Deliverable D4.1: Evaluation of best estimate ECLIPSE climate forcing and their uncertainty

Two sets of best estimates and uncertainty ranges are provided in this deliverable. That is estimates over the industrial era (1750-2012) and estimates relative to emissions. The basis for the estimates are available literature from model intercomparison studies such as main results from AeroCom and ACCMIP (Myhre et al., 2013; Shindell et al., 2013; Stevenson et al., 2013), related studies to these projects (Bowman et al., 2013; Lee et al., 2013; Samset et al., 2013; Stier et al., 2013) as well as simulations made within ECLIPSE. AeroCom and ACCMIP are global model intercomparison activities with many modelling groups participating. The final estimates are based on judgements from the ECLIPSE participants.

The best estimate radiative forcing over the industrial era (1750-2012) is shown in Table 1. These estimates are based on abundance changes over the industrial era. More relevant for Work Packages within ECLIPSE is estimates of emissions for the various components causing perturbations to the radiative balance. Table 2 shows best estimates for forcing normalized to emissions and its uncertainty for emitted compounds.

Table 1: Best estimate radiative forcing over the industrial era (1750-2012). Uncertainties are given as 5-95% confidence interval.

Components	Best estimates present day (Wm^{-2})
Sulphate	-0.4 ±0.2
BC	+0.35 ±0.25
OC	-0.05 ±0.05
Nitrate	-0.1 ±0.1
Aerosol cloud interaction	-1.0 ±1.0
Ozone total	+0.35 ±0.2
Ozone precursors	+0.5 ±0.2

Table 2: Best estimate radiative forcing normalized to emissions. Uncertainties are given as 5-95% confidence interval.

	Components	Best estimates (mWm^{-2}/Tg)
Aerosol RF	SO_2	-3.5 ± 2.0
	BC	+45.0 ± 35.0
	OC	-4.0 ± 4.0
	NOx	-0.75 ± 0.75
	NH_3	-1.0 ± 1.0
	Aerosol cloud interactions	-3.0 ± 3.0
O_3 and CH_4 RF	CO	0.25 ± 0.1
	VOC	0.50 ± 0.25
	NOx	-1.0 ± 0.75

The main results in Table 2 are based on results in Table 3-6. For some of the components the total emissions are uncertain, e.g. for BC (Bond et al., 2013). On one hand normalized radiative forcing will have smaller uncertainties than changes over the industrial era, but on the other hand the regional

(and seasonal) differences as shown in Table 4-5 introduces additional enhancement in the range in the normalized forcing. Table 3 shows results from AeroCom Phase II with changes in the emissions over the industrial era. Results in this table are based on simulations from 15 global aerosol models. Table 4 shows ECLIPSE results from various regions and seasonal variation based on one global model (OsloCTM2). In Table 5 a multi-model study from HTAP and ECLIPSE simulations for 4 regions are shown. HTAP results are derived based on multi-model simulations with 20% reductions in emissions in 4 specific regions. Table 6 shows 1850-2000 ozone and methane normalized radiative forcings from ACCMIP (Stevenson et al., 2013). These are based on six global chemistry models for changes over the industrial era. In the estimates provided in Table 2 for emissions of CO, VOC and NOx on ozone and CH_4 it has been taken into account that perturbations of current emissions have a different effect compared to changes in the emissions over the whole industrial era as well as differences between OsloCTM2 used for results in Table 4 compared to multi-model mean values in ACCMIP (Stevenson et al., 2013). Table 4 shows that in many cases emissions from East Asia and Europe have different radiative forcing compared to emissions in rest of the world. This is also highly relevant for aerosol cloud interactions (not shown in Table 4).

The radiative forcing due to nitrate is sensitive to a change in emissions of NO_X and ammonia (NH_3). The results shown in Table 4 are all based on a 20% reduction of anthropogenic emissions. A sensitivity test with a 20% increase of the East Asian NH_3 summer emissions gave a 24% higher normalized radiative forcing due to nitrate compared to a 20% emission reduction. For East Asian NO_X emissions during summer, the normalized radiative forcing due to nitrate were about 8% lower when the emissions were increased instead of decreased by 20%. In the estimates in Table 2 it is taken into account that OsloCTM2 has relatively small negative RF due to nitrate compared to other models (Myhre et al., 2013).

Table 3: Results from 15 global aerosol models with AeroCom Phase II (Myhre et al., 2013).

Emitted compound	Normalized forcing (mWm^{-2}/Tg)
SO_2	-3.53 (-5.51 to -1.54)
OC	-3.78 (-6.31 to -1.26)
BC	+45.3 (+15.1 to 75.6)

Table 4: Normalized radiative forcing by emission (all units mWm^{-2}/Tg) from OsloCTM2 for ECLIPSE with regional emissions. EAS is emissions from East Asia, EUR is emissions from Europe and ROW is emissions from rest of the world. The radiative forcing due to short-lived O_3, methane and methane-induced O_3 is taken into account for the ozone precursors (CO, NO_X and VOC). Emissions are given as follows Tg(CO), Tg(NO_2), Tg(VOC), Tg(SO_2), Tg(NH_3), Tg(BC), Tg(OC).

		EAS summer	EUR summer	ROW summer	EAS winter	EUR winter	ROW winter
Aerosol RF	**SO_2**	-3.34	-4.74	-4.49	-1.48	-1.64	-3.04
	OC	-3.87	*-8.10*	-5.55	-3.04	-2.87	-6.29
	BC	66.3	67.4	*77.9*	25.6	31.8	58.7
	NO_X	-0.235	-0.366	-0.231	-0.692	-0.277	-0.374
	NH_3	-0.603	-0.991	-0.445	-1.17	-0.752	-0.726

O_3 and CH_4 RF	**CO**	0.237	0.219	0.257	0.256	0.246	0.271
	NO_X	-0.347	-0.736	-1.20	-0.492	-0.391	-1.67
	VOC	0.483	0.447	0.638	0.262	0.309	0.571

Table 5: Normalized radiative forcing by emission (all units mWm^{-2}/Tg) from 9 models in HTAP experiments (Samset et al., in preparations). Variations in the normalized forcing is due to abundances from the global aerosol models, whereas radiative transfer calculations are based on a homogenous method (Samset and Myhre, 2011). NA is emissions from North America, EU is from Europe, SA is from South Asia and ES is East Asia.

	NA	EU	SA	EA
SO_2	-3.11 (-4.53 to -1.69)	-3.07 (-4.58 to -1.57)	-5.58 (-8.26 to -2.89)	-2.59 (-4.19 to -0.98)
OC*	-3.60 (-4.95 to -2.25)	-3.43 (-5.04 to -1.82)	-4.92 (-5.98 to -3.86)	-2.84 (-4.06 to -1.61)
BC	45.21 (15.28 to 75.14)	48.10 (25.79 to 70.40)	69.96 (22.25 to 117.68)	51.10 (-1.65 to 103.85)

**Assumed POM/OC ratio of 1.4 for POM emissions in HTAP*

Table 6: Results from 6 global atmospheric chemistry models within ACCMIP (Stevenson et al., 2013). The normalized forcings are given per Tg(CO), Tg(NO_2) and Tg(NMVOC) for emissions of CO, NO_X and NMVOC, respectively. Uncertainties are given as 5-95% confidence interval.

Emitted compound	Normalized forcing (mWm^{-2}/Tg)
NO_X	-1.84 (-3.17 to -0.503)
CO	0.168 (0.116 to 0.219)
NMVOC	0.891 (0.406 to 1.39)

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