

# Supporting Information for “Attribution of stratospheric and tropospheric ozone changes between 1850 and 2014 in CMIP6 models”

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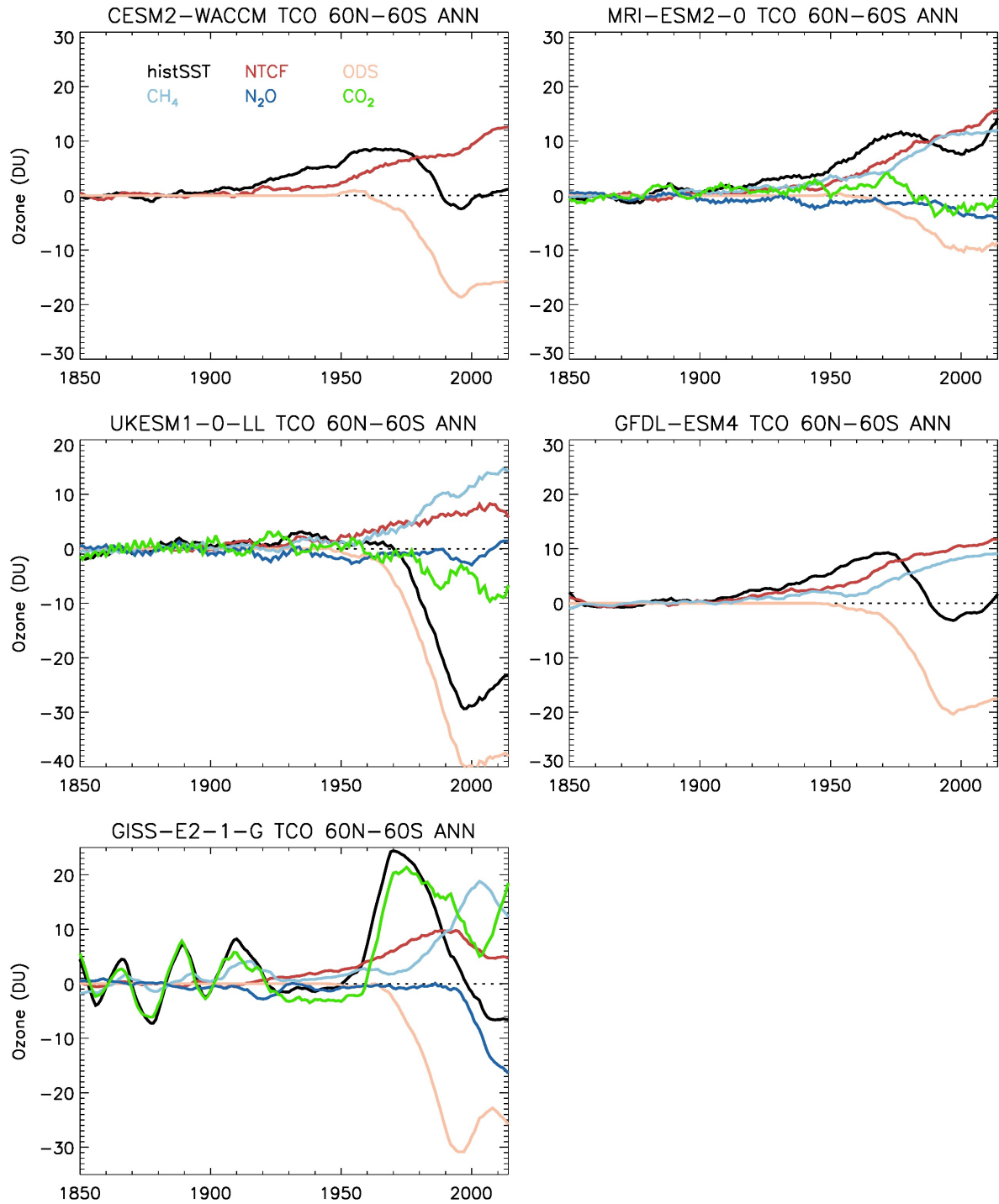
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## References

- Liu, G., Liu, J., Tarasick, D. W., Fioletov, V. E., Jin, J. J., Moeini, O., ... Osman, M. (2013). A global tropospheric ozone climatology from trajectory-mapped ozone soundings. *Atmospheric Chemistry and Physics*, *13*(21), 10659–10675. doi: 10.5194/acp-13-10659-2013
- Liu, J., Tarasick, D. W., Fioletov, V. E., McLinden, C., Zhao, T., Gong, S., ... Moeini, O. (2013). A global ozone climatology from ozone soundings via trajectory mapping: a stratospheric perspective. *Atmospheric Chemistry and Physics*, *13*(22), 11441–11464. doi: 10.5194/acp-13-11441-2013
- Oltmans, S., Lefohn, A., Shadwick, D., Harris, J., Scheel, H., Galbally, I., ... Kawasato, T. (2013). Recent tropospheric ozone changes – a pattern dominated by slow or no growth. *Atmospheric Environment*, *67*, 331-351. doi: 10.1016/j.atmosenv.2012.10.057
- Tarasick, D., Carey-Smith, T., Hocking, W., Moeini, O., He, H., Liu, J., ... Merrill, J. (2019). Quantifying stratosphere-troposphere transport of ozone using balloon-borne ozonesondes, radar windprofilers and trajectory models. *Atmospheric Environment*, *198*, 496-509. doi: 10.1016/j.atmosenv.2018.10.040
- Ziemke, J. R., Chandra, S., Duncan, B. N., Froidevaux, L., Bhartia, P. K., Levelt, P. F., & Waters, J. W. (2006). Tropospheric ozone determined from Aura OMI and MLS: Evaluation of measurements and comparison with the Global Modeling Initiative’s Chemical Transport Model. *Journal of Geophysical Research: Atmospheres*, *111*(D19). doi: 10.1029/2006JD007089

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**Figure S1.** Near-global (60N-60S) total column ozone changes between 1850 and 2014, and the contributions from ODSs, the near-term climate forcers (NTCFs), methane, N<sub>2</sub>O, and CO<sub>2</sub> in individual models.

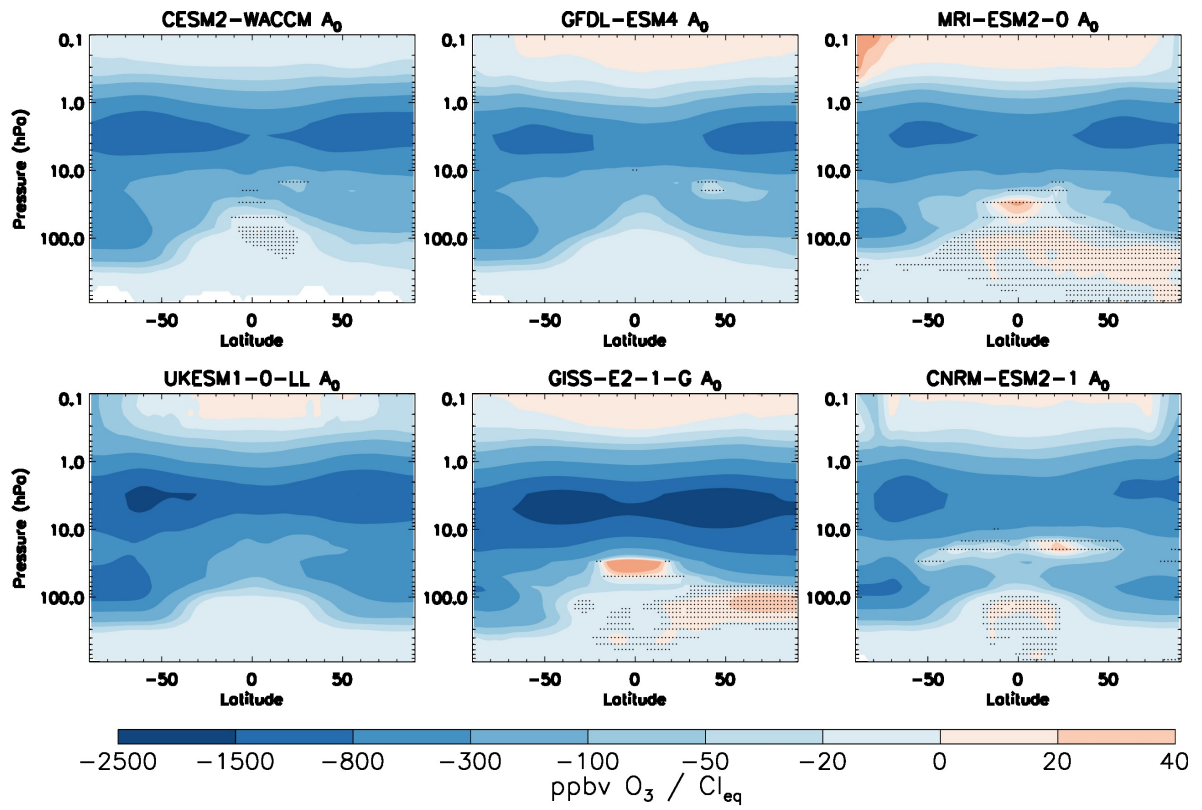
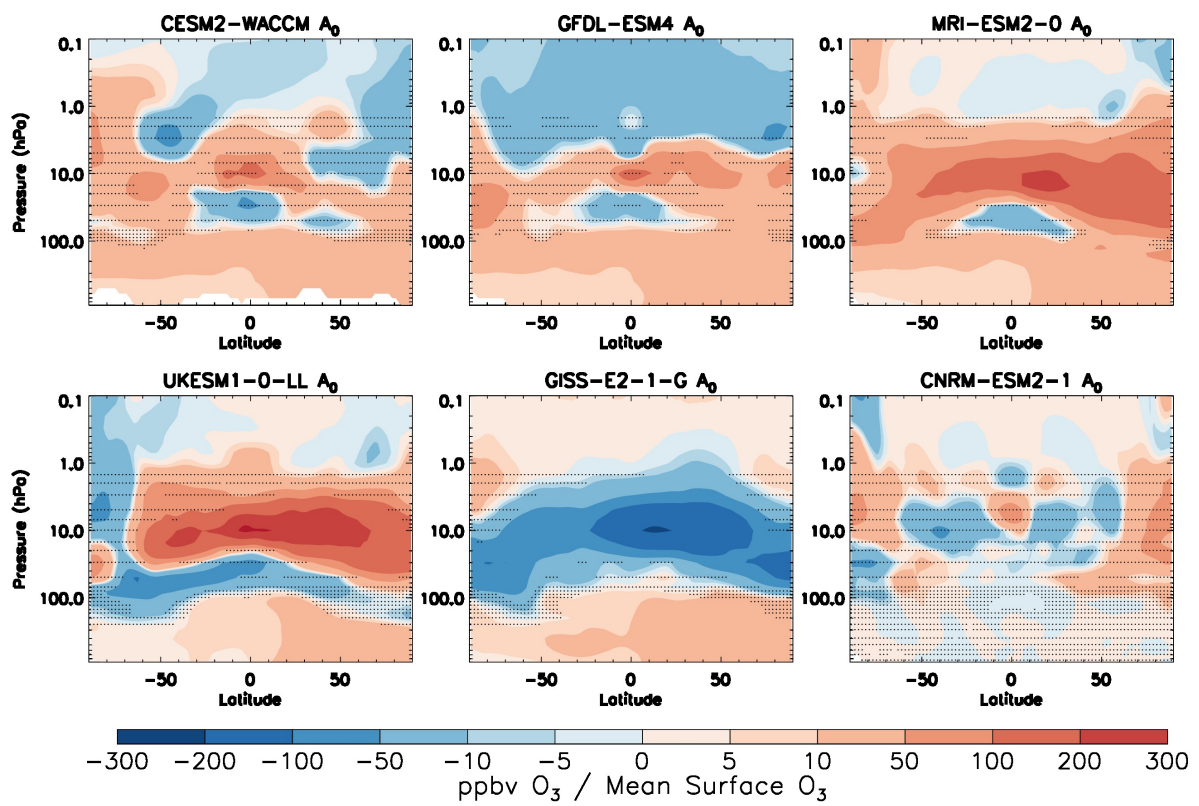


Figure S2. Response of ozone changes (ppbv) to changes in  $Cl_{eq}$  (normalised to the range of 0 to 1) between 1850 and 2014.



**Figure S3.** Response of ozone changes (ppbv) to changes in ozone precursors (expressed as mean surface ozone changes normalised to the range of 0 to 1) between 1850 and 2014.

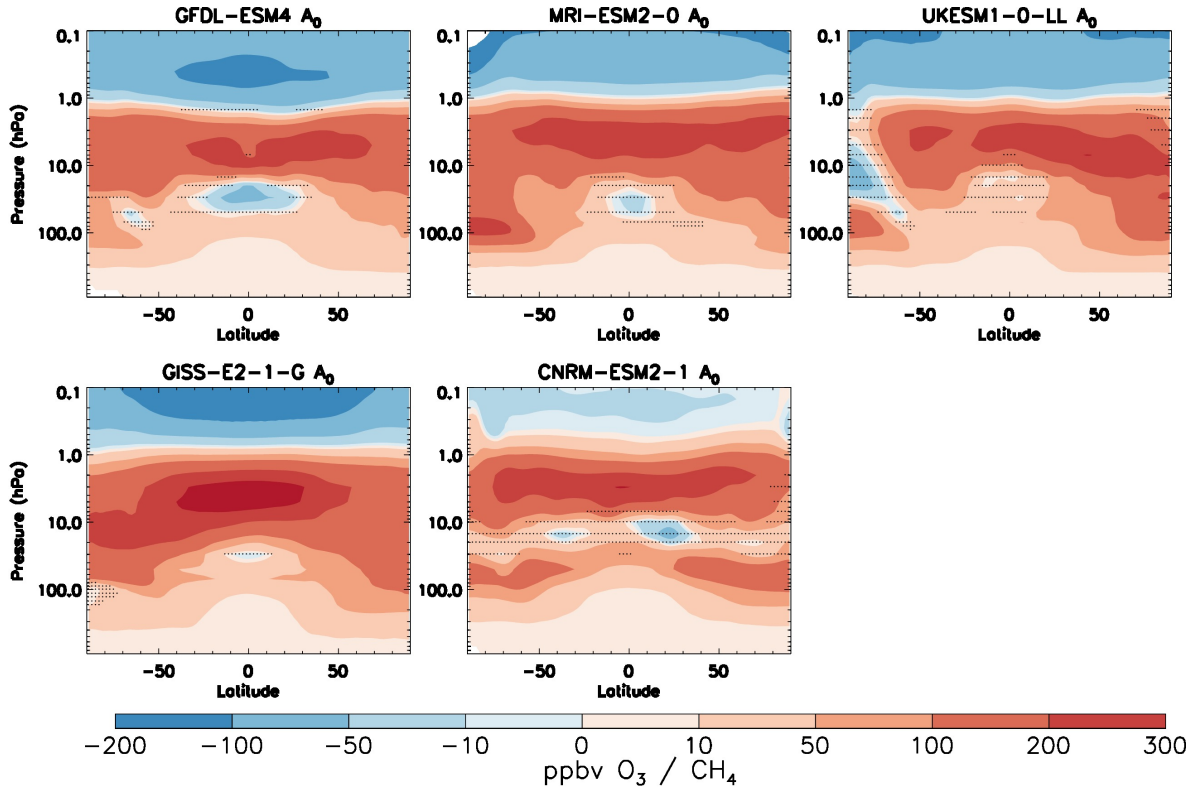
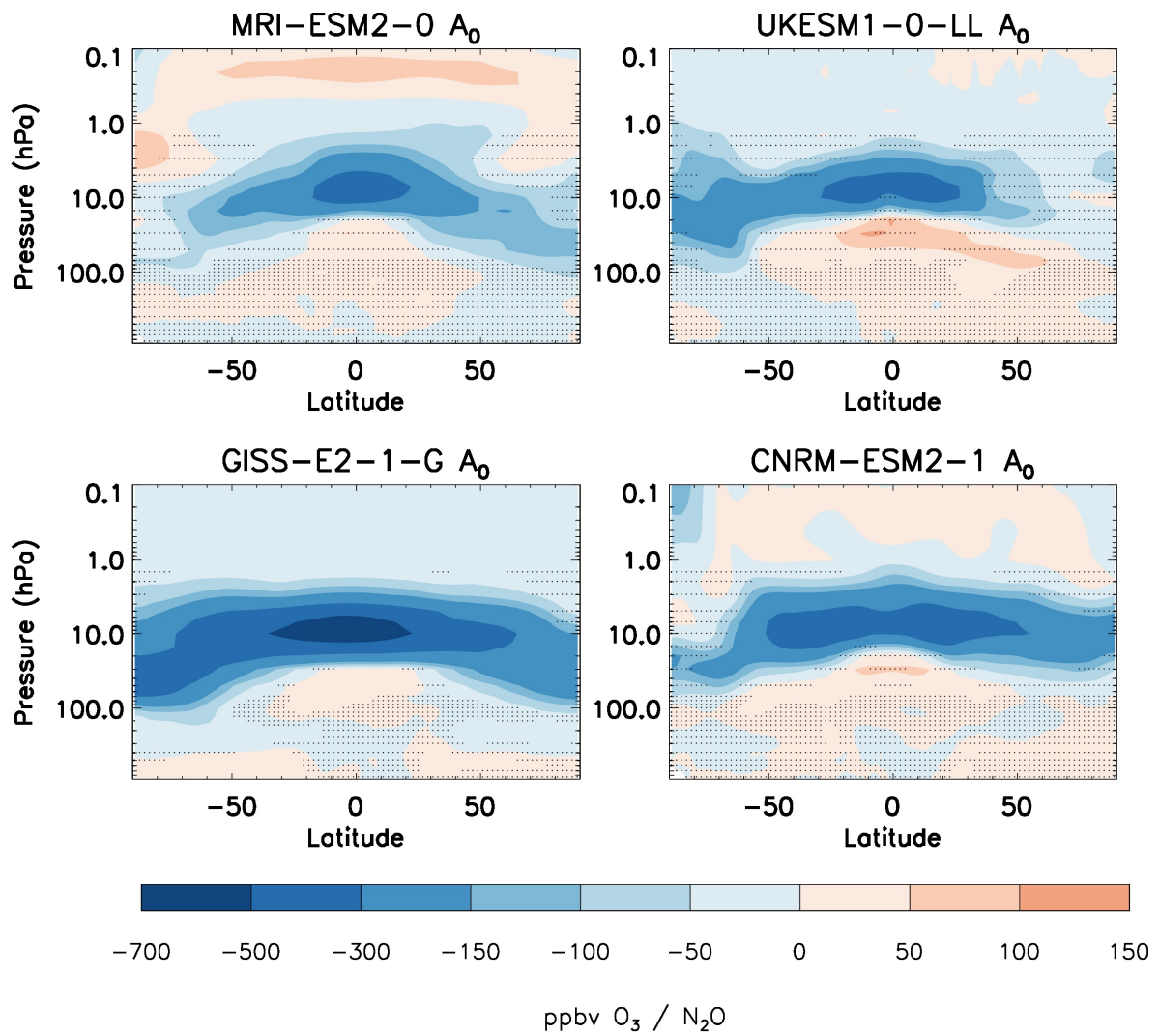
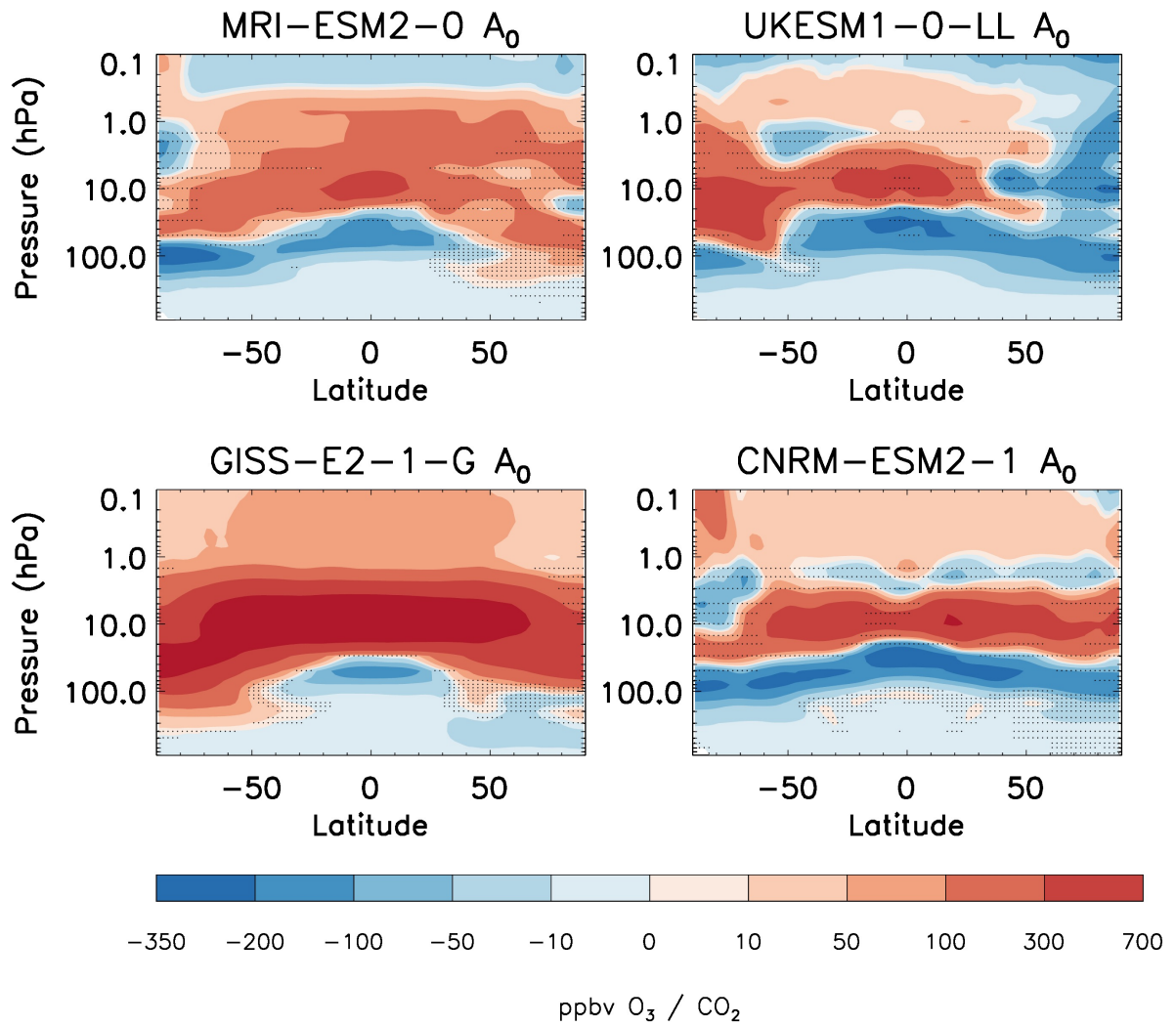


Figure S4. Response of ozone changes (ppbv) to changes in methane (normalised to the range of 0 to 1) between 1850 and 2014.

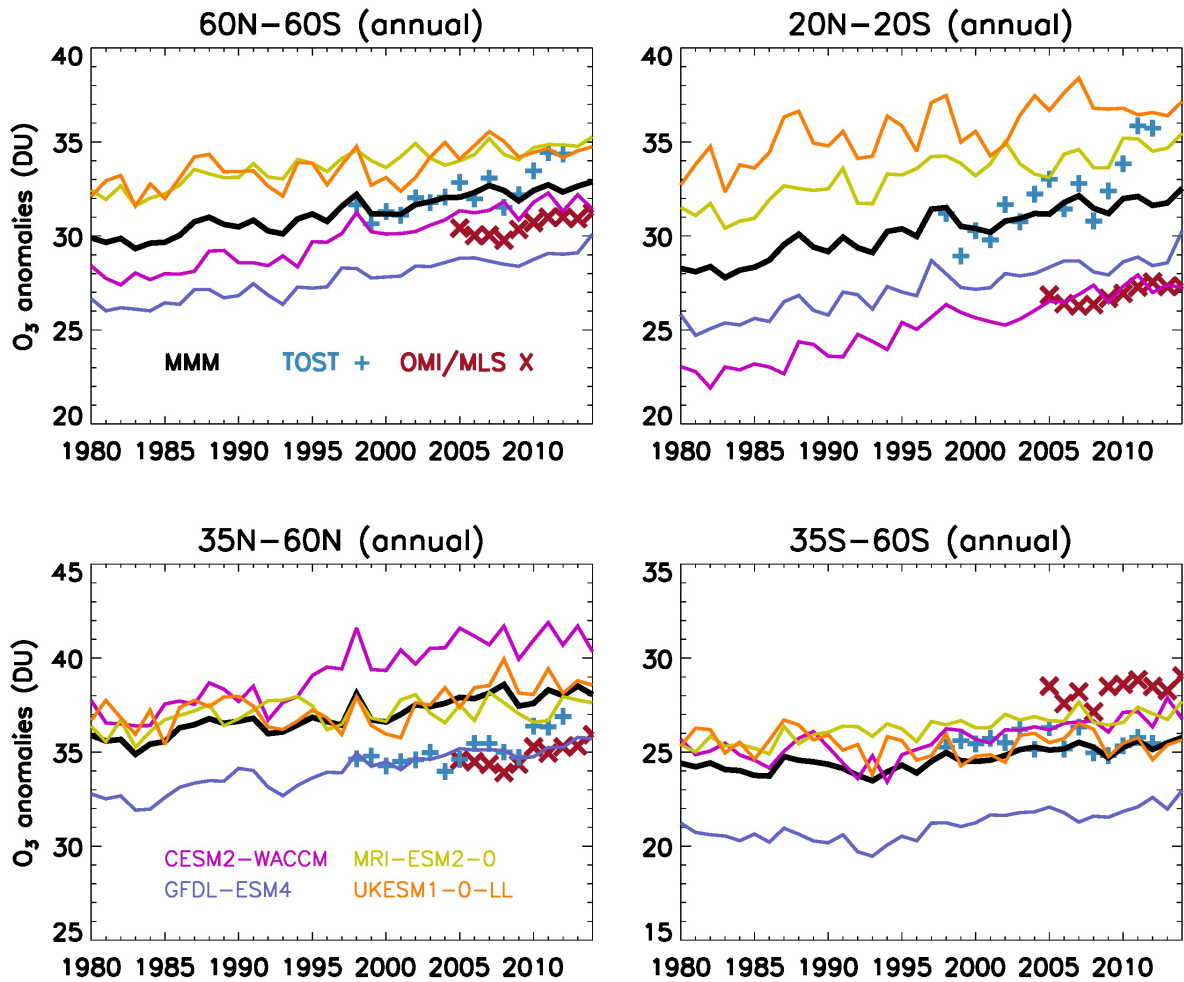


**Figure S5.** Response of ozone changes (ppbv) to changes in  $N_2O$  (normalised to the range of 0 to 1) between 1850 and 2014.



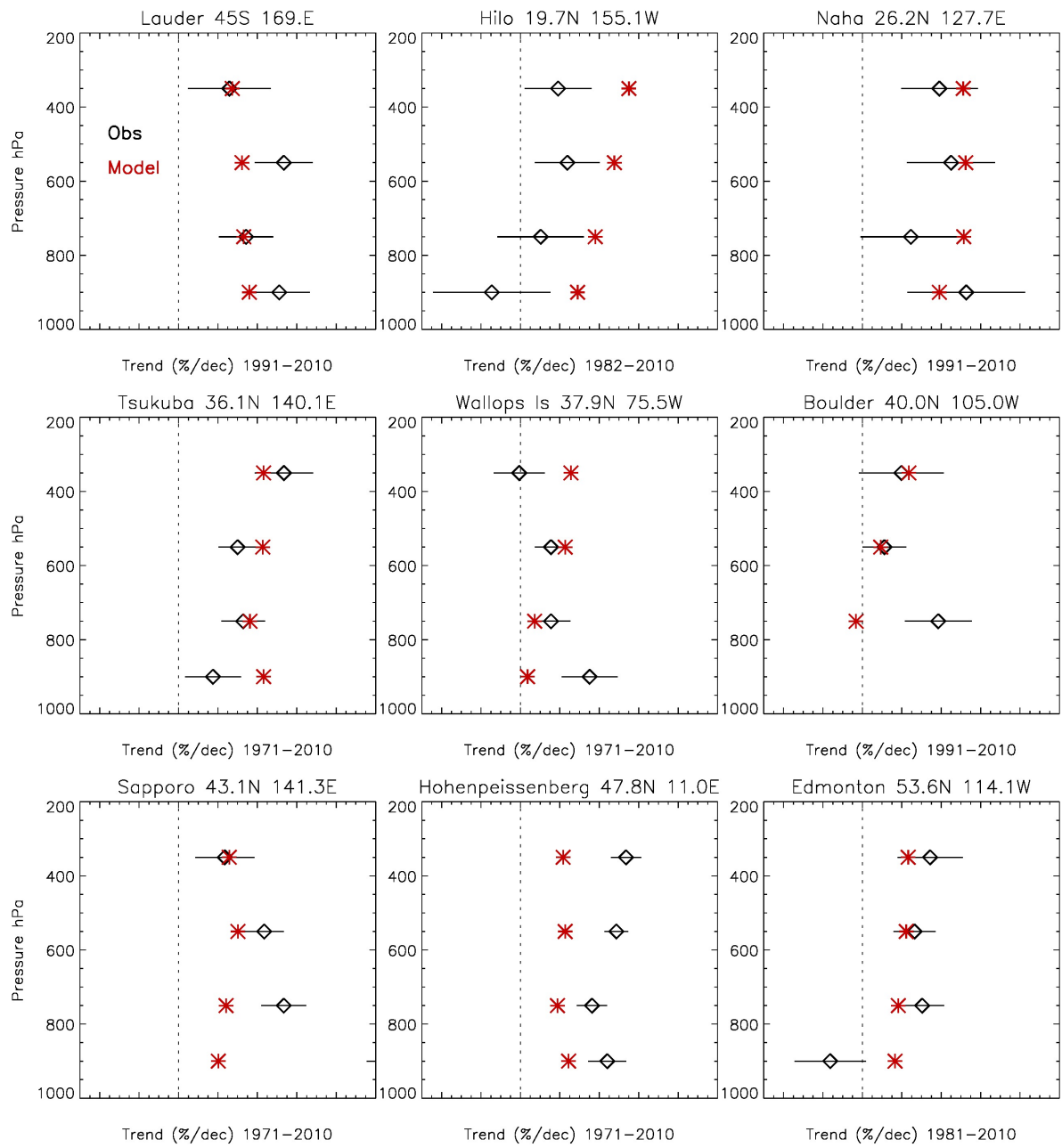
**Figure S6.** Response of ozone changes (ppbv) to changes in CO<sub>2</sub> (normalised to the range of 0 to 1) between 1850 and 2014.





**Figure S7.** Observed (symbols) and modelled tropospheric ozone columns for individual models (coloured lines) and the MMM (thick black line). Observations are the TOST (“+”) (G. Liu et al., 2013; J. Liu et al., 2013; Tarasick et al., 2019)(1998-2012) and OMI/MLS (“x”) (Ziemke et al., 2006) (2005-2014) tropospheric ozone columns respectively.





**Figure S8.** Modelled and the observed ozone trends. Observed trends from long-term ozone sonde observations are available in Oltmans et al. (2013).

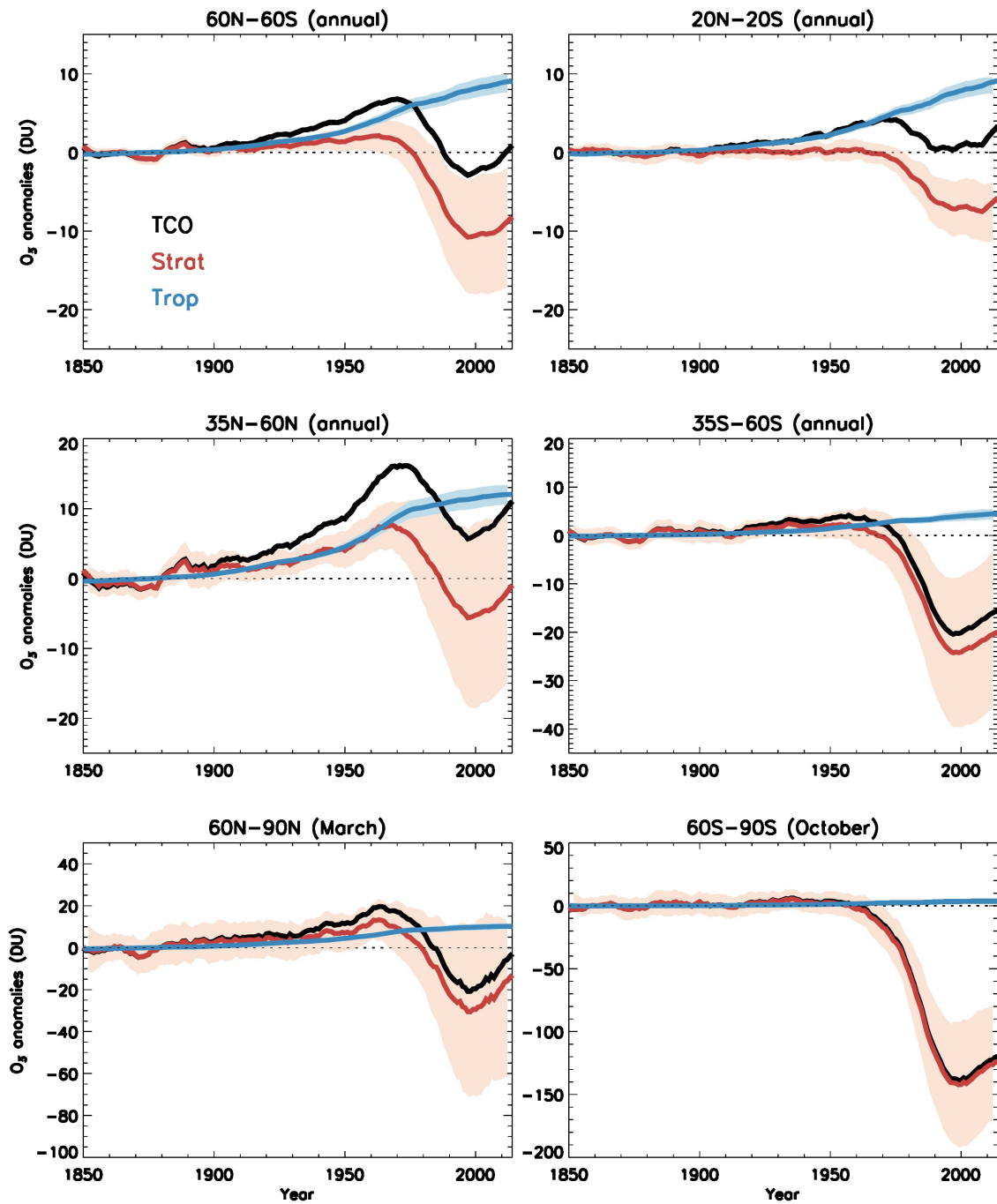
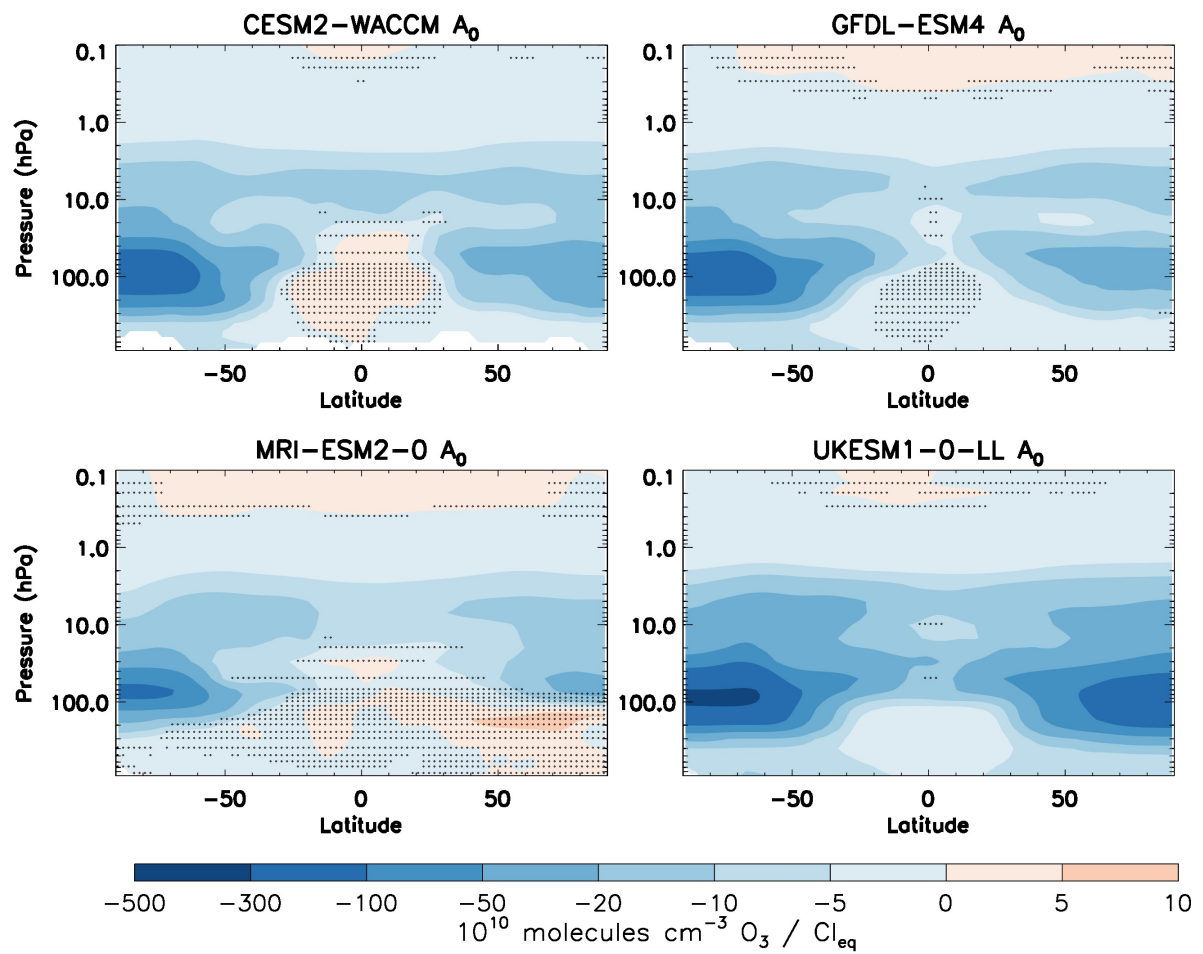
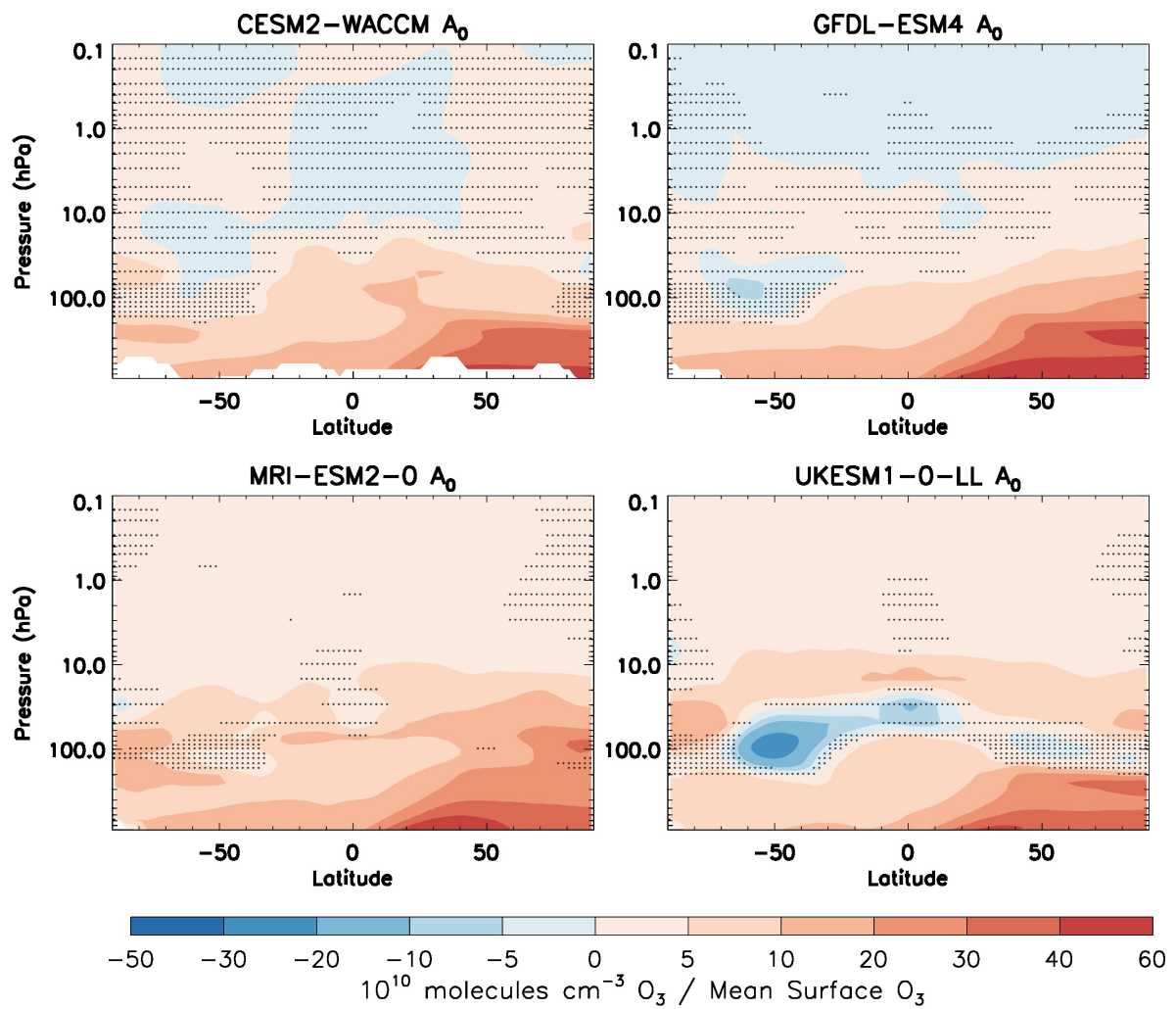


Figure S9. Same as Figure 10 in the main paper but results are from the coupled *historical* simulation. Data are available from the ESGF archive (<https://esgf-node.llnl.gov/search/cmip6/>).



**Figure S10.** Response of ozone changes ( $10^{10}$  molecules  $\text{cm}^{-3}$ ) to changes in  $\text{Cl}_{eq}$  (normalised to the range of 0 to 1) between 1950 and 2014 calculated from the coupled *historical* and *hist-1950HC* simulations. Data are available from the ESGF archive (<https://esgf-node.llnl.gov/search/cmip6/>).



**Figure S11.** Response of ozone changes ( $10^{10}$  molecules  $\text{cm}^{-3}$ ) to changes in NTCFs (normalised to the range of 0 to 1) between 1850 and 2014 calculated from the coupled *historical* and *hist-piNTCF* simulations. Data are available from the ESGF archive (<https://esgf-node.llnl.gov/search/cmip6/>).

**Table S1.** Ozone trends (MMM)  $\pm 2\sigma$  error in *histSST* and due to forcings over 1979-1999 (35N-60N). Units are in %/decade.

Pressure	histSST	ODSs	NTCFs	GHGs	Methane	LLGHGs
1 hPa	<b>-3.53±1.21</b>	<b>-3.32±1.44</b>	-0.12±0.43	-0.08±0.81	0.58±0.62	-0.54±1.13
2 hPa	<b>-5.48±1.24</b>	<b>-6.08±1.52</b>	0.03±0.50	0.57±0.80	<b>1.13±0.51</b>	-0.66±0.94
3 hPa	<b>-5.21±1.04</b>	<b>-5.92±1.19</b>	0.22±0.72	0.50±0.99	<b>0.99±0.66</b>	-0.51±1.56
5 hPa	<b>-3.59±0.88</b>	<b>-3.93±0.95</b>	0.44±0.69	-0.11±0.92	<b>0.82±0.68</b>	-0.90±1.49
7 hPa	<b>-2.46±0.78</b>	<b>-2.50±0.82</b>	0.46±0.62	-0.42±0.83	<b>0.66±0.65</b>	-1.11±1.19
10 hPa	<b>-1.43±0.82</b>	<b>-1.30±0.79</b>	0.43±0.78	-0.56±0.82	0.58±0.66	<b>-1.14±1.14</b>
15 hPa	<b>-0.90±0.90</b>	-0.50±0.89	0.47±0.92	-0.86±1.22	<b>0.58±0.52</b>	<b>-1.37±1.27</b>
20 hPa	-0.98±1.04	-0.44±0.97	0.51±0.85	-1.05±1.50	<b>0.53±0.45</b>	<b>-1.51±1.32</b>
30 hPa	<b>-1.92±1.02</b>	<b>-1.48±1.05</b>	0.08±0.59	-0.53±1.08	0.36±0.42	-1.01±1.13
50 hPa	<b>-3.19±2.02</b>	<b>-2.87±2.07</b>	-0.38±1.10	0.06±1.37	0.45±0.75	-0.21±1.94
70 hPa	<b>-3.49±2.96</b>	<b>-3.06±2.74</b>	0.16±1.42	-0.59±1.74	0.97±1.24	-1.39±2.68
80 hPa	<b>-3.50±3.38</b>	<b>-3.06±3.00</b>	0.36±1.60	-0.80±1.87	1.27±1.33	-2.01±2.91
90 hPa	-3.44±3.64	-3.08±3.09	0.44±1.86	-0.80±2.15	<b>1.54±1.49</b>	-2.40±3.37
100 hPa	-3.38±3.89	<b>-3.15±3.14</b>	0.48±2.20	-0.70±2.57	1.73±1.78	-2.60±4.19
115 hPa	-3.34±4.20	<b>-3.35±3.30</b>	0.58±2.54	-0.58±3.09	1.76±2.29	-2.63±5.25
130 hPa	-3.34±4.58	<b>-3.64±3.51</b>	0.66±2.74	-0.36±3.50	1.65±2.91	-2.41±6.13
150 hPa	-3.19±4.96	<b>-3.96±3.61</b>	0.83±2.89	-0.06±3.84	1.65±3.47	-2.21±7.09
170 hPa	-2.89±5.07	<b>-4.08±3.53</b>	1.06±2.96	0.12±3.97	1.77±3.59	-2.30±7.56
200 hPa	-2.23±4.86	<b>-4.09±3.57</b>	1.40±2.79	0.46±3.58	1.98±3.16	-2.18±6.87
250 hPa	-0.55±3.84	<b>-3.74±3.35</b>	1.83±2.25	1.36±2.25	<b>2.00±1.94</b>	-1.07±4.09
300 hPa	1.18±2.80	<b>-2.93±2.63</b>	<b>2.35±1.78</b>	<b>1.76±1.44</b>	<b>2.03±1.20</b>	-0.51±2.36
400 hPa	<b>2.56±1.98</b>	<b>-1.80±1.60</b>	<b>2.81±1.36</b>	<b>1.56±1.00</b>	<b>2.04±0.87</b>	-0.75±1.53
500 hPa	<b>2.54±1.74</b>	<b>-1.54±1.32</b>	<b>2.70±1.29</b>	<b>1.38±0.95</b>	<b>1.98±0.76</b>	-0.87±1.38
600 hPa	<b>2.14±1.51</b>	<b>-1.48±1.20</b>	<b>2.42±1.26</b>	<b>1.20±0.89</b>	<b>1.95±0.67</b>	-0.95±1.28
700 hPa	<b>1.83±1.42</b>	<b>-1.36±1.11</b>	<b>2.16±1.28</b>	<b>1.03±0.82</b>	<b>1.93±0.60</b>	-1.07±1.17
850 hPa	1.22±1.29	<b>-1.14±1.12</b>	<b>1.86±1.60</b>	0.46±0.75	<b>1.88±0.50</b>	<b>-1.42±0.96</b>
925 hPa	1.30±1.42	-0.95±1.04	<b>2.00±1.74</b>	0.25±0.79	<b>1.94±0.50</b>	<b>-1.69±0.94</b>
1000 hPa	0.98±1.20	-0.63±1.47	2.00±2.29	-0.39±0.91	<b>2.09±0.65</b>	<b>-2.48±1.31</b>

**Table S2.** Ozone trends (MMM)  $\pm 2\sigma$  error in *histSST* and due to forcings over 1979-1999 (20N-20S). Units are in %/decade.

Pressure	histSST	ODSs	NTCFs	GHGs	Methane	LLGHGs
1 hPa	<b>-1.92±0.71</b>	<b>-1.88±0.72</b>	0.01±0.42	-0.05±0.43	0.54±0.62	-0.63±0.84
2 hPa	<b>-3.49±1.07</b>	<b>-3.76±1.24</b>	0.01±0.46	0.26±0.70	<b>1.21±0.65</b>	-0.81±0.92
3 hPa	<b>-3.77±0.97</b>	<b>-3.95±1.21</b>	0.23±0.52	-0.05±0.88	<b>1.19±0.68</b>	<b>-1.09±1.01</b>
5 hPa	<b>-2.62±0.69</b>	<b>-2.47±0.93</b>	0.54±0.58	-0.70±0.75	<b>0.82±0.72</b>	<b>-1.28±0.95</b>
7 hPa	<b>-1.66±0.90</b>	<b>-1.44±1.26</b>	0.53±0.70	-0.75±1.20	0.63±0.88	-0.97±1.51
10 hPa	-0.99±1.05	-0.67±1.28	0.13±0.95	-0.45±1.63	0.19±0.76	-0.16±1.74
15 hPa	<b>-0.86±0.74</b>	-0.43±0.67	0.22±0.61	-0.65±1.10	-0.04±0.39	-0.55±1.24
20 hPa	<b>-0.87±0.66</b>	-0.64±0.80	0.32±0.63	-0.55±0.93	0.09±0.36	-0.74±0.88
30 hPa	-1.02±1.48	-0.86±0.90	0.06±1.23	-0.23±1.29	0.38±0.80	-0.65±1.62
50 hPa	-1.32±2.20	<b>-1.55±1.44</b>	-0.16±1.56	0.39±1.77	0.79±1.25	-0.16±2.56
70 hPa	-1.05±2.82	-2.49±3.27	-0.27±1.84	1.71±3.22	1.50±2.73	0.69±5.96
80 hPa	-0.54±2.95	-2.99±4.21	0.30±2.07	2.15±4.06	1.29±2.83	1.49±7.03
90 hPa	0.46±2.96	-3.20±4.68	0.89±2.10	2.77±4.43	1.14±2.53	2.06±7.32
100 hPa	1.85±2.82	-3.13±4.63	1.80±2.21	3.18±4.49	1.10±2.09	2.55±6.85
115 hPa	<b>3.43±2.71</b>	-2.71±3.55	<b>2.86±2.18</b>	3.27±3.78	1.33±1.58	2.21±5.06
130 hPa	<b>4.69±2.60</b>	-2.14±2.40	<b>3.69±2.08</b>	<b>3.14±2.88</b>	<b>1.59±1.50</b>	1.54±3.18
150 hPa	<b>5.57±2.31</b>	<b>-1.48±1.35</b>	<b>4.36±1.86</b>	<b>2.69±1.98</b>	<b>1.86±1.58</b>	0.61±1.81
170 hPa	<b>5.90±1.99</b>	<b>-1.13±0.91</b>	<b>4.64±1.69</b>	<b>2.39±1.58</b>	<b>1.93±1.57</b>	0.14±1.78
200 hPa	<b>6.01±1.66</b>	<b>-0.91±0.75</b>	<b>4.78±1.47</b>	<b>2.15±1.40</b>	<b>1.92±1.41</b>	-0.18±1.85
250 hPa	<b>5.98±1.51</b>	<b>-0.78±0.71</b>	<b>4.76±1.28</b>	<b>2.00±1.40</b>	<b>1.89±1.22</b>	-0.36±1.80
300 hPa	<b>5.90±1.48</b>	<b>-0.74±0.73</b>	<b>4.68±1.19</b>	<b>1.96±1.43</b>	<b>1.85±1.13</b>	-0.40±1.76
400 hPa	<b>5.66±1.43</b>	-0.73±0.75	<b>4.52±1.08</b>	<b>1.87±1.42</b>	<b>1.76±0.98</b>	-0.40±1.69
500 hPa	<b>5.45±1.26</b>	<b>-0.78±0.71</b>	<b>4.39±0.97</b>	<b>1.83±1.35</b>	<b>1.79±0.85</b>	-0.47±1.56
600 hPa	<b>5.25±1.16</b>	<b>-0.96±0.65</b>	<b>4.34±0.97</b>	<b>1.86±1.34</b>	<b>1.86±0.79</b>	-0.55±1.35
700 hPa	<b>5.03±1.03</b>	<b>-1.11±0.58</b>	<b>4.48±1.11</b>	<b>1.65±1.15</b>	<b>1.87±0.73</b>	-0.66±0.98
850 hPa	<b>5.56±1.16</b>	<b>-1.31±0.90</b>	<b>5.87±1.84</b>	1.00±1.44	<b>2.10±0.64</b>	<b>-1.13±0.81</b>
925 hPa	<b>5.29±1.10</b>	<b>-1.40±0.85</b>	<b>5.82±1.15</b>	<b>0.87±0.76</b>	<b>2.01±0.52</b>	<b>-1.14±0.74</b>
1000 hPa	<b>4.38±1.07</b>	<b>-1.57±1.12</b>	<b>5.04±0.86</b>	<b>0.91±0.82</b>	<b>2.26±0.39</b>	<b>-1.36±0.87</b>

**Table S3.** Ozone trends (MMM)  $\pm 2\sigma$  error in *histSST* and due to forcings over 1979-1999 (35S-60S). Units are in %/decade.

Pressure	histSST	ODSs	NTCFs	GHGs	Methane	LLGHGs
1 hPa	<b>-3.53±1.12</b>	<b>-3.27±1.27</b>	0.09±0.33	-0.35±0.64	0.72±0.91	-1.07±1.29
2 hPa	<b>-5.68±1.46</b>	<b>-6.27±2.00</b>	-0.22±0.51	0.81±0.98	<b>1.28±0.55</b>	-0.58±0.81
3 hPa	<b>-5.50±1.25</b>	<b>-6.18±1.74</b>	-0.37±0.71	1.05±1.10	<b>1.34±0.79</b>	-0.35±1.53
5 hPa	<b>-4.12±0.84</b>	<b>-4.69±1.24</b>	-0.17±1.01	0.75±1.16	<b>1.13±0.85</b>	-0.31±2.24
7 hPa	<b>-3.08±0.73</b>	<b>-3.54±1.15</b>	0.04±0.93	0.42±1.17	<b>0.96±0.71</b>	-0.32±2.13
10 hPa	<b>-2.03±0.76</b>	<b>-2.24±1.04</b>	0.21±0.83	0.01±1.31	<b>0.83±0.71</b>	-0.57±2.23
15 hPa	<b>-1.41±0.85</b>	<b>-1.40±1.02</b>	0.22±0.86	-0.23±1.28	0.47±0.76	-0.55±2.14
20 hPa	<b>-1.29±1.00</b>	-1.27±1.30	0.18±0.75	-0.21±1.43	0.37±0.72	-0.47±2.02
30 hPa	<b>-1.65±1.15</b>	-1.54±1.70	0.00±0.52	-0.11±1.33	0.23±0.46	-0.27±1.46
50 hPa	<b>-3.70±2.11</b>	<b>-3.01±2.22</b>	-0.35±0.76	-0.34±1.05	0.15±0.58	-0.45±1.33
70 hPa	<b>-6.20±2.79</b>	<b>-5.23±2.81</b>	-0.21±1.10	-0.75±1.46	0.32±0.80	-1.16±2.05
80 hPa	<b>-7.14±3.01</b>	<b>-6.25±3.12</b>	-0.08±1.22	-0.81±1.71	0.43±0.96	-1.42±2.40
90 hPa	<b>-7.65±3.24</b>	<b>-6.92±3.48</b>	0.13±1.44	-0.85±2.00	0.62±1.07	-1.81±2.75
100 hPa	<b>-7.90±3.55</b>	<b>-7.41±3.95</b>	0.34±1.78	-0.83±2.37	0.85±1.23	-2.24±3.21
115 hPa	<b>-7.83±4.03</b>	<b>-7.70±4.69</b>	0.55±2.29	-0.69±2.96	1.19±1.56	-2.74±4.04
130 hPa	<b>-7.61±4.52</b>	<b>-7.75±5.40</b>	0.74±2.71	-0.60±3.51	1.44±1.85	-3.14±4.76
150 hPa	<b>-7.43±4.93</b>	<b>-7.82±6.04</b>	0.95±3.01	-0.56±3.88	1.62±2.00	-3.36±5.26
170 hPa	<b>-7.41±4.98</b>	<b>-8.00±6.34</b>	1.19±3.08	-0.60±3.89	1.72±2.05	-3.34±5.50
200 hPa	<b>-7.46±4.90</b>	<b>-8.38±6.47</b>	1.51±3.17	-0.59±3.72	1.83±2.16	-2.93±5.44
250 hPa	<b>-5.98±4.54</b>	<b>-7.67±5.48</b>	1.76±3.06	-0.07±3.33	<b>1.97±1.90</b>	-2.20±4.10
300 hPa	-2.87±3.45	<b>-5.76±3.83</b>	2.08±2.39	0.81±2.55	<b>1.91±1.28</b>	-1.47±2.77
400 hPa	0.68±1.92	<b>-3.59±2.10</b>	<b>2.69±1.62</b>	1.58±1.98	<b>1.80±0.80</b>	-0.90±1.92
500 hPa	1.22±1.73	<b>-3.19±1.90</b>	2.82±1.45	1.59±1.90	<b>1.82±0.70</b>	-0.91±1.84
600 hPa	1.15±1.70	<b>-3.19±1.94</b>	<b>2.82±1.38</b>	1.52±1.83	<b>1.85±0.67</b>	-0.97±1.84
700 hPa	0.87±1.71	<b>-3.39±2.07</b>	<b>2.80±1.32</b>	1.46±1.77	<b>1.87±0.66</b>	-0.98±1.87
850 hPa	0.17±1.84	<b>-3.96±2.35</b>	<b>2.85±1.35</b>	1.28±1.68	<b>1.79±0.67</b>	-0.92±1.86
925 hPa	-0.03±1.97	<b>-4.14±2.41</b>	<b>3.12±1.52</b>	1.00±1.68	<b>1.78±0.66</b>	-0.93±1.88
1000 hPa	0.17±2.22	<b>-3.62±2.76</b>	<b>3.21±1.25</b>	0.63±1.55	<b>1.76±0.70</b>	-1.14±1.78



**Table S4.** Ozone trends (MMM)  $\pm 2\sigma$  error in *histSST* and due to forcings over 2000-2014 (35N-60N). Units are in %/decade.

Pressure	histSST	ODSs	NTCFs	GHGs	Methane	LLGHGs
1 hPa	<b>1.85±0.74</b>	1.03±1.43	0.58±1.18	0.23±1.88	-0.05±1.28	0.70±3.48
2 hPa	<b>2.63±1.08</b>	1.28±2.19	0.47±1.26	0.88±2.60	-0.53±1.02	2.01±3.84
3 hPa	<b>2.31±1.25</b>	0.65±2.24	0.28±1.21	1.39±2.62	<b>-0.93±0.92</b>	2.99±3.54
5 hPa	<b>1.86±1.58</b>	0.17±1.60	0.63±1.39	1.06±2.03	-0.60±1.13	2.04±3.13
7 hPa	1.72±1.80	0.02±1.65	1.06±1.56	0.64±2.03	0.10±1.81	0.69±3.60
10 hPa	<b>1.51±1.91</b>	-0.07±1.82	1.13±1.43	0.46±2.36	0.38±1.84	0.24±3.83
15 hPa	1.22±2.16	0.04±1.49	0.82±1.72	0.36±2.57	-0.03±1.33	0.73±3.79
20 hPa	1.15±2.30	0.00±1.30	0.63±1.61	0.51±2.27	-0.32±1.09	1.28±3.03
30 hPa	1.06±1.46	-0.06±1.18	0.30±0.94	0.81±1.48	-0.37±0.87	1.50±1.89
50 hPa	0.84±1.70	0.60±2.88	-0.12±1.63	0.36±2.58	-0.06±2.14	0.50±4.75
70 hPa	0.96±2.98	1.37±3.73	0.27±2.25	-0.68±2.92	0.94±2.19	-2.20±4.06
80 hPa	1.27±3.35	1.55±3.85	0.59±2.75	-0.87±3.34	1.65±2.16	-3.30±4.56
90 hPa	1.54±3.72	1.57±4.00	0.83±3.06	-0.86±3.69	2.17±2.33	-3.84±5.25
100 hPa	1.78±4.11	1.59±4.22	1.01±3.33	-0.82±4.06	2.57±2.61	-4.13±5.94
115 hPa	2.12±4.65	1.65±4.85	1.18±3.91	-0.71±4.93	3.01±2.82	-4.39±7.20
130 hPa	2.26±5.04	1.62±5.61	1.33±4.55	-0.69±5.80	<b>3.15±3.06</b>	-4.49±8.50
150 hPa	2.16±5.26	1.63±6.41	1.44±5.14	-0.91±6.45	2.85±3.35	-4.50±9.63
170 hPa	2.07±5.10	1.83±6.62	1.58±5.31	-1.33±6.35	2.55±3.56	-4.72±9.73
200 hPa	2.23±4.58	2.14±6.41	1.95±4.91	-1.86±5.42	2.45±3.55	-5.34±8.55
250 hPa	2.66±3.65	1.29±5.35	2.66±3.34	-1.30±4.03	2.09±3.06	-4.48±6.96
300 hPa	<b>2.84±2.81</b>	0.19±3.77	<b>2.83±2.30</b>	-0.19±2.83	1.32±2.19	-2.15±5.37
400 hPa	<b>2.57±2.02</b>	-0.23±2.02	<b>2.28±1.84</b>	0.51±1.47	0.71±1.48	-0.35±3.09
500 hPa	<b>2.22±1.85</b>	-0.19±1.70	<b>1.85±1.74</b>	0.56±1.34	0.63±1.40	-0.12±2.81
600 hPa	<b>1.82±1.75</b>	-0.13±1.67	1.44±1.67	0.51±1.34	0.62±1.37	-0.16±2.78
700 hPa	1.36±1.67	-0.10±1.62	1.04±1.60	0.42±1.32	0.62±1.32	-0.26±2.75
850 hPa	0.47±1.62	-0.02±1.67	0.23±1.66	0.27±1.34	0.47±1.21	-0.23±2.40
925 hPa	<b>0.27±1.91</b>	-0.02±1.65	0.08±1.73	0.21±1.29	0.36±1.22	-0.15±2.30
1000 hPa	0.30±2.67	-0.27±2.78	0.05±2.22	0.53±2.09	0.25±1.59	0.28±3.30

**Table S5.** Ozone trends (MMM)  $\pm 2\sigma$  error in *histSST* and due to forcings over 2000-2014 (20N-20S). Units are in %/decade.

Pressure	histSST	ODSs	NTCFs	GHGs	Methane	LLGHGs
1 hPa	<b>0.75±0.65</b>	-0.22±0.98	-0.28±1.11	1.25±1.60	-0.45±1.37	1.83±3.34
2 hPa	<b>1.42±0.87</b>	0.19±1.16	-0.12±1.09	1.35±2.17	-0.33±1.08	1.88±3.77
3 hPa	<b>1.41±1.13</b>	0.39±1.21	-0.05±0.99	1.07±2.38	-0.45±0.96	1.84±3.54
5 hPa	0.81±1.38	0.38±1.20	0.13±1.06	0.31±1.86	-0.76±1.23	1.46±2.64
7 hPa	0.73±1.71	0.57±1.69	0.55±1.50	-0.39±2.02	-0.21±1.18	0.51±2.40
10 hPa	0.77±1.78	0.95±1.61	0.57±1.83	-0.75±2.17	0.66±1.61	-0.92±3.47
15 hPa	0.27±1.26	0.53±1.02	0.15±1.17	-0.41±1.52	0.15±1.13	-0.55±2.41
20 hPa	-0.08±0.90	-0.27±0.95	0.03±1.50	0.16±1.59	-0.37±1.19	0.12±2.57
30 hPa	-0.50±1.09	-0.29±1.57	0.32±2.17	-0.52±3.01	-0.46±1.87	-0.69±4.83
50 hPa	-0.39±1.68	1.09±2.32	0.22±1.99	-1.70±3.06	0.08±1.70	-2.01±4.82
70 hPa	1.22±2.85	2.17±4.10	0.47±2.13	-1.42±4.07	1.27±2.52	-2.97±6.60
80 hPa	2.39±3.30	2.39±4.14	1.82±2.01	-1.81±4.39	1.55±2.73	-3.48±7.21
90 hPa	3.38±3.42	2.51±3.46	<b>2.77±2.21</b>	-1.90±4.28	1.91±2.85	-4.16±7.11
100 hPa	<b>4.18±3.59</b>	2.58±2.96	<b>3.72±2.46</b>	-2.11±4.05	2.21±2.82	-4.72±6.52
115 hPa	<b>4.69±3.75</b>	2.30±2.51	<b>4.20±2.67</b>	-1.80±3.65	2.30±2.72	-4.52±6.05
130 hPa	<b>4.92±3.79</b>	1.93±2.11	<b>4.53±2.75</b>	-1.54±3.24	2.30±2.55	-4.26±5.42
150 hPa	<b>5.02±3.54</b>	1.39±1.57	<b>4.63±2.65</b>	-1.00±2.50	2.06±2.11	-3.25±4.28
170 hPa	<b>4.96±3.19</b>	1.04±1.21	<b>4.65±2.49</b>	-0.73±2.06	<b>1.87±1.79</b>	-2.59±3.55
200 hPa	<b>4.88±2.55</b>	0.70±0.91	<b>4.59±2.27</b>	-0.40±1.71	<b>1.69±1.51</b>	-1.87±2.95
250 hPa	<b>4.76±2.07</b>	0.50±0.78	<b>4.42±2.10</b>	-0.16±1.57	<b>1.47±1.25</b>	-1.27±2.45
300 hPa	<b>4.69±1.83</b>	0.48±0.70	<b>4.29±1.95</b>	-0.07±1.51	<b>1.37±1.14</b>	-1.05±2.19
400 hPa	<b>4.45±1.64</b>	0.42±0.64	<b>4.04±1.79</b>	-0.01±1.41	<b>1.24±1.10</b>	-0.87±1.99
500 hPa	<b>4.09±1.61</b>	0.36±0.63	<b>3.84±1.71</b>	-0.10±1.25	<b>1.24±1.06</b>	-1.05±1.88
600 hPa	<b>3.93±1.52</b>	0.42±0.58	<b>3.71±1.52</b>	-0.20±1.02	<b>1.23±0.88</b>	-1.26±1.53
700 hPa	<b>3.68±1.40</b>	0.45±0.52	<b>3.43±1.32</b>	-0.19±0.81	<b>1.04±0.69</b>	<b>-1.17±1.05</b>
850 hPa	<b>3.41±1.63</b>	0.39±0.51	<b>3.42±1.59</b>	-0.40±0.88	<b>0.73±0.59</b>	<b>-1.11±1.06</b>
925 hPa	<b>3.35±1.37</b>	0.27±0.47	<b>3.46±1.41</b>	-0.39±0.82	<b>0.72±0.53</b>	-1.11±1.17
1000 hPa	<b>3.26±1.56</b>	0.44±0.56	<b>3.52±1.53</b>	<b>-0.70±0.63</b>	<b>0.92±0.67</b>	<b>-1.63±1.10</b>

**Table S6.** Ozone trends (MMM)  $\pm 2\sigma$  error in *histSST* and due to forcings over 2000-2014 (35S-60S). Units are in %/decade.

Pressure	histSST	ODSs	NTCFs	GHGs	Methane	LLGHGs
1 hPa	<b>1.32±1.00</b>	0.54±1.50	0.02±0.88	0.77±1.74	-0.88±1.07	1.70±2.80
2 hPa	<b>2.45±1.20</b>	1.43±2.38	0.34±1.22	0.68±2.37	-0.21±1.41	0.88±4.37
3 hPa	<b>2.50±1.20</b>	1.38±2.18	0.41±1.44	0.70±2.33	0.33±1.60	0.40±4.34
5 hPa	<b>1.94±1.28</b>	1.08±1.64	0.44±1.22	0.42±1.83	0.62±2.12	-0.14±3.96
7 hPa	<b>1.47±1.31</b>	0.73±1.30	0.63±1.06	0.11±1.28	0.27±1.77	-0.15±3.03
10 hPa	1.05±1.55	-0.03±0.95	0.67±1.03	0.42±1.13	-0.29±1.38	0.81±2.01
15 hPa	0.82±1.72	-0.26±0.92	0.65±0.91	0.44±1.53	-0.40±1.81	1.19±1.94
20 hPa	0.89±1.70	0.15±1.03	0.83±0.84	-0.09±1.40	-0.18±1.82	0.45±2.06
30 hPa	0.66±1.36	0.14±1.18	0.87±1.21	-0.35±1.25	-0.15±1.23	0.17±2.13
50 hPa	0.05±1.65	-0.12±1.51	-0.35±2.65	0.52±3.22	-0.68±1.67	2.31±4.31
70 hPa	0.24±2.15	-0.28±2.09	-0.63±3.22	1.15±4.47	-0.48±2.12	3.31±5.48
80 hPa	0.53±2.42	-0.24±2.32	-0.46±3.34	1.22±4.71	-0.35±2.23	3.29±5.84
90 hPa	0.75±2.75	-0.15±2.52	-0.33±3.51	1.23±4.75	-0.41±2.20	3.30±5.94
100 hPa	0.92±3.03	-0.00±2.72	-0.33±3.69	1.25±4.82	-0.59±2.19	3.42±6.22
115 hPa	0.91±3.39	0.06±3.03	-0.55±4.11	1.40±5.08	-1.04±2.28	3.96±6.77
130 hPa	0.85±3.78	0.18±3.18	-0.80±4.69	1.47±5.50	-1.32±2.42	4.33±7.53
150 hPa	0.79±4.37	0.48±3.06	-1.06±5.54	1.37±5.99	-1.44±2.84	4.51±8.44
170 hPa	0.77±4.88	0.90±2.74	-1.01±6.59	0.89±6.39	-1.36±3.59	4.17±9.42
200 hPa	0.64±5.47	1.58±3.24	-0.72±8.11	-0.22±6.80	-1.07±4.69	2.92±10.67
250 hPa	0.80±4.67	1.92±3.60	0.33±7.50	-1.45±5.58	-0.41±4.43	0.48±8.90
300 hPa	1.50±2.92	1.40±2.16	1.50±5.09	-1.40±3.62	0.08±2.91	-0.46±5.35
400 hPa	<b>2.27±1.94</b>	0.78±0.99	2.18±3.11	-0.69±2.28	0.35±1.69	-0.26±2.91
500 hPa	<b>2.30±1.91</b>	0.62±1.04	2.14±2.86	-0.46±2.15	0.35±1.53	-0.07±2.84
600 hPa	<b>2.24±1.90</b>	0.51±1.06	2.06±2.83	-0.33±2.13	0.39±1.51	0.02±2.84
700 hPa	<b>2.17±1.89</b>	0.41±1.12	1.98±2.86	-0.22±2.16	0.42±1.45	0.13±2.75
850 hPa	<b>2.02±1.98</b>	0.26±1.37	1.70±3.01	0.06±2.32	0.43±1.44	0.29±2.80
925 hPa	1.71±2.12	0.13±1.58	1.09±3.14	0.48±2.50	0.45±1.49	0.29±2.82
1000 hPa	1.52±2.06	-0.19±2.08	0.52±2.75	1.22±2.62	0.56±1.78	0.68±3.62