Norsk institutt for luftforskning
Norwegian Institute for Air Research

Monitoring of long-range transported air pollutants in Norway

Annual Report 2018

Wenche Aas, Markus Fiebig, Sverre Solberg and Karl Espen Yttri

NILU report 8/2019

NILU report 8/2019 Norwegian Environment Agency M-1395 | 2019	ISBN: 978-82-425-2970-1 ISSN: 2464-3327	CLASSIFICATION: A – Unclassified (open report)
DATE 18.06.2019	SIGNATURE OF RESPONSIBLE PERSON Ole-Anders Braathen, Deputy Director (sign.)	NUMBER OF PAGES 126

TITLE

Monitoring of long-range transported air pollutants in Norway

Annual Report 2018

PROJECT LEADER

Wenche Aas

NILU PROJECT NO.

O-113007/O-113008

AUTHOR(S)
Wenche Aas, Markus Fiebig, Sverre Solberg and Karl Espen Yttri

QUALITY CONTROLLER

Kjetil Tørseth

REPORT PREPARED FOR

Norwegian Environment Agency
Postboks 5672 Sluppen, 7485 Trondheim

CONTRACT REF.

Contract number 17078061

This report presents results from the monitoring of atmospheric composition and deposition of air pollution in 2018, and focuses on main components in air and precipitation, particulate and gaseous phase of inorganic constituents, particulate carbonaceous matter, ground level ozone and particulate matter. 2018 was a special year with elevated ozone levels during the whole summer season due to prolonged heat and drought.

NORWEGIAN TITLE

Overvåking av langtransportert forurenset luft og nedbør. Atmosfæriske tilførsler 2018.

KEYWORDS

Atmosphere and climate/ Atmosfære og klima/	Aerosols and particles/ Aerosoler og partikler	Ground level ozone/ Bakkenært ozon	Acid rain and eutrophication/ Sur nedbør og overgjødsling

ABSTRACT (in Norwegian)

Denne rapporten omhandler resultater fra overvåkningsprogrammet for langtransportert forurenset luft og nedbør og atmosfæriske tilførsler i 2018. Rapporten presenterer målinger av uorganiske hovedkomponentene i luft og nedbør, partikulært karbonholdig materiale, partikkelmasse og bakkenært ozon. 2018 var et spesielt år med forhøyede ozonnivåer gjennom hele sommersesongen på grunn av langvarig varme og tørke.

PUBLICATION TYPE: Digital document (pdf)	COVER PICTURE: Source: NILU, Birkenes Observatory

Contents

Sammendrag

Overvåkingsprogrammet for langtransporterte luftforurensninger som presenteres i denne rapporten, omhandler målinger av svovel- og nitrogenforbindelser i luft og nedbør, elementært og organisk karbon (EC/OC) i partikler, bakkenært ozon, partikkelmasse (PM_{10} og $PM_{2.5}$) og størrelsesfordeling av partikkelantall på 16 norske bakgrunnsstasjoner. I tillegg rapporteres målinger av levoglukosan på Birkenes.

Hovedmålet er å kvantifisere nivåene og dokumentere eventuelle endringer i atmosfærisk tilførsel, noe som er viktig for å kunne evaluere luftforurensningenes effekt på økosystem, helse, materialer og klima. Programmet startet i 1973 med målinger av svovel- og nitrogenforbindelser og ble senere utvidet med bakkenært ozon (1985), partikler og EC/OC (2000/1) og størrelsesfordeling av partikkelantall (2010).

Kjemisk sammensetning og geografisk fordeling
De høyeste konsentrasjonene av svovel, nitrogen og partikkelmasse måles vanligvis ved Birkenes i Aust-Agder. Dette skyldes nærhet til utslippsområdene på kontinentet. Noen stasjoner i innlandet påvirkes av regional landbruksaktivitet og kan ha noe høyere ammoniumnivå. De høyeste nivåene av EC, OC og NO_2 observeres på Hurdal i Akershus, sannsynligvis på grunn av at denne regionen er relativt tett befolket, og har relativt mye veitrafikk. Målestasjonene i Finnmark opplever hvert år høye nivåer av sulfat på grunn av påvirkning fra nærliggende smelteverk på Kola-halvøya i Russland. Den høyeste våtavsetningen av svovel og nitrogen skjer langs kysten fra Aust-Agder til Hordaland.

Sekundære uorganiske forbindelser (SIA: sulfat, nitrat og ammonium) utgjorde en større andel av PM_{10} (35%) på Birkenes enn på de to andre stasjonene, hvilket reflekterer områdets nærhet til store antropogene utslippsområder på det europeiske kontinentet, mens organisk karbon materiale hadde en relativt større andel på Kårvatn (45%) og Hurdal (44%). Sjøsaltpartikler utgjorde en betydelig andel (19%) av PM_{10} på Birkenes, men betydelig lavere enn andelen organisk karbon materiale (30%). Mineralstøv ble estimert å utgjøre 13% av PM_{10} på Birkenes.

Episoder
Det var bare noen få episoder med høye døgnverdier av svovel- og nitrogenforbindelser i 2018. Kildeområdene for episodene i Sør-Norge er hovedsakelig kontinentet, mens de høyeste episodene i nord, skyldes ofte forurenset luft fra Russland.

2018 var et år med forhøyede ozonnivåer gjennom hele sommersesongen selv om maksimumsnivåene ikke var veldig høye. Dette var mest markant på stasjonene i den sørlige delen av landet. De forhøyede ozonnivåene i sommersesongen skyldes de ekstreme værforholdene i Sør-Norge med langvarig varme og tørke.

Overskridelser
Årsmiddelkonsentrasjonene av PM_{10} og $PM_{2.5}$ lå langt under nasjonale og internasjonale grenseverdier (EU) og retningslinjer (WHO) for luftkvalitet på alle målestasjonene. Heller ikke døgnmiddelverdier (PM_{10}) overskred grenseverdier og retningslinjer.

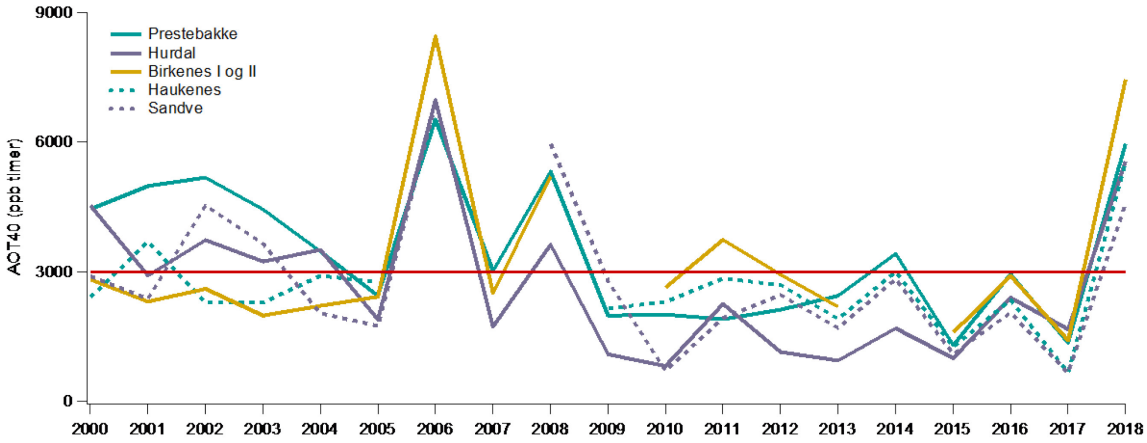
EUs grenseverdi («target value») for ozon knyttet til beskyttelse av vegetasjon og helse har ikke blitt overskredet på mange år i Norge. EUs langtidsmål for ozon («long-term objective») knyttet til helse ble derimot brutt på alle stasjoner unntatt Zeppelinfjellet, og langtidsmålet for beskyttelse av landbruksvekster ble overskredet på fem stasjoner i Sør-Norge i 2018. Seks-måneders (april-september) AOT40 (Accumulated exposure over the threshold of 40 ppb) var også høyt på de norske

stasjonene, og UN-ECEs grenseverdi for skog ble overskredet på 6 av 8 stasjoner i 2018. WHOs retningslinje for luftkvalitet for ozon, og de nasjonale retningslinjene satt av Folkehelseinstituttet, overskrides i varierende grad hvert eneste år i Norge. Overskridelsen av disse retningslinjene var spesielt stor i 2018. EUs grenseverdi for informasjon til publikum ble derimot ikke overskredet i 2018 og har heller ikke blitt brutt på mange år i Norge.

Trender

Konsentrasjonene av nitrogen- og svovelkomponenter i luft og nedbør i 2018 var noe høyere enn nivået i 2017, mens i et lengre perspektiv er det tydelig nedgang i nivåene. Årsmiddelkonsentrasjonene av PM_{10} og $PM_{2.5}$ i 2018 var innenfor ett standardavvik av langtidsmidlet, mens årsmiddelkonsentrasjonen av OC var den høyeste observert på mer enn 10 år for Birkenes og kun marginalt lavere enn det høyeste årsmidlet rapportert for Hurdal og Kårvatn. En oversikt over alle trendene er vist i tabell 1. Trendene gjenspeiler i stor grad utslippsreduksjonene som har skjedd på det europeiske kontinentet de siste tiårene, men årlige variasjoner i meteorologi kan skjule noe av effekten av utslippsreduksjonene, spesielt for ozon. På grunn av den varme og tørre sommeren i 2018 var nivået av bakkenært ozon uvanlig høyt og en så omfattende overskridelse av grenseverdiene for vegetasjon har ikke forekommet i landet på over 10 år, se Figur 1. 3-måneders AOT40 på Birkenes i 2018 var den nest høyeste verdien som har blitt målt i Norge siden starten av 1990-tallet

De ekstreme værforholdene i 2018 med langvarig varme og tørke viser hvor store koblinger det er mellom klima og luftforurensninger. Et viktig vitenskapelig spørsmål er i hvilken grad de positive effektene av utslippstiltak som har blitt foretatt i Europa de siste 20 årene eller mer kan bli oppveiet av framtidige klimaendringers påvirkning på luftforurensningene. Selv om det er usannsynlig at værforhold som man hadde i 2018 vil bli det normale, er det sannsynlig at slike forhold vil forekomme oftere.



Figur 1: Tremåneders AOT40-verdi (1 mai -31 juli) for ozonstasjoner i Sør-Norge i perioden 2000-2018. EUs langtidsmål på 3000 ppb-timer for beskyttelse av vegetasjon er markert i rødt.

Summary

The atmospheric monitoring programme presented in this report includes observations of sulfur- and nitrogen compounds in air and precipitation, elemental- and organic carbon (EC/OC) in aerosols, ground level ozone, particulate matter (PM_{10} and $PM_{2.5}$) and aerosol size distribution, at a total of 16 sites in the Norwegian rural background environment. In addition, observations of levoglucosan at the Birkenes Observatory are reported.

The main objective is to quantify the levels of these pollutants and to document any changes in atmospheric pollution, which is important for studies on its influence on ecosystems, human health, materials and climate change. The program started in 1973 with measurements of sulfur and nitrogen compounds and was later extended with ozone (1985), aerosol particles, carbonaceous aerosols (2000/1), and aerosol size distribution (2010).

Chemical composition and geographical distribution
The highest concentrations of sulfur, nitrogen and particular matter are typically observed at Birkenes in Aust-Agder. However, some inland sites are influenced by regional agricultural activities and experience somewhat higher ammonium levels. The highest EC-, OC- and NO_2-levels are seen in Hurdal in Akershus, likely due to influence from the more densely populated region surrounding this site, including road traffic. The sites in Finnmark experience high levels of sulfate due to influence from the nearby smelters at the Kola Peninsula in Russia. The highest wet deposition of inorganic ions occurred along the coast from Aust-Agder to Hordaland.

Secondary inorganic aerosol (SIA: sulfate, nitrate and ammonium) was the most abundant fraction of PM_{10} (34%) at Birkenes, reflecting the site's proximity to major anthropogenic emission regions in continental Europe, followed by organic matter (30%), sea salt (19%) and mineral dust (13%). Organic matter dominated by far at the Kårvatn (45%) and Hurdal (44%) sites.

Episodes
There were only a few episodes with high concentrations of sulfur- and nitrogen-components in 2017. The source area for episodes in Southern Norway is mainly the continent, while at Svalbard and Northern Norway the episodes are due to polluted air arriving from Russia.

2018 was a year with elevated ozone levels during the whole summer season although the peak values were not particularly high. This was most pronounced for the stations in the southern part of the country. The elevated ozone levels in the summer season corresponds with the extreme weather conditions experienced in South Norway with prolonged heat and drought.

Exceedances
PM_{10}- and $PM_{2.5}$-observations were all well below the EU limit-values, the national limit-values and the WHO and the National Air Quality Guidelines on an annual as well as on a 24-hour basis.

EU's ozone target values for protection of human health and vegetation have not been exceeded for many years in Norway. EU's long-term objective for protection of human health was however, violated at all the stations except at the Zeppelin Mountain in 2018. WHO's air quality guideline for ozone as well as the national guidelines are exceeded every year in Norway to a varying extent. The exceedance of these guidelines was particularly pronounced in 2018. EU's information threshold to the public was not exceeded in 2018 and has not been broken for many years in Norway. EU's long-term objective for protection of vegetation was exceeded at five stations in Southern Norway in

2018. The six-months AOT40 value (April-September) showed high values as well, and UN-ECE's critical level for forests was exceeded at 6 of the 8 stations in 2018.

Trends

The concentration levels of nitrogen compounds in air and precipitation were in 2018 somewhat higher than in 2017, but the long term trends are declining. The annual mean concentration of PM_{10} and $PM_{2.5}$ were within one standard deviation of the long-term mean, whereas the OC annual mean was the highest observed for more than a decade at Birkenes, and almost equally high as the highest annual mean observed at the Hurdal and Kårvatn sites.

An overview of the long-term trends are shown in Table 1 The trends reflect to a large extent the emission reductions which have taken place in the European continent the last decades, although inter-annual variations in meteorology could mask the effect of the emission reductions, particularly for ozone. The prolonged heat and drought during the summer season in 2018 caused widespread exceedance of the long-term objective, which hasn't been seen in Norway for over ten years, Figure 1. The 3-months AOT40 value (for protection of vegetation) at Birkenes in 2018 was the second highest value observed in Norway since the early 1990s.

The highly unusual weather conditions in 2018, with prolonged heat and drought, highlights the strong links between climate and air pollution. An essential scientific question is to what extent the positive consequences from emission abatement policies in Europe that have taken place during the last 20 years or more could be outweighed by negative consequences on air pollution linked to future climate change. Although it is unlikely that weather conditions as those experienced in 2018 will become the normal, it is likely that such conditions could become more frequent.

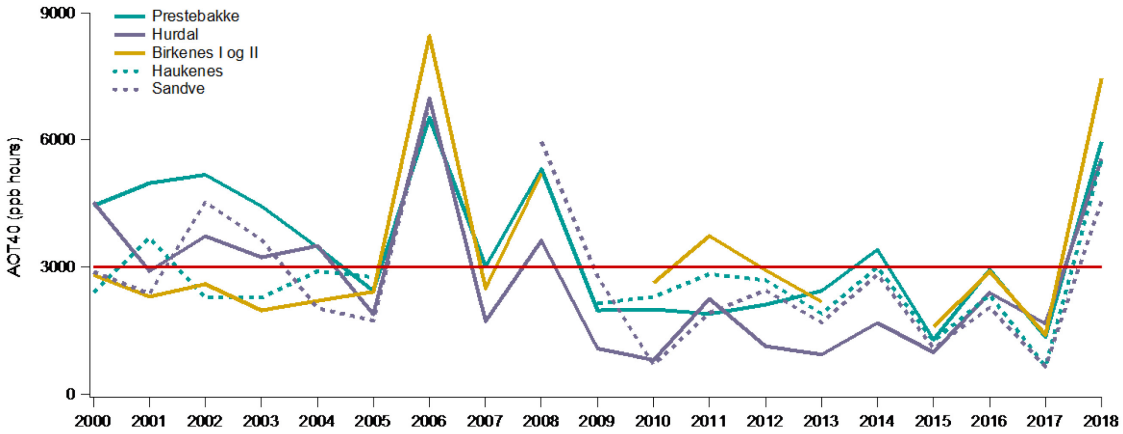


Figure 1: 3 months' AOT40 values (1 May - 31 July) for the years 2010 – 2018. The EU directive's long-term objective of 3000 ppb hours for protection of vegetation is indicated by the line.

Table 1: Trends in annual levels using Mann-Kendall test and Sen slope estimates. The Note that trends are given for sites with significant change only.

Component	Sites	1980-2018	1990- 2018	2000-2018
SO_2	3-4 sites[1)]	almost 100%	-78% - -93%	-58% - -62%
SO_2	Zeppelin	-88%	-76%	-64%
SO_4^{2-}in aerosols	3-4 sites[1)]	-86 - -91%	-72% - -81%	-50% - -61%
SO_4^{2-} in aerosols	Zeppelin	-67%	-43%	-27%
SO_4^{2-} in precipitation	All (8 – 12 sites)	-77 - -97%	-53% - -89%	-40% --72%[2)]
NO_2	4 sites[1)]		-39% - -68%	-34% - -47%
NO_3^- in precipitation	S and SW sites	-43 - -53%	-29% - -52%	3 sites: -20% - -36%
HNO_3+NO_3^- in air	4 sites[1)]		Hurdal: -31%	Not sign.trend
NH_4^+ in precipitation	S and SW sites	-50 - -67%	+80% - -55%	Not sign.trend
NH_3+NH_4^+ in air	4 sites[1)]		3 sites: +64% - -41%	Tustervatn -55%
PM_{10}	Birkenes			-33%
$PM_{2.5}$	Birkenes			-45% (2001-2018)
OC	Birkenes			-25% - -35% (2001-2018)
EC	Birkenes			-48% - -54% (2001-2018)
TC	Birkenes			-33% - -38% (2001-2018)
O_3, 3-months AOT40	4 sites[3)]			Kårvatn only: -65% (1996-2018)
O_3, 8h >100 µg/m^3	4 sites[3)]			-63% - -88% (1996-2018)

[1)] Birkenes, Nordmoen/Hurdal, Kårvatn, Tustervatn. Nordmoen/Hurdal was not part of 1980-2018
[2)] Tustervatn without significant trend in this period
[3)] Kårvatn, Sandve, Tustervatn and Prestebakke

Monitoring of long-range transported air pollutants in Norway

Annual Report 2018

1 The monitoring programme 2018

The atmospheric monitoring programme presented in this report focuses on particulate and gaseous phase inorganic constituents, particulate carbonaceous matter, ground level ozone and particulate matter in the Norwegian rural background environment. The main objective is to quantify the levels of these pollutants and to document any changes in the atmospheric long-range transported pollution. An important goal is to measure the effectiveness of the protocols, i.e. the 1999 Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (UN/ECE, 1999)

The monitoring sites are located in areas where the influence of local sources are minimal, and thus the sites being representative for a wider region. Regular sampling of precipitation on a daily basis in Southern Norway dates back to 1973. After that, the measurement program and the monitoring network was expanded to provide improved information on atmospheric contribution of air pollution for all of Norway.

After the conclusion of the SNSF *("acid rain's effects on forest and fish")* project in 1979, a national monitoring program organized by the Norwegian Environment Agency was initiated in 1980. Several changes in the content of the measurement programme, as well as in the number and distribution of monitoring sites, has taken place during the 40 years life-time of this monitoring programme, although only small changes since 2011. The measurements presented in the current report are part of different national projects and programmes:

- *The National monitoring programme on behalf of The Norwegian Environment Agency:*
  - Ozone at four sites (Birkenes, Tustervatn, Kårvatn, Zeppelin)
  - Daily measurements of NO_2 at four sites (Birkenes, Hurdal, Tustervatn, Kårvatn)
  - Weekly measurements of particulate matter (PM_{10} and $PM_{2.5}$) and EC/OC at three sites (Birkenes, Hurdal, Kårvatn)
  - High time-resolution measurements of particle number and size distribution at Birkenes
  - Daily measurements of particulate and gaseous inorganic compounds in air and precipitation at two sites (Birkenes and Zeppelin; weekly for precipitation at Ny-Ålesund)
  - Meteorology at three sites (Birkenes, Zeppelin and Hurdal)
  - Inorganic ions in precipitation at Svanvik (part of the programme for ICP Material)
- *Measurement programme to preserve long-time data series on behalf of the Ministry of Climate and Environment, co-financed by NILUs internal monitoring programme (these measurements are in 2019 taken over by the Norwegian Environment Agency) :*
  - Daily measurements of particulate and gaseous inorganic compounds in air and precipitation at three sites (Hurdal, Kårvatn and Tustervatn)
  - Weekly measurements of main inorganic ions in precipitation at eight sites (Vikedal, Treungen, Haukeland, Brekkebygda, Høylandet, Nausta, Vatnedalen, Løken). The observations at Haukeland stopped in April 2018.
  - Ozone at three sites (Hurdal, Sandve and Prestebakke)
- *Norway-Russia programme on behalf of The Norwegian Environment Agency:*
  - Weekly measurements of main inorganic ions in air and precipitation at Karpbukt
- *Local air pollution program, co-financed by the municipalities in Porsgrunn, Skien and Bamble:*
  - Ozone at Haukenes

Data and results from the national monitoring programme of air pollutants are also included in various international regional programmes. Five of the sites are part of EMEP (European Monitoring and Evaluation Programme) under the CLRTAP (Convention on Long-range Transboundary Air Pollution, http://www.unece.org/env/lrtap). Data from several of the sites are also being reported to CAMP (Comprehensive Atmospheric Monitoring Programme) under OSPAR (the Convention for the Protection of the marine Environment of the North-East Atlantic, http://www.ospar.org); AMAP (Arctic Monitoring and Assessment http://www.amap.no) and WMO/GAW (The World Meteorological Organization, Global Atmosphere Watch programme, http://www.wmo.int). A subset of the data are also reported to EEA (European Environmental Agency, http://www.eea.europa.eu/) as required in the EU air quality directive (EU, 2008). Near real time data of ozone is reported continuously to both Norwegian (http://www.luftkvalitet.info) and European (EEA) air quality warning services). All the data are openly available at http://ebas.nilu.no.

The present report is one of four reports, which cover the national monitoring of atmospheric composition in the Norwegian rural background environment. The other three reports are published separately, of which the first focuses on persistent organic pollutants and heavy metals (Nizzetto et al., 2019), the second covers the monitoring of the ozone layer and UV (Svendby et al. 2018), whereas the third is on climate gases and aerosol particles influence on climate (Myhre et al., 2018). The site locations and key information on the monitoring programme at the actual sites are illustrated in Figure 1.1. Detailed station information, monitoring program and measurement frequencies are provided in Annex 2, whereas sampling methods and chemical analysis are described in Annex 3.

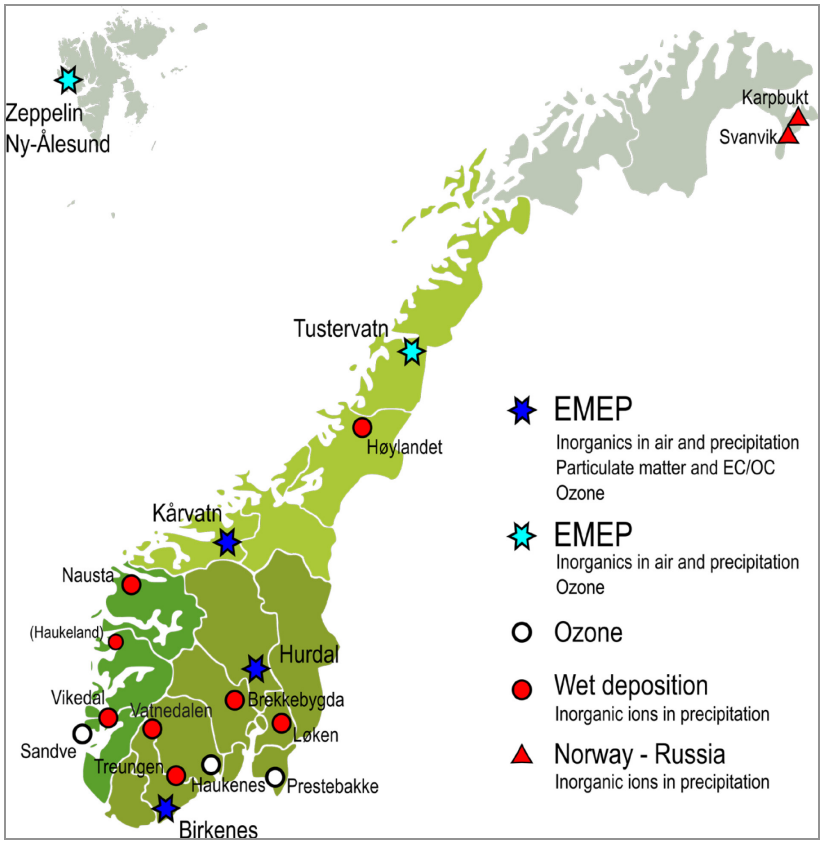


Figure 1.1: Norwegian background sites and their measurement programme 2018. Details are found in Annex 2. The colour codes indicate the different regions/zones used in EU's Ambient Air Quality Directive (2008).

2 The weather in Norway 2018

The variation in meteorological conditions from year to year is decisive for the observed concentrations of pollutants in air and precipitation. The atmospheric state, i.e. the large-scale synoptic situation with distribution of high- and low-pressure systems, temperature, stability, humidity etc. are controlling the pollutant levels in air as well as the surface dry deposition and wash-out at the Norwegian monitoring stations.

In 2018 the annual average temperature for country as a whole was 1.4°C above the normal (all normal refer to the 1961-1990 period) while the average precipitation was close to the normal (Met. Institute, 2019). This makes 2018 the 13th warmest year since 1900. The annual temperature anomaly on the mainland was largest in southeast Norway (2-2.5°C above the normal). In the Arctic, Ny-Ålesund had an annual mean temperature that was 4.3°C above the normal and the region experienced the 3rd warmest year since the start of the measurements in the Arctic.

Although 2018 was not a "record-year" with respect to the annual mean temperature or precipitation, a large number of temperature records were set this year. These records were mainly linked to very dry and cold conditions in South Norway in March and very hot and dry conditions in May and July.

The year started with milder conditions in most of the country in January, amounting to 3-5°C above the normal in the southeast with 200-300% of the normal precipitation in the same region. This was associated with low pressure systems following a southerly track, setting up winds from the south and southeast with transport of wet and mild air masses into the southern areas. This weather pattern continued in February and was followed by a high-pressure ridge being established in the north. This lead to very dry conditions in the north (Troms and parts of Finnmark) with only 25% of the normal precipitation. Inner areas of SE Norway however, received 200% of the normal precipitation this month. As a consequence, outer (coastal) regions in SE-Norway had 300% of the normal snow depth by the end of February.

The high pressure system gradually moved southwards in March leading to a blocking-high situation in the southern half of the country while northerly, onshore winds with frontal passages and precipitation dominated in the far north. This lead to low temperatures and very dry conditions in the southern part and many sites experienced record-low minimum temperatures and low precipitation amount in that area. Whereas the southern areas had down to 25% of the normal precipitation and temperatures 3-6°C below the normal, Finnmark received 200- 350% of the normal precipitation in March. The high-pressure system continued to determine the weather also in the first part of April, followed by transport of air masses from the south and southeast in the last part of the month. This lead to drier conditions than normal in the north whereas the mountain and inland areas in south Norway received 200-250% of the normal precipitation this month. The temperature was above the normal in the entire country in April.

In May, a very strong and very persistent heat wave started in the southern part of the country. The average temperature for the whole country was 4.4°C above the normal, making May 2018 the warmest May measured since the start of the statistics in 1900. In the southeast, the average temperature was 5-7°C above the normal and many sites experienced record-high maximum temperatures, peaking at 32.7°C at Etne, Hordaland 30 May. The heat wave was associated with dry conditions in many areas with 50% of the monthly precipitation. Stations in the Arctic experienced the 90th month in a row with mean temperatures above the normal.

The dry weather continued in southern Norway in June with regions receiving only 25% of the normal precipitation. Temperatures above the normal continued in June, although not as extreme as in May and were on average 2-3°C above the normal in S-Norway. The country was "split in two" weather-wise this month, with the northern part from Trøndelag to Finnmark receiving much more precipitation than normal (above 300% of the normal in some regions) and mean temperatures 1-3°C below the normal in most of that area. The persistent heat wave continued and intensified in the southern part in July and now also extended to the northern part of the country. Mean temperatures were well above the normal and total precipitation well below the normal in the whole country this month leading to a country average temperature 4.3°C above the normal, making July 2018 (together with July 2014) the hottest July observed since the start of the statistics in 1900. Some areas in the far north (Finnmarksvidda) and the southeast experienced mean temperatures 5-7°C above the normal. More than 40 stations registered record-high monthly mean and daily maximum temperatures this month and many sites also broke the record for low precipitation amount. A peak temperature of 34.7°C was observed at Åndalsnes (Møre og Romsdal) 28 July. The precipitation amount for the country as a whole was only 55% in July, making it the second driest July since 1900. In the Arctic, the station at Ny-Ålesund broke the record for high precipitation amount, receiving 99 mm this month.

For most of the country, the extreme heat and drought ended in August with many areas receiving 200-300% of the normal precipitation and for the country as a whole 160% of the normal, making this the wettest August since 1900. The westerly and south-westerly winds that broke up the persistent high-pressure did, however, not bring large amounts of precipitation to the areas in the southeast which received only 50 % of the normal precipitation in this month leading to severe drought in the agricultural areas after months with little precipitation and high temperatures. In the far north, very high temperatures were experienced in the beginning of August, linked to the so-to-speak "last breath" of the heat wave with a peak temperature of 32.8°C at Banak on 1st August.

In September westerly and south-westerly winds continued, leading to warmer and wetter conditions in most of the country. Particularly high precipitation amounts were received in W-Norway with 300-400% of the normal amounts. For the country as a whole, this September (together with the Septembers in three other years) was the wettest since 1900. The westerly winds continued also in October leading to wet conditions in W-Norway and Nordland with 200-250% of the normal precipitation whereas it was dry in SE-Norway, Troms and Finnmark.

In November, the prevailing weather pattern changed now bringing winds from the south and southeast over the country associated with a high-pressure system to the east. This lead to very dry conditions in W-Norway and Trøndelag while SE-Norway and Finnmark received 150-200% of the normal precipitation. The southerly winds brought warm air masses, and the country average was 3.7° above the normal this month while mountainous regions in the southeast experienced mean temperatures as high as 6-8° C above the normal. The southerly winds also lead to high precipitation amounts in the Arctic, and Ny-Ålesund received 95 mm, corresponding to almost 300% of the normal for November. In December a similar pattern as in November was seen with higher mean temperatures all over the country (on average 2.2°C above the normal), wet conditions in the southeast and at Finnmarksvidda (200-300% of the normal) and dry conditions elsewhere. Very high precipitation amounts were observed in the Arctic also in December with 100 mm at Ny-Ålesund, corresponding to more than 300% of the normal precipitation.

3 Inorganic components

3.1 Observations in 2018

3.1.1 Chemical composition in precipitation

All sulfate values given in the present report are adjusted for the contribution of sulfate associated with sea salt. The sea-salt sulfate content is calculated based on the ratio of sodium, or magnesium and chloride, to sulfate in seawater, and is according to the procedures suggested by EMEP (EMEP/CCC, 2013). From 2013, measurements of precipitation on a daily basis, as recommended by EMEP and WMO/GAW, is conducted at the four EMEP sites on the Norwegian main land, the other sites with weekly sampling.

Monthly and annual concentrations and wet depositions for all sites are listed in Annex A.1.1-A.1.19, and all years in A.1.21, while Table 3.1 lists the annual mean concentrations and depositions at all stations for 2018.

Regional distribution of mean concentrations and wet depositions are shown in Figure 3.1 and Figure 3.2. Table 3.1, Figure 3.1 and Figure 3.2 show that the ion content decreases along a South to North transect excluding the county of Finnmark. The highest concentrations of sulfate, nitrate and ammonium are seen in south and southeast while the wet depositions are highest in southwest, correlated to the high precipitation amount on the west coast. The sites in Finnmark are influenced by emissions from Russia and the content of sulfate is particularly high.

Table 3.1 shows that all regions, except the most continental parts of southern Norway and Finnmark, observed significant amounts of sea salts. At most sites, there was an excess of cations, which probably is due to the content of bicarbonate or other anions of weak acids that are not determined. At Vatnedalen it also seems to be a problem with the sea salt ions of unclear reason.

As seen for previous years, the highest annual mean concentrations for the major components were generally observed at the Birkenes site (Table 3.1); the exceptions were observed for sulfate, which were higher for Karpbukt and Svanvik due to the influence of emissions from Nikel (Russia). Being situated only 20 km from the Skagerrak coastline, Birkenes is the site in Norway being the most influenced by long-range transport from the European Continent and UK, hence this finding is to be expected. However, some inland sites are influence by regional agricultural activities and experience somewhat higher ammonium concentrations, i.e. Treungen, Hurdal and Løken. The highest wet deposition loads of sulfate, nitrogen components and strong acid occurred along the coast from Aust-Agder to Hordaland.

Table 3.1: Annual volume weighted mean concentrations and total wet deposition of inorganic ions at Norwegian background stations, 2018.
**: Corrected for contribution from sea salt.*

Site	Volume weighted annual mean concentrations (mg/L)									Wet deposition (mg/m², H⁺: µekv/m²)									Volume weighted annual mean concentrations in equivalence units (µekv/)										Ion bal.
	pH	SO_4* mg S/l	NO_3 mg N/l	NH_4 mg N/l	Ca mg/l	K mg/l	Mg mg/l	Na mg/l	Cl mg/l	mm	H+ µekv/m²	SO_4* mg S/m²	NO_3 mg N/m²	NH_4 mg N/m²	Ca mg/m²	K mg/m²	Mg mg/m²	Na mg/m²	Cl mg/m²	H(+) µekv/l	SO_4*(2-) µekv/l	SO_4(2-) µekv/l	NO_3(-) µekv/l	NH_4(+) µekv/l	Ca(2+) µekv/l	K(+) µekv/l	Mg(2+) µekv/l	Na(+) µekv/l	Cl(-) µekv/l	kat./an.
Birkenes	4.95	0.20	0.43	0.44	0.14	0.09	0.18	1.49	2.60	1515	17124	310	655	673	216	137	271	2265	3947	11	12	21	31	31	7	2	15	65	73	1.06
Vatnedalen	5.51	0.10	0.13	0.13	0.10	0.11	0.04	0.83	0.84	967	2987	94	122	127	100	109	36	806	809	3	6	7	9	9	5	3	3	36	24	1.52
Treungen	5.02	0.15	0.30	0.28	0.10	0.05	0.05	0.37	0.62	878	8389	133	260	247	88	48	44	326	542	10	9	11	21	20	5	1	4	16	17	1.13
Løken	5.14	0.17	0.27	0.26	0.21	0.18	0.10	0.51	0.88	619	4443	103	167	161	133	113	62	313	545	7	11	13	19	19	10	5	8	22	25	1.26
Hurdal	5.04	0.17	0.30	0.31	0.14	0.10	0.06	0.49	0.81	901	8260	156	270	278	125	91	57	438	726	9	11	13	21	22	7	3	5	21	23	1.18
Brekkebygda	4.98	0.15	0.24	0.20	0.15	0.08	0.05	0.36	0.60	1003	10538	151	245	197	150	78	53	364	602	10	9	11	17	14	7	2	4	16	17	1.21
Vikedal	5.38	0.09	0.16	0.22	0.17	0.11	0.25	2.15	3.81	2807	11723	250	449	618	484	313	709	6034	10690	4	6	17	11	16	8	3	21	94	107	1.08
Nausta	5.40	0.05	0.09	0.13	0.08	0.07	0.13	1.09	1.88	2045	8078	94	179	263	168	153	264	2233	3839	4	3	9	6	9	4	2	11	47	53	1.15
Kårvatn	5.34	0.05	0.08	0.09	0.11	0.11	0.16	1.29	2.24	1196	5432	66	96	111	132	126	186	1544	2683	5	3	10	6	6	5	3	13	56	63	1.14
Høylandet	5.63	0.06	0.05	0.18	0.16	0.14	0.28	2.28	4.16	948	2244	53	51	169	148	135	263	2167	3941	2	4	16	4	13	8	4	23	99	117	1.11
Tustervatn	5.36	0.05	0.07	0.09	0.09	0.09	0.10	0.87	1.54	1192	5214	58	81	107	106	107	121	1037	1835	4	3	7	5	6	4	2	8	38	43	1.16
Svanvik	4.83	0.33	0.12	0.08	0.12	0.17	0.11	0.46	0.79	356	5266	117	42	29	42	59	41	162	281	15	21	23	9	6	6	4	9	20	22	1.12
Karpbukt	4.91	0.32	0.10	0.21	0.16	0.12	0.14	1.11	1.96	567	6954	181	58	118	92	70	82	629	1111	12	20	26	7	15	8	3	12	48	55	1.12
Ny-Ålesund	5.39	0.10	0.07	0.06	0.29	0.13	0.46	3.63	6.46	484	1986	49	33	31	141	64	223	1757	3124	4	6	26	5	4	14	3	38	158	182	1.05

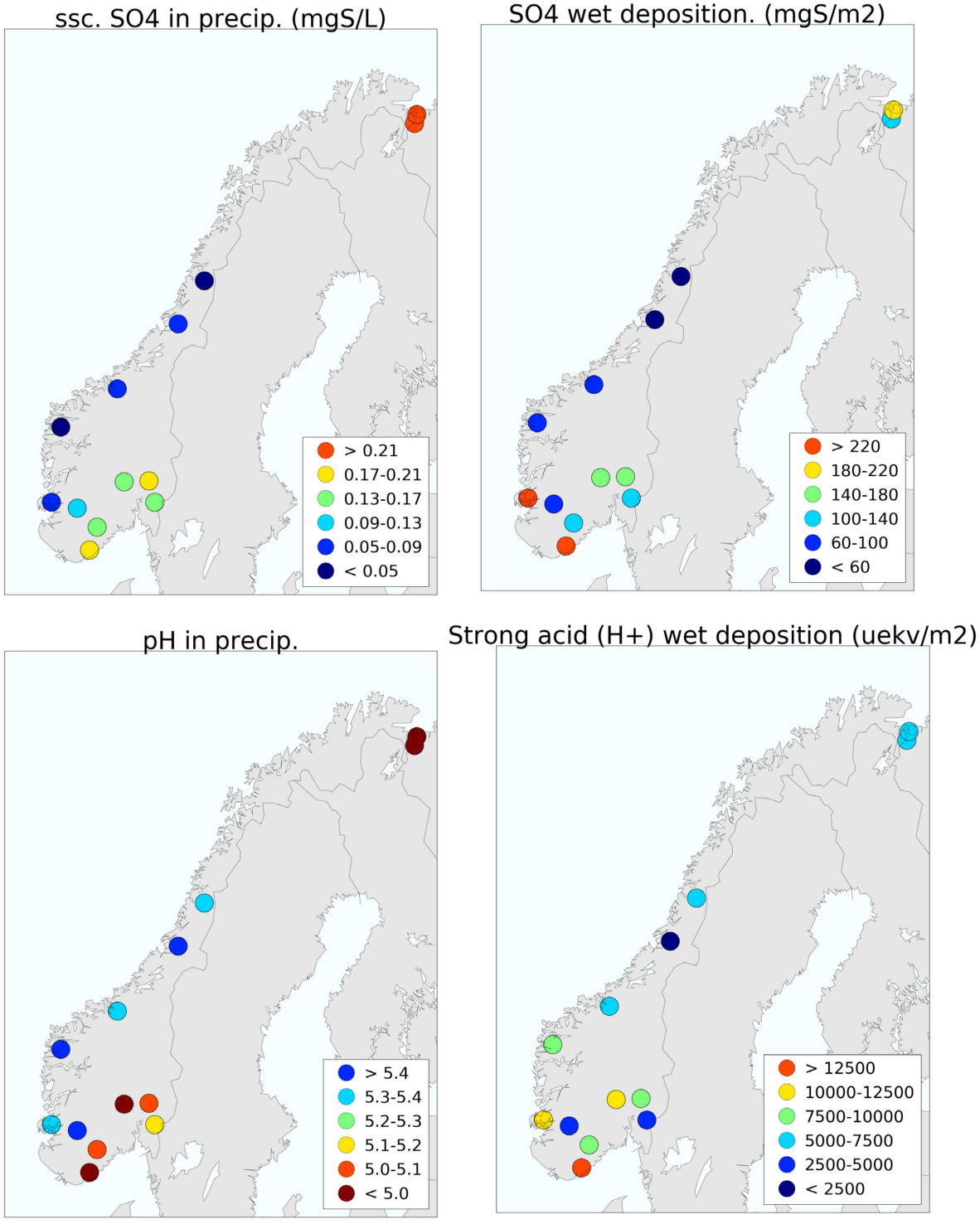


Figure 3.1: Annual volume weighted mean concentrations and total wet deposition of sulfate (sea salt corrected) and strong acid (pH), 2018. Note that the coulours only resemble the spatial distribution and do not indicate any exceedenes of limit values or similar

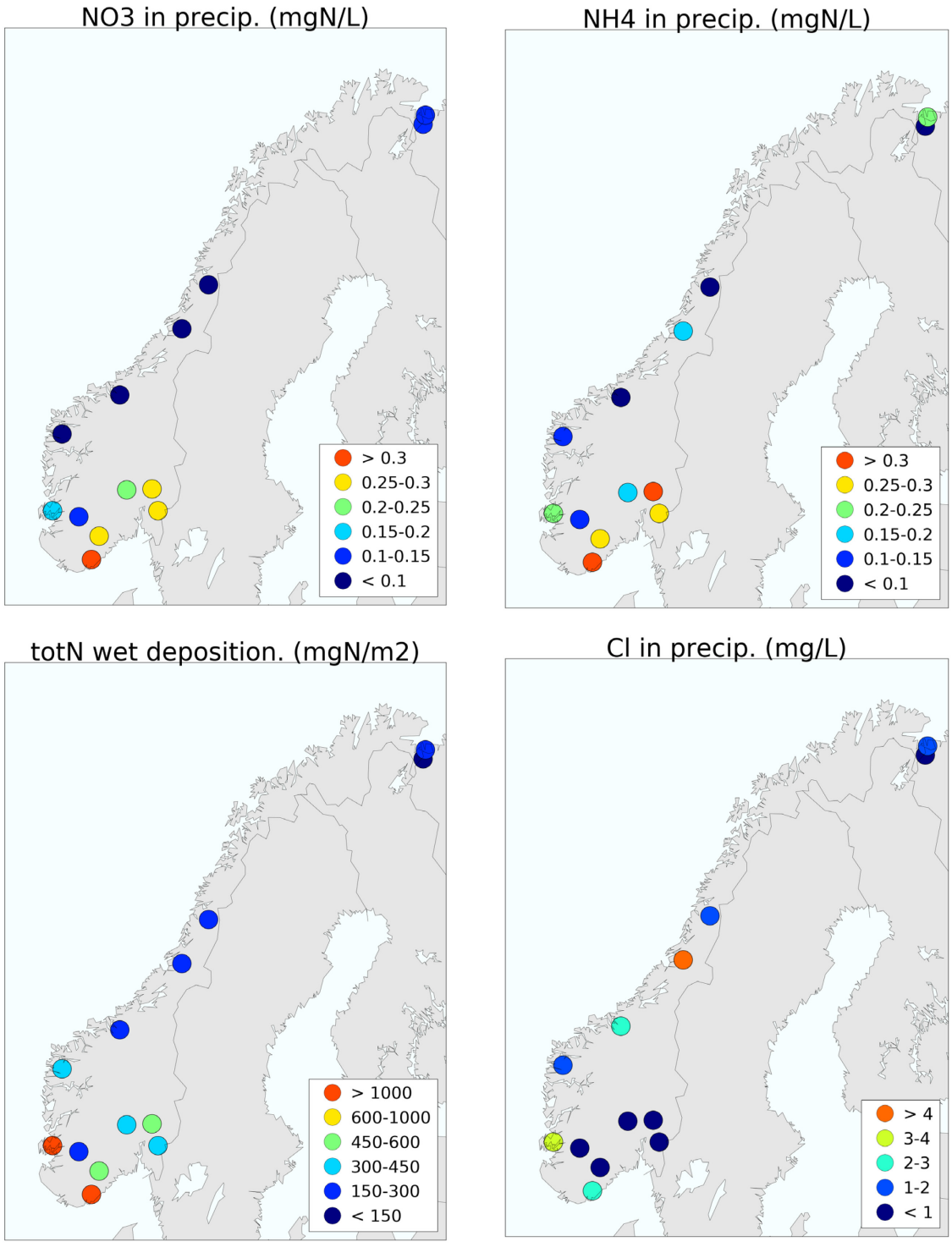


Figure 3.2: Annual volume weighted mean concentrations of nitrate, ammonium, chloride and total wet deposition of nitrogen (nitrate + ammonium), 2018.Note that the colours only resemble the spatial distribution and do not indicate any exceedenes of limit values or similar.

Figure 3.3 shows monthly volume weighted mean concentrations and wet deposition of sulfate, nitrate and ammonium in different parts of Norway, 2018. All the monthly data are given in the tables in Annex 1. There are quite large variabilities in the concentrations as well as depositions throughout the year, though it is not a general pattern common for all regions and components. In 2018, the highest concentrations were for most ions seen in March to May. For wet deposition the high levels were seen in February due to high concentrations and in August to October due to much precipitation. The measured wet deposition of sulfate, shows that between 32% and 43% of the annual total deposition arrives during the ten days with highest deposition at the four sites with daily measurements during the whole year (Table A1.20).

Figure 3.3: Monthly volume weighted mean concentrations (left: a),c),e)) and wet deposition (right: b),d),f)) of sea salt corrected sulfate (top) nitrate (middle), ammonium (bottom) in different parts of Norway, 2018, S, SW: South and South west is the average of the sites Birkenes, Vatnedalen, Treungen and Vikedal; E: East (Løken, Hurdal, Brekkebygda); NW: Northwest (Nausta and Kårvatn); N: North (Høylandet and Tustervatn).

3.1.2 Chemical composition in air

Daily measurements of inorganic components in air was carried out at five sites in 2018, And all of these are EMEP sites (Figure 1.1). Table 3.2 shows the annual mean concentrations while the monthly data are given in A.1.22-A.1.33. The monthly means of the sulfur and nitrogen components are illustrated in Figure 3.4. The maximum and percentile concentrations of SO_2, SO_4^{2-}, sum of (NO_3- + HNO_3), NH_4^+ and sum of (NH_3 + NH_4^+) are given in Table 3.3 to Table 3.8.

Table 3.2: Annual mean concentrations of inorganic components in air at Norwegian background stations, 2018.

	SO_2	SO_4^{2-}	NO_2	sum NO_3	NO_3	sum NH_4	NH_4	Mg	Ca	K	Cl	Na
	µg-S/m³	µg-S/m³	µg-N/m³	µg-N/m³	µg-N/m³	µg-N/m³	µg-N/m³	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³
Birkenes II	0.10	0.26	0.32	0.24	0.19	0.47	0.25	0.06	0.05	0.06	0.54	0.45
Hurdal	0.04	0.18	0.60	0.13	0.09	0.29	0.13	0.02	0.04	0.05	0.14	0.16
Kårvatn	0.03	0.12	0.18	0.05	0.04	0.6	0.06	0.02	0.04	0.03	0.18	0.15
Tustervatn	0.04	0.13	0.11	0.04	0.03	0.35	0.06	0.03	0.02	0.04	0.37	0.25
Zeppelinfjellet	0.04	0.10	-	0.03	0.01	0.11	0.02	0.03	0.02	0.03	0.35	0.23

Annual mean concentrations of sulfur dioxide in air are quite low at all the sites, in 2018 the highest mean concentration was observed at the Birkenes Observatory with 0.10 µg S/m³. The highest daily average was observed at Hurdal with 2.0 µg S/m³ on 30 September. This day the air masses were transported from the North Sea and UK. Though it might also be a contamination, this day it is also enhanced NH_3 and HNO_3 concentrations. The highest annual mean particulate sulfate level was measured at Birkenes (0.26 µg S/m³), but the highest episodes were observed at Zeppelin and Hurdal with 1.7 µg S/m³.

Highest NO_2 levels were observed in Hurdal with an annual mean of 0.6 µg N/m³. This station is influenced by the relatively high traffic emissions in region. The highest daily mean level of NO_2 was also measured at Hurdal with 7.9 µg N/m³ on 7 February. The concentrations of NO_2 show an expected temporal pattern with a winter maximum and summer minimum (Figure 3.5). During winter, there is reduced vertical mixing and the atmospheric residence time is longer due to low photochemical activity.

The highest annual mean concentrations for the sum of nitrate (NO_3^- + HNO_3), and for NH_4^+, were observed at Birkenes with 0.24 µg N/m³ and 0.25 µg N/m³, respectively. The highest annual average of the sum of ammonium (NH_3 + NH_4^+) was observed at Kårvatn, probably due to the influence of agricultural activity in the region.

Table 3.3: Number of daily, observations 50-, 75-, 90-percentile concentrations, max and annual mean concentrations for SO_2 in air at Norwegian background station in 2018.

Site	No. of observations	SO_2 (µg S/m³)					
		Percentile conc.			Max concentration	Date	Annual mean concentration
		50%	75%	90%			
Birkenes II	364	0.04	0.15	0.28	0.74	10.06.2018	0.10
Hurdal	355	0.01	0.04	0.09	1.98	30.09.2018	0.04
Kårvatn	362	0.01	0.03	0.06	0.53	16.03.2018	0.03
Tustervatn	361	0.01	0.03	0.08	1.15	15.03.2018	0.04
Zeppelin	357	0.01	0.03	0.08	0.83	23.03.2018	0.04

Table 3.4: Number of daily, observations 50-, 75-, 90-percentile concentrations, max- and annual mean concentrations for SO_4 in aerosols at Norwegian background station in 2018.

Site	No. of observations	SO_4^{2-} (µg S/m³)					
		Percentile conc.			Max concentration	Date	Annual mean concentration
		50%	75%	90%			
Birkenes II	363	0.20	0.36	0.52	1.38	07.03.2018	0.26
Hurdal	358	0.12	0.23	0.4	1.70	07.02.2018	0.18
Kårvatn	362	0.06	0.18	0.31	0.73	14.04.2018	0.12
Tustervatn	361	0.09	0.17	0.28	0.76	18.01.2018	0.13
Zeppelin	356	0.07	0.12	0.19	1.76	25.04.2018	0.10

Table 3.5: Number of daily, observations 50-, 75-, 90-percentile concentrations, max and annual mean concentrations for NO_2 in air at Norwegian background station in 2018.

Site	No. of observations	NO_2 (µg N/m³)					
		Percentile conc.			Max concentration	Date	Annual mean concentration
		50%	75%	90%			
Birkenes II	365	0.27	0.39	0.56	1.71	09.02.2018	0.32
Kårvatn	366	0.14	0.22	0.32	2.15	02.03.2018	0.18
Tustervatn	328	0.08	0.13	0.23	0.51	18.01.2018	0.11
Hurdal	365	0.39	0.61	1.17	7.89	07.02.2018	0.60

Table 3.6: Number of daily, observations 50-, 75-, 90-percentile concentrations, max- and annual mean concentrations of the sum of nitrate and nitric acid in air at Norwegian background station in 2018.

Site	No. of observations	NO_3^-+HNO_3 (µg N/m^3)					
		Percentile conc.			Max concentration	Date	Annual mean concentration
		50%	75%	90%			
Birkenes II	362	0.13	0.26	0.56	3.6	09.02.2018	0.24
Hurdal	356	0.08	0.16	0.30	1.76	12.02.2018	0.13
Kårvatn	361	0.03	0.06	0.14	0.41	22.05.2018	0.05
Tustervatn	361	0.03	0.05	0.08	0.75	21.05.2018	0.04
Zeppelin	357	0.02	0.03	0.04	0.25	25.04.2018	0.03

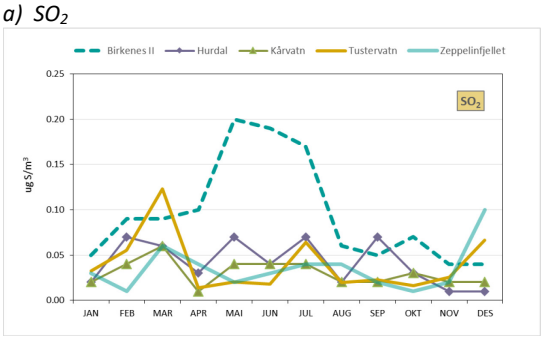
Table 3.7: Number of daily, observations 50-, 75-, 90-percentile concentrations, max- and annual mean concentrations of ammonium in aerosols at Norwegian background station in 2018.

Site	No. of observations	NH_4^++NH_3 (µg N/m^3)					
		Percentile conc.			Max concentration	Date	Annual mean concentration
		50%	75%	90%			
Birkenes II	364	0.25	0.61	1.12	5.2	09.02.2018	0.47
Hurdal	356	0.20	0.38	0.61	2.25	30.09.2018	0.29
Kårvatn	362	0.45	0.90	1.31	2.73	05.07.2018	0.60
Tustervatn	360	0.26	0.49	0.74	2.31	21.05.2018	0.35
Zeppelin	357	0.09	0.14	0.20	0.81	04.11.2018	0.11

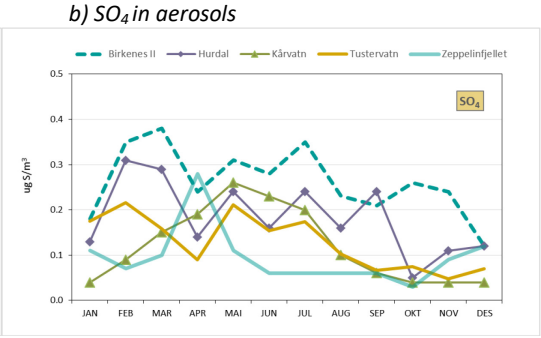
Table 3.8: Number of daily, observations 50-, 75-, 90-percentile concentrations, max- and annual mean concentrations of the sum of ammonium and ammonia in air at Norwegian background station in 2018.

Site	No. of observations	NH_4^+ (µg N/m^3)					
		Percentile conc.			Max concentration	Date	Annual mean concentration
		50%	75%	90%			
Birkenes II	364	0.12	0.30	0.64	4.61	09.02.2018	0.25
Hurdal	356	0.07	0.18	0.32	1.48	07.03.2018	0.13
Kårvatn	362	0.01	0.07	0.21	0.54	14.04.2018	0.06
Tustervatn	360	0.02	0.08	0.17	0.93	21.05.2018	0.06
Zeppelin	357	0.01	0.02	0.05	0.44	25.04.2018	0.02

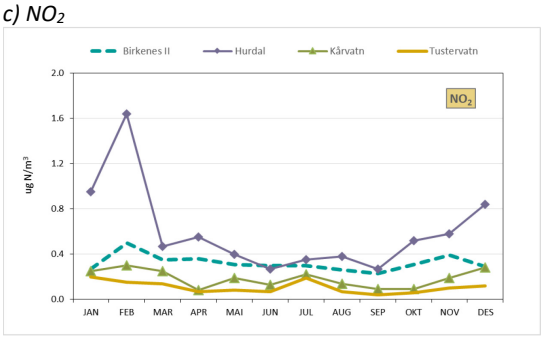
a) SO_2



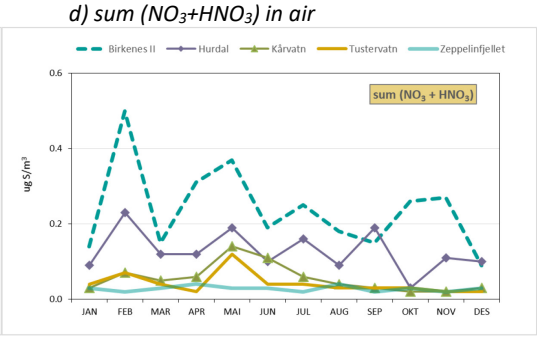
b) SO_4 in aerosols



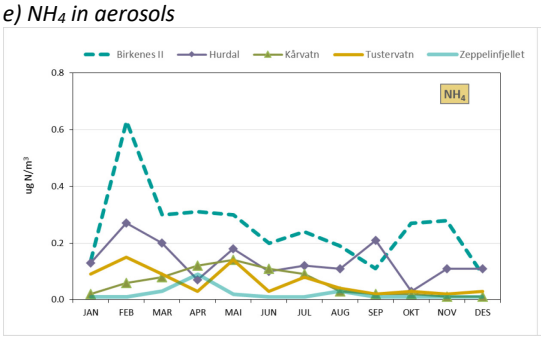
c) NO_2



d) sum (NO_3+HNO_3) in air



e) NH_4 in aerosols



f) sum (NH_4+NH_3) in air

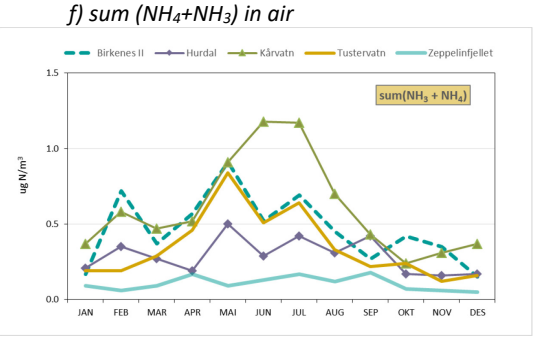


Figure 3.4: Monthly mean concentrations of sulfur- and nitrogen components in air at the five EMEP sites in Norway in 2018. Unit: µg(S or N)/m³.

3.1.3 Total deposition of sulfur and nitrogen

Table 3.9 and Figure 3.5 present estimates of the total dry deposition of sulfur and nitrogen compounds and the measured wet deposition in the growing season from May to October (summer) and winter months from January to April and November to December. Dry deposition is calculated on the basis of the mean concentrations of SO_2, SO_4^{2}, NO_2, sum of nitrate (NO_3^- + HNO_3), and sum of ammonium (NH_3 + NH_4^+) and deposition velocities given in the table text (Dovland and Eliassen, 1976; Dollard and Vitols, 1980; Fowler, 1980; Garland, 1978; Voldner and Sirois, 1986; Hicks et al., 1987).

For the sum of nitrate (NO_3^- + HNO_3), it is assumed that HNO_3 contributes with 25% and NO_3^- with 75%, whereas for the sum of ammonium (NH_3 + NH_4^+) NH_3 is presumed to contribute with 8% and NH_4^+ by 92% (Ferm, 1988). The dry deposition velocities of gases and particles are highly variable and uncertain quantities. The deposition of particles (SO_4^{2-}, NO_3^-, and NH_4^+) increases with wind speed and with the ground's roughness (forest coverage etc.). The deposition of gases (SO_2, NO_2, HNO_3, and NH_3) depends on the biological activity of the

vegetation and surface type (water, mountains, etc.). The deposition is for most gases far greater on wet surfaces than when the surfaces are dry. In winter, the deposition is small because of low biological activity, and because the surface is often covered by snow and ice. The stable layer of air close to the ground in winter also reduces the transport of contaminants to the ground.

The wet deposition contribute most to the total deposition at all the sites on the mainland, for both nitrogen and sulfur, and the total deposition is highest in southern Norway (Figure 3.5 and Table 3.9). Dry deposition of sulfur contributes to the total deposition with 25-29% in summer and 4-22% in winter except at Svalbard where the dry deposition is higher due low precipitation amount. Dry deposition of nitrogen contributes between 23-43% in summer and 4-21% in winter to the total nitrogen load.

Table 3.9: Estimated dry deposition and measured wet deposition of sulfur and nitrogen at Norwegian background stations 2018.

Dry deposition = measured air concentrations · dry deposition velocity from literature
Dry deposition velocities used: SO_2: 0.1 cm/s (winter) - 0.7 cm/s (summer). SO_4: 0.2-0.6 cm/s, NO_2: 0.1-0.5 cm/s, HNO_3: 1.5-2.5 cm/s, NO_3: 0.2-0.6 cm/s, NH_4: 0.2-0.6 cm/s, NH_3: 0.1-0.7 cm/s. Sum nitrate = 25% HNO_3 + 75% NO_3. Sum ammonium = 8% NH_3 + 92% NH_4.
The %- values indicate the estimated contributed of dry deposition to the total deposition for winter (W) and summer (S) Summer = May - October, winter = January - April and November - December.
For Zeppelin, wet deposition is taken from Ny-Ålesund.

	Sulfur (mg S/m²)						**Nitrogen (mg N/m²)**					
	Dry deposition		Wet deposition		% dry deposition		Dry deposition		Wet deposition		% dry deposition	
	Winter	Summer	Winter	Summer	% W	% S	Winter	Summer	Winter	Summer	% V	% S
Birkenes	9	40	211	98	4	29	40	112	945	381	4	23
Hurdal	6	23	88	68	7	25	18	133	299	248	6	35
Kårvatn	3	18	18	48	16	27	21	96	78	129	21	43
Tustervatn	5	15	17	42	22	27	13	59	59	129	18	32
Zeppelin-fjellet*	5	9	30	18	14	33	-	-	63	86	-	-

*Used the wet deposition at Ny-Ålesund.

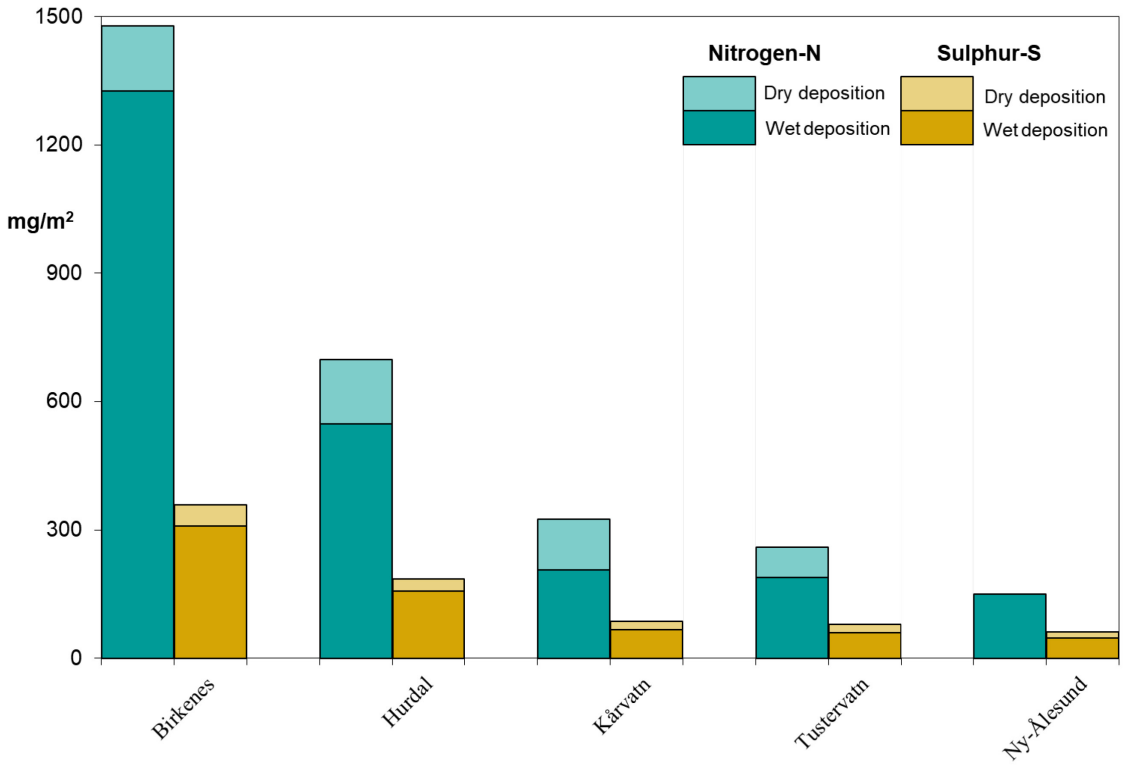


Figure 3.5: Total deposition (wet+ dry) of sulfur-S (SO_2, SO_4^{2-}) and nitrogen-N (NO_2, NH_4^+, NH_3, NO_3^-, HNO_3) at Norwegian background stations 2018.

3.2 Trends

An important goal of the monitoring programme is to measure the effectiveness of the protocols, i.e. the 1999 Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (UN/ECE, 1999). Since Norway is downwind of the major emission sources in Continental Europe, the monitoring in Norway can give indications on the overall emission reductions in Europe. The objective of the multicomponent Gothenburg Protocol from 1999 was to reduce European emissions of sulfur by 63% in 2010 compared to 1990. Similarly, the target for nitrogen oxides and ammonia was a reduction of 41% and 17%, respectively. In 2012, the Gothenburg Protocol was revised, and new emissions targets were defined for 2020 with 2005 as the base year. The 27 EU countries have committed to the following emission reductions with the numbers for Norway in brackets; SO_2: 59% (10%), NO_x: 43% (23%), nmVOC: 28% (40%), ammonia: 6% (8%) and $PM_{2.5}$: 22% (30%).

Figure 3.6-Figure 3.8 show the time series of annual mean concentrations of main ions in precipitation, in air and total deposition at selected sites in Norway with long time series. The concentration levels in 2018 were in general a bit higher or equal compared to 2017(Figure 3.6).

Table 3.10 and 3.11 shows the trends for four different periods, 1980-, 1990-, 2000-, and 2005-2018 for all sites with measurements in these respective periods.

For the statistical analysis, the non-parametric “Mann-Kendall Test” has been used on annual means for detecting and estimating trends (Gilbert, 1987). The Mann-Kendall test has become

a standard method when missing values occurs and when data are not normally distributed. In parallel to this, the Sen's slope estimator has been used to quantify the magnitude of the trends.

For sulfur, there has been a significant reduction at all the sites for all the sulfur components in air and precipitation from both 1980 and 1990 to 2018. Since 1980, the content of sulfate in precipitation in Norway has decreased by 77-98%. The reductions in airborne concentrations of sulfate have been similar, between 86% and 91% at the Norwegian mainland, while for sulfur dioxide the trend is almost 100%. The calculated linear trend for this long period gives reductions higher than 100%, which illustrates the problem of assuming linearity when the trend is higher in one part of the period. Somewhat lower reductions are observed at the Zeppelin Observatory; 88% for sulfur dioxide and 67% for sulfate, Table 3.10.

The reductions since 1990 have been between 53% and 89% (sulfate in precipitation), 78-93% (sulfur dioxide) and 72-81% (sulfate in air) for the sites at the mainland. From 2000, all sites except Tustervatn have observed a significant reduction of sulfate in precipitation between 40% and 72%. For sulfur dioxide and sulfate in air, there are significant reductions at all mainland sites (except Kårvatn for SO_2) with 58-62% and 50-61%, respectively. Trends from 2005 are also calculated since this is the references year for the Gothenburg protocol. The observed sulfur reductions at most sites are smaller than the target of 59% emission reductions, which is to be reached within 2020.

The nitrate and ammonium concentrations in precipitation have significantly decreased at most sites south of Kårvatn, 43-55% for nitrate and 50-67% for ammonium since 1980. The air measurements did not start as early as the ones for precipitation, thus trend analysis for these have only been done from 1990.

For nitrate in precipitation, most sites show a significant decrease between 29% and 52% from 1990 to 2018. Most of the sites also show a decrease of ammonium, but some show a significant increase. There is a decrease in the observed ammonium in air for all the four sites at the mainland, between 53-70%, while the levels of sum nitrate and sum ammonium varied, some sites with a decrease and others with an increase. This might be due to changes in local emissions or changes in chemical regime; less sulfate cause more ammonium to be associated with particulate nitrate.

The NO_2 concentration has decreased at all four sites, between 39-68% from 1990 and 34-47% from 2000. The observed reductions in concentration levels of sulfur and nitrogen species are in agreement with reported downwards trends in pollutant emissions in Europe (Tørseth et al., 2012; Colette et al., 2016).

Calcium is significantly reduced at most sites since 1980, which is consistent with emission reductions from anthropogenic sources in Europe (Hellsten et al., 2007). The contribution of sea salts are influenced by meteorological conditions and vary from year to year. A significant reduction is seen at Treungen from 1980-2018, while an increase at Løken in the period 1990-2018.

Table 3.10: Trends in annual mean concentrations of inorganic ions in precipitation. Only significant trends are shown (p=0.05).Shaded area means not available data, while the signs indicate increase or decrease in percent change for the whole period.

	ssc SO_4^{2-}				NO_3^-				NH_4^+			
	1980-2018	1990-2018	2000-2018	2005-2018	1980-2018	1990-2018	2000-2018	2005-2018	1980-2018	1990-2018	2000-2018	2005-2018
Birkenes	-92	-82	-62	-56	-43	-38	-	-	-53	-38	-	-
Treungen	-88	-76	-53	-	-43	-40	-	-32	-	-	-	-
Vatnedalen	-95	-85	-62	-52	-43	-44	-	-	-50	-38	-	-
Løken	-98	-87	-58	-41	-53	-47	-21	-21	-63	-42	-	-
Nordmoen/Hurdal		-82	-54	-46		-35	-20	-25		-	-	-
Gulsvik/Brekkebygda	-97	-84	-62	-55	-55	-52	-	-34	-67	-55	-	-43
Vikedal		-89	-72	-60		-35	-36	-25		-	-	-
Nausta		-82	-67	-		-29	-	-		80	84	-
Kårvatn	-77	-53	-40	-	-	-	-	-	-	-	-	-
Høylandet		-81	-72	-62		-	-	-65		76	-	-
Tustervatn	-89	-68	-	-	-	-	-	-20	-	-31	-43	-39
Ny-Ålesund	-84	-84	-54	-	-	-	-	-	-	-	-	-

Table 3.10 (cont.)

Trends in annual mean concentrations of inorganic ions in precipitation.

	mm				Mg^{2+}				Ca^{2+}			
	1980-2018	1990-2018	2000-2018	2005-2018	1980-2018	1990-2018	2000-2018	2005-2018	1980-2018	1990-2018	2000-2018	2005-2018
Birkenes	30	41	-	-	-	-	-	-	-34	-	72	52
Treungen	-	-	-	-	-	-57	-	-	-	-	-	-
Vatnedalen	-	-	-	-	-	-	-	-	-34	-	-	-
Løken	-	-	-	-	-	-	75	-	-49	-	58	59
Nordmoen/Hurdal		19	-	-		-	-	-		68	-	-
Gulsvik/Brekkebygda	62	76	-	-	-	-	-	-	-	-	-	-
Vikedal		-	-	-		-	-	-		-	-	-
Nausta		-31	-	-41		-	-	-		-	-	-
Kårvatn	-	-	-	-	-	-	-	-	-30	-	-	-
Høylandet		-	-	-		-	-	-		-	-	-
Tustervatn	-	-25	-23	-	-	-	-	-	-35	-	-	-
Ny-Ålesund	-	-	-	68	-	-46	-59	-52	-42	-52	-75	-78

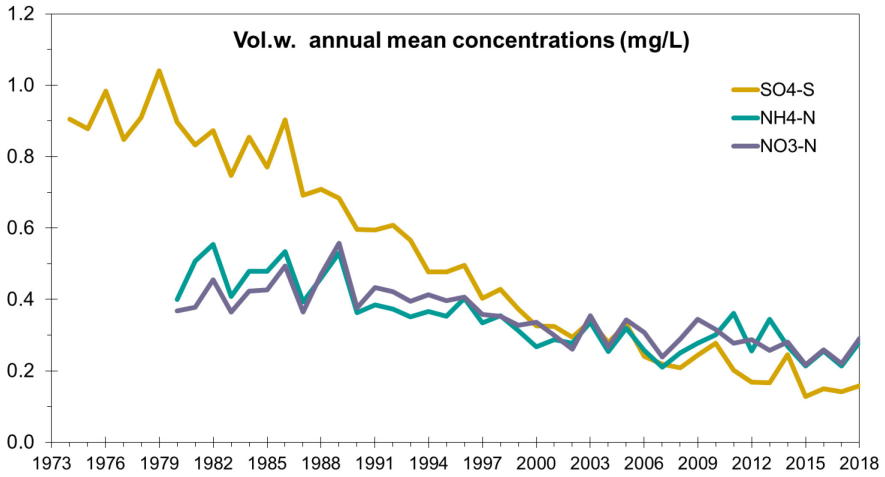
Table 3.11: Trends in annual mean concentrations of inorganic components in air. Only significant trends are shown (p=0.05). Shaded area means not available data, while the signs indicate increase or decrease in percent change for the whole period.

	SO_2				SO_4^{2-}			
	1980-2018	1990-2018	2000-2018	2005-2018	1980-2018	1990-2018	2000-2018	2005-2018
Birkenes	~ -100%	-93	-58	-	-86	-73	-51	-38
Nordmoen/Hurdal		-93	-61	-52		-81	-61	-46
Kårvatn	~ -100%	-78	-	-	-88	-72	-50	-39
Tustervatn	~ -100%	-90	-62	-	-91	-78	-59	-54
Zeppelin	-88	-76	-64	-	-67	-43	-27	-

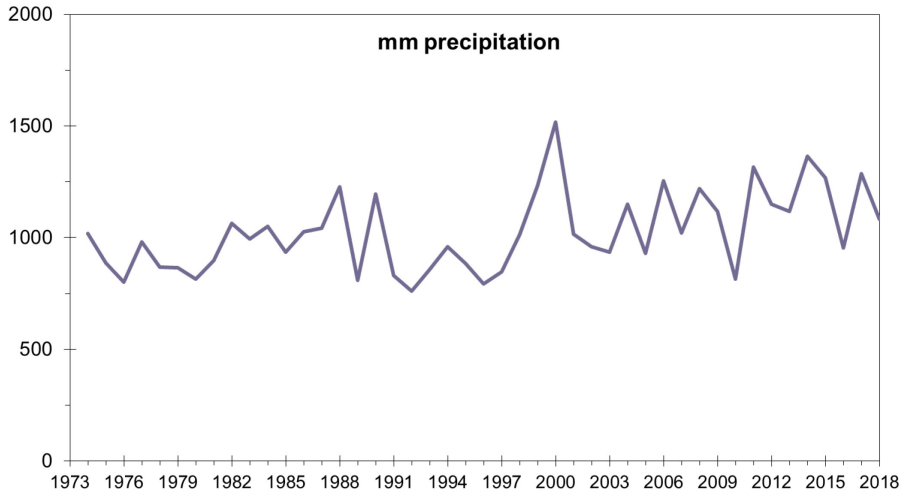
	NO_2				$sum(NO_3+HNO_3)$			
	1980-2018	1990-2018	2000-2018	2005-2018	1980-2018	1990-2018	2000-2018	2005-2018
Birkenes		-67	-47	-33		-	-	-
Nordmoen/Hurdal		-68	-34	-27		-31	-	-
Kårvatn		-39	-47	-		-	-	-
Tustervatn		-55	-41	-		-	-	-
Zeppelin						-	-	-

	$sum(NH_4^+ + NH_3)$				NH_4^+			
	1980-2018	1990-2018	2000-2018	2005-2018	1980-2018	1990-2018	2000-2018	2005-2018
Birkenes		-26	-	-40		-55	-	-
Nordmoen/Hurdal		-41	-	-53		-70	-	-
Kårvatn		64	-	-49		-53	-	-
Tustervatn		-	-55	-67		-56	-40	-
Zeppelin		409	-	-66		-	-	-

a)



b)



c)

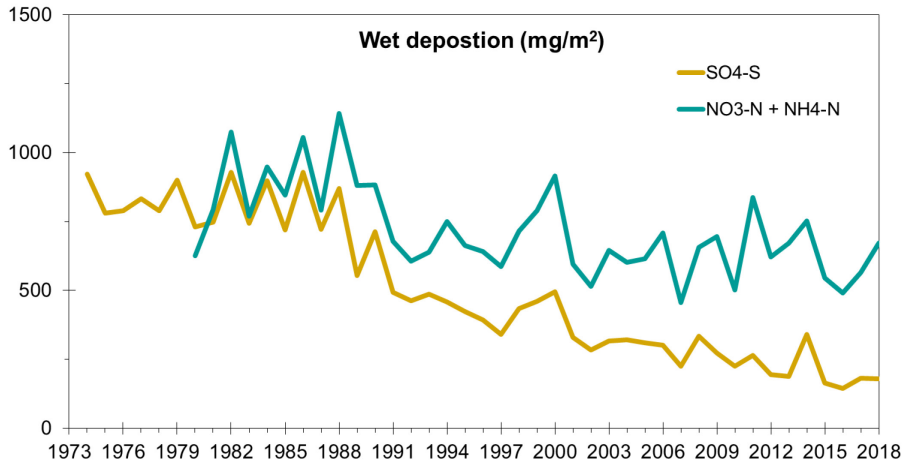
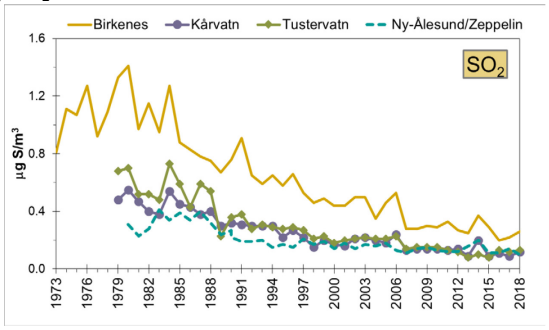
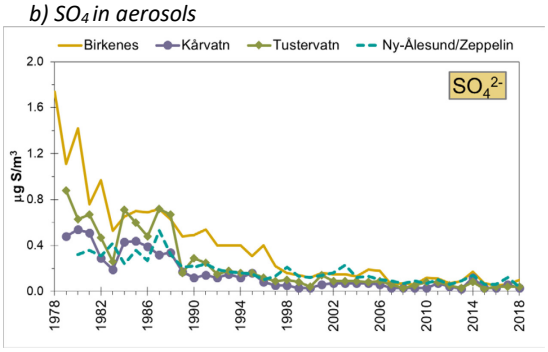


Figure 3.6: Average volume weighted annual mean concentrations (a), precipitation amount (b) and wet deposition (c) for sea salt corrected sulfate, nitrate and ammonium at five representative sites in southern Norway (Birkenes, Vatnedalen, Treungen, Gulsvik and Løken), 1974-2018.

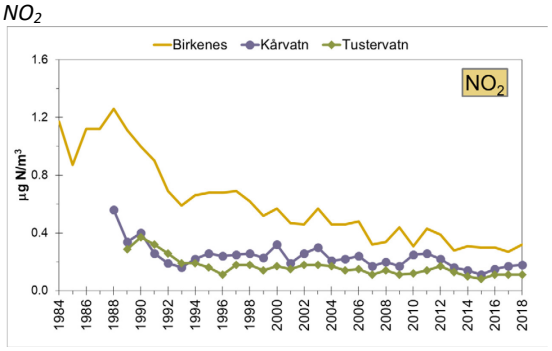
a) SO_2



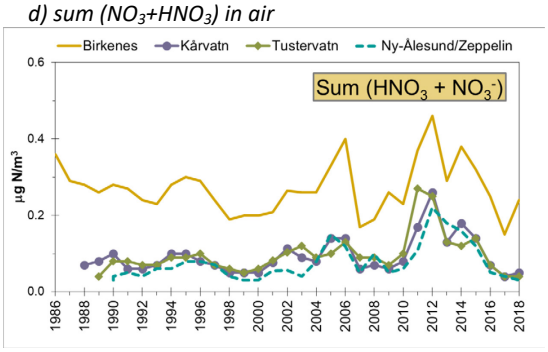
b) SO_4 in aerosols



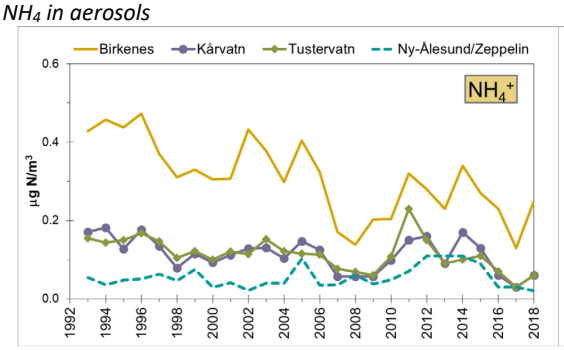
c) NO_2



d) sum (NO_3+HNO_3) in air



e) NH_4 in aerosols



f) sum (NH_4+NH_3) in air

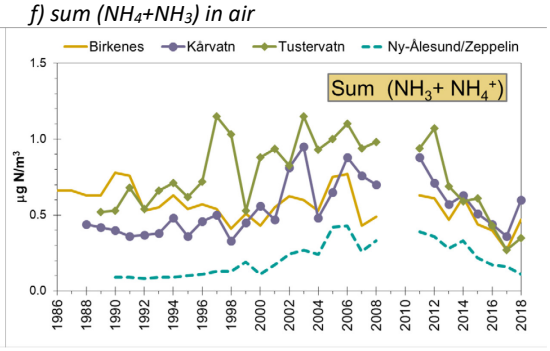


Figure 3.7: Annual mean concentrations of sulfur and nitrogen components in air at four Norwegian EMEP sites, 1973-2018.

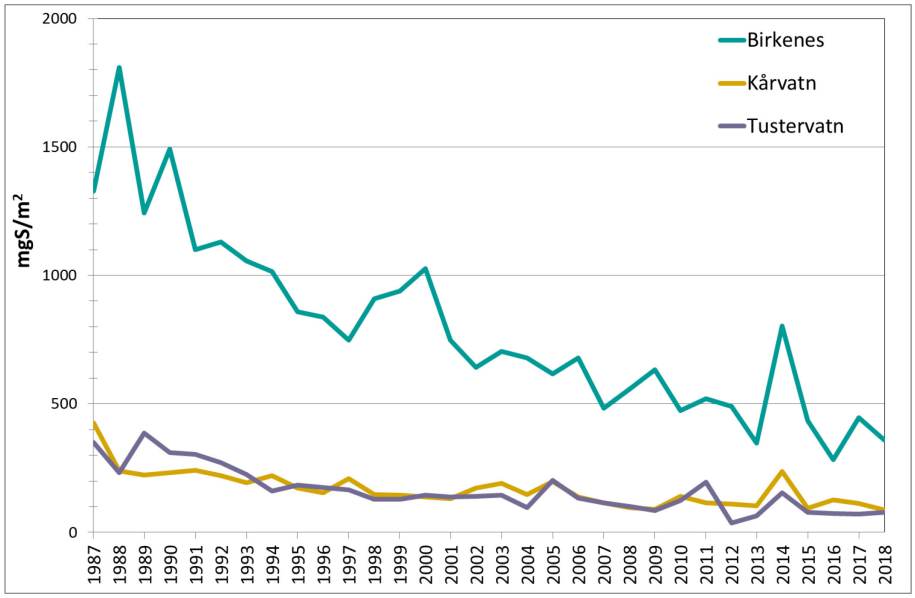


Figure 3.8: Trends in total deposition (wet + dry) of sulfur at three Norwegian EMEP sites, 1987-2018.

3.3 Summary

For most of the main inorganic components, the highest annual mean concentrations in 2018 were measured at Birkenes, which is the station in Norway most affected by long-range transport of pollutants. However, some inland sites are influenced by regional agricultural activities and experience somewhat higher ammonium concentrations. For NO_2, the highest levels are seen in Hurdal, which is influenced by the relatively high traffic-emission in the region. Karpbukt and Svanvik, situated close to the Russian border, experience high sulfate-concentrations due to emissions from the smelters in Kola Peninsula. The highest wet deposition loads of sulfate, nitrogen components and strong acid occurred along the coast from Aust-Agder to Hordaland.

The concentration levels in 2018 were in general somewhat higher compared to 2017, but there is a clear decline in a longer time perspective. There are large reductions in sulfur in all parts of Norway, since 1980 more than 90%, since 1990 around 70% (depending on the compound), and since 2000 about 50-60%, while from 2005 between 30-50%. Thus, most sites show smaller reduction trends than the European target of 59% emission reductions set by the Gothenburg protocol to be reached within 2020 using 2005 as the reference year.

Nitrate- and ammonium-concentrations in precipitation have decreased significantly at most sites in southern Norway, around 50% for both components, since 1980, and somewhat less from 1990. The NO_2-concentration has also decreased significantly of the order of 39-68% from 1990. These observed reductions are in line with reported emission reduction on the European continent (Colette et al, 2015), although most sites show lower trends in oxidized nitrogen than the target of 43% reductions in NOx-emissions set by the Gothenburg protocol.

4 EC and OC

4.1 Introduction

Monitoring of Elemental Carbon (EC) and Organic Carbon (OC) in PM_{10} and $PM_{2.5}$ takes place at three rural background sites: The Birkenes Observatory and the Hurdal and Kårvatn sites. The time series at the Birkenes Observatory dates back to 2001 and to 2010 at Hurdal and Kårvatn.

Annual and monthly mean concentrations of EC and OC in PM_{10} and $PM_{2.5}$ for 2018 are shown in Figure 4.1 and Table A.1.35:, whereas annual mean concentrations for EC and OC in PM_{10} and $PM_{2.5}$ for the period 2001 – 2018 are listed in Table A.1.36:.

Incidences of $PM_{2.5} > PM_{10}$ on a monthly basis are typically due to a different number of samples for the two size fractions, but for low levels, measurement uncertainties can have an influence as well, in particular for EC. OC in $PM_{10\text{-}2.5}$ is derived from the observed values of OC in PM_{10} and $PM_{2.5}$ and is discussed in the report for a better understanding of the observed data, but is not listed in any table. Background information on the carbonaceous aerosol (here: EC and OC) can be found in Annex 3.

4.2 Concentrations of OC in PM_{10}, $PM_{2.5}$ and $PM_{10\text{-}2.5}$

The annual mean concentration of OC in PM_{10} (0.85 – 1.27 µg C/m^3) and $PM_{2.5}$ (0.65 – 0.88 µg C/m^3) at Norwegian rural background sites are amongst the lowest in Europe. Fine fraction OC (69 – 76%) was the major fraction of OC in PM_{10} at all sites on an annual basis. This is as expected as the major sources, primary emissions from combustion of fossil fuel and biomass and secondary particle formation from biogenic and anthropogenic precursors typically generate fine aerosol particles. Coarse fraction OC occasionally dominates on a monthly basis. This is observed for the second half of the vegetative season and is attributed to the presence of primary biological aerosol particles (PBAP), such as e.g. fungal spores.

The annual mean concentration of OC in PM_{10} at Hurdal was 30-50% higher than at Birkenes and at Kårvatn. The difference in concentration was explained almost equally by the fine and coarse fraction of PM_{10} (Table A.1.35:). We speculate that the more densely populated and anthropogenic influenced region surrounding the Hurdal site is the main explanation for the observed increment of fine fraction OC. This is also in line with the higher NO_2 concentrations seen for this site, which has been explained by high emissions from vehicular traffic in this region (see Chapter 3.1.2). Coarse OC are associated with PBAB, likely of local to regional origin, but there is no apparent explanation why the source strength is stronger at Hurdal compared to the other sites.

There was a seasonal variability with increased levels of OC in summer (April - September) compared to winter (October - March) for all sites and size fractions; the seasonality being more pronounced for the coarse than the fine fraction, and with large variability between sites. This reflects increased levels of Secondary Organic Aerosols (SOA), and Biogenic Secondary organic Aerosols (BSOA) in particular, contributing to the fine fraction, and PBAP contributing to the coarse fraction during the vegetative season (See Yttri et al. 2011 a, b). The highest OC levels were seen in May at all sites, and were associated with the long lasting heat wave affecting southern Norway, facilitating transport of polluted air masses from continental Europe and formation of secondary organic pollutants, as well as an early onset of PBAP emissions; as confirmed by source specific organic tracers.

A certain level of covariance was observed between the sites, both with respect to seasonality and episodes of increased levels. Seasonal covariance is likely driven by the weather situation. As an example, temperature is decisive for the formation of SOA and pollen release in the summer half year as well as for the need for domestic heating in the winter half year. Episodes of long-range

transported air pollution is well known to affect large regions. Finally, prolonged sampling time (here: weekly) could also contribute to mask differences between sites.

The annual mean concentration of OC in PM_{10}, $PM_{2.5}$ and $PM_{10-2.5}$ was within +SD of the long-term mean at all sites. At Birkenes, equally high OC levels as seen for 2018 has not been observed for more than a decade, and at Hurdal and Kårvatn OC levels were close to the highest annual mean observed (Note that the annual mean for 2010 at Hurdal and Kårvatn do not cover an entire year). Note that the measurements for Hurdal and Kårvatn dates back to 2010, and to 2001 for Birkenes.

4.3 Concentrations of EC in PM_{10} and $PM_{2.5}$

The annual mean concentration of EC in PM_{10} (0.05 – 0.12 µg C/m^3) and $PM_{2.5}$ (0.05 – 0.11 µg C/m^3) at Norwegian rural background sites are amongst the lowest in Europe. EC results from incomplete combustion of fossil fuel and biomass and emissions are thus almost exclusively associated with the fine fraction of PM_{10}. EC levels at Hurdal were 50 - 60% higher than at Birkenes and 120 – 140% higher than at Kårvatn, considering both the PM_{10} and $PM_{2.5}$ size fractions. The wide ranges and differences between size fractions are misleading and result from the very low levels and "decimal-issues". As argued for OC in Chapter 4.2, , we assume that the higher levels of EC at Hurdal is caused by the more densely populated and anthropogenic influenced region surrounding the site; albeit crude, EC is regarded as a tracer of anthropogenic activity. EC was a minor contributor to the total carbon (TC) concentration; i.e., 6 – 9% (PM_{10}) and 7 – 11% ($PM_{2.5}$). The annual mean EC/TC ratio was within or less than –SD of the long-term EC/TC mean at all sites.

There was a seasonal variability with increased levels of EC in winter (October - March) compared to summer (April - September) at all sites. This seasonality was minor at Kårvatn, modest at Birkenes, and pronounced at Hurdal (Table A.1.35:). Increased levels of EC in winter could be associated with increased emissions from e.g. residential wood burning, but also meteorological inversion preventing dispersion could play an important role. Increased concentrations of levogluosan at Birkenes (Table 4.2), in the heating season, clearly shows that EC from residential wood burning contributes to the observed seasonality of EC.

The annual mean concentration of EC was equal to or within –SD of the long-term mean at all sites.

4.4 Relative contribution of EC and OC to PM

The relative contribution of OC to PM_{10} (18 – 27%) and $PM_{2.5}$ (24 - 28%) annually was rather similar, and for Birkenes somewhat lower than for the two other sites, in particular for the PM_{10} size fraction. The highest OC fraction was seen for Kårvatn, but only marginally higher compared to Hurdal. The OC fraction of PM_{10} was higher in summer than in winter at Birkenes and Hurdal, but the other way around at Kårvatn, although by a short margin. The contribution of OC to PM showed a statistically significant upward trend both for PM_{10} (3%) and for $PM_{2.5}$ (16%) for 2001 – 2018 at Birkenes (Table 4.1)

The relative contribution of OC to $PM_{10-2.5}$ was 10 - 23% on an annual basis, and more pronounced in summer in summer (13 – 38%) compared to winter (7 – 25%). A statistically significant upward trend (46%) was shown for the OC fraction in $PM_{10-2.5}$ at Birkenes for the period 2001 – 2018.

EC accounted for 1.5 – 2.4% of PM_{10} annually and somewhat higher for $PM_{2.5}$ (2.2 – 3.4%), reflecting that EC is associated with fine aerosol particles. EC was more abundant in the winter-time aerosol (1.8 – 4.0% for PM_{10} and 4.0 – 5.4% for $PM_{2.5}$) than the summer-time aerosol (1.0 – 1.4% for PM_{10} and 1.8 – 2.4% for $PM_{2.5}$). A decrease in the relative contribution of EC to PM_{10} (-27%) and $PM_{2.5}$ (-12%) was observed for 2001 – 2018 at Birkenes, which was statistically significant for both size fractions.

4.5 Trends for concentrations of EC and OC

The Mann Kendall method described in Chapter 3.2 was used for trend analysis of concentrations of EC and OC. The shorter time series for the sites Hurdal and Kårvatn (8 years) allow for an assessment of the Birkenes site only (Table 4.1). The time series of OC in PM_{10}, $PM_{2.5}$ and $PM_{10-2.5}$, and that of EC in PM_{10} and $PM_{2.5}$, at the Birkenes Observatory are shown in Figure 4.1.

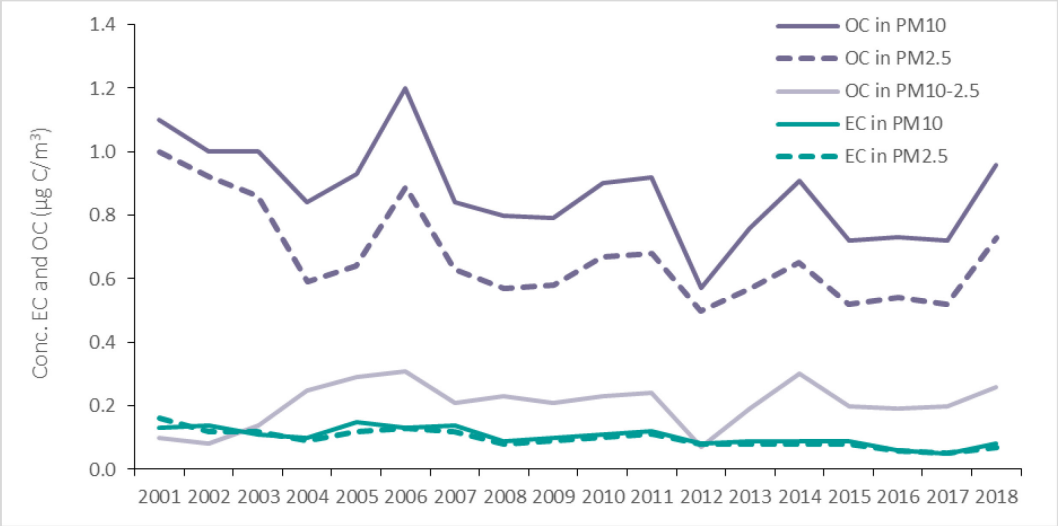


Figure 4.1: Annual mean time series of EC and OC, as observed at the Birkenes Atmospheric Observatory (2001 – 2018).

There was a statistically significant downward trend for the annual mean concentration of OC in both PM_{10} (-25%) and $PM_{2.5}$ (-35%) at Birkenes for the period 2001 – 2018. For OC in $PM_{10-2.5}$, a statistically significant increase of 27% was observed for the same period. EC showed a statistically significant downward trend for both PM_{10} (-48%) and $PM_{2.5}$ (-54%) for 2001 – 2018.

*Table 4.1: Trends in annual mean mass concentration of OC, EC and TC in PM_{10} (2001 - 2018) and $PM_{2.5}$ (2001 - 2018) using Mann-Kendall test and Sen slope estimates; * significant level 0.05..*

Site	PM_{10}	% change	$PM_{2.5}$	% change
Birkenes				
OC	*	-25%	*	-35%
EC	*	-48%	*	-54%
TC	*	-33%	*	-38%

Trends are calculated for time series extending 10 years

4.6 Concentrations of levoglucosan, mannosan and galactosan in PM_{10}

Measurements of levoglucosan, mannosan and galactosan in PM_{10} takes place at the Birkenes Observatory, and is used to estimate the contribution of biomass burning to the carbonaceous aerosol (here: OC and EC) and to PM.

The annual mean concentration of levoglucosan in PM_{10} observed at the Birkenes Observatory was 9.8 ng m^{-3} (Table 4.2). The seasonality was pronounced with higher levels in the heating season. Low levoglucosan levels in summer may partly reflect increased degradation by the OH radical, but higher emissions from residential wood burning in winter compared to summer explains most of the seasonality.

A seasonally consistent levoglucosan/mannosan ratio indicates that emissions from one source (residential wood burning) prevails, and supports one emission ratio when estimating OC and EC levels from levoglucosan (here: 10 for OC and 2 for EC). Influence from wild and agricultural fires in summer is likely, but the magnitude of these sources remains speculative.

We estimate that biomass burning contributed 15-19% to OC and 29% to EC, annually, considering both PM_{10} and $PM_{2.5}$. The fraction attributed to biomass burning in winter was 30-35% for OC and around 45% for EC, whereas it was ≤1.5% (OC) and <7% (EC) in summer, considering both size fractions. Spring and fall are transition seasons with relative contributions lower than in winter and higher than in summer. Biomass burning can be the major source of both OC and EC on a weekly basis in the heating season; i.e. emissions are attributed to wood burning for residential heating.

Ongoing studies suggest that long-range transported (LRT) air pollution from continental Europe explains elevated biomass burning aerosol levels observed at the Birkenes Observatory. LRT is decisive not only for episodes of high concentrations, but also largely explains the mean concentration.

Table 4.2.: Annual mean concentrations of levoglucosan, mannosan and galactosan in PM_{10} at Birkenes for 2017-2018. Seasonal mean concentrations for 2018. Unit: ng m^{-3}.

Year		Levoglucosan	Mannosan	Galactosan
2017	**Annual**	8.2	1.3	0.32
2018	**Annual**	9.8	1.6	0.39
	Winter	13.5	2.2	0.60
	Spring	13.6	2.0	0.54
	Summer	1.4	0.25	0.04
	Fall	10.6	2.0	0.41

Winter = DJF; Spring = MAM; Summer = JJA; Fall = SON.

4.7 Summary

Observed annual mean concentrations of carbonaceous aerosol in the Norwegian rural background environment are amongst the lowest in Europe (OC < 1.3 µg C m^{-3} and EC < 0.12 µg C m^{-3}), and a statistically significant downward trend was observed for OC (-25 - -35%) and EC (-48 - -54%) in PM_{10} and $PM_{2.5}$ for the period 2001 – 2018. Nevertheless, the 2018 annual mean OC levels were the highest observed for more than a decade at the Birkenes Observatory and amongst the highest observed at Hurdal and Kårvatn.

Measurements complementary to OC and EC are needed for an assessment of sources. Previous source apportionment studies of the carbonaceous aerosol in the Norwegian rural background environment show that natural sources, biogenic secondary organic aerosol (BSOA) and primary biological aerosol particles (PBAP), dominate the organic aerosol in summer, whereas anthropogenic sources, fossil fuel and biomass burning, dominate in winter. With a few exceptions, EC can be considered exclusively anthropogenic. Estimates based on levoglucosan measurements suggest that biomass burning contributed 15-19% to OC and 29% to EC at the Birkenes Observatory annually, considering both PM_{10} and $PM_{2.5}$, and 30-35% for OC and around 45% for EC in winter.

5 Particulate matter, mass concentrations

5.1 Introduction

Monitoring of the PM_{10} and $PM_{2.5}$ mass concentration takes place at three rural background sites; the Birkenes Observatory and the Hurdal and Kårvatn sites. The time series at Birkenes dates back to 2000/1, whereas measurements were initiated in 2010 at the two other sites. At Birkenes, high time resolution measurement of the aerosol size distribution for the size range 0.01 – 10 µm, was initiated in 2010, whereas high time resolution measurements of PM_{10} started in 2017.

Annual and monthly mean mass concentrations of PM_{10}, $PM_{10\text{-}2.5}$ and $PM_{2.5}$ for 2018, obtained by gravimetric measurements, are shown in Table A.1.37:, whereas annual mean mass concentrations of PM_{10}, $PM_{10\text{-}2.5}$ and $PM_{2.5}$ for the time period 2000 – 2018 are listed in Table A.1.38:. Time series of PM_{10} and $PM_{2.5}$ for 2018 are shown in Figure 5.1. Note that $PM_{10\text{-}2.5}$ is derived from the observed values of PM_{10} and $PM_{2.5}$; i.e. the difference between PM_{10} and $PM_{2.5}$. Incidences of $PM_{2.5} > PM_{10}$ and $\Sigma PM_{2.5}$, $PM_{10\text{-}2.5} \neq PM_{10}$ on a monthly basis are typically due to a different number of samples for PM_{10} and $PM_{2.5,}$ but for low levels measurement uncertainties can have an influence as well. Annual means of aerosol particle number (*N*) concentrations for ultrafine ($0.02 < D_p < 0.1$ µm), accumulation mode (D_p = 0.1 - 1.0 µm) and coarse mode (D_p = 1.0 – 10 µm) particles, are shown in Table 5.4. 24 hours mean concentrations of PM_{10} derived from high time resolution measurements, were used to asses violation of national and international limit values and air quality guidelines. Background information on PM can be found in Annex 3.

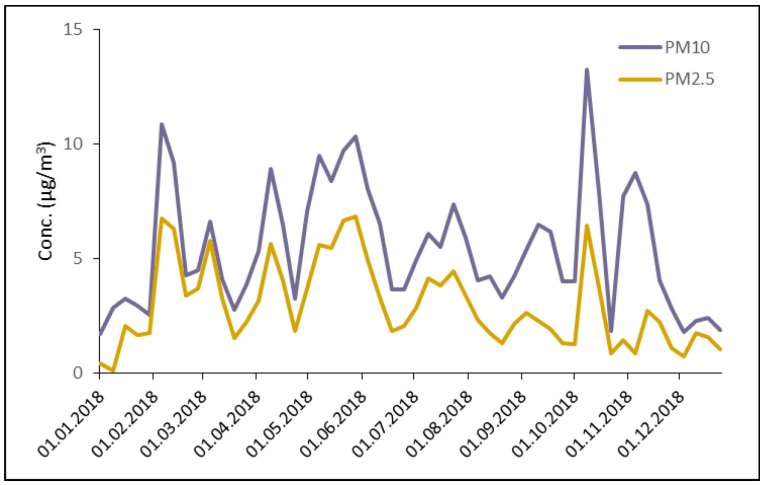
5.2 PM_{10}, $PM_{2.5}$ and $PM_{10\text{-}2.5}$ concentrations

The annual mean mass concentration of PM_{10} (3.2 - 5.4 µg/m^3) and $PM_{2.5}$ (2.3 – 3.2 µg/m^3) at the Norwegian rural background sites are amongst the lowest in Europe. $PM_{2.5}$ was the major fraction of PM_{10} at all sites on an annual basis, accounting for 55% at Birkenes, 66% at Hurdal and 71% at Kårvatn. $PM_{10\text{-}2.5}$ was occasionally the major fraction of PM_{10} on a monthly basis, and are typically attributed to natural sources, such as sea salts, primary biological aerosol particles (PBAP), and mineral dust, which can be both of natural and anthropogenic origin.

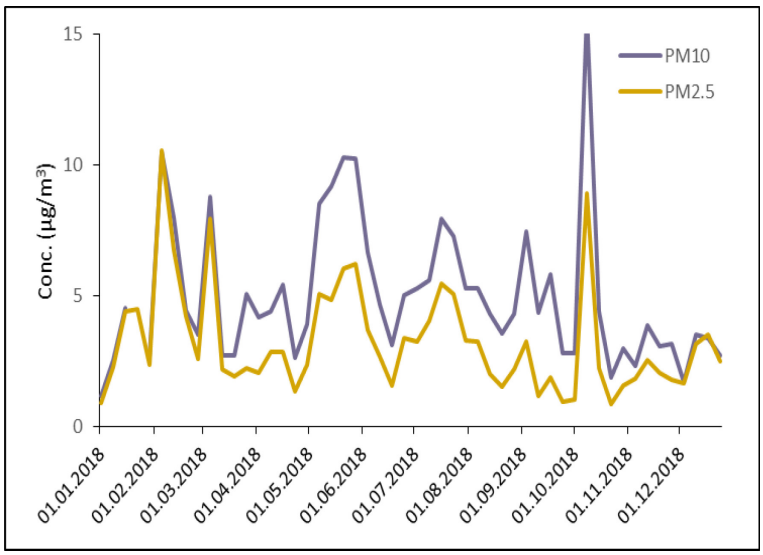
The PM_{10} annual mean was within –SD of the long-term mean at Birkenes, within +SD at Hurdal and equal to the long term mean at Kårvatn. For $PM_{2.5}$, the annual mean observed at Hurdal and Kårvatn equaled the long-term mean, whereas it was within –SD for Birkenes. The $PM_{10\text{-}2.5}$ annual mean was within +SD at all sites. Note that the measurements for Hurdal and Kårvatn dates back to 2010, whereas measurements at Birkenes were initiated in 2000/2001.

Higher levels of PM_{10} at Birkenes compared to Hurdal and Kårvatn is consistent with previous years, except for 2017. This is explained by the higher $PM_{10\text{-}2.5}$ fraction at Birkenes, as well as a higher $PM_{2.5}$ fraction when compared to Kårvatn. The higher $PM_{10\text{-}2.5}$ fraction at Birkenes was largely attributed to the sea salt aerosol, which was 3 times higher compared to the two other sites, reflecting its proximity to the coast (20 km). It can also be speculated that a larger fraction of NO_3^- reside in the coarse fraction of PM_{10} at Birkenes, following from the reaction between gaseous HNO_3 and coarse mode NaCl. Coarse fraction organic matter (OM), dominated by PBAP, was 1.6 – 1.9 times higher at Hurdal compared to Birkenes and Kårvatn, thus counteracting some of the discrepancy attributed to the lower sea salt aerosol contribution when compared to Birkenes

a) Birkenes



b) Hurdal



c) Kårvatn

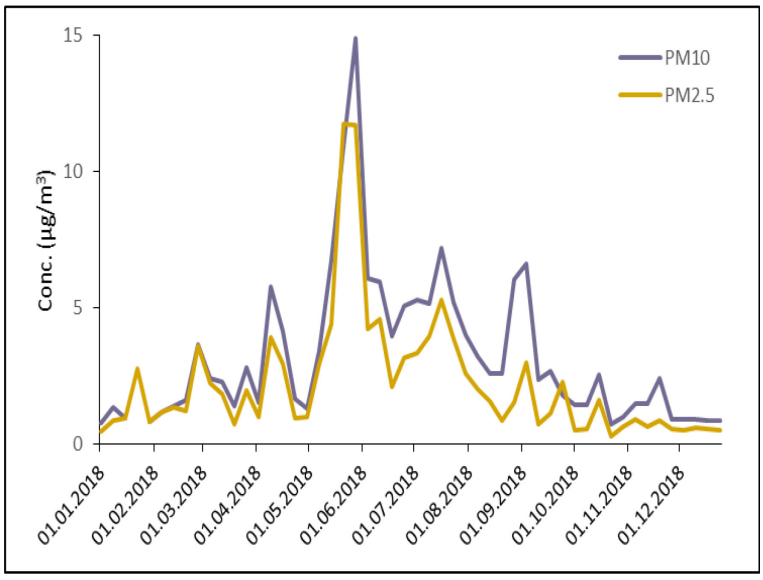


Figure 5.1: Time series of PM_{10} and $PM_{2.5}$ mass concentration for Birkenes (a), Hurdal (b) and Kårvatn (c) for 2018. Unit µg/m³. Note that the time series have been harmonized in time for comparability; i.e. they all start on the same date (01.01.2018).

The annual mean $PM_{2.5}$ concentration was higher at Hurdal compared to Birkenes and Kårvatn, which is consistent with previous years. For Kårvatn the difference is explained by lower levels of OM, EC and secondary inorganic aerosol constituents (SIA) (i.e. SO_4^{2-}, NO_3^- and NH_4^+, typically residing in the fine fraction of PM_{10}). SIA levels are higher at Birkenes than at the two other sites, particularly compared to Kårvatn, even though a larger fraction of SIA, and NO_3^- in particular, likely is associated with the coarse fraction of PM_{10} at Birkenes. The higher $PM_{2.5}$ concentration at Hurdal compared to Birkenes is caused by a higher OM (and EC) level. Differences in the OC to OM conversion factor, a factor used to account for other elements than carbon associated with OC, could contribute to the observed differences as well, but remains speculative.

The highest PM_{10} (and $PM_{2.5}$ for Birkenes and Kårvatn) monthly mean was observed in May at all sites and was explained by a long lasting heat wave affecting southern Norway, facilitating transport of polluted air masses from continental Europe, formation of secondary organic pollutants, as well as an early onset of PBAP emissions. Notably, a mineral dust concentration of 2 µg m^{-3} was estimated for May, which was 3 times higher than the estimated annual mean (0.7 µg m^{-3}).

The 2018 PM_{10} and $PM_{2.5}$ time series at Birkenes were episodic (Figure 5.1), reflecting episodes of long-range atmospheric transport, but also emissions from local to regional scale sources, such as e.g. sea spray. Some of these periods observed at Birkenes were also seen at Hurdal, and to some extent at Kårvatn. Weekly mean concentrations exceeding 10 µg m^{-3} were observed at all sites for PM_{10}, but not for $PM_{2.5}$. The highest weekly mean (17.5 µg m^{-3}) was observed at Birkenes, but maximum concentrations at Hurdal (16.4 µg m^{-3}) and Kårvatn (15.1 µg m^{-3}) were almost equally high. The PM_{10} concentration exceeded 10 µg m^{-3} at Birkenes for six weeks, four at Hurdal, and two at Kårvatn. Secondary inorganic aerosol (SIA) was the major fraction of PM_{10} for four of the six samples for which PM_{10} exceeded 10 µg m^{-3} at Birkenes, and NO_3^- was the dominating SIA species, whereas organic matter (OM) dominated two samples. Notably, mineral dust made a 20 – 30 % contribution for the two samples dominated by OM, appearing in spring. At Hurdal and Kårvatn, the highest weekly means were all dominated by OM, except one at the Hurdal site, for which SIA was marginally higher than OM.

The fine fraction of PM_{10} was the most abundant for all but one of the samples with a PM_{10} level exceeding 10 µg m^{-3}, but by quite a small margin for quite a few of them. This reflects a noticeable influence of coarse fraction PM as well, originating mainly from sea salt aerosol, PBAP, NO_3^-, and mineral dust.

Source apportionment studies (Yttri et al., 2011a, b) show that natural sources dominate OM in PM_{10} at Norwegian rural background sites in summer, with biogenic secondary organic aerosol (BSOA) being the major source followed by primary biological aerosol particles (PBAP), whereas wild fires occasionally make a noticeable contribution.

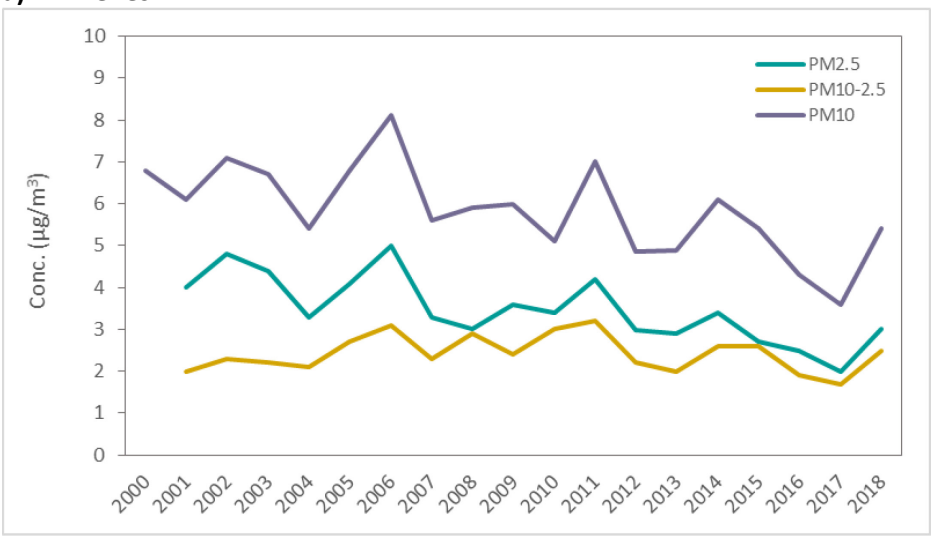
5.3 Trends

The Mann Kendall method described in Chapter 3.2 was used for trend analysis of PM concentrations. Only time series extending 10 years was assessed; i.e. Birkenes (Table 5.1). A statistically significant downward trend was observed for the annual mean concentration of PM_{10} at Birkenes, corresponding to a decrease of -33% from 2000 to 2018 (32% for the period 2001-2018). The observed downward trend for $PM_{2.5}$ was also statistically significant, corresponding to a decrease of -45% from 2001 to 2018. A significant decrease of -10% was calculated for $PM_{10-2.5}$.

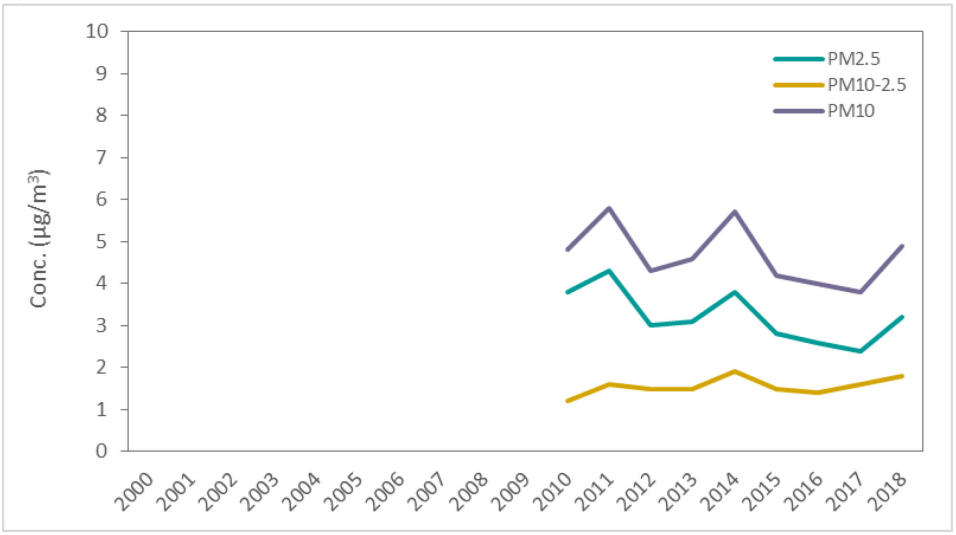
*Table 5.1: Trends in annual mean mass concentration of PM_{10} (2000 - 2018) and $PM_{2.5}$ (2001 – 2018) at Birkenes) using Mann-Kendall test and Sen slope estimates; * significant level 0.05.*

Site	PM_{10}	% change	$PM_{2.5}$	% change
Birkenes	*	-33%	*	-45%

a) Birkenes



b) Hurdal



c) Kårvatn

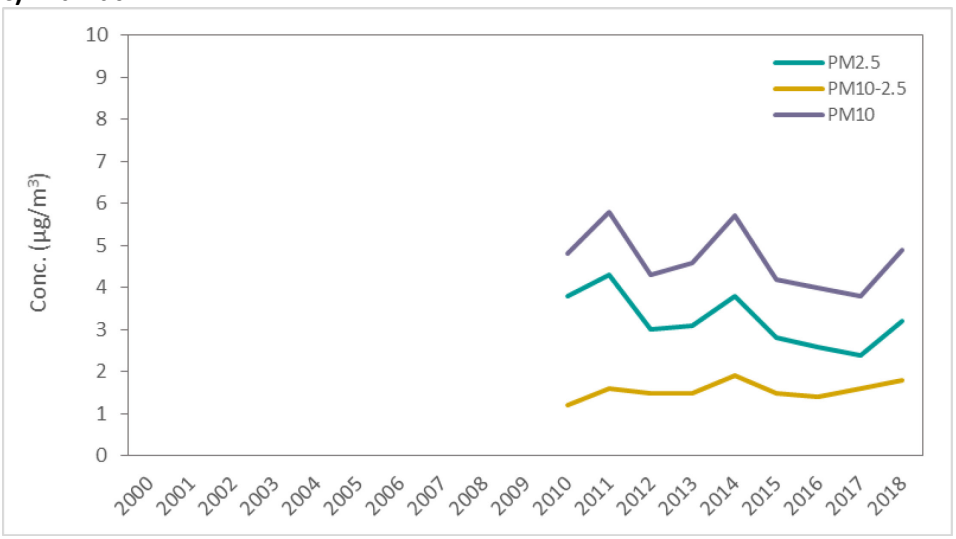


Figure 5.2: Annual mean time series of PM_{10}, $PM_{2.5}$ and $PM_{10\text{-}2.5}$ mass concentration for Birkenes (a), Hurdal (b) and Kårvatn (c) for 2001 – 2018. Unit µg/m³.

5.4 Compliance with EU limit values and Air-Quality Guidelines for PM_{10} and $PM_{2.5}$

The EU annual limit value for PM_{10} and $PM_{2.5}$ (See Table 5.2 for EU limit values and Air-Quality Guidelines for PM_{10} and $PM_{2.5}$) was far from being violated at any of the three sites; the highest annual mean concentrations observed being approximately 13% of the annual limit values. This was also the case when compared to the WHO Air-Quality Guidelines (AQG); the highest annual mean concentrations accounting for 27 – 32% of the annual AQG.

New national limit values for PM_{10} and $PM_{2.5}$ were implemented 1st of January 2016 (Table 5.2). These are less stringent than the WHO AQG, and thus far from being violated at any of the three sampling sites in 2018. The National Air-Quality Guidelines (FHI, 2013) are more stringent than the WHOs with respect to $PM_{2.5}$, still, the highest annual mean observed for PM_{10} and $PM_{2.5}$ in the Norwegian rural background environment in 2018, accounted for no more than 27% and 40% of the PM_{10} and $PM_{2.5}$ National AQG, respectively.

The highest 24-hour mean PM_{10} concentration observed for 2018 was 24.4 µg m^{-3}, and thus did not violate any limit values or AQG.

Table 5.2: EU limit values and Air-Quality Guidelines for PM_{10} and $PM_{2.5}$.

	24-hours	Annual
EU limit values		
PM_{10}	50 µg/m^3 (≤ 35 days yr^{-1})	40 µg/m^3
$PM_{2.5}$		25 µg/m^3
National Limit values[1)]		
PM_{10}	50 µg/m^3 (≤ 30 days yr^{-1})	25 µg/m^3
$PM_{2.5}$		15 µg/m^3
WHO Air-Quality Guidelines		
PM_{10}	50 µg/m^3	20 µg/m^3
$PM_{2.5}$	25 µg/m^3 (the 99th percentile)	10 µg/m^3
National Air-Quality Guidelines[1,2)]		
PM_{10}	30 µg/m^3	20 µg/m^3
$PM_{2.5}$	15 µg/m^3	8 µg/m^3

1) New national limit values. Implemented from the 1st of January 2016.

2) National Air-Quality Guidelines (In Norwegian: Luftkvalitetskriterier). Revised 2013

5.5 Chemical composition of particulate matter

EC and OC were measured in the PM_{10} and $PM_{2.5}$ size fractions at the Birkenes, Hurdal and Kårvatn sites, whereas the major inorganic anions (SO_4^{2-}, NO_3^-, Cl^-) and cations (Ca^{2+}, Mg^{2+}, K^+, Na^+, NH_4^+) were obtained from open filter face samplers with a cut-off size exceeding 10 µm equivalent aerodynamic diameter (EAD). However, most of these species typically reside within the PM_{10} fraction. Occasionally, sea salt aerosol larger than PM_{10} could be collected, i.e. during stormy weather conditions at Birkenes, at a southerly wind direction. The data obtained from the monitoring program appear to be well suited for a mass closure of PM_{10}, except that species representing mineral dust are not included. For 2014 - 2018, the PM10 filter samples collected at Birkenes were analyzed with respect to iron (Fe), which allows for calculating/estimating the mineral dust content.

Mass closure of $PM_{2.5}$ and $PM_{10-2.5}$ would include a larger degree of uncertainty than for PM_{10}, as default assumptions would have to be made according to the size distribution of the inorganic species analyzed, of which the largest uncertainty would be associated with that of NO_3^-, thus this is not performed.

The annual mean chemical mass composition of PM_{10} is shown in Figure 5.3 . The speciated mass explained 59 – 76% of the annual mean concentration of PM_{10} for the three sites, approaching full mass closure (77 – 88%) when allowing for other elements than carbon for OC and EC. The PM_{10} SIA fraction (and levels) was noticeably higher at Birkenes (35%) compared to Hurdal (23%) and Kårvatn (19%), reflecting the proximity of Birkenes to important SIA-precursor emission source regions in continental Europe. NO_3^- was the most abundant single (SIA) species at Birkenes, although by a short margin compared to SO_4^{2-}. At Kårvatn, SO_4^{2-} was more abundant than NO_3^- and NH_4^+ combined, and at Hurdal SO_4^{2-} nearly equaled the sum of NO_3^- and NH_4^+.

Converting OC to OM using a factor of 1.7 (Yttri et al., 2007), made OM (45%) more than twice as abundant as SIA at Kårvatn, nearly (OM = 44%) twice as high as SIA at Hurdal, whereas OM (30%) nearly equaled the SIA contribution at Birkenes. The higher relative contribution of EC at Hurdal (2.6%) compared to Kårvatn (1.4) and Birkenes (1.5%) is consistent with previous years, likely reflecting the more densely populated and anthropogenic influenced region surrounding the Hurdal site.

Situated approximately 20 km from the coastline, Birkenes experienced a substantial 19% sea salt aerosol contribution to PM_{10}, which is the lowest since 2012. Nevertheless, the sea salt contribution at Birkenes wa 1.8 times higher than at Kårvatn (11%) and 3 times higher than at Hurdal (6.5%).

Based on Fe measurements in PM_{10} at Birkenes and knowledge about mineral dust composition in Europe (Alastuey et al., 2016), an annual mean mineral dust concentration of 0.7 µg m-3 was estimated for Birkenes for 2018, corresponding to 13% of PM10 annually. This fraction was considerably higher compared to the previous four years (7 - 9%), and allows for a complete mass closure of PM10 for 2018. Mineral dust levels and its relative contribution to PM10 peaked in spring and summer, accounting for 20% of PM10 in May and July.

Statistically significant up- or downward trends were observed for all species and fractions relative to PM that was addressed, except for NH_4^+ (Table 5.3). The SO_4^{2-}, EC and TC fractions of PM_{10}, and the EC fraction of $PM_{2.5}$, all had a statistically significant downward trend for the period 2001 - 2018, being most pronounced for SO_4^{2-} (-32%). The SO_4^{2-} fraction was the only one with an annual mean for 2018 that was below –SD of the long-term mean. The relative contribution of all other species and fractions to PM were within ±SD. The sea salt aerosol fraction of PM_{10} increased substantially (185%) at Birkenes in 2001 - 2018, partly due to an increased sea salt aerosol level, but also due to lower PM_{10} levels. The NO_3^- fraction has also increased considerably (91%) for the period in question. For OC (PM_{10} and $PM_{2.5}$) and TC ($PM_{2.5}$) there was a minor upward trend, being slightly higher for the fractions in $PM_{2.5}$ compared to PM_{10}.

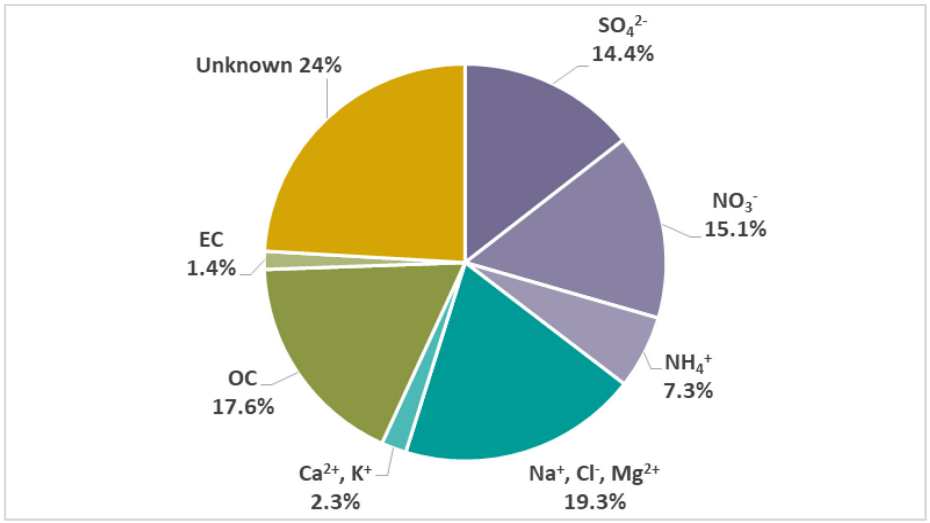
Based on levoglucosan (Table 4.2) we estimate that biomass burning emissions contributed 6-11% to PM annually, considering both PM_{10} and $PM_{2.5}$. The fraction attributed to biomass burning in winter was 12-19%, whereas it was ≤1% in summer, considering both size fractions. Spring and fall are transition seasons with relative contributions lower than in winter and higher than in summer. Biomass burning occasionally exceeded 20% on a weekly basis, all in the heating season, thus emissions are attributed to wood burning for residential heating.

Table 5.3: Trends in relative contribution of selected aerosol particle species and fractions to mass concentration of PM_{10} and $PM_{2.5}$ using Mann-Kendall test and Sen slope estimates, significant level 0.05.

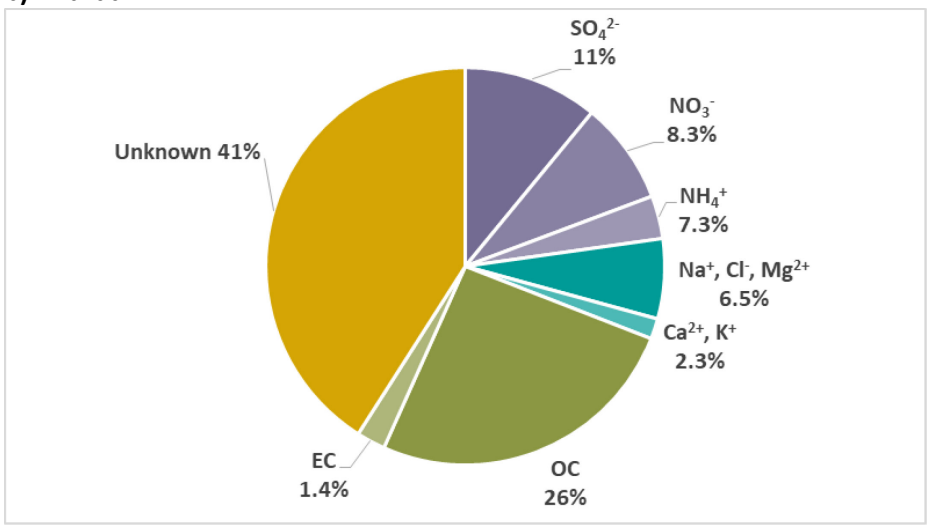
Site	Species/Fraction	Time period	Change (%)
Birkenes	SO_4^{2-} to PM_{10}	2001 – 2018	-31%
	NO_3^- to PM_{10}	2001 – 2018	82%
	NH_4^+ to PM_{10}	2001 – 2018	not significant
	ΣNa^+, Cl^-, Mg^{2+} to PM_{10}	2001 – 2018	158%
	OC_{PM10} to PM_{10}	2001 – 2018	2%
	EC_{PM10} to PM_{10}	2001 – 2018	-26%
	TC_{PM10} to PM_{10}	2001 – 2018	- 6%
	$OC_{PM2.5}$ to $PM_{2.5}$	2001 – 2018	15%
	$EC_{PM2.5}$ to $PM_{2.5}$	2001 – 2018	-12%
	$TC_{PM2.5}$ to $PM_{2.5}$	2001 – 2018	12%

Trends are calculated for time series extending 10 years

a) Birkenes



b) Hurdal



c) Kårvatn

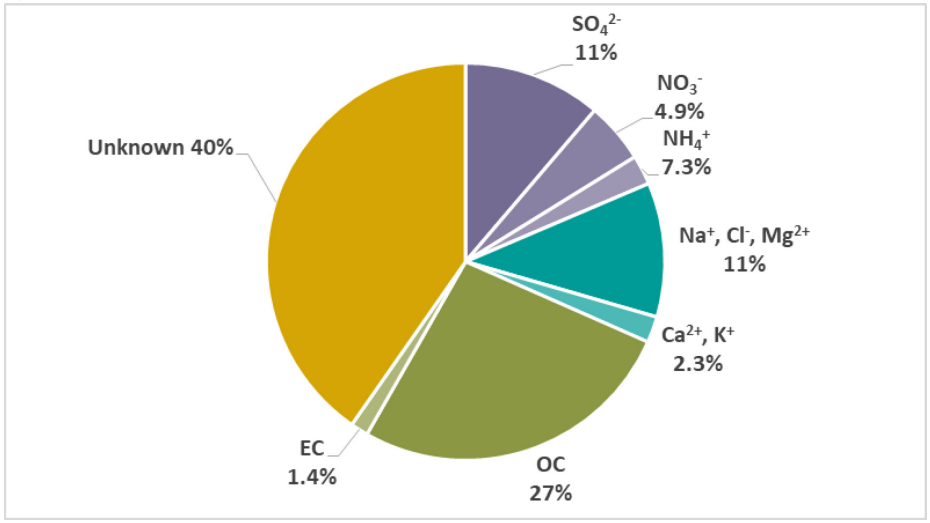


Figure 5.3 Annual mean chemical composition of PM_{10} at the Birkenes Observatory a), the Hurdal site b) and the Kårvatn site c) for 2018. The annual mean mass concentration for PM_{10} in 2018 was 5.4 µg/m³ at the Birkenes Observatory, 4.9 µg/m³ at the Hurdal site, and 3.2 µg/m³ at the Kårvatn site.

5.6 Particle number concentrations

The annual mean particle number concentration for the size range in particle diameter 0.02 < *Dp* < 10 µm (N_{Tot}) at Birkenes for 2018 was 13% higher than the long-term mean, but still within one standard deviation of the long-term mean. The annual mean number concentration of ultrafine particles N_{UF} (0.01 < *Dp* < 0.1 µm) (8% higher) and of accumulation mode particles N_{Acc} (0.1 < *Dp* < 1.0 µm) (28% higher) size fractions were higher than the long-term mean as well, which is to be expected as nuclei and Aitken mode particles, and to some extent the lower size fractions of the accumulation mode, dominate the particle number concentration. The annual mean N_{CM} (1 – 10 µm) size fraction could not be established due to problems with an instrument after factory calibration and maintenance. The problems have meanwhile been addressed. The missing data on N_{CM} have no detectable influence on determining N_{Tot}. The higher-than-average annual mean for 2018 was mainly attributed to higher particle concentrations in spring and fall, caused by early onset and long duration of summer temperatures.

72% of N_{Tot} was attributed to N_{UF} and 28% to N_{Acc} at Birkenes for 2018, whereas the fraction associated to particles in the range 1.0 – 10 µm, i.e. the coarse mode, could not be established. However, the fraction of particle number in the coarse mode is usually negligible at Birkenes. The fraction of N_{tot} attributed to N_{UF} and N_{Acc} do not vary much between years, whereas the variability is slightly higher for N_{CM}, due to low levels and thus larger uncertainty. N_{UF} was the dominating fraction regardless of season, accounting for 70 – 80% of N_{tot}. The 72% contribution of N_{UF} to N_{tot}, and the corresponding 28% contribution of N_{Acc} to N_{Tot}, in 2017 are not considered major deviations compared to previous years. Typically, the N_{UF} fraction drops in winter, whereas the N_{Acc} fraction increases correspondingly, so also for 2018.

Table 5.4: Number concentrations for ultrafine, accumulation mode and coarse mode particles at Birkenes for 2010 – 2018 and their relative share to the total concentration. Unit: cm^{-3}.

Year ***N*** (cm^{-3})	Ultrafine particles (***Dp*** **<0.1µm)**	(%)	Accumulation mode particles **(0.1 µm < *Dp*.< 1.0 µm)**	(%)	Coarse mode particles **(1.0 µm < *Dp*< 10 µm)**	(%)	Total concentrations **(*Dp* = 0.01 - 10 µm)**
2010	973	73	362	27	0.256	0	1336
2011	1047	74	371	26	0.565	0	1418
2012	889	77	263	23	0.375	0	1152
2013	1020	77	304	23	0.391	0	1324
2014	1279	74	456	26	0.338	0	1735
2015	1326	77	390	23	0.340	0	1717
2016	1063	75	357	25	0.392	0	1421
2017	943	78	272	22	0.267	0	1216
2018	1151	72	444	28	--	--	1596

5.7 Summary

Observed annual mean concentrations of PM_{10} and $PM_{2.5}$ in the Norwegian rural background environment are amongst the lowest in Europe (< 5.4 µg/m^3). International and national limit values and air quality guidelines were not violated in 2018, neither on an annual nor on a 24-hours basis.

Secondary inorganic aerosol constituents (SIA) (35%) dominated PM_{10} at the southernmost site Birkenes, reflecting the proximity to major anthropogenic emission regions in continental Europe. The relative contribution of organic matter (30%) was marginally lower than SIA, whereas sea salt aerosol (19%) constitute slightly less. A first time attempt to quantify mineral dust showed a 13% contribution to PM_{10} at Birkenes. Organic matter was clearly the largest fraction at the Hurdal (44%) and Kårvatn (45%) sites.

There was a significant downward trend for both PM_{10} and $PM_{2.5}$ (-33% - -45%) for the period 2000/01 – 2018, which is in line with emission reductions of primary and secondary sources in Europe. However, measurements of source specific compounds and high time-resolution measurements, along with transport modelling, are needed for a more detailed assessment of sources and source regions. Estimates based on levoglucosan measurements, suggest that biomass burning contributed 6-11% to PM annually, considering both PM_{10} and $PM_{2.5}$. The fraction attributed to biomass burning in winter was 12-19%, whereas it was < 1% in summer, considering both size fractions.

6 Ground-level ozone

Ozone in the troposphere originates from photo-chemical reactions in the atmosphere between volatile organic compounds (VOCs), carbon monoxide (CO), methane (CH_4) and nitrogen oxides (NOx) under the influence of solar radiation, as well as from the transport of stratospheric ozone into the troposphere. VOCs, CO and CH_4 are emitted from anthropogenic sources such as road and ship traffic, leakage of natural gas, use of solvents and chemicals etc., and NOx is mainly emitted from traffic and power plants. In addition, biogenic sources (trees and plants) contribute significantly to the emission of VOCs and CH_4 and to a smaller extent to NOx (microbiological activity in soils). On a global basis lightning is also an important source of NOx in the troposphere. Thus, tropospheric ozone is the result of what is produced by both natural and man-made processes. Furthermore, the weather conditions have a strong influence on the efficiency of the ozone formation since the chemical reactions are generally favoured by solar radiation and high temperatures.

Once formed, tropospheric ozone is only slowly degraded by chemical reactions with OH, HO_2 and NO_2. The chemical lifetime of ozone in the free troposphere is of the order of several weeks. At the land surface, however, dry deposition and uptake in vegetation are effective loss mechanisms for ozone. Ozone dry deposition is determined by the local topography and land use and could be very important for the concentrations observed at surface monitoring sites in summer, particularly at continental stations with a strong diurnal cycle in surface temperature. This influence will be most apparent during nights with stable atmospheric conditions while the daytime values will be less affected due to a deeper atmospheric mixing layer.

Ozone has negative impacts on health, vegetation and materials. According to European Environment Agency (EEA) particulate matter (PM) and surface ozone are Europe's most problematic pollutants in terms of harm to human health (EEA, 2014). Furthermore, surface ozone is considered to be the most damaging air pollutant to vegetation in Europe today, with significant effects on the growth of trees, on vegetation in general, and on important agricultural crops.

The health effects regards particularly asthmatics and people with chronic respiratory disorders. Effects on the vegetation regards particularly crops but also forests and natural vegetation. Prolonged exposure have shown negative impacts on forests. Materials such as rubber and other polymer compounds can also be damaged by ozone. As opposed to other pollutants, the baseline level of ozone, i.e. the concentration level in remote areas far from emission source regions, is fairly close to the threshold levels for effects on human health and vegetation. Thus, the environmental problems related to surface ozone is a regional and widespread phenomenon.

6.1 Monitoring network

Measurements of ozone has been going on in Norway since 1975, first in Telemark and from 1977 also around the Oslo fjord and in subsequent years extended to the whole country. EU's air quality directive (AQD) (EU, 2008: Directive 2008/50/EC) which is implemented in Norwegian legislation contains the thresholds and objectives regarding ozone levels and the requirements as to the number of monitoring sites. According to the directive, the country should be divided into a number of zones. The stations in the individual zones as of 2018 are indicated in the map in chapter 1 (Figure 1.1). The EU directive gives requirements for the minimum number of monitoring sites within each zone and for the country as a whole.

The ozone monitoring network in 2018 consisted of eight stations. Seven of these were operated by NILU, while the Porsgrunn municipality was operating the station at Haukenes. The station at Haukenes can be classified as suburban while the rest are rural background stations which implies that the sites are not affected by local emissions. The data from Haukenes were reported to the air

quality database at NILU where a final validation is done by the National Reference Laboratory for ambient air quality measurements.

Table 6.1 shows the monitoring sites and data capture for 2018, which was 91% or higher at all stations. The measuring method and principles are given in Annex 3.

Table 6.1: Ozone monitoring sites and data capture based on hourly values in 2018.

St.nr.	Station name	Period	Data capture
NO0043	Prestebakke	01.01.18- 31.12.18	99%
NO0056	Hurdal	01.01.18- 31.12.18	99%
NO0489	Haukenes	01.01.18 - 31.12.18	91%
NO0002	Birkenes II	01.01.18 - 31.12.18	98%
NO0052	Sandve	01.01.18 - 31.12.18	97%
NO0039	Kårvatn	01.01.18 - 31.12.18	99%
NO0015	Tustervatn	01.01.18 - 31.12.18	99%
NO0042	Zeppelin	01.01.18 - 31.12.18	100%

6.2 Ground-level ozone in Norway

In the scientific literature one often distinguishes between the “background” and the “baseline” level (e.g. Oltmans et al., 2013), in which the former refers to the pre-historic levels in an unpolluted atmosphere whereas the latter refers to the present levels in the northern hemisphere, far away from any emission areas.

The northern hemispheric ozone baseline level varies between 40 and 80 $\mu g/m^3$ throughout the year and is typically highest in spring. On top of this baseline level, episodes with long-range transport of more polluted air masses increase the ozone levels regularly during the summer season. During winter the situation is the opposite, i.e. the transport of polluted air masses from the European continent leads to reduced ozone levels due to the titration reaction $O_3 + NO \rightarrow NO_2$. This difference between winter and summer is explained by the intensity of the solar UV-radiation which leads to a fast photochemistry in summer and a corresponding slow and inefficient photochemistry in winter.

The ozone levels at a monitoring site is also influenced by local effects near the station such as dry deposition to the surface and episodes of local NOx emissions. In general, the Norwegian rural ozone stations are not much influenced by nearby emissions, but occasional short-term episodes of ozone degradation due to local NOx sources cannot be ruled out totally. These local effects will result in a reduction in ozone and thus an underestimation of the regional ozone exposure. Hence, in summary, the level of ozone is the net result of a hemispheric, a regional and a local component.

In Norway summertime episodes of elevated ozone are often associated with a high pressure located over the European continent, typically over Central or Eastern parts, setting up a southerly or southwesterly transport of warm, polluted air masses to the country. Ozone episodes are typically a fair-weather phenomenon associated with hot and sunny days. Furthermore, the highest ozone levels are often experienced just at the end of such fair-weather periods which is explained by an approaching cold front setting up an effective transport of photochemically processed air masses from the continent.

6.3 Norwegian ozone levels in 2018

Time series of daily maximum ozone values through 2018 are given in Figure 6.1 together with the climatological mean seasonal cycle (30 days running mean) based on the previous 18 years of data. Note that for Birkenes, the 2018 data are from the Observatory (Birkenes II), whereas the climatological means are based on measurements at the old location, which gave systematically lower levels due to stronger surface dry deposition.

The time series indicate that 2018 was a year with numerous periods with daily maximum ozone above the climatological mean in the whole period May-September, most pronounced for the stations in the southern part of the country. The elevated ozone levels in the summer season 2018 corresponds with the extreme weather conditions experienced in South Norway with prolonged heat and drought as outlined in Ch 2.

The smoothed seasonal cycles (14 days' running mean) in ground-level ozone in 2018 are shown in Figure 6.2 together with the climatological mean seasonal cycles for the period 2000-2017 for each site. This shows that particularly for Prestebakke, Hurdal, Haukenes and Birkenes the mean ozone levels in 2018 were substantially above the climatological mean for long periods of the summer season. For Sandve, Kårvatn and Tustervatn the mean levels were less elevated compared to the climatology.

In the summer season the ozone concentrations at many stations vary systematically over the day, particularly on days without strong winds. The concentration is low during stable night-time conditions, e.g. when inversions develop, and then rises quickly in the morning when the heating of the ground leads to the ozone rich air being mixed down. The highest levels are typically observed in the afternoon. This diurnal cycle is the result of ozone deposition to the ground combined with the daily cycle in vertical atmospheric exchange.

The mean diurnal cycle in ozone during April-September 2018 are shown for three selected sites in Figure 6.3. The strongest cycle is seen at Kårvatn, a valley inland station with a strong cycle in the height of the atmospheric mixed layer. A less pronounced ozone cycle is seen at Sandve, a coastal station where night-time inversions are less frequent. In contrast to this, the ozone values at the Zeppelin Mountain shows no diurnal cycle.

The diurnal cycle in ground-level ozone is a result of dry deposition to the surface combined with increased atmospheric stability during night-time. Since the deposition of ozone to water and ice/snow surfaces is very small and the monitoring site on the Zeppelin mountain is located above the planetary boundary layer there is no visible diurnal cycle in ozone at that site.

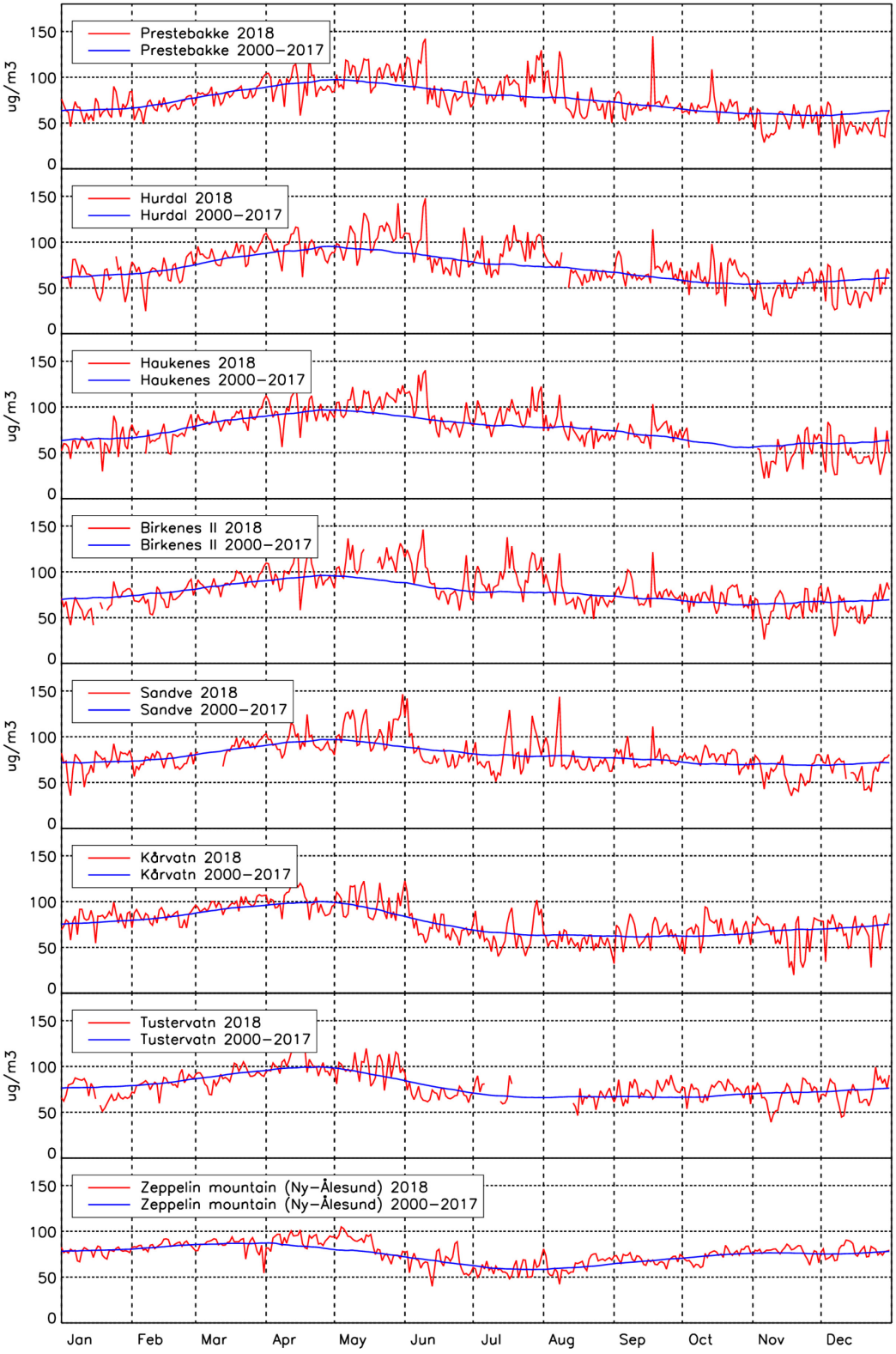


Figure 6.1: Daily maximum ozone concentrations in 2018 (red) together with the 30 days' running mean of the daily maxima for the years 2000-2017 (blue).

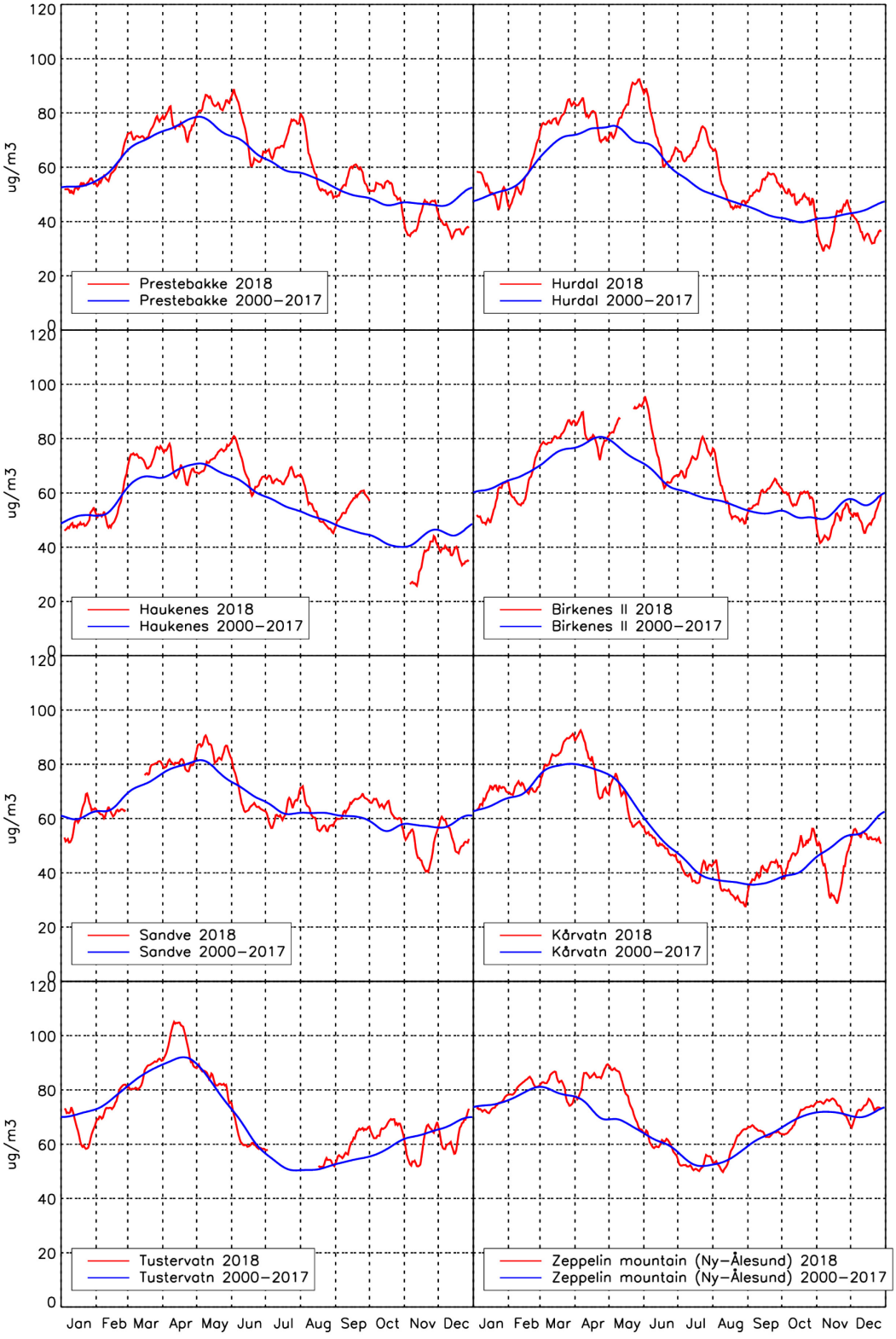


Figure 6.2: The 14 days' running mean ozone concentrations in 2018 (red) together with the corresponding mean concentrations based on all years 2000-2017 (blue).

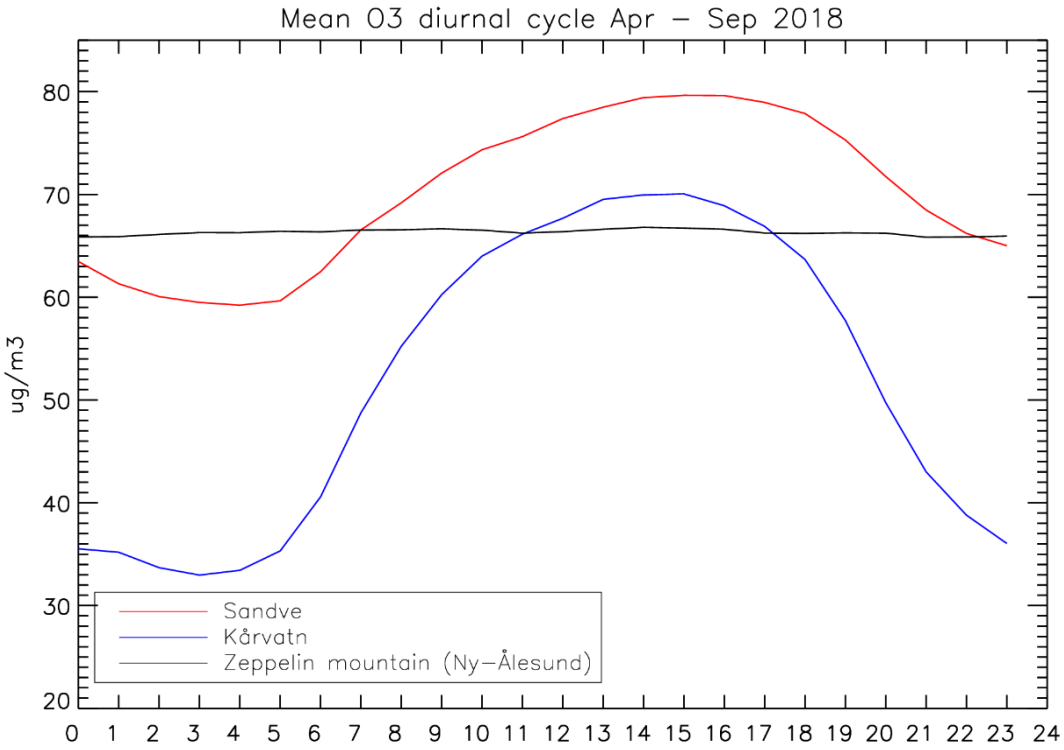


Figure 6.3: The mean diurnal cycle in ozone at three of the monitoring sites; Sandve, Kårvatn and Zeppelin Mountain during April-September 2018.

6.4 Exceedances of the limit values for protection of human health

Ground-level ozone can cause health problems, and the concentration level should not exceed certain limit values. Various air quality criteria for ozone for the protection of health are given in Table 6.2. EU's third daughter directive relating to ozone in ambient air was derived in 2002 (EU, 2002), and in 2008 a new air quality directive was adopted (EU, 2008). WHO has also defined certain air quality guidelines for ground-level ozone (WHO, 2006). Norway has implemented EU's air quality directive and information and warning bulletins are broadcasted to the public in case of exceedance of the information threshold (180 µg/m^3) and alert threshold (240 µg/m^3), respectively.

In 2013 a new set of national air quality guidelines were defined for ozone and other species. The national and the WHO guidelines as well as the EU directive values are given in Table 6.2.

Table 6.2: Limit values for ground-level ozone for the protection of human health.

Value (µg/m^3)	Averaging time (hours)	Ref	Description
180	1	EU (2008)	EU's information threshold
240	1	EU (2008)	EU's alert threshold
120	8[1)]	EU (2008)	EU's target value. 8-hour mean value not to be exceeded on more than 25 days per year averaged over 3 years. To be fulfilled by 1.1.2010
120	8[1)]	EU (2008)	EU's long-term objective.
100	8[1)]	WHO (2006)	WHO's air quality guideline (global update 2005)
100	1	FHI (2013)	National air quality guideline (update 2013)
80	8[1]	FHI (2013)	National air quality guideline (update 2013)

1) The highest 8-hour running mean value for each day calculated such that the 8-hour periods are assigned to the day on which the period ends.

The exceedances of the limit values for health are given in Table 6.3. The table shows the number of days with exceedance of WHO's air quality guideline of 100 µg/m^{3}and EU's long-term objective of 120 µg/m^3. The number of hours with exceedance of EU's information threshold of 180 µg/m^3 is also given as well as the annual hourly max value together with the date(s) that value occurred. The total number of hours with ozone data and days with at least 75% data capture through the year is given for reference. The exceedances based on the 8 hour mean values were only calculated for days with at least 75% data capture.

Table 6.3: For all sites in 2018 the number of hours with data and the number of days with at least 75% data capture together with the exceedances of health related air quality limits; national air quality guidelines, WHO guideline and EU's limit values as given in Table 6.2 as well as the annual maximum and the date when it occurred.

			National AQ guidelines		WHO	EU directive			
Station	Hours	Days	Days	Hours	Days	Days	Hours	Max. hourly value (µg/m^3)	Date
		>75%	8h > 80 µg/m^3	1h > 100 µg/m^3	8h > 100 µg/m^3	8h > 120 µg/m^3	1h > 180 µg/m^3		
Prestebakke	8691	365	128	372	37	6	0	145	18.09.2018
Hurdal	8646	364	124	355	38	5	0	148	10.06.2018
Haukenes	7979	336	121	323	33	3	0	140	10.06.2018
Birkenes II	8562	362	145	557	48	9	0	146	09.06.2018
Sandve	8479	357	112	320	31	6	0	146	31.05.2018
Kårvatn	8688	365	133	330	29	1	0	124	13.04.2018
Tustervatn	8140	347	132	354	31	1	0	124	15.04.2018
Zeppelin	8719	365	121	28	3	0	0	105	04.05.2018

The values in Table 6.3 further confirms that 2018 was a year with unusually high ozone levels. The annual hourly peak levels were not particularly high (highest peak 148 µg/m^3), but the intermediate levels, i.e. days and hours with values above 100 µg/m^3 and 120 µg/m^3, were substantially higher than in the previous years. Whereas 2017 was a year with the lowest number of episodes and exceedances since the start of the monitoring, 2018 had the highest number of episodes and exceedances for many years.

EU's target value for the protection of human health are met in Norway with a very good margin. The long-term objective (=LTO, i.e. max 8h value < 120 µg/m^3) and thereby also WHO's and

Norwegian air quality guidelines is on the other hand exceeded to a variable extent every year. In 2018 the LTO was exceeded at all stations except Zeppelin Mountain.

The WHO guideline was broken at all sites (including Zeppelin Mountain) in 2018. This reflects that the WHO guideline level of 100 µg/m^3 as an 8-hours mean is close to the baseline level, implying that a small change in the mean level will lead to a large change in the number of days with exceedances. The highest hourly ozone concentration in 2018 was 148 µg/m^3 observed at Hurdal 10 June.

The ozone levels and exceedances vary strongly from year to year which is also indicated by Figure 6.4, showing the number of days with exceedance of the 8-hour mean value of 120 µg/m^3 for the period 2000-2018. Table 6.4 gives the annual peak values and number of days with exceedance of the LTO from 2005 to 2018. The main reason for the inter-annual variations is variations in the large scale weather conditions from one year to another. Over time, long-term changes in the European emissions of NOx and VOC as well as gradual trends in the hemispheric baseline level of ozone will be important.

Table 6.4: The annual maximum hourly ozone concentration and the number of days that EU's long-term objective was exceeded during 2005-2018 at one or more stations. Note that the monitoring network have changed over this period and thus the values are not directly comparable from year to year.

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Annual hourly max. (µg/m^3)	144	186	139	160	142	145	168	130	124	147	148	140	135	148
Number of dates with exceedance of EU's long-term objective of 120 µg/m^3 [a)]	7	28	8	16	9	3	12	2	2	4	2	4	1	22

a) Running 8-h mean

The EU directive requires the countries to sustain monitoring stations in all air quality zones where the long-term objective has been broken in the last five years. As shown in Figure 6.4, this limit value has been exceeded at all stations the last five years. In 2018 the LTO was broken at 22 days which is the highest number of dates since the peak year in 2006. The number of exceedances per station was the highest at Birkenes with 9 days of exceedances in 2018.

The updated national guidelines (FHI, 2013) are even stricter than the WHO guideline (Table 6.2) and both the 80 µg/m^3 (8-h mean) and 100 µg/m^3 (1-h mean) were exceeded for long periods of the year in the whole country (except on Spitsbergen) as shown by Table 6.3. In 2018 the number of hourly values exceeding 100 µg/m^3 was on the order of ten times higher than in 2017.

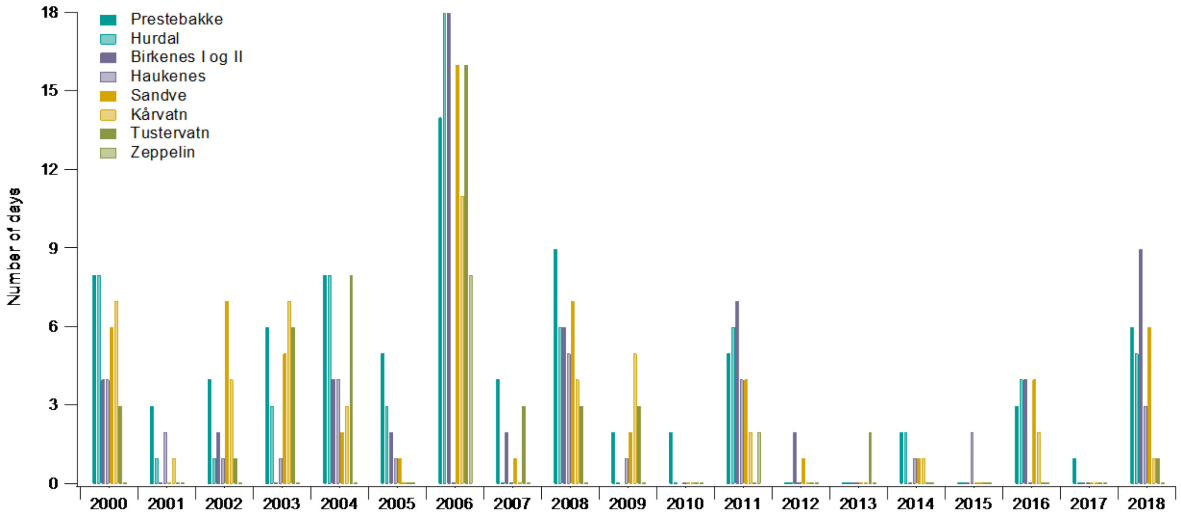


Figure 6.4: The number of days with a maximum daily 8-h mean ozone concentration above 120 µg/m^3 for the period 2000-2018. Note that the Birkenes site has been moved, and data before 2010 refer to the old location. See text for more explanations.

6.5 Exceedance of the threshold values for protection of vegetation

Threshold levels for ozone exposure to vegetation has been set both by EU and UN-ECE. Within EU and to some extent within UN-ECE the limit values are based on the cumulative exposure over the threshold value of 40 ppb (= 80 µg/m^3) and the parameter is termed AOT40 ("Accumulated exposure over the threshold of 40 ppb") as listed in Table 6.5. AOT40 is calculated as the sum of the differences between the hourly mean concentration and 40 ppb for each hour where the ozone concentration exceeds 40 ppb during a certain pre-defined growing season.

EU's air quality directive (EU, 2008) includes a target value (to be reached by 2010) and a long-term objective (without any deadline) for a 3-months AOT40 value relevant for semi-natural vegetation. UN-ECE (the Mapping Manual published by Mills et al., 2017) also provides 3-months critical levels for agricultural crops and semi-natural vegetation as well as a 6-months critical level for forests.

The procedure for calculating AOT40 differs, however, between the EU legislation and UN-ECE. According to the EU directive (EU, 2008) AOT40 should be based on the measured hourly ozone values from 08:00 – 20:00 CET (Central European Time) from 1 May – 31 July. UN-ECE on the other hand defines the hours with a global radiation > 50 W/m2 to be included in the AOT calculation. Furthermore, UN-ECE defines growing seasons that vary with geographical location and altitude and, in addition, they require that the ozone values should be interpolated to the canopy height before calculating AOT40. When local meteorological measurements are not available, the Mapping Manual (Mills et al., 2017) includes tables for converting the measured ozone data to ozone levels at canopy height based on the land cover and surface data. Due to these complications, we use the much simpler 3-months AOT40 definition as stated in the EU directive in this report.

There is no critical level for 6-months AOT40 in the EU directive, and thus we use the UN-ECE definition for this although in a simplified way. For calculation of the 6-months AOT40 we use the measured data directly without any interpolation to canopy height. This is justified by the fact that the difference between ozone at the inlet height (typically 3-10 m above ground) and the typical canopy height for forests is small. Since the vertical gradient in ozone is largest near the surface, the

main problem of interpolation is from the monitor's inlet height to the canopy height of smaller plants.

Table 6.5: Limit values for the protection of vegetation from ozone exposure.

AOT40 (ppb hours)	Period	Reference	Comment
3000	3-months growing season	Mills et al., 2017	UN-ECE's critical level for agricultural crops and semi-natural vegetation [1)]
5000	1 April – 30 Sept	Karlsson et al., 2003; 2005	UN-ECE's critical level for forests [1)]
9000	1 May – 31 July	EU, 2008	EU's target value for vegetation. Should be averaged over five years [2)]
3000	1 May – 31 July	EU, 2008	EU's long-term objective for vegetation [2)]

1) UN-ECE's AOT values should be based on the hours with global incoming radiation > 50 W/m^2
2) EU's AOT values should be based on the period 08-20 CET and
3) EU's AOT values should be based on the period 08-20 CET

Research in recent years have shown that the AOT40 based critical levels for vegetation should be replaced with the so-called flux based critical levels (Mills et al., 2011) when assessing the actual impact on plants. The flux based levels (named POD_Y) takes into account various environmental conditions such as soil moisture, solar radiation, leaf area, vertical stability of the atmosphere, land cover etc, and thus provides a better estimate of the real ozone exposure of the plants. Comparison between AOT40 based levels and POD_Y levels with ozone exposure experiments in the field have indeed confirmed that the flux approach is better suited for direct assessments of the actual effect from ozone on vegetation. Concentration based AOT40 values continue to be used, however, where the meteorological data and calculations from flux models are not available.

Table 6.6 shows the 3-months AOT40 values based on the definition in the EU directive (08:00-20:00 CET) for the period 1 May – 31 July 2018. Figure 6.5 shows the same 3-months AOT40 value for the years 2000-2018. EU's target value of 9000 ppb hours has not been exceed for many years in Norway. The long-term objective of 3000 ppb hours was, however, exceeded at five stations in Southern Norway in 2018; Prestebakke, Hurdal, Haukenes, Birkenes and Sandve. A so widespread exceedance of the long-term objective hasn't been seen in Norway for over ten years.

The highest 3-months AOT40 value in 2018 was recorded at Birkenes with 7463 ppb hours (corrected for data capture) which is the second highest value observed in Norway since the start of the regular monitoring in the early 1990s. The highest value occurred in 2006, also at Birkenes (at the former location of the site), with 8167 ppb hours. The fact that nearly record-high AOT40 levels are seen in 2018 considering the substantial reduction in ozone precursors that has taken place in Europe since the 1990s highlights the strong link between climate conditions and surface ozone levels. This link has been investigated in many model studies, and 2018 was apparently a real-life extreme scenario in this respect.

Table 6.7 shows the 6 months AOT40 values for forests (April-September) 2018 as based on the UN-ECE definition (using the hours with a global radiation > 50 W/m2), and the corresponding plot for the years 2000-2018 are shown in Table 6.6. The critical level of 5000 ppb hours for forests was exceeded at 6 of the 8 stations in 2018 and only Kårvatn and the Zeppelin Mountain had values below this limit value. The highest 6-months AOT40 value was seen at Birkenes with 7932 ppb hours.

Table 6.6: Data capture and 3-month's AOT40 values for vegetation for the period 1 May - 31 July 2018 (unit: ppb hours) according to the definitions in the EU directive.

Station	*Data capture (%)*	*AOT40 (corrected for data capture)*
Prestebakke	99	5964
Hurdal	98	5561
Haukenes	99	5535
Birkenes II	94	7463
Sandve	99	4569
Kårvatn	99	2284
Tustervatn	87	2338
Zeppelin	99	994

Table 6.7: Data capture and 6-month's AOT40 values for forests for the period 1 April – 30 September 2018 (unit: ppb hours) according to the definitions in UN-ECE's Mapping Manual.

Station	**Data capture (%)**	**AOT40 (corrected for data capture)**
Prestebakke	99	6625
Hurdal	98	5398
Haukenes	99	5937
Birkenes II	96	7932
Sandve	99	5609
Kårvatn	98	4371
Tustervatn	85	5550
Zeppelin	99	1933

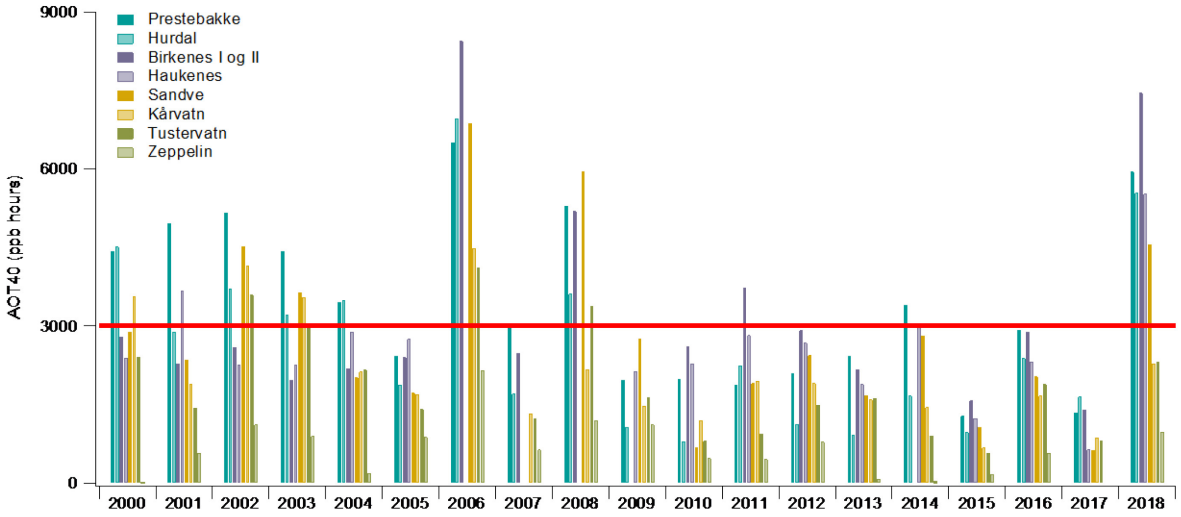


Figure 6.5: 3 months' AOT40 values (1 May - 31 July) for the years 2008 - 2018 (based on UN-ECE's definition of daylight hours). The EU directive's long-term objective of 3000 ppb hours is indicated by the line. Note that the Birkenes site has been moved, and data before 2010 refer to the old location. See text for more explanations.

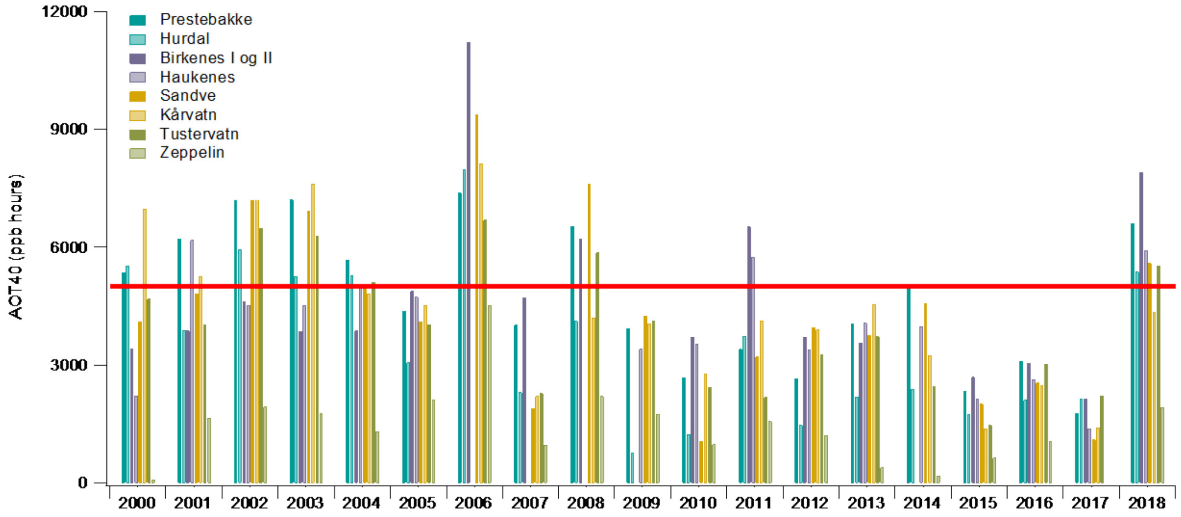


Figure 6.6: 6 months' AOT40 values (1 April - 30 September) for the years 2000 - 2018 (based on UN-ECE's definition of daylight hours, > 50 W/m^2). The critical level for forests (5000 ppb hours) is indicated by the line. Note that the Birkenes site has been moved, and data before 2010 refer to the old location.

6.6 Long-term trends in ground level ozone

Owing to its long atmospheric lifetime the long-term trends of ground-level ozone in Norway are the net result of large-scale trends in the hemispheric baseline level with regional/European effects superimposed. Recent studies of the hemispheric baseline ozone indicates a doubling of the mean O_3 from the 1950s up to about the year 2000 followed by a decade with no growth or even reductions in O_3 at some sites, particularly in summer (Logan et al., 2012). Recent studies also indicate a change in

the mean seasonal cycle of the baseline O_3 with the seasonal maximum being shifted from summer to spring in recent years. In contrast to the consistent picture for the baseline, the findings are more mixed for European monitoring stations. Tørseth et al. (2012) found strong declines in the highest O_3 values in the UK and Netherlands and no clear trends in Austria and Switzerland for the period 1990-2010.

Changes in monitoring network (both station locations and instrumentation/methods) is an obstacle to trend assessments. One needs consistent time series from stations running over multiple decades to detect surface ozone trends. A detailed inspection of the Norwegian monitoring history of ground-level ozone was carried out in 2003 (Solberg, 2003) which revealed many technical issues related to the monitoring procedures before 1997 when much more strict guidelines for the QA/QC work was put in operation. Before that year, a monitor in the field could be operating for years without calibration until it finally broke down and, additionally, the performance and stability of the ozone monitors were generally of poorer quality. The review in 2003 provided recommendations for selection of time periods with more reliable ozone for each station to be used for trend analyses. For simplicity we decided to base the trends only on the years from 1996 and onwards in the present chapter.

Figure 6.7 - Figure 6.9 show the development in three ozone metrics from 1990 to 2018; 3-months AOT40 (May-July), the number of days with an 8-h running max exceeding 100 µg/m^3 (WHO guideline) and the 97-percentile of the daily max 8-h running mean April-September. The latter metric corresponds approximately to the annual 4th highest value used in the ozone trend assessment within the EMEP TFMM (Colette et al., 2016) and IGAC TOAR (Tropospheric ozone assessment research) programs.

Results for four stations with long-term monitoring history are given: Prestebakke, Sandve, Kårvatn and Tustervatn. The values for all years are shown, however only the data from 1996 and onwards were included in the Mann-Kendall/Sen's slope trend estimate. Furthermore, the data from 1998 from Prestebakke were excluded from the analyses based on the mentioned evaluation of the monitoring history (see Solberg, 2003 for details). The trend lines are only given when a statistically significant (p=0.05) trend is found.

Downward levels are calculated for the 3-months AOT40 at all four sites, but the trend is statistically significant (p=0.05) only for Kårvatn with a reduction corresponding to 2.95%/year relative to 1995 as a start year.

In contrast, the number of days with a maximum 8-h concentration exceeding 100 ug/m3 shows a significant reduction at all four sites, and the 97-percentile of the daily max 8-h concentration shows a significant reduction at all sites except Sandve.

A reduction in high ozone concentrations are expected due to the substantial reduction in European man-made emissions of NOx and VOC the last decades. The analyses shown here are in line with this. The selection of ozone metric, time period, station and the monitoring procedures are, however, crucial for the estimated trend values. Within the IGAC initiative TOAR a very long list of various ozone metrics is presently used for global trend assessments. Whereas trends in ozone guideline metrics (AOT, exceedance of limit values etc.) are the main interest of the effect community, these metrics are not necessarily the metrics most relevant for evaluating the effect of man-made emission abatement.

Furthermore, observational trends are the combined result of the influence from inter-annual meteorological variability and changes in man-made emissions of ozone precursors. Only supporting modelling data could indicate the influence of each of these effects separately.

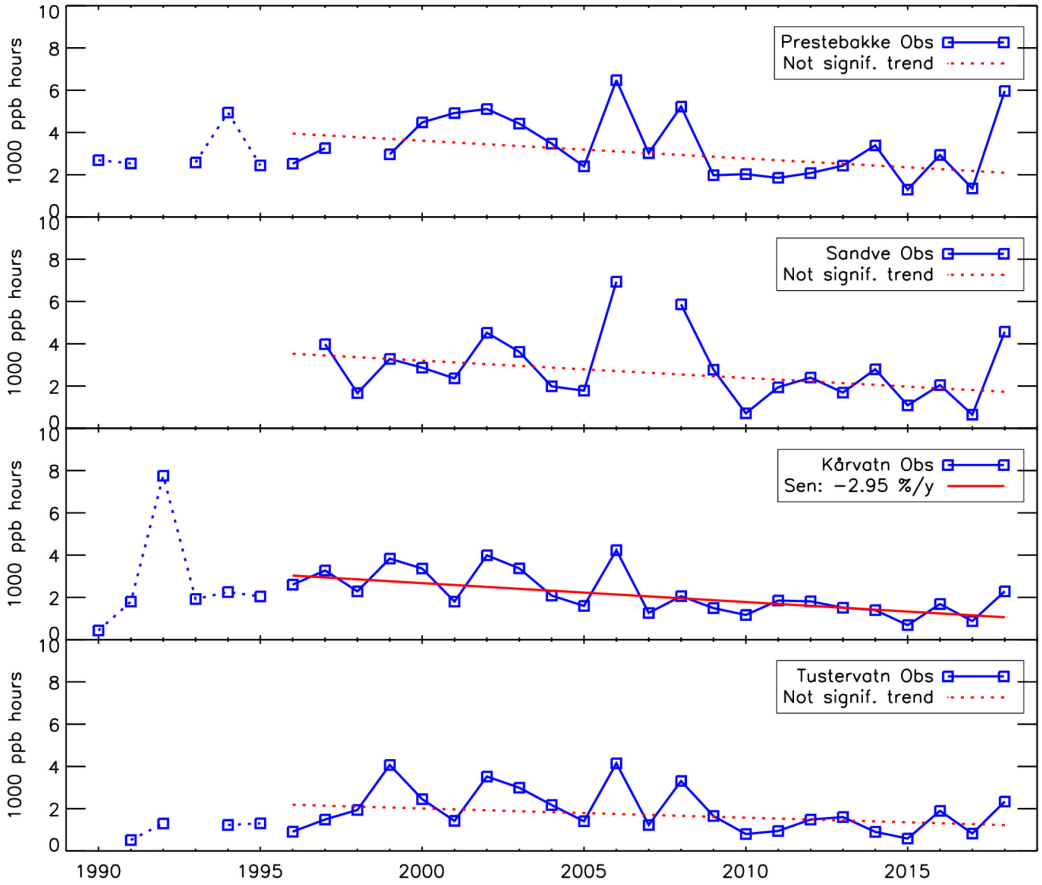


Figure 6.7: The 3-months AOT40 value according to the EU directive (May - July, hours 8-20 CET) during 1990-2018 for four sites. The estimated Sen's slope based on annual data for 1996-2018 are marked in red. Data from the first years (1990-1995) are uncertain and not included in the trend calculations and marked with a dotted line. Note also that all data from Prestebakke in 1998 were not used due to data quality concerns. The percentage trend value refers to 1995 as the start year.

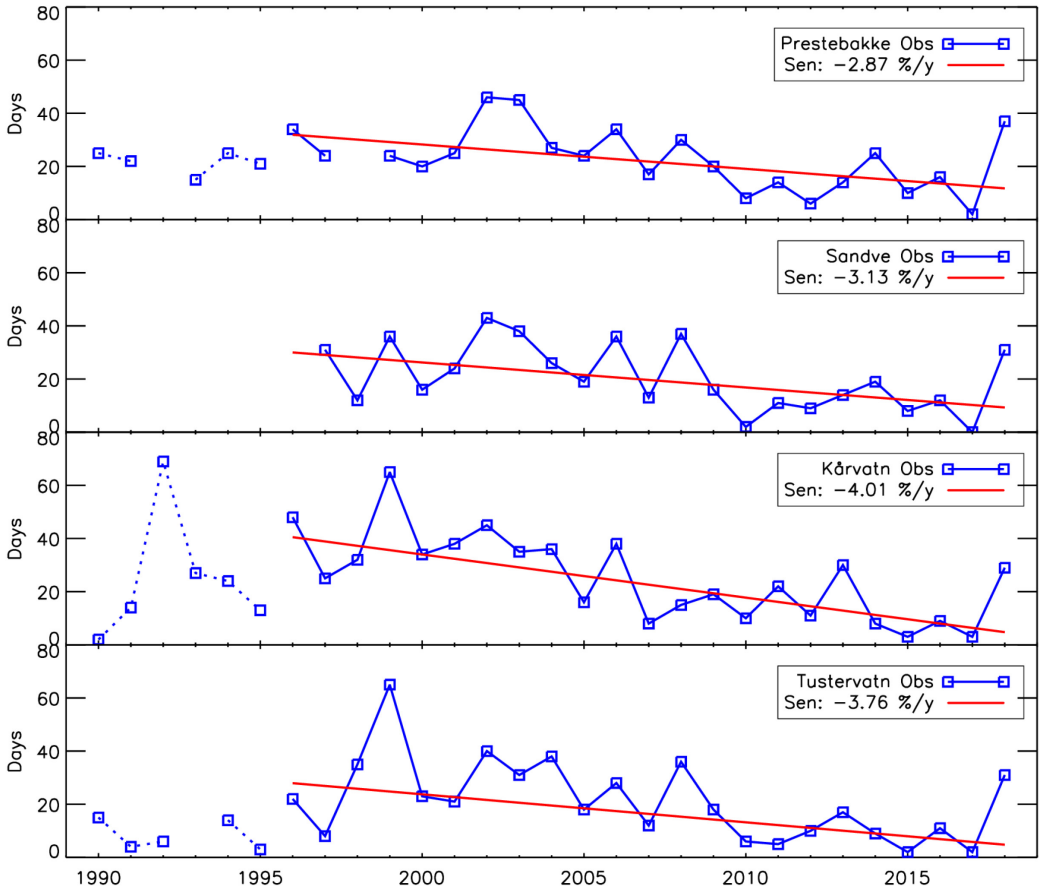


Figure 6.8: Same as Figure 6.7 for the number of days with a maximum 8-h running mean ozone concentration exceeding 100 µg/m^3 (WHO guideline).

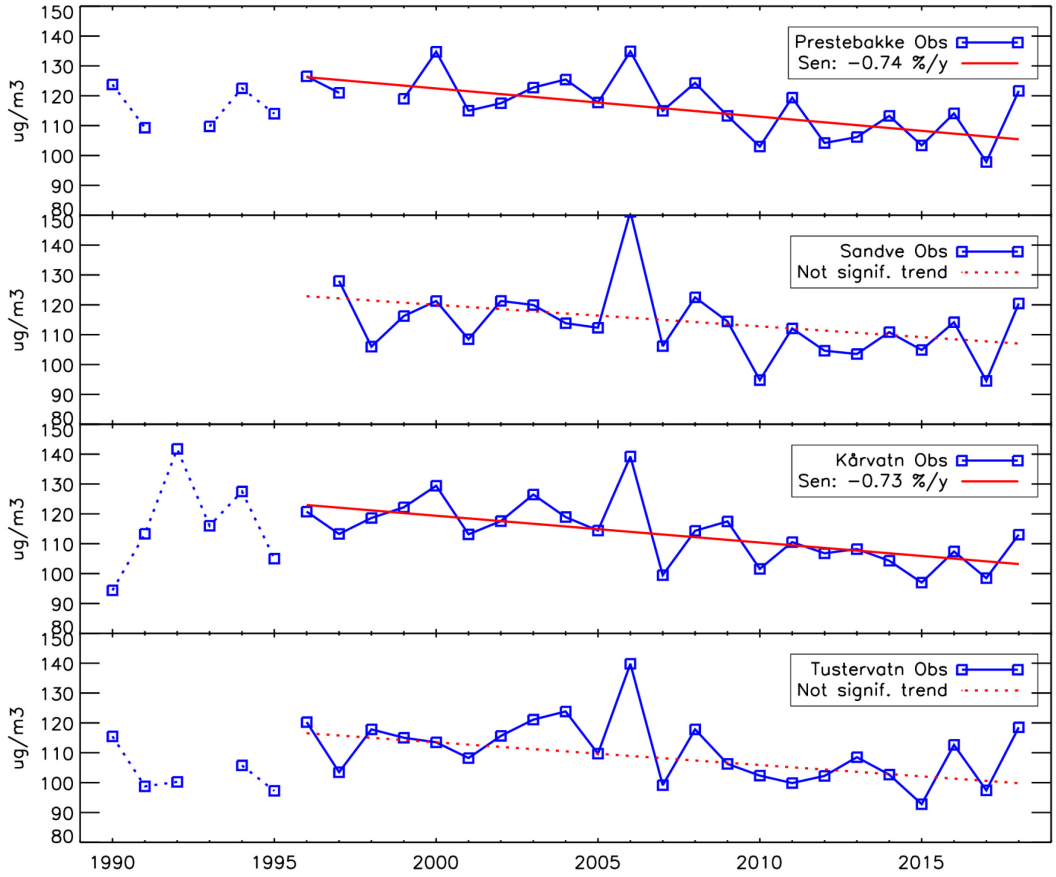


Figure 6.9: Same as Figure 6.7 for the 97-percentile of the daily maximum 8-h running mean ozone concentration April-September.

6.7 Surface ozone in the extreme year 2018

As outlined in Chapter 2 the summer of 2018 was weather-wise an extreme year in southern parts of Norway with prolonged heat and drought starting in mid-May and lasting until August with numerous weather-records being set. Tropospheric ozone is known to be closely linked to the weather conditions and thus the 2018 summer could be regarded a real-life "test-case" or a sign of what to expect with continued climate change in the coming years. Climate predictions don't say that 2018 conditions will become the normal, but rather that we should expect larger variabilities from year to year and thus that years like 2018 may become more frequent in the future.

The observed levels of surface ozone in 2018 indeed confirms a link between the summer weather and the ozone levels. It is interesting, though, to see that whereas the peak levels of ozone were not particularly high in 2018, the intermediate levels of ozone were elevated during prolonged periods of the year leading to exceedances of EU's long-term objective at most stations and also exceedances of critical levels for vegetation at many sites.

Without numerical model calculations we don't know the direct reasons or sources for the elevated ozone levels seen in Norway in 2018. Certainly, photochemical reactions that generate ozone are promoted by the type of weather conditions that were experienced in summer 2018 with a persistent high-pressure system leading to few clouds, strong solar radiation and high temperatures.

Thus, more effective ozone formation in the European boundary layer is a likely reason for the observed levels.

Additionally, it is likely that the extreme drought in Norway and other parts of North Europe lead to plants closing their stomata to reduce their loss of water and thereby that the uptake of ozone was reduced. Under normal conditions uptake in vegetation is an important loss mechanism for surface ozone but the efficiency of this process is controlled by the soil water content (as well as the vertical mixing, land cover etc.). This process is one of the reasons why the maps for potential ozone damage to plants deduced from AOT40 and POD as explained above, differs. Whereas AOT40 only depends on the atmospheric concentrations which normally show a north to south gradient in Europe (highest in the south), the ozone flux into plants (estimated by POD) is relatively higher in the north due to frequent drought in south Europe and high soil water content in the north.

A third likely reason for the elevated ozone levels in 2018 is that the weather condition were influenced by very persistent high-pressure systems which in turn are associated with sinking vertical motion, stable thermal stratification in the atmosphere and ineffective vertical mixing. This leads to pollutants emitted from the surface being trapped in the boundary layer.

6.8 Summary

The surface ozone levels in Norway 2018 were characterized by elevated concentrations in South Norway during the whole summer season although the peak levels were not particularly high. As a consequence, limit values for vegetation linked to 3-months AOT40 for plants and 6-months AOT40 for forest were exceeded at many sites in the country. The highest 3-months AOT40 value was recorded at Birkenes with 7463 ppb hours which is the second highest 3-months AOT40 observed in Norway since the early 1990s. EU's long term objective for human health was exceeded at all stations except Zeppelin Mountain at Spitsbergen. The unusually high ozone levels were linked to the extreme weather conditions experienced in the summer half year in parts of the country with prolonged heat and drought.

In Norway, the levels of ground level ozone is determined by a baseline-level varying between 50-100 $\mu g/m^3$ (minimum in autumn, maximum in late spring) with a number of summertime photochemical ozone episodes superimposed on this baseline. The baseline does not change that much from year to year, but the photochemical episodes vary substantially between years depending on the summer weather conditions and the European emissions. Whereas the summer weather conditions vary considerably from one year to another, the European precursor emissions have been steadily reduced over the last 20 years. Thus, a gradual decline in ozone episodes are expected in Norway although a certain amount of "noise" in the time series is expected due to the variation in the weather conditions, and to some extent this noise could mask the effect of the emission reductions.

The highly unusual conditions in 2018 highlights the strong links between climate and air pollution. An essential scientific question is to what extent the positive consequences from emission abatement policies in Europe that have taken place during the last 20 years or more could be outweighed by negative consequences on air pollution linked to future climate change. Although it is unlikely that weather conditions as those experienced in 2018 will become the normal, it is likely that such conditions could become more frequent.

It should be said, though, that the limit values for vegetation used in this report are based on the AOT40 concept which is a measure of the atmospheric concentrations integrated over time. Experimental studies show, however, that much more complex indicators such as the flux based approach, estimating the actual uptake of ozone by plants is limited by the soil water content, and in severe drought conditions like in 2018, the uptake of ozone and the subsequent vegetation damage

will be limited by the plants closing their stomata. One reason why so high levels of AOT40 were observed in Norway in 2018 may actually be that the uptake in vegetation was inhibited by the drought. One should therefore be careful with linking the elevated ozone levels directly to crop reduction or plant damage. For human health, however, it is the atmospheric levels that matters and the widespread exceedance of EU's long-term objective should be a matter of concern.

7 References

Berglen, T.F., Dauge, F., Andresen, E., Tønnesen, D., Vadset, M., Våler, R.L. (2018) Grenseområdene Norge - Russland. Luft- og nedbørkvalitet kalenderåret 2017. Kjeller, NILU (Miljødirektoratet rapport, M-1069/2018) (NILU report, 14/2018).

Castillejos, M., Borja-Aburto, V.H., Dockery, D.W., Gold, D.R., Loomis, D. (2000) Airborne coarse particles and mortality. *Inhal. Toxicol., 12*, 61-72.

Cavalli, F., Viana, M., Yttri, K.E., Genberg, J., Putaud, J.-P. (2010) Toward a standardised thermal-optical protocol for measuring atmospheric organic and elemental carbon: the EUSAAR protocol. *Atmos. Meas. Tech., 3*, 79–89, doi:10.5194/amt-3-79-2010.

Colette, A., Aas, W., Banin, L., Braban, C.F., Ferm, M., González Ortiz, A., Ilyin, I., Mar, K., Pandolfi, M., Putaud, J.-P., Shatalov, V., Solberg, S., Spindler, G., Tarasova, O., Vana, M., Adani, M., Almodovar, P., Berton, E., Bessagnet, B., Bohlin-Nizzetto, P., Boruvkova, J., Breivik, K., Briganti, G., Cappelletti, A., Cuvelier, K., Derwent, R., D'Isidoro, M., Fagerli, H., Funk, C., Garcia Vivanco, M., González Ortiz, A., Haeuber, R., Hueglin, C., Jenkins, S., Kerr, J., de Leeuw, F., Lynch, J., Manders, A., Mircea, M., Pay, M.T., Pritula, D., Putaud, J.-P., Querol, X., Raffort,V., Reiss, I., Roustan, Y., Sauvage, S., Scavo, K., Simpson, D., Smith, R.I., Tang, Y.S., Theobald, M., Tørseth, K., Tsyro, S., van Pul, A., Vidic, S., Wallasch, M., Wind, P. (2016) Air pollution trends in the EMEP region between 1990 and 2012. Joint Report of the EMEP Task Force on Measurements and Modelling (TFMM), Chemical Co-ordinating Centre (CCC), Meteorological Synthesizing Centre-East (MSC-E), Meteorological Synthesizing Centre-West (MSC-W). Kjeller, NILU (EMEP: TFMM/CCC/MSC-E/MSC-W Trend Report) (EMEP/CCC, 01/2016).

Dockery, D.W., Pope, C.A., Xu, X.P., Spengler, J.D., Ware, J.H., Fay, M.E., Ferris, B.G., Speizer, F.E. (1993) An association between air-pollution and mortality in 6 United-States cities. *New Engl. J. Med., 329*, 1753-1759.

Dollard, G.J., Vitols, V. (1980) Wind tunnel studies of dry deposition of SO_2 and H_2SO_4 aerosols. In: *Internat. conf. on impact of acid precipitation. Sandefjord 1980*. Ed. by D. Drabløs and A. Tollan. Oslo-Ås (SNSF-prosjektet), pp. 108-109.

Donaldson, K., Stone, V., Seaton A., MacNee, W. (2001) Ambient particle inhalation and the cardiovascular system: Potential mechanisms. *Environ. Health Perspect., 109*, 523-527.

Dovland, H., Eliassen, A. (1976) Dry deposition on snow surface. *Atmos. Environ., 10*, 783-785.

Eckhardt, S., Hermansen, O., Grythe, H., Fiebig, M., Stebel, K., Cassiani, M., Baecklund, A., and Stohl, A. (2013) The influence of cruise ship emissions on air pollution in Svalbard – a harbinger of a more polluted Arctic?, *Atmos. Chem. Phys*., 13, 8401-8409, doi:10.5194/acp-13-8401-2013.

EEA (2014) Air pollution by ozone across Europe during summer 2013. Overview of exceedances of EC ozone threshold values: April–September 2013. Copenhagen, European Environment Agency (EEA Technical report 3/2014).

EMEP/CCC (2014) Manual for sampling and chemical analysis. Kjeller, Norwegian Institute for Air Research (EMEP/CCC Report 1/95) (Last rev. February 2014). **URL:** http://www.nilu.no/projects/ccc/manual/index.html.

EU (2002) Directive 2002/3/EC of the European Parliament and of the Council of 12 February 2002 relation to ozone in ambient air. *Off. J. Eur. Com.,* L 067, 09/03/2002, 14-30.

EU (2008) Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe. *Off. J. Eur. Com.,* L 141, 11/06/2008, 1-44.

Ferm, M. (1988) Measurements of gaseous and particulate NH_3 and HNO_3 at a background station: interpretation of the particle composition from the gas phase concentrations. Proceedings from Cost 611 Workshop Villefrance sur Mer, 3-4 May 1988, pp. 4-13.

FHI (2013) Luftkvalitetskriterier. Virkninger av luftforurensning på helse. Oslo, Nasjonalt folkehelseinstitutt (Rapport, 2013:9).

Fowler, D. (1980) Removal of sulfur and nitrogen compounds from the atmosphere in rain and by dry deposition. In: *Internat. conf. on impact of acid precipitation. Sandefjord 1980*. Ed. by D. Drabløs and A. Tollan. Oslo-Ås (SNSF-prosjektet), pp. 22-32.

Garland, J.A. (1978) Dry and wet removal of sulfur from the atmosphere. *Atmos. Environ., 12*, 349-362.

Gilbert, R.O. (1987) Statistical methods for environmental pollution monitoring. New York, Van Nostrand Reinhold Co.

Hellsten, S., van Loon, M., Tarrason, L., Vestreng, V., Tørseth, K., Kindbom, K., Aas, W. (2007) Base cations deposition in Europe. Stockholm, Swedish Environmental Research Institute (IVL Report B1722).

Hicks, B.B., Baldocchi, D.D., Meyers, T.P., Hosker Jr., R.P., Matt, D.R. (1987) A preliminary multiple resistance routine for deriving dry deposition velocities from measured quantities. *Water, Air, Soil Pollut., 36*, 311-329.

Kärenlampi, L., Skärby, L. (Eds) (1996) Critical levels for ozone in Europe: testing and finalising the concepts. UNECE Workshop Report. University of Kuopio, Department of Ecology and Environmental Science.

Logan, J.A., Staehelin, J., Megretskaia, I.A., Cammas, J.P., Thouret, V., Claude, H. et al. (2012) Changes in ozone over Europe: analysis of ozone measurements from sondes, regular aircraft (MOZAIC) and alpine surface sites. *J. Geophys Res. Atmos 2012, 117(9)*:D09301.

LRTAP (2011) Mapping critical levels for vegetation. In: *Manual on methodologies and criteria for modelling and mapping critical loads and levels and air pollution effects, risks and trend, chapter 3*. **URL:** http://icpvegetation.ceh.ac.uk/manuals/mapping_manual.html.

MET (2016) Været i Norge. Klimatologisk oversikt året 2016. Oslo, Meteorologisk institutt. (MET info 13/2016).

MET (2018) Været i Norge. Klimatologisk oversikt året 2017. Oslo, Meteorologisk institutt. (MET info 13/2017).

Mills, G., Pleijel, H., Braun, S., Büker, P., Bermejo, V., Calvo, E., Danielsson, H., Emberson, L., González Fernández, I., Grünhage L., Harmens, H., Hayes, F., Karlsson, P.-E., Simpson, D. (2011) New stomatal flux-based critical levels for ozone effects on vegetation. *Atmos. Environ., 45*, 5064-5068.

Myhre, C. L., Svendby, T., Hermansen, O., Lunder, C., Fiebig, M., Hansen, G., Schmidbauer, N., & Krognes, T. (2017). Monitoring of greenhouse gases and aerosols at Svalbard and Birkenes in 2016 - Annual report. Kjeller, NILU (Miljødirektoratet rapport, M-871/2016) (NILU report, 39/2017).

Nizzetto, P.B., Aas, W., Warner, N. (2018) Monitoring of environmental contaminants in air and precipitation, annual report 2017. Kjeller, NILU (Miljødirektoratet rapport, M-1062/2018) (NILU report, 13/2018).

Oltmans, S.J., Lefohn, A.S., Shadwick, D., Harris, J.M., Scheel, H.E., Galbally, I., Tarasick, D.W., Johnson, B.J., Bunke, E.-G., Claude, H., Zeng, H., Nichol, S., Schmidlin, F., Davies, J., Cuevas, E., Redondas, A., Naoe, H., Nakano, T., Kawasato, T. (2013) Recent tropospheric ozone changes – A pattern dominated by slow or no growth. *Atmos. Environ., 67*, 331–351, doi:10.1016/j.atmosenv.2012.10.057.

Ostro, B.D., Broadwin, R., Lipsett, M.J. (2000) Coarse and fine particles and daily mortality in the Coachella Valley, California: a follow-up study. *J. Expo. Anal. Environ. Epidemiol., 10*, 412-419.

Salmi, T., Määttä, A., Anttila, P., Ruoho-Airola, T., Amnell, T. (2002) Detecting trends of annual values of atmospheric pollutants by the Mann-Kendall test and Sen's slope estimates – the Excel template application MAKESENS. Helsinki, Finnish Meteorological Institute (Report code FMI-AQ-31).

Schwartz, J., Dockery, D.W, Neas, L.M. (1996) Is daily mortality associated specifically with fine particles? *J. Air Waste Manag. Assoc., 46*, 927-939.

Schwartz, J., Neas, L.M. (2000) Fine particles are more strongly associated than coarse particles with acute respiratory health effects in schoolchildren. *Epidemiology, 11*, 6-10.

Seinfeld, J.H., Pandis, S.N. (1998) Atmospheric chemistry and physics. New York, Wiley.

Solberg, S. (2003) Monitoring of boundary layer ozone in Norway from 1977 to 2002. Kjeller, NILU (NILU OR, 85/2003).

Svendby, T.M., Hansen, G.H., Stebel, K., Bäcklund, A., & Dahlback, A. (2017). Monitoring of the atmospheric ozone layer and natural ultraviolet radiation. Annual report 2016. Kjeller, NILU (Miljødirektoratet rapport, M-803/2017) (NILU report, 31/2017).

Tørseth, K., Aas, W., Breivik, K., Fjæraa, A.M., Fiebig, M., Hjellbrekke, A.G., Myhre, C.L., Solberg, S., Yttri, K.E. (2012) Introduction to the European Monitoring and Evaluation Programme (EMEP) and observed atmospheric composition change during 1972–2009. *Atmos. Chem. Phys. 12*, 5447-5481

UN/ECE (1999) The 1999 Gothenburg Protocol to the 1979 convention on long-range transboundary air pollution to abate acidification, eutrophication and ground-level ozone. **URL:** http://www.unece.org/env/lrtap/multi_h1.htm.

UN-ECE (1996) Manual on methodologies and criteria for mapping critical levels/loads and geographical areas where they are exceeded. Berlin, Umweltbundesamt (UBA Texte 71/96).

Voldner, E.C., Sirois, A. (1986) Monthly mean spatial variations of dry deposition velocities of oxides of sulfur and nitrogen. *Water, Air, Soil Pollut., 30*, 179-186.

Weather, Vol. 72 (issue 2-12) and Vol. 73 (issue 1-2), Royal Met. Soc., 2017-2018.

Whitby, K.T. (1978) Physical characteristics of sulfur aerosols. *Atmos. Environ., 12*, 135-159.

WHO (2006) Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global update 2005. Summary of risk assessment. Geneva, World Health Organization.

Yttri, K.E., Aas, W., Bjerke, A., Cape, J.N., Cavalli, F., Ceburnis, D., Dye, C., Emblico, L., Facchini, M.C., Forster, C., Hanssen, J.E., Hansson, H.C., Jennings, S.G., Maenhaut, W., Putaud, J.P., Tørseth, K. (2007b) Elemental and organic carbon in PM10: a one year measurement campaign within the European Monitoring and Evaluation Programme EMEP. *Atmos. Chem. Phys., 7*, 5711–5725.

Yttri, K.E., Simpson, D., Nøjgaard, J.K., Kristensen, K., Genberg, J., Stenström, K., Swietlicki, E., Hillamo, R., Aurela, M., Bauer, H., Offenberg, J.H., Jaoui, M., Dye, C., Eckhardt, S., Burkhart, J.F., Stohl, A., Glasius, M. (2011b) Source apportionment of the summer time carbonaceous aerosol at Nordic rural background sites. *Atmos. Chem. Phys., 11*, 13339–13357.

Yttri, K.E., Simpson, D., Stenström, K., Puxbaum, H., Svendby, T. (2011a) Source apportionment of the carbonaceous aerosol in Norway quantitative estimates based on 14C, thermal-optical and organic tracer analysis. *Atmos. Chem. Phys., 11*, 9375–9394.

Annex 1

Results from the monitoring programme

Table A.1.1: Monthly and annual volume weighted mean pH at Norwegian background stations

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	4.94	5.01	4.61	5.44	5.81	5.13	5.45	5.38	5.11	5.08	4.72	4.73	4.95
Vatnedalen	5.66	5.46	5.83	5.97	5.8	5.79	5.52	5.77	5.29	5.59	5.29	5.55	5.51
Treungen	4.87	4.79	4.76	5.79	5.88	4.92	5.1	5.37	5.2	5.18	4.92	4.85	5.02
Løken	4.96	4.78	4.95	5.71	5.72	5.24	5.36	5.45	5.32	5.35	5.09	4.98	5.14
Hurdal	4.81	4.54	4.77	5.64	5.68	5.6	5.2	5.72	5.3	5.35	4.97	4.77	5.04
Brekkebygda	4.81	4.62	4.63	5.88	5.53	5.27	5.17	4.99	5.21	5.26	4.97	4.82	4.98
Vikedal	5.46	5.41	5.58	5.88	5.87	5.43	5.67	5.26	5.35	5.34	5.28	5.47	5.38
Haukeland	5.38	5.1	5.28	5.56	-	-	-	-	-	-	-	-	-
Nausta	5.37	5.37	5.38	5.6	5.69	5.26	5.37	5.31	5.33	5.49	5.4	5.64	5.4
Kårvatn	5.45	5.13	5.48	5.54	5.82	5.62	4.72	5.22	5.4	5.43	5.17	5.42	5.34
Høylandet	6.08	-	5.79	6.03	5.93	5.42	5.66	5.73	5.47	5.63	5.68	5.65	5.63
Tustervatn	5.37	5.21	5.5	5.54	5.64	5.32	5.17	5.37	5.4	5.5	5.09	5.38	5.36
Svanvik	5.06	5.27	4.94	4.71	4.63	4.56	4.97	4.79	4.69	5.1	5.01	-	4.83
Karpbukt	5.05	5.27	5.59	4.9	5.32	5.23	4.62	4.7	4.94	4.99	4.9	4.96	4.91
Ny-Ålesund	6.03	5.22	5.18	4.86	5.17	6.25	5.39	5.37	5.39	5.41	5.79	5.21	5.39

Table A.1.2: Monthly and annual volume weighted average concentrations of sulfate (sea salt corrected) in precipitation at Norwegian background stations. Unit: mg S/L.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	0.15	0.36	0.41	0.19	0.33	0.2	0.26	0.21	0.12	0.13	0.23	0.15	0.2
Vatnedalen	0.07	0.1	0.2	0.26	0.2	0.16	0.15	0.1	0.06	0.09	0.06	0.04	0.1
Treungen	0.11	0.31	0.26	0.18	0.23	0.17	0.17	0.16	0.11	0.2	0.13	0.1	0.15
Løken	0.18	0.19	0.11	0.2	0.45	0.2	0.19	0.22	0.06	0.27	0.15	0.06	0.17
Hurdal	0.23	0.35	0.12	0.1	0.27	0.19	0.19	0.19	0.06	0.26	0.14	0.21	0.17
Brekkebygda	0.19	0.31	0.32	0.14	0.26	0.18	0.17	0.09	0.03	0.2	0.14	0.15	0.15
Vikedal	0.04	0.1	0.11	0.21	0.29	0.19	0.19	0.13	0.04	0.07	0.05	0.03	0.09
Haukeland	0.07	0.04	0.05	0.07	-	-	-	-	-	-	-	-	-
Nausta	0.01	0.03	0.07	0.1	0.19	0.11	0.09	0.07	0.03	0.02	0.05	0.01	0.05
Kårvatn	0.07	0.07	0.07	0.1	0.17	0.2	0.21	0.07	0.01	0.03	0.05	0.02	0.05
Høylandet	0.13	-	0.07	0.09	0.19	0.14	0.12	0.07	0.01	0.01	0.02	0.02	0.06
Tustervatn	0.04	0.05	0.06	0.06	0.14	0.12	0.08	0.06	0.01	0.02	0.07	0.01	0.05
Svanvik	0.18	0.2	0.15	0.4	1.04	0.59	0.37	0.31	0.43	0.19	0.1	-	0.33
Karpbukt	0.13	0.11	0.21	0.32	0.38	0.49	0.49	0.42	0.29	0.25	0.17	0.1	0.32
Ny-Ålesund	0.04	0.18	0.16	0.52	0.18	0.53	0.08	0.02	0.06	0.17	0.08	0.08	0.1

Table A.1.3: Monthly and annual volume weighted average concentrations of nitrate in precipitation at Norwegian background stations. Unit: mg N/L.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	0.31	1.04	0.54	0.34	0.53	0.27	0.41	0.41	0.19	0.17	0.54	0.36	0.43
Vatnedalen	0.09	0.26	0.44	0.53	0.36	0.14	0.12	0.11	0.04	0.11	0.25	0.15	0.13
Treungen	0.24	0.88	0.45	0.36	0.36	0.24	0.2	0.32	0.16	0.42	0.27	0.25	0.3
Løken	0.26	0.69	0.33	0.39	0.44	0.36	0.23	0.26	0.08	0.2	0.34	0.19	0.27
Hurdal	0.3	0.95	0.37	0.3	0.35	0.27	0.21	0.36	0.13	0.33	0.26	0.34	0.3
Brekkebygda	0.36	0.6	0.5	0.33	0.51	0.2	0.06	0.16	0.05	0.13	0.2	0.32	0.24
Vikedal	0.09	0.22	0.21	0.41	0.52	0.17	0.38	0.14	0.1	0.11	0.18	0.14	0.16
Haukeland	0.08	0.2	0.2	0.24	-	-	-	-	-	-	-	-	-
Nausta	0.06	0.15	0.14	0.23	0.36	0.09	0.13	0.08	0.03	0.05	0.16	0.06	0.09
Kårvatn	0.06	0.19	0.11	0.21	0.23	0.18	0.56	0.06	0.01	0.02	0.09	0.04	0.08
Høylandet	0.18	-	0.09	0.12	0.23	0.09	0.02	0.04	0.01	0.01	0.01	0.06	0.05
Tustervatn	0.07	0.13	0.07	0.08	0.18	0.12	0.11	0.07	0.02	0.03	0.1	0.09	0.07
Svanvik	0.15	0.12	0.07	0.24	0.37	0.1	0.11	0.1	0.12	0.11	0.15	-	0.12
Karpbukt	0.15	0.07	0.06	0.08	0.2	0.08	0.12	0.1	0.13	0.09	0.08	0.08	0.1
Ny-Ålesund	0.02	0.17	0.22	0.12	0.09	0.29	0.06	0.03	0.03	0.05	0.07	0.05	0.07

Table A.1.4: Monthly and annual volume weighted average concentrations of ammonium in precipitation at Norwegian background stations. Unit: mg N/L.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	0.21	1.15	0.5	0.51	0.94	0.28	0.69	0.63	0.23	0.11	0.43	0.21	0.44
Vatnedalen	0.07	0.19	0.48	0.77	0.44	0.11	0.08	0.11	0.03	0.22	0.15	0.08	0.13
Treungen	0.12	0.84	0.37	0.57	0.66	0.16	0.12	0.42	0.19	0.41	0.19	0.13	0.28
Løken	0.17	0.47	0.22	0.66	0.73	0.4	0.22	0.17	0.11	0.16	0.32	0.11	0.26
Hurdal	0.22	0.65	0.21	0.45	0.63	0.48	0.15	0.57	0.16	0.4	0.2	0.24	0.31
Brekkebygda	0.19	0.5	0.47	0.41	0.71	0.24	0.06	0.1	0.03	0.13	0.11	0.16	0.2
Vikedal	0.08	0.12	0.3	0.71	0.91	0.33	0.6	0.2	0.15	0.17	0.21	0.18	0.22
Haukeland	0.06	0.1	0.11	0.3	-	-	-	-	-	-	-	-	-
Nausta	0.06	0.17	0.18	0.33	0.54	0.11	0.18	0.1	0.04	0.08	0.22	0.2	0.13
Kårvatn	0.08	0.15	0.12	0.31	0.42	0.32	0.29	0.06	0.03	0.02	0.04	0.05	0.09
Høylandet	0.66	-	0.24	0.38	0.49	0.13	0.14	0.11	0.06	0.13	0.21	0.21	0.18
Tustervatn	0.07	0.07	0.08	0.21	0.27	0.17	0.1	0.09	0.04	0.08	0.07	0.06	0.09
Svanvik	0.03	0.06	0.04	0.06	0.44	0.07	0.05	0.09	0.09	0.16	0.09	-	0.08
Karpbukt	0.13	0.17	0.45	0.17	0.34	0.75	0.04	0.08	0.11	0.11	0.04	0.01	0.21
Ny-Ålesund	0.07	0.12	0.17	0.11	0.06	0.07	0.04	0.05	0.04	0.07	0.05	0.05	0.06

Table A.1.5: Monthly and annual volume weighted average concentrations of calcium in precipitation at Norwegian background stations. Unit: mg/L.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	0.13	0.17	0.14	0.25	0.25	0.13	0.24	0.17	0.19	0.14	0.08	0.05	0.14
Vatnedalen	0.11	0.14	0.25	0.35	0.14	0.09	0.12	0.1	0.06	0.11	0.14	0.09	0.1
Treungen	0.07	0.09	0.11	0.25	0.18	0.13	0.17	0.1	0.09	0.18	0.04	0.04	0.1
Løken	0.16	0.2	0.1	0.44	0.5	0.16	0.32	0.69	0.22	0.17	0.08	0.05	0.21
Hurdal	0.12	0.18	0.07	0.42	0.3	0.11	0.16	0.18	0.08	0.21	0.07	0.05	0.14
Brekkebygda	0.18	0.1	0.19	0.37	0.24	0.28	0.19	0.1	0.05	0.18	0.1	0.14	0.15
Vikedal	0.2	0.42	0.13	0.27	0.22	0.18	0.13	0.11	0.22	0.07	0.09	0.14	0.17
Haukeland	0.15	0.14	0.26	0.07	-	-	-	-	-	-	-	-	-
Nausta	0.08	0.06	0.08	0.15	0.17	0.15	0.07	0.06	0.06	0.06	0.05	0.13	0.08
Kårvatn	0.14	0.08	0.25	0.14	0.17	0.37	0.32	0.05	0.09	0.05	0.03	0.08	0.11
Høylandet	0.59	-	0.21	0.17	0.42	0.2	0.13	0.12	0.11	0.08	0.08	0.11	0.16
Tustervatn	0.13	0.03	0.11	0.08	0.29	0.15	0.07	0.06	0.08	0.06	0.04	0.13	0.09
Svanvik	0.14	0.23	0.08	0.27	0.31	0.15	0.08	0.09	0.14	0.12	0.04	-	0.12
Karpbukt	0.19	0.17	0.12	0.13	0.36	0.13	0.21	0.13	0.16	0.19	0.17	0.1	0.16
Ny-Ålesund	0.14	0.46	0.35	0.42	0.41	3.02	0.2	0.15	0.18	0.34	0.39	0.27	0.29

Table A.1.6: Monthly and annual volume weighted average concentrations of potassium in precipitation at Norwegian background stations. Unit: mg/L.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	0.06	0.1	0.09	0.11	0.07	0.08	0.15	0.09	0.14	0.06	0.08	0.08	0.09
Vatnedalen	0.08	0.08	0.15	0.18	0.11	0.15	0.08	0.07	0.12	0.15	0.14	0.09	0.11
Treungen	0.05	0.05	0.04	0.07	0.04	0.07	0.06	0.07	0.06	0.08	0.03	0.06	0.05
Løken	0.05	0.08	0.04	0.18	0.2	0.21	0.22	0.75	0.27	0.32	0.06	0.06	0.18
Hurdal	0.07	0.12	0.05	0.13	0.14	0.17	0.22	0.2	0.06	0.09	0.06	0.08	0.1
Brekkebygda	0.09	0.07	0.35	0.17	0.05	0.16	0.11	0.01	0.02	0.08	0.05	0.1	0.08
Vikedal	0.15	0.12	0.15	0.08	0.03	0.13	0.09	0.1	0.17	0.06	0.09	0.11	0.11
Haukeland	0.1	0.06	0.11	0.04	-	-	-	-	-	-	-	-	-
Nausta	0.09	0.06	0.1	0.07	0.03	0.12	0.09	0.03	0.04	0.05	0.08	0.24	0.07
Kårvatn	0.08	0.07	0.16	0.07	0.07	0.43	0.2	0.04	0.09	0.08	0.04	0.1	0.11
Høylandet	0.59	-	0.11	0.05	0.17	0.18	0.28	0.15	0.1	0.11	0.1	0.11	0.14
Tustervatn	0.09	0.04	0.07	0.05	0.06	0.15	0.12	0.06	0.14	0.08	0.05	0.09	0.09
Svanvik	0.02	0.09	0.06	0.04	0.05	0.07	0.64	0.04	0.11	0.16	0.01	-	0.17
Karpbukt	0.09	0.09	0.1	0.07	0.23	0.27	0.09	0.08	0.17	0.11	0.11	0.06	0.12
Ny-Ålesund	0.05	0.31	0.17	0.18	0.25	0.53	0.04	0.08	0.08	0.16	0.11	0.17	0.13

Table A.1.7: Monthly and annual volume weighted average concentrations of magnesium in precipitation at Norwegian background stations. Unit: mg/L.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	0.15	0.19	0.15	0.13	0.04	0.07	0.05	0.08	0.41	0.17	0.17	0.11	0.18
Vatnedalen	0.04	0.05	0.07	0.07	0.03	0.04	0.03	0.01	0.05	0.04	0.03	0.04	0.04
Treungen	0.05	0.08	0.03	0.03	0.03	0.03	0.04	0.03	0.07	0.09	0.04	0.05	0.05
Løken	0.07	0.1	0.02	0.05	0.09	0.08	0.07	0.3	0.17	0.11	0.08	0.04	0.1
Hurdal	0.04	0.1	0.03	0.15	0.06	0.04	0.04	0.07	0.1	0.04	0.04	0.05	0.06
Brekkebygda	0.04	0.06	1.04	0.05	0.04	0.05	0.03	0.02	0.03	0.04	0.02	0.05	0.05
Vikedal	0.44	0.11	0.2	0.07	0.06	0.3	0.05	0.19	0.5	0.13	0.15	0.25	0.25
Haukeland	0.27	0.11	0.22	0.02	-	-	-	-	-	-	-	-	-
Nausta	0.15	0.07	0.12	0.05	0.04	0.25	0.04	0.05	0.14	0.14	0.06	0.29	0.13
Kårvatn	0.19	0.15	0.38	0.08	0.05	0.26	0.08	0.04	0.2	0.08	0.02	0.23	0.16
Høylandet	1.5	-	0.29	0.07	0.09	0.16	0.12	0.1	0.32	0.27	0.29	0.31	0.28
Tustervatn	0.19	0.02	0.11	0.08	0.08	0.06	0.01	0.04	0.16	0.11	0.05	0.2	0.1
Svanvik	0.06	0.21	0.17	0.09	0.13	0.07	0.26	0.03	0.07	0.13	0.02	-	0.11
Karpbukt	0.24	0.22	0.25	0.19	0.15	0.08	0.06	0.06	0.07	0.27	0.32	0.07	0.14
Ny-Ålesund	0.15	1.12	0.61	0.6	0.78	2.34	0.16	0.3	0.3	0.58	0.32	0.59	0.46

Table A.1.8: Monthly and annual volume weighted average concentrations of sodium in precipitation at Norwegian background stations. Unit: mg/L.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	1.2	1.59	1.26	1.1	0.22	0.58	0.27	0.67	3.52	1.35	1.43	0.81	1.49
Vatnedalen	0.95	0.95	1.85	1.42	0.78	1.09	0.67	0.78	0.7	0.88	0.57	0.74	0.83
Treungen	0.56	0.69	0.21	0.16	0.08	0.18	0.12	0.25	0.49	0.65	0.35	0.31	0.37
Løken	0.49	0.83	0.17	0.23	0.28	0.39	0.15	0.62	0.9	0.53	0.67	0.13	0.51
Hurdal	0.29	0.87	0.29	1.17	0.38	0.3	0.09	0.49	0.78	0.31	0.36	0.25	0.49
Brekkebygda	0.43	0.57	7.25	0.34	0.25	0.16	0.09	0.15	0.23	0.17	0.18	0.3	0.36
Vikedal	3.62	0.75	1.82	0.56	0.38	2.44	0.34	1.54	4.33	1.23	1.3	2.15	2.15
Haukeland	2.32	1.01	2.43	0.29	-	-	-	-	-	-	-	-	-
Nausta	1.28	0.63	1.18	0.5	0.29	2.07	0.22	0.4	1.14	1.14	0.61	2.51	1.09
Kårvatn	1.61	1.33	3.47	0.71	0.37	2.06	0.48	0.29	1.66	0.67	0.12	1.88	1.29
Høylandet	12.55	-	2.41	0.7	0.64	1.33	1.08	0.87	2.58	2.26	2.43	2.52	2.28
Tustervatn	1.7	0.19	0.94	0.69	0.65	0.57	0.15	0.39	1.34	0.99	0.44	1.69	0.87
Svanvik	0.24	1.57	1.31	0.52	0.53	0.27	0.1	0.09	0.29	1.01	0.13	-	0.46
Karpbukt	1.9	1.91	2.11	1.46	1.19	0.89	0.35	0.29	0.39	1.99	2.51	0.42	1.11
Ny-Ålesund	1.15	9.39	4.56	4.69	6.42	16.61	0.96	2.4	2.36	4.7	2.25	4.72	3.63

Table A.1.9: Monthly and annual volume weighted average concentrations of chloride in precipitation at Norwegian background stations. Unit: mg N/L.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	2.14	2.89	2.17	1.73	0.27	0.95	0.39	1.11	6.22	2.32	2.41	1.4	2.6
Vatnedalen	1.12	1.09	2.35	1.32	0.51	0.98	0.44	0.48	0.91	0.97	0.77	0.68	0.84
Treungen	0.81	1.26	0.4	0.26	0.11	0.3	0.19	0.41	0.84	1.01	0.62	0.57	0.62
Løken	0.9	1.5	0.32	0.38	0.23	0.6	0.23	1.06	1.62	1.04	1.15	0.24	0.88
Hurdal	0.5	1.42	0.49	1.96	0.47	0.46	0.12	0.71	1.36	0.5	0.59	0.42	0.81
Brekkebygda	0.66	1.05	12.8	0.52	0.3	0.24	0.11	0.22	0.36	0.25	0.31	0.52	0.6
Vikedal	6.71	1.42	2.91	0.93	0.61	4.37	0.47	2.86	7.4	2.27	2.24	3.91	3.81
Haukeland	4.19	1.81	4.13	0.47	-	-	-	-	-	-	-	-	-
Nausta	2.31	1.14	1.85	0.79	0.46	3.65	0.31	0.66	2.01	1.93	1.06	4.24	1.88
Kårvatn	2.93	2.24	5.73	1.18	0.52	3.64	0.75	0.47	2.99	1.19	0.23	3.24	2.24
Høylandet	23.62	-	4.43	1.27	1.08	2.26	1.81	1.51	4.88	4	4.36	4.39	4.16
Tustervatn	3.07	0.37	1.71	1.19	1.18	0.97	0.21	0.71	2.34	1.78	0.81	2.92	1.54
Svanvik	0.43	2.94	2.27	0.84	0.78	0.41	0.2	0.13	0.47	1.83	0.26	-	0.79
Karpbukt	3.56	3.41	3.98	2.54	1.94	1.17	0.57	0.43	0.65	3.88	4.47	0.73	1.96
Ny-Ålesund	2.17	16.76	8.37	8.32	11.82	32.23	1.7	4.22	4.15	8.25	4.02	8.04	6.46

Table A.1.10: Monthly and annual precipitation amount at Norwegian background stations. Unit: mm.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	253.92	174.67	46.13	76.89	64	72.84	23.2	100.15	249.47	51.01	221.66	181.22	1515.17
Vatnedalen	70.01	31.3	5.08	37.82	12.58	86	41.68	196.16	274.24	123.09	36.54	52.58	967.07
Treungen	113.8	49.69	20.44	50.85	42.05	48.69	51.57	75.84	160.07	31.91	142.37	90.84	878.13
Løken	89.85	19.65	14.1	38.35	21.04	45.81	39.26	36.99	88.37	49.5	110.78	65.69	619.39
Hurdal	126.84	43.82	20	60.3	28.6	58.7	46.39	68.81	173.5	62.66	126.12	85.62	901.36
Brekkebygda	106.53	83.7	15	47.8	35.7	102.5	65.9	137.81	163.46	29.2	107.33	107.7	1002.62
Vikedal	238.89	233.52	48.1	150.1	52.5	126.7	54.15	364.86	619.73	606.21	214.96	97.1	2806.81
Haukeland	222.21	120.23	72.6	37.6	-	-	-	-	-	-	-	-	-
Nausta	132.22	96.6	48.7	129.9	47.47	117.38	70.17	285.05	444.68	387.33	87.62	197.41	2044.53
Kårvatn	39.1	29	44.8	49.9	32.9	69.8	37.54	170.96	222.64	210.58	14.98	274.05	1196.25
Høylandet	37.03	-	53.2	57.3	34	82.67	20.02	157.76	201.71	158.03	10.9	135.7	948.33
Tustervatn	61.4	13.8	57.7	45.3	34.1	83.4	100.5	218.8	217.09	187.6	87.51	85.15	1192.35
Svanvik	24.01	9.32	45.62	20.92	5.47	32.43	60.47	79	38.45	34.16	6.32	-	356.17
Karpbukt	31.4	24.8	65.52	25.48	21.1	61.07	75.62	98.31	55.63	45.02	35.57	27.83	567.35
Ny-Ålesund	69.58	59.57	5.94	9.08	18.86	3.71	67.55	38.33	56.69	26.44	61.38	66.47	483.6

Table A.1.11: Monthly and annual wet deposition of strong acid (H^+) at Norwegian background stations. Unit: µekv/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	2904	1640	1118	279	37644	570	81	394513	1930	427	4223	3314	17124
Vatnedalen	154	86993	57282	41	26465	139	125	105847	73848	21796	219	149	2987
Treungen	1546	798	356	82	41125	710	413	1116	1005	210	1715	1263	8389
Løken	990	318	158	75	3118	263	172	130	416	339	907	659	4443
Hurdal	1943	1185	336	139	7583	147	295	1011815	866	281	1475	1399	8260
Brekkebygda	1648	1998	352	62	104	548	446	1416	1000	204	1176	1644	10538
Vikedal	834	4268	127	196	70	473	116	90986	2782	12734	1881	332	11723
Haukeland	935	1831	378	100	-	-	-	-	-	-	-	-	-
Nausta	566	413	203	323	96	640	301	1423	2082	1583	2200	511	8078
Kårvatn	138	216	149	145	50	167	715	1033	890	1261	91	1048	5432
Høylandet	31	-	87	54	40	315	1640	294	685	12077	23	300	2244
Tustervatn	260	84	181	131	77	400	675	942	863	1125	693	353	5214
Svanvik	210	50	520	411	130	889	647	1294	780	268	52	-	5266
Karpbukt	279	132	744	1309	101	355	1806	1639	596	454	440	300	6954
Ny-Ålesund	64	359	7	126	126	2	274	163	321	7655	8862	3574	1986

Table A.1.12: Monthly and annual wet deposition of sulfate (sea salt corrected) at Norwegian background stations. Unit: mg S/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	37	63	19	15	21	14	6	21	29	7	50	27	310
Vatnedalen	5	3	1	10	3	13	6	20	18	11	2	2	94
Treungen	13	15	5	9	10	8	9	12	18	6	18	9	133
Løken	16	4	2	7	9	9	7	8	5	13	17	4	103
Hurdal	29	15	2	6	8	11	9	13	11	16	18	18	156
Brekkebygda	20	26	5	7	9	18	11	12	5	6	15	17	151
Vikedal	10	23	5	32	15	24	10	47	25	45	11	3	250
Haukeland	16	5	4	3	-	-	-	-	-	-	-	-	-
Nausta	1	3	3	13	9	13	7	19	12	9	5	1	94
Kårvatn	3	2	3	5	6	14	8	11	2	7	1	4	66
Høylandet	5	-	4	5	6	12	2	11	3	2	0	2	53
Tustervatn	2	1	4	3	5	10	8	12	2	5	6	1	58
Svanvik	4	2	7	8	6	19	22	24	17	7	1	-	117
Karpbukt	4	3	14	8	8	30	37	41	16	11	6	3	181
Ny-Ålesund	3	11	1	5	3	2	5	1	3	4	5	5	49

Table A.1.13: Monthly and annual wet deposition of nitrate at Norwegian background stations. Unit: mg N/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	78	182	25	26	34	20	9	41	46	9	120	65	655
Vatnedalen	6	8	2	20	5	12	5	23	12	13	9	8	122
Treungen	28	44	9	18	15	12	10	25	25	13	38	23	260
Løken	23	14	5	15	9	16	9	10	7	10	38	12	167
Hurdal	38	42	7	18	10	16	10	25	22	21	32	29	270
Brekkebygda	38	50	8	16	18	20	4	22	9	4	22	35	245
Vikedal	22	51	10	61	27	22	21	52	64	66	39	14	449
Haukeland	17	25	15	9	-	-	-	-	-	-	-	-	-
Nausta	7	15	7	30	17	11	9	24	15	18	14	12	179
Kårvatn	3	6	5	10	8	12	21	11	3	5	1	12	96
Høylandet	7	-	5	7	8	7	0	6	1	1	0	9	51
Tustervatn	4	2	4	3	6	10	11	16	4	5	9	8	81
Svanvik	4	1	3	5	2	3	6	8	5	4	1	-	42
Karpbukt	5	2	4	2	4	5	9	10	7	4	3	2	58
Ny-Ålesund	2	10	1	1	2	1	4	1	2	1	4	3	33

Table A.1.14: Monthly and annual wet deposition of ammonium at Norwegian background stations. Unit: mg N/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	53	201	23	39	60	20	16	63	57	6	94	39	673
Vatnedalen	5	6	2	29	6	10	3	21	7	28	5	4	127
Treungen	13	42	8	29	28	8	6	32	30	13	27	12	247
Løken	15	9	3	25	15	18	9	6	10	8	35	7	161
Hurdal	28	28	4	27	18	28	7	39	27	25	25	21	278
Brekkebygda	21	42	7	20	25	25	4	14	5	4	12	18	197
Vikedal	20	27	15	107	48	41	32	72	92	102	44	18	618
Haukeland	14	12	8	11	-	-	-	-	-	-	-	-	-
Nausta	8	16	9	43	25	12	13	27	19	31	19	40	263
Kårvatn	3	4	5	15	14	22	11	10	7	5	1	13	111
Høylandet	24	-	13	21	17	11	3	17	11	21	2	28	169
Tustervatn	4	1	4	9	9	14	10	20	9	15	6	5	107
Svanvik	1	1	2	1	2	2	3	7	4	5	1	-	29
Karpbukt	4	4	29	4	7	46	3	8	6	5	1	0	118
Ny-Ålesund	5	7	1	1	1	0	3	2	2	2	3	3	31

Table A.1.15: Monthly and annual wet deposition of calcium at Norwegian background stations. Unit: mg Ca /m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	33	29	7	19	16	9	6	17	48	7	17	9	216
Vatnedalen	8	5	1	13	2	7	5	21	16	13	5	5	100
Treungen	8	5	2	13	8	6	9	8	15	6	6	3	88
Løken	14	4	1	17	11	7	12	25	19	8	9	3	133
Hurdal	16	8	1	26	9	6	8	12	13	13	9	4	125
Brekkebygda	19	8	3	18	8	28	12	14	7	5	10	15	150
Vikedal	49	97	6	40	11	23	7	38	135	45	20	13	484
Haukeland	33	17	19	2	-	-	-	-	-	-	-	-	-
Nausta	11	6	4	20	8	18	5	18	26	23	4	25	168
Kårvatn	6	2	11	7	6	26	12	8	20	11	0	23	132
Høylandet	22	-	11	10	14	16	3	20	23	13	1	15	148
Tustervatn	8	0	6	4	10	13	7	13	18	11	4	11	106
Svanvik	3	2	4	6	2	5	5	7	5	4	0	-	42
Karpbukt	6	4	8	3	8	8	16	13	9	9	6	3	92
Ny-Ålesund	9	27	2	4	8	11	14	6	10	9	24	18	141

Table A.1.16: Monthly and annual wet deposition of potassium at Norwegian background stations. Unit: mg K/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	16	17	4	8	4	6	4	9	35	3	17	14	137
Vatnedalen	6	2	1	7	1	13	3	14	34	18	5	5	109
Treungen	6	3	1	4	2	4	3	5	10	2	4	5	48
Løken	5	2	1	7	4	10	9	28	24	16	7	4	113
Hurdal	9	5	1	8	4	10	10	14	10	6	8	7	91
Brekkebygda	9	6	5	8	2	16	7	2	4	2	5	11	78
Vikedal	35	28	7	12	2	17	5	36	106	35	20	11	313
Haukeland	23	7	8	2	-	-	-	-	-	-	-	-	-
Nausta	12	6	5	9	2	14	6	8	18	19	7	47	153
Kårvatn	3	2	7	3	2	30	8	6	20	16	1	27	126
Høylandet	22	-	6	3	6	15	6	24	21	17	1	15	135
Tustervatn	5	1	4	2	2	13	12	12	29	15	4	8	107
Svanvik	0	1	3	1	0	2	39	3	4	5	0	-	59
Karpbukt	3	2	6	2	5	17	7	8	10	5	4	2	70
Ny-Ålesund	3	18	1	2	5	2	3	3	5	4	7	11	64

Table A.1.17: Monthly and annual wet deposition of magnesium at Norwegian background stations. Unit: mg /m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	37	33	7	10	3	5	1	8	102	9	37	19	271
Vatnedalen	3	1	0	3	0	3	1	3	13	5	1	2	36
Treungen	6	4	1	1	1	1	2	2	11	3	6	5	44
Løken	6	2	0	2	2	4	3	11	15	5	9	3	62
Hurdal	5	4	1	9	2	2	2	4	17	3	5	4	57
Brekkebygda	4	5	16	3	1	5	2	3	5	1	2	6	53
Vikedal	105	27	9	11	3	38	3	68	310	78	32	24	709
Haukeland	59	13	16	1	-	-	-	-	-	-	-	-	-
Nausta	19	6	6	7	2	29	3	14	62	52	6	58	264
Kårvatn	7	4	17	4	2	18	3	6	45	16	0	63	186
Høylandet	55	-	16	4	3	13	2	15	65	42	3	42	263
Tustervatn	12	0	7	4	3	5	1	10	35	21	4	17	121
Svanvik	1	2	8	2	1	2	15	2	3	4	0	-	41
Karpbukt	7	5	17	5	3	5	4	5	4	12	11	2	82
Ny-Ålesund	10	66	4	5	15	9	11	12	17	15	20	39	223

Table A.1.18: Monthly and annual wet deposition of sodium at Norwegian background stations. Unit: mg /m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	305	277	58	85	14	42	6	67	878	69	316	148	2265
Vatnedalen	66	30	9	54	10	94	28	154	193	109	21	39	806
Treungen	64	34	4	8	4	9	6	19	79	21	50	28	326
Løken	44	16	2	9	6	18	6	23	80	26	74	8	313
Hurdal	36	38	6	70	11	18	4	34	135	19	46	21	438
Brekkebygda	46	48	109	16	9	17	6	20	37	5	19	33	364
Vikedal	864	175	87	84	20	309	19	562	2680	747	279	209	6034
Haukeland	516	122	176	11	-	-	-	-	-	-	-	-	-
Nausta	169	61	57	65	14	242	15	113	505	443	53	496	2233
Kårvatn	63	39	155	36	12	144	18	49	370	142	2	516	1544
Høylandet	465	-	128	40	22	110	22	137	520	357	26	342	2167
Tustervatn	104	3	54	31	22	47	15	85	292	186	39	144	1037
Svanvik	6	15	60	11	3	9	6	7	11	35	1	-	162
Karpbukt	60	47	138	37	25	55	26	28	22	90	89	12	629
Ny-Ålesund	80	559	27	43	121	62	65	92	134	124	138	314	1757

Table A.1.19: Monthly and annual wet deposition of chloride at Norwegian background stations. Unit: mg /m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	543	504	100	133	18	69	9	112	1553	118	534	254	3947
Vatnedalen	78	34	12	50	6	84	18	94	249	119	28	36	809
Treungen	92	62	8	13	5	15	10	31	134	32	88	52	542
Løken	81	30	5	15	5	28	9	39	143	51	127	16	545
Hurdal	63	62	10	118	13	27	6	49	236	31	75	36	726
Brekkebygda	70	88	192	25	11	24	7	31	58	7	33	56	602
Vikedal	1604	332	140	140	32	554	25	1044	4585	1375	481	380	10690
Haukeland	930	217	300	18	-	-	-	-	-	-	-	-	-
Nausta	306	111	90	103	22	429	22	187	893	748	93	837	3839
Kårvatn	114	65	257	59	17	254	28	80	665	251	3	889	2683
Høylandet	875	-	236	73	37	186	36	238	985	633	48	595	3941
Tustervatn	188	5	99	54	40	81	21	155	509	334	71	248	1835
Svanvik	10	27	104	18	4	13	12	10	18	62	2	-	281
Karpbukt	112	85	261	65	41	72	43	42	36	175	159	20	1111
Ny-Ålesund	151	998	50	75	223	120	115	162	235	218	247	534	3124

Table A.1.20: The 10 highest daily wet deposition of sea salt corrected sulfate, 2018.

Site	Date	SO_4 wet dep mgS/m^2	Precip mm'	% av annual SO_4 dep	pH
Birkenes	10.11.2018	16.5	53.3	5.3	4.74
	10.02.2018	15.8	21.0	5.1	5.55
	11.02.2018	15.5	51.6	5.0	5.05
	15.01.2018	14.9	71.2	4.8	4.90
	20.12.2018	11.2	58.9	3.6	4.67
	10.05.2018	10.0	28.7	3.2	6.12
	15.02.2018	9.9	26.9	3.2	5.31
	09.02.2018	8.0	22.3	2.6	5.49
	07.09.2018	7.7	86.0	2.5	5.18
	21.09.2018	6.6	31.6	2.1	5.37
	sum			37.5	
	10.nov	16.5	53.3	5.3	4.74
Hurdal	14.01.2018	13.0	7.2	8.4	4.13
	10.02.2018	8.2	11.6	5.3	4.30
	30.10.2018	7.9	27.4	5.1	5.52
	20.12.2018	7.8	8.1	5.0	4.09
	02.11.2018	6.6	13.5	4.2	4.71
	16.01.2018	5.9	24.7	3.8	4.95
	28.07.2018	5.5	24.8	3.5	5.15
	10.05.2018	4.5	13.1	2.9	5.69
	17.06.2018	4.0	30.9	2.6	5.61
	10.11.2018	4.0	39.5	2.5	4.95
	sum			43.2	

Site	Date	SO4 wet dep mgS/m2	Precip mm'	% av annual SO4 dep	pH
Tustervatn	01.08.2018	2.5	20.7	4.6	5.38
	17.03.2018	2.2	24.5	4.1	5.64
	18.07.2018	2.0	11.6	3.7	4.97
	03.11.2018	1.9	12.7	3.5	4.92
	11.11.2018	1.8	25.6	3.3	5.13
	14.06.2018	1.6	7.6	3.0	5.12
	24.07.2018	1.5	29.9	2.8	5.26
	03.06.2018	1.4	4.1	2.6	5.58
	11.08.2018	1.3	25.2	2.3	5.18
	24.08.2018	1.2	17.8	2.3	5.08
	sum			32.1	

Table A.1.20 continued:

Site	Date	SO4 wet dep mgS/m2	Precip mm'	% av annual SO4 dep	pH
Kårvatn	22.06.2018	3.4	19.8	5.1	5.57
	10.05.2018	3.2	21.3	4.8	5.84
	10.08.2018	2.7	54.7	4.1	5.24
	03.06.2018	2.5	5.7	3.7	5.37
	27.06.2018	2.1	12.6	3.2	5.71
	19.04.2018	2.1	8.5	3.2	5.64
	21.06.2018	2.0	12.0	3.1	5.62
	17.07.2018	1.8	8.0	2.7	5.08
	23.10.2018	1.7	28.8	2.6	5.43
	25.01.2018	1.5	8.1	2.2	5.26
	sum			34.8	

Table A.1.21a: Volume weighted annual mean concentrations and wet deposition of main components in precipitation at Norwegian background stations in 1973-2013, and estimated dry deposition of sulfur and nitrogen for the 1987-2018.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m²	NO_3-N mg/m²	NH_4-N mg/m²	H+ mekv/m²	S mg/m²	N mg/m²
Birkenes	1973	1.06				0.11	4.27	1072	1136			58		
	1974	1.11	0.50	0.52	0.23	0.19	4.25	1563	1735	782	813	88		
	1975	1.01	0.49	0.45	0.19	0.17	4.27	1341	1354	657	603	72		
	1976	1.18	0.63	0.50	0.17	0.12	4.21	1434	1692	903	717	88		
	1977	1.04	0.54	0.54	0.17	0.17	4.27	1597	1661	862	862	86		
	1978	1.17	0.62	0.57	0.17	0.12	4.11	1242	1453	770	708	96		
	1979	1.25	0.57	0.65	0.22	0.15	4.09	1560	1950	889	1014	127		
	1980	1.23	0.57	0.63	0.22	0.11	4.16	1160	1427	661	731	80		
	1981	1.04	0.52	0.53	0.20	0.13	4.21	1316	1369	684	697	81		
	1982	1.05	0.56	0.72	0.22	0.21	4.27	1592	1663	887	1140	86		
	1983	0.91	0.49	0.50	0.24	0.17	4.33	1313	1195	646	650	62		
	1984	1.09	0.57	0.63	0.21	0.19	4.24	1603	1755	905	1003	93		
	1985	0.98	0.58	0.57	0.16	0.09	4.24	1409	1375	810	805	80		
	1986	1.01	0.60	0.69	0.19	0.15	4.26	1613	1622	966	1108	88		
	1987	0.74	0.43	0.46	0.13	0.13	4.38	1576	1168	671	719	65	159	248
	1988	0.83	0.58	0.61	0.15	0.13	4.25	1986	1649	1159	1211	113	159	257
	1989	0.90	0.76	0.63	0.19	0.19	4.27	1228	1106	934	776	67	136	238
	1990	0.71	0.47	0.46	0.14	0.21	4.37	1861	1325	869	852	79	167	254
	1991	0.75	0.57	0.50	0.14	0.19	4.33	1247	930	710	618	59	170	232
	1992	0.74	0.52	0.44	0.12	0.13	4.37	1344	991	703	589	57	138	188
	1993	0.77	0.55	0.51	0.15	0.23	4.37	1245	960	683	634	54	96	158
	1994	0.63	0.55	0.51	0.15	0.12	4.48	1397	886	768	707	46	128	212
	1995	0.53	0.48	0.42	0.09	0.14	4.47	1411	743	684	589	47	115	213
	1996	0.60	0.53	0.47	0.12	0.15	4.42	1192	714	630	563	45	123	205
	1997	0.52	0.50	0.45	0.10	0.13	4.50	1244	648	618	559	40	100	207
	1998	0.52	0.44	0.41	0.10	0.12	4.50	1596	836	710	649	53	74	143
	1999	0.47	0.43	0.36	0.11	0.15	4.59	1843	856	794	659	48	83	171
	2000	0.40	0.45	0.34	0.10	0.19	4.56	2415	949	1083	823	67	78	164
	2001	0.43	0.42	0.39	0.08	0.10	4.63	1604	673	680	629	38	75	177
	2002	0.35	0.33	0.32	0.10	0.12	4.72	1574	558	516	497	30	83	204
	2003	0.46	0.50	0.47	0.12	0.11	4.59	1375	630	693	644	35	74	171
	2004	0.36	0.36	0.33	0.12	0.14	4.69	1700	615	617	567	35	63	178
	2005	0.43	0.47	0.42	0.13	0.18	4.68	1241	531	586	522	26	86	226
	2006	0.32	0.42	0.34	0.10	0.15	4.70	1833	582	775	624	36	96	269
	2007	0.30	0.33	0.28	0.11	0.12	4.75	1441	439	471	400	26	45	122
	2008	0.26	0.35	0.29	0.13	0.20	4.77	1990	511	692	570	34	46	141
	2009	0.33	0.44	0.36	0.10	0.15	4.72	1807	591	792	660	34	43	-
	2010	0.38	0.46	0.36	0.10	0.08	4.69	1113	421	511	401	23	53	*106*
	2011	0.26	0.39	0.42	0.12	0.19	4.86	1779	461	685	752	25	60	*162*
	2012	0.23	0.38	0.33	0.16	0.13	4.86	1989	448	756	648	28	43	215
	2013	0.21	0.35	0.37	0.17	0.16	4.97	1427	303	501	522	15	45	152

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m²	NO_3-N mg/m²	NH_4-N mg/m²	H+ mekv/m²	S mg/m²	N mg/m²
Birkenes	2014	0.31	0.35	0.35	0.16	0.18	4.77	2331	732	813	818	17	71	193
(cont.)	2015	0.18	0.29	0.28	0.15	0.16	4.91	2173	387	633	614	27	48	165
	2016	0.17	0.35	0.29	0.15	0.16	4.91	1414	245	489	414	12	37	133
	2017	0.20	0.31	0.29	0.17	0.14	4.95	2088	408	648	611	11	39	102
	2018	0.20	0.43	0.44	0.14	0.18	4.95	1515	310	655	673	11	49	152
Vatnedalen	1974	0.54				0.06	4.59	884	477			23		
	1975	0.53	0.17	0.22		0.09	4.85	994	527	169	219	14		
	1976	0.50	0.20	0.36	0.12	0.10	4.85	715	358	143	257	10		
	1977	0.44	0.21	0.25	0.13	0.06	4.71	761	335	160	190	15		
	1978	0.41	0.17	0.23	0.14	0.10	4.62	862	353	147	198	21		
	1979	0.56	0.22	0.20	0.20	0.06	4.38	948	531	209	190	40		
	1980	0.45	0.16	0.10	0.14	0.06	4.55	799	360	128	80	23		
	1981	0.49	0.19	0.18	0.14	0.09	4.49	900	441	171	162	29		
	1982	0.38	0.18	0.17	0.13	0.08	4.62	967	366	174	159	23		
	1983	0.29	0.13	0.10	0.14	0.08	4.76	1249	363	166	130	22		
	1984	0.40	0.18	0.13	0.16	0.08	4.59	762	306	138	102	20		
	1985	0.43	0.22	0.18	0.15	0.04	4.57	794	343	173	145	21		
	1986	0.51	0.21	0.19	0.13	0.07	4.54	987	506	212	183	29		
	1987	0.41	0.17	0.15	0.12	0.04	4.60	732	298	122	107	19		
	1988	0.37	0.23	0.20	0.13	0.08	4.55	898	334	207	182	25		
	1989	0.34	0.22	0.29	0.13	0.08	4.78	980	337	218	285	16		
	1990	0.27	0.14	0.12	0.14	0.11	4.71	1465	394	203	169	28		
	1991	0.32	0.20	0.17	0.29	0.12	4.69	865	280	172	147	18		
	1992	0.29	0.17	0.11	0.15	0.10	4.75	1055	301	175	112	19		
	1993	0.23	0.18	0.10	0.23	0.44	4.82	891	203	159	92	13		
	1994	0.28	0.22	0.15	0.08	0.08	4.75	1006	286	217	155	18		
	1995	0.25	0.18	0.13	0.11	0.10	4.82	823	206	147	108	12		
	1996	0.32	0.23	0.21	0.16	0.04	4.78	601	191	140	124	10		
	1997	0.24	0.15	0.14	0.22	0.10	4.95	858	204	130	121	10		
	1998	0.25	0.18	0.28	0.13	0.06	5.01	903	232	163	260	9		
	1999	0.24	0.16	0.24	0.12	0.08	5.05	1132	265	184	277	10		
	2000	0.15	0.14	0.15	0.11	0.08	5.02	1296	199	184	189	12		
	2001	0.15	0.09	0.10	0.12	0.05	5.27	709	103	65	73	4		
	2002	0.22	0.14	0.17	0.15	0.08	5.02	590	129	82	98	6		
	2003	0.17	0.17	0.14	0.16	0.06	4.97	802	140	132	117	9		
	2004	0.16	0.12	0.20	0.19	0.06	5.30	970	158	122	192	5		
	2005	0.18	0.15	0.14	0.16	0.05	5.17	1071	197	161	148	7		
	2006	0.12	0.16	0.12	0.12	0.06	5.17	1011	119	163	116	7		
	2007	0.10	0.11	0.13	0.17	0.10	5.31	845	84	89	110	4		
	2008	0.10	0.17	0.13	0.24	0.14	5.35	1016	104	171	135	5		
	2009	0.17	0.18	0.15	0.20	0.04	5.35	815	139	147	120	4		
	2010	0.19	0.15	0.19	0.17	0.04	5.40	619	115	91	118	2		
	2011	0.09	0.11	0.24	0.17	0.07	5.51	1225	115	132	294	4		
	2012	0.08	0.13	0.12	0.15	0.04	5.44	828	67	109	95	3		
	2013	0.09	0.14	0.35	0.14	0.05	5.50	983	92	133	344	3		

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m²	NO_3-N mg/m²	NH_4-N mg/m²	H+ mekv/m²	S mg/m²	N mg/m²
Vatnedalen	2014	0.17	0.15	0.17	0.23	0.07	5.44	957	160	141	167	4		
(cont.)	2015	0.07	0.09	0.12	0.16	0.10	5.50	1166	84	105	140	4		
	2016	0.09	0.08	0.11	0.14	0.17	5.30	814	70	64	93	5		
	2017	0.08	0.10	0.12	0.08	0.03	5.52	1272	106	132	155	3		
	2018	0.10	0.13	0.13	0.10	0.04	5.51	967	94	122	127	3		
Treungen	1974	0.94	0.38	0.33	0.14	0.07	4.27	1039	977	395	343	56		
	1975	0.91	0.37	0.34	0.15	0.06	4.26	894	814	331	304	49		
	1976	1.05	0.50	0.42	0.11	0.06	4.20	706	741	353	297	45		
	1977	0.81	0.44	0.39	0.11	0.05	4.32	1165	944	513	454	56		
	1978	0.87	0.38	0.41	0.14	0.04	4.21	945	822	359	387	58		
	1979													
	1980	0.88	0.37	0.39	0.14	0.04	4.23	759	668	281	296	45		
	1981	0.86	0.39	0.46	0.12	0.05	4.29	949	816	370	437	49		
	1982	0.84	0.45	0.50	0.14	0.07	4.32	1130	948	504	563	54		
	1983	0.83	0.40	0.43	0.18	0.05	4.35	1091	908	431	471	48		
	1984	0.77	0.36	0.27	0.15	0.05	4.27	1196	919	436	325	64		
	1985	0.68	0.39	0.37	0.13	0.04	4.33	892	608	350	333	41		
	1986	1.07	0.57	0.63	0.14	0.07	4.19	1030	1097	582	650	66		
	1987	0.68	0.37	0.37	0.13	0.07	4.39	1133	768	424	418	46		
	1988	0.75	0.50	0.45	0.10	0.05	4.27	1348	1006	670	612	73		
	1989	0.76	0.61	0.44	0.10	0.06	4.26	754	572	456	329	41		
	1990	0.63	0.42	0.37	0.06	0.07	4.37	1184	747	503	433	51		
	1991	0.59	0.42	0.34	0.13	0.06	4.42	811	480	343	278	31		
	1992	0.60	0.40	0.34	0.08	0.05	4.44	923	556	365	310	33		
	1993	0.59	0.41	0.32	0.11	0.09	4.46	803	472	329	258	28		
	1994	0.54	0.44	0.35	0.08	0.05	4.49	1016	544	448	356	33		
	1995	0.50	0.44	0.40	0.09	0.08	4.48	903	452	394	361	30		
	1996	0.49	0.40	0.37	0.10	0.05	4.49	838	408	335	312	27		
	1997	0.41	0.37	0.32	0.12	0.06	4.56	887	364	330	282	24		
	1998	0.48	0.40	0.41	0.09	0.04	4.53	959	462	386	397	28		
	1999	0.35	0.32	0.31	0.06	0.06	4.67	1329	463	427	406	28		
	2000	0.33	0.36	0.31	0.08	0.07	4.59	1563	510	566	483	40		
	2001	0.30	0.28	0.27	0.05	0.04	4.77	1141	346	324	314	19		
	2002	0.32	0.27	0.28	0.08	0.04	4.79	933	295	251	262	15		
	2003	0.35	0.36	0.35	0.09	0.04	4.67	1002	349	366	350	22		
	2004	0.31	0.30	0.26	0.10	0.06	4.79	1271	393	379	336	21		
	2005	0.34	0.38	0.37	0.11	0.06	4.75	897	308	338	329	16		
	2006	0.23	0.28	0.20	0.09	0.05	4.79	1522	355	433	310	25		
	2007	0.23	0.24	0.18	0.08	0.04	4.82	1006	226	243	178	15		
	2008	0.21	0.28	0.26	0.11	0.08	4.93	1150	239	318	294	13		
	2009	0.21	0.34	0.25	0.07	0.06	4.82	1213	260	408	302	18		
	2010	0.28	0.34	0.32	0.07	0.03	4.79	849	241	289	271	14		
	2011	0.19	0.26	0.23	0.09	0.05	4.95	1177	227	308	270	13		
	2012	0.15	0.28	0.23	0.07	0.05	4.96	1092	167	307	247	12		

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m²	NO_3-N mg/m²	NH_4-N mg/m²	H+ mekv/m²	S mg/m²	N mg/m²
Treungen	2013	0.17	0.27	0.30	0.09	0.06	5.12	1150	190	305	349	9		
(cont.)	2014	0.21	0.28	0.26	0.11	0.07	4.90	1463	312	406	384	13		
	2015	0.12	0.21	0.19	0.11	0.07	4.96	1153	143	243	214	13		
	2016	0.16	0.27	0.30	0.09	0.07	4.98	957	150	263	284	10		
	2017	0.14	0.22	0.24	0.11	0.05	5.12	1186	169	265	288	8		
	2018	0.15	0.30	0.28	0.10	0.05	5.02	878	133	260	247	10		
Løken	1973	1.03				0.06	4.48	569	586			19		
	1974	0.94				0.08	4.43	831	781			31		
	1975	1.03	0.41	0.42		0.08	4.32	657	677	269	276	31		
	1976	1.20	0.49	0.50	0.40	0.09	4.39	533	640	261	267	22		
	1977	0.96	0.41	0.43	0.22	0.07	4.41	699	671	287	301	27		
	1978	1.10	0.48	0.52	0.24	0.07	4.25	597	657	287	310	34		
	1979	1.03	0.49	0.57	0.30	0.07	4.22	784	808	384	447	47		
	1980	0.97	0.39	0.49	0.25	0.08	4.33	695	674	271	341	33		
	1981	0.77	0.36	0.51	0.20	0.06	4.48	700	539	252	357	23		
	1982	1.06	0.60	0.79	0.24	0.11	4.33	885	908	515	679	40		
	1983	0.91	0.47	0.62	0.28	0.10	4.42	656	595	311	404	25		
	1984	0.91	0.49	0.76	0.30	0.10	4.45	747	678	365	567	27		
	1985	0.86	0.47	0.51	0.30	0.09	4.36	894	768	421	459	39		
	1986	0.96	0.57	0.56	0.26	0.08	4.31	701	671	399	391	34		
	1987	0.79	0.40	0.45	0.17	0.06	4.40	861	679	348	387	35		
	1988	0.76	0.49	0.49	0.20	0.08	4.31	882	669	435	429	43		
	1989	0.92	0.69	0.57	0.18	0.10	4.26	421	389	292	239	55		
	1990	0.74	0.47	0.44	0.12	0.08	4.36	719	530	337	313	31		
	1991	0.65	0.50	0.44	0.18	0.09	4.41	722	467	359	320	28		
	1992	0.61	0.44	0.38	0.11	0.05	4.46	686	418	302	261	24		
	1993	0.66	0.44	0.38	0.18	0.05	4.46	714	468	316	270	25		
	1994	0.43	0.37	0.29	0.30	0.06	4.64	740	316	277	213	17		
	1995	0.52	0.43	0.36	0.24	0.09	4.56	656	340	282	235	18		
	1996	0.51	0.39	0.39	0.28	0.09	4.62	673	344	264	264	16		
	1997	0.42	0.40	0.41	0.16	0.06	4.63	549	229	220	223	13		
	1998	0.45	0.39	0.38	0.14	0.07	4.63	717	319	278	272	17		
	1999	0.38	0.36	0.35	0.10	0.06	4.71	1011	383	362	353	20		
	2000	0.33	0.33	0.24	0.07	0.06	4.60	1053	332	349	249	26		
	2001	0.33	0.31	0.26	0.13	0.04	4.75	818	265	253	213	14		
	2002	0.26	0.29	0.25	0.12	0.04	4.84	856	226	244	215	12		
	2003	0.33	0.37	0.34	0.15	0.05	4.72	651	212	244	221	12		
	2004	0.23	0.28	0.20	0.13	0.07	4.80	953	222	267	189	15		
	2005	0.34	0.38	0.32	0.14	0.06	4.77	686	236	260	217	12		
	2006	0.21	0.34	0.30	0.09	0.06	4.79	967	205	324	287	16		
	2007	0.24	0.30	0.28	0.16	0.06	4.92	727	177	216	204	9		
	2008	0.19	0.28	0.22	0.13	0.09	4.90	997	192	283	223	13		
	2009	0.17	0.32	0.29	0.11	0.06	5.06	837	140	267	247	7		
	2010	0.23	0.29	0.24	0.12	0.04	4.95	664	150	193	158	8		

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m²	NO_3-N mg/m²	NH_4-N mg/m²	H+ mekv/m²	S mg/m²	N mg/m²
Løken	2011	0.21	0.25	0.41	0.14	0.08	5.12	1100	228	278	452	8		
(cont.)	2012	0.16	0.27	0.23	0.12	0.05	5.04	762	124	204	173	7		
	2013	0.17	0.27	0.49	0.14	0.09	5.22	834	145	229	405	5		
	2014	0.23	0.28	0.25	0.18	0.09	4.91	965	225	275	244	12		
	2015	0.12	0.26	0.23	0.15	0.08	5.01	851	105	223	195	8		
	2016	0.17	0.30	0.31	0.12	0.06	5.03	692	117	210	217	9		
	2017	0.12	0.25	0.21	0.18	0.06	5.12	797	96	196	169	8		
	2018	0.17	0.27	0.26	0.21	0.10	5.14	619	103	167	161	7		
Nordmoen	1987	0.72	0.37	0.33	0.14	0.03	4.34	1016	727	375	335	46	148	348
	1988	0.88	0.48	0.46	0.13	0.04	4.25	1085	960	519	500	61	171	357
	1989	0.88	0.57	0.40	0.14	0.05	4.26	816	719	463	328	44	144	356
	1990	0.77	0.44	0.35	0.10	0.05	4.31	822	636	366	286	40	137	332
	1991	0.59	0.40	0.31	0.09	0.04	4.43	781	459	312	240	29	117	284
	1992	0.58	0.40	0.27	0.10	0.03	4.42	821	473	327	218	31	99	276
	1993	0.56	0.37	0.25	0.08	0.03	4.45	927	517	340	236	33	84	246
	1994	0.45	0.39	0.29	0.07	0.03	4.55	828	373	326	242	23	97	280
	1995	0.53	0.37	0.33	0.12	0.06	4.49	791	415	292	257	25	88	279
	1996	0.43	0.34	0.23	0.14	0.04	4.52	837	358	286	195	25	91	303
	1997	0.33	0.31	0.26	0.07	0.02	4.63	775	254	240	202	18		
	1998	0.36	0.28	0.21	0.11	0.03	4.64	817	293	224	173	19		
	1999	0.37	0.31	0.26	0.08	0.03	4.65	1014	376	316	262	22		
Hurdal	1998	0.38	0.29	0.28	0.09	0.03	4.68	853	325	249	236	18	54	172
	1999	0.39	0.33	0.31	0.08	0.03	4.67	1110	434	367	344	24	64	169
	2000	0.31	0.31	0.24	0.07	0.05	4.64	1336	418	408	314	30	57	170
	2001	0.33	0.36	0.29	0.08	0.03	4.69	961	318	347	275	20	52	
	2002	0.25	0.27	0.26	0.09	0.03	4.79	732	183	197	187	12	60	
	2003	0.32	0.35	0.32	0.09	0.04	4.66	830	263	289	268	18	63	
	2004	0.24	0.27	0.28	0.11	0.03	4.84	903	219	241	248	13	53	189
	2005	0.35	0.43	0.44	0.12	0.05	4.89	739	258	317	324	9	65	268
	2006	0.23	0.33	0.35	0.15	0.05	5.06	1043	245	348	370	9	74	273
	2007	0.26	0.28	0.36	0.23	0.05	5.13	809	208	228	295	6	37	195
	2008	0.20	0.32	0.31	0.19	0.06	5.10	1068	219	338	335	8	32	189
	2009	0.21	0.27	0.24	0.14	0.04	5.09	909	188	249	222	7	29	-
	2010	0.28	0.35	0.36	0.09	0.02	4.88	809	224	283	291	11	34	144
	2011	0.23	0.32	0.47	0.13	0.04	5.04	1300	295	415	605	12	49	203
	2012	0.17	0.27	0.21	0.07	0.03	4.93	1129	186	308	239	13	35	230
	2013	0.17	0.26	0.38	0.15	0.05	5.18	896	156	233	340	6	28	182
	2014	0.24	0.28	0.25	0.17	0.06	4.88	1172	278	327	293	13	52	190
	2015	0.14	0.25	0.24	0.10	0.05	4.98	1059	149	267	255	11	22	183
	2016	0.18	0.31	0.32	0.13	0.04	5.01	866	159	272	281	10	26	142
	2017	0.12	0.19	0.24	0.12	0.03	5.23	956	115	181	228	6	24	118
	2018	0.17	0.30	0.31	0.14	0.06	5.04	901	156	270	278	9	29	151

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m²	NO_3-N mg/m²	NH_4-N mg/m²	H+ mekv/m²	S mg/m²	N mg/m²
Gulsvik	1974	0.81	0.38	0.28	0.13	0.04	4.28	783	634	298	219	41		
	1975	0.89	0.40	0.34	0.21	0.05	4.36	560	498	224	190	24		
	1976	0.85	0.38	0.30	0.10	0.03	4.35	641	545	244	192	29		
	1977	0.77	0.39	0.35	0.13	0.03	4.35	683	526	266	239	31		
	1978	0.94	0.40	0.38	0.16	0.03	4.22	693	651	277	263	42		
	1979	1.27	0.53	0.62	0.23	0.04	4.11	790	1003	419	490	61		
	1980	0.78	0.25	0.27	0.13	0.03	4.33	667	520	167	180	31		
	1981	0.86	0.35	0.40	0.13	0.03	4.30	628	540	220	251	31		
	1982	0.89	0.44	0.52	0.22	0.05	4.38	778	696	346	408	33		
	1983	0.94	0.40	0.58	0.25	0.05	4.39	664	623	263	384	27		
	1984	0.87	0.40	0.58	0.25	0.04	4.41	946	819	382	547	37		
	1985	0.73	0.35	0.72	0.16	0.04	4.55	686	499	240	492	20		
	1986	0.89	0.48	0.51	0.15	0.04	4.30	804	711	382	409	40		
	1987	0.74	0.37	0.46	0.14	0.03	4.42	916	679	337	421	35		
	1988	0.67	0.41	0.38	0.09	0.03	4.33	1023	688	420	386	48	136	
	1989	0.76	0.54	0.55	0.15	0.06	4.42	668	507	360	369	25	88	
	1990	0.75	0.45	0.53	0.09	0.03	4.43	753	562	338	398	28	100	
	1991	0.60	0.42	0.46	0.13	0.04	4.58	506	302	212	235	13	97	
	1992	0.56	0.35	0.38	0.13	0.03	4.60	666	371	235	255	17	83	
	1993	0.50	0.33	0.40	0.12	0.03	4.66	680	343	222	269	15	60	
	1994	0.50	0.43	0.39	0.23	0.03	4.61	643	320	277	249	16	72	
	1995	0.56	0.39	0.42	0.12	0.04	4.54	634	354	249	268	18	64	
	1996	0.48	0.37	0.51	0.16	0.06	4.71	657	318	241	335	13	67	
	1997	0.35	0.32	0.33	0.12	0.04	4.74	704	247	225	232	13	52	
Brekkebygda	1998	0.38	0.29	0.25	0.08	0.02	4.62	886	336	256	224	21	36	
	1999	0.38	0.30	0.27	0.09	0.02	4.71	845	318	254	227	16	41	
	2000	0.37	0.29	0.23	0.17	0.06	4.69	1261	451	363	285	26	40	
	2001	0.31	0.25	0.29	0.08	0.04	4.81	*865*	*269*	*223*	*265*	*13*		
	2002	0.25	0.18	0.30	0.15	0.04	5.10	*839*	*208*	*155*	*255*	*7*		
	2003	0.30	0.26	0.28	0.17	0.06	4.89	852	257	224	242	11		
	2004	0.26	0.19	0.21	0.22	0.07	5.03	851	218	159	180	8		
	2005	0.36	0.33	0.35	0.12	0.03	4.87	754	275	249	267	10		
	2006	0.26	0.26	0.29	0.12	0.04	4.92	934	243	247	268	11		
	2007	0.18	0.18	0.16	0.13	0.03	4.98	1093	201	196	175	11		
	2008	0.23	0.31	0.32	0.12	0.03	4.94	950	220	298	299	11		
	2009	0.25	0.33	0.25	0.09	0.03	4.96	924	233	308	228	10		
	2010	0.24	0.24	0.33	0.07	0.02	5.03	831	200	203	272	8		
	2011	0.23	0.28	0.45	0.09	0.03	5.04	1387	320	388	629	13		
	2012	0.15	0.26	0.27	0.16	0.03	5.17	1086	165	282	289	7		
	2013	0.17	0.22	0.25	0.13	0.04	5.21	1202	207	268	304	7		
	2014	0.24	0.25	0.21	0.24	0.05	4.94	1105	269	276	234	11		
	2015	0.10	0.18	0.19	0.14	0.04	5.13	997	105	178	187	7		
	2016	0.15	0.23	0.24	0.10	0.03	5.01	892	136	209	217	10		

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m^2	NO_3-N mg/m^2	NH_4-N mg/m^2	H+ $mekv/m^2$	S mg/m^2	N mg/m^2
Brekkebygda	2017	0.12	0.17	0.15	0.09	0.02	4.98	1092	130	190	167	10		
(cont.)	2018	0.15	0.24	0.20	0.15	0.05	4.98	1003	151	245	197	10		
Vikedal	1984	0.51	0.24	0.27	0.24	0.25	4.57	1932	985	465	516	52		
	1985	0.63	0.30	0.33	0.21	0.20	4.45	2223	1390	672	734	79		
	1986	0.56	0.25	0.30	0.15	0.26	4.53	3017	1680	752	898	89		
	1987	0.54	0.27	0.34	0.13	0.18	4.51	1943	1059	519	663	60		
	1988	0.43	0.26	0.25	0.13	0.24	4.51	2694	1163	712	684	84		
	1989	0.53	0.32	0.23	0.14	0.26	4.46	2998	1582	949	704	104		
	1990	0.44	0.22	0.31	0.15	0.35	4.58	3341	1463	724	1036	88		
	1991	0.44	0.26	0.27	0.14	0.33	4.60	2962	1293	764	797	75		
	1992	0.40	0.22	0.24	0.12	0.22	4.70	3214	1281	710	771	64		
	1993	0.41	0.24	0.27	0.22	0.48	4.69	2009	818	484	545	41		
	1994	0.47	0.28	0.30	0.15	0.36	4.64	2744	1277	780	833	63		
	1995	0.35	0.23	0.23	0.13	0.24	4.72	2635	914	607	609	50		
	1996	0.31	0.23	0.28	0.16	0.16	4.78	1819	556	416	513	30		
	1997	0.35	0.20	0.28	0.24	0.39	4.75	2472	870	504	684	44		
	1998	0.32	0.24	0.25	0.11	0.21	4.77	2690	872	646	678	46		
	1999	0.27	0.22	0.22	0.12	0.27	4.82	3108	840	689	675	47		
	2000	0.25	0.22	0.22	0.12	0.26	4.82	2918	734	645	631	45		
	2001	0.26	0.22	0.28	0.11	0.20	4.96	2353	616	529	652	26		
	2002	0.29	0.26	0.39	0.14	0.24	4.94	2239	658	574	878	26		
	2003	0.26	0.25	0.29	0.11	0.21	4.86	2792	714	708	805	38		
	2004	0.17	0.19	0.29	0.12	0.23	5.08	2816	488	532	819	23		
	2005	0.21	0.21	0.29	0.15	0.31	5.07	3033	639	646	888	26		
	2006	0.18	0.22	0.24	0.15	0.28	5.10	2771	500	607	679	22		
	2007	0.14	0.17	0.28	0.22	0.40	5.24	3147	435	532	865	18		
	2008	0.14	0.17	0.20	0.22	0.42	5.24	2986	434	506	612	17		
	2009	0.17	0.20	0.26	0.10	0.20	5.33	2545	430	500	673	12		
	2010	0.29	0.28	0.31	0.28	0.12	5.26	1834	529	506	569	10		
	2011	0.11	0.18	0.37	0.15	0.34	5.33	3319	364	612	1224	16		
	2012	0.10	0.17	0.28	0.12	0.21	5.34	2557	268	427	724	12		
	2013	0.12	0.18	0.41	0.21	0.29	5.48	2534	304	467	1049	8		
	2014	0.17	0.18	0.27	0.22	0.27	5.21	2891	480	516	788	6		
	2015	0.06	0.15	0.22	0.21	0.47	5.24	3283	182	490	729	19		
	2016	0.10	0.18	0.25	0.15	0.33	5.14	2487	258	439	615	7		
	2017	0.06	0.12	0.16	0.14	0.26	5.25	3570	227	421	564	6		
	2018	0.09	0.16	0.22	0.17	0.25	5.38	2807	250	449	618	4		

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m²	NO_3-N mg/m²	NH_4-N mg/m²	H+ mekv/m²	S mg/m²	N mg/m²
Haukeland	1974	0.31	0.13	0.15	0.17	0.29	4.70	3901	1207	522	582	78		
	1975	0.36	0.10	0.17	0.17	0.37	4.73	4551	1636	431	753	85		
	1976	0.59	0.23	0.45	0.18	0.25	4.59	1808	1060	417	813	46		
	1982	0.48	0.18	0.20	0.14	0.24	4.56	3688	1756	674	722	101		
	1983	0.32	0.14	0.14	0.15	0.26	4.70	4769	1536	647	687	96		
	1984	0.42	0.16	0.28	0.20	0.22	4.63	2792	1157	454	783	65		
	1985	0.44	0.21	0.26	0.13	0.15	4.61	2930	1276	606	768	71		
	1986	0.36	0.16	0.20	0.12	0.20	4.71	4009	1459	621	796	77		
	1987	0.44	0.20	0.28	0.16	0.18	4.61	2493	1100	498	692	61		
	1988	0.35	0.21	0.28	0.14	0.24	4.63	3123	1096	642	872	74		
	1989	0.32	0.18	0.15	0.13	0.26	4.71	4525	1426	798	691	88		
	1990	0.27	0.13	0.15	0.11	0.29	4.79	5017	1364	665	744	82		
	1991	0.30	0.16	0.18	0.15	0.29	4.75	3744	1126	617	678	66		
	1992	0.32	0.17	0.17	0.14	0.22	4.77	4436	1421	768	771	76		
	1993	0.34	0.19	0.26	0.26	0.65	4.77	2891	974	556	760	50		
	1994	0.30	0.18	0.20	0.16	0.28	4.83	3670	1108	668	751	55		
	1995	0.21	0.14	0.17	0.11	0.22	4.89	3631	766	505	616	47		
	1996	0.27	0.19	0.26	0.11	0.14	4.85	2201	586	416	566	31		
	1997	0.17	0.14	0.12	0.08	0.14	4.87	3569	769	550	844	36		
	1998	0.22	0.15	0.19	0.09	0.17	4.93	3492	760	513	649	41		
	1999	0.21	0.15	0.17	0.11	0.23	4.99	4315	864	641	743	44		
	2000	0.20	0.15	0.15	0.13	0.28	4.95	3692	752	557	539	41		
	2001	0.18	0.15	0.22	0.09	0.18	5.08	2865	518	442	637	24		
	2002	0.23	0.19	0.22	0.16	0.25	4.97	2644	603	496	576	29		
	2003	0.15	0.14	0.13	0.11	0.18	4.96	3624	540	496	476	40		
	2004	0.12	0.12	0.10	0.09	0.19	5.01	3669	436	452	372	36		
	2005	0.19	0.14	0.14	0.11	0.17	5.06	4394	818	624	610	39		
	2006	0.15	0.17	0.13	0.12	0.17	5.03	3454	504	594	462	32		
	2007	0.09	0.09	0.10	0.12	0.23	5.18	4124	367	374	424	27		
	2008	0.09	0.13	0.12	0.15	0.31	5.16	3649	342	475	441	25		
	2009	0.11	0.12	0.11	0.07	0.15	5.20	3105	335	362	328	19		
	2010	0.17	0.19	0.16	0.05	0.08	5.13	2355	407	438	375	18		
	2011	0.08	0.11	0.20	0.11	0.25	5.22	4196	343	465	823	25		
	2012	0.07	0.10	0.09	0.09	0.19	5.27	3707	254	383	336	20		
	2013	0.08	0.11	0.16	0.11	0.21	5.29	3415	259	360	557	17		
	2014	0.10	0.11	0.12	0.16	0.19	5.15	3512	359	400	437	7		
	2015	0.05	0.10	0.08	0.19	0.31	5.06	4324	230	440	364	7		
	2016	0.06	0.08	0.11	0.13	0.32	5.14	3230	207	267	350	7		
	2017	0.06	0.09	0.10	0.14	0.23	5.21	3607	211	328	350	6		
	2018	-	-	-	-	-	-	-	-	-	-	-		

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m²	NO_3-N mg/m²	NH_4-N mg/m²	H+ mekv/m²	S mg/m²	N mg/m²
Nausta	1985	0.29	0.13	0.09	0.09	0.12	4.70	1943	561	246	177	39		
	1986	0.27	0.10	0.08	0.09	0.16	4.74	2314	614	227	176	42		
	1987	0.27	0.12	0.11	0.09	0.11	4.72	1969	523	236	213	37		
	1988	0.21	0.13	0.09	0.14	0.23	4.68	2253	476	302	193	47		
	1989	0.21	0.12	0.07	0.10	0.23	4.80	3330	708	407	227	53	91	
	1990	0.23	0.11	0.07	0.09	0.23	4.78	3549	808	380	254	58	72	
	1991	0.19	0.12	0.09	0.12	0.30	4.83	2411	470	291	219	35	80	
	1992	0.21	0.13	0.07	0.09	0.15	4.80	2962	633	373	205	47	73	
	1993	0.23	0.13	0.10	0.17	0.39	4.87	2215	509	277	211	30	78	
	1994	0.20	0.12	0.15	0.10	0.19	4.96	2747	563	339	415	30	66	
	1995	0.18	0.11	0.13	0.08	0.17	4.91	2510	451	283	321	31	64	
	1996	0.20	0.15	0.14	0.07	0.10	4.87	1575	312	241	225	21		
	1997	0.15	0.12	0.13	0.11	0.23	5.01	2428	361	294	316	24		
	1998	0.13	0.12	0.12	0.07	0.15	5.00	2583	346	298	317	26		
	1999	0.14	0.10	0.08	0.07	0.16	4.99	2880	400	300	225	30		
	2000	0.14	0.10	0.08	0.11	0.26	4.98	2272	314	238	192	24		
	2001	0.13	0.10	0.09	0.06	0.14	5.01	2173	284	226	196	21		
	2002	0.16	0.13	0.13	0.09	0.16	5.00	1852	290	246	244	19		
	2003	0.12	0.12	0.14	0.11	0.21	5.01	2615	322	319	355	25		
	2004	0.10	0.10	0.08	0.07	0.13	5.12	2803	280	286	233	21		
	2005	0.19	0.12	0.14	0.07	0.15	5.10	3195	597	369	435	25		
	2006	0.11	0.13	0.11	0.07	0.17	5.09	2341	264	309	261	19		
	2007	0.07	0.08	0.10	0.10	0.20	5.26	3084	211	239	313	17		
	2008	0.06	0.10	0.13	0.18	0.45	5.24	2464	140	247	327	14		
	2009	0.09	0.09	0.10	0.06	0.13	5.27	2074	183	181	208	11		
	2010	0.11	0.14	0.16	0.03	0.05	5.23	1588	172	214	255	9		
	2011	0.07	0.09	0.21	0.10	0.17	5.41	2814	197	254	587	11		
	2012	0.04	0.08	0.17	0.10	0.17	5.50	2180	83	174	363	7		
	2013	0.07	0.09	0.29	0.08	0.14	5.55	2277	153	207	666	6		
	2014	0.10	0.10	0.19	0.15	0.18	5.24	1725	178	170	326	6		
	2015	0.05	0.08	0.13	0.15	0.21	5.27	2533	124	198	327	14		
	2016	0.07	0.09	0.15	0.13	0.29	5.13	1477	104	136	227	7		
	2017	0.08	0.10	0.15	0.10	0.16	5.17	1293	99	126	196	7		
	2018	0.05	0.09	0.13	0.08	0.13	5.40	2045	94	179	263	4		
Kårvatn	1978	0.16	0.05	0.09	0.11	0.13	4.98	1317	211	66	119	14		
	1979	0.23	0.09	0.08	0.10	0.10	4.63	1248	287	112	100	29		
	1980	0.20	0.07	0.08	0.11	0.13	4.88	1225	245	86	98	16		
	1981	0.20	0.08	0.15	0.17	0.25	4.96	1101	220	88	165	12		
	1982	0.26	0.08	0.11	0.15	0.16	4.87	995	256	78	112	13		
	1983	0.14	0.05	0.06	0.18	0.20	5.08	1918	265	100	106	16		
	1984	0.24	0.10	0.18	0.22	0.18	5.04	914	216	91	166	8		
	1985	0.20	0.07	0.10	0.15	0.11	5.00	1462	298	100	149	15		
	1986	0.20	0.07	0.13	0.10	0.11	4.95	1277	260	89	162	14		
	1987	0.24	0.09	0.12	0.15	0.17	4.87	1464	357	129	176	20	68	

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m²	NO_3-N mg/m²	NH_4-N mg/m²	H+ mekv/m²	S mg/m²	N mg/m²
Kårvatn	1988	0.11	0.06	0.09	0.13	0.19	5.09	1550	164	91	143	13	76	149
(cont.)	1989	0.11	0.06	0.12	0.13	0.26	5.11	1539	168	97	187	12	55	116
	1990	0.11	0.05	0.07	0.07	0.14	5.07	1520	173	69	105	13	60	107
	1991	0.12	0.06	0.10	0.12	0.24	5.14	1619	190	102	170	12	52	89
	1992	0.10	0.07	0.06	0.11	0.18	5.17	1620	159	113	94	11	62	97
	1993	0.10	0.06	0.12	0.12	0.18	5.16	1423	148	87	169	10	45	88
	1994	0.11	0.07	0.08	0.12	0.15	5.12	1475	168	100	120	11	53	124
	1995	0.08	0.05	0.06	0.10	0.15	5.17	1661	134	80	106	11	39	107
	1996	0.09	0.07	0.10	0.10	0.13	5.16	1170	107	79	115	8	47	126
	1997	0.09	0.06	0.11	0.12	0.23	5.22	1842	171	109	208	11	38	129
	1998	0.08	0.06	0.11	0.09	0.19	5.21	1451	123	86	164	9	25	90
	1999	0.09	0.07	0.08	0.07	0.13	5.22	1304	115	93	100	8	31	107
	2000	0.09	0.05	0.08	0.10	0.23	5.26	1243	110	63	104	7	27	135
	2001	0.07	0.05	0.07	0.07	0.21	5.31	1523	103	71	113	7	28	108
	2002	0.10	0.07	0.10	0.08	0.11	5.26	1295	135	88	132	7	37	185
	2003	0.09	0.08	0.12	0.12	0.23	5.19	1664	154	128	192	11	36	196
	2004	0.06	0.04	0.07	0.11	0.16	5.40	2001	110	75	129	8	37	105
	2005	0.09	0.05	0.08	0.12	0.19	5.33	1733	162	93	139	8	35	153
	2006	0.08	0.08	0.14	0.09	0.13	5.29	1218	96	93	167	6	42	199
	2007	0.05	0.04	0.11	0.11	0.22	5.40	1930	94	74	220	8	22	129
	2008	0.05	0.07	0.08	0.13	0.22	5.37	1426	74	106	115	6	23	127
	2009	0.05	0.05	0.08	0.06	0.09	5.46	1310	69	68	102	5	20	-
	2010	0.08	0.05	0.12	0.03	0.06	5.36	1465	119	74	176	6	22	47
	2011	0.06	0.05	0.17	0.10	0.20	5.48	1500	85	70	259	5	31	70
	2012	0.06	0.06	0.12	0.12	0.21	5.42	1523	85	91	179	6	26	170
	2013	0.04	0.06	0.13	0.14	0.22	5.45	1432	57	80	182	5	16	110
	2014	0.18	0.11	0.10	0.21	0.16	5.03	1099	193	124	109	9	45	146
	2015	0.06	0.08	0.09	0.15	0.18	5.20	1343	79	111	118	8	15	112
	2016	0.07	0.10	0.11	0.10	0.16	5.19	1543	107	157	163	6	19	91
	2017	0.05	0.04	0.06	0.09	0.11	5.26	1758	88	75	111	5	24	64
	2018	0.05	0.08	0.09	0.11	0.16	5.34	1196	66	96	111	5	21	117
Høylandet	1987*	0.34	0.15	0.36	0.14	0.18	4.98	803	269	124	292	9	97	
	1988	0.22	0.11	0.17	0.16	0.20	5.00	1311	283	147	224	13	95	
	1989	0.17	0.10	0.14	0.20	0.45	5.11	1590	270	162	220	12		
	1990	0.21	0.10	0.13	0.14	0.26	4.92	1605	337	162	214	19		
	1991	0.23	0.11	0.20	0.21	0.31	5.10	1312	302	146	257	10		
	1992	0.15	0.09	0.15	0.16	0.36	5.16	1415	214	122	215	10		
	1993	0.20	0.12	0.20	0.17	0.35	5.10	1145	230	138	234	9		
	1994	0.15	0.09	0.22	0.12	0.25	5.23	1182	175	107	265	7		
	1995	0.17	0.10	0.22	0.17	0.27	5.20	1509	259	153	332	9		
	1996	0.16	0.10	0.21	0.16	0.26	5.11	813	132	84	167	6		
	1997	0.14	0.10	0.22	0.17	0.32	5.25	1418	196	145	308	8		
	1998	0.12	0.08	0.22	0.13	0.19	5.46	1456	173	123	316	5		
	1999	0.14	0.10	0.27	0.13	0.19	5.41	1195	171	125	342	5		

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m²	NO_3-N mg/m²	NH_4-N mg/m²	H+ mekv/m²	S mg/m²	N mg/m²
Høylandet	2000	0.12	0.08	0.21	0.18	0.35	5.36	1183	150	95	248	5		
(cont.)	2001	0.14	0.08	0.24	0.17	0.38	5.37	1282	177	107	314	5		
	2002	0.14	0.11	0.27	0.16	0.22	5.40	855	117	91	233	3		
	2003	0.11	0.10	0.23	0.22	0.37	5.25	1536	170	154	359	9		
	2004	0.06	0.08	0.21	0.21	0.35	5.57	1390	87	105	298	4		
	2005	0.15	0.10	0.26	0.16	0.29	5.44	1786	263	180	470	7		
	2006	0.11	0.14	0.32	0.17	0.33	5.47	1182	131	160	381	4		
	2007	0.08	0.12	0.38	0.25	0.49	5.88	1070	85	126	407	1		
.	2008	0.11	0.11	0.33	0.32	0.51	5.78	1030	117	109	337	2		
	2009	0.07	0.11	0.27	0.11	0.18	5.68	1152	85	122	315	2		
	2010	0.13	0.09	0.31	0.07	0.10	5.68	926	124	83	284	2		
	2011	0.06	0.07	0.49	0.19	0.35	5.86	1632	101	111	797	2		
	2012	0.04	0.11	0.32	0.21	0.33	5.83	1360	61	155	440	2		
	2013	0.06	0.08	0.34	0.17	0.24	5.67	1551	94	119	529	3		
	2014	0.20	0.11	0.34	0.29	0.25	5.28	999	197	109	338	5		
	2015	0.03	0.06	0.14	0.13	0.21	5.46	1148	31	64	163	4		
	2016	0.05	0.05	0.17	0.14	0.27	5.47	1283	67	69	213	3		
	2017	0.04	0.04	0.18	0.14	0.25	5.47	1502	65	64	277	3		
	2018	0.06	0.05	0.18	0.16	0.28	5.63	948	53	51	169	2		
Tustervatn	1973	0.24				0.18	4.94	1336	321			15		
	1974	0.28				0.11	4.88	695	195			9		
	1975	0.25				0.33	4.91	1756	439			22		
	1976	0.27				0.16	4.97	1064	287			11		
	1977	0.30	0.09	0.11	0.17	0.16	4.91	1111	333	100	122	14		
	1978	0.23	0.08	0.10	0.16	0.16	4.85	1128	259	90	113	16		
	1979	0.28	0.08	0.13	0.15	0.11	4.73	1168	327	93	152	22		
	1980	0.27	0.08	0.14	0.47	0.16	4.98	858	229	71	122	9		
	1981	0.18	0.07	0.10	0.21	0.15	5.00	1099	198	77	110	11		
	1982	0.16	0.08	0.09	0.22	0.47	4.98	1385	227	109	121	15		
	1983	0.20	0.06	0.09	0.16	0.22	4.90	1665	337	101	142	21		
	1984	0.24	0.09	0.09	0.12	0.10	4.85	1056	250	94	89	15		
	1985	0.22	0.08	0.10	0.12	0.15	4.93	1344	298	107	132	16		
	1986	0.26	0.09	0.12	0.12	0.15	4.88	1060	278	94	131	14		
	1987	0.22	0.08	0.11	0.12	0.12	4.89	1163	253	98	133	15	96	
	1988	0.13	0.07	0.09	0.13	0.15	5.04	1159	145	83	106	10	88	131
	1989	0.19	0.08	0.10	0.18	0.40	5.00	1825	346	137	178	18	40	119
	1990	0.16	0.09	0.14	0.11	0.21	4.99	1508	245	133	214	16	65	125
	1991	0.17	0.10	0.14	0.14	0.21	5.04	1400	242	137	197	13	62	148
	1992	0.15	0.08	0.15	0.19	0.37	5.12	1507	223	126	221	11	49	123
	1993	0.14	0.08	0.16	0.24	0.50	5.19	1340	182	111	209	9	44	126
	1994	0.10	0.08	0.13	0.12	0.15	5.24	1117	114	87	144	6	48	147
	1995	0.09	0.06	0.12	0.13	0.21	5.22	1515	136	96	186	9	47	132
	1996	0.12	0.09	0.16	0.15	0.18	5.11	1084	132	97	176	8	44	139
	1997	0.08	0.06	0.18	0.17	0.30	5.34	1528	121	98	271	7	44	199

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S	NO_3-N	NH_4-N	Ca	Mg	pH		SO_4-S	NO_3-N	NH_4-N	H+	S	N
		mg/l	mg/l	mg/l	mg/l	mg/l		mm	mg/m²	mg/m²	mg/m²	mekv/m²	mg/m²	mg/m²
Tustervatn	1998	0.07	0.06	0.16	0.11	0.18	5.39	1407	100	90	230	6	30	178
(cont.)	1999	0.09	0.08	0.17	0.07	0.08	5.38	1133	96	90	191	5	34	180
	2000	0.10	0.06	0.15	0.11	0.20	5.33	1313	116	80	191	6	29	164
	2001	0.08	0.06	0.15	0.10	0.19	5.36	1449	107	94	223	6	31	182
	2002	0.09	0.07	0.14	0.11	0.17	5.38	1162	103	82	157	5	38	207
	2003	0.07	0.07	0.18	0.16	0.26	5.32	1513	111	112	274	7	35	196
	2004	0.04	0.07	0.17	0.20	0.23	5.50	1428	62	97	243	5	34	167
	2005	0.12	0.08	0.18	0.15	0.19	5.39	1302	163	109	241	5	39	185
	2006	0.08	0.10	0.13	0.12	0.20	5.30	1208	97	119	153	6	37	219
	2007	0.07	0.08	0.14	0.13	0.26	5.28	1293	91	106	174	7	24	163
	2008	0.07	0.08	0.09	0.16	0.22	5.33	1165	80	93	101	5	22	172
	2009	0.05	0.06	0.11	0.06	0.10	5.40	1155	63	71	126	5	22	-
	2010	0.11	0.08	0.15	0.06	0.08	5.35	913	101	75	141	4	23	42
	2011	0.11	0.07	0.14	0.12	0.20	5.34	1535	168	100	216	7	28	97
	2012	0.03	0.07	0.14	0.11	0.23	5.41	769	20	56	105	3	17	215
	2013	0.04	0.05	0.14	0.09	0.10	5.39	1148	49	60	164	5	16	137
	2014	0.14	0.08	0.11	0.19	0.25	5.06	893	128	74	94	9	27	123
	2015	0.05	0.07	0.09	0.17	0.24	5.26	1444	65	106	134	8	14	137
	2016	0.05	0.07	0.09	0.09	0.13	5.24	1031	55	73	93	6	19	87
	2017	0.04	0.05	0.10	0.10	0.16	5.34	1318	50	72	125	5	21	62
	2018	0.05	0.07	0.09	0.09	0.10	5.36	1192	58	81	107	4	20	72
Karpdalen	1991	0.91	0.16	0.14	0.16	0.28	4.33	256	233	42	36	12		
	1992	0.96	0.20	0.31	0.26	0.35	4.43	315	302	62	98	12		
	1993	0.86	0.24	0.23	0.29	0.43	4.41	258	223	61	59	10		
	1994	0.60	0.23	0.18	0.15	0.21	4.58	414	250	96	73	11		
	1995	0.63	0.19	0.18	0.35	0.31	4.52	383	241	71	69	11		
	1996	0.49	0.15	0.17	0.20	0.24	4.62	458	224	69	76	24		
	1997	0.60	0.12	0.13	0.17	0.31	4.52	264	158	31	34	8		
Karpbukt	1999	0.36	0.13	0.13	0.11	0.13	4.74	551	198	72	73	10		
	2000	0.38	0.10	0.10	0.11	0.20	4.66	507	193	52	52	11		
	2001	0.40	0.09	0.11	0.14	0.21	4.79	612	241	58	67	10		
	2002	0.25	0.18	0.30	0.15	0.04	5.10	839	208	155	255	7		
	2003	0.27	0.09	0.11	0.18	0.29	4.88	582	158	54	66	8		
	2004	0.34	0.09	0.06	0.19	0.22	4.85	613	208	56	35	9		
	2005	0.42	0.11	0.19	0.16	0.26	4.84	633	264	68	120	9		
	2006	0.39	0.14	0.11	0.12	0.21	4.73	506	195	71	54	9		
	2007	0.39	0.10	0.14	0.15	0.21	5.00	678	265	65	94	7		
	2008	0.37	0.12	0.12	0.19	0.29	4.83	507	186	60	60	8		
	2009	0.41	0.12	0.09	0.12	0.20	4.88	526	218	64	47	7		
	2010	0.30	0.07	0.07	0.12	0.21	4.83	595	178	45	43	9		
	2011	0.38	0.11	0.15	0.12	0.15	4.76	553	212	61	85	10		
	2012	0.20	0.07	0.13	0.12	0.21	4.91	593	117	44	76	7		
	2013	0.33	0.09	0.16	0.25	0.44	4.93	516	170	44	84	6		
	2014	0.40	0.11	0.15	0.18	0.21	4.84	571	229	64	88	14		

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S	NO_3-N	NH_4-N	Ca	Mg	pH		SO_4-S	NO_3-N	NH_4-N	H+	S	N
		mg/l	mg/l	mg/l	mg/l	mg/l		mm	mg/m²	mg/m²	mg/m²	mekv/m²	mg/m²	mg/m²
Karpbukt	2015	0.29	0.08	0.11	0.19	0.23	4.87	403	116	33	46	5		
(cont.)	2016	0.27	0.07	0.12	0.13	0.25	4.87	693	185	51	84	13		
	2017	0.27	0.08	0.16	0.16	0.20	4.95	594	159	46	96	11		
	2018	0.32	0.10	0.21	0.16	0.14	4.91	567	181	58	118	12		
Svanvik	1987	0.68	0.12	0.21	0.13	0.10	4.49	365	247	42	76	12	711	173
	1988	0.57	0.13	0.13	0.18	0.14	4.49	390	221	52	50	13	602	160
	1989	0.72	0.12	0.10	0.19	0.12	4.47	424	306	50	42	14	571	130
	1990	0.48	0.13	0.08	0.11	0.13	4.50	266	127	36	22	8	691	123
	1991	0.56	0.14	0.16	0.08	0.09	4.55	389	218	55	61	11	652	139
	1992	0.51	0.12	0.22	0.10	0.10	4.71	432	220	53	93	8	422	165
	1993	0.62	0.16	0.23	0.16	0.14	4.66	331	207	52	78	7	530	135
	1994	0.58	0.17	0.35	0.12	0.12	4.71	379	219	66	132	7	541	111
	1995	0.59	0.11	0.19	0.13	0.13	4.62	395	233	45	74	9	642	133
	1996	0.44	0.16	0.22	0.22	0.17	4.73	352	154	57	76	7	471	125
	1997	0.48	0.14	0.29	0.20	0.14	4.79	278	134	39	82	4	637	145
	1998	0.50	0.13	0.27	0.13	0.15	4.74	346	168	44	89	6	947	157
	1999	0.36	0.13	0.18	0.08	0.07	4.86	463	164	59	84	6	444	175
	2000	0.52	0.15	0.24	0.11	0.10	4.69	436	222	64	106	9	388	159
	2001	0.65	0.13	0.30	0.15	0.14	4.90	374	239	50	114	5	461	
	2002	0.45	0.11	0.30	0.20	0.24	4.96	425	190	45	129	5	569	
	2003	0.33	0.13	0.27	0.17	0.16	4.97	371	121	47	99	4		
	2004-2008													
	2009	0.82	0.14	0.16	0.13	0.09	4.40	323	257	44	51	13		
	2012	0.32	0.09	0.08	0.10	0.08	4.86	522	169	47	43	7		
	2013-2017													
	2018	0.33	0.12	0.08	0.12	0.11	4.83	356	117	42	29	15		
Ny-Ålesund	1981	0.24	0.05	0.05	1.03	0.41	5.11	366	88	20	17	3		
(tørr-														
avsetning	1982	0.39	0.08	0.05	0.92	2.01	5.01	206	80	16	10	2		
fra Zeppelin)	1983	0.25	0.05	0.10	0.40	0.42	5.13	237	59	11	24	2		
	1984	0.64	0.17	0.21	0.71	0.93	4.60	366	233	62	76	9		
	1985	0.61	0.14	0.13	0.71	1.29	4.72	237	144	33	31	5		
	1986	0.40	0.07	0.49	0.55	0.58	4.98	306	122	20	150	3		
	1987	0.69	0.12	0.10	0.64	0.91	4.63	390	271	46	40	9		
	1988	0.27	0.07	0.21	0.54	0.58	5.18	307	84	21	64	2		
	1989	0.38	0.05	0.06	0.87	1.48	5.55	295	113	15	19	1	35	
	1990	0.33	0.07	0.06	0.52	0.79	4.92	410	137	30	26	5	41	20
	1991	0.34	0.11	0.10	0.80	1.13	4.96	424	145	47	44	5	35	27
	1992	0.43	0.10	0.11	0.80	1.03	5.11	272	116	27	29	2	31	21

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S	NO_3-N	NH_4-N	Ca	Mg	pH		SO_4-S	NO_3-N	NH_4-N	H+	S	N
		mg/l	mg/l	mg/l	mg/l	mg/l		mm	mg/m^2	mg/m^2	mg/m^2	mekv/m^2	mg/m^2	mg/m^2
Ny-Ålesund (tørr-	1993	0.29	0.10	0.08	0.51	0.91	5.02	489	140	47	41	5	32	29
avsetning	1994	0.32	0.08	0.29	0.59	0.63	5.35	280	90	22	80	1	24	30
fra Zeppelin)	1995	0.30	0.10	0.15	0.89	0.79	5.26	238	71	23	36	1	25	
(cont)	1996	0.36	0.13	0.32	0.56	0.90	4.92	504	181	64	162	6	26	
	1997	0.34	0.10	0.44	1.46	2.98	5.60	320	109	32	139	8	27	
	1998	0.27	0.13	0.19	0.78	1.18	5.24	193	42	24	35	1	31	
	1999	0.31	0.19	0.21	1.06	1.30	5.04	227	61	43	50	2	29	
	2000	0.16	0.08	0.10	0.47	0.49	5.37	423	63	32	42	2	24	
	2001	0.15	0.08	0.07	0.56	0.83	5.35	358	52	27	24	2	35	
	2002	0.10	0.08	0.11	1.31	1.34	5.41	544	53	44	61	2	30	
	2003	0.26	0.11	0.12	1.67	2.21	5.50	207	53	23	25	1	32	
	2004	0.23	0.12	0.10	0.93	1.01	5.13	253	57	29	25	2	26	
	2005	0.19	0.09	0.09	1.28	0.89	5.45	212	40	19	18	1	32	
	2006	0.20	0.08	0.18	1.21	1.19	5.43	341	70	27	61	1	22	
	2007	0.19	0.05	0.12	0.79	1.11	5.89	304	59	14	37	1	19	
	2008	0.11	0.1	0.26	1.09	0.8	5.74	282	32	28	72	1	22	
	2009	0.13	0.09	0.05	0.35	0.44	5.45	219	28	20	11	0.8	21	
	2010	0.11	0.11	0.2	0.51	1.21	5.23	211	23	22	42	1.2	18	
	2011	0.07	0.08	0.3	0.56	1	5.51	294	21	24	89	0.9	25	
	2012	0.06	0.06	0.05	0.3	0.47	5.51	373	23	22	17	1.1	20	
	2013	0.10	0.07	0.09	0.47	0.63	5.38	268	27	18	24	1.1	19	
	2014	0.47	0.09	0.08	0.44	0.6	4.78	311	145	29	25	16.6	35	
	2015	0.11	0.1	0.09	0.55	0.79	5.12	356	40	36	30	2.7	16	
	2016	0.07	0.06	0.08	0.30	0.48	5.49	490	36	28	38	3.2	16	
	2017	0.13	0.09	0.07	0.37	0.53	5.20	313	40	27	22	6.3	31	
	2018	0.10	0.07	0.06	0.29	0.46	5.39	484	49	33	31	4.1	14	

Table A.1.21b: Volume weighted annual mean concentrations and wet deposition of main components in precipitation and estimated dry deposition of sulfur and nitrogen at Norwegian background stations which has been closed down.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S	NO_3-N	NH_4-N	Ca	Mg	pH		SO_4-S	NO_3-N	NH_4-N	H+	S	N
		mg/l	mg/l	mg/l	mg/l	mg/l		mm	mg/m²	mg/m²	mg/m²	mekv/m²	mg/m²	mg/m²
Lista	1973	1.01				1.31	4.33	851	860			40		
	1974	1.06				1.00	4.28	1208	1280			63		
	1975	1.10				1.06	4.30	1109	1220			56		
	1976	1.37				1.21	4.23	922	1263			54		
	1977	0.95				1.09	4.34	1114	1058			51		
	1978	1.01	0.50	0.45	0.51	1.07	4.27	931	940	466	419	50		
	1979	1.27	0.63	0.57	0.53	1.04	4.09	1157	1469	729	659	94		
	1980	1.05	0.59	0.54	0.47	1.00	4.22	953	1001	562	515	57		
	1981	0.90	0.47	0.50	0.60	1.36	4.34	1037	933	487	519	47		
	1982	1.09	0.65	0.60	0.85	1.82	4.29	1070	1161	699	645	55		
	1983	0.88	0.49	0.40	0.77	1.69	4.36	1198	1051	584	480	53		
	1984	0.92	0.61	0.47	0.86	2.12	4.28	1002	923	613	474	53		
	1985	1.11	0.80	0.68	0.76	1.74	4.20	996	1110	793	681	63		
	1986	0.95	0.63	0.57	1.06	2.66	4.30	1293	1230	816	739	65		
	1987	0.86	0.55	0.55	0.65	1.48	4.35	1169	1004	647	638	52		
	1988	0.75	0.67	0.57	0.82	2.02	4.28	1585	1189	1054	895	84		
	1989	0.83	0.86	0.52	1.21	3.23	4.30	1053	877	904	552	53		
	1990	0.74	0.55	0.42	1.07	3.01	4.38	1565	1156	856	653	65		
	1991	0.75	0.83	0.60	1.36	3.76	4.32	1031	771	858	615	49		
	1992	0.72	0.60	0.41	1.02	2.54	4.38	1376	985	826	561	57		
	1993	0.81	0.80	0.68	2.10	1.79	4.39	845	686	673	579	34		
	1994	0.56	0.57	0.52	0.91	2.37	4.56	1180	659	678	615	33		
	1995	0.67	0.73	0.62	1.15	3.05	4.48	896	599	658	555	30		
	1996	0.62	0.74	0.67	0.88	2.20	4.42	910	564	673	607	35		
	1997	0.55	0.55	0.56	0.94	2.54	4.52	1219	666	666	682	37		
	1998	0.59	0.62	0.53	0.97	2.44	4.46	1240	637	767	661	43		
	1999	0.44	0.60	0.48	1.11	3.00	4.63	1273	547	762	614	30		
	2000	0.45	0.64	0.49	1.28	3.45	4.54	1651	711	1064	808	47		
	2001	0.45	0.59	0.55	0.63	1.55	4.77	1428	639	847	787	24		
	2002	0.47	0.71	0.56	0.99	2.18	4.69	1132	534	808	628	23		
Søgne	1989	1.12	0.93	0.91	0.31	0.43	4.34	1151	1289	1067	1050	53	212	
	1990	0.79	0.60	0.48	0.25	0.52	4.33	1807	1425	1084	872	85	237	612
	1991	0.94	0.66	0.58	0.23	0.47	4.30	1133	1063	750	662	57	245	559
	1992	0.79	0.59	0.49	0.19	0.34	4.33	1280	1011	752	623	60	192	365
	1993	0.95	0.71	0.63	0.26	0.26	4.33	1112	1061	786	699	52	148	326
	1994	0.76	0.62	0.54	0.19	0.31	4.39	1441	1092	894	781	58	173	349
	1995	0.61	0.54	0.45	0.19	0.34	4.45	1213	735	651	552	43	151	350
	1996	0.87	0.75	0.69	0.31	0.36	4.32	1044	910	786	725	50	175	305
	1997	0.67	0.60	0.63	0.20	0.34	4.46	1215	809	733	760	42	123	304
	1998	0.70	0.60	0.55	0.24	0.39	4.45	1333	939	812	740	45	110	268
	1999	0.63	0.57	0.50	0.21	0.34	4.50	1667	1 053	947	840	53	112	249
	2000	0.47	0.54	0.48	0.21	0.38	4.53	2029	980	1100	975	60	96	245
	2001	0.48	0.52	0.47	0.14	0.21	4.61	1569	756	816	737	38	106	
	2002	0.44	0.42	0.34	0.20	0.28	4.64	1608	704	679	552	37	114	
	2003	0.59	0.68	0.68	0.29	0.28	4.59	1271	749	863	865	32	101	
	2004	0.43	0.47	0.45	0.24	0.36	4.72	1601	697	760	717	30	89	
	2005	0.46	0.59	0.55	0.28	0.44	4.64	1176	535	700	644	27	99	
	2006	0.41	0.52	0.41	0.23	0.37	4.68	1714	707	884	707	35	156	
	2007	0.31	0.43	0.29	0.23	0.40	4.80	1237	379	538	362	20	70	
	2008	0.36	0.40	0.35	0.28	0.54	4.83	1697	610	676	601	25	62	
	2009	0.36	0.47	0.43	0.25	0.38	4.77	1633	592	763	699	27	63	
Skreådalen	1973	0.50				0.19	4.60	2185	1093			55		
	1974	0.55				0.18	4.47	2460	1350			83		
	1975	0.57	0.18	0.17		0.19	4.55	2436	1389	438	414	69		
	1976	0.60	0.24	0.23		0.17	4.55	1687	1012	405	388	48		
	1977	0.57	0.27	0.28	0.15	0.13	4.55	2057	1174	550	569	57		
	1978	0.49	0.20	0.26	0.20	0.29	4.52	1769	867	354	460	53		
	1979	0.61	0.26	0.28	0.16	0.14	4.33	2311	1410	601	647	108		
	1980	0.48	0.21	0.21	0.15	0.17	4.54	1949	936	409	409	56		

Table A.1.21b, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual	Annual total wet deposition				Dry deposition	
		SO_4-S	NO_3-N	NH_4-N	Ca	Mg	pH	precip	SO_4-S	NO_3-N	NH_4-N	H+	S	N
		mg/l	mg/l	mg/l	mg/l	mg/l		mm	mg/m²	mg/m²	mg/m²	mekv/m²	mg/m²	mg/m²
Skreådalen	1981	0.49	0.20	0.28	0.16	0.18	4.58	2260	1107	452	633	59		
cont.	1982	0.57	0.28	0.37	0.17	0.22	4.52	2519	1436	709	933	76		
	1983	0.43	0.19	0.26	0.18	0.23	4.70	2843	1221	551	734	57		
	1984	0.46	0.24	0.23	0.16	0.21	4.59	1762	802	415	401	46		
	1985	0.59	0.32	0.33	0.15	0.12	4.48	1895	1117	610	616	63		
	1986	0.53	0.29	0.30	0.15	0.19	4.51	2439	1289	698	734	75		
	1987	0.47	0.28	0.29	0.14	0.16	4.54	1639	767	451	471	48	152	
	1988	0.41	0.28	0.28	0.12	0.14	4.55	2255	926	622	632	64	153	
	1989	0.43	0.28	0.28	0.15	0.20	4.56	2519	1087	704	696	70	143	355
	1990	0.39	0.23	0.22	0.13	0.26	4.61	3346	1293	775	732	82	170	415
	1991	0.41	0.27	0.25	0.15	0.24	4.61	2172	894	583	547	53	125	279
	1992	0.37	0.24	0.23	0.12	0.16	4.70	2728	1017	647	627	55	118	254
	1993	0.29	0.22	0.25	0.30	0.56	4.81	2006	586	437	493	31	82	256
	1994	0.38	0.28	0.31	0.31	0.25	4.77	2214	842	619	695	37	104	330
	1995	0.30	0.24	0.24	0.16	0.21	4.75	2083	624	510	500	37	96	257
	1996	0.30	0.28	0.31	0.14	0.12	4.78	1463	438	404	455	25	91	329
	1997	0.25	0.23	0.29	0.21	0.33	4.92	2071	508	472	609	25	73	280
	1998	0.32	0.27	0.31	0.17	0.15	4.83	1961	636	525	621	29	53	254
	1999	0.25	0.23	0.24	0.14	0.23	4.93	2521	618	583	606	30	60	229
	2000	0.23	0.24	0.25	0.14	0.21	4.90	2997	671	705	750	37	58	225
	2001	0.23	0.23	0.33	0.12	0.11	5.10	1887	424	435	619	15	56	260
	2002	0.22	0.23	0.35	0.19	0.20	5.17	1996	443	461	698	14	63	270
	2003	0.24	0.26	0.28	0.14	0.14	4.89	2115	501	545	600	27	48	165
	2004	0.16	0.19	0.21	0.14	0.15	5.07	2531	401	487	528	22	50	239
Valle	1990	0.40	0.27	0.20	0.07	0.11	4.51	1504	607	409	306	46		
	1991	0.47	0.32	0.25	0.14	0.10	4.52	912	432	287	227	28		
	1992	0.46	0.28	0.22	0.13	0.10	4.59	1120	519	318	242	29		
	1993	0.42	0.26	0.23	0.19	0.27	4.66	1052	445	276	243	23		
	1994	0.49	0.37	0.30	0.17	0.11	4.58	1230	608	461	373	32		
	1995	0.33	0.28	0.20	0.13	0.11	4.63	926	303	256	183	22		
	1996	0.38	0.33	0.25	0.17	0.07	4.60	836	316	273	206	21		
	1997	0.30	0.26	0.20	0.12	0.11	4.70	1085	323	280	220	22		
	1998	0.33	0.28	0.29	0.09	0.05	4.67	1179	393	330	336	25		
	1999	0.28	0.22	0.15	0.08	0.07	4.74	1284	335	281	192	23		
	2000	0.26	0.29	0.24	0.10	0.07	4.70	1618	422	467	395	32		
Solhomfjell	1991	0.63	0.44	0.40	0.14	0.08	4.44	878	552	389	355	32		
	1992	0.69	0.47	0.39	0.12	0.07	4.44	958	662	447	376	35		
	1993	0.66	0.45	0.38	0.15	0.08	4.47	920	611	412	347	31		
	1994	0.60	0.48	0.38	0.12	0.06	4.50	1150	686	550	442	36		
	1995	0.55	0.45	0.43	0.14	0.08	4.51	1073	590	484	464	33		
	1996	0.61	0.45	0.41	0.17	0.07	4.46	908	551	410	377	31		
Møsvatn	1993	0.28	0.22	0.14	0.07	0.07	4.69	699	194	155	99	14		
	1994	0.32	0.27	0.17	0.07	0.02	4.66	788	250	209	136	17		
	1995	0.28	0.22	0.14	0.06	0.02	4.65	660	186	147	92	15		
	1996	0.30	0.27	0.21	0.07	0.02	4.66	592	178	161	126	13		
	1997	0.21	0.22	0.18	0.08	0.03	4.77	705	150	155	129	12		
	1998	0.24	0.20	0.15	0.07	0.02	4.79	783	188	154	114	13		
	1999	0.22	0.21	0.16	0.08	0.03	4.89	777	171	169	125	10		
	2000	0.19	0.21	0.16	0.06	0.03	4.79	1000	189	212	159	16		
Lardal	1990	0.70	0.45	0.35	0.09	0.07	4.33	1340	938	599	469	62	99	199
	1991	0.72	0.47	0.36	0.12	0.08	4.38	847	609	401	306	35	144	231
	1992	0.68	0.47	0.38	0.13	0.07	4.42	892	610	421	338	34	91	154
	1993	0.65	0.42	0.32	0.09	0.05	4.45	967	625	402	313	35	66	134
	1994	0.52	0.45	0.35	0.08	0.05	4.53	1216	631	542	429	36	78	159
	1995	0.65	0.47	0.42	0.11	0.09	4.42	1179	764	556	497	45		
	1996	0.50	0.36	0.29	0.11	0.06	4.49	940	472	341	269	30		
	1997	0.58	0.45	0.43	0.31	0.17	4.61	640	373	288	276	16		
	1998	0.52	0.42	0.36	0.12	0.07	4.50	975	505	414	362	31		
	1999	0.43	0.36	0.31	0.08	0.05	4.61	1371	581	492	424	33		
	2000	0.39	0.38	0.30	0.09	0.09	4.54	1809	703	693	550	53		
	2001	0.36	0.33	0.31	0.09	0.05	4.71	1224	442	408	381	24		
	2002	0.34	0.25	0.25	0.10	0.04	4.82	1142	383	285	288	17		

Table A.1.21b, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual	Annual total wet deposition				Dry deposition	
		SO_4-S	NO_3-N	NH_4-N	Ca	Mg	pH	precip	SO_4-S	NO_3-N	NH_4-N	H+	S	N
		mg/l	mg/l	mg/l	mg/l	mg/l		mm	mg/m²	mg/m²	mg/m²	mekv/m²	mg/m²	mg/m²
Prestebakke	1986	1.08	0.54	0.47	0.23	0.19	4.20	699	753	380	328	44		
	1987	0.78	0.42	0.37	0.16	0.08	4.37	830	650	349	307	35	212	343
	1988	0.77	0.47	0.37	0.16	0.15	4.25	989	758	466	370	55	219	307
	1989	0.97	0.69	0.47	0.18	0.21	4.22	697	678	478	330	42	191	301
	1990	0.87	0.57	0.42	0.18	0.18	4.28	816	710	465	342	42	157	252
	1991	0.79	0.55	0.43	0.20	0.25	4.37	805	638	445	346	35	98	190
	1992	0.83	0.60	0.47	0.16	0.15	4.35	832	687	497	392	37	140	154
	1993	0.74	0.47	0.36	0.17	0.13	4.41	775	573	364	278	30	119	228
	1994	0.53	0.39	0.24	0.17	0.13	4.48	892	477	352	216	29	138	234
	1995	0.65	0.54	0.46	0.18	0.17	4.45	746	487	406	346	26	126	
	1996	0.64	0.56	0.43	0.27	0.18	4.42	656	419	368	283	25	126	
	1997	0.42	0.39	0.29	0.08	0.06	4.52	813	338	317	237	24	97	
	1998	0.53	0.45	0.38	0.32	0.20	4.66	842	449	377	328	18	77	
	1999	0.50	0.48	0.34	0.15	0.17	4.52	1182	590	564	394	36	90	
	2000	0.36	0.40	0.30	0.20	0.15	4.60	1181	449	474	351	30	84	
Fagernes	1990	0.41	0.22	0.16	0.10	0.02	4.53	550	228	119	86	16		
	1991	0.38	0.21	0.24	0.22	0.04	4.75	395	150	84	94	7		
	1992	0.43	0.24	0.19	0.10	0.01	4.63	656	279	160	126	15		
	1993	0.26	0.15	0.12	0.08	0.02	4.77	619	162	95	74	10		
	1994	0.28	0.25	0.15	0.08	0.02	4.70	586	166	146	88	12		
	1995	0.32	0.22	0.29	0.14	0.07	4.81	465	151	101	134	7		
	1996	0.25	0.23	0.20	0.17	0.03	4.78	635	159	145	124	11		
	1997	0.21	0.15	0.16	0.09	0.02	4.89	565	116	83	92	6		
	1998	0.21	0.17	0.16	0.13	0.03	4.87	583	125	97	92	8		
	1999	0.20	0.18	0.12	0.08	0.01	4.86	633	125	113	75	9		
	2000	0.19	0.19	0.19	0.10	0.02	4.85	757	150	147	145	11		
	2001	0.16	0.16	0.14	0.12	0.02	5.01	649	103	104	92	6		
	2002	0.19	0.15	0.15	0.13	0.02	4.99	632	119	94	96	6		
Osen	1988	0.53	0.31	0.26	0.13	0.02	4.43	832	442	254	215	31	139	
	1989	0.52	0.27	0.15	0.14	0.03	4.47	786	410	214	122	27	95	145
	1990	0.55	0.28	0.27	0.23	0.03	4.48	711	393	198	192	23	90	123
	1991	0.34	0.26	0.20	0.08	0.02	4.58	647	222	168	129	17	77	107
	1992	0.44	0.37	0.18	0.13	0.02	4.55	725	318	207	133	20	68	103
	1993	0.37	0.26	0.18	0.10	0.02	4.62	764	283	195	140	18	53	94
	1994	0.30	0.27	0.19	0.08	0.02	4.69	636	192	172	120	13	69	112
	1995	0.44	0.27	0.26	0.12	0.03	4.59	612	271	167	157	16	62	108
	1996	0.32	0.26	0.26	0.14	0.03	4.71	574	183	147	151	11	64	112
	1997	0.22	0.20	0.18	0.10	0.02	4.83	708	158	139	126	11	48	108
	1998	0.30	0.23	0.24	0.09	0.02	4.77	655	198	152	155	11	35	97
	1999	0.26	0.24	0.20	0.08	0.02	4.83	750	191	182	149	11	46	114
	2000	0.22	0.20	0.17	0.06	0.03	4.72	971	229	198	165	18	38	118
	2001	0.20	0.20	0.20	0.07	0.01	4.95	768	150	152	153	9	38	137
	2002	0.25	0.19	0.25	0.11	0.03	4.91	738	182	140	184	9	44	157
	2003	0.20	0.22	0.20	0.09	0.02	4.87	661	135	146	133	9	41	138
Valdalen	1994	0.32	0.29	0.19	0.10	0.03	4.70	536	172	153	103	11		
	1995	0.43	0.30	0.37	0.13	0.04	4.68	518	221	153	194	11		
	1996	0.27	0.20	0.29	0.11	0.03	4.91	724	193	142	211	9		
	1997	0.26	0.21	0.22	0.13	0.03	4.89	710	185	152	154	9		
	1998	0.22	0.19	0.16	0.08	0.02	4.88	700	156	130	115	9		
	1999	0.21	0.22	0.19	0.12	0.02	5.05	692	147	150	131	8		
	2000	0.20	0.19	0.20	0.07	0.03	4.92	817	165	154	165	10		
Ualand	1992	0.49	0.30	0.22	0.16	0.31	4.53	2404	1171	714	530	71		
	1993	0.49	0.32	0.24	0.22	0.56	4.53	1531	745	492	365	46		
	1994	0.52	0.38	0.30	0.15	0.33	4.51	2125	1106	802	630	65		
	1995	0.45	0.37	0.27	0.14	0.31	4.51	1838	824	682	499	57		
	1996	0.40	0.32	0.24	0.14	0.23	4.54	1561	631	496	375	45		
	1997	0.44	0.33	0.32	0.19	0.36	4.58	1948	855	648	622	51		
	1998	0.47	0.38	0.29	0.16	0.31	4.52	1992	928	761	584	59		
	1999	0.32	0.30	0.20	0.16	0.37	4.65	2487	798	736	509	55		
	2000	0.31	0.31	0.21	0.19	0.41	4.65	2681	819	832	572	61		

Table A.1.21b, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual	Annual total wet deposition				Dry deposition	
		SO_4-S	NO_3-N	NH_4-N	Ca	Mg	pH	precip	SO_4-S	NO_3-N	NH_4-N	H+	S	N
		mg/l	mg/l	mg/l	mg/l	mg/l		mm	mg/m²	mg/m²	mg/m²	mekv/m²	mg/m²	mg/m²
Voss	1990	0.29	0.15	0.08	0.10	0.15	4.68	2053	595	300	169	43		
	1991	0.28	0.18	0.11	0.10	0.18	4.67	1214	342	213	130	26		
	1992	0.27	0.16	0.07	0.06	0.07	4.70	1627	436	255	110	32		
	1993	0.24	0.13	0.08	0.16	0.31	4.82	1162	282	148	96	17		
	1994	0.28	0.16	0.12	0.21	0.14	4.79	1473	408	234	178	24		
	1995	0.21	0.14	0.12	0.08	0.11	4.82	1439	303	208	168	22		
	1996	0.26	0.20	0.19	0.08	0.05	4.76	869	222	174	163	15		
	1997	0.22	0.15	0.24	0.16	0.34	5.00	1275	220	181	152	17		
	1998	0.18	0.14	0.11	0.06	0.10	4.87	1411	250	204	159	19		
	1999	0.18	0.13	0.09	0.06	0.11	4.88	1641	178	211	157	22		
	2000	0.16	0.14	0.12	0.08	0.13	4.91	1844	296	249	214	23		
	2001	0.15	0.13	0.11	0.06	0.07	5.02	1256	183	164	137	12		
	2002	0.18	0.14	0.13	0.08	0.10	4.92	1078	191	149	140	13		
Selbu	1990	0.16	0.06	0.02	0.06	0.10	4.84	1339	220	83	31	19		
	1991	0.18	0.09	0.06	0.11	0.22	4.94	1336	240	125	80	15		
	1992	0.14	0.07	0.03	0.11	0.20	4.95	1402	193	103	45	16		
	1993	0.15	0.09	0.06	0.11	0.17	5.01	1290	193	117	80	13		
	1994	0.16	0.09	0.11	0.07	0.12	5.02	1143	179	105	129	11		
	1995	0.15	0.08	0.12	0.08	0.13	5.01	1411	206	113	166	14		
	1996	0.13	0.08	0.13	0.19	0.18	5.15	1039	132	86	131	7		
	1997	0.11	0.06	0.10	0.16	0.20	5.26	1682	183	105	172	9		
	1998	0.10	0.06	0.10	0.09	0.13	5.20	1333	139	80	131	8		
	1999	0.10	0.07	0.06	0.09	0.10	5.17	1303	133	93	82	9		
	2000	0.14	0.08	0.09	0.15	0.26	5.11	1138	162	87	98	9		
	2001	0.11	0.05	0.06	0.15	0.22	5.19	1540	166	84	86	10		
Namsvatn	1991	0.18	0.11	0.20	0.08	0.12	5.13	1014	181	115	198	8		
	1992	0.14	0.10	0.12	0.12	0.19	5.12	1081	155	105	129	8		
	1993	0.14	0.10	0.17	0.15	0.16	5.20	1004	144	98	172	6		
	1994	0.14	0.10	0.17	0.29	0.11	5.18	902	129	94	152	6		
	1995	0.16	0.10	0.20	0.11	0.15	5.18	1201	188	121	243	8		
	1996	0.17	0.12	0.20	0.11	0.11	5.10	697	117	86	139	6		
Øverbygd	1987*	0.23	0.05	0.08	0.12	0.14	4.92	424	100	23	35	5		
	1988	0.20	0.06	0.05	0.09	0.10	4.84	555	112	33	30	8		
	1989	0.16	0.06	0.06	0.09	0.18	4.98	794	125	45	51	8		
	1990	0.22	0.06	0.07	0.10	0.15	4.90	708	152	44	52	9		
	1991	0.25	0.09	0.07	0.11	0.18	4.90	706	176	60	49	9		
	1992	0.17	0.07	0.06	0.12	0.18	5.08	662	109	44	38	6		
	1993	0.17	0.07	0.07	0.26	0.43	5.06	680	117	48	45	6		
	1994	0.20	0.10	0.13	0.12	0.14	5.03	538	108	56	68	5		
	1995	0.11	0.06	0.11	0.14	0.11	5.13	659	73	42	74	5		
	1996	0.14	0.07	0.10	0.10	0.15	5.01	527	72	35	52	5		
	1997	0.10	0.06	0.11	0.16	0.28	5.13	603	59	37	69	4		
	1998	0.13	0.05	0.06	0.08	0.07	5.13	576	73	32	34	4		
	1999	0.13	0.05	0.07	0.06	0.07	5.13	811	103	44	53	6		
	2000	0.10	0.04	0.05	0.06	0.09	5.18	750	76	33	39	5		
	2001	0.11	0.04	0.05	0.09	0.15	5.24	721	75	30	38	4		
	2002	0.12	0.05	0.07	0.15	0.15	5.30	654	79	33	47	3		
	2003	0.07	0.04	0.08	0.14	0.16	5.25	907	65	40	72	5		
	2004	0.10	0.04	0.05	0.08	0.10	5.23	818	82	35	44	5		
	2005	0.16	0.06	0.14	0.08	0.06	5.26	745	118	43	105	4		
	2006	0.11	0.07	0.10	0.10	0.15	5.26	671	76	47	68	4		
Jergul	1977	0.45	0.13	0.11	0.20	0.04	4.75	344	155	45	38	6		
	1978	0.43	0.10	0.11	0.13	0.02	4.52	351	151	35	39	11		
	1979	0.59	0.18	0.13	0.14	0.03	4.33	306	181	55	40	14		
	1980	0.42	0.12	0.09	0.12	0.03	4.57	262	110	31	24	7		
	1981	0.46	0.13	0.12	0.11	0.02	4.57	434	200	56	52	12		
	1982	0.36	0.13	0.14	0.10	0.03	4.65	473	172	62	65	11		
	1983	0.41	0.11	0.11	0.13	0.04	4.60	382	156	41	43	10		
	1984	0.50	0.15	0.22	0.14	0.03	4.50	342	172	50	76	11		
	1985	0.43	0.12	0.34	0.13	0.05	4.63	406	174	49	137	10		
	1986	0.49	0.16	0.14	0.12	0.04	4.60	250	122	40	34	6		
	1987	0.41	0.12	0.10	0.11	0.03	4.67	296	121	35	29	6	180	

Table A.1.21b, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m^2	NO_3-N mg/m^2	NH_4-N mg/m^2	H+ mekv/m^2	S mg/m^2	N mg/m^2
Jergul	1988	0.30	0.13	0.10	0.09	0.03	4.65	406	122	54	40	9	134	81
cont.	19T89	0.42	0.14	0.15	0.09	0.03	4.63	385	163	54	59	9	77	66
	1990	0.22	0.15	0.08	0.04	0.03	4.69	276	62	41	23	6	114	68
	1991	0.31	0.14	0.10	0.05	0.03	4.65	377	118	51	37	8	108	100
	1992	0.23	0.13	0.05	0.08	0.03	4.80	449	101	60	22	7	92	66
	1993	0.29	0.14	0.07	0.11	0.06	4.74	343	99	47	22	6	97	53
	1994	0.24	0.15	0.07	0.06	0.03	4.78	269	65	41	17	4	65	58
	1995	0.25	0.11	0.07	0.06	0.03	4.76	459	116	49	32	8	94	62
	1996	0.18	0.12	0.10	0.14	0.06	4.91	310	56	38	29	4	63	53
Karasjok**	1997	0.15	0.11	0.13	0.10	0.06	5.03	212	32	23	27	9	81	45
	1998	0.35	0.14	0.16	0.09	0.03	4.81	354	124	50	59	6	131	61
	1999	0.20	0.12	0.13	0.07	0.02	5.04	410	76	50	56	4	75	53
	2000	0.25	0.11	0.13	0.07	0.03	4.97	303	68	34	40	3	70	67
	2001	0.24	0.13	0.23	0.11	0.04	5.22	366	82	49	83	2	60	57
	2002	0.21	0.13	0.19	0.12	0.06	5.11	297	62	38	57	2	49	40
	2003	0.18	0.14	0.18	0.12	0.07	5.12	307	56	43	55	2	55	53
	2004	0.20	0.13	0.16	0.11	0.04	5.14	332	65	43	54	2	54	62
	2005	0.24	0.13	0.16	0.08	0.03	5.12	410	98	54	64	3	66	63
	2006	0.22	0.17	0.21	0.12	0.05	5.14	351	77	59	74	3	57	74
	2007	0.20	0.13	0.18	0.13	0.06	5.15	398	78	81	73	3	38	38
	2008	0.17	0.14	0.14	0.26	0.07	5.22	372	64	53	52	2	42	43
	2009	0.32	0.13	0.16	0.19	0.06	5.14	345	111	45	56	2	49	53
Andøya	2011	0.06	0.08	0.16	0.24	0.61	5.23	1345	75	102	212	8		
Svanvik	1987	0.68	0.12	0.21	0.13	0.10	4.49	365	247	42	76	12	711	173
	1988	0.57	0.13	0.13	0.18	0.14	4.49	390	221	52	50	13	602	160
	1989	0.72	0.12	0.10	0.19	0.12	4.47	424	306	50	42	14	571	130
	1990	0.48	0.13	0.08	0.11	0.13	4.50	266	127	36	22	8	691	123
	1991	0.56	0.14	0.16	0.08	0.09	4.55	389	218	55	61	11	652	139
	1992	0.51	0.12	0.22	0.10	0.10	4.71	432	220	53	93	8	422	165
	1993	0.62	0.16	0.23	0.16	0.14	4.66	331	207	52	78	7	530	135
	1994	0.58	0.17	0.35	0.12	0.12	4.71	379	219	66	132	7	541	111
	1995	0.59	0.11	0.19	0.13	0.13	4.62	395	233	45	74	9	642	133
	1996	0.44	0.16	0.22	0.22	0.17	4.73	352	154	57	76	7	471	125
	1997	0.48	0.14	0.29	0.20	0.14	4.79	278	134	39	82	4	637	145
	1998	0.50	0.13	0.27	0.13	0.15	4.74	346	168	44	89	6	947	157
	1999	0.36	0.13	0.18	0.08	0.07	4.86	463	164	59	84	6	444	175
	2000	0.52	0.15	0.24	0.11	0.10	4.69	436	222	64	106	9	388	159
	2001	0.65	0.13	0.30	0.15	0.14	4.90	374	239	50	114	5	461	
	2002	0.45	0.11	0.30	0.20	0.24	4.96	425	190	45	129	5	569	
	2003	0.33	0.13	0.27	0.17	0.16	4.97	371	121	47	99	4		
	2004-8													
	2009	0.82	0.14	0.16	0.13	0.09	4.40	323	257	44	51	13		
	2012	0.32	0.09	0.08	0.10	0.08	4.86	522	169	47	43	7		

Table A.1.22: Monthly and annual mean concentration of sulfur dioxide in air at Norwegian background stations. Unit: µg S/m3.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes II	0.05	0.09	0.09	0.1	0.2	0.19	0.17	0.06	0.05	0.07	0.04	0.04	0.1
Hurdal	0.02	0.07	0.06	0.03	0.07	0.04	0.07	0.02	0.07	0.03	0.01	0.01	0.04
Kårvatn	0.02	0.04	0.06	0.01	0.04	0.04	0.04	0.02	0.02	0.03	0.02	0.02	0.03
Tustervatn	0.03	0.06	0.12	0.01	0.02	0.02	0.06	0.02	0.02	0.02	0.03	0.07	0.04
Zeppelin	0.03	0.01	0.06	0.04	0.02	0.03	0.04	0.04	0.02	0.01	0.02	0.1	0.04

Table A.1.23: Monthly and annual mean concentration of sulfate in aerosol at Norwegian background stations. Unit: µg S/m3.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes II	0.18	0.35	0.38	0.24	0.31	0.28	0.35	0.23	0.21	0.26	0.24	0.12	0.26
Hurdal	0.13	0.31	0.29	0.14	0.24	0.16	0.24	0.16	0.24	0.05	0.11	0.12	0.18
Kårvatn	0.04	0.09	0.15	0.19	0.26	0.23	0.2	0.1	0.06	0.04	0.04	0.04	0.12
Tustervatn	0.17	0.22	0.16	0.09	0.21	0.15	0.17	0.1	0.07	0.08	0.05	0.07	0.13
Zeppelin	0.11	0.07	0.1	0.28	0.11	0.06	0.06	0.06	0.06	0.03	0.09	0.12	0.1

Table A.1.24: Monthly and annual mean concentration of nitrogen dioxide in air at Norwegian background stations. Unit: µg N/m3.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes II	0.27	0.5	0.35	0.36	0.31	0.3	0.3	0.26	0.23	0.31	0.39	0.29	0.32
Hurdal	0.95	1.64	0.47	0.55	0.4	0.27	0.35	0.38	0.27	0.52	0.58	0.84	0.6
Kårvatn	0.25	0.3	0.25	0.08	0.19	0.13	0.22	0.14	0.09	0.09	0.19	0.28	0.18
Tustervatn	0.2	0.15	0.14	0.07	0.08	0.07	0.19	0.07	0.04	0.06	0.1	0.12	0.11

Table A.1.25: Monthly and annual mean concentration of sum of nitrate and nitric acid in air at Norwegian background stations. Unit: µg N/m3.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes II	0.14	0.5	0.15	0.31	0.37	0.19	0.25	0.18	0.15	0.26	0.27	0.09	0.24
Hurdal	0.09	0.23	0.12	0.12	0.19	0.1	0.16	0.09	0.19	0.03	0.11	0.1	0.13
Kårvatn	0.03	0.07	0.05	0.06	0.14	0.11	0.06	0.04	0.03	0.02	0.02	0.03	0.05
Tustervatn	0.04	0.07	0.04	0.02	0.12	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.04
Zeppelin	0.03	0.02	0.03	0.04	0.03	0.03	0.02	0.04	0.02	0.03	0.02	0.03	0.03

Table A.1.26: Monthly and annual mean concentration of nitrate in aerosol at Norwegian background stations. Unit: µg N/m^3.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes II	0.12	0.48	0.11	0.26	0.21	0.12	0.15	0.14	0.11	0.23	0.25	0.07	0.19
Hurdal	0.07	0.2	0.08	0.1	0.12	0.06	0.09	0.06	0.15	0.02	0.1	0.08	0.09
Kårvatn	0.02	0.04	0.03	0.04	0.09	0.09	0.04	0.03	0.01	0.01	0.01	0.01	0.04
Tustervatn	0.03	0.05	0.03	0.01	0.1	0.03	0.03	0.02	0.01	0.02	0.01	0.01	0.03
Zeppelin	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01

Table A.1.27: Monthly and annual mean concentration of sum of ammonium and ammonia in air at Norwegian background stations. Unit: µg N/m^3.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes II	0.17	0.72	0.37	0.57	0.91	0.52	0.69	0.45	0.27	0.42	0.35	0.15	0.47
Hurdal	0.21	0.35	0.27	0.19	0.5	0.29	0.42	0.31	0.42	0.17	0.16	0.17	0.29
Kårvatn	0.37	0.58	0.47	0.52	0.91	1.18	1.17	0.7	0.43	0.24	0.31	0.37	0.6
Tustervatn	0.19	0.19	0.29	0.46	0.84	0.51	0.64	0.33	0.22	0.24	0.12	0.16	0.35
Zeppelin	0.09	0.06	0.09	0.17	0.09	0.13	0.17	0.12	0.18	0.07	0.06	0.05	0.11

Table A.1.28: Monthly and annual mean concentrations of ammonium in aerosols at Norwegian background stations. Unit: µg N/m^3.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes II	0.14	0.63	0.3	0.31	0.3	0.2	0.24	0.19	0.11	0.27	0.28	0.09	0.25
Hurdal	0.13	0.27	0.2	0.07	0.18	0.1	0.12	0.11	0.21	0.03	0.11	0.11	0.13
Kårvatn	0.02	0.06	0.08	0.12	0.14	0.11	0.09	0.03	0.02	0.02	0.01	0.01	0.06
Tustervatn	0.09	0.15	0.09	0.03	0.14	0.03	0.08	0.04	0.02	0.03	0.02	0.03	0.06
Zeppelin	0.01	0.01	0.03	0.09	0.02	0.01	0.01	0.03	0.01	0.01	0.01	0.01	0.02

Table A.1.29: Monthly and annual mean concentrations of magnesium in aerosols at Norwegian background stations. Unit: µg/m^3.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes II	0.05	0.04	0.03	0.04	0.06	0.06	0.05	0.06	0.12	0.08	0.07	0.03	0.06
Hurdal	0.01	0.01	0.01	0.02	0.03	0.02	0.03	0.02	0.04	0.01	0.02	0.01	0.02
Kårvatn	0.01	0.01	0.02	0.02	0.04	0.05	0.04	0.01	0.02	0.01	0.01	0.02	0.02
Tustervatn	0.03	0.01	0.03	0.03	0.07	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.03
Zeppelin	0.04	0.04	0.03	0.05	0.04	0.02	0.01	0.01	0.04	0.01	0.02	0.04	0.03

Table A.1.30: Monthly and annual mean concentrations of calcium in aerosols at Norwegian background stations. Unit: µg/m^3.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes II	0.02	0.02	0.03	0.08	0.17	0.07	0.07	0.04	0.05	0.05	0.04	0.01	0.05
Hurdal	0.01	0.01	0.02	0.04	0.12	0.05	0.05	0.03	0.04	0.02	0.02	0.02	0.04
Kårvatn	0.01	0.01	0.01	0.07	0.1	0.09	0.07	0.01	0.02	0.01	0.01	0.03	0.04
Tustervatn	0.02	0.01	0.01	0.03	0.06	0.02	0.03	0.02	0.02	0.01	0.01	0.01	0.02
Zeppelin	0.03	0.01	0.01	0.06	0.02	0.02	0.01	0.01	0.03	0.01	0.02	0.02	0.02

Table A.1.31: Monthly and annual mean concentrations of potassium in aerosols at Norwegian background stations. Unit: µg/m^3.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes II	0.03	0.09	0.06	0.04	0.07	0.05	0.05	0.06	0.07	0.06	0.06	0.04	0.06
Hurdal	0.06	0.06	0.05	0.04	0.04	0.02	0.04	0.03	0.06	0.03	0.04	0.06	0.05
Kårvatn	0.01	0.05	0.02	0.05	0.03	0.04	0.05	0.03	0.03	0.02	0.01	0.01	0.03
Tustervatn	0.04	0.05	0.03	0.03	0.05	0.03	0.05	0.05	0.01	0.04	0.05	0.02	0.04
Zeppelin	0.02	0.02	0.06	0.04	0.04	0.03	0.03	0.02	0.03	0.01	0.03	0.03	0.03

Table A.1.32: Monthly and annual mean concentrations of chloride in aerosols at Norwegian background stations. Unit: µg/ m^3.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes II	0.55	0.47	0.3	0.26	0.19	0.51	0.2	0.43	1.55	0.9	0.76	0.34	0.54
Hurdal	0.1	0.07	0.08	0.13	0.08	0.17	0.09	0.13	0.43	0.16	0.13	0.11	0.14
Kårvatn	0.05	0.11	0.15	0.19	0.31	0.43	0.21	0.12	0.21	0.11	0.05	0.16	0.18
Tustervatn	0.41	0.06	0.32	0.35	0.72	0.59	0.12	0.32	0.45	0.45	0.34	0.3	0.37
Zeppelin	0.48	0.52	0.33	0.42	0.54	0.23	0.14	0.15	0.43	0.18	0.31	0.45	0.35

Table A.1.33: Monthly and annual mean concentrations of sodium in aerosols at Norwegian background stations. Unit: µg/ m^3.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes II	0.38	0.36	0.29	0.3	0.32	0.48	0.36	0.43	1.04	0.64	0.57	0.25	0.45
Hurdal	0.08	0.09	0.11	0.16	0.16	0.2	0.25	0.16	0.38	0.12	0.13	0.09	0.16
Kårvatn	0.05	0.1	0.12	0.16	0.28	0.4	0.22	0.12	0.13	0.08	0.05	0.11	0.15
Tustervatn	0.27	0.08	0.25	0.23	0.5	0.37	0.14	0.22	0.28	0.28	0.21	0.19	0.25
Zeppelin	0.24	0.32	0.23	0.3	0.38	0.16	0.11	0.1	0.27	0.11	0.19	0.29	0.23

Table A.1.34a: Annual mean concentrations of sulfur and nitrogen components in air at Norwegian background stations from 1973-2018. Units μg S/m³ and μg N/m³.

Site	År	Annual mean concentrations of main components in air (μg/m³)					
		SO_2-S	SO_4-S	NO_2-N	(HNO_3+NO_3)-N	(NH_4+NH_3)-N	NH_4-N
Birkenes	1973		0.81				
	1974		1.11				
	1975		1.07				
	1976		1.27				
	1977		0.92				
	1978	1.74	1.09				
	1979	1.11	1.33				
	1980	1.42	1.41				
	1981	0.76	0.97				
	1982	0.97	1.15				
	1983	0.53	0.95				
	1984	0.65	1.27	1.17			
	1985	0.70	0.88	0.87			
	1986	0.69	0.83	1.12	0.36	0.66	
	1987	0.72	0.78	1.12	0.29	0.66	
	1988	0.63	0.75	1.26	0.28	0.63	
	1989	0.48	0.67	1.11	0.26	0.63	
	1990	0.49	0.76	1.00	0.28	0.78	
	1991	0.54	0.91	0.90	0.27	0.76	
	1992	0.40	0.65	0.69	0.24	0.53	
	1993	0.40	0.59	0.59	0.23	0.55	0.43
	1994	0.40	0.65	0.66	0.28	0.63	0.46
	1995	0.31	0.58	0.68	0.30	0.54	0.44
	1996	0.40	0.66	0.68	0.29	0.57	0.47
	1997	0.22	0.53	0.69	0.24	0.54	0.37
	1998	0.16	0.46	0.62	0.19	0.41	0.31
	1999	0.14	0.49	0.52	0.20	0.51	0.33
	2000	0.12	0.44	0.57	0.20	0.43	0.31
	2001	0.16	0.44	0.47	0.21	0.55	0.31
	2002	0.15	0.50	0.46	0.27	0.62	0.43
	2003	0.15	0.50	0.57	0.26	0.60	0.38
	2004	0.13	0.35	0.46	0.26	0.53	0.30
	2005	0.19	0.46	0.46	0.33	0.75	0.40
	2006	0.18	0.53	0.48	0.40	0.77	0.32
	2007	0.06	0.28	0.32	0.17	0.43	0.17
	2008	0.07	0.28	0.34	0.19	0.49	0.14
	2009	0.06	0.30	0.44	0.26		0.20
Birkenes II	2010	0.12	0.29	0.31	0.23		0.20
	2011	0.11	0.33	0.43	0.37	0.63	0.32
	2012	0.07	0.27	0.39	0.46	0.61	0.28
	2013	0.09	0.25	0.28	0.29	0.47	0.23
	2014	0.17	0.37	0.31	0.38	0.62	0.34
	2015	0.07	0.29	0.30	0.32	0.44	0.27
	2016	0.05	0.20	0.30	0.25	0.40	0.23

Table A.1.34a, cont.

Site	År	Annual mean concentrations of main components in air (µg/m³)					
		SO_2-S	SO_4-S	NO_2-N	(HNO_3+NO_3)-N	(NH_4+NH_3)-N	NH_4-N
Birkenes II	2017	0.06	0.22	0.27	0.15	0.27	0.13
(cont.)	2018	0.10	0.26	0.32	0.24	0.47	0.25
Nordmoen	1986	0.50	0.90	2.00	0.30	0.60	
	1987	0.60	0.80	3.30	0.40	0.70	
	1988	0.70	0.90	3.00	0.30	0.60	
	1989	0.40	0.80	2.60	0.30	0.70	
	1990	0.40	0.70	2.50	0.30	0.70	
	1991	0.30	0.80	2.60	0.20	0.60	
	1992	0.21	0.56	2.43	0.21	0.53	
	1993	0.25	0.59	2.09	0.21	0.54	0.42
	1994	0.23	0.58	2.56	0.28	0.62*	0.45
	1995	0.19	0.54	2.25	0.27	0.54	0.44
	1996	0.16	0.58	2.48	0.28	0.60	0.48
	1997			2.00			
	1998			1.64			
	1999			1.71			
Hurdal	1997	0.18	0.41	1.10		0.53	0.29
	1998	0.14	0.33	1.12	0.18	0.42	0.21
	1999	0.09	0.39	1.04	0.18	0.39	0.27
	2000	0.08	0.35	1.00	0.19	0.37	0.25
	2001	0.10	0.33		0.17	0.34	0.21
	2002	0.10	0.37		0.25	0.46	0.25
	2003	0.11	0.43		0.23	0.48	0.27
	2004	0.11	0.31	0.59	0.18	0.51	0.18
	2005	0.12	0.40	0.83	0.24	0.66	0.29
	2006	0.13	0.43	0.78	0.26	0.66	0.24
	2007	0.06	0.22	0.78	0.17	0.45	0.15
	2008	0.04	0.21	0.73	0.16	0.44	0.11
	2009	0.04	0.21	0.71	0.17		0.12
	2010	0.07	0.21	0.66	0.16		0.18
	2011	0.10	0.26	0.79	0.34	0.71	0.41
	2012	0.06	0.22	0.76	0.30	0.49	0.19
	2013	0.04	0.17	0.69	0.18	0.37	0.15
	2014	0.09	0.29	0.55	0.22	0.49	0.25
	2015	0.05	0.14	0.64	0.27	0.42	0.24
	2016	0.03	0.17	0.61	0.16	0.30	0.15
	2017	0.04	0.14	0.64	0.09	0.20	0.09
	2018	0.04	0.18	0.60	0.13	0.29	0.13
Kårvatn	1979	0.48	0.48				
	1980	0.54	0.55				
	1981	0.51	0.47				
	1982	0.29	0.40				
	1983	0.19	0.38				
	1984	0.43	0.54				
	1985	0.44	0.45				
	1986	0.39	0.43				

Table A.1.34a, cont.

Site	År	Annual mean concentrations of main components in air (µg/m³)					
		SO_2-S	SO_4-S	NO_2-N	(HNO_3+NO_3)-N	(NH_4+NH_3)-N	NH_4-N
Kårvatn	1987	0.32	0.38				
(cont.)	1988	0.34	0.40	0.56	0.07	0.44	
	1989	0.17	0.30	0.34	0.08	0.42	
	1990	0.12	0.32	0.40	0.10	0.40	
	1991	0.14	0.31	0.26	0.06	0.36	
	1992	0.12	0.30	0.19	0.06	0.37	
	1993	0.15	0.30	0.16	0.07	0.38	0.17
	1994	0.12	0.30	0.22	0.10	0.48	0.18
	1995	0.16	0.22	0.26	0.10	0.36	0.13
	1996	0.08	0.27	0.24	0.08	0.46	0.18
	1997	0.05	0.22	0.25	0.07	0.50	0.14
	1998	0.05	0.15	0.26	0.05	0.33	0.08
	1999	0.03	0.20	0.23	0.05	0.45	0.12
	2000	0.03	0.17	0.32	0.05	0.56	0.09
	2001	0.06	0.16	0.19	0.08	0.47	0.11
	2002	0.07	0.21	0.26	0.11	0.81	0.13
	2003	0.07	0.22	0.30	0.09	0.95	0.13
	2004	0.07	0.20	0.21	0.08	0.48	0.10
	2005	0.07	0.18	0.22	0.14	0.65	0.15
	2006	0.06	0.24	0.24	0.14	0.88	0.13
	2007	0.03	0.13	0.17	0.06	0.76	0.06
	2008	0.03	0.14	0.20	0.07	0.70	0.06
	2009	0.03	0.14	0.17	0.06		0.06
	2010	0.03	0.14	0.25	0.08		0.10
	2011	0.07	0.13	0.26	0.17	0.88	0.15
	2012	0.04	0.14	0.22	0.26	0.71	0.16
	2013	0.02	0.09	0.16	0.13	0.57	0.09
	2014	0.12	0.20	0.14	0.18	0.63	0.17
	2015	0.03	0.09	0.11	0.14	0.51	0.13
	2016	0.03	0.11	0.15	0.07	0.44	0.06
	2017	0.06	0.09	0.17	0.04	0.36	0.03
	2018	0.03	0.12	0.18	0.05	0.60	0.06
Tustervatn	1979	0.88	0.68				
	1980	0.63	0.70				
	1981	0.67	0.52				
	1982	0.47	0.52				
	1983	0.26	0.48				
	1984	0.71	0.73				
	1985	0.60	0.59				
	1986	0.48	0.43				
	1987	0.72	0.59				
	1988	0.67	0.54				
	1989	0.16	0.23	0.29	0.04	0.52	
	1990	0.29	0.36	0.37	0.08	0.53	
	1991	0.25	0.38	0.32	0.08	0.68	
	1992	0.15	0.28	0.26	0.07	0.54	

Table A.1.34a, cont.

Site	År	Annual mean concentrations of main components in air (µg/m³)					
		SO_2-S	SO_4-S	NO_2-N	(HNO_3+NO_3)-N	(NH_4+NH_3)-N	NH_4-N
Tustervatn	1993	0.18	0.31	0.19	0.07	0.66	0.16
(cont.)	1994	0.16	0.29	0.19	0.09	0.71	0.14
	1995	0.16	0.28	0.16	0.09	0.62	0.15
	1996	0.12	0.29	0.11	0.10	0.72	0.17
	1997	0.09	0.27	0.18	0.07	1.15	0.15
	1998	0.10	0.21	0.18	0.06	1.03	0.11
	1999	0.08	0.23	0.14	0.05	0.53	0.12
	2000	0.04	0.18	0.17	0.06	0.88	0.10
	2001	0.14	0.20	0.15	0.08	0.94	0.12
	2002	0.09	0.21	0.18	0.10	0.83	0.11
	2003	0.09	0.22	0.18	0.12	1.15	0.15
	2004	0.09	0.21	0.17	0.09	0.93	0.12
	2005	0.08	0.21	0.14	0.10	1.00	0.12
	2006	0.09	0.23	0.15	0.13	1.10	0.11
	2007	0.06	0.14	0.11	0.09	0.94	0.08
	2008	0.03	0.15	0.14	0.09	0.98	0.07
	2009	0.05	0.15	0.11	0.07		0.06
	2010	0.08	0.15	0.12	0.10		0.11
	2011	0.08	0.13	0.14	0.27	0.94	0.23
	2012	0.05	0.12	0.17	0.25	1.07	0.15
	2013	0.03	0.08	0.13	0.13	0.69	0.09
	2014	0.08	0.10	0.10	0.12	0.59	0.10
	2015	0.02	0.08	0.08	0.14	0.61	0.11
	2016	0.04	0.13	0.11	0.07	0.43	0.07
	2017	0.04	0.12	0.11	0.04	0.27	0.03
	2018	0.04	0.13	0.11	0.04	0.35	0.06
Ny-Ålesund	1980	0.32	0.31				
	1981	0.36	0.23				
	1982	0.31	0.28				
	1983	0.42	0.41				
	1984	0.24	0.34				
	1985	0.36	0.39				
	1986	0.27	0.34				
	1987	0.53	0.40				
	1988	0.32	0.32				
	1989	0.21	0.24				
	1990	0.22	0.27		0.03		
Zeppelin	1990	0.21	0.22		0.04	0.09	
	1991	0.24	0.19	0.02	0.05	0.09	
	1992	0.19	0.19	0.02	0.04	0.08	
	1993	0.17	0.20	0.03	0.06	0.09	0.05
	1994	0.16	0.15	0.05	0.06	0.09	0.04
	1995	0.15	0.17		0.08	0.10	0.05
	1996	0.10	0.15		0.08	0.11	0.05
	1997	0.13	0.21		0.07	0.13	0.06
	1998	0.21	0.17		0.04	0.13	0.05

Table A.1.34a, cont.

Site	År	Annual mean concentrations of main components in air (µg/m³)					
		SO_2-S	SO_4-S	NO_2-N	(HNO_3+NO_3)-N	(NH_4+NH_3)-N	NH_4-N
Zeppelin	1999	0.13	0.19		0.03	0.19	0.08
(cont.)	2000	0.12	0.14		0.03	0.11	0.03
	2001	0.14	0.18		0.06	0.17	0.04
	2002	0.16	0.14		0.06	0.24	0.02
	2003	0.23	0.17		0.04	0.27	0.04
	2004	0.12	0.16		0.08	0.24	0.04
	2005	0.13	0.18		0.15	0.42	0.10
	2006	0.10	0.13		0.12	0.43	0.03
	2007	0.09	0.11		0.05	0.26	0.04
	2008	0.07	0.14		0.10	0.33	0.06
	2009	0.09	0.15		0.05		0.04
	2010	0.07	0.13		0.06		0.05
	2011	0.10	0.12		0.11	0.39	0.07
	2012	0.06	0.12		0.22	0.36	0.11
	2013	0.09	0.16		0.18	0.28	0.11
	2014	0.14	0.20		0.16	0.33	0.11
	2015	0.06	0.11		0.12	0.22	0.09
	2016	0.06	0.11		0.05	0.17	0.03
	2017	0.12	0.14		0.04	0.16	0.03
	2018	0.04	0.10		0.03	0.11	0.02

1) Due to contamination of ammonia, only NH4-N concentrations are reported in 2009 and 2010.

Table A.1.34b: Annual mean concentrations of sulfur and nitrogen components in air at Norwegian background stations which has been closed down. Units μg S/m3 and μg N/m3.

Site	År	Annual mean concentrations of main components in air at closed sites, (μg/m³)				
		SO_2-S	SO_4-S	NO_2-N	(HNO_3+NO_3)-N	(NH_4+NH_3)-N
Søgne	1989	1.00	1.00	3.10	0.50	1.50
	1990	0.90	1.00	2.70	0.50	1.80
	1991	1.10*	1.20*	2.80*	0.50*	1.70*
	1992	0.62**	0.87**	1.54**	0.42**	0.94**
	1993	0.68	0.81	1.80	0.40	0.88
	1994	0.77	0.77	1.62	0.44	0.89
	1995	0.51	0.72	1.19	0.43	0.98
	1996	0.83	0.85	1.33	0.46	0.95
	1997	0.47	0.63	1.11	0.38	0.94
	1998	0.40	0.55	1.04	0.32	0.87
	1999	0.30	0.57	0.96**	0.33	0.68
	2000	0.27	0.48	1.12	0.33	0.62
	2001	0.28	0.58		0.31	0.72
	2002	0.29	0.59		0.33	0.67
	2003	0.31	0.64		0.41	0.89
	2004	0.29	0.44		0.31	0.69
	2005	0.30	0.55		0.62	1.06
	2006	0.41	0.75		0.48	0.94
	2007	0.21	0.37		0.23	0.61
	2008	0.15	0.32		0.26	0.42
	2009	0.24	0.36		0.31	0.52
Skreådalen	1975		1.00			
	1976		1.09			
	1977		0.80			
	1978	1.62	0.96			
	1979	0.95	0.95			
	1980	1.32	1.18			
	1981	0.72	0.86			
	1982	0.82	0.90			
	1983	0.50	0.82			
	1984	0.80	1.04	0.73		
	1985	0.59	0.79	0.52		
	1986	0.82	0.83	0.70		
	1987	0.66	0.74	0.76		
	1988	0.71	0.67	0.80		
	1989	0.44	0.64	0.63	0.25	1.66
	1990	0.46	0.70	0.62	0.23	2.07
	1991	0.49	0.67	0.61	0.21	1.37
	1992	0.32	0.56	0.41	0.19	1.26
	1993	0.39	0.53	0.45	0.21	1.38
	1994	0.32	0.57	0.63	0.24	1.44
	1995	0.22	0.43	0.46	0.22	1.45
	1996	0.30	0.54	0.42	0.25	1.66
	1997	0.14	0.42	0.53	0.18	1.41
	1998	0.13	0.34	0.51	0.15	1.34
	1999	0.09	0.37	0.40	0.15	1.17
	2000	0.09	0.35	0.38	0.15	1.13
	2001	0.11	0.34	0.29	0.23	1.38
	2002	0.11	0.39	0.39	0.26	1.21
	2003[1)]	*0.07*	*0.33*	*0.34*	*0.15*	*0.94*
	2004	0.09	0.30	0.43	0.24	1.01
Prestebakke	1986	1.10	1.20	1.50	0.40	0.80
	1987	1.30	1.10	1.80	0.40	0.90
	1988	1.00	1.10	1.7**	0.3**	0.7**
	1989	0.70	0.90	1.50	0.30	0.80
	1990	0.50	0.80	1.30	0.30	0.70
	1991	0.50	0.80	1.40	0.30	0.70
	1992	0.48	0.70	1.02	0.28	0.65
	1993	0.50	0.75	1.20	0.28	0.68
	1994	0.48	0.73	1.03	0.29	0.68
	1995	0.39	0.66		0.31	0.67
	1996	0.35	0.76		0.32	0.81
	1997	0.26	0.54		0.24	0.58
	1998	0.19	0.52		0.24	0.56
	1999	0.17	0.55		0.27	0.39
	2000	0.16	0.46		0.27	0.57

Table A.1.34b, cont.

Site	År	Annual mean concentrations of main components in air at closed sites, (µg/m³)				
		SO_2-S	SO_4-S	NO_2-N	(HNO_3+NO_3)-N	(NH_4+NH_3)-N
Osen	1988	0.67	0.72			
	1989	0.38	0.52	0.88	0.15	0.39
	1990	0.22	0.46	0.64	0.12	0.36
	1991	0.25	0.49	0.59	0.12	0.36
	1992	0.17	0.37	0.50	0.11	0.30
	1993	0.22	0.38	0.53	0.11	0.28
	1994	0.19	0.42	0.44	0.14	0.34
	1995	0.19	0.38	0.41	0.15	0.31
	1996	0.13	0.40	0.40	0.14	0.37
	1997	0.09	0.30	0.48	0.10	0.35
	1998	0.08	0.26	0.45	0.10	0.37
	1999	0.06	0.20	0.38	0.08	0.31
	2000	0.04	0.24	0.38	0.08	0.29
	2001	0.08	0.24	0.33	0.12	0.38
	2002	0.07	0.28	0.38	0.11	0.51
	2003	0.08	0.29	0.45	0.13	0.46
Svanvik	1987	6.40	0.90	1.00	0.10	0.60
	1988	5.80	0.90	0.9**	0.1**	0.5**
	1989	5.40	0.60	0.70	0.10	0.40
	1990	7.20	0.70	0.80	0.10	0.40
	1991	5.90	0.70	0.80	0.10	0.50
	1992	3.25	0.57	0.76	0.07	0.67
	1993	4.32	0.53	0.57	0.07	0.51
	1994	4.15	0.37	0.56	0.07	0.42
	1995	5.07	0.48	0.58	0.10	0.49
	1996	3.30	0.47	0.54	0.07	0.55
	1997	4.85	0.49	0.59	0.07	0.63
	1998	6.83	0.54	0.70	0.07	0.78
	1999	3.92	0.53	0.53	0.06	0.91
	2000	3.15	0.45	0.51	0.05	0.84
	2001	4.07	0.52		0.08	0.90
	2002	4.31	0.43		0.10	0.75
Jergul	1977		0.58			
	1978	0.89	0.54			
	1979	1.52	0.74			
	1980	1.55	0.75			
	1981	1.28	0.56			
	1982	0.79	0.54			
	1983	0.81	0.65			
	1984	1.18	0.79	0.43		
	1985	1.42	0.80	0.29		
	1986	1.01	0.69	0.46		
	1987	1.67	0.77	0.51		
	1988	1.23	0.66	0.45	0.09	0.22
	1989	0.40	0.39	0.28	0.08	0.20
	1990	0.81	0.45	0.35	0.07	0.19
	1991	0.80	0.47	0.31	0.08	0.18
	1992	0.53	0.40	0.28	0.07	0.17
	1993	0.58	0.44	0.21	0.08	0.17
	1994	0.44	0.31	0.16	0.09	0.16
	1995	0.59	0.34	0.16	0.11	0.15
	1996	0.32	0.30	0.18	0.08	0.15
Karasjok	1997	0.48	0.32	0.20	0.07	0.16
	1998	0.91	0.34	0.25	0.06	0.19
	1999	0.51	0.36	0.25	0.05	0.18
	2000	0.35	0.27	0.25	0.08	0.16
	2001	0.40	0.29	0.20	0.06	0.14
	2002	0.30	0.24	0.18	0.08	0.11
	2003[1)]	0.20	0.26	0.21	0.08	0.14
	2004	0.32	0.25	0.19	0.11	0.15
	2005	0.31	0.30	0.17	0.11	0.16
	2006	0.29	0.28	0.14	0.16	0.12
	2007	0.19	0.19	0.14	0.08	0.11
	2008	0.35	0.22	0.19	0.07	0.10
	2009	0.18	0.25	0.15	0.09	0.12
Andøya	2010	0.11	0.20		0.05	
	2011	0.05	0.17		0.06	0.11

1) Measured from 25 May 2003.

** One month missing.*

*** Two months missing.*

Table A.1.35: Annual and monthly mean concentrations of OC, EC and TC in PM10 and PM2.5 at the sites Birkenes, Hurdal and Kårvatn for 2018.

Month	PM_{10}			$PM_{2.5}$		
	OC	EC	TC	OC	EC	TC
Birkenes						
January	0.41	0.04	0.45	0.41	0.06	0.47
February	0.70	0.09	0.79	0.64	0.08	0.72
March	0.84	0.10	0.95	0.75	0.10	0.86
April	0.89	0.09	0.99	0.74	0.09	0.83
May	2.20	0.13	2.33	1.67	0.10	1.77
June	1.30	0.06	1.35	0.97	0.05	1.02
July	1.45	0.06	1.50	1.14	0.06	1.21
August	0.86	0.03	0.90	0.60	0.04	0.64
September	0.85	0.04	0.89	0.44	0.04	0.48
October	0.84	0.09	0.92	0.54	0.08	0.62
November	0.73	0.11	0.83	0.50	0.10	0.59
December	0.38	0.06	0.44	0.33	0.07	0.39
Annual mean	0.96	0.08	1.03	0.73	0.07	0.80
Hurdal						
January	0.74	0.11	0.85	0.69	0.11	0.81
February	1.13	0.19	1.31	1.12	0.18	1.29
March	0.88	0.11	1.00	0.83	0.11	0.94
April	0.77	0.10	0.87	0.63	0.09	0.72
May	2.35	0.12	2.48	1.63	0.10	1.74
June	1.46	0.05	1.51	0.99	0.05	1.04
July	1.85	0.07	1.92	1.46	0.06	1.53
August	1.44	0.07	1.51	0.67	0.07	0.74
September	1.65	0.06	1.71	0.51	0.05	0.56
October	1.41	0.18	1.59	0.76	0.15	0.90
November	0.70	0.14	0.84	0.56	0.13	0.70
December	0.73	0.18	0.91	0.68	0.19	0.88
Annual mean	1.27	0.12	1.39	0.88	0.11	0.99
Kårvatn						
January	0.29	0.03	0.33	0.32	0.04	0.36
February	0.50	0.07	0.57	0.50	0.07	0.57
March	0.62	0.06	0.69	0.57	0.06	0.63
April	0.53	0.06	0.59	0.47	0.06	0.53
May	1.62	0.06	1.68	1.60	0.08	1.68
June	1.08	0.02	1.11	0.93	0.04	0.96
July	1.43	0.03	1.46	1.11	0.04	1.15
August	1.38	0.04	1.38	0.58	0.03	0.61
September	1.53	0.05	1.56	0.83	0.05	0.89
October	0.53	0.03	0.56	0.24	0.03	0.27
November	0.32	0.04	0.36	0.27	0.04	0.31
December	0.21	0.07	0.28	0.19	0.07	0.25
Annual mean	0.85	0.05	0.89	0.65	0.05	0.69

Table A.1.36: Annual mean concentrations of OC, EC and TC in PM10 and PM2.5 at Birkenes Hurdal and Kårvatn for the period 2001 - 2018.

Year	PM_{10}			$PM_{2.5}$		
	OC	EC	TC	OC	EC	TC
Birkenes						
2001	1.10	0.13	1.30	1.00	0.16	1.20
2002	1.00	0.14	1.20	0.92	0.12	1.00
2003	1.00	0.11	1.20	0.86	0.12	0.98
2004	0.84	0.10	0.94	0.59	0.09	0.68
2005	0.93	0.15	1.10	0.64	0.12	0.75
2006	1.20	0.13	1.30	0.89	0.13	1.00
2007	0.84	0.14	0.98	0.63	0.12	0.75
2008	0.80	0.09	0.89	0.57	0.08	0.65
2009	0.79	0.10	0.89	0.58	0.09	0.67
2010	0.90	0.11	1.00	0.67	0.10	0.78
2011	0.92	0.12	1.00	0.68	0.11	0.80
2012	0.57	0.08	0.64	0.50	0.08	0.58
2013	0.76	0.09	0.84	0.57	0.08	0.65
2014	0.91	0.09	1.00	0.65	0.08	0.73
2015	0.72	0.09	0.81	0.52	0.08	0.60
2016	0.73	0.06	0.80	0.54	0.06	0.60
2017	0.72	0.05	0.78	0.52	0.05	0.58
2018	0.96	0.08	1.03	0.73	0.07	0.80
Hurdal						
2010	1.30	0.16	1.40	0.87	0.15	1.00
2011	1.30	0.17	1.50	0.89	0.17	1.10
2012	0.86	0.13	0.99	0.60	0.12	0.73
2013	1.05	0.14	1.19	0.76	0.14	0.90
2014	1.30	0.11	1.42	0.82	0.11	0.93
2015	0.99	0.14	1.14	0.72	0.13	0.86
2016	0.94	0.09	1.04	0.66	0.10	0.76
2017	1.15	0.10	1.25	0.74	0.09	0.84
2018	1.27	0.12	1.39	0.88	0.11	0.99
Kårvatn						
2010	0.98	0.06	1.00	0.85	0.07	0.92
2011	0.88	0.07	0.95	0.67	0.07	0.74
2012	0.72	0.05	0.78	0.56	0.05	0.62
2013	0.75	0.06	0.81	0.53	0.06	0.59
2014	0.95	0.05	1.00	0.66	0.06	0.71
2015	0.64	0.04	0.68	0.47	0.05	0.52
2016	0.70	0.04	0.74	0.49	0.04	0.53
2017	0.66	0.03	0.69	0.50	0.04	0.53
2018	0.85	0.05	0.89	0.65	0.05	0.69

Table A.1.37: Annual and monthly mean concentrations of PM10, PM10-2.5 and PM2.5 at Birkenes, Hurdal and Kårvatn for 2018. Unit µg/m3.

Month	***Birkenes***			***Hurdal***			***Kårvatn***		
	$PM_{2.5}$	$PM_{10\text{-}2.5}$	PM_{10}	$PM_{2.5}$	$PM_{10\text{-}2.5}$	PM_{10}	$PM_{2.5}$	$PM_{10\text{-}2.5}$	PM_{10}
JAN	1.2	1.2	2.7	2.6	0.2	2.2	1.2	0.3	0.8
FEB	4.7	2.1	6.8	6.0	0.6	6.5	1.4	0.2	1.6
MAR	3.3	1.1	4.4	3.5	1.2	4.7	2.0	0.5	2.4
APR	3.6	2.3	5.8	2.3	1.9	4.2	2.2	1.0	3.2
MAY	5.7	3.4	9.1	4.9	3.5	8.4	6.0	1.1	6.9
JUN	3.4	2.6	6.0	3.2	2.3	5.4	4.4	1.9	6.3
JUL	3.8	2.2	6.1	4.4	2.1	6.4	4.0	1.6	5.6
AUG	2.0	2.1	4.0	2.4	2.1	4.5	1.7	1.9	3.5
SEP	2.1	3.4	5.5	1.9	3.2	5.1	1.8	1.9	3.6
OCT	2.9	3.6	6.4	3.1	2.8	5.9	0.7	0.8	1.5
NOV	1.8	4.8	6.6	2.0	1.1	3.1	0.8	0.8	1.6
DEC	1.2	0.9	2.1	2.6	0.3	2.8	0.6	0.4	0.9
2018	*3.0*	*2.5*	*5.4*	*3.2*	*1.8*	*4.9*	*2.3*	*1.1*	*3.2*

Table A.1.38: Annual mean mass concentrations of PM10. PM10-2.5. PM2.5 and PM1 at Birkenes, Hurdal and Kårvatn for the period 2000 - 2018.

Year	PM_1	$PM_{2.5}$	$PM_{10-2.5}$	PM_{10}
Birkenes				
2000				6.8
2001		4.0	2.0	6.1
2002		4.8	2.3	7.1
2003		4.4	2.2	6.7
2004		3.3	2.1	5.4
2005		4.1	2.7	6.8
2006	3.7	5.0	3.1	8.1
2007	2.7	3.3	2.3	5.6
2008	2.2	3.0	2.9	5.9
2009		3.6	2.4	6.0
2010		3.4	3.0	5.1
2011		4.2	3.2	7.0
2012		3.0	2.2	4.9
2013		2.9	2.0	4.9
2014		3.4	2.6	6.1
2015		2.7	2.6	5.4
2016		2.5	1.9	4.3
2017		2.0	1.7	3.6
2018		3.0	2.5	5.4
Hurdal				
2010		3.8	1.2	4.8
2011		4.3	1.6	5.8
2012		3.0	1.5	4.3
2013		3.1	1.5	4.6
2014		3.8	1.9	5.7
2015		2.8	1.5	4.2
2016		2.6	1.4	4.0
2017		2.4	1.6	3.8
2018		3.2	1.8	4.9
Kårvatn				
2010		3.2	0.9	3.9
2011		2.6	1.1	3.6
2012		2.5	1.0	3.4
2013		2.2	0.9	3.1
2014		3.3	1.1	4.3
2015		1.5	0.9	2.3
2016		1.6	1.0	2.5
2017		1.5	0.7	2.1
2018		2.3	1.1	3.2

Annex 2

Detailed information of the monitoring programme

Table A.2.1: Site locations and station keepers for the background sites in 2017.

Stasjon	Fylke	m.o.h.	Bredde N	Lengde E	Start dato	Stasjonsholder	Adresse
Birkenes	Aust-Agder	190	58° 23'	8° 15'	nov-71	Olav Lien	4760 Birkeland
Birkenes II		219					
Vatnedalen	Aust-Agder	800	59° 30'	7° 26'	nov-73	Lilly Vatnedalen	4694 Bykle
Treungen	Telemark	270	59° 01'	8° 32'	sep-74	Per Ø. Stokstad	4860 Treungen
Haukenes	Telemark	20	59° 12'	9° 31'	apr-79		
Prestebakke	Østfold	160	59° 00'	11° 32'	nov-85	NILU	2027 Kjeller
Løken	Akershus	135	59° 48'	11° 27'	mar-72	Anne Mørch	1960 Løken
Hurdal	Akerhus	300	60° 22’	11° 04’	jan-97	Thomas Sørlien	2090 Hurdal
Brekkebygda	Buskerud	390	60° 18'	9° 44'	des-97	Anton Brekka	3534 Sokna
Vikedal II	Rogaland	60	59° 32'	5° 58'	jan-84	Harald Leifsen	4210 Vikedal
Sandve	Rogaland	40	59° 12'	5° 12'	jun-96	Jan M. Jensen	4272 Sandve
Haukeland	Hordaland	204	60° 49'	5° 35'	aug-81	Henning Haukeland	5198 Matredal
Nausta	Sogn og Fjordane	230	61° 34'	5° 53'	des.84	Sverre Ullaland	6043 Naustdal
Kårvatn	Møre og Romsdal	210	62° 47'	8° 53'	feb-78	Erik Kårvatn	6645 Todalen
Høylandet	Nord-Trøndelag	60	64° 39'	12° 19’	feb-87	Jakob Olav Almås	7977 Høylandet
Tustervatn	Nordland	439	65° 50'	13° 55'	des-71	Are Tustervatn	8647 Bleikvassli
Karpbukt	Finnmark	20	69° 40’	30° 22’	okt-98	Roy Hallonen	9900 Kirkenes
Ny-Ålesund	Svalbard	8	78° 55'	11° 55'	1974	NP forskningsst.	9173 Ny-Ålesund
Zeppelin	Svalbard	474	78° 54'	11° 53'	sep-89	NP forskningsst.	9173 Ny-Ålesund

Table A.2.2:Measurement programme at Norwegian background stations in 2017, including the environmental contaminants reported in Nizzetto et al. (2017).

	Air							precipitation			
	hourly		daily		weekly		2d per week	Daily	Weekly		monthly
Stasjon	Metr.	Ozone	main	NO_2	$PM_{2,5}$, PM_{10} + EC/OC	HM.	POPs	main	main	HM	POPs
Birkenes	X	X	X	X	X	X[b]	X[d]	X		X[b]	X[e]
Vatnedalen									X		
Treungen									X		
Haukenes		X									
Prestebakke		X									
Løken									X		
Hurdal	X	X	X	X	X			X		X[a]	
Brekkebygda									X		
Vikedal									X		
Sandve		X									
Haukeland									X		
Nausta									X		
Kårvatn		X	X	X	X			X		X[a]	
Høylandet									X		
Tustervatn		X	X	X				X			
Andøya	X					X[b]	X[g]				
Karpbukt									X		
Svanvik										X[b]	
Zeppelin, Ny-Ålesund	X	X	X			X[c]	X[g]		X		
Total number	4	7+1	5	4	3	3	3	4	9	4	1

Metr. = meteorology

main.precip = amount (mm), pH, conductivity, SO_4, NO_3, Cl, NH_4, Ca, K, Mg, Na

main air = SO_2, SO_4, $HNO_3 + NO_3$; $NH_4 + NH_3$, Ca, K, Mg, Na, Cl

HM [a] = Pb, Cd and Zn

[b] = Pb, Cd, V, Cr, Co, Ni, Cu, Zn, As and Hg

[c] = Pb, Cd, V, Cr, Mn, Co, Ni, Cu, Zn, As

POPs [d] = α- og γ-HCH, HCB, DDTs, Chlordanes, PCBs, PBDE, HBCD, PAHs, PFAS

[e] = α- og γ-HCH, HCB, PCB

[f] = α- og γ-HCH, HCB, HCHs, DDTs, PCBs, PBDEs, PFAS

[g] = α- og γ-HCH, HCB, DDTs, Chlordanes, PCBs, BDE, HBCDs, PAHs, PFAS, Siloxanes, SCCP, MCCP

Annex 3

Sampling and chemical analysis (incl. background information on PM and EC/OC and levoglucosan)

Main components in precipitation

For precipitation sampling, a NILU Precipitation Collector (funnel + bucket type) is used (P.no. 9713,RS1). The bucket has a size of 2.5 litre, and the diameter of the collecting surface is 200 mm. The collector is placed 2 meters above ground. In winter, during snow conditions, the bulk + funnel collector is exchanged with a so-called Particulate Fallout Collector (P.no. 9711, SF1), see figure on the right of the two bulk collector types. The material used for the collectors is high density polyethylene.

The precipitation sampler is emptied and cleaned with distilled water between each sampling period (daily or weekly), also in periods when there has been no precipitation. The precipitation amount is measured by volume at the site, and an aliquot of the sample is sent to NILU for chemical analysis.

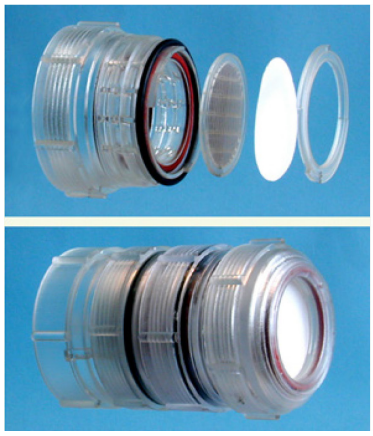
pH is measured with potentiometric method and conductivity with a conductivity meter. Anions and cations are measured with an ion chromatograph. The detection limit for the different ions are given in the table below:

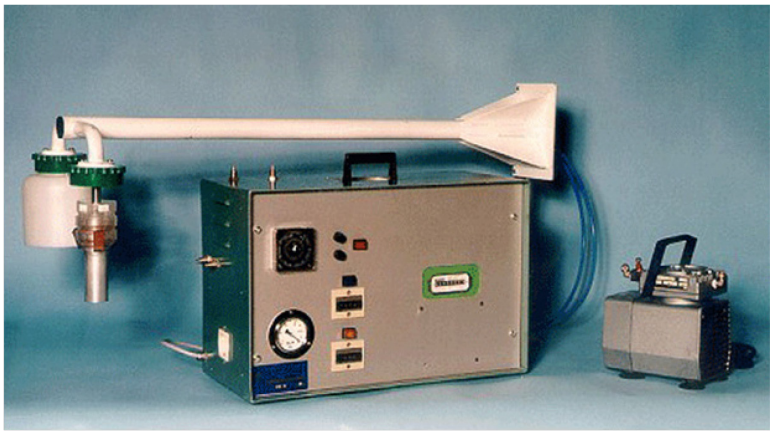
Parameter	Detection limit (unit)
SO_4^{2-}	0.01 (mg S/l)
NO_3^-	0.01 (mg N/l)
NH_4^+	0.01 (mg N/l)
Na^+	0.01 (mg Na/l)
Cl^-	0.01 (mg Cl/l)
K^+	0.01 (mg K/l)
Ca^{2+}	0.01 (mg Ca/l)
Mg^{2+}	0.01 (mg Mg/l)

Main components in air

The main ions in air is sampled with a three stage filterpack using the NILU filter holder system designed for sampling of particles and gaseous compounds, see figure below. The first filter in the air stream is an aerosol filter (Zeflour 2 µm) for collecting the airborne particles containing SO_4^{2-}, NH_4^+, NO_3^-, Ca^{2+}, K^+, Cl^-, Na^+. This is followed by an alkaline (KOH) impregnated filter (Whatman 40), which will collect HNO_3, SO_2, HNO_2, HCl, and other volatile acidic substances. Nitric acid and sulfur dioxide will react with potassium hydroxide on this impregnated filter to give potassium nitrate and potassium sulphite. Oxidizing species in air e.g. ozone are believed to convert most of the sulphite to sulfate during the sampling. The third filter (Whatman 40) is acid-impregnated (oxalic acid) for absorbing alkaline air component such as NH_3. The filter pack method is biased in separating gaseous nitrogen compounds from aerosols and therefore the sum is reported. In other words, the concentration of nitrates in air equals the sum of the nitrate found on the aerosol filter and nitrate found on the alkaline impregnated filter. The same for ammonium, where the sum of ammonium concentration equals the sum of ammonium collected on the aerosol front filter and ammonia collected on the acid impregnated filter.

The filterpack samplers does not have a pre-impactor, but the air intake has a cylindrical vertical plastic section covering the filter holder – about 15 cm wide and 25 cm high. This air intake reduces the sampling efficiency for large particles such as soil dust particles, large sea spray droplets, large pollen, and fog droplet, thus the size cut off is approximately PM_{10} except for strong sea salt episodes when larger particles are collected.





After exposure, the filter holders are sent to NILU for chemical analysis. The filters are put into a test tubes with additions of extraction solution. Hydrogen peroxide solution is used for the alkaline filter in order to oxidize any remaining sulphite to sulfate. An HNO_3 is added to the acid impregnated filter. The aerosol Teflon© filters are given an ultrasonic treatment before analysis in order to obtain a complete extraction. The ions are analysed using an ion chromatograph, and the detection limits are given below:

Parameter	Detection limit (unit)
SO_2	0.01 (µg S/m^3)
SO_4^{2-}	0.01 (µg S/m^3)
Sum (NO_3^-+HNO_3)	0.01 (µg N/m^3)
Sum (NH_4^++NH_3)	0.05-0.1 (µg N/m^3)
Na^+	0.02 (µg Na/m^3)
Cl^-	0.02 (µg Cl/m^3)
K^+	0.02 (µg K/m^3)
Ca^{2+}	0.02 (µg Ca/m^3)
Mg^{2+}	0.02 (µg Mg/m^3)

Nitrogen dioxide

NO_2 is determined with the manual NaI glass sinter method. Ambient air with a flow rate of about 0.5 l/min is drawn through an air intake (inverted funnel) and a glass filter impregnated with sodium iodide (NaI) and sodium hydroxide (NaOH). Nitrogen dioxide is absorbed in the filter, and the iodide reduces NO_2 to nitrite. The nitrite formed on the glass filter is extracted with deionized water. After extraction the nitrite concentration can be determined spectrophotometrically at 540 nm after a reaction with sulphanilamide and N-(1-naphthyl)-ethylenediamine (NEDA). The detection limit for this method is 0.03 µg N/m^3.

Ozone

Ozone (O_3) is determined with the UV-absorption method (UV light at 254 nm) using a monitor with continuous measurements. The results are given in hourly resolution.

Particles (Mass, EC/OC, and levoglucosan)

Background

Size is the most fundamental parameter describing an aerosol, being decisive for transport and removal, and essential for understanding the effects of the ambient aerosol. Aerosol are most commonly defined by their equivalent aerodynamic diameter, defined as, that of a spherical particle of unit density (1 g cm^{-3}), having a settling velocity equal to that of the particle in question. The size distribution of the tropospheric aerosol is commonly divided into three major modes (Whitby, 1978); the nuclei mode, the accumulation mode and the coarse mode, all having different formation processes, leading to different characteristics of the aerosol. Tropospheric aerosols are either emitted directly (primary) or formed in the trophosphere by oxidation of precursor gases (secondary) (Seinfeld and Pandis, 1998). The sources of tropospheric aerosols are both natural (e.g. windborne dust, sea spray, volcanic activity, biomass burning) and anthropogenic (fuel combustion, industrial processes, non-industrial fugitive sources and transportation sources), and hence its chemical composition is highly diverse, including amongst others: sulfate (SO_4^{2-}), nitrate (NO_3^-), ammonium (NH_4^+), organic carbon (OC), which is a bulk fraction of numerous organic molecules, light absorbing/refractory carbon (BC/EC), aluminum and silicon (major constituents of mineral dust), inorganic cations (e.g., K^+, Na^+, Ca^{2+} $Mg^{2+)}$ and anions (e.g., Cl^-).

The adverse health effects of the ambient aerosol is well recognized (e.g., Dockery et al., 1993; Schwarz et al., 1996), causing various types of cardiopulmonary diseases, e.g., chronical obstructive pulmonary disease, ischemic heart disease, lung cancer and pneumonia. Although the statistical evidence between ambient air particulate mass (e.g., PM_{10} and $PM_{2.5}$) and adverse health effects are well documented, there is considerable doubt concerning the causal relationship. Thus, other relevant parameters such as the particle number size distribution, the surface and the chemical composition of the aerosol must be considered when addressing this issue. There is strong evidence that fine particles are more hazardous than coarse ones (Schwartz et al., 1996, Schwartz and Neas, 2000), although coarse particles are associated with adverse health effects as well (Castillejos et al., 2000; Ostro et al., 2000). An increasing number of experimental studies have been devoted to the number of ultrafine particles (d_p< 100 nm), which potentially play a role in the cardiovascular effects commonly associated with exposure to particulate matter (Donaldson et al., 2001). Concerning the chemical composition, WHO has given the general advice that that primary combustion derived particles are particularly important as they "*are often rich in transition metals and organic compounds, and also have a relatively high surface area*". However, more knowledge is needed concerning the ambient aerosol chemical composition and its contribution to the adverse effects seen on human health.

The tropospheric aerosol has an influence on the radiation budget both directly, by scattering and absorption of sunlight and terrestrial radiation, and indirectly, by influencing cloud reflectivity and lifetime. Both effects lead to a mostly cooling effect for the Earth's surface. The particle size distribution is essential for quantifying the magnitude of both direct and indirect aerosol climate effect, whereas particle chemical composition influences aerosol absorption and the lower size limit of particles acting as cloud condensation nuclei.

The tropospheric aerosol also plays an important role when it comes to acidification and eutrophication of water bodies. This is attributed to the content of secondary inorganic species such

as SO_4^{2-}, NO_3^- and NH_4^+, which typically are associated with accumulation mode particles, enabling long-range transport and deposition in regions far from where the precursors where emitted.

Elemental (EC) and organic (OC) carbon are abundant fractions of the ambient aerosol particle, thus contributing to the aerosol particle influence on the radiation budget both directly, by scattering and absorption of sunlight, and indirectly, by cloud formation. Likewise does the carbonaceous fraction contribute to the adverse health effects observed; i.e., respiratory and cardiovascular diseases. EC enters the atmosphere exclusively as a primary (i.e., direct particulate) emission, whereas OC includes both primary aerosol particles and secondary aerosol particles, of which the latter is formed from gaseous precursors oxidized in the atmosphere. The carbonaceous fraction can be of both anthropogenic and natural origin; e.g., EC and OC from incomplete combustion of fossil fuel (e.g. vehicular tailpipe emissions) and biomass (residential wood burning and wild fires), OC from oxidation of gaseous emissions from coniferous and deciduous trees, and OC associated with primary biological aerosol particles (PBAP). EC and OC are typically associated with the fine aerosol particle, although OC can appear in the coarse fraction as well, e.g. the PBAPs or due to condensation of OC on coarse aerosol particles. Despite the importance of the carbonaceous aerosol, detailed apportionment and quantification of its sources is still difficult due to the large number of sources, the complexity of atmospheric formation and the vast number of organic compounds associated with the aerosol.

EC and OC are simply operational definitions, and do not provide information about the source *pr. se*, thus additional measurements to EC and OC are required to provide information about the carbonaceous aerosol sources and their relative share. Source apportionment studies (Yttri et al., 2011a, b), using a combination of ^{14}C and organic tracers, show that natural sources dominates OC in PM_{10} at Norwegian rural background sites in summer, of which OC associated with the biogenic secondary organic aerosol (BSOA) is the major source followed by OC associated with PBAP. In winter, anthropogenic sources dominates OC in PM_{10}, i.e., emissions from fossil fuel combustion and residential wood burning. The picture is rather similar for OC in PM_1, except that OC associated with PBAP is of much less importance in summer than seen for PM_{10}. Combustion of fossil fuel appears to be the major source of EC regardless of season and size fraction, but EC from residential wood burning increases substantially in winter.

Levoglucosan is a thermal degradation product of cellulose with a low vapor pressure and a high emission factor from combustion of biomass (Locker, 1988; Simoneit et al., 1999; Oja and Suuberg, 1999), and thus well suited to trace biomass-burning aerosol in the ambient atmosphere. Aqueous-phase reaction with OH radical in deliquescent particles appears to be the most efficient pathway causing depletion of levoglucosan in the atmosphere. The ½ values (the time until half of the levoglucosan has been degraded) for levoglucosan in the atmosphere is debated and likely to vary with photochemical activity and OH concentrations, being a function of temperature and season (Hennigan et al., 2010; Yttri et al., 2014).

Levoglucosan is considered the most robust and reliable tracer of biomass burning, and is commonly used to trace biomass burning aerosol, not only qualitatively, but also quantitatively by combing ambient concentrations with emission ratios, or as input along with other species to e.g. positive matrix factorization (PMF). For studies using levoglucosan as biomass burning tracer in Norway, see Yttri et al., 2005, 2007a, b, 2009, 2011a, b, 2014, 2019, in prep. Although levoglucosan appears to be best suited to trace biomass burning emissions in winter and on a local to regional scale, conservative estimates of the biomass burning aerosol concentration can still be provided for the remote environment.
Emission ratios used to convert observed ambient concentrations of levoglucosan to OC and EC from biomass burning, are associated with great uncertainty. In the present report, we use an

OC/levoglucosan ratio of 10 and an EC/levoglucosan ratio of 2. These ratios are based on non-published positive matrix factorization (PMF) analysis results for PM and PM species observed at Birkenes, which are consistent with results presented in the scientific literature e.g. by Zotter et al. (2017). A factor of 2 was used to convert biomass burning OC to OM, and a factor of 1.1 for biomass burning EC.

Sampling and chemical analysis

PM_{10} and PM2.5 are obtained using Kleinfiltergerät samplers (one sampler pr. size faction), collecting filter samples on a weekly basis. The ambient aerosol particles are collected on prefired (850 °C for 3 hrs) quartz fibre filters (Whatman QM-A, 47 mm). The quartz fibre filters are conditioned (20 °C; 50% RH; 48 hrs) prior to and after being exposed. The mass concentration of the quartz fibre filters are determined gravimetrically. The uncertainty of the PM mass concentrations obtained for PM_{10} and $PM_{2.5}$ is estimated to be around 0.1 – 0.15 µg/m^3 for a sampling volume of 386 m^3.

Number concentration measurements at Birkenes dates back to 2010. The number concentration of ultrafine particles (D_p <0.1 µm), accumulation mode particles (0.1 µm < D_p < 1.0 µm) and coarse mode particles (D_p = 0.01 - 10 µm) are obtained by combined measurements of a Differential Mobility Particle Spectrometer (DMPS) and an Optical Particle Spectrometer (OPS). The DMPS measures the particle number size distribution ranging from 0.01 – 0.8 µm particle diameter, whereas the OPS covers the range from 0.25 µm to 30 µm. The DMPS and the OPS provide method specific measures of the particle diameter, i.e. the electrical mobility particle diameter and the optical particle diameter, respectively. Thus, when merging these two measures into one particle number size distribution (PNSD) time series, the PNSD must agree within 25% in particle diameter in their overlapping size range.

In May 2017 a continuous, direct aerosol mass instrument was installed at Birkenes, a so called tapered element oscillating microbalance (TEOM) instrument with a size cut off to measure PM_{10} mass. The TEOM Monitor draws (then heats) ambient air through a filter at constant flow rate, continuously weighing the filter and calculating near real-time mass concentrations of particulate matter. The mass is corrected with a factor 1.1 based on an intercomparison campaign which the TEOM with gravimetric measurements, which is the reference method.

Thermal-Optical Analysis of EC, OC and TC in PM_{10} and $PM_{2.5}$ are performed on the same filter samples as the mass concentration of PM_{10} and $PM_{2.5}$ are obtained from. The T-O analysis are performed according to the EUSAAR-2 protocol (Cavalli *et al*., 2010). The analytical detection limit of the TOA instruments is 0.2 µg C/cm^2, corresponding to methodological detection limit of 0.007 µg C m^{-3} for a sampling volume of 386 m^3 and an exposed filter area of 13.4 cm^2.

Concentrations of the biomass burning tracer levoglucosan (mannosan and galactosan) is determined in the same PM_{10} filter samples as the mass concentration, EC, OC and TC, using ultra-performance liquid chromatography (UPLC) in combination with high-resolution time-of-flight mass spectrometry (HR-TOF MS) operated in the negative electrospray ionization (ESI-) mode, and according to a modified version of the analytical method described by Dye and Yttri (2005). The methodological detection limit is approximately 20 – 90 pg m^{-3} for a sampling volume of 386 m^3 and an exposed filter area of 13.4 cm^2.

References:

Dye, C., Yttri, K.E. (2005) Determination of monosaccharide anhydrides in atmospheric aerosols by use of high-resolution mass spectrometry combined with high performance liquid chromatography. *Anal. Chem., 77,* 1853-1858.

Hennigan, C. J., Sullivan, A. P., Collett Jr., J. L., and Robinson, A. L. (2010) Levoglucosan stability in biomass burning particles exposed to hydroxyl radicals. *Geophys. Res. Lett., 37,* L09806, doi:10.1029/2010GL043088.

Locker, H.B. (1998) PhD Dissertation, Dartmouth College, Hanover, NH.

Oja, V. and Suuberg, E. M. (1999) Vapor Pressures and Enthalpies of Sublimation of D-glucose, D-xylose, Cellobiose, and Levoglucosan. *J. Chem. Eng. Data, 33,* 26–29.

Simoneit, B. R. T., Schauer, J. J., Nolte, C. G., Oros, D. R., Elias, V.O., Fraser, M. P., Rogge,W. F., and Cass., G. R. (1999) Levoglucosan, a tracer for cellulose in biomass burning and atmospheric particles. *Atmos. Environ., 33, 173–182*.

P. Zotter, V. G. Ciobanu, Y. L. Zhang, I. El-Haddad, M. Macchia, K. R. Daellenbach, G. A. Salazar, R.-J. Huang, L. Wacker, C. Hueglin7, A. Piazzalunga, P. Fermo, M. Schwikowski, U. Baltensperger, S. Szidat, and A. S. H. Prévôt (2014) Radiocarbon analysis of elemental and organic carbon in Switzerland during winter-smog episodes from 2008 to 2012 – Part 1: Source apportionment and spatial variability. *Atmos. Chem. Phys., 14,* 13551–13570. doi:10.5194/acp-14-13551-2014.

Yttri, K. E., Dye, C., Slørdal, L. H., and Braathen, O.-A. (2005) Quantificationof monosaccharide anhydrides by negative electrospray HPLC/HRMS-TOF – Application to aerosol samples from an urban and a suburban site influenced by small scale wood burning. *J. Air Waste Manage. Assoc., 55,* 1169–1177.

Yttri, K.E., Dye, C. and Kiss, G. (2007a) Ambient aerosol concentrations of sugars and sugar-alcohols at four different sites in Norway. *Atmos. Chem. Phys., 7,* 4267-4279. doi:10.5194/acp-7-4267-2007.

Yttri, K.E., Aas, W., Bjerke, A., Cape, J.N., Cavalli, F., Ceburnis, D., Dye, C., Emblico, L., Facchini, M.C., Forster, C., Hanssen, J.E., Hansson, H.C., Jennings, S.G., Maenhaut, W., Putaud, J.P. and Tørseth, K. (2007b) Elemental and organic carbon in PM_{10}: a one year measurement campaign within the European Monitoring and Evaluation Programme EMEP. *Atmos. Chem. Phys., 7,* 5711–5725, doi:10.5194/acp-7-5711-2007.

Yttri, K. E., Dye, C., Braathen, O.-A., Simpson, D., and Steinnes,E. (2009) Carbonaceous aerosols in Norwegian urban sites. *Atmos. Chem. Phys., 9,* 2007–2020, doi:10.5194/acp-9-2007-2009.

Yttri, K.E., Simpson, D., Stenström, K., Puxbaum, H., Svendby, T. (2011a) Source apportionment of the carbonaceous aerosol in Norway - quantitative estimates based on 14C, thermal-optical and organic tracer analysis. *Atmos. Chem. Phys., 11,* 9375-9394. doi:10.5194/acp-11-9375-2011.

Yttri, K.E., Simpson, D., Nøjgaard, J.K., Kristensen, K., Genberg, J., Stenström, K., Swietlicki, E., Hillamo, R., Aurela, M., Bauer, H., Offenberg, J.H., Jaoui, M., Dye, C., Eckhardt, S., Burkhart, J.F., Stohl, A., Glasius, M. (2011b) Source apportionment of the summer time carbonaceous aerosol at Nordic rural background sites. *Atmos. Chem. Phys., 11,* 13339-13357. doi:10.5194/acp-11-13339-2011.

Yttri, K.E., Lund Myhre, C., Eckhardt, S., Fiebig, M., Dye, C., Hirdman, D., Ström, J., Klimont, Z., Stohl, A. (2014) Quantifying black carbon from biomass burning by means of levoglucosan – a one-year time series at the Arctic observatory Zeppelin. *Atmos. Chem. Phys., 14,* 6427-6442. doi:10.5194/acp-14-6427-2014.

Yttri K.E. Arve Bjerke, Sabine Eckhardt, Nikolaos Evangeliou, Markus Fiebig, Anne-Gunn Hjellbrekke, Cathrine Lund-Myhre, Stephen Matthew Platt, Sverre Solberg, Andreas Stohl, Jason Surratt, Kjetil Tørseth and Wenche Aas (2018) 15 years of carbonaceous aerosol measurement at the Birkenes Observatory – Norway (In prep.).

NILU – Norwegian Institute for Air Research

NILU – Norwegian Institute for Air Research is an independent, nonprofit institution established in 1969. Through its research NILU increases the understanding of climate change, of the composition of the atmosphere, of air quality and of hazardous substances. Based on its research, NILU markets integrated services and products within analyzing, monitoring and consulting. NILU is concerned with increasing public awareness about climate change and environmental pollution.

NILU's values: *Integrity - Competence - Benefit to society*
NILU's vision: *Research for a clean atmosphere*

NILU – Norwegian Institute for Air Research
P.O. Box 100, NO-2027 KJELLER, Norway

E-mail: nilu@nilu.no
http://www.nilu.no

ISBN: 978-82-425-2970-1
ISSN: 2464-3327

Norsk institutt for luftforskning
Norwegian Institute for Air Research