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Atmospheric Chemistry and Physics Discussions

Interactive comment on "The total ozone field separated into meteorological regimes. Part II: Northern Hemisphere mid-latitude total ozone trends" *by* R. D. Hudson et al.

R. D. Hudson et al.

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The authors would like to thank the reviewer for his positive and thoughtful feedback.

Response to Specific Comments

1. The results for the trends given in the paper were the result of a regression analysis using time series. The terms consisted of four harmonics of the annual cycle, and a linear time term. This is the same approach used in previous analyses by other authors. What we failed to realize when we wrote the paper was that there are two sources of error for the fitting constants. The first is the error which comes about because of the fitting model, in other words, the error of the fit. In previous analyses done on similar time series, the monthly data was assumed to have no error, and the error of

the fit is obtained from the difference between the calculated and measured values (the residual) using standard statistical techniques. The error that we have calculated is the error in the constants which arises from the uncertainty in the measurements. The overall error in the constants will be the root mean square of these two errors. Given that the error of the constants depends on the residuals, we have included the effects of QBO and the solar cycle in the regression fit. The new error estimates in the paper will reflect this fact and include an explanation similar to that above. The error estimates are about a factor of two larger than in the current version of the paper.

(i) [6188, 2] The Wilks reference will be removed.

(ii) [6187 and following] The term 'error of the mean' used in the paper is more properly referred to as the 'standard error of the mean'. It is the accuracy with which the mean value can be evaluated. The standard deviation is the half width of the spread of the data about that mean. The standard error of the mean is the standard deviation divided by the square root of the number of degrees of freedom of the data. We calculated this quantity for each monthly mean. The difference between these quantities will be described further in the revised paper. All quoted uncertainties are 2-sigma.

(iii) [6187,25-27] The 5% convergence criteria was chosen based on the spatial resolution of the TOMS data, 1° latitude by 1.25° longitude. In each iteration, any change in the area of a particular regime will have a minimum value given by the area of a pixel. This error due to the pixel size varies from 2-4% of the regime areas, depending on latitude. Thus, the resolution of the data does not allow for a 1% convergence criteria. The authors have chosen a slightly more conservative convergence criterion of 5% to allow for any additional error arising from variability in the ozone data within a regime.

(iv) A description of how our errors were obtained is above. The errors in the paper will be changed to reflect this new procedure.

(v) [6189, 19-25] Again, a more detailed explanation of the errors will be included in the final manuscript.

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2. The fundamental assumption in our method is that total ozone acts as a dynamical tracer on synoptic timescales (Danielsen et al., 1970; Wohltmann, 2005). This assumption is valid in the absence of chemistry occurring on shorter timescales than dynamics. Therefore, because our boundaries are calculated on a daily basis, they are subject to changes in ozone chemistry on timescales shorter than a day. However, ozone in the lower stratosphere, which dominates the day-to-day variability in total ozone, typically has a chemical lifetime on the order of several weeks (Brasseur and Solomon, 1984). With specific regard to the susceptibility of the long term total ozone trends, experiments were done to determine the sensitivity of the total ozone trends to the boundary. We widened the boundary by one, two, and three pixels in both latitude and longitude, and calculated the resulting trends. It should be emphasized that as we increase the boundary size, we become increasingly independent of the exact choice for our boundaries. The trends calculated for each of the widened boundaries vary very little. Therefore, independent of boundary choice, the only way we can reconcile the larger zonal trend with those in the regimes is the relative areas of the regimes have changed. In addition, when our calculated total ozone and relative area trends are used to calculate the trend in zonal total ozone, we get a self-consistent result. We also conducted an experiment to test whether a latitudinally dependent chemical trend in ozone over time would affect the placement of the regime boundaries. We used two runs from the NASA Goddard 3D CTM, one run with full chemical ozone depletion, and another run with no chemical ozone depletion. This model has a 4° x 5° resolution, and importantly, the dynamics are run offline. Therefore, the positions of the upper-troposphere fronts will be the same in both runs. We then used our method to determine the boundaries on a daily basis for both runs and compared the relative areas calculated from 1983 - 2003. There was little to no difference in the relative areas between the two runs. In addition, when the results for several days after 2003, when there would be a maximum amount of ozone depleted, were compared. The boundaries calculated were remarkably similar. This experiment and its results will be included in the final manuscript.

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Brasseur, G. and Solomon, S.: Aeronomy of the Middle Atmosphere, D. Reidel Publishing Company, Dordrecht, Holland, 441pp., 1984. Danielsen, E., Bleck, R., Shedlovsky, J., Wartburg, A., Haagenson, P., and Pollock, W.: Observed distribution of radioactivity, ozone, and potential vorticity associated with tropopause folding, 75, 2353-2361. Wohltmann, I., Rex, M., Brunner, D., and Mader, J.:Integrated equivalent latitude as a proxy for dynamical changes in ozone column, Geophys. Res. Lett., 32, L09811, doi:10.1029/2005GL022497, 2005.

3. We have limited our analysis to the use of the TOMS data which has a gap between 1993 and 1996. Since the referee's comments were posted we have looked at the relative role of chemistry and dynamics for the period 1996 through 2003. For the period 1996 to 2003 we find that the zonal total ozone trend, using the full regression model, is -1.8 ś 1.7% per decade. This error is considerably larger than for the period 1979 to 1991, and this increase in the error is seen in all of the trends (both total ozone and area) for the period 1996-2003. The trend in the relative area for the tropical regime for the period 1996-2003 is the same as that for 1979-1991 within the experimental error. The trend for the midlatitude is slightly higher, and that for the polar regime is the same. The problem is that the errors in the slopes become comparable to the slopes themselves. Hence the calculation of the relative contributions of chemistry and dynamics will have much larger error bars. What is needed is to fill the data gap between 1993 and 1996. We are working on this using the TOVS data, but the analysis is at an early stage. We are willing to include a brief discussion of these results in the paper if the referee feels they are important.

4. The authors will include these recent references to total ozone trend analysis.

5. Figure 1b of this work is the more correct figure. Figure 2b of Hudson et al. (2003) was created using version 7 TOMS data, and an older version of our separation method.

6. A monthly trend analysis has been done, but will be discussed in a future paper.

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Technical Comments - [Abstract] Will include the finding that about one third of the trend in northern mid-latitude ozone from January 1979 to May 1991 can be attributed to changes in the relative areas of the regimes over time.

- [6185, 27on] The newer method presented in this paper was not run using the version 7 data. However, based on previous comparisons of the two datasets, the authors expect that the effect on both the total ozone and relative area trends would be minimal.

- [6186, 24] Upon experimentation with several values of potential temperature, the position of the sharpest PV gradient on the 550K surface was chosen as the best representation of the polar vortex boundary.

- [6187, 5] The line reads, 'the total ozone within each regime shows that there is a small dependence (relative to the zonal data) of total ozone with latitude.' The latitude dependence within a regime is meant to be compared to that of the zonally averaged total ozone, which is much larger.

- [6187, 7-10] The line should read 'small errors in the determination on the location of the upper-level fronts'. This will be corrected in the final manuscript.

- [6187, 25on] As discussed above, a 5% convergence limit corresponds to about a change of one pixel about the boundary, or a change of 2-4% in the regime area. This error should be random. The standard deviations of the measurements of the relative areas over a month are considerably larger, about 20%.

- [6188, 3 (eg)] The error of the monthly mean, whether it be total ozone or relative area. This will be clarified in the final manuscript.

- [6192, 20on] The number of significant digits will be corrected.

- [Fig 1(b)] The caption will be corrected to read, 'The one-degree zonally averaged total ozone data within the tropical (red stars), midlatitude (green stars), polar (blue stars), and arctic (light blue stars) regimes for March 11, 1990. The new boundary values.....' -The authors will experiment with putting error bars on the figure.

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Interactive Comment

- [Fig 2] The purpose of Figure 2 is to show the variability within the relative area monthly mean, or in other words, the daily variability of the upper-level fronts. -The time period 1980-1990 was chosen as a representative time period. -This figure will be removed from the final manuscript

- [Fig 4, 6] The time period of the calculated monthly climatology will be added to the figure caption.

Possible Additional References -The suggested references will be included. The Wohltmann reference was used in the original manuscript, 6186, 17.

Interactive comment on Atmos. Chem. Phys. Discuss., 6, 6183, 2006.

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Interactive Comment