

Monitoring of long-range transported air pollutants in Norway

Annual Report 2019

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ABSTRACT This report presents results from the monitoring of atmospheric composition and deposition of air pollution in 2019, 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. In 2019, it was an unusual wide-spread episode during April causing high concentrations of most pollutants at several sites.		
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ABSTRACT (in Norwegian) Denne rapporten omhandler resultater fra overvåkningsprogrammet for langtransportert forurenset luft og nedbør og atmosfæriske tilførsler i 2019. Rapporten presenterer målinger av uorganiske hovedkomponentene i luft og nedbør, partikulært karbonholdig materiale, partikkelmasse og bakkenært ozon. I 2019 ble det observert en uvanlig omfattende episode med høye konsentrasjoner av luftforurensing på flere stasjoner.		
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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 (PM₁₀ og PM_{2.5}) og størrelsesfordeling av partikkelantall på 16 norske bakgrunnsstasjoner. I tillegg rapporteres målinger av levoglukosan på Birkenes. For første gang rapporteres nivåer av OC og EC for den arktiske stasjonen Zeppelin på Svalbard.

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

Birkenes i Agder observerer vanligvis de høyeste nivåene av luftforurensning på grunn av nærhet til utslippsområdene på kontinentet. Noen stasjoner i innlandet påvirkes av regional landbruksaktivitet som kan gi relativt høyt ammoniumnivå. De høyeste nivåene av EC, OC og NO₂ observeres på Hurdal i Akershus, sannsynligvis på grunn av at denne regionen er relativt tett befolket, og har relativt mye veitrafikk. Målestasjon 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 Agder til Hordaland.

Organisk materiale utgjorde den største fraksjonen av PM₁₀ ved alle stasjonene (34 – 46%), fulgt av sekundære organiske forbindelser (SIA) (17 – 29%) og sjøsaltpartikler (6 – 21%), mens mineralstøv ble estimert å utgjøre 13% av PM₁₀ på Birkenes. Både konsentrasjonen og det relative bidraget av SIA og sjøsaltpartikler til PM₁₀ var betydelig høyere ved Birkenes-observatoriet enn for de to andre stasjonene, hvilket reflekterer områdets nærhet til henholdsvis store antropogene utslippsområder på det europeiske kontinentet og til havet.

Episoder

Hvert år observeres det episoder med langtransportert luftforurensning forårsaket av meteorologi, som fremmer langtransport, kombinert med høye utslipp. I 2019 var det en spesielt langvarig hendelse gjennom april. April 2019 var den andre-varmeste og nest-tørreste april i Norge siden 1900, forårsaket av et vedvarende høytrykksystem i Europa med varm og tørr luft over en lengre periode. Episoden inneholdt forurensning fra omfattende branner i Øst-Europa, støv sannsynligvis fra Sahara, samt forurensning fra trafikk og industri på det kontinentale Europa. Episoden i april førte til høye ozonnivåer på mange steder, spesielt på Tustervatn i Nordland, hvor det ble observert det nest høyeste ozonnivået siden oppstarten av overvåkingen i 1989. Stasjonene som måler karbonholdige partikler opplevde også usedvanlige høye nivåer i denne aprilepisoden. Forhøyede levoglukosan-nivåer målt på Birkenes, kombinert med transportmodellering og satellittbilder, peker på jordbruksbranner i Øst-Europa. Analyse av sporelementer viser også et betydelig bidrag av mineralstøv.

Overskridelser

Årsmiddelkonsentrasjonene av PM₁₀ og PM_{2.5} lå langt under nasjonale og internasjonale grenseverdier (EU) og retningslinjer (WHO) for luftkvalitet på alle målestasjonene. Heller ikke døgnmiddelverdier (PM₁₀) 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 Zeppelifjellet, og langtidsmålet for beskyttelse av landbruksvekster ble overskredet på en stasjon (Birkenes) i 2019. UN-ECEs grenseverdi for skog ble overskredet på fire stasjoner i 2019. WHO's retningslinjer for luftkvalitet for ozon, og de nasjonale retningslinjene satt av Folkehelseinstituttet, overskrides i varierende grad hvert eneste år i Norge. EUs grenseverdi for informasjon til publikum ble ikke overskredet i 2019 og har heller ikke blitt brutt på mange år i Norge.

Trender

Konsentrasjonene av nitrogen- og svovelkomponenter i luft og nedbør i 2019 var noe lavere enn nivået i 2018, mens i et lengre perspektiv er det tydelig nedgang i nivåene. Årsmiddelkonsentrasjonene av PM₁₀ og PM_{2.5}, samt OC og EC i 2019 var innenfor ett standardavvik av langtidsmidlet. 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.

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 (PM₁₀ 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. OC- and EC-measurements for the Arctic site Zeppelin are reported for the first time.

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 programme started in 1973 with measurements of sulfur and nitrogen compounds and was later extended with ozone (1985), aerosol particles, carbonaceous aerosol (2000/1), and aerosol size distribution (2010).

Chemical composition and geographical distribution

Birkenes in Agder commonly observe the highest levels of air pollution due to its proximity to the emission regions at the continent. Some inland sites are influenced by regional agricultural activities and experience relatively high ammonium levels. The highest EC-, OC- and NO₂-levels are seen in Hurdal in Akershus, likely due to influence from the more densely populated region surrounding this site, including road traffic. The site 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 Agder to Hordaland.

Organic matter was the major fraction of PM₁₀ at all sites (34 – 46%), followed by secondary inorganic aerosol (SIA) (17 – 29%) and sea salt aerosol (6 – 21%), whereas a 13% contribution of mineral dust was estimated at the Birkenes Observatory. The SIA and sea salt aerosol contribution was substantially higher at the southernmost site Birkenes due to the proximity to major anthropogenic emission regions in continental Europe and to the sea, respectively.

Episodes

Every year there are episodes of air pollution caused by meteorology, favouring long range transport of air masses, combined with high emissions. In 2019, there was a special large-scale event during April, which caused high concentrations of many pollutants at several of the mainland sites. April 2019 was the second warmest and second driest April in Norway since 1900 caused by a persistent high-pressure system in Europe with warm and dry air for a long period. The episode carried pollution from extensive fires in Eastern Europe, including Ukraine and western Russia, as well as dust from probably Sahara, as well as pollution from transport and industry in continental Europe. This April-episode caused elevated ozone levels at several sites, particularly at Tustervatn in Nordland, experiencing the second highest ozone level since the start of the monitoring in 1989. The sites measuring carbonaceous aerosol also experienced atypically high levels during this period. Elevated levoglucosan-concentrations observed at Birkenes, combined with Flexpart transport modelling and satellite images, point to agricultural fires in Eastern Europe. Trace element analysis show a substantial influence of mineral dust as well.

Exceedances

PM₁₀- 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 2019. WHO's air quality guideline for ozone as well as the national guidelines are exceeded every year in Norway at a varying extent. EU's information threshold to the public was not exceeded in 2019 and has not been broken for many years in Norway. EU's long-term objective for protection of vegetation was exceeded at one station (Birkenes) in 2019. UN-ECE's critical level for forests was exceeded at four stations in 2019.

Trends

The concentration levels of nitrogen- and sulfur compounds in air and precipitation were in 2019 somewhat lower than in 2018, and the long term trends are substantially declining. The annual mean concentration of PM₁₀, PM_{2.5}, OC and EC were all within one standard deviation of the long-term mean. An overview of the long-term trends are shown in Table 1.1 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.

Table 1.1: Trends in annual levels using Mann-Kendall test and Sen slope estimates. Note that trends are given for sites with significant change only.

Component	Sites	1980-2019	1990- 2019	2000-2019
SO ₂	3-4 sites ¹⁾	almost 100%	-75% - -95%	-54% - -61%
SO ₂	Zeppelin	-89%	-75%	-61%
SO ₄ ²⁻ in aerosols	3-4 sites ¹⁾	-86 - -93%	-72% - -82%	-50% - -63%
SO ₄ ²⁻ in aerosols	Zeppelin	-68%	-44%	-28%
SO ₄ ²⁻ in precipitation	All (8 – 12 sites)	-77 - -98%	-55% - -91%	-39% --73% ²⁾
NO ₂	4 sites ¹⁾		-40% - -69%	-39% - -47%
NO ₃ ⁻ in precipitation	S and SW sites	-43 - -53%	-27% - -53%	4 sites: -25% - -40%
HNO ₃ +NO ₃ ⁻ in air	4 sites ¹⁾		Hurdal: -37%	Not sign.trend
NH ₄ ⁺ in precipitation	S and SW sites	-52 - -68%	+78% - -56%	Not sign.trend
NH ₃ +NH ₄ ⁺ in air	4 sites ¹⁾		2 sites: -31% - -48%	3 sites: -40% - -65%
PM ₁₀	Birkenes			-34%
PM _{2.5}	Birkenes			-45% (2001-2019)
OC	Birkenes			-20% - -31% (2001-2019)
EC	Birkenes			-49% - -55% (2001-2019)
TC	Birkenes			-31% - -36% (2001-2019)
O ₃ , 3-months AOT40	4 sites ³⁾		Kårvatn only: -63% (1996-2019)	
O ₃ , 8h >100 µg/m ³	4 sites ^{3b)}			-64% - -81% (1996-2019)

¹⁾ Birkenes, Nordmoen/Hurdal, Kårvatn, Tustervatn. Nordmoen/Hurdal was not part of 1980-2019

²⁾ Tustervatn without significant trend in this period

³⁾ Kårvatn, Sandve, Tustervatn and Prestebakke ; ^{3b)} Not sign. trend for Prestebakke

Monitoring of long-range transported air pollutants in Norway

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1 The monitoring programme 2019

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 programme 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 programme 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 (Birkesnes, Tustervatn, Kårvatn, Zeppelin)
 - Daily measurements of NO₂ at four sites (Birkesnes, Hurdal, Tustervatn, Kårvatn)
 - Weekly measurements of particulate matter (PM₁₀ and PM_{2.5}) and EC/OC at three sites (Birkesnes, Hurdal, Kårvatn)
 - High time-resolution measurements of particle number and size distribution at Birkesnes
 - Daily measurements of particulate and gaseous inorganic compounds in air and precipitation at two sites (Birkesnes and Zeppelin; weekly for precipitation at Ny-Ålesund)
 - Meteorology at three sites (Birkesnes, 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 taken in 2019 taken over by the Norwegian Environment Agency in 2019 :*
 - 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 seven sites (Vikedal, Treungen, Brekkebygda, Høylandet, Nausta, Vatnedalen, Løken).
 - Ozone at three sites (Hurdal, Sandve and Prestebakke)
 - Levoglucosan at Birkesnes
- *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 programme, co-financed by the municipalities in Porsgrunn, Skien and Bamble:*
 - Ozone at Haukenes
- *Funding from the Ministry of Climate and Environment to support the monitoring activities at the Zeppelin Observatory*
 - EC/OC, levoglucosan and other organic tracers at Zeppelin

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., 2020), the second covers the monitoring of the ozone layer and UV (Svendby et al. 2019), whereas the third is on climate gases and aerosol particles influence on climate (Myhre et al., 2019). The site locations and key information on the monitoring programme at the actual sites are illustrated in Figure 1.1. Detailed station information, monitoring programme and measurement frequencies are provided in Annex 2, whereas sampling methods and chemical analysis are described in Annex 3.

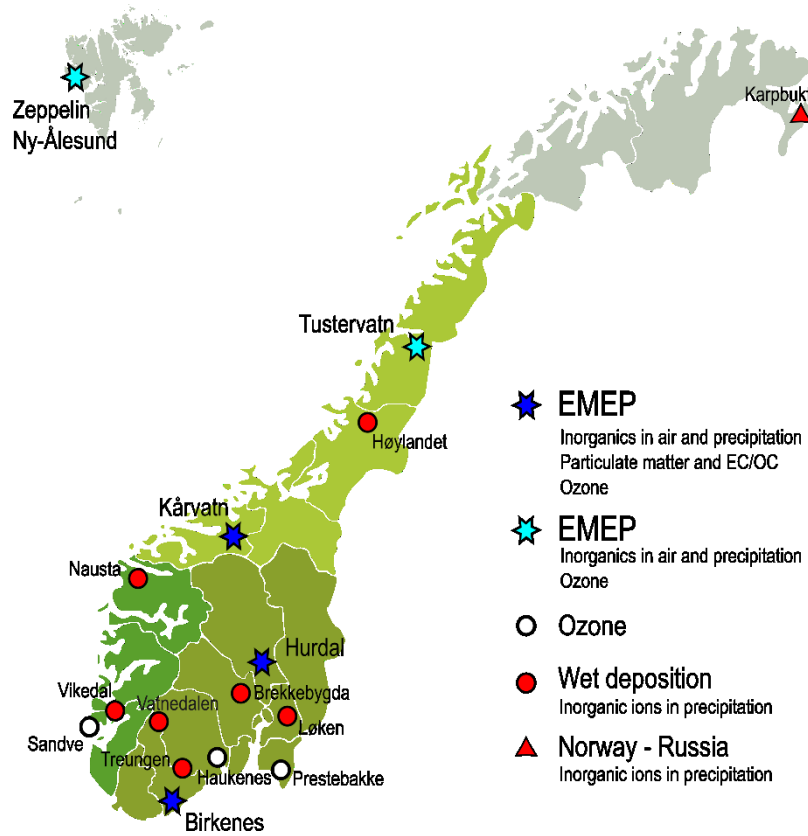


Figure 1.1: Norwegian background sites and their measurement programme 2019. Details are found in Annex 2. The colour codes indicate the different regions/zones used in EU's Ambient Air Quality Directive (2008).

2 The weather in Norway 2019

The variation in meteorological conditions from year to year is decisive for the observed concentrations of pollutants in air and precipitation in Norway. At rural sites, the level of pollutants is mostly determined by atmospheric transport from other countries. The distribution of high- and low-pressure systems controls this transport and temperature, humidity and precipitation are determining the degree of deposition, washout and chemical transformation in the air masses. Knowledge of the meteorological conditions and how it varies from day to day and from south to north is therefore important for understanding the air pollutant levels.

In 2019, the annual average temperature for the country as a whole was 1.2°C above the normal (all normals refer to the 1961-1990 period), while the average precipitation was 15 % higher than the normal (Met. Institute, 2020). This makes 2019 the 20th warmest year and the 15th wettest year since 1900. Except for a few sites in Troms and Finnmark, the average temperature exceeded the normal in the entire country. The highest temperature anomalies were observed at Spitsbergen with an annual average temperature around 3°C above the normal. At the meteorological station at Svalbard airport the monthly mean temperatures have been above the normal every single month since December 2010.

January - March was characterised by temperatures above the normal and much higher precipitation than normal in most of the country. Frequent low-pressure systems coming in from the west lead to strong winds and precipitation particularly in western and northern Norway. The mean temperature in the Arctic was around 5°C above the normal in January. In February the mean temperature at the mainland of Norway was 3.5°C above the normal, implying that it was among the 15-20 warmest February months since 1900. Temperature records were broken at several sites this month, peaking at Landvik near Grimstad with 18.7 °C on 26 February. Some sites in Nordland and Troms received three times the normal precipitation in February. March was also warmer and wetter than normal. The mean precipitation for the country as a whole was 160 % of the normal, which implies that it was among the 10 wettest March months since 1900. Some areas in SE Norway received three times the normal precipitation this month.

Following the three months of mild and wet conditions, April was an exceptionally warm and dry month. For the country as a whole, this was the second warmest and the second driest April since 1900 with a mean temperature 3.3°C above the normal and with only 40 % of the mean precipitation. Temperature records were broken at several sites, and the temperature anomaly was particularly high in Finnmark and at the west coast with mean temperatures 4-5°C above the normal. The month was dominated by southerly and south-easterly winds, and during 20-27 April an episode with high levels of surface ozone and particles was observed in certain areas. This episode is discussed in more detail in the report.

By the end of April, the weather situation changed completely, and strong northerly winds with polar air masses lead to low temperatures in the entire country. Later in May, SE Norway was influenced by several low-pressure systems causing heavy rainfall. The country as a whole received 175 % of the normal precipitation, making this month the 4th wettest May since 1900. At many sites on the western coast, May was colder than April. The wet conditions continued in June in many areas particularly in southeast and North Norway, which received more than twice the normal precipitation. Some areas in the south experienced episodes with sudden extreme rain events.

By the first part of July, the weather gradually became drier and warmer, and a heatwave influenced many parts of the country later that month. A peak temperature of 35°C was observed in Nordland (Mosjøen) in this period. The month as a whole was warmer and drier than normal. By August more variable weather conditions were observed with more precipitation than normal on the west coast,

but some areas in North Norway experienced only 50 % of the normal precipitation. The dominating mild and wet conditions continued in most of the country in September. A peak temperature of 28°C was observed as late as 21 September in Buskerud.

October brought a marked change in the weather with cold and dry conditions. The mean temperature was 1.4°C below the normal and the precipitation 70 % of the normal, but areas in the south-east received more precipitation than normal, up to twice the average. These conditions continued in November when record-dry conditions were seen in the western part, whereas the southeast received 2-2.5 times the normal precipitation caused by frequent low-pressure passages in the southeast.

December was very mild and wet with a mean temperature 3.4°C above the normal and 140% of the normal precipitation, which means it was among the 20th warmest and the 10th wettest December months since 1900. This was linked to frequent low-pressure systems both in the southern and northern parts.

3 Inorganic components

3.1 Observations in 2019

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, 2014). 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 2019.

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 site in Finnmark are influenced by emissions from Russia and the content of sulfate is particularly high (Berglen et al., 2019)

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 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. 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, 2019.

*: Corrected for contribution from sea salt.

Site	Volume weighted annual mean concentrations										Wet deposition										Volume weighted annual mean concentrations in equivalence units										Ion bal. kat./an.
	pH	SO ₄ *	NO ₃	NH ₄	Ca	K	Mg	Na	Cl		H+	SO ₄ *	NO ₃	NH ₄	Ca	K	Mg	Na	Cl		H+	SO ₄ *	NO ₃	NH ₄	Ca	K	Mg	Na	Cl	H+	
		mg S/l	mg N/l	mg N/l	mg/l	mg/l	mg/l	mg/l	mg/l	mm	µekv/m ²	S/m ²	N/m ²	N/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	mg/m ²	µekv/l	µekv/l	µekv/l	µekv/l	µekv/l	µekv/l	µekv/l	µekv/l	µekv/l	µekv/l	µekv/l	
Birkenes	4.99	0.16	0.26	0.24	0.12	0.08	0.09	0.74	1.25	2010	20593	313	526	481	241	170	187	1491	2516	10	10	14	19	17	6	2	7	32	35	1.12	
Vatnedalen	5.72	0.10	0.11	0.14	0.08	0.13	0.03	0.92	0.79	1033	1980	105	111	140	88	130	35	954	822	2	6	8	8	10	4	3	2	40	22	1.70	
Treungen	5.15	0.12	0.19	0.20	0.11	0.07	0.03	0.20	0.35	1644	11627	196	307	326	175	114	47	332	580	7	7	9	14	14	5	2	2	9	10	1.26	
Løken	5.23	0.13	0.23	0.25	0.17	0.20	0.05	0.33	0.56	1004	5952	134	231	254	168	198	51	330	562	6	8	10	16	18	8	5	4	14	16	1.35	
Hurdal	5.12	0.14	0.20	0.20	0.13	0.10	0.03	0.15	0.26	1260	9642	181	254	258	166	126	34	186	329	8	9	10	14	14	6	3	2	7	7	1.29	
Brekkebygda	5.10	0.14	0.21	0.20	0.14	0.09	0.03	0.14	0.23	1135	9022	163	244	223	164	101	31	159	257	8	9	10	15	14	7	2	2	6	6	1.30	
Vikedal	5.38	0.09	0.11	0.14	0.16	0.20	0.22	1.80	3.08	2937	12285	253	319	405	465	601	654	5277	9039	4	6	15	8	10	8	5	18	78	87	1.14	
Nausta	5.45	0.06	0.10	0.17	0.12	0.10	0.17	1.44	2.50	1876	6676	118	186	320	225	196	322	2707	4692	4	4	11	7	12	6	3	14	63	71	1.15	
Kårvatn	5.30	0.05	0.07	0.09	0.13	0.11	0.19	1.53	2.66	1508	7526	77	107	138	191	169	280	2312	4005	5	3	11	5	6	6	3	16	67	75	1.14	
Høylandet	5.51	0.06	0.07	0.20	0.16	0.15	0.33	2.79	4.93	1221	3769	76	90	249	196	182	406	3402	6015	3	4	19	5	14	8	4	27	121	139	1.10	
Tustervatn	5.18	0.12	0.07	0.13	0.15	0.13	0.26	2.23	3.84	1133	7443	138	79	144	175	146	291	2525	4355	7	7	19	5	9	7	3	21	97	108	1.10	
Karpbukt	4.96	0.24	0.09	0.08	0.20	0.10	0.21	1.72	2.97	527	5764	125	49	40	103	50	112	906	1562	11	15	24	6	6	10	3	17	75	84	1.07	
Ny-Ålesund	5.61	0.20	0.11	0.19	0.56	0.21	0.73	5.16	8.83	162	395	32	18	31	90	34	119	837	1434	2	12	39	8	14	28	5	60	224	249	1.13	

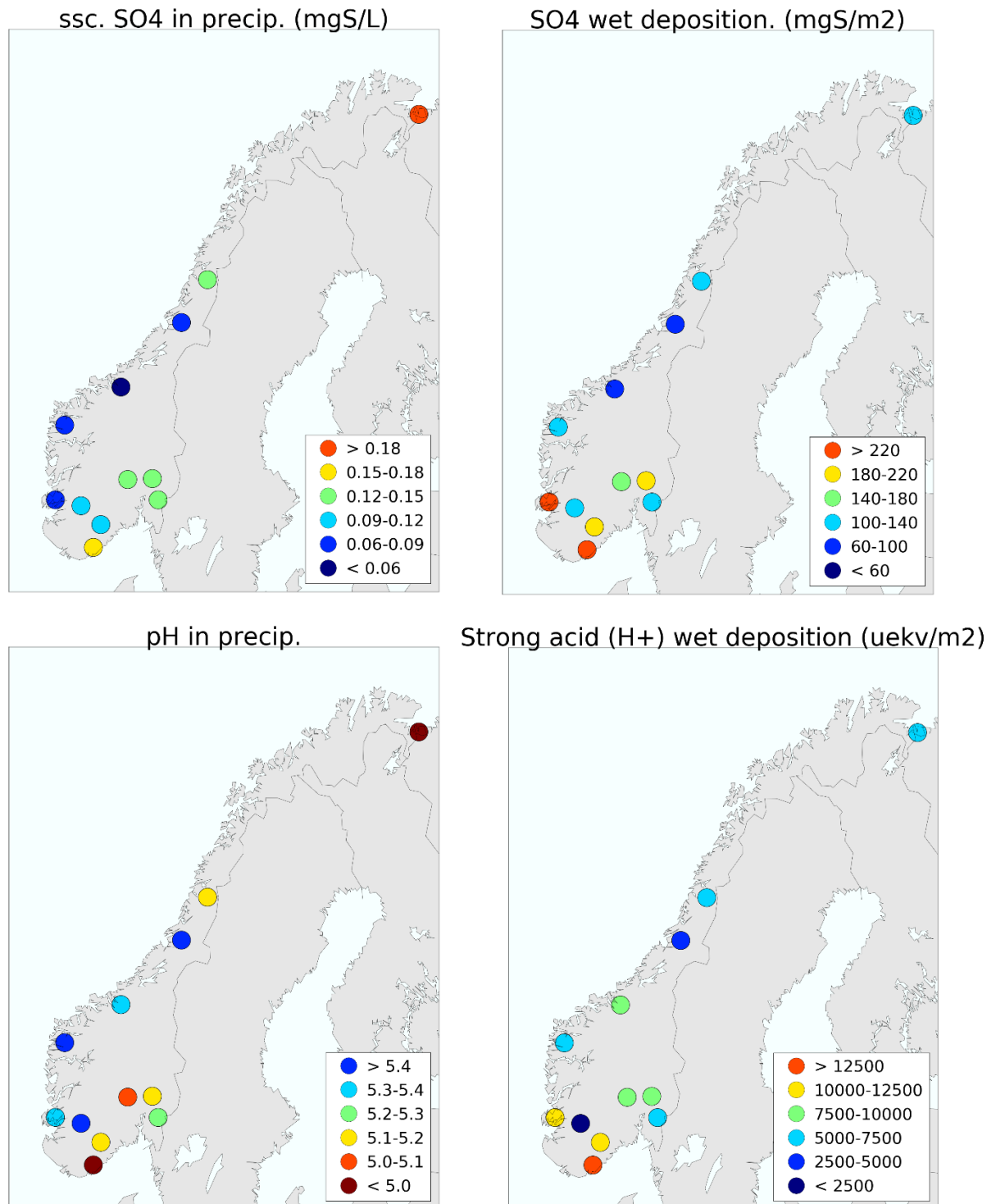


Figure 3.1: Annual volume weighted mean concentrations and total wet deposition of sulfate (sea salt corrected) and strong acid (pH), 2019. Note that the colours only resemble the spatial distribution and do not indicate any exceedances of limit values or similar

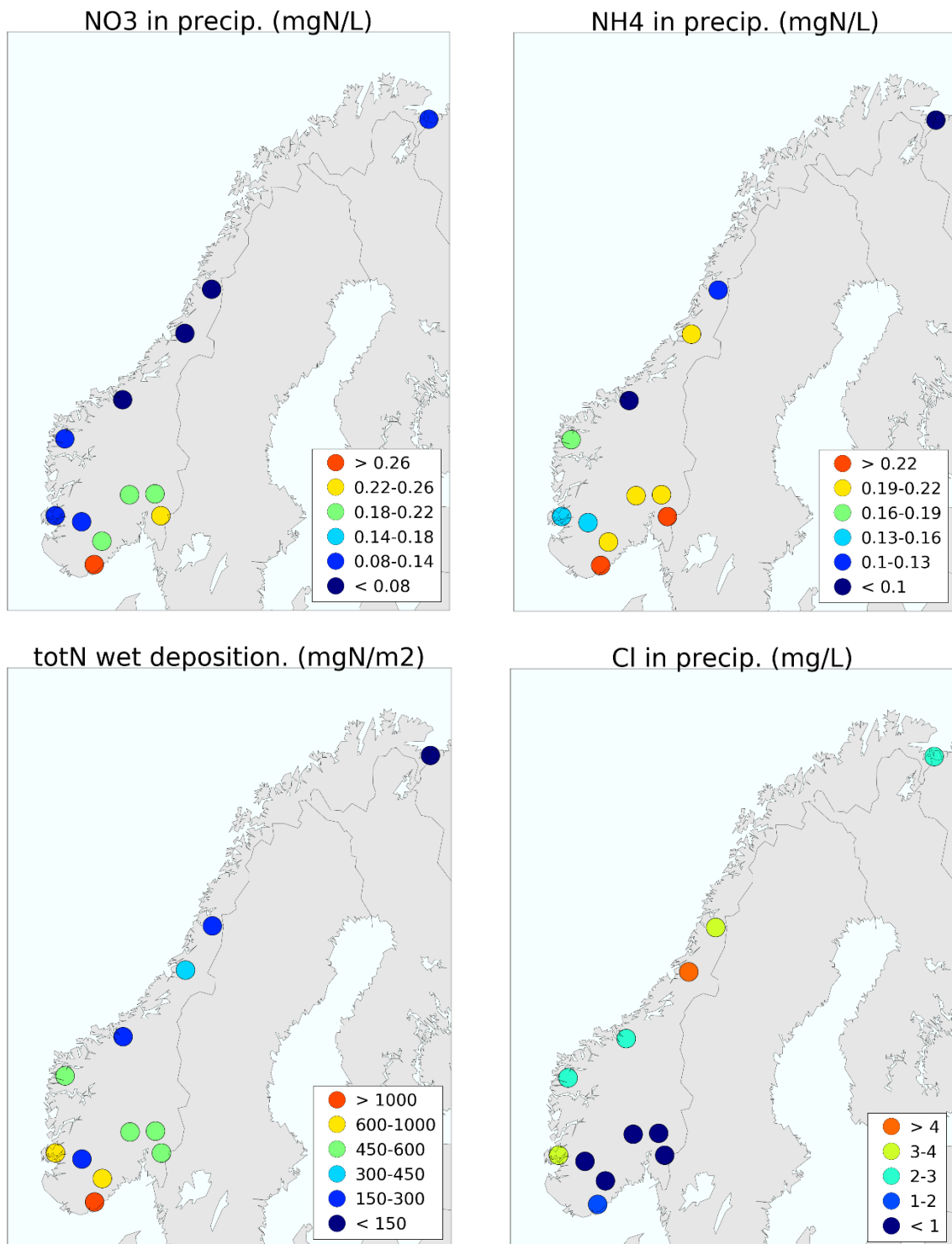


Figure 3.2: Annual volume weighted mean concentrations of nitrate, ammonium, chloride and total wet deposition of nitrogen (nitrate + ammonium), 2019. Note that the colours only resemble the spatial distribution and do not indicate any exceedances of limit values or similar.

Figure 3.3 shows monthly volume weighted mean concentrations and wet deposition of sulfate, nitrate and ammonium in different parts of Norway, 2019. 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 2019, the highest concentrations were for most ions seen in April. For wet deposition the highest levels were seen in May to August, but there are large variations between regions and periods. The measured wet deposition of sulfate, shows that between 32% and 56% 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).

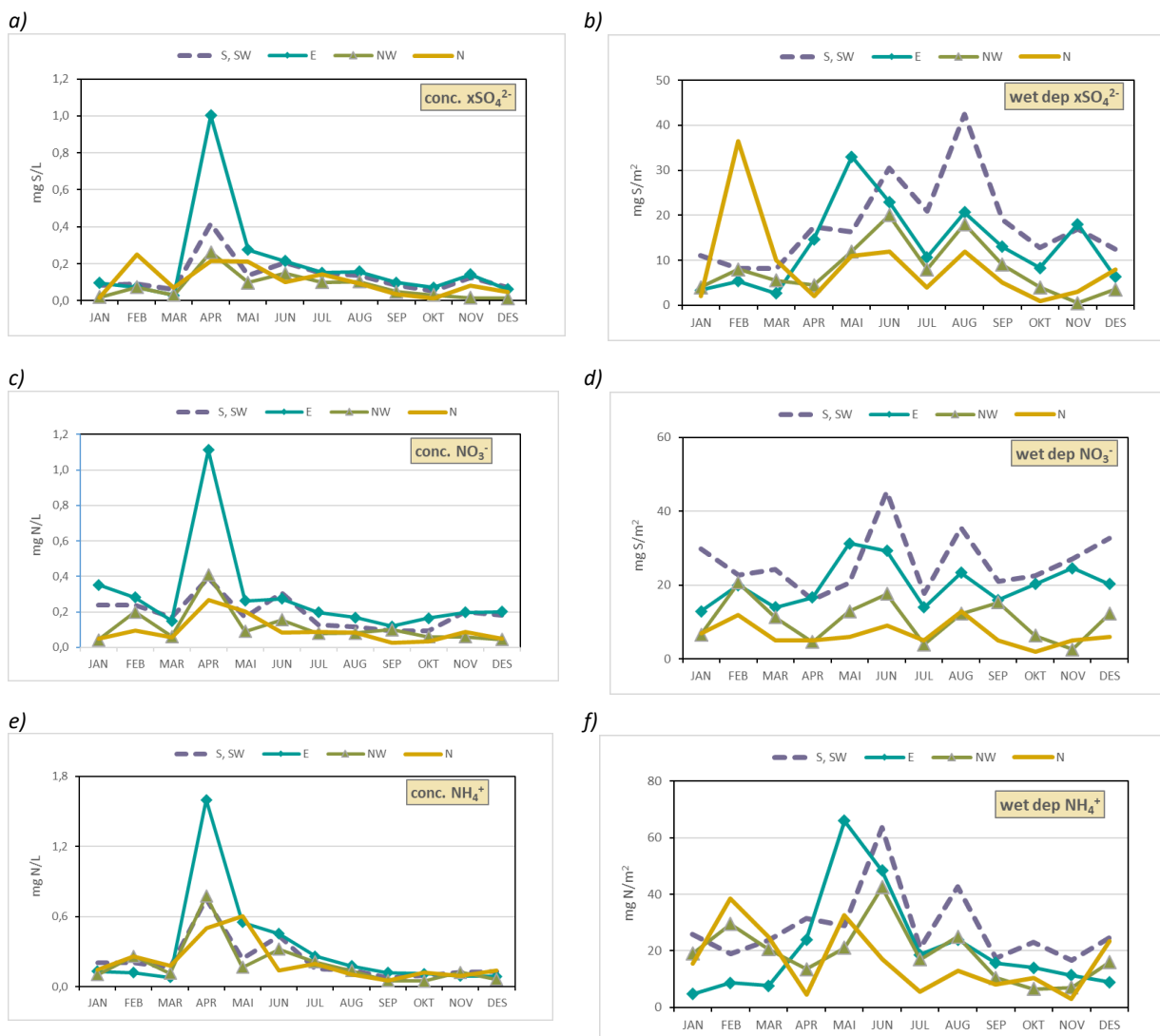


Figure 3.3: Monthly volume weighted mean concentrations (left: a),c),e)) and wet deposition (right: b),d),f)) of sea salt corrected sulfate (top) nitrate (middle), ammonium (bottom) in different parts of Norway, 2019, S, SW: South and South west is the average of the sites Birkenes, Vatnedalen, Treungen 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 2019, 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 $(\text{NO}_3^- + \text{HNO}_3)$, NH_4^+ and sum of $(\text{NH}_3 + \text{NH}_4^+)$ 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, 2019.

	SO ₂ µg-S/m ³	SO ₄ ²⁻ µg-S/m ³	NO ₂ µg-N/m ³	sum NO ₃ µg-N/m ³	NO ₃ µg-N/m ³	sum NH ₄ µg-N/m ³	NH ₄ µg-N/m ³	Mg µg/m ³	Ca µg/m ³	K µg/m ³	Cl µg/m ³	Na µg/m ³
Birkenes II	0.07	0.20	0.32	0.15	0.12	0.32	0.16	0.06	0.05	0.06	0.50	0.42
Hurdal	0.04	0.14	0.50	0.09	0.06	0.24	0.10	0.02	0.04	0.04	0.14	0.14
Kårvatn	0.03	0.10	0.16	0.04	0.02	0.46	0.06	0.02	0.03	0.03	0.18	0.14
Tustervatn	0.05	0.14	0.14	0.06	0.05	0.37	0.08	0.03	0.03	0.03	0.38	0.26
Zeppelin	0.08	0.11	-	0.03	0.01	0.12	0.03	0.04	0.03	0.05	0.32	0.24

Annual mean concentrations of sulfur dioxide in air are quite low at all the sites, in 2019 the highest, though quite low mean concentration was observed at the Zeppelin Observatory with 0.07 µg S/m³. The highest daily average was observed at Zeppelin and Tustervatn with 1.2 µg S/m³ on 15 January and 25 April. At Zeppelin this episode was caused by air masses arriving from Russia (Siberia) while at Tustervatn it was long range transport of air pollution from continental Europe. This latter episode was also seen at Hurdal and Kårvatn, both for SO₂ and SO₄²⁻ and several other components. The episode in April is described in more details in Chapter 7.

The highest annual mean particulate sulfate level was measured at Birkenes (0.20 µg S/m³), while the highest episodes were observed at Tustervatn and Kårvatn and Hurdal due to the above mentioned episode. Highest NO₂ levels were observed in Hurdal with an annual mean of 0.5 µg N/m³. This station is influenced by the relatively high traffic emissions in the region. The highest daily mean level of NO₂ was also measured at Hurdal with 8.3 µg N/m³ on 13 December. The concentrations of NO₂ show an expected temporal pattern with a winter maximum and summer minimum especially at Hurdal (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 (NO₃⁻ + HNO₃) and the sum of ammonium (NH₃ + NH₄⁺) were observed at Birkenes with 0.15 - 0.16 µg N/m³. Elevated levels were also observed at Tustervatn and Kårvatn, these sites are somewhat influenced by agricultural activity in their regions.

Table 3.3: Number of daily, observations 50-, 75-, 90-percentile concentrations, max and annual mean concentrations for SO₂ in air at Norwegian background station in 2019.

Site	No. of observations	SO ₂ (µg S/m ³)					
		Percentile conc.			Max concentration	Date	Annual mean concentration
50%	75%	90%					
Birkenes II	365	0.03	0.09	0.19	0.47	16.07.2019	0.07
Hurdal	366	0.01	0.04	0.08	0.76	22.04.2019	0.04
Kårvatn	365	0.01	0.02	0.05	0.43	24.04.2019	0.03
Tustervatn	359	0.01	0.04	0.10	1.22	25.04.2019	0.05
Zeppelin	356	0.01	0.04	0.18	1.21	15.01.2019	0.08

Table 3.4: Number of daily, observations 50-, 75-, 90-percentile concentrations, max- and annual mean concentrations for SO₄²⁻ in aerosols at Norwegian background station in 2019.

Site	No. of observations	SO ₄ ²⁻ (µg S/m ³)					
		Percentile conc.			Max concentration	Date	Annual mean concentration
50%	75%	90%					
Birkenes II	366	0.15	0.28	0.46	1.43	24.01.2019	0.20
Hurdal	366	0.08	0.19	0.34	1.21	22.04.2019	0.14
Kårvatn	365	0.04	0.12	0.24	1.71	25.04.2019	0.10
Tustervatn	359	0.09	0.17	0.28	1.13	26.04.2019	0.14
Zeppelin	356	0.08	0.15	0.24	0.75	01.05.2019	0.11

Table 3.5: Number of daily, observations 50-, 75-, 90-percentile concentrations, max and annual mean concentrations for NO₂ in air at Norwegian background station in 2019.

Site	No. of observations	NO ₂ (µg N/m ³)					
		Percentile conc.			Max concentration	Date	Annual mean concentration
50%	75%	90%					
Birkenes II	365	0.30	0.41	0.53	2.07	15.02.2019	0.32
Hurdal	364	0.34	0.55	0.88	8.28	13.12.2019	0.50
Kårvatn	365	0.15	0.20	0.27	0.75	25.11.2019	0.16
Tustervatn	365	0.13	0.18	0.22	0.69	08.07.2019	0.14

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 2019.

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	365	0.08	0.17	0.36	1.50	17.02.2019	0.15
Hurdal	366	0.05	0.11	0.19	1.03	18.02.2019	0.09
Kårvatn	365	0.02	0.04	0.08	0.47	25.04.2019	0.04
Tustervatn	359	0.03	0.05	0.11	0.99	19.04.2019	0.06
Zeppelinfjellet	356	0.02	0.03	0.04	0.22	07.07.2019	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 2019.

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	365	0.06	0.20	0.42	1.97	24.01.2019	0.16
Hurdal	366	0.04	0.12	0.25	1.24	22.04.2019	0.10
Kårvatn	365	0.01	0.04	0.14	1.36	25.04.2019	0.06
Tustervatn	359	0.01	0.07	0.20	1.47	24.01.2019	0.08
Zeppelinfjellet	356	0.01	0.03	0.08	0.20	29.08.2019	0.03

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 2019.

Site	No. of observations	NH ₄ ⁺ (µg N/m ³)					
		Percentile conc.			Max concentration	Date	Annual mean concentration
50%	75%	90%					
Birkenes II	365	0.18	0.39	0.78	2.41	22.04.2019	0.32
Hurdal	366	0.16	0.29	0.50	1.81	22.04.2019	0.24
Kårvatn	365	0.28	0.62	1.08	3.11	26.08.2019	0.46
Tustervatn	355	0.25	0.51	0.80	2.03	01.06.2019	0.37
Zeppelinfjellet	356	0.12	0.16	0.21	0.44	09.11.2019	0.12

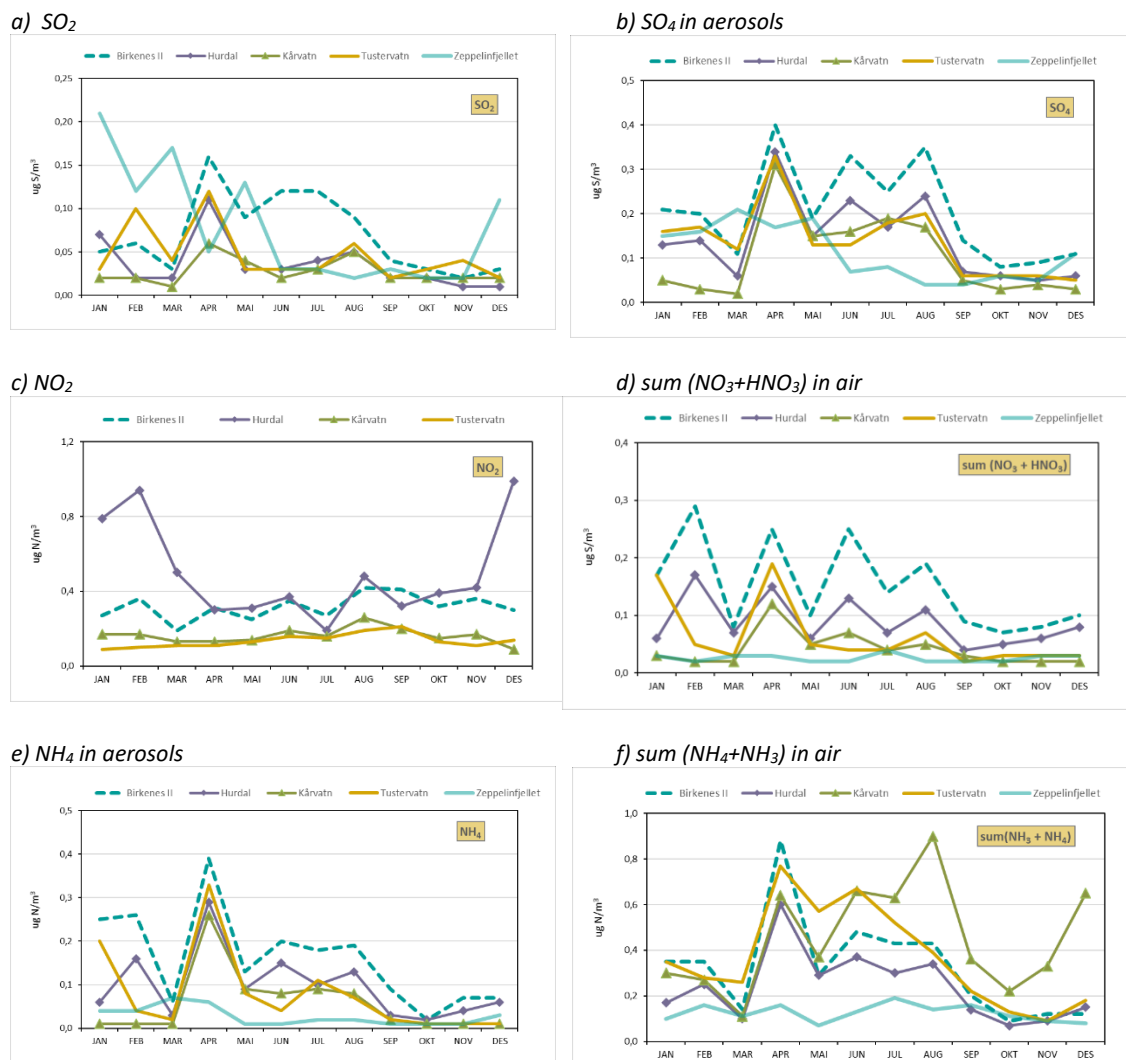


Figure 3.4: Monthly mean concentrations of sulfur- and nitrogen components in air at the five EMEP sites in Norway in 2019. Unit: $\mu\text{g(S or N)}/\text{m}^3$.

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 ($\text{NO}_3^- + \text{HNO}_3$), and sum of ammonium ($\text{NH}_3 + \text{NH}_4^+$) 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 ($\text{NO}_3^- + \text{HNO}_3$), it is assumed that HNO_3 contributes with 25% and NO_3^- with 75%, whereas for the sum of ammonium ($\text{NH}_3 + \text{NH}_4^+$) 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 15-30% in summer and 3-7% in winter except at Svalbard where the dry deposition is higher due low precipitation amount. Dry deposition of nitrogen contributes between 13-34% in summer and 6-17% 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 2019.

Dry deposition = measured air concentrations · dry deposition velocity from literature

Dry deposition velocities used: SO₂: 0.1 cm/s (winter) - 0.7 cm/s (summer). SO₄: 0.2-0.6 cm/s, NO₂: 0.1-0.5 cm/s, HNO₃: 1.5-2.5 cm/s, NO₃: 0.2-0.6 cm/s, NH₄: 0.2-0.6 cm/s, NH₃: 0.1-0.7 cm/s. Sum nitrate = 25% HNO₃ + 75% NO₃. Sum ammonium = 8% NH₃ + 92% NH₄.

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/m ²)						Nitrogen (mg N/m ²)					
	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	7	30	156	157	4	16	31	78	495	513	6	13
Hurdal	5	18	60	121	7	13	16	107	193	328	7	25
Kårvatn	3	15	26	50	10	23	19	71	89	155	17	31
Tustervatn	6	16	36	88	13	15	20	59	112	112	15	34
Zeppelin-fjellet*	6	12	30	18	17	41	-	-	20	37	-	-

*Used the wet deposition at Ny-Ålesund.

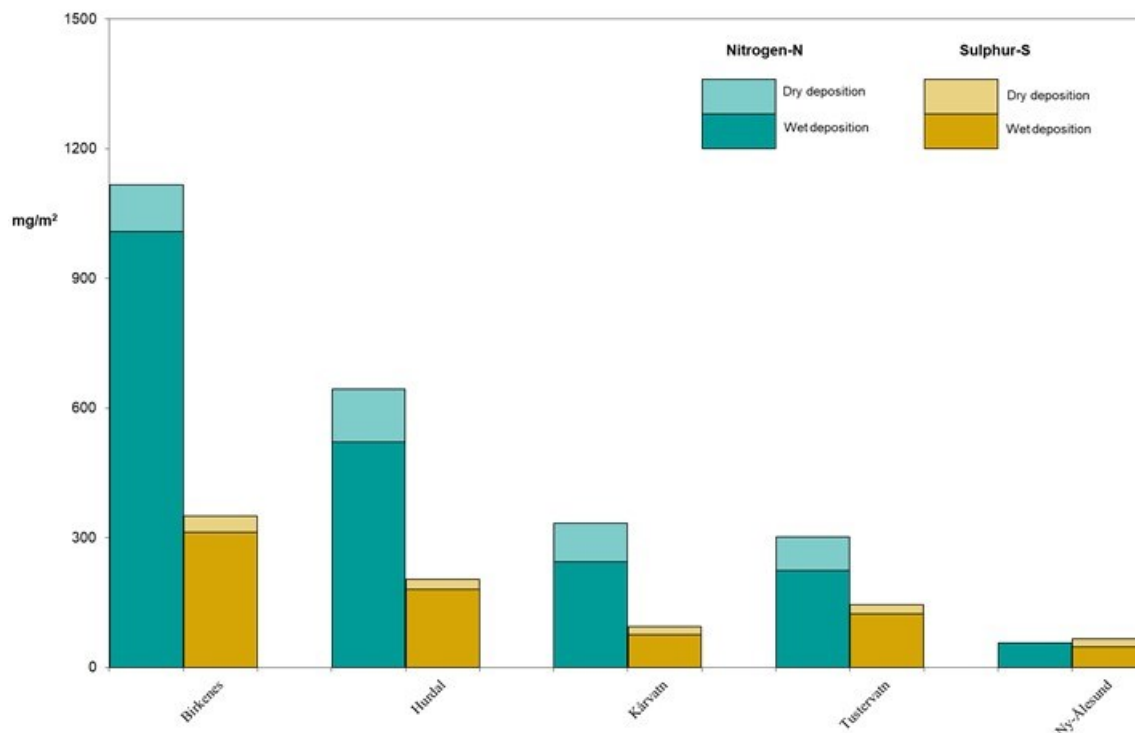


Figure 3.5: Total deposition (wet+ dry) of sulfur-S (SO_2 , SO_4^{2-}) and nitrogen-N (NO_2 , NH_4^+ , NH_3 , NO_3^- , HNO_3) at Norwegian background stations 2019.

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 2019 were in general a bit lower or equal compared to 2018 (Figure 3.6).

Table 3.10 and 3.11 shows the trends for four different periods, 1980-, 1990-, 2000-, and 2005-2019 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 2019. 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 93% 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; 89% for sulfur dioxide and 68% for sulfate, Table 3.10.

The reductions since 1990 have been between 65% and 88% (sulfate in precipitation), 75-95% (sulfur dioxide) and 72-82% (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 39% and 71%. For sulfur dioxide and sulfate in air, there are significant reductions at all mainland sites (except Kårvatn for SO₂) with 54-61% and 50-63%, respectively. Most of the sites with trends from 2005 show an observed sulfur reduction in precipitation close to the target of 59% emission reductions, which is to be reached within 2020. For sulfate in air the trends in between 40-50%.

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 27% and 53% from 1990 to 2019. Most of the sites also show a decrease of ammonium, but some show a significant increase. There is a decrease in the observed ammonium from 1990 (but not from 2000) and a decrease from 1990 for sum ammonium at three of the four sites at the mainland, around 50%; while for sum nitrate only one site show a significant decrease. For nitrogen species, the annual variations vary somewhat more than for sulfur species due more influence of changes in local emissions, which can make it more difficult to detect trends in long range transport of air pollution.

The NO₂ concentration has decreased at all four sites, between 40-69% from 1990 and 39-47% 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). However an increase in calcium at three sites from 2000, which is not consistent for the 2005-2019 period, indicates that there are variations in the contribution from mineral dust influencing the trends. The contribution of sea salts are influenced by meteorological conditions and vary from year to year. A significant reduction is seen at Treungen from 1980-2019, but only at Ny Ålesund there is a consistent decrease in seas salt ions (Mg²⁺ and Ca²⁺) for all the periods since 1990.

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- 2019	1990- 2019	2000- 2019	2005- 2019	1980- 2019	1990- 2019	2000- 2019	2005- 2019	1980- 2019	1990- 2019	2000- 2019	2005- 2019
Birkenes	-93	-83	-65	-63	-45	-43	-28	-34	-55	-41	-	-
Treungen	-96	-86	-64	-55	-46	-46	-28	-	-52	-41	-	-
Vatnedalen	-91	-77	-51	-	-44	-41	-	-35	-	-	-	-
Løken	-98	-88	-59	-50	-55	-48	-25	-27	-64	-42	-	-
Nordmoen/Hurdal		-84	-55	-54		-37	-27	-43		-	-	-42
Gulsvik/Brekkebygda	-97	-85	-63	-61	-57	-53	-	-38	-68	-56	-32	-47
Vikedal		-91	-73	-64		-38	-40	-36		-	-	-
Nausta		-83	-66	-		-27	-	-		78	81	-
Kårvatn	-77	-55	-39	-	-	-	-	-	-	-	-	-
Høylandet		-80	-71	-71		-32	-38	-70		78	-	-
Tustervatn	-87	-65	-	-	-	-	-	-20	-	-27	-40	-
Ny-Ålesund	-87	-83	-	-	-	-	-	-	-	-	-	-

Table 3.10 (cont.)

Trends in annual mean concentrations of inorganic ions in precipitation.

	mm				Mg ²⁺				Ca ²⁺			
	1980- 2019	1990- 2019	2000- 2019	2005- 2019	1980- 2019	1990- 2019	2000- 2019	2005- 2019	1980- 2019	1990- 2019	2000- 2019	2005- 2019
Birkenes	35	46	-	-	-	-	-	-	-34	-	63	-
Treungen	24	32	-	-	-	-	-	-	-31	-	30	-
Vatnedalen	-	-	-	-	-	-59	-	-	-	-	-	-51
Løken	-	-	-	-	-	-	-	-	-46	-	59	75
Nordmoen/Hurdal		24	-	-		-	-	-		64	-	-
Gulsvik/Brekkebygda	68	79	-	-	-	-	-	-	-	-	-	-
Vikedal		-	-	-		-	-	-		-	-	-
Nausta	-	-32	-	-47	-	-	-	-	-	-	-	-
Kårvatn	-	-	-	-	-	-	-	-	-	-	-	-
Høylandet		-	-	-		-	-	-		-	-	-
Tustervatn	-	-23	-21	-	-	-	-	-	-34	-	-	-
Ny-Ålesund	-	-	-	-	-	-43	-58	-56	-42	-47	-74	-84

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⁻			
	1980-2019	1990-2019	2000-2019	2005-2019	1980-2019	1990-2019	2000-2019	2005-2019
Birkenes	~ -100%	-95	-55	-	-86	-74	-54	-41
Nordmoen/Hurdal		-91	-61	-56		-82	-63	-50
Kårvatn	~ -100%	-75	-	-	-88	-72	-50	-42
Tustervatn	~ -100%	-91	-54	-	-93	-77	-52	-41
Zeppelin	-89	-75	-61	-	-68	-44	-28	-

	NO ₂				sum(NO ₃ +HNO ₃)			
	1980-2019	1990-2019	2000-2019	2005-2019	1980-2019	1990-2019	2000-2019	2005-2019
Birkenes		-68	-47	-34		-	-	-
Nordmoen/Hurdal		-69	-39	-32		-37	-	-
Kårvatn		-40	-43	-		-	-	-
Tustervatn		-52	-39	-		-	-	-
Zeppelin						-	-	-

	sum(NH ₄ ⁺ +NH ₃)				NH ₄ ⁺			
	1980-2019	1990-2019	2000-2019	2005-2019	1980-2019	1990-2019	2000-2019	2005-2019
Birkenes		-31	-40	-54		-51	-	-
Nordmoen/Hurdal		-48	-	-69		-68	-	-
Kårvatn		-	-45	-63		-	-	-
Tustervatn		-	-65	-78		-54	-	-
Zeppelin		249	-	-81		-	-	-

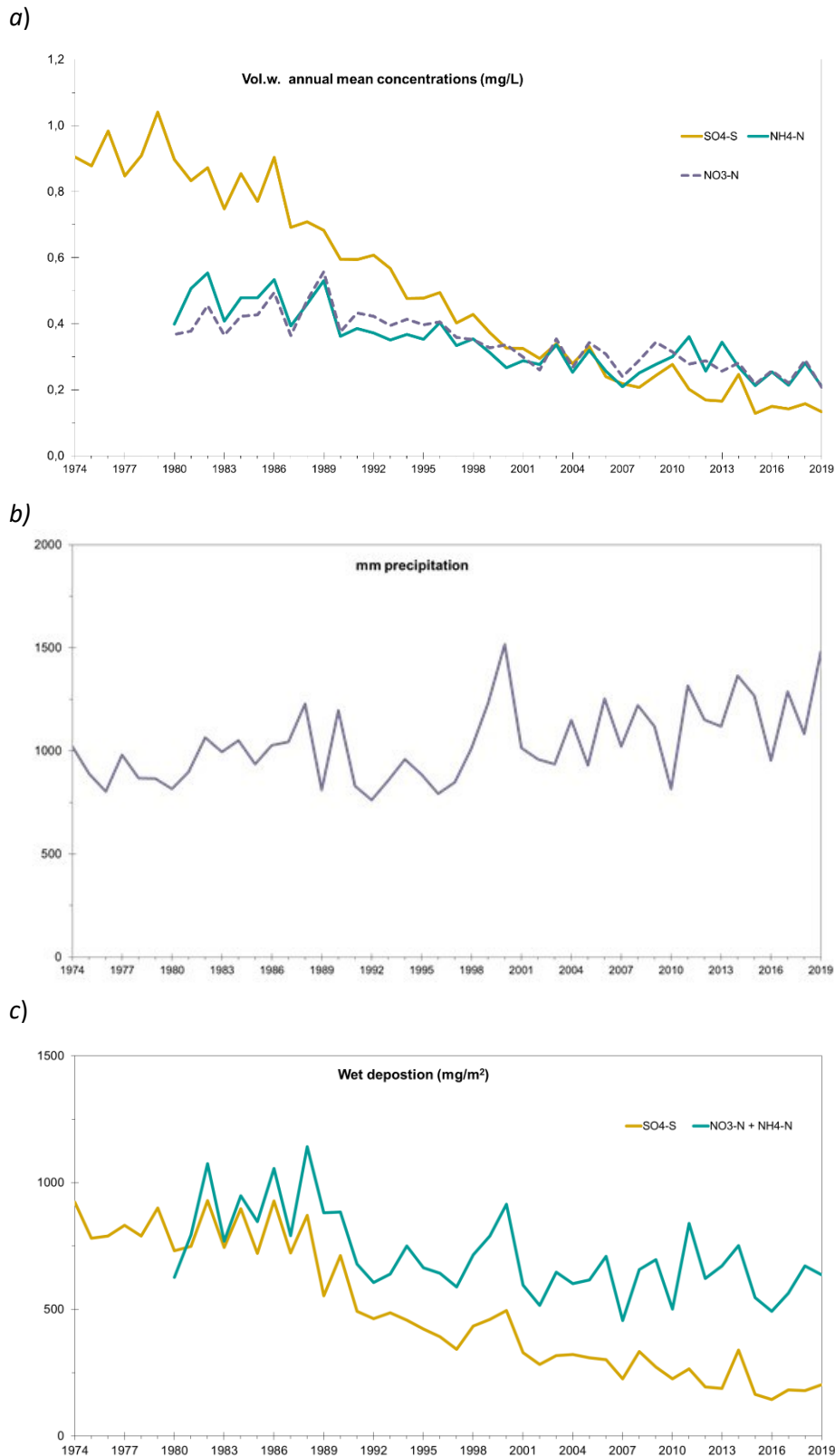


Figure 3.6: Average volume weighted annual mean concentrations (a), precipitation amount (b) and wet deposition (c) for sea salt corrected sulfate, nitrate and ammonium at five representative sites in southern Norway (Birkenes, Vatnedalen, Treungen, Gulsvik and Løken), 1974-2019.

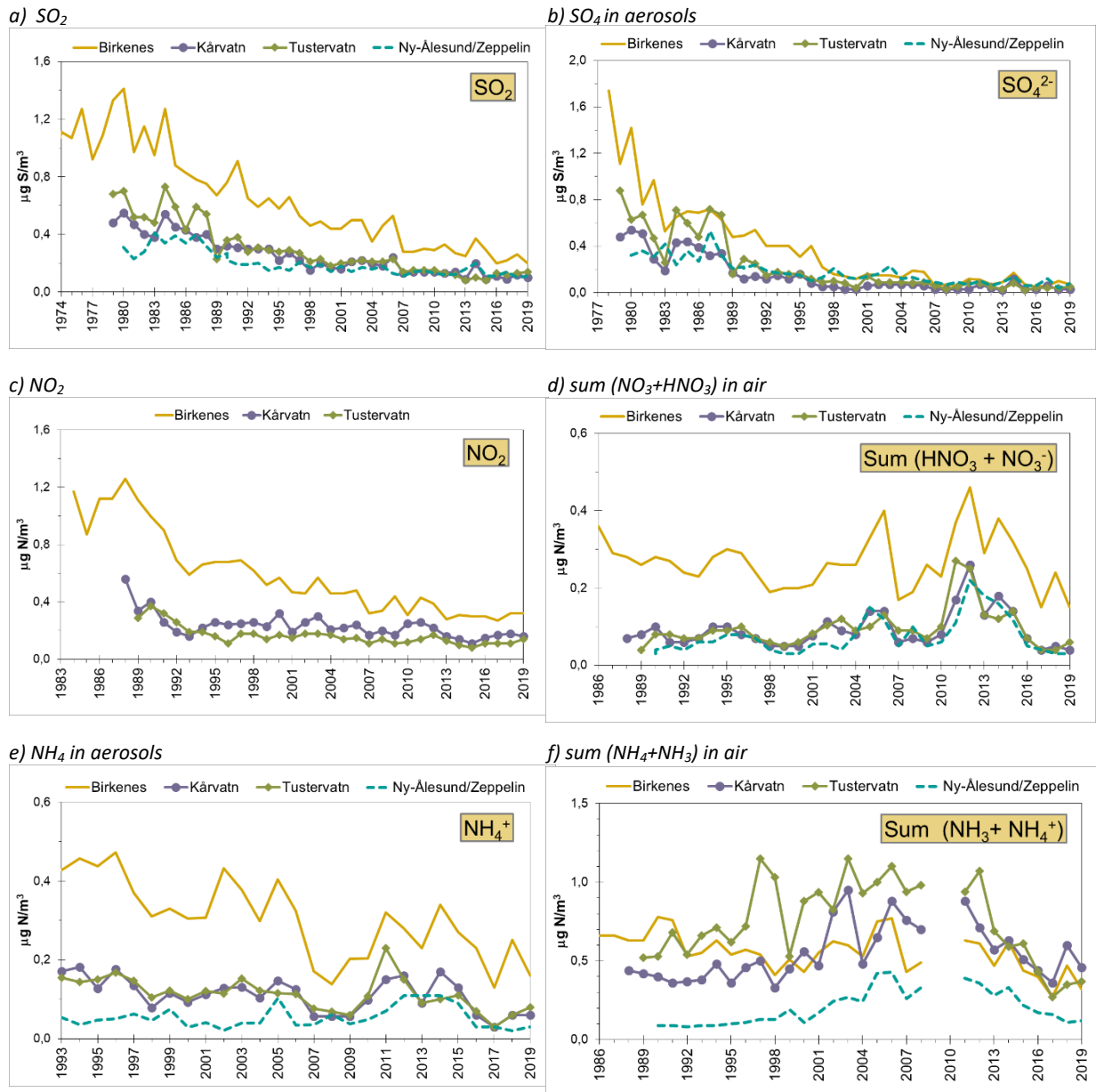


Figure 3.7: Annual mean concentrations of sulfur and nitrogen components in air at four Norwegian EMEP sites, 1973-2019.

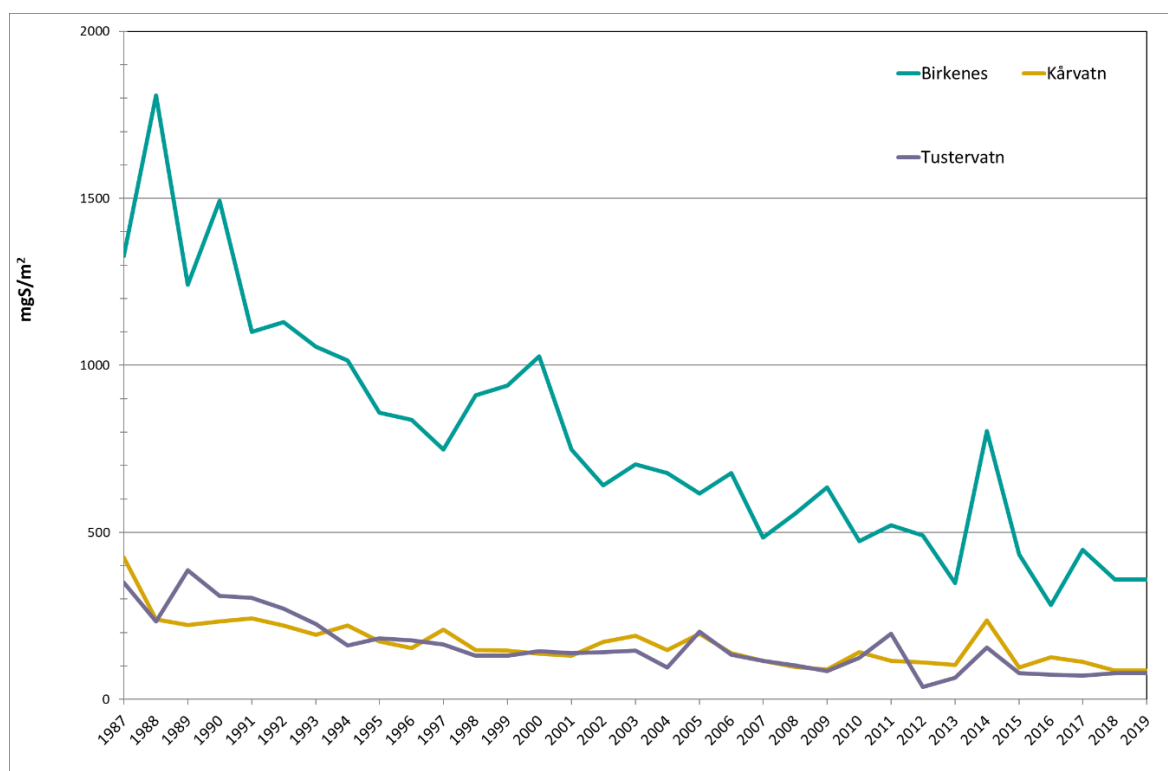


Figure 3.8: Trends in total deposition (wet + dry) of sulfur at three Norwegian EMEP sites, 1987-2019.

3.3 Summary

For most of the main inorganic components, the highest annual mean concentrations in 2019 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, 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 2019 were in general a bit lower compared to 2018. In a longer 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 most sites show trends in sulfate in precipitation close to the European target of 59% emission reductions set by the Gothenburg protocol to be reached within 2020.

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 40-69% from 1990. These observed reductions are in line with reported emission reduction at the European continent (Colette et al, 2015), although most sites show lower trends in oxidized nitrogen than the target of 43% reductions in NO_x emissions set by the Gothenburg protocol from 2005.

4 EC and OC

4.1 Introduction

Monitoring of Elemental Carbon (EC) and Organic Carbon (OC) in PM₁₀ 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. For 2019, OC and EC measurements in PM₁₀ for the remote Arctic site Zeppelin Observatory was included.

Annual and monthly mean concentrations of EC and OC in PM₁₀ and PM_{2.5} for 2019 are shown in Table A.1.35, whereas annual mean concentrations for EC and OC in PM₁₀ and PM_{2.5} for the period 2001 – 2019 are listed in Table A.1.36.

Incidences of PM_{2.5} > PM₁₀ 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_{10-2.5} is derived from the observed values of OC in PM₁₀ 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 PM₁₀, PM_{2.5} and PM_{10-2.5}

The annual mean concentration of OC in PM₁₀ (0.69 – 1.23 µg C/m³) and PM_{2.5} (0.53 – 0.71 µg C/m³) at Norwegian rural background sites are amongst the lowest in Europe. Fine fraction OC (58 – 77%) was the major fraction of OC in PM₁₀ 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 typically 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 PM₁₀ at Hurdal was 30-80% higher than at Birkenes and at Kårvatn. The difference in concentration was largely explained by the coarse fraction of PM₁₀. Coarse OC is mainly associated with PBAP of local to regional origin. The measurements do not allow for explaining why the source strength is so much higher at Hurdal compared to the other sites, and we are left with concluding that it reflects variability in the local vegetation. 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 NO₂ and EC concentrations seen for this site, which has been explained by high emissions from vehicular traffic in this region (see Chapter 3.1.2)

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 in the vegetative season (See Yttri et al. 2011 a, b). The highest levels of fine OC were seen in April, which experienced temperatures high above normal and precipitation below normal at all sites, and at Birkenes the monthly mean exceeded 2 µg C m⁻³, which rarely occurs. Several sources contributed to the elevated levels observed in April, including emissions from wildfires in Eastern Europe in the last week of April, as confirmed by unusually high levoglucosan levels at the actual time of the year at Birkenes. Indeed, a weekly mean OC concentration exceeding 4 µg C m⁻³ was seen for two of the weeks in April. The April

episode caused elevated concentration for many species across several sites in Norway and is described in more details in Chapter 7.

There was a certain level of covariance between sites both with respect to seasonality and high concentration episodes. This was driven by fine fraction OC and was particularly pronounced for the two southernmost sites, Birkenes and Hurdal. Such seasonal covariance is driven by climatological factors. As an example, temperature is decisive for the formation of SOA and pollen release in summer as well as for domestic heating in winter. 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_{2.5} was within -SD of the long-term mean at all sites, whereas coarse OC was higher than +SD at Birkenes and Hurdal and within -SD at Kårvatn. Consequently, OC in PM₁₀ was within +SD at Birkenes and Hurdal and within -SD at Kårvatn. The annual mean coarse OC observed at Hurdal and Birkenes in 2019 was the highest and second highest seen so far. Consequently, OC in PM₁₀ at these two sites was only marginally lower than the previous year despite that fine OC was rather low.

The annual mean OC concentration at the Zeppelin Observatory was 7 - 12 times lower than that observed at rural background sites on the Norwegian mainland. The seasonality of OC largely resembled that of rural sites at the Norwegian mainland, except that the increased level in the vegetative season associated with BSOA and PBAP started 1 - 2 months later. The biomass burning tracer levoglucosan was elevated in the heating season but also in late summer and early fall, showing the influence of residential wood burning and wild fires, respectively.

4.3 Concentrations of EC in PM₁₀ and PM_{2.5}

The annual mean concentration of EC in PM₁₀ (0.05 – 0.11 µg C/m³) and PM_{2.5} (0.05 – 0.10 µg C/m³) 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 PM₁₀. EC levels at Hurdal were 25 - 40% higher than at Birkenes and 100 – 120% higher than at Kårvatn, considering both the PM₁₀ 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., 7 – 8% (PM₁₀) and 9 – 12% (PM_{2.5}). The annual mean EC/TC ratio was within ±SD of the long-term EC/TC mean at all sites, except for PM₁₀ at Birkenes where it was just below -SD.

The very high monthly mean seen for April explains the somewhat deviating seasonality of EC compared to previous years, causing a slightly higher mean for summer than in winter at Birkenes, marginally higher levels in winter than in summer at Hurdal, and noticeably higher levels in summer than in winter at Kårvatn. A mix of EC from fossil fuel combustion and from agricultural fires, a certain contribution from residential heating cannot be excluded, contributed to the high monthly mean for April. The contribution of biomass burning to EC (and OC) have been estimated based on levoglucosan measurements (Chapter 4.6).

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

The annual mean EC concentration at the Zeppelin Observatory was 5 - 11 times lower than that observed at rural background sites on the Norwegian mainland. EC was elevated in winter compared to summer, and more pronounced than at the rural background sites. The annual mean EC/TC ratio at

Zeppelin (9%) was slightly higher than calculated for rural background sites. This finding was most pronounced in winter and spring, and may reflect issues such as different source regions, source composition and removal processes.

4.4 Relative contribution of EC and OC to PM

The relative contribution of OC to PM₁₀ (20 – 27%) and PM_{2.5} (23 – 28%) annually was rather similar, and for Birkenes somewhat lower than for the two other sites. The OC fraction was higher in summer than in winter, but less pronounced for PM_{2.5} than for PM₁₀. The relative contribution of OC to PM_{10-2.5} was 13 – 27% on an annual basis, and more pronounced in summer (21 – 33%) than in winter (4 – 13%).

EC accounted for 1.7 – 2.4% of PM₁₀ annually and somewhat higher for PM_{2.5} (2.6 – 3.7%), reflecting that EC is associated with fine aerosol particles. EC was more abundant in the winter-time aerosol (1.8 – 3.7% for PM₁₀ and 3.5 – 5.4% for PM_{2.5}) than the summer-time aerosol (1.4 – 1.6% for PM₁₀ and 2.4 – 2.6% for PM_{2.5}).

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 (9 years) allow for an assessment of the Birkenes site only (Table 4.1). The time series of OC in PM₁₀, PM_{2.5} and PM_{10-2.5}, and that of EC in PM₁₀ and PM_{2.5}, at the Birkenes Observatory are shown in Figure 4.1.

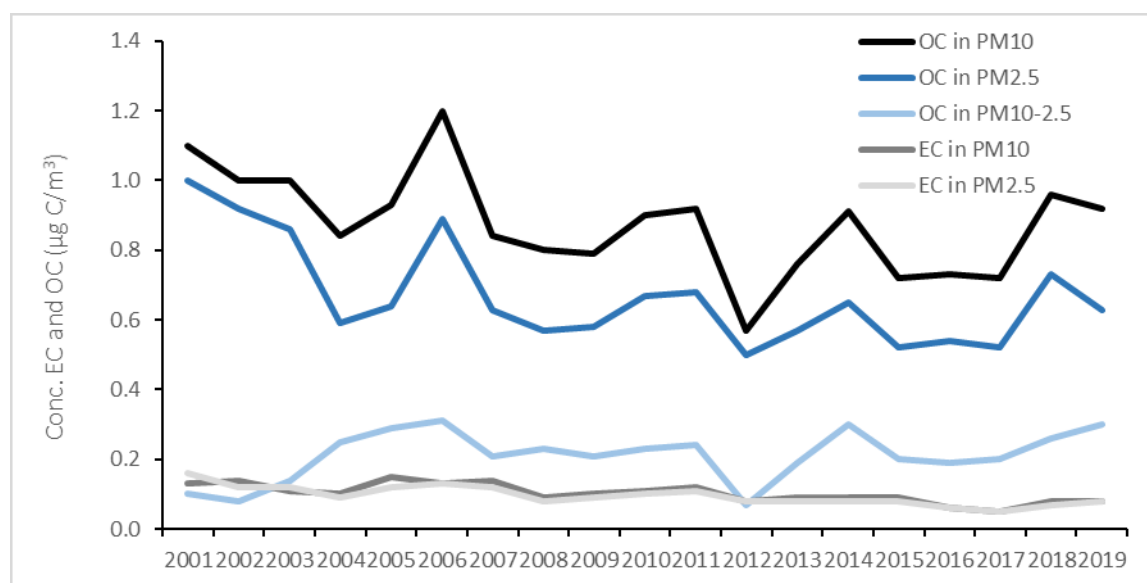


Figure 4.1: Annual mean time series of EC and OC, as observed at the Birkenes Atmospheric Observatory (2001 – 2019).

There was a statistically significant downward trend for the annual mean concentration of OC in both PM₁₀ (-20%) and PM_{2.5} (-31%) at Birkenes for the period 2001 – 2019. EC showed a statistically significant downward trend for both PM₁₀ (-49%) and PM_{2.5} (-55%) for 2001 – 2019.

Table 4.1: Trends in annual mean mass concentration of OC, EC and TC in PM₁₀ (2001 - 2019) and PM_{2.5} (2001 - 2019) using Mann-Kendall test and Sen slope estimates; significant level is set to 0.05.

Site	PM ₁₀	% change	PM _{2.5}	% change
Birkenes				
OC	*	-20%	*	-31%
EC	*	-49%	*	-55%
TC	*	-31%	*	-36%

Trends are calculated for time series extending 10 full years.

No statistically significant upward or downward trends was observed for OC to PM for neither of the size fractions. A decrease in the relative contribution of EC to PM₁₀ (-25%) was observed for 2001 – 2019 at Birkenes.

4.6 Concentrations of levoglucosan, mannosan and galactosan in PM₁₀

Measurements of levoglucosan, mannosan and galactosan in PM₁₀ 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 PM₁₀ observed at the Birkenes Observatory was 8.3 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. The elevated concentrations in the beginning and the end of April are associated with long range transport from agricultural fire emissions in the Belarus and Western parts of Russia (Se Chapter 7).

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: 12.7 for OC in PM₁₀, 11.1 for OC in PM_{2.5}, and 1.96 for EC (Yttri et al., in prep.)). Some influence from wild and agricultural fires in the vegetative season is likely, but the magnitude of these sources remains speculative except for such major episodes as seen in April.

We estimate that biomass burning contributed 11-17% to OC and 21% to EC, annually, considering both PM₁₀ and PM_{2.5}. The fraction attributed to biomass burning in winter was 40% for OC and 33-37%-56% for EC, whereas it was ≤2.5% (OC) and <5% (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.

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 PM₁₀ at Birkenes for 2017-2019. Seasonal mean concentrations for 2019. Unit: ng m⁻³.

Year		Levoglucosan	Mannosan	Galactosan
2017	Annual	8.2	1.3	0.32
2018	Annual	9.8	1.6	0.39
2019	Annual	8.3	1.4	0.29
	Winter	16.7	2.7	0.61
	Spring	8.3	1.2	0.26
	Summer	1.3	0.3	0.05
	Fall	6.9	1.3	0.23

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 < 1.2 µg C m⁻³ and EC < 0.11 µg C m⁻³), and a statistically significant downward trend was observed for OC (-20 - -31%) and EC (-49 - -55%) in PM₁₀ and PM_{2.5} for the period 2001 – 2019.

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, as also agricultural and wild fires as seen in April 2019 typically are initiated by anthropogenic activity. Estimates based on levoglucosan measurements suggest that biomass burning contributed 11-17% to OC and 21% to EC at the Birkenes Observatory annually, considering both PM₁₀ and PM_{2.5}, and 40% for OC and around 33-37% for EC in winter.

5 Particulate matter, mass concentrations

5.1 Introduction

Monitoring of the PM₁₀ 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 PM₁₀ started in 2017.

Annual and monthly mean mass concentrations of PM₁₀, PM_{10-2.5} and PM_{2.5} for 2019, obtained by gravimetric measurements, are shown in Table A.1.37; whereas annual mean mass concentrations of PM₁₀, PM_{10-2.5} and PM_{2.5} for the time period 2000 – 2019 are listed in Table A.1.38. Time series of PM₁₀ and PM_{2.5} for 2019 are shown in Figure 5.1. Note that PM_{10-2.5} is derived from the observed values of PM₁₀ and PM_{2.5}; i.e. the difference between PM₁₀ and PM_{2.5}. Incidences of PM_{2.5} > PM₁₀ and ΣPM_{2.5}, PM_{10-2.5} ≠ PM₁₀ on a monthly basis are typically due to a different number of samples for PM₁₀ 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 PM₁₀ derived from high time resolution measurements, were used to assess violation of national and international limit values and air quality guidelines. Background information on PM can be found in Annex 3.

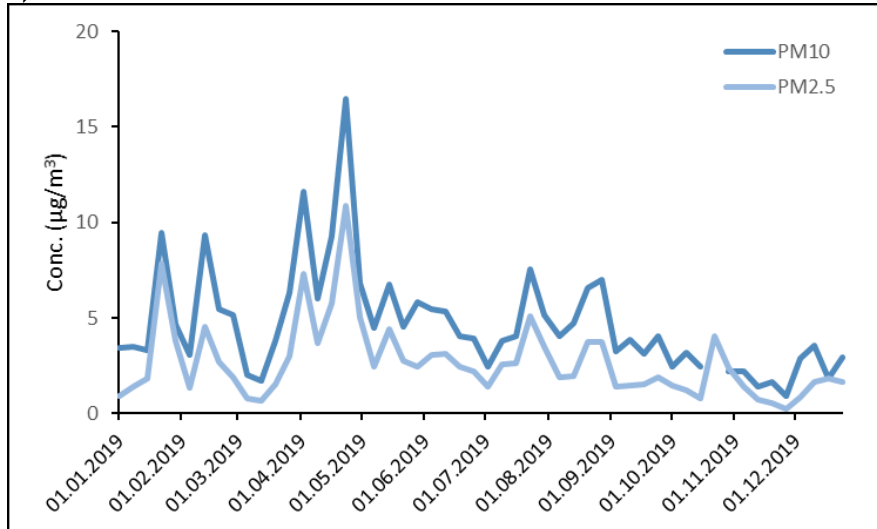
5.2 PM₁₀, PM_{2.5} and PM_{10-2.5} concentrations

The annual mean mass concentration of PM₁₀ (2.9 – 4.6 µg/m³) and PM_{2.5} (1.9 – 2.7 µg/m³) at the Norwegian rural background sites are amongst the lowest in Europe. PM_{2.5} was the major fraction of PM₁₀ at all sites on an annual basis, accounting for 59% at Birkenes and Hurdal and 66% at Kårvatn. PM_{10-2.5} was occasionally the major fraction of PM₁₀ on a monthly basis, and is typically attributed to natural sources, such as sea salts, primary biological aerosol particles (PBAP), and mineral dust.

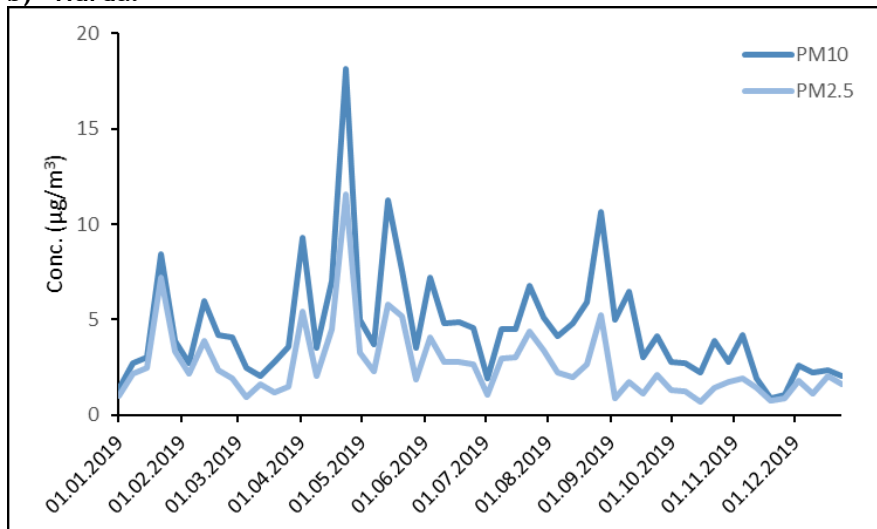
The PM₁₀ and PM_{2.5} annual means were within –SD of the long-term mean at all sites. At Birkenes, the PM_{10-2.5} annual mean was within -SD of the long-term mean, whereas it was slightly higher than +SD at Hurdal and Kårvatn. Note that the measurements for Hurdal and Kårvatn dates back to 2010, whereas measurements at Birkenes were initiated in 2000/2001.

The PM₁₀ annual mean was equally high at Birkenes and Hurdal in 2019, unlike previous years when the PM₁₀ level typically has been slightly higher at Birkenes. This has been explained by the somewhat higher PM_{10-2.5} fraction at Birkenes, as well as a higher PM_{2.5} fraction when compared to Kårvatn, but this gap has narrowed substantially over the last 10 years of sampling. The higher PM_{10-2.5} fraction at Birkenes is 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 NO₃⁻ reside in the coarse fraction of PM₁₀ at Birkenes, following from the reaction between gaseous HNO₃ and coarse mode NaCl. Coarse fraction organic matter (OM), dominated by PBAP, was 1.7 times higher at Hurdal compared to Birkenes, thus counteracting some of the discrepancy attributed to the lower sea salt aerosol contribution when compared to Birkenes.

a) Birkenes



b) Hurdal



c) Kårvatn

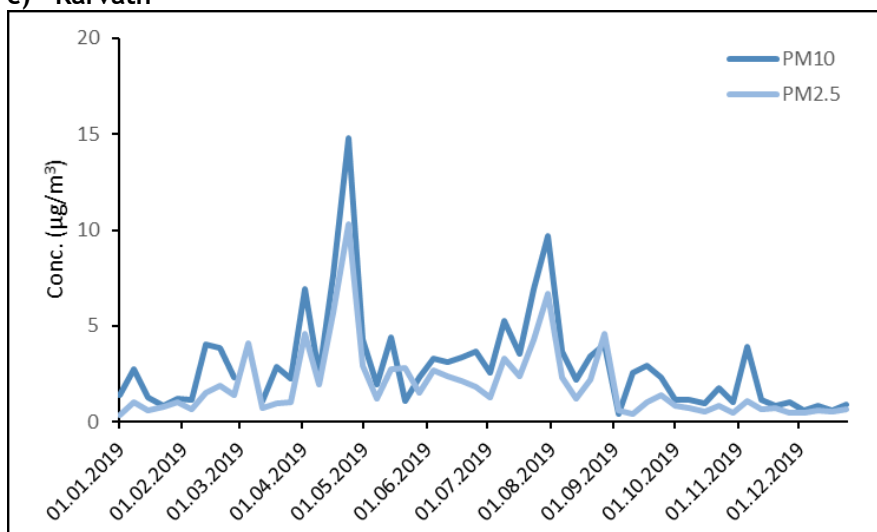


Figure 5.1: Time series of PM₁₀ and PM_{2.5} mass concentration for Birkenes (a), Hurdal (b) and Kårvatn (c) for 2019. Unit $\mu\text{g}/\text{m}^3$. Note that the time series have been harmonized in time for comparability; i.e. they all start on the same date (01.01.2019).

The annual mean $PM_{2.5}$ concentration was equally high at Hurdal and Birkenes but noticeably higher compared to Kårvatn. The difference with respect to Kårvatn 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 were 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 highest PM_{10} , $PM_{2.5}$ and $PM_{10-2.5}$ monthly means were observed in April at all sites. Southerly air masses caused temperatures high above normal and precipitation below normal at all sites and facilitated transport of air pollution from continental Europe, formation of secondary organic pollutants, as well as an early onset of PBAP emissions. Emissions from wild and agricultural fires in Belarus and western parts of Russia contributed substantially to PM levels in April (See Chapter **Error! Reference source not found.**), as did mineral dust from the African continent. Indeed, we estimated a mineral dust concentration of $3.1 \mu\text{g m}^{-3}$ for April, which was 5 times higher than the estimated annual mean ($0.6 \mu\text{g m}^{-3}$).

The 2019 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 $10 \mu\text{g m}^{-3}$ were observed at all sites both for PM_{10} and $PM_{2.5}$. The highest weekly mean ($19.6 \mu\text{g m}^{-3}$) was observed at Hurdal, but maximum concentrations at Birkenes ($17.8 \mu\text{g m}^{-3}$) and Kårvatn ($15.9 \mu\text{g m}^{-3}$) were almost equally high. The PM_{10} concentration exceeded $10 \mu\text{g m}^{-3}$ at Birkenes for four weeks, three at Hurdal, and two at Kårvatn. Secondary inorganic aerosol (SIA) was the major fraction of PM_{10} for two of the four samples for which PM_{10} exceeded $10 \mu\text{g m}^{-3}$ at Birkenes, whereas organic matter (OM) dominated two samples. Notably, mineral dust made a 24 – 27 % contribution for the two samples dominated by OM, appearing in spring. At Hurdal and Kårvatn, the highest weekly means were all dominated by OM, and for one of the weeks coarse OC was more abundant than fine OC.

The fine fraction was most abundant for most of the samples with a PM_{10} level exceeding $10 \mu\text{g m}^{-3}$, the coarse fraction was higher for one of the samples, equally high for one, and marginally lower for one. This reflects a noticeable influence of coarse fraction PM as well, originating mainly from sea salt aerosol, PBAP, mineral dust and NO_3^- .

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.

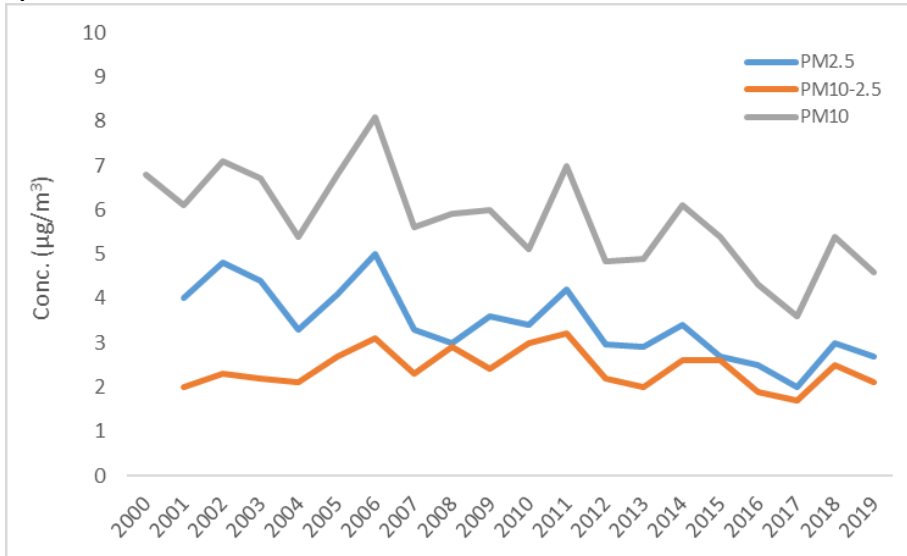
5.3 Trends

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 PM₁₀ at Birkenes, corresponding to a decrease of -33% from 2000 to 2019 (-34% for the period 2001-2019). The observed downward trend for PM_{2.5} was also statistically significant, corresponding to a decrease of -45% from 2001 to 2019. No significant trend was calculated for PM_{10-2.5}.

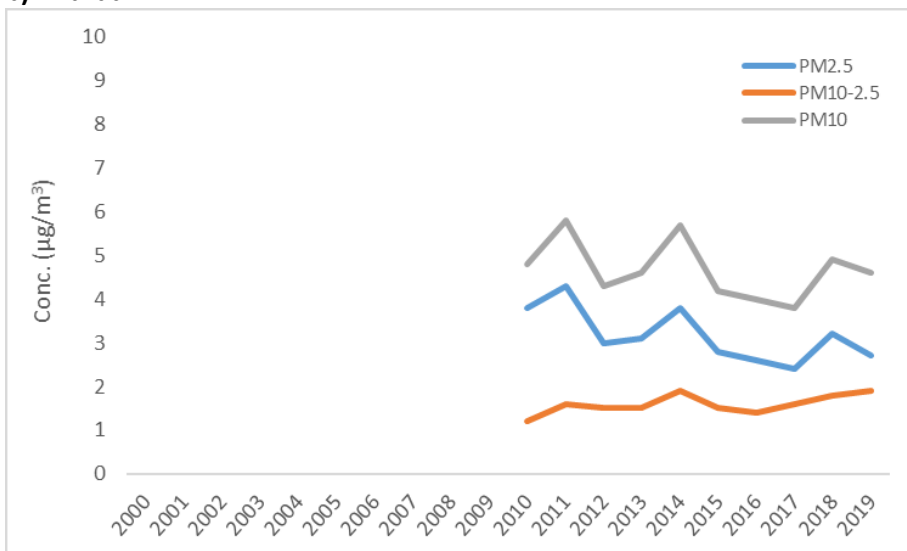
*Table 5.1: Trends in annual mean mass concentration of PM₁₀ (2000 - 2019) and PM_{2.5} (2001 – 2019) at Birkenes) using Mann-Kendall test and Sen slope estimates; * significant level 0.05.*

Site	PM ₁₀	% change	PM _{2.5}	% change
Birkenes	*	-33%	*	-45%

a) Birkenes



b) Hurdal



c) Kårvatn

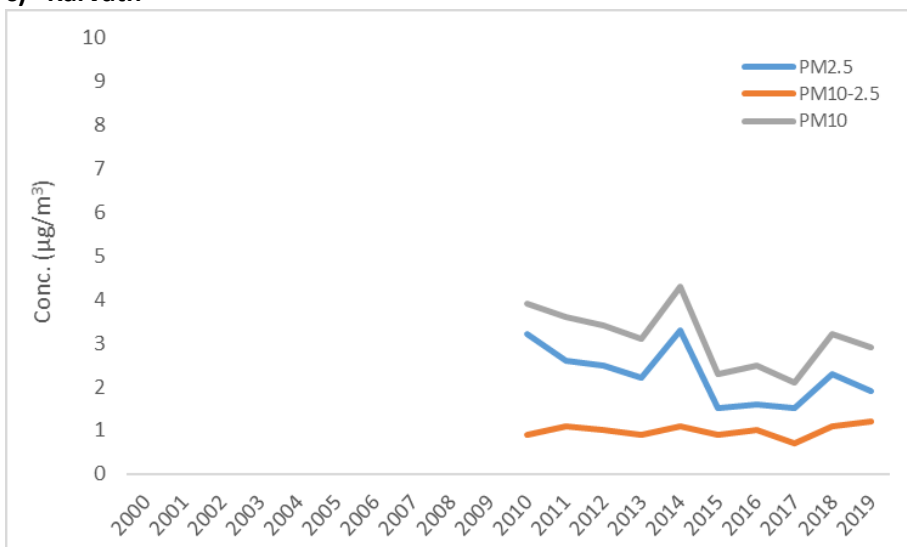


Figure 5.2: Annual mean time series of PM_{10} , $PM_{2.5}$ and $PM_{10-2.5}$ mass concentration for Birkenes (a), Hurdal (b) and Kårvatn (c) for 2001 – 2019. Unit $\mu\text{g}/\text{m}^3$.

5.4 Compliance with EU limit values and Air-Quality Guidelines for PM₁₀ and PM_{2.5}

The EU annual limit value for PM₁₀ and PM_{2.5} (See Table 5.2 for EU limit values and Air-Quality Guidelines for PM₁₀ and PM_{2.5}) was far from being violated at any of the three sites in 2019; the highest annual mean PM concentrations observed being approximately 11% of the annual limit value. This was also the case when compared to the WHO Air-Quality Guidelines (AQG); the highest annual mean concentrations accounting for 23 – 27% of the annual AQG.

New national limit values for PM₁₀ 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 2019. The National Air-Quality Guidelines (FHI, 2013) are more stringent than the WHO's with respect to PM_{2.5}, still, the highest annual mean observed for PM₁₀ and PM_{2.5} in the Norwegian rural background environment in 2019, accounted for no more than 23% and 34% of the PM₁₀ and PM_{2.5} National AQG, respectively.

The highest 24-hour mean PM₁₀ concentration observed for 2019 was 24.0 µg m⁻³, and thus did not violate any limit values or AQG. No 24-hour measurements are performed for PM_{2.5}. Unfortunately, the instrument underwent critical repair when the highest weekly means for PM₁₀ and PM_{2.5} were observed at Birkenes.

Table 5.2: EU limit values and Air-Quality Guidelines for PM₁₀ 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 values¹⁾		
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 99 th 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) 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 PM₁₀ and PM_{2.5} size fractions at the Birkenes, Hurdal and Kårvatn sites, whereas the major inorganic anions (SO₄²⁻, NO₃⁻, Cl⁻) and cations (Ca²⁺, Mg²⁺, K⁺, Na⁺, NH₄⁺) 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 PM₁₀ fraction. Occasionally, sea salt aerosol larger than PM₁₀ could be collected, i.e. during stormy weather conditions at Birkenes, at a southerly wind direction. The data obtained from the monitoring programme appear to be well suited for a mass closure of PM₁₀, except that species representing mineral dust are not included. For 2014 - 2019, 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 PM₁₀, 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 NO₃⁻, thus this is not performed.

The annual mean chemical mass composition of PM₁₀ is shown in Figure 5.3. The speciated mass explained 55 – 74% of the annual mean concentration of PM₁₀ for the three sites, approaching full mass closure (73 – 89%) when allowing for other elements than carbon for OC and EC. The PM₁₀ SIA fraction (and levels) was noticeably higher at Birkenes (29%) compared to Hurdal (18%) and Kårvatn (17%), reflecting the proximity of Birkenes to important SIA-precursor emission source regions in continental Europe. SO₄²⁻ was the most abundant single (SIA) species at all sites, and at Birkenes and Hurdal it was approximately equally high as the sum of NO₃⁻ and NH₄⁺, whereas it was almost twice as high at Kårvatn.

Converting OC to OM using a factor of 1.7 (Yttri et al., 2007) made OM more than twice as abundant as SIA at Hurdal (46%) and Kårvatn (40%), whereas OM only was slightly higher at Birkenes (34%). The higher relative contribution of EC at Hurdal (2.2%) compared to Birkenes (1.7%) and Kårvatn (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 21% sea salt aerosol contribution to PM₁₀, which is 2 – 3 time higher than at Kårvatn (12%) and Hurdal (6.4%).

Based on Fe measurements in PM₁₀ at Birkenes and knowledge about mineral dust composition in Europe (Alastuey et al., 2016), an annual mean mineral dust concentration of 0.6 µg m⁻³ was estimated for Birkenes for 2019, corresponding to 13% of PM₁₀ annually. This was identical to the previous year but noticeably higher than for 2014 - 2017 (7 - 9%), and allows for a complete mass closure of PM₁₀ for 2019; i.e. when using OM for mass closure. Mineral dust levels and its relative contribution to PM₁₀ peaked in spring and summer, typically accounting for 10 – 16% of PM₁₀, except for April which experienced a substantial 28% contribution.

Statistically significant up- or downward trends were observed for fractions of SO₄²⁻, NO₃⁻, EC and sea salt aerosol particles (Table 5.3), and all for PM₁₀. The SO₄²⁻ and EC fractions of PM₁₀ both had a statistically significant downward trend for the period 2001 - 2019, being more pronounced for SO₄²⁻ (-34%) than for EC (-25%). The SO₄²⁻ fraction was the only one with an annual mean for 2019 that was below -SD of the long-term mean. The sea salt aerosol fraction of PM₁₀ increased substantially (143%) at Birkenes in 2001 - 2019, partly due to an increased sea salt aerosol level, but also due to lower PM₁₀ levels. The NO₃⁻ fraction has also increased considerably (69%) for the period in question.

Based on levoglucosan measurements (Table 4.2) we estimate that biomass burning emissions contributed 5-9% to PM annually, considering both PM₁₀ and PM_{2.5}. The fraction attributed to biomass burning in winter was 11-21%, whereas it was ≤1.5% in summer, considering both size fractions. Spring

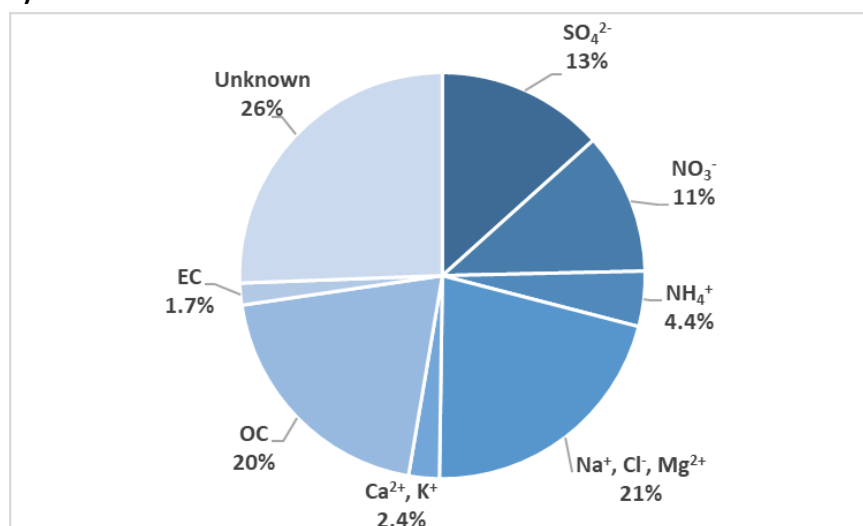
and fall are transition seasons with relative contributions lower than in winter and higher than in summer. Occasionally, high levels can be observed also in these seasons, such as in 2019, due to influence from agricultural and wild fires. Biomass burning occasionally exceeded 20% on a weekly basis for PM_{10} and 30% for $PM_{2.5}$ in the heating season, thus emissions are attributed to wood burning for residential heating. The very high contributions calculated for April are discussed in Chapter 7.

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

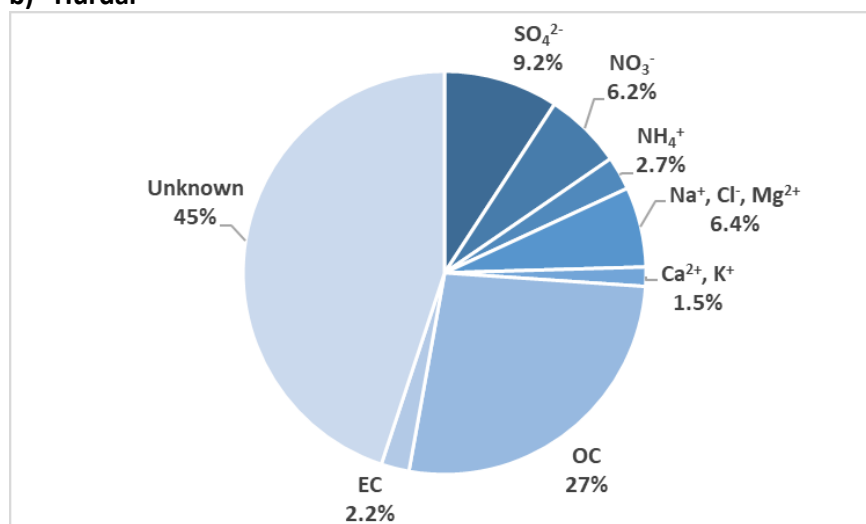
Site	Species/Fraction	Time period	Change (%)
Birkenes	SO_4^{2-} to PM_{10}	2001 – 2019	-34%
	NO_3^- to PM_{10}	2001 – 2019	69%
	NH_4^+ to PM_{10}	2001 – 2019	not significant
	$\Sigma Na^+, Cl^-, Mg^{2+}$ to PM_{10}	2001 – 2019	143%
	$OC_{PM_{10}}$ to PM_{10}	2001 – 2019	Not significant
	$EC_{PM_{10}}$ to PM_{10}	2001 – 2019	-25%
	$TC_{PM_{10}}$ to PM_{10}	2001 – 2019	Not significant
	$OC_{PM_{2.5}}$ to $PM_{2.5}$	2001 – 2019	Not significant
	$EC_{PM_{2.5}}$ to $PM_{2.5}$	2001 – 2019	Not significant
	$TC_{PM_{2.5}}$ to $PM_{2.5}$	2001 – 2019	Not significant

Trends are calculated for time series extending 10 years

a) Birkenes



b) Hurdal



c) Kårvatn

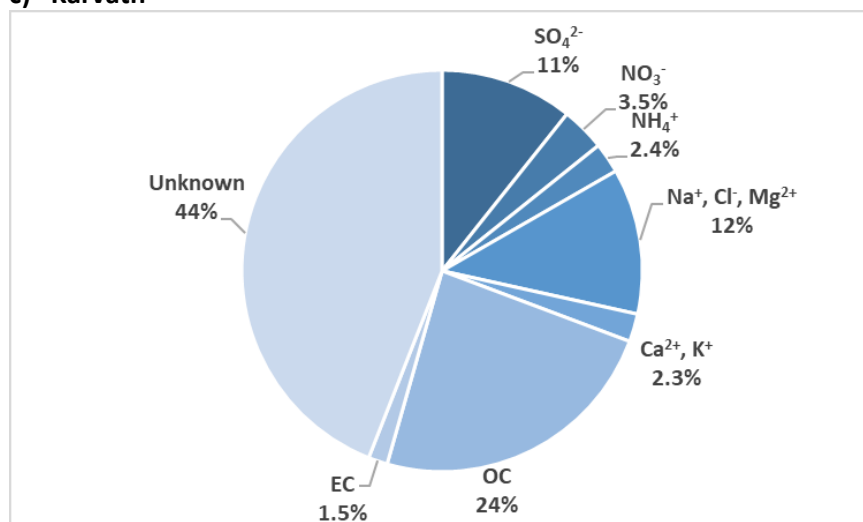


Figure 5.3 Annual mean chemical composition of PM₁₀ at the Birkenes Observatory a), the Hurdal site b) and the Kårvatn site c) for 2019. The annual mean mass concentration for PM₁₀ in 2019 was 4.6 µg/m³ at the Birkenes Observatory and at the Hurdal site and 2.9 µg/m³ at the Kårvatn site.

5.6 Particle number concentrations

The annual mean particle number concentration for the size range in particle diameter $0.01 < Dp < 10 \mu\text{m}$ (N_{Tot}) at Birkenes for 2019 was slightly lower (4%) than the long-term mean, but within one standard deviation of the long-term mean. The annual mean number concentration of the ultrafine particles N_{UF} ($0.01 < Dp < 0.1 \mu\text{m}$) (2% lower) and the accumulation mode particles N_{Acc} ($0.1 < Dp < 1.0 \mu\text{m}$) (9% lower) were lower 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} ($1 - 10 \mu\text{m}$) size fraction could not be established for the entire year of 2019 due to problems with the optical particle counter. The missing N_{CM} data on have no detectable influence on determining N_{Tot} .

77% of N_{Tot} was attributed to N_{UF} and 23% to N_{Acc} at Birkenes for 2019, whereas the fraction associated with particles in the range $1.0 - 10 \mu\text{m}$, i.e. the coarse mode, could not be established. However, the fraction of particle number in the coarse mode is typically 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 – 81% of N_{Tot} . Typically, the N_{UF} fraction drops in winter, whereas the N_{Acc} fraction increases correspondingly, so also for 2019.

Table 5.4: Number concentrations for ultrafine, accumulation mode and coarse mode particles at Birkenes for 2010 – 2019 and their relative share to the total concentration. Unit: cm^{-3} .

Year N (cm^{-3})	Ultrafine particles ($Dp < 0.1 \mu\text{m}$)		Accumulation mode particles ($0.1 \mu\text{m} < Dp < 1.0 \mu\text{m}$)		Coarse mode particles ($1.0 \mu\text{m} < Dp < 10 \mu\text{m}$)		Total concentrations ($Dp = 0.01 - 10 \mu\text{m}$)
		(%)		(%)		(%)	
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
2019	1049	77	321	23	--	--	1370

5.7 Summary

Observed annual mean concentrations of PM_{10} and $\text{PM}_{2.5}$ in the Norwegian rural background environment are amongst the lowest in Europe ($< 4.6 \mu\text{g}/\text{m}^3$). International and national limit values and air quality guidelines were not violated in 2019, neither on an annual nor on a 24-hours basis.

Organic matter (34 – 46%) was the major fraction of PM_{10} at all sites, followed by secondary inorganic aerosol (SIA) (17 – 29%) and sea salt aerosol (6 – 21%), whereas a 13% contribution of mineral dust was estimated at the Birkenes Observatory. The SIA and sea salt aerosol contribution was substantially higher at the southernmost site Birkenes due to the proximity to major anthropogenic emission regions in continental Europe and to the sea, respectively.

There was a significant downward trend for both PM_{10} and $\text{PM}_{2.5}$ (-34% - -45%) for the period 2000/01 – 2019, 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 7-12% to PM annually, considering both PM_{10} and $\text{PM}_{2.5}$. The fraction attributed to biomass burning in winter was 11-21%, whereas it was $< 2.5\%$ 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 (CH₄) and nitrogen oxides (NO_x) under the influence of solar radiation, as well as from the transport of stratospheric ozone into the troposphere. VOCs, CO and CH₄ are emitted from anthropogenic sources such as road and ship traffic, leakage of natural gas, use of solvents and chemicals etc., and NO_x is mainly emitted from traffic and power plants. In addition, biogenic sources (trees and plants) contribute significantly to the emission of VOCs and CH₄ and to a smaller extent to NO_x (microbiological activity in soils). On a global basis lightning is also an important source of NO_x 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, HO₂ and NO₂. 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 regard particularly asthmatics and people with chronic respiratory disorders. Effects on the vegetation regards particularly crops but also forests and natural vegetation. Prolonged exposure has 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 2019 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 2019 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 2019, which was 94% 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 2019.

St.nr.	Station name	Period	Data capture
NO0043	Prestebakke	01.01.19- 31.12.19	99%
NO0056	Hurdal	01.01.19- 31.12.19	99%
NO0489	Haukenes	01.01.19- 31.12.19	94%
NO0002	Birkenes II	01.01.19 - 31.12.19	99%
NO0052	Sandve	01.01.19 - 31.12.19	99%
NO0039	Kårvatn	01.01.19 - 31.12.19	99%
NO0015	Tustervatn	01.01.19 - 31.12.19	99%
NO0042	Zeppelin	01.01.19 - 31.12.19	99%

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 $\mu\text{g}/\text{m}^3$ 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 $\text{O}_3 + \text{NO} \rightarrow \text{NO}_2$. 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 NO_x 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 NO_x 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 2019

Time series of daily maximum ozone values through 2019 are given in Figure 6.1 together with the climatological mean seasonal cycle (30 days running mean) based on previous years of data (2000-2018). The time series indicate a few marked episodes in 2019, most pronounced in the last part of April when more or less all stations show a marked peak lasting for many days. In addition, most stations show a less marked episode in late August and then a few sites (Prestebakke and Hurdal) show a short spike by the end of June.

The April episode was linked to transport of particularly warm air masses from south and southeast, and very likely extensive agricultural fires in East Europe contributed to the high ozone levels. Ineffective surface dry deposition of ozone in the Nordic countries this early in the season presumably also caused the ozone levels to remain high for many days. Peak ozone levels were recorded also in Sweden and Finland during late April and the episode is discussed in more detail in a separate chapter.

The smoothed seasonal cycles (14 days' running mean) in ground-level ozone in 2019 are shown in Figure 6.2 together with the climatological mean seasonal cycles for the period 2000-2018 for each site. The April episode is very distinct in this plot in particular for Prestebakke, Hurdal and Tustervatn.

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 2019 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.

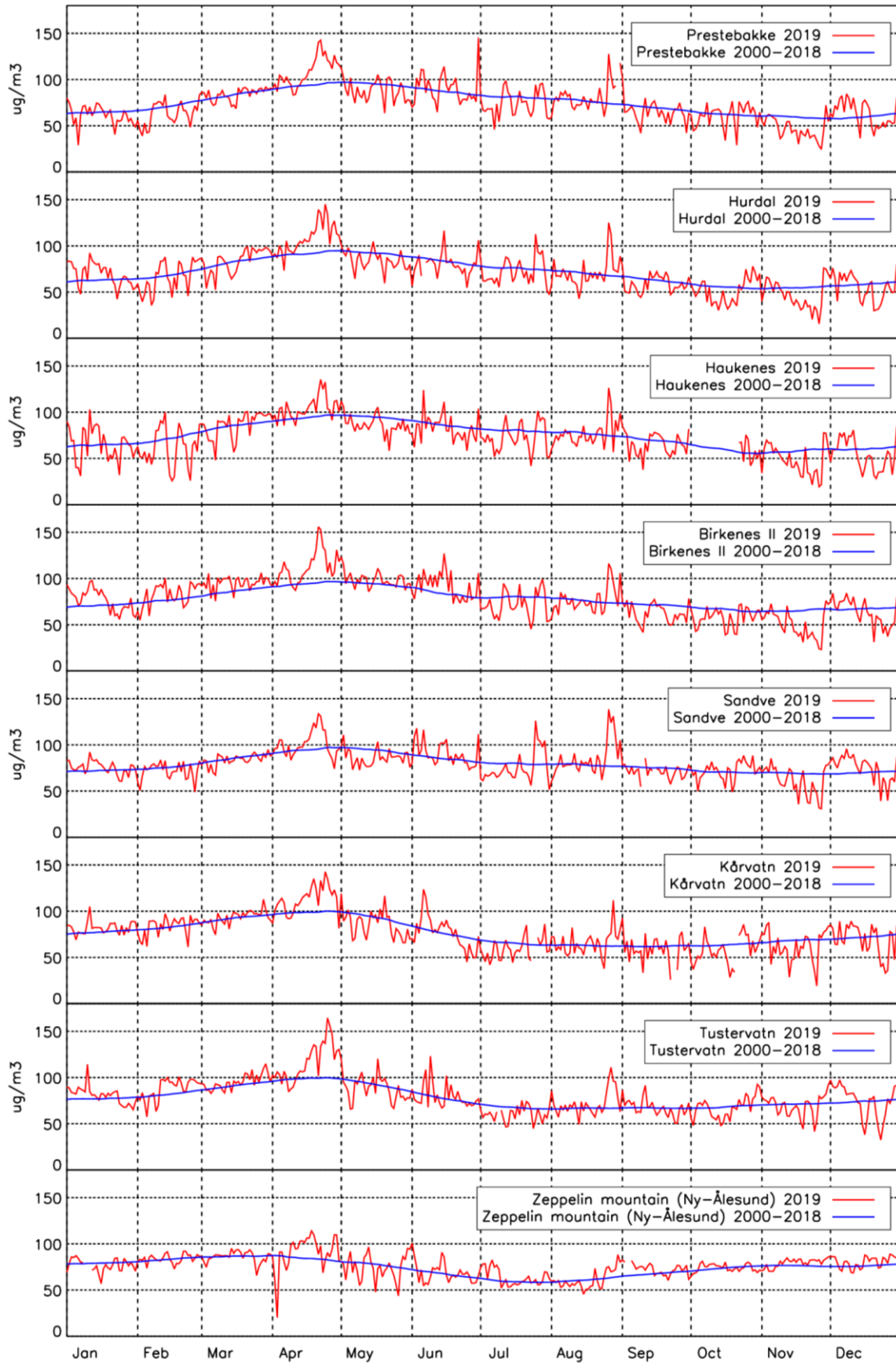


Figure 6.1: Daily maximum ozone concentrations in 2019 (red) together with the 30 days' running mean of the daily maxima for the years 2000-2018 (blue).

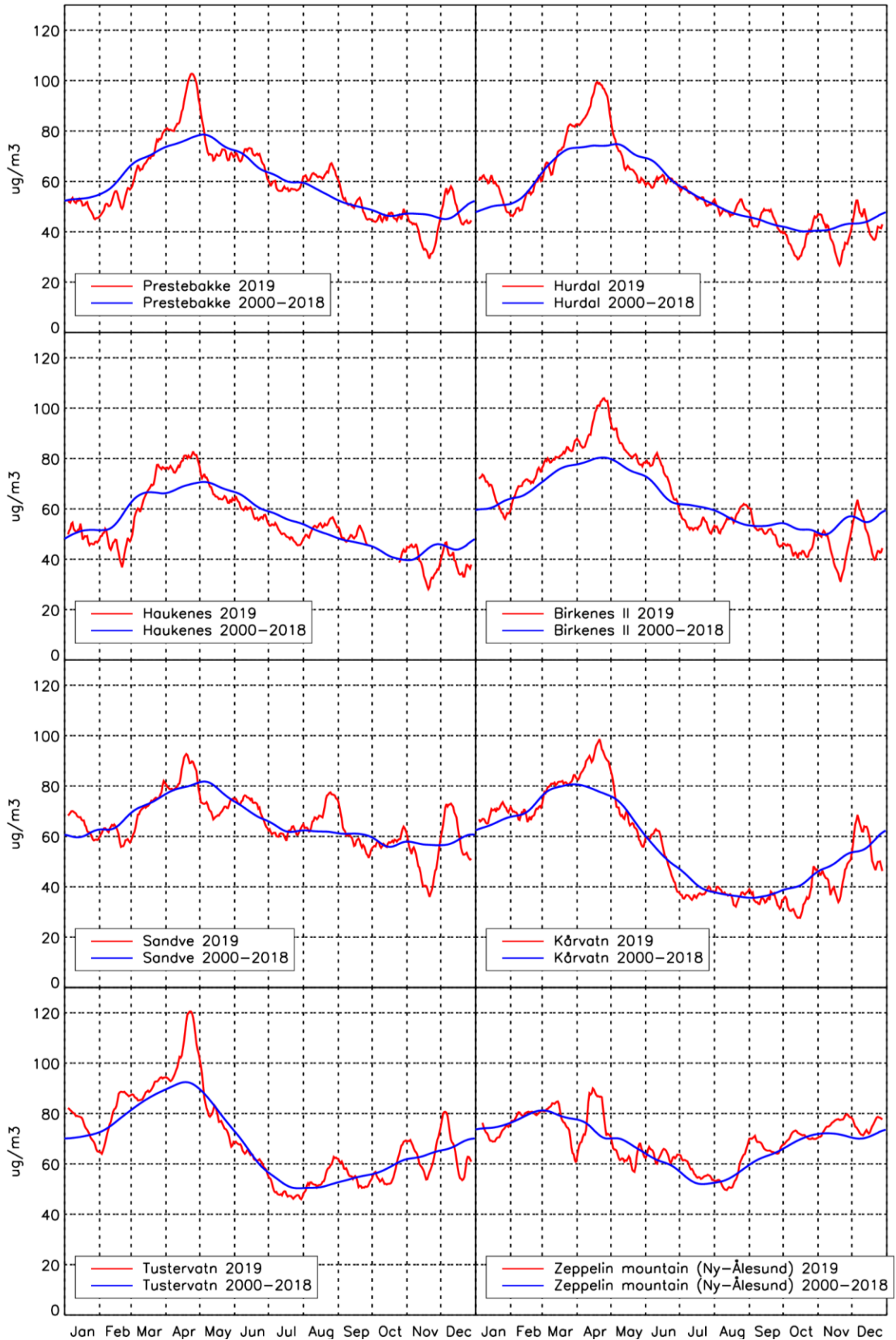


Figure 6.2: The 14 days' running mean ozone concentrations in 2019 (red) together with the corresponding mean concentrations based on all years 2000-2018 (blue).

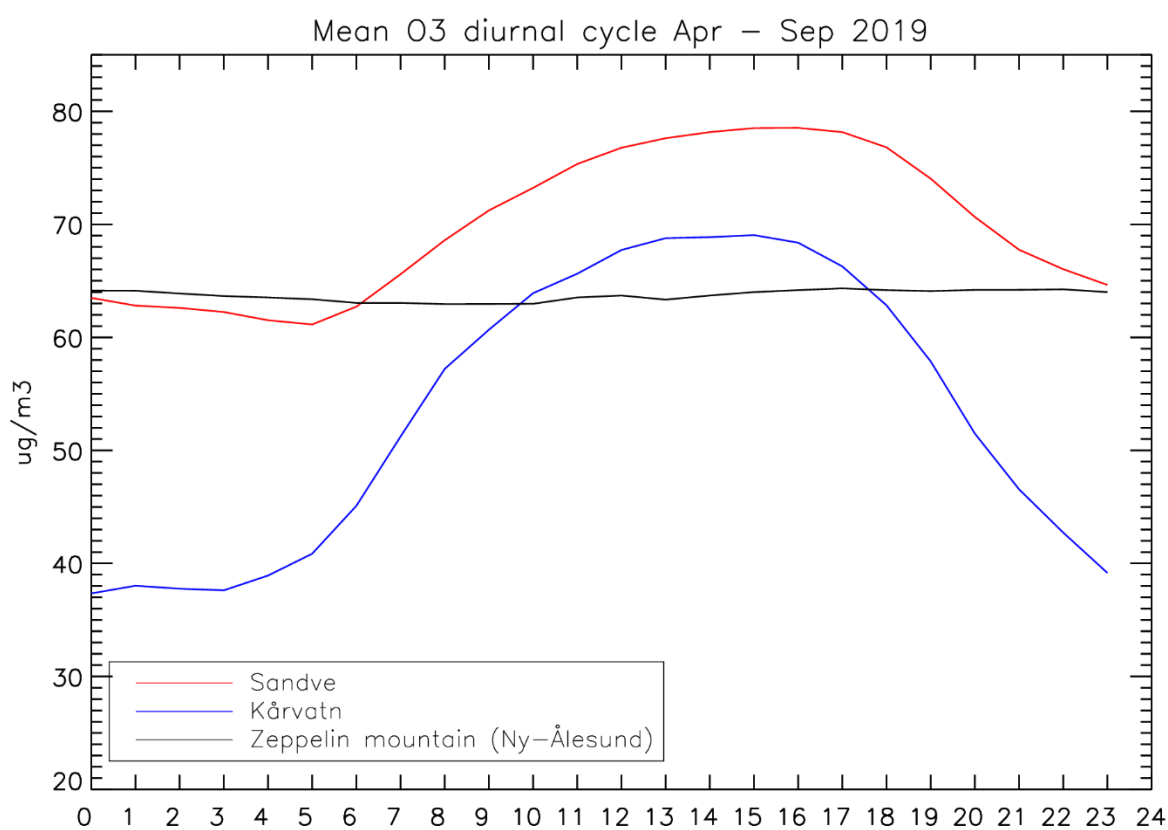


Figure 6.3: The mean diurnal cycle in ozone at three of the monitoring sites; Sandve, Kårvatn and Zeppelin Mountain during April-September 2019.

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 $\mu\text{g}/\text{m}^3$) and alert threshold (240 $\mu\text{g}/\text{m}^3$), 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 ($\mu\text{g}/\text{m}^3$)	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 $100 \mu\text{g}/\text{m}^3$ and EU's long-term objective of $120 \mu\text{g}/\text{m}^3$. The number of hours with exceedance of EU's information threshold of $180 \mu\text{g}/\text{m}^3$ 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 hours mean values were only calculated for days with at least 75% data capture.

Table 6.3: For all sites in 2019 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.

Station	Hours	National AQ guidelines			WHO	EU directive		Max. hourly value ($\mu\text{g}/\text{m}^3$)	Date
		Days	Days	Hours	Days	Days	Hours		
		>75%	8h > $80 \mu\text{g}/\text{m}^3$	1h > $100 \mu\text{g}/\text{m}^3$	8h > $100 \mu\text{g}/\text{m}^3$	8h > $120 \mu\text{g}/\text{m}^3$	1h > $180 \mu\text{g}/\text{m}^3$		
Prestebakke	8663	365	104	326	26	9	0	145	30.06.2019
Hurdal	8702	365	93	224	22	5	0	145	24.04.2019
Haukenes	8266	346	103	186	20	3	0	135	22.04.2019
Birkenes II	8713	365	149	445	37	7	0	156	21.04.2019
Sandve	8694	365	126	252	20	6	0	138	26.08.2019
Kårvatn	8691	365	135	355	28	8	0	143	24.04.2019
Tustervatn	8699	365	145	530	31	13	0	165	25.04.2019
Zeppelin	8644	364	126	151	10	0	0	114	18.04.2019

EU's information threshold (hourly value $> 180 \mu\text{g}/\text{m}^3$) has not been exceeded since 2006 and in 2019 the highest hourly ozone level was $165 \mu\text{g}/\text{m}^3$. It is remarkable that this peak level was recorded at Tustervatn in northern Norway, and the value is the second highest ozone concentration measured at this station since the monitoring started in 1989. Only during the strong ozone episode in 2006 (Stohl et al., 2007) higher ozone levels have been recorded at Tustervatn. The peak level in 2019 occurred during the April episode (25 April) and is likely a result of transport of warm air masses from southeast combined with extensive agricultural fires in East Europe.

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 $< 120 \mu\text{g}/\text{m}^3$) and thereby also WHO's and Norwegian

air quality guidelines is on the other hand exceeded to a variable extent every year. In 2019 the LTO was exceeded at all stations except Zeppelin Mountain. The highest number of days with exceedances was seen at Tustervatn with 13 days which is very unusual and is discussed in more detail in the mentioned chapter on the April episode.

The WHO guideline was broken at all sites (including Zeppelin Mountain) in 2019. This reflects that the WHO guideline level of $100 \mu\text{g}/\text{m}^3$ 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 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 $120 \mu\text{g}/\text{m}^3$ for the period 2000-2019. Table 6.4 gives the annual peak values and number of days with exceedance of the LTO from 2006 to 2019. 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 NO_x 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 2006-2019 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.

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Annual hourly max. ($\mu\text{g}/\text{m}^3$)	186	139	160	142	145	168	130	124	147	148	140	135	148	165
Number of dates with exceedance of EU's long-term objective of $120 \mu\text{g}/\text{m}^3$ ^{a)}	28	8	16	9	3	12	2	2	4	2	4	1	22	17

^{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 2019 the LTO was broken at 17 days which is the second highest number of dates since the peak year in 2006. As mentioned above, the highest number of exceedances was observed at Tustervatn (13 days).

The updated national guidelines (FHI, 2013) are even stricter than the WHO guideline (Table 6.2) and both the $80 \mu\text{g}/\text{m}^3$ (8-h mean) and $100 \mu\text{g}/\text{m}^3$ (1-h mean) were exceeded for long periods of the year in the whole country as shown by Table 6.3.

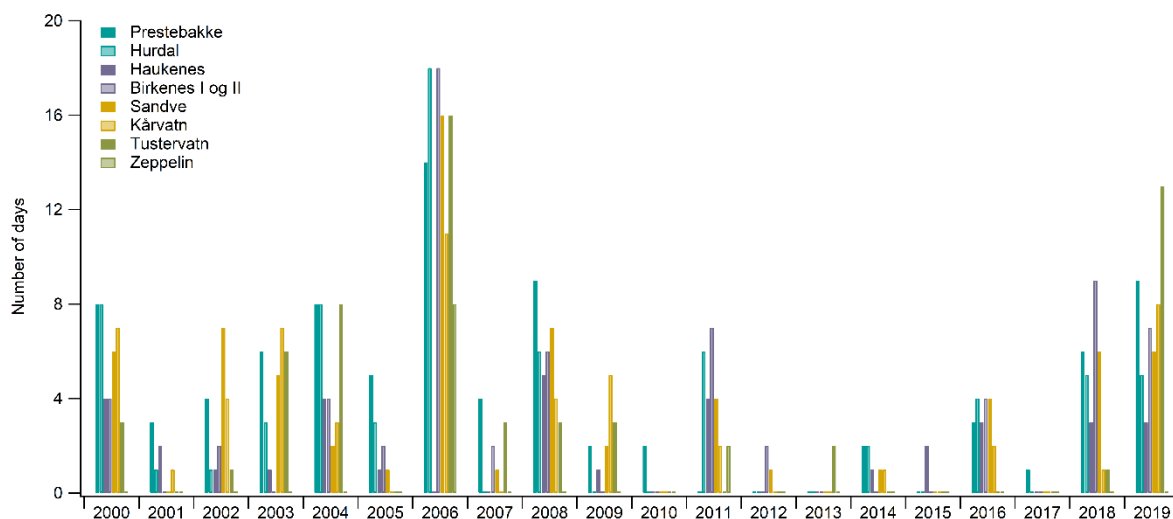


Figure 6.4: The number of days with a maximum daily 8-h mean ozone concentration above $120 \mu\text{g}/\text{m}^3$ for the period 2000-2019. Note that the Birkenes site has been moved, and data before 2010 refer to the old location. See text for more explanations.

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 ($= 80 \mu\text{g}/\text{m}^3$) 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 $> 50 \text{ W}/\text{m}^2$ 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/m²

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 6.5 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 2000-2019. EU's target value of 9000 ppb hours has not been exceeded for many years in Norway. The long-term objective of 3000 ppb hours was exceeded only at Birkenes with 3557 ppb (corrected for data capture). This low number of exceedances of the critical level for vegetation reflects that the main ozone episode in 2019 occurred in April, before the defined 3-months period.

Table 6.6 shows the 6 months AOT40 values for forests (April-September) 2019 as based on the UN-ECE definition (using the hours with a global radiation > 50 W/m²), and the corresponding plot for the years 2001-2019 are shown in Table 6.6. The critical level of 5000 ppb hours for forests was exceeded at 4 of the 8 stations in 2019 (Prestebakke, Birkenes, Kårvatn and Tustervatn). The highest 6-months AOT40 value was seen at Birkenes with 6772 ppb hours.

Table 6.6: Data capture and 3-month's AOT40 values for vegetation for the period 1 May - 31 July 2019 (unit: ppb hours) according to the definitions in the EU directive.

Station	Data capture (%)	AOT40 (corrected for data capture)
Prestebakke	99	2153
Hurdal	99	1005
Haukenes	99	1253
Birkenes II	98	3557
Sandve	98	1509
Kårvatn	99	1245
Tustervatn	98	1358
Zeppelin	99	398

Table 6.7: Data capture and 6-month's AOT40 values for forests for the period 1 April – 30 September 2019 (unit: ppb hours) according to the definitions in UN-ECE's Mapping Manual.

Station	Data capture (%)	AOT40 (corrected for data capture)
Prestebakke	99	5226
Hurdal	100	3357
Haukenes	99	3488
Birkenes II	99	6772
Sandve	98	4253
Kårvatn	99	5135
Tustervatn	98	5712
Zeppelin	99	1589

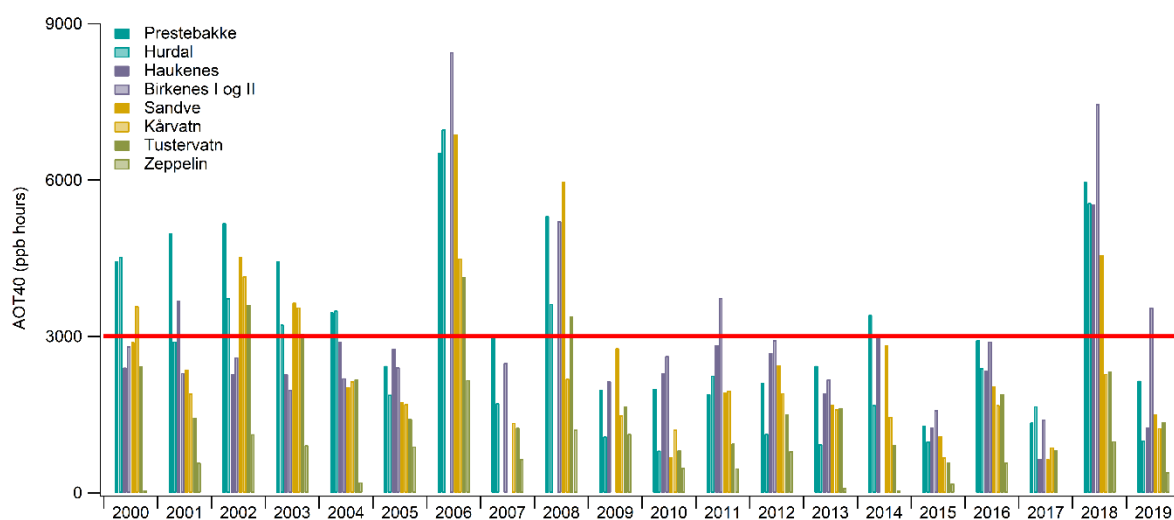


Figure 6.5: 3 months' AOT40 values (1 May - 31 July) for the years 2000 - 2019 (based on UN-ECE's definition of daylight hours). The EU directive's long-term objective of 3000 ppb hours is indicated by the line. Note that the Birkenes site has been moved, and data before 2010 refer to the old location. See text for more explanations.

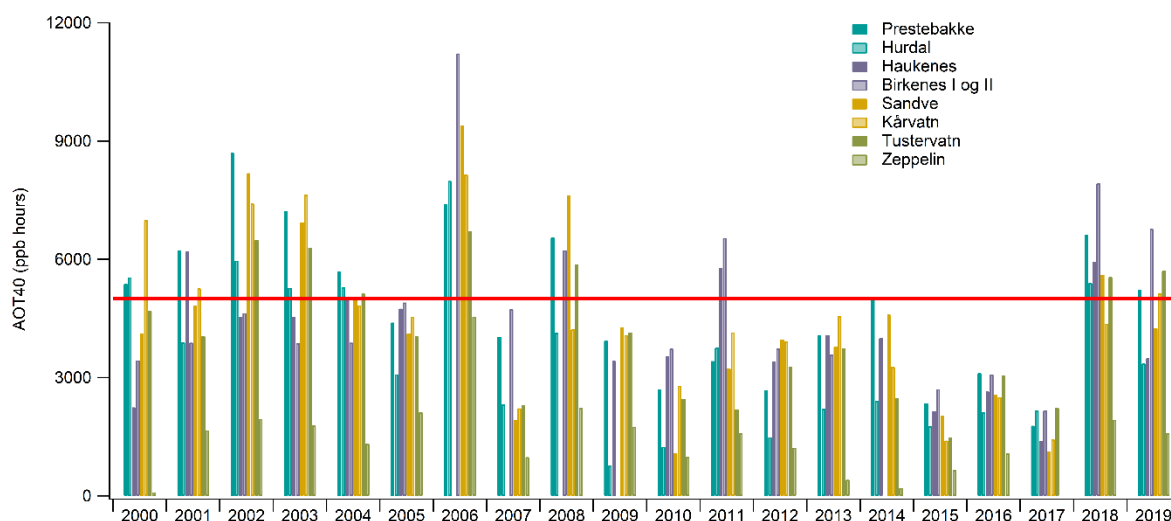


Figure 6.6: 6 months' AOT40 values (1 April - 30 September) for the years 2000 - 2019 (based on UNECE's definition of daylight hours, $> 50 \text{ W/m}^2$). The critical level for forests (5000 ppb hours) is indicated by the line. Note that the Birkenes site has been moved, and data before 2010 refer 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 indicate 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 2019; 3-months AOT40 (May-July), the number of days with an 8-h running max exceeding $100 \mu\text{g}/\text{m}^3$ (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) programmes.

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 2.72%/year relative to 1995 as a start year.

In contrast, the number of days with a maximum 8-h concentration exceeding 100 $\mu\text{g}/\text{m}^3$ shows a significant reduction at three sites (Sandve, Kårvatn and Tustervatn, but not Prestebakke), and the 97-percentile of the daily max 8-h concentration shows a significant reduction at Prestebakke and Kårvatn.

A reduction in high ozone concentrations are expected due to the substantial reduction in European man-made emissions of NO_x 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.

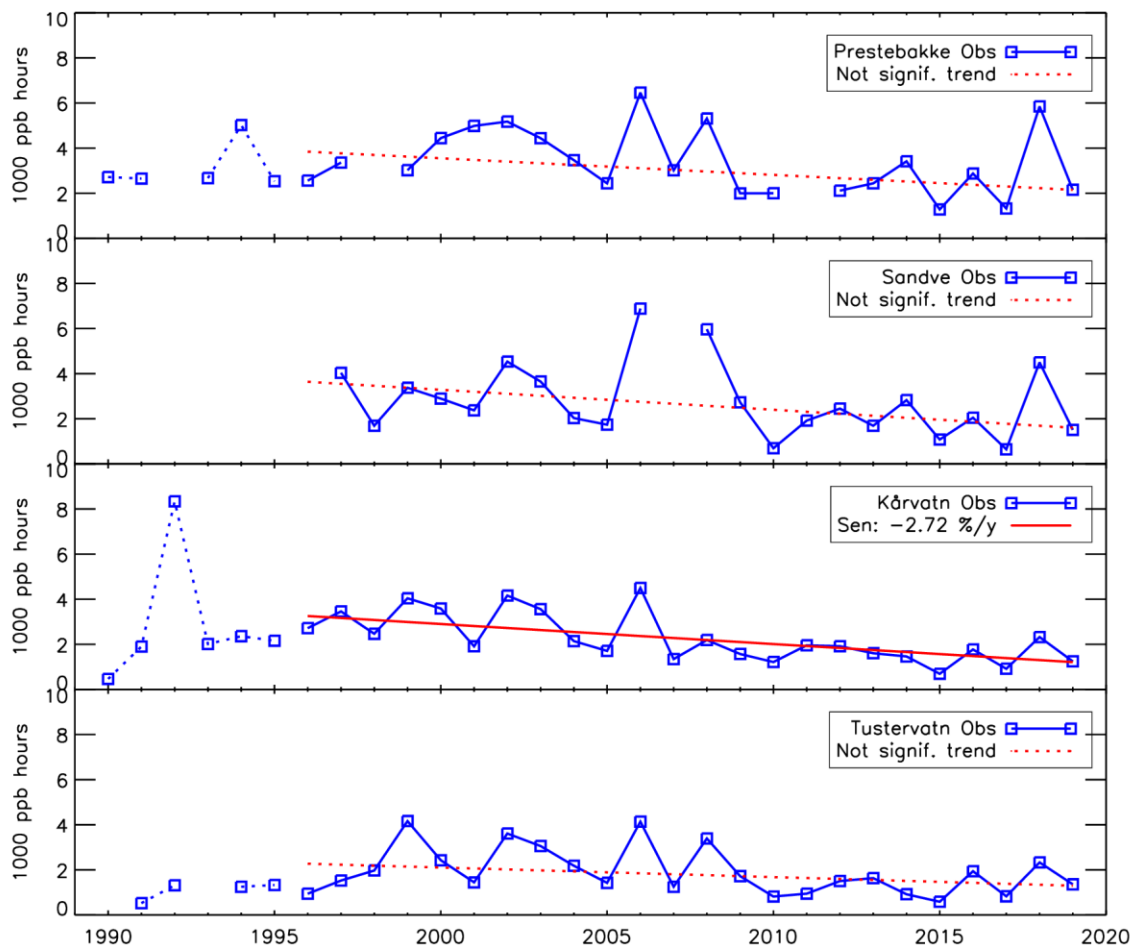


Figure 6.7: The 3-months AOT40 value according to the EU directive (May - July, hours 8-20 CET) during 1990-2019 for four sites. The estimated Sen's slope based on annual data for 1996-2018 are marked in red. Data from the first years (1990-1995) are uncertain and not included in the trend calculations 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.

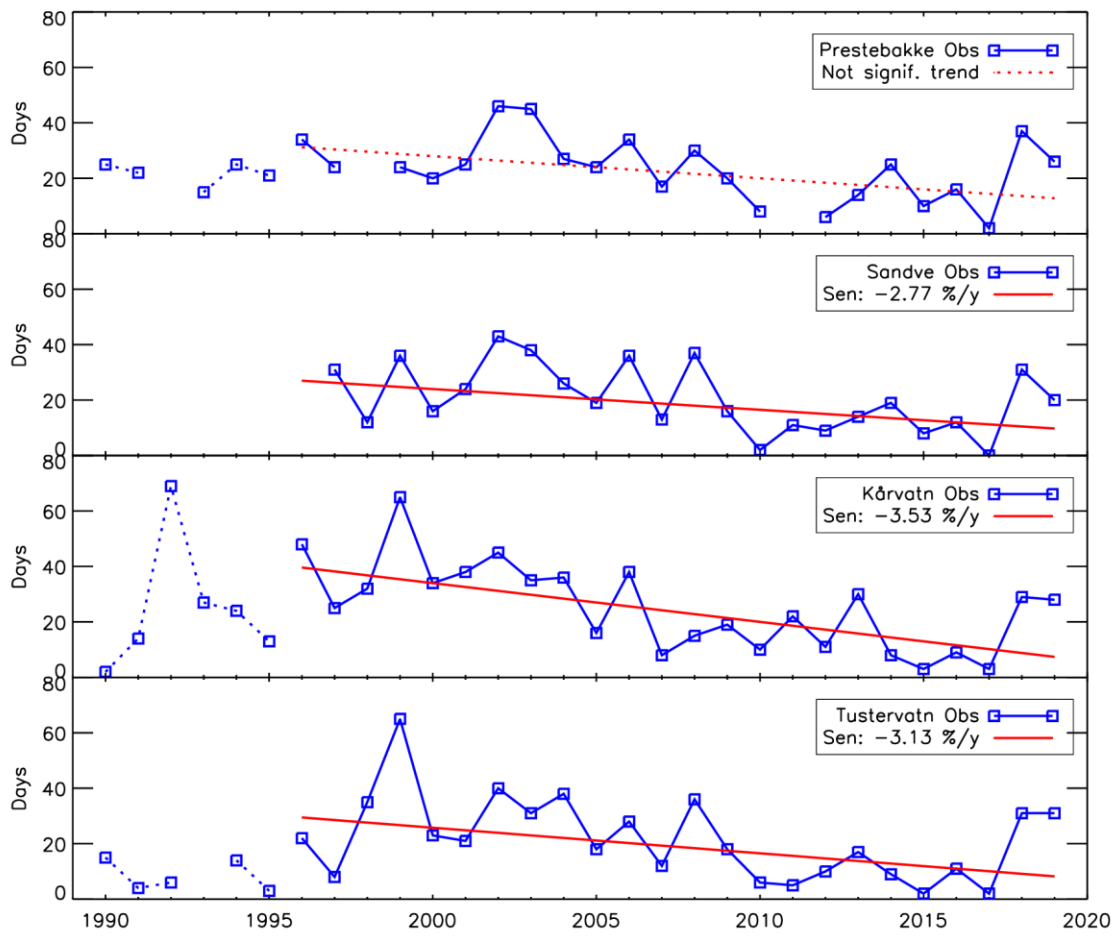


Figure 6.8: Same as Figure 6.7 for the number of days with a maximum 8-h running mean ozone concentration exceeding $100 \mu\text{g}/\text{m}^3$ (WHO guideline).

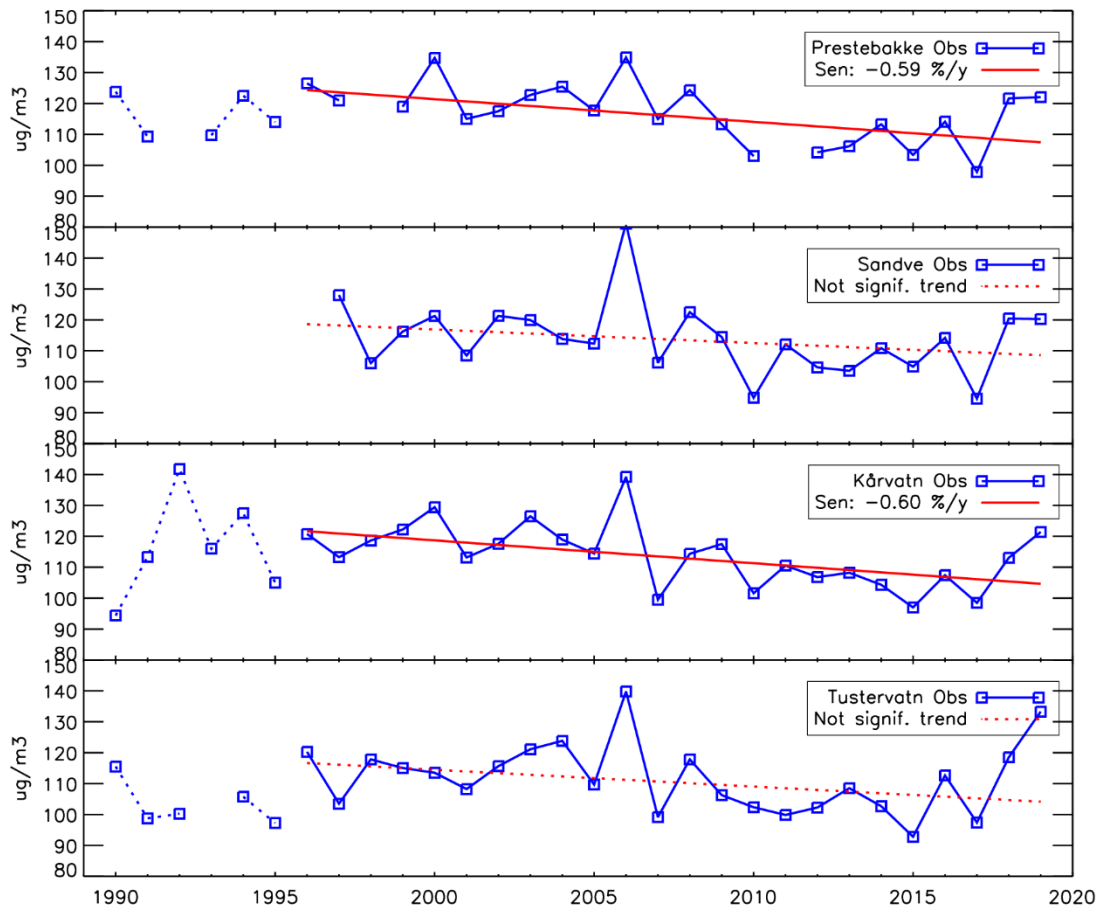


Figure 6.9: Same as Figure 6.7 for the 97-percentile of the daily maximum 8-h running mean ozone concentration April-September.

6.7 Summary

The surface ozone levels in Norway 2019 were characterized by one very marked and long-lasting episode in April as well as shorter episodes in August and late June. The critical level for vegetation linked to 3-months AOT40 for plants covering the period May-July was thus exceeded only at Birkenes whereas the 6-months AOT40 for forest covering April-September were exceeded at four sites. The highest hourly ozone concentration in 2019 was measured at Tustervatn ($165 \mu\text{g}/\text{m}^3$) and the highest number of exceedances of EU's long-term objective of max 8-hours daily max of $120 \mu\text{g}/\text{m}^3$ (13 days) was also seen at this station. This is remarkable as the ozone levels normally is higher in the southern part of the country. The reason behind the high ozone levels in the north was a long-lasting episode in April linked to transport of warm air masses from south and southeast. Emission from extensive agricultural fires in East Europe combined with ineffective surface dry deposition of ozone likely contributed to the higher levels of ozone.

In Norway, the levels of ground level ozone are determined by a baseline-level varying between 50-100 $\mu\text{g}/\text{m}^3$ (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.

7 The April 2019 episode

7.1 Meteorology and ground level ozone

April 2019 was the second warmest and second driest April in Norway since 1900. Areas in the far north and at the west coast experienced a monthly mean temperature 4-5°C above the normal, and many sites in the southeast had only 25 % of the normal precipitation. Particularly high temperatures were seen in the last part of the month, peaking at 25°C at Nesbyen 29 April. Associated with these weather extremes, high levels of several pollutants were observed.

The reason for these extremes was a persistent high-pressure system. At the start of the month an extensive high-pressure area was located over the northeastern part of the Eurasian continent. In the following days it moved slowly and was centered over mid-Norway in the middle of April. Gradually, the high-pressure area was displaced southeastwards setting up southerly and southeasterly winds to the Nordic countries as seen by Figure 7.1.

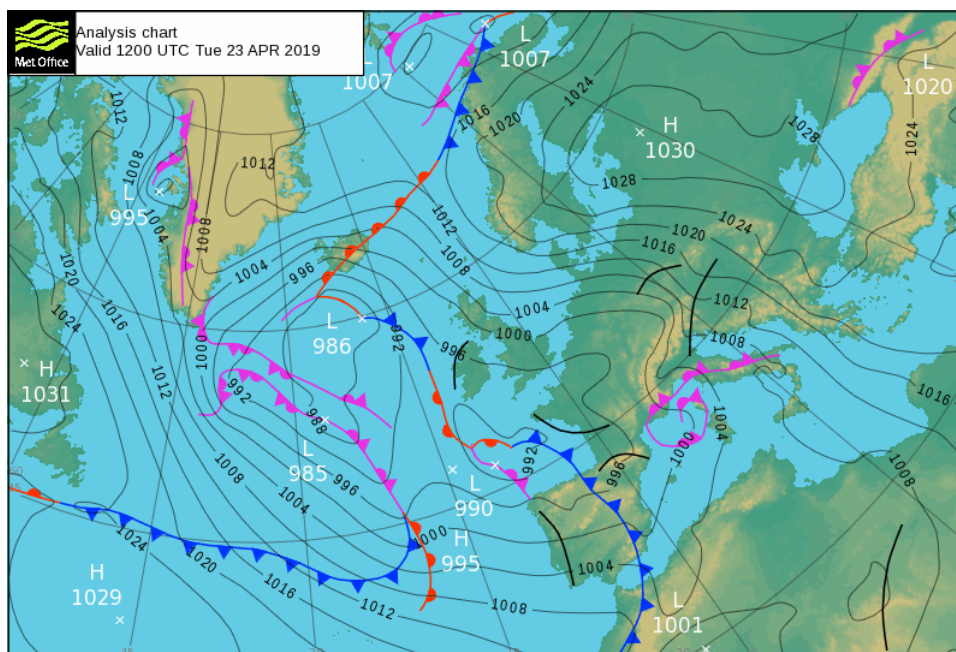


Figure 7.1: Surface pressure chart for 23 April 2019 12 UTC showing the high-pressure region in the east and low-pressure over the Atlantic setting up south-southeasterly flow into the Nordic countries. (Used with permission by © British Crown copyright, Met Office <http://www.metoffice.gov.uk/about-us/legal/tandc#Use-of-Crown-Copyright> <http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3>)

This type of weather pattern is called a blocking high, implying that it blocks all the fronts and low-pressure systems than normally travels from west to east into Scandinavia. The blocking high will deflect the jet stream that determines the path of the low-pressure systems and cause the lows to travel either northwards over the ocean to the Arctic or southwards towards the Mediterranean. When the high-pressure system is located southeast of the Nordic countries as in the last part of April 2019, southerly winds will typically carry warm and dry continental air masses to Scandinavia.

This weather situation is often associated with elevated levels of pollutants in Norway for several reasons: Firstly, the air masses entering the country could have a long residence time over the European continent, meaning that surface emissions are accumulated in the air masses for many days. Secondly, the high-pressure region is associated with stable air masses without efficient vertical mixing. This means that the emissions that are accumulated in the air masses on the way to the Nordic

countries will be trapped in a shallow surface layer. Thirdly, high temperatures as seen in these situations is likely to cause the formation of ozone and secondary aerosol particles. Finally, the dry deposition of ozone, which normally is the main loss mechanism of this pollutant will be reduced in these situations due to drought causing the vegetation to close their stomata. The dry conditions also imply reduced wet removal of aerosols. In the April 2019 episode large areas in the Nordic region was still snow-covered, thus both the ozone uptake in vegetation and the dry deposition to the surface was likely very inefficient.

The meteorological conditions described favoured the accumulation of pollutants in the air masses that affected the Nordic countries. However, other important factors likely contributed to the high pollutant levels observed. On the 24 April, met.no announced that air masses carrying Saharan dust would cover large parts of the country the next days, a phenomenon clearly visibly from satellites. Indeed, outflow of mineral dust from the African continent can be seen over the Mediterranean Ocean south of Sicily in.

Equally important (or maybe more important) was extensive fires in Eastern Europe, including Ukraine and western Russia. Figure 7.1 shows a picture from the MODIS satellite identifying fires by their infrared (heat) radiation. Numerous fires are seen over a large area upwind of the Nordic countries. A narrow plume of hazy air masses is seen entering southern Sweden. These fires are most likely agricultural fires used to burn farmland in early springtime in this region.

Backward trajectory calculations with the Flexpart model (Stohl et al., 2005; Pisso et al., 2019) can be used to identify the surface source region for the pollutants measured at the Norwegian monitoring stations, or the so-called footprint emission sensitivity. Examples of this are shown in Figure 7.3 for air masses arriving at Tustervatn 24 and 25 April, respectively. These maps indicate a close agreement between the wildfires and the source region for the air masses arriving at Tustervatn these days.

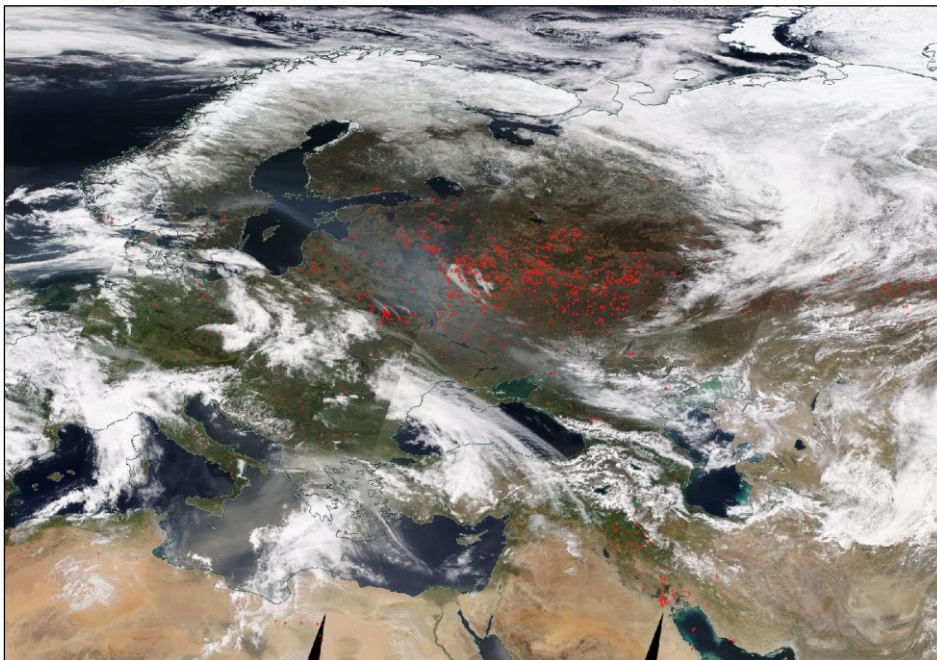


Figure 7.2: MODIS satellite picture from 24 April 2019 with wildfires marked as red dots on the map. A tongue of hazy air masses is stretching from the fire areas into southern Sweden (acknowledgement: <https://lance-modis.eosdis.nasa.gov/>).

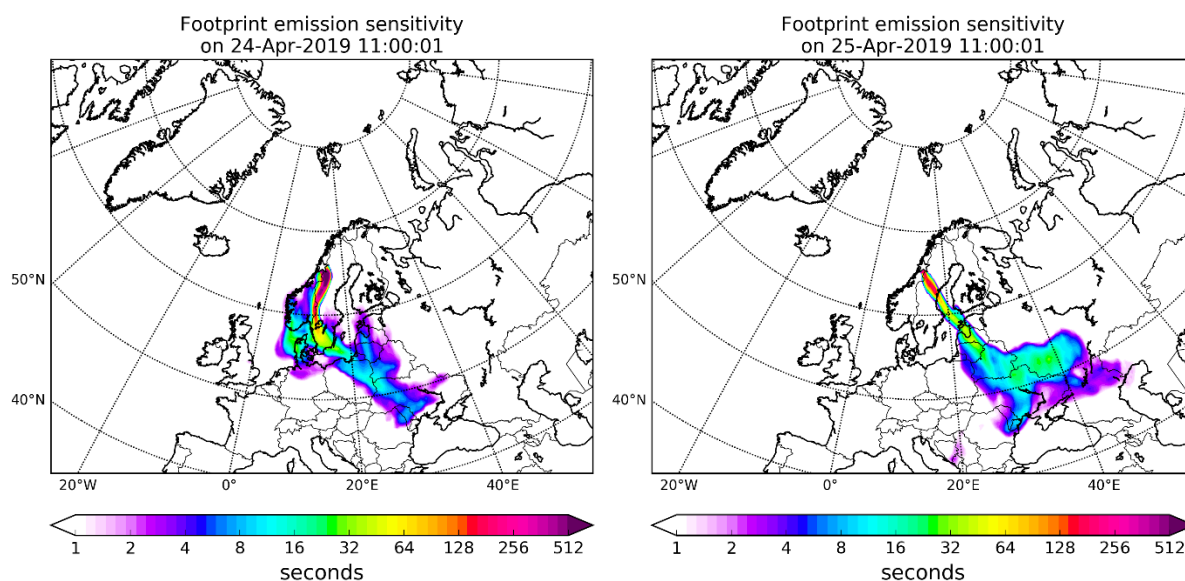


Figure 7.3: Footprint emission sensitivities calculated with the Flexpart model (Pisso et al., 2019) for the Tustervatn site.

Figure 7.4 shows the hourly ozone concentrations measured at three of the national monitoring stations (Kårvatn, Hurdal and Tustervatn) for the period 10 April to 10 May 2019. These time series show the build-up of the episode where the daily maximum levels are very close at these three sites. Then, during several days (25 - 28 April) the ozone level at Tustervatn stays particularly high and significantly higher than the other sites. This period matches the period with transport from the wildfire regions (Figure 7.3) and thus it is likely that emission from these fires lead to ozone formation that added on to the already high levels of ozone.

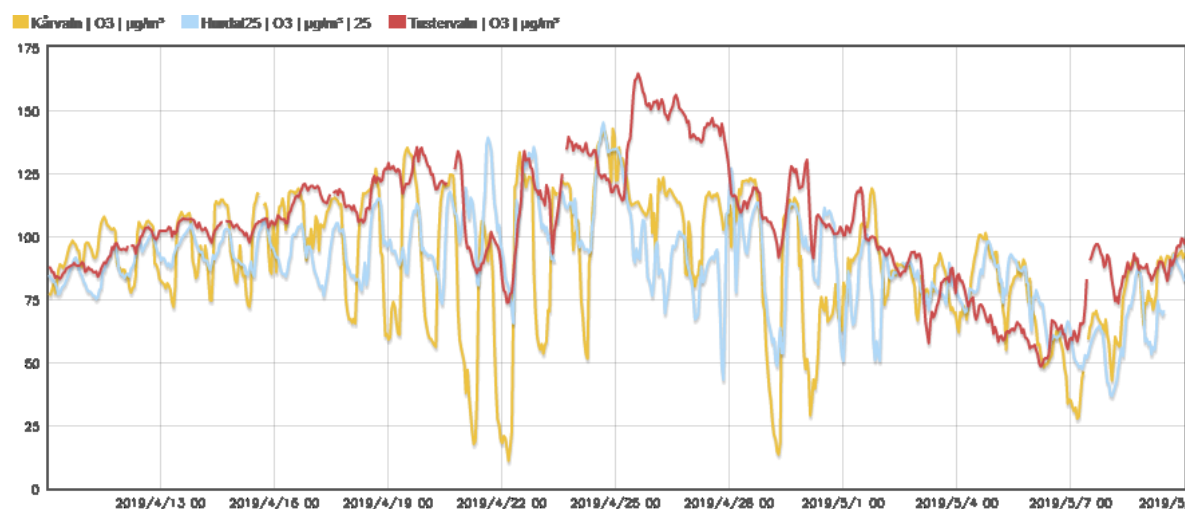


Figure 7.4: Hourly ozone concentrations ($\mu\text{g}/\text{m}^3$) at Kårvatn, Hurdal and Tustervatn during the period 10 April - 10 May 2019.

7.2 PM variables

Particulate matter was elevated for large parts of April at Birkenes, Hurdal and Kårvatn, and particularly in the first (3 – 10 April) and the last week (24 April – 1 May) of the month, differing from O_3 , which was elevated only in the last part of April. The weekly mean PM_{10} concentration was higher in the last week ($15.9 - 19.6 \mu\text{g m}^{-3}$) of April compared to the first one ($7.5 - 12.7 \mu\text{g m}^{-3}$) but both were

dominated by the fine fraction (PM_{2.5}) (60 – 70%). Hourly concentrations of PM_{0.8} calculated from the particle counter measurements at Birkenes exceeded 30 µg m⁻³ for the period considered, whereas the maximum 24-hour mean was 26.4 µg m⁻³. Considering all of April, 11 days experienced PM_{0.8} concentrations higher than 15 µg m⁻³, all of them associated with the two episodes in question, thus violating the National Air Quality Guideline for PM_{2.5}. Our calculations also indicate that the WHO Air-Quality Guidelines for PM_{2.5} was violated, as the 99th percentile of PM_{0.8} for 2019 was 25.7 µg m⁻³.

The episode affected large parts of southern Norway, thus also the air pollution level in urban areas. PM levels observed in Oslo were clearly enhanced, particularly for PM_{2.5}, which is less influenced than PM₁₀ by resuspended road dust of local origin peaking at this time of the year (www.luftkvalitet.info). The PM_{2.5} levels observed at Birkenes and Hurdal at the two actual weeks in April amounted to 60% of that observed at urban background sites in Oslo.

The more extensive suit of aerosol particle measurements at Birkenes compared to Hurdal and Kårvatn allows for a verification of the aerosol particle sources indicated by the combination of FLEXPART footprints and satellite images (c shows that the mineral dust species Al, Fe and Ti were elevated for all of April, particularly for the two periods in question. A mineral dust concentration of 3.1 µg m⁻³ was calculated for April, which was 5 times higher than the estimated annual mean (0.6 µg m⁻³). Mineral dust made a 28% contribution to PM₁₀ in April, which was comparable to that seen for the two episodes (24 – 27%), although a higher mineral dust concentration (4.1 µg m⁻³) was calculated for the last week. In addition to the agricultural fires in Western Russia, Belarus and the Ukraine clearly visible in the satellite images (Figure 7.5), outflow of mineral dust from the African continent can be seen over the Mediterranean Ocean south of Sicily in the bottom right image, which the FLEXPART footprint nicely links to the elevated levels of mineral dust at Birkenes for the last week of April. The footprint for the first week of April does not include the African continent, not even for the preceding 30 days, hence the mineral dust has a different origin. Except from Northern Africa and the Eastern Mediterranean the two footprints are remarkable similar, covering the Balkans and Eastern Europe. A vast part of this region is arable land subject to agricultural activity, which could be a possible source, as can wind-blown dust from semi-arid and dry areas governed by favorable meteorological conditions, but this remains speculative. There are only minor differences in the mineral dust composition at Birkenes for all of April, which could indicate that most of the mineral dust has a common origin. A 30 – 40% contribution of coarse aerosol particles as indicated in Figure 7.5 Figure 7.6 panel a match well with a profound mineral dust contribution of nearly 30% for April, as mineral dust mainly resides in the coarse fraction of PM₁₀.

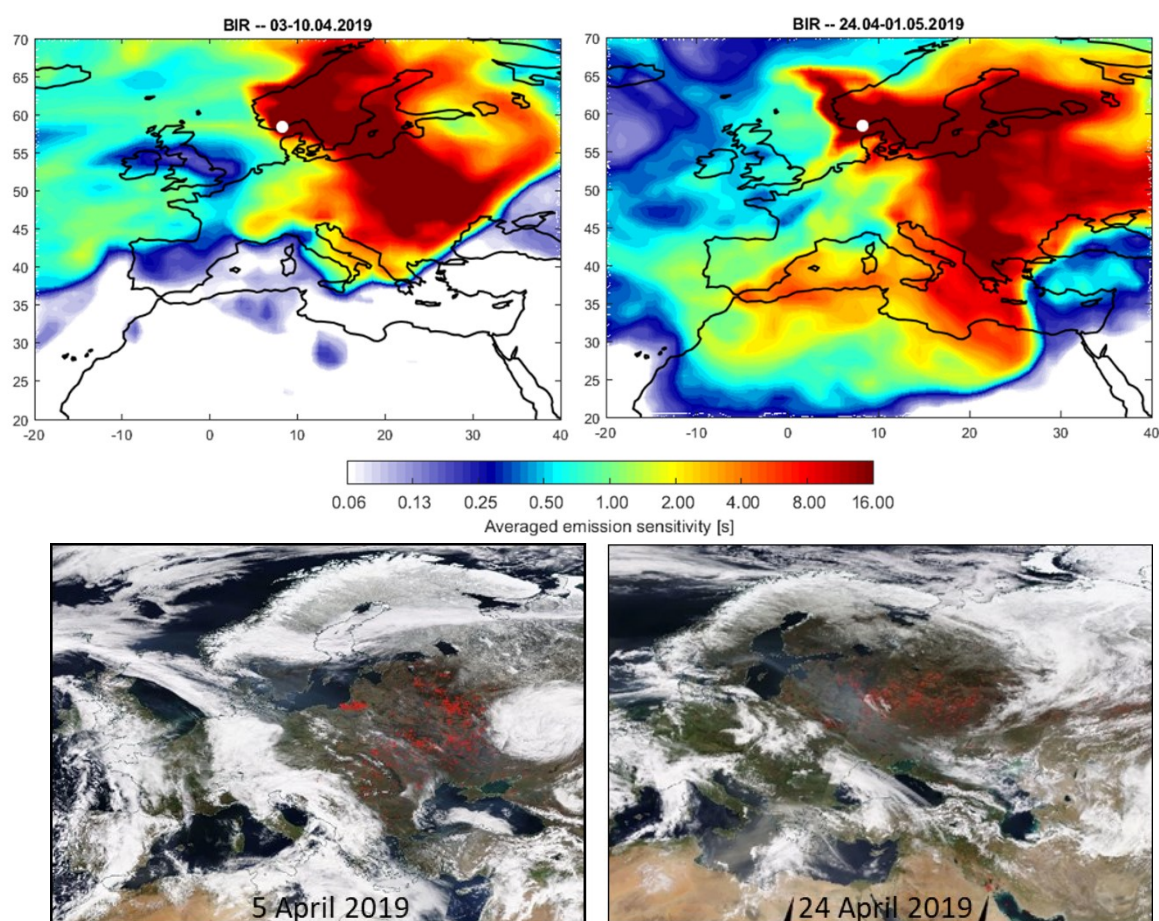


Figure 7.5: Footprint emission sensitivities calculated using the Flexpart model (Pisso et al., 2019) for the periods 3–10 April (top left) and 24 April–1 May (top right) at the Birkenes Observatory and MODIS satellite picture from 5 April (bottom left) and 24 April 2019 (bottom right) with wildfires marked as red dots on the maps.

As for the mineral dust elements, the highest levels of OC and EC were seen for the two episodes in April (Figure 7.6, panel d and f). Indeed, the weekly mean concentrations for OC in PM_{10} are the second ($4.4 \mu\text{g C m}^{-3}$) and third ($4.0 \mu\text{g C m}^{-3}$) highest reported since measurements started in 2001, whereas for $PM_{2.5}$ it was the 5th and the 10th highest. This is in line with previous findings, showing that the highest values of OC observed at Birkenes are associated with emissions from major agricultural- and wild-fires in Eastern Europe, hundreds of kilometers away (Yttri et al., 2007; Yttri et al., in prep.).

Highly elevated levels of the biomass burning tracer levoglucosan were seen for both weeks (Figure 7.6 panel e). Levoglucosan alone cannot be used to differentiate between emissions from residential wood burning and wild and agricultural fires for transient periods (spring and fall). However combining the FLEXPART footprints, the MODIS satellite pictures and the levoglucosan measurements clearly point to agricultural fires in Western Russia and Belarus for both episodes (Figure 7.5). We have used emission ratios reported by Yttri et al. (2014) to provide an estimate of the contribution of these fires to the observed PM_{10} level. We emphasize that these are crude estimates only, as for the estimates made for mineral dust. We find that the contribution from the fires to PM_{10} was twice as high for the first week ($33 \pm 6\%$) compared to the second week ($17 \pm 3\%$).

A noticeable part of OC (18 – 34%) was present in the coarse fraction of PM₁₀, particularly in the first week. There can be several explanations to this, including primary biological aerosol particles (PBAP) and carbonate (CO₃²⁻) carbon from mineral dust, which predominantly reside in the coarse fraction. Further, raging fires can cause a strong pyroconvection that effectively facilitates entrainment of coarse particles to high altitudes, enabling them to atmospheric transport over long distances.

Work in progress (Yttri et al., in prep.) suggests that climatological and meteorological conditions that favor transport of mineral dust from southern latitudes to Norway in spring and early summer also favors formation and transport of biogenic secondary organic aerosol (BSOA). Further, such warm air masses can also initiate emission of PBAP locally in Norway. Additional tracer analysis is needed to assess if this was the case also in April 2019.

Secondary inorganic aerosol (SIA) were not signature species of the two events but still made a 20 – 22% contribution to PM₁₀. Contribution from sea salt aerosol was negligible (<2.5%).

To sum up, the chemical composition of the aerosol particles points to mineral dust (24 – 27%), carbonaceous aerosol from agricultural fires (17 – 34%), carbonaceous aerosol from other sources than agricultural fires (29 – 34%) and SIA (20 – 22%) as the major sources of the elevated PM levels observed at Birkenes in April 2019.

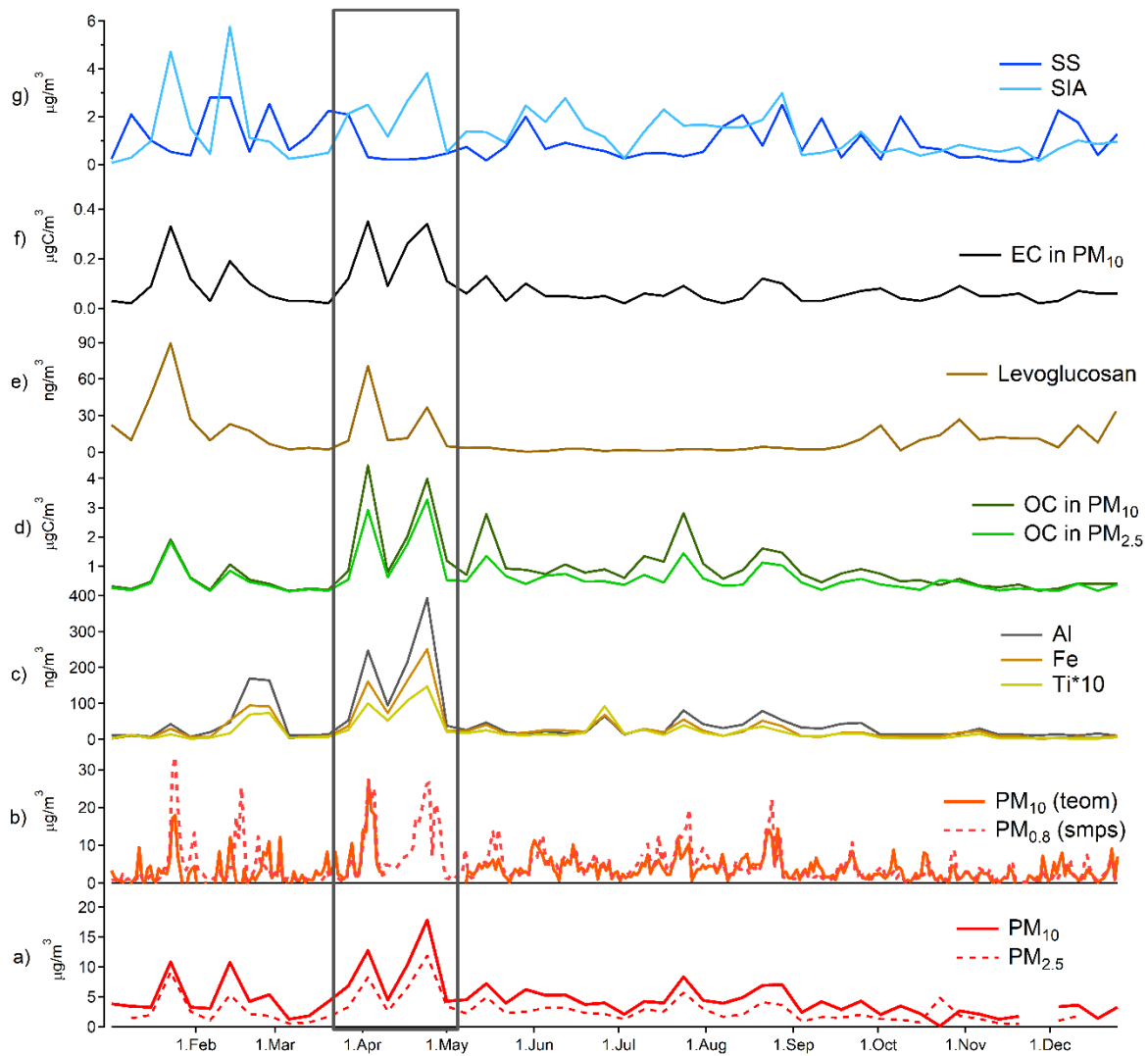


Figure 7.6: Mass concentration (weekly) of PM_{10} and $PM_{2.5}$, (panel a); Mass concentration (24-hour) of PM_{10} and $PM_{0.8}$ (panel b); Aluminum (Al), iron (Fe) and titan (Ti) in PM_{10} (weekly) (panel c); Organic carbon (OC) in PM_{10} and $PM_{2.5}$ (weekly) (panel d); Levoglucosan in PM_{10} (weekly) (panel e); EC in PM_{10} (weekly) (panel f); Secondary inorganic aerosol (SIA = Sum of SO_4^{2-} , NO_3^- and NH_4^+) and sea salt aerosol (SS = Sum of Na^+ , Cl^- and Mg^{2+}) (24-hour) (open filter face) (panel g). All measurements are from the Birkenes Observatory.

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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	2019
Birkenes	4.59	4.84	5.12	5.65	5.18	5.37	5.44	5.29	4.98	5.01	4.82	4.90	4.99
Vatnedalen	5.61	5.60	5.61	5.76	5.81	5.77	5.72	5.77	5.86	5.63	5.69	5.67	5.72
Treungen	4.92	4.99	5.07	5.74	5.38	5.36	5.16	5.34	5.17	5.19	5.01	5.01	5.15
Løken	4.98	5.01	5.05	5.44	5.89	5.51	5.52	5.27	5.35	5.57	4.90	5.08	5.23
Hurdal	4.71	4.83	5.17	5.26	5.30	5.49	5.26	5.22	5.10	5.14	5.08	4.95	5.12
Brekkebygda	4.86	4.89	5.20	6.06	4.95	5.69	5.53	5.07	5.17	5.09	4.93	5.11	5.10
Vikedal	5.47	5.43	5.37	5.70	5.51	5.24	5.30	5.25	5.39	5.61	5.30	5.41	5.38
Nausta	5.54	5.68	5.58	5.70	5.45	5.41	5.59	5.30	5.53	5.43	5.49	5.40	5.45
Kårvatn	5.49	5.42	5.30	5.41	5.24	5.49	5.51	5.52	4.97	5.43	5.51	5.59	5.30
Høylandet	5.77	5.87	5.80	5.76	5.99	5.34	5.44	5.24	5.33	5.51	5.57	5.71	5.51
Tustervatn	5.56	4.69	5.21	5.42	5.67	5.45	5.45	5.44	5.43	5.44	5.09	5.41	5.18
Karpbukt	5.00	4.99	4.85	4.78	4.66	5.10	5.07	4.64	5.09	5.22	5.17	4.90	4.96
Ny-Ålesund	5.09	5.50	5.27	5.66	5.80	5.70	6.59	5.78	5.27	6.31	5.60	6.66	5.61

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	2019
Birkenes	0.25	0.13	0.06	0.54	0.22	0.16	0.14	0.15	0.16	0.09	0.16	0.12	0.16
Vatnedalen	0.03	0.08	0.05	0.22	0.16	0.23	0.13	0.13	0.06	0.05	0.12	0.08	0.10
Treungen	0.06	0.06	0.03	0.47	0.17	0.20	0.14	0.12	0.09	0.08	0.10	0.07	0.12
Løken	0.08	0.07	0.04	1.21	0.21	0.25	0.15	0.16	0.07	0.09	0.15	0.07	0.13
Hurdal	0.10	0.08	0.03	0.97	0.30	0.19	0.13	0.15	0.09	0.06	0.15	0.07	0.14
Brekkebygda	0.10	0.07	0.02	0.93	0.30	0.22	0.17	0.16	0.14	0.06	0.12	0.05	0.14
Vikedal	0.02	0.07	0.07	0.29	0.07	0.23	0.17	0.14	0.05	0.02	0.03	0.03	0.09
Nausta	0.02	0.10	0.03	0.34	0.11	0.14	0.11	0.10	0.06	0.03	0.03	0.01	0.06
Kårvatn	0.02	0.03	0.03	0.21	0.09	0.16	0.09	0.12	0.04	0.03	0.01	0.02	0.05
Høylandet	0.02	0.04	0.02	0.00	0.34	0.10	0.17	0.09	0.02	0.02	0.08	0.07	0.06
Tustervatn	0.01	0.41	0.11	0.24	0.12	0.10	0.13	0.10	0.06	0.00	0.08	0.02	0.12
Karpbukt	0.13	0.12	0.27	0.31	0.58	0.17	0.20	0.62	0.30	0.19	0.13	0.18	0.24
Ny-Ålesund	0.22	0.13	0.28	0.23	0.28	0.11	1.17	0.16	0.15	0.24	0.08	0.70	0.20

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	2019
Birkenes	0.54	0.26	0.18	0.52	0.34	0.26	0.18	0.19	0.27	0.19	0.25	0.29	0.26
Vatnedalen	0.09	0.16	0.12	0.19	0.11	0.37	0.12	0.12	0.02	0.04	0.12	0.07	0.11
Treungen	0.22	0.21	0.15	0.34	0.22	0.30	0.14	0.16	0.13	0.15	0.17	0.21	0.19
Løken	0.29	0.30	0.19	1.17	0.23	0.35	0.17	0.18	0.10	0.22	0.26	0.24	0.23
Hurdal	0.33	0.26	0.14	1.47	0.27	0.20	0.15	0.17	0.09	0.14	0.17	0.22	0.20
Brekkebygda	0.42	0.29	0.13	0.72	0.28	0.32	0.26	0.16	0.18	0.13	0.17	0.16	0.21
Vikedal	0.12	0.25	0.18	0.43	0.08	0.32	0.09	0.06	0.01	0.03	0.12	0.13	0.11
Nausta	0.08	0.29	0.07	0.76	0.14	0.16	0.13	0.09	0.01	0.06	0.11	0.05	0.10
Kårvatn	0.02	0.06	0.05	0.18	0.06	0.15	0.03	0.04	0.15	0.06	0.04	0.03	0.07
Høylandet	0.03	0.13	0.09	0.06	0.36	0.08	0.01	0.06	0.02	0.04	0.06	0.06	0.07
Tustervatn	0.08	0.07	0.03	0.29	0.09	0.09	0.12	0.11	0.04	0.03	0.10	0.04	0.07
Karpbukt	0.04	0.11	0.09	0.15	0.13	0.08	0.08	0.13	0.14	0.07	0.09	0.09	0.09
Ny-Ålesund	0.03	0.04	0.06	0.16	0.10	0.07	0.54	0.08	0.14	0.11	0.09	0.10	0.11

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	2019
Birkenes	0.34	0.14	0.13	1.01	0.39	0.39	0.30	0.29	0.21	0.11	0.14	0.17	0.24
Vatnedalen	0.10	0.17	0.14	0.24	0.25	0.58	0.15	0.13	0.03	0.02	0.07	0.07	0.14
Treungen	0.07	0.09	0.08	0.80	0.37	0.42	0.20	0.22	0.09	0.12	0.12	0.11	0.20
Løken	0.18	0.24	0.15	1.39	0.72	0.51	0.13	0.23	0.09	0.19	0.11	0.13	0.25
Hurdal	0.10	0.08	0.07	1.60	0.56	0.33	0.21	0.20	0.07	0.10	0.11	0.11	0.20
Brekkebygda	0.13	0.05	0.04	1.70	0.41	0.61	0.40	0.11	0.22	0.04	0.05	0.04	0.20
Vikedal	0.24	0.30	0.23	0.68	0.10	0.42	0.04	0.04	0.02	0.10	0.10	0.14	0.14
Nausta	0.16	0.37	0.15	1.37	0.26	0.36	0.33	0.10	0.13	0.05	0.21	0.06	0.17
Kårvatn	0.07	0.09	0.06	0.39	0.11	0.26	0.10	0.32	0.01	0.05	0.09	0.07	0.09
Høylandet	0.17	0.37	0.29	0.24	1.11	0.13	0.19	0.06	0.04	0.17	0.19	0.20	0.20
Tustervatn	0.10	0.18	0.09	0.53	0.25	0.15	0.20	0.16	0.08	0.07	0.05	0.06	0.13
Karpbukt	0.03	0.05	0.11	0.18	0.12	0.08	0.07	0.14	0.10	0.09	0.03	0.04	0.08
Ny-Ålesund	0.08	0.06	0.17	0.34	0.13	0.07	0.89	0.14	0.15	0.10	0.07	0.18	0.19

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	2019
Birkenes	0.05	0.08	0.09	0.63	0.17	0.16	0.11	0.10	0.12	0.08	0.07	0.16	0.12
Vatnedalen	0.07	0.11	0.08	0.17	0.07	0.17	0.09	0.05	0.06	0.05	0.07	0.14	0.08
Treungen	0.06	0.07	0.05	0.49	0.13	0.19	0.10	0.12	0.06	0.07	0.05	0.09	0.11
Løken	0.08	0.07	0.05	0.19	0.16	0.29	0.24	0.10	0.12	0.30	0.16	0.16	0.17
Hurdal	0.04	0.07	0.07	1.77	0.14	0.23	0.09	0.09	0.04	0.06	0.17	0.06	0.13
Brekkebygda	0.29	0.15	0.06	1.33	0.11	0.22	0.15	0.11	0.11	0.08	0.12	0.11	0.14
Vikedal	0.23	0.15	0.11	0.30	0.10	0.24	0.21	0.13	0.18	0.11	0.14	0.19	0.16
Nausta	0.15	0.32	0.13	0.16	0.10	0.07	0.08	0.06	0.17	0.11	0.05	0.10	0.12
Kårvatn	0.16	0.08	0.11	0.14	0.09	0.22	0.11	0.11	0.10	0.13	0.18	0.10	0.13
Høylandet	0.15	0.23	0.34	0.34	0.22	0.07	0.14	0.08	0.05	0.13	0.21	0.24	0.16
Tustervatn	0.31	0.28	0.18	0.19	0.14	0.14	0.19	0.11	0.08	0.07	0.10	0.07	0.15
Karpbukt	0.07	0.11	0.25	0.16	0.24	0.12	0.22	0.27	0.35	0.39	0.24	0.12	0.20
Ny-Ålesund	0.10	0.23	1.77	0.31	0.60	0.32	3.10	0.46	0.64	1.20	0.58	2.52	0.56

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	2019
Birkenes	0.06	0.05	0.06	0.11	0.10	0.04	0.04	0.11	0.25	0.05	0.03	0.08	0.08
Vatnedalen	0.10	0.33	0.14	0.12	0.19	0.19	0.24	0.07	0.09	0.10	0.10	0.09	0.13
Treungen	0.01	0.02	0.01	0.15	0.20	0.05	0.04	0.05	0.24	0.06	0.02	0.04	0.07
Løken	0.05	0.05	0.04	0.20	0.56	0.27	0.83	0.24	0.08	0.08	0.05	0.05	0.20
Hurdal	0.03	0.04	0.03	0.35	0.60	0.08	0.05	0.04	0.02	0.03	0.04	0.06	0.10
Brekkebygda	0.15	0.06	0.06	0.33	0.20	0.26	0.09	0.03	0.11	0.02	0.04	0.06	0.09
Vikedal	0.22	0.12	0.09	0.51	0.07	0.05	0.40	0.50	0.10	0.09	0.06	0.13	0.20
Nausta	0.12	0.13	0.11	0.12	0.10	0.07	0.13	0.04	0.14	0.10	0.13	0.13	0.10
Kårvatn	0.16	0.07	0.10	0.07	0.08	0.07	0.06	0.16	0.16	0.10	0.13	0.06	0.11
Høylandet	0.15	0.20	0.30	0.31	0.26	0.08	0.27	0.07	0.04	0.16	0.13	0.18	0.15
Tustervatn	0.26	0.24	0.14	0.09	0.13	0.08	0.15	0.07	0.04	0.19	0.04	0.06	0.13
Karpbukt	0.05	0.06	0.19	0.12	0.07	0.04	0.11	0.16	0.21	0.20	0.06	0.06	0.10
Ny-Ålesund	0.10	0.13	1.50	0.15	0.21	0.11	0.53	0.10	0.23	0.19	0.20	0.81	0.21

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	2019
Birkenes	0.09	0.14	0.15	0.07	0.07	0.04	0.02	0.10	0.11	0.06	0.05	0.17	0.09
Vatnedalen	0.03	0.04	0.09	0.04	0.02	0.03	0.02	0.02	0.04	0.02	0.01	0.07	0.03
Treungen	0.03	0.05	0.03	0.06	0.04	0.03	0.02	0.02	0.03	0.02	0.01	0.06	0.03
Løken	0.03	0.11	0.05	0.13	0.07	0.05	0.05	0.06	0.04	0.03	0.02	0.07	0.05
Hurdal	0.02	0.03	0.02	0.20	0.06	0.03	0.01	0.02	0.01	0.01	0.02	0.04	0.03
Brekkebygda	0.05	0.04	0.01	0.15	0.07	0.04	0.02	0.02	0.02	0.01	0.01	0.03	0.03
Vikedal	0.68	0.31	0.26	0.09	0.04	0.10	0.10	0.14	0.30	0.15	0.09	0.31	0.22
Nausta	0.33	0.28	0.31	0.07	0.11	0.05	0.06	0.03	0.27	0.08	0.05	0.20	0.17
Kårvatn	0.49	0.19	0.29	0.04	0.18	0.04	0.02	0.03	0.08	0.07	0.28	0.10	0.19
Høylandet	0.52	0.55	0.87	0.90	0.22	0.06	0.10	0.03	0.09	0.34	0.34	0.41	0.33
Tustervatn	0.74	0.68	0.41	0.13	0.08	0.03	0.04	0.01	0.03	0.17	0.06	0.13	0.26
Karpbukt	0.19	0.17	0.57	0.35	0.14	0.08	0.25	0.26	0.24	0.55	0.14	0.08	0.21
Ny-Ålesund	0.27	0.49	4.66	0.54	0.72	0.38	1.25	0.49	0.80	0.72	0.68	2.59	0.73

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	2019
Birkenes	0.77	1.12	1.23	0.18	0.48	0.26	0.15	0.85	0.84	0.53	0.40	1.36	0.74
Vatnedalen	1.20	1.34	1.40	1.00	0.88	0.77	0.83	0.69	0.95	0.60	0.98	1.26	0.92
Treungen	0.24	0.38	0.25	0.11	0.20	0.13	0.08	0.22	0.19	0.18	0.10	0.53	0.20
Løken	0.20	0.91	0.51	0.47	0.19	0.17	0.25	0.54	0.22	0.16	0.12	0.54	0.33
Hurdal	0.18	0.22	0.20	0.38	0.14	0.09	0.06	0.18	0.04	0.06	0.14	0.37	0.15
Brekkebygda	0.40	0.21	0.13	0.23	0.12	0.19	0.17	0.12	0.09	0.05	0.08	0.20	0.14
Vikedal	5.63	2.52	2.25	0.37	0.47	0.76	0.65	0.99	2.39	1.42	0.56	2.46	1.80
Nausta	2.76	2.32	2.68	0.45	0.99	0.39	0.56	0.24	2.04	0.64	0.60	1.77	1.44
Kårvatn	4.01	1.63	2.44	0.22	1.50	0.22	0.17	0.19	0.63	0.59	2.26	0.92	1.53
Høylandet	4.33	4.70	7.58	7.99	1.80	0.58	0.55	0.18	0.84	2.68	2.59	3.21	2.79
Tustervatn	6.32	5.92	3.51	1.01	0.69	0.28	0.23	0.12	0.23	1.66	0.56	1.11	2.23
Karpbukt	1.55	1.36	5.20	2.83	1.06	0.68	2.02	2.12	1.66	4.37	1.12	0.67	1.72
Ny-Ålesund	2.06	3.79	37.02	3.90	4.49	2.32	6.48	2.91	6.15	4.66	4.15	19.91	5.16

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	2019
Birkenes	1.31	1.89	2.19	0.35	0.82	0.41	0.29	1.40	1.37	0.87	0.72	2.25	1.25
Vatnedalen	1.22	1.37	1.95	0.49	0.53	0.44	0.49	0.45	0.83	0.45	0.70	1.45	0.79
Treungen	0.49	0.67	0.44	0.20	0.34	0.24	0.14	0.37	0.32	0.31	0.19	0.85	0.35
Løken	0.37	1.58	0.88	0.69	0.35	0.32	0.35	0.84	0.36	0.27	0.25	0.95	0.56
Hurdal	0.34	0.38	0.34	0.66	0.25	0.20	0.13	0.31	0.08	0.10	0.26	0.58	0.26
Brekkebygda	0.60	0.36	0.22	0.37	0.24	0.28	0.18	0.19	0.14	0.10	0.16	0.31	0.23
Vikedal	9.66	4.32	4.06	0.50	0.69	1.24	1.09	1.65	4.22	2.36	1.00	4.19	3.08
Nausta	4.83	3.97	4.80	0.78	1.65	0.62	0.87	0.40	3.55	1.11	1.06	3.03	2.50
Kårvatn	7.11	2.85	4.41	0.41	2.48	0.39	0.32	0.31	1.06	0.98	3.63	1.49	2.66
Høylandet	7.76	8.35	13.53	13.89	2.86	0.92	0.85	0.30	1.36	4.77	4.62	5.78	4.93
Tustervatn	10.90	10.00	6.32	1.89	1.22	0.52	0.40	0.22	0.40	2.78	1.00	1.87	3.84
Karpbukt	2.75	2.44	8.07	4.92	1.71	1.14	3.39	3.52	2.94	7.91	1.89	1.14	2.97
Ny-Ålesund	3.56	7.05	62.02	6.52	8.04	4.02	11.09	5.25	10.48	8.07	6.61	33.75	8.83

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	2019
Birkenes	113.32	124.41	175.50	54.70	105.66	144.44	90.56	269.80	221.13	221.20	277.20	211.60	2009.53
Vatnedalen	56.12	40.10	48.84	27.56	73.04	74.06	63.89	183.42	164.01	135.39	48.02	118.98	1033.43
Treungen	131.52	49.78	97.80	51.10	98.56	153.75	199.39	228.62	138.98	205.80	165.71	123.39	1644.40
Løken	26.39	65.51	78.91	8.99	95.28	90.97	60.90	117.38	131.39	131.38	112.93	84.27	1004.30
Hurdal	41.57	73.53	104.20	17.77	141.27	147.45	71.51	143.23	154.05	119.51	148.80	97.50	1260.40
Brekkebygda	39.67	73.13	101.20	17.50	121.53	82.97	83.01	145.55	112.94	123.20	114.60	119.50	1134.80
Vikedal	200.60	161.50	254.09	33.31	205.89	212.87	198.56	552.22	397.46	394.91	46.66	278.73	2936.80
Nausta	142.10	138.54	220.26	13.78	94.37	165.76	78.97	295.03	148.68	144.94	31.95	401.66	1876.06
Kårvatn	244.75	88.69	145.75	21.03	151.96	102.05	84.42	63.37	267.63	118.00	79.11	141.60	1508.37
Høylandet	136.00	126.49	124.86	1.95	43.96	147.23	18.10	140.33	180.97	91.00	21.26	188.40	1220.56
Tustervatn	81.35	167.84	154.66	17.68	63.27	94.51	41.44	113.90	117.10	79.42	48.12	153.86	1133.17
Karpbukt	66.93	41.38	15.24	11.55	37.32	96.26	43.16	36.06	33.77	52.33	41.34	51.20	526.55
Ny-Ålesund	0.31	14.40	5.40	47.00	6.59	6.31	1.89	40.22	17.49	9.10	12.40	1.20	162.31

Table A.1.11: Monthly and annual wet deposition of strong acid (H^+) at Norwegian background stations. Unit: $\mu\text{ekv}/\text{m}^2$.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes	2922	1342	1320	121	704	613	327	3612	72404	2186	4220	2662	20593
Vatnedalen	137	76	120	4723	114	249	34047	760905	74776	320	98	30203	1980
Treungen	1592	495	833	93	409	664	1474	1039	28942	1314	1628	1206	11627
Løken	273	625	707	2104	122	110184	12440	641	2575	1953	1420	690	5952
Hurdal	817	992	706	97	2446	11338	138890	873	2597	1951	1239	1092	9642
Brekkebygda	549	23055	644	15	1365	12307	245	1239	751	993	1360	925	9022
Vikedal	684	596	1093	2360	629	14145	644	1486899	1510	971	401	1604	12285
Nausta	413	24261	316726	533	336	789	317567	1511	409	33470	109	20984	6676
Kårvatn	796	340	1959	2985	1891	321	3237	190	2872	436	245	6220	7526
Høylandet	230	169	221600	35664	45	1192	120	813	835	283	57	1882	3769
Tustervatn	226	3395	963	1299	197	45670	13160	416	594	287	393	1020	7443
Karpbukt	667	423	213	190	664	755	361	815	274	187	289	637	5764
Ny-Ålesund	2	46	29	103	10	13	0	66	11120	4	31	0	395

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

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes	29	16	11	30	23	24	13	41	36	20	45	25	313
Vatnedalen	2	3	2	6	11	17	9	23	9	7	6	9	105
Treungen	8	3	3	24	17	31	29	28	13	16	16	8	196
Løken	2	5	3	11	20	23	9	18	9	11	17	6	134
Hurdal	4	6	3	17	43	27	9	21	14	7	23	7	181
Brekkebygda	4	5	2	16	36	19	14	23	16	7	14	6	163
Vikedal	5	11	17	10	14	50	33	78	18	8	1	8	253
Nausta	3	13	7	5	10	24	9	29	8	4	1	5	118
Kårvatn	5	3	4	4	14	16	7	7	10	4	0	2	77
Høylandet	3	5	3	0	15	14	3	12	4	2	2	13	76
Tustervatn	1	68	17	4	7	10	5	12	6	0	4	3	138
Karpbukt	9	5	4	4	21	16	9	22	10	10	5	9	125
Ny-Ålesund	0	2	2	11	2	1	2	6	3	2	1	1	32

Table A.1.13: Monthly and annual wet deposition of nitrate at Norwegian background stations.

Unit: mg N/m².

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes	61	33	32	28	36	38	16	50	59	42	69	62	526
Vatnedalen	5	6	6	5	8	28	8	21	3	6	6	8	111
Treungen	29	11	14	17	22	46	28	36	18	32	28	26	307
Løken	8	20	15	11	22	32	10	22	13	29	29	21	231
Hurdal	14	19	14	26	38	30	11	24	14	17	26	21	254
Brekkebygda	17	21	13	13	34	26	21	24	21	15	19	19	244
Vikedal	24	41	45	14	17	69	19	35	4	10	6	35	319
Nausta	11	40	15	10	13	26	10	26	2	8	3	20	186
Kårvatn	5	5	8	4	10	15	2	2	40	7	4	5	107
Høylandet	4	17	11	0	16	12	0	9	4	4	1	12	90
Tustervatn	7	12	5	5	6	9	5	13	5	2	5	6	79
Karpbukt	3	4	1	2	5	8	3	5	5	4	4	5	49
Ny-Ålesund	0	1	0	7	1	0	1	3	3	1	1	0	18

Table A.1.14: Monthly and annual wet deposition of ammonium at Norwegian background stations.

Unit: mg N/m².

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes	39	17	23	55	41	56	27	78	46	24	40	36	481
Vatnedalen	6	7	7	7	18	43	9	23	5	3	3	9	140
Treungen	10	4	7	41	37	65	40	50	12	25	20	14	326
Løken	5	16	12	13	69	46	8	27	12	25	12	11	254
Hurdal	4	6	7	29	79	48	15	29	11	12	16	11	258
Brekkebygda	5	4	4	30	50	51	33	16	24	5	6	5	223
Vikedal	48	48	58	23	20	90	8	20	7	40	4	39	405
Nausta	22	51	32	19	25	59	26	30	19	7	7	22	320
Kårvatn	16	8	9	8	17	26	8	20	2	6	7	10	138
Høylandet	23	47	36	0	49	19	3	8	7	15	4	38	249
Tustervatn	8	30	14	9	16	15	8	18	9	6	2	9	144
Karpbukt	2	2	2	2	4	8	3	5	3	5	1	2	40
Ny-Ålesund	0	1	1	16	1	0	2	6	3	1	1	0	31

Table A.1.15: Monthly and annual wet deposition of calcium at Norwegian background stations.
Unit: mg/m².

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes	6	10	15	34	18	23	10	27	27	18	20	33	241
Vatnedalen	4	4	4	5	5	13	5	10	10	7	4	17	88
Treungen	8	4	5	25	13	29	20	29	8	15	9	11	175
Løken	2	5	4	2	15	27	14	11	16	40	19	13	168
Hurdal	2	5	7	31	20	35	7	13	6	8	26	6	166
Brekkebygda	12	11	6	23	13	19	12	16	12	10	14	14	164
Vikedal	47	24	27	10	20	52	41	69	71	44	6	53	465
Haukeland	21	44	28	2	10	12	6	17	26	16	2	42	225
Nausta	40	7	16	3	14	23	10	7	27	16	14	14	191
Kårvatn	20	29	42	1	10	11	3	12	9	12	4	45	196
Høylandet	25	47	28	3	9	14	8	12	9	6	5	10	175
Tustervatn	5	5	4	2	9	11	9	10	12	21	10	6	103
Svanvik	0	3	10	15	4	2	6	19	11	11	7	3	90
Karpbukt	6	10	15	34	18	23	10	27	27	18	20	33	241
Ny-Ålesund	4	4	4	5	5	13	5	10	10	7	4	17	88

Table A.1.16: Monthly and annual wet deposition of potassium at Norwegian background stations.
Unit: mg /m².

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes	7	7	11	6	11	5	4	29	55	11	9	17	170
Vatnedalen	5	13	7	3	14	14	16	13	15	13	5	11	130
Treungen	1	1	1	8	20	8	8	13	33	13	3	5	114
Løken	1	3	3	2	53	25	50	29	11	10	6	5	198
Hurdal	1	3	3	6	84	11	3	5	3	3	6	6	126
Brekkebygda	6	5	6	6	24	22	7	5	12	3	4	7	101
Vikedal	45	20	23	17	15	12	79	275	42	36	3	36	601
Nausta	17	19	24	2	9	11	10	12	21	15	4	52	196
Kårvatn	39	6	14	2	13	7	5	10	43	12	10	8	169
Høylandet	20	26	37	1	11	12	5	10	8	15	3	34	182
Tustervatn	21	41	21	2	8	8	6	8	5	15	2	9	146
Karpbukt	3	3	3	1	2	4	5	6	7	11	2	3	50
Ny-Ålesund	0	2	8	7	1	1	1	4	4	2	2	1	34

Table A.1.17: Monthly and annual wet deposition of magnesium at Norwegian background stations.
Unit: mg /m².

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes	10	17	26	4	7	6	2	27	24	14	14	36	187
Vatnedalen	2	1	4	1	1	3	1	3	7	3	1	8	35
Treungen	4	2	3	3	4	4	3	6	5	5	2	8	47
Løken	1	7	4	1	7	4	3	7	5	4	2	6	51
Hurdal	1	3	2	3	8	4	1	3	1	1	3	4	34
Brekkebygda	2	3	1	3	8	3	2	3	2	1	1	3	31
Vikedal	137	49	65	3	9	20	20	78	121	60	4	86	654
Nausta	47	39	69	1	11	8	5	8	41	11	2	81	322
Kårvatn	119	17	42	1	28	4	2	2	22	8	22	14	280
Høylandet	71	70	108	2	10	9	2	4	17	31	7	76	406
Tustervatn	60	114	64	2	5	3	1	2	3	13	3	20	291
Karpbukt	12	7	9	4	5	8	11	9	8	29	6	4	112
Ny-Ålesund	0	7	25	25	5	2	2	20	14	7	8	3	119

Table A.1.18: Monthly and annual wet deposition of sodium at Norwegian background stations.
Unit: mg /m².

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes	87	139	217	10	51	38	14	230	187	117	112	287	1491
Vatnedalen	67	54	68	28	64	57	53	127	156	82	47	150	954
Treungen	31	19	25	6	20	20	17	50	26	37	16	65	332
Løken	5	60	40	4	18	16	15	63	29	21	13	46	330
Hurdal	8	16	21	7	20	14	4	25	7	7	21	36	186
Brekkebygda	16	16	14	4	15	16	14	18	10	6	10	24	159
Vikedal	1130	407	572	12	96	162	129	546	950	560	26	686	5277
Nausta	392	322	589	6	93	64	44	72	303	92	19	709	2707
Kårvatn	982	145	356	5	229	23	14	12	168	70	179	130	2312
Høylandet	589	595	946	16	79	85	10	25	153	243	55	605	3402
Tustervatn	514	994	544	18	44	27	9	13	27	132	27	171	2525
Karpbukt	104	56	79	33	39	66	87	76	56	228	46	34	906
Ny-Ålesund	1	55	200	183	30	15	12	117	108	42	51	24	837

Table A.1.19: Monthly and annual wet deposition of chloride at Norwegian background stations.
Unit: mg /m².

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes	149	235	385	19	87	60	26	379	303	192	198	476	2516
Vatnedalen	69	55	95	14	39	33	32	83	137	61	34	172	822
Treungen	64	33	43	10	34	37	27	85	45	65	31	105	580
Løken	10	103	70	6	33	29	21	99	48	36	28	80	562
Hurdal	14	28	36	12	36	30	9	44	12	13	39	57	329
Brekkebygda	24	26	23	6	29	24	15	28	16	12	18	37	257
Vikedal	1937	698	1032	17	143	265	216	910	1675	932	47	1168	9039
Nausta	687	550	1057	11	156	103	69	119	529	161	34	1218	4692
Kårvatn	1740	253	643	9	377	40	27	19	282	116	288	211	4005
Høylandet	1056	1056	1689	27	126	136	15	43	246	434	98	1088	6015
Tustervatn	887	1678	977	33	77	49	17	25	47	221	48	287	4355
Karpbukt	184	101	123	57	64	110	147	127	99	414	78	59	1562
Ny-Ålesund	1	102	335	306	53	25	21	211	183	73	82	40	1434

Table A.1.20: The 10 highest daily wet deposition of sea salt corrected sulfate, 2019.

Site	Date	SO ₄ wet dep mgS/m ²	Precip mm'	% av annual SO ₄ dep	pH
Birkenes	26.09.2019	19,5	60,8	6,2	4,89
	24.04.2019	14,8	7,0	4,7	5,69
	31.01.2019	13,9	35,7	4,4	4,38
	25.01.2019	9,5	20,7	3,0	4,57
	18.11.2019	8,7	41,4	2,8	4,94
	20.07.2019	7,9	37,4	2,5	5,72
	09.05.2019	7,8	43,3	2,5	5,21
	24.10.2019	7,3	16,2	2,3	4,72
	10.08.2019	6,2	62,1	2,0	5,53
	08.06.2019	5,2	36,8	1,6	5,43
	sum			32,2	

Hurdal	09.05.2019	14,9	36,3	8,2	5,01
	12.06.2019	10,6	39,3	5,9	5,53
	18.11.2019	10,0	28,5	5,5	4,95
	27.09.2019	9,4	58,9	5,2	4,95
	06.06.2019	7,7	38,4	4,2	5,43
	18.05.2019	7,1	25,2	3,9	5,56
	27.04.2019	6,8	7,6	3,8	4,99
	21.05.2019	6,1	10,4	3,4	0,00
	26.04.2019	5,5	7,0	3,0	5,73
	24.10.2019	4,3	10,5	2,4	4,77
	sum			45,5	

Site	Date	SO ₄ wet dep mgS/m ²	Precip mm'	% av annual SO ₄ dep	pH
Tustervatn	16.02.2019	25,2	6,7	18,3	3,71
	12.02.2019	17,6	9,2	12,7	4,01
	22.02.2019	8,7	21,7	6,3	4,76
	15.02.2019	8,3	11,5	6,0	4,62
	23.07.2019	3,5	23,2	2,5	5,33
	01.09.2019	3,1	14,3	2,3	5,31
	26.08.2019	3,0	5,3	2,2	5,97
	22.03.2019	2,5	15,9	1,8	5,22
	07.06.2019	2,5	12,1	1,8	5,22
	29.08.2019	2,4	19,7	1,7	5,31
	sum			55,7	

Table A.1.20 continued:

Site	Date	SO4 wet dep mgS/m2	Precip mm'	% av annual SO4 dep	pH
Kårvatn	30.04.2019	5,6	28,2	7,3	5,41
	16.09.2019	3,4	113,1	4,4	5,45
	28.06.2019	3,0	13,1	3,9	6,01
	08.08.2019	2,7	4,4	3,5	6,38
	04.05.2019	2,6	21,9	3,4	5,18
	03.05.2019	2,5	22,8	3,3	5,16
	07.06.2019	2,0	14,0	2,5	5,22
	20.06.2019	1,8	11,3	2,3	5,62
	02.05.2019	1,7	15,6	2,2	5,08
	16.06.2019	1,7	6,6	2,2	5,47
	sum				35,2

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 1987-2019.

Site	Year	Annual vol. weighted mean concentrations						Annual precip mm	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		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
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 mm	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		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
Birkenes (cont.)	2014	0.31	0.35	0.35	0.16	0.18	4.77	2331	732	813	818	17	71	193
	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
	2019	0,16	0,26	0,24	0,12	0,09	4,99	2010	313	526	481	10	37	109
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			

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip mm	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		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	
Vatnedalen (cont.)	2013	0.09	0.14	0.35	0.14	0.05	5.50	983	92	133	344	3			
	2014	0.17	0.15	0.17	0.23	0.07	5.44	957	160	141	167	4			
	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			
	2019	0,10	0,11	0,14	0,08	0,03	5,72	1033	105	111	140	2			
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				

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip mm	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		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
Treungen (cont.)	2012	0.15	0.28	0.23	0.07	0.05	4.96	1092	167	307	247	12		
	2013	0.17	0.27	0.30	0.09	0.06	5.12	1150	190	305	349	9		
	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		
	2019	0,12	0,19	0,20	0,11	0,03	5,15	1644	196	307	326	7		
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			

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip mm	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		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
Løken (cont.)	2010	0.23	0.29	0.24	0.12	0.04	4.95	664	150	193	158	8		
	2011	0.21	0.25	0.41	0.14	0.08	5.12	1100	228	278	452	8		
	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		
	2019	0,13	0,23	0,25	0,17	0,05	5,23	1004	134	231	254	6		
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	
2019	0,14	0,20	0,20	0,13	0,03	5,12	1260	181	254	258	8	23	123	

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip mm	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		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
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 mm	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		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 (cont.)	2017	0.12	0.17	0.15	0.09	0.02	4.98	1092	130	190	167	10		
	2018	0.15	0.24	0.20	0.15	0.05	4.98	1003	151	245	197	10		
	2019	0,14	0,21	0,20	0,14	0,03	5,10	1135	163	244	223	8		
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			
2019	0,09	0,11	0,14	0,16	0,22	5,38	2937	253	319	405	4			

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip mm	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		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
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			
2019	0,06	0,10	0,17	0,12	0,17	5,45	1876	118	186	320	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		

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip mm	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		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
Kårvatn (cont.)	1987	0.24	0.09	0.12	0.15	0.17	4.87	1464	357	129	176	20	68	
	1988	0.11	0.06	0.09	0.13	0.19	5.09	1550	164	91	143	13	76	149
	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	
2019	0,05	0,07	0,09	0,13	0,19	5,30	1508	77	107	138	5	23	123	
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			

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip mm	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		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	
Høylandet (cont.)	1999	0.14	0.10	0.27	0.13	0.19	5.41	1195	171	125	342	5			
	2000	0.12	0.08	0.21	0.18	0.35	5.36	1183	150	95	248	5			
	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			
2019	0,06	0,07	0,20	0,16	0,33	5,51	1221	76	90	249	3				
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		

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip mm	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		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
Tustervatn (cont.)	1997	0.08	0.06	0.18	0.17	0.30	5.34	1528	121	98	271	7	44	199
	1998	0.07	0.06	0.16	0.11	0.18	5.39	1407	100	90	230	6	30	178
	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	
2019	0.12	0.07	0.13	0.15	0.26	5.18	1133	138	79	144	7	21	78	
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			

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precipitation mm	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			mg/m ²	mg/m ²	mg/m ²	mekv/m ²	mg/m ²	mg/m ²
Karpbukt (cont.)	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		
	2015	0.29	0.08	0.11	0.19	0.23	4.87	403	116	33	46	5		
	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		
	2019	0,24	0,09	0,08	0,20	0,21	4,96	527	125	49	40	11		
Ny-Ålesund (tørr-avsetning fra Zeppelin)	1981	0.24	0.05	0.05	1.03	0.41	5.11	366	88	20	17	3		
	1982	0.39	0.08	0.05	0.92	2.01	5.01	206	80	16	10	2		
	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
	1993	0.29	0.10	0.08	0.51	0.91	5.02	489	140	47	41	5	32	29
	1994	0.32	0.08	0.29	0.59	0.63	5.35	280	90	22	80	1	24	30
	1995	0.30	0.10	0.15	0.89	0.79	5.26	238	71	23	36	1	25	
	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		

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precipitation mm	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		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
Ny-Ålesund (tørr-avsetning fra Zeppelin) (cont)	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	
	2019	0,20	0,11	0,19	0,56	0,73	5,61	162	32	18	31	2,5	19	

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 mm	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		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
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 precip mm	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		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
Skreådalen cont.	1981	0.49	0.20	0.28	0.16	0.18	4.58	2260	1107	452	633	59		
	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		
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			

Table A.1.21b, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip mm	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		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
Haukeland cont.	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			
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			
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		

Table A.1.21b, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip mm	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		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
Fagernes (cont.)	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			
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		

Table A.1.21b, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip mm	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		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
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	
	1988	0.30	0.13	0.10	0.09	0.03	4.65	406	122	54	40	9	134	81
	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	

Table A.1.21b, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip mm	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		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
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			
2013-2017														
2018	0,33	0,12	0,08	0,12	0,11	4,83	356	117	42	29	15			

Table A.1.22: Monthly and annual mean concentration of sulfur dioxide in air at Norwegian background stations. Unit: $\mu\text{g S}/\text{m}^3$.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes II	0.05	0.06	0.03	0.16	0.09	0.12	0.12	0.09	0.04	0.03	0.02	0.03	0.07
Hurdal	0.07	0.02	0.02	0.11	0.03	0.03	0.04	0.05	0.02	0.02	0.01	0.01	0.04
Kårvatn	0.02	0.02	0.01	0.06	0.04	0.02	0.03	0.05	0.02	0.02	0.02	0.02	0.03
Tustervatn	0.03	0.10	0.04	0.12	0.03	0.03	0.03	0.06	0.02	0.03	0.04	0.02	0.05
Zeppelinfjellet	0.21	0.12	0.17	0.05	0.13	0.03	0.03	0.02	0.03	0.02	0.02	0.11	0.08

Table A.1.23: Monthly and annual mean concentration of sulfate in aerosol at Norwegian background stations. Unit: $\mu\text{g S}/\text{m}^3$.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes II	0.21	0.20	0.11	0.40	0.19	0.33	0.25	0.35	0.14	0.08	0.09	0.11	0.20
Hurdal	0.13	0.14	0.06	0.34	0.15	0.23	0.17	0.24	0.07	0.06	0.05	0.06	0.14
Kårvatn	0.05	0.03	0.02	0.31	0.15	0.16	0.19	0.17	0.05	0.03	0.04	0.03	0.10
Tustervatn	0.16	0.17	0.12	0.33	0.13	0.13	0.18	0.20	0.06	0.06	0.06	0.05	0.14
Zeppelinfjellet	0.15	0.16	0.21	0.17	0.19	0.07	0.08	0.04	0.04	0.06	0.05	0.11	0.11

Table A.1.24: Monthly and annual mean concentration of nitrogen dioxide in air at Norwegian background stations. Unit: $\mu\text{g N}/\text{m}^3$.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes II	0.27	0.36	0.19	0.31	0.25	0.35	0.27	0.42	0.41	0.32	0.36	0.30	0.32
Hurdal	0.79	0.94	0.50	0.30	0.31	0.37	0.19	0.48	0.32	0.39	0.42	0.99	0.50
Kårvatn	0.17	0.17	0.13	0.13	0.14	0.19	0.16	0.26	0.20	0.15	0.17	0.09	0.16
Tustervatn	0.09	0.10	0.11	0.11	0.13	0.16	0.15	0.19	0.21	0.13	0.11	0.14	0.14

Table A.1.25: Monthly and annual mean concentration of sum of nitrate and nitric acid in air at Norwegian background stations. Unit: $\mu\text{g N}/\text{m}^3$.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes II	0.17	0.29	0.08	0.25	0.10	0.25	0.14	0.19	0.09	0.07	0.08	0.10	0.15
Hurdal	0.06	0.17	0.07	0.15	0.06	0.13	0.07	0.11	0.04	0.05	0.06	0.08	0.09
Kårvatn	0.03	0.02	0.02	0.12	0.05	0.07	0.04	0.05	0.03	0.02	0.02	0.02	0.04
Tustervatn	0.17	0.05	0.03	0.19	0.05	0.04	0.04	0.07	0.02	0.03	0.03	0.03	0.06
Zeppelinfjellet	0.03	0.02	0.03	0.03	0.02	0.02	0.04	0.02	0.02	0.02	0.03	0.03	0.03

Table A.1.26: Monthly and annual mean concentration of nitrate in aerosol at Norwegian background stations. Unit: $\mu\text{g N}/\text{m}^3$.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes II	0.14	0.26	0.07	0.18	0.07	0.19	0.08	0.16	0.07	0.05	0.07	0.08	0.12
Hurdal	0.04	0.15	0.05	0.10	0.04	0.10	0.03	0.09	0.03	0.04	0.05	0.07	0.06
Kårvatn	0.01	0.01	0.01	0.07	0.03	0.05	0.03	0.03	0.01	0.01	0.01	0.01	0.02
Tustervatn	0.15	0.03	0.02	0.15	0.03	0.03	0.03	0.05	0.01	0.01	0.02	0.01	0.05
Zeppelinfjellet	0.01	0.01	0.02	0.02	0.01	0.01	0.02	0.01	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: $\mu\text{g N}/\text{m}^3$.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes II	0.35	0.35	0.14	0.88	0.29	0.48	0.43	0.43	0.20	0.09	0.12	0.12	0.32
Hurdal	0.17	0.25	0.10	0.60	0.29	0.37	0.30	0.34	0.14	0.07	0.09	0.15	0.24
Kårvatn	0.30	0.27	0.11	0.64	0.37	0.66	0.63	0.90	0.36	0.22	0.33	0.65	0.46
Tustervatn	0.35	0.28	0.26	0.77	0.57	0.67	0.52	0.39	0.22	0.13	0.09	0.18	0.37
Zeppelinfjellet	0.10	0.16	0.11	0.16	0.07	0.13	0.19	0.14	0.16	0.11	0.09	0.08	0.12

Table A.1.28: Monthly and annual mean concentrations of ammonium in aerosols at Norwegian background stations. Unit: $\mu\text{g N}/\text{m}^3$.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes II	0.25	0.26	0.06	0.39	0.13	0.20	0.18	0.19	0.09	0.02	0.07	0.07	0.16
Hurdal	0.06	0.16	0.03	0.29	0.09	0.15	0.10	0.13	0.03	0.02	0.04	0.06	0.10
Kårvatn	0.01	0.01	0.01	0.26	0.09	0.08	0.09	0.08	0.02	0.01	0.01	0.01	0.06
Tustervatn	0.20	0.04	0.02	0.33	0.08	0.04	0.11	0.07	0.02	0.01	0.01	0.01	0.08
Zeppelinfjellet	0.04	0.04	0.07	0.06	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.03	0.03

Table A.1.29: Monthly and annual mean concentrations of magnesium in aerosols at Norwegian background stations. Unit: $\mu\text{g}/\text{m}^3$.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes II	0.05	0.08	0.08	0.04	0.04	0.07	0.03	0.09	0.06	0.04	0.01	0.06	0.06
Hurdal	0.02	0.03	0.02	0.03	0.02	0.03	0.01	0.05	0.01	0.01	0.01	0.02	0.02
Kårvatn	0.04	0.02	0.01	0.03	0.03	0.02	0.02	0.03	0.02	0.01	0.01	0.02	0.02
Tustervatn	0.04	0.08	0.07	0.04	0.03	0.03	0.02	0.03	0.02	0.01	0.01	0.03	0.03
Zeppelinfjellet	0.04	0.05	0.06	0.07	0.03	0.03	0.03	0.02	0.02	0.04	0.04	0.04	0.04

Table A.1.30: Monthly and annual mean concentrations of calcium in aerosols at Norwegian background stations. Unit: $\mu\text{g}/\text{m}^3$.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes II	0.02	0.06	0.03	0.19	0.03	0.05	0.07	0.05	0.03	0.02	0.01	0.02	0.05
Hurdal	0.02	0.02	0.02	0.17	0.03	0.04	0.03	0.04	0.02	0.01	0.01	0.01	0.04
Kårvatn	0.02	0.01	0.01	0.14	0.03	0.03	0.05	0.04	0.01	0.01	0.02	0.01	0.03
Tustervatn	0.02	0.04	0.03	0.12	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.03
Zeppelinfjellet	0.01	0.02	0.03	0.03	0.02	0.04	0.04	0.01	0.02	0.04	0.02	0.08	0.03

Table A.1.31: Monthly and annual mean concentrations of potassium in aerosols at Norwegian background stations. Unit: $\mu\text{g}/\text{m}^3$.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes II	0.04	0.07	0.05	0.09	0.05	0.08	0.05	0.08	0.05	0.12	0.04	0.05	0.06
Hurdal	0.03	0.07	0.03	0.07	0.05	0.03	0.01	0.03	0.02	0.03	0.03	0.05	0.04
Kårvatn	0.02	0.05	0.02	0.09	0.05	0.02	0.05	0.04	0.03	0.01	0.02	0.01	0.03
Tustervatn	0.05	0.04	0.03	0.03	0.03	0.02	0.03	0.04	0.02	0.01	0.01	0.02	0.03
Zeppelinfjellet	0.03	0.05	0.05	0.10	0.08	0.02	0.05	0.02	0.02	0.03	0.05	0.03	0.05

Table A.1.32: Monthly and annual mean concentrations of chloride in aerosols at Norwegian background stations. Unit: $\mu\text{g}/\text{m}^3$.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes II	0.55	0.91	1.00	0.19	0.27	0.38	0.16	0.74	0.59	0.46	0.11	0.69	0.50
Hurdal	0.24	0.31	0.23	0.08	0.10	0.11	0.03	0.26	0.08	0.09	0.04	0.11	0.14
Kårvatn	0.54	0.24	0.15	0.09	0.26	0.13	0.09	0.09	0.14	0.11	0.04	0.27	0.18
Tustervatn	0.57	1.22	1.02	0.18	0.25	0.24	0.11	0.21	0.20	0.11	0.13	0.35	0.38
Zeppelinfjellet	0.44	0.43	0.50	0.63	0.16	0.15	0.07	0.17	0.22	0.37	0.43	0.31	0.32

Table A.1.33: Monthly and annual mean concentrations of sodium in aerosols at Norwegian background stations. Unit: $\mu\text{g}/\text{m}^3$.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Birkenes II	0.40	0.65	0.63	0.20	0.28	0.50	0.22	0.69	0.44	0.35	0.12	0.53	0.42
Hurdal	0.16	0.22	0.18	0.10	0.12	0.22	0.06	0.28	0.08	0.09	0.04	0.10	0.14
Kårvatn	0.31	0.15	0.10	0.09	0.23	0.17	0.13	0.12	0.11	0.05	0.03	0.18	0.14
Tustervatn	0.37	0.70	0.60	0.16	0.20	0.19	0.10	0.20	0.14	0.09	0.10	0.23	0.26
Zeppelinfjellet	0.30	0.29	0.35	0.48	0.15	0.13	0.08	0.12	0.20	0.25	0.28	0.22	0.24

Table A.1.34a: Annual mean concentrations of sulfur and nitrogen components in air at Norwegian background stations from 1973-2019. Units $\mu\text{g S}/\text{m}^3$ and $\mu\text{g N}/\text{m}^3$.

Site	År	Annual mean concentrations of main components in air ($\mu\text{g}/\text{m}^3$)					
		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

Table A.1.34a, cont.

Site	År	Annual mean concentrations of main components in air ($\mu\text{g}/\text{m}^3$)					
		SO ₂ -S	SO ₄ -S	NO ₂ -N	(HNO ₃ +NO ₃)-N	(NH ₄ +NH ₃)-N	NH ₄ -N
Birkenes II (cont.)	2016	0.05	0.20	0.30	0.25	0.40	0.23
	2017	0.06	0.22	0.27	0.15	0.27	0.13
	2018	0.10	0.26	0.32	0.24	0.47	0.25
	2019	0.07	0.2	0.32	0.15	0.32	0.16
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	
2019	0.04	0.14	0.50	0.09	0.24	0.10	
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				

Table A.1.34a, cont.

Site	År	Annual mean concentrations of main components in air ($\mu\text{g}/\text{m}^3$)					
		SO ₂ -S	SO ₄ -S	NO ₂ -N	(HNO ₃ +NO ₃)-N	(NH ₄ +NH ₃)-N	NH ₄ -N
Kårvatn (cont.)	1984	0.43	0.54				
	1985	0.44	0.45				
	1986	0.39	0.43				
	1987	0.32	0.38				
	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	
2019	0.03	0.10	0.16	0.04	0.46	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				

Table A.1.34a, cont.

Site	År	Annual mean concentrations of main components in air ($\mu\text{g}/\text{m}^3$)					
		SO ₂ -S	SO ₄ -S	NO ₂ -N	(HNO ₃ +NO ₃)-N	(NH ₄ +NH ₃)-N	NH ₄ -N
Tustervatn (cont.)	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	
	1993	0.18	0.31	0.19	0.07	0.66	0.16
	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	
2019	0,05	0,14	0,14	0,06	0,37	0,08	
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		

Table A.1.34a, cont.

Site	År	Annual mean concentrations of main components in air ($\mu\text{g}/\text{m}^3$)					
		SO ₂ -S	SO ₄ -S	NO ₂ -N	(HNO ₃ +NO ₃)-N	(NH ₄ +NH ₃)-N	NH ₄ -N
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
	1999	0.13	0.19		0.03	0.19	0.08
	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	
2019	0,08	0,11	-	0,03	0,12	0,03	

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 $\mu\text{g S}/\text{m}^3$ and $\mu\text{g N}/\text{m}^3$.

Site	År	Annual mean concentrations of main components in air at closed sites, ($\mu\text{g}/\text{m}^3$)				
		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	

Table A.1.34b, cont.

Site	År	Annual mean concentrations of main components in air at closed sites, ($\mu\text{g}/\text{m}^3$)				
		SO ₂ -S	SO ₄ -S	NO ₂ -N	(HNO ₃ +NO ₃)-N	(NH ₄ +NH ₃)-N
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	
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			

Table A.1.34b, cont.

Site	År	Annual mean concentrations of main components in air at closed sites, ($\mu\text{g}/\text{m}^3$)				
		SO ₂ -S	SO ₄ -S	NO ₂ -N	(HNO ₃ +NO ₃)-N	(NH ₄ +NH ₃)-N
Jergul (cont.)	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
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 PM_{2.5} at the sites Birkenes, Hurdal, Kårvatn and Zeppelin for 2019.

Month	PM ₁₀			PM _{2.5}		
	OC	EC	TC	OC	EC	TC
Birkenes						
January	0.71	0.11	0.83	0.66	0.14	0.81
February	0.60	0.11	0.70	0.50	0.10	0.61
March	0.33	0.04	0.38	0.26	0.03	0.30
April	2.65	0.25	2.95	2.01	0.23	2.25
May	1.38	0.07	1.47	0.75	0.06	0.81
June	0.87	0.05	0.93	0.58	0.06	0.64
July	1.43	0.05	1.49	0.72	0.05	0.77
August	1.09	0.06	1.15	0.66	0.06	0.72
September	0.79	0.05	0.84	0.48	0.05	0.53
October	0.55	0.05	0.60	0.37	0.05	0.42
November	0.36	0.06	0.41	0.28	0.05	0.34
December	0.35	0.05	0.40	0.27	0.06	0.32
Annual mean	0.93	0.08	1.01	0.63	0.08	0.71
Hurdal						
January	0.87	0.16	1.02	0.79	0.15	0.95
February	0.59	0.14	0.73	0.56	0.13	0.69
March	0.39	0.08	0.46	0.32	0.06	0.39
April	1.97	0.21	2.19	1.64	0.20	1.85
May	1.61	0.07	1.70	0.89	0.07	0.96
June	1.86	0.07	1.94	0.81	0.07	0.88
July	1.41	0.07	1.47	0.92	0.06	0.97
August	1.92	0.08	1.99	0.78	0.07	0.85
September	2.17	0.09	2.25	0.51	0.05	0.56
October	0.97	0.10	1.06	0.38	0.08	0.45
November	0.48	0.08	0.56	0.39	0.08	0.47
December	0.52	0.11	0.63	0.47	0.11	0.59
Annual mean	1.23	0.11	1.34	0.71	0.10	0.81
Kårvatn						
January	0.19	0.02	0.22	0.18	0.03	0.21
February	0.34	0.04	0.39	0.34	0.05	0.38
March	0.19	0.02	0.21	0.22	0.02	0.24
April	1.49	0.18	1.67	1.36	0.18	1.54
May	0.57	0.03	0.59	0.63	0.04	0.67
June	0.87	0.03	0.89	0.76	0.04	0.79
July	1.28	0.04	1.32	0.87	0.05	0.92
August	1.72	0.05	1.80	0.94	0.06	1.00
September	0.78	0.03	0.81	0.45	0.04	0.48
October	0.41	0.03	0.44	0.22	0.03	0.25
November	0.23	0.04	0.29	0.19	0.03	0.22
December	0.19	0.02	0.28	0.19	0.02	0.21
Annual mean	0.69	0.05	0.74	0.53	0.05	0.58

Table A.1.35, cont.

Month	PM ₁₀			PM _{2.5}		
	OC	EC	TC	OC	EC	TC
Zeppelin						
January	0.145	0.030	0.175			
February	0.112	0.025	0.137			
March	0.107	0.026	0.134			
April	0.067	0.010	0.077			
May	0.065	0.010	0.075			
June	0.139	0.009	0.148			
July	0.222	0.011	0.232			
August	0.127	0.008	0.135			
September	0.111	0.005	0.116			
October	0.032	0.002	0.034			
November	0.042	0.004	0.045			
December	0.090	0.020	0.110			
Annual mean	0.100	0.010	0.110			

Table A.1.36: Annual mean concentrations of OC, EC and TC in PM₁₀ and PM_{2.5} at Birkenes Hurdal, Kårvatn and Zeppelin for the period 2001 - 2019.

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
2019	0.93	0.08	1.01	0.63	0.08	0.71
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
2019	1.23	0.11	1.34	0.71	0.10	0.81
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
2019	0.69	0.05	0.74	0.53	0.05	0.58
Zeppelin						
2019	0.11	0.01	0.10			

Table A.1.37: Annual and monthly mean concentrations of PM_{10} , $PM_{10-2.5}$, and $PM_{2.5}$ at Birkenes, Hurdal and Kårvatn for 2019. Unit $\mu\text{g}/\text{m}^3$.

Month	<i>Birkenes</i>			<i>Hurdal</i>			<i>Kårvatn</i>		
	$PM_{2.5}$	$PM_{10-2.5}$	PM_{10}	$PM_{2.5}$	$PM_{10-2.5}$	PM_{10}	$PM_{2.5}$	$PM_{10-2.5}$	PM_{10}
JAN	3.9	1.5	5.1	3.2	0.7	3.9	0.7	0.8	1.5
FEB	2.7	2.7	5.5	2.8	1.4	4.2	1.3	1.4	2.7
MAR	1.5	2.1	3.6	1.3	1.5	2.7	1.6	1.1	1.5
APR	7.0	4.0	10.9	5.8	3.5	9.3	5.5	2.3	7.8
MAY	3.2	2.0	5.2	3.8	2.6	6.4	2.3	1.2	2.8
JUN	2.7	2.1	4.9	3.0	2.3	5.3	2.2	1.0	3.3
JUL	3.0	1.6	4.6	2.9	1.5	4.4	3.0	1.8	4.9
AUG	2.8	2.5	5.3	3.0	3.0	6.0	3.2	1.6	4.4
SEP	1.7	2.1	3.8	1.6	3.4	5.0	1.0	1.7	2.1
OCT	2.0	1.5	2.1	1.2	1.7	2.9	0.7	0.5	1.2
NOV	0.9	0.9	1.8	1.3	0.9	2.2	0.7	1.0	1.7
DEC	1.3	1.7	2.7	1.6	0.6	2.3	0.6	0.2	0.9
2019	2.7	2.1	4.6	2.7	1.9	4.6	1.9	1.2	2.9

Table A.1.38: Annual mean mass concentrations of PM_{10} , $PM_{10-2.5}$, $PM_{2.5}$ and PM_1 at Birkenes, Hurdal and Kårvatn for the period 2000 - 2019.

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
2019		2.7	2.1	4.6
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
2019		2.7	1.9	4.6
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
2019		1.9	1.2	2.9

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
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 Vatnedalen	X	X	X	X	X	X ^b	X ^d	X	X	X ^b	X ^e
Treungen Haukenes		X							X		
Prestebakke Løken		X							X		
Hurdal	X	X	X	X	X			X		X ^a	
Brekkebygda									X		
Vikedal Sandve		X							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		
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, SO₄, NO₃, Cl, NH₄, Ca, K, Mg, Na

main air = SO₂, SO₄, HNO₃ + NO₃; NH₄+ NH₃, 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, MCCC

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)

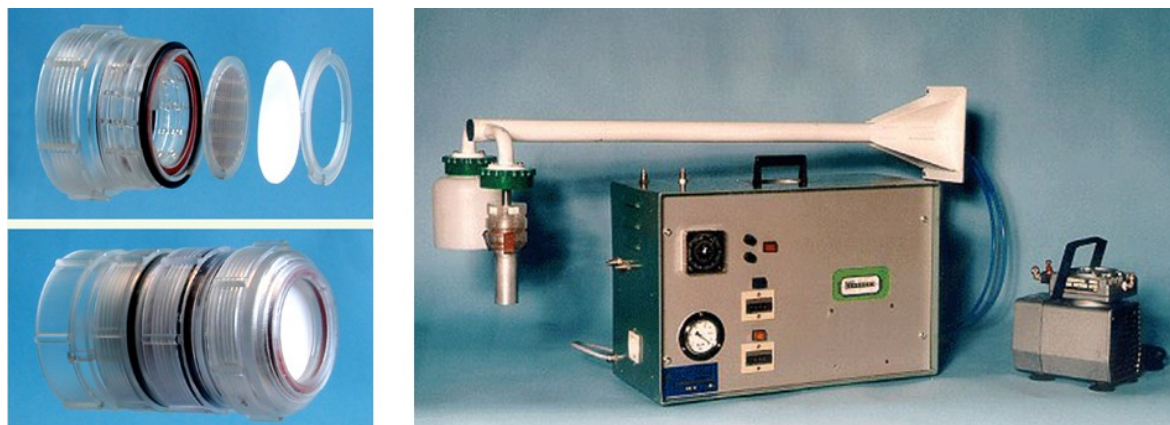


Main components in air

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 PM₁₀ 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 HNO₃ 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 (unit)	limit
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

NO₂ 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 NO₂ 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/m³.

Ozone

Ozone (O₃) 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. Aerosols 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 troposphere 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., chronic obstructive pulmonary disease, ischemic heart disease, lung cancer and pneumonia. Although the statistical evidence between ambient air particulate mass (e.g., PM_{10} and $\text{PM}_{2.5}$) 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 ($d_p < 100 \text{ nm}$), 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 were 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 $\frac{1}{2}$ 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 combining 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 12.7 and an EC/levoglucosan ratio of 1.96. These ratios are based on positive matrix factorization (PMF) analysis results for PM and PM species observed at Birkenes (Yttri et al., in prep.), 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

PM₁₀ and PM_{2.5} are obtained using KleinfILTERGERÄT samplers (one sampler pr. size fraction), collecting filter samples on a weekly basis. The ambient aerosol particles are collected on pre-fired (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 PM₁₀ and PM_{2.5} is estimated to be around 0.1 – 0.15 µg/m³ for a sampling volume of 386 m³.

Number concentration measurements at Birkenes dates back to 2010. The number concentration of ultrafine particles ($D_p < 0.1 \mu\text{m}$), accumulation mode particles ($0.1 \mu\text{m} < D_p < 1.0 \mu\text{m}$) and coarse mode particles ($D_p = 0.01 - 10 \mu\text{m}$) 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 PM₁₀ 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 PM₁₀ and PM_{2.5} are performed on the same filter samples as the mass concentration of PM₁₀ and PM_{2.5} are obtained from for the sites Birkenes, Hurdal and Kårvatn. At Zeppelin, ambient aerosol filter samples for subsequent analysis of OC, EC and TC were obtained using a Digitel high-volume sampler with a PM₁₀ inlet, collecting filter samples on a weekly basis. These quartz fibre filters (PALLFLEX Tissuequartz 2500QAT-UP; 150 mm in diameter) were pre-fired (850 °C for 3 hrs) but not conditioned, and were arranged according to the quartz fiber filter behind quartz fiber filter (QBQ) set up, which allows for an estimate of the positive sampling artefact of OC. 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/cm², corresponding to methodological detection limit of 0.007 µg C m⁻³ for a sampling volume of 386 m³ and an exposed filter area of 13.4 cm² for the sites Birkenes, Hurdal and Kårvatn, and a detection limit of 0.005 µg C m⁻³ for a sampling volume of 6720 m³ and an exposed filter area of 154 cm² for Zeppelin.

Concentrations of the biomass burning tracer levoglucosan (mannosan and galactosan) is determined in the same PM₁₀ 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 m³ and an exposed filter area of 13.4 cm².

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