SUPPLEMENTAL MATERIAL

Air quality and radiative forcing impacts of anthropogenic volatile organic compound emissions from ten world regions

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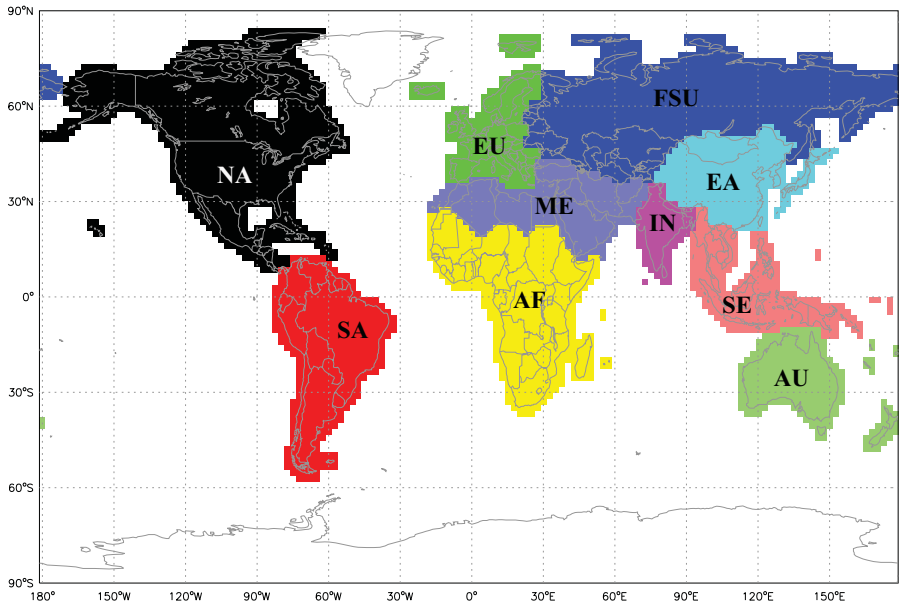
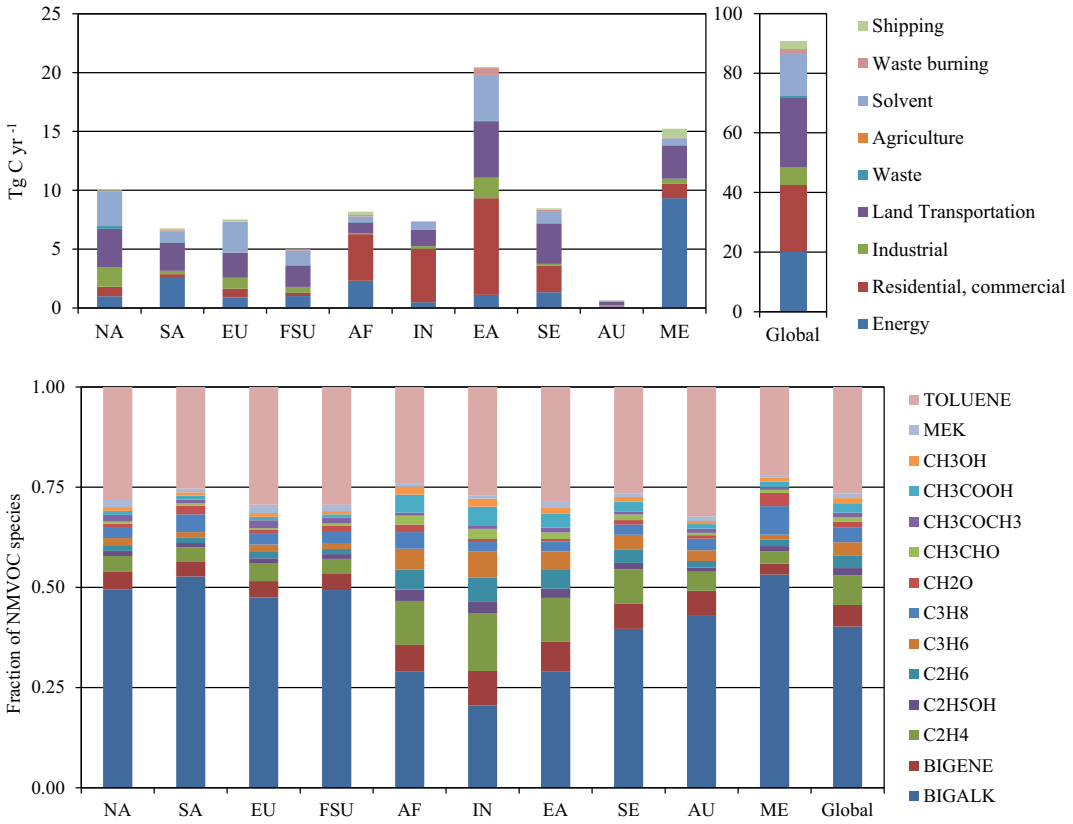


Figure S1. Definition of 10 regions.



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3 Figure S2. Annual average anthropogenic NMVOC emissions (Tg C yr^{-1}) by region and
4 sector (top), and by region and fraction of individual MOZART-4 NMVOC species (bottom)
5 for the base simulation, from the RCP8.5 emissions inventory for the year 2005.

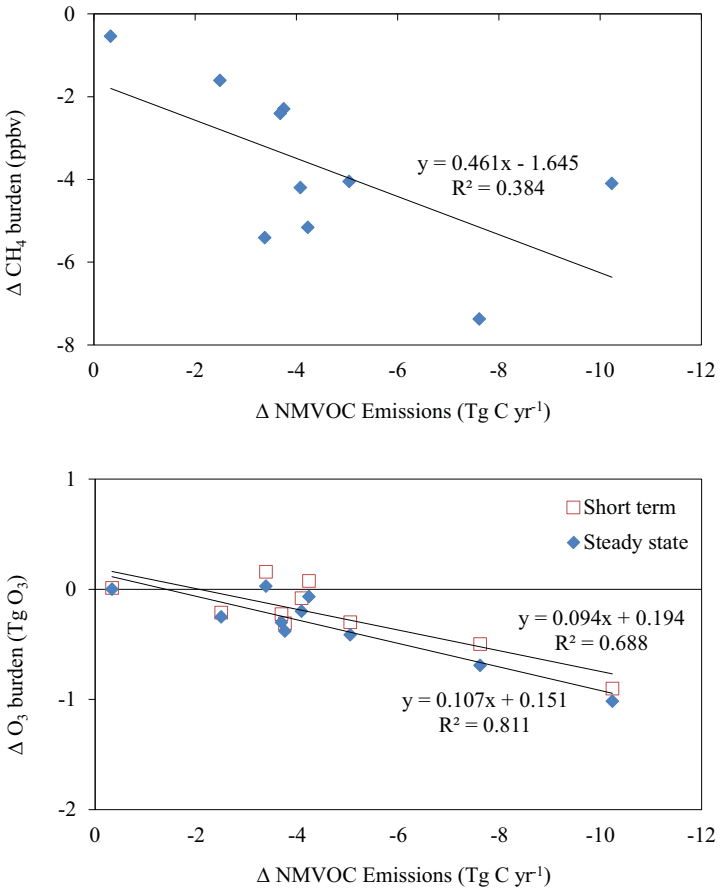


Figure S3. Changes in tropospheric CH_4 (top) and short-term and steady-state surface O_3 (bottom) as a function of NMVOC emissions change for each of the regional reductions relative to the base.

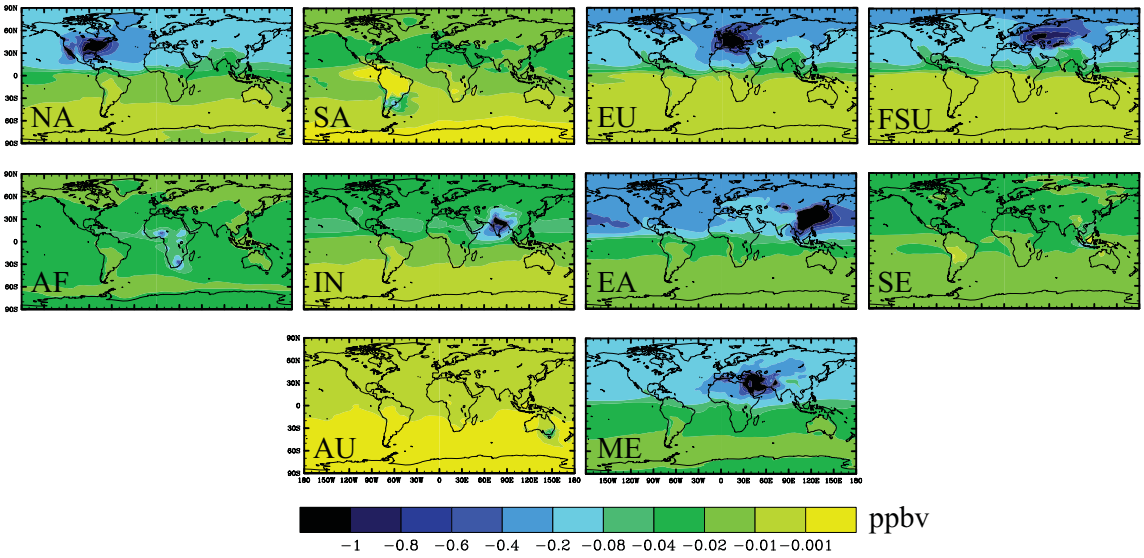
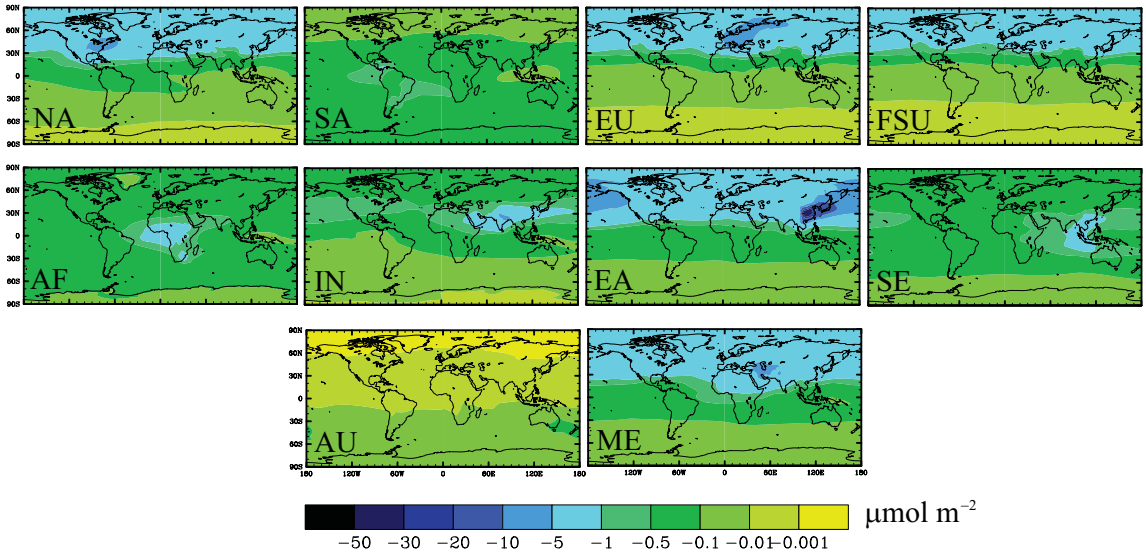


Figure S4. Global distribution of annual average changes in steady-state surface O_3 (ppbv) for each of the regional reduction simulations relative to the base.



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3 Figure S5. Global distribution of annual average changes in tropospheric PAN (μmol m^{-2}) for

4 each of the regional reduction simulations relative to the base.

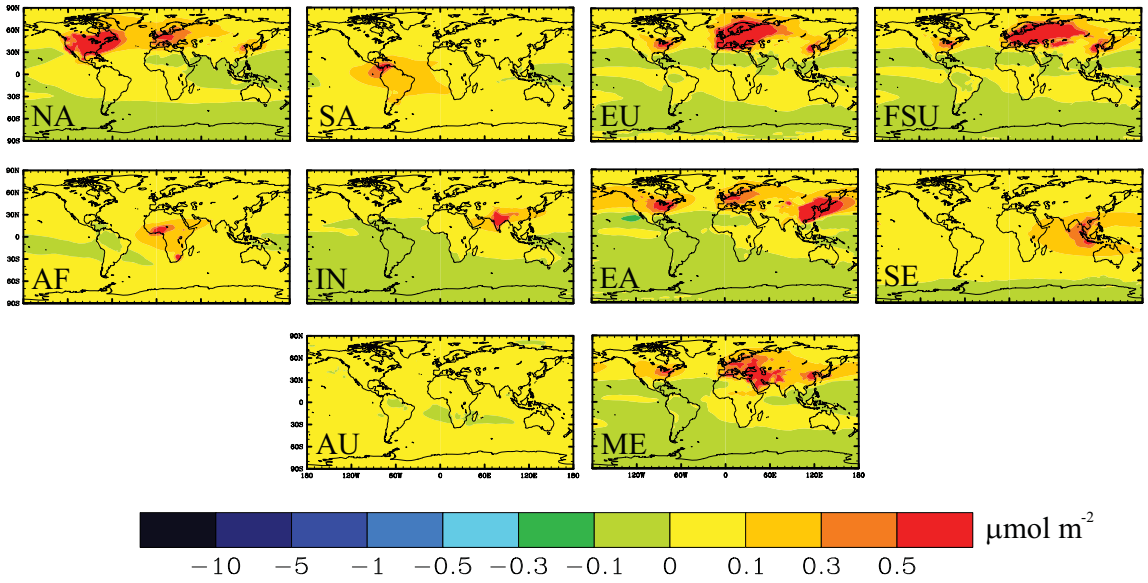


Figure S6. Global distribution of annual average changes in tropospheric NO_x (NO_x = NO + NO_2) (μmol m^{-2}) for each of the regional reduction simulations relative to the base.

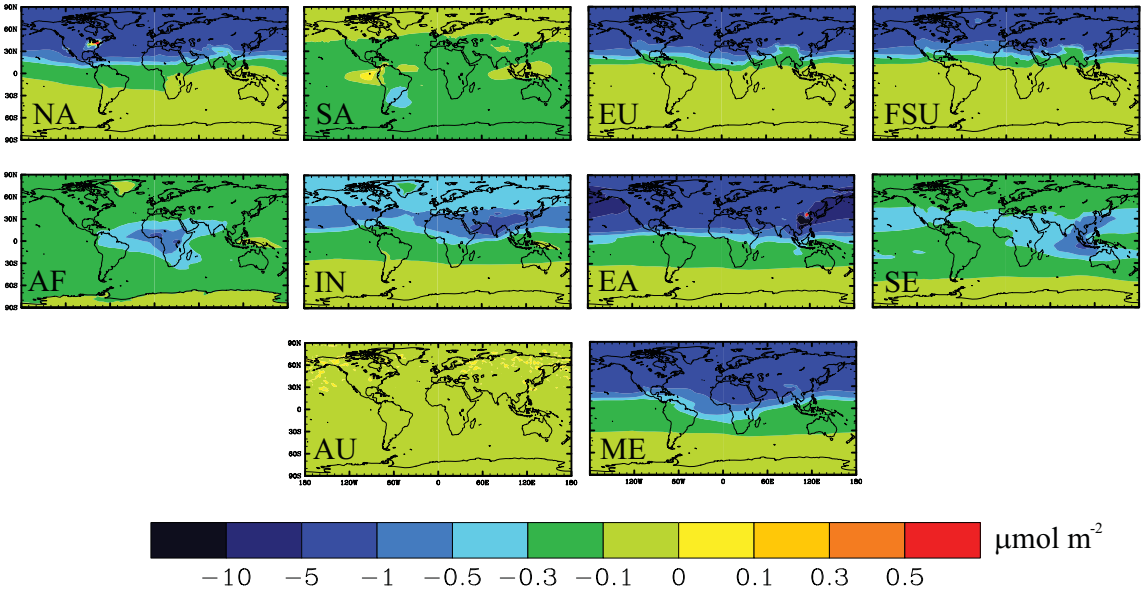


Figure S7. Global distribution of annual average changes in tropospheric NO_y (NO_y = NO + NO_2 + HNO_3 + PAN + HONO + NO_3 + N_2O_5 + organic nitrates + particulate nitrate + all other reservoir species) (μmol m^{-2}) for each of the regional reduction simulations relative to the base.

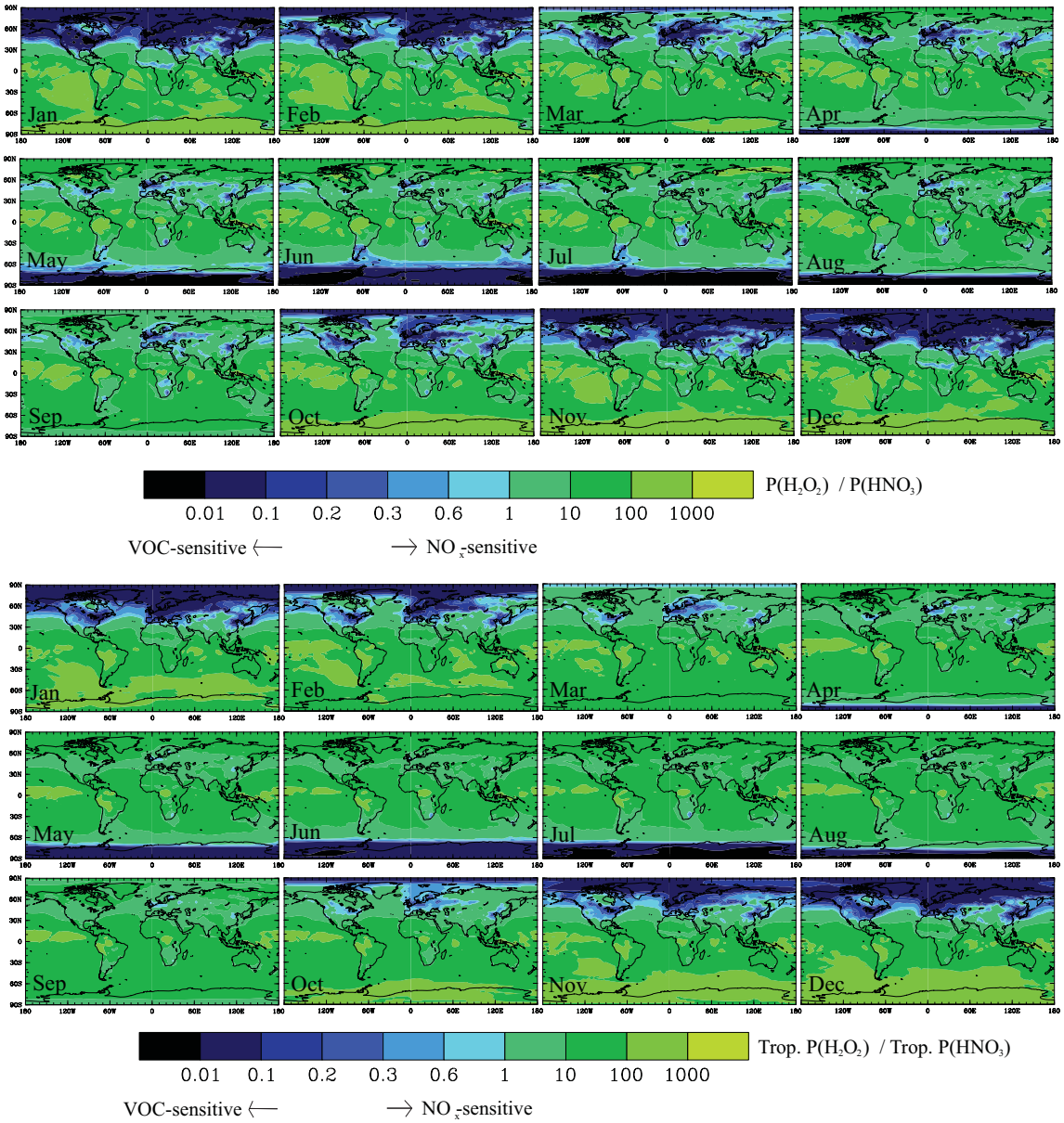
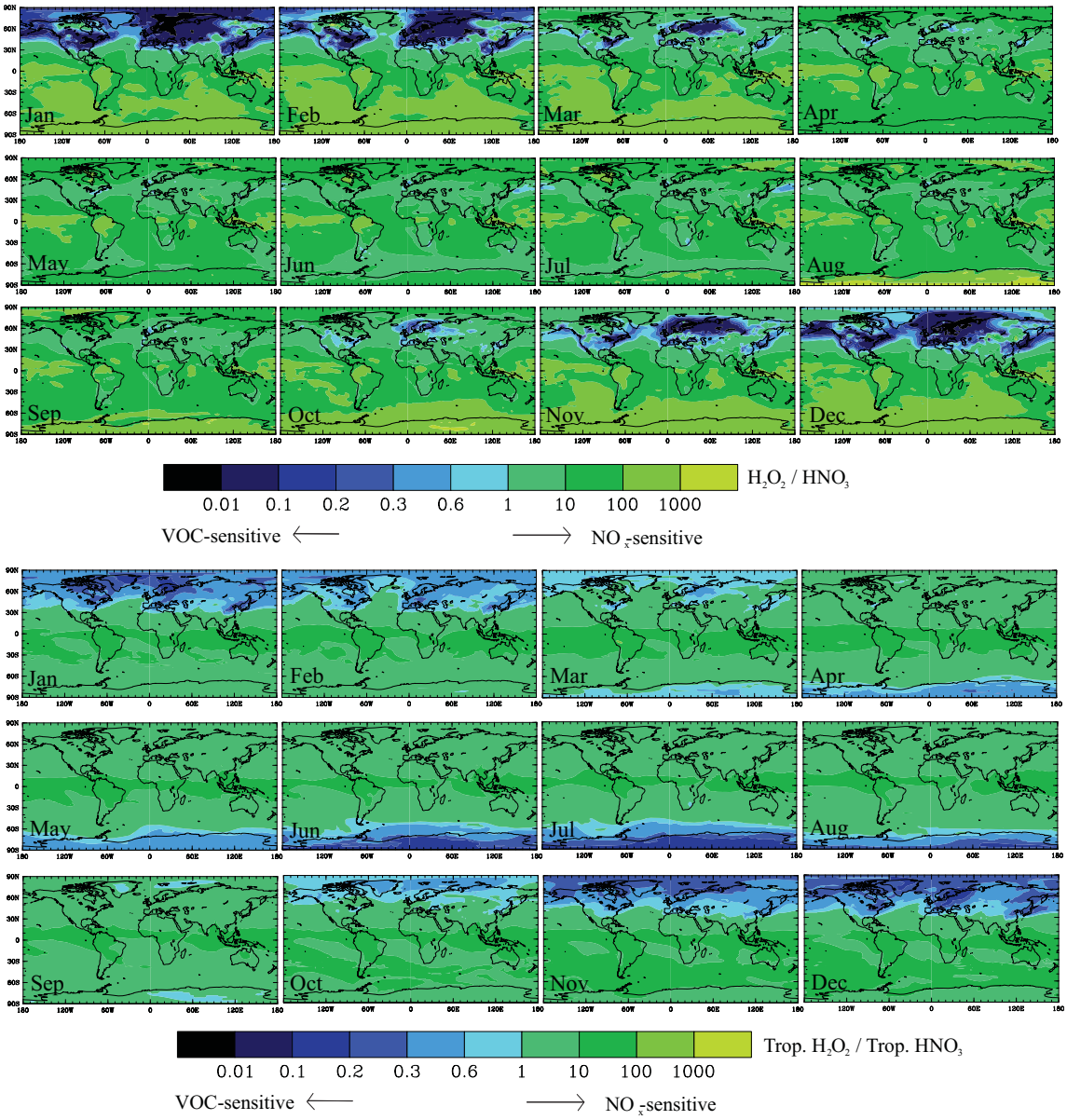


Figure S8. Global distribution of monthly average surface (top) and tropospheric column (bottom) H_2O_2 production / HNO_3 production ($P(H_2O_2)$ / $P(HNO_3)$) for the base simulation, where the transition between VOC-sensitive and NO_x-sensitive regimes is ~0.2 (Liu et al., 2010).



S9. Global distribution of monthly average surface (top) and tropospheric column (bottom) H_2O_2 / HNO_3 for the base simulation, where the transition between VOC-sensitive and NO_x-sensitive regimes is ~0.3 to 0.6 (Sillman et al., 1997).

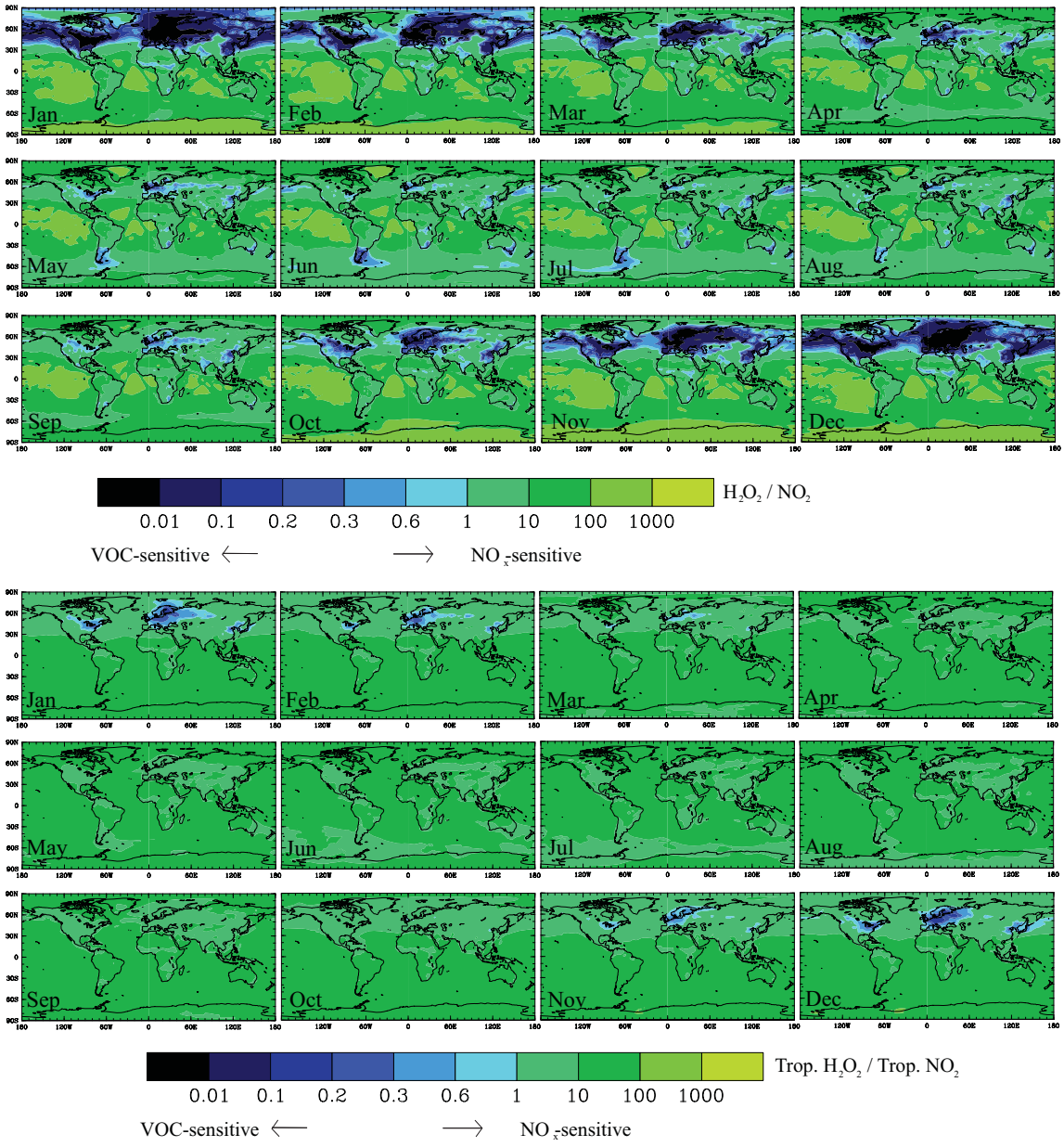


Figure S10. Global distribution of monthly average surface (top) and tropospheric column (bottom) H_2O_2 / NO_2 for the base simulation, where the transition between VOC-sensitive and NO_x-sensitive regimes is ~0.2 to 0.35 (Sillman et al., 1997).

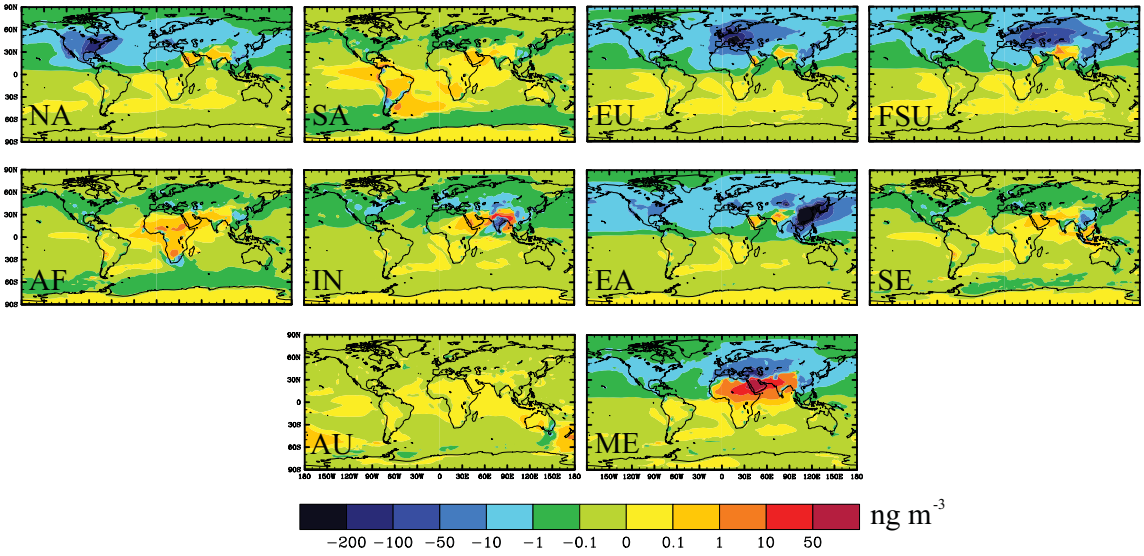


Figure S11. Global distribution of annual average changes in surface SO_4^{2-} (ng m^{-3}) for each of the regional reduction simulations relative to the base.

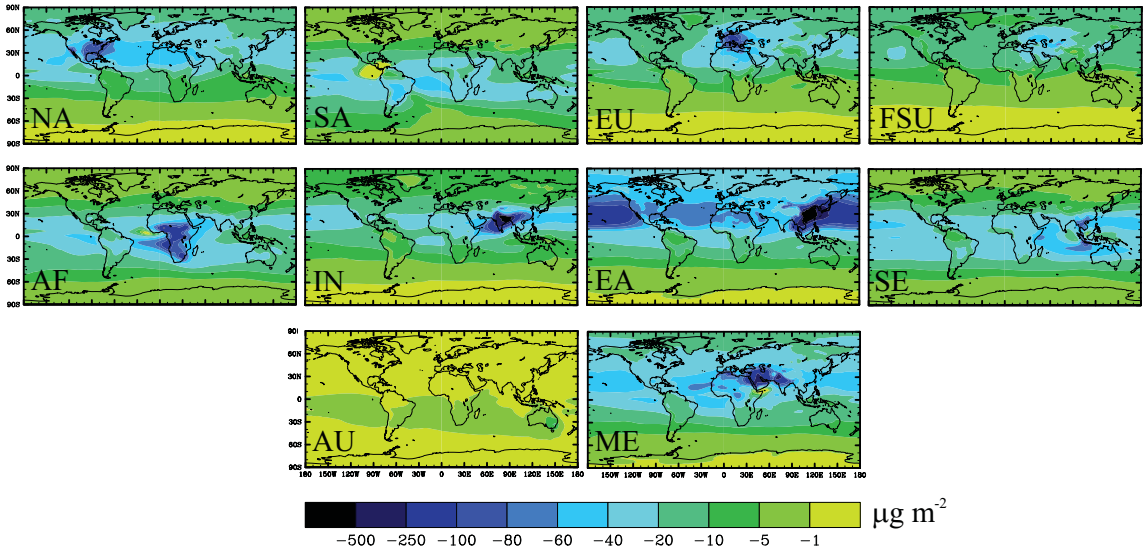


Figure S12. Global distribution of annual average changes in tropospheric H_2O_2 (μg m^{-2}) for each of the regional reduction simulations relative to the base.

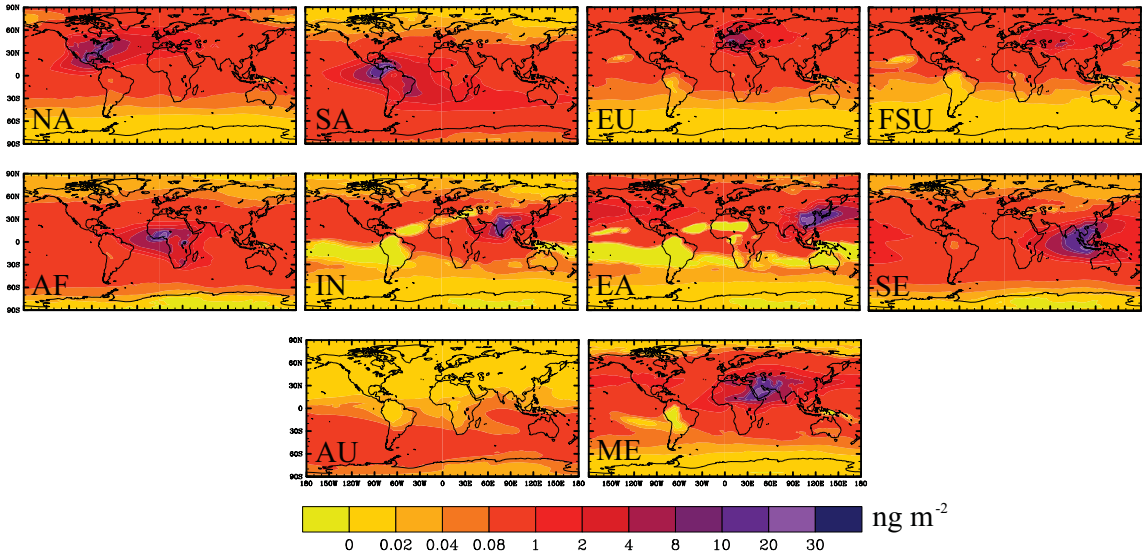
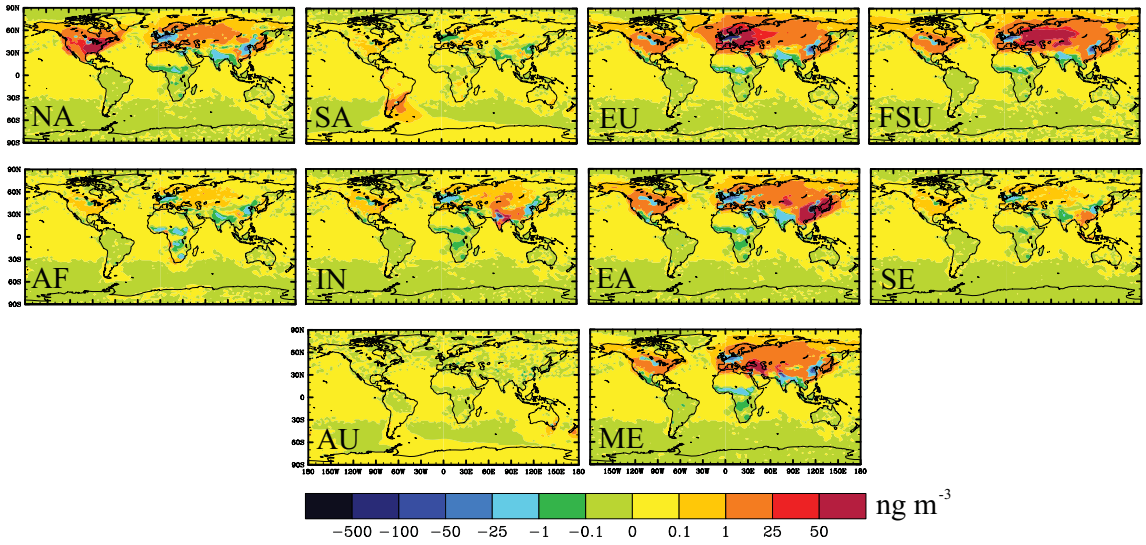


Figure S13. Global distribution of annual average changes in tropospheric OH (ng m^{-2}) for each of the regional reduction simulations relative to the base.



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3 Figure S14. Global distribution of annual average changes in surface NO_3^- (expressed as

4 NH_4NO_3 in ng m^{-3}) for each of the regional reduction simulations relative to the base.

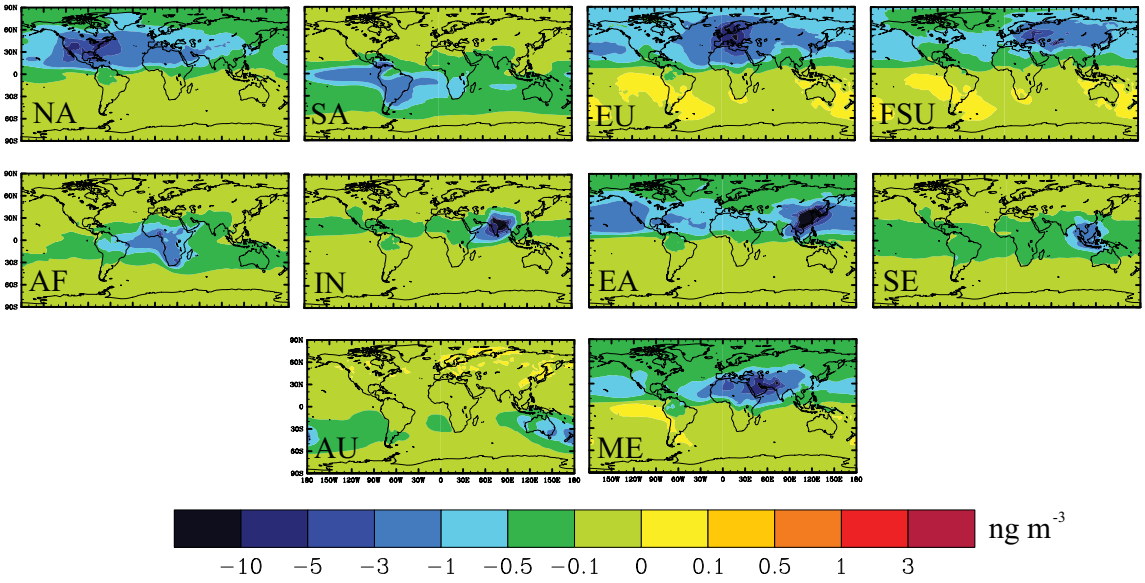


Figure S15. Global distribution of annual average changes in surface SOA (ng m^{-3}) for each of the regional reduction simulations relative to the base.

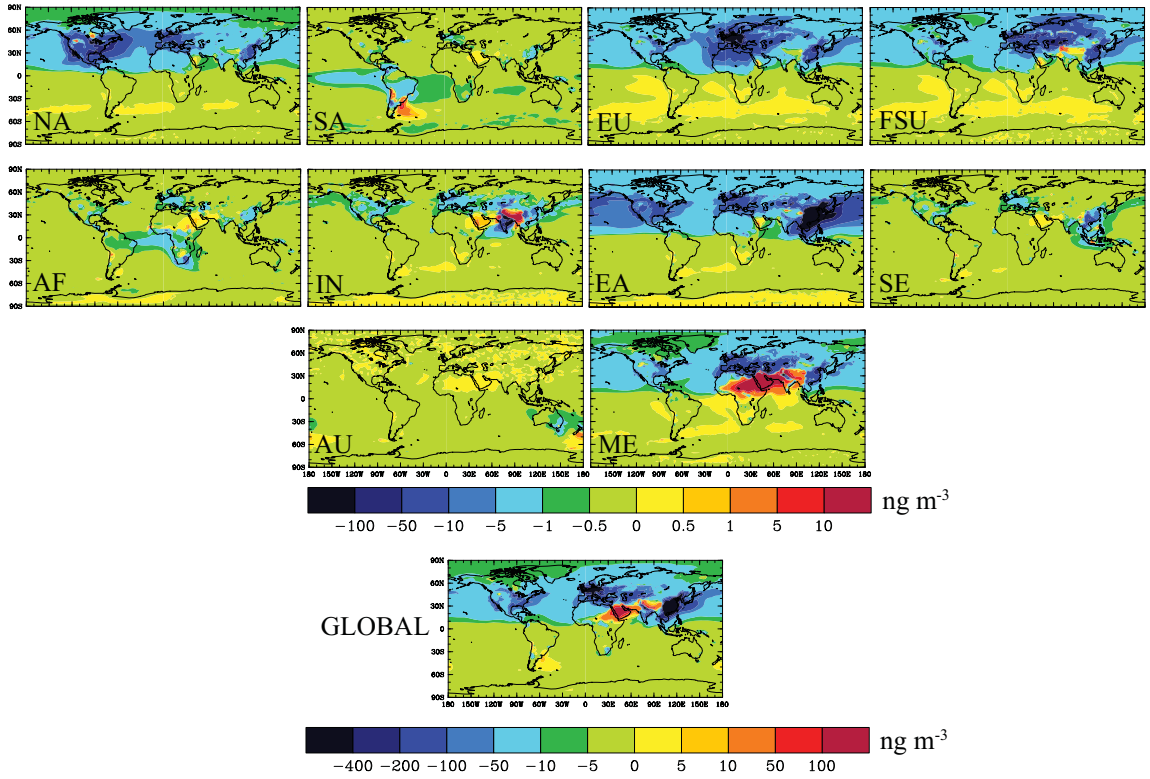


Figure S16. Global distribution of annual average changes in surface $PM_{2.5}$ (sum of BC, OC, $(NH_4)_2SO_4$, NH_4NO_3, SOA) (ng m^{-3}) for the global and regional reduction simulations relative to the base.

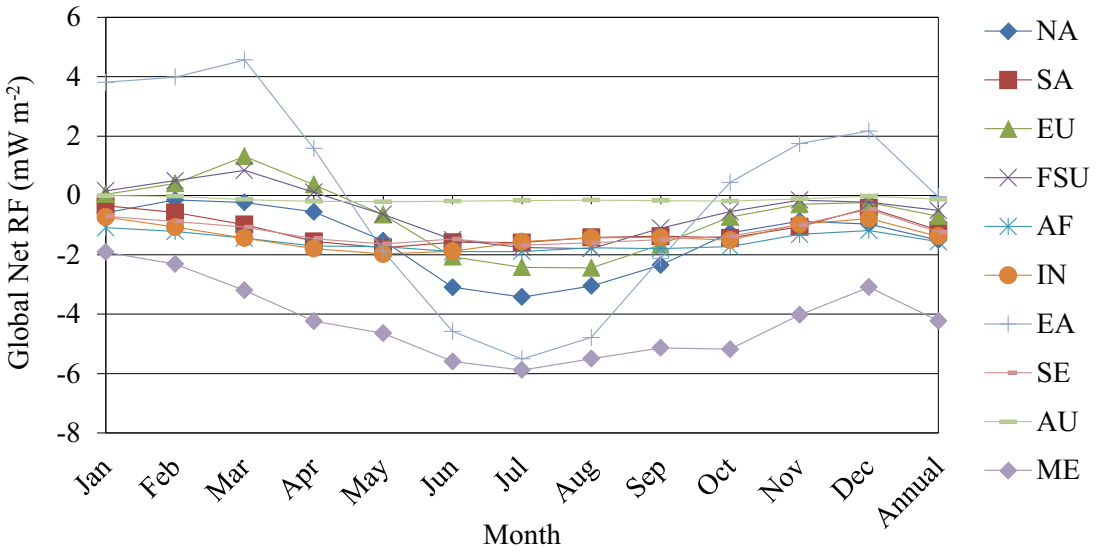
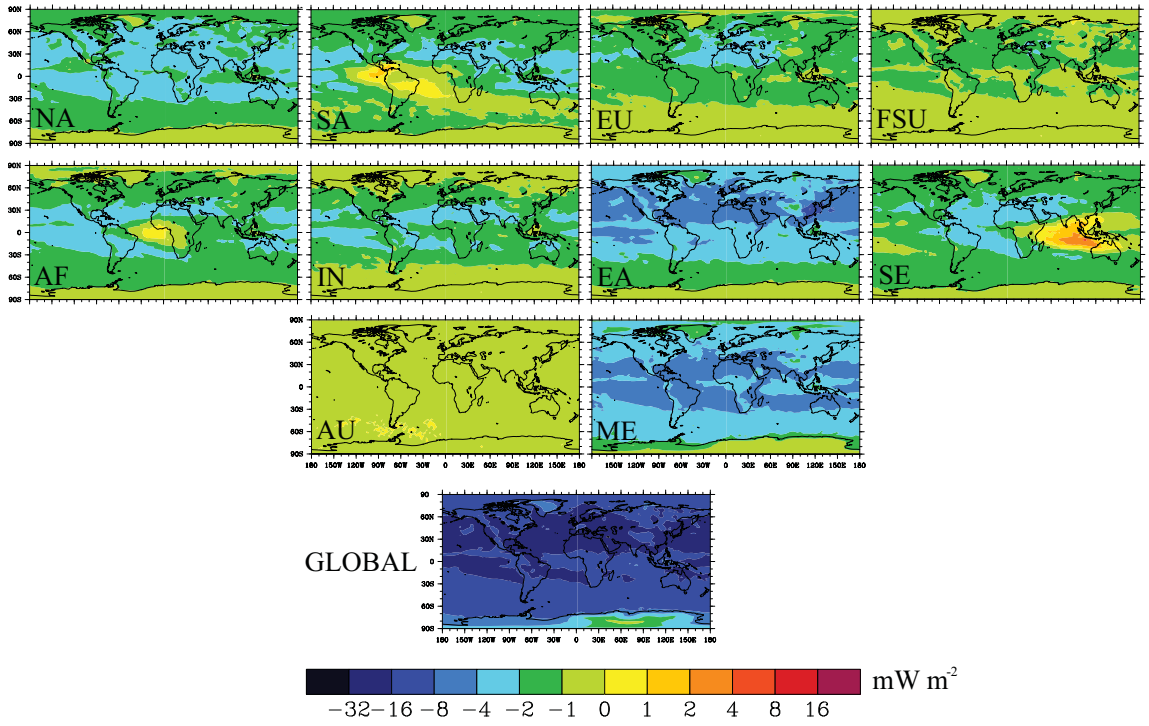


Figure S17. Global monthly and annual average net RF (mW m^{-2}) due to changes in tropospheric steady-state O_3, CH_4, and SO_4^{2-} for each regional CO reduction simulation minus the base simulation.



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3 Figure S18. Annual average changes in longwave (infrared) radiation (mW m^{-2}) due to
4 changes in tropospheric steady-state O_3, CH_4, and SO_4^{2-} for the regional reduction simulations
5 minus the base simulation.

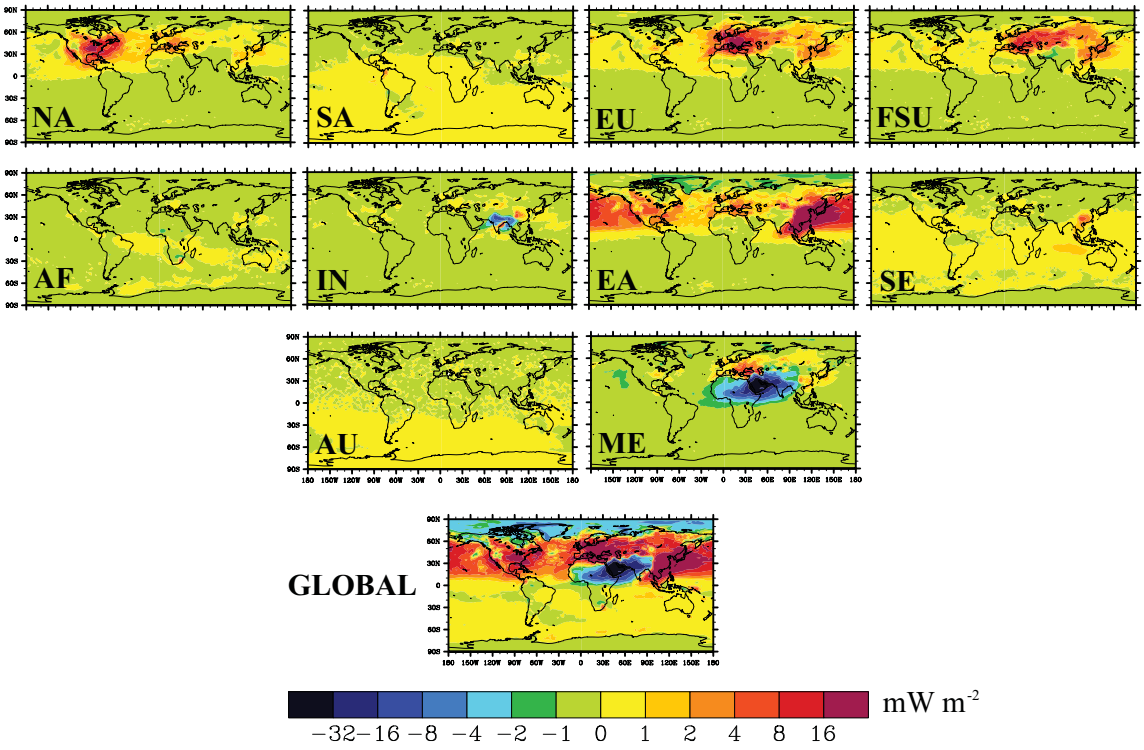

Figure S19. Annual average changes in shortwave (solar) radiation (mW m^{-2}) due to changes in tropospheric steady-state O_3, CH_4, and SO_4^{2-} for the regional reduction simulations minus the base simulation.

1 Table S1. Anthropogenic NMVOC emission species in MOZART-4 simulations (Emmons et
2 al., 2010).

MOZART-4 species	Description
BIGALK	C_5H_{12}, lumped alkanes (C > 3)
BIGENE	C_4H_8, lumped alkenes (C > 3)
C2H4	ethene
C2H5OH	ethanol
C2H6	ethane
C3H6	propene
C3H8	propane
CH2O	formaldehyde
CH3CHO	acetaldehyde
CH3COCH3	acetone
CH3COOH	acetic acid
CH3OH	methanol
MEK	$CH_3C(O)CH_2CH_3$, methyl ethyl ketone
TOLUENE	$C_6H_5(CH_3)$, lumped aromatics

Table S2. Annual total anthropogenic, biomass burning, and natural NMVOC emissions by region and globally for the year 2005 (Tg C yr^{-1}) in the base simulation.

Anthropogenic	NA	SA	EU	FSU	AF	IN	EA	SE	AU	ME	Global
Shipping	0.13	0.16	0.18	0.02	0.26	0.03	0.07	0.10	0.03	0.76	2.64
Waste burning	0.09	0.13	0.02	0.10	0.14	0.03	0.58	0.14	0.02	0.06	1.31
Solvents	2.90	0.88	2.61	1.22	0.48	0.63	3.87	1.00	0.12	0.57	14.30
Agriculture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Waste	0.25	0.04	0.04	0.06	0.03	0.03	0.08	0.03	0.00	0.02	0.58
Land transportation	3.25	2.40	2.11	1.81	0.89	1.40	4.79	3.44	0.25	2.82	23.18
Industrial	1.67	0.29	0.93	0.51	0.11	0.22	1.74	0.13	0.08	0.41	6.08
Residential, commercial	0.81	0.32	0.74	0.26	3.96	4.56	8.21	2.29	0.05	1.25	22.46
Energy	0.99	2.54	0.89	1.02	2.31	0.48	1.11	1.33	0.13	9.33	20.13
Total anthropogenic	10.10	6.76	7.52	4.99	8.17	7.38	20.47	8.47	0.67	15.23	90.67
Biomass burning											
Grassland fires	0.48	1.49	0.09	0.98	12.15	0.06	0.08	0.21	1.20	0.01	16.75
Forest fires	1.79	4.18	0.07	2.90	1.77	0.59	0.42	9.79	0.31	0.00	21.83

Natural											
$C_{10}H_{16}$	12.12	37.72	2.20	5.84	16.77	1.77	4.27	20.61	4.18	0.52	107.08
Isoprene	61.75	227.85	7.94	19.17	158.57	16.59	20.08	136.10	75.69	6.76	738.21

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Table S3. Source-receptor matrix of annual average steady-state changes in surface O_3 concentrations (pptv), for the regional reduction simulations, with the United States (US) also defined as a receptor in addition to the 10 regions.

	Receptor										
Source	NA	SA	EU	FSU	AF	IN	EA	SE	AU	ME	US
NA	-426.8	-16.2	-174.7	-137.6	-45.1	-45.2	-100.4	-28.2	-9.8	-127.6	-657.2
SA	-18.0	-7.6	-20.6	-16.5	-12.6	-19.8	-18.9	-15.5	-7.9	-23.7	-22.0
EU	-143.6	-10.3	-915.4	-303.3	-56.8	-36.7	-144.2	-25.9	-5.6	-278.5	-138.4
FSU	-113.2	-6.5	-222.5	-525.0	-26.0	-30.4	-173.4	-22.2	-3.9	-134.7	-108.6
AF	-23.7	-23.3	-22.1	-18.6	-72.0	-27.0	-21.6	-20.0	-21.5	-29.5	-24.3
IN	-31.4	-12.7	-29.1	-31.7	-25.6	-843.3	-53.4	-36.5	-8.8	-50.7	-33.1
EA	-258.5	-25.5	-214.5	-263.5	-63.6	-111.3	-1594.4	-273.8	-15.9	-170.7	-280.3
SE	-25.1	-13.8	-25.4	-21.1	-19.9	-25.4	-26.4	-30.1	-13.6	-30.6	-27.9
AU	-1.7	-0.4	-1.9	-1.5	-1.4	-2.0	-1.9	-1.4	-5.1	-2.1	-1.9
ME	-143.6	-32.9	-216.9	-228.7	-114.9	-258.2	-164.7	-61.9	-20.1	-922.3	-147.7

Table S4. Source-receptor matrix of annual average steady-state changes in surface O_3 concentrations per unit change in NMVOC emissions (pptv (Tg C yr^{-1})$^{-1}$), for the regional reduction simulations, with the United States (US) also defined as a receptor in addition to the 10 regions.

	Receptor										
Source	NA	SA	EU	FSU	AF	IN	EA	SE	AU	ME	US
NA	84.53	3.21	34.60	27.25	8.93	8.95	19.88	5.59	1.94	25.27	130.16
SA	5.33	2.25	6.10	4.88	3.73	5.86	5.59	4.59	2.34	7.01	6.51
EU	38.21	2.74	243.6	80.71	15.12	9.77	38.37	6.89	1.49	74.11	36.83
FSU	45.33	2.60	89.10	210.23	10.41	12.17	69.44	8.89	1.56	53.94	43.49
AF	5.80	5.70	5.41	4.55	17.62	6.61	5.29	4.90	5.26	7.22	5.95
IN	8.51	3.44	7.89	8.60	6.94	228.67	14.48	9.90	2.39	13.75	8.98
EA	25.26	2.49	20.96	25.75	6.21	10.88	155.80	26.76	1.55	16.68	27.39
SE	5.93	3.26	6.00	4.98	4.70	6.00	6.24	7.11	3.21	7.23	6.59
AU	5.08	1.20	5.68	4.48	4.18	5.98	5.68	4.18	15.24	6.27	5.68
ME	18.85	4.32	28.48	30.03	15.08	33.90	21.62	8.13	2.64	121.09	19.39

Table S5. Changes in global annual average tropospheric PAN (ΔPAN) per unit change in NMVOC emissions (ΔE), PAN production (P_{PAN}), and PAN production (ΔP_{PAN}) per ΔE for the global and regional reductions.

Reduction region	ΔPAN / ΔE (Gg PAN (Tg C yr^{-1}) $^{-1}$)	ΔP_{PAN} (Tg PAN yr^{-1})	ΔP_{PAN} / ΔE (Tg PAN (Tg C yr^{-1})$^{-1}$)
NA	10.3	-18.4	3.65
SA	4.7	-4.0	1.18
EU	12.8	-16.1	4.30
FSU	14.0	-9.7	3.88
AF	4.4	-7.1	1.74
IN	5.7	-10.3	2.79
EA	9.9	-36.5	3.57
SE	5.4	-5.5	1.30
AU	6.0	-0.5	1.38
ME	8.0	-28.8	3.78
Global	8.5	-138.3	3.05

Table S6. Source-receptor matrix of annual average changes in surface SO_4^{2-} concentrations (ng m^{-3}) for the regional reduction simulations, with the United States (US) also defined as a receptor in addition to the 10 regions.

	Receptor										
Source	NA	SA	EU	FSU	AF	IN	EA	SE	AU	ME	US
NA	-27.30	-0.06	-7.16	-2.59	-0.26	-0.07	-3.11	-0.57	-0.01	-1.88	-50.76
SA	-0.16	-0.37	-0.34	-0.10	0.02	-0.08	-0.29	-0.11	-0.04	-0.01	-0.31
EU	-2.60	-0.03	-93.20	-16.51	-1.26	-0.02	-6.49	-0.77	-0.01	-12.13	-4.25
FSU	-2.02	-0.02	-15.97	-37.87	-0.38	0.21	-11.67	-0.78	0.00	-5.86	-3.35
AF	-0.29	-0.04	-0.60	-0.24	0.06	0.02	-0.50	-0.11	-0.07	0.04	-0.45
IN	-0.56	-0.03	-1.11	-1.26	0.01	-34.62	-2.46	0.46	-0.01	-0.63	-0.91
EA	-5.75	-0.11	-7.91	-9.26	-0.38	-1.94	-313.71	-33.48	-0.03	-2.24	-9.75
SE	-0.36	-0.02	-0.68	-0.21	-0.01	-0.17	-2.90	-1.32	-0.04	-0.04	-0.59
AU	0.00	0.00	-0.02	-0.01	0.00	0.00	-0.01	-0.01	-0.03	0.00	-0.01
ME	-2.23	-0.05	-13.57	-11.56	3.61	6.90	-5.73	-0.54	-0.02	10.55	-3.86

Table S7. Regional and global annual average changes in surface $PM_{2.5}$ concentrations (in ng m^{-3} and %) for the global NMVOC reduction simulation.

	$\Delta PM_{2.5}$ (ng m^{-3})	% change
NA	-40.22	-0.99
SA	-3.00	-0.08
EU	-197.10	-1.79
FSU	-49.28	-0.83
AF	-3.57	-0.06
IN	-66.09	-0.41
EA	-383.86	-2.30
SE	-49.97	-0.76
AU	-1.76	-0.10
ME	-6.51	-0.12
US	-61.94	-1.05
Global	-28.02	-0.89

Table S8. Source-receptor matrix of annual average changes in surface $PM_{2.5}$ concentrations (ng m^{-3}) for the regional reduction simulations, with the United States (US) also defined as a receptor in addition to the 10 regions.

	Receptor										
Source	NA	SA	EU	FSU	AF	IN	EA	SE	AU	ME	US
NA	-20.79	-0.21	-14.38	-2.56	-0.84	-1.46	-6.33	-0.89	-0.03	-3.63	-32.27
SA	-0.28	-1.32	-0.47	-0.10	-0.34	-0.35	-0.45	-0.30	-0.36	-0.12	-0.35
EU	-3.10	-0.09	-108.62	-8.90	-2.28	-1.13	-10.73	-1.12	-0.01	-13.74	-4.45
FSU	-2.33	-0.05	-18.81	-19.98	-0.67	-0.40	-12.22	-1.09	-0.01	-5.85	-3.41
AF	0.36	-0.42	-0.89	-0.22	-1.42	-0.50	-0.82	-0.28	-0.26	-0.19	-0.50
IN	-0.69	-0.10	-1.99	-1.08	-0.17	-49.96	-2.15	-0.29	-0.03	-0.67	-1.02
EA	-7.05	-0.26	-16.65	-6.25	-0.95	-5.64	-325.08	-42.52	-0.05	-3.82	-11.07
SE	-0.45	-0.23	-1.00	-0.21	-0.23	-0.67	-3.48	-2.57	-0.25	-0.20	-0.66
AU	0.00	-0.04	-0.04	-0.01	-0.02	-0.02	-0.03	-0.07	-0.66	0.00	-0.01
ME	-2.56	-0.18	-17.59	-7.58	3.88	2.63	-8.83	-0.96	-0.04	24.77	-3.96

Table S9. Source-receptor matrix of annual average percentage changes (%) in surface $PM_{2.5}$ concentrations for the regional reduction simulations, with the United States (US) also defined as a receptor in addition to the 10 regions.

	Receptor										
Source	NA	SA	EU	FSU	AF	IN	EA	SE	AU	ME	US
NA	-0.511	-0.006	-0.131	-0.043	-0.014	-0.009	-0.038	-0.014	-0.002	-0.065	-0.546
SA	-0.007	-0.034	-0.004	-0.002	-0.006	-0.002	-0.003	-0.005	-0.021	-0.002	-0.006
EU	-0.076	-0.002	-0.988	-0.151	-0.037	-0.007	-0.064	-0.017	-0.001	-0.248	-0.075
FSU	-0.057	-0.001	-0.171	-0.338	-0.011	-0.003	-0.073	-0.017	0.000	-0.106	-0.058
AF	-0.009	-0.011	-0.008	-0.004	-0.023	-0.003	-0.005	-0.004	-0.015	-0.004	-0.009
IN	-0.017	-0.002	-0.018	-0.018	-0.003	-0.312	-0.013	-0.004	-0.002	-0.012	-0.017
EA	-0.174	-0.007	-0.152	-0.106	-0.015	-0.035	-1.947	-0.650	-0.003	-0.069	-0.187
SE	-0.011	-0.006	-0.009	-0.004	-0.004	-0.004	-0.021	-0.039	-0.014	-0.004	-0.011
AU	0.000	-0.001	0.000	0.000	0.000	0.000	0.000	-0.001	-0.038	0.000	0.000
ME	-0.063	-0.005	-0.160	-0.128	0.063	0.016	-0.053	-0.015	-0.002	0.447	-0.067

Table S10. Comparison of GWP_{20} and GWP_{100} estimates, due to regional changes in NMVOC emissions, to the multimodel mean ± 1 standard deviation of Fry et al. (2012), where the regional definitions differ slightly.

	Current study		Fry et al. (2012)	
Source Region	GWP_{20}	GWP_{100}	GWP_{20}	GWP_{100}
North America	9.20	3.27	15.5 ± 6.8	4.80 ± 2.35
Europe	5.36	2.05	17.2 ± 7.1	5.33 ± 2.47
East Asia	-1.13	0.08	15.7 ± 5.0	4.82 ± 1.73
South Asia	12.7	4.08	26.5 ± 5.3	8.31 ± 1.92

Table S11. Comparison of global and regional anthropogenic (including biomass burning emissions) and total NO_x (Tg N yr^{-1}) and NMVOC (Tg C yr^{-1}) emissions from the base simulations to the multimodel mean ±1 standard deviation of Fiore et al. (2009), where the regional definitions differ slightly.

	Current study					Fiore et al. (2009)				
	Global	NA	EU	EA	IN	Global	NA	EU	EA	SA
Anthropogenic NO_x	37.8	6.6	3.7	6.8	2.0	32.5 ±6.0	7.4 ±0.4	7.3 ±0.6	6.0 ±1.4	2.4 ±0.4
Total NO_x	45.8	7.5	4.2	7.4	2.5	46.5 ±5.7	8.5 ±0.8	8.4 ±1.1	7.1 ±1.4	3.3 ±0.5
Anthropogenic NMVOC	129.3	12.4	7.7	21.0	8.0	96.8 ±41.8	16 ±7.0	19.0 ±11	16 ±6.5	10 ±3.9
Total NMVOC	974.5	86.2	17.8	45.3	26.4	630 ±221	62 ±24	37 ±13	48 ±14	33 ±8.8

Table S12. Comparison of global tropospheric CH_4, O_3, and SO_4^{2-} responses per unit emissions from 4 regional reductions to the multimodel mean ±1 standard deviation of Fry et al. (2012), where the regional definitions differ slightly.

	Current study				Fry et al. (2012)			
	NA	EU	EA	IN	NA	EU	EA	SA
Global CH_4 (ppbv (Tg C $yr^{-1})^{-1}$)	0.80	0.61	0.40	0.65	0.50 ±0.54	0.45 ±0.41	0.46 ±0.42	0.86 ±0.34
Global O_3 (Tg O_3 (Tg C $yr^{-1})^{-1}$)	0.059	0.082	0.088	0.061	0.12 ±0.05	0.12 ±0.05	0.12 ±0.04	0.11 ±0.04
Global SO_4^{2-} (Gg SO_4^{2-} (Tg C $yr^{-1})^{-1}$)	0.32	0.60	1.01	0.0092	-0.12 ± 0.43	0.11 ± 0.69	-0.40 ±0.38	-0.039 ±0.18