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Air Pollution Problems in the Northern Region of Fennoscandia included Kola

Proceedings from the Seminar at Svanvik, Norway, 1-3 June 1993

Edited by:
Bjarne Sivertsen

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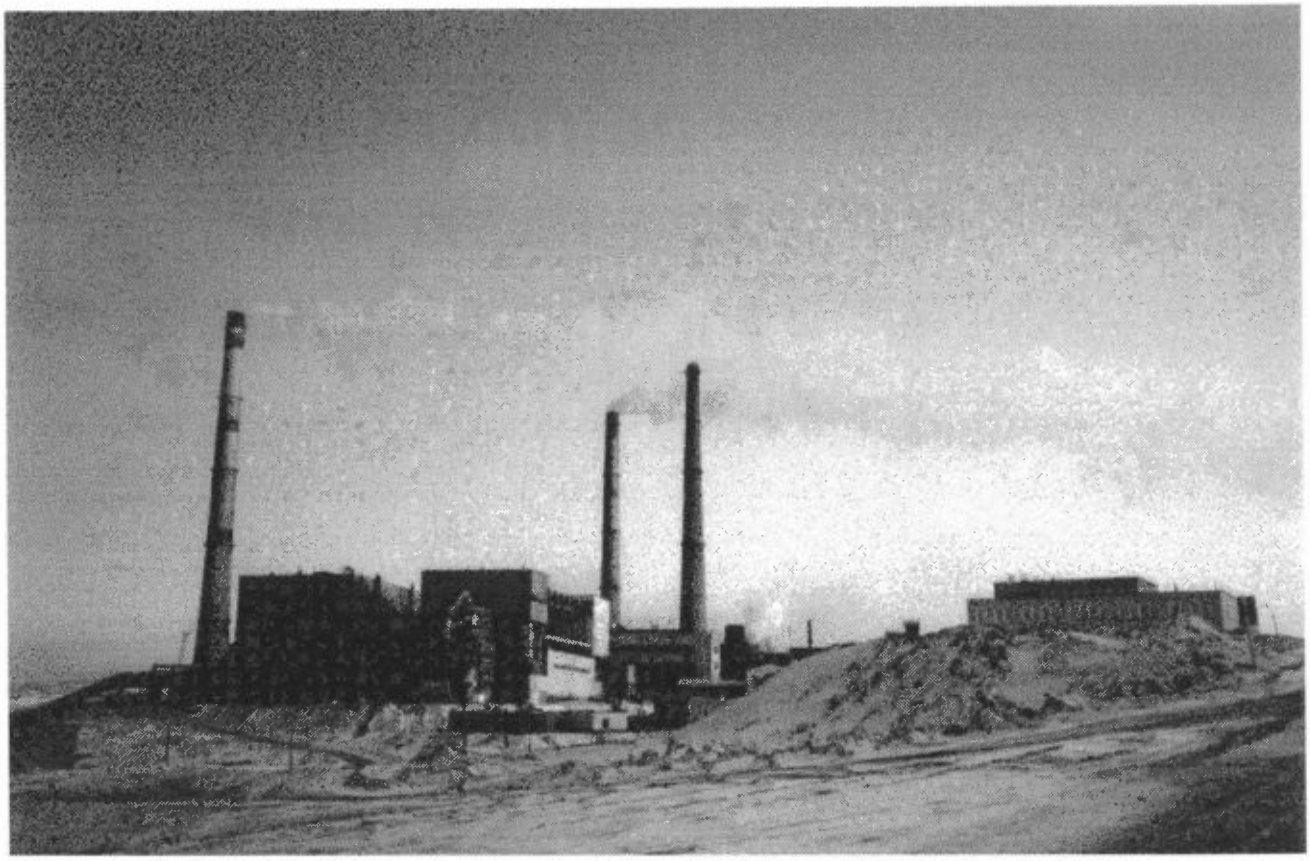

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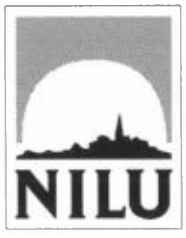

Norwegian Institute for Air Research
Norsk institutt for luftforskning

Instituttveien 18, P.O. Box 100, N-2007 Kjeller
Telephone: 63 89 80 00
Telefax: 63 89 80 50
Telex: 74 854 nilu n

Contents

Summary

This seminar has proven a valuable exchange of information between three of the expert groups within the bilateral co-operation on environmental issues between Norway and Russia. several important aspects have been discussed, and I feel that the papers and presentations have given a sound state of the art regarding the air pollution issues.

In brief I would like to make the following short statements as a conclusion from the seminar:

- Emissions 785.000 tonnes/y: SO_2, PM, NOx ....
- Emissions should be reduced to 30.000 tonnes?
- Monitoring on Russian side: Nikel, Montchegorsk, Hibiri, Kislaya $\rightarrow$ SO_2 > 400 µg/m^3.
- Area with annual SO_2 > 25 µg/m^3 ~ 2000 km^2.
- Episode concentration 1992 > 1000 µg/m^3 - no significant reduction!
- Sevettijärvi, Finland SO^2 max > 500 µg/m^3 - easterly wind SO_2 average: ~ 30 µg/m^3.
- Model estimates being improved/with observations.
- Nickel deposition in snow, strong gradients, Nikel: 193 mg/m^2.
- Radioactivity consequences: Local monitor and model - Finnmark, Norway modelling.
- Total damage area increased from 55 to 415 km^2 (1973-88).
- Critical load is exceed in ~ 7000 km^2 - severly exceeded in ~ 1000 km^2.
- Emission reduction of 70% will reduce areas in Norway e.a. Cl from 70% to ~10%.
- Surface water at Kola sensitive to acidity (buffer decr.)
- High nickel concentrations within 30 km from Nikel and Montchegorsk.
- Good correlation: Model estimates/vegetation damage.
- Damage area ~5000 km^2.
- Strong gradients in heavy metal concentrations in vegetation/animals.
- Highest enrichment factor F for Ni, Cu, Cr, Co.
- Increase crown density (Nesector) 78-81% (1988-92)
- Good correlation: occur of lichens/SO_2 concentrations.
- Vitality of birch less than in the rest of Norway.
- Decrease lichens in an area of ~3.000 km^3.

Bjarne Sivertsen
Norwegian Institute for Air Research

Air Pollution Problems in the Northern Region of Fennoscandia included Kola

Proceedings from the Seminar at Svanvik, Norway, 1-3 June 1993

1. Introduction

On January 15, 1988, a joint agreement on co-operation on environmental problems was signed by the governments of Norway and the former Soviet-Union. The objective of the agreement was to jointly solve environmental problems. The co-operation should include joint investigations on the effects of pollution and realisation of proper measures in order to reduce the pollution burden in the area.

The first meeting of the joint Commission on Environmental Co-operation was held in Oslo in August 1988. The Soviet delegation was headed by Mr. Valentin G. Sokolovskij from Goskompriroda and Mr. Oddmund Graham from the Ministry of Environment was the head of the Norwegian delegation. Several expert groups have been established under the Joint Commission, these are the expert group on:

- Local air pollution
- Modelling of transboundary air pollution
- Effects on the terrestrial ecosystem
- Effects on the aquatic ecosystem
- Oil pollution in the Bbarents Sea
- Seabirds
- Salmon
- Health effect

The bilateral agreement was revised during 1992 and is today signed between Russia and Norway. The expert group on studies of local air pollution problems planned the seminar on air pollution problems in the Northern region of Fennoscandia. The final programme was established during the 6th meeting of the expert group in Apatiti in March 1993. the following members of the group were responsible for the programme:

From Russia:	Mr. Alexander Baklanov, INEP, Kola Science Centre
	Mrs. Tatjana Makarova, INEP, Kola Science centre
	Mr. Evgeny Olesik, Murmansk Oblkompriroda
	Mr. Alexei Namjatov, Murmansk Hydromet
FromNorway:	Mr. Bjarne Sivertsen, NILU
	Mr. Leif Otto Hagen, NILU
	Mr. Per-E. Fiskebeck, Fylkesmannen i Finnmark
	Mr. Tor Johannessen, SFT

2. Lectures

2.1. Environmental problems in the Murmansk region

Evgenij Olesik
Murmansk Oblkompriroda

Summary

The Murmansk Region is rich on animals and nature, and we feel on the Russian side that we have something to fight for. The interest among the population of the environmental issues has been increasing during the last few years.

The Murmansk Environmental Committee (Oblkompriroda) is divided into twelve subgroups. Practically all the enterprises at Kola Peninsula are being controlled by the Environmental Committee. When the pollution is too high compared to the standards, the industries are being punished economically. There is about 6.000 air pollution sources in the region. Half of them have installed cleaning equipment.

The total emissions of pollutants in the region are about 750.000 tonnes/year. The main components are SO_2: 516.00 tonnes/year, CO: 111.000 tonnes/year, NOx: 35.000 tonnes/year. It seems like the emissions during 1992 will be reduced by 16.000 tonnes/year. This is happening in spite of the fact that old cleaning equipment seem to be reduced in quality.

The main air pollution sources in the Murmansk region is the Norilsk Nickel Plants. The emissions from the Nickel smelters is about 180.000 tonnes SO_2/year. It is desirable to reduce these emissions to about 30.000 tonnes/year. Other sources in the area include energy production (11%), production of apatit (2,4%), military operations (4%).

The general economical situation in Russia is bad today. There are problems in implementing the requirements and the goals for reduction of air pollutants. On the other hand there is an increase in interest among people for environmental issues, which we hope will bring another situation to the northern regions and to the Murmansk region in particular.

2.2. Air Quality Status in the Border Areas of Norway and Russia

B. Sivertsen, L.O. Hagen, M.J. Aarnes
Norwegian Institute for Air Research,
P.O. Box 64, N-2001 Lillestrøm, Norway

2.2.1. Introduction

The Norwegian Institute for Air Research (NILU) has been measuring air pollutants close to the border between Norway and Russia since 1974. The work at present is carried out as a part of the bilateral agreement on the environment between Norway and Russia. NILU is undertaking the studies on behalf of the Norwegian State Pollution Control Authority (SFT). It includes comprehensive investigations of air quality, precipitation chemistry, atmospheric corrosion and various environmental impacts starting from October 1988.

2.2.2. Monitoring programme

During 1992 air quality data were collected at 5 locations, precipitation chemistry at 3 locations and meteorological parameters at 4 locations on the Norwegian side of the border. On the Russian side air quality was measured at 4 locations, precipitation chemistry at 3 locations and meteorological parameters also at 3 locations (see Figure 1)..

SO_2 has been measured continuously at Viksjøfjell, Svanvik, SOV 1, Maajavri, SOV 3 and Nikel, while diurnal samples are collected at Kirkenes, Karpdalen, Holmfoss and Svanvik. Continuous measurements of SO_2 are necessary to register the high short term peak concentrations during episodes. A typical feature of SO_2 concentrations at the monitoring stations is represented by low long term average concentrations whereas the peak values (24 hour averages or shorter) are well above air quality guidelines.

From 1990 the joint programme for studying air quality and precipitation chemistry was carried out at three sites on each side of the Norwegian-Russian border. The Norwegian measuring sites were Viksjøfjell, Karpdalen and Svanvik. The measurements on the Russian side of the border were started in January/February 1990. SO_2 data for the whole period have been exchanged between the two countries.

After discussions with the Pechenganikel Combinate and the Murmansk Hydromet a new SO_2 monitoring station was established inside the town of Nikel in September 1991. Also in September 1991 measurements of wind and suspended particles were started at Maajavri, while the measurement programme on the Norwegian side was reduced. From June 1992 the measurements at SOV 3 stopped, and in December 1992 also the SOV 1 station was stopped.

2.2.3. Summary of results, summer 1992

During the summer season 1992 (April-September) the general SO_2 concentrations at the Norwegian monitoring stations were at the same level as in earlier summer seasons.

Table 1: Summary of measurement results. SO_2 concentrations during the summer season 1992 (µg/m³)

Site	Month	Monthly average	Max. 24 h average	No. days-obs.	No. days >50	No. days >90	No. days >300	Max 1 h average	No. hours obs.	No. hours >100	No. hours >350	No. hours >700	No. hours >1000
Viksjøfjell	April 1992	20	77	30	4	0	0	377	684	30	2	0	0
	May	17	125	31	3	2	0	901	706	29	7	2	0
	June	11	62	30	1	0	0	459	684	25	1	0	0
	July	17	108	31	2	1	0	910	707	33	3	1	0
	August	22	100	31	3	2	0	1 027	708	46	4	2	1
	Sept.	24	132	30	4	2	0	457	686	46	3	0	0
	Apr.-Sept.	19	132	183	17	7	0	1 027	4 175	209	20	5	1
Svanvik	Apr. 1992	15	143	30	3	1	0	523	683	34	4	0	0
	May	2	17	31	0	0	0	84	702	0	0	0	0
	June	4	20	30	0	0	0	457	681	5	1	0	0
	July	8	130	31	2	1	0	615	700	15	3	0	0
	August	8	56	31	1	0	0	242	702	18	0	0	0
	Sept.	5	42	30	0	0	0	134	680	6	0	0	0
	Apr.-Sept.	7,0	143	183	6	2	0	615	4 148	78	8	0	0
SOV 1	April 1992	19	96	29	4	1	0	315	661	45	0	0	0
	May	2	17	31	0	0	0	146	702	2	0	0	0
	June	5	20	7	0	0	0	186	130	1	0	0	0
	July	4	59	31	1	0	0	549	685	6	1	0	0
	August	13	107	23	2	1	0	309	508	24	0	0	0
	Sept.	8	73	30	2	0	0	424	686	16	1	0	0
	Apr.-Sept.	8,7	107	151	9	2	0	549	3 372	94	2	0	0
Maajavri (SOV 2)	April 1992	29	350	30	4	1	1	2 610	657	37	11	5	3
	May	17	134	31	3	2	0	705	702	40	6	1	0
	June	22	128	30	4	2	0	584	664	50	7	0	0
	July	22	105	31	6	1	0	1 113	698	44	10	1	1
	August	32	182	22	4	2	0	1 286	483	47	12	4	1
	Sept.	42	313	30	7	3	1	1 324	684	75	19	3	2
	Apr.-Sept.	27	350	174	28	11	2	2 610	3 888	293	65	14	7
SOV 3	April 1992	15	89	30	2	0	0	515	688	21	4	0	0
	May	12	59	31	2	0	0	564	706	26	2	0	0
	June	9	25	11	0	0	0	271	254	5	0	0	0
	July												
	August												
	Sept.												
	Apr.-Sept.	13	89	72	4	0	0	564	1 648	52	6	0	0
Nikel	April 1992	107	626	30	11	10	4	1 811	683	163	75	29	16
	May	31	219	31	6	5	0	1 373	710	48	19	8	4
	June	71	469	28	9	9	2	1 868	615	79	36	19	9
	July	57	391	30	9	5	2	2 052	667	59	32	16	8
	August	72	350	29	10	7	3	1 778	660	95	40	15	9
	Sept.	102	727	30	8	8	3	2 634	674	109	56	34	17
	Apr.-Sept.	73	727	178	53	44	14	2 634	4 009	553	258	121	63

The short term average concentrations were far above the Norwegian and international guideline values. At Viksjøfjell, where the highest values were most often measured at the Norwegian side, the average value during the monitoring period was 19 µg/m³, the highest 24-hour average was 132 µg/m³, and the highest 1-hour

average value was 1 027 µg/m3. The guidelines for protection of human health are 40 µg/m3 (Norway), 90 µg/m3 (Norway) and 350 µg/m3 (World Health Organization- WHO), respectively. The guidelines for protection of vegetation are even lower. At Maajavri and Nikel the average concentrations, the highest daily average value and the frequency of 1-hour average values above 350 µg/m3 are usually higher than at the Norwegian stations.

The measurements show that SO_2 concentrations increase from southwest towards northeast in Sør-Varanger and that they are even higher on the Russian side of the border.

Measurements of suspended particles at Viksjøfjell, Svanvik and Maajavri show concentrations well below the guideline values suggested in Norway and by WHO.

2.2.4. Continuous records July 1992

An example of a continuous one hour average record of SO_2 concentrations at three monitoring stations in the area is shown in Figure 2 for July 1992. The records show as in earlier periods that very high SO_2 concentration levels occurs occationally. At Viksjøfjell there are two cases of concentrations higher than 350 µg/m3. At Svanvik there was only one case, and at Nikel there was at least twelve cases, some of them lasting for hours. The highest one-hour average concentration in Nikel exceeded occationally 2 000 µg/m3. This indicate that the air quality conditions in the city of Nikel might in some periods during the summer season be even worse than expected.

The episodes on 26 July 1992 indicate that there has been winds from the north resulting in short term concentrations in Nikel well above 1.000 µg/m3. This wind is turning to become wind from east, and at Svanvik later in the afternoon we had a maximum one-hour concentration exceeding 600 µg/m3.

2.2.5. SO_2 concentration versus wind direction

Figure 3 shows the average SO_2 concentration as a function of wind directions during the summer season of 1992. By looking at the lower part of the figure this illustrates clearly that the monitoring station in Nikel is impacted by air pollution sources north and northeast of the station. It is no doubt that these sources are the Nikel smelter. When it is blowing from the smelter area towards the city, average concentrations during the whole summer season are as high as about 400-800 µg/m3. At Maajavri we see an impact of SO_2 from two different wind directions. One indicates when it is blowing from the Nikel smelter towards the monitoring site, the second one when it is blowing from Zapoljarnij towards the monitoring site. The average concentrations with winds from the Nikel smelter are around 300 µg/m3. At Viksjøfjell we also see two maximum wind directions. During cases with winds from the smelters in Nikel and Zapoljarnij the average SO_2 at these sites are about 150 µg/m3.

All the monitoring sites show a clear wind dependency on the SO_2 concentration distributions, which indicates that at all stations the major sources for SO_2 are the smelters in Nikel and Zapoljarnij.

2.2.6. An air pollution summer episode

Air pollution episodes linked to certain large scale meteorological conditions occur both in the summer and winter time. We have earlier described winter episodes (Hagen and Sivertsen, 1992). Figure 4 shows one example of a summer episode occurring from 27 to 28 June 1992. We see that this episode starts with winds from the north which results in very high concentrations in the city of Nikel. In the early morning of 27 June the concentrations are between 700-800 µg/m^3. At the same time the wind shifts from northerly to easterly and the air pollution plume hits the Svanvik area with concentrations of more than 400 µg/m^3. As the wind turns further to the southeast and south also Maajavri and Viksjøfjell were affected by SO_2 concentrations ranging from 200-300 µg/m^3 as one hour averages. The wind speed during this period was at Viksjøfjell ranging from 2-4 m/s and at Svanvik the wind was about 1 m/s. We also see that the wind at Svanvik is much more varying and changing direction than the wind at Viksjøfjell. This June 1992 episode occurred when a small high pressure ridge touched into the eastern part of the Kola peninsula, while a deep low pressure moved into the Nowegian Sea from the west. This resulted in the turning of wind directions from north via east to southeast and south. The synoptic situation is classical for most of the air pollution episodes that have been recorded in this region.

2.2.7. Summary of 1992 results

A summary of the one hour average SO_2 concentrations measured at all stations during the summer season (April-September 1992) is shown in Figure 5. The highest one hour average concentrations were measured in Nikel at 2634 µg/m^3. Maajavri had 2610 µg/m^3 as the highest one hour average SO_2 concentration during the summer season 1992. Also at Viksjøfjell the one hour average SO_2 concentration exceeded 1000 µg/m^3.

The percentage of hours exceeding 350 µg/m^3 ranged from 6,4% in Nikel through 1,6% at Maajavri, 0,5% at Viksjøfjell down to 0,2% in Svanvik. This means that even in Svanvik we had eight hours exceeding the WHO air quality standard. At Viksjøfjell we had twenty hours exceeding the WHO standard and in Nikel we had as much as 258 hours during which the WHO air quality standard was exceeded during the summer season 1992.

The average concentration distribution for the whole year of 1992 has been estimated by using a long term Gaussian type air quality model. The result of these estimates is shown in Figure 6. The result of these estimates indicate that an area of more than 4000 km^2 was covered by annual average concentrations

exceeding 10 µg/m³. On Norwegian territory about 10-20 km² are covered by average concentrations of more than 25 µg/m³.

The measured monthly average concentrations at Viksjøfjell is also shown in Figure 6. The monthly average concentrations ranged from the lowest value of 11 µg/m³ in June 1992 to 54 µg/m³ in November 1992. The exceedance of 350 µg/m³ varies from one hour in June 1992 to 20 hours during November 1992.

2.2.8. Precipitation chemistry

Measurements of precipitation chemistry indicated that the pH-value in precipitation were lower in Karpdalen than in Svanvik and Noatun. Concentrations of Pb, Cd and Zn during the summer 1992 were at the same level as the concentrations usually found at background stations in the south-eastern part of Norway, but higher than in the western and northern part of the country.

Table 2: Wet deposition (mg/m²)

	Summer 1991		Summer 1992		Background
	Karpdalen	Svanvik	Karpdalen	Svanvik	South Norway
SO_4	1090	480	1230	630	
NO_3	160	95	270	160	
Ni	1,6	2,8	1,3	2,9	0,2
Zn	1,3	0,87	1,5	0,97	0,6
Cu	1,6	2,4	1,5	4,2	0,2
As	0,13	0,27	0,24	0,40	0,006
Pb	0,31	0,29	0,54	0,35	0,2

Annual total deposition (1991): Svanvik : 880 mg/m² SO_4-S
Birkenes : 1100 mg/m² SO_4-S

Wet deposition of Ni, Cu and As were at the same level in 1992 as in 1991, and higher than in the rest of Norway. Ni and Cu deposition at Svanvik were about ten times the amount in background areas of Southern Norway.

2.2.9. Conclusions and future plans

From the last year of measurements there is no sign of a considerable reduction of the emissions at the Nikel Combinate smelters. The total area of impact exceeding the proposed air quality guideline values are still in the order of 1000 to 2000 km². The highest short term episode concentrations are still 5 to 10 times above WHO guideline values.

To further study the exceedings of critical levels and critical loads, the meteorological air quality- and precipitation chemistry data will be used to evaluate monthly, seasonal and annual average impact (concentrations and depositions) of sulphur compounds and of nickel and copper.

We will also look in more details into selected episodes, and try to estimate the highest 1 hr. average (and if possible 24h average) SO_2 concentrations in selected receptor points in the whole area. The receptor points will be discussed with the terrestrial expert group.

2.2.10. References

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Figure 1: Map of the monitoring stations in the border areas of Norway and Russia

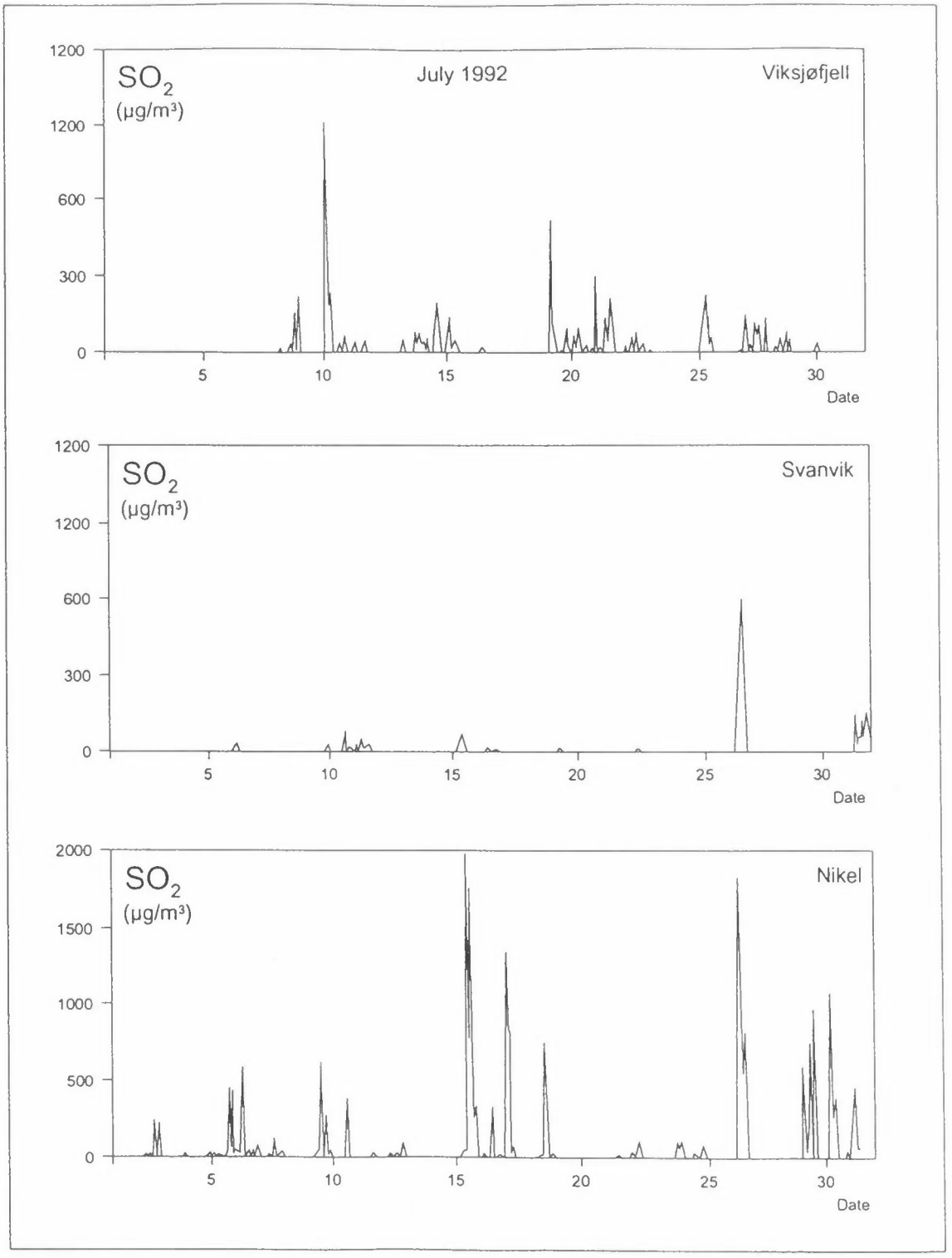


Figure 2: Continuous records of 1 hour average SO_2 concentrations

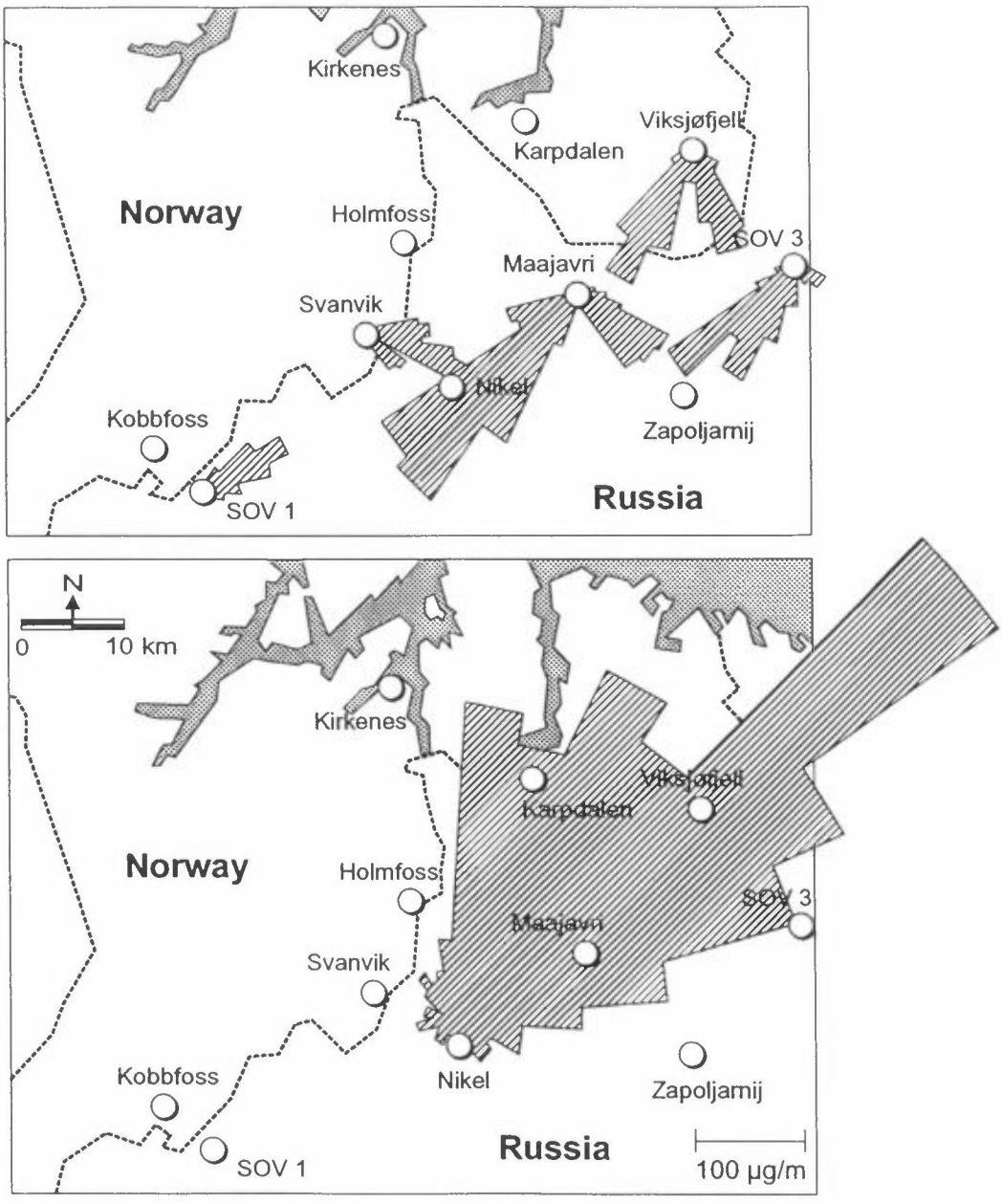


Figure 3: Average SO_2 concentrations ($\mu g/m^3$) as a function of wind directions (April-September 1992).

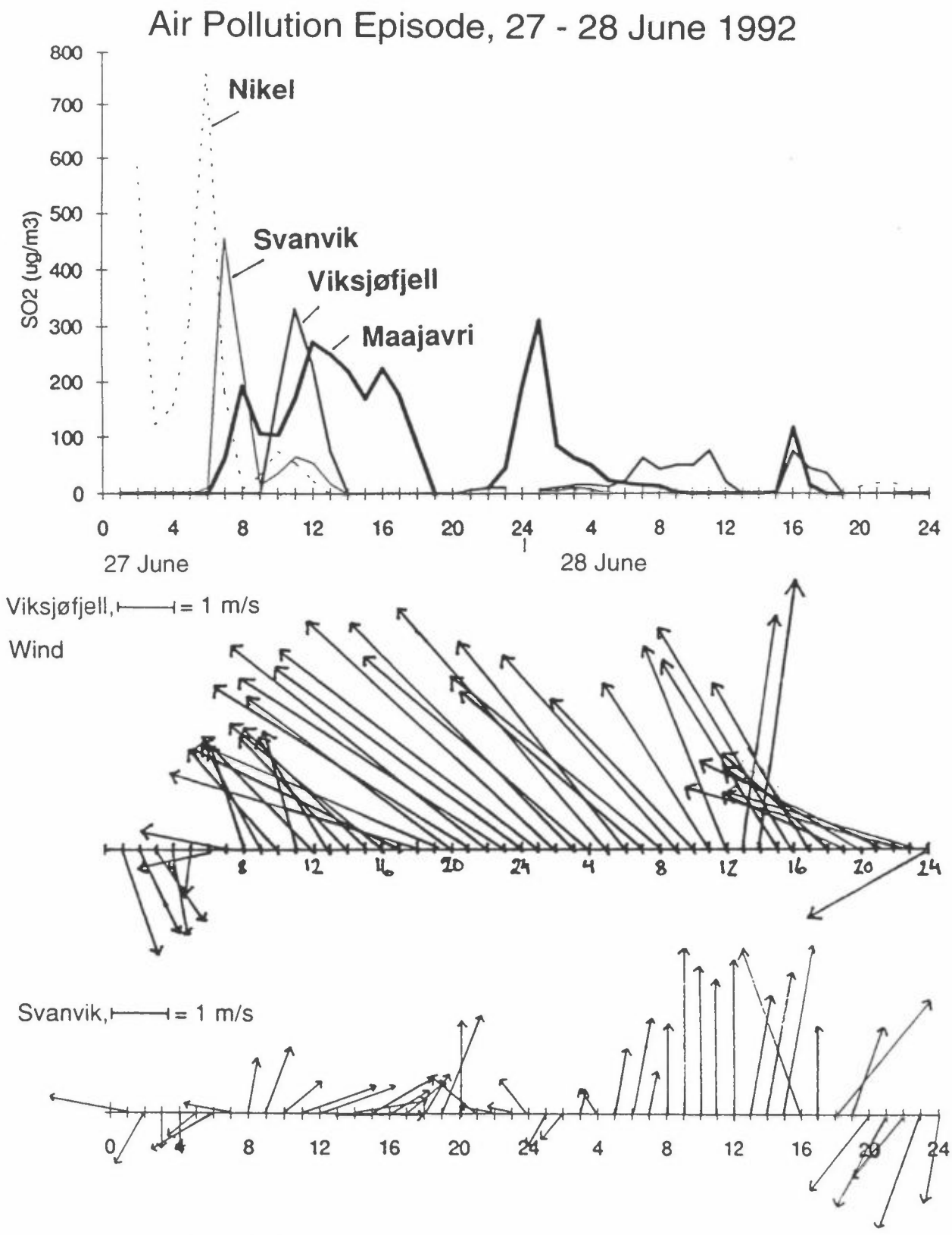


Figure 4: SO_2 concentrations and winds during a summer type air pollution episode in the border areas (27-28 June 1992)

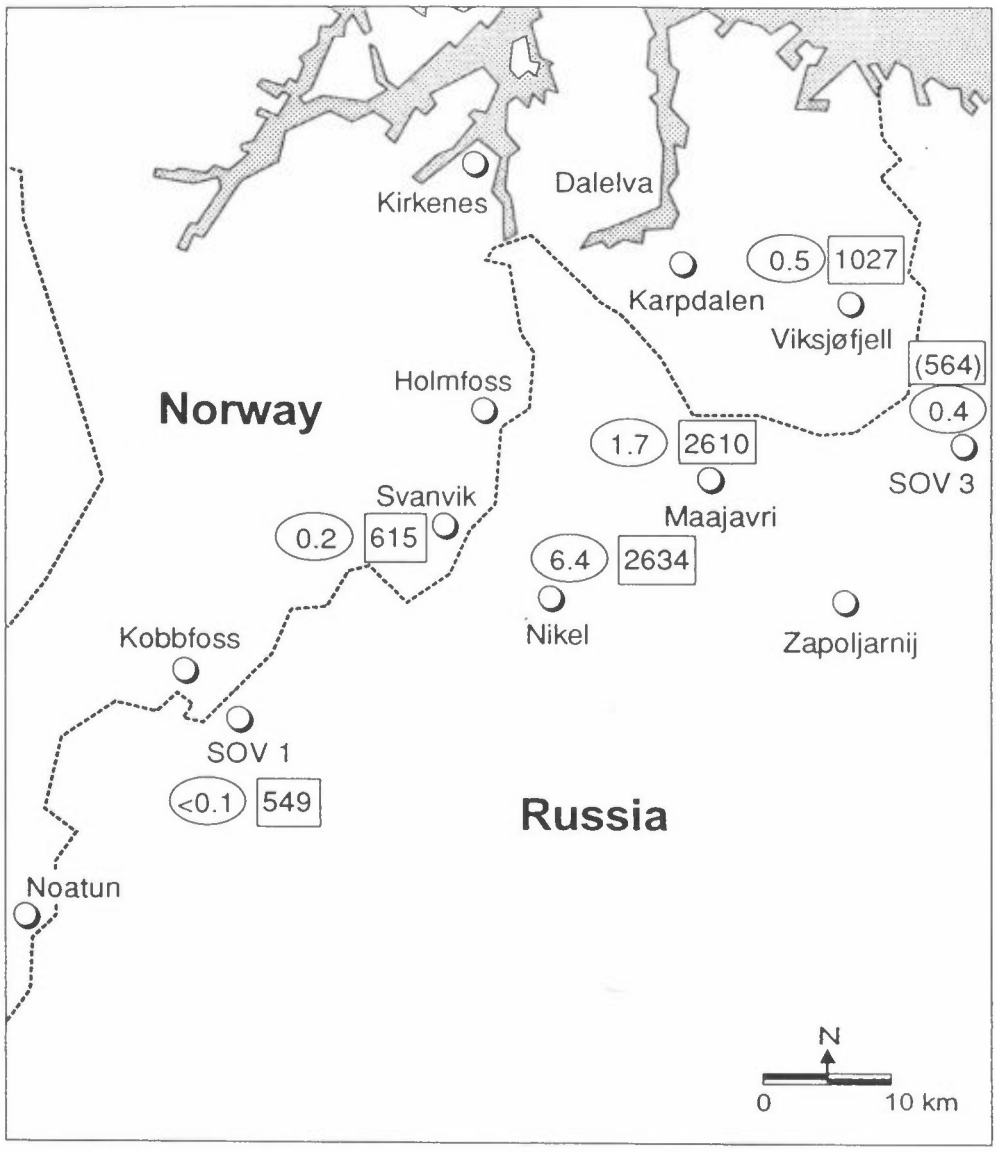


Figure 5: Summary of 1 hour average SO_2 concentrations measured in the border areas during the summer 1992.
Max. 1 hour average (µg/m³)
Percent of time exceeding 350 (µg/m³)

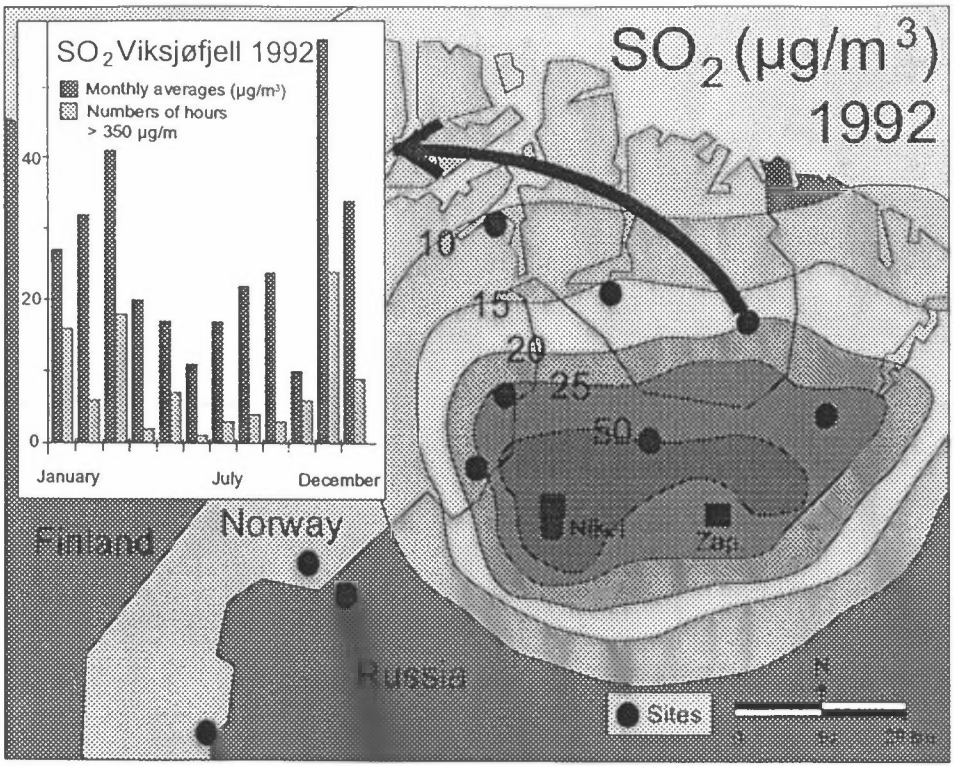


Figure 6: The estimated annual average SO_2 concentrations during 1992. Measured monthly averages and number of hours exceeding 350 µg/m³ are given for Viksjøfjell for each month during 1992.

2.3. The Monitoring and Modelling of the Atmosphere Pollution in Industrial Districts of Kola North

A. Baklanov, E. Kljuchnikova, I. Rodjushkina, A. Smagin
INEP, KSC, RAS

The main sources of environmental pollution of Kola Peninsula are the enterprises extracting and working up ore, the thermo-electric power station, the boiler-house, transport highways. Metallurgical plants and boiler-houses emit into the atmosphere aerosol of metals (Ni, Cu, Co, Mn, Ar, Cr, Zn and other) as oxides, dissolved and undissolved salts, dust, ash and other elements, being included in ore, petroleum and coal. The main volume of gaseous emission amounts SO_2, NO_x, CO.

Throughout the region the amount of emitted harmful substances from motor transport and stationary sources was 866900 t in 1990,including: solid - 77200 t, liquid and gaseous - 789800 t.

For evaluation of estimation the atmosphere pollution of the region there has been created the system of data bases, included 11 towns of Kola Peninsula . The data bases contains the information about quantity of pollutants, emitted into the atmosphere, and their composition. This information allows us to get some statistical data about the region pollution.

The smelters cause the main emission precipitation from the stationary sources - account for 76% of total pollution. More then 70% of them belong to the "Pechenganickel" and "Severonickel" smelters. In 1990 total emission of harmful matters into the atmosphere from the "Pechenganickel" plant was 267000 t and from "Severonickel" - more then 255000 t. The system of data bases contains more detail information about these two smelters, which is necessary for calculations of the atmosphere pollution.

The quantity of emission is unsteady . In Fig. 1,3 there are diagrams of change of SO_2 emission from the "Pechenganickel" and "Severonickel" smelters during last 20 years.

2.3.1. Informational system of monitoring and prediction of aerotechnogenic pollution

Over a period of the last 10 years on the Kola Peninsula there exist the networt on the town atmosphere pollution measurements in 11 towns, including the Murmansk HYDROMET and other units. Up to now there was ou a system on regional and background atmospheric monitoring.

So INEP RAS with other organizations began creating ecological information system for Kola North. One of the part of the EcoInformSystem is the system on monitoring and simulation of aerotechnogenic pollution.

At the Fig.3 is offered a structure of monitoring of aerotechnogenic pollution of the Kola Peninsula environment.

During 1990-91 the system of automatized controlling the local atmospheric pollution was installed in the "Pechenganickel" and "Severonickel" vicinity. It includes russian-norwegian controllng stations - SOV1, SOV2, SOV3, disposed in the district of "Pechenganickel" concern and also control stations in Kislaya bay Khibinystation, base "Imandra" and Lapland national reserve, disposed in the district of "Severonickel" plant (Fig.4). Besides, the placing of the automatized controlling stations in the Kovdor, Verkhnetulomsky and Krasnoshelje districts is planned.

Except monitoring stations, the system includes: the system of collection and processing the atmosphere pollution data and meteoinformation, data bases of sourses and levels of polution, wind descriptions, and the complex of mathematical models for estimation of the regional atmosphere pollution and definition of contribution to pollution from various sources of emission.

Depending on the task peculiarity and domain scale different (some) types of dispersion models are used here:

- the models of Gaussian type;
- the numerical mesoscale models of atmosphere (Fig.5-7) dynamic and pollution dispersion;
- the trajectory models of regional scale.

2.3.2. The present atmosphere pollution

In this report let us consider the estimation of atmosphere polution of 3 industrial districts of Kola region-zones caused by "Severonickel", "Pechenganickel" concerns .

For carrying out calculations of average for a period atmosphere pollutions in these districts the sector Gaussian type model was used.

2.3.2.1. Pechenganickel concern vicinity

The "Pechenganickel" plant has operated since 1946, when in Nickel township the treatment of local sulfide-nickel ores containing about 6.5% sulphure started. In 1959 mining of Zhdanov deposit ores and their processing at the plant in Zapolyarny. Began since 1971 the retreatment of cuppro-nickel ore with a high (up to 30%) sulphur content is being produced in Norilsk mining and metallurgical company.

The sharp increase in disharges in 1974 (+150000 t/year) and 1984 (+170000 t/year) has been caused by the upgrowth of the Norilsk ore retreatment. Having adopted for the USSR the Maximum Allowable concentration of SO_2 per day and more long period in the inhabited objects, (MAC) amounts 50 mkg/m^3.

The "Pechenganickel" concern is situated on 2 industrial grounds: smelting shop is situated in town Nickel and kilning shop - in town Zapolyarny, at 20 km distance. So all sources of pollution are devided into two groups.

An industrial emission over the zone of Zapolyarny is 28.8 % from total emission of the plant. Now on the plant zone there are more then 300 sources of harmful invading

emissions, including 240 sources.

Accoding to the modelling results the zone of average concentrations exceeding MAC, covers, in the winter season 1990/91, an area of 700 km^2 and partially is spread out on the Norway territory - northwards and north-westwards from Nickel and Zapolyarny and in the summer period - 400 km. So, tendency of decreasing of SO_2 emission and, accordingli, of aerotechnogenic loading from "Pechenganickel" concern is confirmed for last years.

The calculations have showed that during winter period of 1991/92 the zone of exceeding day-average MAC for SO2 (50mkg/m3) has occupied about 700 km^2 area (Fig.8a), during summer period - 350 km2 (Fig.8b).

Exceedance of standards prescribed by IUFRO for a forest zone (25mkg/m3) has been observed in winter period on the area of 2000km2, in summer period this area was 1300 km2. Modelling month-average SO2-concentrations were compared wth the data of atmospheric monitoring from the stations SOV1, SOV2, SOV3, Viksjofjell, Svanvik.

By monitoring data (Fig.9) of the Russian stations situated near the Russian-Norwagian border, the MAC exceedance in the winter season was observed most often on SOV2 - 30-60% . This station is situated 15 km northwards from Nickel and Zapolyarny. In the summer months the time duration with the MAC exceedance made up 6-35% in some months. Per year -31%, average concentration 56.6 mkg/m^3 (Fig.10.) On the SOV1 station 25 km remoted from Nickel and 47 km from Zapolyarny south-westwards, the yearly average concentration made up 11.7 mkg/m^3, MAC exceedance - 4%. The utmost unfavourable time was January 1990, when the estimated monthly average SO_2 concentration in the wide areal, exceeded 50 mkg/m^3(MAC). The absolute maximum of monthly, daily and hourly average concentration at all monitoring stations has been observed in this month. The maximum of the hour average concentrations on SOV1 accounts for - 1208 mkg/m^3, SOV2 - 2956 mkg/m^3.

The average concentrations for the summer growing season in 1990 at SOV1 - 9.6 mkg/m^3, SOV2 - 27.9 mkg/m^3. During the growing season the maximum of the hour average concentrations were: SOV1 - 558 mkg/m^3, SOV2 - 1071 mkg/m^3, SOV3 - 1250 mkg/m^3.

2.3.2.2. Khibiny area

The south part of Khibiny mining massif and adjacent district is most industriallized. So environment of this district is more subject to technogenic influence.

First of all it was brought about by mining units effect,, such as "Apatit", on the landscapes and surface waters. And the atmosphere basin is subject to a heavy pollution too.

Problems of local air pollution under open mining works of the "Apatit" in Khibiny mining massif were under the consideration earlier. In this work the estimation of aerotechnogenic pollution of Apatity district by less important emission sources (Apatity Thermo-electric power plant and dusting surfaces of tailing-dumps of ANCM-2 and

ANCM-3) has been made.

The atmosphere pollution by waste emissions from Apatity Thermo-electric power plant (ATEPP).

Harmful emissions into the atmosphere from sources of Apatity account for 52200 t/year, including : solid - 139 t/year, SO2 - 29430 t/year, COx - 800 t/year, benzpiren - 0.267 t/year. The main pollution source is a concentration factory. It emits more than 89,6% of the total volume of invading substances.

To evaluate the influence of ATEPP emissions on the air pollution of the district the series of calculations has been made.

The information about recurrence of wind direction in the area of location of ATEPP is cited in Fig.12. The calculations show that the year-average SO2-concentrations in the atmosphere of investigated district don't exceed MAC adopted for citizens. Fig.11 describes the field of atmosphere pollution by SO2 as a result of concentration factory operation. Maximum pollution from emission sources is forecasted for the East and minimal - for South-East.

For the territory of Apatity the calculated year-average SO2-concentration is 1-7 mkg/m3.

2.3.2.3. Severonickel concern vicinity

Air basin conditions of Monchegorsk and its environment immediately depends on production activity of "Severonickel" plant. Town Monchegorsk is situated north-eastwards from the plant in the zone of prevailing wind directions.

The most dangerous situations of the atmosphere pollution in the town results from the declining of southern air streams, owing to the mountains Sopchuaivench and Nydyaivench bareer.

Meridianal location of the mountain relief main elements, coupled with significant recurence of air temperature nearsurface inversions experiences significant influance on the impact zone formation. Under conditions of near to the surface and rised inversions the emission localization within 6 km radius occur. Maximum among recorded concentrations of sulphide gase (4 mkg/m^3) was indicated at a 4 km distance south-westwards of industrial site (averaging period is 20 min). At a 6 km distance the SO_2 concentrations near the background (3 - 4 mkg/m^3) account for about 20% of time. Under pollution conditions the sulfide gas content can varies from 50 to 250% during a day time.

By weak transfer in subinversion layer the polluted air is spread along the relief depressions. Sulfide gase concentrations up to 300-600 mkg/m^3 are observed there at a range of 10-12 km.

When the atmosphere state is unstable and wind is weak (7 m/c) the air pollution by

sulphide gase is noted at a distance over 30 km, from a lee side. The SO_2 maximum concentrations exceed by 500 mkg/m^3 on the Lapland nature reserve territory (31 km south westwards from facilities), in Kislaya bay of Imandra lake (40 km south-southeastwards of the facilities) the maximum of recorded SO_2 concentrations was 200 mkg/m^3(Fig.13).

Average for a month sulfide gas content within 15 km south-southeastwards from the plant accounted 70 mkg/m^3, the maximum was 260 mkg/m^3 (annual emission being 23400 t).

By data of continuous air sampling from January to March 1992 the maximum of sulphide gase daily average concentrations made up 14 mkg/m^3 on the east shore of Imandra Lake (Khibiny station, 35 km south-eastwards from the industrials).

By the data of Murmansk Hydrometeorological Service an excessive average content of phormaldehyde (over 2.4 - MAC) was observed in Monchegorsk air, the average content of other polluting admixtures did not exceed Sanitary standards. Maximum concentrations of nitrogen and sulphure dioxide were 2.2-2.4 as high as MAC, these of dust and carbon oxide 1.2-1.4 as high.

Over a period of recent 5 years the level of air pollution by hidrogen dioxide, phenol, sulphide anhydride and phormaldehyde has described, this by dust and carbon oxide did not change.

Set of calculations of average annual concentrations of invading substance in the lower atmosphere within the industrial zone of activity has been made. For making forecast estimations of air pollution the industrial zone of 25 km radius was considered.

The calculations show that SO_2 content in the atmosphere of the area considered exceeds maximum allowable daily standard for a human being on the territory over 400 km^2 (fig.14), of nickel hydroaerozols - about 60 km^2 (fig.15), unsoluble nickel oxide - 300 km^2 (fig.16). That's why the area with exceeding content of invading substances has been calculated on ingredient data for compounds with maximum MAC.

The effect of invading matters totall is not taken into account there, as well as the admixtures chemical transformations.

2.3.3. Prediction of ecological situation change in the district under reconstruction of Pechenganickel and Severonockel concerns.

The results of the atmosphere pollution simulation and the system of monitoring around the "Severonickel" and "Pechenganickel" concerns show, that the area of air pollution is above-norm and, as concequence, it is the zone of aerotechnogenic destruction. On the territory, subjected to industrial pollution for many years, the process of degradation of nature proceeds intensively. The area of woods defeat due to industrial emissions for the period 1983-88 increased n 80 ha/years. And the speed of extension of dead woods areals is 3 ha/year for this period.

To stop the process of full degradation of ecosystem, arising rom industrial pollution, it

is necessary essentially to reduce emissions of pollutants into the atmosphere.

2.3.3.1. Pechenganickel concern.

For evaluation of efficiency of supported reconstruction of the "Pechenganickel" concern a number of calculations of ecological situation change in this region under different variants of reconstruction of concern has been constructed.

1. The use of the Vanyukov's technology. Reducing of SO_2 emission in both industrial zones by 80% uniformly for low and high sources. In this case the average concentration is 25 mkg/m^3 (recommended by IOFRO as allowed load for woods during 6 months) observed on the area of 400 km^2 and in the zone of 60 km^2 exceeds MAC for human being (50 mkg/m^3) in winter . Loads on ecosystems reduced in this case, but essential change of ecological situation did not take place.

2. Use the technology of firm Outukumpu. Reducing of SO_2 emissions in both industrial sites by 95% uniformly for low and high sources. In this case in winter average concentrations meet Russiann standards of MAC for human baing and there is exceedance of MAC only for woods in small area about 10 km^2. And this zone is localized in the north part of Nikel, where ecosystem has been destroyed completely.

3. Reducing SO_2 emission on indusrial site of Nickel by 95% without reconstruction on the industrial site of Zapolyarny. Only high sources emit about 14000 t/year and 72000 t/year correspondingly. In realizing this variant of reconstruction, the zone with invading substunses exceedance by 25 mkg/m^3 during winter time covers about 20 km area. The district of maximum pollution is in the vicinity of Zapolyarny . In the near-border district, the north is fatal for some types of vegetation.

4. Reducing SO_2 emission on industrial sites of Nickell by 95% without reconstruction sites of Zapolyarny. Only by high sources it is emitted 158000 t/year, 163000 t/year of invading substances, respectively. The realization of this variant of the plant reconstruction will allow to reduce SO_2 concentration up to 1-5 mkg/m^3 into the atmosphere (Fig. 18).

2.3.3.1. Severonickel concern

For "Severonickel" concern a number of calculations on reducing SO_2 emissions into the atmosphere comparing with 1990 level was made. Several variants were taken into consideration:

1. Emission from low sources contribute to strong pollution of the terriitory, subjected to influence of the concern. More evidently this effect has been shown in the region investigated and heavily polluted. So the variant of reducing SO_2 emission from low sources was taken into consideration. In this case SO_2 concenteration, exceeded MAC for human being, it will be observed on the territory about 70 km^2, and for woods about 300 km^3 . And loads on various types of vegetation

will exceed admitted standards.

2. Lowering SO_2 emissions by 80% both for high and low sources will lead to reducing above-norm pollution for woods up to 50 km^2. The average consentration in the town Monchegorsk will be less then 10-12 mkg/m^3 .

3. In lowering SO_2 emissions by 85% both for high and low sources the domain with pollutant concentration more then 25 mkg/m^3 will be reduced up to 20 km^2. The affected zone with fir-trees and pine-trees (7-9 mkg/m^3) will be reduced up to 20 km^2 (Fig.19).

4. Lowering SO_2 emission by 95% both for high and low sources. The loads on main types of vegetation do not exceed a critical level. This variant is more admissible contrary to other considered zones (Fig.20).

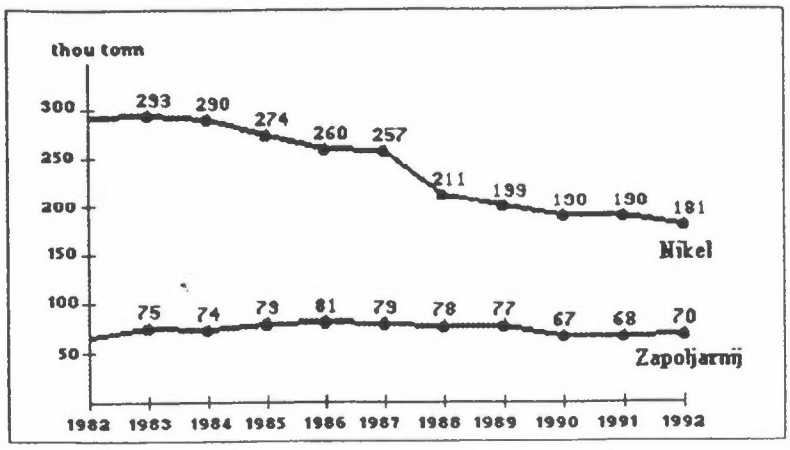


Figure 1: SO_2 emissions at the atmosphere by Pechenganickel complex

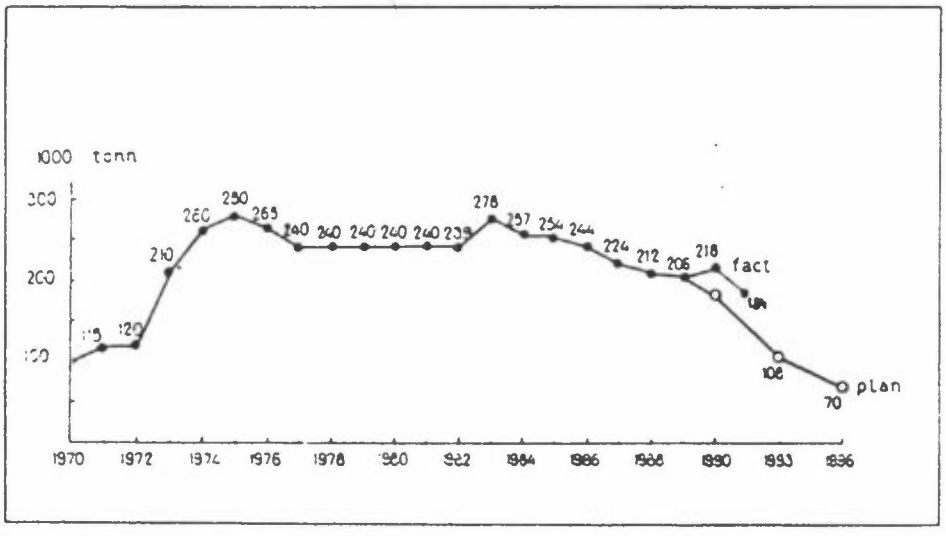


Figure 2: SO_2 emission by "Severonickel" plant

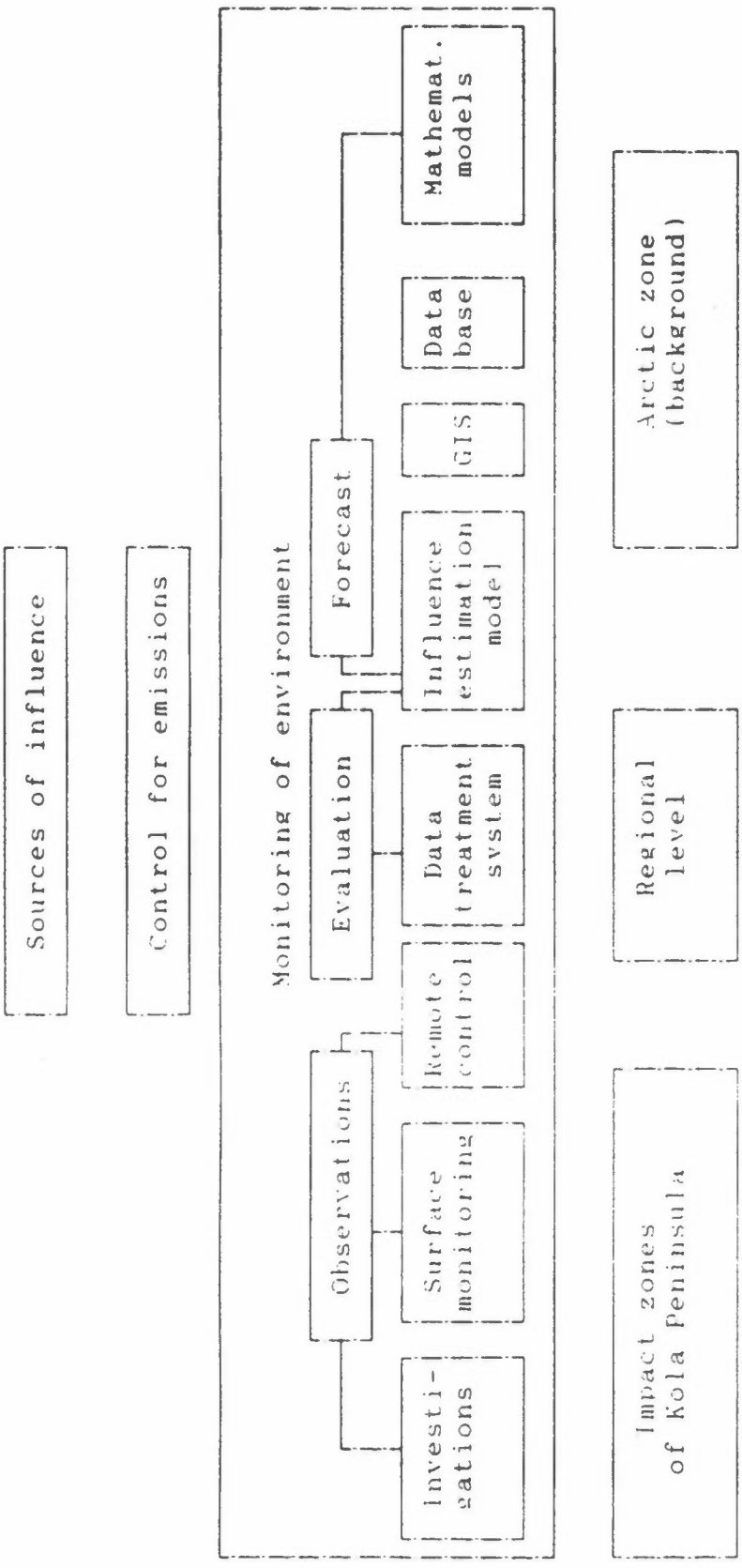


Figure 3: Scheme of ecological monitoring on Kola Peninsula

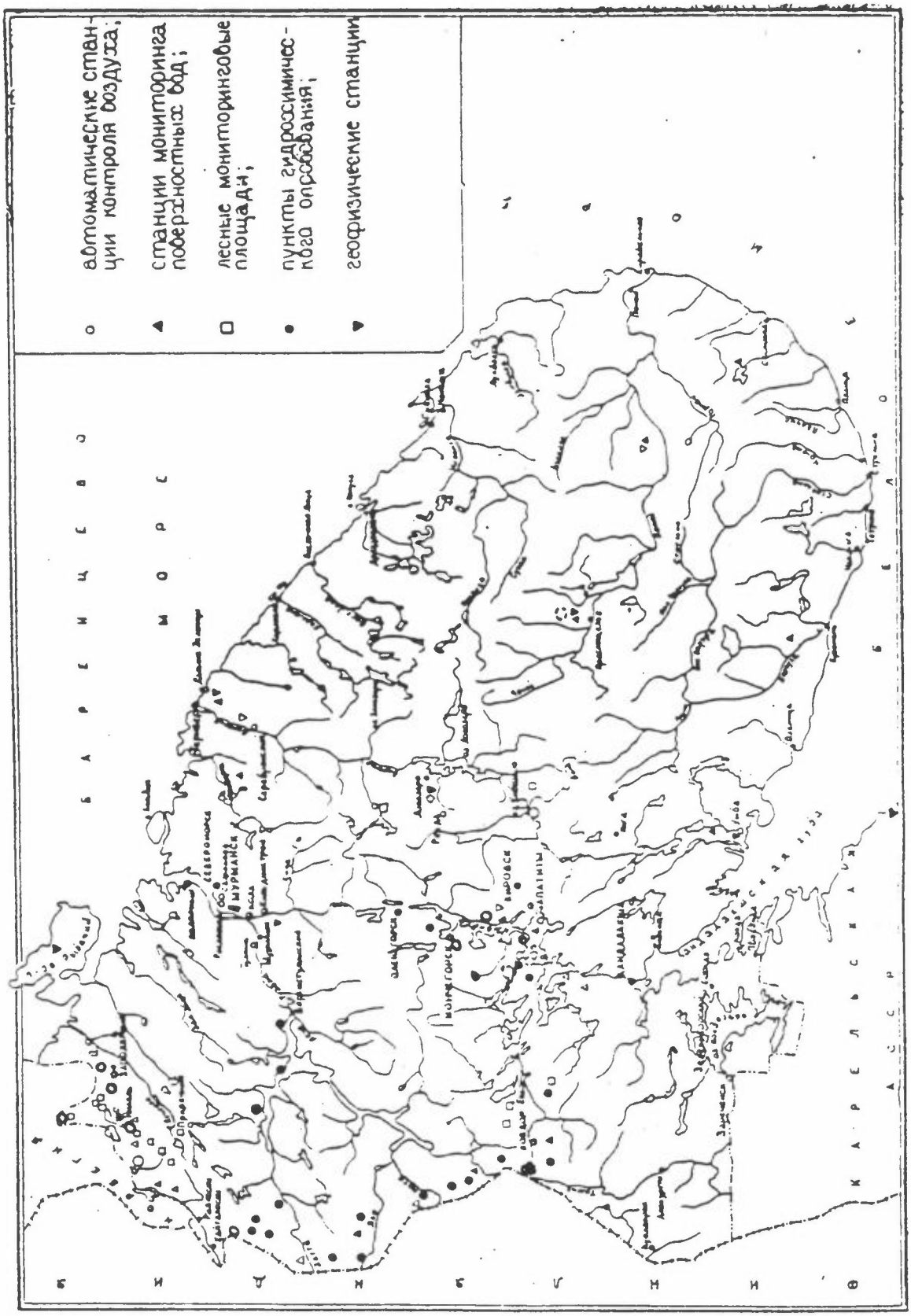


Figure 4: Map of ecological monitoring stations

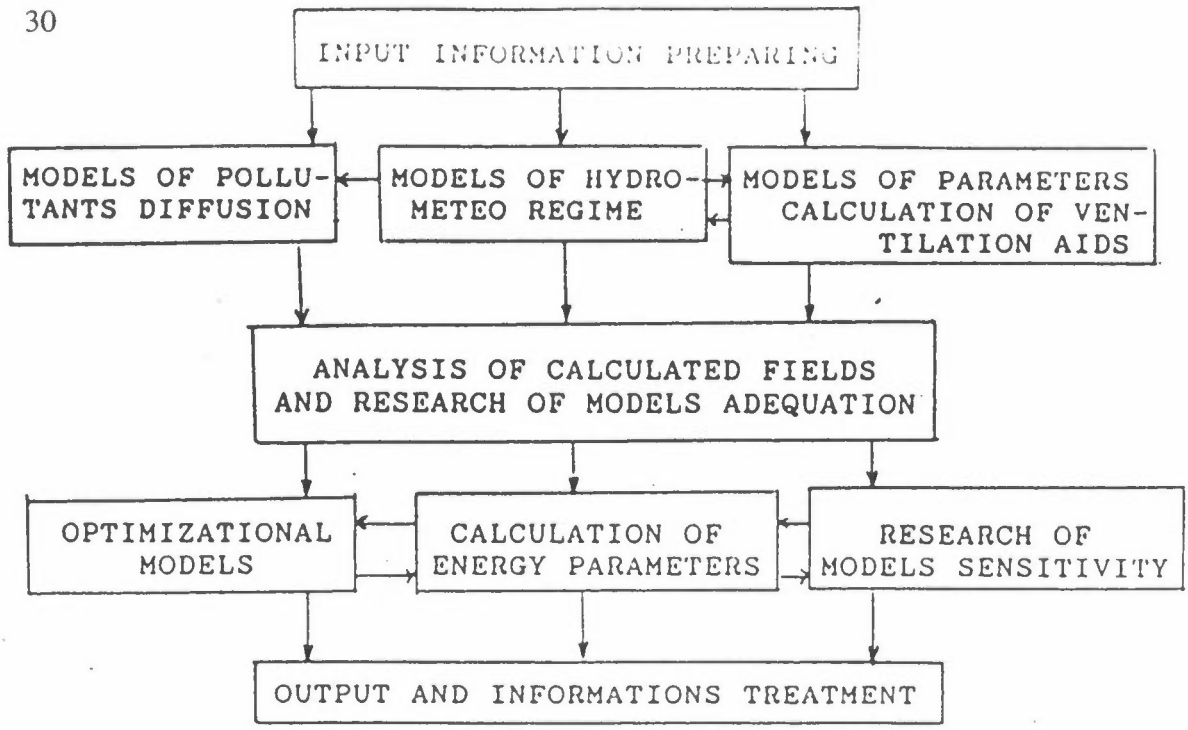


Figure 5: General scheme of the package of mathematical models for study of hydrometeoregime and the environment preservation

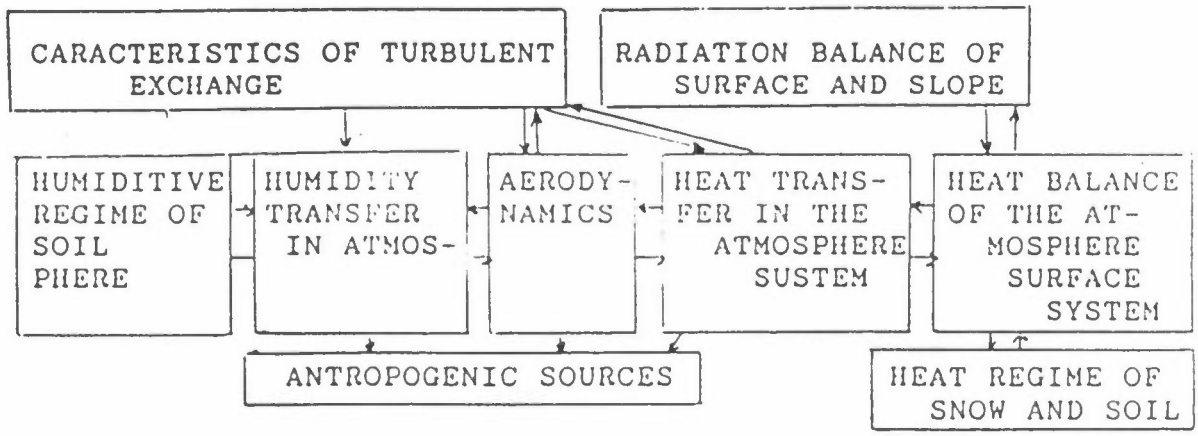


Figure 6: A scheme of the hydrotermodynamic atmosphere model

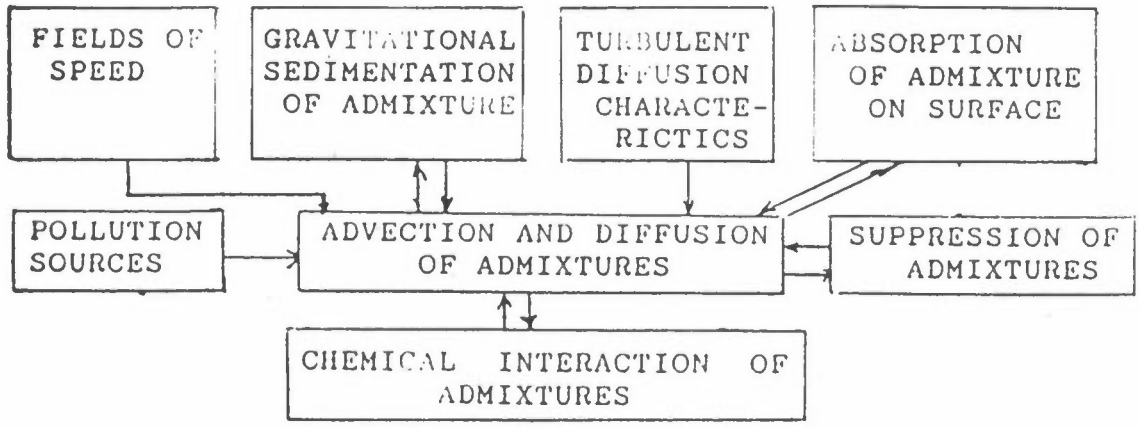


Figure 7: A scheme of admixture spreading model

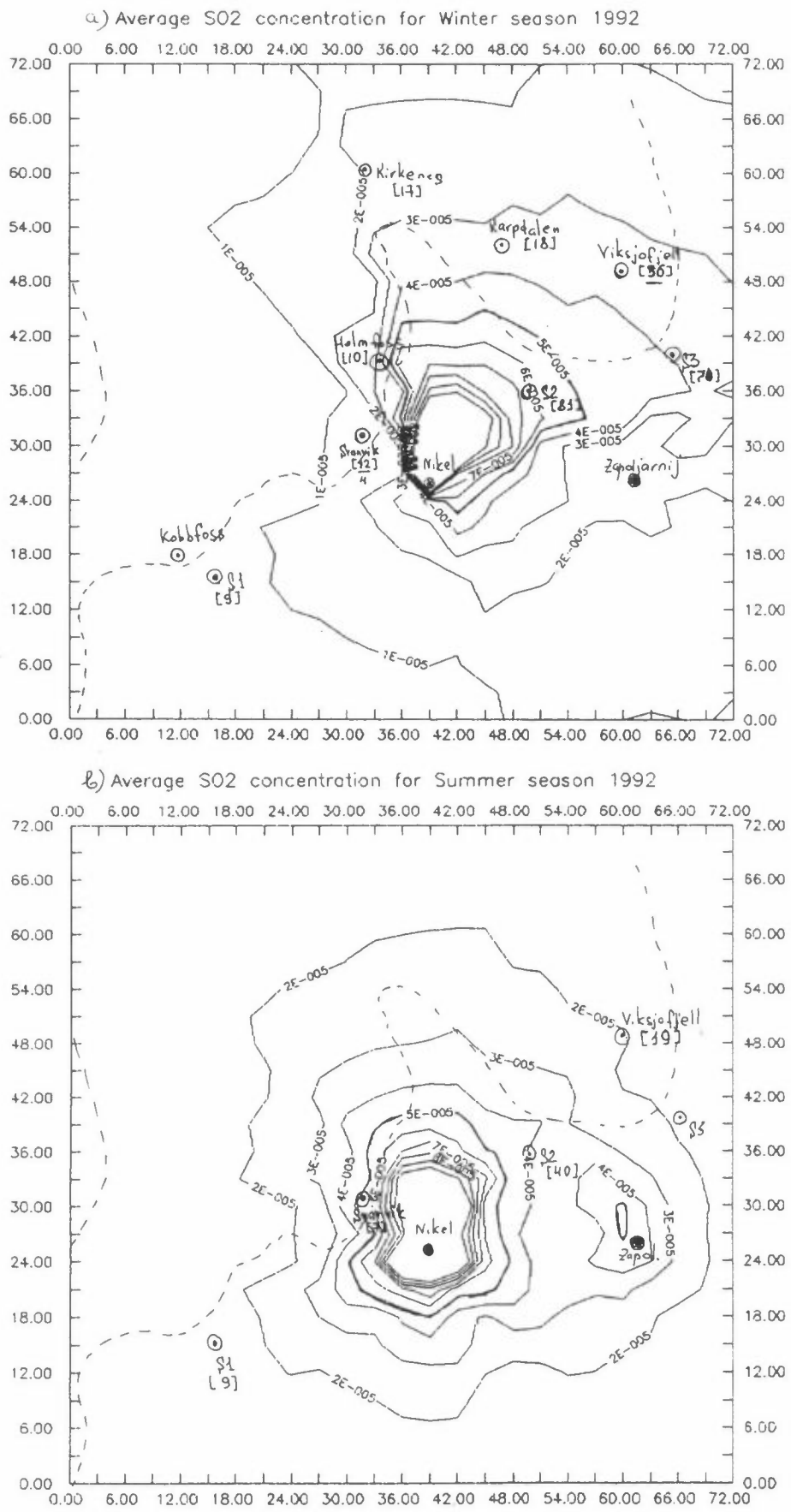
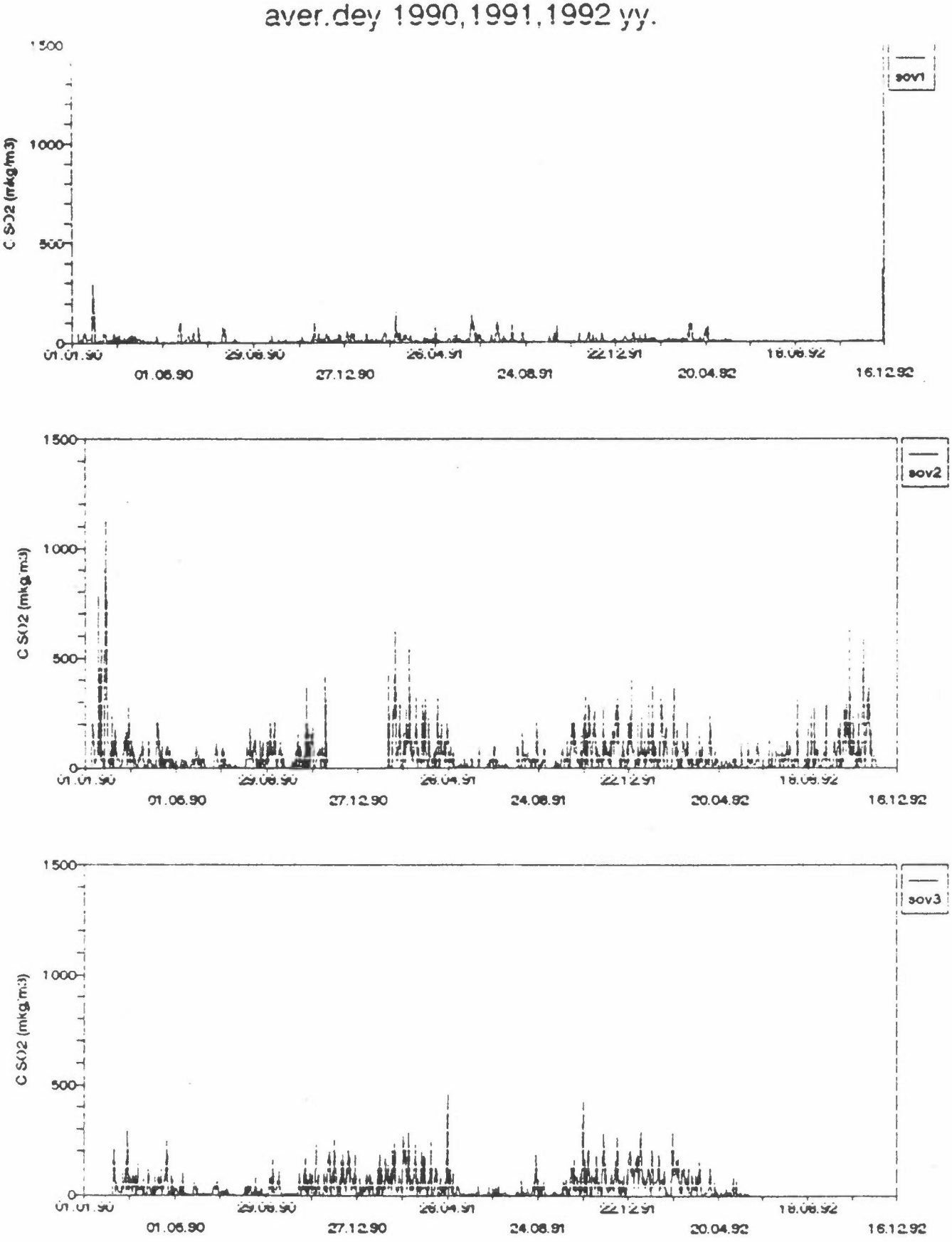


Figure 8: Estimated average concentration of SO_2 (µg/m³) in the Pechenganickel company vicinity for a) winter season 1991/92and b) summer season 1992.


aver.dey 1990,1991,1992 yy.
sov1
sov2
sov3
C SO2 (mkg/m3)
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24.08.91
20.04.92
16.12.92

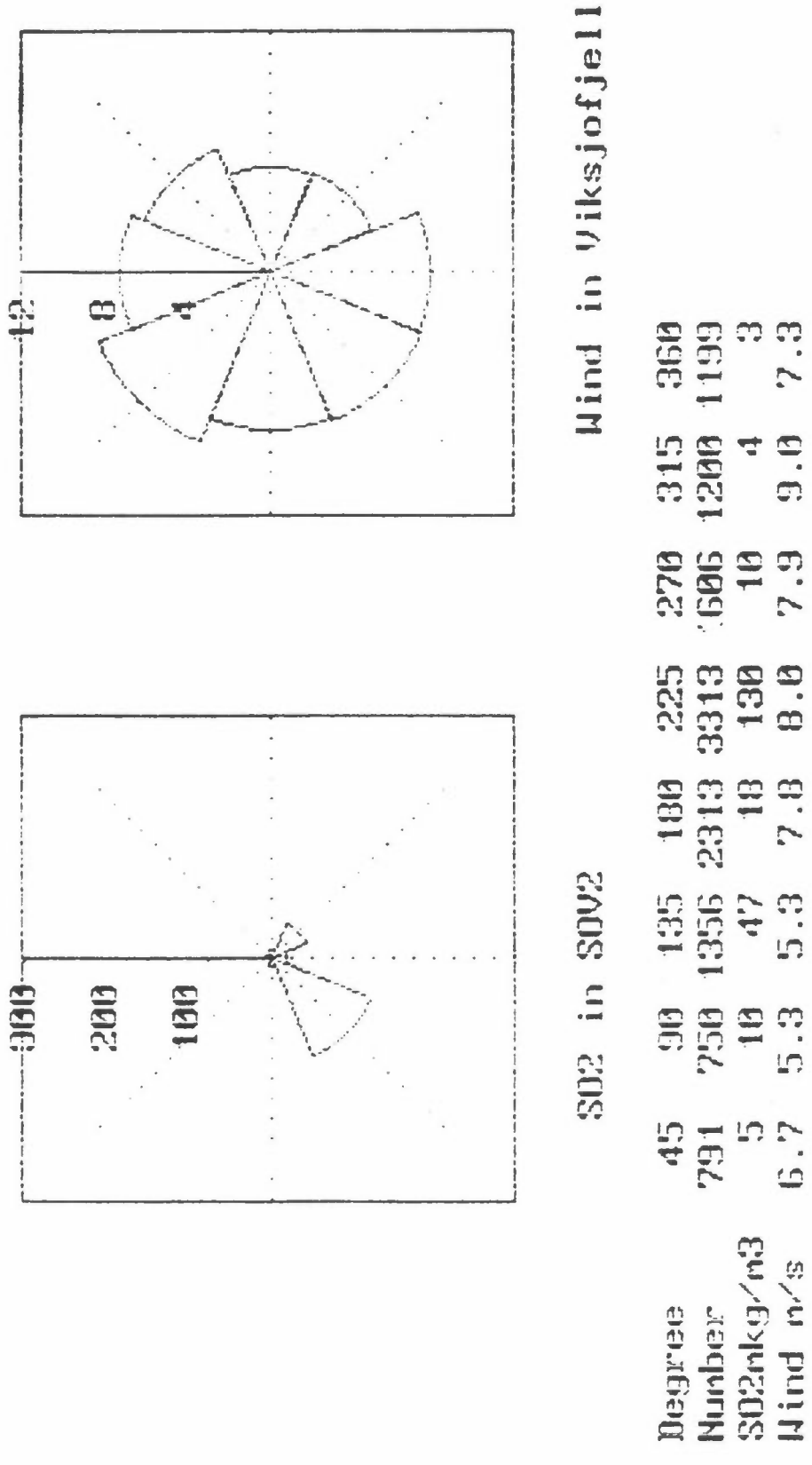
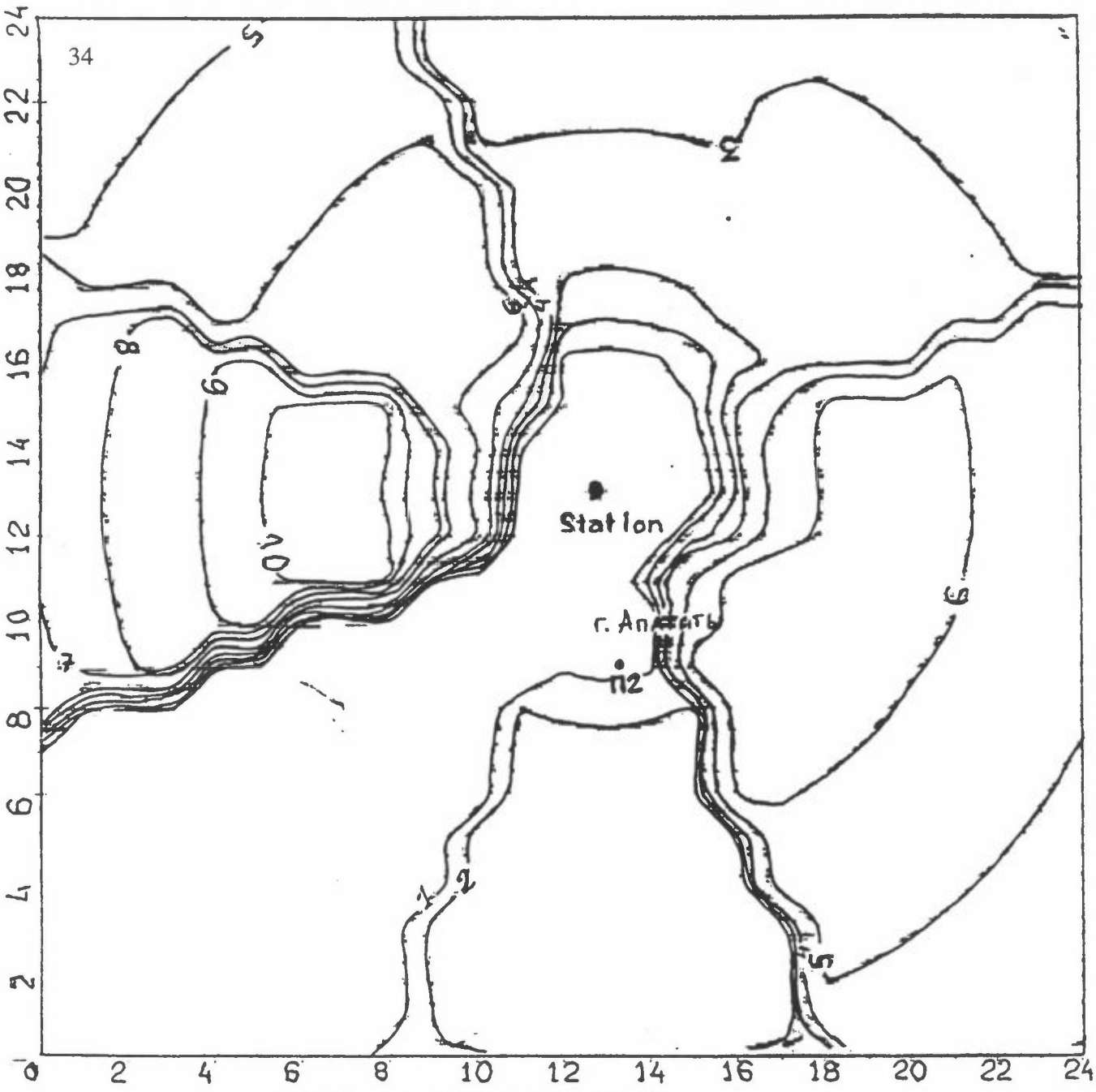


Figure 10: SO_2 concentration and wind rose at the period 9.1.1990-24.10.1992



Levels of annual concentration :

1	2.00000 ug/m3	2	3.00000 ug/m3
3	4.00000 ug/m3	4	5.00000 ug/m3
5	7.00000 ug/m3	6	10.00000 ug/m3
7	15.00000 ug/m3	8	17.00000 ug/m3
9	20.00000 ug/m3	10	22.00000 ug/m3

Figure 11: Estimated average concentration of SO2 at the Apatity Power Station vicinity

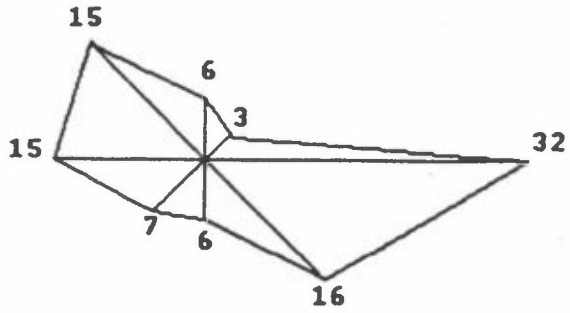
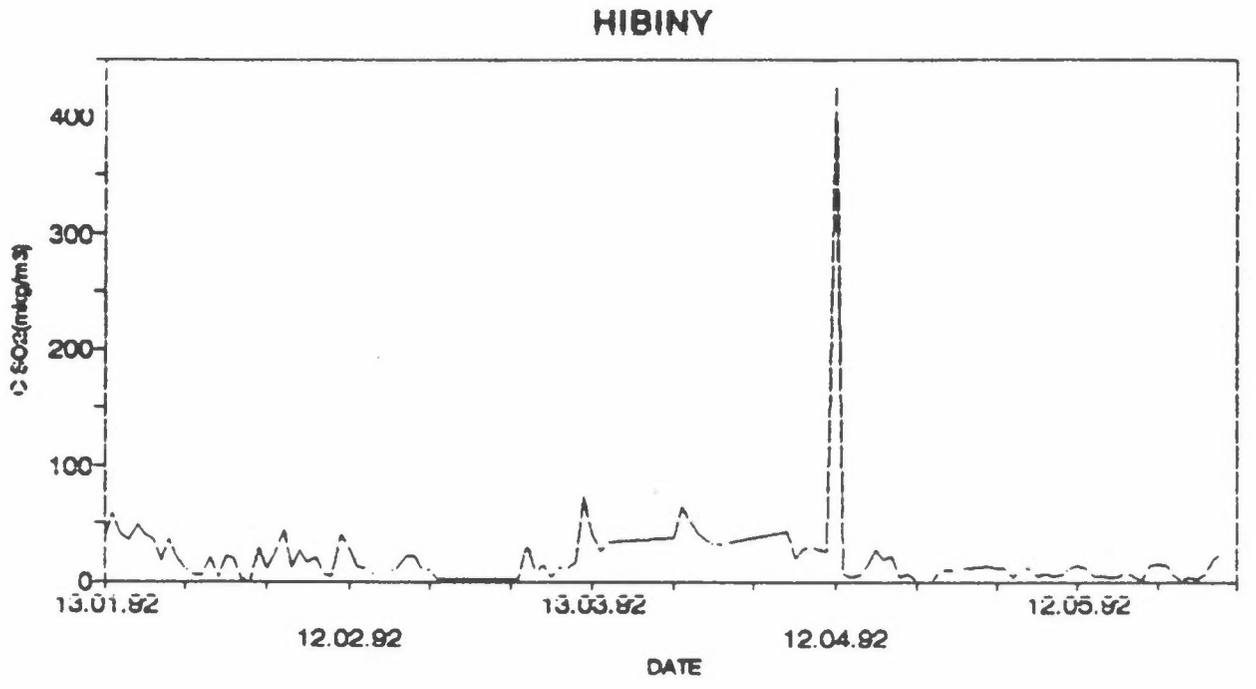


Figure 12: Frequence of wind direction at the Apatity meteostation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12.05.92
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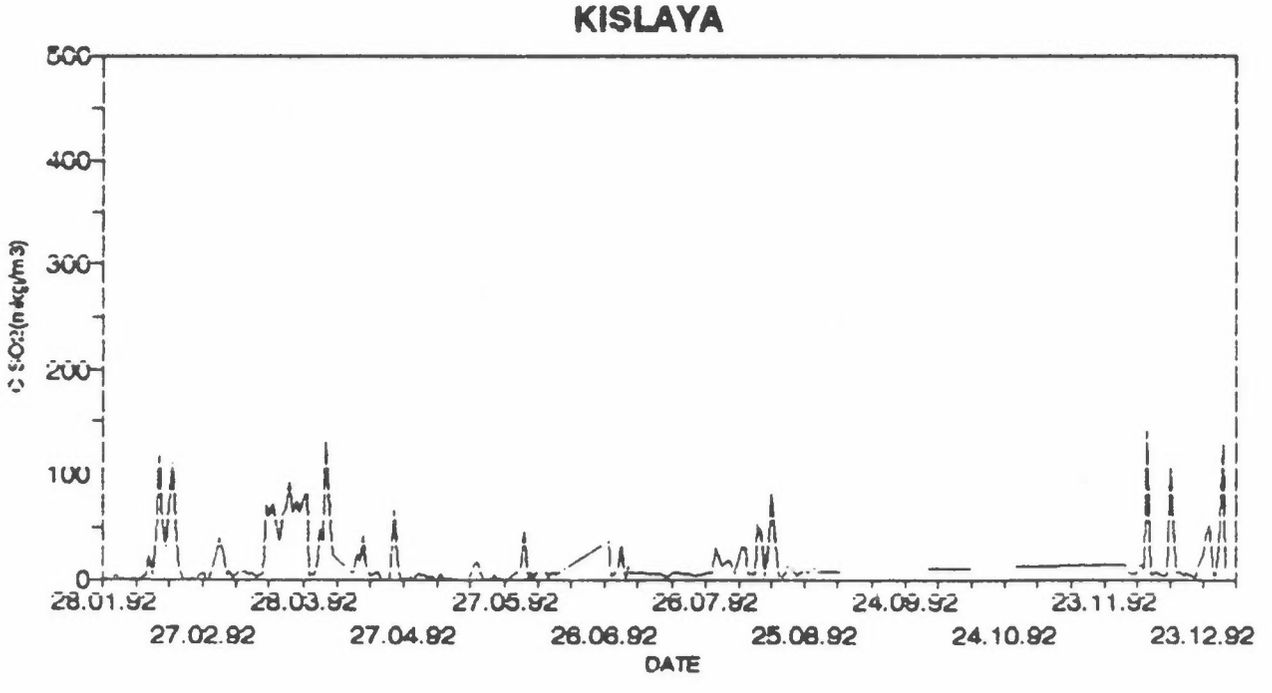
KISLAYA
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Figure 13:

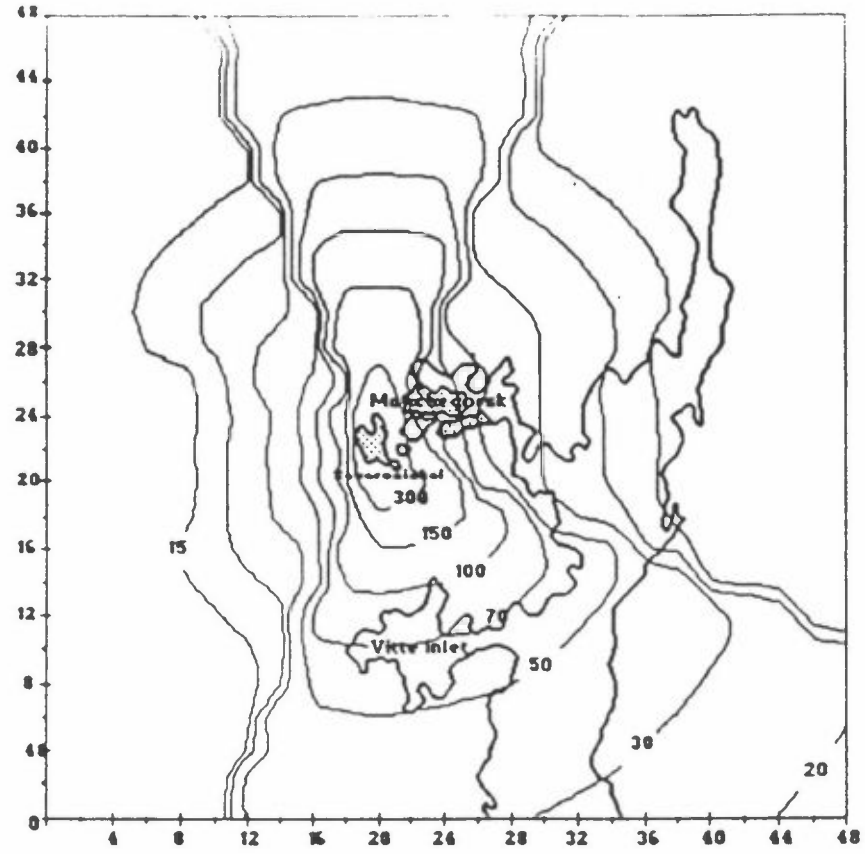


Figure 14: Estimated average annual concentration of SO_2

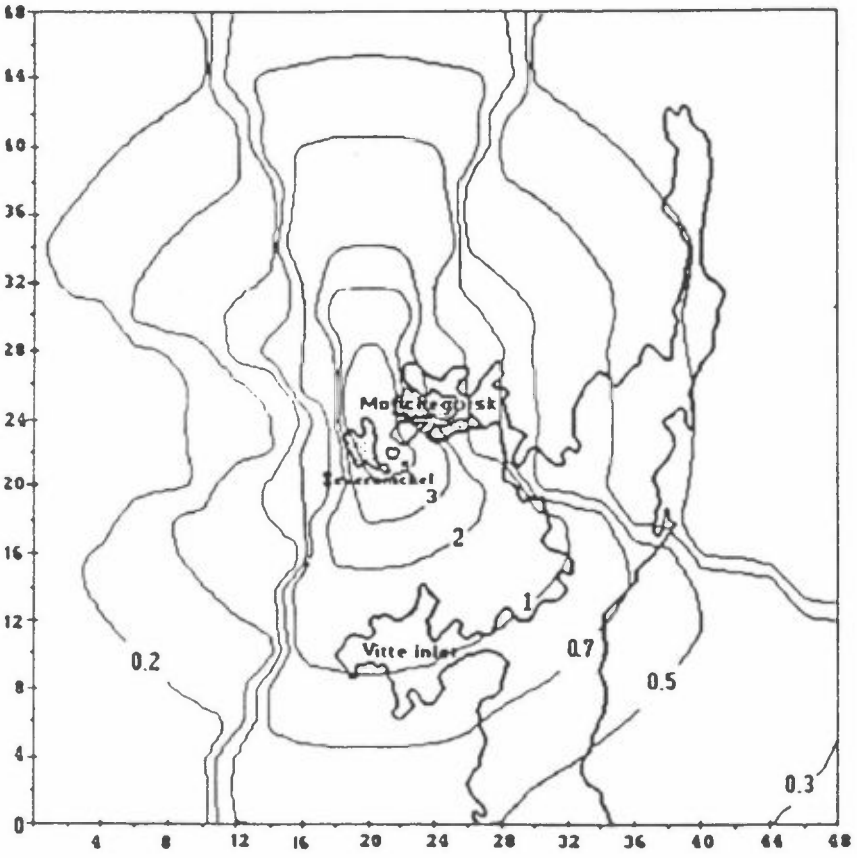


Figure 15: Estimated average annual concentration of nickel (insoluble)

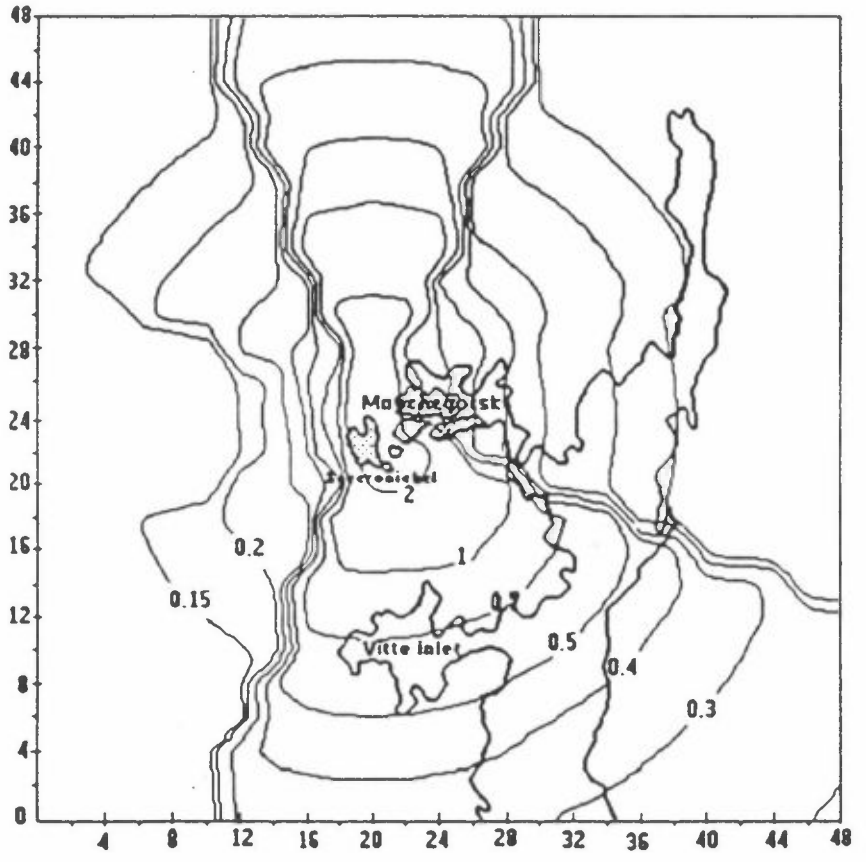


Figure 16: Estimated average annual concentration of copper

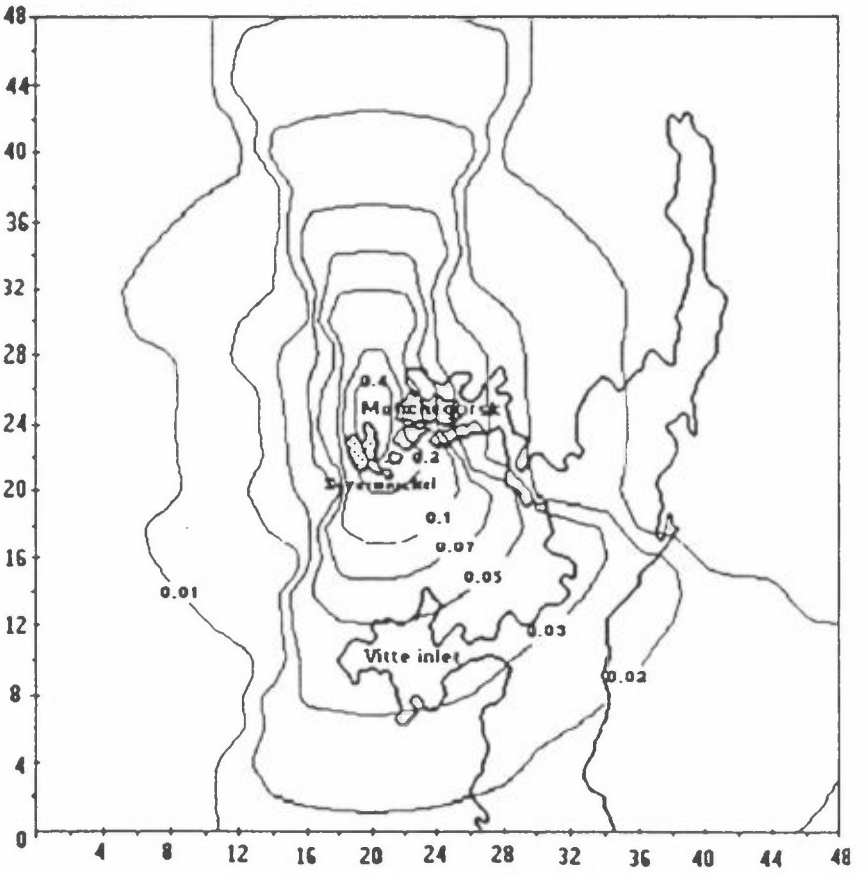


Figure 17: Estimated average annual concentration of cobalt

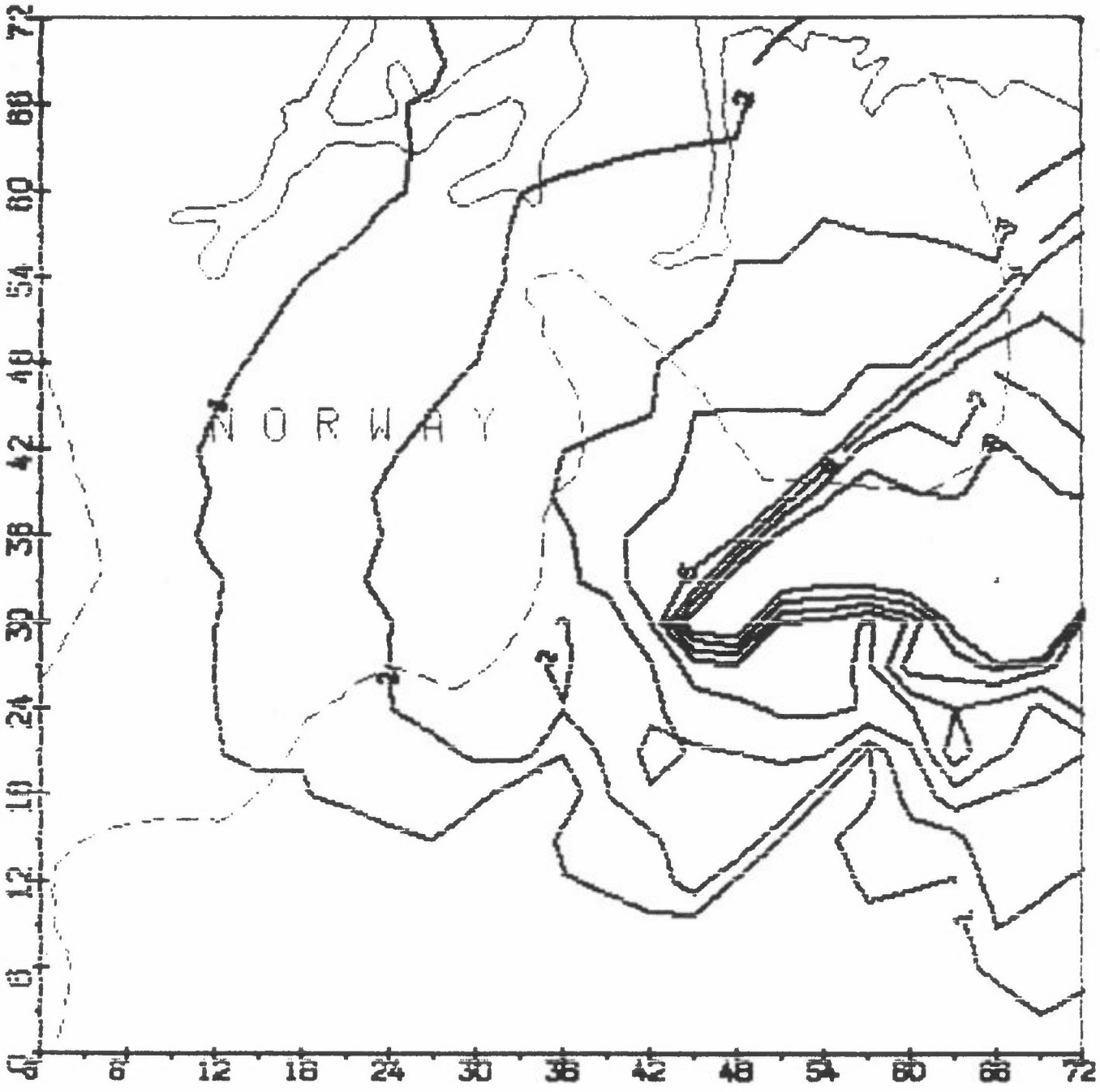
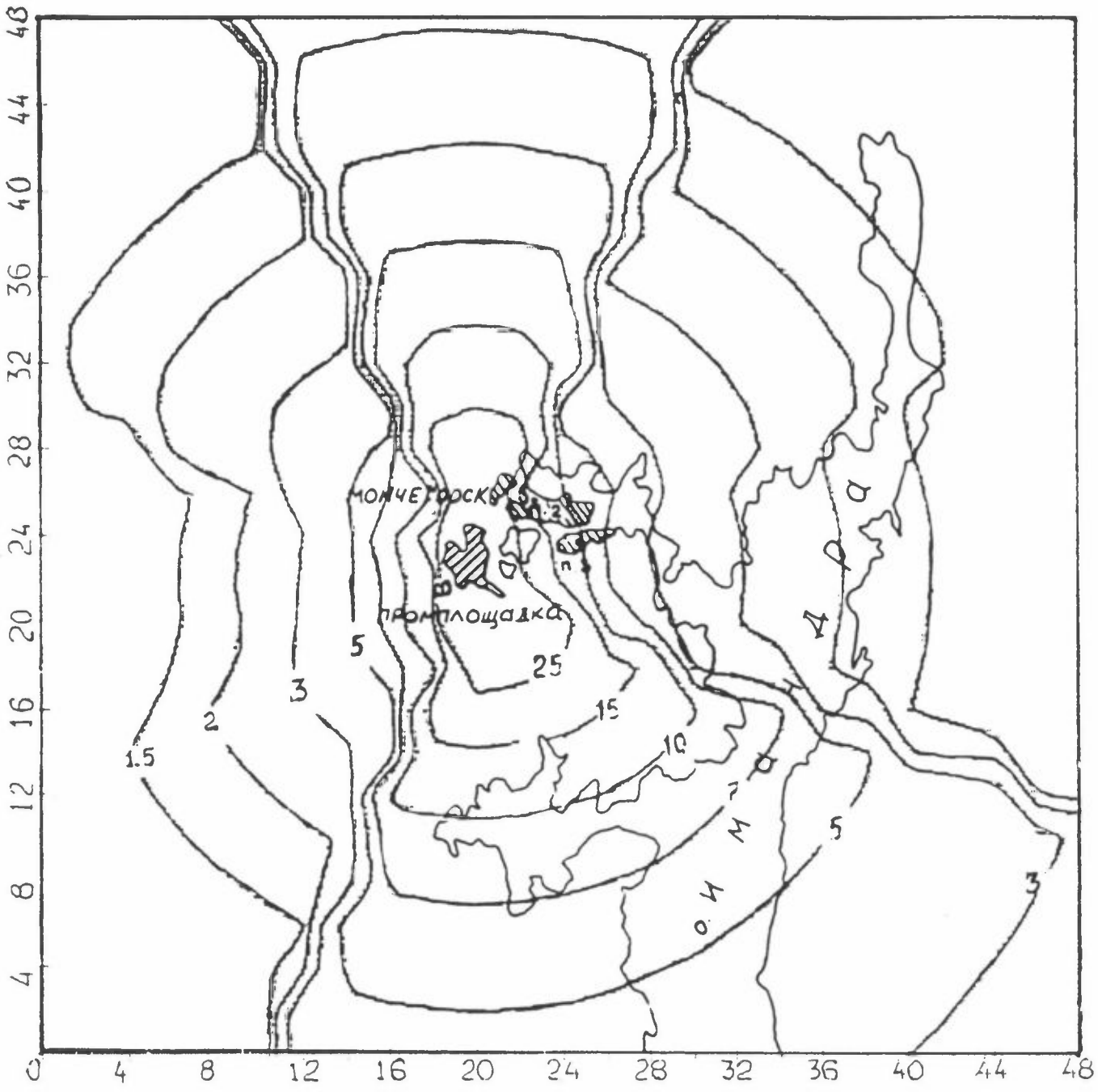


Figure 18: Estimated average concentration of SO_2 in the Pechenganickel company vicinity for winter season
- 95% decrease of emissions for Nikel
- 75% decrease of emissions for Zapoljarnij



Levels of annual concentration :

1	1.50000 ug/m3	2	2.00000 ug/m3
3	3.00000 ug/m3	4	5.00000 ug/m3
5	7.00000 ug/m3	6	10.00000 ug/m3
7	15.00000 ug/m3	8	25.00000 ug/m3

Figure 19: Estimated average concentration of SO_2 (85% - decreasing of source emission)

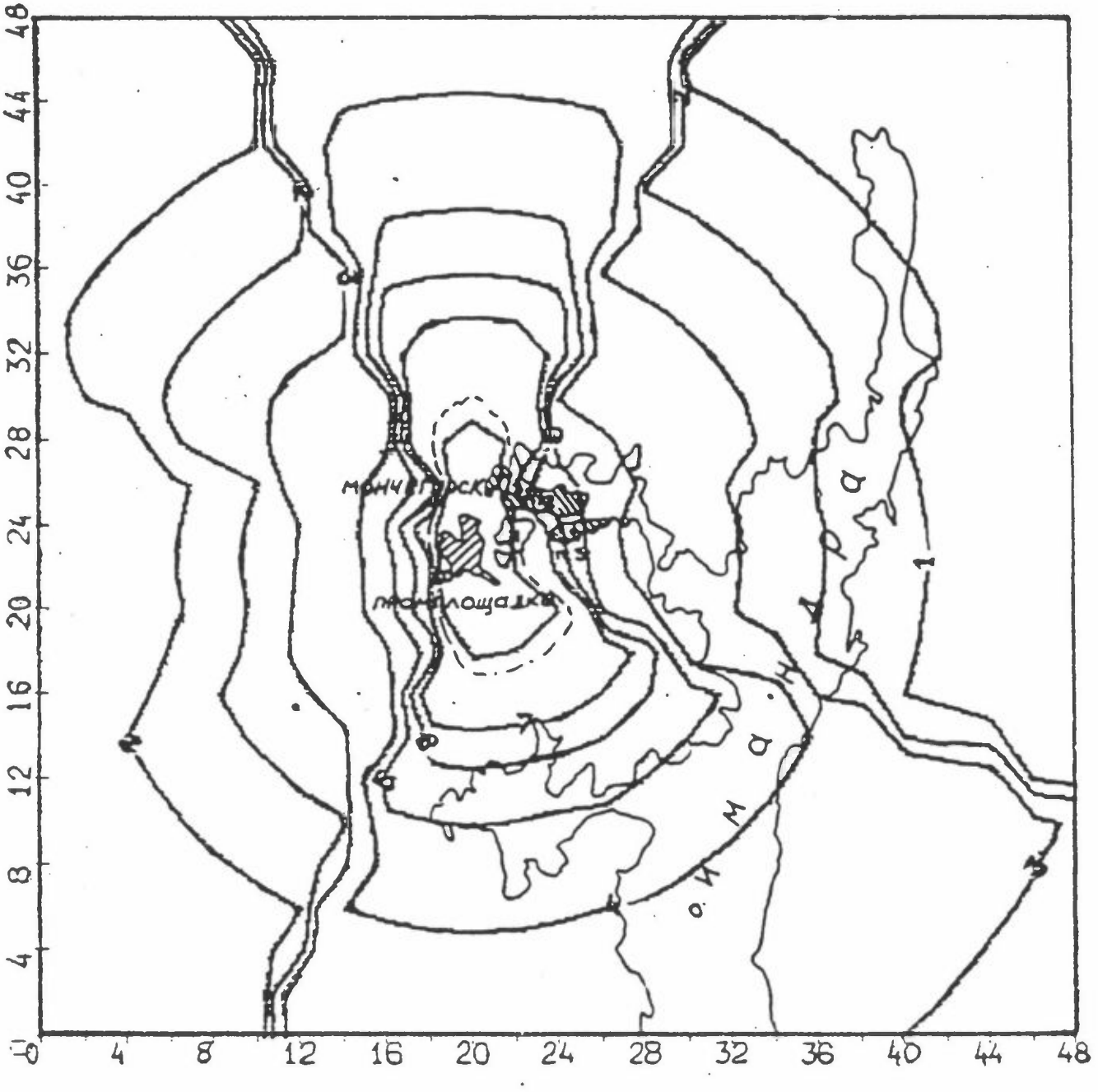


Figure 20: Estimated average concentration of SO_2 (95% - decreasing of source emission)

2.4. Air Pollutants in Sevettijärvi. Summary of the Measurements in 1992

A. Virkkula, M. Mäkinen, T. Pakkanen and R. Hillamo
Finnish Meteorological Institute, Air Quality Department,
Sahaajankatu 22E, SF-00810 Helsinki, Finland

Håkan Johansson and Maria Djupström
Environmental Physics, Department of Physics
Chalmers University of Technology, Gothenburg, Sweden

1. GENERAL

The Sevettijärvi measurement station is located (N 69° 35', E 28° 50'), not far from the Finnish-Norwegian border and about 60 km from the pollution sources in Nikel. The first measurements were taken in the summer of 1991 and the monitoring program has been in full action since the beginning of 1992. The work is part of The Lapland Forest Damage Project. Gaseous air pollutants have been monitored by Differential Optical Absorption Spectroscopy (DOAS) and aerosols by a virtual impactor and a Condensation Particle Counter (CPC). The direction and speed of wind have also been measured.

DOAS determined hourly average concentrations of SO_2, NO_2 and O_3. Aerosol particles were collected by a virtual impactor in two size ranges: fine particles with aerodynamic diameter < 2.5 μm and coarse particles with aerodynamic diameter > 2.5 μm. The filters were changed every second day. Total mass concentration was determined by an electronic microbalance and major ionic species were analyzed by ion chromatography. Trace elements were analyzed during several pollution episodes by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and Atomic Absorption Spectrophotometry (AAS). Some samples were also analyzed by Energy Dispersive X-ray Fluorescence (EDXRF) spectrometer in Gothenburg, Sweden. In addition to the routine measurements, the particle size distributions were measured during one week in March, 1992.

The source areas of SO_2, NO_2, and condensation nuclei were determined generally using wind roses. The source areas and transport routes for some episodes were also analyzed using trajectories.

2. RESULTS

The monthly average concentrations of SO_2, NO_2, and O_3 are presented in Table 1. Most monthly averages of SO_2 were rather low, whereas several fairly high but short peaks were detected (Fig. 1). Statistical analyses of the SO_2 peaks were done. When the SO_2 data were compared with wind data, it was seen that most SO_2 comes primarily from Nikel (Fig. 2a). This was also expected since, by far, the largest emissions in the vicinity come from that area. The average SO_2 concentration in the sector pointing towards Nikel was 32 $\mu g/m^3$. Wind distribution rose (Fig. 2b) shows that wind blows only rarely from Nikel.

The three highest hourly average concentrations of SO_2 in 1992 are given below in $\mu g/m^3$.

July 26: 524 $\mu g/m^3$, November 17: 472 $\mu g/m^3$, April 2: 390 $\mu g/m^3$

Estimated critical thresold concentration of daily averaged SO_2 is 70 $\mu g/m^3$ (Kauppi et al. 1990). Five daily averages exceeding this level were detected during the whole year.

In winter there were much fewer SO_2 peaks than in other times of the year. In summer the peaks lasted the shortest time and also their average exposure (= time integral of concentration) was lower than in other times of the year. Spring and autumn have been the most "active" peak times. The peaks in spring and autumn have also had the highest exposures. Highest daily concentrations occurred in spring and autumn, as well.

SO_2 concentrations have been very similar to those measured at Jäniskoski measurement station (Laurila, Tuovinen, 1991, and Laurila et al., 1991). For example, the 99 % percentile point of the cumulative distribution is 100 $\mu g/m^3$ at both stations. Yearly average concentration at both the stations is about 5 $\mu g/m^3$.

Around some pollution episodes, visibility has decreased significantly, due to fog, either just before, during or just after the detected SO_2 peak. The CPC measurements have shown that most SO_2 peaks occur simultaneously with high particle number concentrations. These condensation nuclei may contribute to formation of fogs. The fact that episodes occur, to which fog is connected, raises an interesting question: what do the fog droplets consist of, when the fog appears just before, after or during the episode? This should be investigated further. The pH of fogs coming from the east should be measured in order to find out whether they are acidic. But, even if the fog itself is not acidic, it makes the vegetation moist. When the pollution plume arrives, SO_2 starts to dissolve in the water on the vegetation. When SO_2 dissolves in an aqueous solution, S will be oxidized and finally form sulphate.

NO_2 concentration has been low all the time, usually around the detection limits (about 0.5 $\mu g/m^3$). When NO_2 and wind data are combined to with wind data, it can be seen that NO_2 comes from almost the same direction as SO_2.

Hourly average concentrations during 1992 of O_3 have been plotted in Fig. 3. Monthly average concentrations and monthly averages of maximum daily concentrations have also been plotted in Fig. 3. At the end of May and at the beginning of June there was a period of high O_3 concentrations. Trajectories for this episode, which has been detected on all measurement stations in Lapland, have been calculated (Tuovinen, Laurila, 1993). They show, that this episode has come from the south: regions between England and Germany.

The CPC measurement data, SO_2 measurement data, weight of filters and wind data have been used in choosing the virtual impactor filters to be analyzed for trace metals. Sulfate and ammonium were predominately associated with fine particles. The mass concentration of sulfate varied consistently with the total mass concentration (Fig. 4) (Selin et al., 1992). The mass concentration of ammonium and potassium correlated clearly, during episode periods, with each other and with total mass concentration. Cl, Na, and Mg were found in both size ranges and there was a strong correlation among them. These ions are typical seasalt ions. Zn and Pb were predominately associated with fine particles and their mass concentration correlated well with each other (Fig. 4). Also, the mass concentration of Ni and Cu in the fine

particle fraction varied consistently with each other. Some correlation was found with the mass concentrations of SO_2 and V in the fine fraction.

The chemical compositions of some pollution episodes have been plotted in Fig. 5. As shown by the trajectory calculation above, the episode at the end of May has arrived from regions between England and Germany. The chemical composition is clearly different from those episodes arriving from Nikel. According to the trajectory analysis, three source areas dominated: 1) the industrial area in and around Nikel, 2) Northern Atlantic, and 3) the rest of Europe.

TABLE 1. MONTHLY AVERAGE CONCENTRATIONS OF GASES.

	SO_2			NO_2			O_3			
	$[SO_2]$	#h	#d	$[NO_2]$	#h	#d	$[O_3]$	$[O_3m]$	#h	#d
JANUARY	1.3	535	24	0.4	256	24	75.0	79.3	534	24
FEBRUARY	1.3	677	29	0.8	343	29	75.5	81.3	673	29
MARCH	2.2	686	31	0.6	44	14	84.1	89.9	685	31
APRIL	11.6	693	30	0.9	278	29	93.0	100.2	693	30
MAY	1.6	722	31	0.4	696	31	88.2	99.3	723	31
JUNE	2.7	681	29	0.5	656	29	74.7	89.1	681	29
JULY	3.4	709	30	0.5	672	30	60.8	70.3	708	30
AUGUST*	11.8	298	13	0.6	288	13	64.2	73.7	298	13
SEPTEMBER	2.8	711	30	0.7	712	30	62.4	75.0	712	30
OCTOBER	1.2	725	31	0.5	723	31	73.0	78.4	721	31
NOVEMBER	17.5	707	30	1.4	697	30	64.7	72.5	707	30
DECEMBER	2.9	736	31	0.7	645	31	71.5	77.4	735	31
YEAR	4.8	7880	339	0.4	7865	321	74.4		7870	339

All concentrations are expressed in $\mu g/m^3$. They are corrected for temperature 0°C according to

$$C_{T=273K} = (T/273K) \times C_{\text{no temperature correction}}$$

#h: Number of hours, when values have been acceptable.
#d: Number of days, when acceptable values exist.
O_3m: Monthly averages of daily O_3 maxima.

* Due to instrument failure, measurements were collected only on 11 days during August.

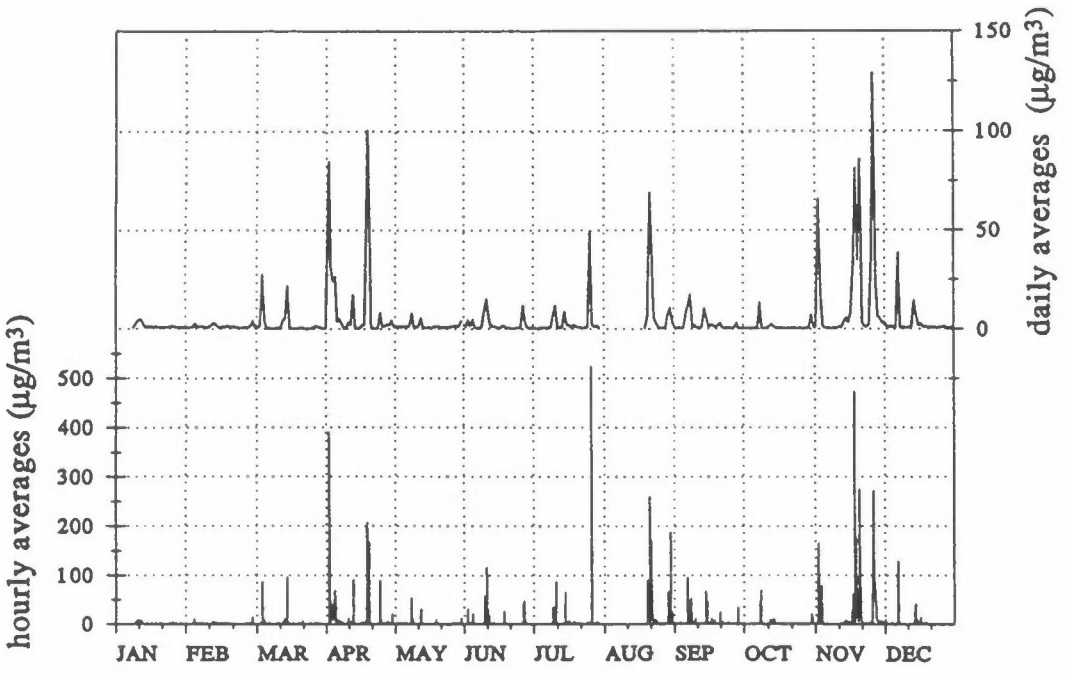


Figure 1. SO_2 concentration at Sevettijärvi in 1992.

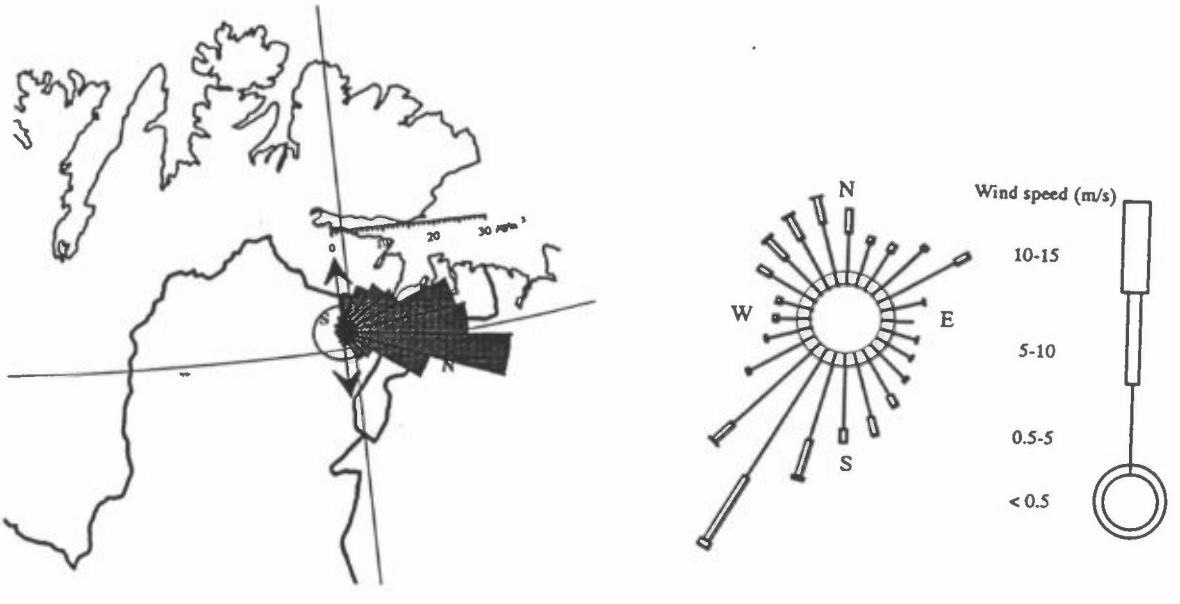


Figure 2. Wind rose of SO_2. a: Average concentrations in each sector, b: Wind distribution in each direction on April 1 - December 31.

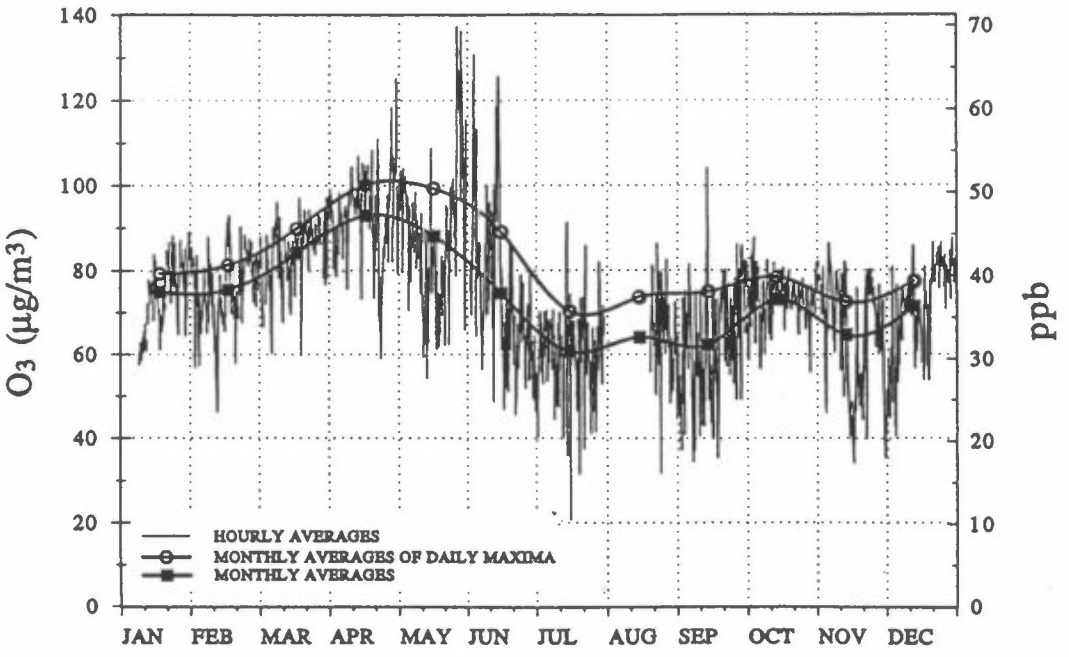


Figure 3. Hourly averages of ozone concentration at Sevettijärvi in 1992.

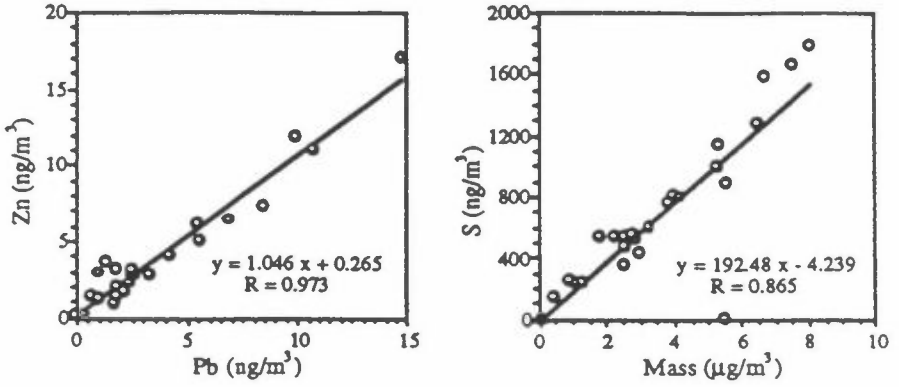


Figure 4. Correlation diagrams Zn-Pb and S-total mass in the fine particles at Sevettijärvi (Selin et al., 1992)

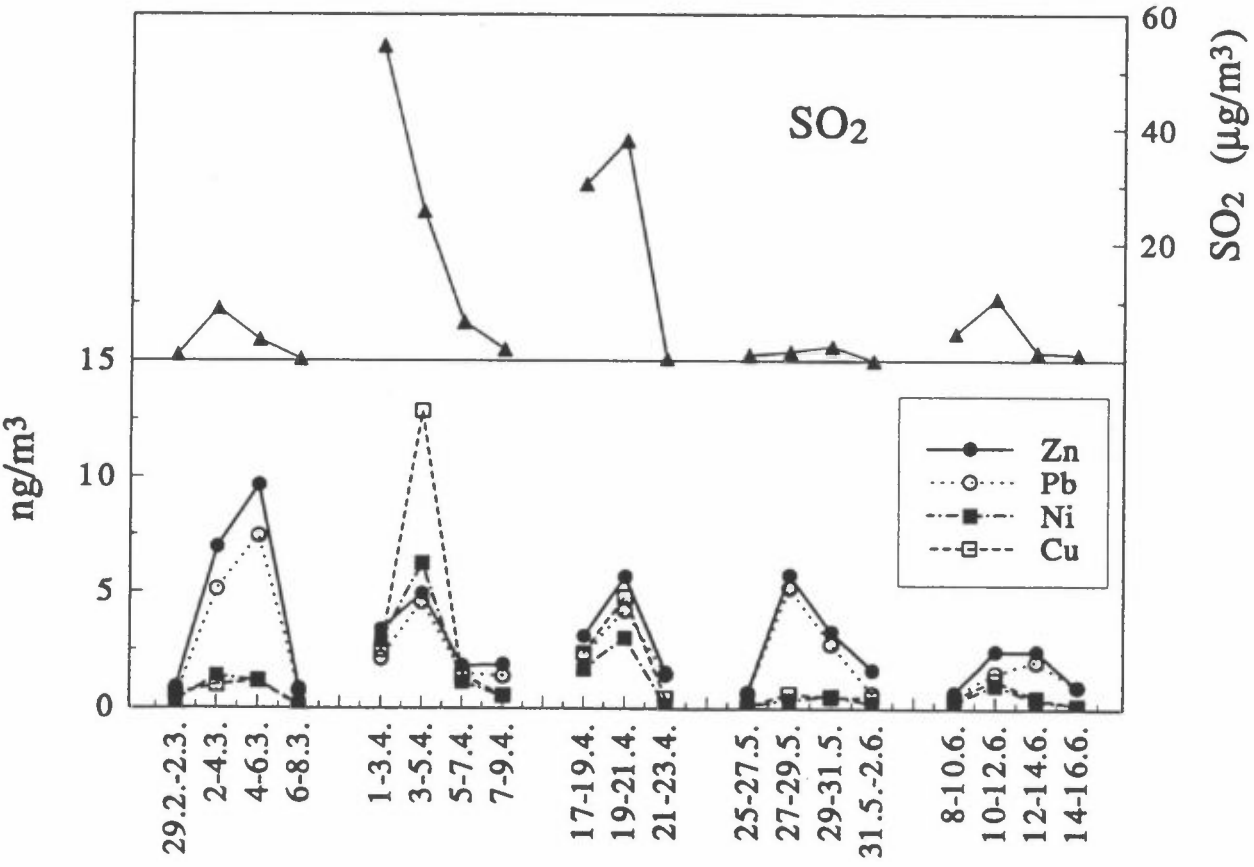


Figure 5. Chemical composition of some pollution episodes at Sevettijärvi. Above also the corresponding two-day averages of SO_2 has been plotted.

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2.5. Variability of sulphur dioxide and ozone concentrations in Northern Finland

Juha-Pekka Tuovinen and Tuomas Laurila
Finnish Meteorological Institute, Air Quality Department,
Sahaajankatu 22 E, SF-00810 Helsinki, Finland

Abstract

We summarize our present understanding of the atmospheric concentrations of oxidised sulphur and ozone in northernmost continental Europe. The following issues are discussed in more detail:

1. *Air pollution monitoring in Northern Finland - past, present, future.*
2. *Temporal and spatial variability of SO_2 concentrations.*
3. *Acid deposition and its origin.*
4. *Impact of the smelter emissions in the Kola Peninsula on air quality.*
5. *O_3 concentrations and exposure as compared to proposed guideline values.*

2.5.1. Introduction

Air pollution from the Kola Peninsula has been the subject of great public concern during this decade, resulting in a considerable amount of monitoring and research activities (e.g. Tikkanen *et al.*, 1992; Sivertsen *et al.*, 1992). From the atmospheric point of view, the Kola Peninsula plays an interesting role being, in addition to Norilsk in Siberia, the only significant source of sulphur dioxide (0.6 Tg a^{-1}) north of the Arctic Circle (Tuovinen *et al.*, 1993). Another relatively new aspect of the concern felt for nature and human health in northern Europe concerns the presence of photochemical pollution, or more specifically elevated tropospheric concentrations of ozone. Even though the episodic enhancement of ozone concentrations is much less frequent in the north compared to Central Europe, episodes do also reach this area (Beck and Grennfelt, 1993).

Sulphur dioxide has been monitored extensively in the border areas between Norway and Russia, resulting in an in-depth characterisation of the local influence of one of the two main sources in the Kola Peninsula, i.e. the Pechenganikel smelter complex (Sivertsen *et al.*, 1992). In this presentation, a survey is made of the variability of SO_2 and O_3 on a regional scale in northernmost Europe, based on recent observations made in Northern Finland. A more extensive study of the role of sulphur pollution, including data on particulate sulphate and acid deposition, has been presented by Tuovinen *et al.* (1993). Finnish measurements of background ozone have been analysed comprehensively by Hakola *et al.* (1991) and Laurila and Lättilä (1993).

2.5.2. Sulphur dioxide

The availability of reliable instruments for continuous monitoring of SO_2 also at low concentrations has opened an important gateway to the understanding of the variability in background air quality. Prior to this, and the recognition of the threat

posed by the industrial activities in the Kola Peninsula, SO_2 was only measured in Northern Finland at two stations with monthly sampling (Kevo and Sodankylä, see Fig. 1). In contrast to these data, continuous (hourly-averaged) data have been obtained since May 1990, when the Finnish Meteorological Institute started measuments at Jäniskoski using a sensitive Thermo Electron TEI-43S pulsed UV fluorescence monitor. Checked against concomitant filter measurements, the quality of these measurements has proved excellent (Markkanen *et al.*, 1992). Later similar instruments were also installed at Sammaltunturi (data in Table 1), Raja-Jooseppi (data not presented here), and at Virolahti in Southern Finland. The Sevettijärvi station, established under the Lapland Forest Damage Project, is equipped with an instrument based on differential optical absorption spectroscopy (Virkkula *et al.*, this report; Virkkula *et al.*, 1993). Results from all these temporally highly-resolved measurements are shown in Table 1. Virolahti, representing the most polluted background area in Finland, is included for comparison. Cumulative frequency distributions of earlier data from Jäniskoski have been presented by Tuovinen and Laurila (1992), whose preliminary data from Sammaltunturi are shown here in a corrected form. It should be noted that the technique employed at Sevettijärvi differs from that at the other stations, most notably in that it integrates over a 1-km horizontal path, and therefore may not be strictly comparable.

The variability of SO_2 concentration in Northern Finland contains three different scales: (1) the Arctic/Atlantic background, (2) episodes of long-range transport from the south and (3) short-term peaks from the Kola Peninsula. The air masses related to the first category contain little SO_2 (often $<<$ 1 $\mu g\ m^{-3}$), as the mean residence time of SO_2 is short compared to transport times from e.g. North America. The second category includes the well-established large-scale influence of the main European source areas. During these episodes the highest daily mean concentrations may reach ~50 $\mu g\ m^{-3}$. Exposure to southern pollution is more probable in winter, when a southerly flow is favoured under typical synoptic conditions. During some winter episodes, trajectory calculations imply that distant Russian sources may also be of significance (Tuovinen *et al.*, 1993). In summer, the frequency of north-easterly winds is at its highest, and the plumes from the Kola Peninsula frequently sweep over Northern Finland, also being clearly distinguishable at the western station of Sammaltunturi. The highest concentrations listed in Table 1 belong to this group. The characteristic duration of these exposures is a few hours.

The local influence of the large source in the Kola Peninsula is spread over much of northernmost continental Europe. However, when this influence is temporally averaged it is diluted so much that almost the whole of Northern Finland lies in the concentration range of 1-5 $\mu g\ m^{-3}$, while 20 $\mu g\ m^{-3}$ is exceeded over areas of several thousand km^2 in Kola and also in a limited area in Norway (Tuovinen *et al.*, 1993; Sivertsen *et al.*, 1992). On the other hand, the concentrations in Northern Finland are clearly higher than those in the remote Arctic and on the Norwegian coast.

The general view of arctic air pollution features elevated winter concentrations and low summer levels, produced meteorologically by variations in the extent of

the Arctic air mass and the location of large-scale atmospheric pressure waves with respect to emission sources situated at lower latitudes in Eurasia (e.g. Barrie, 1986; Ottar, 1989). Local sources alter the characteristics of the sulphur climate so much that over large areas the normal annual cycle of the controlling processes is overshadowed by the seasonal distribution of the local wind direction. This has been observed at Jäniskoski (75 km SW of Nikel) and at Sevettijärvi (60 km W of Nikel) where elevated monthly mean concentrations also occur in summer. At Jergul in Norway (220 km W of Nikel), however, no corresponding enhancement is observable (Tuovinen *et al.*, 1993), although there too the summer concentrations are on average much higher in easterly flow (Tuovinen, 1990).

Table 1: Statistical properties of the hourly-averaged SO_2 concentration ($\mu g\ m^{-3}$) distribution at three stations in Northern Finland (see Fig. 1) and at Virolahti situated in the south-eastern corner of Finland. The data from Sevettijärvi are described in detail by Virkkula et al. (1993).

	Sammal-tunturi 67°58' N 24°07' E 560 m a.s.l.	**Jäniskoski** 68°58' N 28°47' E 118 m a.s.l.	**Sevetti-järvi** 69°35' N 28°50' E 130 m a.s.l.	**Virolahti** 60°31' N 27°41' E 4 m a.s.l.
Arithm. mean				
Jul. - Sept. 1991		5.8		1.2[a]
Oct.- Dec. 1991	1.0	3.3		2.2[a]
Jan. - Mar. 1992	0.9	(1.5)[b]	1.6	3.7[a]
Apr. - Jun. 1992	1.2	(5.5)[c]	5.3	2.2 (2.2[a])
Maximum				
Jul. - Sept. 1991		166		
Oct.- Dec. 1991	45	223		
Jan. - Mar. 1992	56	(137)[b]	97	
Apr. - Jun. 1992	29	(236)[c]	380	28
99th percentile				
Jul. - Sept. 1991		93		
Oct.- Dec. 1991	14	145		
Jan. - Mar. 1992	8.3	(22)[b]	12	
Apr. - Jun. 1992	12	(118)[c]	97	14
90th percentile				
Jul. - Sept. 1991		12		
Oct.- Dec. 1991	2.5	5.5		
Jan. - Mar. 1992	1.9	(1.7)[b]	2.7	
Apr. - Jun. 1992	2.9	(7.8)[c]	7.4	5.0
75th percentile				
Jul. - Sept. 1991		1.4		
Oct.- Dec. 1991	0.7	1.2		
Jan. - Mar. 1992	0.7	(0.7)[b]	1.2	
Apr. - Jun. 1992	0.9	(2.9)[c]	1.7	2.5
50th percentile				
Jul. - Sept. 1991		0.6		
Oct.- Dec. 1991	0.2	0.4		
Jan. - Mar. 1992	0.3	(0.4)[b]	0.7	
Apr. - Jun. 1992	0.3	(0.9)[c]	1.0	1.4

a) Based on daily filter sampling and ion chromatography. b) 1 January - 12 February. c) 9 April - 12 June.

It is interesting to compare the results of the spring of 1992 from the northern sites with those from Virolahti, which is situated close to the main SO_2 source regions in Finland and Central Europe, and regionally influenced by e.g. the large Estonian power plants and the St Petersburg region. In the available concurrent data of three months the highest short-term concentrations are about the same at Virolahti and Sammaltunturi but, as the southern coast is influenced by a variety of sources, the lower end of the distribution is higher there than in western Lapland (the 25th percentile at Virolahti in this data is about 0.7 $\mu g\ m^{-3}$). Comparison of a longer record of observations implies that, except for the period of the winter maximum of typically 3 months, mean concentrations in the north-eastern corner exceed the levels experienced in southern Finland.

Concerning a general description of pollution climate and reporting of results, one single parameter is clearly insufficient under conditions like those of Northern Finland, where occasional peaks are superimposed on a low base level. The arithmetic mean obscures the high peak-to-mean ratio, and therefore much of the essential variation. In addition, when calculated from these kind of data, the arithmetic mean and the lowest percentiles, including the median, may include a significant relative error due e.g. to difficulties in setting the zero level.

2.5.3. Ozone

A summary of recent observations of surface ozone in Northern Finland is presented in Table 2 in the form of parameters that have been proposed in definitions of critical ozone levels. The mean concentrations in Table 2 are calculated from the beginning of April to the end of September during daytime (10-17) hours according to the definition of the guideline value (25 ppb) for the protection of vegetation by the Nordic Council of Ministers (NMR). For short-term concentrations, maximum 1-hour averages have been suggested, e.g. 75 ppb by the UN Economic Commission for Europe (UN-ECE) and 100 ppb by the Commission of the European Communities. For a summary of various guideline values, see Laurila and Lättilä (1993).

As an alternative to these kinds of indices, cumulative types which accumulate ozone concentrations above a threshold value have gained popularity in North America in relating the observed harmful effects to ambient ozone concentrations (e.g. Lefohn *et al.*, 1989). In Europe, it has been suggested recently that critical levels could be estimated based on the exposure above a threshold value of 40 ppb for daylight hours during the growing season (UN-ECE, 1992). This definition has been used in this presentation, though it is important to recognize that the value of this kind of exposure index depends strongly on the chosen threshold concentration (Laurila and Lättilä, 1993; Tuovinen and Laurila, 1993). When calculating the exposures presented in Table 2, the growing season was assumed to be determined by the period when the daily average temperature is higher than 5 °C, and the daylight hour defined as one for which the solar elevation exceeds 3°.

Table 2: Arithmetic mean and the maximum of 1-hour averaged ozone concentrations, the exposure of ozone above a 40-ppb threshold at three stations in Northern Finland (see Fig. 1) and at Virolahti situated in the south-eastern corner of Finland. The data from Sevettijärvi are described in detail by Virkkula et al. (1993). The mean is calculated for a daily 7-hour period (10-17) from April to September. The exposure is calculated for daylight hours during the growing season. Results are not corrected for missing data.

	Oulanka	**Sammal-tunturi**	**Sevetti-järvi**	**Virolahti**
	66°19' N	67°58' N	69°35' N	60°31' N
	29°25' E	24°07' E	28°50' E	27°41' E
	310 m a.s.l.	560 m a.s.l.	130 m a.s.l.	4 m a.s.l.
Mean (ppb)				
1990	34			34
1991	34			38
1992	35	36	37	39
Maximum (ppb)				
1990	71			71
1991	59			68
1992	72	79	65	72
Exposure (ppb h)				
1990	390			2870
1991	830			3490
1992	4740	3690	2570	7020

At every station the mean concentrations exceed the guideline value of 25 ppb suggested for daytime during the growing season by UN-ECE and NMR, the latter of which considered the growing season to extend from April to September. This period may not be an appropriate value for the north, though the situation with respect to the 25-ppb level does not change if another period is chosen, the present-day concentrations being seldom below this value during daytime. Maximum short-term concentrations may occasionally exceed 75 ppb, but the exceedance of 100 ppb seems highly improbable under present conditions. In the light of these parameters, the differences between the southern and northern parts of Finland do not seem to be significant, and more or less the same is true for the year-to-year variations at different stations.

A different picture emerges, however, if one considers the 'excess' ozone or the accumulated exposure. This index gives a much wider relative range of values than the averages. It is also more dependent on the degree of photochemical pollution and therefore more suitable for use in policy-making (Laurila and Lättilä, 1993). However, it should be noted that there is a clear but nonlinear relation between these indices, whereas nothing is implied about the connection

between the index and the actual response of vegetation (Tuovinen and Laurila, 1993). The absolute value of the exposure, E, is also sensitive to changes in the threshold concentration, β: $(\beta/E)dE/d\beta \approx -4...-6$, if $\beta = 40$ ppb, as calculated from the 1992 data.

Ozone exposures are accumulated during a limited number of days, this number being the smaller the higher the threshold. In the north, the main part of the total exposure is accumulated in spring when the highest concentrations occur, possibly within just a few episodes (Laurila and Lättilä, 1993). This makes the definition and application of an exposure-based index problematic, since the index becomes highly sensitive to the start of the accumulation period, as illustrated by Tuovinen and Laurila (1993). In addition, there may exist especially sensitive growing periods for certain plants.

A typical episode of elevated ozone concentrations is depicted in Fig. 2. Formation of a high pressure area over southern Scandinavia makes the arctic air mass withdraw temporarily from northern Fennoscandia and the flow become southerly. For a few days, air rich in ozone and its precursors is advected from Central Europe clockwise to northernmost Europe over the North Sea, as shown by the trajectories. In these favourable conditions (see temperature in the upper figure) ozone is produced in the boundary layer along the path, and as depletion by dry deposition to a water surface is minimal, concentrations become strongly elevated.

2.5.4. Conclusions

The present routine measurements of background air quality provide a full picture of sulphur dioxide and ozone in Northern Finland. Sulphur dioxide concentrations vary strongly in time and space in this area. This variation is to a large extent due to the regional influence of large emissions in the Kola Peninsula, producing distinct features in the sulphur climate. Whereas the range of mean SO_2 concentrations covers several decades from those typical of the vicinity of intense sources to those of the clean Atlantic, ozone shows the northwards slowly decreasing gradient of the main precursor regions' influence. Episodes of photochemically-enhanced ozone concentrations are also observed in Northern Finland. Proposed critical levels of ozone are reached everywhere, and those of SO_2, and sulphur deposition derived from this, are reached locally in the north-eastern corner of Finland. This basic picture seems to be in accordance with observations of microscopic injuries in pine needles. A recent study by Sutinen *et al.* (1993) indicates that ozone-specific symptoms are found widely in Northern Finland, while those related to sulphur pollution are only abundant within the area experiencing the highest SO_2 concentrations.

2.5.5. References

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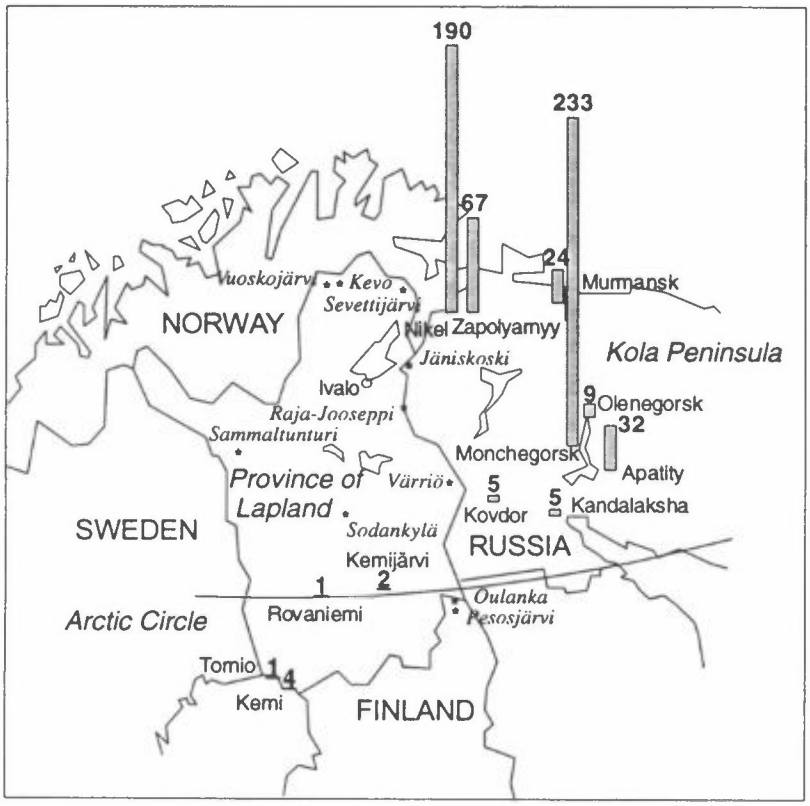
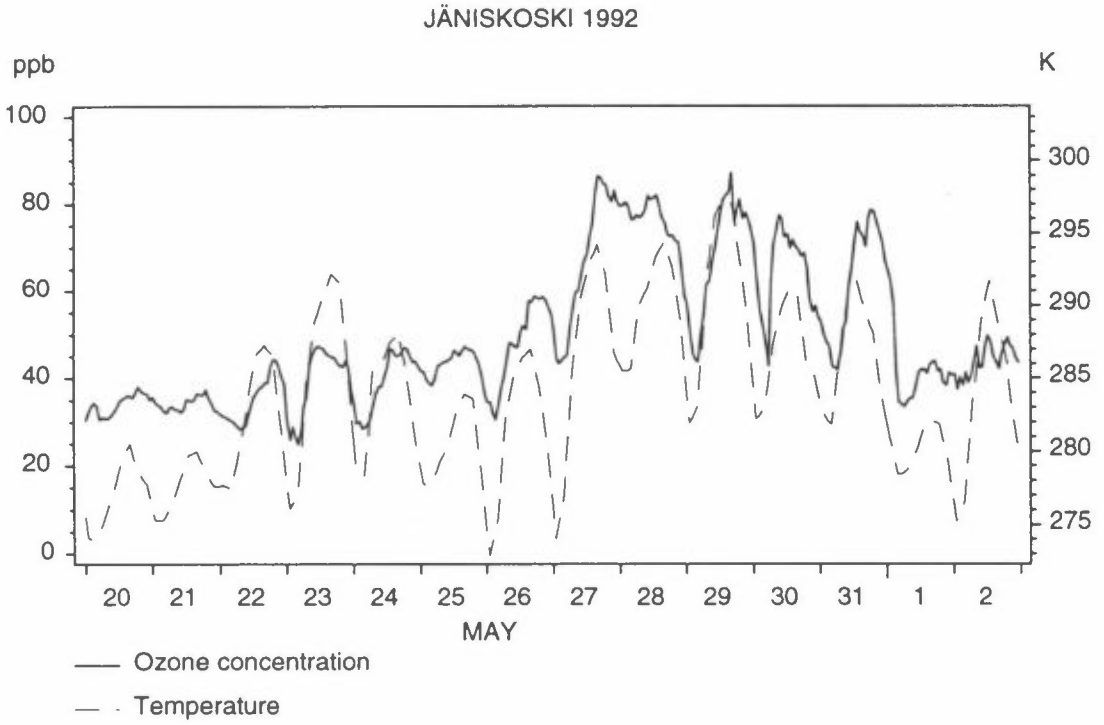


Station	*Established*	*Network*
Sodankylä	*Jan. 1970*	*N/B*
Kevo	*Apr. 1972*	*N*
Vuoskojärvi	*Nov. 1987*	*I*
Pesosjärvi	*Jul. 1988*	*I*
Oulanka	*Oct. 1989*	*E*
Värriö	*Dec. 1989*	*S*
Jäniskoski	*May 1990*	*E/S*
Sammaltunturi	*Sept. 1991*	*S*
Sevettijärvi	*Sept. 1991*	*S*
Raja-Jooseppi	*Aug. 1992*	*S*

N = National programme
B = WMO BAPMoN
I = ECE Integrated Monitoring
E = ECE EMEP
S = Special programme

Figure 1: Measurement stations and emission sources. The locations of measurement stations in Northern Finland run by the Finnish Meteorological Institute are indicated by asterisks. The bars indicate the annual SO_2 emissions in 1990 from the Kola Peninsula in Russia and from the province of Lapland in Finland in Gg (10^3 tonnes) of SO_2 (Tuovinen et al., 1993). Network refers to different measurement programmes (for details, see e.g. Leinonen & Juntto, 1992). Sulphur dioxide and ozone are monitored using continuous analysers at Jäniskoski, Raja-Jooseppi, Sammaltunturi and Sevettijärvi. Jäniskoski is a Russian station belonging to the international monitoring programme EMEP (code SU1, called Rayakosky within EMEP). It was modernised by the Finnish Meteorological Institute in 1990 and has since been run in co-operation between Finland and Russia.



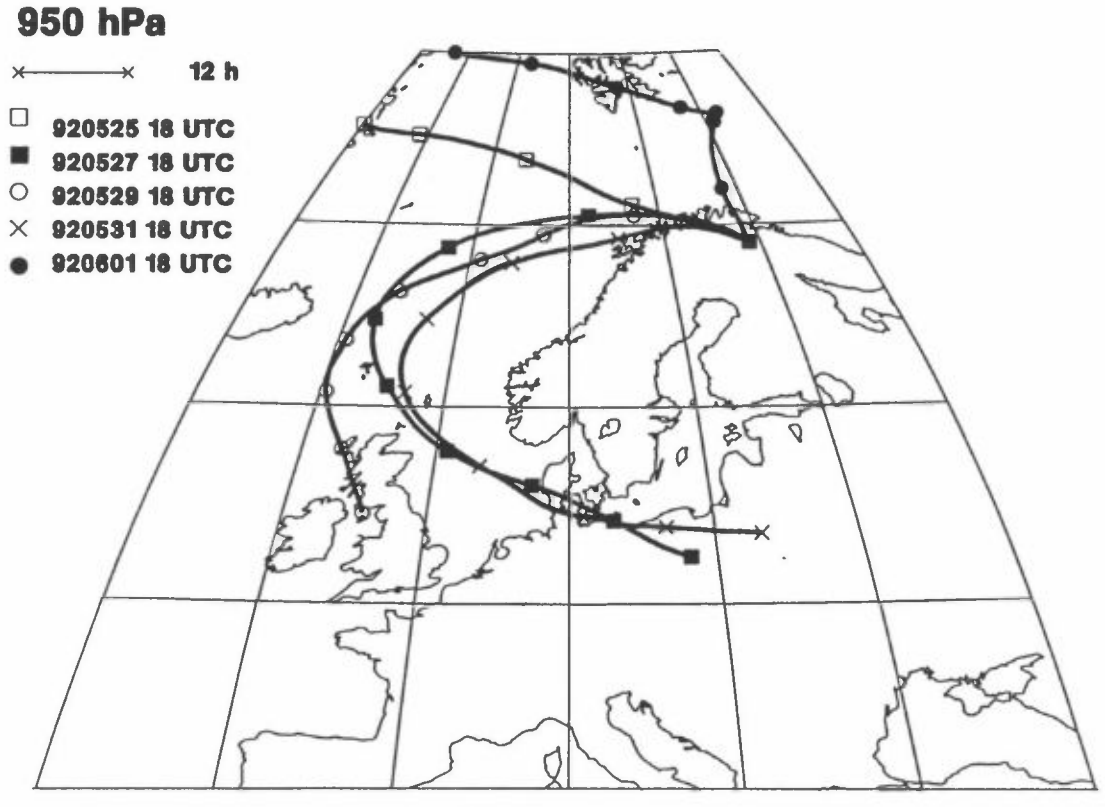


Figure 2: A typical ozone episode in Northern Fennoscandia. The upper figure shows the time series of O_3 concentration at Jäniskoski (left scale) and surface temperature at a nearby station (right scale). The lower figure shows the concurrent three-dimensional back trajectories arriving at Jäniskoski at the 950 hPa level. The date indicates the arrival time.

2.6. Modelling the Dispersion of Air Pollution from the Nikel Smelters

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

Abstract

The Norwegian Institute for Air Research (NILU) has performed dispersion calculations of air pollution from the nickel smelters in Kola.

The model used in the calculations of long term average concentrations is a Gaussian type dispersion model. The model calculates concentrations and dry deposition of gasses and particles with varies sizes in a given grid net. The plume rise is calculated according to Briggs formulas. The height dependency of the wind is described by a power law wind profile. The model takes also into account the effects of buildings. The input to the model is emission data for up to 50 point sources and line sources together with a frequency distribution of the wind and stability.

The emissions of air pollutants from the nickel smelters were presented by Artobolewski in 1989. On the expert group meeting in Apatity in March 1993, NILU received new annual data for the sulphur dioxide (SO_2) emissions for the period 1980-1992 (Ryaboshapko, 1993). This information has been used in the calculations of annual average SO_2 concentrations for 1990 to 1992.

The results from the modelling of the long term average concentrations of SO_2 for the period 1989-1992 will be presented. The summer average dry deposition values for nickel (Ni) and cupper (Cu) for the period 1990-1992 has also been estimated. Episodes will be discussed based upon calculations performed in 1991. Plans for use of mesoscale puff trajectory type models during selected air pollution episodes will be briefly discussed.

2.6.1. Introduction

The Norwegian Institute for Air Research (NILU) has performed model calculations of the dispersion of air pollution from the nikel smelters at Kola. The NILU type dispersion models have been applied for estimates of SO_2 concentrations as monthly and seasonal averages and for short term average concentrations during air pollution episodes. Model descriptions and preliminary results were presented by Hellevik and Sivertsen (1991). Results from air quality modelling were also presented by Sivertsen et al. (1991).

2.6.2. Model description.

2.6.2.1. Long-term averages

The model used in the calculations of long term average concentrations is a Gaussian type dispersion model. The model calculates concentrations and dry depositions of gases and particles with varies sizes in a given grid net. The plume rise is calculated according to Briggs formulas. The height dependency of the wind is described by a power law wind profile. The model takes into account the effects of buildings. The input to the model is emission data for up to 50 point

sources and line sources together with a frequency distribution of the wind and stability. The model take into account building induced turbulence, and separates low sources and high sources. Different meteorological data can be used for different categories of sources.

2.6.2.2. Episodes

A puff-trajectory model has been used to calculate transport and dispersion of air pollution during so called air pollution episodes. The model can be used for a great number of sources and receptor points. The meteorological input is given for meteorological time steps of 1 hour. The model treats the emission that is released from a source as a series of puffs. Constant meteorological conditions is assumed in each time step. In each time step the puff centre is calculated and a Gaussian distribution is assumed. Each puff has a centre and a volume that is determined by the wind, the atmospheric stability and the time since the release from the source. The plume rise is calculated according to Briggs formulas.

2.6.3. Emissions

The emissions of air pollutants from the nikel smelters were presented by Artobolewski in 1989. On the expert group meeting in Apatity in March 1993, NILU received updated annual data for the sulphur dioxide (SO_2) emissions for the period 1980-1992 (Ryaboshapko, 1993). Table 1 presents the emissions in 1989 given for the different sources in Nikel, Zapoljarnij and Kirkenes.

Table 1: Maximum emissions of SO_2 from the industrial sources in Nikel, Zapoljarnij and Kirkenes in 1989.

Source nr.	Emission of SO_2 (g/s)	Stack height (m)	Tempera-ture (K)	Release velocity (m/s)	Stack diameter (m)	Location
1	364	35	292	3.0	6.5	Nikel
2	11	32	292	3.4	3.2	Nikel
3	69	30	292	6.9	1.4	Nikel
4	27	35	292	2.9	4.2	Nikel
5	71	30	292	3.6	1.8	Nikel
6	107	35	292	3.6	4.2	Nikel
7	71	35	292	2.2	11.4	Nikel
8	14	10	292	23.4	0.8	Nikel
9	27	35	292	2.3	3.0	Nikel
10	34	35	292	6.6	2.0	Nikel
11	7	30	292	7.9	1.2	Nikel
12	17	30	292	7.5	1.0	Nikel
13	5	30	292	8.9	0.6	Nikel
14	5	30	292	8.9	0.6	Nikel
15	5	40	292	1.0	3.8	Nikel
16	7	20	342	12.0	0.8	Nikel
17	7	20	292	0.4	4.0	Nikel
18	23	15	372	10.5	1.3	Nikel
19	21	15	372	10.5	1.3	Nikel
20	14	20	292	11.1	0.8	Nikel
21	11	20	292	18.7	0.9	Nikel
22	34	15	292	18.8	1.5	Nikel
23	139	10	292	1.7	1.8	Nikel
24	20	30	292	8.4	0.8	Nikel
25	243	32	292	10.6	2.6	Nikel
26	27	35	292	8.9	2.0	Nikel
27	17	30	292	9.8	1.2	Nikel
28	34	30	292	6.2	2.0	Nikel
29	30	23	292	12.1	1.7	Nikel
30	7	30	292	7.9	1.2	Nikel
31	3	30	292	11.7	0.8	Nikel
32	47	30	292	16.3	1.6	Nikel
33	1286	150	392	8.8	5.0	Nikel
34	3549	160	372	10.2	6.0	Nikel
35	1202	160	392	6.6	6.0	Nikel
36	14	40	292	13.8	0.6	Nikel
37	5	40	292	9.9	1.2	Nikel
38	7	40	292	23.1	0.8	Nikel
39	32	90	373	3.0	4.0	Nikel
40	5260	100	390	14.1	4.0	Zapoljarnij
41	171	80	453	14.2	3.1	Zapoljarnij
42	83	90	433	6.0	3.5	Zapoljarnij
43	27	30	390	10.0	4.0	Kirkenes

In the last years the emissions from the nikel smelters have been reduced. Figure 1 shows the trend in the emission reductions together with the annual variation in the emissions in 1990. To calculate the annual averaged concentrations in the years 1989 to 1992, the emissions from the different sources in 1989 shown in Table 1 were scaled with the annual emission data given in Table 2.

Table 2: Annual emissions of sulphur dioxide tonnes SO_2/y

Year	Nikel	Zapoljarnij
1980	313.2	69.8
1981	289.9	70.5
1982	292.7	65.1
1983	293.2	75.5
1984	290.5	74.9
1985	274.9	79.3
1986	261.1	81.5
1987	257.8	79.7
1988	211.5	78.6
1989	199.6	77.8
1990	190.1	67.3
1991	190.0	68.0
1992	181.0	70.0

2.6.4. Long term average concentrations of SO_2

To obtain a best possible description of the dispersion conditions for the low and elevated sources, NILU has used the meteorological measurements at Viksjøfjell to describe the transport of the emissions from the elevated sources. To describe the transport of the emissions from the low sources the meteorological measurements in Svanvik were used.

Monthly average concentrations of SO_2 were estimated for March and July 1992 to show the variation of the concentration pattern in winter compared with summer. Figure 2 shows the average concentrations of SO_2 in March 1992. The concentration pattern is stretched towards the north east because of prevailing winds from around south west. The figure shows very strong gradients west of Svanvik.

Figure 3 shows the average concentrations of SO_2 in July 1992. Compared with the concentration pattern estimated for March, the pattern is stretched towards the south due to the prevailing winds from the north in the summer season. The differences in the concentration pattern is caused by the annual variation of the prevailing wind regimes. During winter cold winds are blowing from the continent towards open sea water. In summer there is a prevailing northerly wind from the cold arctic ocean towards the heated continent. The concentration gradients west of Svanvik are sharpest during the winter season.

Table 3 shows both the estimated and observed concentrations of SO_2 for March and July 1992. The table shows also the estimated and observed long term annual averages of SO_2 for the years 1989,1990,1991 and 1992.

Table 3: Observed (O)and estimated (E) concentrations of SO_2 ($\mu g/m^3$) for the given periods.

Period		Viksjøfjell	Svanvik	SOV1	Majavri	SOV3
July 1992	(O)	21	6			
	(E)	13	30	13	27	7
March 1992	(O)	64	22			
	(E)	38	30	11	47	28
Year 1989	(O)	44	12			
	(E)	24	18	14	58	20
Year 1990	(O)	32	14	12	53	35
	(E)	23	28	15	53	20
Year 1991	(O)	36	12	11	61	46
	(E)	25	30	15	55	28
Year 1992	(O)	26	7	11	50	
	(E)	23	30	12	49	18

Table 3 shows that the estimated and observed values of SO_2 are comparable for the stations located in the mean wind direction. The estimated annual average concentrations for SO_2 at Viksjøfjell is lower than the observed values. The difference between the estimated and observed values decrease from 1989 towards 1992, when the observed and estimated values are almost equal.

The observed values for Svanvik is much lower than the estimated concentrations of SO_2. This is due to the very strong concentration gradients which is not reflected in the simple Gaussian type model. The station is located close to the sources and not in the mean wind direction. The grid size in the calculations is 5 km. The estimated concentrations averaged over one grid square are therefore higher than the observed and real values.

The observed and estimated concentrations of SO_2 at SOV1 and at
Maajavri gives a good correlation with observations because the monitoring sites are located in the mean wind direction in reasonable distances from the sources. At SOV3 the observed SO_2 concentrations are higher than the estimated values.

The Figures 4 to 8 shows the annual average concentrations of SO_2 for 1989-1992.

The largest uncertainties connected to the calculations are:

The observed meteorological measurements at Svanvik describing the local dispersion conditions around Nikel. Small changes in the local transport direction at Nikel could give large differences in the estimated concentration at Svanvik.

The emissions is divided in low and elevated sources. The maximum height of the "low sources" is about 40 meters. Wind observations from Svanvik have been applied to estimate transport for all sources with height less than 40. Some of the higher of these sources have probably been transported by a more regional scale wind pattern reflected by wind measurements at Viksjøfjell. A different use of meteorological input data could give a better agreement between observed and estimated concentrations at Viksjøfjell and SOV3.

2.6.5. Dry deposition of nickel and copper

In addition to the calculations of the long term averaged SO_2 concentrations, the dry deposition of copper and nickel in the summer season were estimated.

In earlier calculated dry deposition of copper and nickel (Sivertsen et al., 1991) the particle size distribution was assumed as presented in Table 4.

Table 4: The size distribution of the particles containing copper and nickel.

Particle size	Deposition velocity	Distribution
x < 2 µm	0.05 cm/s	15%
2 µm < x < 5 µm	0.7 cm/s	35%
5 µm < x < 10 µm	1.0 cm/s	35%
10 µm < x < 20 µm	2.0 cm/s	10%
20 µm < x	2.5 cm/s	5%

Observed and estimated values of copper and nickel concentrations are shown in table 5. The observed concentrations of nikel were lower than the estimated values. The size distribution of the particles assumed in table 4 gives too many small particles. A greater part of heavy particles will increase the estimated dry deposition of copper and nickel near the sources, leading to reduced concentrations at greater distances. Figure 9 shows the estimated dry deposition of nickel.

Table 5: Observed and estimated concentrations of nickel (ng/m³) at Viksjøfjell and Svanvik 1990.

Station	Measured	Estimated
Viksjøfjell	18.6	25.0
Svanvik	2.9	40.0

2.6.6. Future work

Selected episodes will be studied in the near future, and model estimates will be performed for the following episodes:

26-29 July 1991
1-5 April 1992
27-29 June 1992

All these episodes were characterized by high pressure situations, low wind speed conditions and high SO_2 concentrations at several of the monitoring sites.

The calculations will give the time variation of the concentration pattern during the episodes. Concentrations will be estimated for Viksjøfjell and Svanvik together with selected areas given by the terrestrial group under the joint Norwegian-Russian Commission on Environmental Co-operation.

The calculations using the puff-trajectory model will also give a maximum concentration pattern during the selected episodes.

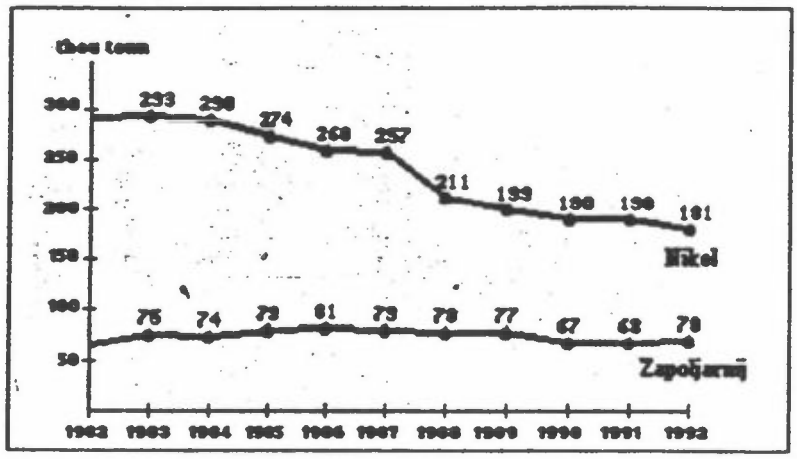
In addition there will be given a maximum concentration pattern during the summer season 1992 on a monthly basis. There will also be given a frequency distribution of hours exceeding certain limits given by the terrestrial expert group.

2.6.7. References

Hellevik, O., Sivertsen, B. (1991) Air quality in the border areas between Norway and USSR. Model description and preliminary modelling results. Lillestrøm (NILU OR 23/91).

Sivertsen, B., Hagen, L.O., Hellevik, O., Henriksen, J.F. (1991) Luftforurensninger i grenseområdene Norge/Sovjetunionen, januar 1990-mars 1991. Lillestrøm (NILU OR 69/91).

a)



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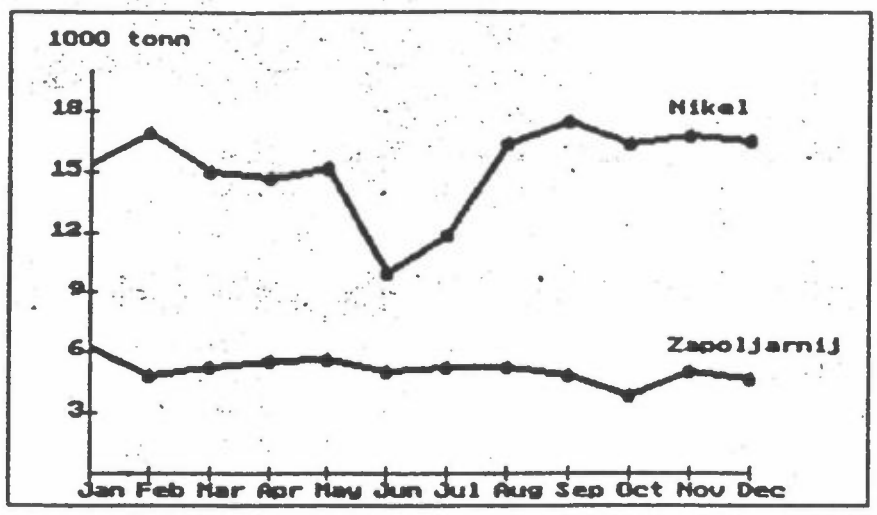

Figure 1: a) The annual emissions from the Pechenganickel complex in the years 1982-1992.
b) The monthly emissions from the Pechenganickel complex in 1990.

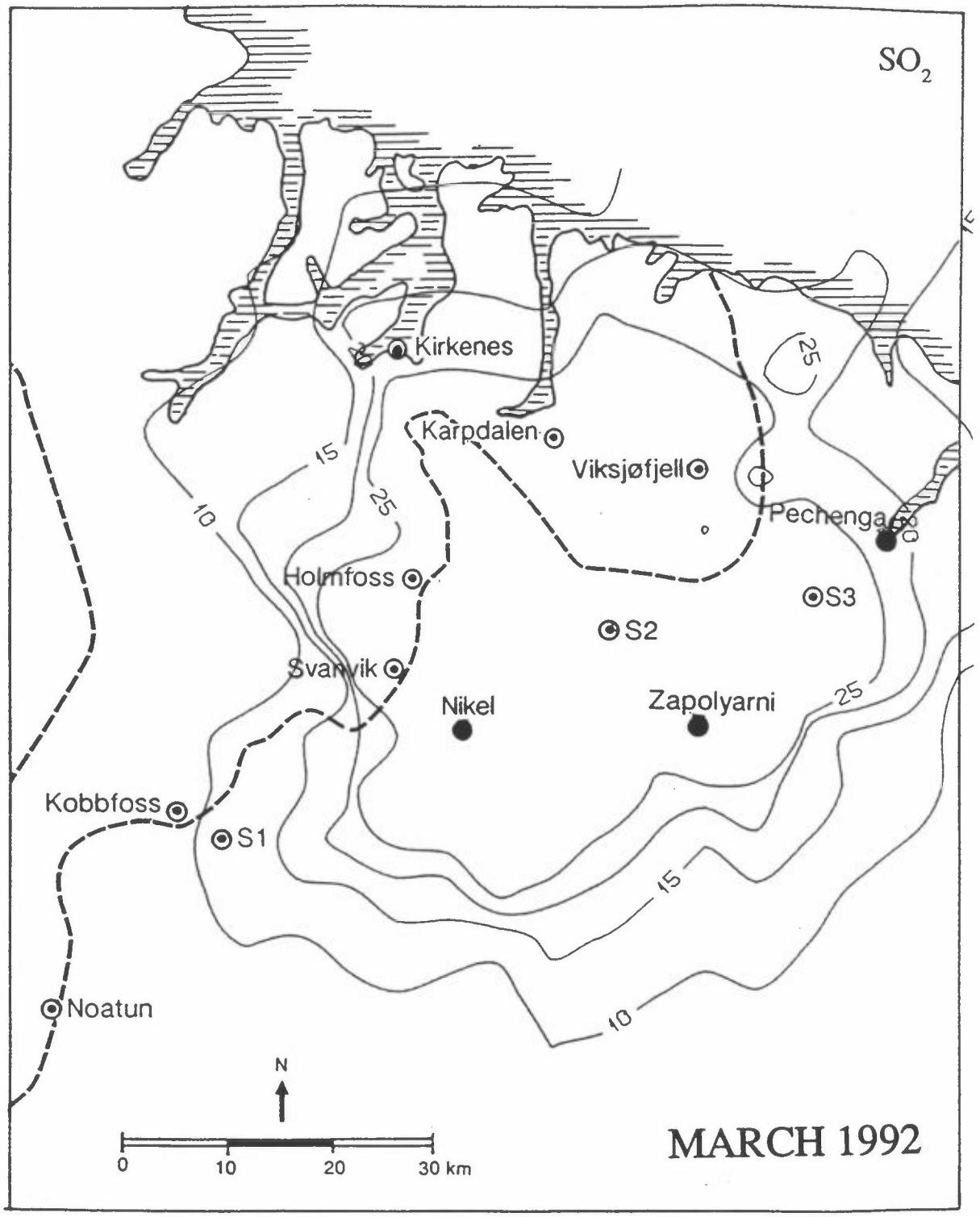

Figure 2: Monthly averaged concentrations of SO_2 (µg/m³) in March 1992.

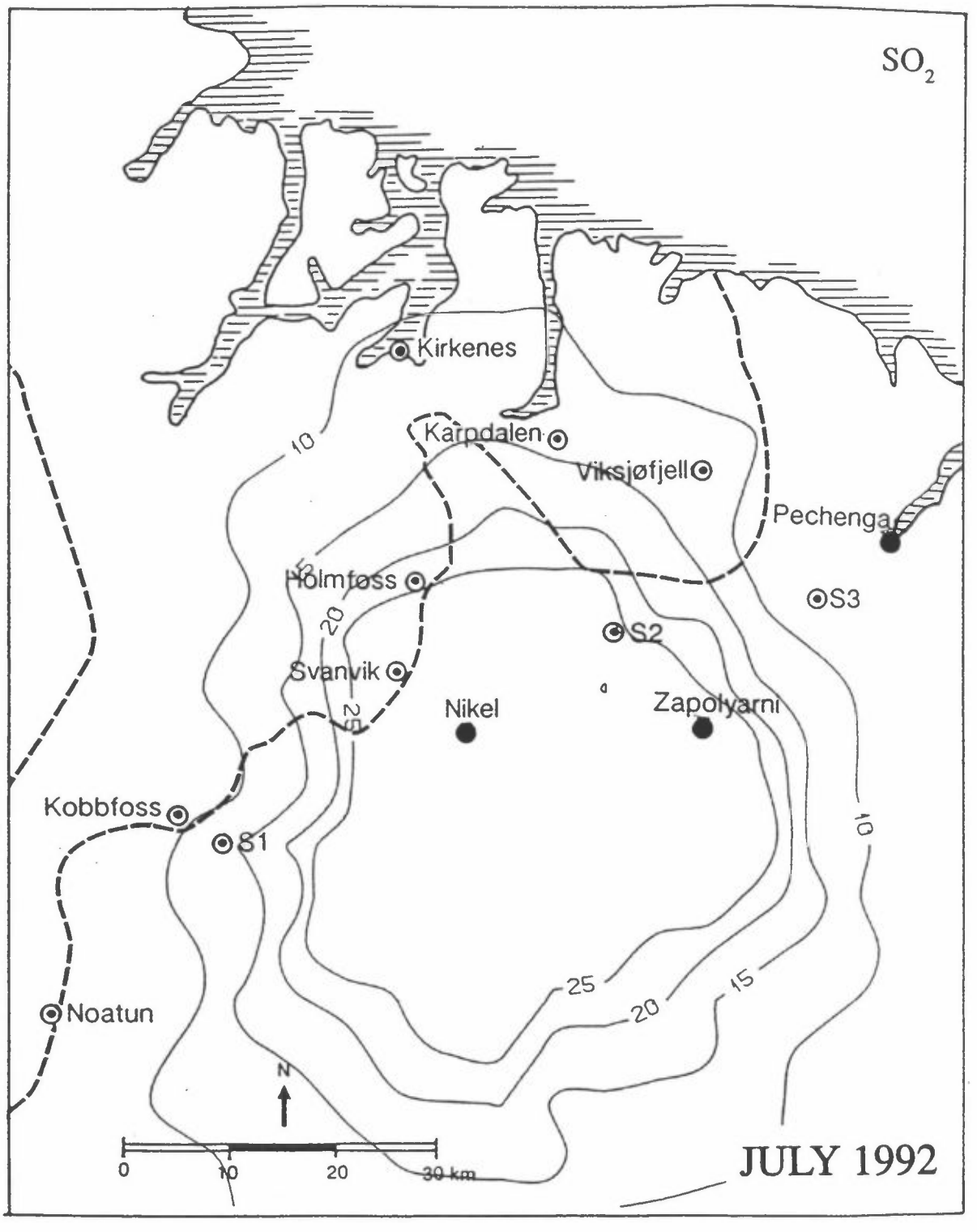

Figure 3: Monthly averaged concentrations of SO_2 (µg/m³) in July 1992.

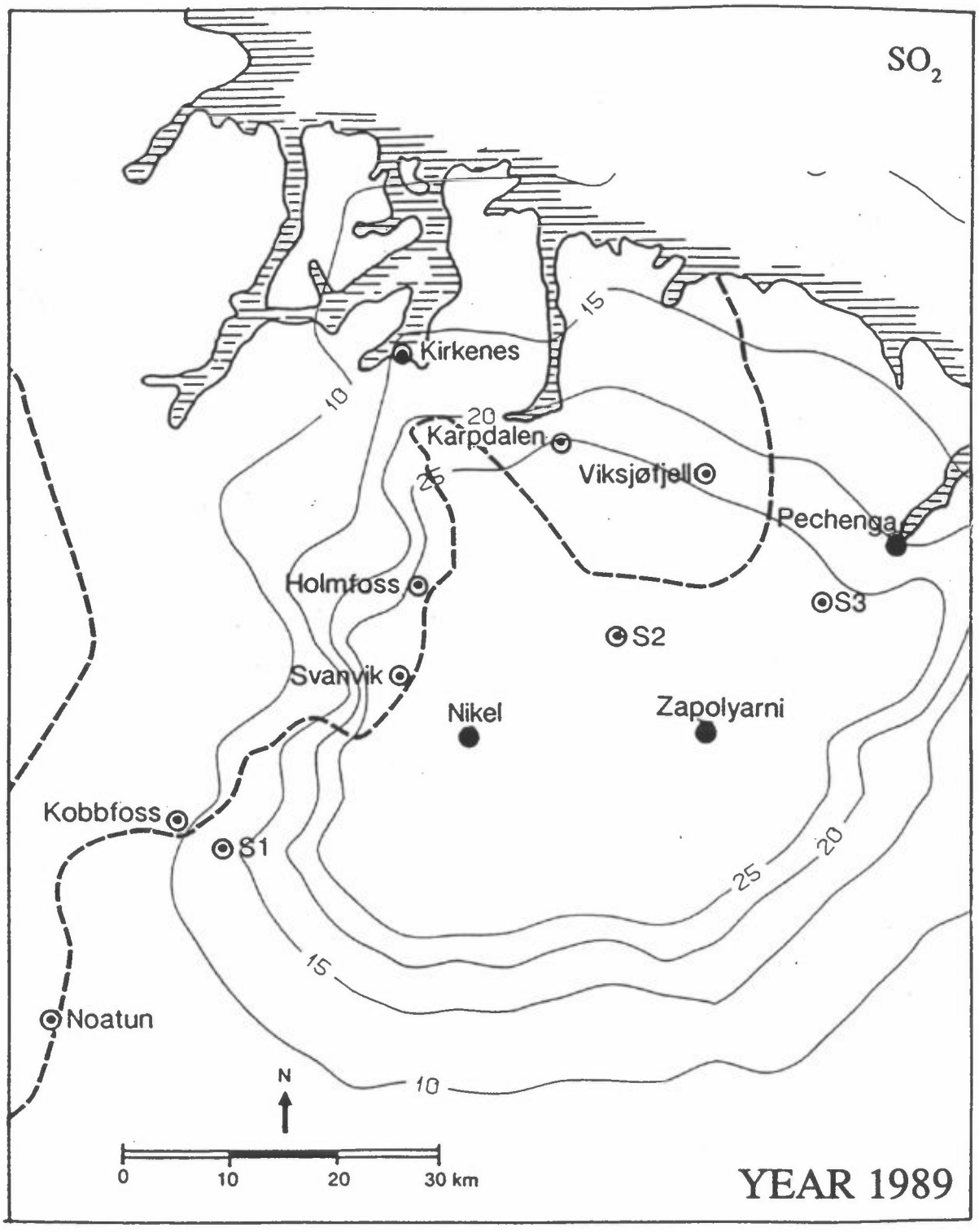

Figure 4: Annual averaged concentrations of SO_2 (µg/m³) in 1989.

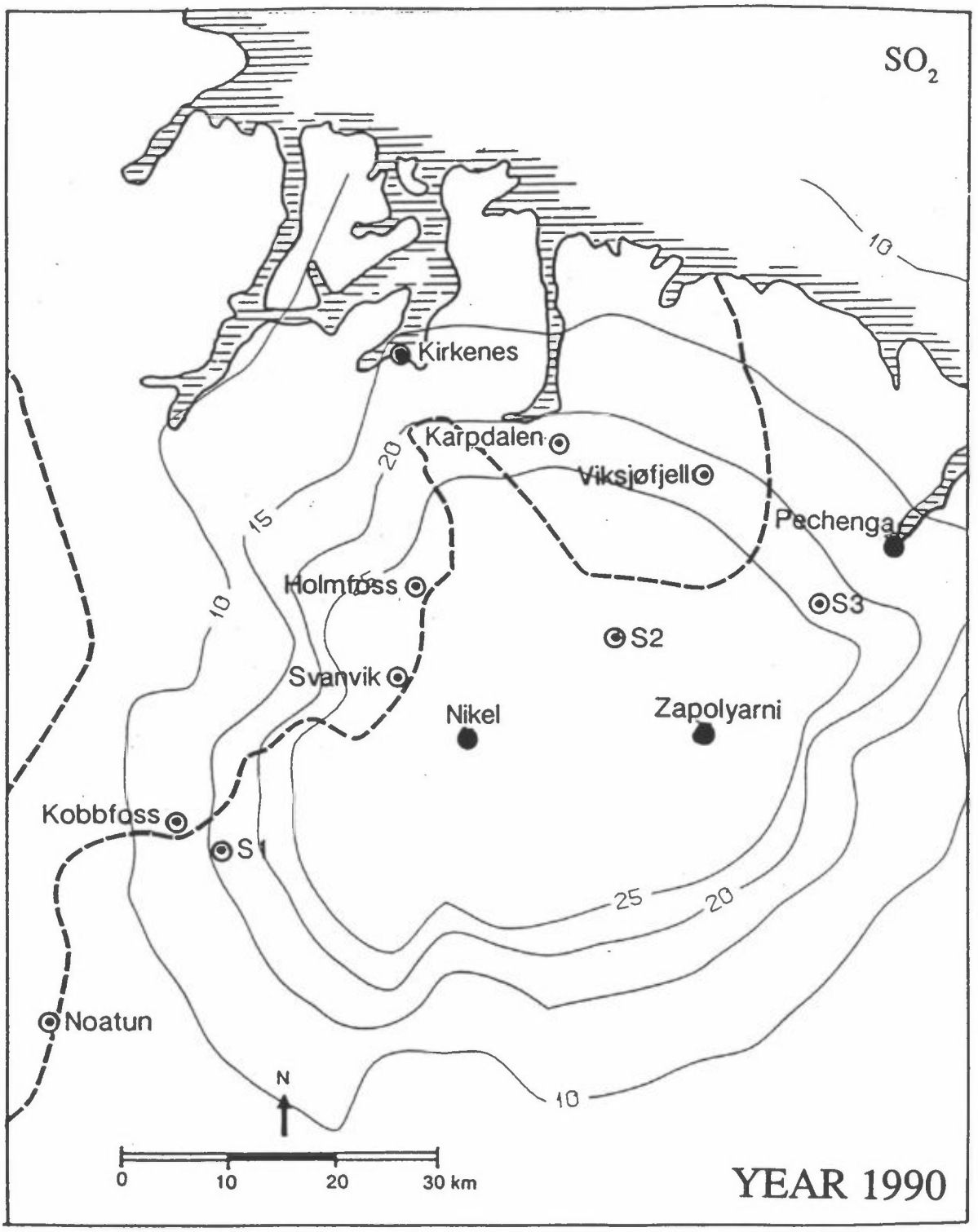

Figure 5: Annual averaged concentrations of SO_2 ($\mu g/m^3$) in 1990.

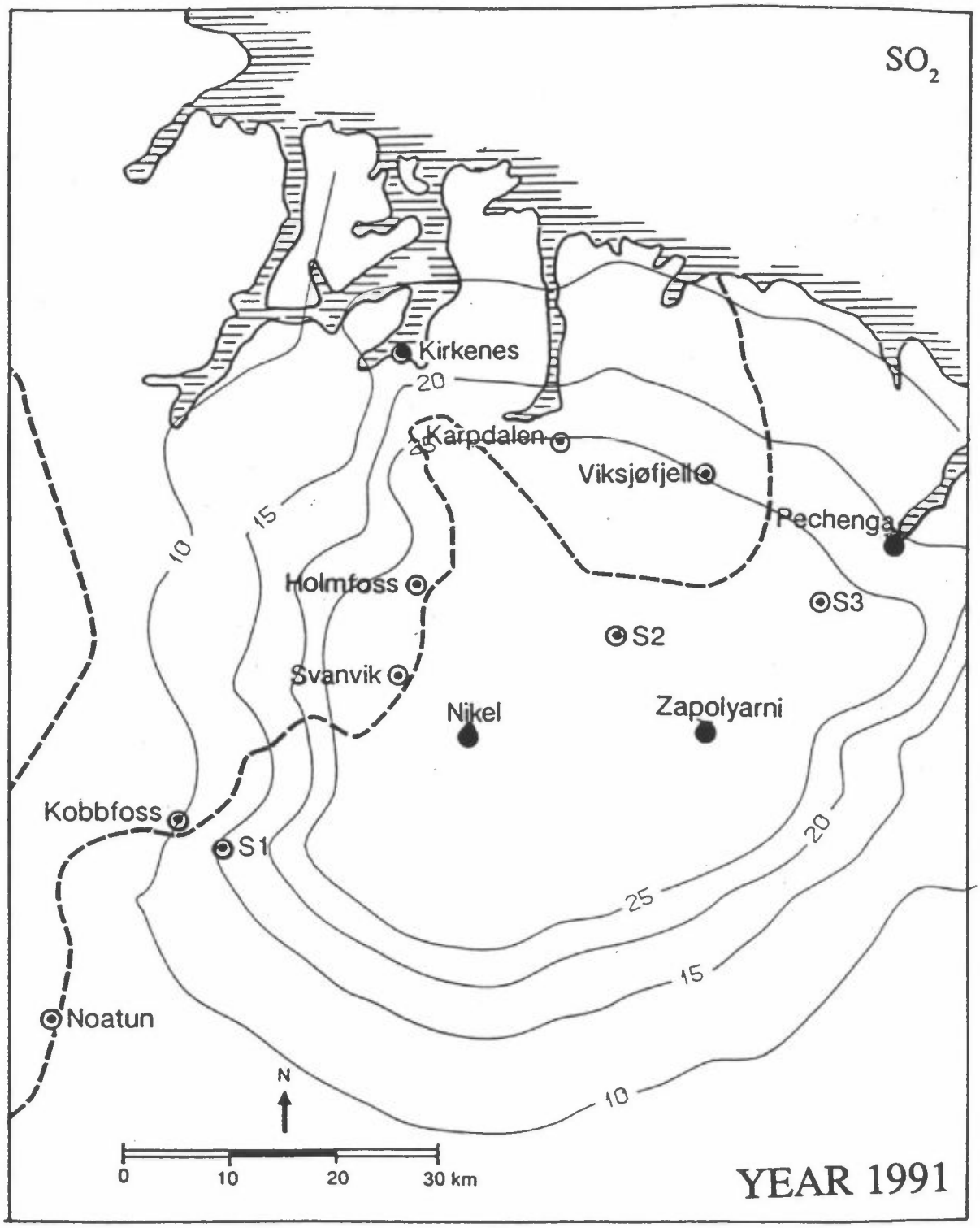

Figure 6: Annual averaged concentrations of SO_2 (µg/m³) in 1991.

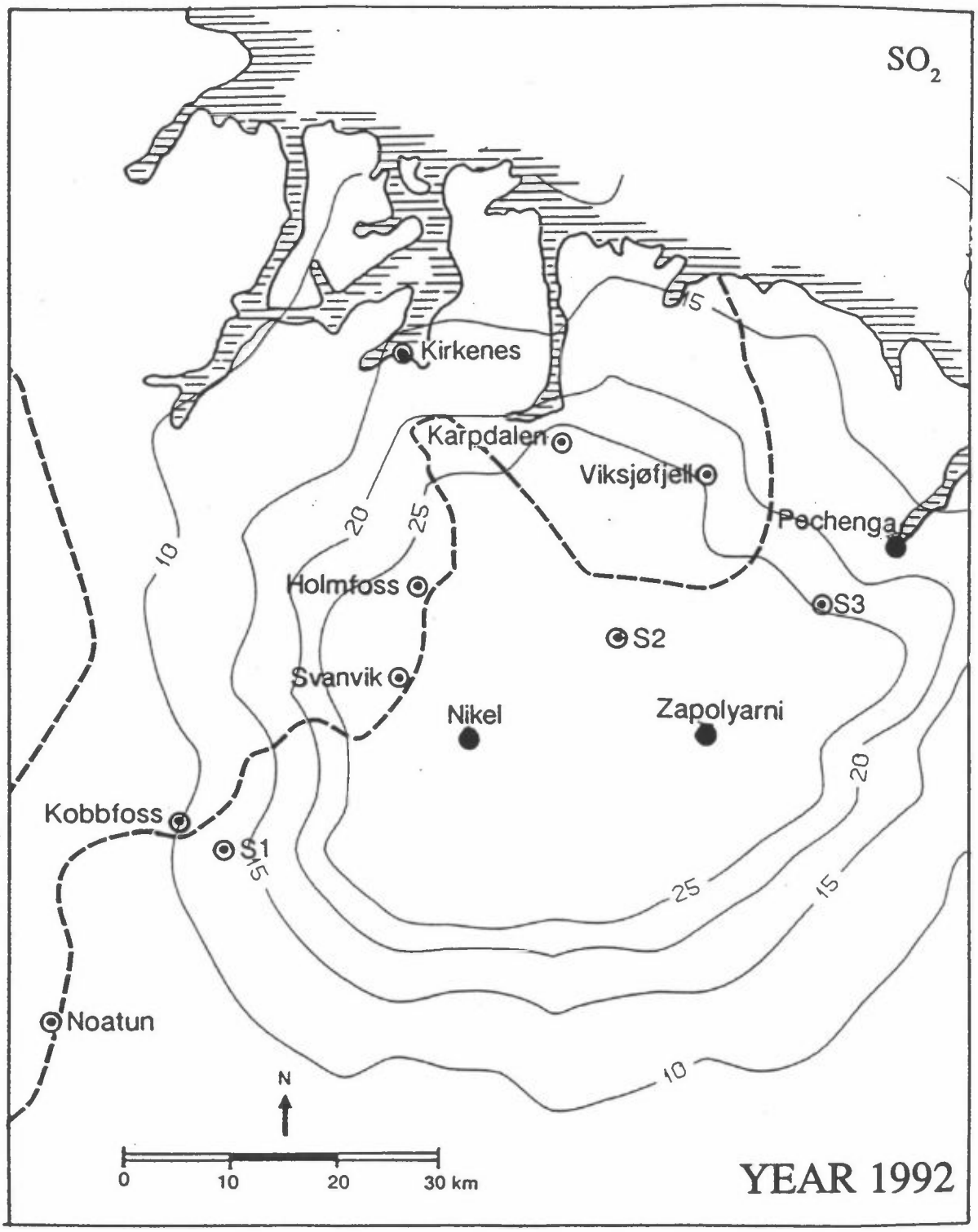

Figure 7: Annual averaged concentrations of SO_2 ($\mu g/m^3$) in 1992.

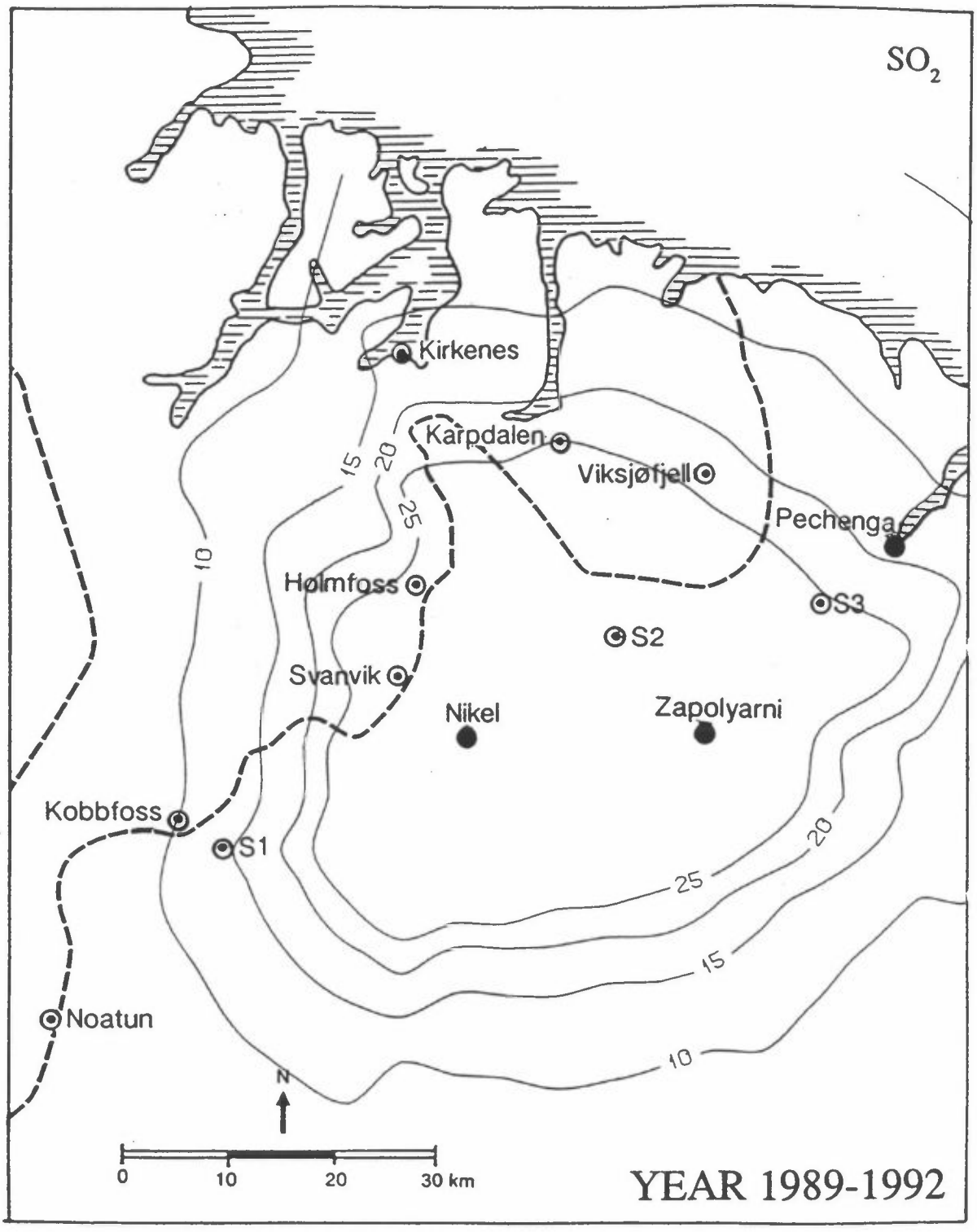

Figure 8: Annual averaged concentrations of SO_2 ($\mu g/m^3$) in the period 1989-1992.

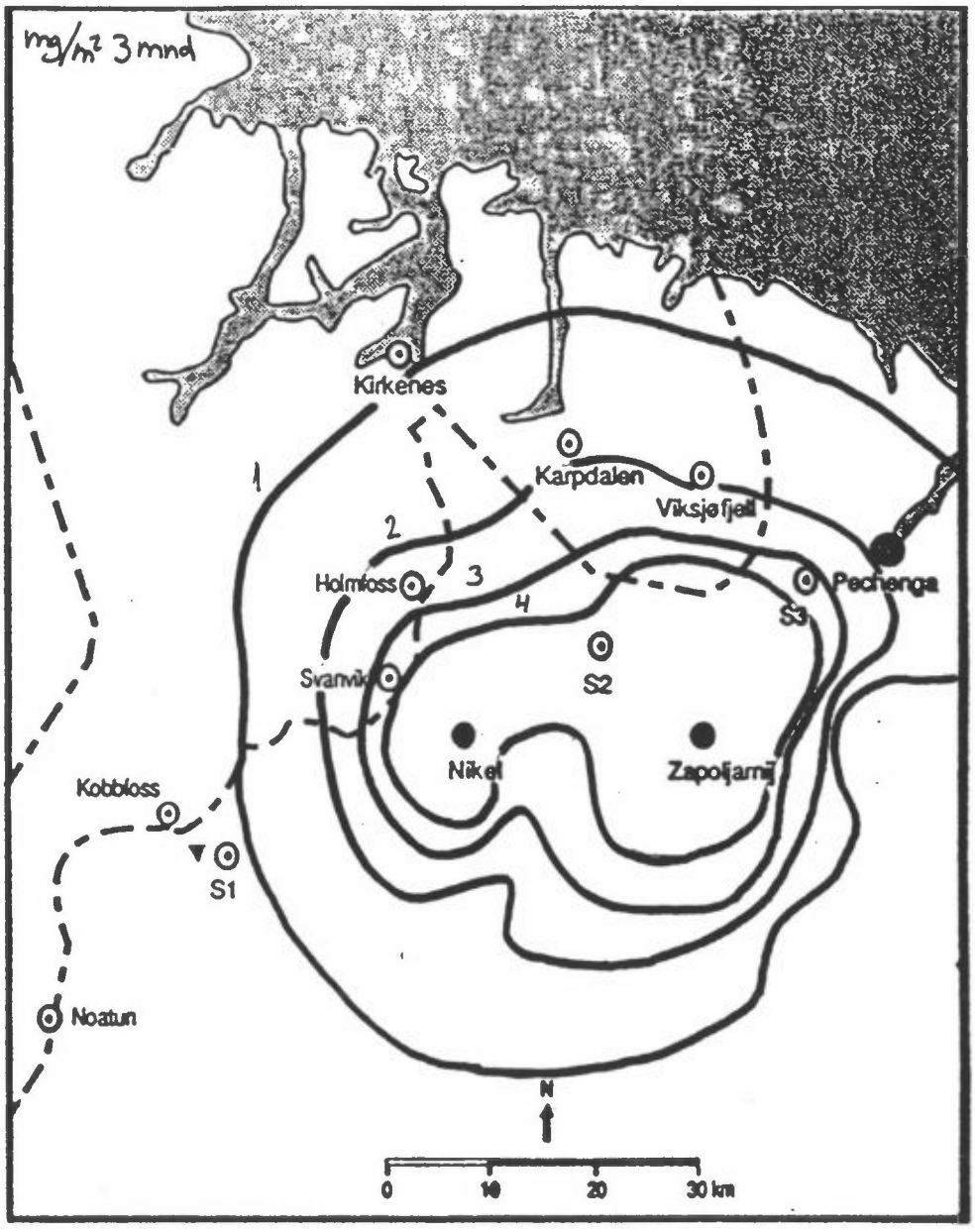

Figure 9: Summer averaged dry deposition of Ni (mg/m² 3mnd) in 1990.

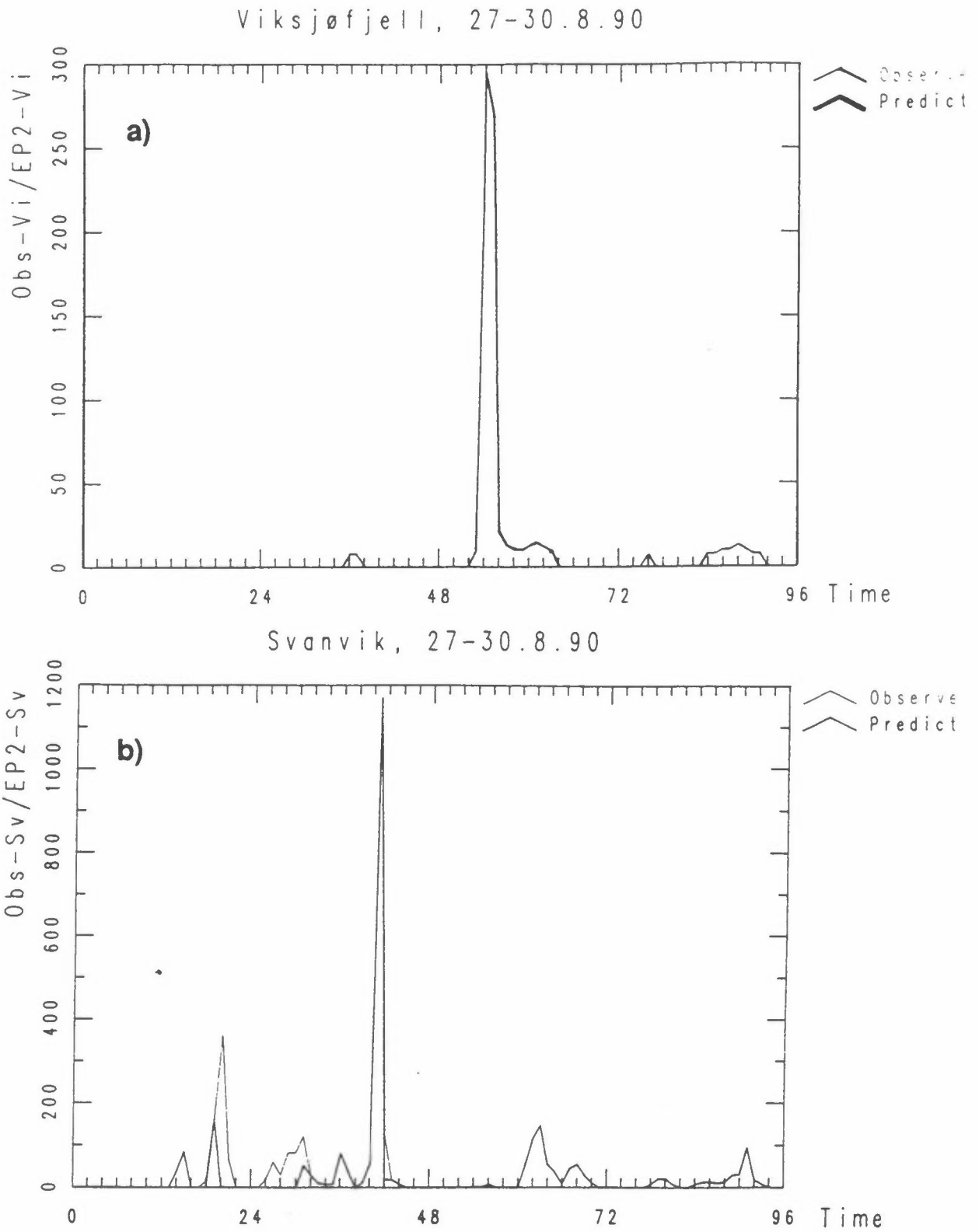

Figure 10: Estimated and observed 1 hour values of SO_2 for the period 27-30.8.1990.
a) Viksjøfjell.
b) Svanvik

2.7. Results of the Snow Cover Pollution Investigations at Russian-Norwegian Border Area

T.D. Makarova, N.E. Ratkin and V.V. Koshkin
Institute of the North Industrial Ecology Problems
Fersman st., 14, Apatity, Murmansk reg., Russia

G.M. Varshal, T.V. Komarova
Institute of Geochemistry and Analytics Chemistry
Kosygin st., 13, Moscow, Russia

The chemical composition of snowcover throughout the territory of Russia-Norway boarder has been investigated in 1991-1993 at late March - early April annually.

The sampling scheme of sites is shown at Fig.1. The sampling sites are located in typical tundra and forest landscapes with various forms of relief: on tops and slopes of hills, in the river valleys. Earlier, in 1986 and 199Ø during October - May the investigation of snowcover chemical composition in fixed layers near Nickel and Monchegorsk have been conducted. It was determined, that by the end of winter the pollutants accumulated in low layers of snow. That´s why the snow samples were taken throughout the snowcover depths to the soil itself.

The pH, the value of content of macrocomponents, and of Ni, Cu, Co were determined for all samples.

For every type of landscape the water capacity of snow has been estimated (Fig.2). The same data are presented in a threedimentional space (Fig.3). The maximum water capacity of snow is being observed in a forest on N and NE slopes. On the tops of unforest hills the minimum has been noticed The element accumulation has been calculated and mapped on the base of water capacity data . In Fig.4 Ni accumulation is shown; in Fig.5 the same data are in three-dimentional space. Maximum Ni accumulation is 52Ø.2 mg/m2. Minimum Ni accumulation is Ø.14 mg/m2.

For Cu (Fig.6 and 7) and SO4 (Fig.8 and 9) the maximum and minimum accumulation values were 193 and Ø.13 mg/m2 and 89ØØ and 98Ø mg/m2, respectively.

Additionally, the content of other 14 elements was determined in 24 snow samples.

After filtration of thawed water through membrane ultra filters with pores of 4ØØ nm diameter there has been determined a content of microtraces in a phase of actual solution and suspension as well. The suspension has been treated in succession - by Ø.1 m HCl, then aqua regia and at last a mixture of hydrofluoric and chroric acids. The analysis of fractions has been carried out by atomic-emission method and JCP spectroscopy. The results of determining the forms of availability of microelements in samples of thawed water show that about 9Ø n% of Ni, Cu and other elements occur in the phase of actual solution of they are easily leached by Ø.1 in HCl. The order of leaching can be shown as follows: Pb (56-66%) > Cu(44-61%) > V(44-5Ø%) > Ni(17-25%). Thus, a prior part of total content of microelements occur in alive (active) easily separating form when interacting with natural organic acids, available for assimilation by alive organisms. Relative content of less available forms of microorganisms in thawed water is low: for Cu Ø.5-5 %, for Pb 7-12 %, for Ni 5-12 %, for Zn 14-2Ø %.

However, 41-45 % of Sr, included in the rock-forming silicate minerals, dessolves only at the last stage of

analysis, in a mixture with perfluoric and chloric acids.

By ionic chromatography method it has been proved that in a phase of solution alongside with sulphates the other S components occur: sulphate, tiosulphate. Their total contribution to general S balance exceed sulphate contribution for 3Ø % of samples. The results are the preliminary, however they show that it is necessary to consider not only sulphates but other S compounds in estimating loads of anthropogenic S and investigating the area acidification. Close correlation between Ca, Mg, Ni, Cu testifies that the "Pechenganikel" combinate is the main pollution source by alkaline elements (Table 1.).

Ca and Mg elements occur in the snow cover predominantly in a soluble form (Table 2 and 3). It provides the environment acidification. Thus, the ecological effect of emissions into the atmosphere is being determined both by SO2 quantity and a balance of acidforming and alkaline matters of dust-gase emissions. It must be taken into consideration when applying technologies of the emission reduction.

Remark: the work has been carried out with a financial support of Russia funds of fundamental investigations.

Table 1: Foras of elements in snow cover in distance 7 km from source, % of total

	Ca	Mg	K	Na	Cu	Ni	Zn	Mn
	True solution							
	78	65	66	94	65	80	92	74
	Filtrates							
0.1 N HCl	6	12	11	2	15	4	8	10
HNO3+H2SO4	8	14	10	1	18	14	6	8
HF+HClO4	8	9	13	3	2	2	4	8

Table 2: Foras of elements in snow cover in distance 2,5 km from source, % of total

	Ca	Mg	K	Na	Cu	Ni	Zn	Mn	Al	Cd	Pb	Sr
	True solution											
	91	73	85	91	77	95	83	84	11	91	15	88
	Filtrates											
0.1 N HCl	4	10	6	2	15	1	8	5	31	3	70	4
HNO3+H2SO4	3	10	3	1	8	4	6	4	20	3	9	3
HF+HClO4	2	7	6	6	0.2	0.3	3	8	38	3	6	5

Table 3: Correlation between chemical components in snow cover

	Co	Ni	Cu	Sr	Ca	SO4	Mg	V	Al	Cr	Fe	HCO3	H+	Mn	Na	Cl	‡
Co		0.99	0.95	0.98	0.98	0.96	0.84	-	-	-	-	-	-	-	-	-	-
Ni	0.99		0.98	0.95	0.96	0.85	0.80	-	-	-	-	-	-	-	-	-	-
Cu	0.95	0.98		0.87	0.92	0.84	0.72	-	-	-	-	-	-	-	-	-	-
Sr	0.98	0.95	0.87		0.92	0.86	0.80	-	-	-	-	-	-	-	-	-	-
Ca	0.98	0.96	0.92	0.92		0.89	0.83	-	-	-	-	-	-	-	-	-	-
SO4	0.96	0.85	0.84	0.86	0.89		0.80	-	-	-	-	-	-	-	-	-	-
Mg	0.84	0.80	0.72	0.80	0.83	0.80		-	-	-	-	-	-	-0.63	-	-	-
V	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-
Al	-	-	-	-	-	-	-	-		0.51	0.51	-0.48	0.55	-	-	-	-
Cr	-	-	-	-	-	-	-	-	0.51		-	-	-	-	-	-	-
Fe	-	-	-	-	-	-	-	-	0.51	-		-	-	-	-	-	-
HCO3	-	-	-	-	-	-	-	-	-0.48	-	-		-0.69	-	-	-	-
H+	-	-	-	-	-	-	-	-	0.55	-	-	-0.69		-	0.46	-	-
Mn	-	-	-	-	-	-	-	-0.63	-	-	-	-	-		-	-	-
Na	-	-	-	-	-	-	-	-	-	-	-	-	0.46	-		0.52	-
Cl	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.46		-
‡	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	

\- correlation absences (P=0.95)

‡ F, Ti, Ba, K, B, Zr, Zn, Pb, Cd

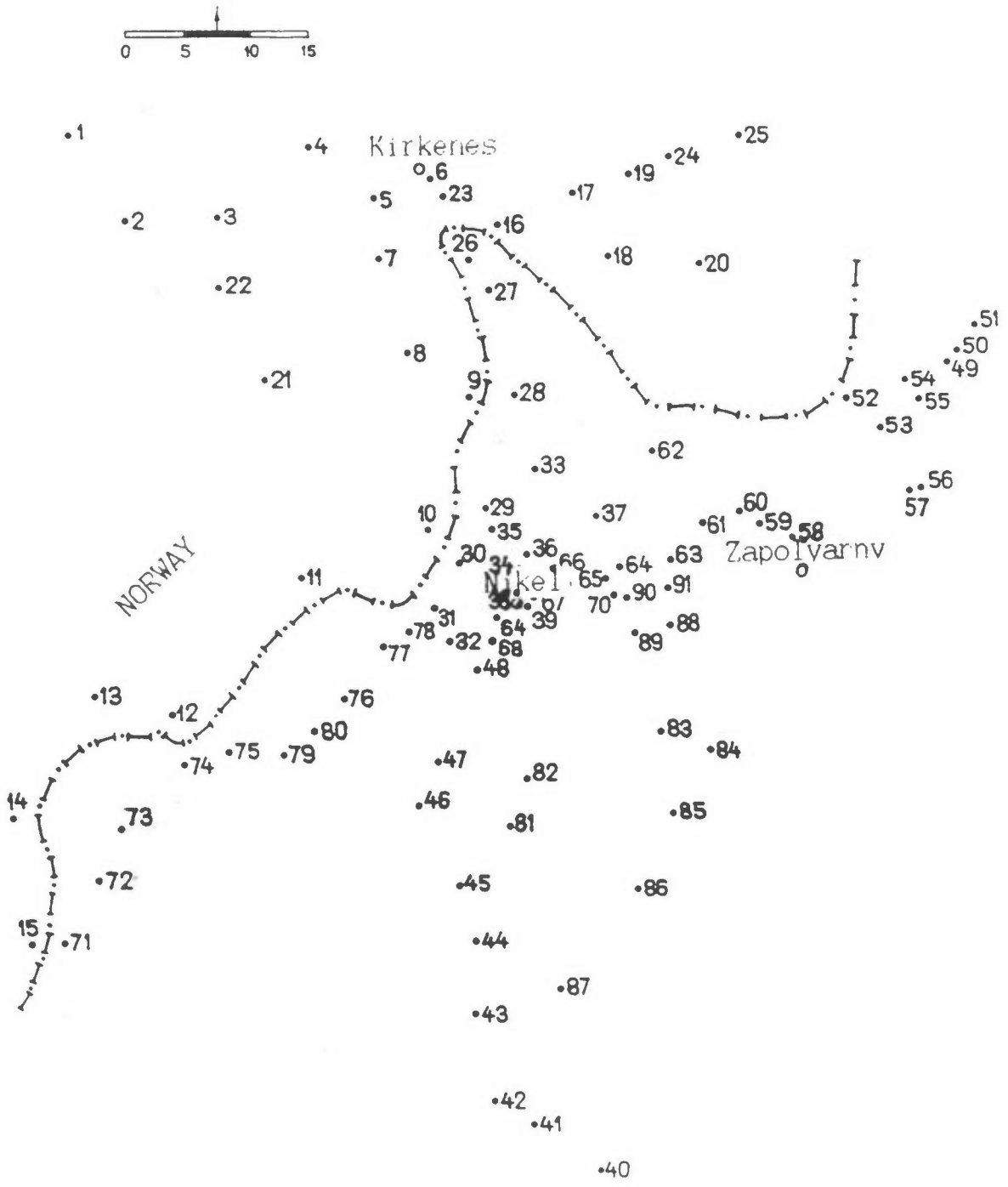

Figure 1: Sampling site

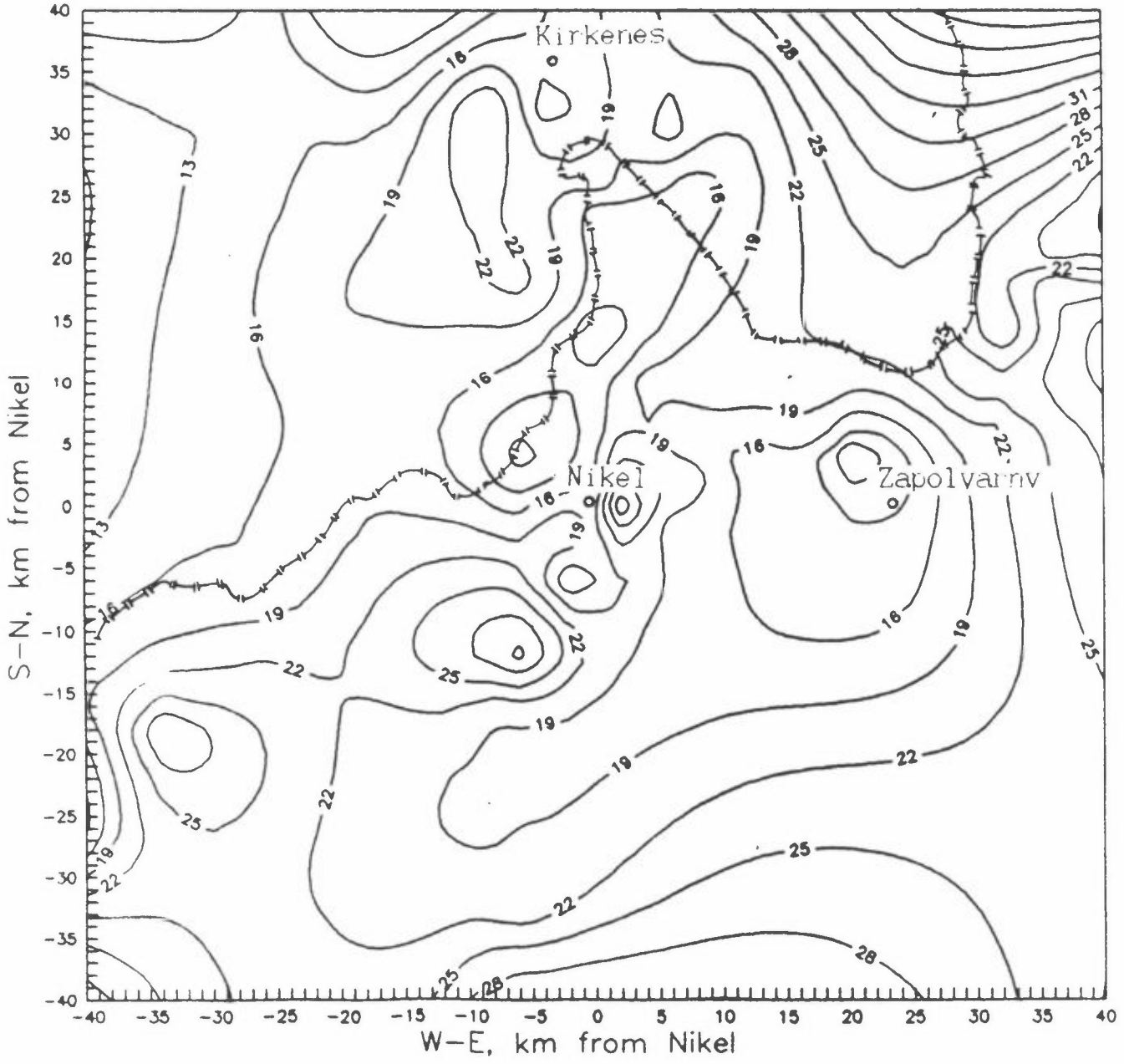

Figure 2: Water capacity, g/cm² (Nikel, March 1992)

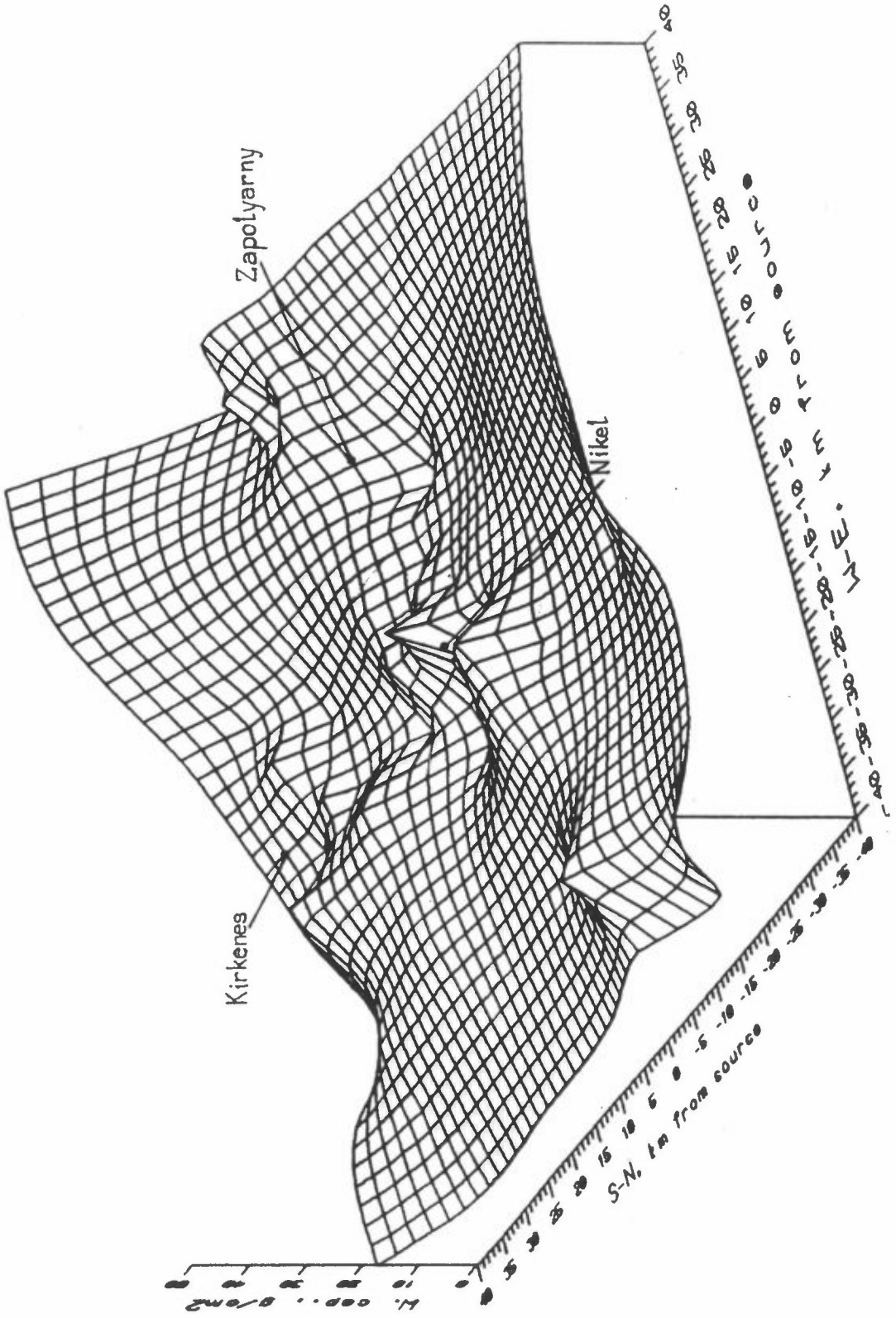

Figure 3: Water capacity, g/cm² (Nikel, March 1992)

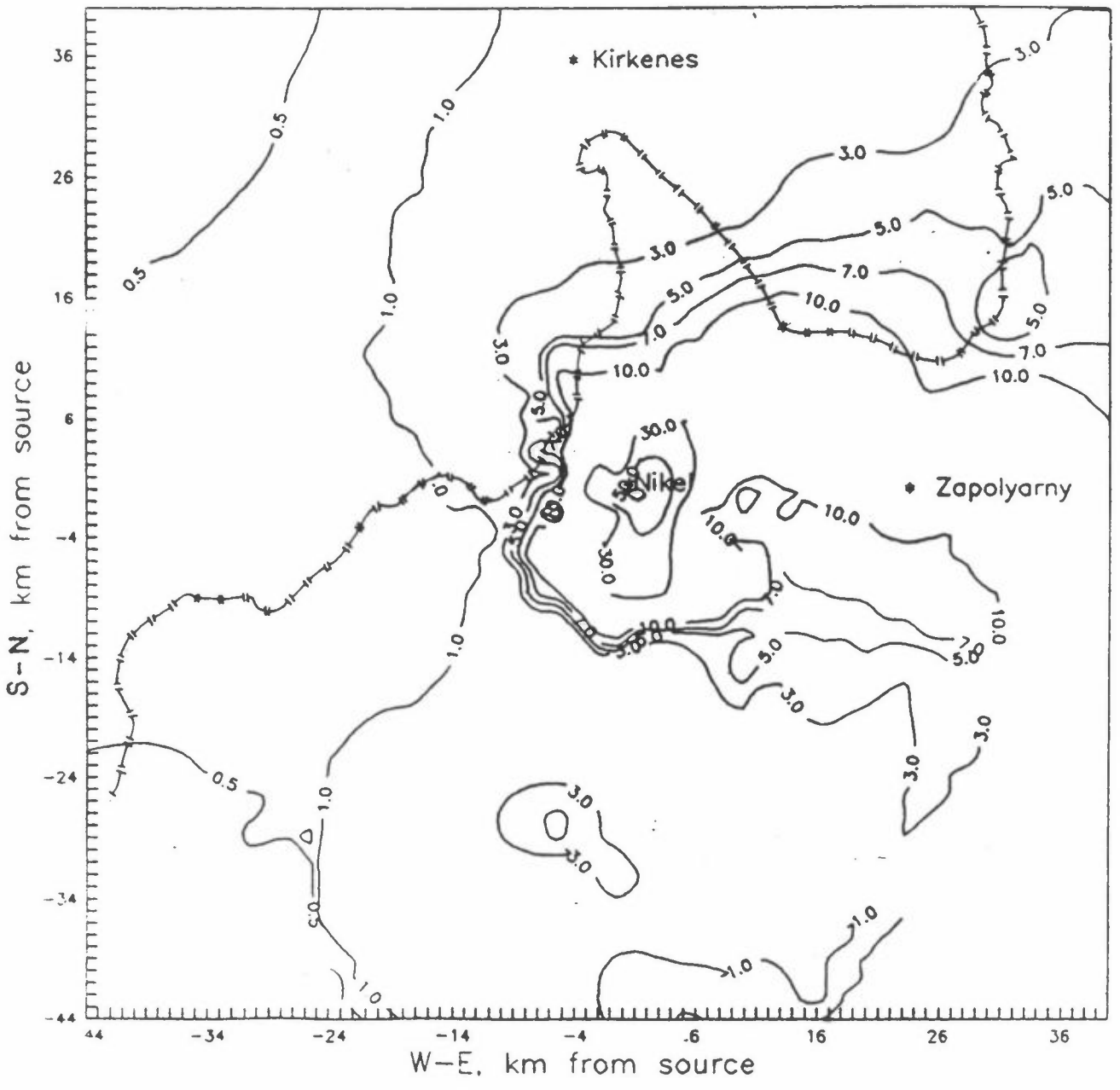

Figure 4: Ni accumulation in snow around Nikel (March, 1992), mg/m²

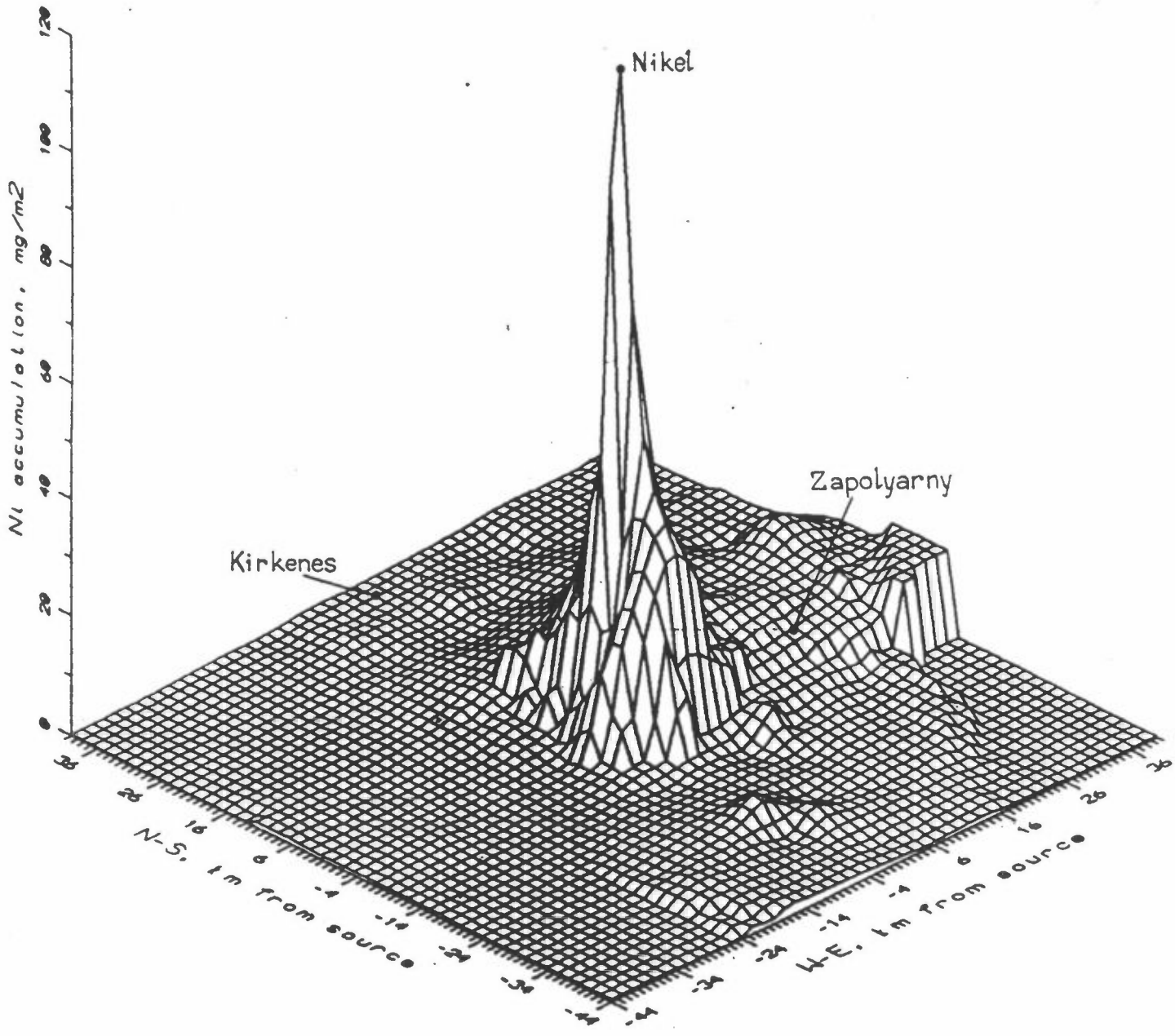

Figure 5: Ni accumulation in snow around Nikel (March, 1992), mg/m²

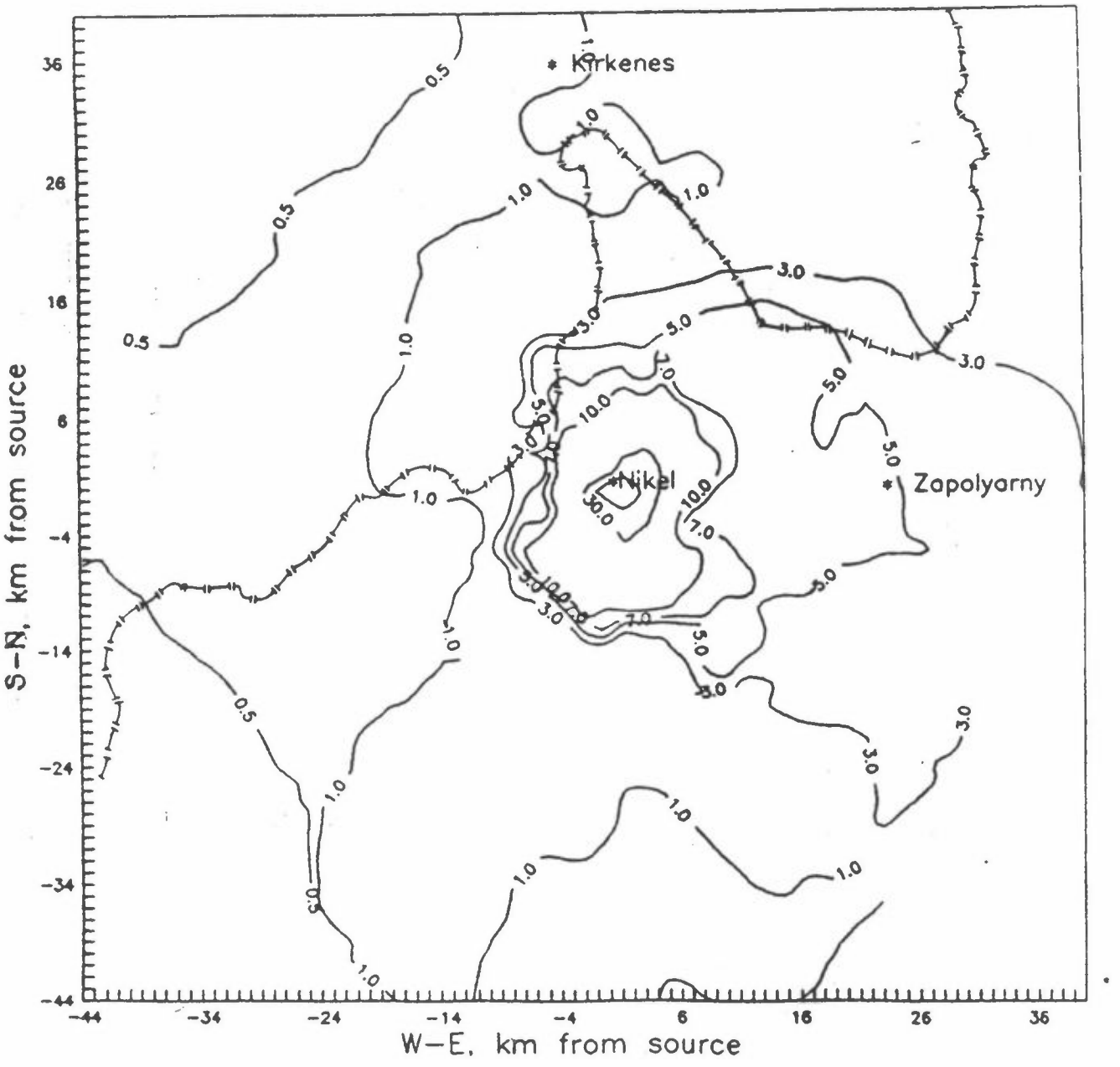

Figure 6: Cu accumulation in snow around Nikel (March 1992), mg/m²

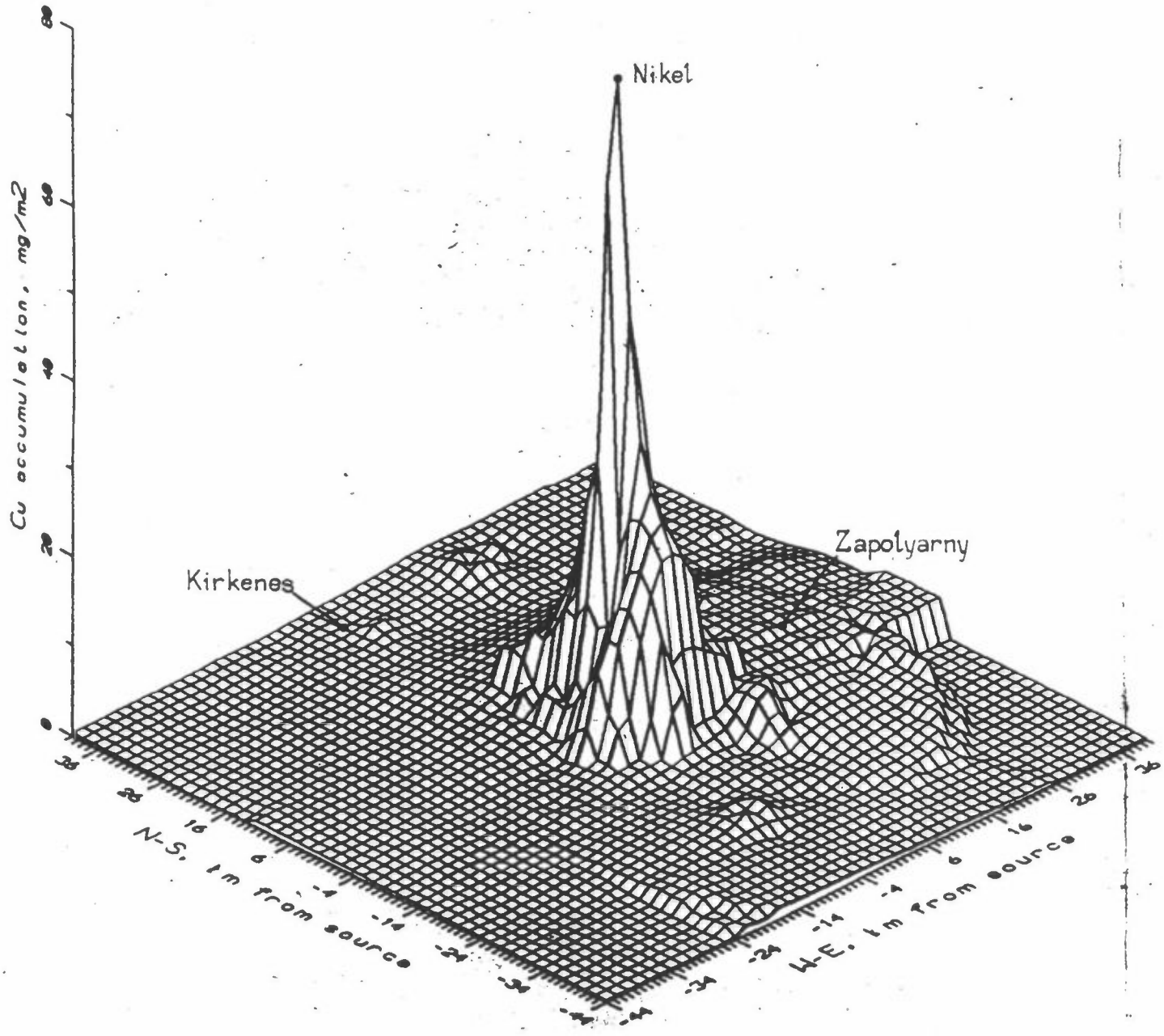

Figure 7: Cu accumulation in snow around Nikel (March, 1992), mg/m²

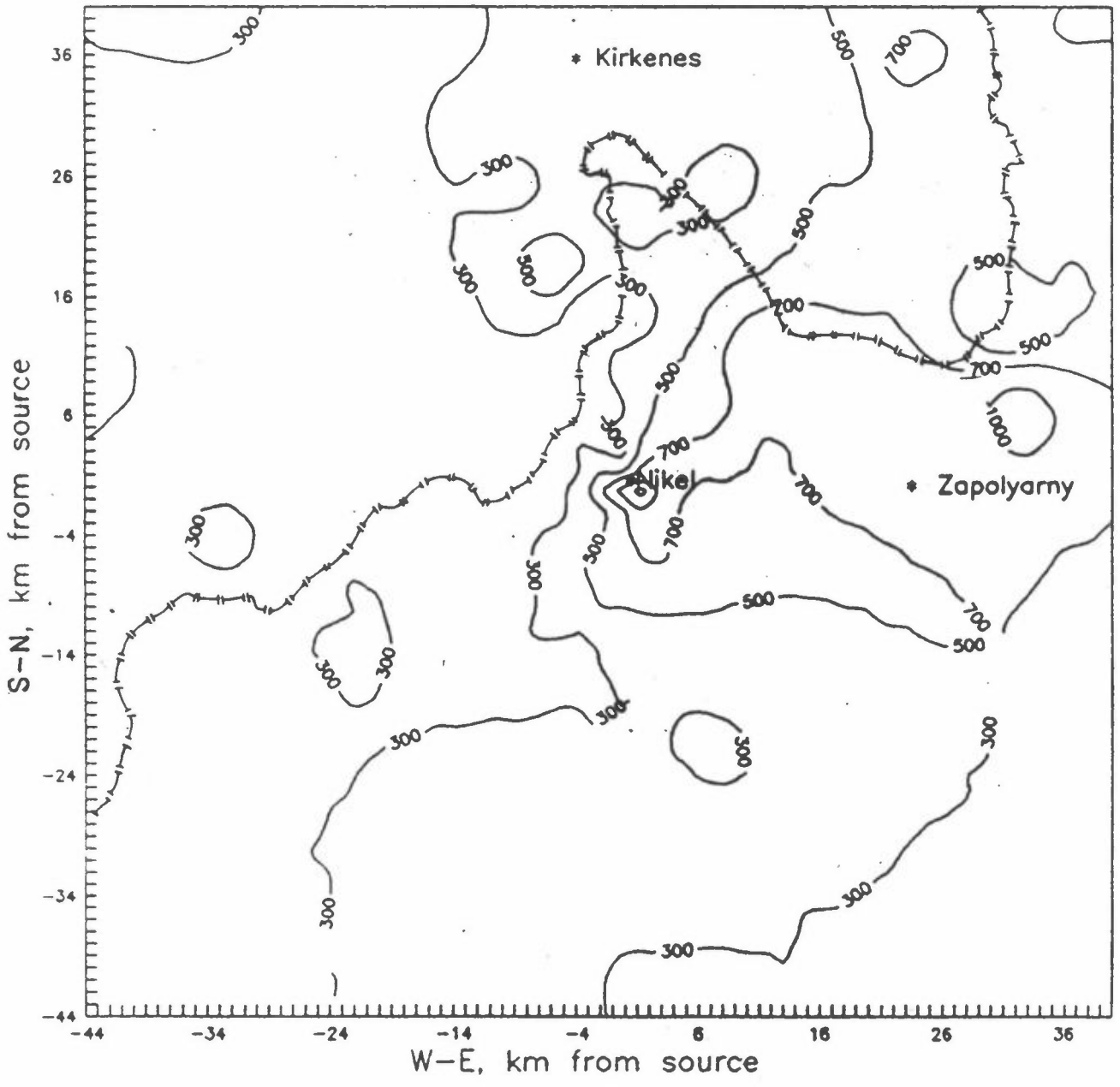

Figure 8: SO_4 accumulation in snow around Nikel (March, 1992),mg/m²

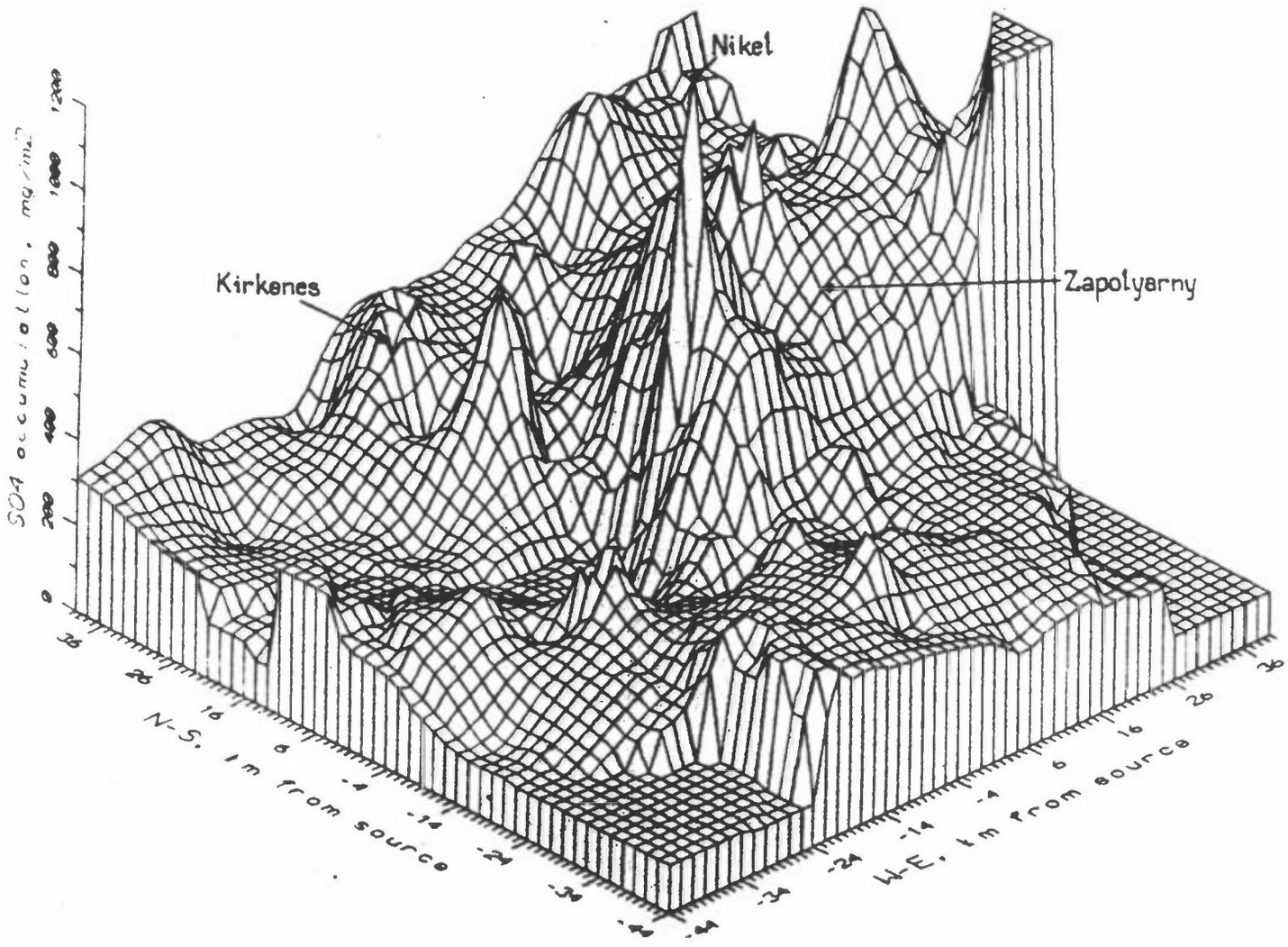

Figure 9: SO_4 accumulation in snow around Nikel (March, 1992),mg/m²

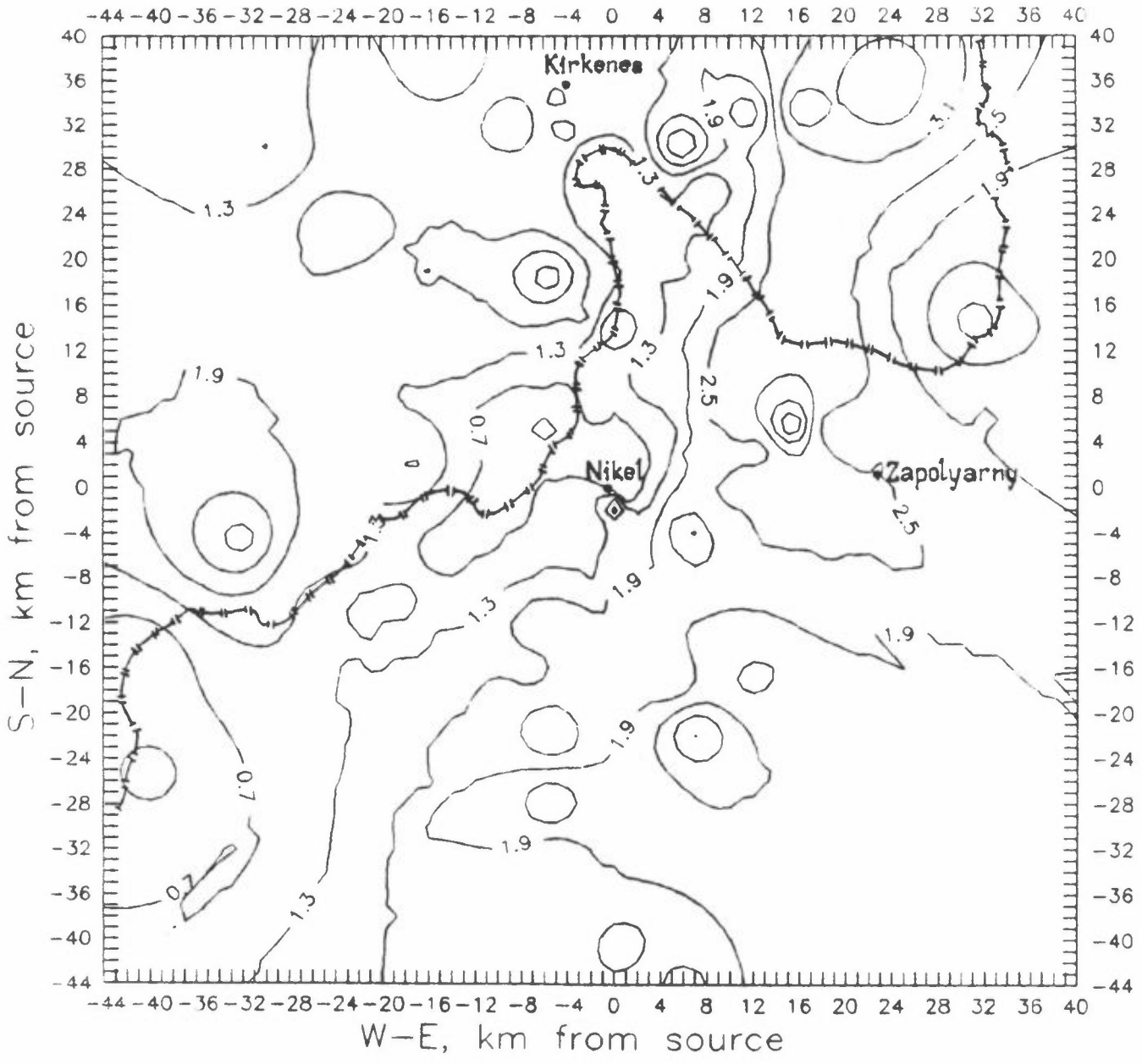

Figure 10: H^+ accumulation in snow around Nikel (1992) mg/m²

2.8. The Investigation of Atmosphere Pollution from Mining Industry on Kola Peninsula on the Base of 3-Dimensional Models.

O. Yu. Rigina, INEP, Apatity

One of the main sources of technogenic influence on the environment of Kola Peninsula are units of the mining complex. Mining and processing enterprises are located in Kirovsk, Apatity, Olenegorsk, Kowdor, Rewda, and Nickel, and most of them are situated in complex orography, such as Khibiny massif, and Lovozerskie tundras.

The recovery and processing of mineral resources can have an adverse effect on the environment, in particular causing the alteration of the landscape, hydrogeological and geochemical changes, atmospheric, soil and water pollution and even microclimatic changes. The complexity of the physical processes, the multidisciplinary nature of the system and the difficulty of conducting experiments often mean that the only way of quantifying environmental effects is by mathematical modelling. Such approach allows a range of environmental consequences to be assessed at the mining feasibility stage of a project.

The impact of mining units on the atmosphere, as a rule, has been local or meso-scale, but these subjects have the complex structure of reliefs (tailing dumps, open pits, industrial grounds) and of sources (dusting surfaces, explosion works). Therefore, use of traditional methods of calculation for such tasks is limited.

To calculate distribution of speed and of temperature of air flows we use the model of atmosphere dynamics in complex orography conditions, which is based on the following system of three-dimensional hydro-thermodynamic equations:

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial P}{\partial x_i} + \frac{\partial(-\overline{u_i' u_j'})}{\partial x_j} - \beta_T g T \delta_{i3} + J_i ,$$

$$\frac{\partial T}{\partial t} + u_j \frac{\partial T}{\partial x_j} = \frac{L}{c_p}\varphi + \frac{\partial}{\partial x_j}\nu_{T_j}\frac{\partial T}{\partial x_j} \tilde{Q}_2 + J_T ,$$

$$\frac{\partial q}{\partial t} + u_j \frac{\partial q}{\partial x_j} = \frac{\partial}{\partial x_j}\nu_{q_j}\frac{\partial q}{\partial x_j} - \varphi + J_q ,$$

$$\frac{\partial u_j}{\partial x_j} = 0 , \quad -\overline{u_i' u_j'} = \nu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) - \frac{1}{3}\overline{u_n' u_n'}\,\delta_{ij} ,$$

$$i, j, k = \overline{1,3} ,$$

where t denotes time
u_i are rate components in the cartesian co-ordinate system
ρ is density
P is pressure
T is temperature deviation from the background temperature
γ is moisture
ε_P is the thermal coefficient of volume expansion
l is the Coriolis parameter
L is the latent heat of evaporation
φ is the condensation rate
I_i, I_T, I_γ are the anthropogenic sources of pulse, heat and moisture
ν_i, ν_T, ν_γ are the ratios of turbulent transfer of pulse, heat and moisture

with a description of turbulent terms on the base of the model of subset Smagorinski's turbulence and corresponding range of limit conditions.

The emission and transformation of dangerous elements in the environment is modelled by:

$$\frac{\partial C_k}{\partial t} + u_j \frac{\partial C_k}{\partial x_j} - W_g \frac{\partial C_k}{\partial x_3} = \frac{\partial}{\partial x_j} D_{kj} \frac{\partial C_k}{\partial x_j} + J_k$$

where C_k is the impurity concentration for k-th component; k=1,n
n is number of contaminating elements
Wg is the gravity settling ratio
D_{kj} is the impurity diffusion ratio
I_k are the mining induced contamination sources.

Application in solving of equations of the model in a complex field of the fictitious fields method allows us to model atmosphere dynamics and impurities distribution in the places with unspecified relief. For the construction of energetically balanced, discrete approximations of the equations and range conditions of the model, the variational-differential method is used. Solution of a system of finite-differential equations is carried out by the splitting method.

Depending on the concrete units and tasks, models are modified and suitable parameters are selected.

Let us consider, for example, the use of the models for some typical mining units.

1. Mining is known to be a main source of supply of mineral resources. As a rule, due to irrational utilization of raw materials, the deposit exploitation is accompanied with vast waste products which results in global environment contamination.

The largest quantity of industrial waste products is formed by opencasting and averages 80-90 % of a total mined rock.

Waste materials are mostly overburden rocks (60-65%), ecologically not very hazardous and result mainly in the mechanical pollution of nature.

Waste tailings - slimes have a much more hazardous effect upon the environment.

Tailings are kept in storage in so-called tailing-dumps, formed, as a rule, in negative terrains (valleys of rivers, brooks, lakes, creeks and so on). At an early stage of their formation the dumps have a small adverse effect on the environment, covering some area of natural land. But because of the limitation of tailing dump size, the dump height steadily increases.

At a certain stage the tailing surface, once sheltered by surrounding uplifts and plantations of trees, leaves the wind shadow and enters the zone of intensive air flows.

Mining conditions cause an ever-increasing amount of waste tailings in dumps, sufficiently intensive height growth of the dumps and their surface fall within the zone of jet flows of a surface atmospheric layer. Wind velocity can reach 8-9 m/sec at 40-50 m height that is enough to keep down 97.3% of raised sand particles in state suspension at a 1.5 km distance.

The influence of the height and geometrical shape of tailings dumps over air flows variation was studied on the basis of mathematical modelling. Predictive estimations of possible dust concentration in the air basin in a region for unfavourable weather conditions when tailings dumps (in growth of its height) were made by running on an air flow is constructed graphically (see Fig.1,2).

The elaborated model can be used as methodical base for forecast calculations of dust concentration in the districts of tailing dumps siting.

Since tailing dumps are located in the conditions of complex orography and their formation is characterized by technogenic relief changes, field of velocity is rather inhomogeneous in space. Inhomogeneity of field of velocity and height growth of dusting surface greatly effect the distribution of dust in the atmosphere and conditions of its separation from a surface.

This model was used to forecast estimations for operating apatite tailing dumps of Concern "Apatite" near river Chernaya as well as designed tailing dump of Udocan Mining and processing enterprise. Both dumps are situated in the complex orography.

The relief of simulated district of tailing dump site of Concern "Apatite" is cited in Fig.3.

The calculations were carried out for typical unfavourable meteo-conditions, leading to sources of dusty storms and aerosol smogs in this district.

Fig.4 describes the calculation of dust pollution in lower layer of atmosphere from a working tailing dump of Apatite-Nepheline Concentrating mill-2 (ANCM-2) when wind directions are toward Apatity residential districts.

The calculations show that under present height of dump and in the absence of measures against dust formation, the concentration of dust can exceed 12 MAC (Maximal Available Concentration) in Apatity.

The calculations of possible dust concentration from newly designed tailing dumps of ANCM-2 and ANCM-3 in the Chernaya river valley were carried out.

Fig.5 describes isolines of dust concentration in the surface layer atmosphere from a tailing dump in the last stage of filling up and without protective measures.

As we can see, under E-ES wind directions, the town Apatity is in the zone of over-normative concentration of dust from ANCM-3 tailing dump, as well as settlement Titan - under S-ES wind directions.

The results are evidence of the sources of dusty storms and aerosol smogs in the region of working tailing dumps. Most expediently is to foresee preventive measures against dust formation at the stage of tailing dumps design making use of mathematical modelling methods for atmosphere dumps content prediction in this zone.

Thus prediction of air basin dust loading by mathematical modelling allows to foresee and to include into the project methods for practical dust suppression and preventing the erosion of tailing waste surface at an early stage of design work.

2. One of the more important problem for open pits is maintenance of normal atmosphere conditions at the working places within the open pit.

Inside a deep quarry there is a sharp relaxing of air flow and less potential for natural ventilation (See Fig.6).

The artificial activization of the atmosphere's ability for pollutants' dissipation and carrying out is considered as one of ways for air pollution level to decrease in localized zones.

It is attempted to insert the active influence on the processes of pollutants spreading in the atmosphere in such open systems, as open pits. Lump of calculations of the works concerning artificial ventilation of deep open pits were carried out.

The methodology and the models of artificial impact methods estimation on the processes at atmosphere local zones ventilation of open pits were elaborated. The structure of air streams and the conditions of pollutant transport under influence on the atmosphere of artificial turbulent current of different type (isothermal and ventilation) was investigated using numerical three-dimensional turbulent atmosphere model. The estimation of efficiency of such methods for normalization problem solution of the local zones atmosphere and necessary electric power needs for realization of artificial ventilation system were received.

Fig.7 describes the results of a simulation of artificial ventilation of Saamski quarry of Concern "Apatite" by 2 fans, worked as "cascade", under different atmosphere stabilities.

When uniform atmosphere stability, 2 recirculating cells arise, pollution is diluted as the result of the effective intermix of air in the zone of working jets, and the pollution is taken away from the open pit.

When stratified atmosphere stability work of "cascade" scheme becomes uneffective.

3. The next problem is recovery of mineral resources by open method with use of blast-hole drilling, which are an important source of pollution of the air basin and surface.

   It is suggested to calculate pollution of atmosphere of open pit and its surrounding after mass explosions using 3-dimensional mathematical models of atmosphere dynamics and pollution transport when complex orography.

   As the process of development of a dust and gas cloud (DGC) consists of 2 stages, the calculation is divided into 2 stages: the forming of DGC after explosion and the dissipation of DGS into atmosphere.

   It is expedient to use simplified semi-empirical formulas for calculation of 1 stage of DGC forming and use them as input parameters.

   On the next stage the transport and diffusion of formed DGC into atmosphere under influence from meteorological factors and relief is calculated by quasi-3-dimensional models of atmosphere dynamics and pollution transport.

   The calculations for open pit of Concern "Apatite", Ore mining and processing enterprises from Olenegorsk and Kowdor were carried out.

   The results of the calculations show the sanitary zone and unfavourable meteosituations, when it is expedient to carry out explosion works, are defined.

This problem is more actual for open pit "Dzelezny" of Kowdor, where a considerable part of the settlement Kowdor gets in the sanitary zone (see Fig.8).

Results of calculations show, that for satisfaction of normal sanitary-hygienic conditions it is necessary to remove the residential district from this area or to change the technology of explosion works in open pits.

In Figure 9 there are isolines of concentration of dust (vertical cross-section), which describe the process of 3-component dust spreading after an explosion.

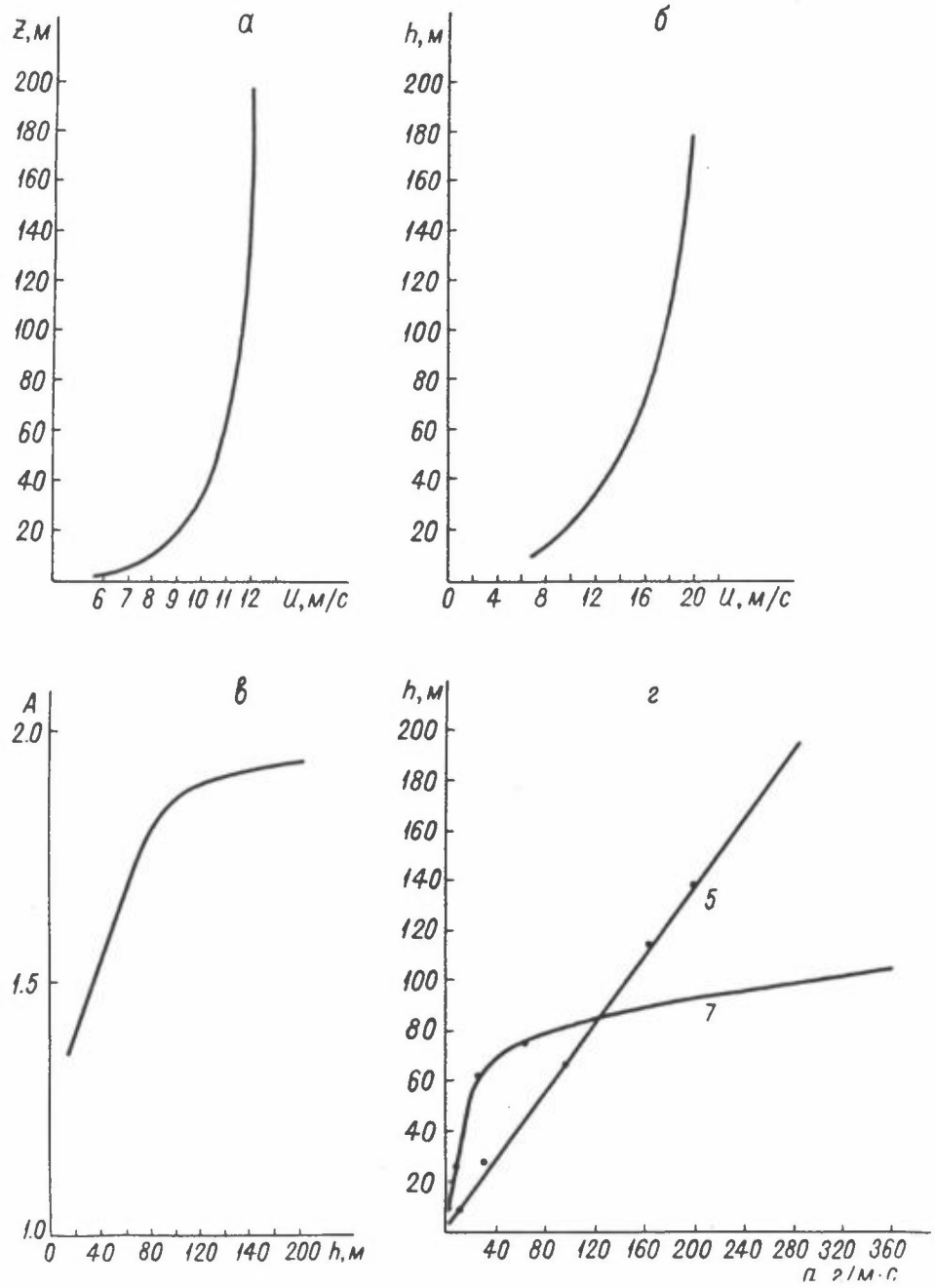

Figure 1: Dependence of flow wind and intensity of dusting upon height of tailing dump:

- *a) initial wind profile ;*
- *b) speed at the health of 10 m above surface in depend on dump height h;*
- *c) coefficient of wind intensification A(h);*
- *d) intensity of dusting of surface q in depend on increasing of dump height h.*

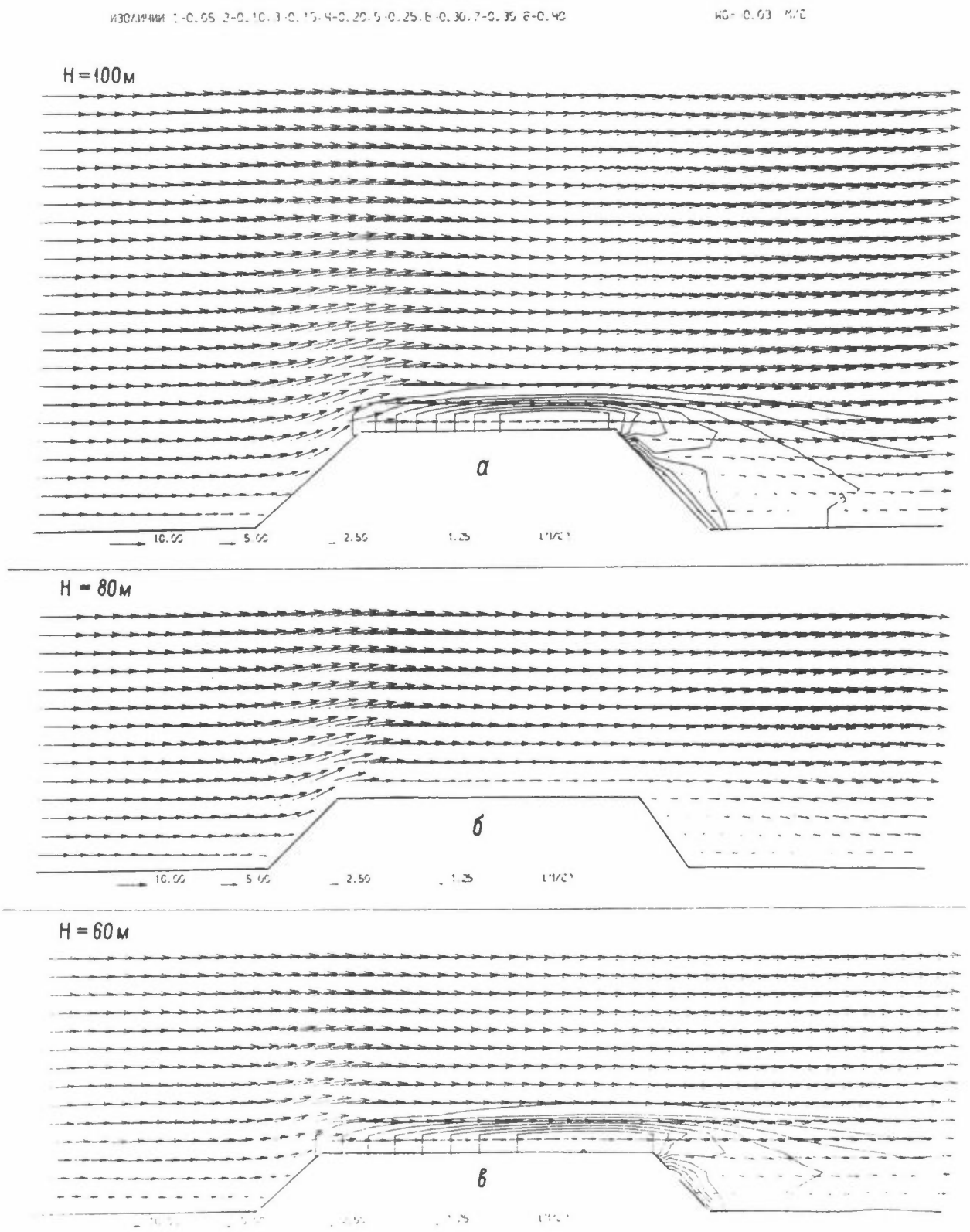

Figure 2: Vector field of velocity and isolines of concentration of dust from the tailing dump when background speed U = 8 m/sec in depend upon height.

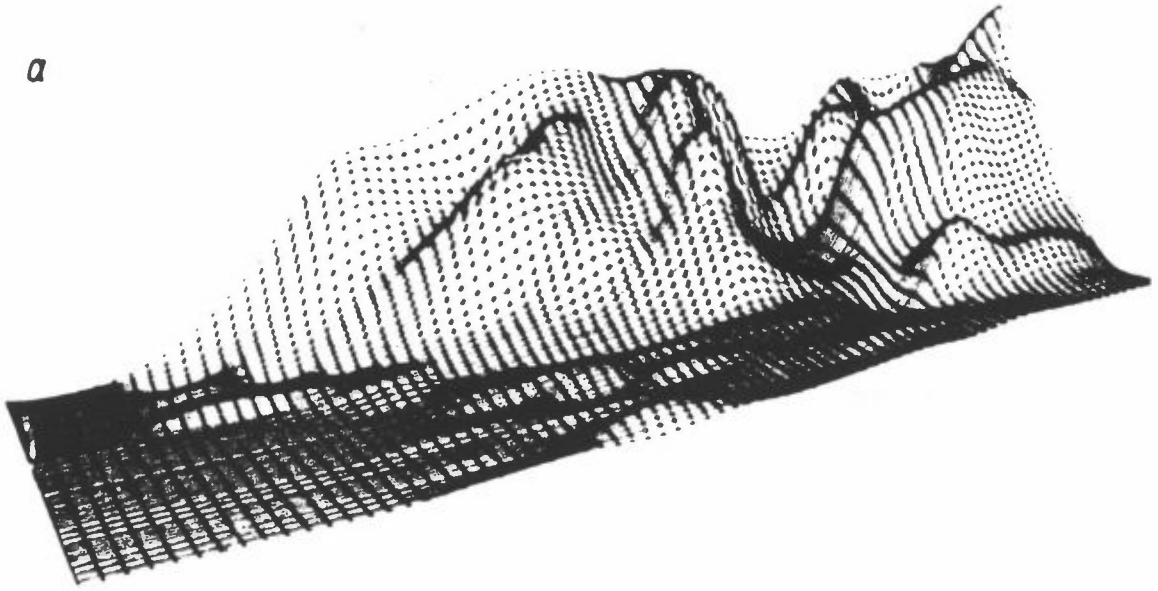

Figure 3: The relief of the district of tailing dump of "Apatite" company.

б

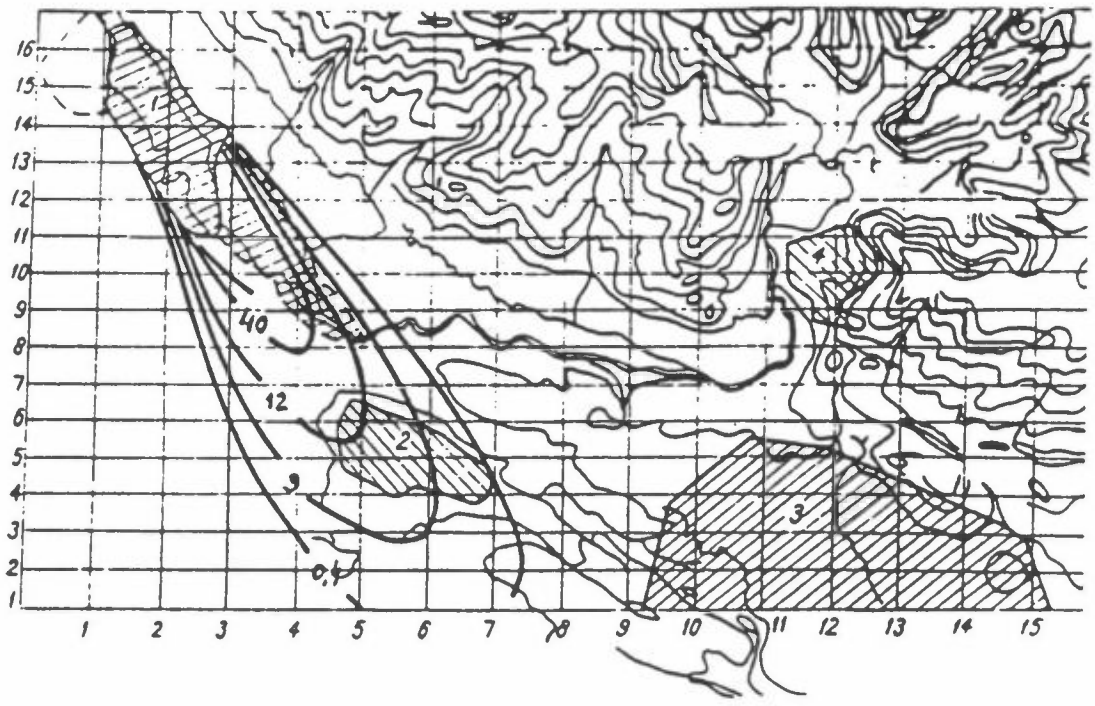

Figure 4: Calculation of pollution from operating tailing dump of ANCM-2 when unfavourable meteo-conditions.

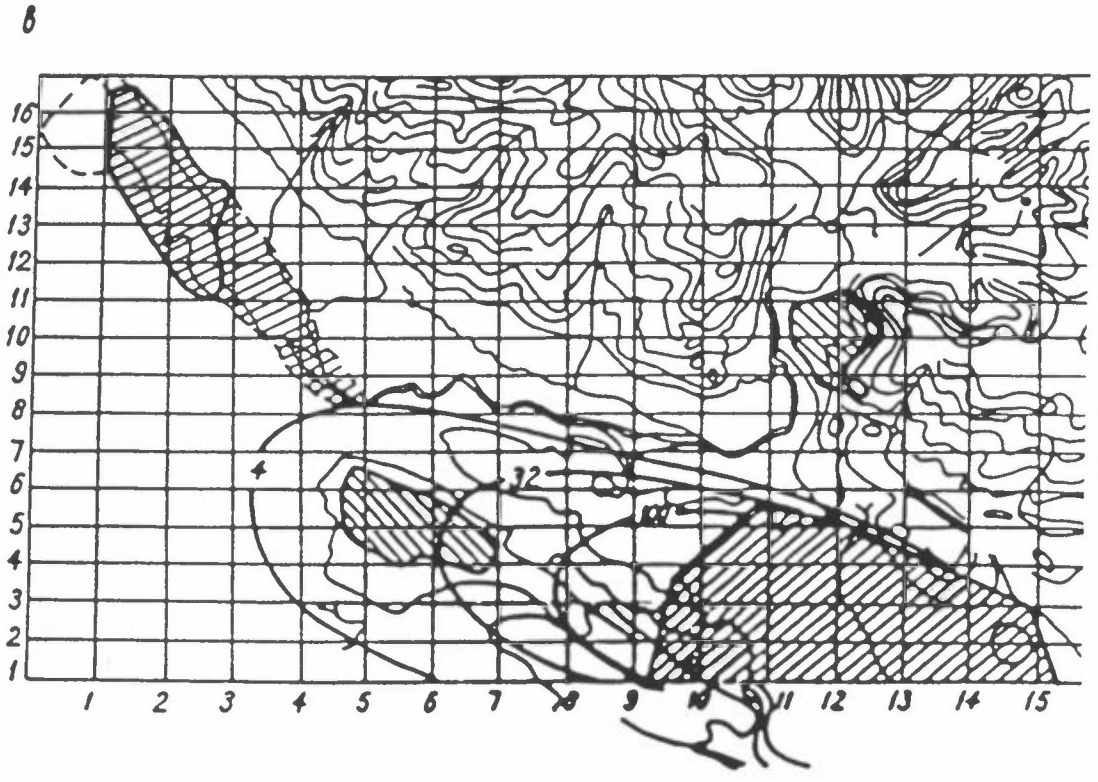

Figure 5: Isolines of dust concentration in a low layer of the atmosphere, when wind velocity U= 6 m/sec at the last stage of development of projected tailing dump and without protection measures.

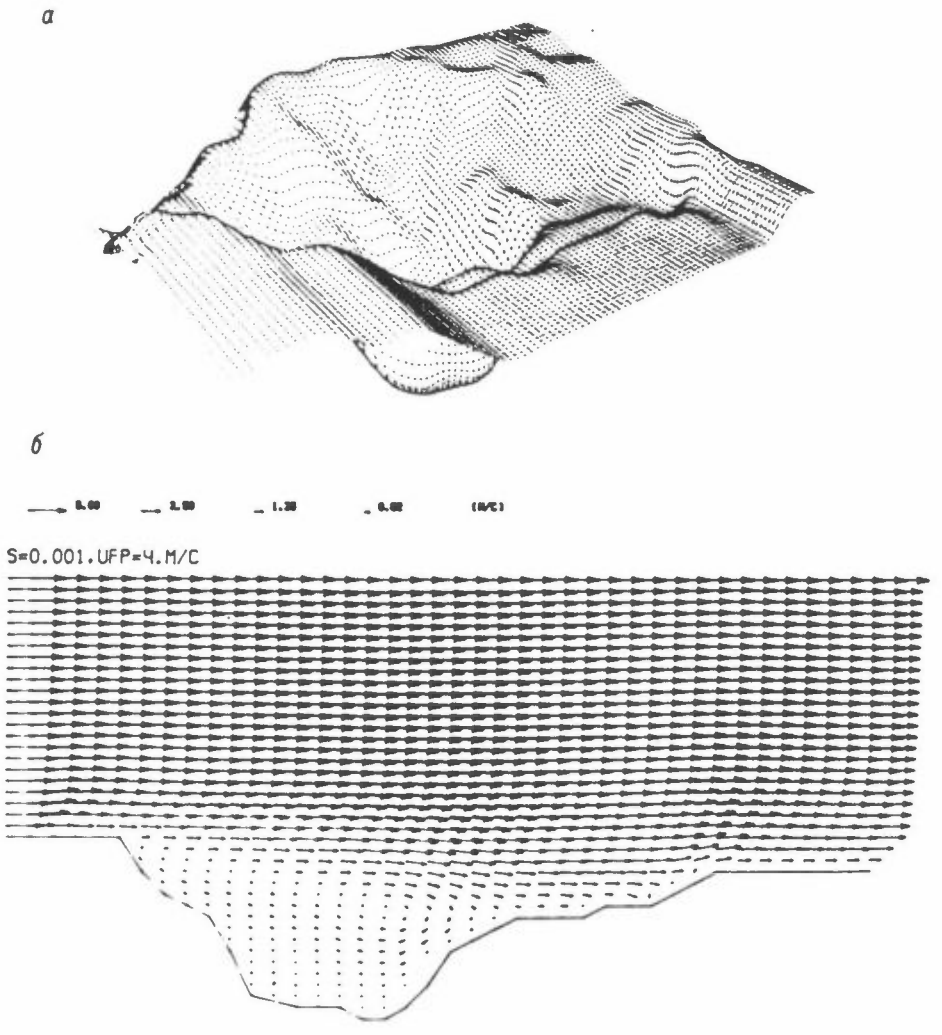

Figure 6: Relief of open pit and vector field of velocity when natural ventilation.

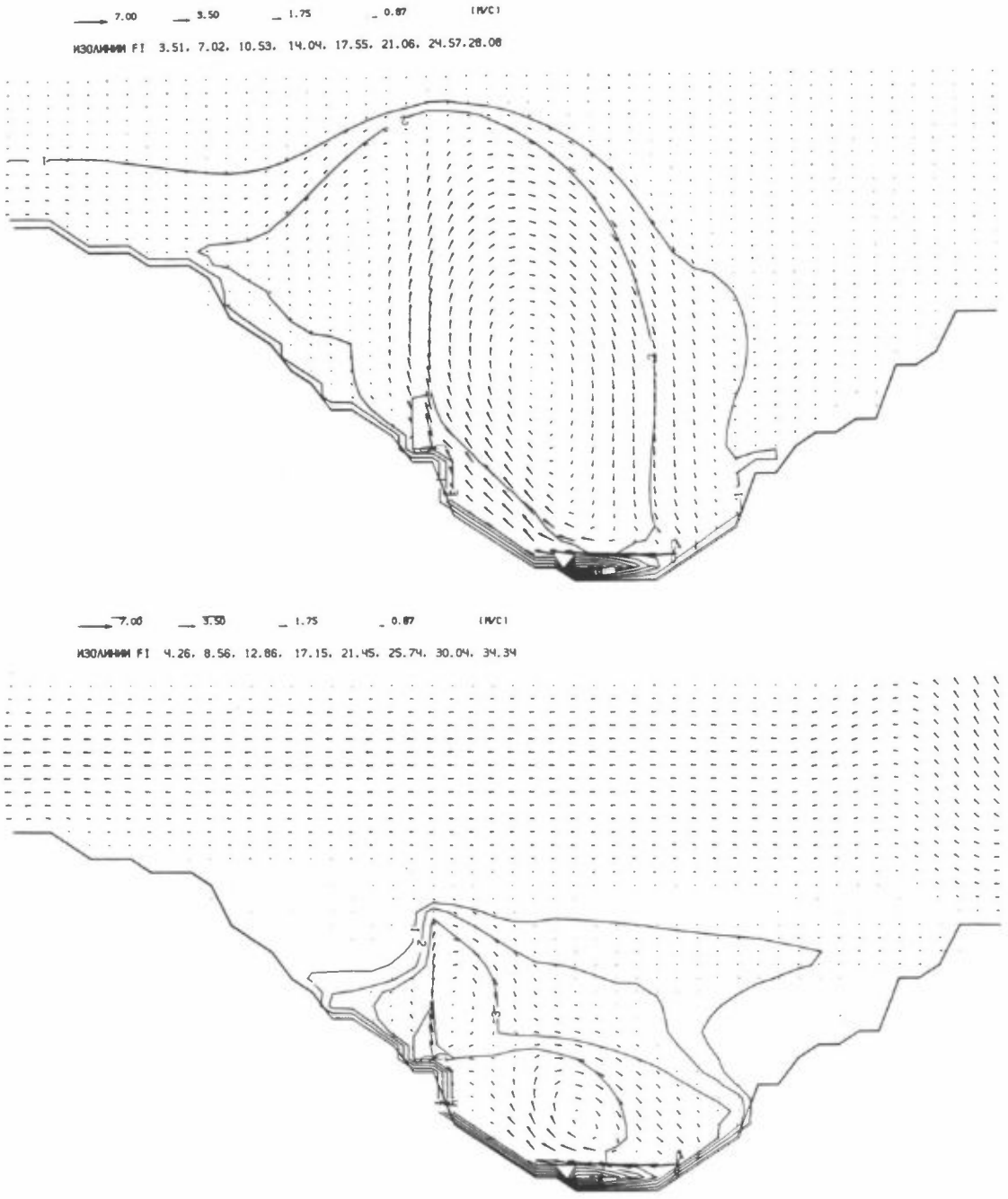

Figure 7: Vertical cross-section: isolines of admixture concentration and vector field of velocity resulting from artificial ventilation of Saamski open pit of concern "Apatite":

a) uniform atmospheric stability;

b) stratified atmospheric stability.

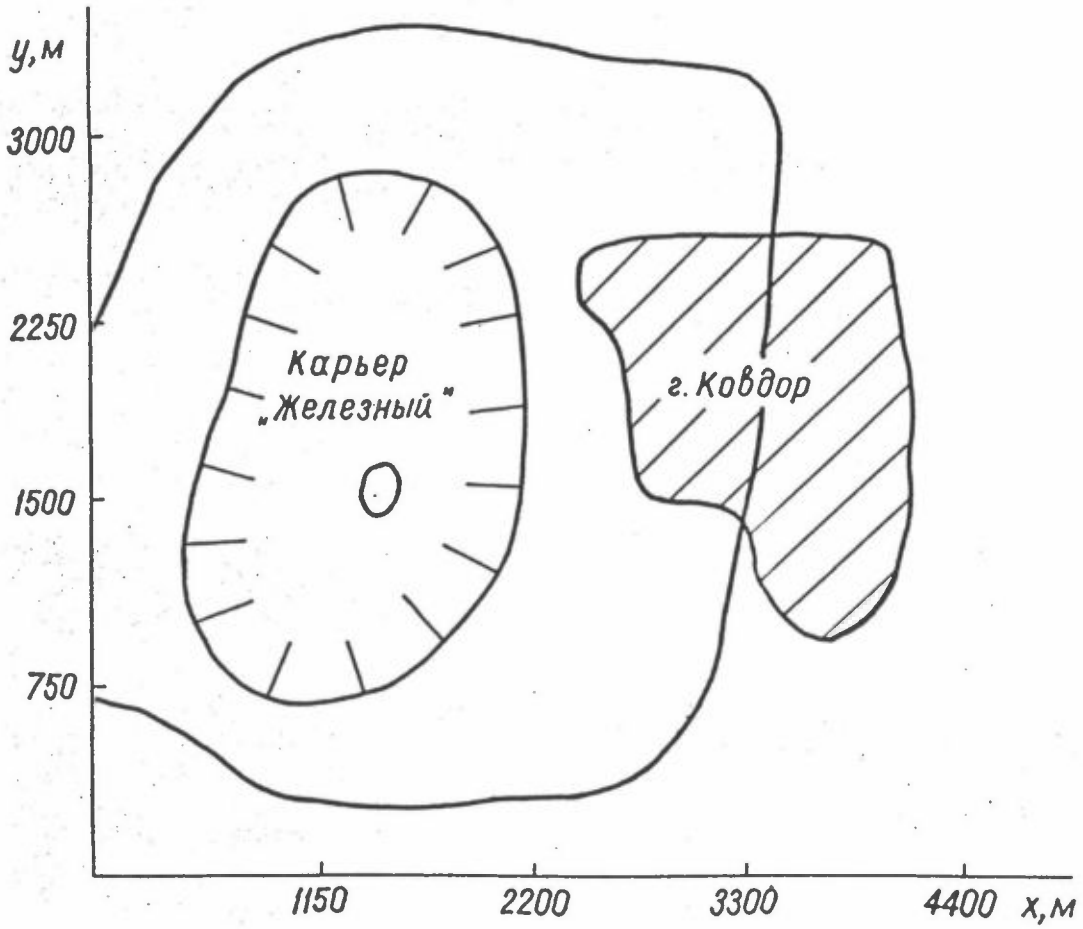

Figure 8: Calculated sanitary zone around open pit "Dzelezny" of Kowdor ore-dressing plant.

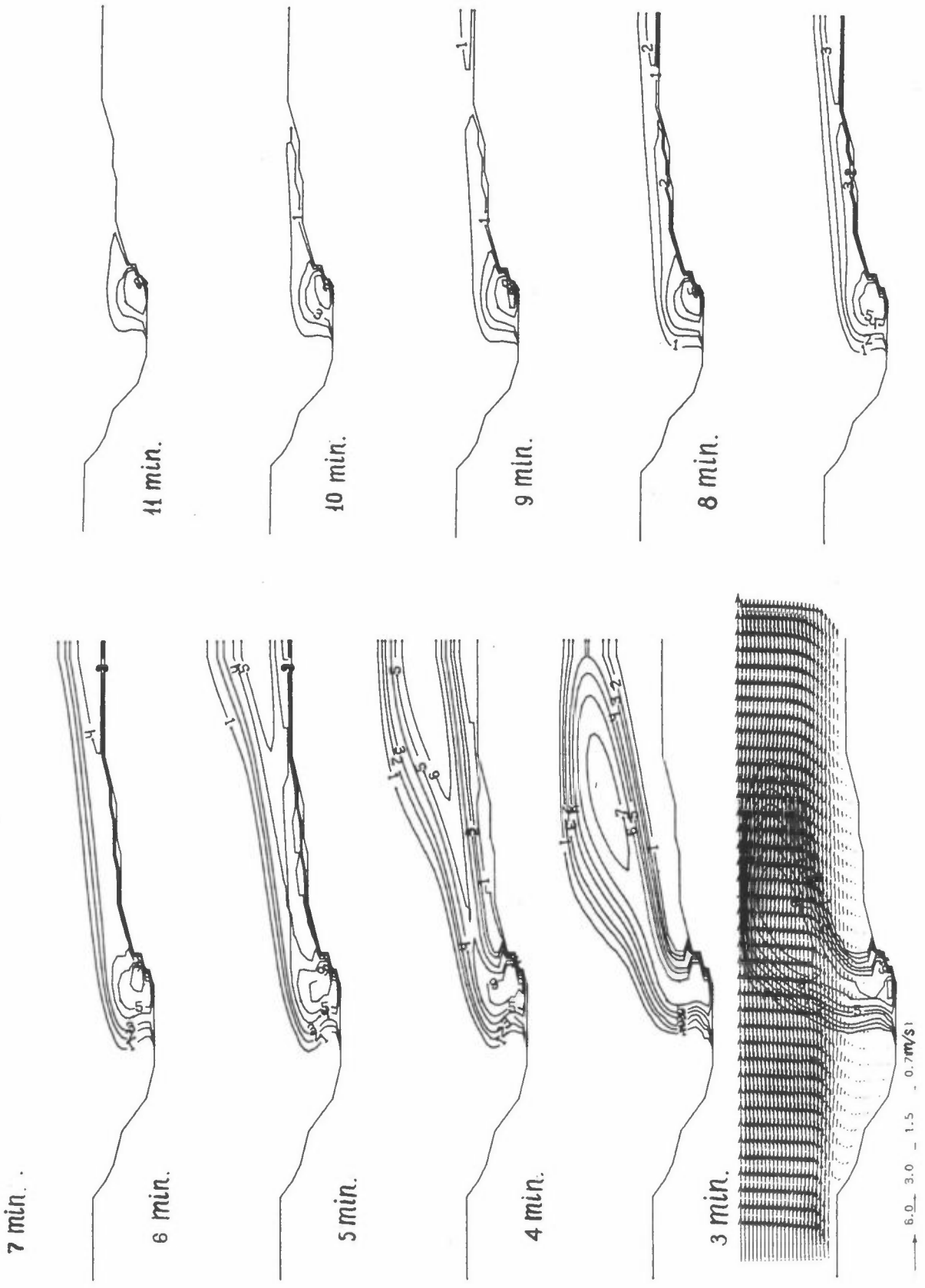

Figure 9: Gas and dust cloud distribution after blasting in an open pit operation when background wind U=4m/sec; vertical cross-section.

2.9. The simulation of radioactive pollution of the environment after hypothetical accident on the Kola Nuclear Power Plant

Baklanov A.A., Barsukov I.V., Mahura A.G., Morozov S.V., INEP KSC RAS

Abstract

This article presents a short description of the problems of modelling the distribution of radionuclides from Kola Nuclear Power Plant in the border of creation the Automatic System of Control of Radiation Situation for the Kola Atomic Station. The article is divided into several parts: A short description of the Automatic System of Control of Radiation Situation, the physical-geographical peculiarities and the meteorological characteristics of the 30-km zone, the simulation of wind velocity fields, the scenario of hypothetic accident, the description of using models, and the results and conclusions.

2.9.1. Introduction

The Arctic region of Russia, because of its geographical and sociological features, is under the constant and increasing threat of radioactive pollution. Mainly it is connected with a great number of military projects on nuclear weapons tests and naval atomic bases situated in the region. Now some territories of the Arctic region of Russia are ecologically unfavourable. Special attention has to be paid to the radiation conditions which in the Kola Peninsula and other Arctic regions threaten to turn disastrous.

The following sources of potentially danger radioactive pollution are to be pointed out (Fig.1 - "The map of Risk Objects of Arctic and Russian North"):

- Nuclear power installations of Kola, Bilibinskaya, Leningrad Nuclear Power Stations;
- atomic ice-breaking Fleet;
- Northern Navy with ships and submarines equipped with nuclear power installations and bearing nuclear weapons;
- shipbuilding and shiprepairing plants both civil and military;
- nuclear weapons tests on Novaya Zemlya;
- underground nuclear explosions with "peaceful" aims;
- enterprises specialized on treatment and utilization of radioactive raw materials;
- depositories of nuclear weapons, nuclear fuel, radioactive waste products and wrecked submarines;
- radiative waste products depository places;
- submerged atomic ships;
- deposition of the radioactive precipitation after Chernobyl Nuclear Power Station's accident;
- the flowing of Siberian rivers into northern seas, where are situated the enterprises of radioactive circle from cities Krasnojarsk, Tomsk, Cheljabinsk and others.

2.9.2. The Automatic System of Control of Radiation Situation for the Kola Nuclear Power Plant (KNPP).

KNPP is one of the dangerous objects of radioactive risk on the Kola Peninsula. The KNPP consists of 4 acting energy units each with 440 MWton power. The first and second energy units form the 1-st turn of KNPP, 3-rd and 4-th - second turn. Both turns are situated on common industrial ground on the shore of Glubokaya bay of Imandra lake. Radioactive control is carried out by the multi channel installation "System" and the apparatus complex "Seival". The radius of sanitary-protective zone is equal to 5 km.

Further it is proposed the construction of the third turn of KNPP at the individual industrial ground at the Imandra lake shore too.

Approximately 163 thousand people live in 50-km zone of KNPP, the population density is about 21 people per 1 square km. Most of the population lives in the urban settlements of Polyarnye Zori, Kandalaksha, Afrikanda, Apatity, Kirovsk and others.

The main sources of air pollution in 100-km zone are the enterprises of the cities of Monchegorsk (plant "Severonickel"), Apatity (mining-dressing factories, power electric station), Kandalaksha (aluminium plant), Kirovsk (mining-dressing factories, non-ferrous metallurgy) and Kovdor.

KNPP conducts the work on elaboration of the automatic system of control of radioactive situation for 30-km zone of atomic station with the Radium Institute (Sankt-Petersburg), Institute of the North Industrial Ecology Problems (Apatity) and other organizations. The 5 sensors for the control of radioactive situation are disposed in the sanitary-protective zone now (Fig.2).

The principle of this system is as follows :

- The tasks on determination of common quantity of emitted radionuclides, on estimation of the order of damage of reactor active zone and on determination of the accident scenario, using data of radiological control in industrial ground of atomic station;

- The radioactive situation on the territory near atomic station and the evolution of distribution of radioactive cloud on large distances are forecasted, using collection of software of various levels of complexity and operational meteorological information;

- The radioactive situation, the possible levels of irradiation, the ecological consequences and taking steps to notify the consequences of accident are analyzed, using system of information treatment;

- The coordination of actions for various security services and for population is provided, using management post.

It is very difficult to reckon on availability exhaustive information in dangerous situation, especially in the initial stage. Therefore, the preliminary estimations are made on the basis previously prepared information about the possible sources of accident and their types. Mathematical simulation of physical processes of atmospheric dynamics and transport of radioactive emissions from potential sources play the considerable role in preparation of these data.

Of the many diverse factors with potential ecological consequences of accident situations, the considerable part belongs to local and regional conditions. They are: placement of accident objects, geographical peculiarities, climatic conditions, density and quantity of population, character of urban settlements and others. Therefore, the task of creation centres on ecological monitoring and on forecast of accident consequences, is especially actual for the regional level exactly.

2.9.3. The physical-geographical peculiarities and the meteorological characteristics of the 30-km zone of KNPP.

The ground of acting turn of KNPP is situated on the cape of a narrow peninsula, deeply jutted into Imandra lake.

The relief of this region is complex. There are many hills, hollows, water objects (Fig.3). Most of territory (more then 50 per cent) is covered by the water surface of Imandra lake. The height, dominating over the ground surface (approximately 400 metre over sea level - Lyasaya height), is situated in the south - south - west direction from KNPP . The main components of vegetable canopy are forest, bushes, moss.

Although KNPP is disposed north of the Pole circle, the climate is rather mild.

The direction and velocity of wind in most cases are dependent on configuration of the relief. The nearest meteorological station is disposed in the settlement Zasheek.

The analyze of meteorological data shows (Table 1, 2), that in the winter period the south-west directions of wind are predominate, the probability of temperature inversions is high. The summer period is characterized by the north, north-east directions of wind, the most quantities of liquid precipitations, and the domination of "stratus", continuous and low clouds.

Table 1: The meteorological parameters at the meteorological station Zaaheek

Meteorological parameters	Summer, July (average)	Winter, January (average)	Year (average)
Temperature of air (^{O}C)	+13.9	-13.0	-1.0
Quantity of precipitation (mm)	755	401	650
Humidity (%)	72	85	78
Velocity of wind (m/sec)	3.8	3.3	3.8
Quantity of clouds: Common	6.7	7.3	7.5
Lower	4.8	5.9	5.9

Table 2: The probability of wind directions in the seasons on the height 10 m

Season	N	NE	E	SE	S	SW	W	NW	Calm
Spring	17	9	5	6	15	24	9	15	9
Summer	23	16	7	6	16	17	6	9	6
Autumn	10	7	6	7	19	24	24	10	8
Winter	10	7	8	9	19	28	9	10	11
Year	15	10	6	7	16	24	9	13	8

The slight unstable, neutral and slight stable conditions of atmosphere are more probable for the region of atomic station disposition. Water, used for cooling, is realeased into the western part of Babinskaya Imandra lake. As a result of this action, the wide territory of water surface of Molochnaya bay doesn't freeze all winter.

These geographic, climatic and orographic factors influence the formation of meteorological parameters fields, both velocity and direction of wind and temperature and humidity within the Atmospheric Boundary Layer (ABL), and impact on the distribution of emissions from KNPP. The registration of these factors under mathematic simulation of atmospheric dynamics and transport of radionuclides is necessary. It will allow increased reliability of results of estimation of a radiation situation at the region of KNPP acting turns.

2.9.4. The simulation of wind velocity fields.

The main step on the forecasting of radionuclides distribution is the simulation of wind velocity components fields in the KNPP region, taking into account the physical-geographical peculiarities.

The 3-dimensional model of atmospheric hydrodynamic in the non-hydrostatic approach was used as a basic model.

The modelling was carried out for the domains with sizes (Fig.4, 5) :

- 16 by 16 km - for more detail registration of the complex terrain of nearest zone of KNPP;
- 80 by 80 km - under the modelling for the cities Apatity and Kirovsk.

The forecast for a past accident situation was conducted for the more unfavourable weather conditions - the neutral and the slight stable conditions of atmosphere and the wind directions in Polyarnye Zori, Apatity, Kirovsk. The data about the skin surface temperature was used for the simulation.

The results of modelling of wind velocity fields for two domains for various seasons and times of day (Table 3) are presented (Fig. 6, 7).

Table 3: The typical situations for simulation of wind fields

Period of year	Time of day
Summer (July)	Night - 3 h
Summer (July)	Day - 13 h
Winter (January)	Night - 3 h
Winter (January)	Day - 13 h

Call attention to :

- the structure of wind flow over the orographic non-homogeneous surface results in further changes of the character of pollution;
- the horizontal velocity in X-direction is distributed sufficiently uniformly in the winter period over the ice cover of Imandra lake;
- the non-uniform velocity wind distribution, connected with the differences between water and soil heating, is observed in the summer period.

The analysis of the data obtained allows us to make conclusions about essential influences of orographic effects on the formation of wind flow structure at various times of the day and year.

2.9.5. The scenario of hypothetic accident

The PWR-440 type reactor, used at the KNPP, is one of the most widely distributed in the Russian energetic. It is a pressured-water type of reactor. The reactor consist of the case with active zone containing intra-case devices. The exterior diameter of the case is equal to 3840 mm., the height - 23.4 m., the walls thickness of the cylindrical part of the body - 140 mm. Other main characteristics of the reactor PWR-440 are shown in the Table 4.

Table 4: The main characteristics of PWR-400 reactor

Characteristics of reactor	PWR-440
Thermal capacity. MWt (Thermal)tU	1.375
Electric power, Mwt (el.)	440
Number of circulation loops	6
Pressure, MPa	
in reactor	12.3
in the steam generator	4.6
Temperature, °C	
in inlet temperature	286
reactor outlet temperature	296
Consumption of the heat-tranfer-agent, cub. metre/hour	15.000
Inner diameter of the body, m	3.560
Body height (the coved excluded), m	11.8
Active zone parameters, m	
diameter	2.880
height	2.460
Uranium consumption, tonne	41.5
Mass of the heat-transfer agent, tonne	200

According to the hypothetic accident definition the localization systems and the fuse of heat releasing elements, would be destroyed causing the maximum possible emission of radioactive substances into the atmosphere. This emission is released under the destruction of all protective shields, separated the radioactivity, accumulated inside of the heat releasing elements from the environment. It is supposed the rupture of the main circulating pipe-line and the destruction of reactor case.

If we assume that the large leakage of transfer-heat-agent is the first reason of accident, then the process of the accident motion may be divided into the following stages :

1. During 1 hour, when the depressurization of heat releasing elements and the fuse of the most share of active zone are observed;
2. the momentary steam explosion;
3. during several days, when the outlet into the atmosphere of radioactive products division under the processes of fuel evaporation and fuse interaction with concrete of reactor mine.

The absolute quantities of radioactivity emission into environment due to hypothetic accident in energy units of the 1-st KNPP turn are presented in the Table 5.

Table 5: Absolute quantities of radioactivity emission into environment due to hypothetic accident in energy units of the 1 phase of the KNPP (in Mln.curie)

Groups of radionuclides	Accumulated activity	1. grade	2. grade	3. grade
Kr-85, Kr-85m, Kr-87, Kr-88, Xe-133, Xe-135	140.122	4.063	87.016	49.043
J-131, J-132, J-133, J-134, J-135	299.9	9.297	185.938	104.665
Cs-134, Cs-137	7.68	0.246	5.483	1.951
Sb-124, Sb-125	68.22	0.154	23.98	10.226
Ba-140, Sr-89, Sr-90	142.87	1.443	48.65	3.057
Ru-103, Mo-90	109.66	0.002	54.83	32.896
Y-90, Y-91, Zr-95, Nb-95, La-140, Ce-141, Ce-144, Eu-154	525.143	0.01	0.315	0.357
All radionuclides	1293	15.215	406.212	202.197

2.9.6. The models

Emissions from sources are transported and distributed within the atmosphere, suffering additional changes such as :

- Radioactive disintegration;
- falling on the skin surface;
- washing by precipitation;
- dry precipitation;
- chemical transformations.

Sufficiently many models for description of distribution of radioactive emissions from atomic stations are employed. The following spectra of models (Fig.8), in dependent from the solving task, are used in our work.

The Gaussian model is one of the simplest models for calculating the distribution of emissions and requires the minimum set of input data. However, the normal law isn't true in the vertical direction. The application of ABL upper boundary is based on in the assumption, that the concentration of admixture is homogeneous by the height within the mixing layer. The velocity of wind is measured only at one point, and the trajectory of radioactive cloud is represented by the straight line. This circumstance limits the model application to the distances approximately 10-15 km.

The models of this type are used by us for rough estimation and under normal exploitation, but, for a more detailed description of emissions distribution from the atomic station the application of higher order models is desirable.

In the cases when it is necessary to take into account temporal and spatial wind velocity changes and, when it is possible to receive the necessary information about the velocity in several points (observation stations), the " Lagrangian cloud model" is used.

The trajectory of the cloud centre is calculated under the wind field in several points. This model may be used from the local to the regional scales.

The 3-dimensional wind field is used in the most complex 3-dimensional models. Here, it is possible to account for the relief influence, the roughness, the wind change, the atmosphere stability and other factors. The spatial vertical structure of the wind field and the character of turbulence are determinated due to the ABL models. In the case when the carrying out of admixture origins beyond the limits of ABL via their upper boundary, then the models would be to reproduce the exchange mechanism with the free atmosphere (i.e. it is necessary to account for vertical currents).

The coefficient of turbulent diffusion in the vertical direction is similar to the coefficient of turbulent exchange by quantity of motion and by heat. The choice of diffusion coefficients in the horizontal direction depends on the spatial and temporal scales of solved task.

For the calculation of diffusion parameters, and further admixture concentrations in the mixing layer it is necessary to determine such parameters as :

- the dynamical (friction) velocity;
- the turbulent flux of heat;
- the height of the mixing layer;
- the vertical gradient of wind velocity;
- the standard deviations of wind velocity components - on the base of meteorological and aerological observations. The various types of parametrization, taking into account the distribution of turbulent characteristics, are used for these aims.

The effective height of source; the increasing of admixture under the radioactive disintegration, the washing by precipitation, the dry precipitation and others - are important and they are taken into account under the simulation of emissions distribution.

2.9.7. Results and conclusions.

The main goal of the radioactive situation forecast for a KNPP accident is to determine the radiation levels personel and the public will receive from radionuclides in the air and on the soil surface.

The most danger offer the radionuclides of cloud, transporting on large distances from the emission place under influence of air flows and settling on the large territories, when the cloud is transported.

It is proposed under the calculations, that the cloud consists of radionuclides N-components; The dose loading on the moment of emission cloud passage is determined.

Several results and conclusions were made after our work:

I. The set of the dose loading maps (atlas) for typical situations was received in the result of calculations (for example Fig.9, 10, 11, 12). This set of maps will be used for the preliminary analysis of accident consequences.

II. The relief influence (mountain Khibiny) observed under the modelling of emissions distribution in the direction Apatity-Kirovsk. This influence determines the magnitude of radioactive danger for these cities.

III. The spatial trajectory model, which is more economic on calculation time is elaborated to take into account the relief for the operative forecast of radioactive consequences at the KNPP.

IV. Recently, for the investigation secondary consequences and the risk from the radioactive accidents is carried out the preparation of input data for model "MACCS" by collaborates of our institute. This model "MACCS" was developed by scientists from the Sandia National Laboratory, US. We plan to conduct the calculations for the Kola Peninsula using this model. This work is carried out with the Norwegian scientists cooperation.

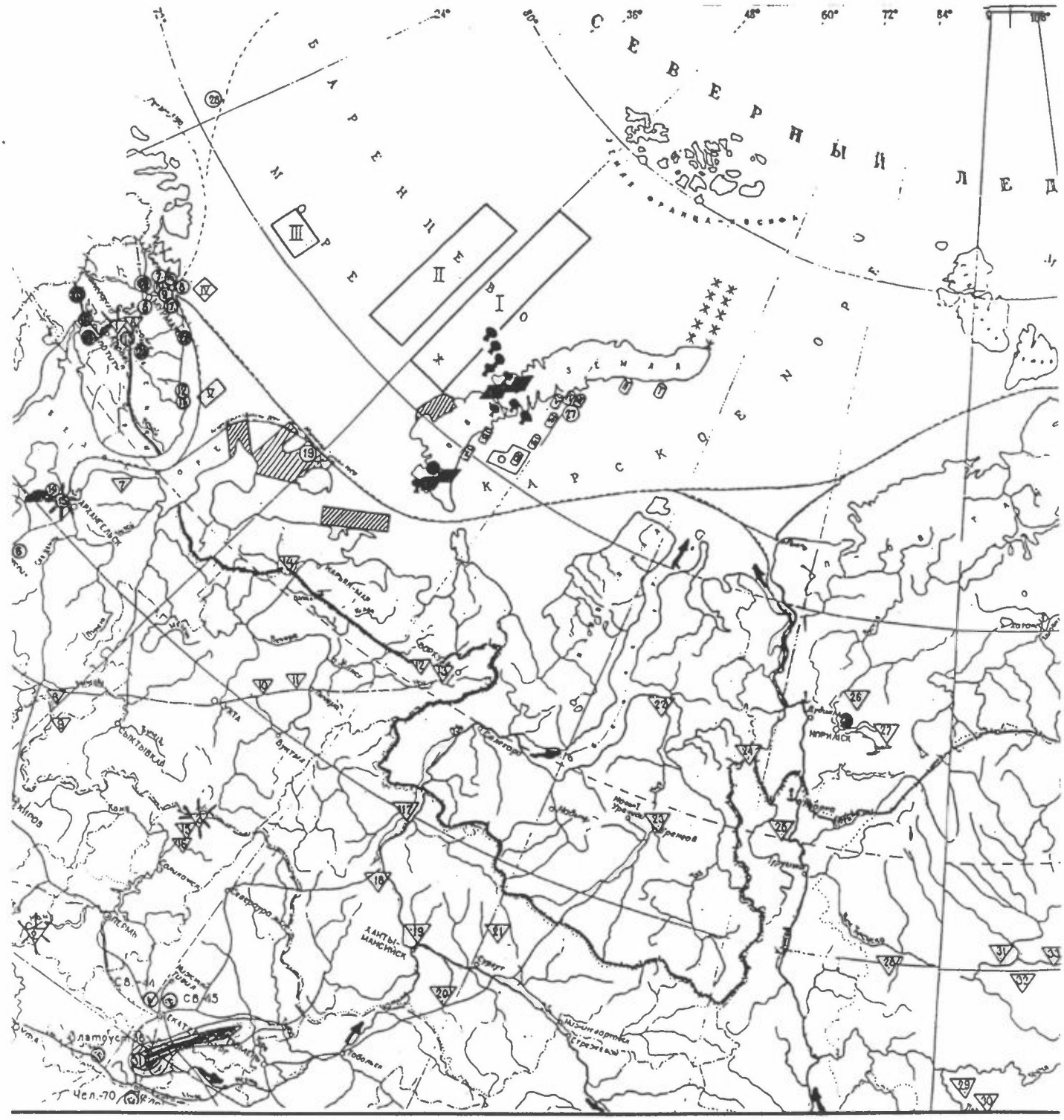

Figure 1: Map of risk objects of Arctic and Russian North

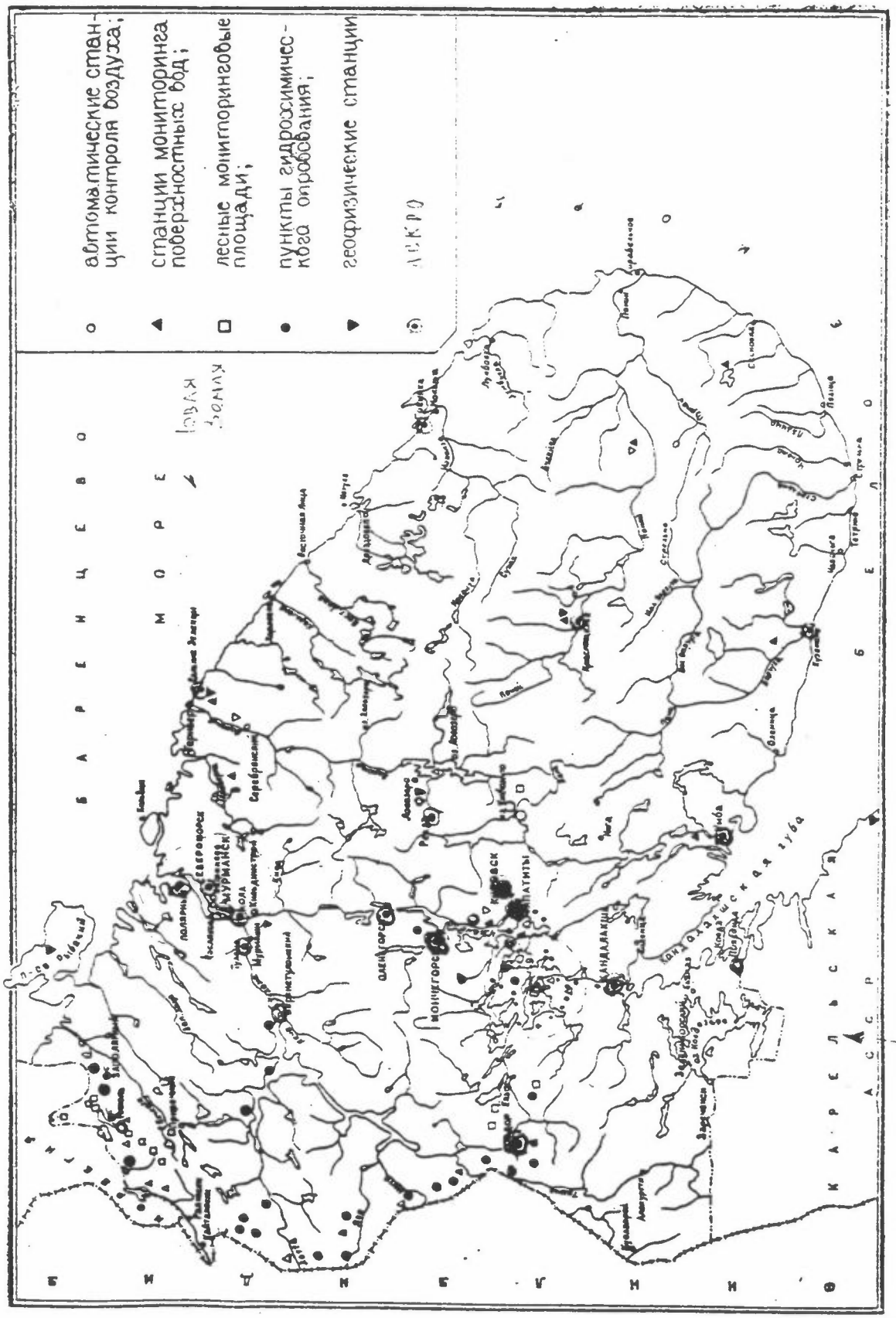

Figure 2a): Sensors for the control of radioactive situation

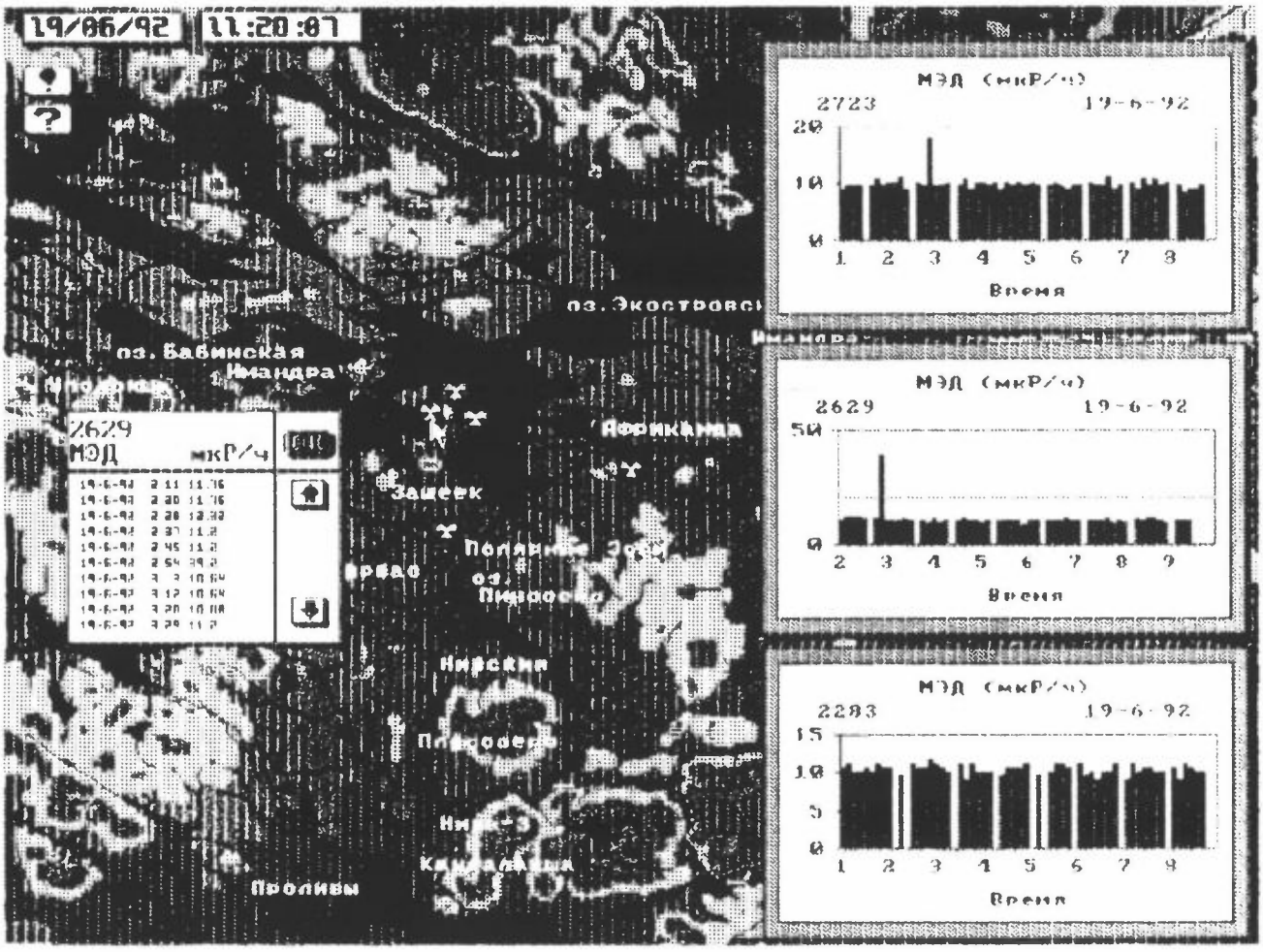

Figure 2b): Sensors for the control of radioactive situation

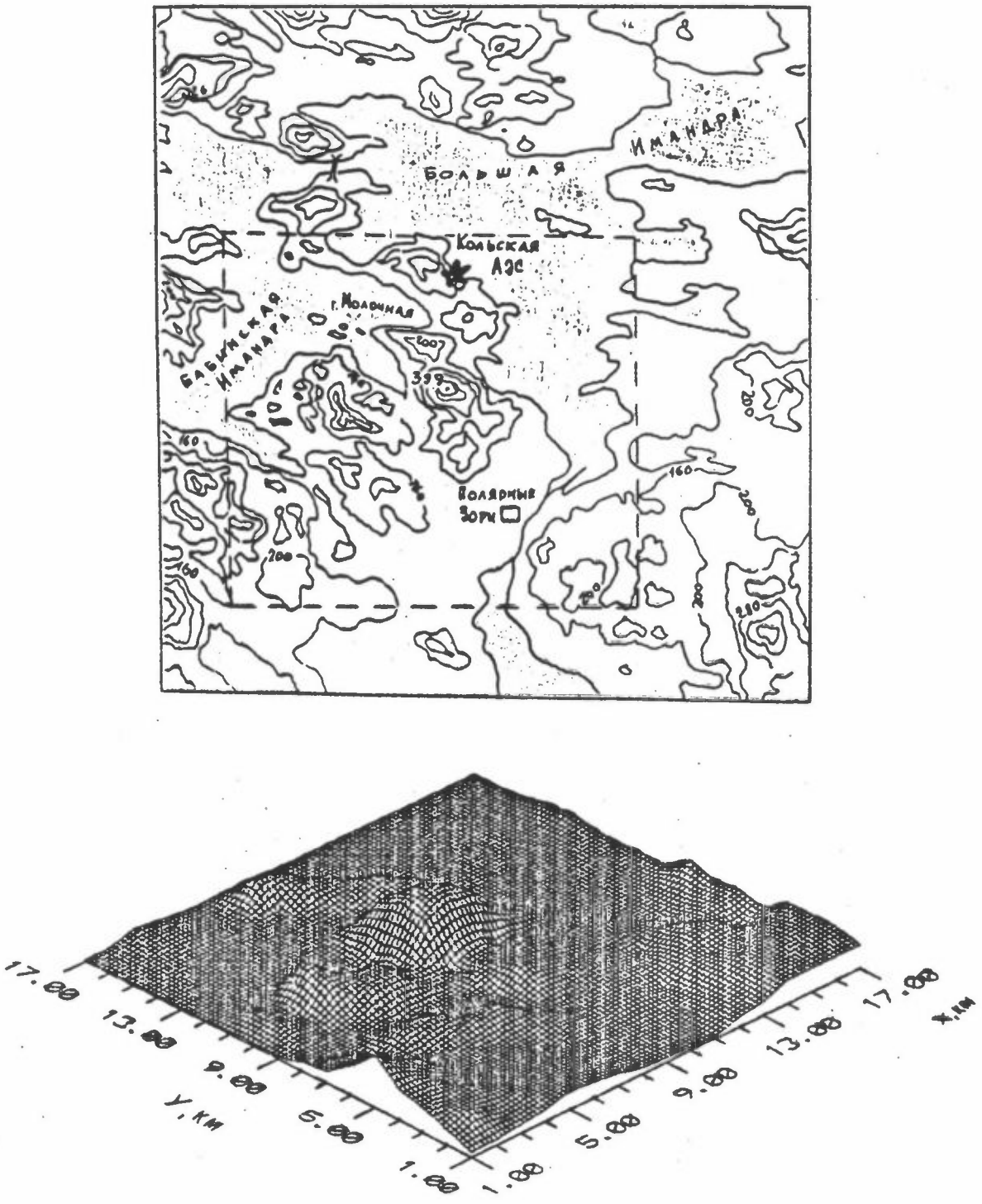

Figure 3: *Physical and geographical features of the location area of Kola nuclear power station and surface of the area used in numerical simulation*

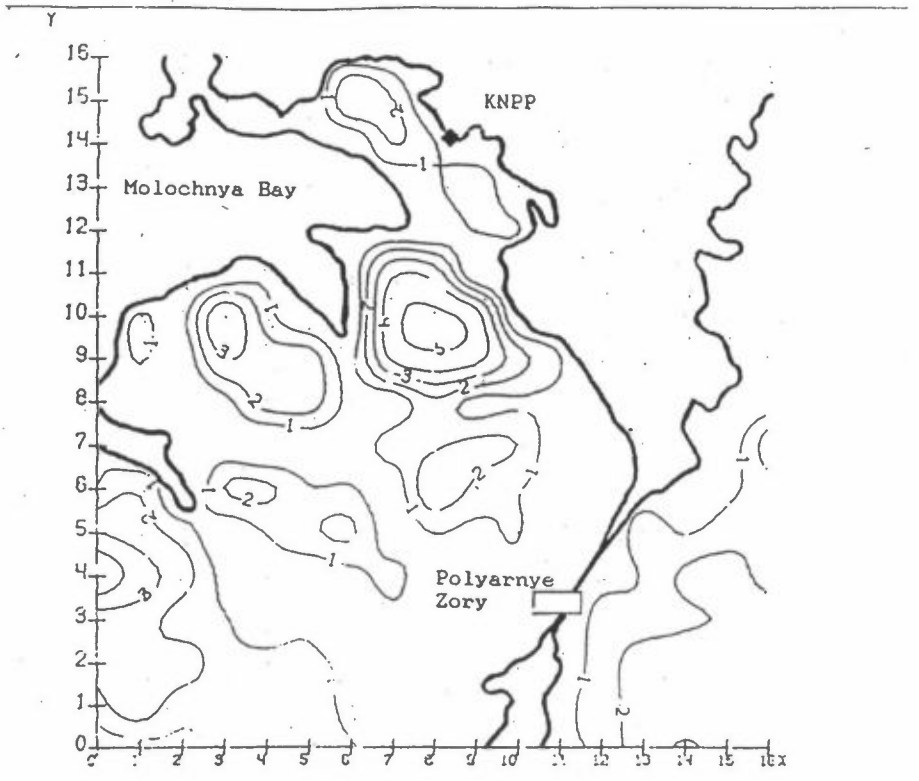

Figure 4: The modelling domain with sizes 16×16 km (isolines of relief 1-160, 2-185, 3-220, 4-260, 5-310 m)

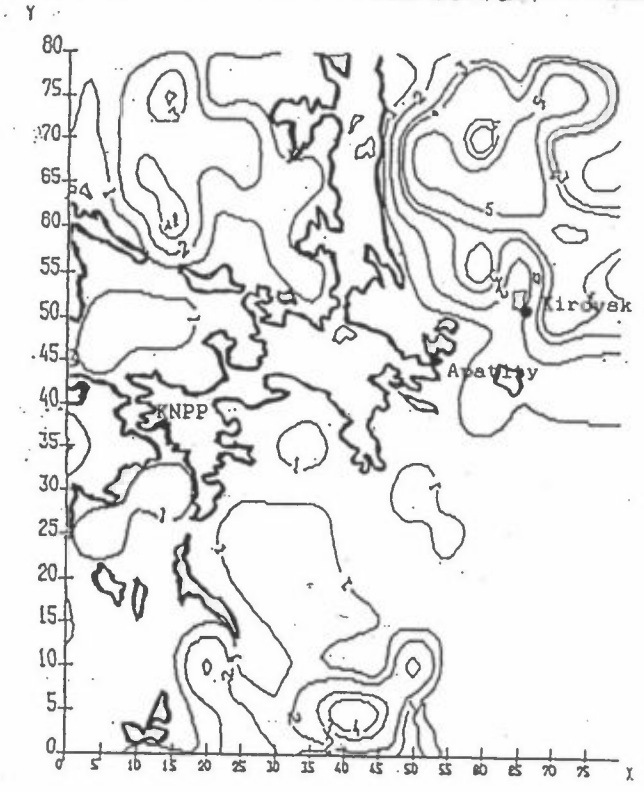

Figure 5: The modelling domain with sizes 80×80 km (isolines of relief 1-180, 2-300, 3-500, 4-600, 5-800 m)

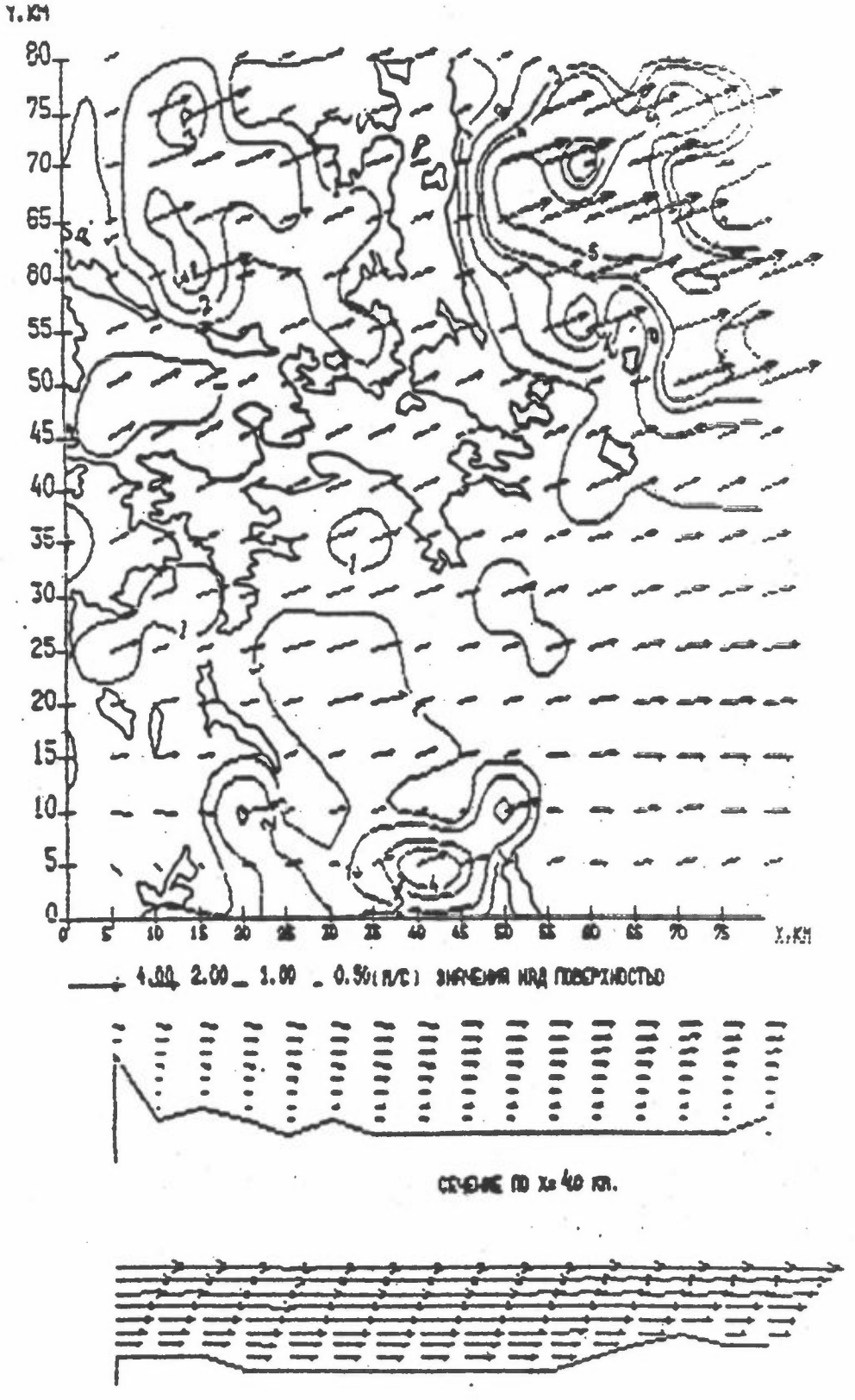
Y, KM
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
X, KM
4.00 2.00 1.00 0.50 (M/C) ЗНАЧЕНИЯ НАД ПОВЕРХНОСТЬЮ
СЕЧЕНИЕ ПО X= 40 КМ.

Figure 6:

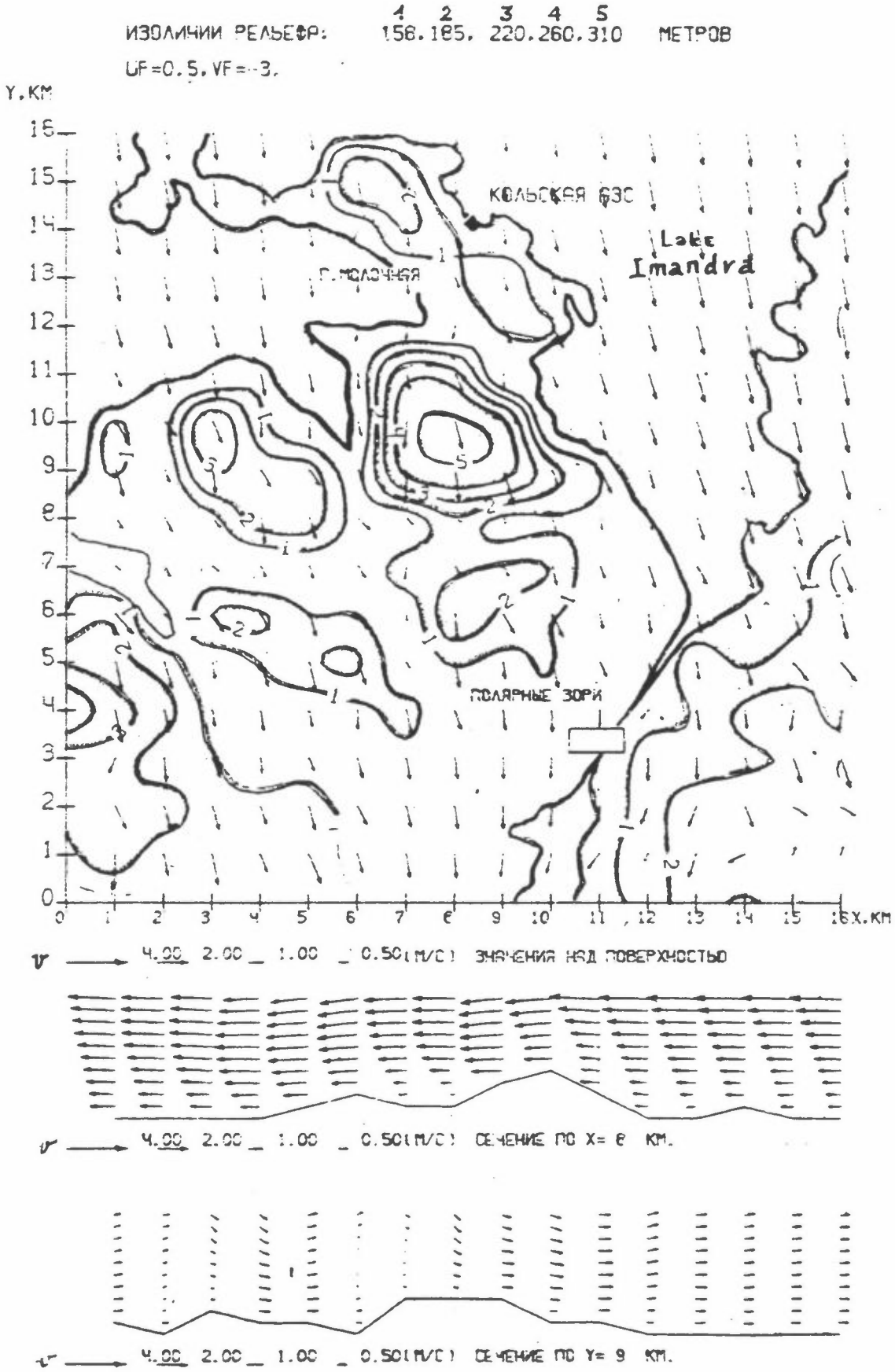

Figure 7: Vector field of wind velocities taking into account the local relief

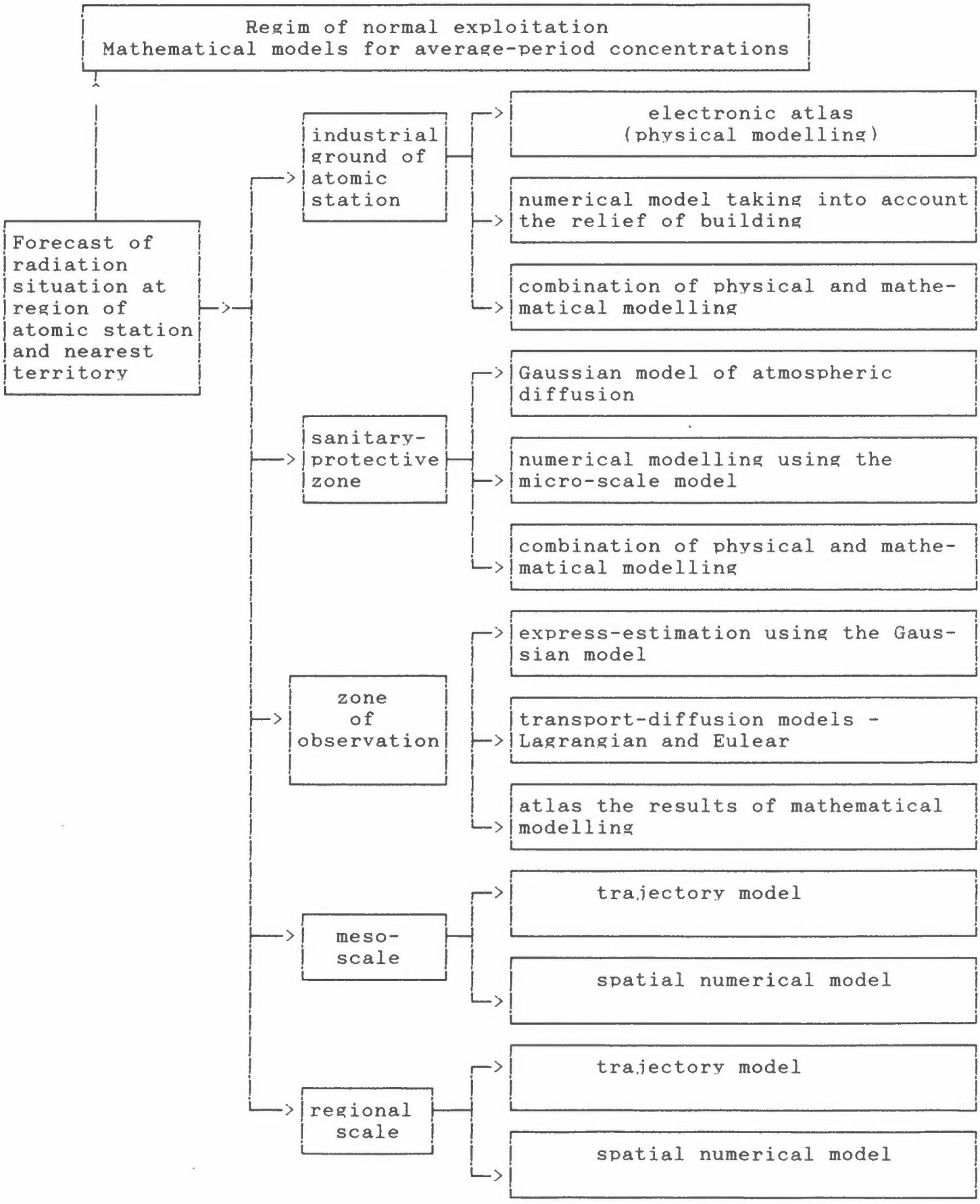

Figure 8: Structure of software for transport modelling

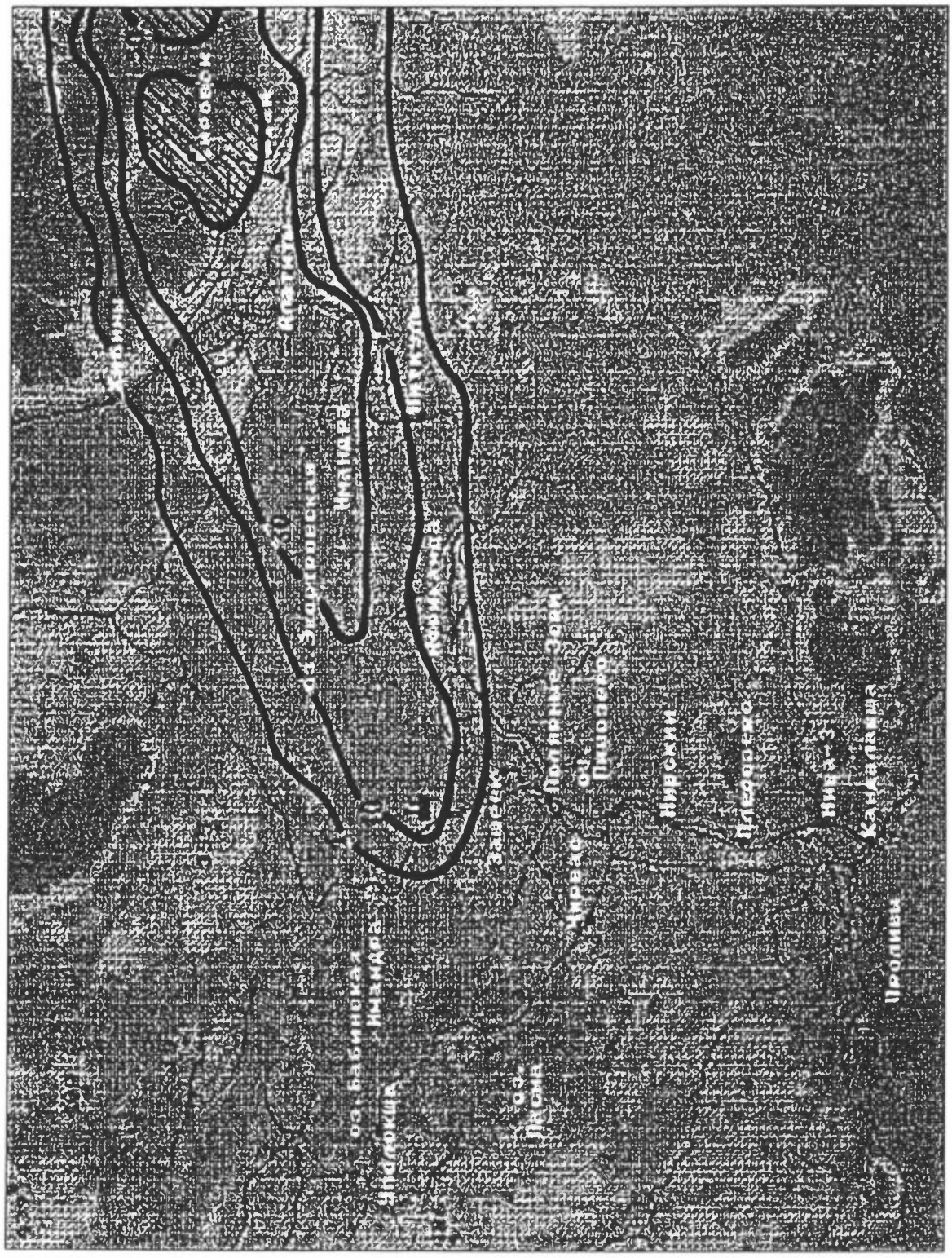

Figure 9: *The calculation of consequences of hypothetic accident at KNPP for Apatity and Kirovsk, carryed out by INEP KSC RAS. Personal radiation dose for thyroid gland 10 Sv*

2.10. Calculation of risk to the Norwegian population from potential accidents at the Kola Nuclear Power Plant. Status report April/May 1993

Ulf Tveten
Institute for energiteknikk
Kjeller, Norway

Summary of the presentation

This presentation reported the status at the current time. The tasks that had been carried out at the time were:

- Rough evaluation of the situation, including availability of release data.
- Collection of data on population and some environmental aspects.
- Observation of special conditions in the area.
- Preliminary set of calculations had been carried out, to identify problem areas.

Release

Unfortunately an accident analysis for the power plant in question has never been carried out. The International Atomic Energy Agency have plans for carrying out such analyses for nuclear power reactors in Eastern Europe, but it is not expected that these plans will be carried out in the near future. Accordingly accident source terms specific for the Kola Nuclear Power Plant are not available, and for the purpose of these calculations one was forced to choose a source term typical of a very large release from a Western type power reactor. The probability of such a release from a Western reactor will be very small, but this probability is not applicable to an Eastern reactor. For this reason all results from these calculations will have to be presented as the relationship between consequences and conditional probabilities; by which is meant that all calculations are performed assuming that the release has taken place. The real probability of a certain consequence magnitude is obtained by multiplying this conditional probability by the probability of the release taking place, but the latter is unknown at the time being.

Dispersion calculations

The calculations performed at this stage were performed with the risk calculation model MACCS currently employed by the U.S. Nuclear Regulatory Commission for calculations of this type. Basis for the statistical distribution of the results is a meteorology file containing observed meteorological data for each hour of a whole year. From this file is chosen in a semi-random manner a certain number of (ca. 100) weather sequences for which calculations are performed. Each weather sequence will give different results, and in this manner a statistical distribution is obtained.

The dispersion model employed is a simple straightline Gaussian model. Dry and wet deposition are included. Any bias due to the simplified model will usually be on the conservative side.

Exposure pathways

The model contains the following exposure pathways:

- Inhalation from the passing cloud.
- Direct radiation from the passing cloud.
- Direct radiation from contamination on the ground.
- Exposure via nutrition.
- Inhalation of resuspended materials.

The nutrition pathways relevant in Finnmark are:

- Crops for human consumption.
- Sheep.
- Cattle.
- Reindeer.
- Moose and other game.
- Drinking water.
- Fish.

The main benefit of these preliminary analyses of the problem is a better understanding of the peculiarities of the nutrition pathways in Finnmark.

Crops for human consumption

There is some production of animal fodder in Finnmark, but very limited production of crops for human consumption. The total area for crops for human consumption is only about 0.4 km^2, which is mostly used for growing potatoes. A small area is used for growing strawberries, and there is also a very modest production of Swedish turnip, carrots and cabbage. Almost 80% of all this production takes place in the Alta municipality. The crop yields (kg plant/m^2) are quite low compared to values from more temperate climates. Crops for human consumption contribute very little to the population dose in Finnmark.

Sheep

In 1992 about 13.000 lambs and 2.700 sheep were slaughtered in Finmark, with an average weight of meat per animal of 16 kg for lambs and 25 kg for sheep. It is assumed that all fodder is produced locally, but this may be a pessimistic assumption.

To make more dependable calculations of the dose via mutton, more information on the grazing patterns of sheep in these areas are needed. Since crop yields in this climate are low, it is expected that sheep have to graze larger areas than in more

temperate climates, and the daily intake of radioactivity may for this reason be larger than in other types of areas. The contribution via this pathway to the population dose does not seem to be among the largest, but is nevertheless significant.

Cattle

There is considerable milk production in Finnmark. Yearly production is more than 25.000 tons from more than 4.000 milk cows. It is assumed in these preliminary calculations that all fodder is harvested locally, and this assumption may be overly pessimistic. The milk exposure pathway seems to give the largest contribution to the population dose of all the nutrition pathways.

There are about 5.500 cattle for meat production in Finnmark. The amount of meat per animal is 200 kg and the age at slaughtering is 2 years. In addition there is meat from dairy animals, with an average age of 4 years at slaughtering. The meat pathway is less important than the milk pathway.

Reindeer

In 1990 there were about 173.500 reindeer in Finnmark and about 68.500 of these were slaughtered that year. It is expected, however, that the number of animals will be reduced in the future. The reason for this is that the area is really not large enough to support that many reindeer.

There are special difficulties with calculations of radioactivity transfer via this exposure pathway, since the diet of reindeer consists to a large extent of lichens. Lichens, as opposed to grass, does not die in winter, and radioactivity deposited upon lichens will be reduced at a much slower rate than radioactivity deposited upon grass. None of the models available for such calculations, however, are able to handle different reduction rates for different animals. At present we are forced to use either the reduction rate for lichens or the reduction rate for grass when calculating both cattle and reindeer. In either case one of the two will be treated incorrectly.

Reindeer seems to be the most important of the meat nutrition exposure pathways, but all meat exposure pathways together are less important than milk. This conclusion may have to be modified when a more stringent treatment of the reindeer meat exposure pathway becomes available.

Moose and other game

Meat from moose and other game has been treated in the calculations in the same manner as meat from reindeer. It contributes little to the population dose.

Drinking water

Post-Chernobyl experience from Norway shows that radioactive cesium or strontium deposited on lakes or rivers only to a quite small extent remains dissolved in water. After a relatively short time period the radioactive materials are attached to particles and undergo sedimentation.
For this reason drinking water is of concern as an exposure pathway only relatively short time after deposition. It may also be of concern if the source of drinking water is a cistern, especially if the water level was low before the deposition took place.

Fish

Fish is of much larger concern in Finnmark, relative to the other exposure pathways, than in most other geographical areas. The yearly catch of fish in Finnmark is considerable, namely more than 400 tons.

The available model for calculating transfer of radioactive materials via freshwater fish is very simplistic. In most geographical areas the model is acceptable, since the contribution to the population dose via freshwater fish is quite negligible compared to the contributions via other nutrition exposure pathways. But in Finnmark this is not true, and a more realistic calculation model is required.

Results

Because of the obvious weaknesses of these preliminary calculations, no results from the calculations were presented.

Possible future tasks

During the preliminary calculations a large number of areas were identified where future work should be performed. Many of the weaknesses observed are of little or no consequence in geographical areas where such calculations have been performed up till now; namely in temperate to subtropical climates. The conditions in an arctic climates are, however, so different that these weaknesses become of major importance.

Some of the problem areas concern aspects of the dispersion calculations, ranging from more suitable representation of the rain data on the meteorological data file, to discussion of the overlying concern of what is proper representation of the risk of a reactor accident: a probability distribution, or the consequences of the worst possible combination of release and weather conditions.
A major group of possible future tasks concerns attempts to identify or determine data that are truly representative of arctic conditions. Most of the data available at present, particularly for the nutrition pathways (e.g. soil characteristics), were determined from observations/experiments in temperate climates. In some cases the models themselves also need to be modified to be appropriate for conditions in Finnmark. This concerns in particular transfer of radioactive materials via reindeer

meat and via freshwater fish. The importance of wild berries and mushrooms, both for human consumption and as part of the diet of animals, should also be considered.

It would also be appropriate to collect data on population and production of food-stuffs in Nordland and Troms in the same manner as has already been done for Finnmark. At present all of Norway apart from Finnmark will have to be treated as a homogenous type of area, which is obviously far from the truth.

2.11. Multitemporal Landsat image data for mapping the effects of air pollution on vegetation in the Kirkenes-Pechenga area in the period 1973-1988

H. Tømmervik, B.E. Johansen and J.P. Pedersen
NORUT Information Technology
N-9005 Trømsø, Norway

Abstract

The main objective with this project was to assess the feasibility of using optical remote sensing (Landsat MSS data) for mapping of vegetation cover changes in the period 1973-1988 due to air pollution impact in the border areas between Norway and Russia. During the project we produced vegetation maps for 4 different years (1973, 1979, 1985 and 1988), change detection maps, and statistics. One of the main changes in the vegetation maps produced for the different years was that the area with lichen dominated vegetation cover types had decreased from 2569 km^2 in 1973 to 405 km^2 in 1988. Bare rock, eroded heath, and contaminated (damaged) areas had increased from 257 km^2 in 1973 to 1324 km^2 in 1988. Comparison of the vegetation cover maps and the change detection maps with the total number of emissions of SO_2 presented shows a strong correlation between the dwarf shrub-lichen cover changes in the forests and heath land and the dramatic increase of the emissions in the period 1973-1988. The total area affected by air pollution increased from approx. 400 km^2 in 1973 to approx. 5000 km^2 in 1988. In the end this study concluded that feasibility of using optical remote sensing (Landsat MSS data) for mapping of vegetation cover changes due to air pollution impact was successful.

NORUT Information Technology has in the period 1988-93 performed a research project on studies of the effects of air pollution on the terrestrial ecosystems in the Varanger (Norway) and Nikel-Pechenga (Russia) areas.

The study area covers approximately 10.000 km^2, and includes parts of Russia, Norway and Finland. The main objective of this project has been to assess the feasibility of using optical remote sensing data (Landsat MSS data) for mapping of vegetation cover changes in the period 1973 - 1988 due to air pollution impact in the border areas between Norway and Russia. Vegetation maps from 4 different years, respectively 1973, 1979, 1985, and 1988 were generated by using satellite remote sensing data in combination with ground truth measurements. In addition a vegetation change map was produced from the individual vegetation maps (figure 3).

Air pollution emanating from the nickel-processing industries in Nikel-Pechenga, and Monchegorsk in the Kola Peninsula are the main sources contributing to the environmental problems on the Norwegian side of the border. The emissions of SO_2 from the Nikel-Pechenga smelters increased from a level of 204.000 tons of SO_2 in 1973 up to a maximum of 400.000 metric tons in 1979. Since 1979 the emissions have decreased, to 354.000 metric tons in 1985, and down to about 273.000 metric tons in 1990 (Traaen et al. 1991). The high levels of SO_2 emissions in the period 1974 to 1988 resulted in a severe degradation of the natural environments in the area of Nikel-Pechenga.

The satellite vegetation maps cover approximately 9880 km^2 of the Pasvik area. One of the main changes observed from the individual 4 vegetation maps was that the areas of lichen dominated vegetation cover types had decreased from 2569 km^2 in 1973 to 405 km^2 in 1988 (yellow areas in figure 1). Bare rock, eroded heath, and contaminated (damaged) areas had increased from 257 km^2 in 1973 to 1324 km^2 in 1988 (violet areas in figure 1). The areas covered by a dense lichen carpet are easily separated from areas without lichen cover.

Intact lichen heaths and woodlands are located to the areas of Neiden and westwards. Near the pollution sources in Nikel and Zapolyarnij the emissions of SO_2 have resulted in a total disappearance of the reindeer lichen cover *(Cladina sp.)*. The reindeer lichens within in the forest areas near the factories in Nikel and at Zapolyarnij have been replaced by cup lichens like *Cladonia sulphurina, C. cornuta, and C. amaurocraea*.. These lichen species are not usable as food for the reindeer (Tømmervik et al. 1993).

A vegetation change detection map was produced from the individual vegetation maps (figure 3). This map especially identifies the effects of air pollution on vegetation and other changes in the vegetation caused by forestry, forest fires and grazing by reindeer. The estimated 6 month average SO_2 concentrations in the air ($\mu g/m^3$) are presented in the map in figure 2 (Sivertsen et al. 1992).

Comparison of the total lichen cover with the total number of emissions of SO_2 (figure 4) shows a strong correlation between the dwarf shrub-lichen cover changes in the forests and heath land and the dramatic increase of the emissions in the period 1973 - 1988. The area damaged and affected by air pollution increased from approx. 400 km^2 in 1973 to more than 5000 km^2 in 1988.

Six zones have been identified in the vegetation change map (figure 3). The zones reflect the variablity of changes from heavily polluted and damaged areas (Zone 1 and Zone 2) in the Nikel and Zapolyarnij-Pechenga area in east (Russia) to the Gardsjøen lake in the west (Norway) with no visible damage to vegetation (Zone 6). Heavy metal analysis of lichen in the same areas confirm the results derived from the Landsat satellite data. Samples of nickel concentrations in lichen show an increase of more than thirty times over this area (Meland 1991).

The study has shown a total environmental deterioration of an area of 760 km^2 in the Nikel-Pechenga area caused by air pollution (Zone 1 and Zone 2). In addition air pollution is obviously seen to have caused extensive damage to vegetation in an area of 2000 km^2, mostly affecting Empetrum-Lichen heaths, and Lichen and Empetrum dominated birch and pine forests (Zone 3). In an area of 1900 km^2 intermediate and small damage to the lichen vegetation was observed (Zone 4). In an area of 770 km^2, only episodic and minor damage was observed (Zone 5). In the remaining area of 3190 km^2 no damage caused by air pollution could be observed (Zone 6). Lakes, rivers and sea cover approximately 1390 km^2.

This study has shown that the critical levels/loads of air pollution are exceeded for the Lichen-Empetrum heath and the Lichen-Empetrum dominated birch and pine

forests in the eastern parts of the study area (Zone 1, Zone 2 and Zone 3). Aamlid (1992) reported that the critical loads of air pollution were exeeded for growth of lichens on birch trunks in the eastern parts of Southern Varanger.

Low coverage of lichens on trunks at the most polluted areas, and corresponding accumulation of emitted elements, support the hypothesis that the reduced lichen vegetation is caused by air pollution in the eastern parts near to Nikel-Pechenga. The biodiversity has also decreased in the eastern part of the study area (Zone 1, Zone 2, and Zone 3) near the site of the nickel processing factories.

Finally, this study has demonstrated that optical remote sensing such as Landsat MSS data is useful and applicable source of information for mapping of vegetation cover changes due to air pollution.

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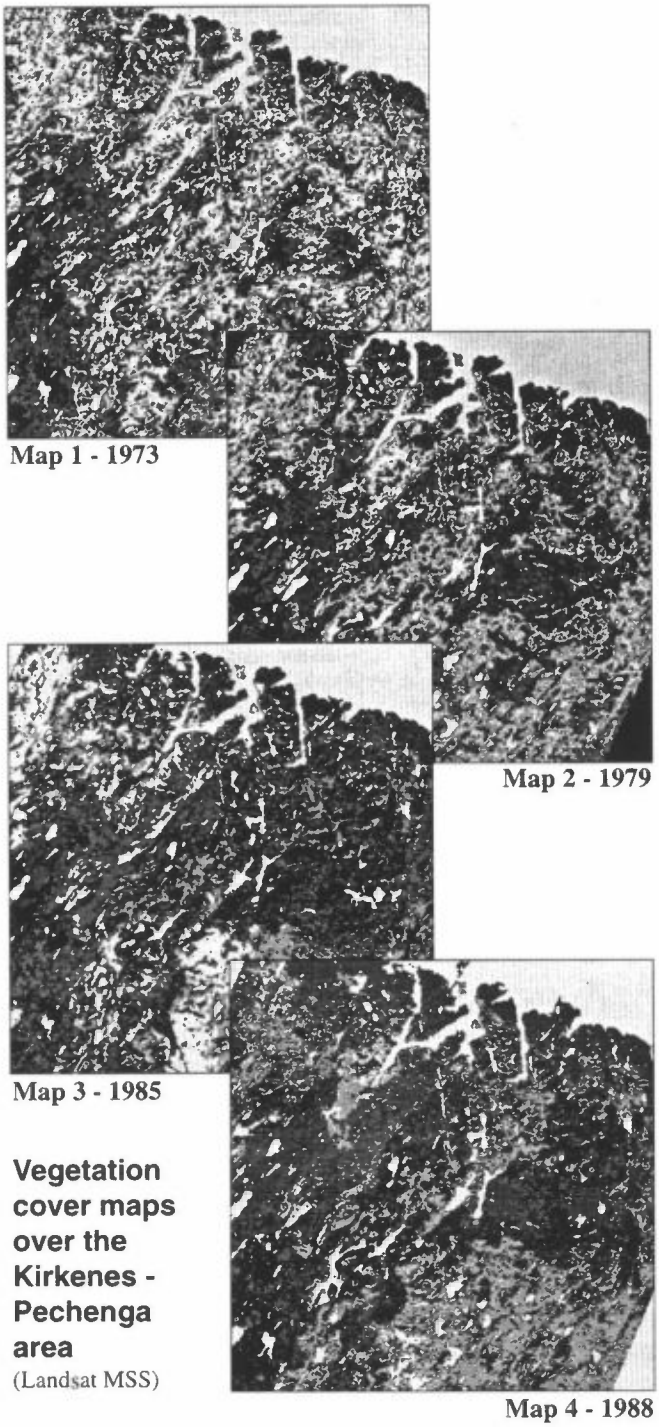

Figure 1.
Vegetation cover maps over the Kirkenes - Pechenga area based on data from Landsat MSS from 1973, 1979, 1985, and 1988, respectively.

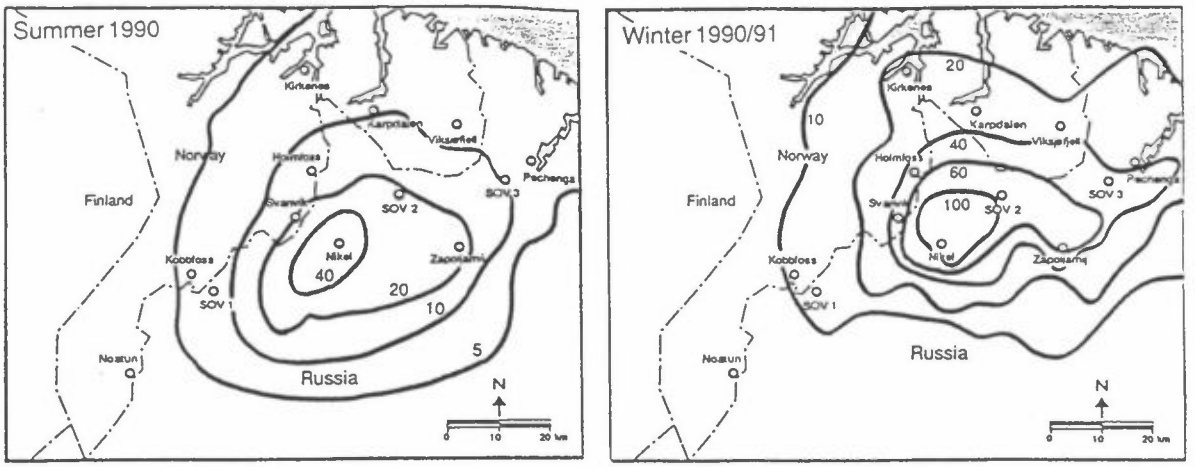

Figure 2. Estimated 6 month average SO_2 concentrations in the air ($\mu g/m^3$). After Sivertsen et al. 1992

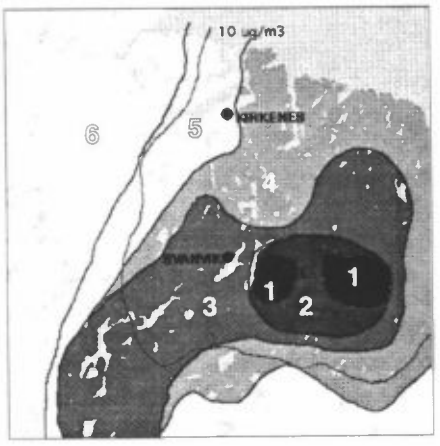

Figure 3.
Change detection map derived from analysis of the maps in fig. 1. This map shows areas exposing different degrees of vegetation changes due to air pollution , forest fires, forestry and grazing (reindeer). We have also superimposed the isoline for 10 $\mu g/m^3$ SO_2 concentration in air. (Isoline from Sivertsen et al. 1992).

Figure 4. Relationship between increase of emissions of SO_2 and decrease of lichen dominated vegetation communities.

2.12. Critical loads of sulphur for surface waters in the Norwegian/Russian border areas

Tor S. Traaen, Tatjana Moiseenko**, Arne Henriksen* and Richard R. Wright**

**Norwegian Instiute for Water Research, Oslo*

***Institute of North Industrial Ecology Problems, Apatity*

ABSTRACT

Surface waters in Sør-Varanger and the northern part of Pechenga region are sensitive to acid deposition. At the present deposition of sulphur critical loads are exceeded for 70% of the areas in Sør-Varanger. In the Russian border areas, which are generally less sensitive to acid deposition, critical loads are exceeded in 30% of the area. If sulphur depositions continue at present levels it is likely that an increasing number of lakes will become cronically acid in the years to come. To achieve a lasting protection of surface waters in the border areas sulphur depositions have to be reduced by approximately 75%.

CRITICAL LOADS BY THE STEADY STATE STATE WATER CHEMISTRY METHOD.

The calculations of critical loads and critical load exceedances are made using The Steady State Water Chemistry Method (Henriksen et al. 1990). The method is based on the Acid Neutralizing Capacity of water (ANC). ANC is defined as the difference between the sum of concentrations of base cations (calcium, magnesium, sodium and potassium) and the sum of strong acid anions (chloride, sulphate and nitrate). ANC is the function of the content of bicarbonate, hydronium, inorganic aluminium and organic ions in the water. If inputs of sulphur and nitrogen via precipitation and dry deposition give concentrations of strong anions that are higher than the concentration of base cations in runoff, the ANC is negative. This means that the critical load has been exceeded. For protection of fish, a remaining ANC of 20 µeq/l is recommended (ANC_{limit} = 20 µeq/l). Hence, an ANC_{limit} of 20 µeq/l is used in the calculations of critical loads.

The mapping of critical loads and exeedance of critical load in the Norwegian/Russian border areas is a joint project under the Working Group for Water and Environmental Problems under the Norwegian/Russian Environmental Protection Commission. Water chemistry data are provided by Norwegian Institute for Water Research (NIVA) and Institute of North Industrial Ecology Problems (INEP). Sulphur deposition data are estimated from deposition maps provided by Norwegian Institute for Air Research, NILU (Sivertsen et al. 1991, Sivertsen et al. 1992, Sivertsen et al. 1993). The deposition data on the russian side, particularly for the areas more than 50 km from Nikel, are quite crude estimations. The data for critical load exceedance for these areas should therefore be regarded as preliminary.

Surface waters in Sør-Varanger and the northern part of the Pechenga area are very sensitive to acid deposition. Calculations show that 90% of the area in Sør-Varanger has a critical load less than 50 keq/km^2/yr (0.8 gS/m^2/yr). Corresponding area on the russian side is approx. 30% (fig.1).

At the current sulphur depositions the critical loads are exceeded in 70% of the area in Sør-Varanger (fig.2). At 50 and 70% reduction of sulphur deposition the exceeded area will be reduced to respectively 27 and 7%. On the russian side (Fig.3) critical loads are exceeded for 30% of the area. At deposition reductions of 50 and 70% exceeded area will be reduced to respectively 6 and 2%.

Colour maps of critical loads and critical load exceedances are shown in Traaen et al. 1993.

Almost the whole area of Sør-Varanger is sensitive to acid rain. On the russian side, most of the sensitive areas are in the north towards the Barents Sea. Critical loads are exceeded in most of Sør-Varanger. Only in southern parts of Pasvik, in the most westwards parts of Sør-Varanger and in the lower parts of River Grense-Jakobselva there are still areas where critical loads are not exceeded. On russian side most of the exceeded areas are situated around Nikel/Zapoljarnyy and in the northernmost parts of the investigated area. These areas have high sulphur depositions and partly low critical loads.

THE USE OF MAGIC MODEL IN THE CALIBRATED CATCHMENT DALELVA.

Continuous monitoring of flow, pH, conductivity and air temperature were started in the calibreated cathment Dalelva in the summer 1988. Further, samples for chemical analysis are collected weekly.

Dalelva Brook is strongly affected by acid deposition. During snowmelt the brook lose all bicarbonate buffer, and episodes with a pH lower than 5.0 have been recorded. During most of the year, Dalelva has a pH close to 6.0. The dynamic MAGIC model, using data for precipitation, runoff and soil chemistry was applied for Dalelva (Wright and Traaen 1992). Model calculations showed that the water quality is not yet in equilibrium with the current sulphur deposition. The reason for this is that soil acidification will continue so that the concentrations of base cations in the runoff will decrease. If sulphur depositions are not reduced, an increasing acidification is likely to occur in the years to come. On the other hand, a 95% reduction of sulphur deposition will improve the water quality close to pristine condition within 10 to 20 years (fig.4).

CONCLUSIONS

The investigations of critical loads and critical load exceedances have demonstrated the necessity of great reductions in sulphur depositions. To provide a lasting protection of lakes in the border areas sulphur depositions should be reduced by at least 75%. Model calculations also show that the acidification will increase if the sulphur depositions continue at the present level. To avoid comprehensive damages due to acidification, actions to reduce pollution should be performed within a few years.

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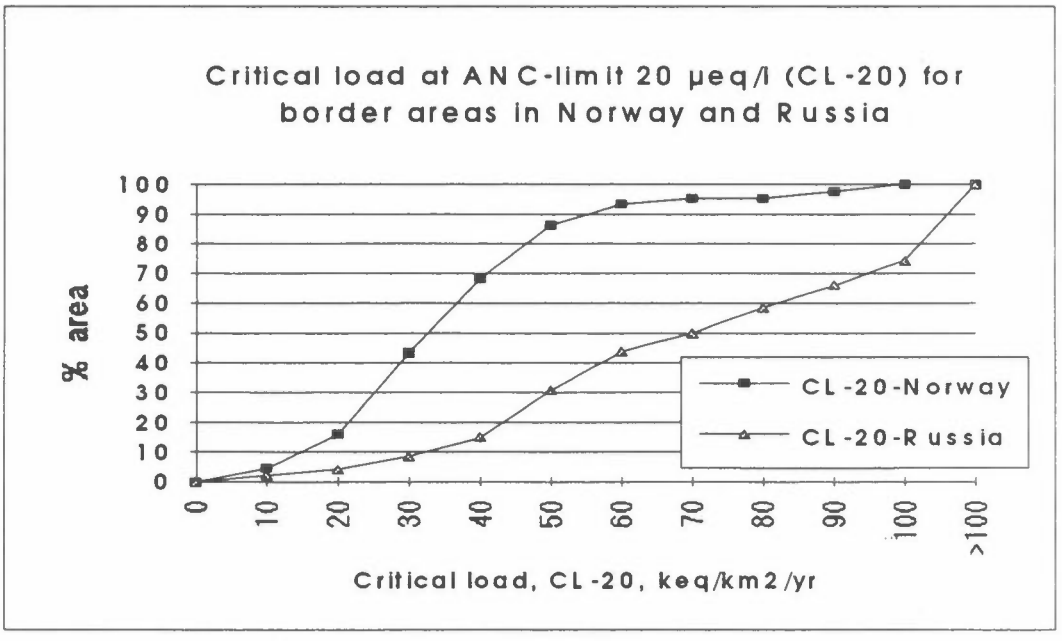


Fig.1. Critical load of sulphur for lakes in the Norwegian/Russian border areas.

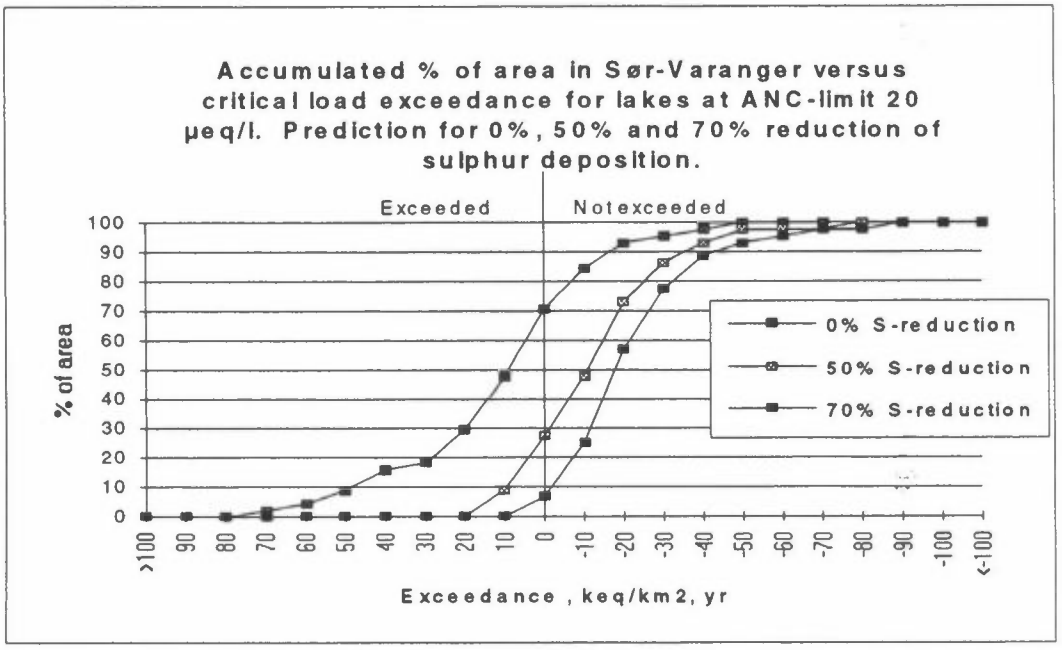


Fig.2. Critical load exceedance for lakes in Sør-Varanger. Present status and predictions for 50% and 70% reduction of sulphur deposition.

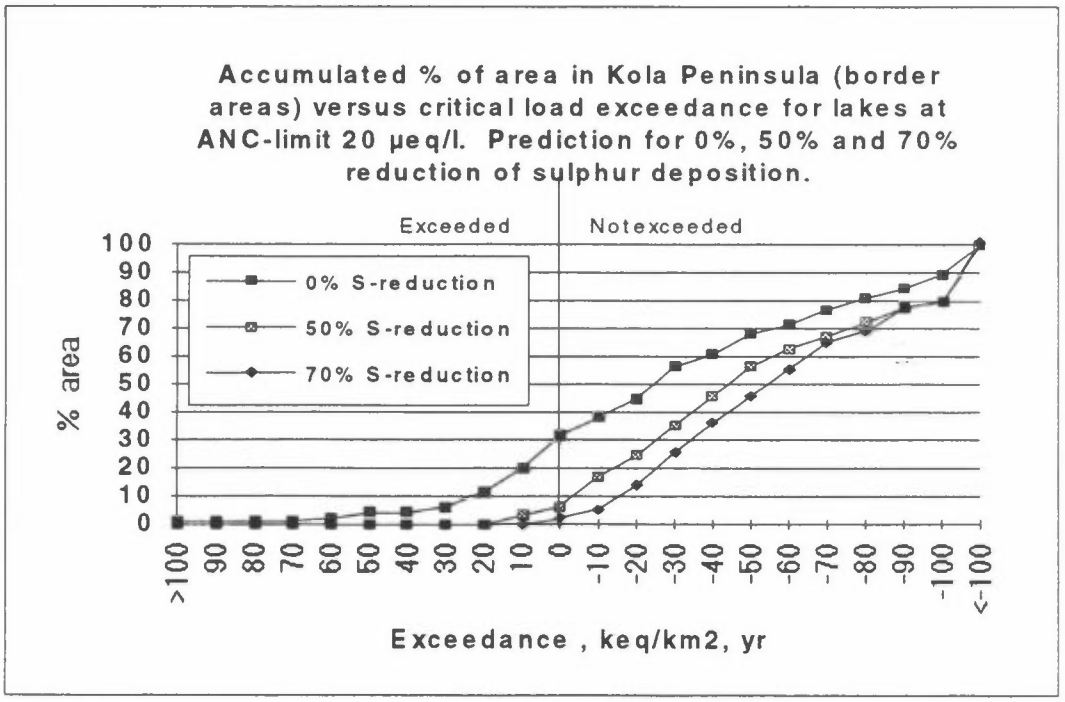


Fig.3. Critical load exceedance for lakes in and Kola Peninsula. Present status and predictions for 50% and 70% reduction of sulphur deposition.

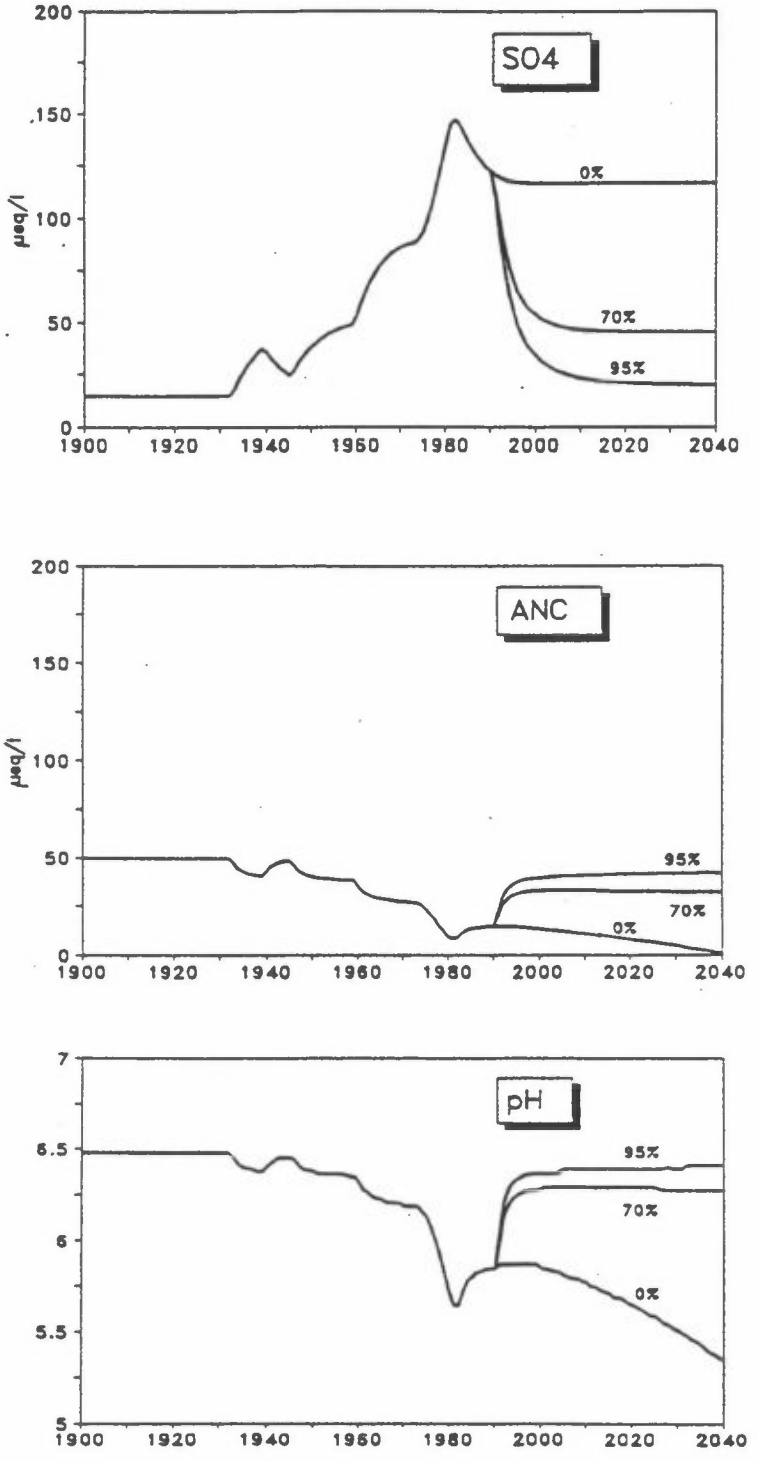
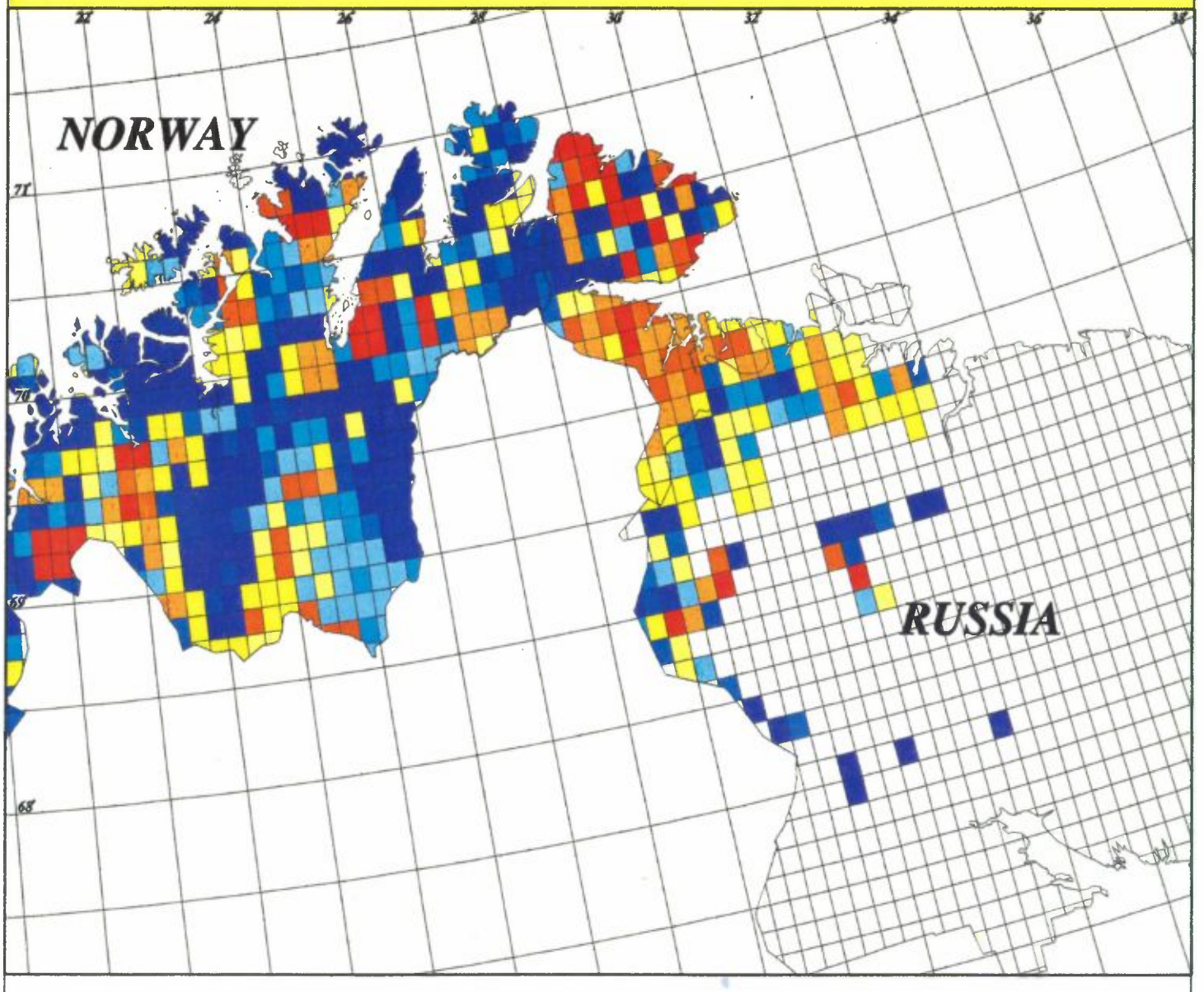


Fig.4. SO_4, ANC and pH in Dalelva River as simulated by the MAGIC model for the last 90 years and the future 50 years at 0, 70 and 95% reduction of sulphur depositions. (From Wright and Traaen 1992).

Critical Loads - surface waters

ANC_{Limit} = 20 µeq · l^{-1}



keq · km^{-2} · yr^{-1}	gS · m^{-2} · yr^{-1}
0 - 12.5	0 - 0.19
12.5 - 25.0	0.20 - 0.39
25.0 - 37.5	0.40 - 0.59
37.5 - 50.0	0.60 - 0.79
50.0 - 62.5	0.80 - 0.99
62.5 - 75.0	1.00 - 1.19
75.0 - 87.5	1.20 - 1.39
87.5 - 100.0	1.40 - 1.59
100.0- 112.5	1.60 - 1.79
> 112.5	> 1.80

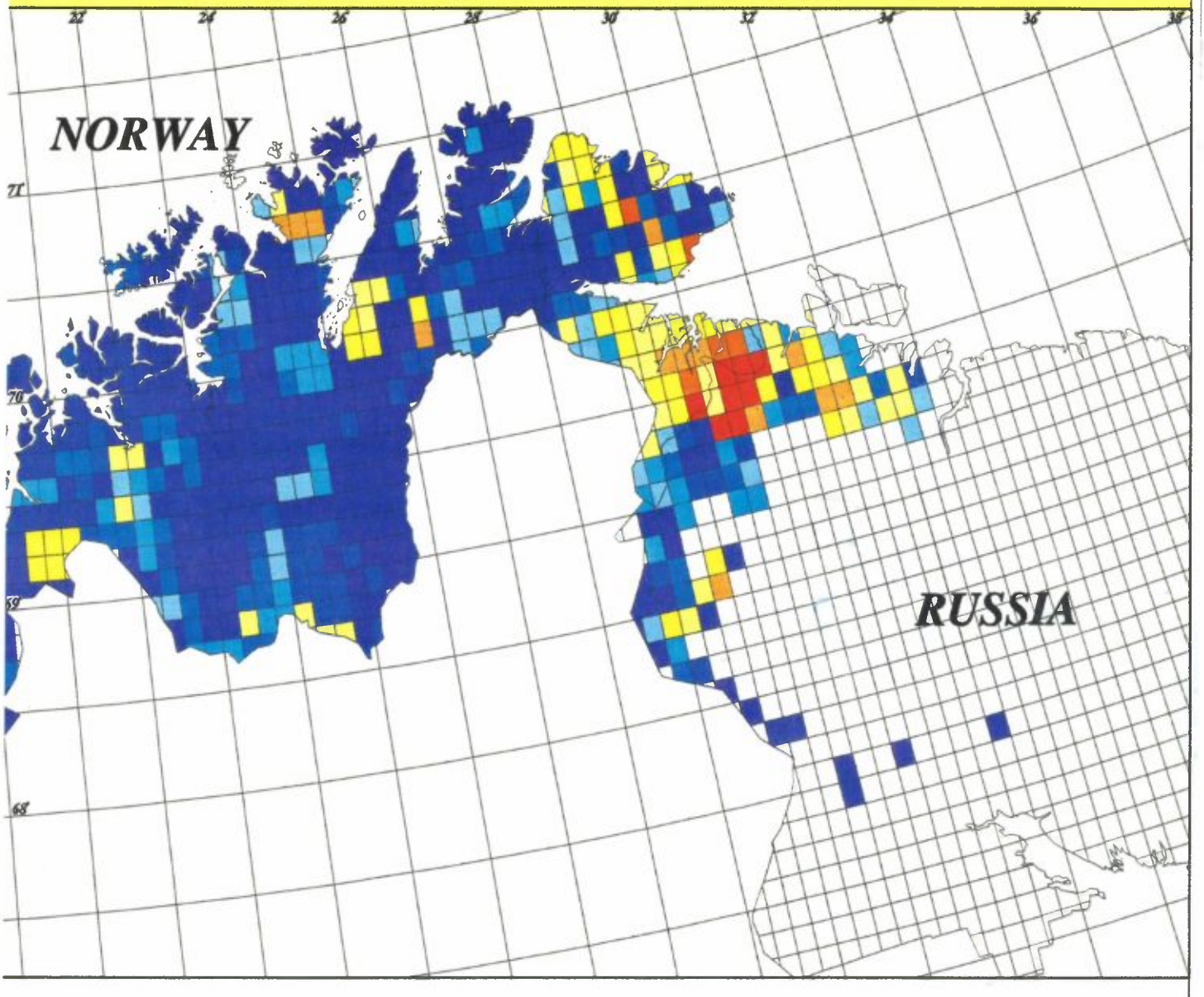
100 km

NIVA NIJOS SFT NILU

Critical Load Exceedance - surface waters

Amounts of sulphur

ANC_{Limit} = 20 ueq l^{-1}



keq · km^{-2} · yr^{-1}	gS · m^{-2} · yr^{-1}
> 50	> 0.80
50.0 - 37.5	0.79 - 0.60
37.5 - 25.0	0.59 - 0.40
25.0 - 12.5	0.39 - 0.20
12.5 - 0	0.19 - 0.00
0 - -12.5	-0.00 - -0.19
-12.5 - -25.0	-0.20 - -0.39
-25.0 - -37.5	-0.40 - -0.59
-37.5 - -50.0	-0.60 - -0.79
< -50	< -0.80

100 km

NIVA NEP NIJOS SFT NILU

2.13. Acidification and pollution by heavy metals of Kola surface waters

Tatjana Moiseenko
Institute of North Industrial Ecology Problems
14 Fersman str., Apatity, Murmansk region, 184200, Russia

Abstract

Precipitation falling on the Kola North is severely polluted by strong acids and heavy metals due to emissions from large local enterprises. Large areas in the affected region are sensitive to acid precipitation due to the climatological and geological conditions. Based on extensive chemical analyses of lake and rivers water samples collected in the region in 1989-1992 it was demonstrated that extensive surface water acidification has taken place, particularly on the mountains remote tundra regions. In the industrial centre (30 km zone of fume emissions spread) the buffer capacity increase and nickel and copper high concentrations are observed. The situation on Kola North is a unique opportunity to study the ecological effect of acidification and heavy metal pollution at several ecosystem levels.

Introduction

The Kola Peninsula represents the North - Eastern part of Fennoscandia, it is located behind the Polar Circle. The phenomenon of waters acidification is well known in Scandinavian countries like Norway, Sweden and Finland (SFT, 1987; Monitor, 1986; Forsius at al.). Up to 1989 the Kola North remained unstudied territory regarding the water acidification evaluation. At the same time acidic precipitations impact on its territory is being stipulated by activity of the "Pechenganickel" and "Severonickel" companies as the biggest local metallurgy enterprises. Emission of sulphureous gases is 568 thousand ton. Simultaneously with the acidic impact the Kola North surface waters are being polluted by heavy metals. It is well known that the toxicity of heavy metals for the biota is essentially

increasing in the acidic medium.
In 1989-1992 special researches on the Kola Peninsula territory were performed.
The goal is to indicate the specificity and intensity of the surface water acidification and pollution by heavy metals.

Materials and methods

The study is conducted in the following aspects.
1. The territory-wide examination of small lakes in a period from September 20 to October 10 (in all 284 lakes were investigated). In our works we took into account criteria of lakes selection and applied the methods used in Norway (SFT, 1987).
2. The acidic episodes indication on rivers during flood period. The intensive daily observations on water quality variations in the flood period were conducted; on the two stream: 1-15 km distance from "Pechenganickel" and 30 km - from "Severonickel".
3. Water pollution by heavy metals and their behaviour in the acidified medium.
Water sampling and analysis are performed according to the usual chydrochemical methods (Rond et al., 1975). After unification and methodic verification the water samples were simultaneously analyzed in the Institute of North Industrial Ecology Problems (INEP), Norwegian Institute for Waters Research (NIVA)- 140 samples, in the water and Environment District Office of Lapland (LAVI) - 100 samples. The following indices were determined: pH, main ions (Ca, Mg, K, Na, SO_4, HCO_3, Cl), organic matters, turbidity, chromaticity and metals (Ni, Co, Cu, Zn, Al).

Results and Discussion

Depositions of sulphur, nickel and copper

According to the data by T.Makarova (1989) the present average regional level of anthropogenic sulphur deposition on the Kola Peninsula is approximately 0.7-1.0 gSm^{-2} yr^{-1}. Deposition values

in the industrial regions in the north-west and central parts are 3-10 gSm^{-2} yr^{-1}, and near the local sources even 30 gSm^{-2} yr^{-1}. In the western parts of Finnmark the sulphur deposition is 0.2-0.6 gSm^{-2} yr^{-1}, in the eastern part near the border area of the Murmansk region 1.0-1.2 gSm^{-2} yr^{-1} (Kryuchkov & Makarova, 1989; Hoem & Joranger, 1988; Juntto S., 1988).

The average pH values of precipitation in Northern Fennoscandia are 4.5-4.7 (Juntto S., 1988). According to the data by T.Makarova (1989) the pH of the precipitations in the eastern part of the Kola peninsula is 4.7. Around industrial sites where pH of precipitation is measured as low as 3.4, alkaline precipitation up to pH 7.6 is also observed. The high pH-values are due to emission of alkaline dust particles (Makarova and Ratkin, 1989).

The dust particles emitted to the atmosphere also contain heavy metals, being a main source of pollution of the Kola North surface waters. The depositions of heavy metals around metallurgical enterprises area are 29-310 $\mu g \cdot m^{-2} day^{-1}$ of nickel and 35-280 $\mu g \cdot m^{-2} day^{-1}$ of copper (Makarova and Ratkin, 1990). The air pollution by metals has a more local distribution than sulphur around the metallurgical enterprises.

Sensitivity of territory

According to the climatological and geological conditions, the most part the Kola North territory is sensitive to water acidification, especially the northern tundra, where small lakes are typical and the underlying stratum is presented by acidic bedrock exposures (granites, basalt). In the centre of the Peninsula the mountains Khibiny and Lovozero are formed by alkaline rocks (apatite-nepheline syenites). The metallurgical enterprises from which the sulphur deposition is the highest, are however located in areas with basic and ultrabasic rocks with sufficient buffer capacity (Murmansk region atlas 1971), thus rendering them less sensitive to acidification.

Sulphate contents and Lake acidification

Extra influx of sulphates to the Kola North catchments is the

main factor, influencing the water acidification. According to the data by A.Henriksen at al.(1990), the sulphates content in the lakes on the western Fennoscandia, that not undergoing the impact of acidic precipitations and having no geological sources, is normal 10-15 μeq/l. Sulphate content in the Kola North lakes is substantially higher in comparison with the North of contiguous regions - Norway and Finland. Typical range of values is 75 - 100 μeq/l (fig 1). Around the industrial centres the sulphates content in the lakes exceeds 200 μeq/l, sulphates a prevailing position in the water anion composition.
On the Kola territory the processes of lakes acidification are indicated: 5.6% of the examined lakes had ph < 5 and 13,5% - pH < 6, more than 30% are in state of acidification risk (ANC < 50 μeq/l and HCO_3 < SO_4) Regarding, that in the Kola Peninsula water formation conditions are heterogenous, we distinguished 7 regions during the analysis of the data obtained (fig 2). In the industrial regions a long with the high sulphate content buffer capacity of most of the lakes remains high (ANC > 200 μeq/l), that is due to the natural factors and dust emission influence. At the same time strongly acidified small lakes with pH < 5.0 are located on the mountains with in the limits of these regions (Kuorpukas, Chuna, Volchii, Monche). The critical situation with the waters acidification appeared also in northern and eastern tundra part. This territories are extremely vulnerable to the acidic impact.

Heavy metals

Heavy metals are the upmost hazardous kind of the Kola North water pollution. High copper and nickel concentrations (toxic level) are observed in the lakes situated in radius up to 30 km from the metallurgical enterprises (fig. 3). In the Pechenga area the nickel indies in water are often 20-30 μg/l. In the small acidified lakes on the Kuorpukas mountain the nickel content exceeds 70 μg/l. The analogous high heavy metals indices are typical for the Monchegorsk area. The metals background indices Ni and Cu < 1 μg/l) remain in the lakes remote from the industrial centres of eastern (D.Zelentsy, Yenozero, Babye lake et al) and south-western regions. In the industrial centres heavy

metals contents are correlating with the concentrations of the base cation Ca+Mg (r = 0.70, n = 45).

The rapid changes of waters quality during the flood time

The surface waters supply of subarctic regions is stipulated by precipitations, more then a half (40-60%) of the annual runoff export is going to the rivers in the spring flood period. This period of maximum water rise reflects more informatively the depositions level and areas of aerotechnogenic pollution distribution. In the spring flood waters the maximum Ca+Mg (> 200 μeq/l) concentrations are typical for the rivers of industrial centres: Pechenga, Monchegorsk, Kovdor et al. But on the biggest part of the territory the ion balance of river systems waters is unstable and the preconditions for waters acidification are being formed. The most critical situation is generated in a radius of 30-100 km around the metallurgical complexes. The alkalinity is decreasing in 4-6 times and in some cases has a zero index. A short-term pH < 5 was indicated in stream.
In remote regions (more then 30 km) distance from smeltes, the common regularity for different rivers in the flood period could be retraced: the main part of the ions (H+) and heavy metals (Cu, Ni, Co, etc) is coming to the streams with first portions of snow melting waters. Simultaneously by the minimum water pH indices the metals maximum indices. That have particularly hazardous fore the subarctic fauna. In the industrial (before 15 km) centres heavy metals influx in the stream with dust particle and buffer capacity of rivers water increase (fig. 4).

Conclusion

In the Kola North according to the climatological and geological conditions of waters formation, the most part of territory is sensitive to the waters acidification.
The acidic precipitation impact on the catchments is considerably higher in comparison to other regions of the Arctic and Subarctic. Sulphate content (after correction for the sea salt)

in the Kola North lakes is typical 75-150 μeq/l.
Of the 284 lakes under inspection 13,5% had pH < 6 and 5,6% < 5; about 30% were in a critical state (alkalinity under 50 μeq/l). Acidified lakes occur on mountains (Kourpuukas -, Chuna -, Volchij -, Moncha-tundra) as well as in the remote regions, where the sensitivity of the territory to the acid load is high. In the industrial centres with high sulphates (> 200 μeq/l) and heavy metals (Ni > 20 μg/l; Cu > 10 μg/l) concentrations high acid-neutralizing capacity is observed (ANC > 100 μeq/l) due to the alkaline dust emission from the local enterprises.
In the flood-time a critical situation is generated 30- 100 km from the metallurgy complexes. The ion balance of river waters is unstable ($HCO_3 < SO_4$) and acidic episodes are observed on a number of mountain rivers. This period of low values (4,4 - 4,7) is a short-time one (5 -7 days), but may be especially hazardous due to high level of heavy metals (Ni content in rivers more than 20 μg/l occurrence).

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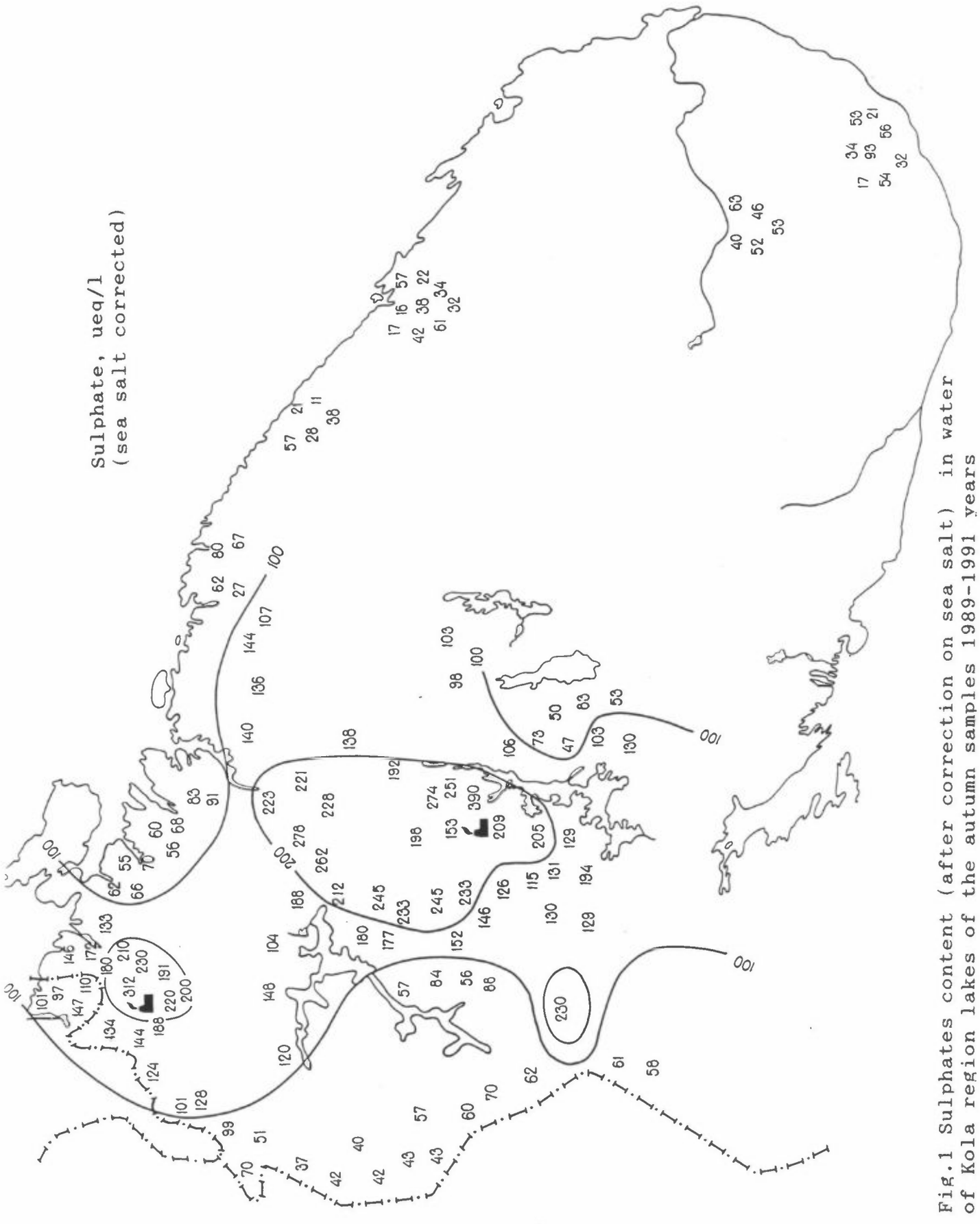

Fig.1 Sulphates content (after correction on sea salt) in water of Kola region lakes of the autumn samples 1989-1991 years

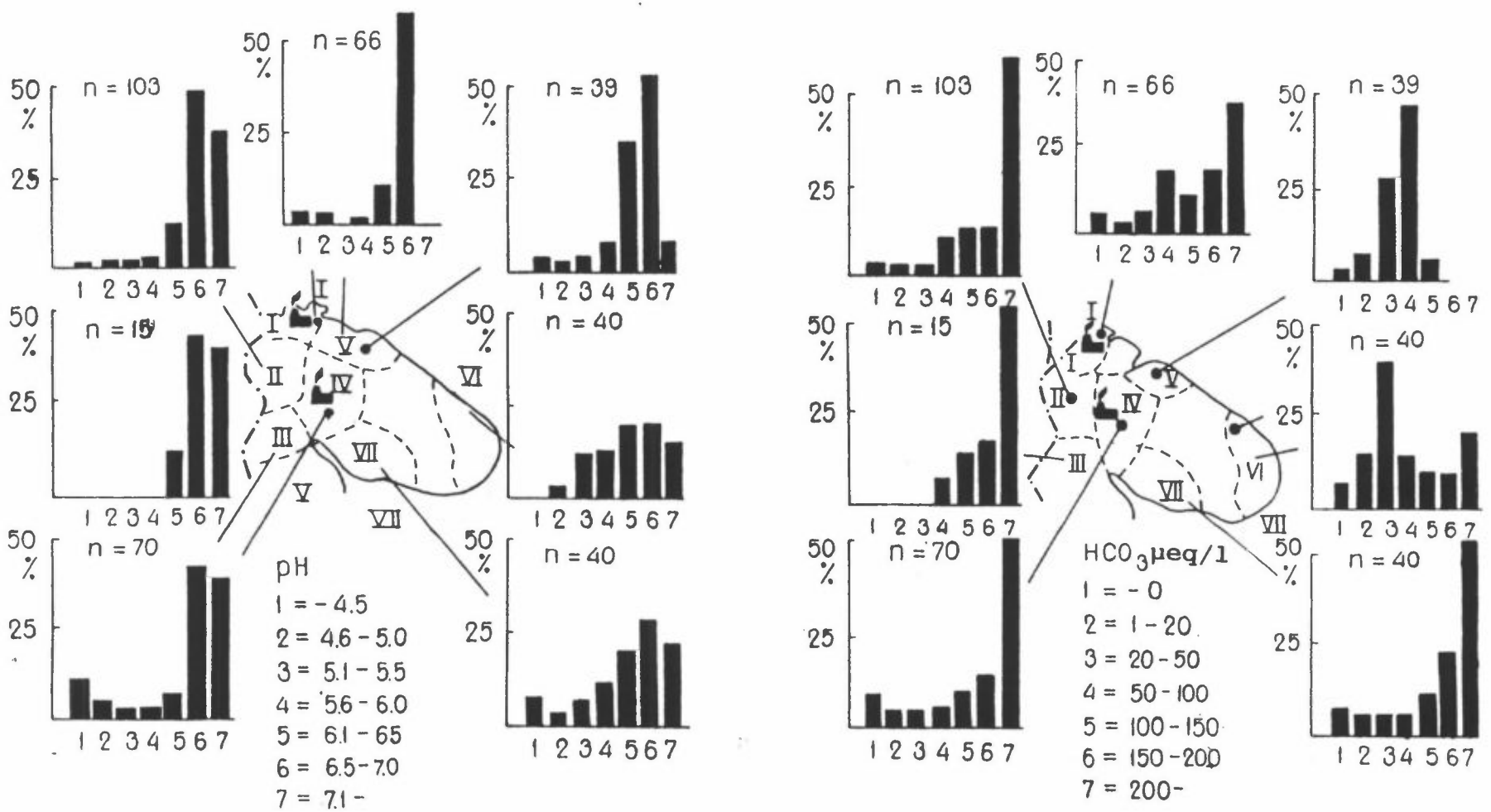

Fig. 2: The distribution of pH and alkalinity values of the autumn samples from lakes of different areas of the Kola region

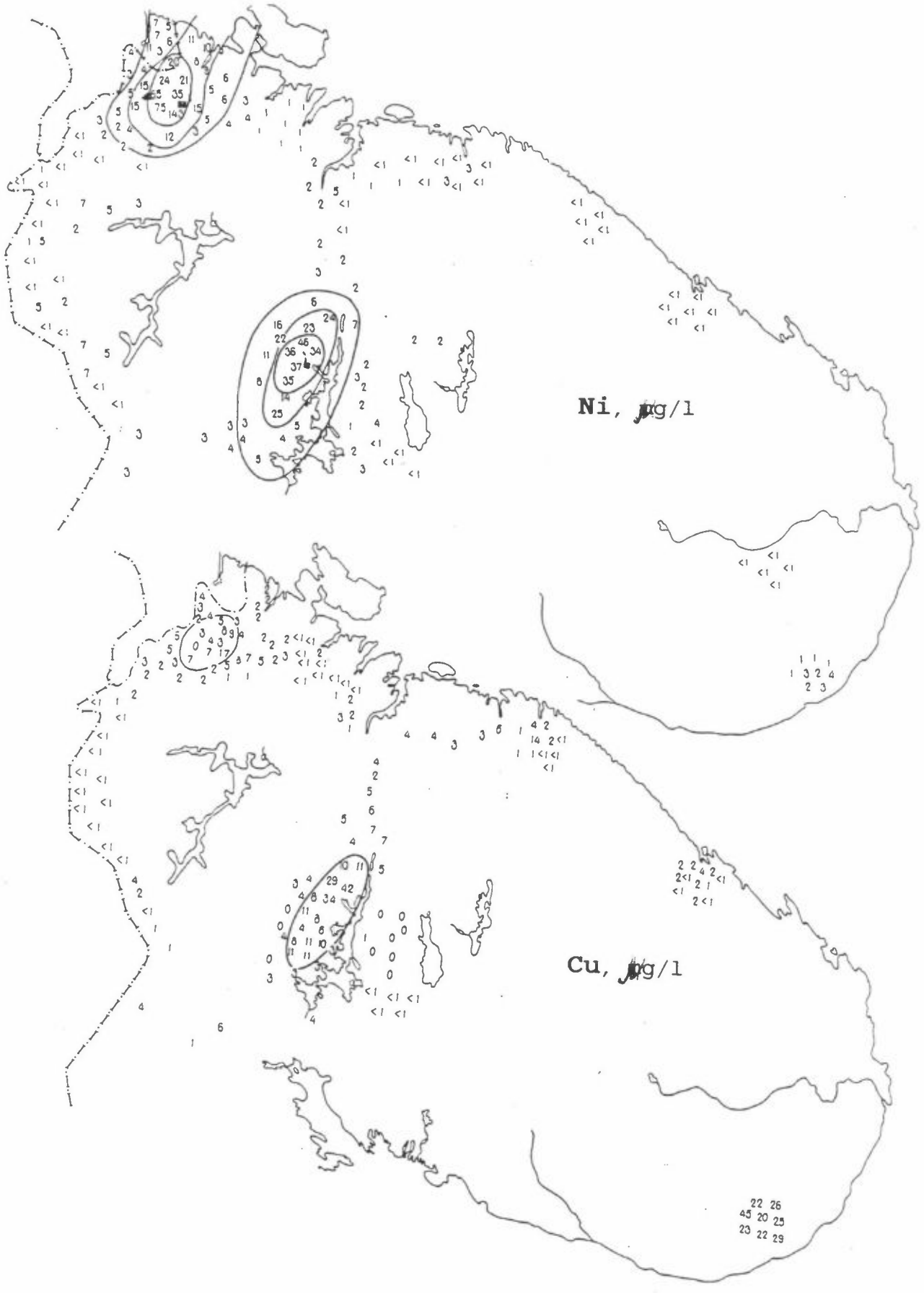

Fig. 3. Nickel and Copper content in water of Kola region lakes of the autumn samples 1989-1991 ears

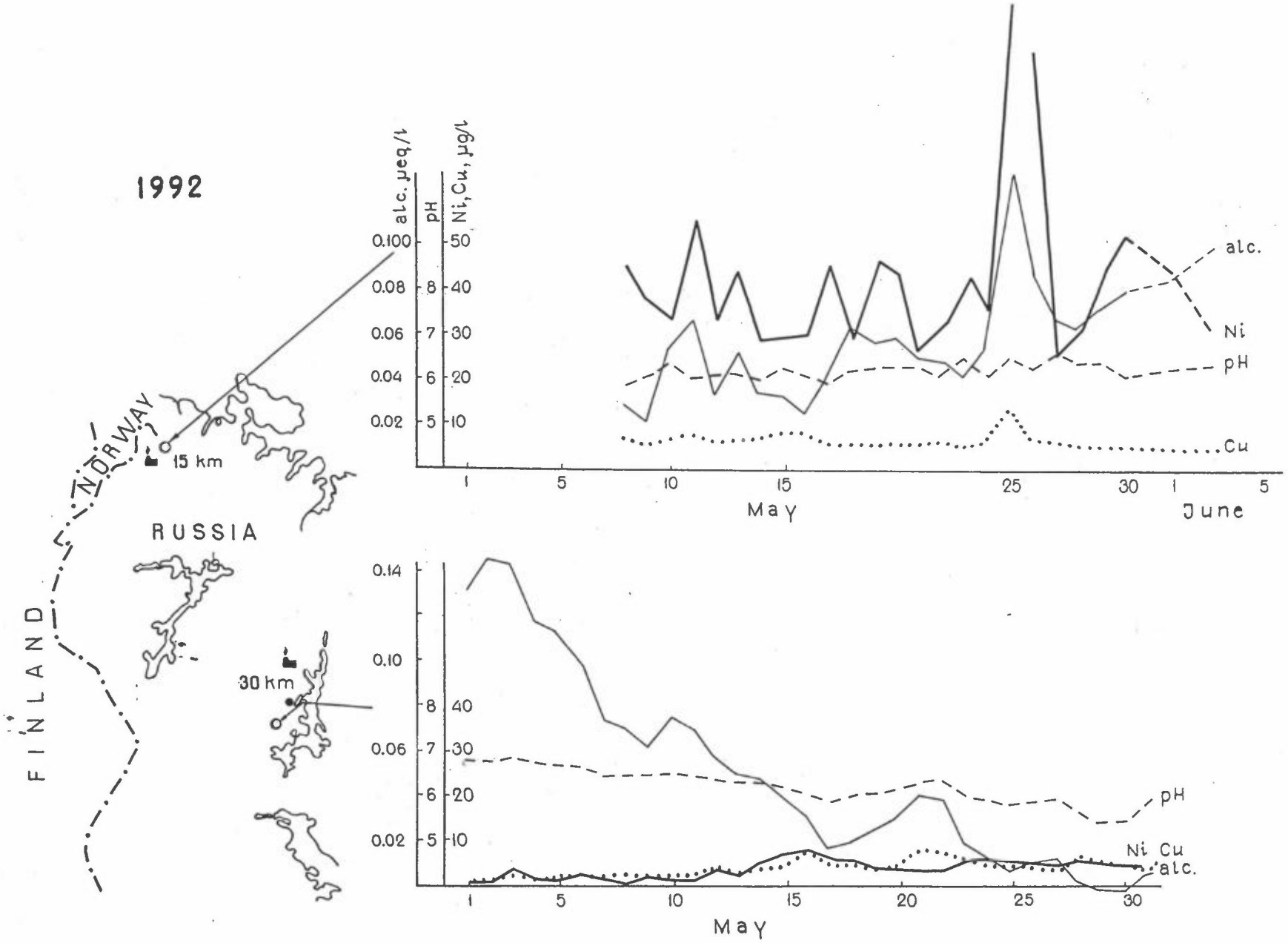

Fig. 4. Changes of same hydrochemical indices in the flood - time on the streams: 1-15 km distance from "Pechenganickel" and 2-30 km distance from "Severonickel".

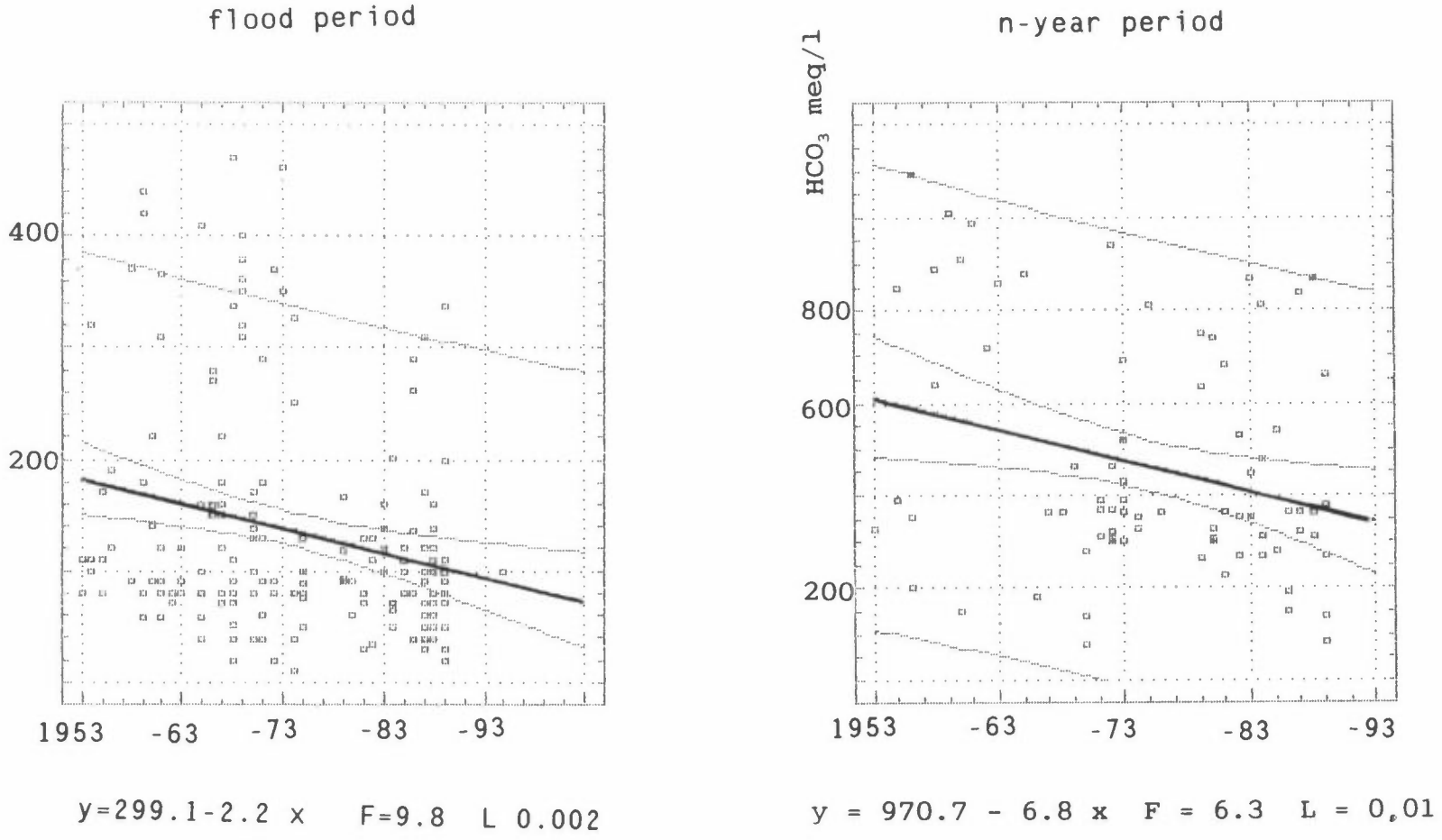

Fig. 5. Long-term trend towards alcalinity decrease on the Kola North big rivers

2.14. Mapping of terrestrial effects in the border area. Summary of activities and results

Jon Jerre
State Pollution Control Authority (SFT)
P.O.Box 8100 Dep, 0032 Oslo, Norway

Abstract

The terrestrial expert group started its work in late 1989. Through monitoring and seperat investigations, the geographical extent and variation with time of effects on the terrestrial ecosystem has been studied. Both field investigations and the use of remote sensing (satellite pictures) have been important tools. The preliminary conclusion is that the main problem for the vegetation is the direct effect of SO_2, in combination with deposition of heavy metals. Satellite pictures covering approx. 10,000 km^2 show that more than 70 % is affected by air pollution, a number which has increased over the years. In 1993/94 efforts will be made to establish more refined critical level maps.

2.14.1. Introduction

This lecture gives a brief status and overall picture of the work of the terrestrial expert group and of the effects on the terrestrial ecosystem in the border area. Under the joint Norwegian-Russian commission on cooperation on environmental problems there are 8 expert groups. Three of these are closely linked to eachother; the expert group on air pollution, the expert group on water pollution and the expert group on studies of effects of air pollution on the terrestrial ecosystem.

2.14.2. The Terrestrial Expert Group

During the 70- and 80-ties air pollution and its effects was studied through some seperate investigations, e.g. heavy metals in mosses in Sør-Varanger. The terrestrial expert group had its first meeting in Oslo in January of 1990. The activities initiated by the terrestrial expert group were the first comprehensive investigations performed in the border area.

The expert group consists of:

Evgenia Pastukhova	Research Institute for Nature Conservation Head of the Russian delegation
Rodion Karaban	Institute for Global Climate and Ecology
Vyacheslav Nikonov	Kola Science Centre
Natalia Vassilieva	Research Institute for Nature Conservation
Jon Jerre	State Pollution Control Authority Head of the Norwegian delegation
Else Løbersli	Directorate for Nature Management
Hans Tømmervik	NORUT IT
Kåre Venn	Norwegian Forest Research Institute

The activities of the terrestrial expert group are based on four elements; studying the effects of air pollution on the terrestrial ecosystem through monitoring activities and separate studies, joint field investigations, exchange of scientists and joint symposiums. In March 1992 the first joint symposium was arranged in Svanvik with 40 participants from Russia, Norway, Finland and Sweden. The proceedings from the symposium are available by contacting the SFT at the above address. The next symposium is scheduled for September 1994 in Russia

The projects initiated and performed by the expert group have focused on:

- Mapping the geographical extent of the pollution effects on the terrestrial ecosystem by field studies and remote sensing (satellite images)
- Studying variation with time of the damage. The monitoring activities gives information about changes from year to year, whereas older satellite pictures give information about the situation back to the beginning of the 70-ties.
- Studies of mechanisms causing impacts by the air pollution and studies of dose/response relationships.
- Studies of heavy metals in animals.

The results from these investigations have given useful information about the extent, and variation with time, of the effects on the terrestrial ecosystem. The main focus in the time to come will be to establish critical levels for the terrestrial ecosystem in the area. This will be done in close cooperation with the expert group on air pollution.

2.14.3. Effects in general

Sulphur compounds can affect the vegetation either directly through dry deposition, when the gas is entering the part of the plants above the ground. Or the compunds can affect the vegetation indirectly through wet deposition by acidification of the soil.

Sulphur dioxide which is taken up by the plant, can be transformed to sulphate which then is utilized by the plant. However, when this capacity is full, and no more SO_2 can be transformed, an accute injury occures by death of parts of the leaves. This process occures when a plant is exposed to high concentrations of SO_2 for some hours. Such damage has been observed at concentrations of 1,000 $\mu g/m^3$, and such levels occur far into the Norwegian region.

Also at lower levels damage can be identified, not visulally, but through chemical analysis or reduced productivity.

2.14.4. Critical loads and levels

Under the Convention on Long Range Transboundary Air Pollution (LRTAP) a Task Force on Mapping has been established. The Task Force has elaborated a manual on how to map critical loads/levels. The manual describes different

methods for establishing critical loads by the individual countries. Most of the work under the Convention has so far been concentrated on critical loads rather levels.

The Convention has also established a set of critical levels. In 1978 the International Union of Forest Research Organisations (IUFRO) proposed a set of critical levels for forest. The table below summarizes these critical levels.

Vegetation category	Critical level µg $(SO_2)/m^3$	Time period	Comment
Cynobacterial Lichens (*)	10	Annual mean	
Forest ecosystem and Natural vegetation (*)	15	Annual mean and half year mean (winter)	At low temeratures
Forest ecosystem and Natural vegetation (*)	20	Annual mean and half year mean (winter)	At high temperatures
Agricultural crops (*)	30	Annual mean and half year mean (winter)	
Forest (**)	150	1 hour mean	

(*): Task Force on Mapping (1993)
(**): IUFRO (1978)

Such critical levels are simplified since they do not, or only to a slight degree, take into account that also climate conditions (temperature, rainfall, winds) affect the impact of air pollution. As a slight compensation for the temperature effect, two critical levels are given. The Norwegian-Russian border area falls into the "low temperature" category, the 15 µg $(SO_2)/m^3$ value.

Measurements and calculations done by the expert group on air pollution show that both the long term (6 months mean) and the short term (1-hour mean) critical levels are exceeded over large areas, also on the Norwegian side of the border. At Viksjøfjell i Norway hourly mean concentrations above 3,000 µg/m^3 have been measured. During such episodes severe accute damage has been obeserved even in Norway. According to the calculations, the concentrations can exceed 1,000 µg/m^3 (1-hr) at distances of 50 km from Nikel under certain meteorological situations.

2.14.5. Satellite pictures

Based on field investigations and remote sensing (satellite pictures) one has been able to identify most of the area affected by air pollution. In a work performed by Hans Tømmervik et. al. (1993) more than 10,000 km^2 on both the Norwegian and Russian side has been investigated by remote sensing (satellite pictures). This

study shows that approx. 7,300 km² is affected by air pollution. The area is divided into 5 zones according to the following gradation:

Zone number	Area (km²)	%	Description of effect
1	800	7.8	Total damage
2	1945	19.0	Severe damage
3	1958	19.1	Intermediate damage
4	2625	25.7	Minor damage
5	2903	28.4	Slight or no damage
Total	10231	100.0	

Comparing the satellite pictures and maps showing the contours for the critical levels for lichens (10 µg/m³) one observes good correlation.

By comparing recent satellite pictures with older ones from 1973 one has seen that the affetced area has increased from 415 km² in 1973 to above 5,000 km² in 1988 (Tømmervik et. al. 1992). Also, the area which is total or severe damaged has increased by a factor 14 in the same period.

Also field investigations (E.V. Pastukova et. al. and by N.P. Vassilieva, both 1992) show that large areas on the whole Kola Peninsula are very sensitive and are affected by the emissions in Nikel and Zapoljarnij.

2.14.6. Heavy metals

Heavy metals in animals have been investigated by both Russian and Norwegian scientists; reindeer, moose, sheep (Sivertsen, 1992) and birds (J.A. Kålås et. al., 1992) have been studied in Norway and small mammals and frogs have been studied in Russia (Glazov, 1992). The Russian study shows that there is a strong gradient of several heavy metals in tissues of vertebrate animals, especially within an area of 10-15 km distance from Nikel. In the Norwegian study one also has found high levels of i.e. nickel, arsenic and copper in samples from reindeer. The veterinary authorities in Norway have, however, concluded that the elevated levels in reindeer do not represent any toxicological risk to the animals. Nor do they consider the levels to be of any significance for human consumption.

2.14.7. Preliminary conclusions

Both the direct and indirect effect of the sulphur compounds has an impact on the vegetation. But the preliminary conclusion from the investigations in the area is that the main problem is the high concentration of sulphur compounds together with the impact of heavy metals (nickel, copper). High long-term concentrations of these pollutants are observed mainly on the Russian side of the border. The critical levels (half year mean) for SO_2 adopted by the international organizations, are substantially exceeded. On the Norwegian side of the broder the long-term concentrations are rather low and the main problem seems to be the episodes with high SO_2 -concentrations under certain meteorological conditions.

The terrestrial expert group has so far concluded that the episodes with high concentrations of SO_2 during some hours is the main problem, especially in Norway. In addition, the large deposition of heavy metals (nickel, copper) affects the situation.

2.14.8. Establishing critical levels

Since the main problem is the high concentration of SO_2, the terrestrial expert group will now focus its work on establishing critical levels for the vegetation in the border area. The critical levels given by the Convention on LRTAP and IUFRO do only to a slight degree take into consideration other effects such as rainfall, wind, temperature. The expert group will, therefore, try to include also such effects and draw adjusted critical levels maps. The work will be performed in close cooperation with the expert group on air pollution. This expert group will first produce maps showing where the internationally accepted critical levels are exceeded. These calculations will be compared with the results from the field investigation performed by the terrestrial expert group this summer. Thereafter, revised maps for critical levels for SO_2 will be drawn.

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2.15. Effects on terrestrial ecosystems

Dan Aamlid, Tor Myking and Kåre Venn
Norwegian Forest Research Institute
Høgskoleveien 12, N-1432 Ås, Norway

Abstract

Assessment of crown density of birch during a five year period has shown a slight improvement of the mean tree vitality in the monitored area. However, detailed analyses regarding the most polluted area, the Jarfjord region, have shown that birches growing at the most polluted plots have lower crown density than elsewhere in that area.

The epiphytic lichens on birch stems were absent in rather large areas (about 250 km^2) in the eastern part of the investigated area, and showed decreased coverage in even larger areas (up to 3000 km^2).

Chemical analyses of plant material have shown that uptake or accumulation of heavy metals and sulphur occur for all the analysed species, including berries. These results are also of importance in a food web context. Also when using chemical concentrations as indicators, more than 3000 km^2 of Norwegian territory might be influenced.

Deposition measurements have verified the significant load of sulphur (sulphate-sulphur) in the area. However, the annual deposition in eastern Finnmark is still small compared to the situation in the surroundings of Nikel.

Continued monitoring will provide information on the state of the forest ecosystem, and will serve as a valuable basis for determination of critical levels in the area. The monitoring will also reveal the effect of changes in emissions, if they eventually occur.

2.16. Heavy metals in terrestrial ecosystems

Eiliv Steinnes
Departemnt of Chemistry, University of Trondheim, AVH
N-7055 Dragvoll, Norway

Abstract

The airborne supply of heavy metals to Northern Fennoscandia is briefly reviewed with emphasis on the Norwegian/Russian border area. The extent of surface soil contamination and plant uptake of some elements emitted by local smelters is discussed. besides copper and Nickel, the elements arsenic, chromium, cobalt and selenium have been studied in particular. Some results indicating the extent of contamination of terrestrial animals are also presented.

3. Poster session

3.1. A Regional Perspective on Air Pollution in Arctic Europe: Fennoscandia.

Kevin Barrett
EMEP/MSC-W, det Norske Meteorologiske Institutt
PB 43 Blindern, 0313 Oslo 3, NORWAY.

Whilst many ramifications of the Kola emissions may be considered from a `local' perspective, current negotiations between European countries on strategies for future control of sulphur emissions following the expiry of the 1985 Helsinki Protocol (the `30% Club' for sulphur reductions) place emphasis on the role of long range transboundary fluxes. Large point source emissions as at Nikel make an important contribution to these. Furthermore, in a difficult economic climate, increasing attention is being given to geographical targetting of abatement measures, by which means resources are focused to those locations from which the greatest benefit from abatement may be achieved. The geographical extent of the influence of Kola emissions, and the influence of more distant emissions upon the Fennoscandian environment are, therefore, pertinent subjects. This paper seeks to explore some of these aspects. Beginning with sulphur, the dispersion from Kola is illustrated and is compared with the contribution of more distant sources to depositions in Arctic Europe. A similar theme is examined in the case of nitrogen emissions, in addition to which comment is made as to source regions for ozone episodes in Fennoscandia, and to Kola's role in nitrogen supply to the Baltic Sea. The suggestion throughout is that from an international perspective there may be some desire to control sulphur emissions from Kola, but more importantly control of more distant sources for both nitrogen and sulphur may be required to ensure protection of Fennoscandia.

3.1.1. EMEP/MSC-W grid square to grid square model

For a number of years the Meteorological Synthesising Centre, West (MSC-W) of EMEP (the European Monitoring and Evaluation Programme) at the Norwegian Meteorological Institute (DNMI) has operated an acid deposition model in order to estimate national transboundary budgets of acidifying components (e.g. Eliassen and Saltbones, 1982, and Sandnes and Styve, 1992). However, the demand for evaluation of cost effective targetting of abatement strategies has required reconfiguration of this model in order to provide additional grid square to grid square budgets (Barrett, 1992). On this occasion this model has been used to condider emissions from Kola.

The model is a single layer lagrangian model with a horizontal resolution of 150km, and extending vertically between the ground and the top of the mixing layer. Meteorological data is provided by the DNMI Numerical Weather Prediction model, into which actual observations are incorporated every six hours. Emission data for sulphur dioxide, nitrogen dioxide and ammonia is supplied by

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[1]work completed as a contribution to EMEP from the Department of the Environment of the United Kingdom.

member countries of the UN ECE 1979 Geneva Convention on Long Range Transboundary Air Pollution; academic literature is used in the case of NH_3 for those countries yet to supply official data. A full model description and quality evaluation is given in Sandnes and Styve (1992). The model is suited to long range transport over the synoptic scale, and hence is a supplement to and not a replacement for local scale modelling of the region (e.g. Larsen, 1993, this volume). In the present study except where specifically mentioned, the model has been run over a five year period covering 1985, 88, 89, 1990 and 1991 thereby giving estimates of average depositions.

3.1.2. Geographical extent of depositions arising from Kola

The geographical extent of possible adverse impact may affect international pressure to abate emissions from Kola. Figures 1 and 2 illustrate the deposition `footprint' which may be expected as a consequence of sulphur emissions from the two largest source squares, which include the Nikel, Zapoljarnij and Montsjegorsk complexes. The scale chosen is based on an approximation of the critical load for sensitive aquatic systems in the region of 0.3g sulphur m^{-2} a^{-1} (e.g. Traaen, 1993, this volume). Deposition bands shown are divided at 5%, 10%, 50% and 100% of this value. Kola may make an important contribution to adverse effects upon senstive locations within the highlighted region.

As much of northern Scandinavia is considered sensitive to acid deposition, the Kola emissions may have an international importance which can be seen to extend beyond the Norwegian/Russian border area. The zones of influence at the scales shown reach a considerable distance into Finland, and across northern Sweden and Norway. However, current deposition exceeds critical loads by the greatest amount for squares in southern Norway, and it is upon these that past Norwegian concerns have been focused. It appears that sulphur emissions from the Arctic area are largely being deposited in the north, and are not contributing heavily to the sensitive southern sites. Nevertheless, exceedence of critical loads in some parts of Finnmark and western Kola is quite high and the relative significance attached to these sites in future may become a factor in the degree of political interest shown in Kola emissions.

Approaching this from the other direction, those grid squares contributing most to the average rate of sulphur deposition across the whole of the Arctic land surface area, along with the size of their contribution, are shown in figure 3. The dominant role played by Kola sources is confirmed, but with an indication that some sources far to the south also contribute an appreciable amount to the total sulphur deposition. Hence, the ultimate effectiveness which abatement of Kola alone would achieve is limited in part by the contributions from these more distant sources. Some of these remote source squares may contribute as much as 10% of the 0.3g sulphur m^{-2} a^{-1} criteria across the whole arctic, although as shown in table 1, they are relatively minor as compared to the local inputs to the Nikel region itself. Despite this, an arguement exists for a comprehensive strategy.

3.1.3. The supply of nitrogen

Through soil chemistry, nitrogen deposition can also play a role in acidification. Figure 4 indicates those squares which contribute most to the average rate of oxidised nitrogen deposition across the whole of the Arctic land surface. The importance of Kola sources is clearly much less than with sulphur. The absence of major fossil-fuelled power generation in the region combined with the generally longer atmospheric lifetime of oxidised nitrogen focuses more attention on southern emissions, including the possibility that sources more south than the displayed region are also important. The role of nitrogen in the critical load balance for the region will affect the need for control of such distant sources, possibly within an integrated sulphur-nitrogen abatement programme.

From another perspective, oxides of nitrogen are key players in the production of tropospheric photooxidants. Potentially damaging episodes of ozone have been observed in Fennoscandia, for example during May 1992, as shown by Tuovinen (1993, this volume). In remote areas ozone production is approximately proportional to NO_x concentrations (Sillman et al., 1990). As calculation of deposition of nitrogen oxides in the model is dependent on their atmospheric concentrations, it is possible to use source allocated nitrogen deposition data as an indication of the areas which may contribute to ozone episodes. For May 1992 figures 5 and 6 show the principal contributing sources of NO_2 and PAN (in the model the latter is consequent upon nitrogen dioxide). Although not shown here, nitrate deposition was found to originate from much the same source squares. Source allocated daily deposition data is not available, and hence the figure shows the principle sources of nitrogen contributed to Fennoscandia throughout the whole of the month. The standard deviation of daily NO_2 air concentration contributions from the distant sources, however, is available and is very large, reaching over 1000% of the value of the mean contributed concentration in some cases. This indicates the episodicity of these contributions, and it is supported by the data provided by Tuovinen indicating that nitrogen oxides occured in large quantities during only a short period during May. If distant sources actually were the cause of these concentrations the suggestion is that control measures devised purely at a local level for the purposes of protecting Fennoscandia from oxidant damage may be inadequate.

Whilst an arguement can be formulated for a comprehensive control strategy in order to protect Fennoscandia, it is much less certain that control of Kola is an equal requirement for the protection of other areas. For nitrogen especially, emissions from Kola can be readily shown to be of lesser importance to sensitive receptor areas to the south. The atmospheric supply of nitrogen to the Baltic and North Seas has been of increasing interest within the forums of the Paris and Helsinki Commissions with respect to eutrophication. In figure 7 the source squares contributing most oxidised nitrogen to the whole of the Baltic sea surface are shown. From this it is evident that within this particular political arena emissions from Kola are unlikely to be a prime candidate for targetting of control measures. The significance of nitrogen from Kola for terrestrial receptors in

Scandinavia will be more complex due to interrelationships with sulphur in acidity budgets, although will still be a smaller contribution than from other sources.

3.1.4. Conclusions

Due essentially to their relative magnitudes, sulphur emissions from Kola are likely to have a greater environmental significance than nitrogen. It is also possible to forsee some interest in sulphur abatement measures at the level of multi-national negotiations. Nevertheless, the dictates of meteorology appear to largely restrict the zone of influence to the Arctic region, and to Kola. In addition, abatement of emissions from Kola may constitute only a part of that necessary to ensure protection of the European Arctic. Distant emission sources contribute a proportion of the critical load of sulphur for sensitive sites, and may be the dominant sources of nitrogen and of photo-oxidant precursors in the region. It is suggested that a local strategy may have strong benefits in reducing sulphur deposition, but that a more geographically comprehensive strategy may be necessary with reference to other forms of atmospheric pollution.

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Table 1: Percentage of total sulphur deposited in square 16,30 (Nikel region) and in square 16,29 (south of Nikel) contributed by principal sources:

Source region	**Contrib. as % of total**	
	to Nikel region	**to south of Nikel**
Former USSR	92.0	51.7
- of which from Kola/Karelia	91.0	41.4
Norway, Finland, Sweden	1.7	10.3
United Kingdom, Germany	1.2	6.9
Natural marine emissions	0.6	3.4
Inattributable sources	4.6	24.1

Data extracted from Iversen et al., 1991.

Figure 1

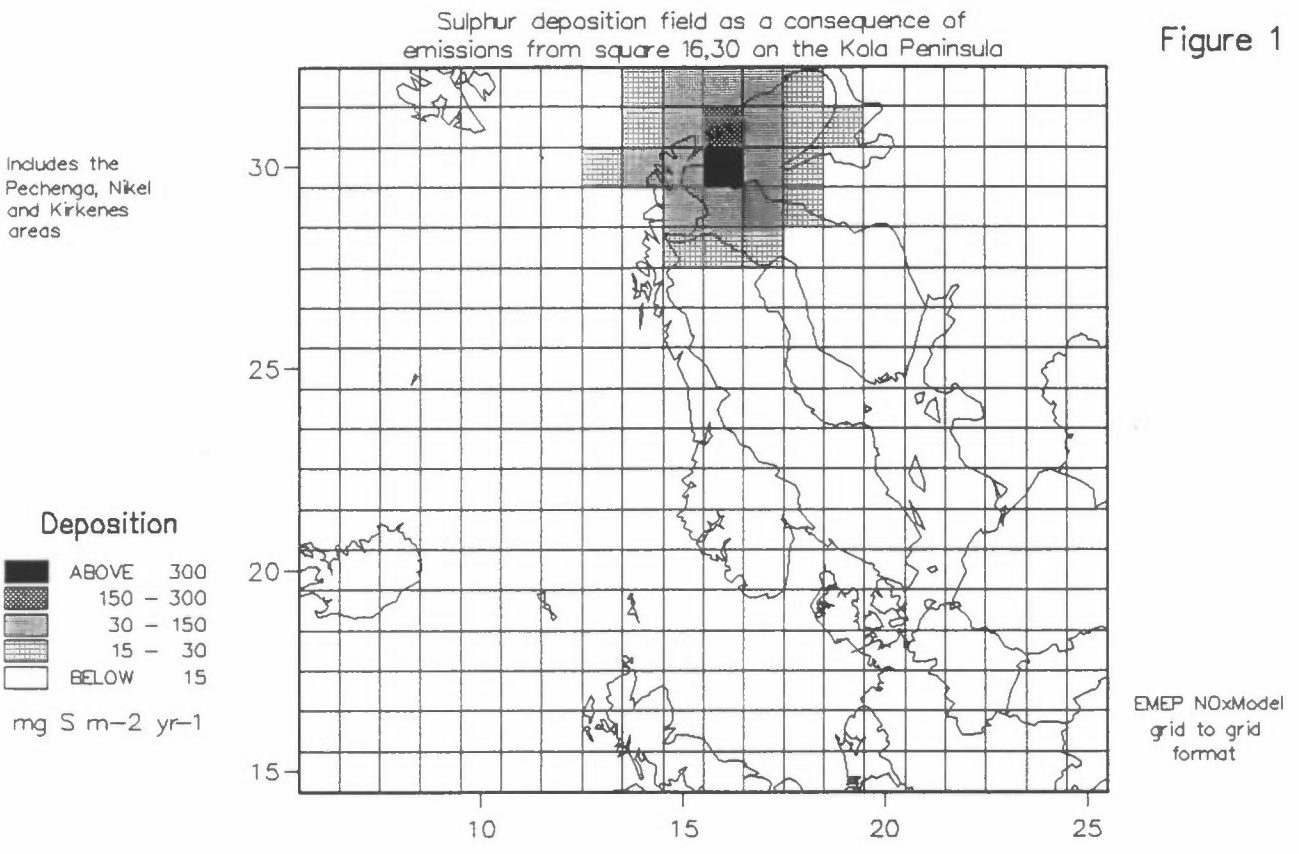
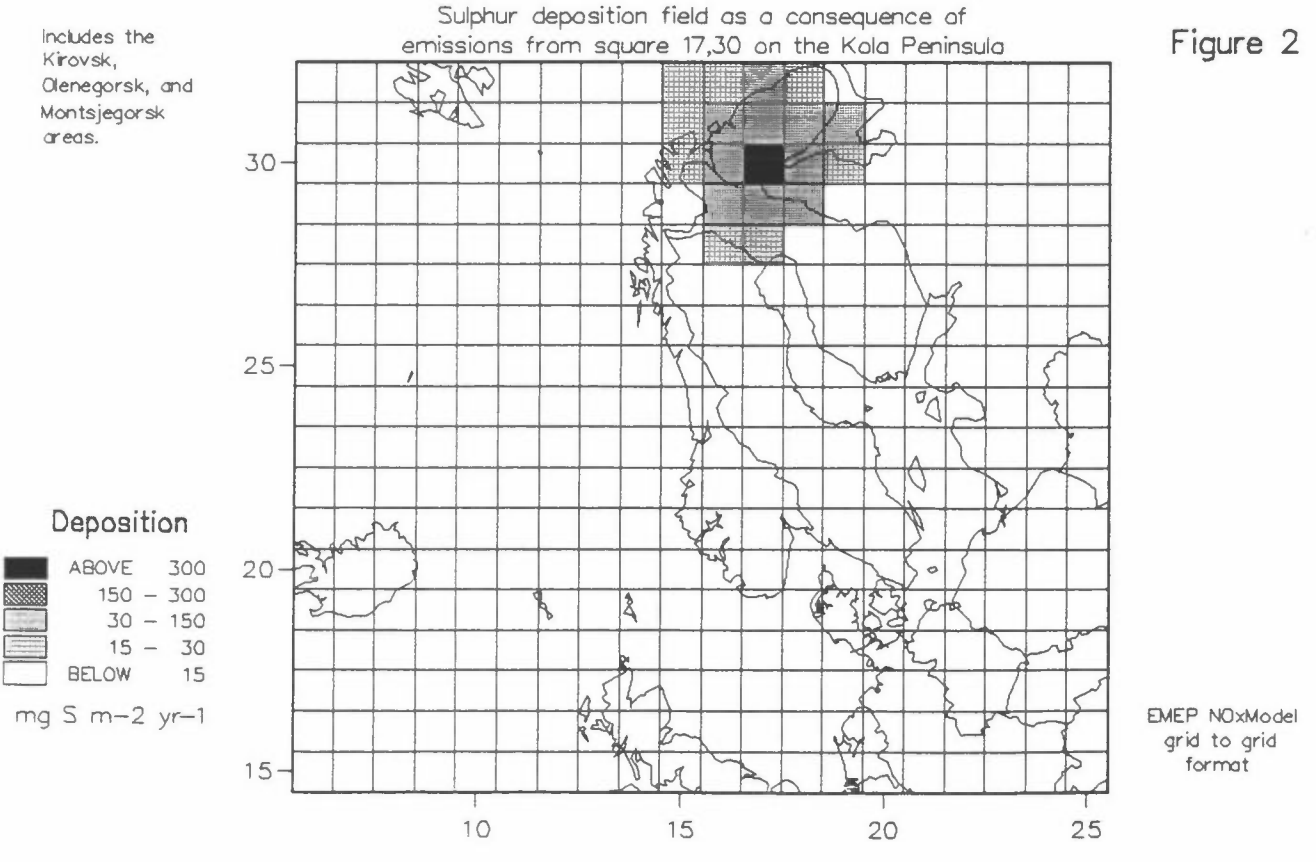
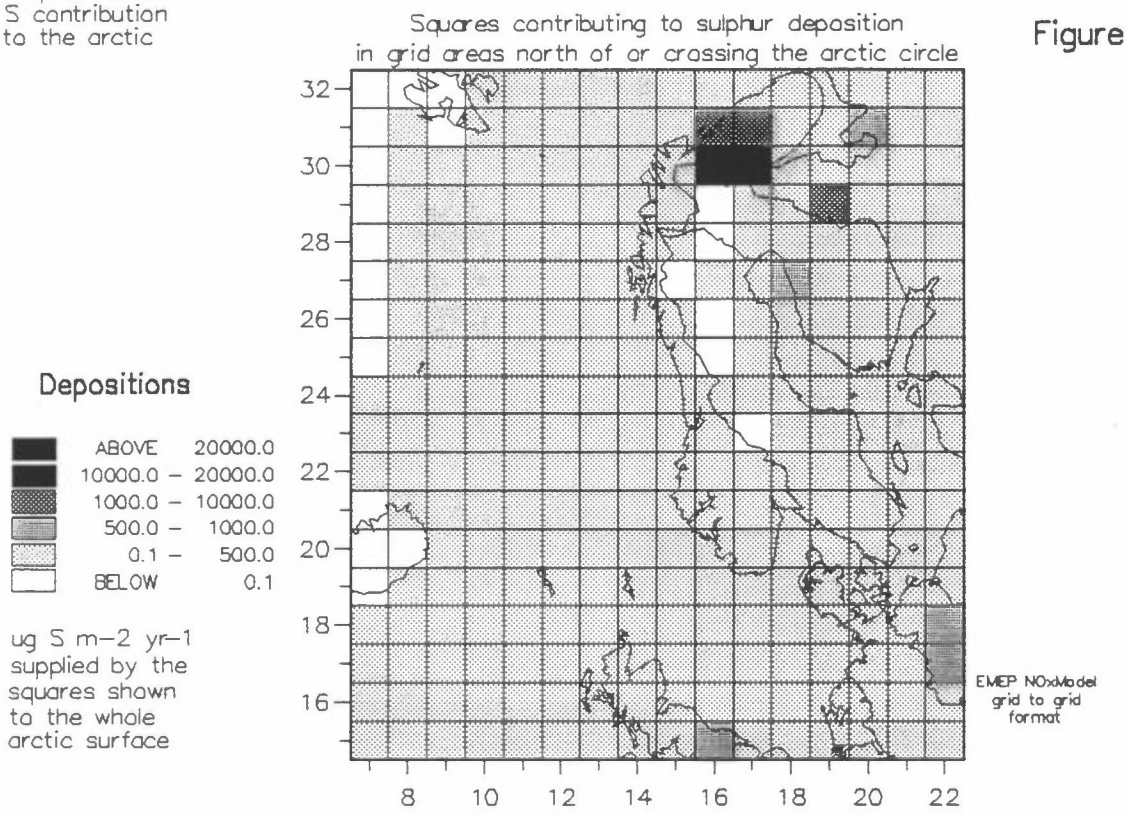


Figure 2



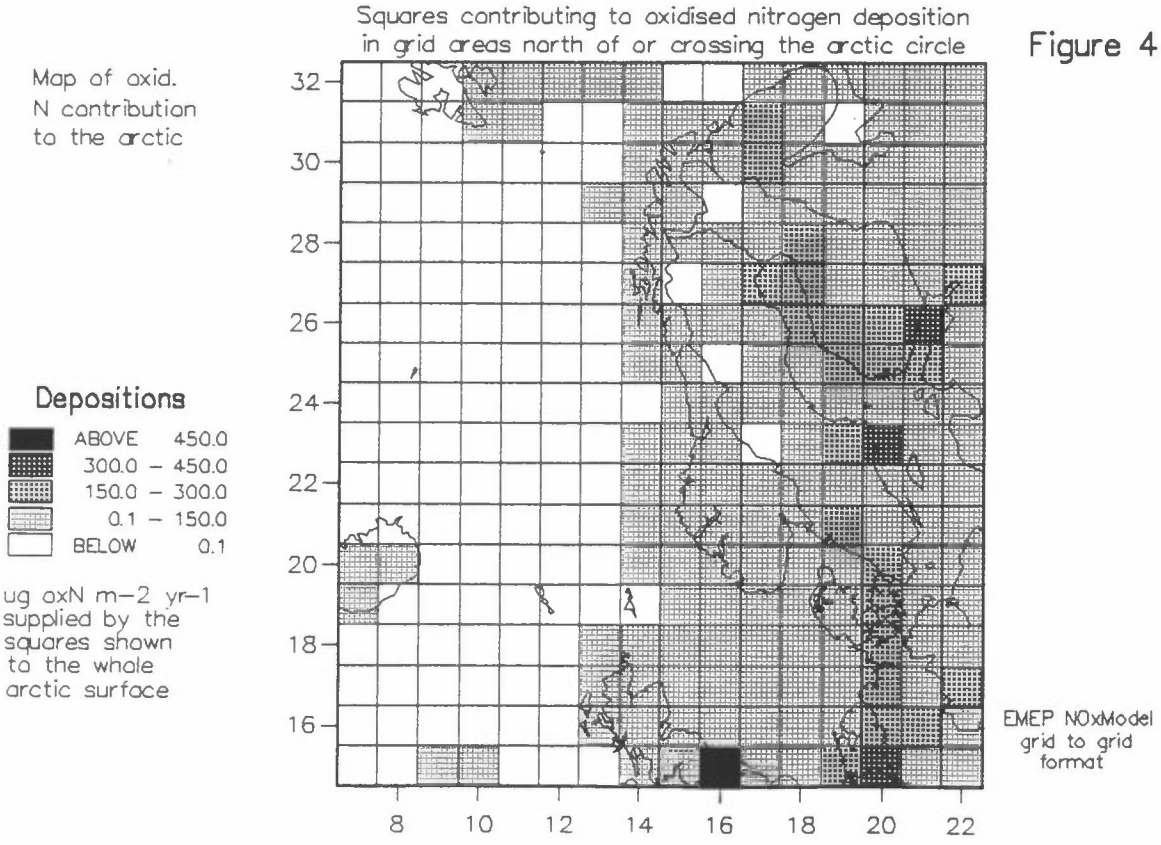
Map of total S contribution to the arctic

Figure 3



Map of oxid. N contribution to the arctic

Figure 4



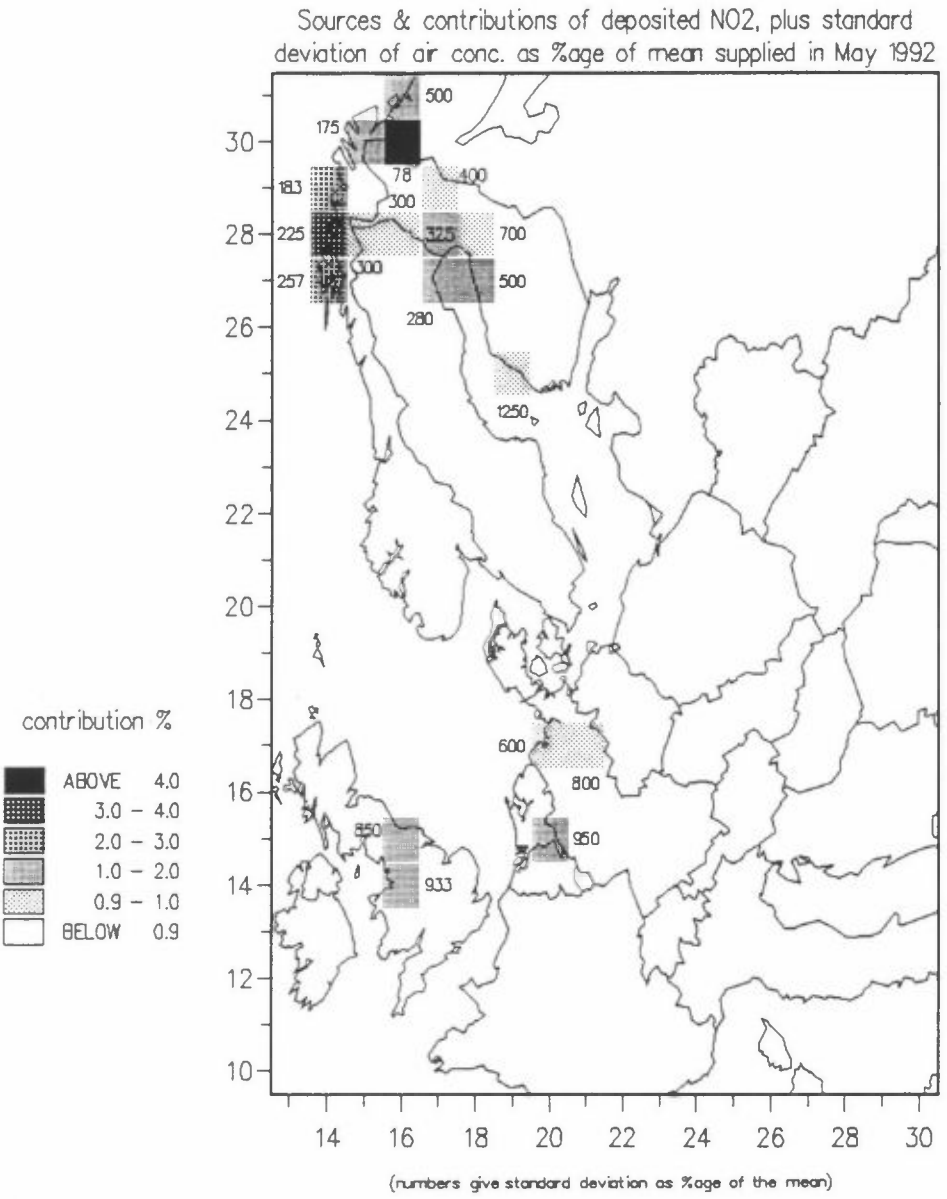


Figure 5

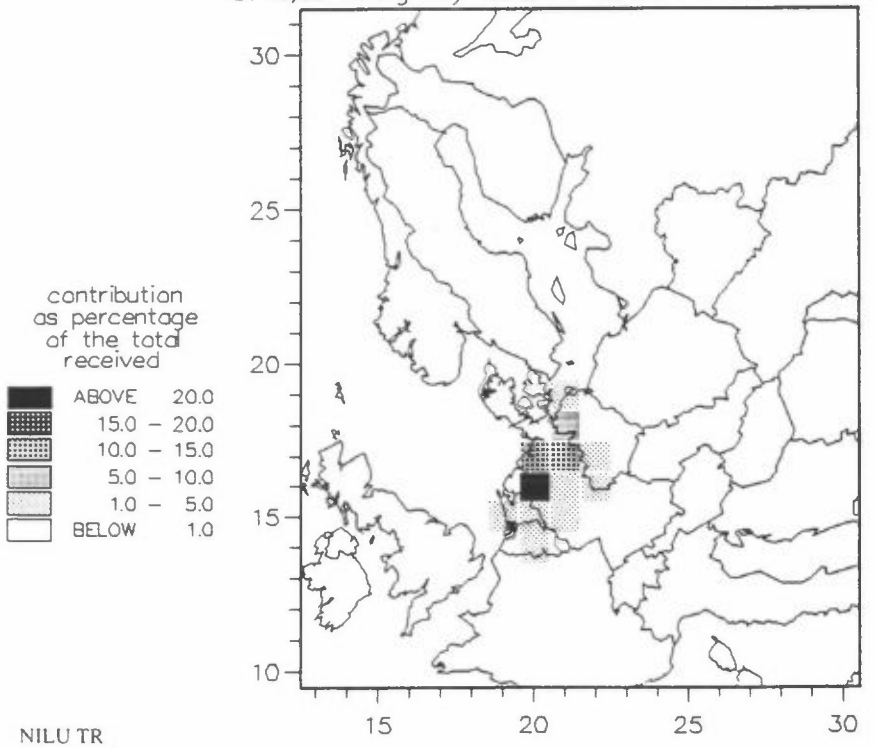
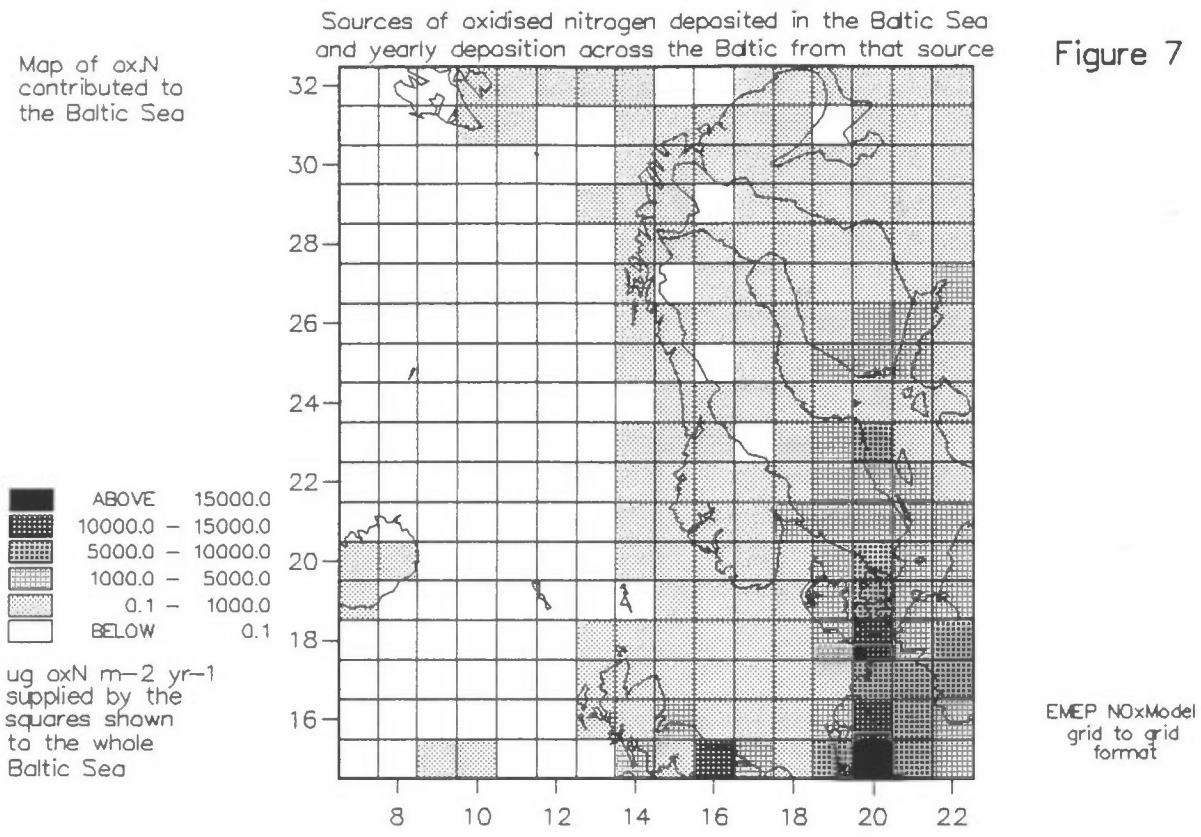


Figure 6

Figure 7


Sources of oxidised nitrogen deposited in the Baltic Sea
and yearly deposition across the Baltic from that source
Map of oxN
contributed to
the Baltic Sea
ABOVE 15000.0
10000.0 – 15000.0
5000.0 – 10000.0
1000.0 – 5000.0
0.1 – 1000.0
BELOW 0.1
ug oxN m–2 yr–1
supplied by the
squares shown
to the whole
Baltic Sea
32
30
28
26
24
22
20
18
16
8
10
12
14
16
18
20
22
EMEP NOxModel
grid to grid
format

3.2. The Evaluation of mean for Period Atmosphere Pollution In The Pechenga Region

Irina Rodjushkina, INEP KSC RAS

The main source of atmospheric pollution in the Russian-Norwegian border region is the "Pechenganickel" company of "Norilski nickel" concern. The activity of this company has a destructive effect on the ecological situation of the region, harmful influence of emissions on Pechenga region vegetation was established on an area of about 95 thousand hectare. Norwegian investigations show that the contamination of air and vegetation by company emissions be observed also in the border region of Norway.

Every year the company puts about 265 thousand tonnes of pollutants into the atmosphere, including dust of nickel oxides and sulphur, hydro-aerosols of nickel solution, copper, cobalt, sulphur dioxide and others.

If the nature degradation zone in this region increases the determination of aerotechnogenic loading on the forest ecosystem in the "Pechenganickel" company vicinity and the prediction of ecological situation change in the district under company reconstruction are important tasks. With this aim the calculations were carried out and the aerotechnogenic pollution zones were determined on the basis of the mathematical modelling, the data bases about emission sources and the meteorological information.

In the past few years, the amount of atmospheric pollutants decreased due to company measures. For example, SO_2 emission has been reduced more then 100 thousand tons over the past decade (Fig. 1). It is difficult to give the correct prognosis of the future situation because of the time-variable character of atmospheric effluents. Quantity of SO_2 emission have changed from 3380 to 6200 tons monthly for Zapoljarny and from 11000 to 17500 tonnes monthly for Nickel (Fig. 2). The above data are for 1990. We haven't the same information for 1991-92 period.

The characteristics of emission sources (temperature, velocity and volume of effluents) were estimated as constant during period of averaging.

The Gaussian type sector model was exploited to calculate average concentrations of main pollutants near the Norwegian-Russian border region. The calculations near surface level were made on 25*25 point grid with 3 km step.

Average season calculations of air pollution were made for the periods: winter season 1989/90, 1990/91, 1991/92, summer season 1990, 1991, 1992. The mean monthly calculations of sulphur dioxide contamination were executed for 1990, 1991 and 1992 every month.

The meteorological data from Viksjøfjell and Svanvik meteostations, prepared by NILU, are most representative for this region and are used for computing.

The contamination calculations were carried out, in general, for sulphur dioxide. The like calculations for dust, nickel, copper, cobalt were implemented only for 1990. The results of the model give an estimate of the areas of above-normative sulphur dioxide and heavy metals air pollution.

The zone of average concentrations exceeding CCL (50 mkg/m^3) covered in the winter of 1990/91 an area 800 km^2 and partially spread out on the Norwegian territory - northwards and north-westwards of Nickel and Zapoljarnij (Fig. 3). In the summer of 1990 the territory of above-normative contamination of SO_2 consists of about 400 km^2. An insignificant decrease of SO_2 atmospheric emissions in 1992 in comparison with 1990 (6500 tonnes) had a slight influence on the ecological situation change in this region.

For estimation of the modelling results the every month calculating SO_2 concentration and experimental data comparison was executed for SOV1, SOV2, SOV3 Russian stations (Fig. 4) and Svanvik, Viksjøfjell Norwegian stations (Fig. 5).

The results of atmospheric pollution simulation and the system of monitoring in environs of "Pechenganickel" concern show a large area of above-normative air pollution and, as a consequence, the zone of aerohechnogenic destruction. In this territory, which has been subject to industrial pollution for many years, the process of degradation of nature proceeds intensively. The area of woods defeat from industrial emissions has increased on 80 ha/year for the period 1983 -1988. The speed of extension of dead woods areas is 3 ha/year for this period.

To stop the process of extension of full degradation ecosystem zones in the environs of industrial grounds, it is necessary to essentially reduce emission of pollutants into atmosphere.

Calculations of the change in the ecological situation were done for different variants of supported "Pechenganickel" concern reconstruction to evaluate the efficiency of reconstruction.

1. Use of Vanyukov's technology proposes reducing SO_2 emission in both industrial grounds, 80% uniformly for low and high sources. In this case the average concentration 25 mkg/m^3 (recommended by IOFRO as the allowed load for woods during 6 months) is observed on the area of 400 km^2 and in a 60 km^2 zone can exceed MAC for human health (50mkg/m^3) in winter (Fig. 6). Loads on ecosystem have been reduced, but the ecological situation doesn't change.

2. The technology of the firm Outukumpu intends to reduce SO_2 emissions in the both industrial grounds, 95% uniformly for low and high sources. In this case the mean concentrations for winter season of the full district satisfy Russian standards of MAC for human health and MAC for woods (Fig. 7) is only exceeded in a small area - about 10km^2. This zone is located in north of Nickel, where the ecosystem has been destroyed by now.

The main influence on atmospheric pollution in this region is company emissions from low sources. There low sources have a greater influence 20-25 km distance from source where SO_2 concentration exceeds healthy levels for both humans and vegetation. Variations of company reconstruction without reduction of low sources emissions will not allow essential change of ecological situation in this region. Therefore, emission from low sources will not be assumed in future working of best company reconstruction variant.

3. Reducing SO_2 emission in industrial ground of Nickel 95% without reconstruction in industrial ground of Zapolyarny. All emissions planing from high sources only are 15800 t/year and 72000 t/year accordingly. Under this variant of reconstruction, the zone of exceeding of 25mkg/m^3 in winter will be about 20 km^2, and in summer - 15 km^2. The district of maximum pollution is in the environs of Zapolyarny (Fig. 8). In the near-border district, north part from concern the average seasonal SO_2 concentrations decrease to 10-15 mkg/m^3. This value doesn't exceed that admitted for human health standards, but is fatal for some kind of vegetation.

4. Reducing SO_2 emissions in industrial ground of Nickel 95% and of Zapolyarny 75%. Emission is planing from high sources only, and is made 15800 t/year 16300 t/year accordingly. The realization of this variant of concern reconstruction will reduce SO_2 concentration to 1-5mkg/m^3 in the atmosphere (Fig. 9).

Analysis of calculations results showed that the sufficient change of ecological situation in this region will be possible by realizing of the last variant. In this case influence on humans and vegetation will not destructive as now.

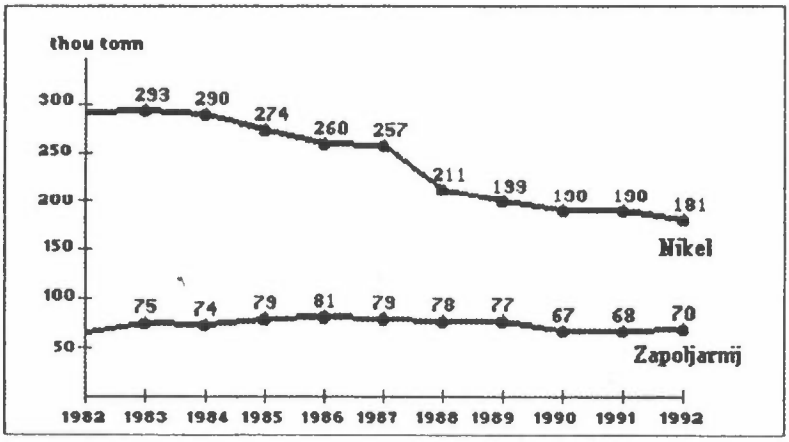


Fig. 2. SO_2 emissions at the atmosphere by Pechenganickel complex

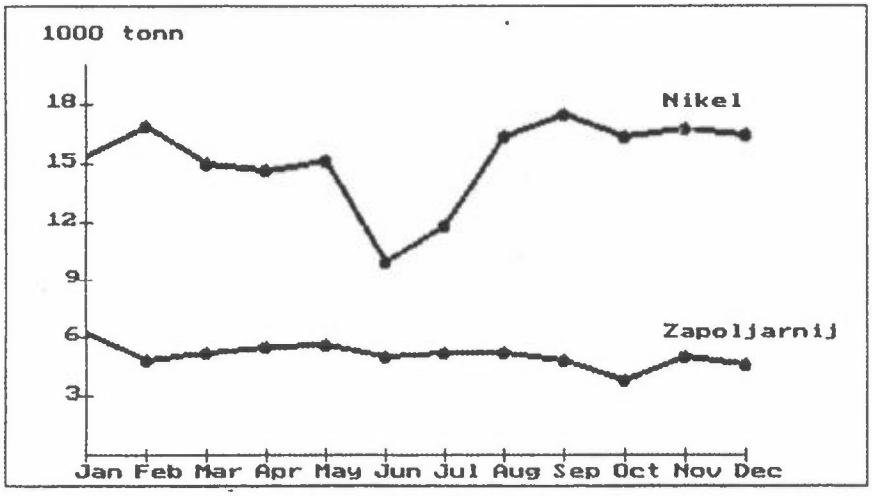


Fig. 1. The SO_2 monthly emissions by Pechenganickel complex in 1990.

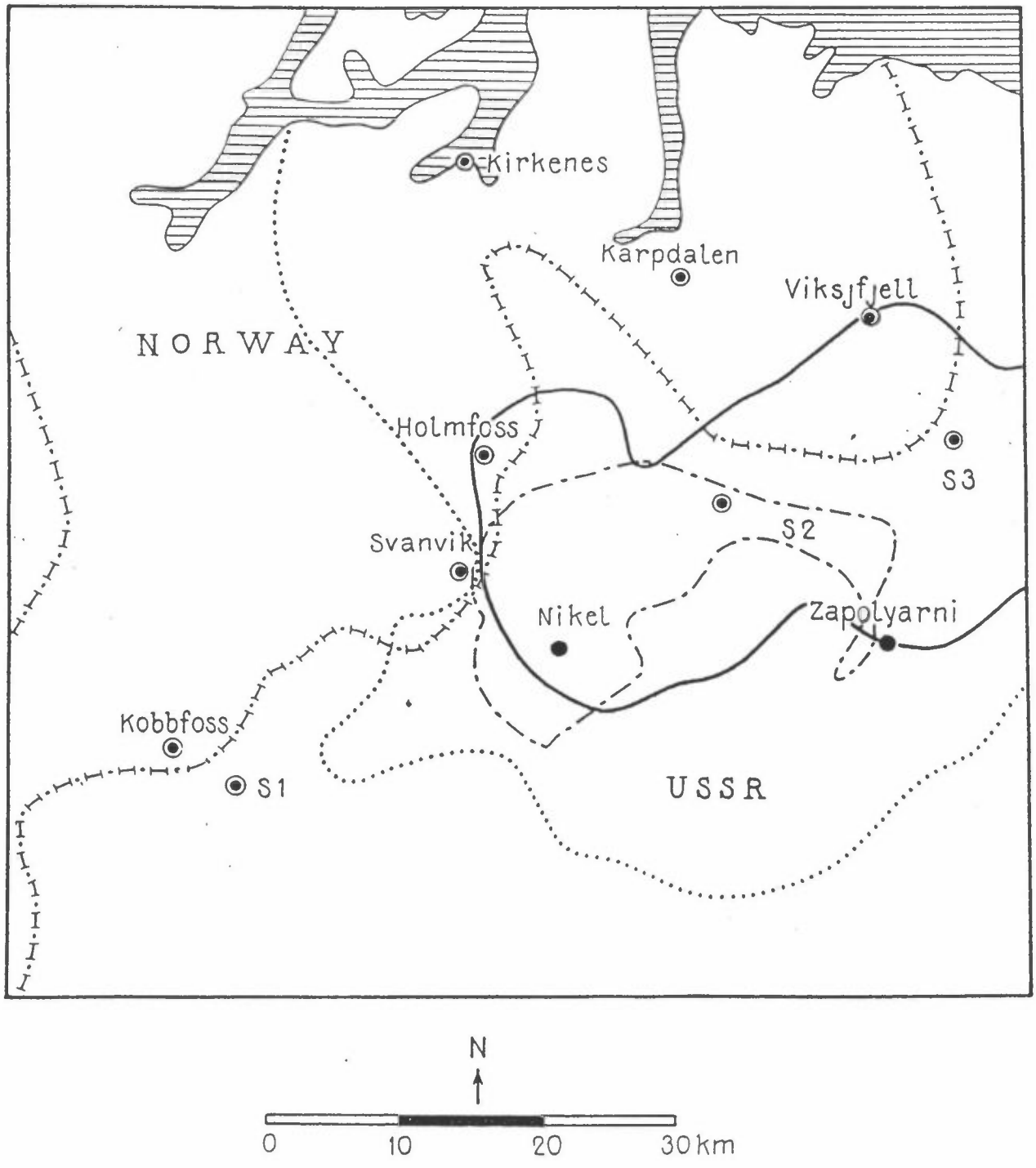


Fig. 3. Zones of mean season SO2 concentration exceeding CCL:
Summer season 1990:
Winter season 1990/91:
..... January 1990.

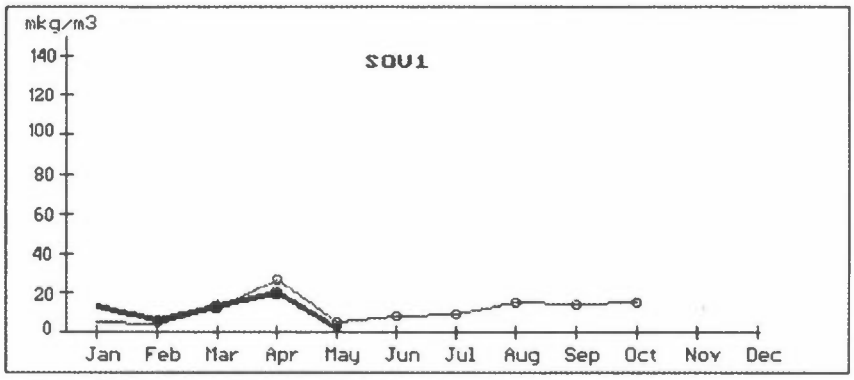


Fig. 4.1. The model estimated and observed monthly average concentration of SO_2

▬ observed concentration
— estimated concentration

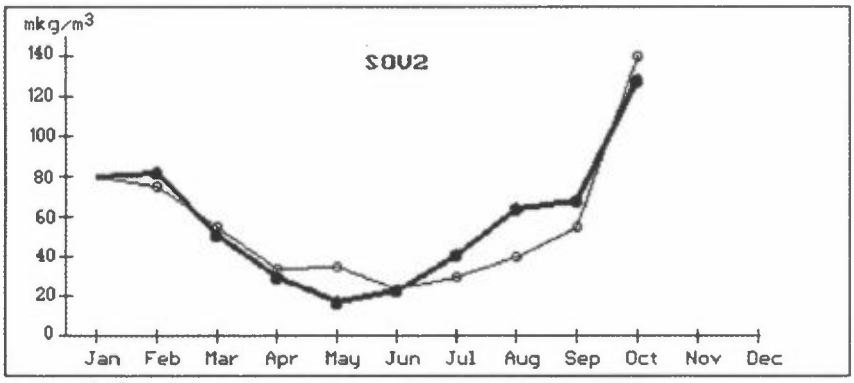


Fig. 4.2. The model estimated and observed monthly average concentration of SO_2

▬ observed concentration
— estimated concentration

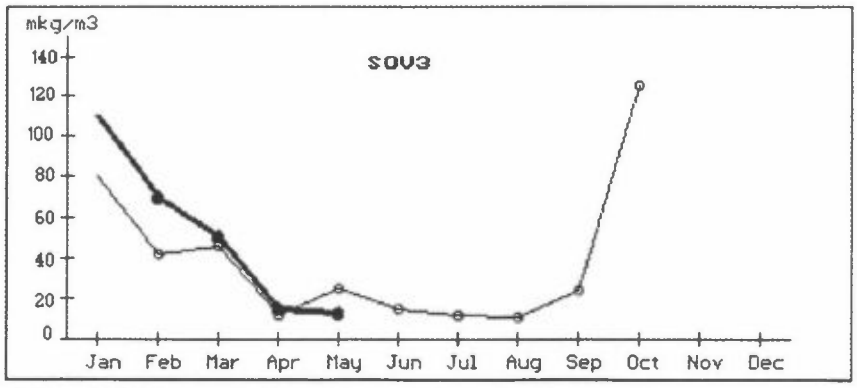


Fig. 4.3. The model estimated and observed monthly average concentration of SO_2

▬ observed concentration
— estimated concentration

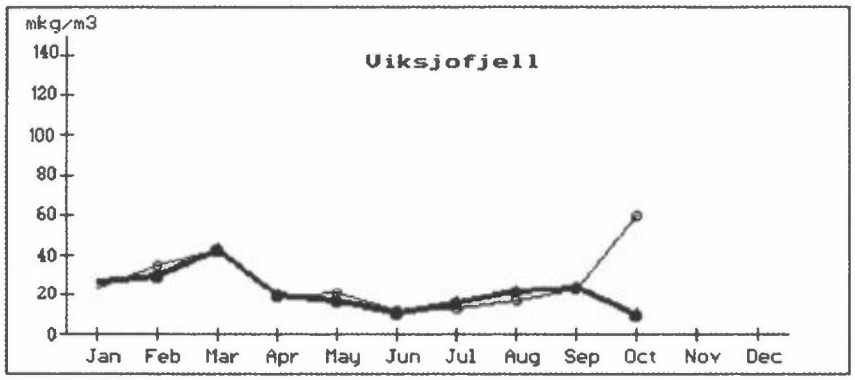


Fig.5. The model estimated and observed monthly average concentration of SO_2

observed concentration
estimated concentration

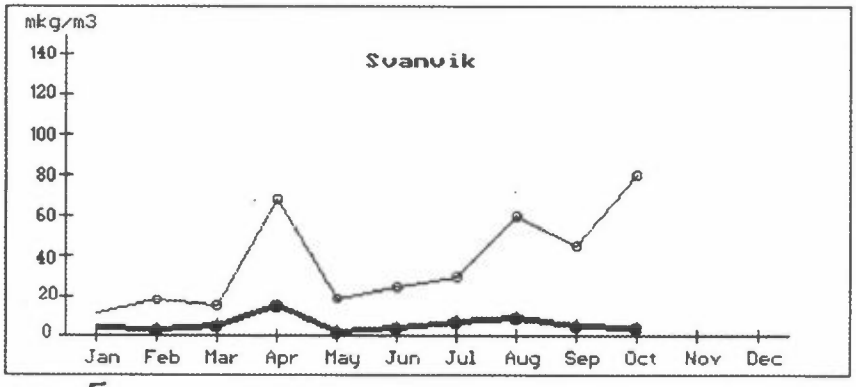
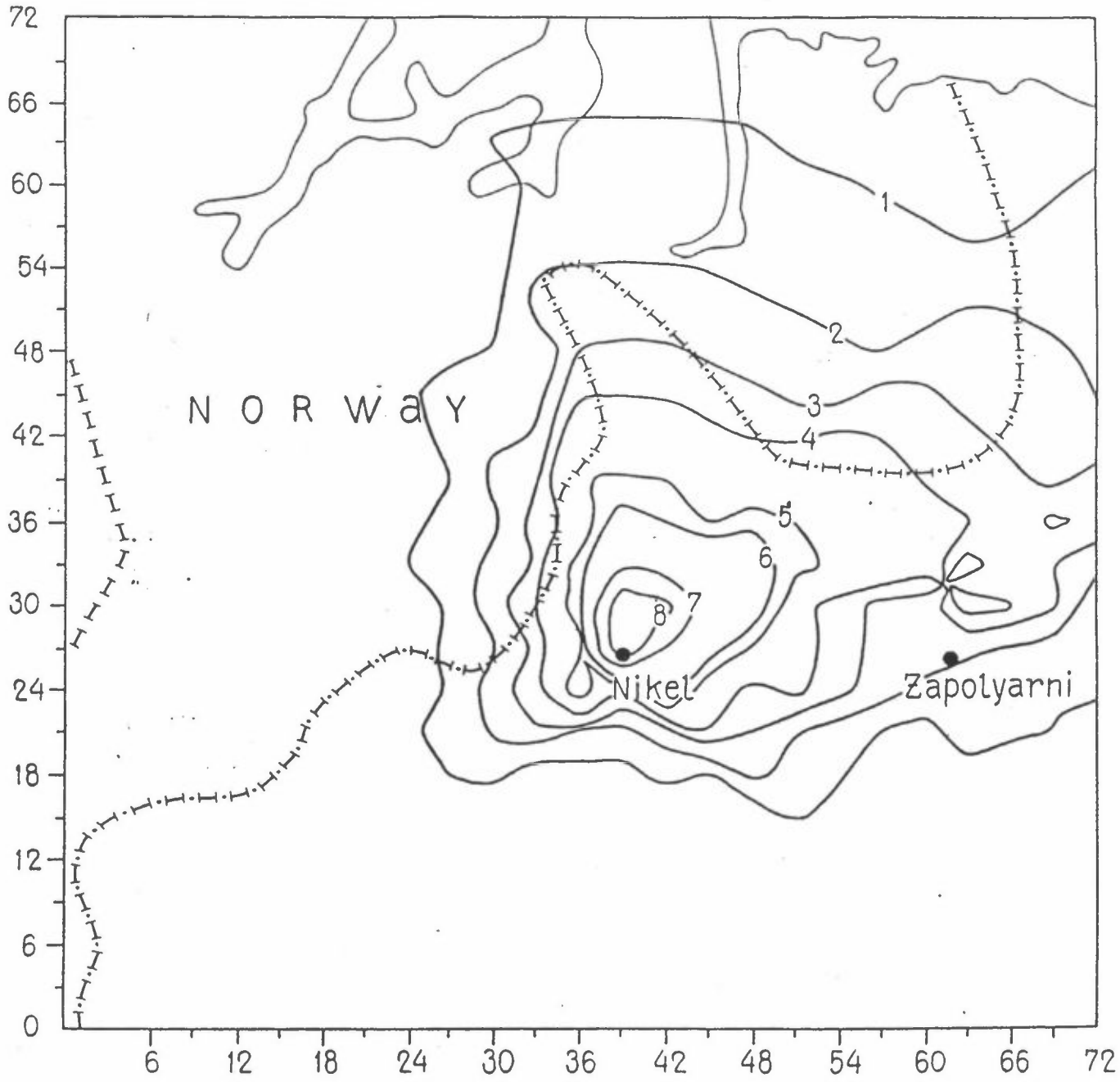


Fig.5 The model estimated and observed monthly average concentration of SO_2

observed concentration
estimated concentration

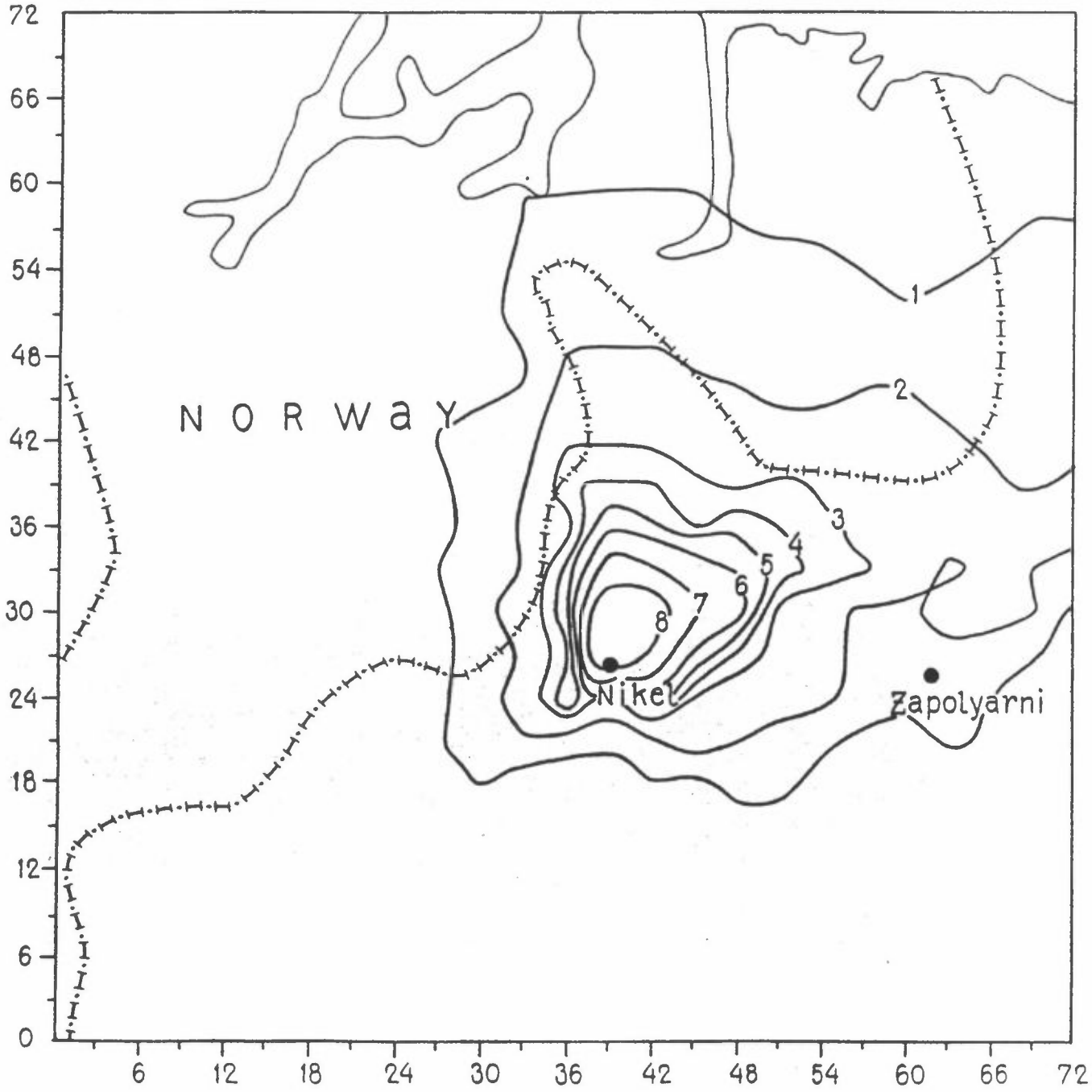
Fig. 6. Estimated average concentration of SO2 for winter season.
- 80% decreasing of emissions from Nikel;
- 80% decreasing of emissions from Zapoljarnij.



Levels of concentration:

1.	10 mkg/m3	2.	15 mkg/m3
3.	20 mkg/m3	4.	25 mkg/m3
5.	40 mkg/m3	6.	50 mkg/m3
7.	100 mkg/m3	8.	150 mkg/m3

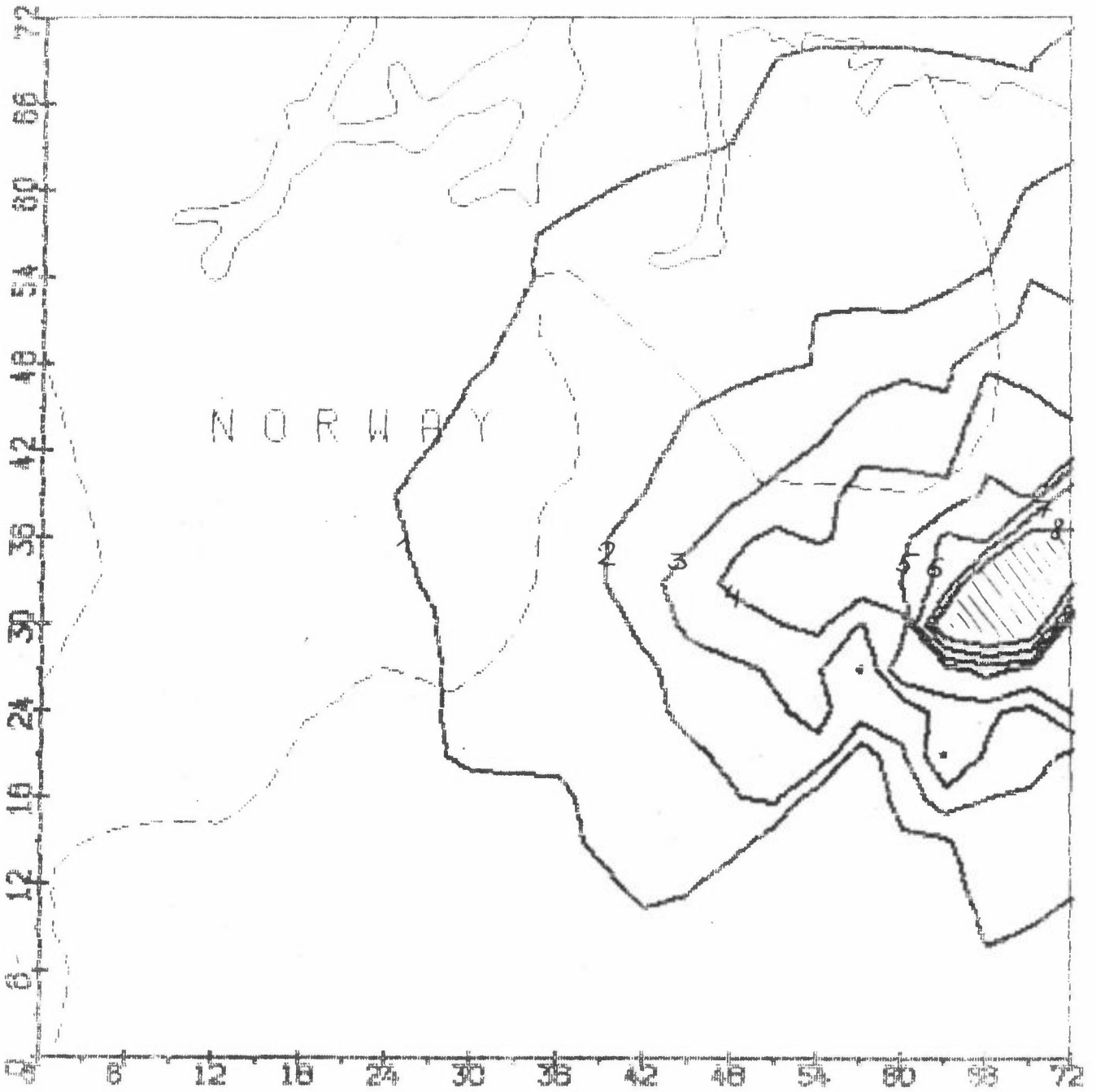
Fig.7 Estimated average concentration of SO2
(95% decrease of emissions)
for winter season 1990 (meteo: Viksjofjell)



Levels of concentration of SO2

1	3.000 µg/m3	2	5.000 µg/m3
3	8.000 µg/m3	4	10.000 µg/m3
5	12.000 µg/m3	6	15.000 µg/m3
7	20.000 µg/m3	8	30.000 µg/m3

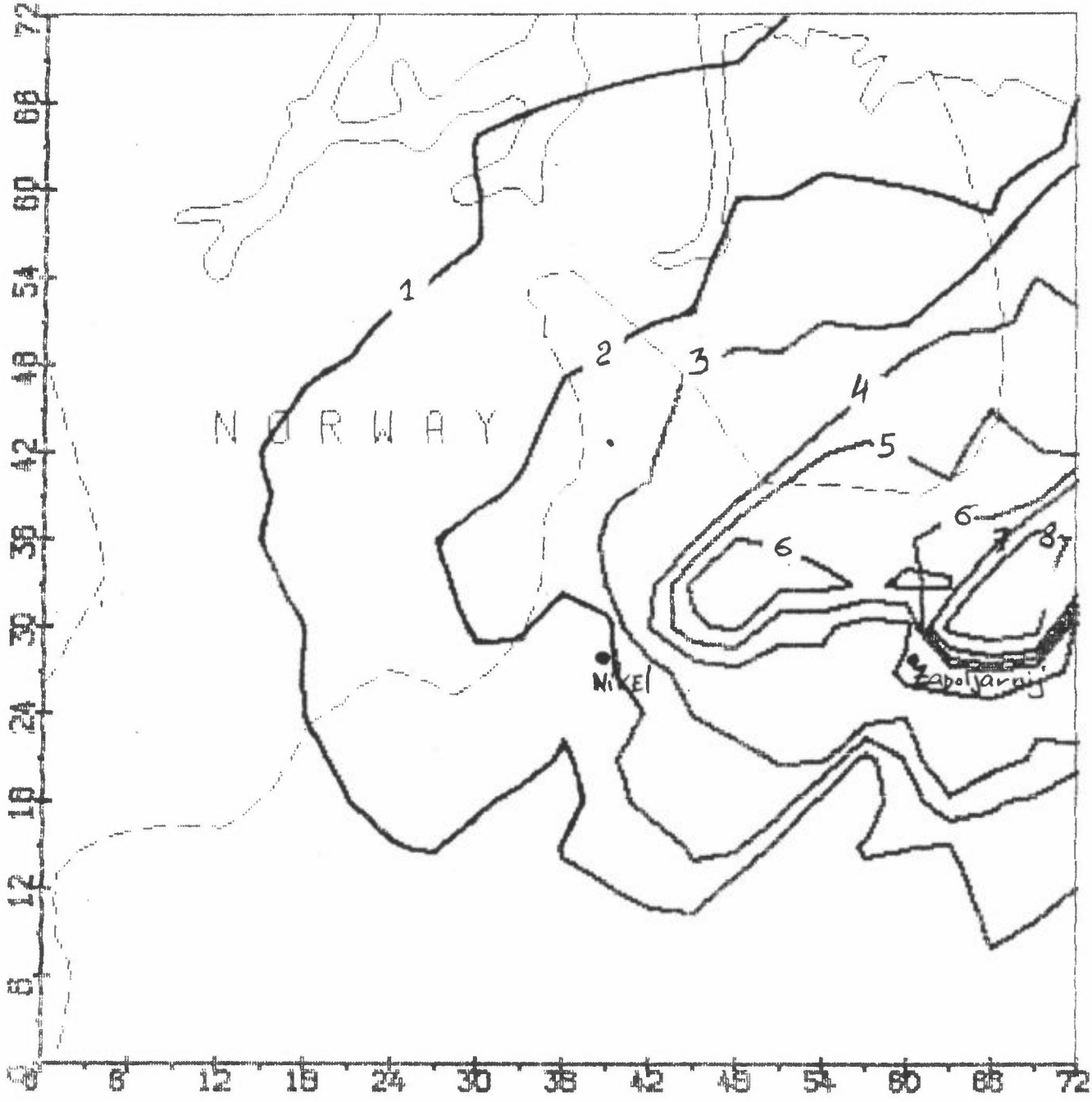
Fig. 8. Estimated average concentration of SO2
for Winter season
(95% decreasing of emmissions for Nikel)



Levels of concentration of SO2

1	3.000 ug/m3	2	5.000 ug/m3
3	7.000 ug/m3	4	9.000 ug/m3
5	12.000 ug/m3	6	15.000 ug/m3
7	20.000 ug/m3	8	25.000 ug/m3

Fig. 9. Estimated average concentration of SO2
for Winter season
95% decreasing of emmissions for Nikel
75% decreasing of emmissions for Zapoljarnij



Levels of concentration of SO2

1	1.000 ug/m3	2	1.500 ug/m3
3	2.000 ug/m3	4	3.000 ug/m3
5	4.000 ug/m3	6	5.000 ug/m3
7	6.000 ug/m3	8	8.000 ug/m3

3.3. Snow pollution of the Kola Peninsula

A. Baklanov[A], D.A. Jaffe[B] and B.M. Cerundolo[B]*
[A]Institute of North Ecological Problems, Kola Science Centre, 184210 Apatity, Russia
[B]Geophysical Institute and Department of Chemistry University of Alaska, Fairbanks, Alaska 99775-0800, USA
**Author to whom communication should be addressed*

Abstract.- Snow samples collected from the Kola Peninsula, Russia (at both remote locations and in the vicinity of major emission sources) during the late spring of 1991 were analyzed for pH, conductivity, F^-, Cl^-, NO_3^-, SO_4^{2-} and metals. The concentrations of SO_4^{2-} and several metals were substantially enhanced in the vicinity of the Monchegorsk smelter, and F^-- was enhanced near Kandalaksha, site of a major aluminum smelter. However despite the higher SO_4^{2-} concentrations near Monchegorsk, pH was not significantly lower. This later effect appears to be a result of neutralization reactions from the deposited metal compounds. Using the measured SO_4^{2-} wintertime depositions, we calculate that no more than 1% of the wintertime Monchegorsk SO_2 emissions are removed to the snow within 20 km.

Snow can serve as an integrating receptor of atmospheric pollutant concentrations (Jaffe & Zukowski, 1992). Over the course of a winter season, contaminants are removed to the snow via wet and dry deposition in varying amounts. In this study we have measured the concentrations of several pollutants in the snowpack in both remote and impacted areas of the Kola Peninsula. The data can then be used to determine the spatial deposition patterns of pollutants in this region.

Snowpack samples were collected from various regions of the Kola Peninsula in April 1991 (Fig. 1). At each site measurements of the snowpack water equivalent were made to determine deposition rates.

Samples were collected into pre-cleaned polyethylene bottles and analysis for F^-, Cl^-, NO_3^-, SO_4^{2-} (ion chromatography), metals (plasma emission spectroscopy), pH and conductivity was conducted. Details of the sampling and analysis procedures are given by Cerundolo (1992).

Snowpack concentration data are shown in the Table. Substantially elevated non-seasalt SO_4^{2-}, Cu, and Ni concentrations are located in the vicinity of the Monchegorsk smelter. Measured pH and SO_4^{2-} concentrations as a function of distance from the Monchegorsk smelter are shown in Fig. 2 and Cu and Ni concentrations - in Fig. 3. High F^- concentrations were found near Kandalaksha, site of an aluminum smelter. Despite significantly higher SO_4^{2-} concentrations in the vicinity of the Monchegorsk smelter, pH was not significantly lowered. Our interpretation of this result is that the co-emitted metal compounds act to neutralize some of the acidity which would otherwise be present. A comparison of the observed SO_4^{2-} deposition rates near Monchegorsk with the known SO_2 emissions leads to the conclusion that during the 6 month winter period less than 1% of the SO_2 emissions are removed to the snowpack within 20 km (Cerundolo, 1992).

Modeling has been used to determine the impact of the Monchegorsk emissions on the surrounding environment (Ratkin & Makarova, 1992; Baklanov & Rodjushkina, 1993). An example of this work is shown in Fig. 4 which shows modeled SO_2 and SO_4^{2-} concentrations for 1990 as a function of distance from the Severonikel smelter complex.

References

Jaffe, D.A. & Zukowski, M.B. 1992. Nitrate deposition to the Alaskan snowpack. *Atm.Env.* (in press)

Cerundolo, B.M. 1992. Snow chemistry of the Kola Peninsula, Russia. M.S. thesis, University of Alaska Fairbanks, Fairbanks, Alaska USA 99775. 83 p.

Baklanov, A.A. & Rodjushkina, I.A. 1993. Pollution of the ambient air by "Severonikel" smelter complex: observations and modeling. *In:* Kozlov, M.V. e.a. (eds.). Aerial Pollution in the Kola Peninsula: Proc. of Internat. Workshop, St.-Petersburg, April 14-16, 1992. Edited by M. Kozlov, E. Haukiaja, V. Yarmishko

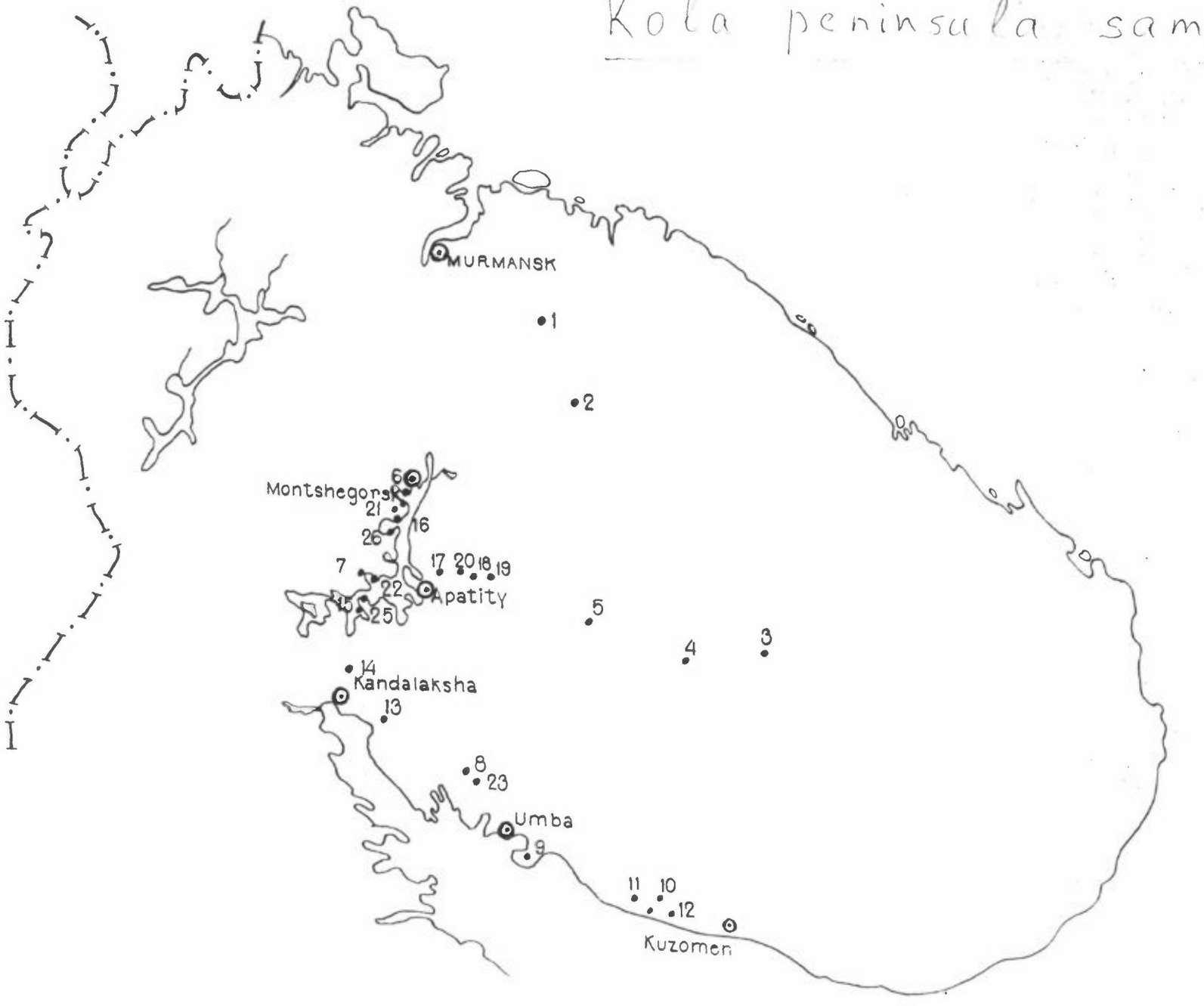
Ratkin, N.E. & Makarova, T.D. 1992. Role of snow cover in the Murmansk region landscape pollution. *In:* Kalabin, G.V. & Makarova, T.D. (eds.) Ecological and Geographical Problems of the Kola Peninsula. Apatity. P. 20-35.

Table. Average of samples, classified by sites in Kola Peninsula.

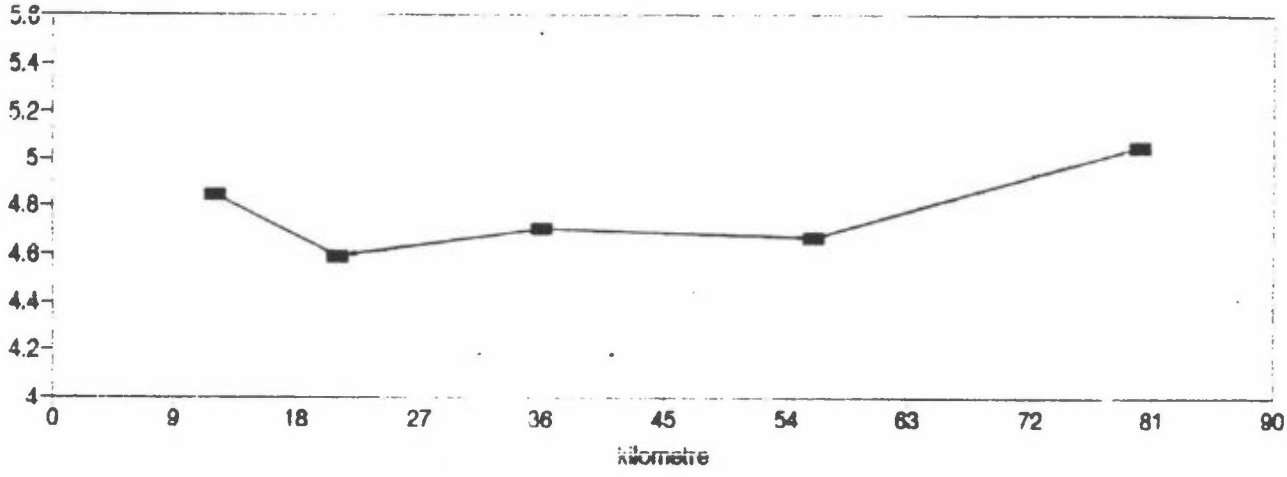
site	pH	cond	density	x depth	cl PPM	uequ/L [Cl-]	so4 PPM	uequ/L [SO4=]	no3 PPM	uequ/L [NO3-]	f	uequ/L [F-]	uequ/L [Na+]	ppm [Na+]	uequ/L [H+]
1	4.8	21	0.253	55.17	2.89	83.77	1.31	27.29	0.497	8.02			79.95	1.84	15.85
2	4.88	15.4	0.2834	57.4	1.55	44.93	1.21	25.21	0.65	10.48			58.98	1.36	13.18
3	4.5	20.8	0.3216	63.31	0.883	25.59	1.55	32.29	0.996	16.06			28.71	0.66	31.62
4	4.63	15.4	0.3408	66.47	0.77	22.32	0.954	19.88	0.918	14.81			18.67	0.43	23.44
5	4.77	17.8	0.2346	101	1.17	33.91	1.61	33.54	1	16.13			44.08	1.01	16.98
6	4.85	19.2	0.2652	60	0.551	15.97	2.57	53.54	1.21	19.52			17.03	0.39	14.13
7	4.71	14.8	0.2634	82.23	0.392	11.36	1.23	25.63	1.14	18.39			12.85	0.30	19.50
8	4.53	18.1	0.2352	75.37	0.357	10.35	1.43	29.79	1.26	20.32			12.09	0.28	29.51
9	4.48	20.6	0.263	76.3	0.488	14.14	1.61	33.54	1.24	20.00			14.09	0.32	33.11
10	4.55	28.1	0.2854	75.1	2.06	59.71	1.92	40.00	1.42	22.90			66.8	1.54	28.18
11	4.47	24.4	NA	89.67	1.05	30.43	1.72	35.83	1.6	25.81			24.4	0.56	33.88
12	4.44	30.3	NA	65.4	2.23	64.64	2.01	41.87	1.46	23.55			76.51	1.76	36.31
13	4.71	17.2	0.2901	86.3	0.477	13.83	1.63	33.96	1.18	19.03	0.852	44.84	31.89	0.73	19.50
14	5.05	16.2	0.3632	65.6	0.484	14.03	1.6	33.33	1.23	19.84	2.06	108.42	50.72	1.17	8.91
15	4.67	14.1	0.2888	78.3	0.415	12.03	1.08	22.50	1.23	19.84			13.27	0.31	21.38
16	4.59	17.7	0.287	94.7	0.515	14.93	1.94	40.42	1.12	18.06			17.53	0.40	25.70
17	4.56	15	0.2668	70.5	0.423	12.26	1.39	28.96	1.39	22.42			9.21	0.21	27.54
18	4.72	17.8	0.2912	72.2	0.864	25.04	1.72	35.83	1.09	17.58			27.63	0.64	19.05
19	4.62	19.7	NA	102.2	0.858	24.87	2.02	42.08	0.979	15.79			31.98	0.74	23.99
20	4.83	13.2	NA	77	0.609	17.65	1.51	31.46	0.698	11.26			21.58	0.50	14.79

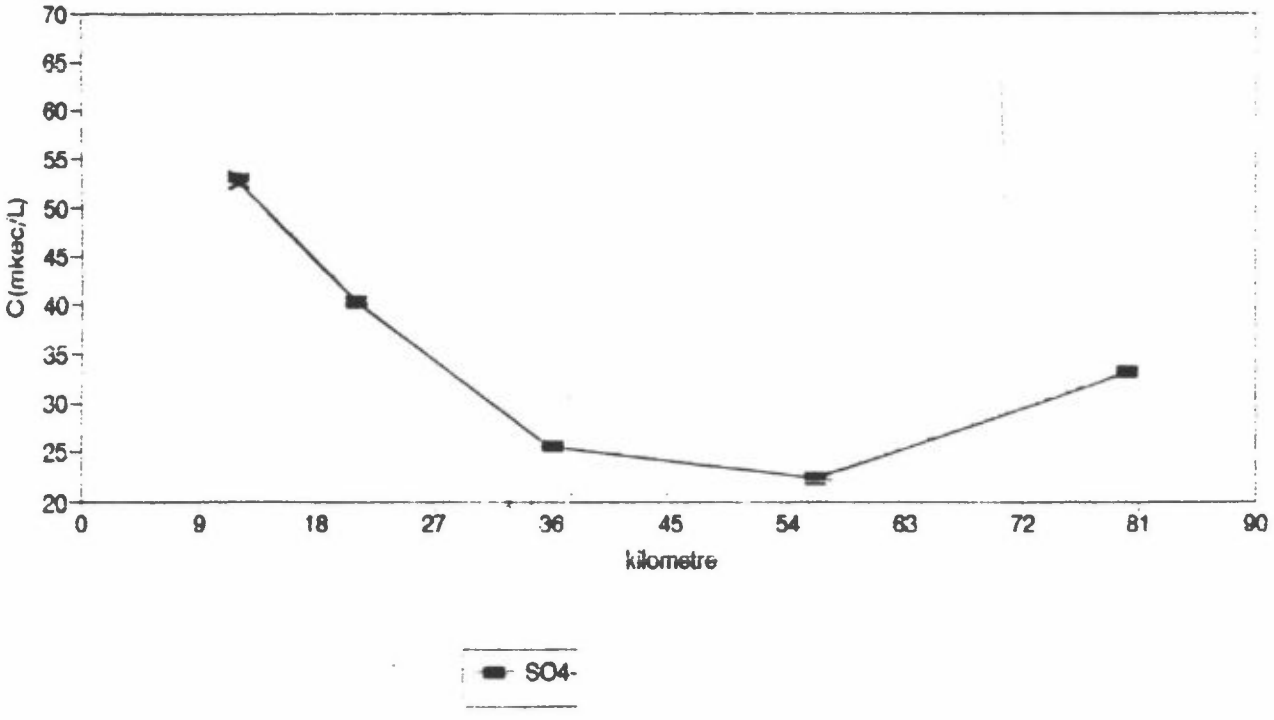
Table 1 (continued).

site	uequ/L [Ca++]	ppb [Ca++]	uequ/L [Cu+]	ppb [Cu+]	uequ/L [Ni]	ppb [Ni++]	Sea Salt SO4=	nss SO4=	ppm SO4=	Molar S/N	uequ/L [Zn++]	ppb [Zn++]	ueq/l [Mg++]	ppb [Mg++]
1	4.36	87.37	0.863	54.84	0.33	9.69	19.99	7.30	0.35	0.71	-0.113	-3.69	15.22	185.00
2	4.18	83.77	0.97	61.63	0.08	2.35	14.75	10.46	0.50	0.77	0.04	1.31	9.18	111.58
3	2.95	59.12	0.493	31.33	-0.34	-9.98	7.18	25.11	1.21	1.21	0.26	8.50	5.6	68.07
4	2.63	52.71	0.7	44.48	-0.51	-14.97	4.67	15.21	0.73	0.80	0.02	0.65	4.77	57.98
5	6.74	135.07	0.7	44.48	0.21	6.16	11.02	22.52	1.08	1.08	0.11	3.60	8.05	97.85
6	6.7	134.27	27.19	1727.65	6.83	200.49	4.26	49.28	2.37	1.95	0.52	17.00	5.38	65.39
7	5.07	101.60	2.37	150.59	0.21	6.16	3.21	22.42	1.08	0.94	0.37	12.09	3.32	40.35
8	3.53	70.74	0.91	57.82	0.15	4.40	3.02	26.77	1.29	1.02	0.14	4.58	3.2	38.90
9	2.98	59.72	0.513	32.60	-0.2	-5.87	3.52	30.02	1.44	1.16	0.22	7.19	3.87	47.04
10	5.01	100.40	0.6	38.12	0.05	1.47	16.70	23.30	1.12	0.79	0.08	2.61	13.25	161.05
11	3.58	71.74	0.31	19.70	-0.91	-26.71	6.10	29.73	1.43	0.89	0.27	8.82	6.72	81.68
12	4.4	88.18	0.37	23.51	0.24	7.05	19.13	22.74	1.09	0.75	0.12	3.92	12.87	156.43
13	5.48	109.82	0.85	54.01	-0.06	-1.76	7.97	25.99	1.25	1.06	0.19	6.21	5.03	61.14
14	13.82	276.95	0.54	34.31	-0.52	-15.26	12.68	20.65	0.99	0.81	0.47	15.36	6.27	76.21
15	4.31	86.37	0.95	60.36	0.35	10.27	3.32	19.18	0.92	0.75	0.24	7.84	3.51	42.66
16	4.89	98.00	11.01	699.58	1.7	49.90	4.38	36.04	1.73	1.54	0.1	3.27	4.84	58.83
17	5.28	105.81	3.85	244.63	0.36	10.57	2.30	26.66	1.28	0.92	-0.05	-1.63	3	36.47
18	16.6	332.66	1.77	112.47	0.03	0.88	6.91	28.92	1.39	1.27	0.55	17.98	6.91	83.99
19	8.74	175.15	1.46	92.77	0.19	5.58	8.00	34.08	1.64	1.67	0.35	11.44	6.26	76.09
20	11.14	223.25	1.7	108.02	-0.11	-3.23	5.40	26.06	1.25	1.79	0.37	12.09	5.22	63.45

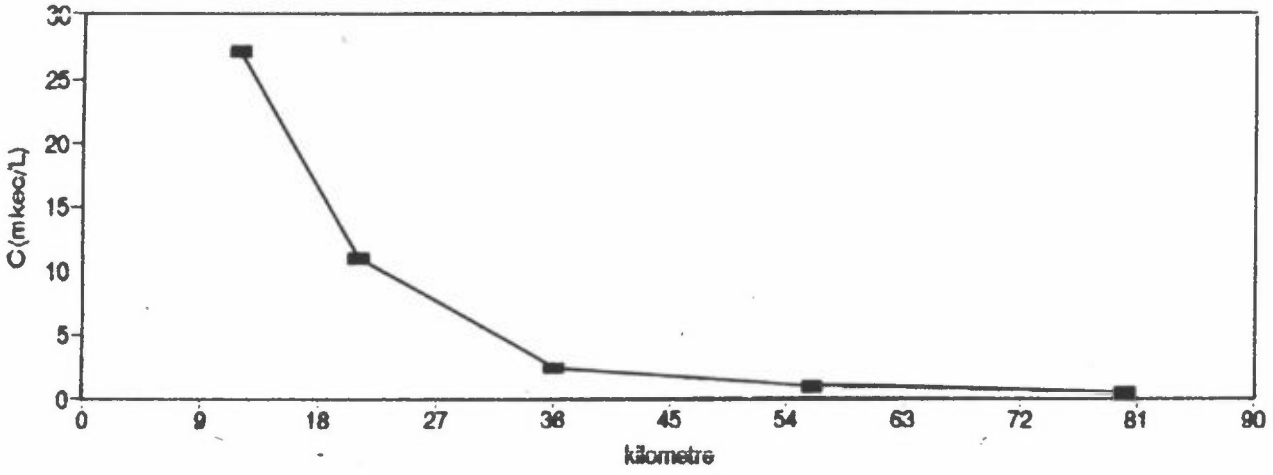

Kola peninsula sample sites
MURMANSK
1
2
Montshegorsk
6
21
16
26
7
17
20
18
19
22
Apatity
15
25
5
4
3
14
Kandalaksha
13
8
23
Umba
9
11
10
12
Kuzomen

section Monchgorck-Kandalakcha

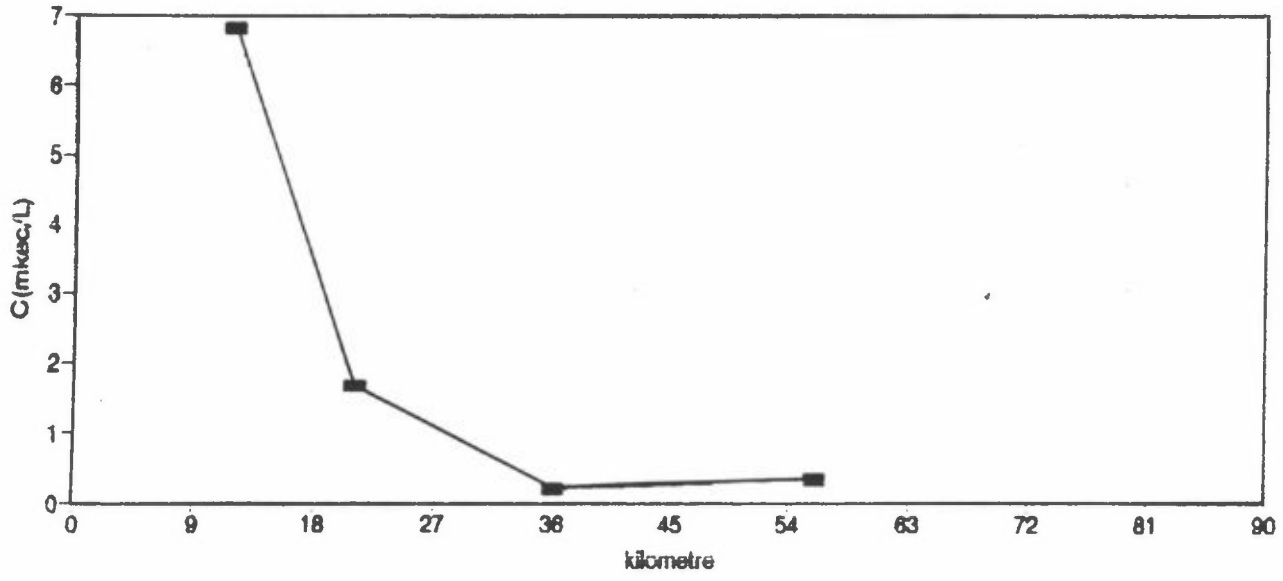




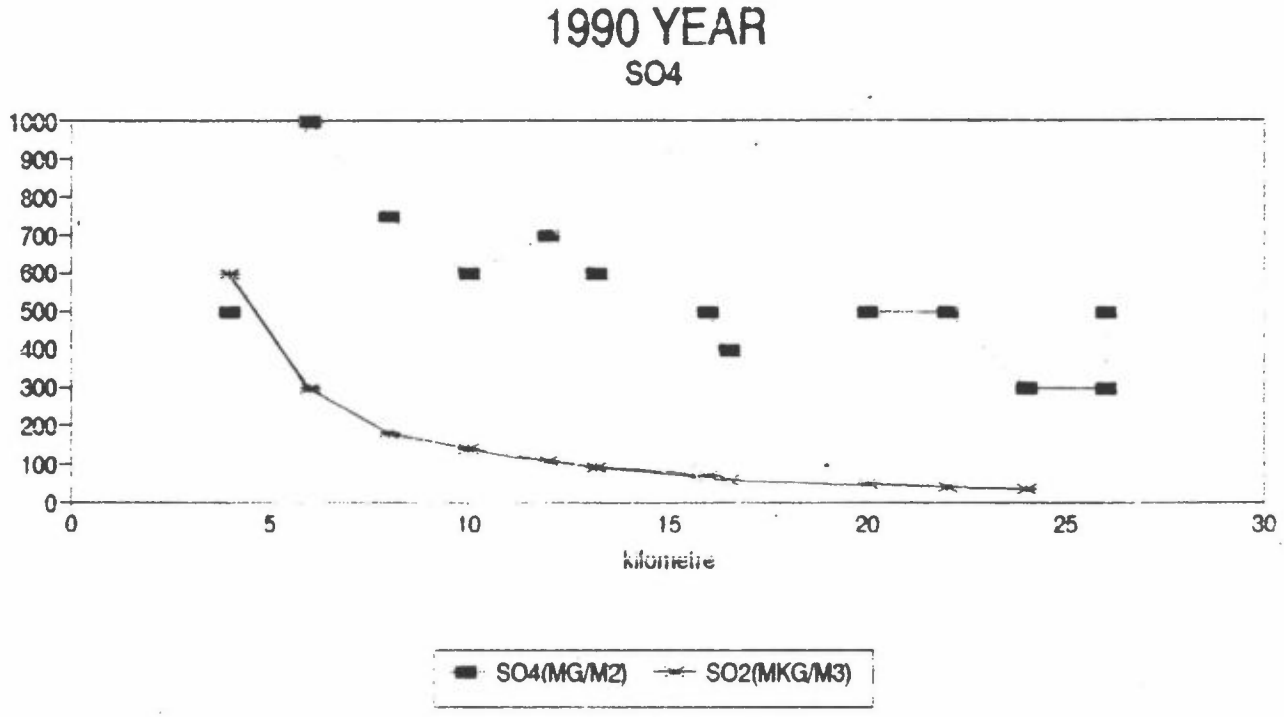
HEAVY METAL



CU++



NI++


1990 YEAR
SO4
1000
900
800
700
600
500
400
300
200
100
0
0
5
10
15
20
25
30
kilometre
SO4(MG/M2)
SO2(MKG/M3)

4. List of Participants

**Seminar on Air Pollution Problems in the Northern Region of Fennoscandia included Kola,
Svanvik, 1-3 June 1993**

Surname	First name	Institution	Country
Aamlid	Dan	Norwegian Forest Research Institute	NORWAY
Airaksinen	Kirsti	The Finnish Forest Research Institute, Rovaniemi Research Station	FINLAND
Baklanov	Alexander A.	INEP, Kola Science Centre	RUSSIA
Barrett	Kevin	The Norwegian Meteorological Institute	NORWAY
Barsukov	Igor	INEP, Kola Science Centre	RUSSIA
Brännstrøm	Gunnar	Länsstyrelsen i Norrbottn	SWEDEN
Chigov	Vladimir E.		RUSSIA
Derome	John	The Finnish Forest Research Institute, Rovaniemi Research Station	FINLAND
Dutchak	Sergey V.	Kola Science Centre	RUSSIA
Fiskebeck	Per.-E.	Finnmark County	NORWAY
Gavrilov	Alexander		RUSSIA
Grigorijan	Vigen T.		RUSSIA
Hagen	Leif Otto	Norwegian Institute for Air Research	NORWAY
Ilchenko	Yuri		RUSSIA
Jerre	Jon	State Pollution Control Authority	NORWAY
Johannessen	Tor	State Pollution Control Authority	NORWAY
Kalabin	Gennadiy V.	INEP, Kola Science Centre	RUSSIA
Karaban	Rodion	Institute of Global Climate and Ecology	RUSSIA
Kismul	Viggo	State Pollution Control Authority	NORWAY
Larsen	Mona	Norwegian Institute for Air Research	NORWAY
Løbersli	Else	Directorate for Nature management	NORWAY
Mahura	Alexander G.	INEP, Kola Science Centre	RUSSIA
Makarova	Tatjana D.	INEP, Kola Science Centre	RUSSIA
Miljaev	Vitaliy B.	State Committee of Nature, Res. Centre "Ecology", Dept. Atmospheric Control	RUSSIA
Moiseenko	Tatjana D.	INEP, Kola Science Centre	RUSSIA

Surname	First name	Institution	Country
Namjatov	Alexey A.	Hidromet	RUSSIA
Nenonen	Marjaleena	Water and Environment, District of Lapland	FINLAND
Nergård	Knut M.	Fylkesmannen i Troms, Miljøvernavdelinga	NORWAY
Nikonov	Vjacheslav V.	INEP, Kola Science Centre	RUSSIA
Olesik	Evgeniy P.	Murmansk Regional Environmental Affair Committee	RUSSIA
Pastukhova	Evgenia	Res. Inst. on Nature Conservation and Reserve	RUSSIA
Poprushko	Leonid A.		RUSSIA
Ratkin	Nikolay E.	INEP, Kola Science Centre	RUSSIA
Rigina	Olga Y.U.	INEP, Kola Science Centre	RUSSIA
Rodyushkin	Ilija	INEP, Kola Science Centre	RUSSIA
Rodyushkina	Irina A.	INEP, Kola Science Centre	RUSSIA
Sivertsen	Bjarne	Norwegian Institute for Air Research	NORWAY
Steinnes	Eilif	University of Trondheim, AVH, Dep. of Chemistry	NORWAY
Tausnev	Nikolay L.	INEP, Kola Science Centre	RUSSIA
Tikkanen	Eero	The Finnish Forest Research Institute, Rovaniemi Research Station	FINLAND
Traaen	Tor S.	Norwegian Institute for Water Research	NORWAY
Tuovinen	Juha-Pekka	Finnish Meteorological Institute, Air Quality Dep.	FINLAND
Tveten	Ulf	Institutt for energiteknikk	NORWAY
Tømmervik	Hans A.	NORUT IT	NORWAY
Varshal	Salina M.		RUSSIA
Vassilieva	Natalia	Res. Inst. of Nature Conservation and Reserves	RUSSIA
Virkkula	Aki	Finnish Meteorological Institute, Air Quality Dep.	FINLAND
Volkov	Fiodor F.	Pechenganickel Mining and Metalurgical Complex	RUSSIA

5. Seminar Programme

Tuesday 1 June 1993

12.30 **Lunch**

14.30 **Opening of the seminar**

14.45 **Milyajev, V.B.**
Time and space characterictics of atmospheric pollution sources of the northwestern region of Russia

15.15 **Volkov, F.F.**
The Pechenga Nikel Complex actions on air pollution reductions.

15.30 **Sivertsen, B.**
Air quality status in the border area of Norway and Russia

16.15 **Coffee**

16.45 **Klyushnikova, E.M. & Smagin, A.V.**
Measurements and meteo-conditions for SO_2 pollution in the Pechenga Nikel area.

17.15 **Namyatov, A.A. , Lisienko, T.G. and Pavlova, T.V.**
The system of monitoring contemporary levels of pollution in the industrial district of Kola Peninsula.

17.45 **Virkkula, A., Mäkinen, M., Pakkanen, T. and Hillamo, R.**
Air pollutants in Sevettijärvi: Summary of the measurements in 1992.

18.15 **Tuovinen, J.-P. and Laurila, T.**
The variability of SO_2 and O_3 in Northern Finland

20.00 **Dinner**

Wednesday 2 June 1993

09.00 **Ryaboshapko, A. and Brukhanov, P.**
Monitoring and model calculations of sulphur loads over the northern regions of Fennoscandia.

09.30 **Baklanov, A.**
The simulation and evaluation of atmospheric pollution in the industrial districts of Kola Peninsula.

10.00 **Larsen, M.**
Modelling the dispersion of air pollution from the Nikel smelters.

10.30 **Coffee**

11.00 **Gavrilov, A.V.**
Stochastic turbulent diffusion modelling and its application to prediction of atmospheric pollution from the Northwest Russian region nuclear power stations.

11.30 **Makarova, T.D, Ratkin, N.E. and Warshal, Sh. M.**
Results of the snow cover pollution investigations in the Kola Peninsula.

12.00 **Brukhanov, P.**
Heavy metals in the atmosphere and in vegetation of the Pechenga area.

12.30 **Lunch**

14.00 **Baklanov, A., Mahura, A.G. and Marazov, S.V.**
The simulation of radioactive pollution of the environment after hypothetical accident on the Kola nucelar power plant.

14.30 **Tveten, U.**
Potential risk to the Norwegian population from reactor accidents at the Kola nuclear reactors.

15.00 **Gytarski, M. and Karaban, R.**
Estimated air pollution levels and forest ecosystem assessment in the vicinity of the Kola industrial enterprises.

15.30 **Coffee**

16.00 **Tømmervik, H.**
Multitemporal Landsat image data for mapping the effects of air pollution on vegetation in the Kirkenes-Pechenga area in the period 1973-1988.

16.30 **Poster session; 5 min presentations**

19.00 **Dinner**

Thursday 3 June 1993

08.30 **Traaen, T.**
Critical loads of sulphur for surface waters in the Norwegian/Russian border areas.

09.00 **Moiseenko, T.**
Ecological effects of airborne contaminants on freshwater: Acidification and heavy metals.

9.30 **Jerre, J.**
Mapping of terrestric effects in the border areas.

10.00 **Coffee**

10.30 **Nikonov, V.V.& al.**
Contamination and acidity of soil on the Kola Peninsula.

11.00 **Aamlid, D.**
Effects on terrestric ecosystems.

11.30 **Steinnes, E.**
Heavy metals in terrestrial ecosystems.

12.00 **Summary, conclusions and closing of the seminar**

12.30 **Lunch**

Norwegian Institute for Air Research (NILU)
P.O. Box 100
N-2007 Kjeller - Norway

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Proceedings from the Seminar at Svanvik, Norway, 1-3 June 1993

PROJECT LEADER

Bjarne Sivertsen

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AUTHOR(S)

Editor: Bjarne Sivertsen

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CLIENT
State Pollution Control Authority
P.O. Box 8100, Dep.
0032 OSLO

ABSTRACT

Proceedings from a seminar held in Svanvik, Norway 1-3 June 1993 on Air Pollution Problems in the Northern Region of Fennoscandia included Kola. The expert group on studies of local air pollution problems under the Joint Norwegian- Russian Commission on Environment Co-operation planned the seminar. The final programme was established during the 6th meeting of the expert group in Apatity in March 1993.

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