Dispersion calculations of SO₂-concentrations in Sør-Varanger

May 1st–October 25th, 1994

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Summary

On assignment from Anders Selnes and Tone Smith-Sivertsen, of the Institute for Community Medicine, University of Tromsø, Norwegian Institute for Air Research (NILU) has carried out dispersion calculations of emission to air of sulphur dioxide from the nickel smelters in Nikel and Zapoljarnij, and from A/S Sydvaranger in Kirkenes during the period May 1st-October 25th, 1994.

Selnes and Smith-Sivertsen are analysing the possible health effects of exposure to pollution from the nickel industry on the Kola peninsula. A health examination has been carried out in the community of Sør Varanger in the same period. NILU has evaluated the air quality (SO_2-concentrations) in the area around the home for each participant the same day, and two days before they met for health examination. NILU's dispersion model EPISODE was used to perform these calculations.

Hourly ground level concentrations of sulphur dioxide (2 m above the ground) have been calculated for 20x18 grid squares, (each square is 5x5 km^2) for the period May 1st–October 25th, 1994. In addition, hourly concentrations of sulphur dioxide were calculated for all subgrid squares (1x1 km^2).

Calculated concentrations of SO_2 were compared to measurements at two stations in Sør-Varanger. Assuming a spatial uncertainty of 5 km, the correlation between calculated and measured concentrations was good. The correlation was best at Svanvik.

Spatial uncertainty in the calculated values is a result of e.g. sharp gradients between the iso-lines describing the concentrations in the area, unpredicted variations in dispersion conditions (wind direction, wind speed) and large distances from the emission source to point of calculation. Since a constant emission strength was used, variations in the emission due to temporary standstill of operations or increased/reduced emissions will not be reflected in the model, nor will spatial variations in the dispersion conditions of the atmosphere.

Data (results) for all receptor points are given on a hourly basis from May 1st until October 25th. The results were presented in five files, each file containing results from five receptor points. For each hour and receptor point, four values are given:

- Calculated average concentration in a 5x5 km^2 grid square surrounding the station.
- Calculated average concentration in a 1x1 km^2 grid square surrounding the station.
- Lowest calculated concentration (1x1 km^2 grid square) within a radius of 5 km.
- Highest calculated concentration (1x1 km^2 grid square) within a radius of 5 km.

The results from the dispersion calculations will be compared to the participant's lung function at the day of the health examination. This work is performed to verify whether possible health effects can be identified. The health study will be carried out by Selnes and Smith-Sivertsen.

We want to point out that the calculated concentrations for the receptor points must be used cautiously. The results will, however, give an indication of whether elevated SO_2-concentrations may have occurred at the chosen receptor point the day the health examination was carried out, but the exact concentration or concentration level will remain somewhat uncertain.

Dispersion calculations of SO_2-concentrations in Sør-Varanger
May 1st–October 25th, 1994

1. Introduction

Norwegian Institute for Air Research has on assignment from Ph.D. students Anders Selnes and Tone Smith-Sivertsen, Institute for Community Medicine, University of Tromsø, performed dispersion calculations of sulphur dioxide as a result of emissions of SO_2 into the air from the nickel smelters in Nikel and Zapoljarnij, and A/S Syd Varanger in Kirkenes during the period May 1st–October 25th, 1994.

Selnes and Smith-Sivertsen are studying possible health effects as a result of the emissions of SO_2 from the nickel industry on the Kola peninsula. The health conditions of the study population in the county of Sør-Varanger have been examined by Selnes and Smith-Sivertsen.

The health examination proceeded from May until October 1994 and included the entire county of Sør-Varanger. In addition to the health examination, the lung function of the participants was measured. All inhabitants in the age 18–69 had to answer a questionnaire concerning social situation, occupation, housing situation, health and lifestyle.

NILU has estimated the air quality (SO_2-concentrations) in the vicinity of the inhabitants' home the same day, and two days before they met for the health examination. The SO_2-concentrations were calculated by the dispersion model EPISODE at NILU.

The results of the dispersion calculations will be compared to the participants' lung function the day they met for the health examination to see if possible effects can be identified. This work will be done by Selnes and Smith-Sivertsen.

In addition to the calculated SO_2-concentrations, hourly measured temperature and humidity data for Viksjøfjell and Svanvik are presented by NILU, on request.

2. Model description

Dispersion calculations have been performed with NILUs dispersion model EPISODE 2.1 (Walker and Grønskei, 1992; Grønskei, Walker and Gram, 1993). The calculations were performed on an hourly basis for the period May 1st 0100–October 25th 1600, 1994.

EPISODE can calculate concentrations from area, line and point sources. Only point sources are accounted for here. Dispersion from the different point sources are modelled as individual plume segments. The dispersion height is a function of stack height, temperature, emission speed and wind speed. The total height of dispersion for each plume segment may vary from hour to hour.

The smoke plumes are transported along wind trajectories (wind direction and wind speed). The smoke plumes are at the same time expanding depending on the actual turbulent movement of the air masses. It is assumed that the plume has a Gaussian concentration distribution both in the horizontal and vertical directions.
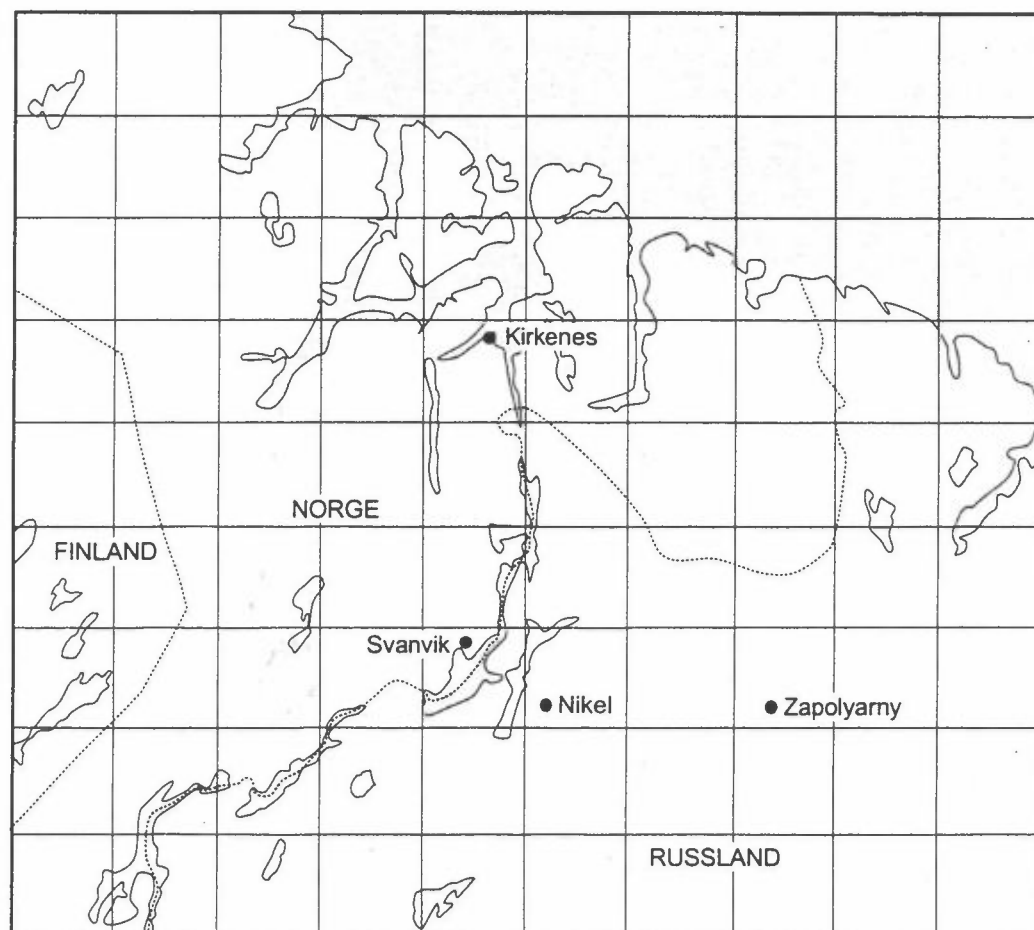

Figure 1:   Calculation area in Sør-Varanger. Each grid square is 10x10 km². The bottom left corner has UTM-coordinates (340,000, 7,680,000).

Horizontal and vertical standard deviations are calculated based on dispersion parameters (turbulence).

3. Input data

3.1 Definition

A 20x18 grid forms the basis of the calculation area. Each grid square is 5x5 km^2. Every 25 km^2 main grid square is divided into 5x5 sub-grid squares. Each sub-grid square is 1 km^2. The resolution of the model is therefore 1 km^2. In figure 1 the area of calculation is shown. Three vertical layers of 100, 100 and 400 m where used.

3.2 Emission data.

Only emissions from point sources (industry) were calculated. Other possible emissions, such as heating and traffic were not considered in the calculations. The main impact of sulphur dioxide in the area is related to industrial emissions. This means that the area- and traffic sources can be ignored.

Table 1 gives a general view of the point sources accounted for in the calculations. These cover the sources in the cities of Nikel, Zapoljarnij and Kirkenes. The emissions in Kirkenes are much smaller than the emissions in Nikel and Zapoljarnij.

3.3 Meteorological data

Horizontal homogenous temperature fields and the vertical temperature gradient are used in the EPISODE calculations. The temperature field 2 m above ground level is defined by the temperature measured at Svanvik, the temperature difference between 10 and 2 m measured at Viksjøfjell, is used as the vertical temperature gradient of the field. This temperature difference also gives an indication of atmospheric stability in the area on an hourly basis.

Test calculations were performed both for homogenous and inhomogenous wind fields. The inhomogenous wind fields were based on simultaneous use of the wind measurements at Svanvik and Viksjøfjell. Wind at Svanvik was used for calculations in the lower layers of the atmosphere (0–100 m), while wind at Viksjøfjell was used for the upper layers (200–600 m). These results were compared to the calculations performed with homogenous wind fields (i.e. the wind in all three vertical layers was equal to the wind at Viksjøfjell). The results of these test runs revealed that simple homogenous wind gave the best correlation between measured and calculated concentrations at the measurement stations Svanvik and Viksjøfjell. This probably reflects the fact that wind at Viksjøfjell is more representative for a greater part of the calculation area, and especially the areas between the large sources in Nikel and Zapoljarnij and the measurement stations in Norway. The wind at Svanvik is locally influenced and is therefore not representative for broad calculation areas. This is probably also true for the other receptor points in the calculation area. Based on these results, calculations have been performed with homogenous hourly wind fields based only upon measurements of wind at Viksjøfjell.

Table 1: Emission sources in Nikel, Zapoljarnij and Kirkenes.

Source number	Source strength SO$_2$ (g/s)	Stack height (m)	Temperature (K)	Stack gas 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

Based on wind and temperature data from Viksjøfjell, horizontal and vertical dispersion parameters for the plumes, σ_v and σ_w were calculated with NILUs meterological pre-processor MEPDIM (Bøhler, 1996). Horizontal and vertical dispersion is calculated in accordance to the formulas presented by Irwin (Irwin, 1983) and Venkatram (Venkatram, 1984).

An average surface roughness of 0,3 m was adopted for the whole grid area. The mixing height was set to 1000 m.

In the calculations, wet- and dry deposition were not considered.

4. Results

Hourly fields (20x18 grid squares) of ground level SO_2-concentrations (2 m above ground) were calculated for the whole period, May 1st 1994 0100–October 25th 1994 1600. The results are presented as mean concentrations for the square ($5x5$ km^2).

In addition, hourly fields of SO_2-concentrations in all sub-grid squares ($1x1$ km^2) were calculated for the same period. These results refer to mean concentrations for each km^2-square.

Figure 2 and 4 present observed and calculated concentrations at the measurement stations Svanvik and Viksjøfjell. Only the period July 15th–30th 1994 for Svanvik and the period September 1st–15th 1994 for Viksjøfjell is presented in the figures. This to give the best possible graphical presentation of the results. As indicated in the figures, the correlation between measured and calculated values differ. This is first of all due to uncertainties in the dispersion conditions (wind direction and speed). It is especially difficult to make the plume impinge the measurement stations at the right time because of the large distances between the sources of emission and points of measurement. A slight difference in wind direction or speed can easily result in larger differences of the positioning of the plume close to the measurement stations. Hence, a spatial variation of at least 5–6 km has to be considered.

In addition to uncertainties of wind direction/wind speed, variations in the strength of emissions may occur which are not accounted for in the model. The model assumes constant emission from the sources, while daily variation of emissions may occur because of changes in operating conditions, temporary standstill in operations, increased emission, etc. This can result in uncertainties in the concentration levels at the measurement stations which are difficult to quantify.

Also, uncertainties in the actual turbulence of the atmosphere may result in errors in the horizontal and vertical dispersion of the plumes. This can result in deviations from the concentration levels at the measurement stations.

Figure 3 and 5 present the observed and calculated concentrations with a spatial uncertainty of 5 km at the measurement stations for the same periods. This is done by choosing the hourly value in the concentration field (within a 5 km radius) that best correlates with the measured value. The figure reveals that this yields a far better correlation between measured and calculated concentrations. Hence, most of the differences at the measurement stations can be explained by spatial uncertainty (sharp gradients in the concentration field surrounding the stations).
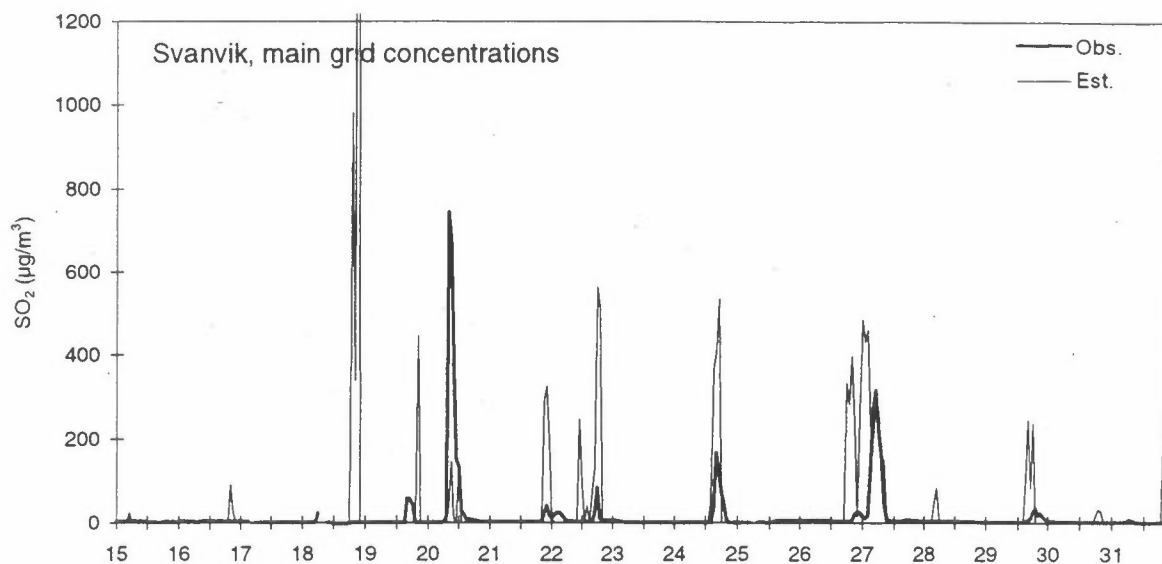
Figure 2: *Measured and calculated SO$_2$-concentrations at Svanvik.*
Unit: µg SO$_2$/m^3.
Period: 94.07.15 0100–94.07.31 2400.
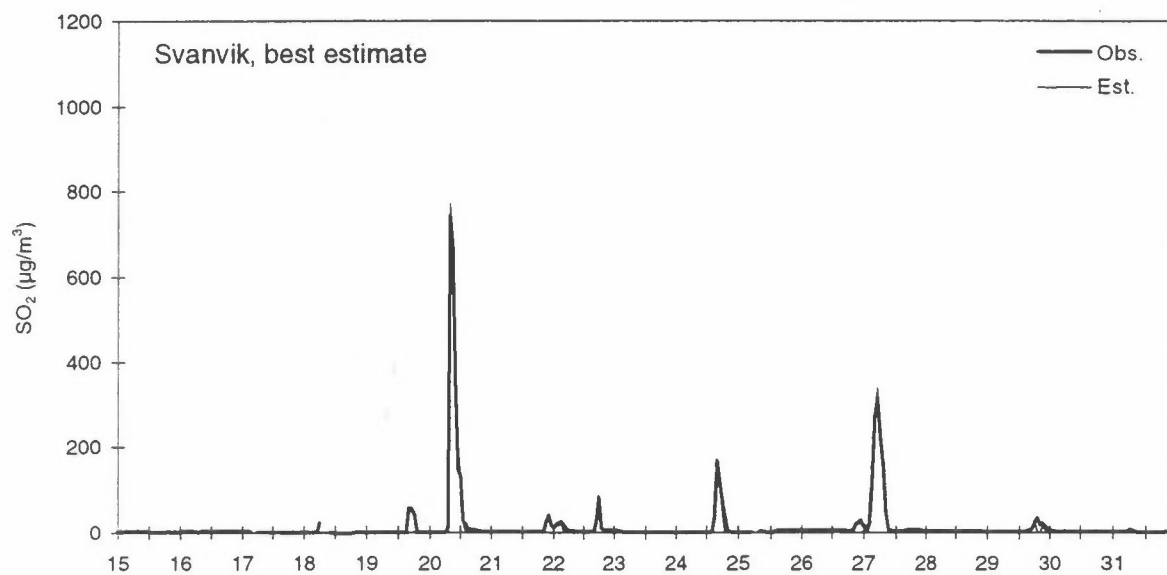

Figure 3: *Measured and calculated SO$_2$-concentrations at Svanvik. Filtered for*
spatial uncertainty.
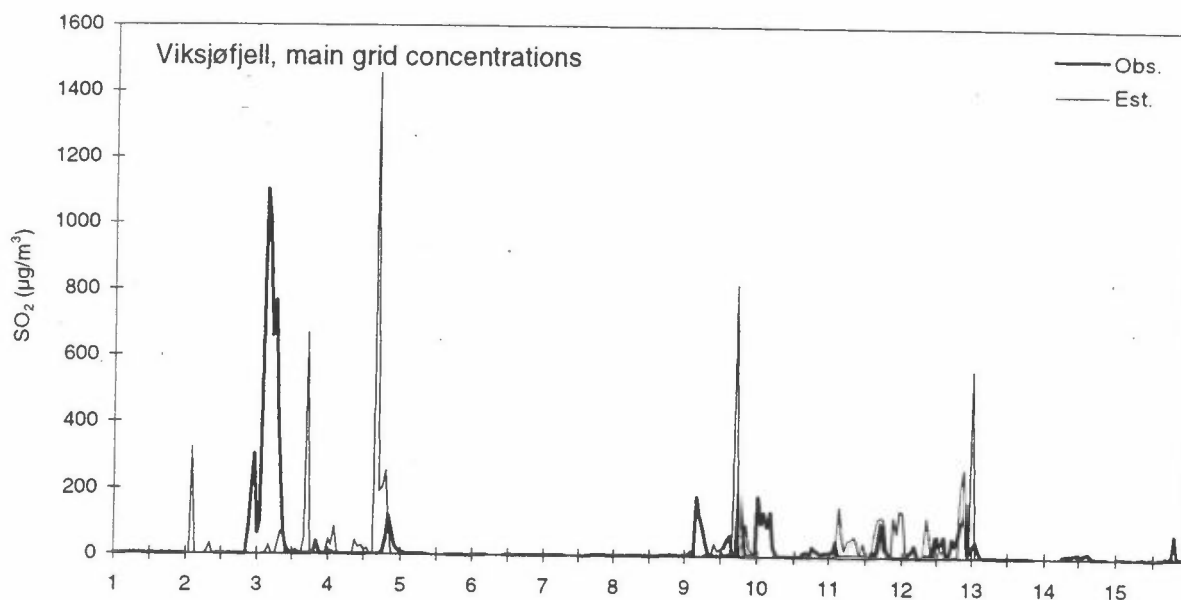*Unit: µg SO$_2$/m^3.*
Period: 94.07.15 0100–94.07.31 2400.

Figure 4: Measured and calculated SO₂-concentrations at Viksjøfjell.
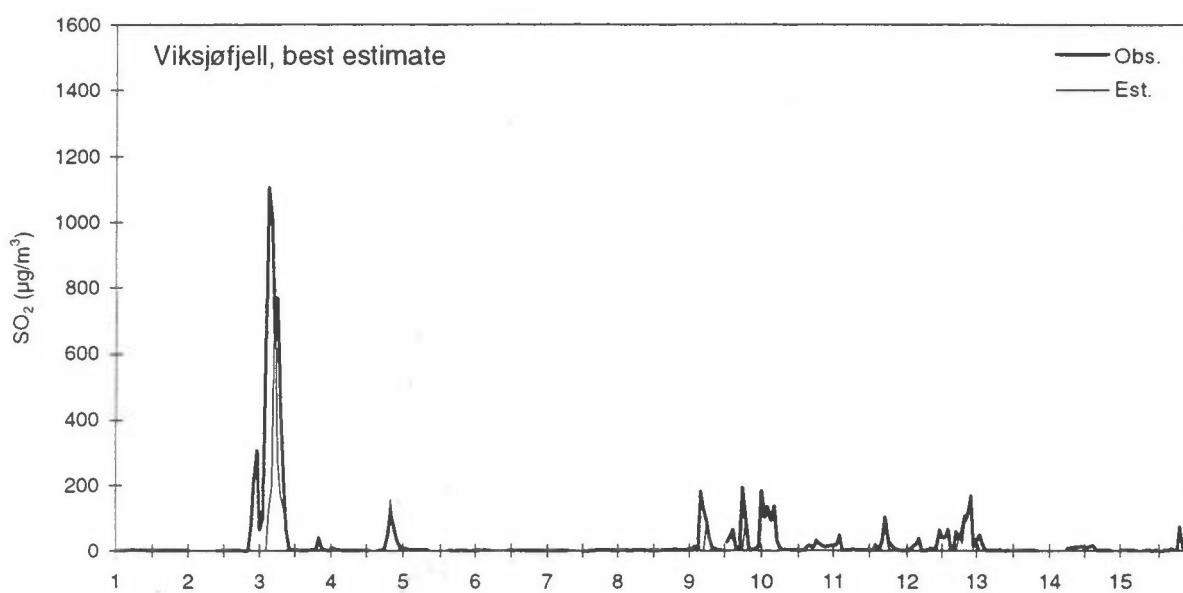Unit: µg SO₂/m³.
Period: 94.09.01 0100–94.09.15 2400.

Figure 5: Measured and calculated SO₂-concentrations at Viksjøfjell. Filtered
for spatial uncertainty.
Unit: µg SO₂/m³.
Period: 94.09.01 0100–94.09.15 2400.

In addition, the correlation between the measured and calculated SO₂-concentrations presented in Figure 2–5 is presented as x,y-scatterplots in Figure 6 and Figure 7.
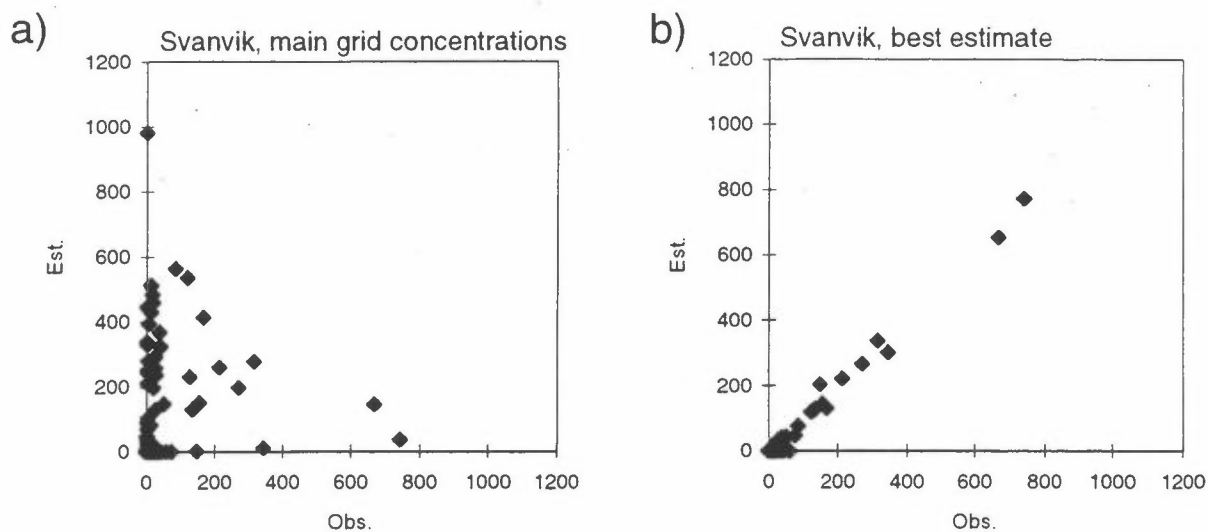

Figure 6: X,Y-scatterplot of measured and calculated SO₂-concentrations at Svanvik.
Unit: µg SO₂/m³.
Period: 94.07.15 0100–94.07.31 2400.
a) Main grid concentration.
b) Filtered for spatial uncertainty ("best estimate").

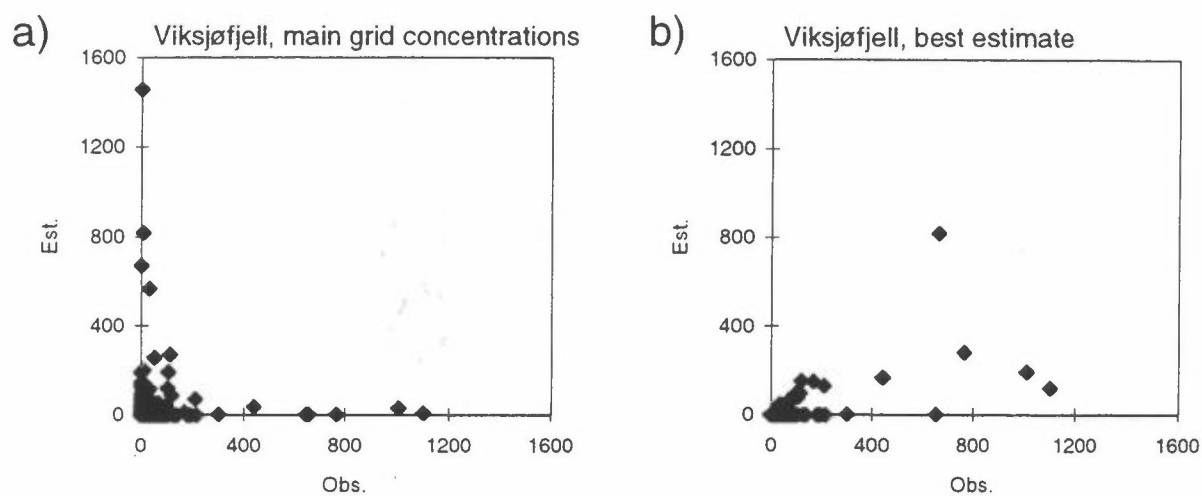Figure 7: X,Y-scatterplot of measured and calculated SO₂-concentrations at Viksjøfjell.
Unit: µg SO₂/m³.
Period: 94.09.01 0100–94.09.15 2400.
a) Main grid concentration.
b) Filtered for spatial uncertainty ("best estimate").

Hourly SO$_2$-concentrations on ground level were calculated for 24 additional places in Sør Varanger using the same method as for Svanvik and Viksjøfjell. The receptor points are presented in appendix A.

The results are presented in data files, with 4 numbers for every hour:

- Calculated average concentration in a 5x5 km^2 grid square surrounding the station.
- Calculated average concentration in a 1x1 km^2 grid square surrounding the station.
- Lowest calculated concentration (1x1 km^2 grid square) within a radius of 5 km.
- Highest calculated concentration (1x1 km^2 grid square) within a radius of 5 km.

In addition, calculations of 24-hour average concentrations in the 5x5 km^2 grid square surrounding the station is calculated.

5. Conclusion

Considering the above mentioned moments of uncertainty, in addition to the relatively few available meteorological measurement stations in Sør-Varanger, the correlation between the measured and the calculated concentration presented in Figure 4 and 5 are good.

An evaluation of the dispersion model is performed by estimating some central statistical parameters that describe the validity of the model. The results of this evaluation are given in Tables 2 and 3 for spatially filtered and non-filtered data, respectively.

Table 2: *Model evaluation based on observed and calculated (25 km^2 grid square) hourly average values of SO$_2$ at Viksjøfjell and Svanvik. Period: 94.05.01.–94.10.25.*

Station/ parameter	Svanvik			Viksjøfjell		
	Obs.		Calc.	Obs.		Calc.
Amount	4 203		4 203	3 361		3 361
Average value	7,1		16,4	17,9		13,5
Standard deviation	32,4		88,3	62,9		105,0
Maximum value	743,0		2 990,9	1 102,4		2 589,3
RMSE		88,1			119,3	
RMSEs		292,7			3 238,8	
RMSEu		7 473,0			10 990,5	
Correlation		0,21			0,06	

Table 3:   Model evaluation based on observed and calculated, spatially filtered, hourly average values of SO₂ at Viksjøfjell and Svanvik. Period: 94.05.01.–94.10.25.

Station/ parameter	Svanvik			Viksjøfjell		
	Obs.		Calc.	Obs.		Calc.
Amount	4 203		4 203	3 361		3 361
Average value	7,1		5,0	17,9		5,1
Standard deviation	32,4		29,2	62,9		36,6
Maximum value	743,0		771,0	1 102,4		1 012,1
RMSE		14,2			56,2	
RMSEs		41,7			2 447,1	
RMSEu		159,8			707,5	
Correlation		0,90			0,49	

In addition to the calculated SO_2-concentrations for the 25 geographical receptor points, calculation of the lowest and highest values for each receptor point is also given. These values give an indication of the uncertainty of the numbers given in the result files. The uncertainty may be due to several isolated factors, or it could be a result of the circumstances described in Chapter 4.

Uncertainty in the concentration values presented in the result files for each measurement station may also vary in time, depending on whether the plume hits the receptor point at the exact time.

We want to point out that the calculated concentrations for the receptor points must be used cautiously. The results will, however, give an indication of whether elevated SO_2-concentrations may have occurred at the chosen receptor point the day the health examination was carried out, but the exact concentration or concentration level will remain somewhat uncertain.

6. References

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Walker, S.E. og Grønskei, K.E. (1992) Spredningsberegninger for on-line overvåking i Grenland; Programbeskrivelse og brukerveiledning. Lillestrøm (NILU OR 55/92).

Appendix A

Receptor points

Bjørnevatn
Bugøyfjord
Bugøynes
Elvenes
Grense Jakobselv
Hesseng
Holmfoss
Jakobnes
Jarfjord/Jarfjord botn
Karpbukt
Kirkenes
Lanabukt
Langfjorddalen
Langvasseid
Melkefoss
Neiden
Ropelv
Sandnes
Skogfoss
Skrotnes
Storbukt
Strand
Svanvik
Tårnet
Vaggetem

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ABSTRACT
Hourly dispersion calculations of SO_2 in Sør-Varanger during the period 1 May 0100–25 October 1600 in 1994. The calculations have been performed with NILU's dispersion model EPISODE 2.1 for a 20x18 km grid square with a 5 km resolution, in addition to a sub-grid for the same area with a 1 km resolution. The calculations indicate a good correlation between observed and calculated concentrations, assuming a spatial uncertainty of 5 km.

NORWEGIAN TITLE

Spredningsberegninger av SO_2 i Sør-Varanger 1. mai–25 oktober 1994

KEYWORDS		
Dispersion calculations	Sulphur dioxide	Sør-Varanger

ABSTRACT (in Norwegian)
Det er utført timevise spredningsberegninger av SO_2 i Sør-Varanger i perioden 1. mai kl 01–25. oktober kl 16. Beregningene er utført med NILUs spredningsmodell EPISODE versjon 2.1 i et rutenett på 20x18 ruter med en oppløsning på 5 km samt i subgrid som dekker området med en oppløsning på 1 km. Beregningene viser et bra samsvar mellom observerte og beregnete verdier når man tar hensyn til en romlig usikkerhet i størrelsesorden 5 km.