Atmos. Chem. Phys. Discuss.,
https://doi.org/10.5194/acp-2018-828-AC3, 2018

Atmospheric Chemistry and Physics Discussions
Open Access

Interactive comment on "Relationship between erythema effective UV radiant exposure, total ozone and cloud cover in southern England UK: 1991–2015" *by* Nezahat Hunter et al.

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Received and published: 26 October 2018

Response to referee comments:

Interactive comment on "Relationship between erythema effective UV radiant exposure, total ozone and cloud cover in southern England UK: 1991–2015" by Nezahat Hunter et al.

Anonymous Referee #2 Received and published: 4 October 2018

This manuscript explores the changes in erythema effective UV radiant exposure over a 25 year period, and the associated changes in total ozone and cloud cover that might be expected to influence UV radiation at the ground. This is a significant time series for ground-based UV radiation measurements and as such the results are instructive. The ozone and cloud cover data have been taken from longer datasets for stations relatively close to Chilton, the location for the UV measurements. The work is well presented but appears as a statistical exercise somewhat lacking in atmospheric interpretation. It raises a number of queries that must be addressed before publication of a final paper.

Section 2.1 The previous paragraph states that monthly UV doses are considered in the manuscript. Section 2.1 then details how a daily dose was calculated. Please specify how a monthly dose was then determined – is it the sum of all days in the month, or the average of all days in the month (that is it becomes a mean daily dose for the month). How was missing data treated? Was there a limit to the number of missing hours allowed for calculation of a daily dose, and similarly what were restrictions on missing days in determining a monthly dose? The same questions apply to the external datasets that have been used for ozone and cloud cover. What were the minimum number of years that contributed to the overall monthly average for each of the 3 data sets?

Response: Monthly mean data for UV doses, total ozone and cloud cover are averaged from summing all daily values by month and then dividing by the number of days in the month. There are missing measurements in the daily data sets, but they are not significant to report in the manuscript; missing values are accounted only about 3% of the daily recorded UV dose and about 8% of the daily recorded total ozone and there was no missing values for cloud cover data. The statistical package used here excludes all missing values for the analysis.

Please provide a brief statement on the traceability and stability of calibration of the radiometers over the 25 year period. What is the associated uncertainty in the measurements and how can you be sure that there has been no drift, short- or long-term, in the measurement system?

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Response: The broadband detectors measuring erythema effective UV radiation are calibrated annually using a double-grating spectroradiometer. The spectroradiometer is calibrated and is traceable to national standards. The daily radiant exposure for 22 clear days during May–October between 2003 and 2015 was compared to the daily radiant exposure from the double-grating spectroradiometer and the data from the broadband detectors was found to be within 10% of the spectroradiometer data on all these days. (Hooke, 2017) Relevant text has been added into section 2.1 (see Line 100-105).

Reference: Hooke, R.J., Higlett, M.P., Hunter, N. and O'Hagan, J.B., 2017. Long term variations in erythema effective solar UV at Chilton, UK, from 1991 to 2015. Photochemical & Photobiological Sciences, 16(11), pp.1596-1603.

Section 2.3 Seasonal variations have been removed from the data, but have longer term cycles been considered e.g. QBO and 11 (or 22) year solar cycle?

Response: We have not taken into account the QBO (quasi-biennial oscillation) or the solar cycle in the analysis. The explanation for this is as follows: We agree with the review that the quasi-biennial oscillation (QBO) and the 11-year solar cycle are also factors that affect UV levels, particularly through their impact on ozone and clouds (Den Outer, 2005). Since the period of the QBO is approximately 2.3 years it affects short term variability rather than long term trends (Harris et al., 2008, Den Outer et al., 2005). This fluctuation is small in comparison to the 25 year timescale being analysed in this paper. Relevant text has been added into section 2.3 (see Line 157-163).

The 11-year solar cycle has a longer period and therefore has the potential to impact long term trends, however its effect on erythema effective UV levels is small (Den Outer, 2005, Diffey, 2002). We have investigated whether solar activities (the 11-year solar cycle is a cycle of sunspot activity, i.e. the number of sunspots) affect the changes in UV radiation at Chilton. The relationship between UVR values and total sunspot numbers was studied and the relationship between sunspots and UVR also appeared to be reciprocal; UVR being high when sunspot is low, and vice versa. However, using t-test, the correlation between UVR values at Chilton and sunspot numbers was not statistically significant (P=0.27) during the time period from 1991 to 2015. Thus, we have decided not to include the results in this manuscript.

References: Den Outer, P.N., Slaper, H. and Tax, R.B., 2005. UV radiation in the Netherlands: Assessing longâĂŘterm variability and trends in relation to ozone and clouds. Journal of Geophysical Research: Atmospheres, 110(D2). Harris, N.R., Kyrö, E., Staehelin, J., Brunner, D., Andersen, S.B., Godin-Beekmann, S., Dhomse, S., Hadjinicolaou, P., Hansen, G., Isaksen, I. and Jrrar, A., 2008. Ozone trends at northern mid-and high latitudes–a European perspective. In Annales Geophysicae (Vol. 26, No. 5, pp. 1207-1220). Diffey, B.L., 2002. Sources and measurement of ultraviolet radiation. Methods, 28(1), pp.4-13.

Please explain, or at least reference, the statistical techniques used (DW, MK, SS).

Response: We have now extended the paragraph and some references have been added in section 2.3 (see Line 173-184).

Section 3.1 Figure 1 – how were 'outliers' identified? In all seasons except winter the outliers from one year are clearly within the bounds of acceptable data for other years, so why have these data points been excluded? If they were beyond possibility for the site then there would be good reason to exclude the points, but this is not the case. In winter there are a large number of outliers – how did you determine that these data were unreliable? Please provide a clear justification for removing what appear to be valid data points from the analysis. Response: In statistical term, outliers known as the extreme data points are outside the typical pattern of the other data sets. It is possible to delete outliers from the data set before analysis or use non-parametric statistical methods that are less influenced by outliers. We did not remove them because these points could be real measurements. The UV dose values might have fluctuated more especially in winter at this site due to natural variations which affect UV dose, in particular extremely low total ozone often occurs in winter. We should also bear in mind that the winter data had the lowest UV dose level among the rest of seasons in Chilton. The text has been revised in section 3.1 (Line 208-212).

Define seasons i.e. which months have been used as 'winter'

Response: Done, see Table 1 (winter: December, January and February).

Section 3.2 The annual ozone cycle is as one would expect at these latitudes. Comment on this and causes of e.g. low ozone events / particular occurrences e.g. in 2011. Note summer ozone (when UV is high) has very small and non-significant trends over any time period. The significant ozone trends in winter will influence the very low UV doses at that time of year, but have little practical influence on overall annual dose of UV. This fact is somewhat lost in dealing only in percentage deviations from average, where the winter % has the same weight as the summer %. Further comments on the implications for absolute UV doses are needed throughout.

Response: Text has been added in section 3.2 see Line 317-321 and also section 3.3, see Line 337-338.

Figure 3 – again please justify 'outliers'.

Response: Done, see section 3.2, Line 281-282

Fig 3b – what are the black line and the grey dashed line? The latter is not the mean value, as described in the text.

Response: Done, see section 3.2, Line 285-287

Section 3.3 Line 300 – comment on this with respect to Radiation Amplification Factors. Also comment on why RAF apparently changes with season or with period considered.

Response: Text has been added in various sections regarding the Radiation Amplification Factor (RAF). It is in section 3.3 (Line 347-348, 358-360 and 368-371), section 3.4 (Line 429-430 and 448-450) and section 4.4 (Line 662-667) and in Abstract.

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Section 3.5 Line 366-7 – qualify this statement, it is not necessarily a global truth. Also further down the paragraph you show that for a 1% change in cloud or ozone the response in H is greater for ozone. Response: We have now deleted this sentence in Line 366-7 in section 3.5.

Section 4 Lines 430 – 444 This does not produce a convincing argument for the analysis in this manuscript vs that of the previous publication. Both are described as 'best/better described by two linear trends'. Since both works use the same data set, how can the two linear trend selections be so different in the pivot point used to change from one trend to the next? This needs further justification. The overall change (full data set) should be the same for both analyses since the underlying data is the same. Is this the case?

Response: Yes, the data used here are the same data set that previously published. In our previous published study, the analyses were based on annual mean anomaly data from the daily data, while the analyses performed here are monthly mean deviation data from the monthly data. Although annual data and monthly means show similar pattern, we have decided using monthly data in order to examine the effects of total ozone and cloudiness changes on the Her. Some relevant text has been added in section 2.3, see Line 151-155.

With regard to the pivot point, the previous paper split the time series due to geophysical phenomena – that is, the ozone turning point in the mid-1990s (WMO, 2014). This paper splits the time series according to statistical analysis. Clarification has been made, see section 4.1, Line 490-498.

Ref: WMO, Scientific Assessment of Ozone Depletion: 2014, World Meteorological Organisation (WMO), Geneva, Switzerland, 2014.

Section 4.4 – discussion on aerosols. This is rather inconclusive. If AOD has been stable at Chilton then changes in aerosol/pollution cannot explain any changes in H. What is left as an explanation?

Response: We do not have aerosol data to clarify your comments. It may be attributed to the variability in weather condition from climate change.

Lines 642-8 This (and the similar paragraph in the abstract) is almost counter-intuitive in trying to manufacture associations between small changes in H, ozone and cloud cover. 1991-2004 has increased H associated with decreased cloud and no significant change in ozone (section 4, the abstract says there is an upward trend in ozone). 2004 – 2015: section 4 says there is a slowdown in the upward trend in H, and in the next sentence says there is a significant decrease in H. Both cannot be correct. The abstract only mentions a decrease in H. This is associated with a marginal upward trend in ozone and no significant change in cloud. The abstract and discussion should be made consistent with each other. The abstract implies that both increasing and decreasing H occur at the same time as increasing ozone, but increasing H is more strongly linked to reductions in cloud cover, while there is no significant change in cloud over the period that H is reducing. Added to which all changes are small and occur within a very variable signal. Such a comment in the abstract, that all changes are small and some are not statistically significant, seems necessary.

Response: Done, see Abstract Line 28-33 and section 4.4, Line 718-723.

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