

Reply to Reviewer #2

2 Weber et al., Global total ozone recovery trends attributed to ODS changes
derived from five merged ozone datasets, doi:10.5194/acp-2021-1058

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Reviewer comments are provided here with our replies written in italics.

6 The manuscript “Global total ozone recovery trends derived from five merged ozone datasets” by M.
Weber provides an update to a study published by the first author in 2018, with four more years of data
8 added to the five analyzed datasets (four satellite datasets and one dataset comprised of ground-based
measurements). A multiple linear regression is applied to annual mean data from the period 1979 to
10 2020 to determine total column ozone (TCO) trends in different broad latitudinal bands for the period in
which concentrations of ozone-depleting substances (ODSs) increased in the atmosphere, and for the
12 period after the peak concentrations had been reached. The multiple linear regression includes next to
the typical proxies also several dynamical variables (e.g. a proxy for the Brewer-Dobson circulation (BDC)
14 or the Antarctic/Arctic Oscillation (AAO/AO)) which is one of the main differences to other trend
analyses based on TCO data. The authors find with this method significant positive trends (related to the
16 reduction in ODSs in the atmosphere) for the period 1997-2020 for the near-global mean (60S-60N), as
well as for the Northern hemisphere mid-latitudes for which the trend is near zero if the dynamical
18 proxies are not included in the regression.

The manuscript is very well written and well structured, mostly the data and methods are explained in
20 enough detail to allow the reader to understand what is going on (in a few cases I found the description
slightly too short and I have mentioned them in the details below), and the topic lays clearly within the
22 scope of the ACP journal. There are a few minor things that I commented about below that are easy to
fix, but there are two main points that I think need careful adjustment of the manuscript or some
24 additional thought.

→ *We address these points (see specific replies below).*

26 I recommend the publication of the manuscript after revisions.

Two main points:

28 Attempting an attribution with a multiple linear regression that includes non-orthogonal proxies is
tricky. Especially if several proxies include a trend. The hope then is, that the regression is able to
30 separate the trend contribution from the different proxies based on the additional variability the proxies
provide. However, it is possible that trends are not assigned correctly to the different proxies which
32 would falsify the signal of the trend that if of interest, in this case here, the trend caused by ODSs and
not by changes in dynamical variables. The authors argue that with the addition of the dynamical proxies
34 the variability of the time series' are matched better by the regression results. There are two points that
make me somewhat doubtful of this statement: (1) the pre-1996 trends change clearly with the
36 introduction of the dynamical proxies (Figures 3 and 4) although the main trend signal should be coming
from ODS-related changes in this period; (2) the signal from the SH Brewer Dobson circulation proxy in
38 the NH polar regions that cannot really be explained. I think the manuscript needs more discussion of

40 these points to strengthen the claim that the addition of the dynamical proxies can indeed robustly
42 isolate the ODS-related trends. For the first point I raised I would suggest to check the older literature
44 about regression results for the pre-1996 period where dynamical proxies have been used. I have added
46 two references in the comments below that might be worth checking out. And there might even be
48 more that could be checked and where the results could be compared to the pre-1996 ODS-related
50 trends calculated here. For the second point I raised I think it would be helpful to do some sensitivity
test to check the robustness of the trend results and the contribution of the individual proxies: (I) not
using the trend proxy but JUST the dynamical proxies, how do their contributions change if at all; (II) use
some of the dynamical proxies only in the regions where they occur, e.g. AAO only in the SH, AO only in
the NH, etc.; how does the contribution of these proxies change (if at all), and how does the ODS-related
trend change? I think these sensitivity test will go a long way to show the robustness of the results
presented here in this manuscript.

→ We added two new tables to summarise the results from new sensitivity tests we carried out. New
52 Table 4 shows different MLR settings applied to the median total ozone timeseries in broad zonal bands
(as defined in Table 3). Here the results from the standard and full MLR are listed. In addition, we applied
54 an iterative MLR approach where statistically insignificant terms (2sigma criterion) are successively
excluded before the final MLR run. In order to document the changes from the MLR fits to the period up
56 to and including 2016 as in W18, the results of the different MLR settings applied to the current data for
the shorter period is provided in Table S1 (Supplement). Note that the results in Table S1 may differ from
58 W18 as the merged datasets have been updated and data before 2017 may have changed as well.

The following can be concluded from these additional sensitivity tests:

60 “The inclusion of the dynamical proxies generally improved the MLR fit (r^2 and chi values). Except for the
62 NH zonal band (35N-60N) the various MLR settings yield nearly the same post ODS-peak trends for all
broad zonal bands (new Table 4). There are, however, larger changes in the trends before the middle
64 1990s. In the extratropics the early-period trends are lower (-4.0%/decade vs. -1.9%/decade in the NH
and -3.1%/decade vs. 1.9%/decade in the SH) in the standard retrieval. This means that atmospheric
66 dynamics and transport changes contributed to lower early-period extratropical total ozone trends in the
standard regression (due to the lack of these dynamical terms in the MLR). The opposite is the case in the
tropics where the early-period trends in the standard MLR are slightly higher than in the full MLR. This
68 opposite behavior is consistent with ozone transport patterns due to the Brewer-Dobson circulation.

*The only significant changes in the post ODS-peak trends are seen in the NH extratropics. In the standard
70 MLR this trend is zero, while the full and iterative MLR show trends of a half per cent per decade. The
sum of the ODS-related trend (full MLR) and atmospheric dynamics contribution (difference in the trends
72 between full and standard MLR) cancel to result in a zero trend in the standard MLR. The negative
dynamical trend contribution in the NH is further discussed later in the paper. The correlation between
74 regression and observations are substantially lower in the standard retrieval ($r^2=0.74$ vs. 0.88) which
means that the standard MLR seems not to capture all variability and changes in total ozone.*

76 *The results shown in Table 4 are compared with the results from the MLR applied to the period limited up
to 2016 (same period as in W18) as shown in Table S1 (Supplement). Results from the shorter time period
78 are nearly identical to those shown in Table 3. There is one notable change. The uncertainties of the NH
trends from the full MLR up to 2020 are reduced such that these trends have become barely significant*

80 *(2sigma). The Post-ODS-peak trend of the standard MLR is slightly positive up to 2016 but statistically insignificant and within the uncertainties not different from the current results."*

82

I think it is really important to clarify throughout the manuscript (including the title!) what kind of trends the authors talk about. Mostly, the trends that are discussed are the trends that are attributed to the reduction of ODSs in the atmosphere WITHOUT any contribution of dynamics to the trend. In many places this is not totally clear since the trends are only called "recovery trends". However, for me this is the main point of the manuscript and the difference to other studies. It would therefore be extremely important and very helpful if the authors could be more specific in how they name the trends throughout the manuscript (e.g. instead of referring in the abstract in line 11 to "The near global trend of the median of all datasets..." it would be better to be more specific and refer to "The near global ODS-related trends ...", and specifying this in the title like "Global total ozone recovery trends attributed to ODS changes derived from five merged ozone datasets")

→ *We agree. The title has been changed accordingly and we made appropriate changes in the text in order to refer to ODS-related rather than recovery trends.*

Minor comments:

96 Line 10: "... is indeed on slowly recovering..." – remove the "on". → *done*

Line 16: data from which phase of CCMI? Please specify. → *add "(Phase 1 CCMI REF-C2 scenario)"*

98 Line 71: It is not clear in this section what the spatial coverage of the described datasets is. I assume 90S-90N since also polar regions are analyzed. Please add this information to the dataset descriptions.
100 → *added at the end of the paragraph (l. 82): "All datasets cover the entire earth except for months and latitudes under polar night conditions (winter months)."*

102 Line 72: "ground-based" instead of "ground" → *done*

Line 78: "ground based Brewers, ..." - remove the "ground based" since it is already mentioned at the beginning of the sentence. → *done*

Line 80: Add also here the information from which phase of the CCMI project simulations was analyzed.
106 → *changed to "Phase 1 CCMI Initiative" (add "Phase 1")*

Line 129: It is not clear how and by whom the ground-based dataset was updated. The references for the dataset are relatively old, therefore it would be good to add a few words on how the dataset was updated to the year 2020. → *The data set is a data product provided by the WOUDC and updated regularly. It is available from <https://woudc.org/archive/Projects-Campaigns/ZonalMeans/>. We added this information after the text in line 131: "The data set is a data product provided by the WOUDC and updated regularly"*

Line 135: The word "belt" is used here, although it is only explained in the following sentence what exactly is meant by it. This should be switched to make it clearer for the reader what is meant by "belt".
→ *We replaced the corresponding sentences (lines 134-137) with "Then, for each station and for each month the deviations from the climatology were calculated, and a zonal mean value for a particular month was estimated as a mean of these deviations. The calculations were done for 5°-wide latitudinal*

118 zones. In order to take into account various densities of the network across regions, the deviations of the
120 stations were first averaged over 5° by 30° cells, and then the zonal mean was calculated by averaging
these first set of averages over the 5°-wide latitudinal zone."

Line 154: the data were bias-corrected. It would be nice to give here a range of biases that needed to be
122 adjusted. I understand that the biases can be different for the broad latitude bands and datasets, but
some kind of number/range would be nice here. → *The various biases between datasets are irrelevant
124 and do not change the derived trends.*

Line 169: "applies" should be "apply" → *done*

126 Line 175: "." is missing after the parenthesis. → *done*

Line 176: The year 1996 is the time for maximum EESC concentrations for which region of the globe?
128 Tropics? Everything besides the polar regions? → *"... and some years later (t0=2000) in the polar
regions" is replaced by "except for the polar regions (>60°) where t0=2000" and removed the next
130 sentence.*

Line 177: It would be good to give the exact latitude ranges here which define the polar regions. → *see
132 the previous comment.*

Line 190: The end of the sentence is slightly misleading. I would add "for these years" before "were
134 calculated" to clarify that only for the years with too many missing data no annual means were
calculated. → *change second sub phrase after "and" to: "and for these years annual mean data were
136 treated as missing data,"*

Line 226: What about the pre-1996 trends? Did they stay very similar to W18 as well? → *see reply to the
138 general comment above.*

Line 248: "agree" instead of "agrees" → *done*

140 Line 255-257: It might be nice to add here a table with the trends reported from W18 and calculated
here. It would provide a nice overview of things that changed and things that stayed roughly the same
142 (just for the multi-observational median, not each individual dataset) → *see reply to the general
comment above and New Table 4 and S1.*

144 Line 269: "ground-based" instead of "ground"? → *done*

Line 285: Are there any studies that report on trends pre-1996 based on regression methods that use
146 also dynamical proxies? There is one looking at ozone soundings at Payerne (Weiss et al., JGR, Vol. 106,
D19, 22685-22694, 2001), and one looking at individual TCO station measurements (Maeder et al., 2007,
148 <https://doi.org/10.1029/2006JD007694>) but there might be even more analyzing total column ozone
data with dynamical proxies. As mentioned above, I think it would be helpful to provide an estimate
150 how well the ODS-related trends compare with earlier findings for the pre-1996 period since they did
change quite a bit with the introduction of the dynamical proxies. → *see reply to the general comment
152 above. The older studies mainly used a piecewise linear trend (PLT) model and thus are difficult to
compare. In W18 we discuss the various trend models and our decision to use preferably the ILT method
154 in W18 (and this study).*

156 Line 305/306: Couldn't this signal be a spurious regression result where the attribution did not work
properly between the trend proxy and the dynamical proxies also including a trend? I think some
sensitivity test (as mentioned above) would be helpful here to test the robustness of this signal. →
158 MARK (see general comments) → *see reply to the general comment above. It appears that the post-ODS
trends are in most cases unchanged regardless of the number of extra terms used in the MLR. The linear
160 trend term is the only low-frequency term in the MLR equations, while the dynamical proxies have some
high-frequency contributions. This makes the trend estimates rather robust and less sensitive to the
162 various other terms used in the MLR.*

Line 316: "." missing after the parenthesis. → *done*

164 Line 331: "have" instead of "has" → *done*

166 Line 366-368. This sentence seems somehow out of place here. I think it needs a little more explanation
and detail. → *We omit this sentence, as we did not discuss the possible impact of tropospheric ozone on
column trends. The impact is possibly rather small when using annual and zonal means.*