An investigation of base cation deposition in Finland

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The deposition of the base cations Na^+, K^+, Ca^{2+} and Mg^{2+} in 1998 was estimated for Finland using measurement data for precipitation and air quality. The highest deposition for all compounds was measured near the southern coast, and it decreased gradually northwards. Deposition of sodium and magnesium increased again in the far north in the vicinity of the Arctic Ocean. The estimated ranges for the annual deposition of sodium, magnesium, potassium and calcium in Finland were 90–610 mg m^{-2}, 10–80 mg m^{-2}, 30–160 mg m^{-2} and 30–210 mg m^{-2}, respectively. Similar values have been published for large areas of Sweden and Norway. During the last decade the sum of the base cation concentration in bulk precipitation decreased by 15%–35% in all areas in Finland. The non-sea-salt fraction declined in bulk precipitation approximately as much. An especially large reduction occurred in the southeastern part of Finland, where the wet deposition of base cations decreased almost as much as the wet deposition of sulphur.

Introduction

The base cation ions, sodium (Na^+), potassium (K^+), magnesium (Mg^{2+}) and calcium (Ca^{2+}) are important nutrients to the forest. They are leached from the soil by acidic deposition in a greater amount than by neutral rain water. In the Finnish soils where the mineral content and the weathering rate are low, atmospheric deposition may be a significant source for base cations. The deposition of the base cations is also an important element in determining the total deposited acidity in the critical loads approach. The possible decline in the base cation deposition will

partly offset the positive effect of the reductions in sulphate and nitrogen deposition. Thus, detailed knowledge of the deposition of base cations is needed for planning and implementing the international emission reduction policies.

Mappings of the base cation deposition for the whole of Europe have been made for 1989 by van Leeuwen *et al.* (1996) and Draaijers *et al.* (1997) and for 1990 by Lee *et al.* (1999). In these studies, Finland, situated on the edge of the study area with a fairly low base cation deposition, was described mostly by the lowest class of the deposition scale. Forsius *et al.* (2001) reported about recent decline in base cation deposition at

several station of the International Cooperative Programme on Integrated Monitoring (ICP IM). At the two Finnish stations included, the downward trend was significant for the sum of Ca^{2+} and Mg^{2+} for the time period 1989–1998. Ukonmaanaho *et al.* (1998) found no significant trends for the sum of base cations Ca^{2+}, Mg^{2+}, and K^+ in deposition at the four Finnish ICP IM stations for the slightly shorter period 1989–1995. Laurila (1990) discussed the wet deposition trends of Mg^{2+} in the 1970s and 1980s at three stations in southeast, southwest and central Finland. The concentration of Mg^{2+} in precipitation decreased generally at all stations. In the southeast, an increase was detected when the wind direction during the precipitation was from the south, which reflected the increasing emissions of the Estonian oil shale power plants.

For critical load calculations, the base cation deposition has been quantified and mapped in Europe based on continental EMEP data (Dowling *et al.* 1993), and national submissions (Johansson 1999, Posch *et al.* 1999, 2001). Järvinen and Vänni (1990) reported about a decrease in calcium deposition in north and central Finland and unchanged deposition in the south in the time period 1972–1989.

Lövblad *et al.* (2000) have estimated the base cation deposition in Sweden for 1996 by different methods. The Match model results base on data assimilation on concentrations of base cations in air and precipitation from Swedish as well as some Norwegian and Finnish stations, land use information, meteorological data and a regional atmospheric dispersion model including modules for emission and deposition. Tørseth and Semb (1998) have made estimates of K^+ and Ca^{2+} deposition in Norway for 1993–1996.

The Nordic Council of Ministers started a Nordic project "Strategies for mapping base cation deposition in the Nordic countries" in 1998. The estimates of base cation deposition in Finland presented in this work are based on data collected under this Nordic project.

The aim of this paper is to assess the base cation deposition fields in Finland for the target year 1998 and to study the temporal changes in the deposition. While the method used in this paper leads to a fairly rough estimate of total deposition, it provides information needed about the regional variations within the country.

Material and methods

In this study, the inverse distance weighting (IDW) interpolation method was used for the deposition field calculations. Wet deposition was calculated by multiplying the annual bulk concentration field by the precipitation field. Dry deposition was estimated from the seasonal mean airborne concentration fields and the dry deposition velocities for two seasons and two land use classes.

The location of the stations from where monitoring data of air quality and precipitation concentration were included in this estimate is presented in Table 1 and Fig. 1. Detailed information on the background air quality monitoring programmes as well as the measuring stations and the sampling and analysis methods is available in the annual report of Air Quality Measurements of the Finnish Meteorological Institute (FMI) (Leinonen 2001). The methods used in the projects to obtain the airborne concentrations are described in detail also in Paatero *et al.* (2001) and Ricard *et al.* (2002a).

Table 1. Location of the stations. Available data: A = air quality, P = concentration in precipitation.

Name	Location		Data
	N	E	
Guttorp	60°15´	20°12´	P
Hailuoto	65°00´	24°41´	P
Hietajärvi	63°10´	30°43´	P
Hyytiälä	61°51´	24°17´	A
Kevo	69°45´	27°01´	A, P
Kotinen	61°14´	25°04´	P
Oulanka	66°19´	29°24´	P
Pallas	68°00´	24°15´	A
Pesosjärvi	66°18´	29°30´	P
Punkaharju	61°48´	29°20´	A, P
Sevettijärvi	69°35´	28°50´	A
Sodankylä	67°22´	26°39´	P
Sotkamo	64°06´	28°17´	P
Särkijärvi	67°55´	23°55´	P
Utö	59°47´	21°23´	P
Virolahti	60°32´	27°41´	P
Vuoskojärvi	69°44´	26°57´	P
Ähtäri	62°32´	24°13´	P

Part of the deposition of Mg^{2+}, K^+ and Ca^{2+} originates from the sea spray. The division into sea-salt and non-sea-salt fractions for both the wet and dry deposition was based on the assumption that sea spray is the only source for sodium ions. The ratio of sodium to the other base cations in sea water was then used to calculate the sea-salt fractions (Weast 1971, Asman *et al.* 1981).

Wet deposition

The measurement of base cations in precipitation is especially sensitive to contamination by local sources of dust and to changes in the sampling and analytical methods (Hedin *et al*. 1994). In order to minimize the effect of sampling on the results, the data for the concentration field assessment were derived exclusively from the background air quality monitoring programme of the FMI. Thus the criteria for the location of the stations, the sampling procedure, and the cleaning of the samplers were uniform enough for this study, facilitating the construction of a comparable data set.

The bulk deposition concentration was available from 15 stations. The longest time series (for Mg^{2+}) began already in 1973. All the other base cations have been monitored since 1985. The background air quality monitoring is carried out mainly in connection with international monitoring programmes: UN/ECE EMEP (United Nations Economic Commission for Europe, Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Pollutants in Europe), UN/ECE IM (Integrated Monitoring), and HELCOM (Baltic Marine Environmental Protection Commission). Measurements at the national monitoring stations supplement the network to cover the whole country.

Precipitation samples were collected with NILU type bulk deposition samplers on a daily or weekly basis, and the samplers were cleaned after every sampling period. Samples were analysed on a daily, weekly or monthly basis. Base cation concentrations were analysed by atomic absorption spectrophotometry until 1992, whereafter ion chromatography was used. The manuals of the monitoring programmes EMEP (EMEP
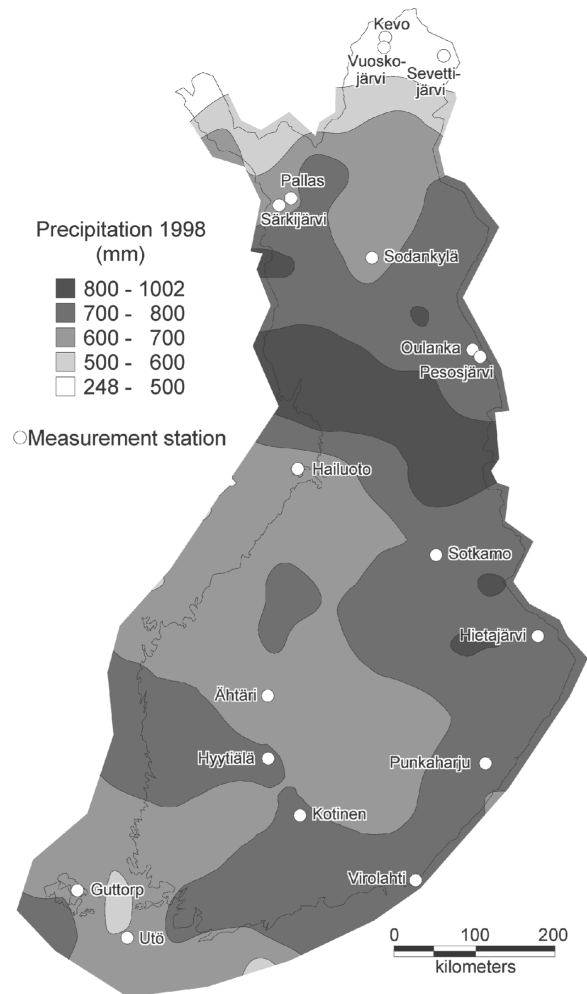

Fig. 1. Measuring stations and precipitation amount in 1998.

1996) and IM (Environment Data Centre 1993) were followed in the sampling, analysis and quality control.

The annual mean concentration of the base cations in precipitation was interpolated by the IDW method to a 5 km × 5 km grid. The annual precipitation field was likewise interpolated by the IDW method from the observations of the 416 meteorological stations. A wet deposition estimate was calculated for each grid node by multiplying the concentration value by the amount of precipitation. The weight factor related to the distance between the location of interest and the observation point was proportional to the second power of the distance. This enhanced the significance of the closest observation.

For the southwestern station of Utö, situated on a rocky island open to the sea, only half of the

concentration of the sea salt compounds Na$^+$ and Mg^{2+} was used in the interpolation in order to restrict the very strong sea salt effect in the area near the coast.

Dry deposition

The airborne concentration of base cations has mainly been analysed during projects of short duration. However, for the stations Punkaharju and Kevo data were available for a longer period, 1989–1999, excluding the years 1993 and 1994. For the target year, 1998, of the assessment, results from five stations with particulate base cation concentration were available. Different sampling equipment was used and the sampling time ranged from 24 hours to 1 month. However, the flow rate in all measurements was approximately the same (15 l min^{-1}) which gave a rather comparable upper limit of the particle size to the samples. The sampling times at the stations did not overlap totally, at two stations the measurements lasted from the summer of 1998 to summer 1999.

    Dry deposition was estimated by a combination of interpolated seasonal airborne concentrations and seasonal dry deposition velocities for different land use classes. The method has been used in an assessment of base cation deposition in Norway and is discussed in detail by Tørseth and Semb (1998). The deposition velocities used in Norway were applied in this investigation and are given in Table 2. We used the EMEP land use classification in a 50 km × 50 km grid by Sandnes (1995), but divided the land use into only two classes, one for forest and one for other areas.

Table 2. Applied deposition velocities (cm s^{-1}) for different base cations for the different land use categories and seasons.

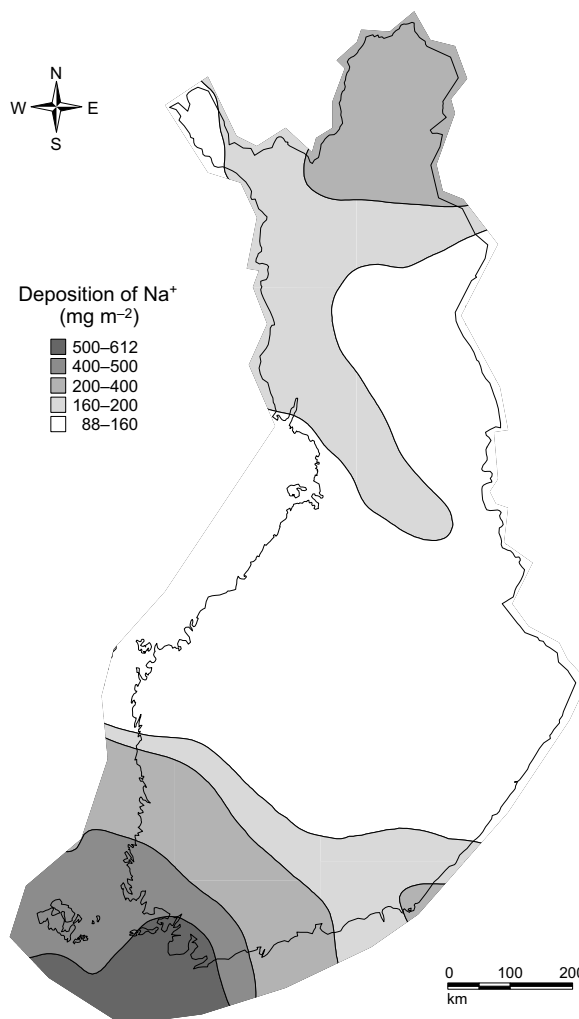| Compound	Land use			
	Forest		Other	
	Summer	Winter	Summer	Winter
Non-sea-salt K	1	1	0.25	0.1
Na, Mg, Ca, sea-salt K	2	2	1	0.25

Fig. 2. Deposition of sodium in 1998.

Results and discussion

Estimated deposition of base cations in 1998

The general pattern of the estimated annual total deposition of all base cations was rather similar: the highest values were reached near the southern coast (Figs. 2–5). The deposition of components which are mainly of sea salt origin, Na$^+$ and Mg^{2+}, increased again in the far north in the vicinity of the Arctic Ocean. The method used in this study certainly underestimated the deposition of base cations of sea salt origin to the first 1–5 km from the coast line, because the monitoring stations have been placed offshore in order to avoid contamination by sea water carried with high winds.
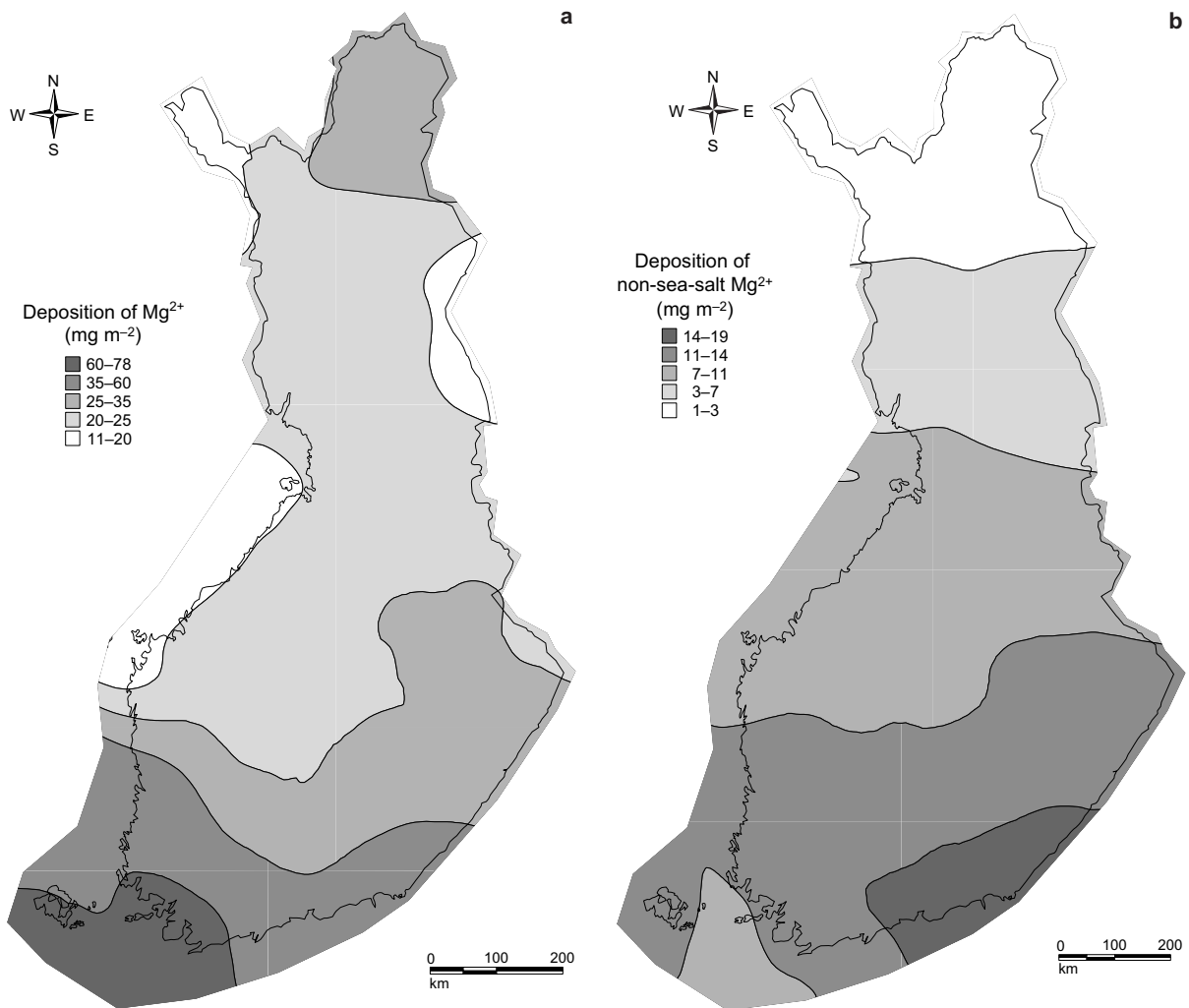
Fig. 3. Deposition of magnesium (**a**) and non-sea-salt magnesium (**b**) in 1998.

For accurate estimates the wet deposition should be measured as wet-only deposition. Our calculations for wet deposition were based on results from open bulk samplers, which collected also some part of the dry deposition. However, according to Swedish parallel wet and bulk measurements for five years at four rural stations, the difference was only approximately 10% as a mean value (Lövblad *et al*. 2000).

The amount of precipitation in Finland in 1998 (Fig. 1) varied between 446 and 1020 mm, which was 1.1–1.8 times the average of the standard period 1961–1990. The lowest values below 600 mm were measured in the far north and along the coast line of the Gulf of Bothnia. The highest precipitation occurred in the eastern part of central Finland. A zone of maximum precipitation, 900–1000 mm, ran from the northwest to the southeast over the western Lapland and

the central part of the country (Finnish Meteorological Institute 1999.)

Na⁺ deposition

The estimated annual deposition of Na⁺ was in the range of 90–610 mg m⁻² (Fig. 2). The maximum deposition occurred in the southwestern part of the country, which is open to the Baltic Proper and its heavy sea salt deposition with southwesterly winds. The isolines in the southern part of the country ran mainly from the northwest to the southeast. Higher values occurred also in the far north, where especially the low terrains northeast from the Lake Inari are influenced by the sea salt coming from the Barents Sea. The projection from the corner of the Bothnian Bay to the southeast with elevated
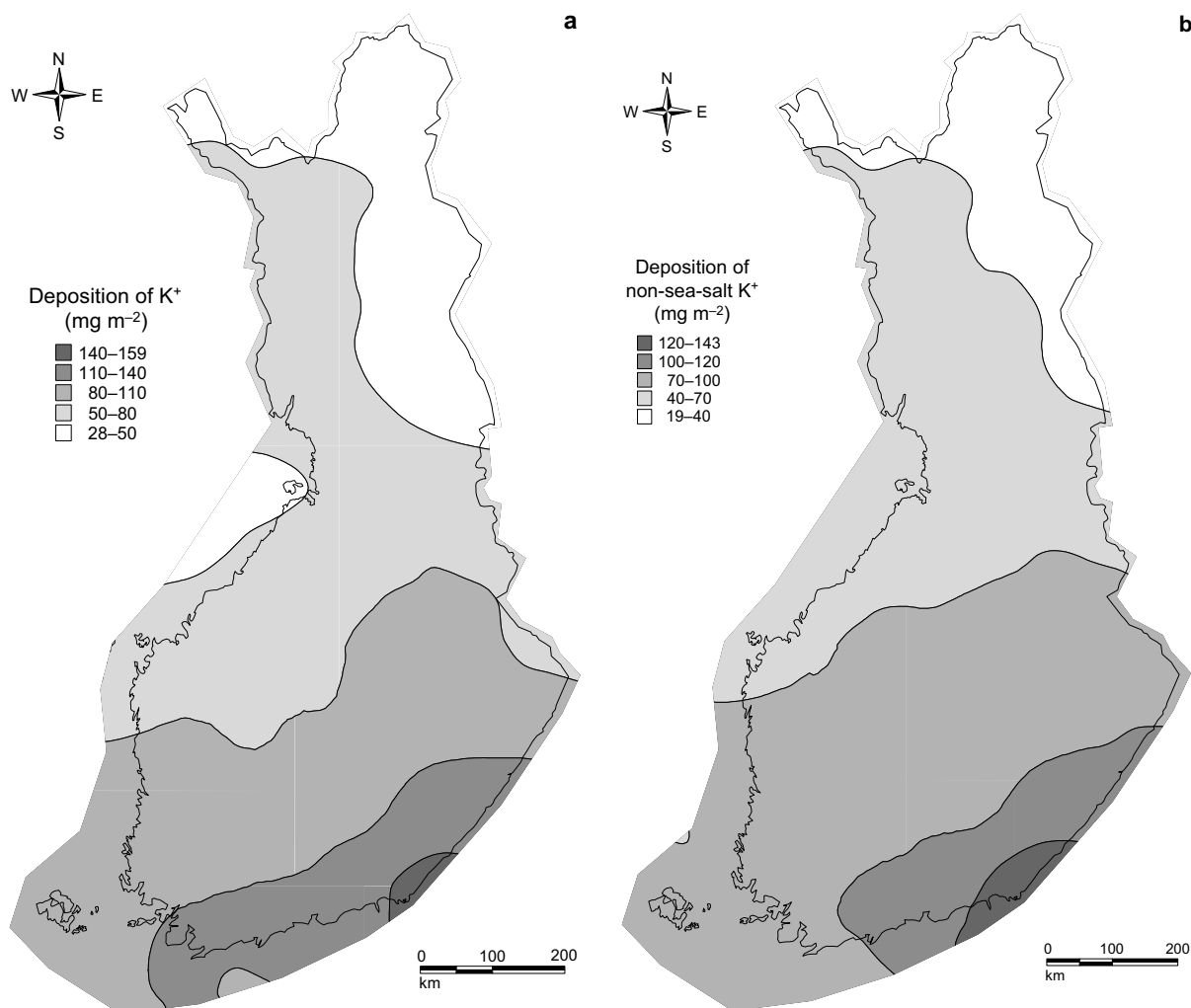
Fig. 4. Deposition of potassium (**a**) and non-sea-salt potassium (**b**) in 1998.

Na^+ deposition reflected the zone that had high precipitation values in 1998. Large areas of the country receive Na^+ less than 160 mg m^{-2}.

The estimate of the dry deposition of Na^+, as well as the other base cations, was of a more tentative nature than that of the wet deposition because of fewer measuring stations that had also different programmes. On the other hand, the maps do not try to describe the variation in deposition in detail but rather with five magnitude classes and only a few isolines. In the southern part of Finland the dry deposition of Na^+ was estimated to be about 30% of the total, in some areas in the north it accounted for up to 60% of the total.

Swedish calculations for 1996 with the Eulerian atmospheric transport modelling system MATCH showed that the total Na^+ deposition originates mainly from the sea salt or from sources outside the country. The deposition was in the range of 100–300 mg m^{-2} in most areas in central and northern Sweden. In the south the deposition was 300–800 mg m^{-2} and the west coast received Na^+ up to 1000 mg m^{-2}. The Swedish calculations gave 20%–50% as the share of the dry deposition in the total sodium deposition, with higher percentages in the north (Lövblad *et al.* 2000).

Mg^{2+} deposition

The estimated total and non-sea-salt deposition of Mg^{2+} in Finland was within the ranges of 10–80 mg m^{-2} and 1–20 mg m^{-2}, respectively (Fig. 3). The total deposition of Mg^{2+} closely resembled that of Na^+ because both of them originate mainly from the seawater. The maximum area of precipitation in eastern central Finland
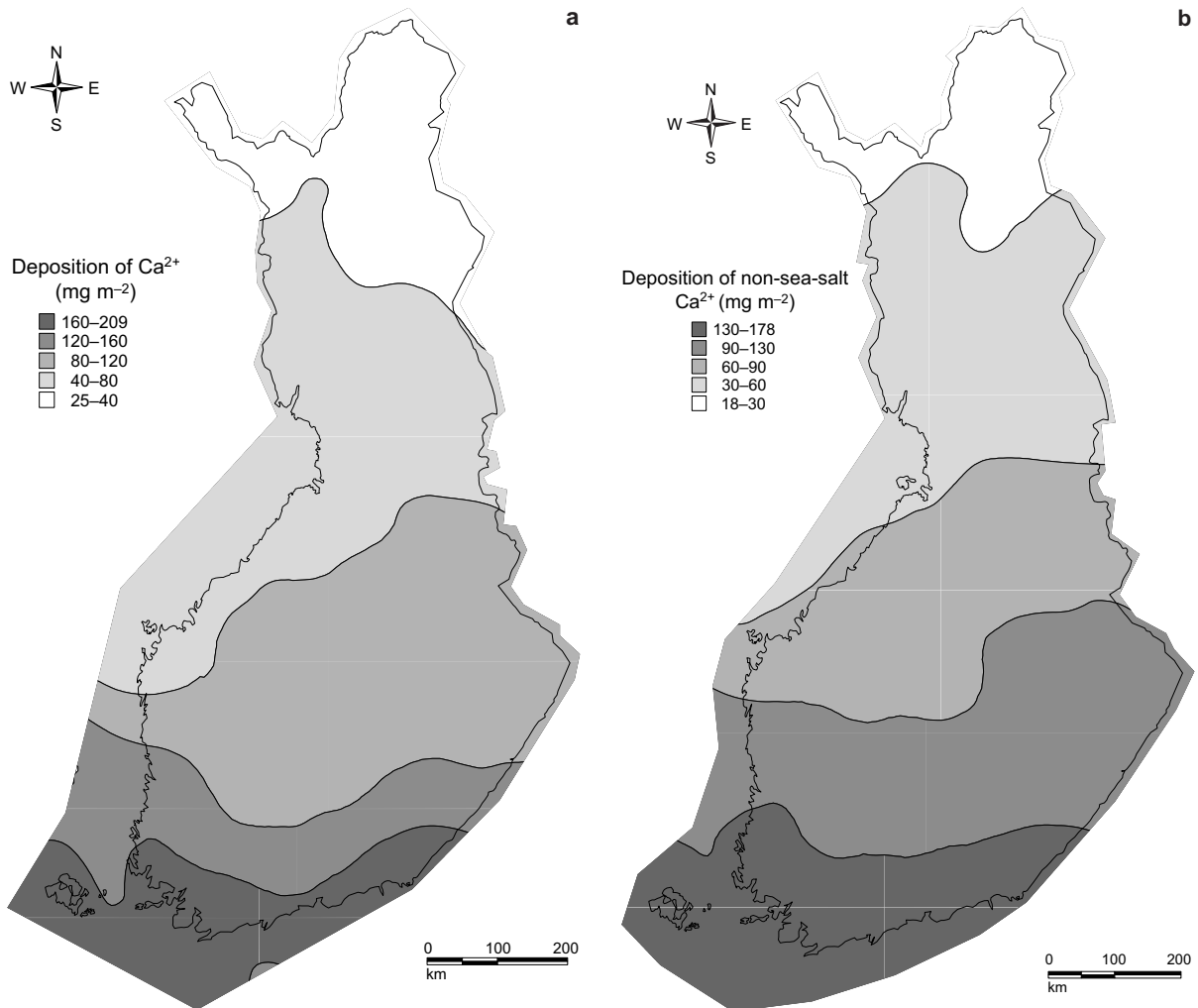
Fig. 5. Deposition of calcium (**a**) and non-sea-salt calcium (**b**) in 1998.

and the minimum along the western coast line were reflected in the deposition map. The non-sea-salt Mg^{2+} deposition had a maximum in the southeastern part of the country with the isolines running from the northeast to the southwest. Near the southeastern border of Finland there are large Estonian power plants using oil-shale. The fly ash particles contain not only a large fraction of Ca^{2+} but also Mg^{2+} and K^+ that are emitted from the high stacks in large quantities (Kaasik and Soukand 2000). A major part of the non-sea-salt Mg^{2+} deposition in southeastern Finland was most likely transported from the southern shore of the Gulf of Finland. The fraction of the Mg^{2+} dry deposition of the total was calculated to be about the same as that of the Na^+ deposition.

The total Mg^{2+} deposition in Sweden, according to the MATCH-model, was 0–60 mg m^{-2} in the central and northern parts of the country,

80–120 mg m^{-2} in the south and up to 160 mg m^{-2} in the west coast. In Sweden, the non-sea-salt Mg^{2+} contribution was neglible, and the contribution of the dry deposition was 20%–40%. The higher percentages were estimated for the northern part of the country. (Lövblad *et al*. 2000).

K$^+$ deposition

A major part of the K$^+$ deposition is derived from sources other than sea spray, e.g. the burning of wood and other bio-fuels. Figure 4 shows rather similar total and non-sea-salt K$^+$ deposition. The area of highest deposition, values up to 150–170 mg m^{-2}, was near the southeastern coast, the isolines there ran from the northeast to the southwest reflecting the distance from the

high emission area of the Estonian power plants. The maximum precipitation area in the northwest was also evident in the deposition maps. The main parts of the country received less than 20% of the K^+ deposition in the dry fraction.

According to the MATCH model, the annual total K^+ deposition in Sweden was 0–115 mg m^{-2} in the central and northern parts of the country, and up to 160 mg m^{-2} in the south. In the whole country, the deposition was mostly long range transported. According to the Swedish estimate the dry deposition contributed approximately 10% to the total deposition throughout the country (Lövblad *et al.* 2000). Tørseth and Semb (1998) estimated that the deposition of non-sea-salt K^+ was 50–200 mg m^{-2} in large areas of inland Norway as a mean value for 1993–1996.

Ca²⁺ deposition

Finally, the total Ca^{2+} deposition in Finland decreased gradually from the south to the north, with the slight bending of the isolines caused by the exceptionally high and low precipitation zones (Fig. 5). According to our estimate, the southernmost part of the country received annually up to 210 mg m^{-2} of total Ca^{2+} deposition, and the northernmost area less than 40 mg m^{-2}. There was not much difference in the total and non-sea-salt deposition (Fig. 5). For most parts of the country, the dry deposition fraction was smaller than 20% of the total deposition.

Values calculated with the MATCH model were rather similar for Sweden: 40–140 mg m^{-2} in the central and northern parts of the country,

and up to 220 mg m^{-2} in the south. The domestic contribution in Sweden was smaller than 10%, and the dry fraction accounted for approximately 10% (Lövblad *et al.* 2000). The estimate for non-sea-salt Ca^{2+} deposition in Norway was up to 160 mg m^{-2} in large areas of inland Norway as a mean value for 1993–1996 (Tørseth and Semb 1998).

Trends in base cation deposition

Time series of the concentration of base cations in precipitation from the FMI monitoring programmes were available for 10–15 years, depending on the measuring station. In all areas of the country, the concentration of the sum of the base cations in precipitation decreased 15%–35% between the years 1989 and 2000 (Table 3). For this calculation, we chose monitoring stations that have been operational for at least 10 years at the same location in order to avoid changes in concentration due to the effect of different local land use.

At the station Guttorp in the southwestern part of the country, the concentration of the base cations was exceptionally high in 1999, after a rather homogeneous time series in the 1990s. Because no explanation was found for the sudden increase of base cations for only one year, the latter time series at this station was limited to the years 1996–1998. The other southwestern station Utö was relocated in 1989, so only data since 1990 were used in the calculations. The two southwestern stations are located in totally different surroundings: Utö is on a rocky island on the border of the Baltic proper, Guttorp is in

Table 3. Decline of base cation (BC) concentration in precipitation (%). Change in volume-weighted means of the years 1989–1993 and 1996–2000, range given for different regions. A negative number means an increase in the concentration.

Location of stations	Sum of total BC	Sum of nss BC	nss Ca	nss K
SE Finland	35	30–45	45	10–40
SW Finland	20*–30^	0*–35^	–5*–15^	10*–65^
Southern Finland	30	35	40	20
Central Finland	20–35	20–30	20–35	15–25
Southern Lapland	30	15–30**	35	–20–0**
Northern Lapland	15	25**–40	35**–50	–15**–40

Different time series: ^ = 1990–1993; * = 1996–1998; ** = 1996–1999.

the inner parts of a large island. Results from these two stations differed greatly: the lower value of the scale in Table 3 was always measured at Guttorp, the higher one at Utö.

At the two northern stations Pesosjärvi and Vuoskojärvi, the monitoring activity ended in 1999, therefore the latter mean value was calculated from only four years 1996–1999.

The decrease in the base cation concentration was 30%–35% at the stations in the central and southern parts of the country and in southern Lapland. The non-sea-salt fraction of the sum of the base cation concentration declined approximately as much; only at Guttorp no decrease was observed. At the stations in the far north, during the last decade the reduction of the non-sea-salt component was substantially larger than the decrease of the sea-salt component. The observed decline of non-sea-salt base cations in air and precipitation is supposed partly to be the result of declining emissions of fly ash from energy production and industrial plant (Lee and Pacyna 1999, Kaasik and Soukand 2000).

Ca^{2+} is the major component of the non-sea-salt base cation concentration in precipitation. Its concentration declined widely, even more than the sum of the non-sea-salt base cation concentration. At the stations in the southeastern part in the country and in the far north, the reduction was most dramatic: the concentration in the end of the 1990s was nearly half of that in the early 1990s. At the stations in the southwest the non-sea-salt calcium concentrations either slightly increased or the decrease was rather low.

Results for the changes in non-sea-salt K^+ concentration in precipitation differed largely among the stations. However, a reduction of 10%–40% could be detected at most stations.

The changes in the base cation deposition are particularly interesting in comparison with the deposition of acidifying components (Fig. 6). The short-term oscillations of the time series of the annual values were filtered off by the moving and weighted average method Gaussian filter. Mitchell *et al*. (1966) and Heino (1994) used this method in the visualization of climatological time series. According to Mitchell *et al*. (1966) the Gaussian density function coefficients give an ideal shape of a low pass filter for the visual inspection of possible systematic changes. Since

the weighting factors come from the density function in the Gaussian distribution, the peak values affect the mean value gradually and the curve settles down showing better the long-term trends.

In southern and central Finland, the sulphur deposition decreased rapidly during the monitoring period (Fig. 6). This is due to the heavy emission reduction actions in Finland and elsewhere in Europe (Vestreng 2000). At the stations in the southeast, a marked decline in the base cation deposition in bulk precipitation was observed as well. This cuts off part of the positive effect of the reduced sulphur deposition. At the stations in other parts of the country, the sulphur deposition declined much more than the base cation deposition. In the south-western station as well as in the far north, no clear long-term change in the base cation deposition could be detected.

The sum of base cation deposition in bulk precipitation levelled off at about 20 meq m^{-2} at stations in the southeast. At the station in the southwest, the deposition fluctuated around the same value. At all other stations the bulk base cation deposition reached the level of 5–10 meq m^{-2}.

Figure 7 shows the time series of the particulate base cation concentrations at two stations: Kevo, which is situated in the far north, and Punkaharju in the southeast. A downward trend is visible for all components at both stations: all the mean values for the latter measuring period were lower than the mean value of the previous years. The percent decline of the base cation concentration in the particles was approximately the same as that in the bulk precipitation; the mean value of the years 1995–1999 was about 20%–30% lower than the mean value of the years 1989–1992. The non-sea-salt fraction of the base cations in particles declined about 15%–30% in the same time period.

Reliability of the estimates

The quality of results in interpolation of monitoring data is difficult to measure. However, the good comparability of our values with values in maps of the other Nordic countries is one indicator for the satisfying quality of the result.

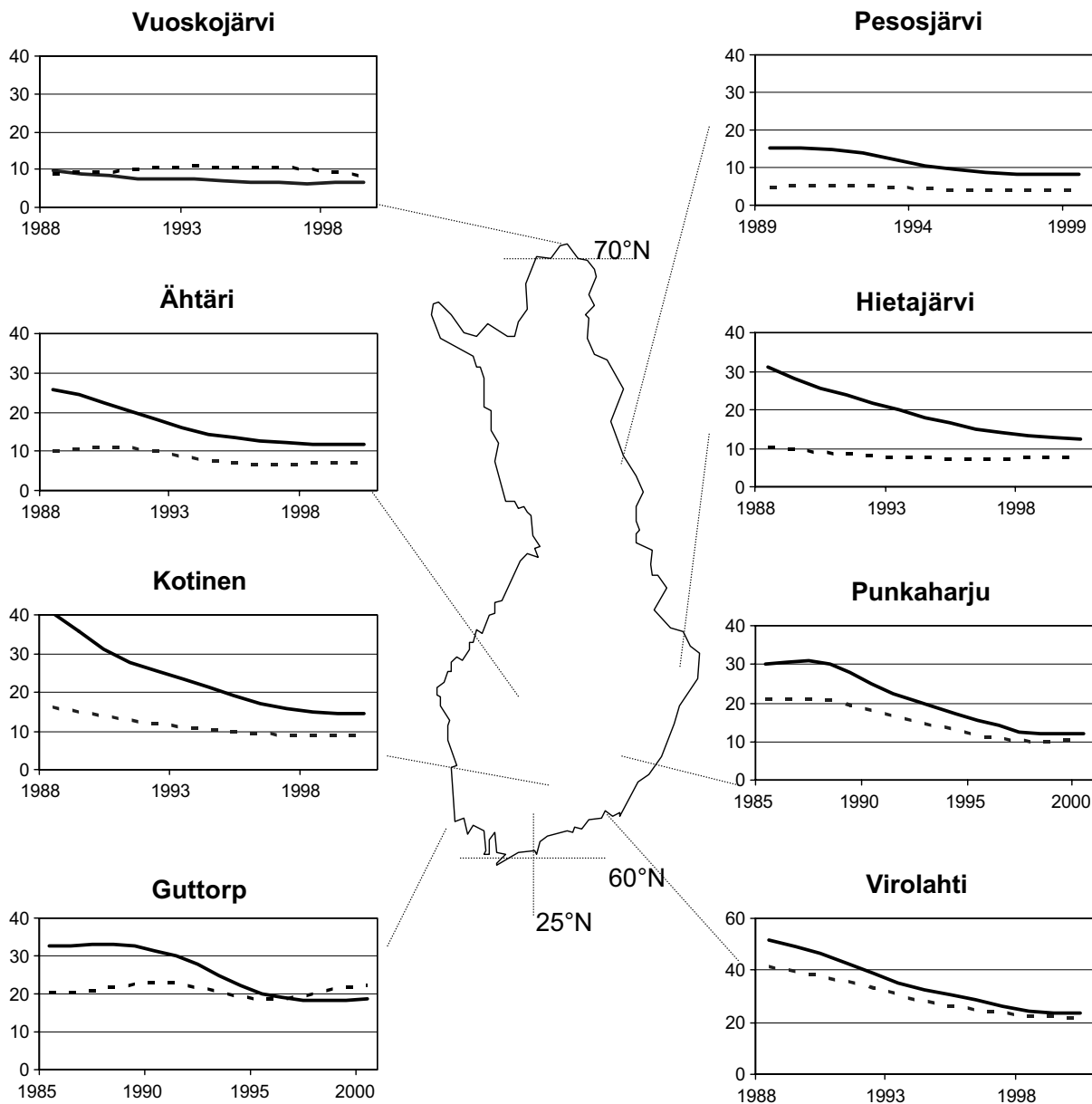The large-scale estimates for wet deposi-

Fig. 6. Gaussian smoothing curves showing the trends in sulphate (solid line) and base cation (dashed line) deposition in bulk precipitation at stations in different parts of the country (unit meq. m^{-2}). Note that the whole available time series were used in the calculation and the period at some stations exceeds that used in Table 3.

tion in Finland can be considered fairly reliable because they were based on a dense network of precipitation amount and a rather homogeneous concentration field. Small-scale local differences could not be evaluated with this type of method. The concentration of the base cations in the precipitation is low, but the whole chain of the data from sampling to analysis and data checking has been under detailed quality control. The use of bulk collectors in monitoring overestimated the wet deposition slightly.

The open area deposition results of the Finnish ICP Forest programme for 1998 (Lindroos *et al.* 2000) fitted rather well within the isolines in our maps of the wet deposition. At only two of the twelve ICP Forest stations the deposition of the base cations in the open area was notably different than that given in our map: at the western coast in central Finland, the ICP-Forest results were slightly higher and at the SE coast they were lower. The sampling procedure and the location of the open area stations in the ICP-
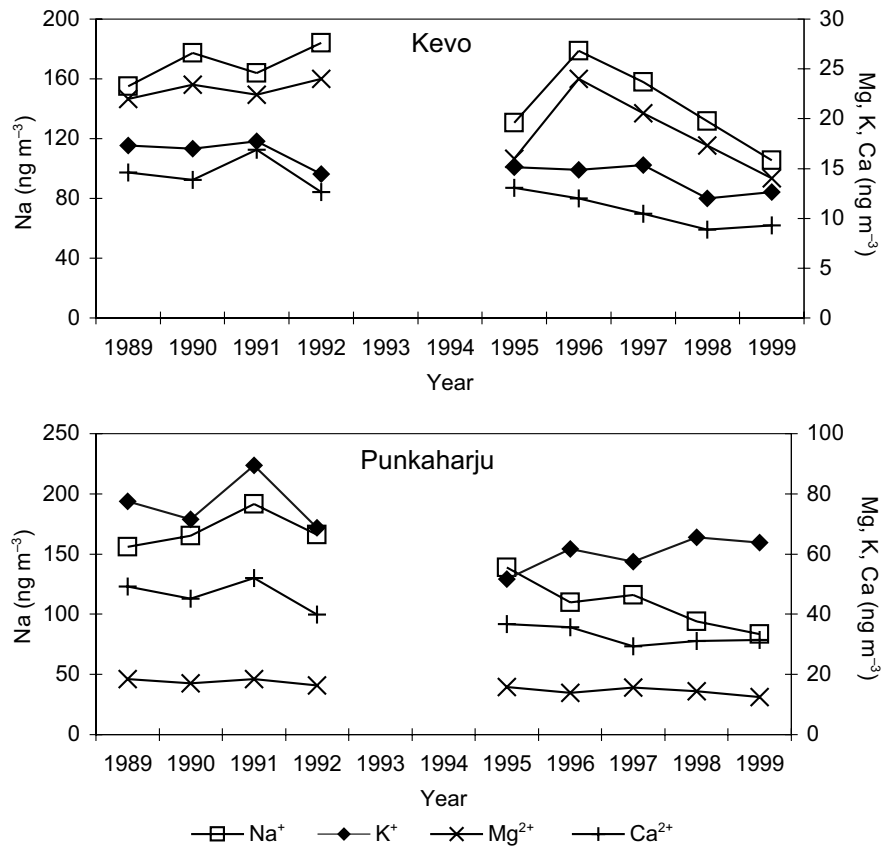
Fig. 7. Time series of the particulate base cation concentration (sea-salt + non-sea-salt) at stations Kevo and Punkaharju in 1989–1999. No measurements in 1993–1994.

Forest programme were rather similar to those of the FMI which enabled the comparison of the results.

Larger uncertainties were found in the dry deposition fraction of the estimates because of only few measurement series were available and because of the use of fixed seasonal deposition velocities. The used deposition velocities have a great effect on the dry deposition estimate. The deposition velocity is highly dependent on the size of the particles, the nature of the deposition surface and the meteorological conditions, such as relative humidity and wind speed. Virkkula *et al.* (1999) calculated deposition values for a snow surface in Sevettijärvi from measurements in 1993–1994. Their estimate for Ca^{2+}, 0.39 cm s^{-1} as a mean value for five winter months, does not deviate much from the value used in this study for the winter period. According to recent studies by Ricard *et al.* (2002b), most of the mass of Na^+, Mg^{2+}, Ca^{2+} and K^+ is in particles with mean aerodynamic diameters around 3.5–4.0 μm during the summer in Sevettijärvi. In winter the concentrations there

are lower, but most of the mass of the marine components Na^+ and Mg^{2+} is found in particles of about 2.5–3.0 μm. Pakkanen *et al.* (2001) presented an aerosol size distribution for a rural station in southern Finland. The elements Na, K, Mg and Ca are also there present in the coarse mode, in particles with the mean aerodynamic diameter of about 4–5 μm. These results support our choice of rather high deposition velocities.

Throughfall sample results of the base cations could not be used to supplement the sparse concentration map without correction, because of the internal circulation of the elements (Ferm and Hultberg 1999). To improve the estimate of the dry deposition fraction, more monitoring data of particulate base cations as well as further studies about deposition velocities would be necessary. In southern Sweden, a new measurement technique with diffusive samplers for dry deposition has been introduced (Ferm *et al.* 2000). The use of this method in monitoring would also improve the estimates.

Anttila (1990) has published the first evaluation of Finnish base cation emissions for 1987.

According to this evaluation, the main sources of base cations are soil dust, energy production, industrial processes, traffic and seawater. When an updated emission survey of base cations for Finland and the rest of Europe will be available, calculations with mathematical dispersion models could be evaluated.

The interannual variation in meteorology influences many factors of the deposition e.g. the precipitation amount and the importance of different sources. Recalculations of the estimates to a mean value of several years would thus give a more general view of the deposition.

Conclusions

The deposition of the base cations Na^+, K^+, Ca^{2+} and Mg^{2+} in 1998 was estimated for Finland using measurement data for bulk precipitation and air quality. The estimated ranges for the annual deposition of sodium, magnesium, potassium and calcium in Finland in 1998 were 90–610 mg m^{-2}, 10–80 mg m^{-2}, 30–160 mg m^{-2} and 30–210 mg m^{-2}, respectively. The depositions were approximately at the same level as in Sweden (Lövblad, *et al.* 2000) and Norway (Tørseth and Semb 1998).

Hedin *et al.* (1994) reported about steep declines in atmospheric base cation deposition in regions of Europe and North America. The results of this study show a similar development in Finland. Part of the positive effect of the declined acid deposition in Finland is thus lost. For the wet deposition, the largest decrease in the base cation deposition occurred in southeastern Finland. Further studies are needed to evaluate whether the decreased base cation emission from the southern shore of the Gulf of Finland has negative effects on the Finnish ecosystems.

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