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Atmospheric Chemistry and Physics Discussions

Interactive comment on "High levels of ultraviolet radiation observed by ground-based instruments below the 2011 Arctic ozone hole" *by* G. Bernhard et al.

G. Bernhard et al.

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We thank the reviewer for his or her comments, which are repeated below, followed by our response.

Comment 1

17260,27: I think that the uncertainty estimates for the Canadian Brewers might be too optimistic, although they come from an accepted publication, because in the winter spring periods the UVB signals are very weak and the stray light becomes more

important (so the uncertainty of a single monochromator increases), and in addition, the calibration checks were done every 1-2 years. Similar doubts due to low signals may arise also for the other instruments used in the study. Of course an increased uncertainty estimate will not alter qualitatively the results of the study.

Response

This comment is very similar to the first comment by Reviewer #1. As pointed out in the response to that reviewer's concern (including our response to the follow-up comment by Reviewer #1), stray light is not a significant contributor to the overall uncertainty, even at the small solar elevations prevailing during the "low-ozone" period. Because measurements at 315 nm are well above the detection limit of Brewer photometers on 1 March, photon noise is also not a significant contributor to the overall uncertainty.

The following sentence will be added to the manuscript:

"The effect of uncertainties in the stray light correction on the accuracy of the measurements was analyzed and the associated uncertainty in UVI data was found to be smaller than 1%."

Comment 2

1762,21: It would be good to provide here an uncertainty estimate of the spectral extrapolation, as it was dome for the Canadian Brewers in 17259,17.

Response

The following sentence will be added to the manuscript: "The extrapolation method has been tested using solar spectra measured between 290 and 400 nm by two Bentham spectroradiometers, concluding that extrapolation uncertainties are smaller than $\pm$0.2% for Brewer MkIII data. For the Brewer MKII data, uncertainties are smaller than $\pm$1% for SZA<60° but may reach up to $\pm$3% for larger SZAs. In absolute terms, errors

remain below $\pm$0.03 UVI units."

Comment 3

17263, 3: Have the data been corrected for the 1-6% drift established by comparison to the QASUME instrument?

Response

The following will be added to the manuscript:

"Data have not been adjusted to the irradiance scale of the QASUME instrument."

Comment 4

17264, 5-11: These criteria look like arbitrarily selected. Why the length of the accepted data gaps are different at different sites? Why 1° is selected for the SZA?

Response

For all but two sites (Jokioinen and Resolute), the "length of the accepted data gaps" was consistently set to 7300 s (2 hours). This is a reasonable setting considering that some sites provided only 1-2 measurements per hour (Table 1). During some periods, the measurement frequency at Jokioinen and Resolute was reduced such that a "gap criterion" of 7300 s would have led to too many missing days of data, and in turn to problems in calculating a meaningful average daily dose for every day of the year. (Low sampling frequencies at Jokioinen during morning and afternoon hours are partly caused by the fact that measurements at this site do not occur at specific times but at specific air mass values.) We agree that the uncertainty of daily doses increases when large gaps have to be filled by interpolation and we will therefore add the following sentence to the manuscript: "By permitting data gaps longer than two hours during

some periods at Jokioinen and Resolute, CEDs calculations for the two sites have a larger uncertainty than for the other sites."

It is important for the accurate calculation of CED that measurements during noon-time hours - when radiation levels typically peak - are available. The "1°-criterion" was coded into the software to ensure that measurement close to solar noon are present. In practice, the criterion only affected calculations for Resolute, Barrow, and Summit. (For all other sites, the "time criterion" (e.g., gaps < 7300 s) proved to be sufficient.) Data for Resolute, Summit, and Barrow were re-calculated with the "1°-criterion" turned off, and compared with the originally produced data set. For the annual cycle of the climatological dose (i.e., the blue lines in supplement "DailyDose.pdf"), bias and standard deviation of the two data sets are 0.01% and 0.18% for Resolute; 0.09% and 1.11% for Summit; and 0.42% and 1.86% for Barrow. Hence, while the choice of 1° is somewhat arbitrary, the effect of the filter is rather small and we therefore feel that this effect does not warrant a more detailed discussion in the paper.

Comment 5

17264, 15-16: Please explain how the start of the periods was calculated form UV measurements. It is not clear as it stands now.

Response

The sentence

"The start of the periods for Alert, Eureka, Ny-Ålesund, and Resolute was based on UV measurements because ozone was already depleted before the day when solar elevation became large enough for OMI measurements."

will be changed to

"The start of the periods for Alert, Eureka, Ny-Ålesund, and Resolute is the day when

UV measurements in 2011 exceeded the 90th percentile of historical measurements. The start was based on UV data because ozone was already depleted before the day when solar elevation became large enough for OMI measurements."

Comment 6

17264, 21-22: "two consecutive days or more than 3 days in total", in each year?

Response

"per year" will be added to the sentence.

Comment 7

17266: 25-27: Can these results be considered representative also for the Canadian stations where, presumably, the weather regimes are different?

Response

Because the Canadian sites are at a similar latitude than Ny-Ålesund, results from Ny-Ålesund are used below for discussing the effect of subsampling on measurements at the Canadian sites.

While the weather regimes for the Canadian sites are indeed different from the weather at Ny-Ålesund (for example, Ny-Ålesund is affected by the gulf stream, leading to warmer temperatures), we feel that conclusions derived from the Ny-Ålesund data can be adapted to the Canadian sites. A good overview of the average weather conditions at Eureka, Resolute and Longyearbyen (a coastal station like Ny-Ålesund, 100 km south-east of Ny-Ålesund) is available from the website http://weatherspark.com: Eureka: http://weatherspark.com/averages/27709/Eureka-Nunavut-Canada Resolute: http://weatherspark.com/averages/28354/Resolute-Nunavut-Canada Longyear-

byen: http://weatherspark.com/averages/28884/Longyearbyen-Spitsbergen-Svalbard-and-Jan-Mayen

These web resources indicate that the "chance of at least some snow on the ground" during March and April is about 60-70% for Eureka and Resolute, and 30-35% for Longyearbyen. The "median cloud cover" for the two months is between 30-50% at Eureka and Resolute, while it is between 66% and 78% for Longyearbyen. Because snow cover (and in turn albedo) is larger at the Canadian sites, while cloud cover is smaller, it can be expected that UVI variability at the Canadian sites is smaller compared to Svalbard. Hence, the effect of subsampling at the Canadian sites should be smaller than the effect indicated in Fig. 2 for Ny-Ålesund. This reasoning supports one of the paper's conclusions that the relatively low sampling rates of the Canadian Brewer spectrophotometers is not an important source of uncertainty. During July, there is insignificant snow cover and the median cloud cover exceeds 85% at all sites. Hence, UVI variability and the effect of subsampling at Eureka, Resolute, and Ny-Ålesund should be very similar.

For the sake of brevity, we do not intend to include this discussion in the manuscript.

Comment 8

17267, 8-19: Would the overall picture change if climatological means based on the common years (e.g., 2001-2010) are used instead?

Response

Using only data from 2001 - 2010 for calculating the climatological means, Figure 3 and the associated plots of the supplement file LocalNoon_ss15min.pdf were redrawn. Our reply includes a supplement in zip-format, which contains the following files:

- LocalNoon_ss15min.pdf (UV Index averaged over a period of ± 1 hour centered at local solar noon using data of all years; data of Norwegian sites were subsampled at

15 min intervals.) This file is identical with the original supplement file of the ACPD paper.

- LocalNoon_ss15min_2001-2010.pdf. This file includes the redrawn plots using only data from 2001 - 2010 for calculating the climatological mean and the associated statistics (10th and 90th percentiles, minimum and maximum).

- Statistics.pdf. This file includes two tables, named Table 4a and Table 5A, which compare the statistics for the two scenarios. The two tables have the same layout as Tables 4 and 5 of the ACPD manuscript. Statistics where the difference between the two datasets is large are printed bold red. Specifically, the following cases are highlighted: (1) difference in the day-of-year when the maximum anomaly occurred, (2) difference in the UVI anomaly is larger than 10%, and (3), the difference in "Days too early" exceeds two days.

The following conclusions can be drawn from this material:

- For Eureka, Summit and Finse, the first year of data was in 2001 or later. The recalculated datasets for these sites are therefore identical with the original datasets. There are no spring-time data for Alert before 2001, so the results for this site are also identical. The difference for Andøya is negligible as measurements at this site started in 2000.

- Climatological means based on all available data have smaller day-to-day variability than means based on the 2001-2010 period, as can be expected. This suggests that statistics based on the full data set (as presented in the ACPD manuscript) are more accurate. This is particularly the case for Resolute where data gaps present a problem when calculating the mean using data from 2001-2010 only (compare the two PDF files). Results for Resolute based on the 2001-2010 period should therefore be treated with caution.

- For all Scandinavian sites, the day-of-year when the maximum anomaly occurred is

identical for the two datasets.

- The difference in the UVI anomaly is larger than 10% only for Trondheim, Østerås, and Blindern. The relatively large differences for Østerås, and Blindern (-12% and +24%, respectively) are not surprising considering the large variability from clouds at these sites.

- The difference in the "Days too early" statistic exceeds 2 days only at Sodankylä (6 days) and Jokioinen (20 days). The larger difference for Jokioinen is due to the comparatively large day-to-day variability of the climatological mean when only data from 2001-2010 are considered. This example clearly shows that more accuate statistics can be achieved when a long data record is available, in particular for sites with large cloud variability. To emphasize this fact, the following statement will be added to the manuscript:

"Statistics for sites with long data records (e.g., Barrow, Sodankylä) are generally the most robust. Results from sites with short records (Summit, Finse) or large data gaps (Resolute) should be interpreted with caution."

From this analysis we conclude that the overall picture would not change if climatological means were based on the common years (2001-2010) only.

Comment 9

17269, 25: I do not see the reason for moving the explanation to another section?

Response

Section 6 (Results) deals mostly with observations while Section 7 (Discussion) centers on the interpretation of observations. We therefore think that the explanation why anomalies for data product (3) are systematically smaller than anomalies for data products (1), (2) and (4) has a better "home" in Section 7 (specifically p17273, l25 - 17274,

l7). Since the explanation is relatively long (12 lines), moving it to Section 6 would adversely affect the flow of reporting observations.

Comment 10

17270, 29: I am not sure about the significance of this estimate (5.3 stds) given the very small absolute doses in conjunction with the uncertainties of the single Brewers under low signal conditions. No doubt that the ozone depletion signal on UV was detectable at the sites examined, but I am a bit skeptical about the validity of the absolute changes reported.

Response

The enhancement by 5.3 standard deviations was observed at Eureka. It is true that this large relative increase is associated with a small absolute dose (see top left panel of Fig. 6.). However, this low value is still well above the detection limit of the single Brewer spectrophotometer and our analysis (Comment 1) suggests that the measurement of erythemal irradiance is only weakly affected by stray light. We therefore conclude that the stated enhancement is accurate.

Comment 11

17273, 3-24: I have the feeling that these paragraphs do not belong here. They look to me isolated without clear connection to the text before and after. Maybe the authors can consider moving them to the Introduction.

Response

The section in questions has two paragraphs. The first paragraph compares the mechanism that led to the low-ozone event of 2011 with the conditions that lead to “ozone mini-holes”. We will move this paragraph to the Introduction as the reviewer suggests.

The second paragraph is a discussion on whether the occurrence of clear-skies over much of Scandinavia during the peak of the low ozone episode could be linked to the strong polar vortex observed in 2011. We feel that this paragraph should remain in the Discussion, but it will be moved directly below the paragraph discussing the effect of sky condition on UV levels (e.g., p17272, l9 - l23). Hence, the new sequence will be: (1) Large UV anomalies in 2011 were partly caused by minimal cloud cover this year; (2) there could be a link between the strong vortex of 2011 and the low cloud cover; (3) higher-than-normal surface albedo was additionally contributing to the UV anomaly at some sites.

Comment 12

17273, 26-28: This sentence is unclear to me. Please rephrase.

Response

The sentence will be changed from:

“There is little difference depending on whether the single measurements closest to local solar noon or the average of measurements within a two hour period centered about the noon is evaluated.”

to

“There is little difference depending on whether the single measurement closest to local solar noon (data product (1)) or the average of measurements within a two hour period centered about the noon (data product (2)) is evaluated.”

Comment 13

17275, 16-20: This sentence is not very relevant to the first sentence of the paragraph.

Maybe it belongs and should be connected to the following paragraph “Because surface UV

Response

The paragraph break will be changed such that the new paragraph starts with “The noontime solar elevation on 30 March is 12° at Alert. . .” and continues with “Because surface UV. . .”

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Technical comments:

17264, 25: Change “site” to “sites”

17268, 15: Replace “and” with “-“.

17269, 28: Change to: “Relative increases for CED range

17270, 5: Maybe “metric” would be a better word instead of “measure”.

17270, 9: Change “large” to “largest”.

17270, 10: Change “early” to “earlier”.

17270, 14: Delete “a” after “UVI for”.

17270, 19: Change to: “2011 with the average doses determined for the same period from all years.”

17273, 29: Delete “evaluating”

17274, 1: Replace “UV anomalies based on” with “for”.

17274, 1: Delete “phenomenon”

17274, 8: Replace “UVI Anomalies” with “Relative anomalies” (UV doses cannot result in UVI anomalies!)

17275, 14: Change to “At the high-latitude Arctic sites”

17276, 2: Change to “particularly”

17276, 13-14: Change to plural “deviations” (2 occurrences).

17297, 2: Change to “The average climatological dose for”

Response

All technical comments shown above will be addressed as suggested.

Please also note the supplement to this comment:
http://www.atmos-chem-phys-discuss.net/13/C5611/2013/acpd-13-C5611-2013-supplement.zip

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Interactive comment on Atmos. Chem. Phys. Discuss., 13, 17253, 2013.