Statlig program for forurensingsovervåking

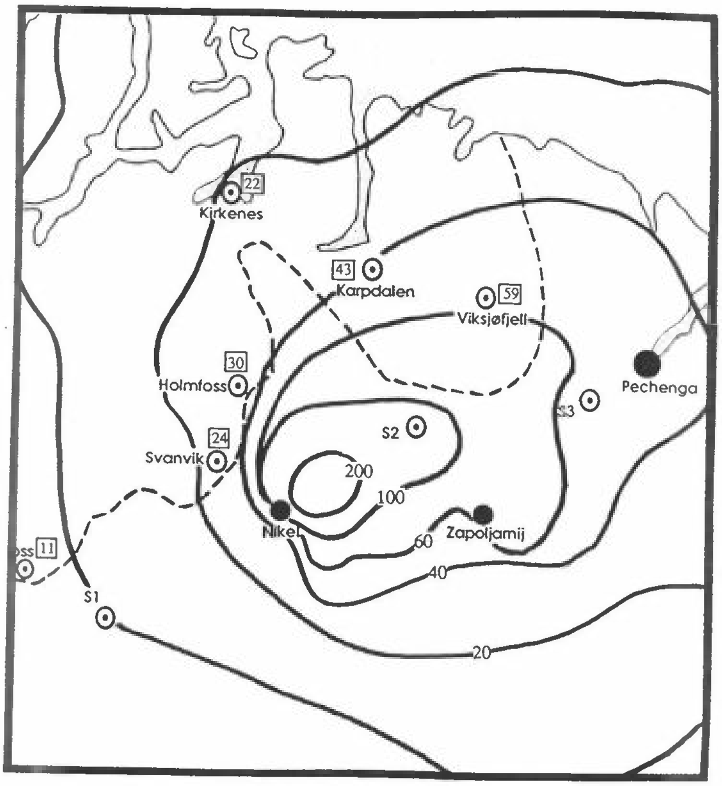
Oppdragsgiver: Statens forurensningstilsyn

Deltakende institusjon: NILU

Rapport nr.: 439/91

Air Quality in the Border Areas Between Norway and USSR

Model Description and Preliminary Modelling Results



TA 730/1991

NILU
Norsk institutt for luftforskning

Statlig program for forurensningsovervåking

Det statlige programmet omfatter overvåking av forurensningsforholdene i

luft og nedbør
grunnvann
vassdrag og fjorder
havområder
skog

Overvåkingen består i langsiktige undersøkelser av de fysiske, kjemiske og biologiske forhold.

Hovedmålsettingen med overvåkingsprogrammet er å dekke myndighetenes behov for informasjon om forurensningsforholdene med sikte på best mulig forvaltning av naturressursene.

Hovedmålet spenner over en rekke delmål der overvåkingen bl.a. skal:

gi informasjon om tilstand og utvikling av forurensningssituasjonen på kort og lang sikt.

registrere virkningingen av iverksatte tiltak og danne grunnlag for vurdering av nye forurensningsbegrensende tiltak.

påvise eventuell uheldig utvikling i resipienten på et tidlig tidspunkt.

over tid gi bedre kunnskaper om de enkelte vannforekomsters naturlige forhold.

Sammen med overvåkingen vil det føres kontroll med forurensende utslipp og andre aktiviteter.

Overvåkingsprogrammet finansieres i hovedsak over statsbudsjettet. Statens forurensningstilsyn er ansvarlig for gjennomføring av programmet.

Resultater fra de enkelte overvåkingsprosjekter publiseres i årlige rapporter.

Henvendelser vedrørende programmet kan i tillegg til de aktuelle institutter rettes til Statens forurensningstilsyn, Postboks 8100 Dep, 0032 Oslo 1, tlf. 22 57 34 00.

NILU OR : 23/91
REFERENCE: O-8976
DATE : JANUARY 1991
ISBN : 82-425-0243-9

AIR QUALITY IN THE BORDER AREAS BETWEEN NORWAY AND USSR

MODEL DESCRIPTION AND PRELIMINARY MODELLING RESULTS

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Prepared for the expert meeting in January 1991

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NORWAY

TABLE OF CONTENTS

SUMMARY

This report describes the dispersion models used to calculate the dispersion of sulphur dioxide (SO_2) in the border area between Norway and USSR. Two types of models have been applied; one based upon a multiple source Gaussian plume formulation for long term average concentration estimates ("CONDEP") and one mesoscale puff-trajectory model for estimates of hourly average concentrations ("INPUFF").

The emissions of SO_2 from the two smelters has been devided into 43 point and volume sources; 39 in Nikel, 3 in Zapoljarnij. We have also included emissions from the A/S Sydvaranger stack in Kirkenes.

Meteorological measurements at Svanvik and Viksjøfjell have been used to describe meteorology in the area.

In the estimates of monthly average concentrations using the CONDEP model the emissions from the high soures are transported and dispersed with the wind as measured at Viksjøfjell (11 sources). SO_2-emissions from the other 32 "low" sources are transported and dispersed with wind data taken from Svanvik. The total plume height including plume rise, is taken into accorent in the selection of high and low sources.

The puff trajectory model INPUFF was used to estimate hourly concentrations for selected episodes. At the moment there is no data for estimating three dimensional wind fields in the area. In the first model runs meteorological data from Viksjøfjell were used for these calculations. These model estimates have not been finalized, and further studies and developments have to be undertaken.

The monthly estimated mean concentrations of SO_2 are presented for the months January to June 1990. The average SO_2-concentrations are also estimated for the winter season 1989-90 and for the summer season 1990.

The model performance (CONDEP) has shown to be considerably better in winter than during the summer season. This might be due to the quality of input data. It is shown that the assumption of constant emission rates in time lead to an overestimate of the SO_2 concentrations during summer. To improve the model performance we will need more information about the time variation of the emission rates.

AIR QUALITY IN THE BORDER AREAS BETWEEN NORWAY AND USSR

MODEL DESCRIPTION AND PRELIMINARY MODELLING RESULTS

1 USE OF DISPERSION MODELS

The calculation of SO_2-dispersion in the border areas between Norway and USSR has been based upon the use of two types of dispersion models:

- A multiple source Gaussian model (CONDEP)
- A mesoscale puff trajectory model (INPUFF)

1.1 MULTIPLE SOURCE GAUSSIAN TYPE MODEL

The model CONDEP has been developed at NILU and was used to calculate monthly average concentrations of SO_2. The model is described by Bøhler (1987).

CONDEP calculates long term sector averaged concentrations for twelve 30^o-sectors in specified receptor locations or in a given grid. The input consists of source data for up to 50 point and line sources and a meteorological joint frequency matrix of four wind speed classes, four stability classes and twelve wind sectors, based on hourly values. The output from the model consists of a table listing effective plume heights for each source and meteorological condition considered. Another table presents sector average concentrations and surface deposition values in specified receptor points or in a specified grid.

The model takes into account the effects of stack downwash, building turbulence, wind profiles, dry deposition, topography and penetration through an elevated stable layer.

The diffusion of air pollutants in the lower atmosphere is strongly influenced by the local atmospheric stability. The diffusion of effluents is more rapid in the unstable than in the stable atmosphere.

In the NILU data input for this type of dispersion model, the atmospheric stability is usually devided into four classes. The stability classes are often defined by vertical temperature gradients or by direct measurements of the standard deviation of the horizontal wind direction fluctuations, where such data are available. The stability classes are defined as shown in Table 1.

Table 1: Stability classes defined in CONDEP, based upon measurements of the temperature difference between 36 m and 10 m along a mast.

Stability class	Temperature gradient dT (36-10)(deg)	Corresponds to:	
		Pasquill	Brookhaven
Unstable	dT < -0,5	A + B + C	$A_1 + B_2$
Neutral	-0,5 ≤ dT < 0	D	C
Slightly stable	0 ≤ dT < 0,5	E	-
Stable	dT ≥ 0,5	F	D

The height dependency of the wind speed is described by a power law:

$$\bar{u}(z) = \bar{u}(z_o) \left(\frac{z}{z_o}\right)^m$$

with

z = height above ground,
z_o = reference height above ground,
$\bar{u}$ = time average wind speed,
m = wind profile exponent.

The wind profile exponent can be specified by the user. In the NILU models the values given i Table 2 have been applied as standard values.

Table 2: The value of the wind profile exponents used in CONDEP as function of stability classes.

Stability class	m
Unstable	0.20
Neutral	0.28
Slightly stable	0.36
Stable	0.42

These types of models assume homogeneous and stationary wind and turbulence which give a Gaussian distribution of the plume concentration perpendicular to the transport direction. The diffusion parameters σ_y and σ_z are defined as the standard deviations of the concentration distributions in the lateral and vertical directions.

When direct turbulence measurements are not available, the following form of diffusion parameters is used:

$$\sigma_y(x) = ax^p, \qquad \sigma_z(x) = bx^q.$$

where a, b, p and q are empirical constants given for the four stability classes used.

An effluent emitted vertically from a stack can rise due to its momentum or can be brought downward by the low pressure in the wake of the stack, which occurs depending on the ratio of the exit gas velocity, W_s, to the crosswind velocity, U. The effect of this is incorporated in CONDEP.

The plume rise due to momentum or buoyancy is estimated using Briggs algorithm (Briggs, 1969, 1971 and 1975).

The effect of elevated terrain on the ground level concentrations is included by reducing the effective plume height, h_m, assuming

$$H = h_m - \Delta H_t \ , \qquad \Delta H_t = k \cdot h_t$$

where h_t is the height of terrain above stack base level. In the model CONDEP the effective topography, ΔH_t, is a direct input from the user. A method to evaluate the effect of a hill on a source as a function of distance from the source is given in Table 3 below.

Table 3: Terrain factor, k, to evaluate the effect of a hill on a source with stack height h_s.

Distance (x)	k
$0 < x \leq 5\ h_s$	0.7
$5\ h_s < x \leq 10\ h_s$	0.5
$10\ h_s < x \leq 20\ h_s$	0.3
$20\ h_s < x \leq 30\ h_s$	0.1
$30\ h_s < x$	0.0

Building effects are incorporated in the model. Briggs (1979) has outlined a useful procedure for estimating the effective height of emission incorporating building induced disturbances to the flow.

Dry deposition of an effluent emitted from a source is calculated. Adverse effects of deposition are mainly caused by long term values of dry deposition.

The deposition method used in the model CONDEP is the "partial reflection" model summarized by Overcamp (1976). This theory includes a reflection coefficient, α, in the image source term in the Gaussian dispersion formula, which is thus a fraction of the strength of the real source. This coefficient has been determined by setting the deposition flux equal to the difference in fluxes from the real and the image terms. The plume is also allowed to "tilt" to incorporate gravitational settling of large particles.

1.2 MESOSCALE PUFF TRAJECTORY MODEL

The model INPUFF is used to calculate the dispersion of SO_2 on an hourly basis. Our intension have been to use INPUFF to describe episodic occurrences of high concentration of pollutants.

INPUFF is a Gaussian integrated puff trajectory model with a wide range of applications. The implied modelling scale is from tens of meters to tens of kilometers. The model is capable of addressing the accidental release of a substance over several minutes, or of modelling the more typical continuous plume from a stack.

Computations in INPUFF can be made for multiple point sources at up to 100 receptor locations. INPUFF is primarily designed to model a single event during which one meteorological transition period may occur. The user has the option of specifying the wind field for each meteorological period at up to 100 grid locations or allowing the model to default to a homogeneous wind field.

A graphical representation of the INPUFF model is given in Figure 1. Here the first puff (A) was first exposed to wind from east-southeast, followed by slightly stronger winds from the south and the south-southeast. The second puff (B) was released after the winds had shifted to wind from south.The third puff was released when the wind was from the south-southeast. Puffs A, B, and C represent the location of the three emitted puffs at time t_3 .

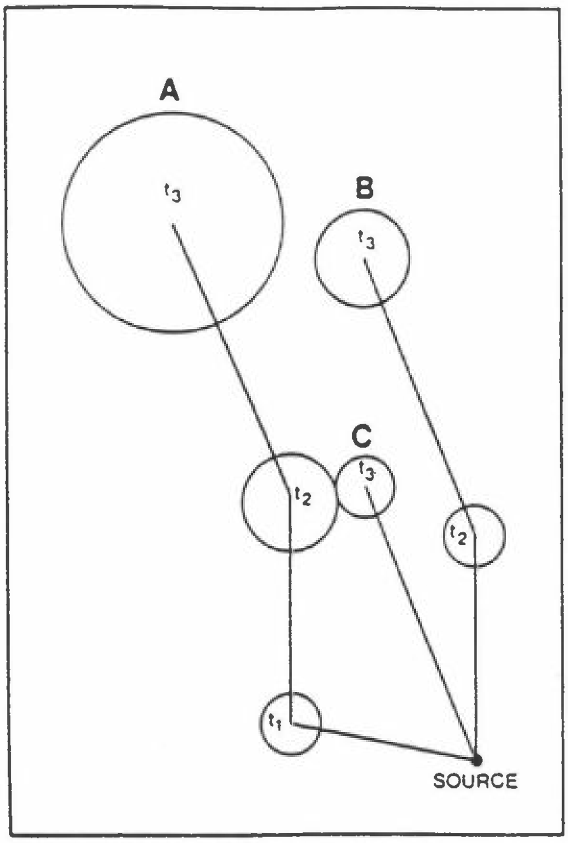

Figure 1: Gaussian puff model.

In Gaussian-puff algorithms, source emissions are treated as a series of puffs emitted into the atmosphere. Constant conditions of wind and atmospheric stability are assumed during a time interval. The diffusion parameters are functions of travel time. During each time step, the puff centers are determined by the trajectory and the in-puff distributions are assumed to be Gaussian. Thus, each puff has a centre and a volume which are determined separately by the mean wind, atmospheric stability, and travel time.

Plume rise is calculated using the methods of Briggs (1969, 1971, 1974 and 1975). Although plume rise from point sources is usually dominated by buoyancy, plume rise due to momentum is also considered.

Three dispersion algorithms can be used within INPUFF for dispersion downwind of the source:

* P-G scheme as discussed by Turner (1970),
* On-site scheme formulated by Irwin (1983), and
* Long travel time scheme.

In our estimates we will use the on-site scheme, based upon data from Viksjøfjell or Svanvik (Chapter 3).

Rao (1982) gave analytical solutions of a gradient-transfer model for dry deposition of pollutants from a plume. His solutions treat gravitational settling and dry deposition of pollutants in a physically realistic manner, and are subject to the same basic assumptions and limitations associated with Gaussian plume models. His equations for deposition and settling were incorporated in several air quality models. The equations used in INPUFF are the same as those used by Rao and Snodgrass, (1982), except they are cast in terms of travel time instead of wind speed and downwind distance.

2 EMISSION DATA

Emission data of sulphur dioxide (SO_2) and particulate matter from Nikel and Zapoljarnij has been provided by the Soviet delegation of the expert panel. Data on emissions in Kirkenes were reported by the Norwegian State Control Authorities (SFT).

For input to our models we used these emission parameters:

- coordinates (x,y) of the sources (km)
- emission rate (g/s)
- height of the stack (m)
- stack gas temperature (K)
- stack gas velocity (m/s)
- stack diameter (m)
- stack gas volume flow (m^3/s)

Table 4 shows the emission data used in the model calculations. The emission rate used is maximum hourly release rate.

In the calculations with the model CONDEP the dispersion from sources No 1-32 (low sources) was calculated with wind data from Svanvik. The dispersion from sources No 33 to 43 (high sources) was calculated using wind data from Viksjøfjell. The sources were divided into these categories due to the height of their plume rise.

Table 4: Emission data for Nikel, Zapoljarnij and Kirkenes. Based upon maximum hourly release rates.

Source No.	Emission rate (g/s)	Stack height (m)	Temperature (K)	Stack diameter (m)	Stack gas velocity (m/s)	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	30	30	400	10.0	4.0	Kirkenes

3 METEOROLOGICAL INPUT DATA

3.1 METEOROLOGICAL DATA FOR CONDEP

For the model CONDEP the meteorological input data was the joint frequency matrices of four stability classes, four wind speed classes and twelve wind sectors hourly averages on a monthly basis.

In the model calculations, winds from both Svanvik and Viksjøfjell were used. The joint frequency matrices for both sites have therefore been established.

The joint frequency matrices for the winter season 1989/90 (1 October 1989 to 31 March 1990) and the summer season 1990 (1 April to 30 September 1990) are shown in Tables 5 to 8. The frequency matrices for the other months (1 January to 30 June 1990) are given in Appendix A.

The estimated SO_2 concentrations for the two sets of sources and meteorological data have been added to give the total estimated SO_2 concentration distributions for the area considered.

Table 5: Joint frequency distribution (in %) in classes of stability (I: unstable, IV: stable), wind speeds and wind directions from the winter 1989-90 (1 October 1989 to 31 March 1990) for Svanvik (10 m).

JOINT FREQUENCY DISTRIBUTION OF STABILITY, WIND SPEED AND WIND DIRECTION

Class I: Unstable DT < -.5 Degrees C
Class II: Neutral -.5 < DT < .0 Degrees C
Class III: Light stable .0 < DT < .5 Degrees C
Class IV: Stable .5 < DT Degrees C

Calm: U less or equal .3 m/s

Wind-direction	.0- 1.0 m/s I	II	III	IV	1.0- 2.0 m/s I	II	III	IV	2.0- 3.0 m/s I	II	III	IV	over 3.0 m/s I	II	III	IV	Rose
30	.0	.1	.1	.0	.0	.4	.2	.0	.0	.1	.0	.0	.0	.3	.0	.0	1.4
60	.0	.4	.4	.0	.0	.6	.4	.0	.0	.3	.0	.0	.0	.3	.0	.0	2.6
90	.0	.4	.3	.1	.0	.9	.1	.0	.0	.8	.1	.0	.0	.3	.0	.0	2.9
120	.0	.0	.2	.1	.0	.2	.2	.0	.0	.2	.1	.0	.0	.5	.1	.0	1.6
150	.0	.4	.4	.4	.0	.5	.4	.1	.0	.3	.2	.0	.0	.9	.2	.0	3.7
180	.0	.6	1.1	.3	.0	.9	1.1	.2	.0	1.8	.9	.2	.0	5.7	1.3	.1	14.0
210	.0	.6	1.5	.9	.0	1.7	2.0	.4	.0	2.3	1.3	.3	.0	5.1	1.7	.0	17.8
240	.0	1.0	1.7	1.0	.0	1.8	1.2	.5	.0	1.8	.9	.1	.0	1.1	1.3	.1	12.5
270	.0	1.0	1.1	.6	.0	1.0	.5	.0	.0	.7	.3	.0	.0	1.5	.2	.0	6.8
300	.0	.5	.7	.3	.0	1.0	.3	.0	.0	.5	.1	.0	.0	1.5	.0	.0	4.9
330	.0	.5	.5	.0	.0	.9	.2	.0	.0	1.2	.1	.0	.0	1.2	.0	.0	4.5
360	.0	.2	.2	.0	.0	.4	.2	.0	.0	1.1	.0	.0	.0	2.1	.0	.0	4.2
Calm	.0	3.4	9.7	9.8													23.0
Total	.0	9.1	17.9	13.6	.0	10.4	6.6	1.2	.0	11.0	4.0	.6	.0	20.5	4.8	.3	100.0

	.0- 1.0 m/s	1.0- 2.0 m/s	2.0- 3.0 m/s	over 3.0 m/s	
Occurrence	40.6 %	18.2 %	15.6 %	25.6 %	100.0 %
Wind speed	.3 m/s	1.5 m/s	2.6 m/s	4.5 m/s	2.0 m/s

Frequency of occurrence of the stability classes

	Class I	Class II	Class III	Class IV	
Occurrence	.1 %	50.9 %	33.4 %	15.6 %	100.0 %

Table 6: Joint frequency distribution (in %) in classes of stability (I: unstable, IV: stable), wind speed and wind directions from the winter 1989-90 (1 October 1989 to 31 March 1990) for Viksjøfjell (25 m).

Delta T : VIKSJØFJELL
Wind : VIKSJØFJELL
Period : 01.10.89. - 31.03.90.
Unit : Percent

JOINT FREQUENCY DISTRIBUTION OF STABILITY, WIND SPEED AND WIND DIRECTION

Class I: Unstable DT < -.5 Degrees C
Class II: Neutral -.5 < DT < .0 Degrees C
Class III: Light stable .0 < DT < .5 Degrees C
Class IV: Stable .5 < DT Degrees C

Calm: U less or equal .3 m/s

Wind-direction	.0- 2.0 m/s I	II	III	IV	2.0- 4.0 m/s I	II	III	IV	4.0- 6.0 m/s I	II	III	IV	over 6.0 m/s I	II	III	IV	Rose
30	.0	.1	.2	.0	.0	.2	.3	.0	.0	.3	.1	.0	.0	.9	.1	.0	2.2
60	.0	.2	.2	.0	.0	.5	.4	.0	.0	.1	.3	.0	.1	.8	.2	.0	3.0
90	.0	.1	.2	.0	.0	.5	.3	.1	.0	.6	.3	.1	.0	.7	.1	.0	3.1
120	.0	.2	.4	.1	.0	.8	.3	.0	.0	1.0	.2	.1	.0	.9	.5	.0	4.4
150	.0	.2	.5	.1	.0	1.2	1.3	.7	.0	.9	.4	.1	.0	1.9	.7	.3	8.2
180	.0	.1	.2	.3	.0	.9	1.2	.7	.0	.7	.6	.4	.0	6.7	2.2	.6	14.5
210	.0	.1	.1	.2	.0	.6	.7	.5	.0	.2	.4	.2	.0	4.9	2.7	1.0	11.7
240	.0	.2	.5	.3	.0	2.0	1.5	1.8	.0	.8	1.3	1.5	.0	7.2	6.6	2.2	25.8
270	.0	.1	.2	.4	.0	.6	.5	.6	.0	.4	.7	.7	.0	4.3	1.7	.6	10.8
300	.0	.1	.4	.2	.0	.3	.5	.4	.0	.4	.2	.1	.0	2.2	.9	.0	5.8
330	.0	.1	.3	.1	.0	.4	.3	.0	.0	.3	.1	.0	.0	4.4	.3	.0	6.3
360	.0	.0	.2	.1	.0	.3	.4	.1	.0	.3	.2	.0	.0	1.7	.1	.0	3.3
Calm	.0	.1	.6	.2													.9
Total	.0	1.6	3.8	2.1	.0	8.5	7.5	4.9	.0	5.9	4.8	3.2	.1	36.8	16.2	4.8	100.0
Occurrence	7.5 %				20.9 %				13.8 %				57.8 %				100.0 %
Wind speed	1.1 m/s				3.2 m/s				4.9 m/s				10.6 m/s				7.6 m/s

Frequency of occurrence of the stability classes

	Class I	Class II	Class III	Class IV	
Occurrence	.1 %	52.7 %	32.2 %	15.0 %	100.0 %

Table 7: Joint frequency distribution (in %) in classes of stability (I: unstable, IV: stable), wind speed and wind directions from the summer 1990 (1 April to 30 September 1990) for Svanvik (10 m).

Delta T : VIKSJØFJELL
Wind : SVANVIK
Period : 01.04.90. - 30.09.90.
Unit : Percent

JOINT FREQUENCY DISTRIBUTION OF STABILITY, WIND SPEED AND WIND DIRECTION

Class I: Unstable DT < -.5 Degrees C
Class II: Neutral -.5 < DT < .0 Degrees C
Class III: Light stable .0 < DT < .5 Degrees C
Class IV: Stable .5 < DT Degrees C

Calm: U less or equal .3 m/s

Wind-direction	.0- 1.0 m/s				1.0- 2.5 m/s				2.5- 4.0 m/s				over 4.0 m/s				Rose
	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	
30	.0	1.8	1.1	.2	.0	6.5	.2	.1	.0	2.0	.0	.0	.0	.6	.0	.0	12.6
60	.0	1.7	.7	.1	.0	5.3	.3	.0	.0	1.5	.0	.0	.0	.2	.0	.0	9.9
90	.0	1.2	.8	.1	.2	4.1	.4	.0	.1	1.2	.0	.0	.0	.2	.0	.0	8.3
120	.0	.5	.4	.2	.0	1.4	.3	.0	.0	.4	.0	.0	.0	.4	.0	.0	3.8
150	.0	.9	.9	.4	.0	1.3	.5	.1	.0	.5	.2	.0	.0	.1	.0	.0	5.1
180	.0	.6	.8	.4	.0	2.5	1.3	.3	.0	1.6	.7	.0	.0	.3	.4	.1	9.0
210	.0	.4	.6	.2	.0	2.9	1.8	.7	.0	1.8	1.3	.1	.0	1.3	1.4	.1	12.8
240	.0	.8	.8	.3	.0	2.1	1.0	.3	.0	1.8	.5	.0	.0	1.3	.3	.0	9.1
270	.0	.8	.4	.2	.0	1.6	.3	.1	.0	1.4	.3	.0	.0	.7	.2	.0	6.1
300	.0	1.0	.4	.1	.0	1.2	.3	.0	.0	1.5	.1	.0	.0	.7	.0	.0	5.5
330	.0	1.1	.6	.2	.0	1.3	.2	.0	.0	2.2	.1	.0	.0	2.3	.1	.0	8.1
360	.0	.4	.3	.1	.0	1.2	.1	.0	.0	1.0	.0	.0	.0	.9	.0	.0	4.0
Calm	.0	1.8	3.1	.9													5.8
Total	.0	13.1	10.8	3.4	.3	31.3	6.9	1.7	.2	17.0	3.3	.3	.0	9.0	2.5	.3	100.0
Occurrence	27.3 %				40.2 %				20.8 %				11.7 %				100.0 %
Wind speed	.6 m/s				1.8 m/s				3.2 m/s				5.1 m/s				2.1 m/s

Frequency of occurrence of the stability classes

	Class I	Class II	Class III	Class IV	
Occurrence	.6 %	70.4 %	23.4 %	5.6 %	100.0 %

Table 8: Joint frequency distribution (in %) in classes of stability (I: unstable, IV: stable), wind speed and wind directions from the summer 1990 (1 April to 30 September 1990) for Viksjøfjell.

Delta T : VIKSJØFJELL
Wind : VIKSJØFJELL
Period : 01.04.90. - 30.09.90.
Unit : Percent

JOINT FREQUENCY DISTRIBUTION OF STABILITY, WIND SPEED AND WIND DIRECTION

Class I: Unstable DT < -.5 Degrees C
Class II: Neutral -.5 < DT < .0 Degrees C
Class III: Light stable .0 < DT < .5 Degrees C
Class IV: Stable .5 < DT Degrees C

Calm: U less or equal .3 m/s

Wind-	.0- 2.0 m/s				2.0- 4.0 m/s				4.0- 6.0 m/s				over 6.0 m/s				
direction	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	Rose
30	.0	.2	.0	.0	.0	1.4	.4	.0	.0	2.3	.1	.0	.0	4.9	.0	.0	9.3
60	.0	.2	.0	.0	.0	1.1	.6	.0	.0	1.8	.2	.0	.1	2.7	.1	.0	6.7
90	.0	.2	.1	.0	.1	1.1	.3	.0	.0	1.8	.0	.0	.1	1.0	.0	.0	4.9
120	.0	.0	.0	.0	.0	.8	.4	.0	.0	2.2	.7	.2	.0	1.6	.6	.0	6.7
150	.0	.1	.0	.0	.0	.8	.4	.0	.0	1.7	1.4	.6	.0	1.4	1.6	.1	8.5
180	.0	.1	.0	.0	.0	.4	.2	.1	.0	1.4	1.1	.2	.0	2.6	2.9	.7	9.9
210	.0	.1	.0	.0	.0	.2	.4	.0	.0	1.3	.9	.1	.1	4.9	4.0	2.2	14.1
240	.0	.1	.1	.0	.0	.8	.3	.0	.0	2.0	.6	.1	.1	4.3	2.9	.7	11.9
270	.0	.1	.0	.0	.0	.5	.1	.0	.0	.3	.1	.0	.0	2.7	1.0	.2	5.1
300	.0	.1	.0	.0	.0	.7	.2	.0	.0	1.4	.1	.0	.0	4.5	.2	.0	7.2
330	.0	.2	.0	.0	.0	.7	.3	.0	.0	1.2	.1	.0	.0	4.1	.1	.0	6.7
360	.0	.1	.1	.0	.0	1.0	.2	.0	.0	2.1	.3	.0	.0	5.2	.1	.0	9.1
Calm	.0	.0	.0	.0													.0
Total	.0	1.5	.6	.1	.1	9.7	3.8	.3	.0	19.4	5.6	1.3	.4	39.7	13.6	3.9	100.0
Occurrence	2.2 %				13.8 %				26.3 %				57.7 %				100.0 %
Wind speed	1.4 m/s				3.3 m/s				4.9 m/s				9.4 m/s				7.2 m/s

Frequency of occurrence of the stability classes

	Class I	Class II	Class III	Class IV	
Occurrence	.5 %	70.3 %	23.6 %	5.6 %	100.0 %

3.2 METEOROLOGICAL DATA FOR INPUFF

INPUFF calculates SO_2 concentrations on an hourly basis.

Meteorological input data are given for every hour during the integration time.

The measured meteorological parameters used are:

- Wind direction (degrees)
- Wind speed (m/sec)
- Sigma theta, horizontal standard deviation of wind direction fluctuations (radians)
- Air temperature (K)
- Vertical temperature difference (T_{25} - T_{10}) (deg)
- Anemometer height (m)

These parameters are used to estimate the input parameters to INPUFF (see Table 9).

The data shown in Table 7 are from Viksjøfjell from the first days of January 1990. Sigma phi, which is the standard deviation of vertical wind directions (radians), has been estimated from similarity theory using profile data (T_{25} - T_{10}).

The stability classes are defined from the Bulk Richardson number, Ri_b:

$$Ri_b = \frac{g(\Delta\theta/\Delta Z)Z^2{}_m}{Tu^2}$$

where Z_m is the geometric mean height of temperature measurements, u is the wind speed at the upper level and $\Delta\theta/\Delta Z$ is the difference in potential temperature.

The mixing height Z_i during neutral conditions is determined from:

$$Z_i = 0.3\ u_*/f$$

where f is the Coriolis parameter and u_* is the surface friction velocity.

For stable conditions the following formula is used to calculate the mixing height:

$$Z_i = 0.4\ (u_* L/f)^{1/2}$$

where L is the Monin-Obukhov length.

Table 9: An example of meteorological input data to INPUFF.

Date	h	Wind direction (degrees)	Wind speed (m/sec)	Temperature (K)	Stability class	Sigma theta (rad)	Sigma phi (rad)	Mixing height (m)
1.1.90	01	275.0	13.0	269.4	4	.159	.101	3198.8
1.1.90	02	294.1	14.7	269.1	4	.112	.094	1252.7
1.1.90	03	300.0	15.0	268.6	4	.113	.094	1292.1
1.1.90	04	316.9	15.5	268.4	4	.136	.099	3805.6
1.1.90	05	326.2	13.9	268.3	4	.154	.101	3421.5
1.1.90	06	324.1	16.0	268.2	4	.108	.095	1429.4
1.1.90	07	325.0	16.4	267.6	4	.091	.095	1484.2

4 ESTIMATED SEASONAL AVERAGE CONCENTRATIONS

The seasonal average concentrations of SO_2 have been estimated for the winter season (1 October 1989 to 31 March 1990) and the summer season (1 April to 31 August 1990). The model CONDEP has been used for these calculations. The concentrations of SO_2 is measured at seven stations on the Norwegian side of the border. These stations are: Kirkenes, Karpdalen, Viksjøfjell, Holmfoss, Svanvik, Kobbfoss and Noatun. On the Sovjet side measurements started at two locations in January 1990 and at the third station in February 1990.

Figure 2 shows the estimated winter average concentrations of SO_2 and Figure 3 the estimated summer average concentrations of SO_2.

Figure 4 shows the estimated concentrations for the winter season plotted against the observed values for the seven stations in Norway.

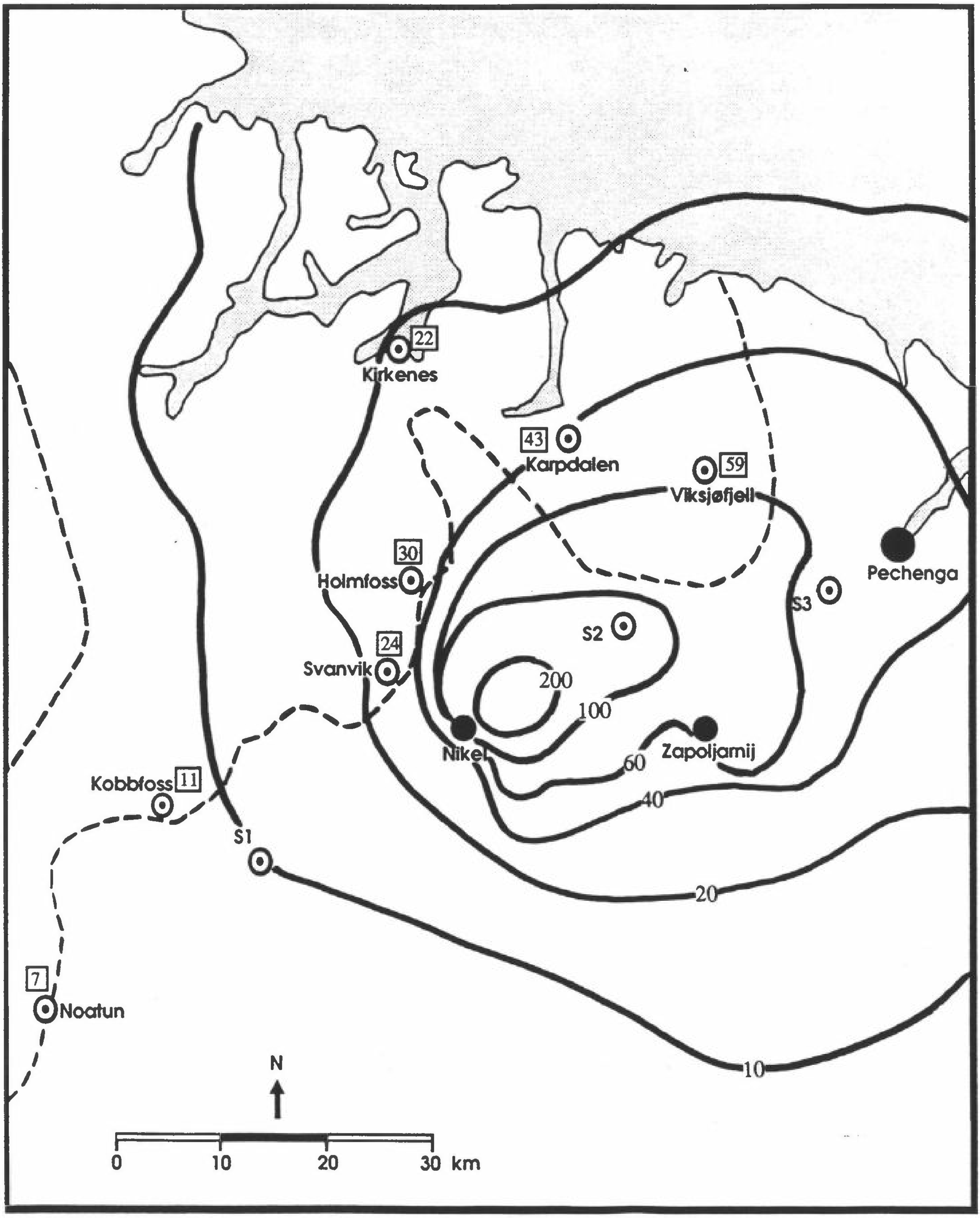

Figure 2: Estimated average concentrations of SO_2 for the winter season 1989/90 ($\mu g/m^3$). Observed concentrations are also indicated at the Norwegian sides.

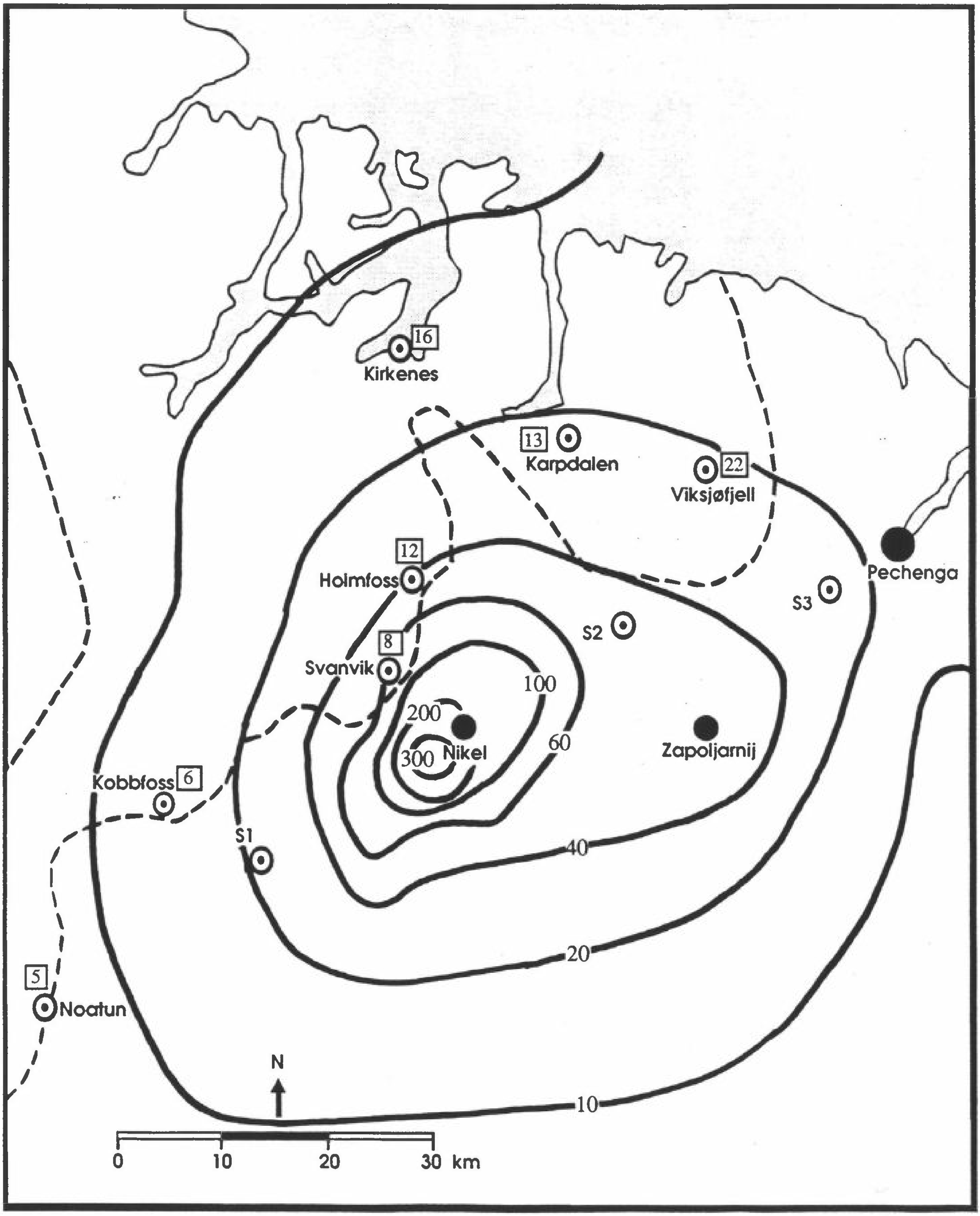

Figure 3: Estimated average concentration of SO_2 for the summer season 1990 ($\mu g/m^3$). Observed concentrations are indicated on the Norwegian side.

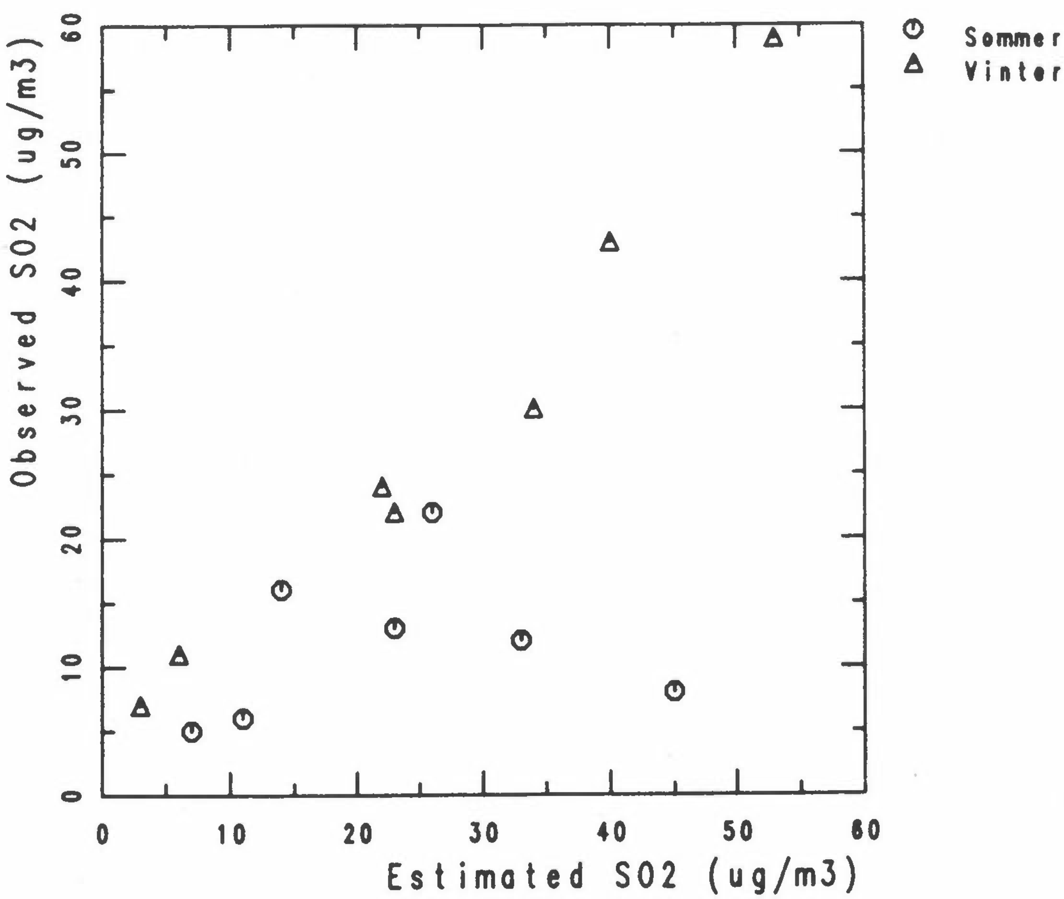

Figure 4: Estimated seasonal concentrations of SO_2 plotted against observed values for the summer and the winter season.

The figure shows that the estimated values for the winter correspond well to the observed values. The correlation coefficient is 0.981. The least squares regression line is given by $E = 0.974 \cdot 0 - 1.405$ where E is estimated value and 0 observed value.

For the summer season the correlation coefficient is 0.185 and the least square regression line is given by $E = 0.411 \cdot 0 + 17.896$.

The correlation between observed and estimated concentrations is much less for the summer season than for the winter season. Part of this might be caused by reduced SO_2 emissions, and that emissions of SO_2 vary strongly with time during the summer months.

5 ESTIMATED MONTHLY AVERAGE CONCENTRATIONS

The monthly average concentrations are estimated for the six months January 1990-June 1990.

Figure 5 shows the observed concentrations for all six months plotted agains the estimated values for all observed sites.

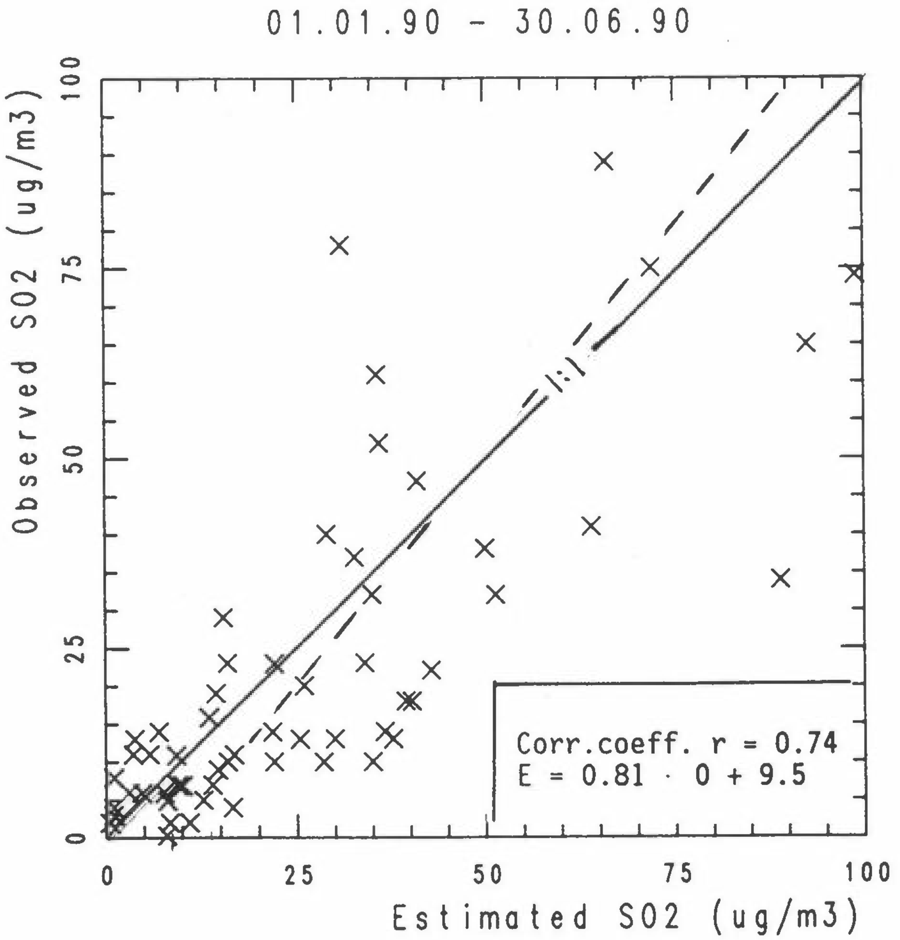

Figure 5: Observed monthly average concentrations of SO_2 plotted against estimated values for the months January-June 1990.

The maps showing the monthly average concentrations of SO_2 are presented in Appendix B.

6 DEPOSITION

The dry deposition was estimated for the winter season (1 October 1989 to 31 March 1990) and the summer season (1 April to 30 September 1990).

Figure 6 shows the estimated dry deposition of SO_2 for the winter season. The maximum deposition for the winter season was about 5 g/m^2. The deposition velocity used for winter estimates was 0.1 cm/sec, which is representative for snow covered ground.

Figure 7 shows the dry deposition for the summer season. The maximum deposition was greater than 5 g/m^2 out to a distance of 10 km from the sources in Nikel. The deposition velocity for summer estimates was 0,3 cm/sec, which is representative for an area covered with grass and scattered trees.

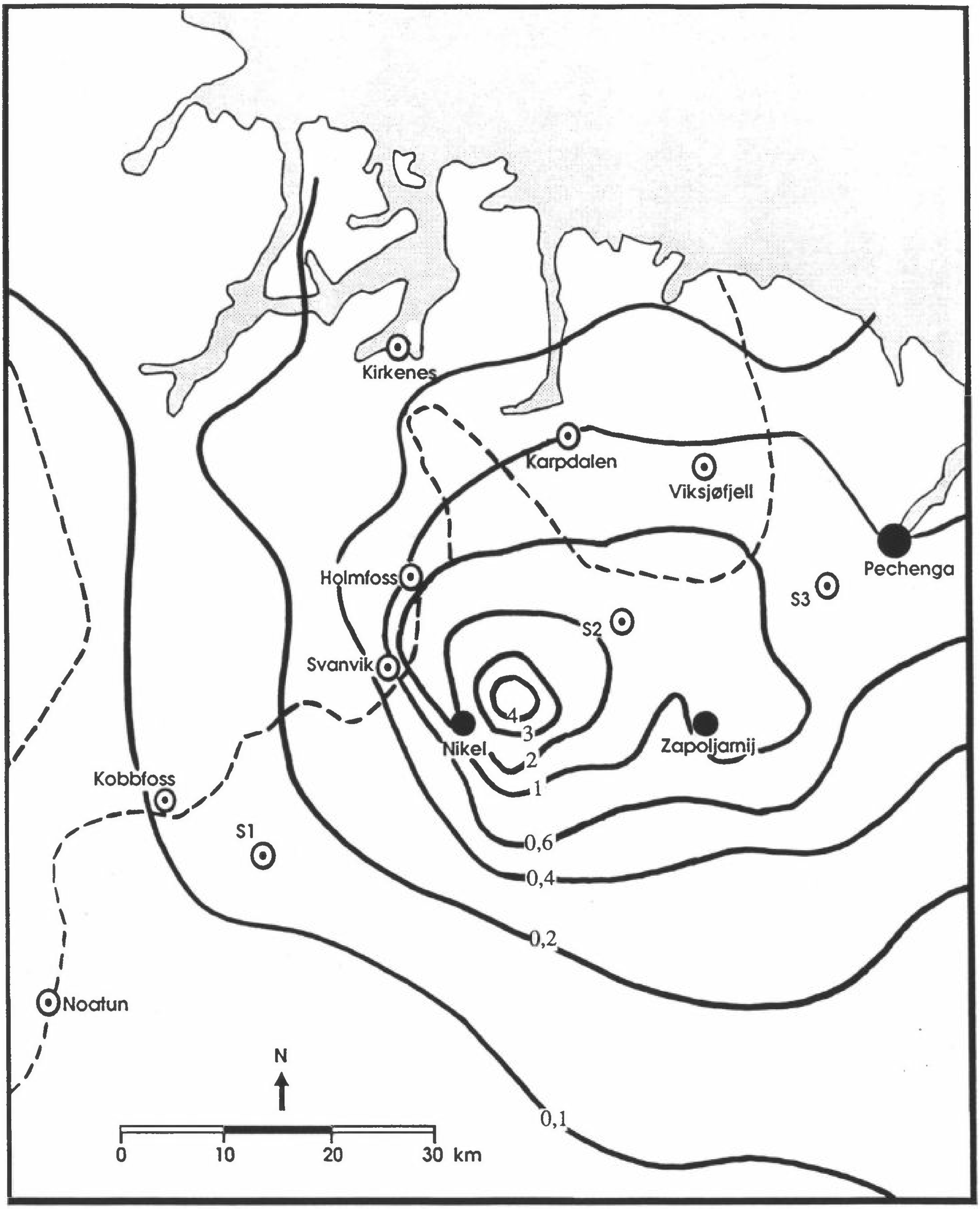

Figure 6: Estimated dry deposition of SO_2 for the winter season 1989/90 (g/m^2).

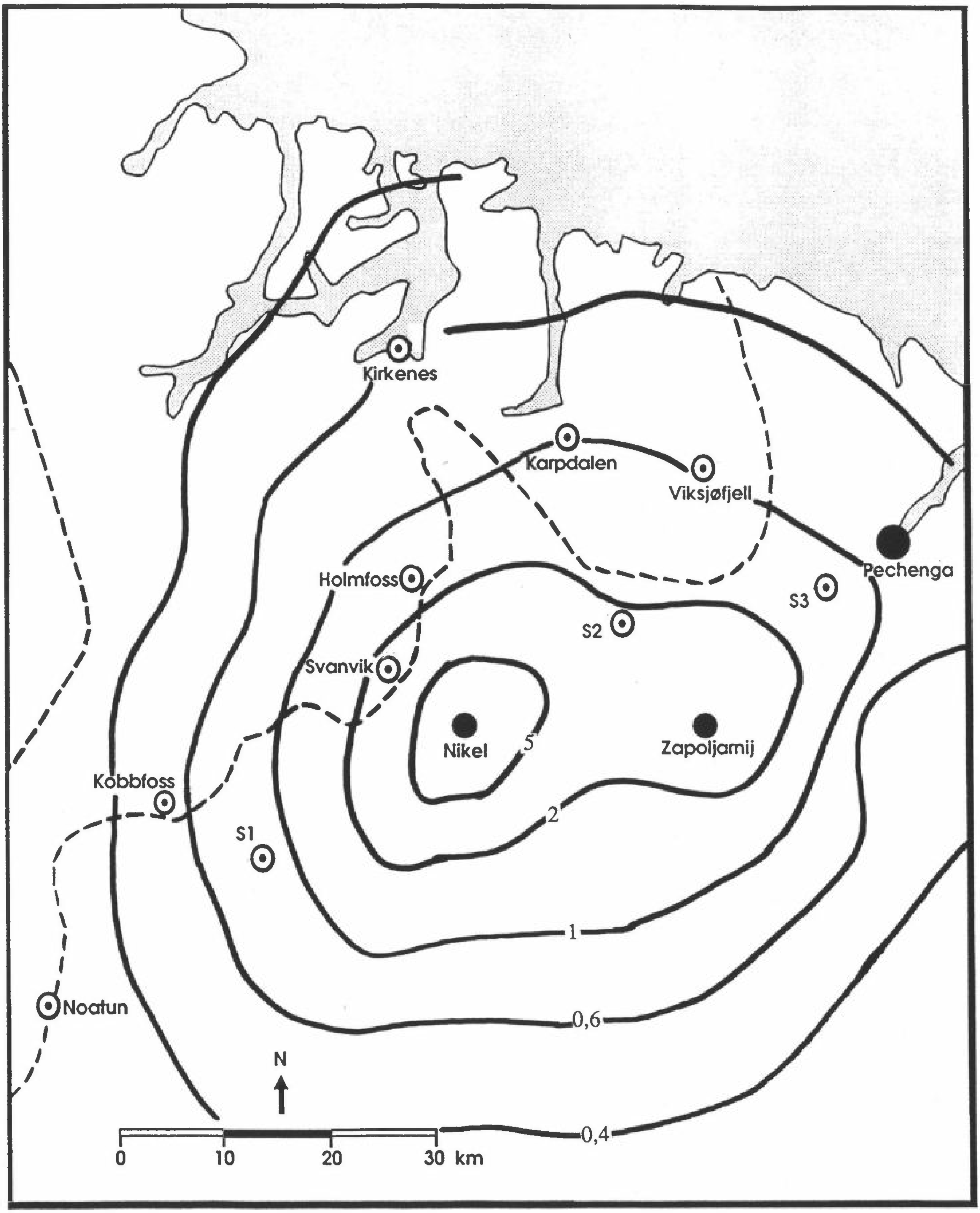

Figure 7: Estimated dry deposition of SO_2 for the summer season 1990 (g/m^2).

7 SELECTED EPISODES

Several air pollution "episodes" with observed high concentrations of SO_2 in the area have been selected for analyses. Table 8 summarizes the observed SO_2 concentrations.

Table 10: Episodes with high hourly SO_2 concentrations in µg/m³ at several monitoring stations in the border area between Norway and the Sovjet Union during 1990.

Date	VIKSJØFJELL			KARPDALEN			SVANVIK			SOV 1			SOV 2			SOV 3		
	Max.	h	Aver.	Max.	h	Aver.	Max.	h	Aver.	Max.	h	Aver.	Max.	h	Aver.	Max.	h	Aver.
18.-19.1.	1014	16	162	312	05	185	163	12	69	63	02-04	53	1403	16	243			
19.-20.1.	1997	23	372	442	23	228	139	21	76	53	08	33	1737	18	771			
20.-21.1.	763	23	186	280	08	72	45	18	27	35	10-16	25	757	13	139			
21.-22.1.	1097	07	133	121	02	32	13	08,01	5	10	08-11, 13-14	8	2608	07	153			
22.-23.1.	589	16	192	723	18	172	30	03	11	21	02, 05-07	14	2499	08	436			
27.-28.1.	1536	02	363	333	14	107	23	11,07	12	88	11	23	1121	17	406			
28.-29.1.	46	09	18	171	20	80	114	08	37	13	15	2	2788	15	662			
29.-30.1.	42	12	6	547	02	197	2458	21	841	1208	03	341	2956	16	1114			
30.-31.1.	2974	23	139	812	12	543	992	08	323	512	08	160	1095	18	395			
23.-24.2.	962	08	106	338	12	26	0	-	0	78	24	7	719	07	93	112	06	20
24.-25.2.	962	08	144	471	10	83	-	-	0	54	22	6	548	08	140	346	14	75
4.- 5.3.	1097	10	146	373	12	107	0	-	0	8	09	1	558	09	100	442	08	60
7.- 8.4.	163	07	8	8	07	0,4	11	03-05	2	5	05	2	1609	04	269	79	07	10
8.- 9.4.	1020	09	99	364	14	67	17	10	1	10	09	2	1041	08	133	161	10	34
28.-29.8.	296	06	26	1057	05	133	1170	17	68									

8 ESTIMATED ONE HOUR AVERAGE CONCENTRATIONS

So far only a few of the episodes in Table 10 have been selected for model estimates using the INPUFF model. One of these episodes occurred during the last days of January 1990.

During low wind and stable meteorological conditions it has proven difficult to estimate concentrations from hour to hour in receptor points at distances up to 40 km away from the source areas. Only during strong wind and turbulent conditions these estimates have been successful so far. We are, however, working on an improved description of sources and wind data.

Figure 8 shows an example for one day with well defined wind conditions.

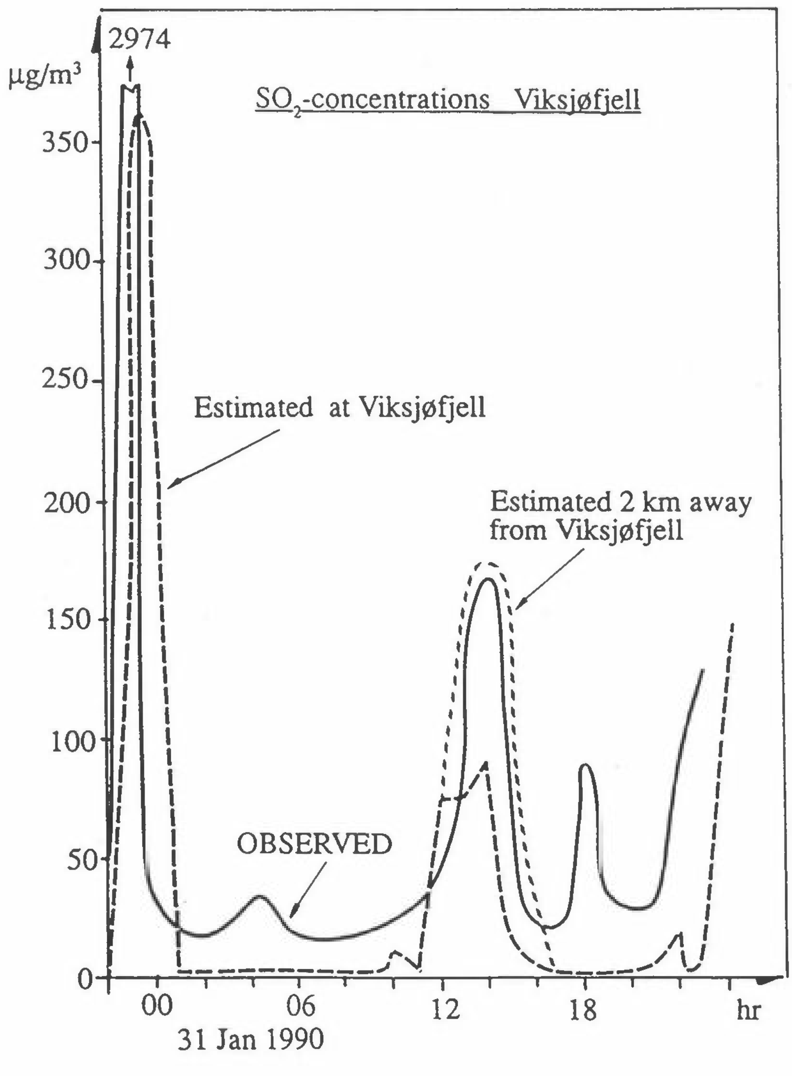

Figure 8: Observed and estimated hourly SO_2 concentrations at Viksjøfjell on 31 January 1990.

9 DISCUSSION

The CONDEP model performance applied to the SO_2 emissions in Nikel and Zapoliarnij has shown significant differences between winter and summer conditions. This might be due to the quality and representativity of the input data, (emission rates and meteorological data), or to the general model performance (physical descriptions).

A major weakness in the model calculations has been the use of constant emission rates in time. No data have been made available to include time variable emission rates. There are reasons to believe that the SO_2 emissions have been less during the summer months 1990 than they were during the winter 1989/90. To illustrate this we have presented the discrepancies between monthly estimated SO_2 concentrations and measured SO_2 concentrations in Figure 9.

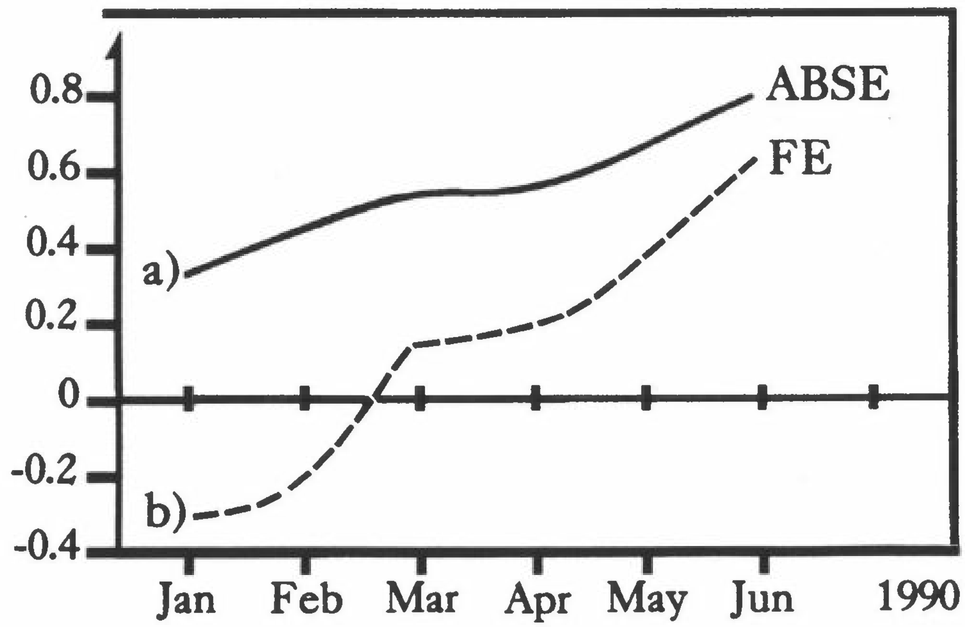

Figure 9: The relative difference between model estimated (E) and observed (O) monthly average SO_2 concentrations illustrated from January to June 1990 by:
a) The absolute error; $ABSE = \Sigma 2|E-O|/\Sigma(E+O)$
b) The fractional error; $FE = \Sigma[2(E-O)/(E+O)]/N$

From Figure 9 we see that the average absolute error is about 40% during the winter months, which is acceptable. The model usually underestimates the observed concentrations at the monitoring sites, which might mean that the actual emission rates have been larger than we have assumed in the model. Also the meteorological dispersion conditions (low winds, stable air) might have been inadequately represented in the model. In May and June the estimated errors have increased to 60-80%. During these months the model overestimates the SO_2 concentrations. There are reasons to believe that the actual SO_2 emission rates have been lower than we have assumed in the model calculations (for example due to vacation periods).

To improve the model performance it will be necessary to have better information about the emissions, included temporary reductions, production changes and vacation periods.

During air pollution episodes, especially in January 1990, the meteorological dispersion conditions have been complex. Most of these episodes were characterized by a high pressure centre on Kola or north east of Kola. In the border areas the winds were usually nearly calm or from the south and south east with strong variation in time. Both surface inversions and upper inversions due to subsidence were typical during these episodes. Even a three dimensional wind field model would hardly reproduce these conditions. Our meteorological stations have been located far from the emission sites. Even when we distinguished between high sources (Viksjøfjell wind) and low sources (Svanvik wind) the model did not reproduce the observed SO_2 concentrations. We are working on improvement of the INPUFF model applied at the Nikel smelters. This work will be reported during the Spring of 1991.

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APPENDIX A

Monthly joint frequency distributions
for January to September 1990 for wind data from
Svanvik (10 m) and Viksjøfjell (25 m)

Table A1: Joint frequency distribution (in %) in classes of stability (I: unstable, IV: stable), wind speeds and wind directions for January 1990 at:
a) Viksjøfjell (25 m)
b) Svanvik (10 m)

Delta T : VIKSJØFJELL
Wind : VIKSJØFJELL
Period : 01.01.90. - 31.01.90.
Unit : Percent

JOINT FREQUENCY DISTRIBUTION OF STABILITY, WIND SPEED AND WIND DIRECTION

Class I: Unstable DT < -.5 Degrees C
Class II: Neutral -.5 < DT < .0 Degrees C
Class III: Light stable .0 < DT < .5 Degrees C
Class IV: Stable .5 < DT Degrees C

Calm: U less or equal .3 m/s

Wind-	.0- 2.0 m/s				2.0- 4.0 m/s				4.0- 6.0 m/s				over 6.0 m/s				
direction	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	Rose
30	.0	.3	.3	.0	.0	.2	.3	.0	.0	1.0	.0	.0	.0	.0	.0	.0	2.2
60	.0	1.0	.9	.0	.0	1.6	1.2	.2	.0	.5	.0	.0	.0	1.4	.0	.0	6.7
90	.0	.5	.5	.0	.0	.3	.2	.0	.0	1.2	.0	.0	.0	.9	.0	.0	3.6
120	.0	.0	.2	.0	.0	.9	.0	.0	.0	1.0	.0	.0	.0	.2	.0	.0	2.2
150	.0	.9	.9	.5	.0	3.1	5.7	4.2	.0	1.0	.9	.2	.0	.2	.2	.9	18.5
180	.0	.2	.2	1.9	.0	3.5	4.8	3.8	.0	1.6	.5	1.0	.0	5.9	1.7	.3	25.4
210	.0	.2	.0	.7	.0	1.0	.3	1.7	.0	.0	.0	.2	.0	.2	.0	.9	5.2
240	.0	.0	.2	1.0	.0	.0	.0	3.1	.0	.0	.0	.0	.0	1.9	2.9	2.1	11.2
270	.0	.0	.7	.3	.0	.0	.3	.3	.0	.0	.0	1.6	.0	.2	.3	.5	4.3
300	.0	.0	1.2	.5	.0	.0	.3	.7	.0	.2	.0	.0	.0	.7	.0	.0	3.6
330	.0	.0	1.0	.5	.0	.0	.7	.0	.0	.0	.0	.0	.0	4.5	.0	.0	6.7
360	.0	.0	.3	.5	.0	.0	.7	.2	.0	.5	.0	.0	.0	2.4	.0	.0	4.7
Calm	.0	.7	3.3	1.4													5.4
Total	.0	3.8	9.7	7.4	.0	10.6	14.7	14.2	.0	7.1	1.4	2.9	.0	18.3	5.2	4.7	100.0
Occurrence	20.9 %				39.4 %				11.4 %				28.2 %				100.0 %
Wind speed	.9 m/s				3.0 m/s				4.8 m/s				9.6 m/s				4.6 m/s

Frequency of occurrence of the stability classes

	Class I	Class II	Class III	Class IV	
Occurrence	.0 %	39.8 %	31.0 %	29.2 %	100.0 %

Delta T : VIKSJØFJELL
Wind : SVANVIK
Period : 01.01.90. - 31.01.90.
Unit : Percent

JOINT FREQUENCY DISTRIBUTION OF STABILITY, WIND SPEED AND WIND DIRECTION

Class I: Unstable DT < -.5 Degrees C
Class II: Neutral -.5 < DT < .0 Degrees C
Class III: Light stable .0 < DT < .5 Degrees C
Class IV: Stable .5 < DT Degrees C

Calm: U less or equal .3 m/s

Wind-	.0- 1.0 m/s				1.0- 2.5 m/s				2.5- 4.0 m/s				over 4.0 m/s				
direction	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	Rose
30	.0	.0	.3	.1	.0	.4	.0	.0	.0	.0	.0	.1	.0	.0	.0	.0	1.0
60	.0	.4	.9	.1	.0	.3	.1	.0	.0	.7	.0	.1	.0	.3	.0	.0	3.0
90	.0	.6	.6	.1	.0	.7	.0	.0	.0	.9	.0	.0	.0	1.2	.0	.0	4.0
120	.0	.0	.4	.3	.0	.3	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.2
150	.0	.1	1.7	.6	.0	.3	.4	.1	.0	.3	.3	.3	.0	.4	.0	.0	4.6
180	.0	.3	.7	.4	.0	.7	1.0	.0	.0	1.6	.9	.3	.0	1.6	.7	.3	8.5
210	.0	.3	.9	1.3	.0	1.6	2.2	.6	.0	3.5	1.4	.1	.0	3.6	.9	.0	16.3
240	.0	.4	1.6	1.2	.0	1.2	1.2	.7	.0	.0	.7	.3	.0	.0	.0	.0	7.2
270	.0	.1	.3	.6	.0	.3	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.4
300	.0	.1	.1	.3	.0	.7	.0	.0	.0	.0	.0	.0	.0	.3	.0	.0	1.6
330	.0	.4	.6	.0	.0	1.0	.0	.0	.0	1.9	.0	.0	.0	.1	.0	.0	4.0
360	.0	.0	.0	.0	.0	1.0	.0	.0	.0	2.2	.0	.0	.0	.6	.0	.0	3.7
Calm	.0	5.5	16.7	21.3													43.5
Total	.0	8.3	24.7	26.3	.0	8.5	5.2	1.4	.0	10.9	3.3	1.3	.0	8.1	1.6	.3	100.0
Occurrence	59.4 %				15.1 %				15.5 %				9.9 %				100.0 %
Wind speed	.2 m/s				1.9 m/s				3.2 m/s				5.1 m/s				1.4 m/s

Frequency of occurrence of the stability classes

	Class I	Class II	Class III	Class IV	
Occurrence	.0 %	35.8 %	34.8 %	29.4 %	100.0 %

Table A2: Joint frequency distribution (in %) in classes of stability (I: unstable, IV: stable), wind speeds and wind directions for February 1990 at:
a) Viksjøfjell (25 m)
b) Svanvik (10 m)

Delta T : VIKSJØFJELL
Wind : VIKSJØFJELL
Period : 01.02.90. - 28.02.90.
Unit : Percent

JOINT FREQUENCY DISTRIBUTION OF STABILITY, WIND SPEED AND WIND DIRECTION

Class I: Unstable DT < -.5 Degrees C
Class II: Neutral -.5 < DT < .0 Degrees C
Class III: Light stable .0 < DT < .5 Degrees C
Class IV: Stable .5 < DT Degrees C

Calm: U less or equal .3 m/s

Wind-direction	.0- 2.0 m/s I	II	III	IV	2.0- 4.0 m/s I	II	III	IV	4.0- 6.0 m/s I	II	III	IV	over 6.0 m/s I	II	III	IV	Rose
30	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
60	.0	.0	.0	.0	.0	.2	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.3
90	.0	.3	.0	.0	.0	1.6	.0	.0	.0	1.0	.2	.0	.0	1.3	.0	.0	4.4
120	.0	1.0	1.8	.0	.0	2.9	.2	.0	.0	.5	.2	.0	.0	.7	.0	.0	7.2
150	.0	.0	1.8	.0	.0	1.5	.2	.0	.0	1.8	.7	.0	.0	3.8	1.5	.2	11.3
180	.0	.2	.5	.0	.0	.3	.5	.2	.0	.7	.5	.2	.0	23.8	1.1	.2	28.1
210	.0	.7	.0	.2	.0	.7	1.0	.0	.0	.5	.7	.3	.0	8.8	1.6	.3	14.7
240	.0	.0	.0	.0	.0	.7	2.8	.5	.0	.5	1.6	1.8	.0	6.9	9.1	1.6	25.4
270	.0	.0	.0	.2	.0	.3	.5	.3	.0	.0	.5	.0	.0	3.3	1.5	.2	6.7
300	.0	.0	.0	.0	.0	.3	.2	.0	.0	.2	.0	.0	.0	.3	.3	.0	1.3
330	.0	.0	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.2	.0	.0	.5
360	.0	.0	.0	.0	.0	.0	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.2
Calm	.0	.0	.0	.0													.0
Total	.0	2.1	4.4	.3	.0	8.5	5.5	1.0	.0	5.1	4.2	2.3	.0	48.9	15.2	2.4	100.0
Occurrence	6.9 %				15.0 %				11.6 %				66.6 %				100.0 %
Wind speed	1.3 m/s				3.3 m/s				5.1 m/s				11.6 m/s				8.9 m/s

Frequency of occurrence of the stability classes

	Class I	Class II	Class III	Class IV	
Occurrence	.0 %	64.6 %	29.4 %	6.0 %	100.0 %

Delta T : VIKSJØFJELL
Wind : SVANVIK
Period : 01.02.90. - 28.02.90.
Unit : Percent

JOINT FREQUENCY DISTRIBUTION OF STABILITY, WIND SPEED AND WIND DIRECTION

Class I: Unstable DT < -.5 Degrees C
Class II: Neutral -.5 < DT < .0 Degrees C
Class III: Light stable .0 < DT < .5 Degrees C
Class IV: Stable .5 < DT Degrees C

Calm: U less or equal .3 m/s

Wind-direction	.0- 1.0 m/s I	II	III	IV	1.0- 2.5 m/s I	II	III	IV	2.5- 4.0 m/s I	II	III	IV	over 4.0 m/s I	II	III	IV	Rose
30	.0	.6	.2	.0	.0	.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.3
60	.0	.5	.0	.0	.0	1.5	.0	.0	.0	.5	.0	.0	.0	.0	.0	.0	2.4
90	.0	.5	.2	.0	.0	1.5	.2	.0	.0	.6	.0	.0	.0	.2	.0	.0	3.1
120	.0	.0	.0	.0	.0	.2	.8	.0	.0	.3	.2	.0	.0	.2	.0	.0	1.6
150	.0	.3	.2	.3	.0	1.5	1.3	.0	.0	1.0	.2	.0	.0	1.3	.2	.0	6.1
180	.0	1.0	.3	.0	.0	1.1	1.5	.2	.0	7.3	.5	.2	.0	15.8	.5	.0	28.2
210	.0	.2	1.3	.5	.0	2.9	2.4	.3	.0	4.7	.5	.0	.0	5.8	.8	.0	19.4
240	.0	.6	1.0	.5	.0	1.8	2.1	.5	.0	1.6	1.8	.0	.0	.6	.8	.0	11.3
270	.0	1.1	.6	.8	.0	1.3	.8	.0	.0	.6	.0	.0	.0	1.1	.2	.0	6.6
300	.0	.6	.3	.5	.0	1.3	.2	.0	.0	.8	.2	.0	.0	.6	.0	.0	4.5
330	.0	.3	.3	.0	.0	.3	.2	.0	.0	.2	.2	.0	.0	.2	.0	.0	1.6
360	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Calm	.0	2.9	8.9	2.1													13.9
Total	.0	8.7	13.2	4.7	.0	13.7	9.4	1.0	.0	17.6	3.4	.2	.0	25.8	2.4	.0	100.0
Occurrence	26.6 %				24.0 %				21.1 %				28.2 %				100.0 %
Wind speed	.4 m/s				1.7 m/s				3.2 m/s				5.5 m/s				2.7 m/s

Frequency of occurrence of the stability classes

	Class I	Class II	Class III	Class IV	
Occurrence	.0 %	65.8 %	28.4 %	5.8 %	100.0 %

Table A3: Joint frequency distribution (in %) in classes of stability (I: unstable, IV: stable), wind speeds and wind directions for March 1990 at:
a) Viksjøfjell (25 m)
b) Svanvik (10 m)

Delta T : VIKSJØFJELL
Wind : VIKSJØFJELL
Period : 01.03.90. - 31.03.90.
Unit : Percent

JOINT FREQUENCY DISTRIBUTION OF STABILITY, WIND SPEED AND WIND DIRECTION

Class I: Unstable DT < -.5 Degrees C
Class II: Neutral -.5 < DT < .0 Degrees C
Class III: Light stable .0 < DT < .5 Degrees C
Class IV: Stable .5 < DT Degrees C

Calm: U less or equal .3 m/s

	.0- 2.0 m/s				2.0- 4.0 m/s				4.0- 6.0 m/s				over 6.0 m/s				
Wind-direction	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	Rose
30	.0	.0	.0	.0	.0	.7	.3	.0	.0	.0	.0	.0	.0	2.0	.0	.0	3.0
60	.0	.0	.0	.0	.0	.4	.3	.0	.0	.3	.6	.0	.0	1.3	.0	.0	2.9
90	.0	.0	.0	.0	.0	.7	.9	.0	.0	.7	.4	.0	.0	1.3	.6	.0	4.6
120	.0	.0	.0	.0	.0	.7	.0	.0	.0	2.4	.1	.0	.0	3.7	1.4	.0	8.4
150	.0	.0	.0	.0	.0	.3	.1	.0	.0	.3	.1	.0	.0	.9	.9	.4	3.0
180	.0	.0	.0	.0	.0	.0	.1	.0	.0	.0	.6	.4	.0	3.4	5.1	1.3	11.0
210	.0	.0	.1	.0	.0	.3	.0	.0	.0	.1	.3	.0	.0	2.7	5.0	1.9	10.4
240	.0	.0	.0	.0	.0	.3	.6	.4	.0	.1	.6	.4	.0	8.7	9.3	3.1	23.5
270	.0	.0	.0	.0	.0	.1	.7	.1	.0	.3	.6	1.3	.0	5.7	2.4	1.0	12.3
300	.0	.0	.0	.1	.0	.0	.4	.1	.0	.9	.1	.1	.0	3.3	1.9	.0	7.0
330	.0	.0	.0	.0	.0	.0	.1	.1	.0	.1	.1	.0	.0	8.4	.3	.0	9.3
360	.0	.1	.0	.0	.0	.1	.6	.0	.0	.0	.1	.0	.0	3.7	.0	.0	4.7
Calm	.0	.0	.0	.0													.0
Total	.0	.1	.1	.1	.0	3.7	4.1	.9	.0	5.3	3.7	2.3	.0	45.1	26.8	7.7	100.0
Occurrence	.4 %				8.7 %				11.3 %				79.6 %				100.0 %
Wind speed	1.3 m/s				3.5 m/s				5.0 m/s				10.9 m/s				9.5 m/s

Frequency of occurrence of the stability classes

	Class I	Class II	Class III	Class IV	
Occurrence	.0 %	54.2 %	34.8 %	11.0 %	100.0 %

Delta T : VIKSJØFJELL
Wind : SVANVIK
Period : 01.03.90. - 31.03.90.
Unit : Percent

JOINT FREQUENCY DISTRIBUTION OF STABILITY, WIND SPEED AND WIND DIRECTION

Class I: Unstable DT < -.5 Degrees C
Class II: Neutral -.5 < DT < .0 Degrees C
Class III: Light stable .0 < DT < .5 Degrees C
Class IV: Stable .5 < DT Degrees C

Calm: U less or equal .3 m/s

	.0- 1.0 m/s				1.0- 2.5 m/s				2.5- 4.0 m/s				over 4.0 m/s				
Wind-direction	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	Rose
30	.0	.3	.3	.0	.0	.9	.0	.0	.0	.1	.0	.0	.0	.7	.0	.0	2.3
60	.0	.7	.4	.0	.0	1.0	1.0	.0	.0	.6	.1	.0	.0	.7	.0	.0	4.6
90	.0	.6	.4	.3	.0	4.3	.4	.0	.0	.9	.4	.0	.0	.0	.0	.0	7.3
120	.0	.0	.1	.0	.0	.7	.0	.0	.0	.7	.1	.0	.0	1.6	.3	.0	3.6
150	.0	.3	.3	.1	.0	.1	.3	.4	.0	.0	.0	.0	.0	.0	.0	.0	1.6
180	.0	.9	1.3	.4	.0	.4	1.4	1.0	.0	.7	.9	.1	.0	1.9	1.3	.0	10.3
210	.0	.0	1.0	1.1	.0	.9	2.1	.9	.0	.6	1.7	.0	.0	3.9	3.0	.0	15.2
240	.0	.3	.7	.7	.0	3.3	2.0	1.6	.0	1.7	1.3	.6	.0	.6	3.1	.0	15.9
270	.0	.4	1.1	.3	.0	1.6	.9	.0	.0	2.0	.4	.1	.0	2.4	.3	.0	9.6
300	.0	.0	.7	.0	.0	1.3	.0	.3	.0	1.4	.0	.0	.0	.9	.0	.0	4.6
330	.0	.1	.4	.0	.0	1.4	.4	.0	.0	2.4	.0	.0	.0	.9	.0	.0	5.7
360	.0	.0	.3	.1	.0	1.1	.0	.0	.0	4.4	.0	.0	.0	3.6	.0	.0	9.6
Calm	.0	1.7	5.3	2.9													9.9
Total	.0	5.3	12.4	6.0	.0	17.0	8.6	4.1	.0	15.6	5.0	.9	.0	17.0	8.0	.0	100.0
Occurrence	23.7 %				29.8 %				21.5 %				25.0 %				100.0 %
Wind speed	.4 m/s				1.8 m/s				3.2 m/s				5.2 m/s				2.6 m/s

Frequency of occurrence of the stability classes

	Class I	Class II	Class III	Class IV	
Occurrence	.0 %	54.9 %	34.0 %	11.0 %	100.0 %

Table A4: Joint frequency distribution (in %) in classes of stability (I: unstable, IV: stable), wind speeds and wind directions for April 1990 at:
a) Viksjøfjell (25 m)
b) Svanvik (10 m)

Delta T : VIKSJØFJELL
Wind : VIKSJØFJELL
Period : 01.04.90. - 30.04.90.
Unit : Percent

JOINT FREQUENCY DISTRIBUTION OF STABILITY, WIND SPEED AND WIND DIRECTION

Class I: Unstable DT < -.5 Degrees C
Class II: Neutral -.5 < DT < .0 Degrees C
Class III: Light stable .0 < DT < .5 Degrees C
Class IV: Stable .5 < DT Degrees C

Calm: U less or equal .3 m/s

Wind-direction	.0- 2.0 m/s I	II	III	IV	2.0- 4.0 m/s I	II	III	IV	4.0- 6.0 m/s I	II	III	IV	over 6.0 m/s I	II	III	IV	Rose
30	.0	.4	.0	.0	.0	1.0	.0	.0	.0	.3	.0	.0	.0	1.5	.1	.0	3.4
60	.0	.0	.0	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	.6	.0	.0	.7
90	.0	.1	.0	.0	.0	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.4
120	.0	.0	.0	.0	.0	.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.4
150	.0	.0	.0	.0	.0	.0	.1	.0	.0	.3	.4	.0	.0	.4	5.0	.0	6.3
180	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.3	.3	.0	.0	4.7	11.3	2.3	20.0
210	.0	.0	.0	.0	.0	.0	.1	.0	.0	.4	.4	.0	.0	6.5	9.8	7.5	24.8
240	.0	.0	.0	.0	.0	.4	.4	.0	.0	.9	.9	.7	.1	8.4	9.1	2.8	23.8
270	.0	.0	.0	.0	.0	.3	.0	.3	.0	.7	.1	.1	.0	4.3	3.5	1.2	10.6
300	.0	.0	.0	.0	.0	.1	.6	.0	.0	1.0	.4	.0	.0	.9	.3	.0	3.4
330	.0	.1	.0	.0	.0	.3	.3	.0	.0	.4	.6	.0	.0	1.2	.3	.0	3.2
360	.0	.0	.0	.0	.0	1.0	.4	.0	.0	1.0	.1	.0	.0	.3	.0	.0	2.9
Calm	.0	.0	.0	.0													.0
Total	.0	.7	.0	.0	.0	4.1	2.1	.3	.0	6.5	3.4	.9	.1	28.6	39.5	13.8	100.0

	.0- 2.0 m/s	2.0- 4.0 m/s	4.0- 6.0 m/s	over 6.0 m/s	Rose
Occurrence	.7 %	6.5 %	10.7 %	82.1 %	100.0 %
Wind speed	1.4 m/s	3.4 m/s	5.0 m/s	10.8 m/s	9.6 m/s

Frequency of occurrence of the stability classes

	Class I	Class II	Class III	Class IV	
Occurrence	.1 %	39.9 %	44.9 %	15.0 %	100.0 %

Delta T : VIKSJØFJELL
Wind : SVANVIK
Period : 01.04.90. - 30.04.90.
Unit : Percent

JOINT FREQUENCY DISTRIBUTION OF STABILITY, WIND SPEED AND WIND DIRECTION

Class I: Unstable DT < -.5 Degrees C
Class II: Neutral -.5 < DT < .0 Degrees C
Class III: Light stable .0 < DT < .5 Degrees C
Class IV: Stable .5 < DT Degrees C

Calm: U less or equal .3 m/s

Wind-direction	.0- 1.0 m/s I	II	III	IV	1.0- 2.5 m/s I	II	III	IV	2.5- 4.0 m/s I	II	III	IV	over 4.0 m/s I	II	III	IV	Rose
30	.0	1.0	.3	.0	.0	.6	.0	.0	.0	.1	.0	.0	.0	.1	.0	.0	2.2
60	.0	.3	.0	.0	.0	.3	.0	.0	.0	.4	.0	.0	.0	.0	.0	.0	1.0
90	.0	.4	.0	.0	.0	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.7
120	.0	.4	.0	.0	.0	.7	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.3
150	.0	.0	1.5	1.2	.0	.1	.1	.3	.0	.0	.1	.3	.0	.0	.0	.3	4.0
180	.0	.4	1.5	1.0	.0	1.5	2.5	.9	.0	1.0	2.8	.3	.0	.6	2.5	.4	15.5
210	.0	.4	1.0	1.0	.0	3.5	4.0	2.5	.0	3.5	3.5	.6	.0	3.5	7.2	.4	31.5
240	.0	.4	2.1	.7	.0	2.7	3.4	1.2	.0	1.0	1.6	.3	.0	.6	1.3	.0	15.4
270	.0	.3	.9	.4	.0	1.5	.9	.3	.0	2.4	.9	.0	.0	.9	.3	.0	8.7
300	.0	.3	.6	.1	.0	1.2	.9	.1	.1	2.5	.3	.1	.0	.4	.0	.0	6.8
330	.0	.3	.0	.0	.0	.7	1.0	.0	.0	.7	.1	.0	.0	1.3	.1	.0	4.4
360	.0	.0	.0	.0	.0	.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.4
Calm	.0	2.8	3.0	2.2													8.0
Total	.0	7.2	10.8	6.8	.0	13.6	13.0	5.3	.1	11.8	9.5	1.6	.0	7.5	11.5	1.2	100.0

	.0- 1.0 m/s	1.0- 2.5 m/s	2.5- 4.0 m/s	over 4.0 m/s	Rose
Occurrence	24.8 %	31.9 %	23.0 %	20.2 %	100.0 %
Wind speed	.5 m/s	1.8 m/s	3.3 m/s	5.4 m/s	2.6 m/s

Frequency of occurrence of the stability classes

	Class I	Class II	Class III	Class IV	
Occurrence	.1 %	40.2 %	44.8 %	14.9 %	100.0 %

Table A5: Joint frequency distribution (in %) in classes of stability (I: unstable, IV: stable), wind speeds and wind directions for May 1990 at:
a) Viksjøfjell (25 m)
b) Svanvik (10 m)

Delta T : VIKSJØFJELL
Wind : VIKSJØFJELL
Period : 01.05.90. - 31.05.90.
Unit : Percent

JOINT FREQUENCY DISTRIBUTION OF STABILITY, WIND SPEED AND WIND DIRECTION

Class I: Unstable DT < -.5 Degrees C
Class II: Neutral -.5 < DT < .0 Degrees C
Class III: Light stable .0 < DT < .5 Degrees C
Class IV: Stable .5 < DT Degrees C

Calm: U less or equal .3 m/s

Wind-direction	.0- 2.0 m/s I	II	III	IV	2.0- 4.0 m/s I	II	III	IV	4.0- 6.0 m/s I	II	III	IV	over 6.0 m/s I	II	III	IV	Rose
30	.0	.1	.1	.0	.0	2.0	.9	.0	.0	.3	.1	.0	.0	.6	.0	.0	4.1
60	.0	.3	.0	.0	.0	1.1	.4	.0	.0	.4	.1	.0	.0	.4	.0	.0	2.8
90	.0	.3	.1	.0	.0	1.4	.3	.0	.0	.9	.0	.0	.0	.0	.0	.0	3.0
120	.0	.0	.3	.0	.0	.7	.9	.0	.0	.4	.1	.0	.0	.1	.1	.0	2.7
150	.0	.0	.0	.0	.0	.1	.6	.0	.0	.1	.0	.0	.0	.0	.0	.0	.9
180	.0	.0	.1	.0	.0	.6	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.9
210	.0	.0	.0	.0	.0	.1	.3	.0	.0	1.0	.3	.0	.0	1.1	1.0	.7	4.5
240	.0	.0	.0	.0	.0	.6	.4	.0	.0	.4	.3	.0	.0	6.8	3.0	.7	12.2
270	.0	.1	.0	.0	.0	.9	.1	.0	.0	.1	.0	.0	.0	9.5	1.8	.0	12.6
300	.0	.0	.1	.0	.0	2.1	.0	.0	.0	3.3	.1	.0	.0	20.6	1.0	.0	27.2
330	.0	.1	.1	.0	.0	2.1	.4	.0	.0	2.8	.1	.0	.0	13.8	.3	.0	19.9
360	.0	.0	.1	.0	.0	1.6	.3	.0	.0	3.3	.3	.0	.0	3.4	.3	.0	9.2
Calm	.0	.0	.0	.0													.0
Total	.0	1.0	1.1	.0	.0	13.3	4.7	.0	.0	13.0	1.6	.0	.0	56.3	7.5	1.4	100.0
Occurrence	2.1 %				18.0 %				14.6 %				65.2 %				100.0 %
Wind speed	1.3 m/s				3.3 m/s				5.0 m/s				10.0 m/s				7.9 m/s

Frequency of occurrence of the stability classes

	Class I	Class II	Class III	Class IV	
Occurrence	.0 %	83.7 %	14.9 %	1.4 %	100.0 %

Delta T : VIKSJØFJELL
Wind : SVANVIK
Period : 01.05.90. - 31.05.90.
Unit : Percent

JOINT FREQUENCY DISTRIBUTION OF STABILITY, WIND SPEED AND WIND DIRECTION

Class I: Unstable DT < -.5 Degrees C
Class II: Neutral -.5 < DT < .0 Degrees C
Class III: Light stable .0 < DT < .5 Degrees C
Class IV: Stable .5 < DT Degrees C

Calm: U less or equal .3 m/s

Wind-direction	.0- 1.0 m/s I	II	III	IV	1.0- 2.5 m/s I	II	III	IV	2.5- 4.0 m/s I	II	III	IV	over 4.0 m/s I	II	III	IV	Rose
30	.0	.7	.6	.0	.0	5.3	.7	.0	.0	2.1	.1	.0	.0	2.3	.1	.0	11.9
60	.0	1.7	1.3	.0	.0	1.8	.3	.0	.0	.3	.0	.0	.0	.0	.0	.0	5.4
90	.0	1.0	.3	.0	.0	1.7	.3	.0	.0	1.4	.0	.0	.0	.0	.0	.0	4.7
120	.0	.1	.1	.0	.0	.4	.0	.0	.0	.1	.0	.0	.0	.0	.0	.0	.9
150	.0	.4	.0	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.7
180	.0	.0	.4	.1	.0	1.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.6
210	.0	.3	.3	.1	.0	1.6	.6	.3	.0	1.3	.6	.0	.0	.0	.1	.0	5.1
240	.0	.1	.9	.1	.0	1.4	1.1	.3	.0	1.0	.7	.0	.0	1.8	.1	.0	7.7
270	.0	.4	.3	.0	.0	2.8	.6	.0	.0	3.0	.0	.0	.0	3.3	.6	.0	11.0
300	.0	1.1	.1	.0	.0	3.0	.6	.0	.0	5.5	.1	.0	.0	3.7	.3	.0	14.5
330	.0	1.6	.7	.0	.0	2.7	.3	.0	.0	11.2	.3	.0	.0	11.2	.4	.0	28.4
360	.0	.3	.3	.0	.0	1.3	.1	.0	.0	1.4	.0	.0	.0	2.1	.1	.0	5.7
Calm	.0	1.0	1.3	.1													2.4
Total	.0	8.8	6.5	.9	.0	23.0	4.6	.6	.0	27.5	1.8	.0	.0	24.5	1.8	.0	100.0
Occurrence	16.2 %				28.2 %				29.3 %				26.3 %				100.0 %
Wind speed	.6 m/s				1.8 m/s				3.3 m/s				5.3 m/s				3.0 m/s

Frequency of occurrence of the stability classes

	Class I	Class II	Class III	Class IV	
Occurrence	.0 %	83.8 %	14.8 %	1.4 %	100.0 %

Table A6: Joint frequency distribution (in %) in classes of stability (I: unstable, IV: stable), wind speeds and wind directions for June 1990 at:
a) Viksjøfjell (25 m)
b) Svanvik (10 m)

Delta T : VIKSJØFJELL
Wind : VIKSJØFJELL
Period : 01.06.90. - 30.06.90.
Unit : Percent

JOINT FREQUENCY DISTRIBUTION OF STABILITY, WIND SPEED AND WIND DIRECTION

Class I: Unstable DT < -.5 Degrees C
Class II: Neutral -.5 < DT < .0 Degrees C
Class III: Light stable .0 < DT < .5 Degrees C
Class IV: Stable .5 < DT Degrees C

Calm: U less or equal .3 m/s

Wind-direction	.0- 2.0 m/s				2.0- 4.0 m/s				4.0- 6.0 m/s				over 6.0 m/s				
	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	Rose
30	.0	.1	.0	.0	.0	2.5	.0	.1	.0	2.6	.1	.0	.0	11.0	.0	.0	16.6
60	.0	.3	.0	.0	.0	3.2	.0	.1	.0	4.7	.0	.0	.6	11.7	.4	.0	21.1
90	.0	.1	.0	.1	.0	3.8	.1	.0	.1	3.7	.0	.1	.1	2.9	.0	.0	11.3
120	.0	.1	.0	.0	.0	.7	.6	.0	.0	1.6	.4	.4	.0	2.2	.6	.0	6.7
150	.0	.1	.1	.0	.0	1.9	.3	.0	.0	.3	1.0	.3	.0	.0	.4	.0	4.5
180	.0	.1	.0	.0	.0	.7	.3	.1	.0	1.2	.9	.4	.0	.9	1.3	.1	6.2
210	.0	.0	.0	.1	.0	.4	.3	.0	.0	1.2	.3	.1	.0	2.6	1.3	.9	7.3
240	.0	.0	.1	.1	.0	.6	.0	.0	.0	2.5	.3	.0	.3	5.0	.7	.0	9.7
270	.0	.0	.0	.0	.0	.6	.3	.0	.0	.3	.0	.0	.0	.1	.0	.0	1.3
300	.0	.0	.0	.0	.0	.7	.0	.0	.0	.1	.0	.0	.0	.0	.0	.0	.9
330	.0	.0	.0	.0	.0	.3	.3	.0	.0	.3	.0	.0	.0	.1	.0	.0	1.0
360	.0	.1	.0	.0	.0	1.3	.1	.0	.0	1.6	.1	.0	.0	10.0	.0	.0	13.3
Calm	.0	.0	.0	.0													.0
Total	.0	1.2	.3	.4	.0	16.9	2.3	.4	.1	20.1	3.2	1.5	1.0	46.6	4.8	1.0	100.0
Occurrence	1.9 %				19.6 %				24.9 %				53.5 %				100.0 %
Wind speed	1.3 m/s				3.4 m/s				4.9 m/s				8.4 m/s				6.4 m/s

Frequency of occurrence of the stability classes

	Class I	Class II	Class III	Class IV	
Occurrence	1.2 %	84.8 %	10.7 %	3.4 %	100.0 %

Delta T : VIKSJØFJELL
Wind : SVANVIK
Period : 01.06.90. - 30.06.90.
Unit : Percent

JOINT FREQUENCY DISTRIBUTION OF STABILITY, WIND SPEED AND WIND DIRECTION

Class I: Unstable DT < -.5 Degrees C
Class II: Neutral -.5 < DT < .0 Degrees C
Class III: Light stable .0 < DT < .5 Degrees C
Class IV: Stable .5 < DT Degrees C

Calm: U less or equal .3 m/s

Wind-direction	.0- 1.0 m/s				1.0- 2.5 m/s				2.5- 4.0 m/s				over 4.0 m/s				
	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	Rose
30	.0	1.6	.6	.3	.0	12.0	.1	.3	.0	5.4	.0	.0	.0	.9	.0	.0	21.3
60	.0	1.5	.1	.0	.0	11.6	.3	.0	.0	6.2	.3	.0	.0	.1	.0	.0	20.1
90	.0	1.5	.7	.3	.6	14.5	.4	.0	.3	3.8	.3	.0	.0	.6	.0	.0	23.1
120	.0	.0	.4	.4	.0	3.7	.6	.0	.0	1.6	.0	.0	.0	.9	.0	.0	7.6
150	.0	.3	1.0	.3	.0	1.5	.0	.3	.0	.6	.0	.0	.0	.0	.0	.0	4.0
180	.0	.4	.4	.4	.0	.4	.1	.1	.0	.0	.4	.0	.0	.1	.0	.0	2.6
210	.0	.3	.3	.0	.0	1.5	.6	.1	.0	.1	.6	.0	.0	.7	.1	.0	4.4
240	.0	.7	.3	.1	.0	1.9	.1	.0	.0	2.6	.3	.0	.0	.7	.0	.0	6.9
270	.0	.1	.0	.3	.0	.9	.0	.0	.3	2.5	.4	.0	.0	.1	.1	.0	4.8
300	.0	.6	.0	.0	.0	.1	.0	.0	.0	.1	.0	.0	.0	.0	.0	.0	.9
330	.0	.3	.0	.0	.0	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.6
360	.0	.0	.0	.0	.0	.1	.0	.0	.0	.1	.0	.0	.0	.0	.0	.0	.3
Calm	.0	1.3	1.8	.3													3.4
Total	.0	8.7	5.7	2.5	.6	48.6	2.3	.9	.6	23.2	2.3	.0	.0	4.3	.3	.0	100.0
Occurrence	16.9 %				52.4 %				26.1 %				4.6 %				100.0 %
Wind speed	.6 m/s				1.9 m/s				3.1 m/s				4.5 m/s				2.1 m/s

Frequency of occurrence of the stability classes

	Class I	Class II	Class III	Class IV	
Occurrence	1.2 %	84.7 %	10.7 %	3.4 %	100.0 %

Table A7: Joint frequency distribution (in %) in classes of stability (I: unstable, IV: stable), wind speeds and wind directions for July 1990 at:
a) Viksjøfjell (25 m)
b) Svanvik (10 m)

Delta T : VIKSJØFJELL
Wind : VIKSJØFJELL
Period : 01.07.90. - 31.07.90.
Unit : Percent

JOINT FREQUENCY DISTRIBUTION OF STABILITY, WIND SPEED AND WIND DIRECTION

Class I: Unstable DT < -.5 Degrees C
Class II: Neutral -.5 < DT < .0 Degrees C
Class III: Light stable .0 < DT < .5 Degrees C
Class IV: Stable .5 < DT Degrees C

Calm: U less or equal .3 m/s

Wind-	.0- 2.0 m/s				2.0- 4.0 m/s				4.0- 6.0 m/s				over 6.0 m/s				
direction	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	Rose
30	.0	.4	.0	.0	.0	1.6	.1	.0	.0	6.0	.0	.0	.0	10.0	.0	.0	18.2
60	.0	.0	.0	.0	.0	.6	.4	.0	.0	1.7	.0	.1	.0	1.3	.0	.0	4.2
90	.0	.0	.1	.0	.4	.4	.4	.0	.0	3.4	.1	.0	.7	1.0	.0	.0	6.7
120	.0	.0	.0	.0	.1	1.9	.4	.0	.1	2.9	1.9	.4	.3	1.6	1.0	.1	10.8
150	.0	.0	.0	.0	.0	.3	.7	.0	.0	1.7	1.9	.1	.0	3.2	.9	.1	8.9
180	.0	.1	.1	.0	.0	.6	.1	.0	.0	2.3	.7	.0	.0	5.7	.4	.0	10.2
210	.0	.1	.1	.0	.0	.1	.4	.0	.0	.7	.1	.0	.4	5.9	2.6	.0	10.6
240	.0	.3	.3	.0	.0	.6	.1	.0	.0	.6	.0	.0	.0	.3	.0	.0	2.2
270	.0	.0	.0	.0	.0	.3	.1	.0	.0	.1	.1	.0	.0	.4	.1	.0	1.3
300	.0	.1	.0	.0	.0	.3	.0	.0	.0	1.9	.0	.0	.0	.3	.0	.0	2.6
330	.0	.3	.0	.0	.0	.4	.0	.0	.0	2.2	.0	.0	.0	6.0	.0	.0	8.9
360	.0	.0	.3	.1	.0	1.1	.0	.0	.0	4.4	.4	.0	.0	9.0	.0	.0	15.5
Calm	.0	.0	.0	.0													.0
Total	.0	1.4	1.0	.1	.6	8.2	3.0	.0	.1	28.0	5.3	.7	1.4	44.8	5.0	.3	100.0
Occurrence	2.6 %				11.8 %				34.1 %				51.5 %				100.0 %
Wind speed	1.4 m/s				3.3 m/s				4.9 m/s				8.8 m/s				6.6 m/s

Frequency of occurrence of the stability classes

	Class I	Class II	Class III	Class IV	
Occurrence	2.2 %	82.4 %	14.3 %	1.1 %	100.0 %

Delta T : VIKSJØFJELL
Wind : SVANVIK
Period : 01.07.90. - 31.07.90.
Unit : Percent

JOINT FREQUENCY DISTRIBUTION OF STABILITY, WIND SPEED AND WIND DIRECTION

Class I: Unstable DT < -.5 Degrees C
Class II: Neutral -.5 < DT < .0 Degrees C
Class III: Light stable .0 < DT < .5 Degrees C
Class IV: Stable .5 < DT Degrees C

Calm: U less or equal .3 m/s

Wind-	.0- 1.0 m/s				1.0- 2.5 m/s				2.5- 4.0 m/s				over 4.0 m/s				
direction	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	Rose
30	.0	4.8	1.4	.0	.0	15.6	.4	.3	.0	4.0	.0	.0	.0	.1	.0	.0	26.7
60	.0	3.5	1.0	.3	.1	10.7	.3	.1	.0	2.5	.0	.0	.0	.9	.0	.0	19.4
90	.0	1.4	1.0	.0	.9	4.2	.6	.0	.1	.3	.0	.0	.0	.0	.0	.0	8.5
120	.1	.3	.4	.0	.0	.7	.4	.0	.0	.6	.1	.0	.0	.0	.0	.0	2.7
150	.1	.6	.3	.0	.1	2.0	.3	.0	.0	1.2	.4	.0	.0	.0	.0	.0	5.1
180	.0	.7	.3	.1	.0	2.9	1.0	.0	.0	4.0	.0	.0	.0	.3	.1	.0	9.5
210	.0	.1	.1	.0	.0	3.0	1.0	.0	.3	3.2	1.3	.0	.1	1.2	.0	.0	10.4
240	.0	.4	.1	.0	.1	.9	.0	.0	.0	1.7	.1	.0	.0	1.6	.0	.0	5.1
270	.0	.3	.1	.0	.0	1.3	.1	.0	.0	.1	.0	.0	.0	.0	.0	.0	2.0
300	.0	1.2	.1	.0	.0	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.6
330	.0	1.0	.3	.0	.0	2.7	.0	.0	.0	.1	.0	.0	.0	.0	.0	.0	4.2
360	.0	.3	.1	.0	.0	.6	.0	.0	.0	.1	.0	.0	.0	.0	.0	.0	1.2
Calm	.0	.7	2.6	.3													3.6
Total	.3	15.3	8.1	.7	1.3	44.9	4.2	.4	.4	17.9	2.0	.0	.1	4.0	.1	.0	100.0
Occurrence	24.4 %				50.9 %				20.4 %				4.3 %				100.0 %
Wind speed	.7 m/s				1.8 m/s				3.2 m/s				4.8 m/s				1.9 m/s

Frequency of occurrence of the stability classes

	Class I	Class II	Class III	Class IV	
Occurrence	2.2 %	82.2 %	14.5 %	1.2 %	100.0 %

Table A8: Joint frequency distribution (in %) in classes of stability (I: unstable, IV: stable), wind speeds and wind directions for August 1990 at:
a) Viksjøfjell (25 m)
b) Svanvik (10 m)

Delta T : VIKSJØFJELL
Wind : VIKSJØFJELL
Period : 01.08.90. - 31.08.90.
Unit : Percent

JOINT FREQUENCY DISTRIBUTION OF STABILITY, WIND SPEED AND WIND DIRECTION

Class I: Unstable DT < -.5 Degrees C
Class II: Neutral -.5 < DT < .0 Degrees C
Class III: Light stable .0 < DT < .5 Degrees C
Class IV: Stable .5 < DT Degrees C

Calm: U less or equal .3 m/s

Wind-direction	.0- 2.0 m/s I	II	III	IV	2.0- 4.0 m/s I	II	III	IV	4.0- 6.0 m/s I	II	III	IV	over 6.0 m/s I	II	III	IV	Rose
30	.0	.1	.0	.0	.0	.3	.4	.0	.0	3.3	.3	.0	.0	4.1	.0	.0	8.6
60	.0	.4	.1	.0	.0	1.0	.0	.0	.0	2.3	.1	.0	.0	1.4	.0	.0	5.4
90	.0	.4	.1	.0	.0	.7	.1	.0	.0	2.9	.0	.0	.0	1.7	.1	.0	6.1
120	.0	.0	.0	.0	.0	1.4	.3	.0	.0	6.0	.6	.0	.0	1.0	1.6	.0	10.8
150	.0	.4	.1	.0	.0	1.9	.0	.0	.0	6.6	3.6	1.4	.0	.7	.4	.1	15.3
180	.0	.3	.0	.0	.0	.4	.3	.0	.0	2.7	2.9	.7	.0	2.1	2.9	1.1	13.4
210	.0	.1	.0	.0	.0	.4	.7	.0	.0	2.3	2.7	.1	.0	4.9	3.4	.9	15.5
240	.0	.6	.0	.0	.0	1.3	.1	.0	.0	4.0	1.1	.0	.0	2.1	1.9	.0	11.1
270	.0	.0	.0	.0	.0	1.0	.3	.0	.0	.4	.1	.0	.0	.0	.1	.0	2.0
300	.0	.6	.0	.0	.0	.9	.1	.0	.0	1.9	.0	.0	.0	.7	.0	.0	4.1
330	.0	.4	.0	.0	.0	.4	.3	.0	.0	1.1	.0	.0	.0	.7	.0	.0	3.0
360	.0	.4	.0	.0	.0	.4	.1	.0	.0	1.4	.0	.0	.0	2.1	.0	.0	4.6
Calm	.0	.0	.0	.0													.0
Total	.0	3.9	.4	.0	.0	10.1	2.9	.0	.0	34.8	11.4	2.3	.0	21.7	10.4	2.1	100.0
Occurrence		4.3 %				13.0 %				48.5 %				34.2 %			100.0 %
Wind speed		1.4 m/s				3.2 m/s				4.8 m/s				8.2 m/s			5.6 m/s

Frequency of occurrence of the stability classes

	Class I	Class II	Class III	Class IV	
Occurrence	.0 %	70.5 %	25.1 %	4.4 %	100.0 %

Delta T : VIKSJØFJELL
Wind : SVANVIK
Period : 01.08.90. - 31.08.90.
Unit : Percent

JOINT FREQUENCY DISTRIBUTION OF STABILITY, WIND SPEED AND WIND DIRECTION

Class I: Unstable DT < -.5 Degrees C
Class II: Neutral -.5 < DT < .0 Degrees C
Class III: Light stable .0 < DT < .5 Degrees C
Class IV: Stable .5 < DT Degrees C

Calm: U less or equal .3 m/s

Wind-direction	.0- 1.0 m/s I	II	III	IV	1.0- 2.5 m/s I	II	III	IV	2.5- 4.0 m/s I	II	III	IV	over 4.0 m/s I	II	III	IV	Rose
30	.0	2.5	.2	.0	.0	3.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	5.8
60	.0	2.5	.2	.0	.0	6.2	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	9.0
90	.0	3.2	1.4	.0	.0	3.0	.5	.0	.0	.7	.0	.0	.0	.0	.0	.0	8.8
120	.0	2.5	.7	.0	.0	2.6	.9	.4	.0	.2	.0	.0	.0	.0	.0	.0	7.2
150	.0	4.4	1.8	.4	.0	2.5	1.4	.2	.0	.0	.5	.0	.0	.0	.0	.0	11.1
180	.0	2.1	1.1	.4	.0	7.2	1.2	.0	.0	2.8	.2	.0	.0	.0	.0	.0	14.9
210	.0	.2	1.2	.0	.0	4.0	1.9	.2	.0	.9	.0	.0	.0	.0	.0	.0	8.4
240	.0	2.1	.4	.0	.0	2.8	.5	.2	.0	.9	.4	.0	.0	.9	.0	.0	8.1
270	.0	1.9	.5	.2	.0	1.8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	4.4
300	.0	1.1	.4	.4	.0	.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.3
330	.0	1.8	1.2	.5	.0	.9	.2	.0	.0	.5	.0	.0	.0	.0	.0	.0	5.1
360	.0	.7	.0	.0	.0	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.9
Calm	.0	4.4	7.6	2.1													14.1
Total	.0	29.2	16.5	3.9	.0	34.8	6.9	.9	.0	6.0	1.1	.0	.0	.9	.0	.0	100.0
Occurrence		49.6 %				42.5 %				7.0 %				.9 %			100.0 %
Wind speed		.6 m/s				1.7 m/s				2.9 m/s				4.9 m/s			1.2 m/s

Frequency of occurrence of the stability classes

	Class I	Class II	Class III	Class IV	
Occurrence	.0 %	70.8 %	24.4 %	4.7 %	100.0 %

Table A9: Joint frequency distribution (in %) in classes of stability (I: unstable, IV: stable), wind speeds and wind directions for September 1990 at:
a) Viksjøfjell (25 m)
b) Svanvik (10 m)

Delta T : VIKSJØFJELL
Wind : VIKSJØFJELL
Period : 01.09.90. - 30.09.90.
Unit : Percent

JOINT FREQUENCY DISTRIBUTION OF STABILITY, WIND SPEED AND WIND DIRECTION

Class I: Unstable DT < -.5 Degrees C
Class II: Neutral -.5 < DT < .0 Degrees C
Class III: Light stable .0 < DT < .5 Degrees C
Class IV: Stable .5 < DT Degrees C

Calm: U less or equal .3 m/s

Wind-	.0- 2.0 m/s				2.0- 4.0 m/s				4.0- 6.0 m/s				over 6.0 m/s				
direction	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	Rose
30	.0	.0	.1	.0	.0	1.0	.9	.0	.0	1.0	.0	.0	.0	2.7	.0	.0	5.8
60	.0	.0	.0	.0	.0	.3	1.9	.0	.0	1.8	.9	.0	.0	.7	.0	.0	5.6
90	.0	.0	.1	.0	.0	.1	.6	.0	.0	.0	.1	.0	.0	.3	.0	.0	1.3
120	.0	.0	.0	.0	.0	.0	.3	.0	.0	2.8	1.3	.3	.0	4.9	.3	.0	9.9
150	.0	.0	.0	.1	.0	.7	.6	.3	.0	1.8	1.6	1.5	.0	4.3	2.8	.3	14.0
180	.0	.1	.0	.0	.0	.4	.4	.7	.0	1.3	1.2	.0	.0	2.1	1.3	.6	8.3
210	.0	.1	.0	.0	.0	.1	.4	.0	.0	2.4	1.6	.1	.0	9.3	5.6	2.5	22.3
240	.0	.0	.0	.0	.0	1.3	.3	.0	.0	3.7	.6	.0	.0	3.4	2.5	.4	12.3
270	.0	.3	.1	.0	.0	.3	.0	.0	.0	.1	.0	.0	.0	1.5	.3	.0	2.7
300	.0	.0	.0	.0	.0	.0	.0	.0	.0	.1	.0	.0	.0	4.6	.0	.0	4.7
330	.0	.0	.0	.0	.0	.4	.4	.0	.0	.4	.1	.0	.0	2.5	.0	.0	4.0
360	.0	.0	.0	.0	.0	.7	.4	.0	.0	.9	.6	.0	.0	6.1	.4	.0	9.2
Calm	.0	.0	.0	.0													.0
Total	.0	.6	.4	.1	.0	5.6	6.4	1.0	.0	16.4	8.1	1.9	.0	42.2	13.3	3.8	100.0
Occurrence	1.2 %				13.0 %				26.4 %				59.4 %				100.0 %
Wind speed	1.6 m/s				3.3 m/s				5.0 m/s				9.2 m/s				7.3 m/s

Frequency of occurrence of the stability classes

	Class I	Class II	Class III	Class IV	
Occurrence	.0 %	64.8 %	28.2 %	6.9 %	100.0 %

Delta T : VIKSJØFJELL
Wind : SVANVIK
Period : 01.09.90. - 30.09.90.
Unit : Percent

JOINT FREQUENCY DISTRIBUTION OF STABILITY, WIND SPEED AND WIND DIRECTION

Class I: Unstable DT < -.5 Degrees C
Class II: Neutral -.5 < DT < .0 Degrees C
Class III: Light stable .0 < DT < .5 Degrees C
Class IV: Stable .5 < DT Degrees C

Calm: U less or equal .3 m/s

Wind-	.0- 1.0 m/s				1.0- 2.5 m/s				2.5- 4.0 m/s				over 4.0 m/s				
direction	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	Rose
30	.0	.4	2.7	.6	.0	1.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	5.6
60	.0	.6	1.5	.1	.0	.9	.7	.0	.0	.0	.0	.0	.0	.0	.0	.0	3.8
90	.0	.3	1.2	.1	.0	1.0	.4	.0	.0	.9	.0	.0	.0	.6	.0	.0	4.6
120	.0	.3	.4	.6	.0	.9	.1	.0	.0	.3	.0	.0	.0	1.8	.0	.0	4.4
150	.0	.3	.9	.1	.0	1.3	1.5	.1	.0	1.3	.0	.0	.0	.9	.0	.0	6.5
180	.0	.4	1.0	.0	.0	2.8	3.1	.6	.0	1.9	.6	.0	.0	.4	.0	.0	10.9
210	.0	1.5	.0	.1	.0	4.0	2.2	.9	.0	2.4	1.6	.3	.0	2.7	1.0	.0	16.6
240	.0	1.3	.4	.6	.0	2.9	.7	.1	.0	4.3	.0	.0	.0	1.9	.1	.0	12.5
270	.0	1.9	1.0	.4	.0	1.6	.1	.0	.0	.7	.1	.0	.0	.0	.0	.0	6.0
300	.0	1.8	1.2	.4	.0	1.6	.0	.0	.0	.1	.0	.0	.0	.0	.0	.0	5.2
330	.0	1.3	1.3	.6	.0	.7	.0	.0	.0	.3	.0	.0	.0	.6	.0	.0	4.9
360	.0	1.0	1.3	.7	.0	4.4	.3	.0	.0	4.1	.0	.0	.0	3.4	.0	.0	15.3
Calm	.0	.9	2.4	.4													3.7
Total	.0	12.1	15.3	5.0	.0	24.2	9.3	1.8	.0	16.3	2.4	.3	.0	12.2	1.2	.0	100.0
Occurrence	32.4 %				35.2 %				19.0 %				13.4 %				100.0 %
Wind speed	.6 m/s				1.7 m/s				3.2 m/s				4.6 m/s				2.0 m/s

Frequency of occurrence of the stability classes

	Class I	Class II	Class III	Class IV	
Occurrence	.0 %	64.8 %	28.1 %	7.1 %	100.0 %

APPENDIX B

Estimated monthly average concentration
of SO_2 for January-June 1990.
The model CONDEP is used to estimate the concentrations.
The observed concentrations are presented for each
monitoring station.

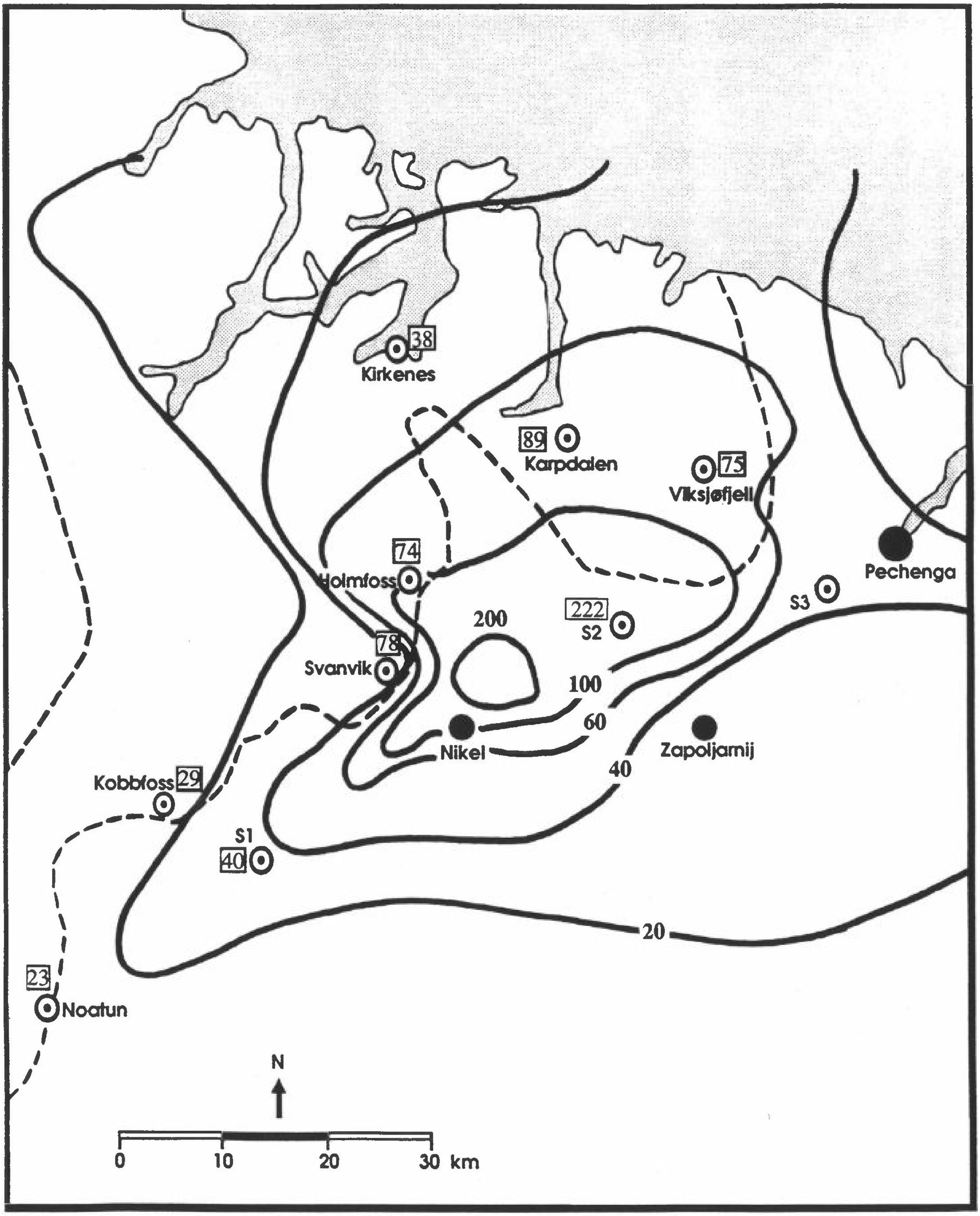

Figure B1: Estimated monthly average concentration of SO_2 for January 1990 ($\mu g/m^3$).

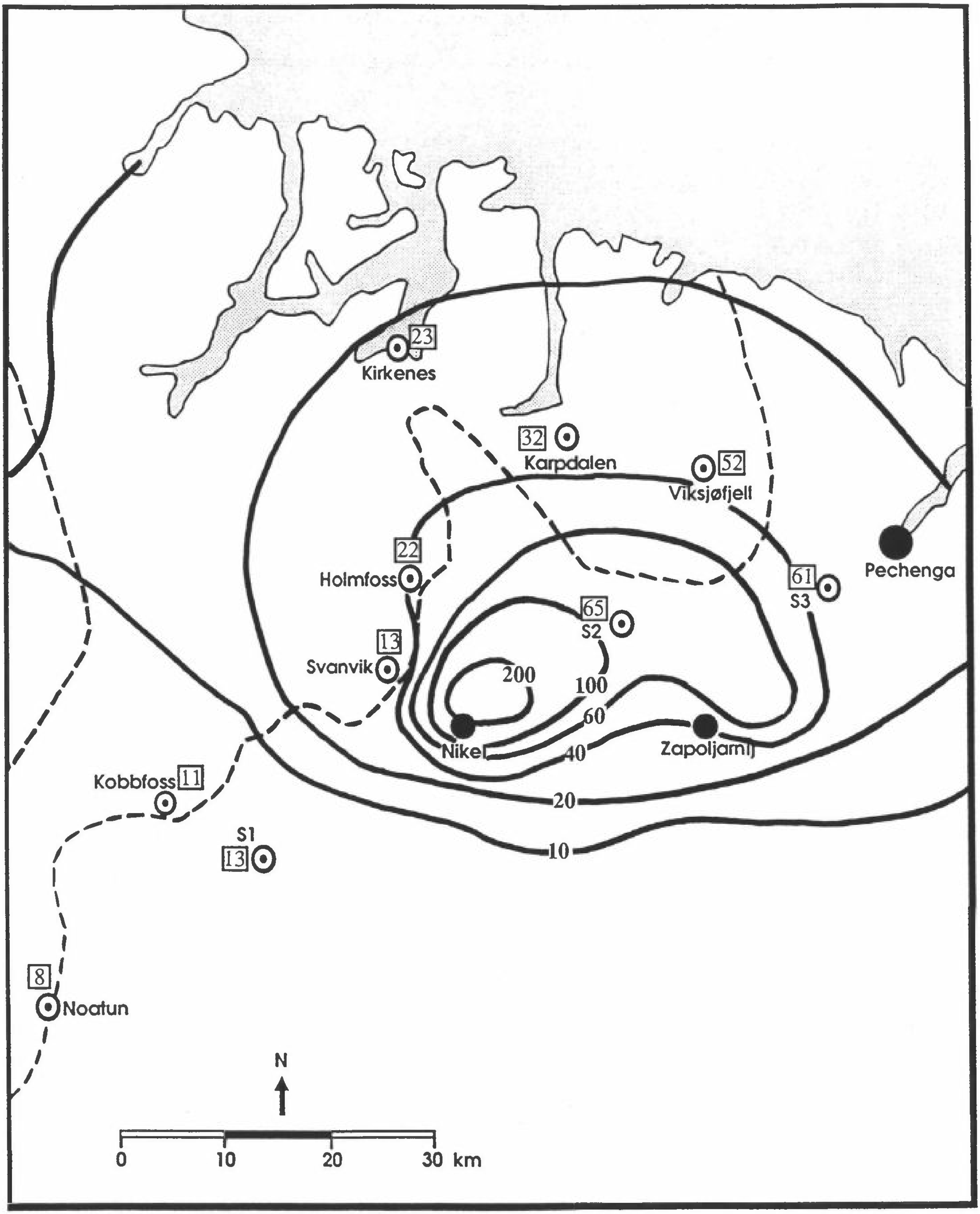

Figure B2: Estimated monthly average concentration of SO_2 for February 1990 ($\mu g/m^3$).

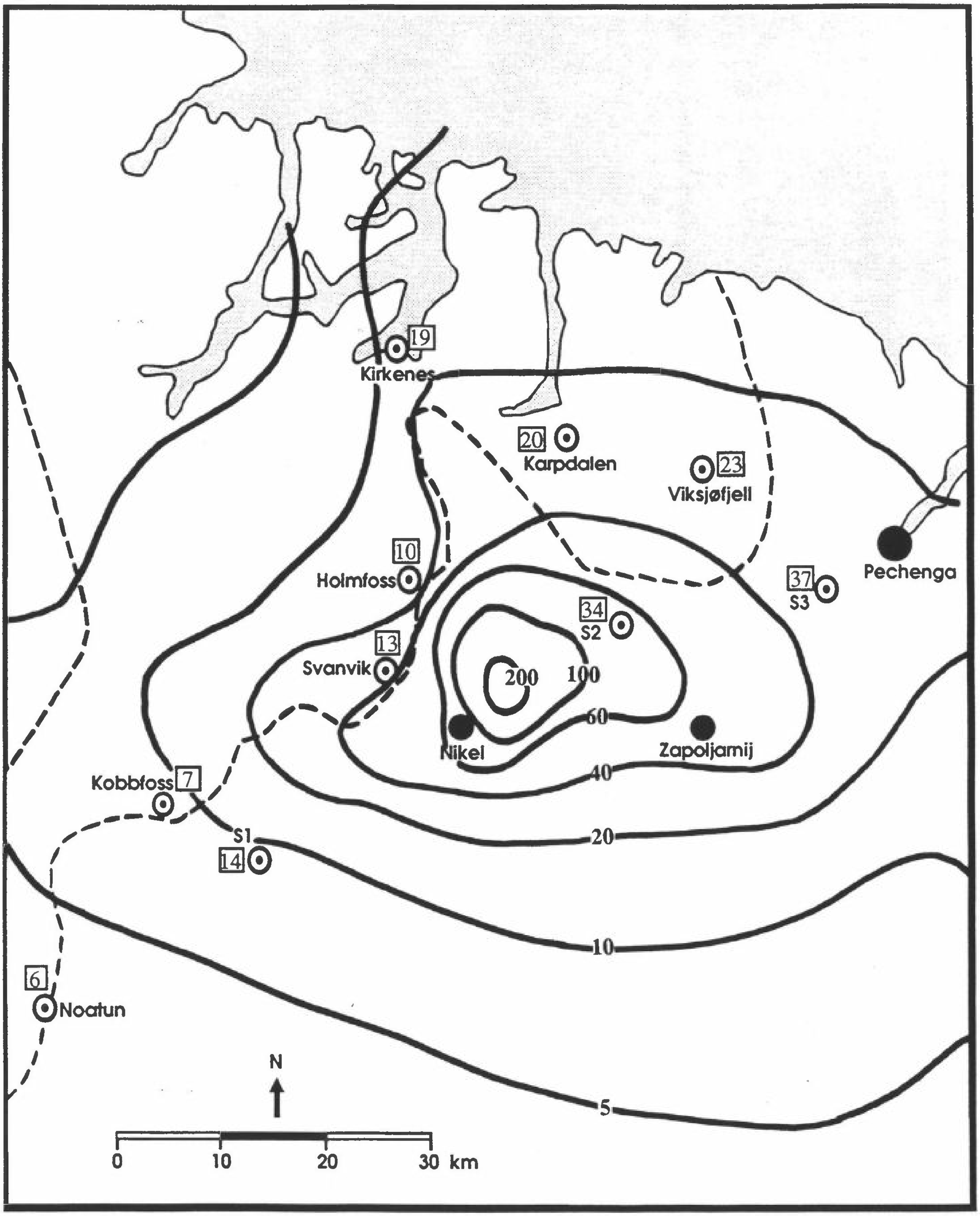

Figure B3: Estimated monthly average concentration of SO_2 for March 1990 ($\mu g/m^3$).

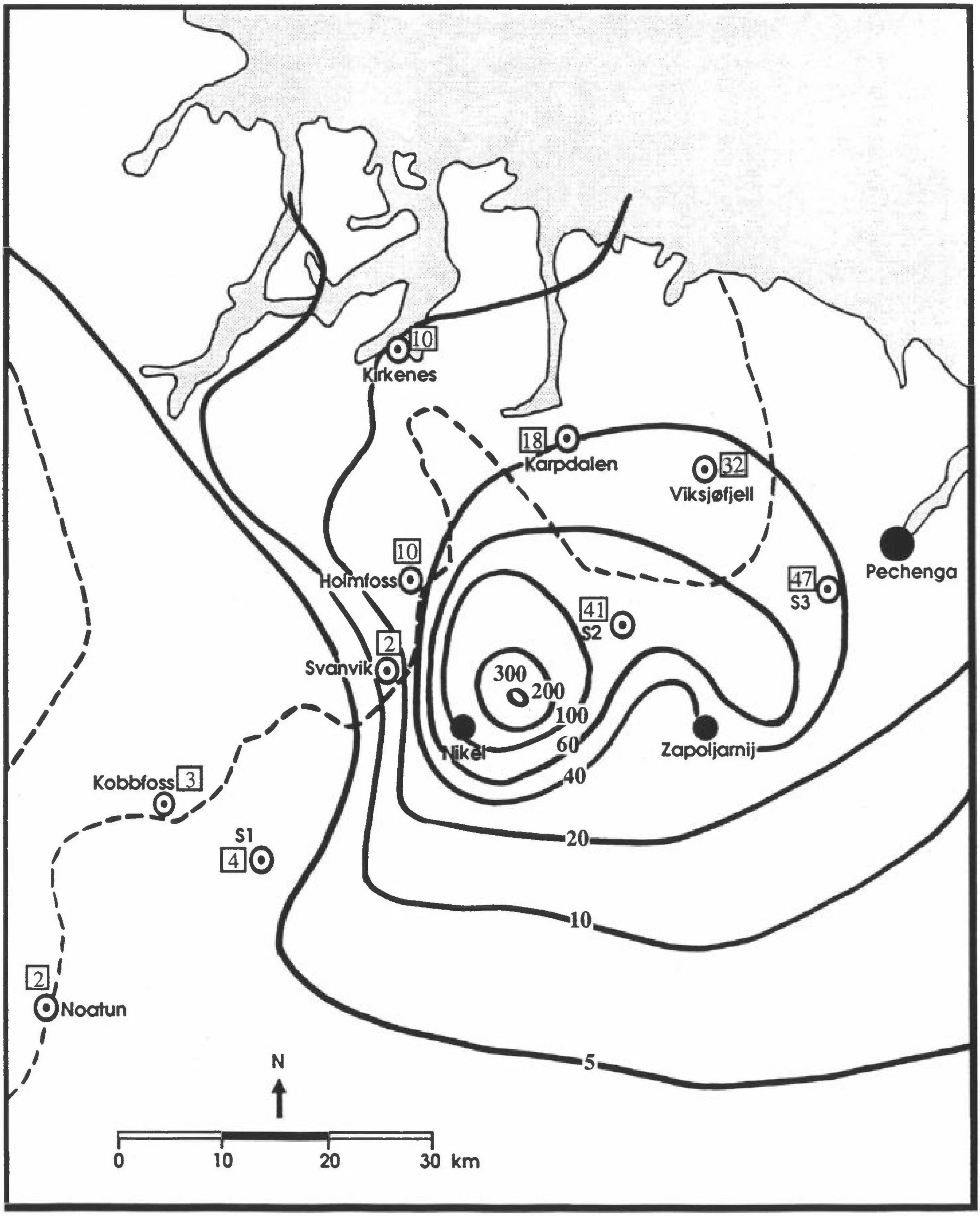

Figure B4: Estimated monthly average concentration of SO_2 for April 1990 ($\mu g/m^3$).

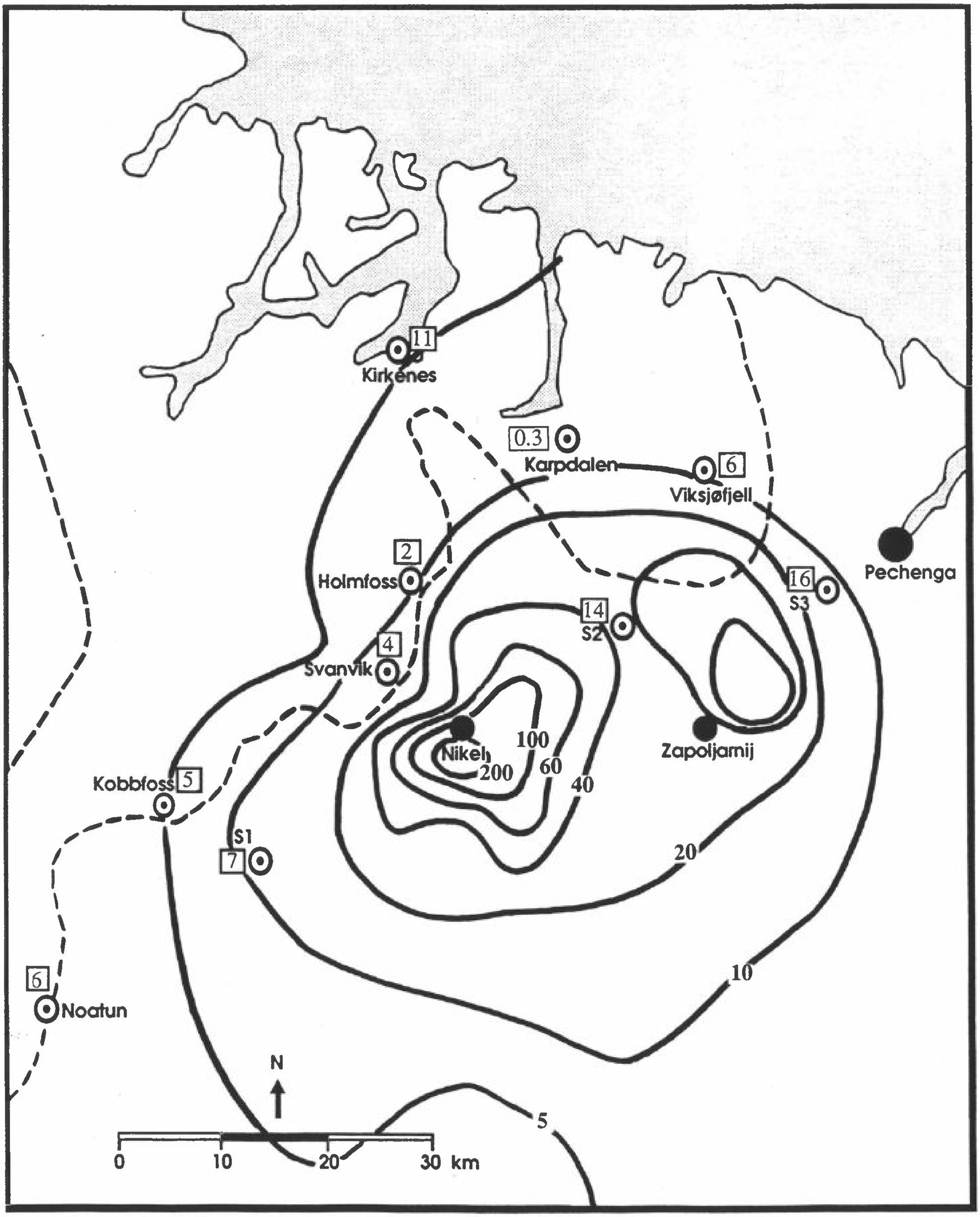

Figure B5: Estimated monthly average concentration of SO_2 for May 1990 ($\mu g/m^3$).

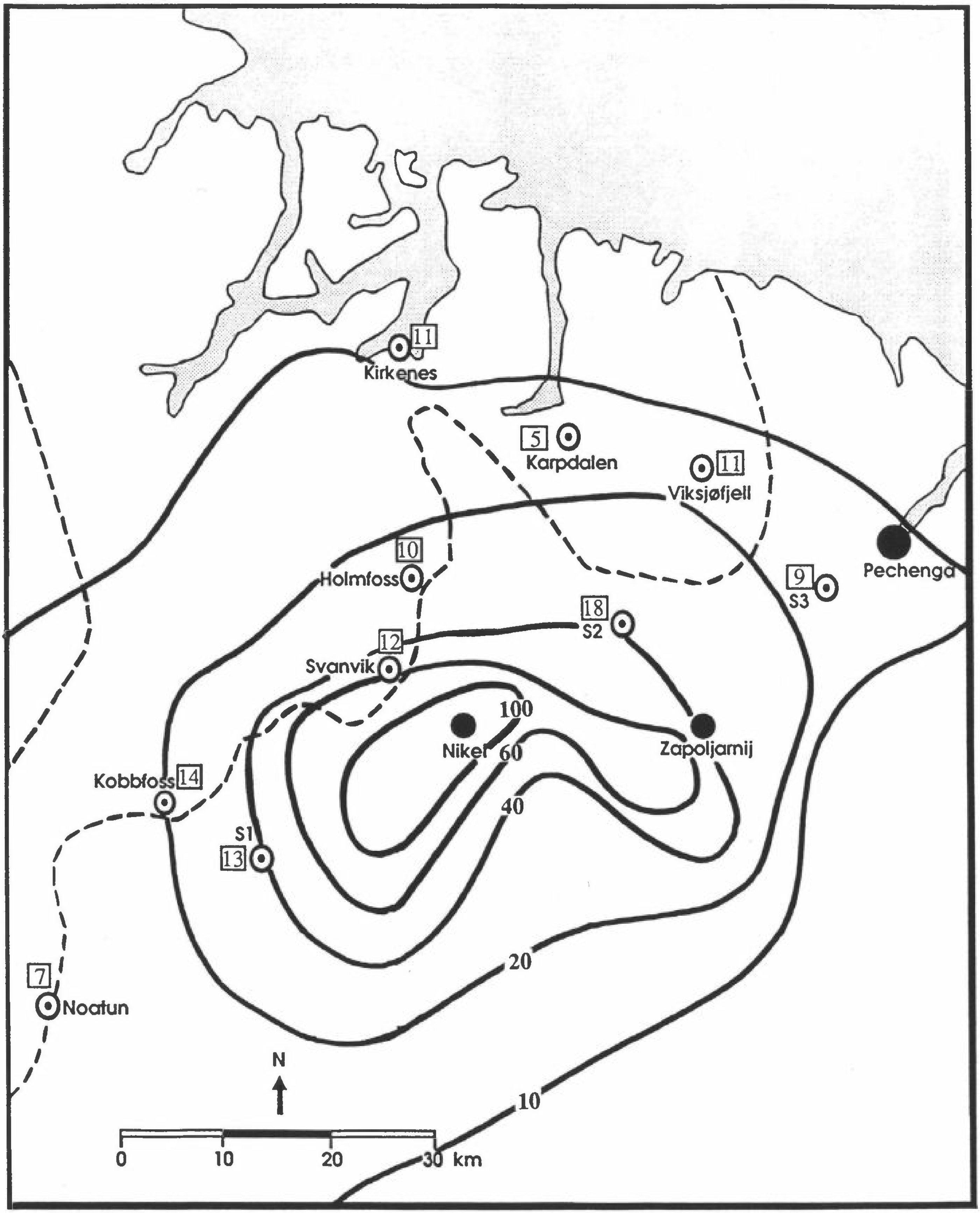

Figure B6: Estimated monthly average concentration of SO_2 for June 1990 ($\mu g/m^3$).

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RAPPORTTYPE OPPDRAGSRAPPORT	RAPPORTNR. OR 23/91	ISBN-82-425-0243-9	
DATO JANUARY 1991	ANSV. SIGN.	ANT. SIDER 54	PRIS NOK 90,-
TITTEL Air quality in the border areas between Norway and USSR Model description and preliminary modelling results.		PROSJEKTLEDER B. Sivertsen NILU PROSJEKT NR. O-8976	
FORFATTER(E) O. Hellevik and B. Sivertsen (Prepared for the expert meeting in January 1991)		TILGJENGELIGHET * A OPPDRAGSGIVERS REF.	

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STIKKORD

Basisundersøkelser	Modellberegning	Sør-Varanger

REFERAT
Rapporten gir en kort beskrivelse av spredningsmodellene CONDEP og INPUFF. Modell CONDEP er brukt til å beregne SO_2-konsentrasjoner for vinterhalvåret 1989/90 samt sommeren 1990 langs grensa mot Sovjetunionen i Sør-Varanger. Det er videre vist månedsmidler av SO_2 for de 6 første månedene i 1990. INPUFF beregner timesvise konsentrasjoner. Bare få beregninger foreligger hittil.

TITLE Air quality in the border areas between Norway and USSR.
Model description and modelling results.

ABSTRACT
The air quality dispersion models CONDEP and INPUFF have been described and used to calculate dispersion of SO_2 in the border area between Norway and USSR. The model CONDEP was used to calculate monthly mean SO_2-consentrations from January to June 1990. The average SO_2-concentrations was also estimated for the winter season 1989-90 and the summer season 1990. INPUFF estimates hourly concentrations for selected episodes. Only a few experiments have been performed so far.

* Kategorier: Åpen - kan bestilles fra NILU A
Må bestilles gjennom oppdragsgiver B
Kan ikke utleveres C