MSC-W Data Note 1/2019
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Transboundary air pollution by main pollutants (S, N, O_3) and PM in 2017

Armenia

H. Klein, M. Gauss, Á. Nyíri, and S. Tsyro

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Contents

1 User guide

This report is one in a series of country-specific notes, complementary to the EMEP Status Report 1/2019. It presents an overview of transboundary pollution of main pollutants (S, N, O_3) and particulate matter (PM) for Armenia in 2017.

All model runs have been performed with the EMEP MSC-W model version rv4.33, 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 2017.

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 2017 have been derived from the 2019 official data submissions to UNECE CLRTAP as of May 2019. The gridded distributions of the 2017 emissions have been provided by the EMEP Centre on Emission Inventories and Projections (CEIP). The emissions for the period of 2000–2016, too, have been derived from the data submissions to UNECE CLRTAP as of May 2019.

The gridded emission data used in the model calculations this year are available on WebDab at:
`http://www.ceip.at/webdab_emepdatabase/emissions_emepmodels`.

Time series *(Chapter 3)* : Time series in depositions and air concentrations are presented for the period of 2000–2017. The calculations are based on a consistent series of model runs, all using the EMEP MSC-W model version rv4.33. For the years 2000–2017, the meteorology of the respective year is used. Thus, interannual variability in the model results is due to changes in both emissions and meteorology. It should also be noted that the emission data and model version are updated regularly (see respective chapters on emissions and model updates in EMEP status report 1/2019), 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 calculate the effect of 15% reductions in emissions only.

The horizontal maps show the reduction in concentrations when emissions are reduced by 15% in Armenia. 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 effects on concentrations in Armenia that would result from a 15% reduction in emissions. In the bar charts, the sum of the *absolute values* of these effects corresponds to 100%. The percentage values (vertical scale in the bar charts) thus give an indication of the relative importance of the various emitter countries that influence concentrations in Armenia (positive or negative, large or small contributions). Again, reductions are represented by positive values. Hence, a negative bar in the chart means that a *reduction* in emissions from an emitter

country would lead to an *increase* in concentration in Armenia. In some countries this can occur because of 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 Armenia in the EMEP measurement network with measurements in 2017 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.

Also shown this year is the evaluation against measurements from the European Environment Agency's Air Quality e-Reporting data base (in the scientific community often referred to as 'AirBase'). In countries with AirBase sites, scatter plots show model performance in regard to chemical species, for which measurements are available.

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).

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 2017.

Code	Country/Region/Source
AL	Albania
AM	Armenia
AST	Asian areas
AT	Austria
ATL	N.-E. Atlantic Ocean
AZ	Azerbaijan
BA	Bosnia and Herzegovina
BAS	Baltic Sea
BE	Belgium
BG	Bulgaria
BIC	Boundary/Initial Conditions
BLS	Black Sea
BY	Belarus
CH	Switzerland
CY	Cyprus
CZ	Czechia
DE	Germany
DK	Denmark
DMS	Dimethyl sulfate (marine)
EE	Estonia
ES	Spain
EU	European Union (EU28)
EXC	EMEP land areas
FI	Finland
FR	France
GB	United Kingdom
GE	Georgia
GL	Greenland
GR	Greece
HR	Croatia
HU	Hungary
IE	Ireland

Code	Country/Region/Source
IS	Iceland
IT	Italy
KG	Kyrgyzstan
KZ	Kazakhstan
LI	Liechtenstein
LT	Lithuania
LU	Luxembourg
LV	Latvia
MC	Monaco
MD	Moldova
ME	Montenegro
MED	Mediterranean Sea
MK	North Macedonia
MT	Malta
NL	Netherlands
NO	Norway
NOA	North Africa
NOS	North Sea
PL	Poland
PT	Portugal
RO	Romania
RS	Serbia
RU	Russian Federation
SE	Sweden
SI	Slovenia
SK	Slovakia
TJ	Tajikistan
TM	Turkmenistan
TR	Turkey
UA	Ukraine
UZ	Uzbekistan
VOL	Volcanic emissions

Table 1: Country/region codes used throughout this report.

1.3 Definitions, statistics used

The following definitions and acronyms are used throughout this note:

SOA - secondary organic aerosol, defined as the aerosol mass arising from the oxidation products of gas-phase organic species.

SIA - secondary inorganic aerosols, 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 the sum: SIA= SO_4^{2-} + NO_3^-(fine) + NO_3^-(coarse) + NH_4^+.

SS - sea salt.

MinDust - mineral dust.

PPM - 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 aerosol diameters between 2.5 μm and 10 μm.

$PM_{2.5}$ - particulate matter with aerodynamic diameter 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} - coarse particulate matter with aerodynamic 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} - particulate matter with aerodynamic diameter 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:

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

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$^{\mathbf{uc}}_{f}$ - 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

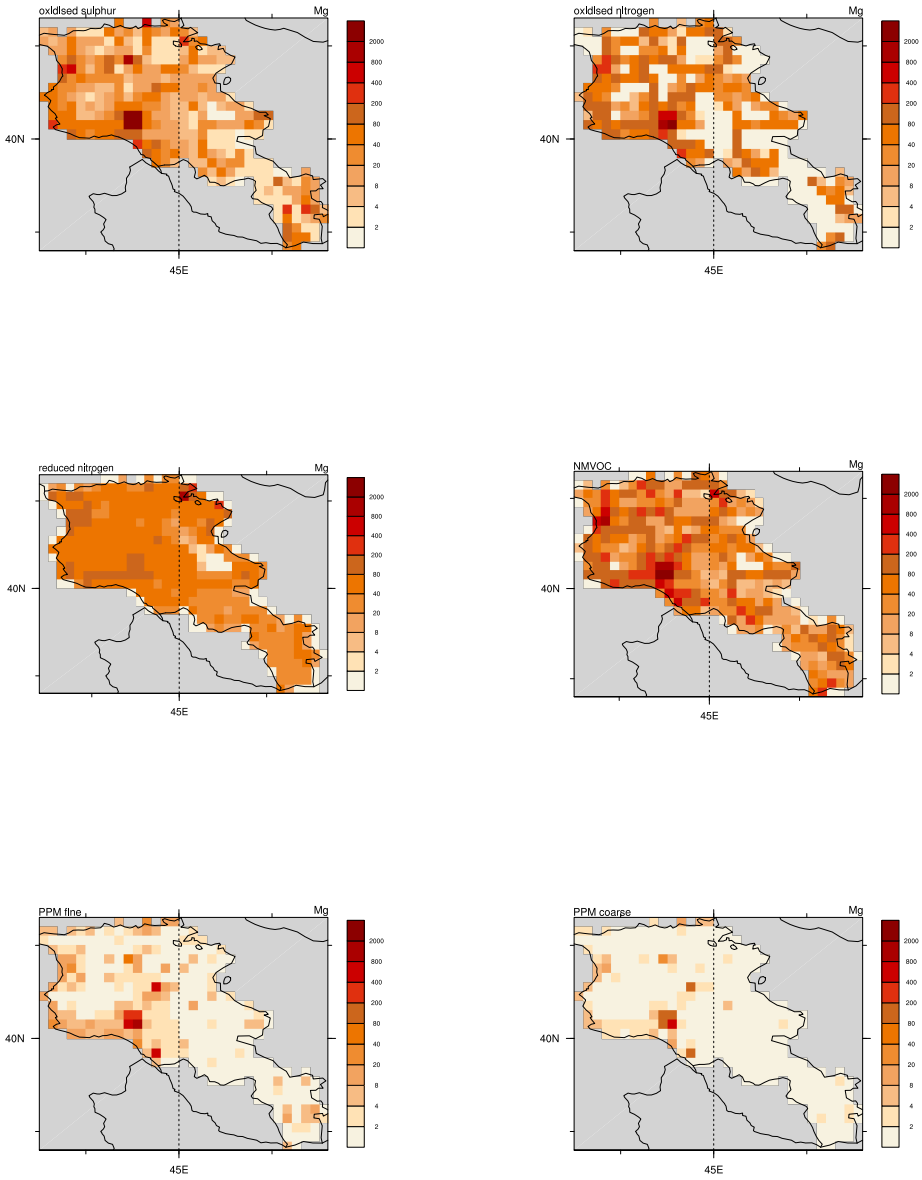

Figure 1: Spatial distribution of emissions from Armenia in 2017.

3 Time series

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

	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
SO_x	8	18	22	26	27	27	28	29	30	31	32	35	39	39
NO_x	10	19	21	24	23	23	23	23	22	22	22	20	18	20
NH_3	14	16	16	17	17	17	18	18	18	18	19	20	20	19
NMVOC	16	32	33	35	35	35	34	34	34	34	34	35	36	36
CO	110	116	114	112	111	110	109	108	107	106	105	106	108	112
$PM_{2.5}$	4	4	4	4	4	4	4	4	4	4	4	4	4	4
PM_{10}	5	5	5	5	5	5	5	5	5	6	6	6	6	6

Table 2: Emissions from Armenia. Unit: Gg. (SO_x given as SO_2, and NO_x as NO_2).

	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
SO_x dep.	15	16	16	17	18	18	18	17	17	14	19	20	24	21
NO_x dep.	6	9	8	9	9	8	9	8	9	8	10	10	10	10
redN dep.	13	15	14	15	16	16	16	16	16	16	18	18	20	18

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

	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
mean ozone	40	41	42	41	41	41	41	41	40	42	41	42	42	42
max ozone	47	48	49	48	49	48	48	48	48	49	49	49	48	50
$AOT40_f^{uc}$	24835	23755	27771	24138	27481	23559	27945	23511	26487	27217	27041	28512	24456	30597
SOMO35	3723	4014	4384	3977	4295	3952	4105	3955	3928	4338	4248	4432	4171	4689
$POD_{1.0,gen\text{-}DF}$	20	25	24	25	25	25	24	25	27	24	23	23	27	24
$PM_{2.5}$ anthrop.	7	7	10	8	9	8	10	7	8	7	11	9	8	10
PM_{10} anthrop.	11	11	17	13	14	13	17	11	11	11	17	14	12	16

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

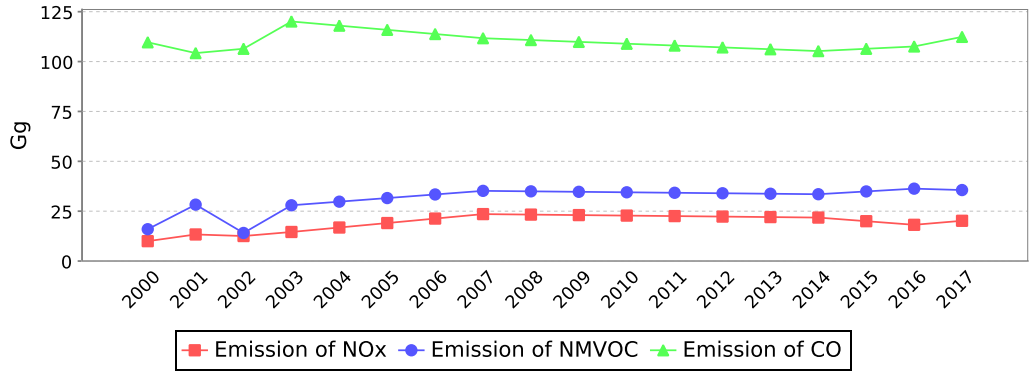

Figure 2: Trends in emissions of photo-oxidant pollution precursors. Unit: Gg (note that NO_x is here given as NO_2).

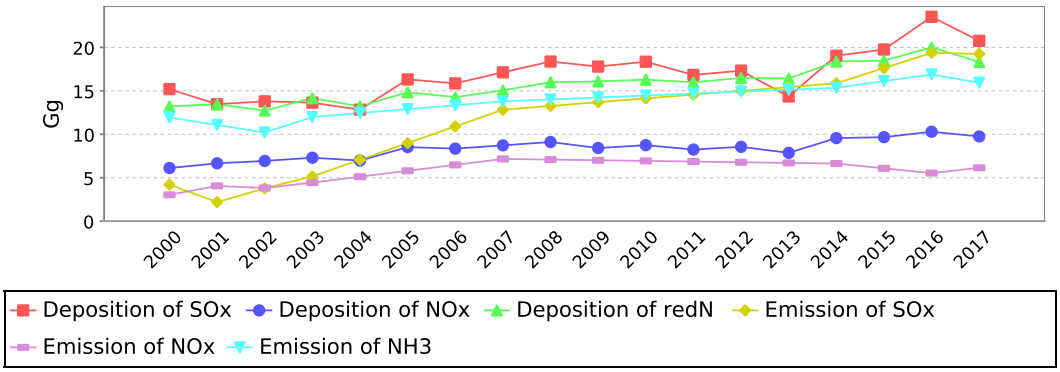

Figure 3: Trends in emissions and depositions of oxidised sulphur, oxidised nitrogen and reduced nitrogen. Unit: Gg(S) or Gg(N).

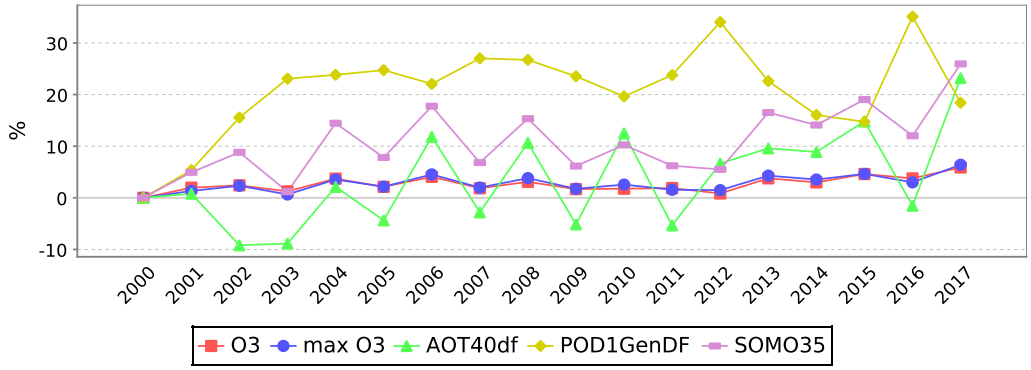

Figure 4: Changes in ozone related pollution relative to 2000. Unit: %. The large changes from year to year in some countries are mainly related to meteorological variability.

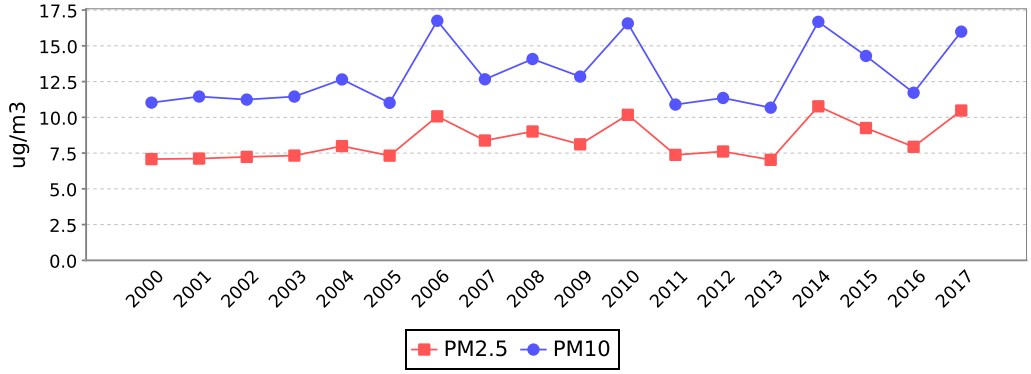

Figure 5: Trends in mean concentrations of particulate matter. Unit: μg/m^3.

4 Transboundary fluxes

4.1 Deposition of oxidised sulphur

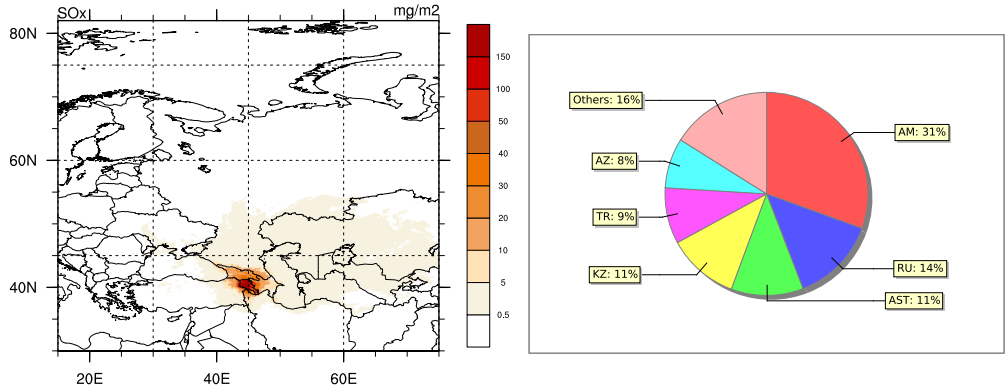

Figure 6: Contribution of emissions from Armenia to deposition of oxidised sulphur in the EMEP domain. Unit: mg(S)/m^2. The pie chart shows the six main receptor areas where oxidised sulphur from Armenia is deposited. Unit: %.

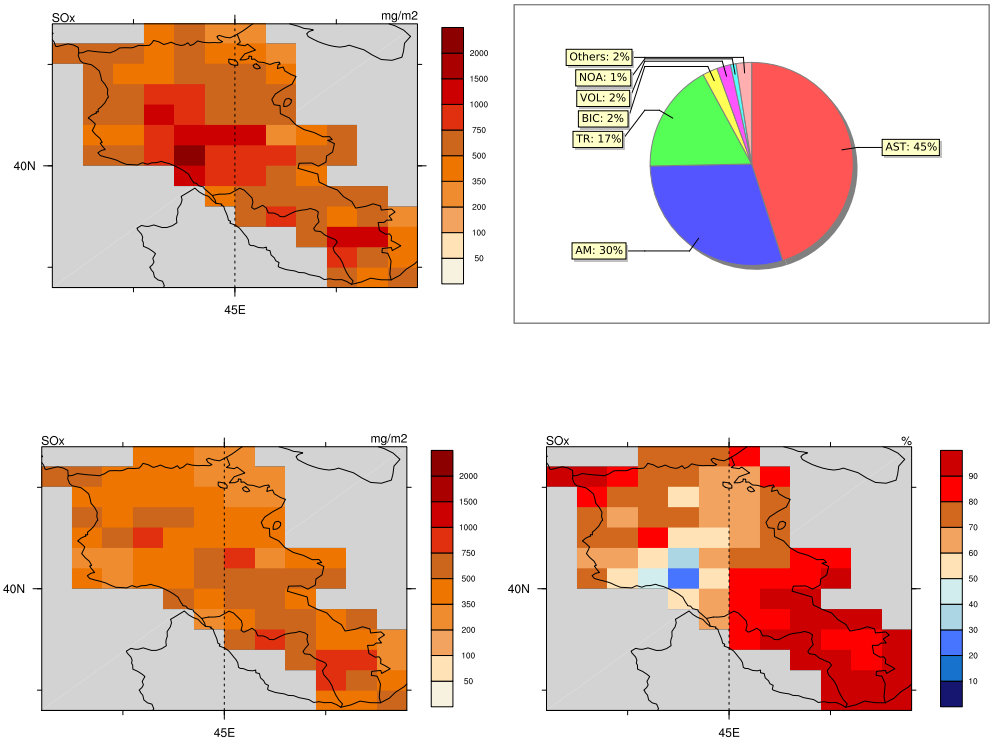

Figure 7: Top left: Deposition of oxidised sulphur in Armenia. Unit: mg(S)/m^2. Top right: The six main contributors to oxidised sulphur deposition in Armenia. Unit: (%). Bottom left: Oxidised sulphur deposition from transboundary sources. Unit: mg(S)/m^2. Bottom right: Fraction of transboundary contribution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

4.2 Deposition of oxidised nitrogen

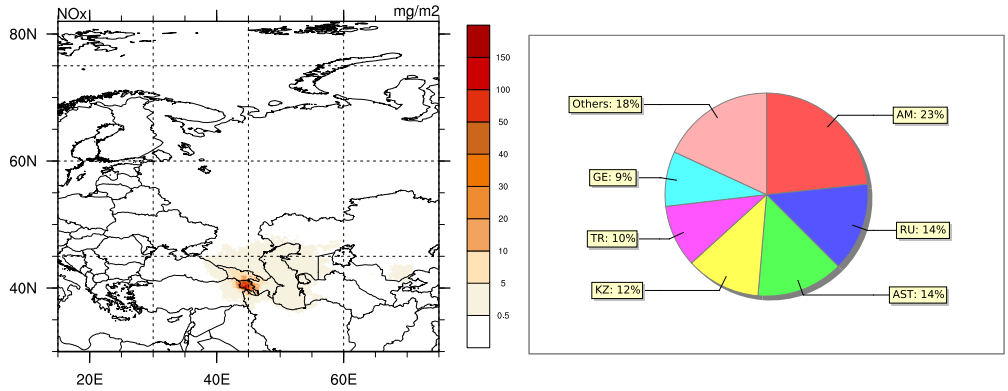

Figure 8: Contribution of emissions from Armenia to deposition of oxidised nitrogen in the EMEP domain. Unit: mg(N)/m^2. The pie chart shows the six main receptor areas where oxidised nitrogen from Armenia is deposited. Unit: %.

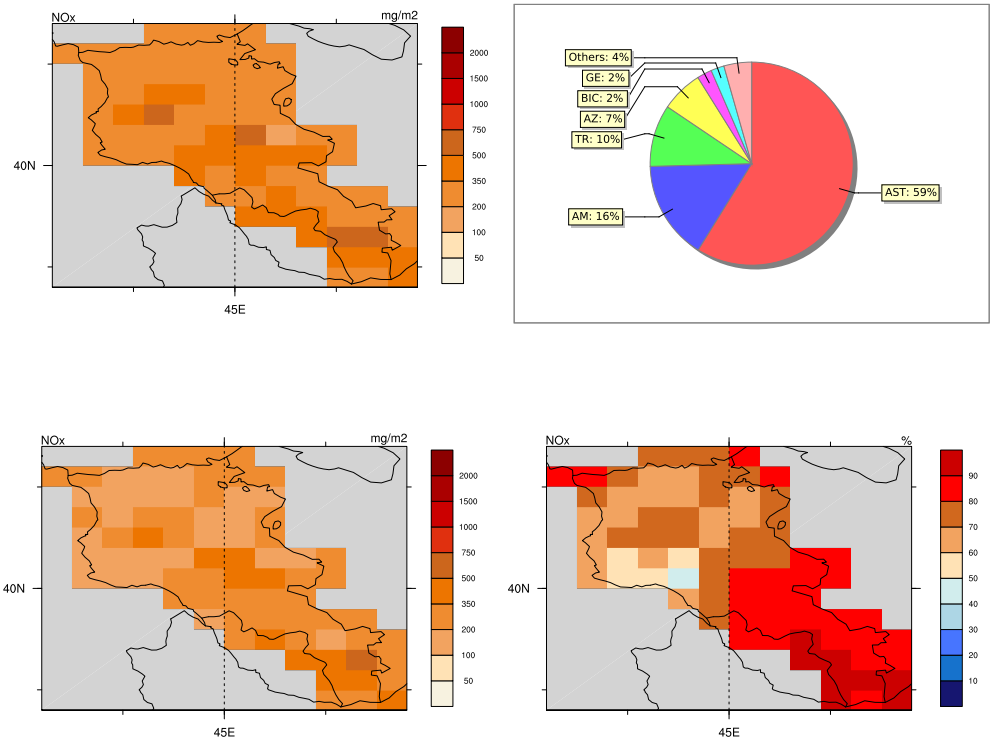

Figure 9: Top left: Deposition of oxidised nitrogen in Armenia. Unit: mg(N)/m^2. Top right: The six main contributors to oxidised nitrogen deposition in Armenia. Unit: %. Bottom left: Oxidised nitrogen deposition from transboundary sources. Unit: mg(N)/m^2. Bottom right: Fraction of transboundary contribution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

4.3 Deposition of reduced nitrogen

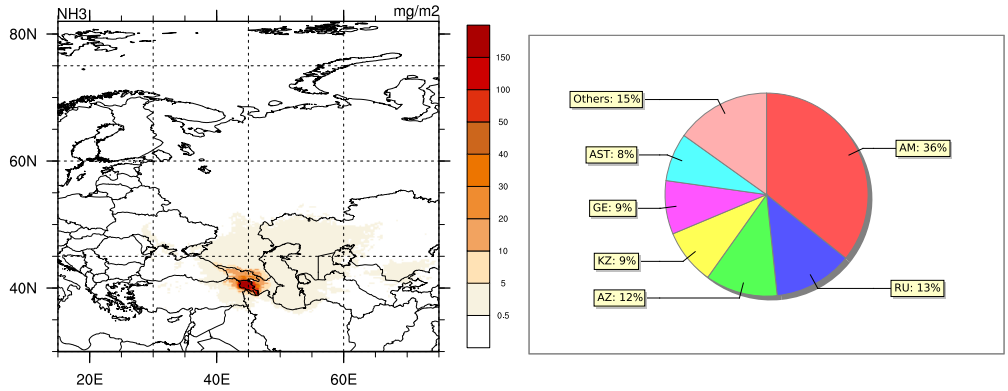

Figure 10: Contribution of emissions from Armenia to deposition of reduced nitrogen in the EMEP domain. Unit: mg(N)/m^2. The pie chart shows the six main receptor areas where reduced nitrogen from Armenia is deposited. Unit: %.

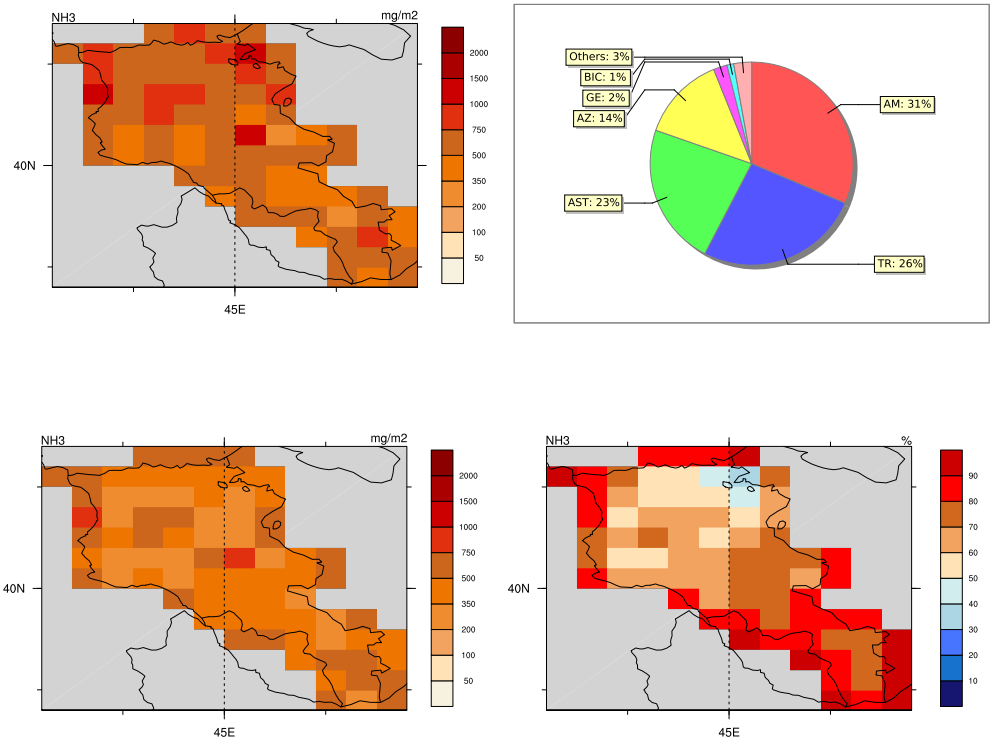

Figure 11: Top left: Deposition of reduced nitrogen in Armenia. Unit: mg(N)/m^2. Top right: The six main contributors to deposition of reduced nitrogen in Armenia. Unit: %. Bottom left: Deposition of reduced nitrogen from transboundary sources. Unit: mg(N)/m^2. Bottom right: Fraction of transboundary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

5 Transboundary concentrations of ozone

5.1 AOT40$_f^{uc}$

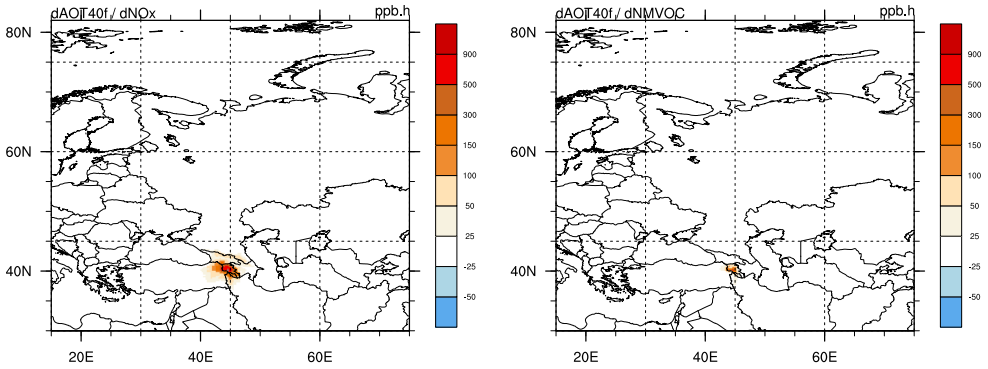

Figure 12: Reduction in AOT40$_f^{uc}$ that would result from a 15% reduction in emissions of NO_x (left) and NMVOC (right) from Armenia. Unit: ppb·h.

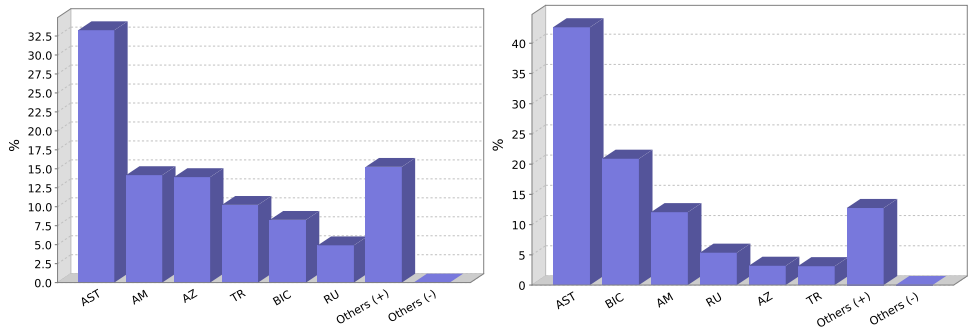

Figure 13: The six most important emitter countries or regions, with respect to their effects on AOT40$_f^{uc}$ in Armenia that would result from reductions in NO_x emissions (left) or NMVOC emissions (right). The sum of the absolute values of the effects of all emitter countries corresponds to 100%. See Section 1.1 for more information.

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

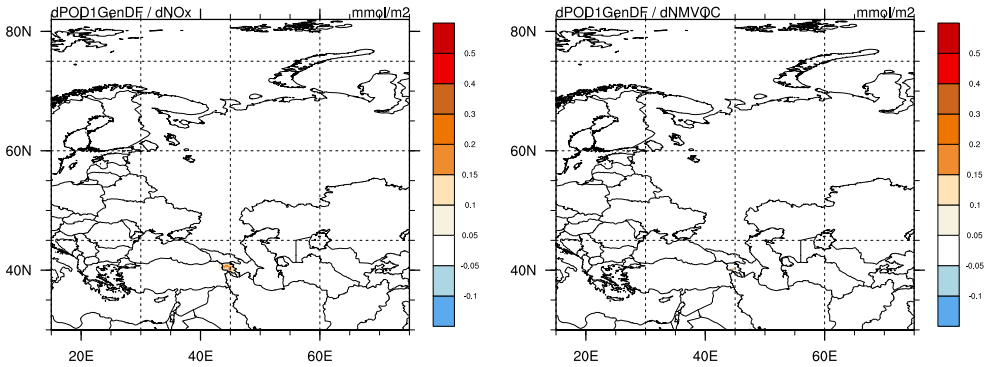

Figure 14: Reduction in $POD_{1.0,gen\text{-}DF}$ that would result from a 15% reduction in emissions of NO_x (left) and NMVOC (right) from Armenia. Unit: mmol/m^2.

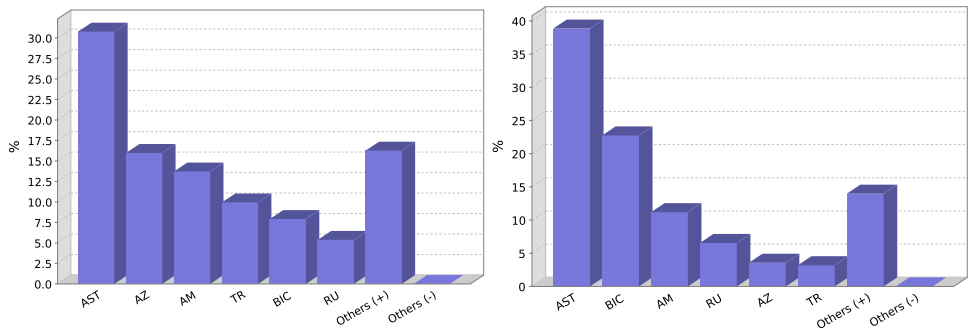

Figure 15: The six most important emitter countries or regions, with respect to their effects on $POD_{1.0,gen\text{-}DF}$ in Armenia that would result from reductions in NO_x emissions (left) or NMVOC emissions (right). The sum of the absolute values of the effects of all emitter countries corresponds to 100%. See Section 1.1 for more information.

5.3 SOMO35 – Risk of ozone damages to human health

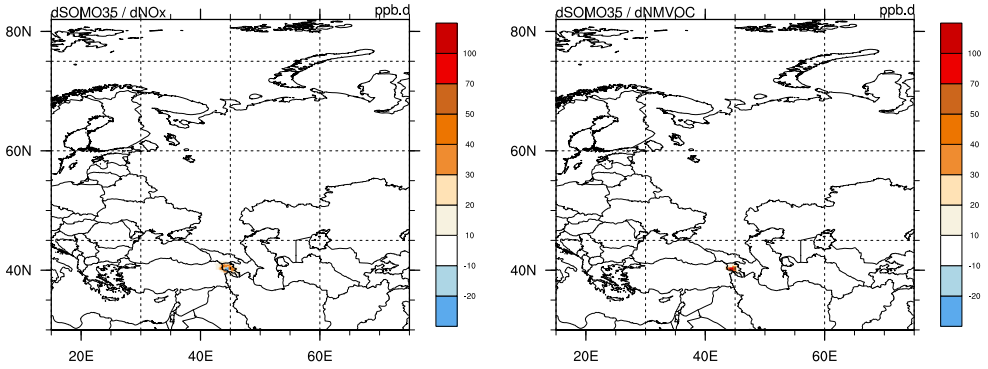

Figure 16: Reduction in SOMO35 that would result from a 15% reduction in emissions of NO_x (left) and NMVOC (right) from Armenia. Unit: ppb·day.

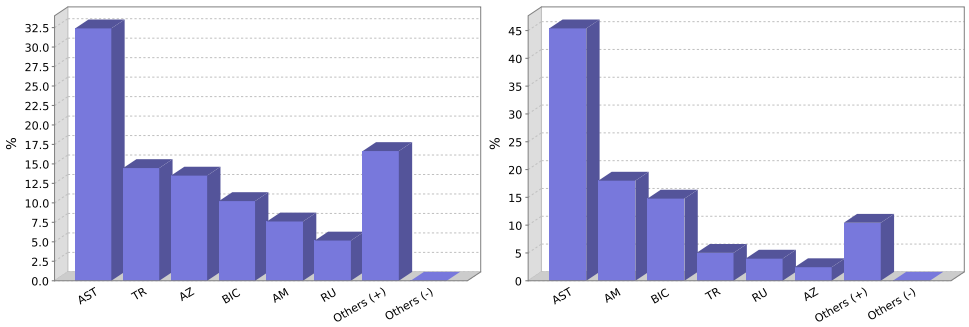

Figure 17: The six most important emitter countries or regions, with respect to their effects on SOMO35 in Armenia that would result from reductions in NO_x emissions (left) or NMVOC emissions (right). The sum of the absolute values of the effects of all emitter countries corresponds to 100%. See Section 1.1 for more information.

6 Transboundary concentrations of particulate matter

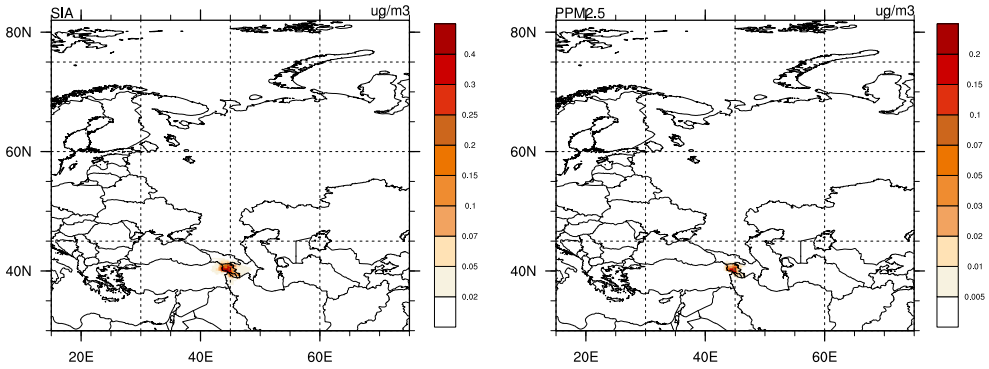

Figure 18: Reduction in concentrations of SIA (left) and $PPM_{2.5}$ (right) that would result from a 15% reduction in emissions from Armenia. Unit: $\mu g/m^3$. Note the difference in scales.

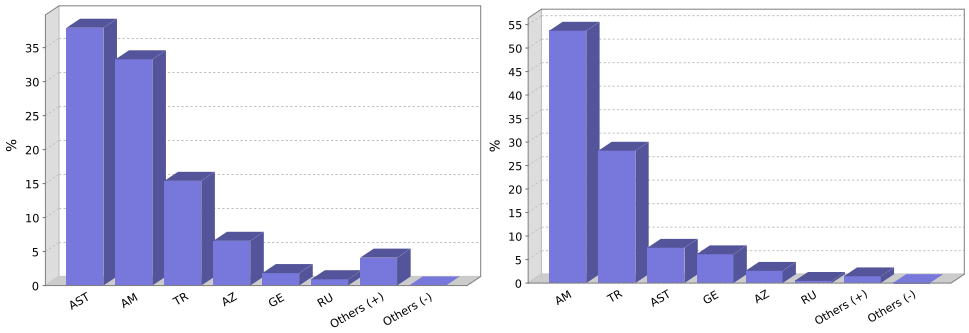

Figure 19: The six most important emitter countries or regions, with respect to their effects on SIA (left) or $PPM_{2.5}$ (right) in Armenia that would result from reductions in emissions. The sum of the absolute values of the effects of all emitter countries corresponds to 100%. See Section 1.1 for more information.

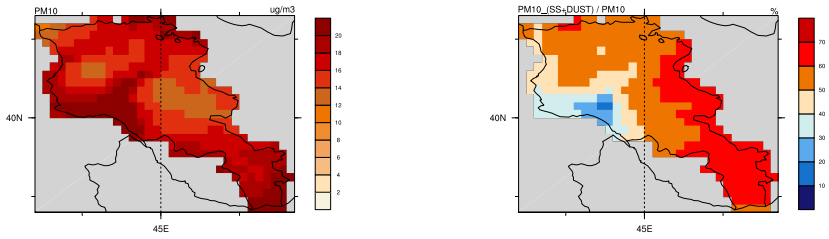

Figure 20: PM_{10} concentration (left) and fraction of natural contributions of PM_{10} (sea salt and natural dust) to total PM_{10} (right) in Armenia.

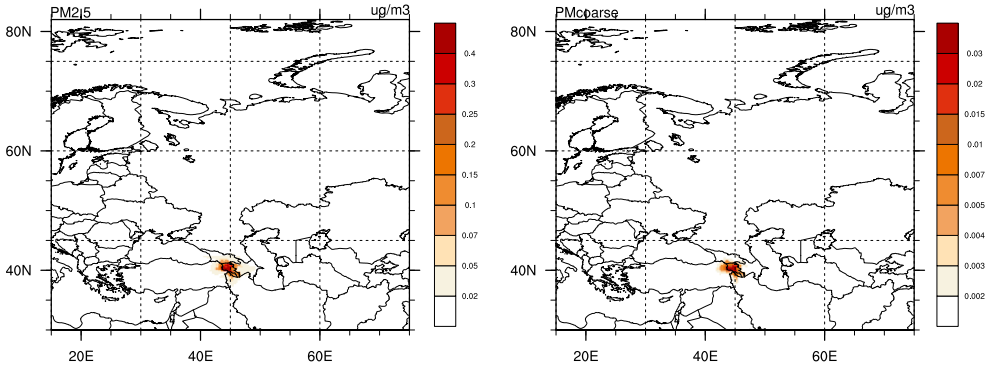

Figure 21: Reduction in $PM_{2.5}$ and PM_{coarse} concentrations that would result from a 15% reduction of emissions from Armenia. Unit: $\mu g/m^3$. Note the different color scales.

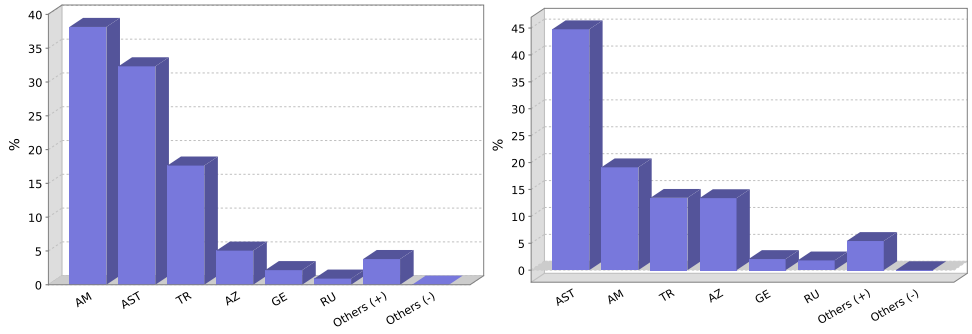

Figure 22: The six most important emitter countries or regions, with respect to their effects on $PM_{2.5}$ (left) or PM_{coarse} (right) in Armenia that would result from reduction in emissions. The sum of the absolute values of the effects of all emitter countries corresponds to 100%. See Section 1.1 for more information.

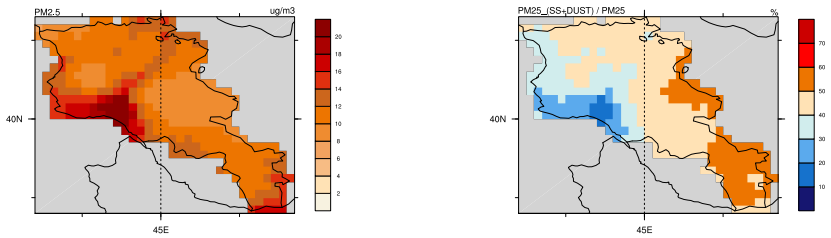

Figure 23: $PM_{2.5}$ concentration (left) and fraction of natural contributions of $PM_{2.5}$ (sea salt and natural dust) to total $PM_{2.5}$ (right) in Armenia.

7 Comparison with observations

Figure 24: Location of stations in Armenia.

A sufficiently consistent set of daily ozone observations in AM for 2017 is not available for this analysis.

Figure 25: Frequency analysis of ozone in Armenia at the stations that reported O_3 for 2017 (Model, Observations).

Component	No.	Bias	Correlation	RMSE
SO2 in Air	1	206%	0.20	0.79
Sulfate in Air	1	45%	0.59	0.36
NO2 in Air	1	127%	-0.33	0.44
NO3- in Air	1	29%	0.55	0.27
NH3+NH4+ in Air	1	-34%	-0.40	2.35
PM10	0			
PM2.5	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 Armenia for stations with a sufficiently consistent set of data available in weekly or higher time-resolution. Standard deviations provide variability ranges between stations.

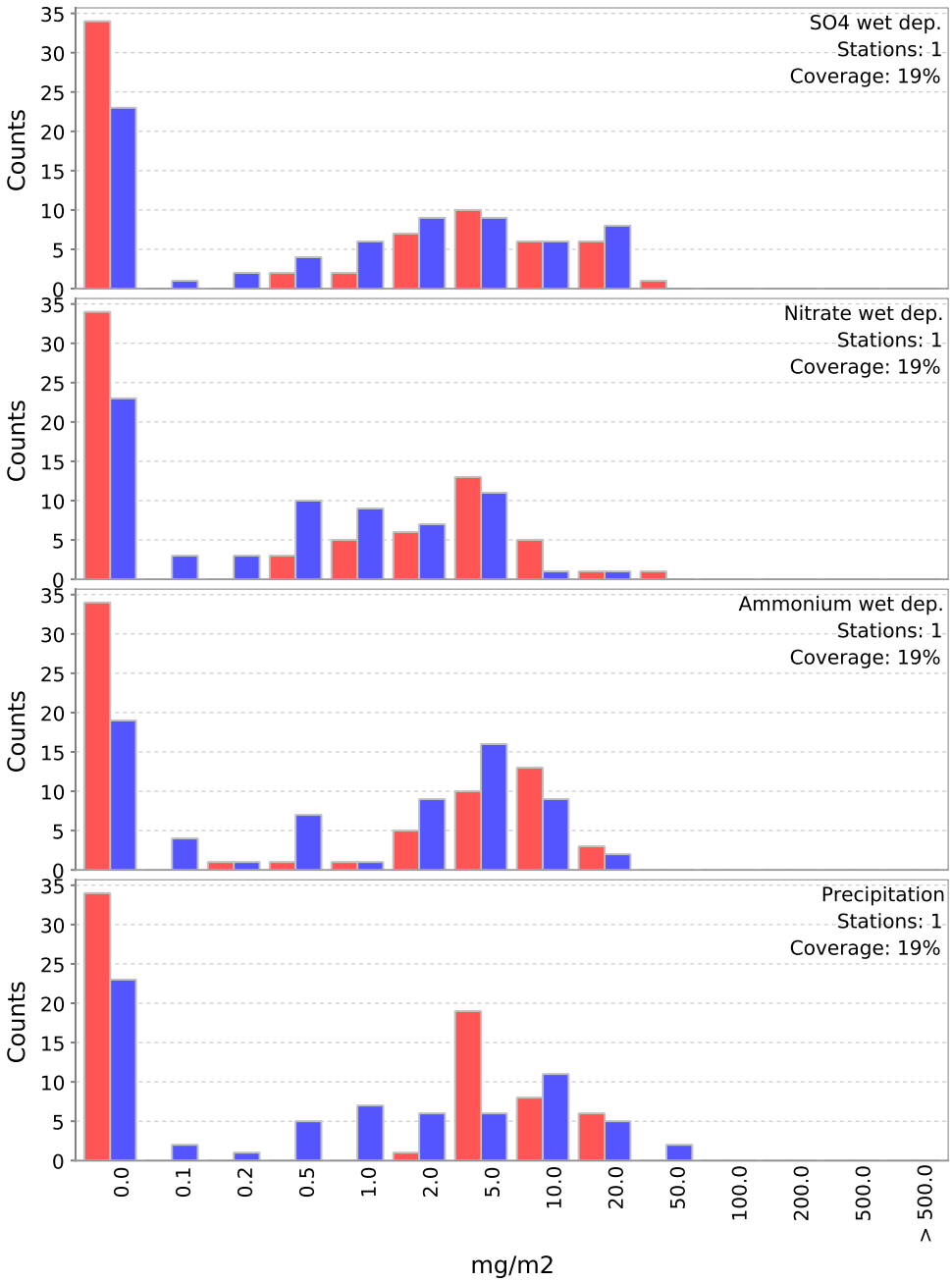

Figure 26: Frequency analysis of depositions in precipitation in Armenia (Model, Observations).

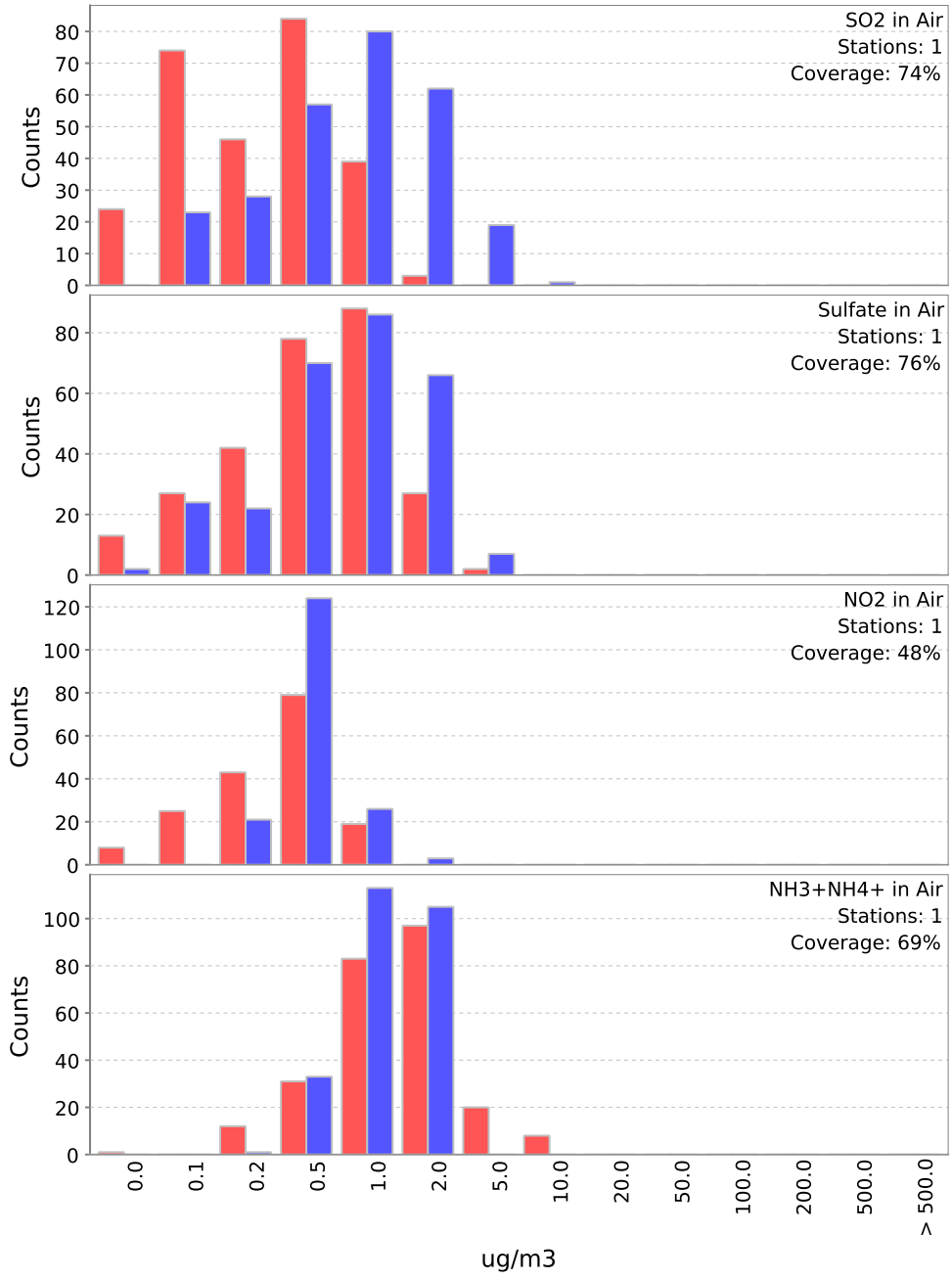

Figure 27: Frequency analysis of air concentrations in Armenia (Model, Observations).

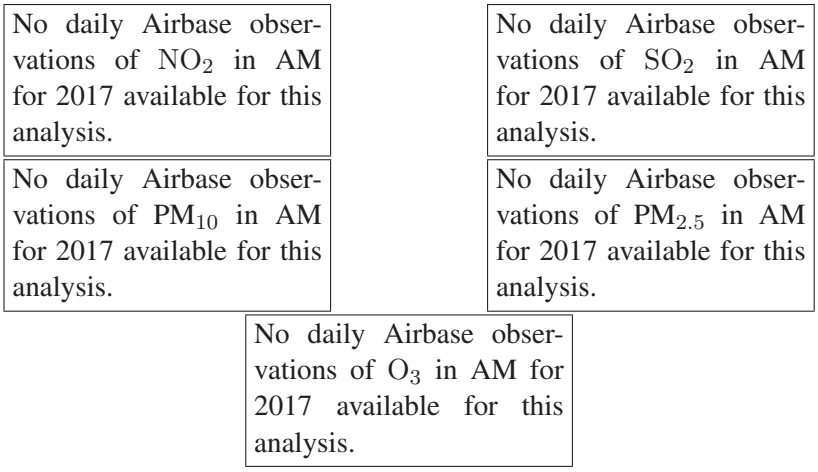

Figure 28: Daily model results versus AirBase observations in Armenia for NO_2, SO_2, O_3, PM_{10} and $PM_{2.5}$ if available.

8 Risk of damage from ozone and particulate matter in Armenia

8.1 Ecosystem-specific AOT40 values

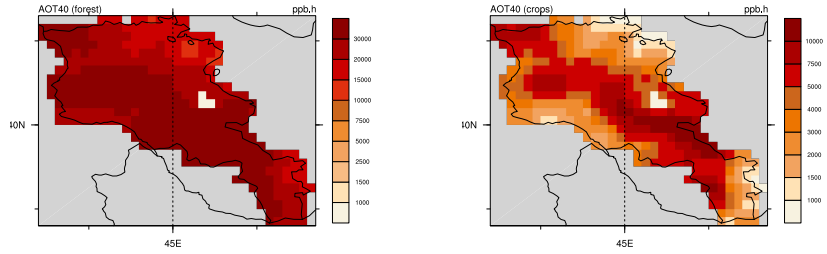

Figure 29: $AOT40_f^{uc}$ and $AOT40_c^{uc}$ in Armenia in 2017. *($AOT40_f^{uc}$: growing season April-September, critical level for forest damage = 5000 ppb·h; $AOT40_c^{uc}$: growing season May-July, critical level for agricultural crops = 3000 ppb·h.)*

8.2 Ecosystem-specific ozone fluxes

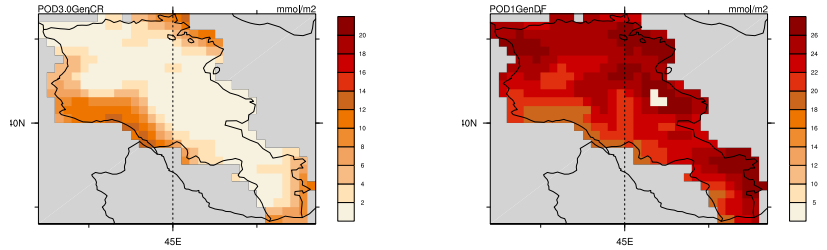

Figure 30: $POD_{3.0,\text{gen-CR}}$ and $POD_{1.0,\text{gen-DF}}$ in Armenia in 2017.

8.3 Health impacts from ozone and particulate matter

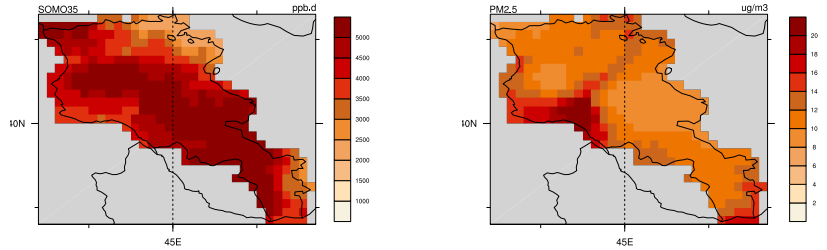

Figure 31: Regional scale SOMO35 and $PM_{2.5}$ in Armenia in 2017.