Supporting Information for "Tropospheric expansion under global warming reduces tropical lower stratospheric ozone"

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1. Figures S1 to S5

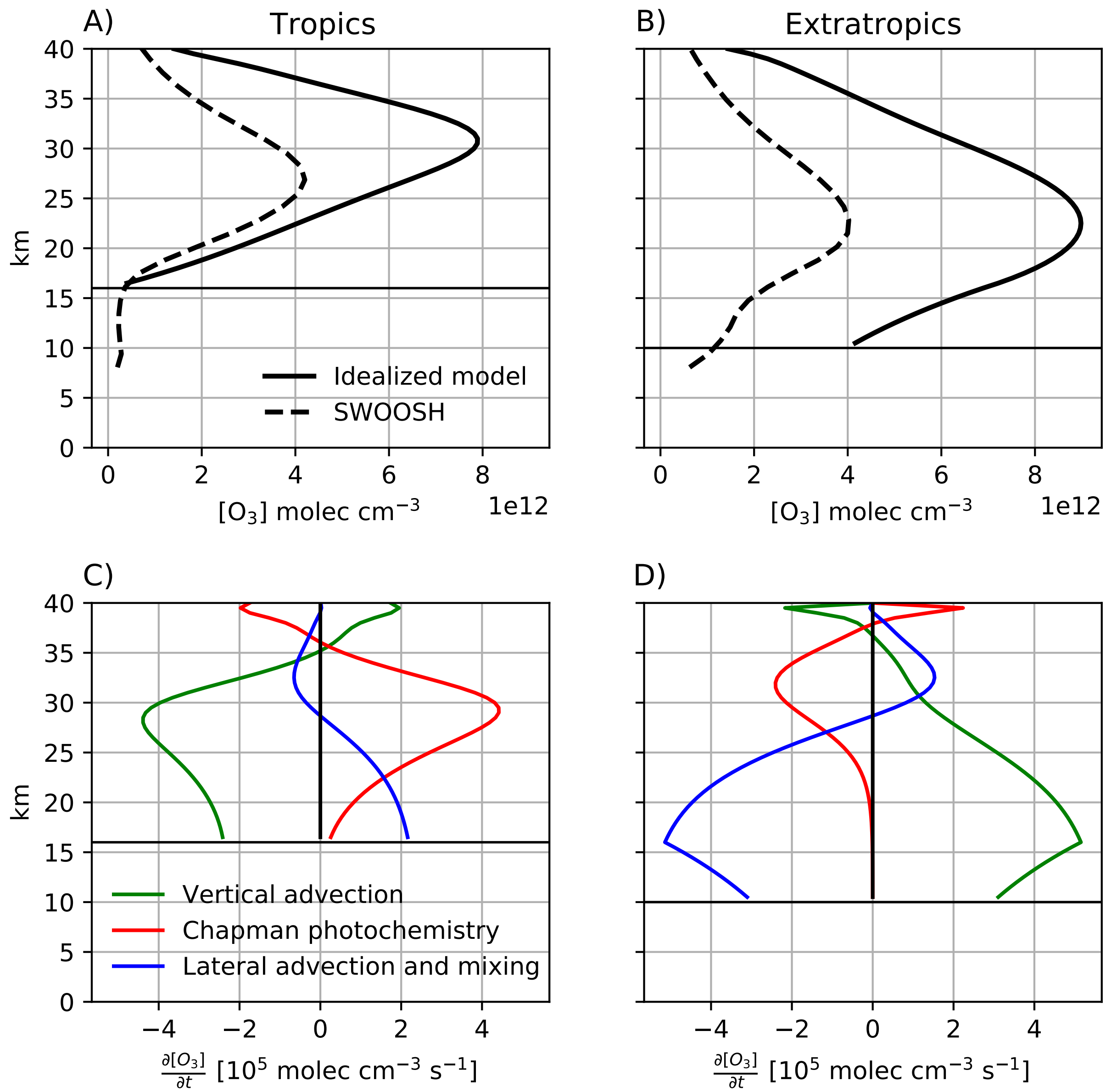

Figure S1. Basic state of the idealized model compared to ozone observations from SWOOSH. (Top row) Tropical (A) and extratropical (B) ozone profiles in idealized model (solid) compared to SWOOSH (dashed). (Bottom row) Tropical (C) and extratropical (D) profiles of ozone tendencies from idealized model.

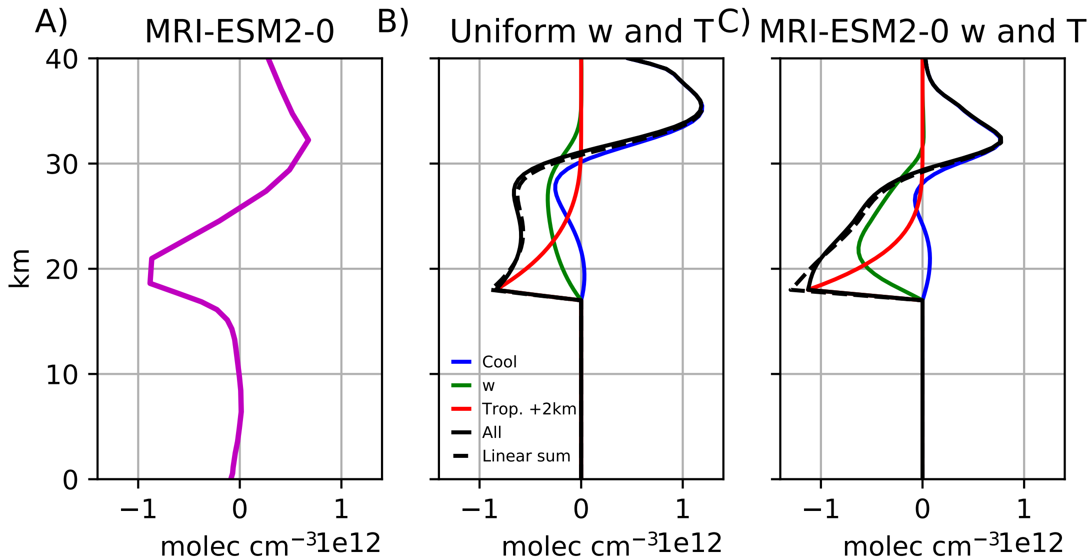

Figure S2. As in Figure 3 in the main body, except the idealized model is run with prescribed temperature and residual upwelling from MRI-ESM2-0 for the basic state and perturbations. (A) Tropical ozone change under quadrupling of CO2 in MRI-ESM2-0. (B) Panel 3E from the main body of the paper, using a temperature background of 240 K, stratospheric cooling perturbation of -10 K, upwelling background of 0.3 mm s^{-1} and strengthening upwelling of 0.05 mm s^{-1}. (C) Idealized model with background state and quadrupled-CO2 perturbations taken from output of MRI-ESM2-0 in piControl and final 100 years of abrupt-4xCO2 experiments. The similarity in the magnitude and vertical structure of ozone changes comparing panels B and C justifies our simplified approach in the main body of the paper.

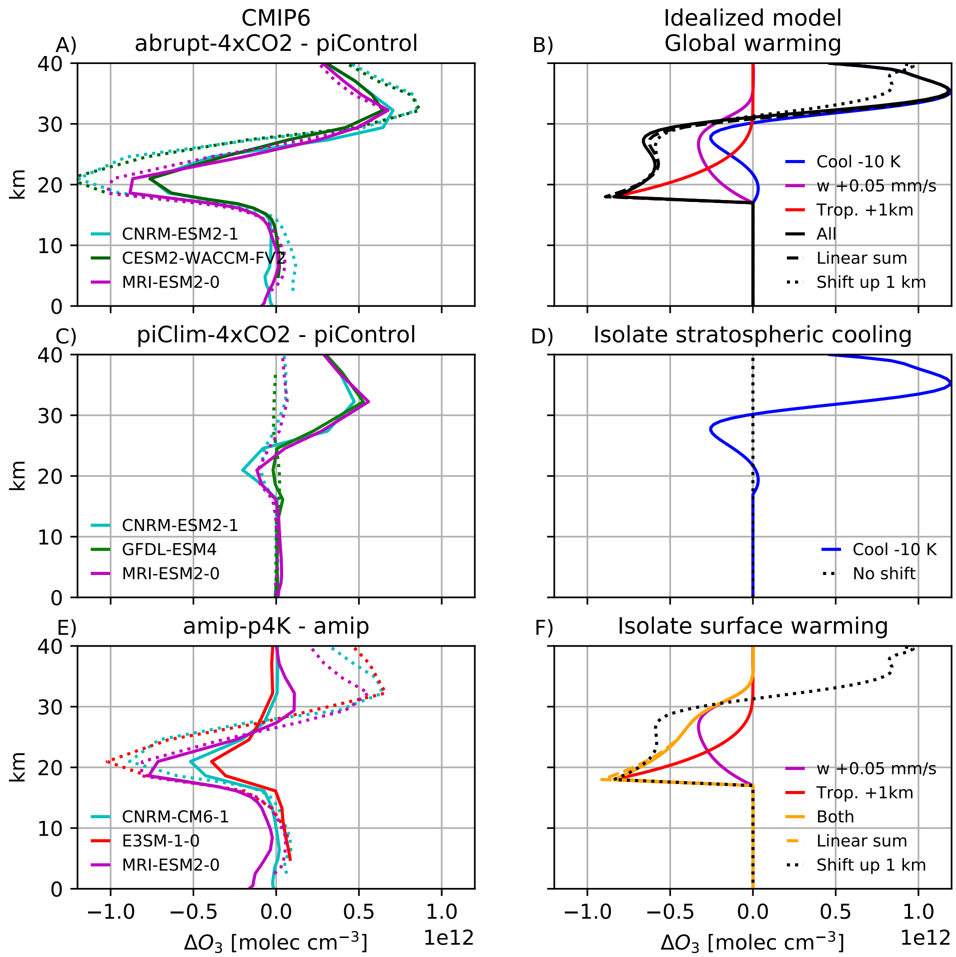

Figure S3. As in Figure 3 of the main paper, but now including the change in ozone that would result from vertical shifts of the ozone profile. For CMIP6 models, the vertical shifts are calculated based on the lapse-rate tropopause calculated for the tropically-averaged temperature interpolated in the vertical with a cubic spline. In the idealized model, the vertical shift is calculated according to the prescribed 1 km shift in the tropopause. Note that the ozone response to a quadrupling of CO2 resembles a vertical shift (panel A). This resemblance results from a coincidence: the increases aloft arise from stratospheric cooling independent of tropospheric expansion (panel C), whereas the decreases below are driven by surface warming (panel E). The ozone response to tropospheric expansion in panel E does not resemble a vertical shift in the upper stratosphere, where dynamically-induced ozone anomalies are erased by photochemical equilibrium.

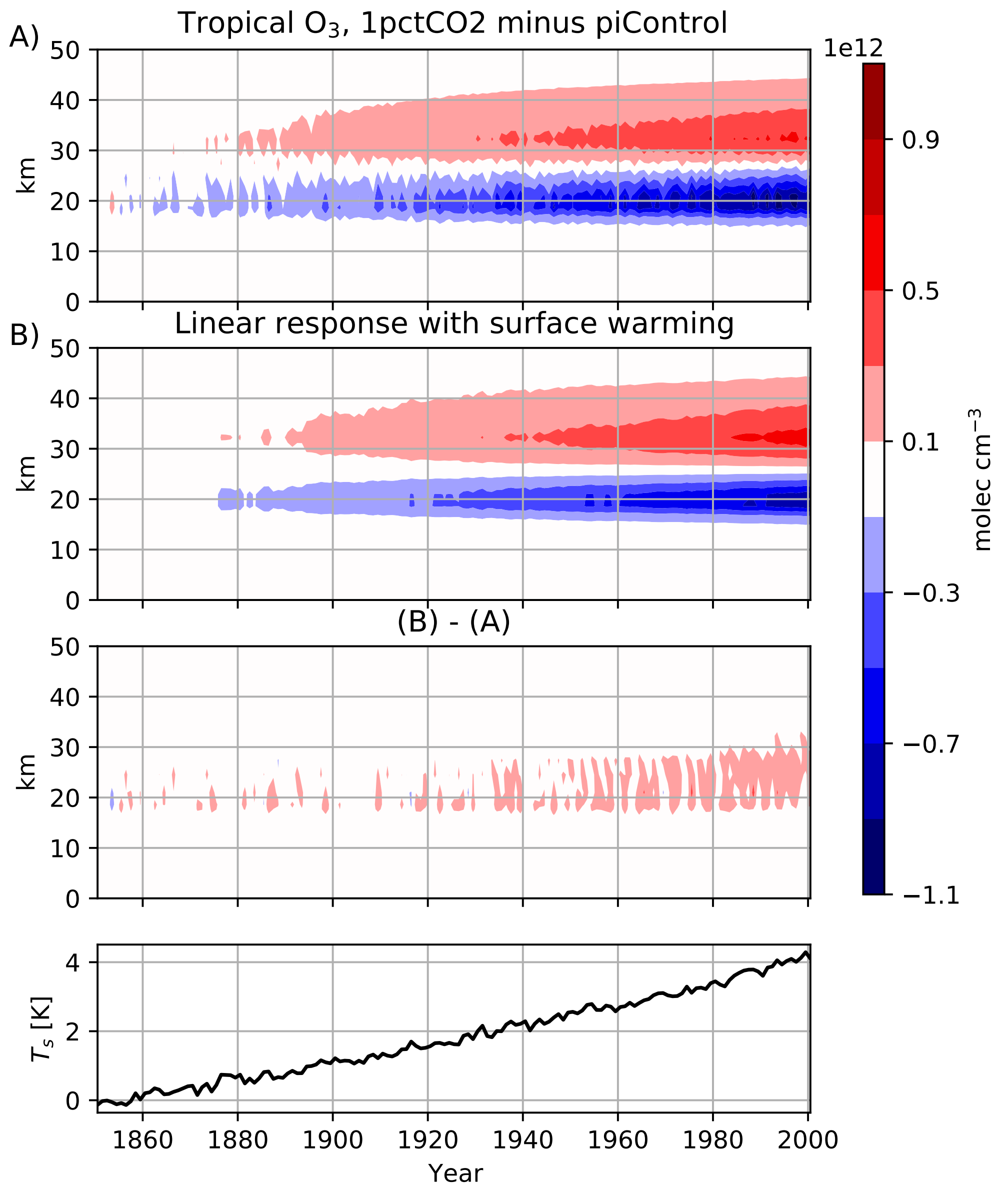

Figure S4. (A) Annually-averaged tropical ozone in 1pctCO2 experiment minus piControl in MRI-ESM2-0. (B) Linear response of tropical O_3 with surface warming calculated by rescaling ozone response under abrupt-4xCO2 by $T_s(t)|_{\text{1pctCO2}}/T_s|_{\text{abrupt-4xCO2}}$. (C) Panel B minus panel A, i.e. nonlinearity in ozone response to surface warming. (D) Global average surface temperature anomaly in 1pctCO2 experiment compared to piControl.

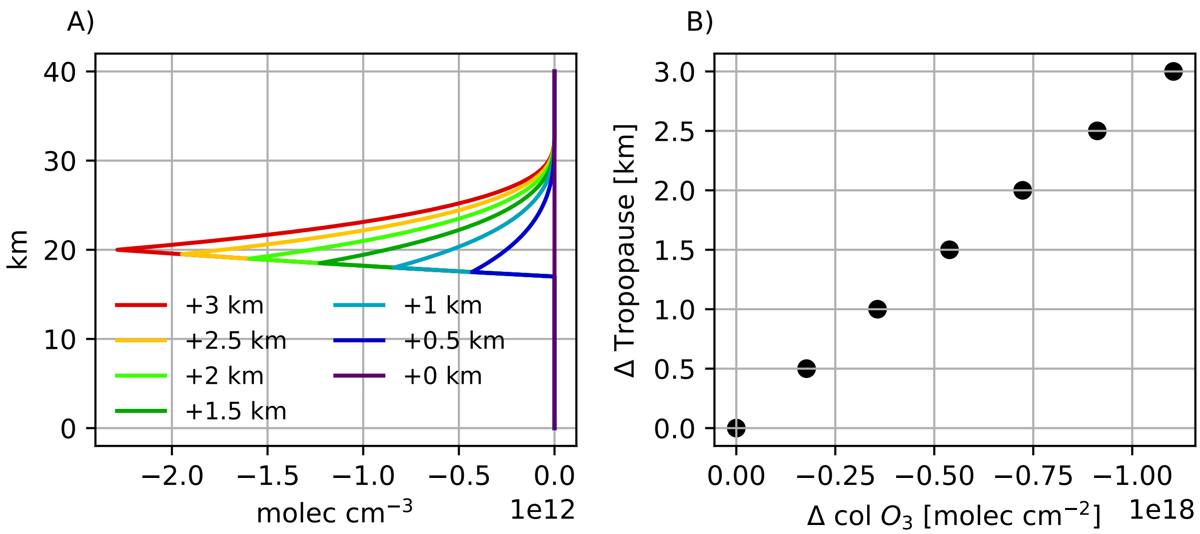

Figure S5. (A) Ozone response as a function of altitude to varying magnitudes of tropospheric expansion in idealized model. (B) Column ozone response. The ozone response to tropospheric expansion is strongly linear, except locally at levels converted from stratospheric to tropospheric.