Response to referee #1

DLM estimates of long-term Ozone trends from Dobson and Brewer Umkehr profiles.
Eliane Maillard Barras et al., Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2022-344.

Dear Referees,
Dear Editor Gaby Stiller,

We would like to thank the referees for the detailed review of the manuscript and for their constructive and helpful comments and suggestions. We have taken the remarks into account and we are presenting the detailed answers in the following. We attach a revised version of the manuscript with marked changes.
We hope that we have satisfactorily addressed the suggestions and remarks.
The referee's comments are given in italic, our responses are given in blue, and the corresponding changes in the manuscript in grey.

Best regards,
Eliane Maillard Barras (on behalf of all co-authors)

The paper focuses on post-2000 ozone profile trend estimates using the Dynamical Linear Modeling (DLM) approach. The method is applied to Umkehr time series obtained from six collocated Dobson and Brewer spectrophotometers based in Arosa/Davos, Switzerland. One of the Dobson instruments (D051) has been homogenized based on two different approaches (the MCH homogenization based on comparisons with the 5 collocated Dobson and Brewer instruments and the NOAA homogenization developed by Petropavlovskikh et al., 2022) before trend estimation. In addition, the DLM approach is applied to the Aura/MLS satellite data record.
The post-2000 trends show similar features (e.g. an increase in ozone in the upper stratosphere) for most altitudes, although with inconsistencies in the level of significance. The authors attribute the differences to remaining inhomogeneities in the ground-based data records. For the lower stratosphere, no clear picture was found.
The paper fits well into the scope of ACP and I recommend publication after having addressed the comments (mostly minor) below.

Specific comments:
P1, L6: I would suggest to mention here the time period which is covered by D051.
The time period has been added.

In this study, the worldwide longest Umkehr dataset (1956-2020) is carefully homogenized using collocated and simultaneous Dobson and Brewer measurements.

P1, L14: What is meant with globally here?
Globally is too general here, we removed it.

The two homogenized data records show common correction periods, except for the 2017-2018 period, and produce corrections similar in magnitude.

P1, L19: "Moreover, a persistent negative trend is estimated in the middle and lower stratosphere with different…" → In the lower stratosphere the trend obtained from D051 is positive though non significant (Fig. 8a).

The lower stratosphere is composed of DL3 and DL4 (see Fig1). The trend in DL4 is negative, significant between 2009 and 2017 and non significant after. The DL3 trend is slightly positive and non significant. As it is difficult to draw a conclusion for the whole lower stratosphere on that basis, we now draw conclusions at the Dobson layer level.

In the lower stratosphere, the trend is negative at 20km with different levels of significance depending on the period and on the dataset.

P2, L45: Do you mean the sensitivity with respect to the length of the fitting period and with respect to the start/end dates?

We refer here to the sensitivity to the start/end dates as Bernet et al. 2019 report on the trend differences with varying starting years and Dietmüller at al. 2021 report on influence of the year to year variability on the trend values and their significance. We modified the sentence accordingly.

The sensitivity of the post-2000 trend magnitude to the start and end years has been extensively discussed (Petropavlovskikh et al., 2019; Bernet et al., 2019; Dietmueller et al.,2021).

P3, L88: Could you please briefly mention, why exactly this specific instrument D051 was selected for homogenization?

Yes, you are right. This was not clear. We amended the text accordingly.

In Arosa/Davos, the Dobson D051 is the station's primary instrument for continuous Umkehr profile time serie. It was dedicated exclusively to Umkehr measurement from 1988 until February 2013, when total ozone measurement was added to the schedule. The number of observations dedicated to Umkehr was not impacted and the number of retrieved Dobson D051 Umkehr profiles was kept to two profiles per day up to now. This frequency in observations allows the computation of statistically reliable monthly means for trend estimations. However, the instrument operations recently suffered from anomalies following technical interventions. Therefore, a complete homogenization of the Dobson D051 Umkehr data record has been performed and is described in this paper.

P4, Sec.2.1: A table which indicates the periods during which the individual instruments at Arosa/Davos are measuring (and how often per week/month) could be helpful.

As suggested by both reviewers, we added a table in the section 2.1.

Instrument		Time range	Time resolution
Dobson	D015	1956-1988	2 profiles/day
	D051	1988-now	2 profiles/day
	D062	1998-now	4-6 profiles/month
	D101	1988-now	4-6 profiles/month
Brewer	B040	1988-now	2 profiles/day
	B072	2005-now	2 profiles/day
	B156	2005-now	2 profiles/day

Table 1. Time ranges and time resolutions of the Dobson and Brewer Umkehr measurements at the Arosa/Davos station.

P5, L132 When the SZA is increasing from 60° to 90° the intensities should decrease.
Yes, correct. We amended the description.

As the SZA is increasing from 60° to 90°, the scattering height is increasing, and the two intensities decrease because of increased absorption and scattering by ozone and air molecules.

P6, Figure 1: What is the difference between these two examples (blue/black curve)? The total ozone column, other atmospheric conditions,…?
These are the morning and afternoon measurements of a random day with slight differences in both TCO and atmospheric conditions. The purpose is to show that an apparent small difference in the N curves can lead to a significant difference in the ozone profiles. This is now mentioned in the caption.

(a) Morning (in black) and afternoon (in blue) N curves at 12 nominal SZAs and (b) their corresponding retrieved ozone profiles in DU as a function of altitude in km and pressure level in hPa. Total column ozone and atmospheric conditions slightly differs between the morning and the afternoon. Altitude ranges of the 10 Dobson layers (DL) are shown in (b). Lower, middle and upper stratospheric ranges are displayed in orange shadings.

P7, Subsection 2.3: I would suggest to remove the entire subsection (see the comment P18, LL386-390 for an explanation).
Agreed. Done. Same for P18 L386-390.

P8, Section 3: Think about subdividing Section 3 into three subsections (e.g., 3.1 MCH homogenization, 3.2 NOAA homogenization, and 3.3 Comparison of both homogenizations)
Agreed. Done.

P8, L196: Could you provide a reference for this 2008 homogenization?
As the 1988 D015 to D051 homogenization has been reprocessed for this study, the 2008 homogenization is finally only a reprocessing of the N values with adapted shaft encoder positioning. This was not published but reported as an internal report. We remove any mention of the 2008 "homogenization" as it should be considered only as a reprocessing and we discuss in more details the correction of the D015 to D051 transition.

The Arosa/Davos Umkehr time series is composed of Dobson D015 measurements from 1956 to 1988 and Dobson D051 since then. The quality of the homogenization of the Dobson D015 to Dobson D051 transition has been ensured by one year of parallel measurements (1988) allowing an adaptation of the D015 N values to the D051 N values. For each SZA, the 1988 mean difference between the D051 and the D015 N values has been added to the D015 values. The 1956-1987 ozone profiles have then been retrieved from the Dobson D015 corrected N values. No statistical correction has been performed on the D015 ozone dataset.
We report here about the complete homogenization of the 1988-2020 Umkehr Dobson D051 time series by comparison to the datasets of the five collocated instruments (two Dobson and three Brewer spectrophotometers) on the N value level.

P8, L211: You state that the black frames in Fig. 2 indicate periods that can be attributed to technical issues, but Table 1 indicates that there was no technical issue in 2010; could you please clarify?
Yes, correct, this is in contradiction. The black frames indicate the anomalies. Most of them can be attributed to technical issues but not in 2010. Text was modified.

If we focus on the post-2000 period, where several collocated and redondant measurements are available, systematic anomalies of the Dobson D051 are noticed (periods in black frames in Figure 2).

P9, Figure 2: In 2014 the comparison of D051 with the three Brewer instruments indicates a strong positive bias from 0-30km and a strong negative bias from 30-50km. Did you investigate this period in more detail?
This period should have been removed. This is an error. The figure has been corrected now. The 2014 anomaly should be considered with caution (P8 L219-220) because of the very reduced number of measurements at that period (many data are missing or have to be flagged because of technical issues during the refurbishment period and during this technical staff transition period). It is therefore very difficult to investigate this period. This is now mentioned in the text.

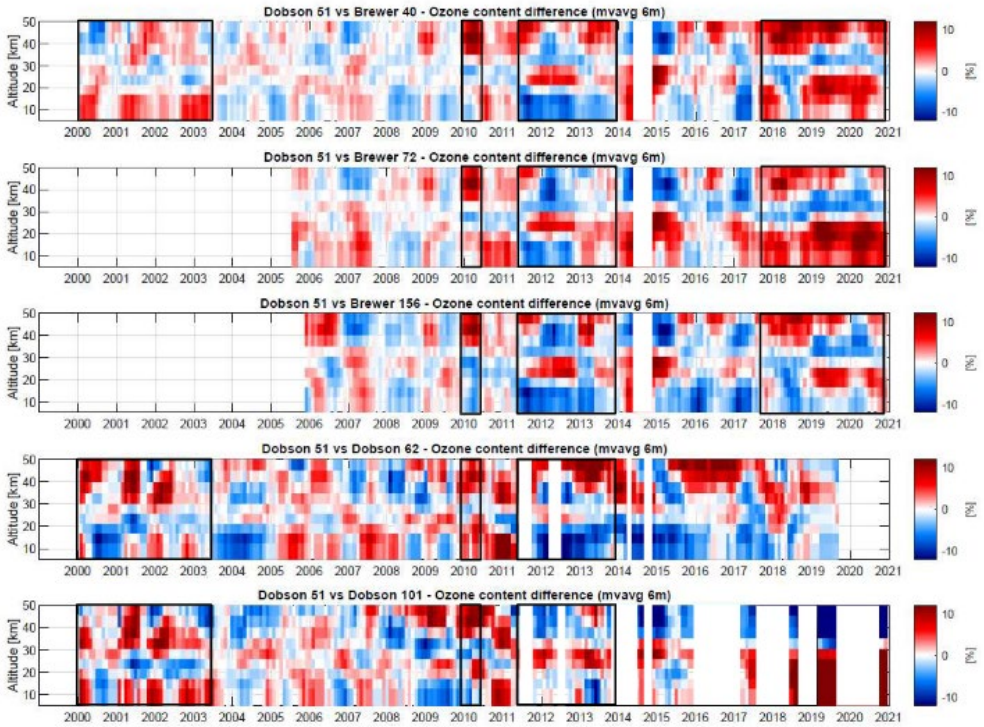


Figure 2. Monthly mean time series of the ozone profiles relative differences for each of the 5 spectrophotometers with respect to D051. The time series are deseasonalized and smoothed by a 6 months moving average.

The comparison of Dobson D051 with the collocated Dobsons around 2014 and after 2018 are to be taken with caution due to the very limited number of measurements of Dobson D051 in 2014 and of Dobson D062 and Dobson D101 during these periods. Around 2014 (technical and staff transition period), many data are missing or have to be flagged because of roof opening issues. After 2018, the Umkehr measurement by Dobson D062 and Dobson D101 have been drastically reduced as priority has

been given to total ozone measurements.

P10, Table 1: What is the meaning of "RtoN" table?
The "RtoN" table is the table mentioned on P5 L138. We added here the definition of the acronym "RtoN".

The logarithm of the ratio of the two wavelengths intensities (R values) is converted to radiance using calibration tables (RtoN table) and reported as N values…

Last row: what is the start date for the homogenization "before 2018/05/01"?

The correction offset is calculated using the 2016.05.01-2018.05.01 (and 2018/05/01-2020/05/01) period and applied to the 1956-2018/04/30 dataset.

P11, L261: I would suggest to write "The MCH homogenization approach" instead of "Our approach".
Modified as suggested.

The MCH homogenization approach is different in that the homogenization process aims to remove artificial steps in the Dobson D051 Umkehr profiles record while maintaining the constant offset between the datasets, …

P12, Fig. 4: Is the MCH correction from 1956 to 1988 applied to D051 or to D015? I would suggest to briefly explain/mention the origin of the correction during that early period, because it was not discussed in the text.
The MCH correction from 1956 to 1988 is applied to D015. We discuss in more details the correction of the D015 to D051 transition. See response to "P8 L196" comment.

P13, L293: A similar feature is seen in 2014; did you investigate this period in more detail?
No, we did not. See response to "P9, Figure 2" comment.

P13, L298: Please add the panel of Fig. 5 you are referring to here.
Reference to Fig.5 (c) has been added.

Due to the occurence of an anomaly in 2018, which is particularly visible in DL8 for all datasets (Fig. 5 c), the last correction applied to the dataset by the NOAA and the MCH homogenizations differ.

P14, L306: The results, that you show, are for an inflection point of 1998.
Yes correct, this is a residual from a previous text version. "2000" has been replaced by "1998" in the 4.1 and 4.2 sections. Trend values are correct only the text had not been adapted.

P15, Fig.6: Please mention in the caption that the black curve belongs to PWLT and the blue to DLM.
Ok, we amended the text.

(a-c) DLM (in blue) and MLR (in black) trend estimates in %/decade ± 2σ of Dobson D051 dataset for 3 DL between 20 and 40 km

P15, L328: Which D051 time series is used here? Uncorrected, MCH homogenized, or NOAA homogenized?

The MCH homogenized time series is used. Mention is done now.

Figure 6 shows the long-term trend estimates from the MCH homogenized Dobson D051 dataset by DLM…

P15, L340: Maybe it is sufficient to define statistical significance (95% confidence level) only once, and then you don't have to mention "at the 95% confidence level" at every single occurrence.
We prefer to mention it each time. It is heavy but it appears 7 times only and so the text does not allow for misunderstanding.

P16, LL348-350: Do you mean here that MLR is more significantly impacted by outliers or boundary values than DLM? Could you provide a reference?
This is not exactly what we mean. Actually, regressions (resulting trends and their uncertainties) are influenced by outliers. But, trends estimated by DLM regression change each year. In case of influential outliers, only the particular year trend value and its uncertainty is influenced by the outliers. This has been rephrased.

Regressions (resulting trends and their uncertainties) are influenced by outliers (Bowerman and O'Connell, 1990). But, trends estimated by DLM regression change each year. Hence, outliers influence only a limited portion of the DLM trend time series.

P16, Fig. 7 caption: Please add the info which Dobson Layers are shown. Moreover, I would suggest to add horizontal lines in the plots which delineate the different stratospheric sectors LS, MS, UpS.
We added now vertical color bars with the same color scheme as in Figure 1 in order to delineate the LS, MS and UpS altitude ranges. We amend the caption accordingly.

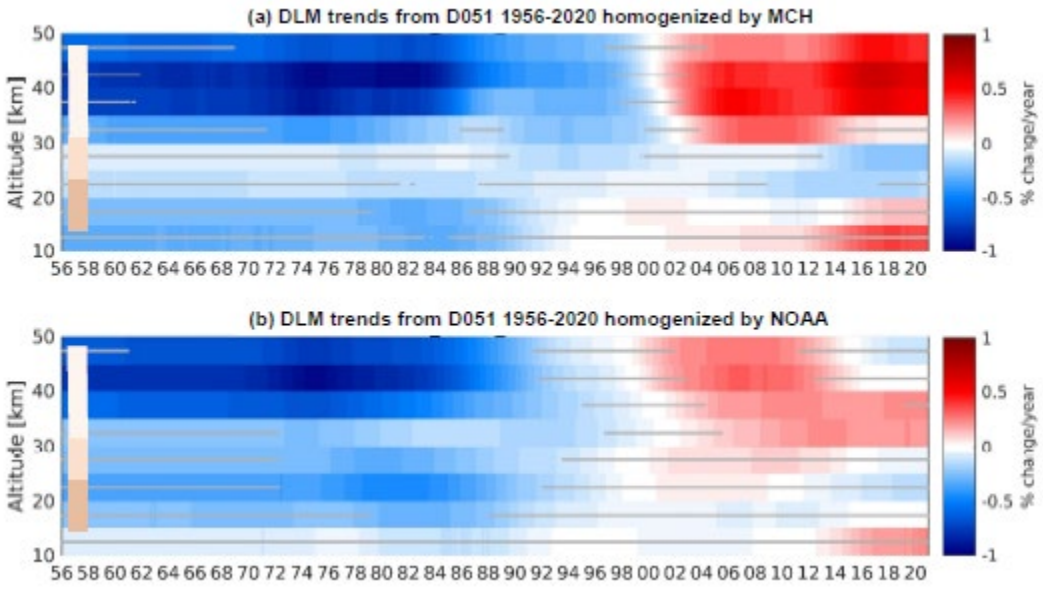
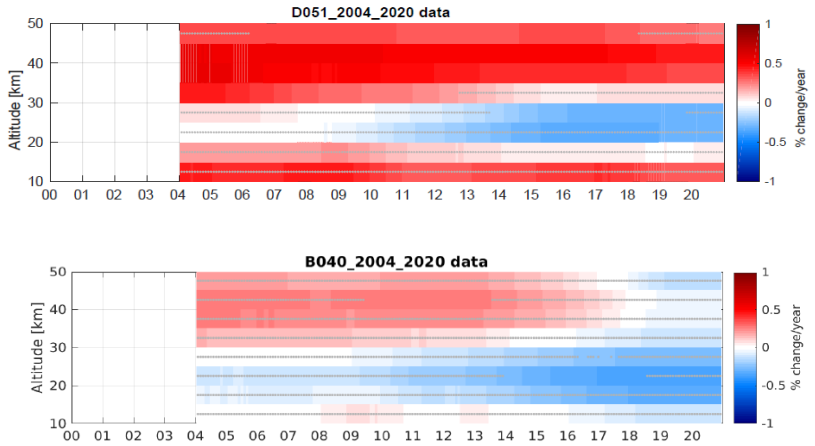


Figure 7. DLM trend estimates in %/year of Dobson D051 1956-2020 from (a) MCH homogenized and (b) NOAA homogenized data records. Grey lines indicate trend estimates non significantly different from

zero at the 95% confidence level. The orange bars indicate the lower, middle and upper stratospheric ranges.

P17, Fig. 8 a+b: Do the DLM trend results for D051 (MCH homogenized) and Brewer B040 change when you use the period 2004-2020? Just to make sure that it is consistent with the trend period used for MLS (panel c).

MCH homogenized D051 and B040 DLM trends for the period 2004-2020 are shown below. The trend values are similar to the DLM trends for the period 2000 to 2020, with slight differences in their significance though. The choice of the period does not explain the lack of consistency with the MLS DLM trend results. As the DLM regression results in a trend variation by year, it is not drastically influenced by the starting year. Note that the color scale range is small and therefore a small difference between non significant positive or negative trends can visually appear as a big difference.



Post 2004 DLM trend estimates in %/year from Dobson D051 and Brewer B040

P17, LL366-368: "The lower stratospheric (LS, DL3&4, 14-24 km) trend estimates are non significantly negative before 1996 but significantly negative between 2008 and 2018 for the MCH homogenized data record and non significantly negative for the NOAA homogenized Dobson D051 record." → For DL 3 and DL 4 in Fig. 7a I cannot see the significant negative trend for MCH D051 between 2008 and 2018. Could you please doublecheck?

Yes, you are right. See response to "P1 L19" comment. DL3 and DL4 trend differences make it difficult to draw a conclusion for the whole lower stratosphere, we describe trends at the Dobson layer level now.

In the lower stratosphere (DL3&4, 14-24 km), the DL3 and DL4 trend estimates are non significantly negative before 1996 but significantly negative between 2008 and 2018 in DL4 for the MCH homogenized data record and non significantly negative for the NOAA homogenized Dobson D051 record.

P17, L374: Please add that MLS trends are shown in panel c.

MLS trends are now mentioned to be shown in Fig 8 c.

The trends estimates of one of the Dobsons (D051), one of the Brewers (B040) and Aura MLS are represented in Figure 8 a, b and c in percent change per year for each altitude level between 10 and 50 km.

P18, L382: Please add that trends are significant only in DL6.
We refer here to the negative trends in MCH homogenized D051 DL4 and DL5. In the post 2000 time range, there are significantly negative for the 2008-2018 (DL4) and since 2014 (DL5).
- a persistent negative trend in DL5 of the middle stratosphere and DL4 of the lower stratosphere with different levels of significance depending…

P18, LL386-390: The comparison with the trends derived from the Boulder and OHP time series is quite limited. In my view this paragraph could be either entirely deleted (since the main focus of this paper is the Arosa record) or a much more detailed comparison (including a plot showing the trends) should be provided. However, for the comparison of trends from various locations the latitudinal and longitudinal variability of the altitude dependent trends should be kept in mind (Sofieva et al., 2021).

We decided to remove this paragraph and the P7 Subsection 2.3 as we want to keep the focus of the paper on the Arosa data record.

P18, LL402-403: To which plot do you refer to here? The agreement between the NOAA homogenized D051 and Aura MLS (Fig. 5) is quite good.
We are referring to Fig5b, where the difference of MCH homogenized D051 and NOAA homogenized towards MLS disagree especially between 2017 and 2019: the difference between the blue curve and the red curve is not constant throughout the 2004-2021 period and is smaller during the 2017-2019 period. We rephrased it for clarity.

The two homogenizations differ in their comparison towards MLS and Brewer B040 on the ozone profiles level in the upper stratosphere, especially for the period 2017-2019.

Technical issues:
** Check that all acronyms are defined, e.g., P2: M2GMI, MERRA2, SCIAMACHY, OMPS,…*
All acronyms are now defined.
** Sometimes the instrument numbers are written including the "B" or "D" (e.g. D051) and sometimes without that letter. I would suggest to use the notation including the letter consistently throughout the manuscript.*
The notation including the letter is now used consistently.
P2, L24: "(MP1, 1987)" → key "MP1" not found in list of references
The reference label has been adapted.
P2, L29: "discrepencies" → "discrepancies"
The typo has been corrected.
P2, L37: "discrepencies" → "discrepancies"
The typo has been corrected.
P2, L43: remove blank before comma
The typo has been corrected.
P2, L50: "applied it on" → "applied it to"
This has been corrected as suggested.
P3, L56: "satellites data records" → "satellite data records"
This has been corrected

P3, L63: "record" -> "records"
The typo has been corrected.
P4, L110: remove blank after "D051"
The typo has been corrected.
P5, L152: define acronym "Mk"
"Mk" has been replaced by "Mark"
P6, Fig. 1 caption: "profiles in DU in functions of" → "profiles in DU as a function of"
This has been corrected as suggested.
P6, L153: "wavelenths" → "wavelengths"
The typo has been corrected.
P7, L187: remove parenthesis from "Waters et al., 2006"
This has been corrected.
P8, L204: do you mean "not flagged" here?
Yes, these data are removed. This has been corrected.
P9, Fig. 2 caption: "time serie are" → "time series are"
The typo has been corrected.
P11, L258: "homogenization remove" → "homogenization removes"
The typo has been corrected.
P11, L272: "both homogenizations differs" → "both homogenizations differ"
The typo has been corrected.
P12, L279: "both corrections of the N values looks" → "both corrections of the N values look"
The typo has been corrected.
P12, L282: "both homogenization" → "both homogenizations"
The typo has been corrected.
P14, L324: "30hPA" → "30hPa"
The typo has been corrected.
P16, L362: "informations" → "information"
This is correct.
P17, Fig. 8 caption: "post" → "Post"
The typo has been corrected.
P19, L421: "homog" → "homogenized"
This has been corrected as suggested.
P21, L504: "serie" → "series"
The typo has been corrected.
P21, L509: DOI missing
DOI has been added.
P22, L510: add blank after "S.M."
The typo has been corrected.
P22, L537: "Mcclure" → "McClure"
The typo has been corrected.
P22, L542: "Deluisi" → "DeLuisi"
The typo has been corrected throughout the References section.
P24, L605: journal missing
Journal has been added