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

Serbia

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Contents

1 Introduction

This note is one of a series of country-specific reports, complementary to the EMEP Status Report 1/2009. It presents overview information on transboundary pollution of main pollutants, ground level ozone and PM relevant for Serbia.

The transboundary contributions presented here are based on source-receptor calculations with the Unified EMEP model using meteorological and emission data for the year 2007. These source-receptor calculations are based on the same version of the Unified EMEP model as presented in the main report (rv 3.1). In addition to the results on transboundary contributions in 2007, source-receptor trend results for ten meteorological years (1997–2006) produced with the same model version are also included in this report. The meteorological driver for year 2007 is HIRLAM 20, while for 1990 and 1997–2006 PARLAM-PS meteorology was used.

Emissions The emissions for 2007 have been derived from the 2009 official data submissions to UN-ECE CLRTAP. The gridded distributions of the 2007 emissions have been provided by the EMEP Centre on Emission Inventories and Projections (CEIP). More detailed information on 2007 emission data is provided in the EEA/CEIP Report *'Inventory review 2009 stage1 and stage2 and review of gridded data'*.

The emissions for 2005 and 2006 have been derived from the respective 2007 and 2008 official data submissions to UN-ECE CLRTAP. The gridded emission data used in our model calculations are the same which are available on WebDab:
`http://www.emep-emissions.at/emission-data-webdab/`.

The emissions for 1990, and 1997–2004 have been derived from the 2006 official data submissions to UN-ECE CLRTAP. For years 1997–2004 a consistent emission dataset was produced, which combined EMEP expert estimates for national and sector total emissions with a common spatial (50×50 km^2) distribution from the 2005 emission database (Base 2005 V9). The spatial allocation of the 2005 emission data is based on more reliable and more complete proxy data than those available in previous years. This is why 2005 was chosen as basis for a common spatial distribution. Consequently, for these years the gridded emission data differ from those on WebDab, while national and sector totals are kept unchanged. More details about the emissions used in the SR trend runs can be found in the EMEP Status Report 1/2009.

Trends Trends on depositions and air concentrations are presented for 1990 and from 1997 to 2006. The calculations are based on a consistent series of model runs, all using the same version of the Unified EMEP model (rv 3.1) and PARLAM-PS metorology.

Transboundary pollution Data are presented in the form of maps, pies and barcharts. 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.

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

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 Serbia. 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. Negative values thus mean an increase of pollution levels.

Comparison with observations The map of monitoring stations shows all stations of Serbia in the EMEP measurement network with measurements in 2007 submitted to EMEP. The frequency analysis plots compare 2007 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.

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).

Trends in transboundary contributions Data for trends in transboundary contributions in 1997–2006 are presented in the form of bar-charts. The data for each year are generated by source-receptor calculations, as described above. 2007 was excluded from the SR trend results, as for this year another meteorological driver was used.

In Section 10.1 the bar charts show the contribution of Serbia (as emitter country) to depositions and concentrations in the five most important receptor countries or areas in the EMEP domain. In Section 10.2 the bar charts show the contributions of the five most important contributors (emitters) to depositions and concentrations over Serbia (as receptor country). The five most important receptors/contributors are chosen on the basis of the 10 years' period. (Please note, that the five most important receptors/contributors might be different in individual years.)

NOTE: This year, for the second time, country reports are presented for Kyrgyzstan, Uzbekistan, Turkmenistan and Tajikistan. Since no trends have been calculated for these countries, only 2007 data are presented. The 2006 data was produced with another meteorological driver, therefore these are not included.
For The Russian Federation and Kazakhstan, trends refer to the area of these countries inside the old EMEP grid (132×111 grid cells). Results for 2007 are also presented for the extended EMEP area (132×159 grid cells), now covering all of Kazakhstan's territory and a larger part of The Russian Federation.

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 present 2007 source-receptor calculations.

Code	Country/Region
AL	Albania
AM	Armenia
ASI	Remaining Asian areas (official)
AST	Remaining Asian areas (extended)
AT	Austria
ATL	Remaining N.-E. Atlantic Ocean
AZ	Azerbaijan
BA	Bosnia and Herzegovina
BAS	Baltic Sea
BLS	Black Sea
BE	Belgium
BG	Bulgaria
BIC	Boundary and Initial Conditions
BY	Belarus
CH	Switzerland
CY	Cyprus
CZ	Czech Republic
DE	Germany
DK	Denmark
EE	Estonia
EMC	EMEP land areas (official)
EXC	EMEP land areas (extended)
ES	Spain
EU	European Community
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
KZ	Kazakhstan (official)
KZT	Kazakhstan (extended)
LT	Lithuania
LU	Luxembourg
LV	Latvia
MD	Republic of Moldova
ME	Montenegro
MED	Mediterranean Sea
MK	The FYR of Macedonia
MT	Malta
NL	Netherlands
NO	Norway
NOA	North Africa
NOS	North Sea
PL	Poland
PT	Portugal
RO	Romania
RS	Serbia
RU	Russian Federation (official)
RUE	Russian Federation (extended)
SE	Sweden
SI	Slovenia
SK	Slovakia
TJ	Tajikistan
TM	Turkmenistan
TR	Turkey
UA	Ukraine
UZ	Uzbekistan

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.

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^+ + SS(fine) + $PPM_{2.5}$

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) + SS(coarse) + PPM_{co}

SOMO35 is 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 is the accumulated amount of ozone over the threshold value of 40 ppb, i.e.:

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

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.

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

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

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. $\mathrm{AF_{st}1.6_{gen\text{-}DF}}$ is used for deciduous forests.

3 Emissions

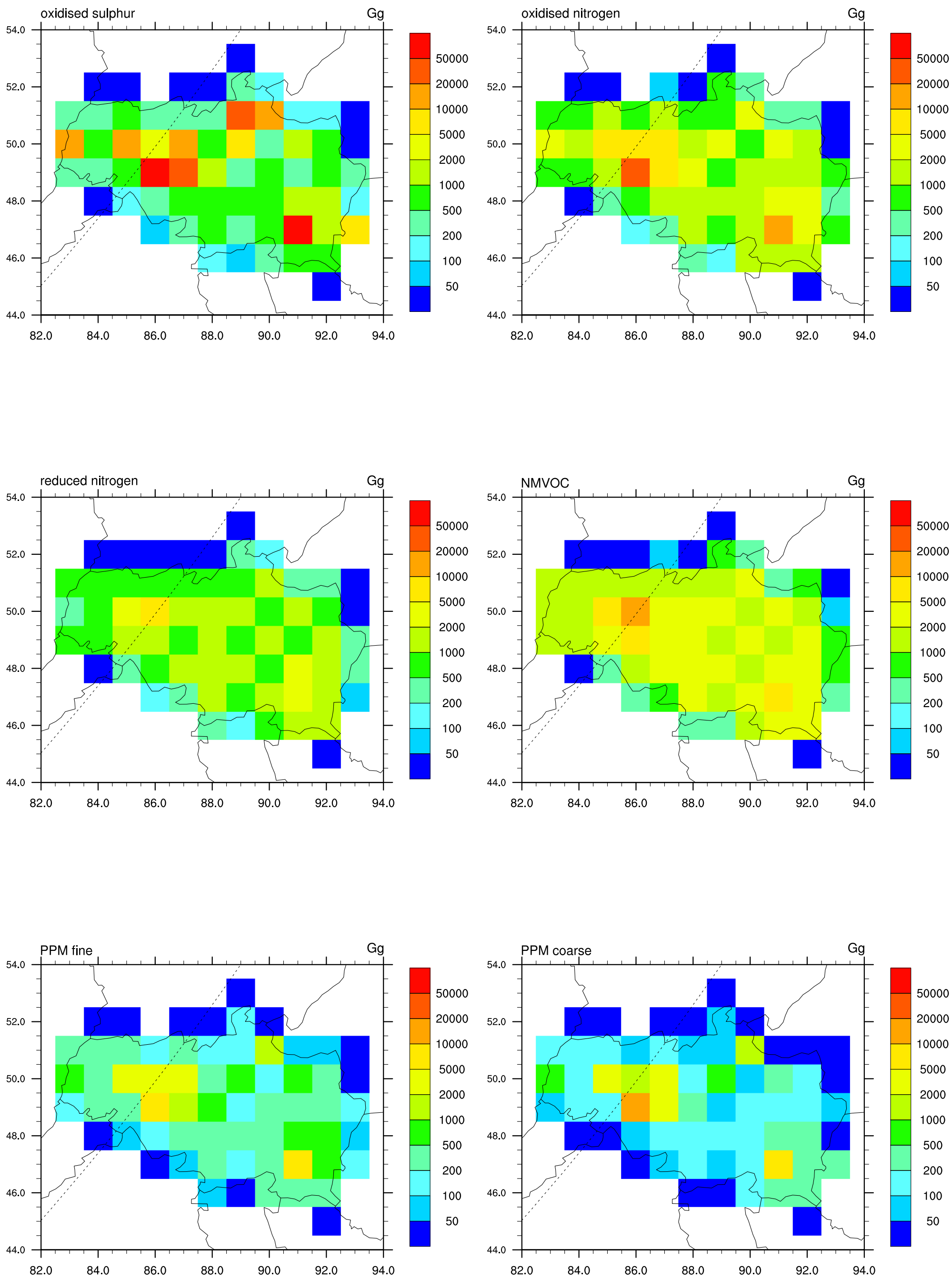

Figure 1: Spatial distribution of emissions from Serbia in 2007.

4 Trends

	1990	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
SO_x		357	351	346	340	329	317	305	293	293	400	428
NO_x		127	126	113	118	121	121	125	128	128	51	130
NH_3		55	55	55	55	56	56	56	57	57	57	57
NMVOC		113	116	118	121	122	124	125	126	126	126	126
CO		305	315	325	335	341	346	352	358	358	358	358
$PM_{2.5}$		45	40	38	39	38	38	37	37	37	37	37
PM_{10}		95	85	80	80	78	77	75	74	74	74	74

Table 2: Emissions from Serbia. Units: Gg.

	1990	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
S dep.	188	133	114	134	97	116	119	98	102	108	118	115
oxN dep.	46	41	36	36	31	36	33	31	32	35	30	33
redN dep.	46	38	34	42	32	40	41	35	38	42	39	37

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

	1990	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
mean ozone	35	34	35	34	34	34	35	35	34	34	34	35
max ozone	46	44	45	45	45	44	45	46	45	44	44	45
AOT40$^{uc}_{f}$	28947	21525	24265	22098	22284	20267	19550	25246	20072	19698	17966	20536
SOMO35	4371	3561	3892	3707	3660	3479	3515	3927	3608	3465	3333	3791
$AF_{st}1.6_{gen\text{-}DF}$	28	25	25	25	23	25	26	22	25	25	24	24
$PM_{2.5}$ anthrop.		10	9	8	8	8	7	8	7	8	8	7
PM_{10} anthrop.		11	10	9	9	8	8	9	8	8	9	8

Table 4: Estimated yearly mean values of air quality indicators averaged over Serbia. Units: daily mean ozone (ppb), daily max ozone (ppb), AOT40$^{uc}_{f}$(ppb·h) SOMO35 (ppb·d), $AF_{st}1.6_{gen\text{-}DF}$ (mmol/m2); and $PM_{2.5}$ ($\mu g/m^3$) and PM_{10} ($\mu g/m^3$) from anthropogenic sources in the model.

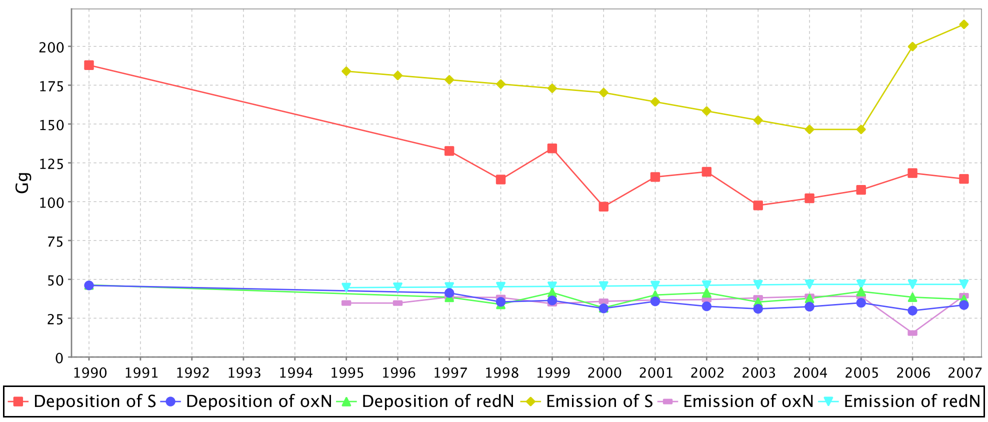

Figure 2: Trends in emissions and depositions of oxidised sulphur, oxidised nitrogen and reduced nitrogen. Units: Gg(S) or Gg(N).

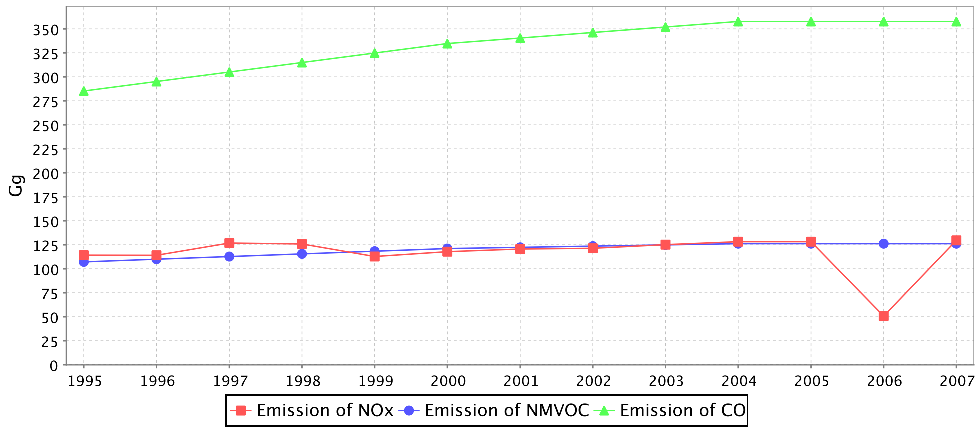

Figure 3: Trends in emissions of photo-oxidant pollution precursors. Units: Gg (note that NO_x is here as NO_2).

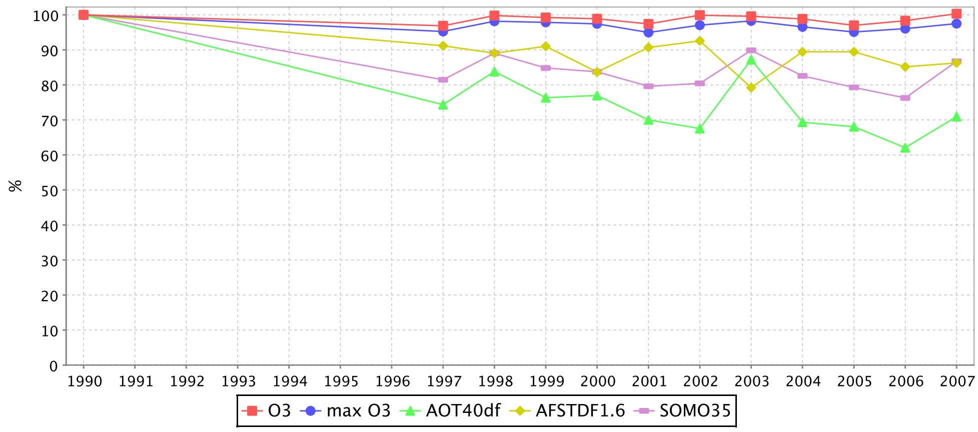

Figure 4: Changes in ozone related pollution relative to 1990. Units: %.

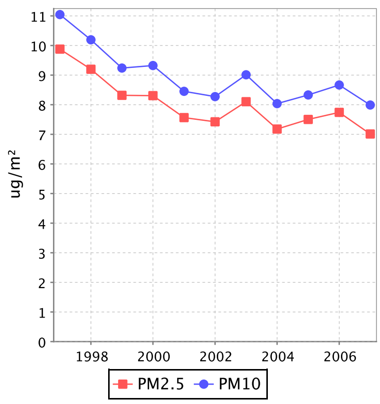

Figure 5: Trends in mean concentrations of particulates since 1997. Units: $\mu g/m^3$.

5 Transboundary fluxes in 2007

5.1 Oxidised sulphur deposition

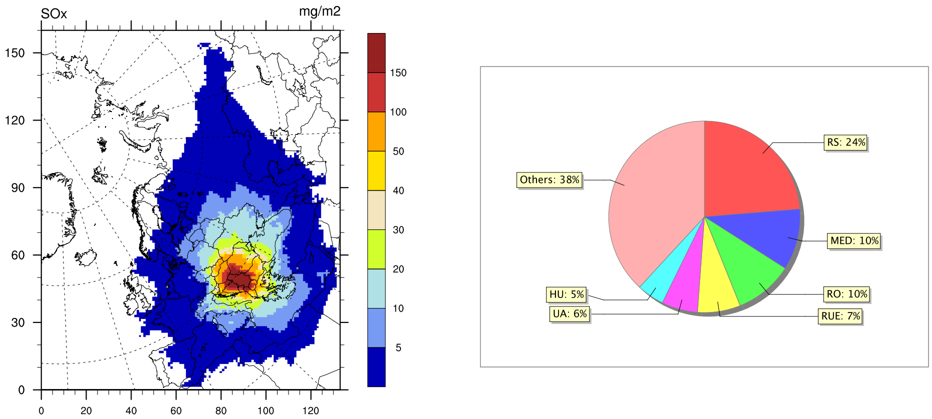

Figure 6: Contribution of emissions from Serbia to deposition of oxidised sulphur in the EMEP domain. Units: mg(S)/m^2. The pie chart shows the six main receptor areas of oxidised sulphur deposition from Serbia. Units: (%).

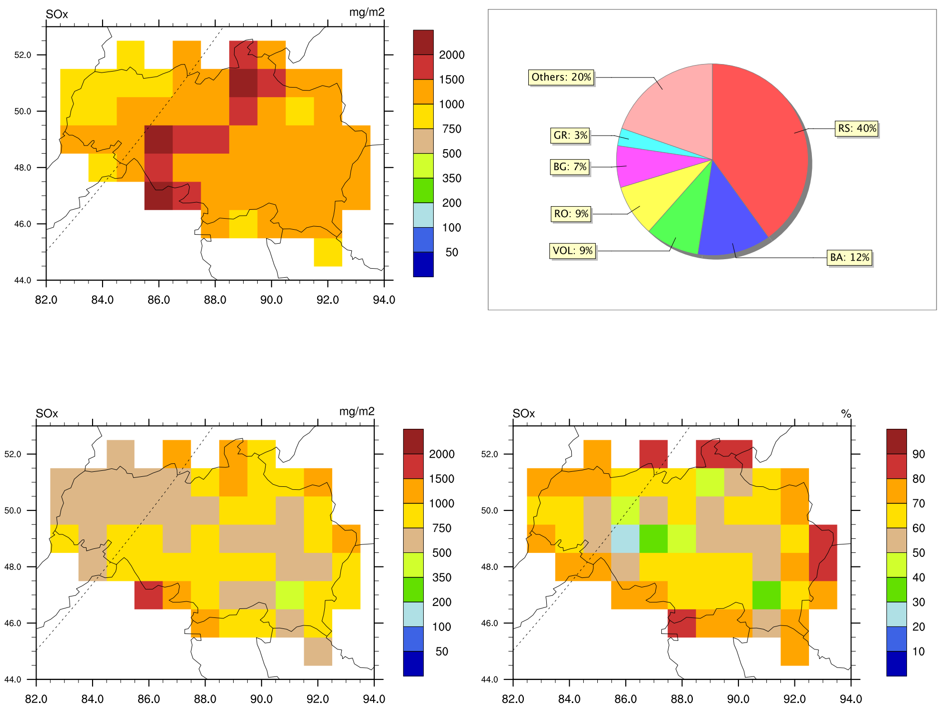

Figure 7: Oxidised sulphur deposition in Serbia (top left figure). Units: mg(S)/m^2. The pie chart shows the six main contributors to oxidised sulphur deposition in Serbia. Units: (%). Oxidised sulphur deposition from transboundary sources (lower left). Units: (mg(S)/m^2). Fraction from transboundary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

5.2 Oxidised nitrogen deposition

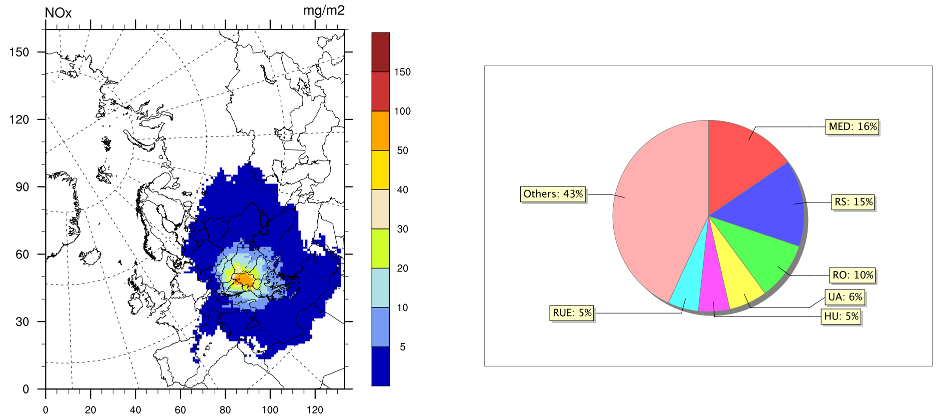

Figure 8: Contribution of emissions from Serbia to deposition of oxidised nitrogen in the EMEP domain. Units: mg(N)/m^2. The pie chart shows the six main receptor areas of oxidised nitrogen deposition from Serbia. Units: (%).

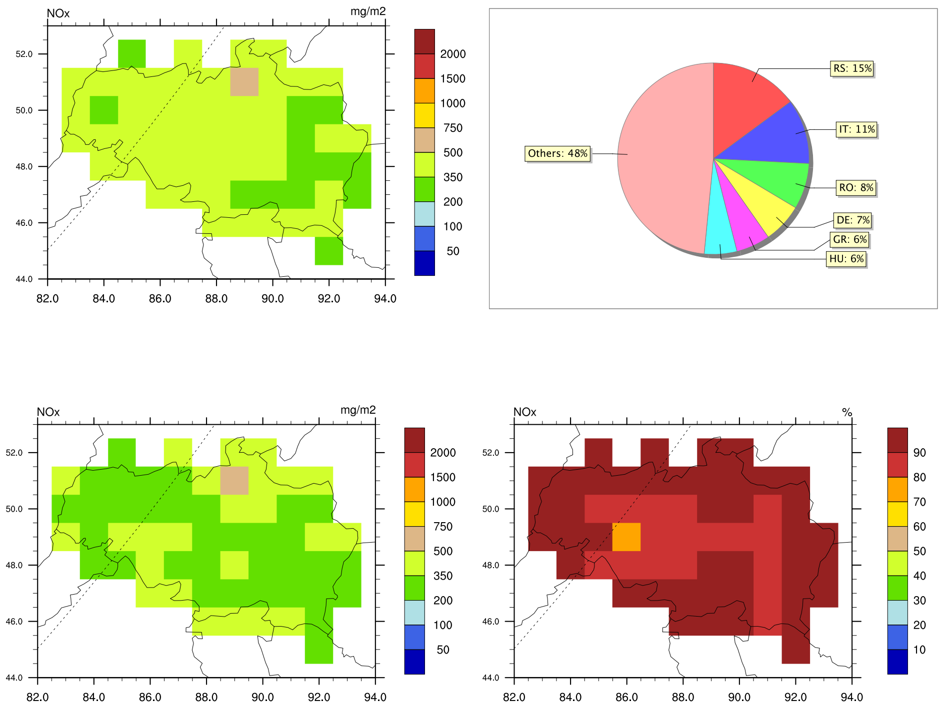

Figure 9: Oxidised nitrogen deposition in Serbia (top left figure). Units: mg(N)/m^2. The pie chart shows the six main contributors to oxidised nitrogen deposition in Serbia. Units: (%). Oxidised nitrogen deposition from transboundary sources (lower left). Units: (mg(N)/m^2). Fraction from transboundary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

5.3 Reduced nitrogen deposition

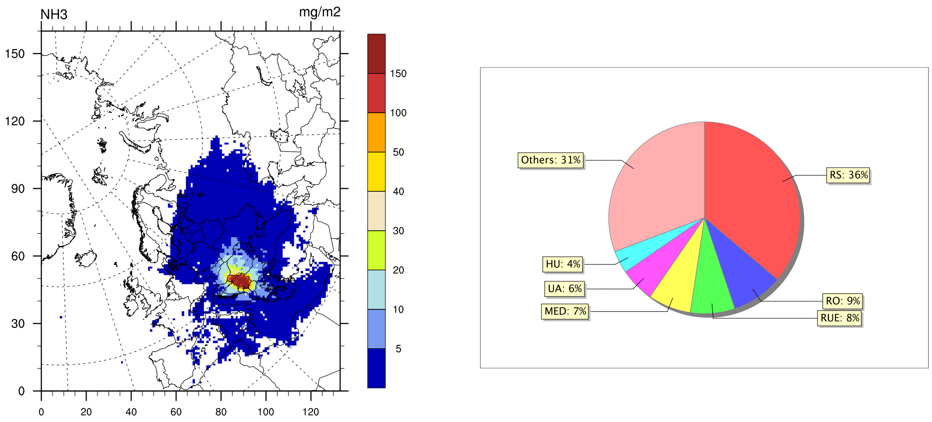

Figure 10: Contribution of emissions from Serbia to deposition of reduced nitrogen in the EMEP domain. Units: mg(N)/m^2. The pie chart shows the six main receptor areas of reduced nitrogen deposition from Serbia. Units: (%).

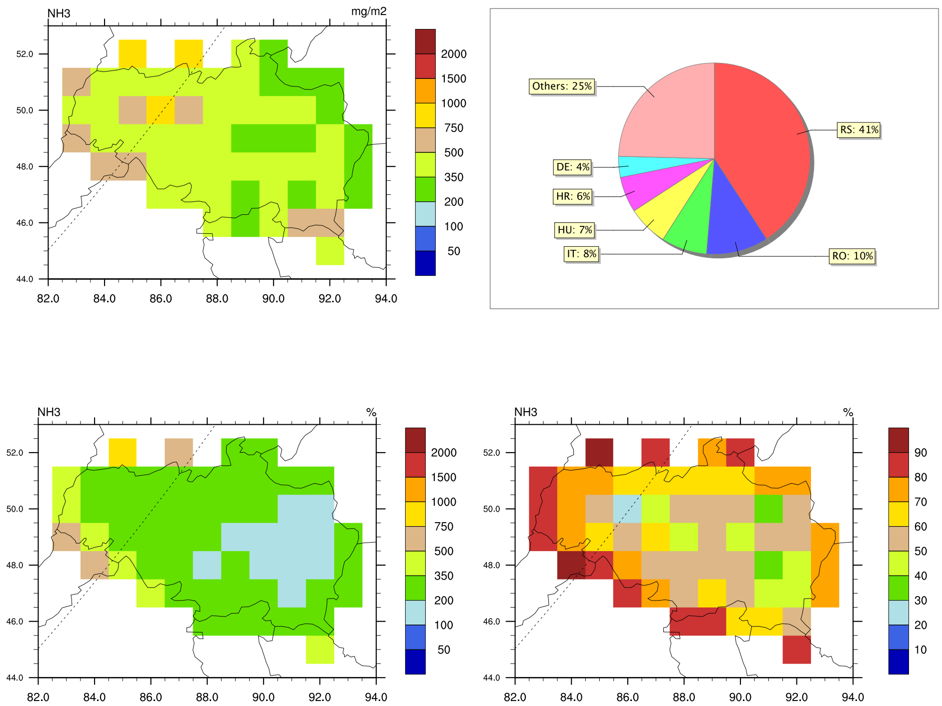

Figure 11: Reduced nitrogen deposition in Serbia (top left figure). Units: mg(N)/m^2. The pie chart shows the six main contributors to reduced nitrogen deposition in Serbia. Units: (%). Reduced nitrogen deposition from transboundary sources (lower left). Units: (mg(N)/m^2). Fraction from transboundary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

6 Transboundary ozone concentrations

6.1 $AOT40_f^{uc}$

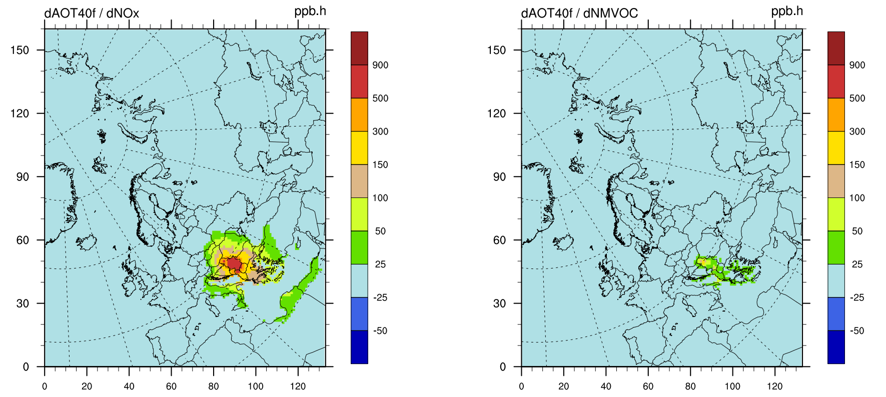

Figure 12: Reduction in $AOT40_f^{uc}$ due to reduction in NO_x (left) and NMVOC (right) emissions from Serbia. Units: ppb·h

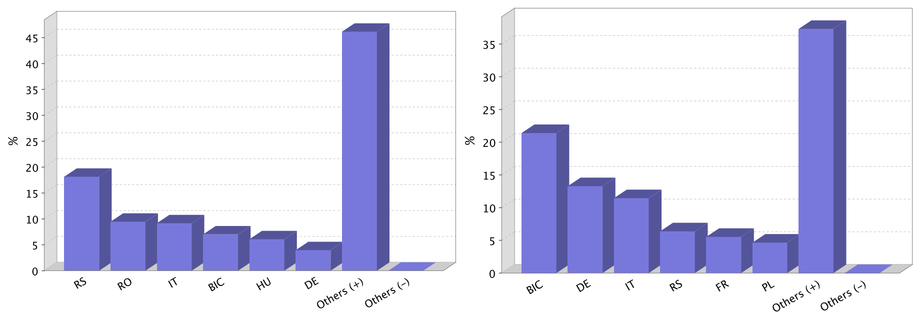

Figure 13: Six most important contributors to $AOT40_f^{uc}$ in Serbia in terms of NO_x (left) and NMVOC (right) emission changes. Units: (%)

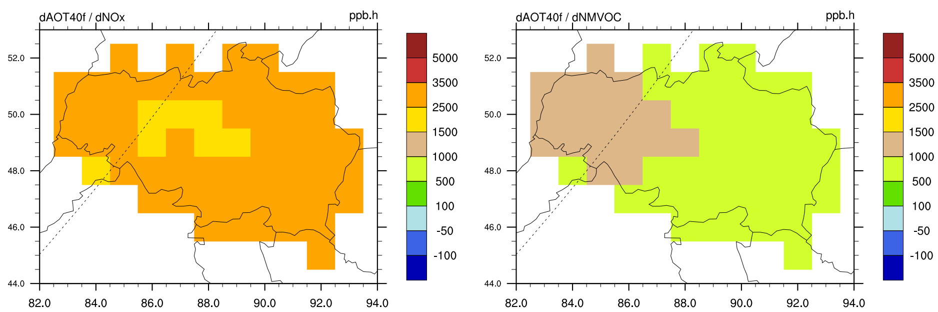

Figure 14: Reduction in $AOT40_f^{uc}$ due to reduction in NO_x (left) and NMVOC emissions (right) from transboundary sources. Units: ppb·h

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

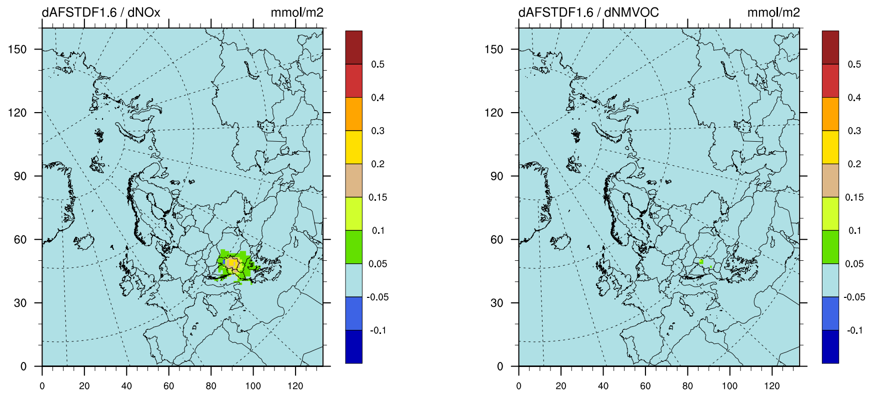

Figure 15: Reduction in $AF_{st}1.6_{gen\text{-}DF}$ due to reduction in NO_x (left) and NMVOC (right) emissions from Serbia. Units: mmol/m^2

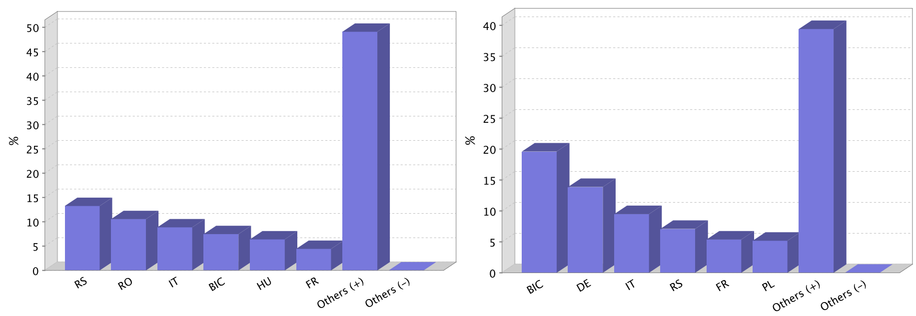

Figure 16: Six most important contributors to $AF_{st}1.6_{gen\text{-}DF}$ in Serbia in terms of NO_x (left) and NMVOC (right) emissions.

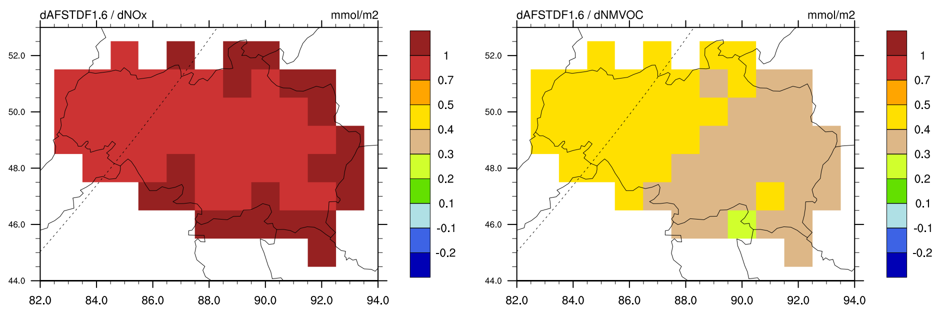

Figure 17: Reduction in $AF_{st}1.6_{gen\text{-}DF}$ due to reduction in NO_x (left) and NMVOC emissions (right) from transboundary sources. Units: mmol/m^2

6.3 SOMO35 – Risk of ozone damages to human health

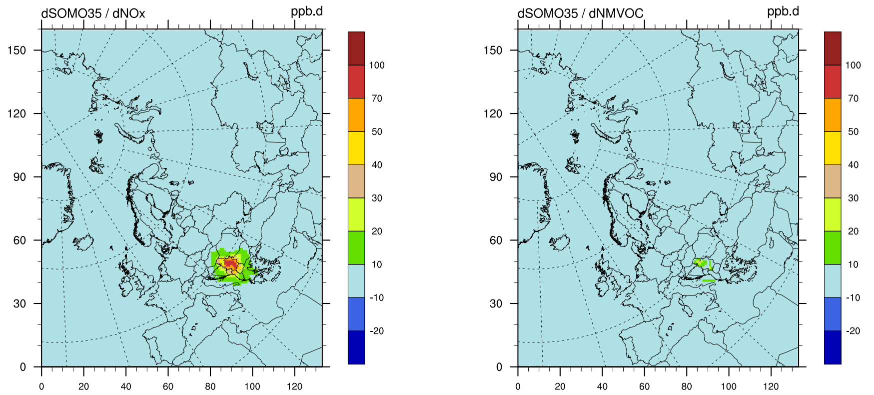

Figure 18: Reduction in SOMO35 due to reduction in NO_x (left) and NMVOC (right) emissions from Serbia. Units: ppb·day

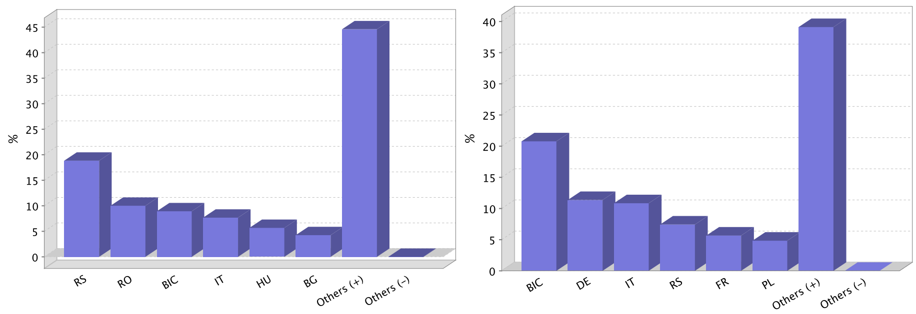

Figure 19: Six most important contributors to SOMO35 in Serbia in terms of NO_x (left) and NMVOC (right) emissions (15% reduction)

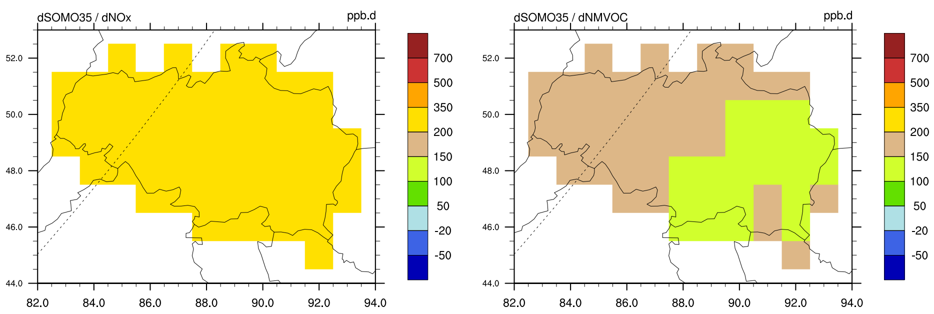

Figure 20: Reduction in SOMO35 due to reduction in NO_x (left) and NMVOC emissions (right) from transboundary sources. Units: ppb·day

7 Transboundary concentrations of particulate matter

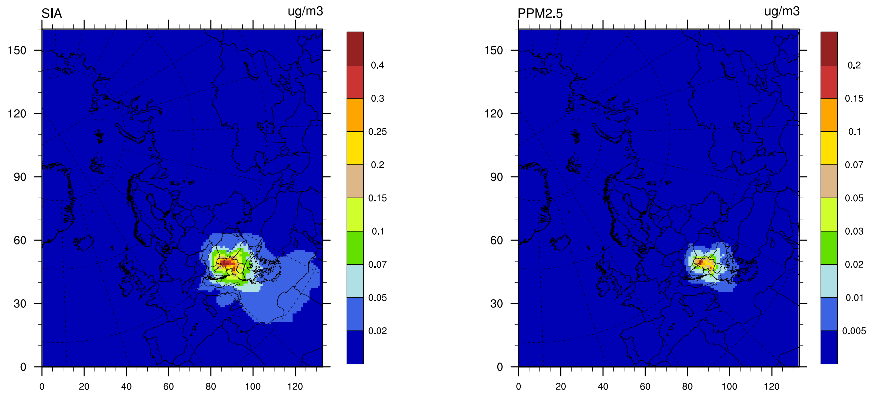

Figure 21: Reduction in SIA and $PPM_{2.5}$ concentrations due to emission reduction from Serbia. Units: $\mu g/m^3$. Note the difference in scales.

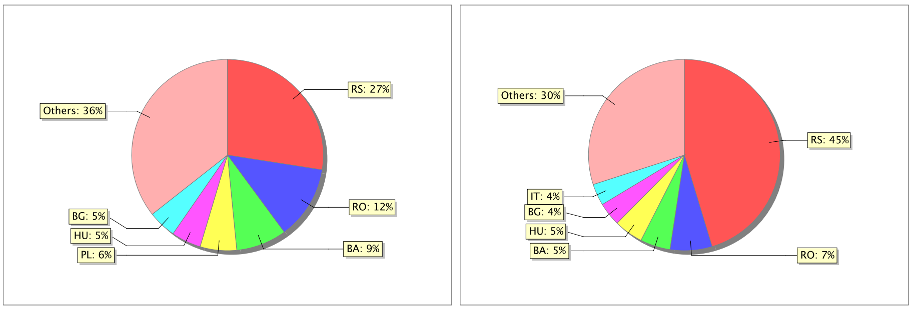

Figure 22: Main contributors to SIA (left) and $PPM_{2.5}$ (right) concentrations in Serbia. Units: (%)

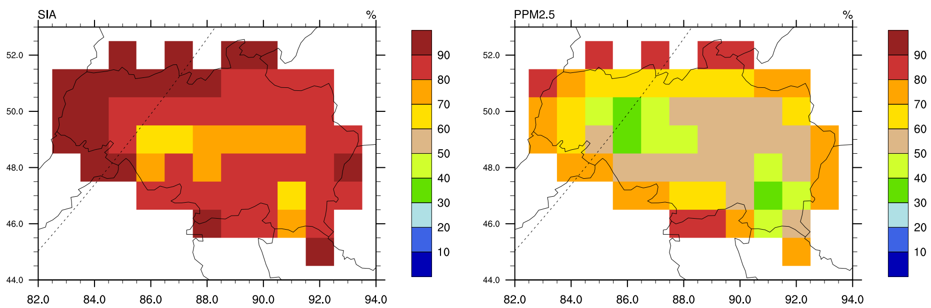

Figure 23: Reduction in SIA and $PPM_{2.5}$ concentrations in Serbia due to emission reductions from transboundary sources. Units: (%)

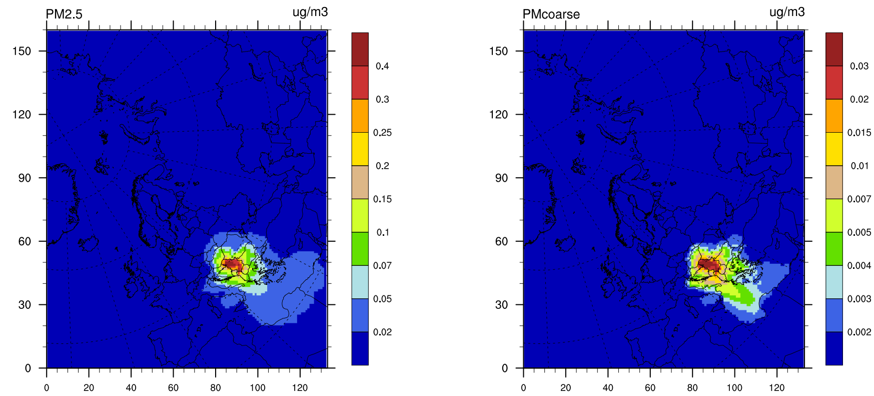

Figure 24: Reduction in $PM_{2.5}$ and PM_{coarse} concentrations due to emission reduction from Serbia. Units: μg/m^3. Note the difference in scales.

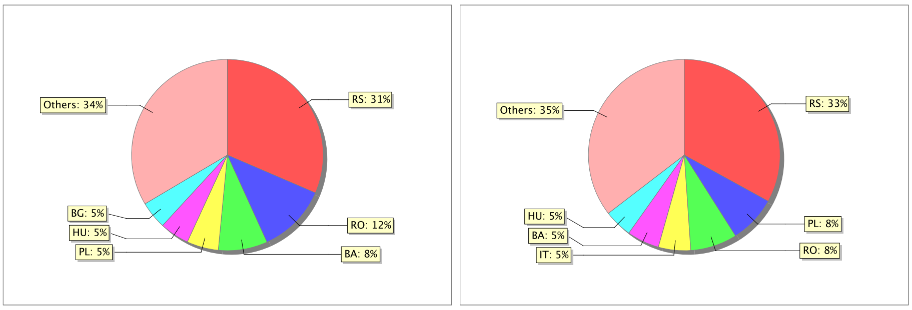

Figure 25: Main contributors to $PM_{2.5}$ (left) and PM_{coarse} (right) concentrations in Serbia. Units: (%)

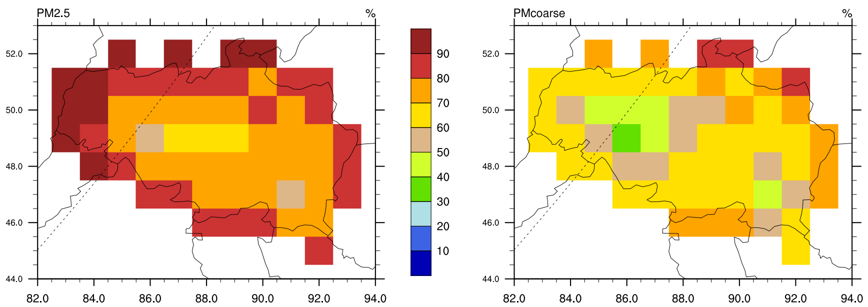

Figure 26: Reduction in $PM_{2.5}$ and PM_{coarse} concentrations in Serbia due to emission reductions from transboundary sources. Units: (%)

8 Comparison with observations

Figure 27: Location of stations in Serbia

A sufficiently consistent set of daily ozone observations in RS for 2007 is not available for this analysis.

Figure 28: Frequency analysis of ozone in Serbia at the stations that reported O_3 in 2007 (Model, Observations)

A sufficiently consistent set of daily wet deposition observations in RS for 2007 is not available for this analysis.

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

A sufficiently consistent set of daily air concentration observations in RS for 2007 is not available for this analysis.

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

Component	No.	Bias	Correlation	RMSE
SO2 in Air	0			
Sulfate in Air	0			
NO2 in Air	0			
Total Nitrate in Air	0			
NH3+NH4+ in Air	0			
Ozone daily max	0			
Ozone daily mean	0			
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 Serbia 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 Serbia in 2007

9.1 Ecosystem-specific AOT40 values

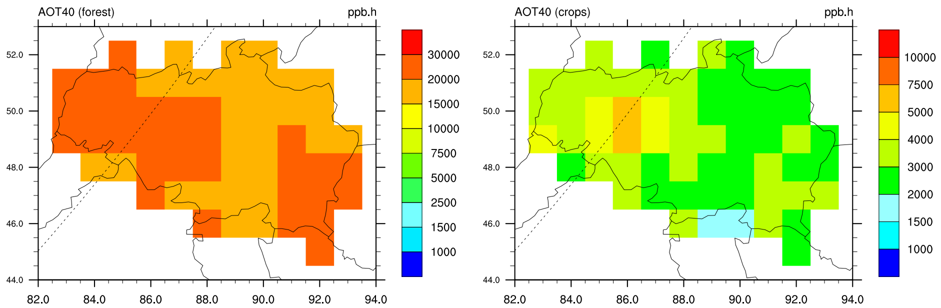

Figure 31: AOT40$_f^{uc}$ and AOT40$_c^{uc}$ in Serbia in 2007.
AOT40$_f^{uc}$(growing season: April-September): The critical level for forest damage is 5000 ppb·h.
AOT40$_c^{uc}$(growing season: May-July): The critical level for agricultural crops is 3000 ppb·h.

9.2 Ecosystem-specific ozone fluxes

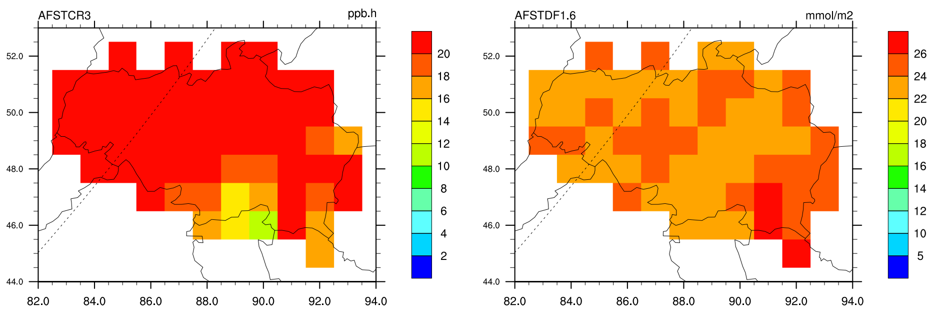

Figure 32: AF$_{st}$3$_{\text{gen-CR}}$ and AF$_{st}$1.6$_{\text{gen-DF}}$ in Serbia in 2007.

9.3 Health impacts from ozone and PM

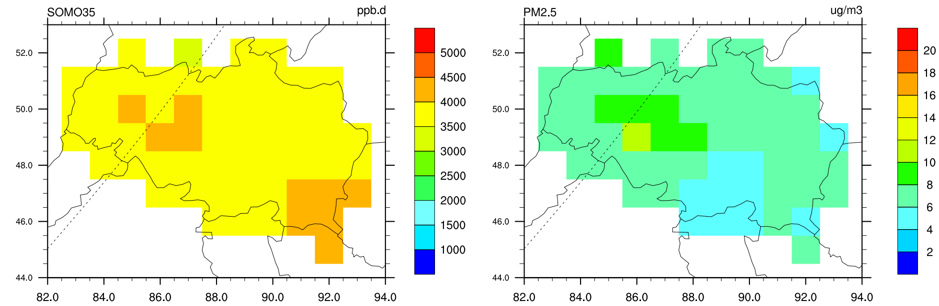

Figure 33: Regional scale SOMO35 and $PM_{2.5}$ in Serbia in 2007.

10 Source-receptor trends for 1997–2006

10.1 Serbia as emitter country

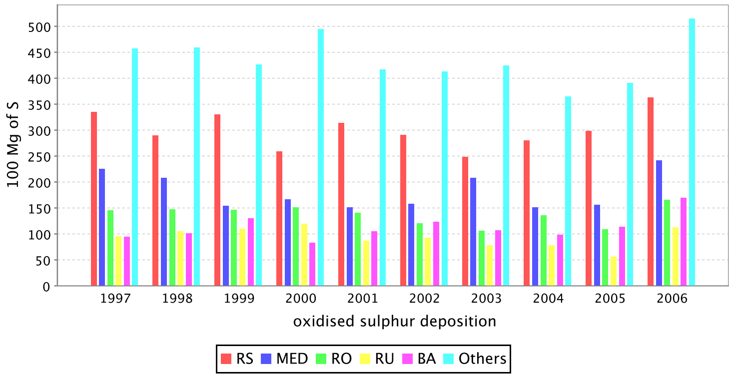

Figure 34: The five most important receptor areas of oxidised sulphur deposition due to emissions from Serbia in the period 1997-2006. Units: 100 Mg of S.

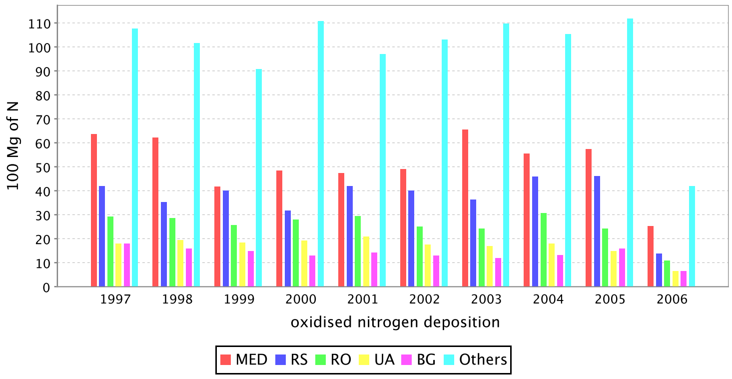

Figure 35: The five most important receptor areas of oxidised nitrogen deposition due to emissions from Serbia in the period 1997-2006. Units: 100 Mg of N.

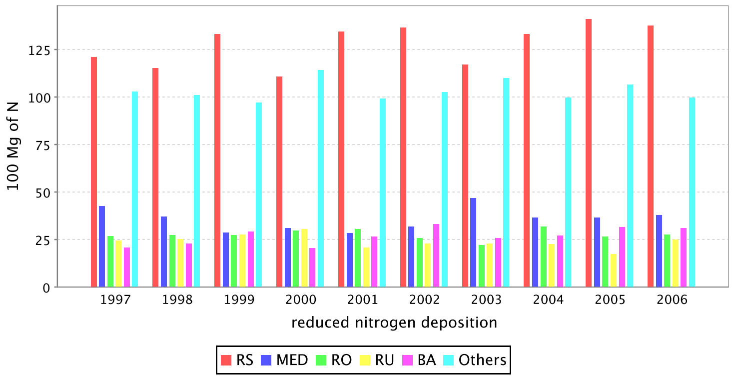

Figure 36: The five most important receptor areas of reduced nitrogen deposition due to emissions from Serbia in the period 1997-2006. Units: 100 Mg of N.

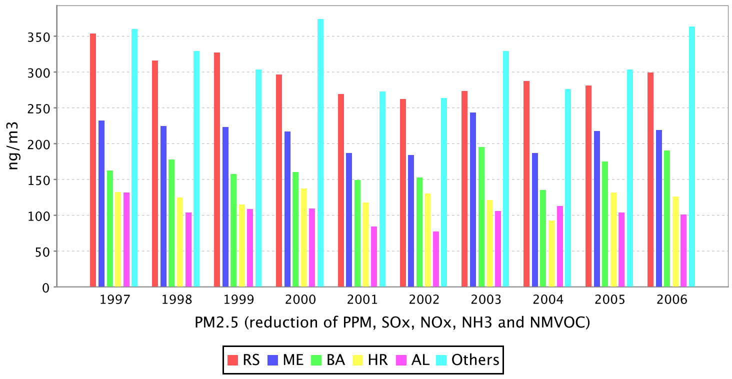

Figure 37: The five most important receptor areas of $PM_{2.5}$ due to emissions from Serbia in the period 1997-2006. Units: ng/m^3.

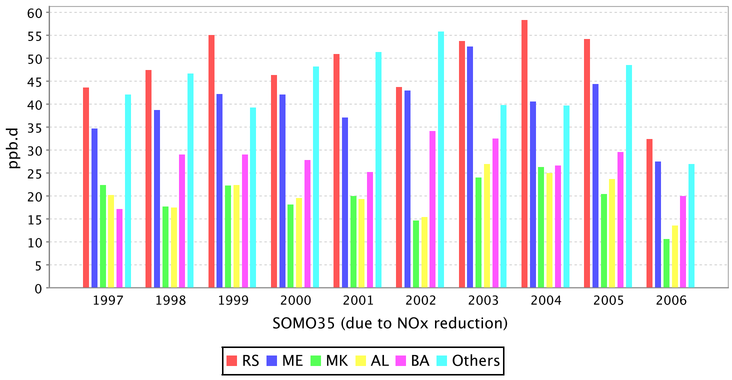

Figure 38: The five most important receptor areas of SOMO35 due to NO_x emissions from Serbia in the period 1997-2006. Units: ppb·d.

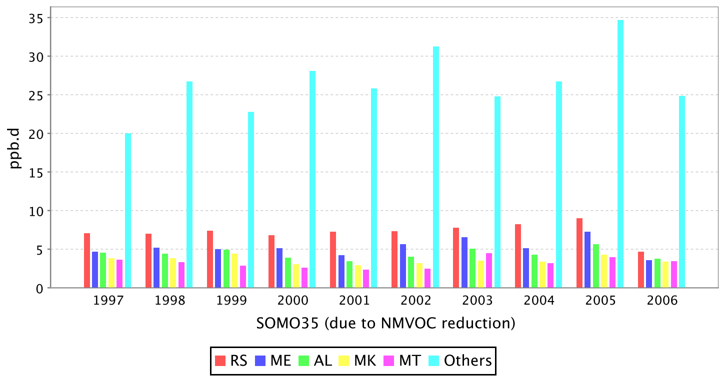

Figure 39: The five most important receptor areas of SOMO35 due to NMVOC emissions from Serbia in the period 1997-2006. Units: ppb·d.

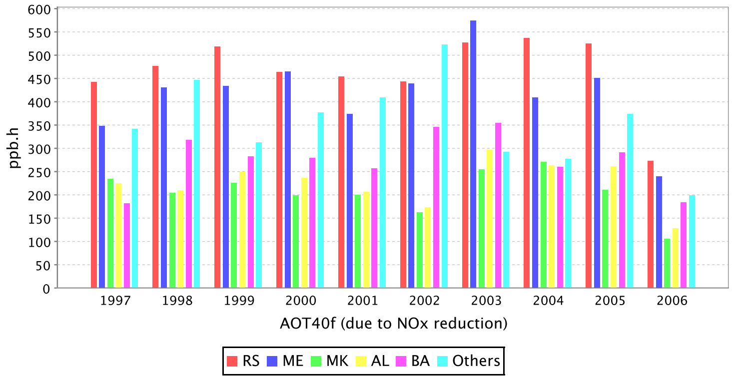

Figure 40: The five most important receptor areas of $AOT40_f^{uc}$ due to NO_x emissions from Serbia in the period 1997-2006. Units: ppb·h.

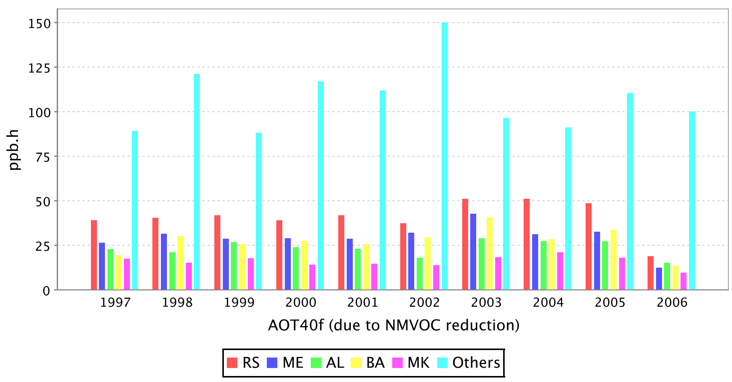

Figure 41: The five most important receptor areas of $AOT40_f^{uc}$ due to NMVOC emissions from Serbia in the period 1997-2006. Units: ppb·h.

10.2 Serbia as receptor country

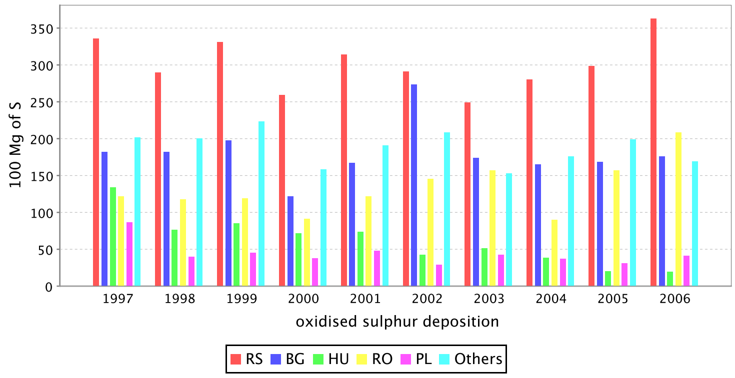

Figure 42: The five most important contributors to deposition of oxidised sulphur in Serbia in the period 1997-2006. Units: 100 Mg of S.

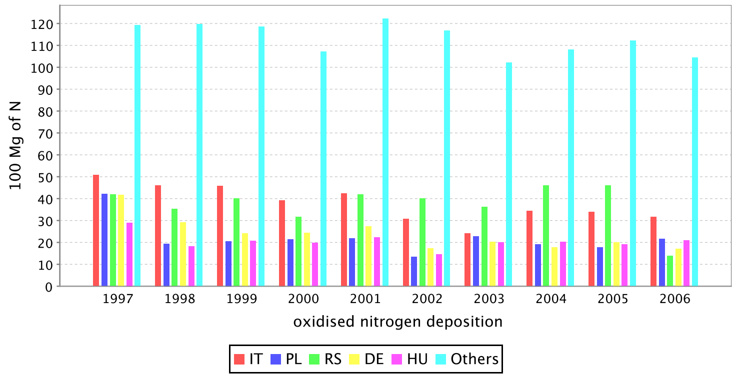

Figure 43: The five most important contributors to deposition of oxidised nitrogen in Serbia in the period 1997-2006. Units: 100 Mg of N.

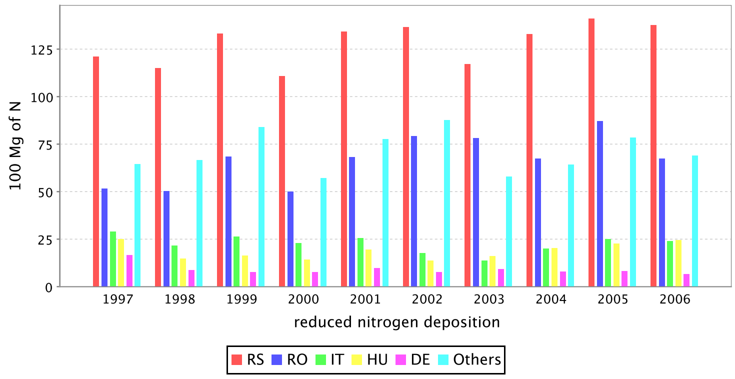

Figure 44: The five most important contributors to deposition of reduced nitrogen in Serbia in the period 1997-2006. Units: 100 Mg of N.

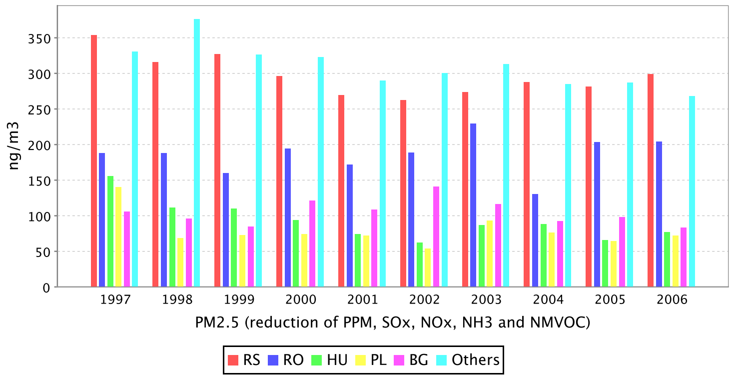

Figure 45: The five most important contributors to $PM_{2.5}$ in Serbia in the period 1997-2006. Units: ng/m^3.

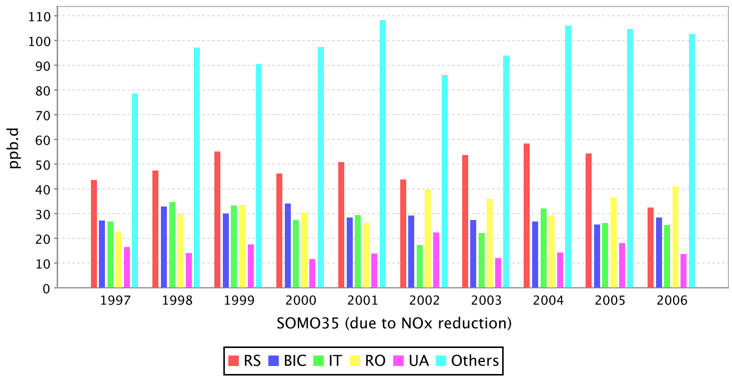

Figure 46: The five most important contributors to SOMO35 in Serbia by NO_x emissions in the period 1997-2006. Units: ppb·d.

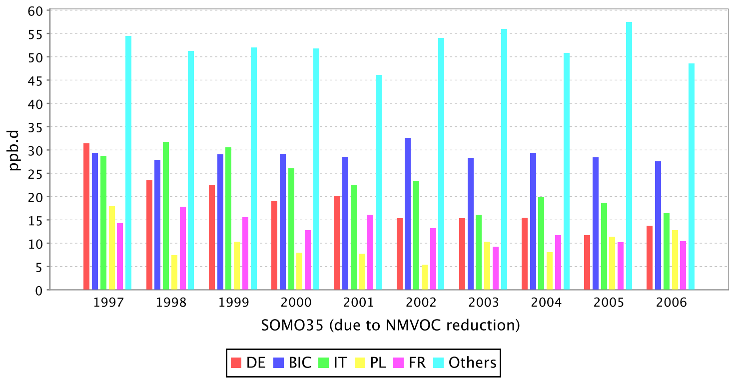

Figure 47: The five most important contributors to SOMO35 in Serbia by NMVOC emissions in the period 1997-2006. Units: ppb·d.

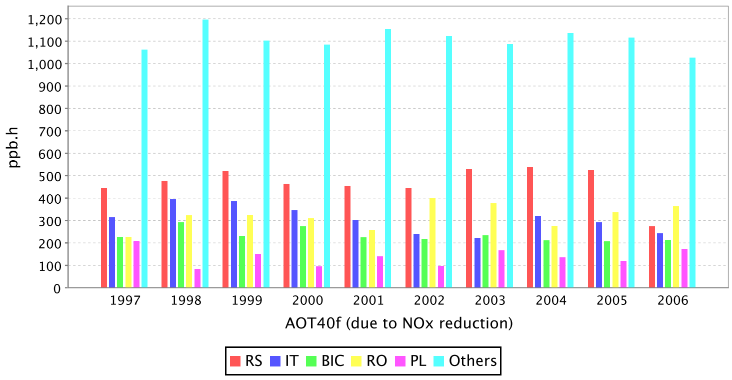

Figure 48: The five most important contributors to $AOT40_f^{uc}$ in Serbia due to NO_x emissions in the period 1997-2006. Units: ppb·h.

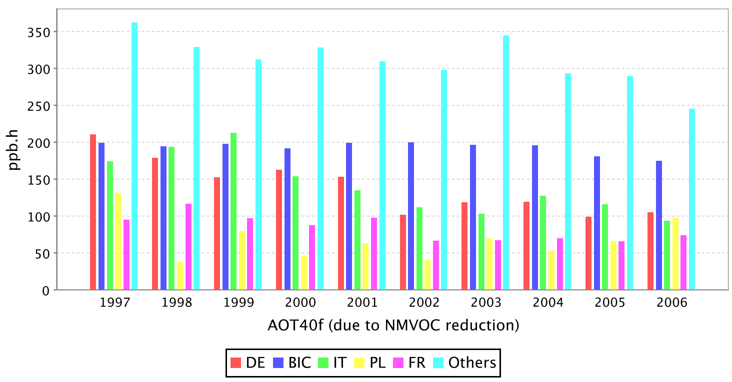

Figure 49: The five most important contributors to $AOT40_f^{uc}$ in Serbia due to NMVOC emissions in the period 1997-2006. Units: ppb·h.