Supplement of

Northern midlatitude baseline ozone: Long-Term changes and the COVID-19 impact

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Introduction

Estimates of the net, long-term baseline ozone change for progressively longer time periods within the past 3 decades are derived in this work and by Chang et al. (2022). Figure S1 plots nine linear line segments representing independent estimates derived by different approaches and spanning different time intervals. Table S1 gives the parameters defining those line segments, which span the time periods selected for the linear fits. Text S1 investigates how the results linear regressions depends upon the year selected for beginning the regression.

Table S1. Linear trends for baseline ozone at northern mid-latitudes, with estimated 95% confidence limits, and corresponding year 2000 intercepts. To reduce the number of required decimal places the slopes are given in units of ppb/decade, while those in the manuscript are given in units of ppb/year. Corresponding line segments are included in Fig. S1.

Reference	Time Interval	Intercept (ppb)	Trend Slope (ppb/decade)
This work	1994-2018	-0.02 ± 0.02	-0.18 ± 0.89
"	1994-2019	-0.07 ± 0.60	-0.42 ± 0.75
"	1994-2020	+0.04 ± 0.63	-0.60 ± 0.79
Chang et al., 2022 (weighted mean)	1994-2019	-0.17 ± 0.59	-0.25 ± 0.14
"	1994-2020	-0.09 ± 0.60	-0.39 ± 0.30
Chang et al., 2022 (Fused - WNA)	1994-2019	-0.53 ± 0.62	+0.35 ± 0.21
"	1994-2020	-0.41 ± 0.60	+0.14 ± 0.21
Chang et al., 2022 (Fused - Europe)	1994-2019	-0.72 ± 0.68	+0.65 ± 0.19
"	1994-2020	-0.54 ± 0.62	+0.36 ± 0.20

Notes. The 1994-2018 results are from a liner fit to all normalized, deseasonalized monthly means in that time period, with the larger confidence limits from the linear fit to the 2-yean means in the same period; the results from the other two periods are calculated from the quadratic fit (i.e., Equation 2 of the manuscript).

The weighted means for all northern mid-latitude stations of Chang et al. (2022) are discussed in the manuscript; other trends are taken with 2-sigma confidence limits from their Table 2. The intercepts of all the Chang et al. (2022) results are derived by normalizing to the 1994-2017 2-year means.

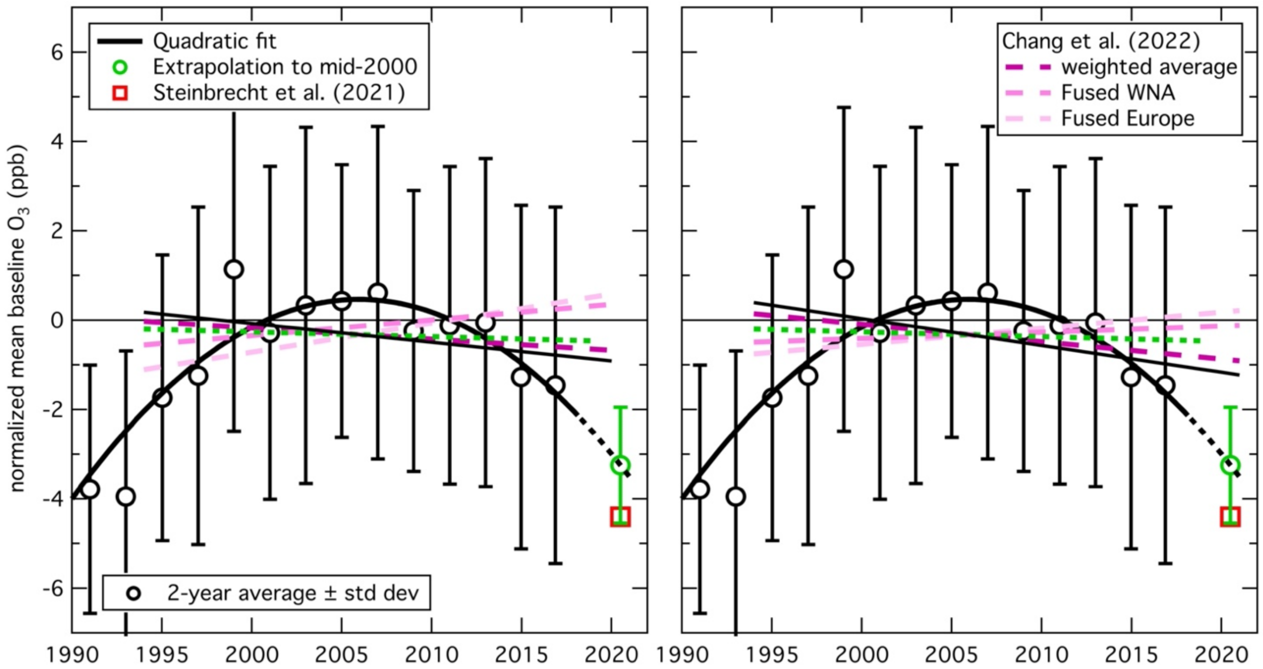

Figure S1. Section of Figure 1 (with axes expanded) that compares linear trends (black line segments) derived from the quadratic fit (black curve), the linear fit to the 1994-2018 monthly means (dotted green line segments) and those derived from Chang et al. (2022) (other colored dashed line segments). The left and right graphs give the Chang et al. (2022) and Equation 2 fits for the 1994-2019 and 1994-2020 periods, respectively. The parameters of all line segments are given in Table S1.

S1. Dependence of linear regression results on choice of initial year of the regression

The Conventional Wisdom and the Linear Trend View, unsurprisingly, predict different expectations of the baseline level of ozone in the year 2020. What is required is the time-dependence (trend) of the ozone content during the period leading to the COVID-19 pandemic. The Linear Trend View calculates the average of this derivative over significant time scales and assumes this constant value to be the local value pre-COVID. The Conventional Wisdom, on the other hand, uses an integral approach that fits the evident long-term non-linear behavior to yield an extrapolated value for the trend appropriate for the pre-COVID period. The major weakness in the Linear Trend View is clear when non-linear behavior exists - the value of the calculated trend depends on the time period chosen for the linear fit; since the data in Figure 1 have sequential ascending and descending legs, this average will necessarily underestimate the local pre-Covid trend. The major weakness in the Conventional Wisdom model is that the data contain substantial variability (inherent in atmospheric phenomena) and the quadratic term necessary to calculate the quantitative pre-Covid. rate of decrease has substantial statistical uncertainty. To illustrate this issue a cursory piece-wise linear trend analysis of the 2-year means plotted in Figure 1 is given here.

Linear approximations are typically applied to a non-linear function to obtain local derivatives of that function, in the spirit of the origins of the Calculus, that is by taking the limit of $\Delta f(x)/\Delta x$ as Δx approaches zero. Here we apply this approach to illustrate the slope of the non-linear ozone change expected in the year 2000 had the COVID-19 pandemic not occurred. A linear regression of the average ozone data values in Figure 1 produces the following graph when the regression interval is varied. Each symbol with error bar shows the slope from a regressed linear trend from a shrinking time period (from a given start year to the most recent 2-year mean (2017)) is analyzed. The standard error bars of these regressed slopes arise from the scatter in the averages themselves, not from the standard deviations of the monthly means included in the individual 2-year averages, which are indicated by the error bars in Figure 1.

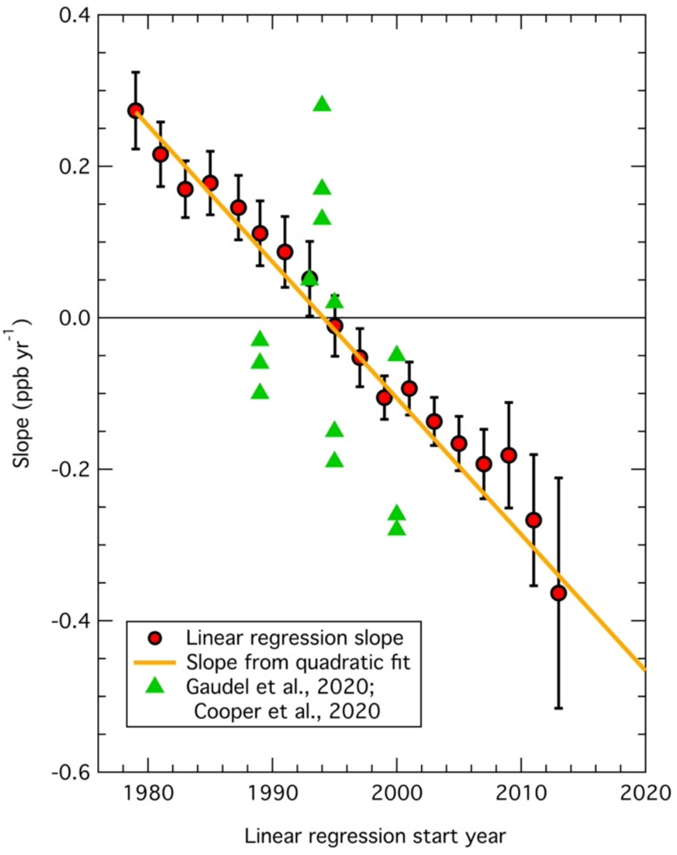

Figure S2. Dependence of slope of linear regressions derived from the 2-year means included in Figure 1 compared to trends derived from two of the Linear Trend View papers. Symbols with error bars give slopes with standard errors derived from linear regressions to all 2-year means (left point) and to progressively one fewer 2-year means (points moving progressively to the right). Line indicates the slope dependence expected from quadratic fit plotted in Figure 1. Triangles give northern midlatitude free troposphere trends reported by Gaudel et al. (2020) in their Table S1a and northern midlatitude surface site trends reported by Cooper et al. (2020) in their Table 2.

Three results are apparent from this analysis:

(1) The non-linearity of the data is obvious. The regressed linear slope depends on the time interval of the data regressed and clearly shows the historic change from an increasing average ozone trend over the entire time period to a decreasing average trend over the period beginning in the mid-1990s, when the time period before the ozone maximum decreases to match the time after the maximum. The green triangles indicate the of starting dates for the trends given in the Linear Trend View references; they are near the time of this crossover, thus resulting in small derived trends.

(2) The quadratic fit given by Equation 1 discussed in the manuscript with necessarily implies that the slope over any selected time interval specified by t_1 and t_2 is equal to $b + c*(t_1 + t_2)$. The line in Figure S2 is derived from the parameter values discussed in the manuscript and $t_2 = 17$, i.e. the value for the most recent 2-year average. There is only small variability of the individual regressed slopes about this line, which is a strong indication of the fidelity with which the quadratic fit describes the overall non-linear long-term ozone changes. Notably, the few slopes derived after a linear regression start time of the mid-2000s are based only on measurements after the quadratic fit reached is maximum, which indicates that the quadratic fit not only accurately describes the early ozone increases, but also accurately describes recent ozone increases as well.

(3) The approximately linear nature of the derived derivatives is a further demonstration that higher order terms in the power series fitting procedure are not statistically significant.

Cursory use of this Newtonian (Leibniz) variation of the Linear Trend treatment yields a conservative linear trend (derivative) of -0.4 ppb/y for the most recent segments of the data. With an ozone deficit of -1.6 ppb apparent in 2017, linear extrapolation of this value for 3 years at -0.4 ppb per year yields an estimated ozone burden in 2020 which is 2.8 ppb lower than the pre Covid average used by Steinbrecht et al. (2021). This value is close to the 3.2 ppb value obtained from the integral treatment described in the MS and explains 70% of the 4 ppb difference observed.