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METEOROLOGISK INSTITUTT
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Transboundary air pollution by main pollutants (S, N, O_3) and PM

The United Kingdom

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1 Introduction

This note is one of a series of country-specific reports, complementary to the EMEP Status Report 1/2007. It presents overview information on transboundary pollution of main pollutants, ground level ozone and PM relevant for the United Kingdom.

The transboundary contributions are based on source-receptor calculations with the EMEP Unified Model using meteorological and emission data for the year 2005. These source-receptor calculations are based on the same version of the EMEP Unified Model as presented in the main report (rv 2.8).

Emissions The emissions for 2005 have been derived from the 2007 official data submissions to UN-ECE CLRTAP. The gridded distributions of these emissions have been derived by scaling with respect to gridded data distributions in year 2005 (Base 2005 V9). The emissions for 1990-2004 have been derived from the 2006 official data submissions to UN-ECE CLRTAP. The gridded distributions of these emissions have been derived by scaling with respect to gridded data distributions in year 2000 (Base 2000 V7). The emissions for 1980 and 1985 have not been updated neither for the 2006 nor the 2007 calculations. They are the same as used in the EMEP Assessment Report. The gridded emission data is available on `http://webdab.emep.int`.

Trends Trends on deposition and air quality data are derived with the EMEP Unified Model. Please note that different years are calculated with different model versions:

- 1980 - 1985: Model rv 2.1.2
- 1990 - 2003: Model rv 2.5
- 2004: Model rv 2.6.
- 2005: Model rv 2.8. Data used throughout this report.

Differences between these model versions are documented in EMEP Report 1/2003, and EMEP Report 1/2004. Differences between rv 2.5, rv 2.6 and rv 2.8 are mainly technical and do not represent any major changes in model description.

Transboundary data Data is presented in the form of maps, pies and bar-charts. The data is generated by source-receptor calculations, where emissions for each emitter of one or more precursors are reduced by 15%. For oxidised sulphur, oxidised nitrogen and reduced nitrogen, the results have been scaled to present data corresponding to all emissions from a emitter. For other components we choose to present the effect of a 15% reduction, as this is a more correct way of describing chemical non-linearities in atmospheric pollution.

The pie charts for depositions and PM give a picture of the relative contributions of the countries or regions to depositions and concentrations over the United Kingdom.

For O_3 and related indicators bar charts are used because in some cases the effect of a reduction of emissions from a country can either increase or decrease O_3 levels elsewhere. The values in the bar charts for ozone indicators show the six most important contributors to AOT40, ozone fluxes and SOMO35 in the United Kingdom.

Since the contributions can be both positive or negative, the relative importance of the contributors has been determined by comparing the absolute value of the contributions.

To give more intuitive pictures on the effect of pollution from a given country, we use positive scales for pollution reductions throughout this note. Note then that negative values will mean increase of pollution levels.

Comparison with Observations The map of monitoring stations shows all stations of the United Kingdom in the EMEP measurement network with measurements in 2005 submitted to EMEP. The frequency analysis plot compare 2005 observation results with the model results. The measurement data is available from CCC: `http://www.nilu.no/projects/ccc/emepdata.html`. The table provides annual statistics of the comparison of model results with observations for each measured components.

Risks from Ozone and PM The maps with ozone and PM values correspond to regional background levels and they are not representative of local point measurements, where these values can be much higher (i.e. in cities).

Country Codes

Many tables and graphs in this report make use of codes to denote countries and regions in the EMEP area. Table 5 provides an overview of these codes and lists the countries and regions included in the present 2005 source-receptor calculations.

Code	Country/Region	Code	Country/Region
AL	Albania	HU	Hungary
AM	Armenia	IE	Ireland
ASI	Remaining Asian areas	IS	Iceland
AT	Austria	IT	Italy
ATL	Remaining N.-E. Atlantic Ocean	KZ	Kazakhstan
ATX	N.-E. Atlantic Ocean, external	LT	Lithuania
AZ	Azerbaijan	LU	Luxembourg
BA	Bosnia and Herzegovina	LV	Latvia
BAS	Baltic Sea	MD	Republic of Moldova
BLS	Black Sea	ME	Montenegro
BE	Belgium	MED	Mediterranean Sea
BG	Bulgaria	MK	The FYR of Macedonia
BIC	Boundary and Initial Conditions	MT	Malta
BY	Belarus	NAT	Natural marine emissions
CH	Switzerland	NL	Netherlands
CY	Cyprus	NO	Norway
CZ	Czech Republic	NOA	North Africa
DE	Germany	NOS	North Sea
DK	Denmark	PL	Poland
EE	Estonia	PT	Portugal
EMC	EMEP land areas	RO	Romania
ES	Spain	RS	Serbia
EU	European Community	RU	Russian Federation
FI	Finland	RUX	Russian Federation, external
FR	France	SE	Sweden
GB	United Kingdom	SI	Slovenia
GL	Greenland	SK	Slovakia
GE	Georgia	TR	Turkey
GR	Greece	UA	Ukraine
HR	Croatia		

Table 1: Country/Region codes used in the source-receptor calculations

Russian Federation means the part of the Russian Federation inside the EMEP domain of calculations. The same applies to the Remaining N.E. Atlantic region and natural marine emission area as well as the countries included in North Africa and Remaining Asian areas. ATX and RUX mean the parts of the Atlantic and Russia outside the EMEP official domain but inside the EMEP domain of calculation. North Africa includes parts of Morocco, Algeria, Tunisia, Libya and Egypt. Asia includes Syria, Lebanon, Israel, parts of Uzbekistan, Turkmenistan, Iran, Iraq and Jordan. The European Community includes Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, The Netherlands, Portugal, Spain, Sweden, United Kingdom, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, Slovenia, Bulgaria and Romania.

2 Definitions, statistics used

The following definitions and acronyms are used throughout this note:

SIA denotes secondary inorganic aerosol and is defined as the sum of sulphate (SO_4^{2-}), nitrate (NO_3^-) and ammonium (NH_4^+). In the Unified EMEP model SIA is calculated as the sum: SIA= SO_4^{2-} + NO_3^-(fine) + NO_3^-(coarse) + NH_4^+

PPM denotes primary particulate matter, originating directly from anthropogenic emissions. It is usually distinguished between fine primary particulate matter, $PPM_{2.5}$ with aerosol diameters below 2.5 μm and coarse primary particulate matter, PPM_{co} with aerosol diameters between 2.5μm and 10μm.

$PM_{2.5}$ denotes fine particulate matter, defined as the integrated mass of aerosol with diameter up to 2.5 μm. In the Unified EMEP model $PM_{2.5}$ is calculated as the sum: $PM_{2.5}$ = SO_4^{2-} + NO_3^-(fine) + NH_4^+ + $PPM_{2.5}$

PM_{10} denotes particulate matter, defined as the integrated mass of aerosol with diameter up to 10 μm. In the Unified EMEP model PM_{10} is calculated as the sum: PM_{10} = $PM_{2.5}$ + NO_3^-(coarse) + PPM_{co}

SOMO35 - The Sum of Ozone Means Over 35 ppb is the new indicator for health impact assessment recommended by WHO. It is defined as the yearly sum of the daily maximum of 8-hour running average over 35 ppb. For each day the maximum of the running 8-hours average for O_3 is selected and the values over 35 ppb are summed over the whole year.

If we let A_8^d denote the maximum 8-hourly average ozone on day d, during a year with N_y days (N_y = 365 or 366), then SOMO35 can be defined as:

$SOMO35 = \sum_{d=1}^{d=N_y} \max\left(A_8^d - 35 \text{ ppb}, 0.0\right)$

where the $\max$ function ensures that only A_8^d values exceeding 35 ppb are included. The corresponding unit is ppb·days (abbreviated also as ppb·d).

AOT40 - the accumulated amount of ozone over the threshold value of 40 ppb, i.e.:

$\mathrm{AOT40} = \int \max(O_3 - 40\,\mathrm{ppb}, 0.0)\,dt$

where the $\max$ function ensures that only ozone values exceeding 40 ppb are included. The integral is taken over time, namely the relevant growing season for the vegetation concerned, and for daytime only. The corresponding unit are ppb·hours (abbreviated to ppb·h).

Although the EMEP model now generates a number of AOT-related outputs, these country reports present results for two “practical” definitions:

$\mathbf{AOT40}_f^{\mathbf{uc}}$ - AOT40 calculated for forests using estimates of O_3 at forest-top (uc: upper-canopy). This AOT40 is that defined for forests by the UNECE Mapping Manual, but using a default growing season of April-September.

$\mathbf{AOT40}_c^{\mathbf{uc}}$ - AOT40 calculated for agricultural crops using estimates of O_3 at the top of the crop. This AOT40 is close to that defined for agricultural crops by the UNECE Mapping Manual, but using a default growing season of May-July, and a default crop-height of 1 m.

AFstY - the accumulated stomatal ozone flux over a threshold Y nmol m^{-2} s^{-1}, i.e.:

$$\text{AFstY}_{gen} = \int \max(F_{st} - Y, 0)\, dt \tag{1}$$

where stomatal flux F_{st}, and threshold, Y, are in nmol m^{-2} s^{-1}, and the `max` function evaluates $\max(A - B, 0)$ to $A - B$ for $A > B$, or zero if $A \leq B$. This integral is evaluated over time, from the start of the growing season (SGS), to the end (EGS).

For the generic crop and forest species the suffix *gen* is applied, e.g. $\text{AF}_{\text{st}}1.6_{\text{gen-DF}}$ is used for deciduous forests.

3 Emissions

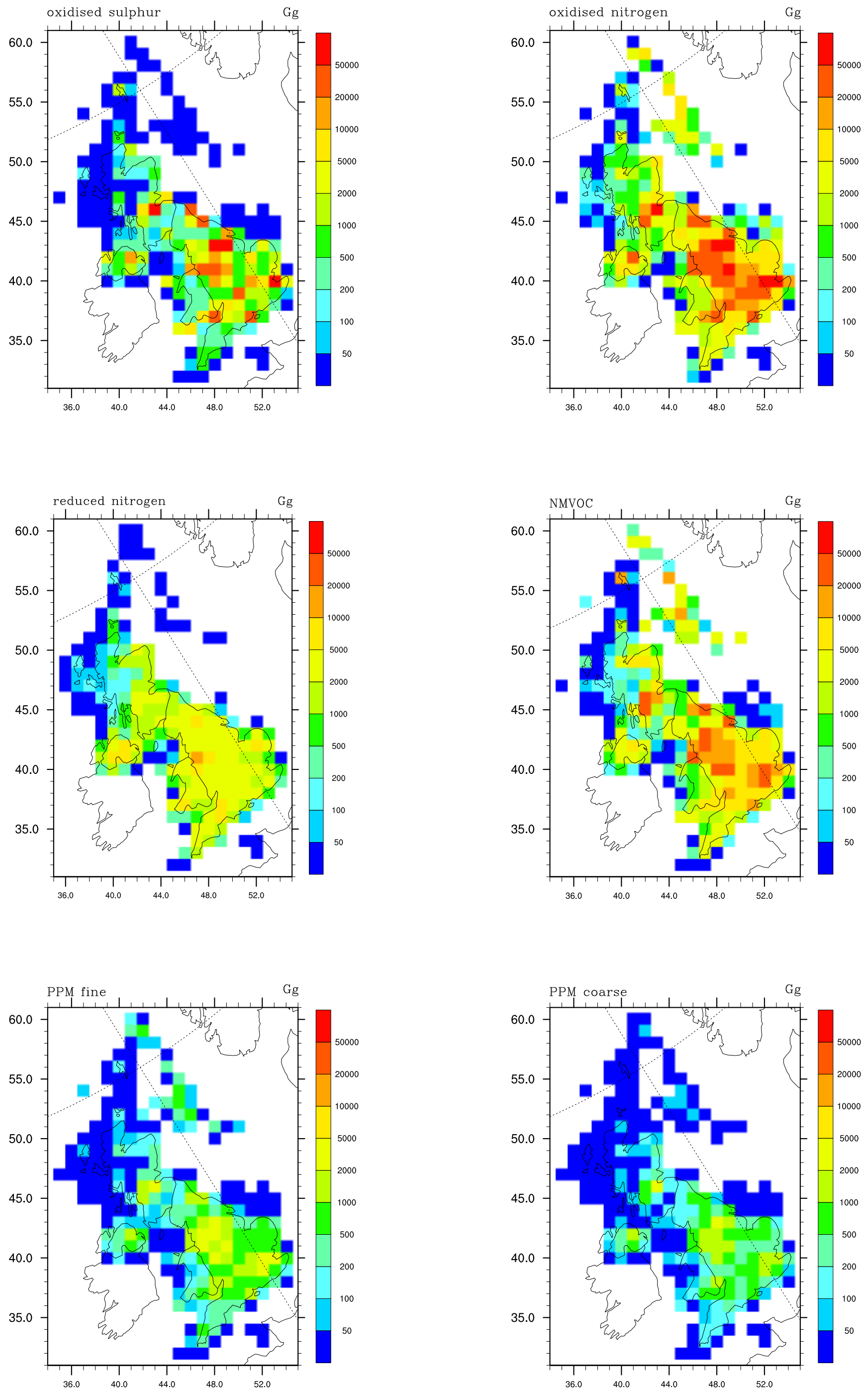

Figure 1: Spatial distribution of emissions from the United Kingdom in 2005.

4 Trends

	1980	1985	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
SO_x	4859	3720	3699	2343	1999	1635	1591	1202	1173	1111	994	973	833	706
NO_x	2580	2540	2932	2355	2277	2121	2052	1936	1857	1799	1693	1685	1621	1627
NH_3	363	363	382	359	362	364	361	358	337	330	319	308	336	318
NMVOC	2410	2513	2396	1939	1832	1766	1617	1463	1348	1252	1175	1073	1024	977
CO	7677	7222	8286	6345	6194	5728	5332	5013	4285	4088	3617	3103	2923	2408
$PM_{2.5}$									108	107	99	96	95	95
PM_{10}									180	176	160	155	154	150

Table 2: Emissions from the United Kingdom. Units: Gg.

	1980	1985	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
S dep.	722	545	439	322	327	268	268	211	213	198	194	168	162	144
oxN dep.	153	146	130	120	142	132	122	120	119	114	117	104	104	103
redN dep.	131	131	127	127	141	138	147	141	140	132	132	112	133	124

Table 3: Estimated deposition of Sulphur(S) and Nitrogen(N) in the United Kingdom. Units: Gg(S) or Gg(N).

	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
mean ozone	28	29	29	28	31	31	29	29	31	31	30	30
max ozone	36	36	37	36	38	38	37	36	38	38	37	38
$AOT40_f^{uc}$	6817	6341	5214	6837	4872	5792	4589	4456	4917	6018	3804	3942
SOMO35	1371	1349	1397	1512	1396	1533	1166	1115	1489	1531	1191	1310
$AF_{st}1.6_{gen\text{-}DF}$	13	13	13	13	13	13	13	12	14	14	12	16
$PM_{2.5}$ anthrop.							5	6	6	8	5	5
PM_{10} anthrop.							6	7	7	9	6	6

Table 4: Estimated yearly mean values of air quality indicators averaged over the United Kingdom. Units: daily mean ozone (ppb), daily max ozone (ppb), $AOT40_f^{uc}$(ppb·h) SOMO35 (ppb·d), $AF_{st}1.6_{gen\text{-}DF}$ (mmol/m2); and $PM_{2.5}$ (μg/m^3) and PM_{10} (μg/m^3) from anthropogenic sources in the model.

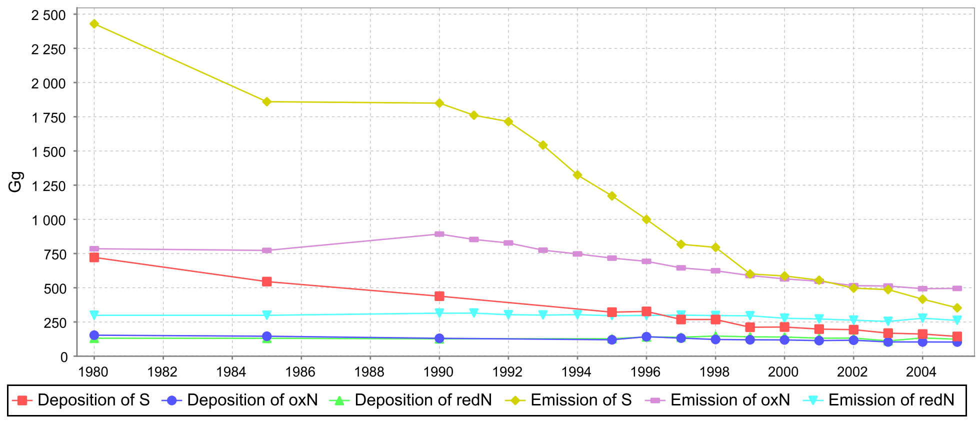

Figure 2: Trends in emissions and depositions of oxidised sulphur, oxidised nitrogen and reduced nitrogen. Units: Gg(S) or Gg (N).

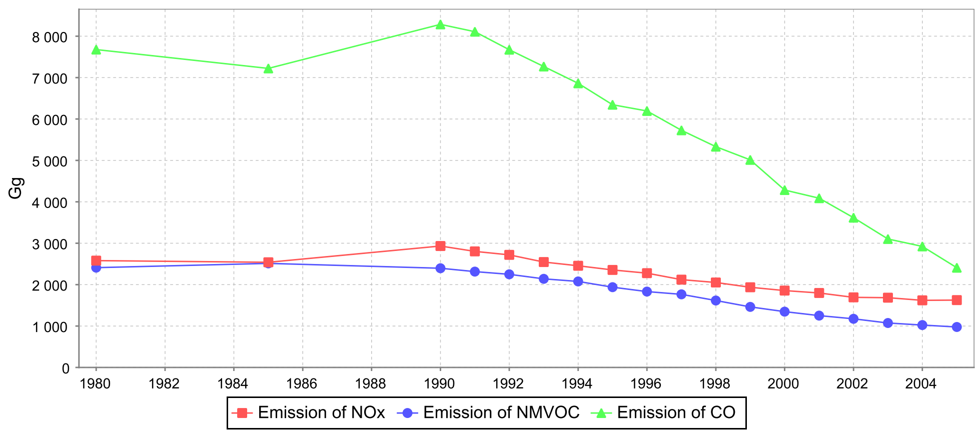

Figure 3: Trends in emissions of photo-oxidant pollution precursors. Units: Gg (note that NO_x is here as NO_2).

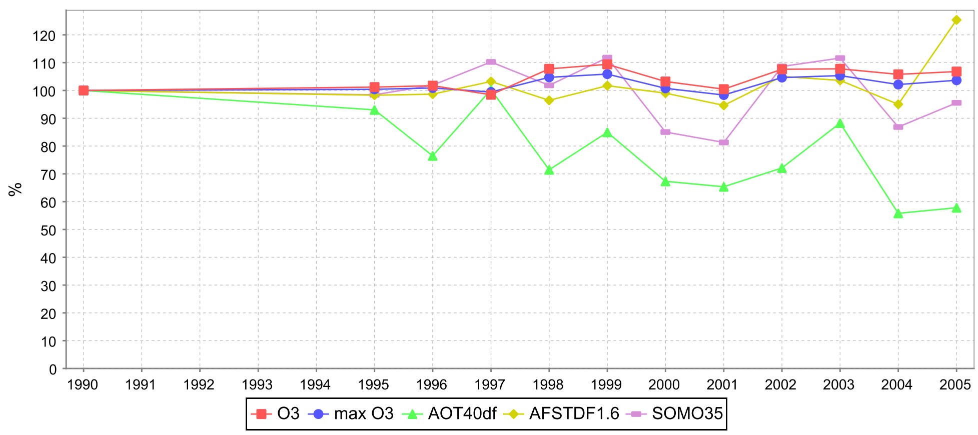

Figure 4: Changes in ozone related pollution relative to 1990. Units: %.

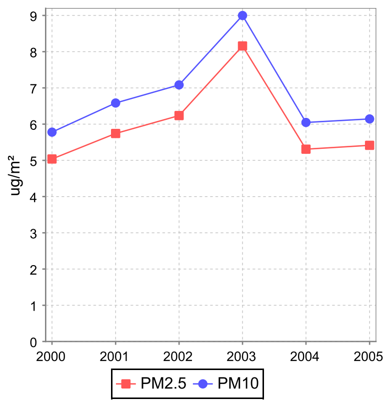

Figure 5: Trends in mean concentrations of particules since 2000. Units: $\mu g/m^3$.

5 Transboundary Fluxes in 2005

5.1 Oxidised sulphur deposition

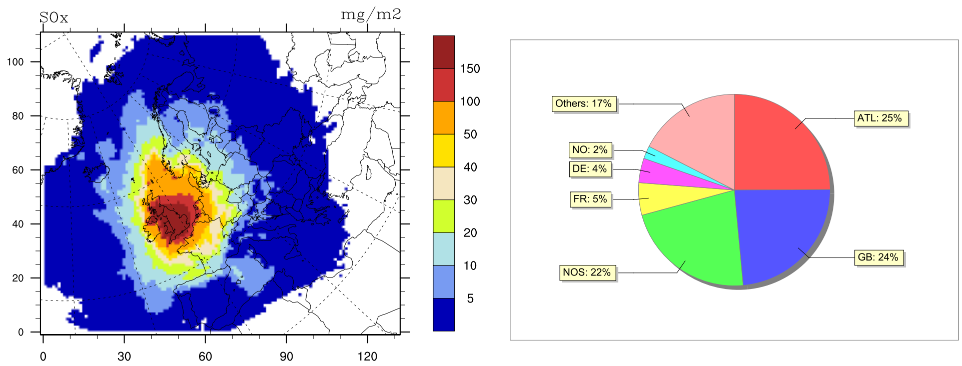

Figure 6: Contribution of emissions from the United Kingdom to oxidised sulphur deposition in the EMEP domain. Units: mg(S)/m^2. The pie chart shows the six main receptor areas of oxidised sulphur deposition from the United Kingdom. Units: (%).

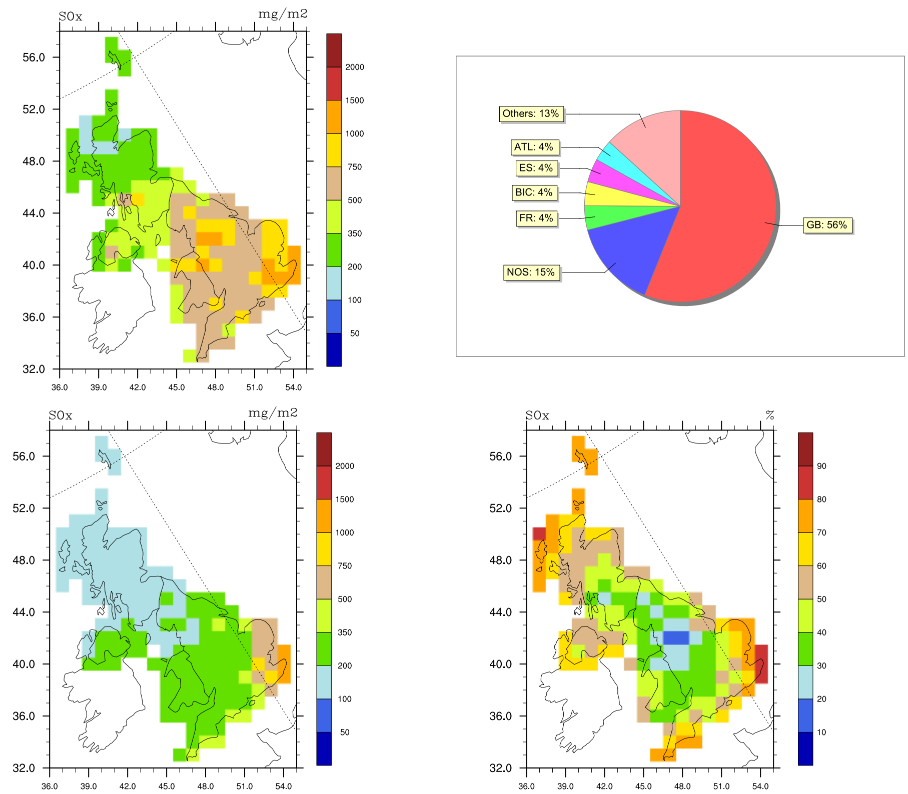

Figure 7: Oxidised sulphur deposition in the United Kingdom (top left figure). Units: mg(S)/m^2. The pie chart shows the six main contributors to oxidised sulphur deposition in the United Kingdom. Units: (%). Oxidised sulphur deposition from transboundary sources (lower left). Units: (mg(S)/m^2). Fraction from transboundary contribution to total deposition (lower right). Units: (%)

5.2 Oxidised nitrogen deposition

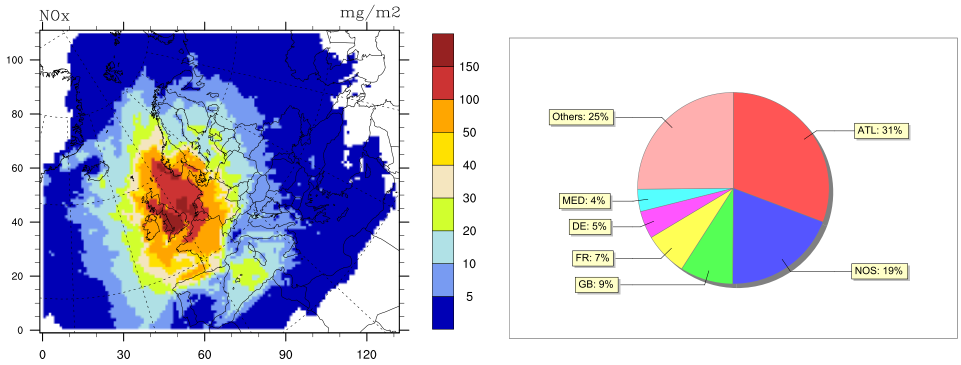

Figure 8: Contribution of emissions from the United Kingdom to oxidised nitrogen deposition in the EMEP domain. Units: mg(N)/m^2. The pie chart shows the six main receptor areas of oxidised nitrogen deposition from the United Kingdom. Units: (%).

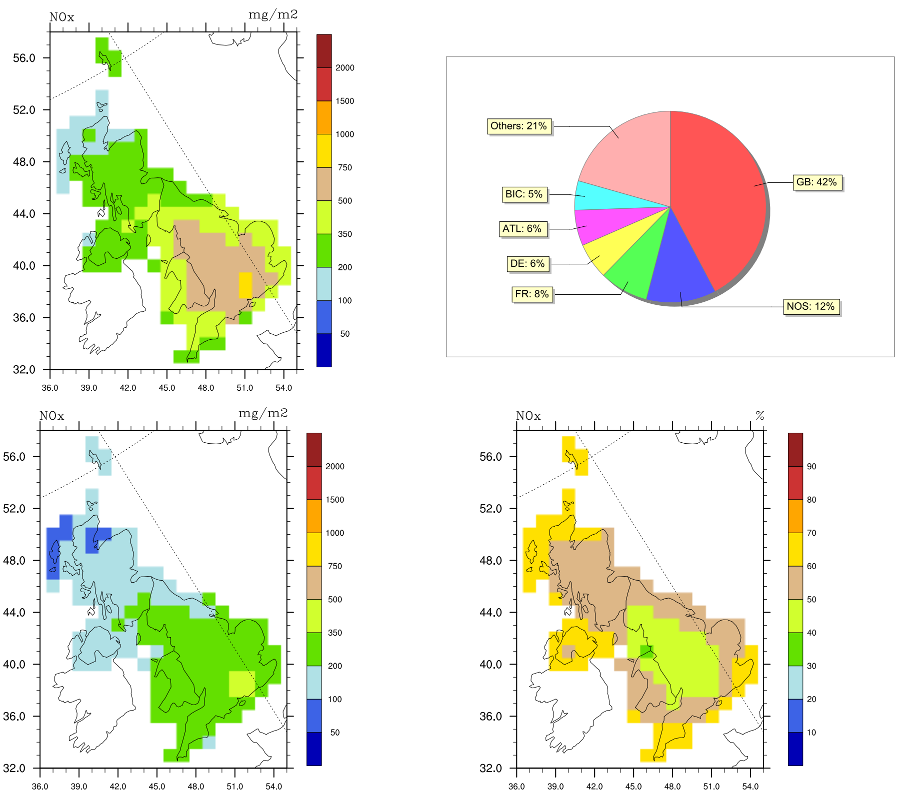

Figure 9: Oxidised nitrogen deposition in the United Kingdom (top left figure). Units: mg(S)/m^2. The pie chart shows the six main contributors to oxidised nitrogen deposition in the United Kingdom. Units: (%). Oxidised nitrogen deposition from transboundary sources (lower left). Units: (mg(S)/m^2). Fraction from transboundary contribution to total deposition (lower right). Units: (%)

5.3 Reduced nitrogen deposition

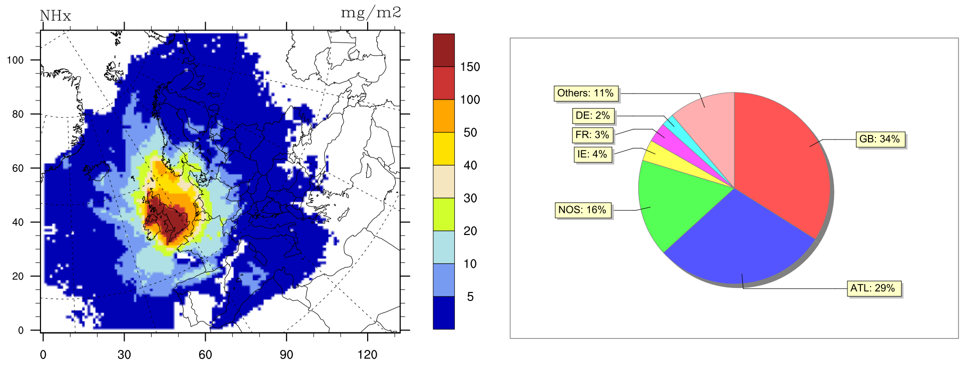

Figure 10: Contribution of emissions from the United Kingdom to reduced nitrogen deposition in the EMEP domain. Units: mg(N)/m^2. The pie chart shows the six main receptor areas of reduced nitrogen deposition from the United Kingdom. Units: (%).

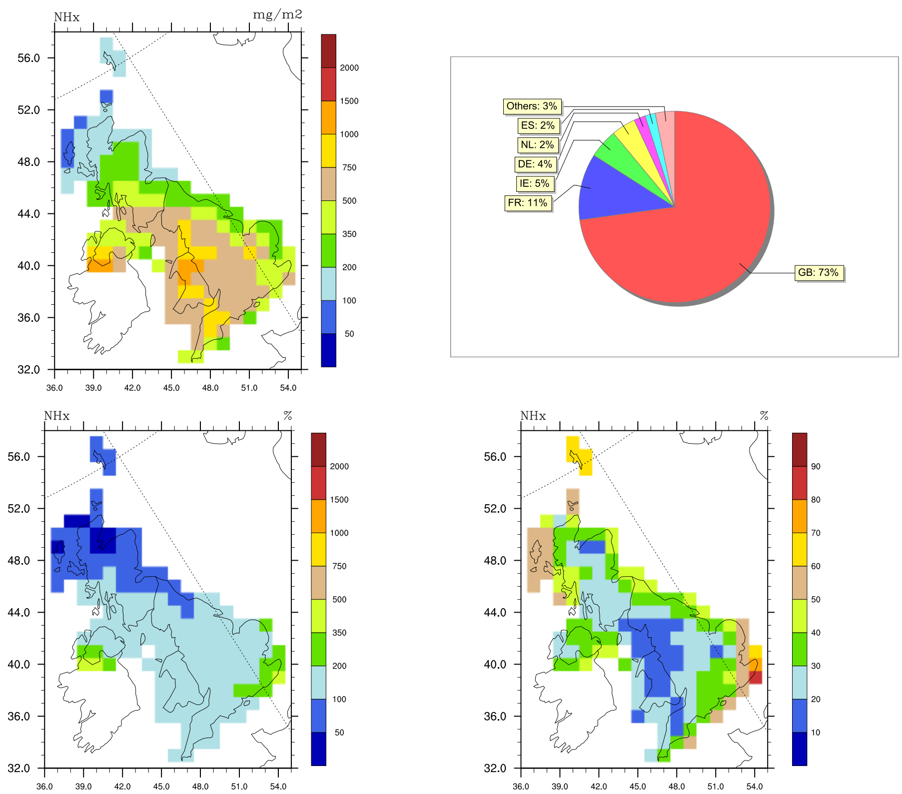

Figure 11: Reduced nitrogen deposition in the United Kingdom (top left figure). Units: mg(S)/m^2. The pie chart shows the six main contributors to reduced nitrogen deposition in the United Kingdom. Units: (%). Reduced nitrogen deposition from transboundary sources (lower left). Units: (mg(S)/m^2). Fraction from transboundary contribution to total deposition (lower right). Units: (%)

6 Transboundary ozone concentrations

6.1 $AOT40_f^{uc}$

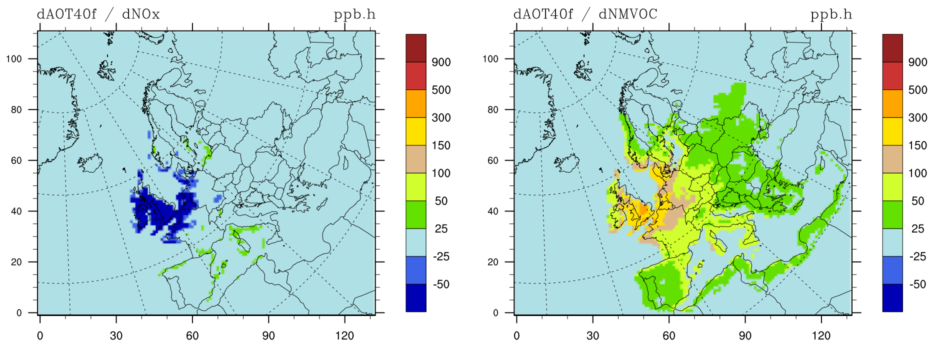

Figure 12: Reduction in $AOT40_f^{uc}$ due to 15% reduction in NO_x(left) and NMVOC (right) emissions from the United Kingdom. Units: ppb·h

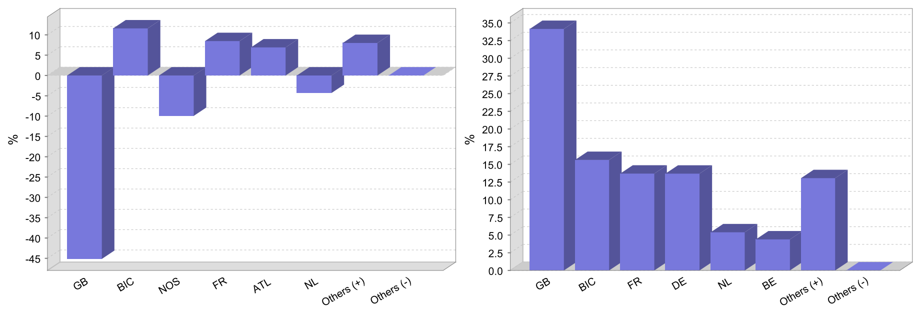

Figure 13: Six most important contributors to $AOT40_f^{uc}$ in the United Kingdom by NO_x(left) and NMVOC (right) emission changes (15% reduction). Units: (%)

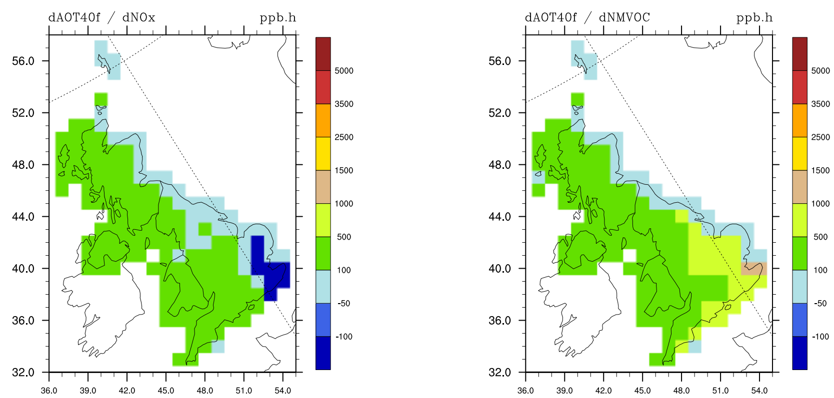

Figure 14: Reduction in $AOT40_f^{uc}$ due to 15% reduction in NO_x (left) and NMVOC emissions (right) from transboundary sources. Units: ppb·h

6.2 $AF_{st}1.6_{gen\text{-}DF}$ – Ozone fluxes to deciduous forests

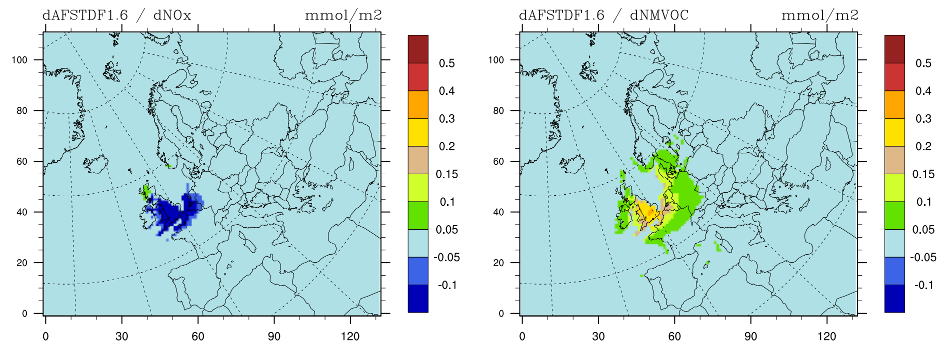

Figure 15: Reduction in $AF_{st}1.6_{gen\text{-}DF}$ due to 15% reduction in NO_x(left) and NMVOC (right) emissions from the United Kingdom. Units: mmol/m^2

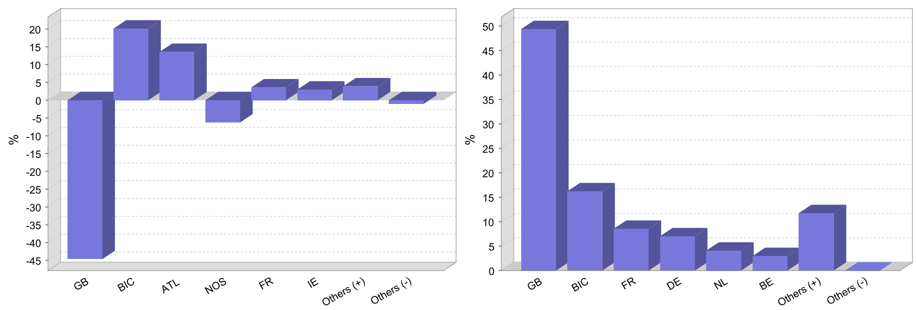

Figure 16: Six most important contributors to $AF_{st}1.6_{gen\text{-}DF}$ in the United Kingdom by NO_x(left) and NMVOC (right) emissions (15% reduction)

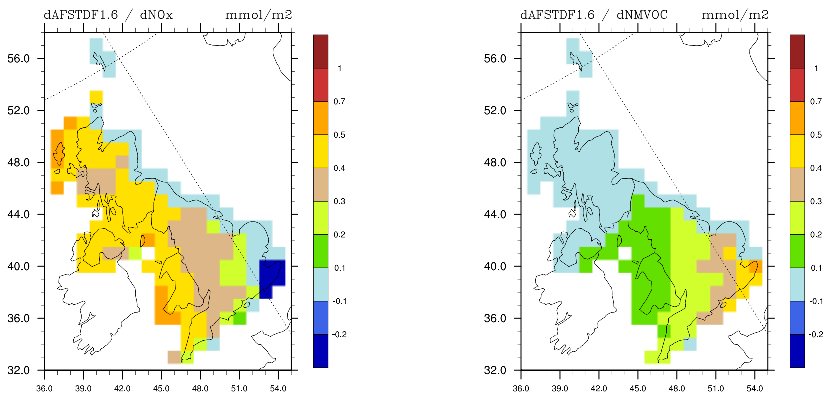

Figure 17: Reduction in $AF_{st}1.6_{gen\text{-}DF}$ due to 15% reduction in NO_x (left) and NMVOC emissions (right) from transboundary sources. Units: mmol/m^2

6.3 SOMO35 – Risk of ozone damages in human health

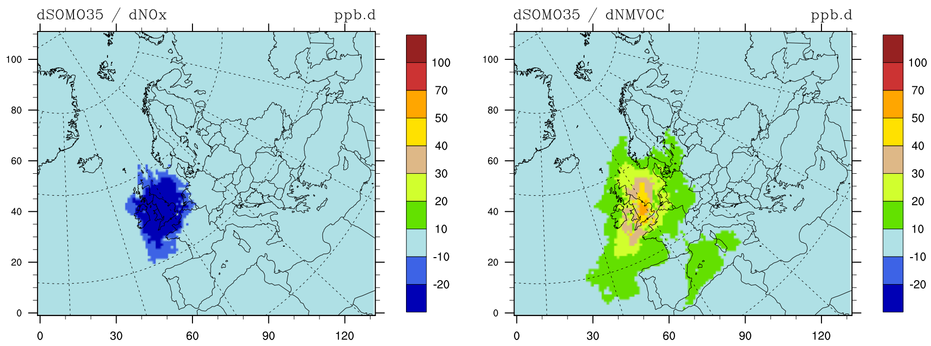

Figure 18: Reduction in SOMO35 due to 15% reduction in NO_x(left) and NMVOC (right) emissions from the United Kingdom. Units: ppb·day

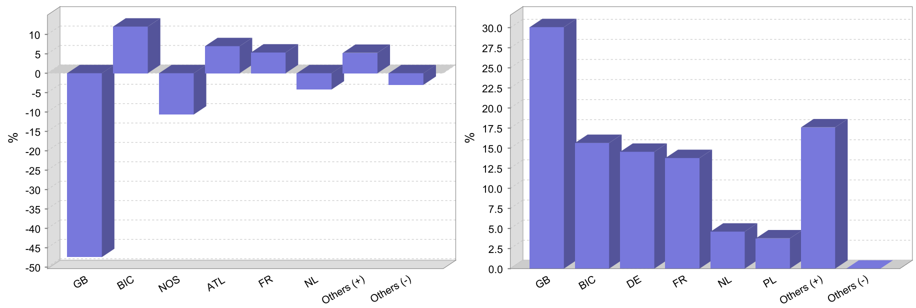

Figure 19: Six most important contributors to SOMO35 in the United Kingdom by NO_x(left) and NMVOC (right) emissions (15% reduction)

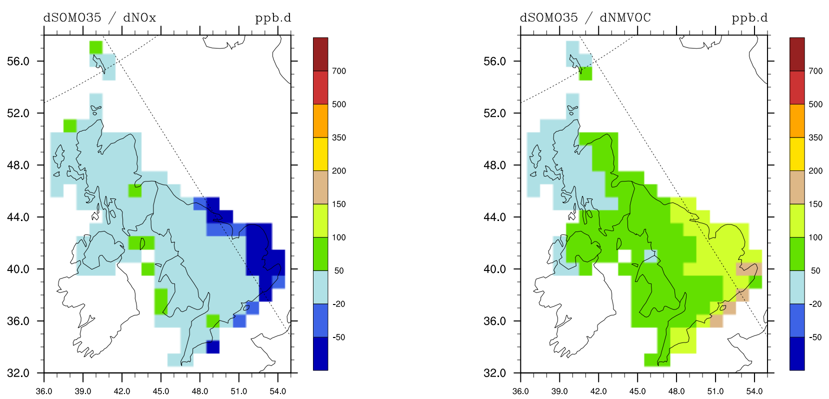

Figure 20: Reduction in SOMO35 due to 15% reduction in NO_x (left) and NMVOC emissions (right) from transboundary sources. Units: ppb·day

7 Transboundary concentrations of particulate matter

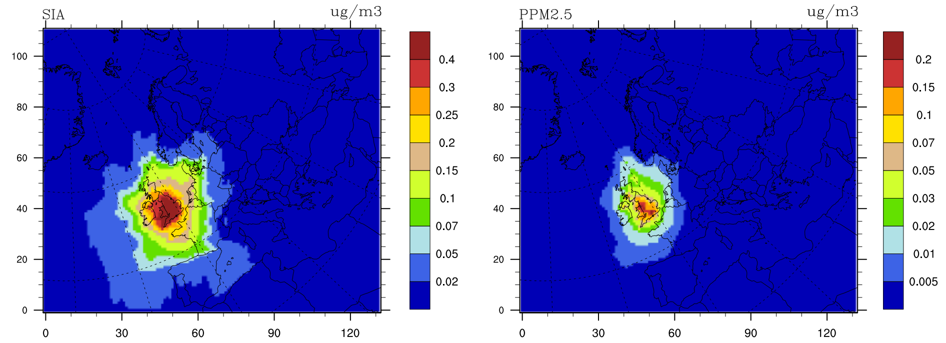

Figure 21: Reduction in SIA and PPM2.5 concentrations due to 15% emission reduction from the United Kingdom. Units: μg/m^3. Note the difference in scales.

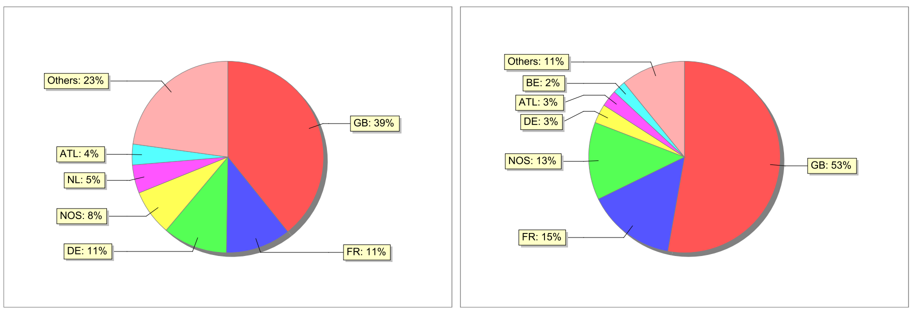

Figure 22: Main contributors to SIA (left) and PPM2.5 (right) concentrations in the United Kingdom. Units: (%)

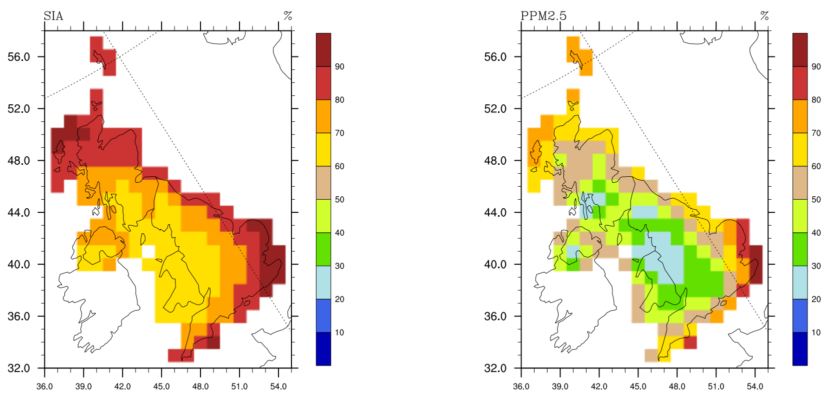

Figure 23: Reduction in SIA and PPM2.5 concentrations in the United Kingdom due to 15% emission reductions from transboundary sources. Units: (%)

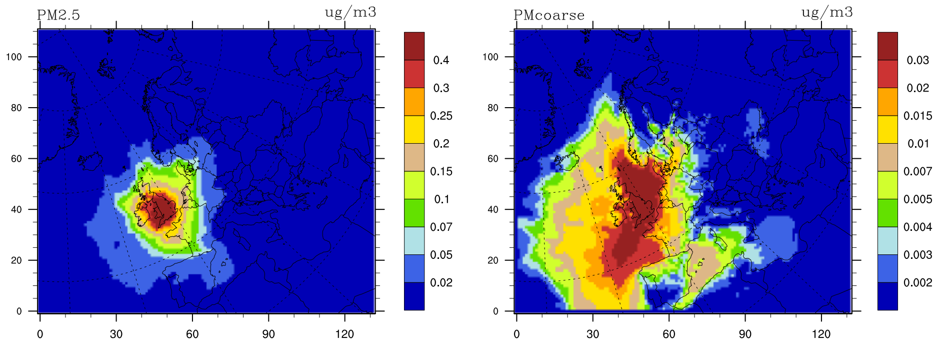

Figure 24: Reduction in PM2.5 and PMcoarse concentrations due to 15% emission reduction from the United Kingdom. Units: μg/m^3. Note the difference in scales.

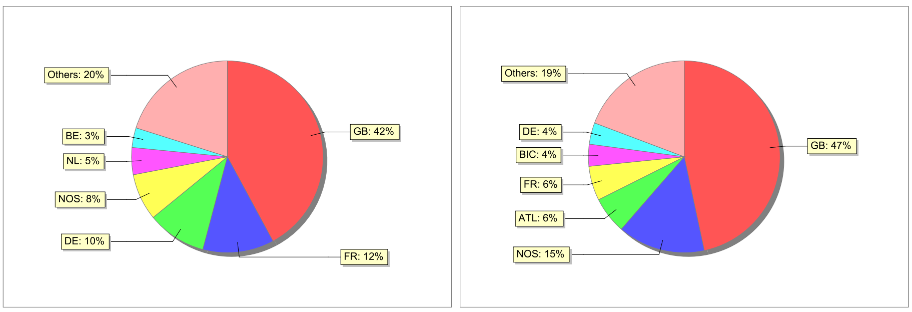

Figure 25: Main contributors to PM2.5 (left) and PMcoarse (right) concentrations in the United Kingdom. Units: (%)

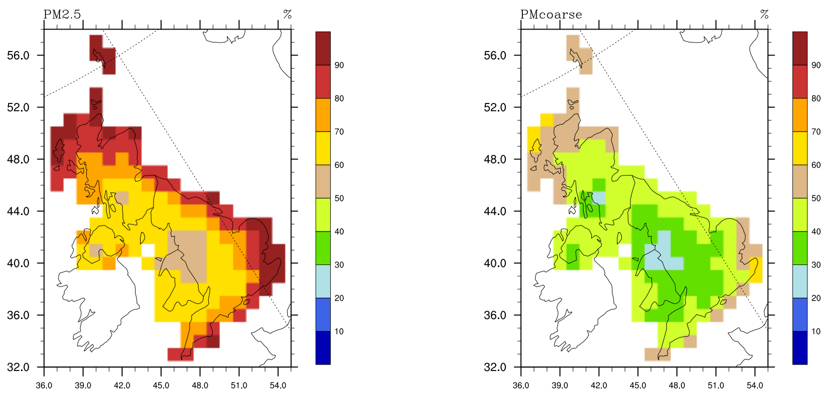

Figure 26: Reduction in PM2.5 and PMcoarse concentrations in the United Kingdom due to 15% emission reductions from transboundary sources. Units: (%)

8 Comparison with Observations

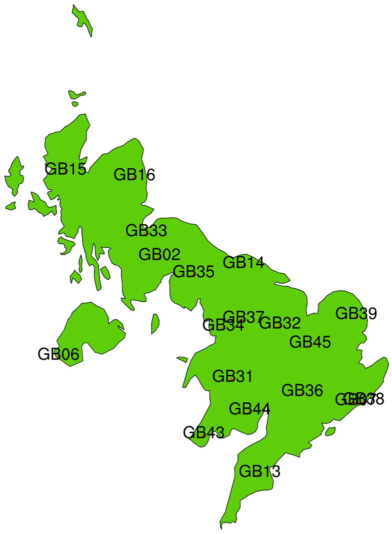

Figure 27: Location of stations in the United Kingdom

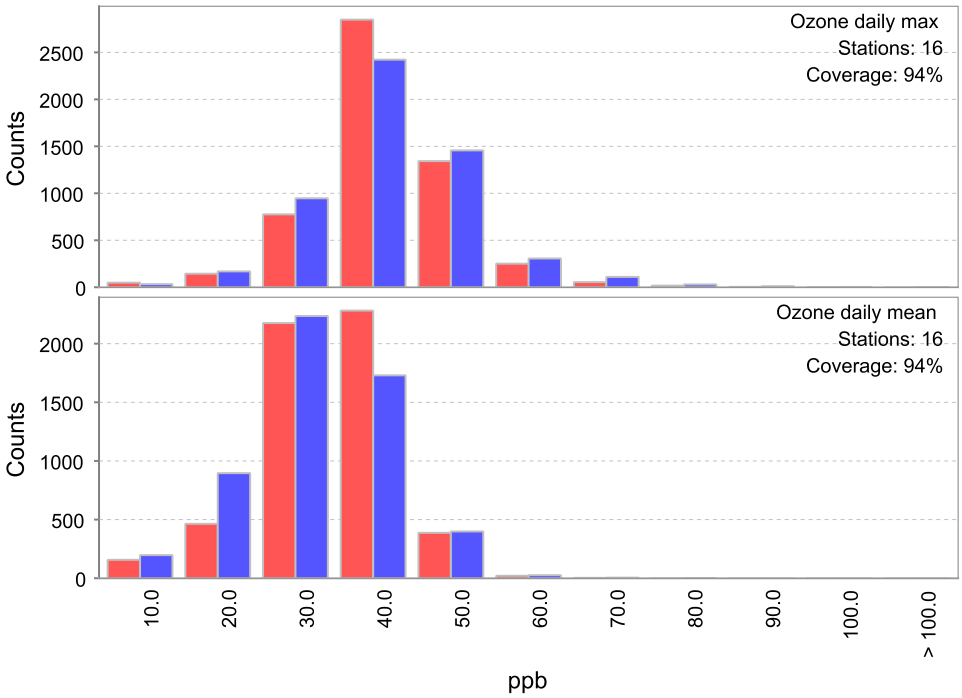

Figure 28: Frequency analysis of ozone in the United Kingdom at the stations that reported O_3 in 2005 (Model, Observations)

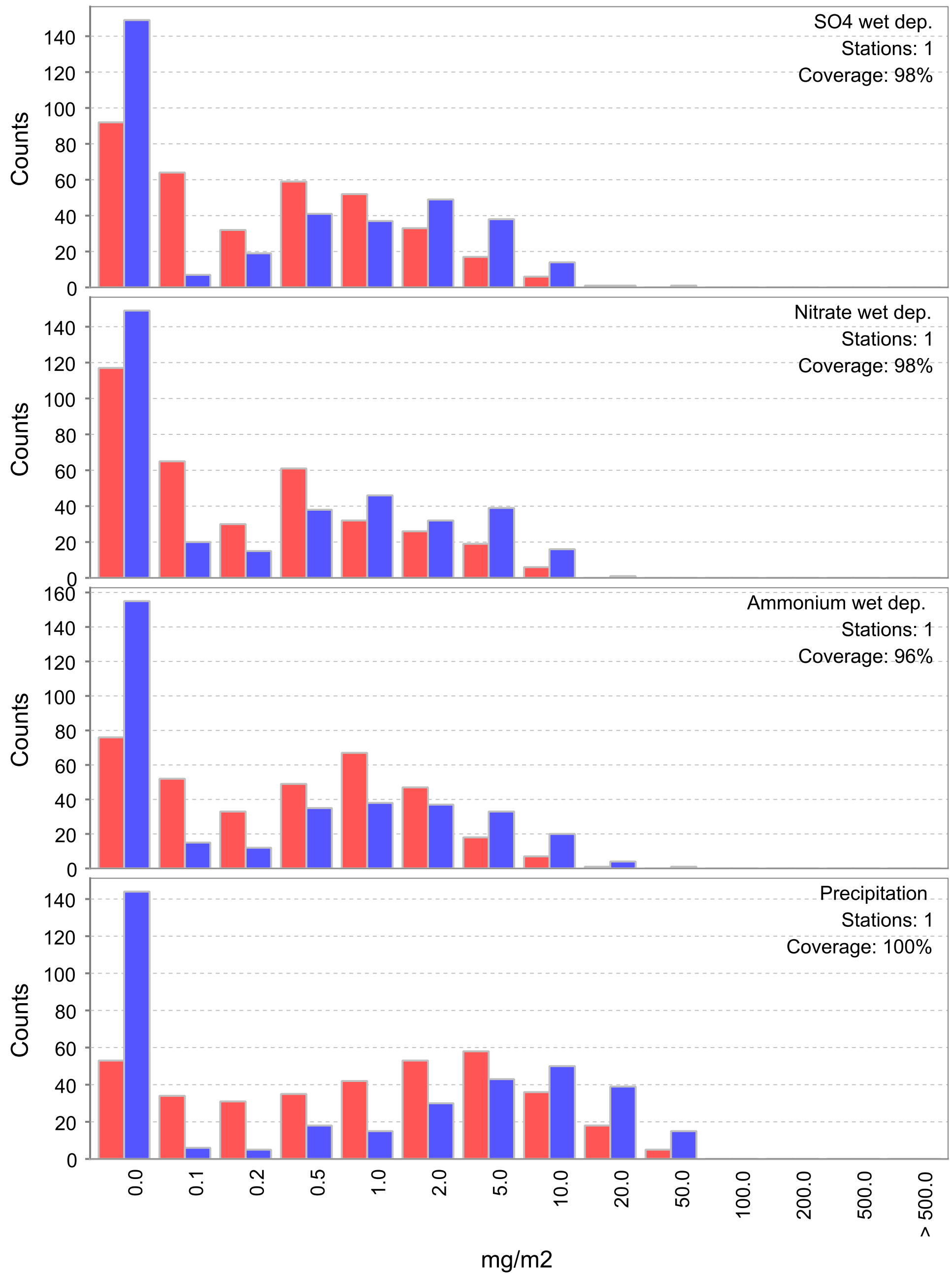

Figure 29: Frequency analysis of depositions in precipitation in the United Kingdom (Model, Observations)

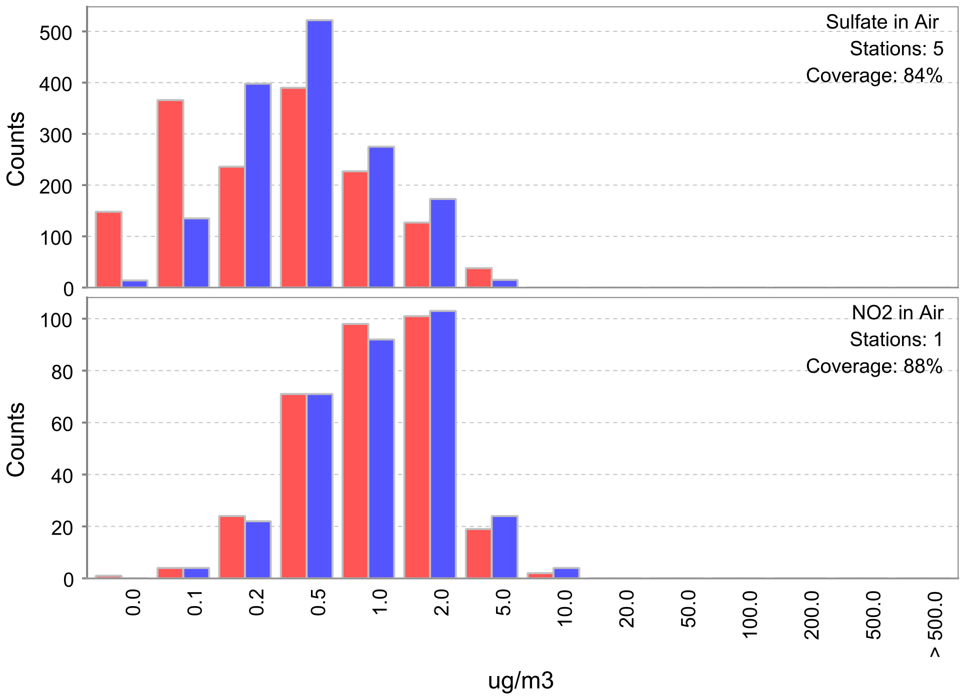

Figure 30: Frequency analysis of air concentrations in the United Kingdom (Model, Observations)

Component	No.	Bias	Correlation	RMSE
SO2 in Air	0			
Sulfate in Air	5	-13%±14%	0.80±0.15	0.23±0.06
NO2 in Air	1	-7%	0.83	0.73
Total Nitrate in Air	0			
NH3+NH4+ in Air	0			
Ozone daily max	16	-1%±7%	0.74±0.17	5.42±1.39
Ozone daily mean	16	6%±10%	0.76±0.11	5.07±1.33
SO4 wet dep.	1	-53%	0.49	8.52
Nitrate wet dep.	1	-60%	0.59	11.63
Ammonium wet dep.	1	-55%	0.67	12.86
Precipitation	1	-36%	0.65	22.81

Table 5: Annual statistics of comparison of model results with observations in the United Kingdom for stations with data available in weekly or higher time-resolution. Standard deviations provide variability ranges between stations.

9 Risk of damage from Ozone and PM in the United Kingdom in 2005

9.1 Ecosystem-specific AOT40 values

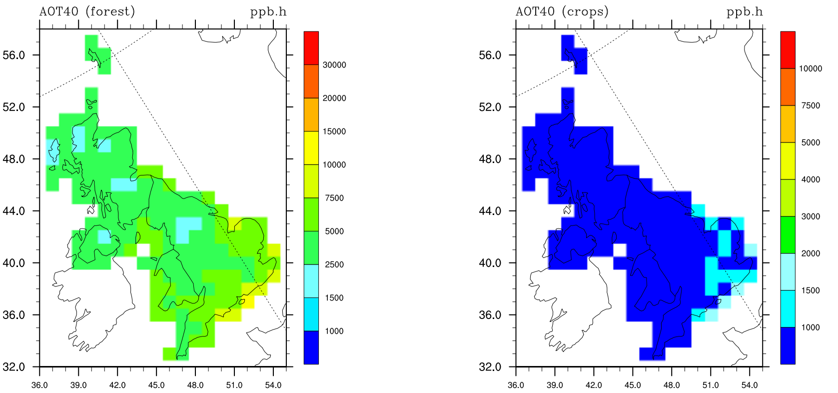

Figure 31: $\text{AOT40}_f^{\text{uc}}$ and $\text{AOT40}_c^{\text{uc}}$ in the United Kingdom in 2005.
$AOT40_f^{uc}$(growing season: April-September): The critical level for forest damage is 5000 ppb·h.
$AOT40_c^{uc}$(growing season: May-July): The critical level for agricultural crops is 3000 ppb·h.

9.2 Ecosystem-specific ozone fluxes

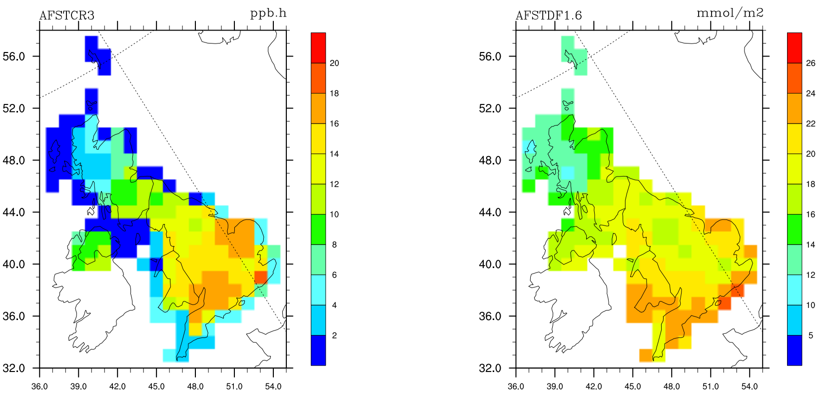

Figure 32: $\text{AF}_{\text{st}}3_{\text{gen-CR}}$ and $\text{AF}_{\text{st}}1.6_{\text{gen-DF}}$ in the United Kingdom in 2005.

9.3 Health impacts from Ozone and PM

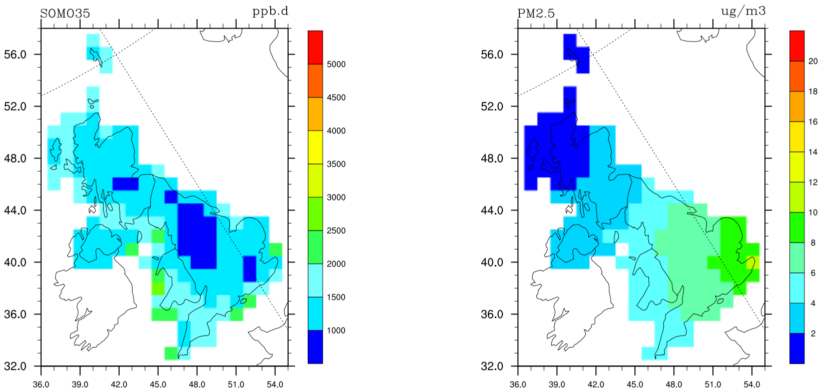

Figure 33: Regional scale SOMO35 and $PM_{2.5}$ in the United Kingdom in 2005.