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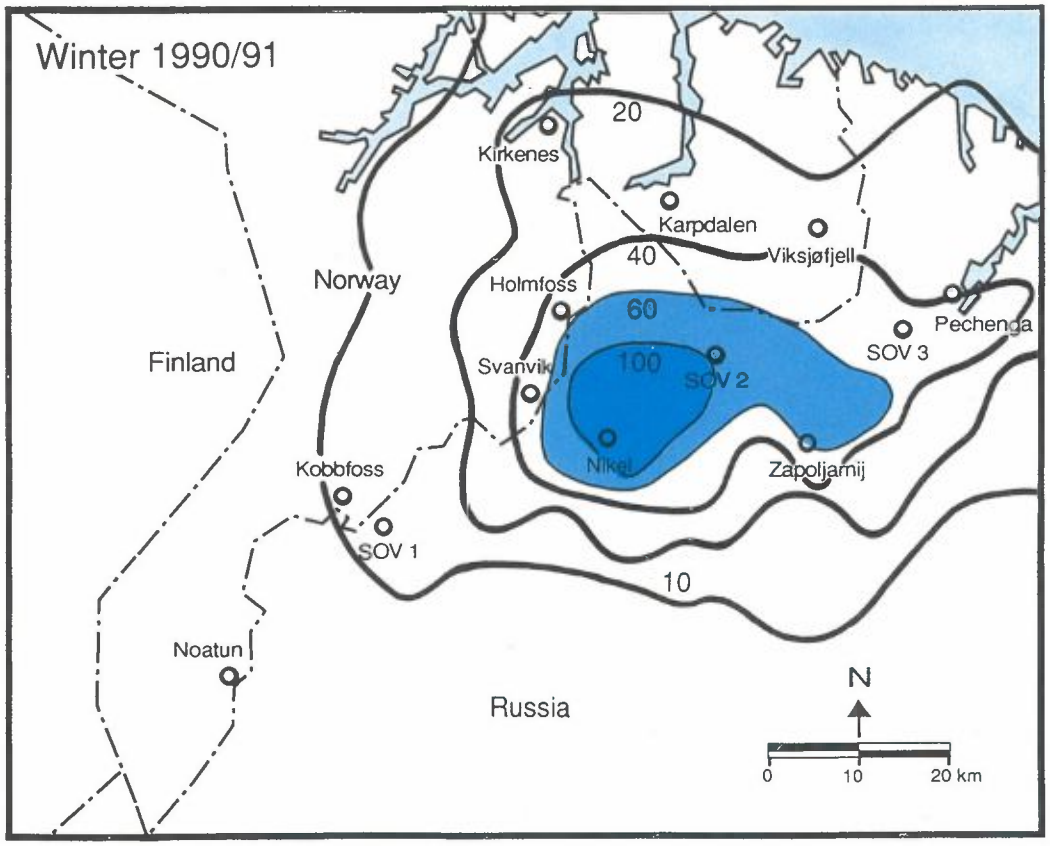
Air Pollution in the Border Areas of Norway and Russia

by

**Bjarne Sivertsen, Tatjana Makarova,
Leif O. Hagen and Alexander A. Baklanov**



Summary report 1990—1991
Presented by the Expert Group on Studies of Local Air Pollution Problems under the Joint Norwegian-Russian Commission on Environmental Co-operation.

The expert group on studies of local air pollution problems under the Joint Norwegian Russian Commission of Environmental Co-operation has been supported by the Norwegian Ministry of Environment (MD) and the Norwegian State Pollution Control Authority (SFT). Scientists from the Norwegian Institute for Air Research (NILU) and from the Institute of Industrial Ecology Problems of the North (INEP) at the Kola Science Centre have been responsible for the programme.

The following persons have participated in the expert group during the study period 1990—91:

Artobolevsky, Valerij	Murmansk Regional Committe on Env. Protection
Baklanov, Alexander	INEP
Fiskebeck, Per-Einar	Dep. of Env. Prot. County Governor of Finnmark
Hagen, Leif Otto	NILU
Kielland, Gabriel	SFT
Makarova, Tatjana	INEP
Sivertsen, Bjarne	NILU

Air Pollution in the Border Areas of Norway and Russia

Summary Report 1990—1991

Summary

An Expert Group on Studies of Local Air Pollution Problems was established in 1988 under the Joint Norwegian-Soviet Commission on Environmental Co-operation. This group has been responsible for a joint monitoring and evaluation programme in the border areas of the two countries. Scientists from the Norwegian Institute for Air Research (NILU) and from the Institute of Industrial Ecology Problems of the North (INEP) at the Kola Science Centre, have been responsible for the intercalibration, data collection, modelling and evaluation.

The air pollution in the border areas are dominated by episodes linked to adverse meteorological conditions. During these episodes the concentrations of SO_2 have exceeded national and international guideline values by a factor of ten at distances of up to 30 km from the smelter industries in Nikel and Zapoljarnij. These smelters represent the main sources of air pollution in the area. Exceedance of seasonal average SO_2 concentration guide-line values was found in an area covering about 2000 km^2 in winter and 700 km^2 in summer.

The deposition of the heavy metals Ni and Cu also exceeded background values by a factor of ten or more within the first 10-30 km from the smelters.

To obtain an air quality which will not exceed given critical level values, the emissions of SO_2 have to be reduced by 90 to 98%.

Introduction

The Joint Norwegian-Russian Commission on Environmental Co-operation was established in 1988. An Expert Group on Local Air Pollution Problems, consisting of three participants from each country, had its first meeting in 1989. The Expert Group has been responsible for the planning and establishment of a joint air quality study and has carried out the monitoring and modelling programme in the border areas of the two countries. A comprehensive measurement programme started on the Norwegian side in 1988. Similar measurements started on the Russian side in January-February 1990. During the joint measurement programme, data and results have been exchanged and compared continuously. Scientists from the Norwegian Institute for Air Research (NILU) and from the Institute of Industrial Ecology Problems of the North (INEP) at the Kola Science Centre have been responsible for the intercalibration, data collection and evaluation.

Several status reports have been produced. From the Norwegian side these reports have been part of the national surveillance programme suported by the Norwegian State Pollution Control Authority (SFT). A final report has been presented from each country as a basis for this summary report (see list of references).

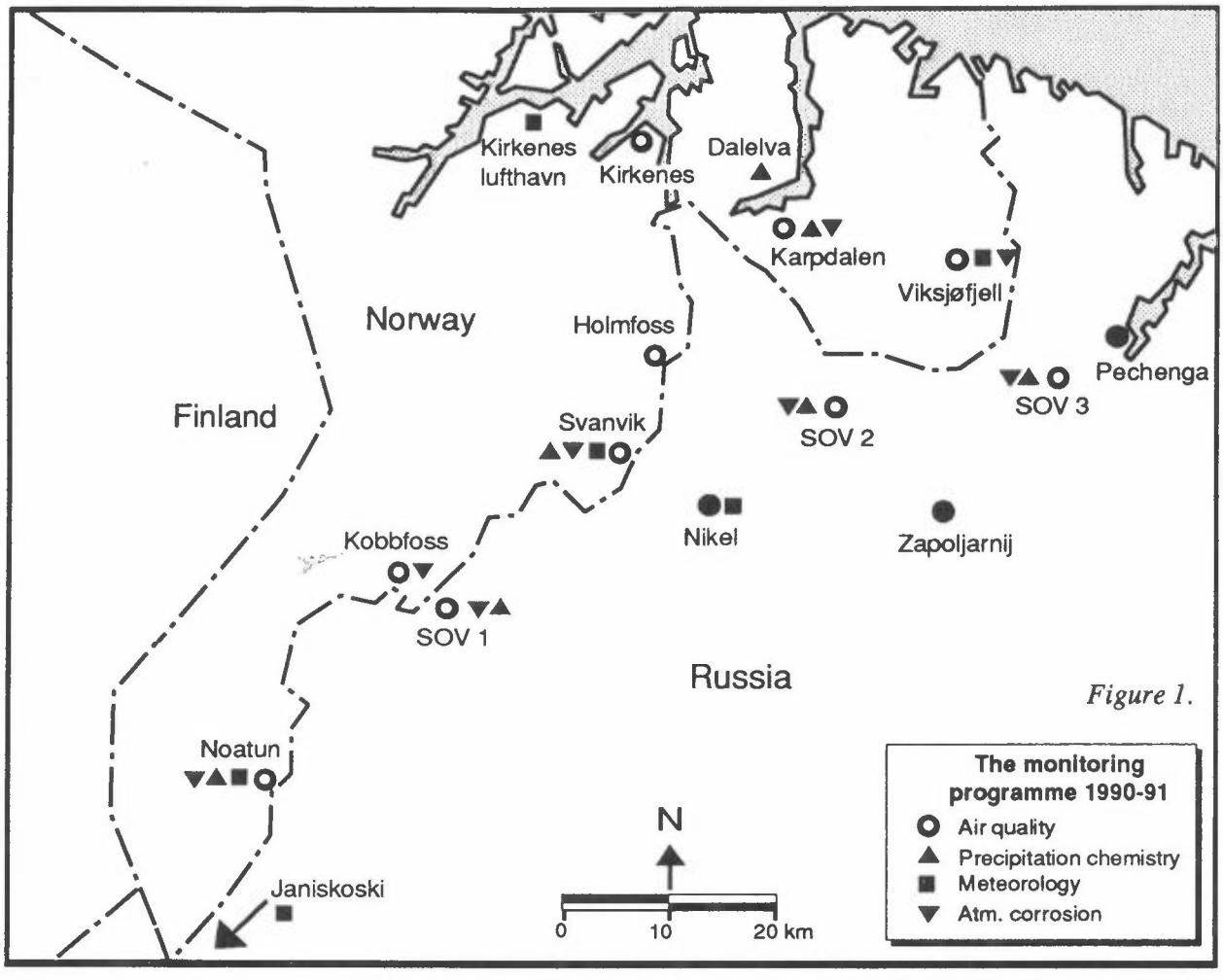


Figure 1.

The Study Area and Measurement Programme

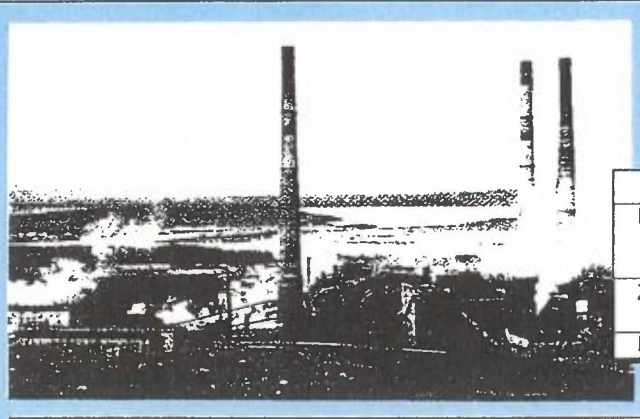
Air quality investigations have been carried out on both sides of the border between Norway and Russia, as indicated in Figure 1. The study area was about (100 x 100) km^2.

SO_2 was measured by continuous monitors at three stations on each side of the border to register the short term concentrations during air pollution episodes. Also 24 h average sampling of SO_2 and suspended particels was performed at a total of ten sites. Particle samples were analysed for 11 elements. Precipitation composition was measured on a weekly basis at three stations at each side of the border. Also snow samples were collected in April 1990 and March 1991 for analysis of precipitation compounds and heavy metals.

Meteorological data were collected every hour at two sites in Norway. Data were also available from the official meteorological stations in Norway (two sites) and Russia (two sites). Wind speed, wind directions, temperatures, turbulence (stability), relative humidity and precipitation have been evaluated for explanation of air quality and for air pollution modelling purposes.

Emissions of Air Pollution

Estimated emissions of air pollutants, such as SO_2, dust and selected heavy metals, have been given by Murmansk Regional Committee of Goskompriroda and the Pechenga Nikel Combinate for the smelters in Nikel and Zapoljarnij, and from the Norwegian State Pollution Control Authority (SFT) for A/S Sydvaranger in Kirkenes. A summary is given in Figure 2.



Emission data

Annual average (1000 ton/year)

	1989	SO_2	NO_x	Dust	Ni	Cu
Nikel	H	153	—	3,8	0,19	0,12
	L	35	—	0,9	0,05	0,03
	P	2	0,2	0,2	—	—
Zapoljarnij	H	82	0,2	5,2	0,23	0,14
	L	—		0,6	0,04	0,02
Kirkenes	H	0,5	—	1,0	—	—

H: High stacks
L: Low sources
P: Power plant

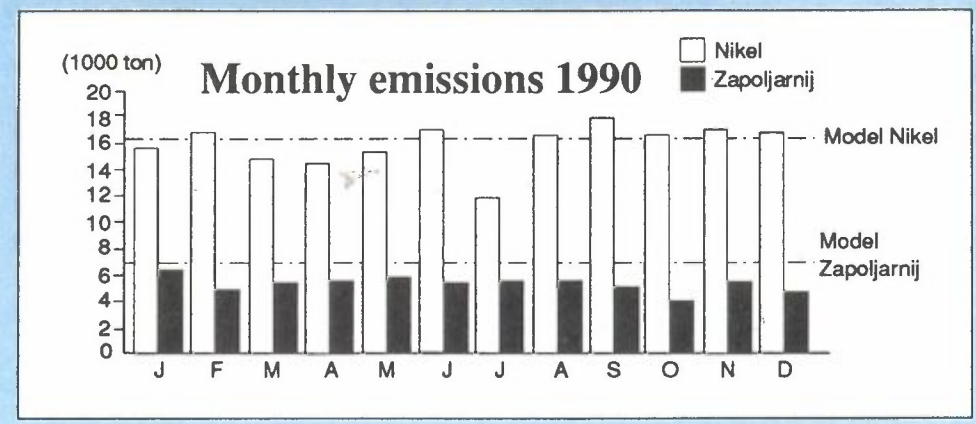


Figure 2.

For model estimates the excact information is needed about the emissions, such as location of stacks, stack dimensions, release temperatures and gas flow rates. These types of data were only given for annual average releases. We also received monthly emission rates from the Combinate for 1990.

Air Quality

Measured SO_2 Concentrations

The continuous records of SO_2 at all sampling sites show that the air pollution problem in the border areas is of episodic character. Long periods occur with low or no impact at the monitoring sites. Occasionally these periods are followed by high concentrations during shorter periods when the smoke plumes from the industries are transported with the wind to the monitoring sites. These episodes are more linked to variations in meteorological conditions than to changes in emission rates.

The ratio of long term average to maximum one hour average SO_2 concentrations is very small as would be expected for emissions from tall stacks. The summer and winter average SO_2 concentrations measured in the area are presented in Figure 3.

During air pollution episodes the typical one hour average peak concentrations were usually about 10 to 25 times higher than the seasonal and monthly average concentrations.

The three highest one hour average concentrations at the six monitoring sites during episodes occurring in winter and summer seasons are presented in Table 1.

Table 1: The 3 highest one hour average SO_2 concentrations ($\mu g/m^3$) at 6 sites during episodes occurring in summer and winter seasons 1990-1991. Also the number of hours (N) with SO_2 concentrations above 350 $\mu g/m^3$ is presented.

SO_2 ($\mu g/m^3$)	Viksjøfjell	Karpdalen	Svanvik	SOV1	SOV2	SOV3
Winter 1989/90	3121	865	2458	1256*	2956*	1182**
	2974	851	2304	1135*	2787*	1026**
	2825	845	2226	1073*	2759*	757**
Summer 1990	1020	1057	1170	558	1637	1250
	899	776	777	395	1609	778
	803	562	532	368	1343	689
Winter 1990/91	1975	1133	1060	425	2247	1362
	1948	940	1036	406	1623	1032
	1697	756	1018	348	1456	1023
N>350 $\mu g/m^3$ 1990	144	92	38	13	312	144
N>350 $\mu g/m^3$ 1.1.-31.3.1991	107	34	23	2	133	89

*) Jan. - Mar. 1990 **) Feb.-Mar. 1990

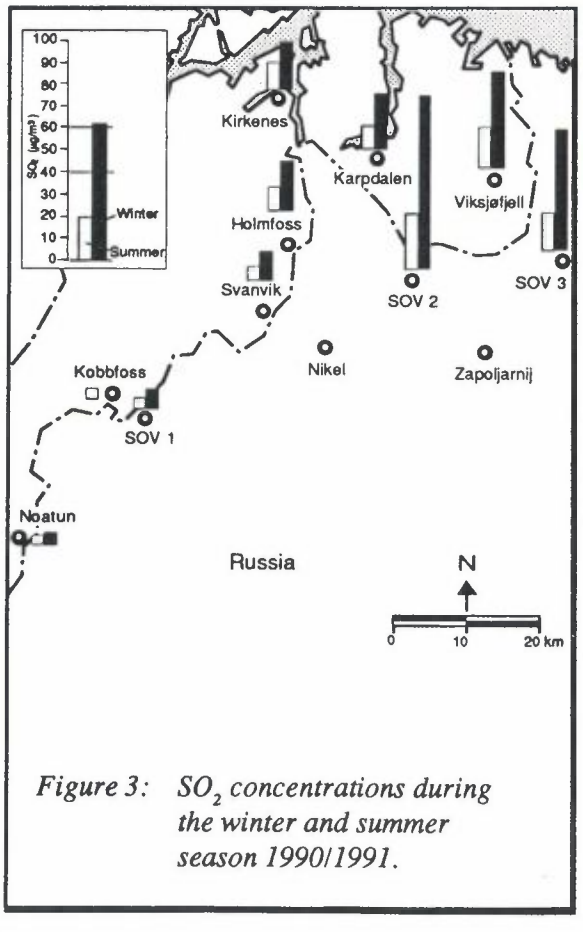


Figure 3: SO_2 concentrations during the winter and summer season 1990/1991.

Model Estimated SO_2 Concentrations

Emission data have been combined with meteorological data to estimate the SO_2 concentration distributions. Dispersion models developed by INEP and NILU have been used. The model results have shown reasonably good agreement with measured long term average concentrations (month-year). The small discrepancies found in the final seasonal concentration distributions between the INEP and NILU estimates may be explained by different ways of handling input data; both emissions and meteorology.

The highest summer and winter average SO_2 concentrations were found on Russian territory within 20 to 30 km from the smelters, as shown in Figure 4. The average concentrations were somewhat higher during the winter season than during summer. Seasonal average concentrations exceeding 50 $\mu g/m^2$ cover an area of about 200 km^2 during the summer and about 800 km^2 during the winter.

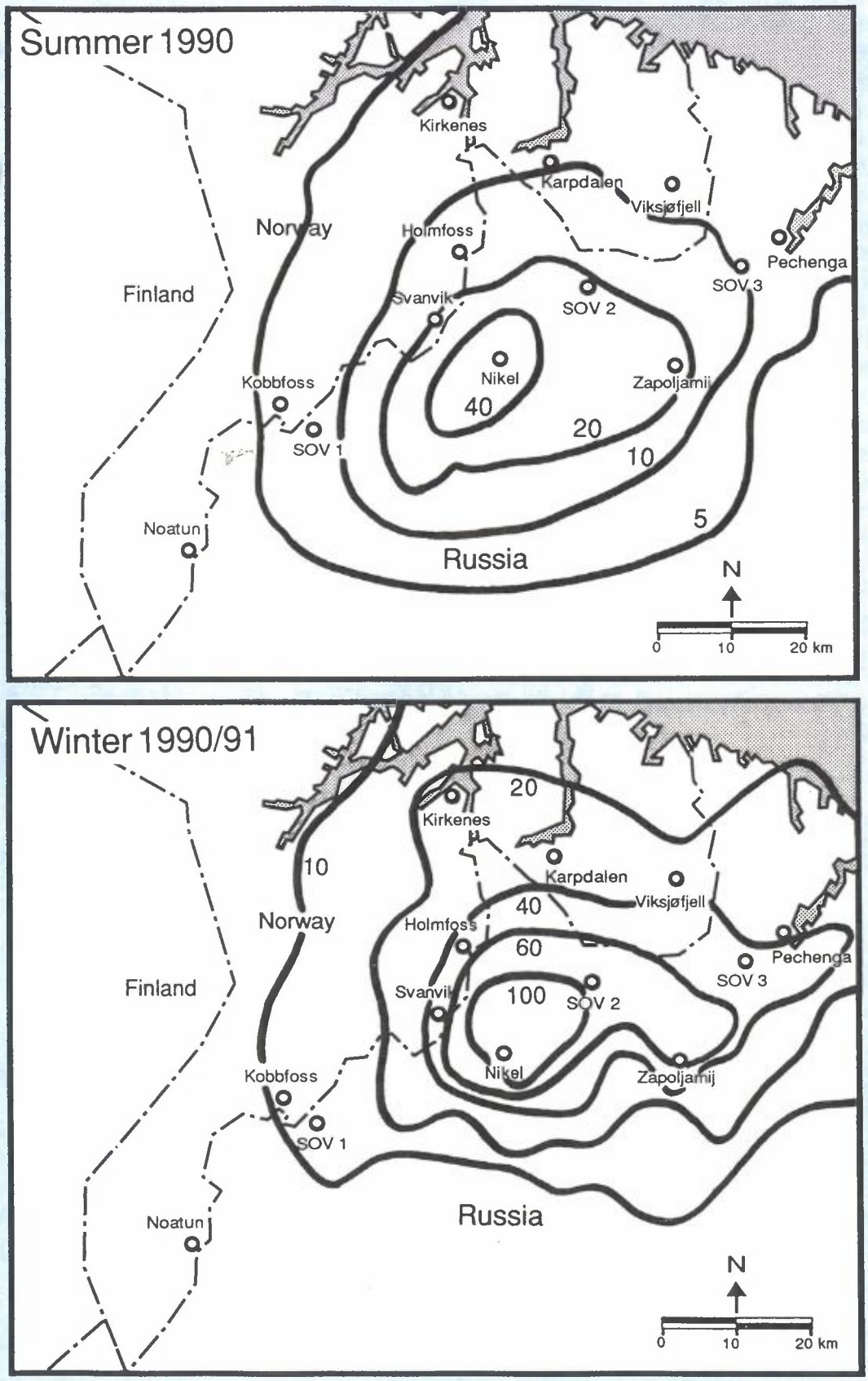


Figure 4: Estimated 6 month average SO_2 concentrations ($\mu g/m^3$)

Heavy Metals in the Air

Filter samples collected at seven sites at the Norwegian side and three sites at the Russian side of the border have been analysed for five different heavy metals, and for additional six elements from the Norwegian sites. The long term average and the maximum 24 h average concentrations of three selected elements; nickel (Ni), copper (Cu) and arsenic (As) are presented in Figure 5. The selected elements usually occur at concentration levels 5 to 10 times higher than those measured at a regional station in Southern Norway (Birkenes) which is exposed to long range transport of air pollutants from Continental Europe.

For other heavy metals, such as vanadium (V), manganese (Mn), iron (Fe), zinc (Zn) and lead (Pb), the levels in the border area were comparable to the background levels at Birkenes, except for Fe in Kirkenes which had much higher concentrations. The highest levels of Cr, Co, Zn and Cd were considerably higher at some locations in the border area than at Birkenes. Co was found more uniformly distributed over the whole area with maximum levels five times higher than those at Birkenes. The highest level of Cd was found in Kirkenes while Cr seems to be associated with emissions from Nikel.

Dry and Wet Deposition

Sulphur and airborne particles containing heavy metals are removed from the atmosphere and transferred to vegetation, soil and water by dry deposition and precipitation scavenging.

Precipitation Chemistry

Data for precipitation amounts and analyses of sulphate, nitrate, heavy metals and other chemical components in precipitation have been used to

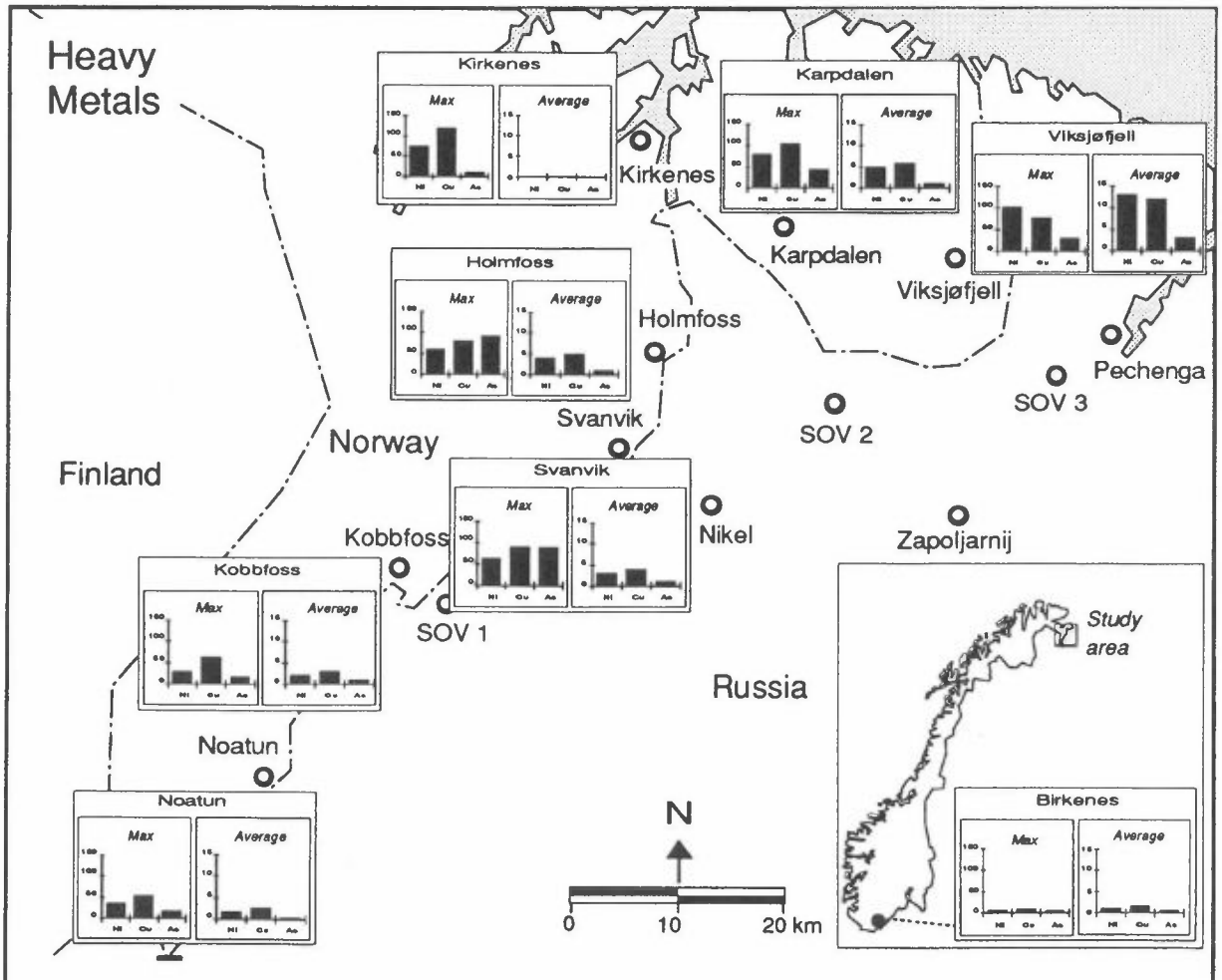


Figure 5: Average (15 months) and 24 h average maximum concentrations of Ni, Cu and As (ng/m³)

calculate total annual deposition rates. Figure 6 shows results for 1990.

The chloride concentration in precipitation increased towards the coast. This indicates that sulphate also will have a marine contribution which is not taken into account in the data. Only 13% of the total SO_4 concentration was of marine origin at Svanvik. The annual average wet deposition of sulphate was at Svanvik 0.3 g/m² and at Dalelva 0.35 g/m² (as S). The wet deposition of sulphate at background stations was in 1989 0.14 g S/m² at Janiskoski and 0.16 g S/m² at Jergul (*Schaug et al., 1991*).

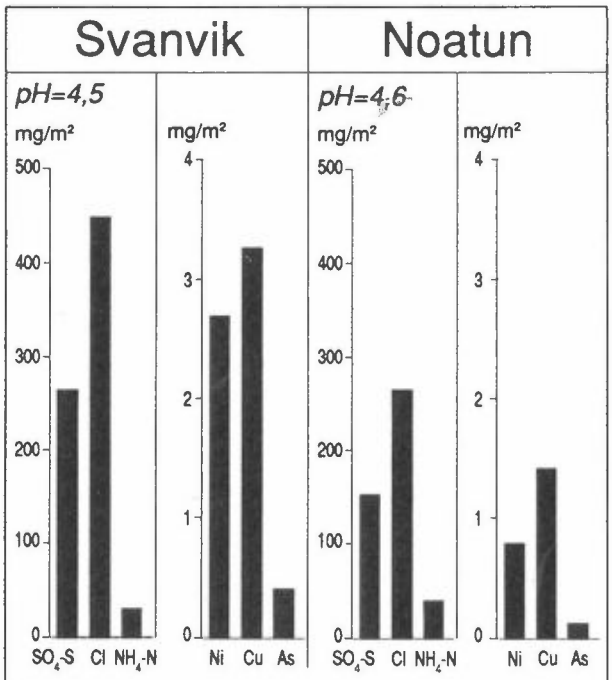


Figure 6: Total wet deposition rates for 1990.

The heavy metals Ni, Cu and As seem to have its main source at the smelters in Nikel and Zapoljarnij. At Svanvik the wet deposition of Ni, Cu and As was about 35% less in 1990 than it was in 1988 and 1989. The amount of precipitation was about 40% less in 1990. The annual average wet deposition at Svanvik measured in 1990 was 2.8 mg/m² and 3.3 mg/m² for Ni and Cu, respectively. Similar analyses in precipitation at the site SOV2 has shown 7.6 mg/m² of Ni. At Noatun the annual average value was 0.8 mg/m² of Ni and 1.4 mg/m² of Cu.

Snow Sampling

Snow samples have been collected at several locations at both sides of the border in April 1990 and in March 1991. The winter deposition pattern of sulphate and selected heavy metals as well as pH values in the snow have been determined.

The sulphate pattern was not well correlated to the SO_2 concentration pattern due to the irregularity in precipitation as a function of wind directions and distances from the smelters. Sulphate will also be partly removed from the snow pack during months of storage, smelting and refreezing. Also pH values in snow are not well correlated to the air pollution long term concentration distribution. High pH values were found close to Nikel, which indicate that the particles emitted from the smelter tend to neutralize the precipitation.

The nickel and copper deposition in snow were reasonably well correlated with SO_2. Large particles are settled close to the smelters both by dry and wet processes. The Ni concentrations decreased rapidly with distance from the smelters as shown in Figure 7. Strong gradients of Ni deposition in snow were observed towards the west and northwest. Within the first 10 km from the smelters the total desposition of Ni was between 10 and 100 mg/m². At Svanvik 4.6 mg/m² of Ni was measured in the snow pack. Samples collected at the Varanger peninsula indicated deposition rates less than 0.1 mg/m².

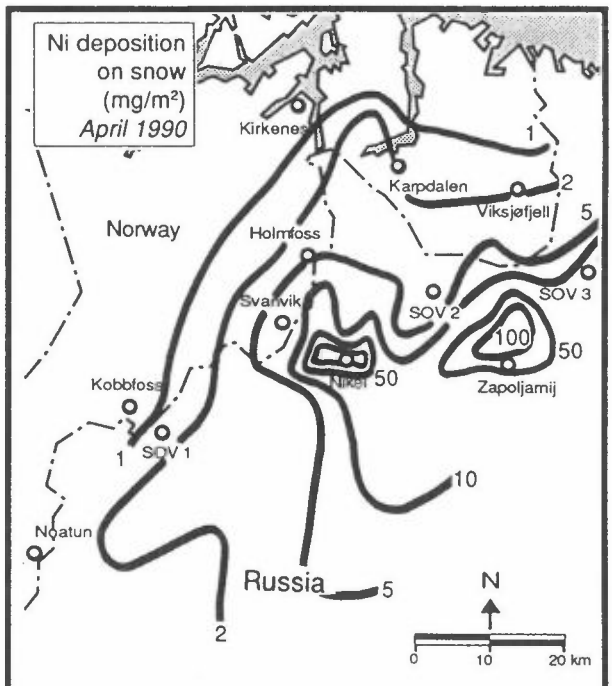


Figure 7: Nickel, deposition on snow, April 1990.

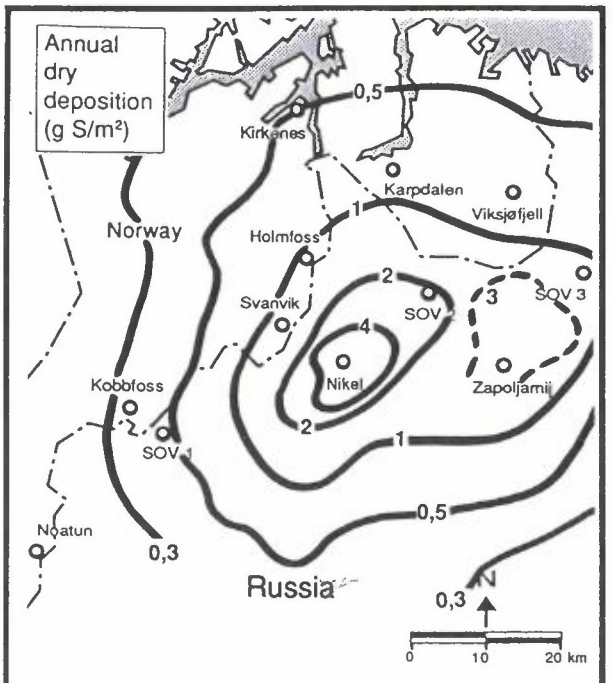


Figure 8: Annual dry deposition of sulphate (gS/m^2) as result of emissions from the smelter industries.

Calculated Dry Depostion from Smelters Emissions

The dry deposition of SO_2 to the ground as a result of emissions from the smelters has been calculated using dispersion models. Different deposition velocities have been applied for summer (0.5 cm/s) and winter season (0.1 cm/s). Also the emission rates have been assumed to be smaller in the summer than in the winter season.

Figure 8 shows that within 10-15 km from the Nikel smelter dry deposition rates of more than 2 g/m^2 as S per year can be found. This is ten times higher than the annual average deposition of sulphur at the background stations Janiskoski and Jergul, which both are dominated by (60-70%) wet deposition. (*SFT 1991, Schaug et al. 1991.*)

Estimates of Total Annual Deposition Rates

The total annual deposition of sulphur and nickel has been estimated from measurements and model calculations for 1990.

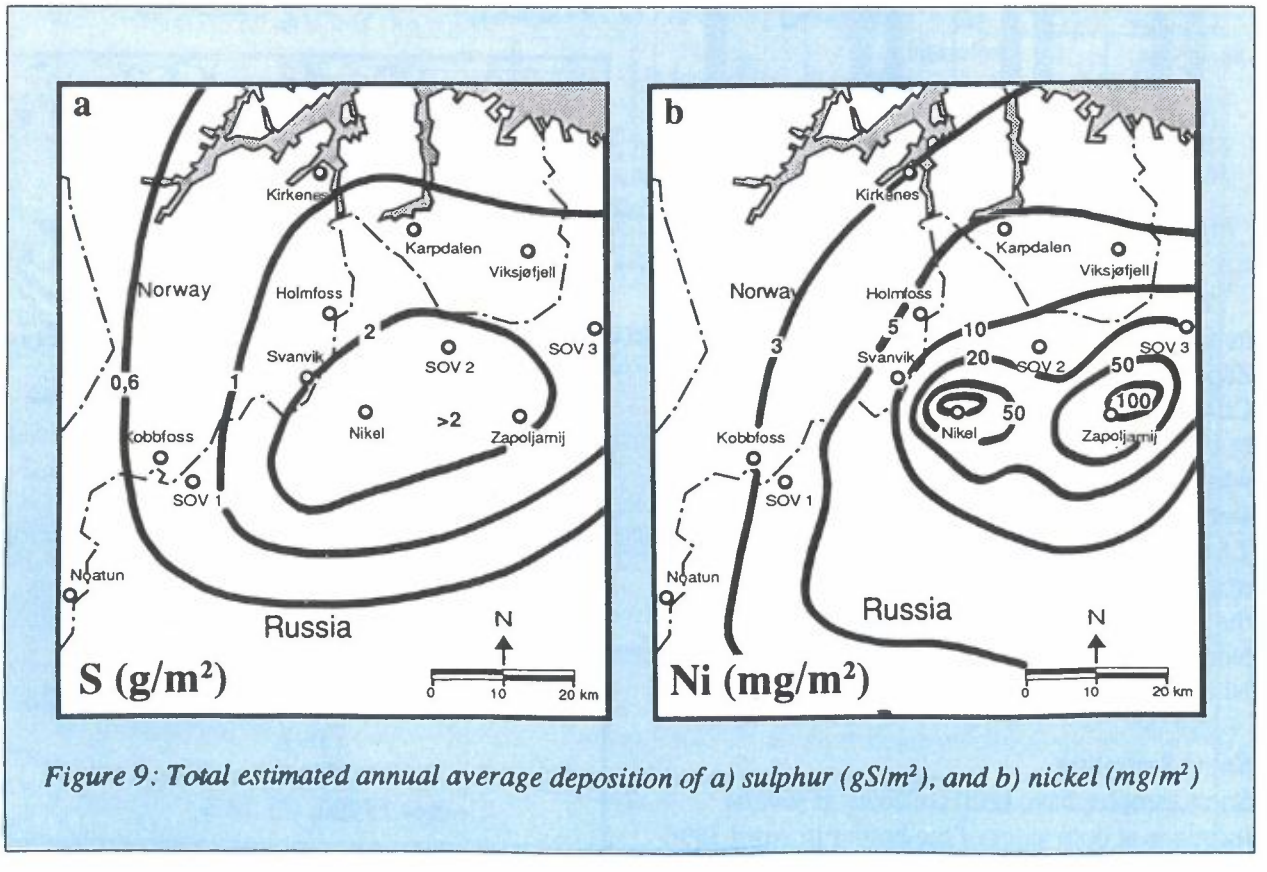


Figure 9: Total estimated annual average deposition of a) sulphur (gS/m^2), and b) nickel (mg/m^2)

These estimates include measurements and calculations of dry and wet depositions. The regional background values as measured in the EMEP network and at the monitoring stations in the border areas have also been included.

Requirements for Emission Reductions

Critical Levels

The critical load or level is defined as the highest level of deposition or concentration at which no harmful effects on the ecosystem are to be expected.

The study of critical loads in the specific border areas of Finnmark and the Murmansk region is being carried out by other expert groups. The conclusions from these expert groups are not available at present. The following discussion below has therefore been based upon present knowledge as presented in the international literature. The critical level values have normally been presented as air quality criteria or air quality guidelines. Air quality guidelines as given for the protection of human health by the World Health Organization (*WHO,1987*) and for protection of forests by the International Union of Forest Research Organization (*IUFRO, 1978*) is presented in Table 2.

The limits given by IUFRO have been presented for the protection of forests. Parts of the vegetation in the northern areas of Finnmark and Kola may be more sensitive to air pollutants than the values given by IUFRO. The criteria for the ecosystem will be finally evaluated when the results from the expert groups on terrestrial and water ecosystems are available.

An expert group on critical levels indicated that for protection of lichens, mosses and some leaf trees the annual average SO_2 concentrations should not exceed 20 µg/m³ (*ECE, 1988*).

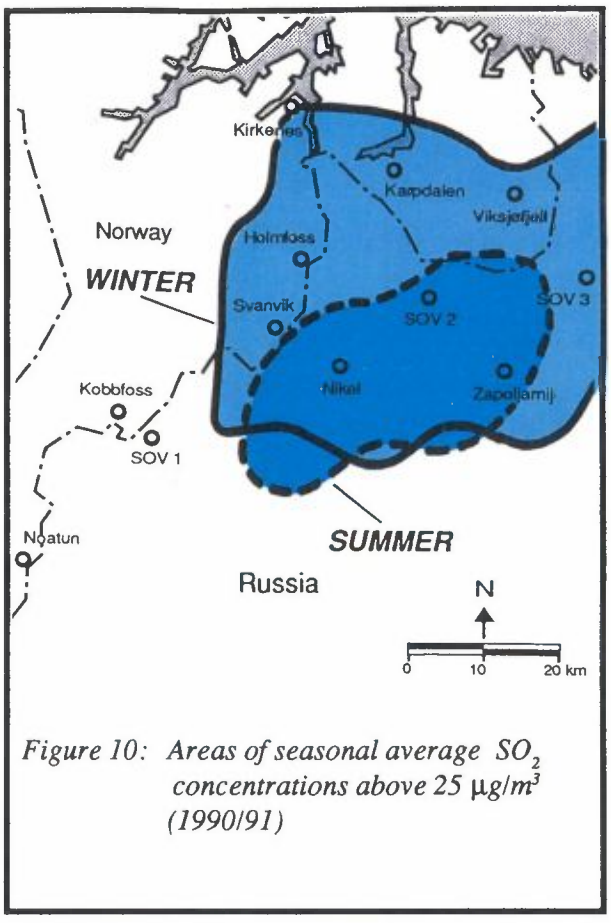


Figure 10: Areas of seasonal average SO_2 concentrations above 25 µg/m³ (1990/91)

Table 2: Examples of proposed air quality guidelines for protection of health and forest as given by WHO (1987) and IUFRO (1978).

Protection of:	Conc. (µg/m3)	Average time	Reference
Health	30	year	WHO, 1987
	350	1 h	WHO, 1987
Forests	25	6 months	IUFRO, 1978
	50	24 h	IUFRO, 1978
	150	1 h	IUFRO, 1978

Seasonal Average SO_2 Concentrations

During the summer and winter seasons 1990/91, the areas within which the seasonal average SO_2 concentrations have exceeded 25 µg/m³ are shown in Figure 10.

During the winter season this area was estimated to ~2000 km². During the summer season 25 µg/m³ as an average SO_2 concentration was exceeded within 700 km².

The seasonal average SO_2 concentration at ground level along the wind direction sector towards the northeast is presented in Figure 11 as a function of the distance from the smelter in Nikel. The average concentrations as a result of the high stack emissions (~80% of the total SO_2 emissions) and from low diffusitive SO_2 sources in the factory building complex have been evaluated separately.

To obtain a seasonal average SO_2 concentration of less than 25 µg/m³ at all distances beyond ~3 km from the plant, the SO_2 emission rates during winter has to be reduced by 85%. To obtain this goal at short distances from the plant the low level fugitive emissions have to be reduced by more than 90%. The emissions from the tall stacks also exceed 25 µg/m³ up to distances of about 25 km.

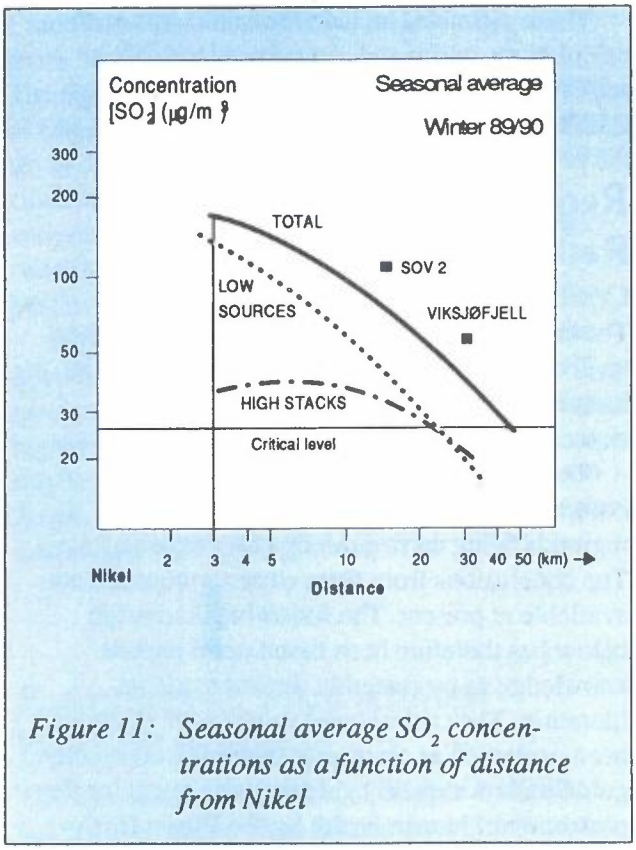


Figure 11: Seasonal average SO_2 concentrations as a function of distance from Nikel

Hourly Average Maximum Concentrations

The maximum one hour average SO_2 concentrations at ground level have been estimated as a function of distance from the smelter in Nikel. Certain meteorological conditions have been considered. One of these is presented in Figure 12. An estimated average wind speed of 3 m/s (measured in Nikel and Svanvik) from the east will carry the air pollution cloud into Norway only 10 km from Nikel. This might happen occasionally, but is not the most probable wind direction. Transport towards the northeast (winds from the southwest) occurs more often. The ground level concentrations will, however, be comparable to the case presented.

The results show that emissions from low sources in the building complex will dominate the SO_2 concentration distribution to about 7 km from Nikel. The total maximum one hour average SO_2 concentration at ground level along the plume axis will exceed 350 µg/m³ up to about 24 km. To obtain a level which will not exceed 350 µg/m³ at

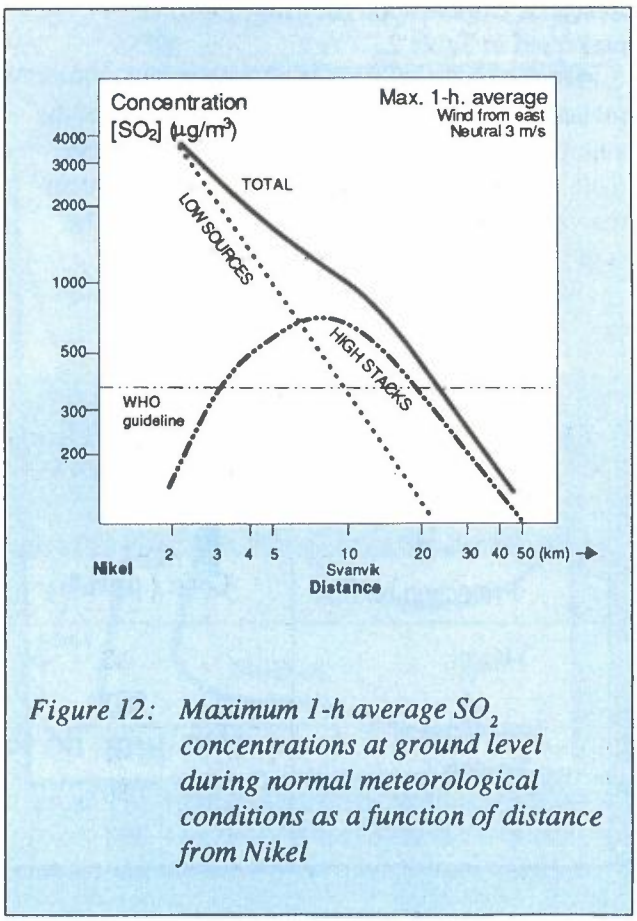


Figure 12: Maximum 1-h average SO_2 concentrations at ground level during normal meteorological conditions as a function of distance from Nikel

Table 3: Maximum expected one hour average SO_2 concentrations at ground level during episodes.

	Max. concentration ($\mu g/m^3$)	Typical distances (km)
Low level sources	>4000	<5 km
High stacks	~2000 >1000	10 - 25 7 - 40
Total	>3500	<20

2 km, the low level sources have to be reduced by 92%. The emissions from high stacks have to be reduced by ~50%

In this estimate we have not considered the most severe episodes including low wind speeds (1 m/s) and strong inversion conditions. Table 3 indicates some of the measured and estimated concentrations for these situations.

These results indicate that a reduction of at least 90% of the total SO_2 emissions has to be implemented to avoid exceedance of 350 $\mu g/m^3$ within 20 km from the smelter. To obtain a maximum average SO_2 concentration of less than 350 $\mu g/m^3$ at 5 km during episodes the low level sources have to be reduced by 92%, the high stack emissions by 84%. To obtain 150 $\mu g/m^3$ at ground level the SO_2 emissions have to be reduced by 98%. Episodes of this kind with 1 h-average SO_2 concentrations exceeding 350 $\mu g/m^3$ occurred in 1990 3-5% of the time during winter and 1-2% of the time during summer at Karpdalen and Viksjøfjell 20-30 km north of the smelters.

Conclusions

The air quality in the border areas has been measured and model estimated by the expert group with participants from Norway and Russia. The same methods for measurements have been applied. The methods and the results have been compared and evaluated.

Good agreement has been found between measurements and estimates and between methods applied by both parties. The results obtained are thus suitable for the proposal of reduction strategies.

The following conclusions can be drawn:

- The air pollution in the border areas has been shown to be dominated by episodes caused by very high SO_2 concentrations.
- Estimates of concentration distribution patterns and total deposition of SO_2 and heavy metals have been presented within one hundred km from the smelters.
- The area influenced by seasonal average concentrations exceeding 25 $\mu g/m^3$ of SO_2 was in 1990 about 2000 km^2 in winter and about 700 km^2 in summer.
- Based on the air quality guidelines given at present it might be necessary to reduce the emissions of SO_2 from the smelter by 90% to obtain the seasonal average concentrations and by 98% to obtain the maximum acceptable one hour average concentration during episodes.

To obtain more definite conclusions, updated results for critical levels and critical loads to protect the ecosystem are needed from the expert groups on terrestrial and water ecosystem. For future surveillance of air pollution in the border areas of Norway and Russia the programme has to be designed to take account of future changes in emissions. A minimum surveillance programme should be maintained in continuous operation for trend analyses.

Data should be transferred on-line to research centres in Norway and Russia for information exchange purposes. A system for information and prediction of air quality should be considered for the area.

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Institute of Industrial Ecology Problems of the North, INEP
Kola Science Centre, 14 Fersman Str., 184200 APATITI
Murmansk Region, Russia.

Norwegian Institute for Air Research
P. O. Box 64, N-2001 Lillestrøm, Norway

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