MSC-W Data Note 1/2020
Date: August 2020

METEOROLOGISK INSTITUTT
Norwegian Meteorological Institute

Transbondary air pollution by sulphur, nitrogen, ozone and particulate matter in 2018

The European Union

H. Klein, M. Gauss, S. Tsyro, Á. Nyíri, H. Fagerli and P. Wind

Data Note 2020

ISSN 1890-0003

Contents

1 User guide

This report is one in a series of country-specific notes, complementary to the EMEP Status Report 1/2020. It presents an overview of transboundary pollution of sulphur, nitrogen, ozone and particulate matter for the European Union in 2018.

All model runs for 2018 have been performed with the EMEP MSC-W model version rv4.35, 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 2018.

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 2018 have been derived from the 2020 official data submissions to UNECE CLRTAP as of May 2020. The gridded distributions of the 2018 emissions have been provided by the EMEP Centre on Emission Inventories and Projections (CEIP). The emissions for the period of 2000–2017 are the same as the ones used last year (i.e. derived from data submissions to UNECE CLRTAP as of May 2019).

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

A special feature this year is an additional emission scenario referred to as *EMEPwRef2C* in this report. EMEPwRef2C contains EMEP emissions as prepared by CEIP (see link above), except that particulate matter emissions from the GNFR sector C (other stationary combustion) have been replaced by estimates from TNO (Netherlands Organisation for Applied Scientific Research). Their data accounts for the emission of condensable organics from residential combustion in all countries. Thus, model runs were done this year for 2018 using either the EMEP emissions as prepared by CEIP or the EMEPwRef2C emissions. In this report, results are shown for both emission datasets where it makes a difference, i.e. for particulate matter. For more details about EMEPwRef2C and about emissions of condensables please consult the respective chapters on emissions and on condensables in the EMEP Status Report 1/2020.

Time series *(Chapter 3)* : Time series in depositions and air concentrations are presented for the period of 2000–2018. The calculations for 2000–2017 were done last year with the EMEP MSC-W model version rv4.33, while 2018 was calculated this year with version rv4.35. For the years 2000–2018, 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 the EMEP Status Report 1/2020), which may lead to differences between results reported here and in earlier reports.

The trend figures in this report show the model results from 2000 through 2018 using the EMEP emission data as prepared by CEIP, but, in the case of particulate matter, one additional data point is appended, depicting the model results for 2018 based on the EMEPwRef2C emission data (see paragraph about *Emissions*).

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 the European Union. 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 the European Union 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 the European Union (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 the European Union. In some countries this can occur because of strong non-linearities in chemistry.

In addition, for $PM_{2.5}$ and PM_{10} we show the total concentrations along with the percentage contribution from natural sources (sea salt and natural dust) to the total concentrations. Transboundary concentrations for particulate matter without emissions of condensable organics have been calculated with the new *Local Fractions* method (see the chapter about Model Updates in the EMEP Status Report 1/2020).

In the figures for ozone, we do not show contributions from areas that are outside the EMEP domain. Until last year these had been included as BIC (Boundary and Initial Condidions) and were calculated by reducing NOx and NMVOC at the model boundary. However, the most important contributor to ozone from areas outside the EMEP domain is ozone itself, transported hemispherically accross the model boundary. Including the BIC contribution that is due to NOx and NMVOC only would be misleading. In principle, the BIC contribution due to hemispherically transported ozone could be included, but we choose here to focus on the contribution from countries within the EMEP domain.

Comparison with observations from the EMEP network *(Chapter 7)* : The map of monitoring stations shows stations of the European Union in the EMEP measurement network with measurements in 2018 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)* : Particularly relevant for health impact, model results for SOMO35 (an ozone indicator) and particulate matter concentrations are shown. However, the results correspond to regional background levels and are not representative of local point measurements where these values can be much higher (e.g. in cities).

1.2 Comparison with observations from EEA

A major effort this year has been put into the development of a web interface that presents a detailed evaluation against measurements from the European Environment Agency's (EEA) Air Quality e-Reporting Database:
https://aerocom-evaluation.met.no/main.php?project=emep.

On that page the user can select the classification of measurement data (rural, urban, non-traffic, or all stations) and view a large number of statistical parameters (bias, correlation, root mean square error, etc.).

The web interface displays the co-located observational and model datasets and contains:

- daily and monthly time series for each station, or averaged per country (or the whole area covered by the model and the measurement network);
- seasonal- and annual-mean diurnal variation for each of the seven days of the week;
- statistics and scatter plots calculated for each station and country;
- an overall evaluation of the results using statistics calculated for each country or the whole area covered by the model and the measurement network.

In all cases, the statistics are calculated using data in monthly resolution by default. Daily statistics are available by adding &stats=daily to the site URL given above.

Evaluation is made for the following chemical species and indicators: NO_2, O_3, $PM_{2.5}$, PM_{10}, and O_3max (maximum daily ozone). Different types of visualization (bar charts, line charts, tables, etc.) are available for viewing and for download. The measurement data have been retrieved from the validated *E1a* stream of EEA and further harmonized and quality-controlled by the GHOST tool (Globally Harmonised Observational Surface Treatment) developed at the Barcelona Supercomputing Center (BSC).

For supplemental evaluation of Elemental Carbon (EC), the modelled absorption coefficient (mainly due to EC) is compared to surface *in-situ* observations of the aerosol light absorption coefficient, accessed through the Global Atmospheric Watch - WDCA database EBAS (http://ebas.nilu.no/). More details about this can be found in the chapter on Elemental Carbon in the EMEP Status Report 1/2020.

1.3 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 2018.

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.

1.4 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:

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

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 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$_f^{\mathbf{uc}}$ - 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.

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

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

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$_{\text{3.0,gen-CR}}$ (or $AF_{st}3_{gen}$) is used for crops.

EMEPwRef2C - an alternative emission scenario used this year for 2018. EMEPwRef2C contains EMEP emissions as prepared by CEIP, except that particulate matter emissions from the GNFR sector C (other stationary combustion) have been replaced by estimates from TNO (Netherlands Organisation for Applied Scientific Research). Their data accounts for the emission of condensable organics from residential combustion in all countries. For more details about EMEPwRef2C and about emissions of condensables please consult the respective chapters on emissions and on condensables in the EMEP Status Report 1/2020.

2 Emissions

2.1 Emissions used in the EMEP MSC-W model calculations

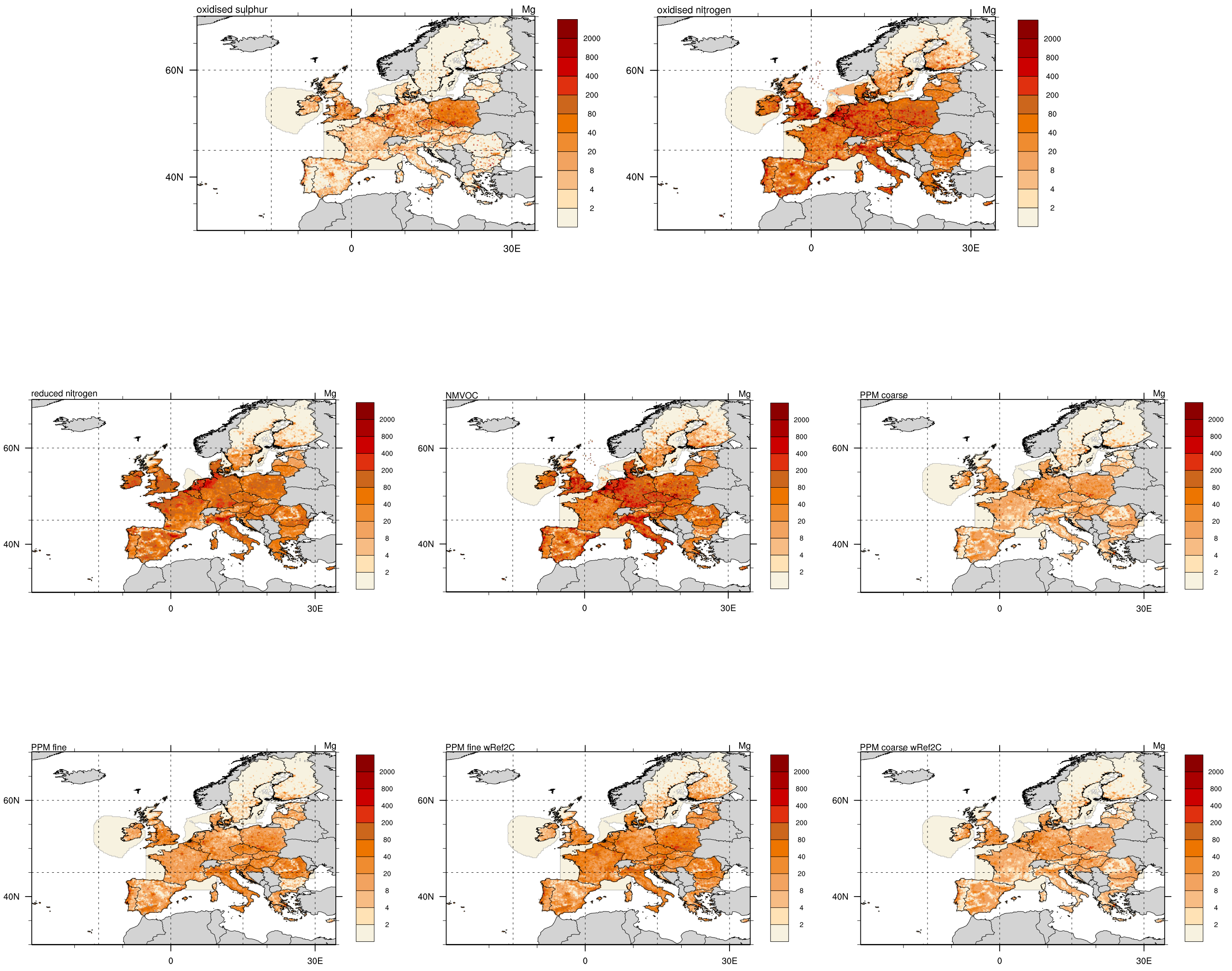

Figure 1: Spatial distribution of emissions from the European Union in 2018. For PPM_{fine} and PPM_{coarse} maps are shown for both EMEP data and EMEPwRef2C data (for more information see paragraph on *Emissions* in Section 1.1).

3 Time series

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

	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2018wRef2C
SO_x	10025	7656	4179	4087	3675	3199	2933	2763	2316	2274	2043	
NO_x	13252	12212	9558	9173	8850	8460	8152	7985	7702	7537	7287	
NH_3	4335	4117	3866	3862	3835	3834	3864	3916	3938	3954	3859	
NMVOC	11556	9636	8070	7628	7461	7210	6987	6956	6932	7014	7014	
CO	37211	30265	25299	22871	22178	21782	20000	19976	19767	19751	19433	
$PM_{2.5}$	1825	1663	1550	1429	1441	1412	1307	1312	1299	1303	1255	1789
PM_{10}	2755	2579	2348	2209	2180	2147	2031	2034	2012	2019	1989	2491

Table 2: Emissions from the European Union. Unit: Gg. (SO_x given as SO_2, and NO_x as NO_2). The *2018wRef2C* column shows results for 2018 based on EMEPwRef2C emissions.

	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018
SO_x dep.	3395	2478	1723	1508	1472	1371	1412	1189	1103	1051	1026
NO_x dep.	2671	2426	2068	1903	1883	1838	1840	1688	1705	1646	1669
redN dep.	2436	2278	2258	2145	2187	2196	2287	2189	2276	2265	2265

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

	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2018wRef2C
mean ozone	34	34	33	33	33	34	34	34	33	34	34	
max ozone	42	42	41	41	41	42	41	42	41	41	42	
$AOT40_f^{uc}$	21502	20372	17698	17741	17464	17148	15983	16610	15073	15377	17667	
SOMO35	2575	2548	2215	2275	2200	2323	2147	2251	2048	2182	2365	
$POD_{1.0,gen\text{-}DF}$	28	27	27	27	24	26	27	24	25	24	26	
$PM_{2.5}$ anthrop.	8	8	6	7	6	6	6	6	6	6	6	6
PM_{10} anthrop.	11	11	9	9	9	8	8	9	8	8	8	9

Table 4: Estimated yearly mean values of air quality indicators averaged over the European Union. 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} ($\mu g/m^3$). The *2018wRef2C* column shows results for 2018 based on EMEPwRef2C emissions.

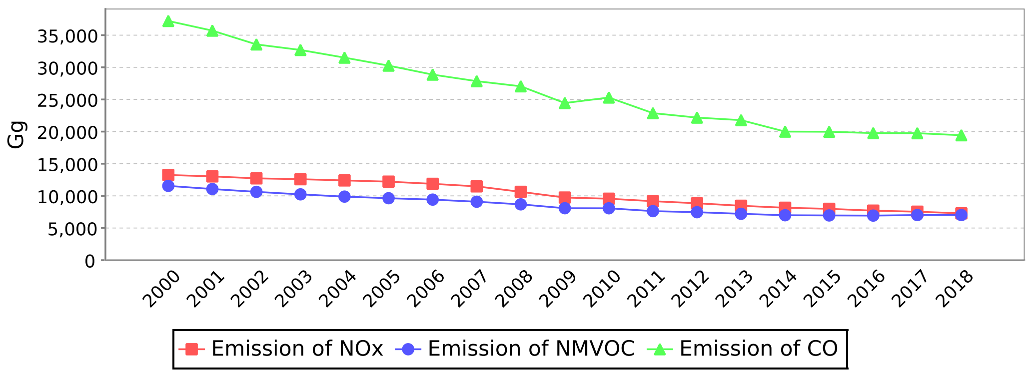

Figure 2: Trends in emissions of photo-oxidant pollution precursors. Unit: Gg (note that NO_x is here given as NO_2).

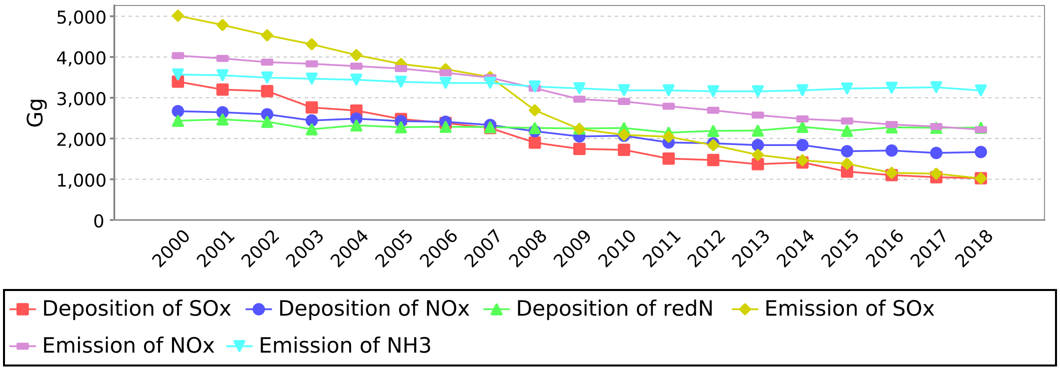

Figure 3: Trends in emissions and depositions of oxidised sulphur, oxidised nitrogen and reduced nitrogen. Unit: Gg(S) or Gg(N).

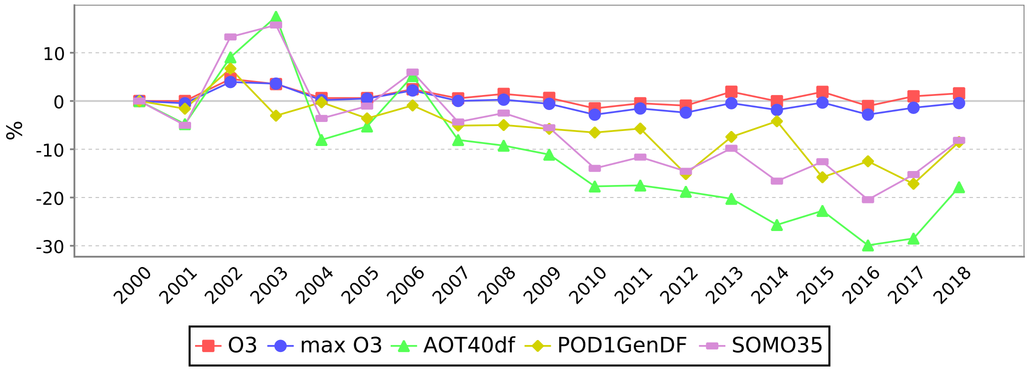

Figure 4: Changes in ozone related pollution relative to 2000. Unit: %. The large changes from year to year in some countries are mainly related to meteorological variability.

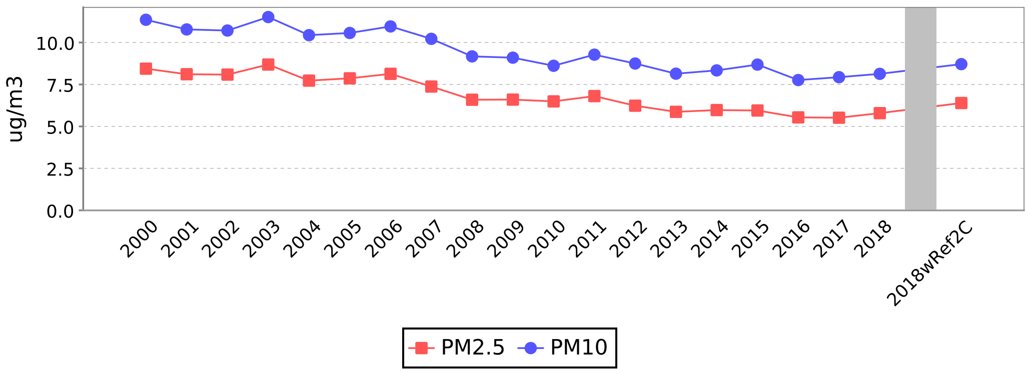

Figure 5: Trends in mean concentrations of particulate matter. Unit: $\mu g/m^3$. The *2018wRef2C* points show results for 2018 based on EMEPwRef2C emissions.

4 Transboundary fluxes

4.1 Deposition of oxidised sulphur

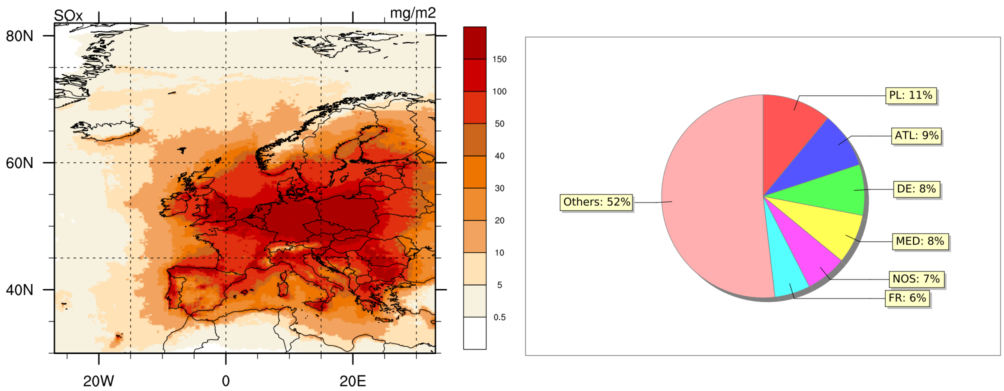

Figure 6: Contribution of emissions from the European Union to deposition of oxidised sulphur in the EMEP domain. Unit: mg(S)/m^2. The pie chart shows the six main receptor areas where oxidised sulphur from the European Union is deposited. Unit: %.

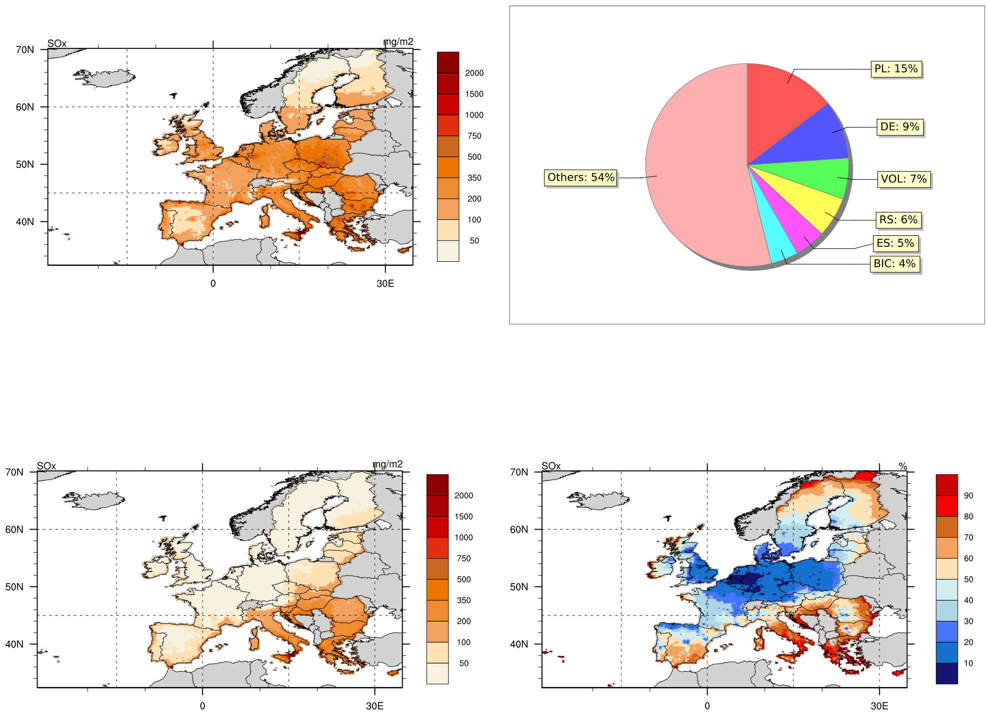

Figure 7: Top left: Deposition of oxidised sulphur in the European Union. Unit: mg(S)/m^2. Top right: The six main contributors to oxidised sulphur deposition in the European Union. Unit: (%). Bottom left: Oxidised sulphur deposition from transboundary sources. Unit: mg(S)/m^2. Bottom right: Fraction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

4.2 Deposition of oxidised nitrogen

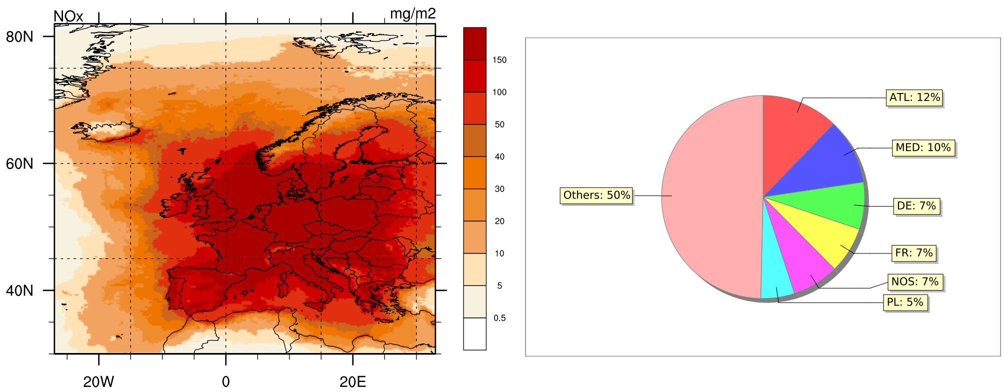

Figure 8: Contribution of emissions from the European Union to deposition of oxidised nitrogen in the EMEP domain. Unit: mg(N)/m^2. The pie chart shows the six main receptor areas where oxidised nitrogen from the European Union is deposited. Unit: %.

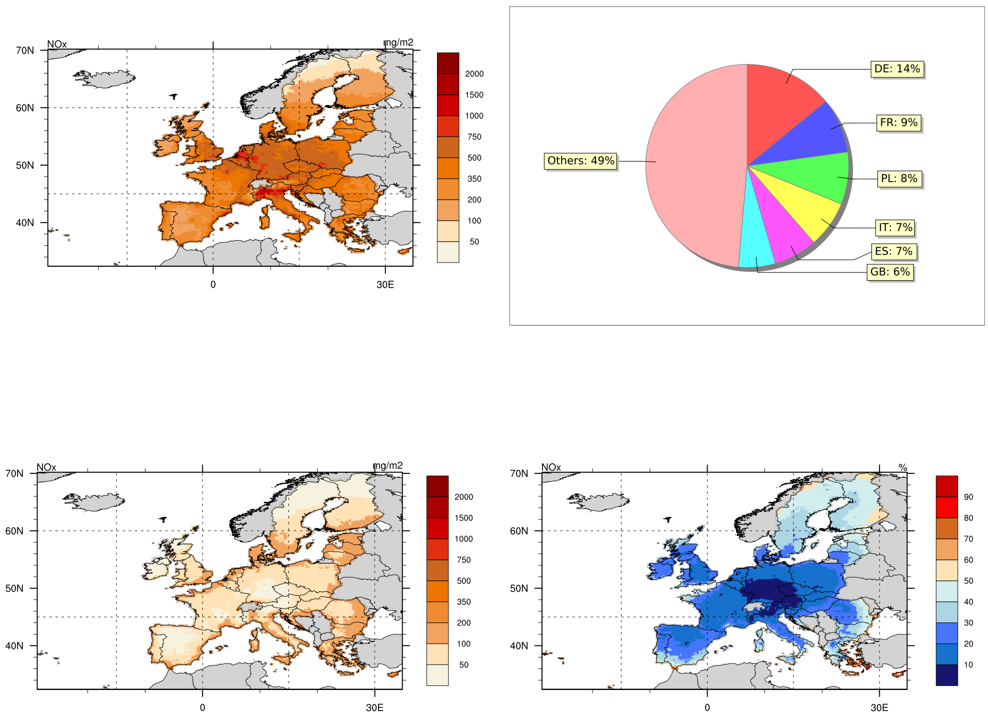

Figure 9: Top left: Deposition of oxidised nitrogen in the European Union. Unit: mg(N)/m^2. Top right: The six main contributors to oxidised nitrogen deposition in the European Union. Unit: %. Bottom left: Oxidised nitrogen deposition from transboundary sources. Unit: mg(N)/m^2. Bottom right: Fraction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

4.3 Deposition of reduced nitrogen

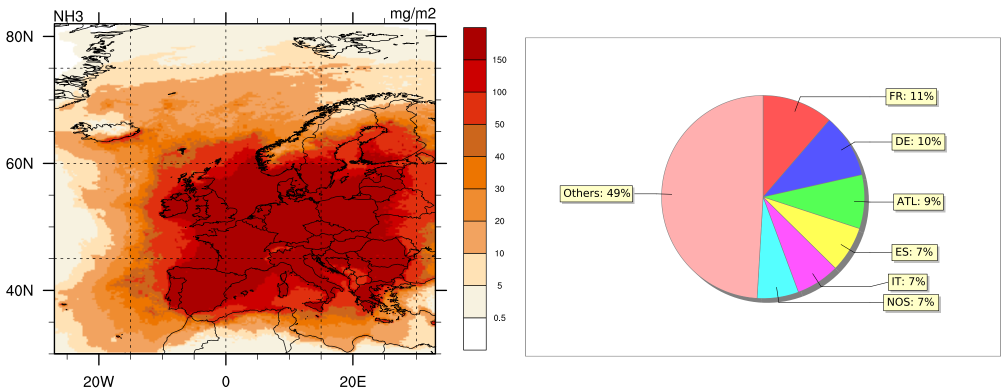

Figure 10: Contribution of emissions from the European Union to deposition of reduced nitrogen in the EMEP domain. Unit: mg(N)/m^2. The pie chart shows the six main receptor areas where reduced nitrogen from the European Union is deposited. Unit: %.

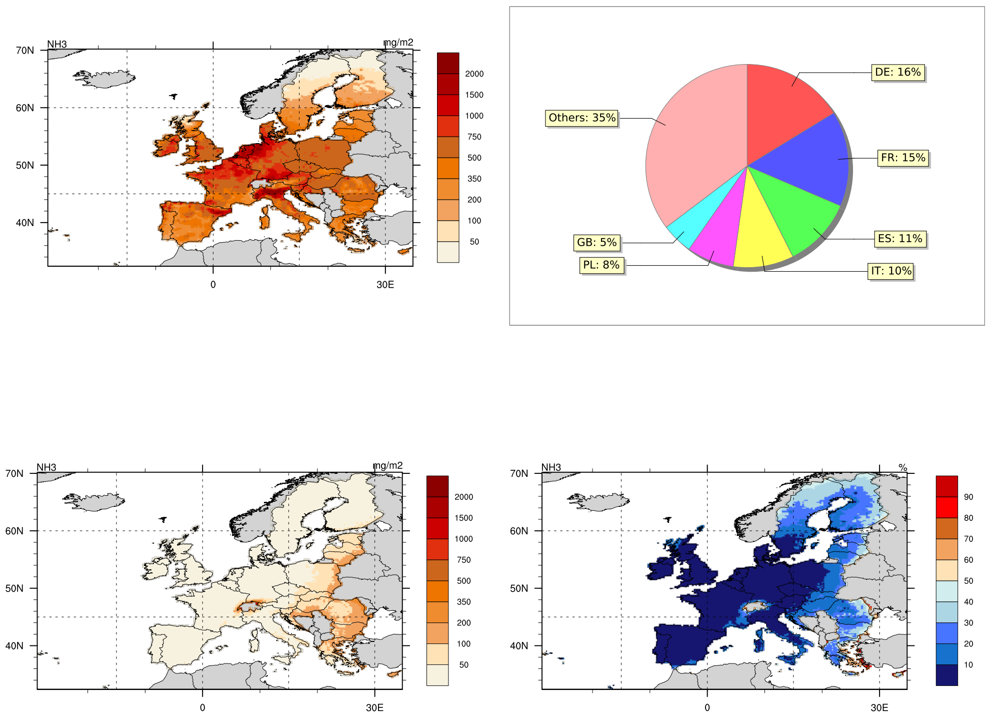

Figure 11: Top left: Deposition of reduced nitrogen in the European Union. Unit: mg(N)/m^2. Top right: The six main contributors to deposition of reduced nitrogen in the European Union. Unit: %. Bottom left: Deposition of reduced nitrogen from transboundary sources. Unit: mg(N)/m^2. Bottom right: Fraction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

5 Transboundary concentrations of ozone

5.1 $AOT40_f^{uc}$

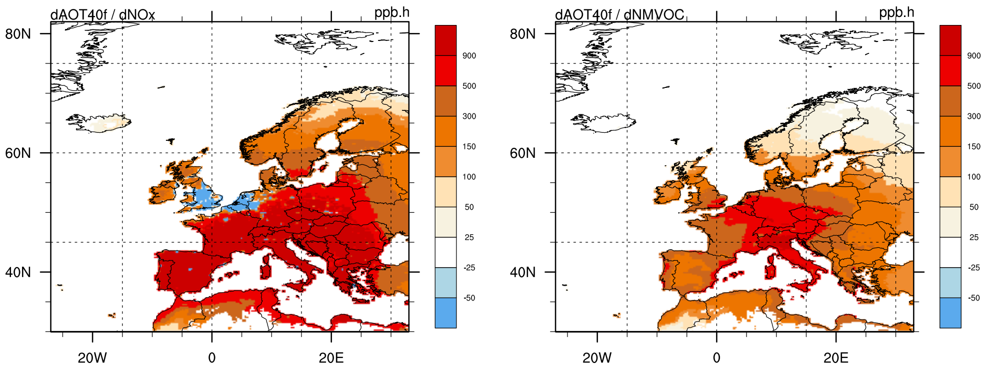

Figure 12: Reduction in $AOT40_f^{uc}$ that would result from a 15% reduction in emissions of NO_x (left) and NMVOC (right) from the European Union. Unit: ppb·h.

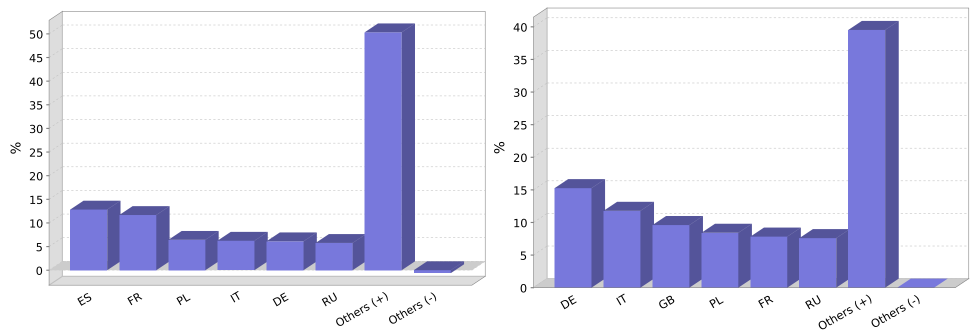

Figure 13: The six most important emitter countries or regions, with respect to their effects on $AOT40_f^{uc}$ in the European Union that would result from reductions in NO_x emissions (left) or NMVOC emissions (right).

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

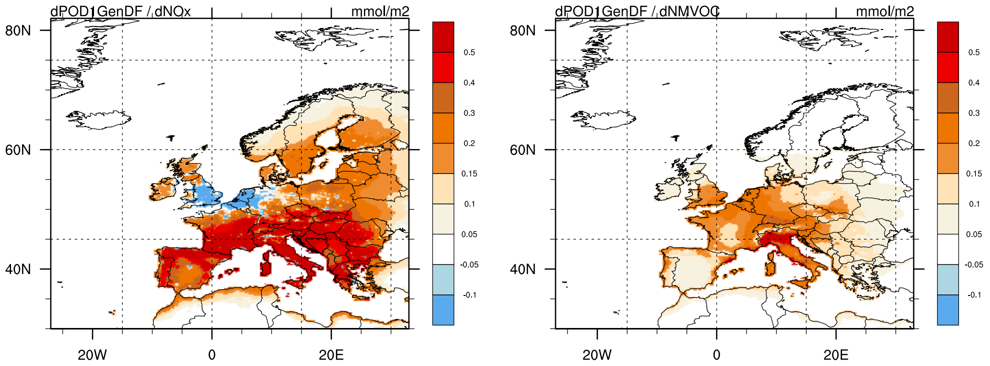

Figure 14: Reduction in $POD_{1.0,gen\text{-}DF}$ that would result from a 15% reduction in emissions of NO_x (left) and NMVOC (right) from the European Union. Unit: mmol/m^2.

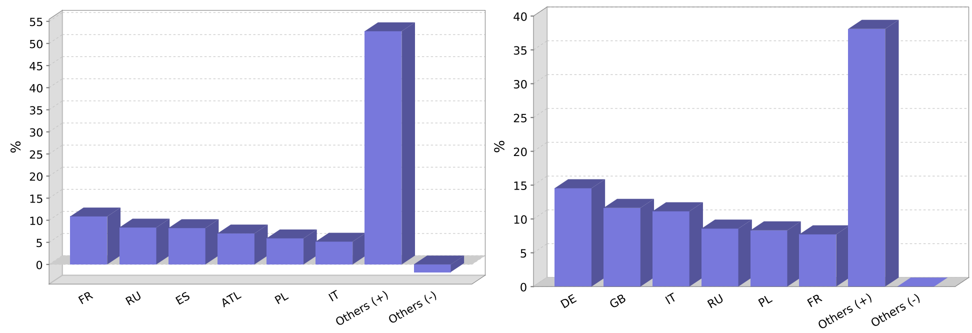

Figure 15: The six most important emitter countries or regions, with respect to their effects on $POD_{1.0,gen\text{-}DF}$ in the European Union that would result from reductions in NO_x emissions (left) or NMVOC emissions (right).

5.3 SOMO35 – Risk of ozone damages to human health

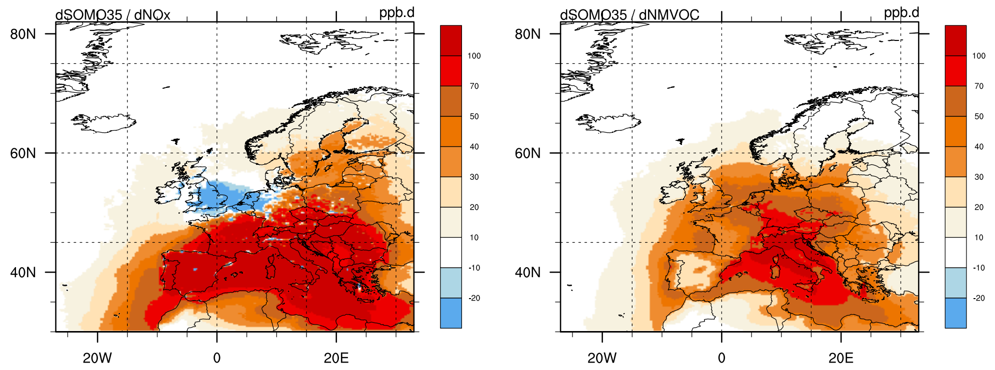

Figure 16: Reduction in SOMO35 that would result from a 15% reduction in emissions of NO_x (left) and NMVOC (right) from the European Union. Unit: ppb·day.

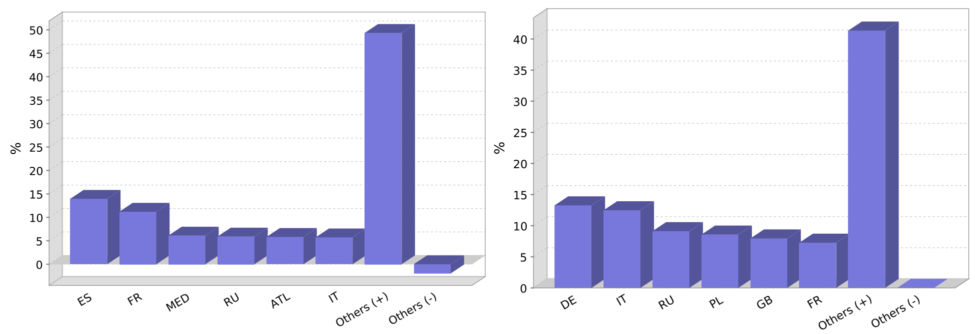

Figure 17: The six most important emitter countries or regions, with respect to their effects on SOMO35 in the European Union that would result from reductions in NO_x emissions (left) or NMVOC emissions (right).

6 Transboundary concentrations of particulate matter

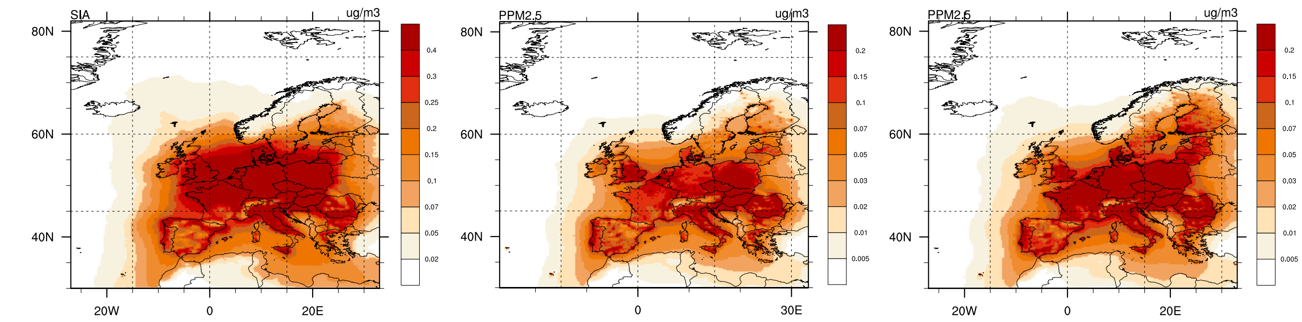

Figure 18: Reduction in concentrations of SIA (left) and $PPM_{2.5}$ (middle: EMEP emissions; right: EMEPwRef2C emissions) that would result from a 15% reduction in emissions from the European Union. Unit: μg/m^3. Note the difference in colorbars. For information about EMEPwRef2C see the paragraph about *Emissions* in Section 1.1.

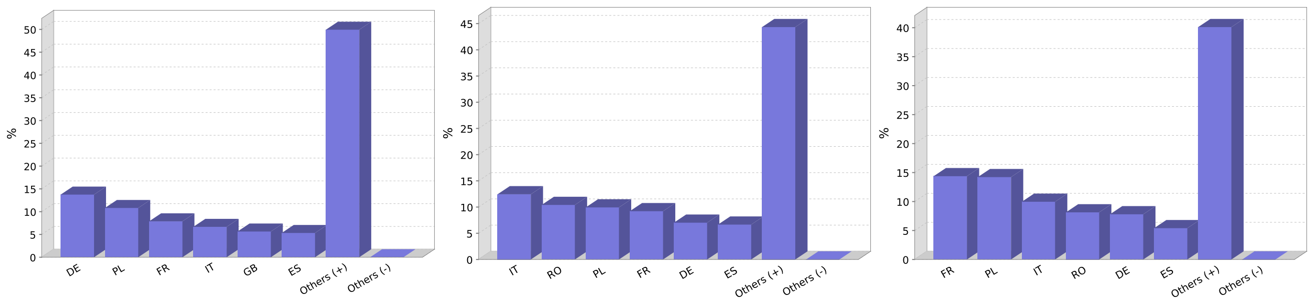

Figure 19: The six most important emitter countries or regions, with respect to their effects on SIA (left) and $PPM_{2.5}$ (middle: EMEP emissions; right: EMEPwRef2C emissions) in the European Union that would result from reductions in emissions. For information about EMEPwRef2C see the paragraph about *Emissions* in Section 1.1.

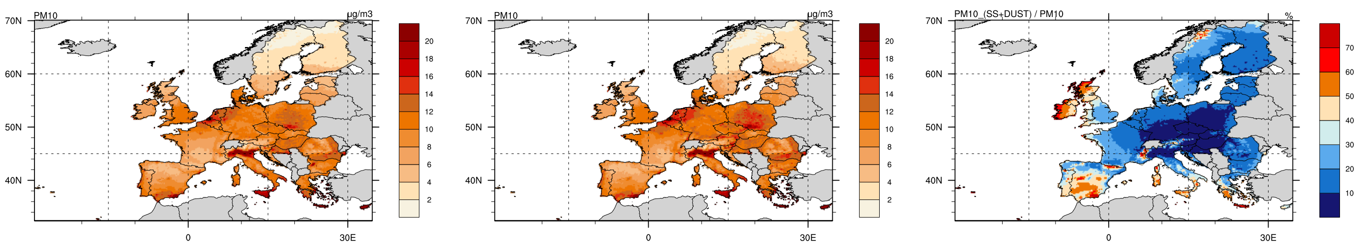

Figure 20: Left: PM_{10} concentration (using EMEP emissions), middle: PM_{10} concentration (using EMEPwRef2C emissions), and right: fraction of natural contributions of PM_{10} (sea salt and natural dust) to total PM_{10} concentration (using EMEPwRef2C emissions) in the European Union. Units: μg/m^3 (left and middle), % (right). For information about EMEPwRef2C see the paragraph about *Emissions* in Section 1.1.

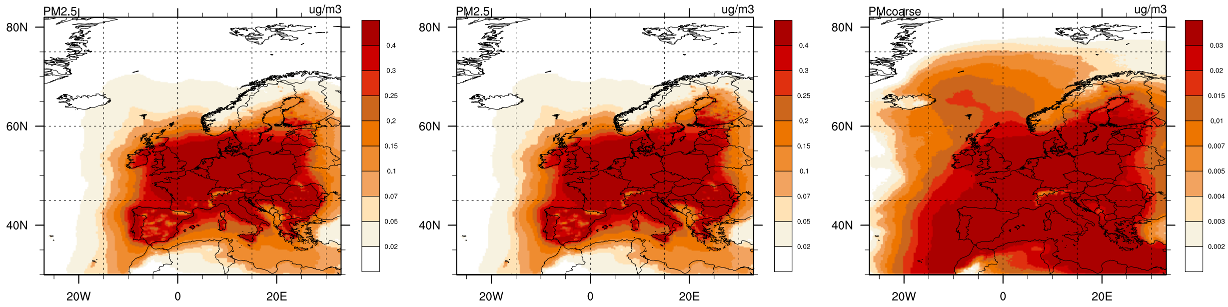

Figure 21: Reduction in $PM_{2.5}$ (left: using EMEP emissions, middle: using EMEPwRef2C emissions) and (right) PM_{coarse} concentrations that would result from a 15% reduction of emissions from the European Union. Unit: $\mu g/m^3$. Note the difference in colorbars. For information about EMEPwRef2C see the paragraph about *Emissions* in Section 1.1.

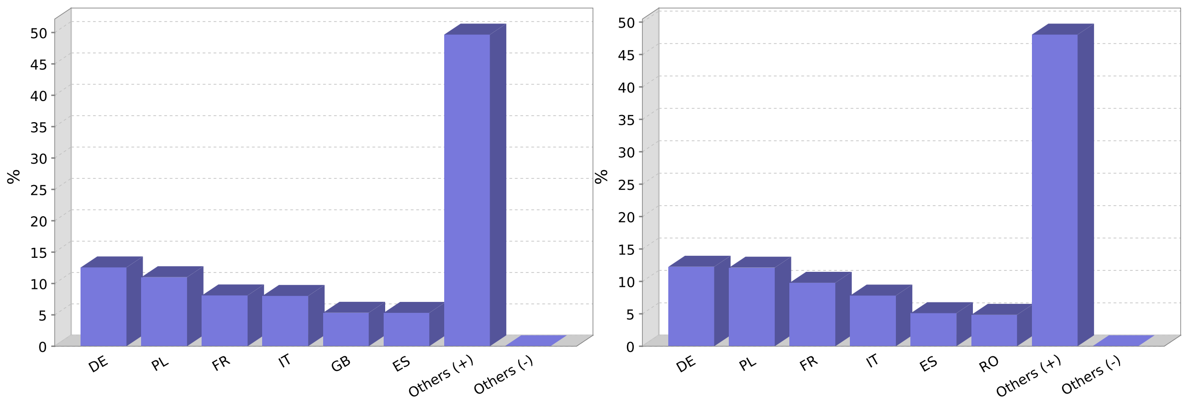

Figure 22: The six most important emitter countries or regions, with respect to their effects on $PM_{2.5}$ in the European Union that would result from reduction in emissions. Left: using EMEP emissions, right: using EMEPwRef2C emissions. For information about EMEPwRef2C see the paragraph about *Emissions* in Section 1.1.

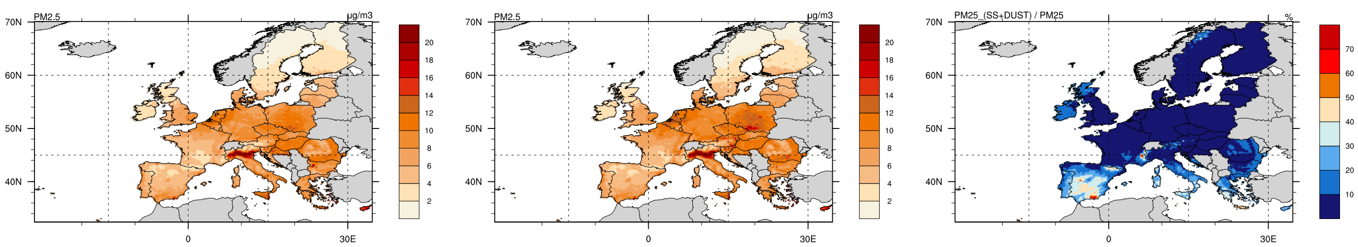

Figure 23: Left: $PM_{2.5}$ concentration (using EMEP emissions), middle: $PM_{2.5}$ concentration (using EMEPwRef2C emissions), and right: fraction of natural contributions of $PM_{2.5}$ (sea salt and natural dust) to total $PM_{2.5}$ concentration (using EMEPwRef2C emissions) in the European Union. Units: $\mu g/m^3$ (left and middle), % (right). For information about EMEPwRef2C see the paragraph about *Emissions* in Section 1.1.

7 Comparison with observations

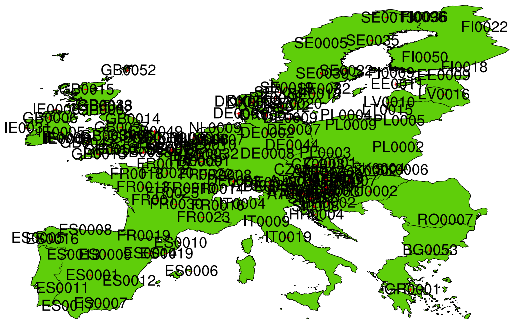

Figure 24: Location of stations in the European Union.

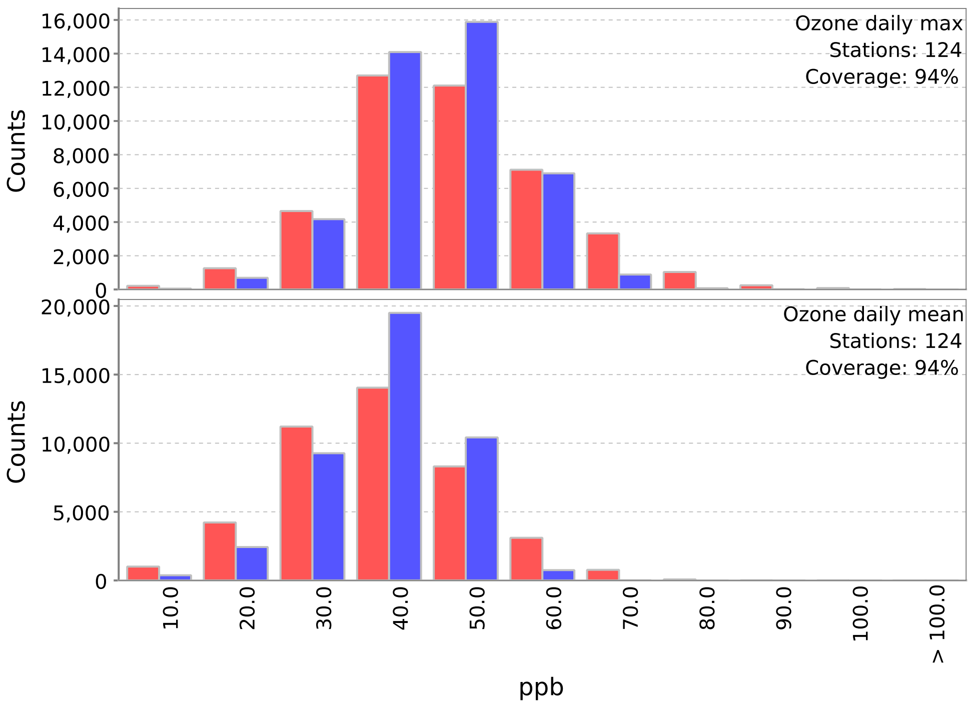

Figure 25: Frequency analysis of ozone in the European Union at the stations that reported O_3 for 2018 (Observations, Model).

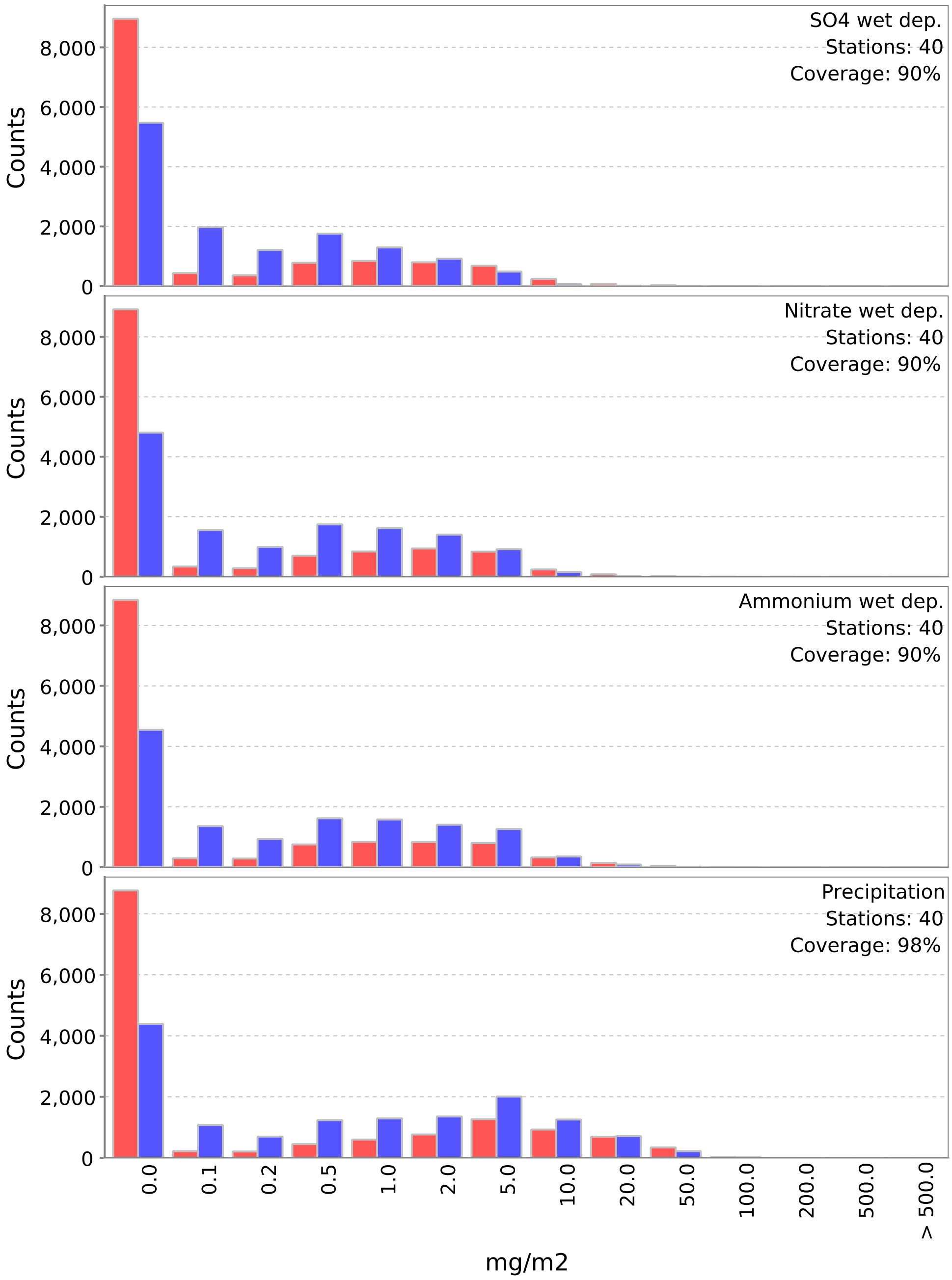

Figure 26: Frequency analysis of depositions in precipitation in the European Union (Observations, Model).

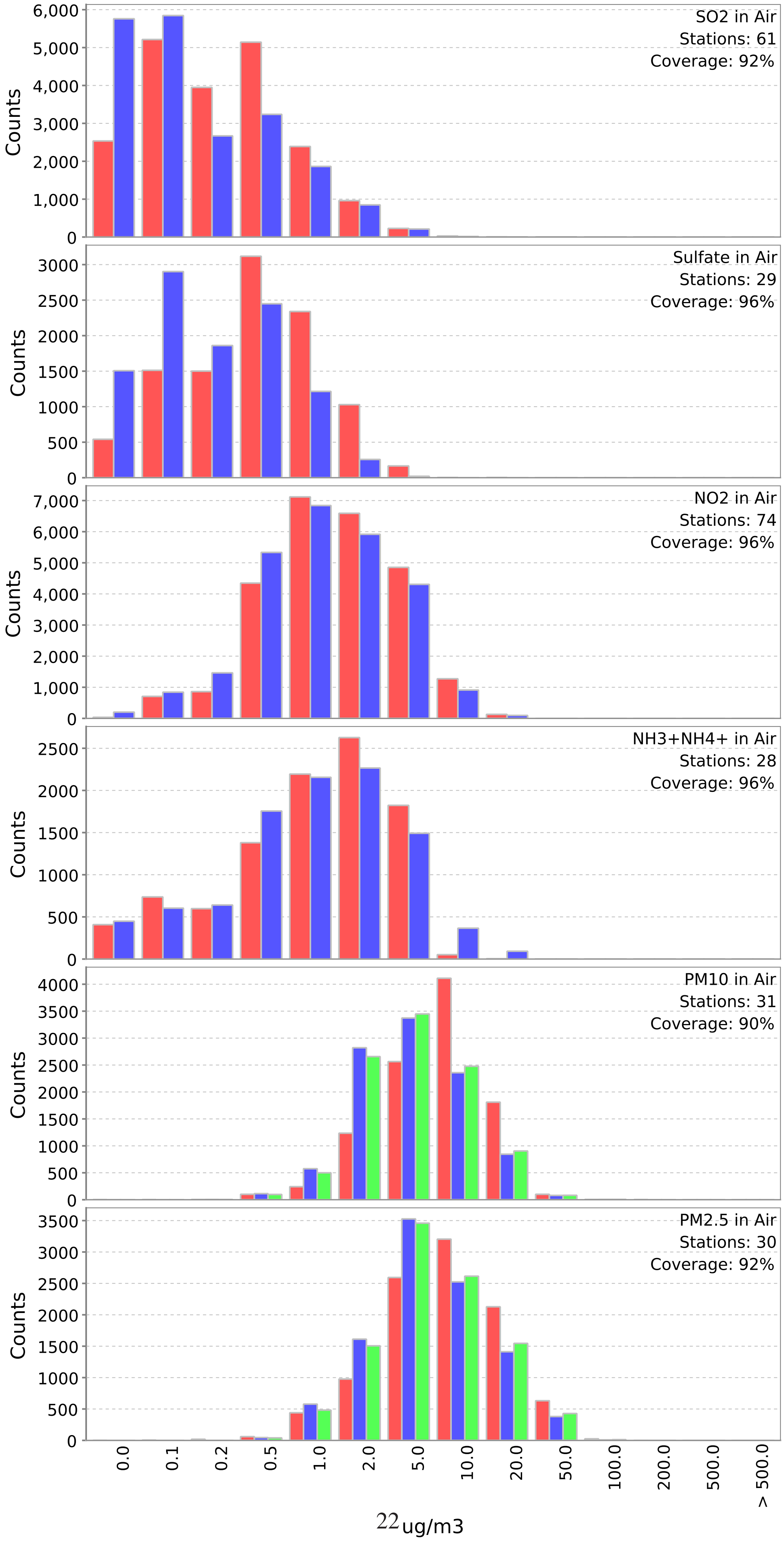

Figure 27: Frequency analysis of air concentrations in the European Union (Observations, Model, Model using EMEPwRef2C emissions (only for PM)). For information about

Component	No.	Bias	Correlation	RMSE
SO2 in Air	64	-24%±74%	0.42±0.28	0.46±0.53
Sulfate in Air	32	-46%±36%	0.64±0.27	0.38±0.19
NO2 in Air	74	33%±89%	0.80±0.26	1.40±0.92
NO3- in Air	33	-28%±24%	0.78±0.29	0.24±0.09
NH3+NH4+ in Air	30	15%±96%	0.53±0.25	1.46±1.23
PM10	30	-27%±18%	0.63±0.22	7.50±2.29
$PM10_{wRef2C}$	30	-25%±16%	0.65±0.22	7.23±2.12
PM2.5	30	-16%±32%	0.64±0.22	4.89±2.05
$PM2.5_{wRef2C}$	30	-11%±29%	0.69±0.22	4.59±1.79
Ozone daily max	124	-4%±8%	0.85±0.09	6.59±3.01
Ozone daily mean	124	2%±14%	0.79±0.10	6.60±2.46
SO4 wet dep.	48	-37%±30%	0.45±0.21	7.79±5.14
Nitrate wet dep.	48	-17%±37%	0.48±0.22	9.26±6.50
Ammonium wet dep.	48	-2%±44%	0.52±0.23	10.94±7.02
Precipitation	48	11%±28%	0.76±0.22	14.58±6.38

Table 5: Annual statistics of comparison of model results with observations in the European Union 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 the European Union

8.1 Ecosystem-specific AOT40 values

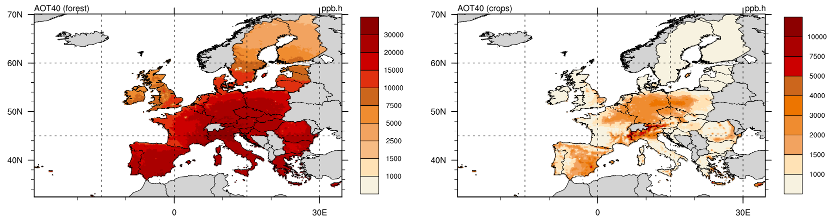

Figure 28: AOT40$_f^{uc}$ and AOT40$_c^{uc}$ in the European Union in 2018. *(AOT40$_f^{uc}$: growing season April-September, critical level for forest damage = 5000 ppb·h; AOT40$_c^{uc}$: growing season May-July, critical level for agricultural crops = 3000 ppb·h.)*

8.2 Ecosystem-specific ozone fluxes

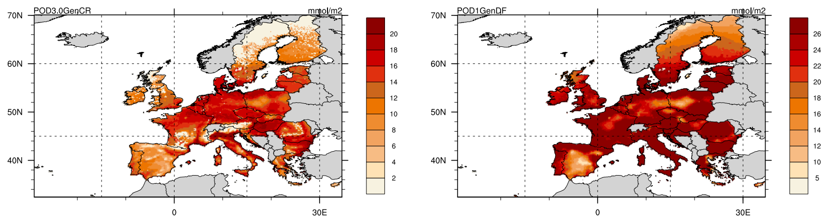

Figure 29: POD$_{3.0,\text{gen-CR}}$ and POD$_{1.0,\text{gen-DF}}$ in the European Union in 2018. Unit: mmol/m^2.

8.3 Health impacts from ozone and particulate matter

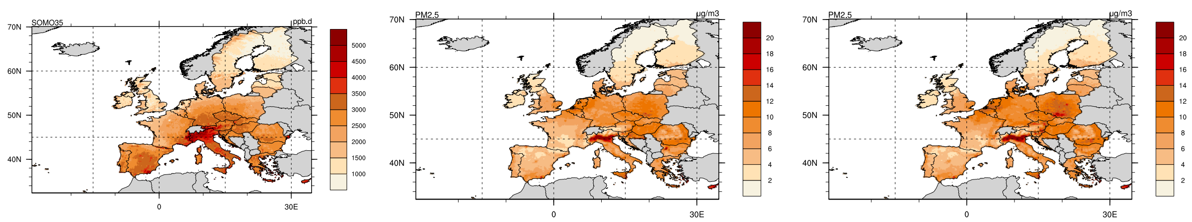

Figure 30: Regional scale SOMO35 (left), PM$_{2.5}$ using EMEP emissions (middle) and PM$_{2.5}$ using EMEPwRef2C emissions (right) in the European Union in 2018. SOMO35 is given in ppb·h, while PM$_{2.5}$ concentrations are given in μg/m^3. For information about EMEPwRef2C see the paragraph about *Emissions* in Section 1.1.