Convention on Long-range Transboundary Air Pollution

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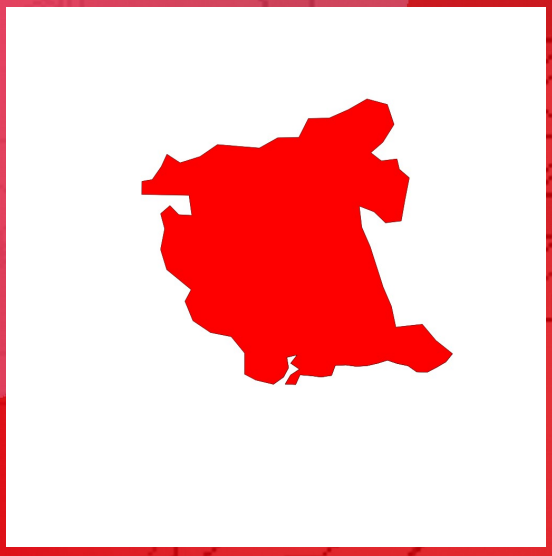
DATA NOTE
MSC-W 1/2015

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

Montenegro



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Transboundary air pollution by main pollutants (S, N, O_3) and PM in 2013

Montenegro

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Data Note 2015

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1 How to read this report

This report is one in a series of country-specific notes, complementary to the EMEP Status Report 1/2015. It presents an overview of transboundary pollution of main pollutants, ground level ozone and particulate matter (PM) for Montenegro in 2013.

All model runs have been performed with the EMEP MSC-W model version rv4.7, 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 2013.

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 2013 have been derived from the 2015 official data submissions to UNECE CLRTAP as of May 2015. The gridded distributions of the 2013 emissions have been provided by the EMEP Centre on Emission Inventories and Projections (CEIP).

The emissions for the period of 2000–2012 have been derived from the latest data submissions to UNECE CLRTAP as of May 2015. The table showing total emissions also contains projections for 2020 from the revised Gothenburg Protocol (except CO emissions, as these are not projected for 2020 in the protocol).

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 (see `http://www.ceip.at`).

Trends *(Chapter 3)* : Trends in depositions and air concentrations are presented for the period of 2000–2013. The calculations are based on a consistent series of model runs, all using the EMEP MSC-W model version rv4.7. For the years 2000–2013, the meteorology of the respective year is used. Thus, interannual variability in the model output is due to changes in both emissions and meteorology. It should also be noted that the emission data and model version have changed since last year's report (see respective chapters on emissions and model updates in EMEP status report 1/2015), which may lead to differences between results reported here and in earlier reports.

Transboundary fluxes *(Chapter 4)* : Data are presented in the form of maps and pie charts. The data are generated by source-receptor calculations, where emissions for each emitter of one or more precursors are reduced by 15%. The results have been scaled up to represent the entire emission from an emitter.

Transboundary concentrations *(Chapters 5 and 6)* : Data are presented in the form of maps and bar charts. Ozone and particulate matter are subject to significant non-linearities in chemistry. Therefore we present the effect of 15% reductions in emissions only.

The horizontal maps show the reduction in concentrations when emissions are reduced by 15% in Montenegro. By convention, reductions in concentrations are represented by

positive values in the maps. Thus, any negative values mean that concentrations increase as a result of an emission reduction (due to non-linearities in chemistry).

The bar charts identify the six most important emitter countries in terms of their effect on concentrations in Montenegro. As these effects can be either positive or negative, the relative importance of each emitter country has been determined by comparing the absolute values of its effect. The given percentages (vertical scale) are not relevant by themselves. However, the charts allow the identification of the 6 most important emitter countries and a straightforward comparison of their effects (positive or negative, large or small). Again, reductions are represented by positive values. Thus, a negative bar in the chart means that a 15% reduction in emissions from an emitter country will lead to an increase in concentration in Montenegro. In some countries this can occur due to strong non-linearities in chemistry.

In addition, for $PM_{2.5}$ and PM_{10} we show total concentration along with the contribution from natural sources (sea salt and natural dust) to the total concentration.

Comparison with observations *(Chapter 7)* : The map of monitoring stations shows stations of Montenegro in the EMEP measurement network with measurements in 2013 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 influenced 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 2013.

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 Union (EU28)
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 throughout this report:‘official’ refers to the area of the country/region which is inside the official EMEP grid domain, while ‘extended’ refers to the area of the country/region inside the extended EMEP grid domain.

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^+.

SOA - secondary organic aerosol.

SS - sea salt.

MinDust - mineral dust.

PPM denotes primary particulate matter, originating directly from anthropogenic emissions. One usually distinguishes between fine primary particulate matter, $PPM_{2.5}$ with 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 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) + MinDust(fine) + SOA(fine) + $PPM_{2.5}$ + 0.27 NO_3^-(coarse) + PM25water. (PM25water: PM associated water)

PM_{coarse} denotes coarse particulate matter, defined as the integrated mass of aerosol with 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) + MinDust(coarse) + PPM_{coarse}.

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

SOx - group of oxidized sulphur components (SO_2, SO_4^{2-}).

NOx - group of oxidized nitrogen components (NO, NO_2, NO_3^-, N_2O_5, HNO_3, etc.).

redN - group of reduced nitrogen components (NH_3 and NH_4^+).

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:

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

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$^{\mathbf{uc}}_{f}$ - 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$^{\mathbf{uc}}_{c}$ - 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$_{Y,gen}$ (or $AF_{st}1.6_{gen}$) is used for forests and POD$_{3.0,\text{gen-CR}}$ (or $AF_{st}3_{gen}$) is used for crops.

2 Emissions

2.1 Emissions used in the EMEP MSC-W model calculations

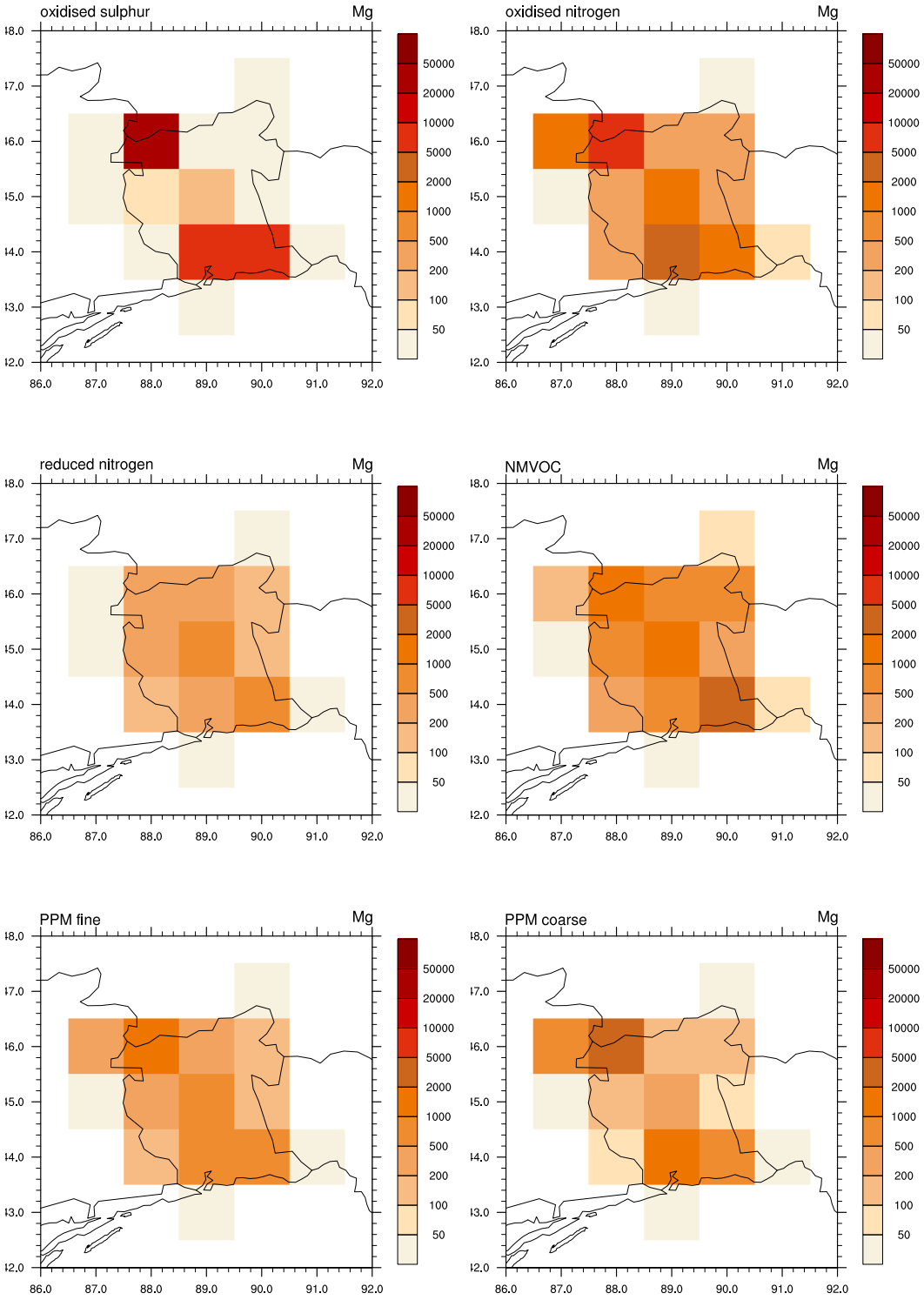

Figure 1: Spatial distribution of emissions from Montenegro in 2013.

3 Trends

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

	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2020
SO_x	14	13	14	12	15	8	28	40	40	40	13
NO_x	9	8	8	8	9	7	10	13	13	14	8
NH_3	6	4	3	3	3	3	3	3	3	3	4
NMVOC	10	8	9	10	10	10	8	9	8	8	8
CO	40	37	36	37	35	29	30	33	32	32	
$PM_{2.5}$	4	5	5	5	6	4	4	5	5	5	5
PM_{10}	8	8	9	8	10	7	8	12	12	13	8

Table 2: Emissions from Montenegro. Unit: Gg.

	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
SOx dep.	18	12	10	12	13	10	13	12	11	12
NOx dep.	6	6	5	5	5	5	5	4	5	4
redN dep.	5	4	4	4	4	4	4	4	4	4

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

	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
mean ozone	42	41	42	40	42	40	40	40	40	40
max ozone	49	48	49	47	48	47	46	47	47	47
$AOT40_f^{uc}$	29999	25453	26521	25149	25881	24163	23142	23607	25860	22491
SOMO35	4572	4169	4464	4034	4280	3853	3799	3785	3909	3875
$POD_{1.0,gen\text{-}DF}$	34	33	33	31	32	32	32	31	30	31
$PM_{2.5}$ anthrop.	8	7	7	8	7	7	7	8	8	7
PM_{10} anthrop.	10	9	9	11	10	9	9	10	10	9

Table 4: Estimated yearly mean values of air quality indicators averaged over Montenegro. 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} ($\mu g/m^3$).

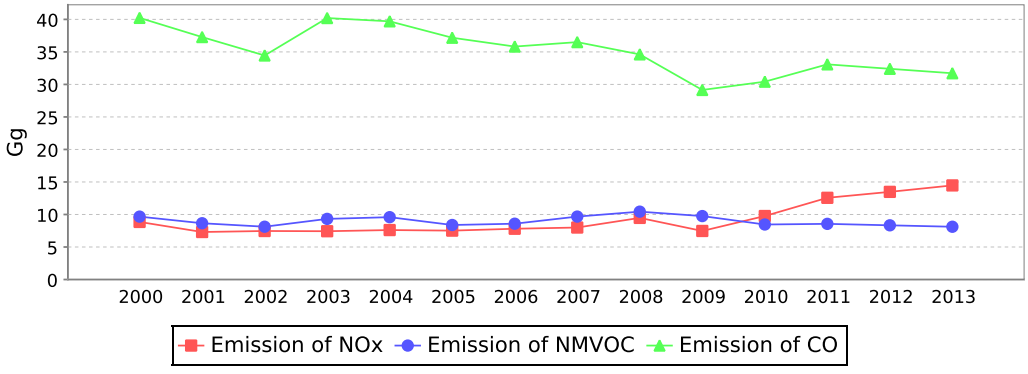

Figure 2: Trends in emissions of photo-oxidant pollution precursors. Unit: Gg (note that NO_x is here given as NO_2).

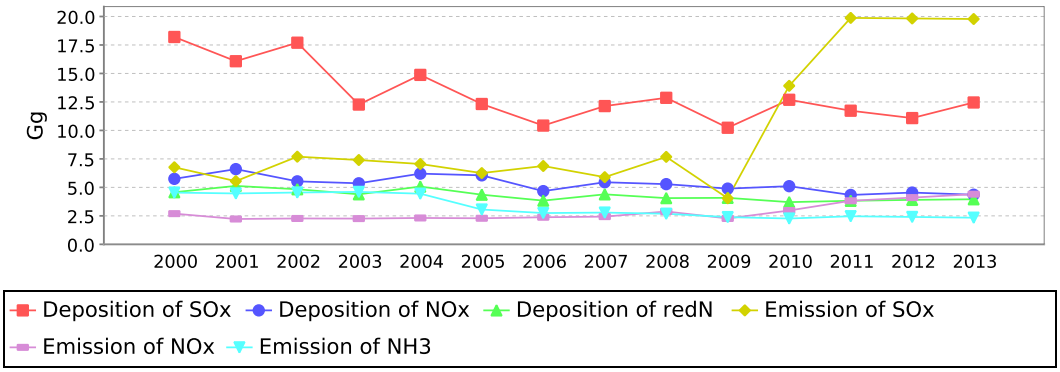

Figure 3: Trends in emissions and depositions of oxidised sulphur, oxidised nitrogen and reduced nitrogen. Unit: Gg(S) or Gg(N).

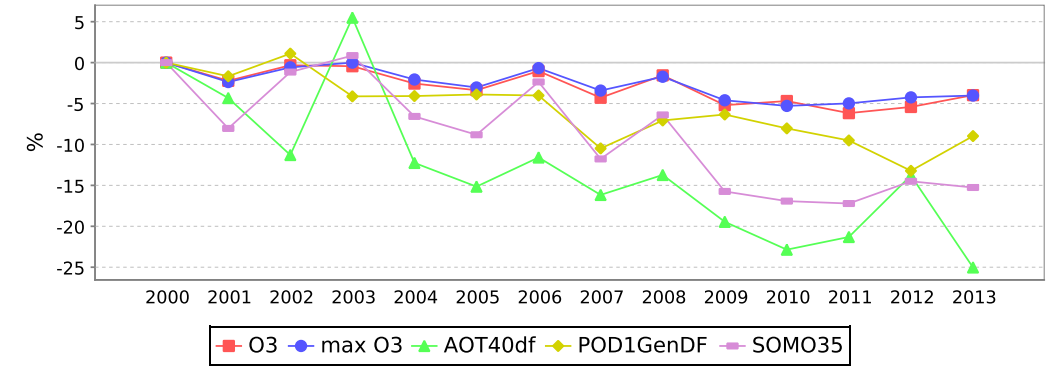

Figure 4: Changes in ozone related pollution relative to 2000. Unit: %. The large changes from year to year in some countries are mainly related to meteorological variability.

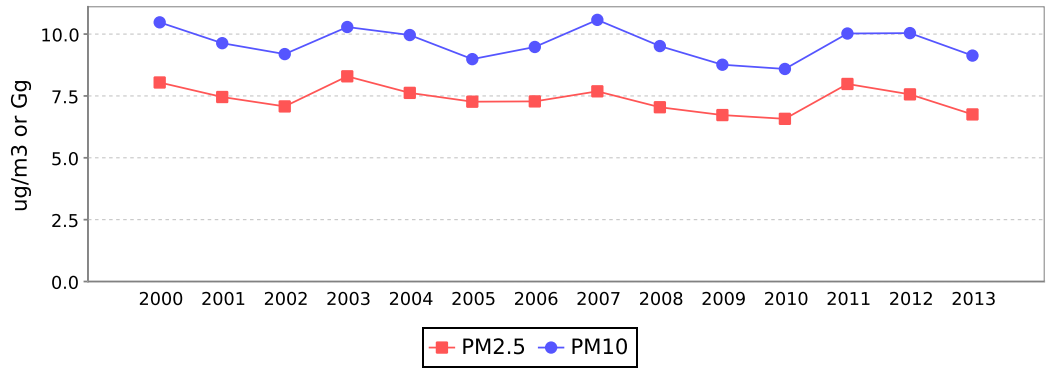

Figure 5: Trends in mean concentrations of particulate matter. Unit: μg/m^3.

4 Transboundary fluxes

4.1 Deposition of oxidised sulphur

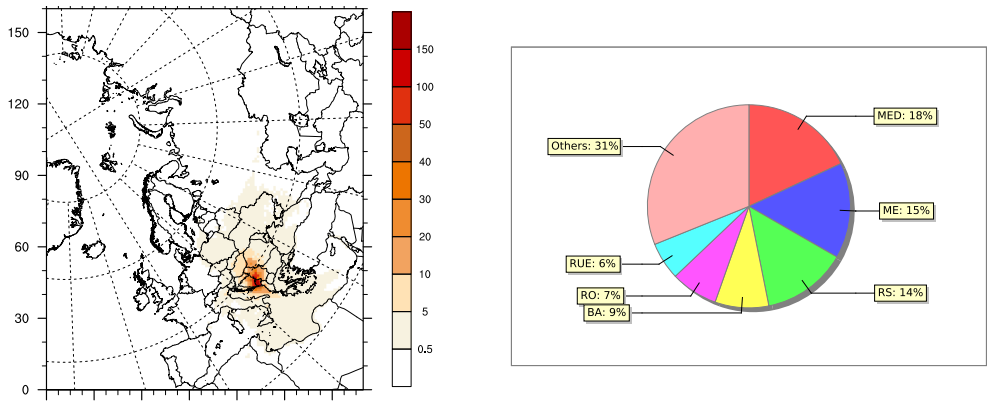

Figure 6: Contribution of emissions from Montenegro to deposition of oxidised sulphur in the EMEP domain. Unit: mg(S)/m^2. The pie chart shows the six main receptor areas where oxidised sulphur from Montenegro is deposited. Unit: %.

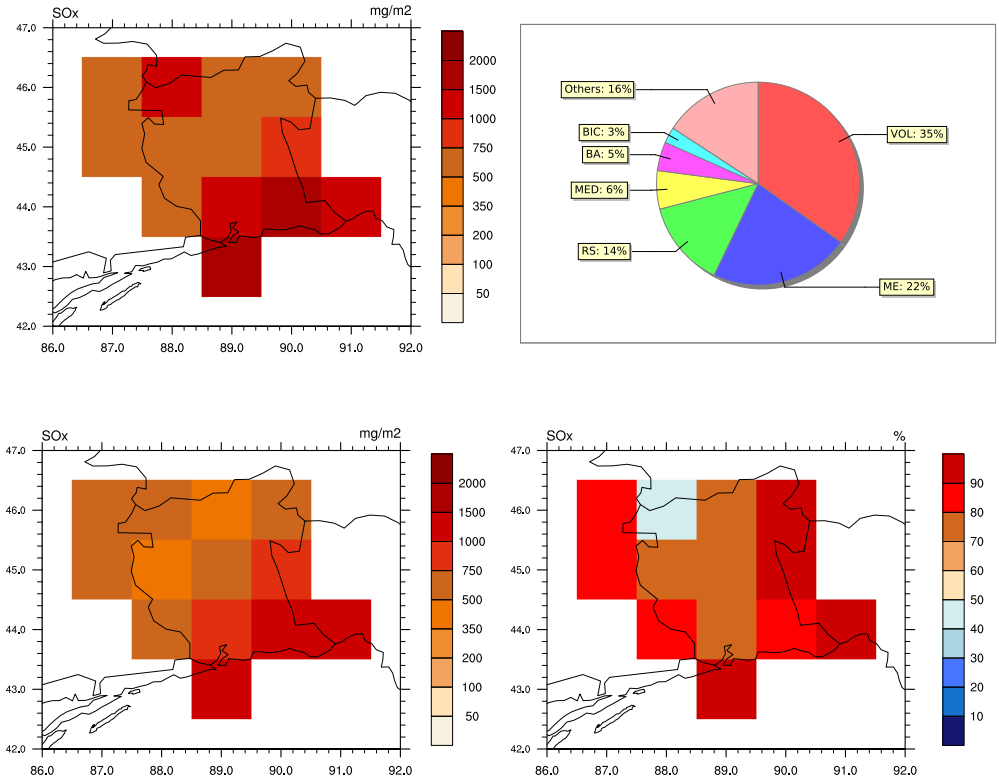

Figure 7: Top left: Deposition of oxidised sulphur in Montenegro. Unit: mg(S)/m^2. Top right: The six main contributors to oxidised sulphur deposition in Montenegro. Unit: (%). Bottom left: Oxidised sulphur deposition from transboundary sources. Unit: mg(S)/m^2. Bottom right: Fraction of transboundary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

4.2 Deposition of oxidised nitrogen

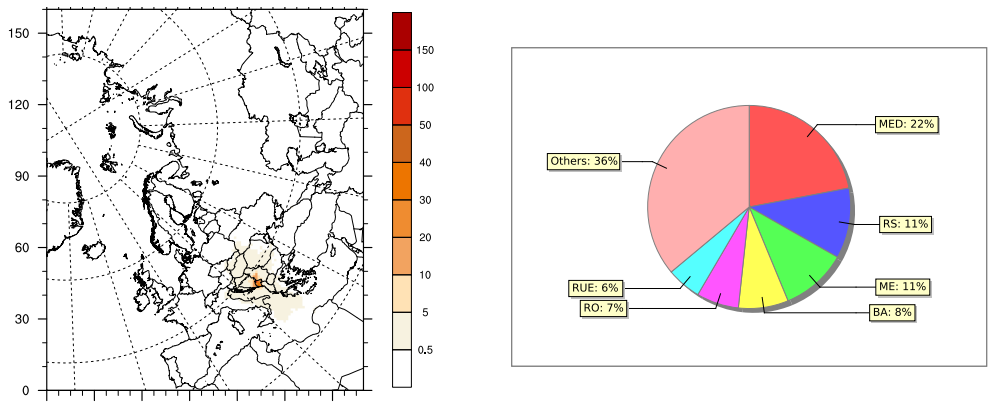

Figure 8: Contribution of emissions from Montenegro to deposition of oxidised nitrogen in the EMEP domain. Unit: mg(N)/m^2. The pie chart shows the six main receptor areas where oxidised nitrogen from Montenegro is deposited. Unit: %.

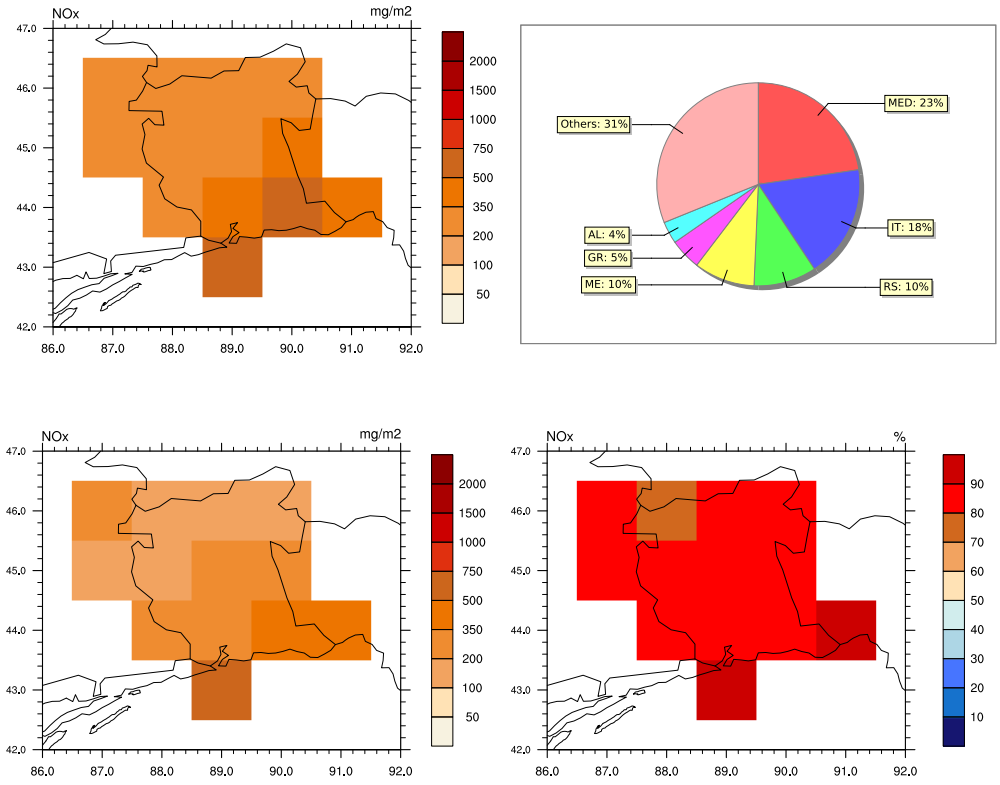

Figure 9: Top left: Deposition of oxidised nitrogen in Montenegro. Unit: mg(N)/m^2. Top right: The six main contributors to oxidised nitrogen deposition in Montenegro. Unit: %. Bottom left: Oxidised nitrogen deposition from transboundary sources. Unit: mg(N)/m^2. Bottom right: Fraction of transboundary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

4.3 Deposition of reduced nitrogen

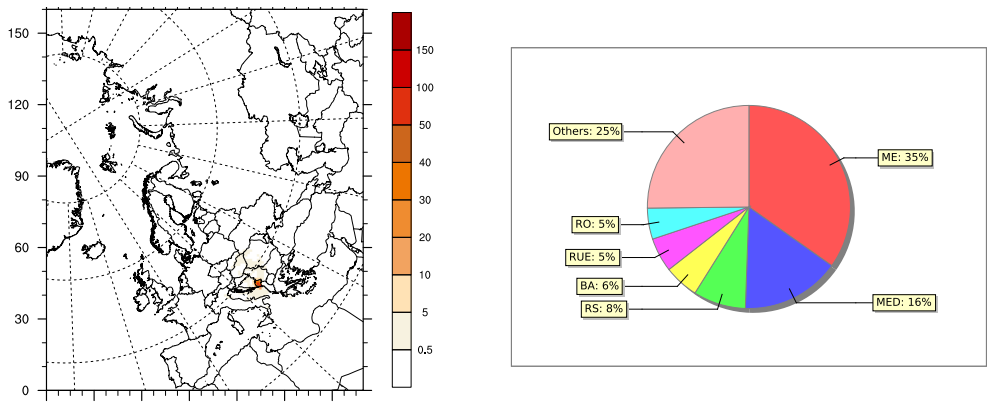

Figure 10: Contribution of emissions from Montenegro to deposition of reduced nitrogen in the EMEP domain. Unit: mg(N)/m^2. The pie chart shows the six main receptor areas where reduced nitrogen from Montenegro is deposited. Unit: %.

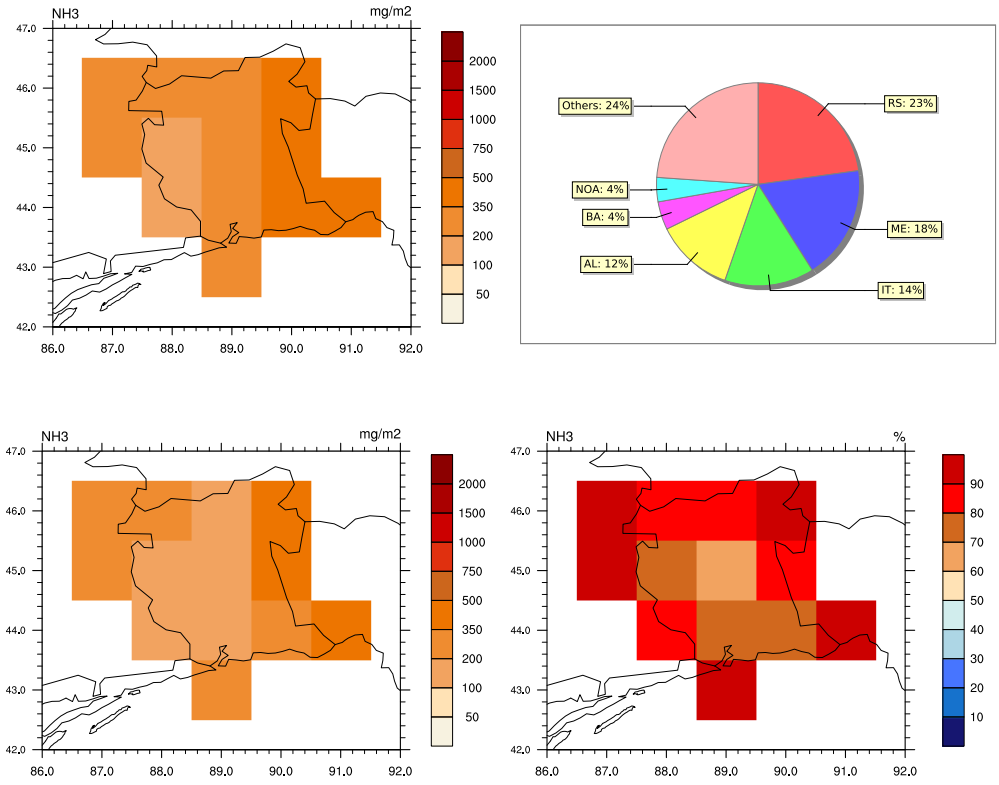

Figure 11: Top left: Deposition of reduced nitrogen in Montenegro. Unit: mg(N)/m^2. Top right: The six main contributors to deposition of reduced nitrogen in Montenegro. Unit: %. Bottom left: Deposition of reduced nitrogen from transboundary sources. Unit: mg(N)/m^2. Bottom right: Fraction of transboundary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

5 Transboundary concentrations of ozone

5.1 $AOT40_f^{uc}$

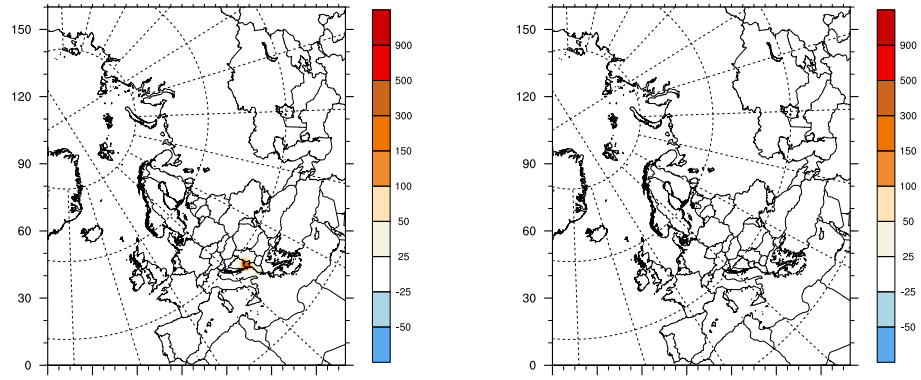

Figure 12: Reduction in $AOT40_f^{uc}$ that would result from a 15% reduction in emissions of NO_x (left) and NMVOC (right) from Montenegro. Unit: ppb·h.

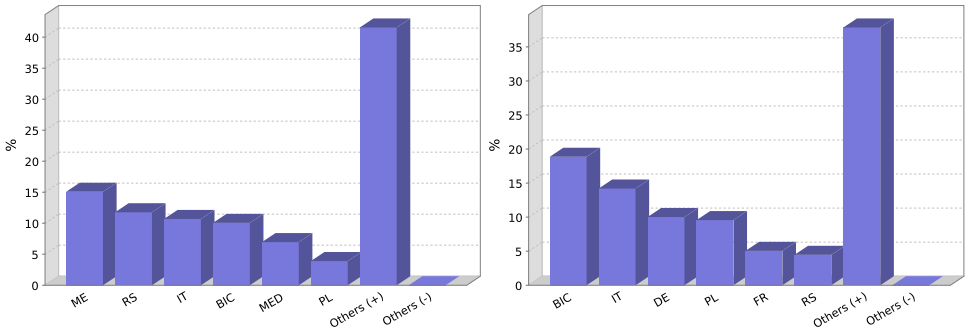

Figure 13: The six most important emitter countries or regions, with respect to the reduction in $AOT40_f^{uc}$ in Montenegro that would result from a 15% decrease in NO_x emissions (left) or NMVOC emissions (right).

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

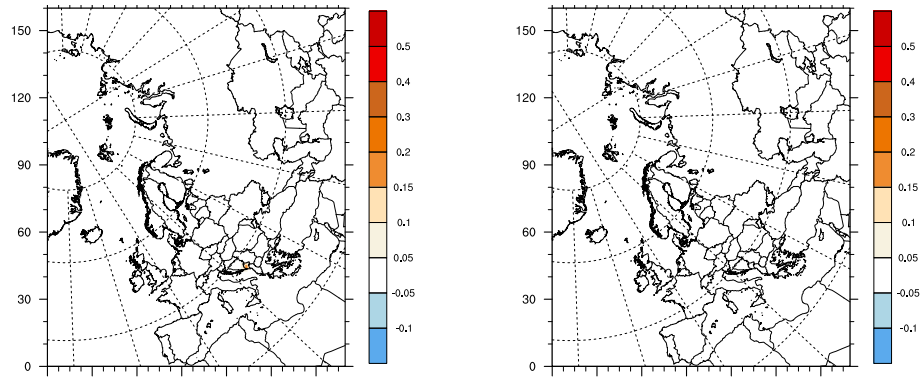

Figure 14: Reduction in $POD_{1.0,gen\text{-}DF}$ that would result from a 15% reduction in emissions of NO_x (left) and NMVOC (right) from Montenegro. Unit: mmol/m^2.

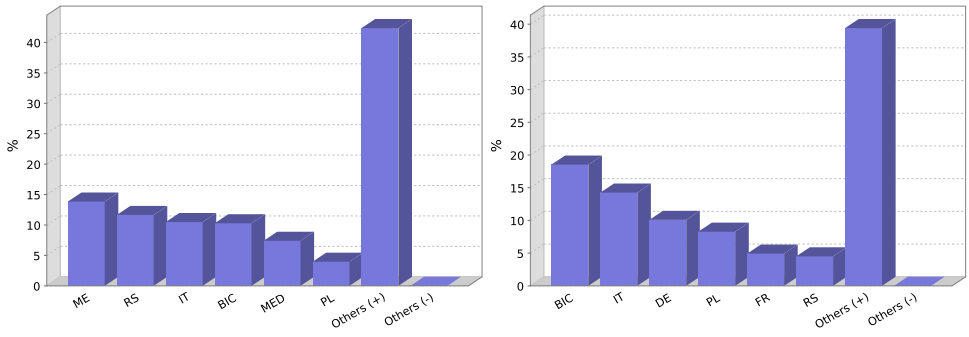

Figure 15: The six most important emitter countries or regions, with respect to the reduction in $POD_{1.0,gen\text{-}DF}$ in Montenegro that would result from a 15% decrease in NO_x emissions (left) or NMVOC emissions (right).

5.3 SOMO35 – Risk of ozone damages to human health

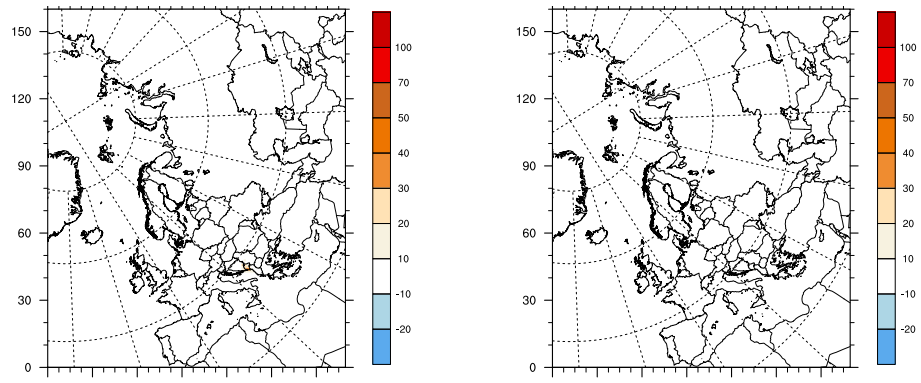

Figure 16: Reduction in SOMO35 that would result from a 15% reduction in emissions of NO_x (left) and NMVOC (right) from Montenegro. Unit: ppb·day.

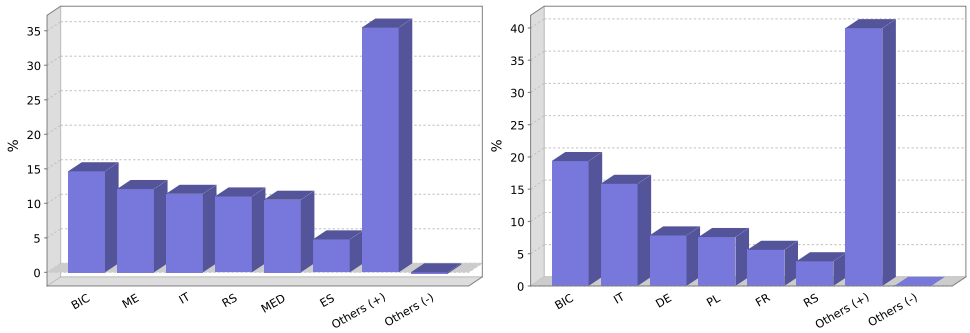

Figure 17: The six most important emitter countries or regions, with respect to the reduction in SOMO35 in Montenegro that would result from a 15% decrease in NO_x emissions (left) or NMVOC emissions (right).

6 Transboundary concentrations of particulate matter

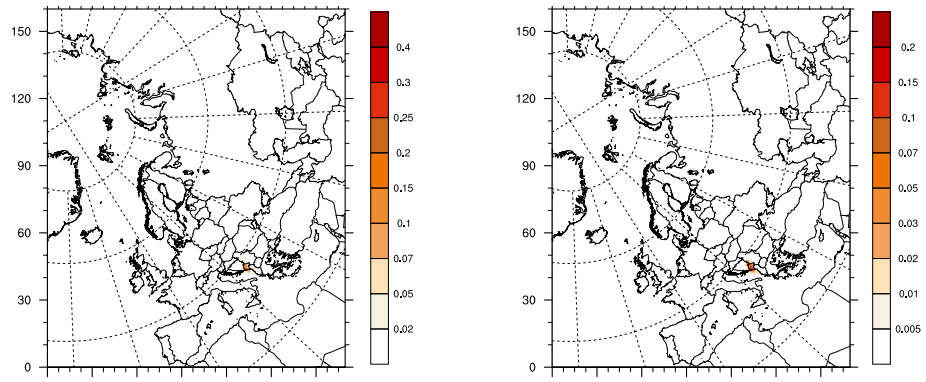

Figure 18: Reduction in concentrations of SIA (left) and $PPM_{2.5}$ (right) that would result from a 15% reduction in emissions from Montenegro. Unit: $\mu g/m^3$. Note the difference in scales.

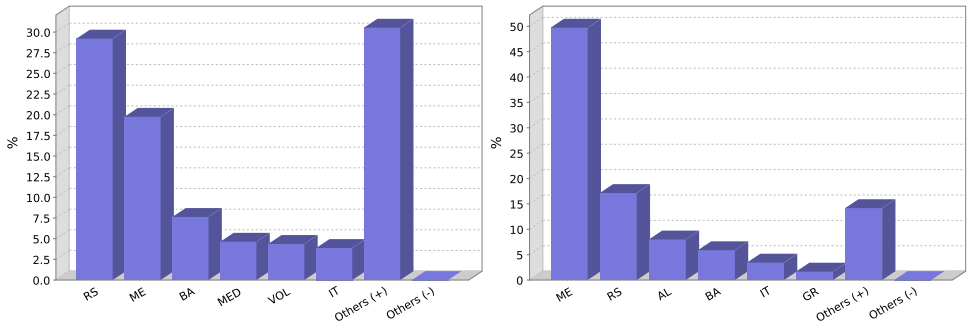

Figure 19: The six most important emitter countries or regions, with respect to the reduction in SIA (left) or $PPM_{2.5}$ (right) in Montenegro that would result from a 15% reduction in emissions.

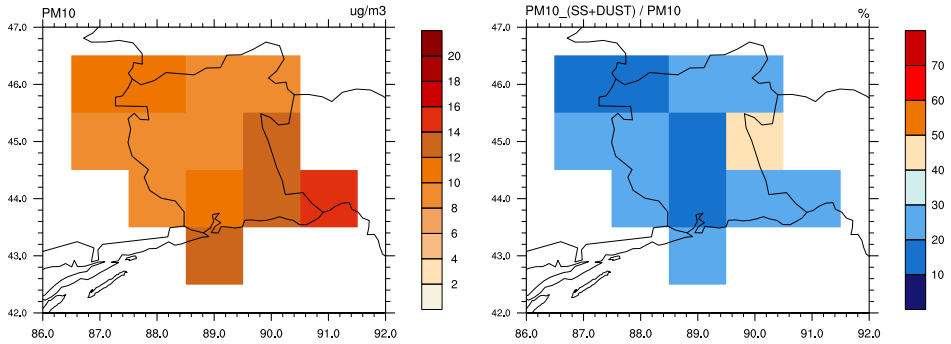

Figure 20: PM_{10} concentration (left) and fraction of natural contributions of PM_{10} (sea salt and natural dust) to total PM_{10} (right) in Montenegro.

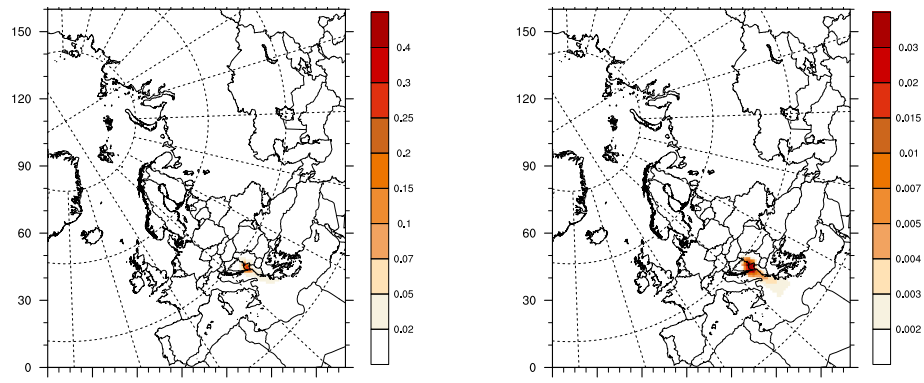

Figure 21: Reduction in $PM_{2.5}$ and PM_{coarse} concentrations that would result from a 15% reduction of emissions from Montenegro. Unit: $\mu g/m^3$. Note the different color scales.

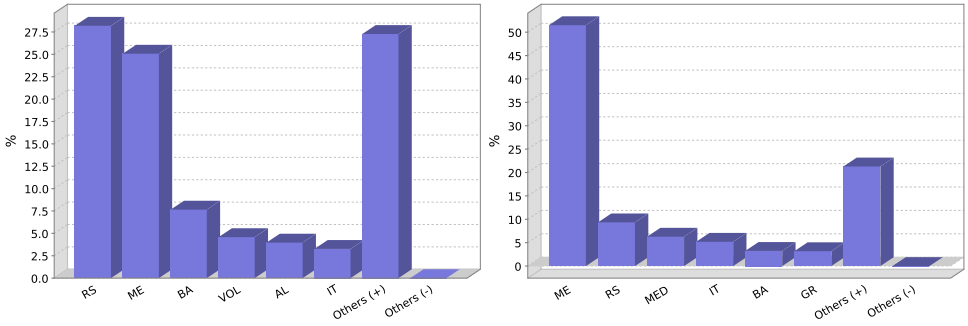

Figure 22: The six most important emitter countries, with respect to the reduction in $PM_{2.5}$ (left) or PM_{coarse} (right) in Montenegro that would result from a 15% reduction in emissions.

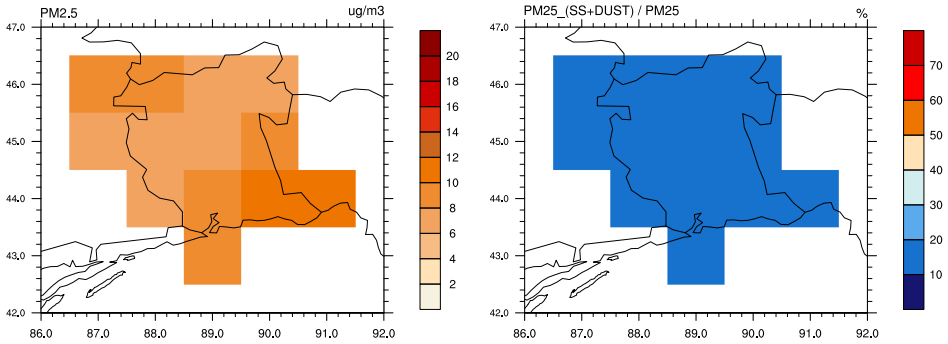

Figure 23: $PM_{2.5}$ concentration (left) and fraction of natural contributions of $PM_{2.5}$ (sea salt and natural dust) to total $PM_{2.5}$ (right) in Montenegro.

7 Comparison with observations

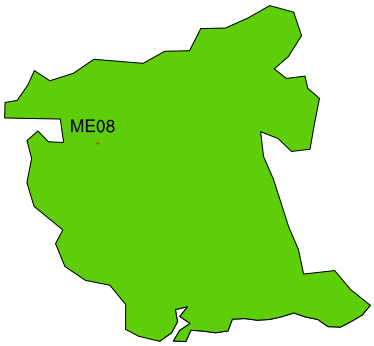

Figure 24: Location of stations in Montenegro.

A sufficiently consistent set of daily ozone observations in ME for 2013 is not available for this analysis.

Figure 25: Frequency analysis of ozone in Montenegro at the stations that reported O_3 for 2013 (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			
PM10	0			
PM2.5	0			
Ozone daily max	0			
Ozone daily mean	0			
SO4 wet dep.	1	-97%	0.04	491.27
Nitrate wet dep.	1	-97%	-0.14	167.93
Ammonium wet dep.	1	-98%	-0.50	166.43
Precipitation	1	-21%	0.40	57.56

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

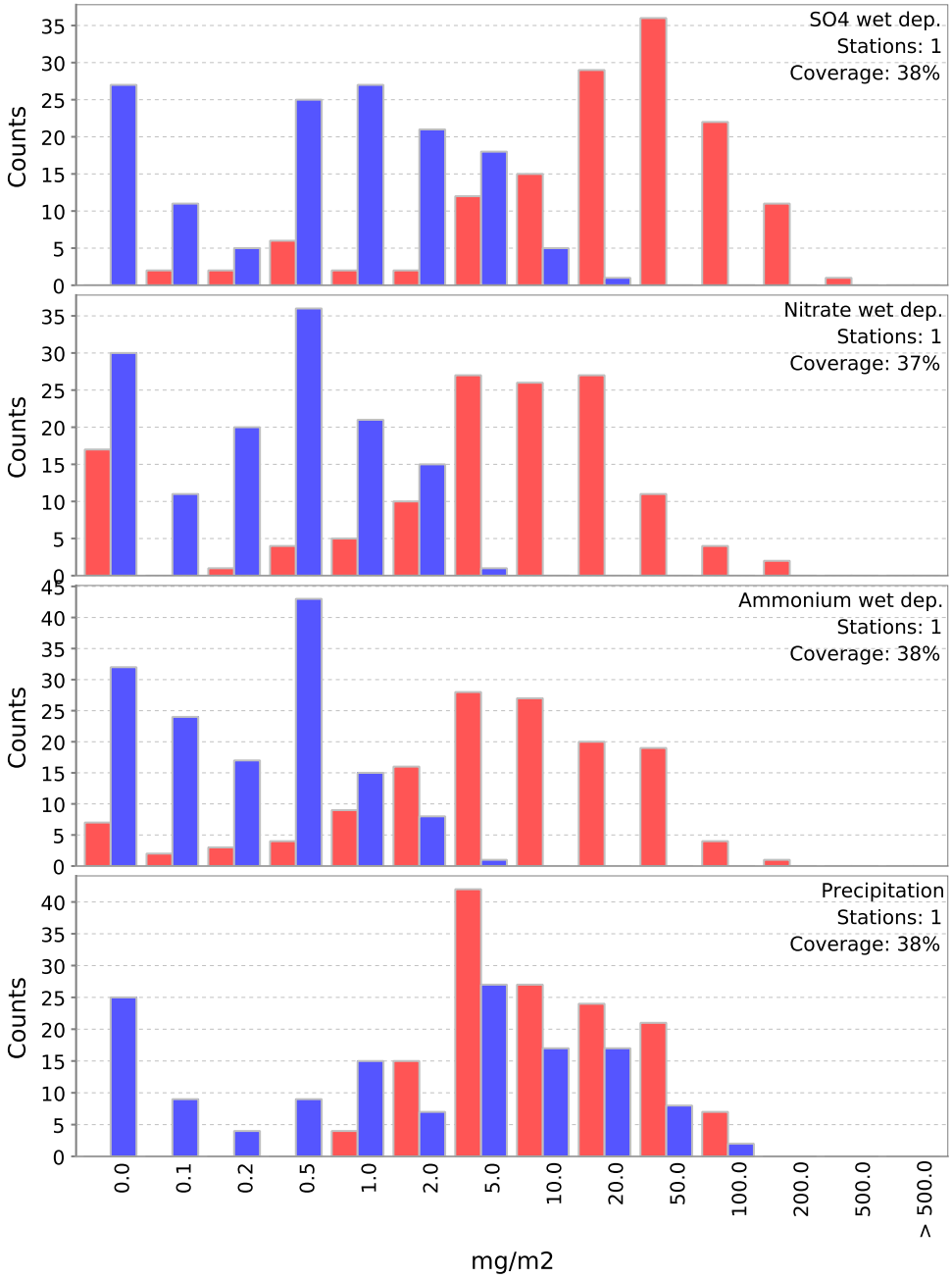

Figure 26: Frequency analysis of depositions in precipitation in Montenegro (Model, Observations).

A sufficiently consistent set of daily air concentration observations in ME for 2013 is not available for this analysis.

Figure 27: Frequency analysis of air concentrations in Montenegro (Model, Observations).

8 Risk of damage from ozone and particulate matter in Montenegro

8.1 Ecosystem-specific AOT40 values

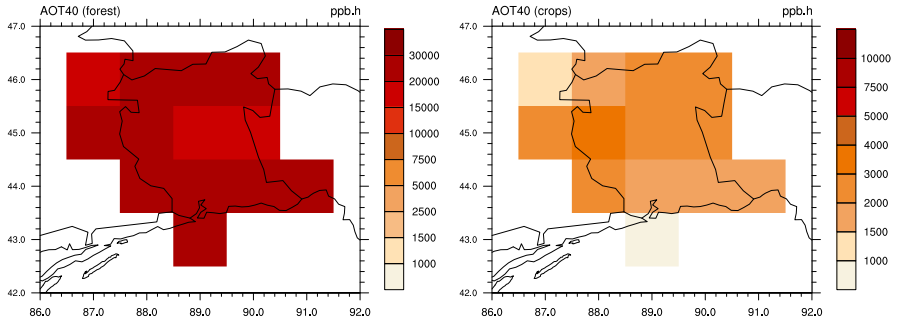

Figure 28: $AOT40_f^{uc}$ and $AOT40_c^{uc}$ in Montenegro in 2013. *($AOT40_f^{uc}$: growing season April-Sept., critical level for forest damage = 5000 ppb·h; $AOT40_c^{uc}$: growing season May-July, critical level for agricultural crops = 3000 ppb·h.)*

8.2 Ecosystem-specific ozone fluxes

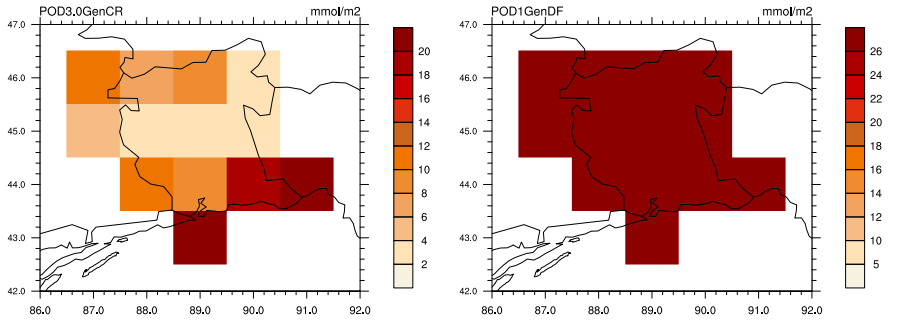

Figure 29: $POD_{3.0,\text{gen-CR}}$ and $POD_{1.0,\text{gen-DF}}$ in Montenegro in 2013.

8.3 Health impacts from ozone and particulate matter

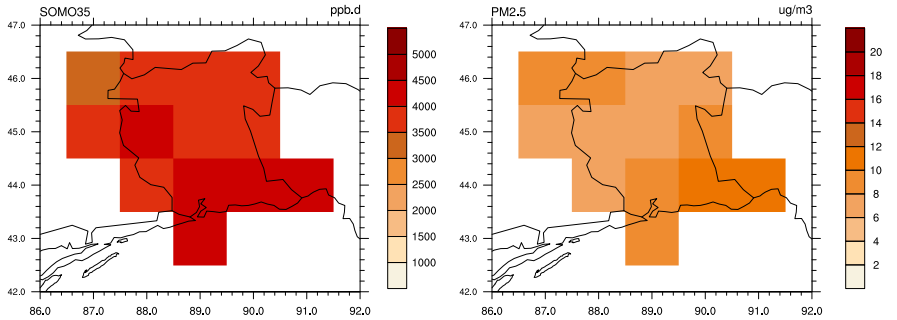

Figure 30: Regional scale SOMO35 and $PM_{2.5}$ in Montenegro in 2013.

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