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Impact Assessment for emissions to air from a planned aluminium smelter in Reyðarfjördur, Iceland

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Summary

Reydaral have asked the Norwegian Institute for Air Research to assess the consequences from emissions to air from a planned aluminium smelter in Reyðarfjördur on the north east coast of Iceland.

The site of the aluminium smelter is located on East Iceland, on the northern side of Reyðarfjördur. The fjord is surrounded by mountains up to 1 000 m high. The fjord is closed at the head of the fjord, and there are only narrow valleys feeding into the fjord. This indicates that the meteorology is strongly influenced by topographical effects. There will also be a tendency of low wind speeds, which is unfavourable for dispersion of pollutants emitted to air. To be able to give good estimations of the impact from the aluminium smelter it has been necessary to analyse the situations giving poor mixing of emissions to air in the fjord. These situations have been discussed with IMO to take advantage of the local knowledge of meteorology.

The following meteorological situations have been discussed and analysed according to potential for poor dispersion:

1. Sea-land breeze
2. Calm conditions
3. Re-entries
4. Vertical vortexes

The study shows that the situations that are most unfavourable for the dispersion in Reyðarfjördur are the situations where the pollutants are transported back and forth in the fjord (Re-entries). These situations are connected to poor dispersion conditions with low wind speeds. These situations are most common during nighttime.

Two emission alternatives have been looked into. Alternative 1 is emissions to air from a production of 280 000 tons of aluminium per year. Alternative 2 is emissions to air from a production of 420 000 tons of aluminium per year. Both alternatives include facilities for anode-baking furnace.

There are three alternatives for SO_2 emissions:

Case 1: Use of high sulphur coke and pitch with no wet scrubbing of the flue gas from the anode furnace.
Case 2: Use of medium low sulphur coke and pitch with no wet scrubbing of the flue gas from the anode furnace.
Case 3: Use of high sulphur coke and pitch and wet scrubbing of the anode furnace flue gas. The emissions from the electrolysis will be as in Case 1.

The following parameters have been estimated:

- SO_2, PM_{10}, and PAH (yearly and winter season)
- Fluorides (growing season)

- SO_2 (24 hour averages, 98 and 99.2 percentiles)
- PM_{10} (24 hour averages, 98 percentile and 90.4 percentile)
- SO_2 (Hourly averages, 99.7 percentile)
- Study of unfavourable dispersion conditions

The emissions of SO_2 that give the highest impact are for case 1. The most restrictive air quality guideline is the Icelandic air quality guideline of 50 $\mu g/m^3$ as a 98 percentile. This guideline is also the most critical for emissions from case 2. The contour lines for 50 $\mu g/m^3$ as a 98 percentile for 1998-1999 and 1999-2000 are shown in figures A, B, C, and D. The corresponding distances to the Air Quality Guideline is given in table A. The 99.7 percentile for hourly averages have similar distances but slightly smaller. The Norwegian air quality guideline for gaseous fluoride for vegetation during the growing season (6 months) of 0.3 $\mu g/m^3$ is critical for emissions from case 3. Table A gives an overview of the critical distances for the different emission alternatives and years.

Table A: Overview of the critical pollutants and air quality guidelines for the different emission alternatives. A more detailed summary is given in each chapter. Numbers in parenthesis are the distance from the nearest corner of the potrooms out the fjord, and the numbers without parenthesis in the direction of Budareyri

	Critical distance (km)		Pollutant	Air quality guideline	Averaging time
280 000 tpy	1999-2000	1998-1999			
Case 1	2.8 (3.0)	3.9 (4.0)	SO_2	50 $\mu g/m^3$ 98 percentile	24 hours
Case 2	0.9 (0.8)	2.4 (2.3)	SO_2	50 $\mu g/m^3$ 98 percentile	24 hours
Case 3	0.7 (0.3)	1.1 (1.0)	Gaseous fluorides	0.3 $\mu g/m^3$	Growing season (6 months)
420 000 tpy					
Case 1	4.0 (3.9)	5.8 (4.2)	SO_2	50 $\mu g/m^3$ 98 percentile	24 hours
Case 2	0.8 (0.8)	2.5 (2.9)	SO_2	50 $\mu g/m^3$ 98 percentile	24 hours
Case 3	1.2 (0.6)	2.1 (1.8)	Gaseous fluorides	0.3 $\mu g/m^3$	Growing season (6 months)

It is seen from the calculations that there are quite some differences between the two years. The year 1999-2000 has higher wind speeds and fewer hours and days with consecutive low wind speed than the year 1998-1999. This gives some information on the variability of the dispersion from year to year. This also illustrates that the 98 percentile is strongly dependent on the number of situations with poor dispersion. This number is larger in 1998-1999 than in 1999-2000.

Figures A-C also show that for impact from SO_2 for emission case 2 and 3 are small compared with case 1. Case 3 is slightly better than case 2.

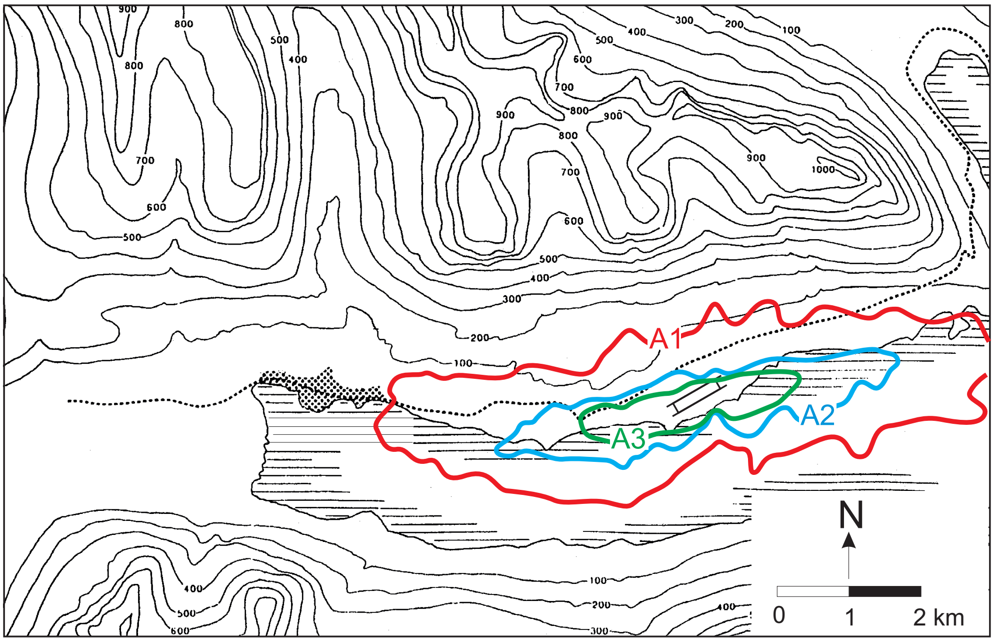

Figure A: Contour lines for the Icelandic air quality guideline for 98 percentile, limiting value 50 µg/m³. Year 1998-99.
A1 = production of 280 000 tpy, emission Case 1.
A2 = production of 280 000 tpy, emission Case 2
A3 = production of 280 000 tpy, emission Case 3

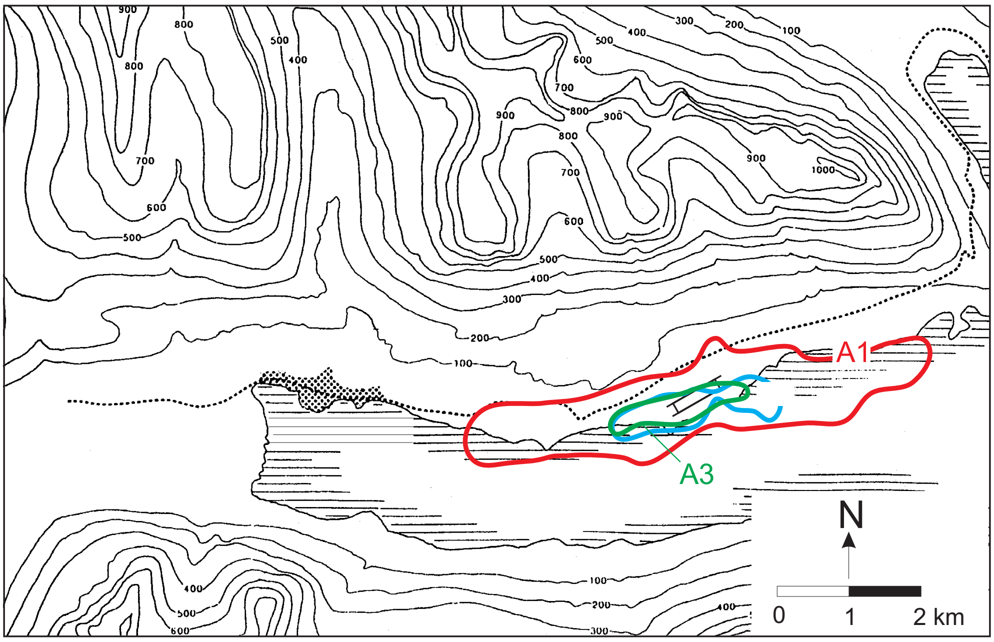

Figure B: Contour lines for Icelandic air quality guideline for 98 percentile, limiting value 50 µg/m³. Year 1999-2000.
A1 = production of 280 000 tpy, emission Case 1.
A2 = production of 280 000 tpy, emission Case 2
A3 = production of 280 000 tpy, emission Case 3

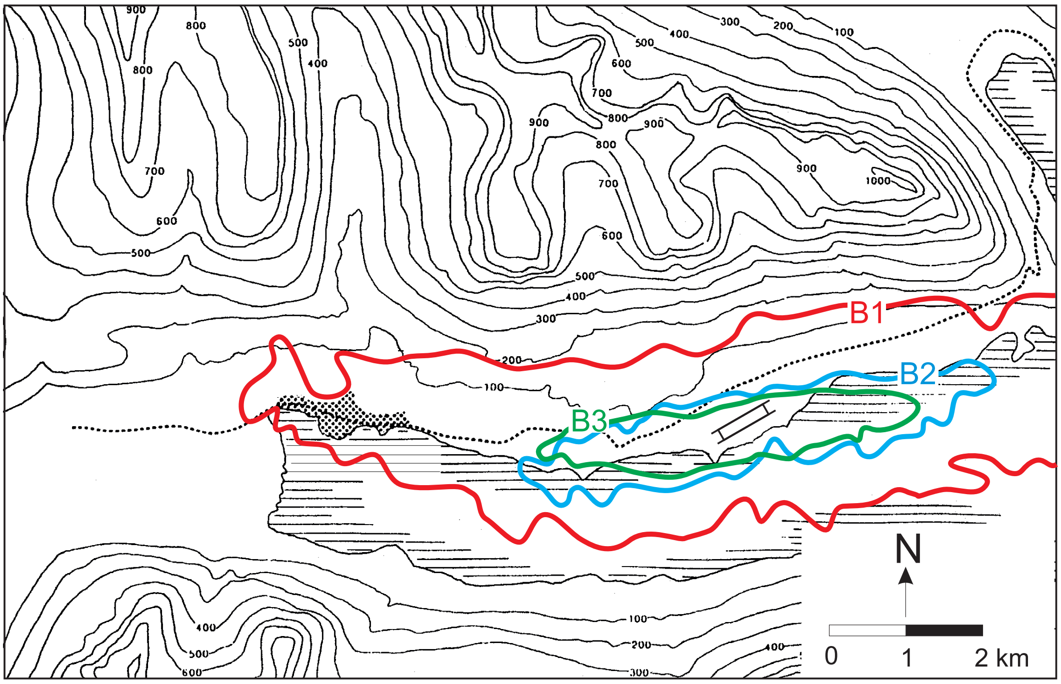

Figure C: Contour lines for the Icelandic air quality guideline for 98 percentile, limiting value 50 µg/m³. Year 1998-99
B1 = production of 420 000 tpy, emission Case 1.
B2 = production of 420 000 tpy, emission Case 2
B3 = production of 420 000 tpy, emission Case 3

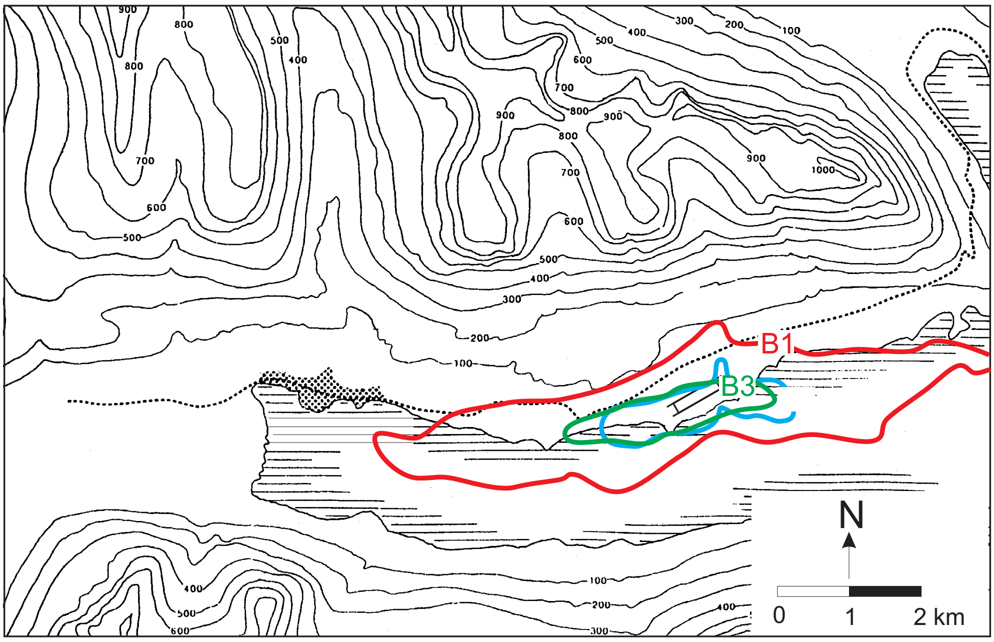

Figure D: Contour lines for the Icelandic air quality guideline for 98 percentile, limiting value 50 µg/m³. Year 1999-2000.
B1 = production of 420 000 tpy, emission Case 1.
B2 = production of 420 000 tpy, emission Case 2
B3 = production of 420 000 tpy, emission Case 3

When defining the "Dilution zone" for the smelter the concentrations of gaseous fluorides averaged over the growing season will have to be taken into account. The Norwegian air quality guideline for vegetation is 0.3 µg/m^3 and the area with concentrations above this guideline will cover a larger area than the SO_2 concentrations for the Icelandic air quality guideline for the 98 percentile for case 3. The figures showing the concentrations of gaseous fluorides are shown in Figures E, F, G and H.

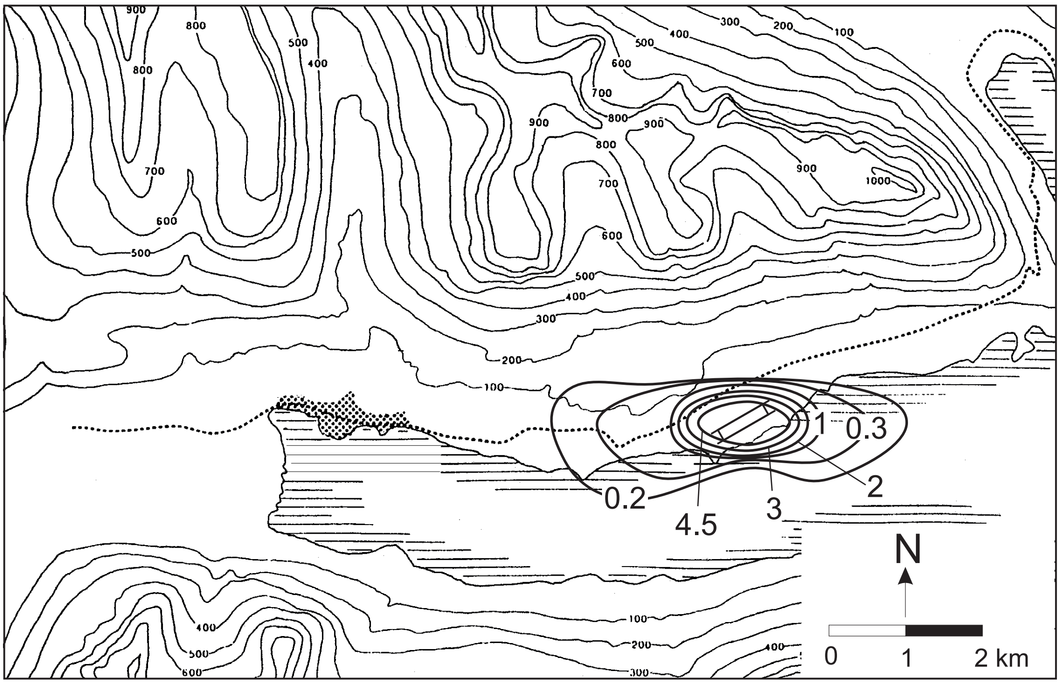

Figure E: Average concentrations for the growing season of gaseous fluorides for 1998-1999 (280 000 tpy). Unit: µg/m^3.

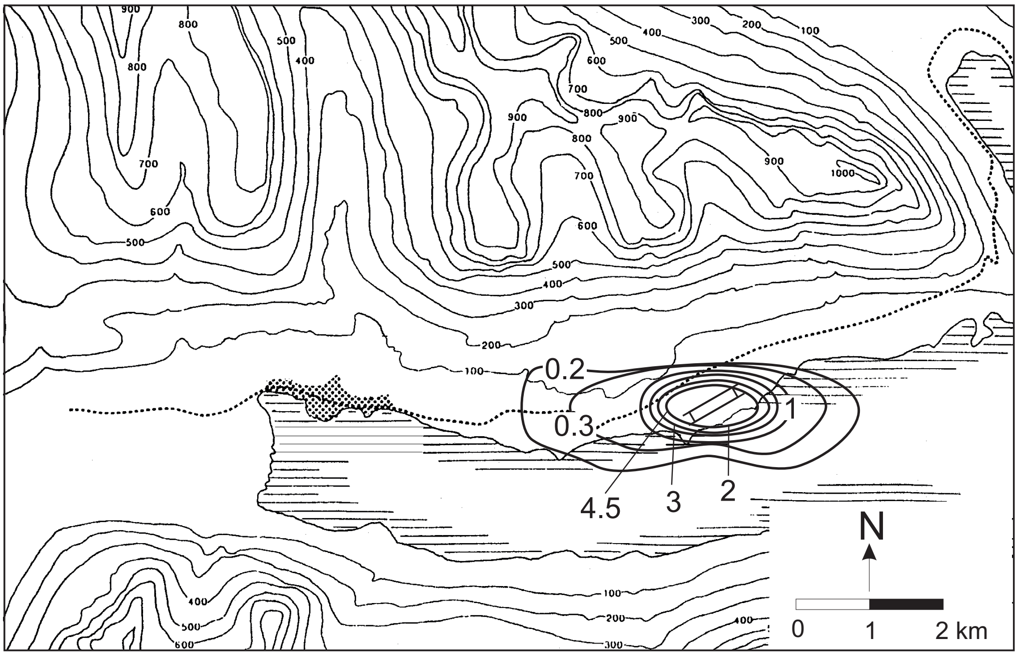

Figure F: Average concentrations for the growing season of gaseous fluorides for 1999-2000 (280 000 tpy). Unit: µg/m^3. Norwegian air quality guideline 0.3 µg/m^3.

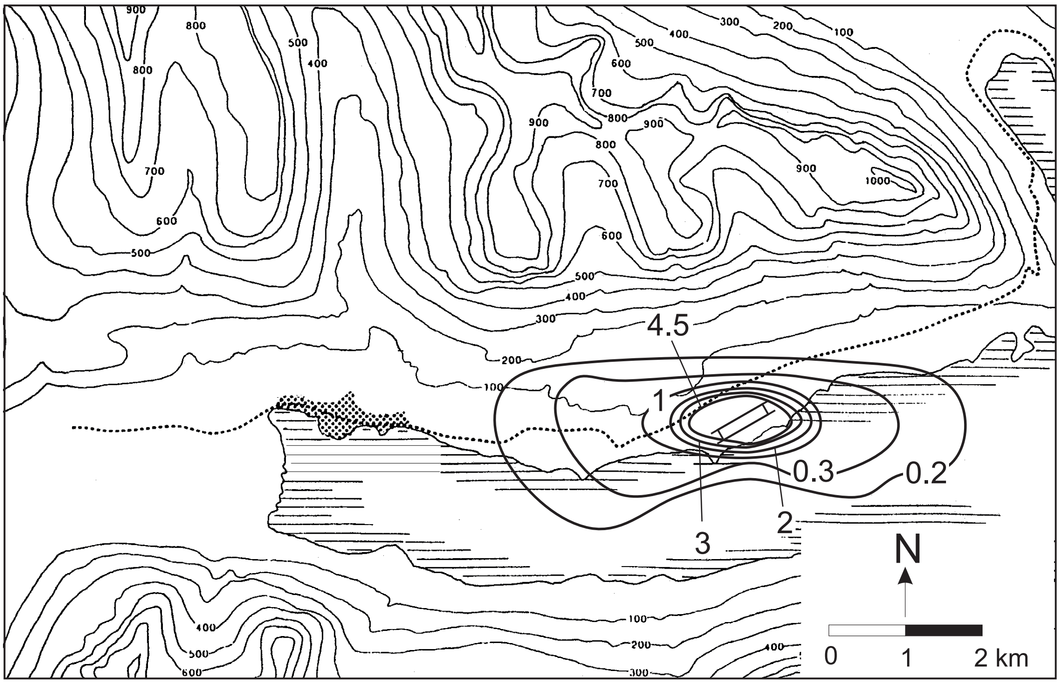

Figure G: Average concentrations for the growing season of gaseous fluorides for 1998-1999 (420 000 tpy). Unit: µg/m^3

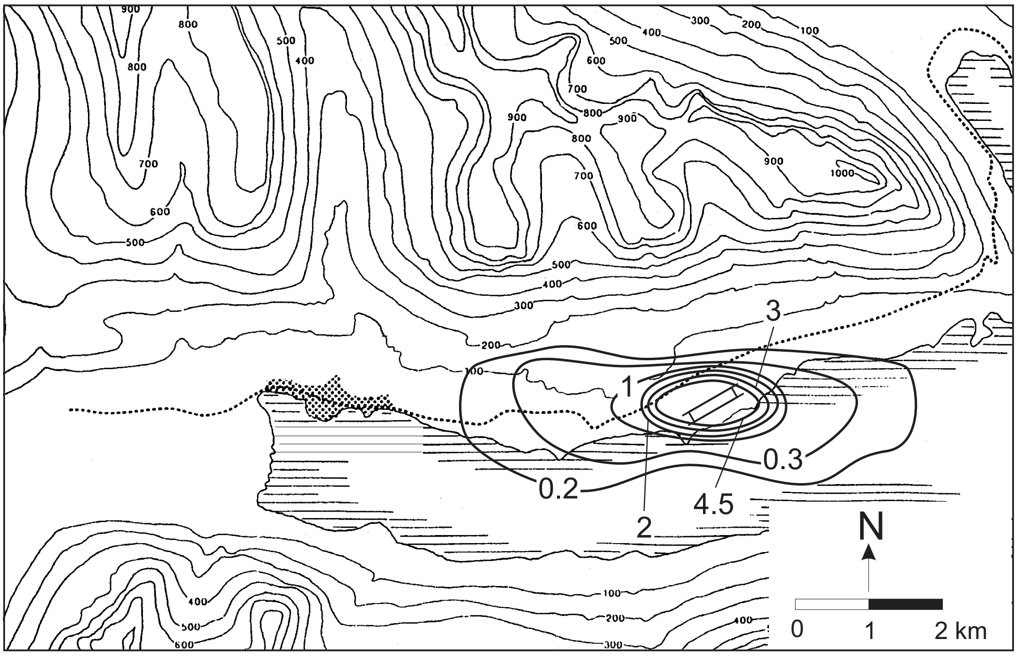

Figure H: Average concentrations for the growing season of gaseous fluorides for 1999-2000 (420 000 tpy). Unit: µg/m³. Norwegian air quality guideline 0.3 µg/m³.

Impact Assessment for emissions to air from a planned aluminium smelter in Reyðarfjördur, Iceland

1. Introduction

Reydaral have asked the Norwegian Institute for Air Research to assess the consequences from emissions to air from a planned aluminium smelter in Reyðarfjördur on the north east coast of Iceland.

Two emission alternatives have been looked into. Alternative 1 is emissions to air from a production of 280 000 tons of aluminium per year. Alternative 2 is emissions to air from a production of 420 000 tons of aluminium per year. Both alternatives include facilities for anode-baking furnace.

There are three alternatives for SO_2 emissions:

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The following parameters have been estimated:

- SO_2, PM_{10}, and PAH (yearly and winter season)
- Gaseous fluorides (growing season)
- SO_2 (24 hour averages, 98 and 99.2 percentiles)
- PM_{10} (24 hour averages, 98 percentile and 90.4 percentile)
- SO_2 (hourly averages, 99.7 percentile)
- Study of unfavourable dispersion conditions

The work is based on earlier investigations in the area, and on meteorological measurements done by the Icelandic Meteorological Office in Reykjavik (IMO).

The measurements of meteorology contain wind speed, wind direction and temperatures in the area for several years. The meteorological period with measurements used in this report has been September 1998 to September 2000. During the last part of the period additional measurements have been conducted. The measurements have been reported by IMO (Sigurdsson et al., 1999, Sigurdsson et al., 2000).

In the main report figures from 1999-2000 are shown. The corresponding figures from 1998-1999 are shown in the appendixes.

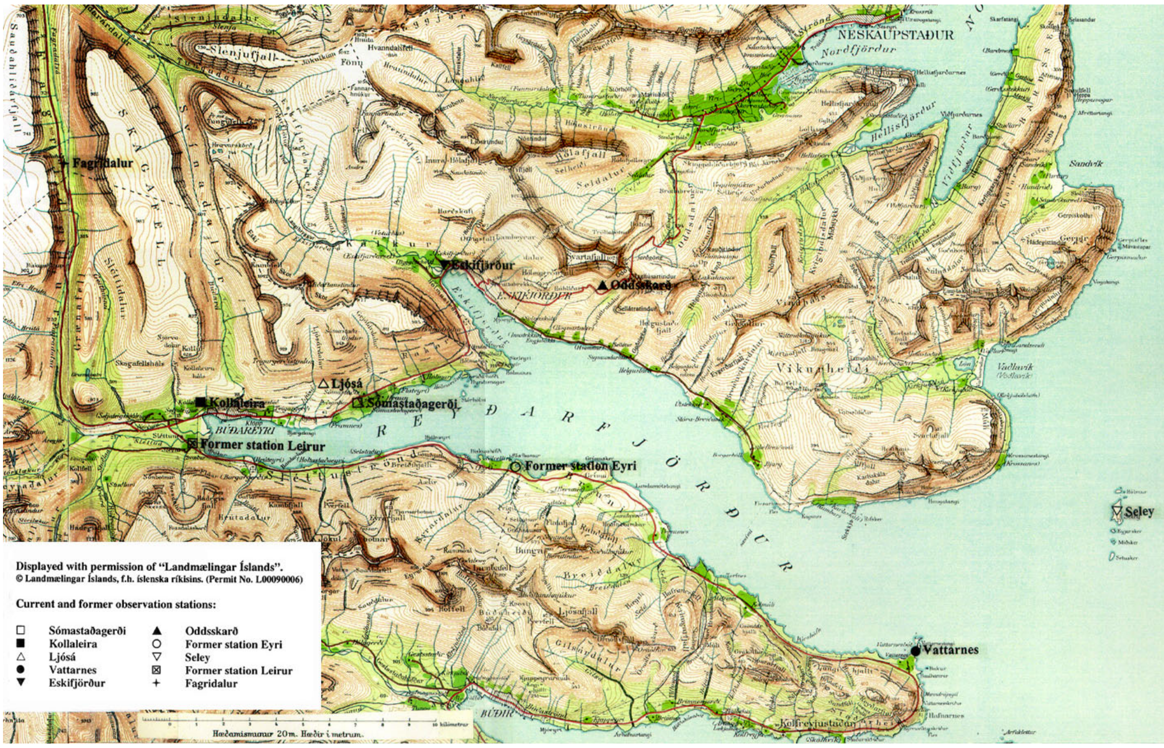


Figure 1: Location of the wind and temperature observations and the planned aluminium smelter.

2. Proposed air quality guidelines

The Icelandic authorities have proposed air quality guidelines for sulphur dioxide and PM_{10}, while no guidelines exist for fluorides. The proposed Icelandic, Norwegian and EU air quality guidelines are presented in Table 1 below. The most restrictive guidelines have been used in this study.

Table 1: Air quality guidelines for SO_2, fluorides and PM_{10} in Iceland, Norway and the EU. Unit: µg/m³.

		Period				
Component	Country	1 Hour	24 h	30 d	6 months	Year
Sulphur dioxide	Iceland [1]		50 [2]			30
Sulphur dioxide	Norway		100 – 150		40 - 60	
Sulphur dioxide veget.	Norway				25	
Sulphur dioxide	EU	350[13]	125 [3]		20,12-8[10]	20
Sulphur dioxide health	EU		75[8]			
Sulphur dioxide health	EU		50[9]			
Fluorides, health [4]	Norway				10	
Fluorides, veget. [5]	Norway		25		0.3	
Fluorides, herbivores [4]	Norway		1.0	0.2 - 0.4		
PM10	Iceland		130 [2]			40
PM10	EU		50 [11]			20 [6]
PM10	EU		25[12]			14-10 [14]
PM10	EU		30-20[8]			
Benzo (a) pyren						0.1-1 ng/m³ [7]

1) Environmental and Food Agency of Iceland (1994).
2) 98-percentile.
3) Not to be exceeded more than 3 times a year.
4) Guideline for total fluorides.
5) Guideline for gaseous fluorides only.
6) To be met 1 January 2010.
7) These values reflect the ambient air standards in Belgium, France, Italy, Netherlands, Sweden, and United Kingdom.
8) Upper evaluation threshold for health (valid from 01.01.2005). Not to be exceeded more than 3 times a year.
9) Lower evaluation threshold for health (valid from 01.01.2005). Not to be exceeded more than 3 times a year.
10) Upper and lower evaluation limit for the ecosystem (valid from 19.07.2001). Winter average.
11) Health, valid from 01.01.2005 may be exceeded 35 times.a year until 01.01.2010, after this date 7 times.
12) 50 percentile to be met 01.01.2005.
13) May be exceeded 24 times a year, valid from 01.01.2005.
14) Upper evaluation threshold for health (valid from 01.01.2005). Not to be exceeded more than 7 times a year.

Benzo(a)pyrene can be used as an indicator for health effects of PAH in air. The US EPA have offered an upper bound lifetime risk that 9 out of 100 000 people exposed to 1 ng BaP per m³ over a lifetime would be at risk of developing cancer. From measurements done by NILU for various aluminium smelters in Norway the content of Benzo(a)pyrene in PAH for emissions from aluminium smelters is 1% of the PAH in winter and 0.5% in summer (Hagen, 1991a, Hagen, 1991b). To compare the ambient air standards for BaP with the estimated PAH concentrations a factor of 1% has been used.

3. Meteorological conditions

The Icelandic Meteorological Office (IMO) in Reykjavik has carried out measurements of wind and temperatures in Reydarfjördur. The measurement programme started in May 1998 at Sómastadagerdi. In June 2000 additional measurement stations were installed. The stations are Vattarnes, Ljosa and Kollaleira 2. In addition to these stations IMO operates an automatic weather station near sea level at the end of Eskifjordur. The Public Roads Administration operates a weather station at Fagridalur and at Oddsskard, 520 m above sea level. The Icelandic Maritime administration operates an automatic weather station on the island Seley outside the mouth of Reyðarfjördur. There are two years of data that have been used in this report. These are from September 1998 to September 2000. The reported measurements from IMO are 10-minute averages. To be able to use these measurements for dispersion calculations valid for one hour, the 10-minute averages have been transformed into hourly averages. There may therefore be some minor differences between the data reported by IMO and the data reported in this report.

3.1 Wind speed and wind direction

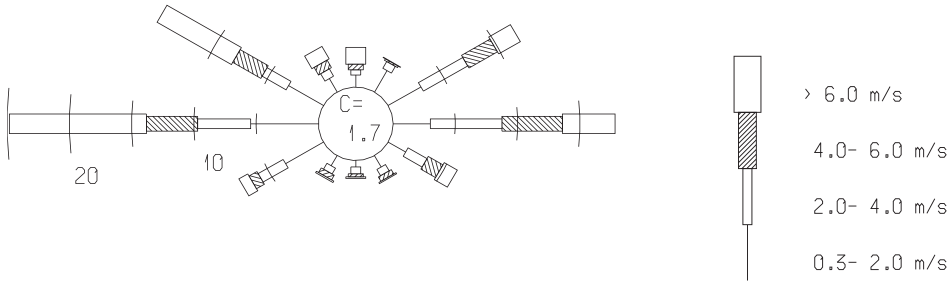
NILU has carried out a statistical evaluation of wind measurements at Sómastadagerdi in the period from September 1998 to September 2000. The wind speed measurements used were carried out at 10-m height. The wind direction frequency distribution in twelve 30-degrees sectors and four wind speed classes for the summer, the winter and for the two years, are presented in Figure 2 and in Figure 3.

The wind roses for the two years 1998-1999 and 1999-2000 shown in Figure 2 and Figure 3 are very similar. The two measurement periods show a strong channelling effect along the east-west oriented valley axis in approximately 40% of the time. The average wind speed for the two years was 4.5 m/s. The predominant wind was down valley winds from west (about 24% of time). Onshore winds (sea breeze) from east occurred in about 17% of time for 1998-2000, mostly during daytime hours.

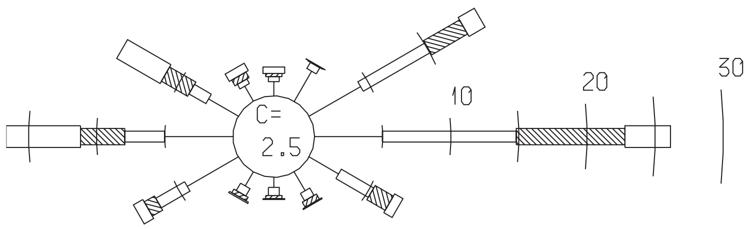
The highest averaged wind speed in one wind sector occurred during down valley winds from west-southwest in both stations. For 1998-2000, westerly winds with higher wind speed than 6 m/s occurred 11.4% of time.

1998/1999

Year



Summer



Winter

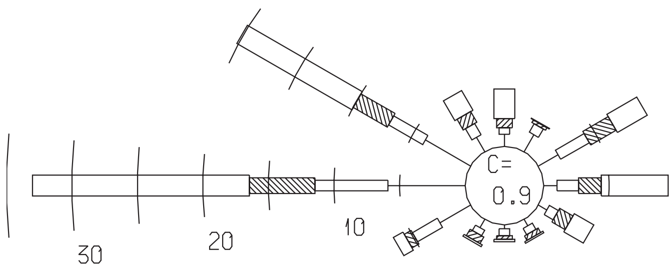


Figure 2: Average wind direction frequency distribution at Somastadagerdi for the summer, the winter and over the year September 1998-September 1999.

1999/2000

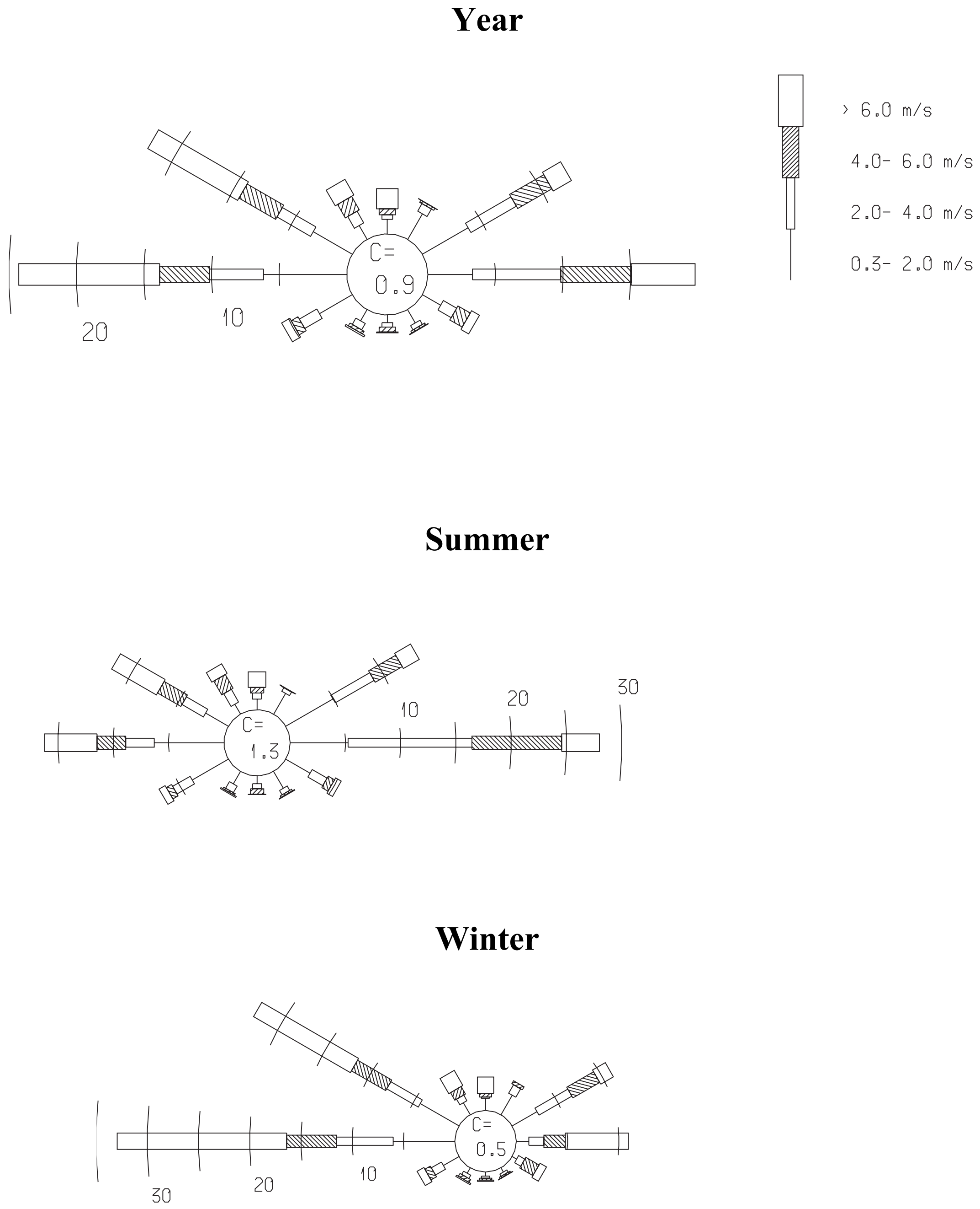
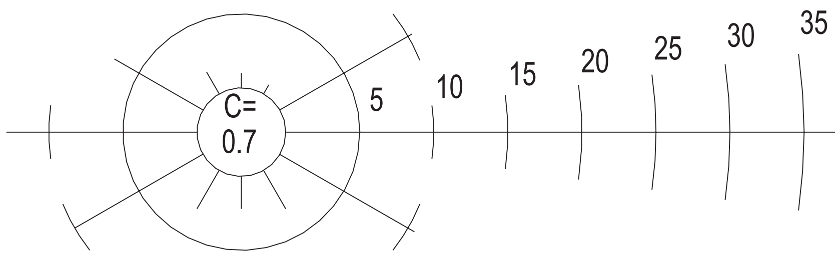


Figure 3: Average wind direction frequency distribution at Sómastadagerdi for the summer, the winter and over the year September 1999-September 2000.

The wind roses for daytime and nighttime for summer are shown in Figure 4 and Figure 5. These show that during the day in summer there are very low frequencies of wind going out the fjord and the main wind direction is onshore wind. During nighttime the main wind direction is out the fjord. This indicates that the wind pattern in the fjord is strongly influenced by local thermal effects during summer. The wind pattern suggests that a local sea breeze is dominating the wind climate in summer. The sea breeze is discussed in more detail in chap. 3.4. It is also seen that calm conditions occur more often at night in summer. During the summer 1999 calm conditions occurred 4.3% at night and 0.7% in daytime, and for summer 2000 2.5% at night and 0.2% during the day. This means that unfavourable dispersion conditions are most common during nighttime. It is also seen that calm conditions were more frequent during summer 1999 than during summer 2000. The occurrence of poor dispersion conditions are therefore more frequent during summer 1999 than during summer 2000.

Summer 1999
Daytime



Night-time

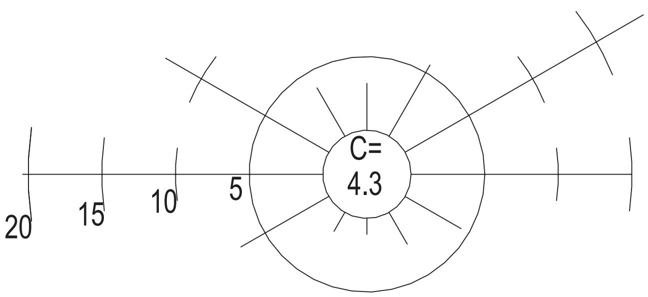
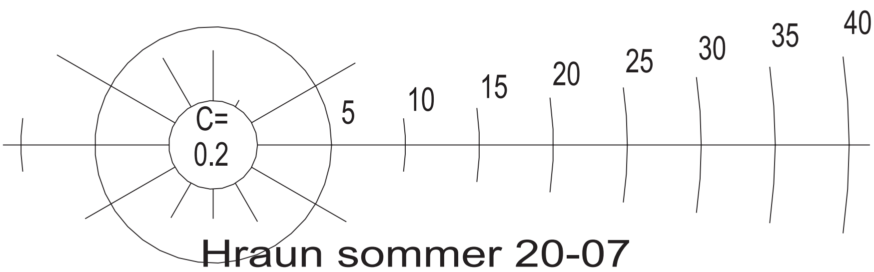
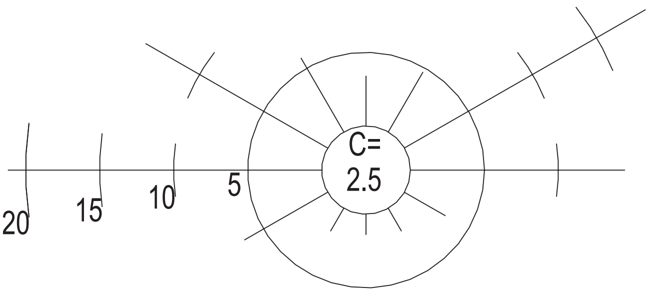


Figure 4: Wind roses for daytime and nighttime summer 1999.

Summer 2000

Daytime





Night-time

Figure 5: Wind roses for daytime and nighttime summer 2000.

4. Atmospheric stability

The stability classification is divided into four classes of stability: Unstable (US), Neutral (N), Light-stable (LS) and Stable (S) conditions. The definition of these classes is given below.

Unstable:	$\Delta T < -0.8°$ C	between 36.5 and 3 m
Neutral:	$-0.8°$ C $< \Delta T < 0°$ C	between 36.5 and 3 m
Light-stable:	$0°$ C $< \Delta T < 0.8°$ C	between 36.5 and 3 m
Stable:	$0.8°$ C $< \Delta T$	between 36.5 and 3 m

4.1 Measurements at Sómastadagerdi in Reydarfjördur

This report has used two years of data measured at Sómastadagerdi (September 1998-September 2000). The measurements of temperature difference (3 and 36.5 m) show a similar picture of stability occurrence for the two years.

The stability distributions for summer and for the year are given in Figure 6. The Figure shows an occurrence of unstable conditions of 3.4 and 6.9 % during the summer (1999 and 2000) and of 1.9 and 3.8 % (1998/99 and 1999/2000) during the year. Unstable conditions occur during daytime, as expected. Stable conditions occurred 14.5 and 13.6% (1999 and 2000) of the time during the summer and 17.3

and 20.3 % (1998/99 and 1999/2000) of the time during the year, mostly during nighttime and winter. The occurrence of stable conditions during the day may be explained by the seawater temperature and the fact that the mountains in the south side of the Reydarfjördur gives shade to Sómastadagerdi during the whole day in winter and probably some days in spring and autumn. In such cold days the sun never breaks the stable conditions built up during the night.

It is also seen that the year 1998-1999 had a higher frequency of stable conditions and a lower frequency of unstable conditions than 1999-2000. This implies that on average the year 1999-2000 had better dispersion conditions than 1998-1999.

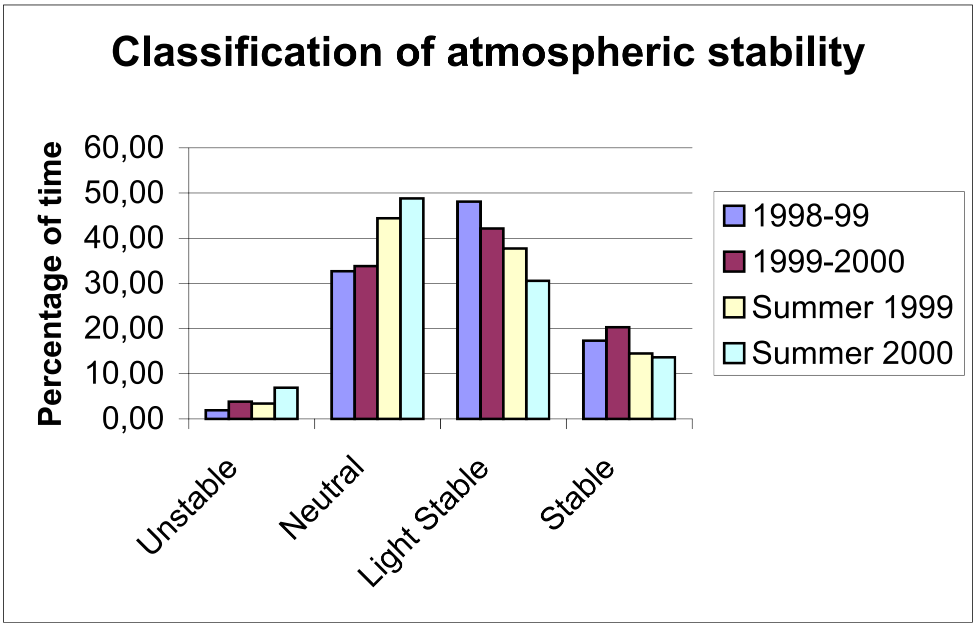


Figure 6: Stability distribution of four classes of stability at Sómastadagerdi for the years 1998-1999 and 1999-2000.

4.2 Meteorological matrixes for dispersion calculations

The meteorological matrixes for the two years are presented in Table 2. Simultaneous observations of wind and stability at Sómastadagerdi have been used to carry out statistical evaluation of a joint frequency distribution of four wind speed classes, twelve wind sectors and four stability classes.

Table 2: Joint frequency distribution of stability, wind speed and wind direction for the years 1998-1999 and 1999-2000.

1998-1999

Calm: U less or equal to 0.3 m/s

	0.0- 2.0 m/s				2.0- 4.0 m/s				4.0- 6.0 m/s				over 6.0 m/s				
Wind dir.	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	Rose
30	0.0	0.2	1.0	0.8	0.0	0.1	0.3	0.2	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	2.8
60	0.0	1.0	1.2	0.7	0.0	1.6	1.9	0.7	0.0	1.2	1.2	0.2	0.0	0.6	1.1	0.1	11.7
90	0.0	1.6	0.9	0.3	0.2	4.0	1.5	0.2	0.5	2.8	1.4	0.1	0.3	1.4	1.8	0.1	17.2
120	0.0	0.9	0.5	0.2	0.1	1.4	0.4	0.0	0.0	0.8	0.7	0.0	0.0	0.3	0.8	0.0	6.1
150	0.0	0.5	0.4	0.2	0.0	0.1	0.3	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.1	0.0	2.0
180	0.0	0.2	0.2	0.1	0.0	0.2	0.2	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.1	0.0	1.3
210	0.0	0.4	0.3	0.3	0.0	0.3	0.2	0.1	0.0	0.1	0.3	0.0	0.0	0.0	0.1	0.0	2.0
240	0.0	0.8	1.5	1.2	0.1	0.9	1.0	0.4	0.1	0.3	0.3	0.0	0.1	0.2	0.6	0.1	7.7
270	0.0	0.7	1.9	2.9	0.0	0.7	2.3	1.2	0.1	1.0	2.3	0.7	0.1	2.4	7.8	1.0	25.3
300	0.0	0.3	1.0	1.9	0.0	0.6	1.1	0.6	0.0	0.8	1.3	0.4	0.0	2.6	3.9	0.4	15.1
330	0.0	0.1	0.5	0.6	0.0	0.1	0.4	0.2	0.0	0.3	0.5	0.1	0.0	0.3	1.0	0.0	4.0
360	0.0	0.1	0.4	0.4	0.0	0.1	0.3	0.0	0.0	0.1	0.4	0.0	0.0	0.3	1.3	0.0	3.4
Calm	0.0	0.3	0.8	0.5													1.6
Total	0.0	7.0	10.7	10.1	0.4	10.1	9.9	3.8	0.9	7.6	8.7	1.7	0.6	8.1	18.7	1.8	100.0
Occurance		27.7 %				24.2 %				18.9 %				29.2 %			
Wind speed		1.1 m/s				3.0 m/s				5.0 m/s				9.1 m/s			

Table 2: Contd.

1999-2000

Calm: U less or equal to 0.3 m/s

Wind dir.	0.0- 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	0.2	0.8	1.2	0.0	0.1	0.3	0.2	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	3.1
60	0.1	1.1	1.6	1.3	0.0	1.5	1.6	0.9	0.0	1.2	1.5	0.2	0.1	0.6	0.7	0.1	12.5
90	0.1	2.0	0.8	0.5	0.5	4.6	1.1	0.1	1.2	2.7	1.2	0.1	0.4	1.7	2.4	0.0	19.2
120	0.1	0.9	0.4	0.3	0.1	0.8	0.2	0.1	0.1	0.5	0.5	0.0	0.1	0.4	0.3	0.0	4.7
150	0.0	0.5	0.3	0.2	0.0	0.2	0.2	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	1.8
180	0.0	0.2	0.1	0.2	0.0	0.2	0.2	0.1	0.1	0.2	0.1	0.0	0.0	0.0	0.1	0.0	1.4
210	0.0	0.4	0.4	0.2	0.0	0.2	0.3	0.0	0.0	0.1	0.1	0.0	0.0	0.1	0.1	0.0	1.9
240	0.0	0.8	1.0	1.1	0.1	0.5	0.5	0.4	0.0	0.2	0.3	0.0	0.1	0.2	0.4	0.0	5.8
270	0.0	0.7	2.0	3.1	0.0	0.6	1.8	1.5	0.1	0.9	1.9	0.9	0.2	1.6	7.2	1.3	23.9
300	0.0	0.3	0.9	2.0	0.0	0.8	1.2	0.9	0.1	0.8	1.3	1.0	0.0	2.3	4.4	0.6	16.8
330	0.0	0.1	0.5	0.6	0.0	0.6	0.3	0.1	0.0	0.8	0.2	0.0	0.0	0.5	0.7	0.0	4.5
360	0.0	0.2	0.4	0.6	0.0	0.2	0.1	0.0	0.0	0.2	0.2	0.0	0.0	0.6	0.8	0.0	3.4
Calm	0.0	0.3	0.5	0.3													1.0
Total	0.4	7.7	9.7	11.4	0.8	10.5	7.8	4.4	1.6	7.8	7.6	2.4	1.0	7.8	17.1	2.1	

5. Emission data

The Aluminium smelter at Reyðarfjördur is planned in two stages. The first stage will have a production of aluminium of 280 000 tpy, in the second phase there will be a production of 420 000 tpy. For each level of production, the emissions of SO_2 may vary over a wide range, depending mainly on the following factors:

- the sulphur content of the coke (mainly), pitch and fuel oil, and to what extent the sulphur in the coke and pitch is volatilised during the baking process.

- whether wet scrubbing is applied, and the efficiency of the scrubbing process, both for the flue gases from the electrolysis and the baking furnace.

Three alternatives for emissions to air of SO_2 have therefore been studied. These are:

Case 1: Use of high sulphur coke and pitch with no wet scrubbing of the flue gas from the anode furnace. The efficiency of the electrolysis flue gas scrubbers is stipulated to 93.4%.

Case 2: Use of medium low sulphur coke and pitch with no wet scrubbing of the flue gas from the anode furnace. The scrubbing efficiency is stipulated to be 98.5% in this case.

Case 3: Use of high sulphur coke and pitch and wet scrubbing of the anode furnace flue gas. The emissions from the electrolysis is assumed to be as in Case 1.

The layout of the aluminium smelter is shown in Figure 7 and the corresponding emissions and emission parameters are shown in Table 3 to Table 6. The following codes have been used for the emission sources:

1) and 2) Potroom 1 and 2. The sources are fugitive emissions from the pots that escape into the potroom. The emissions are ventilated to the atmosphere through a horizontal vent going along the whole length of the potroom.

3), 4) and 5) FTP 1, 2 and 3: The sources are the fume treatment plants of the electrolysis (dry and wet scrubbing).

6) FTC: Fume treatment plant of the anode baking furnace (Cooling, electrostatic precipitator, dry scrubbing).

7) GAP: Green anode plant gas treatment unit (dry scrubbing with coke dust)

8) Casthouse (baghouses)

The emissions and emission parameters have been given by Reydaral based on Norsk Hydro technology.

Table 3 and Table 5 summaries the emissions to air and emission characteristics from the two phases used in the study. Where there have been ranges in the possible emission parameters the most unfavourable alternatives are used in the dispersion calculations.

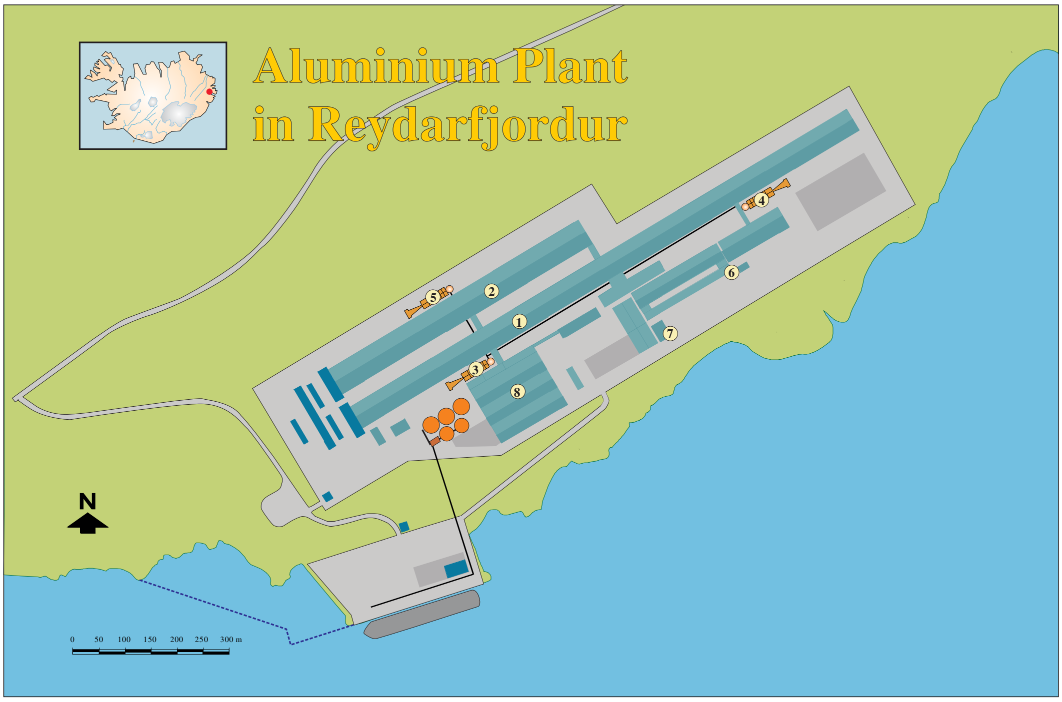


Figure 7: Layout of the aluminium smelter. 1) Potroom 1, 2) Potroom 2, 3), 4) and 5) Fume Treatment Plant (FTP 1, FTP 2, FTP 3), 6) Fume Treatment Carbon (FTC), 7) Green anode plant (GAP), 8) CastHouse

Table 3: Emissions to air from the aluminium smelter at Sómastadagerdi in Reyðarfjördur. Phase 1. (280 000 tpy).

Pos no.		HF	F particulate	PM10	SO2			PAH
		mg/s	mg/s	g/s	g/s			mg/s
					Case 1	Case 2	Case 3	
1	Pot 1	977	799	0.355	3.2	1.66	3.2	0.2
2	Pot 2							
3	FTP 1	89	133	0.093	7.33	0.96	7.33	0.14
4	FTP 2	89	133	0.093	7.33	0.96	7.33	0.14
5	FTP 3							
6	FTC	9.5	10	0.013	34.56	15.20	3.46	37.5
7	GAP			0.076				8.8
8	Cast House				0.4	0.4	0.4	

Table 4: Dispersion characteristics for the different sources, Phase 1. (280 000 tpy).

Pos no.		Gas Volume	Gas Temp	Gas Velocity	Stack Height	Stack Dia.	Potroom Length
		m3/h	°C	m/s	m	m	m
1	Pot 1	24 500 000	30	1	21		1 103
2	Pot 2						
3	FTP 1	1 151 000	15	13	28	5.6	
4	FTP 2	971 000	15	13	28	5.1	
5	FTP 3						
6	FTC	90 000	30 (15*)	13	28	1.6	
7	GAP	19 000	20	6.7	50	1	
8	Cast House	160 000	140	13	28	2.1	

*When wet scrubber is used

Table 5: Emissions to air from the Aluminium smelter at Sómastadagerdi in Reyðarfjördur. Phase 2. (420 000 tpy).

Pos no.		HF	F	PM10	SO2			PAH
		mg/s	mg/s	g/s	g/s			mg/s
					Case 1	Case 2	Case 3	
1	Pot 1	977	799	0.355	3.2	1.66	3.2	0.2
2	Pot 2	488	400	0.178	1.6	0.83	1.6	0.1
3	FTP 1	89	133	0.093	7.33	0.96	7.33	0.14
4	FTP 2	89	133	0.093	7.33	0.96	7.33	0.14
5	FTP 3	89	133	0.093	7.33	0.96	7.33	0.14
6	FTC	12.5	13.5	0.017	46.08	20.27	4.61	50
7	GAP			0.101				11.7
8	Cast House				0.6	0.6	0.6	

Table 6: Dispersion characteristics for the different sources, Phase 2. (420 000 tpy).

Pos no.		Gas Volume	Gas Temp	Gas Velocity	Stack Height	Stack Diameter.	Potroom Length
		m3/h	°C	m/s	m	m	m
1	Pot 1	24 500 000	30	1	21		1 103
2	Pot 2	12 250 000	30	1	21		558
3	FTP 1	1 151 000	15	13	28	5.6	
4	FTP 2	971 000	15	13	28	5.1	
5	FTP 3	1 021 000	15	13	28	5.3	
6	FTC	120 000	30 (15*)	19	28	1.5	
7	GAP	25 000	20	8.8	50	1	
8	Cast House	240 000	140	19	28	2.1	

*When wet scrubber is used.

The positions of the emissions are given in Figure 1 according to position given names in the above tables.

6. Analysis of unfavourable dispersion conditions

The site of the aluminium smelter is located in East Iceland, on the northern side of Reyðarfjördur. Mountains that reach up to 1000 m surround the fjord. The fjord is closed in the head of the fjord and there are only narrow valleys feeding into the fjord. This indicates that the meteorology is strongly influenced by topographical effects. There will also be a tendency of low wind speeds, which is unfavourable for the dispersion of pollutants emitted to the air. To be able to give good estimations of the impact from the aluminium smelter it has been necessary to analyse the situations giving poor mixing in the fjord. These situations have been discussed with IMO to take advantage of the local knowledge of meteorology.

The following meteorological situations have been discussed and analysed according to potential for poor dispersion:

1. Sea-land breeze
2. Calm conditions
3. Re-entries
4. Vertical vortexes

6.1 Sea-land breezes

This situation is characterised by closed vertical cells that can transport emissions back into the fjord. At daytime the land in the fjord is heated and the air above the sea surface in the fjord is pulled towards the head of the fjord close to the ground. A vertical cell is formed where the air in the upper part of the fjord is transported out along the fjord until it reaches the point where the air again is sucked downwards and transported into the fjord. A schematic illustration of this is shown in Figure 8.

This type of situation is often occurring in Reyðarfjördur in spring and summer. This is clearly seen in the difference between the wind roses for summer day and summer nighttime, Figure 4 and Figure 5. The driving force in this cell is clearly seen from the temperature difference between Seley and Sómastadagerdi (Figure 9). Seley is generally colder than Sómastadagerdi in summer, which will favour a motion onshore into the fjord. Figure 10 shows the temperature as a function of time of day for June 2000. A diurnal variation is seen with a maximum in the temperature difference at noon and a minimum during the night. This indicates that a sea breeze is likely to form during the day. To be able to evaluate the impact of this phenomenon for dispersion of emissions to air from the aluminium smelter, it is necessary to get information of the size of the cell both vertically and horizontally and by this estimate the time of one circulation.

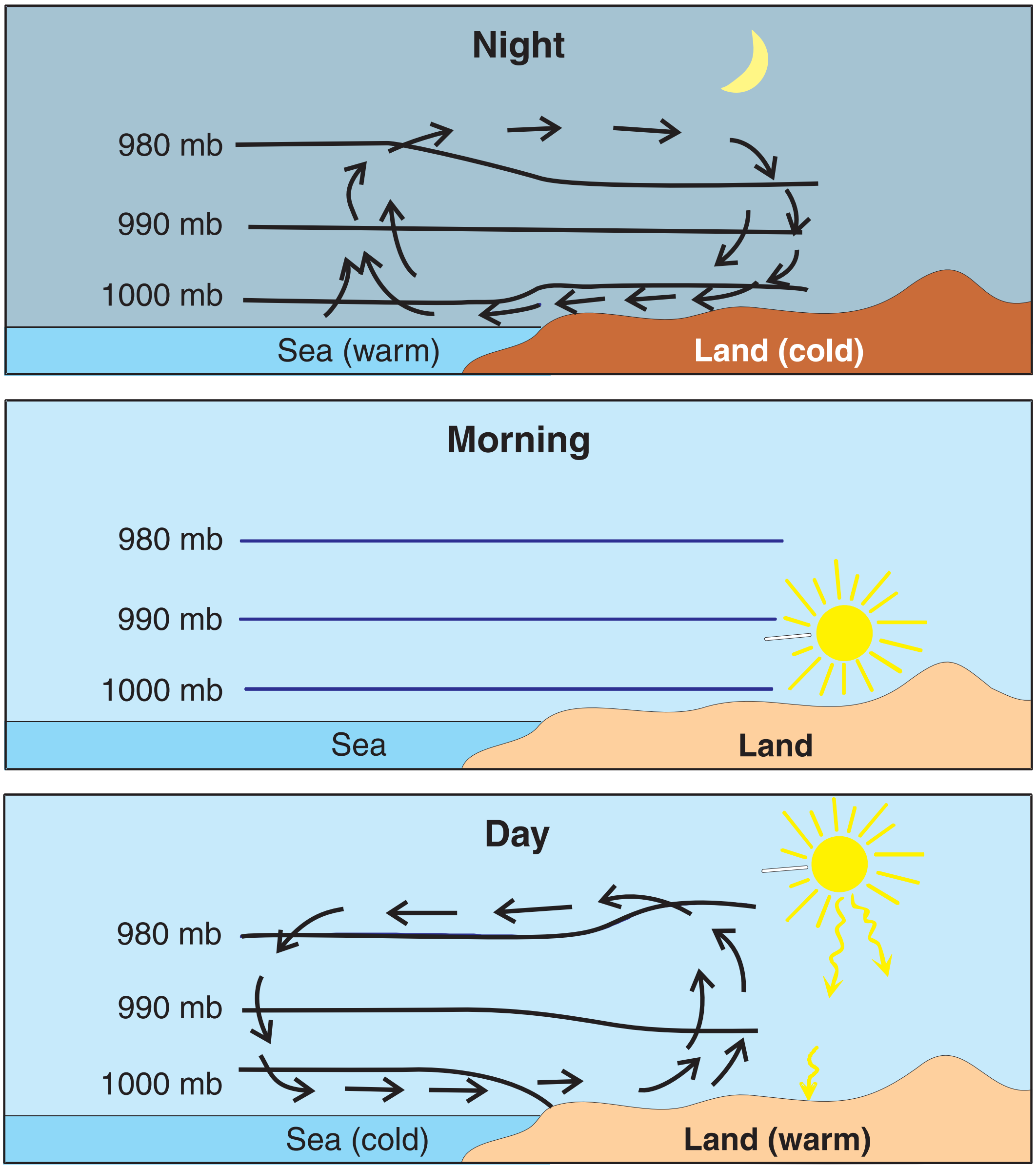


Figure 8: Schematic view of a typical Sea-land breeze.

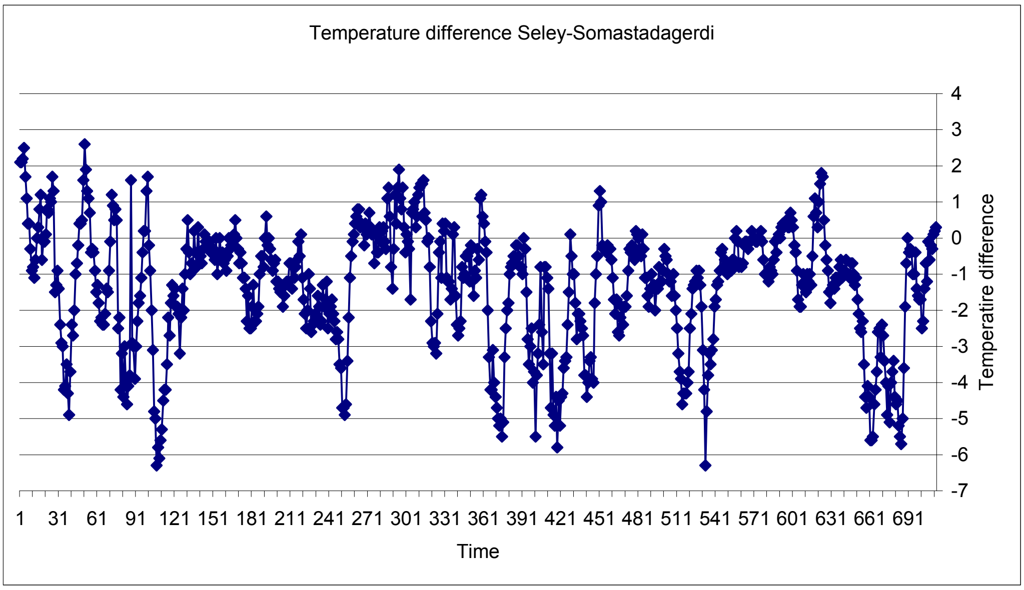


Figure 9: Temperature at Seley minus temperature at Sómastadagerdi for June 2000. Unit: °C.

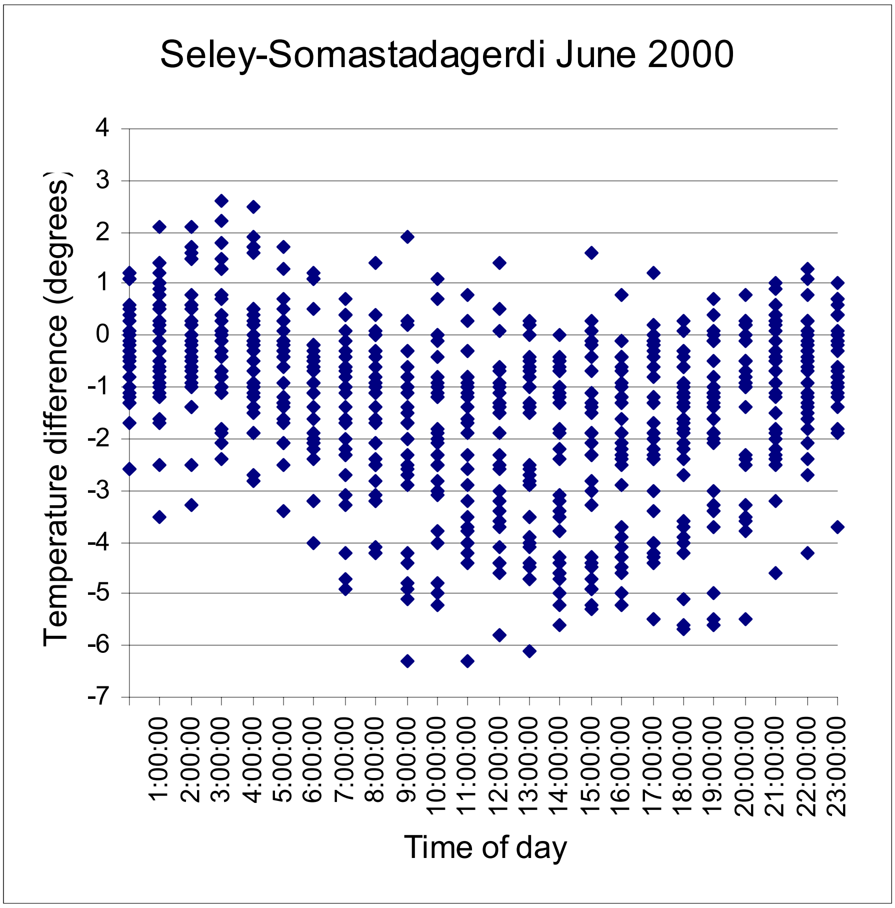


Figure 10: Diurnal variation of temperature difference between Seley and Sómastadagerdi for June 2000.

Figure 11 shows simultaneous measurements of wind direction at Vattarnes at the outlet of the fjord and at Sómastadagerdi. It is seen from the figure that the wind direction at Sómastadagerdi is channelled along the fjord at 90 and 270 degrees. This is not the case for Vattarnes where the highest wind frequency is in the sector 30-180 degrees, corresponding to wind along the coast or onshore. There is a gap in frequency at around 120 degrees at Vattarnes, which corresponds to the axis in the outer part of the fjord. This direction should be predominant if the sea breeze has a dimension that reaches Vattarnes.

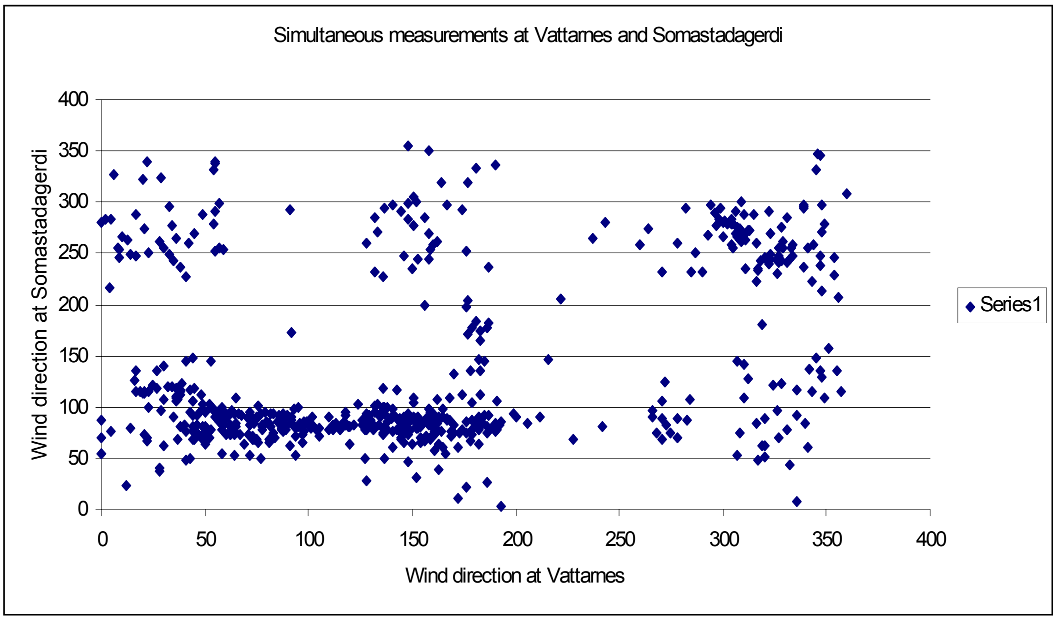


Figure 11: Scatter plot of simultaneous measurements of wind direction at Vattarnes and Sómastadagerdi for June 2000. Unit: degrees.

The measurements from the recent station at Vattarnes, plotted in Figure 11, show that this vertical cell is probably kept within the fjord in the majority of cases. If a cell like this is to develop it will probably stretch for the length of the fjord and be of this size horizontally. This means that the cell is approximately 30 km long. The vertical cell will have to be lower than 1000 m because if it stretches above the surrounding topography the cell will probably be broken down by the synoptic winds. To investigate the height of the cell the station of Ljosa has been used. Ljosa is 280 m above sea level and if the measurements have opposite directions with wind in the fjord at Sómastadagerdi this means that Ljosa is in the upper flow. The height of the cell is then approximately 3-400 m. The measurements plotted in Figure 12 show that this situation is rare (wind at Sómastadagerdi $\approx$ 90 degrees and Ljosa $\approx$ 270 degrees) and does not last for long periods of time. This means that the size of the cell vertically normally is between 300-1000 meters in height. To be lower than this the cell will break down because of shear stress. Or that the formation of a cell is in progress and that this will not last more than 1-2 hours.

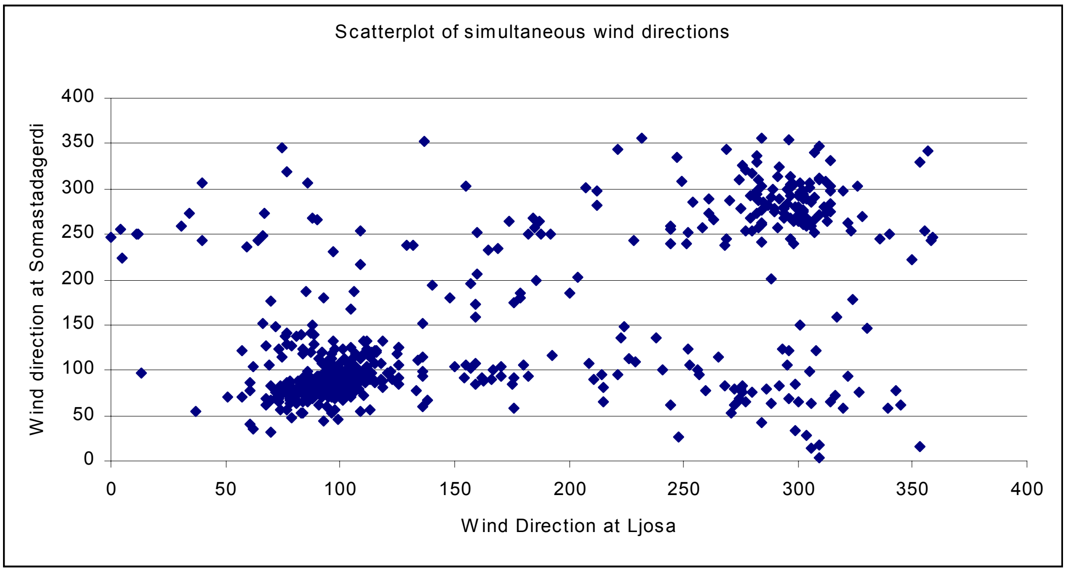


Figure 12: Scatter plot of simultaneous measurements of wind direction (degrees) at Ljosa and Sómastadagerdi for June 2000.

The wind speed at ground level in a land sea breeze is normally high in Iceland. This is because of the high temperature difference between the sea temperature reflected at Seley and the temperature in the head of the fjord (Sómastadagerdi, Kollaleira). The wind speed is normally 3-5 m/s in the daytime cell. The wind speed over all in the cell is probably lower and a wind speed of 3 m/s is used as a typical wind speed. This means that the time frame of one circulation is (3 m/s, 30 km long) approximately 5 hours. One to two circulations may occur during one day. The wind speed will be so high at these hours that dispersion will be good. The daytime cell will be active approximately 6 –10 hours of the day.

The nighttime cell will probably not form in the same way because the sea is cold and the temperature difference between sea and land is not pronounced. The drainage flow will most probably spill out of the fjord mouth and not enter into a circulation cell. This could be seen in Figure 11 where the scatter plot has a cluster where Vattarnes have the direction of ≈ 330 degrees and Sómastadagerdi ≈ 260 degrees.

The evaluation of this type of conditions is that they are not critical for dispersion, because there will not be more than two re-entries, wind speed is relatively high and there are good mixing conditions.

6.2 Calm Conditions

Calm conditions are defined by wind speeds less than 0.4 m/s. In these situations the wind field is not well defined. This means that local effects will dominate. At

Sómastadagerdi calm conditions occur 1.7% in October 1998 to September 1999 and 0.9% in the period October 1999 to September 2000. Calm conditions occur more frequent during summer than winter. For summer 1998-1999 calm conditions occur 2.5% of the time and for 1999-2000 1.3%. In winter the corresponding numbers are 0.9 and 0.5%.

Calm conditions must be persistent for some time to have a significant impact on the 24-hour average concentrations. One period with wind speed smaller or equal to 0.4 m/s for 11 hours was observed at Sómastadagerdi in 1998-1999. In addition one period with 8, two periods with 7, two periods with 6 and three periods with 5 consecutive hours were observed. In 1999-2000 one period with wind speed smaller or equal to 0.4 m/s for 8 hours, one period for 6 hours and two periods for 5 hours were observed. This indicates that the dispersion conditions in 1999-2000 are a lot better than for the year 1998-1999.

These situations are also a subset of the situation where re-entries occur. The situations described here are situations where the pollution is transported either out or in the fjord for long time periods. The situations with calm conditions are rare in Reyðarfjördur. For the two years of data investigated 12 situations were detected. These situations have transport in one direction and will not last more than 11 hours. The situations with re-entries will be worse because of low wind speed and accumulation of pollutants.

6.3 Re-entries

This type of situations are characterised by low wind speeds combined with variable wind direction. The emissions are not transported out of the fjord and the pollutants are transported back and forth in the fjord. The emissions can therefore impact at the same position a number of times. This means that an accumulation of pollutants will occur. The wind will typically change direction along the fjord several times during such an episode and will cause the highest impacts from the aluminium smelter. The wind shifts will have to be frequent because the pollutants will travel approximately 4 km with a 1 m/s wind speed. The wind regime outside the fjord is normally different from inside the fjord so that when the pollutants are transported out of the fjord or above surrounding topography the possibilities of re-entering the fjord is very small. These situations are classified so that the pollutants are kept inside the fjord for some time. One example of this type of situation is shown in Figure 13.

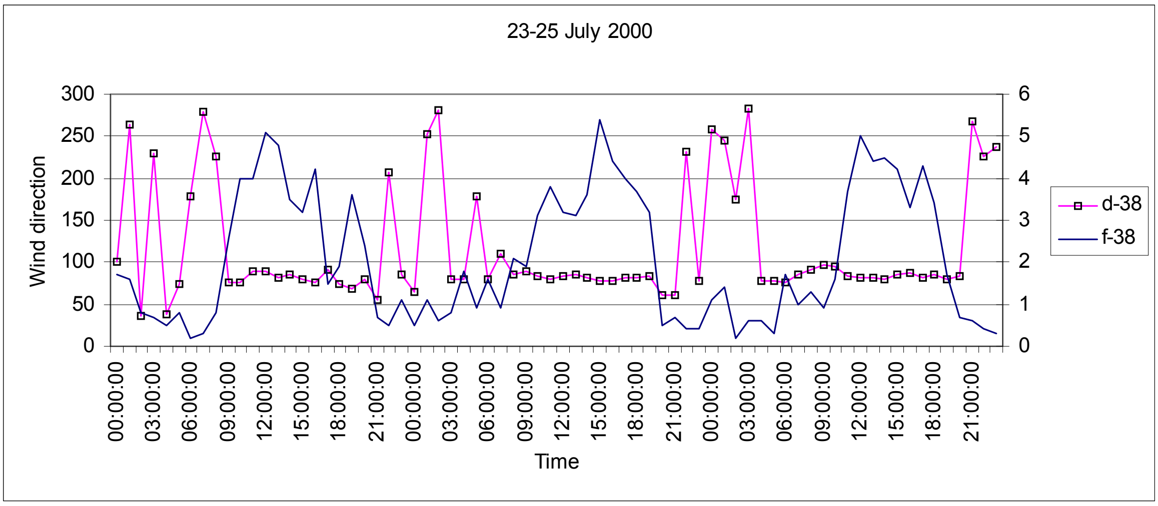


Figure 13: Wind speed ('f-38'. Unit: m/s) and wind direction ('d-38'. Unit: degrees) at Sómastadagerdi for the period of 23-25 July 2000.

The interesting information in Figure 13 is wind speeds below 2 m/s. There are 3 periods lasting for some time when this is the case. They occur during nighttime and last typically from early evening to early morning. The wind direction changes and the air is pumped in and out of the fjord several times. On the 23 of July: 5 times, on the 24 of July: 6 times and on the 25 of July: 4 times. This means that the pollutants will pass over the same area 4-6 times during one night, which will cause an accumulation of the pollutants and high concentrations. During the day the wind speed increases and the fjord is ventilated effectively.

6.4 Vertical vortexes

Vertical vortexes can form when the sun heats some areas of the fjord. These vortexes can form when one side of the fjord is exposed to the sun while the other side is in the shade. The analysis of the data indicates that these vortexes do not persist for more than one-two hours. This means that no defined circulation cells will be formed. They will also most likely have a vertical size higher than the topography and will not enter into the fjord on the downward motion on the other side.

Vertical vortexes can also form when the synoptic wind is perpendicular to the fjord axis and the shear stress causes air to circulate up the leeward side of the fjord and down the other side. This situation is not seen in the data examined. And will also not be critical for the dispersion of the emissions from the smelter because of the good vertical mixing conditions.

7. Model calculations of long term average concentrations

NILU's dispersion model, CONDEP, was used to calculate long-term average concentrations of SO_2, PM_{10}, PAH, and of fluorides. The program CONDEP calculates long-term average concentrations in a given grid for twelve 30° sectors (Bøhler, 1987). The input consists of source and emission data and a joint frequency matrix of meteorological variables. The program takes into account effects of stack downwash, building turbulence, wind profiles, deposition, topography and penetration through an elevated stable layer. The CONDEP model, as most Gaussian plume models, is a conservative model, i.e. it has a higher probability of overestimating concentrations than of underestimating them. The emission data, given in Table 3 to Table 6 and the meteorological matrix, given in Table 2, have been used as input to the long-term average dispersion calculations.

7.1 Summary of modelled concentrations of long term averages

To help give the reader an overview of the results presented in this chapter a brief summary of the main results found from the calculation of the long term concentrations are given.

Table 7 and Table 8 give an overview of the distances where the calculated concentrations reach the respective air quality guidelines. It is seen that SO_2, emission case 1, is estimated to give the largest impact on air quality.

For a production of 280 000 tpy, case 1, the concentration of 30 $\mu g/m^3$ (Icelandic air quality guideline for SO_2) reaches out to a distance of 500 m in the direction of Budareyri. In the opposite direction 30 $\mu g/m^3$ is exceeded out to 700 m for case 1, 200 m for case 2 and 300 m for case 3.

The calculated concentrations higher than the EU air quality guideline for SO_2 of 20 $\mu g/m^3$ stretch out to approximately 800 m towards Budareyri for emission case 1, and 300 m for case 2 and case 3.

For a production of 420 000 tpy the concentration for SO_2 of 30 $\mu g/m^3$ (Icelandic air quality guideline) reaches out to a distance of 400 m for case 1, 2 and 3 in the direction of Budareyri.

The calculated concentrations higher than the EU air quality guideline for SO_2 of 20 $\mu g/m^3$ stretch out to approximately 700 m for case 1, 700 m for case 2 and 500m for case 3.

The air quality guidelines for yearly average concentrations are generally not the most restrictive for emissions to air. The critical averaging time is normally hourly/diurnal averages for pollutants that have an acute effect connected to short time concentrations. For SO_2 this will most likely be percentiles of hourly concentrations or percentiles of diurnal averages.

The guidelines for particulate matter are given for PM_{10} (particulate matter with a diameter less than 10 μm). The emissions are given for total particulate matter. The PM_{10} content in the dust emissions is estimated to 10 % of the weight. The calculations show that the PM_{10} concentrations are well below the air quality guideline for both production alternatives.

There is no air quality guideline for PAH. It is normal to use benzo-a-pyrene (BaP) as an indicator for the carcinogenic effect. As described earlier the air quality guideline for BaP varies with a factor of ten from 0.1-1 ng/m^3. WHO states that there is no lower limit value for PAH. The US EPA has offered an upper bound lifetime risk that 9 out of 100 000 people exposed to 1 ng BaP per m^3 over a lifetime would be at risk of developing cancer. Measurements done in the vicinity of Norwegian aluminium smelters show a content of 1% BaP in the PAH. The transformed air quality guideline for PAH will therefore be 0.01- 0.1 µg/m^3. The calculations show that 0.01 µg/m^3 is exceeded out to a distance of 2.0 km towards Budareyri with a production of 280 000 tpy and 2.3 km with a production of 420 000 tpy. The calculations show no exceeding of the 0.1 µg/m^3 limit for PAH.

The most critical air quality guideline for fluorides is the Norwegian air quality guideline for gaseous fluorides for protecting of vegetation during the growing season, which is 0.3 µg/m^3. This air quality guideline is exceeded out to a distance of 1.4 km towards Budareyri for a production of 280 000 tpy, and 2.2 km for a production of 420 000 tpy.

Table 7: Distances in kilometres to the air quality guideline for calculated yearly concentrations for SO_2, PAH and PM_{10}. Numbers in parenthesis are the distance from the nearest corner of the potrooms out the fjord, and the numbers without parenthesis in the direction of Budareyri.

Yearly concentrations				
	Distance to air quality guideline in kilometres			
	1999-2000		1998-1999	
Air quality guideline	Iceland (30 µg/m^3)	EU (20 µg/m^3)	Iceland (30 µg/m^3)	EU (20 µg/m^3)
280 000 tpy				
SO_2 Case 1	0.5 (0.7)	0.8 (0.8)	0.5 (0.6)	0.8 (0.9)
SO_2 Case 2	- (0.2)	0.3 (0.4)	- (0.2)	0.2 (0.4)
SO_2 Case 3	- (0.3)	0.3 (0.5)	- (-)	0.2 (0.5)
420 000 tpy				
SO_2 Case 1	0.4 (0.5)	0.7 (0.8)	0.2 (0.4)	0.4 (0.5)
SO_2 Case 2	0.4 (0.6)	0.7 (0.8)	0.3 (0.5)	0.3 (0.6)
SO_2 Case 3	0.4 (0.5)	0.5 (0.7)	0.3 (0.5)	0.4 (0.6)
Air quality guideline	Iceland (PM_{10} 40 µg/m^3)	EU (PM_{10} 20 µg/m^3)	Iceland (PM_{10} 40 µg/m^3)	EU (PM_{10} 20 µg/m^3)
PM_{10} 280 000 tpy	- (-)	0.1 (0.1)	- (-)	0.1 (0.2)
PM_{10} 420 000 tpy	- (-)	0.2 (0.2)	- (-)	0.2 (0.2)
Air quality guideline	0.01 µg/m^3 (0.1 ng/m^3 BaP)	0.1 µg/m^3 (1.0 ng/m^3 BaP)	0.01 µg/m^3 (0.1 ng/m^3 BaP)	0.1 µg/m^3 (1.0 ng/m^3 BaP)
PAH 280 000 tpy	2.0 (1.9)	- (-)	1.7 (2.1)	- (-)
PAH 420 000 tpy	2.2 (2.4)	- (-)	2.4 (2.5)	- (-)

Table 8: Distances in kilometres to the air quality guideline for calculated winter concentrations for SO_2 and growing season for gaseous fluorides. Numbers in parenthesis are the distance from the nearest corner of the potrooms out the fjord, and the numbers without parenthesis in the direction of Budareyri.

Winter						
	Distance to air quality guideline (40 $\mu g/m^3$)					
	1999-2000			1998-1999		
280 000 tpy	EU 20 $\mu g/m^3$	EU upper 12 $\mu g/m^3$	EU lower 8 $\mu g/m^3$	EU 20 $\mu g/m^3$	EU upper 12 $\mu g/m^3$	EU lower 8 $\mu g/m^3$
SO_2 Case 1	0.3 (1.2)	0.5 (2.2)	0.8 (3.4)	0.3 (1.0)	0.5(2.1)	0.8 (3.2)
SO_2 Case 2	- (0.3)	0.2 (0.5)	0.4 (0.8)	- (0.2)	0.2 (0.6)	0.4 (1.1)
SO_2 Case 3	0.2 (0.5)	0.4 (0.9)	0.6 (1.3)	0.1 (0.4)	0.3 (0.7)	0.5 (1.1)
420 000 tpy						
SO_2 Case 1	0.4 (1.8)	0.6 (3.1)	1.0 (4.8)	0.4 (1.8)	0.7 (3.0)	1.0 (4.5)
SO_2 Case 2	0.2 (0.3)	0.5 (0.7)	0.8 (0.9)	0.2 (0.4)	0.5 (0.7)	0.8 (1.0)
SO_2 Case 3	0.1 (0.5)	0.3 (0.8)	0.4 (1.2)	0.1 (0.5)	0.3 (0.8)	0.4 (1.1)

Distance in kilometres to air quality guideline for the Growing season		
Air quality guideline	Vegetation 0.3 $\mu g/m^3$	Vegetation 0.3 $\mu g/m^3$
Gaseous fluorides 280 000 tpy	1.4 (1.0)	1.4 (1.1)
Gaseous fluorides 420 000 tpy	2.2 (1.5)	2.0 (1.6)

7.2 Sulphur dioxide

The long-term average calculations of SO_2 concentrations have been carried out for two years, September 1998 to September 1999 and September 1999 to September 2000, and compared with the Icelandic and EU guidelines for one year. The results from the year 1999-2000 are presented here. The results from 1998-1999 are shown in Appendix B. Three cases of emissions of SO_2 have been analysed, for two different production alternatives. Case 1 is based on the use of high sulphur coke and pitch with no wet scrubbing of the flue gas from the anode furnace; Case 2 is based on medium low sulphur content in the coke and pitch used with no wet scrubbing of the flue gas from the anode furnace. Case 3 is identical with Case 1 except a wet scrubber at the anode furnace.

The calculations show that for the production of 280 000 tpy aluminium the concentrations above the EU air quality guideline for SO_2 of 20 $\mu g/m^3$ will be close to the plant. There are, however, concentrations up to 20 µg/m³ for the year 1999-2000, 800 m from the end of the potroom on the west and east side of the plant, for the alternative with highest emissions (case 1). The Icelandic air quality guideline is 30 µg/m³ and the concentrations are below this value within 500 m towards Budareyri and 700 m west of the plant from the potroom, for case 1.

The yearly averaged concentrations from a production of 280 000 tpy for 1999-2000 Case 1, 2 and 3 of the calculations are given in Figure 14 to Figure 16, and from a production of 420 000 tpy in the Figure 17 to Figure 19. The dispersion calculations reflect the channelling of the wind along the valley and fjord axis. The area of higher impact occurred close to the smelter due to the low sources (pot-rooms) and the building influence on the emissions.

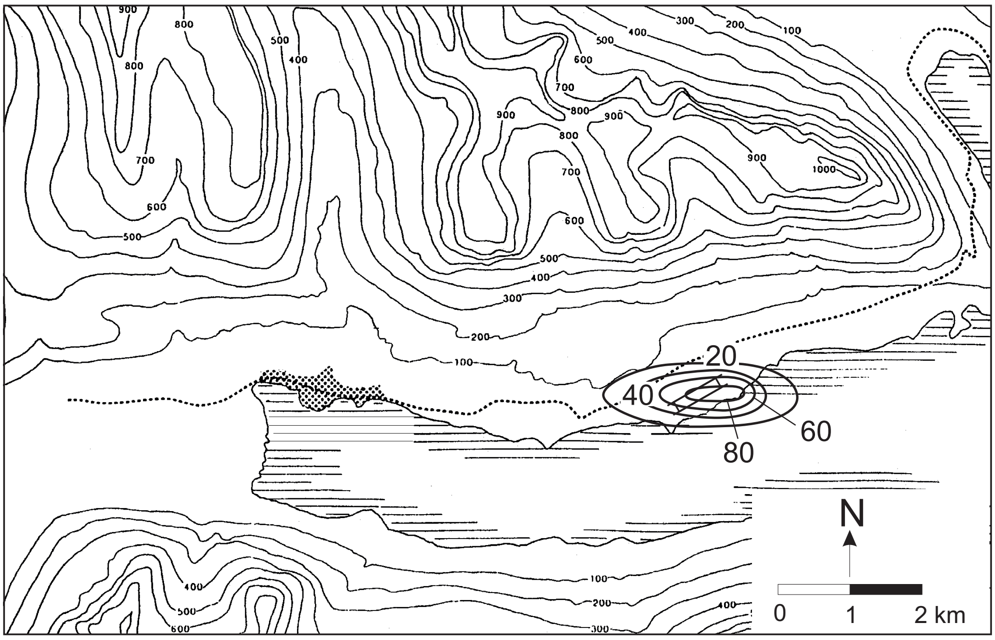


Figure 14: Yearly concentrations of SO_2 for 1999-2000 (280 000 tpy). Case 1. Unit: µg/m³ . The Icelandic air quality guideline is 30 µg/m³, EU air quality guideline is 20 µg/m³.

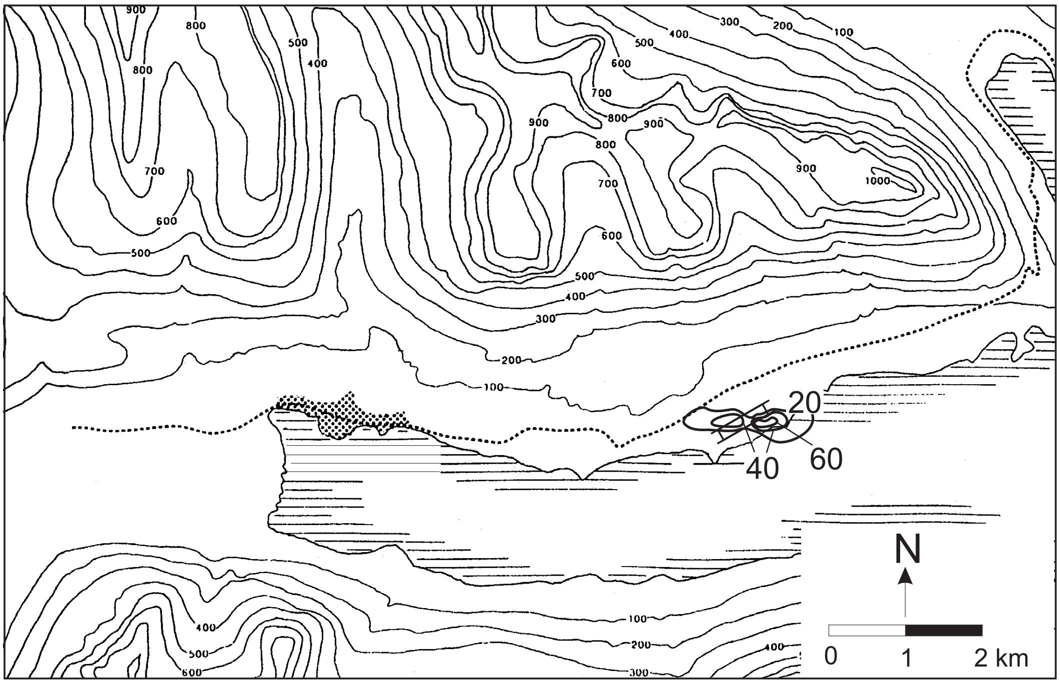


Figure 15: Yearly concentrations of SO_2 for 1999-2000 (280 000 tpy). Case 2. Unit: µg/m³. The Icelandic air quality guideline is 30 µg/m³, EU air quality guideline is 20 µg/m³.

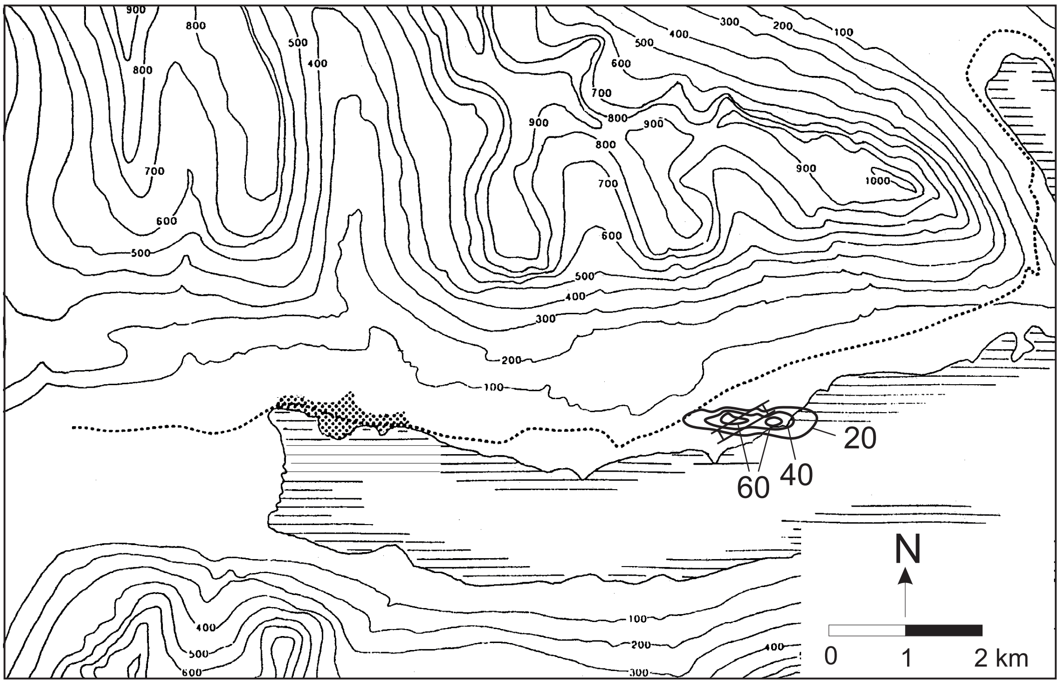


Figure 16: Yearly concentrations of SO_2 for 1999-2000 (280 000 tpy). Case 3. Unit: µg/m³ . The Icelandic air quality guideline is 30 µg/m³, EU air quality guideline is 20 µg/m³.

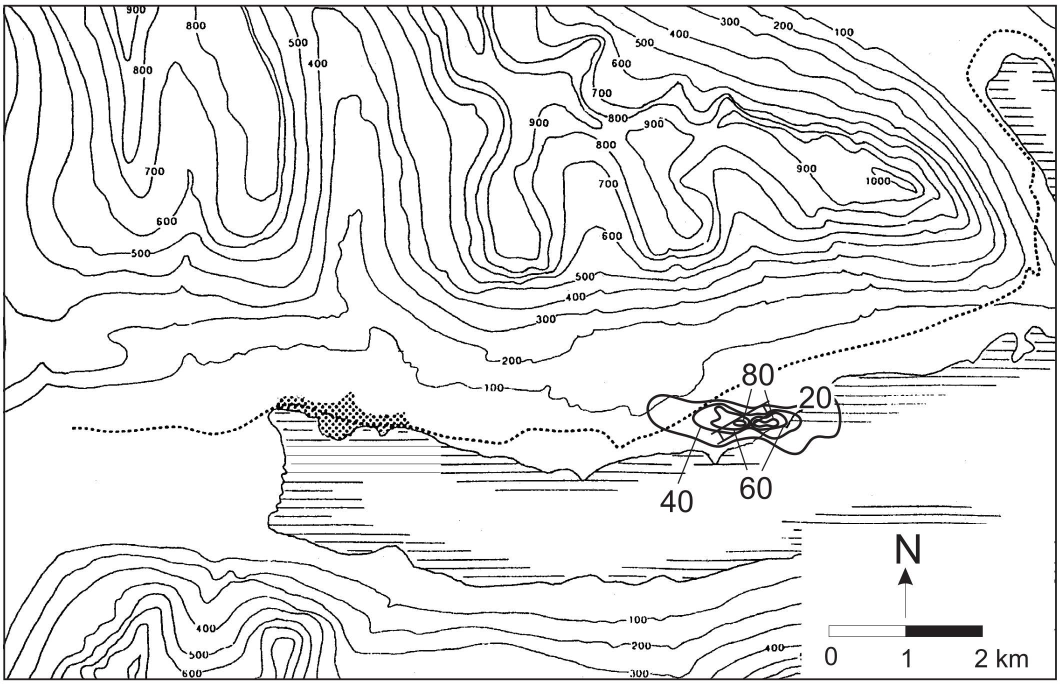


Figure 17: Yearly concentrations of SO_2 for 1999-2000 (420 000 tpy). Case 1. Unit:µg/m^3. The Icelandic air quality guideline is 30 µg/m^3, EU air quality guideline is 20 µg/m^3.

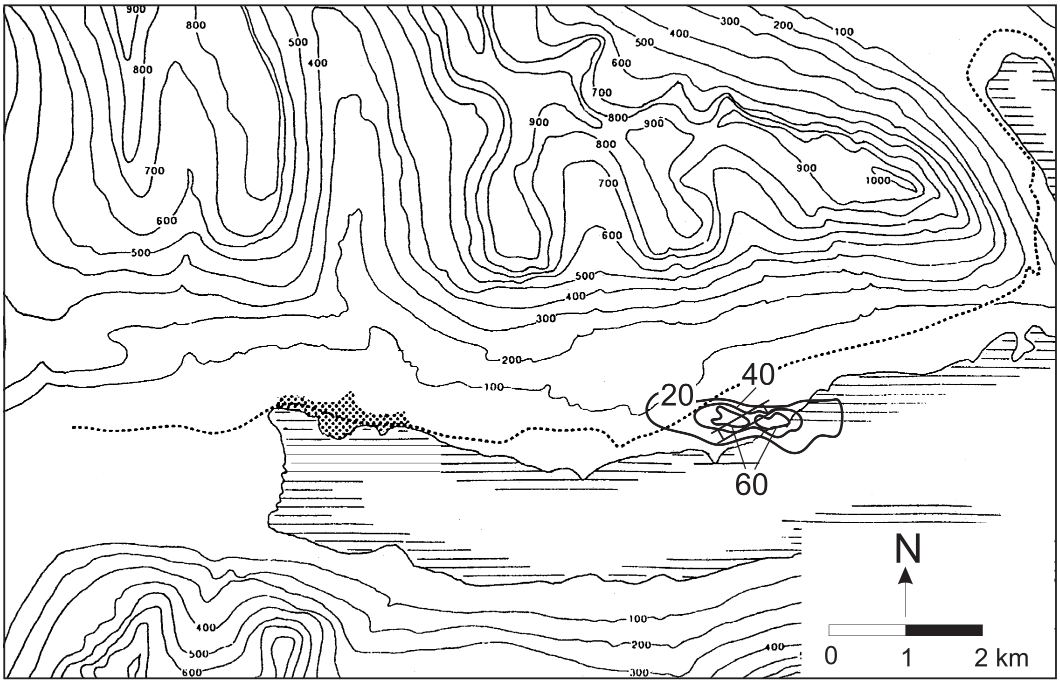


Figure 18: Yearly concentrations of SO_2 for 1999-2000 (420 000 tpy). Case 2. Unit:µg/m^3. The Icelandic air quality guideline is 30 µg/m^3, EU air quality guideline is 20 µg/m^3.

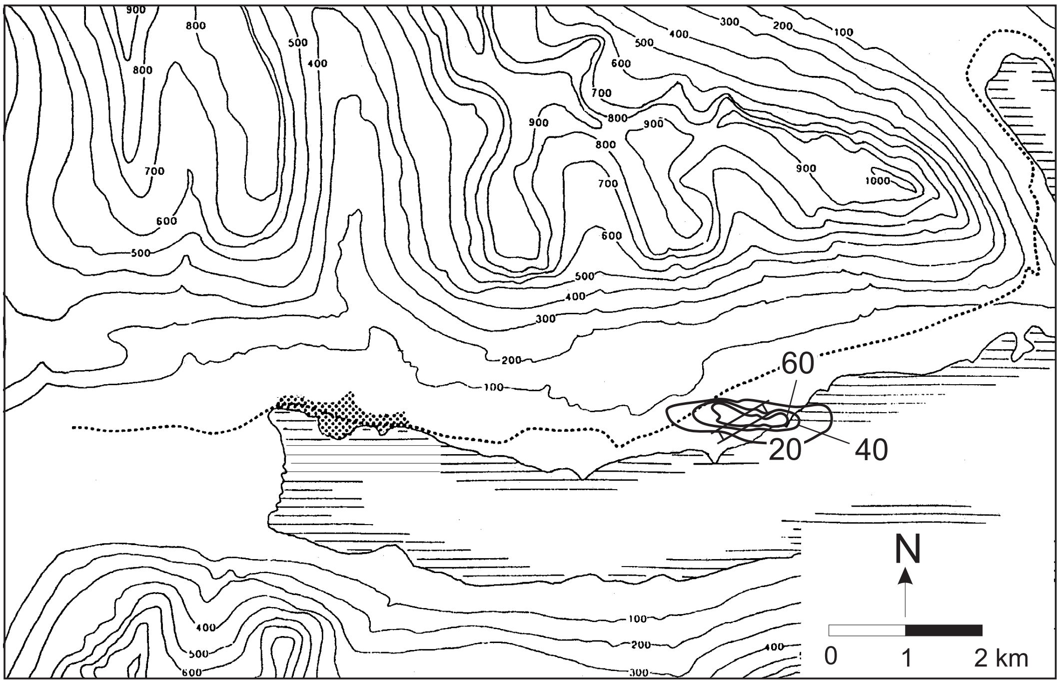


Figure 19: Yearly concentrations of SO_2 for 1999-2000 (420 000 tpy). Case 3. Unit:µg/m³. The Icelandic air quality guideline is 30 µg/m³, EU air quality guideline is 20 µg/m³.

The EU air quality guideline for sulphur dioxide for winter is 20 µg/m³. The EU air quality guidelines also have an upper and lower evaluation threshold. These are 12 µg/m³ (upper) and 8 µg/m³ (lower). When the concentrations exceed the upper evaluation threshold a monitoring network have to be put in operation and a plan to get the concentrations below this limit must be made. In-between the upper and lower limit a simpler monitoring network and or modelling of the dispersion is sufficient.

Concentrations from the winter 1999-2000 are presented in Figure 20 to Figure 25.

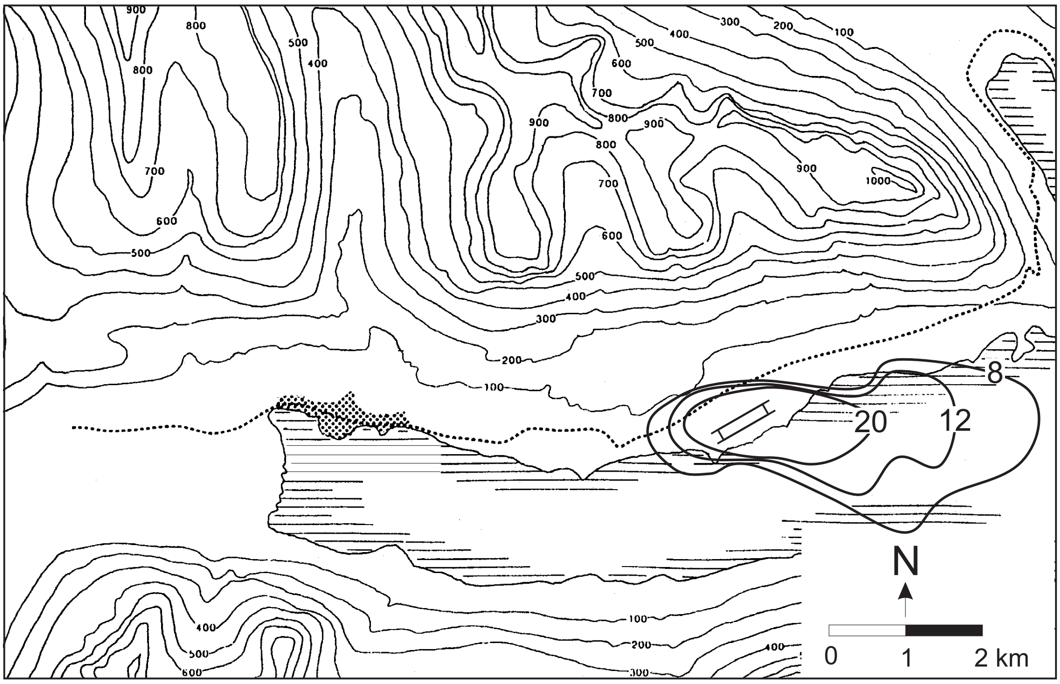


Figure 20: Winter concentrations of SO_2 for 1999-2000. (280 000 tpy). Case 1. Unit: µg/m^3. EU air quality guideline 20 µg/m^3, upper evaluation guideline 12 µg/m^3, lower 8 µg/m^3.

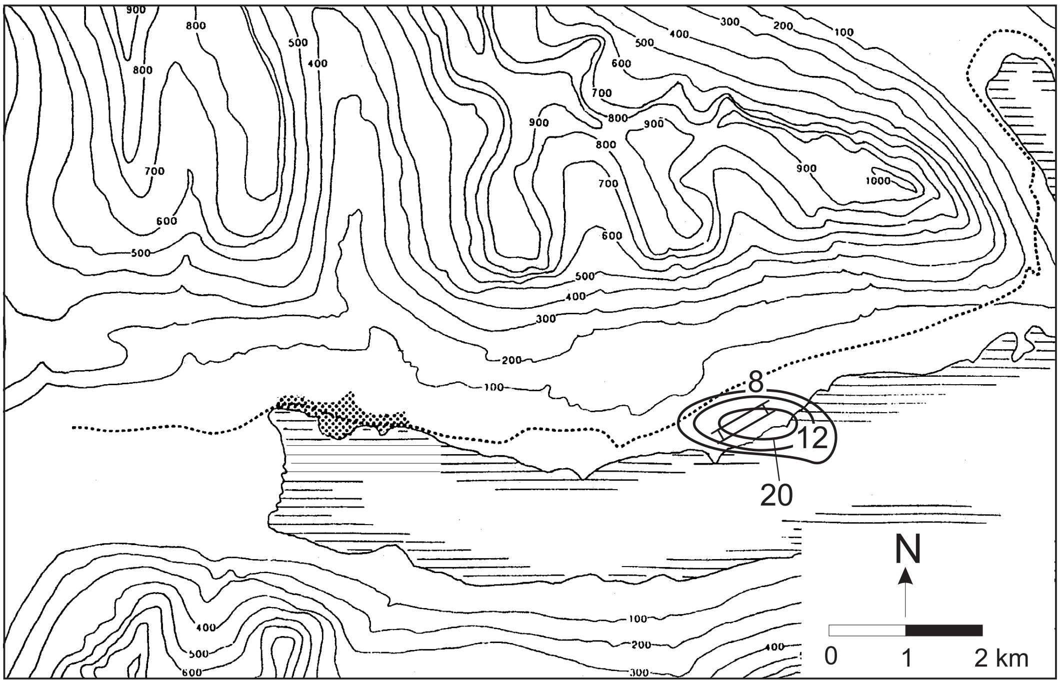


Figure 21: Winter concentrations of SO_2 for 1999-2000. (280 000 tpy). Case 2. Unit: µg/m^3. EU air quality guideline 20 µg/m^3, upper evaluation guideline 12 µg/m^3, lower 8 µg/m^3.

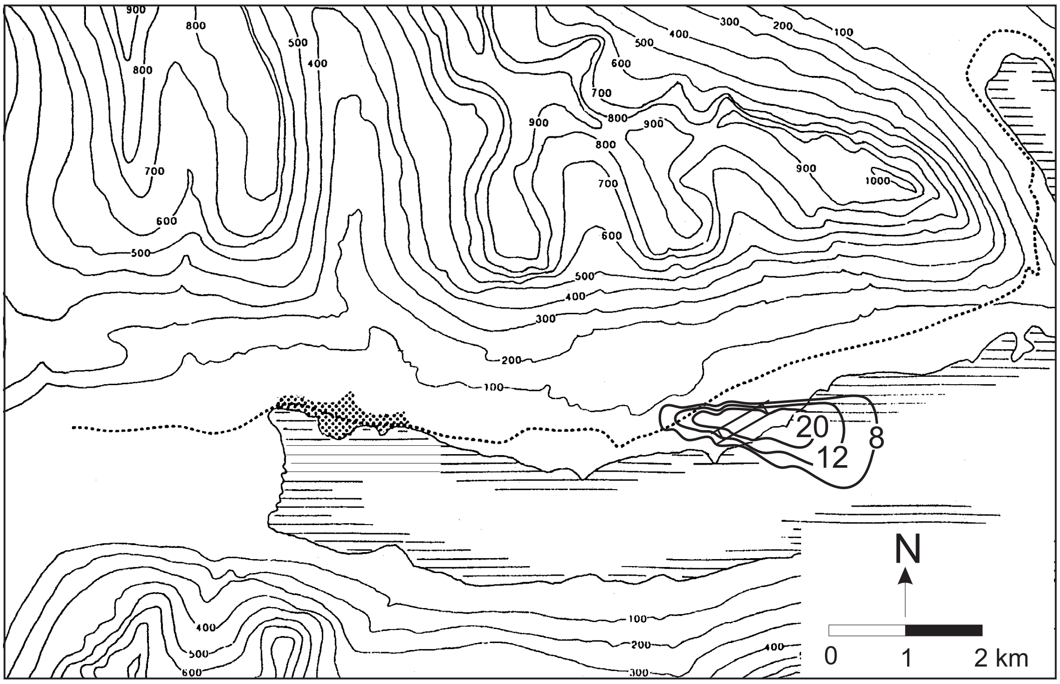


Figure 22: Winter concentrations of SO_2 for 1999-2000. (280 000 tpy). Case 3. Unit: µg/m³. EU air quality guideline 20 µg/m³, upper evaluation guideline 12 µg/m³, lower 8 µg/m³.

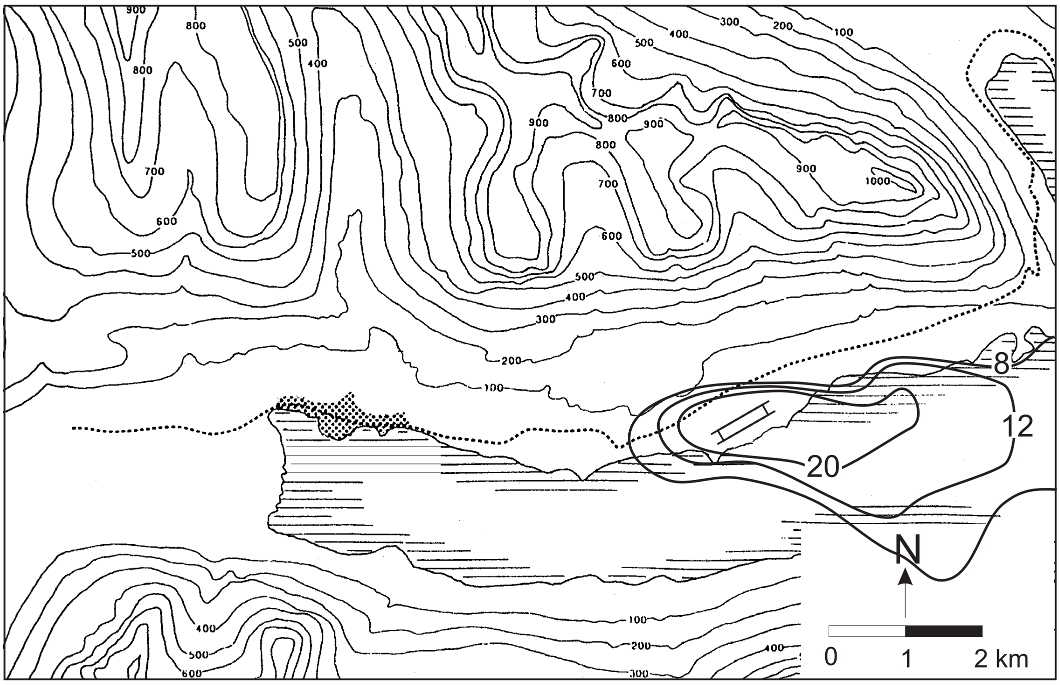


Figure 23: Winter concentrations of SO_2 for 1999-2000. (420 000 tpy). Case 1. Unit: µg/m³. EU air quality guideline 20 µg/m³, upper evaluation guideline 12 µg/m³, lower 8 µg/m³.

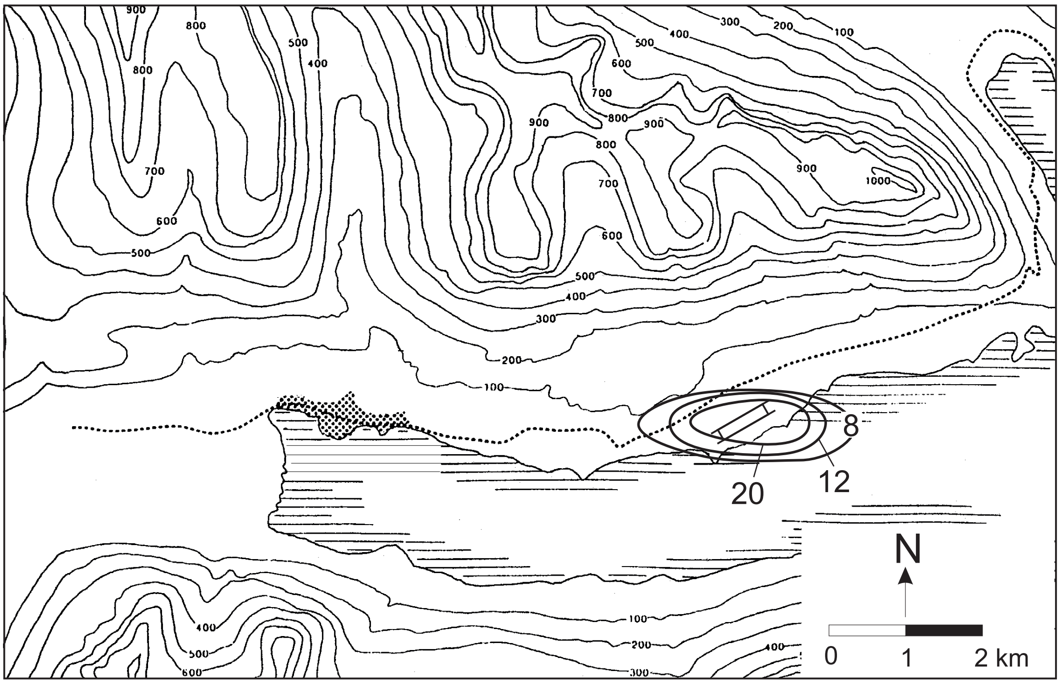


Figure 24: Winter concentrations of SO_2 for 1999-2000. (420 000 tpy). Case 2. Unit: µg/m^3. EU air quality guideline 20 µg/m^3, upper evaluation guideline 12 µg/m^3, lower 8 µg/m^3.

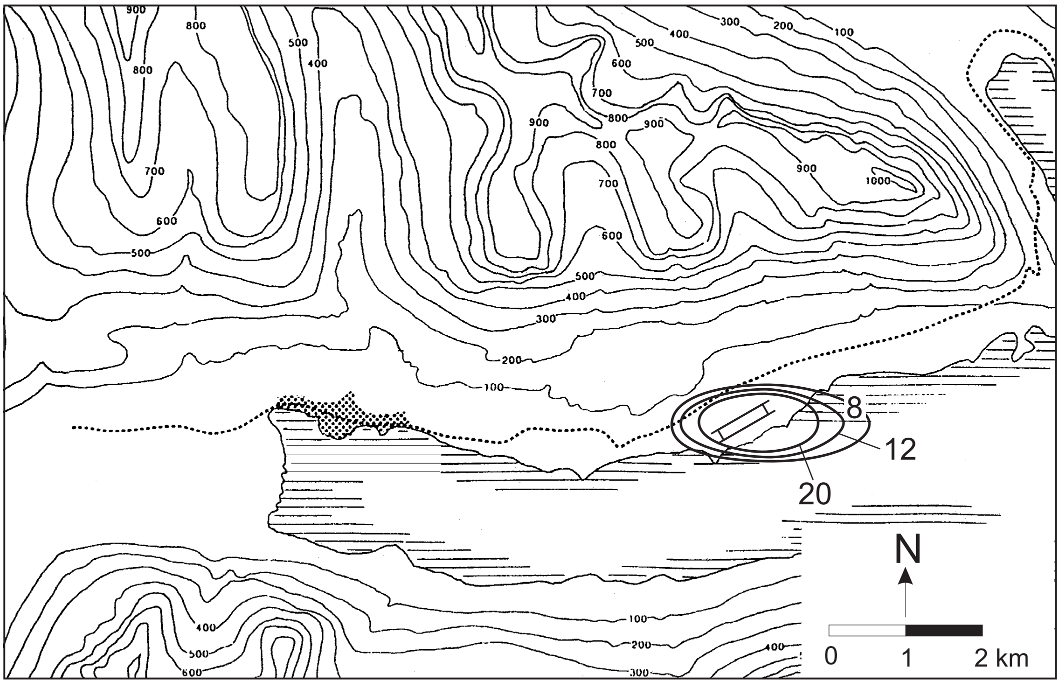


Figure 25: Winter concentrations of SO_2 for 1999-2000. (420 000 tpy). Case 3. Unit: µg/m^3. EU air quality guideline 20 µg/m^3, upper evaluation guideline 12 µg/m^3, lower 8 µg/m^3.

7.3 Gaseous fluorides

The Norwegian air quality guideline for gaseous fluorides for the growing season (6-month average) for vegetation has been used in this study (Table 1). The dispersion calculations were carried out for the growing season (from May to October) to be compared to the Norwegian guideline of gaseous fluorides for vegetation.

The Norwegian air quality guideline for human health, for 6-month average of total fluorides is 10 µg/m^3. Only gaseous fluorides are presented in the figures because the limit for vegetation (0.3 µg/m^3) is stricter than the limit for human health.

The dispersion calculations for gaseous fluorides in the growing season (Figure 26 and Figure 27) show a concentration distribution along the east-west oriented valley axis, due to high occurrence of winds out the fjord (from west and west-north-west) and onshore winds (east) during this season. The uptake of fluorides in vegetation is very complex and dependent on different parameters such as precipitation, duration of daylight, relative humidity, insulation, temperature and the type of vegetation. Taking into account the above mentioned uncertainties, the emission of fluorides exceed the Norwegian air quality guideline for vegetation (0.3 µg/m^3) out to about 1.4 km from the smelter with a production of 280 000 tpy, and approximately 2.2 km with a production of 420 000 tpy.

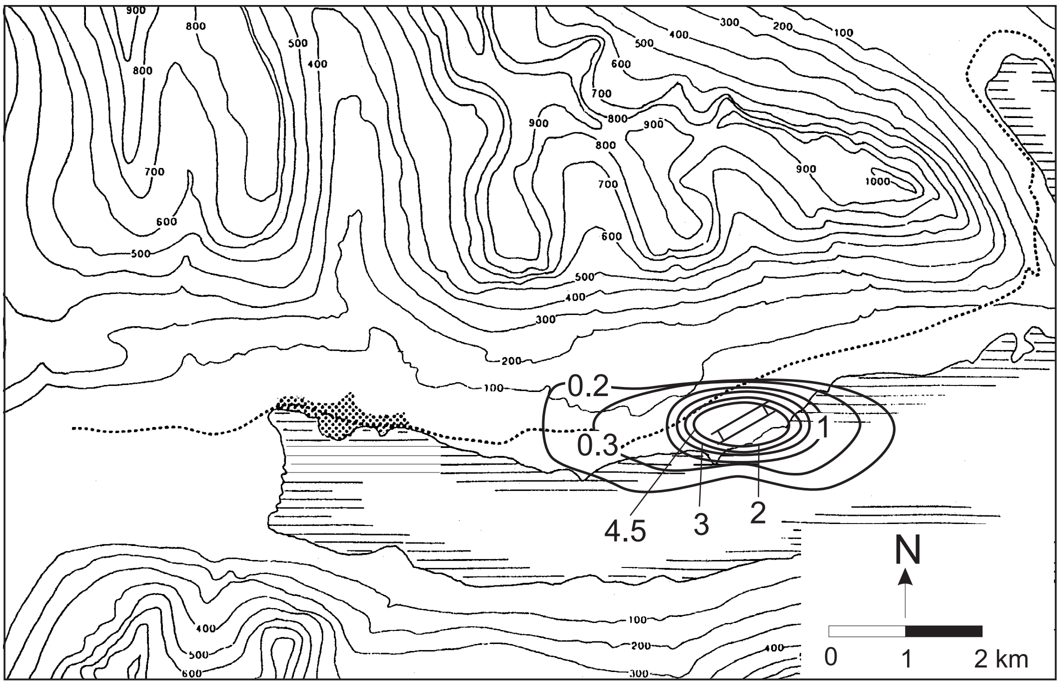


Figure 26: Average concentration for the growing season of gaseous fluorides for 1999-2000 (280 000 tpy). Unit: µg/m^3. Norwegian air quality guideline 0.3 µg/m^3.

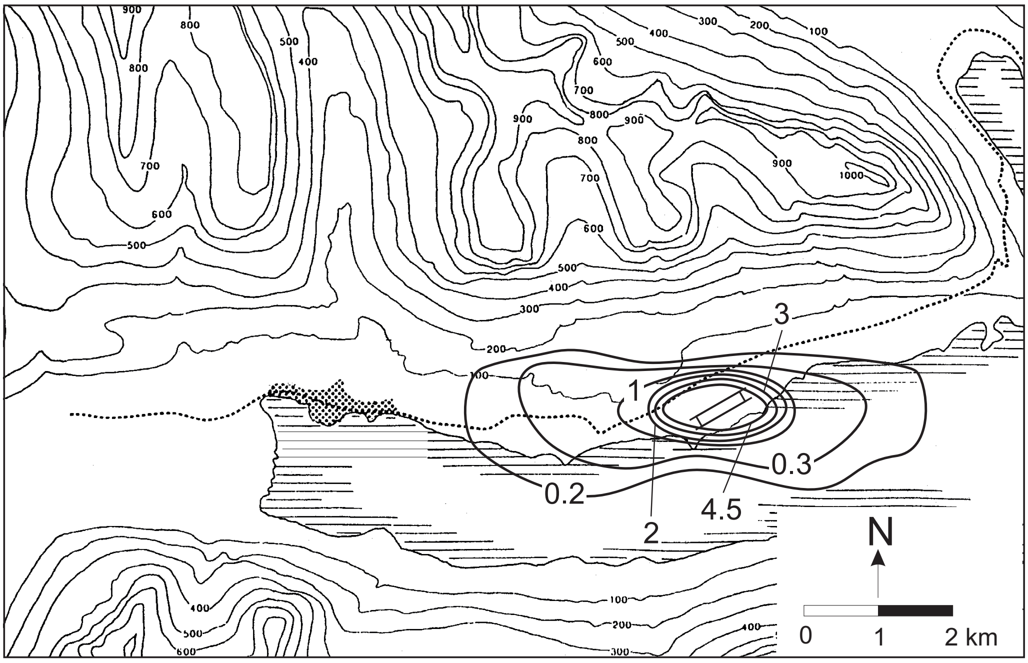


Figure 27: Average concentration for the growing season of gaseous fluorides for 1999-2000 (420 000 tpy). Unit: µg/m^3. Norwegian air quality guideline 0.3 µg/m^3.

7.4 Long term concentrations of Polycyclic Aromatic Hydrocarbons (PAH)

PAH is a group of chemical compounds. BaP is used as a marker for carcinogenic PAH. This is due to its carcinogenity, its stability and so that air quality standard for emitted PAH mixtures may be expressed in terms of one, unambiguously identifiable compound alone. Therefore it is necessary to relate the concentrations of PAH to BaP.

Emissions of PAH are from domestic use of fossil fuels, industry, traffic, fires and volcanic activity. At Reyðarfjördur the emissions will mainly come from the planned aluminium smelter, but also from activities such as the fishmeal factory and from shipping.

To be able to estimate the content of BaP in the PAH emissions from the aluminium smelter, measurements from 1991 around seven aluminium smelters in Norway have been analysed. The study consists of 75 samples in winter and 30 samples in summer. The winter average content of BaP in PAH is 1% and in summer 0.5%. We have used here the winter value. The ambient air standard for BaP is not well defined. Iceland and Norway do not have any standards for this pollutant. WHO's ” Air quality standards for Europe”, states that there are no lower limit for PAH. Countries that have standards for PAH have different levels and they refer to BaP. They vary between 0.1-1 ng/m^3 as an annual mean. This will correspond to a value of 0.01-0.1 µg/m^3 for PAH.

The model calculations for PAH for a production of 280 000 tpy aluminium and for a production of 420 000 tpy aluminium have values higher than 0.1 µg/m^3 only inside and in the vicinity of the plant area. This means that the concentrations of BaP is less than 0.1 ng/m^3 outside the industrial area. This is also 10 times lower than could be expected in a medium city in Norway from other sources. The calculated yearly averaged concentrations for PAH are shown in Figure 28 to Figure 31.

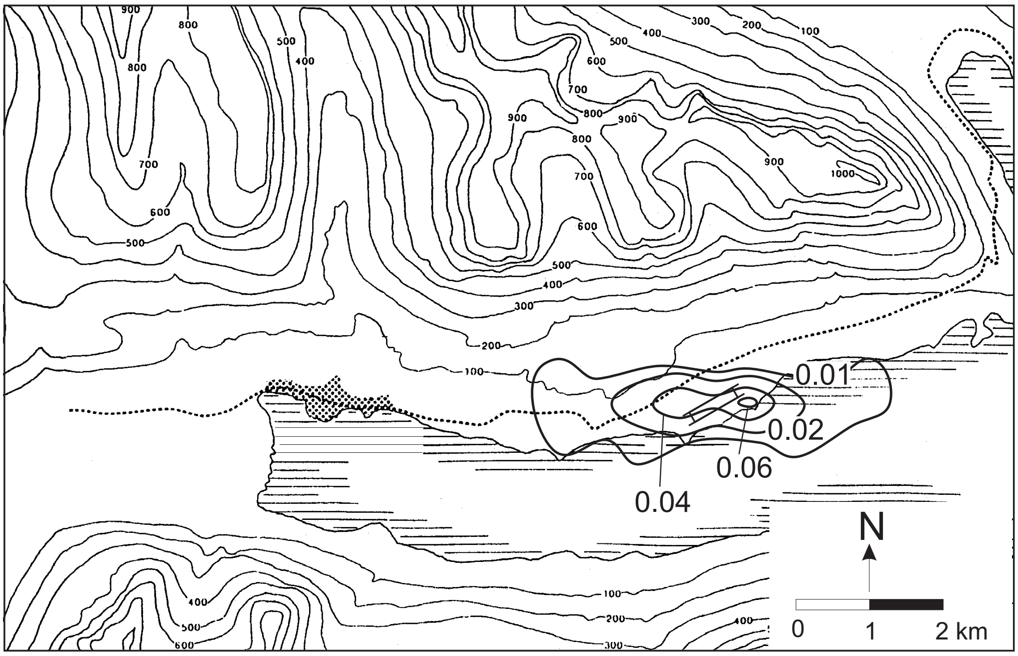


Figure 28: Calculated yearly averages for PAH, 1999-2000 (280 000 tpy). Unit: µg/m^3. Air quality guideline corresponding to PAH 0.01-0.1 µg/m^3.

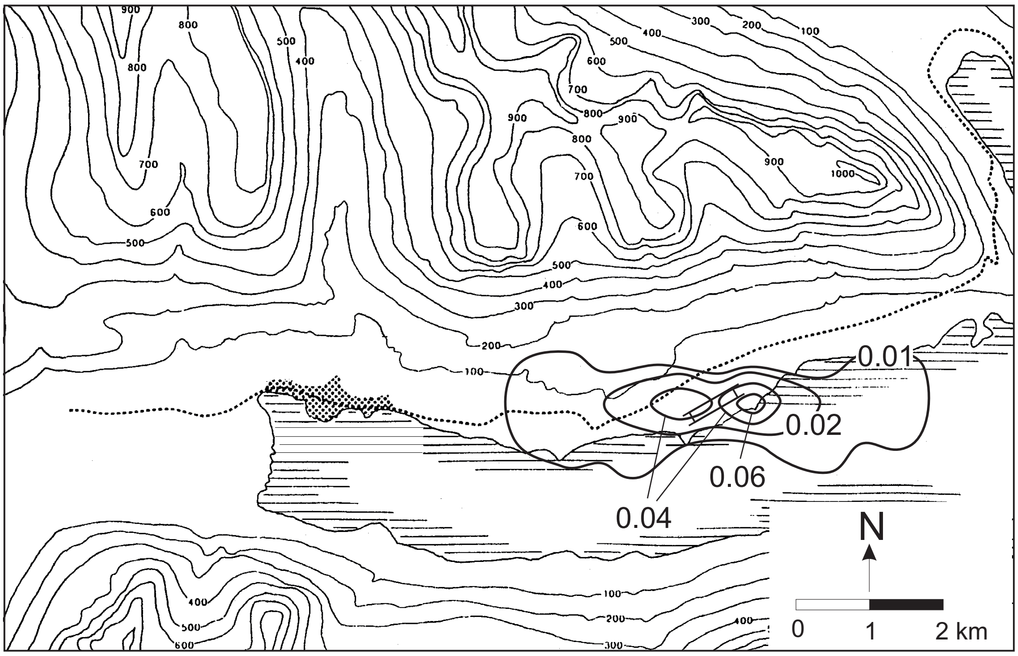


Figure 29: Calculated yearly averages for PAH, 1999-2000 (420 000 tpy). Unit: µg/m^3. Air quality guideline corresponding to PAH 0.01-0.1 µg/m^3.

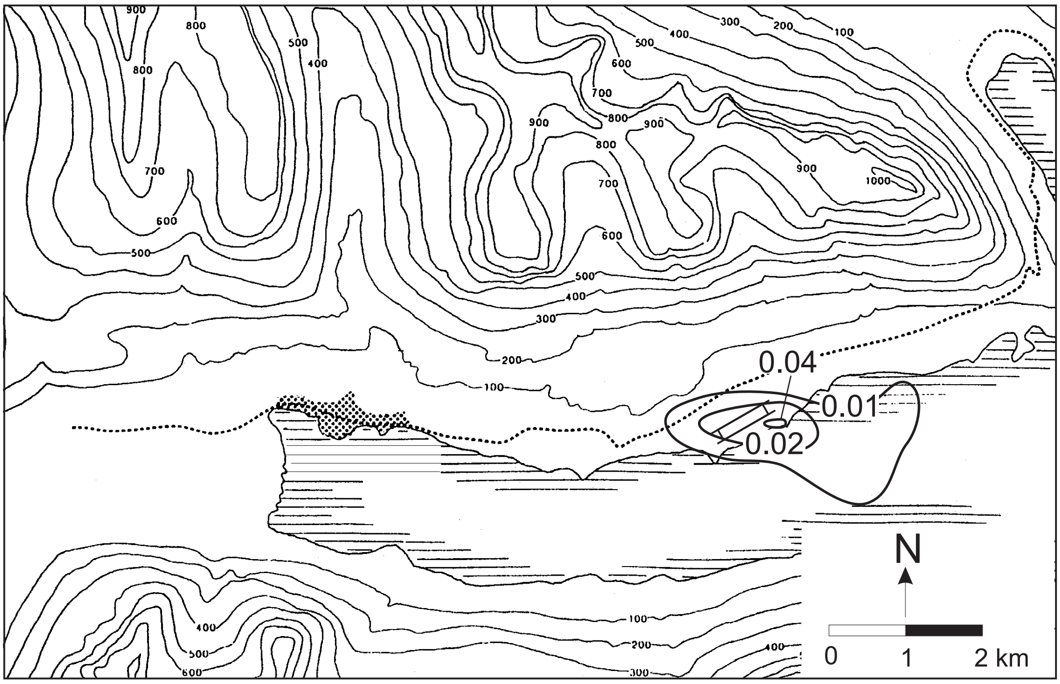


Figure 30: Calculated winter averages for PAH, 1999-2000 (280 000 tpy). Unit: µg/m^3.

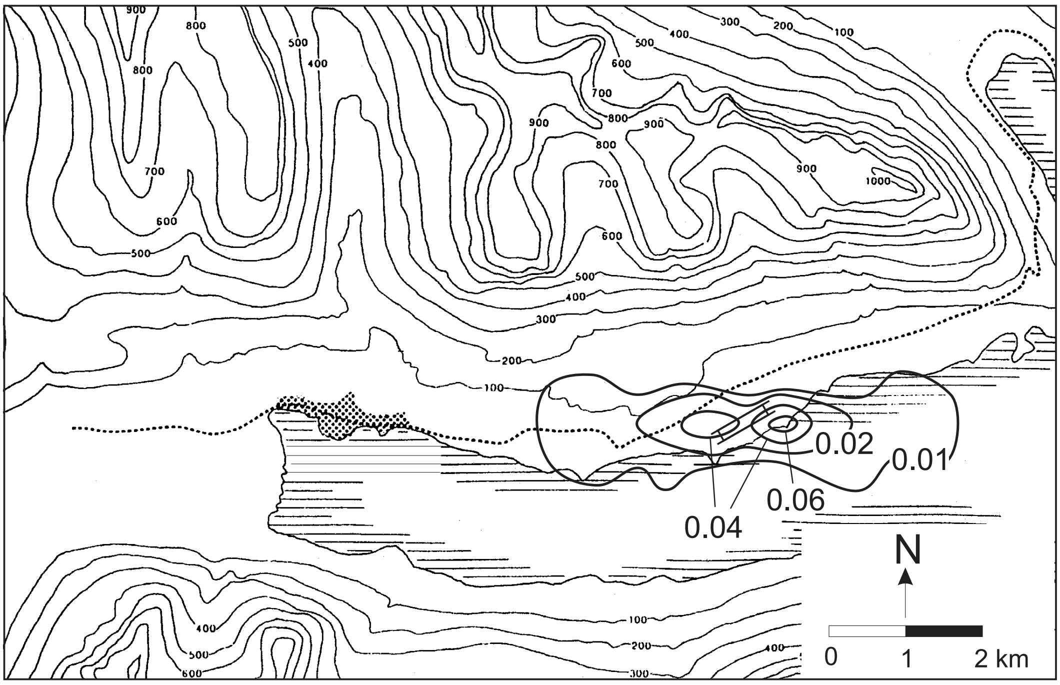


Figure 31: Calculated winter averages for PAH, 1999-2000 (420 000 tpy). Unit: µg/m^3.

7.5 Long term averages for particulate matter (PM_{10})

The emissions of particles come mainly from the potroom and the Green anode plant. The air quality guidelines refer to particulate matter with a diameter less than 10 µm (PM_{10}). The Icelandic ambient air standard for PM_{10} gives a value of 40 µg/m^3 as an annual average. The corresponding EU value is 20 µg/m^3. The content of PM_{10} in the total particle emissions is estimated to 10% of the weight. The dispersion calculations in Figure 14 show that the estimated concentrations of PM_{10} are lower than 2 µg/m^3 outside the industrial area for emissions from a production of 280 000 tpy and for a production of 420 000 tpy. This indicates that the concentration of PM_{10} is ten times lower and therefore the air quality guideline is not exceeded. The calculations are presented in the Figure 32 to Figure 35.

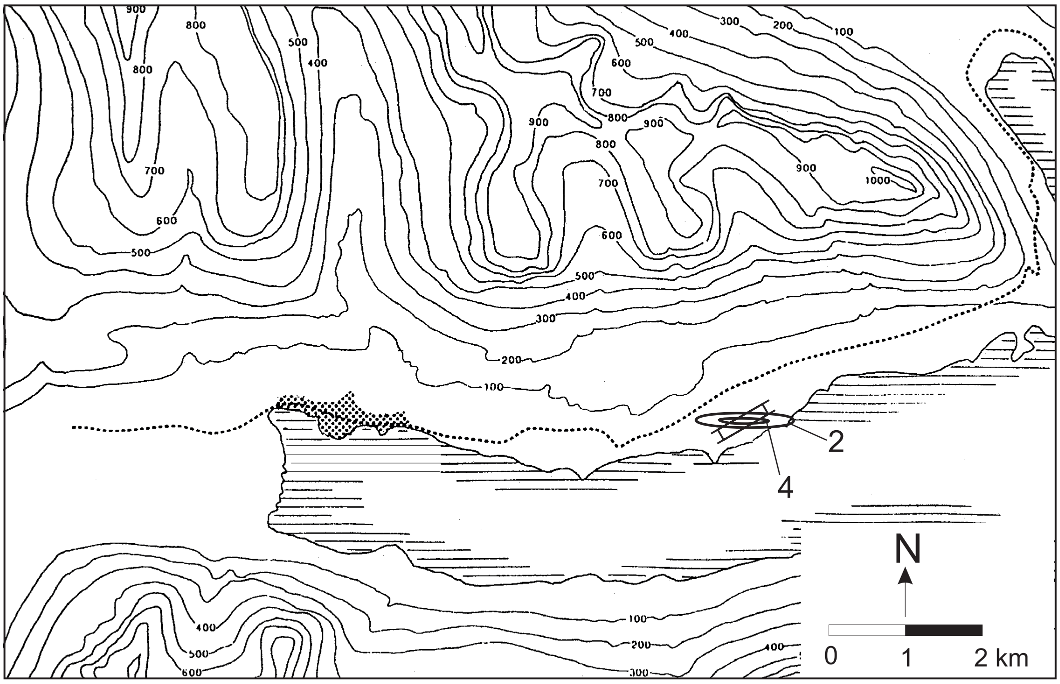


Figure 32: Calculated yearly averaged PM_{10} concentrations for 1999-2000 (280 000 tpy). Unit: µg/m^3. Air quality guidelines for PM_{10} 40 µg/m^3 (Iceland), 20 µg/m^3 (EU).

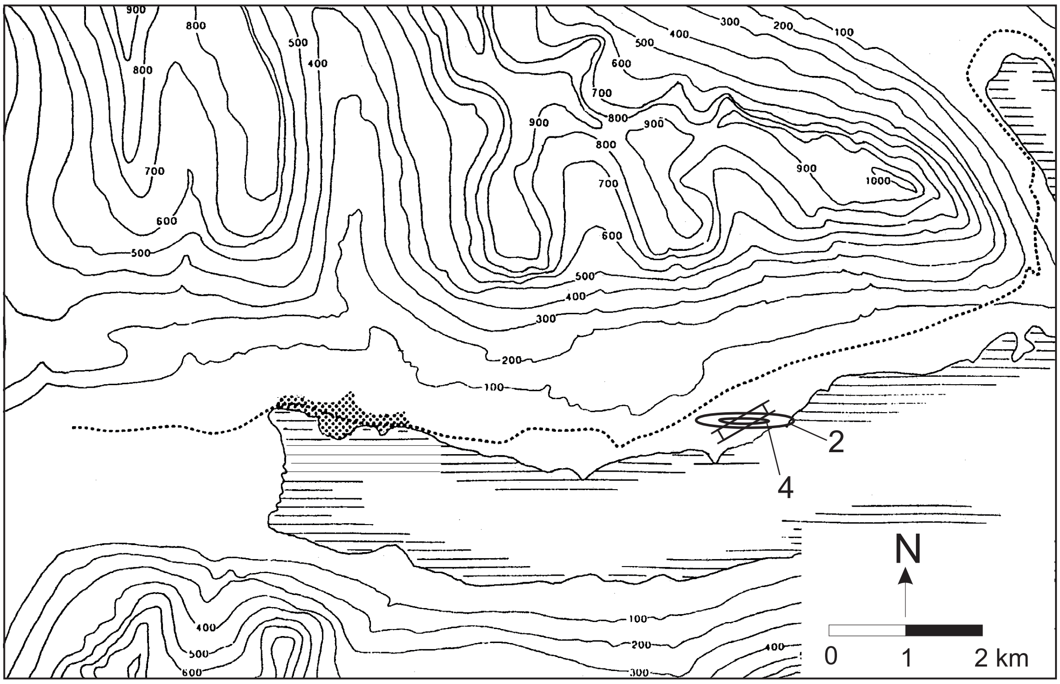


Figure 33: Calculated yearly averaged PM_{10} concentrations for 1999-2000 (420 000 tpy). Unit: $\mu g/m^3$. Air quality guidelines for PM_{10} 40 $\mu g/m^3$ (Iceland), 20 $\mu g/m^3$ (EU).

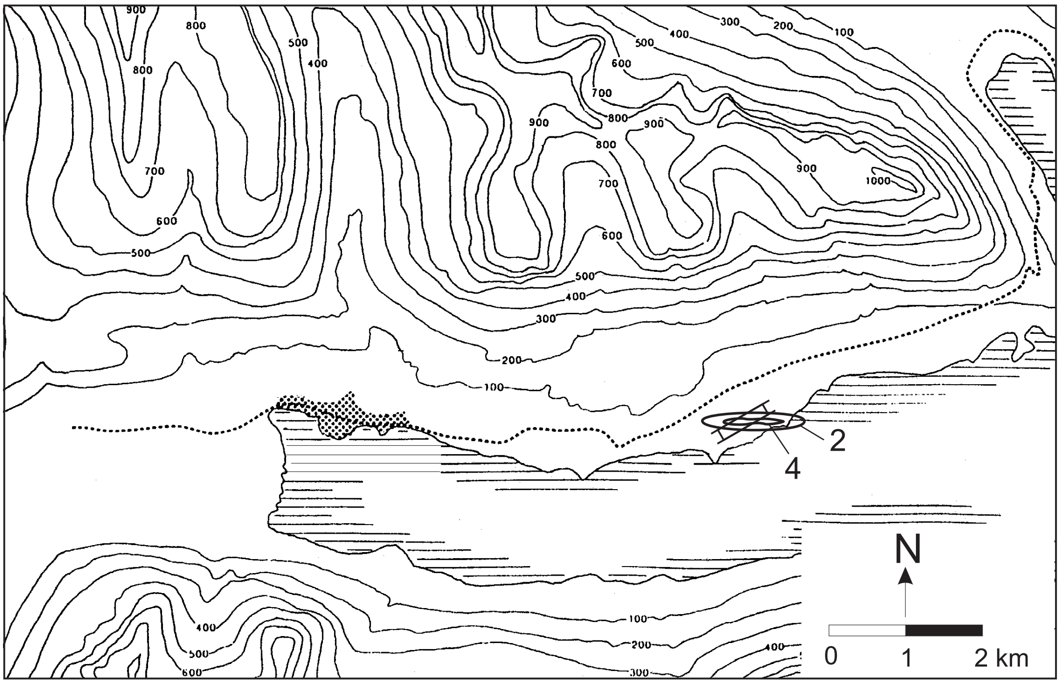


Figure 34: Calculated winter averaged PM_{10} concentrations for 1999-2000 (280 000 tpy). Unit: $\mu g/m^3$. Air quality guidelines for PM_{10} 40 $\mu g/m^3$ (Iceland), 20 $\mu g/m^3$ (EU).

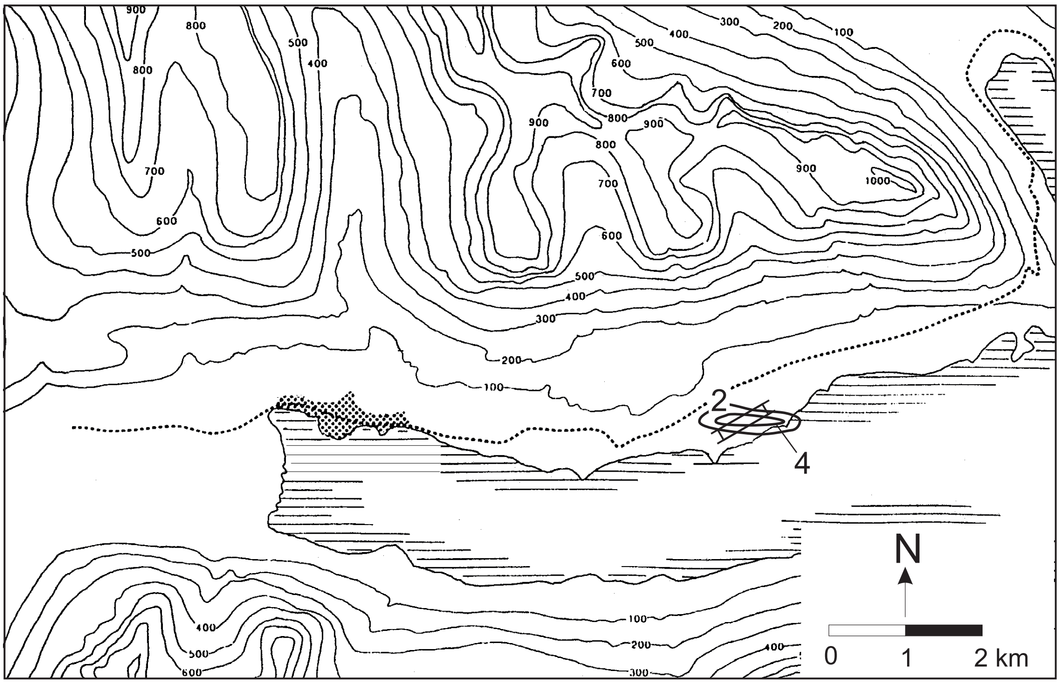


Figure 35: Calculated winter averaged PM_{10} concentrations for 1999-2000 (420 000 tpy). Unit: µg/m^3. Air quality guidelines for PM_{10} 20 µg/m^3 (EU).

8. Estimation of percentile values

8.1 Methodology

Good estimates of the percentiles of concentration in an area are made by studying the critical meteorological situations that can produce high concentrations. This work has focussed on the highest part of the percentile curves, because the highest concentrations determine the percentiles, and the situations with low impact are less important. These critical situations have been studied through detailed analysis of the measured meteorological data. The topography has been evaluated through topographical matrixes in the meteorological model and in the dispersion model. About 310 days with unfavourable dispersion conditions during the two years of meteorological data have been analysed. These conditions are connected to re-entries, calm conditions and vortexes. The dates included in the calculations are listed in Appendix F. The reason for this high number of cases is that all situations that produce high impact must be included. Calculating the percentile in each grid square for each year produces the percentile values and they are plotted as such. This means that the concentrations plotted are not occurring at the same time, but will be representative for the concentration time series at each point.

Treatment of potroom emissions

The NILU models have been specially designed to treat emissions released from potrooms. The potrooms have been treated as elevated volume sources where the length, width and height of the potrooms are defined. The source description ensures that the emissions coming from the potrooms are properly defined, and that the initial dispersion is taken into account.

Treatment of topography

The topography is mainly taken into account through the meteorological measurements. In addition to this a topographical matrix is entered into the model for the long term averages. This topographical matrix is modified with distance from the source because the effect of topography is more significant closer to the source. In addition to this topographical effects induce some of the unfavourable dispersion situations. The hourly averages have been calculated with another model where topography is not included. The topographical effects are here estimated and the concentration fields have been turned according to the meteorological wind fields. The unfavourable dispersion situations have been evaluated in more detail, and topography is one of the problems discussed.

Models and dispersion coefficients

The puff -trajectory model INPUFF, developed at US-EPA and modified at NILU, have been used for situations that are complicated. These situations are typically calm conditions and situations with re-entries, where emission emitted at earlier hours will impact in a later hour. This model is supplied with a possibility of using meteorological gridded information as input. The information could be elaborated by the user or could come from a meteorological model. A simple meteorological model MATHEW have been used for the special situations to estimate the wind flow over the topography using the available meteorological data.

The dispersion calculations, that are the basis for the calculation of the percentiles, are supported by the measurements at Sómastadagerdi. Stability and dispersion coefficients are estimated directly from the measurements of vertical temperature in the tower at Sómastadagerdi and from turbulence measured at 36.5 m. This will ensure that the modelled dispersion is reflecting the dispersion situations in Reyðarfjördur, where the surface roughness is small.

8.2 Summary of results for percentile calculations

The results from the calculations of the percentile values calculated are summarised in Table 9. The table shows the distances from the potrooms to where the air quality guideline no longer is exceeded. The different percentile values are related to the corresponding air quality guideline.

The following percentiles are calculated:

1. SO_2, 98 and 99.2 percentiles for diurnal averaged concentrations, which corresponds to 7 and 3 days where the air quality guideline is exceeded during one year.
2. SO_2, 99.7 percentile based on hourly averages, which corresponds to 24 hours where the air quality guideline is exceeded during one year.
3. PM_{10}, 98 and 90.4 percentiles for diurnal averaged concentrations, which corresponds to 7 and 35 days where the air quality guideline is exceeded.

The calculations show that the Icelandic air quality guideline for SO_2 for diurnal concentrations (98 percentile of 50 $\mu g/m^3$) is the most difficult to comply with.

The distances to where this guideline is exceeded for **case 1** with a production of 280 000 tpy for 1999-2000 is 2.8 km in the direction of Budareyri and 3.0 km out the fjord. For 420 000 tpy the corresponding numbers is 4.0 km and 3.9 km. The corresponding distances for 1998-1999 are for 280 000 tpy 3.9 and 4.0 km, and for 420 000 tpy 5.8 and 2.8 km.

For **case 2** with a production of 280 000 tpy for 1999-2000 the distance is 0.9 km towards Budareyri and 0.8 km out the fjord. For 420 000 tpy the distances are 0.8 km. With a production of 280 000 tpy for 1998-1999 the distances are 2.4 km and 2.3 km, for 420 000 tpy the distances are 2.5 km and 2.9 km

For **case 3** with a production of 280 000 tpy for 1999-2000 the distance is 0.7 km towards Budareyri and 0.3 km out the fjord. For 420 000 tpy the corresponding distances are 1.2 km and 0.6 km. For 1998-1999 and a production of 280 000 tpy the distances are 1.1 km and 1.0 km, and for 420 000 tpy 2.1 km and 1.8 km.

There is quite a substantial difference in the critical distances between the year 1999-2000 and 1998-1999. This is because of the different dispersion conditions for the two periods. 1998-1999 has a higher occurrence of stable atmospheric conditions and calm conditions than 1999-2000. This will have a bigger influence on the percentiles than the yearly averages because the percentiles are determined by a small number of specific cases.

The calculations of concentration of particulate matter show low concentrations and will not exceed the air quality guidelines.

Table 9: Distances in kilometres to air quality guidelines based on percentile values for 24 hour and hourly averaged concentration fields for the different emission alternatives. Distances are in kilometres. Numbers in parenthesis are distance out of the fjord and the numbers without parentheses are distances towards Budareyri.

Percentiles of SO_2 based on 24 hour averages						
			Distance to air quality guideline (m)			
Emission case	Per-centile	AQG	Production 280 000 tpy		Production 420 000 tpy	
			1999-2000	1998-1999	1999-2000	1998-1999
Case 1	98	50	2.8 (3.0)	3.9(4.0)	4.0 (3.9)	5.8 (4.2)
Case 2	98	50	0.9 (0.8)	2.4 (2.3)	0.8(0.8)	2.5 (2.9)
Case 3	98	50	0.7 (0.3)	1.1 (1.0)	1.2 (0.6)	2.1 (1.8)
Case 1	99.2	125	2.5 (2.2)	3.8 (2.7)	3.1 (2.5)	4.5 (3.7)
Case 2	99.2	125	0.4 (0.6)	1.7 (1.6)	1.0 (1.9)	2.0 (3.0)
Case 3	99.2	125	- (-)	0.2 (0.3)	0.3 (-)	1.2 (0.5)
Percentiles of SO_2 based on hourly averages (m)						
Case 1	99.7	350	1.2 (2.1)	4.2 (4)	2.6 (2.5)	5.8 (4.9)
Case 2	99.7	350	0.2 (0.5)	2.0 (2.1)	0.2 (0.7)	2.4 (2.5)
Case 3	99.7	350	0.3 (-)	1.2 (1.0)	0.6 (0.6)	2.1 (1.7)
Percentiles of PM_{10} based on 24 hour averages						
	98	130/50 *	-	-	-	-

	90.4	50	-	-	-	-

* EU guideline valid from 2010

8.3 Sulphur dioxide

The figures below show the concentration distribution for the year 1999-2000 based on the different percentile values. The concentration distribution shows the clear channelling effect of the meteorology. The corresponding figures for 1999-1998 are found in Appendix D. The number of days that have been calculated in these two years are about 310. The majority of days included in the calculations are from 1998-1999. The reason for this is discussed in chapter 3 and 4. The wind speed is in average higher in 1999-2000 than in 1998-1999. The number of hours with wind speeds lower than 0.4 m/s is approximately 25% lower in 1999-2000 than in 1998-2000. The specific dates that have been analysed are found in Appendix F.

The calculations show that the emissions from case 1 have the highest impact on the air quality. This is because of the relatively large emissions from the fume treatment plant of the anode baking furnace. The emissions are through a chimney, which is constructed so that the emissions are transported outside the turbulent wake, created by the nearby buildings. One alternative to lower the concentrations would be to increase the height of the chimney. This will however only have a limited effect inside a fjord like Reyðarfjördur, because of the topographical effects, complicated dispersion conditions, and the accumulation of emissions that are the reasons for the high concentrations determining the percentile values. To decrease the impact on air quality from the smelter the best solution would be to decrease the emissions.

For SO_2 the most restrictive air quality guideline is the Icelandic guideline for the 98 percentile with the limit of 50 $\mu g/m^3$. The distance to where the air quality guideline is exceeded for 1999-2000 and 1998-1999 are shown in Table 9.

Figure 36 to Figure 53 show the calculated concentrations for 1999-2000 with the two production alternatives (280 000 and 420 000 tpy). The corresponding figures for 1998-1999 are shown in appendix D.

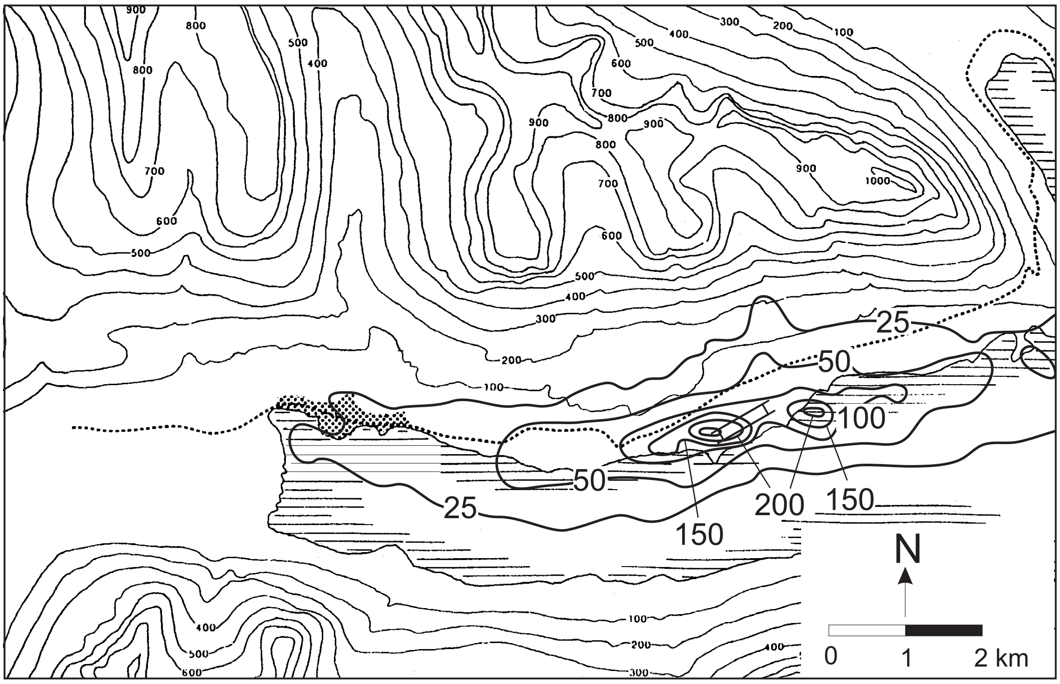


Figure 36: 98 percentile (280 000 tpy) for SO_2 for the year 1999-2000, based on 24-hour averages. Case 1. Unit: µg/m^3. The air quality guideline is 50 µg/m^3.

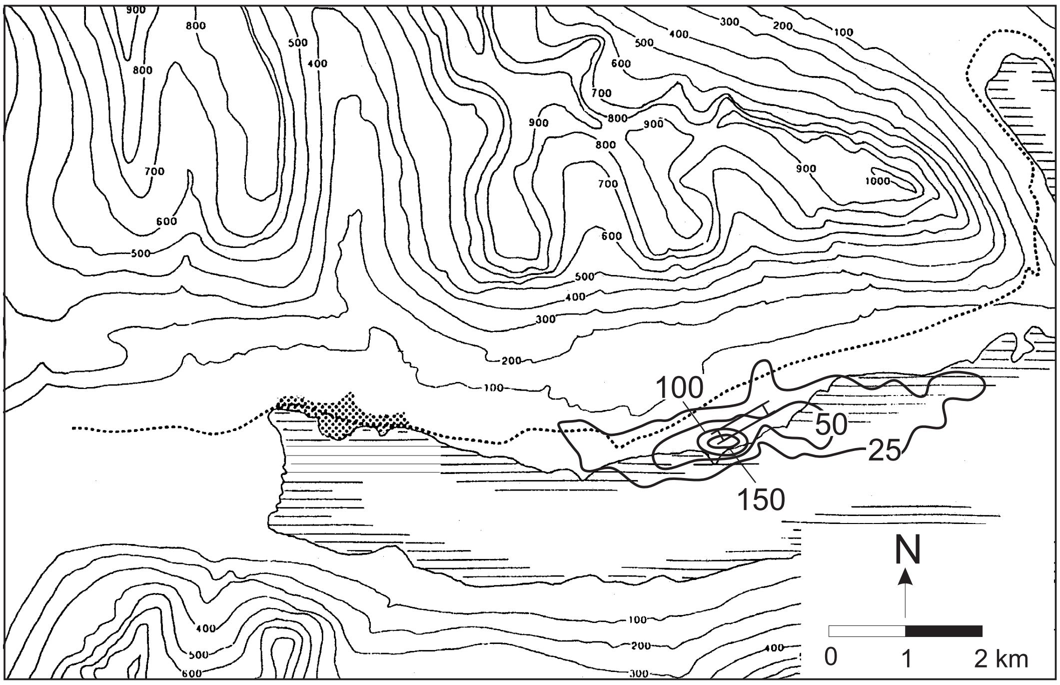


Figure 37: 98 percentile (280 000 tpy) for SO_2 for the year 1999-2000, based on 24-hour averages. Case 2. Unit: µg/m^3. The air quality guideline is 50 µg/m^3.

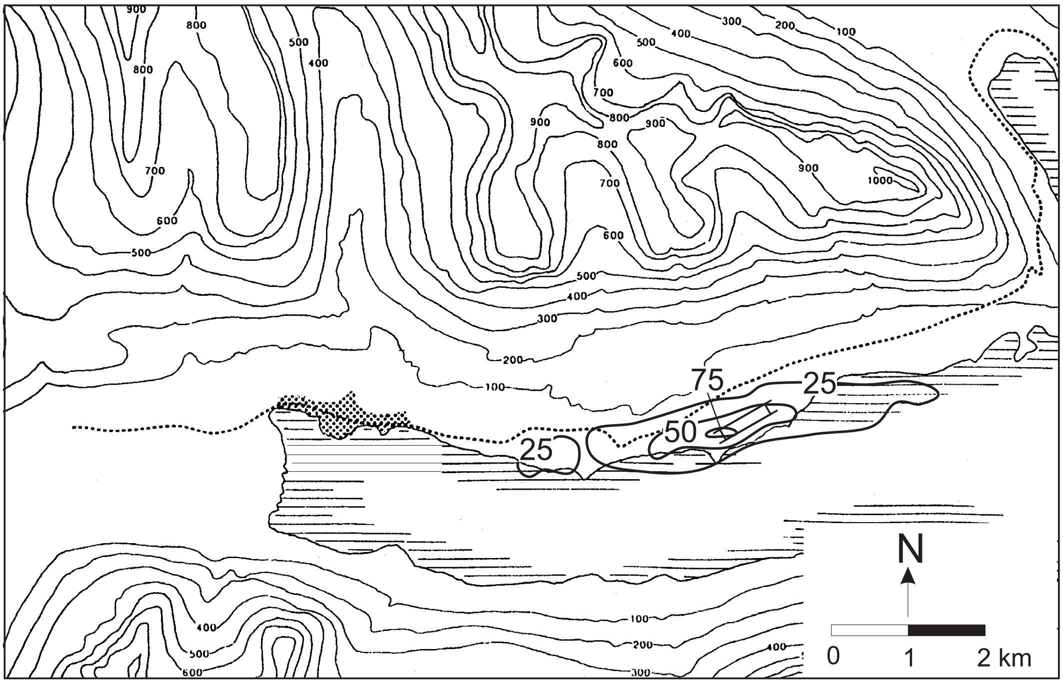


Figure 38: 98 percentile (280 000 tpy) for SO_2 for the year 1999-2000, based on 24-hour averages. Case 3. Unit: µg/m^3. The air quality guideline is 50 µg/m^3.

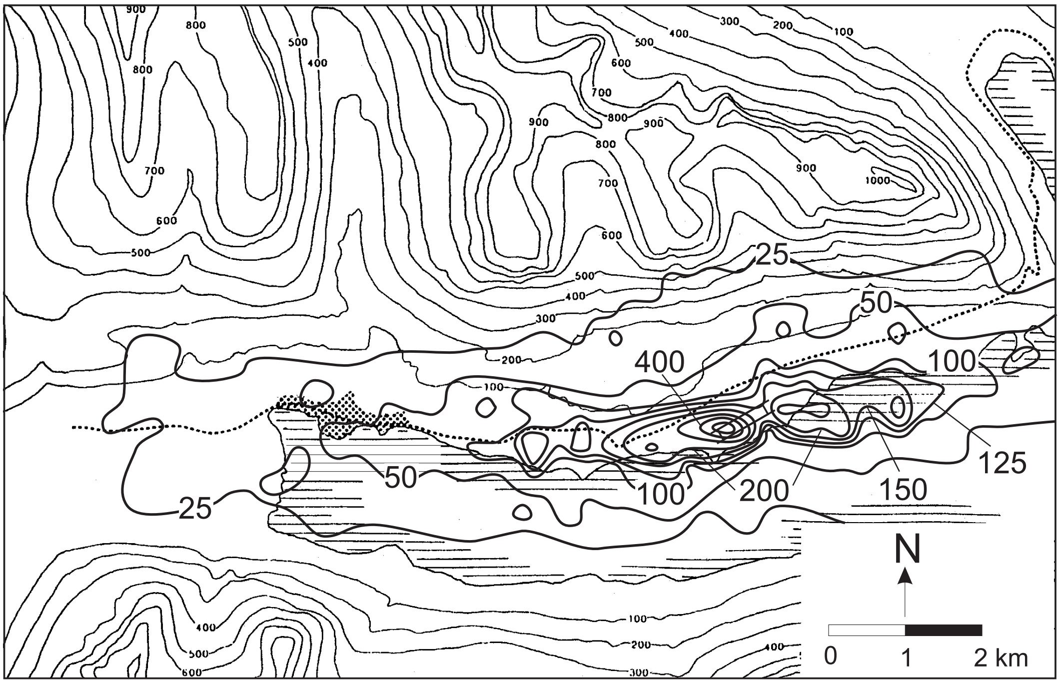


Figure 39: 99.2 percentile (280 000 tpy) for SO2 for the year 1999-2000, based on 24-hour averages. Case 1. Unit: µg/m³. The air quality guideline is 125 µg/m³.

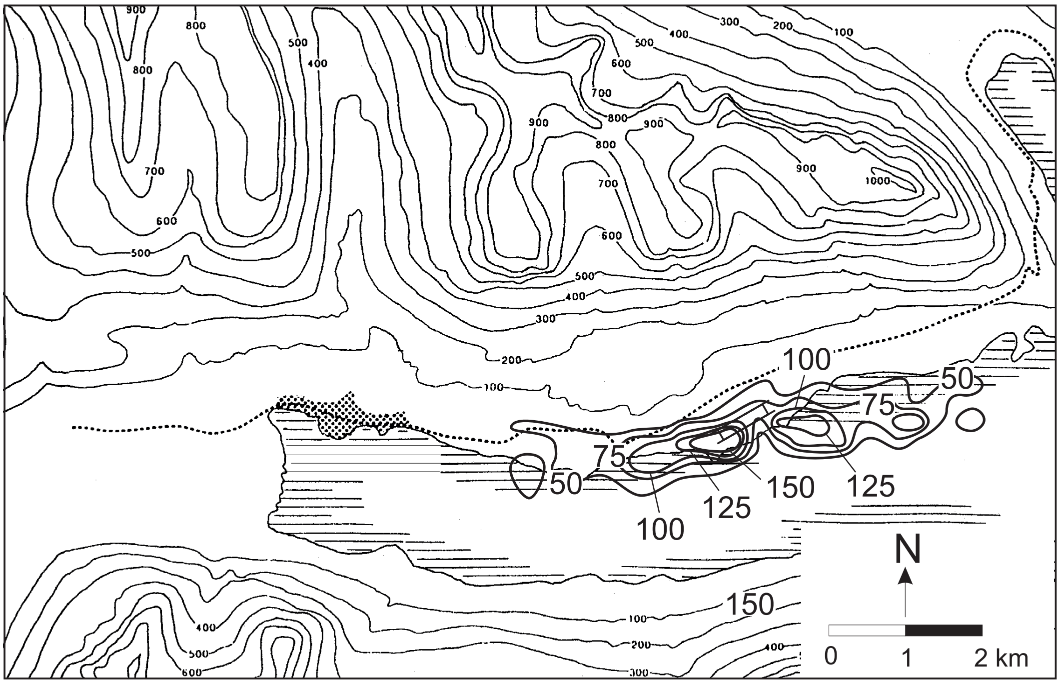


Figure 40: 99.2 percentile (280 000 tpy) for SO_2 for the year 1999-2000, based on 24 hour averages. Case 2. Unit: µg/m^3. The air quality guideline is 125 µg/m^3.

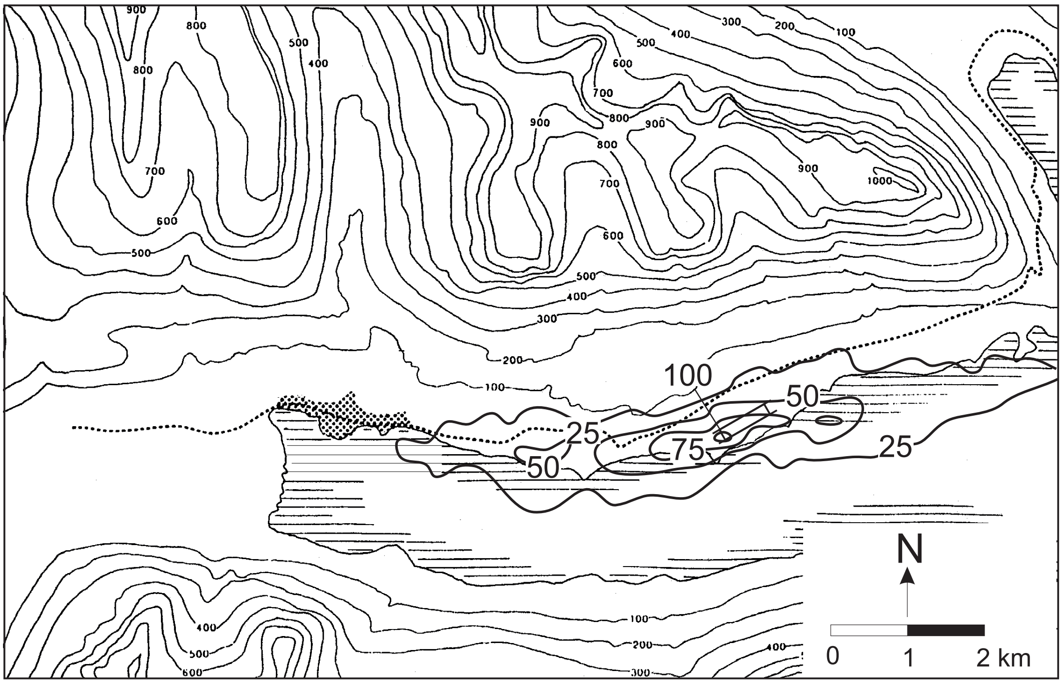


Figure 41: 99.2 percentile (280 000 tpy) for SO_2 for the year 1999-2000, based on 24-hour averages. Case 3. Unit: µg/m^3. The air quality guideline is 125 µg/m^3.

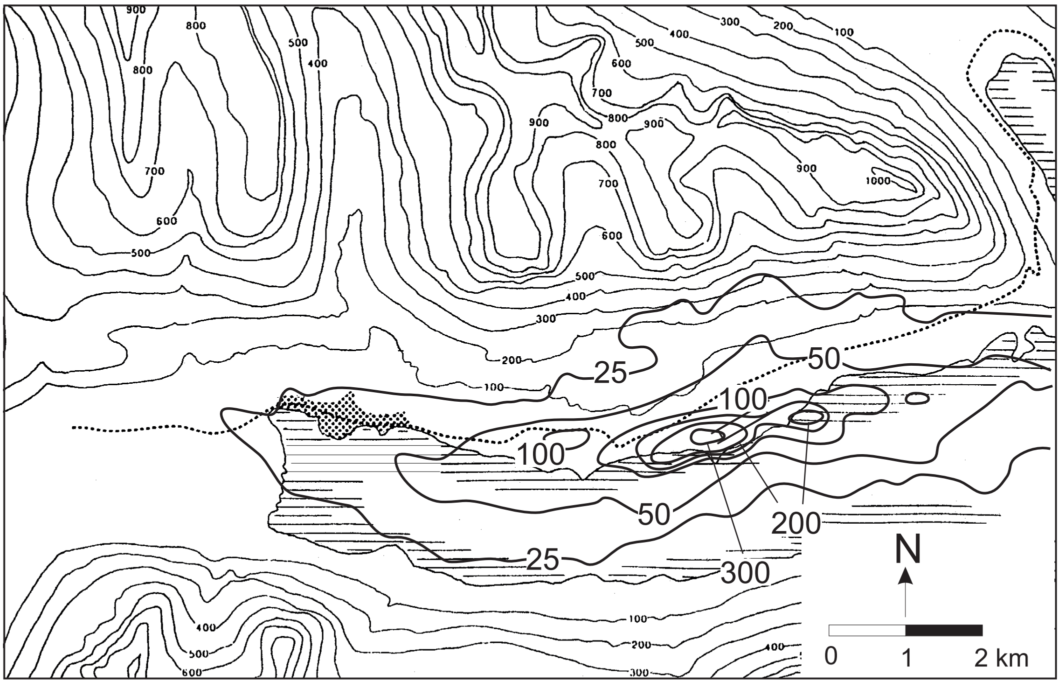


Figure 42: 98 percentile (420 000 tpy) for SO_2 for the year 1999-2000, based on 24-hour averages. Case 1. Unit: µg/m^3. The air quality guideline is 50 µg/m^3.

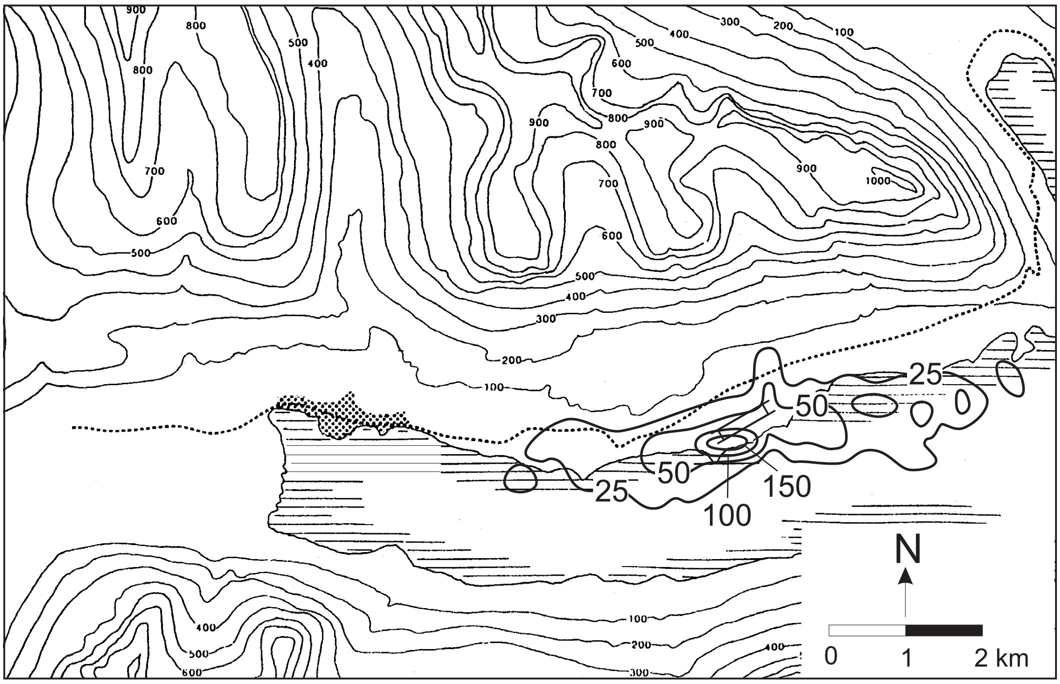


Figure 43: 98 percentile (420 000 tpy) for SO_2 for the year 1999-2000, based on 24-hour averages. Case 2. Unit: µg/m^3. The air quality guideline is 50 µg/m^3.

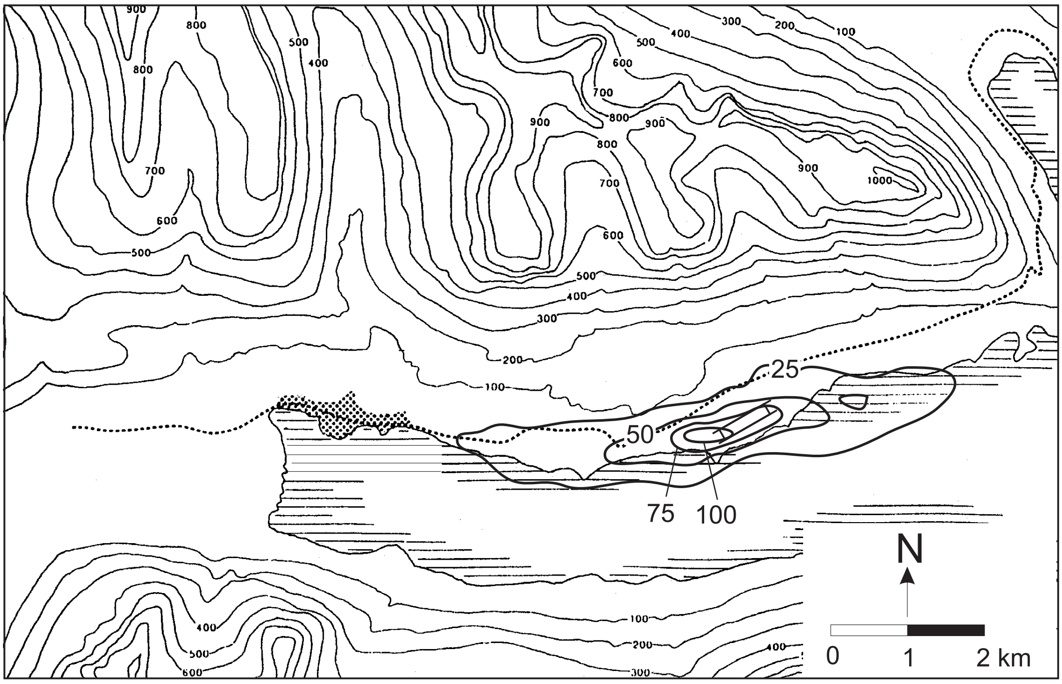


Figure 44: 98 percentile (420 000 tpy) for SO_2 for the year 1999-2000, based on 24-hour averages. Case 3. Unit: $\mu g/m^3$. The air quality guideline is 50 $\mu g/m^3$.

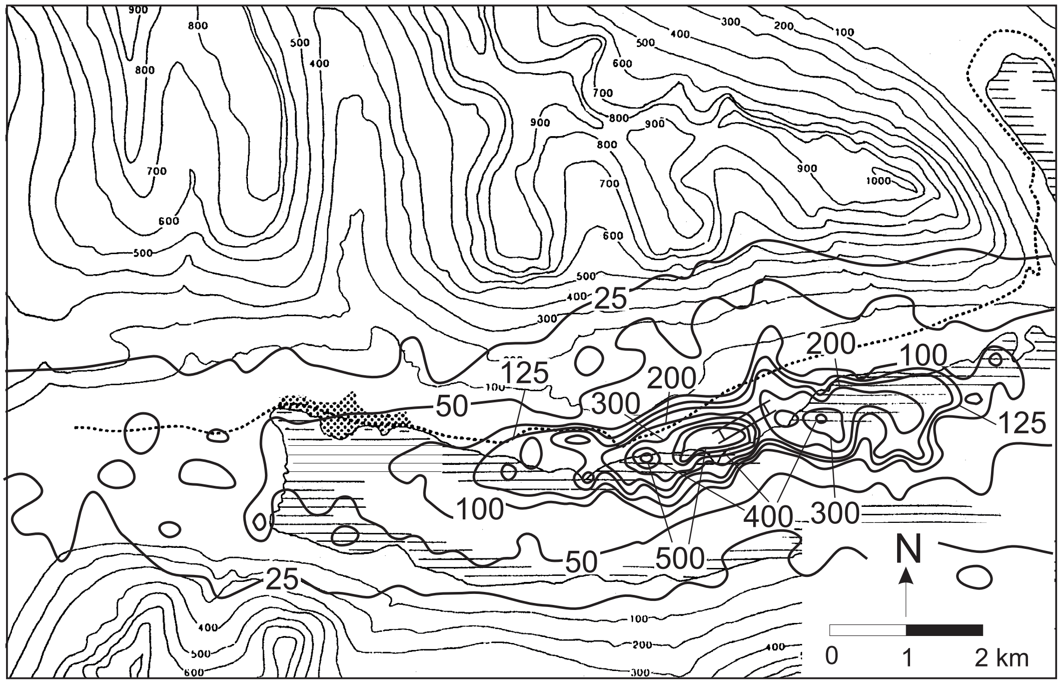


Figure 45: 99.2 percentile (420 000 tpy) for SO_2 for the year 1999-2000, based on 24-hour averages. Case 1. Unit: $\mu g/m^3$. The air quality guideline is 125 $\mu g/m^3$.

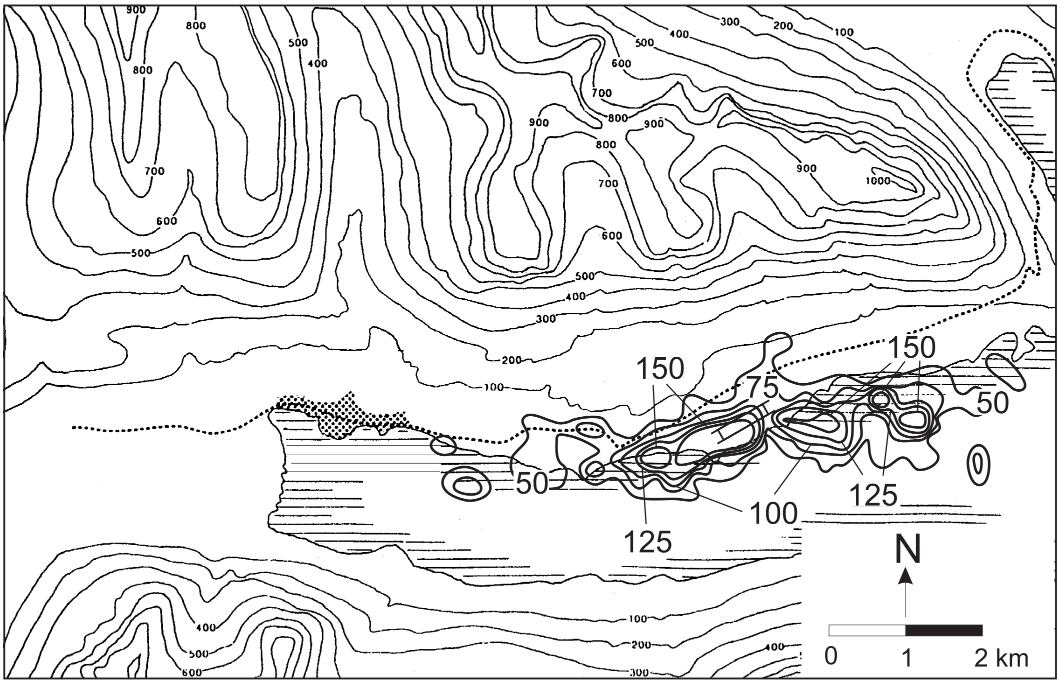


Figure 46: 99.2 percentile (420 000 tpy) for SO_2 for the year 1999-2000, based on 24-hour averages. Case 2. Unit: µg/m^3. The air quality guideline is 125 µg/m^3.

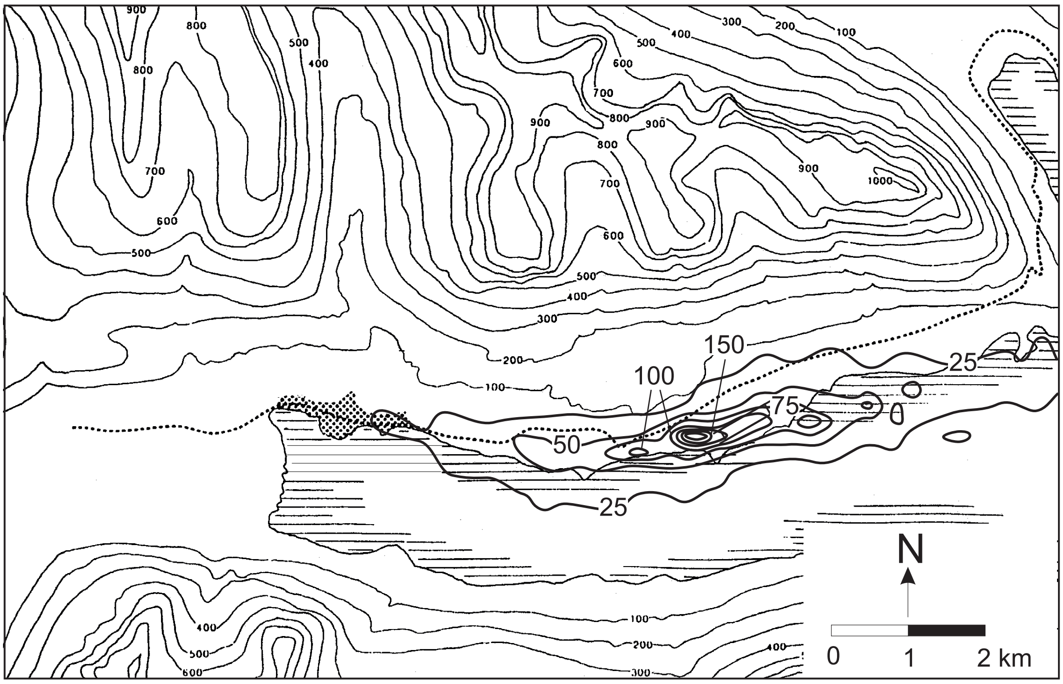


Figure 47: 99.2 percentile (420 000 tpy) for SO_2 for the year 1999-2000, based on 24-hour averages. Case 3. Unit: µg/m^3. The air quality guideline is 125 µg/m^3.

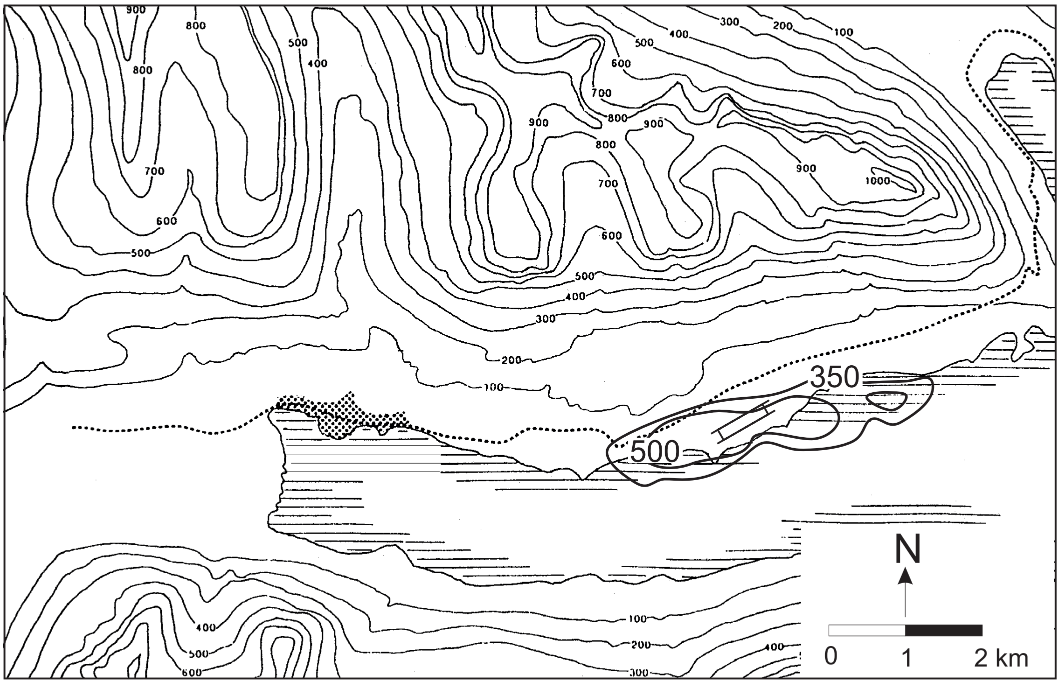


Figure 48: 99.7 percentile (280 000 tpy) for SO_2 for the year 1999-2000, based on hourly averages. Case 1. Unit:µg/m^3. The air quality guideline is 350 µg/m^3.

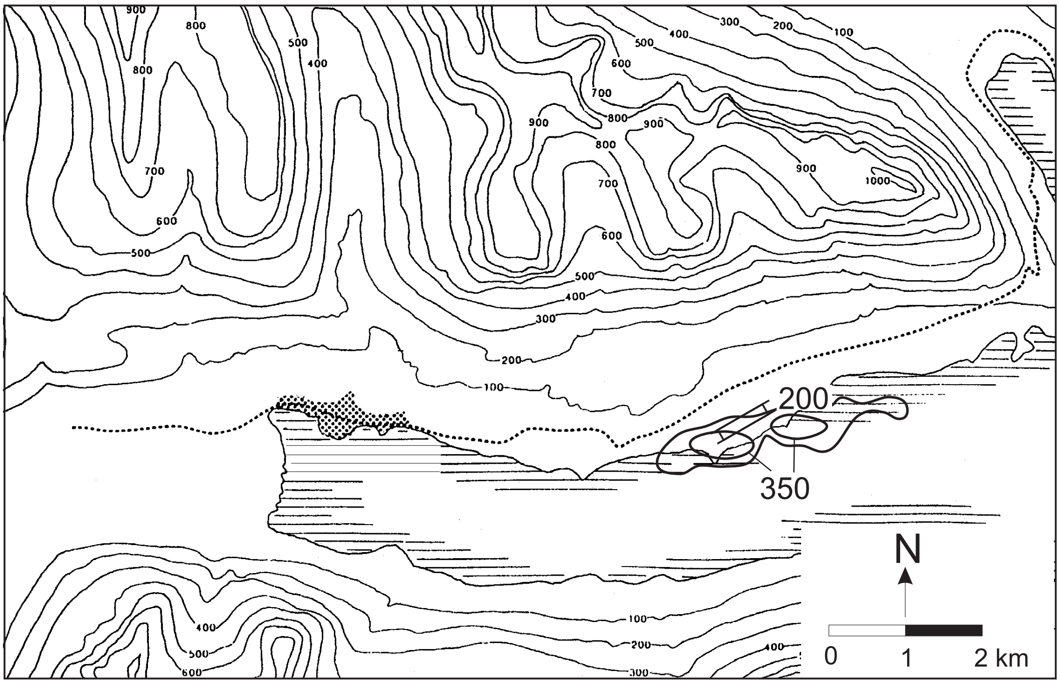


Figure 49: 99.7 percentile (280 000 tpy) for SO_2 for the year 1999-2000, based on hourly averages. Case 2. Unit:µg/m^3. The air quality guideline is 350 µg/m^3.

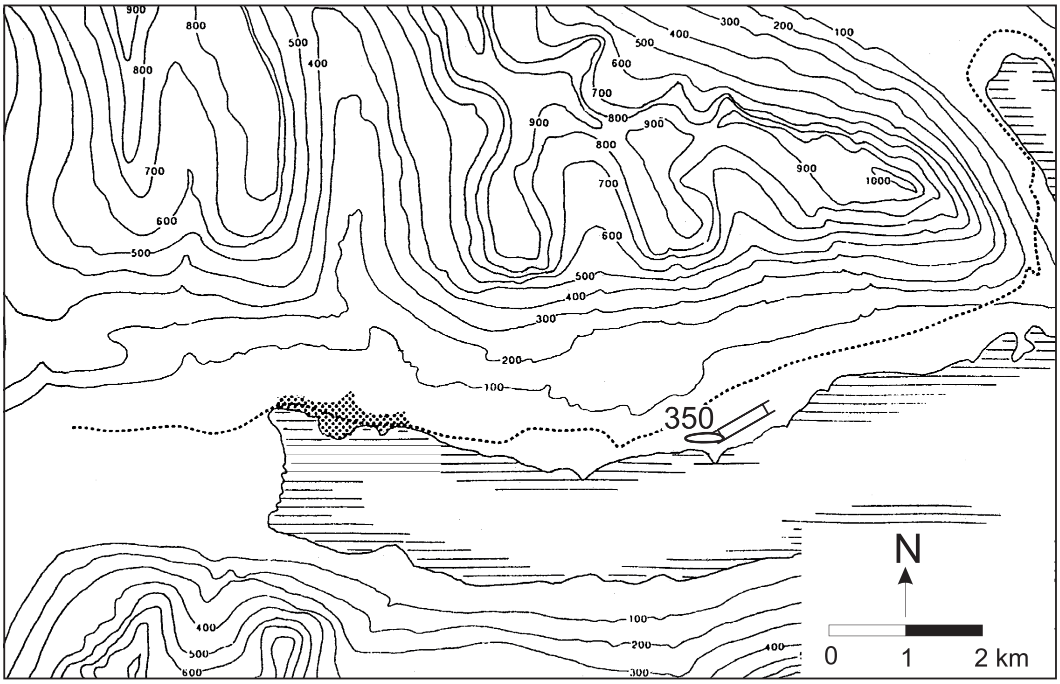


Figure 50: 99.7 percentile (280 000 tpy) for SO_2 for the year 1999-2000, based on hourly averages. Case 3. Unit:µg/m^3. The air quality guideline is 350 µg/m^3.

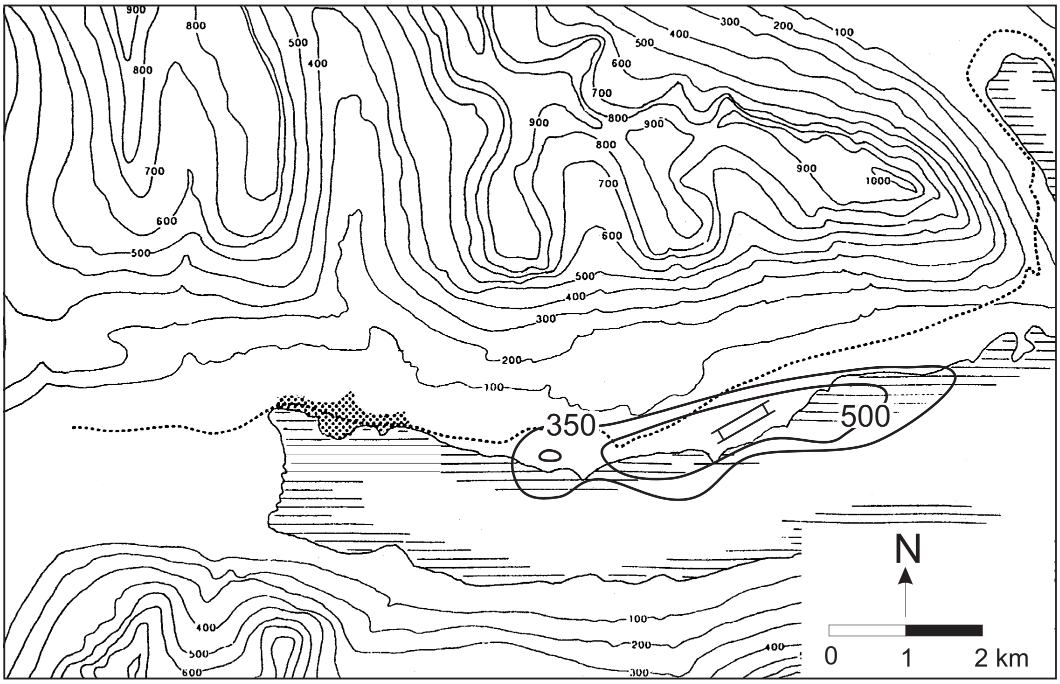


Figure 51: 99.7 percentile (420 000 tpy) for SO_2 for the year 1999-2000, based on hourly averages. Case 1. Unit:µg/m^3. The air quality guideline is 350 µg/m^3.

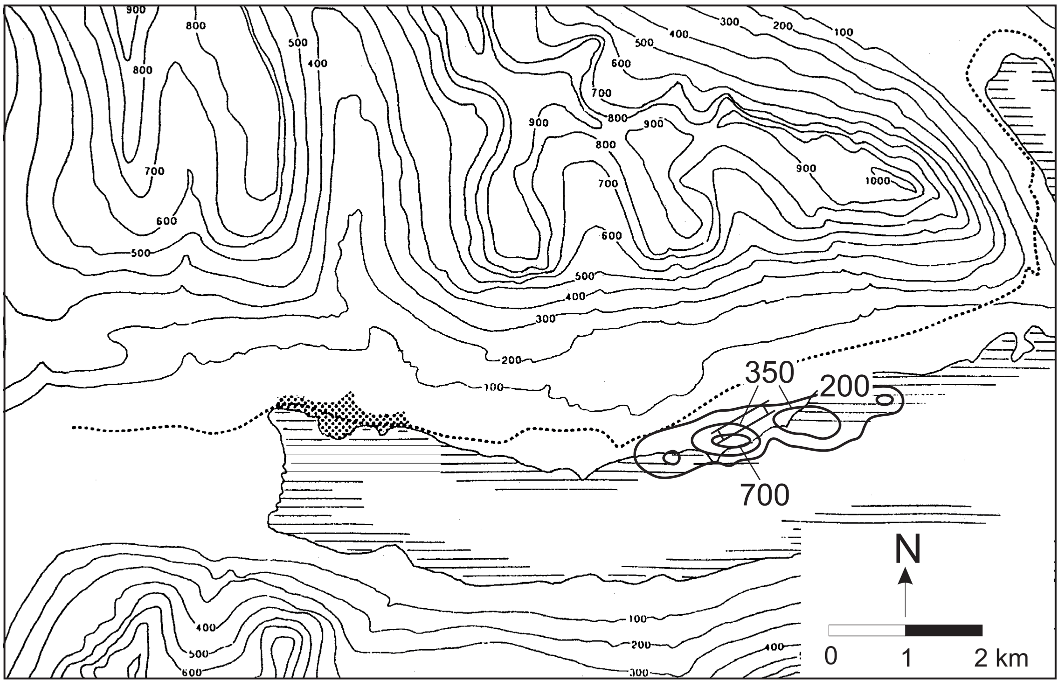


Figure 52: 99.7 percentile (420 000 tpy) for SO_2 for the year 1999-2000, based on hourly averages. Case 2. Unit:µg/m^3. The air quality guideline is 350 µg/m^3.

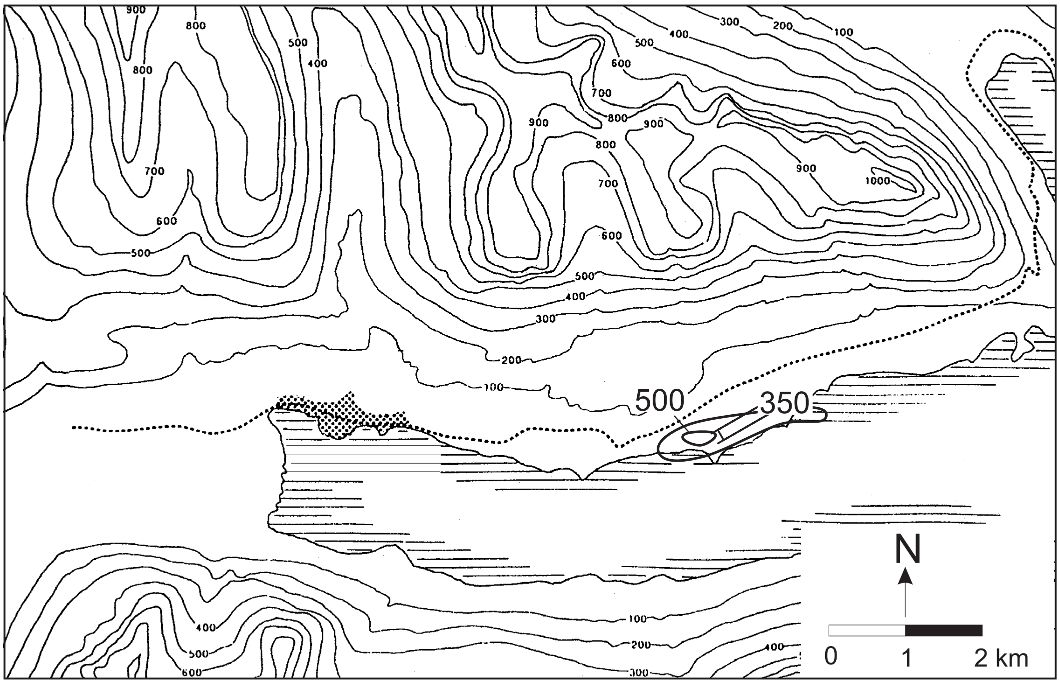


Figure 53: 99.7 percentile (420 000 tpy) for SO_2 for the year 1999-2000, based on hourly averages. Case 3. Unit:µg/m^3. The air quality guideline is 350 µg/m^3.

8.4 Particulate matter PM_{10}

The emission of particulate matter from the Smelter is given as dust. The guidelines relate to particulate matter with a diameter less than 10 µm (PM_{10}). The emissions of PM_{10} have been estimated to 10% of the weight of the total dust emissions. The concentrations that are calculated are PM_{10}.

The calculations show that the impact on the air quality in the fjord is limited and the air quality guideline for PM_{10} is not exceeded at any point for both production alternatives. The results are shown in Figure 54 to Figure 57

The corresponding results for 1998-1999 are shown in Appendix D.

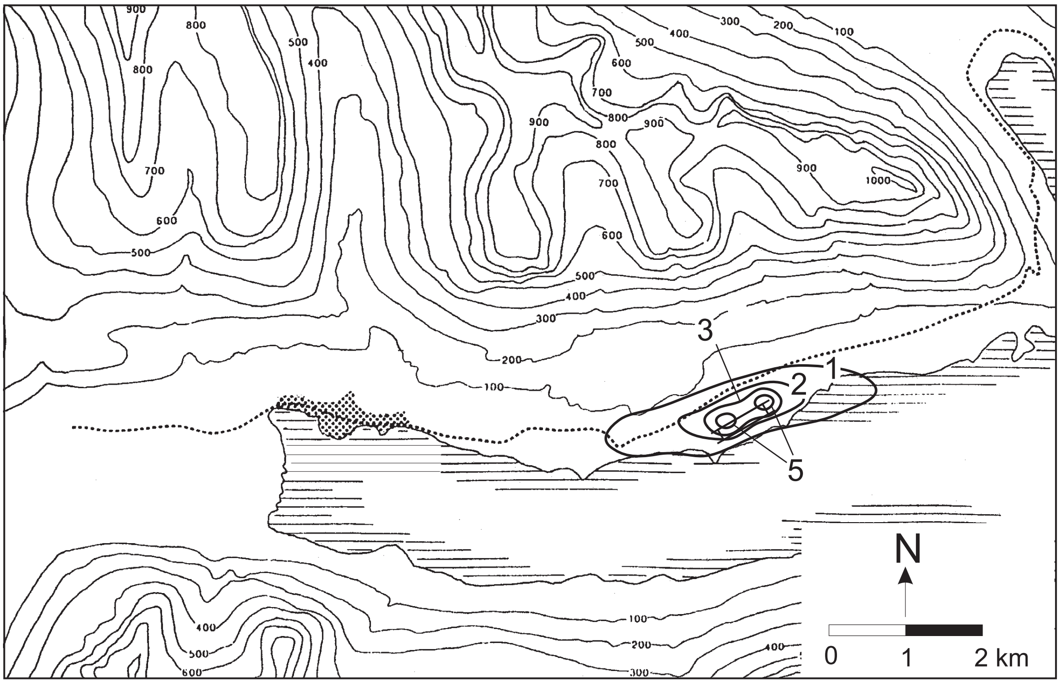


Figure 54: 98 percentile (280 000 tpy) of PM_{10} for the year 1999-2000, based on 24-hour averages. Unit: µg/m^3. The EU air quality guideline is 50 µg/m^3, after 2010.

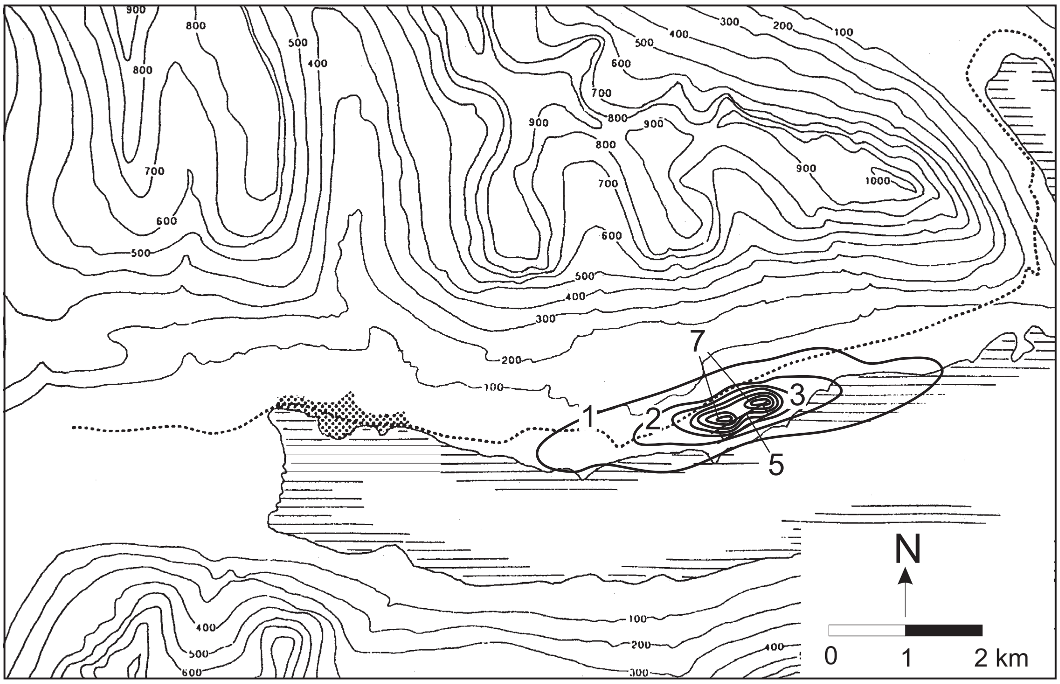


Figure 55: 98 percentile (420 000 tpy) of PM_{10} for the year 1999-2000, based on 24-hour averages. Unit: µg/m³. The EU air quality guideline is 50 µg/m³, after 2010.

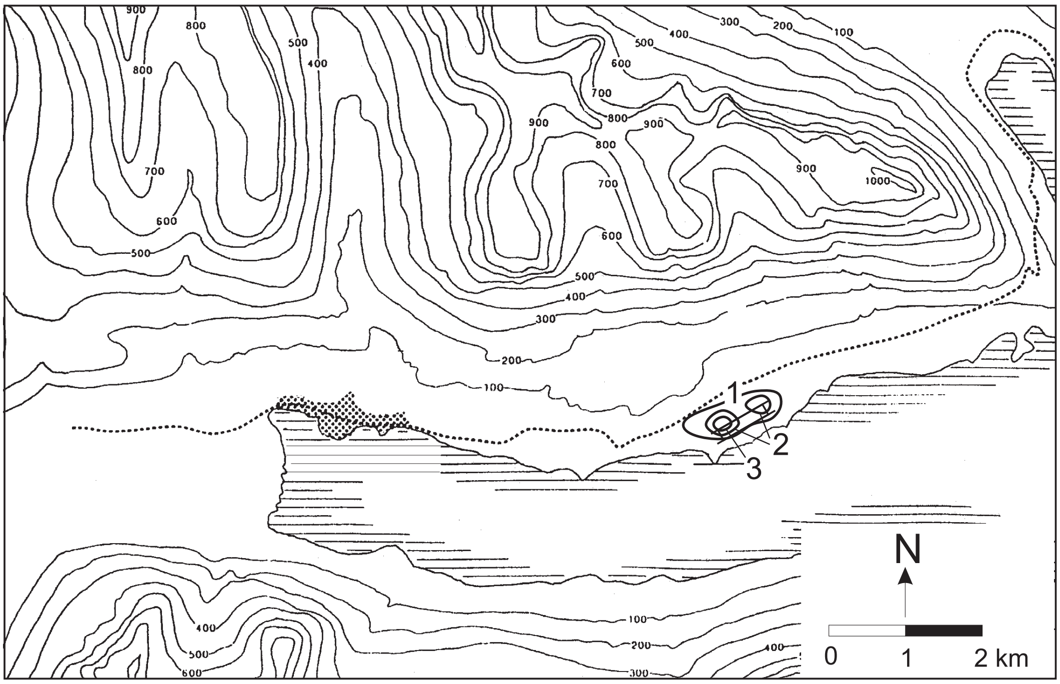


Figure 56: 90.4 percentile (280 000 tpy) of PM_{10} for the year 1999-2000, based on 24-hour averages. Unit: µg/m³. The air quality guideline is 50 µg/m³, between 2005 and 2010.

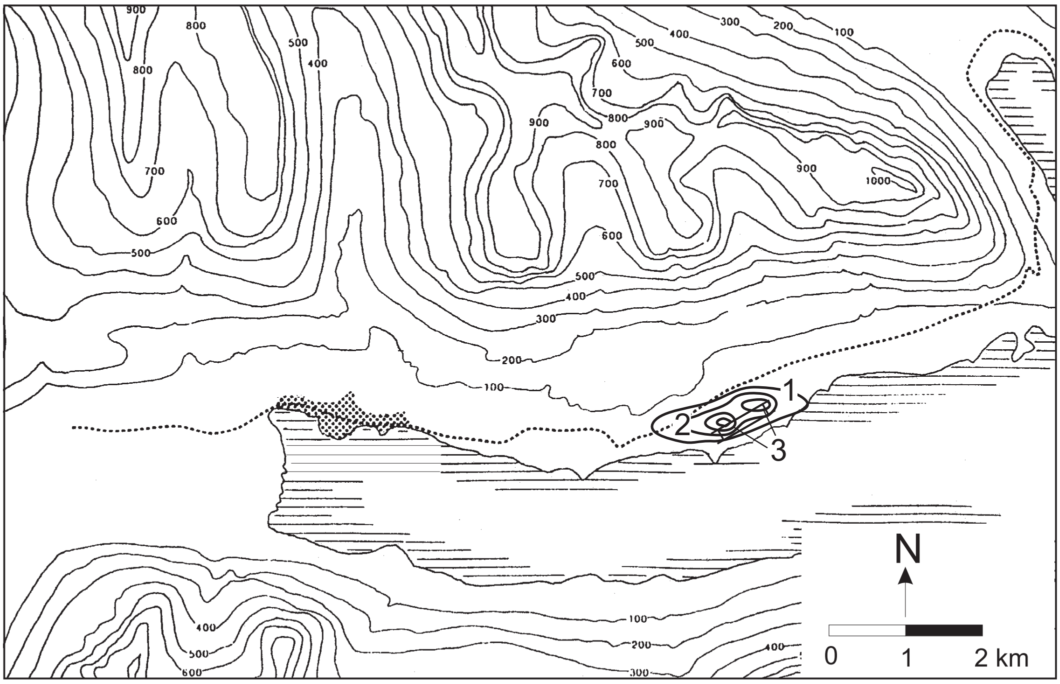


Figure 57: 90.4 percentile (420 000 tpy) of PM_{10} for the year 1999-2000, based on 24-hour averages. Unit: µg/m^3. The air quality guideline is 50 µg/m^3, between 2005 and 2010.

9. Modelling of special situations

The purpose of this modelling exercise is to study in detail situations with especially unfavourable dispersion conditions. The two chosen situations are probably the situations with the highest impact from the smelter because of the large number of re-entries. The periods that have been looked into are periods where the new meteorological sensors are functioning and meteorological information is available for many places in the fjord. The periods that have been studied are the following, 28-30 June 2000 and 21-25 July 2000.

9.1 21-25 July 2000

The synoptic maps show that on the 21 July there was a weak low pressure north of Iceland with a cold front over Reyðarfjördur. This deepened a bit and moved north on the 22. On the 23 the high pressure over the British Isles moved north and covered Iceland. This situation prevailed to the end of the period. The situation was characterised by low wind speeds and changing wind directions. Outside the fjord on the 21 and 22 of July the wind direction was from south at Seley and south south-west at Gangheidi. The wind speed outside the fjord was also high with wind speeds around 10 m/s for these two days. For the 23-25 of July the wind speed was slowly decreasing at Seley with calm conditions in the evening of the 24. Gangheidi had less wind speed and a short time with calm conditions during the night of the 23. The wind speed is shown in Figure 58 and the wind direction in Figure 59.

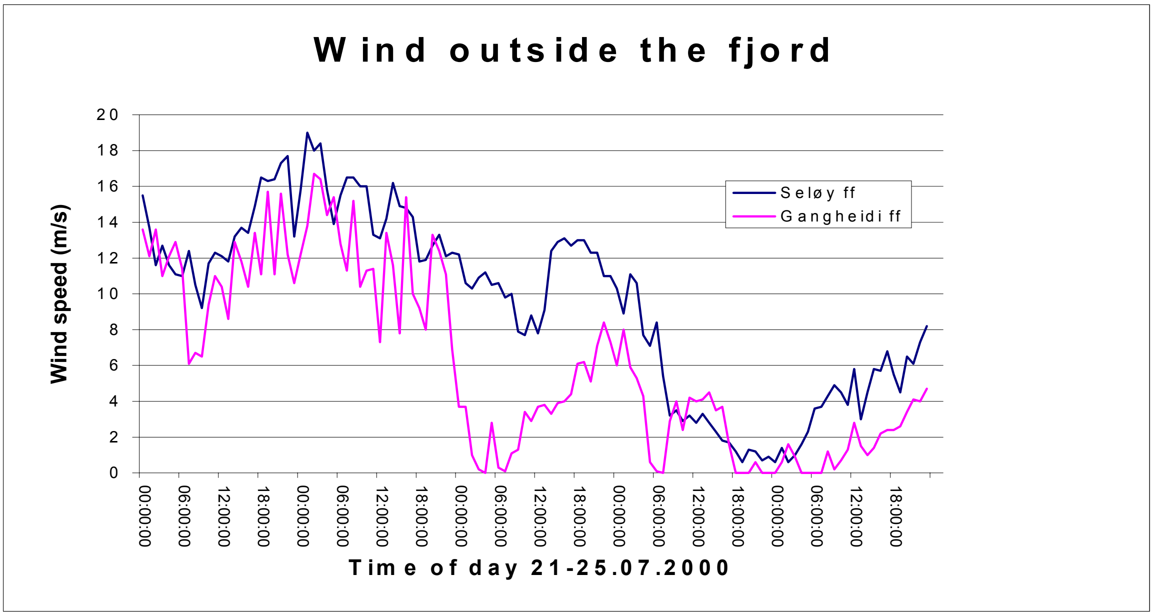


Figure 58: Wind speeds outside of the fjord. Seley is outside the mouth of the fjord and Gangheidi is at the top of the mountains.

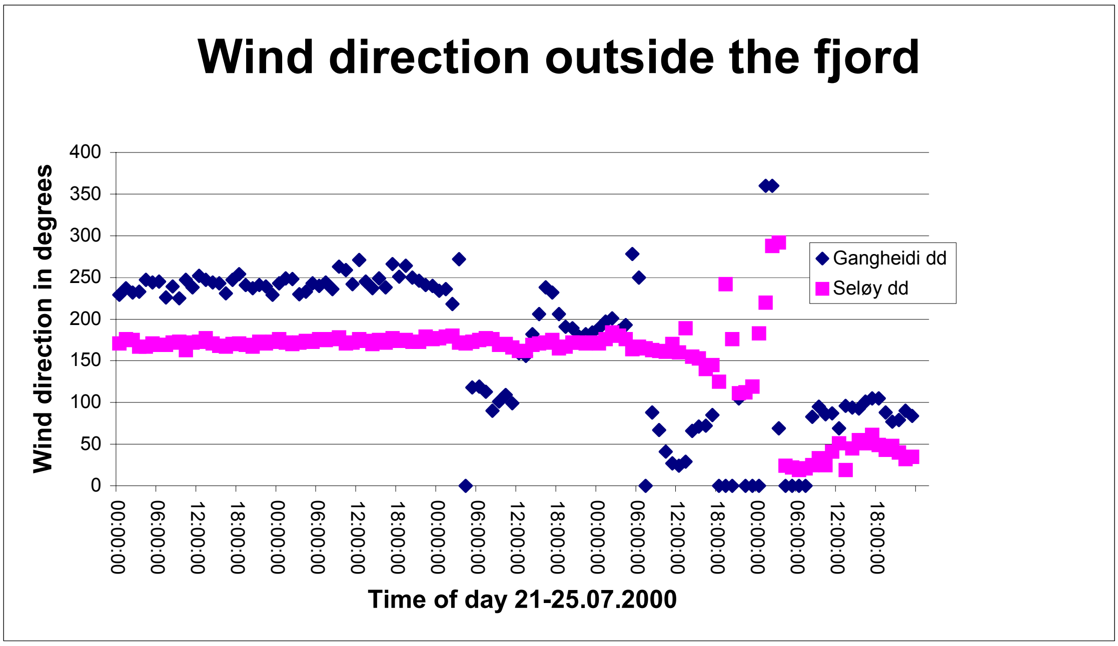


Figure 59: Wind direction at Gangheidi and Seley for the period of 21-25 of July 2000.

From Figure 59 it is seen that the wind direction changes at Gangheidi when the wind speed drops.

The temperature difference between Sómastadagerdi and Seley is shown in Figure 60.

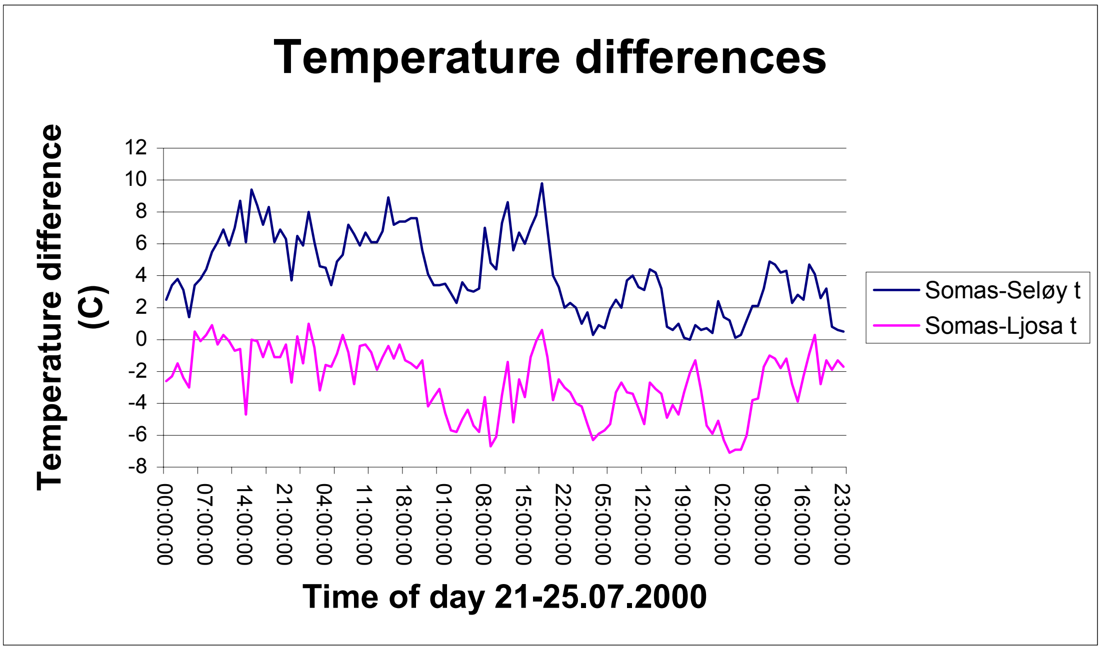


Figure 60: Temperature difference between the outer and the inner part of the fjord, and vertical temperature difference at Sómastadagerdi.

The temperature difference between Sómastadagerdi and Seley show that the temperature outside the fjord is lower than the temperature inside the fjord. The temperature at Ljosa is generally higher than the temperature at Sómastadagerdi. Ljosa is 250 m above Sómastadagerdi and when the temperature difference is more than 2.5°C, the atmosphere is stable. The horizontal temperature difference will favour wind into the fjord when the atmospheric stability is neutral or unstable.

From the observations in the inner part of the fjord at Sómastadagerdi and Kollaleira the wind speed is generally much lower than outside the fjord. The wind speed is all the time lower than 5 m/s and most of the time below 2 m/s. It is also seen that the wind direction during the period is variable and that the wind direction is alternating between transport in and out the fjord. This is the case both at Sómastadagerdi and Kollaleira, a bit further into the fjord. The wind speed is generally lower during night-time. Wind direction and wind speed at Sómastadagerdi is shown in Figure 61 and Figure 62.

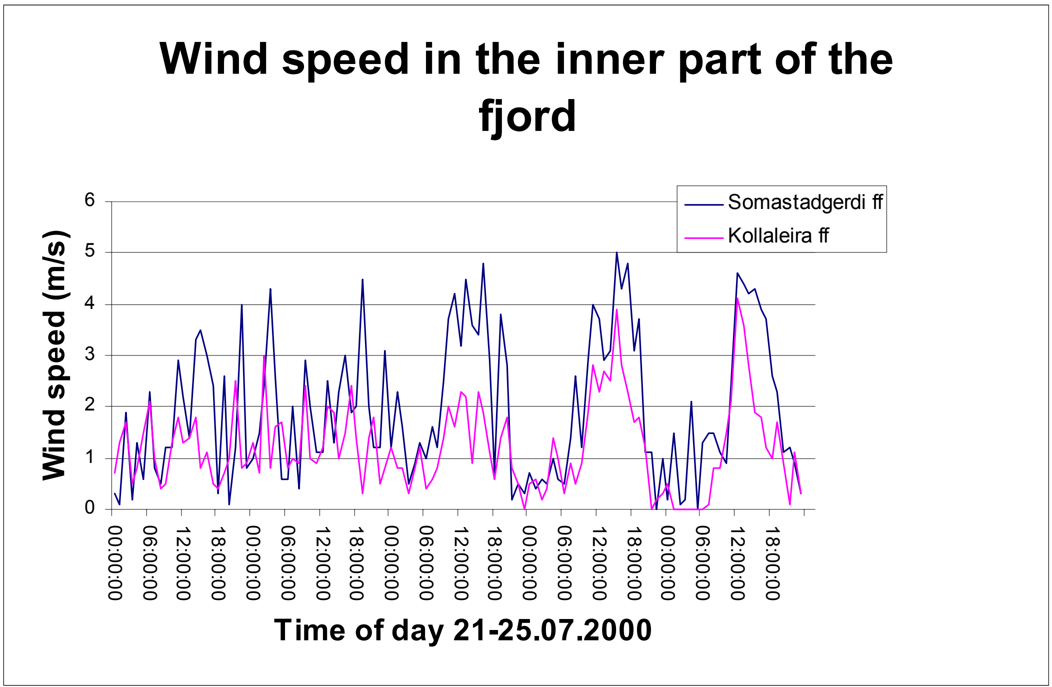


Figure 61: Wind speed in the inner part of the fjord for the period of 21-25 July 2000.

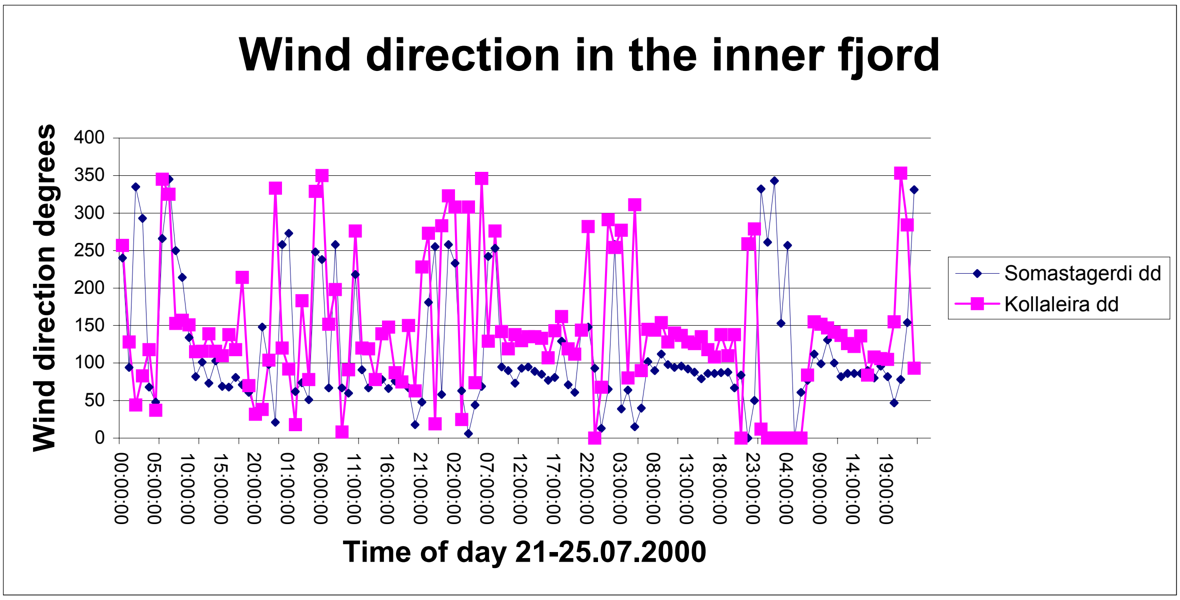


Figure 62: Wind direction in the inner part of the fjord for the period of 21-25 July 2000.

From the measurements at Vattarnes, especially from the temperature differences, it is seen that the meteorology inside and outside the fjord is disconnected. This means that the flow of air into the fjord is limited. The drainage flow under stable conditions stretches to the mouth of the fjord and is also seen at Vattarnes.

The meteorological measurements are diagnosed using a diagnostic meteorological model. This model uses the measurements, topography and the condition that the wind field is divergence free to extrapolate the wind field. The model is applied for these conditions. It is seen from these modellings that the wind direction is following the fjord. In the inner part of the fjord the wind direction has a tendency to go out the small valleys in the side of the fjord. There are too many hours to represent in the dataset so a typical situation is represented here. This is the wind field 24.07.2000 at 03 hours.

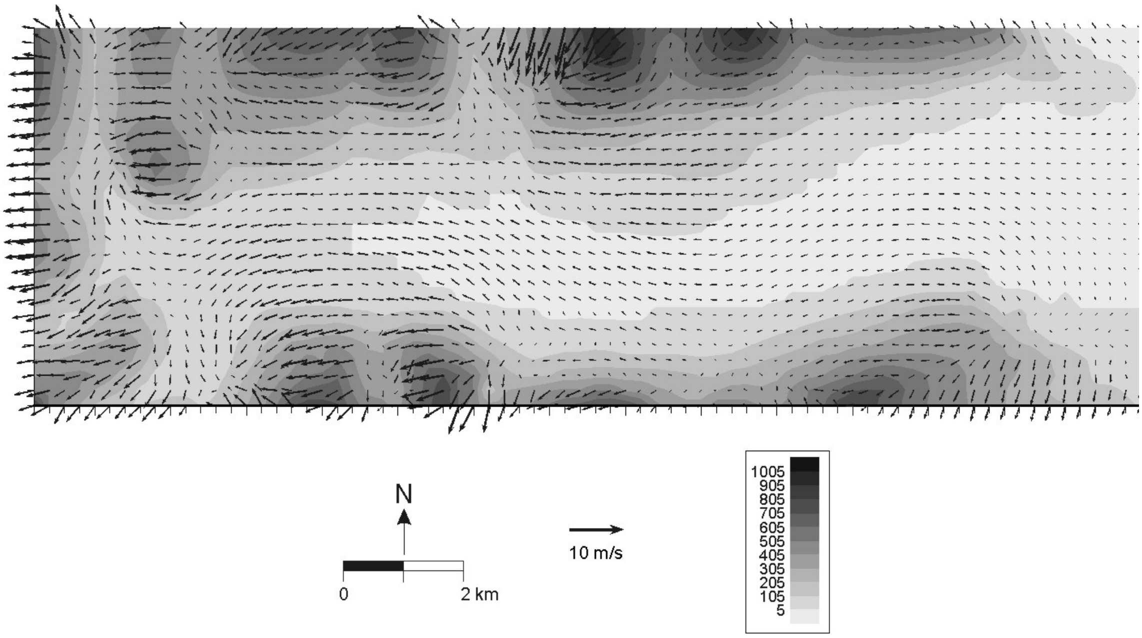


Figure 63: Results from the meteorological modelling of 24.07.2000 at 03 hours.

The impact on air quality from the emissions from the planned aluminium smelter in Reyðarfjördur is complex. To do the modelling of the concentrations the emissions and the output from the meteorological model is used. The modelling is done for SO_2. The results show that the highest concentration levels are generally close to the plant. The results from the dispersion modelling for 280 000 tpy case 1 are shown in Figure 64, for 420 000 tpy case 1 in Figure 65, and for case 2 the corresponding figures are Figure 66 and Figure 67.

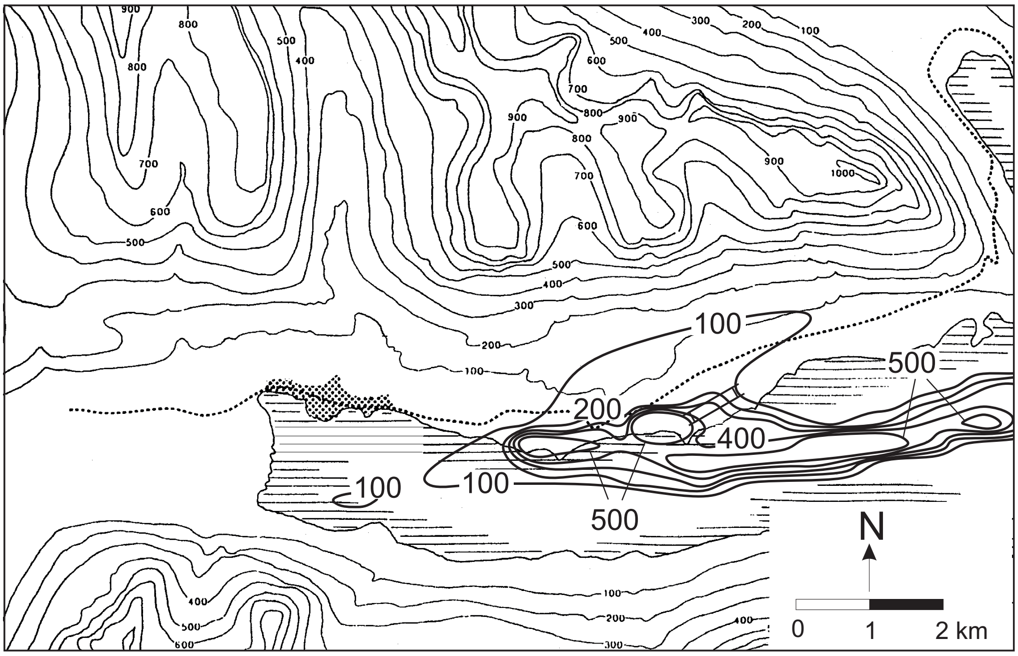


Figure 64: Results from the dispersion modelling for SO_2 for the 24.07.2000 at 03 hours and a production of 280 000 tpy, case 1. The air quality quideline is 350 µg/m³, not to be exceeded more than 24 times a year.

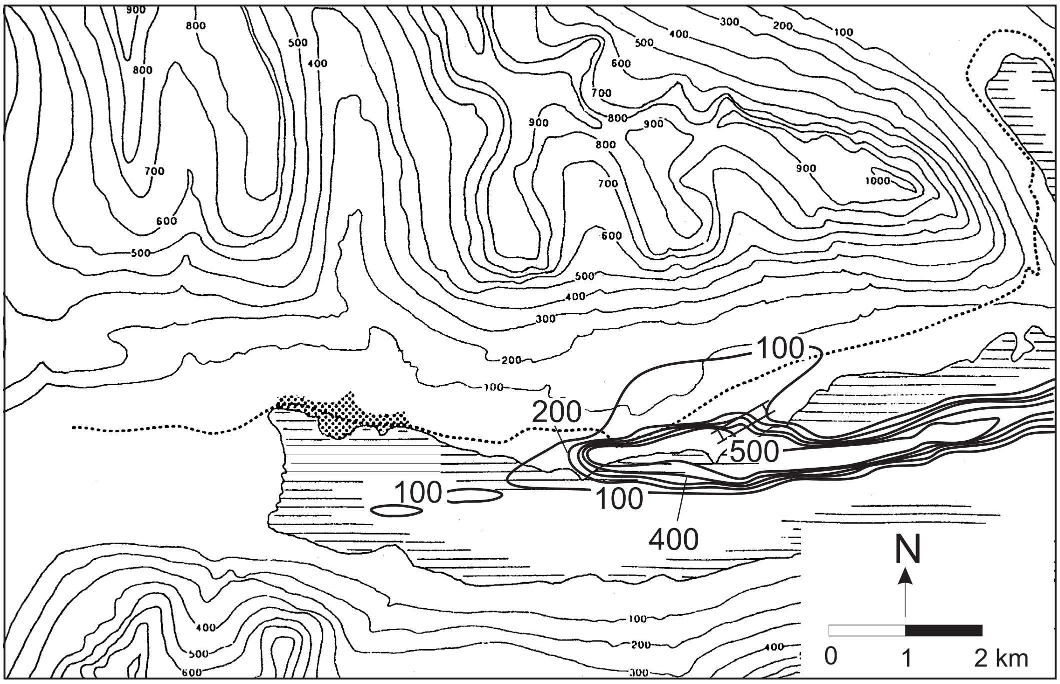


Figure 65: Results from the dispersion modelling for SO_2 for the 24.07.2000 at 03 hours and a production of 420 000 tpy, case 1. The air quality guideline is 350 µg/m³, not to be exceeded more than 24 times a year.

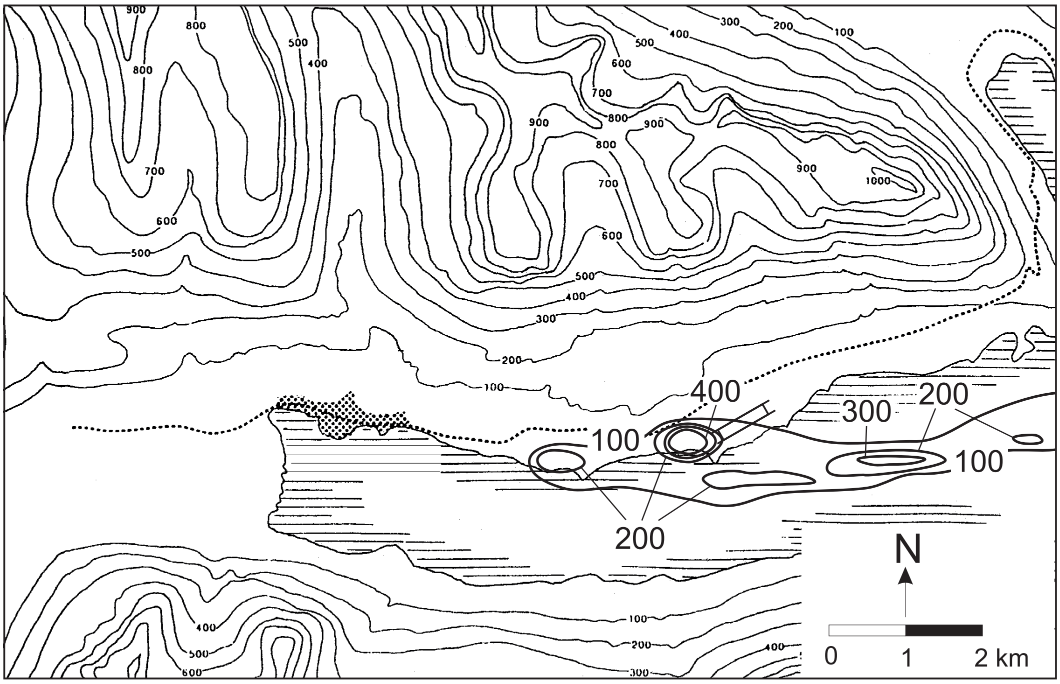


Figure 66: Results from the dispersion modelling of SO_2 for the 24.07.2000 at 03 hours and a production of 280 000 tpy, case 2. The air quality guideline is 350 µg/m³, not to be exceeded more than 24 times a year.

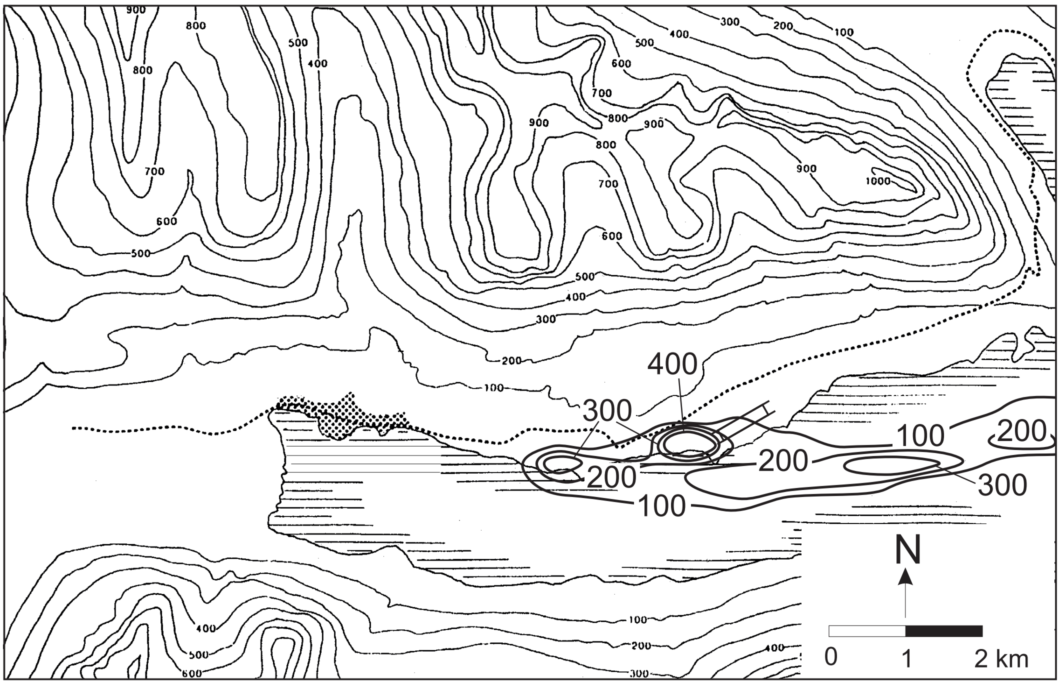


Figure 67: Results from the dispersion modelling of SO_2 for the 24.07.2000 at 03 hours and a production of 420 000 tpy, case 2. The air quality guideline is 350 µg/m³, not to be exceeded more than 24 times a year.

It is seen from the plots that the concentrations for case 1 are high and the 500 µg/m^3 iso-curve stretches out to approximately 3.7 kilometres from the end of the potroom out the fjord for a production of 280 000 tpy. With the production alternative of 420 000 tpy this distance is a bit longer. The one-hour guideline for SO_2 for EU is 350 µg/m^3 allowing 24 values over this limit per year.

The figures for case 2 show that the concentration is less than 50% of the corresponding estimated concentrations from case 1. With a production of 280 000 tpy the estimated concentration distribution show only small areas over 200 µg/m^3, apart from close to the plant. With a production of 420 000 tpy the concentrations increase and the maximum outside the vicinity of the plant is 300 µg/m^3. This shows that the concentrations are estimated to be lower than the corresponding EU guideline, except close to the plant.

The hour chosen for presentation is one of the hours with the highest impact and it shows that the concentrations are distributed on either side of the plant. The hour clearly demonstrates the accumulation effects. The reason for the high concentrations is that the vertical mixing at night is limited (stable conditions), in the morning hours this stable layer breaks up and a fumigation occurs. The breaking up of the stable layer lasts from 0.5-2 hours, depending on the strength of the driving force. This will however increase the mixing at ground level and increase the vertical mixing in the unstable/neutral layer. This effect will also increase the wind speed. A long period with calm conditions and stable conditions like the one shown is therefore considered to give higher impact. This is confirmed by the calculations.

In Figure 68 and Figure 69 the estimated 24 hour averaged concentration distribution for the 24 July 2000 is shown for case 1. The figures show that the Icelandic and EU guideline of 50 µg/m^3 is exceeded over a large area. The Norwegian air quality guideline of 100- 150 µg/m^3 is also exceeded. The highest impact for this day is from Sómastadagerdi towards Budareyri.

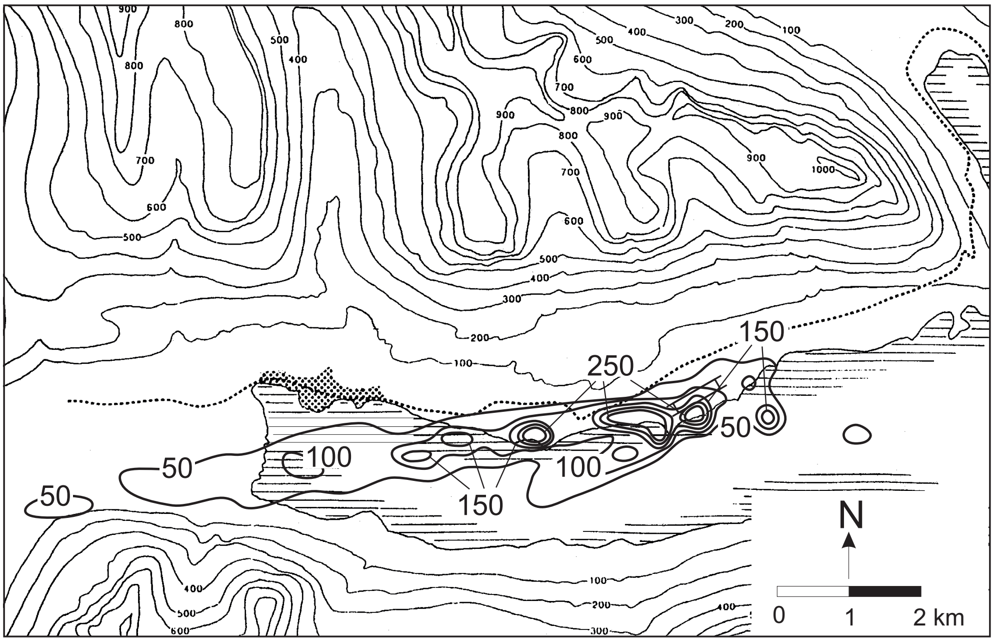


Figure 68: Estimated 24 hour average concentrations of SO_2 for the 24.07.2000 with a production of 280 000 tpy, case 1. The air quality guideline is 50 µg/m³.

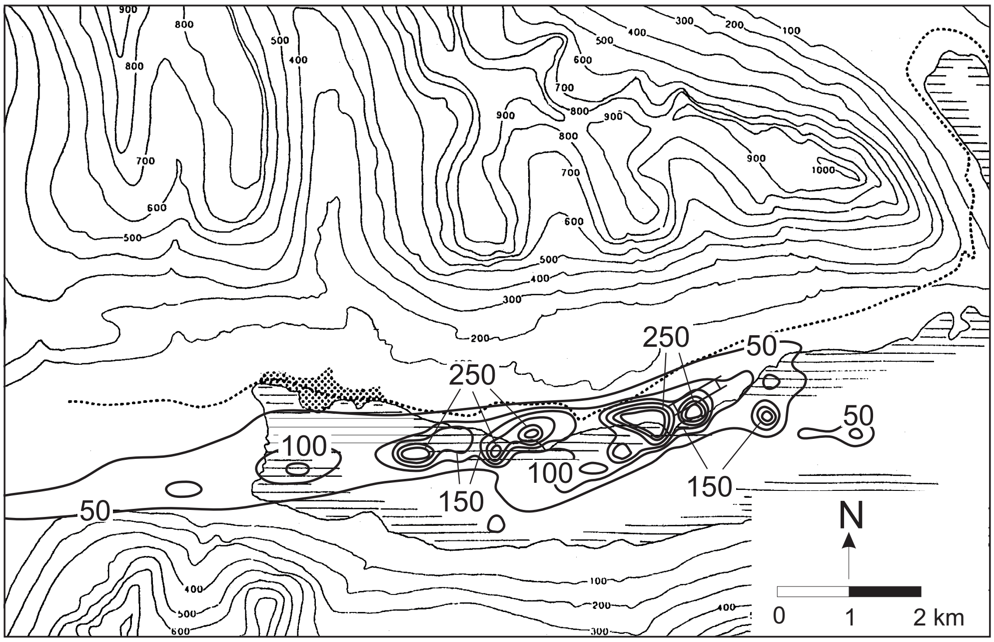


Figure 69: Estimated 24 hour average concentrations of SO_2 for the 24.07.2000 with a production of 420 000 tpy, case 1. The air quality guideline is 50 µg/m³.

Figure 70 and Figure 71 show the corresponding estimated concentrations of SO_2 with a production for case 2. The figures show that the concentrations exceed the Icelandic limit of 50 µg/m^3 out to a distance of 3 km towards Budareiri with a production of 280 000 tpy and approximately 4 km with a production of 420 000 tpy. This limit may be exceeded 7 times per year.

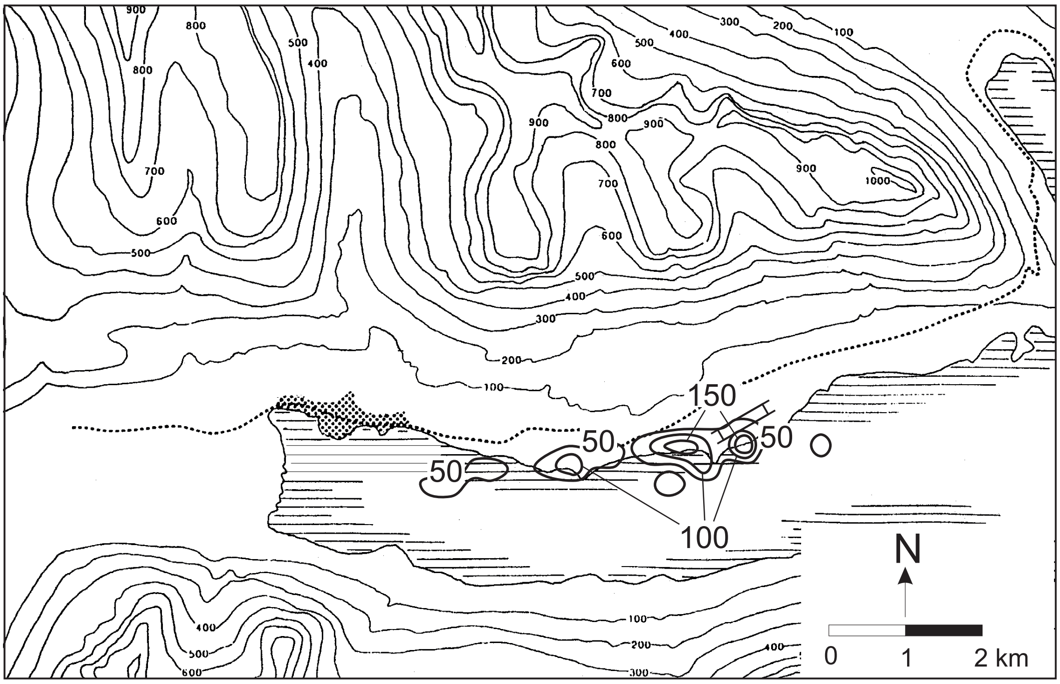


Figure 70: Estimated 24 hour average concentrations of SO_2 for the 24.07.2000 with a production of 280 000 tpy, case 2. The air quality guideline is 50 µg/m³.

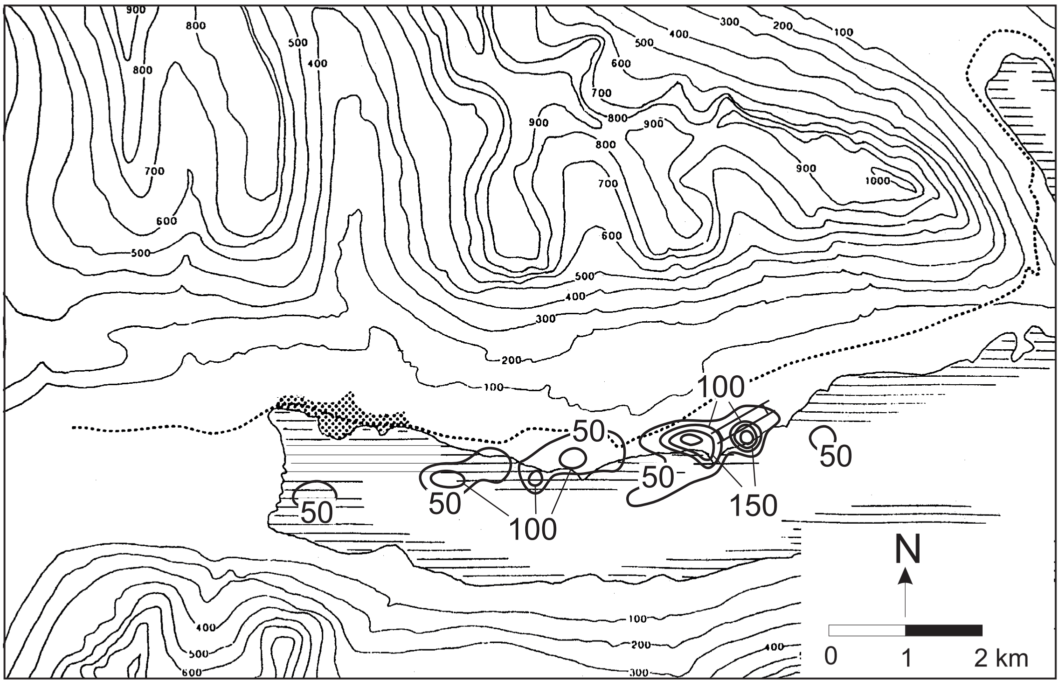


Figure 71: Estimated 24 hour average concentrations of SO_2 for the 24.07.2000 with a production of 420 000 tpy, case 2. The air quality guideline is 50 µg/m³.

9.2 28-30.06.2000

The synoptic maps show that there is a high pressure north of Iceland with a weak warm front over Iceland. This front is slowly moving north. The wind direction measured outside the fjord at Seley and Gangheidi shows southerly winds at Seley and at Gangheidi. The wind is shifting between south and north. The wind speed at Gangheidi is strong in the first part of the period, close to 18 m/s, but during the first 24 hours the wind speed is reduced to close to calm conditions. The wind speed at Gangheidi remains under 2 m/s almost for the rest of the period with only a few hours above 2 m/s. At Seley the wind speed is higher. The weather is cloudy and therefore the drainage wind will be absent or weak. This will favour low wind speeds at nighttime. The wind direction is shown in Figure 72 and the wind speed in Figure 73.

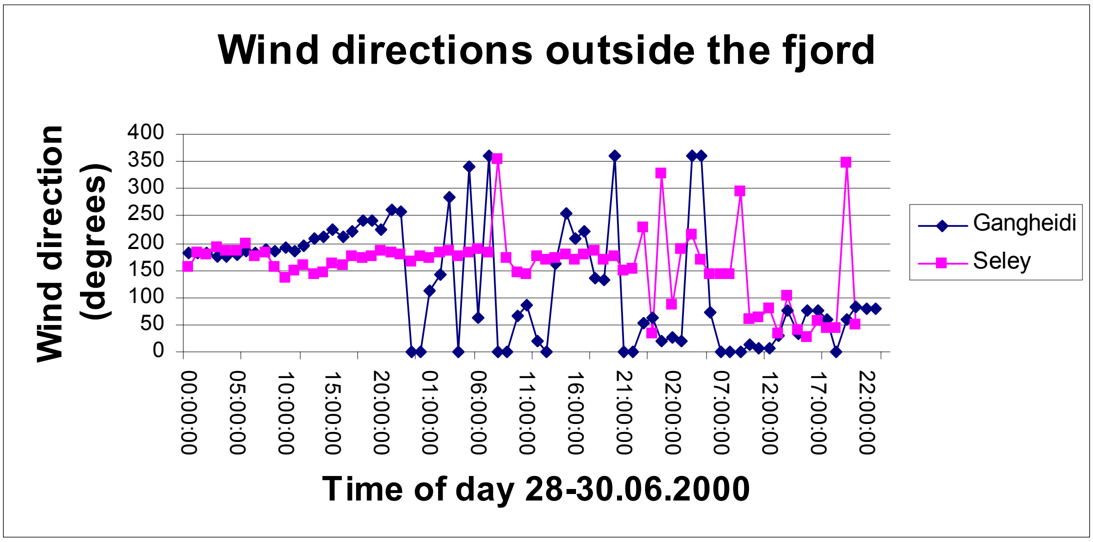


Figure 72: Wind direction outside the fjord in the period of 28-30.06.2000.

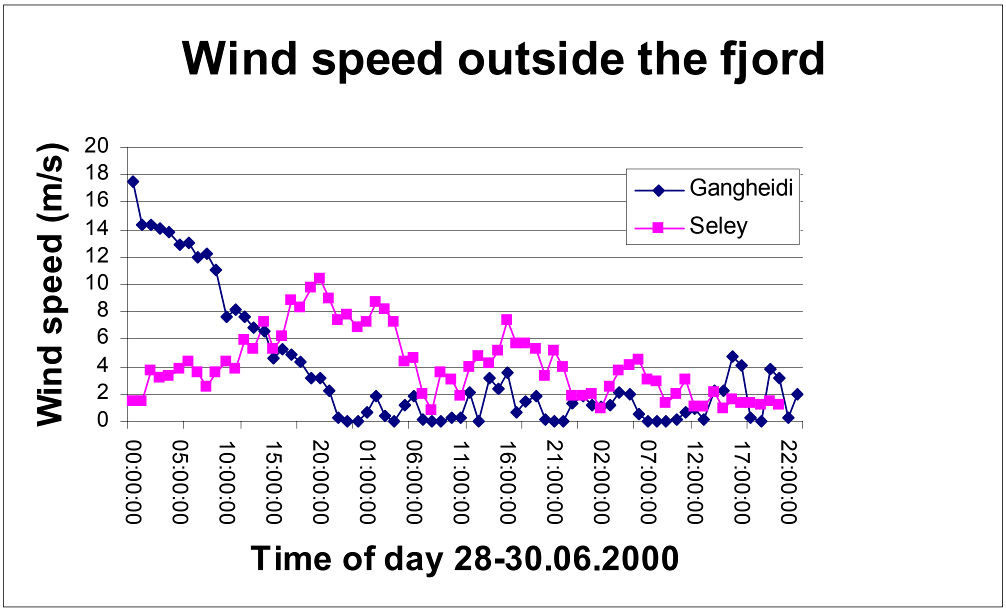


Figure 73: Wind speed outside the fjord in the period 28-20.06.2000.

At Sómastadagerdi the wind direction is easterly, apart from two periods both at nighttime. During the night between 28 and 29 June the wind direction is varying between in and out the fjord. The wind changes direction 6 times during the night. During the night between 29 and 30 June the wind changes 4 times. The wind direction at Kollaleira is a bit more south, probably because Kollaleira is close to the head of the fjord and the wind will have a tendency to follow the shallow valleys in the upper topography. During the wind shifts at nighttime the wind drops below 1 m/s and calm conditions occur.

The temperature difference between Sómastadagerdi and Seley is shown in Figure 74. The temperature difference between Sómastadagerdi and Seley shows that the temperature outside the fjord is lower than the temperature inside the fjord. The temperature at Ljosa is generally higher than the temperature at Sómastadagerdi. Ljosa is 250 m above Sómastadagerdi and when the temperature difference is more than 2.5°C the atmosphere is stable. The horizontal temperature difference will favour wind into the fjord when the atmospheric stability is neutral or unstable.

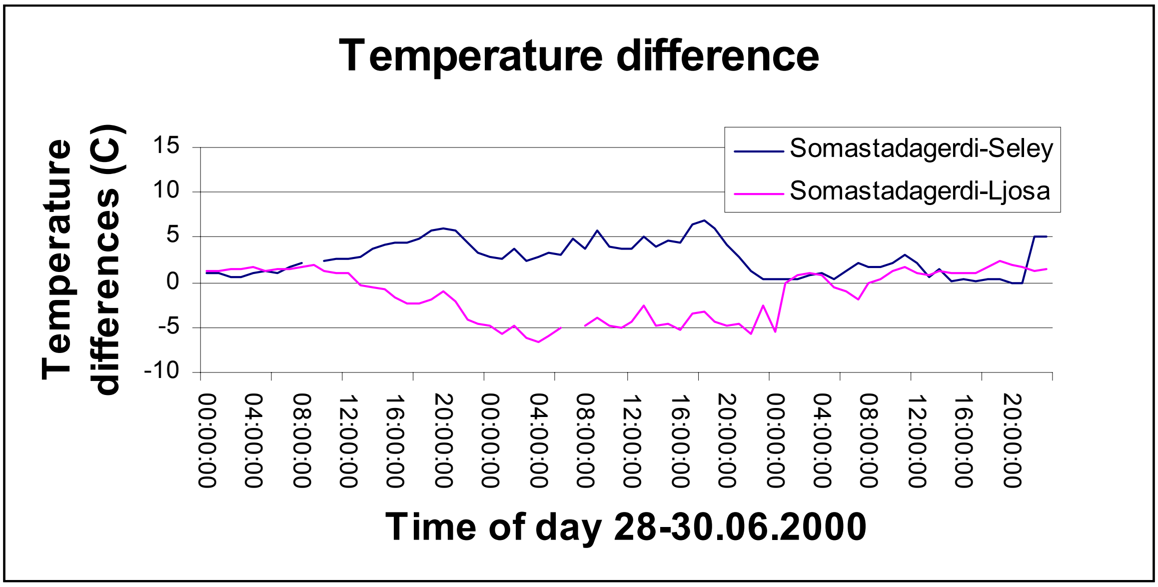


Figure 74: Horizontal temperature difference between Sómastadagerdi and Seley, and vertical temperature difference between Sómastadagerdi and Ljosa for the period 28-30.06.2000.

The wind speed in the inner part of the fjord is shown in Figure 75, and the wind direction is shown in Figure 76. There are two periods with low wind speeds and calm conditions, these are the nights between the 28 and the 29, and between the 29 and 30 of June. At these hours the wind direction is changing and there are respectively 6 and 4 re-entries.

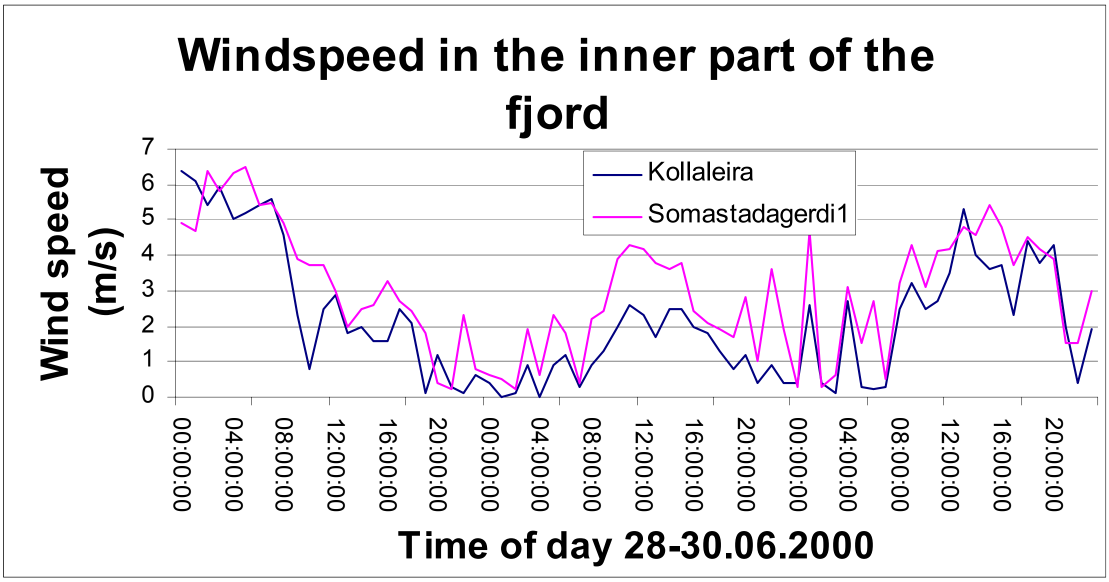


Figure 75: Wind speed in the inner part of the fjord for the period 28-30.06.2000.

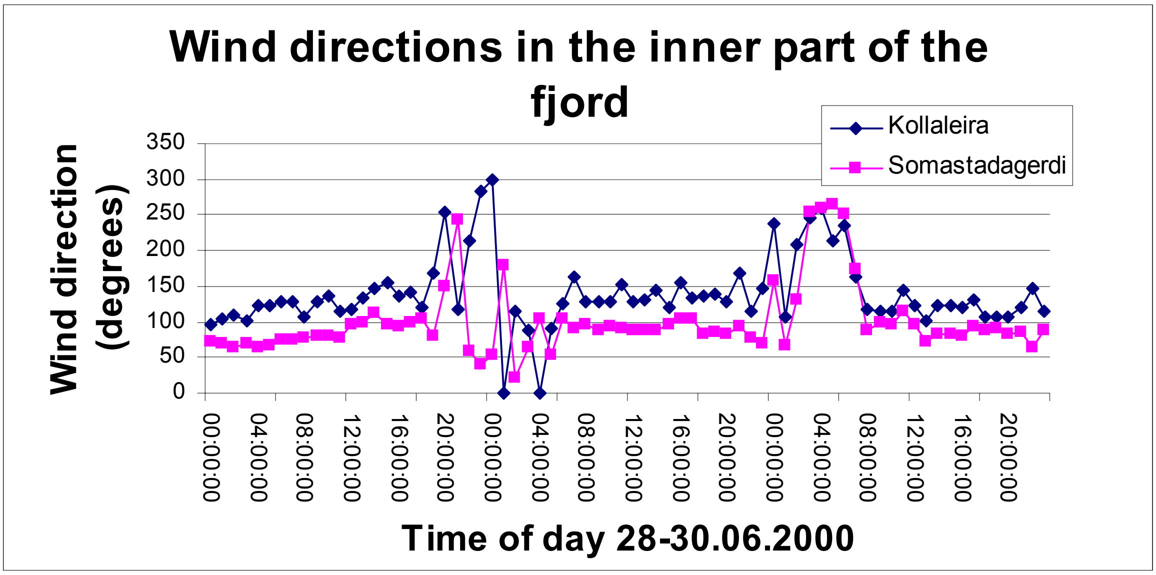


Figure 76: Wind direction in the inner part of the fjord for the period 28-30.06.2000.

The modelling of the meteorological wind field shows that the wind is strongly influenced by the topography. In the inner part the wind flows out the upper valley. The large wind speeds on top of the mountains are artificial and are effects of the meteorological model used. It is seen that the wind field in the inner part of the fjord is weak and that the winds in the outer part of the fjord are stronger with wind speeds of approximately 1.5 m/s. The wind field for the 28.06.2000 at 21 hours is shown in Figure 77.

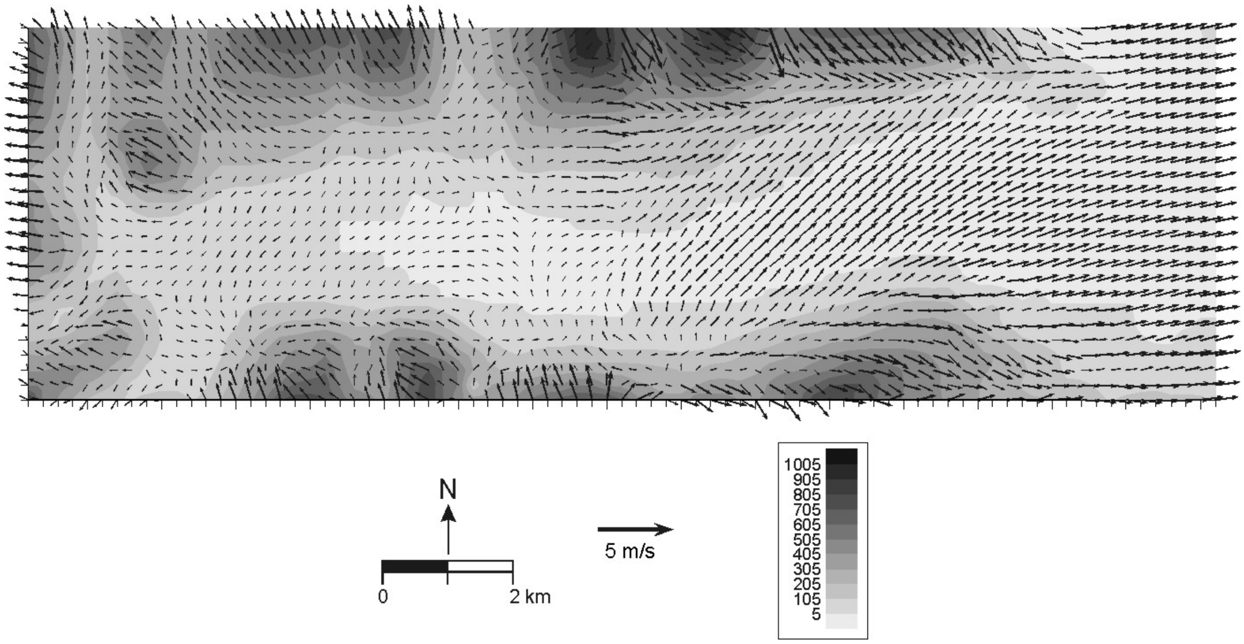


Figure 77: Wind field for the 28.06.2000 at 21 hours.

The concentration field for this hour is shown in Figure 78 and Figure 79. The concentration field is patchy and is covering a relatively small area. For case 1 the concentrations for both production alternatives exceed the EU guide line of 350 µg/m^3 (3 exceedances allowed pr. year). For case 2 the concentrations are only higher than 350 µg/m^3 in a very small area.

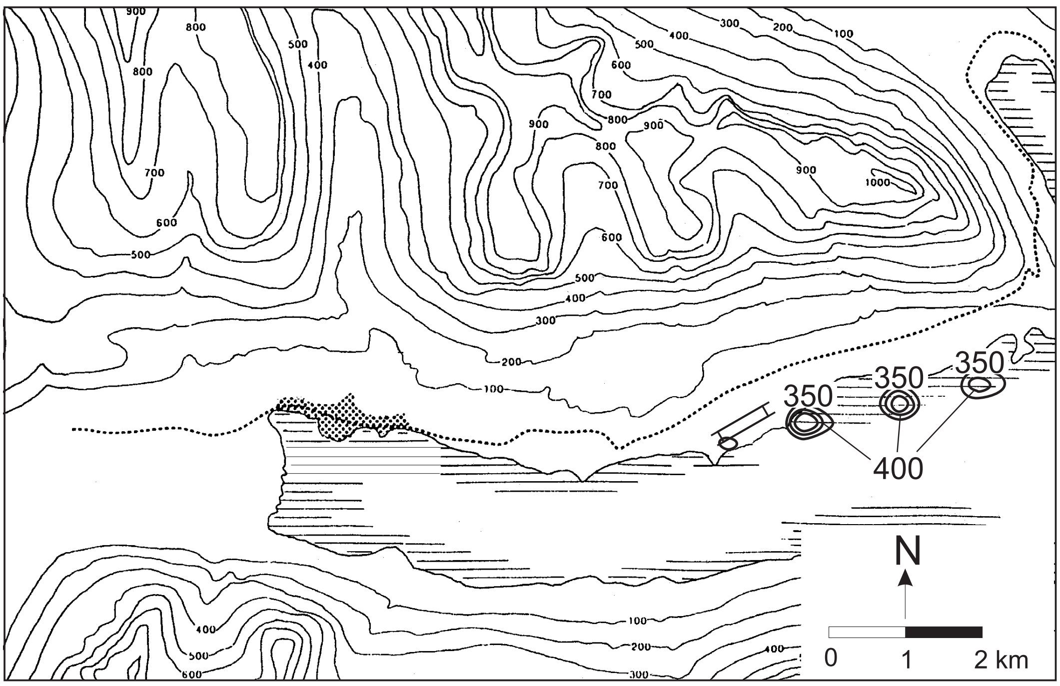


Figure 78: Concentration distribution on the 28.06.2000 at 21 hours for case 2 and a production of 280 000 tpy. The air quality guideline is 350 µg/m³, not to be exceeded more than 24 times a year.

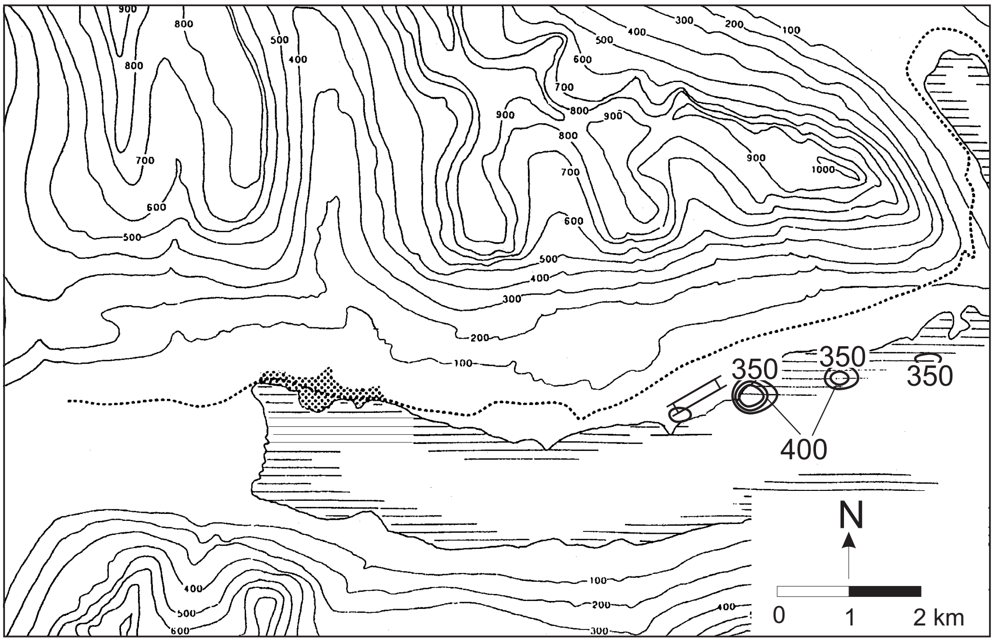


Figure 79: Concentration distribution on the 28.06.2000 at 21 hours for case 2 and a production of 420 000 tpy. The air quality guideline is 350 µg/m³, not to be exceeded more than 24 times a year.

24-hour averages have also been calculated. The wind fields are not presented because of its bulk. The day presented is 28.06.2000. The concentration fields for case 1 and 2 for the two alternative productions are shown in Figure 80 to Figure 83.

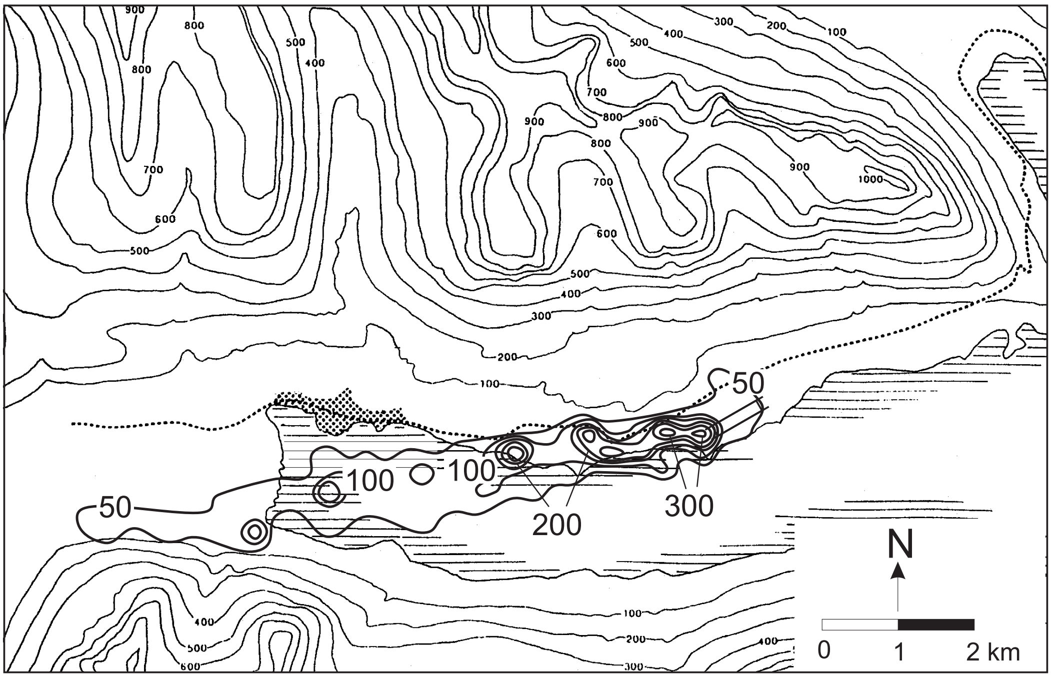


Figure 80: 24 hour averaged concentration for the 28.06.2000 for case 1 and a production of 280 000 tpy. The air quality guideline is 350 µg/m³, not to be exceeded more than 24 times a year.

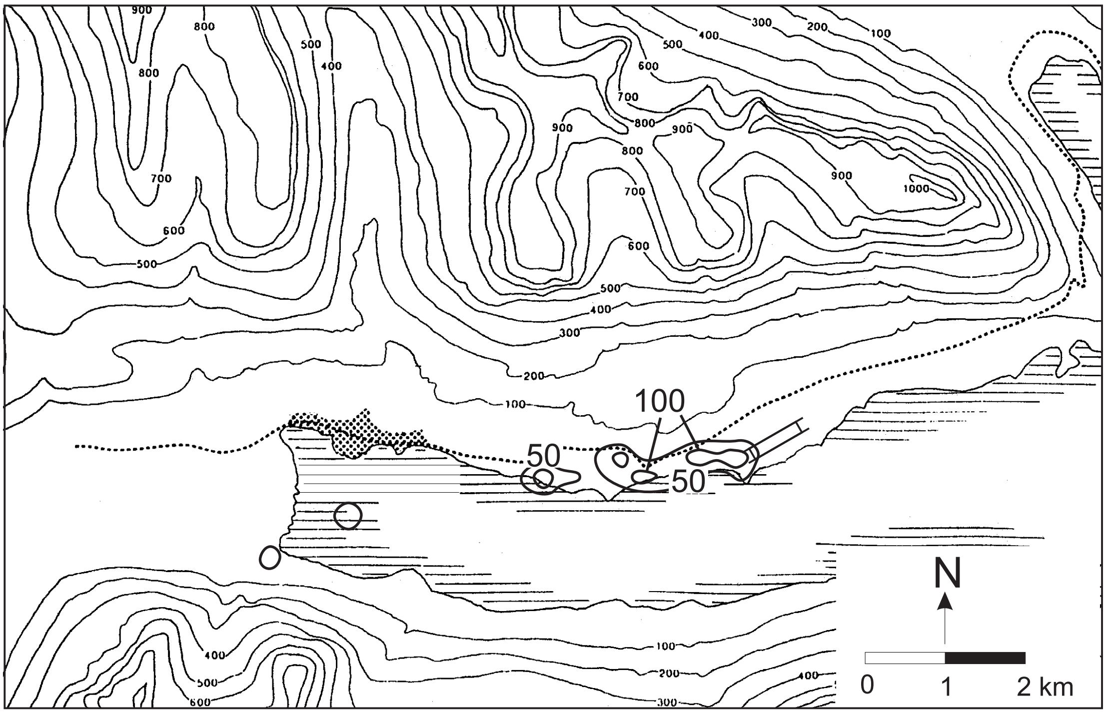


Figure 81: 24 hour averaged concentrations for the 28.06.2000 for case 2 and a production of 280 000 tpy. The air quality guideline is 350 µg/m³, not to be exceeded more than 24 times a year.

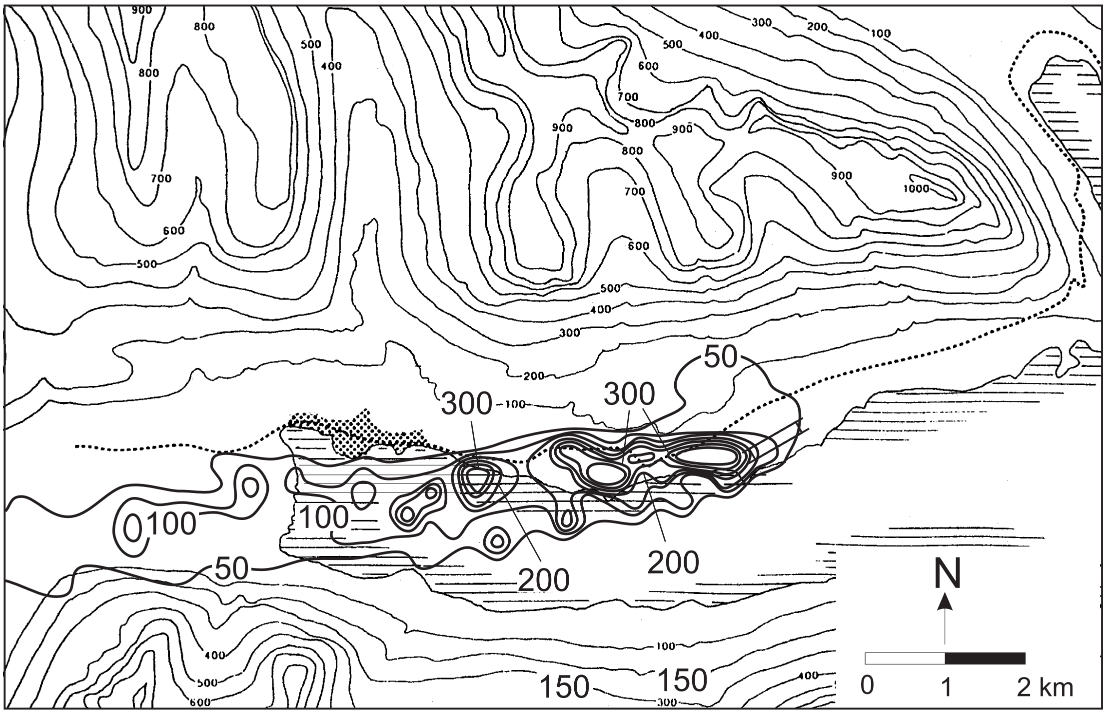


Figure 82: 24 hour averaged concentration for the 28.06.2000 for case 1 and a production of 420 000 tpy. The air quality guideline is 350 µg/m³, not to be exceeded more than 24 times a year.

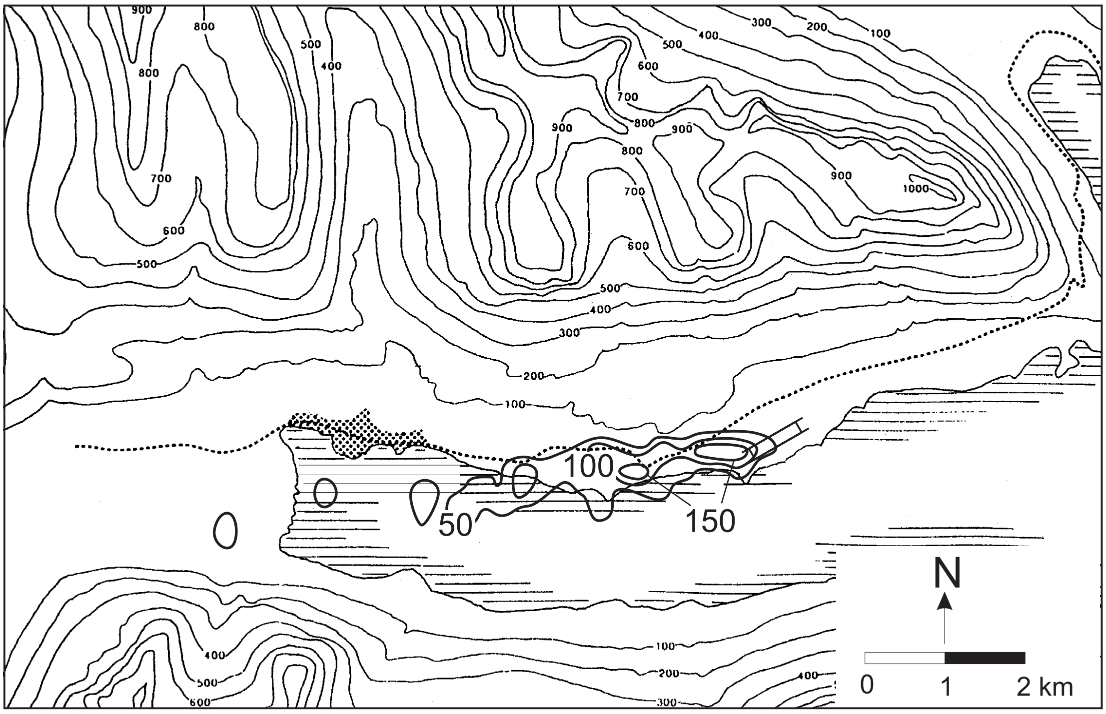


Figure 83: 24 hour averaged concentration for the 28.06.2000 for case 2 and a production of 420 000 tpy. The air quality guideline is 350 µg/m³, not to be exceeded more than 24 times a year.

It is seen from the plots that the concentration distribution is similar to the 98 percentile plots shown earlier in the report. The concentrations are however high and this day is included in the calculations of the 98 percentile values. The concentration field is stretching into the fjord. The pollution travels over water until it reaches the end of the fjord. The concentrations for case 1 for both production alternatives are higher than the Icelandic air quality guideline of 50 µg/m^3 over a large area, and close to the plant the concentrations are above 300 µg/m^3. The concentrations for case 2 are substantially lower. With a production of 280 000 tpy the concentrations are below the air quality guideline for most of the fjord, as it is shown in Figure 81. The concentrations above 100 µg/m^3 are at the most 2.6 km from the potrooms. For the production alternative of 420 000 tpy, shown in Figure 83, the concentrations above 100 µg/m^3 reaches out to approximately the same distance but covers a slightly larger area. Concentrations above 150 µg/m^3 reach out to 1.6 km in the direction of Budareyri.

10. References

Acid News (1997) Results from national forest-damage surveys 1986-1995. Percentage of trees in Classes 2-4 (defoliation > 25 per cent). All species. *Acid News, 1997, 4-5*, 15.

Bøhler, T. (1987) Users guide for the Gaussian type dispersion models CONCX and CONDEP. Lillestrøm (NILU TR 8/87).

Bøhler, T. (1990) Model calculations for a planned aluminium smelter at Reydarfjördur, Iceland. Lillestrøm (NILU OR 34/90).

Environmental and Food Agency of Iceland (1994) Regulations on environmental pollution control nr. 48/1994 (with changes nr. 378/1994 and nr. 536/1994).

EU (1996) Council Directive 96/62/EC of 27 September 1996 on ambient air quality assessment and management. *OJ L, 296,* 21.11.1996 p. 55.

EU (1998) Proposal for a Council Directive relating to limit values for benzene and carbon monoxide in ambient air. COM (1998) 591 final - 98/0333(SYN) (Submitted by the Commission on 20 January 1999).

EU (1999a) Council Directive 1999/30/EC of 22 April 1999 relating to limit values for sulphur dioxide, nitrogen dioxide and oxides of nitrogens, particulate matter and lead in ambient air. *OJ L, 163,* 29.06.1999 p. 41.

Guerreiro, C. and Tshukudu, T. (1998) Model calculations for a planned aluminium smelter at Hraun, Iceland. Lillestrøm (NILU OR 3/98).

Hagen, L.O.(1991a) Kontrollmålinger av PAH i luft ved aluminiumverk vinteren 1991. Lillestrøm (NILU OR 42/91).

Hagen, L.O. (1991b) Kontrollmålinger av PAH i luft og nyttevekster ved aluminiumverk sommeren 1991. Lillestrøm (NILU OR 1/92).

Miljøverndepartementet (1998) Forskrift om grenseverdier for lokal luftforurensning og støy. Oslo (FOR 1997-05-30 nr 490).

Sigurdsson, F.H., and Hjartarson, H. (1986) Vedurathuganir a Reydarfjardarsvædinu. Reykjavik, Veđurstofa Islands.

Sigurdsson, F.H., Hjartarson, H., and Antonsson T.K.(1999) Vindmælingar ad Kollaleiru 1983-1998. Reykjavik, Veđurstofa Islands.

Sigurdsson, F.H., Hjartarson, H., Antonsson T.K., and Arason T. (2000) Additional Wind and Stability Observations at Sómastadagerdi in Reydarfjördur II , November 1999-April 2000. Reykjavik, Veđurstofa Islands.

Sigurdsson, F.H., Hjartarson, H., Antonsson T.K., and Arason T. (1999) Wind and Stability Observations at Sómastadagerdi in Reydarfjördur, May 1998-April 1999. Reykjavik, Veđurstofa Islands.

Sigurdsson, F.H., Hjartarson, H., Antonsson T.K., and Arason T. (2000) Additional Wind and Stability Observations at Sómastadagerdi Reydarfjördur III, May- August 2000. Reykjavik, Veđurstofa Islands.

Umhverfisráðuneytið (1999). Reglugerð um brennisteinsdíoxíð og svifryk í andrúmslofti. Nr.790/1999. Stjórnartíðindi 29. október 1999 (in English: Regulation no.790/1999 on sulfurdioxide and dust in air. Ministry of environment).

World Health Organization (1999) Guidelines for air quality. Geneva.

World Health Organization (1987) Guidelines for air quality for Europe. København, WHO Regional Office for Europe (WHO Regional Publications. European series, 23).

Appendix A

Statistics for the wind speed and wind direction in Reyðarfjördur

Wind roses from Reyðarfjördur 1998-1999

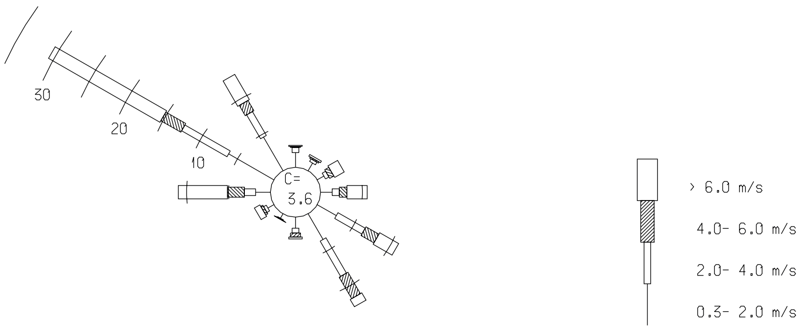


Figure A1: Wind rose from Eskifjordur for 1998-1999.

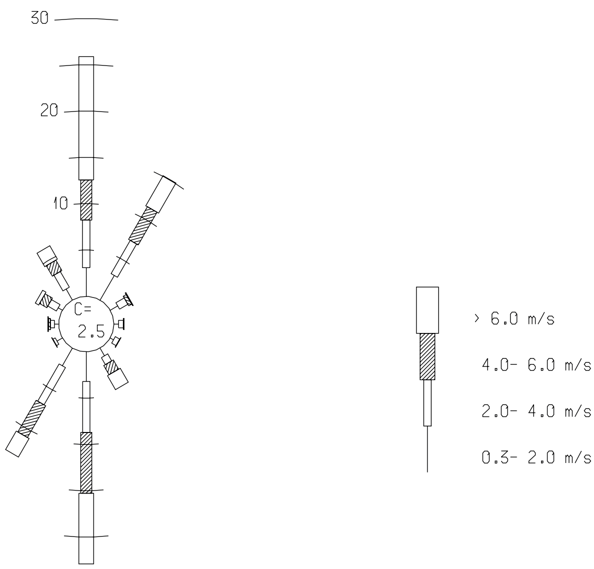


Figure A2: Wind rose for Fagridalur for 1998-1999.

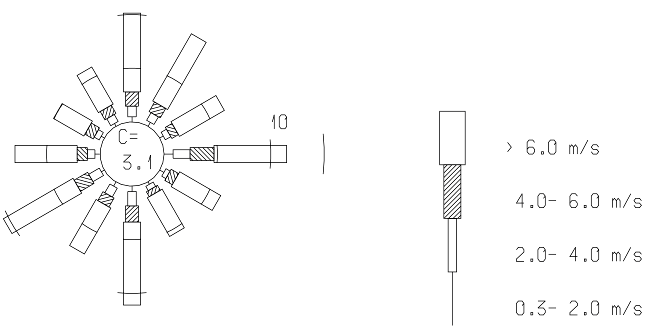


Figure A3: Wind rose from Gagnheidi for 1998-1999.

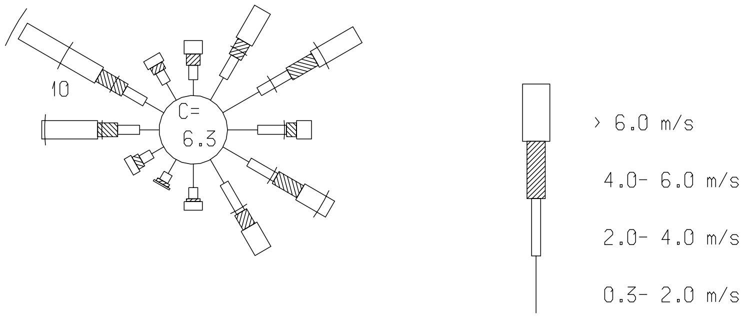


Figure A4: Wind rose from Oddskard for 1998-1999.

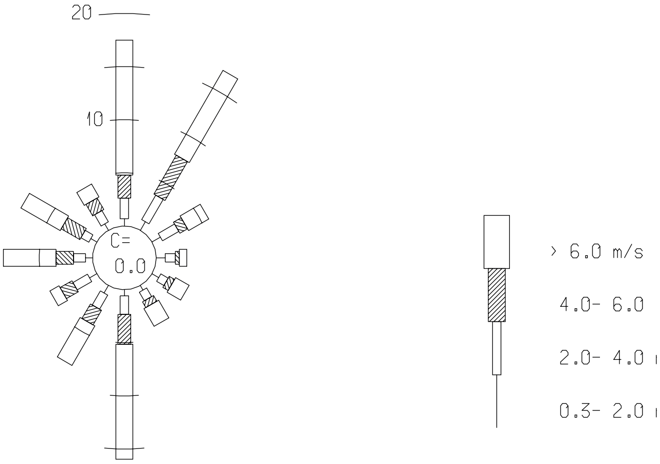


Figure A5: Wind rose from Seley for 1998-1999.

Wind roses from Reyðarfjördur for 1999-2000

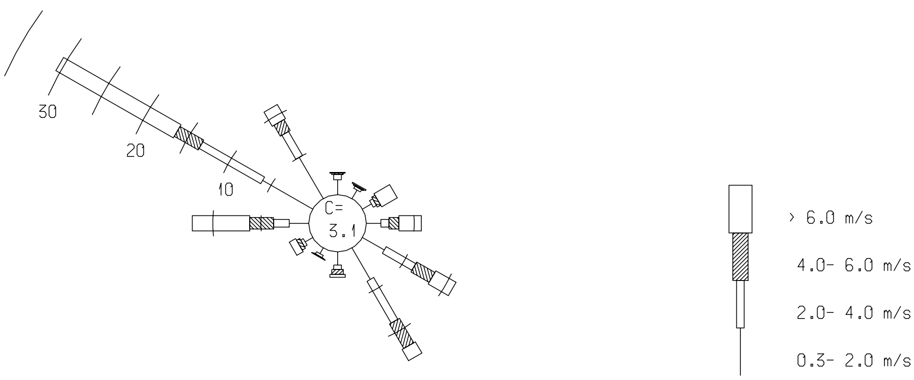


Figure A6: Wind rose form Eskifjordur for 1999-2000.

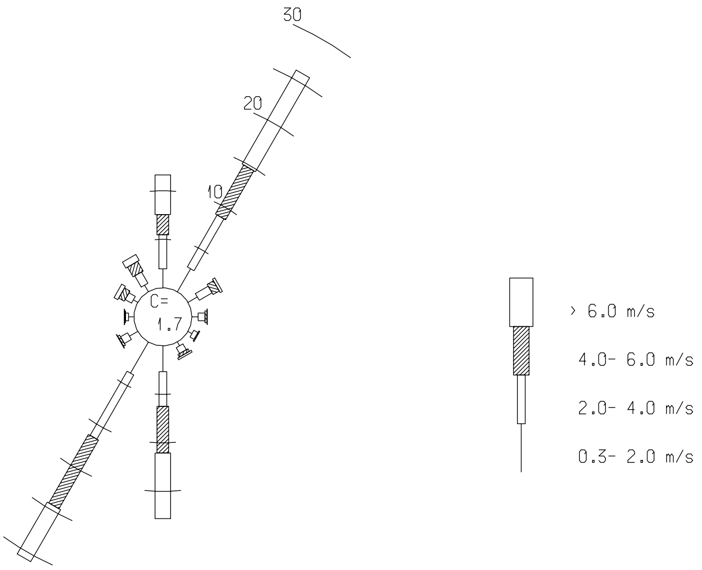


Figure A7: Wind rose from Fagridalur for 1999-2000.

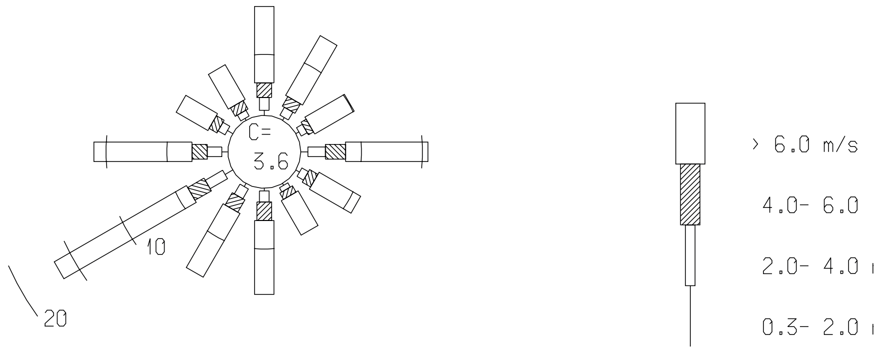


Figure A8: Wind rose from Gagnheidi for 1999-2000.

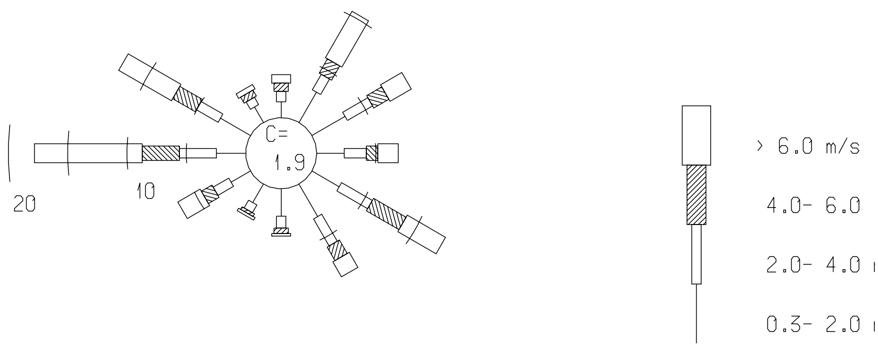


Figure A9: Wind rose from Oddskard for 1999-2000.

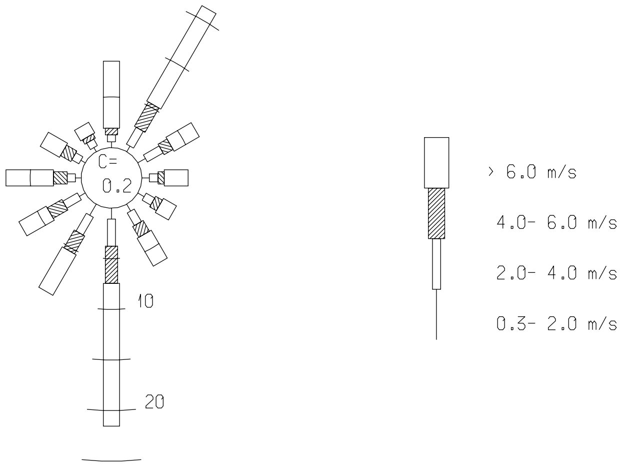


Figure A10: Wind rose from Seley for 1999-2000.

Wind roses for winter 1998-1999

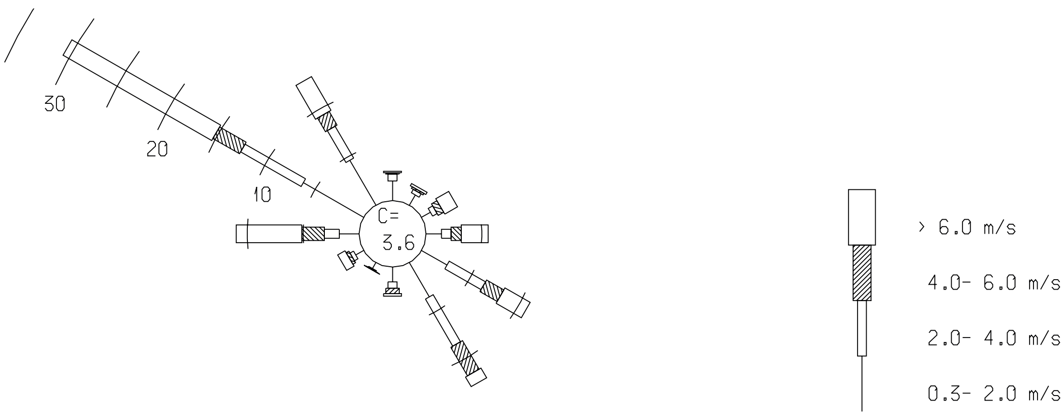


Figure A11: Wind rose from Eskifjordur for 1998-1999.

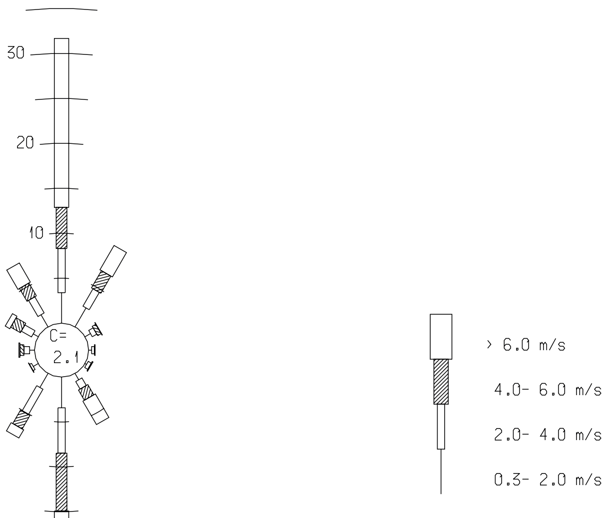


Figure A12: Wind rose from Fagridalur for winter 1998-1999.

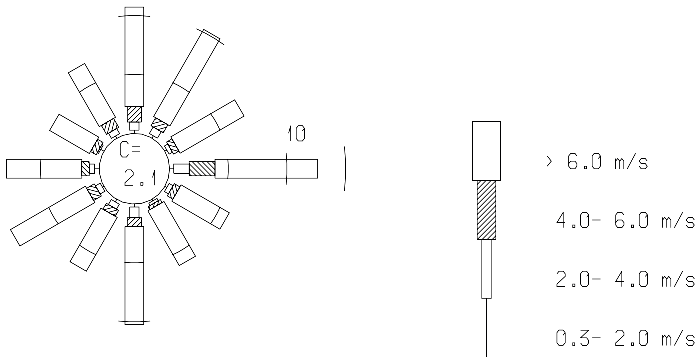


Figure A13: Wind rose from Gagnheidi for winter 1998-1999.

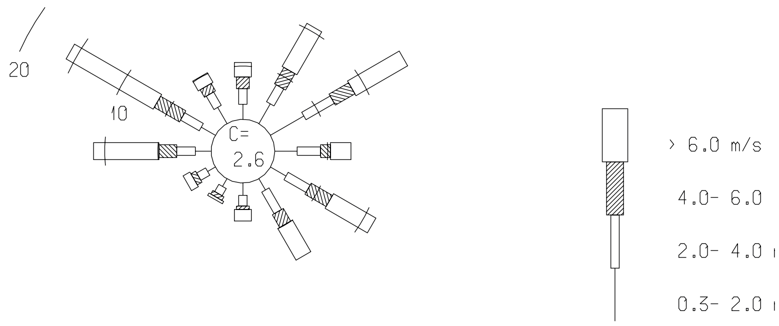


Figure A14: Wind rose from Oddskard for winter 1998-1999.

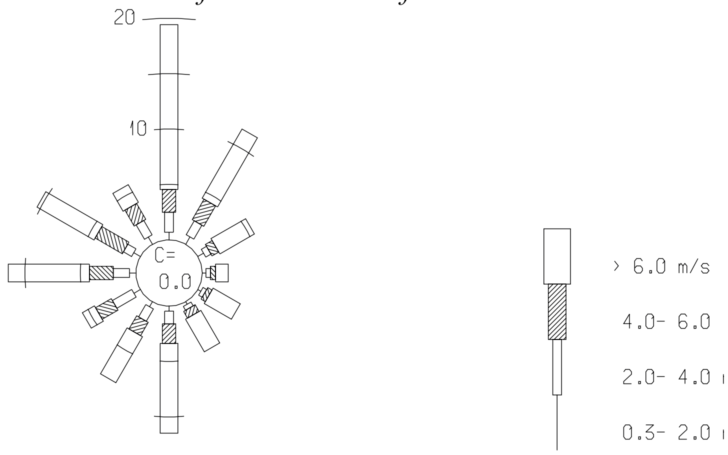


Figure A15: Wind rose from Seley for winter 1998-1999.

Wind roses from winter 1999-2000

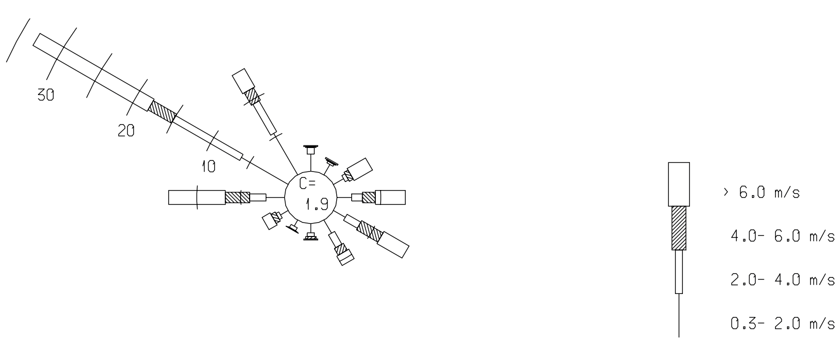


Figure A16: Wind rose from Eskifjordur for winter 1999-2000

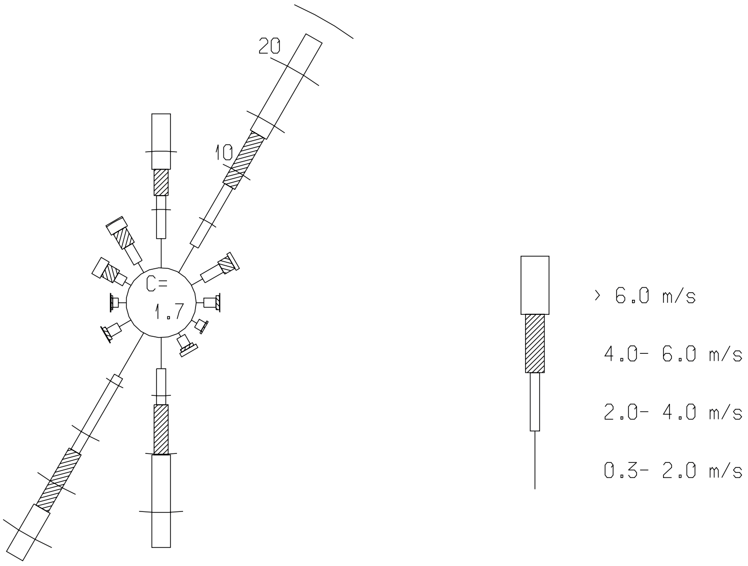


Figure A17: Wind rose from Fagridalur for winter 1999-2000.

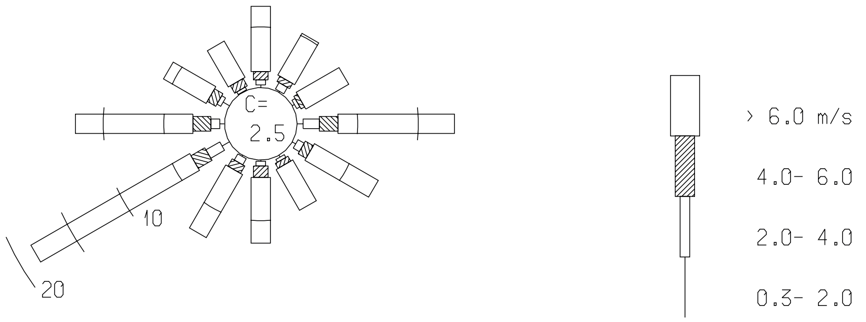


Figure A18: Wind rose from Gagnheidi for winter 1999-2000.

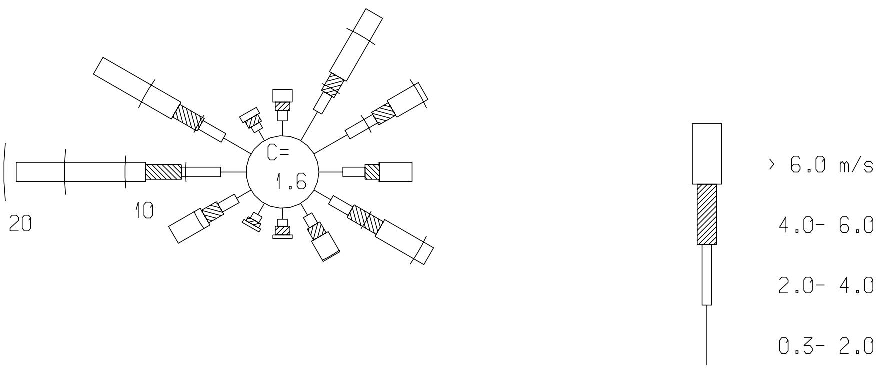


Figure A19: Wind rose from Oddskard for winter 1999-2000.

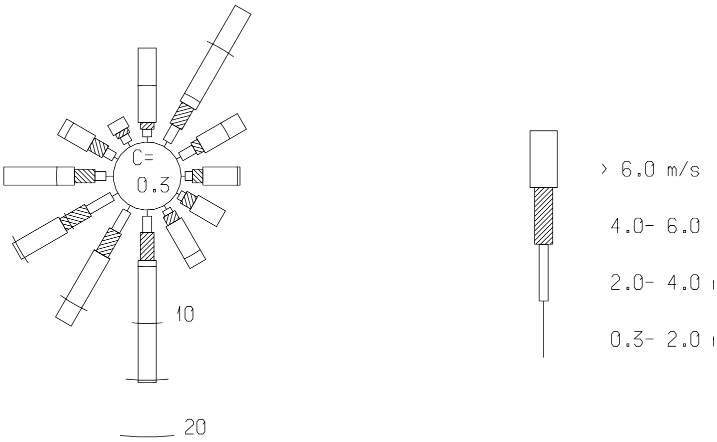


Figure A20: Wind rose from Seley for winter 1999-2000.

Wind roses for summer 1999

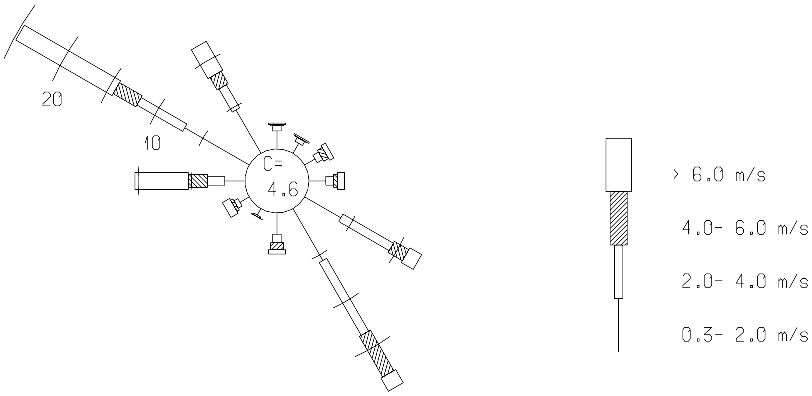


Figure A21: Wind rose from Eskijordur for summer 1999.

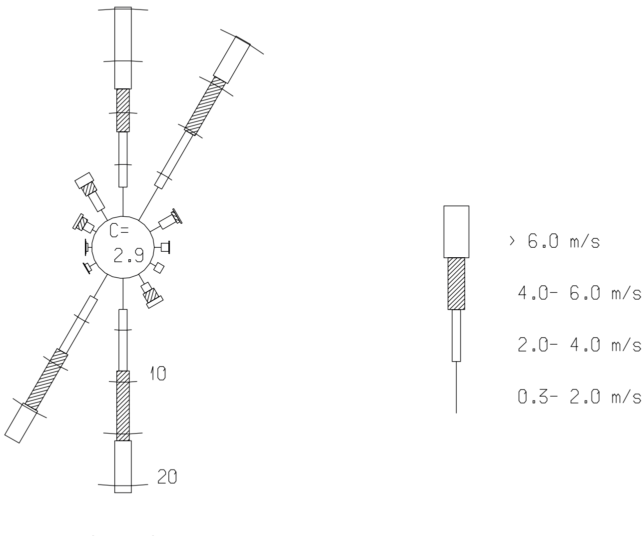


Figure A22: Wind rose from Fagridalur for summer 1999.

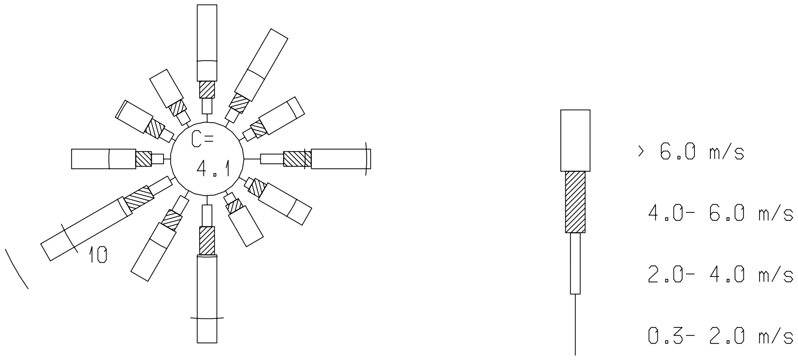


Figure A23: Wind rose from Gagnheidi for summer 1999.

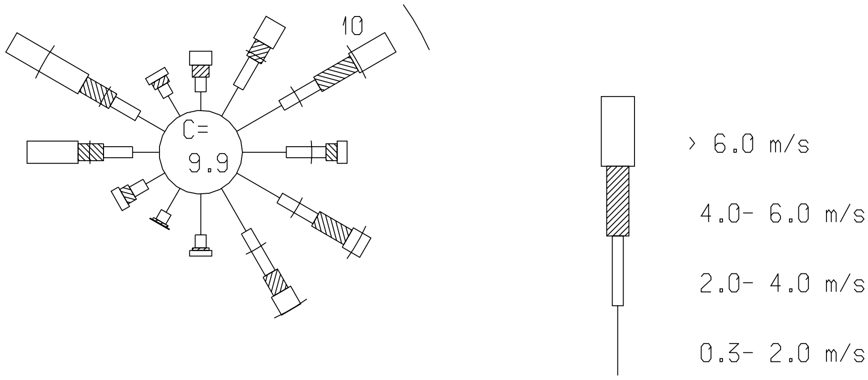


Figure A24: Wind rose from Oddskard for summer 1999.

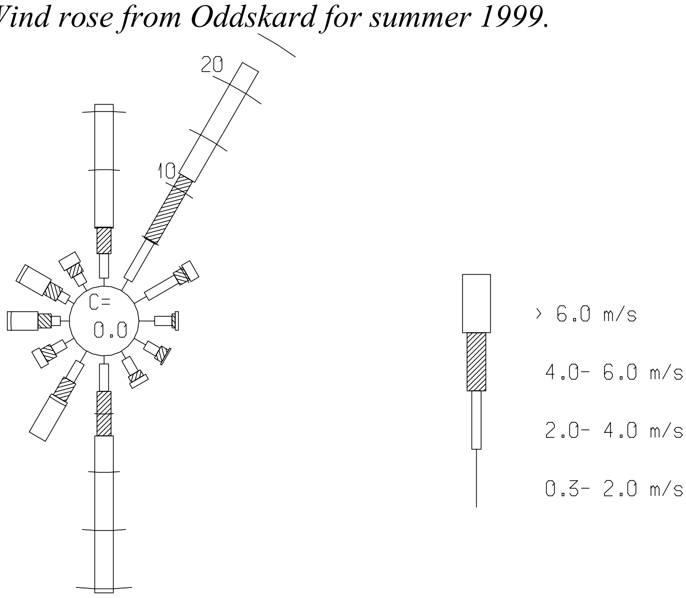


Figure A25: Wind rose from Seley for summer 1999.

Wind roses from summer 2000

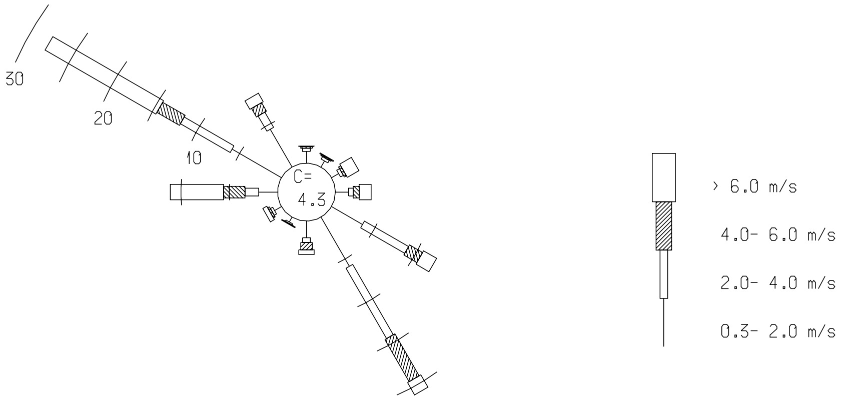


Figure A26: Wind rose from Eskifjordur for summer 2000.

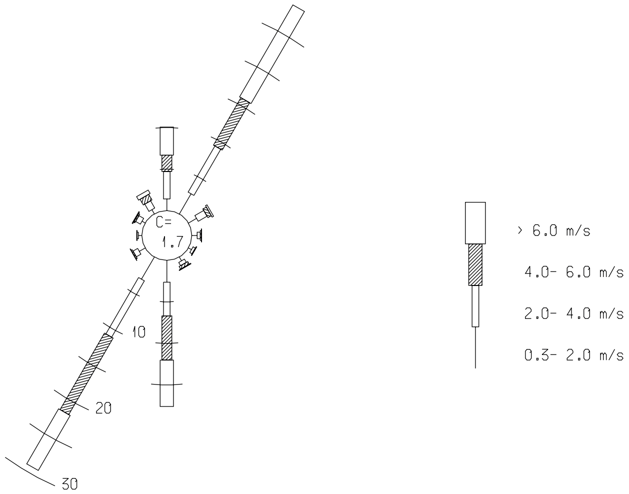


Figure A27: Wind rose from Fagridalur for summer 2000.

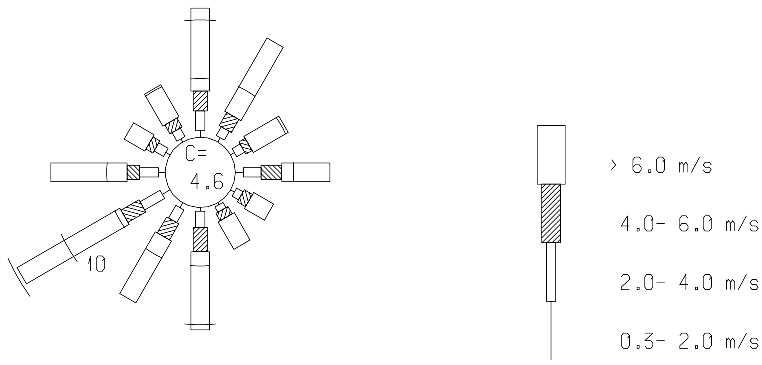


Figure A28: Wind rose from Gagnheidi for summer 2000.

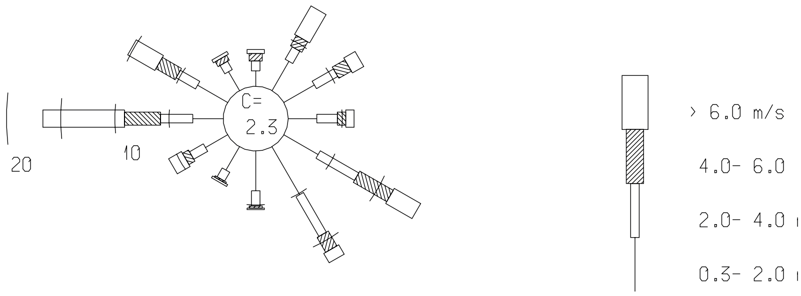


Figure A29: Wind rose from Oddskard for summer 2000.

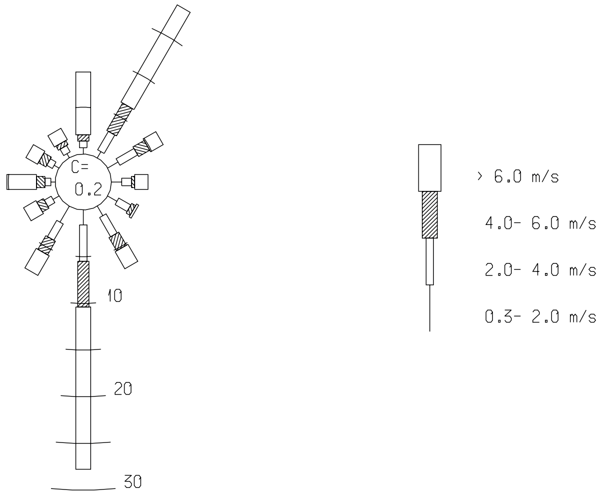


Figure A30: Wind rose from Seley for summer 2000.

Appendix B

Calculation of yearly concentration

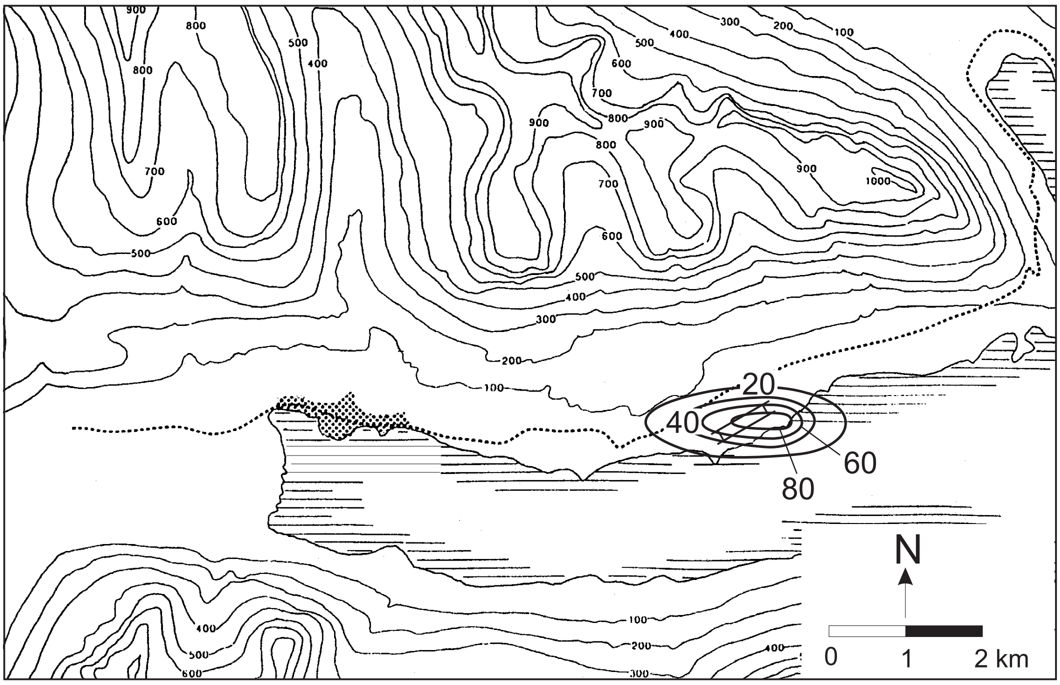


Figure B1: Yearly concentrations of SO_2 for 1998-1999 (280 000 tpy). Case 1. Unit: µg/m³. Icelandic air quality guideline of 30 µg/m³.

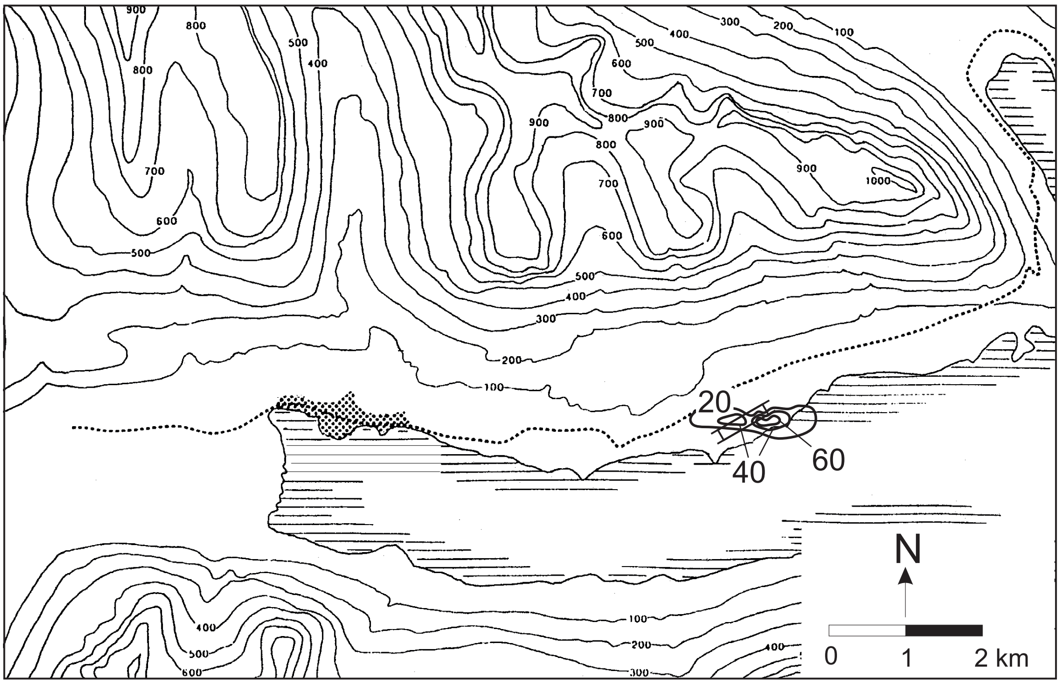


Figure B2: Yearly concentrations of SO_2 for 1998-1999 (280 000 tpy). Case 2. Unit: µg/m³. Icelandic air quality guideline of 30 µg/m³.

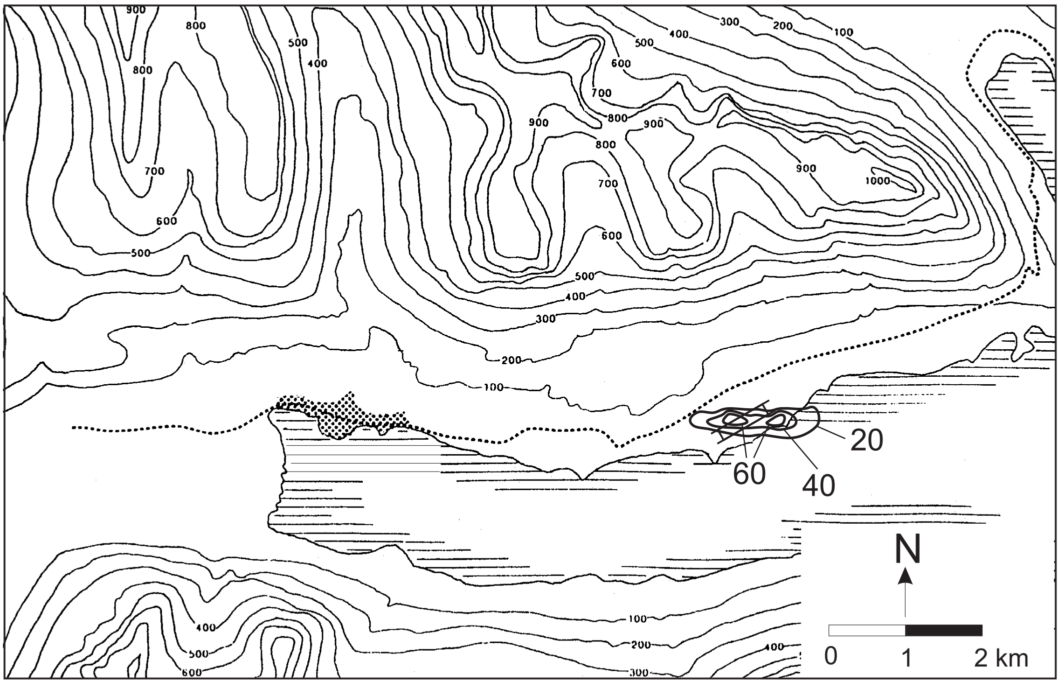


Figure B3: Yearly concentrations of SO_2 for 1998-1999 (280 000 tpy). Case 3. Unit: $\mu g/m^3$. Icelandic air quality guideline of 30 $\mu g/m^3$.

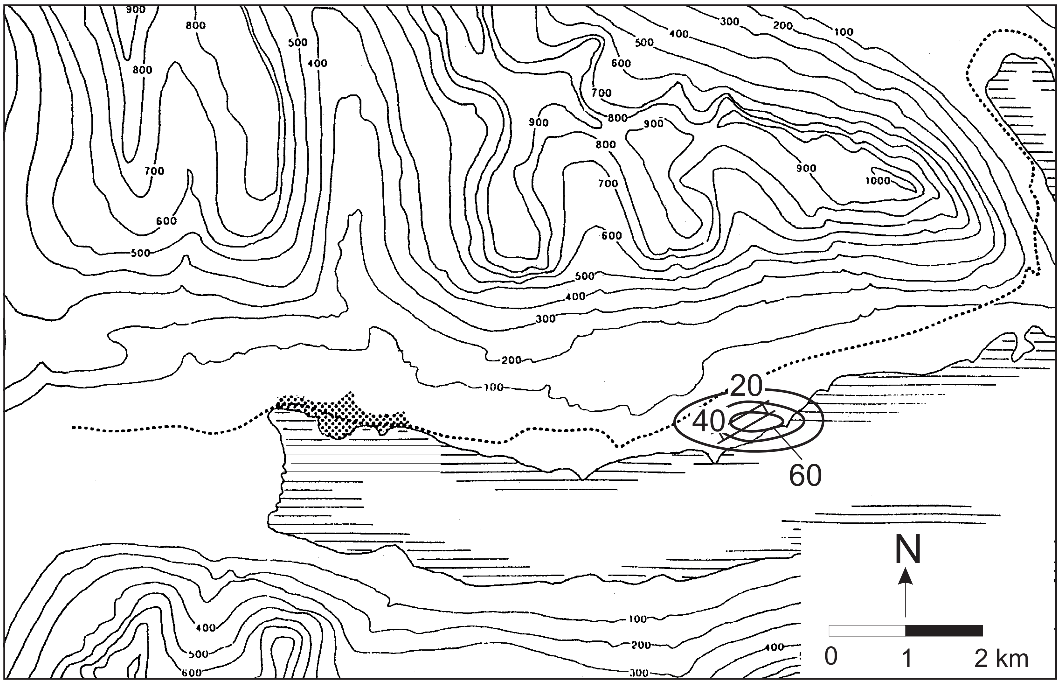


Figure B4: Yearly concentrations of SO_2 for 1998-1999 (420 000 tpy). Case 1. Unit: $\mu g/m^3$. Icelandic air quality guideline of 30 $\mu g/m^3$.

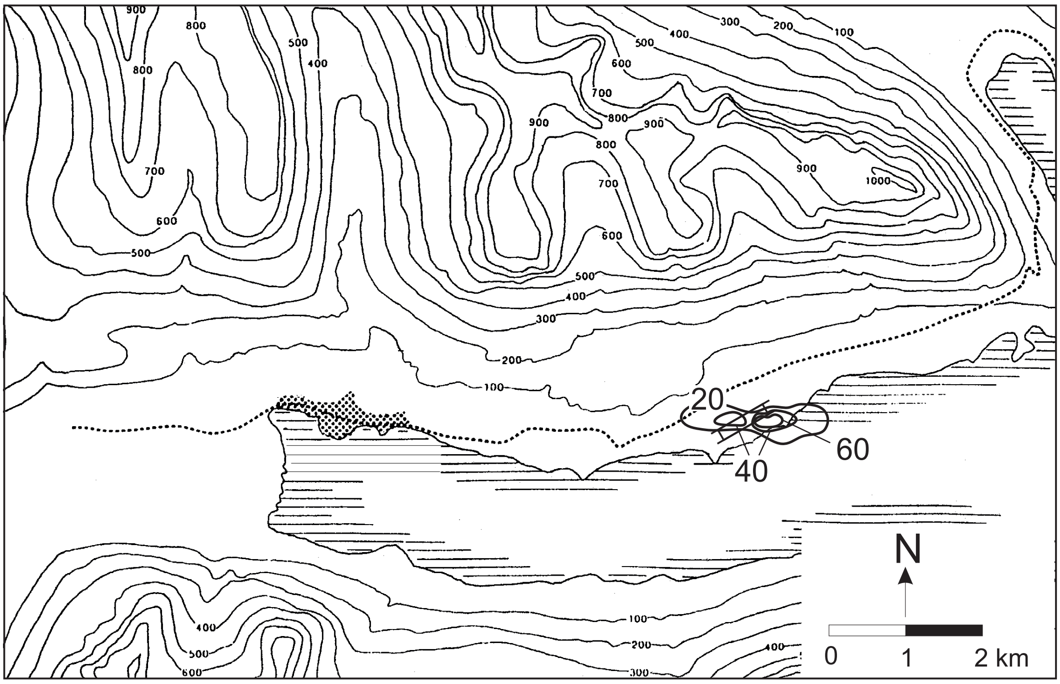


Figure B5: Yearly concentrations of SO_2 for 1998-1999 (420 000 tpy). Case 2. Unit: $\mu g/m^3$. Icelandic air quality guideline of 30 $\mu g/m^3$.

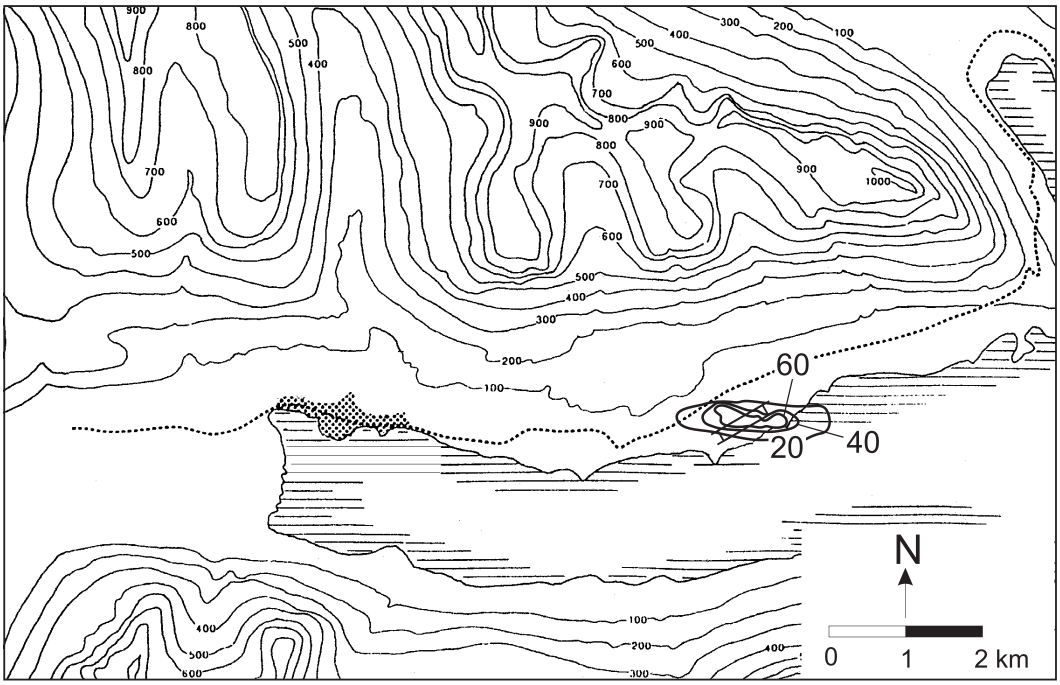


Figure B6: Yearly concentrations of SO_2 for 1998-1999 (420 000 tpy). Case 3. Unit: $\mu g/m^3$. Icelandic air quality guideline of 30 $\mu g/m^3$.

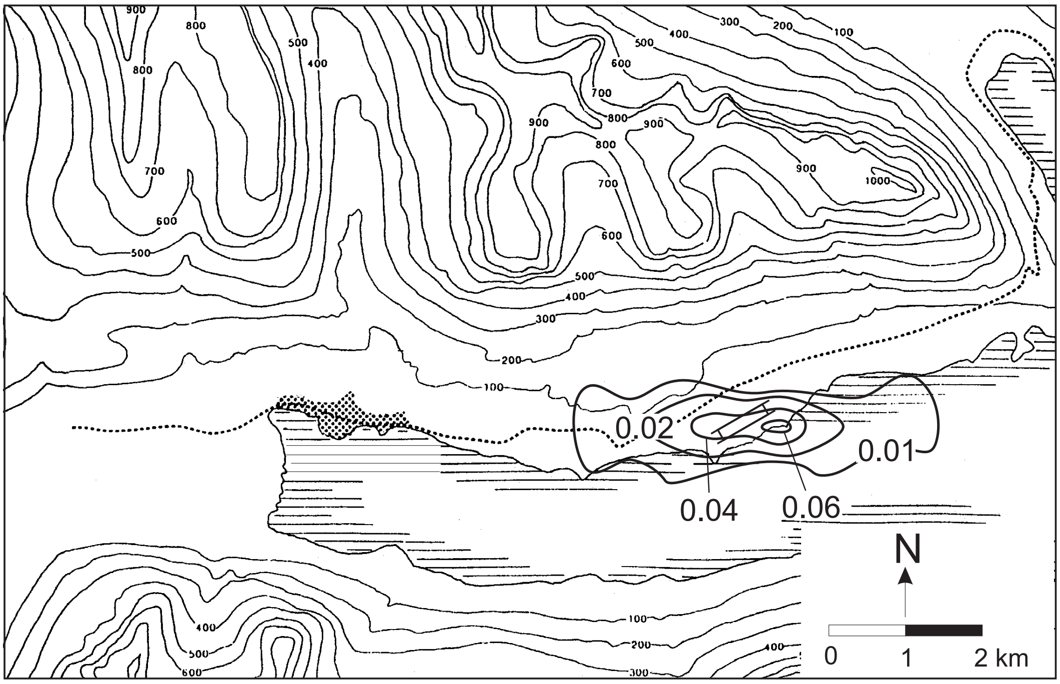


Figure B7: Calculated yearly averages for PAH, 1998-1999 (280 000 tpy). Unit: µg/m^3. Air quality guideline corresponding to PAH 0.01-0.1 µg/m^3.

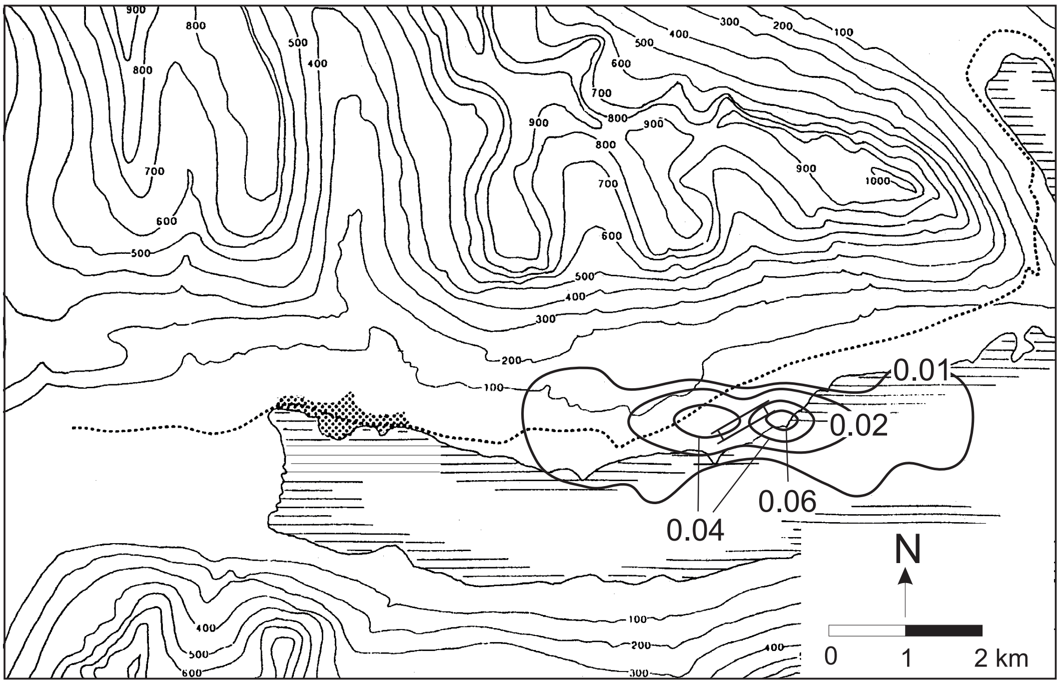


Figure B8: Calculated yearly averages for PAH, 1998-1999 (420 000 tpy). Unit: µg/m^3. Air quality guideline corresponding to PAH 0.01-0.1 µg/m^3.

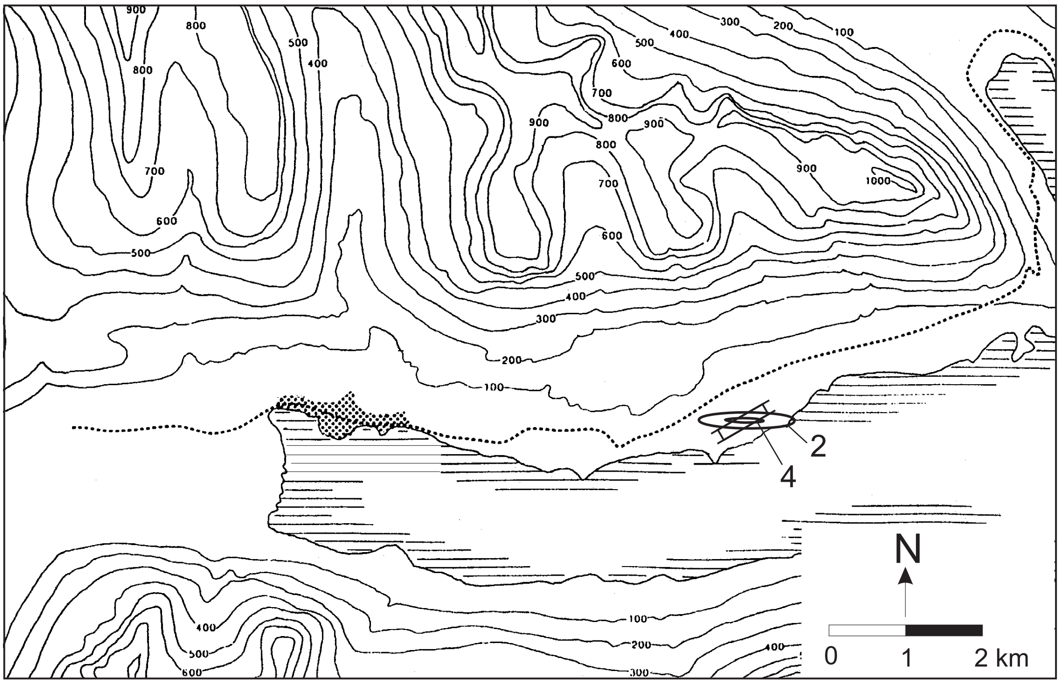


Figure B9: Calculated yearly averaged PM_{10} concentrations for 1998-1999 (280 000 tpy). Unit: µg/m^3. Icelandic air quality guideline 40 µg/m^3, EU 20 µg/m^3.

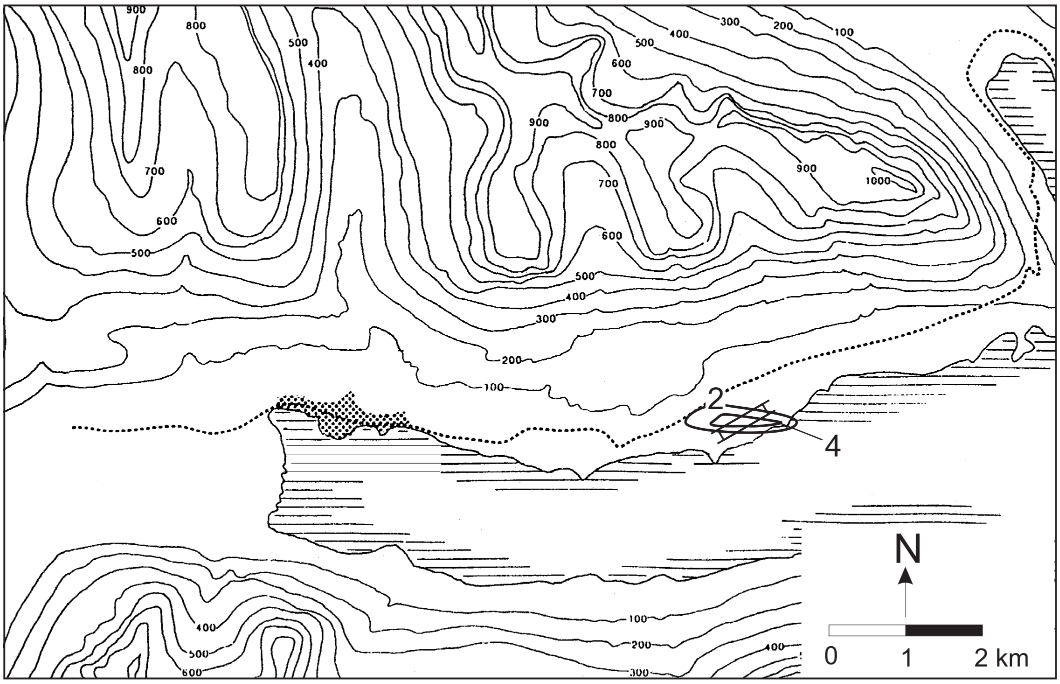


Figure B10: Calculated yearly averaged PM_{10} concentrations for 1998-1999 (420 000 tpy). Unit: µg/m^3. Icelandic air quality guideline 40 µg/m^3, EU 20 µg/m^3.

Appendix C

Calculated winter and growing season concentrations for 1998-1999

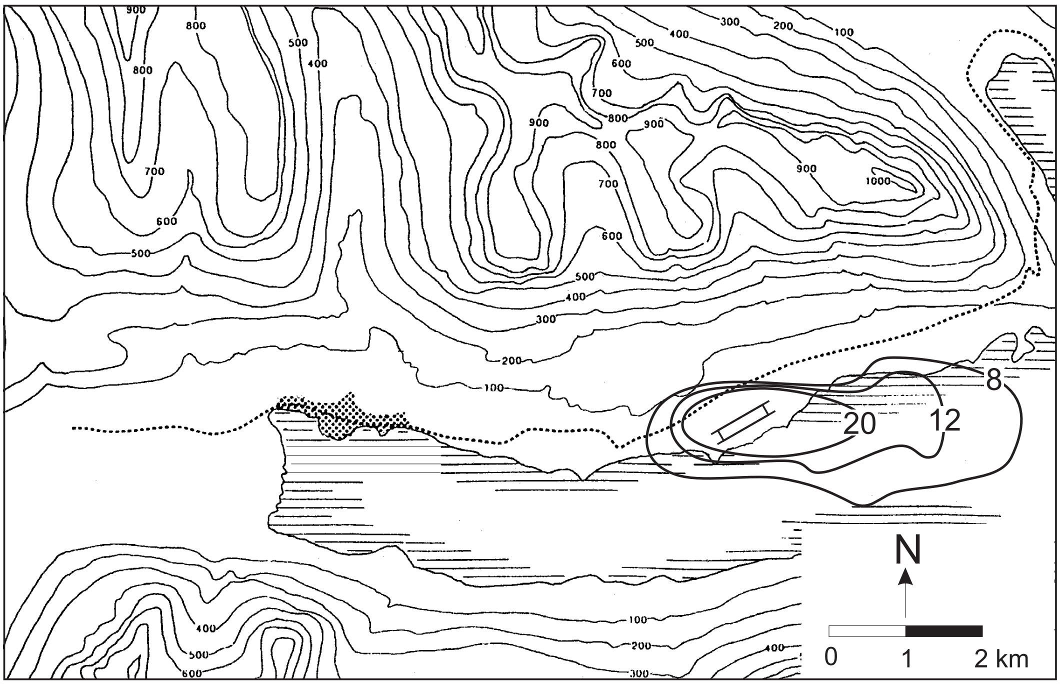


Figure C1: Winter concentrations of SO_2 for 1998-1999. (280 000 tpy). Case 1. Unit: µg/m³. Norwegian air quality guideline 40-60 µg/m³. Norwegian A.Q.G. for vegetation 25 µg/m³ . EU 20 µg/m³.

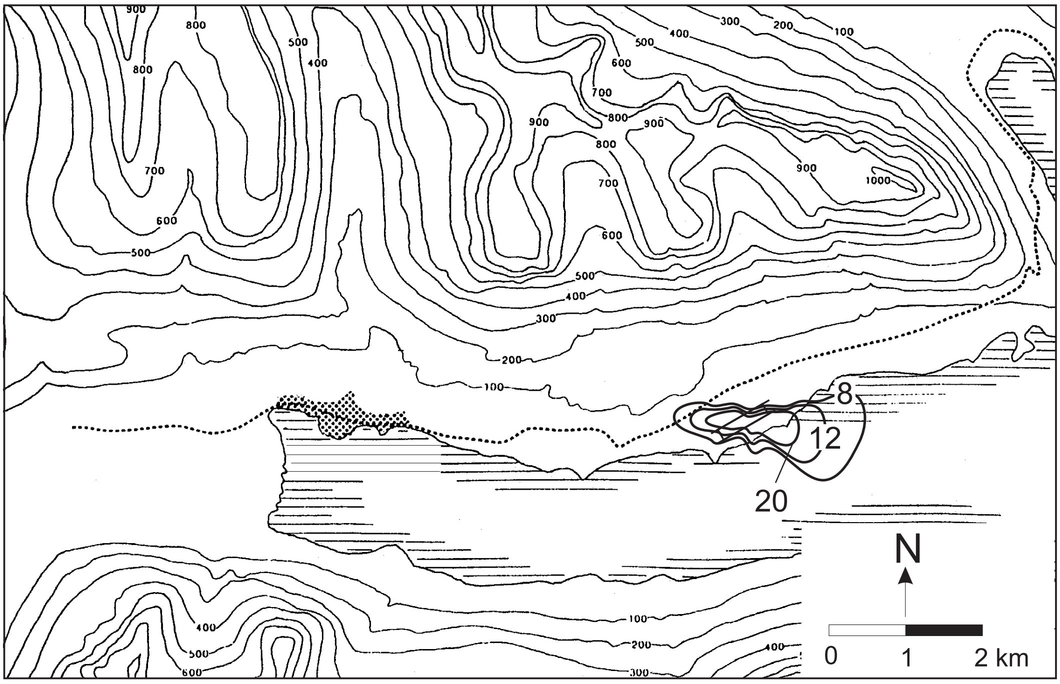


Figure C2: Winter concentrations of SO_2 for 1998-1999. (280 000 tpy). Case 2. Unit: µg/m³. Norwegian air quality guideline 40-60 µg/m³. Norwegian A.Q.G. for vegetation 25 µg/m³. EU 20 µg/m³.

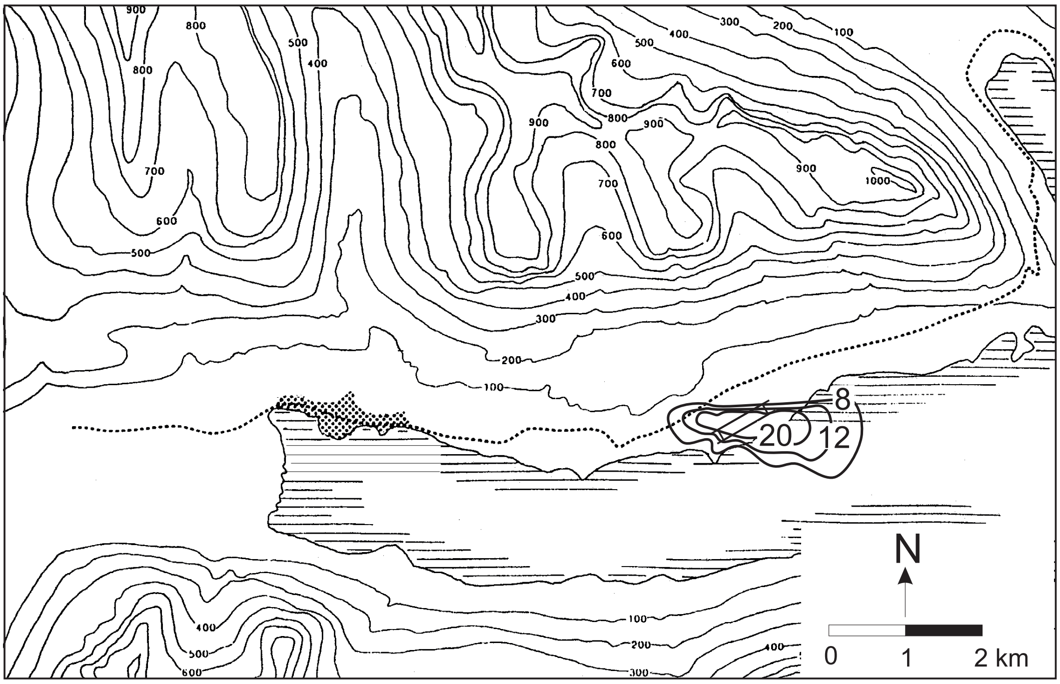


Figure C3: Winter concentrations of SO_2 for 1998-1999. (280 000 tpy). Case 3. Unit: µg/m³. Norwegian air quality guideline 40-60 µg/m³. Norwegian A.Q.G. for vegetation 25 µg/m³ . EU 20 µg/m³.

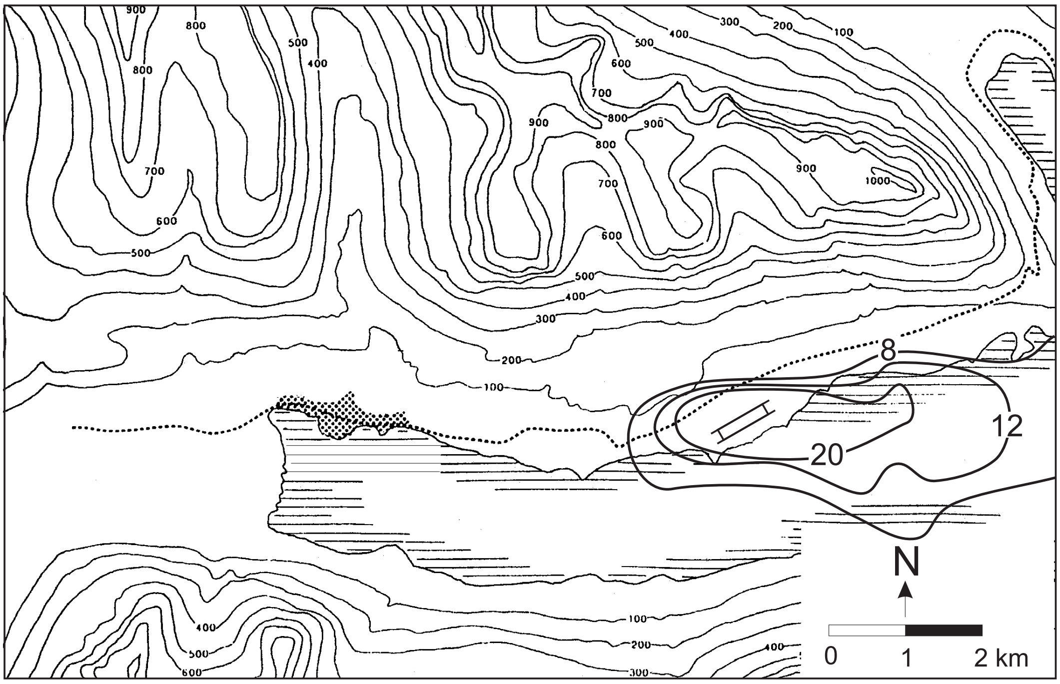


Figure C4: Winter concentrations of SO_2 for 1998-1999. (420 000tpy). Case 1. Unit: µg/m³. Norwegian air quality guideline 40-60 µg/m³. Norwegian A.Q.G. for vegetation 25 µg/m³. EU 20 µg/m³.

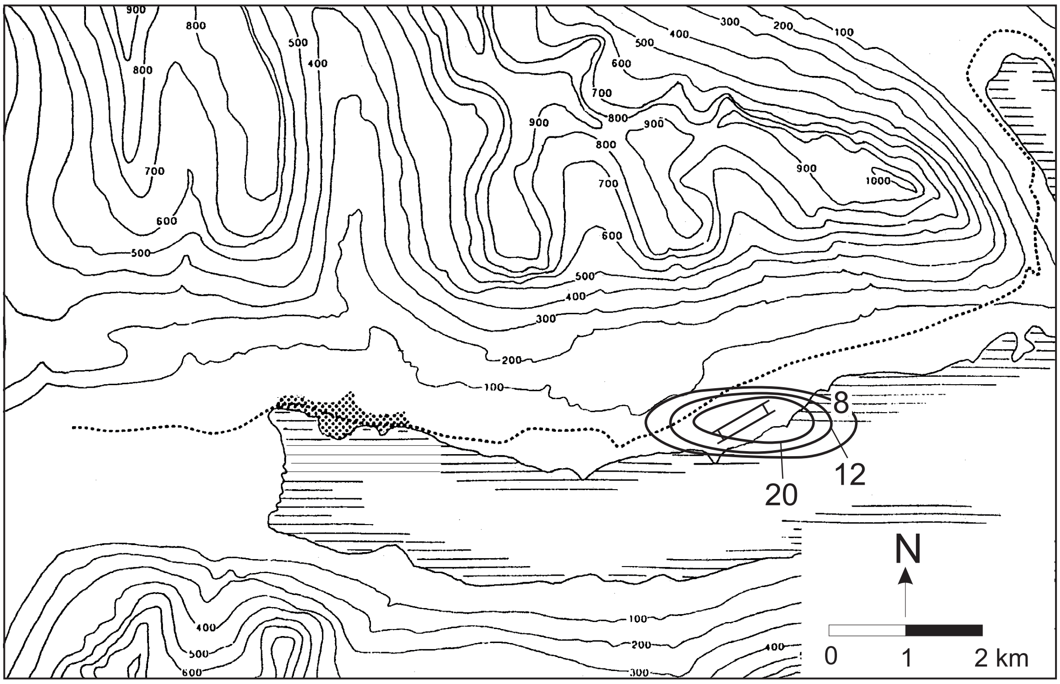


Figure C5: Winter concentrations of SO_2 for 1998-1999. (420 000 tpy). Case 2. Unit: µg/m^3. Norwegian air quality guideline 40-60 µg/m^3. Norwegian A.Q.G. for vegetation 25 µg/m^3 . EU 20 µg/m^3.

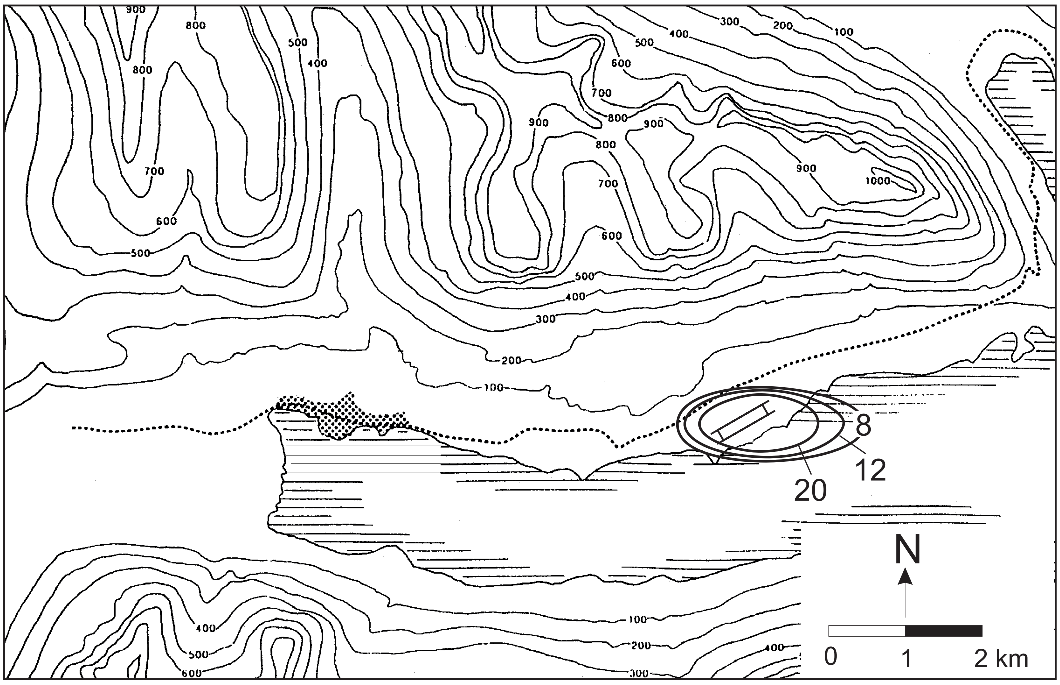


Figure C6: Winter concentrations of SO_2 for 1998-1999. (420 000 tpy). Case 3. Unit: µg/m^3. Norwegian air quality guideline 40-60 µg/m^3. Norwegian A.Q.G. for vegetation 25 µg/m^3 . EU 20 µg/m^3.

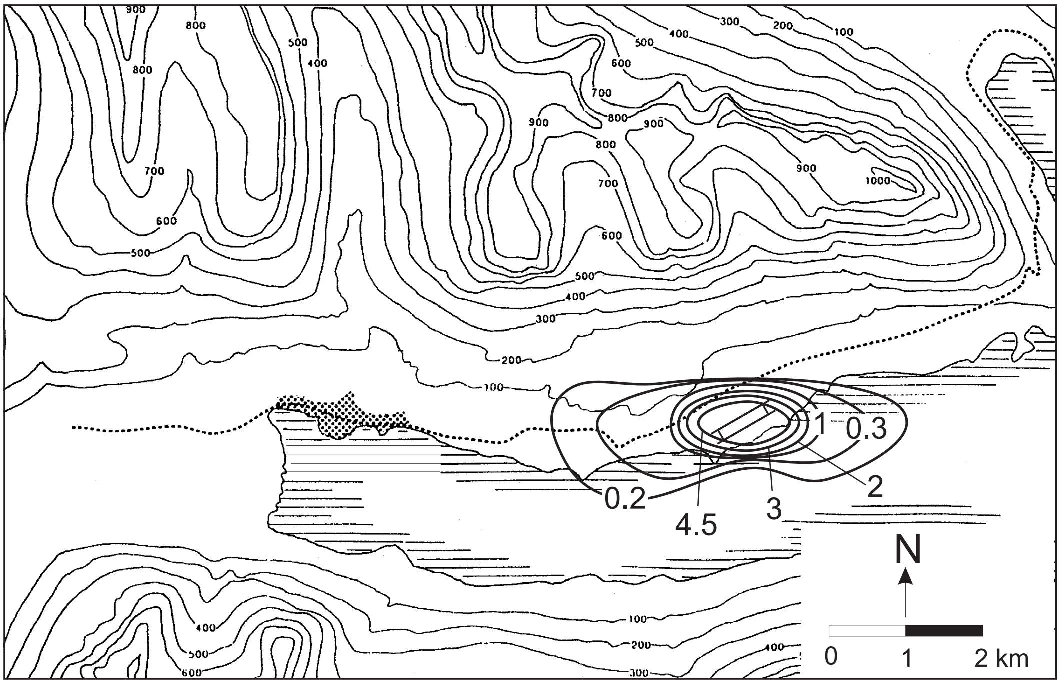


Figure C7:Average concentration for the growing season of gaseous fluorides for 1998-1999 (280 000 tpy). Unit: µg/m³. Norwegian air quality guideline 0.3 µg/m³.

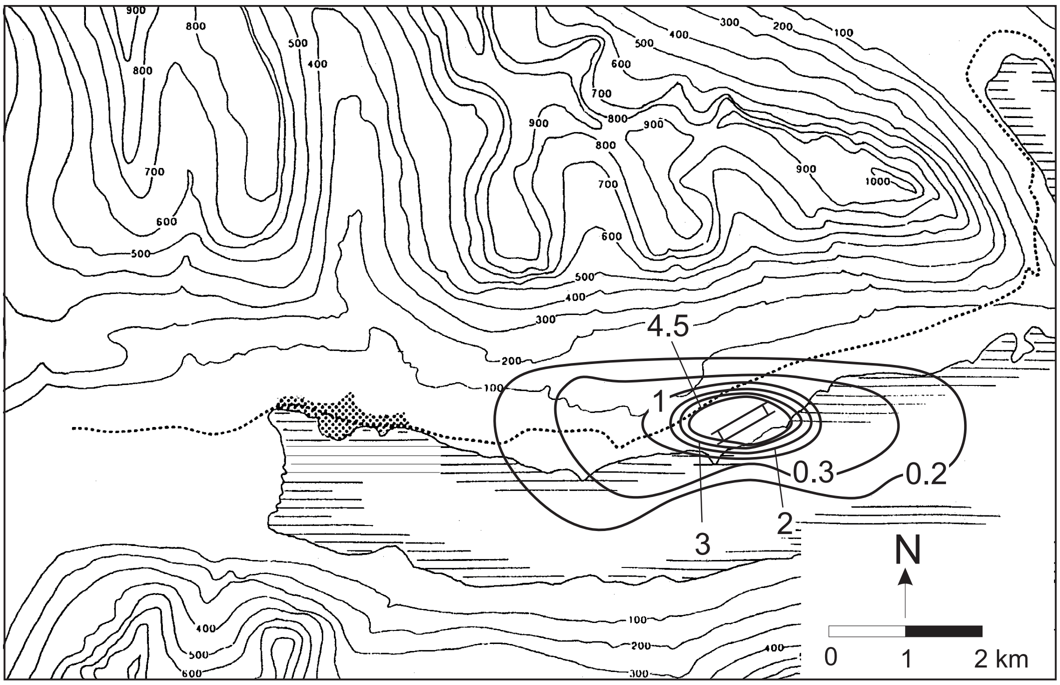


Figure C8:Average concentration for the growing season of gaseous fluorides for 1998-1999 (420 000 tpy). Unit: µg/m³. Norwegian air quality guideline 0.3 µg/m³.

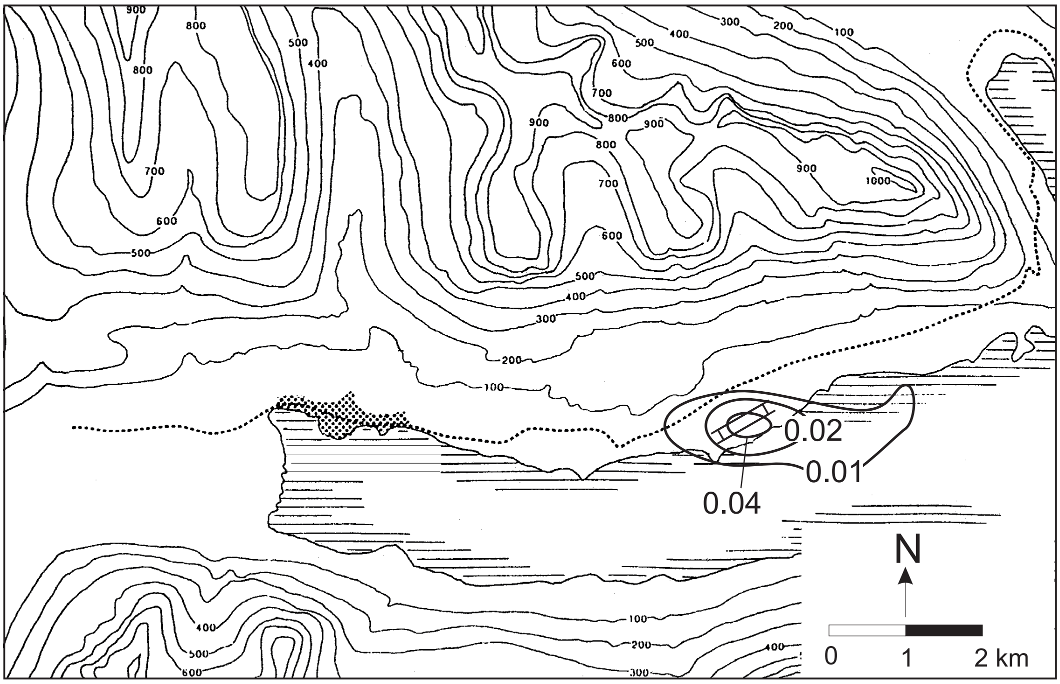


*Figure C9: Calculated winter averages for PAH, 1998-1999 (280 000 tpy).
Unit: µg/m^3.*

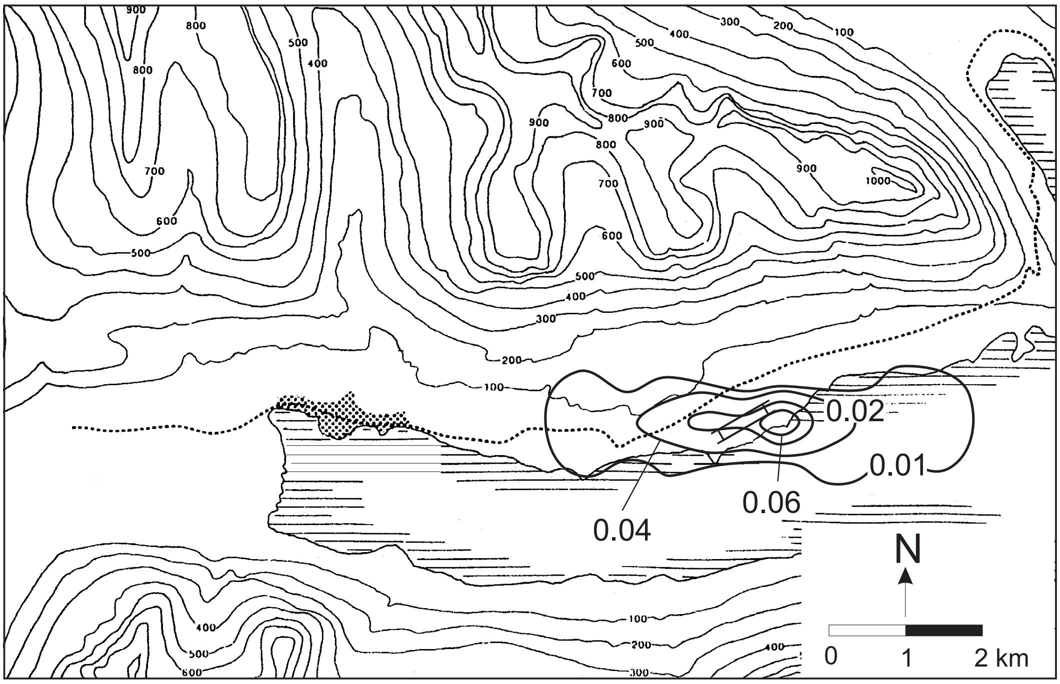


*Figure C10: Calculated winter averages for PAH, 1998-1999 (420 000 tpy).
Unit: µg/m^3.*

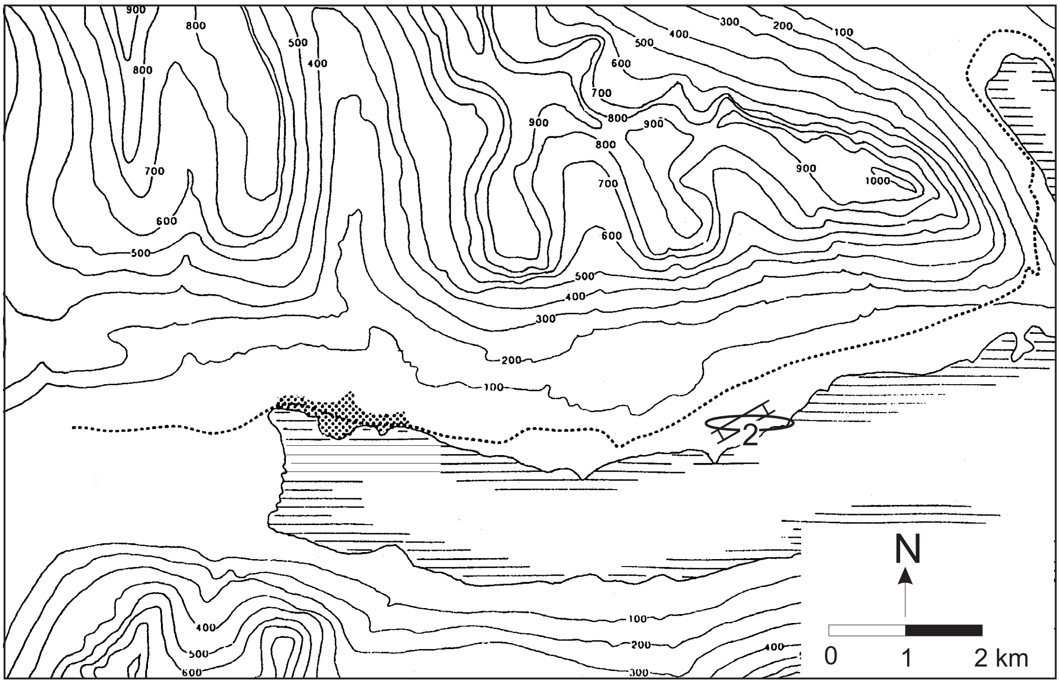


Figure C11: Calculated winter averaged PM_{10} concentrations for 1998-1999 (280 000 tpy). Unit: µg/m³.

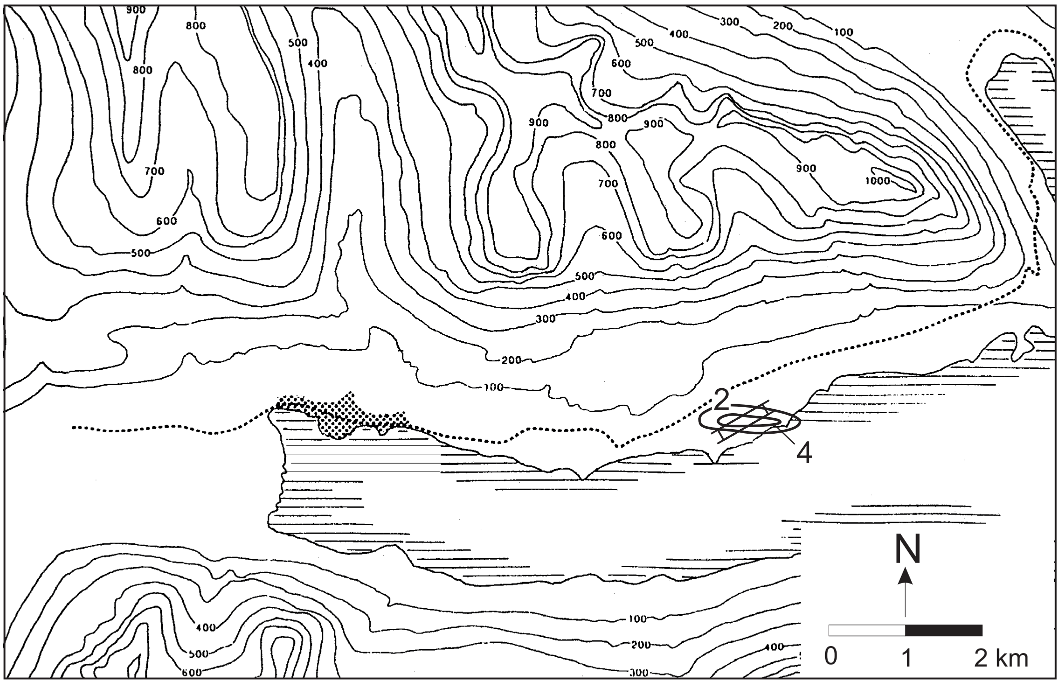


Figure C12: Calculated winter averaged PM_{10} concentrations for 1998-1999 (420 000 tpy). Unit: µg/m³.

Appendix D

Calculated percentiles for diurnal concentrations for 1998-1999

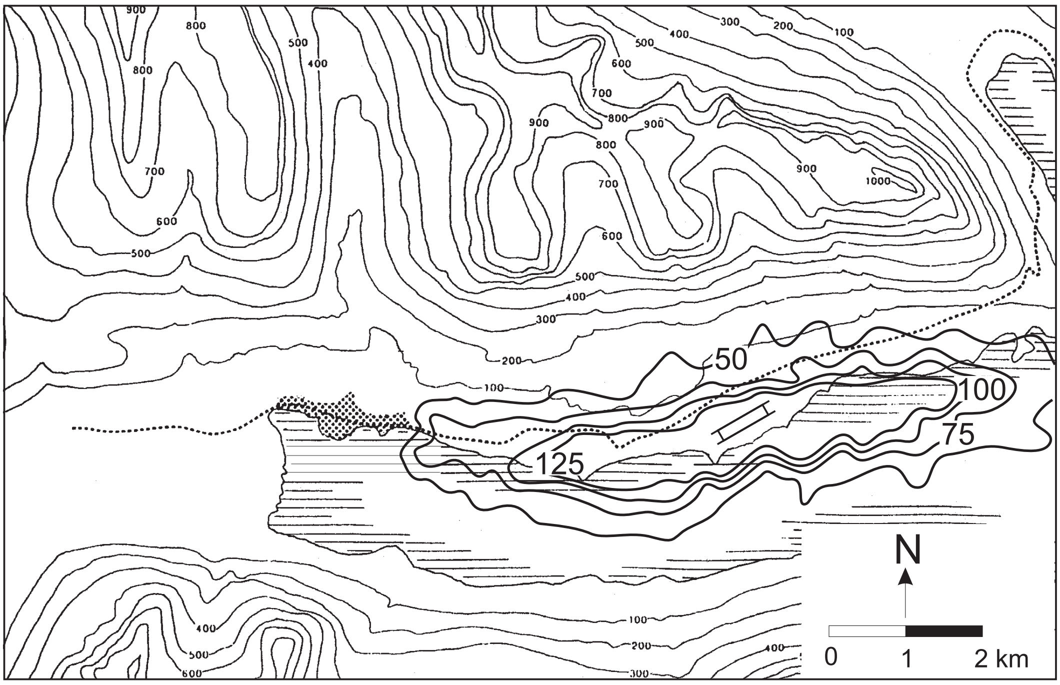


Figure D1: 98 percentile (280 000 tpy) for SO_2 for the year 1998-1999, based on 24 hour averages. Case 1. Unit: µg/m^3. The air quality guideline is 50 µg/m^3.

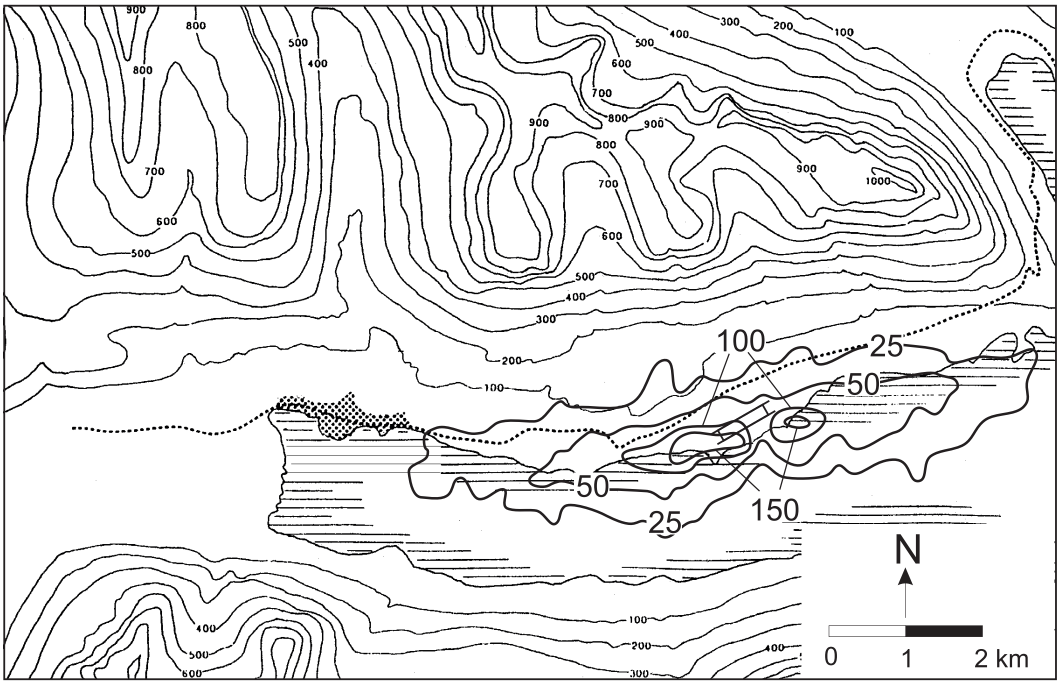


Figure D2: 98 percentile (280 000 tpy) for SO_2 for the year 1998-1999, based on 24 hour averages. Case 2. Unit: µg/m^3. The air quality guideline is 50 µg/m^3.

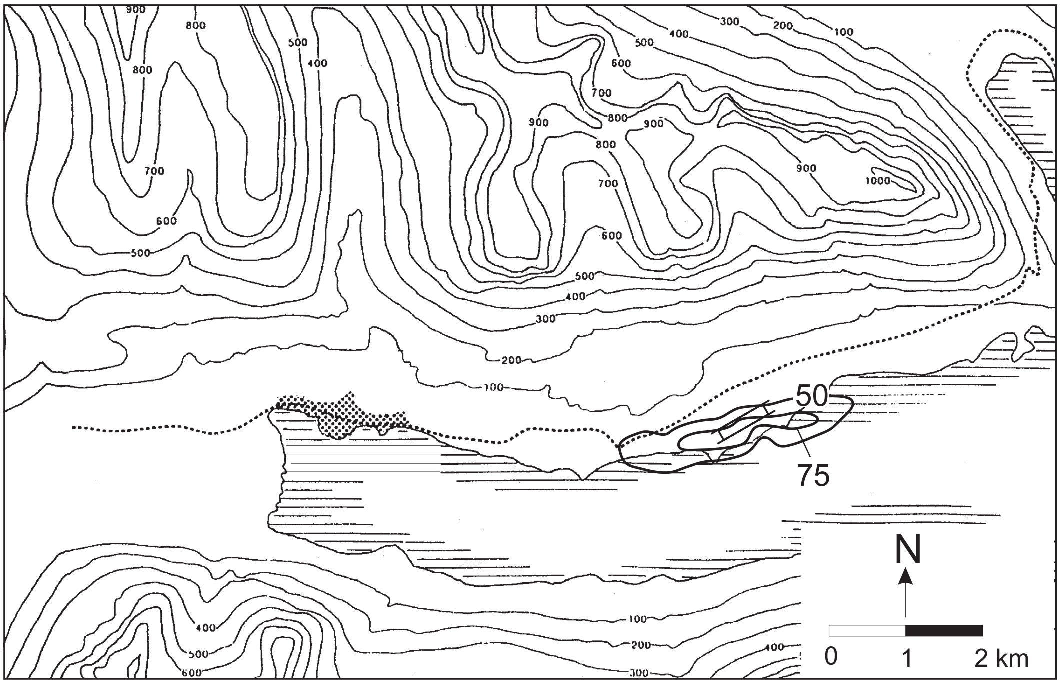


Figure D3: 98 percentile (280 000 tpy) for SO_2 for the year 1998-1999, based on 24 hour averages. Case 3. Unit: µg/m^3. The air quality guideline is 50 µg/m^3.

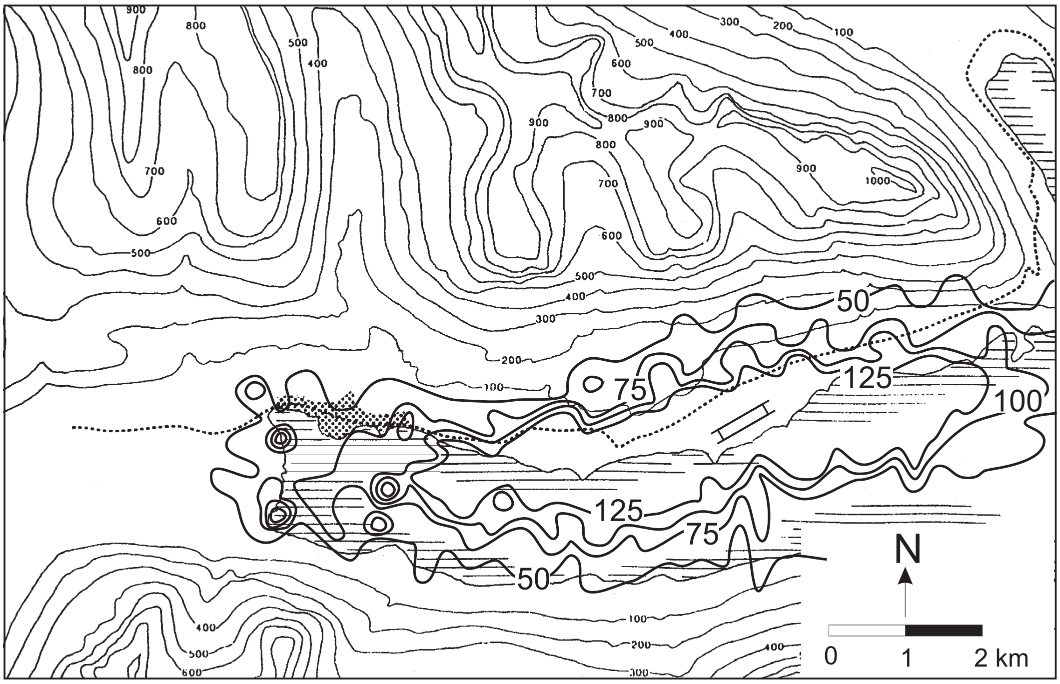


Figure D4: 99.2 percentile (280 000 tpy) for SO_2 for the year 1998-1999, based on 24 hour averages. Case 1. Unit: µg/m^3. The air quality guideline is 125 µg/m^3.

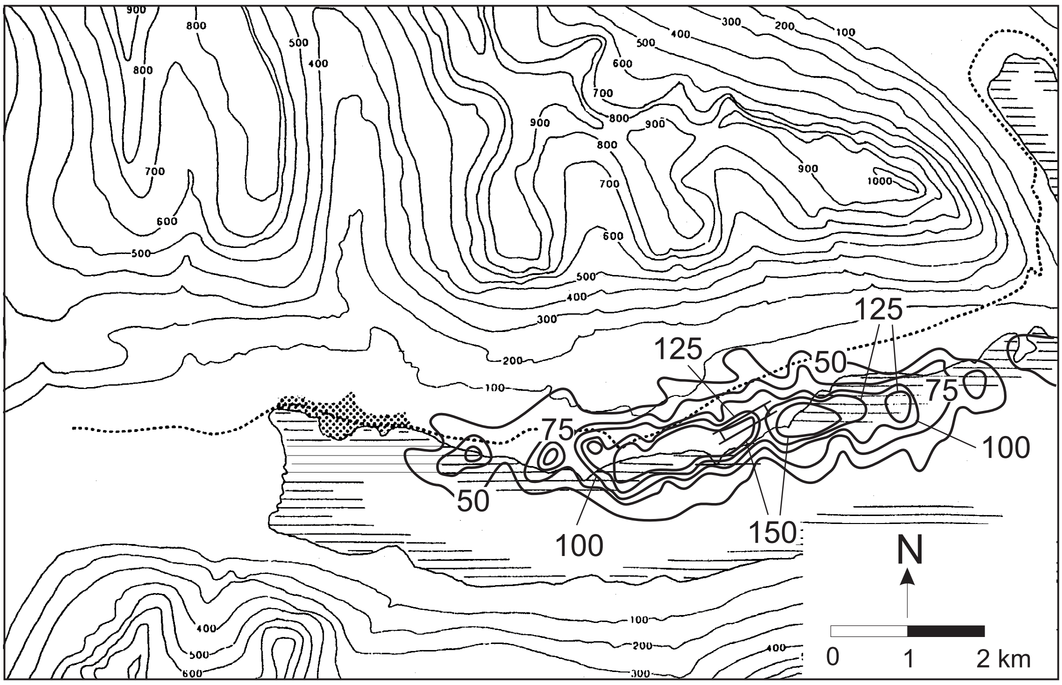


Figure D5: 99.2 percentile (280 000 tpy) for SO_2 for the year 1998-1999, based on 24 hour averages. Case 2. Unit: $\mu g/m^3$. The air quality guideline is 125 $\mu g/m^3$.

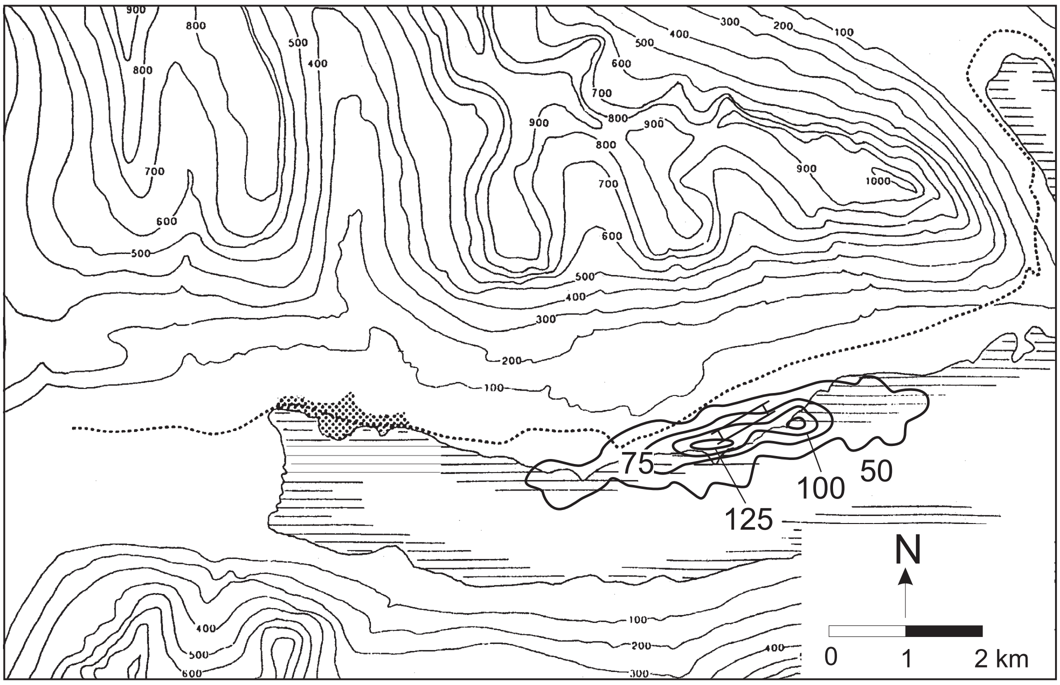


Figure D6: 99.2 percentile (280 000 tpy) for SO_2 for the year 1998-1999, based on 24 hour averages. Case 3. Unit: $\mu g/m^3$. The air quality guideline is 125 $\mu g/m^3$.

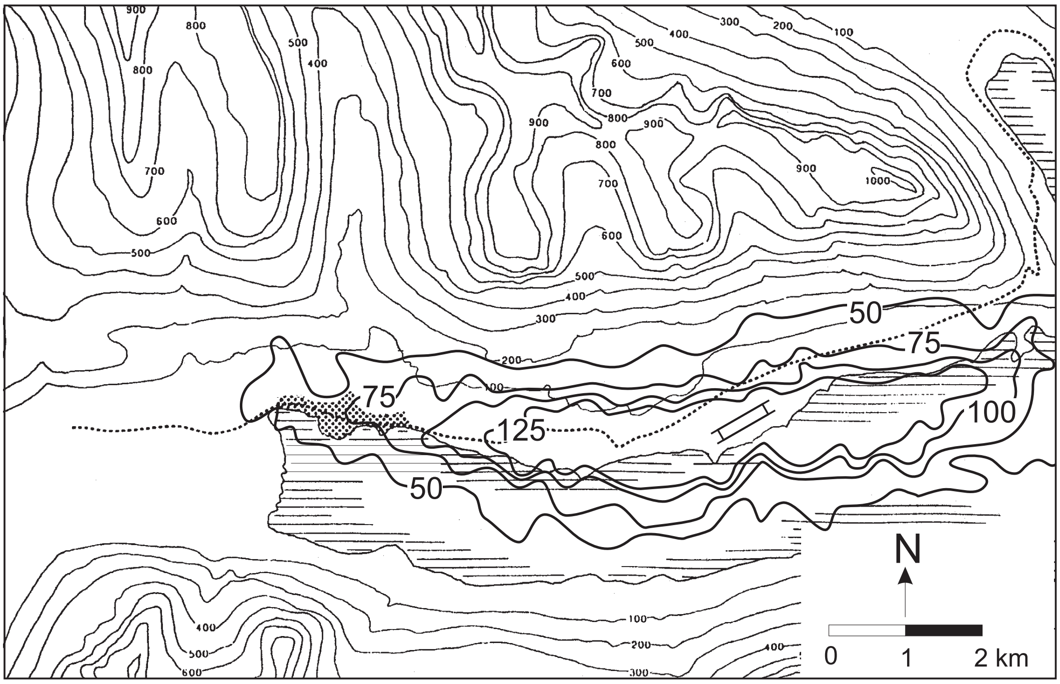


Figure D7: 98 percentile (420 000 tpy) for SO_2 for the year 1998-1999, based on 24 hour averages. Case 1. Unit: µg/m^3. The air quality guideline is 50 µg/m^3.

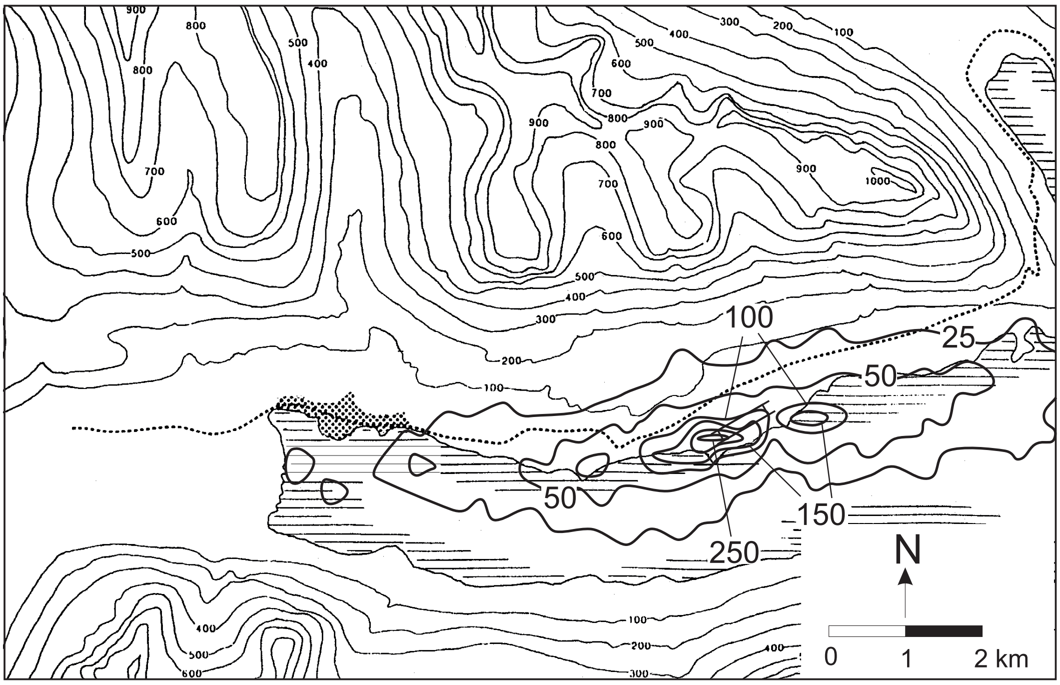


Figure D8: 98 percentile (420 000 tpy) for SO_2 for the year 1998-1999, based on 24 hour averages. Case 2. Unit: µg/m^3. The air quality guideline is 50 µg/m^3.

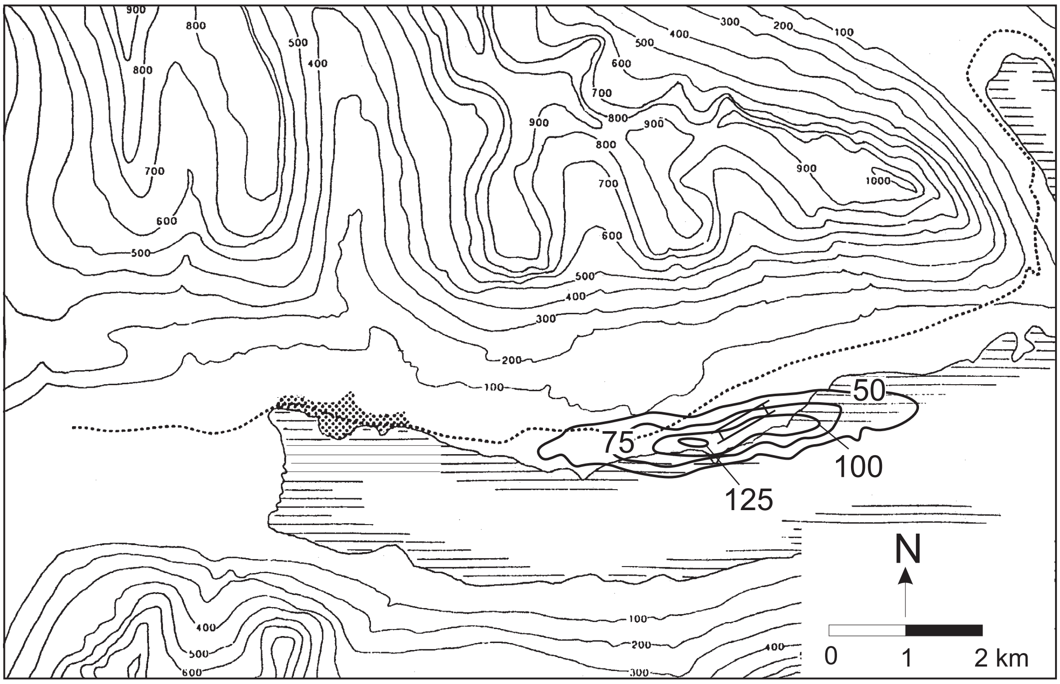


Figure D9: 98 percentile (420 000 tpy) for SO_2 for the year 1998-1999, based on 24 hour averages. Case 3. Unit: µg/m^3. The air quality guideline is 50 µg/m^3.

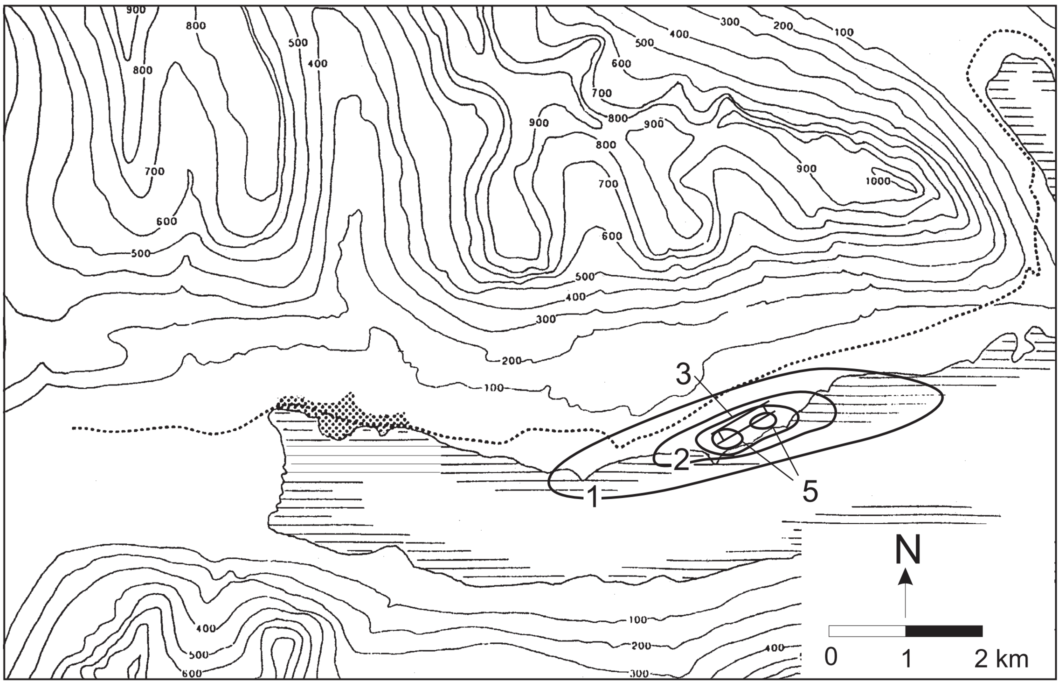


Figure D10: 98 percentile (280 000 tpy) of PM_{10} for the year 1998-1999, based on 24 hour averages. Unit: µg/m^3. The air quality guideline is 50 µg/m^3, after 2010.

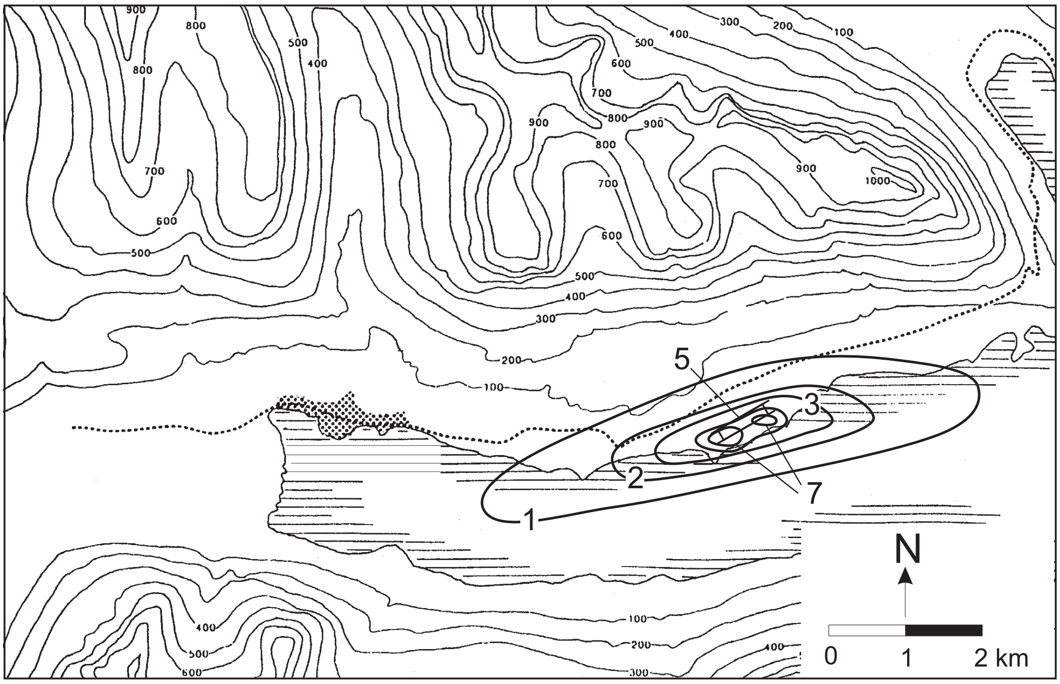


Figure D11: 98 percentile (420 000 tpy) of PM_{10} for the year 1998-1999, based on 24 hour averages. Unit: µg/m^3. The air quality guideline is 50 µg/m³, after 2010.

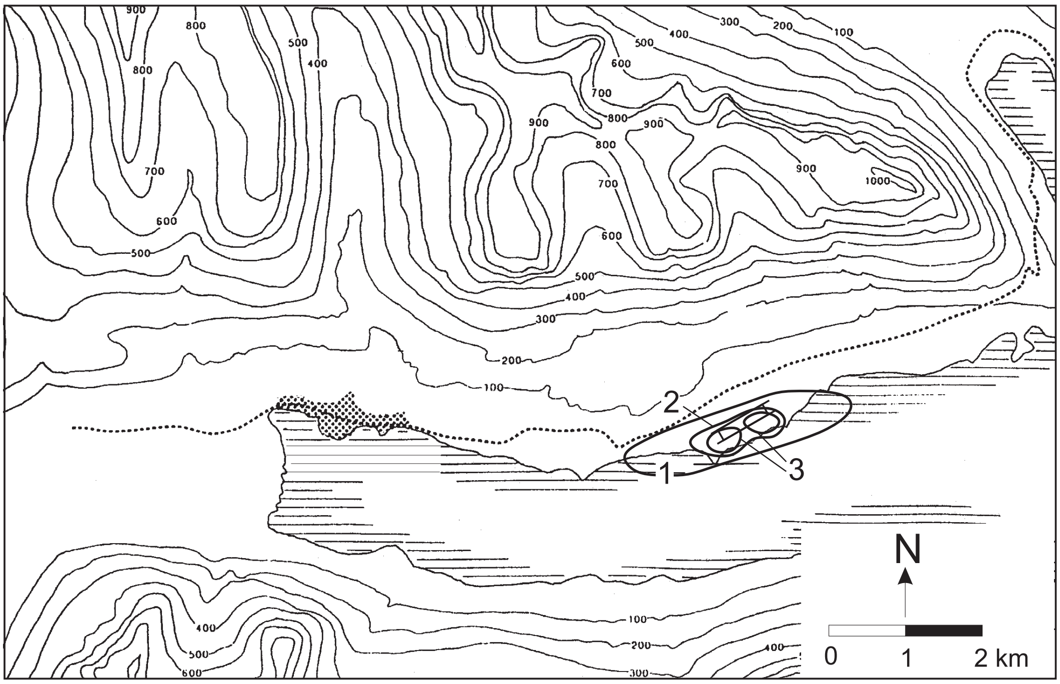


Figure D12 90.4 percentile (280 000 tpy) of PM_{10} for the year 1998-1999, based on 24 hour averages. Unit:µg/m^3. The air quality guideline is 50 µg/m³ between 2005 and 2010.

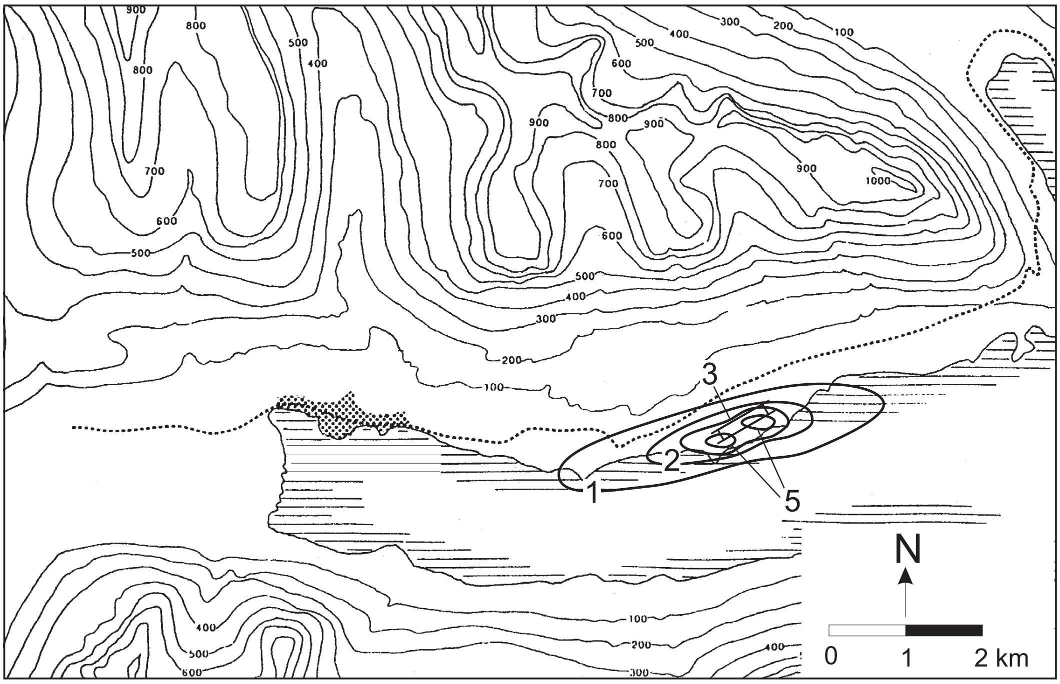


Figure D13: 90.4 percentile (420 000 tpy) of PM_{10} for the year 1998-1999, based on 24 hour averages. Unit:µg/m^3. The air quality guideline is 50 µg/m^3 between 2005 and 2010.

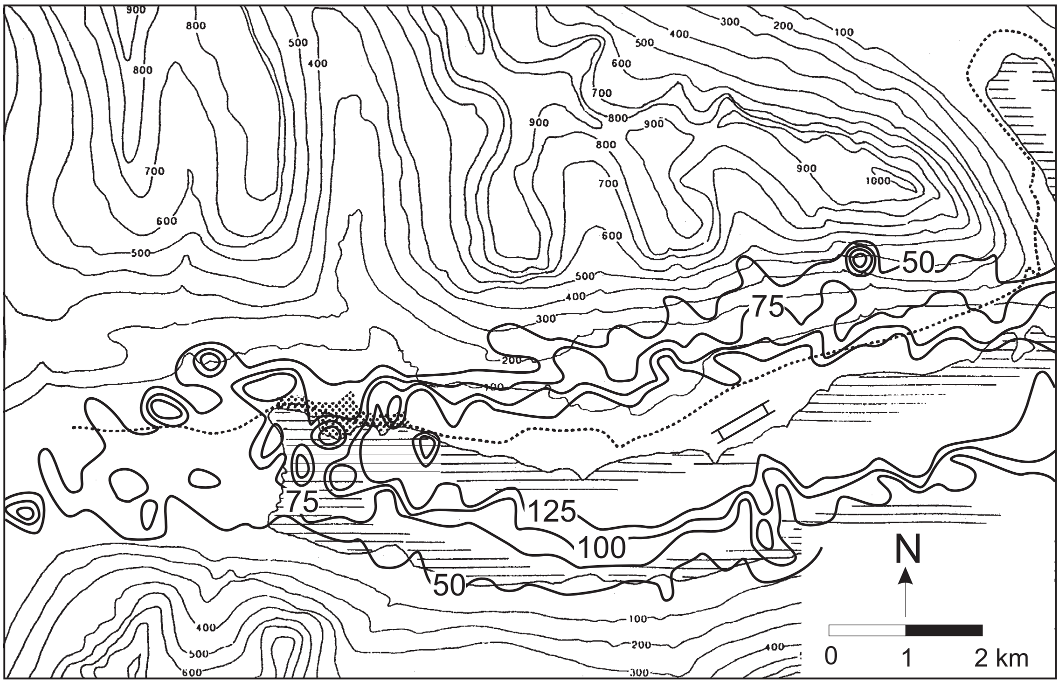


Figure D14: 99.2 percentile (420 000 tpy) for SO_2 for the year 1998-1999, based on 24 hour averages. Case 1. Unit: µg/m^3. The air quality guideline is 125 µg/m^3.

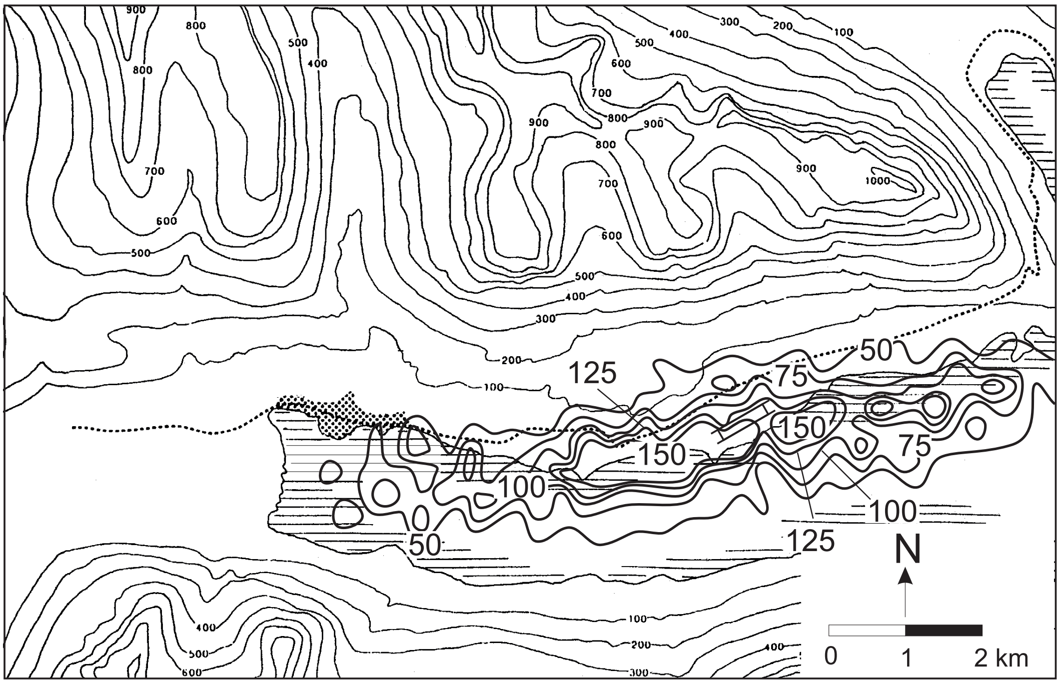


Figure D15: 99.2 percentile (420 000 tpy) for SO_2 for the year 1998-1999, based on 24 hour averages. Case 2. Unit:µg/m^3. The air quality guideline is 125 µg/m^3.

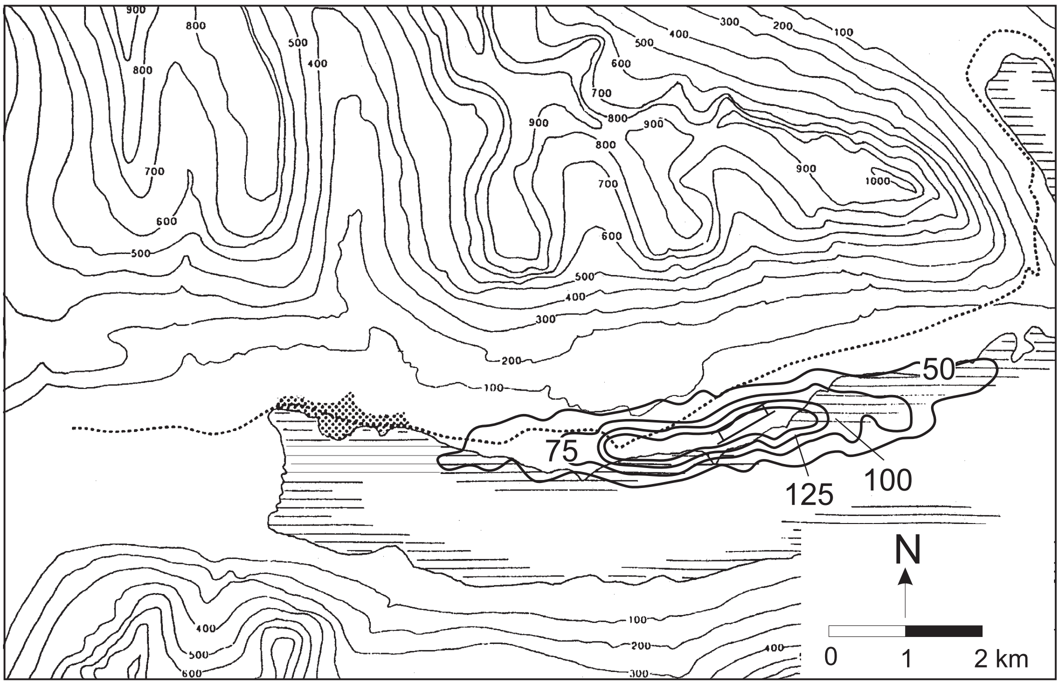


Figure D16: 99.2 percentile (420 000 tpy) for SO_2 for the year 1998-1999, based on 24 hour averages. Case 3. Unit: µg/m^3. The air quality guideline is 125 µg/m^3.

Appendix E

Calculated percentiles based on hourly concentrations for 1998-1999

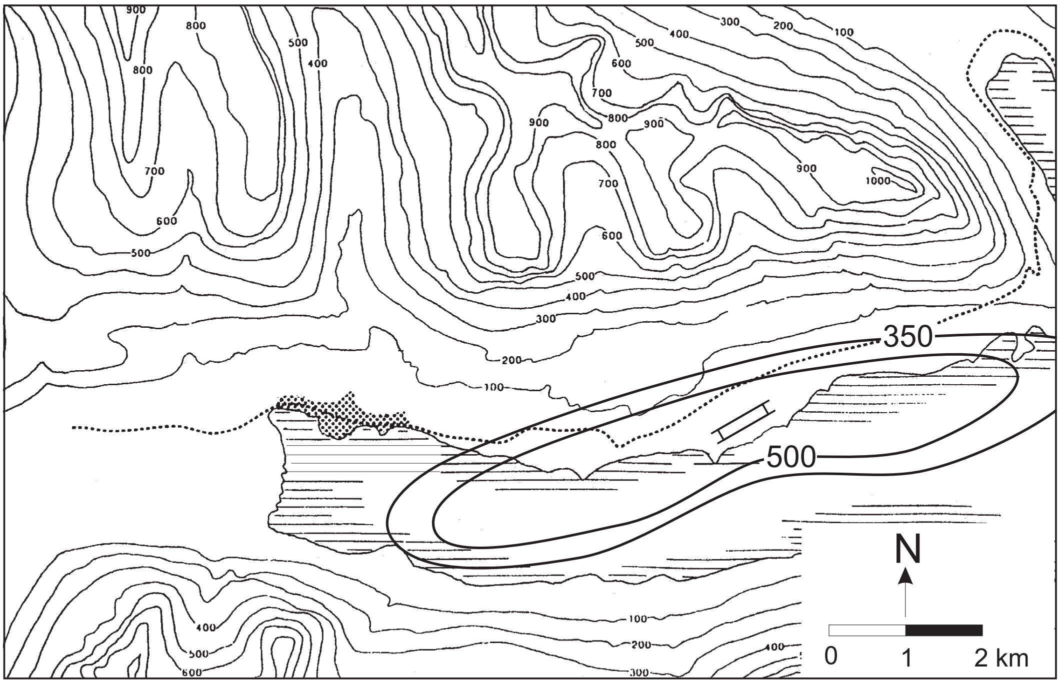


Figure E1: 99.7 percentile (280 000 tpy) for SO_2 for the year 1998-1999, based on hourly averages. Case 1. Unit:µg/m^3. The air quality guideline is 350 µg/m³.

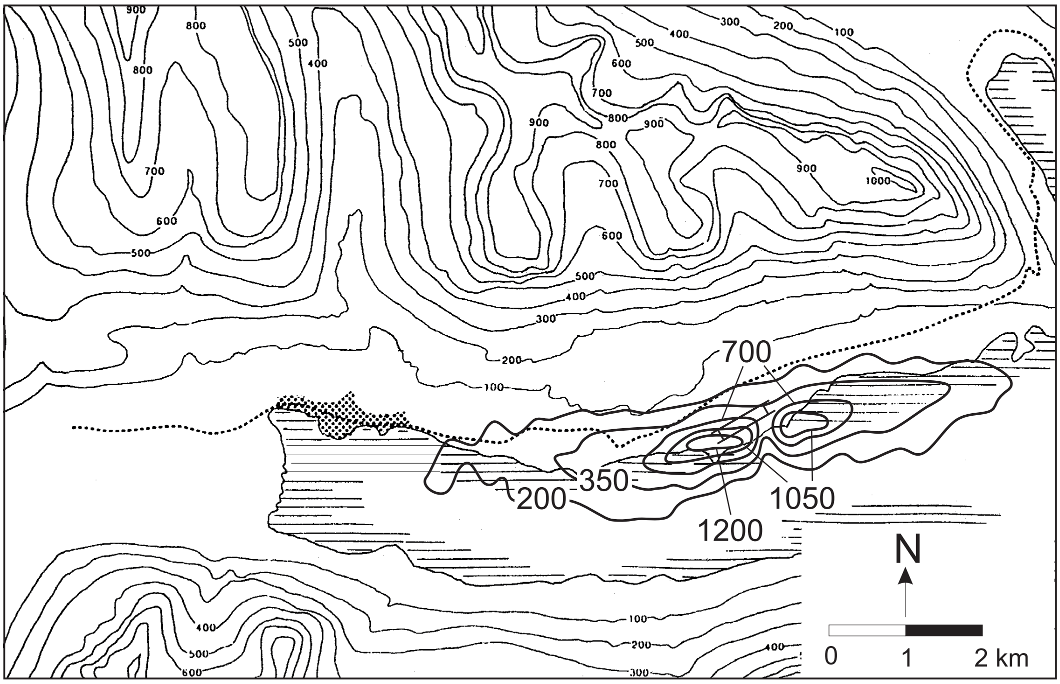


Figure E2: 99.7 percentile (280 000 tpy) for SO_2 for the year 1998-1999, based on hourly averages. Case 2. Unit:µg/m^3. The air quality guideline is 350 µg/m³.

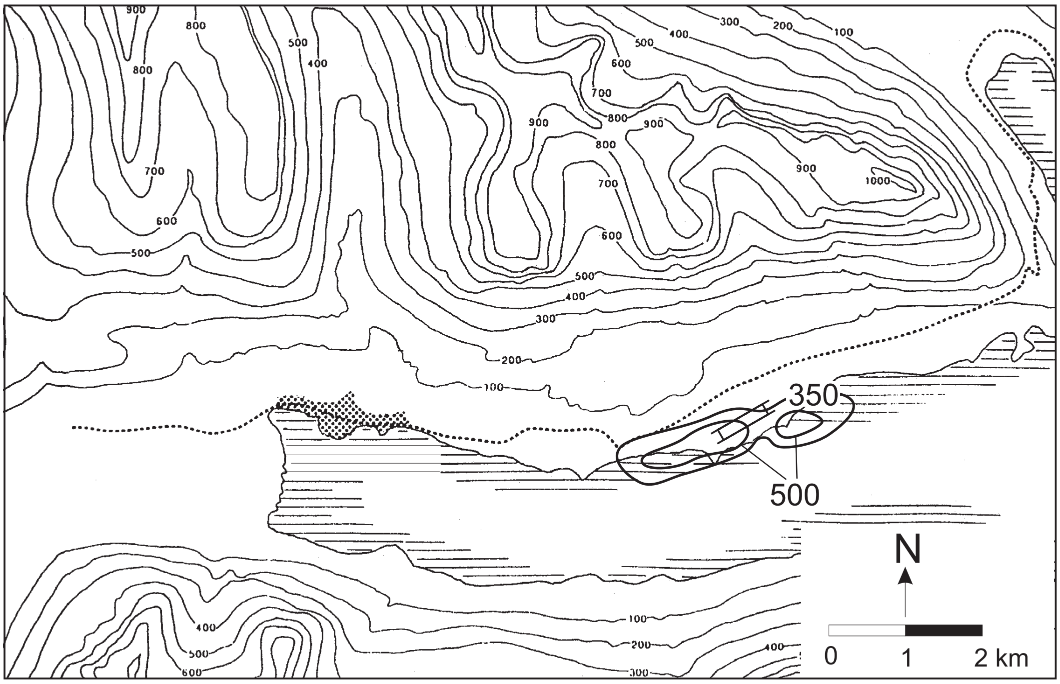


Figure E3: 99.7 percentile (280 000 tpy) for SO_2 for the year 1998-1999, based on hourly averages. Case 3. Unit:µg/m^3. The air quality guideline is 350 µg/m³.

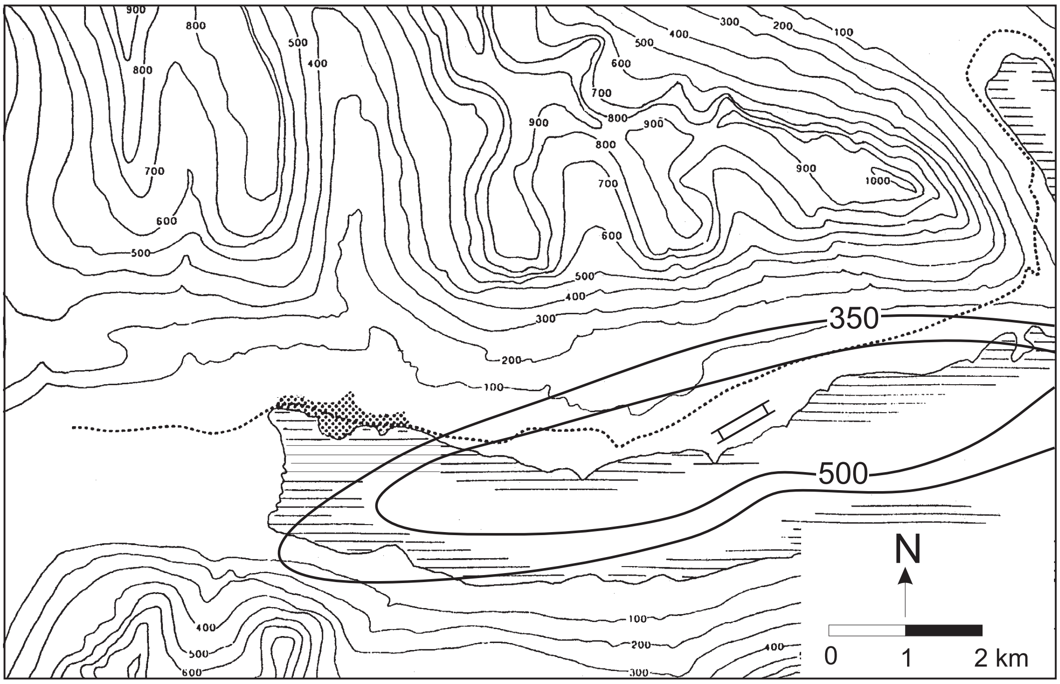


Figure E4: 99.7 percentile (420 000 tpy) for SO_2 for the year 1998-1999, based on hourly averages. Case 1. Unit:µg/m^3. The air quality guideline is 350 µg/m³.

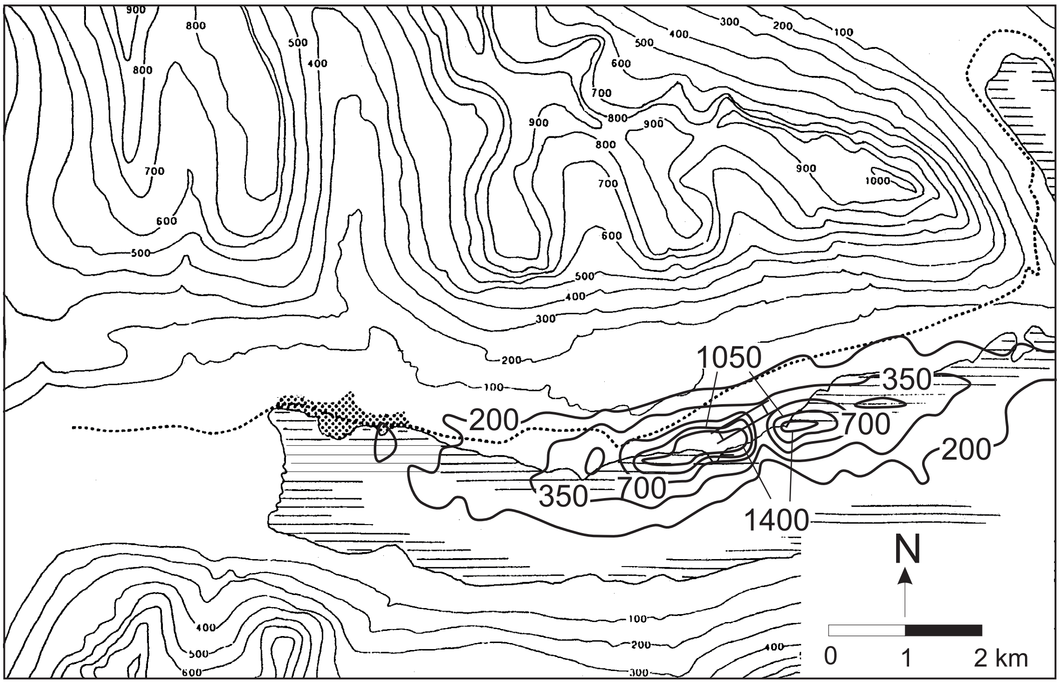


Figure E5: 99.7 percentile (420 000 tpy) for SO_2 for the year 1998-1999, based on hourly averages. Case 2. Unit:µg/m^3. The air quality guideline is 350 µg/m³.

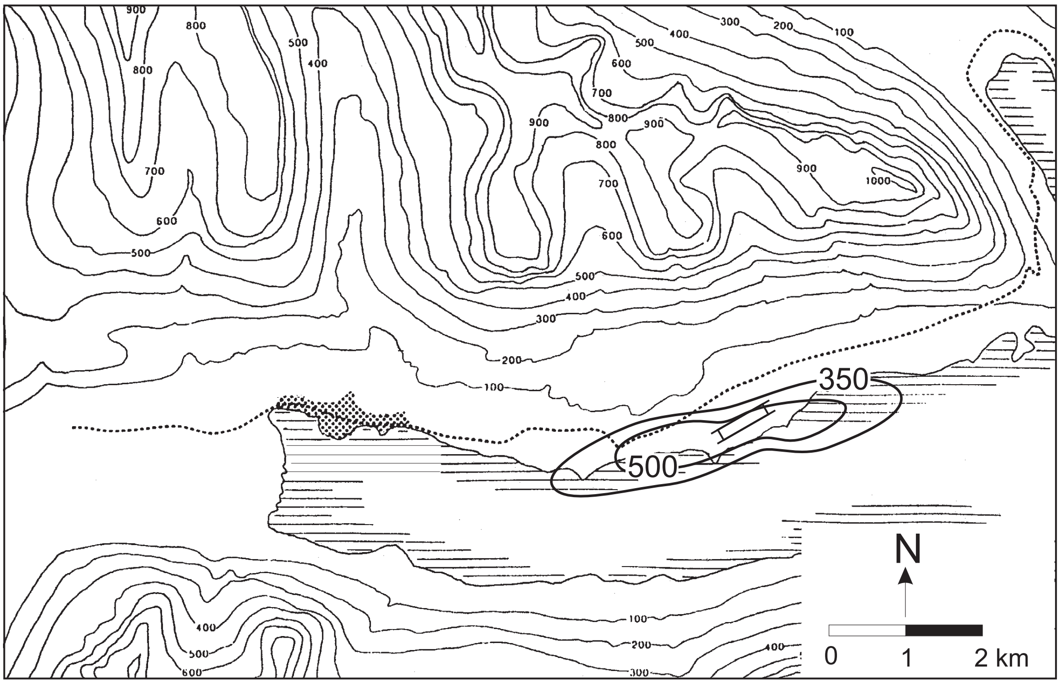


FigurE6: 99.7 percentile (420 000 tpy) for SO_2 for the year 1998-1999, based on hourly averages. Case 3. Unit:µg/m^3. The air quality guideline is 350 µg/m³.

Appendix F

Days included in the percentile calculations

Meteorological situation	Calculated dates
Single re-entry	25-27.5.98, 11-13.5.98, 9-11.5.98, 26-27.3.99, 22-24.3.99, 18-19.3.99, 29.6-1.7.99, 6-7.11.99
Two re-entries	19-21.6.98, 16-18.6.98, 11-13.6.98, 7-9.6.98, 27-29.5.98, 22-24.5.98, 28-30.4.98, 6-8.8.98, 2-4.8.98, 31.7-2.8.98, 5-7.7.98, 8-10.10.98, 2-4.9.98, 21-23.11.98, 14-17.11.98, 27-28.2.99, 22-23.2.99, 28-29.5.99, 14-16.5.99, 19-20.8.99, 25-26.12.99, 16-18.12.99, 26-27.4.00, 13-14.5.00, 10-11.5.00, 29.4-1.5.00
Multiple re-entries	18-20.6.98, 20-22.5.98, 18-20.5.98, 8-10.5.98, 5-7.5.98, 30.4-2.5.98, 26-28.8.98, 25-27.8.98, 24-26.8.98, 18-20.8.98, 27-30.7.98, 24-26.7.98, 10-12.7.98, 2-4.7.98, 30.6-2.7.98, 28-30.9.98, 20-23.9.98, 3-5.9.98, 25-26.12.98, 10-11.12.98, 5-6.12.98, 10-12.11.98, 8-11.2.99, 27-29.1.99, 21-23.1.99, 30.12.98-1.1.99, 23-24.4.99, 26-27.4.99, 19-20.4.99, 26-29.7.99, 6-7-7-99, 30.6-2.7.99, 20-24.6.99, 8-11.6.99, 17-19.10.99, 12-14.10.99, 23-25.9.99, 18-20.9.99, 13-19.8.99, 10-12.8.99, 8-11.8.99, 18-20.12.99, 4-6.4.00
Horizontal vortex	3-5.10.99, 31.7-3.8.99
Vertical vortex	7-9.6.98, 27-28.7.98, 30.9-2.10.98, 25-27.3.99, 18-20.7.99, 27-29.5.99, 17-19.10.99, 27-29.9.99, 29.7-1.8.99, 18-20.12.99
Calm conditions	28-30.5.98, 19-21.5.98, 15-16.8.98, 7-9.8.98, 1-3.8.98, 29-31.7.98, 29.6-1.7.98, 2-4.10.98, 25-26.9.98, 25-27.11.98, 25-27.1.99, 5-7.1.99

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AUTHOR(S) Cristina Guerreiro, Herdis Laupsa and Svein Knudsen		CLASSIFICATION * A CONTRACT REF. Leif Ongstad	

REPORT PREPARED FOR:
Norsk Hydro A.S
Technology & Projects Division
Drammensvn. 264
Vækerø, Oslo

ABSTRACT
NILU has updated the model calculations for a planned aluminium smelter at Somastadagerdi The work is based on earlier investigations in the area, and on meteorological measurements done by the Icelandic Meteorological Office in Reykjavik (IMO). Two alternatives for the smelter's production of aluminium were considered: 280,000 and 420,000 tons of aluminium per year. In addition to this, emissions from an anode-baking furnace for the smelter have been analysed. The following parameters have been estimated: SO_2, PM_{10}, and PAH (yearly and winter season); Gaseous fluorides (growing season); SO_2 (24 hour average, 98 and 99.2 percentile); PM_{10} (24 hour averages, 98 percentile and 90.4 percentile); SO_2 (Hourly averages, 99.7 percentile); Study of unfavourable dispersion conditions.

NORWEGIAN TITLE
Oppdatering av spredningsberegninger for et planlagt aluminiumsverk ved Somastadagerdi, Island.

KEYWORDS		
Aluminium	Model calculations	Meteorology

ABSTRACT (in Norwegian)

* Classification		
	A	Unclassified (can be ordered from NILU)
	B	Restricted distribution
	C	Classified (not to be distributed)