MSC-W Data Note 1/2012
Date: July 2012

METEOROLOGISK INSTITUTT
Norwegian Meteorological Institute

Transboundary air pollution by main pollutants (S, N, O_3) and PM in 2010

Belgium

EMEP/MSC-W: M. Gauss, Á. Nyíri, B. M. Steensen and H. Klein

Data Note 2012

ISSN 1890-0003

Contents

1 How to read this report

This report is one of a series of country-specific notes, complementary to the EMEP Status Report 1/2012. It presents an overview of transboundary pollution of main pollutants, ground level ozone and particulate matter (PM) for Belgium in 2010.

All model runs have been performed with the EMEP/MSC-W model version rv4, using ECMWF-IFS meteorology. The transboundary contributions presented here are based on source-receptor calculations with the EMEP/MSC-W model using meteorological and emission data for the year 2010.

As a basis for their correct interpretation, this section briefly explains what types of results are shown in this report and how they have been calculated.

1.1 The chapters of this report

Emissions *(Chapter 2)* : The emissions for 2010 have been derived from the 2012 official data submissions to UNECE CLRTAP. The gridded distributions of the 2010 emissions have been provided by the EMEP Centre on Emission Inventories and Projections (CEIP). More detailed information on 2010 emission data is provided in the EEA/CEIP Report *"Inventory Review 2012"*.

The emissions for the period of 2000–2010 have been derived from the latest data submissions to UNECE CLRTAP as of May 2012. Consequently, for these years both the gridded emission data and the national and sector totals might differ from those which were used in previous EMEP reports. The spatial allocation of the emission data is, in general, based on the original base grid distribution of the particular year. If this was not available, the distribution from the most recent base grid was applied for the re-gridding of historical emission data.

All model calculations were carried out for the extended EMEP domain. However, expert estimates for the extended domain are available only from year 2007. For those areas where no historical data are given in the EMEP emission inventory, the 2007 gridded emissions were used for the years 2000–2006.

The re-gridded emission data used in the model calculations this year are available on WebDab: `http://www.emep-emissions.at/emission-data-webdab/`.

Trends *(Chapter 3)* : Trends in depositions and air concentrations are presented for the period of 2000–2010. The calculations are based on a consistent series of model runs, all using the EMEP/MSC-W model version rv4. For the years 2000–2010, the meteorology of the respective year is used. This was possible for the first time this year as a consistent set of ECMWF-IFS meteorology for the entire 2000–2010 period has become available to MSC-W. The trend figures also show depositions and air concentrations for 2020, based on a model simulation that uses emission projections for 2020 from the revised Gothenburg Protocol. The model simulation for 2020 uses year 2005 meteorology (because 2005 is the base year of the Protocol). It also uses CO emissions for 2005 (because CO emissions are not projected for 2020 in the Protocol). The results for 2020 have thus to be compared to those for 2005.

Transboundary fluxes and concentrations *(Chapters 4-6)* : Data are presented in the form of maps, pies and bar charts. The data are 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 up to represent the entire emission from an emitter. For other components, which are subject to

significant non-linearities, we present the effect of a 15% reduction only. To give more intuitive pictures on the effect of pollution from a given country, we use positive scales in the maps for pollution reductions. Negative values thus mean an increase of pollution levels.

The pie charts give a picture of the relative contributions from different countries or regions to depositions and concentrations over Belgium.

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 Belgium. Since the contributions can be both positive or negative, the relative importance of each contributor has been determined by comparing the absolute values of the contributions.

Comparison with observations *(Chapter 7)* : The map of monitoring stations shows stations of Belgium in the EMEP measurement network with measurements in 2010 submitted to EMEP. The frequency analysis plots compare daily observation results with the model results. The measurement data are 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 component. Comparison is done only for stations with a sufficiently consistent set of data available in weekly or higher time resolution.

Risks from ozone and PM *(Chapter 8)* : The maps of 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).

NOTE: In this series of country reports, trends are also presented for Kyrgyzstan, Uzbekistan, Turkmenistan and Tajikistan, although, as mentioned above, historical emission data before 2007 are not available. Emissions used for the years 2000–2006 are thus the same as for 2007 for these countries. The presented inter-annual changes of depositions and air concentrations are induced by the emission changes in the old EMEP domain (132×111 grid cells) only.
For the Russian Federation and Kazakhstan, trends refer to the area of these countries inside the extended EMEP domain (132×159 grid cells), now covering all of Kazakhstan's territory and a larger part of the Russian Federation.

1.2 Country codes

Many tables and graphs in this report make use of codes to denote countries and regions in the EMEP area. Table 1 provides an overview of these codes and lists the countries and regions included in the source-receptor calculations for 2010.

Code	Country/Region
AL	Albania
AM	Armenia
AST	Asian Areas, extended EMEP domain
AT	Austria
ATL	Remaining North-East Atlantic Ocean
AZ	Azerbaijan
BA	Bosnia and Herzegovina
BAS	Baltic Sea
BE	Belgium
BG	Bulgaria
BIC	Boundary and Initial Conditions
BLS	Black Sea
BY	Belarus
CH	Switzerland
CY	Cyprus
CZ	Czech Republic
DE	Germany
DK	Denmark
DMS	Natural Marine Emissions
EE	Estonia
ES	Spain
EU	European Union (EU27)
EXC	EMEP land areas (extended)
FI	Finland
FR	France
GB	United Kingdom
GE	Georgia
GL	Greenland
GR	Greece
HR	Croatia
HU	Hungary

Code	Country/Region
IE	Ireland
IS	Iceland
IT	Italy
KG	Kyrgyzstan
KZT	Kazakhstan in the extended EMEP domain
LT	Lithuania
LU	Luxembourg
LV	Latvia
MD	Republic of Moldova
ME	Montenegro
MED	Mediterranean Sea
MK	The former Yugoslav Republic of Macedonia
MT	Malta
NL	Netherlands
NO	Norway
NOA	North Africa
NOS	North Sea
PL	Poland
PT	Portugal
RO	Romania
RS	Serbia
RUE	Russian Federation, extended EMEP domain
SE	Sweden
SI	Slovenia
SK	Slovakia
TJ	Tajikistan
TMT	Turkmenistan
TR	Turkey
UA	Ukraine
UZT	Uzbekistan
VOL	Volcanic emissions

Table 1: Country/region codes used in the source-receptor calculations. 'official' refers to the area of the country/region which is inside the official EMEP grid, while 'extended' refers to the area of the country/region inside the extended EMEP grid.

1.3 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 EMEP/MSC-W model SIA is calculated as SIA= SO_4^{2-} + NO_3^-(fine) + NO_3^-(coarse) + NH_4^+.

SS - sea salt.

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

$PM_{2.5}$ denotes fine particulate matter, defined as the integrated mass of aerosol with dry diameters up to 2.5 μm. In the EMEP/MSC-W model $PM_{2.5}$ is calculated as $PM_{2.5}$ = SO_4^{2-} + NO_3^-(fine) + NH_4^+ + SS(fine) + $PPM_{2.5}$ + 0.27 NO_3^-(coarse).

PM_{coarse} denotes coarse particulate matter, defined as the integrated mass of aerosol with dry diameter between 2.5μm and 10μm. In the EMEP/MSC-W model PM_{coarse} is calculated as PM_{coarse} = 0.73 NO_3^-(coarse)+ SS(coarse) + PPM_{coarse}.

PM_{10} denotes particulate matter, defined as the integrated mass of aerosol with dry diameters up to 10 μm. In the EMEP/MSC-W model PM_{10} is calculated as PM_{10} = $PM_{2.5}$ + PM_{coarse}.

SOMO35 is the Sum of Ozone Means Over 35 ppb is an 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:

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

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 is 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 is ppb·hours (abbreviated to ppb·h).

Although the EMEP model generates a number of AOT-related outputs, in accordance with the recommendations of the UNECE Mapping Manual we will concentrate in this report on two definitions:

AOT40$_f^{uc}$ - 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.

AOT40$_c^{uc}$ - 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.

POD$_Y$ - Phyto-toxic ozone dose, is the accumulated stomatal ozone flux over a threshold Y, i.e.:

$$\text{POD}_Y = \int \max(F_{st} - Y, 0)\, dt \tag{1}$$

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" can be applied, in this report e.g. POD$_{1.0,\text{gen-DF}}$ (or AF$_{\text{st}}1.6_{\text{gen-DF}}$) is used for forests and POD$_{3.0,\text{gen-CR}}$ (or AF$_{\text{st}}3_{\text{gen-CR}}$) is used for crops.

2 Emissions

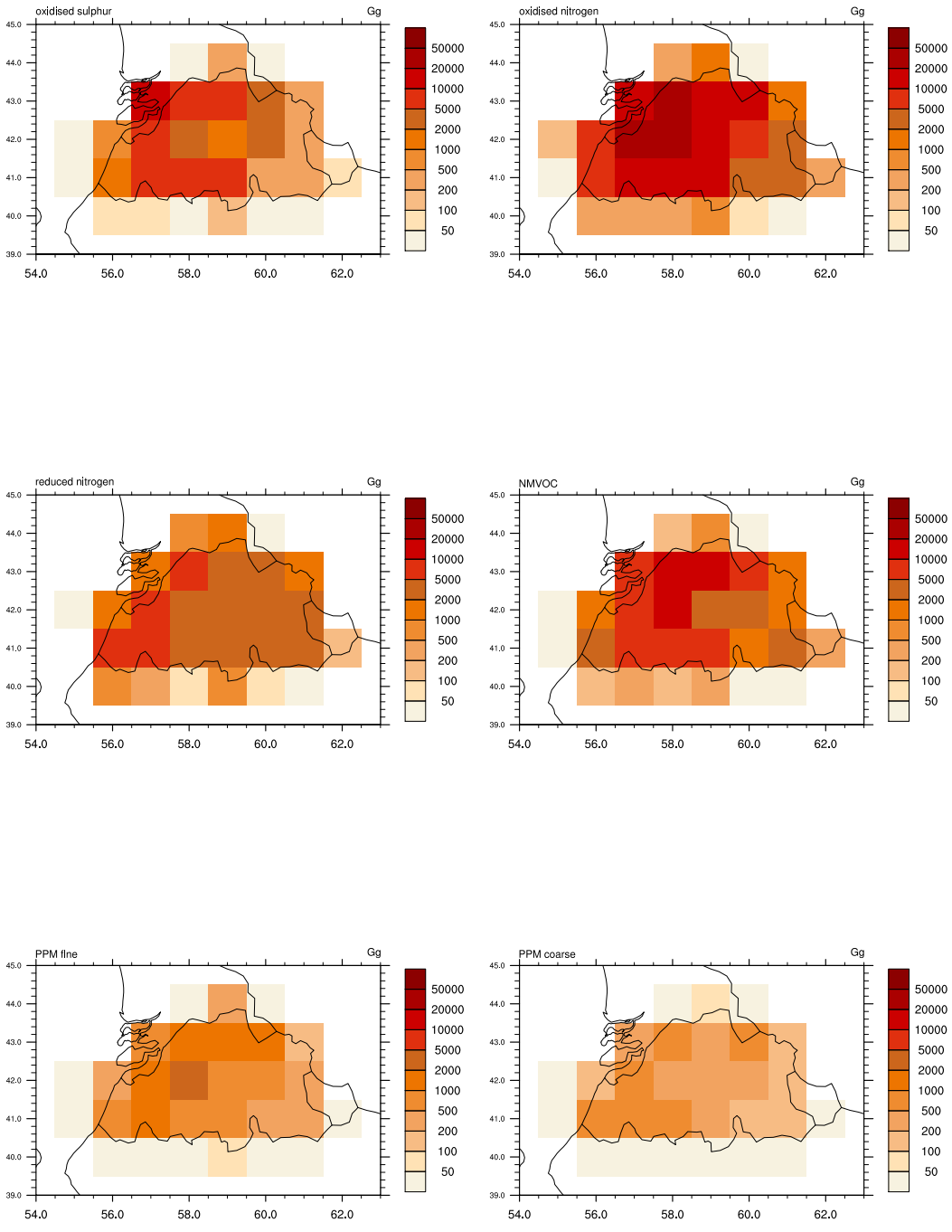

Figure 1: Spatial distribution of emissions from Belgium in 2010.

3 Trends

Important: For correct interpretation of the results shown in this chapter please read the paragraph on *Trends* in Section 1.1.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2020
SO_x	172	167	157	155	158	145	135	125	97	77	67	83
NO_x	332	316	299	297	300	291	265	262	239	207	221	172
NH_3	86	82	80	77	72	71	71	68	67	69	69	70
NMVOC	206	195	181	171	158	143	148	127	118	105	105	113
CO	1028	1013	983	951	898	717	704	618	614	381	461	
$PM_{2.5}$	34	30	30	29	28	24	25	21	20	16	17	19
PM_{10}	46	45	44	44	42	34	34	30	28	23	24	27

Table 2: Emissions from Belgium. Unit: Gg.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2020
S dep.	40	40	36	32	34	32	30	31	25	20	20	21
oxN dep.	25	23	22	21	23	21	22	21	19	18	17	14
redN dep.	38	37	35	31	32	31	33	32	31	30	31	30

Table 3: Estimated deposition of Sulphur (S) and Nitrogen (N) in Belgium. Unit: Gg(S) or Gg(N).

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2020
mean ozone	31	29	31	31	30	31	32	31	31	31	29	33
max ozone	41	40	42	43	41	42	42	40	41	41	38	43
$AOT40_f^{uc}$	19471	17625	19809	25877	19028	17627	24113	14710	15600	17257	13667	16390
SOMO35	2534	2301	2819	3138	2532	2470	2956	2176	2276	2396	2017	2576
$POD_{1.0,gen\text{-}DF}$	34	32	34	33	33	32	33	31	32	32	28	32
$PM_{2.5}$ anthrop.	12	13	13	14	13	13	12	11	10	10	10	10
PM_{10} anthrop.	17	18	17	20	18	18	17	16	14	14	14	14

Table 4: Estimated yearly mean values of air quality indicators averaged over Belgium. Unit: daily mean ozone (ppb), daily max ozone (ppb), $AOT40_f^{uc}$ (ppb·h), SOMO35 (ppb·d), $POD_{1.0,gen\text{-}DF}$ (mmol/m2), $PM_{2.5}$ ($\mu g/m^3$) and PM_{10} ($\mu g/m^3$).

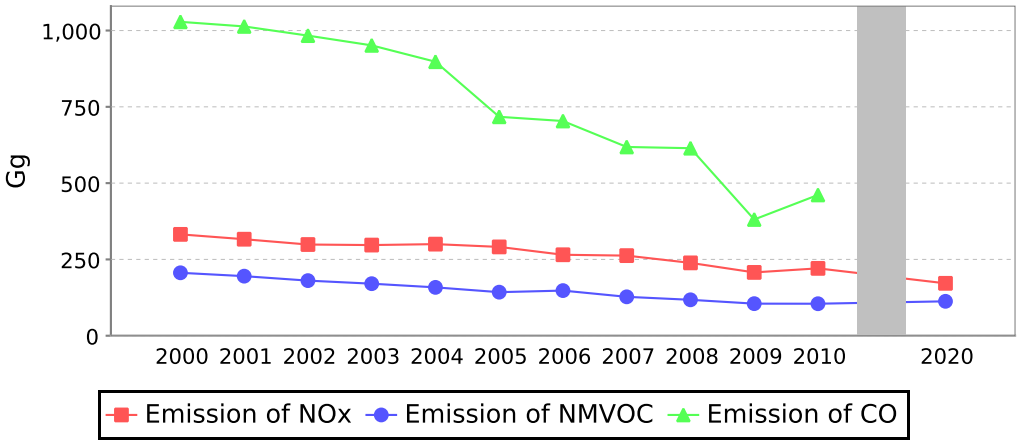

Figure 2: Trends in emissions of photo-oxidant pollution precursors. Unit: Gg (note that NO_x is here given as NO_2).

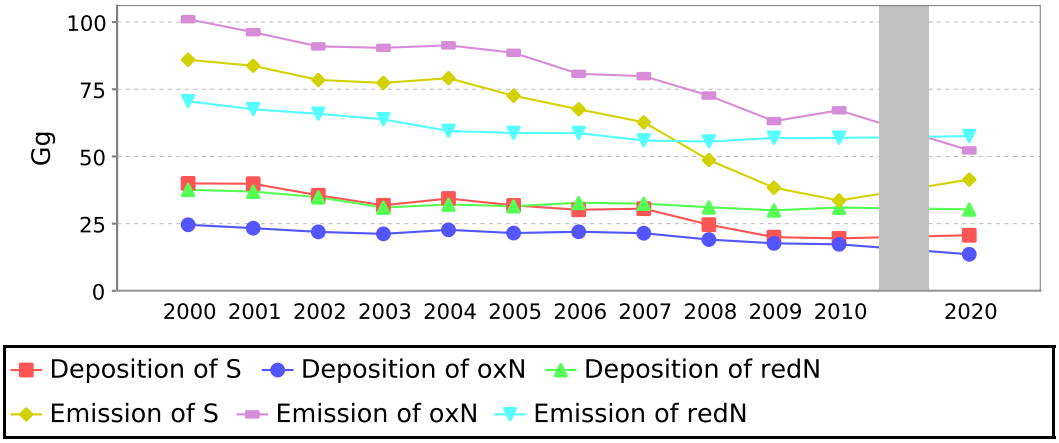

Figure 3: Trends in emissions and depositions of oxidised sulphur, oxidised nitrogen and reduced nitrogen. Unit: Gg(S) or Gg(N).

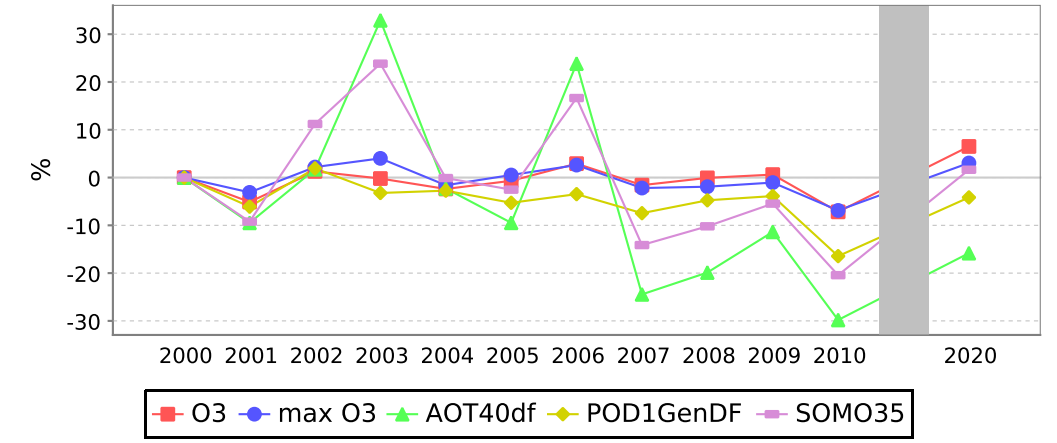

Figure 4: Changes in ozone related pollution relative to 2000. Unit: %. The large changes from year to year in some countries are mainly related to meteorological variability.

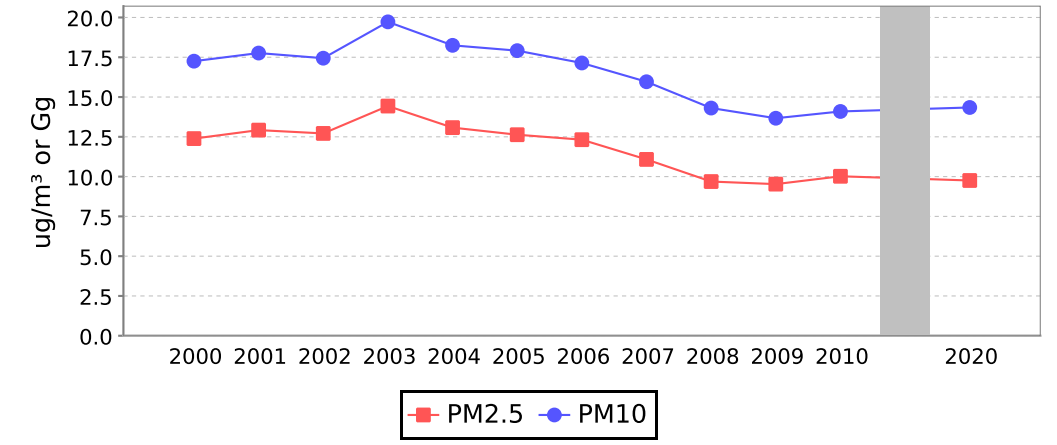

Figure 5: Trends in mean concentrations of particulate matter. Unit: μg/m^3.

4 Transboundary fluxes

4.1 Deposition of oxidised sulphur

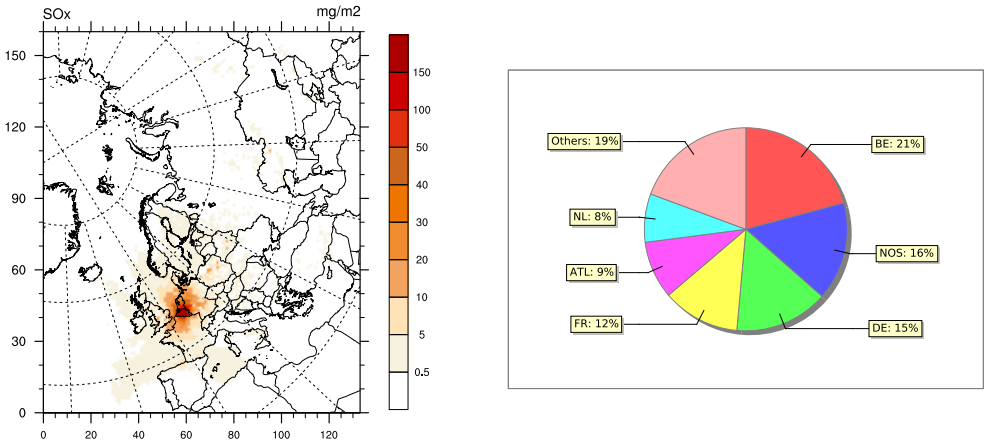

Figure 6: Contribution of emissions from Belgium to deposition of oxidised sulphur in the EMEP domain. Unit: mg(S)/m^2. The pie chart shows the six main receptor areas where oxidised sulphur from Belgium is deposited. Unit: %.

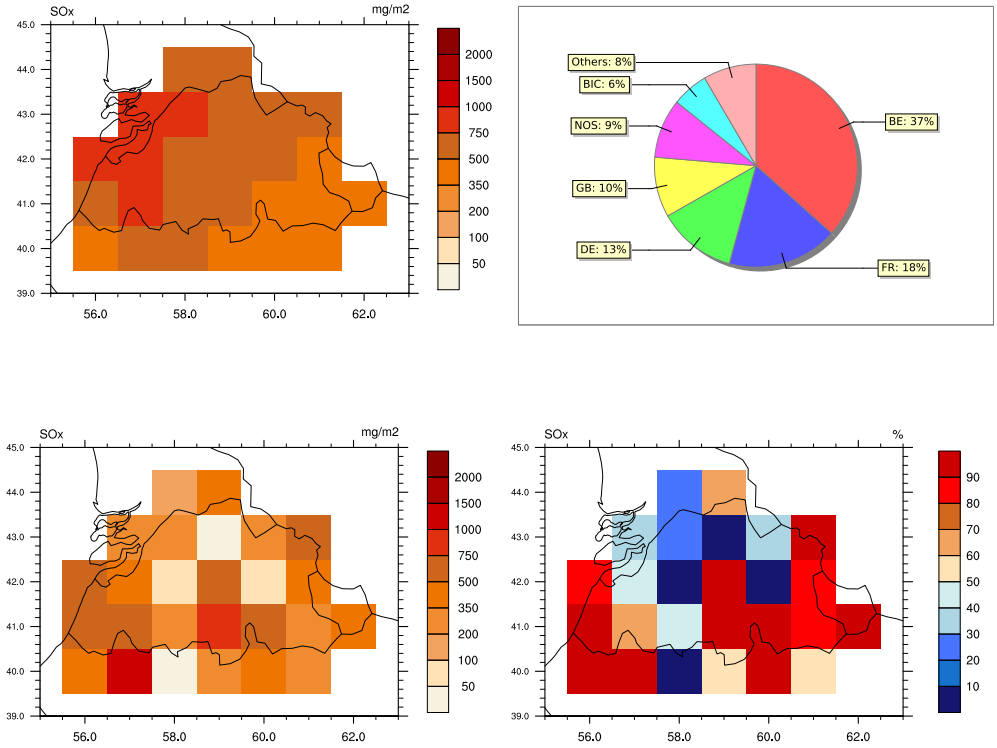

Figure 7: Top left: Deposition of oxidised sulphur in Belgium. Unit: mg(S)/m^2. Top right: The six main contributors to oxidised sulphur deposition in Belgium. Unit: (%). Bottom left: Oxidised sulphur deposition from transboundary sources. Unit: mg(S)/m^2. Bottom right: Fraction of transboundary contribution to total deposition. Unit: %.

4.2 Deposition of oxidised nitrogen

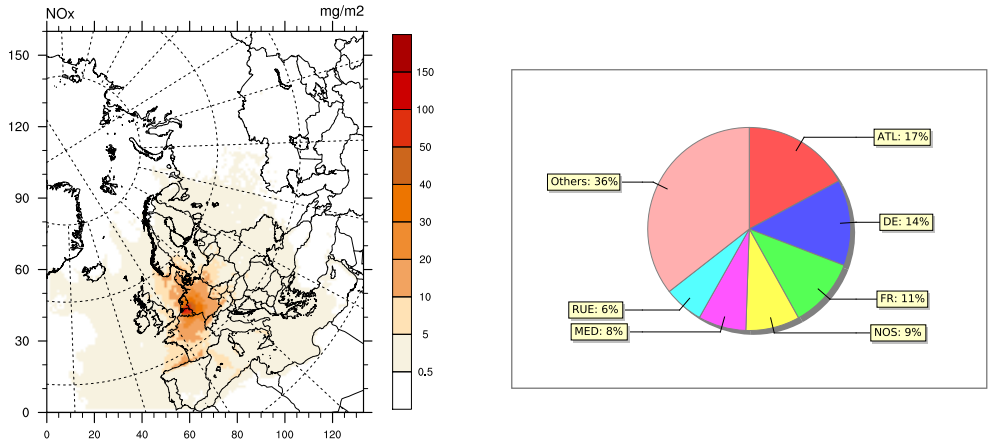

Figure 8: Contribution of emissions from Belgium to deposition of oxidised nitrogen in the EMEP domain. Unit: mg(N)/m^2. The pie chart shows the six main receptor areas where oxidised nitrogen from Belgium is deposited. Unit: %.

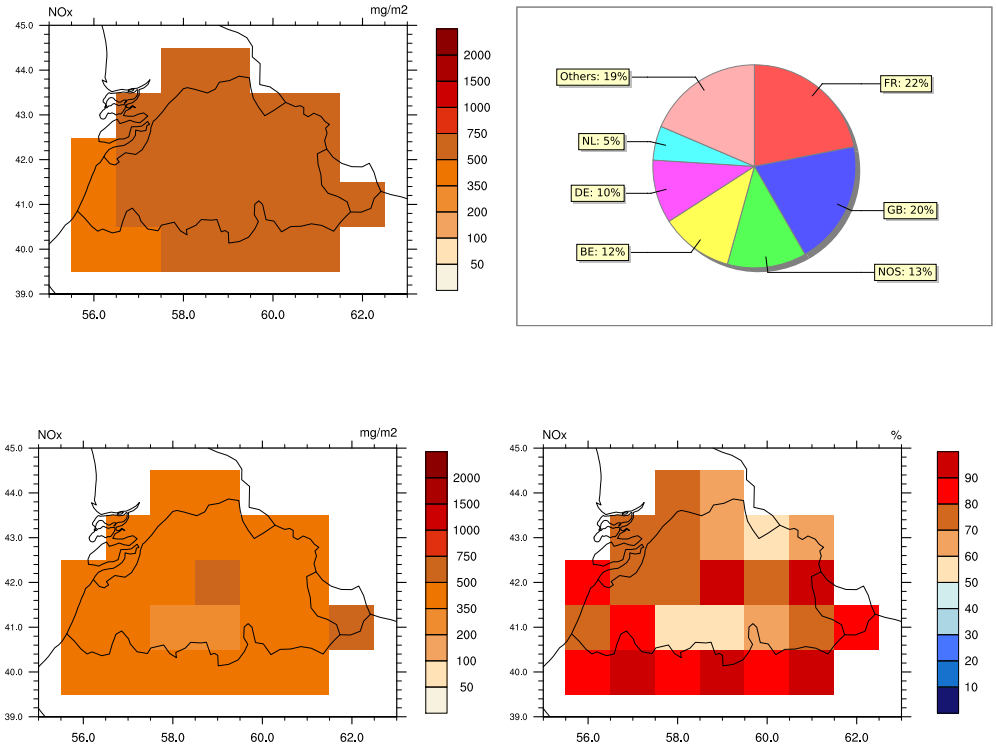

Figure 9: Top left: Deposition of oxidised nitrogen in Belgium. Unit: mg(N)/m^2. Top right: The six main contributors to oxidised nitrogen deposition in Belgium. Unit: %. Bottom left: Oxidised nitrogen deposition from transboundary sources. Unit: mg(N)/m^2. Bottom right: Fraction of transboundary contribution to total deposition. Unit: %.

4.3 Deposition of reduced nitrogen

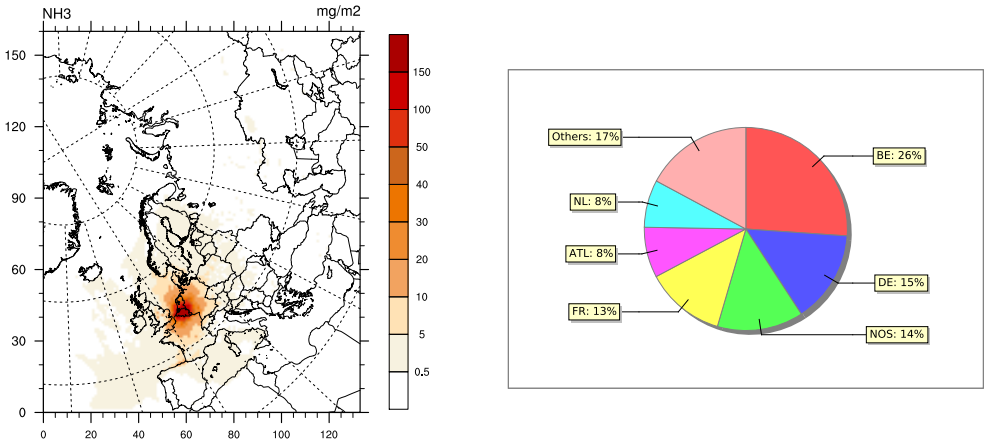

Figure 10: Contribution of emissions from Belgium to deposition of reduced nitrogen in the EMEP domain. Unit: mg(N)/m^2. The pie chart shows the six main receptor areas where reduced nitrogen from Belgium is deposited. Unit: %.

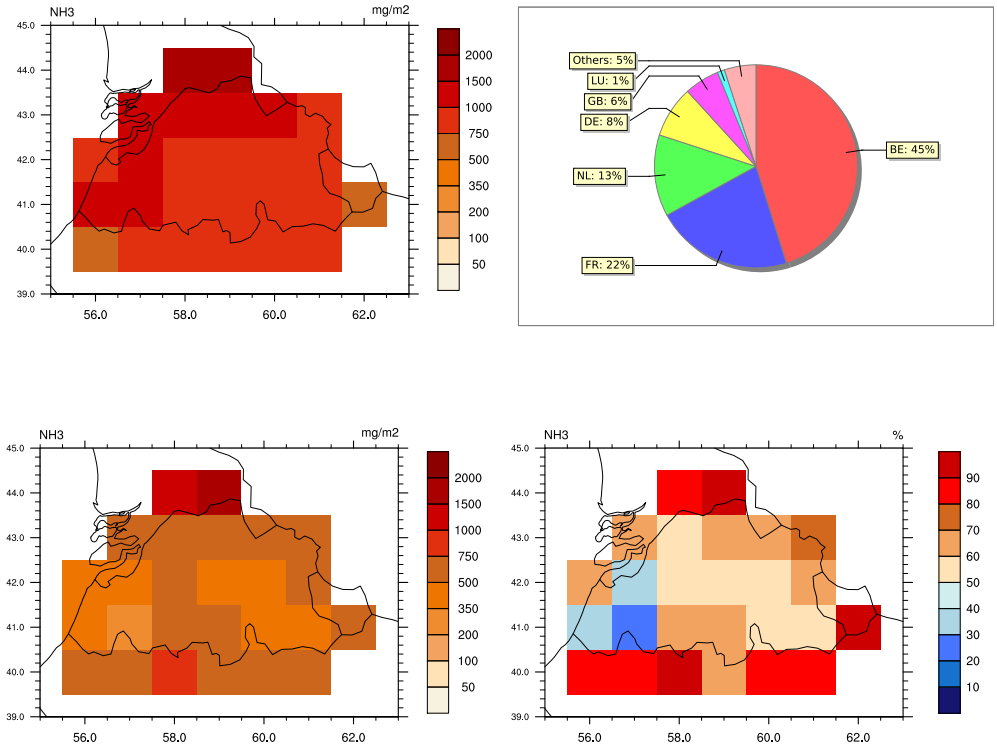

Figure 11: Top left: Deposition of reduced nitrogen in Belgium. Unit: mg(N)/m^2. Top right: The six main contributors to deposition of reduced nitrogen in Belgium. Unit: %. Bottom left: Deposition of reduced nitrogen from transboundary sources. Unit: mg(N)/m^2. Bottom right: Fraction of transboundary contribution to total deposition. Unit: %.

5 Transboundary concentrations of ozone

5.1 AOT40$_f^{uc}$

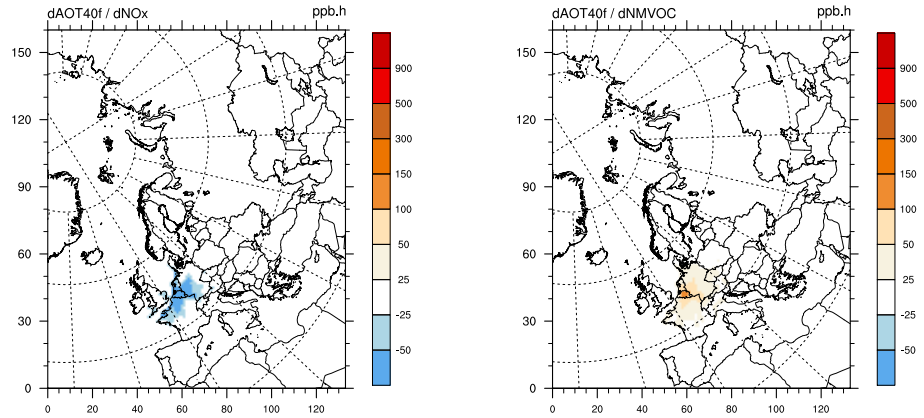

Figure 12: Reduction in AOT40$_f^{uc}$ that would result from a 15% reduction in emissions of NO_x (left) and NMVOC (right) from Belgium. Unit: ppb·h.

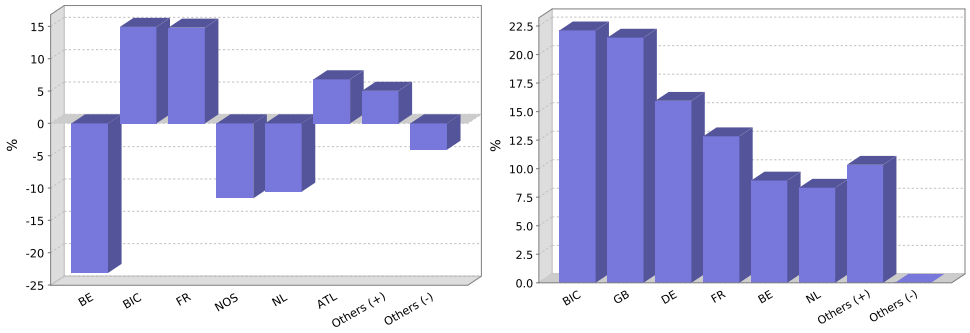

Figure 13: Six most important contributors to AOT40$_f^{uc}$ in Belgium related to emissions of NO_x (left) and NMVOC (right). Unit: %.

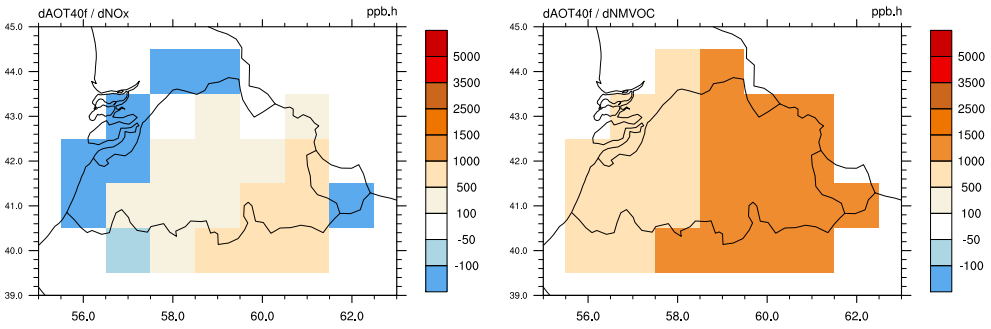

Figure 14: Reduction in AOT40$_f^{uc}$ that would result from a 15% reduction in emissions of NO_x (left) and NMVOC (right) outside Belgium. Unit: ppb·h.

5.2 $POD_{1.0,gen\text{-}DF}$ – Ozone fluxes to deciduous forests

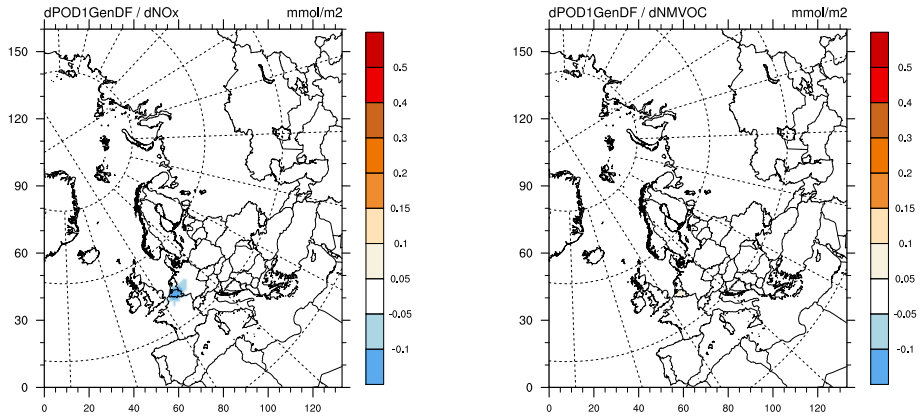

Figure 15: Reduction in $POD_{1.0,gen\text{-}DF}$ that would result from a 15% reduction in emissions of NO_x (left) and NMVOC (right) from Belgium. Unit: mmol/m^2.

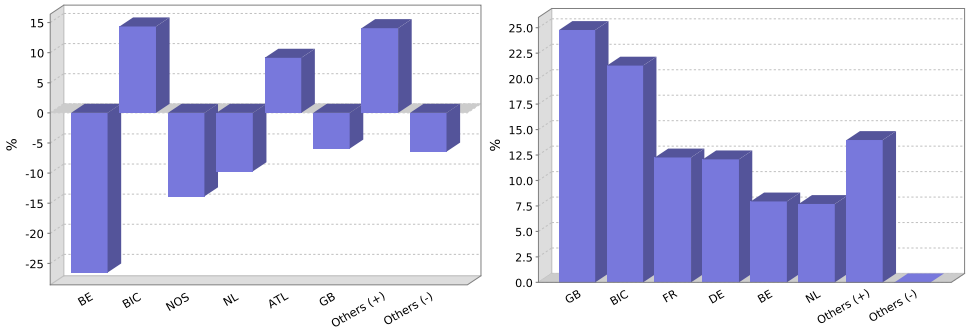

Figure 16: Six most important contributors to $POD_{1.0,gen\text{-}DF}$ in Belgium related to emissions of NO_x (left) and NMVOC (right). Unit: %.

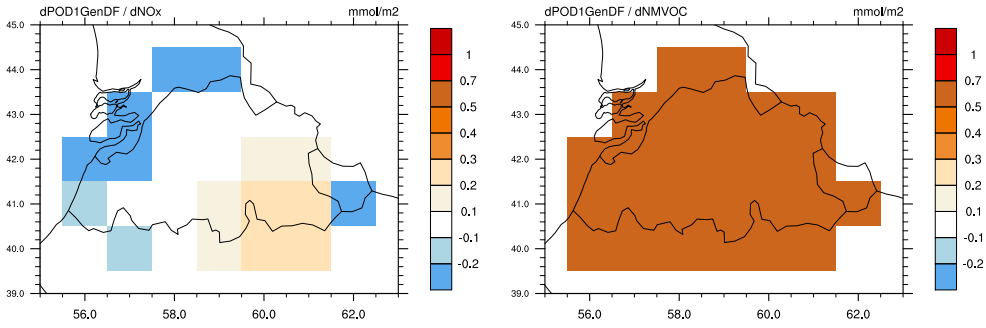

Figure 17: Reduction in $POD_{1.0,gen\text{-}DF}$ that would result from a 15% reduction in emissions of NO_x (left) and NMVOC (right) outside Belgium. Unit: mmol/m^2.

5.3 SOMO35 – Risk of ozone damages to human health

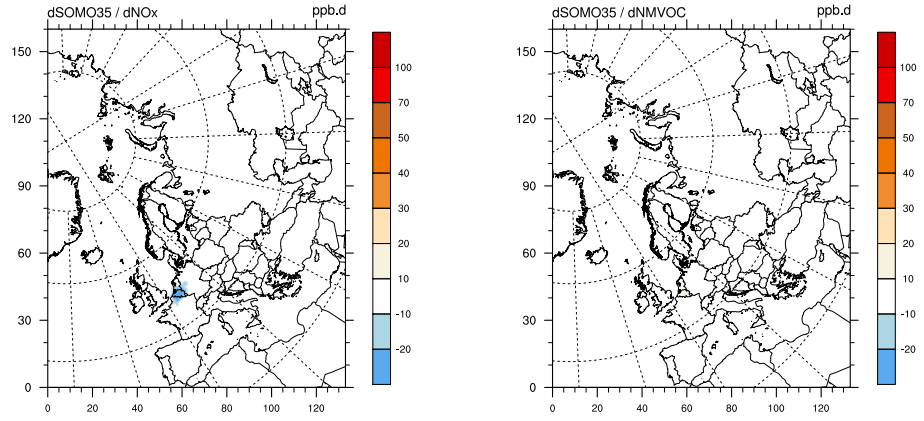

Figure 18: Reduction in SOMO35 that would result from a 15% reduction in emissions of NO_x (left) and NMVOC (right) from Belgium. Unit: ppb·day.

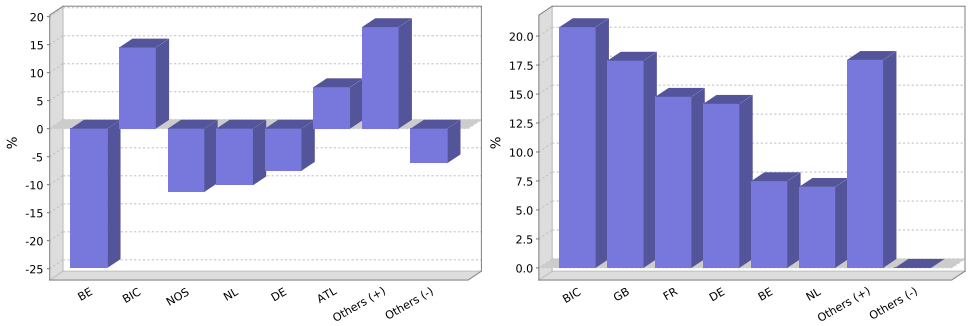

Figure 19: Six most important contributors to SOMO35 in Belgium related to emissions of NO_x (left) and NMVOC (right). Unit: %.

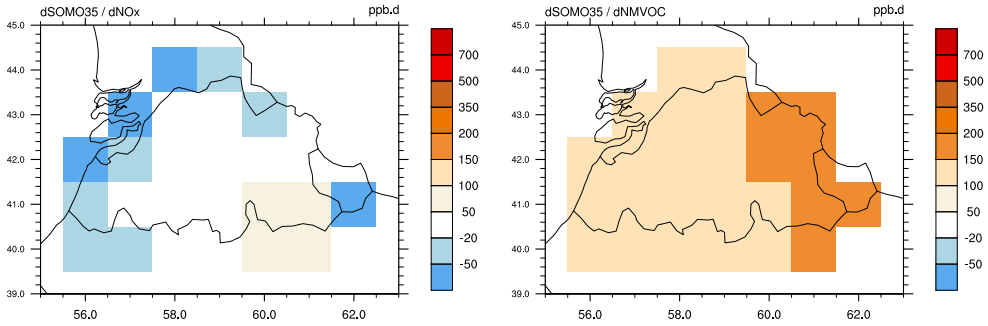

Figure 20: Reduction in SOMO35 that would result from a 15% reduction in emissions of NO_x (left) and NMVOC (right) outside Belgium. Unit: ppb·day.

6 Transboundary concentrations of particulate matter

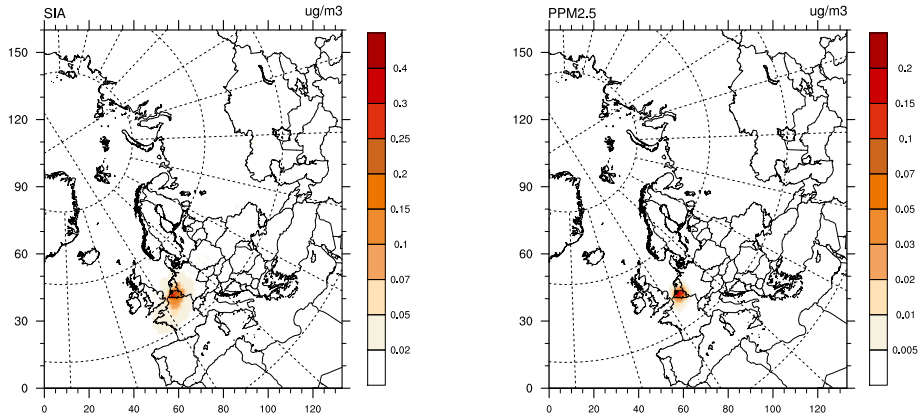

Figure 21: Reduction in concentrations of SIA (left) and PPM2.5 (right) that would result from a 15% reduction in emissions from Belgium. Unit: μg/m^3. Note the difference in scales.

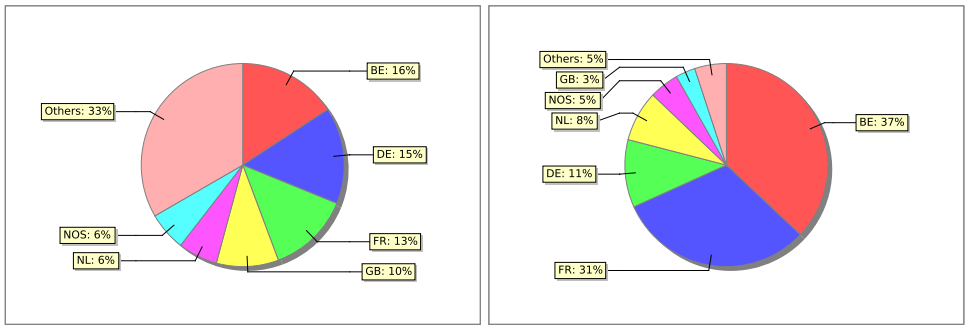

Figure 22: Main contributors to concentrations of SIA (left) and PPM$_{2.5}$ (right) in Belgium. Unit: %.

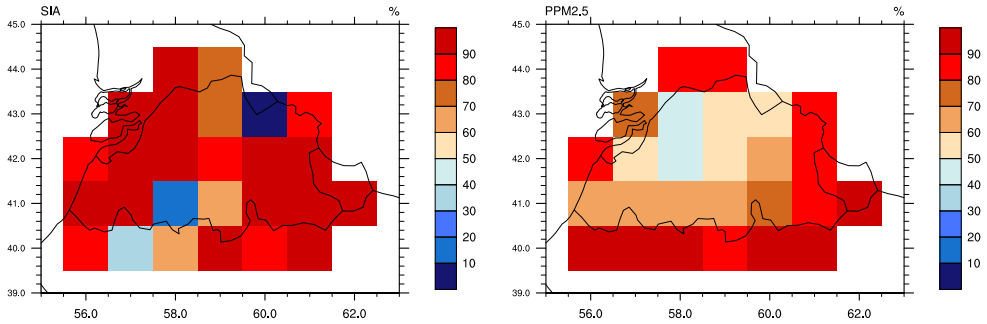

Figure 23: Fraction of transboundary contributions to concentrations of SIA (left) and PPM$_{2.5}$ (right) in Belgium. Unit: %.

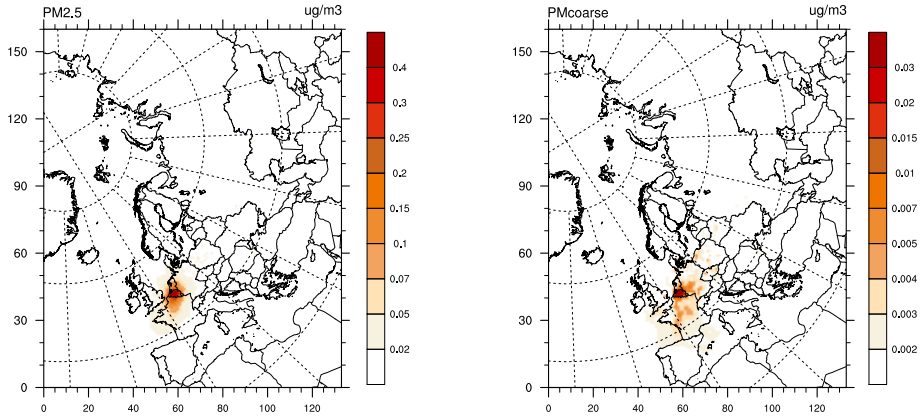

Figure 24: Reduction in $PM_{2.5}$ and PM_{coarse} concentrations that would result from a 15% reduction of emissions from Belgium. Unit: $\mu g/m^3$. Note the different color scales.

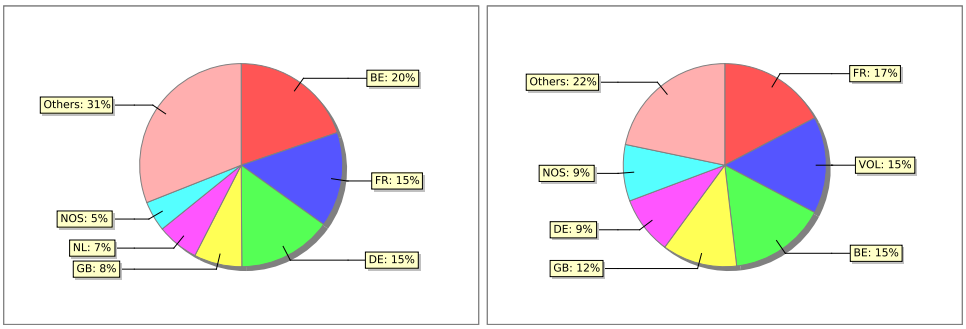

Figure 25: Main contributors to concentrations of $PM_{2.5}$ (left) and PM_{coarse} (right) in Belgium. Unit: %.

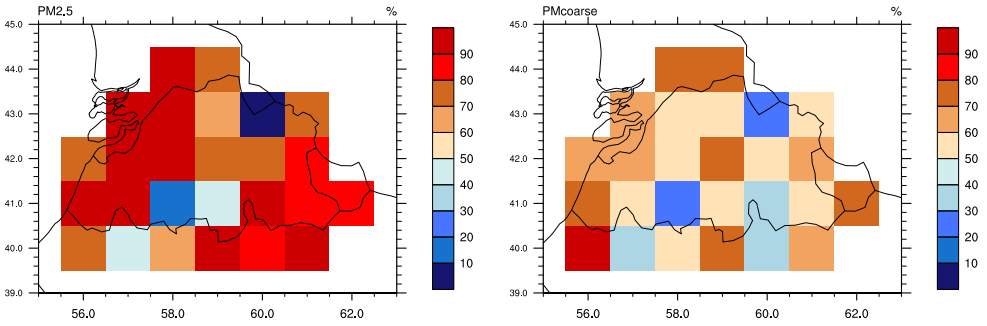

Figure 26: Fraction of transboundary contributions to $PM_{2.5}$ and PM_{coarse} concentrations in Belgium. Unit: %.

7 Comparison with observations

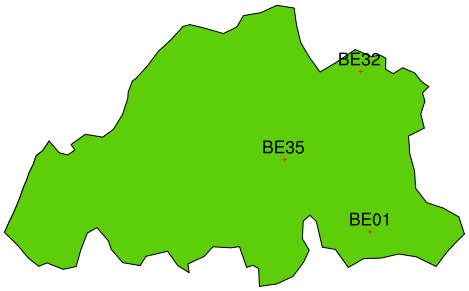

Figure 27: Location of stations in Belgium.

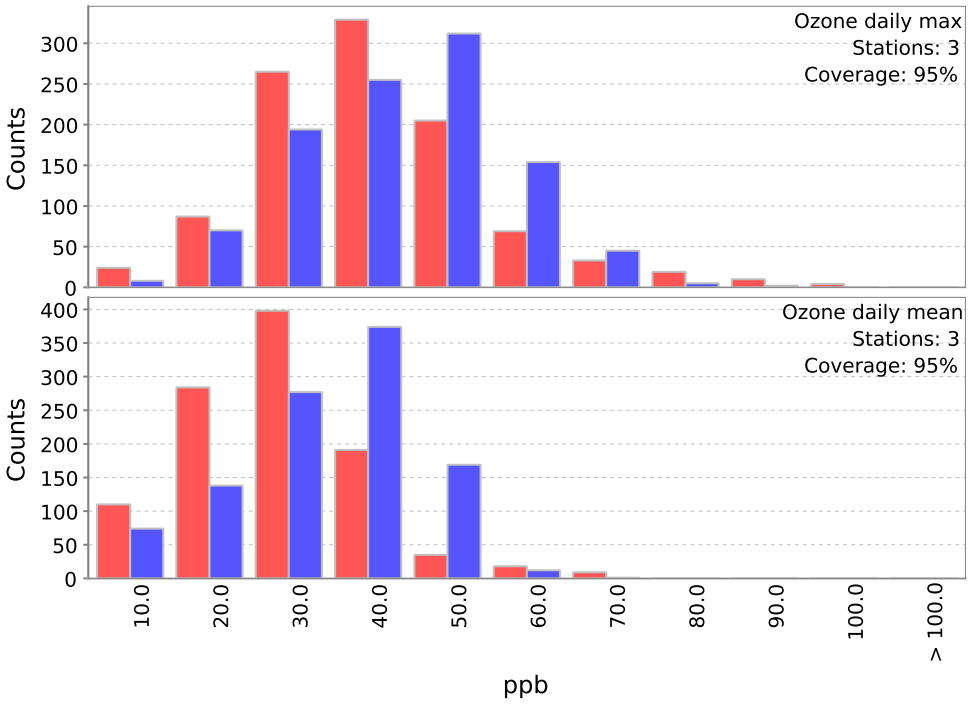

Figure 28: Frequency analysis of ozone in Belgium at the stations that reported O_3 for 2010 (Model, Observations).

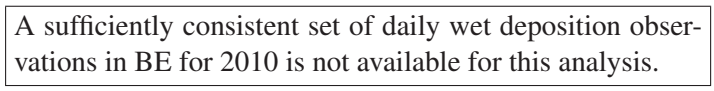

Figure 29: Frequency analysis of depositions in precipitation in Belgium (Model, Observations).

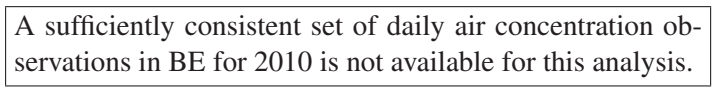

Figure 30: Frequency analysis of air concentrations in Belgium (Model, Observations).

Component	No.	Bias	Correlation	RMSE
SO2 in Air	0			
Sulfate in Air	0			
NO2 in Air	0			
NO3- in Air	0			
NH3+NH4+ in Air	0			
Ozone daily max	3	8%±3%	0.89±0.01	6.21±0.29
Ozone daily mean	3	25%±9%	0.84±0.02	7.93±0.81
SO4 wet dep.	0			
Nitrate wet dep.	0			
Ammonium wet dep.	0			
Precipitation	0			

Table 5: Annual statistics of comparison of model results with observations in Belgium for stations with a sufficiently consistent set of data available in weekly or higher time-resolution. Standard deviations provide variability ranges between stations.

8 Risk of damage from ozone and particulate matter in Belgium

8.1 Ecosystem-specific AOT40 values

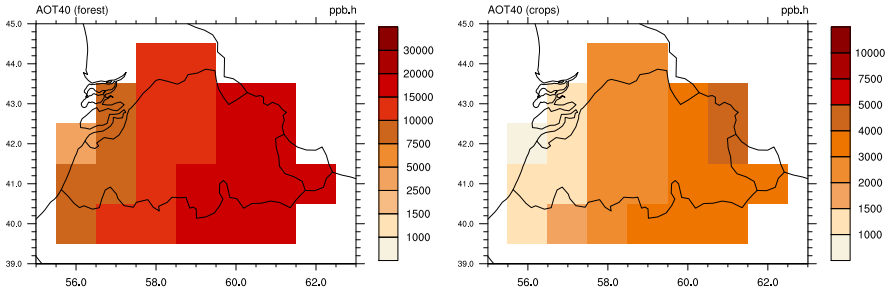

Figure 31: $AOT40_f^{uc}$ and $AOT40_c^{uc}$ in Belgium in 2010. *($AOT40_f^{uc}$: growing season April-Sept., critical level for forest damage = 5000 ppb·h; $AOT40_c^{uc}$: growing season May-July, critical level for agricultural crops = 3000 ppb·h.)*

8.2 Ecosystem-specific ozone fluxes

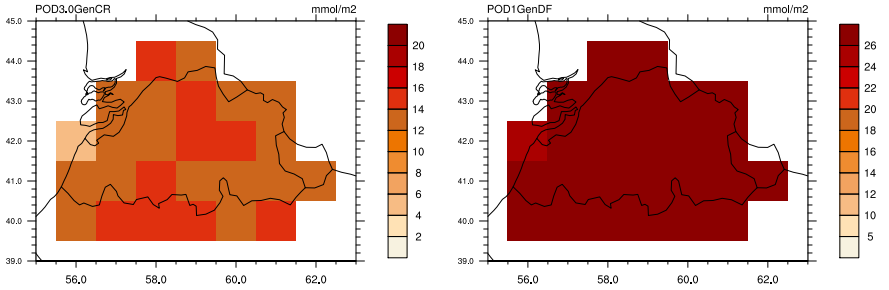

Figure 32: $POD_{3.0,\text{gen-CR}}$ and $POD_{1.0,\text{gen-DF}}$ in Belgium in 2010.

8.3 Health impacts from ozone and particulate matter

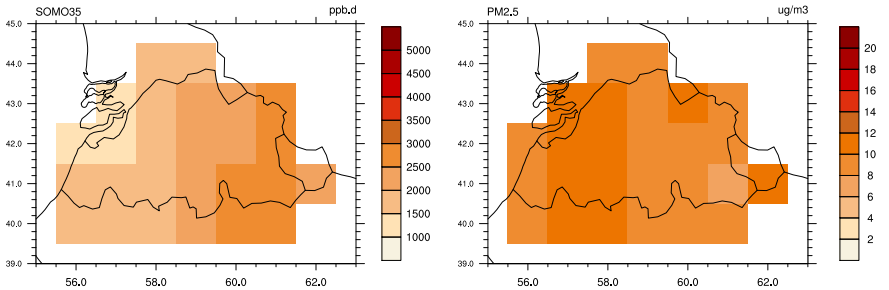

Figure 33: Regional scale SOMO35 and $PM_{2.5}$ in Belgium in 2010.