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Atmospheric Chemistry and Physics Discussions

# *Interactive comment on* "The Evolution of Zonally Asymmetric Austral Ozone in a Chemistry Climate Model" *by* Fraser Dennison et al.

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Thank you for your comments.

*1. Are formal uncertainties obtained for the fitted parameters? The code in the supplement suggests that formal uncertainties are not calculated, but on reading Taubin (1991), it would seem that this should be possible. It would appear from Figure 3 that the uncertainty on the fitted central longitude is relatively small compared with the interannual variability, but it would be useful to make a statement on the accuracy of the fitting. This could be confirmed by fitting to simulated ellipses of known properties.*

Calculating uncertainty in the parameters shows that, as you suggest, the uncertainty is smaller than the interannual variability. Code for calculating the uncertainty will be



added to the supplement.

Text added (pg 4 ln19):

"The quality of fit of the ellipse was assessed by calculating the fraction of non-overlapping area relative to the overlapping area of the 300 DU contour and ellipse. For both the reanalysis and model the contour is well fitted to the ellipse (median fraction of 0.03 in both cases). The uncertainties were also calculated for the individual ellipse parameters; these were found to be much smaller than the inter-annual variability and so are not shown in the figures included here."

*2. Related to 1 above, how well-fitted is the 300 DU contour to an ellipse? Not withstanding the reference to Waugh (1997), an ellipse seems rather an arbitrary function to apply to the total ozone column where overburdens and unburdens of ozone due to tilting of the vortex with height will tend to distort the shape of a particular contour. It would be useful to comment on how small and consistent is the difference in area between the 300 DU contour and the fitted ellipse. The authors should also comment on how the tilting of the vortex could influence the fitted parameters. The effect of tilting when the vortex becomes distorted could be checked by fitting to a suitably chosen contours for two partial columns (e.g. 100 hPa and 10 hPa).*

The ellipse is well fitted to the 300 DU contour – see above.

Vortex tilt was examined as described in the following addition to the text (pg 5 ln1):

"The Antarctic polar vortex is known to tilt westward and equatorward with height (Waugh1999), hence it is possible using total column ozone may obscure certain characteristics. This was investigated by comparing ellipses fitted to ozone mixing ratio contours at different altitudes (4.5 ppmv at 20 km and 9 ppmv at 26km) chosen to produce ellipses of comparable size to the 300 DU ellipses. It was found that all parameters were strongly correlated between the two levels ($r>0.70$); hence, the ellipse fitted to the total column should adequately convey the general state of the vortex."

*3. What is the spatial resolution of the ECMWF data used? How does the spatial resolution of the gridded data influence the accuracy of the ellipse fitting? For example, if the model and reanalysis have different spatial resolutions, how would uncertainties (or spread) in fitted parameters be expected to compare. This could be checked by changing the spatial resolution of the reanalysis data and seeing how the fitted parameters differ compared with those for the original resolution of the reanalysis data.*

Added resolution of the reanalysis to the text (pg4 ln9):

Changing the resolution of the reanalysis to that of the model produces no discernible change in fitted ellipse parameters.

*4. I am unsure how the 2-sigma envelope in Figure 1c for the model ensemble can extend to what looks like 90 degrees south given that the authors state in line 8 of page 4 that they only use fits where the central latitude is north of 89 degrees south. Please clarify. I suggest use of percentiles rather than standard deviations as the envelope you show is symmetrical about the mean but I would expect the true range to be asymmetric (as, for example, by your method you can't have a central latitude greater than 89 degrees south).*

It is only the centre longitude corresponding of these fits that are not used. Figure 1(a) does include points South of 89S.

Text has been changed from:

In the analysis of the centre longitude only data for which the centre is significantly displaced from the pole is used as centres close to the pole have a large uncertainty associated with their longitude

To (pg 4 ln 15):

"Ellipses with centres close to the pole have a larger uncertainty associated with their centre longitude. For this reason, only centre longitudes from ellipses with a centre latitude north of 89S are included in the analysis. "



The truncation of the centre latitude distribution at the pole is sufficiently far along the tail of the distribution that the 95th percentile envelope is little different than 2 sigma envelope.

*5. The timeseries in Figure 3 run from about 1960 to 2090 which makes me wonder if smoothing has been used (although this is not stated in the caption). Please clarify or indicate why the full time span has not been used.*

Yes, the time series has been smoothed with a 15-year running mean. This is now stated in the caption to figure 3.

*6. In the discussion, an effort is made to compare with earlier work, and it is noted that the ellipse centre longitude shifts west in the period 1960-1999, while other studies (e.g Grytsai et al., 2007 using data from 1979 to 2005) show that the extratropical zonal ozone minimum shifted eastward in part of this period. However, the authors do not offer an explanation for these differences. Is it possible to reconcile these differences by considering the longitude of the ellipse fitted to the reanalysis data at its most equatorward latitude? From looking at Figure 1 of Grytsai et al. (2007) this would tend to correspond to the longitude of ozone minimum in their analysis, albeit at a somewhat variable latitude that would depend on the size of the vortex (noting that the shift noted by Grytsai et al. (2007) is more eastward towards the pole).*

There is possibly something to this, although the data is not really definitive.

For example, the ERA-Interim ellipses show a 1979-2005 trend in centre longitude of +7 degrees/decade which is not significant at the 95% level (Confidence Interval is [-5,19])

If taking only ellipses with centre latitude north of 83S gives a similar result: +7 degrees/decade (95%CI [-10,23])

Table 2 from Grytsai 2007 shows the trend in the longitude of the ozone minimum at 80 S over this timespan is quite a bit larger at 23.5 +/- 8.8 degrees/dec

Added the bold text in the section below:

(pg 11 ln 32)

The results presented here support those of Grytsai et al. (2017) in that changes in the concentration of ODSs, more so than changes in GHG concentrations, are linked to the shifting zonally asymmetric ozone distribution. However, the approach taken here – the use of elliptical diagnostics – makes the comparison of the particulars of the results somewhat unclear. While this study shows the ellipse centre longitude moves west and the eccentricity decreases over the 1960-1999 time span while Grytsai et al. (2005, 2007) shows the extra-tropical ozone minima to move eastward and the maxima to be stationary. **There is some suggestion of an eastward trend shown for ERA-Interim in Figure 1(b) however this is not significant at the 95% confidence level and is substantially smaller than that reported by Grytsai et al. (2005).** The fact that the centre longitude moves in the opposite direction to the extra-tropical ozone minima perhaps indicates that it is the rotation of the ellipse that is more descriptive measure of the ozone distribution at mid-latitudes. It is therefore unfortunate that a reliable measure of the rotation was unable to be obtained here due to the models overly-symmetric simulation of ozone. **Interestingly, the results shown here fit with results from the Northern Hemisphere which reveal a westward shift associated with ozone depletion (Peters et al., 2015).**

*Technical corrections:*

Page 2, line 30: its rather than it's - fixed

Page 2, line 33: show the position of ozone minima to differ. . . - fixed

Page 4, line 9: are rather than is – fixed

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