Supplement of Atmos. Chem. Phys., 17, 2709–2720, 2017
http://www.atmos-chem-phys.net/17/2709/2017/
doi:10.5194/acp-17-2709-2017-supplement

Atmospheric Chemistry and Physics Open Access EGU

Supplement of

Multi-model simulations of aerosol and ozone radiative forcing due to anthropogenic emission changes during the period 1990–2015

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Supplementary material

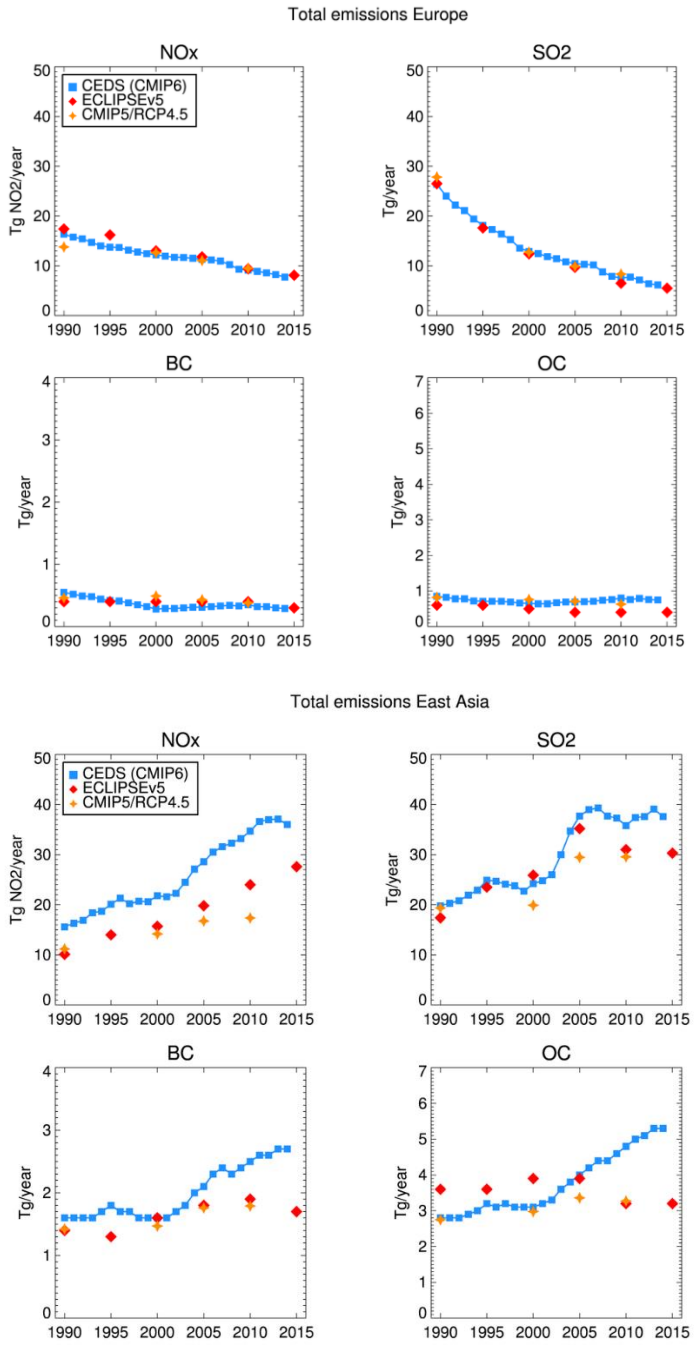

Figure S1: European and east Asian emissions of NOx, SO2, BC and OC for ECLIPSEv5 [*Klimont et al.*, 2016], data applied in Coupled Model Intercomparison Project (CMIP5) [*Lamarque et al.*, 2010], and Community Emissions Data System (CEDS) to be used in CMIP6 (Hoesly et al. in preparations) over the period 1990-2015. Emissions from agricultural waste burning and international aviation and shipping are excluded. The regions follow HTAP2 definitions (www.htap.org/).

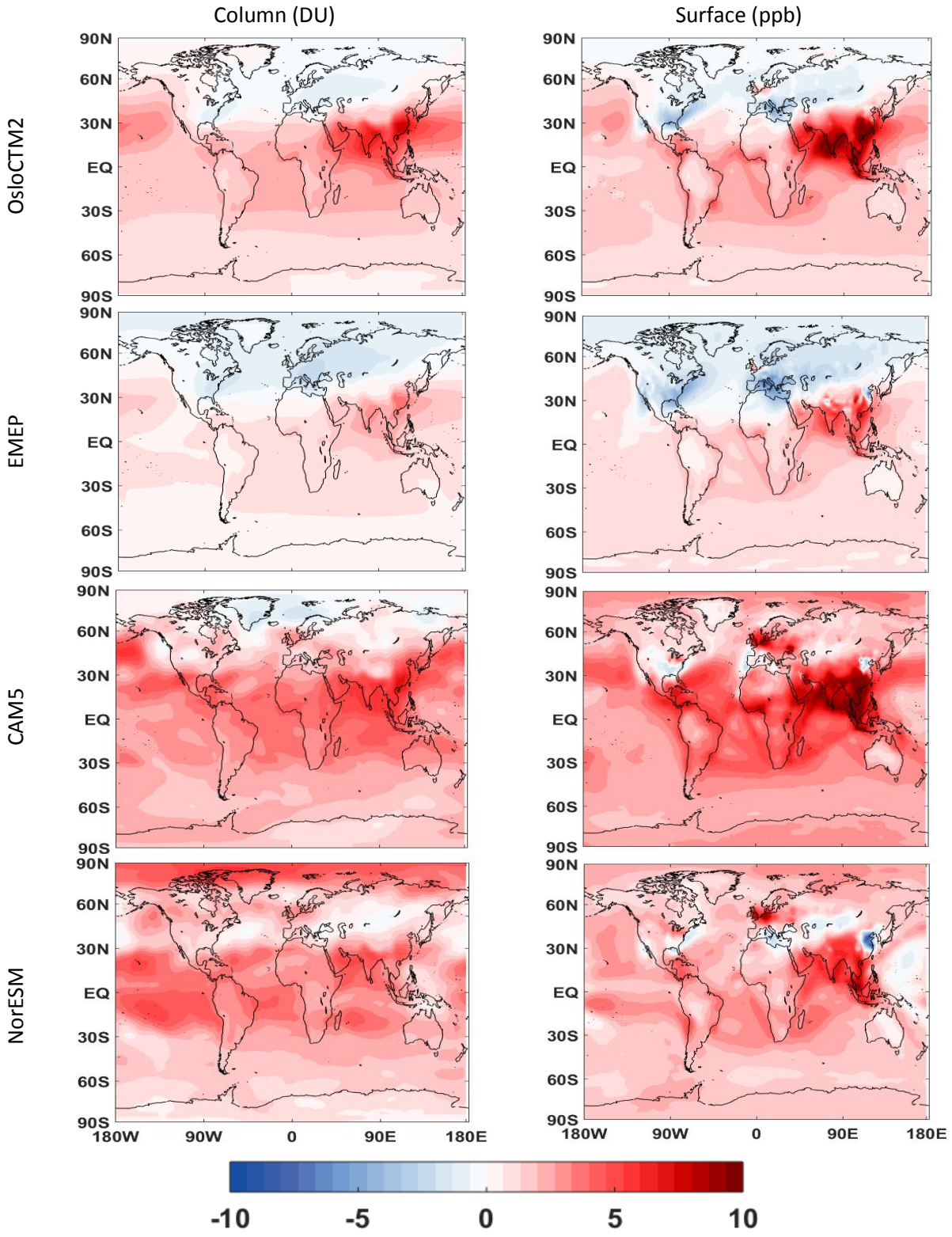

Figure S2: Tropospheric ozone column (Dobson units) and surface ozone changes (ppb) over the 1990-2015 period for four models. Tropopause assumed at ~100 hPa for 30S-30N and ~200 hPa elsewhere. CAM5 and NorESM are 3 year averages (1990:1992 vs. 2013:2015).

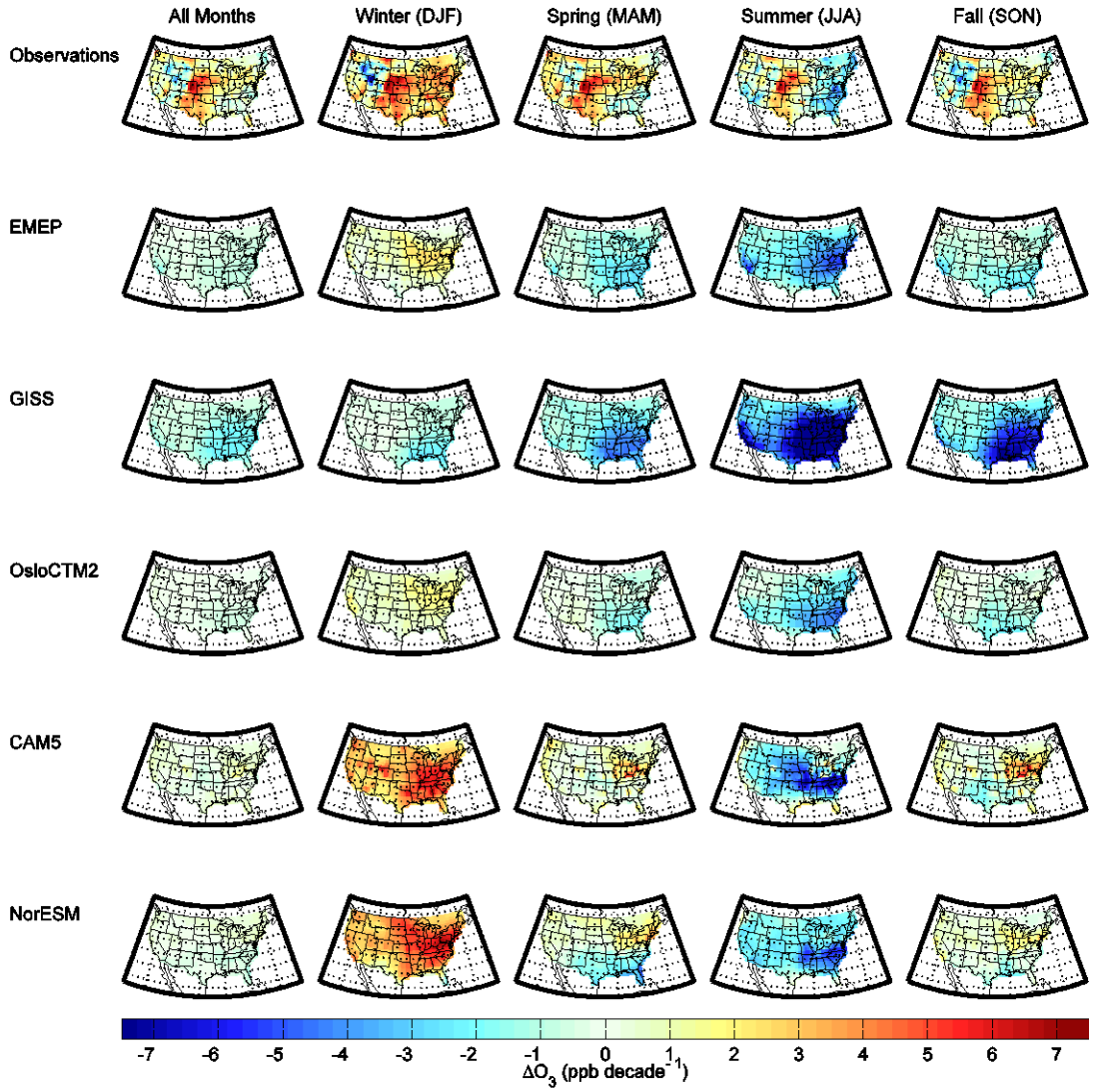

Figure S3. Surface ozone changes (ppb decade^{-1}) in observations and five models over the US. Trends in the observations, CAM5, and NorESM are with respect to 1993-2013. Trends in EMEP, GISS-E2-R, and OsloCTM2 are derived from 5-year intervals from 1990-2015.

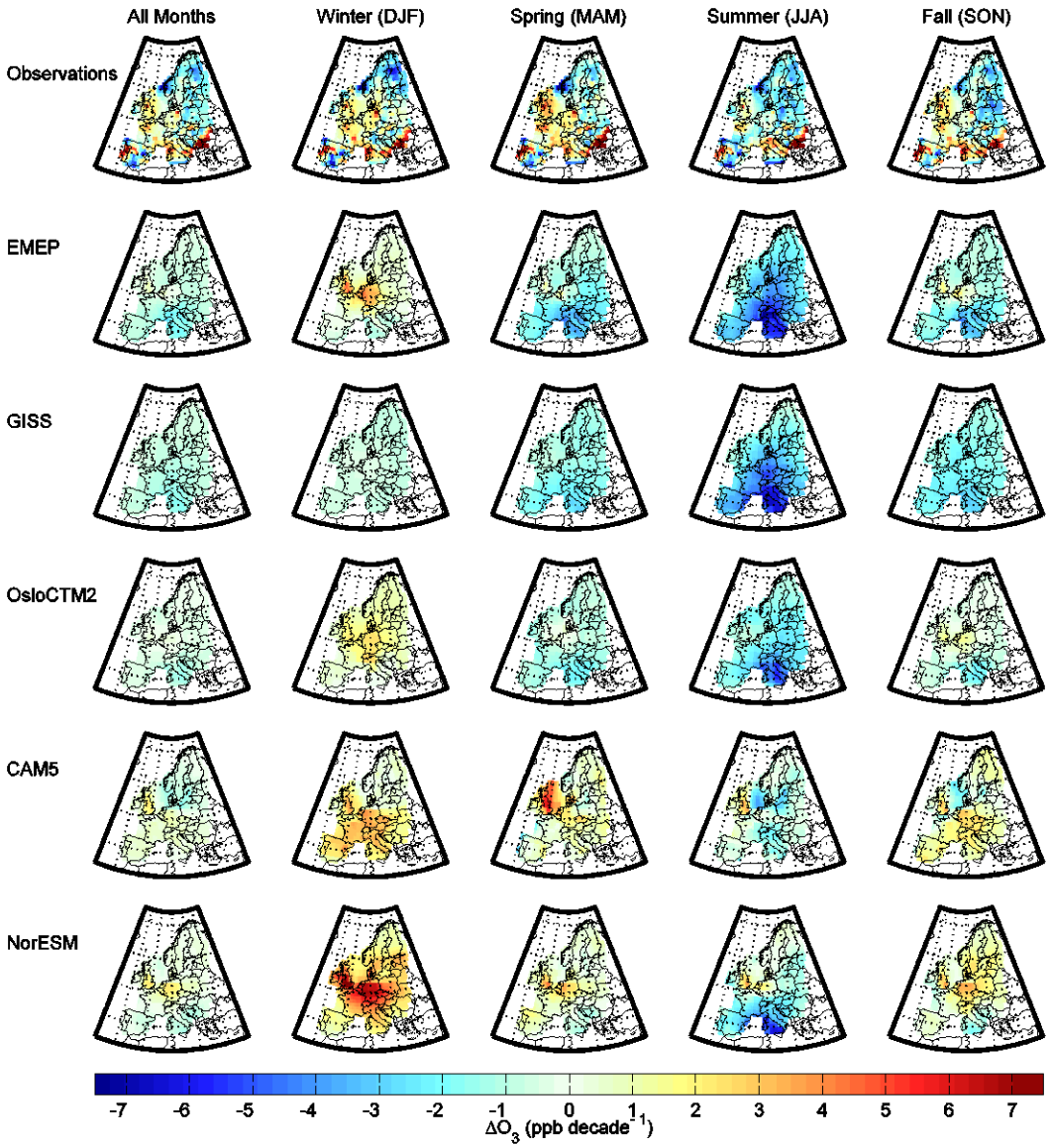

Figure S4. Surface ozone changes (ppb decade^{-1}) in observations and five models over Europe. Trends in the observations, CAM5, and NorESM are with respect to 1997-2013. Trends in EMEP, GISS-E2-R, and OsloCTM2 are derived from 5-year intervals from 1995-2015.

Table S1. Surface ozone trends (ppb decade^{-1}) for the observations (OBS), 5 global CCMs, and the model ensemble mean (EM) averaged over the US, Western US, Eastern US, Europe, Southern Europe, and Northern Europe with respect to the annual mean (ALL), winter (DJF), spring (MAM), summer (JJA), and fall (SON) months.

Region	*Months*	OBS[a]	EMEP[b]	GISS-E2-R[b]	OsloCTM2[b]	CAM5[a]	NorESM[a]	Model Mean[c]
US[d]	All	1.2	-1.0	-3.0	-0.5	0.6	0.4	-0.7
	DJF	2.3	0.9	-0.8	0.9	3.4	3.6	1.6
	MAM	1.6	-1.3	-2.2	-0.5	0.6	0.0	-0.7
	JJA	0.1	-2.5	-5.6	-1.9	-2.2	-2.3	-2.9
	SON	1.0	-1.1	-3.4	-0.5	0.5	0.3	-0.8
Western US	All	1.6	-0.8	-2.0	-0.2	0.3	0.3	-0.5
	DJF	1.8	0.6	-0.3	0.7	2.9	3.0	1.4
	MAM	2.1	-0.9	-1.5	0.0	0.3	-0.1	-0.4
	JJA	1.2	-1.8	-4.1	-1.2	-2.0	-1.8	-2.2
	SON	1.1	-1.0	-2.2	-0.3	-0.1	0.3	-0.7
Eastern US	All	0.9	-1.3	-4.0	-0.8	0.9	0.4	-0.9
	DJF	2.8	1.2	-1.2	1.1	4.0	4.2	1.9
	MAM	1.0	-1.8	-3.0	-1.0	0.9	0.0	-1.0
	JJA	-1.2	-3.2	-7.1	-2.6	-2.3	-2.9	-3.7
	SON	0.9	-1.2	-4.6	-0.7	1.1	0.2	-1.0
Europe[e]	All	-0.1	-1.3	-1.7	-0.6	0.7	0.8	-0.4
	DJF	0.1	0.7	-0.6	1.0	1.6	2.8	1.1
	MAM	0.5	-1.6	-1.5	-1.0	1.0	0.5	-0.5
	JJA	-0.8	-3.1	-3.0	-2.1	-0.6	-1.1	-2.0
	SON	-0.1	-1.3	-1.8	-0.3	0.8	0.8	-0.4
Southern Europe	All	0.7	-1.7	-2.1	-0.8	1.0	0.6	-0.6
	DJF	0.9	0.7	-0.6	1.0	2.3	3.2	1.3
	MAM	1.2	-2.1	-1.8	-1.2	0.8	0.6	-0.7
	JJA	0.0	-3.6	-3.8	-2.5	-0.6	-1.9	-2.5
	SON	0.7	-1.6	-2.1	-0.5	1.3	0.6	-0.5
Northern Europe	All	-1.1	-0.9	-1.3	-0.3	0.3	0.9	-0.3
	DJF	-1.0	0.7	-0.7	1.2	0.6	2.4	0.8

	MAM	-0.5	-1.0	-1.2	-0.7	1.2	0.4	-0.3
	JJA	-1.8	-2.3	-2.0	-1.6	-0.7	-0.2	-1.4
	SON	-1.0	-0.9	-1.5	-0.1	0.1	1.1	-0.3

[a]Trends calculated over 1993-2013 in US and 1997-2012 in Europe.

[b]Trends calculated using 5 year intervals from 1990 to 2015 in US and 1995 to 2015 in EU.

[c]The model mean is calculated by averaging each model's trend at each grid cell, then averaged over the region.

[d]The US domain is split into western and eastern regions at 96°W

[e]The Europe domain is split into southern and northern regions at 53°N

Supplementary text for describing the radiative forcing calculations for greenhouse gases.

The WMO greenhouse gas concentrations and their associated radiative forcing for 2015 (http://www.wmo.int/pages/prog/arep/gaw/ghg/GHGbulletin.html) and the 1990 values in IPCC AR5 [*Prather et al.*, 2013] have been combined to derived the radiative forcing over the 1990-2015 period.

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