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Transboundary air pollution by main pollutants (S, N, O_3) and PM in 2017

France

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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 France 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 France. 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 France 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 France (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 France. 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 France 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	Code	Country/Region/Source
AL	Albania	IS	Iceland
AM	Armenia	IT	Italy
AST	Asian areas	KG	Kyrgyzstan
AT	Austria	KZ	Kazakhstan
ATL	N.-E. Atlantic Ocean	LI	Liechtenstein
AZ	Azerbaijan	LT	Lithuania
BA	Bosnia and Herzegovina	LU	Luxembourg
BAS	Baltic Sea	LV	Latvia
BE	Belgium	MC	Monaco
BG	Bulgaria	MD	Moldova
BIC	Boundary/Initial Conditions	ME	Montenegro
BLS	Black Sea	MED	Mediterranean Sea
BY	Belarus	MK	North Macedonia
CH	Switzerland	MT	Malta
CY	Cyprus	NL	Netherlands
CZ	Czechia	NO	Norway
DE	Germany	NOA	North Africa
DK	Denmark	NOS	North Sea
DMS	Dimethyl sulfate (marine)	PL	Poland
EE	Estonia	PT	Portugal
ES	Spain	RO	Romania
EU	European Union (EU28)	RS	Serbia
EXC	EMEP land areas	RU	Russian Federation
FI	Finland	SE	Sweden
FR	France	SI	Slovenia
GB	United Kingdom	SK	Slovakia
GE	Georgia	TJ	Tajikistan
GL	Greenland	TM	Turkmenistan
GR	Greece	TR	Turkey
HR	Croatia	UA	Ukraine
HU	Hungary	UZ	Uzbekistan
IE	Ireland	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:

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

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:

$\mathbf{AOT40}^{\mathbf{uc}}_{f}$ - 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.

$\mathbf{AOT40}^{\mathbf{uc}}_{c}$ - 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.:

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

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

2 Emissions

2.1 Emissions used in the EMEP MSC-W model calculations

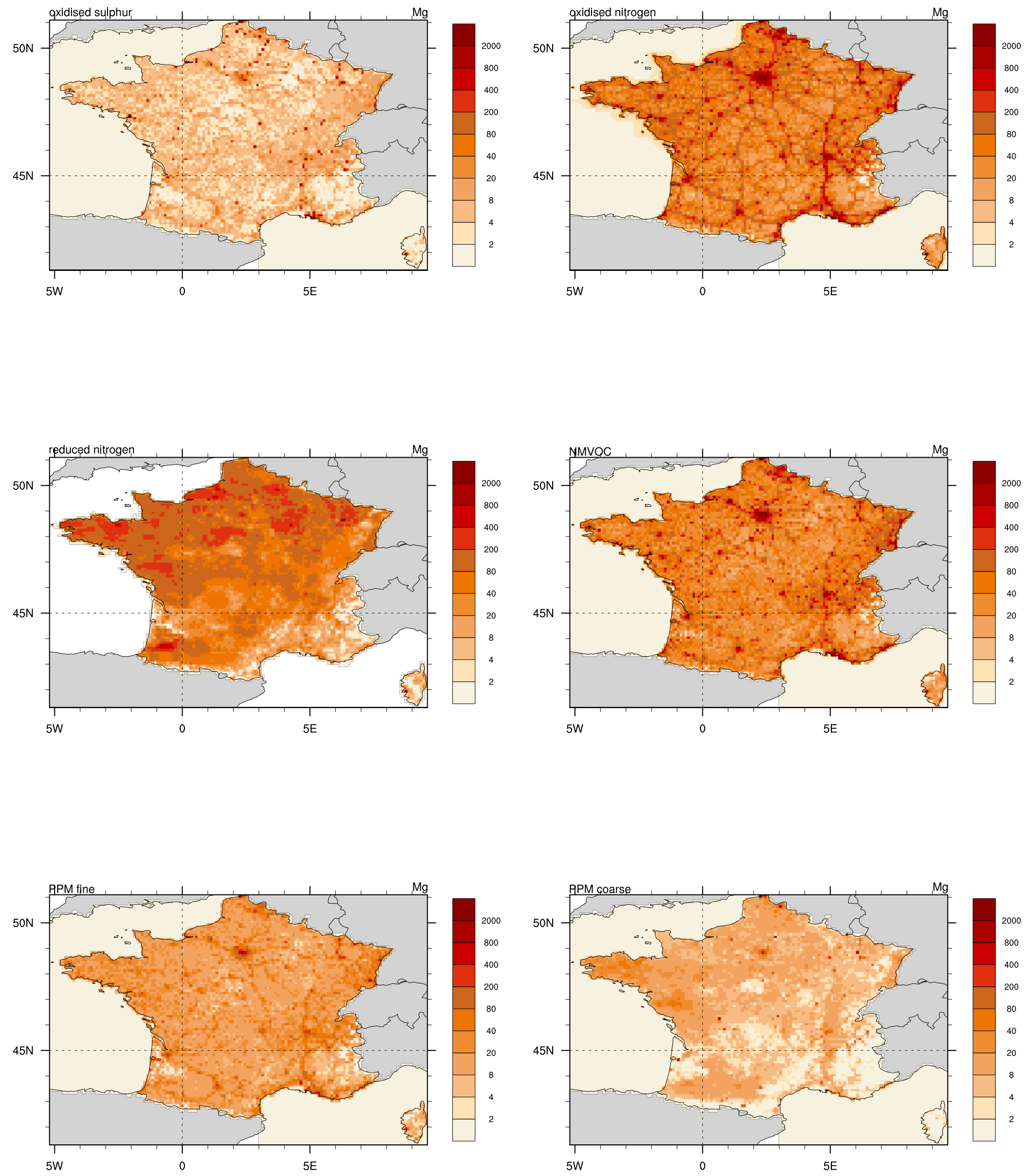


Figure 1: Spatial distribution of emissions from France in 2017.

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	626	460	431	414	353	297	278	254	236	213	173	163	144	144
NO_x	1618	1420	1336	1275	1178	1095	1077	1020	991	980	909	884	843	807
NH_3	646	605	594	601	609	599	604	594	596	594	600	608	609	606
NMVOC	1644	1175	1065	966	891	801	817	736	700	685	661	632	619	612
CO	6506	5240	4662	4496	4282	3816	4211	3535	3195	3259	2732	2688	2738	2695
$PM_{2.5}$	328	260	235	222	216	206	215	189	192	194	168	170	170	164
PM_{10}	438	361	334	319	311	296	306	281	284	284	256	258	258	254

Table 2: Emissions from France. 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.	335	241	229	227	165	139	137	118	126	123	106	89	85	81
NO_x dep.	364	338	326	333	285	268	282	239	243	261	230	208	214	190
redN dep.	378	341	345	369	359	346	350	325	344	361	349	329	352	339

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

	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
mean ozone	34	34	35	34	34	34	33	34	33	34	34	34	33	34
max ozone	42	43	43	42	42	42	41	42	41	42	42	42	41	41
$AOT40_f^{uc}$	21134	21975	23731	18325	18143	19017	18331	18286	15089	17127	16316	16358	14629	13759
SOMO35	2513	2655	2791	2354	2371	2413	2277	2314	1977	2296	2205	2184	2032	2046
$POD_{1.0,gen\text{-}DF}$	34	32	32	33	33	31	30	31	29	30	32	29	28	28
$PM_{2.5}$ anthrop.	8	8	8	8	6	7	6	7	6	6	5	6	5	5
PM_{10} anthrop.	12	11	11	12	9	10	9	9	9	9	8	9	8	8

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

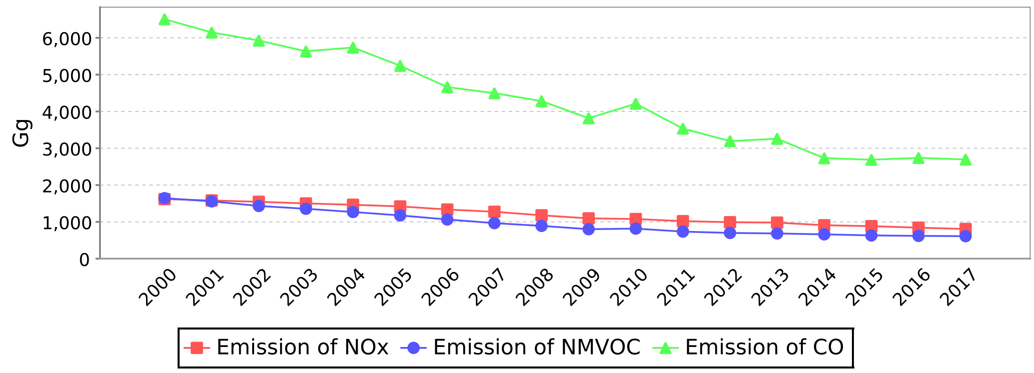


Figure 2: Trends in emissions of photo-oxidant pollution precursors. Unit: Gg (note that NO_x is here given as NO_2).

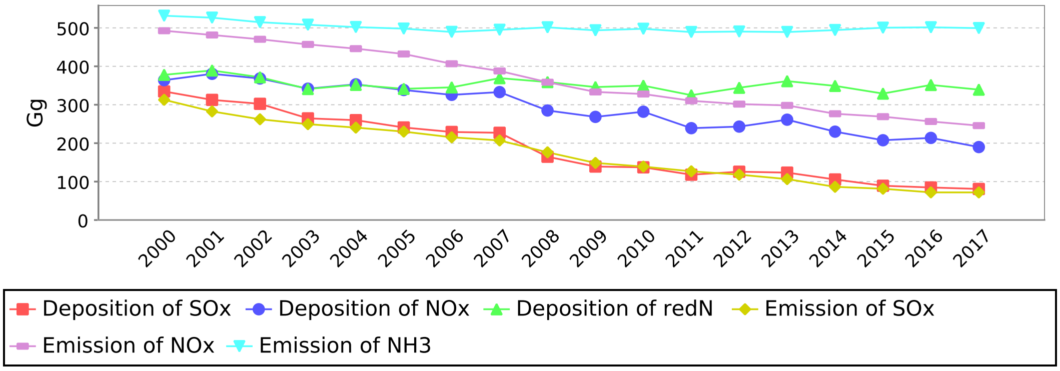


Figure 3: Trends in emissions and depositions of oxidised sulphur, oxidised nitrogen and reduced nitrogen. Unit: Gg(S) or Gg(N).

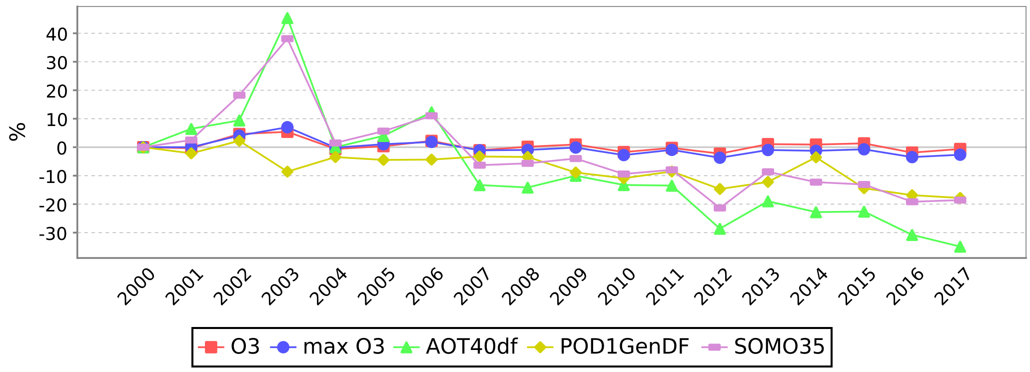


Figure 4: Changes in ozone related pollution relative to 2000. Unit: %. The large changes from year to year in some countries are mainly related to meteorological variability.

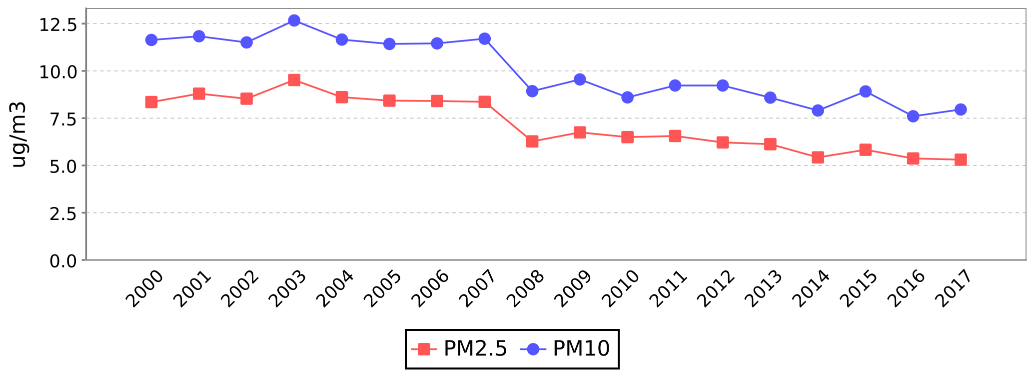


Figure 5: Trends in mean concentrations of particulate matter. Unit: $\mu g/m^3$.

4 Transboundary fluxes

4.1 Deposition of oxidised sulphur

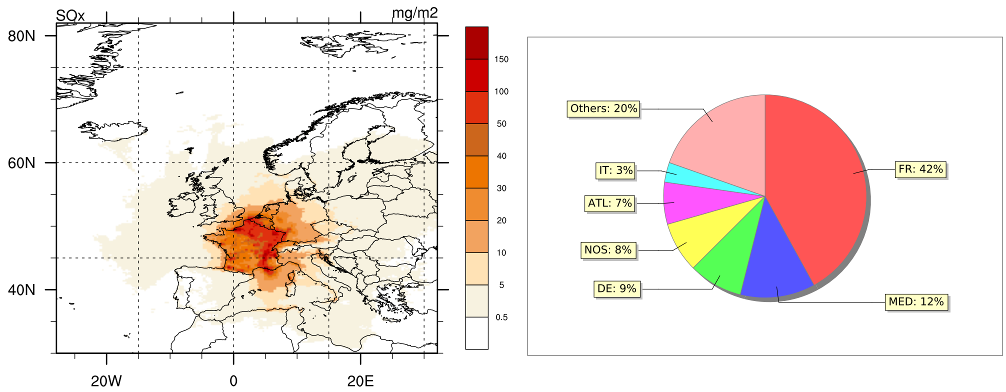


Figure 6: Contribution of emissions from France to deposition of oxidised sulphur in the EMEP domain. Unit: mg(S)/m^2. The pie chart shows the six main receptor areas where oxidised sulphur from France is deposited. Unit: %.

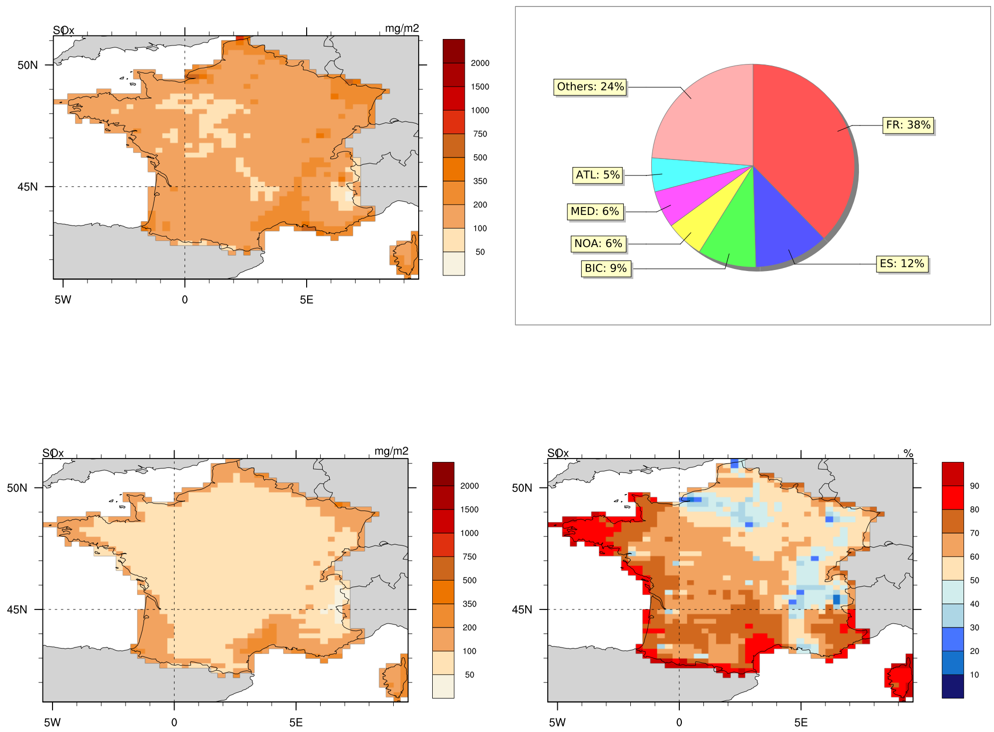


Figure 7: Top left: Deposition of oxidised sulphur in France. Unit: mg(S)/m^2. Top right: The six main contributors to oxidised sulphur deposition in France. Unit: (%). Bottom left: Oxidised sulphur deposition from transboundary sources. Unit: mg(S)/m^2. Bottom right: Fraction of transboundary contribution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

4.2 Deposition of oxidised nitrogen

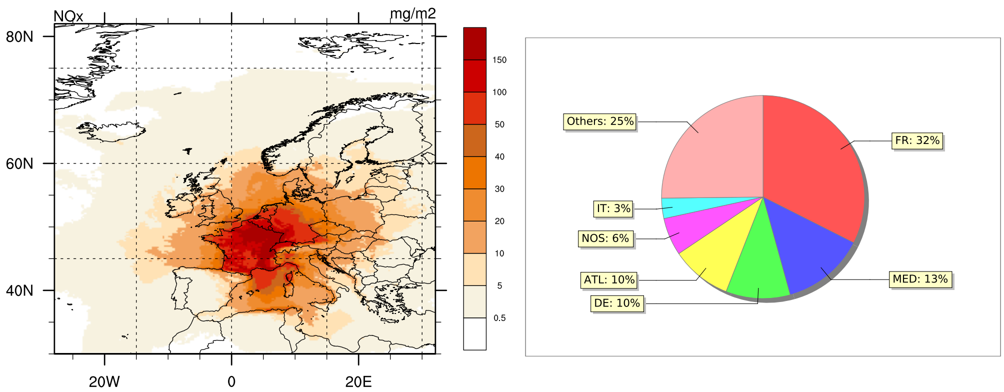


Figure 8: Contribution of emissions from France to deposition of oxidised nitrogen in the EMEP domain. Unit: mg(N)/m^2. The pie chart shows the six main receptor areas where oxidised nitrogen from France is deposited. Unit: %.

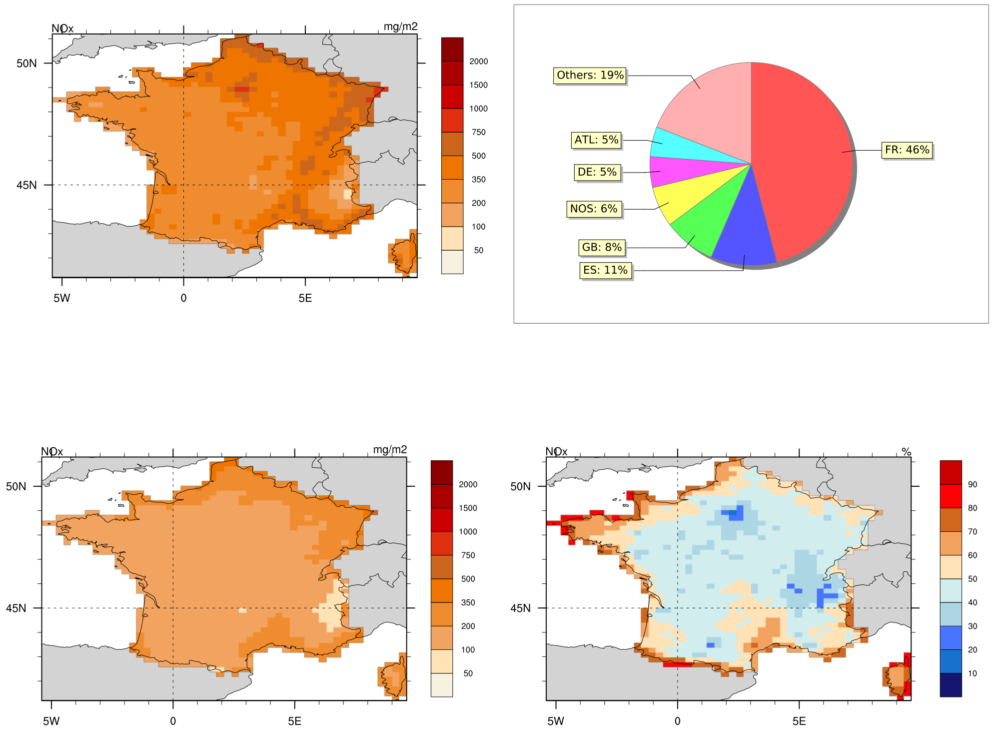


Figure 9: Top left: Deposition of oxidised nitrogen in France. Unit: mg(N)/m^2. Top right: The six main contributors to oxidised nitrogen deposition in France. Unit: %. Bottom left: Oxidised nitrogen deposition from transboundary sources. Unit: mg(N)/m^2. Bottom right: Fraction of transboundary contribution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

4.3 Deposition of reduced nitrogen

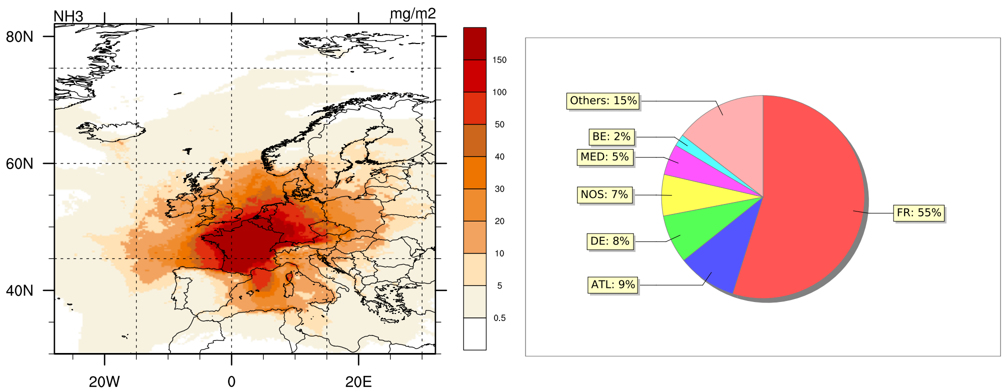


Figure 10: Contribution of emissions from France to deposition of reduced nitrogen in the EMEP domain. Unit: mg(N)/m^2. The pie chart shows the six main receptor areas where reduced nitrogen from France is deposited. Unit: %.

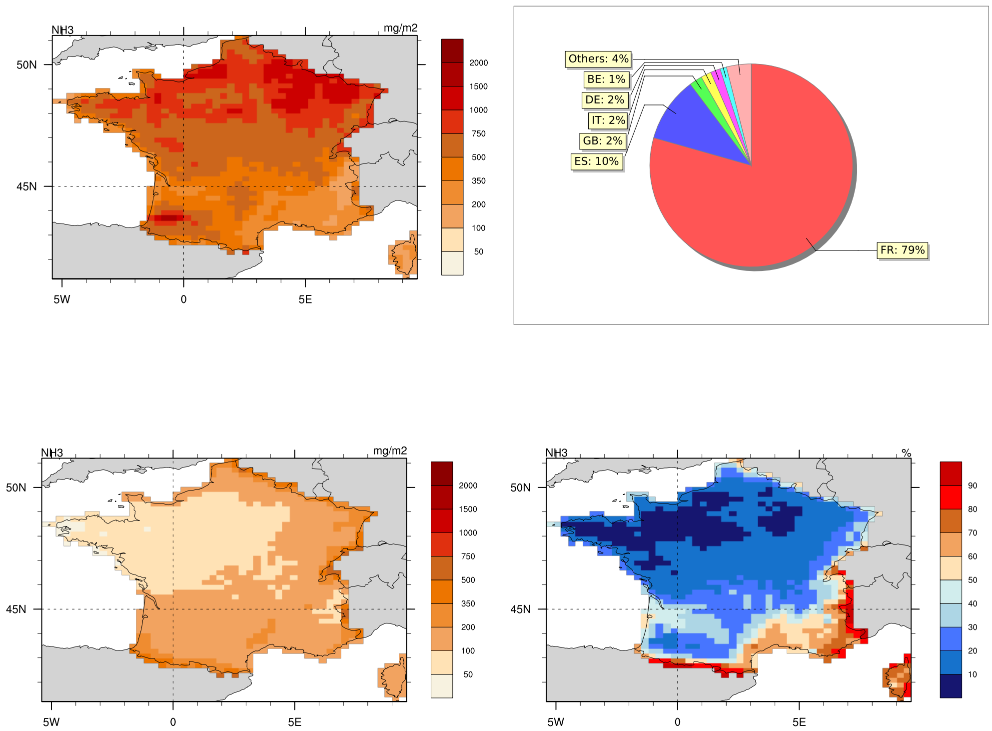


Figure 11: Top left: Deposition of reduced nitrogen in France. Unit: mg(N)/m^2. Top right: The six main contributors to deposition of reduced nitrogen in France. Unit: %. Bottom left: Deposition of reduced nitrogen from transboundary sources. Unit: mg(N)/m^2. Bottom right: Fraction of transboundary contribution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

5 Transboundary concentrations of ozone

5.1 $AOT40_f^{uc}$

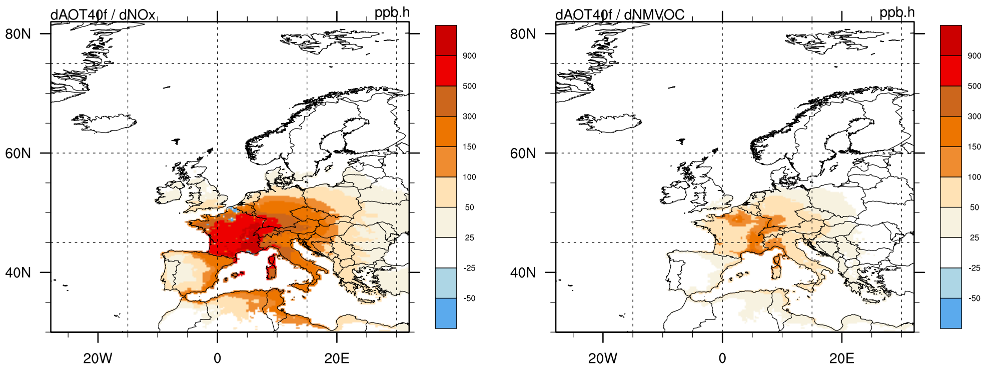


Figure 12: Reduction in $AOT40_f^{uc}$ that would result from a 15% reduction in emissions of NO_x (left) and NMVOC (right) from France. Unit: ppb·h.

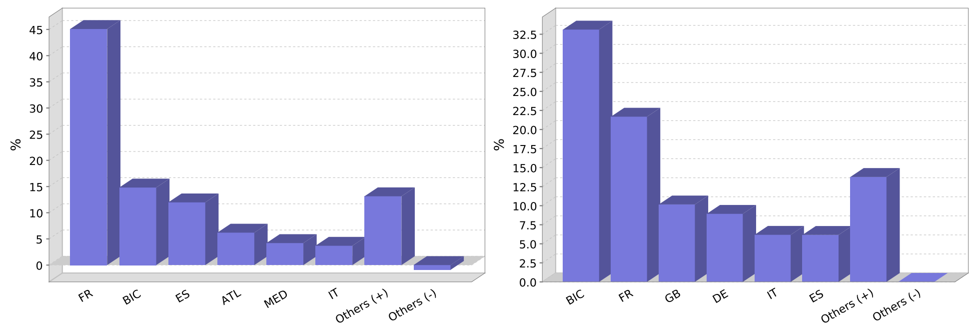


Figure 13: The six most important emitter countries or regions, with respect to their effects on $AOT40_f^{uc}$ in France that would result from reductions in NO_x emissions (left) or NMVOC emissions (right). The sum of the absolute values of the effects of all emitter countries corresponds to 100%. See Section 1.1 for more information.

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

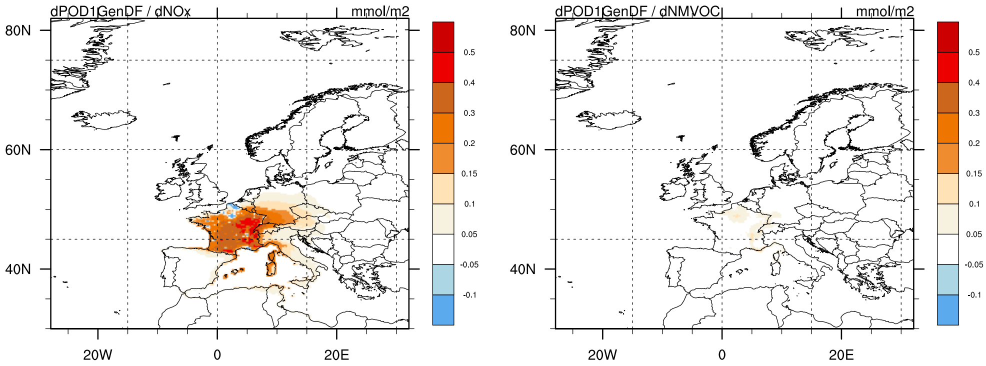


Figure 14: Reduction in $POD_{1.0,gen\text{-}DF}$ that would result from a 15% reduction in emissions of NO_x (left) and NMVOC (right) from France. Unit: mmol/m^2.

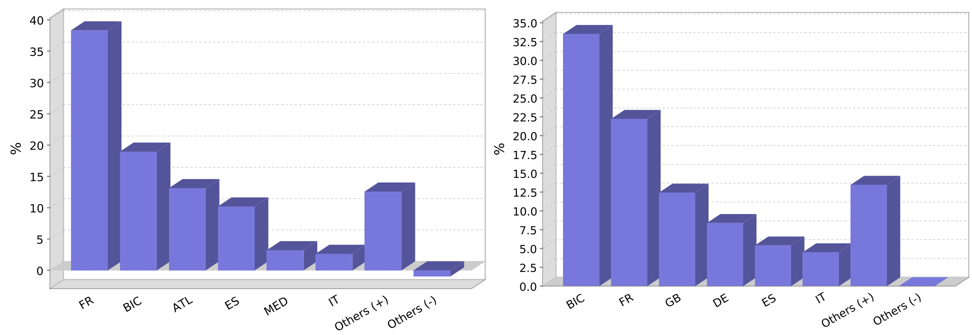


Figure 15: The six most important emitter countries or regions, with respect to their effects on $POD_{1.0,gen\text{-}DF}$ in France that would result from reductions in NO_x emissions (left) or NMVOC emissions (right). The sum of the absolute values of the effects of all emitter countries corresponds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

5.3 SOMO35 – Risk of ozone damages to human health

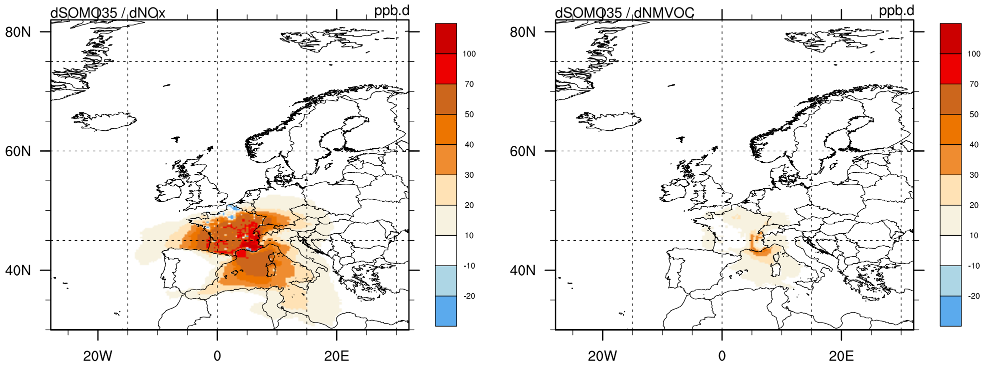


Figure 16: Reduction in SOMO35 that would result from a 15% reduction in emissions of NO_x (left) and NMVOC (right) from France. Unit: ppb·day.

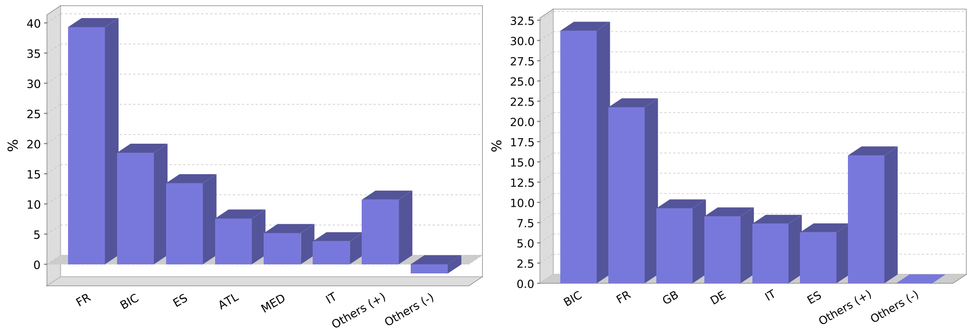


Figure 17: The six most important emitter countries or regions, with respect to their effects on SOMO35 in France that would result from reductions in NO_x emissions (left) or NMVOC emissions (right). The sum of the absolute values of the effects of all emitter countries corresponds to 100%. See Section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

6 Transboundary concentrations of particulate matter

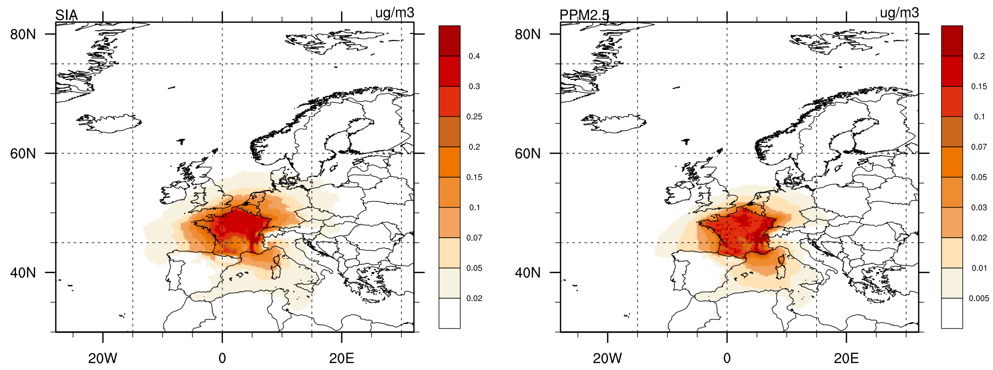


Figure 18: Reduction in concentrations of SIA (left) and $PPM_{2.5}$ (right) that would result from a 15% reduction in emissions from France. Unit: μg/m^3. Note the difference in scales.

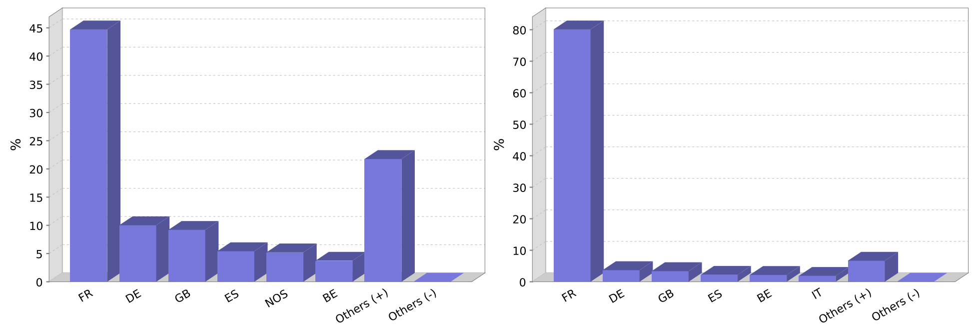


Figure 19: The six most important emitter countries or regions, with respect to their effects on SIA (left) or $PPM_{2.5}$ (right) in France that would result from reductions in emissions. The sum of the absolute values of the effects of all emitter countries corresponds to 100%. See Section 1.1 for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

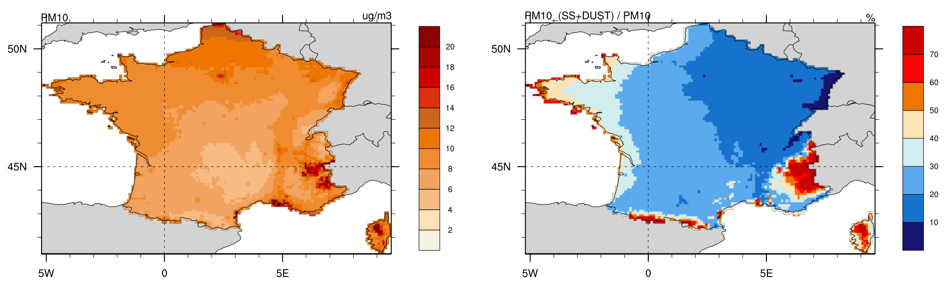


Figure 20: PM_{10} concentration (left) and fraction of natural contributions of PM_{10} (sea salt and natural dust) to total PM_{10} (right) in France.

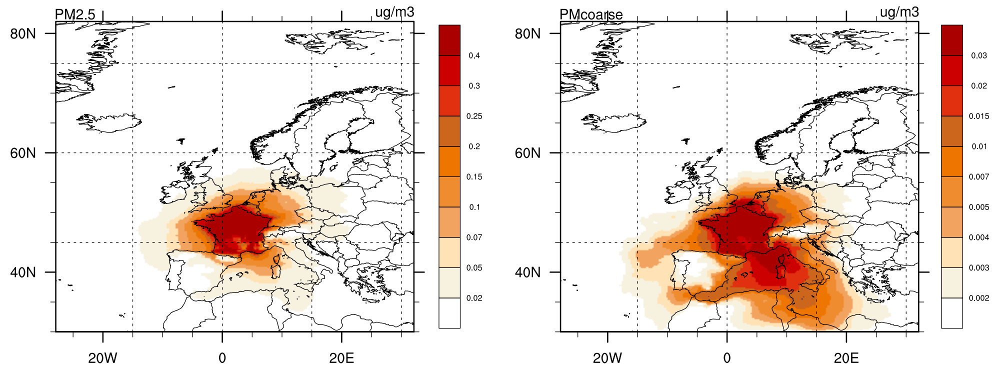


Figure 21: Reduction in $PM_{2.5}$ and PM_{coarse} concentrations that would result from a 15% reduction of emissions from France. Unit: $\mu g/m^3$. Note the different color scales.

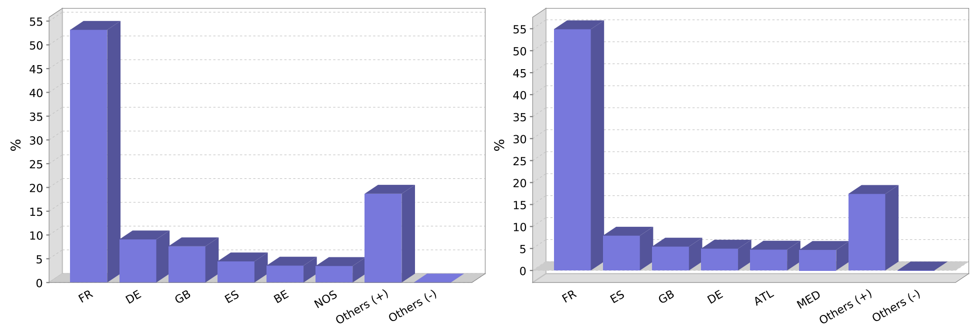


Figure 22: The six most important emitter countries or regions, with respect to their effects on $PM_{2.5}$ (left) or PM_{coarse} (right) in France that would result from reduction in emissions. The sum of the absolute values of the effects of all emitter countries corresponds to 100%. See Section 1.1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

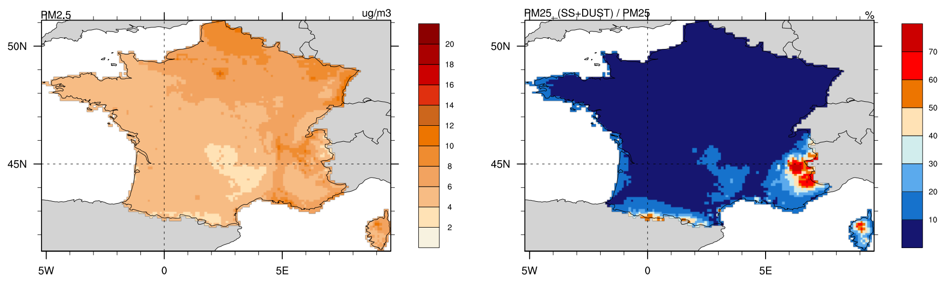


Figure 23: $PM_{2.5}$ concentration (left) and fraction of natural contributions of $PM_{2.5}$ (sea salt and natural dust) to total $PM_{2.5}$ (right) in France.

7 Comparison with observations

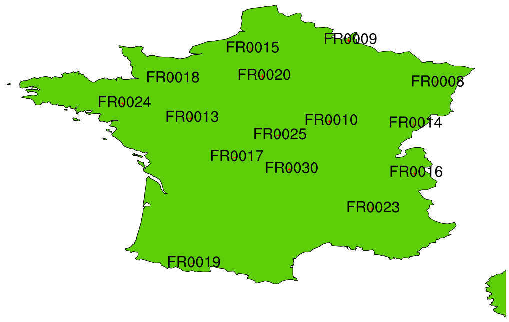


Figure 24: Location of stations in France.

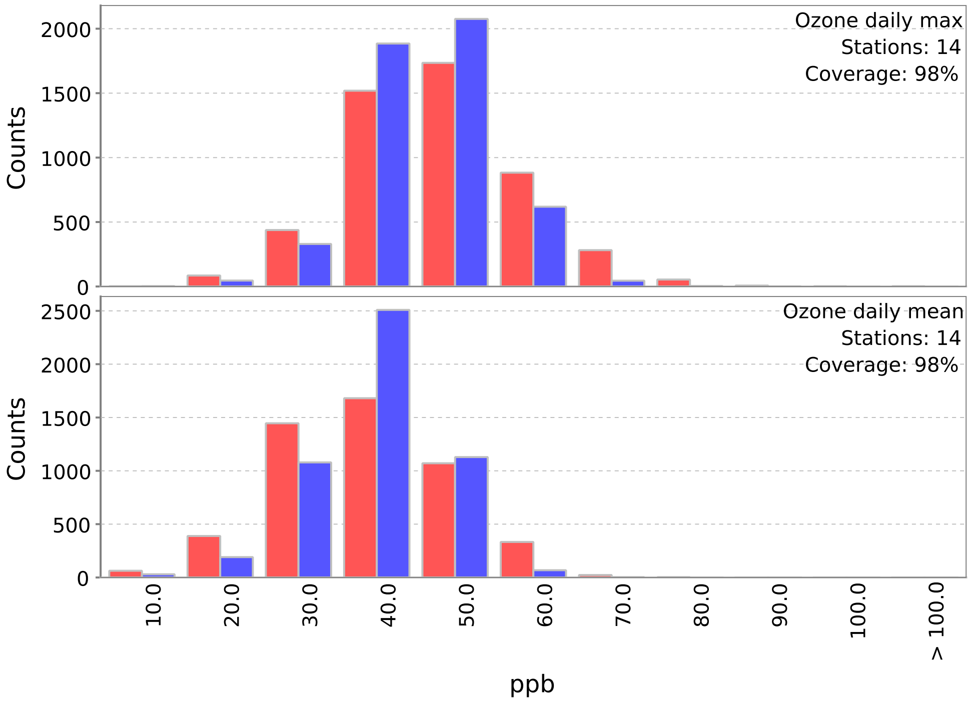


Figure 25: Frequency analysis of ozone in France at the stations that reported O_3 for 2017 (Model, Observations).

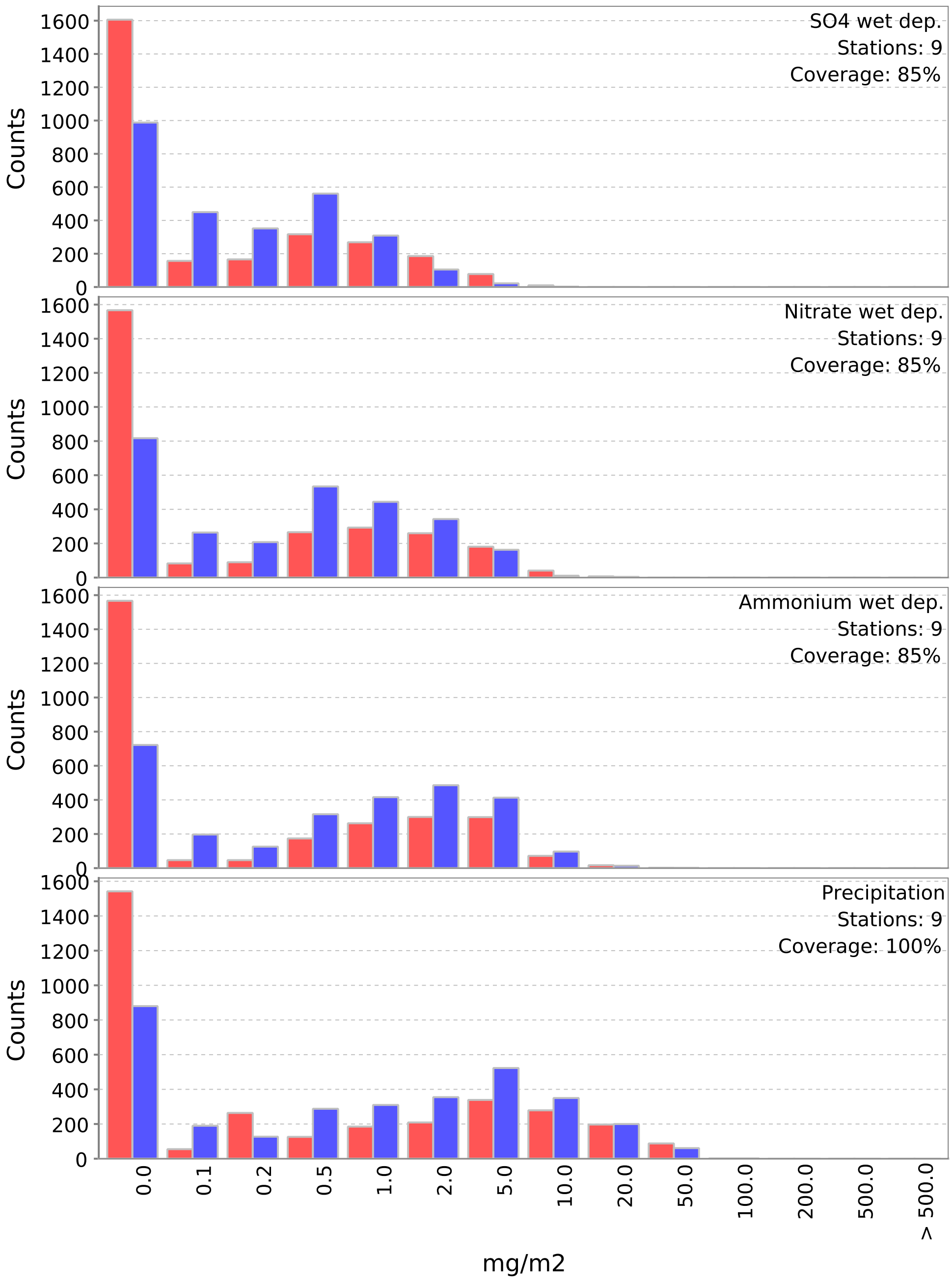


Figure 26: Frequency analysis of depositions in precipitation in France (Model, Observations).

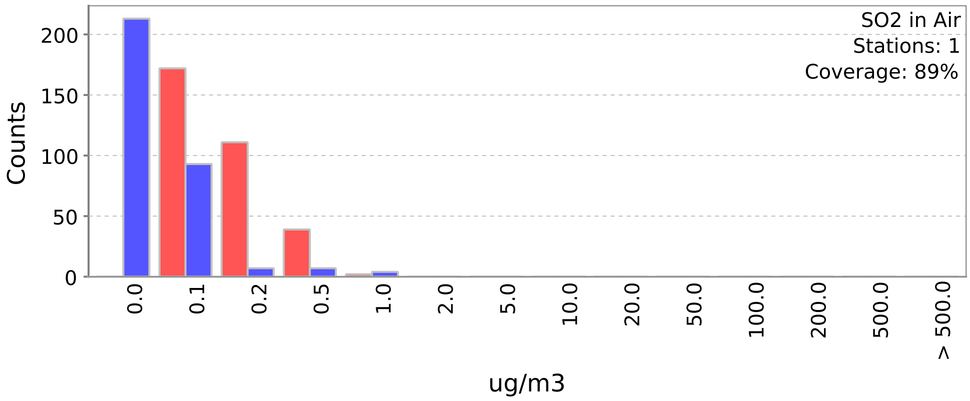
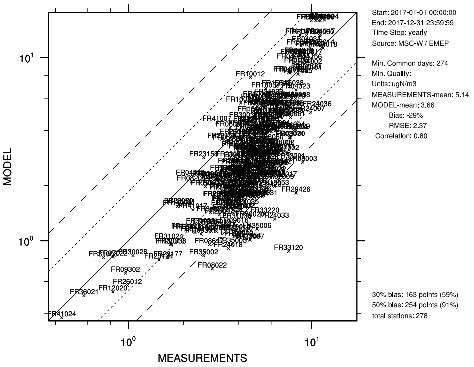


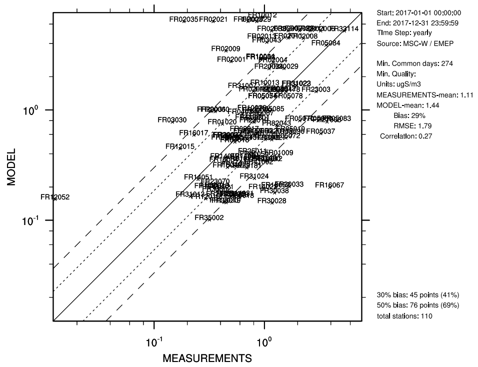
Figure 27: Frequency analysis of air concentrations in France (Model, Observations).

Component	No.	Bias	Correlation	RMSE
SO2 in Air	1	-67%	0.58	0.12
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	14	-4%±7%	0.81±0.11	5.77±1.62
Ozone daily mean	14	2%±13%	0.76±0.09	5.96±1.58
SO4 wet dep.	9	-41%±19%	0.40±0.13	3.81±1.28
Nitrate wet dep.	9	-30%±26%	0.39±0.15	7.81±3.73
Ammonium wet dep.	9	-1%±28%	0.45±0.12	8.47±1.81
Precipitation	9	7%±47%	0.72±0.10	14.47±4.95

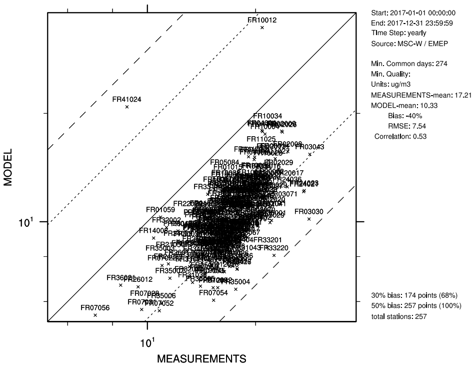
Table 5: Annual statistics of comparison of model results with observations in France for stations with a sufficiently consistent set of data available in weekly or higher time-resolution. Standard deviations provide variability ranges between stations.



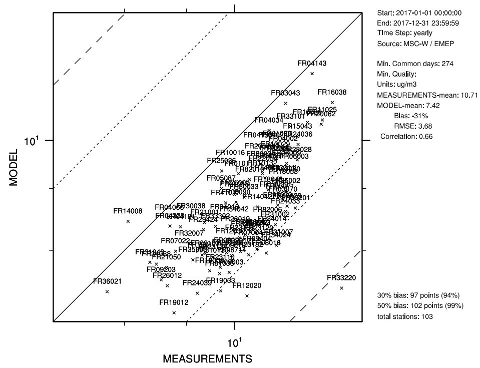
(a) NO_2



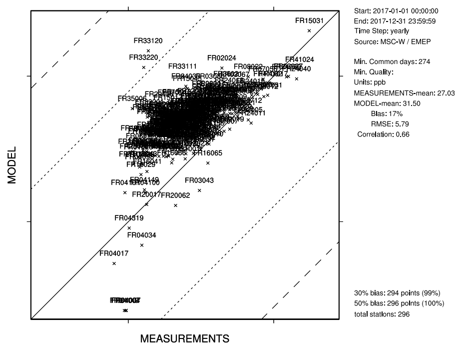
(b) SO_2



(c) PM_{10}



(d) $PM_{2.5}$



(e) O_3

Figure 28: Daily model results versus AirBase observations in France 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 France

8.1 Ecosystem-specific AOT40 values

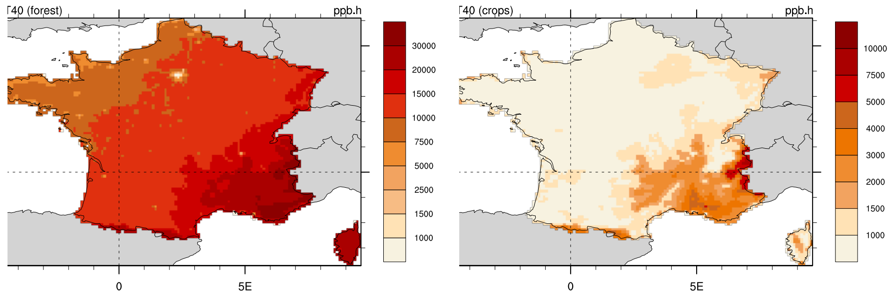


Figure 29: $\mathrm{AOT40}_f^{\mathrm{uc}}$ and $\mathrm{AOT40}_c^{\mathrm{uc}}$ in France in 2017. *($AOT40_f^{uc}$: growing season April-September, critical level for forest damage = 5000 ppb·h; $AOT40_c^{uc}$: growing season May-July, critical level for agricultural crops = 3000 ppb·h.)*

8.2 Ecosystem-specific ozone fluxes

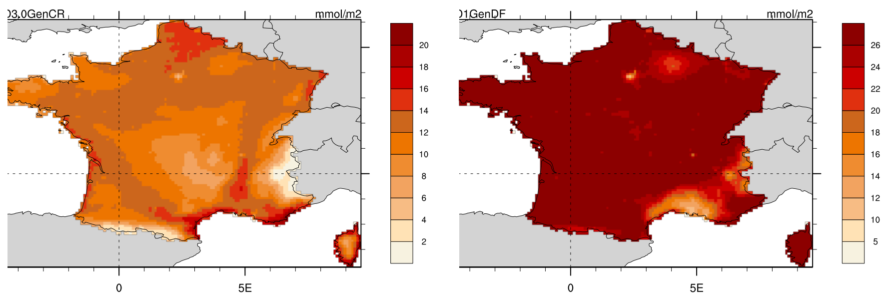


Figure 30: $\mathrm{POD}_{3.0,\mathrm{gen\text{-}CR}}$ and $\mathrm{POD}_{1.0,\mathrm{gen\text{-}DF}}$ in France in 2017.

8.3 Health impacts from ozone and particulate matter

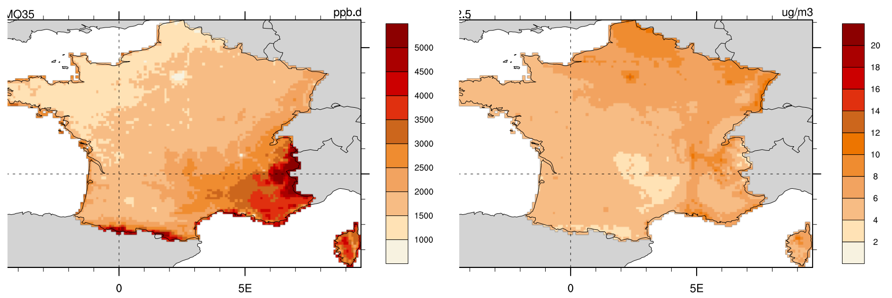


Figure 31: Regional scale SOMO35 and $PM_{2.5}$ in France in 2017.