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Deposition of major inorganic compounds in Norway 1992-1996

Kjetil Tørseth and Arne Semb

NATURENS TÅLEGRENSER

Preface

Nature Tolerance Levels

The programme on Tolerance Levels in Nature was started by the Norwegian Ministry of Environment in 1989. The programme aims to obtain background material for international agreements on reductions of emissions. Within the Convention on Long Range Transboundary Air Pollution the members have decided that new agreements on emission reduction will be based on the principle of critical load.

A steering group with members from the Ministry of Environment has the overall responsibility of the programme. The following departments in the Ministry are represented in the steering group:

- Department of Nature Conservation and Cultural Heritage
- Department for International Co-operation, Air Management and Polar Affairs
- Department for Water, Waste Management and Industry

The administration of the programme has been given to a working group with representatives from the Directorate for Nature Management (DN), Norwegian Pollution Control Authority (SFT) and Norwegian Polar Institute (NP).

The working group has the following representatives:

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Tor Johannessen - SFT
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Summary

The total depositions of sulphur and nitrogen compounds in Norway have been estimated with a grid resolution of 50·50 km², based on available measurements of air and precipitation chemistry. The first estimate was covering the period 1983-87 (Pedersen et al., 1990) while a later work gives results for the period 1988-1992 (Tørseth and Pedersen, 1994). In this report, estimates for the period 1992-1996 are given and compared to the previous estimates. In addition, the depositions of sea-salts and non sea-salt potassium and calcium have been estimated. The results are presented as tabulated values to the individual grid cells, and visualised on geographical maps.

The average total deposition (1992-1996) of the non sea-salt compounds were highest in the south-western part of Norway with maximum sulphur deposition exceeding 1.1 g S/m² in grid cell no. 4, and approx. 1.0 g S/m² in the neighbouring cells (8 and 9). The lowest depositions were observed along the Swedish border from Finnmark in the north down to Oppland in central Norway with values approximately one order of magnitude lower than in the maximum areas. Similarly, deposition values for individual meteorological sites varied from at most 1.6 g S/m² down to 0.07 g S/m². The largest grid cell depositions of oxidised and reduced nitrogen were 1.0 and 0.77 g N/m², whereas the lowest depositions were 0.06 and 0.05 g N/m², respectively. Similarly, total nitrogen deposition for the individual sites varied from 0.11 to 2.28 g N/m²

Estimated total yearly depositions were for the period 1992-96 approximately 114 000 tonnes sulphur and 152 000 tonnes nitrogen. Compared with similar estimates for the period 1983-87 and 1988-1992, there has been a reduction in the sulphur deposition of 33% and 23%, respectively. For nitrogen deposition, corresponding reductions were 14% and 2% for oxidised nitrogen, and 23% and 6% for reduced nitrogen compounds. Also the amounts of precipitation varied significantly between the different periods with 11% lower amounts during the period 1983-87 and 13% higher amounts during 1988-92, compared to 1992-1996. However, changes in precipitation amounts can only to a small extent explain the observed changes in deposition of sulphur and nitrogen

Although we emphasised to use the same methodology, there are some minor differences in the way depositions have been estimated compared to the previous estimates. In addition, the number of measurement sites increased significantly from 1983-87 to 1988-92. Compared to the period 1988-92 we assume that the results are readily comparable, whereas compared to 1983-87 some caution should be made.

Estimates of depositions of sea-salt ions, non sea-salt potassium and non sea-salt calcium have been improved by using a larger number of sites, the application of ambient air concentrations compared to throughfall measurements to quantify dry deposition, and for sea-salts a model describing concentration levels in precipitation as a function of the distance to the coast. Still, however, considerable uncertainty in the estimates are expected.

Sammendrag

De totale avsetninger av svovel og nitrogenforbindelser til Norge har vært estimert basert på målinger av luft- og nedbørkjemi. Det første estimatet omfattet perioden 1983-1987 (Pedersen et al., 1990) mens et senere arbeid dekket perioden 1988-1992 (Tørseth and Pedersen, 1994). I denne rapporten presenteres estimater for perioden 1992-1996 og disse er sammenlignet med de tidligere perioder. I tillegg er det beregnet avsetninger av sjøsalter og ikke-marin kalium og kalsium. Resultatene er vist som tabulerte verdier til et landsdekkende rutenett på 50·50 km2, og visualisert på geografiske kart.

Total avsetning av ikke-marine komponenter var størst i de sør-vestre deler av landet med maksimal svovel deposisjon over 1,1 g/m^2 i rute 4 (Vest-Agder), mens de laveste avsetninger ble registrert langs svenske-grensen fra Finnmark og til Oppland fylke. Tilførselen var omlag en tidel av tilførselen i maksimumsområdet. Fordelingsmønstret for nitrogen (totalt oksidert og redusert) er svært likt det for svovel, med tilsvarende avsetningstall fra 1,77 g/m^2 til 0,11 g/m^2. Totale avsetninger for Norge er beregnet til 114 000 tonn svovel og 152 000 tonn nitrogen. Sammenlignet med periodene 1983-1987 og 1988-1992 har det vært en reduksjon i svovelavsetningen på hhv. 33% og 23%, mens det for nitrogenforbindelser var reduksjoner i størrelsesordenen 14% og 2% (oksiderte forbindelser) og 23% og 6% for reduserte forbindelser. Også mengdene nedbør varierte betydelig mellom de ulike periodene med hhv. 11% mindre i 1983-1987 og 13% mer i perioden 1988-1992. Endringene i nedbørmengde vil bare til en viss grad kunne forklare de observerte variasjoner i tilførsel av svovel og nitrogen, og det antas at endrede utslippsmengder er den viktigste forklaringen til variasjonen mellom periodene. Små ulikheter i metodikken benyttet ved de ulike estimatene, og særlig sammenlignet med 1983-87, gjør imidlertid at direkte sammenligninger ikke kan gjøres ukritisk. De presenterte tilførselstall for sjøsalter og ikke-marin kalsium og kalium antas å inneholde en betydelig usikkerhet sammenlignet med estimatene for svovel og nitrogen.

Deposition of major inorganic compounds in Norway 1992-1996

1. Introduction

In order to evaluate the exceedance of critical loads to the ecosystems, quantified atmospheric input to the system is essential. The atmospheric input of pollutants can be determined from atmospheric dispersion models, by using emission data, meteorological data and parameters describing transformation and removal processes (Barrett et al., 1995). Under the Co-operative programme for the monitoring and evaluation of long-range transmissions of air pollutants in Europe (EMEP), concentration and deposition fields are calculated at two Meteorological Synthesising Centres for all European countries. So far one-layer Lagrangian models and a grid size of 150·150 km^2 have been used, but the grid size has recently been reduced to 50·50 km^2. A multi-layer Eulerian model using a grid size of 50·50 km^2 is also being developed.

Atmospheric inputs may also be inferred from measurements of air and precipitation chemistry. Particularly in a country like Norway, where large topographical features cause large variations in depositions, use of measured concentrations an precipitation amounts makes it possible to determine the inputs by precipitation more directly and with more detailed spatial resolution than are available from models. Dry deposition may also be inferred from measured airborne concentrations. In this case it is essential to take into account seasonal variations and differences in ground cover. The heterogeneity of the surface characteristics are also reflected in the critical loads for specific receptor areas and ecosystems, which makes it desirable to determine atmospheric inputs with the same spatial resolution.

In this work, estimates of the total depositions of all major inorganic compounds (sulphur, nitrogen, non sea-salt base cations (K and Ca) and sea-salts (Na, Mg, Cl, K, Ca, S) of interest in the evaluation of critical loads for acidity and for nutrient nitrogen, are presented. The estimates are based on data available through the national air- and precipitation monitoring program, combined with information about precipitation amounts from the national meteorological network (DNMI). Estimates for the period 1992-1996 are presented and compared with similar estimates for the periods 1983-87 (Pedersen et al., 1990) and 1988-1992 (Tørseth and Pedersen, 1994).

2. Deposition processes

Sulphur and nitrogen compounds can be deposited either by precipitation (wet deposition) or by dry deposition. In precipitation, the major species are sulphate (SO_4^{--}), nitrate (NO_3^-), ammonium (NH_4^+) chloride (Cl), sodium (Na), magnesium (Mg), potassium (K) and calcium (Ca). The major sulphur and nitrogen compounds in air are sulphur dioxide (SO_2) and particulate sulphate (SO_4^{--}),

nitrogen monoxide (NO), nitrogen dioxide (NO_2), nitric acid (HNO_3), particulate nitrate (NO_3^-), ammonia (NH_3) and particulate ammonium (NH_4^+).

Wet deposition is generally 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 usually collects no precipitation sample from such events.

When using measured concentrations in ambient air to infer dry deposition of sulphur and nitrogen, seasonal deposition velocities (Voldner and Sirois, 1986) may be used which summarise the transfer resistance's calculated from more detailed dry deposition models (e.g. Hicks et al., 1987). Such extrapolation from detailed modelling also requires knowledge of climatic conditions and ground cover characteristics. In view of the large uncertainties involved, particularly in connection with variation in ground cover and climatic conditions within Norway, a simplistic approach was chosen. The various dry deposition processes and deposition of fog droplets are described in the literature e.g. Lövblad et al. (1993). Only parts of this discussion will be repeated here. Instead a short description will be given for each component on how the dry deposition has been estimated from the measured concentration of each airborne component. The procedures are chosen to be as simple and straightforward as possible, taking into account differences in ground cover, climatic conditions and exposure to pollutants, which show a considerable geographical variation.

Under dry conditions, the deposition of sulphur dioxide (SO_2) is mainly regulated by stomatal resistance. However, absorption of sulphur dioxide on wetted foliage seems to be an important explanation for "dry deposition" under wintertime conditions. Because sulphur dioxide concentrations in ambient air are relatively high in winter, and because of enhanced frequency and duration of wetness, this may explain a relatively large part of the sulphur deposition as inferred from canopy throughfall measurements, particularly in coastal areas. Snow crystals, on the other hand, do not absorb sulphur dioxide. Therefore, the dry deposition of sulphur dioxide to snow surfaces depends on oxidation of absorbed sulphur dioxide in the liquid-films at the surface nucleated by impurities in the snow (Valdez et al., 1987). The result is a very small deposition of sulphur dioxide to snow surfaces as well as to snow-covered vegetation at temperatures below 0°C. Even nitric acid does not deposit onto snow surfaces at below -2°C (Johansson and Granat, 1987).

From catchment mass balances and canopy experiments in southern Sweden, Hultberg and Grennfelt (1992) found that coniferous forest stands in southern Sweden collected 2-3 times more sulphur than adjoining clear-cut areas. It was also shown that the deposition by throughfall was much larger at the forest edges than inside a larger plot of homogenous forest. The interpretation of these results is somewhat ambiguous, since the excess sulphate in throughfall may be caused both by deposition of sulphur dioxide and by deposition of sulphate aerosol particles. In the former case, the results point to deposition of sulphur dioxide in situations with wet foliage, when aerodynamic resistance is controlling the deposition. The observations were made in areas with typically wet and windy

climate. In other areas it has been found that spruce stands will collect, on average, 30-70% more sulphur dioxide than stands of pine or deciduous trees. This is readily explainable on the basis of higher leaf area index for spruce (Ivens et al., 1990). For sulphur dioxide, therefore, deposition velocity of 0.4 cm/s and 0.8 cm/s have been chosen for non-forested and forested areas, respectively. It is implicated that, while stomatal uptake rate is reduced during the non-growing season, this is largely compensated because of a higher occurrence of wet surfaces under typical Norwegian winter conditions, if there is no frost or snow. The deposition rate for SO_2 has been strongly reduced for all types of surface cover in the presence of a lasting snow cover.

The deposition velocity for NO_2 is not influenced by the presence of wet surfaces and has been shown to be mainly regulated by stomatal control. A generally low deposition velocity of 0.2 to 0.4 cm/s serves to keep the dry deposition of this component relatively insignificant (Johansson, 1987). In winter, stomatal uptake is insignificant, and deposition velocities correspondingly low (0,02 cm/s).

Only the sum of nitric acid and nitrate (in aerosol particles), is available from the monitoring programme. Measurements at Birkenes and Lista have shown that the concentration of nitric acid is only 10-30% of the sum of nitric acid and particulate nitrate (Sorteberg et al, in press; Foltescu et al., 1996). Nitric acid is very reactive and only the aerodynamic transfer resistance is limiting the dry deposition velocity. Cascade impactor measurements indicate that the nitrate is mainly present in the form of particles larger than 2 μm (e.g. Hillamo et al., 1992). A relatively large deposition velocity has therefore been chosen for this component.

The reduced nitrogen species will mainly consist of submicron ammonium sulphates and gaseous ammonia. Several measurements have indicated that the concentration of gaseous ammonia is low (e.g. Tørseth and Semb, 1996). The only exception is in areas influenced by local emissions from farms in connection with animal husbandry and manure. Gaseous ammonia will have a relatively high deposition velocity. The deposition velocities chosen for sulphate and ammonium in aerosols also include deposition by deliquescenting sulphate droplets under conditions with high humidity and advection fogs. Particle growth in periods with high relative humidity (e.g. > 95%) may give significant deposition of sulphate particles, and to coniferous stands in particular. The latter processes are important at sites which are frequently exposed to advection fogs and low clouds. In mountainous regions cloud water deposition may be comparable to annual precipitation (Lovett, 1990; Dollard et al., 1983), but is usually less than 10%. Occult deposition may have a strong effect in the ecosystems because of the relatively high concentrations of pollutants found in cloud and fog water, but is less important for estimating the total deposition in calculations of critical loads using a resolution of 50·50 km^2. The subject of exposure to pollutants in the mountainous areas of Norway has been discussed further by Lükewille and Semb (1997).

Sea-salts generally occur in the coarse particulate mode (>2 μm). In coastal areas sea spray may generate particles larger than 10 μm. These will however be

deposited very fast and normally less than 1-5 km from the coast and will therefore not contribute to the deposition to larger areas. In addition, episodes with high concentration of sea-salts in air will normally be accompanied with large inputs as wet deposition, making the dry deposition of minor importance to the total deposition. Relatively high deposition velocities were chosen for all sea-salt compounds, corresponding well with the excess throughfall of sodium estimated from the Norwegian monitoring programme for forest damage (Solberg et al., 1997),

The larger fraction of calcium and potassium is not derived from sea-salts. For calcium, the main source is assumed to be long range transport of mineral matter (Semb et al., 1995). There are still large uncertainties with respect to emission, transport and deposition of these compounds. 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 some importance locally during winter.

Table 1 summarises the deposition velocities which have been used to infer dry deposition from measured concentrations of the various compounds in this work:

Table 1: Applied deposition velocities (cm/s) for different inorganic compounds to the different landscape types and seasons.

	Land use classification			
Compound	Forest		Other	
	summer	winter	summer	winter
SO_2	0.8	0.1	0.4	0.02
SO_4^{--}, 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	1	0.25
Na, Mg, Cl, ss K, ss Ca, ss S	2	2	1	0.25

3. Data used for mapping

NILU started routine sampling of precipitation and air in background areas on daily basis in 1971, with most sites located in the southernmost parts of Norway. In later years the measuring network has expanded to cover all regions in Norway. In 1996 the network consists of about 40 stations serving different monitoring programmes:

- "Monitoring programme for long range transported polluted air and precipitation" financed by the Norwegian Pollution Control Authority (SFT). In 1996 this programme includes 12 stations, of which 7 are EMEP-stations (European Monitoring and Evaluation Programme).

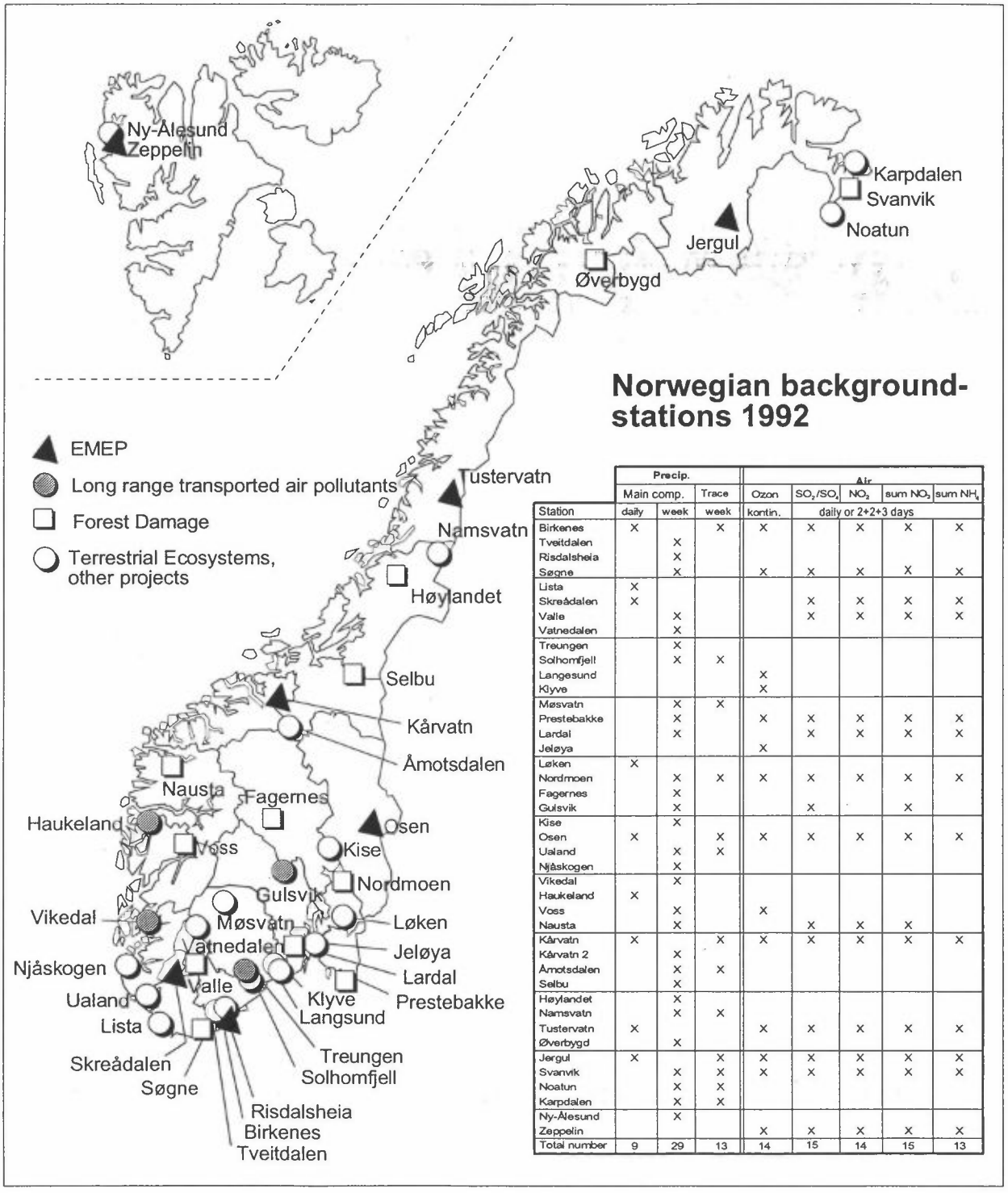
- Since 1985 the "Monitoring programme for forest damage" has been financed by the Norwegian Pollution Control Authority (SFT) and the Ministry of Agriculture, which in 1996 included a total of 13 sites.
- In the "Monitoring programme for Terrestrial Ecosystems" financed by the Directorate for Nature Management, NILU has since 1990 had measurements at 5 sites.

The remaining sites are part of other projects, of which some are financed by NILU. In addition concentrations in precipitation from the Swedish national network and air concentrations at the Swedish EMEP-stations have been used in the statistical analysis (Karin Kindbom, IVL, pers. com.). The Swedish data on wet deposition consist mainly of monthly bulk precipitation chemistry from 32 sites run by the Swedish Environmental Research Institute (IVL). Figure 1 shows the location of the background stations and the measuring programme. All sites 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 and the results for the years used in this report has been published in SFT (1993), SFT (1994), SFT (1995), Tørseth (1996) and Tørseth and Manø (1997).

Precipitation samples are collected in bulk-samplers on a daily or weekly basis. Precipitation amounts are measured by local observers and the samples are sent to NILU for analysis of all main compounds. Analysis results are tested for ion balance and the measured conductivity is compared with calculated conductivity. Filter-pack samples are analysed for SO_2, SO_4, HNO_3+NO_3 and NH_3+NH_4, while absorbing solutions or NaI-impregnated filters are analysed for NO_2. All results are checked against expected values and results from neighbouring sites. Obviously contaminated samples are rejected.

The monitoring of non sea-salt base-cations and of sea-salts in air is only included in the measurement programme at the two sites Birkenes and Nordmoen through the Monitoring programme for forest damage. To provide regional information, ion chromatograms from the ordinary filter sample analysis was investigated to determine ambient concentrations of these ions. These measurements were made available to this project through internal funding by NILU.

The precipitation amount data used for the calculations of the wet deposition is taken from the national meteorological observation network (DNMI). There is generally very good agreement between the recorded sample volumes and the amounts recorded by the official precipitation gauges operated by DNMI. Data from 797 sites for the five-year period 1992-1996 have been applied (DNMI, 1997). Figure 1.1 in Appendix shows the location of the meteorological sites.



Station	Precip. Main comp. daily	Precip. Main comp. week	Precip. Trace week	Air Ozon kontin.	Air SO_2/SO_4 daily or 2+2+3 days	Air NO_2 daily or 2+2+3 days	Air sum NO_3 daily or 2+2+3 days	Air sum NH_4 daily or 2+2+3 days
Birkenes	x		x	x	x	x	x	x
Tveitdalen		x						
Risdalsheia		x						
Søgne		x		x	x	x	x	x
Lista	x							
Skreådalen	x				x	x	x	x
Valle		x			x	x	x	x
Vatnedalen		x						
Treungen		x						
Solhomfjell		x	x					
Langesund				x				
Klyve				x				
Møsvatn		x	x					
Prestebakke		x		x	x	x	x	x
Lardal		x			x	x	x	x
Jeløya				x				
Løken	x							
Nordmoen		x	x	x	x	x	x	x
Fagernes		x						
Gulsvik		x			x		x	
Kise		x						
Osen	x		x	x	x	x	x	x
Ualand		x	x					
Njåskogen		x						
Vikedal		x						
Haukeland	x							
Voss		x		x				
Nausta		x			x	x	x	
Kårvatn	x		x	x	x	x	x	x
Kårvatn 2		x						
Åmotsdalen		x	x					
Selbu		x						
Høylandet		x						
Namsvatn		x	x					
Tustervatn	x			x	x	x	x	x
Øverbygd		x						
Jergul	x		x	x	x	x	x	x
Svanvik		x	x	x	x	x	x	x
Noatun		x	x					
Karpdalen		x	x					
Ny-Ålesund		x						
Zeppelin				x	x	x	x	x
Total number	9	29	13	14	15	14	15	13

Figure 1: Norwegian background stations and measurement programme.

4. Interpolation

The interpolation of the concentrations in precipitation and air from fixed sites to a regular grid is done by "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 for the past 12 years in connection with environmental studies, e.g. on long range transported air pollutants in Europe (Simpson and Olsen, 1990; Schaug et al. 1993).

Linear kriging provides the best linear unbiased estimator for a variable. Non-linear kriging (Armstrong and Matheron, 1986) would give more accurate estimates, but is far more complicated and requires much more statistical information. There are three levels of linear kriging: simple kriging where the expectations of the variable are known; ordinary kriging with unknown but stationary expectations, and universal kriging where there is a drift in the data. In universal kriging the expectations are neither stationary nor known, but their functional form has been identified.

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. All interpolations in this work were performed using universal linear kriging. A grid size of 50·50 km^2 has been applied (EMEP sub-grid). The applied grid is shown in figure 1.2 in Appendix.

5. Data analysis

Seasonal mean airborne concentrations during winter (Jan.-Apr., Nov.- Dec.) and summer (May-October) during 1993-1996 were calculated for SO_2, non sea-salt (nss) SO_4^{--}, NO_2, sum NO_3^-+HNO_3, sum NH_4^++NH_3 , Na, non sea-salt K and non sea-salt Ca. For all compounds but nss K, a significant seasonal variation was evident whereas the inter annual variation was generally small. As a result of this the four year seasonal average concentration values measured at 15 Norwegian sites were interpolated to a 50·50 km^2 grid using the kriging technique to obtain values for the individual grid cells. Concentration fields for Cl and Mg were estimated based on the ratio between these compounds and Na in sea water. In figure 1.4 in Appendix, the correlation between the sea-salt compounds at three selected sites is shown.

The dry deposition of 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, 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 1.3 in Appendix.

The yearly averages of non sea-salt sulphate, nitrate, ammonium, non sea-salt potassium and non sea-salt calcium in precipitation measured at a total of 39 Norwegian and 32 Swedish background stations 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, a general function was fitted (Fig. 2). 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.

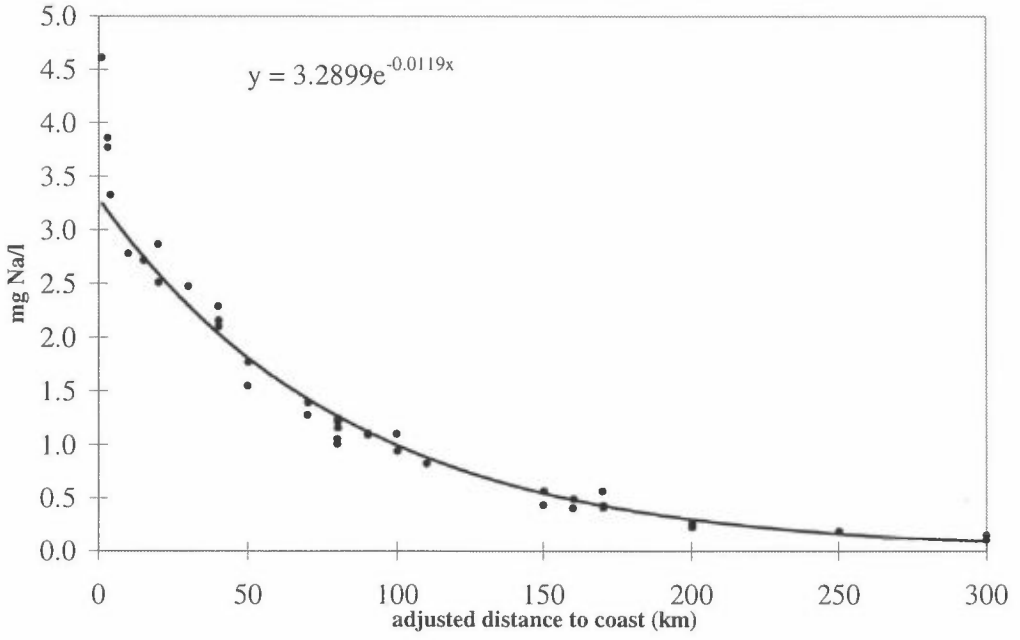


Figure 2: Sodium content in precipitation as a function of regionally adjusted distance to the coast.

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.

The total deposition of the various inorganic compounds during 1992-1996 was calculated as the sum of the dry and wet deposition both for each meteorological site and for each grid cell. The results for the individual sites (deposition values to

forested areas) are visualised on maps in Figures 3-7 whereas land use area weighted results for individual grid cells are given in Table 1.1 in Appendix. The maps are produced using standard interpolation routines.

This report gives only a summary of the results. Deposition estimates for individual years and for the different landscape types are stored in our database, and are available upon request.

6. Results and discussion

Annual average precipitation amounts measured at the DNMI-sites varied between 251 and 3971 mm, with the lowest amounts along the Swedish border in northern Norway and in Oppland county, southern Norway (Table 2). Aggregated to grid cell averages, the amount varied from 329 mm (cell no. 171) to 2803 mm (cell no. 25).

Table 2: Minimum, median and maximum deposition for individual sites and 50·50 grid cells in the period 1992-96.

Compound	Deposition to individual sites (n=797)			Grid cell averaged deposition (n=191)		
Units (mg/m^2 yr)	**min.**	**med.**	**max.**	**min.**	**med.**	**max.**
Precip. (mm)	251	940	3971	330	860	2804
nss S	67	336	1568	106	270	1178
N (oxi)	51	233	1283	67	150	997
N (red)	50	217	993	52	170	767
N (oxi+red)	110	451	2276	119	320	1764
nss K	19	62	228	22	61	166
nss Ca	27	111	302	34	101	220
Na	97	1343	9788	107	1483	6885
Mg	12	162	1179	13	179	829
Cl	173	2398	17497	192	2648	12294
ss S	8	112	819	9	124	576
ss K	3	48	352	4	53	248
ss Ca	4	51	370	4	56	261

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. Maximum average annual depositions of non sea-salt sulphur exceed 1.1 g S/m^2 in grid cell no. 4, whereas the corresponding values in the neighbouring grid cells (8 and 9) were approx. 1.0 g S/m^2. These values are approximately one order of magnitude higher than the sulphur depositions in grid cells 65-66, and 155-162. Similarly, deposition values for individual DNMI-sites varied from at most 1.6 g S/m^2 down to 0.07 g S/m^2.

The pattern of nitrogen deposition is rather similar to the deposition of sulphur. This is partly due to the strong influence of the precipitation frequency and amounts on the deposition of both species. The largest grid cell depositions of oxidised- and reduced nitrogen were 1.0 and 0.77 g N/m^2, whereas the lowest depositions were 0.06 and 0.05 g N/m^2 , respectively. Total nitrogen deposition for the individual DNMI-sites varies from 0.11 to 2.28 g N/m^2 as a yearly mean (1992-1996).

Adding up the values in Table 1.1 gives a total yearly mean deposition in Norway of approximately 114 000 tonnes sulphur and 152 000 tonnes nitrogen. Compared with similar estimates for the period 1983-87 (Pedersen et al., 1990) and 1988-1992 (Tørseth and Pedersen, 1994) there has been a reduction in sulphur deposition of 33% and 23%, respectively. In nitrogen deposition, corresponding reductions were 14% and 2% for oxidised nitrogen, and 23% and 6% for reduced nitrogen compounds. Also the amounts of precipitation varied significantly between the different periods with 11% lower amounts during the period 1983-87 and 13% higher amounts during 1988-92, compared to 1992-1996. However, changes in precipitation amounts can only to a small extent explain the observed changes in deposition of sulphur and nitrogen, since precipitation amounts are to large extent influenced by the distance from the coast and not by the distance to the emission sources of S and N.

Although we emphasised to use the same methodology, there are some minor differences in the way interpolations and extrapolations have been carried out. In addition, the number of measurement sites increased significantly from 1983-87 to 1988-92. For this reason, the deposition estimates for the three periods may not be directly comparable. This is particularly the case for the period 1983-87, whereas between 1988-1992 and 1992-1996, changes in methodology are assumed to be of minor importance. However, the results from are generally compatible with changes in emissions in Northern Europe, with model estimates and with results from individual sites.

Total depositions of sea-salt ions, non sea-salt potassium and non sea-salt calcium have not previously been estimated to Norway. For Sweden and Denmark, estimates for the period 1983-87 have been presented by Lövblad et al. (1992). In contrast to Lövblad et al. (1992), the estimates presented here are based the application of ambient air concentrations compared to throughfall measurements to estimate dry deposition, and for sea-salts a model describing concentration level in precipitation as a function of the distance to the coast. Though this will improve the estimates, still large uncertainties in the estimates are expected, both in terms of amounts and to what extent the inputs represent a net input to the ecosystems, compared to internal circulation within the ecosystems. Measurement data have indicated the input of non sea-salt potassium and non sea-salt calcium have decreased over last few years due to reduced emissions from industrial sources in Central- and Eastern Europe (Semb et al., 1995; Hedin et al., 1994; Tørseth and Manø, 1997). A reduced alkaline input may affect the exceedance of critical loads for acidity. However, this effect is assumed to be of minor importance compared to the changes in input of sulphur.

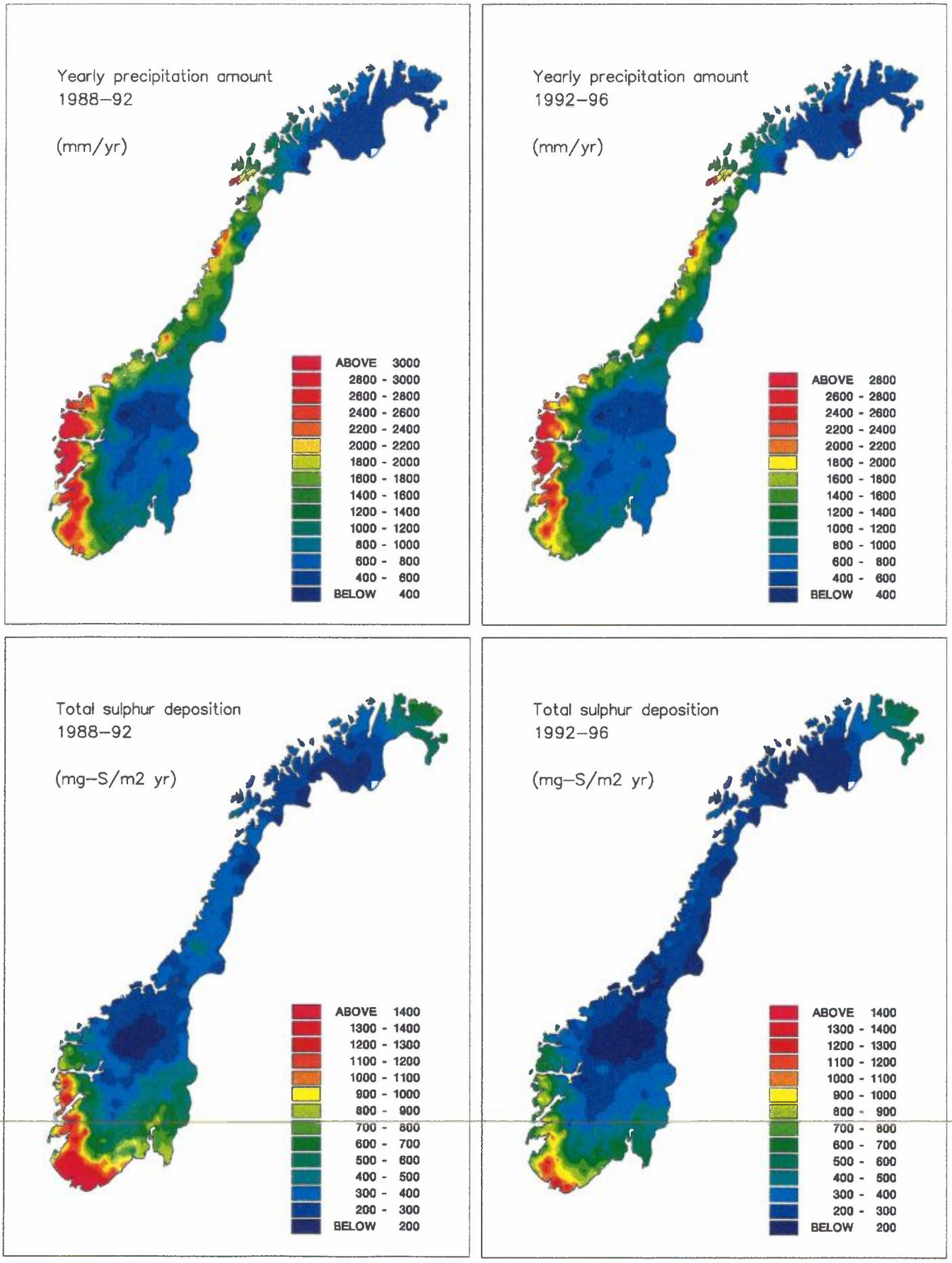


Figure 3: Average precipitation amount 1988-92 and 1992-96, and total nss sulphur deposition, 1988-92 and 1992-96.

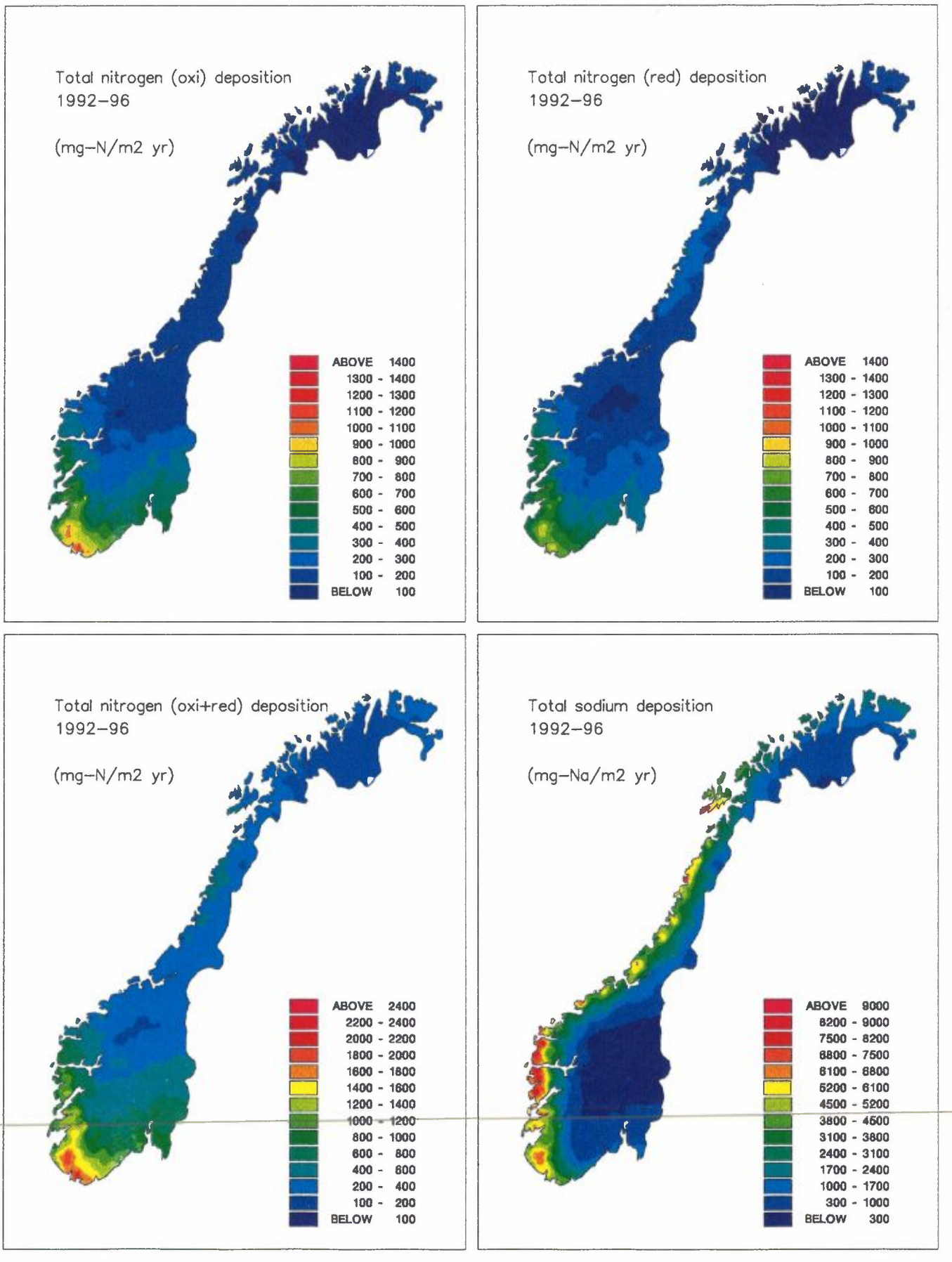


Figure 4: Total deposition of oxidised nitrogen, reduced nitrogen, total nitrogen (oxi+red) (mg N/m² year) and total sodium deposition (mg /m² year), 1992-1996.

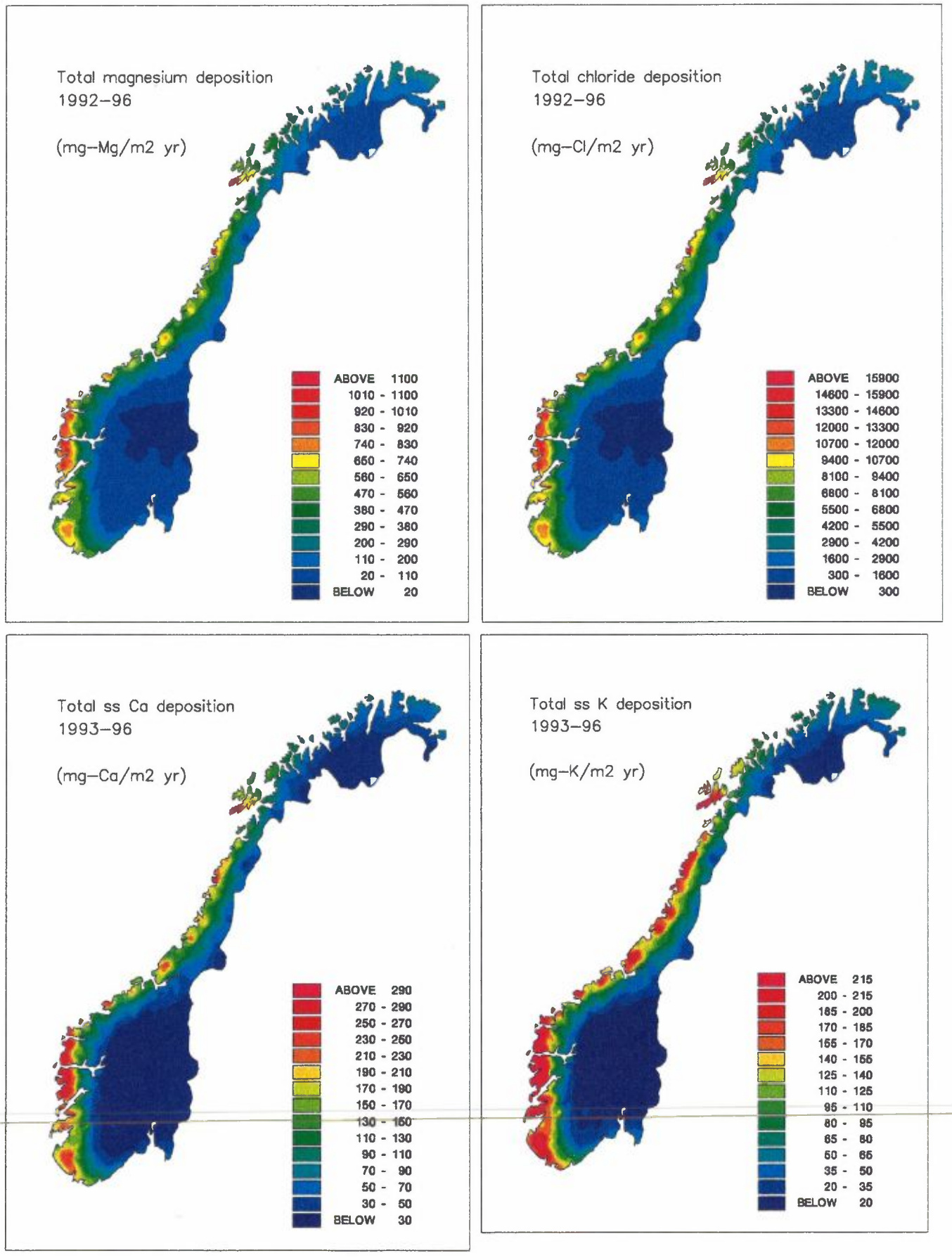


Figure 5: Total deposition of magnesium, chloride, sea-salt calcium and sea-salt potassium, 1992-1996 (mg /m² year).

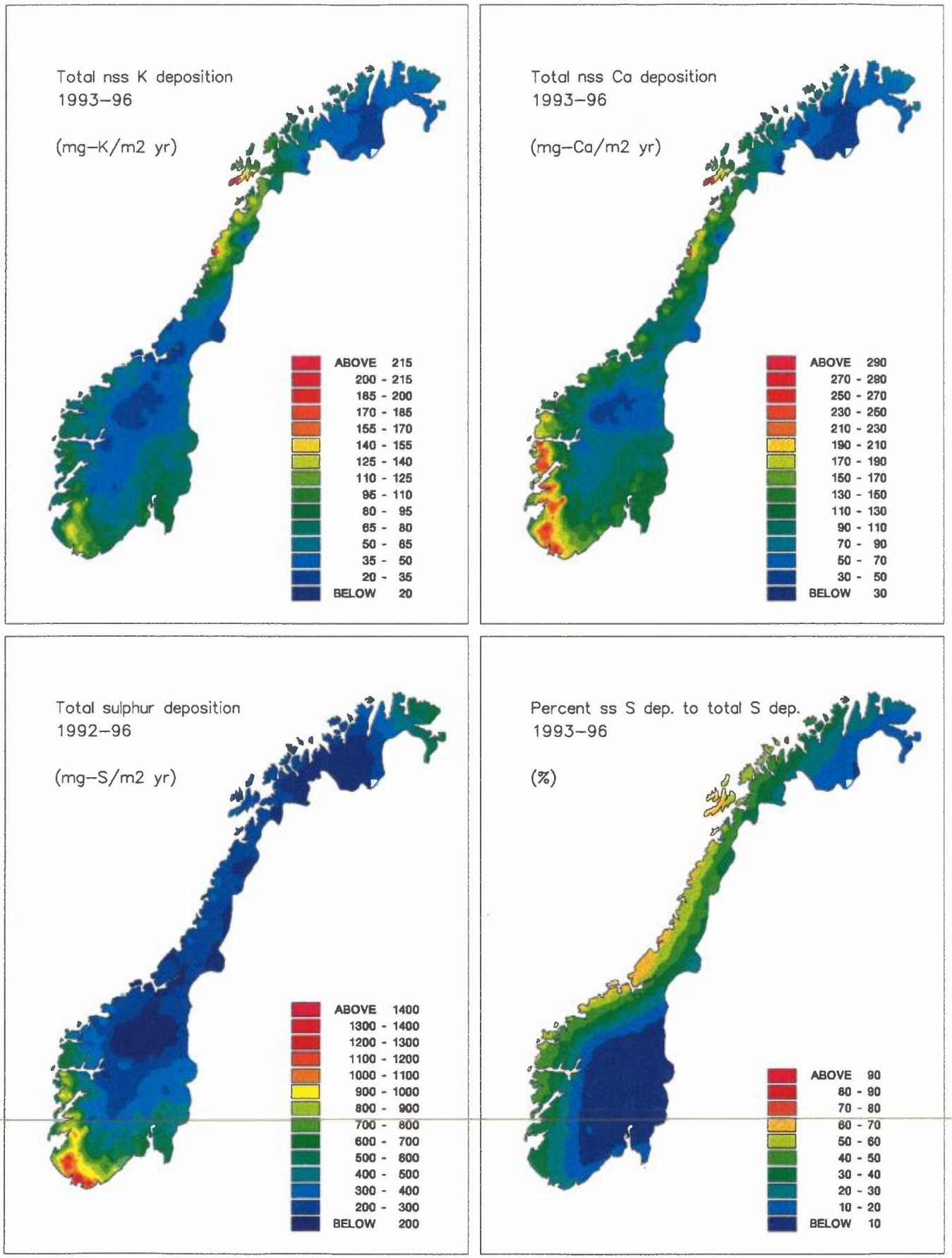


Figure 6: Total deposition of non sea-salt potassium, non sea-salt calcium, total sulphur (non sea-salt + sea-salt) and percent sea-salt to total deposition of sulphur (forest), 1992-1996 (mg /m² year).

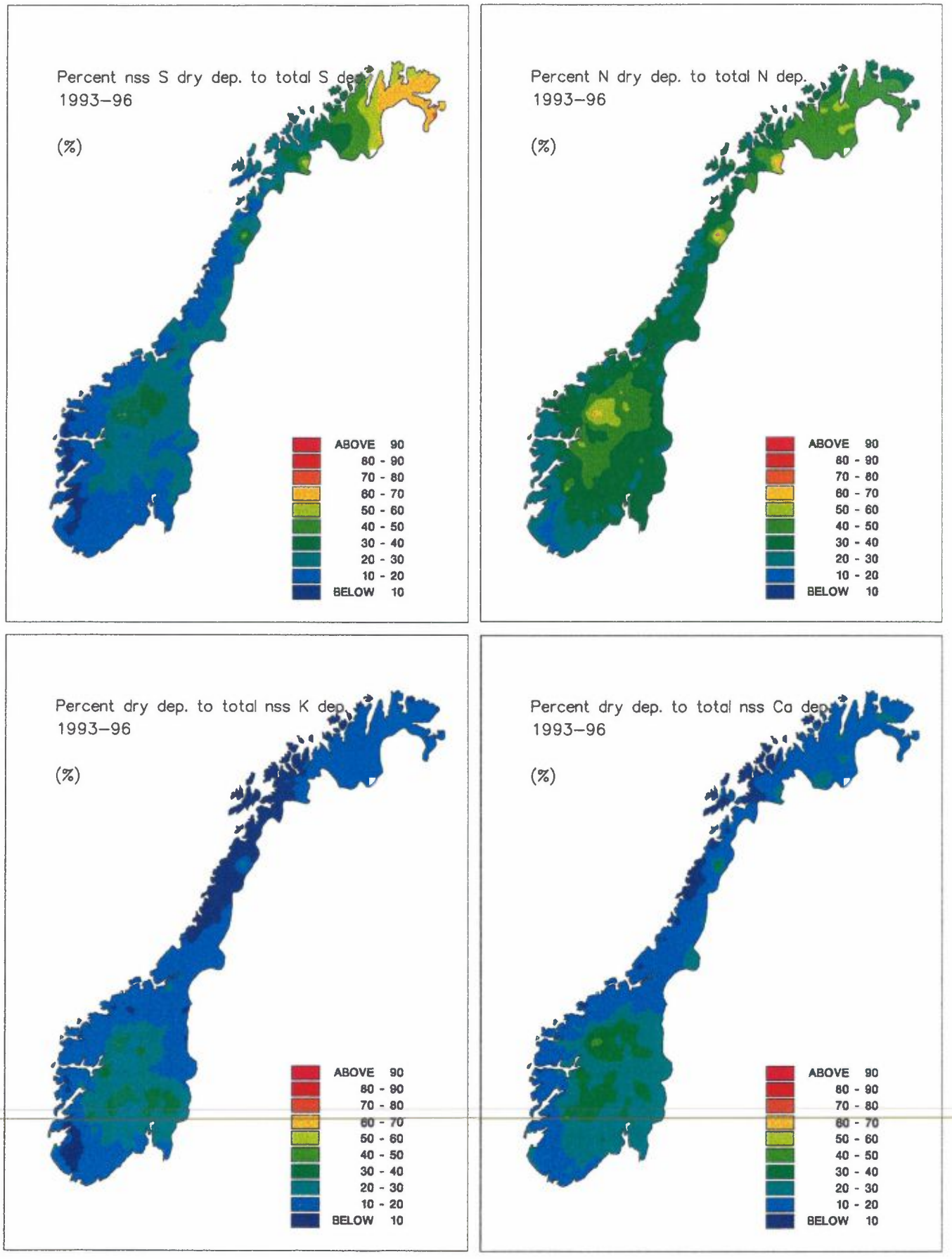


Figure 7: Percent dry deposition to total deposition of sulphur, nitrogen, potassium and calcium (non sea-salt and to forests), 1992-1996 (mg/m² year).

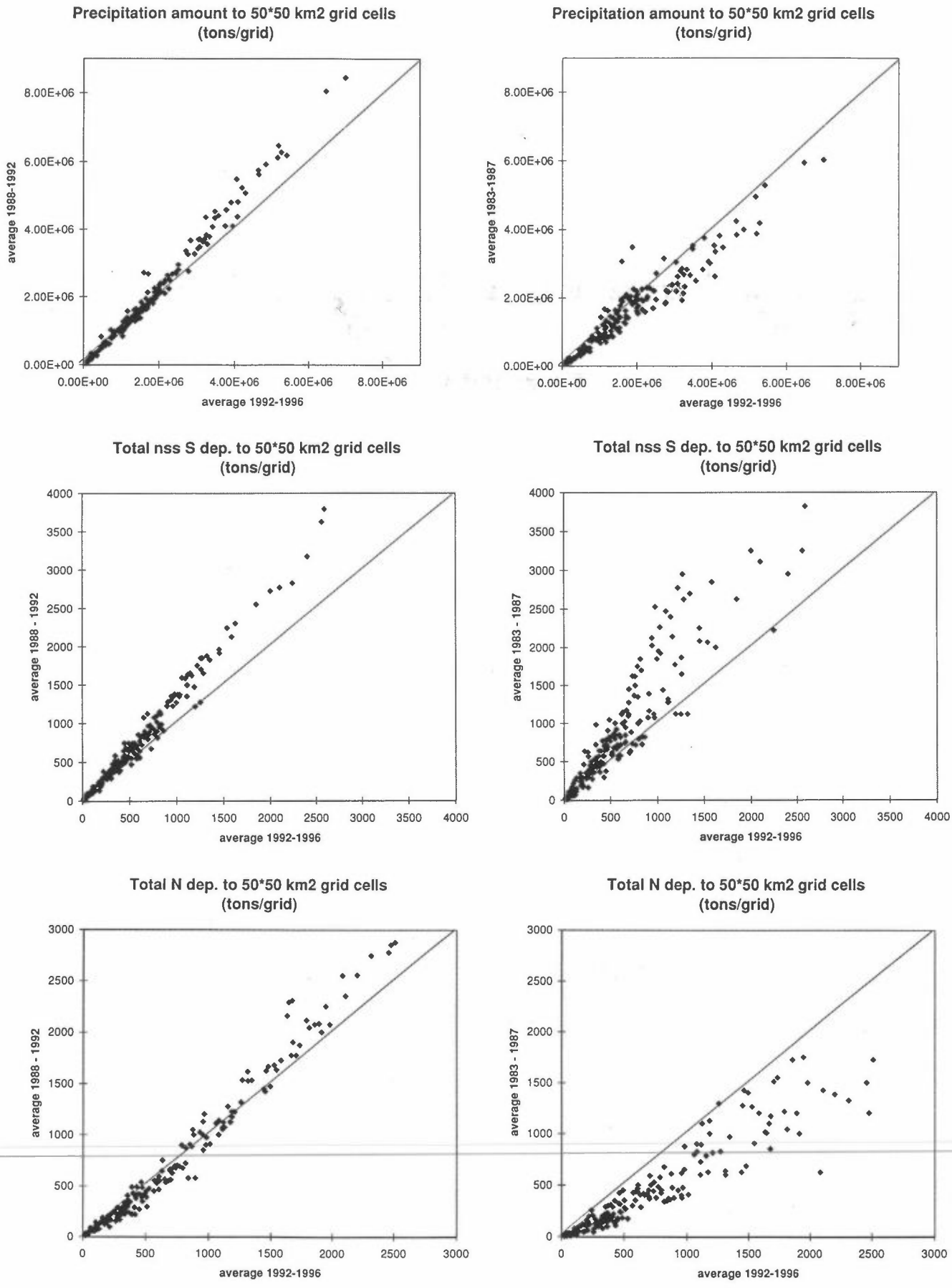


Figure 8: Grid cell averaged precipitation amounts, non sea-salt sulphur and nitrogen deposition in 1992-1996 compared to 1988-1992 and to 1983-87, respectively.

The deposition amounts of sea-salts will be 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. Deposition of sea-salts are particularly large in the coastal zone (0-20 km from the coast) and decreasing exponentially with distance. This deposition pattern is not taken into account in the presented maps, and deposition estimates will be significantly underestimated to these areas.

7. References

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Appendix A

Figures 1.1-1.4 and Table 1.1

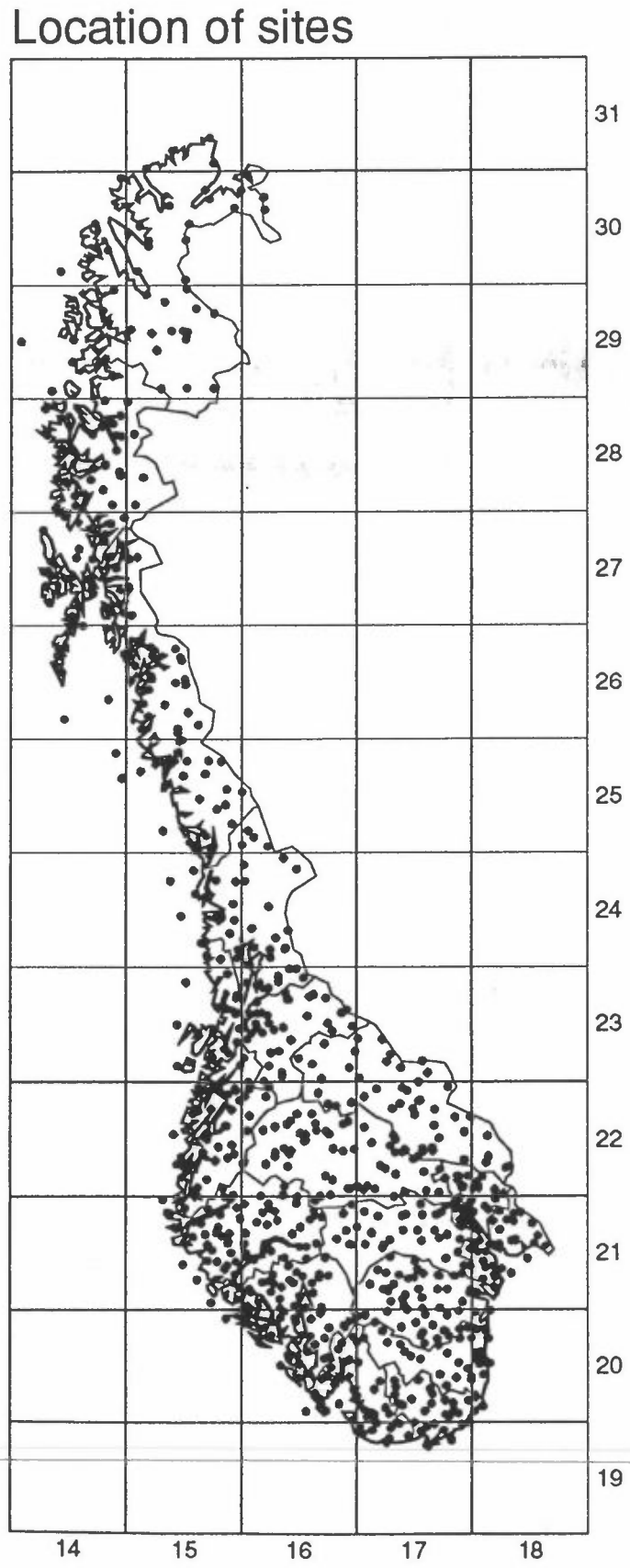

Figure 1.1: Location of the meteorological stations used in estimating deposition of major inorganic compounds.

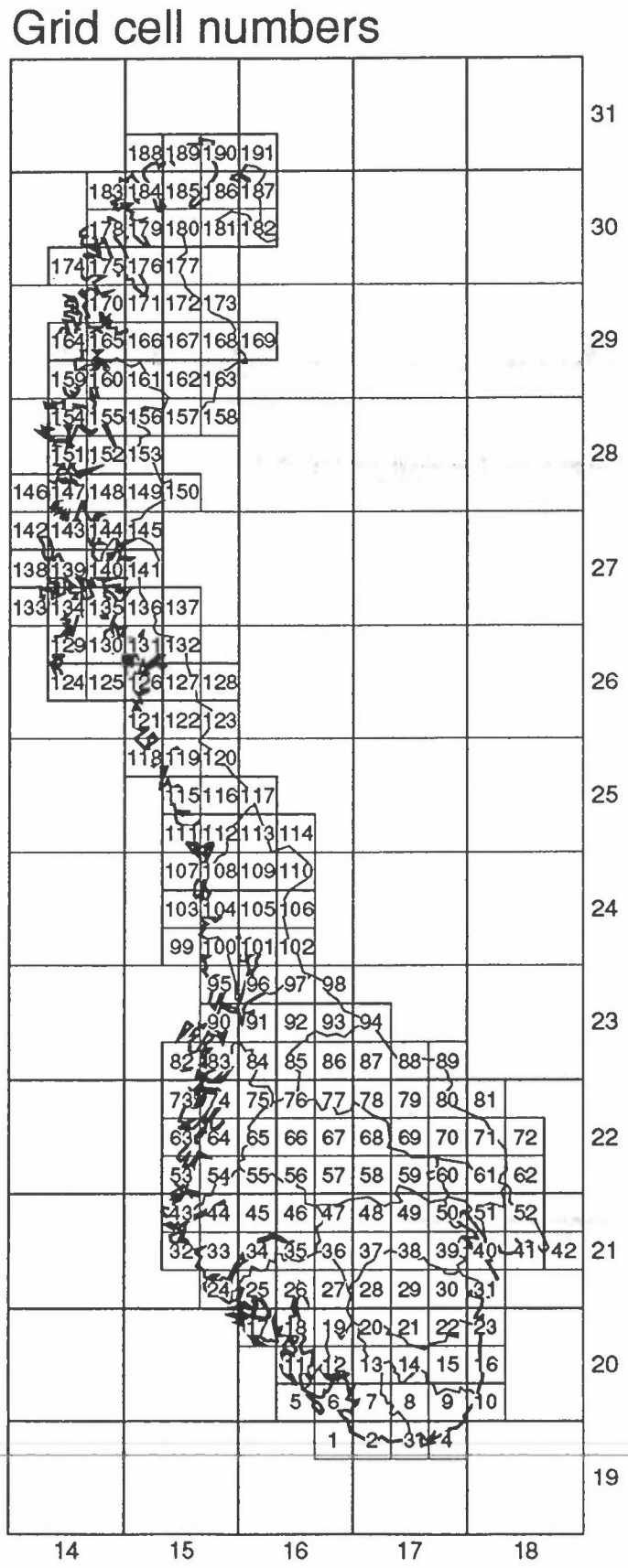

Figure 1.2: The 50·50 km² grid and grid cell numbers (EMEP sub-grid) used for interpolating concentration fields.

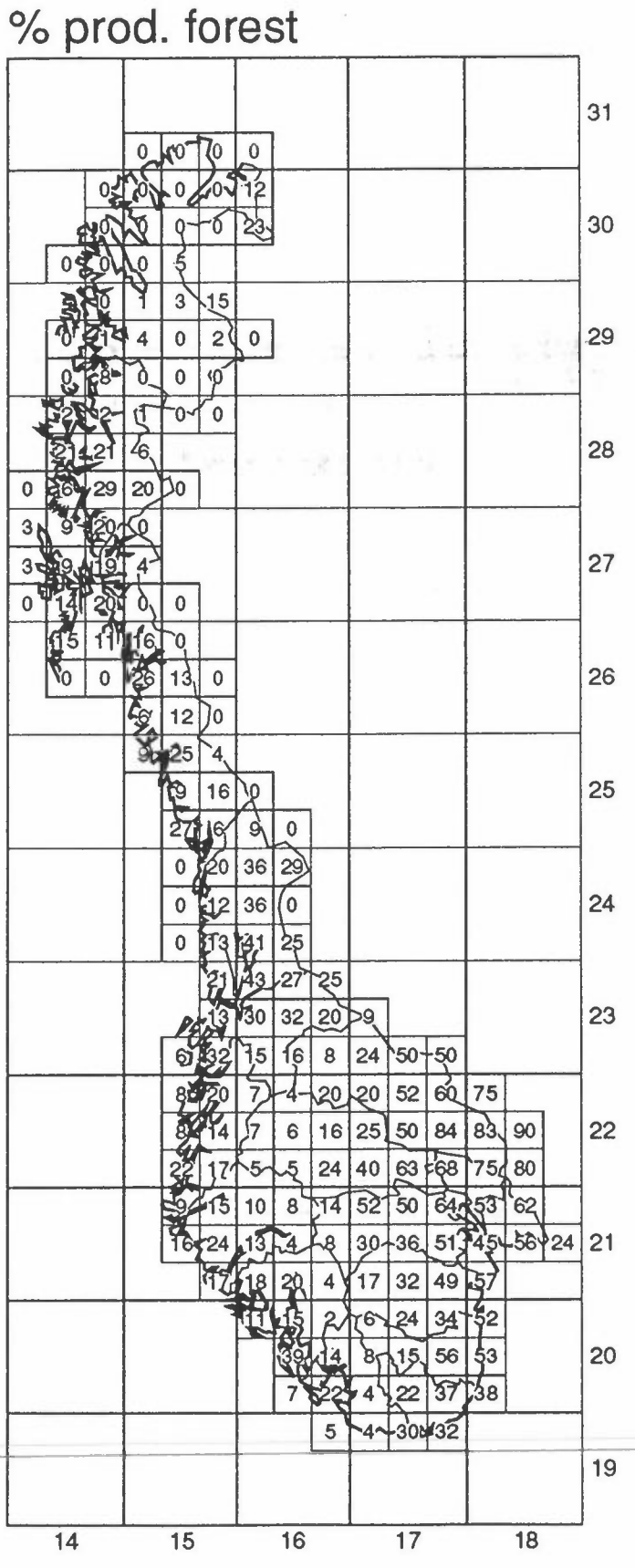

Figure 1.3: Percent productive forest used in estimating dry deposition.

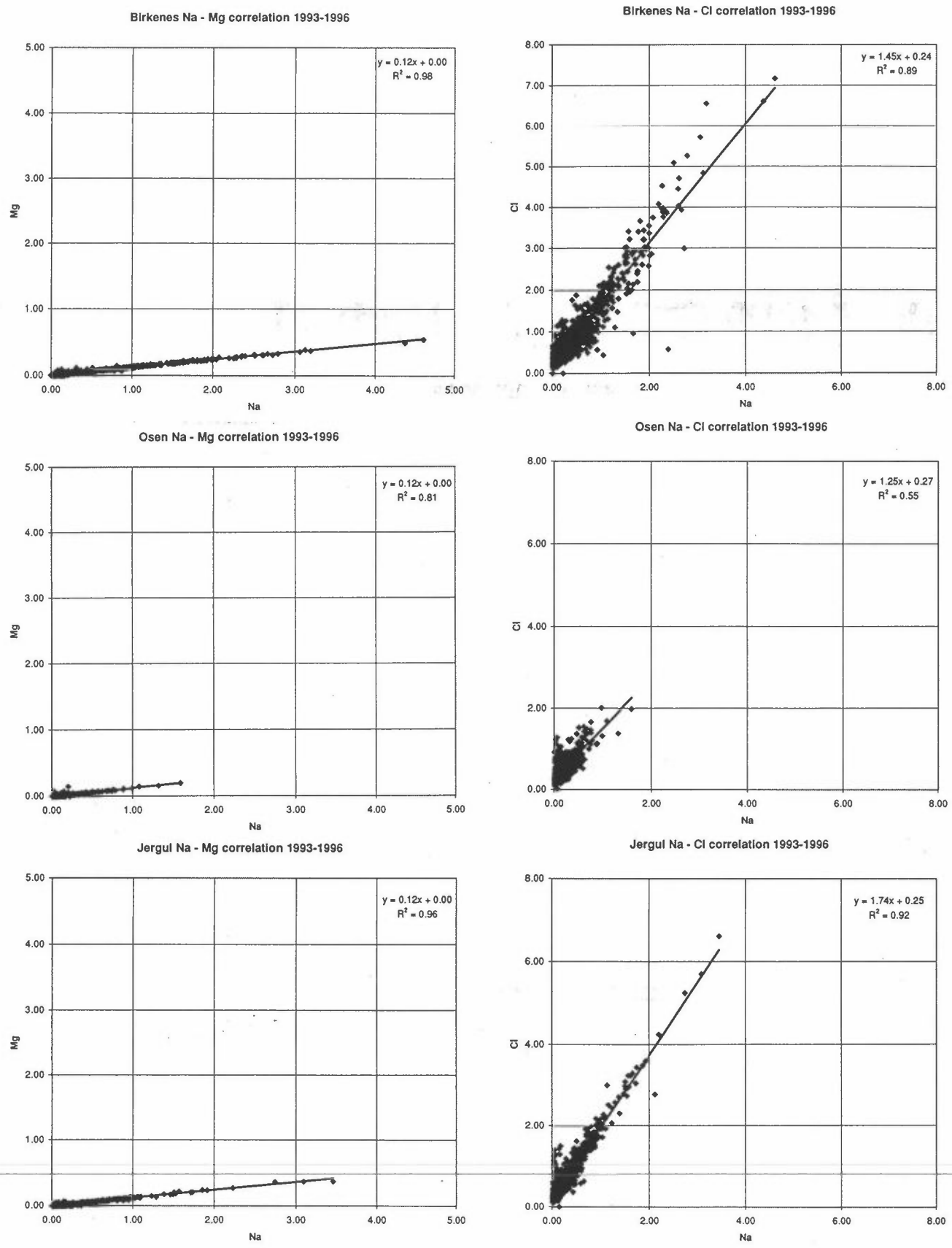

Figure 1.4: Correlation of sodium to magnesium and chloride in air at three selected sites, 1993-1996 (n=1462).

Table 1.1: Values of each 50·50 km² grid cell (see figure 1.2).

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 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 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	1385	667	556	485	60	166	150	174	4606	555	8225	386	67	104	6	15	1
2	1270	1598	876	709	579	72	183	171	192	5074	611	9061	425	1112	1635	92	218	9
3	1060	1601	996	869	685	98	183	199	192	5078	612	9067	425	1056	1647	103	211	6
4	950	1608	1178	997	767	113	164	219	173	4566	550	8154	382	1119	1675	107	208	4
5	430	1335	536	420	404	53	158	131	166	4395	529	7848	368	231	355	23	56	2
6	450	1292	579	499	451	55	148	139	156	4127	497	7370	345	261	427	25	62	6
7	2480	2081	970	817	702	116	199	206	209	5523	665	9862	462	2406	3768	287	510	11
8	2500	1856	1025	895	728	126	145	209	153	4027	485	7191	337	2563	4059	316	522	11
9	2480	1525	1045	893	698	104	127	187	133	3521	424	6288	295	2592	3944	257	463	9
10	280	1152	917	792	596	89	121	164	128	3366	406	6011	282	257	389	25	46	3
11	1310	1911	697	521	507	67	205	159	216	5713	688	10201	478	912	1347	87	208	8
12	2450	2209	859	655	606	88	191	194	201	5298	638	9460	443	2106	3088	216	475	9
13	2500	2107	898	743	653	124	147	208	155	4092	493	7308	343	2245	3490	310	519	3
14	2450	1109	593	518	428	82	50	131	52	1381	166	2466	116	1453	2318	201	320	4
15	2500	1210	802	721	556	86	58	155	61	1616	195	2886	135	2004	3191	214	387	7
16	750	1064	839	738	542	79	81	144	85	2246	271	4010	188	629	960	59	108	7
17	1830	2343	689	455	463	66	248	187	261	6885	829	12294	576	1261	1681	120	342	7
18	1950	2484	790	574	557	75	200	211	211	5571	671	9949	466	1540	2205	146	411	8
19	2500	1860	650	511	480	76	122	164	128	3385	408	6044	283	1625	2479	189	409	10
20	2500	1295	528	443	392	66	60	130	64	1681	203	3003	141	1321	2087	166	326	8
21	2500	903	475	423	342	56	23	107	24	629	76	1123	53	1187	1913	139	268	9
22	2500	1002	634	556	428	70	25	133	26	700	84	1249	59	1585	2460	175	332	11
23	1350	1006	737	663	484	86	56	140	59	1567	189	2799	131	996	1548	117	189	5
24	1150	2460	624	365	397	66	243	174	256	6757	814	12066	566	718	877	75	200	6
25	2500	2804	740	488	517	86	216	205	227	6003	723	10719	502	1851	2513	215	513	11
26	2250	1865	558	406	391	63	107	155	112	2962	357	5289	248	1256	1793	142	350	9
27	2450	1122	394	312	293	53	44	103	46	1216	147	2172	102	965	1481	129	253	4
28	2400	730	314	268	235	38	11	82	12	313	38	559	26	754	1207	92	197	8
29	2500	794	413	369	298	51	17	96	17	459	55	820	38	1032	1668	128	241	10
30	2500	851	541	482	362	67	21	116	22	572	69	1021	48	1352	2110	168	291	11
31	1930	802	602	551	388	83	44	126	46	1219	147	2176	102	1161	1813	161	244	8
32	940	1821	400	240	255	49	199	121	210	5545	668	9902	464	376	466	46	114	2

Table 1.1, cont.

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 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 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
33	2450	2643	594	374	399	76	226	176	238	6287	757	11227	526	1455	1894	187	431	11
34	2360	1474	386	268	270	52	89	109	94	2471	298	4412	207	910	1270	122	258	7
35	2450	1243	367	274	262	55	52	104	54	1435	173	2562	120	899	1314	134	254	7
36	2500	860	317	248	221	42	13	84	14	358	43	639	30	793	1173	104	210	4
37	2500	606	277	239	206	41	8	80	8	224	27	401	19	692	1113	103	199	7
38	2500	785	405	351	282	61	12	104	12	323	39	576	27	1012	1584	153	259	3
39	2500	852	514	455	338	77	18	126	18	487	59	870	41	1285	1983	193	316	8
40	1730	851	593	514	370	92	24	130	26	681	82	1216	57	1027	1530	158	225	10
41	1250	770	611	550	375	89	43	121	45	1188	143	2121	99	764	1157	111	151	8
42	125	765	620	522	374	87	39	119	42	1098	132	1961	92	77	112	11	15	1
43	1375	2239	438	251	257	71	225	143	237	6257	754	11174	524	603	698	98	196	5
44	2500	2074	444	286	291	66	137	141	144	3804	458	6792	318	1110	1444	165	354	10
45	2500	1564	383	270	256	59	62	114	65	1711	206	3056	143	958	1316	148	284	9
46	2400	781	243	186	174	36	20	74	21	556	67	992	47	582	865	86	178	8
47	2500	674	251	206	187	42	7	74	7	196	24	351	16	629	982	106	185	5
48	2500	567	268	238	194	47	7	81	7	189	23	338	16	669	1081	119	203	5
49	2500	711	377	328	257	69	8	103	9	235	28	420	20	943	1464	173	258	6
50	2500	802	488	432	311	78	14	127	15	400	48	714	33	1221	1858	194	317	21
51	2500	763	509	457	322	81	18	124	19	498	60	889	42	1272	1949	203	310	11
52	1210	767	577	522	354	87	27	127	29	762	92	1361	64	698	1059	106	154	4
53	900	1835	331	200	206	68	169	124	178	4709	567	8409	394	298	366	61	112	7
54	2400	1703	338	232	231	68	105	122	110	2906	350	5190	243	812	1112	164	292	5
55	2500	1105	260	193	180	49	34	87	36	939	113	1676	79	649	933	122	217	3
56	2500	751	225	168	147	41	12	68	13	337	41	602	28	562	786	102	169	4
57	2500	732	278	215	179	47	6	79	6	168	20	301	14	695	984	118	197	6
58	2500	663	293	248	203	53	5	90	6	150	18	267	13	733	1127	132	225	7
59	2400	646	341	300	224	66	7	99	7	182	22	325	15	818	1259	157	238	5
60	2500	785	458	405	289	74	11	128	12	308	37	550	26	1145	1736	185	320	11
61	2400	659	455	426	285	75	15	129	16	418	50	746	35	1091	1706	179	310	10
62	250	698	517	477	320	81	10	129	11	292	35	521	24	129	199	20	32	1
63	900	1285	225	140	138	45	126	88	132	3493	421	6238	292	202	250	41	79	4
64	2100	1399	267	186	163	55	82	105	87	2293	276	4095	192	561	734	115	220	8

Table 1.1, cont.

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 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 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	504	125	105	95	28	13	46	13	350	42	626	29	288	459	65	107	5
66	2500	418	126	108	94	27	5	45	5	129	16	231	11	314	503	67	113	11
67	2500	552	192	161	134	38	4	66	4	114	14	204	10	481	739	95	165	8
68	2550	747	310	244	195	60	4	92	4	118	14	211	10	791	1117	152	233	4
69	2500	629	315	273	201	57	6	90	6	162	20	290	14	787	1186	142	226	9
70	2500	641	377	344	237	66	7	107	7	183	22	326	15	942	1452	166	267	3
71	2300	657	425	392	260	67	12	113	12	330	40	588	28	978	1498	155	260	2
72	200	659	487	445	288	73	9	122	9	250	30	446	21	97	147	15	24	1
73	620	1857	284	172	173	63	205	146	216	5699	687	10176	477	176	214	39	91	3
74	2300	1447	259	176	160	58	93	114	98	2581	311	4609	216	595	772	133	263	9
75	2500	1109	229	170	149	52	49	91	52	1375	166	2455	115	571	797	130	227	6
76	2500	598	158	125	103	36	5	60	5	136	16	243	11	395	570	91	150	2
77	2500	470	164	137	108	37	4	58	4	117	14	210	10	410	614	94	146	5
78	2500	580	247	186	142	50	4	79	4	107	13	192	9	618	819	126	197	3
79	2500	692	331	274	200	61	5	92	5	129	15	230	11	827	1185	153	231	8
80	2000	708	381	313	227	65	6	105	6	161	19	288	13	762	1081	129	209	4
81	200	708	427	365	261	66	7	116	7	183	22	327	15	85	125	13	23	1
82	770	1158	167	105	117	36	135	93	143	3766	454	6726	315	129	171	28	72	2
83	1900	1620	270	183	178	53	141	136	149	3924	473	7008	328	514	685	101	258	4
84	2500	798	168	125	111	37	35	70	37	975	117	1741	82	419	591	91	176	5
85	2500	489	136	108	91	30	12	51	12	327	39	584	27	340	496	76	128	4
86	2500	510	172	125	105	42	5	57	6	148	18	264	12	431	575	104	142	4
87	2450	524	224	163	126	49	4	65	4	117	14	210	10	549	707	119	160	3
88	1400	718	326	254	196	79	5	100	5	143	17	255	12	456	630	110	140	2
89	400	752	406	297	228	69	5	106	6	150	18	268	13	163	210	27	42	1
90	1500	1252	183	125	125	33	127	108	134	3533	426	6309	296	274	375	49	162	8
91	2300	938	187	136	124	36	54	84	57	1498	180	2675	125	429	596	82	194	13
92	2500	815	215	152	134	45	26	79	27	722	87	1289	60	537	714	113	197	3
93	2450	594	205	134	115	44	8	67	8	222	27	396	19	502	610	108	165	5
94	800	610	263	163	138	65	5	77	6	146	18	260	12	210	241	52	62	4
95	1400	1734	265	171	190	40	188	144	198	5234	631	9346	438	371	506	56	202	3
96	2100	1082	215	145	144	34	63	97	67	1760	212	3142	147	451	608	71	204	6

Table 1.1, cont.

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 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 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
97	2230	1011	244	157	140	47	31	90	32	851	103	1520	71	545	663	105	200	8
98	600	958	304	184	170	69	16	101	17	453	55	809	38	182	213	41	60	1
99	100	913	124	79	91	22	107	67	113	2982	359	5326	250	12	17	2	7	2
100	2150	1488	230	150	176	45	163	125	171	4521	545	8074	378	495	702	98	269	5
101	2450	954	192	132	136	34	57	85	60	1592	192	2843	133	471	656	84	208	5
102	800	979	224	144	139	47	40	88	42	1101	133	1966	92	179	226	38	71	3
103	400	1272	159	104	148	52	148	116	156	4106	495	7333	344	64	101	21	46	2
104	2500	1263	211	136	166	47	130	101	137	3627	437	6477	304	527	754	118	253	4
105	2500	977	195	135	144	38	58	85	61	1619	195	2891	135	487	696	95	213	2
106	300	674	159	100	106	32	21	57	22	573	69	1024	48	48	62	10	17	1
107	400	1148	174	110	151	49	131	91	138	3645	439	6509	305	70	105	20	37	2
108	2500	1623	275	167	221	66	157	131	165	4368	526	7800	366	688	970	164	328	2
109	2500	1300	260	161	193	50	88	106	93	2447	295	4370	205	650	885	126	266	2
110	2100	657	164	108	117	30	23	60	25	649	78	1159	54	344	473	63	125	2
111	1100	1535	227	130	195	74	176	123	186	4901	590	8751	410	249	357	82	135	2
112	2500	1577	264	165	219	68	145	127	153	4031	486	7197	337	660	959	169	319	3
113	2200	1010	201	128	161	42	53	84	56	1483	179	2648	124	442	636	92	185	5
114	100	674	164	98	120	30	21	56	22	577	69	1029	48	16	22	3	6	1
115	2350	1478	233	138	200	88	151	123	159	4189	505	7481	351	548	795	206	288	3
116	2450	1306	241	149	199	68	90	111	95	2499	301	4463	209	590	852	166	271	3
117	700	747	161	97	127	38	40	63	42	1117	135	1995	94	112	157	27	44	1
118	1100	1450	201	140	223	94	162	131	171	4504	543	8044	377	221	399	103	145	5
119	2390	1704	275	174	250	118	133	156	140	3709	447	6622	310	658	1013	283	374	5
120	1200	1278	242	145	196	83	77	114	81	2140	258	3821	179	291	409	99	136	4
121	2000	1787	266	161	248	124	170	164	179	4714	568	8418	395	533	819	247	329	4
122	2500	1501	262	162	223	107	93	143	98	2589	312	4624	217	655	962	267	357	4
123	400	1278	260	153	201	88	76	127	80	2111	254	3770	177	104	142	35	51	1
124	300	1564	193	112	212	117	181	154	191	5044	608	9006	422	58	97	35	46	2
125	100	827	122	83	130	62	97	80	102	2694	325	4810	225	12	21	6	8	1
126	2300	1422	231	143	223	113	122	143	129	3395	409	6062	284	531	842	261	329	5
127	2400	475	106	73	98	38	26	51	28	735	89	1312	61	255	410	92	122	3
128	200	895	204	118	152	70	54	91	57	1494	180	2668	125	41	54	14	18	1

Table 1.1, cont.

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 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 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
129	400	1439	203	119	203	116	163	152	172	4536	547	8100	380	81	129	46	61	1
130	900	1364	208	124	194	113	155	147	163	4299	518	7676	360	187	285	102	133	2
131	2500	1366	241	140	219	115	85	142	90	2371	286	4234	198	603	897	287	354	3
132	1300	895	182	103	139	74	43	93	45	1190	143	2126	100	237	314	96	121	3
133	100	2101	308	155	247	166	247	220	261	6877	829	12281	576	31	40	17	22	1
134	700	1876	290	152	220	144	213	193	224	5911	712	10555	495	203	260	100	135	4
135	1500	1303	231	131	170	109	131	133	138	3638	438	6497	305	347	451	164	199	5
136	1400	1513	285	150	190	128	101	149	106	2797	337	4994	234	399	475	179	208	1
137	100	895	198	105	128	85	43	96	45	1187	143	2120	99	20	23	9	10	1
138	400	1458	243	124	165	113	169	156	178	4710	568	8411	394	97	116	45	62	2
139	1000	1476	258	134	159	120	163	158	172	4543	547	8113	380	258	293	120	158	4
140	1400	1255	236	128	151	105	103	131	109	2872	346	5129	240	331	391	147	183	4
141	1400	949	213	114	123	87	55	99	58	1518	183	2711	127	298	331	122	139	3
142	400	1200	228	115	124	95	140	114	147	3882	468	6933	325	91	95	38	46	1
143	900	1137	212	111	123	97	129	117	136	3585	432	6401	300	190	211	87	105	2
144	1600	1062	215	116	126	87	76	104	80	2103	253	3756	176	344	386	140	167	5
145	1100	648	153	80	88	63	31	74	33	872	105	1557	73	168	185	70	81	1
146	100	1169	219	112	116	92	138	116	146	3843	463	6863	322	22	23	9	12	1
147	1600	1141	223	119	110	90	128	113	134	3551	428	6341	297	357	367	144	180	4
148	2450	815	188	106	104	73	55	85	58	1541	186	2752	129	461	513	178	208	4
149	2450	587	156	88	82	56	29	63	31	813	98	1452	68	382	415	138	155	2
150	200	648	179	93	97	78	31	73	33	871	105	1556	73	36	38	16	15	1
151	1400	991	227	120	87	76	106	97	111	2935	354	5241	246	318	289	106	136	3
152	2400	841	181	111	85	66	52	86	55	1457	176	2602	122	435	470	158	206	4
153	1800	648	158	90	78	61	32	71	33	879	106	1569	74	285	302	110	128	1
154	1550	890	204	106	89	74	102	97	108	2847	343	5084	238	315	301	115	151	2
155	2300	620	153	85	69	51	39	69	41	1087	131	1942	91	353	353	117	159	7
156	2100	485	138	74	55	47	21	58	22	586	71	1046	49	290	272	99	121	2
157	1300	416	132	73	57	39	17	41	18	464	56	829	39	171	169	51	54	1
158	300	416	160	78	66	42	17	43	18	466	56	832	39	48	43	13	13	1
159	900	813	219	108	85	67	93	89	98	2598	313	4640	217	197	174	60	80	2
160	2500	435	137	76	52	36	27	48	29	760	92	1357	64	342	320	89	121	1

Table 1.1, cont.

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 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 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
161	2500	540	169	84	55	43	19	59	20	530	64	946	44	422	347	108	147	1
162	2500	403	136	73	57	33	11	34	11	301	36	538	25	339	326	82	86	1
163	1500	416	175	79	68	38	9	44	10	254	31	454	21	262	221	57	66	1
164	300	1169	348	145	128	96	114	132	121	3183	383	5684	266	104	82	29	40	2
165	1800	579	219	90	60	60	40	81	42	1102	133	1968	92	393	271	108	146	1
166	2500	448	168	78	64	38	21	51	22	588	71	1050	49	419	356	94	127	3
167	2500	394	149	73	59	31	12	43	12	330	40	589	28	374	329	77	107	4
168	2400	378	196	77	67	32	9	42	10	261	31	466	22	471	345	78	102	1
169	300	378	243	81	74	35	7	42	8	198	24	354	17	73	47	10	13	1
170	2000	717	289	112	99	59	63	83	67	1759	212	3140	147	577	421	119	165	2
171	2400	330	178	67	52	26	19	36	20	524	63	936	44	428	284	63	86	1
172	2300	412	225	81	70	34	17	46	18	462	56	825	39	517	346	78	107	3
173	400	393	277	88	77	35	11	45	11	302	36	540	25	111	66	14	18	1
174	300	849	391	137	122	79	99	101	105	2761	333	4931	231	117	78	24	30	1
175	2200	607	319	103	93	53	62	71	65	1722	207	3075	144	701	432	116	155	1
176	2340	560	326	100	91	47	38	62	40	1069	129	1908	89	764	449	110	146	1
177	1300	383	294	81	73	34	19	48	20	518	62	924	43	382	200	44	62	1
178	900	820	477	146	137	79	96	98	101	2670	322	4768	223	429	255	71	88	1
179	2300	498	364	96	91	43	53	62	56	1474	178	2632	123	838	431	98	142	4
180	2000	469	398	93	92	38	27	57	28	744	90	1328	62	796	372	76	113	2
181	1300	515	461	104	107	42	17	64	17	460	55	821	39	600	273	54	84	1
182	1300	511	560	114	121	45	28	66	29	775	93	1384	65	728	306	58	86	1
183	300	511	423	106	101	43	61	56	64	1685	203	3008	141	127	62	13	17	1
184	1600	501	444	103	102	45	60	59	63	1659	200	2963	139	711	329	72	95	1
185	2500	472	500	104	107	45	49	51	51	1353	163	2416	113	1250	528	112	128	1
186	2300	467	519	102	109	42	41	60	43	1133	137	2024	95	1194	485	96	139	4
187	1400	501	615	114	125	47	39	72	41	1086	131	1940	91	861	335	66	100	3
188	400	742	634	147	154	66	87	99	92	2426	292	4332	203	254	120	26	40	1
189	1400	580	596	126	135	55	69	70	72	1906	230	3404	160	834	365	78	98	1
190	700	580	641	126	142	56	68	75	71	1883	227	3363	158	449	188	39	53	2
191	300	579	668	126	144	54	69	81	72	1914	231	3418	160	200	81	16	24	1
Sum														114538	151852	19989	33412	

Appendix B

Nature Tolerance Levels (Naturens tålegrenser) Reports

Naturens Tålegrenser - Oversikt over utgitte rapporter

1 Nygaard, P. H., 1989. Forurensningers effekt på naturlig vegetasjon en litteraturstudie. Norsk institutt for skogforskning (NISK), Ås.

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11 Wright, R. F., Stuanes, A. Reuss, J.O. & Flaten, M.B. 1990. Critical loads for soils in Norway. Preliminary assessment based on data from 9 calibrated catchments. Norsk institutt for vannforskning (NIVA), O-89153.

11b Reuss, J. O., 1990. Critical loads for soils in Norway. Analysis of soils data from eight Norwegian catchments. Norsk institutt for vannforskning (NIVA), O-89153.

12 Amundsen, C. E., 1990. Bufferprosent som parameter for kartlegging av forsuringsfølsomhet i naturlig jord. Universitetet i Trondheim, AVH (stensil).

13 Flatberg, K.I, Foss, B., Løken,A. & Saastad, S.M. 1990. Moseskader i barskog. Direktoratet for naturforvaltning (DN), notat.

14 Frisvoll, A.A., & Flatberg, K.I., 1990. Moseskader i Sør-Varanger. Norsk institutt for naturforskning (NINA) , Oppdragsmelding 55.

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22 Sivertsen, T. & medarbeidere. 1992. Opptak av tungmetaller i dyr i Sør-Varanger. Direktoratet for naturforvaltning, DN-notat 1991-15.

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28 Brettum, P. 1992. Tålegrenser for overflatevann. Planteplankton. Norsk institutt for vannforskning (NIVA), O-90137/E-90440, rapport-3.

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30 Mortensen, L.M. & Nilsen, J. 1992. Effects of ozone and temperature on growth of several wild plant species. Norwegian Journal of Agricultural Sciences 6: 195-204.

31 Pedersen, H.C., Myklebust, I., Nygård, T. & Sæther, M. 1992. Akkumulering og effekter av kadmium i lirype. Norsk institutt for naturforskning (NINA), Oppdragsmelding 152.

32 Amundsen, C.E. 1992. Sammenligning av relativ forsuringsfølsomhet med tålegrenser beregnet med modeller, i jord. Norges geologiske undersøkelse. NGU-rapport 92.294.

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38 Espelien, I.S. 1993. Genetiske effekter av tungmetaller på pattedyr. En kunnskapsoversikt. Norsk institutt for naturforskning (NINA), Utredning 051.

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ABSTRACT
The total deposition of sulphur and nitrogen compounds in Norway during the period 1988-1992 has been estimated on the basis of available measurement data.

NORWEGIAN TITLE
Avsetning av svovel og nitrogenforbindelser i Norge, 1988-1992

DESCRIPTORS		
Sulphur	Nitrogen	Deposition

ABSTRACT (in Norwegian)
Avsetning av svovel og nitrogenforbindelser i Norge i perioden 1988-1992 er beregnet på basis av målinger av luft- og nedbørkjemi.

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