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Supplement of

Evidence for a continuous decline in lower stratospheric ozone offsetting ozone layer recovery

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Supplementary materials

The following figures provide supporting evidence and information for the main journal article.

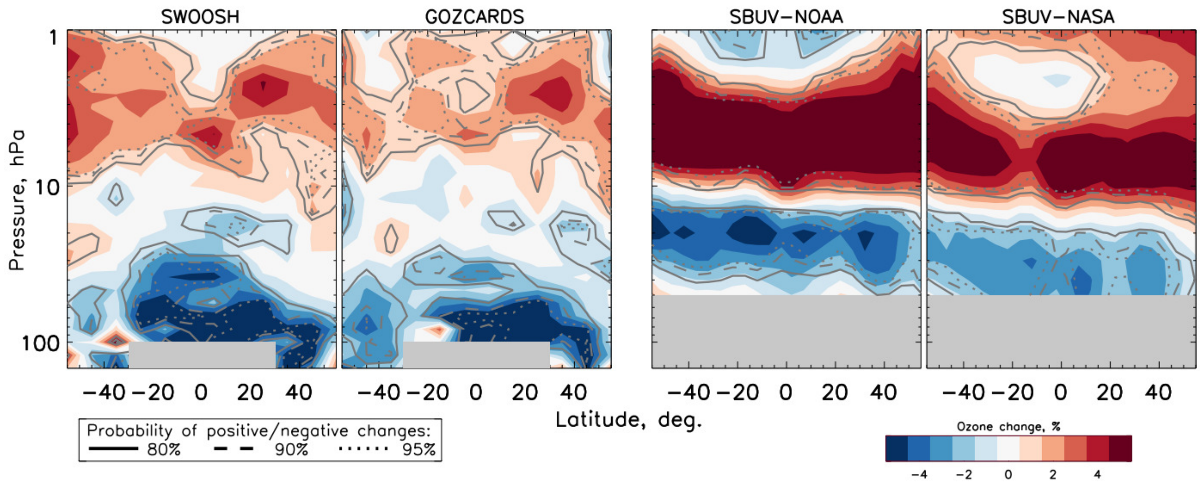

Figure S1: 1998-2016 ozone change. As for Fig. 1 of the main article; from left to right, SWOOSH, GOZCARDS, SBUV-NOAA, and SBUV-NASA composites.

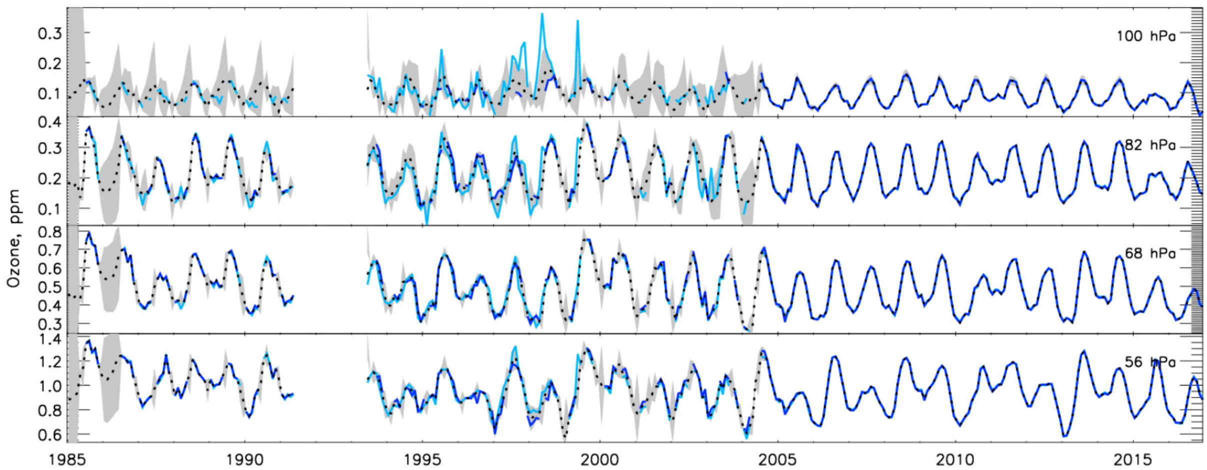

Figure S2: Example results of the merging procedure detailed in Ball et al., 2017, applied to GOZCARDS (dark blue), SWOOSH (light-blue) ozone composites in the 0-10ºN band at four pressure levels indicated in the top right of each panel. The resulting Merged-SWOOSH/GOZCARDS timeseries is shown as a dashed-black line with two standard deviation uncertainty in grey shading.

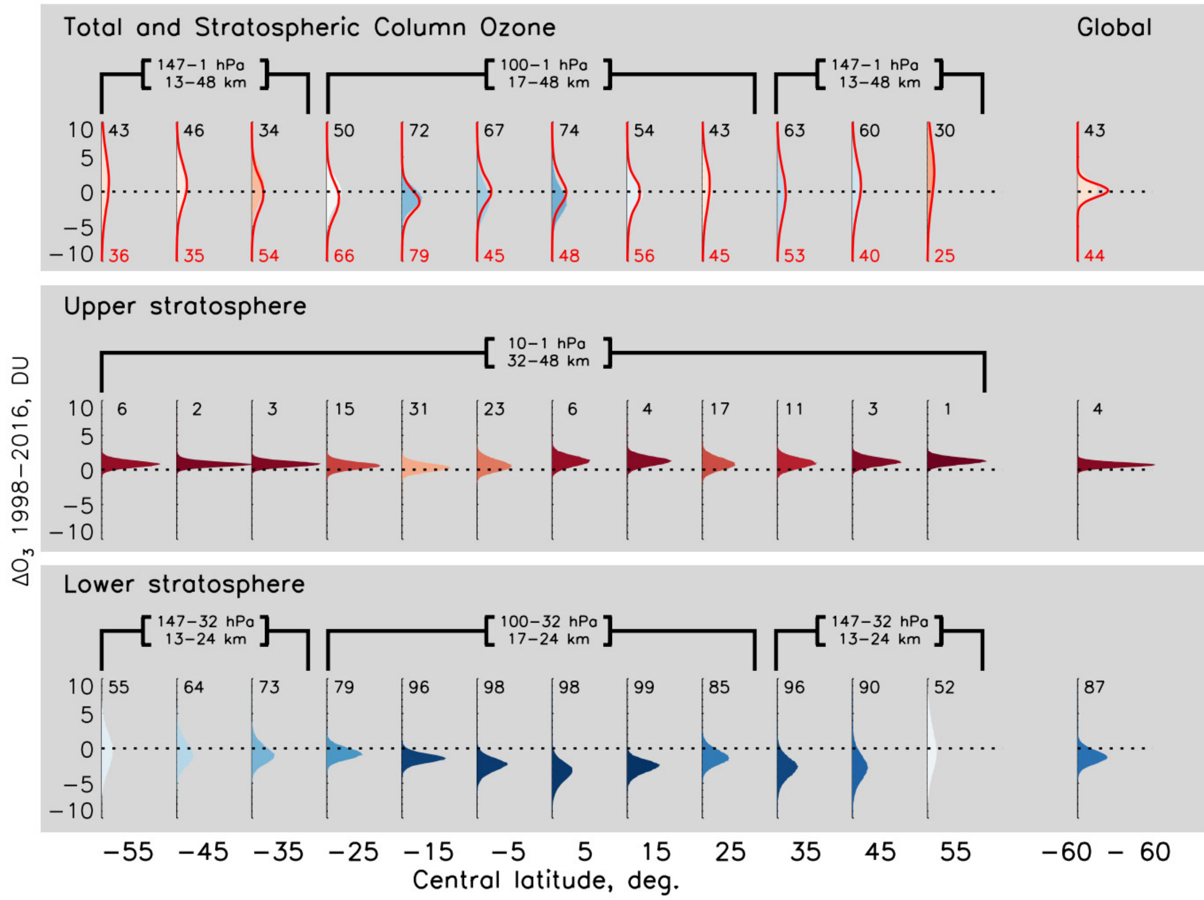

Figure S3: SAGE-II/OSIRIS/OMPS posterior distributions for the 1998-2016 ozone changes. See caption of Fig. 2 of the main article for details.

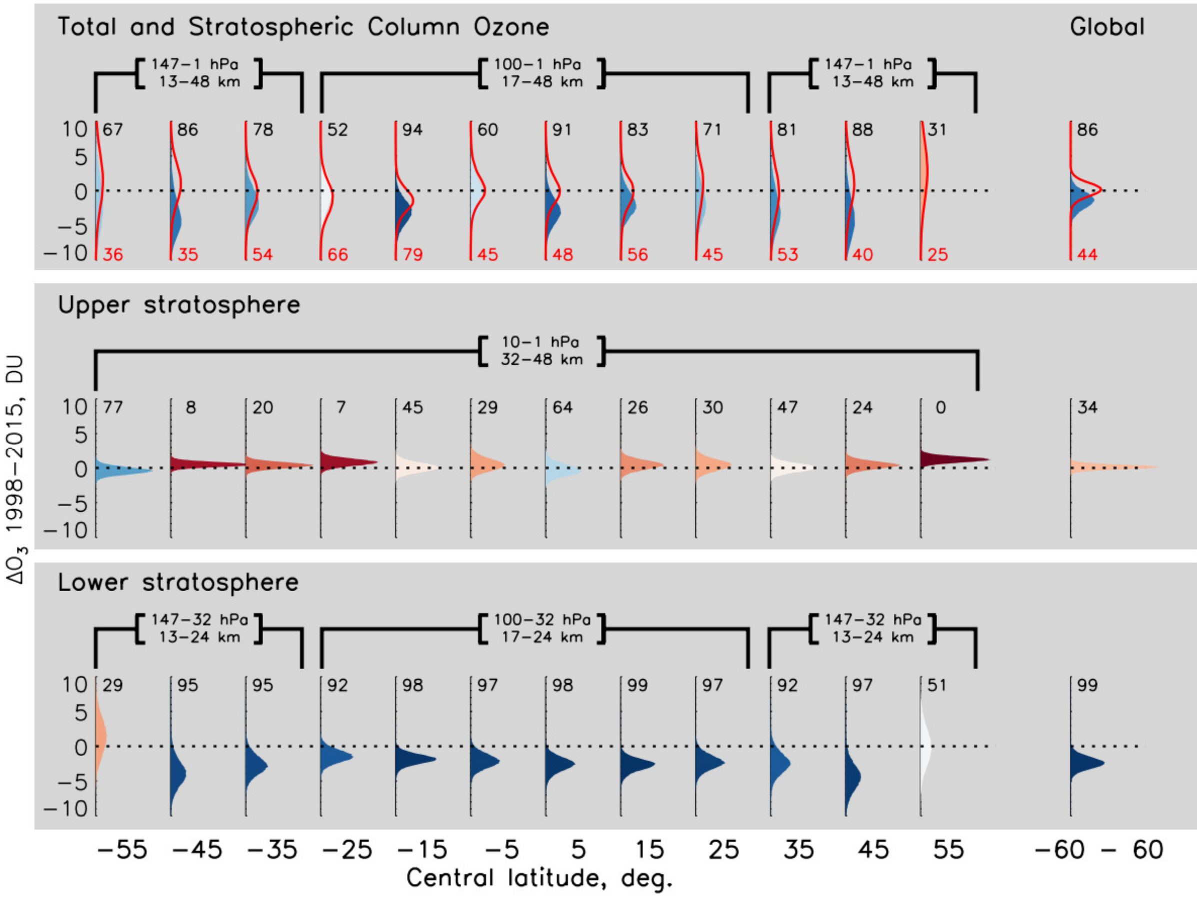

Figure S4: SAGE-II/CCI/OMPS posterior distributions for the 1998-2015 ozone changes. See caption of Fig. 2 of the main article for details.

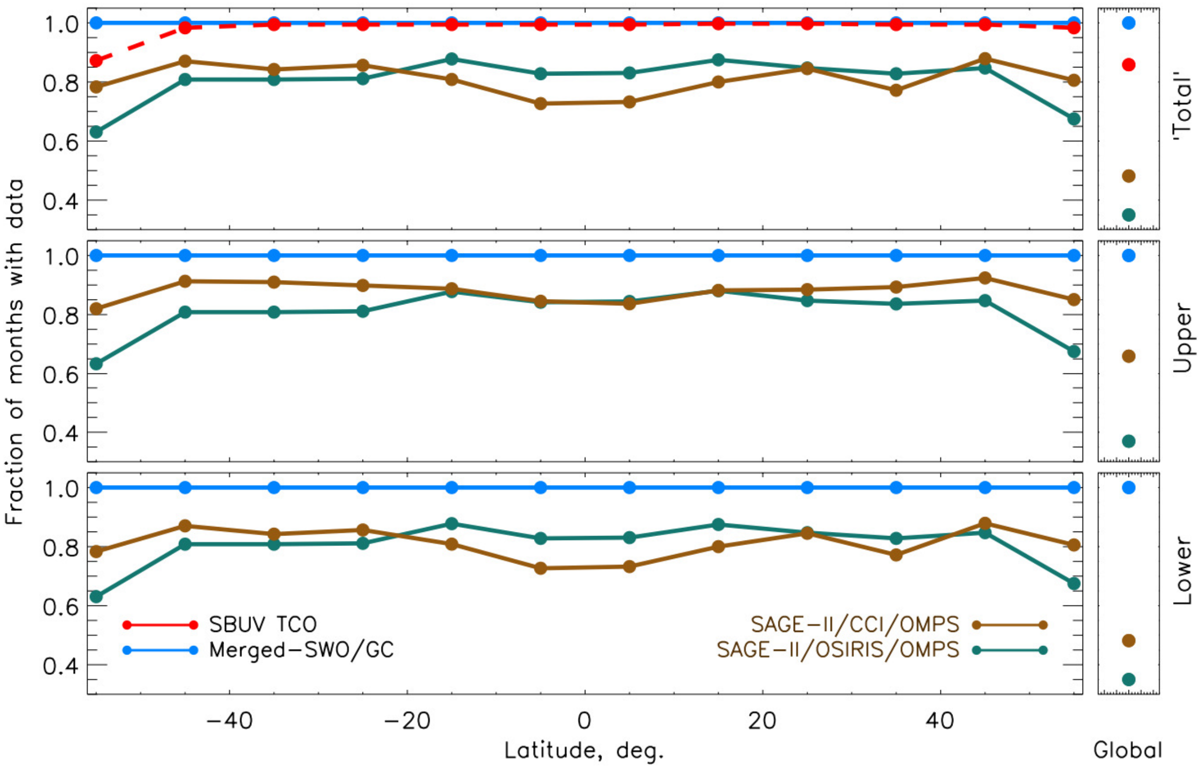

Figure S5: The fraction of data available for the (top) stratospheric column ozone and total column ozone, (middle) upper stratosphere, and (bottom) lower stratosphere posterior estimates in Fig. 2 of the main article, and Figs. S3 and S4. Global (right) are much lower in SAGE-II/OSIRIS/OMPS and SAGE-II/CCI/OMPS because if data are missing in any latitude in a particular month, the global partial column or stratospheric column ozone is assigned no data.

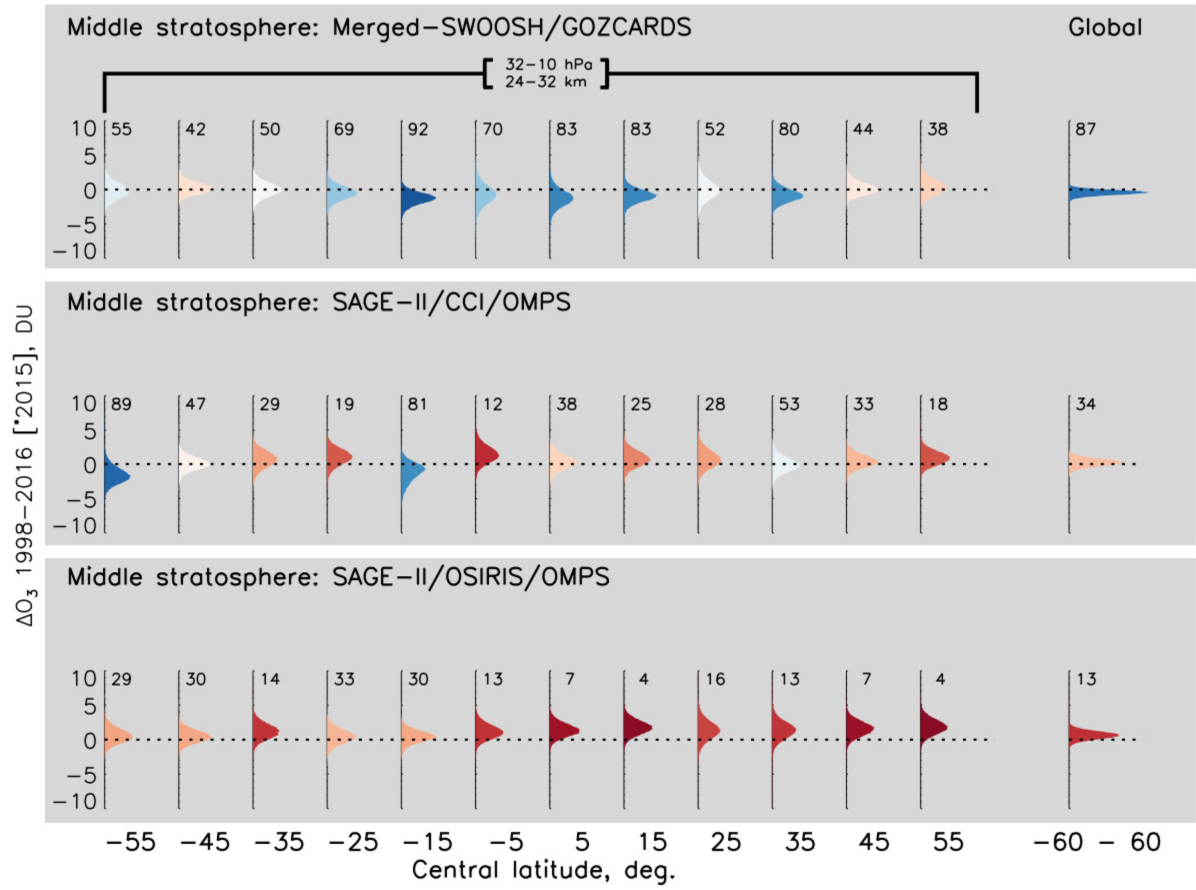

Figure S6: Posterior distributions in the middle stratosphere for the 1998-2015/2016 ozone changes. Similar to panels in Fig. 2 of the main article, but for the middle stratosphere (32-10 hPa, ~24-32 km) for (top) Merged-SWOOSH/GOZCARDS, (middle) SAGE-II/CCI/OMPS, and (bottom) SAGE-II/OSIRIS/OMPS.

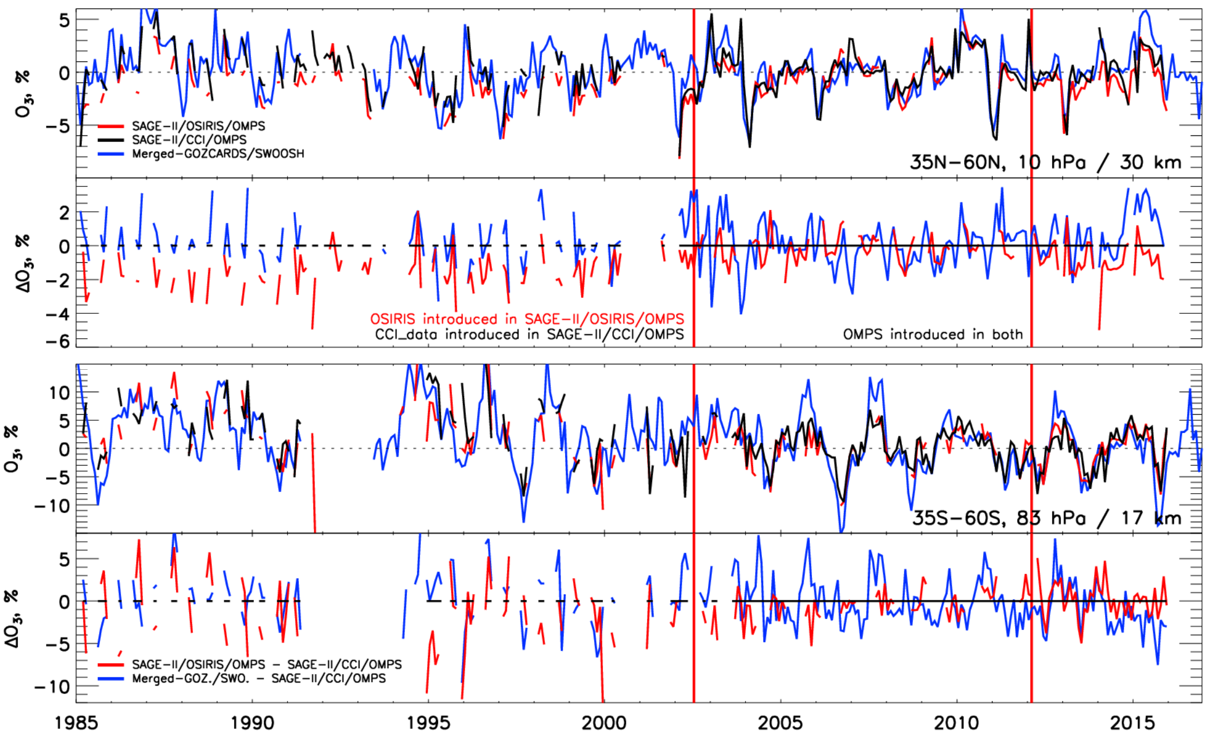

Figure S7: SAGE-II/OSIRIS/OMPS (red), SAGE-II/CCI/OMPS (black) at 30 and 17 km (upper and lower pair, respectively), and Merged-SWOOSH/GOZCARDS (blue) at pressure levels of approximately the same altitudes at 10 and 83 hPa, respectively. The upper panel of each pair shows the deseasonalised changes relative to 2005--2013, and the lower panel shows SAGE-II/OSIRIS/OMPS and Merged-SWOOSH/GOZCARDS relative to (i.e. minus) SAGE-II/CCI/OMPS. Approximate dates when OSIRIS and OMPS were introduced into the composites are shown with vertical red lines, before/after which a shift in the mean appears.

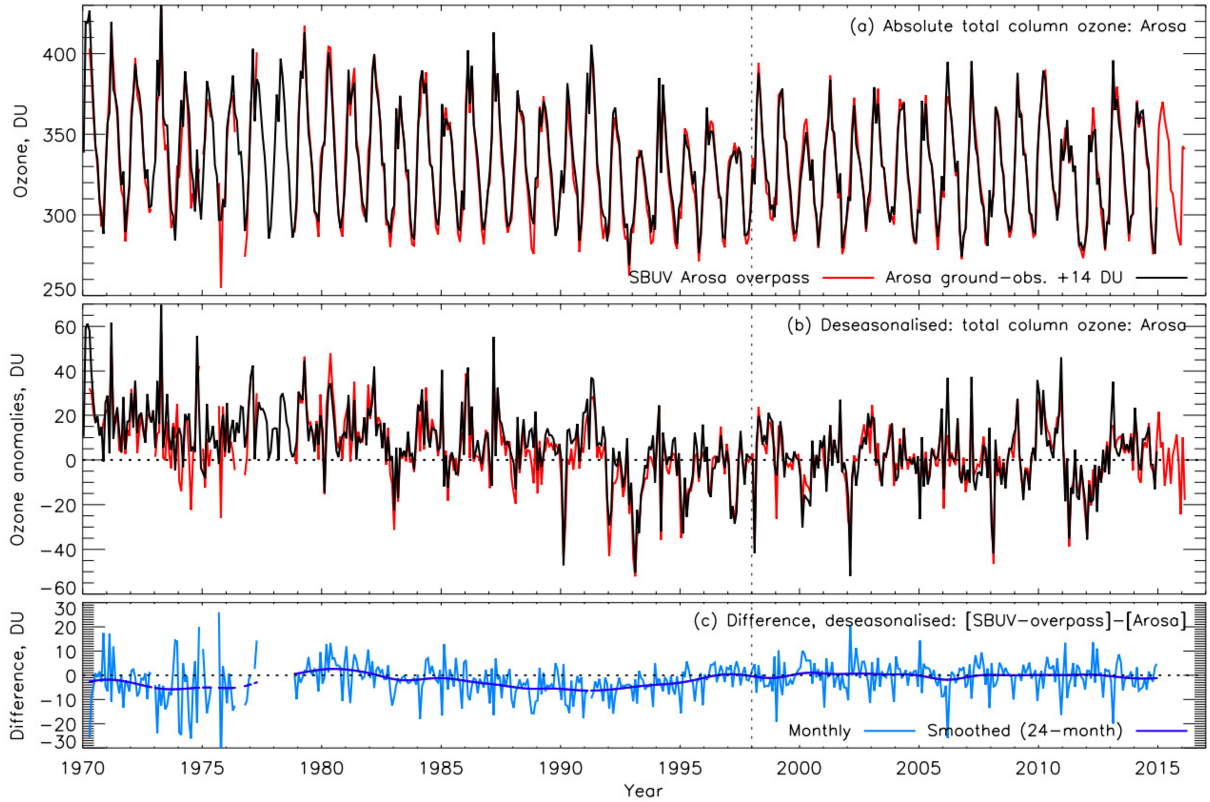

Figure S8: Ozone over Arosa, Switzerland, 1970-2016. (a) Absolute ozone from SBUV total column ozone overpass observations (red) compared to the ground-based Arosa total column ozone observations (black), with Arosa shifted to the SBUV mean for 1998-2013; (b) as for (a) with the seasonal cycle removed; (c) the monthly difference between timeseries in (b) and a 24-month Gaussian smoothing (thick line).

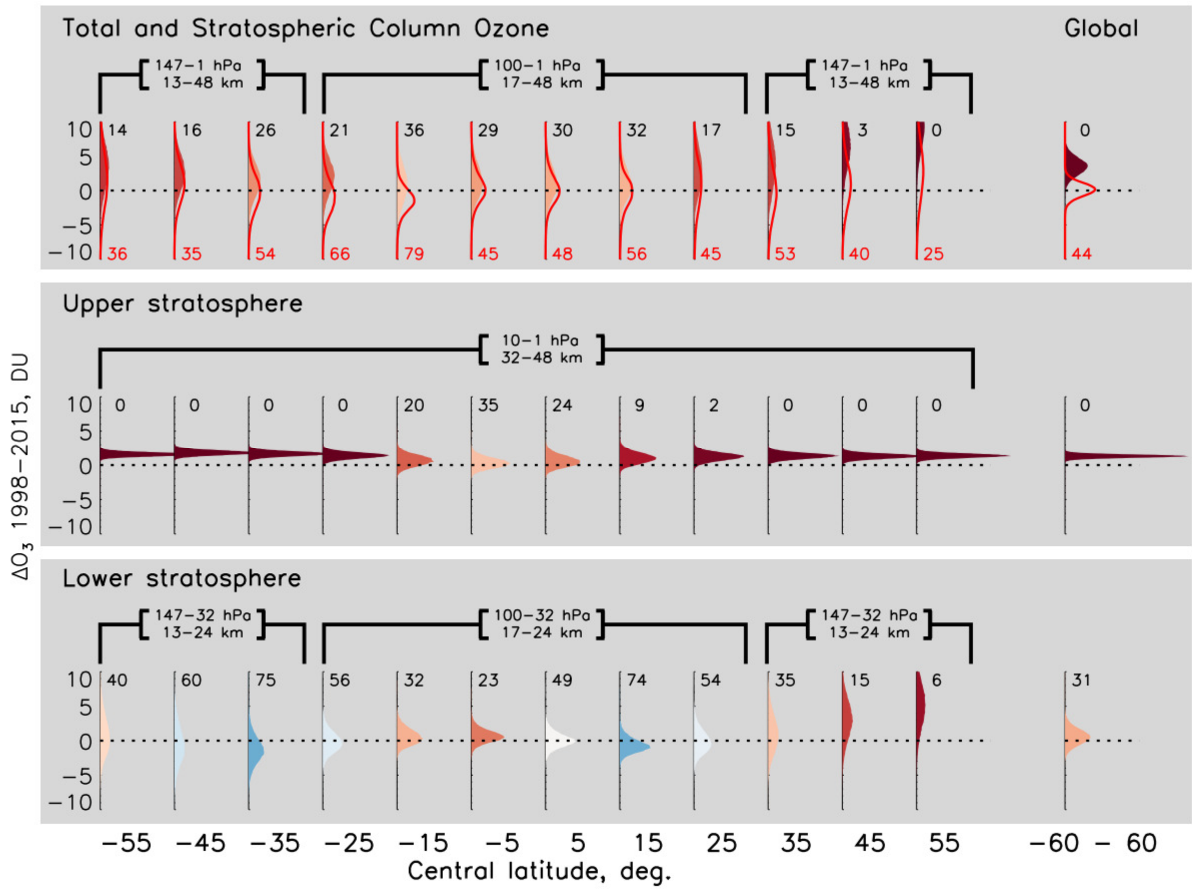

Figure S9: SOCOL-SD posterior distributions for the 1998-2015 ozone changes. See caption of Fig. 2 of the main article for details.

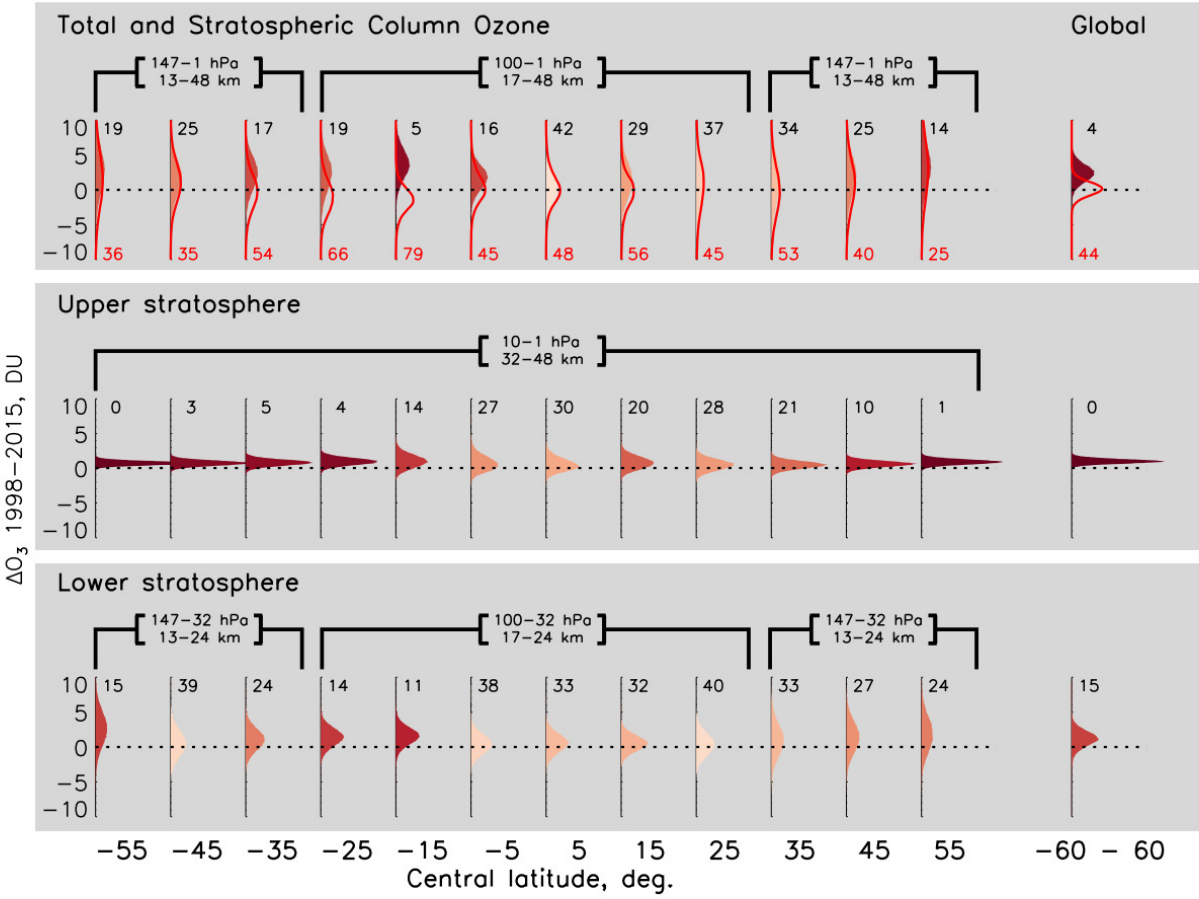

Figure S10: WACCM-SD posterior distributions for the 1998-2014 ozone changes. See caption of Fig. 2 of the main article for details.

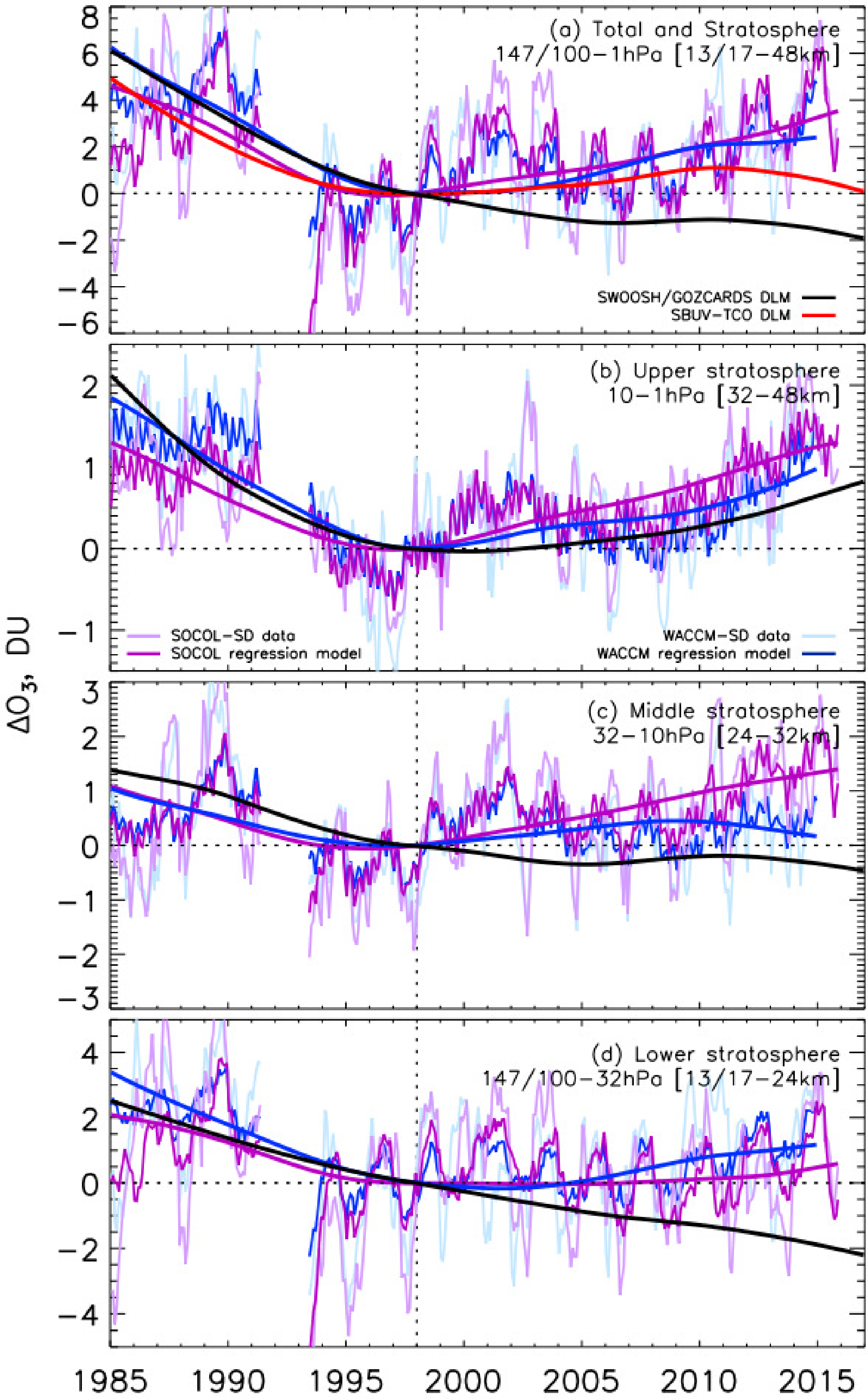

Figure S11: As for Fig. 3 of the main article, but with deseasonalised and regression model timeseries from SOCOL-SD (purple) and WACCM-SD (blue). DLM results for SBUV total column ozone and Merged-SWOOSH/GOZCARDS are retained in this plot from Fig. 3 of the main article; see Fig. 3 of the main article for more details.

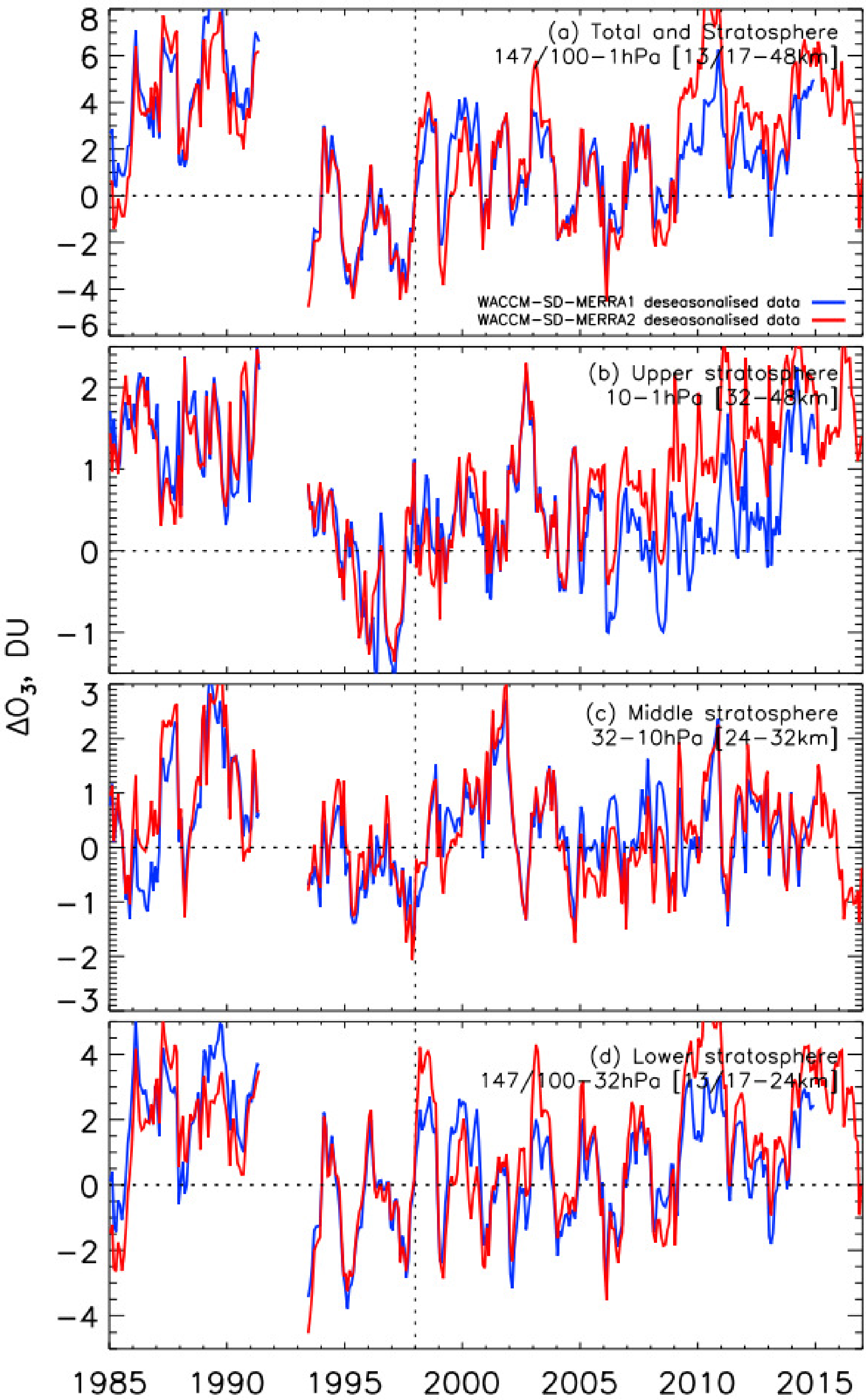

Figure S12: As for Fig. 3 of the main article and Fig. S11, but with deseasonalised model timeseries only from WACCM-SD using MERRA-1 (blue) and MERRA-2 (red).

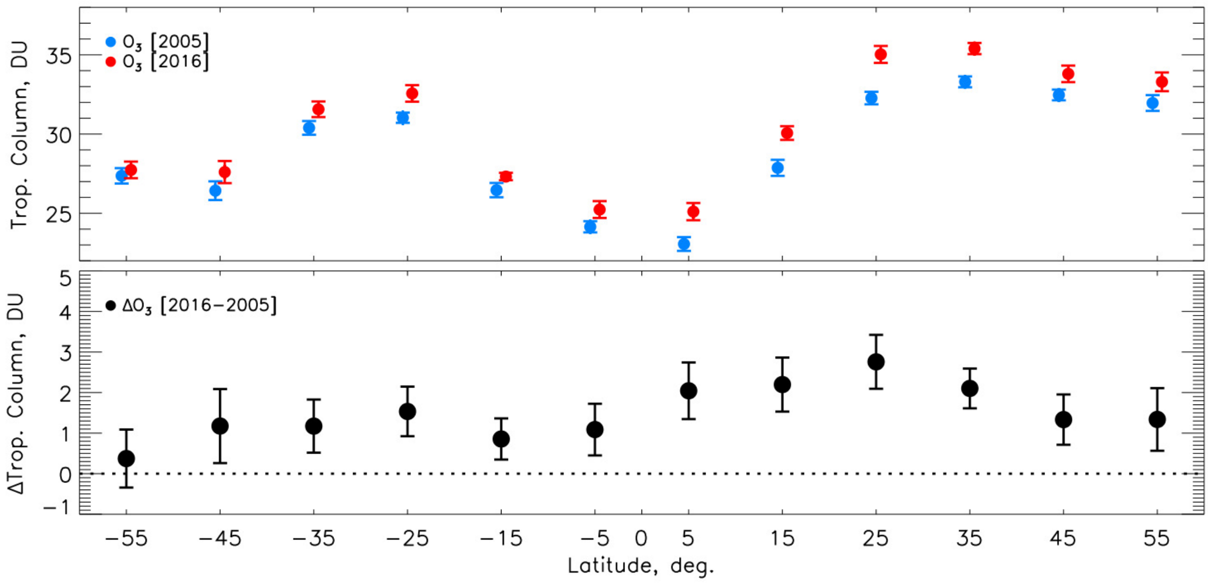

Figure S13: Mean and two standard errors of tropical column ozone change between 2005 and 2016 from OMI/MLS. The upper panel shows the absolute levels in 10º latitude bins in 2005 (blue) and 2016 (red), while the lower panel gives the difference between 2005 and 2016 with combined errors, similar to the right panel of Fig. 4 of the main article.

Supplementary references:

Ball, W. T., Alsing, J., Mortlock, D. J., Rozanov, E. V., Tummon, F., and Haigh, J. D.: Reconciling differences in stratospheric ozone composites, Atmospheric Chemistry & Physics, 17, 12 269–12 302, doi:10.5194/acp-17-12269-2017, 2017.