shifted toward higher than modal values especially in the lowest-SZA months, as seen in Fig. 3, and due to this non-normal distribution, median was considered a more representative measure of central tendency than mean.



	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR
Median SZA	76.11	70.13	61.75	55.60	52.12	53.50	59.27	67.12	74.59

Fig. 3. The distribution of spectral UV measurements in individual months based on SZA and the corresponding median SZA of each month at Marambio Base, 2010–2020.

In the manuscript, we will include Fig. 1, 2 and 3 from this response as panels b, c and d in Fig. 2, and we will add a description similar to the one provided here.

Brewer #199 was calibrated with Canadian traveling standard Brewer #017 in Marambio in 2012 and 2016. The uncertainties of Brewer double monochromator UV spectra measurements are up to 5 %, as shown by, for example, Lakkala et al. (2008), which is comparable to our instrument as the Czech and Finnish meteorological institutes use similar calibration techniques and standards.

Ref.: Lakkala, K., Arola, A., Heikkilä, A., Kaurola, J., Koskela, T., Kyrö, E., Lindfors, A., Meinander, O., Tanksanen, A., Gröbner, J., and Hülsen, G.: Quality assurance of the Brewer spectral UV measurements in Finland, Atmos. Chem. Phys., 8, 3369–3383, 2008.

MC: The Figures 1, 2 and 3 from this response were included as panels b, c and d in Fig. 2 (line 718), and the description of the spectra was extended (lines 110–118). We also added the information about the uncertainties (line 95).

RC3: **Figures 7-9 show artifacts of the ANN model, so some features presented in these figures are not real, and some artefacts lead to wrong conclusions.

Results should be double-checked with a radiative transfer model (which the authors apparently have because they calculate CMFs). It would be simple to model the UV irradiance as a function of SZA for each month for a fixed TOC and CMF. It would be much more convincing to have results based on a physically correct model than the author's ANN model. The following features are likely artefacts of the ANN model:

In Figure 7a, UV irradiances do not asymptotically approach zero for large SZAs but seem to have an offset. In Figure 7b, there is a spurious maximum at about SZA=45 degree. In Figure 7d, large, wavelength-dependent fluctuations are apparent at small wavelengths in particular for March and April, etc.

The greatest artefacts are apparent in Figure 8c. Because of the steep decline of the ozone absorption cross section in the Huggins band, the effect of TOC on UV irradiance becomes very small for wavelengths larger than 340 nm, and in particular for wavelengths larger than 350 nm. Figure 8c contradicts the diminishing effect of changes in TOC on UV irradiance with increasing wavelength. Here, a 10 DU change in TOC has the largest effect on UV irradiance at 363 nm (in January). Furthermore, Figure 8d shows unrealistic spikes in the relative change at about 303 and 305 nm for March and April. The relative change in Figure 8d seems to be constant (albeit small) for wavelengths larger than ~337 nm. Instead the relative change should continuously decrease between 337 and 363 nm.

To check my assertions, I modeled UV spectra for SZA=60 degree and TOC of either 300 or 310 DU (i.e., an increase by 10 DU) using the ozone absorption cross-section by Molina, which is provided up to 350 nm. As expected, the relative change decreased with increasing wavelength and was below 0.02% for wavelengths larger than 345 nm. The absolute change peaked at about 317 nm at a irradiance of 2.1 mW m-2 nm-1, decreased steadily with increasing wavelengths from there onward, and was below 0.02 mW m-2 nm-1 above 348 nm. The difference that I calculate with my radiative transfer model are greatly different both in magnitude and shape of the difference shown in Panel (c), confirming my conclusion that the results of the ANN model are incorrect.

In summary, Figure 8c gives a false impression of the effect of changes in TOC on UV irradiance.

Figure 9c shows unrealistic fluctuations below 310 nm.

In general, I find the “absolute” panels (c) in Figures 7–9 not very helpful because the structure is dominated by the Fraunhofer lines. The relative changes shown in panels (d) are really the interesting ones and the authors should focus their discussion on these panels.

AC: Thank you for this comment and suggestion. Unfortunately, it is impossible to use the radiative transfer model to assess the ANN performance because it requires a precise cloud cover structure data (amounts of water and ice in individual layers), which are not available to us as we only have the percentages from ERA5. Therefore, without increasing the error by attempting to deduce the nature of the clouds, we could not do more than to simulate the clear-sky irradiances.

The ANN artifacts are of course real, they belong to the downside of ANN modeling. However, despite the existence of artifacts, ANNs are in our case the best option, because they can operate with relatively simple datasets such as those available to us. Moreover, ANNs do not need any assumption about the form of (functional) dependence between predictors and predictands, as they are able to learn this dependence directly from the data in the training process, so they can be seen as more general and flexible than conventional modelling methods. Another advantage is that ANNs are not prone to numerical problems in cases of interdependent predictions and they can work well even with data affected by noise, which is typical for empirical series derived from measured data. Also, as stated above, in climatology of solar radiation, ANN models are a quite commonly used tool. For all the above reasons, we consider ANN modeling to be an adequate method for solving the given task.

MC: We pointed out that model artifacts are the downside of ANN modeling (lines 177–178), and we described the artifacts in the Results section (lines 353–357 and 374–375). Due to possible confusion related to the artifacts and the Fraunhofer line domination, we also omitted the absolute change panels (c) from Fig. 7–9 (lines 741–753).

RC3: **Important literature is not cited and results are ignored

The assessment in line 61 that "a complex evaluation of long time series of solar UV irradiance spectra from Antarctica is still missing." is incorrect. For example, measurement of spectral UV irradiance at the South Pole, McMurdo / Arrival Heights, and Palmer Station, have been continuously performed since the early 1990s as part of the National Science Foundation's and NOAA Antarctica UV Monitoring Network, e.g., https://gml.noaa.gov/grad/antuv/. Numerous publications are based on these data and these publications also include quantitative assessments of the effects of ozone, albedo, cloud cover, and other factors on the measured UV spectra. The authors should consult the list of references in Bernhard and Stierle, 2020 (which they have cited), in particular #21, 23, 24, 28, 30, and 43, as well as https://doi.org/10.1029/2004JD004937, which includes a very detailed analysis on the wavelength dependence of cloud attenuation, and the variability in UV radiation caused by variations in total ozone at the South Pole.

AC: Thank you for the note, we apologize that we have omitted several important sources.

MC: All recommended literature was included in the manuscript. The paragraph about spectral UV radiation monitoring in Antarctica was extended (lines 55–57) and relevant results were discussed (lines 295–296, 378, and 388–391).

*****Minor comments**

AC: Thank you for all these comments, suggestions and explanations. Where no further "AC" comment is present, we accepted the suggestion and proceeded to manuscript changes.

RC3: The introduction contains much general information that could be cited and does not have to be included. So the introduction could be shortened substantially

MC: Based on this suggestion, we took out some parts of the introduction, especially the description of UV radiation effects, where we only quoted the relevant works (lines 23–27).

RC3: L21: Include reference to support "since its discovery in 1801."

MC: The following reference was added (lines 23 and 577–578): Hockberger, P. E.: A History of Ultraviolet Photobiology for Humans, Animals and Microorganisms, Photochem. Photobiol., 76, 561–579, 2002.

RC3: L34: Jovanović et al., 2019 is a rather obscure publication. Please add a more standard one.

MC: This publication was be removed from the manuscript and replaced by the following one: Velders, G. J. M., Andersen, S. O., Daniel, J. S., Fahey, D. W., and McFarland, M.: The importance of the Montreal Protocol in protecting climate, PNAS, 104, 4814–4819, 2007 (lines 32 and 685 – 686).

RC3: L37: the paper by Bernhard and Stierle does not report on positive trends in UV irradiance for the month of September. (Positive trends were reported for other months, but not for September).

AC: The sentence speaks about the recent positive trends in TOC, which lead to a decrease (negative trend) in UV radiation in September. Such trend was reported by Bernhard and Stierle, although it was not statistically significant.

MC: The information about the statistical insignificance was added to the manuscript (line 34).

RC3: 41–42: The wavelength ranges for UV-C, UV-B and UV-A radiation should be:

- UV-C: 100–280
- UV-B: 280–315
- UV-A: 315–400

AC: Thank you for the comment, you are right, this is the WHO standard. However, different publications give different scales (e.g., Diffey, 1990), so we will keep a note on the semi-arbitrary nature of the scale.

MC: The scale was changed and the WHO standard was cited (lines 38–40, 692–693).

RC3: L63: I am not convinced that there is a gap. The way SZA and ozone affects UV radiation are well understood. The effect from clouds is more difficult, but assessing the complex effects of clouds with cloud cover data from satellites covering a larger area will do little to capture these intricate effects. Please see also my last "major" comment.

MC: Based on this and the last "major" comment, we rephrased lines 60–61 to "This study aims to contribute to broaden the knowledge of spectral UV irradiance in Antarctica by…", so that the word "gap" is omitted.

RC3: L67: Regarding: "between the southern polar vortex and UV irradiance reaching the Antarctic continent": The paper describes measurements from one particular site, which is on an island and not the Antarctic continent. So these measurements can hardly be representative for the vast Antarctic continent.

MC: In order to avoid confusion, the sentence was rephrased to "…reaching the site" (line 65).

RC3: L93: It was already stated in the previous sentence that the instrument was calibrated in 2012 and 2016. So what does "the spectrum was calibrated in 2012, 2016" add here?

AC: This means that in 2012 and 2016, dispersion test with Hg and Cd spectral lamps was done, and UV response file was updated.

MC: We specified this in lines 88–91.

RC3: L96: What does R6 and R5 mean? What was ratioed? What are Dead time and Run stop tests? Why is “Dead” and “Run” capitalized?

AC: R6 and R5 are called “double ratios” of UV intensities and these are related with total ozone and SO_2 amount. The same ratios of intensities calculated from halogen lamp shows long term stability of spectrometer and differences of extraterrestrial constant. The dead time test of photomultiplier run-stop test of the slit mask are usual daily tests to check correct function of the Brewer spectrophotometer.

MC: The information was included in lines 95–99.

RC3: L100: What wavelength range does "very short wavelengths" refer to? (The range is explained further down. This explanation should be moved up).

AC: We meant wavelengths below 300 nm.

MC: We clarified this in line 103.

RC3: L106: Where wavelengths shifts just analyzed or were they actually corrected?

AC: The wavelength shifts were just analyzed. A dispersion test with HG and CD spectral lamps was done based on wavelengths shifts analyses in 2018 to improve the spectral measurements. The maximal wavelengths shifts were in the Brewer spectrum range (290-363 nm) from +0.02 to -0.08 nm before the application of new constants in 2018. Another two dispersions were collected during calibration on site with traveling Brewer in 2012 and 2016. Spectral data were not corrected backward.

MC: We specified this in lines 89–92.

RC3: L117: According to Figure 4, bottom, cloud cover at Marambio is the norm. So what TOC data were used on cloudy days?

AC: Only direct sun TOC observations were taken in account. Weather at Marambio, including cloud cover, is changeable, therefore we were able to get the direct sun (DS) readings on most days. Moreover, it is possible to take a DS measurements even through a thin cloud cover. The statistics shown in Fig. 4 have been calculated only from the studied cases, i.e. solar UV spectra paired with DS TOC measurements, ERA5 cloud cover, and albedo climatology.

MC: We clarified this in line 125.

RC3: L127: Is “cloudiness” equal to cloud cover? How is cloud cover expressed in this reanalysis data set? Is it in oktas or percent? Is it the fraction of clouds within the 0.25 x 0.25 degree pixel? Since Marambio is on a small island, are the ERA5 data representative? The optical thickness of clouds is at least as important as cloud cover. Hence, it seems that cloud cover from ERA5 reanalysis data is not a good quantity to assess the effects of clouds on UV radiation.

AC: In the study, the terms “cloudiness” and “cloud cover” were used as synonyms (the portion of sky covered by clouds), but to avoid confusion, we will be preferring “cloud cover” in the edited version of the manuscript.

The ERA5 dataset gives cloud cover in percentages (we will specify this in the manuscript). As for the spatial representativeness and the absence of cloud optical thickness, we agree that the dataset has its limitations, even though the cloud cover in the western part of Weddell Sea is quite consistent, affected mostly by large-scale synoptic systems and processes, which are quite well represented in ERA5. Generally, it was the best cloud cover estimate available to us that covered the entire study period (for more information, please see the next point).

MC: The term “cloudiness” was changed to “cloud cover” throughout the manuscript. We also extended the information on the ERA5 dataset (lines 138 and 141–142).

RC3: L128: Regarding “the best correlation (r = 0.26) with”. Best relative to what? Is it indeed r or should it be r^2? If it were r, r^2 would be 0.068, which means that only 6.8% of the variability in the CMF can be explained with ERA5 cloud cover data. This is a rather small fraction, confirming that the ERA5 reanalysis data are not very useful to describe cloud cover at Marambio, which also impacts the significance of results presented later. This should be discussed.

AC: Thank you for the notice. Unfortunately this is the case, most likely due to the omittance of cloud structure information in ERA5 data (i.e. both a cirrostratus and a nimbostratus would get the total cloud cover of 100 %, even when CMF would be greatly different). We only omitted the negative correlation sign, which we will of course correct in the manuscript. The other tested datasets were MERRA2 (r = -0.10) and OMI cloud fraction (r = -0.13). No direct observations from the site covering the entire studied period were available to us, so despite the limitations, related of course also to your previous comment regarding the data representativeness and cloud optical thickness, we decided to use the dataset in the study. This decision was supported by the fact that the inclusion of the ERA5 cloud cover dataset brought a statistically significant improvement in our ANN simulations (see Fig. A1a in the original manuscript’s Appendix 1).

MC: The error in the correlation coefficient was corrected, other datasets (OMI, MERRA2) were mentioned, and the ERA5 dataset limitations were discussed (lines 138–142).

RC3: L130: “then the weighted mean using the clear-sky intensities as weights was derived for each spectrum.” Is difficult to understand. Please rephrase and add detail.

MC: The sentence in lines 143–147 was rephrased as follows: “In order to calculate a single CMF value for the entire spectrum, a weighted mean was used, so the CMFs at each wavelength were multiplied by the corresponding modelled clear-sky UV irradiances, summed up and divided by the clear-sky irradiance integrated through all studied wavelengths.”

RC3: L138: How representative is the OMUVB albedo climatology for the relative small footprint of the observation site considering that there is both ocean and land in the OMUVB pixel? Were there any albedo measurements at Marambio Base that could be used to validate the OMUVB albedo climatology?

AC: Unfortunately there were no albedo measurements at Marambio, which would cover the entire 2010–2020 study period, available to us, so we had to use the OMUVB climatology as the best possible albedo estimate. Of course, its representativeness is limited, as it covers a relatively large area and does not capture individual solid precipitation events and year-to-year changes, but we decided to include the dataset, as it presented a statistically significant improvement to our ANN model (see Fig. A1a in the manuscript’s Appendix 1).

RC3: L153: You only considered the ANN and a regression model. Why didn't you use a physical correct radiative transfer model to detangle the effect of the different explanatory variables considering that all important input variables for such a model were available?

AC: Thank you for the note. It would indeed have been an interesting comparison and it would be great to see the differences between a radiative transfer and an ANN model. However, the problem was that not all the necessary input variables were available, especially when it comes to cloud cover.

MC: We briefly mentioned that due to the relatively simple datasets available to us it was not possible to perform radiative transfer modelling (line 173 – 174) and added a possible future research idea with the intercomparison of radiative transfer, ANN, and regression modelling (lines 448–449).

RC3: L158: What is the difference between testing and validation?

AC: A neural network uses a training subset for "training" (setting the quasi-optimal parameters of the neural network in iterative process). Despite the previous setting of the quasi-optimal complexity of the used network, however, the network may be overtrained in some cases. Therefore, a test subset is randomly selected from the input data before training and it is used to independently check possible overtraining of the network. When overtraining occurs, typically the network error on the training set decreases, but the error on the test set starts to increase. If the error on the test file grows for a certain number of training cycles (usually of the order of hundreds), the training is stopped ("early stopping") and the network with minimal error on the test subset is considered to be the final one. But, for the reasons mentioned above, the results are not independent of either the training or the test subsets, therefore a third (validation) subset is selected before training. This subset is not used for training of the network or checking for overtraining, but only to independently assess the performance of the final trained network. See also TIBCO Statistica® User's Guide, chapter „Network Generalization", cited above.

MC: The difference was briefly explained in lines 180–183.

RC3: L173: Delete: "while it was greater at shorter wavelengths, likely due to the smaller range of the data." This does not make sense to me. My guess is that R^2 is greater at small wavelengths because those depend more on ozone, which (anti)correlates much better with UV radiation than cloud cover.

AC: Thank you for the note. You may be right with the ozone dependency, as a clear, ozone-related Huggins band structure is visible in Fig. 1d.

MC: The interpretation attempt was deleted.

RC3: L183: What 9 months?

AC: We meant the months in which the B199 measurements were available (i.e. August to April).

MC: We clarified this in lines 216–217.

RC3: L197: Delete: "the UVB region". 330 nm is not in the UV-B range.

MC: We rephrased it to "short wavelengths" (line 232).

RC3: L211: I don’t understand “relative differences gradient”

MC: The sentence containing this statement (lines 245–247) was rephrased as follows: “The smaller relative differences at short wavelengths (approximately 300–305 nm) in September and larger ones in October may be possibly attributed to the effect of variable ozone amount, as the ozone deficiency causes a relative increase in UV irradiance at short wavelengths.”

RC3: L212: Regarding: “In October, when the UV irradiance is lower than the overall median, the difference decreases with decreasing wavelengths, while in November, when the median irradiance already exceeds the overall median, the difference increases more steeply.” Looking at Figure 4c, the UV irradiance is higher (not lower) than then overall median in October and the difference increases (not decreases) with decreasing wavelength.

AC: Thank you for noticing this. We meant September and October here.

MC: We took out this sentence entirely as the rephrased sentence mentioned in the previous comment says the same thing.

RC3: L218: Karhu et al. (2003) or Koo et al. (2018) are not good references to cite here. I suggest to cite either the 2022 WMO ozone assessment (https://csl.noaa.gov/assessments/ozone/2022/) instead, which will be published soon, or the 1998 version.

MC: We replaced the citations by the new WMO ozone assessment (lines 251 and 694–695).

RC3: L225–229: While this is more or less correct, the explanation misses the point why both ozone minima and maxima can be observed in November. The main reason is that Marambio is sufficiently far away from the South Pole so that the station can be either below the ozone hole or outside its perimeter where ozone is typically high in November.

MC: This interpretation was added to the manuscript (lines 262–265).

RC3: L269: Attenuation of UV-B irradiance by thin (e.g., cirrus) clouds can be much less than 30%, in particular if snow is on the ground.

MC: We mentioned this in lines 305–306.

RC3: L296–300. I think you mean Fig. 7–9, not Fig. 7-10, in the paragraph.

AC: Yes, thank you for noticing this, it is a leftover from the previous iteration where we took out one figure.

MC: We corrected it accordingly (lines 333–335).

RC3: L299: The sentence “of the relationships of the explanatory variables and UV irradiance, given that all other variables are fixed to their monthly medians.” is confusing. The sentence implies that there are other variables, in addition to explanatory variables and UV irradiance. Better: “Fig 7 shows the relationship between SZA and UV irradiance with the other explanatory variable fixed to their monthly mean. Similar relationships between TOC and UV irradiance and between cloud cover and UV irradiance are shown in Figs. 8 and 9, respectively.”

MC: The suggestion was included in the manuscript (lines 335–337).

RC3: The captions of Figure 7–9 should be rearranged. I suggest (for Figure 7): "Modelled relationships between UV irradiance and SZA for different months. Panel (a) and (b) show the modelled UV irradiance at 305 nm (a) and 340 nm (b) as a function of SZA. Panels (c) and (d) show the change in spectral UV irradiance resulting from an increase in SZA by 1° in absolute (c) and relative (d) terms. Similar captions should be chosen for Figures 8 and 9.

AC: Thank you for the suggestion. As we are taking out panel (c) (see above), we rephrased the captions as follows (for Fig.7):

Modelled relationships between UV irradiance and SZA for different months. Panel (a) and (b) show the modelled UV irradiance at 305 nm (a) and 340 nm (b) as a function of SZA. Panel (c) shows the relative change in spectral UV irradiance resulting from an increase in SZA by 1°, calculated with reference to the monthly median spectra.

We kept the last part of the caption ("calculated with reference to the monthly median spectra"), as it was a suggestion of another referee to avoid possible confusion.

MC: Relevant changes were made in lines 741–753.

RC3: L328: The vertical profile becomes only important for SZA larger than about 75 degrees, when the Umkehr effect starts to become apparent. So the ozone profile does not plan a "substantial" role, unless the SZA is very large.

MC: The large SZA condition was included (line 368).

RC3: L340: Another important reasons why clouds have less influence in Antarctica compared to mid-latitude sites is that high surface albedo prevailing over the Antarctic continent greatly reduces cloud effects due to multiple scattering between clouds and the snow-covered surface. However, this may be of less importance at Marambio compared to the Antarctic continent.

AC: Thank you for the note. Albedo may play some role even at Marambio, as most precipitation falls in solid form and the sea is covered in sea ice in spring and fall.

MC: We included it in the interpretation (lines 388–391), together with the suggested reference of Nichol et al. (2003).

RC3: Figure 10: I find this figure rather confusing and not very helpful. It is obvious that measurement and model don't agree when the model is run with input parameters differing from the actual situation. I think the main point that the authors like to make is that low ozone values can be compensated by large SZAs (e.g., the red lines in Panel b). I would remove the figure from manuscript but let the authors decide.

AC: The figure is indeed not meant as a model validation. As we still find the results quite interesting and case-specific, we would like to present the figure differently, to make it more obvious it was not a model validation but rather a set of case studies showing how the studied variables can compensate the effects of one another (see below). We will also change the description in the results section, focusing more on the potential influence of selected variables and the interpretation of the real situation, trying to avoid any "model vs. observation" comments that may lead to confusion.

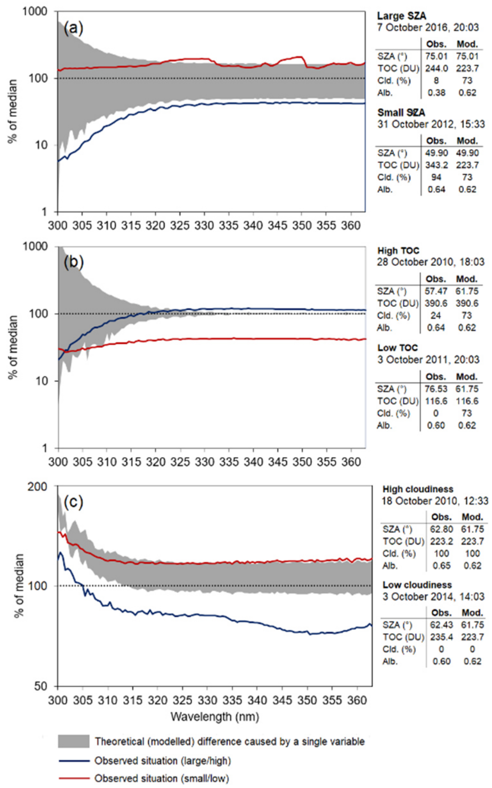


Fig. 4. A new proposed version of Fig. 10 for the manuscript. The grey area, rather than lines, should show the potential effect of the selected variable, while the red and blue lines show the real situation, i.e. the effect of all variables combined.

MC: We changed the interpretation (lines 397–416) and the figure itself (lines 755–759).

RC3: L405: I find it rather strange that the results of nine of the ten ANN models are basically identical but one (ANN01) is rather different. I would have expected a continuous distributions. It would be good if the authors could better explain what's different about ANN01. It seems to me that the training dataset of model ANN01 included outliers.

AC: The different models do not necessarily yield a continuous distribution. The random selection of training/testing/validation subsets and the random initialization of the networks before their training may introduce the influence of random factors into the process, making the model results rather discontinuous.

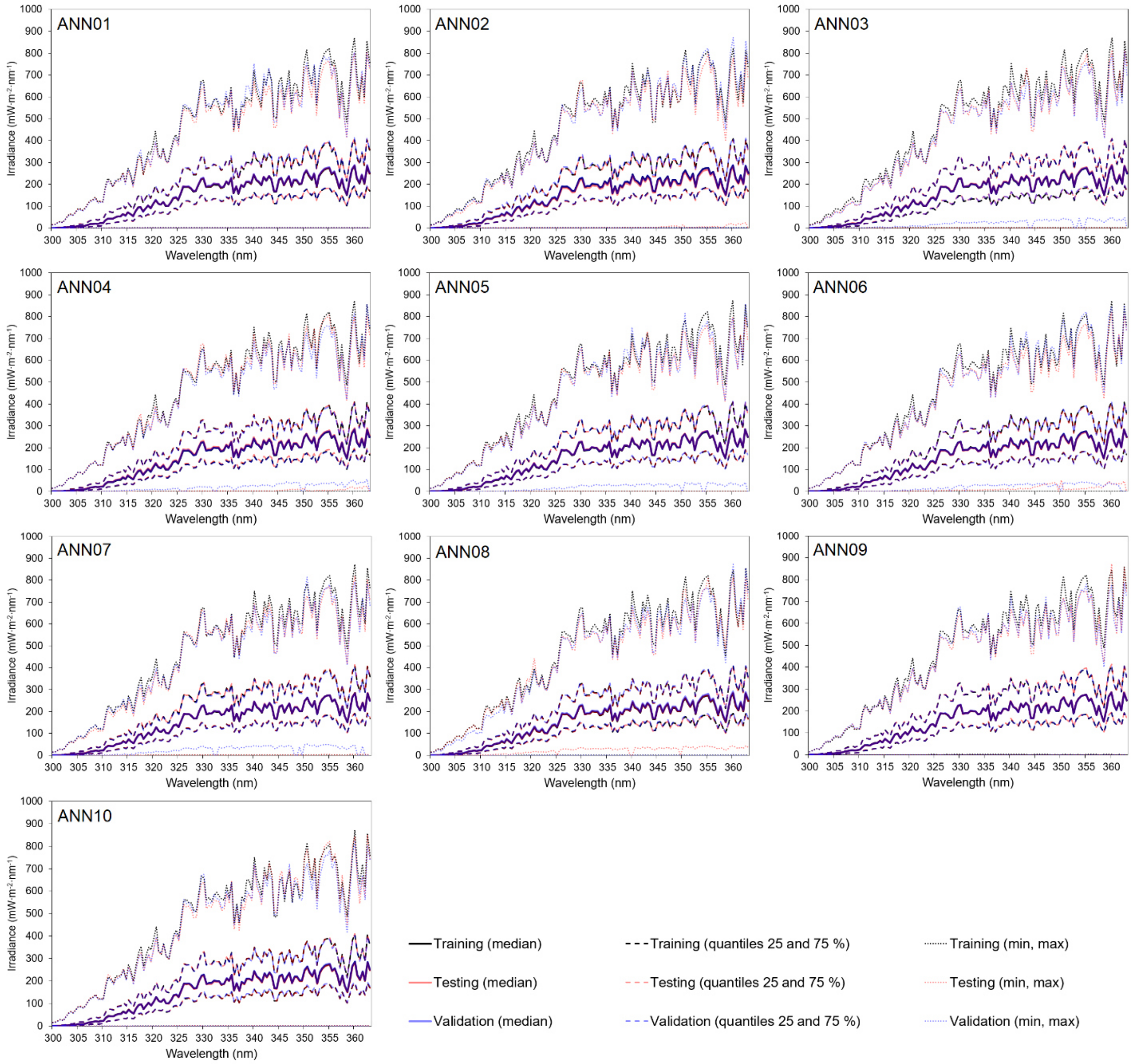


Fig. 5. Statistical characteristics of the spectral UV irradiance in training, testing and validation subsets of the individual ANN models.

As for the presence and distribution of potential outliers, Fig. 5 shows a very similar divisions between the three subsets in all ten ANN models. The differences between the subsets are visible just in the minimal and maximal values, but ANN01 does not show any specifications vastly different to the other nine models. Looking at the structure of the individual subsets' maximal values, it is very similar to for example ANN05, and therefore it does not indicate the presence of outliers. The difference of ANN01 must have been therefore caused by the random initialization of the network.

We assume that if we built another dozens of models (which is unfortunately not within our time scope and computing capacity), some of them, albeit probably a minority, would perform similarly to ANN01.

MC: We included Fig. 5 from this response in Appendix A (lines 760–762) to better illustrate the divisions of the datasets, and a short description was added (lines 457–458).

RC3: ***Comments to language

AC: Many thanks for all the language remarks. Where no additional comments are present, we accepted the suggestion and made respective changes in the manuscript. In the case of specific comments, we are noting the lines in which the changes are present in the revised version of the manuscript (for deletions and general comments, please see the file with tracked changes).

****Comments to language, general**

- The word "while" is used improperly throughout the document. "While" contrasts two different things, like "whereas". For example, one could say: irradiance at 305 nm is small while it is large at 340 nm. "While" is often used in the text instead of "for example", which is an incorrect meaning.
- Change "in average" to "on average" throughout.
- Don't use the expressions "high SZA" and "low SZA". These expressions are confusing because a reader associates "high" with the Sun being high in the sky while the opposite is the case. Use "large SZA" and "small SZA" instead.
- Change "Out of" to just "Of"
- Always place a space between value and unit. (It is done most of the time, but not always.)
- Change "Huggins belt" to "Huggins band"

****Comments to language, specific**

- L7: "assess response of spectral UV radiation to different atmospheric" > "to assess the response …" or better: "assess the dependence of spectral UV radiation on different…"
    - MC: line 7
- L8: "in southern polar" > "in the southern polar"; delete "individual unique" as this is obvious
    - MC: line 8
- L11: "the resolution of 0.5 nm." > a resolution of 0.5 nm." Also please double-check that this is correct for your instrument. To my knowledge, the spectral resolution of a Brewer MK III is 0.6 nm.
    - MC: line 11 (also "resolution" was changed to "sampling interval")
- L12: Define "TOC"
    - MC: line 12
- L13: decline > decrease
    - MC: line 13
- L13: Regarding the sentence: "Also TOC affects particularly the short wavelengths, while at 305 nm, a 10 DU decrease in TOC causes a 7–13 % increase in UV irradiance.", specify what you consider "short" wavelengths. The word "while" implies that 305 nm is a long wavelength because "while" is a word contrasting two different things. So you could say: TOC affects wavelengths below about 340 nm. For example, at 305 nm a 10 DU decrease in TOC causes a 7–13 % increase in UV irradiance."
    - MC: lines 14 – 15
- L17: Specify what "very high" means (e.g., the upper 10% of the distribution)
    - MC: lines 18–19
- L22: Delete "the thorough"

- L23: accounted > attributed
    - MC: line 25
- L25: "lead to melanoma" should refer to humans, not "other organisms"
    - AC: This part was removed based on the first "minor" comment.
- L26: "catalyses vitamin D creation" > "leads to the production of vit D"
    - AC: This part was removed based on the first "minor" comment.
- L29: Cite https://doi.org/10.1038/s41586-021-03737-3 in support of "terrestrial plant productivity"
    - MC: line 27
- L31: "short-wavelength UV irradiance" > "from reaching the surface"
    - MC: line 29
- L32: "in the 1980s" > "in 1985"
    - MC: line 30
- L33: "many events have taken place to eliminate the ozone depletion," > " many efforts have been made to reduce ozone depletion"
    - MC: line 31
- L33: "the 1987 Montreal Protocol and its numerous amendments" > "through the passing of the Montreal Protocol in 1987 and subsequent amendments to this landmark treaty."
    - MC: lines 31–32
- L35: "in September" > "for the month of September"
    - AC: This part was removed based on the first "minor" comment.
- L37: "ozone hole still" > "the ozone hole still"
    - MC: line 35
- L38: Delete "the rare"
- L43: Remove "as it is illustrated even by the possible division at 315 nm" The division is indeed somewhat arbitrary, but the publications cited do not "illustrate" this.
    - MC: The sentence (lines 39–40) was rephrased as follows: "However, this division is semi-arbitrary, as there is no clear, physically defined transition between UVA and UVB bands (e.g., Diffey, 1990; Juzeniene et al., 2011)."
- L48: Indicate that NH means nitrogen hydrogen
    - MC: line 44
- L49: "but due to their respective abundance" > "but due to the difference in their respective abundances"
    - MC: lines 45–46
- L53: precise > large
    - MC: line 49
- L54: "the solar UV spectra" > "solar UV spectra"
    - MC: line 50
- L55: delete "already"
- L57: Delete: "especially without further processing"
- L58: Delete "the UV Index" (The UV Index is not an action spectrum)
- L66: "artificial neural network modelling (ANN)" > "artificial neural network (ANN) modelling"
    - MC: line 64

- L69: Avoid strings of nouns: “solar UV spectral irradiance observation” > “observations of spectral solar UV irradiance”
    - AC: This part was removed based on the first “minor” comment.
- L79: doesn’t > does not
    - MC: line 76
- L80: “all year long” > “at any time of the year”
    - MC: line 77
- L88: “has been performed” > “was performed”
    - MC: lines 85–86
- L89: travel > travelling
    - MC: line 89
- L92: “of HG and CD > “of Hg and Cd” or better “mercury and cadmium”
    - MC: line 90
- L102: “weak transmitted information affected” > “spectral UV irradiance at the Earth surface, which is affected”
    - MC: line 105
- L107: “The 23 260 of the spectra,” > “The subset of 23260 spectra that passed quality control were used for this study and paired with explanatory variables” (if that’s what you mean)
    - AC: Not precisely, as far more spectra (over 40 000) passed the quality control but only the 23 260 of them were successfully paired with explanatory variables based on the criteria explained further (e.g., TOC measurement taken no less than 60 minutes before or after the spectral observation etc.).
    - MC: To avoid confusion, we rephrased the sentence in lines 110–112 as follows: “The subset of 23 260 spectra that passed quality control and was successfully paired with explanatory variables based on selected criteria (see Section 2.3), was used for this study.”
- L109: “It can be seen there were several data gaps, of which the longest occurred “ > “It can be seen that there were several data gaps, the longest of which occurred”
    - MC: lines 112–113
- L113: “has been paired with following explanatory” > “was paired with the following explanatory”
    - MC: line 120
- L115: “belong to” > “are”
    - MC: line 122
- L119: “Therefore, more solar spectra could be matched” > “Therefore, several solar spectra were sometimes matched”
    - MC: line 127
- L120: “provided it was taken within the 60 minute time distance and it was the closest observation.” > “provided that they were taken within 60 minutes of the closest ozone observation”
    - MC: To make it more clear, we rephrased this as follows: “provided the ozone observation was taken within 60 minutes of the spectral measurement and there was no other ozone observation with a shorter interval from the spectral measurement” (lines 128–129).

- L134: “(further).” > “(see Section XX).”
    - AC: This is in the same section, actually the very next paragraph.
    - MC: We rephrased it to “see further below” (line 149).
- L153: “further in this section).” > “further below”
    - MC: line 170
- L162: “more information is included in Appendix” > “see Appendix”
    - MC: line 194
- L166: “However, even in” > “However, even for”; “carried on: median bias values” > carried out: the median bias between measurement and model values”
    - MC: line 198
- L167: delete “then they”
- L168: “tackled” > “removed”
    - MC: line 200
- L169: “fitted between” > “agreed to within”
    - MC: line 201
- L170: “from approximately 310 nm,” > “for wavelengths longer than approximately 310 nm,”; “modelled data was within approximately” > “measured and modelled data agreed within approximately”
    - MC: lines 202–203
- L172: “determination coefficient” > “coefficient of determination”
    - MC: line 204
- L174: “shared variance” is an uncommon term. Use “coefficient of determination” instead.
    - MC: we used “R-squared” (line 206), which we use for coefficient of determination (a suggestion from another anonymous referee).
- L177: “Out of the four explanatory variables, always only a single one was left to its original value, while the three other variables were fixed to their monthly medians” > “Of the four explanatory variables, one was selected and retained at its original value while the three other variables were fixed to their monthly medians. The procedure was then repeated for each of the four variables.”
    - MC: The albedo effects study was taken out (see previous iteration), so we rephrased this as follows: “The procedure repeated for each of the variables except albedo, whose effects were not studied further as its climatology was used” (lines 210–211).
- L195: “increased” > “increases”
    - MC: line 228
- L200 “of the Sun and the studied site” > “of the Sun at Marambio Base”
    - MC: line 234
- L202: “increase in median irradiance varies” > “increase in median irradiance per nm varies”
    - MC: line 237
- L205: Delete “precise”
- L214: “The wave-like Huggins belt” > “The wave-like structure in the Huggins band”
    - MC: lines 247–248
- L217: “for Antarctic” > “for the Antarctic”
    - MC: line 250
- L222: “conditioned” > “depend both on”
    - MC: line 255

- L270: Delete “likely”
- L277: “which may lead to its decline compared to snow cover or glaciated areas” > “which will lead to lower UV radiation compared to snow cover or glaciated areas”
    - MC: line 314
- L307: “indirectly proportional” > “inversely proportional”
    - MC: line 344
- L385: “wavelengths, when at” > “wavelengths. At”
    - MC: line 432
- L390: “at very short wavelengths is most visible.” > “is most visible at very short wavelengths.”
    - MC: lines 437–438