Interactive comment on "The Effect of Instrumental Stray Light on Brewer and Dobson Total Ozone Measurements" by Omid Moeini et al.

Omid Moeini et al. (omidmns@yorku.ca)

The authors would like to thank the reviewer for the thorough and useful review which we have gratefully considered in improving the paper.

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General comments

The article is interesting as the effect of the stray light on the ozone cross section calculation were not studied on the past. I have a few comments which I would the authors to answer, pending those I support the publication of the manuscript. The principal comment i repeat from my first evaluation is why they don't use the (Serdyuchenko 2014) cross section in his calculations, when is now the recommended ozone cross section for Brewer and Dobson. Moreover, some of the discussions of the paper like the AD/CD ozone difference in the Dobson measurements and the Brewer/Dobson differences are also affected with the change of cross section (Redondas 2014). The discussion (Section 3.1) is still difficult to follow especially the Dobson section (see specific comments).

The authors deliberately avoid the use of the Serdyuchenko (2014) cross-sections as it is not the intent of this study to presume to set the cross-section values to be used by the community to measure ozone, but only to provide some additional information about the impact of stray light on the measurements. Changing the cross-sections would not change the significance of this study. The cross-sections can be considered as a variable and the nature of the processes would remain the same. The paper is intended to show the connection between the physics of the instruments and the impact of stray light on the measurements. The first priority in using the results of this study is the provision of an algorithm for correcting the extant ozone historical record (described a paper currently in review) – particularly results measured at large slant column ozone amounts (e.g.: particularly at high latitudes in spring and fall). The inclusion of multiple results would obscure the basic intent of the paper and possibly create confusion in the community. Calculating the ozone absorption coefficients with new cross-sections is beyond the scope of this article and subject of another study which should be supported by WMO. To the best of our knowledge no new data have been submitted to the WOUDC using new cross-sections nor have the historical data been so corrected.

About the Dobson AD-CD difference: This work shows that higher levels of stray light lead to larger differences between AD and CD measurements. This fact is the same for all cross-sections. Redondas et al. (2014) have shown that for the ideal slit functions without stray light, the difference is somewhat lower for the Serdyuchenko (2014) cross-sections as compared with the results using other cross-sections.

The second point to mention is the ETC calculation in section 3.2, is not clear how is calculated, in particular how is related from Chance and Kurucz (table 2). As suggested by the referee Julian Groebner on the discussion on the paper also part of this special number (Redondas et al. 2018). The difference between the use of trapezoid slit and a triangular slit is about 0.7% in a double brewer. I think is usefull to include this case in your calculation.

The ETC calculation and its relation to solar spectrum are discussed and added to the manuscript (see response to specific comments).

The authors believe that repeating all this work with different minor variations (replacing trapezoid slit with triangular slit) and adding all those numbers to the manuscript actually obscures the point of the paper.

The error introduced by the assumption of the fixed air-mass is also showed but could be more illustrative to show the difference in ozone rather than in airmass. The effect on the Dobson record at South Pole was also studied by (Bernhard et al. 2005) a comparison with his results could be also illustrative.

The plot that shows the difference in airmass is replaced with a plot showing the difference in ozone.

Generally, Bernhard et al. (2005) has stated that the effective ozone absorption coefficients, $\Delta\bar{\alpha}_{AD}$ and $\Delta\bar{\alpha}_{CD}$, are smaller at large ozone slant path which is the same result as from the current analysis. They have compared the Dobson data with TOMS and SUV-100 data. To compare those results with this analysis, information about the TOMS and SUV-100 instruments would be required. This is beyond the scope of this article and could be a subject for another study.

Specific comments

Page 2, 30: A basic description of the method is worthwhile, the method is based on the characterization of the instrument and need both the spectral response and the Laser measurements of the slit rather than the dispersion information. A comparison between the Kiedrom/Karppinen model ant this work will be illustrative.

Kiedrom/Karppinen have tried to correct the stray light effect at large ozone slant paths for a single Brewer by changing the weighting coefficients. Here, two types of Brewers and a Dobson instrument are modeled to show the connection between the physics of the instruments and the impact of stray light on the measurements.

Page 3, 7: A reference of the false positive trend due different stray light is advisable.

This is difficult quantify in a really useful way until a reanalysis of an appropriate data set is done. It is considered beyond the scope of the paper and work that needs to be done.

Page 4: There is no explanation of the calibration of the Dobson as is done with the Brewer

The comment is not clear.

The Dobson calibration procedure is described in Evans and Komhyr (2008). Generally, the Dobsons are adjusted to make the slit functions as similar as possible and then only an extraterrestrial value is transferred from a reference instrument traceable to the World Standard Dobson.

Page 5: There is some confusion on the nomenclature of the formulas: please unify B or ETC, F or I.

Revised. “I” and “ETC” are used.

Page 5,29 : A reference of the application of the Barnes correction to the Brewer network will be advisable.

Revised. “the Brewer” is removed from the statement.

Page 6,1: There are several files available at IGACO, which ones are used in this study?.

The following statement has been added to the manuscript:

“For this study the quadratic coefficients on the file ‘Bp.par’ are used for BP cross-sections and the Liu et al. (2007) quadratic approximation, which excludes -273° K data from the quadratic temperature dependence fitting, are used for BDM cross-sections.”

Page 6,20: Could clarify the relation between equations 11, 15,17 and 18. (see also 9,1).

The ozone absorption coefficients $\alpha(\lambda_i)$ are calculated from ozone absorption cross-sections and vertical profiles of ozone and temperature employing equation 15. Due to the finite bandpass of the Brewer and Dobson’s slit functions, the effective ozone absorption coefficients ($\bar{\alpha}(\lambda_i)$) must be calculated either using equation 17 or 18. Equation 17 considers the solar spectrum whereas equation 18 is the simplest approach that can be used to calculate the effective ozone absorption coefficients. The effective ozone absorption coefficients must be used in equation (11).

To prevent any confusion, $\alpha(\lambda_i)$ and $\bar{\alpha}(\lambda_i)$ are used instead of α_i and $\bar{\alpha}_i$ in all equations.

$\alpha(\lambda_i)$ is replaced with $\bar{\alpha}(\lambda_i)$ in equation (11) and $\Delta\alpha$ is replaced with $\Delta\bar{\alpha}$ in equations (3), (8), (9), and (11) to make clear that the effective differential ozone absorption coefficients must be calculated and used in Dobson and Brewer retrievals.

Page 7.15: A mention of a other sources of stray light could be mention, see for example Josefsson and discused.

Revised. The reference and following statement have been added to the manuscript:

“radiation scattered from the atmosphere within field of view of the instrument can also contribute a stray light effect (Josefsson, 1992).”

Josefsson, A. P., (1992), Focused Sun Observation Using a Brewer Ozone Spectrophotometer, *J. Geophys. Res.*, *97*(D14), 15813–15817.

Page 9,1: There is a confusing use of α_i vs α_i^{approx} where are talking about Δα. The same issue for table 3.

Revised.

Page 9,5: Is surprising that the calculation of the operational values agree with yours calculations. In this work you are using a different cross section temperature, brewer uses -45 C but you are using -46.3 C (Table 2). The same nominal wavelengths (Table 1) for both brewers whereas brewer operative wavelengths are slightly different for every instrument, and the same FWHM for all the slits. Can be also useful to have the brewer ozone absorption coefficient for for every wavelength (α_i vs α_i^{approx}) and not only the effective Δα.

Apparently it is a coincidence that those numbers are matched. To validate the procedure, the calculations are repeated for nominal wavelengths of 310.05, 313.50, 316.80 and 320.00 nm with FWHMs of 0.359, 0.555, 0.545 and 0.538 and BP cross-sections at -45 ^{o}C and compared with the value calculated by Redondas et al. (2014) using the same cross-sections for a nominal Brewer. There is a difference of 0.06 % between this value (0.3365) and the value calculated by Redondas et al. (2014) (0.3367) using IGQ4 cross-sections for a nominal Brewer (Table 6) which is identical with our double Brewer in terms of slit functions.

Also, the Brewer ozone absorption coefficients for every wavelength are calculated and reported as suggested by the referee.

The Brewer part of the discussion (section 3.1) is revised and following statements and tables are added to the manuscript:

"To validate the calculations, the $\Delta\bar{\alpha}^{apx}$ is calculated for the double Brewer using an ideal trapezoid slit function and BP cross-sections at -45 ^{o}C without the Barnes (1987) correction. Redondas et al. (2014) have calculated the ozone absorption coefficients for the nominal Brewer which is identical in terms of slit functions, nominal wavelengths and slit FWHMs with the double Brewer of this work using ideal trapezoid slit functions. The IGQ4 cross-sections used in Redondas et al. (2014) are the same as the BP cross-sections employed at this work. The value 0.3367 calculated using IGQ4 cross-sections at -45 ^{o}C (Redondas et al. Table 6) has a difference of 0.06 % with the value 0.3365 calculated here with the same cross-sections at the same temperature (-45 ^{o}C) (Table 3).

To be consistent with Dobson calculations, the BP cross-sections with Barnes (1987) correction and at -46.3 ^{o}C are used for calculation of $\bar{\alpha}_i$ and $\bar{\alpha}_i^{apx}$ presented in tables 4 and 5 for the single and double Brewers.

The contribution of stray light in determining the ozone absorption coefficients can be seen from comparing the $\Delta\bar{\alpha}$ calculated using ideal slit functions (without stray light) with the values ($\Delta\bar{\alpha}$) calculated using modeled slit functions (including stray light). For the single Brewer the results show a 0.7 % difference (modeled slit functions including stray light are less than that of the ideal slit functions) while for the double Brewer the difference is less than 0.01 %.

Comparing $\Delta\bar{\alpha}$ with $\Delta\bar{\alpha}^{apx}$ for both Brewers (single and double using ideal and modeled slit functions) shows a minimum difference of 0.7 % ($\Delta\bar{\alpha}$ higher than $\Delta\bar{\alpha}^{apx}$) for the double Brewer with ideal trapezoid slit functions and a maximum of 0.9 % for single Brewers with ideal triangle slit functions, indicating the role of the solar spectrum in calculating the ozone absorption coefficients.

Table 3: Ozone absorption coefficients calculated here and the value calculated by Redondas et al. (2014)

		$\bar{\alpha}_i^{apx}$ (atm cm^{-1}) calculated for Double Brewer using ideal slits and BP cross-sections at -45 ^{o}C without Barnes (1987) correction	From Redondas (2014) Table 6; effective ozone absorption coefficient calculated using IQG4 B&P cross-sections
Wavelength (nm)	FWHM (nm)	Ideal (trapezoid)	Ideal (trapezoid)
310.05	0.539	1.0044	
313.50	0.555	0.6793	
316.80	0.545	0.3760	
320.00	0.538	0.2935	
$\Delta\bar{\alpha}^{apx}$		0.3365	0.3367

Table 4: Single Brewer ozone absorption coefficients

		Ideal		Model (with Stray light)	
Wavelength (nm)	FWHM (nm)	$\bar{\alpha}_i^{apx}$	$\bar{\alpha}_i$	$\bar{\alpha}_i^{apx}$	$\bar{\alpha}_i$
310.05	0.539	1.0087	1.0127	1.0141	1.0102
313.50	0.555	0.6824	0.6842	0.6828	0.6833
316.80	0.545	0.3774	0.3789	0.3768	0.3789
320.00	0.538	0.2944	0.2962	0.2923	0.2959
$\Delta\bar{\alpha}^{apx}/\Delta\bar{\alpha}$		0.3377	0.3406	0.3407	0.3380

*BP cross-sections at -46.3 with Barnes (1987) correction.

Table 5: Double Brewer ozone absorption coefficients

		Ideal		Model (with Stray light)	
Wavelength (nm)	FWHM (nm)	$\bar{\alpha}_i^{apx}$	$\bar{\alpha}_i$	$\bar{\alpha}_i^{apx}$	$\bar{\alpha}_i$
310.05	0.539	1.0087	1.0127	1.0089	1.0126
313.5	0.555	0.6824	0.6842	0.6826	0.6841
316.8	0.545	0.3773	0.3789	0.3776	0.3789
320	0.538	0.2947	0.2962	0.2950	0.2962
$\Delta\bar{\alpha}^{apx}/\Delta\bar{\alpha}$		0.3384	0.3406	0.3384	0.3405

*BP cross-sections at -46.3 with Barnes (1987) correction.

Page 10,5: An explanation why the calibration method reduces the the discrepancy to 0.7% independent of the level of stray light of the instruments and can be illustrated for example in figure 5.

The following statement has been added:

"In the Dobson AD pair calibration, scale factors are calculated for different ranges of airmass. The data from the instrument being calibrated are scaled to the data from the reference instrument. Then the CD pair data of the calibrated instrument are scaled to its AD pair data."

Page 10,15: Please describe the calculation of the ETC, how is compared with the calculation of Kiedrom and (Karppinen 2015).

The following statement and plot have been added to the manuscript:

"To calculate the ETC, the instrument absorption function using the solar spectrum (Chance and Kurucz, 2010), Eqs. (1) and (2) and the retrieval algorithm of the Brewer (or Dobson) for an assumed constant amount of ozone (325 DU in this study) is calculated and plotted as a function of ozone slant path. The best fit to the data with airmass less than 2 (less than 3 for the Dobson instruments) is found and extrapolated to zero airmass. Figure 5 shows the best fit to the single Brewer data:

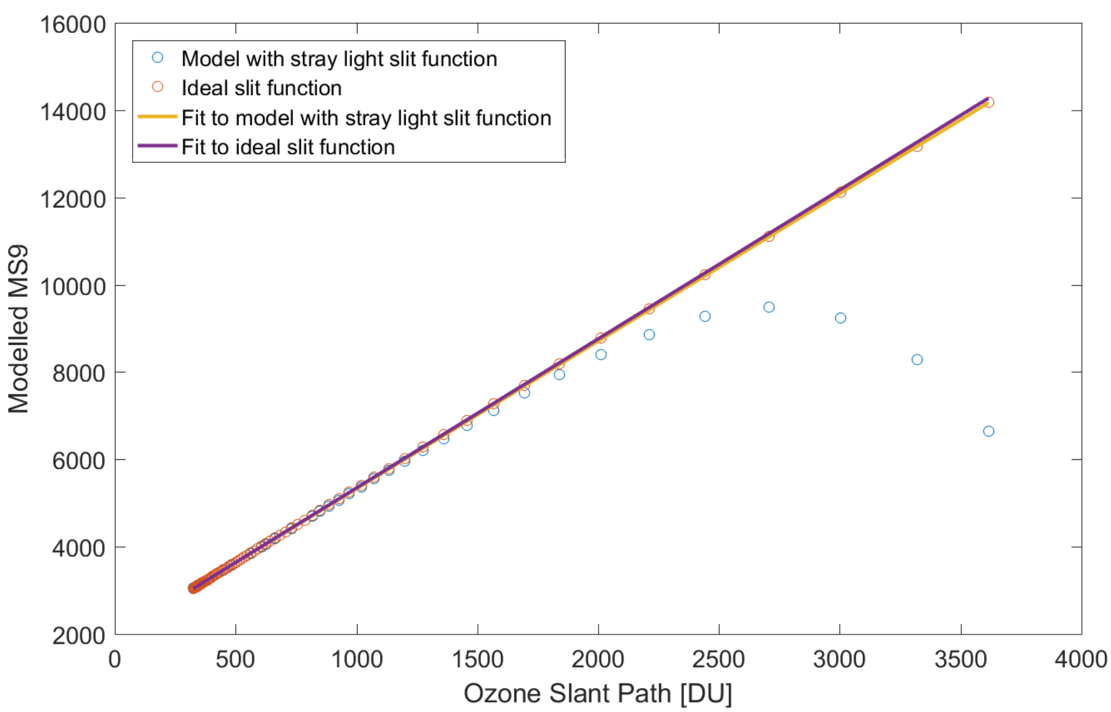


Figure 5: Example of Langley plot fitted to a modeled single Brewer data

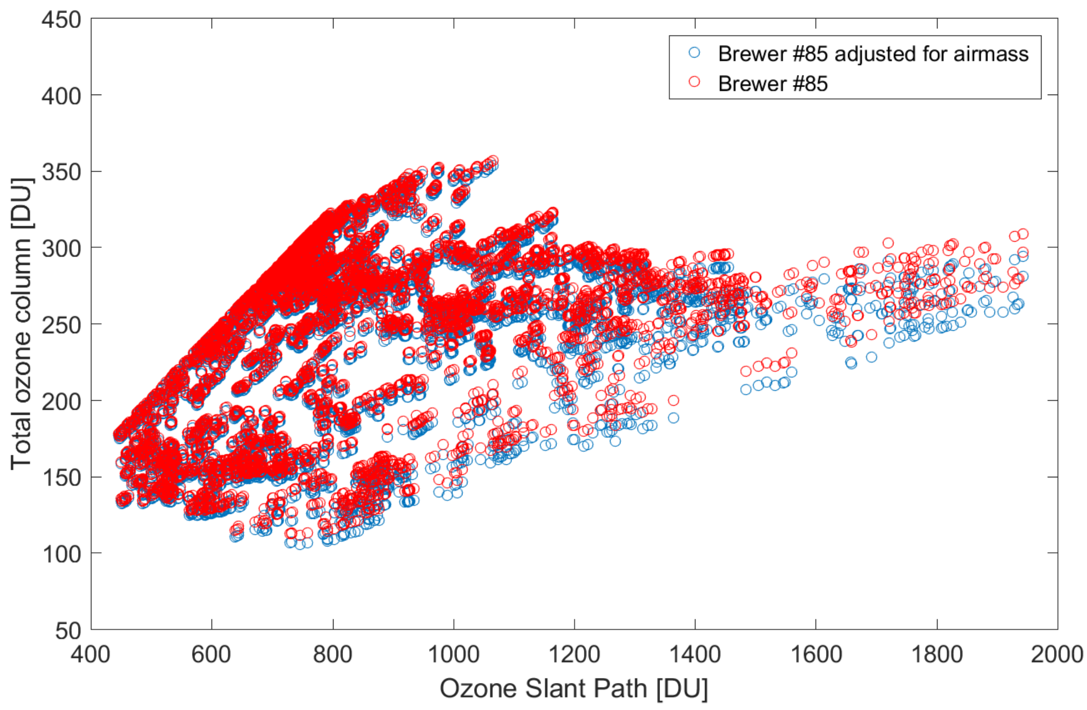
For the single Brewer the ETC is calculated as 1945.4 for a modeled trapezoid slit function with stray light which is comparable with 2020 as calculated by Kiedrom et al. (2008) noting the slight differences in the slit functions and solar spectrum. Karppinen et al. (2015) have reported 3218 for ETC value for slit functions with stray light. However, they used LibRadtran 1.6-beta radiative transfer model to scale their data to be matched with real data."

Page 10.25: Consider also to discuss the case of early spring at high latitudes, with low sun and high ozone content.

This is a good suggestion but beyond the scope of this study. We chose the South Pole as it is important for the detection of ozone recovery and is being used for trend analysis and satellite validations. With ozone recovery in future more data collected at large ozone slant paths would be available which may cause an error in the trend analysis or satellite validation due to the effect of stray light.

Page 11.15: Consider to plot corrected /uncorrected South Pole Brewer to illustrate the error due air mass calculation.

The following plot has been added to the manuscript.



Page 12: A better description of the data-set might be provided or referenced: number of simultaneous measurement, if the data are available at WOUDC/NDACC databases, the QA/QC results of calibrations and how stable are in time the comparison between Dodson instruments, and brewer-dobson will help to interpret the comparison.

The following statements have been added to the manuscript:

“The Brewer data for the South Pole site are available at the WOUDC website. Due to the logistic difficulties Brewer #085 was not replaced or calibrated until 2016.

The Dobson data used for this study are freely available at: ftp://aftp.cmdl.noaa.gov/user/evans/York_Omid/. For this study all direct sun Dobson measurements are used while only one measurement representative of the day is reported to the NDACC or WOUDC. A complete description of the South Pole dataset is provided by Evans et al. (2017). The reprocessed data using WinDobson software as described in Evans at al. (2017) are used for the analysis here. Generally, the Dobson instrument at the South Pole site is replaced with a calibrated instrument every four years. The instrument replaced is calibrated against the reference Dobson #083 and the calibration results are used to adjust and post-process the last four years of data collected at the South Pole. The calibration procedure can be found at Evans and Komhyr (2008) and the major calibration or instrument changes regarding the South Pole dataset can be seen in Fig. 5 of Evans et al. (2017).”

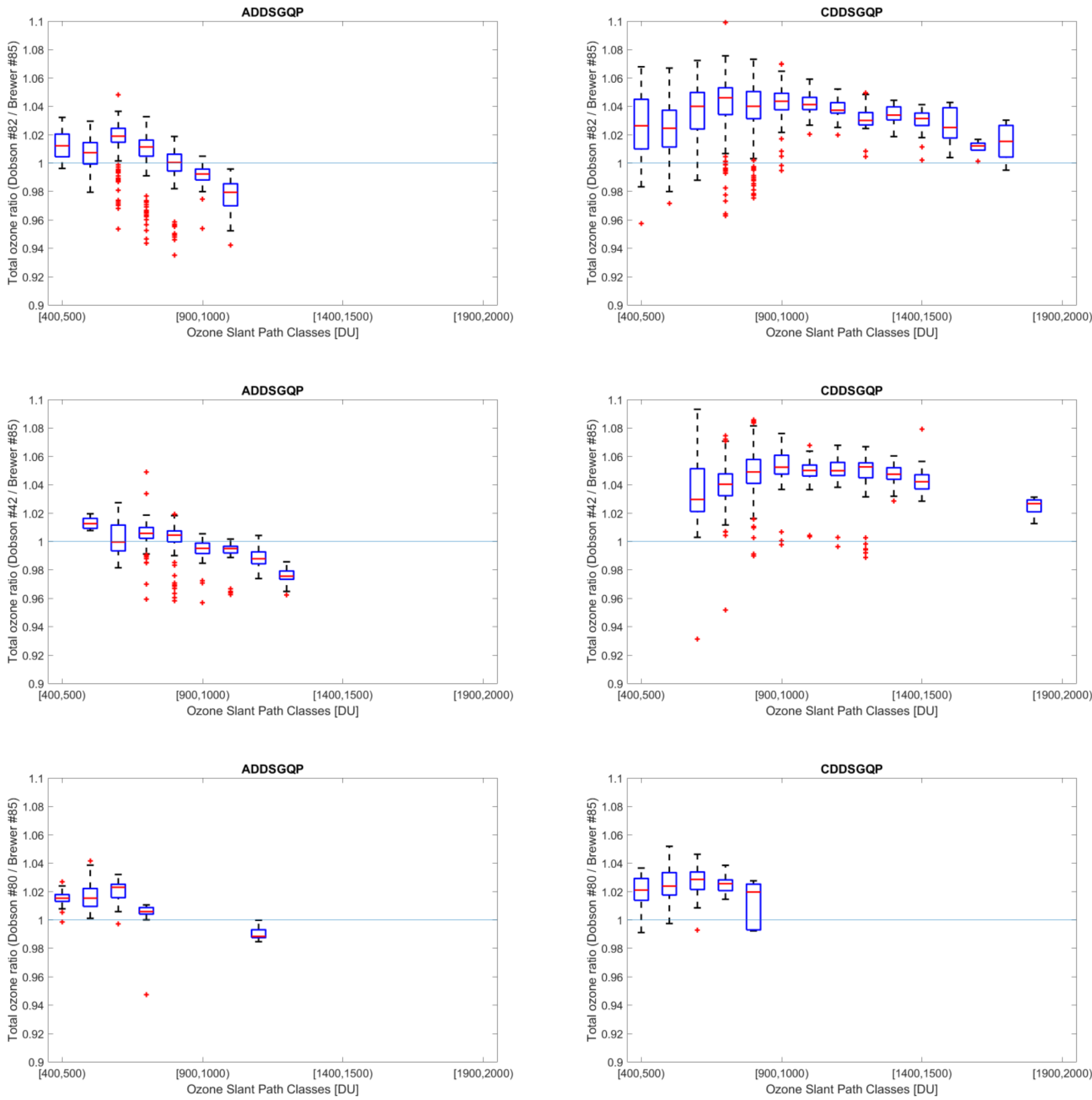
The simultaneous measurements available are summarized in a table and added to the manuscript:

“Table 7: The number of simultaneous measurements in each bin

	Dobson #82		Dobson #42		Dobson #80	
Bins (OSP)	AD	CD	AD	CD	AD	CD
[400 500)	39	33	0	0	45	41
[500 600)	171	143	7	0	63	63
[600 700)	172	113	101	70	57	72
[700 800)	439	313	258	179	11	8
[800 900)	174	235	153	178	5	6
[900 1000)	155	120	30	54	0	1
[1000 1100)	96	125	57	28	0	0
[1100 1200)	4	50	46	67	7	4
[1200 1300)	0	41	36	46	0	2
[1300 1400)	0	43	4	49	3	2
[1400 1500)	0	36	0	19	0	1
[1500 1600)	0	19	0	4	0	0
[1600 1700)	0	6	0	1	0	0
[1700 1800)	0	9	0	1	0	0
[1800 1900)	0	0	0	10	0	0
[1900 2000)	0	0	0	0	0	0
Total	1250	1286	692	706	191	200

Page 12.15: Concerning the analysis , the intervals with a reduced number of observations should be removed, this discard for example most of the Dobson #80 observation for high ozone slant column. Consider to use the same order of the Dobson instruments in plots and enumerations.

The boxes with less than 6 coincident measurements in each bin are removed from the plots.



Page 13,5 : In the conclusions refers that you are using the measured slit but in reality the central part of the slit is not measured, and are also model as trapezoid.

Revised.

References

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