
Baseline study on air and precipitation quality for CO₂ Technology Centre Mongstad

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Scientific report

Preface

CO₂ Technology Centre Mongstad (TCM) will be one of the world's largest facilities for testing and developing CO₂ capture technologies. The operating company TCM DA will operate the facility at Mongstad on behalf the present international owners; Gassnova SF on behalf of the Norwegian Government (75,12 %), Statoil ASA (20 %), A/S Norwegian Shell (2,44 %) and Sasol (2,44 %). The existing agreement commits the partners in the test facility for a period of minimum 5 year from start up of the test period.

A baseline survey of air and precipitation quality has been carried out by NILU-Norwegian Institute for Air Research prior to the start up and operation of TCM. The baseline survey presented here maps the current environmental conditions in air and precipitation on and around the Mongstad site, also with respect to critical parameters in the emissions from amine based CO₂ capture technology such as the degradation products nitrosamines and nitramines. Further, the collected data has been used to design recommendations for an adequate permanent monitoring network in the area.

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Summary

NILU - Norwegian Institute for Air Research has carried out a monitoring campaign around the Mongstad industrial area on behalf of CO₂ Technology Centre Mongstad (TCM). The purpose of the monitoring campaign was to establish the current levels of air and precipitation quality prior to the start-up of the TCM, as well as using the collected data to recommend a permanent surveillance monitoring network in the area. The monitoring for the baseline survey was carried out in April and May 2011.

Based on the model results performed by NILU for TCM (Berglen et al., 2010), three locations were selected during the site survey:

- Sande, north – northwest of Mongstad
- Knarvik, southeast of Mongstad
- Bakka, south-southwest of Mongstad (which serves as background station with minimum exposure from Mongstad)

The prevailing wind directions during the monitoring period were from south and southeast. These are the dominant wind directions also found in previous monitoring campaigns at Mongstad. The wind speed in the monitoring period had mean and maximum values comparable to the previous measurements.

Results from the air and precipitation quality analysis are summarized in the Table below.

Inorganic air	Measured	Short result description
NO ₂ (µg/m ³)	2.3 – 5.1	Standard method, values as expected
O ₃ (µg/m ³)	66	Standard method, values as expected
PM ₁₀ (µg/m ³)	10.6 - 15	Standard method, values as expected
PM _{2.5} (µg/m ³)	7.8 - 10	Standard method, values as expected
NH ₃ (µg/m ³)	0.7 – 5.4	Standard method, impact from farming
SO ₂ (µg/m ³)	0.5 – 1.3	Standard method, values as expected
Organic air		
Amines (7)	ND - 31(ng/m ³)	Novel method, novel component
Nitrosamines(10)	ND	Novel method, novel component
Nitramines(5)	ND	Novel method, novel component
Isocyanates(3)	ND	Novel method, novel component
Formaldehyd	0.5 – 5 µg/m ³	Standard method, values as expected
Precipitation		
Sulfate	0.65 – 0.96 (mg/l)	Standard method, values as expected
Nitrate	0.44 – 0.62 (mg/l)	Standard method, values as expected
Amines (7)	Not analyzed	
Nitrosamines(10)	ND	Novel method, novel component
Nitramines(5)	ND	Novel method, novel component

The analysis of inorganic components in precipitation showed levels well in agreement with the expected background level concentrations in southern Norway.

The inorganic air quality measurements gave low concentrations for both SO₂ and NO₂ and the ozone levels were as expected in the region in this time of the year. For ammonia, the levels were low at Bakka and Knarvik, while some days of elevated values were measured at Sande. The location at Sande has cultivated farmland to the east and north of the station site and it seems that the fertilizing of the farmland has influenced the concentration levels.

The baseline program showed the pre-start levels of some amine related components to be below the obtained detection limits, with the exception of Methylamine, Diethylamine and Dimethylamine. The level of the secondary amines found in the air and the experimental/theoretical formation yield of nitros- and nitramines (Nielsen et. al, 2011) indicates a possible level of the corresponding nitros- and nitramines above the established detection limit in the analysis. Levels ranging from 5 ng/m³ to 25 ng/m³ of these amines could theoretically form from 0.02 to 0.1 ng/m³ nitrosamines and dimethylamine could form up to 0.6 ng/m³ nitramine. The achieved method detection limit for nitrosamines was 0.01 ng/m³, while for the nitramines it was 0.09 ng/m³. Despite this, nitrosamines and nitramines were not found in any of the air samples.

With the level of the components detected in this baseline study, it is recommended that a permanent surveillance program should contain continuous sampling of amines, preferably those that is believed to be emitted from the absorber, either as weekly or half-weekly samples. Additional campaign measurements of 3 to 6 weeks during winter and summer conditions should be performed for nitrosamines and nitramines. Summer and winter campaigns would cover the extremes of the possible formation rates for these components in air. The first campaign should be a summer campaign, during conditions most favourable for the formation of OH-radicals in air. The secondary reaction products from amine based air chemistry like isocyanates and formaldehyde should not be included because the formation would occur at a much larger distance (more than 50 km) from the emissions than nitrosamines and nitramines. The locations of stations should be Bakka and Sande as in the baseline program, while the third station, now at Knarvik, should be moved further southeast from the Mongstad area.

Sammendrag

NILU-Norsk institutt for luftforskning har på oppdrag fra CO₂ Technology Centre Mongstad (TCM) utført en målekampanje for konsentrasjoner i luft og nedbør ved Mongstad. Hensikten med målekampanjen var å fastslå den eksisterende luft- og nedbørkvaliteten rundt Mongstad før oppstart av TCM, samt å benytte datamaterialet til å anbefale et permanent overvåkningsnettet for utslipp fra TCM. Målingene ble utført i april og mai 2011.

Basert på modellberegninger av spredning av utslipp fra TCM (Berglen et al., 2010), ble tre stasjonsplasseringer valgt under befaring i området:

- Sande, nord-nordvest for Mongstad
- Knarvik, sørøst for Mongstad
- Bakka, sør-sørvest for Mongstad (som bakgrunnsstasjon med minimal eksponering av utslipp fra Mongstad)

Framherskende vindretning under måleperioden var vind fra sør og sørøst. Dette samsvarer med dominerende vindretning i tidligere utførte målekampanjer i området. Maksimal og midlere vindstyrke i måleperioden var sammenlignbar med det som er målt tidligere.

Resultatene for luft og nedbør analyser fra måleperioden er oppsummert i tabellen nedenfor.

Uorganisk, luft	Målt	Kort resultatbeskrivelse
NO ₂ (µg/m ³)	2.3 – 5.1	Standard metode, forventet nivå
O ₃ (µg/m ³)	66	Standard metode, forventet nivå
PM ₁₀ (µg/m ³)	10.6 - 15	Standard metode, forventet nivå
PM _{2.5} (µg/m ³)	7.8 - 10	Standard metode, forventet nivå
NH ₃ (µg/m ³)	0.7 – 5.4	Standard metode, lokal aktivitet
SO ₂ (µg/m ³)	0.5 – 1.3	Standard metode, forventet nivå
Organisk, luft		
Aminer (7)	ID - 31(ng/m ³)	Ny metode, nye komponenter
Nitrosaminer(10)	ID	Ny metode, nye komponenter
Nitraminer(5)	ID	Ny metode, nye komponenter
Isocyanater(3)	ID	Ny metode, nye komponenter
Formaldehyd	0.5 – 5 µg/m ³	Standard metodeforventet nivå
Nedbør		
Sulfat	0.65 – 0.96 (mg/l)	Standard metode, forventet nivå
Nitrat	0.44 – 0.62 (mg/l)	Standard metode, forventet nivå
Aminer (7)	Ikke analysert	
Nitrosaminer(10)	ID	Ny metode, nye komponenter
Nitraminer(5)	ID	Ny metode, nye komponenter

ID: Ikke detektert

Nivået av uorganiske komponenter i nedbør, samt konsentrasjoner i luft av nitrogendioksid, svoveldioksid og ozon er som forventet for området og årstiden, med verdier nær ”bakgrunnsnivå”. For ammoniakk viste målingene et høyere nivå

i en periode på Sande. Dette har trolig sammenheng med utslipp fra landbruksvirksomhet (gjødsling). Nivået av uorganiske komponenter i luft var for de fleste komponentene lavere enn deteksjonsgrensen for metoden. Det ble påvist konsentrasjoner over deteksjonsgrensen for Methylamin, Diethylamin and Dimethylamin. Disse komponentene ble funnet i konsentrasjonsnivåer i området 5 til 25 ng/m³. I forhold til eksperimentelle og teoretiske betraktninger om dannelse av nitros- og nitraminer (Nielsen et al., 2011) skulle dette nivået tilsi en forekomst av nitrosamin i området 0,02 til 0,1 ng/m³, og for nitramin opp til 0,6 ng/m³. Det ble imidlertid ikke påvist hverken nitrosaminer eller nitraminer i prøvene. Deteksjonsgrensen som ble oppnådd er anslått til 0,01 ng/m³ for nitrosamin og 0,09 ng/m³ for nitramin.

På bakgrunn av konsentrasjonsnivåene funnet i førundersøkelsen, anbefales det at et permanent måleprogram bør inneholde aminer med prøvetaking på ukentlig eller halv-ukentlig midlingstid. I tillegg bør det utføres intensive kampanjer på 3 til 6 uker med måling av nitrosaminer og nitraminer. Disse bør utføres på ulike årstider. Sekundære reaksjonsprodukter som formaldehyd og isocyanater bør ikke inngå i målekampanjene fordi dannelsen av dem vil skje på størreavstand fra utslippet enn for de primære reaksjonsproduktene. Stasjonsplasseringene på Bakka og Sande bør videreføres i et permanent program. Stasjonen som nå ligger på Knarvik bør flyttes lenger sørøst i forhold til Mongstad.

Baseline study on air and precipitation quality for CO₂ Technology Centre Mongstad

1 Introduction

NILU - Norwegian Institute for Air Research has carried out a monitoring campaign around the Mongstad industrial area on behalf of CO₂ Technology Centre Mongstad (TCM). The purpose of the monitoring campaign was to establish the current levels of air and precipitation quality prior to the start-up of the TCM, as well as using the collected data to recommend an adequate permanent monitoring network in the area.

The components included in the monitoring campaign are shown in Table 1 below. The monitoring for the baseline survey was performed in April and May 2011.

Table 1: Components included in the baseline monitoring program at the different station sites and averaging time for the sampling.

Station	Grunnevikshøgda	Bakka	Knarvik	Sande
Met. Component				
Wind	hour	-	-	-
Precipitation	hour	day	day	day
Temperature	hour	-	-	-
Humidity	hour	-	-	-
Air components				
NO ₂	-	week	week	week
O ₃	-	week	week	week
PM ₁₀	-	day	day	day
PM _{2,5}	-	day	day	day
NH ₃	-	day	day	day
SO ₂	-	day	day	day
Amines (7)	-	week	week	week
Nitrosamines(10)	-	week	week	week
Nitramines(5)	-	week	week	week
Isocyanates(3)	-	week	week	week
Formaldehyd	-	week	week	week
Precipitation components				
Sulfate		After rain	After rain	After rain
Nitrate		After rain	After rain	After rain
Amines (7)		After rain	After rain	After rain
Nitrosamines(10)		After rain	After rain	After rain
Nitramines(5)		After rain	After rain	After rain

2 Location of the monitoring stations

Based on the model results performed by NILU for TCM (Berglen et al., 2010 with an update by Tønnesen, 2011), three general areas was chosen for location of monitoring sites:

- Sande, north – northwest of Mongstad
- Knarvik, southeast of Mongstad
- Bakka, south-southwest of Mongstad (background station)

During the surveillance, the exact locations of three sites were determined. The site of the meteorological measurements was decided to be located at Grunnevikshøgda, the same site as previous monitoring campaigns performed by NILU at Mongstad (Tønnesen, 2008). Criteria for choosing exact placement of the three locations within the areas decided from the dispersion model results were:

- Access to electricity
- Sufficient road quality to be able to support the transport of the station shelter
- Permission to use the selected area
- A local operator willing to carry out the daily operations at the station
- As remote as possible from local pollution sources

An overview of the three locations is shown in Figure 1.

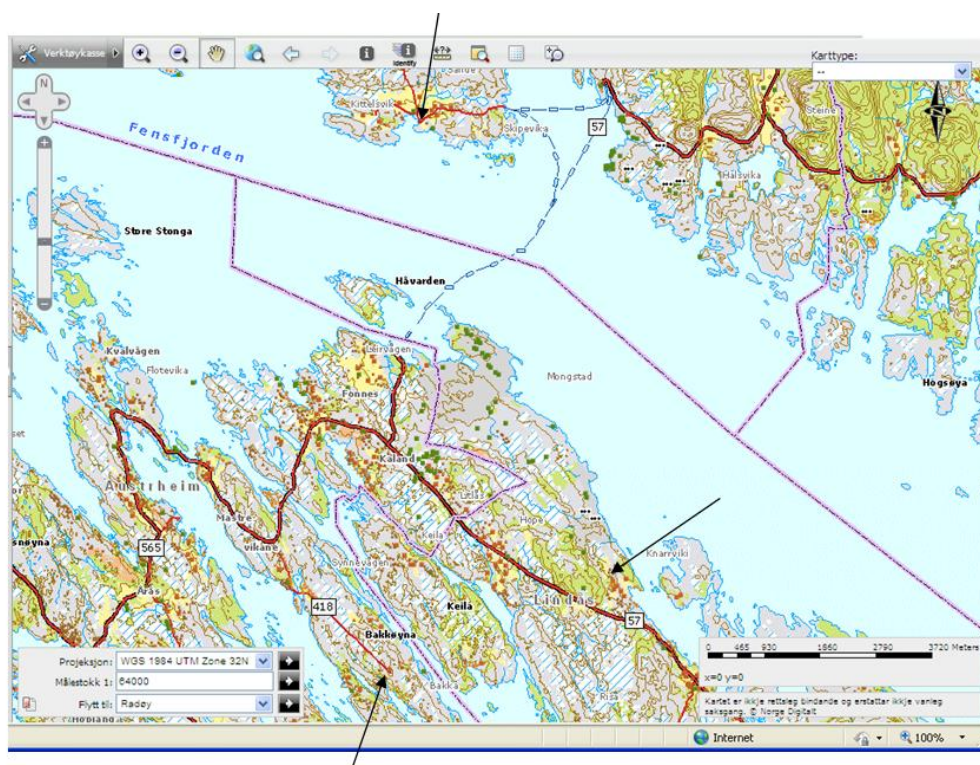


Figure 1: Location of the 3 stations for air and precipitation quality.

A more detailed description of each monitoring site is given in Appendix C.

The location of the stations was changed relative to the last surveillance program for the refinery at Mongstad because updated model results showed different locations of expected maximum impact from the emissions at Mongstad, and also due to the location of new buildings and enterprises to the southeast of the refinery and TCM.

3 Sampling and analysis methods

The components in the monitoring program can be divided into three categories, meteorological components (or parameters), inorganic chemical compounds and organic chemical components. The two first groups, meteorological parameters and inorganic chemical components, well known and long established procedures for sampling and analysis exist. This is, however not the case for the organic chemical components, where both field sampling techniques and analysis of the components are more recently developed.

3.1 Meteorology

The meteorological sampling was done using a Vaisala WXT520 automatic weather station with a data logger developed by NILU. The monitored parameters included wind speed, wind direction, temperature, relative humidity, precipitation and pressure. All parameters were logged by hourly frequency.

(<http://www.vaisala.com/en/products/multiweathersensors/Pages/WXT520.aspx>)
(<http://www.niluinnovation.com/ProductsDivision/DataLogger/tabid/1938/Default.aspx>)

3.2 Inorganic chemical components

The sampling of NO₂ and O₃ was made by weekly passive sampling on impregnated filters. The method used is developed by the Swedish institute IVL. Because these components was measured over one year in the same area in 2007, passive sampling was deemed sufficient for the baseline study purposes. Airborne particles (PM₁₀), SO₂ and NH₃ were measured using the NILU FP-TAC method with three filters in sequence connected to the same airflow control unit. The method applied is NILU U-44. The fine airborne particles (PM_{2.5}) were sampled with the seq4750 sequential sampler, and the filter weight was determined according to NILUs method NILU U-49. Precipitation analysis for inorganic components were made according to methods NILU-U-14 and NILU-U-22.

3.3 Organic chemical components

3.3.1 Amines

The amine analyses have been performed with an in-house validated method which is based on derivatization to improve the behavior towards reversed phase chromatography. The method combines the experience gained from NILU activities (Dye et al. 2008 and 2009) and several previous published works (Kataoka 1996, Sahasrabuddhey 1999, Nielsen et al. 2010).

Sampling

The samples were collected on three series connected quartz fiber filters impregnated with an acid. The filter holder had an open filter interface.

Analysis

Small punches of the filter samples have been prepared by adding a buffer solution and the derivatizing agent in a vial. Isotope labeled amines have been added as internal standards to improve the analysis quality. The instrumental analysis has been performed on a liquid chromatography system equipped with an auto-sampler, a quaternary pump, an on-line degassing system and a diode array detector (UV). The detection has been performed with a Micromass LCT orthogonal-acceleration time-of-flight (TOF) mass spectrometer (MS) equipped with a Z-spray electrospray ion source.

3.3.2 Nitrosamines

The nitrosamines have been analysed by an in-house validated method based on own experience (Dye et al. 2009) and the principles found in OSHA method 27 (www.osha.com). In addition, NILU used an in-house constructed multi-line sampling device to collect large volume samples which enables method detection limits as low as 0.01 ng/m³. The sampler is shown and explained in figure 20 (Appendix D).

Sampling

The samples have been collected on Thermosorb/N adsorbent tubes with open interface.

Analysis

The nitrosamines collected on the Thermosorb/N adsorbents were washed off the adsorbent and the eluate was divided in two aliquots.

Due to the aim of low detection limits a comprehensive sample extract work up was needed to be performed for both analysis aliquots.

One sample aliquot was analyzed by liquid chromatography (HPLC) combined with high resolution mass spectrometry. The second sample aliquot was analyzed by gas chromatography combined with the Thermal Energy Analyzer (TEA). The TEA instrument has a high sensitivity and selectivity towards nitrosamines.

The analytical quality routines were a combination of the standard addition method, internal standard addition and analysis of control samples with known amounts of the analytes.

Precipitation samples (rain water)

The sample analyses were based on the US EPA method 521.

3.3.3 Nitramines

The nitramines were analysed by an in-house validated method based on own experience (Dye et al. 2008 and 2009) and ongoing nitramine activities (Dye et.

al. 2011). In addition, NILU has used an in-house constructed multi-line sampling device to collect large volume samples which enables detection limits below 0.1 ng/m³ (figure 20).

Sampling

The samples were collected on Thermosorb/N adsorbent tubes with open interface.

Analysis

The nitramines collected on the Thermosorb/N adsorbents were washed off the adsorbent and the extract was divided in two aliquots.

Due to the aim of low detection limits a comprehensive sample extract work up was needed to be performed for both analysis aliquots.

One sample aliquot was analysed by liquid chromatography (HPLC) combined with high resolution mass spectrometry. The second sample aliquot was analysed by gas chromatography combined with the Thermal Energy Analyser (TEA). The TEA instrument has a high sensitivity and selectivity towards nitroso- and nitro- containing organic compounds.

The analytical quality routines were a combination of the standard addition method and analysis of control samples with known amounts of the analytes.

Precipitation samples (rain water)

The sample analyses were based on an in house validated solid phase extraction method combining the use of LC/MS (TOF) and GC/TEA.

3.3.4 Isocyanates

The isocyanates were analyzed by an in-house validated method based on the principles found in ISO/DIS 17734-1 and the work reported by Marand et al. 2005.

Sampling

The samples were collected by filter sampling with a filter coated with dibutylamine. The filter interface was open.

Analysis

The exposed filters and adsorbents were extracted and worked up according to Marand et al. 2005. Isotope labeled isocyanates were added as internal standards to improve the analysis quality. The instrumental analysis was performed on a liquid chromatography system equipped with an auto-sampler, a quaternary pump, an on-line degassing system and a diode array detector (UV). The detection was performed with a Micromass LCT orthogonal-acceleration time-of-flight (TOF) mass spectrometer (MS) equipped with a Z-spray electrospray ion source. The TOF instrument is a high resolution mass spectrometer which makes it possible to derive the analyte elemental composition.

3.3.5 Formaldehyde

The formaldehyde was determined by an in-house validated method based on derivatisation with 2,4-dinitrophenylhydrazine (DNPH) (Brombacher et al. 2002).

Sampling

The samples were collected on DNPH coated silica cartridges (Waters) connected to an ozone scrubber.

Analysis

The collected formaldehyde-DNPH derivatives were washed off the cartridges and analysed by a liquid chromatography system equipped with diode array detector (UV). The quality assurance routines were following the guidelines given in EN-17025. The specific analysis in this report was not accredited.

4 Results

4.1 Meteorological conditions

Figure 2 shows the frequency of wind direction during the monitoring period in April and May 2011. The prevailing wind directions during the monitoring period was from south and southeast, these are the dominant wind directions found in previous monitoring campaigns at Mongstad. The frequency of westerly to north westerly winds were less frequent in the current monitoring period than has been registered previously. Ongoing activities at Mongstad in the sampling period would have higher impact at Sande than at Knarvik with the observed wind direction distribution.

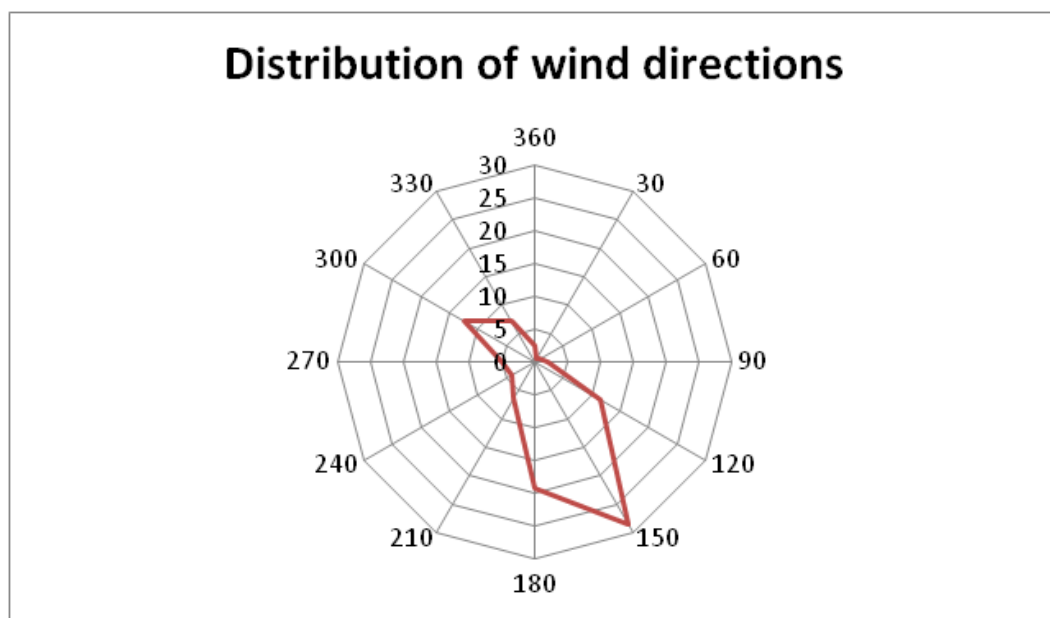


Figure 2: Distributions of wind coming from 30 degree sectors of direction at Mongstad during the monitoring period, divided in 12 sectors. Unit % of time.

The wind speed in the monitoring period had a mean value of 3.8 m/s, which is nearly the same as in the previous measurements (mean wind speed in April 2007 3.9 m/s). Maximum wind speed (as hourly mean value) was 11.2 m/s, again comparable to the previous measurements (13 m/s April 2007).

The air temperature in the monitoring period varied between 21.6 °C and 2.7 °C, and average temperature was 9.0 °C. The temperature was higher in this monitoring campaign than in the 2007 campaign, temperatures in April and May 2011 were more comparable to the conditions in May 2007. The hourly temperature throughout the monitoring period is shown in Figure 3. Maximum hourly precipitation was 11.4 mm. The hourly precipitation is shown in Figure 4. The weather conditions during the sampling period were close to normal for wind and precipitation, and above normal for the air temperature. Given that the sampling period was six weeks, they represent typical springtime conditions at Mongstad.

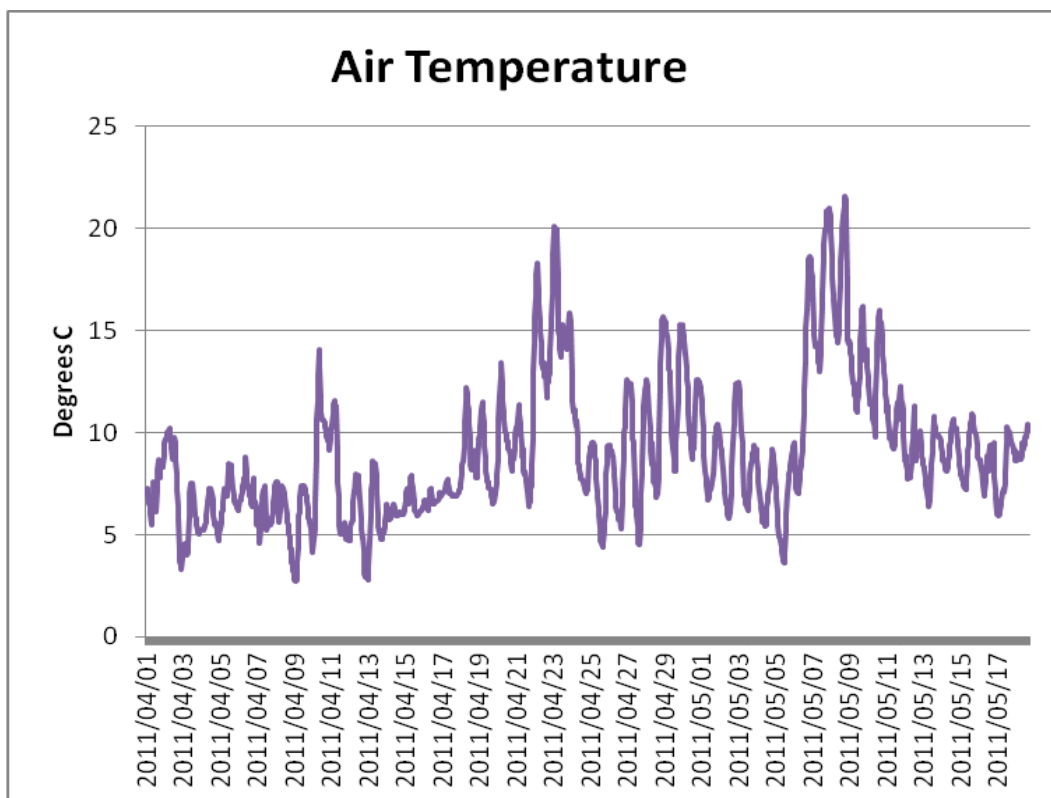


Figure 3: Hourly values of air temperature during the monitoring period.

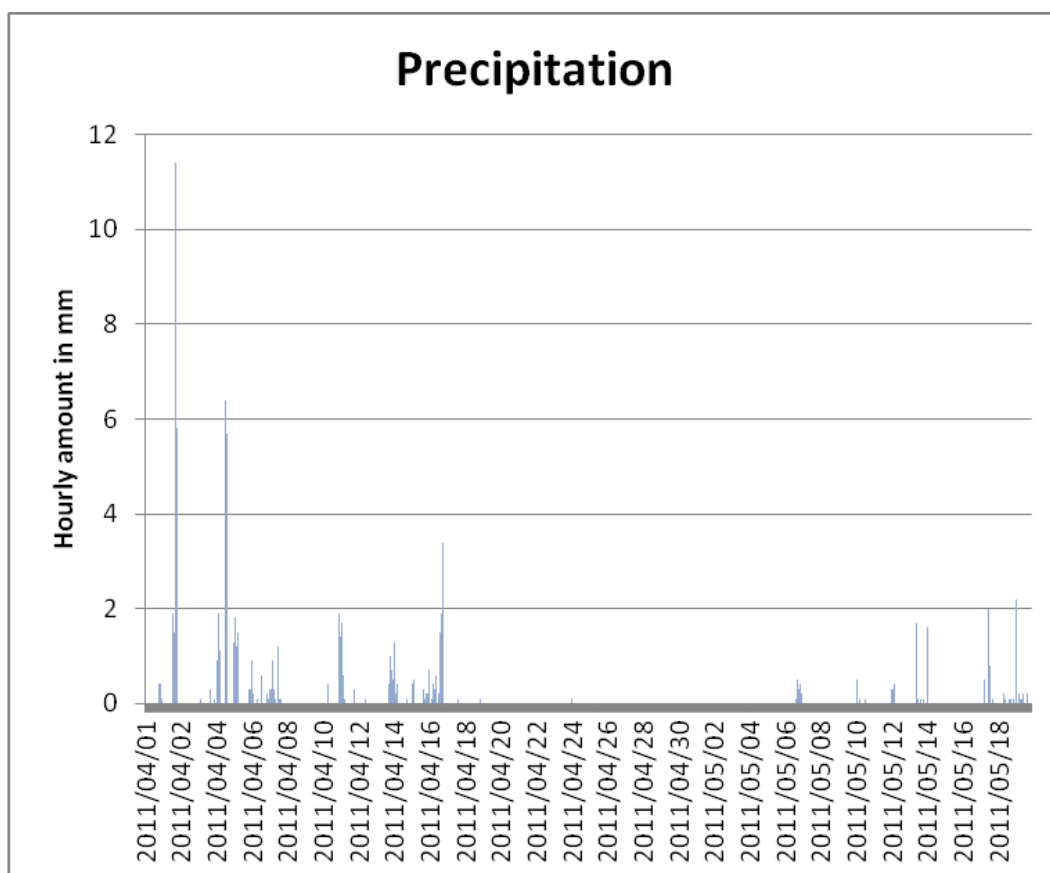


Figure 4: Hourly amount of precipitation during the monitoring period.

4.2 Precipitation quality, inorganic components

The inorganic analysis of the precipitation were carried out for the contents of nitrate, sulphate, ammonium, potassium and calcium. The number of samples varies at the different stations, preliminary due to local variations in the rain pattern regarding distribution in time and the amount of precipitation. The concentrations in all the samples are given in Appendix A. A summary of the measurements is shown in Table 2.

Table 2: Summary of inorganic components in the precipitation. Unit for concentrations: mg/l.

Site		Bakka	Knarvik	Sande
Sample number		7	5	13
Nitrate (as N)	Mean	0.44	0.56	0.62
Nitrate (as N)	Maximum	1.19	1.41	1.57
Sulfate (as S)	Mean	0.66	0.65	0.96
Sulfate (as S)	Maximum	0.92	0.97	1.88
Ammonium (as N)	Mean	0.38	0.49	0.44
Ammonium (as N)	Maximum	1.07	1.58	1.43
Potassium	Mean	0.17	0.17	0.18
Potassium	Maximum	0.30	0.36	0.51
Calcium	Mean	0.24	0.26	0.32
Calcium	Maximum	0.58	0.51	0.98

The levels correspond well to the expected background level concentrations in southern Norway.

4.3 Precipitation quality, organic components

The precipitation samples were of limited volume. For this reason the nitramine and nitrosamine analysis were given priority. No samples contained detectable concentrations of nitramines and nitrosamines. The limits of detection is given in appendix B.

4.4 Air quality, inorganic components

Sampling and analysis of inorganic chemical components included the following: Nitrogen dioxide (NO₂), Ozone (O₃), Sulphur dioxide (SO₂), Ammonia (NH₃) and airborne particles in two size fractions (PM₁₀ and PM_{2.5}).

4.4.1 NO₂

Weekly average values of NO₂ are shown in Figure 5 and Table 3. The average for the whole period was 2.3 µg/m³ at Bakka, 5.1 µg/m³ at Knarvik and 3,5 µg/m³ at Sande. Given the prevailing wind direction (from south-southeast), the location of the stations and contribution from local road traffic, the variation of levels at the three stations were as expected, and comparable to previous results in the area.

The maximum weekly average concentration occurred at Knarvik during the 4th week. During this week, wind direction from north and northwest was more frequent than for the rest of the sampling period. A likely cause for the elevated concentration levels at Knarvik this week is activity at the refinery and at the Mongstad supply base.

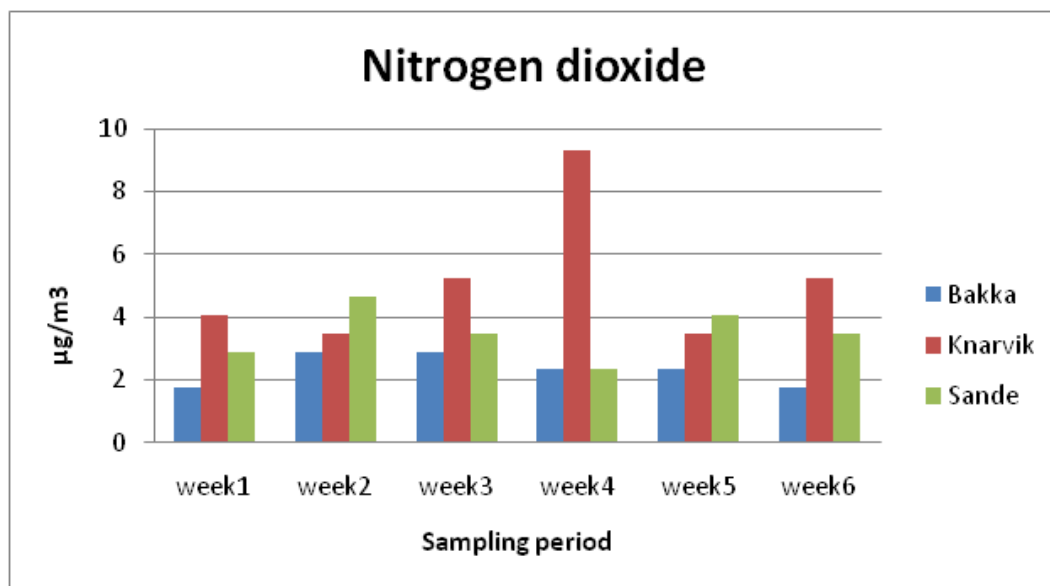


Figure 5: Results from NO_2 -sampling at the three monitoring sites.

Table 3: Results from NO_2 -sampling at the three monitoring sites. Unit $\mu g/m^3$.

Period	Bakka	Knarvik	Sande
7-14 April	1.7	4.1	2.9
14-21 April	2.9	3.5	4.7
21-28 April	2.9	5.2	3.5
28 April – 5 May	2.3	9.3	2.3
5 – 12 May	2.3	3.5	4.1
12- 19 May	1.7	5.2	3.5

4.4.2 O_3

The weekly average values of ozone are shown in Figure 6. The sample for week 4 at Bakka show a result that is strange compared to the other samples, given that ozone does not have any local sources. If the filter sample has been in direct contact with water, the method might provide an overestimate of the actual concentration. By disregarding this value, the average concentration for all stations and all periods becomes $66 \mu g/m^3$. This level is normal considering the location and the time of the year.

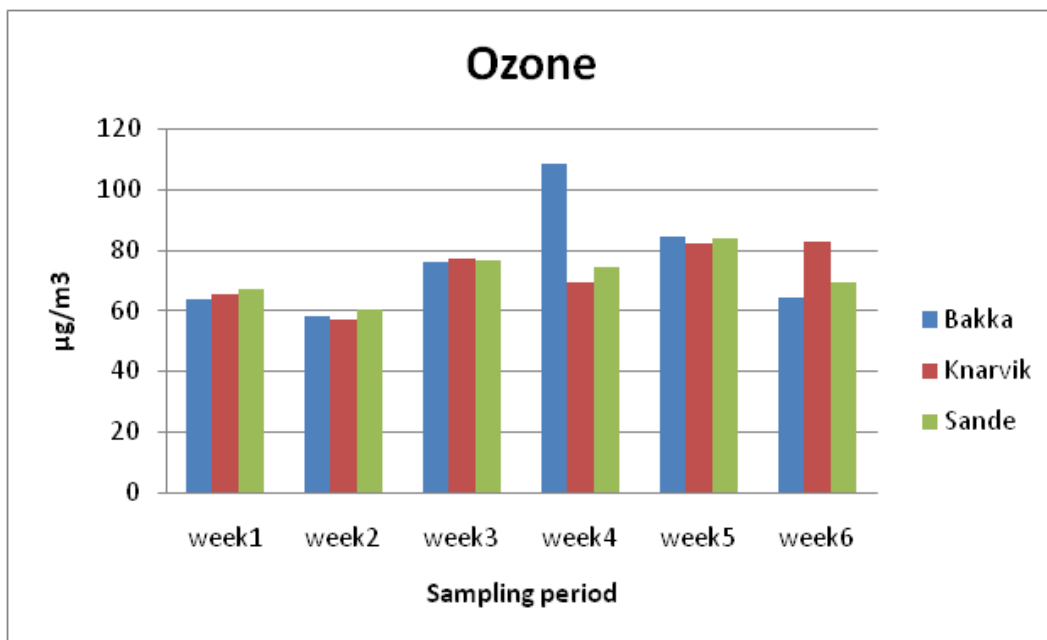


Figure 6: Results from O_3 -sampling at the three monitoring sites.

Table 4: Results from O_3 -sampling at the three monitoring sites. Unit $\mu\text{g}/\text{m}^3$.

Period	Bakka	Knarvik	Sande
7-14 April	64	65	67
14-21 April	58	57	60
21-28 April	76	77	77
28 April – 5 May	108*	69	75
5 – 12 May	84	82	84
12- 19 May	64	83	69

*:Value disregarded in the analysis of the results

4.4.3 SO₂

The results from monitoring of sulphur dioxide are shown in Figure 7 and Table 5. The results show that the concentrations of sulphur dioxide are low, and the variability of the levels is small considering how low the actual concentrations are.

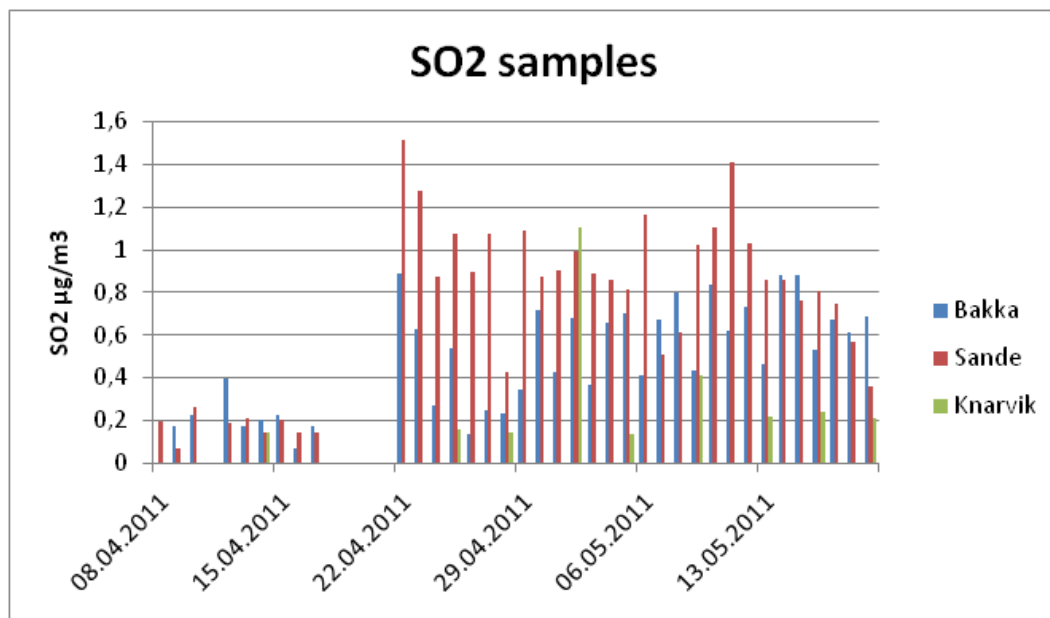


Figure 7: Daily averages of SO₂-concentrations (3 and 4 day averages at Knarvik).

Table 5: Average concentration and maximum daily concentration of SO₂ at the three sites (sampling interval at Knarvik was 3 and 4 days). Unit µg/m³.

Site	Bakka	Knarvik	Sande
Average	1.0	0.5	1.3
Maximum	1.7	2.2	3.0

4.4.4 NH_3

The results for ammonia are shown in Figure 8 and Table 6.

Table 6: Average concentrations and maximum daily concentration of NH_3 at the three sites (sampling interval at Knarvik was 3 and 4 days). Unit $\mu g/m^3$.

Site	Bakka	Knarvik	Sande
Average	1.6	0.7	5.4
Maximum	3.0	2.1	30.4

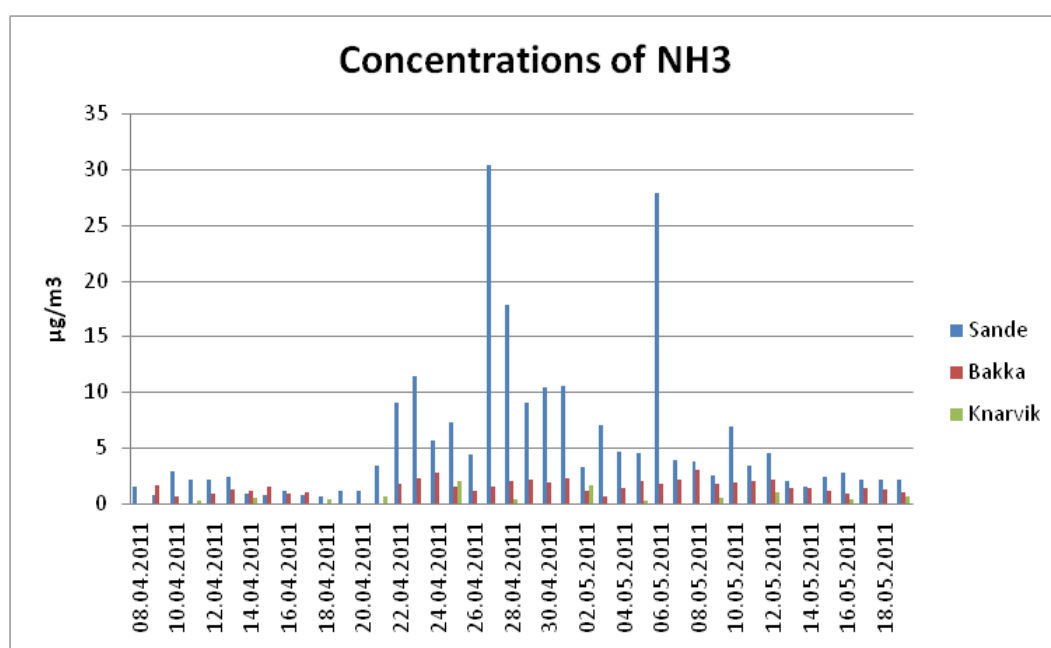


Figure 8: Results from ammonia sampling at the three monitoring sites. The sampling frequency was daily at Bakka and Sande, and three times weekly at Knarvik. Unit $\mu g/m^3$,

The location at Sande had cultivated farmland to the east and north of the station site. Even though the prevailing wind direction was from southeast, it seems obvious that the fertilizing of the farmland has clearly influenced the concentration level in the sampling period, especially in the days with high maximum temperature.

4.4.5 PM_{10} and $PM_{2.5}$

The sampling of PM_{10} was done using the same instruments as for NH_3 , which means that there are daily samples at Bakka and Sande and 3 and 4 days samples at Knarvik. The sampling of $PM_{2.5}$ was made with an automatic sequential sampler. The measured concentrations of PM_{10} are shown in Figure 9 and Table 7.

Table 7: Results from PM_{10} sampling at the three monitoring sites. The sampling frequency was daily at Bakka and Sande, and three times weekly at Knarvik. Unit $\mu g/m^3$.

Site	Bakka	Knarvik	Sande
Average	15	10.6	11.5
Maximum	48.1	19.9	45.2

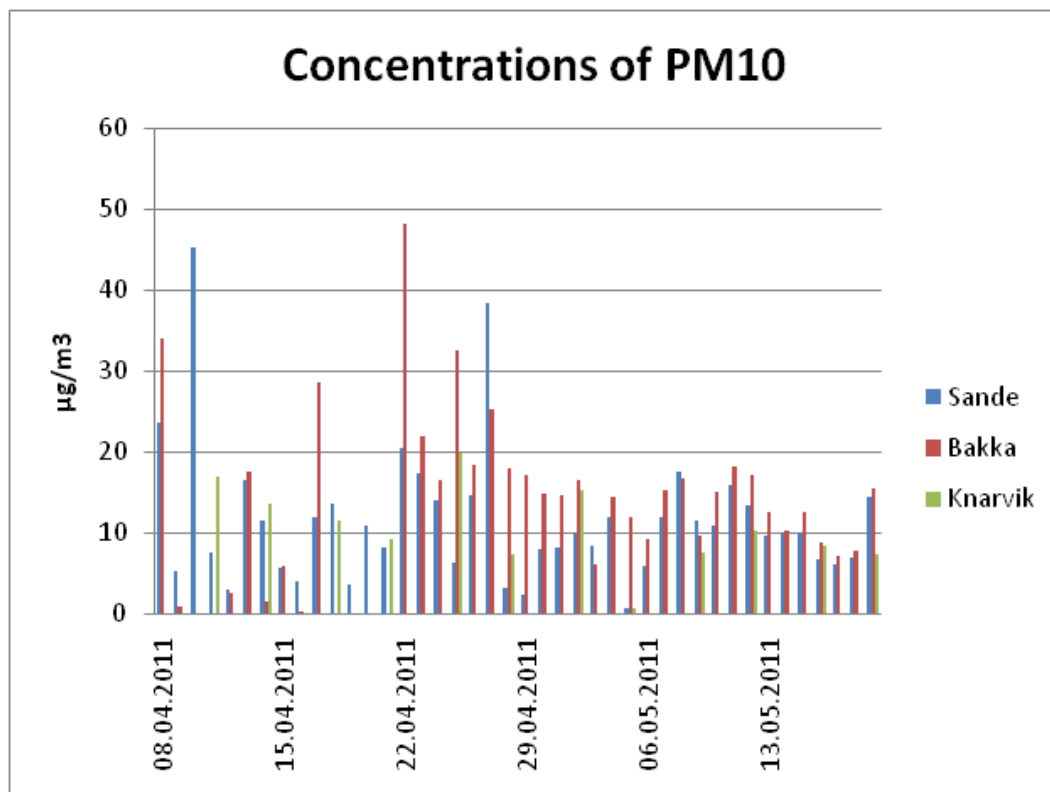


Figure 9: Results from PM_{10} sampling at the three monitoring stations. The sampling frequency was daily at Bakka and Sande, and three times weekly at Knarvik.

The concentrations of $PM_{2.5}$ are shown in Figure 10 and Table 8.

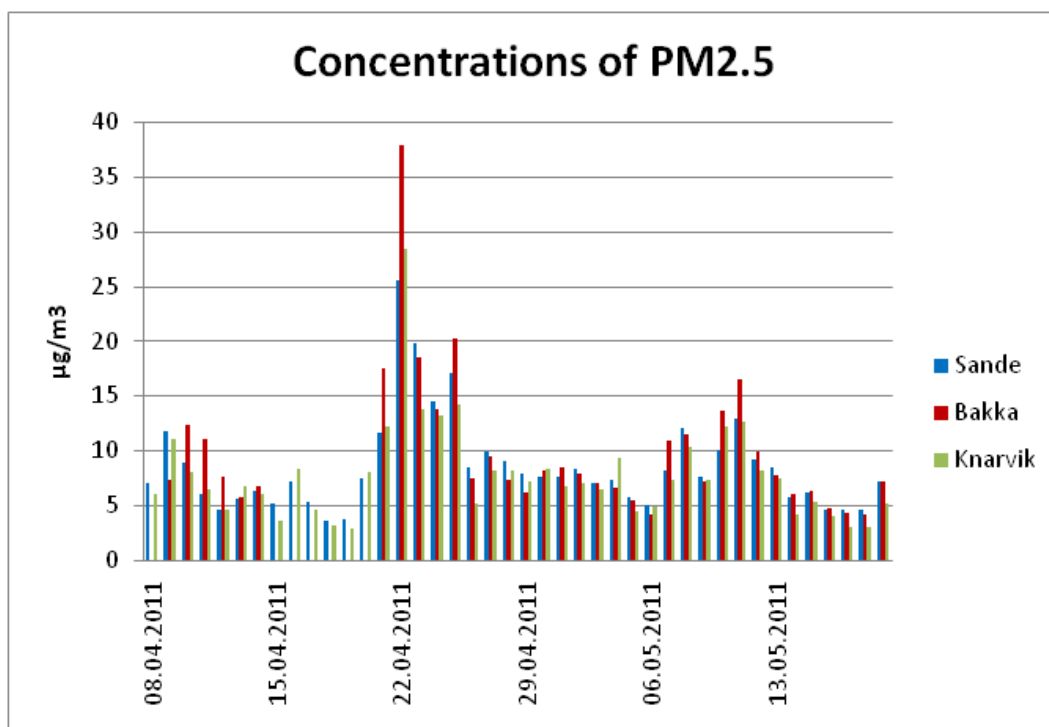


Figure 10: Results from $PM_{2.5}$ sampling at the three monitoring stations.

Table 8: Measured concentrations of $PM_{2.5}$ at the three stations. Unit $\mu\text{g}/\text{m}^3$.

Site	Bakka	Knarvik	Sande
Average	9.9	7.8	8.4
Maximum	37.8	28.4	25.4

For low concentrations of airborne dust (less than $4 \mu\text{g}/\text{m}^3$), the two methods for dust sampling can give (and have given) results where the $PM_{2.5}$ concentrations are larger than the PM_{10} concentrations. For these cases, the $PM_{2.5}$ measurements represent a better estimate of the PM_{10} concentration, because low level concentrations of airborne dust is dominated by particles with small diameter caused by long-range air pollution transport, and the $PM_{2.5}$ sampler is specially designed for particle collection, whereas the filter package method used for PM_{10} is a multifunctional device.

4.5 Air quality, organic components

Nitrosamines, nitramines and isocyanates

The compound classes nitrosamines, nitramines and isocyanates were not detected above the detection limits in any samples (see appendix B). This indicates that the sites are currently not impacted by any sources of these compounds. Trace amounts of nitrosamines and isocyanates has previously been reported close to local sources (Oury et al. 1997), however, no data is found from ambient air without local sources.

The measurement procedures of nitrosamines and nitramines aimed at detection limits relevant for the EPA/IRIS risk level of $0.07 \text{ ng}/\text{m}^3$ for nitrosamines. In order to reach such low detection limits some method adjustments were needed

compared to the OSHA method 27. The instrumental limit of detection ($S/N = 3$) was approximately $10 \text{ pg}/\mu\text{L}$ in the sample extract for the least sensitive compounds. In order to reach this extract concentration the sample volume was increased by use of 10 double (two connected in series) parallel exposed Thermosorb/N tubes for each nitrosamine and each nitramine sample. The sample extracts from each tube (2 mL) were combined and the resulting 20 mL was reduced to $100 \mu\text{L}$ after a sample clean-up procedure (two unpublished NILU-methods, one for nitramines and one for nitrosamines). The parameters of the different methodological steps in this study are given in table 9 along with the corresponding validation parameters found in the literature.

Table 9: Sampling parameters in this study compared with validated parameters.

	Validated parameters	TCM baseline study
Capacity	1000 ng/tube	< 1ng/tube
Sampling flow rate	2 L/min.	2 L/min.
Sample volume	0.9 m^3	20 m^3
Relative humidity	<80%	?***
Number of tubes per sample	1 and 2	1 and 2*
Sample desorption (75% DCM+25%MeOH)	2 mL	2 mL
Sample clean-up	None	NILU validated
Extract enrichment	None	NILU validated

*: Due to problems with Thermosorb/N supply some samples were collected with one tube.

**: Some of the days in the sampling period were rainy.

The Thermosorb/N tubes are primary developed for artifact free measurement of occupational exposure to nitrosamines. However, the sampling performance has proven to be good in other aspects as well, i.e. cigarette smoke, chamber experiments (Nielsen et al. 2010) and outdoor sampling over artificial turf areas by RIVM. Thus, Thermosorb/N is probably among the best suited sampling adsorbents for outdoor air.

Table 9 show that the sample volumes are exceeding previously validated values. Although two tubes were connected in series, the higher sampling volumes may have lead to partial break through for the most volatile compound(s), however, this need to be validated. In general, analyte break through will result in too low measured concentrations. The average relative humidity for the sampling period is not measured. Increased humidity seems to cause decreased break through volume, this effect need to be validated for outdoor measurements.

How sure can we be that the nitrosamine concentrations are really low at the sampling sites? With an unrealistic worst case sampling scenario with break through values as high as 90%, the reported detection limits would increase from $0.01 \text{ ng}/\text{m}^3$ to $0.1 \text{ ng}/\text{m}^3$. In such scenario the values are still below the $0.3 \text{ ng}/\text{m}^3$ guideline for sum of nitros- and nitramines provided by the Norwegian Institute of Public Health.

Due to the recently developed sample clean-up procedure and enrichment step, the low ng/m^3 detection limit can be reached with 10 (double) tubes exposed to only 1 m^3 each in future studies, e.g. a total of 10 m^3 . Thus, the remaining method step to validate is the humidity impact in 1 m^3 ambient air samples collected at events higher than 80% relative humidity.

Amines

The results from the amine analysis are tabulated in Appendix B. The most important findings are given in figures 11-13.

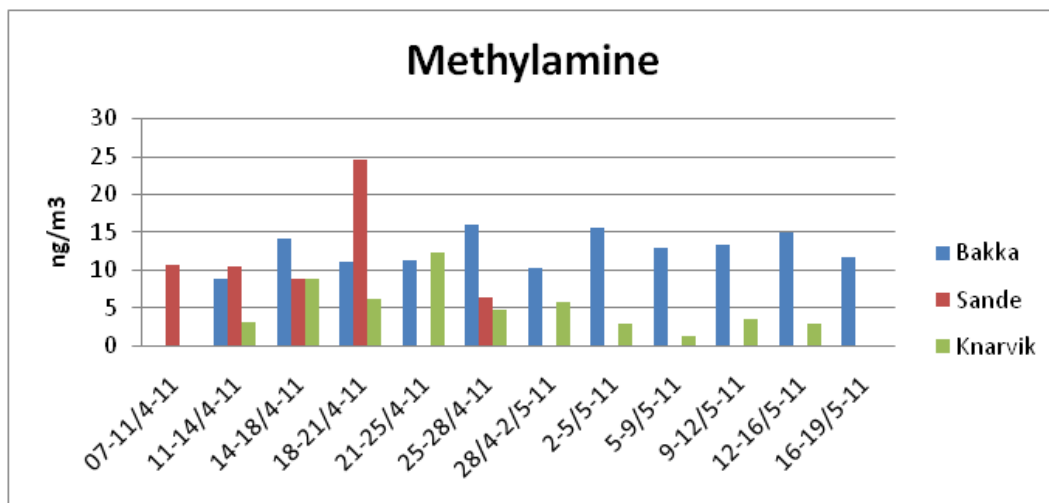


Figure 11: Results from the methylamine measurements.

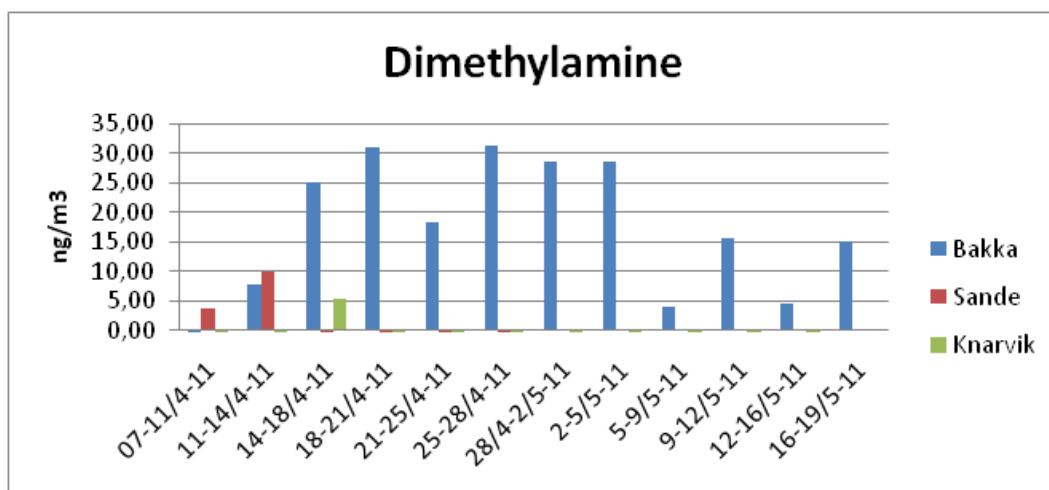


Figure 12: Results from the dimethylamine measurements.

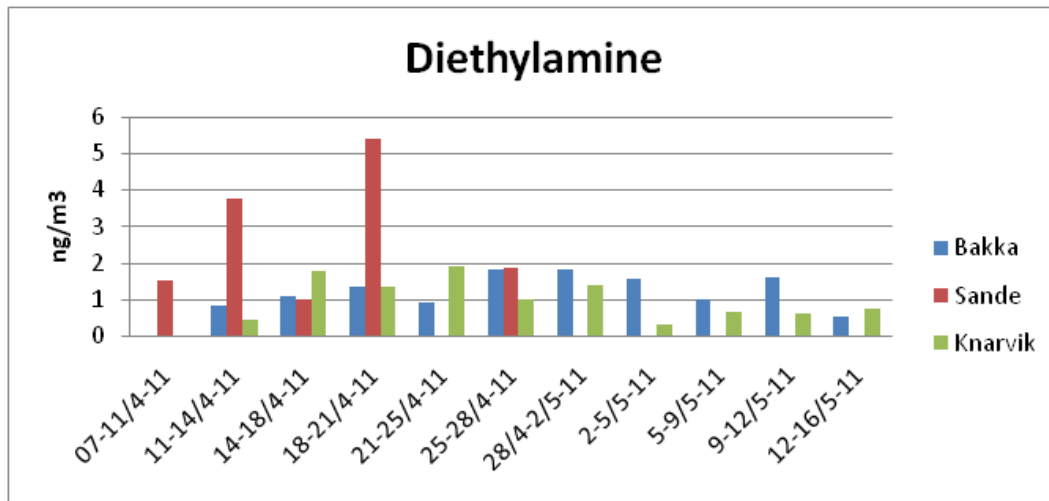


Figure 13: Results from the diethylamine measurements.

The data presented in the figures 11-13 are blank level corrected. The correction has been accomplished by subtracting the field blanks from the samples (average plus 3 times standard deviation, $n=10$). Low measurement values of dimethylamine have been lost in the field blank correction, this appears as missing bars in figure 12. From 28/4 to 19/5 the Sande amine data was lost due to technical problems with the sampling equipment.

The number of collected samples in this study is rather limited to draw firm conclusions about the amine baseline level. In addition, the concentration of amines in Norwegian ambient air is sparsely described in the literature. By comparing the results obtained in other studies (Grönberg et al., 1992, VandenBoer et al., 2011), rather good agreement is seen in the level from the Swedish coast line and Canadian ambient air. However, due to low natural level of amines significant fluctuations may be expected if local sources are introduced. Possible differences in seasonal amine fluxes may also be a source of fluctuations in amine concentrations. Due to the lack of knowledge about amine concentrations in ambient air, more measurements are needed to provide reliable answers.

Formaldehyde

The formaldehyde analysis results are given in Figure 14.

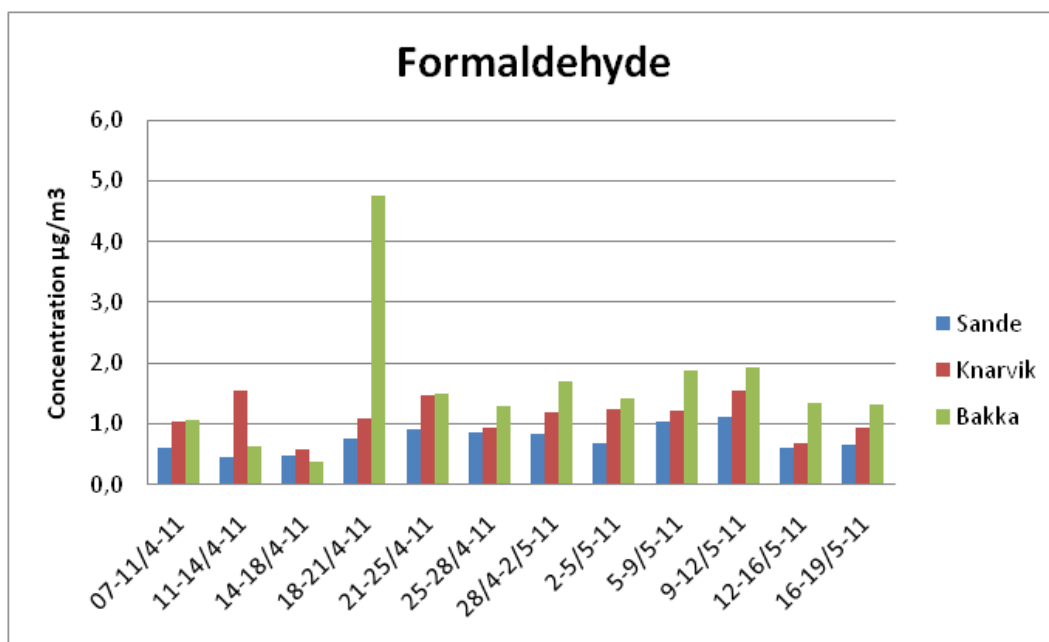


Figure 14: Results from the formaldehyde measurements. Concentrations in $\mu\text{g}/\text{m}^3$.

Formaldehyde is a natural occurring compound connected to the atmospheric chemistry and photo oxidation of organic compounds. For this reason the level of formaldehyde has a natural diurnal and seasonal cycle with highest levels around noon and summer time. In addition, formaldehyde is generated in combustion processes and is emitted from a wide range of anthropogenic sources. The concentrations given in figure 13 are comparable with the Birkenes site (springtime) in Norway (rural), with some minor differences between the sites which are likely caused by differences in local sources. The levels are significant lower than typical Norwegian residential indoor levels ($5\text{-}50 \mu\text{g}/\text{m}^3$).

5 Measured vs expected concentrations of nitrosamines and nitramines

The baseline program show the pre-start levels of some amine related components to be below the obtained detection limits, with the exception of Methylamine, Diethylamine and Dimethylamine. The level of the secondary amines found in the air, and the experimental/theoretical formation yield of nitros- and nitramines obtained in Teflon chamber experiments (Nielsen et. al, 2011), indicates a possible level of the corresponding nitros- and nitramines above the established detection limit in the analysis. Levels of from $5 \text{ ng}/\text{m}^3$ to $25 \text{ ng}/\text{m}^3$ of these amines could theoretically form from 0.02 to $0.1 \text{ ng}/\text{m}^3$ nitrosamines. This estimate is based on "Steady state" for rural conditions (0.4% of the parent amine). Dimethylamine has a potential yield of 2.5% towards formation of nitramines, and could cause up to $0.6 \text{ ng}/\text{m}^3$ nitramine as an air concentration. The achieved detection limit for nitrosamines were $0.01 \text{ ng}/\text{m}^3$, while for the nitramines it was $0.09 \text{ ng}/\text{m}^3$. Despite this, nitrosamines and nitramines were not found in any of the air samples. This may be explained by the possible occurrence

of environmental sinks which are not taken into account in the current model calculations.

6 Recommendations for permanent monitoring

The rationale for the three sites chosen for the baseline study was for two of them to be within the expected area of maximum impact from emissions at TCM, and the third to be in an area of low impact. Apart from these general criteria, other criteria were listed in Chapter 2. The results show that for certain periods and certain components, local sources do have some influence on the monitoring results. These occurrences are listed in Table 10. Possible sources for the impact are also shown.

Table 10: Local impact at stations during the measurement campaign.

Station	Period	Component	Possible source
Knarvik	Week 4	NO ₂	Supply base to the north
Bakka	Week 4	Ozone	Failure with passive sampler ?
Sande	22/4-12/5	NH ₃	Emissions from fertilizing
Sande,Bakka	22/4+27/4	PM ₁₀	Resuspended dust, sea salt ?
Sande	18-21/4	Methyl- and Dimethylamine	Ocean ?
Bakka	18-21/4	Formaldehyd	Wood burning ?

The impact of ammonia at the Sande location was already expected when the station was selected. Due to the fact that this emission will be limited to a short period in the spring, and that the Sande location has obvious merits regarding the possibility to detect impacts from the emissions at TCM, the location is recommended for further use in permanent surveillance. During the baseline study, the station was operated from 2-phase electricity. For a permanent station, establishing 3-phase electricity supply is strongly recommended, because the temperature inside the shelter would need cooling, and then the power demand would be too high for 2-phase electricity. Recommendations for a permanent surveillance are summarized for the components in the baseline study below.

Inorganic air	Recommendation
NO ₂	Hourly monitoring due to air chemistry
O ₃	Hourly monitoring due to air chemistry
PM ₁₀	Not necessary
PM _{2,5}	Hourly monitoring due to air chemistry
NH ₃	Daily values, hourly in campaigns
SO ₂	Not necessary
Organic air	
Amines (7)	Amines from emission inventory
Nitrosamines(10)	In campaigns
Nitramines(5)	In campaigns
Isocyanates(3)	Will not occur in detectable amount
Formaldehyd	Will not occur in detectable amount
Precipitation	
Sulfate	Not necessary, PH should be measured
Nitrate	Uncertain
Amines (7)	Amines from emission inventory
Nitrosamines(10)	In campaigns
Nitramines(5)	In campaigns

Campaigns are recommended twice per year, with a duration of 3 to 6 weeks.

For the background location at Bakka, the equipment shelter was placed close to the local buildings. This might explain the elevated level of formaldehyde, because this component is emitted by wood burning. The location at Bakka have been chosen as a background location for ozone, nitrogen oxides and particles in a recently started monitoring campaign. The shelter has been moved 50 m away from the local buildings. With this adjusted location, the site is recommended as a background station in a permanent surveillance program.

At Knarvik, the distance to the Mongstad supply base is short, and the angle between wind directions giving impact from the base and the refinery and TCM is less than 15 degrees. The level of NO₂ impact was generally higher at Knarvik than at the other locations. A more suitable placement might be a little further to the northwest or further to the southeast around Sundsbø.

With the level of the components detected in the baseline study, it is recommended that a permanent surveillance program should contain continuous sampling of amines, preferably those that are believed to be emitted from the absorber, either as weekly or half-weekly samples. Additional campaign measurements of 3 to 6 weeks during winter and summer conditions should be performed for nitrosamines and nitramines. Summer and winter campaigns would cover the extremes in the possible formation rates for these components in air. The first campaign should be a summer campaign, during conditions most favourable for the formation of OH-radicals in air. The secondary reaction products from amine based air chemistry like isocyanates and formaldehyde should not be included because the formation would occur at a much larger distance (more than 50 km) from the emissions than nitrosamines and nitramines.

7 Conclusions

The baseline program show the pre-start levels of most amine related components to be below the obtained detection limits, with the exception of Methylamine, Diethylamine and Dimethylamine. Results and achieved detection limits for the different components are summarized in Appendix B. The level of the secondary amines found in the air, and the possible formation yield of nitros- and nitramines from them indicates a possible level of the corresponding nitros- and nitramines well above the established detection limit in the analysis. Despite this, nitrosamines and nitramines were not found in any of the air samples. A possible explanation to this is that the deposition rate of nitrosamines and nitramines on natural surfaces is a significant sink for concentrations in the air. Further field sampling of air concentrations should take this possibility into account.

Inorganic air	Measured	Short result description
NO ₂	2.3 – 5.1 (µg/m ³)	Standard method, values as expected
O ₃	66 (µg/m ³)	Standard method, values as expected
PM ₁₀	10.6 – 15 (µg/m ³)	Standard method, values as expected
PM _{2.5}	7.8 – 10 (µg/m ³)	Standard method, values as expected
NH ₃	0.7 – 5.4 (µg/m ³)	Standard method, impact from farming
SO ₂	0.5 – 1.3 (µg/m ³)	Standard method, values as expected
Organic air		
Amines (7)	ND - 31(ng/m ³)	Novel method, novel component
Nitrosamines(10)	ND	Novel method, novel component
Nitramines(5)	ND	Novel method, novel component
Isocyanates(3)	ND	Novel method, novel component
Formaldehyd	0.5 – 5 (µg/m ³)	Standard method, values as expected
Precipitation		
Sulfate	0.65 – 0.96 (mg/l)	Standard method, values as expected
Nitrate	0.44 – 0.62 (mg/l)	Standard method, values as expected
Amines (7)	Not analyzed	
Nitrosamines(10)	ND	Novel method, novel component
Nitramines(5)	ND	Novel method, novel component

A permanent surveillance programme should be carried out at the locations of expected maximum impact. The location at Sande should be used in such a programme. A better location than Knarvik should be found to the southeast of Mongstad, possibly in the Sundsbø area. The components in the programme should contain components relevant to the emission itself and the air chemistry, i.e NO_x, particles, O₃, NH₃ and amines. The nitrosamines and nitramines, which are harder to measure and are expected to be present at lower levels in air should be monitored during campaigns using specially developed equipment. The initial campaigns should be performed at the time of the year where the formation in air of these components is expected to be at its highest, that is, during the summer.

Acknowledgements

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Appendix A

Inorganic components in precipitation

	Cl	NO3_N	SO4_S	Na	NH4_N	K	Mg	Ca
	mg/l	mgN/l	mgS/l	mg/l	mgN/l	mg/l	mg/l	mg/l
Sande 7.4.11	17.62	0.00	0.96	7.56	-0.01	0.23	0.64	0.20
Sande 11.4.11	30.72	0.25	1.50	14.17	0.29	0.51	1.18	0.98
Sande 12.4.11	14.61	0.51	1.06	7.47	0.50	0.25	0.60	0.95
Sande 15.4.11	4.13	0.20	0.74	2.12	0.21	0.16	0.14	0.21
Sande 16.4.11	8.52	1.57	1.88	3.84	0.77	0.20	0.35	0.24
Sande 18.4.11	7.36	0.11	0.57	4.59	0.08	0.13	0.40	0.19
Sande 07.05.2011	2.64	1.20	0.91	1.10	0.83	0.10	0.08	0.17
Sande 10.05.2011	1.51	1.43	1.34	0.59	1.43	0.20	0.05	0.27
Sande 12.05.2011	5.06	1.51	0.96	2.57	1.11	0.10	0.22	0.24
Sande 14.05.2011	1.82	0.31	0.41	0.74	0.12	0.08	0.07	0.05
Sande 16.05.2011	7.67	0.55	0.88	4.36	0.15	0.15	0.35	0.31
Sande 17.05.2011	1.25	0.13	0.19	0.38	0.11	0.04	0.03	0.08
Sande 19.05.2011	15.72	0.28	1.04	8.67	0.11	0.24	0.76	0.27
Bakka 8.4.11	8.62	0.03	0.47	3.90	-0.01	0.13	0.29	0.11
Bakka 12- 16.04.2011	3.46	0.69	0.81	1.09	0.35	0.08	0.12	0.17
Bakka 16- 18.4.2011	4.85	0.16	0.55	2.64	0.12	0.08	0.21	0.10
Bakka 6- 7.5.11	2.75	1.41	0.92	1.01	1.07	0.21	0.13	0.58
Bakka 11- 12.5.11	1.56	1.10	0.75	0.54	0.99	0.30	0.12	0.30
Bakka 18.5.11	2.02	0.21	0.35	0.75	0.12	0.13	0.07	0.13
Bakka 19.5.11	6.34	0.34	0.78	3.73	0.03	0.27	0.35	0.28
Knarvik 8.4.11	7.09	0.03	0.50	3.66	0.01	0.14	0.28	0.12
Knarvik 11- 11.4.11	3.82	0.31	0.52	1.16	0.38	0.10	0.10	0.18

18.4.11								
Knarvik 12.04.2011	6.96	0.38	0.62	2.78	0.35	0.12	0.21	0.51
Knarvik 7.5.11	2.44	1.19	0.97	0.90	1.58	0.36	0.09	0.21
Knarvik 16- 19.5.11	4.99	0.31	0.63	2.23	0.16	0.15	0.23	0.28

Appendix B

Results for organic compounds

Amine results

Stasjon	Dato	Ethanolamine	2-amino-2-methyl- propanol	Methylamine	Ethylamine	Dimethylamine	Piperazine	Diethylamine
		ng/m3	ng/m3	ng/m3	ng/m3	ng/m3	ng/m3	ng/m3
Bakka	11-14/4-11	<0.01	<0.01	9	<0.01	8	<0.01	0.8
Bakka	14-18/4-11	<0.01	<0.01	14	<0.01	25	<0.01	1.1
Bakka	18-21/4-11	<0.01	<0.01	11	<0.01	31	<0.01	1.3
Bakka	21-25/4-11	<0.01	<0.01	11	<0.01	18	<0.01	0.9
Bakka	25-28/4-11	<0.01	<0.01	16	<0.01	31	<0.01	1.8
Bakka	28/4-2/5-11	<0.01	<0.01	10	<0.01	29	<0.01	1.8
Bakka	2-5/5-11	<0.01	<0.01	15	<0.01	29	<0.01	1.6
Bakka	5-9/5-11	<0.01	<0.01	13	<0.01	4	<0.01	1.0
Bakka	9-12/5-11	<0.01	<0.01	13	<0.01	16	<0.01	1.6
Bakka	12-16/5-11	<0.01	<0.01	15	<0.01	5	<0.01	0.5
Bakka	16-19/5-11	<0.01	<0.01	12	<0.01	15	<0.01	1.1
Sande	07-11/4-11	<0.01	<0.01	11	<0.01	4	<0.01	1.5
Sande	11-14/4-11	<0.01	<0.01	10	<0.01	10	<0.01	3.8
Sande	14-18/4-11	<0.01	<0.01	9	<0.01	<0.01	<0.01	1.0
Sande	18-21/4-11	<0.01	<0.01	25	<0.01	<0.01	<0.01	5.4
Sande	21-25/4-11	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Sande	25-28/4-11	<0.01	<0.01	6	<0.01	<0.01	<0.01	1.9

Stasjon	Dato	Ethanolamine	2-amino-2-methyl- propanol	Methylamine	Ethylamine	Dimethylamine	Piperazine	Diethylamine
		ng/m ³	ng/m ³	ng/m ³	ng/m ³	ng/m ³	ng/m ³	ng/m ³
Knarvik	11-14/4-11	<0.01	<0.01	3	<0.01	<0.01	<0.01	0.4
Knarvik	14-18/4-11	<0.01	<0.01	9	<0.01	5	<0.01	1.8
Knarvik	18-21/4-11	<0.01	<0.01	6	<0.01	<0.01	<0.01	1.3
Knarvik	21-25/4-11	<0.01	<0.01	12	<0.01	<0.01	<0.01	1.9
Knarvik	25-28/4-11	<0.01	<0.01	5	<0.01	<0.01	<0.01	1.0
Knarvik	28/4-2/5-11	<0.01	<0.01	6	<0.01	<0.01	<0.01	1.4
Knarvik	2-5/5-11	<0.01	<0.01	3	<0.01	<0.01	<0.01	0.3
Knarvik	5-9/5-11	<0.01	<0.01	1	<0.01	<0.01	<0.01	0.6
Knarvik	9-12/5-11	<0.01	<0.01	3	<0.01	<0.01	<0.01	0.6
Knarvik	12-16/5-11	<0.01	<0.01	3	<0.01	<0.01	<0.01	0.7

Isocyanate results

Stasjon	Dato	Methylisocyanate	Ethylisocyanate	Propylisocyanate
		ng/m³	ng/m³	ng/m³
Knarvik	07-14/4-11	<0.001	<0.001	<0.001
Knarvik	14-21/4-11	<0.001	<0.001	<0.001
Knarvik	21-28/4-11	<0.001	<0.001	<0.001
Knarvik	28/4-5/5-11	<0.001	<0.001	<0.001
Knarvik	5-12/5-11	<0.001	<0.001	<0.001
Knarvik	12-19/5-11	<0.001	<0.001	<0.001
Sande	07-14/4-11	na	na	na
Sande	14-21/4-11	<0.001	<0.001	<0.001
Sande	21-28/4-11	<0.001	<0.001	<0.001
Sande	28/4-5/5-11	<0.001	<0.001	<0.001
Sande	5-12/5-11	<0.001	<0.001	<0.001
Sande	12-19/5-11	<0.001	<0.001	<0.001
Bakka	07-14/4-11	<0.001	<0.001	<0.001
Bakka	14-21/4-11	<0.001	<0.001	<0.001
Bakka	21-28/4-11	<0.001	<0.001	<0.001
Bakka	28/4-5/5-11	<0.001	<0.001	<0.001
Bakka	5-12/5-11	<0.001	<0.001	<0.001
Bakka	12-19/5-11	<0.001	<0.001	<0.001

Formaldehyde results

Formaldehyde

Stasjon	Sande	Knarvik	Bakka
Dato	µg/m³	µg/m³	µg/m³
07-11/4-11	0.6	1.0	1.1
11-14/4-11	0.5	1.6	0.6
14-18/4-11	0.5	0.6	0.4
18-21/4-11	0.8	1.1	4.8
21-25/4-11	0.9	1.5	1.5
25-28/4-11	0.9	0.9	1.3
28/4-2/5-11	0.8	1.2	1.7
2-5/5-11	0.7	1.2	1.4
5-9/5-11	1.1	1.2	1.9
9-12/5-11	1.1	1.5	1.9
12-16/5-11	0.6	0.7	1.4
16-19/5-11	0.7	0.9	1.3

Nitrosamine results

Air samples Samples were collected in the following periods: 07-14/4-11, 14-21/4-11, 21-28/4-11, 28/4-5/5-11, 5-12/5-11, 12-19/5-11. No results were above the tabulated detection limits.

<i>Nitrosamine</i>	<i>Limit of detection n ng/m³ *</i>	<i>Limit of detection n (200 mL) ng/L *</i>
N-nitrosodiethanolamine	0.09	150
Nitrosopiperidine	0.01	5
Nitrosodiethylamine	0.01	5
Nitrosodimethylamine	0.01	5
Nitroso-N-methylethylamine	0.01	5
Nitrosomorpholine	0.01	5
Nitroso-N-propylamine	0.01	5
Nitrosopyrrolidine	0.01	5
Nitrosopiperazine	0.09	150
Dinitrosopiperazine	**	**

Rain samples from the following dates were analysed.

bakka 8/4
bakka 12/4-16/4
bakka 6/5-7/5
bakka 11/5-12/5
Bakka 16/5-18/5
bakka 18/5
bakka 19/5
Knarvik 7/5
Knarvik 16/5-19/5
Sande 7/4-8/4
Sande 12/4
Sande 15/4
Sande 16/4
Sande 18/4

Nitramine results

Air samples Samples were collected in the following periods: 07-14/4-11, 14-21/4-11, 21-28/4-11, 28/4-5/5-11, 5-12/5-11, 12-19/5-11. No results were above the tabulated detection limits.

<i>Nitramine</i>	<i>Limit of detection ng/m³</i>	<i>Limit of detection (200 mL) ng/L</i>
N-Nitro-ethanolamine	0.05	100
N-Nitro-piperazine	0.09	100
N-Nitro-methylamine	0.09	400
N-Nitro-dimethylamine	0.09	100
2-methyl-2-nitroamino-propanol	0.05	100

Rain samples from the following dates were analysed.

bakka 8/4
bakka 12/4-16/4
bakka 6/5-7/5
bakka 11/5-12/5
Bakka 16/5-18/5
bakka 18/5
bakka 19/5
Knarvik 7/5
Knarvik 16/5-19/5
Sande 7/4-8/4
Sande 12/4
Sande 15/4
Sande 16/4
Sande 18/4

Appendix C
Monitoring Sites

Sande

Communications to Sande is ferry from Leirvåg. The ferry operates with hourly departures from Leirvåg and Slørvåg at each side of Fensfjorden. The area at Sande is mostly cultivated grassland (pasture), which during the monitoring campaign will be a source to emissions of NH_3 . The selected site, shown in Figure 15 is as remote as possible from the pasture areas and still connected to the local infrastructure. The station holder is the closest neighbor to the station site. The brown coloured buildings at the map closest to the site are boat-houses. Figure 16 shows the view towards the south-southeast from the small knoll south of the station site. The Mongstad industrial facility can be seen centrally in the picture.

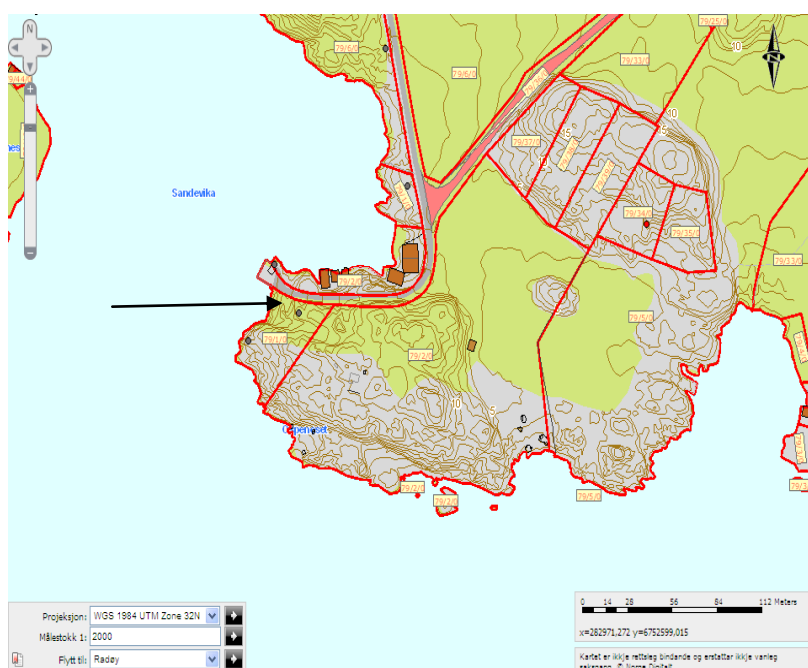


Figure 15: Location of the station site at Sande.





Figure 16: View towards south southwest from the small knoll south of the station site

Knarvik

Knarvik is the only alternative location for a station southeast of Mongstad when accessibility and availability of electricity is considered. One site close to the small boat harbor was investigated, but due to ongoing terrain improvement work in the close vicinity, it was discarded. A site on the north side of Knarvik was found. The selected station site is shown in Figure 17. The station operator has worked for NILU in that capacity earlier.

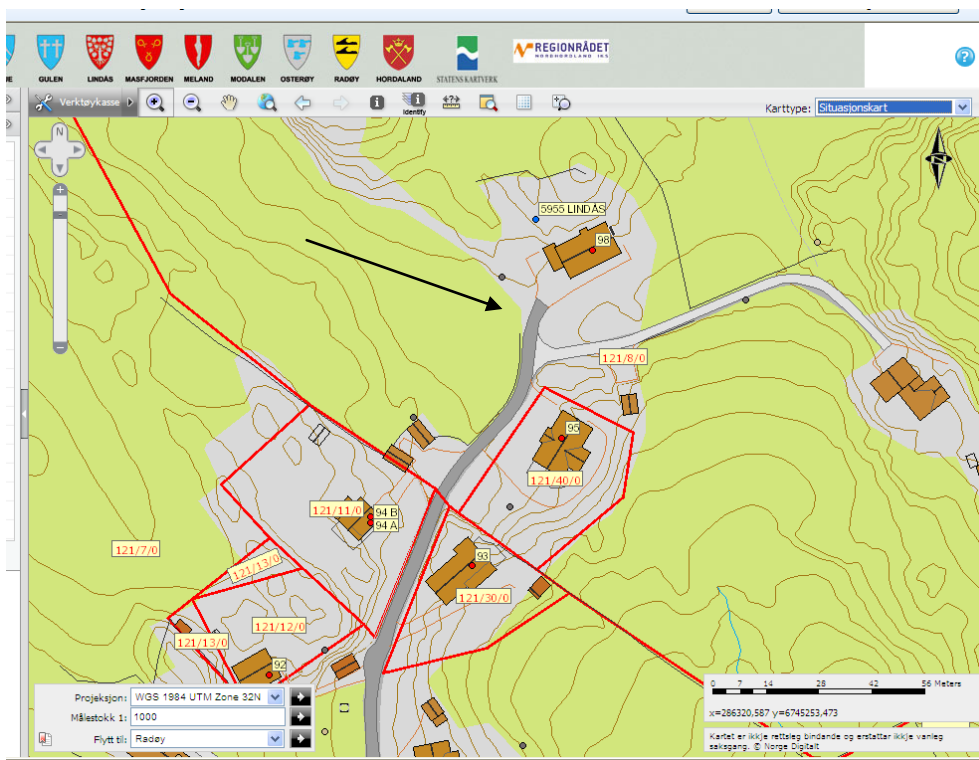




Figure 17: Location of the station site at Knarvik. The picture show the view towards northwest. Mongstad supply center is just behind the light tower in the center of the picture.

Bakka

A location further south on Bakkøyna was not investigated further due to the lack of road-capacity. The selected site is surrounded by wood/shrub and pastures no longer in use. There are only four houses with permanent residents in this area. The location relative to TCM is in the area of minimal exposure according to the model results (ref).

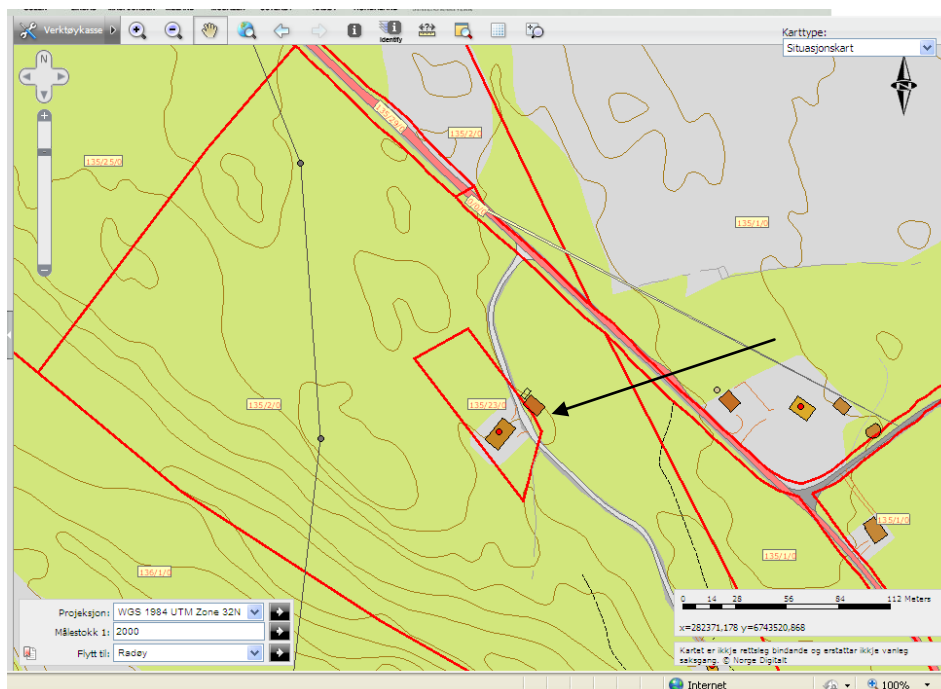


Figure 18: Location of the station site at Bakka.

The picture in figure 19 shows the view from the intended placement of the station towards Mongstad.



Figure 19: View towards Mongstad (north) from the intended location of the station at Bakka.

Appendix D
Multiline sampler

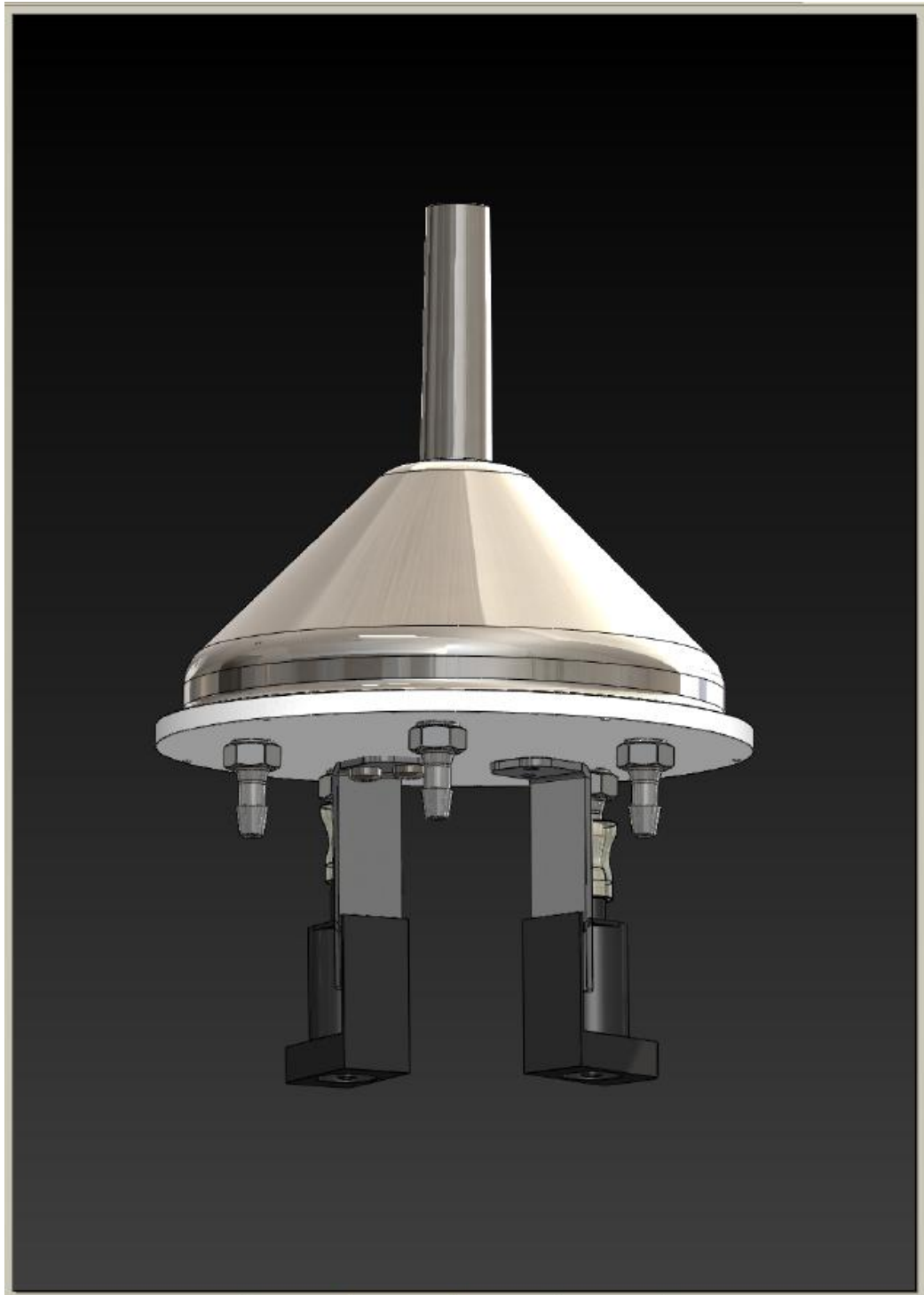


Figure 20: Multiline sampler. Air suction through the upper tube, five filter holder mountings in the lower part. Two mounted filter holders are shown on the figure. The sampler allows increased volume flow without exceeding the specified maximum flow over each filter. One sample consist of 5 single filter or 5 double filters (serie connected).

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