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Air Pollution in the Border Areas of Norway and Russia

Summary Report
April 1991 - March 1993

by

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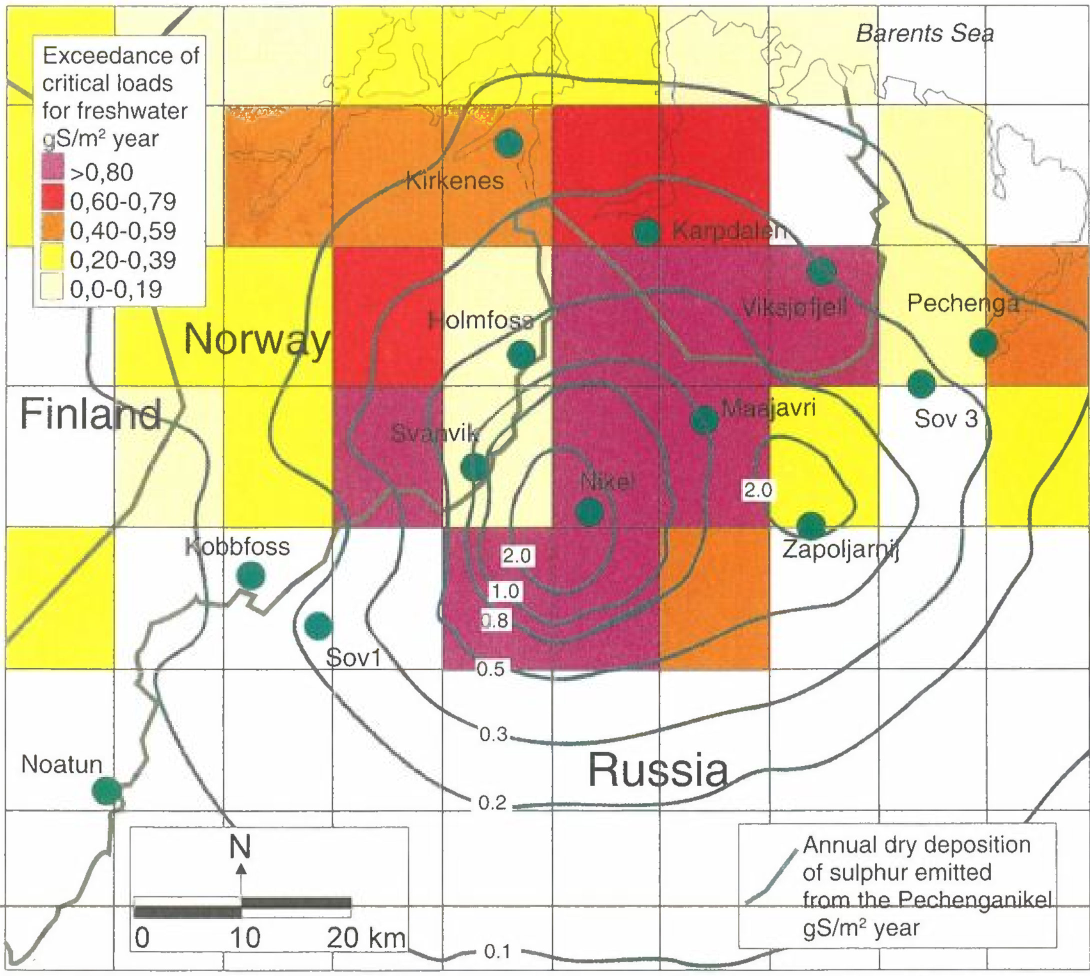

Presented by the Expert Group on Studies of Local Air Pollution Problems under the Joint Norwegian-Russian Commission on Environmental Co-operation.

Preface

The expert group:

The expert group on studies of local air pollution problems under the Joint Norwegian-Russian Commission on 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 Northern Ecological Problems (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 1991-93:

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Summary

An Expert Group on Studies of Local Air Pollution Problems was established in 1988. The group, which is working under the Joint Norwegian-Russian Commission on Environmental Co-operation, 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 Northern Ecological Problems (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.

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.

The annual average emissions of sulphur have been reduced by about 40% at Nikel from 1982 to 1992. The result of this can also be seen in average SO_2 concentration levels. The injuries on vegetation have been shown to correlate well with SO_2 concentrations.

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1. The measurement programme

Air quality, precipitation chemistry and meteorology have been measured at both sides of the border as part of the bilateral co-operation since 1990. Detailed investigations started on the Norwegian side in 1988, and simplified air quality measurements have been undertaken in Sør-Varanger since 1974.

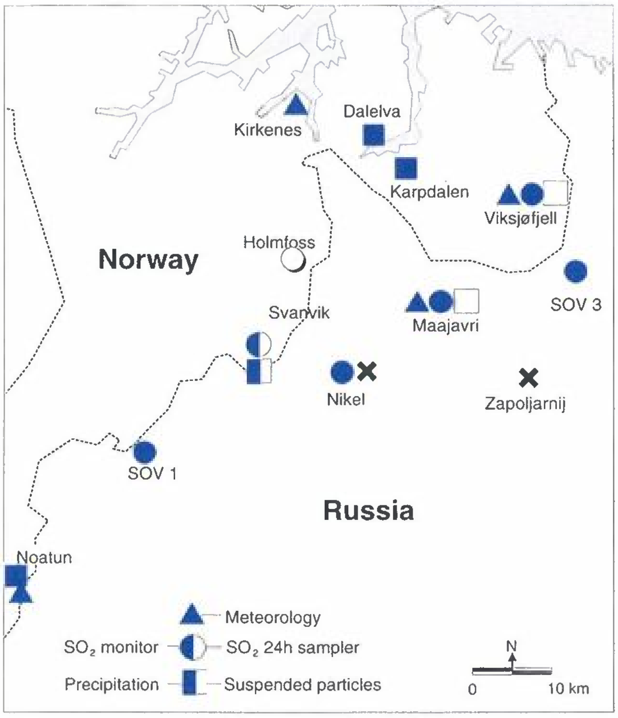

Figure 1: The measurement programme in the border areas of Norway and Russia

During the period 1 April 1991-31 March 1993 air quality data were collected at 5 locations in Norway and at 3 locations in Russia. Precipitation chemistry was analyzed from 3 locations in Norway, and meteorological data were obtained from 4 stations in Norway and 1 in Russia. See Figure 1.

2. The air pollution problem

2.1 Sulphur dioxide (SO_2)

Very high SO_2 concentrations occurring occasionally during so called air pollution episodes represent the largest air pollution problem in the border areas of Norway and Russia. During such episodes the highest one hour average concentrations might be almost as high on the Norwegian side of the border as at the more frequently impacted sites in Russia.

Table 1 summarizes mean and maximum SO_2 concentrations measured during the summer and winter seasons 1 April 1991-31 March 1993 at 4 sites.

The seasonal (6 months) average concentrations ranged from 4 $\mu g/m^3$ (in Svanvik) to 86 $\mu g/m^3$ (at Maajavri), while the natural background value is less than 1.0 $\mu g/m^3$ as measured at Jergul 200 km west of the border areas. Compared to the Norwegian air quality criteria of 40 $\mu g/m^3$, the half year average concentrations were not exceeded at the two Norwegian monitoring sites, while in Russia the guideline values were exceeded by about hundred percent both in Nikel (summer 1992) and at Maajavri (winter 1992/93).

The Russian 24 h average norm at 50 $\mu g/m^3$ was exceeded frequently as shown in Table 1. Compared to the World Health Organization (WHO) air quality guideline value for 1 h average SO_2 of 350 $\mu g/m^3$ the highest one hour average concentrations were exceeded by a factor 4 to 8 at all stations. These episodes represent a major problem, knowing that acute leaf damages might occur at levels of around 1000 $\mu g/m^3$. This is also the level at which people might smell SO_2.

Table 1: Half year SO_2 statistics, April 1991 - March 1993

a) Concentrations

Season and year	Concentrations (µg/m3)	Viksjøfjell	Svanvik	Maajavri	Nikel
Summer 1991 (Apr.-Sep.)	Mean value Max. 24 h value Max. 1 h value	19 191 1329	10 144 1578	27 320 1911	- - -
Winter 1991/92 (Oct.-March)	Mean value Max. 24 h value Max. 1 h value	36 259 2065	4 70 461	81 406 2016	37 486 2669
Summer 1992 (Apr.-Sep.)	Mean value Max. 24 h value Max. 1 h value	19 132 1027	7 143 615	27 350 2610	73 727 2634
Winter 1992/93 (Oct.-March)	Mean value Max. 24 h value Max. 1 h value	34 227 2573	11 288 671	86 596 2501	43 698 2783

b) Number of observations

Season and year	Number of observations	Viksjøfjell	Svanvik	Maajavri	Nikel
Summer 1991 (Apr.-Sep.)	24 h v. > 50* 24 h v. > 90 1 h v. > 350	22 6 31	11 4 15	34 13 86	- - -
Winter 1991/92 (Oct.-March)	24 h v. > 50* 24 h v. > 90 1 h v. > 350	48 22 85	3 0 1	90 61 304	27 17 96
Summer 1992 (Apr.-Sep.)	24 h v. > 50* 24 h v. > 90 1 h v. > 350	19 7 20	6 2 8	26 11 65	53 44 258
Winter 1992/93 (Oct.-March)	24 h v. > 50* 24 h v. > 90 1 h v. > 350	46 18 70	13 6 9	59 42 224	42 28 117

**Russian air quality norm*

The average SO_2 concentrations as function of the wind directions are presented in Figure 2.

The highest average SO_2 concentrations occurred in Nikel during winds from north east (from the smelter!). The concentrations were on the average about 250 μg/m³ for all cases with these wind directions. In Svanvik the highest SO_2 concentrations occurred for winds from around east (from Nikel), and at Maajavri and Viksjøfjell the highest concentrations occurred at winds from south east and south west (from Nikel and Zapoljarnij).

It is clear from the figures that the SO_2 emissions from the smelters in Nikel and Zapoljarnij are the main reasons for the high SO_2 concentrations measured at all sites in the area.

Only in Kirkenes it seems to be a local contribution of SO_2, especially during the winter season. The winter average SO_2 concentrations (μg/m³) in Holmfoss, Karpdalen and Kirkenes were:

Station	Winter		
	1991/92	1992/93	Average
Holmfoss	10	17	13.5
Karpdalen	18	23	20.5
Kirkenes	17	24	20.5

The expected contribution from the Nikel smelter to Kirkenes is about 10 to 12 μg/m³, which indicate a local average winter contribution of about 8-10 μg/m³ SO_2 in Kirkenes.

The monthly variation of SO_2 concentrations is presented for the four main stations in Figure 3.

The winter averages are usually highest at Viksjøfjell and Maajavri. The highest monthly maximum concentrations were measured at Maajavri in November 1992. The November 1992 averages were 57 μg/m³ at Viksjøfjell and 144 μg/m³ at Maajavri. In Nikel the highest monthly average SO_2 concentrations occurred in April 1992 at 107 μg/m³.

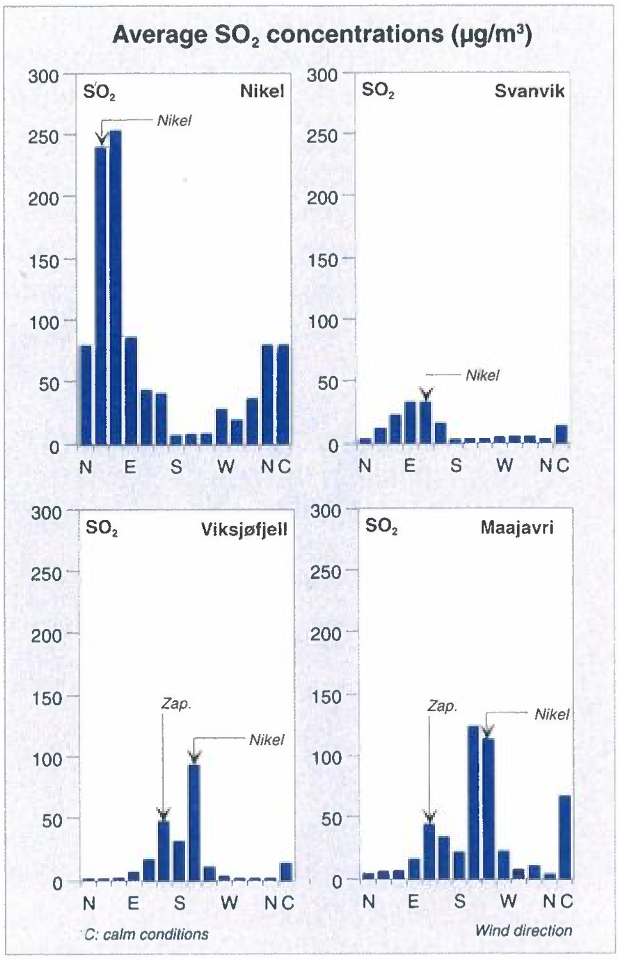

Figure 2: Average SO_2 concentrations as a function of the wind directions.
- Wind from Viksjøfjell for SO_2 at Viksjøfjell and Maajavri.
- Wind from Svanvik for SO_2 at Svanvik and Nikel.

2.2 Air pollution episodes

Air pollution episodes occur in the area during specific meteorological conditions. The most typical situations were characterized by a high pressure area situated on the Kola peninsula or over the northern part of Russia, with a low pressure front system moving eastwards across the Norwegian ocean towards the Barents Sea.

Some of the typical episodes that occurred from April 1991 to March 1993 are presented in Table 2.

After the episode occurring from 27 to 28 June 1992 vegetation injuries were observed both in

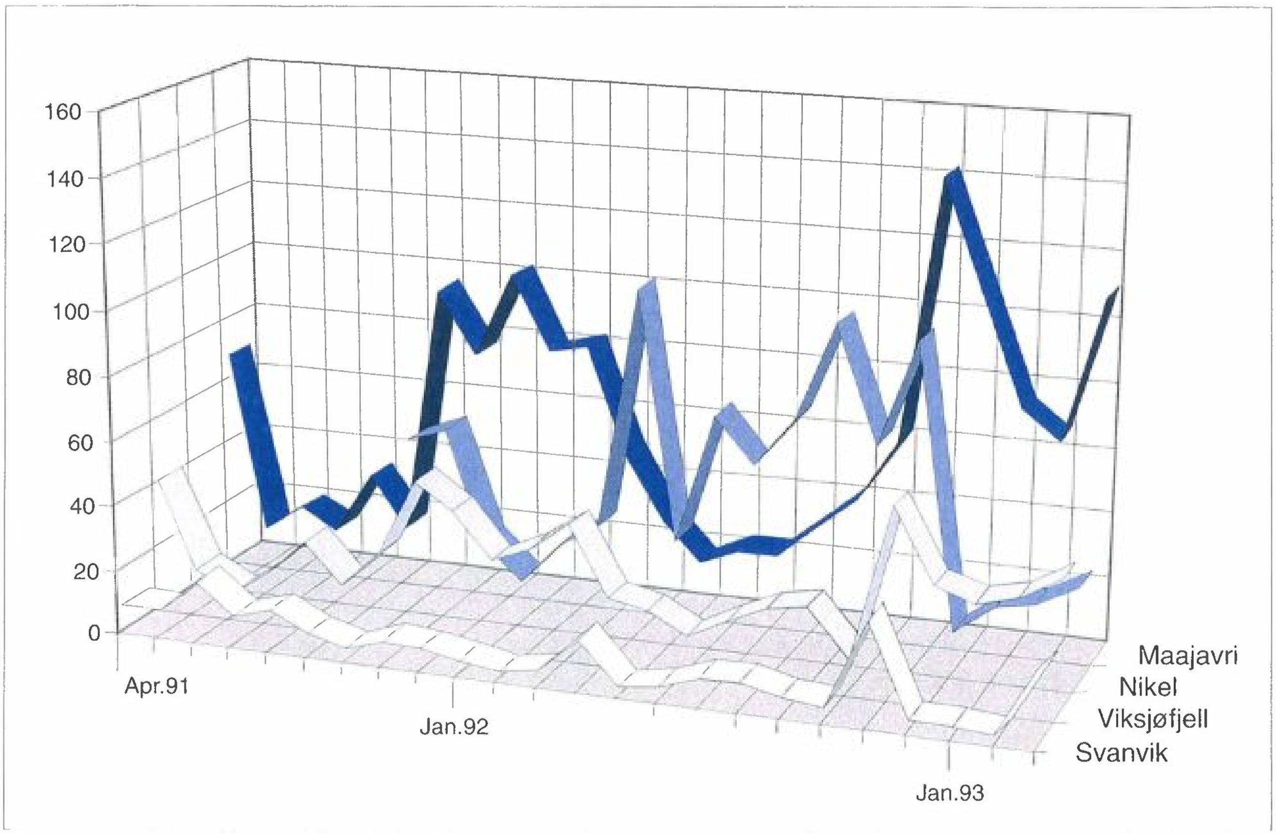

Figure 3: The monthly variation of SO_2 at Svanvik, Viksjøfjell, Nikel and Maajavri from April 1991 to March 1993 ($\mu g/m^3$).

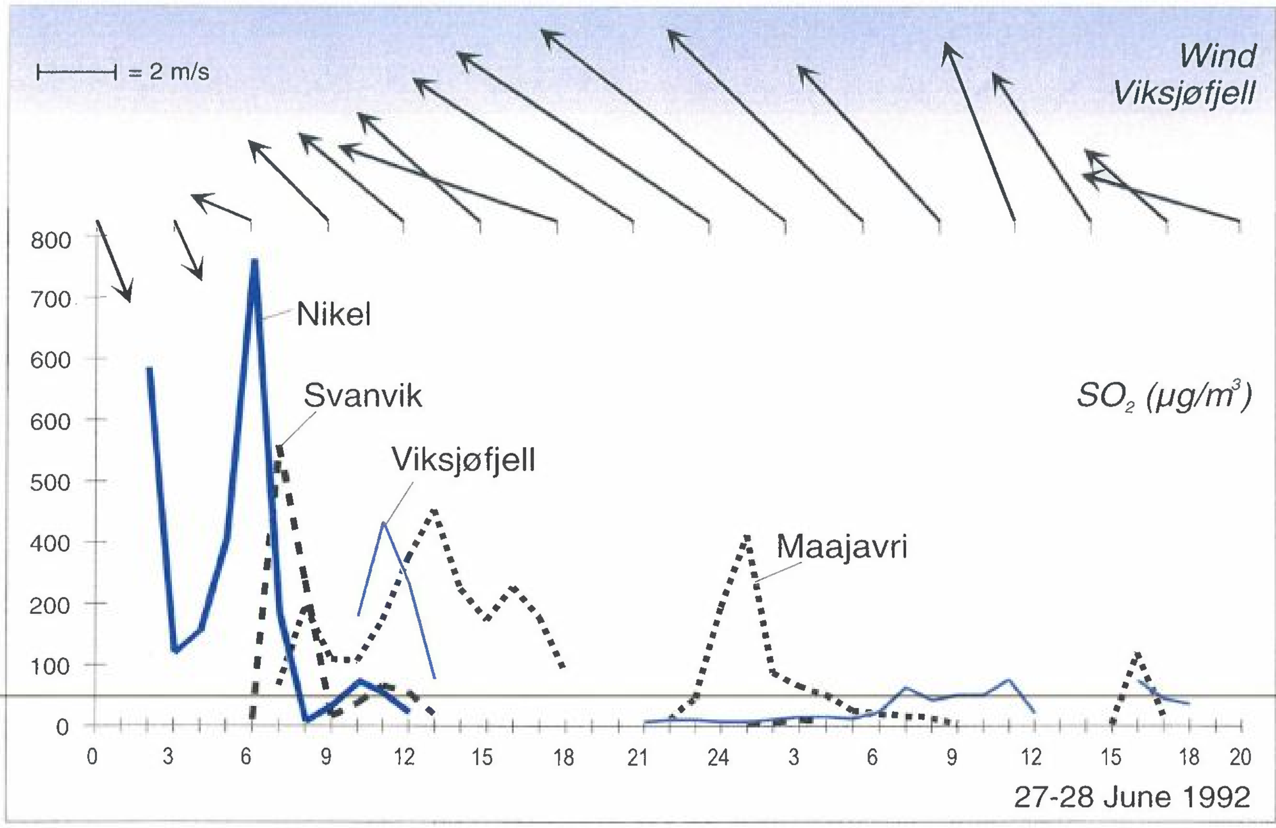

Figure 4: One hour average SO_2 concentrations at 4 sites and wind at Viksjøfjell from 0100 hrs on 27 June to 2000 hrs on 28 June 1992.

field studies and from satellite images.

SO_2 concentrations and wind observations from this episode is presented in Figure 4.

The episode started with winds from north turning east leading to high concentrations in Nikel and later in Svanvik. As the wind turned to blow from around south east the air pollutants were transported northwards towards Kirkenes, Karpdalen, Maajavri and Viksjøfjell. The highest concentrations measured at Nikel was 764 µg/m³, at Svanvik 457 µg/m³, at Viksjøfjell 333 µg/m³ and at Maajavri 311 µg/m³. The wind at Viksjøfjell indicate that the emissions from Zapoljarnij could have caused the impact at the latter two stations. This also indicate that the concentrations might have been higher in areas where we have no monitoring stations.

Table 2: Selected air pollution episodes occurring in the border areas of Norway and Russia during April 1991 to March 1993. The highest one hour average concentrations (µg/m³) and the number of hours N above 350 µg/m³ are presented.

Episodes	Nikel		Svanvik		Viksjøfjell		Maajavri	
	Max. 1 h	N	Max. 1 h	N	Max. 1 h	N	Max. 1 h	N
26-27 July 1991	-	-	729	6	1328	4	888	3
1-5 April 1992	1732	27	459	1	226	0	347	0
27-28 June 1992	764	2	457	1	333	0	311	0
13-14 Oct 1992	2783	3	72	0	667	5	1235	16
17-21 Nov 1992	1784	20	387	3	489	1	201	0
19-20 Jan 1993	8	0	0	0	999	2	1384	8

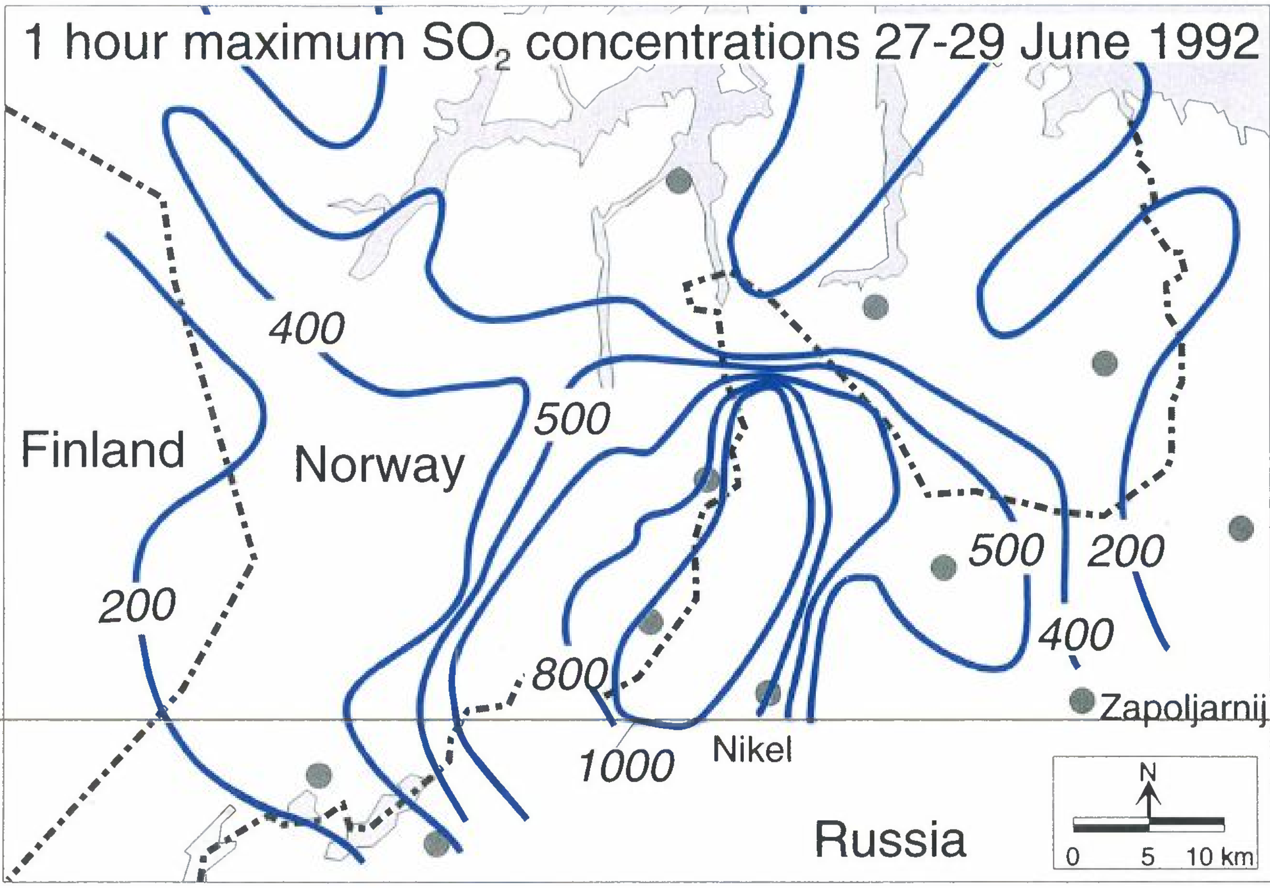

Figure 5: Model estimated 1 h maximum SO_2 concentration during the June 1992 episode (µg/m³).

Figure 5 shows the model estimated maximum 1 h average concentrations during this episode regardless when during the episode.

The one hour average maximum concentrations occurred along the border between Norway and Russia, about 3 to 8 km west of the Nikel smelter. From the wind data there are reasons to believe that this happened in the morning of 27 June just after a wind shift from northerly to weak easterly winds. An area of about 150 km^2 was impacted by SO_2 concentrations exceeding 1000 µg/m^3. On a June morning like this, it is likely that vegetation injuries have occurred.

2.3 Suspended dust

Concentrations of suspended particles in air ($PM_{2,5}$ and PM_{10}) were measured at Svanvik, Viksjøfjell and Maajavri. In addition to gravimetric measurements of concentrations, selected filters were analyzed for heavy metals. Table 3 summarizes the highest 48 h or 72 h average $PM_{2,5}$ and PM_{10} concentrations.

The highest PM_{10} concentration of 30.5 µg/m^3 was measured at Maajavri during the summer season 1992. The seasonal average of 10 µg/m^3 for the summer 1992 was also the highest value measured in the area. This is well below the Norwegian air quality criteria level of 40 µg/m^3 (SFT, 1992).

Table 3: Maximum 48 h or 72 h average concentrations (µg/m^3) of suspended particles less than 2,5 µm ($PM_{2,5}$) and 10 µm (PM_{10}) during the seasons summer 1991 to winter 1992/93 at three locations.

	$PM_{2,5}$			PM_{10}		
	Viksjøfjell	**Svanvik**	**Maajavri**	**Viksjøfjell**	**Svanvik**	**Maajavri**
Summer 1991	13.1	-	-	17.5	-	-
Winter 1991/92	8.0	19.0	23.8	12.8	20.1	28.4
Summer 1992	21.0	14.1	14.2	24.0	24.4	30.5
Winter 1992/93	10.4	18.6	20.0	15.5	22.0	24.6

2.4 Heavy metals

Concentrations of selected elements were determined for days when the highest SO_2 concentrations occurred.

Table 4 summarizes the maximum 48 h or 72 h average element concentrations during April 1992 to March 1993.

Ni and Cu concentrations are about 10 to 20 times higher in the border areas than at background stations in Southern Norway. Co, As and Cd concentrations are about 5 to 10 times higher and Zn and Cr is 1 to 2 times higher.

Most of the major elements (Fe, Ni, Cu, Mn and Co) are found in the coarse fraction (2,5 to 10 µm) while the elements Cd, Pb, Zn and As are found mainly in the fine fraction as shown in Figure 6.

2.5 Deposition

Sulphur and aerosols are removed from the atmosphere and deposited on vegetation, soil, water and snow cover by wet and dry deposition processes.

2.5.1 Wet deposition

Measurements of precipitation chemistry indicated that the pH values were lower and the sulphur concentrations higher at Karpdalen (most impacted by the Nikel smelter) than at Svanvik and Noatun. This indicate that the aerosols and particles from the smelter are alkaline and

Table 4: Yearly mean values and max. 48 h or 72 h mean values of heavy metals, April 1992 to March 1993 (ng/m³). The values are compared with the 1985/86 analyses at the background station Birkenes in Southern Norway.

Station	Viksjøfjell		Svanvik		Maajavri		Birkenes	
Element	Yearly mean value	Max value	Yearly mean value	Max value	Yearly mean value	Max value	Yearly mean value	Max value
V	0,9	15,7	0,8	15,6	2,8	24,8	1,9	13,0
Cr	(-)	8,5	(-)	4,4	1,3	13,5	0,7	5,2
Mn	0,6	4,8	0,9	2,5	1,8	6,7	4,6	24,0
Fe	72,1	670,3	70,2	331,7	198,7	938,3	61,0	618,0
Co	0,4	8,8	0,2	3,7	1,1	4,0	0,1	0,6
Ni	9,0	149,0	4,8	76,8	26,6	98,8	1,1	7,4
Cu	7,4	136,1	4,2	63,2	20,9	123,2	1,6	10,0
Zn	2,4	30,9	1,7	21,7	7,3	53,9	15,0	114,0
As	1,3	17,6	0,8	17,6	4,5	40,8	0,6	4,6
Cd	0,09	1,2	(-)	1,2	0,4	6,0	0,1	1,2
Pb	1,1	15,8	1,2	10,8	3,6	33,6	11,0	106,0

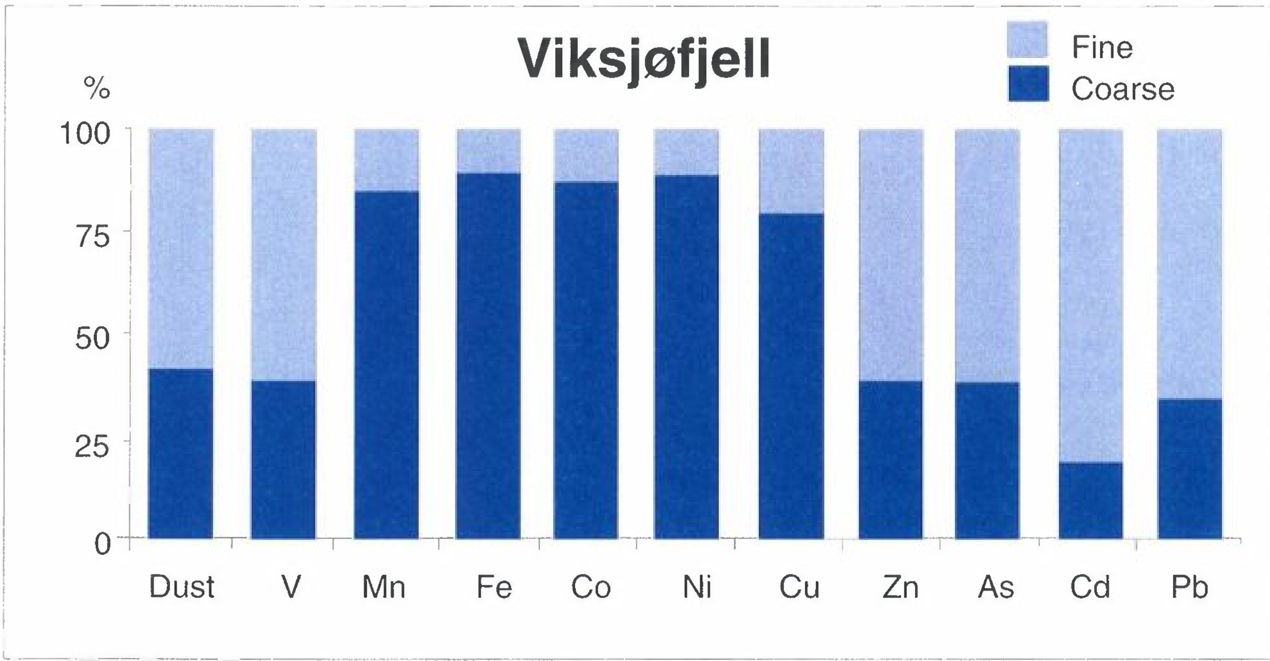

Figure 6: Distribution of elements in fine (<2.5 µm) and coarse fraction (2.5-10 µm) and suspended dust at Viksjøfjell (1992-93). A similar pattern can be seen at Maajavri and Svanvik.

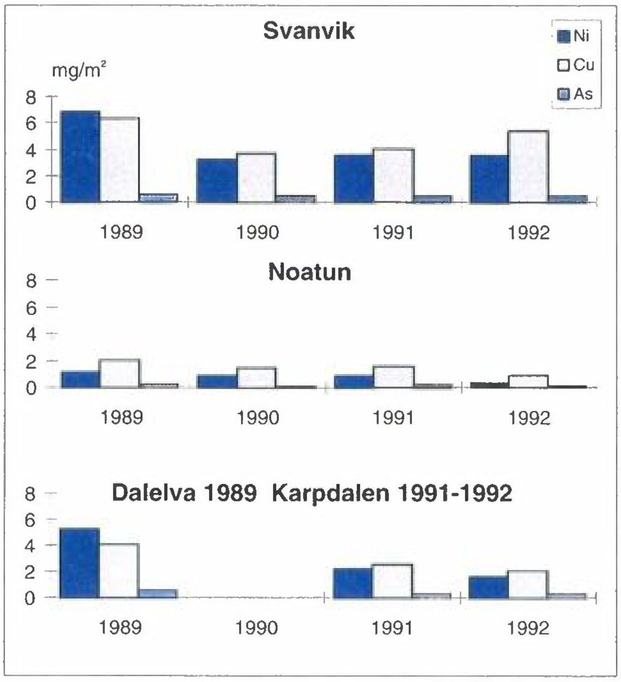

Figure 7: Total annual wet deposition of Ni, Cu and As in Svanvik, Noatun and Karpdalen (1989-1992).

neutralize the acid sulphur deposition. This is confirmed by the snow pack analyses.

The total annual wet deposition of Ni, Cu and As is shown in Figure 7.

The wet deposition of Ni, Cu and As has not changed significantly from 1989 to 1992. The Cu deposition in Svanvik was slightly higher in 1992 than in 1990.

2.5.2 Dry and total deposition

Earlier estimates have indicated that about 80% of the total sulphur deposition is dry.
The total annual sulphur deposition along the border between Norway and Russia should thus be about 2 g S/m^2 (Svanvik).

About 50% of the total element deposition can be referred to as dry deposition, which indicate a total annual Ni-deposition in Svanvik of about 10 mg/m^2.

3. Trends

The total annual sulphur emissions at the Nikel smelter have been reduced during the last ten years from 310 000 tonnes in 1980 to about 180 000 tonnes in 1992. This has also caused a reduction in the annual average SO_2 concentrations as shown in Figure 8. The emissions in Zapoljarnij are about 80 000 tonnes and have changed very little during the period 1980-1992.

The air pollution episodes with very high SO_2 concentrations which is the main problem in the area, are dependent upon specific meteorological conditions. These situations still have SO_2 levels of nearly ten times the WHO air quality guideline values, and it is difficult to see any clear trends or reductions in the episode concentration levels.

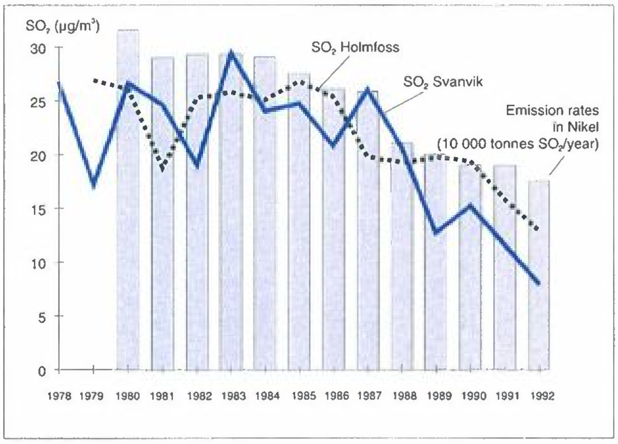

Figure 8: SO_2 emission rates (tonnes/year) and annual average SO_2 concentrations in Svanvik and Holmfoss (1978-1992) ($\mu g/m^3$).

4. Air pollution impact

The terrestrial expert group within the bilateral co-operation has presented different impact zones in the border areas, based upon satellite observations (Tømmervik et al., 1993). Figure 9 shows classified damages to the surface vegetation.

The estimated isoline for annual average SO_2 concentration of 10 $\mu g/m^3$ (1990) is shown.

Zone 1, 2 and 3 covers an area of 1270 km^2 in Norway and 3433 km^2 in Russia. The damage

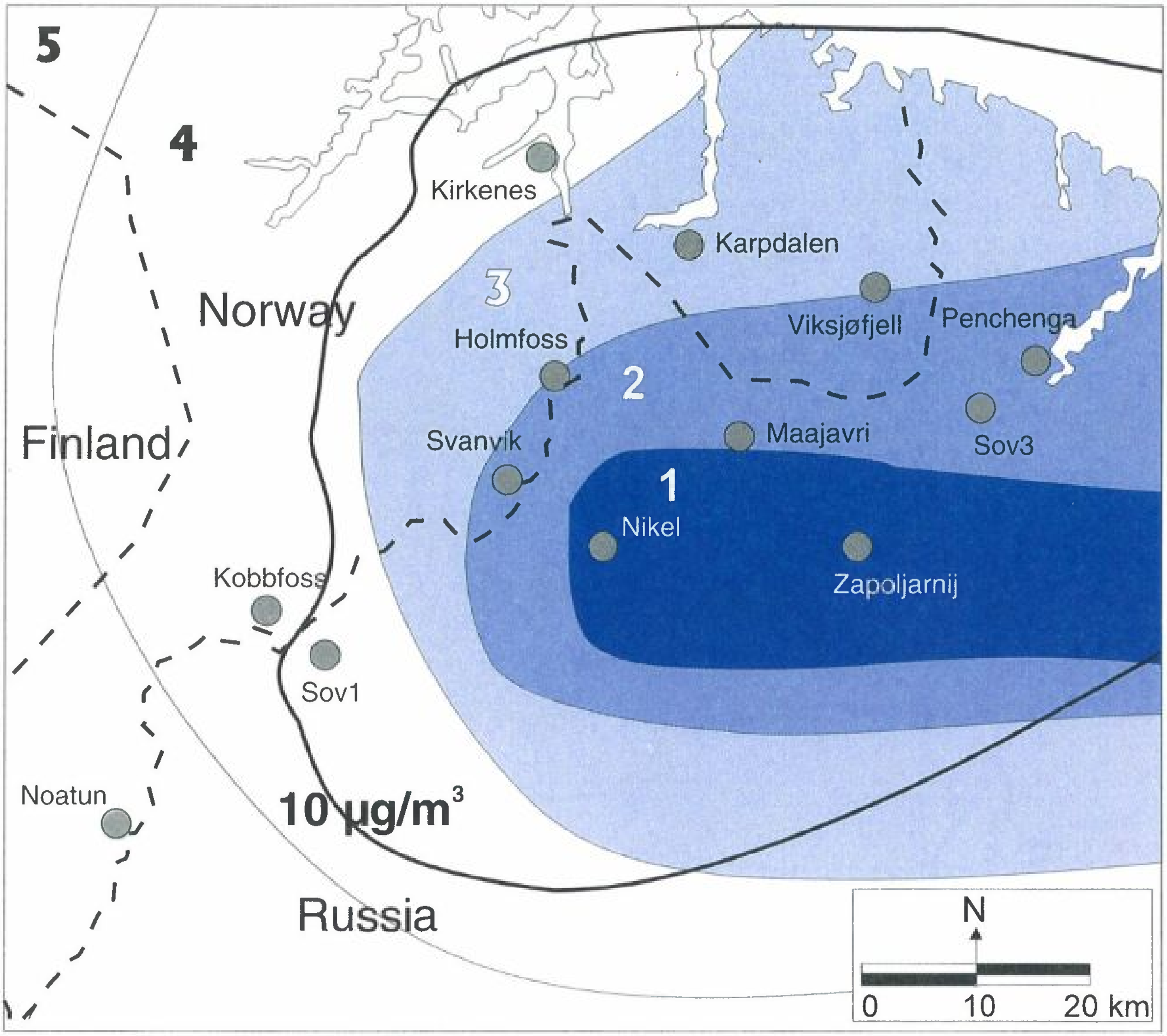

Figure 9: Different damage zones in the border areas of Norway and Russia.

Zone 1: Vegetation damage
Zone 2: Large injuries
Zone 3: Average injuries
Zone 4: Slightly injured
Zone 5: Small or no injuries

and injury areas 1, 2 and 3 coincide with the measured and estimated annual average SO_2 concentration level of about 10 µg/m^3.

The annual deposition of sulphur has also been compared to the critical load values for fresh water systems in the border areas in Figure 10.

Most of the Kola peninsula is sensitive to freshwater acidification. However, in the border areas, some regions have basic and ultrabasic rocks with sufficient buffer capacity thus rendering them less sensitive to acidification. This is also the case in the middle part of Pasvik. From the nickel smelters there are also emissions of basic dust which reduces the acidification. In spite of these facts, Figure 10 shows that there is a correlation between exceedance of critical loads and sulphur deposition caused by emissions from the smelters.

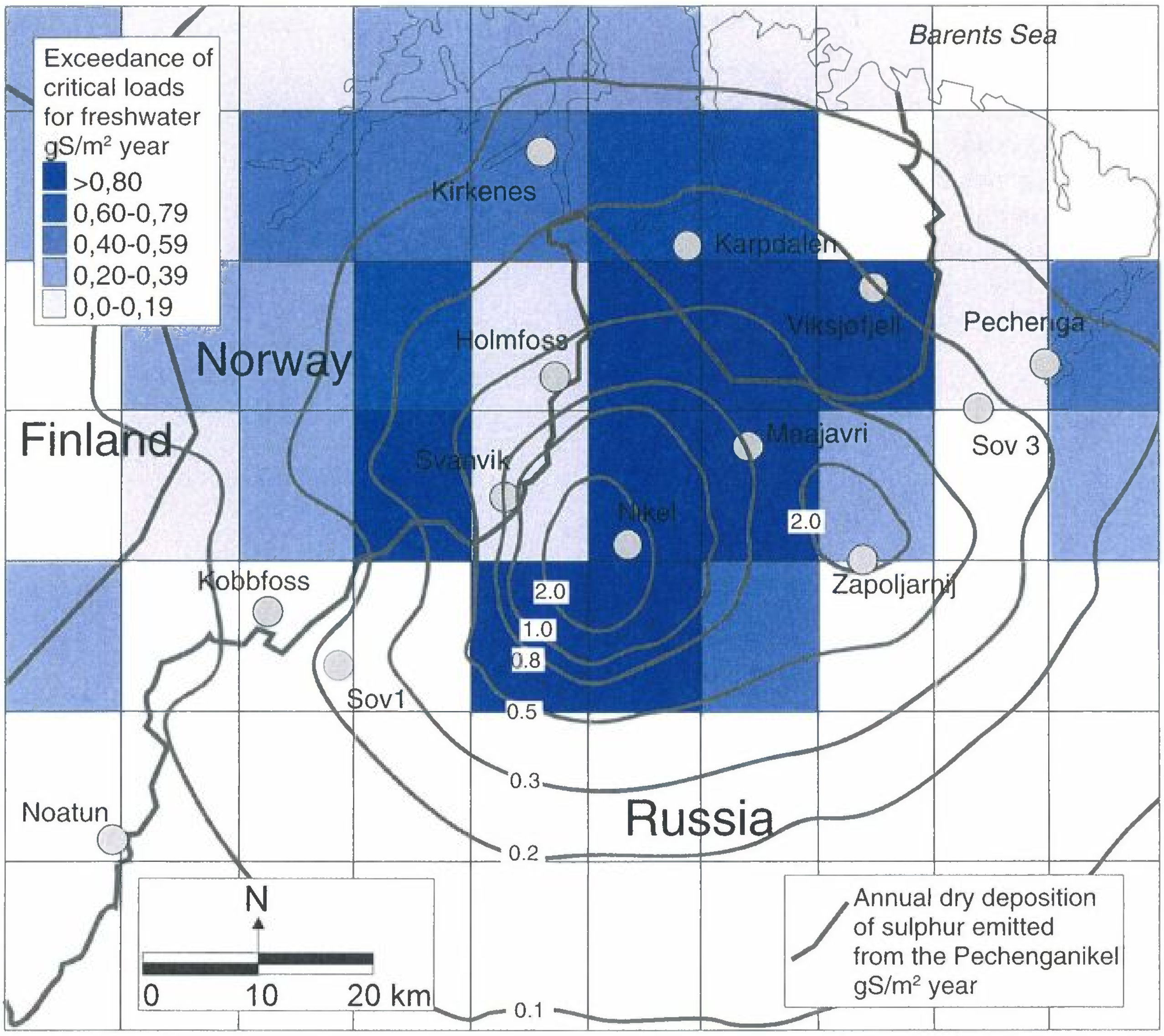

Figure 10: Exceedance of critical loads for freshwater compared to the deposition rate g S/m2) of sulphur emitted from the smelters in the border areas.

5. Model estimates

Information about the emission rates at the different sources in the area and meteorological dispersion conditions have been used to establish air quality models. Estimates have been performed for monthly, seasonal and annual SO_2 concentrations.

Figure 11 shows the annual average SO_2 concentration distribution for 1992.

During 1992 an area of about 1200 km^2 had SO_2 concentrations exceeding 25 $\mu g/m^3$ as an annual average, out of which 2-300 km^2 was on the Norwegian side of the border. About 4800 km^2 experienced a 1992 average concentration in excess of 10 $\mu g/m^3$.

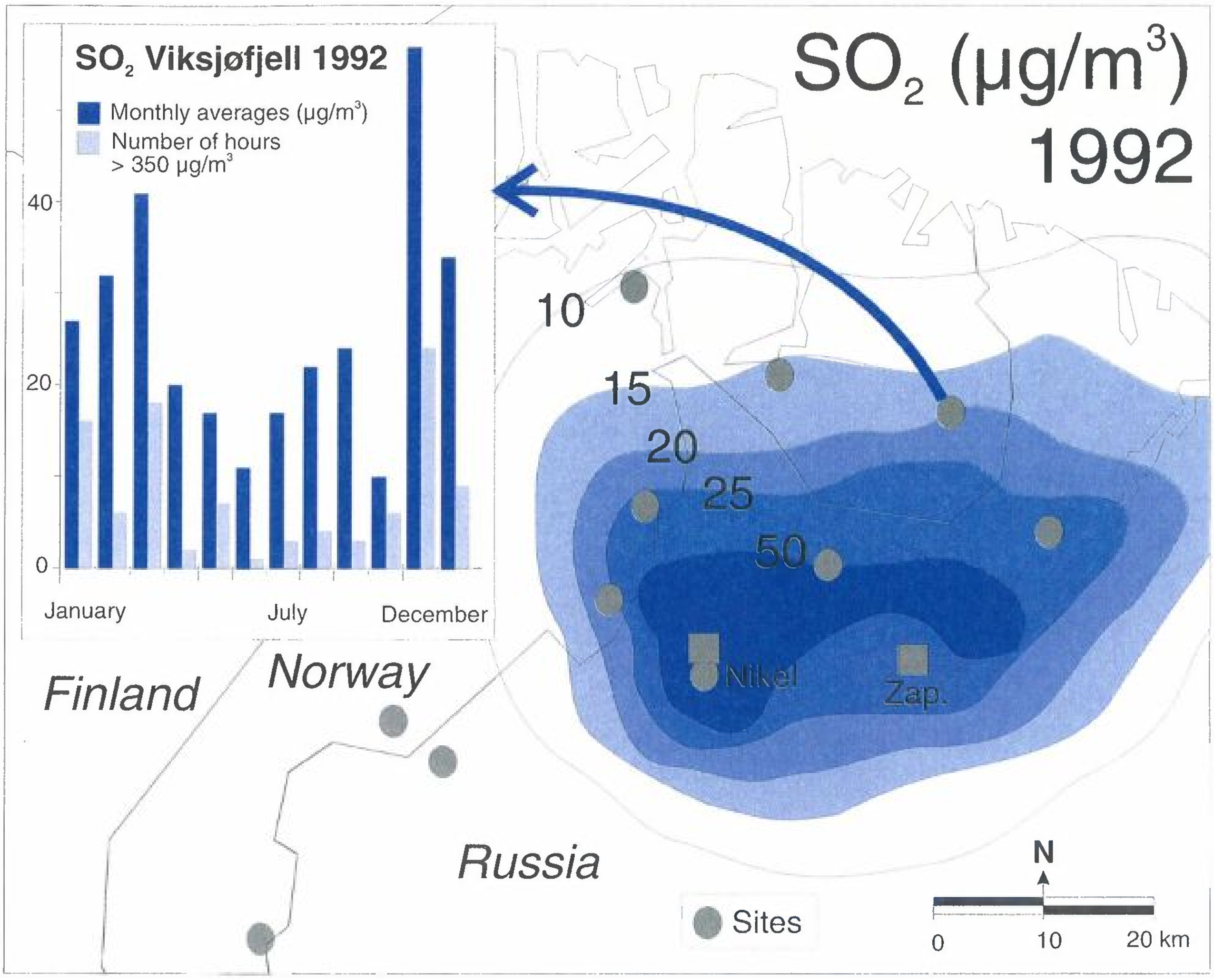

Figure 11: The model estimate of annual average SO_2 concentration distribution for 1992.

6. Discussion and conclusions

The work within the expert group has shown that:

- Very high SO_2 concentrations might occur during episodes,
- the annual average SO_2 concentrations have decreased since 1980,
- concentrations of Ni and Cu are about 10 to 20 times higher in the border areas than in Southern Norway,
- sulphur deposition rates due to emissions from the Pechenganikel smelters are well correlated to vegetation injuries and exceedance of critical loads,
- model estimates indicate that an area of about 1200 km^2 had SO_2 concentrations exceeding 25 $\mu g/m^3$ as an annual average.

The future work will improve the knowledge about air quality impact and various effects on man, nature and materials. A permanent monitoring and surveillance programme will be established to follow the developments and possible reconstructions at the Pechenganikel smelters.

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