ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

RAPORTTEJA
RAPPORTER
REPORTS
2008:6

EFFECTS OF KOLA AIR POLLUTION ON THE ENVIRONMENT IN THE WESTERN PART OF THE KOLA PENINSULA AND FINNISH LAPLAND - FINAL REPORT

JUSSI PAATERO
VLADIMIR DAUVALTER
JOHN DEROME
JUKKA LEHTO
JARI PASANEN
TIMO VESALA
JUHA MIETTINEN
ULLA MAKKONEN
ELLA-MARIA KYRÖ
JUSSI JERNSTRÖM
LUDMILLA ISAEVA
KIRSTI DEROME

RAPORTTEJA
RAPPORTER
REPORTS

No. 2008:6 UDC 504.054

EFFECTS OF KOLA AIR POLLUTION ON THE ENVIRONMENT IN THE WESTERN PART OF THE KOLA PENINSULA AND FINNISH LAPLAND - FINAL REPORT

Jussi Paatero[1], Vladimir Dauvalter[2], John Derome[3], Jukka Lehto[4], Jari Pasanen[5], Timo Vesala[6], Juha Miettinen[5], Ulla Makkonen[1], Ella-Maria Kyrö[6], Jussi Jernström[4], Ludmilla Isaeva[2] and Kirsti Derome[3]

1. Finnish Meteorological Institute
2. Institute of North Industrial Ecology Problems, Apatity, Russia
3. Rovaniemi Research Unit, Finnish Forest Research Institute
4. University of Helsinki, Laboratory of Radiochemistry
5. Lapland Regional Environment Centre
6. University of Helsinki, Department of Physics

Ilmatieteen laitos
Meteorologiska institutet
Finnish Meteorological Institute
Helsinki 2008

ISBN 978-951-697-686-3
ISSN 0782-6079

Yliopistopaino
Helsinki 2008

FINNISH METEOROLOGICAL INSTITUTE

Series title, number and report code of publication
Reports 2008:6

Published by
Finnish Meteorological Institute
(Erik Palménin aukio 1) , P.O. Box 503
FIN-00101 Helsinki, Finland

Date December 2008

Authors

Jussi Paatero, Vladimir Dauvalter, John Derome, Jukka Lehto, Jari Pasanen, Timo Vesala, Juha Miettinen, Ulla Makkonen, Ella-Maria Kyrö, Jussi Jernström, Ludmilla Isaeva and Kirsti Derome

---

Title

EFFECTS OF KOLA AIR POLLUTION ON THE ENVIRONMENT IN THE WESTERN PART OF THE KOLA PENINSULA AND FINNISH LAPLAND - FINAL REPORT

Abstract

The metallurgical industry at Kola peninsula, north-west Russia is the most important source of air pollution next to Norilsk, Siberia in the Arctic. The non-ferrous metal smelters in the area emit huge quantities of sulphur dioxide, metals and inhalable particles to the atmosphere. These pollutants have a serious impact to the atmosphere and biosphere at Kola peninsula and Finnish Lapland. In the immediate vicinity of certain industrial plants even "industrial deserts" have been created due to the pollutants.

The Academy of Finland conducted an extensive research programme on Russia in flux in 2003-2007. As a part of this programme a project was conducted in order to create an integrated analysis of past and present atmospheric emissions of pollutants from Kola area, their dispersion patterns in the atmosphere, and their effects on the environment at Kola area, Russia and Finnish Lapland.

Even though the sulphur emissions to the atmosphere from the metallurgical industry of the Kola peninsula have decreased after the 1980s they are still bigger than the whole emissions of Finland. In Finland the westerly winds are dominating taking often the emitted air pollutants further away from Finland. Yet, during easterly winds the concentrations of sulphur dioxide,aerosol particles and metals in the air increase radically close to the Finnish-Russian border. The acidification of small lakes in Finland was reduced after the early 1990s due to the lower atmospheric load, both from the Kola peninsula and from the densely industrialised and populated parts of Europe. However, during the new millenium this positive development seems to have leveled out. In Finland the pollutant emissions from the smelters seem to have no clear impact on the terrestrial environment, there is no east to west gradients in neither metal contents of berries nor in pine tree condition.

Publishing unit
Air Quality Research

Classification (UDK)
504.054

Keywords
Kola, Lapland, air pollutants

ISSN and series title
0782-6079 Reports

ISBN
978-951-697-686-3

Language
English

Sold by
Finnish Meteorological Institute / Library
P.O.Box 503, FIN-00101 Helsinki
Finland

Pages 26

Price

Note

ILMATIETEEN LAITOS

Julkaisun sarja, numero ja raporttikoodi
Raportteja 2008:6

Julkaisija Ilmatieteen laitos, (Erik Palménin aukio 1)
PL 503, 00101 Helsinki
Julkaisuaika Joulukuu 2008

Tekijä(t) Projektin nimi

Jussi Paatero, Vladimir Dauvalter, John Derome, Jukka Lehto, Jari Pasanen, Timo Vesala, Juha Miettinen, Ulla Makkonen, Ella-Maria Kyrö, Jussi Jernström, Ludmilla Isaeva ja Kirsti Derome

---

Nimeke

KUOLAN ILMANSAASTEIDEN VAIKUTUS YMPÄRISTÖÖN KUOLAN NIEMIMAAN LÄNSIOSASSA JA SUOMEN LAPISSA - LOPPURAPORTTI

Tiivistelmä

Luoteis-Venäjällä, Kuolan niemimaalla sijaitsevan metallurgisen teollisuuden päästöti ilmakehään ovat suurin yksittäinen ilmansaasteiden lähde arktisella alueella Siperian Norilskin jälkeen. Värimetallisulatot levittävät suuria määriä rikkidioksidia, metalleja ja pienhiukkasia ilmakehään. Näillä saasteilla on lähialueilla suuria ympäristövaikutuksia, sulattojen ympärille on muodostunut jopa "teollisuuserämaita".

Suomen Akatemia järjesti Muuttuva Venäjä –tutkimusohjelman vuosina 2003-2007. Osana tätä ohjelmaa Ilmatieteen laitoksen johtama konsortio tutki Kuolan ilmansaasteiden päästöjä, kulkeutumista ja vaikutuksia ympäristöön Kuolan niemimaalla ja Suomen Lapissa.

Vaikka Kuolan rikkipäästöt ovat vähentyneet 1980-lukuun verrattuna, ne ovat edelleen yhtä suuret kuin koko Suomen päästöt. Alueella vallitsevien länsituulten ansiosta useimmiten päästöt kulkeutuvat itään ja koilliseen. Mutta itätuulilla voidaan havaita suuria pitoisuuksia rikkidioksidia, pienhiukkasia ja metalleja. Pienten järvien happamoituminen väheni 19990-luvulla, mutta 2000-luvulla tämä myönteinen kehitys on tasaantunut. Maaympäristöön päästöillä ei Suomen puolella näytä olevan suurta vaikutusta, sillä marjojen metallipitoisuuksilla tai mäntyjen kunnolla ei Suomen puolella ole itä-länsi –suuntaista gradienttia.

Julkaisijayksikkö
Ilmanlaadun tutkimus

Luokitus (UDK) 504.064
Asiasanat Kuola, Lappi, ilmansaasteet

ISSN ja avainnimike
0782-6079 Raportteja

ISBN 978-951-697-686-3
Kieli englanti

Myynti
Ilmatieteen laitos / Kirjasto
PL 503, 00101 Helsinki

Sivumäärä 26
Hinta
Lisätietoja

EFFECTS OF KOLA AIR POLLUTION ON THE ENVIRONMENT IN THE WESTERN PART OF THE KOLA PENINSULA AND FINNISH LAPLAND - FINAL REPORT

INTRODUCTION

The mining and metallurgical industry on the Kola Peninsula, north-west Russia, is, after Norilsk, the largest source of air pollutants in the Arctic. The non-ferrous smelters (primarily nickel and copper) at Monchegorsk, Nikel and Zapoljarnij, the apatite mines at Apatity and Kirovsk, the aluminium smelter at Kandalaksha and the iron ore mines and mills at Kovdor and Olenegorsk, emit huge quantities of sulphur dioxide, metals and inhalable particles into the atmosphere (Figure 1). These gas- and particle-phase pollutants have a serious impact on the atmosphere and biosphere on the Kola Peninsula, NE Norway and in Finnish Lapland. Pollutant levels are so high that "industrial deserts" even have been created in the immediate vicinity of the smelters (Figures 2 and 3). The emission of sulphur compounds (primarily gaseous SO_2 and sulphate particles) has resulted in the acidification of many aquatic environments in the region. A high proportion of the metals emitted into the atmosphere eventually accumulate in the food chains, causing extensive ecotoxicological effects. The pollutants also affect the traditional way of living of the indigenous people living in the area, as well as probably the health of all the inhabitants in the region (Virkkula et al. 1995, Virkkula et al. 1997, Wichmann & Peters 2000, Virkkula et al. 2003).

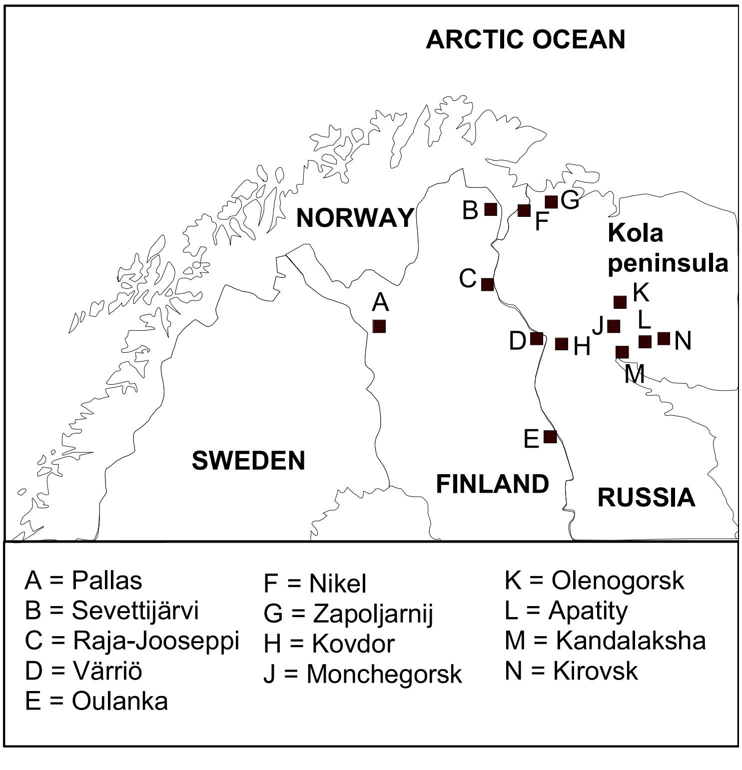

Figure 1. Map of the study area.

The Academy of Finland implemented an extensive, internationally oriented research programme on "Russia in flux" during 2003-2007. The programme consisted of 30 separate projects with ca. 100 researchers representing various fields of scientific research. This report presents the results of one of these projects, the purpose of which was to carry out an integrated analysis of past and present atmospheric emissions of pollutants from the Kola area, their transport and dispersion patterns in the atmosphere, and their effects on climate and terrestrial and aquatic ecosystems in the Kola area, NW Russia and in Finnish Lapland.

Figure 2. The copper-nickel smelters at Monchegorsk (Photo: Finnish Meteorological Institute).

Figure 3. Destroyed forest ecosystems in the immediate vicinity of the Monchegorsk smelters (Photo: Finnish Meteorological Institute).

ATMOSPHERIC EMISSIONS AND DISPERSION

The environment in the border area between Russia, Norway and Finland has been significantly affected by emissions from the nonferrous metal industry at the Pechenganikel smelter complex (Nickel/Zapolyarny) and Severonikel smelter complex (Monchegorsk) on the Kola Peninsula since the 1930s. Both plants are currently subsidiaries of the MMC Norilsk Nickel Group The main gaseous air pollutants emitted by the industry are SO_2 and, to a lesser extent, also NO_2. The emissions of particle-bound metals include e.g. nickel, copper and arsenic. In addition to the emissions from the high stacks of the smelters, the plants also produce diffuse emissions that complicate the modelling of their atmospheric transport and dispersion. The emission data for the Pechenganikel smelter complex at Nikel and Zapolyarny (shown in Figure 4) are based on mass balance calculations performed by the company. There was a radical increase in sulphur emissions during the 1970s when the smelter started to process ore from Norilsk, Siberia, that has a high sulphur content (almost 27%). During the 1990s, however, SO_2 emissions started to decline due to reduced production related to the economic problems in Russia and the enhanced use of local ore with a lower sulphur content. Although the SO_2 emissions have decreased significantly since the 1980s, the values are currently still relatively high. For example, in 2004 about 110 000 tonnes of

SO_2 were emitted from the smelter, which is approximately the same order of magnitude as the total annual sulphur emissions in Finland (83 500 tonnes as sulphur dioxide, see www.ymparisto.fi).

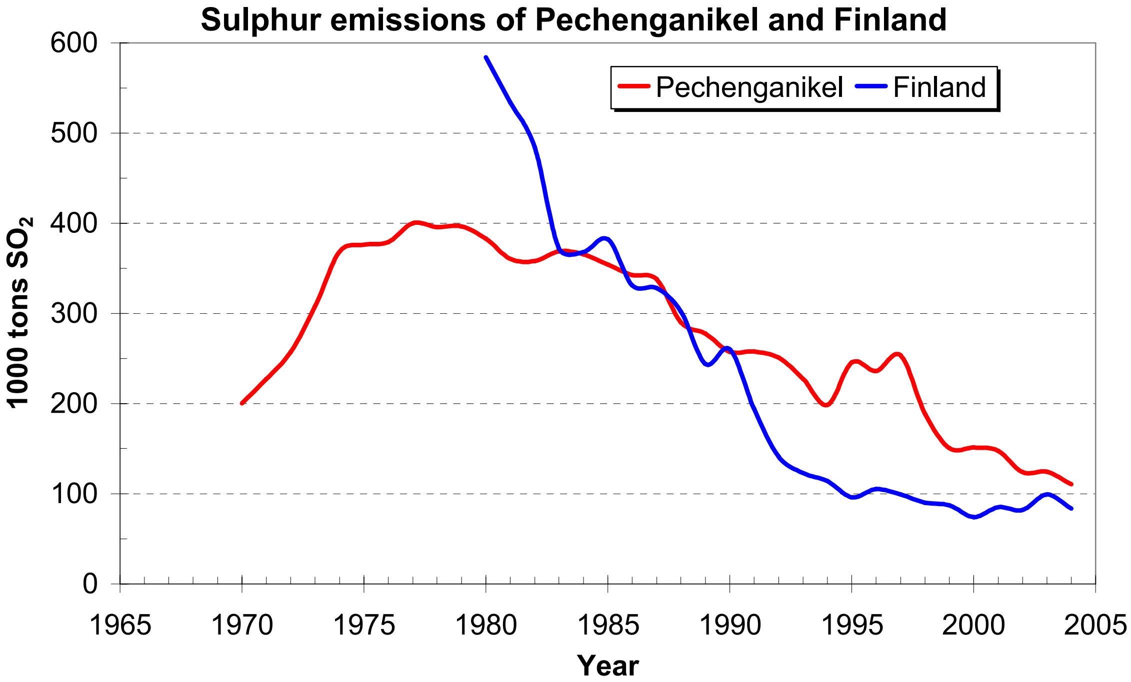

Figure 4. Sulphur emissions (1000 tonnes of SO_2) from the Pechenganikel smelter complex and total sulphur emissions in Finland (Data: Kola GMK Company and Finnish Ministry of Environment, www.ymparisto.fi).

The Severonikel complex (Monchegorsk) is the largest smelter on the Kola Peninsula, and processes enriched copper and nickel ore and nickel matte from the Norilsky Combine and the Pechenganikel Plant. The plant also uses scrap metal and waste and raw materials from domestic and international suppliers. Wastewater and atmospheric emissions from the plant are formed during the hydro- and pyrometallurgical processing of the raw materials and in the production of sulphuric acid from the production waste. In addition, heavy oil (230 000 tonnes in 2002) is burnt in a power plant to provide heat and part of the electricity supply to the plant.

The sulphate and metal emissions reported by the Severonikel complex are presented in Figures 6 and 7. Sulphur emissions were at their maximum (287 000 tonnes) in 1990, and declined during the 1990's to below 50 000 tonnes per year. Copper and nickel emissions peaked at over 6 000 tonnes per years in the late 1980s, but fell during the first half of the 1990s to below 1 000 tonnes per year.

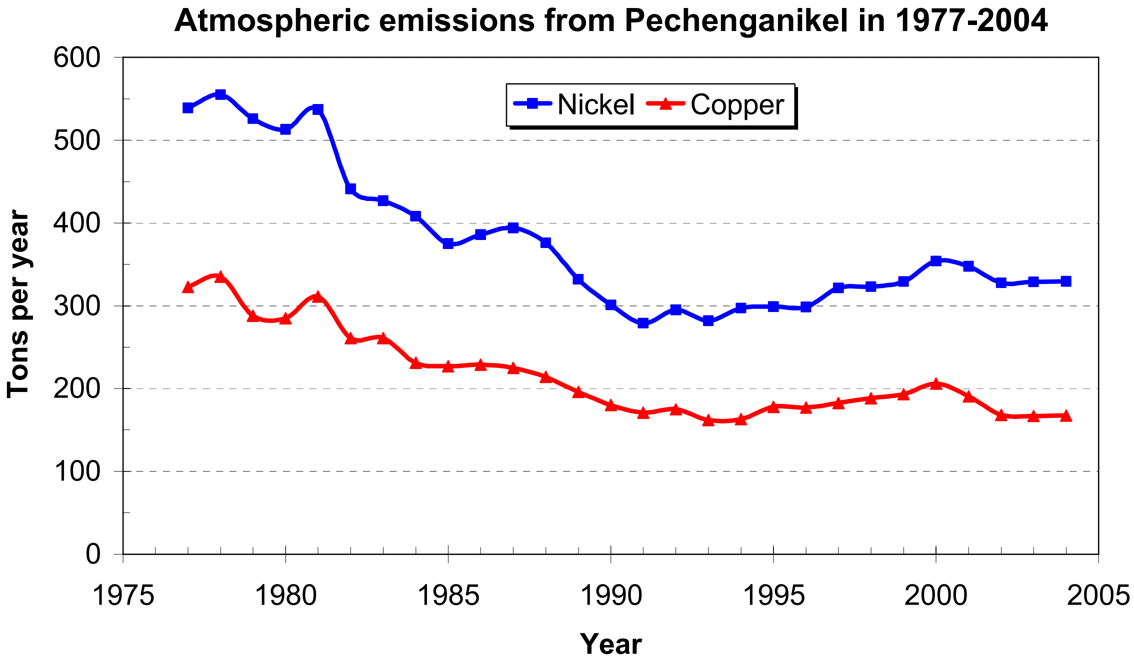

Figure 5. Metal emissions from the Pechenganikel smelter complex (Data: Kola GMK Company).

.

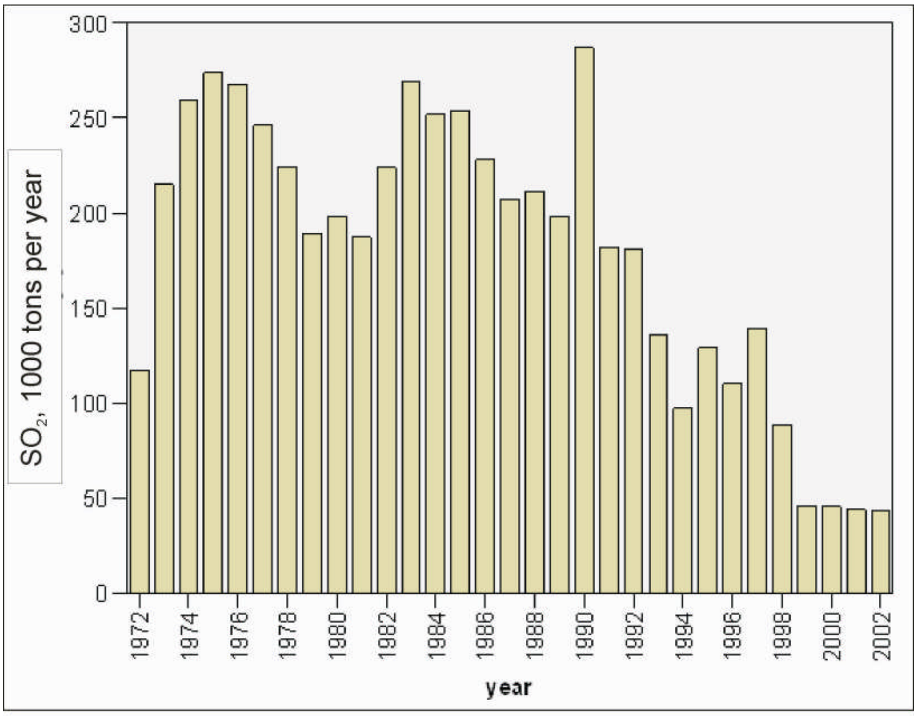

Figure 6. Sulphur emissions (as SO_2) from the Monchegorsk smelter complex during 1972-2002 (Miettinen, 2008).

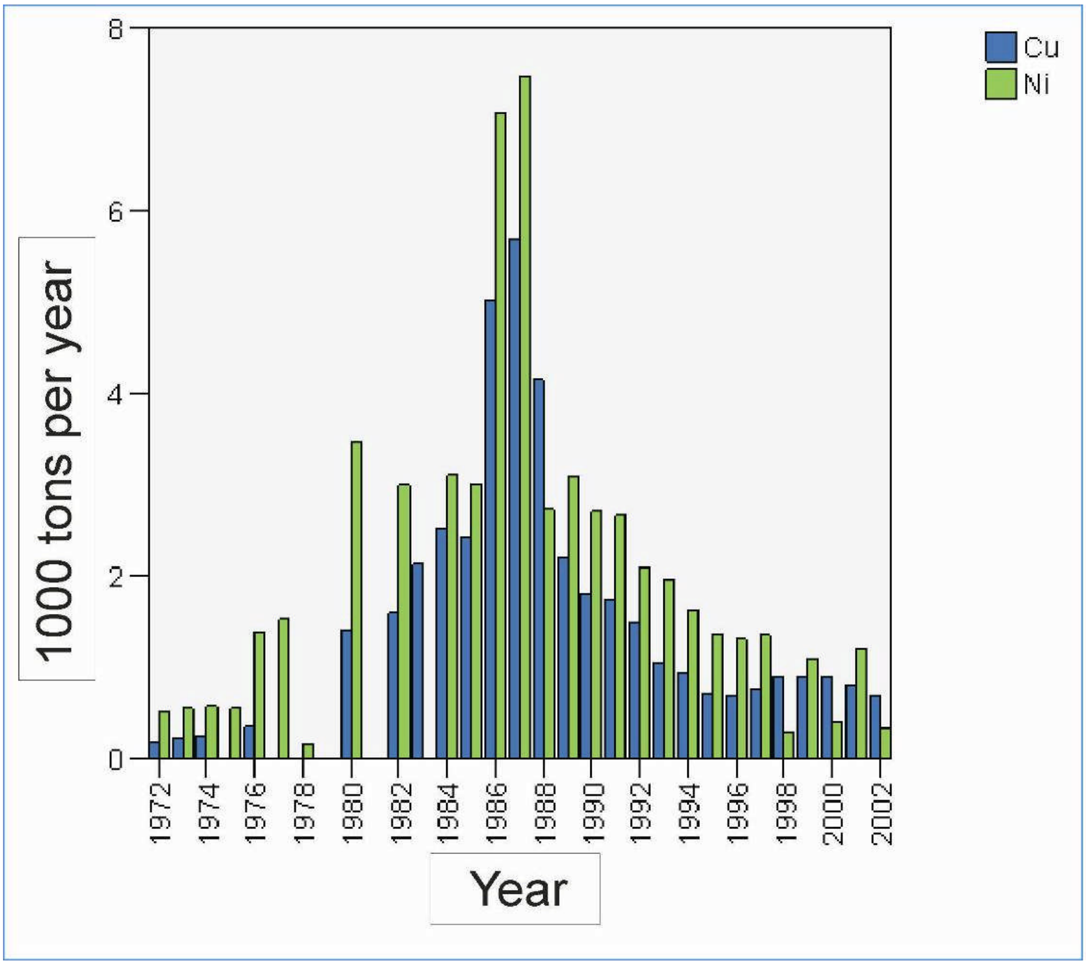

Figure 7. Copper and nickel emissions from the Monchegorsk smelter complex (Miettinen, 2008).

The dispersion characteristics of the atmospheric emissions were studied by calculating a one-year set of daily air mass trajectories 96 hours forwards from Nikel. The starting height was 500 m a.s.l. and the starting time 12 UTC. The trajectory model was NOAA/HYSPLIT (Stein et al. 2007). Because westerly winds are dominating in the latitudes where Finland and the Kola Peninsula are located, in most cases the emissions are transported to the northeast. In autumn, for instance, there are cases where the emissions have been transported to the Far East in only four days (Figure 8).

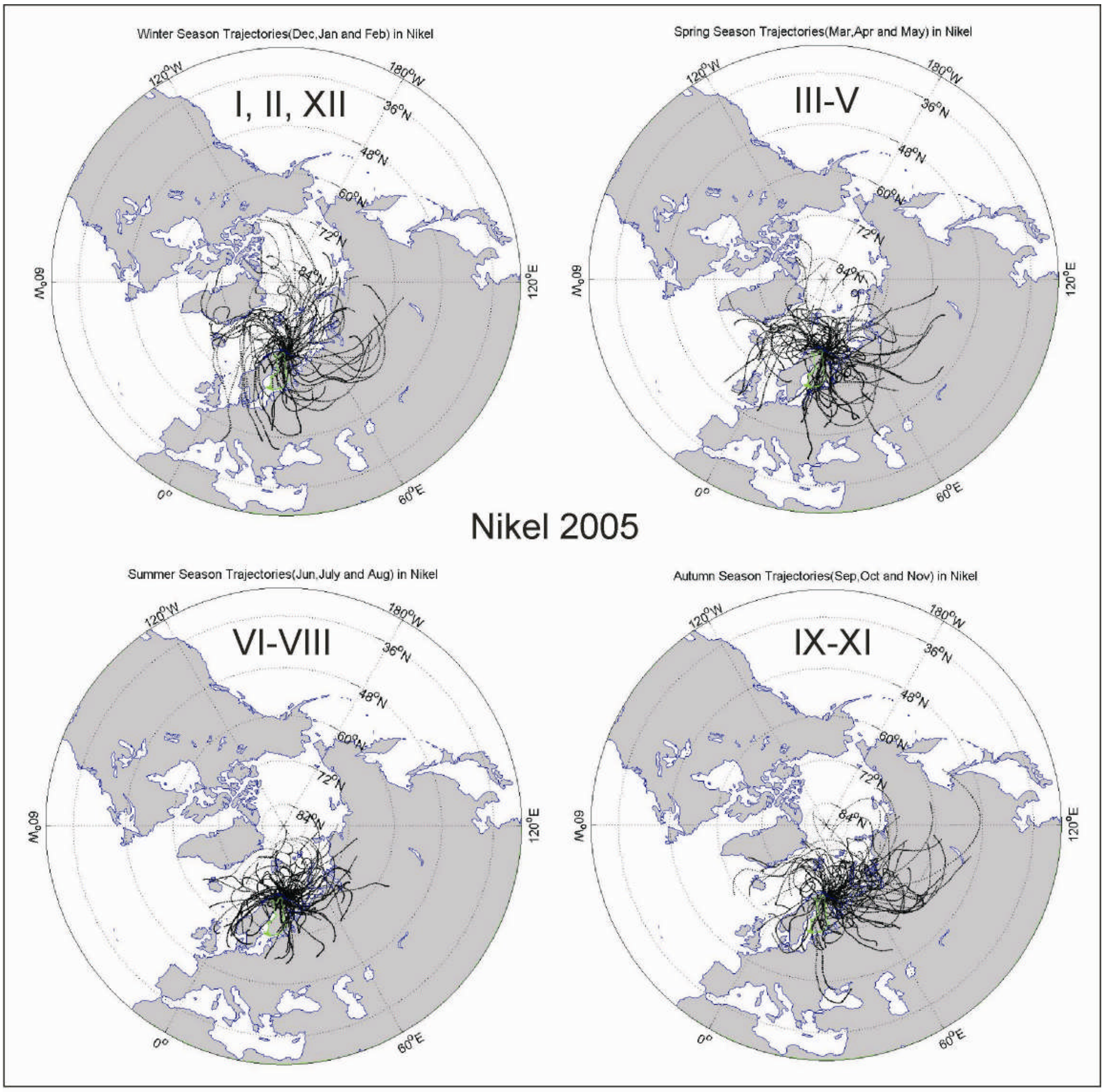

Figure 8. Daily NOAA/HYSPLIT trajectories starting at 12 UTC from Nikel, Russia, 500 m above sea level in 2005 (Stein et al. 2007).

AIRBORNE AND DEPOSITED POLLUTANTS

The daily SO_2 concentrations in the air at Raja-Jooseppi (Finland) during 1992-2006 are presented in Figure 9. The concentrations are usually close to zero, but high peaks do occasionally occur. In 2002, for example, there were 15 episodes with a SO_2 concentration exceeding 10 µg/m^3. These peaks are related to the presence of air masses coming from the smelters at Nikel and Monchegorsk to the north-east and south-east. Peaks of this magnitude hardly ever occur even in industrial areas, and of course never in the uninhabited background areas in Finland. However, the EU air quality regulations allow three exceedances of a daily concentration of 125 µg/m^3 per year. Emissions from the Kola smelters can be detected even in western Lapland, 200 km west of Raja-

Jooseppi. Hatakka et al. (2003) reported that the average SO_2 concentration was 1.7 µg/m^3 during periods with easterly winds, 0.7 µg/m^3 during southerly winds, and 0.3 µg/m^3 during north-westerly winds.

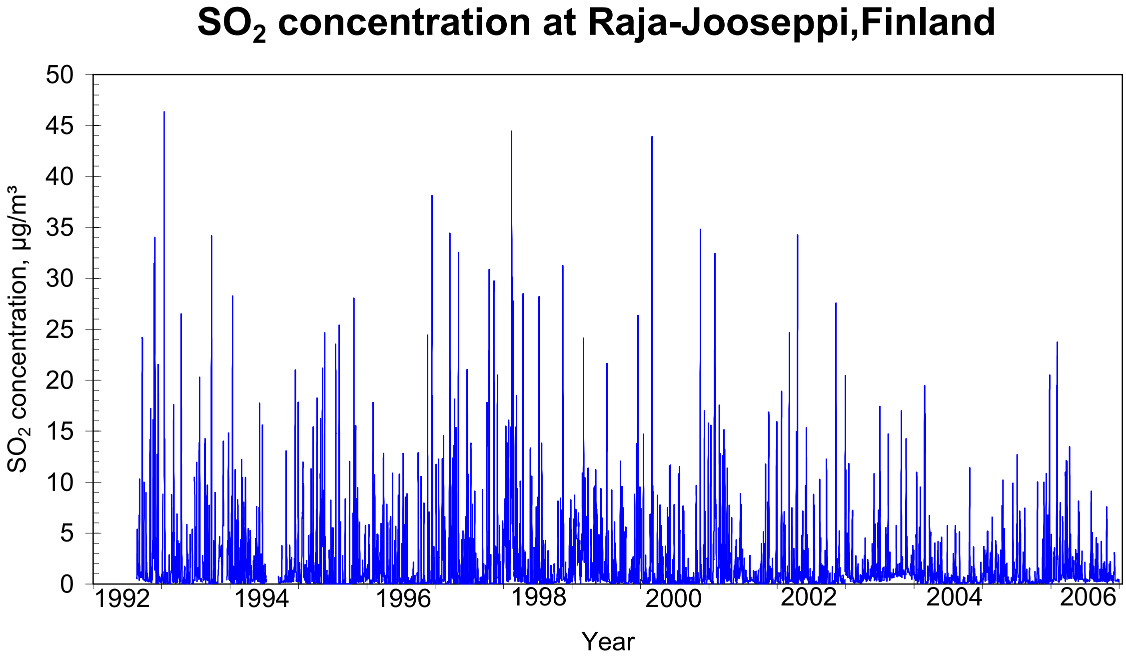

Figure 9. Daily average SO_2 concentrations (µg/m^3) in the air at Raja-Jooseppi, Finnish Lapland (68°29'N, 28°18'E) during 1992-2006.

The deposition of copper and nickel as a function of distance westwards from the Pechenganikel smelter is depicted in Figure 10. The deposition levels decrease rapidly with increasingt distance from the smelter. The copper concentration in forest mosses also decreases at a similar rate. The deposition values at a distance of 55 km are from the Sevettijärvi air quality monitoring station, located about 15 km to the west of the Finnish-Norwegian border. In contrast, the deposition values at a distance of 130 km were recorded at Kevo, which has values similar to those found in background area in western Lapland. Thus only the immediate border area in the NE corner of Finnish Lapland is affected by metal deposition. The situation with respect to metal deposition is very similar at Värriö (Finland) (Figure 11). The nickel concentration in the air is only occasionally higher at Värriö, close to the Finnish-Russian border, compared to the values recorded in Pallas, western Lapland. However, the concentration is clearly below the annual average limit value of 20 ng/m^3 permitted by the EU air quality directive.

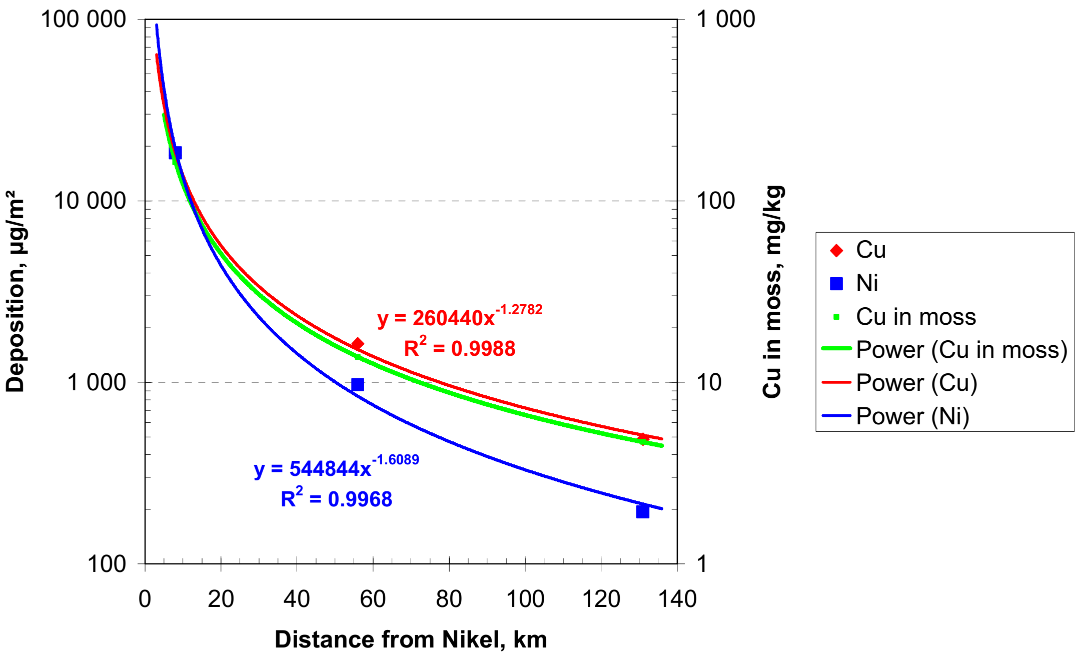

Figure 10. The deposition of copper and nickel as a function of distance westwards from the Pechenganikel smelter (left vertical axis). The copper concentration in forest mosses is also presented (right vertical axis, data: Norwegian Forest and Landscape Institute).

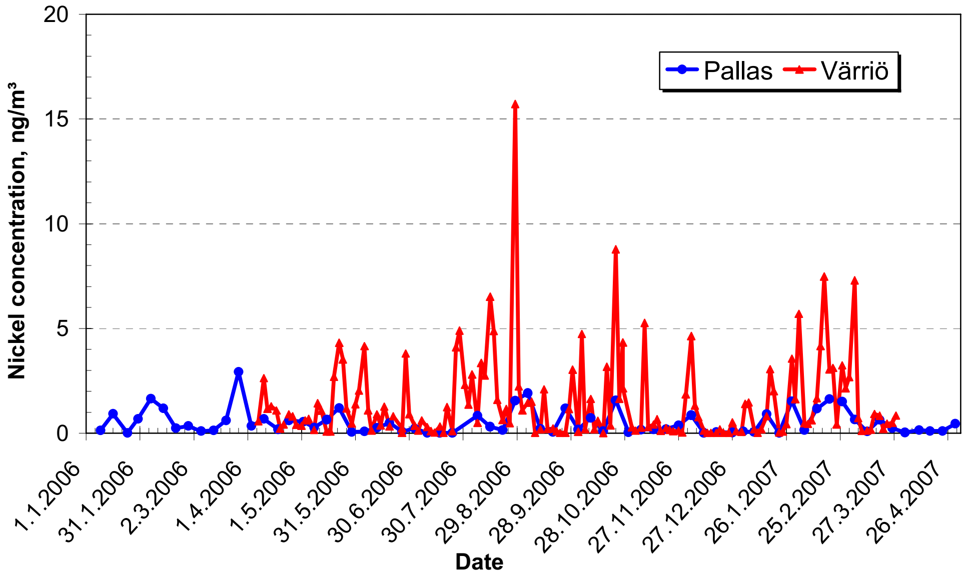

Figure 11. Concentration of nickel in the air (ng/m^3) at Värriö (eastern Lapland) and at Pallas (western Lapland). The EU limit value is an annual average of 20 ng/m^3.

The mean and median concentrations for the trace gases at the SMEAR I station at Värriö are low (Table 1). However, the SO_2 and O_3 concentrations especially can occasionally reach very high levels. According to the EU directive, the hourly and annual limits for SO_2 are 350 µg/m^3 and 20 µg/m^3, respectively. For NO_2 the corresponding values are 200 µg/m^3 and 40 µg/m^3, and for NO_x the annual limit is 30 µg/m^3. The mean and median value for O_3 corresponds to satisfactory air quality (very unlikely health effects/mild environmental impacts) and the 99th percentile to fair air quality (unlikely health effects/clear impacts on vegetation, material impacts). For sulphur dioxide, the 99th percentile corresponds to satisfactory air quality and is two orders of magnitude higher than the median value. The average SO_2 concentration modelled by Tuovinen et al. (1993) at Värriö from July 1990 to June 1991 was 4 µg/m^3, which is twice the average concentration during our measurement period.

Table 1. Mean, median, 99th percentile and maximum values for trace gases measured at the SMEAR I station, Värriö 1991-2008.

	SO_2	NO_x	NO_2	O_3
Mean [µg m-3]	2.2	0.9	0.8	68.8
Median [µg m-3]	0.5	0.5	0.5	69.3
99 % [µg m-3]	25.1	5.2	5.1	116.4
Data coverage	86% (1991–)	88% (1995–)	88% (1995–)	80% (1991–)

We have estimated the SO_2 dry deposition, D_{dry}, using the formula

$$D_{dry} = \sum C(t) v_{dry} \Delta t$$

i.e. by multiplying the average concentration in the air *C(t)* at time *(t)* during the time period Δt and dry deposition velocity v_{dry}, and by summing it over 1) one-year periods to assess whether there are changes in annual dry-deposited sulphur during the whole 20-year period, and 2) over selected wind direction sectors in order to estimate the contribution of the individual sectors. For v_{dry} we have used the deposition velocity onto snow of 0.2 cm/s (Tuovinen et al. 1993) As the highest SO_2 concentrations in Värriö occur during the winter, it is a good approximation to use the deposition velocity onto snow for the whole period.

The mean and 99th percentile of SO_2, NO_x and aerosol particle volume concentrations are presented as a function of wind direction in Figure 12. It is evident from the figure that the main source areas for SO_2 are Nikel and Montchegorsk, in the north and east, respectively. For NO_x, in addition to Montchegorsk, long-range transport from Central Europe is also very clear. The highest particle volume concentrations occur in connection with north-easterly and south-westerly winds, and the smallest when the wind direction is northwest. This is when the air is blowing from the Arctic Ocean and the aerosol population is relatively young: as a result, the total volume of the particles is small (Tunved et al., 2006). The sum of SO_2 deposition as a function of wind direction is also shown in Figure 12. Even though the SO_2 concentrations in air coming from the Nikel direction are as high as those from the Monchegorsk direction, Monchegorsk dominates the dry deposition of SO_2.

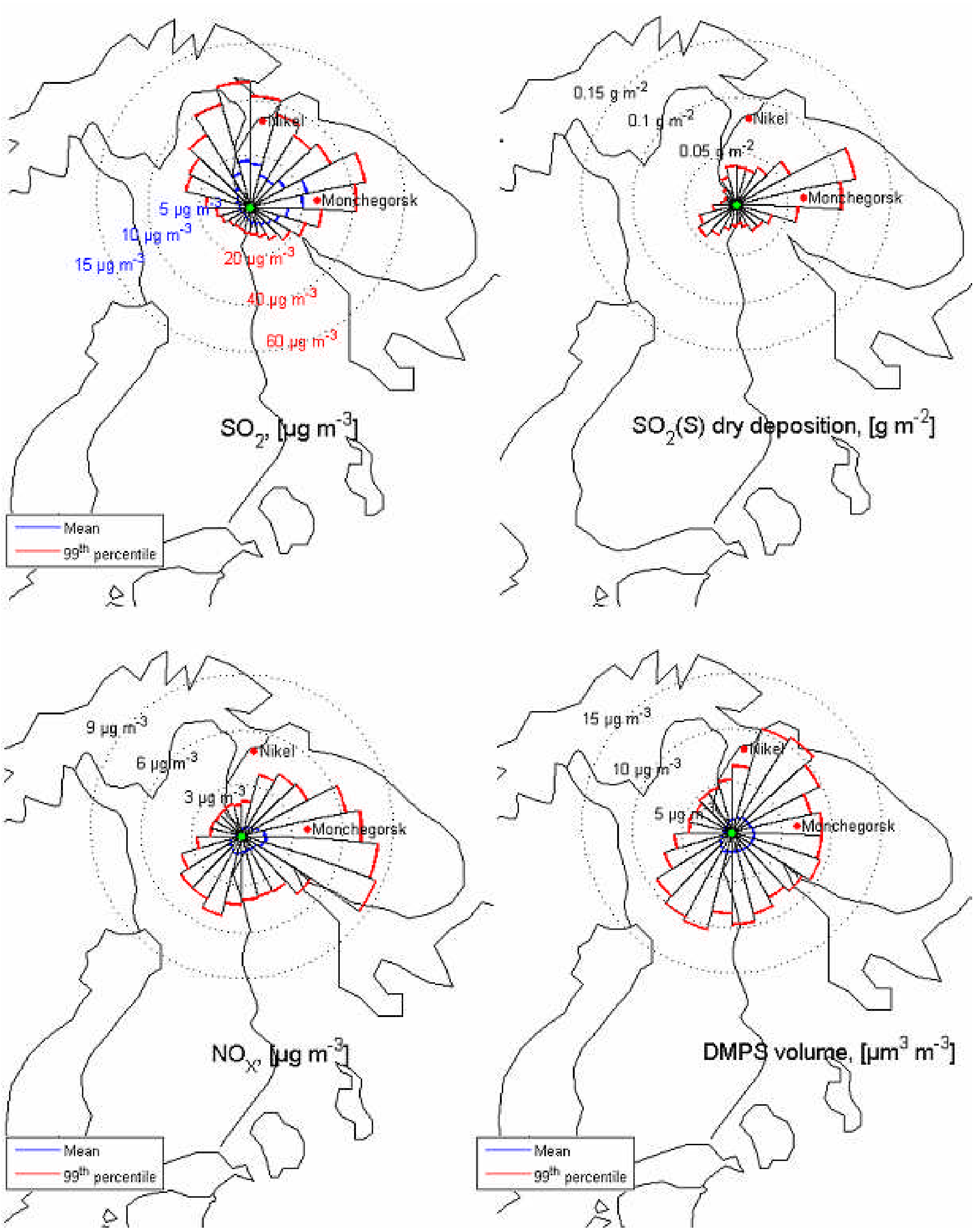

Figure 12. The mean and 99th percentile of SO_2, NO_x and aerosol particle volume concentrations at Värriö (Finland) as a function of wind direction.

AQUATIC ENVIRONMENT

The Finnish environmental authorities are carrying out an extensive monitoring programme of surface waters in Finland. The water quality data for 30 small lakes in Finnish Lapland during 1990–2006 are reviewed here (Miettinen 2008). The report concentrates on south-eastern Finnish Lapland (municipalities of Salla, Posio, Ranua, Savukoski, Sodankylä), and the results are compared to the results for the northernmost part of Lapland (Inari municipality). Sulphur emissions from the Kola Peninsula, as well as the deposition of sulphate in Lapland, declined during the 1990's. As a result, the number of lakes with alkalinity values below the critical level (20 µeq/l) fell in Finnish Lapland close to the pre-acidification level (Figure 13). Sulphate concentrations in lake waters declined along with the decrease in sulphate deposition during the 1990's. Since the year 2000, however, this trend has levelled off (Figure 14). Metal concentrations in the lakes do not show any clear pattern in the area, except for the slightly elevated nickel concentrations in Inari and Salla municipalities. However, the mean copper and nickel concentrations are close to pre-acidification level.

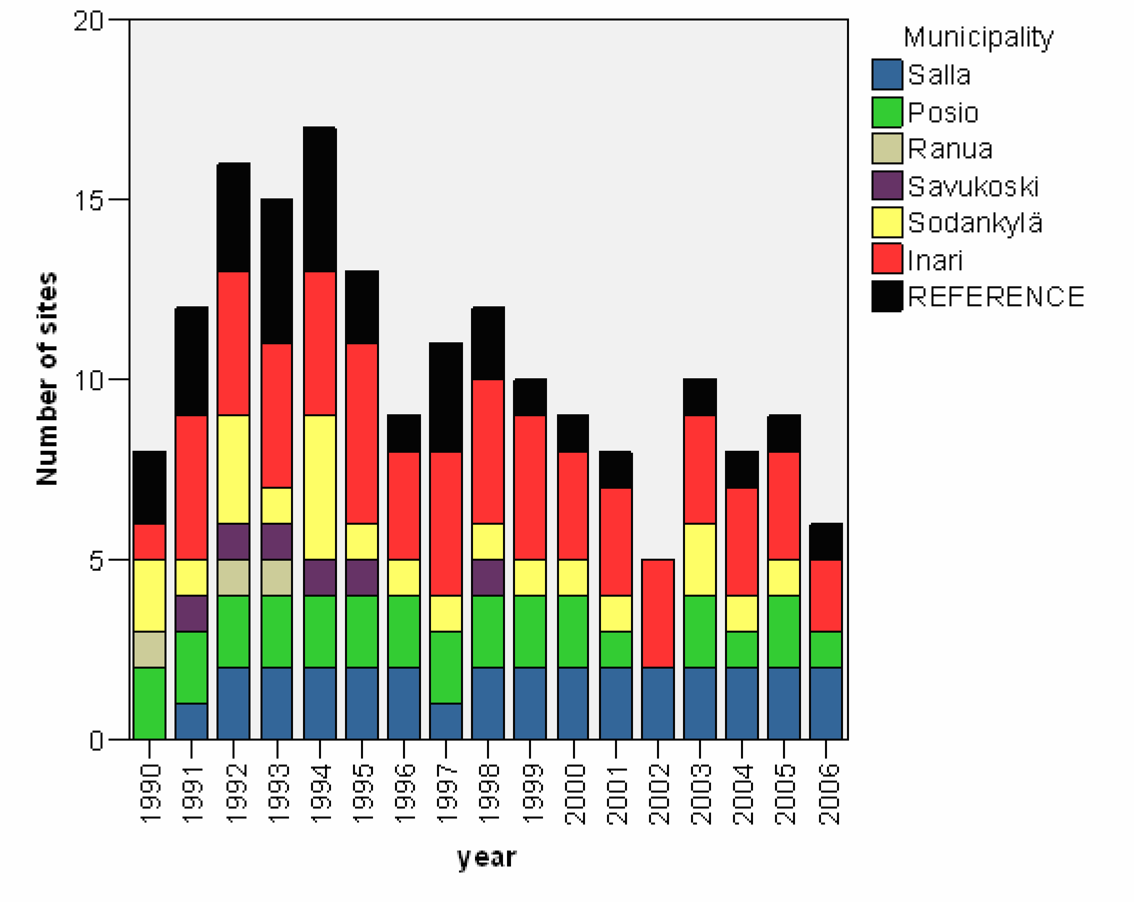

Figure 13. Number of lakes with an autumnal alkalinity value of below 20 µeq/l in south-eastern Lapland and in the reference area in western Lapland during 1990-2006.

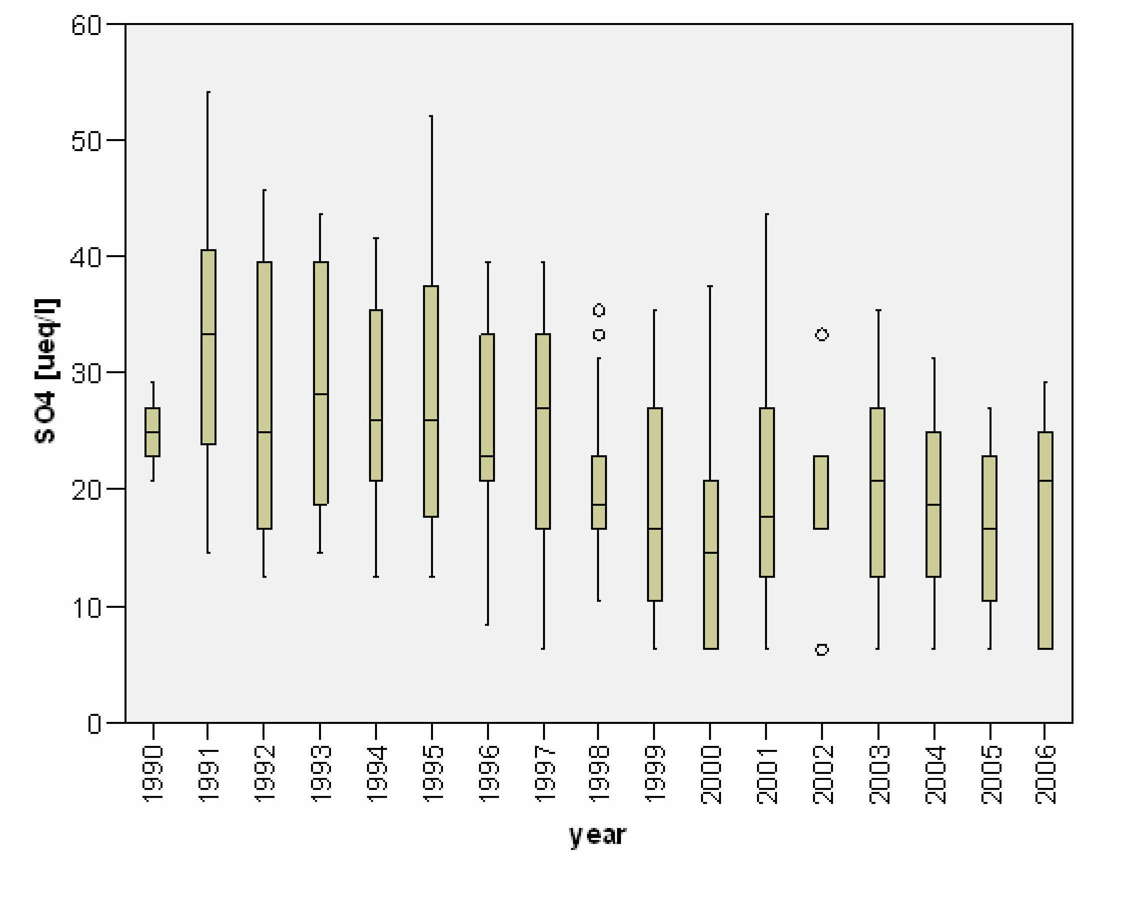

Figure 14. Autumnal sulphate concentrations [µeq/l] in lake waters: mean values in the combined Salla, Posio, Ranua, Savukoski and Sodankylä area.

Lake Umbozero, located about 60 km to the east of Monchegorsk, is the second largest lake on the Kola Peninsula and is exposed to both airborne and river transported pollution from the nearby metallurgical and mining industries. Unlike the neighbouring Lake Imandra, relatively little information is available about the state of pollution in Lake Umbozero. Sediment cores collected at different locations in the lake were studied with respect to the concentration and mobility of the heavy metals Co, Cu, Fe, Mn, Ni, Pb, U and Zn. In addition, one of the cores was dated using the lead-210 method (Figure 15; Häsänen 1977). The distribution of metals in the sediments varied between the cores although, in general, the concentrations were at approximately the same level throughout the lake, thus indicating uniform horizontal distribution of the metals. Compared with Lake Imandra, the concentration of most of the metals was significantly lower and corresponded to the levels measured in sediments in other parts of the Murmansk Region (Oblast). Presumably the Khibina Mountains, which are located between the Monchegorsk smelter complex and Lake Umbozero, channel the movement of air currents away from the east, thus reducing the atmospheric load of metals on the lake. An overall increase in metal concentrations was found in the sediment layers representing long-range atmospheric transport during the industrial era. The sediment layers were subjected to four-step sequential extraction in order to determine the distribution of the metal between soluble, exchangeable, carbonate and residual fractions. Manganese, U, and Zn were generally found in the exchangeable fraction, thus indicating higher mobility; Mn and U were also found extensively in the carbonate fraction (Jernström et al., 2008).

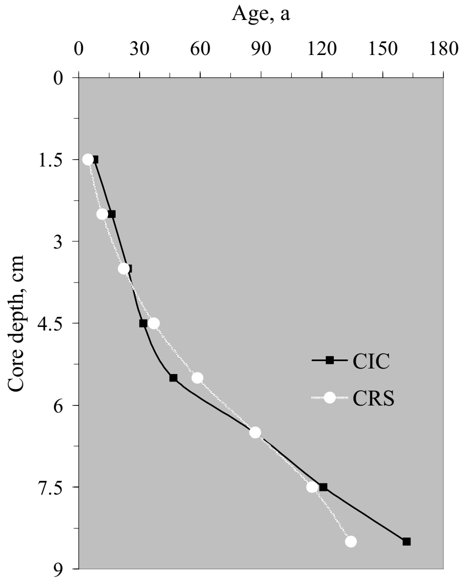

Figure 15. Age profiles of sediment core S9 from Lake Umbozero. CIC and CRS refer to the dating models applied: constant initial concentration and constant rate of supply, respectively.

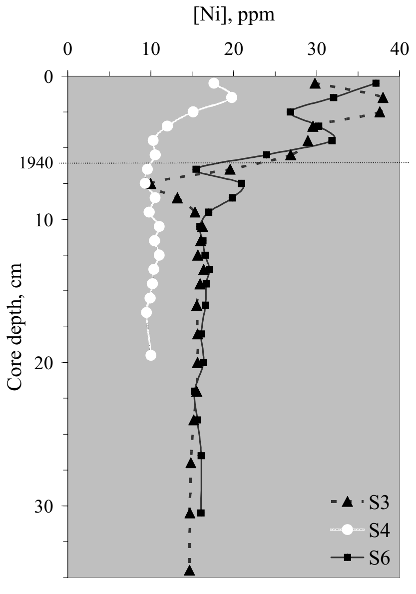

Figure 16. Total extracted concentration of Ni in three sediment cores. The time line (1940) is based on the dating results for core S9.

TERRESTRIAL ECOSYSTEMS

Metals in berries

In this part of the project concerning forest ecosystems, the impact of air pollutants on heavy metal concentrations in edible mushrooms and berries was investigated. Air pollutants pose a threat not only to the health and vitality of forest ecosystems, but also to the human population through the ingestion of berries and mushrooms collected in the affected areas. A number of studies have already been carried out on heavy metal concentrations in berries and wild mushrooms in the Laplandia Biosphere Reservation in Russia, as well as in forest berries along a transect running through Lapland as a part of the Lapland Forest Damage Project (1990-1995). In order to be able to obtain an overall picture of heavy metal concentrations in berries and mushrooms in the region, supplementary information was gathered from the area lying between the Laplandia Biosphere Reservation and the Russian-Finnish border, as well as more extensive information about the situation in the neighbouring parts of eastern Lapland. The work was carried out as a cooperative project between the Rovaniemi Research Unit, Finnish Forest Research Institute, and the Institute of North Industrial Ecology Problems, Apatity, in Russia.

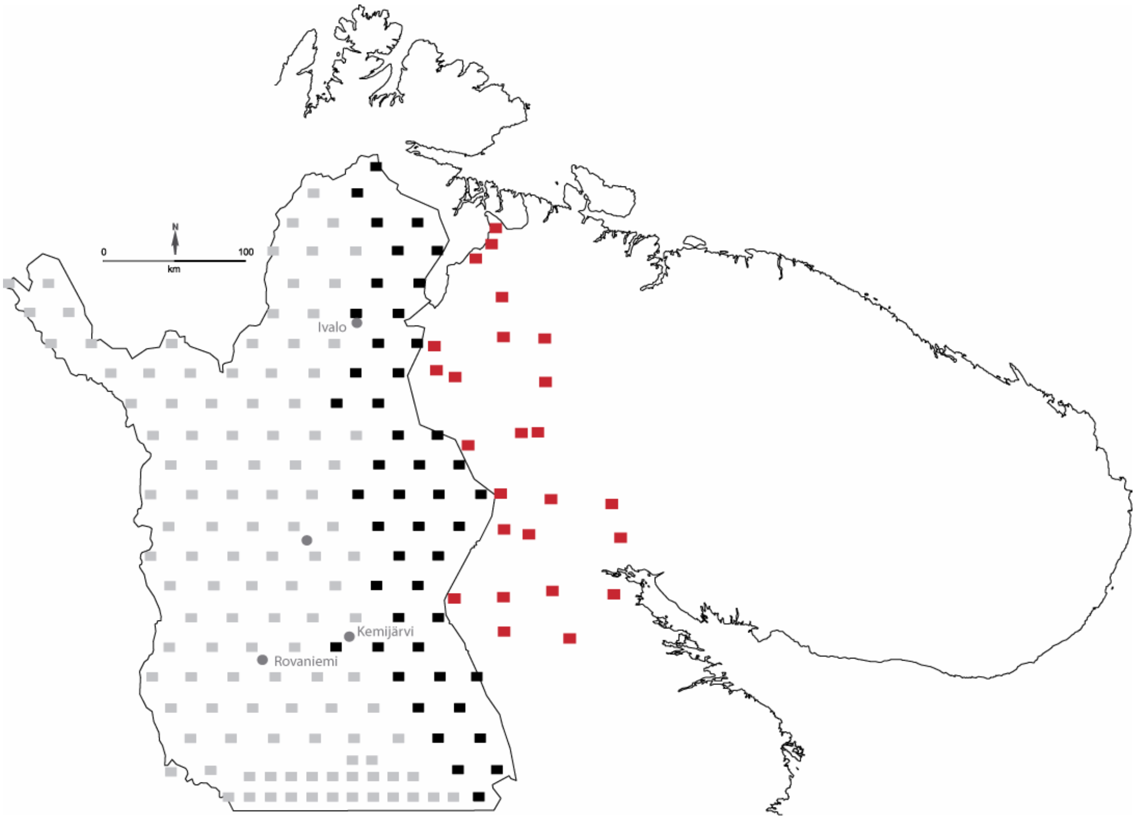

Figure 17. Sampling points in Eastern Finnish Lapland (black squares) and in the western parts of the Kola Peninsula (red squares). The plots in Finland were originally established as a part of the 8th National Forest Inventory in 1985, and in Lapland are spaced over a 24 km x 32 km grid.

Berry and edible mushroom samples were collected from ca. 40 permanent sample plots (ICP Forests, Level I plots) in the central and eastern parts of Finnish Lapland and from 30 sample plots in the area lying between the Laplandia Biosphere Reservation and the Russian-Finnish border (Figure 17). The berry samples were bilberry (Vaccinium myrtillus), lingonberry (V. vitis-idaea) and crowberry (Empetrum nigrum), and the mushroom samples cep (Boletus spp., Suillus spp.), milk cap (Lactarius spp.) and Russula spp. The mushrooms were collected as "group" samples, and no attempt was made to determine the mushrooms at the individual species level. The results for bilberry, lingonberry and crowberry are presented in Figures 18-20.

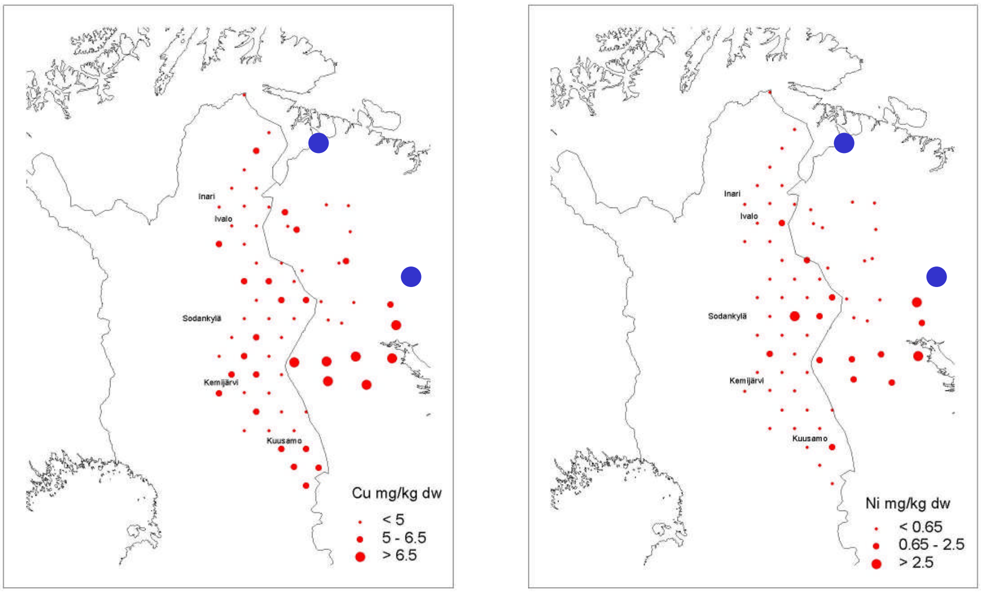

Figure 18. Cu and Ni concentrations (mg/kg dry weight) in bilberries (Vaccinium myrtillus) in Finnish Lapland and the western part of the Kola Peninsula. The blue circles indicate the locations of the Cu-Ni smelters.

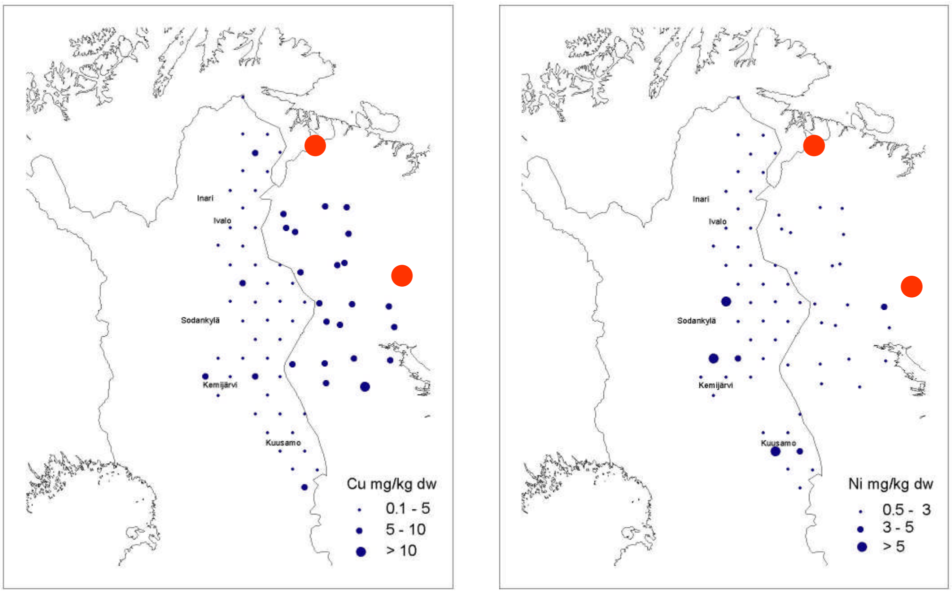

Figure 19. Cu and Ni concentrations (mg/kg dry weight) in lingonberries (Vaccinium vitis-idaea) in Finnish Lapland and the western part of the Kola Peninsula. The red circles indicate the locations of the Cu-Ni smelters.

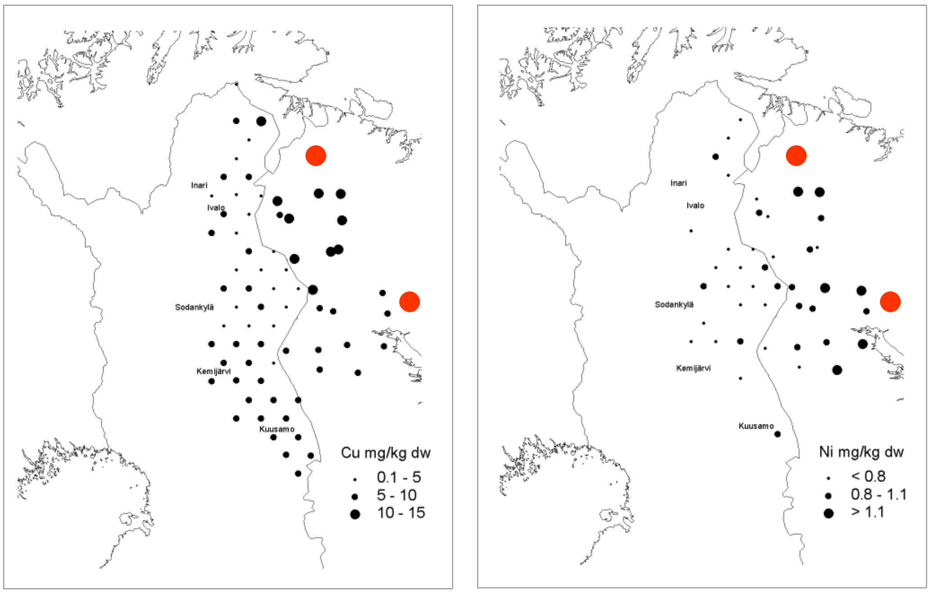

Figure 20. Cu and Ni concentrations (mg/kg dry weight) in crowberries (Empetrum hermaphroditum) in Finnish Lapland and the western part of the Kola Peninsula. The red circles indicate the locations of the Cu-Ni smelters.

Berry-producing plants have a rooting system, and therefore obtain their nutrients (including heavy metals) from the soil. The heavy metals and sulphate in plants (and therefore also in edible berries) can be derived from deposition (wet and dry deposition) directly on the above-ground parts of the plants as well as from the soil, depending on the chemical composition of the bedrock, accumulation of metals and sulphate derived from earlier deposition, and contamination of the site by scrap metal and shotgun pellets. In addition, plants have a selective ability to take up metals from the soil, the capacity to store toxic metals in inert parts of the plant (e.g. tree stems), and mechanism designed to prevent the accumulation of toxic metals in their reproductive organs (e.g. seeds/berries).

It is clear that metal emissions from the smelters on the Kola Peninsula have relatively little effect on metal concentrations in berries in Finnish Lapland, and even in Russia there is a very short east-west gradient in metal concentrations (Figure 21). This lack of an accumulation pattern in berries is especially clear in the case of the Ni concentrations in bilberries (Figure 18): there are a number of plots with clearly elevated concentrations in eastern Lapland, while the plots closer to the Monchegorsk emission source have lower concentrations. This is presumably due to the regional distribution of Ni-bearing minerals in the bedrock, and not to nickel deposition patterns.

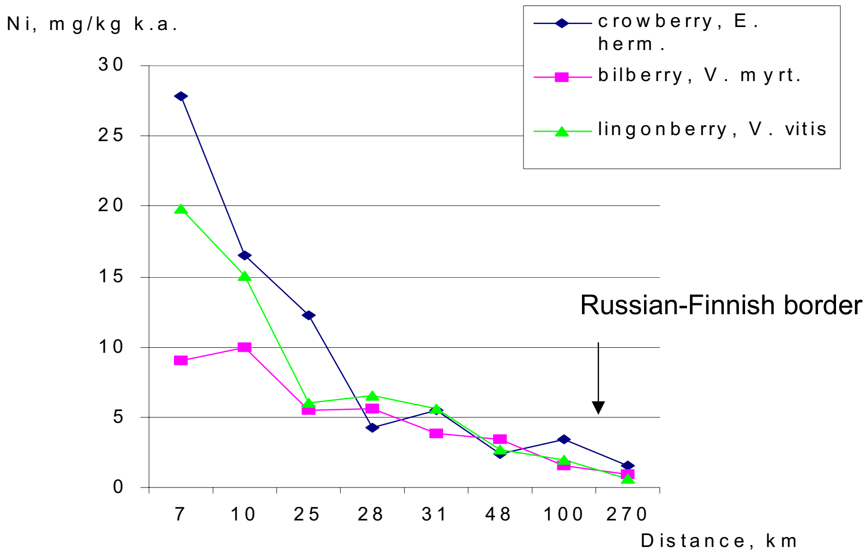

Figure 21. Ni concentrations (mg/kg dry weight) in berries along a transect running from Monchegorsk to the west.

Pine forest condition

The condition of Scots pine forests in northern Finland was studied using an optical spectrometer in the summers of 2005 and 2006. The instrument was originally designed and built at the Finnish Meteorological Institute for studying the effects of air pollutants in population centres and close to industrial plants (Jokinen et al. 2000). In this project it was used for the first time in background areas (Figure 22). The instrument measures the solar light reflected by pine needles. The instrument consists of a light-collecting optical system, a colour-recognition sensor, a shutter, a videocamera, a GPS satellite positioning receiver, a laser distance meter, and a computer. The video camera is used for storing information about the general environment at the measurement point. The colour recognition sensor is based on a refraction grating, and it measures the intensity of reflected light in the 400-800 nm wavelength region. The spectrum is divided into 128 channels using a photo diode array. The normal measurement distance is 50-100 m. The instrument is aimed at a point where no other objects (e.g. larger tree branches) are visible, in order to ensure that the collected light is primarily reflected from the needles. Aiming the instrument, collection of the spectrum and storage of the data usually takes about one minute.

Analysis of the condition of pine trees is based on the relative reflectance of orange compared to that of other colours, because chlorophyll has a strong absorption peak in the orange band. The more the pine needles contain chlorophyll, the greater is the reduction in the intensity of the reflected orange light compared to that in other light bands. The amount of chlorophyll in the needles is positively correlated with the vitality of the pine tree or trees at the measuring point.

The results of pine forest condition mapping are presented in Figure 23. There appear to be no detectable signs of a decrease in the vitality of pine forests in Lapland that could be attributed to air pollutants derived from the Kola peninsula. All the variation is within the normal range of vitality caused by soil type and moisture and fertility conditions, as well as other factors such as the local climatic conditions, and attack by insects and plant pathogens. Many of the northernmost measurement points were close to the northern limit for pine forests. In contrast to the results of a spatially more comprehensive study carried out six years earlier (Jokinen et al., 2000), the effects of industrial activities in the town of Kemijärvi are not visible.

Figure 22. Field measurements using the optical spectrometer (Photo: Finnish Meteorological Institute).

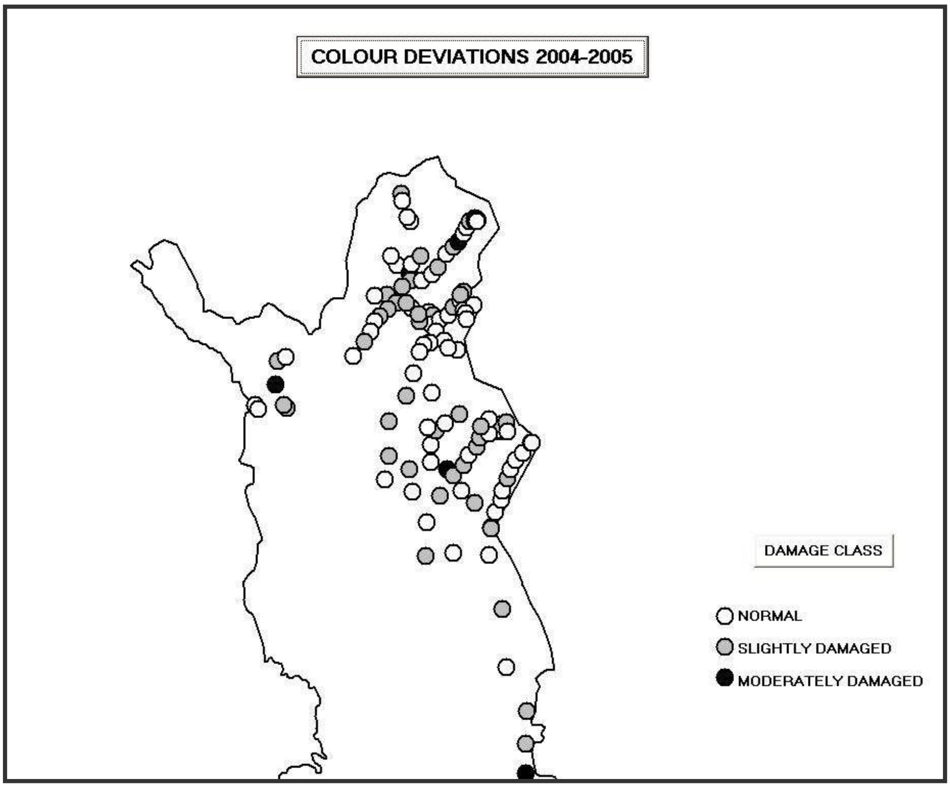

Figure 23. Results of the pine forest condition mapping.

CONCLUSIONS

Even though emissions of sulphur and metals into the atmosphere from the smelter complexes on the Kola Peninsula have decreased since the 1980s, they are still larger than the total emissions for Finland. In Finnish Lapland the prevailing winds are westerly, which carries the air pollutants away from Finland. During periods with easterly winds, however, the concentrations of SO_2, aerosol particles and metals in the air increase strongly close to the Finnish-Russian border. The acidification of small lakes in Finnish Lapland has decreased since the early 1990s due to the lower atmospheric load, both from the Kola Peninsula and from the densely industrialised and populated parts of Europe. However, this positive development appears to have levelled off during the current century. Heavy metal and SO_2 emissions from the smelters seem to have no clear impact on the terrestrial environment: there are no clear east-west gradients in either the metal concentrations in berries or in pine tree vitality. In the future, research on the ecological effects of the emitted pollutants should be concentrated in areas to the north-east of the smelters where the exposure to air pollutants is the heaviest.

ACKNOWLEDGEMENTS

This project was financed by the Finnish Ministry of Environment and was a part of the Research Programme on Russia In Flux, conducted by the Academy of Finland. The deposition measurements in northernmost Finland were financed by the EU, Interreg IIIA Kolarctic programme managed by the Regional Council of Lapland. The authors would like to thank the United States National Oceanic and Atmospheric Administration, Air Resources Laboratory for the access to the HYSPLIT trajectory calculation system, and the Norwegian Institute for Air Research and the Norwegian Forest and Landscape Institute for providing metal concentration data. Fruitful cooperation with the Institute of North Industrial Ecology Problems, Kola Science Centre, Russian Academy of Sciences, and the Laplandia Biosphere Reserve is gratefully acknowledged. The authors would like to thank also the station managers at the monitoring stations, and laboratory staff and scientists of the participating institutes for their contribution to this project.

REFERENCES

Häsänen, E., 1977. Dating of sediments, based on ^{210}Pb measurements. *Radiochem. Radioanal. Lett.* 31, p. 207-214.

Jernström, J., Lehto, J., Dauvalter, V.A., Hatakka A., Leskinen, A. and Paatero, J., 2008. Heavy metals in bottom sediments of Lake Umbozero in Murmansk Region, Russia. Accepted for publication in *Environmental Monitoring and Assessment*.

Jokinen, J., Haarala, S., Jokela, T. and Pesonen, R., 2000. *Kemijärven ilmanlaadun vaikutusten seurantatutkimus vuonna 1999. Mäntypuuston vauriokartoitus ja mittaukset värintunnistimella* (Follow-up study of air quality effects at Kemijärvi in 1999. Mapping of pine forest damages and measurements with a colour recognition sensor). Finnish Meteorological Institute, Air Quality Research, Helsinki. 28 p.

Stein, A.F., Isakov, V., Godowitch, J. and Draxler R.R., 2007. A hybrid modeling approach to resolve pollutant concentrations in an urban area. *Atmos. Environ.* 41, p. 9410-9426.

Tunved, P., Hansson, H.-C., Kerminen, V.-M., Ström, J., Dal Maso, M., Lihavainen, H., Viisanen, Y., Aalto, P.P., Komppula, M. and Kulmala, M., 2006. High Natural Aerosol Loading over Boreal Forests. *Science* 312, p. 261 – 263.

Tuovinen, J.-P., Laurila ,T., Lättilä, H., Ryaboshapko, A., Brukhanov, P. and Korolev, S., 1993. Impact of the sulfur-dioxide sources in the Kola-peninsula on air-quality in northernmost Europe. *Atmos. Environ.* 27, p. 1379-1395.

Wichmann, H.-E. and Peters, A., 2000. Epidemiological evidence of the effects of ultrafine particle exposure. *Phil. Trans. R. Soc. Lond.* A358, p. 2751-2769.

Virkkula, A., Mäkinen, M., Hillamo, R. and Stohl, A., 1995. Atmospheric aerosol in the Finnish Arctic: particle number concentrations, chemical characteristics, and source analysis. *Water, Air, & Soil Poll.* 85, p. 1997-2002.

Virkkula, A., Hillamo, R.E., Kerminen, V.-M. and Stohl, A., 1997. The influence of Kola Peninsula, continental European and marine sources on the number concentrations and scattering coefficients of the atmospheric aerosol in Finnish Lapland. *Boreal Environ. Res.* 2, p. 317-336.

Virkkula, A., Teinilä, K., Hillamo, R. and Stohl, A., 2003: A decade of trace gas measurements using DOAS in Finnish Lapland. *Boreal Environ. Res.* 8, p. 351–363.

RAPORTTEJA — RAPPORTER — REPORTS

1986: 1. Savolainen, Anna Liisa et al., 1986. Radioaktiivisten aineiden kulkeutuminen Tshernobylin ydinvoimalaonnettomuuden aikana. Väliaikainen raportti. 39 s.

2. Savolainen, Anna Liisa et al., 1986. Dispersion of radioactive release following the Chernobyl nuclear power plant accident. Interim report. 44 p.

3. Ahti, Kari, 1986. Rakennussääpalvelukokeilu 1985-1986. Väliraportti Helsingin ympäristön talvikokeilusta 18.11.-13.3.1986. 26 s.

4. Korhonen, Ossi, 1986. Pintatuulen vertailumittauksia lentoasemilla. 38 s.

1987: 1. Karppinen, Ari et al., 1987. Description and application of a system for calculating radiation doses due to long range transport of radioactive releases. 50 p.

2. Venäläinen, Ari, 1987. Ilmastohavaintoihin perustuva arvio jyrsinturpeen tuotantoedellytyksistä Suomessa. 35 s.

3. Kukkonen, Jaakko ja Savolainen, Anna Liisa, 1987. Myrkyllisten kaasujen päästöt ja leviäminen onnettomuustilanteissa. 172 s.

4. Nordlund, Göran ja Rantakrans, Erkki, 1987. Matemaattisfysikaalisten ilmanlaadun arviointimallien luotettavuus. 29 s.

5. Ahti, Kari, 1987. Rakennussäätutkimuksen loppuraportti. 45 s.

6. Hakola, Hannele et al., 1987. Otsonin vaihteluista Suomessa yhden vuoden havaintoaineiston valossa. 64 s.

7. Tammelin, Bengt ja Erkiö, Eero, 1987. Energialaskennan säätiedot – suomalainen testivuosi. 108 s.

1988: 1. Eerola, Kalle, 1988. Havaintojen merkityksestä numeerisessa säänennustuksessa. 36 s.

2. Fredrikson, Liisa, 1988. Tunturisääprojekti 1986-1987. Loppuraportti. 31 s.

3. Salmi, Timo and Joffre, Sylvain, 1988. Airborne pollutant measurements over the Baltic Sea: meteorological interpretation. 55 p.

4. Hongisto, Marke, Wallin, Markku ja Kaila, Juhani, 1988. Rikkipäästöjen vähentämistoimenpiteiden taloudellisesti tehokas valinta. 80 s.

5. Elomaa, Esko et al., 1988. Ilmatieteen laitoksen automaattisten merisääasemien käyttövarmuuden parantaminen. 55 s.

6. Venäläinen, Ari ja Nordlund, Anneli, 1988. Kasvukauden ilmastotiedotteen sisältö ja käyttö. 63 s.

7. Nieminen, Rauno, 1988. Numeeristen paine- ja ja korkeuskenttäennusteiden objektiivinen verifiointisysteemi sekä sen antamia tuloksia vuosilta 1985 ja 1986. 35 s.

1989: 1. Ilvessalo, Pekko, 1989. Yksittäisestä piipusta ilmaan pääsevien epäpuhtauksien suurimpien tuntipitoisuuksien arviointimenetelmä. 21 s.

1992: 1. Mhita, M.S. and Venäläinen, Ari, 1991. The variability of rainfall in Tanzania. 32 p.

2. Anttila, Pia (toim.), 1992. Rikki- ja typpilaskeuman kehitys Suomessa 1980-1990. 28 s.

1993: 1. Hongisto, Marke ja Valtanen Kalevi, 1993. Rikin ja typen yhdisteiden kaukokulkeutumismallin kehittäminen HIRLAM-sääennustemallin yhteyteen. 49 s.

2. Karlsson, Vuokko, 1993. Kansalliset rikkidioksidin analyysivertailut 1979 - 1991. 27 s.

1994: 1. Komulainen, Marja-Leena, 1995. Myrsky Itämerellä 28.9.1994. Säätilan kehitys Pohjois-Itämerellä M/S Estonian onnettomuusyönä. 42 s.

2. Komulainen, Marja-Leena, 1995. The Baltic Sea Storm on 28.9.1994. An investigation into the weather situation which developed in the northern Baltic at the time of the accident to m/s Estonia. 42 p.

1995: 1. Aurela, Mika, 1995. Mikrometeorologiset vuomittausmenetelmät - sovelluksena otsonin mittaaminen suoralla menetelmällä. 88 s.

2. Valkonen, Esko, Mäkelä, Kari ja Rantakrans, Erkki, 1995. Liikenteen päästöjen leviäminen katukuilussa - AIG-mallin soveltuvuus maamme oloihin. 25 s.

3. Virkkula, Aki, Lättilä, Heikki ja Koskinen, Timo, 1995. Otsonin maanpintapitoisuuden mittaaminen UV-säteilyn absorbtiolla: DOAS-menetelmän vertailu suljettua näytteenottotilaa käyttävään menetelmään. 29 s.

4. Bremer, Pia, Ilvessalo, Pekko, Pohjola, Veijo, Saari, Helena ja Valtanen, Kalevi, 1995. Ilmanlaatuennusteiden ja -indeksin kehittäminen Helsingin Käpylässä suoritettujen mittausten perusteella. 81 s.

1996: 1. Saari, Helena, Salmi, Timo ja Kartastenpää, Raimo, 1996. Taajamien ilmanlaatu suhteessa uusiin ohjearvoihin. 98 s.

1997: 1. Solantie, Reijo, 1997. Keväthallojen alueellisista piirteistä ja vähän talvipakkastenkin. 28 s.

1998: 1 Paatero, Jussi, Hatakka, Juha and Viisanen, Yrjö, 1998. Concurrent measurements of airborne radon-222, lead-210 and beryllium-7 at the Pallas-Sodankylä GAW station, Northern Finland. 26 p.

2 Venäläinen, Ari ja Helminen, Jaakko, 1998. Maanteiden talvikunnossapidon sääindeksi. 47 s.

3 Kallio, Esa, Koskinen, Hannu ja Mälkki, Anssi, 1998. VII Suomen avaruustutkijoiden COSPAR-kokous, Tiivistelmät. 40 s.

4 Koskinen, H. and Pulkkinen, T., 1998. State of the art of space weather modelling and proposed ESA strategy. 66 p.

5 Venäläinen, Ari ja Tuomenvirta Heikki, 1998. Arvio ilmaston läm- penemisen vaikutuksesta teiden talvikunnossapidon kustannuksiin. 19 s.

1999: 1 Mälkki, Anssi, 1999. Near earth electron environment modelling tool user/software requirements document. 43 p.

2 Pulkkinen, Antti, 1999. Geomagneettisesti indusoituvat virrat Suomen maakaasuverkostossa. 46 s.

3 Venäläinen, Ari, 1999. Talven lämpötilan ja maanteiden suolauksen välinen riippuvuus Suomessa.16 s.

4 Koskinen, H., Eliasson, L., Holback, B., Andersson, L., Eriksson, A., Mälkki, A., Nordberg, O., Pulkkinen, T., Viljanen, A., Wahlund, J.-E., Wu, J.-G., 1999. Space weather and interactions with scacecraft : spee final report. 191 p.

2000: 1 Solantie, Reijo ja Drebs, Achim, 2000. Kauden 1961 - 1990 lämpöoloista kasvukautena alustan vaikutus huomioiden, 38 s.

2 Pulkkinen, Antti, Viljanen, Ari, Pirjola, Risto, and Bear working group, 2000. Large geomagnetically induced currents in the Finnish high-voltage power system. 99 p.

3 Solantie, R. ja Uusitalo, K., 2000. Patoturvallisuuden mitoitussadannat: Suomen suurimpien 1, 5 ja 14 vrk:n piste- ja aluesadantojen analysointi vuodet 1959 - 1998 kattavasta aineistosta. 77 s.

4 Tuomenvirta, Heikki, Uusitalo, Kimmo, Vehviläinen, Bertel, Carter, Timothy, 2000. Ilmastonmuutos, mitoitussadanta ja patoturvallisuus: arvio sadannan ja sen ääriarvojen sekä lämpötilan muutoksista Suomessa vuoteen 2100. 65 s.

5 Viljanen, Ari, Pirjola, Risto and Tuomi, Tapio, 2000. Abstracts of the URSI XXV national convention on radio science. 108 p.

6 Solantie, Reijo ja Drebs, Achim, 2000. Keskimääräinen vuoden ylin ja alin lämpötila Suomessa 1961 - 90. 31 s.

7 Korhonen, Kimmo, 2000. Geomagneettiset mallit ja IGRF-appletti. 85 s.

2001: 1 Koskinen, H., Tanskanen, E., Pirjola, R., Pulkkinen, A., Dyer, C., Rodgers, D., Cannon, P., Mandeville, J.-C. and Boscher, D., 2001. Space weather effects catalogue. 41 p.

2 Koskinen, H., Tanskanen, E., Pirjola, R., Pulkkinen, A., Dyer, C., Rodgers, D., Cannon, P., Mandeville, J.-C. and Boscher, D., 2001. Rationale for a european space weather programme. 53 p.

3 Paatero, J., Valkama, I., Makkonen, U., Laurén, M., Salminen, K., Raittila, J. and Viisanen, Y., 2001. Inorganic components of the ground-level air and meteorological parameters at Hyytiälä, Finland during the BIOFOR project 1998-1999. 48 p.

4 Solantie, Reijo, Drebs, Achim, 2001. Maps of daily and monthly minimum temperatures in Finland for June, July, and August 1961-1990, considering the effect of the underlying surface. 28 p.

5 Sahlgren, Vesa, 2001. Tuulikentän alueellisesta vaihtelusta Längelmävesi-Roine -järvialueella. 33 s.

6 Tammelin, Bengt, Heimo, Alain, Leroy, Michel, Rast, Jacques and Säntti, Kristiina, 2001. Meteorological measurements under icing conditions : EUMETNET SWS II project. 52 p.

2002: 1 Solantie, Reijo, Drebs, Achim, Kaukoranta, Juho-Pekka, 2002. Lämpötiloja eri vuodenaikoina ja eri maastotyypeissä Alajärven Möksyssä. 57 s.

2\. Tammelin, Bengt, Forsius, John, Jylhä, Kirsti, Järvinen, Pekka, Koskela, Jaakko, Tuomenvirta, Heikki, Turunen, Merja A., Vehviläinen, Bertel, Venäläinen, Ari, 2002. Ilmastonmuutoksen vaikutuksia energiantuotantoon ja lämmitysenergian tarpeeseen. 121 s.

2003: 1. Vajda, Andrea and Venäläinen, Ari, 2003. Small-scale spatial variation of climate in northern Finland. 34 p.

2\. Solantie, Reijo, 2003. On definition of ecoclimatic zones in Finland. 44 p.

3\. Pulkkinen, T.I., 2003. Chapman conference on physics and modelling of the inner magnetosphere Helsinki, Finland, August 25 -29, 2003. Book of abstracts. 110 p.

4\. Pulkkinen, T. I., 2003. Chapman conference on physics and modelling of the inner magnetosphere Helsinki, Finland, August 25 -29, 2003. Conference program. 16 p.

5\. Merikallio, Sini, 2003. Available solar energy on the dusty Martian atmosphere and surface. 84 p.

6\. Solantie, Reijo, 2003. Regular diurnal temperature variation in the Southern and Middle boreal zones in Finland in relation to the production of sensible heat. 63 p.

2004: 1. Solantie, Reijo, Drebs, Achim and Kaukoranta, Juho-Pekka, 2004. Regular diurnal temperature variation in various landtypes in the Möksy experimental field in summer 2002, in relation to the production of sensible heat. 69 p.

2\. Toivanen, Petri, Janhunen, Pekka and Koskinen, Hannu, 2004. Magnetospheric propulsion (eMPii). Final report issue 1.3. 78 p.

3. Tammelin, Bengt et al., 2004. Improvements of severe weather measurements and sensors – EUMETNET SWS II project. 101 p.

4. Nevanlinna, Heikki, 2004. Auringon aktiivisuus ja maapallon lämpötilan vaihtelut 1856 - 2003. 43 s.

5. Ganushkina, Natalia and Pulkkinen, Tuija, 2004. Substorms-7: Proceedings of the 7th International Confrence on Substorms. 235 p.

6. Venäläinen, Ari, Sarkkula, Seppo, Wiljander, Mats, Heikkinen, Jyrki, Ervasto, Erkki, Poussu, Teemu ja Storås, Roger, 2004. Espoon kaupungin talvikunnossapidon sääindeksi. 17 s.

7. Paatero, Jussi and Holmen, Kim (eds.), 2004. The First Ny-Ålesund - Pallas-Sodankylä atmospheric research workshop, Pallas, Finland 1 - 3 March 2004 - Extended abstracts. 61 p.

8. Holopainen, Jari, 2004. Turun varhainen ilmastollinen havaintosarja. 59 s.

2005: 1. Ruuhela, Reija, Ruotsalainen, Johanna, Kangas, Markku, Aschan, Carita, Rajamäki, Erkki, Hirvonen, Mikko ja Mannelin, Tarmo, 2005. Kelimallin kehittäminen talvijalankulun turvallisuuden parantamiseksi. 47 s.

2. Laurila, Tuomas, Lohila, Annalea, Tuovinen, Juha-Pekka, Hatakka, Juha, Aurela, Mika, Thum, Tea, Walden, Jari, Kuronen, Pirjo, Talka, Markus, Pesonen, Risto, Pihlatie, Mari, Rinne, Janne, Vesala, Timo, Ettala, Matti, 2005. Kaatopaikkojen kaasupäästöjen ja haihdunnan mikrometeorologisten mittausmenetelmien kehittäminen (MIKROMETKAA). Tekesin Streams –ohjelman hankkeen loppuraportti. 34 s. (Ei julkaistu – Not published)

3. Siili, Tero, Huttunen, Emilia, Koskinen, Hannu ja Toivanen, Petri (toim.), 2005. Kymmenes Suomen avaruustutkijoiden kokous (FinCospar) Kokousjulkaisu. 57 s.

4. Solantie, Reijo and Pirinen, Pentti, 2005. Diurnal temperature variation in inversion situations. 34 s.

5. Venäläinen, Ari, Tuomenvirta, Heikki, Pirinen, Pentti and Drebs, Achim, 2005. A basic Finnish climate data set 1961 – 2000 – description and illustrations. 24 p.

6. Tammelin, Bengt, Säntti, Kristiina, Dobech, Hartwig, Durstewich, Michel, Ganander, Hans, Kury, Georg, Laakso,

Timo, Peltola, Esa, Ronsten, Göran, 2005. Wind turbines in icing environment: improvement of tools for siting, certification and operation – NEW ICETOOLS. 127 p.

2006:

1. Mälkki, Anssi, Kauristie, Kirsti and Viljanen Ari, 2006. Auroras Now! Final Report, Volume I. 73 p.
2. Pajunpää, K. and Nevanlinna, H. (eds), 2006. Nurmijärvi Geophysical Observatory : Magnetic results 2003. 47 p.
3. Pajunpää, K. and Nevanlinna, H. (eds), 2006. Nurmijärvi Geophysical Observatory : Magnetic results 2004. 47 p.
4. Pajunpää, K. and Nevanlinna, H. (eds), 2006. Nurmijärvi Geophysical Observatory : Magnetic results 2005. 49 p.
5. Viljanen, A. (toim.), 2006. Sähkömagnetiikka 2006. Tiivistelmät – Abstracts. 30 s.
6. Tuomi, Tapio J. & Mäkelä, Antti, 2006. Salamahavainnot 2006 - Lightning observations in Finland, 2006. 39 p.
7. Merikallio, Sini, 2006. Preliminary report of the analysis and visualisation software for SMART-1 SPEDE and EPDP instruments. 70 p.
8. Solantie, Reijo, Pirinen, Pentti, 2006. Orografian huomioiminen loka- huhtikuun sademäärien alueellisissa analyyseissä. 34 s.
9. Ruosteenoja, Kimmo, Jylhä, Kirsti, Räisänen, Petri, 2006. Climate projections for the Nordic CE project – an analysis of an extended set of global regional climate model runs. 28 p.
10. Merikallio, Sini, 2006. Analysis and visualisation software for DEMETER Langmuir Probe instrument. 31 p.

2007:

1. Solantie, Reijo, Järvenoja, Simo, Pirinen, Pentti, 2007. Keskimääräisten kuukauden minimilämpötilojen alueellinen jakauma kautena 1992 – 2005 Suomessa sekä muutos kaudesta 1961 – 1990. 59 s.
2. Pulkkinen, Tuija, Hari, Ari-Matti, Haukka, Harri, Leinonen, Jussi, Toivanen, Petri, Koskinen, Hannu, André, Mats, Balasis, Georgios, Boscher, Daniel, Dandouras, Iannis, Grande, Mauel, De Keyser, John, Glassmeier, Karl-Heinz, Hapgood, Mike, Horne, Richard, Ivchenko, Nikolay, Santolik, Ondrej, Torkar, Klaus; Trotignon, Jean Gabriel, Vennerstrøm, Susanne, 2007. Waves and acceleration of relativistic particles (WARP). 36 p.

3. Harri, A-M., Leinonen, J., Merikallio, S., Paton, M., Haukka, H., Polkko, J., Linkin, V., Lipatov, V., Pichkadze, K., Polyakov, A., Uspensky, M., Vasquez, L., Guerrero, H., Crisp, D., Haberle, R., Calcutt, S., Wilson, C., Taylor, P., Lange, C., Daly, M., Richter, L., Jaumann, R., Pommereau, J-P., Forget, F., Lognonne, Ph., Zarnecki, J., 2007. MetNet – In situ observational network and orbital platform to investigate the Martian environment. 35 p.

4. Venäläinen, Ari, Saku, Seppo, Kilpeläinen, Tiina, Jylhä, Kirsti, Tuomenvirta, Heikki, Vajda, Andrea, Räisänen, Jouni, Ruosteenoja, Kimmo, 2007. Sään ääri-ilmiöistä Suomessa. 81 s.

5. Tuomi, Tapio J. & Mäkelä, Antti, 2007. Salamahavainnot 2007 - Lightning observations in Finland, 2007. 47 p.

6. Pajunpää, K. and Nevanlinna, H. (eds), 2007. Nurmijärvi Geophysical Observatory : Magnetic results 2006. 49 p.

2008 1. Pajunpää, K. and Nevanlinna, H. (eds), 2008. Nurmijärvi Geophysical Observatory : Magnetic results 2007. 49 p.

2. Verronen, Pekka T. (ed), 2008. 1st international HEPPA workshop 2008, Book of abstracts. 81 p.

3. Gregow, Hilppa, Venäläinen, Ari, Laine, Mikko, Niinimäki, Niina, Seitola, Teija, Tuomenvirta, Heikki, Jylhä, Kirsti, Tuomi, Tapio ja Mäkelä, Antti, 2008. Vaaraa aiheuttavista sääilmiöistä Suomen muuttuvassa ilmastossa. 99 s.

4. Tuomi, Tapio J. & Mäkelä, Antti, 2008. Salamahavainnot 2008 – Lightning observations in Finland, 2008. 49 p.

5. Heino, Raino and Tolonen-Kivimäki, Outi (eds), 2008. Finnish national report on systematic observations for climate – 2008. 27 p.

6. Paatero, Jussi, Dauvalter, Vladimir, Derome, John, Lehto, Jukka, Pasanen, Jari, Vesala, Timo, Miettinen, Juha, Makkonen, Ulla, Kyrö, Ella-Maria, Jernström, Jussi, Isaeva, Ludmilla and Derome, Kirsti, 2008. Effects of Kola Air Pollution on the Environment in the Western Part of the Kola Peninsula and Finnish Lapland - Final Report. 26 p.

Ilmatieteen laitos
Erik Palménin aukio 1, Helsinki
tel. (09) 19 291
www.fmi.fi

ISBN 978-951-697-686-3
ISSN 0782-6079
Yliopistopaino
Helsinki 2008