

Auxiliary Materials for Fiore et al., 2008: Multi-model Estimates of Intercontinental Source-Receptor Relationships for Ozone Pollution

Model	Resolution (lon x lat x layers)	Institution	Model contact	Anthropogenic emission inventory for O₃ precursors	Driving meteorology (year 2001)
CAMCHEM-3311m13	2.5°x2°x30	NCAR, USA	Peter Hess	POET for 1997 ^a ; CO fossil fuel and biofuel from a MOPITT inversion ^b	NCEP
ECHAM5-HAMMOZ-v21	2.81°x2.81° x21	EPFL, Switzerland	Gerd Folberth	RETRO	ECMWF ERA-40
EMEP-rv26 (NH only)	1°x1°x20	EMEP, Norway	Jan Eiof Jonson, Peter Wind	IER / Uni-Stuttgart, based on EDGAR2000; EMEP	ECMWF ERA-40
FRSGC/UCI v01	2.81°x2.81°x 37	Lancaster University, UK	Oliver Wild	ACCENT/AR4 ^c	ECMWF IFS ^d
GEMAQ-EC	2°x2°x20	Environment Canada	Sunling Gong	AURAMS (regional Canadian, US and Mexico); EDGAR elsewhere	Canadian Meteorological Centre (CMC)
GEMAQ-v1p0	4°x4°x28	York University, Canada	Alexandru Lupu	EDGAR v2	CMC
GEOSChem-v07	2.5°x2°x30	Harvard University, USA	Rokjin Park	Bey et al., 2001 ^e	NASA GEOS-4
GEOSChem-v07-res4x5	5°x4°x30	CIEMAT, Spain	Marta Garcia Vivanco	EMEP emissions EPA/NEI99 inventory	NASA GEOS-4
GISS-PUCCINI-modelA	5°x4°x23	NASA GISS, USA	Drew Shindell	As for modelE below	NCEP, via linear relaxation
GISS-PUCCINI-modelE	5°x4°x23	NASA GISS, USA	Drew Shindell	ACCENT/AR4, with EA emissions of CO and NO _x times 1.66	NCEP, via linear relaxation
GMI-v02f	2.5°x2°x42	NASA GSFC, USA	Bryan Duncan	Harvard's merged inventory (NEI99, BRAVO, Streets, EMEP)	NASA GEOS-4
LMDz3-INCA1	3.75°x2.5° x19	LSCE, France	Sophie Szopa	RETRO	ECMWF-ERA40
LLNL-IMPACT-T5a	2.5°x2°x48	LLNL, USA	Cynthia Atherton, Dan Bergmann	POET	NASA GEOS4-ceres
MOZARTGFD L-v2	1.88°x1.88° x28	GFDL, USA	Arlene Fiore	EDGAR v2	NCEP
MOZECH-v16	2.81°x2.81° x31	FZ Julich, Germany	Martin Schultz, Sabine Schröder	RETRO	ECMWF ERA-40
OsloCTM2	2.81°x2.81° x40	University of Oslo, Norway	Michael Gauss	EDGAR v3.2	ECMWF-IFS
STOC-HadAM3-v01	5°x5°x19	University of Edinburgh, UK	Ian MacKenzie	ACCENT/AR4	HadAM3 GCM with observed 2001 SSTs and sea ice (PCMDI)
STOCHEM-HadGEM	3.75x2.5° x20	Met Office, Hadley Centre, UK	Kirsty Pringle, Michael Sanderson	ACCENT/AR4	HadGEM GCM with HadCM3 SSTs and sea ice
TM5-JRC-cy2-ipcc-v1	1°x1°x25	JRC, Italy	Frank Dentener, Elina Marmer	ACCENT/AR4	ECMWF
ULAQ-v02	5.625°x5°	Universita' degli	Veronica	ACCENT/AR4	GCM with

	x26	Studi de L'Aquila, Italy	Montanaro, Giovanni Pitari		Hadley Centre SSTs
UM-CAM-v01	3.75°x2.5° x19	University of Cambridge, UK	Guang Zeng	ACCENT/AR4	GCM with Hadley Centre SST and sea ice (GISST 2.0)

Table A1. Model resolution, institution, contact person, and brief description of the anthropogenic emission inventory and meteorology used in the HTAP simulations. For further description of model characteristics see: <http://www.mi.uni-hamburg.de>List-classification-and-detail-view-of-model-entr.567.0.html>.

- a) Granier, C. et al. (2004), Present and future surface emissions of atmospheric compounds, European Commission report EVK 2199900011. (Available at <http://www.aero.jussieu.fr/projet/ACCENT/POET.php>)
- b) Pétron, G., C. Granier, B. Khattatov, V. Yudin, J. Lamarque, L. Emmons, J. Gille, and D. P. Edwards (2004), Monthly CO surface sources inventory based on the 2000-2001 MOPITT satellite data, *Geophys. Res. Lett.*, 31, L21107, doi:10.1029/2004GL020560.
- c) Year 2000 emissions based on EDGAR v3.2, see Stevenson, D.S., et al. (2006), Multi-model ensemble simulations of present-day and near-future tropospheric ozone, *J. Geophys. Res.*, 111, D08301, doi:10.1029/2005JD006338.
- d) Integrated Forecast System: pieced-forecast fields for 2001 generated by Univ. of Oslo
- e) Bey, I., et al., Global modeling of tropospheric chemistry with assimilated meteorology: Model description and evaluation, *J. Geophys. Res.*, 106, 23,073-23,096, 2001.

MODEL	NO _x (Tg N a ⁻¹)					NMVOC (Tg C a ⁻¹)					CO (Tg a ⁻¹)				
	global	EU	NA	EA	SA	global	EU	NA	EA	SA	global	EU	NA	EA	SA
CAMCHEM-3311m13	43.4	9.2	8.2	6.8	3.4	829.2	60.6	92.4	55.5	36.7	1225	106	154	221	145
ECHAM5-HAMMOZ-v21	42.0	7.2	8.3	6.6	3.5						1122	85	107	154	124
EMEP-rv26	34.0	7.4	7.7	7.1	3.5						643	76	117	130	96
FRSGCUCI-v01	49.2	8.4	8.8	6.9	3.0	623.4	33.5	57.3	50.5	33.8	1078	74	131	129	74
GEMAQ-EC	39.3	12.1	5.5	6.6	2.6										
GEMAQ-v1p0	39.7	8.1	9.2	5.1	2.3	904.1	41.6	77.0	65.0	46.7	1175	166	168	159	112
GEOSChem-v07	45.5	7.9	9.0	6.4	3.7	597.7	15.8	51.7	34.8	21.1	909	90	115	193	88
GISS-PUCCINI-modelA	54.8	8.5	8.8	10.6	3.1	344.9	26.9	29.0	31.7	24.1	1094	70	117	191	74
GISS-PUCCINI-modelE	56.4	8.6	8.9	10.8	3.1	344.9	26.9	29.0	31.7	24.1	1018	69	111	170	67
GMI-v02f	44.4	7.5	8.0	5.8	3.1	563.2	32.0	60.1	42.0	31.6	1120	101	134	194	99
LMDZ3-INCA1	46.8	7.3	8.6	7.2	3.8	942.9	56.7	100.1	77.0	45.3	860	67	74	127	108
LLNL-IMPACT-T5a	54.9	9.7	8.8	7.3	4.2	632.1	23.3	53.2	36.2	30.7	1115	111	130	153	124
MOZARTGFDL-v2	41.9	8.6	9.4	5.2	2.6	732.9	32.4	68.7	48.9	36.8	1089	130	124	134	105
MOZECH-v16	46.3	7.4	8.9	7.0	3.6	926.2	44.7	107.0	62.0	36.9	1124	85	107	154	124
OsloCTM2	46.2	8.3	8.3	7.9	4.0	445.3	53.1	51.8	42.9	30.5	1060	100	134	164	111
STOC-HadAM3-v01	52.5	8.6	9.0	7.1	3.2	713.2	52.2	70.9	50.0	43.8	1099	74	129	127	76
STOCHEM-HadGEM	50.1	8.3	8.7	6.8	2.8	867.5	45.8	75.3	66.4	40.8	1148	73	131	131	77
TM5-JRC-cy2-ipcc-v1	48.8	8.5	8.7	6.4	3.0	550.3	34.6	50.3	47.0	32.4	1076	75	127	123	74
ULAQ-v02	44.7	8.0	8.2	7.0	3.6	141.3	24.7	19.9	26.2	14.2	1186	79	145	150	77
UM-CAM-v01	49.4	8.7	8.9	7.0	3.3	616.9	32.7	56.4	47.4	34.6	1094	81	137	131	79
MEAN	46.5	8.4	8.5	7.1	3.3	629.9	37.3	61.5	47.7	33.2	1064	90	126	155	97
STD DEV	5.7	1.1	0.8	1.4	0.5	221.4	12.6	23.7	13.5	8.8	135	25	20	30	23
MEDIAN	46.2	8.4	8.7	6.9	3.3	623.4	33.5	57.3	47.4	33.8	1094	81	129	153	96

Table A2: Total emissions of O₃ precursors, globally and in the source-receptor regions in Figure 1.

MODEL	Anthrop. NO _x (Tg N a ⁻¹)					Anthrop. NMVOC (Tg C a ⁻¹)					Anthrop. CO (Tg a ⁻¹)				
	global	EU	NA	EA	SA	Global	EU	NA	EA	SA	global	EU	NA	EA	SA
CAMCHEM-3311m13	30.2	7.9	7.2	6.0	2.6	123.4	39.0	24.3	17.3	10.4	681	85	127	189	106
ECHAM5-HAMMOZ-v21	6.2	7.1	5.4	2.1								61	67	118	85
EMEP-rv26	7.2	7.3	6.6	3.0		6.7	7.5	7.2	4.8			75	117	128	94
FRSGCUCI-v01	28.6	7.4	7.3	5.5	2.1	116.0	21.3	15.6	19.2	11.4	471	67	95	95	62
GEMAQ-v1p0	26.6	7.6	8.2	4.5	1.8	85.9	20.1	12.9	13.2	12.3	685	153	121	130	100
GEOSChem-v07	28.5	7.0	7.6	5.5	2.5	56.4	6.4	12.5	13.9	7.9	546	85	107	174	61
GISS-PUCCINI-modelA	42.9	7.5	7.6	9.7	2.4	131.6	22.0	16.9	21.1	12.6	1094	70	117	191	74
GISS-PUCCINI-modelE	42.9	7.5	7.5	9.3	2.3	131.6	22.0	16.6	19.9	12.1	1018	69	111	170	67
GMI-v02f	38.7	6.8	7.5	5.4	2.4	65.0	6.2	12.4	13.2	8.7	931	91	114	182	91
LMDZ3-INCA1	28.0	6.3	7.1	5.4	2.2	93.1	20.5	24.3	17.4		476	62	67	114	86
LLNL-IMPACT-T5a	41.9	8.2	7.2	6.1	2.7	24.8	5.0	2.5	1.9	2.5	571	96	110	138	114
MOZARTGFDL-v2	29.8	8.3	8.8	4.7	2.1	49.6	10.6	6.6	7.8	8.2	556	111	100	112	72
MOZECH-v16	28.1	6.2	7.1	5.4	2.1	77.1	17.1	21.1	14.1	8.0	480	61	67	118	85
OsloCTM2	36.8	7.3	7.4	7.3	3.4	205.3	46.5	32.6	28.6	20.5	815	83	111	146	100
STOC-HadAM3-v01	27.8	7.7	7.4	5.6	2.2	94.3	21.6	15.6	19.2	11.4	471	69	97	97	63
STOCHEM-HadGEM	27.8	7.2	7.0	5.4	2.1	97.8	21.4	15.8	19.4	11.5	470	66	94	94	61
TM5-JRC-cy2-ipcc-v1	28.3	7.5	7.3	5.5	2.2	113.5	24.5	17.7	24.1	14.1	471	67	96	95	61
ULAQ-v02			7.1	5.7	2.4										
UM-CAM-v01	28.9	7.6	7.1	5.6	2.2	86.9	19.7	14.2	17.8	10.3	477	69	99	97	63
MEAN	32.5	7.3	7.4	6.0	2.4	96.8	19.4	15.7	16.1	10.4	661	80	101	133	80
STD DEV	6.0	0.6	0.4	1.4	0.4	41.8	11.1	7.1	6.5	3.9	214	23	19	35	18
MEDIAN	29.4	7.5	7.3	5.5	2.2	92.3	20.1	15.6	17.3	10.4	563	70	103	123	79

Table A3: Same as Table A2 but for anthropogenic emissions. Regional anthropogenic emissions were taken from the difference between the total emissions reported in SR1 vs SRNxx multiplied by 5 (SR3xx, SR4xx, and SR5xx were used preferentially over SR6xx); for global anthropogenic emissions (and regional if none were available via the previous approach) we used those reported as anthropogenic in the SR1 emissions file, or as communicated by the model contact in Table A1.

	NA	EU	EA	SA	# models
<i>-20% [CH₄] (SR2)</i>					
	-1.15(-1.11)±0.23	-1.25(-1.16)±0.30	-1.08(-1.07)±0.22	-1.32(-1.25)±0.24	18
<i>-20% NO_x Emissions (SR3)</i>					
NA	<i>-0.76(-0.76)±0.20</i>	-0.22(-0.21)±0.07	-0.12(-0.12)±0.03	-0.10(-0.10)±0.03	17
EU	-0.08(-0.09)±0.03	-0.46(-0.40)±0.21	-0.12(-0.12)±0.04	-0.15(-0.14)±0.04	16
EA	-0.11(-0.12)±0.04	-0.08(-0.09)±0.03	-0.62(-0.63)±0.17	-0.09(-0.09)±0.04	17
SA	-0.03(-0.03)±0.02	-0.04(-0.03)±0.02	-0.10(-0.08)±0.03	-1.07(-1.06)±0.21	17
<i>-20% NMVOC Emissions (SR4)</i>					
NA	-0.29(-0.28)±0.14	-0.11(-0.10)±0.05	-0.07(-0.07)±0.03	-0.05(-0.04)±0.03	14
EU	-0.10(-0.10)±0.05	-0.47(-0.44)±0.26	-0.13(-0.13)±0.06	-0.10(-0.11)±0.06	15
EA	-0.07(-0.08)±0.03	-0.06(-0.06)±0.03	-0.31(-0.30)±0.14	-0.04(-0.05)±0.02	14
SA	-0.03(-0.02)±0.02	-0.03(-0.02)±0.02	-0.06(-0.03)±0.11	-0.18(-0.18)±0.10	13
<i>-20% CO Emissions (SR5)</i>					
NA	<i>-0.10(-0.10)±0.02</i>	-0.06(-0.06)±0.02	-0.04(-0.04)±0.01	-0.03(-0.03)±0.01	14
EU	-0.03(-0.03)±0.01	-0.11(-0.10)±0.05	-0.04(-0.03)±0.01	-0.03(-0.03)±0.01	15
EA	-0.05(-0.04)±0.02	-0.05(-0.04)±0.02	-0.13(-0.12)±0.03	-0.04(-0.04)±0.01	14
SA	-0.02(-0.02)±0.00	-0.02(-0.02)±0.00	-0.03(-0.03)±0.00	-0.10(-0.09)±0.03	14
<i>-20% ALL Emissions (SR6 = NO_x+NMVOC+CO+aerosols)</i>					
NA	-1.04(-1.03)±0.23	-0.37(-0.37)±0.10	-0.22(-0.24)±0.05	-0.17(-0.19)±0.04	15
EU	-0.19(-0.18)±0.06	-0.82(-0.68)±0.29	-0.24(-0.24)±0.08	-0.24(-0.25)±0.05	15
EA	-0.22(-0.23)±0.06	-0.17(-0.17)±0.05	-0.91(-0.86)±0.23	-0.17(-0.17)±0.05	15
SA	-0.07(-0.07)±0.03	-0.07(-0.07)±0.03	-0.14(-0.13)±0.03	-1.26(-1.18)±0.26	15

Table A4. The model ensemble annual mean change in surface O₃ (ppb) averaged over the receptor regions (columns) to 20% decreases in global CH₄ concentrations (SR2) and in O₃ precursor emissions (SR3 through SR6) in the source regions (rows). The median model response is given in parentheses, followed by the standard deviation across the models. Responses to domestic emissions are italicized; foreign SR responses >10% of the domestic mean response are shown in bold.

RECEPTOR REGION	NA (MAM)			EU (MAM)			EA (MAM)			SA (SON)		
SOURCE REGION (xx)	EU	EA	SA	NA	EA	SA	NA	EU	SA	NA	EU	EA
FRSGCUCI-v01	0.03	0.03	0.00	0.00	-0.03	0.00	0.00	0.02	-0.07	0.00	0.04	0.05
GEMAQ-v1p0	0.03	0.00	0.00	0.00	0.04	0.06	0.04	0.05	0.05	0.00	0.00	0.04
STOC-HadAM3-v01	0.03	0.03	0.00	0.00	0.00	0.00	-0.03	0.00	0.00	0.00	0.00	0.04
UM-CAM-v01	0.03	0.00	0.00	0.02	0.00	0.00	-0.03	0.00	-0.04	0.00	0.00	0.00
EMEP-rv26	0.12	0.11	1.43	0.11	0.04	1.13	0.10	0.13	3.14	0.00	0.08	0.08
GISS-PUCCINI-modelE	0.00	0.00	0.00	0.04	0.00	0.00	0.06	0.00	0.06	0.00	0.00	0.00
GMI-v02f	0.21	0.24	0.17	0.15	0.22	0.33	0.10	0.35	0.13	0.05	0.10	0.15
CAMCHEM-3311m13	0.20	0.24	0.14	0.14	0.17	0.00	0.13	0.21	0.29	0.11	0.24	0.17
MOZARTGFDL-v2	0.16	0.29	0.00	0.21	0.30	0.25	0.20	0.19	0.14	0.20	0.41	0.08
TM5-JRC-cy2-ipcc-v1	0.32	0.23	0.57	0.32	0.23	0.33	0.44	0.30	0.46	0.50	0.43	0.14
median(bold models)	0.03	0.01	0.00	0.00	0.00	0.00	-0.02	0.01	-0.02	0.00	0.00	0.04
median (non-bold models)	0.18	0.23	0.16	0.15	0.19	0.29	0.11	0.20	0.21	0.08	0.17	0.11

Table A5. Additivity of single species versus multi-species emissions perturbations, during the season of maximum intercontinental influence. Additivity is estimated here as ratio-1, where the ratio is the sum of the surface O₃ responses in the receptor region resulting from individual 20% decreases in anthropogenic NO_x, VOC, and CO emissions in the foreign source regions (SR3xx-SR1)+(SR4xx-SR1)+(SR5xx-SR1) divided by the surface O₃ response resulting from combined 20% decreases in the O₃ precursor emissions (SR6xx-SR1). A positive value thus indicates a more-than-linear relationship (*i.e.*, the sum of the ozone responses to the single species perturbations is larger than the ozone response to multi-component emissions changes) and negative values indicate less-than-linear responses. Models shown in bold do not include changes in emissions of aerosol and precursors in the SR6 simulations. Aerosol-oxidant interactions through chemistry and radiation are included in GMI and CAMCHEM, while the remaining models include only chemical interactions. Median values are given for two groups of models based on inclusion of aerosol emission reductions in SR6. These results suggest that the aerosol reductions included in the SR6 simulations tend to decrease the ozone response relative to the response without coincident changes in aerosol emissions.

	NA	EU	EA	SA
NA	0.15	0.16	0.14	0.17
EU	0.14	0.16	0.13	0.16
EA	0.17	0.18	0.16	0.20
SA	0.15	0.17	0.14	0.18

Table A6. Surface O₃ decrease (ppb) over the receptor regions (columns) resulting from a 20% reduction in regional anthropogenic CH₄ emissions in the source regions (rows), estimated using the model ensemble mean response to the 20% decrease in global CH₄ abundance (Table A4), the ensemble mean feedback factor (Table 2 in the main text), and the EDGAR 3.2 FT2000 emissions inventory [Olivier *et al.*, 2005] as described in Section 5.3.

Olivier, J. G. J., *et al.* (2005), Recent trends in global greenhouse gas emissions: Regional trends and spatial distribution of key sources, in Non-CO₂ Greenhouse Gases (NCGG-4), edited by A. van Amstel, pp. 325– 330, Millpress, Rotterdam, Netherlands.

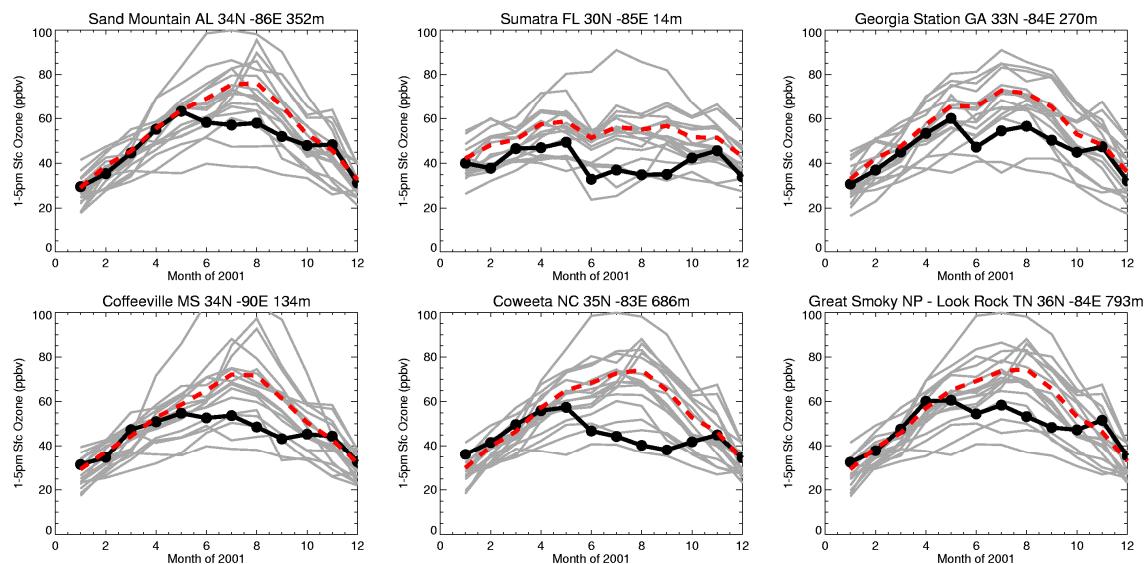


Figure A1. Afternoon (1-5p.m. local time) mean surface O₃ concentrations (ppb) at the Southeastern CASTNet sites for the observations (black circles), individual models (grey lines) and the model ensemble mean (red dashed line). Results are included from the following models: CAMCHEM, ECHAM5-HAMMOZ, EMEP, FRSGC/UCI, GEMAQ-EC, GEMAQ-v1p0, GEOSChem-v07, GEOSChem-4x5, GISS-PUCCINI-modelE, GMI-v02f, LMDz3-INCA1, LLNL-IMPACT, MOZARTGFDL, MOZECH, OsloCTM2, TM5-JRC, UM-CAM.

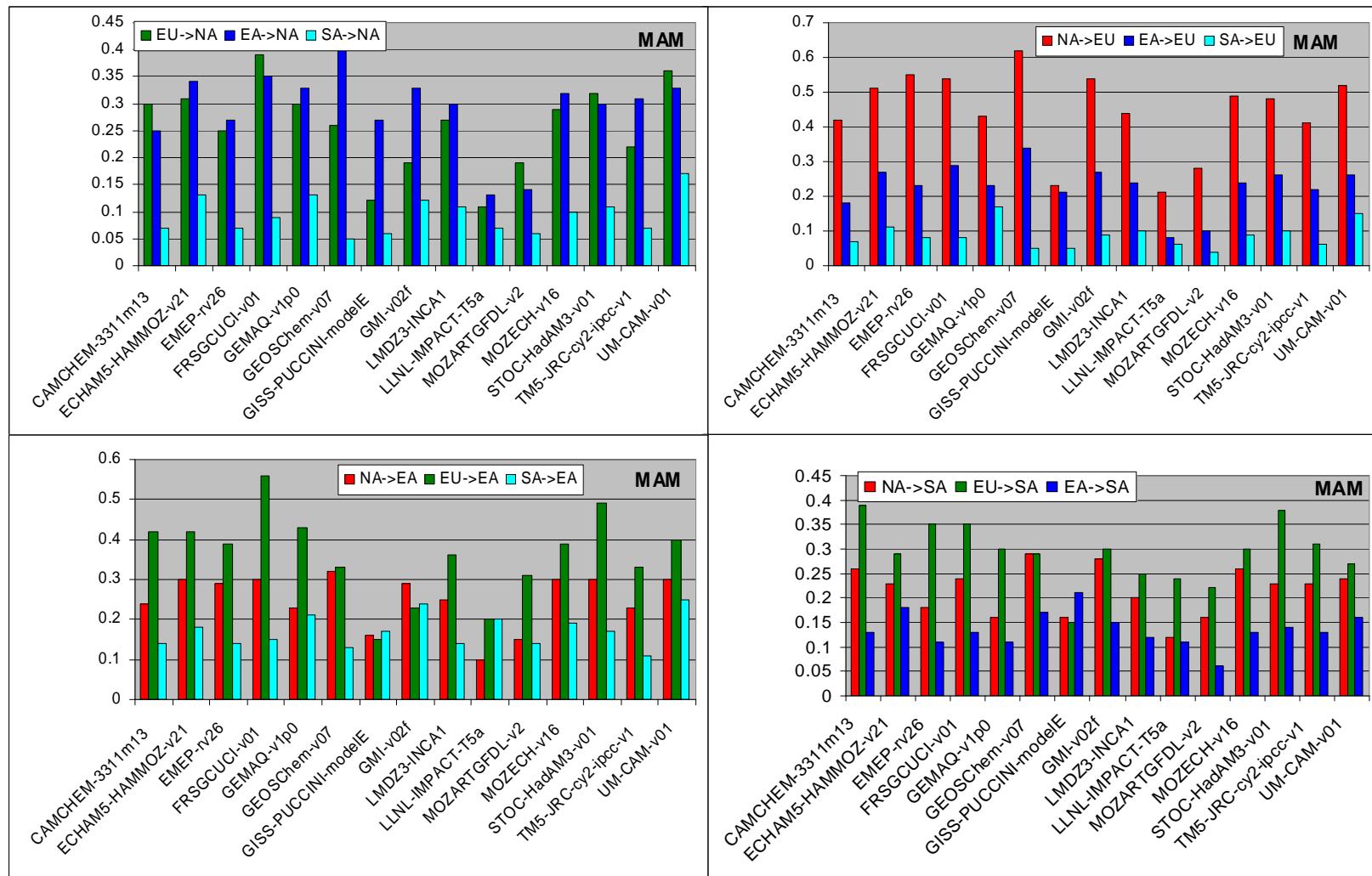


Figure A2. Decrease in surface O₃ resulting from combined 20% decreases in anthropogenic NO_x, CO, and NMVOC emissions (SR1-SR6) in each foreign source region during spring (March-April-May).

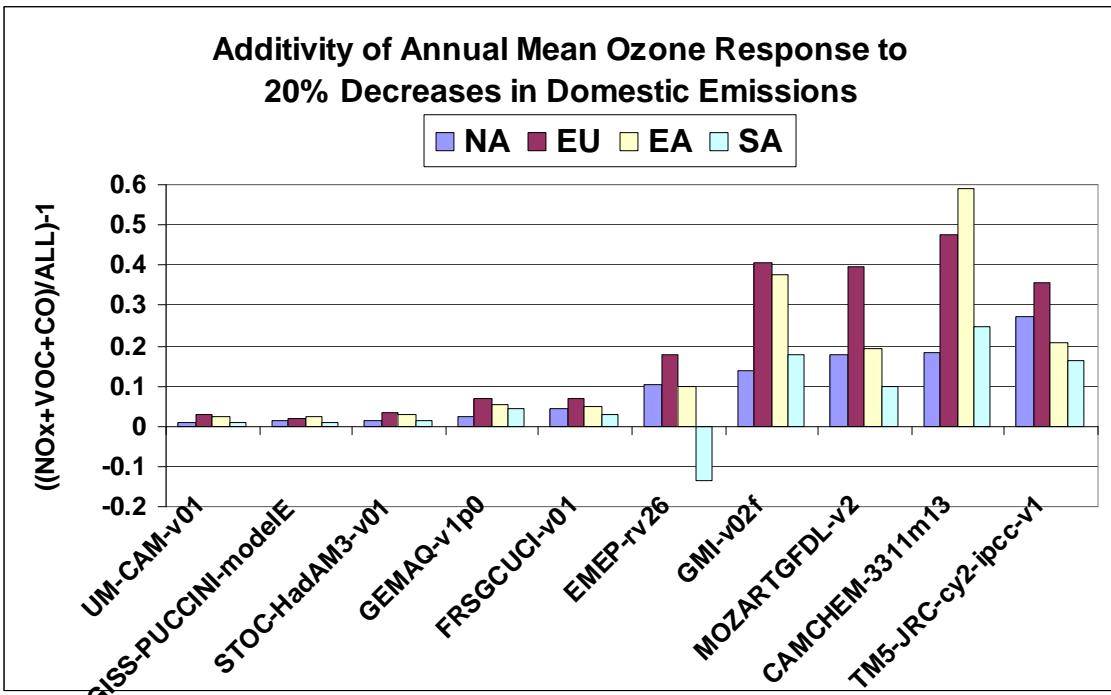


Figure A3. The ratio of the sum of the surface O₃ response in the receptor regions resulting from individual 20% decreases in domestic anthropogenic NO_x, VOC, and CO emissions (SR3+SR4+SR5) to the response resulting from combined 20% decreases in all domestic precursor emissions (SR6), minus one. All models indicate a more-than-linear relationship (*i.e.*, positive ratio) except for the SA response in the EMEP model (negative). The models are ranked according to the additivity of the responses over NA. The models which also include emission reductions of aerosols and their precursors in SR6 are GISS-PUCCINI-modelE, EMEP-rv26, GMI-v02f, MOZARTGFDL-v2, CAMCHEM-3311m13, TM5-JRC-cy2-ipcc-v1; models without aerosol interactions all indicate additivity to within 7%.

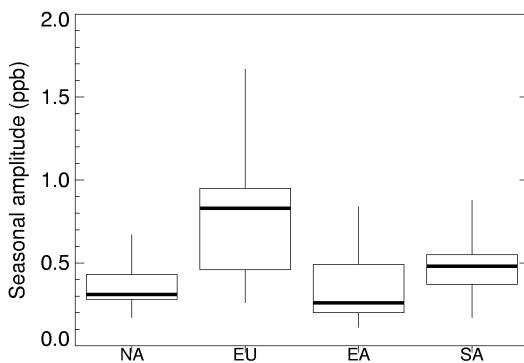


Figure A4. Seasonal amplitude (difference of months with maximum and minimum values) of the surface O₃ response to a 20% decrease in atmospheric CH₄ (SR2-SR1) in each receptor region (ppb), for the median (thick horizontal line) and full range of the responses in the 18 models (vertical line). The boxes enclose the 25th to 75th percentiles.