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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Comparison of UV climates at Summit, Greenland; Barrow, Alaska and South Pole, Antarctica" *by* G. Bernhard et al.

G. Bernhard et al.

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We thank Referee #2 for his or her thoughtful suggestions. The referee comments are repeated below, followed by our response.

Comment 1 (General): I would have liked to see a little more focus on the UVB (erythemally weighted results) and the presentation of relative contributions of the parameters influencing the UV-climate. Also, some more overall "climatological" numbers on time-integrated UV-radiation levels (year-round, seasonal, year to year variability) could be valuable additions to the presented analyses, which focuses on the comparison of the solar zenith angle dependence. "Comparison of UV irradiance measurements at . . . ." would be a better suited title for the presented analysis. Despite the fact that nearly three years of data is a short period I could live with the presented title if climatological numbers are added, and some additional analysis is done with respect to the overall effects of the major factors influencing the Uv at these sites in relation to the climatological numbers (clouds, albedo, altitude etc).

Response: We will add a table to the paper providing a climatology of noontime irradiance at 345 nm and of the UV Index. Statistical parameters will include average, median, and 5th and 95th percentiles. More details on the table are provided below. In addition, the following text will be added to the conclusions: "Additional comparisons of UV measurements at UVSIMN sites are currently being prepared and will be published in a book titled 'UV Radiation in Global Change: Measurements, Modeling and Effects on Ecosystems' This publication will discuss noontime measurements and daily doses as functions of Day of Year, and will complement results presented in this paper." We will also add a new figure showing frequency distribution of cloud modification factors for Summit to better describe the effect of clouds at this site. We believe that the effects of ozone and aerosols have already been adequately addressed in the original version of the paper. The title of the paper will be changed to "Comparison of UV irradiance measurements at Summit, Greenland; Barrow, Alaska; and South Pole, Antarctica."

Comment 2 (Abstract Lines 8-9): Impacts of clouds - give more climatological numbers here, such as average cloud modification factors for the three sites.

Response: A new figure showing frequency distribution of cloud modification factors for Summit plus associated text will be added to the manuscript. More details are provided below. Similar frequency distributions for South Pole and Barrow have already been published by Bernhard et al. [2004; 2007], and these papers will be referenced. The text in the abstract will be changed from "Clouds have little impact at both sites,..." to "Clouds attenuate irradiance at 345 nm at both sites by less than 6% on average, ...

ACPD
8, S4169–S4179, 2008

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Comment 3 (Abstract Lines 11-12): Unclear to which sites the remarks on aerosol effects refer to?

Response: "at Barrow" will be added to the abstract.

Comment 4 (Abstract Line17): Maximum UV-indices for SPO and SUM are given. It should be noted however that 16 years of data records or only 3 (SUM) influence the record high values. Would 95 percentile of the readings at the lowest SZA not be a better, more stable measure to mention in the abstract and the paper. Why not include Barrow's high value as well? In addition to the highest values also the median values could be of interest.

Response: The maximum UV Index for Barrow (5.0) will be added to the abstract. The other points raised by the reviewer will be addressed in the body of the paper to keep the abstract concise (see additional comments below).

Comment 5 (Page 4952, Line 25-26): Could a summarizing statement be added on the instrument performance in the intercomparison: spectral irradiance readings within x % in the UV-range from .. to .. for sza;..

Response: The following text will be added: "Measurements of spectral irradiance in the UV-A agreed to within 5% with measurements of a reference spectroradiometer of the Network for the Detection of Stratospheric Change (NDSC). Differences at 300 nm were smaller than 8%."

Comment 6 (Page 4954, Lines 24-29): Indicate the average ratio and the average sd compared to that average ratio. Is this averaging over the full measurement period and all individual data recordings with sza smaller than 85?

ACPD

8, S4169–S4179, 2008

Response: Average and standard deviation for all six sub-periods will be included in the final version of Figure 1. The "average standard" deviation was calculated as the average of 18 different standard deviations (6 periods, 3 wavelengths). The final version will include the standard deviation calculated over all data points regardless of the associated period or wavelength (The values for the two calculation methods agree to within 0.001.) The text will be changed to: "For solar zenith angle (SZA) smaller than 85°, standard deviations of the ratios of SUV/GUV range between 0.010 and 0.022 for all periods and wavelengths. The standard deviation calculated from all data points is 0.015, ..."

Comment 7 (Figure 1): The results for 320, 340 and 380 nm look very similar. That gives confidence but it is preferable to also choose a wavelength in the UVB (310 or 305 nm). I could live with an inclusion of a UVB wavelength and less separate values in the UVA and a textual remark on the equivalence at other UVA wavelengths.

Response: Due to the high total ozone columns prevailing at Summit, measurements of the GUV 305 nm channel are very noisy for SZA larger than 75°. Moreover, the 305 nm channel of the GUV at Summit was unfortunately affected by some non-linearity (˜3%) at gain-changing points and this affected measurements for SZA between than 65° and 75°, depending on total ozone. Due to these limitations, measurements of the GUV can only be used for testing the stability of the SUV when the SZA is smaller than 65°. We therefore decided not to include measurements of this channel. Changes of SUV calibration functions depend smoothly on wavelength and we therefore have confidence that the good relative stability of GUV and SUV measurements between 320 and 380 nm applies also to the 300-320 nm interval.

Comment 8 (Page 4956, Line 5): The comparison of OMI ozone and ozone from the spectral measurements at SUM (1.010 +/- 0.019) is indicated, but unclear is if this sd refers to each individual measured spectrum or to daily averages/medians? Please clarify.

Response: The standard deviation was calculated from individual time-matches of SUV and OMI measurements. We think this is clear since daily averages of ozone are not discussed in the paper. Adding this information would complicate the sentence unnecessarily. We therefore decided not to change the text.

Comment 9 (Page 4956 lines 15-30 and first paragraph of 4957): Can temperature related effects be excluded in the seasonal patterns of 2006 and 2007?

Response: All parts of the instrument are actively temperature controlled to within +/- 1° and differences in measurements of different years due to instrument temperature variations can therefore be excluded. The absorption cross section of ozone depends on atmospheric temperatures, and this dependences also affects UV measurements. However, Figure 2 shows the ratio of measurement and model at 345 nm where absorption by ozone is negligible. We are not aware of any temperature effect that might affect UV irradiance at this wavelength appreciably. No change to manuscript.

Comment 10 (Figure 2): I fail to see that the yearly pattern for 2005 is significantly different from 2006 and 2007. It appears may be there is more scatter at the start of 2005 but the relevant time period in 2005 (between 18 May and 1 August) lacks data so I doubt the significance. Unless further evidence is available I would suggest to shorten this section, or at least make it less certain: might be in stead of is absent.

Response: We agree that the difference in the yearly pattern is subtle (For the period 9-March - 17-May, the average ratio of measurement to model is 0.972 for 2005, 0.939 for 2006 and 0.958 for 2007. Compared to 2005, the ratios for 2006 and 2007 are low by 3.4% and 1.4%.) From reviewing all available evidence we still believe that these

ACPD

8, S4169–S4179, 2008

Interactive Comment

small differences are due to atmospheric processes and not instrument related. The winter of 2004-2005 was very unusual as indicated by anomalous low stratospheric temperature, low total ozone amounts and low tropopause height. It is therefore reasonable to assume that atmospheric circulation patterns were unusual in the spring of 2005, modifying the transport of aerosol-rich air to Summit. To ease the concerns of the reviewer, we will add the sentence: "A more quantitative assessment of aerosol effects is not possible due the lack of aerosol measurements at SUM and the gap in UV measurements between 18-May and 1-August 2005."

Comment 11 (Page 4957, Figure 3 panel b): I fail to see the relevance of panel b in Fig 3: What is the argument to plot the ozone versus SZA. No word is said in the text on this plot and it probably reflects predominantly the seasonal pattern. It could be interesting to see how stable the ozone determination method is in relation to the sza, but then it should be plotted differently (relative change of ozone value over the day/sza).

Response: Measurements of UV irradiance were plotted versus SZA (Figure 4 and 7), and it is therefore sensible to also plot total ozone versus SZA. By doing so, the large difference between spring and summer for a given SZA is best empathized, and we think that Figure 3b is particular helpful when discussing Figure 7. The ratio of total ozone calculated from SUV spectra shown in Figure 3 to total ozone measured by OMI does not exhibit any systematic dependence on SZA for SZA$<83^\circ$. The good agreement between SUV and OMI ozone data was already mentioned in the paper ("For SZAs smaller than 80°, the ratio of SUV-150B and OMI measurements is 1.010+/-0.019 (+/-1 sigma).")

Comment 12 (Page 4958 line 23): Clouds at BAR can reduce UV by more than 75% is not very specific. Better to give some median or 95 percentile indication of cloud effects (or both). Same holds for the number mentioned in the abstract.

ACPD

8, S4169–S4179, 2008

Response: The text will be modified as follows: "Between 16-June and 30-September, clouds reduce irradiance at 345 nm by 33% on average; attenuation by more than 74% is observed for 5% of all spectra measured during this period."

Comment 13 (Page 4961 line 5-7): The overall maximum of the observed UV-index can be dependent on the number of observational years, unless the year to year variability is low. Add average and or median values for the UV indices, and use 95 percentile values, which are less depending on the number of years.

Response: The bullet points will be changed to: - The overall maximum UV Index is 6.7 at SUM, 5.0 at BAR and 4.0 at SPO. The maximum value for SUM is likely biased low due to the short data record for this site. To reduce this bias, we also calculated the 99th percentile of the UV Index measured within 3° of the lowest SZA observed at the three sites. The values are 6.2 at SUM, 4.4 at BAR and 3.5 at SPO. - At SZA=70°, UV Indices vary between 0.8 and 1.8 at SUM, 0.0 and 1.2 at BAR, and 1.0 and 3.4 at SPO. Average, median, 5th, and 95th percentiles at SZA=70° are, respectively, 1.2, 1.2, 0.9, 1.6 for SUM; 0.7, 0.7, 0.3, 1.0 for BAR; and 1.9, 1.7, 1.2, 2.9 for SPO.

Comment 14 (Page 4961, line 8-9): More than 50 % on average is very flexible: 80% or 90 % fit in that and so does 51%. More exact description should be possible.

Response: The sentence will be changed to: "For SZAs between 70° and 75°, UV Indices measured at SPO during the period of the ozone hole exceed maximum indices observed at SUM by 50-60% on average. For SZAs between 77° and 85°, the difference is about 75% (Figures 8a and 8b)".

Comment 15 (Page 4962 line 25-26): The peak (at SZA 84 in figure 8 b) is a consequence of the small ozone column observed on this day. I do not understand this sentence, because I thought all days where sza 84 is reached are included so not single days, or is this sza reflecting the lowest sza per day ?!! I do understand that again the seasonal dependence of the ozone value somehow is reflected in this plot. See comment on figure 3b.

Response: The sentence refers to the peak in the South Pole data set. At the South Pole, the variation of SZA within one day is smaller than 0.4° in October. It is therefore possible to associated a specific day with a specific SZA. The seasonal change of the UV Index at South Pole is therefore implicitly conveyed in this plot. For other sites, all measurements for a given season (spring or summer) are included in each SZA-bin. To avoid confusion, the phrase "on this day" will be replaced by "at this SZA".

Comment 16 (Pages 4961-4962): I think here some overall statistics and climatological numbers are lacking. Numbers like: year round, monthly and/or seasonal integrated UV-doses (for erythemally weighted UV) for the three sites. Such numbers would in my view be expected when UV-climate is indicated in the title. In addition I think the paper would further improve if frequency distributions on cloud modification factors would be added (less detailed but comparable to fig 7 in Bernhard etal 2007; see for instance fig 6 in PN den Outer etal JGR vol 110 D02203 doi 10.1029/2004JD004824). Also a simplified version of fig 8 in the Bernhard et al 2007 paper would be a useful addition in the data-analysis to my opinion.

Response: While preparing this manuscript, we have also prepared a paper comparing the UV climate at all seven sites of the UVSIMN. This paper has been accepted for publication in the Springer book "UV Radiation in Global Change: Measurements, Modeling and Effects on Ecosystems," edited by Wei Gao and James Slusser. Comparisons are based on average and maximum UV Index as well as average and maximum erythemal dose. Data are presented as a function of Day of Year. One important conclusion of this paper was that differences between sites depend very much upon the selection of the quantity used for the comparison. Since the ACP manuscript focuses on instantaneous values rather than daily, monthly or annual doses, we will not discuss the climatology of these quantities here. We will provide a reference to the book chapter instead.

To address the concern of the referee that climatological values are lacking, we will include a new table, showing a climatology of noontime irradiance at 345 nm and of the noontime UV Index. The following text will also be added: "Table 1 provides a climatology of irradiance at 345 nm and the UV Index. The climatology is based on spectra measured close to local solar noon. The following times (provided in universal time) were associated with noon: Summit: 15:00; Barrow: 22:00; and South Pole: 00:00. These times were selected because spectra starting at these times are available for all years. To set up the climatology, average and median as well as the 5th and 95th percentiles were calculated for every month from all available noontime measurements. For SUM, all four statistical parameters peak in June, both for irradiance at 345 nm and the UV Index. For BAR and irradiance at 345 nm, the four parameters are highest in May. This shift of maximum values by one month towards spring is a consequence of the larger albedo and lower cloudiness in spring. The UV Index at BAR is also skewed toward the spring, although to a lesser extent than irradiance at 345 nm. UV irradiances at SPO have their maximum in December but it is worth noting that the 95th percentile for the UV Index is almost identical for November and December. This is due to the low total ozone amounts in November, which almost offsets the larger SZA for this month."

Following the suggestion of the reviewer, we will also include an additional plot, showing frequency distribution of irradiance at 345 nm relative to the irradiance for clear-sky. The following text will be added: "The effect of clouds on irradiance at 345 nm has been quantified for South Pole (Bernhard et al., 2004) and Barrow (Bernhard et al., 2007) in great detail. Here we present a similar analysis for Summit. The effect of clouds is described with frequency distributions of transmittance T, defined as the ratio of measured spectral irradiance at 345 nm to the associated clear sky irradiance

ACPD

8, S4169–S4179, 2008

Interactive Comment

value calculated with the model. Using the same method as applied by Bernhard et al. (2007), transmittances were corrected for the bias of 1-6% between clear sky measurements and model values discussed earlier (e.g., Figure 2). Transmittance values calculated from spectra measured at SZAs smaller than 85° were selected from data of all years and binned into 0.02-wide intervals to set up two frequency distributions for spring and summer. Figure 7a shows the frequency distribution of T for spring (defined here as period between 1-March and 21-June). Figure 7b shows a similar distribution for summer (22-June -12-October). Both distributions display a distinct maximum at T=1, marking clear-sky conditions. The clear-sky peak is more pronounced in spring than summer, indicating that clouds are more frequent in the summer. The distribution for summer also shows a secondary maximum at 0.9, which is a sign for extended periods of overcast conditions. The average transmittance is 0.965 for spring and 0.942 for summer. Attenuation by clouds by more than 17% ($T<0.83$) is observed only for 1.2% of all cases in spring. The corresponding fraction for summer is 2.9%. Enhancement of irradiance at 345 nm by clouds is less than 10%, with few ($<$ 0.5%) exceptions."

Figure 8 of Bernhard et al. [2007] presents an elaborate modeling-based analysis of the effects of ozone, aerosols, albedo, clouds, and Sun-Earth distance on spectral irradiance at 305 nm and the UV Index for Barrow. Albeit a similar analysis would be possible also for Summit, we think that the effects of ozone, aerosols, and clouds have already been described in sufficient detail in this manuscript. Presenting the method by Bernhard et al. [2007] also would lead to some duplication and would increase the length of the manuscript substantially. We therefore decided not to implement the reviewer's suggestion.

Technical corrections

Page 4951 line 2 Lehmann, 200 should be 2005 Page 4953 line 7 omit "of" from "with a surface albedo of larger than 0.97 year-round" Page 4959 line 28 3202m versus 6m

ACPD

8, S4169–S4179, 2008

Interactive Comment

=> 8m on page 4953

Three technical corrections corrected as suggested.

Interactive comment on Atmos. Chem. Phys. Discuss., 8, 4949, 2008.

ACPD

8, S4169–S4179, 2008

Interactive Comment