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Deposition of major inorganic compounds in Norway 2012-2016

Wenche Aas [1)], Anne-Gunn Hjellbrekke [1)], Hilde Fagerli [2)], Anna Benedictow [2)]

[1)] NILU – Norwegian Institute for Air Research, Kjeller, Norway
[2)] Meteorological institute, Oslo, Norway

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ABSTRACT

This report contains estimates of atmospheric deposition of major inorganic compounds in Norway for the period 2012 to 2016 using two different methods, one observational based method while the other combining atmospheric transport model with observations. Both methods show similar clear spatial gradient in the atmospheric deposition with highest loads in south and south-west. The combined method has improved the spatial information of the deposition pattern for wet deposition. For dry deposition, there are quite large uncertainties in the estimated dry deposition velocities in both methods. Compared to the previous period 2007-2011, there is a decrease in the total sulfur deposition in Norway of 9%. For total nitrogen there are minor changes. Compared to the 1978-1982 period, the reductions in sulfur and nitrogen depositions are 75% and 20% respectively.

NORWEGIAN TITLE

Avsetning av svovel og nitrogenforbindelser i Norge, 2012-2016

KEYWORDS

Atmosphere and climate | Long-range transport of air pollutants | Acid rain and eutrophication

ABSTRACT (in Norwegian)

Avsetning av svovel og nitrogenforbindelser i Norge for perioden 2012 til 2016 er beregnet ved bruk av to forskjellige metoder, en observasjonsbasert metode, mens den andre kombinerer atmosfærisk transportmodell med observasjoner. Begge metodene viser en tydelig gradient med høyest avsetning i sør og sørvest. Den kombinerte metoden har bedre romlig informasjon, spesielt for våtavsetning. For tørravsetning er det ganske store usikkerheter i estimerte verdier for begge metodene. Sammenlignet med forrige periode 2007-2011 er det en nedgang i total svovelavsetning i Norge på 9%. For totalt nitrogen er det små endringer. Sammenlignet med 1978-1982 er det henholdsvis 75% og 20% reduksjon i svovel- og nitrogenavsetningen.

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Preface

Within the Convention on Long Range Transboundary Air Pollution (LRTAP), the members have decided that emission reductions should be based on the principle of critical loads. Every five year The Norwegian Institute for Water Research (NIVA) calculate exceedances of critical loads for water and soil in Norway based on atmospheric deposition estimates done by NILU – The Norwegian Institute for Air Research, and for this report also by The Norwegian Meteorological Institute (MET).

This work is done on behalf of the Norwegian Environment Agency. Estimates of critical loads and depositions cover periods from 1978-1982 up to this report which contains atmospheric deposition for 2012-2016. The maps of exceedances of critical loads are reported separately by NIVA.

The work in this report has been led by Wenche Aas at NILU in co-operation with Hilde Fagerli at MET. Anne Hjellbrekke (NILU) has been responsible for implementing the new combined method, and Espen Sollum (NILU) has been responsible for developing the mapping tools. Anna Benedictow (MET) has performed the EMEP/MSC-W model calculations.

NILU and MET have been subcontracted by NIVA, who has been contracted by the Norwegian Environment Agency. Contact persons at NIVA and the Norwegian Environment Agency are Kari Austnes and Gunnar Skotte, respectively.

Kjeller, December 2017

Wenche Aas
Senior scientist

Contents

Summary

This report contains estimates of atmospheric deposition of major inorganic compounds in Norway for the period 2012 to 2016 using two different methods. The deposition of sulfur and nitrogen have been compared with previous periods back to 1978.

The traditional method, based on observations and statistical interpolation, has limitations in especially the spatial representativeness and in the simplification of the dry deposition calculation. Since the spatial resolution of the reported emissions in the EMEP/MSC-W chemical transport model has improved the latter years, it is recognised that these calculations have a potential to fill the gaps in the observational based method, and improve the deposition estimates. Thus, a new method combining model calculations with observations has been developed and applied for the 2012-2016 period.

Comparing the results for the old method with the previous period 2007-2011 estimated using the same approach, there is a decrease in the total sulfur deposition in Norway of 9%. For total nitrogen there are minor changes (1% increase), though oxidized nitrogen has increased by 7% while reduced nitrogen decreased by 5%. There is a significant decreasing trend in the sulfur deposition from the first assessment in 1978-1982 with a 75% reduction. The trend in sulfur deposition is very well correlated with the total emission trends in Europe. For nitrogen, the trend is less clear. The deposition was higher in the beginning of the measurement period and there has been a decrease of 20% since 1980 and 10% since 1990.

There is a very clear spatial gradient in the atmospheric deposition, seen by both methods, with the highest deposition loads in the south and south-west. This is due to the different level of precipitation amount in Norway, which is highest on the west coast, combined with highest contribution of long range transported air pollution from the continent to southern Norway.. The wet deposition is the most important factor for the total deposition of inorganic compounds. In the areas with the highest total deposition, wet deposition contributes with 80-90% depending on compounds and method.

The combined method have improved the spatial information of the deposition pattern and for wet deposition, it probably gives more realistic deposition than the observational based method. For dry deposition, there are quite large uncertainties in the estimated dry deposition velocities in both the methods. Further, there are also quite large uncertainties in the observations as well as the reported emissions of especially NH_3. It is recommended to further explore improvements in the combined method to give more confident in especially the dry deposition processes.

Deposition of major inorganic compounds in Norway 2012‑2016

1 Introduction

In order to evaluate the exceedance of critical loads to the ecosystems, quantified atmospheric input to the system is essential. There are three different approaches for calculating the atmospheric deposition: 1) from measurements of air and precipitation chemistry combined with statistical interpolation, 2) from atmospheric chemical dispersion models using emission data, meteorological data and parameters describing transformation and removal processes or 3) combine observations and atmospheric model calculations, often called data assimilation or data-model fusion.

The atmospheric deposition estimates have in Norway historically been done using method 1) and have been reported every five years: 1978-1982 (Hole and Tørseth, 2002), 1983-1987 (Pedersen et al., 1990), 1988-1992 (Tørseth and Pedersen, 1994), 1992-1996 (Tørseth and Semb, 1997), 1997-2001 (Hole and Tørseth, 2002), 2002-2006 (Aas et al., 2006) and 2007-2011 (Aas et al , 2012). This report contains atmospheric deposition for 2012-2016 and these results have been compared to earlier periods for trend assessment.

There are two main limitations with this traditional observational based method. Firstly, at the Norwegian mainland, there are currently only 12 regional sites with precipitation chemistry and 4 with gas and aerosols measurements. Thus, there are large areas of Norway where these sites not necessarily are representative, and the uncertainty in the interpolation between these sites is large. Secondly, the dry deposition is not measured directly and it is necessary to estimate the deposition velocities based on literature values combined with information on climatic conditions and ground cover. These are very crude estimates, both spatially and temporally and do not take into account the interaction between species, i.e. co-deposition.

The atmospheric chemical transport models usually have a much higher spatial and temporal coverage and can potentially fill the gaps and limitations of the observational based method. In this report the dispersion model developed by the Norwegian Meteorological Institute (MET) under the Co-operative programme for monitoring and evaluation of long-range transmissions of air pollutants in Europe (EMEP) (Simpson et al., 2012), has been included. This model has recently been updated to a finer resolution of 0.1^0 x 0.1^o. In 2017, Parties to the CLRTAP Convention (including Norway) reported emissions in 0.1x0.1 degree for the first time, and these developments give new improved possibilities for calculating high resolution deposition in Norway. These model calculations have been combined with observations to potentially give the best estimates of the atmospheric deposition.

The model-measurement combined method has been implemented for the 2012-2016 and the results are compared with the old method, and the differences are discussed.

2 Methodology

2.1 Measurement based deposition

2.2.1 Input data

NILU started routine sampling of precipitation and air in background areas on a daily basis in 1971, with sites located in the southernmost parts of Norway. In later years the measuring network has expanded to cover all regions in Norway, though the number of sites have varied throughout the decades the national monitoring programme has been in operation. In this investigation we have used 12 Norwegian stations for the period 2012-2016 (Aas et al., 2013-2017). In addition, concentrations in precipitation and air from the Swedish, Danish, Finnish and Russian EMEP stations have been used in the statistical analysis (Hjellbrekke, 2017; data available from http://ebas.nilu.no/). Additional data from the national network in Sweden have also been included (personal com. Håkan Blomgren, IVL, data available from http://www.ivl.se/miljo). The precipitation amount data used for the calculations of the wet deposition is taken from the national meteorological observation network (MET) in addition to the NILU sites. Data from in total 300 automatic meteorological sites for the five-year period 2012-2016 have been used (MET, 2012-2016).

All the sites with atmospheric chemical composition measurements are located in rural areas and are believed to generally give good estimates of long range transported pollutants. In regions with local sources such as emissions from industry, traffic or agriculture, pollutant levels may be significantly higher. In this work no corrections for local sources have been performed. Information about the sites, methodology and the results for the years used in this report have been published annually in reports from the national monitoring program (Aas et al. 2013, 2014, 2015, 2016, 2017). Maps of all the sites used are illustrated in Figure 1.

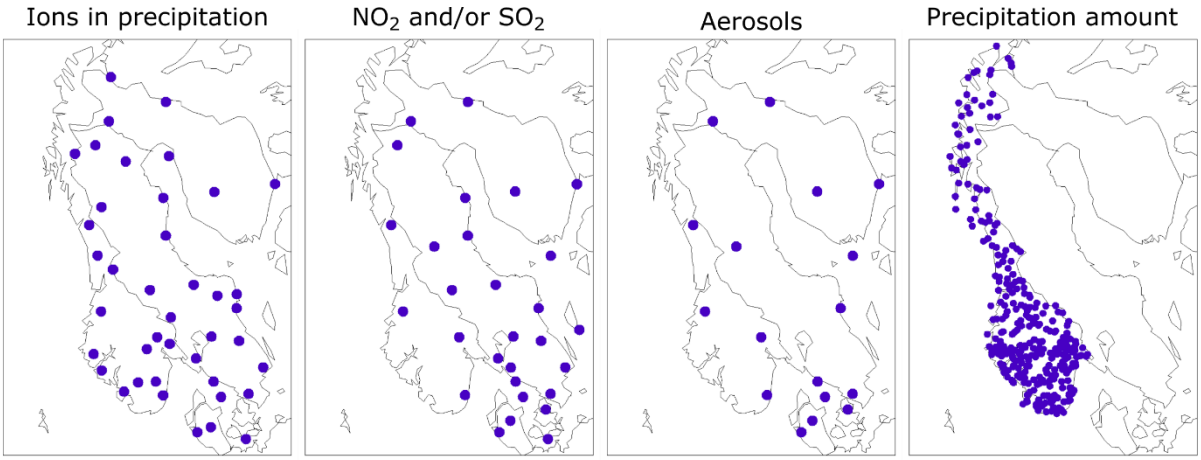

Figure 1: Overview of the sites used in this study

2.2.2 Calculating wet- and dry deposition

Wet deposition is obtained from measured precipitation amounts and the concentration of chemical species in the precipitation samples. This procedure does not include deposition by fog or dew, since the usual precipitation sampler generally collects no precipitation sample from such events.

For dry deposition, the measured concentrations in ambient air have been combined with seasonal deposition velocities for the different compounds. The various dry deposition processes and deposition are described in the literature (e.g. Fowler et al 2009), and discussion of the deposition velocities chosen for this study is presented in earlier reports (i.e. Aas et al, 2012). An important note is that the same procedure and deposition velocities have been used for all the periods. However, it is recognized that for the latter decades there is a significant change in the atmospheric composition due to the large reductions in sulfur dioxide emissions, causing possible changes in the dry deposition velocities (Fagerli and Aas, 2008; Fowler et al., 2009).

Table 1: Deposition velocities (cm/s) for different inorganic compounds applied to the different landscape types and seasons (nss: non sea salt).

	Land use classification			
Compound	Forest		Other	
	summer	winter	summer	Winter
SO_2	0.8	0.1	0.4	0.02
SO_4^{2-}, sum (NH_3+NH_4^+)	0.4	0.4	0.2	0.1
NO_2	0.4	0.02	0.2	0.02
Sum (HNO_3+NO_3^-)	2.0	2.0	1.0	0.25
nss K^+	1	1	0.25	0.1
nss Ca^{2+}	2	2	1	0.25
Sea salt ions	2	2	1	0.25

2.2.3 Interpolation using the kriging technique

The interpolation of the concentrations in precipitation and air from fixed sites to a regular grid is done by linear "kriging", which is a statistical method that can be used to estimate unknown data from neighbouring measurements. The method was originally developed for geostatistical purposes (Matheron, 1963; Journel and Huijbregts, 1981), but has also been used in connection with environmental studies, e.g. on long range transported air pollutants in Europe (Simpson and Olsen, 1990; Schaug et al., 1993).

All interpolations in this work were performed using ordinary linear kriging, where the expectations of the variable are known. The kriging weights are computed from a variogram, which measures the degree of correlation among sample values in the area as a function of distance and direction of samples. A grid size of 50×50 km^2 has been applied (the old EMEP grid). The applied grid is shown in Figure 1.1 in Appendix A.

2.2.4 Data analysis

Five year averages of the seasonal mean airborne concentrations during winter (Jan.-Apr., Nov.- Dec.) and summer (May-Oct.) were calculated for SO_2, non-sea-salt (nss) SO_4^{2-}, NO_2, sum NO_3^-+HNO_3, sum NH_4^++NH_3, Na^+, non-sea-salt K^+ and non-sea-salt Ca^{2+} for the four Norwegian sites combined with the Nordic measurements. These average contractions were interpolated to a 50×50 km^2 grid using the kriging technique to obtain values for the individual grid cells.

The dry deposition was estimated from the concentration fields and assessed dry deposition velocities for the two seasons, respectively. The dry deposition estimate was given for each meteorological site and for two land type categories; productive forests and other land use (e.g. unproductive land, rocks, agricultural land). When estimating the grid cell average dry deposition was weighted on the distribution of land use types in the individual grid cells. The applied statistics on percentage productive forest in each cell is shown in Figure 1.2 in Appendix A.

The annual averages of non-sea-salt sulphate, nitrate, ammonium, non-sea-salt potassium and non-sea-salt calcium in precipitation have been used to calculate a concentration field for each year using the kriging interpolation.

For the sea-salt derived ions, the number and the location of the sites are not sufficient to generate concentrations fields. However, concentrations may be described as a function of distance from the coast weighted by the wind speed and direction in the prevailing precipitation forming air masses. Based on annual median values of sodium concentration in precipitation at the background sites for the period 2007-2011, a general function was fitted. From this function, concentration values were given to each individual meteorological site as a function of distance from the coast and by climatic regions. Further, concentrations for the other sea-salt derived ions were estimated by their expected ratio to sodium based on the content in sea-water.

To provide annual wet deposition values for each meteorological site, the precipitation amount at the site was multiplied with the interpolated concentration in the respective grid cell. The average wet deposition to each grid cell was estimated as the average deposition to the meteorological sites within the grid cell. For grid cells with no meteorological sites, the value of a representative neighbouring cell was chosen. The average precipitation amounts in the individual grid cells are given in Table 1.1 in Appendix A.

The total deposition of the various inorganic compounds during 2012-2016 was calculated as the sum of the dry and wet deposition both for each meteorological site and for each grid cell. The deposition estimated at each meteorological sites are visualized using standard interpolation routines in Figure 3 and Figure 4, whereas results for individual 50x50 km grid cells are given in Table 1.1 in Appendix A.

This report gives only a summary of the results. Deposition estimates for individual years and components are available upon request.

2.2. EMEP/MSC-W model

The EMEP/MSC-W model is a Eulerian chemical transport model. A thorough description of the model can be found in Simpson et al., 2012 and model updates are described in the EMEP status Report 1 (years 2013-2017). For the model calculations performed for this project, the version described and documented in EMEP Status report 1/2017 has been used (rv4.15). The model resolution is 0.1 degree x 0.1 degree, with 34 vertical layers.

2.2.1 EMEP/MSC-W model input data

The model has been run for 5 years: 2012-2016, with the following input data:

Meteorology: ECMWF meteorology (IFS40r1 for 2014-2016, IFS38r2 for 2012-2013), interpolated to 0.1 degree x 0.1 degree.

Domain: -29.95E-39.95W 34.95S-72.95N

Emissions: For 2015 and 2016 the emissions reported to EMEP for 2015 has been used (2016 is not yet available). Since the emissions reported to EMEP for the years before 2015 are on a coarser resolution (50x50km^2), the emissions for countries that contribute substantially to Norwegian depositions for previous years are scaled using country totals, but keeping the spatial resolution. This means that for 2012, 2013 and 2014, the emissions from Norway, Poland, Great Britain, Sweden, Germany, Denmark, France and Russia has been scaled to the total country emissions reported to EMEP for the respective years.

For ship emissions, the FMI AIS data for 2016 has been used as basis. The 2015 ship emissions has been set equal to 2016, whilst the ship emissions for the Baltic Sea and the North Sea for the previous years have been scaled with 0.8 for SO_x (loosely based on the comparison of TNO-MACC-III ship emissions for 2011 and its comparison to FMI AIS data for shipping. This factor can be explained by the stricter SECA regulations implemented from January 2015 for the North Sea and the Baltic Sea. See chapter 10 in EMEP Status Report 1/2017 for further explanation).

Volcanic emissions (mostly SO_2) from the Holuhraun eruption (August 2014 to the end of February 2015) has been implemented in the model runs.. The source has been estimated to be around 12600 kt, more than 3 times the amount of anthropogenic SO_2 emissions for all European Union countries for the year 2014. A detailed EMEP/MSC-W model study of the air pollution effect of the Holuhraun eruption has been published recently (Steensen et al., 2016), and we refer to that paper for further details.

2.2.2 EMEP/MSC-W model output data

The EMEP/MSC-W model has been used to generate the following output:

- Air concentrations of SO_2, NO_2, NH_3, NH_4^+, HNO_3, fine and coarse NO_3^-
- Dry deposition velocities of SO_2, NO_2, NH_3, NH_4^+, HNO_3, fine and coarse NO_3^-
- Wet deposition of sulfur, reduced nitrogen and oxidized nitrogen
- Dry deposition of sulfur, reduced nitrogen and oxidized nitrogen

In the EMEP/MSC-W model, dry deposition velocities are calculated for 16 land-use categories. The land-use database gives the fractional coverage of different land-cover types within each surface grid cell. This allows sub-grid modelling using a so-called mosaic approach – allowing for example ecosystem specific deposition estimates.

For European scale modelling the land-cover data are derived from the CORINE system and from the Stockholm Environment Institute at York (SEIY) system (www.york.ac.uk/http://www.sei-international.org/landcover). The basic principle used was to apply CORINE data wherever available, thereafter SEIY data. In addition, the more detailed SEIY data (especially on agriculture) was used to guide the split of the broader CORINE categories into the EMEP land-classes needed by the model. The final merge of these data was done at the LRTAP Coordination Centre for Effects (CCE at RIVM, Posch et al. 2005).

Average dry deposition velocities for each grid can be calculated combining the dry deposition velocities for each land-cover class with the fractional land-cover for each grid. It is the average grid dry deposition velocities that have been used in the combined method (section 2.3).

2.3 Combined method

2.3.1 Observations used

Annual total precipitation is retrieved from the seNorge2 archive at met.no, which is a high resolution (1km x 1km) climatological dataset obtained through statistical interpolation of in-situ observations from the Norwegian Climatological Database (eklima.no) and European Climate Assessment & Dataset (ecad.eu) (Lussana et al., 2017). The number of stations used for interpolation varies with time, but it is between 500-600 Norwegian stations for total precipitation in the period 1957-2015.

Observations of nitrogen and sulfur components in air and precipitation are taken from the same sites as described in 2.2.1. The precipitation chemistry data are aggregated to annual volume weighted means, while the air and aerosol measurements are aggregated to monthly means. In difference from the observational based method where the sum of nitrate (HNO_3 and NO_3^-) and sum of ammonium (NH_3+NH_4^+) are used, in this method we use the observed concentrations of gas and aerosols individually, but being aware of the possible bias in the separation between these two compartments.

2.3.2 Combination of observations and model calculations

The method was developed to be used making combined maps for EMEP (Hjellbrekke and Tarrason, 2001) adjusted for new grid for the EMEP/MSC-W model. For all measurement points, the difference between the measured value at that point and the modelled value in the corresponding grid cell is calculated. This difference is interpolated spatially using radial basis functions, giving a continuous two-dimensional function describing the difference at any point within the modelled grid. The combined maps are derived adjusting the model results with the interpolated differences, giving large weight to the observed values close to stations, and using the modelled values in areas with no observations. The range of influence of the measured values has been set to 500 km for all the species. However, we recognize that since gases deposit more quickly than aerosols they should have had a lower rate of influence (lower radius). But due to the few number of sites a high radius was set to be able to cover the whole country.

The dry deposition rates are taken from the EMEP model using the monthly averages for each species specified for each grid cell. For nitrate, the model use different rates for coarse and fine nitrate, while the observations are in aerosols, the sum of fine and coarse size fractions. To estimate the monthly dry deposition rate the distribution between fine and coarse nitrate in the modelled concentrations are used to weigh the deposition rates. To compare the dry deposition rates with the observational method (Table 1), the monthly deposition rates are averaged to five year seasonal deposition rates and illustrated in Figure 2. These maps show quite big differences between the components, and the deposition velocities range from high for HNO_3, NH_3 and SO_2 to lower for NO_3^-. NH_4^+, SO_4^{2-}, NO_2 in that order. Most components have a higher deposition rate during summer.

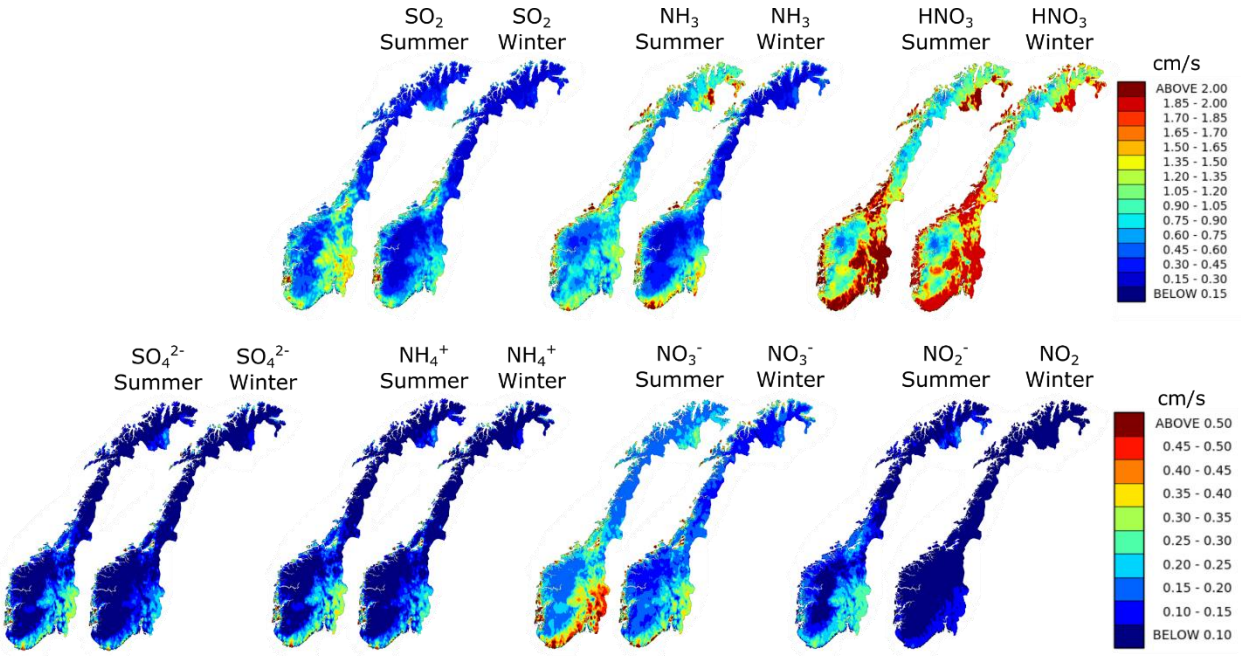

Figure 2: Average seasonal deposition rates (cm/s) for the different compounds used in the combined method.

3 Results and discussion, 2012-2016

3.1 Measurement based deposition

Annual average precipitation amounts measured at the MET sites varied between around 300 to 3700 mm (Table 2), with the highest amount on the west coast and lowest amounts along the Swedish border in northern Norway and in Oppland county, southern Norway (Figure 3).

The total deposition of the non-sea-salt compounds were highest in the south-western part of Norway as a combination of relatively high concentrations and large precipitation amounts, whereas the lowest depositions were observed along the Swedish border from Finnmark in the north down to Oppland in central Norway as well as the mountain area in southern Norway. The highest deposition of non-sea salt sulfur was around 450 mgS/m^2y, and around 800 mgN/m^2y for both reduced and oxidised nitrogen The total deposition of sulfur and nitrogen interpolated from all sites are shown in Figure 3.

The wet deposition is the most important factor for deposition of inorganic compounds (Figure 4), with 90% contribution to the total deposition for sulfur and reduced nitrogen in the areas with highest deposition loads. For oxidised nitrogen the relative contribution of dry deposition is more important, but wet deposition still contribute with 80% or more in the high deposition areas. In areas with little precipitation the dry deposition is relatively more important, but still most areas are below 30% dry deposition, except for oxidized nitrogen which has more than 40% dry deposition in part of Eastern Norway and Finnmark County.

Table 2: Minimum, median and maximum deposition for 300 individual sites in the period 2012-2016.

	Min	Median	Max
Average annual precipitation amount, 2012-2016	276	991	3705
total non-sea salt sulfur dep (mg S/m^2y)	46	167	480
total oxidised nitrogen dep (mg N/m^2y)	45	231	842
total reduced nitrogen dep (mg N/m^2y)	45	264	841

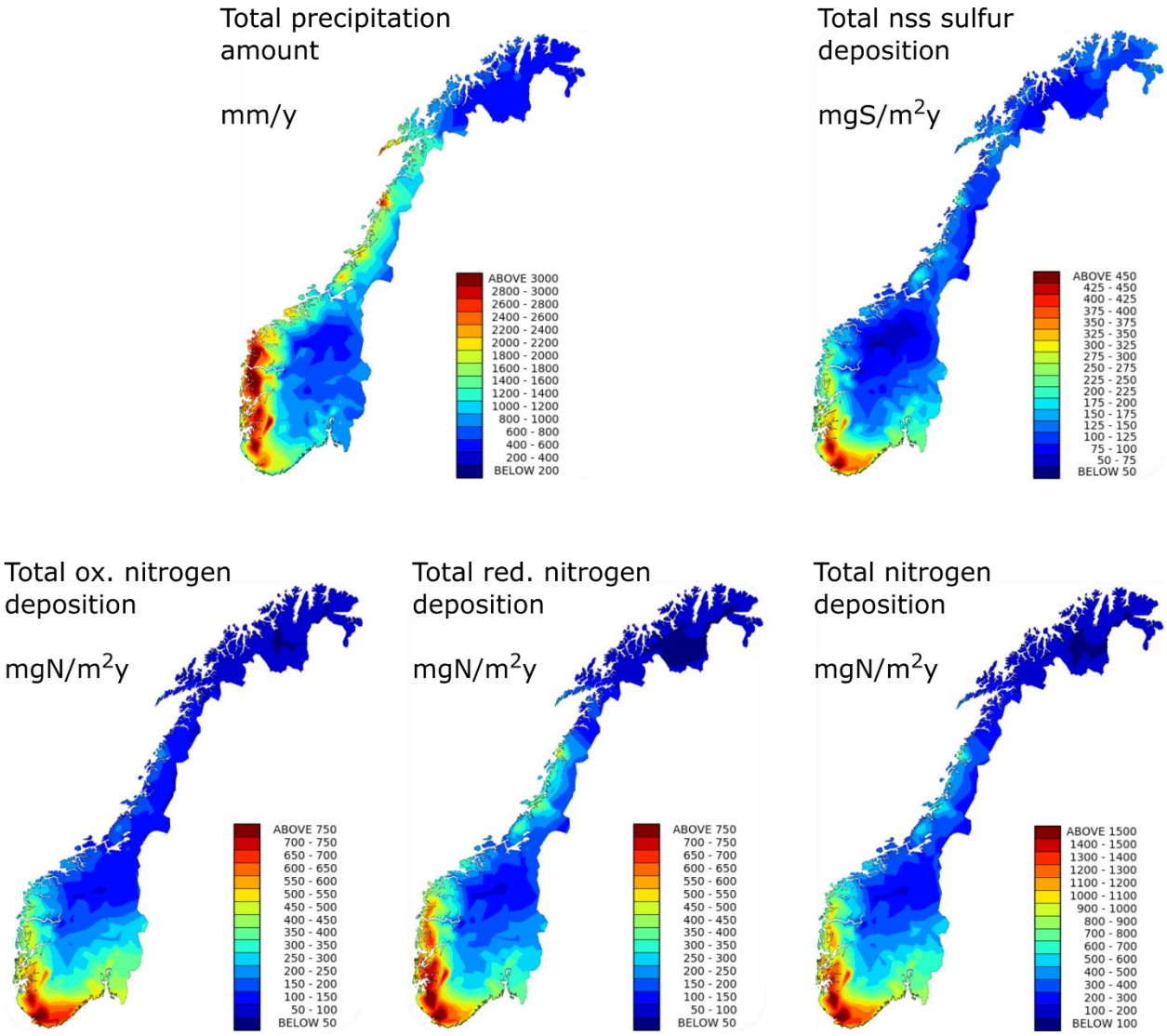

Figure 3: Spatial distribution of the precipitation amount and the total deposition of non-sea salt sulfur and nitrogen the annual average in the period 2012-2016.

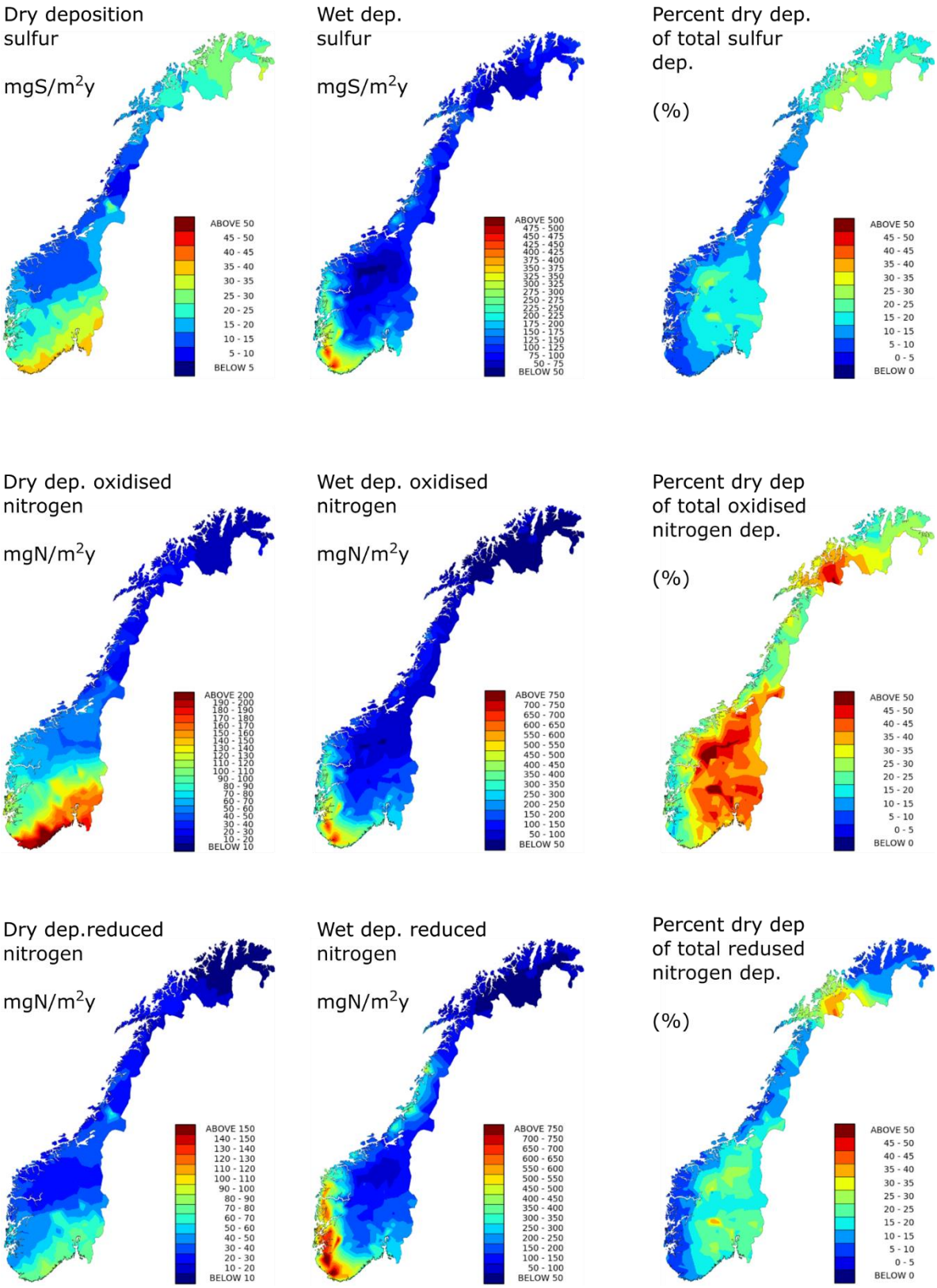

Figure 4: Spatial distribution of the wet and dry deposition of non sea salt sulfur, oxidised nitrogen and reduced nitrogen, and the percent dry of total deposition for 2012-2016.

The spatial distribution of deposition of base cations and sea salt are illustrated with calcium, potassium and sodium in Figure 5. For calcium, the main source is assumed to be long-range transport of mineral matter. In addition, there may also be local sources by e.g. agricultural activities, soil dust, pollen and bird droppings. For potassium, domestic wood combustion may be of importance locally during winter. The deposition amounts of sea-salts are dependent on the frequency of westerly winds, and in particular the frequency of winter storms. It is assumed that there are no other significant sources of sodium, magnesium or chloride than from sea-spray. Concentrations of sodium was calculated from a function based on distance from the coast as described in Chapter 2.4.2.

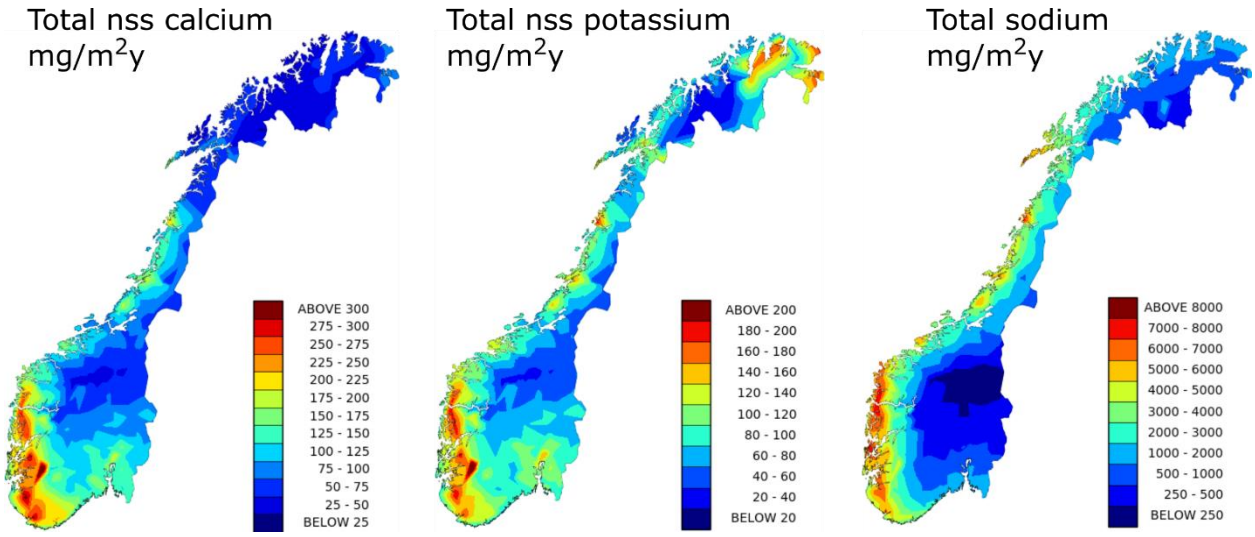

Figure 5: Spatial distribution of the non-sea salt calcium, non-sea salt potassium and sodium oxidised 2012-2016.

The deposition at the 300 individual sites is redistributed into 50x50 km^2 grids and the average annual deposition in each grid is given in Table 1.1 in Appendix A. Summing up all the grids gives a total annual mean deposition in Norway of approximately 47 000 tonnes sulfur and 142 000 tonnes nitrogen (Figure 6).

Comparing with the previous period 2007-2011, there is a decrease in sulfur deposition of 9%. For total nitrogen there is a minor change (1% increase), though oxidised nitrogen have increased by 7% while reduced nitrogen decreased by 5%. The total depositions for all the five years period are summed up in Table 3.

Table 3: Total deposition of inorganic compounds in Norway (tonnes/year).

Period	nss S	N (oxi)	N (red)	tot N	nss K	nss Ca	Na
1978-1982	197 368	83 882	93 342	177 224	27 702	43 061	567 215
1983-1987	171 710	93 456	93 602	187 058			
1988-1992	149 688	82 462	76 782	159 245			
1992-1996	117 289	80 251	71 602	151 852	19 989	33 412	580 811
1997-2001	87 206	73 564	77 572	151 136	23 769	25 890	604 045
2002-2006	73 852	75 612	79 244	154 856	28 092	34 266	470 022
2007-2011	53 724	62 798	77 524	140 321	27 360	32 770	581 889
2012-2016	46 886	68 166	73 494	141 660	28 327	32 630	561 756

The trends in sulfur deposition from the first assessment in 1978-1982 are shown in Figure 6, and the total deposition to Norway compared to the European sulfur emissions are shown in Figure 7. There is a significant decreasing trend in sulfur deposition since 1980, a decrease of 75% of the total amount deposited in Norway. The trend in sulfur deposition is very well correlated with the total emission trends in Europe, Figure 6, and are in line with observations for the rest of Europe (Tørseth et al., 2012; Colette et al, 2016). For nitrogen the trend is less clear. The deposition was higher in the first two five year periods (Figure 8 and Figure 9), and there has been a decrease of 20% since 1980, and a decrease of 10% since 1990. But for this last five year period the deposition was actually slightly higher than the previous period, which is in contradiction to the general downward trends in especially NOx emissions in Europe (Figure 9).

The EMEP/MSC-W model calculations for oxidized nitrogen deposition in Norway show a downward trend since 2000 (EMEP Data Note 1/2016 for Norway), whilst reduced nitrogen deposition is modelled to be at the same level. The reasons for the apparent contradicting results might be that the reported emissions for Norway are underestimated the later years or that local or nearby influence have increased. In Europe, the average trends in the observations have been a decrease of 20-40% for the different nitrogen compounds from 1990-2012 (Colette et al, 2016).

Total depositions of sea-salt ions, non-sea-salt potassium and non-sea-salt calcium were estimated in five of the previous seven year periods. There are relatively large uncertainties in these estimates due to possible influence of local sources, uncertain deposition velocities and the effect of sea salt correction. There is a reduction of 24% in the calcium deposition since the late seventies, but no major change since the 1992-1996 period, which is in line with

the emission changes of calcium and observed trends in Europe (Hellsten et al., 2007). For potassium there is no trend.

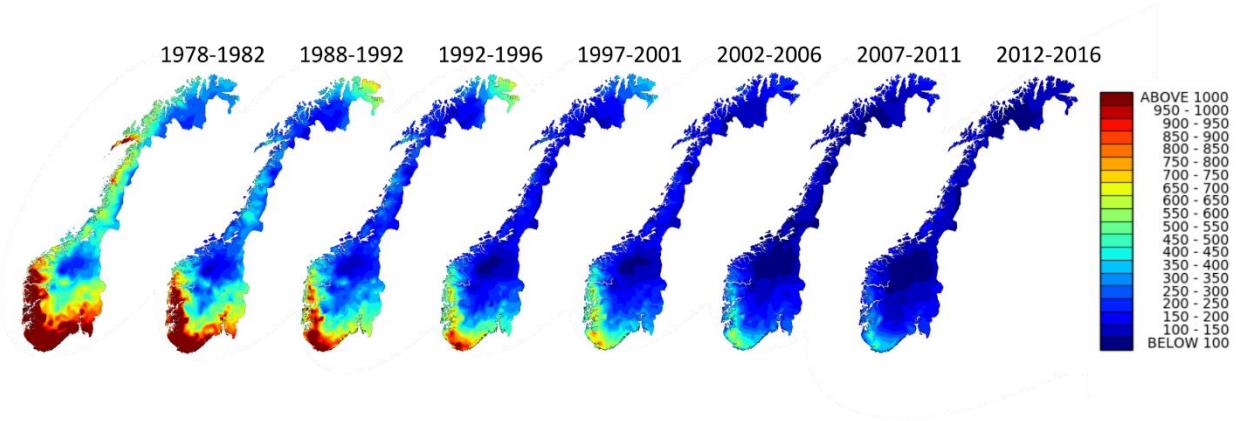

Figure 6: Trend in deposition of non sea salt sulfur in Norway (mgS/m^{2}y).

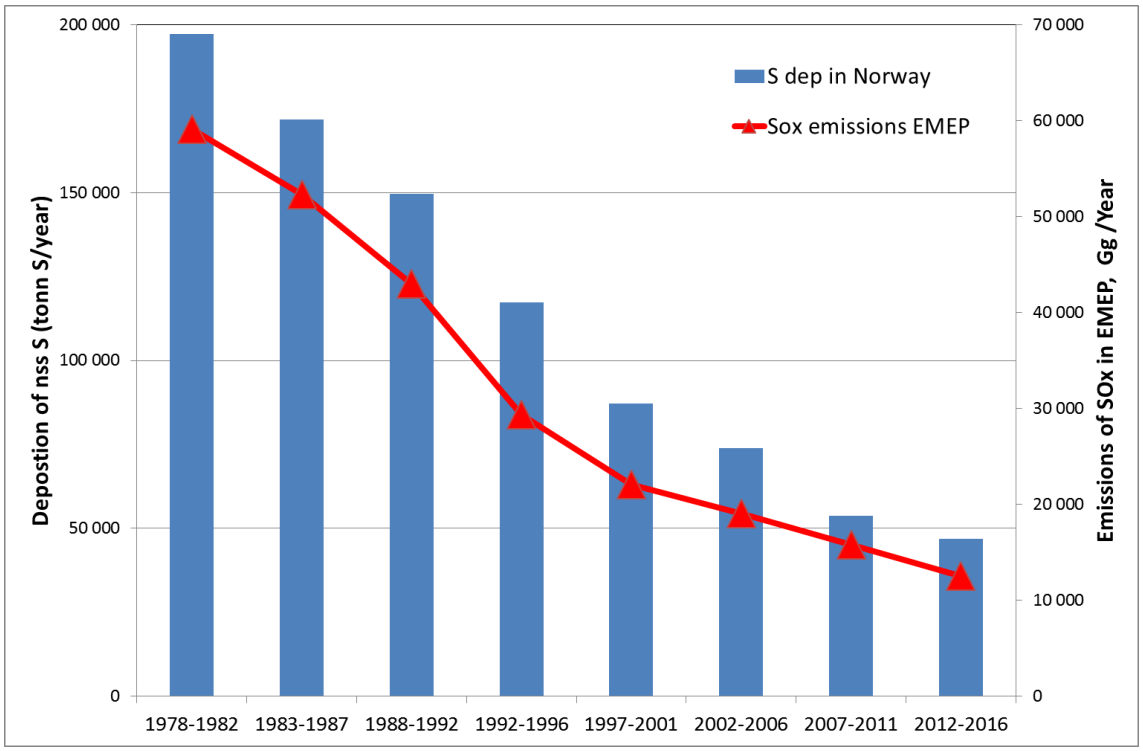

Figure 7: Deposition of non-sea salt sulfur in Norway (tonnes/year) compared with total S (GgS/year) emissions in Europe.

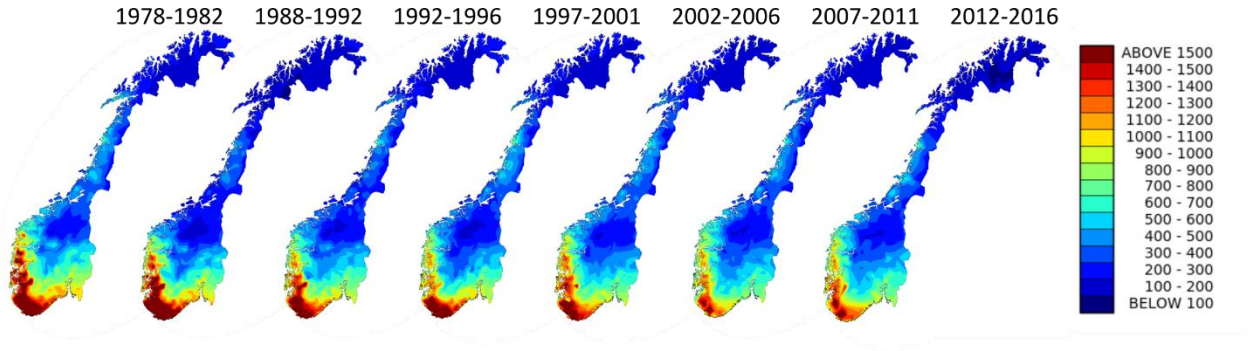

Figure 8: Trend in deposition of total nitrogen in Norway (mgS/m^{2}y).

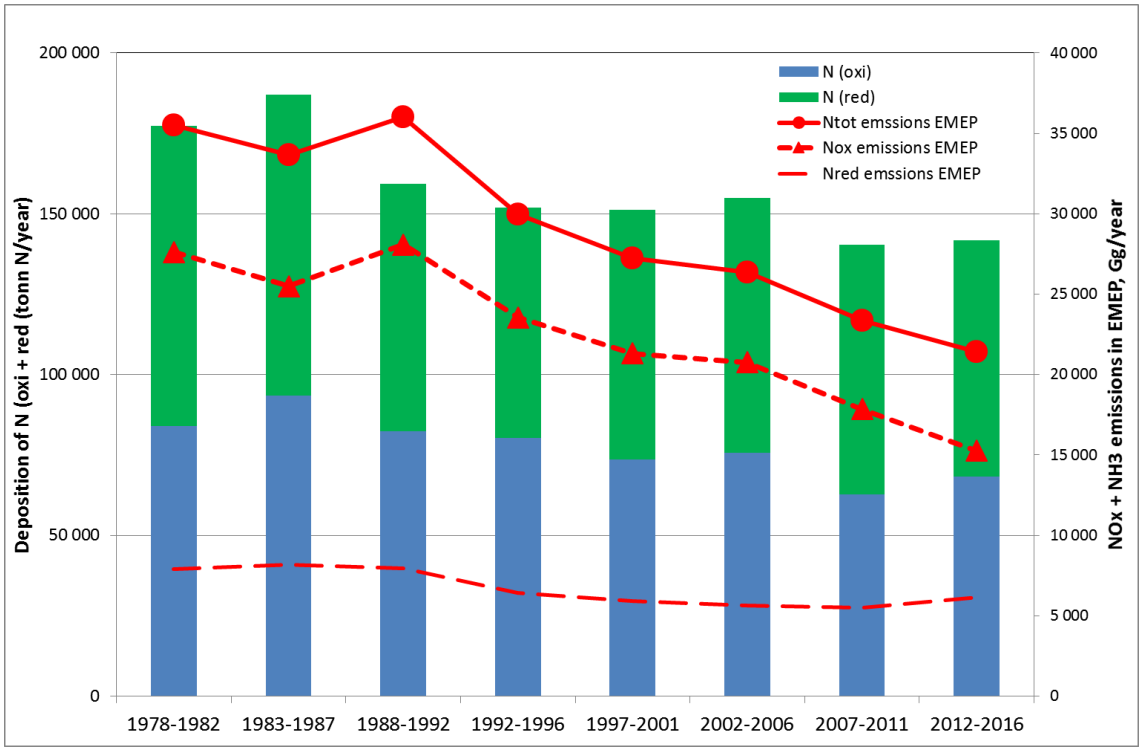

Figure 9: Deposition of nitrogen in Norway (tonnes/year) compared with nitrogen (GgN/year) emissions in Europe.

3.2 Combined method

The average annual total deposition of sulfur and nitrogen for 2012-2016 using the combined method is illustrated in Figure 10. The total deposition of nitrogen and sulfur show highest deposition in south of Norway which is closest to the main emission sources in Europe. The deposition is also high on the west coast due to high precipitation amount combined with moderate level of air pollution.

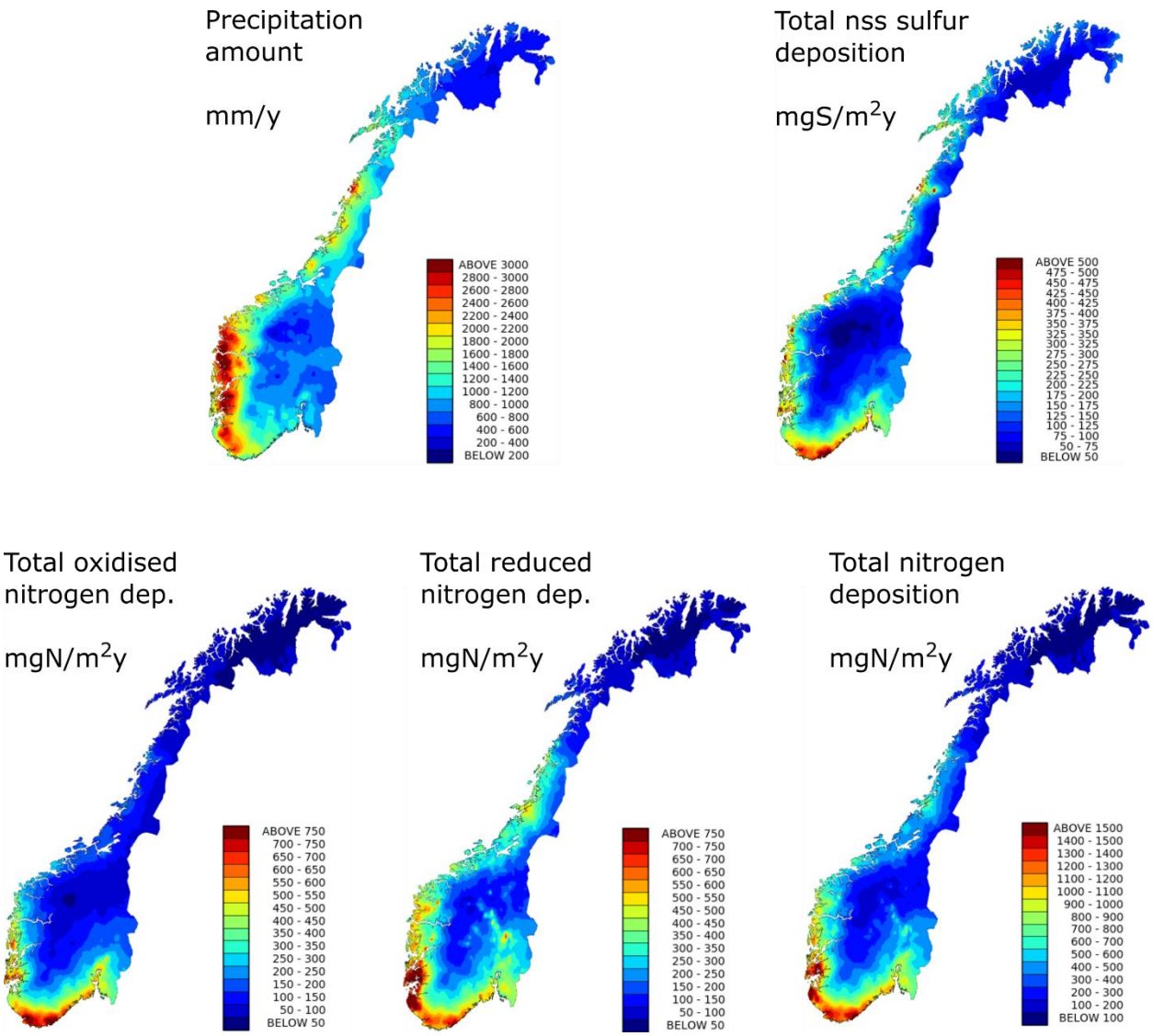

Figure 10: Spatial distribution of the total deposition of non-sea salt sulfur, oxidised nitrogen and reduced nitrogen for 2012-2016.

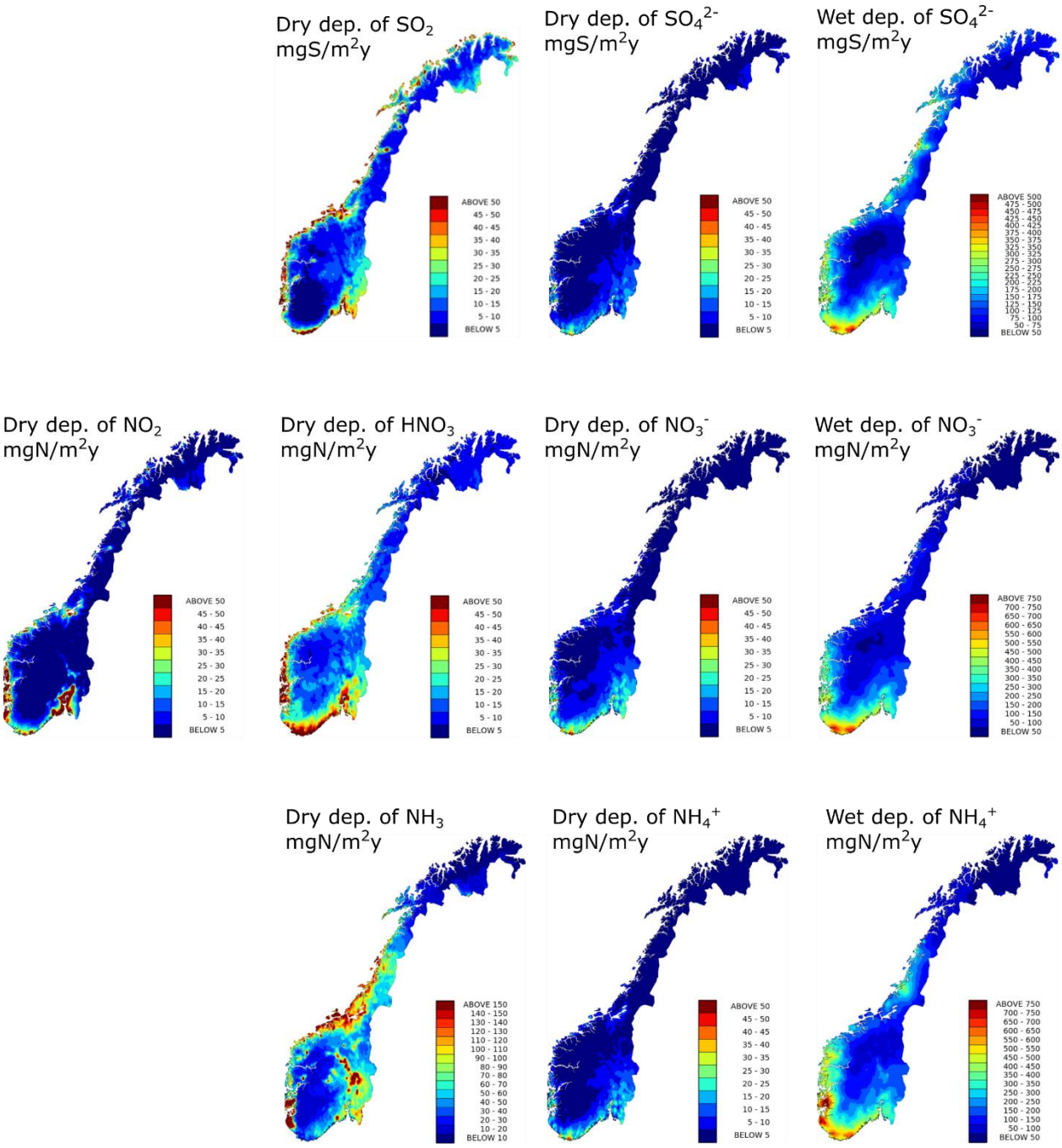

Figure 11: Spatial distribution of the wet and dry deposition of non-sea salt sulfur, oxidised nitrogen and reduced nitrogen compounds for 2012-2016.

The total deposition can be split up into contribution of the different components in gas phase, aerosols and precipitation. The deposition of all the individual components are mapped in Figure 11. There are a few interesting things to note from these maps:

- Wet deposition is the dominant contribution for all species as also seen for the observational method.
- The dry deposition of gases contributes more than the dry deposition of aerosols. This is reflected in the much higher dry deposition velocities of most gases compared to the aerosol components (Figure 2).
- Dry deposition of SO_2 is high along the whole coastal area. The high levels, especially in the north, are influenced by the volcanic emissions from the Holuhraun eruption from August 2014 to the end of February 2015. There are also elevated concentrations along the coast in other periods, indicating influence from ship emissions in addition to long range transport from the continent.
- High NH_3 deposition in the inland of Eastern Norway (Oppland and Hedmark) and at the West coast in Rogaland county. This is due to high reported emissions in these regions.
- High NH_3 deposition at the North-West coast. This is due to combination of relatively high observed NH_3 concentration combined with the high deposition velocity (Figure 2).
- The NO_2 deposition along the west coast and in the Oslo fjord as well as some indication of deposition along the E6 road from Oslo to Trondheim resembling the influence emissions from ships and traffic.

3.3 Discussion, comparing the two approaches

The results from the two methods have been compared and the differences in total deposition amount and the percent differences are illustrated in Figure 12. There is a clear pattern with the highest absolute differences is in the southwest, in Rogaland county while the percent highest differences are in the mountain areas and in North Norway in Finnmark county.

If comparing the total deposition in Norway as calculated for the old method given in Table 3, the new method estimates 4 kilo tonnes more total deposition of sulfur and 2 kilo tonnes more reduced nitrogen, while 12 kilo tonnes less total deposition of oxidised nitrogen deposition. This correspond to a per cent difference of 8%, 4% and -18% respectively.

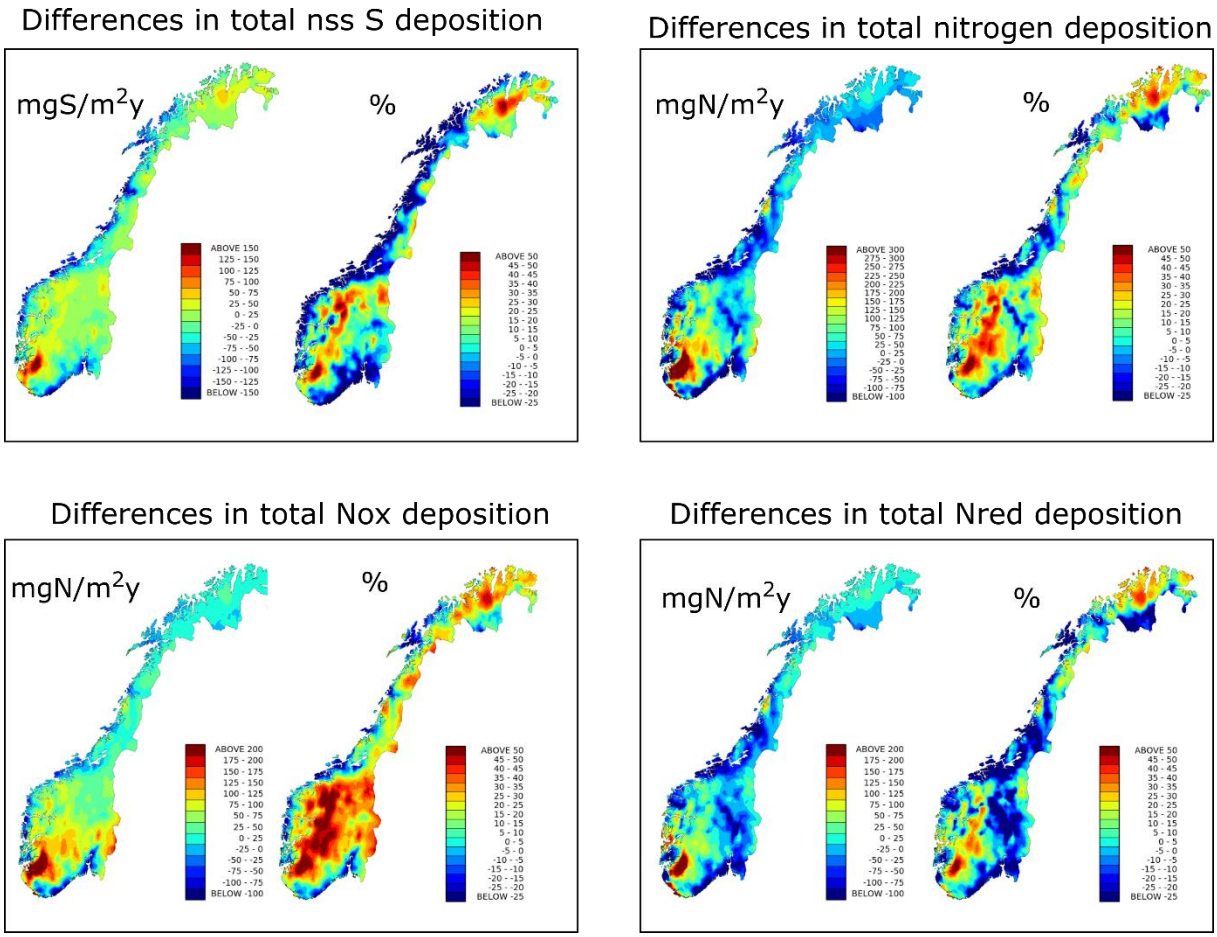

Figure 12: Differences in the total deposition of non-sea salt sulfur, oxidised nitrogen and reduced nitrogen compounds for 2012-2016 compared the old observational based method with the new approach combining observation and model. The difference map is calculated by observational based method - combined method. Thus, negative values (blue) show that the new combined method overestimate the deposition while red indicated an underestimation by the new method (or overestimation by the old method)

The main differences observed and the possible reasons behind these can be summed up in the following points:

- For both nitrogen and sulfur, the deposition is higher in the south-west (Rogaland county) for the observational based method compared to the combined method. This is due to the kriging method, which distributes higher concentrations to the west coast than the EMEP model calculates. The concentrations derived from the kriging in this area are probably positively biased since there are few sites in this region to guide the kriging method. The difference is enhanced by the high precipitation loading.
- Higher deposition along the coast, especially along the south coast, for the combined method compared to observational based method. The kriging method gives lower concentration especially in the southern Norway around the Birkenes area than what is actually the observed concentration at the site. This negative bias is a weakness of the method, which moves the gradient away from the site. The EMEP model tends to

give higher concentrations along the coast since the model assumes wash out of the air pollution faster than the kriging method.

- The depositions are lower in the mountain areas and in the Finnmark county with the combined method. This is because the EMEP model has a higher gradient from the coast to mountains where the pollution is washed out faster than the gradient obtained with the kriging method. In Finnmark there might be emissions in the region i.e. in Russia which is not included in the model.
- The nitrogen depositions in the inland of eastern Norway, in Oppland and Hedmark counties are higher for the combined method. This is mainly due to the high NH_3 emissions reported for this region, which is not found by the observational method.
- Higher dry deposition of NH_3 along the coast in Northern Norway (Nordland county) in the combined method. This is caused by the relatively high NH_3 observed at Tustervatn and Kårvatn combined with a high dry deposition velocity from the model (in the observation based method, dry deposition for NH3+NH4+ was calculated, assuming an average dry deposition velocity for NH3+NH4+. With relatively high NH3 concentrations from observations, the dry deposition of NH3 becomes higher).
- The combined method is giving a generally lower deposition for oxidised nitrogen than the observational method. This can partly be explained by the very different dry deposition rates used for nitrate. In the observational method a Vd of 2.0 cm/s for the sum (HNO_3+NO_3^-) is used over forest (Table 1), while nitrate in in the combined method is mostly well below 0.5 cm/s (Figure 2). Even though HNO_3 has a much higher deposition velocity in the combined method, the low concentrations of HNO_3 do not compensate to give sufficient total dry deposition of oxidised nitrogen.

To sum up, the methods are comparable and resemble the same general pattern of deposition throughout the country with higher deposition closer to the main emission sources in Europe, but with some regional differences. The combined method has improved the spatial information of the deposition pattern and for wet deposition it probably gives more realistic deposition than the old observation method. For dry deposition there are quite large uncertainties in the estimated dry deposition velocities in both methods. Further, there are also quite large uncertainties in the observations as well as the reported emissions of especially NH_3. The relatively few sites, especially for air components, makes it difficult to estimate the distance of influence of the measurements when adjusting the model results. Considering these uncertainties, there is higher confidence in the deposition estimates of sulfur than nitrogen.

It is recommended to further explore improvement in the combined method to give more confidence in especially the dry deposition processes. Further it is not sure that method used for correcting the EMEP/MSC-W model by using a gradient influence of the observation is the best option. There are other options for data assimilation, i.e. using original higher time resolution and explore different radius of influence for different components. Chemical data assimilation of air concentrations (e.g. 3DVar) are used by the EMEP/MSC-W model in the Copernicus Atmosphere Monitoring Service. At present, it is unclear how such a data

assimilation scheme will impact dry and wet deposition, but this could be explored in the future.

Within the Bedre Byluft project, an EMEP/MSC-W model version with a resolution of 2.5kmx2.5km for Norway is being developed at the moment (based on AROME meteorology). Clearly, such fine resolution calculations may refine the estimates presented here even further, if emissions of a sufficient resolution and quality is available.

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Appendix A

Figures 1.1-1.2 and Table 1.1

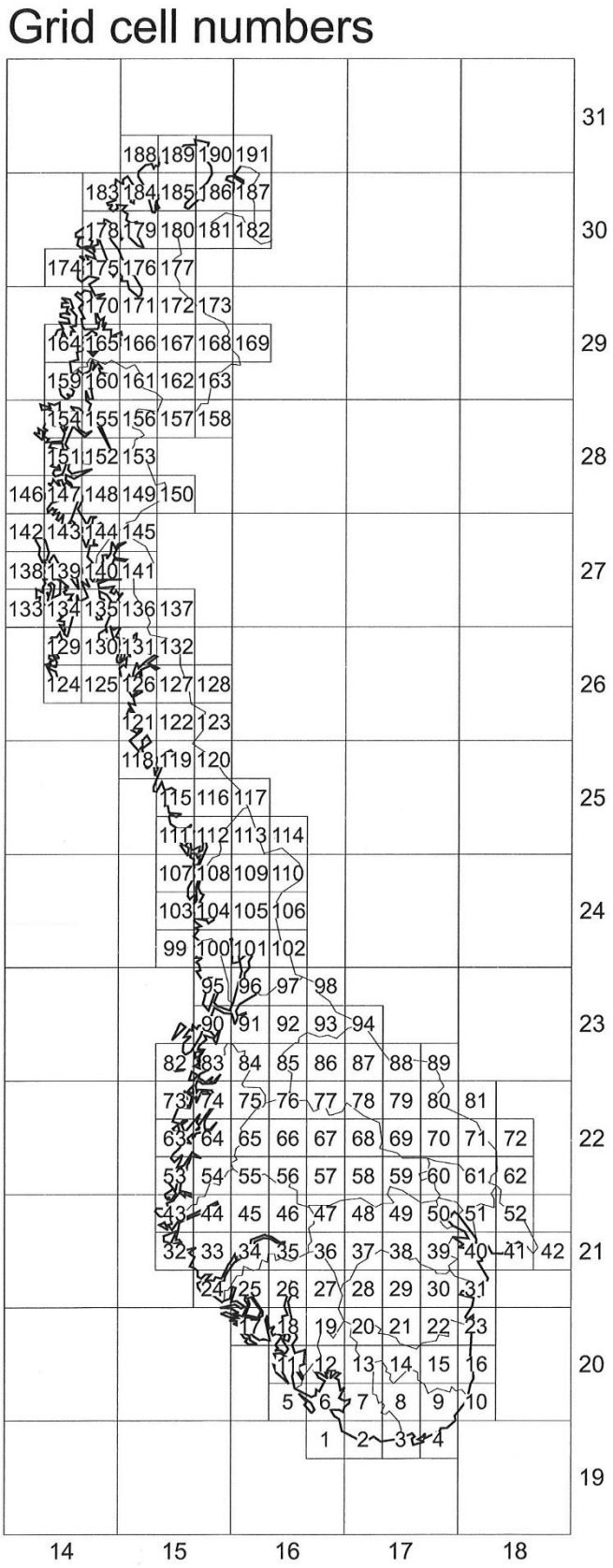

Figure 1.1: The 50x50 km² grid and grid cell numbers (EMEP sub-grid) used for interpolating concentration fields.

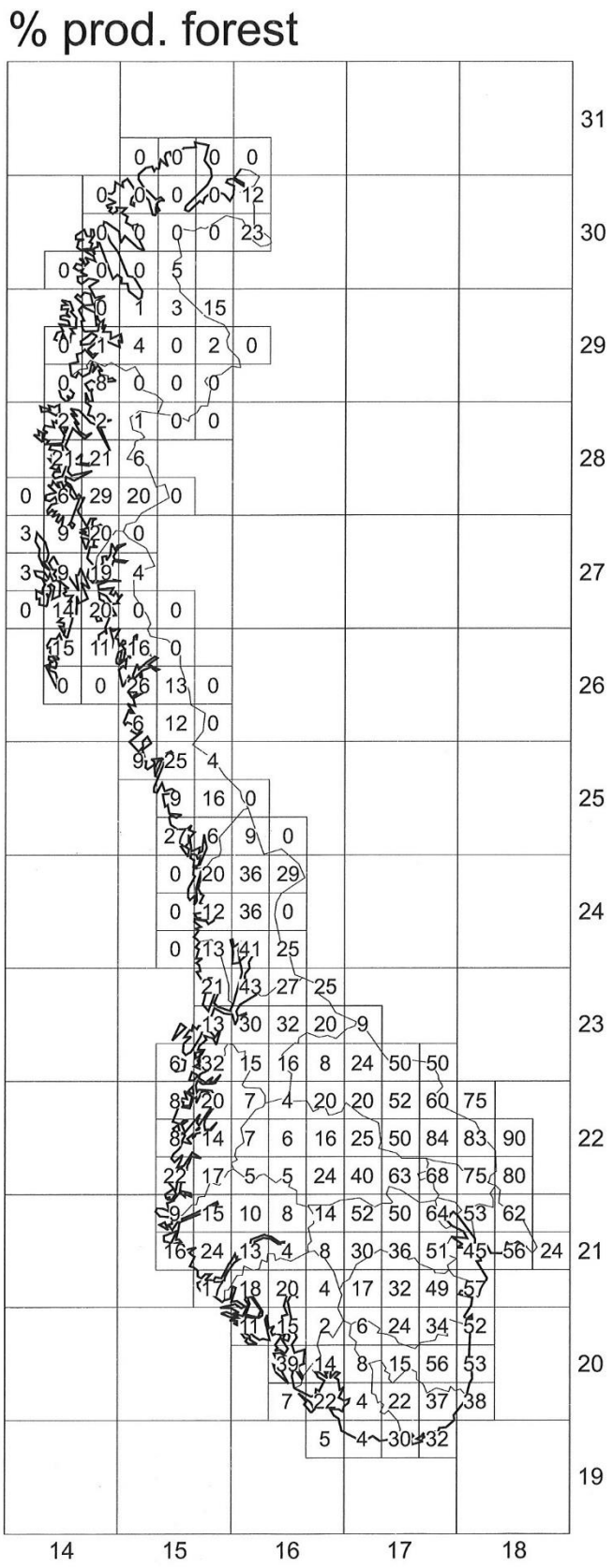

Figure 1.2: Percent productive forest used in estimating dry deposition.

Table 1.1: Values of each 50x50 km² grid cell, 2012-2015 (see Figure 1.1).

Grid cell no.	Total area (km2)	Average precipitation amount (mm)	Total nss S dep. (mg S/m2 yr)	Total N (oxi) (mg N/m2 yr)	Total N (red) (mg N/m2 yr)	Total N (red+oxi) (mg N/m2 yr)	Total nss K (mg/m2 yr)	Total ss K (mg /m2 yr)	Total nss Ca (mg/m2 yr)	Total ss Ca (mg/m2 yr)	Total Na (mg/m2 yr)	Total Mg (mg/m2 yr)	Total Cl (mg/m2 yr)	Total ss S (mg S/m2 yr)	Total nss S deposition (ton S in grid)	Total N (oxi) deposition (ton N in grid)	Total N (red) deposition (ton N in grid)	Total N deposition (ton N in grid)	Total nss K deposition (ton K in grid)	Total nss Ca deposition (ton Ca in grid)	Number of meteorol. sites in grid
1	100	1478	221	401	429	830	88	176	142	185	4889	589	8730	409	22	40	43	83	9	14	1
2	1270	1549	255	455	487	942	100	149	162	157	4137	498	7387	346	324	578	619	1197	126	206	3
3	1060	1856	336	639	605	1244	123	180	207	189	4990	601	8911	418	356	677	641	1318	131	219	3
4	950	1973	381	724	681	1405	129	166	220	175	4614	556	8239	386	362	688	646	1334	123	209	3
5	430	1262	151	276	335	611	74	123	112	129	3415	411	6098	286	65	119	144	263	32	48	1
6	450	1574	223	417	453	871	91	153	151	161	4246	512	7582	355	100	188	204	392	41	68	4
7	2480	2541	370	624	708	1332	150	220	240	231	6108	736	10906	511	918	1547	1757	3303	373	594	5
8	2500	2162	369	646	663	1310	145	147	238	155	4086	492	7296	342	922	1616	1659	3274	364	596	4
9	2480	1885	374	694	638	1332	128	136	218	143	3788	456	6764	317	928	1721	1583	3303	317	541	2
10	280	1515	344	656	586	1242	103	129	186	136	3600	434	6429	301	96	184	164	348	29	52	1
11	1310	2434	278	501	619	1121	131	274	211	288	7615	917	13598	637	364	657	811	1468	172	276	1
12	2450	2552	309	537	687	1223	137	191	228	201	5302	639	9468	444	756	1315	1682	2997	335	558	4
13	2500	2133	286	497	572	1069	144	136	222	143	3784	456	6757	317	714	1243	1430	2673	359	556	2
14	2450	1594	256	463	451	914	121	82	185	87	2292	276	4093	192	626	1134	1106	2240	297	453	3
15	2500	1698	337	640	547	1186	123	81	208	85	2240	270	4000	188	842	1599	1366	2965	307	521	3
16	750	1341	320	622	507	1129	90	97	170	102	2693	324	4808	225	240	466	381	847	68	127	5
17	1830	2553	230	385	508	892	142	222	204	234	6167	743	11013	516	420	704	929	1633	260	374	3
18	1950	2639	260	432	580	1013	156	175	229	184	4854	585	8669	406	507	843	1132	1975	303	447	4
19	2500	2547	277	467	611	1078	155	161	243	170	4479	540	7999	375	692	1167	1528	2695	387	607	2
20	2500	1738	210	383	417	800	137	89	197	94	2478	299	4425	207	526	957	1042	1999	342	492	5
21	2500	1126	172	345	302	647	102	31	147	33	875	105	1562	73	429	863	756	1619	255	368	3
22	2500	1226	230	455	379	834	87	34	137	36	941	113	1680	79	576	1138	947	2086	217	344	3
23	1350	1310	294	573	464	1036	86	58	150	61	1604	193	2863	134	397	773	626	1399	116	203	1
24	1150	3131	252	415	572	988	169	246	243	259	6843	824	12220	573	289	478	658	1136	194	279	4
25	2500	2887	237	401	500	901	148	185	216	194	5130	618	9160	429	593	1002	1250	2252	369	541	3
26	2250	1883	184	329	376	705	113	110	164	115	3045	367	5438	255	415	740	846	1586	255	369	5
27	2250	1040	121	251	251	503	82	62	114	65	1711	206	3055	143	273	565	566	1131	184	256	1
28	2400	924	123	254	236	490	89	19	119	20	526	63	938	44	296	610	566	1175	213	286	3
29	2500	892	139	305	249	554	90	21	121	23	596	72	1065	50	348	763	622	1386	225	302	3
30	2500	990	187	403	317	720	85	29	123	30	797	96	1424	67	468	1006	793	1799	212	307	5
31	1930	1233	268	527	420	948	93	58	145	61	1621	195	2895	136	516	1017	811	1829	179	280	2

Grid cell no.	Total area (km2)	Average precipitation amount (mm)	Total nss S dep. (mg S/m2 yr)	Total N (oxi) (mg N/m2 yr)	Total N (red) (mg N/m2 yr)	Total N (red+oxi) (mg N/m2 yr)	Total nss K (mg/m2 yr)	Total ss K (mg /m2 yr)	Total nss Ca (mg/m2 yr)	Total ss Ca (mg/m2 yr)	Total Na (mg/m2 yr)	Total Mg (mg/m2 yr)	Total Cl (mg/m2 yr)	Total ss S (mg S/m2 yr)	Total nss S deposition (ton S in grid)	Total N (oxi) deposition (ton N in grid)	Total N (red) deposition (ton N in grid)	Total N deposition (ton N in grid)	Total nss K deposition (ton K in grid)	Total nss Ca deposition (ton Ca in grid)	Number of meteorol. sites in grid
32	940	2824	207	332	461	792	133	245	179	258	6818	821	12176	571	194	312	433	745	125	168	1
33	2450	2689	207	350	492	842	139	178	197	187	4936	595	8814	413	507	858	1205	2064	340	483	3
34	2360	1194	102	192	213	405	66	59	91	62	1632	197	2914	137	242	453	502	955	155	216	2
35	2450	1356	133	231	260	491	86	53	114	56	1467	177	2620	123	325	565	637	1202	212	280	5
36	2500	813	101	198	198	396	70	14	91	15	384	46	685	32	251	495	495	989	175	227	4
37	2500	852	124	261	233	494	89	14	114	15	387	47	691	32	309	653	583	1235	222	284	1
38	2500	793	128	248	222	470	88	13	107	13	354	43	632	30	319	619	556	1175	220	269	1
39	2500	989	189	390	315	705	104	24	135	25	657	79	1174	55	473	975	787	1762	261	337	5
40	1730	1161	246	464	387	851	106	43	149	45	1196	144	2135	100	426	802	670	1472	184	257	3
41	1250	940	237	457	362	819	97	49	126	52	1365	164	2437	114	297	572	452	1024	121	158	4
42	125	940	260	428	367	795	91	50	113	52	1385	167	2474	116	32	53	46	99	11	14	1
43	1375	2359	173	273	374	647	132	180	164	189	5002	603	8932	419	238	375	515	890	182	225	3
44	2500	2307	170	282	409	691	116	130	157	137	3613	435	6451	302	425	706	1022	1728	290	392	7
45	2500	1811	149	249	330	578	99	74	135	78	2067	249	3692	173	372	622	824	1446	248	337	5
46	2400	751	80	156	157	313	58	26	71	27	718	87	1282	60	191	373	378	751	138	169	5
47	2500	868	109	203	200	403	79	12	94	12	323	39	577	27	273	508	500	1008	198	235	1
48	2500	581	98	236	188	424	69	15	87	15	407	49	728	34	244	589	470	1059	173	218	4
49	2500	929	161	332	283	615	113	18	138	18	488	59	872	41	403	830	707	1537	284	344	4
50	2500	916	186	384	314	698	116	23	143	24	635	77	1134	53	465	960	785	1744	289	357	10
51	2500	934	205	400	329	729	112	31	141	33	860	104	1536	72	511	999	823	1822	281	352	4
52	1210	923	228	439	356	795	104	37	134	39	1026	124	1833	86	276	532	431	962	125	162	1
53	900	1469	117	200	248	448	88	135	108	143	3765	454	6723	315	105	180	223	403	79	97	1
54	2400	1951	148	235	316	551	109	102	133	108	2844	343	5078	238	355	564	758	1321	262	320	3
55	2400	563	59	120	115	236	41	18	51	19	508	61	907	42	140	289	277	565	99	123	1
56	2500	886	94	164	177	341	69	11	85	12	307	37	548	26	235	410	442	852	174	212	1
57	2500	684	92	179	162	341	64	10	76	11	282	34	503	24	230	448	406	853	160	190	2
58	2500	689	110	223	186	409	75	11	89	11	302	36	539	25	275	558	464	1022	187	222	2
59	2400	818	150	306	251	557	99	14	123	14	380	46	678	32	361	735	602	1337	237	294	1
60	2500	886	183	363	298	661	106	19	135	20	536	65	956	45	457	907	744	1651	265	338	4
61	2467	758	171	360	285	644	90	21	120	22	589	71	1051	49	421	887	702	1589	222	296	3
62	250	765	190	400	312	712	91	17	121	18	475	57	849	40	47	100	78	178	23	30	1
63	900	1857	142	210	284	494	111	192	131	202	5344	644	9544	447	127	189	256	445	100	118	1
64	2100	954	81	138	159	298	61	45	71	47	1250	151	2232	105	170	291	335	625	129	149	2

Grid cell no.	Total area (km2)	Average precipitation amount (mm)	Total nss S dep. (mg S/m2 yr)	Total N (oxi) (mg N/m2 yr)	Total N (red) (mg N/m2 yr)	Total N (red+oxi) (mg N/m2 yr)	Total nss K (mg/m2 yr)	Total ss K (mg /m2 yr)	Total nss Ca (mg/m2 yr)	Total ss Ca (mg/m2 yr)	Total Na (mg/m2 yr)	Total Mg (mg/m2 yr)	Total Cl (mg/m2 yr)	Total ss S (mg S/m2 yr)	Total nss S deposition (ton S in grid)	Total N (oxi) deposition (ton N in grid)	Total N (red) deposition (ton N in grid)	Total N deposition (ton N in grid)	Total nss K deposition (ton K in grid)	Total nss Ca deposition (ton Ca in grid)	Number of meteorol. sites in grid
65	2300	361	42	86	78	164	31	6	37	7	177	21	316	15	96	197	179	377	71	85	1
66	2500	401	50	101	91	192	36	5	42	6	151	18	270	13	125	253	228	480	89	105	4
67	2500	640	88	158	150	308	59	8	69	8	213	26	380	18	220	395	374	769	148	172	3
68	2550	692	109	197	176	373	68	8	80	8	218	26	390	18	277	502	450	952	173	203	4
69	2500	711	131	250	205	455	72	10	93	11	281	34	502	24	328	625	512	1137	180	233	3
70	2500	875	185	371	298	669	98	14	130	15	394	47	704	33	462	928	746	1674	246	324	2
71	2300	811	182	367	290	657	82	13	110	13	354	43	632	30	418	844	668	1512	189	252	1
72	200	788	195	385	292	678	86	16	110	17	453	55	810	38	39	77	58	136	17	22	1
73	620	2245	168	232	343	574	141	194	164	205	5401	651	9645	452	104	144	213	356	87	102	1
74	2300	1606	131	196	244	440	106	87	122	92	2425	292	4330	203	302	451	562	1013	244	281	2
75	2500	1167	97	148	179	327	81	52	91	54	1432	173	2557	120	242	369	448	817	201	227	2
76	2500	422	54	94	91	185	35	7	41	7	187	23	335	16	134	236	227	463	88	103	2
77	2500	607	87	146	135	281	50	5	60	6	145	18	260	12	217	366	337	703	126	150	4
78	2500	547	88	158	146	303	51	7	59	7	187	23	334	16	221	394	364	758	126	149	1
79	2500	866	154	265	231	496	83	10	100	11	288	35	514	24	384	662	579	1241	208	250	2
80	2000	794	155	280	229	509	73	12	94	13	343	41	612	29	310	560	457	1017	145	187	2
81	200	881	190	344	264	609	80	13	99	14	364	44	650	30	38	69	53	122	16	20	1
82	770	1272	102	146	199	346	84	120	99	126	3327	401	5941	278	78	113	153	266	65	76	1
83	1900	1379	133	169	205	373	87	89	107	94	2487	300	4442	208	252	321	389	709	164	203	2
84	2500	720	74	109	116	225	56	30	64	31	827	100	1477	69	185	272	291	563	140	160	1
85	2500	537	69	108	105	213	44	13	53	13	349	42	623	29	172	269	262	531	110	132	3
86	2500	560	81	119	121	240	45	6	54	7	174	21	310	15	203	298	303	601	112	134	4
87	2450	621	102	158	151	309	53	6	63	7	178	21	318	15	251	388	369	756	131	155	1
88	1400	883	156	243	225	468	76	10	89	10	277	33	494	23	219	340	316	655	106	125	1
89	400	882	170	266	231	497	82	9	90	9	248	30	443	21	68	106	92	199	33	36	1
90	1500	955	92	119	159	278	65	89	83	94	2486	300	4439	208	138	178	239	416	97	124	1
91	2300	1135	117	146	186	331	80	58	100	61	1604	193	2864	134	270	335	427	762	184	229	2
92	2500	709	87	117	133	250	51	27	64	28	740	89	1321	62	217	293	333	626	127	160	1
93	2450	652	99	134	146	280	52	12	63	12	327	39	584	27	242	328	357	686	128	154	3
94	800	673	110	139	148	287	55	5	63	5	130	16	232	11	88	111	118	229	44	50	1
95	1400	1647	159	175	270	445	104	151	135	158	4184	504	7472	350	222	245	378	623	146	189	1
96	2100	1052	118	143	185	327	69	58	87	61	1614	194	2882	135	247	299	388	687	146	183	5
97	2230	936	121	130	158	288	55	35	74	37	971	117	1734	81	269	289	353	642	123	165	4

Grid cell no.	Total area (km2)	Average precipitation amount (mm)	Total nss S dep. (mg S/m2 yr)	Total N (oxi) (mg N/m2 yr)	Total N (red) (mg N/m2 yr)	Total N (red+oxi) (mg N/m2 yr)	Total nss K (mg/m2 yr)	Total ss K (mg /m2 yr)	Total nss Ca (mg/m2 yr)	Total ss Ca (mg/m2 yr)	Total Na (mg/m2 yr)	Total Mg (mg/m2 yr)	Total Cl (mg/m2 yr)	Total ss S (mg S/m2 yr)	Total nss S deposition (ton S in grid)	Total N (oxi) deposition (ton N in grid)	Total N (red) deposition (ton N in grid)	Total N deposition (ton N in grid)	Total nss K deposition (ton K in grid)	Total nss Ca deposition (ton Ca in grid)	Number of meteorol. sites in grid
98	2230	843	110	122	146	268	50	18	68	19	495	60	884	41	246	272	326	597	112	151	1
99	600	929	128	136	165	301	53	15	71	16	412	50	735	34	77	81	99	180	32	43	1
100	2150	1796	173	178	307	485	114	166	143	175	4612	556	8235	386	372	382	661	1043	246	308	2
101	2450	990	120	134	176	310	59	58	78	61	1615	195	2884	135	295	328	431	758	145	191	2
102	800	954	131	124	155	279	47	35	66	37	970	117	1731	81	104	99	124	223	38	53	1
103	400	1569	127	151	273	424	106	176	128	185	4896	590	8742	410	51	60	109	170	43	51	1
104	2500	1415	131	144	249	393	94	118	117	124	3282	395	5860	275	328	360	621	982	235	292	2
105	2500	1092	126	135	198	333	68	65	89	68	1803	217	3220	151	315	337	496	833	170	222	2
106	300	1046	139	110	148	259	45	30	63	31	824	99	1472	69	42	33	45	78	13	19	1
107	400	1650	142	149	308	457	104	185	136	195	5146	620	9190	431	57	60	123	183	42	54	1
108	2500	1724	158	167	341	508	120	138	149	145	3824	461	6829	320	394	418	853	1271	299	372	2
109	2500	1236	141	157	294	451	99	67	130	71	1873	226	3345	157	353	393	735	1128	249	324	1
110	2100	752	96	104	148	252	45	26	59	27	710	86	1267	59	202	218	310	529	95	124	2
111	1100	1691	143	166	323	489	106	158	131	166	4395	529	7848	368	157	182	355	537	116	144	2
112	2500	1568	132	146	295	441	103	133	136	140	3707	447	6619	310	330	365	737	1102	256	341	1
113	2200	851	82	96	175	270	59	39	78	42	1096	132	1957	92	180	210	384	595	130	172	1
114	100	785	86	89	146	235	49	23	61	24	626	75	1117	52	9	9	15	23	5	6	1
115	2350	1452	118	138	260	398	85	118	106	124	3273	394	5845	274	277	325	610	935	201	250	2
116	2450	1239	104	126	218	344	75	80	102	84	2226	268	3975	186	254	308	535	843	183	251	1
117	700	985	90	100	174	274	61	50	79	53	1395	168	2491	117	63	70	122	192	42	55	1
118	1100	1642	126	154	300	453	106	146	127	154	4069	490	7265	341	138	169	330	499	116	140	3
119	2390	1482	117	149	263	412	91	102	115	107	2830	341	5054	237	280	356	629	986	218	276	3
120	1200	1097	88	109	171	280	66	60	84	64	1677	202	2994	140	106	130	206	336	79	101	3
121	2000	1503	130	139	245	383	97	141	109	149	3923	473	7005	328	260	277	489	766	193	218	1
122	2500	1388	122	132	224	357	88	89	99	94	2485	299	4438	208	304	331	561	891	219	247	1
123	400	1097	101	105	171	277	69	63	70	66	1743	210	3113	146	40	42	69	111	28	28	1
124	300	1593	104	134	199	333	94	149	116	157	4132	498	7378	346	31	40	60	100	28	35	2
125	100	1423	132	127	191	318	88	160	75	168	4439	535	7927	372	13	13	19	32	9	8	1
126	2300	1082	105	101	134	235	58	99	52	105	2765	333	4938	231	241	233	308	541	133	120	1
127	2400	1102	107	99	133	231	62	53	53	56	1476	178	2635	124	257	237	318	555	148	127	1
128	200	1099	110	96	145	241	68	63	56	66	1747	210	3119	146	22	19	29	48	14	11	1
129	400	1813	150	130	176	306	84	199	90	209	5526	666	9868	463	60	52	70	122	34	36	1
130	900	1273	121	100	144	245	66	116	55	122	3234	390	5775	271	109	90	130	220	59	50	1

Grid cell no.	Total area (km2)	Average precipitation amount (mm)	Total nss S dep. (mg S/m2 yr)	Total N (oxi) (mg N/m2 yr)	Total N (red) (mg N/m2 yr)	Total N (red+oxi) (mg N/m2 yr)	Total nss K (mg/m2 yr)	Total ss K (mg /m2 yr)	Total nss Ca (mg/m2 yr)	Total ss Ca (mg/m2 yr)	Total Na (mg/m2 yr)	Total Mg (mg/m2 yr)	Total Cl (mg/m2 yr)	Total ss S (mg S/m2 yr)	Total nss S deposition (ton S in grid)	Total N (oxi) deposition (ton N in grid)	Total N (red) deposition (ton N in grid)	Total N deposition (ton N in grid)	Total nss K deposition (ton K in grid)	Total nss Ca deposition (ton Ca in grid)	Number of meteorol. sites in grid
131	2500	1283	128	106	145	251	68	72	56	76	1997	241	3566	167	320	264	363	627	169	141	2
132	1300	1107	120	93	124	217	90	48	66	51	1341	162	2394	112	155	121	161	282	117	86	1
133	700	1600	157	101	123	224	55	176	43	185	4886	589	8725	409	110	71	86	156	38	30	1
134	700	2252	214	129	160	289	75	205	59	216	5701	687	10180	477	150	90	112	202	52	41	1
135	1500	1616	156	119	172	291	81	140	67	147	3888	468	6944	325	234	179	258	436	122	101	1
136	1400	1275	137	98	135	233	103	82	76	86	2276	274	4065	191	192	137	189	326	144	106	1
137	100	1275	148	104	141	245	127	57	83	60	1596	192	2850	134	15	10	14	25	13	8	1
138	400	1226	123	76	84	160	41	126	33	132	3492	421	6236	292	49	30	34	64	16	13	2
139	1000	1349	136	85	103	188	47	123	35	130	3425	413	6116	287	136	85	103	188	47	35	1
140	1400	1321	165	98	111	208	129	115	90	121	3198	385	5712	268	231	137	155	291	181	126	1
141	1400	1214	149	95	122	217	95	69	59	73	1929	232	3445	161	208	133	170	303	133	83	1
142	400	973	102	67	84	151	35	110	28	115	3048	367	5443	255	41	27	34	60	14	11	1
143	900	816	107	68	79	146	82	75	60	79	2086	251	3725	175	97	61	71	132	74	54	1
144	1600	1047	134	87	103	189	92	79	72	83	2199	265	3927	184	214	139	164	303	147	115	1
145	1100	770	100	63	72	135	54	28	43	29	771	93	1377	65	110	69	80	149	59	48	1
146	100	968	101	64	80	144	34	112	27	118	3106	374	5546	260	10	6	8	14	3	3	1
147	1600	964	125	74	88	162	95	88	70	93	2456	296	4386	206	199	119	140	259	152	111	1
148	2450	684	99	71	76	147	61	41	47	43	1147	138	2048	96	243	173	186	359	148	114	1
149	2450	492	74	58	59	117	27	25	24	26	690	83	1232	58	181	142	144	286	67	58	1
150	200	492	75	53	56	108	30	23	25	24	632	76	1129	53	15	11	11	22	6	5	1
151	1400	980	135	82	92	174	99	86	72	90	2388	288	4263	200	189	115	129	244	138	101	3
152	2400	571	90	61	65	126	56	34	42	36	938	113	1676	79	216	147	155	302	134	101	1
153	1800	531	82	56	53	109	36	21	30	22	589	71	1052	49	147	100	95	195	64	54	1
154	1550	792	114	64	73	137	82	73	60	77	2020	243	3608	169	176	100	113	213	127	92	1
155	2300	458	73	49	49	98	37	40	30	43	1125	136	2010	94	168	113	113	226	85	69	1
156	2100	509	82	54	49	103	38	19	32	20	520	63	929	44	171	114	103	216	81	68	1
157	1300	486	85	53	48	102	41	18	33	19	497	60	888	42	110	69	63	132	54	43	1
158	300	497	93	58	49	107	49	56	38	59	1568	189	2801	131	28	17	15	32	15	11	1
159	900	787	94	48	51	98	26	75	21	79	2083	251	3720	174	85	43	46	88	24	19	1
160	2500	509	90	47	43	91	41	28	31	29	767	92	1370	64	225	118	109	227	103	78	1
161	2500	486	86	47	40	87	40	14	31	15	394	47	703	33	215	117	101	217	99	77	1
162	2500	463	82	52	46	98	38	14	31	15	395	48	706	33	206	129	115	245	95	77	1
163	1500	531	100	59	51	110	64	11	43	12	310	37	553	26	150	89	76	165	96	65	1

Grid cell no.	Total area (km2)	Average precipitation amount (mm)	Total nss S dep. (mg S/m2 yr)	Total N (oxi) (mg N/m2 yr)	Total N (red) (mg N/m2 yr)	Total N (red+oxi) (mg N/m2 yr)	Total nss K (mg/m2 yr)	Total ss K (mg /m2 yr)	Total nss Ca (mg/m2 yr)	Total ss Ca (mg/m2 yr)	Total Na (mg/m2 yr)	Total Mg (mg/m2 yr)	Total Cl (mg/m2 yr)	Total ss S (mg S/m2 yr)	Total nss S deposition (ton S in grid)	Total N (oxi) deposition (ton N in grid)	Total N (red) deposition (ton N in grid)	Total N deposition (ton N in grid)	Total nss K deposition (ton K in grid)	Total nss Ca deposition (ton Ca in grid)	Number of meteorol. sites in grid
164	300	796	144	79	80	159	86	73	42	77	2025	244	3617	170	43	24	24	48	26	12	1
165	300	683	110	58	60	118	66	60	47	63	1658	200	2960	139	33	17	18	35	20	14	1
166	2150	442	79	45	38	84	32	21	30	23	597	72	1066	50	169	97	82	180	69	63	2
167	2500	430	88	46	39	85	65	13	38	13	349	42	623	29	221	116	96	212	163	95	1
168	2400	475	98	53	41	94	61	7	39	8	201	24	358	17	235	127	98	225	147	94	1
169	300	503	104	58	42	100	60	44	41	46	1221	147	2180	102	31	17	13	30	18	12	1
170	2000	761	148	78	81	159	81	57	41	60	1591	192	2841	133	296	156	162	318	162	82	1
171	2400	660	144	76	70	146	157	32	72	34	890	107	1590	75	346	183	167	350	376	173	1
172	2300	410	96	49	39	89	72	12	40	13	336	40	599	28	221	114	91	204	166	92	1
173	400	442	106	56	42	99	69	51	42	53	1405	169	2508	118	43	23	17	39	28	17	1
174	300	723	142	75	77	152	80	71	39	74	1967	237	3512	165	42	23	23	46	24	12	1
175	2200	612	133	68	69	138	73	51	36	54	1416	171	2529	119	293	150	152	303	161	79	1
176	2340	469	125	56	58	114	164	31	65	32	850	102	1519	71	292	131	136	267	384	153	1
177	1300	401	99	51	43	94	71	18	32	19	492	59	878	41	129	66	56	122	92	42	1
178	900	612	133	68	69	137	73	64	36	67	1770	213	3160	148	120	61	62	124	66	32	1
179	2300	491	127	58	61	119	167	45	67	48	1258	152	2246	105	291	132	141	274	384	155	2
180	2000	397	107	49	48	97	92	20	41	21	544	66	972	46	215	98	96	194	183	82	2
181	1300	450	112	53	48	101	69	22	38	23	612	74	1093	51	145	69	63	132	90	50	1
182	1300	480	130	62	53	114	143	23	75	24	636	77	1136	53	169	80	69	149	186	97	1
183	300	612	133	68	69	138	73	68	36	71	1877	226	3353	157	40	20	21	41	22	11	1
184	1600	491	128	58	62	120	175	46	74	48	1266	152	2260	106	205	93	99	192	280	119	1
185	2500	402	110	50	50	100	119	40	53	42	1103	133	1969	92	276	124	125	250	299	134	1
186	2300	527	137	59	62	121	143	31	70	32	849	102	1516	71	314	137	143	279	330	162	1
187	1400	520	148	63	65	128	169	30	92	31	823	99	1470	69	207	89	91	179	236	129	2
188	400	551	147	64	71	135	222	62	94	66	1735	209	3098	145	59	26	28	54	89	38	1
189	1400	575	151	65	70	135	179	65	90	68	1806	218	3224	151	211	91	98	189	250	126	1
190	700	575	155	66	72	138	184	54	93	57	1497	180	2673	125	108	46	50	96	129	65	1
191	300	495	159	58	53	111	103	55	70	58	1522	183	2719	127	48	18	16	33	31	21	1

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NILU – Norwegian Institute for Air Research
P.O. Box 100, NO-2027 KJELLER, Norway

E-mail: nilu@nilu.no
http://www.nilu.no

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