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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Measurements of UV radiation on rotating vertical plane at the ALOMAR Observatory (69° N, 16° E), Norway, June 2007" *by* P. Sobolewski et al.

P. Sobolewski et al.

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The new manuscript has been prepared including the reviewers' suggestions and comments. Below our response to each mentioned problem is shown.

Reviewer 1 comments: General comments.

"The analysis is not sufficient and the interpretation of physical phenomena is not clear. The way the initial analysis have been presented here makes the acceptance of this work in ACP very difficult by only answering the question below, as the first steps-methodology have to be changed"

***The manuscript has been rewritten. We calculate daily means of the ratio between

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output of the vertical and horizontal unit for each day during the period of measurements at the ALOMAR observatory. Based on the auxiliary data collected at this site (total ozone, aerosols optical depth) we run model calculations showing model counterparts of the observed data for clear-sky and overcast (deep low level cloud) conditions. The suggested ratio ˜0.5 between daily means measured by two biometers (basic results of the manuscript) have been supported also by the model simulations for the ALOMAR site in the period March 1- June 30, 2007. Actual total ozone, climatological values of albedo, aerosols characteristics, and homogeneous deep cloud (an option for overcast simulations) are used as the input parameters. The authors are aware that the hypothesis that two units have similar spectral properties needs a verification by laboratory measurements. We also agree that an application of the conversion matrix, which is obtained from standard calibration procedure for horizontal instrument, to output of vertical receiver needs further validation. Essential part of the manuscript is a comparison of the measured data (collected at the ALOMAR observatory) with the model data that allows to draw conclusion about variability of the ratio and support reliability of the measuring system.

Specific general comments:

"..figure 3 (and number of points shown there) suggest that measurements at each azimuth angle is used for comparison with horizontal KZ instrument. I do not see any physical meaning of Figure 4 if a full 33 minutes average scan is not used or else analysis for separate azimuth and zenith angles is not present ....for high solar zenith angles I would expected that tilted surface KZ ... would be higher than the ones measured by horizontal KZ"

*** In the revised manuscript we focus on the daily means of the ratio between both KZ (see new added Tab.2 and Tab.3). Previous Fig.3 has been slightly modified, see new Fig.2 with different calculations of the relative azimuth. New Figs. 2 and 3 have been drawn to examine the enhancement effects, i.e., the ratio $>$ 1 for the erythemally weighted irradiance that is impossible to obtain under clear-sky conditions (as it is

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illustrated in Fig. 2a). Previous Fig.4 has been deleted. We have no enough number of measured data points to draw a graph showing a dependence of the ratio on SZA, relative azimuth, and total ozone. Instead we draw Fig.4 to illustrate a dependence of the ratio on SZA and relative azimuth for selected orientation of the vertical biometer.

"....there is no information on solar zenith angle range used and what is the impact on the whole analysis. Also what about clouds? Cloudy or not cloudy conditions are very important for such analysis"

*** New Fig.4 is added to show impact of SZA on the ratio for selected cloudless day. In the revised paper there are model simulations (for clear-sky and overcasts conditions) for the period March 1-June 30, 2007. Thus, the overall impact of seasonal change of SZA on the ratio is illustrated (see new Fig.5). We add also Tab.1 to provide information about cloudiness for each day. In the revised paper we address several times an issue of cloud impact on the ratio. For example, see (Sect.2.2) comparison of the observed and modeled (for clear-sky and overcast conditions) ratios in Tab.2 and Tab.3

" ...then main conclusion of the authors is that there is a factor of 0.5 between daily mean doses Give the weak methodology, no physical explanation can be derived from that number as it is really a random number depending on the atmospheric condition, solar elevation range, azimuth rotation choice, for the specific place and period..."

*** The revised manuscript addresses problem of the variability of the factor. The suggested factor ˜0.5 between daily means measured by two biometers have been supported by the observed daily means of the ratio for the period June 2-14, model simulations (separately for clear-sky and overcast conditions) for the period June 2-14 and March 1- June 30, 2007. It has been found that almost all of the daily values of the ratio are within the range 0.5 +/- 0.1.

" ...I have some objections about the use of the calibration matrix converting KZ measurements to CIE weighted UV. My impression is that can be used only for horizontal surface instruments and certain alternations have to be made for vertical one ..."

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*** In the revised manuscript we use only one alternation of the calibration matrix to be applied for the conversion of the vertical receiver output. The incident angle is between the normal to the instrument diffuser and the sunline. SZA is always selected in case of calculations for horizontal unit. We are aware that standard approach to building the calibration matrix is based on observations and model simulations for a horizontal plane. Construction of calibration matrix for the vertical unit is not yet resolved problem. We address that problem in the revised manuscript (Sec. 2.1) "Thus, it seems that our horizontal unit provides valuable data in spite of lack of its own calibration matrix. However, a comparison of the UV irradiances by the vertical and horizontal unit should be treated with caution because an assumption that the instruments are identical is not supported by laboratory investigations of their spectral characteristics (e.g. action spectrum, cosine error also depending on azimuth). Model calculations will provide a kind of validation of the measured ratios between instrument output ....Similarly as for erythemaly weighted data we have no additional arguments for the instruments output instruments' identity and reliability of the data taken by the by vertical unit. Only model calculations provide some insight into the reliability of the calculated ratios."

Specific comments:

-Page 26, line 4. "UVB and UVA measured by both radiometers can be clarified in this section too."

*** We add some new lines describing the instrument. "The biometr has broad spectral response optimized for measurements of erythemal and UVA part of UV irradiance. It measures the irradiance in two spectral bands with a single sensor providing separate output for the erythemally weighted irradiance and integrated UVA irradiance with two separate analog voltage output for each band. The K&Z biometer is temperature stabilized at 25C. The nominal accuracy of the measured daily sum is expected at best 5%" (beginning of Section 2.1)

- "Why day162 are so different than the one of 163? (figure 4)"

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*** Previous Figure 4 has been deleted. The daily pattern for selected two days is not shown in the revised manuscript. We add Tab.1 showing cloud-characteristic for the period of the observations at ALOMAR. Day 162 = June 11. Very heavy cloudiness appeared throughout that day (see Tab.1).

- "There is no explanation based on physical or atmospheric phenomena to interpret results of figure 5."

*** This Figure has been deleted. In the revised manuscript we do not discuss differences in the histograms rather we focus on daily averages of vertical and horizontal instrument output.

- "The argument presented in the last of general comments have to be considered for Vitamin-D results and weighting with this action spectrum."

*** The Vit.D3 weighted UV radiation is obtained only from the model simulations and the results are visualized in new Fig.4. There is no measured data to be discussed at this point. Vit.D3 weighting is only use to show how sensitive the ratio between vertical and horizontal unit output is to the spectral weighting.

- "There is no explanation of what plane azimuth-sun azimuth means exactly at description of the XX' axis of Fig.6. What is the meaning of angles higher than 180 degrees?"

*** In the revised manuscript we define the relative azimuth in different way, i.e., difference between azimuth of the normal to vertical plane (instrument diffuser) and the sun azimuth. The range of relative azimuth is 0-180 degree. Values higher than 90 degree are for the biometer being in shadow. We use new relative azimuth values for drawing new Fig. 2, 3, and 4.

-"If there are snow free conditions then surface albedo of 0.03 can be used."

*** We explain in the revised manuscript: "Albedo value in UV range of 0.05 represents climatological mean at 360 nm for the site derived from Tanskanen (2004) albedo data base. During the ALOMAR campaign there is no snow, so the albedo value used

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seems valid." (Sect. 3)

Reviewer 2 comments:

General comments:

" ....There are number of points need to address .... What is the variability or standard deviation of the data that provides an average of approximately 0.5? Secondly, the data in the paper collected over small time frame and it would be invalid to suggest that it applies for the remainder of year. Also some information for solar zenith angle range, ozone range and cloud cover range over the measurement period would be useful"

*** In the revised manuscript we support the factor 0.5 adding new data and results from observations and radiative model simulations. We focus on daily statistical characteristics showing ratio between the daily means of doses by the vertical and horizontal biometer, and the daily mean of the ratio between temporary (intraday) irradiances by both units. We discuss results of our measurements at ALOMAR for the period June 2-14, 2007, model simulations with reliable input mostly coming from auxiliary measurements input for the same period (separately for clear-sky and overcast conditions), model simulations for the period March 1- June 30, 2007 with actual total ozone for clear-sky and overcast conditions. Information of ozone, cloudiness, and aerosol properties during the measurement campaign are summarized new Table 1. The effects related to the configuration of the vertical unit (SZA and azimuth impact on the ratio) are illustrated in new Figure 4.

Specific comments:

" .... with a broadband instrument, the term scan does not apply"

*** The term "scan" is not used in the revised manuscript,

" ... Figure 3 presents the irradiances on a vertical plane. What is the azimuth of the vertical plane? Alternatively, if it is rotating it should be outlined in the text"

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*** Previous Figure 3 has been deleted. Vertical plane rotated during those days.

" ...the year should be 2006"

*** Erroneous year has been replaced by 2006.

" ... the largest difference between the maximum and minimum are for UVA ....the UVB that is referred to is the erythemal UV and this needs to be changed .... It would be useful to have a possible explanation for why this occurs"

*** UVB term is replaced by erythemal UV in the whole revised manuscript. We suggest an explanation for the largest difference for UVA. "It seems that it is caused by the ozone absorption causing a cut off of direct sun component of UV-B radiation for high SZA. Whereas, the direct sun component within UVA range is still present and it contributes stronger to radiation measured by vertical biometer (smaller the cosine effects) because for high SZA there is possibility that this unit is looking directly at the sun disk but the horizontal unit practically does not see the sun line (Figs. 4b and 4d)"

" In Figure 2, it may be useful to plot the difference between the UV GUV511 and the UV KippZonen"

*** Previous Figure 2 has been deleted according to the reviewer 3 suggestion, i.e., all necessary information is included in Tab.1 and in the revised text.

" In Figures 5 and 6, the caption refer to various "action spectra". The only action spectrum employed is really the erythemal action spectrum as the UVA is not weighted with any action spectrum."

*** Previous Figures 5 and 6 do not appear in the revised manuscript. Term "various spectra" appears in new Figure 4 and 5 caption, where 3 action spectra are mentioned. In our opinion UVA represents a kind of weighting of UV because a relation between different parts of UV is changed when compared to original spectrum.

"In Figure 8, the caption refers to ozone changing between 200-550 DU in 25 DU steps.

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Interactive Comment

It should be clearer in the figure which points are for the low ozone level and which are for the high ozone level"

*** Previous Figure 8 has been deleted. There is no such calculations in the revised manuscript. Instead , the ratio pattern has been calculated for the period March 1-June 30 using measured total ozone values (see new Figure 5).

Reviewer 3 comments:

General: "...The general conclusion of the authors , i.e., a factor of 0.5 between the daily mean dose on a vertically and on a horizontally receiver is very weak because it depends on coincidental atmospheric conditions during half month at position 70 north during the time of midnight sun"

*** The manuscript has been rewritten taken into account the reviewers' comments. The definition of the relative azimuth has been changed. Now it represents the value of angle between the normal to the vertical receiver (instrument diffuser) and the sun azimuth. The range of relative azimuth is 0-180 degree. In the revised manuscript we support the factor 0.5 adding new data and results from observations and radiative model simulations. We focus on daily statistical characteristics showing ratio between the daily means of doses by the vertical and horizontal biometer, and the daily means of the ratio between temporary (intraday) irradiances by both units. We discuss results of our measurements at ALOMAR for the period June 2-14, 2007, model simulations with reliable input mostly coming from auxiliary measurements for the same period (separately for clear-sky and overcast conditions), model simulations for the period March, 1 - June 30, 2007 with actual total ozone for clear-sky and overcast conditions. Information of ozone, cloudiness, and aerosol properties during the ALOMAR campaign are summarized new Table 1. The effects related to the configuration of the vertical unit (SZA and azimuth impact on the ratio) are illustrated in new Figure 4. We agree that the results are only for specific site, i.e., northern high latitude site during midnight sun (observations) and late winter/spring (model simulations), but we think that the

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paper can be treated as a pilot study. Evidently, more efforts are needed to calculate latitude/longitude differences of relation between output of vertically and horizontally oriented receivers.

Major improvements:

Page 24/line 14: "relative UV exposure" should be defined with an equation, at least on page 27. Is there any difference between "relative" and "normalized". Does "rotating vertical plane" mean values averaged over the azimuth from 0 to 360."

*** The term relative UV exposure does not appear in Introduction. Here we simply write "Main objective of this paper is an examination of ratio between weighted irradiances measured on vertically oriented receiver (being a crude approximation of human face randomly oriented towards Sun) and those on horizontal receiver in the Arctic.". Term relative UV exposure appear first time at the beginning of Sec.2.2. "Fig. 2 presents a dependence of the relative exposure (temporary ratio of vertical to horizontal UV weighted irradiance)". The definition is so simple that inclusion of new equation is not necessary. The term "normalized" has been deleted and it appears only in introduction when describing other author experiment and here it is not mixed with term "relative exposure." Term "Rotating vertical plane" is used in the revised manuscript only for description of the motion of the vertically oriented receiver. It has nothing to do with any averaging procedure.

25/1 "What is the effects of dark horizon that can be seen in Fig 1 for a small section? How is the sky obstruction for other azimuths?";

*** We explain in the revised manuscript: "The horizon line for the observing site is obscured on West/North - North directions by the laboratory facilities and mountain (see Fig.1). We excluded measurements between 19-20 hour of local time because of the building shadowing. Moreover, some measurements especially for the sector West/North-North-East/North are not examined because of a weak instrument signal caused by low solar elevations $<$5%."

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" The solar zenith angles must be mentioned, in general and in combination with the azimuth"

*** This has been added. "During back rotation 6 records are done at random azimuth and solar zenith angles. "Moreover new Fig.4 illustrate the complexity of the combined azimuth/SZA effects on the ratio vertical/horizontal unit for selected fixed (throughout the whole day) azimuths."

25/10-15 "Has it been taken into account in the analysis of the measurements that the cosine of the direct sun on the vertical receiver is different to that for the horizontal one, used for the calibration matrix. This should be discussed."

*** In calculation of output by the vertically oriented receiver we use the incident angle for transforming output in Volts to absolute unit (W per square meter) by means of the calibration matrix. The incident angle is the angle between the normal to the instrument diffuser and sun line. (see Sec.2.1)

25/18 ";Fig 2 can be omitted ... To compare the results of different figures (e.g. Fig.3) either day of the year or the date should be used."

*** Previous Fig.2 and Fig.3 have been deleted.

26/15 "What is the information content of Fig.3, ... the differences between horizontal and vertical plane ....must be discussed in general ...."

*** The manuscript has been rewritten and previous Fig.3 has been deleted. Now, a correspondence between the irradiance measured by vertical and horizontal receiver is supported by additional calculations based on measurements and model simulations taking into account specific atmospheric conditions for the ALOMAR site (see for example new Tables 2 and 3, and Fig.5).

26/23 "Here clearly has to be mentioned that the measurements on the vertical plane are not averaged over azimuth, but individual for each azimuth ... how would the figure look like, if cloudy and cloud free data have been separated? What is the effects of

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solar elevation"

*** The previous Fig.4 has been deleted. It has been clarified in the revised manuscript: "Fig. 2 presents a dependence of the relative exposure (temporary ratio of vertical to horizontal UV weighted irradiance) on relative azimuth, fi_rel, i.e., an angle between azimuth of the normal to vertical receiver (instrument diffuser) and the sun azimuth. All temporary measurements for the period June 2-14 are shown" (beginning of the Sec.2.2). In the revised manuscript the cloud effects are discussed on the daily basis (see new Table 1, 2 and 3). The effects of SZA, and angle between sun and instrument azimuth are illustrated for clear-sky conditions in Fig. 4 using the model simulations. We have no perfect clear-sky conditions during the measurements period, so the observed ratios are effected by cloud even if the sun is not obscured by clouds. It seems that from statistical point of view it is more safe to examine daily statistics of the weighted irradiances from the observations by the biometers as an accuracy of temporary output is sometimes difficult to estimate especially for low solar elevation.

26/27 "how is the mean ratio calculated? Simply the mean over all measurements? At least the mean solar elevation and the relative amount of cloudiness should be mentioned."

*** The overall ratio from the measurements is not calculated in the revised manuscript instead we show day-to-day variability of the daily mean of the relative exposure and the ratio between daily doses by the vertical and horizontal receiver. The observed daily means and hypothetical clear-sky and overcast results are shown in new Table 2 and Table 2. The mean solar elevation effects and the cloud effects are illustrated (new Figure 5), based on the model simulations, for longer period March 1-June 30, 2007.

26/28 "For Figure 5 the differences between UVI and UVA should be discussed?";

*** Fig.5 has been deleted as the overall characteristics derived from individual measurements of the relative exposure are not further discussed in the revised manuscript.

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27/22 "Fig.6 How is it possible that the difference between the azimuth of sun and instrument become larger than 180 The explanation "...large negative azimuth ... plane is illuminated by direct sun." I do not understand..";

*** It has been changed. Now, we use an angle between the normal to the vertically oriented receiver and the sun azimuth. It is called relative azimuth in the text and its range is within 0-180 degree. Such definition simplifies the analysis. The specific effects of instrument/sun configuration on the ratio are illustrated in new Figure 4, where the daily pattern of SZA and the relative azimuth are also shown.

28/12 "Why are the data modeled for 21 March? Why are data compared with measurements from June only? What about solar elevation?"

*** The model simulations for two days (March 21 and June 21) with artificial ozone have been deleted. Such modeling prepared data for the regression model. In the revised manuscript we do not carry statistical model to estimate clear-sky values of the temporary relative exposure. We focus on validation of the factor 0.5 generality for the whole year, so the model data are prepared for the period March, 1 - June 30, 2007 for clear-sky and overcast (dense low level cloud). The seasonal change of SZA is included in the model calculations.

29/3 and 7 "why for modeling of UVA not real spectral sensitivity curve of instrument has been taken into account"

*** The spectral sensitivity of the instrument for UVA was not known. Kipp and Zonen provide a factor to transform the model output in volts to integrated irradiance (in W/m2) over UVA range. We are aware that using model simulations we do not reproduce the measurements at ALOMAR observatory by the biometers having specific spectral responses. The quality of the radiative model for inclined surfaces was supported by its authors. Here, we examine possible range of the ratio (vertical/horizontal receiver) variability using model simulations supposing various action spectra. The measured values are somewhere between two extreme case: very heavy homogeneous cloud

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and clear-sky conditions, see for example Table 3 results.

29/13-23. "What part of the variability in Fig.8 is due to solar elevation, what due to ozone variations? Is it correct that all other variable have been not changed? Same question as for Fig.6 with respect to the azimuth difference larger than 180"

*** New Figures 2 and 3 being equivalent previous Fig.6 and 8 have been prepared but the azimuth difference is calculated in different way (see our response to problem 27/22). These Figures shown temporary relative exposure as a function of the relative azimuth for the whole period of the ALOMAR campaign combining all other effects. Comparison of the data shown in Fig.2 and Fig.3 let us discuss the effect of shadowing and notify that there are some enhancements possible for erythemally weighted UV on vertical receiver. The effects of specific configuration of both instruments on the temporary ratio are illustrated in Fig.4.

32/14 "Validity and variability of the averaged ratio 0.5 .."

*** The manuscript has been rewritten to support the factor 0.5 by adding new data and results from observations and radiative model simulations. See also our response to general comment of the reviewer 3.

36/Tab.1 "To give more importance to this table, the variability - as mentioned already for Fig.8 due to solar elevation and due to ozone should be mentioned";

*** Previous Table 1 has been deleted and replaced by Tab.2 and Tab.3 where the daily statistical characteristics are shown. The internal (within day) and seasonal (March, 1 - June, 30, 2007) variability of the proposed factor are illustrated in Fig 4 and Fig.5, respectively.

Minor improvements: 25/4 "What direction is azimuth 0?"

*** It has been clarified in the revised manuscript: "Temporary weighted irradiances are collected for 8 prescribed azimuth angles fi= 0 (North), 45o, 90o (East), 135o, 180o (South), 225o, 270o (West), and 315o." (see Section.2.1).

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28/8 "Radonic instead Rodonic"

*** It has been corrected.

39 "Fig.3 x=Axis of is not time but day or something similar."

*** Previous Fig.3 has been deleted.

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