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*Supplement of*

## **Global and regional radiative forcing from 20 % reductions in BC, OC and SO<sub>4</sub> – an HTAP2 multi-model study**

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**Table S-1:** Model treatment of OA/OC and aerosol schemes.

	Submitted OC or OA	SOA treatment	Aerosol parametrization
<b>SPRINTARS</b>	OA	SOA included in OA	An aerosol module in SPRINTARS predicts mass mixing ratios of the main tropospheric aerosols: carbonaceous (BC and organic matter; OM), sulfate, soil dust, and sea salt, and the precursor gases of sulfate, i.e. sulfur dioxide (SO <sub>2</sub> ) and DMS. SPRINTARS is coupled with the radiation and cloud/precipitation schemes in the GCM for calculating the direct, semi-direct, and indirect effects of aerosols. In the calculation of the direct effect, the refractive indices depending on wavelengths, size distributions, and hygroscopic growth are considered for each type of aerosol. The aerosol semi-direct effect is also included as a consequence of a link between the GCM and aerosol module. Number concentrations for cloud droplets and ice crystals are prognostic variables as well as their mass mixing ratios, and changes in their radii and precipitation rates are calculated for the indirect effect. More detailed descriptions of SPRINTARS can be found in Takemura et al. (2000) for the aerosol transport, Takemura et al. (2002) for the aerosol direct effect, and Takemura et al. (2005) for the aerosol indirect effect on water and ice clouds.
<b>OsloCTM3</b>	OC	SOA not included in OC	Bulk parameterization of carbonaceous aerosols with conversion from hydrophobic to hydrophilic mode determined by latitudinally and seasonally varying aging timescales (Skeie et al., 2011). Coupled sulfur cycle/oxidant chemistry scheme (Berglen et al. 2004).
<b>GOCART</b>	OC	---	Aerosol particle sizes from 0.01 to 10 μm are included with parameterized hygroscopic growth, which depends on the ambient relative humidity (RH) and aerosol type. The only wet phase chemistry in GOCART is SO <sub>2</sub> +H <sub>2</sub> O <sub>2</sub> → sulfate, where H <sub>2</sub> O <sub>2</sub> is a prescribed field from the GEOS-Chemistry Climate Model.
<b>C-IFS</b>	OC	---	The MACC aerosol scheme is a bulk scheme with 3 size bins for desert dust and sea-salt, organic and black carbon as well as sulphate and SO <sub>2</sub> (Morcrette et al., 2009).
<b>CHASER-T42</b>	OC	---	The chemical component of CHASER calculates aerosols in cooperation with SPRINTARS, and considers chemical processes/interactions of aerosols including nitrate formation based on ISORROPIA as well as sulfate formation. An aerosol module in SPRINTARS predicts mass mixing ratios of the main tropospheric aerosols, see the aerosol parametrization for SPRINTARS above for further details.
<b>CHASER-T106</b>	OC	---	(as above)
<b>CAMchem</b>	OA	SOA included in OA	CAM4-chem uses a bulk aerosol scheme for black carbon, organic carbon, sulfate, ammonium and ammonium nitrate. Sea salt and dust each have 4 size bins and emissions are calculated online. SOA are derived using the 2-product model approach using laboratory-determined yields for SOA formation from photooxidation of monoterpenes, isoprene and aromatics.
<b>GEOS5</b>	OA	---	GEOS5 considers two OA tracers (i.e. hydrophilic and hydrophobic) and convert hydrophobic OA to hydrophilic OA in 2.5 days. Aerosol particle sizes from 0.01 to 10 μm are included with parameterized hygroscopic growth, which depends on the ambient relative humidity and aerosol type. The only wet phase chemistry in GEOS5-GOCART is SO <sub>2</sub> +H <sub>2</sub> O <sub>2</sub> → sulfate, where H <sub>2</sub> O <sub>2</sub> is a prescribed field from the GEOS-Chemistry Climate Model.
<b>GEOSCHEM ADJOINT</b>	OC	---	sulfate, sulfate on surface of sea-salt aerosol, inorganic nitrate, inorganic nitrates on surface of sea-salt aerosol, ammonium, hydrophilic BC, hydrophobic BC, hydrophilic OC, hydrophobic OC, dust (4 bins), accumulation mode sea salt, coarse mode sea salt
<b>EMEPrv48</b>	OC	---	Two size-modes for particles, although our definitions of particle-size depend a little on the compound.

**Table S-2:** BC burden (BD) changes and direct radiative forcing (DRF), global, annual mean, when reducing emissions by 20 % within the indicated region. DRF was calculated using full 4D AFE profiles. Burden is given in  $\text{mgm}^{-2}$  and radiative forcing is given in  $\text{mWm}^{-2}$ .

Model	NAM		EUR		SAS		EAS		RBU		MDE	
	BD	DRF	BD	DRF	BD	DRF	BD	DRF	BD	DRF	BD	DRF
OsloCTM3	-1.3	-2.2	-1.3	-2.7	-7.1	-11.0	-7.7	-12.4	-0.3	-0.5	-0.25	-0.44
GEOS5	-1.8	-3.1	-1.5	-2.3	-9.5	-17.9	-10.3	-17.3	-0.5	-0.8	---	---
CHASERT42	-3.1	-4.6	-3.2	-4.7	-15.9	-26.4	-16.2	-24.4	-0.7	-1.0	-0.0	0.3
CHASERT106	-2.5	-3.2	-2.7	-3.3	-12.3	-17.6	-13.2	-16.1	---	---	---	---
GOCART	-2.1	-3.5	-2.2	-3.3	-13.4	-30.9	-14.2	-26.3	-0.6	-0.0	-0.3	-0.5
SPRINTARS	-1.5	-2.5	-2.0	-3.6	-14.7	-22.4	-14.9	-20.9	-1.5	-2.55	-1.4	-2.5
CAMchem	-1.4	-1.9	-1.7	-2.3	-7.9	-11.9	-8.9	-11.9	-0.4	-0.5	-0.2	-0.2
C-IFS	-1.5	-1.8	-1.2	-1.5	-7.1	-9.7	-6.7	-7.8	---	---	---	---
GEOSCHEM	-1.5	-2.4	-1.4	-1.9	-9.1	-18.4	-9.8	-15.9	-0.4	-0.5	-0.2	-0.4
EMEPv48	---	---	---	---	---	---	---	---	---	---	---	---
<b>Mean</b>	<b>-1.9</b>	<b>-2.8</b>	<b>-1.9</b>	<b>-2.8</b>	<b>-10.8</b>	<b>-18.5</b>	<b>-11.3</b>	<b>-17.0</b>	<b>-0.6</b>	<b>-0.8</b>	<b>-0.4</b>	<b>-0.6</b>
<b>Median</b>	<b>-1.5</b>	<b>-2.5</b>	<b>-1.7</b>	<b>-2.7</b>	<b>-9.5</b>	<b>-17.9</b>	<b>-10.3</b>	<b>-16.1</b>	<b>-0.5</b>	<b>-0.5</b>	<b>-0.2</b>	<b>-0.4</b>
<b>Std.dev.</b>	<b>0.6</b>	<b>0.9</b>	<b>0.6</b>	<b>0.9</b>	<b>3.2</b>	<b>6.6</b>	<b>3.2</b>	<b>5.7</b>	<b>0.4</b>	<b>0.8</b>	<b>0.4</b>	<b>0.9</b>

**Table S-3:** OA burden (BD) changes and direct radiative forcing (DRF), global, annual mean, when reducing emissions by 20 % within the indicated region. DRF was calculated using full 4D AFE profiles. Burden is given in  $\text{mgm}^{-2}$  and radiative forcing is given in  $\text{mWm}^{-2}$ .

Model	NAM		EUR		SAS		EAS		RBU		MDE	
	BD	DRF	BD	DRF	BD	DRF	BD	DRF	BD	DRF	BD	DRF
OsloCTM3	-5.7	0.9	-6.3	0.8	-39.3	7.1	-35.1	5.0	-2.8	0.3	-0.6	0.1
GEOS5	-6.8	1.1	-6.5	0.9	-64.4	11.5	-53.56	7.36	-1.1	0.0	---	---
CHASERT42	-16.7	3.2	-11.5	1.9	-118.5	21.6	-65.4	10.3	-2.5	0.4	-1.2	0.2
CHASERT106	-11.8	2.3	-8.8	1.5	-82.1	15.0	-50.0	7.6	---	---	---	---
GOCART	-5.0	0.8	-4.1	0.5	-48.6	8.6	-39.6	5.6	-1.5	0.2	-0.5	0.1
SPRINTARS	-6.8	1.3	-6.0	1.0	-48.8	9.1	-41.4	6.6	0.7	-0.2	-1.5	0.2
CAMchem	-5.1	0.9	-4.6	0.7	-30.4	5.5	-23.0	3.2	-0.4	0.0	0.0	-0.0
C-IFS	-3.7	0.7	-3.0	0.5	-32.1	5.8	-20.3	3.0	---	---	---	---
GEOSCHEM	-3.9	0.6	-4.0	0.5	-35.0	6.3	-30.2	4.2	-1.0	0.1	-0.5	0.1
EMEPv48	-11.2	2.0	-8.5	1.4	-35.1	7.0	-29.0	4.5	---	---	---	---
<b>Mean</b>	<b>-7.3</b>	<b>1.3</b>	<b>-6.1</b>	<b>0.9</b>	<b>-55.5</b>	<b>10.1</b>	<b>-39.8</b>	<b>5.9</b>	<b>-1.2</b>	<b>0.1</b>	<b>-0.7</b>	<b>0.1</b>
<b>Median</b>	<b>-5.7</b>	<b>0.9</b>	<b>-6.0</b>	<b>0.8</b>	<b>-48.6</b>	<b>8.6</b>	<b>-39.6</b>	<b>5.6</b>	<b>-1.1</b>	<b>0.1</b>	<b>-0.6</b>	<b>0.1</b>
<b>Std.dev.</b>	<b>4.0</b>	<b>0.8</b>	<b>2.5</b>	<b>0.6</b>	<b>27.3</b>	<b>5.0</b>	<b>13.9</b>	<b>2.2</b>	<b>1.1</b>	<b>0.2</b>	<b>0.5</b>	<b>0.1</b>

**Table S-4:** SO<sub>4</sub> burden (BD) changes and direct radiative forcing (DRF), global, annual mean, when reducing emissions by 20 % within the indicated region. DRF was calculated using full 4D AFE profiles. Burden is given in mgm<sup>-2</sup> and radiative forcing is given in mWm<sup>-2</sup>.

Model	NAM		EUR		SAS		EAS		RBU		MDE	
	BD	DRF	BD	DRF	BD	DRF	BD	DRF	BD	DRF	BD	DRF
OsloCTM3	-34.7	7.5	-23.8	4.5	-42.6	9.9	-78.1	16.1	-13.2	2.3	-33.6	6.4
GEOS5	-27.2	6.3	-18.6	3.6	-61.3	13.5	-78.1	15.8	-12.0	2.3	---	---
CHASERT42	-67.1	17.8	-43.5	10.1	-111.2	27.1	-142.2	32.7	-19.2	4.7	-89.4	19.0
CHASERT106	-45.2	12.8	-34.0	8.0	-79.5	20.1	-91.7	21.8	---	---	---	---
GOCART	-28.2	6.2	-29.6	5.0	-30.8	7.5	-115.7	21.3	-19.1	2.8	-36.7	6.7
SPRINTARS	-47.3	13.0	29.8	6.9	-64.7	16.5	-140.4	35.5	-12.5	2.7	-58.7	12.7
CAMchem	-31.2	8.4	-23.9	5.4	-52.5	13.1	-81.2	16.8	-12.4	2.9	-55.7	10.9
C-IFS	-40.5	10.5	-19.7	4.4	-57.1	13.7	-88.0	20.0	---	---	---	---
GEOSCHEM	-19.9	4.7	-20.2	3.8	-24.4	6.1	-82.1	16.4	-11.7	2.3	-47.6	8.8
EMEPv48	-29.1	7.2	-24.2	5.3	-43.0	10.8	-60.4	12.5	-24.1	4.5	---	---
<b>Mean</b>	<b>-37.9</b>	<b>9.7</b>	<b>-20.4</b>	<b>5.7</b>	<b>-58.2</b>	<b>14.2</b>	<b>-99.7</b>	<b>21.8</b>	<b>-14.2</b>	<b>2.9</b>	<b>-53.6</b>	<b>10.8</b>
<b>Median</b>	<b>-34.7</b>	<b>8.4</b>	<b>-23.8</b>	<b>5.0</b>	<b>-57.1</b>	<b>13.5</b>	<b>-88.0</b>	<b>20.0</b>	<b>-12.5</b>	<b>2.7</b>	<b>-51.6</b>	<b>9.9</b>
<b>Std.dev.</b>	<b>13.3</b>	<b>4.0</b>	<b>19.3</b>	<b>2.0</b>	<b>24.7</b>	<b>6.1</b>	<b>24.7</b>	<b>6.9</b>	<b>3.1</b>	<b>0.8</b>	<b>18.4</b>	<b>4.3</b>

**Table S-5:** Indication of which model groups performed which experiments.

	<i>Base</i>	<i>NAMreduced</i>	<i>EURreduced</i>	<i>SASreduced</i>	<i>EASreduced</i>	<i>RBUREduced</i>	<i>MDEreduced</i>
OsloCTM3	X	X	X	X	X	X	X
GEOS5	X	X	X	X	X	X	
CHASERT42	X	X	X	X	X	X	X
CHASERT106	X	X	X	X	X		
GOCART	X	X	X	X	X	X	X
SPRINTARS	X	X	X	X	X	X	X
CAMchem	X	X	X	X	X	X	X
C-IFS	X	X	X	X	X		
GEOSCHEM	X	X	X	X	X	X	X
EMEPv48	X	X	X	X	X	X	

	<b>NAM</b>	<b>EUR</b>	<b>SAS</b>	<b>EAS</b>	<b>RBU</b>	<b>MDE</b>	<b>ARC</b>
<b>NAMreduced</b>	-406 ± 62	-132 ± 53	-32 ± 64	-44 ± 34	-81 ± 43	-60 ± 29	-93 ± 58
<b>EURreduced</b>	-32 ± 18	-768 ± 139	-30 ± 45	-77 ± 53	-289 ± 107	-189 ± 73	-122 ± 52
<b>SASreduced</b>	-59 ± 51	-43 ± 49	-1639 ± 395	-331 ± 149	-40 ± 45	-258 ± 102	-41 ± 42
<b>EASreduced</b>	-83 ± 38	-40 ± 26	-95 ± 51	-564 ± 91	-83 ± 39	-37 ± 24	-66 ± 39
<b>RBUreduced</b>	-49 ± 36	-235 ± 61	-30 ± 117	-142 ± 61	-564 ± 126	-92 ± 71	-168 ± 56
<b>MDEreduced</b>	-80 ± 242	-103 ± 158	-511 ± 787	-241 ± 239	-166 ± 193	-2676 ± 166	-93 ± 206

**Table S-6:** Table of source-receptor relationships for radiative forcing from BC (numbers behind Fig. 9 (e) and 9 (f)), with source regions given as rows and receptor regions as columns. Values are multi-model medians and one standard deviation, and the unit is  $\text{mWm}^{-2}\text{Tg}^{-1}$ .

	<b>NAM</b>	<b>EUR</b>	<b>SAS</b>	<b>EAS</b>	<b>RBU</b>	<b>MDE</b>	<b>ARC</b>
<b>NAMreduced</b>	78 ± 49	12 ± 13	1.5 ± 5.0	2.1 ± 2.1	5.3 ± 4.7	3.6 ± 4.6	2.5 ± 2.1
<b>EURreduced</b>	2.6 ± 4.7	105 ± 60	6.7 ± 6.6	6.7 ± 4.6	22 ± 15	25 ± 16	3.8 ± 1.9
<b>SASreduced</b>	3.0 ± 2.6	2.7 ± 2.5	254 ± 139	18 ± 19	1.7 ± 1.4	12 ± 9	0.8 ± 0.7
<b>EASreduced</b>	3.3 ± 2.5	1.3 ± 1.9	3.8 ± 6.8	73 ± 30	5.1 ± 2.4	2.3 ± 1.6	1.0 ± 0.8
<b>RBUreduced</b>	2.0 ± 16	31 ± 17	2.1 ± 19.5	10 ± 6	57 ± 23	8.1 ± 8.8	4.9 ± 2.3
<b>MDEreduced</b>	4.4 ± 133.1	23 ± 52.8	73 ± 102	19 ± 8	16 ± 45	303 ± 117	2.2 ± 33.0

**Table S-7:** Table of source-receptor relationships for radiative forcing from OA (numbers behind Fig. 9 (c) and 9 (d)), with source regions given as rows and receptor regions as columns. Values are multi-model medians and one standard deviation, and the unit is  $\text{mWm}^{-2}\text{Tg}^{-1}$ .



	<b>NAM</b>	<b>EUR</b>	<b>SAS</b>	<b>EAS</b>	<b>RBU</b>	<b>MDE</b>	<b>ARC</b>
<b>NAMreduced</b>	37 ± 11	8.9 ± 5.7	0.6 ± 1.7	1.3 ± 1.2	2.9 ± 2.1	1.9 ± 2.3	1.8 ± 0.8
<b>EURreduced</b>	1.5 ± 0.9	85 ± 30	7.3 ± 4.5	6.6 ± 3.0	20 ± 9.1	29 ± 10.6	2.9 ± 1.2
<b>SASreduced</b>	1.8 ± 1.6	1.7 ± 1.6	171 ± 58	15 ± 14	1.2 ± 0.9	12 ± 8	0.5 ± 0.4
<b>EASreduced</b>	4.4 ± 2.1	2.3 ± 1.3	3.2 ± 4.8	50 ± 11	4.9 ± 2.2	1.3 ± 1.3	1.2 ± 0.9
<b>RBUreduced</b>	1.8 ± 1.1	15 ± 6	2.7 ± 4.8	11 ± 4.4	50 ± 13	6.9 ± 6.1	5.1 ± 1.9
<b>MDEreduced</b>	3.5 ± 1.4	12 ± 5	66 ± 27	16 ± 7	11 ± 5	198 ± 57	1.5 ± 0.6

**Table S-8:** Table of source-receptor relationships for radiative forcing from SO<sub>4</sub> (numbers behind Fig. 9 (a) and 9 (b)), with source regions given as rows and receptor regions as columns. Values are multi-model medians and one standard deviation, and the unit is mWm<sup>-2</sup>Tg<sup>-1</sup>.

**Table S-9:** As Table 4, but for the four HTA1 regions. Response to Extra-Regional Emission Reductions (RERER), averaged over the 10 participating models. A high RERER value means that the given region is very sensitive to extra-regional emission reductions. The top table shows RERER for column aerosol burdens, the bottom table shows RERER for DRF calculated using vertically, spatially and temporally resolved AFE profiles.

<b>Burden</b>	<b>NAM</b>	<b>EUR</b>	<b>SAS</b>	<b>EAS</b>
<b>BC</b>	0.57 ± 0.09	0.58 ± 0.06	0.23 ± 0.06	0.28 ± 0.05
<b>OA</b>	0.57 ± 0.14	0.63 ± 0.07	0.20 ± 0.07	0.33 ± 0.04
<b>SO<sub>4</sub></b>	0.51 ± 0.10	0.71 ± 0.05	0.50 ± 0.05	0.35 ± 0.03
<b>DRF</b>	<b>NAM</b>	<b>EUR</b>	<b>SAS</b>	<b>EAS</b>
<b>BC</b>	0.71 ± 0.09	0.72 ± 0.07	0.29 ± 0.04	0.41 ± 0.05
<b>OA</b>	0.58 ± 0.15	0.65 ± 0.08	0.20 ± 0.04	0.37 ± 0.08
<b>SO<sub>4</sub></b>	0.47 ± 0.09	0.68 ± 0.05	0.35 ± 0.04	0.35 ± 0.07