



Supplement of

Inconsistencies between chemistry–climate models and observed lower stratospheric ozone trends since 1998

William T. Ball et al.

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Inconsistencies between chemistry climate model and observed lower stratospheric ozone trends since 1998 (Ball et al.)

Supplementary materials

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

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SWV Stratospheric water vapour TCO Total column ozone	SST	Sea surface temperature
TCO Total column ozone	SWV	Stratospheric water vapour
	тсо	Total column ozone
WMO World Meteorological Organisation	WMO	World Meteorological Organisation

2. Observations and reanalysis datasets		
BASIC _{SG}	Bayesian integrated and consolidated ozone composite (SWOOSH + GOZCARDS)	
ERA-Interim	Interim European Centre for Medium-Range Weather reanalysis	
GOZCARDS	Global OZone Chemistry And Related trace gas Data records for the Stratosphere	
JRA-55	Japanese 55-year reanalysis	
MERRA-2	Modern-Era Retrospective analysis for Research and Applications, Version 2	
MSU4	Microwave sounding unit-4 (temperature)	
SBUV MOD	Solar-backscatter ultra-violet merged ozone data	
SWOOSH	Stratospheric Water and OzOne Satellite Homogenized dataset	

3. List of chemistry climate models (not disambiguated)

CAM3.5, CCSRNIES, CMAM, CNRM-ACM, LMDZ, MRI, Niwa-SOCOL, SOCOL/SOCOLv3, ULAQ, UMSLIMCAT, UMUKCA-METO, UMUKCA-UCAM, WACCM/WACCM-CESM

4. Sea surface temperature and Sea ice cover datasets CCSM3, CNRM-CM3, ECHAM5-MPIOM, HadGEM1, MIROC, MRI-CGCM2.3.3, OPA/LIM



Figure S1: Nino 3.4 index that represent ENSO variability and events, from observations (thick, black in each panel), and sets of the models grouped depending on if they use a specified SST across multiple models (**panels 1, 2 and 6**), for ensembles of the same model (**panels 2, 3 and 5**), or an interactive ocean (**panel 4**). All data have been standardized by subtracting the mean and dividing by the standard deviation of the data (NIWA-SOCOL is standardized post-2002 due to the discontinuity at the end of 2002 where SST data sets are changed). Observational data are from https://psl.noaa.gov/data/correlation/nina34.data.



Figure S2: Sensitivity of DLM estimated in (**top-to-bottom**) total column ozone (TCO), lower stratospheric ozone (LSO₃), stratospheric water vapour (SWV), and temperature by latitude-band (**left-toright**): SH, equatorial, NH and quasiglobal (60°S-60°N). In each plot, the left violin is without regressors, and the right is with (see section 2.2 of the main article).



Figure S3: Latitude-pressure ozone multi-model mean changes over 1998-2016. (**left**) MMM including CAM3.5 that lacks data <5 hPa; (**middle**) MMM without CAM3.5 (as in Fig. 3b, for comparison); (**right**) MMM sensitivity test, i.e. MMM without CAM3.5, CNRM-ACM, UMUKCA-METO, UMUKCA-UCAM, UMSLIMCAT. See caption of Fig. 3 and Methods for details.



Figure S4: Stratospheric 1998-2016 60°S-60°N changes in models and observations. As for Fig.2: (**a**) Total column ozone, (**b**) lower stratospheric ozone, (**c**) stratospheric water vapour, (**d**) temperature. See Fig. 2 caption for details.



Figure S5: Stratospheric 1998-2016 50°S-50°N changes in models and observations. (a) Total column ozone, (b) lower stratospheric ozone, (c) stratospheric water vapour, (d) temperature. See caption of Fig. 2 for details.



Figure S6: Total column ozone 1998-2016 changes in models and observations. See Fig. 2 caption for details.



Figure S7: Latitude-pressure ozone changes over 1998-2016. Ensemble members for five ensemble mean models from Fig. 3. See Fig. 3 caption for details.



Figure S8: Tropical (20°S-20°N) residual upwelling for 1979-2017 at (**top-to-bottom**) 67, 80 and 96 hPa. Residual upwelling for ERA-Interim (orange/red) and JRA-55 (light/dark-blue) with non-linear trends for 1979-2017 and 1998-2017; the PDFs represent the change since 1998 in each case and are the same as in Fig. 4b.



Figure S9: Effective mixing since 1998 from reanalyses. (**a**) 40°S-20°S and (**b**) 20°-40°N. The PDFs of the changes over 1998-2016 and 1998-2017 are the same as those presented in Fig. 4.



Figure S10: Latitude-pressure ozone changes in the 21st Century since 1998. (**Top row**) MRI, (**bottom**) UMUKCA-UCAM; (**left**) 1998-2016* is the ensemble member (e1) from Figs. S7 and 3, respectively; (**right**) 1998-2016, -2032, -2067, and -2099 using change estimated from non-linear trend calculated using whole period to 2099. See Fig. 3 caption for details.