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Monitoring of long-range transported air pollutants in Norway

Annual Report 2020

Wenche Aas, Sabine Eckhardt, Markus Fiebig, Stephen M. Platt
Sverre Solberg, Karl Espen Yttri and Christine Groot Zwaaftink

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AUTHOR(S) Wenche Aas, Sabine Eckhardt, Markus Fiebig, Sverre Solberg, Stephen M. Platt, Karl Espen Yttri and Christine Groot Zwaaftink	QUALITY CONTROLLER Kjetil Tørseth
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ABSTRACT

This report presents results from the monitoring of atmospheric composition and deposition of air pollution in 2020, 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. The level of pollution in 2020 was generally low and this can partly be explained by special weather conditions in the first months with mostly clean, marine air from the west. The extensive restrictions on human activity in connection with the pandemic in Europe, have probably also contributed to lower levels of air pollution at the Norwegian background stations. In 2020, it was an unusual wide-spread episode during October causing high concentrations of most pollutants at all the sites.

NORWEGIAN TITLE

Overvåking av langtransportert forurenset luft og nedbør. Atmosfæriske tilførsler 2020.

KEYWORDS

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

ABSTRACT (in Norwegian)

Denne rapporten omhandler resultater fra overvåkningsprogrammet for langtransportert forurenset luft og nedbør og atmosfæriske tilførsler i 2020. Rapporten presenterer målinger av uorganiske hovedkomponentene i luft og nedbør, partikulært karbonholdig materiale, partikkelmasse og bakkenært ozon. Forurensningsnivået i 2020 var generelt lavt noe som delvis kan forklares med spesielle værforhold de første månedene med hovedsakelig ren, marin luft fra vest. De omfattende restriksjonene på menneskelig aktivitet i forbindelse med pandemien i Europa, har trolig også bidratt til lavere nivåer av luftforurensninger på de norske bakgrunnsstasjonene. I 2020 ble det observert en uvanlig omfattende episode med høye konsentrasjoner av luftforurensing på alle 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 (PM_{10} og $PM_{2.5}$) og størrelsesfordeling av partikkelantall på 16 norske bakgrunnsstasjoner. I tillegg rapporteres målinger av levoglukosan på Birkenes og 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 NO_2 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 PM_{10} ved alle stasjonene (27 – 40%), fulgt av enten sekundære organiske forbindelser (SIA) (12 – 25%) eller sjøsaltpartikler (9.7 – 25%), mens mineralstøv ble estimert å utgjøre 13% av PM_{10} på Birkenes. Både konsentrasjonen og det relative bidraget av SIA og sjøsaltpartikler til PM_{10} 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
Luftforurensningen i regional bakgrunn i Norge kommer i hovedsak fra kilder utenfor våre landegrenser, og hvert år observeres det episoder med spesielt høye verdier av langtransportert luftforurensning forårsaket av meteorologi, som fremmer langtransport, kombinert med høye utslipp. I begynnelsen av oktober 2020 ble det observert en usedvanlig luftforurensningsepisode i Norge og ellers i Nord-Europa. Episoden forårsaket høye PM_{10}- og $PM_{2.5}$-konsentrasjoner over nesten hele Norge, inkludert flere byer, samt i Arktis. Simuleringer viser at episoden stammer fra Sentral-Asia og ble dannet av en støvstorm. Foruten mineralstøv, førte luftmassene med seg forurensning fra flere skogbranner i Ukraina og Sør-Russland. Svært høye verdier av mineralkomponenter ble målt, og det ble anslått at mineralstøv i løpet av denne episoden bidro med 25-45% til PM_{10} på de norske bakgrunnsstasjonene, mens skogbrannene bidro med 8-21%.

Overskridelser

Årsmiddelkonsentrasjonene av PM_{10} og $PM_{2.5}$ lå langt under nasjonale og internasjonale (EU og WHO) grenseverdier og retningslinjer for luftkvalitet på alle målestasjonene. De nasjonale og internasjonale 24-timers grensene for PM_{10} ble overskredet ved to anledninger under langtransportepisoden i oktober som også forårsaket overskridelser på 38 av 47 bystasjoner i Norge.

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 brutt på to stasjoner. Verken EUs langtidsmål for beskyttelse av landbruksvekster eller UN-ECEs grenseverdi for skog ble overskredet i 2020. WHOs retningslinjer for luftkvalitet for ozon, og de nasjonale anbefalinger satt av Folkehelseinstituttet, overskrides i varierende grad hvert eneste år i Norge. EUs grenseverdi for informasjon til publikum ble ikke overskredet i 2020 og har heller ikke blitt brutt på mange år i Norge.

Trender

Forurensningsnivået i 2020 var generelt lavt sammenlignet med 2019 noe som delvis kan forklares med spesielle værforhold de første månedene med hovedsakelig ren, marin luft fra vest. De omfattende restriksjonene på menneskelig aktivitet i forbindelse med pandemien i Europa, har trolig også bidratt til lavere nivåer av luftforurensninger på de norske bakgrunnsstasjonene.

Nivåene av bakkenært ozon var spesielt lave i 2020, noe som skyldtes få episoder og generelt lave konsentrasjoner gjennom det meste av sommerhalvåret. Det er sannsynlig at dette kan forklares med en kombinasjon av tre faktorer: Gradvis reduserte utslipp av ozonforløpere de siste 20 årene, værforhold som var ugunstige for fotokjemisk ozondannelse, og reduserte utslipp knyttet til nedstenging av store områder i samfunnslivet i Europa (særlig transport) på grunn av pandemien.

En oversikt over de langsiktige trendene er vist i tabell 1.1 (table 1.1 etter engelsk sammendrag). Da Norge er nedstrøms de største utslippskildene i Europa, gjenspeiler de observerte trendene i stor grad utslippsreduksjonene som har funnet sted på det europeiske kontinentet de siste tiårene, selv om årlige variasjoner i meteorologi kan maskere effekten av utslippsreduksjonene, spesielt for ozon. Reduksjonene i trender i utslipp for svovel- og nitrogenforbindelser er i samsvar med målet for utslippsreduksjoner satt av Gøteborg-protokollen som skal nås innen 2020.

Summary

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

The main objective is to quantify the levels of these pollutants and to document any changes in atmospheric pollution, which is important for studies on its influence on ecosystems, human health, materials and climate change. The 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 on the continent. Some inland sites are influenced by regional agricultural activities and experience relatively high ammonium levels. The highest EC-, OC- and NO_2-levels are seen in Hurdal in Akershus, likely due to influence from the more densely populated region surrounding this site, including road traffic. The site in Finnmark experiences 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 PM_{10} at all sites (27 – 40%), followed either by secondary inorganic aerosol (SIA) (12 – 25%) or sea salt aerosol (9.7 – 25%), 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
The air pollution in regional areas in Norway is mainly from sources outside the national border, and every year there are episodes of high concentrations of air pollution caused by meteorology, favouring long range transport of air masses, combined with high emissions. In the beginning of October 2020, an exceptional air pollution episode was observed in Norway, and elsewhere in northern Europe. The episode caused high PM_{10}- and $PM_{2.5}$-concentrations at all the sites in Norway, including urban sites, as well as in the Arctic. Simulations show that the episode originated in Central Asia during a dust storm. Besides mineral dust, the plume carried pollution from several wildfires in Ukraine and southern Russia. Very high values of crustal elements were measured and it was estimated that during this episode mineral dust contributed 25 to 45% to PM_{10} at the Norwegian background sites, while 8-21% was attributed to biomass burning.

Exceedances
PM_{10}- and $PM_{2.5}$-observations were all well below the EU limit-values, the national limit-values and the WHO and the National Air Quality Guidelines (AQG) on an annual basis. The 24-hour EU-limit value, the national limit-value and the WHO and the national AQG for PM_{10} were exceeded for 2 days during the long-range mineral dust and wildfire episode in October, which also caused exceedances at 38 out of 47 urban Norwegian sites.

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 violated at two stations in 2020. 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 2020 and has not been for many years in Norway. Neither EU's long-term objective for protection of vegetation or UN-ECE's critical level for forests, were exceeded in 2020.

Trends

The level of pollution in 2020 was generally low compared to 2019. This can partly be explained by special weather conditions in the first months with mostly clean, marine air from the west. The extensive restrictions on human activity in connection with the pandemic in Europe, have probably also contributed to lower levels of air pollution at the Norwegian background stations.

Surface ozone levels were particularly low in 2020. This was a result of few episodes and low mean levels during most of the summer season. It is likely that this was a combined effect of three drivers: long-term reductions in European emission of precursors; unfavourable weather conditions for ozone formation; and finally reduced emissions of ozone precursors due to the mentioned lockdown in parts of 2020.

An overview of the long-term trends are shown in Table 1.1. Since Norway is downwind of the major emission sources in Europe, the trends in observations reflect to a large extent the emission reductions which have taken place in the European continent the last decades, although inter-annual variations in meteorology could mask the effect of the emission reductions, particularly for ozone. The reductions in sulfur and nitrogen species are close to the European target in emission reductions set by the Gothenburg protocol to be reached within 2020.

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	1990- 2020	2000-2020
SO_2	4 sites[1)]	-87% - - ~100%	-53% - -82%
SO_2	Zeppelin	-73%	-62%
SO_4^{2-}in aerosols	4 sites[1)]	-75% - -91%	-65% - -90%
SO_4^{2-} in aerosols	Zeppelin	-41%	-35%
SO_4^{2-} in precipitation	11 sites[2)]	-57% - - ~100%	-39% --73%[3)]
NO_2	4 sites[1)]	-43% - -~100%	-50% - -83%
NO_3^- in precipitation	11 sites[2)]	-19% - -61%[4)]	8 sites: -27% - -46%
HNO_3+NO_3^- in air	4 sites[1)]	Hurdal: -43%	Hurdal: -44%
NH_4^+ in precipitation	11 sites[2)]	7 sites: +63% - -69%	5 sites: +62% - -45%
NH_3+NH_4^+ in air	4 sites[1)]	3 sites: +49% - -38%	Tustervatn: -71%
PM_{10}	Birkenes		-35% (2000-2020)
$PM_{2.5}$	Birkenes		-43 - -51% (2001-2020)
OC	Birkenes		-23% - -32% (2001-2020)
EC	3 sites		-39% - -62% (2001-2020)
TC	Birkenes		-28% - -38% (2001-2020)
O_3, 3-months AOT40	4 sites[5)]		-57% - -74% (1996-2020)
O_3, 8h >100 µg/m^3	4 sites[5)]		-60% - -92% (1996-2020)

[1)] Birkenes, Nordmoen/Hurdal, Kårvatn, Tustervatn.
[2)]All the sites (Table 3,1) except Karbukt and Ny Ålesund
[3)]Not significant trend at Tustervatn
[4)]Not significant trend at Kårvatn[5)] Kårvatn, Sandve, Tustervatn and Prestebakke

Monitoring of long-range transported air pollutants in Norway

Annual Report 2020

1 The monitoring programme 2020

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. The measurement programme and the monitoring network was then 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 (Birkenes, Tustervatn, Kårvatn, Zeppelin)
  - Daily measurements of NO_2 at four sites (Birkenes, Hurdal, Tustervatn, Kårvatn)
  - Weekly measurements of particulate matter (PM_{10} and $PM_{2.5}$) and EC/OC at three sites (Birkenes, Hurdal, Kårvatn)
  - High time-resolution measurements of particle number and size distribution at Birkenes
  - Daily measurements of particulate and gaseous inorganic compounds in air and precipitation at two sites (Birkenes and Zeppelin; weekly for precipitation at Ny-Ålesund)
  - Meteorology at three sites (Birkenes, Zeppelin and Hurdal)
  - Inorganic ions in precipitation at Svanvik (part of the programme for ICP Material)
- *Measurement programme to preserve long-time data series on behalf of the Ministry of Climate and Environment, co-financed by NILUs internal monitoring programme 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 Birkenes

- *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., 2021), the second covers the monitoring of the ozone layer and UV (Svendby et al. 2020), whereas the third is on climate gases and aerosol particles influence on climate (Myhre et al., 2020). 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.

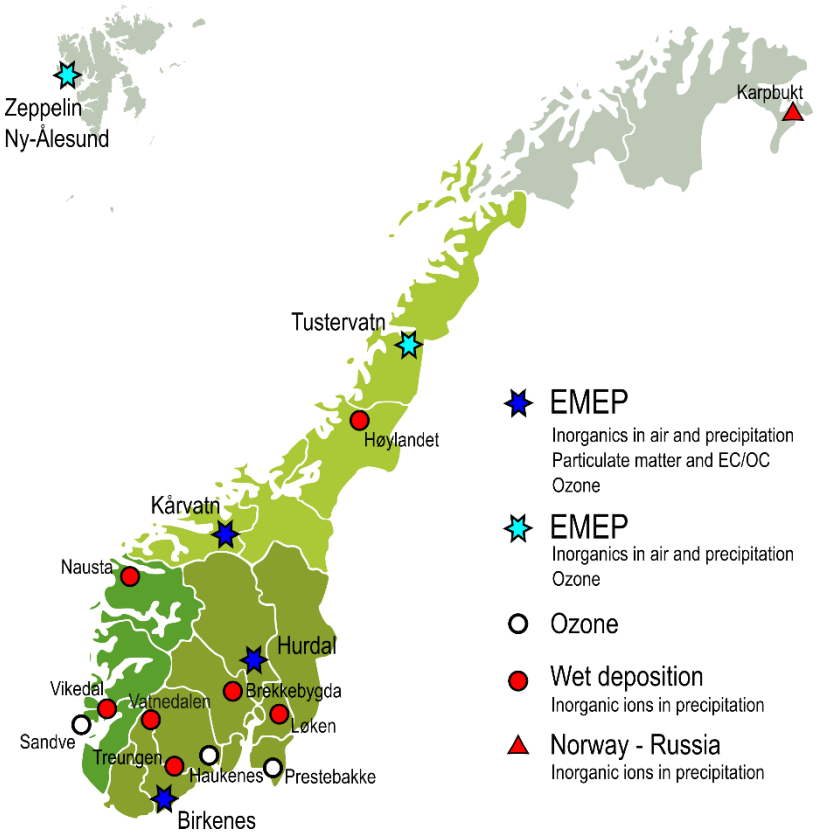


Figure 1.1: Norwegian background sites and their measurement programme 2019. Details are found in Annex 2. The colour codes indicate the different regions/zones used in EU's Ambient Air Quality Directive (2008).

2 The weather in Norway 2020

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.

For the country as a whole, 2020 was the warmest and the second wettest since the start of the meteorological time series in 1900. The annual mean temperature was 2.4°C above the normal and the annual mean precipitation 125% above the normal (Met. Institute, 2021). All normals refer to the 1961-1990 period, whereas a new 30y normal (1991-2020) will be used in following years.

The mean temperature exceeded the normal in the entire country and particularly large exceedances (3-4°C) were seen in the southeast. The mean precipitation also exceeded the normal in nearly the whole country except for a few areas that normally are very dry. The mean temperatures were high also in the Arctic with 2.2-3.2°C above normal at Spitsbergen. A new temperature record was set at Svalbard airport with 21.7°C 21 July.

The whole period from January to the middle of March was characterized by low pressure systems travelling from the Atlantic and crossing the country, leading to persistent winds from the SW-NW sector. This entire period was dominated by marine air masses over the country leading to heavy precipitation and very mild conditions, particularly in the southern part. Areas in the southeast experienced monthly mean temperatures more than 8°C above the normal and some stations in the western country received four times the normal precipitation. Particularly strong cyclonic activity was seen in February leading to many periods with strong winds.

By around 20 March the very persistent weather pattern with passing lows was broken and a high-pressure system developed over the UK and southern Norway. In the following days, the high moved slowly to the southeast setting up easterly winds over most of central Europe while Norway was again influenced by the westerly winds, being north of the high-pressure. It is worth mentioning that this major shift in the weather pattern over Europe coincided with the introduction of the first Covid-19 lockdown in most European countries making the interpretation of the air pollution data and the lockdown effect difficult.

In the beginning of April, the pattern with westerly winds and low-pressure systems returned to the country followed by a period with transport of warmer air masses from the south. Then, around the middle of the month a marked high-pressure was established over S-Norway and drifted slowly to the north leading to fair weather and high temperatures in many areas.

In May, an outbreak of cold air masses from the Arctic hit the country and caused the monthly mean temperature to be 1.1°C below the normal. At the end of the month a high-pressure system developed in the south and then moved northwards leading to easterly winds and high temperatures in large parts of the country in June.

July was again dominated by low-pressure activity in the southern part leading to mean temperatures 1.5-2.5°C below the normal whereas areas in the far north had mean temperatures above the normal. The unstable weather conditions continued into the first part of August and was

then followed by a period with dryer and warmer conditions in the south and very wet conditions in the north.

Low pressure activity and westerly winds then dominated to the middle of September followed by a prolonged period with a high-pressure system leading to winds from the southeast and high temperatures lasting to the middle of October when an outbreak of cold Arctic masses hit the country.

November and December were dominated by cyclonic activity with marine air masses from the western sector. Particularly strong low-pressure systems passed the country in December with frequent episodes of mild, southerly air masses leading to very strong precipitation in the southern part. Several areas received 4-5 times the normal precipitation this month.

3 Inorganic components

3.1 Observations in 2020

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 2020.

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., 2020)

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, 2020.
**: Corrected for contribution from sea salt.*

Site	Volume weighted annual mean concentrations									Wet deposition										Volume weighted annual mean concentrations in equivalence units										Ion bal.
	pH	SO_4* mg S/l	NO_3 mg N/l	NH_4 mg N/l	Ca mg/l	K mg/l	Mg mg/l	Na mg/l	Cl mg/l	mm	H+ µekv/m²	SO_4* mg S/m²	NO_3 mg N/m²	NH_4 mg N/m²	Ca mg/m²	K mg/m²	Mg mg/m²	Na mg/m²	Cl mg/m²	H+ µekv/l	SO_4* µekv/l	NO_3 µekv/l	NH_4 µekv/l	Ca µekv/l	K µekv/l	Mg µekv/l	Na µekv/l	Cl µekv/l	H+ µekv/l	kat./an.
Birkenes	5.04	0.16	0.29	0.28	0.16	0.09	0.17	1.41	2.43	2286	21107	363	664	646	355	199	380	3218	5558	9	10	17	21	20	8	2	14	61	69	1.08
Vatnedalen	5.53	0.07	0.06	0.03	0.17	0.15	0.05	0.94	1.08	1280	3816	88	81	41	211	196	64	1208	1384	3	4	8	5	2	8	4	4	41	30	1.51
Treungen	5.21	0.09	0.15	0.16	0.10	0.05	0.04	0.32	0.55	1587	9801	145	233	253	164	84	67	504	879	6	6	7	11	11	5	1	3	14	16	1.26
Løken	5.19	0.10	0.22	0.23	0.14	0.12	0.07	0.52	0.91	1000	6490	101	217	233	136	121	70	518	909	6	6	9	16	17	7	3	6	23	26	1.24
Hurdal	5.20	0.10	0.20	0.19	0.10	0.07	0.04	0.35	0.56	1441	9175	149	290	277	148	96	58	497	805	6	6	8	14	14	5	2	3	15	16	1.20
Brekkebygda	5.22	0.09	0.15	0.12	0.10	0.11	0.03	0.20	0.32	1420	8569	132	210	172	143	149	37	282	454	6	6	7	11	9	5	3	2	9	9	1.30
Vikedal	5.44	0.06	0.11	0.19	0.21	0.19	0.31	2.72	4.69	3560	12988	224	396	683	740	673	1092	9673	16703	4	4	18	8	14	10	5	25	118	132	1.12
Nausta	5.48	0.04	0.07	0.12	0.11	0.11	0.20	1.74	3.04	3047	10126	120	212	355	330	336	601	5311	9263	3	2	12	5	8	5	3	16	76	86	1.11
Kårvatn	5.49	0.04	0.04	0.09	0.11	0.11	0.20	1.67	2.98	1773	5738	68	74	167	201	192	351	2963	5275	3	2	11	3	7	6	3	16	73	84	1.11
Høylandet	5.62	0.02	0.04	0.17	0.16	0.14	0.33	3.05	5.08	1207	2931	21	53	208	196	171	403	3676	6127	2	1	17	3	12	8	4	27	133	143	1.16
Tustervatn	5.49	0.03	0.05	0.11	0.12	0.10	0.20	1.73	2.98	1360	4383	44	63	143	159	140	268	2346	4050	3	2	11	3	8	6	3	16	75	84	1.14
Karpbukt	4.95	0.31	0.08	0.05	0.14	0.09	0.15	1.80	2.36	504	5646	157	42	25	69	44	74	906	1190	11	19	26	6	4	7	2	12	78	67	1.17
Ny-Ålesund	5.76	0.11	0.07	0.08	1.00	0.34	1.29	9.71	16.72	228	395	25	16	19	229	77	295	2217	3818	2	7	47	5	6	50	9	106	422	472	1.14

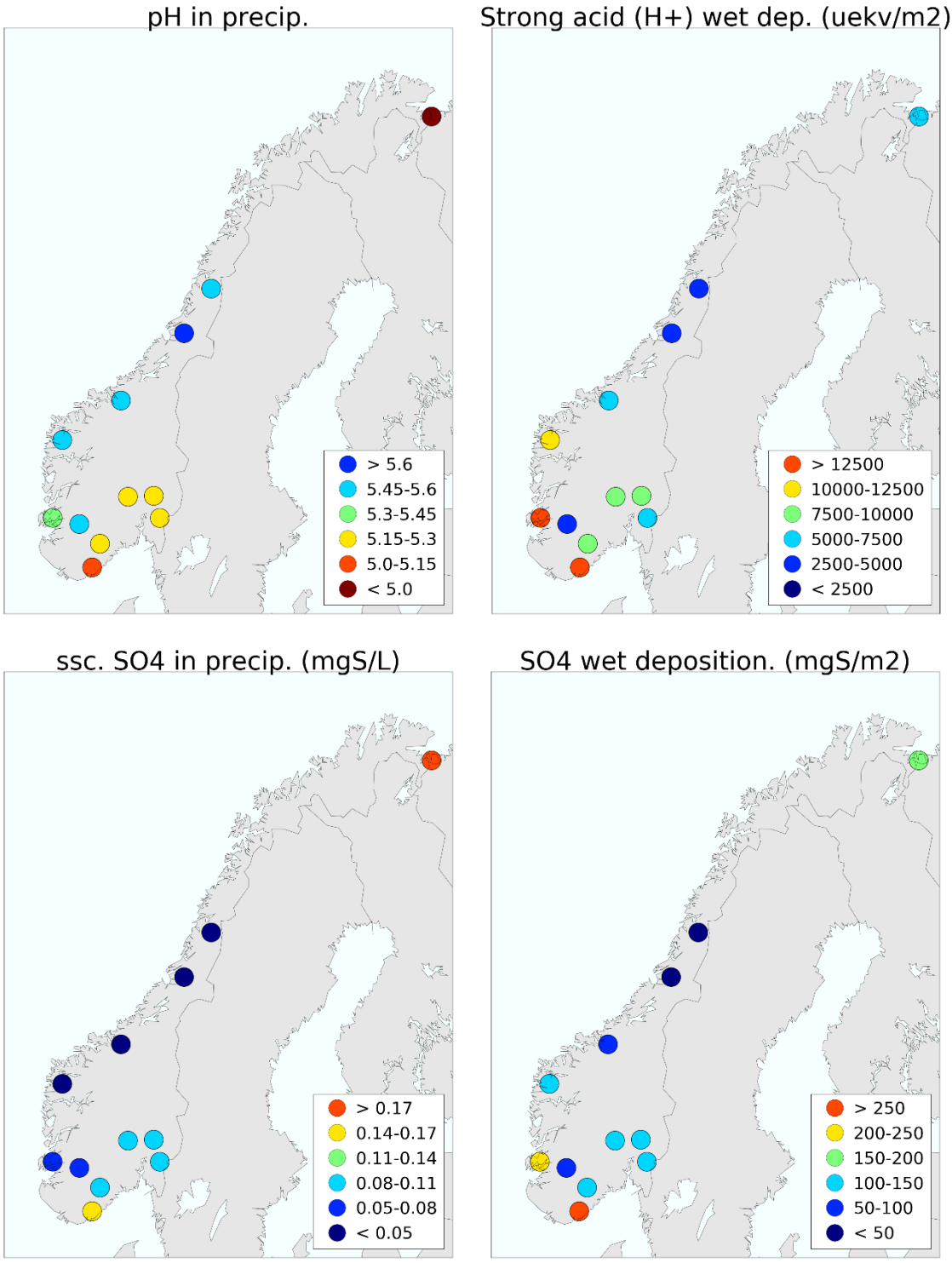


Figure 3.1: Annual volume weighted mean concentrations and total wet deposition of sulfate (sea salt corrected) and strong acid (pH), 2020. Note that the colours only resemble the spatial distribution and do not indicate any exceedances of limit values or similar

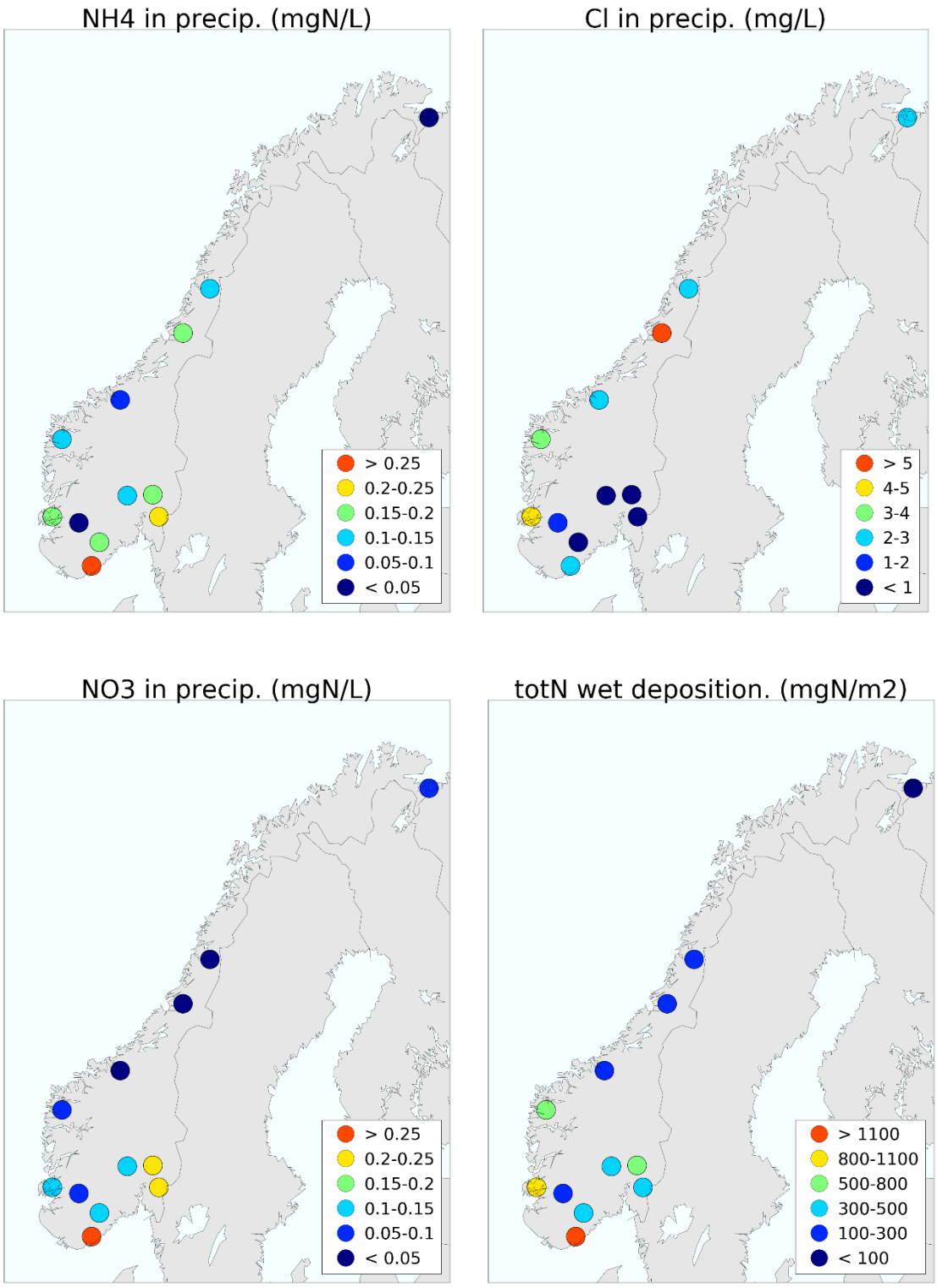


Figure 3.2: *Annual volume weighted mean concentrations of nitrate, ammonium, chloride and total wet deposition of nitrogen (nitrate + ammonium), 2020.Note that the colours only resemble the spatial distribution and do not indicate any exceedances of limit values or similar.*

Figure 3.3 shows average monthly volume weighted mean concentrations and wet deposition of the main components in precipitation from all the sites in Norway, 2020. The monthly data for each sites are given in the tables in Annex 1. There are quite large variabilities in the concentrations as well as depositions throughout the year. It is somewhat larger amount of precipitation in winter causing enhanced wet deposition in winter compared to the summer period. In 2020, the highest concentrations for sulfate was seen during the summer period, for ammonium highest in spring. For nitrate there is no pattern except low concentrations in July and highest wet deposition during winter. Sea salt concentrations represented with sodium is highest in winter, while dust represented with Ca has some high concentrations in the spring. The measured wet deposition of sulfate, shows that between 31% and 38% 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).

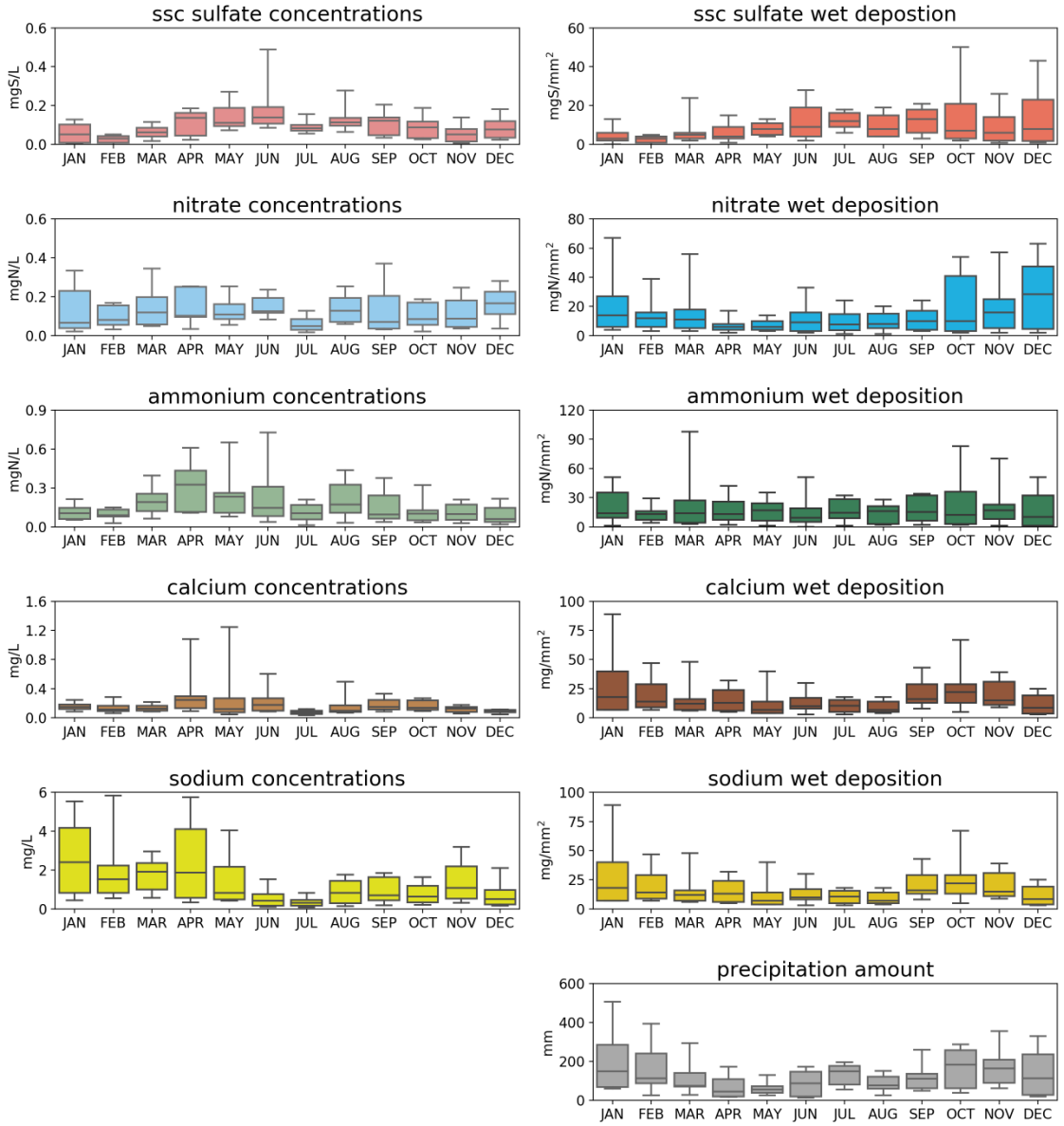


Figure 3.3: Box and whisker plots showing the median, lower and upper quartiles of the monthly volume weighted mean concentrations (left) and wet deposition (right) of major components in precipitation at the 13 sites in Norway, 2020.

3.1.2 Chemical composition in air

Daily measurements of inorganic components in air was carried out at five sites in 2020. All of these are EMEP sites (Figure 1.1). Table 3.2 shows the annual mean concentrations while the monthly data are given in A.1.22-A.1.33. The monthly means of the sulfur and nitrogen components are illustrated in Figure 3.4. The maximum and percentile concentrations of SO_2, SO_4^{2-}, sum of (NO_3- + HNO_3), NH_4^+ and sum of (NH_3 + NH_4^+) are given in Table 3.3 to Table 3.8.

Table 3.2: Annual mean concentrations of inorganic components in air at Norwegian background stations, 2020.

	SO_2	SO_4^{2-}	NO_2	sum NO_3	NO_3	sum NH_4	NH_4	Mg	Ca	K	Cl	Na
	µg-S/m³	µg-S/m³	µg-N/m³	µg-N/m³	µg-N/m³	µg-N/m³	µg-N/m³	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³
Birkenes II	0.060	0.190	0.298	0.165	0.130	0.397	0.146	0.083	0.063	0.069	0.87	0.66
Hurdal	0.027	0.102	0.348	0.080	0.062	0.179	0.079	0.025	0.037	0.050	0.20	0.17
Kårvatn	0.027	0.073	0.146	0.035	0.022	0.460	0.035	0.022	0.028	0.030	0.21	0.18
Tustervatn	0.028	0.076	0.141	0.034	0.019	0.331	0.032	0.034	0.022	0.023	0.42	0.28
Zeppelin	0.069	0.109	-	0.025	0.014	0.164	0.023	0.050	0.053	0.050	0.42	0.28

The highest annual mean concentrations of sulfur dioxide in 2020 was observed at Zeppelin with 0.07 µg S/m³, followed by Birkenes with 0.06 µg S/m³ . The highest daily average was observed at Birkenes and Zeppelin with 1.4 µg S/m³ on 21 May and 22 February. These episodes were causes by air masses arriving respectively from the British Isles and Siberian. The highest monthly averages of sulfur dioxide is seen during spring (Figure 3.5).

Annual mean concentrations of particulate sulfate are very low at all the sites compared to previous years. In 2020 the highest concentration was measured at Birkenes (0.19 µg S/m³), while the highest episodes (1.03 µg S/m³), was observed Kårvatn 23 September and Birkenes 2 October. The episode at Kårvatn are with air masses from west (possible sources in UK), while the one at Birkenes together with the highest episode seen at Hurdal and Tustervatn, highest episode was 3 October is part of a large scale episode described in more details in Chapter 7. In the beginning of October all the Norwegian sites observed an exceptionally high aerosol episode with dust and biomass burning sources from east. These air masses also carried polluted air from more anthropogenic sources. The highest monthly averages of sulfate in air is seen during summer (Figure 3.5), but the seasonal variations are not very pronounced.

Highest NO_2 levels were observed in Hurdal with an annual mean of 0.35 µg N/m³. This station is influenced by the relatively high traffic emissions in region. But the level is much lower that what was observed in 2019. The highest daily mean level of NO_2 was measured at Hurdal with 3.6 µg N/m³ on 2 December. The low concentrations of NO_2 in 2020 is partly due to the exceptional year with lockdown and less emissions of NO_2. In addition the period January to the middle of March was characterized by unusual weather conditions with much westerly wind with clean marine air masses (See chapter 2 for details of the weather in 2020). The concentrations of NO_2 show a 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 (NO_3^- + HNO_3) and of ammonium (NH_4^+) were observed both at Birkenes with 0.17 and 0.15 µg N/m³, respectively. For the sum of ammonium (NH_4^+ + NH_3) high levels were also observed also at Tustervatn and

Kårvatn, these sites are more influence of agricultural activity in their regions. The seasonality of reduced nitrogen components with largest levels during spring is clearly seen in Figure 3.5.

For sodium there is highest episode in winter when sea salt episodes are more frequent while for Ca the highest concentrations are seen in October caused by the large dust episode as described in Chapter 7.

Table 3.3: Number of daily, observations 50-, 75-, 90-percentile concentrations, max and annual mean concentrations for SO_2 in air at Norwegian background station in 2020.

Site	No. of observations	SO_2 (µg S/m^3)					
		Percentile conc.			Max concentration	Date	Annual mean concentration
		50%	75%	90%			
Birkenes II	349	0.025	0.083	0.139	1.441	21.05.2020	0.060
Hurdal	363	0.010	0.030	0.057	0.402	07.08.2020	0.027
Kårvatn	366	0.010	0.026	0.059	0.397	09.06.2020	0.027
Tustervatn	366	0.010	0.024	0.077	0.350	28.09.2020	0.028
Zeppelin	352	0.010	0.055	0.165	1.420	21.02.2020	0.069

Table 3.4: Number of daily, observations 50-, 75-, 90-percentile concentrations, max- and annual mean concentrations for SO_4 in aerosols at Norwegian background station in 2020.

Site	No. of observations	SO_4^{2-} (µg S/m^3)					
		Percentile conc.			Max concentration	Date	Annual mean concentration
		50%	75%	90%			
Birkenes II	351	0.133	0.256	0.418	1.031	02.10.2020	0.190
Hurdal	363	0.056	0.118	0.260	0.880	03.10.2020	0.102
Kårvatn	366	0.037	0.092	0.163	1.033	23.09.2020	0.073
Tustervatn	366	0.053	0.111	0.171	0.870	03.10.2020	0.076
Zeppelin	351	0.070	0.170	0.265	0.854	25.07.2020	0.109

Table 3.5: Number of daily, observations 50-, 75-, 90-percentile concentrations, max and annual mean concentrations for NO_2 in air at Norwegian background station in 2020.

Site	No. of observations	NO_2 (µg N/m³)					
		Percentile conc.			Max concentration	Date	Annual mean concentration
		50%	75%	90%			
Birkenes II	349	0.233	0.370	0.584	1.371	23.03.2020	0.298
Hurdal	352	0.263	0.415	0.658	2.606	02.12.2020	0.348
Kårvatn	367	0.126	0.168	0.235	0.693	15.08.2020	0.146
Tustervatn	363	0.127	0.173	0.233	0.477	03.12.2020	0.141

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 2020.

Site	No. of observations	NO_3^-+HNO_3 (µg N/m³)					
		Percentile conc.			Max concentration	Date	Annual mean concentration
		50%	75%	90%			
Birkenes II	351	0.082	0.192	0.362	1.703	25.03.2020	0.165
Hurdal	363	0.035	0.084	0.168	1.542	27.03.2020	0.080
Kårvatn	366	0.020	0.035	0.064	0.437	19.06.2020	0.035
Tustervatn	359	0.020	0.034	0.056	0.854	28.09.2020	0.034
Zeppelin	352	0.020	0.020	0.038	0.225	05.10.2020	0.025

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 2020.

Site	No. of observations	NH_4^+ (µg N/m³)					
		Percentile conc.			Max concentration	Date	Annual mean concentration
		50%	75%	90%			
Birkenes II	351	0.056	0.168	0.426	1.767	26.03.2020	0.146
Hurdal	363	0.014	0.076	0.222	1.798	27.03.2020	0.079
Kårvatn	366	0.005	0.028	0.088	0.478	05.08.2020	0.035
Tustervatn	366	0.005	0.037	0.083	0.485	03.10.2020	0.032
Zeppelin	352	0.005	0.027	0.073	0.341	25.07.2020	0.023

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 2020.

Site	No. of observations	$NH_4^+ + NH_3$ (µg N/m³)					
		Percentile conc.			Max concentration	Date	Annual mean concentration
		50%	75%	90%			
Birkenes II	351	0.255	0.474	0.812	3.480	06.04.2020	0.397
Hurdal	363	0.115	0.219	0.380	2.305	27.03.2020	0.179
Kårvatn	366	0.287	0.555	0.979	3.892	14.06.2020	0.460
Tustervatn	363	0.182	0.455	0.870	2.646	17.06.2020	0.331
Zeppelin	352	0.150	0.228	0.297	0.820	22.10.2020	0.164

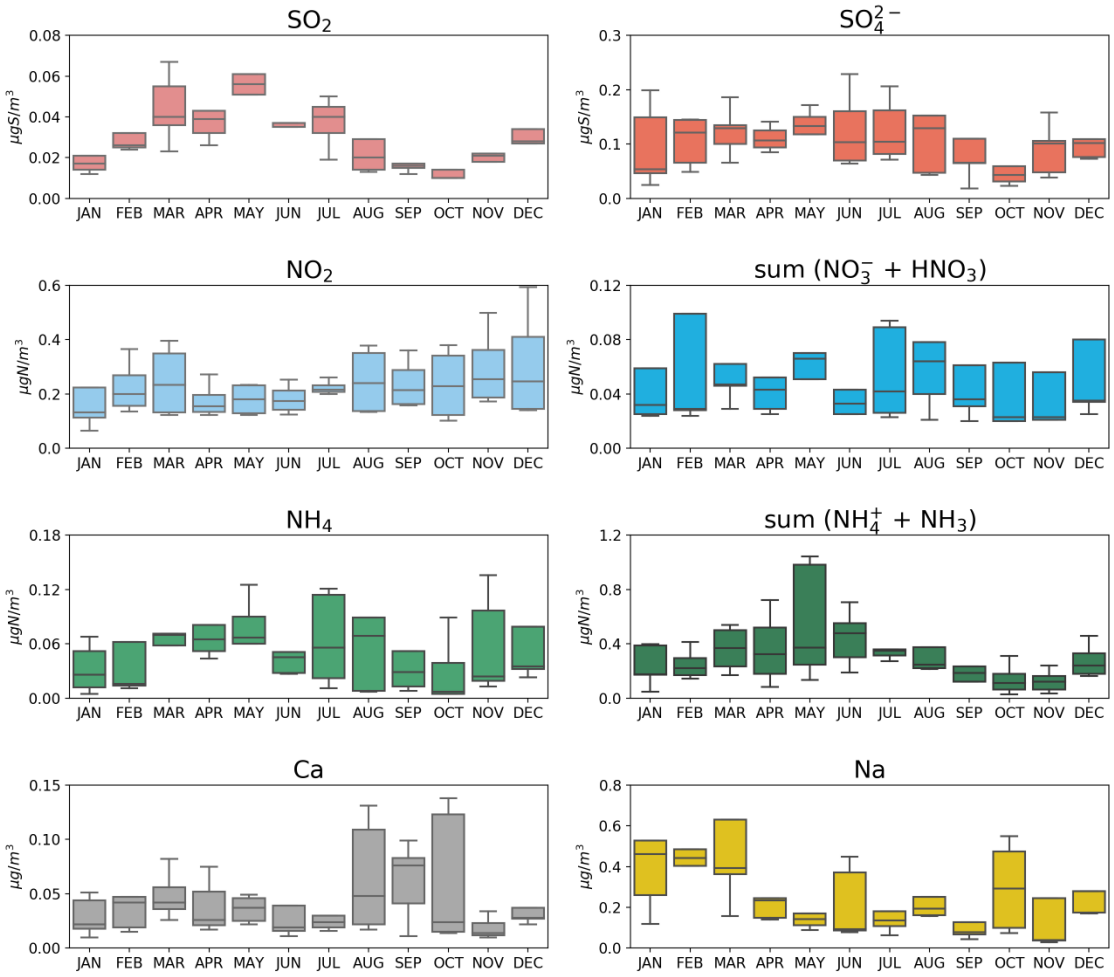


Figure 3.4: Box and whisker plots showing the median, lower and upper quartiles of the monthly mean concentrations of inorganic components in air at the five EMEP sites in Norway in 2020.

3.1.3 Total deposition of sulfur and nitrogen

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

For the sum of nitrate (NO_3^- + HNO_3), it is assumed that HNO_3 contributes with 25% and NO_3^- with 75%, whereas for the sum of ammonium (NH_3 + NH_4^+) NH_3 is presumed to contribute with 8% and NH_4^+ by 92% (Ferm, 1988). The dry deposition velocities of gases and particles are highly variable and uncertain quantities. The deposition of particles (SO_4^{2-}, NO_3^-, and NH_4^+) increases with wind speed and with the ground's roughness (forest coverage etc.). The deposition of gases (SO_2, NO_2, HNO_3, and NH_3) depends on the biological activity of the vegetation and surface type (water, mountains, etc.). The deposition is for most gases far greater on wet surfaces than when the surfaces are dry. In winter, the deposition is small because of low biological activity, and because the surface is often covered by snow and ice. The stable layer of air close to the ground in winter also reduces the transport of contaminants to the ground.

The wet deposition contribute most to the total deposition at all the sites on the mainland, for both nitrogen and sulfur, and the total deposition is highest in southern Norway (Figure 3.5 and Table 3.9). Dry deposition of sulfur contributes to the total deposition with 18-29% in summer and 2-14% in winter except at Svalbard where the dry deposition is higher due low precipitation amount. Dry deposition of nitrogen contributes between 16-40% in summer and 4-12% 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 2020.

	Sulfur (mg S/m²)						Nitrogen (mg N/m²)					
	Dry deposition		Wet deposition		% dry deposition		Dry deposition		Wet deposition		% dry deposition	
	Winter	Summer	Winter	Summer	% W	% S	Winter	Summer	Winter	Summer	% V	% S
Birkenes	5	31	227	137	2	19	33	95	830	482	4	16
Hurdal	3	16	81	69	3	18	13	84	301	268	4	24
Kårvatn	2	13	17	51	9	21	16	73	125	114	12	39
Tustervatn	3	11	16	27	14	29	12	63	114	93	9	40
Zeppelin*	6	11	5	22	54	34	-	-	21	16	-	-

Dry deposition = measured air concentrations · dry deposition velocity from literature Dry deposition velocities used: SO_2: 0.1 cm/s (winter) - 0.7 cm/s (summer). SO_4: 0.2-0.6 cm/s, NO_2: 0.1-0.5 cm/s, HNO_3: 1.5-2.5 cm/s, NO_3: 0.2-0.6 cm/s, NH_4: 0.2-0.6 cm/s, NH_3: 0.1-0.7 cm/s. Sum nitrate = 25% HNO_3 + 75% NO_3. Sum ammonium = 8% NH_3 + 92% NH_4.

The %- values indicate the estimated contributed of dry deposition to the total deposition for winter (W) and summer (S) Summer = May - October, winter = January - April and November - December. For Zeppelin, wet deposition is taken from Ny-Ålesund.

*Used the wet deposition at Ny-Ålesund.

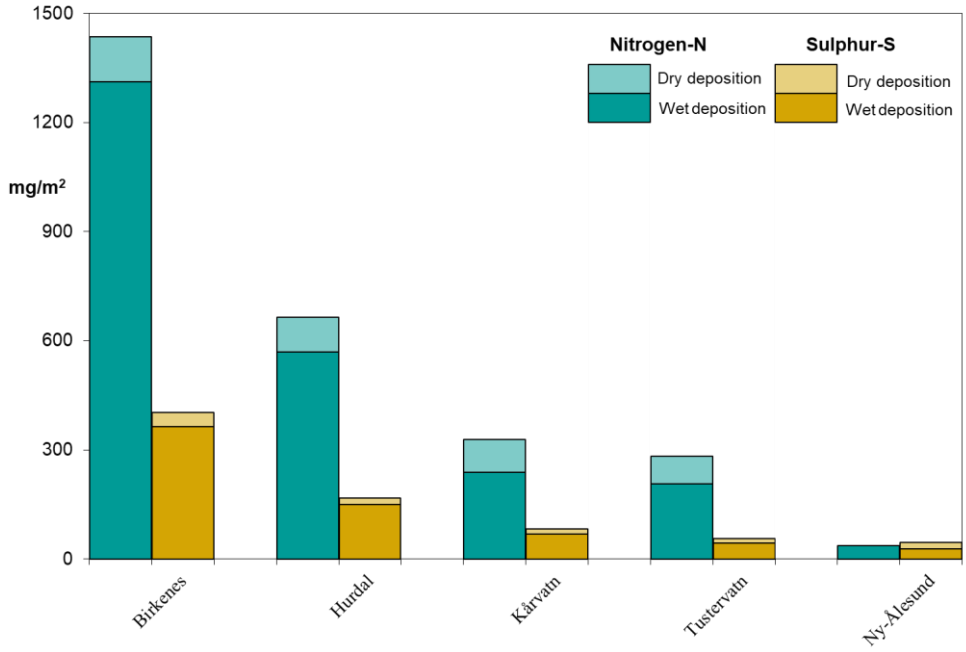


Figure 3.5: Total deposition (wet+ dry) of sulfur-S (SO_2, SO_4^{2-}) and nitrogen-N (NO_2, NH_4^+, NH_3, NO_3^-, HNO_3) at Norwegian background stations 2020.

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 3.9 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 2020 were in general a lower compared to 2020, especially for nitrogen dioxide and sulfate (Figure 3.7). For nitrogen species this is probably due to the exceptional year with lockdown and less emissions of NO_2 (Solberg et al. 2021)

Table 3.10 and Table 3.11 shows the trends for different periods: 1980-2000, 1990-2010 and 1990-, 2000-, and 2005-2020 for all sites with measurements in these respective periods. Since the sulfur trend is not linear, it is not calculated trends for the whole period 1980-2020.

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. The python package pyMannKendall has been used to calculate the trends and Sen lope (Hussain et al. 2019).

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 2020. Since 1990, the content of sulfate in precipitation in Norway has decreased by 57% to almost 100%. The reductions in airborne concentrations of sulfate have been similar, between 75% and almost 91% at the Norwegian mainland, while for sulfur dioxide the trend is almost 100%. The calculated linear trend for this long period gives reductions higher than 100%, which illustrates the problem of assuming linearity when the trend is higher in one part of the period. Somewhat lower reductions are observed at the Zeppelin Observatory; 73% for sulfur dioxide and 41% for sulfate, Table 3.10.

Most of the sites with trends from 2005 show an observed sulfur reduction close to the target of 59% emission reductions, which is to be reached within 2020. For sulfate in air the trends in between 37-70%, while in precipitation between 36-85%.

The nitrate concentrations in precipitation have significantly decreased at most sites, about 30-60% for nitrate, while for ammonium there are fewer sites with significant trend, but hose with have a decrease around 40% except at Nausta where there is an increase since 1990. For the air components it is fewer sites with significant trend (Table 3.11), but when only looking at ammonium it is a significant reduction of around 60-80% (not shown) at the mainland sites . The ammonium trend is very much connected to the SO_2 trend, less SO_2 will give less $SO_4(NH_4)_2$.

For nitrogen species, the annual variations vary somewhat more than for sulfur species (Figure 3.7) due more influence of changes in local emissions, which can make it more difficult to detect significant trends in long range transport of air pollution.

The NO_2 concentration has decreased at all four sites, between 43% to almost 100% from 1990 and 37-54% from 2000 (Figure 3.8 and Table 3.11), while between 35-41% since 2005 except at Tustervatn which do not experience significant trend for this latter period.

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 2005-2020 period, indicates that there are variations in the contribution from mineral dust influencing the trends also visual in the trend figures (Figure 3.6 and Figure 3.8). The contribution of sea salts are influenced by meteorological conditions and vary from year to year. A significant increase in Sodium is seen at Vatnedalen since 2000 , and there are other periods with significant increase or decrease at other sites, but there is not a general trend in sea salt contribution .

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; Colette et al., 2021).

The trends in wet deposition follow to a large extent the trends in concentrations in precipitation though with larger variabilities (not sown) due to the annual variations in precipitation amount. Change in climate may influence the trends in wet deposition. i.e due to more or less precipitation. It seems to be an increase in precipitation at some of the sites in southern Norway since 1990 (Table 3.10) and this may counteract some of the decreasing trend in emission.

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. Reductions larger than 100% are due to uncertainties in the statistical method used.

	ssc SO_4^{2-}					NO_3^-					NH_4^+				
Site	1980-2000	1990-2010	1990-2020	2000-2020	2005-2020	1980-2000	1990-2010	1990-2020	2000-2020	2005-2020	1980-2000	1990-2010	1990-2020	2000-2020	2005-2020
Birkenes	-68	-71	-88	-60	-57	-18	-35	-47	-33	-35	-44	-38	-42	-	-
Brekkebygda	-68	-81	-111	-83	-85	-	-44	-61	-	-48	-56	-	-69	-45	-64
Hurdal		-75	-95	-58	-56		-24	-40	-35	-41		-	-	-	-41
Høylandet		-55	-85	-81	-84		-	-40	-46	-64		87	-	-	-
Karpbukt		-74	-67	-26	-38		-60	-59	-	-		-66	-	-	-
Kårvatn	-83	-43	-57	-50	-	-27	-	-	-	-	-	-	-	-	-
Løken	-69	-86	-102	-64	-54	-38	-41	-53	-29	-30	-68	-45	-42	-	-
Nausta		-72	-90	-75	-58		-	-36	-27	-		-	63	62	-
Ny-Ålesund	-84	-81	-93	-	-	-	-	-29	-	-	615	-	-46	-	-
Treungen	-64	-79	-93	-70	-59	-	-34	-55	-34	-38	-25	-31	-44	-29	-
Tustervatn	-75	-56	-65	-	-	-	-	-19	-	-32	99	-	-34	-40	-
Vatnedalen	-62	-64	-84	-62	-36	-	-	-50	-34	-46	-	-	-	-	-
Vikedal		-74	-101	-81	-70		-19	-45	-46	-38		-	-	-31	-33

	Na^+					Ca^{2+}					mm				
	1980-2000	1990-2010	1990-2020	2000-2020	2005-2020	1980-2000	1990-2010	1990-2020	2000-2020	2005-2020	1980-2000	1990-2010	1990-2020	2000-2020	2005-2020
Birkenes	-	-	-	-	-	-65	-	42	66	-	-	-	82	51	-
Brekkebygda	-	-	-	-	-	-37	-	-	-	-	-	72	111	44	30
Hurdal		-	-	-	-		98	57	-	-		-	37	-	-
Høylandet		-	-	-	-		-	-	-	-		-	-	-	-
Karpbukt		-	-31	-	-		-	-	-	-		122	61	-	-
Kårvatn	-	-	-	-	-	-53	-	-	-	-	-	-	-	-	-
Løken	-	-47	-	-	-	-52	-	-	44	-	-	-	-	-	-
Nausta		-	-	-	-	-	-	-	-	-		-	-	-	-
Ny-Ålesund	-	-	-	-	-	-	-	-52	-73	-	-	-	-	-	-
Treungen	-	-	-	-	-	-50	-	-	34	-	-	-	48	-	-
Tustervatn	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vatnedalen	-	-46	-	140	101	-	-	-	-	-	-	-	-	-	-
Vikedal		-	-	-	-	-	-	-	-	-		-	-	-	-

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 periods. Reductions larger than 100% are due to uncertainties in the statistical method used.

	SO_2					SO_4^{2-}				
	1980-2000	1990-2010	1990-2020	2000-2020	2005-2020	1980-2000	1990-2010	1990-2020	2000-2020	2005-2020
Birkenes	-88	-111	-110	-65	-	-58	-63	-75	-71	-59
Nordmoen/Hurdal		-104	-110	-75	-89		-76	-91	-90	-70
Kårvatn	-122	-88	-87	-48	-	-71	-61	-79	-65	-51
Tustervatn	-107	-91	-94	-80	-	-70	-59	-76	-76	-67
Zeppelin	-82	-64	-73	-65	-	-	-28	-41	-35	-37

	NO_2					sum(NO_3+HNO_3)				
	1980-2000	1990-2010	1990-2020	2000-2020	2005-2020	1980-2000	1990-2010	1990-2020	2000-2020	2005-2020
Birkenes		-59	-70	-52	-37		-	-	-	-
Nordmoen/Hurdal		-99	-128	-54	-41		-28	-43	-44	-54
Kårvatn		-	-43	-49	-35		-	-	-	-
Tustervatn		-52	-56	-37	-		-	-	-	-
Zeppelin							-	-	-	-73

	sum(NH_4^++NH_3)					Na^+				
	1980-2000	1990-2010	1990-2020	2000-2020	2005-2020	1980-2000	1990-2010	1990-2020	2000-2020	2005-2020
Birkenes		-44	-39	-	-		-	39	36	-
Nordmoen/Hurdal		-56	-62	-	-72		-	-	-	-
Kårvatn		83	49	-	-		-	-	-20	-
Tustervatn		54	-	-71	-78		-	-	-	-
Zeppelin		265	131	-	-		-	-	-	-

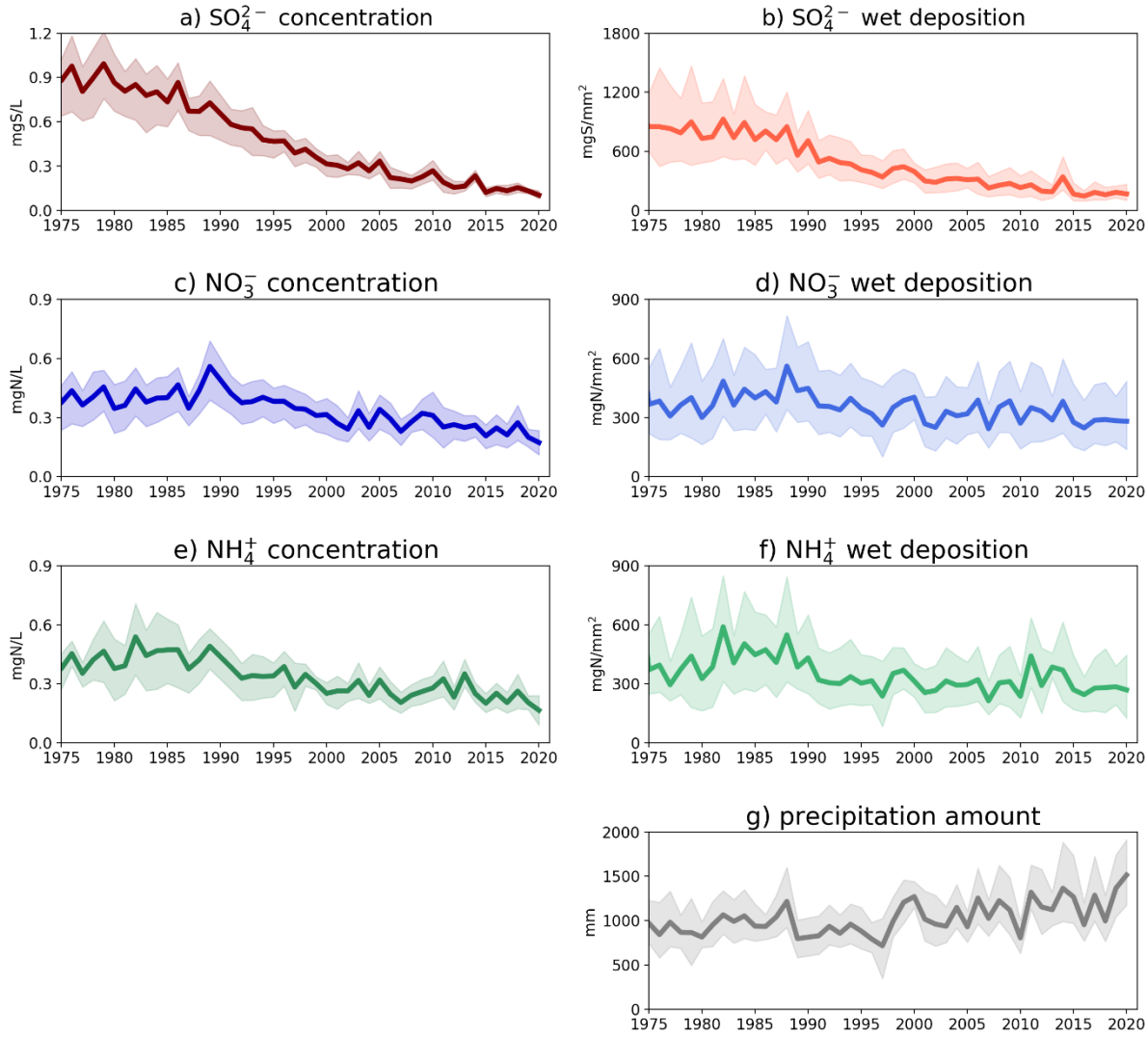


Figure 3.6: Average volume weighted annual mean concentrations and wet deposition of sea salt corrected sulfate, nitrate and ammonium at five representative sites in southern Norway (Birkenes, Vatnedalen, Treungen, Gulsvik and Løken), 1975-2020. The solid lines are the average between the sites and the shaded areas indicate the 95% confidence interval around the mean.

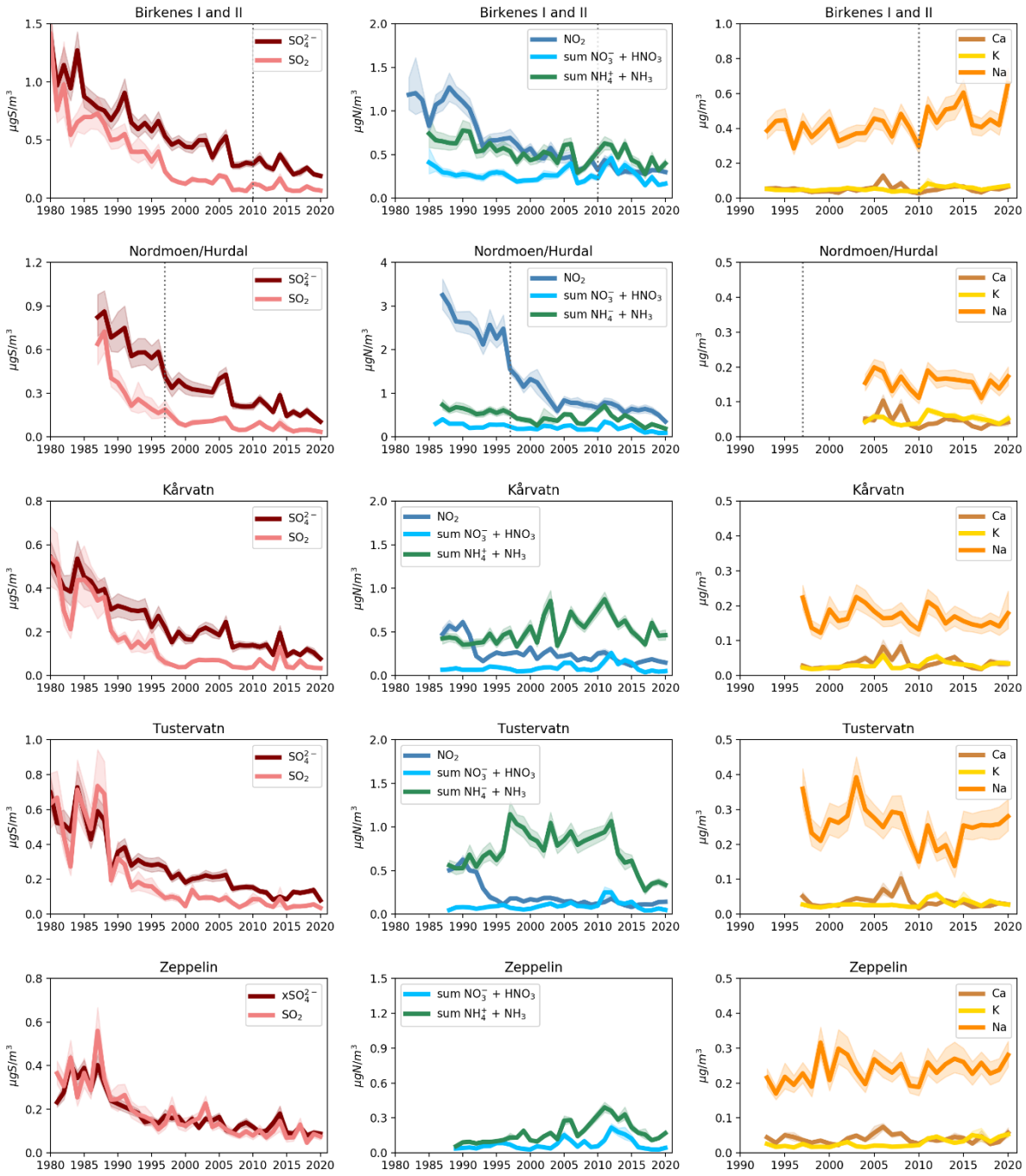


Figure 3.7: Average annual mean concentrations of the main components in air at the Norwegian EMEP sites, 1980-2020. The solid line is the annual averages and shaded areas indicate 95% confidence interval of daily or weekly concentrations around the mean.

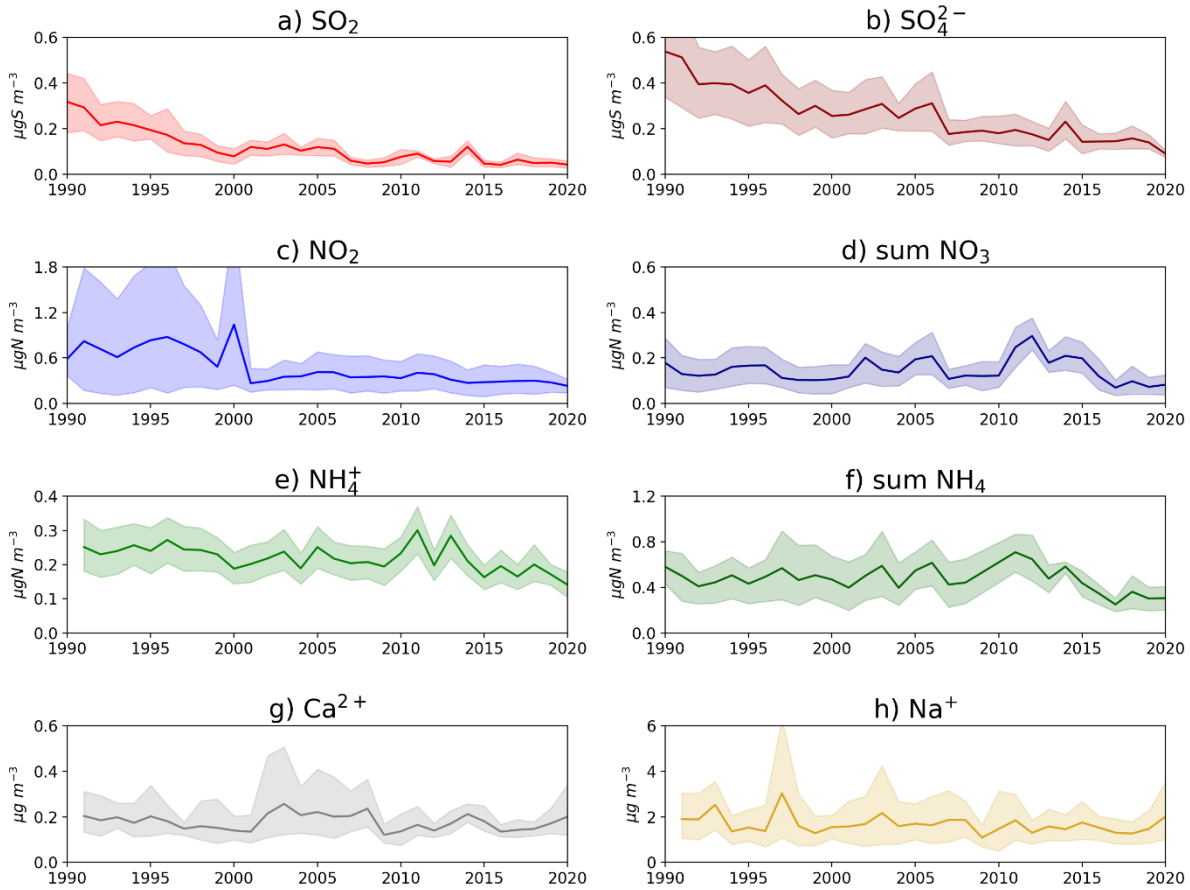


Figure 3.8: Average in annual mean concentrations at Birkenes, Hurdal/Nordmoen, Kårvatn, Tustervatn and Zeppelin, 1990-2020. The solid line is the average between the sites and shaded areas indicate 95% confidence interval around the mean.

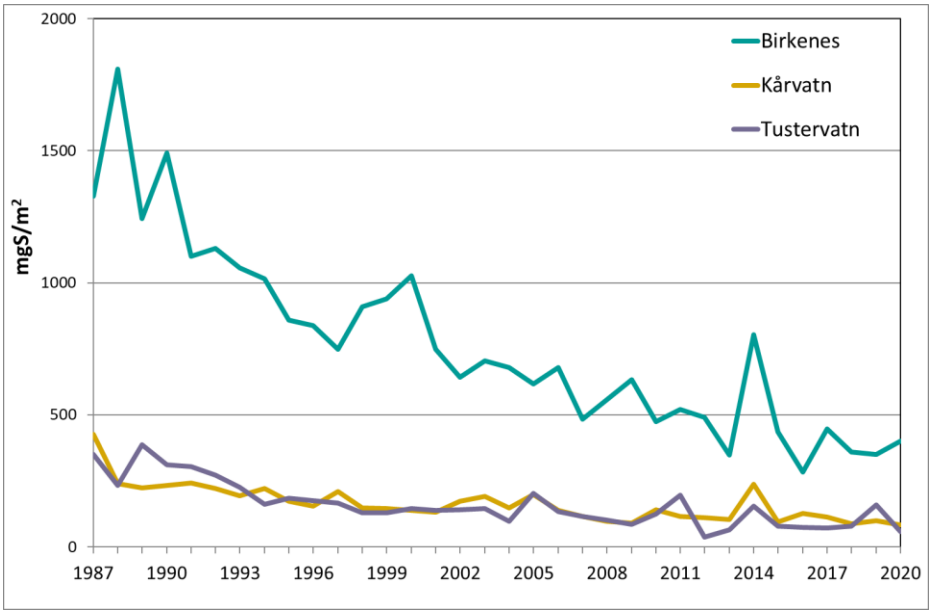


Figure 3.9: Trends in total deposition (wet + dry) of sulfur at three Norwegian EMEP sites, 1987-2020.

3.3 Summary

For most of the main inorganic components, the highest annual mean concentrations in 2020 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 2020 were in general a lower compared to 2019, especially for nitrogen dioxide and sulfate. This can be partly explained by special weather conditions in the first months with mostly clean, marine air from the west. The extensive restrictions on human activity in connection with the pandemic in Europe have probably also contributed to lower levels of air pollution at the Norwegian background stations. In a longer perspective, there are large reductions in sulfur in all parts of Norway, since 1990 around 80-90% (depending on the compound), and since 2005 about 50-60%, 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 30-60% for nitrate and 30-40 for ammonium since 1990. The NO_2-concentration has also decreased significantly with more than 42% since 1990, and between 35-41% since 2005 , close to the European target of 43% emission reductions set by the Gothenburg protocol to be reached within 2020.

These observed reductions are in line with reported emission reduction at the European continent .

4 EC and OC

4.1 Introduction

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

Annual and monthly mean concentrations of EC and OC in PM_{10} and $PM_{2.5}$ for 2020 are shown in Table A.1.35:, whereas annual mean concentrations for EC and OC in PM_{10} and $PM_{2.5}$ for 2001 – 2020 are listed in Table A.1.36:.

Incidences of $PM_{2.5} > PM_{10}$ (monthly) 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, particularly for EC. OC in $PM_{10-2.5}$ is derived from the observed values of OC in PM_{10} and $PM_{2.5}$ and is discussed in the report for a better understanding of the observed data but is not listed in any table. Background information on the carbonaceous aerosol (here: EC and OC) can be found in Annex 3. No OC/EC data for $PM_{2.5}$ is reported for 1 January to 17 August for Kårvatn, due to a malfunctioning part of the size segregating inlet of the filter sampler.

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

The annual mean concentration of OC in PM_{10} (0.68–0.95 µg C/m^3) and $PM_{2.5}$ (0.57–0.58 µg C/m^3) at Norwegian rural background sites are amongst the lowest in Europe. Fine fraction OC (61 – 70%) was the major fraction of OC in PM_{10} at all sites on an annual basis. This is as expected as the major sources, primary emissions from combustion of fossil fuel and biomass and secondary particle formation from biogenic and anthropogenic precursors, typically generate fine aerosol particles. Coarse fraction OC occasionally dominates for certain months. This is typically observed for the second half of the growing season and is attributed to the presence of primary biological aerosol particles (PBAP), such as e.g. fungal spores.

The annual mean concentration of OC in PM_{10} at Hurdal was 16-40% higher than at Birkenes and at Kårvatn. The difference in concentration was largely explained by the coarse fraction of PM_{10}. Coarse OC is mainly associated with PBAB 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 speculating that it reflects variability in the local vegetation. The fine fraction OC increment at Hurdal compared to Birkenes has narrowed substantially over the last two years. We speculate that the influence of local emissions in the densely populated and anthropogenic influenced region surrounding the Hurdal site has been reduced and thus being relatively more influenced by LRT. A similar finding is made for fine EC and NO_2 (see Chapter 3.1.2), which historically higher levels have been explained by higher emissions from vehicular traffic in this region.

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. This reflects increased levels of Secondary Organic Aerosols (SOA), and Biogenic SOA (BSOA) in particular, contributing to the fine fraction, and PBAP contributing primarily to the coarse fraction in the growing season (See Yttri et al. 2011 a, b; Yttri et al. 2021), as well as reduced emissions from residential heating in the non-heating season. A pronounced covariance was observed between sites with respect to seasonality and high concentration episodes; increased levels in June, most of August and in the transition September/October was observed at all sites. Seasonal covariance is driven by climatological factors, e.g., temperature is decisive for the formation of SOA and pollen release in summer as well as for domestic heating in winter, and episodes of LRT air pollution is well known to affect large regions.

Prolonged sampling time (here: weekly) could potentially mask differences between sites. The highest monthly mean for OC in PM_{10} and $PM_{2.5}$ was observed in June, which experienced temperatures high above normal at all sites. The monthly mean for OC exceeded 2 µg C m^{-3} for the PM_{10} fraction all sites. Notably, the LRT episode in October, being a mixture of emissions of mineral dust from Central Asia and wildfires in Ukraine, carried carbonate Carbon, contributing 0.05 – 0.11 µg C m^{-3} to the carbonaceous aerosol.

Annual means of OC and EC were generally low in 2020. This was particularly pronounced at Hurdal and Kårvatn, where annual means for EC were the lowest observed so far, so also for fine OC at Hurdal. For OC in PM_{10}, only 2016 (Hurdal) and 2017 (Kårvatn) were lower. At Birkenes, fine OC equaled the second lowest annual mean of 2016.

The annual mean OC concentration at the Zeppelin Observatory was 3-5 times lower than that observed at rural background sites on the Norwegian mainland. Notably, the annual mean OC concentration at Zeppelin doubled from the previous year. This was largely driven by increased OC levels in the transition July/August, where the OC concentration exceeded 2 µg C m^{-3} for the first week, and in the beginning of October. Supporting analysis show that BB, PBAP, and particularly BSOA, contributed to the elevated levels in the transition July/August, and model simulations suggest that wildfires in western Russia were the driving force (Figure 4.1). The October episode, which is clearly visible in , was due to the same plume that caused enhanced levels of OC and EC at the rural background sites on the Norwegian mainland, and which extended into the European Arctic. The weekly OC concentration observed for this episode was 0.8 µg C m^{-3}.

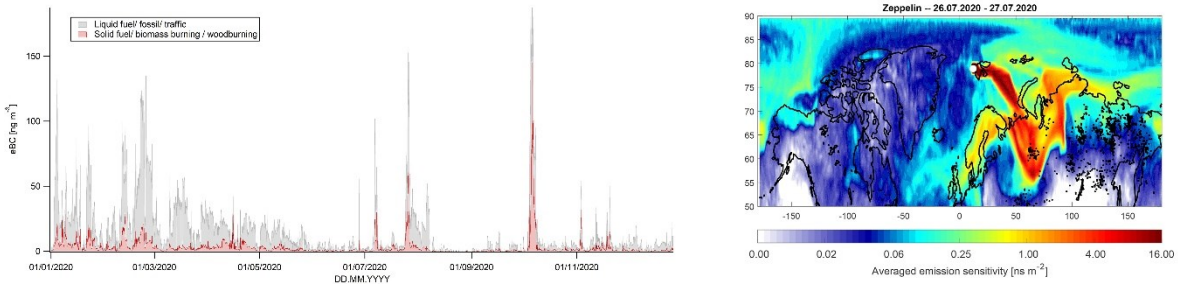


Figure 4.1: Source apportionment of equivalent BC (eBC) into biomass burning (eBC_{BB}) and fossil fuel (eBC_{FF}) categories at the Zeppelin Observatory for 2020 (left panel) and footprint associated with elevated concentrations of eBC_{BB} at Zeppelin Observatory 26 – 27 of July 2020 (right panel). Black dots on the map are fire locations based on the GFED (Global Fire Emission Database) dataset

The OC level at Zeppelin was increased in summer compared to winter. This seasonality is explained by increased BSOA and PBAP levels in summer, but unlike the rural background sites on the Norwegian mainland also BB emissions from wildfires make a substantial contribution. BB emissions from residential wood burning contributes to OC in the heating season along with emissions from combustion of fossil fuel. Efficient transport of polluted air masses to the Arctic in winter and accumulation caused by the favourable conditions forming Arctic haze, cause increased levels in winter/spring.

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

The annual mean concentration of EC in PM_{10} (0.03-0.08 µg C/m^3) and $PM_{2.5}$ (0.06-0.07µg C/m^3) at Norwegian rural background sites are amongst the lowest in Europe. EC results from incomplete combustion of fossil fuel and biomass and emissions are thus almost exclusively associated with the fine fraction of PM_{10}. EC levels at Hurdal and Birkenes were quite similar but substantially (167%) higher than at Kårvatn. As argued for fine OC in Chapter 4.2, the increment observed for Hurdal compared to Birkenes has been equaled and we speculate that this is due to a reduction of local emissions in the 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., 4 – 9% (PM_{10}) and 10 – 11% ($PM_{2.5}$). EC levels were generally low in 2020, and at Hurdal and Kårvatn the annual means were the lowest since measurements started in 2010.

EC levels are typically higher in winter compared to summer, so also for Birkenes and Hurdal in 2020, whereas it was the other way around at Kårvatn. Note though, that for such low levels observed at Norwegian rural background sites, seasonality becomes highly susceptible to occasional events. E.g., the monthly mean might vary by a factor of two between two consecutive months (June vs. July). An increased monthly mean for October was observed at all sites and was explained by the LRT episode briefly mentioned in chapter 4.2 and discussed in more detail in chapter 7.

The contribution of biomass burning to EC (and OC) have been estimated based on levoglucosan measurements (Chapter 4.6).

The annual mean EC concentration at the Zeppelin Observatory was 2-5 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 (8%) was within the range calculated for rural background sites, but relatively higher in winter/spring compared summer/fall than at the rural background sites, which might reflect issues such as different source regions, source composition and removal processes.

4.4 Relative contribution of EC and OC to PM

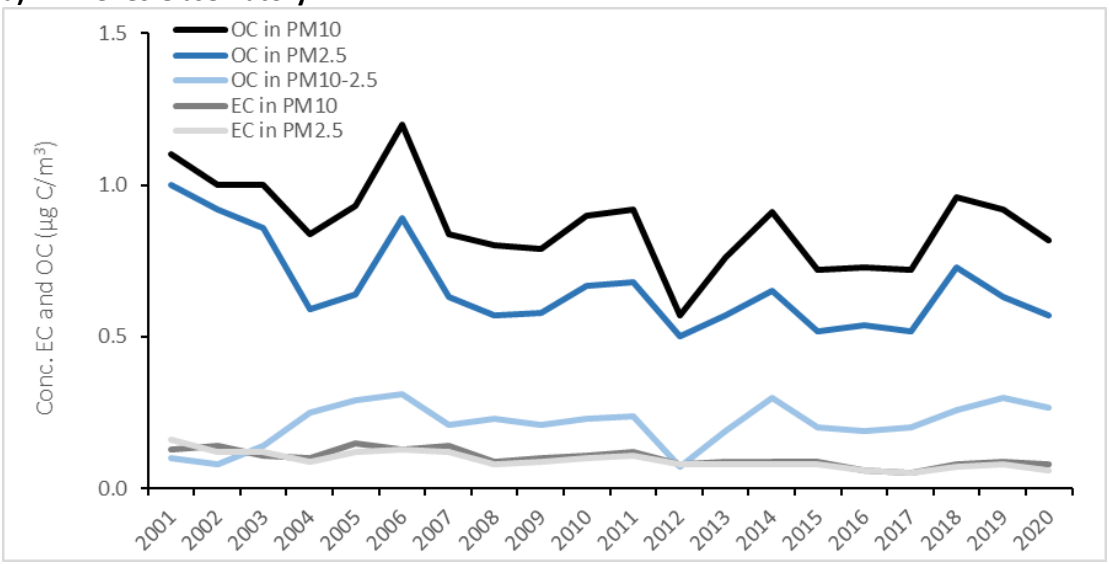
The relative contribution of OC to PM_{10} (16 – 23%) and $PM_{2.5}$ (23 - 26%) annually was rather similar, and for Birkenes somewhat lower than for the two other sites. The OC fraction was higher in summer than in winter at Birkenes and Hurdal, but the other way around at Kårvatn. The relative contribution of OC to $PM_{10-2.5}$ was 10 - 35% on an annual basis, and more pronounced in summer than in winter.

EC accounted for 1.0 –2.5% of PM_{10} annually was and somewhat higher for $PM_{2.5}$ (2.4–3.2%), reflecting that EC is associated with fine aerosol particles. EC was more abundant in the winter-time aerosol than in the summer-time aerosol.

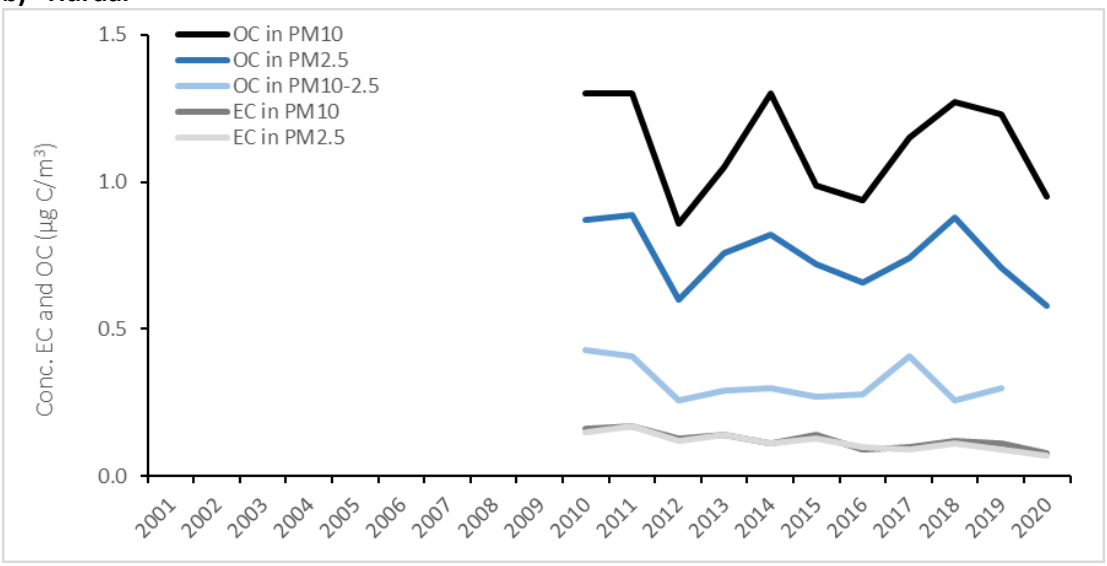
4.5 Trends for concentrations of EC and OC

The Mann Kendall method described in Chapter 3.2 was used for trend analysis of concentrations of EC and OC. Fort the first time, trend analysis for the time series for the sites Hurdal and Kårvatn (10 years) has been included as well, as they now extend 10 years (Table 4.1). The time series of OC in PM_{10}, $PM_{2.5}$ and $PM_{10-2.5}$, and that of EC in PM_{10} and $PM_{2.5}$, are shown in Figure 4.2.

a) Birkenes Observatory



b) Hurdal



c) Kårvatn

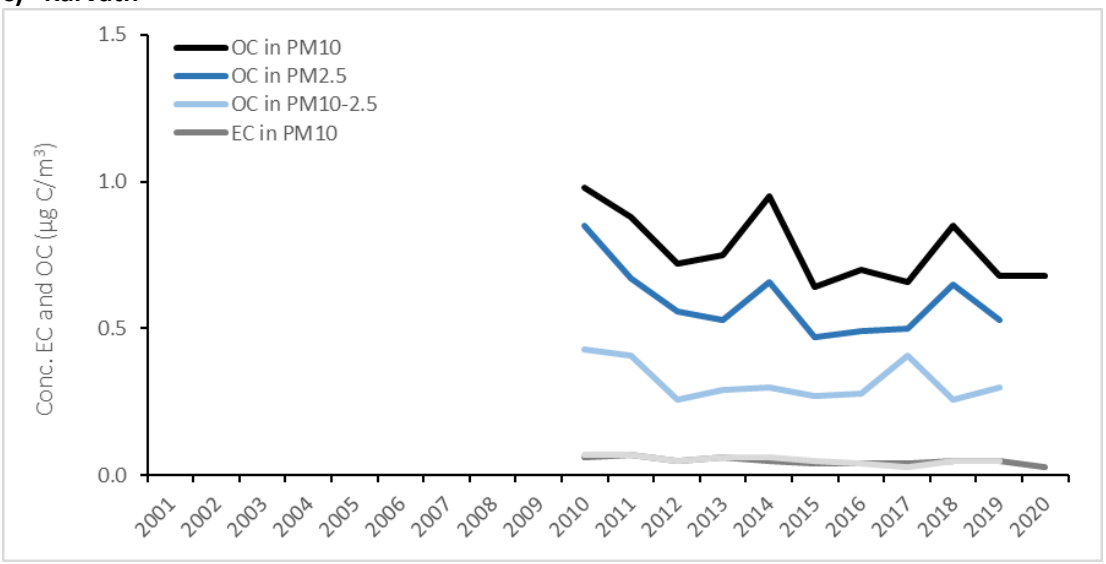


Figure 4.2: Annual mean time series of OC and EC at the Birkenes Observatory (2001 – 2020) (a), Hurdal (2010 - 2020) (b) and Kårvatn (2010 - 2020) (c). Unit µg C/m³.

There was as statistically downward trend for EC at all sites ranging from -53% to -56% for PM_{10} and from -39% to -62% for $PM_{2.5}$, with the most pronounced decrease seen for Birkenes, having the longest time series. Significantly downward trends for OC (and TC) were calculated only for Birkenes, and the decrease was only half of that seen for EC. We explain this discrepancy by the substantial contribution from natural sources (BSOA and PBAP) that are not subject to abatement.

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

Site	PM_{10}	% change	Year	$PM_{2.5}$	% change	Year
Birkenes			2001-2020			2001-2020
OC	*	-23%		*	-32%	
EC	*	-56%		*	-62%	
TC	*	-28%		*	-38%	
Hurdal			2010-2020			2010-2020
OC		-1%			-23%	
EC	*	-53%		*	-52%	
TC		-8%			-22%	
Kårvatn			2010-2020			
OC		-14%			-12%	
EC	*	-53%		*	-39%	
TC		-17%			-18%	

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

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

The annual mean concentration of levoglucosan in PM_{10} observed at the Birkenes Observatory was 7.7 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 concentration in the beginning of October is associated with LRT from wild-fire emissions in the Ukraine (See Chapter 7) (Groot Zwaaftink et al., subm.).

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 PM_{10}, 11.1 for OC in $PM_{2.5}$, and 1.96 for EC (Yttri et al., 2021)). Some influence from wild and agricultural fires in the growing season is likely, but the magnitude of these sources remains speculative except for such major episodes as seen in October.

We estimate that biomass burning contributed 12-17% to OC and 19-25% to EC, annually, considering both PM_{10} and $PM_{2.5}$. The fraction attributed to biomass burning in winter was 30-38% for OC and 26-30 for EC, whereas it was ≤2% (OC) and <6% (EC) in summer, considering both size fractions. Spring and fall are transition seasons with relative contributions typically lower than in winter and higher than in summer. LRT air pollution from continental Europe seems to explain elevated biomass burning aerosol levels observed at the Birkenes Observatory (Yttri et a., 2021) and to be decisive not only for episodes of high concentrations, but also the mean concentration.

Table 4.2.: Annual mean concentrations of levoglucosan, mannosan and galactosan in PM_{10} at Birkenes for 2017-2020. Seasonal mean concentrations for 2020. 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
2020	**Annual**	7.7	1.3	0.33
	Winter	7.7	1.3	0.34
	Spring	10.7	1.7	0.42
	Summer	1.6	0.32	0.04
	Fall	10.6	1.9	0.50

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 < 1.0 µg C m^{-3} and EC < 0.08 µg C m^{-3}), being only 2-5 times higher compared to the remote Arctic environment (OC < 0.2 µg C m^{-3} and EC < 0.016 µg C m^{-3}). Indeed, the lowest annual mean EC concentrations observed so far were recorded for the Hurdal and Kårvatn sites. A near doubling of the annual mean OC concentrations was observed at the remote Arctic site. A statistically significant downward trend was observed for EC (-39% - - 62%) at all rural background sites, whereas for OC (-23 - -32%) a statistically significant downward trend was seen exclusively for the Birkenes Observatory.

Measurements complementary to OC and EC are needed for an assessment of sources. 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. Work in progress suggest a similar pattern for the remote Arctic. With a few exceptions, EC can be considered exclusively anthropogenic, as also wildfires, as seen in October 2020, typically are initiated by anthropogenic activity. Estimates based on levoglucosan measurements suggest that biomass burning contributed 12-17% to OC and 19-25% to EC at the Birkenes Observatory annually, considering both PM_{10} and $PM_{2.5}$, and 30-38% for OC and 26-30% for EC in winter.

5 Particulate matter, mass concentrations

5.1 Introduction

Monitoring of the PM_{10} and $PM_{2.5}$ mass concentration takes place at three rural background sites; the Birkenes Observatory and the Hurdal and Kårvatn sites. The time series at Birkenes dates 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 0.02 – 10 µm, was initiated in 2010, whereas high time resolution measurements of PM_{10} started in 2017.

Annual and monthly mean mass concentrations of PM_{10}, $PM_{10\text{-}2.5}$ and $PM_{2.5}$ for 2020, obtained by gravimetric measurements, are shown in Table A.1.37:, whereas annual mean mass concentrations of PM_{10}, $PM_{10\text{-}2.5}$ and $PM_{2.5}$ for the time period 2000 – 2020 are listed in Table A.1.38:. Time series of PM_{10} and $PM_{2.5}$ for 2020 are shown in Figure 5.1. Note that $PM_{10\text{-}2.5}$ is derived from the observed values of PM_{10} and $PM_{2.5}$; i.e., the difference between PM_{10} and $PM_{2.5}$. Incidences of $PM_{2.5} > PM_{10}$ and $\Sigma PM_{2.5}$, $PM_{10\text{-}2.5} \neq PM_{10}$ at monthly time resolution are typically due to a different number of samples for PM_{10} and $PM_{2.5,}$ but for low levels measurement uncertainties can have an influence as well. Annual means of aerosol particle number (*N*) concentrations for ultrafine ($0.02 < D_p < 0.1$ µm), accumulation mode (D_p = 0.1 - 1.0 µm) and coarse mode (D_p = 1.0 – 10 µm) particles, are shown in Table 5.4. 24 hours mean concentrations of PM_{10} derived from high time resolution measurements, were used to assess violation of national and international limit values and air quality guidelines. Background information on PM can be found in Annex 3.

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

The annual mean mass concentration of PM_{10} (2.9 – 5.2 µg/m^3) and $PM_{2.5}$ (2.2 – 2.5 µg/m^3) at the Norwegian rural background sites are amongst the lowest in Europe. For the first time in 20 years of measurements, $PM_{10\text{-}2.5}$ was the major fraction of PM_{10} at Birkenes on an annual basis, accounting for 52%. At Hurdal, $PM_{2.5}$ was the major fraction accounting for 54% of PM_{10}. $PM_{10\text{-}2.5}$ was the major fraction of PM_{10} for 7 months at Birkenes and four at Hurdal, and is typically attributed to natural sources, such as sea salts, primary biological aerosol particles (PBAP), and mineral dust.

The PM_{10} annual means were within –SD of the long-term mean at all sites, $PM_{2.5}$ were outside -SD of long-term mean, whereas the $PM_{10\text{-}2.5}$ annual mean was outside +SD of the long-term mean. Note that the measurements for Hurdal and Kårvatn started in 2010, whereas measurements at Birkenes were initiated in 2000/2001.

The PM_{10} annual mean at Birkenes was 27% higher compared to Hurdal and 79% higher compared to Kårvatn. The discrepancy is largely explained by the higher $PM_{10\text{-}2.5}$ fraction at Birkenes, as well as a higher $PM_{2.5}$ fraction when compared to Kårvatn. The higher $PM_{10\text{-}2.5}$ fraction at Birkenes 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 NO_3^- reside in the coarse fraction of PM_{10} at Birkenes, following from the reaction between gaseous HNO_3 and coarse mode NaCl. Coarse fraction organic matter (OM), dominated by PBAP, was 1.4 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.

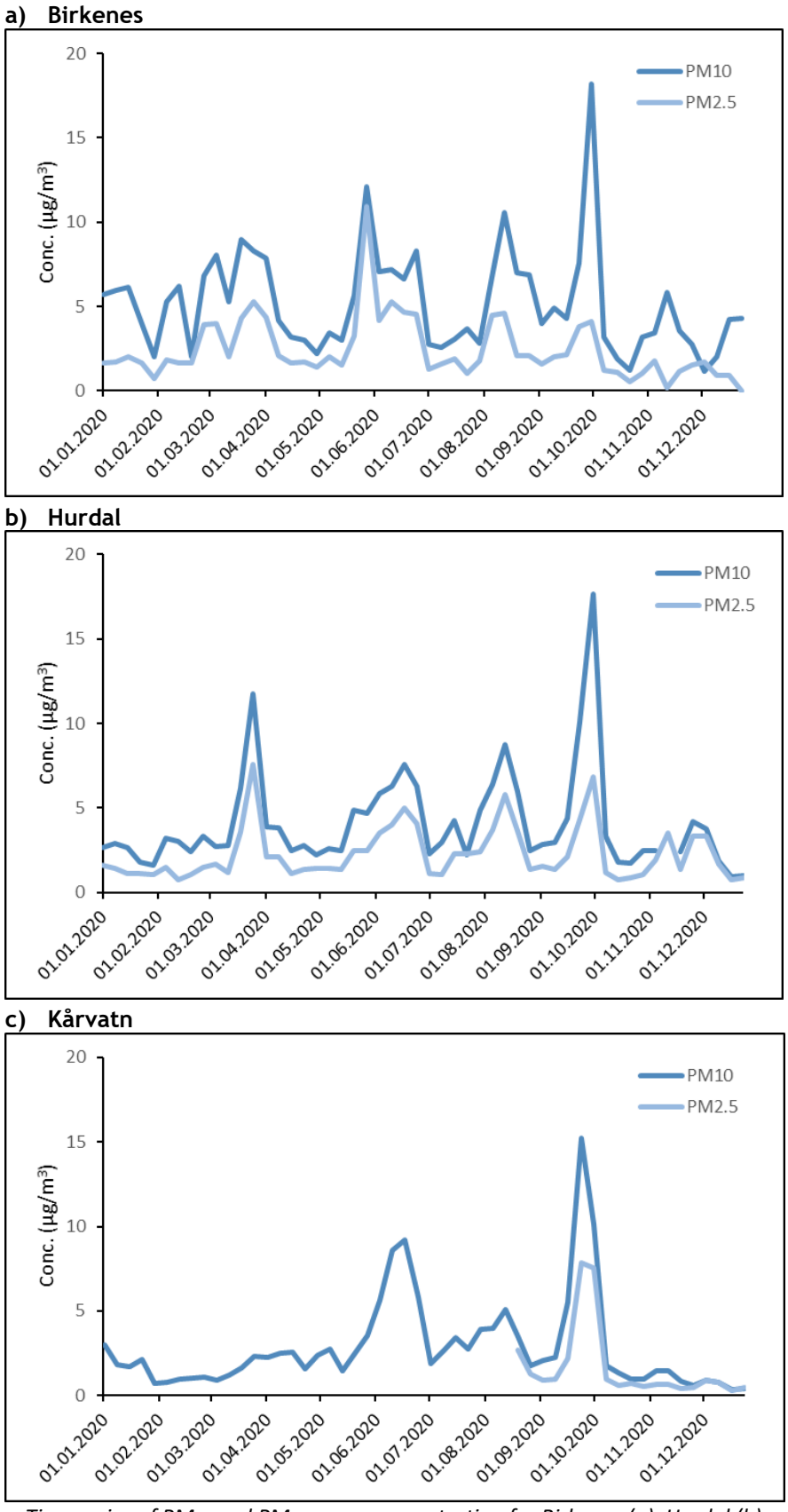


Figure 5.1: Time series of PM_{10} and $PM_{2.5}$ mass concentration for Birkenes (a), Hurdal (b) and Kårvatn (c) for 2020. Unit µg/m^3. Note that the time series have been harmonized in time for comparability, i.e., they all start on the same date (01.01.2020).

The annual mean $PM_{2.5}$ concentration was 14% higher at Birkenes compared to Hurdal. The difference was largely explained by the higher inorganic fraction at Birkenes and the secondary inorganic aerosol constituents (SIA) (i.e., SO_4^{2-}, NO_3^- and NH_4^+, typically residing in the fine fraction of PM_{10}) particularly, although a larger fraction of SIA, and NO_3^- in particular, likely is associated with the coarse fraction of PM_{10} at Birkenes.

The 2020 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 sea spray. Some of these periods observed at Birkenes were also seen at Hurdal, and to some extent at Kårvatn. Weekly mean concentrations exceeding 10 µg m^{-3} were observed at all sites for PM_{10} but only at Birkenes for $PM_{2.5}$. The highest weekly mean PM_{10} concentration was observed at Hurdal (22.2 µg m^{-3}), but maximum concentrations at Birkenes (18.7 µg m^{-3}) and Kårvatn (21 µg m^{-3}) were almost equally high. The PM_{10} concentration exceeded 10 µg m^{-3} at Birkenes for three weeks, and two at Hurdal and Kårvatn. Organic matter (OM) was the major fraction of PM_{10} for two of the three weeks at Birkenes, whereas mineral dust (34-40%) dominated the week with the highest PM_{10} concentration. Mineral dust was also the major fraction for the week with the highest PM_{10} concentration at Hurdal (25-31%) and at Kårvatn (36-45%), whereas SIA (Hurdal) and OM (Kårvatn) dominated the other one.

The fine fraction is typically the most abundant when PM_{10} levels exceed 10 µg m^{-3}. For 2020, the coarse fraction was most abundant at all sites for the week experiencing the highest PM_{10} level, due to a major contribution of LRT mineral dust from Central Asia.

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 wildfires occasionally make a noticeable contribution.

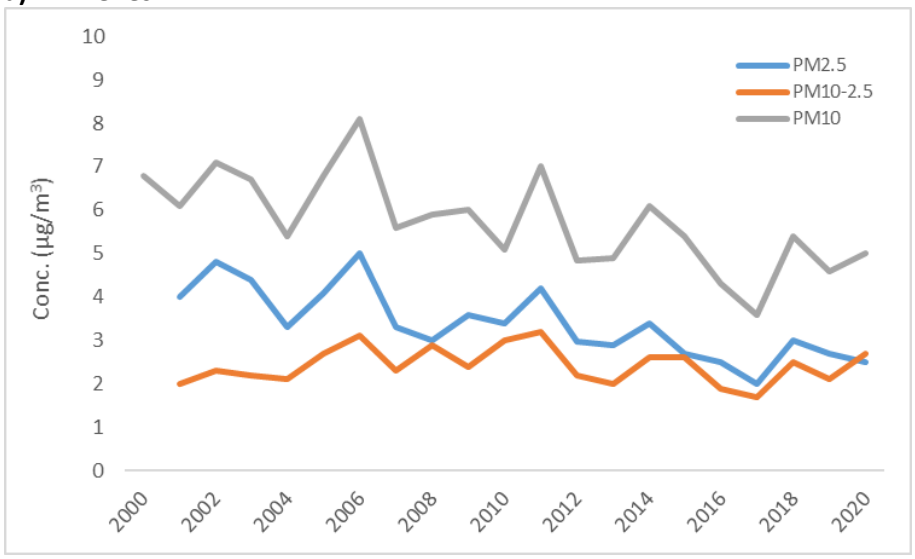
5.3 Trends

The Mann Kendall method described in Chapter 3.2 was used for trend analysis of PM concentrations. In 2020, all PM time series extended 10 years and were thus assessed (Table 5.1). A statistically significant downward trend for the annual mean concentration of PM_{10} was only observed at Birkenes (-35%). For $PM_{2.5}$, there was a statistically significant downward trend both for Birkenes (-51%) and for Hurdal (-43%).

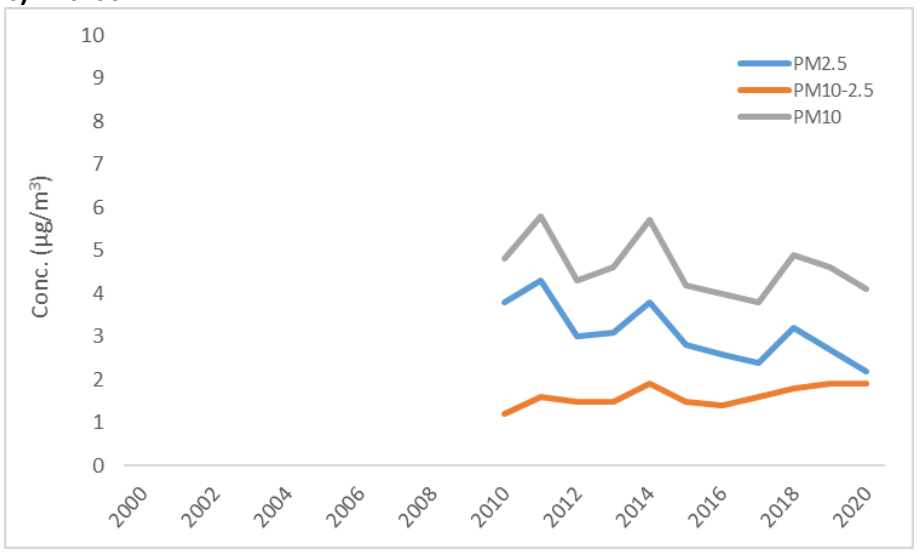
*Table 5.1: Trends in annual mean mass concentration of PM_{10} and $PM_{2.5}$, using Mann-Kendall test and Sen slope estimates; * significant level 0.05.*

Site	PM_{10}	% change	Year	$PM_{2.5}$	% change	Year
Birkenes	*	-35%	2000-2020	*	-51%	2000-2020
Hurdal		-	2010-2020	*	-43%	2010-2020
Kårvatn		-	2010-2020		-	2010-2020

a) Birkenes



b) Hurdal



c) Kårvatn

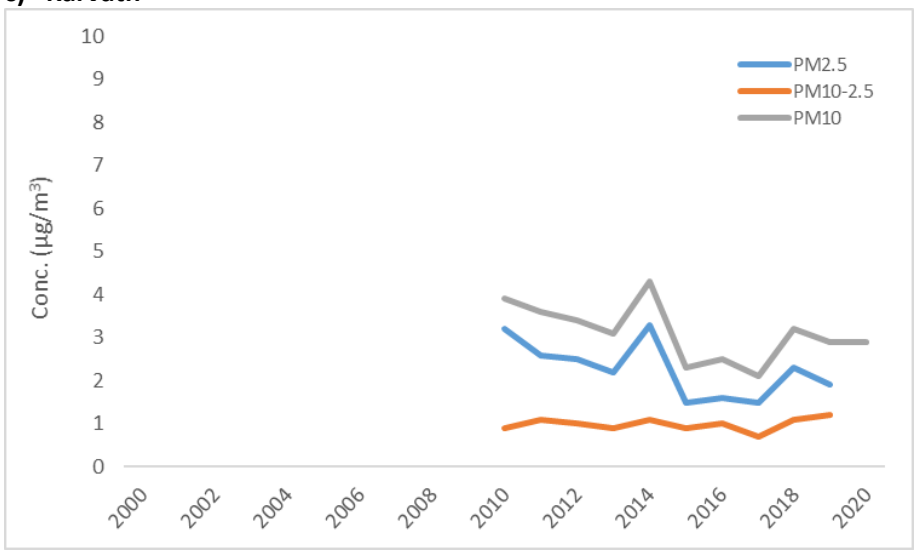


Figure 5.2: Annual mean time series of PM_{10}, $PM_{2.5}$ and $PM_{10-2.5}$ mass concentration for Birkenes (a), Hurdal (b) and Kårvatn (c) for 2001 – 2020. Unit µg/m³.

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

The EU annual limit value for PM_{10} and $PM_{2.5}$ (See Table 5.2 for EU limit values and Air-Quality Guidelines for PM_{10} and $PM_{2.5}$) was far from being violated at any of the three sites in 2020; the highest annual mean PM concentrations observed being approximately 10% 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 25-26% of the annual AQG.

National annual limit values for PM_{10} and $PM_{2.5}$ are less stringent than the WHO AQG, and thus far from being violated at any of the three sampling sites in 2020. The National Air-Quality Guidelines (FHI, 2013) are more stringent than the WHOs with respect to $PM_{2.5}$, still, the highest annual mean observed for PM_{10} and $PM_{2.5}$ in the Norwegian rural background environment in 2020, accounted for no more than 26% and 31% of the PM_{10} and $PM_{2.5}$ National AQG, respectively.

The two highest 24-hour mean PM_{10} concentration observed for 2020 was 66 µg m^{-3} and 61 µg m^{-3} and thus exceeded both limit values and AQG. These highly elevated concentrations were observed on the 2nd and 3rd of October and were caused by a long-range atmospheric transport episode carrying a mixture of mineral dust from Central Asia and emissions from wildfires in Ukraine. This episode is discussed in more detail in Chapter 7. No 24-hour measurements are performed for $PM_{2.5}$.

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

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

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

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

5.5 Chemical composition of particulate matter

EC and OC were measured in the PM_{10} and $PM_{2.5}$ size fractions at the Birkenes, Hurdal and Kårvatn sites, whereas the major inorganic anions (SO_4^{2-}, NO_3^-, Cl^-) and cations (Ca^{2+}, Mg^{2+}, K^+, Na^+, NH_4^+) were obtained from open filter face samplers with a cut-off size exceeding 10 µm equivalent aerodynamic diameter (EAD). However, most of these species typically reside within the PM_{10} fraction. Occasionally, sea salt aerosol larger than PM_{10} could be collected, i.e., during stormy weather conditions at Birkenes, at a southerly wind direction. The data obtained from the monitoring programme appear to be well suited for a mass closure of PM_{10}, except that species representing mineral dust are not included. For 2014 - 2020, the PM_{10} 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 higher uncertainty than for PM_{10}, as default assumptions would have to be made according to the size distribution of the inorganic species analyzed, of which the largest uncertainty would be associated with that of NO_3^-, thus this is not performed.

The annual mean chemical mass composition of PM_{10} is shown in Figure 5.3. The speciated mass explained 53 – 70% of the annual mean concentration of PM_{10} for the three sites, and 69 – 81% when allowing for other elements than carbon for OC and EC. The PM_{10} SIA fraction (and levels) was somewhat higher at Birkenes (25%) compared to Hurdal (17%) and Kårvatn (12%), reflecting the proximity of Birkenes to important SIA-precursor emission source regions in continental Europe. SO_4^{2-} was the most abundant single (SIA) species at all sites, but only marginally higher than NO_3^- at Birkenes and Hurdal, whereas it was 1.5 times higher than sum of NO_3^- and NH_4^+ at Kårvatn.

The OM fraction (27-40%) (here: OM:OC = 1.7; See Yttri et al., 2007) was noticeably higher than for SIA (12-25%) at all sites, and by as much as a factor of two at Hurdal and a factor of three at Kårvatn. The higher relative contribution of EC at Hurdal (2.0%) compared to Birkenes (1.5%) and Kårvatn (1.2%) was consistent with previous years, however, the level of EC in PM_{10} at Hurdal and at Birkenes was equally large for 2020, thus it was the lower mass concentration of PM_{10} which is explains the observed difference.

Situated approximately 20 km from the coastline, Birkenes experienced a substantial 25% sea salt aerosol contribution to PM_{10}, which was substantially higher than at Kårvatn (14%) and at Hurdal (9.7%). Notably, 2020 was the first year where the sea salt fraction of PM_{10} was equally high (Birkenes) or higher (Kårvatn) than the SIA fraction.

Based on Fe measurements in PM_{10} at Birkenes and knowledge about mineral dust composition in Europe (Alastuey et al., 2016), an annual mean mineral dust concentration of 0.7 µg m^{-3} was estimated for Birkenes for 2020, corresponding to 13% of PM_{10} annually. This was identical to the two previous years but noticeably higher than for 2014 - 2017 (7-10%) and allows for a more complete mass closure of PM_{10} of 94% for 2020; i.e., when using OM for mass closure. Mineral dust levels and its relative contribution to PM_{10} was elevated for most of the growing season, accounting for 8 – 18% of PM_{10} in April – September. Mineral dust explained 41% of PM_{10} in October caused mainly by a major long-range atmospheric transport episode in the first week of the month, bringing mineral dust from Central Asia to Northern Europe (see Chapter 7).

Statistically significant downward trends were observed for fractions of SO_4^{2-} (-40%) and EC (-29%) at Birkenes for 2001 - 2020, whereas there was as substantial significant upward trend for the sea salt fraction (157%) (Table 5.3), all for PM_{10}. The SO_4^{2-} fraction for 2020 was by far the lowest observed, being less than two times the negative standard deviation of the long-term mean, reflecting the lowest annual mean SO_4^{2-} concentration observed at Birkenes. The increasing sea salt fraction was explained both by an increased sea salt aerosol level and a decreasing PM_{10} level.

At Hurdal, there was a statistically significant downward trend for the fraction of all SIA constituents to PM_{10}, being somewhat more pronounced for NO_3^- and NH_4^+ (both -77%) than for SO_4^{2-} (-54%). As for Birkenes, the hitherto lowest annual mean for SO_4^{2-} was reported at Hurdal for 2020. A statistically significant downward trend in the EC fraction of PM_{10} of -41% was calculated. The OC fraction of PM_{10} (27%) and $PM_{2.5}$ (33%) was significantly increased. We explain this by OC being dominated by natural sources not subject to abatement, whereas there at the same time has been a noticeable reduction in PM mainly driven by reduced SIA levels.

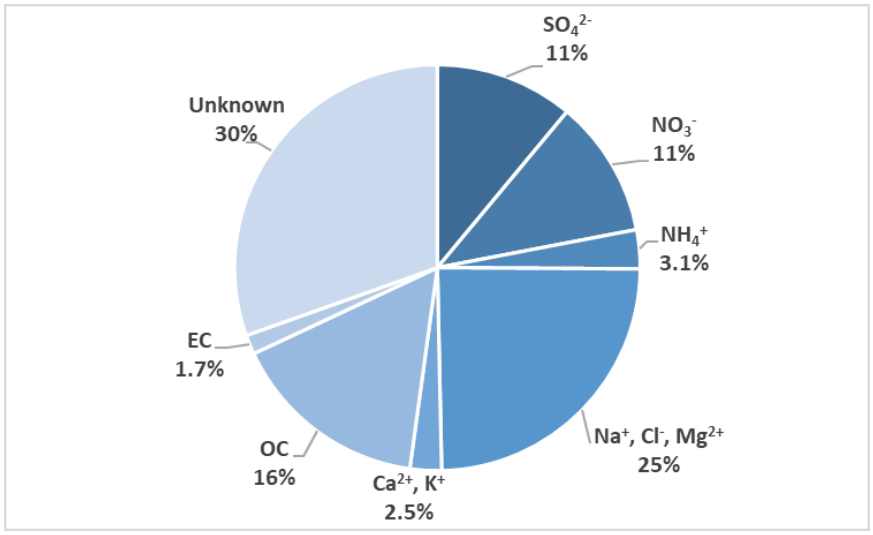
At Kårvatn, statistically significant changes were observed for the NO_3^- (-90%) and NH_4^+(-81%) fractions of PM_{10}, with reductions comparable to that observed at Hurdal. Care should be made not to compare percentages calculated for Hurdal and Kårvatn with Birkenes, as trend calculations are made for 2001 – 2020 at Birkenes and for 2010 – 2020 at the two other sites.

Based on levoglucosan measurements (Table 4.2) we estimate that biomass burning emissions contributed 4-9% to PM annually, considering both PM_{10} and $PM_{2.5}$. The fraction attributed to biomass burning in winter was 5-12%, whereas it was ≤1.5% in summer, considering both size fractions. Spring and fall are transition seasons with relative contributions typically lower than in winter and higher than in summer. Occasionally, high levels can be observed in these seasons, and for 2020 the highest relative contribution was calculated for fall, i.e., 6-17% when considering both size fractions. Biomass burning occasionally exceeded 30% on a weekly basis for PM_{10} and 40% for $PM_{2.5}$, typically in the heating season, thus emissions are attributed to wood burning for residential heating. For the episode on the 2-3 of October see discussions in Chapter 7.

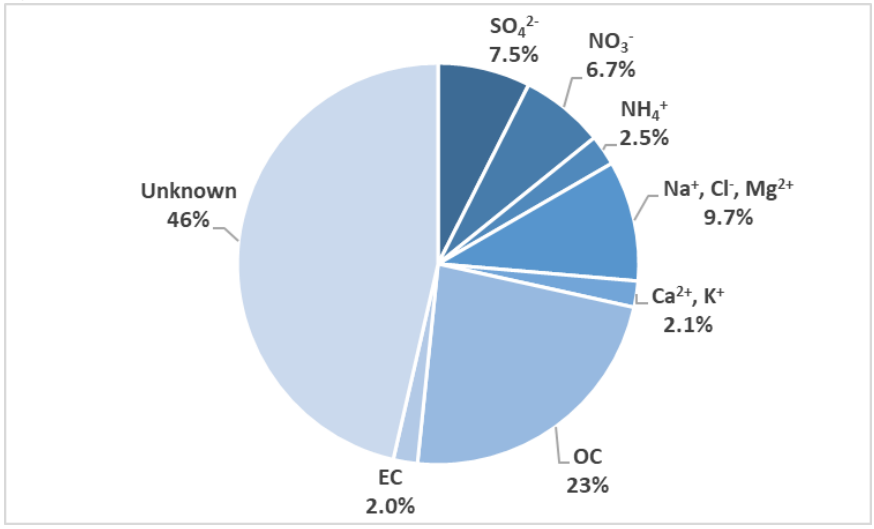
*Table 5.3: Trends in aerosol particle species fractions of PM_{10} and $PM_{2.5}$ mass concentration using Mann-Kendall test and Sen slope estimates, *significant level 0.05. Only statistically significant results are shown in the table.*

Site	Species/Fraction	Year		Change (%)
Birkenes	SO_4^{2-} to PM_{10}	2001 – 2020	*	-40%
	ΣNa^+, Cl^-, Mg^{2+} to PM_{10}	2001 – 2020	*	157%
	EC_{PM10} to PM_{10}	2001 – 2020	*	-29%
Hurdal	SO_4^{2-} to PM_{10}	2001 – 2020	*	-54%
	NO_3^- to PM_{10}	2001 – 2020	*	-77%
	NH_4^+ to PM_{10}	2001 – 2020	*	-77%
	OC_{PM10} to PM_{10}	2001 – 2020	*	27%
	EC_{PM10} to PM_{10}	2001 – 2020	*	-41%
	$OC_{PM2.5}$ to $PM_{2.5}$	2001 – 2020	*	33%
Kårvatn	NO_3^- to PM_{10}	2001 – 2020	*	-90%
	NH_4^+ to PM_{10}	2001 – 2020	*	-81%

a) Birkenes



b) Hurdal



c) Kårvatn

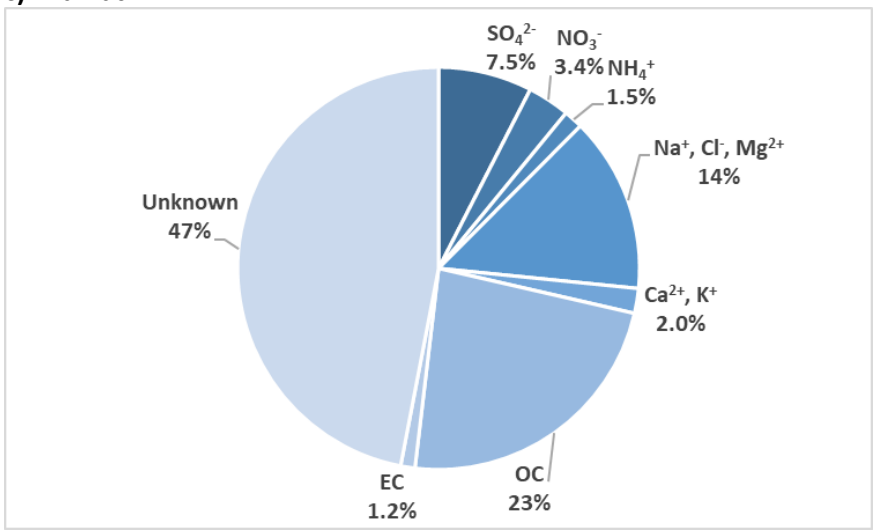


Figure 5.3 Annual mean chemical composition of PM_{10} at the Birkenes Observatory a), the Hurdal site b) and the Kårvatn site c) for 2020. The annual mean mass concentration for PM_{10} in 2020 was 5.2 µg/m^3 at the Birkenes Observatory, 4.1 µg m^{-3} at the Hurdal site and 2.9 µg/m^3 at the Kårvatn site.

5.6 Particle number concentrations

The annual mean particle number concentration for the size range in particle diameter 0.02 < *Dp* < 10 µm (N_{Tot}) at Birkenes for 2020 was slightly lower (9%) 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} (0.02 < *Dp* < 0.1 µm) (5% lower) and the accumulation mode particles N_{Acc} (0.1 < *Dp* < 1.0 µm) (22% 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 µm) size fraction could not be established for the entire year of 2020 due to problems with the optical particle counter. The missing N_{Cm} data on have no detectable influence on determining N_{Tot}.

79% of N_{Tot} was attributed to N_{UF} and 21% to N_{Acc} at Birkenes for 2020, whereas the fraction associated with particles in the range 1.0 – 10 µm, i.e. the coarse mode, could not be established. However, the fraction of particle number in the coarse mode is 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 2020.

No significant upward or downward trends were calculated for N_{Tot}, N_{Acc}, N_{Uf}.(Figure 5.4).

Table 5.4: Number concentrations for ultrafine, accumulation mode and coarse mode particles at Birkenes for 2010 – 2020 and their relative share to the total concentration. Unit: cm^{-3}.

Year	Ultrafine particles		Accumulation mode particles		Coarse mode particles		Total concentrations
N (cm^{-3})	(***Dp*** **<0.1µm)**	(%)	**(0.1 µm <** ***Dp*****.< 1.0 µm)**	(%)	**(1.0 µm <** ***Dp*** **< 10 µm)**	(%)	**(*Dp* = 0.02 – 10 µm)***
2010	973	73	362	27	0.256	0	1336
2011	1047	74	371	26	0.565	0	1418
2012	889	77	263	23	0.375	0	1152
2013	1020	77	304	23	0.391	0	1324
2014	1279	74	456	26	0.338	0	1735
2015	1326	77	390	23	0.340	0	1717
2016	1063	75	357	25	0.392	0	1421
2017	943	78	272	22	0.267	0	1216
2018	1151	72	444	28	--	--	1596
2019	1049	77	321	23	--	--	1370
2020	1021	79	275	21	--	--	1296

*The total concentration for the period 2018-2020 includes only particles in the size range 0.02 – 1 µm.

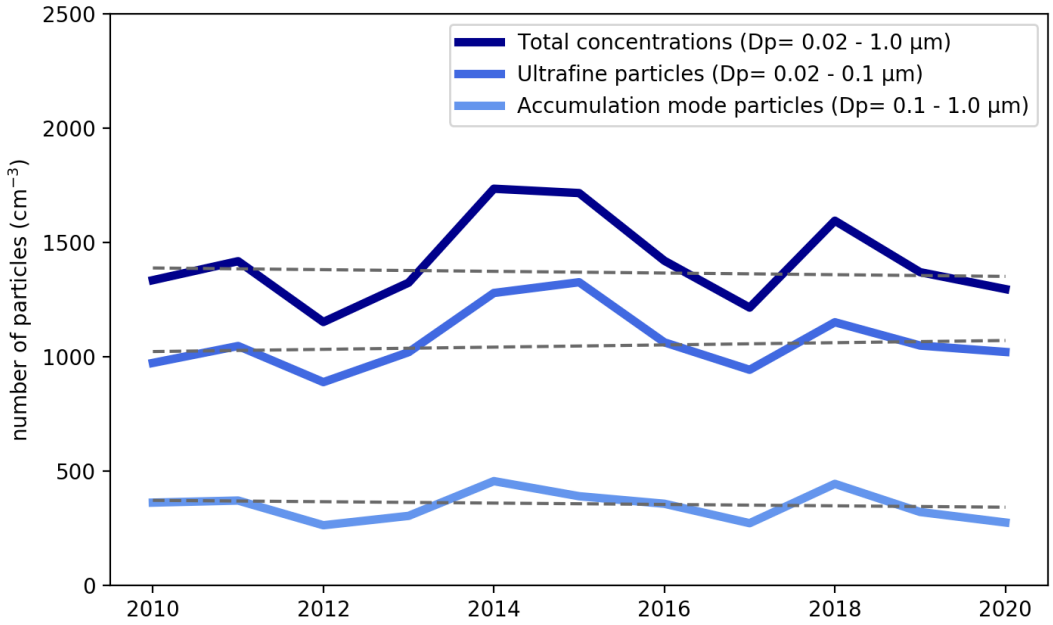


Figure 5.4: Trends in size distribution at Birkenes, 2010-2020. Dashed line indicate the non-significant Sen slopes

5.7 Summary

Observed annual mean concentrations of PM_{10} and $PM_{2.5}$ in the Norwegian rural background environment are amongst the lowest in Europe (< 5.2 µg/m^3). For the first time in 20 years of measurements, $PM_{10-2.5}$ was the major fraction of PM_{10} at Birkenes on an annual basis. International and national limit values and air quality guidelines were not violated on an annual basis in 2020. At the Birkenes Observatory, the 24-hour EU and national limit values for PM_{10} were exceeded twice, thus the allowed number of exceedance days were not violated, although causing a violation of the 24-hour WHO and national air quality guidelines.

Organic matter (27–40%) was the major fraction of PM_{10} at all sites, followed by sea salt aerosol (SSA) (9.7-25%) and secondary inorganic aerosol (SIA) (12-25%) at Birkenes, SSA at Kårvatn and SIA at Hurdal, whereas a 13% contribution from mineral dust was estimated at the Birkenes Observatory. The SIA and sea salt aerosol contribution were substantially higher at the southernmost site Birkenes due to the proximity to major anthropogenic emission regions in continental Europe and to the sea, respectively. Estimates based on levoglucosan measurements suggest that biomass burning contributed 4-9% to PM_{10} and $PM_{2.5}$ at Birkenes annually.

There was a significant downward trend for PM_{10} (-35%) (2000-2020) at Birkenes and for $PM_{2.5}$ at Birkenes (-51%) (2001-2020) and Hurdal (-43%) (2010-2020), which is in line with emission reductions of primary and secondary sources in Europe.

6 Ground-level ozone

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

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

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

The health effects 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 2020.

St.nr.	Station name	Period	Data capture
NO0043	Prestebakke	01.01.20-31.12.20	97%
NO0056	Hurdal	01.01.20-31.12.20	99%
NO0489	Haukenes	01.01.20-31.12.20	94%
NO0002	Birkenes II	01.01.20-31.12.20	99%
NO0052	Sandve	01.01.20-31.12.20	99%
NO0039	Kårvatn	01.01.20-31.12.20	92%
NO0015	Tustervatn	01.01.20-31.12.20	100%
NO0042	Zeppelin (Ny-Ålesund)	01.01.20-31.12.20	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 $\mu g/m^3$ throughout the year and is typically highest in spring. On top of this baseline level, episodes with long-range transport of more polluted air masses increase the ozone levels regularly during the summer season. During winter the situation is the opposite, i.e. the transport of polluted air masses from the European continent leads to reduced ozone levels due to the titration reaction $O_3 + NO \rightarrow NO_2$. This difference between winter and summer is explained by the intensity of the solar UV-radiation which leads to a fast photochemistry in summer and a corresponding slow and inefficient photochemistry in winter.

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

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

6.3 Norwegian ozone levels in 2020

Time series of daily maximum ozone values through 2020 are given in Figure 6.1 together with the climatological mean seasonal cycle (30 days running mean) based on previous years of data (2000-2019). The time series indicate that 2020 was a year with few episodes overall. Most sites show a narrow peak by the end of June and some longer periods with elevated levels in August. The peak levels were, however, fairly moderate and in August the baseline ozone level is at a minimum meaning that episodes on top of this baseline will also be low compared to air quality guide lines.

The June episode was linked to the establishment of a high-pressure area over southern Scandinavia in the last part of the month followed by an approaching low-pressure system with a passing cold front by the end of the month setting up southerly winds that brought polluted and chemically exposed air masses into the country. This is a very common weather pattern associated with elevated surface ozone levels in Norway. The peak levels during this short episode was, however, minor and well below 150 µg/m^3. The annual peak ozone level (134 µg/m^3) was observed in August which is very unusual since this is the time when the hemispheric baseline level is very low. These daily maximum levels indicate an almost complete lack of ozone episodes until the minor June episode.

The smoothed seasonal cycles (14 days' running mean) in ground-level ozone in 2020 are shown in Figure 6.2 together with the climatological mean seasonal cycles for the period 2000-2019 for each site. These timeseries show several interesting patterns:

- As discussed above, the timeseries show few episodes through the year.
- Additionally, the mean levels lie substantially below the 2000-2019 climatology in March-July.
- Finally, the mean levels in Jan-Feb are considerably higher than the climatology.

The last point reflects the unusual weather conditions these months (as discussed in the meteorology chapter) with very persistent westerly winds bringing marine unpolluted, background air masses into the country. In mid-winter polluted air masses typically show reduced ozone levels due to the titration effect between NO and O_3. The consistently low ozone levels during the following months (March/April-July) is likely a combined result of the generally reduced precursor emissions in Europe compared to the 2000-2019 reference and the reduced emissions linked to the Covid-19 lockdown that started in mid-March in most European countries. Then, on top of this, the general weather conditions during the summer half year was not favorable for ozone formation which resulted in a low number of episodes.

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 2020 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.

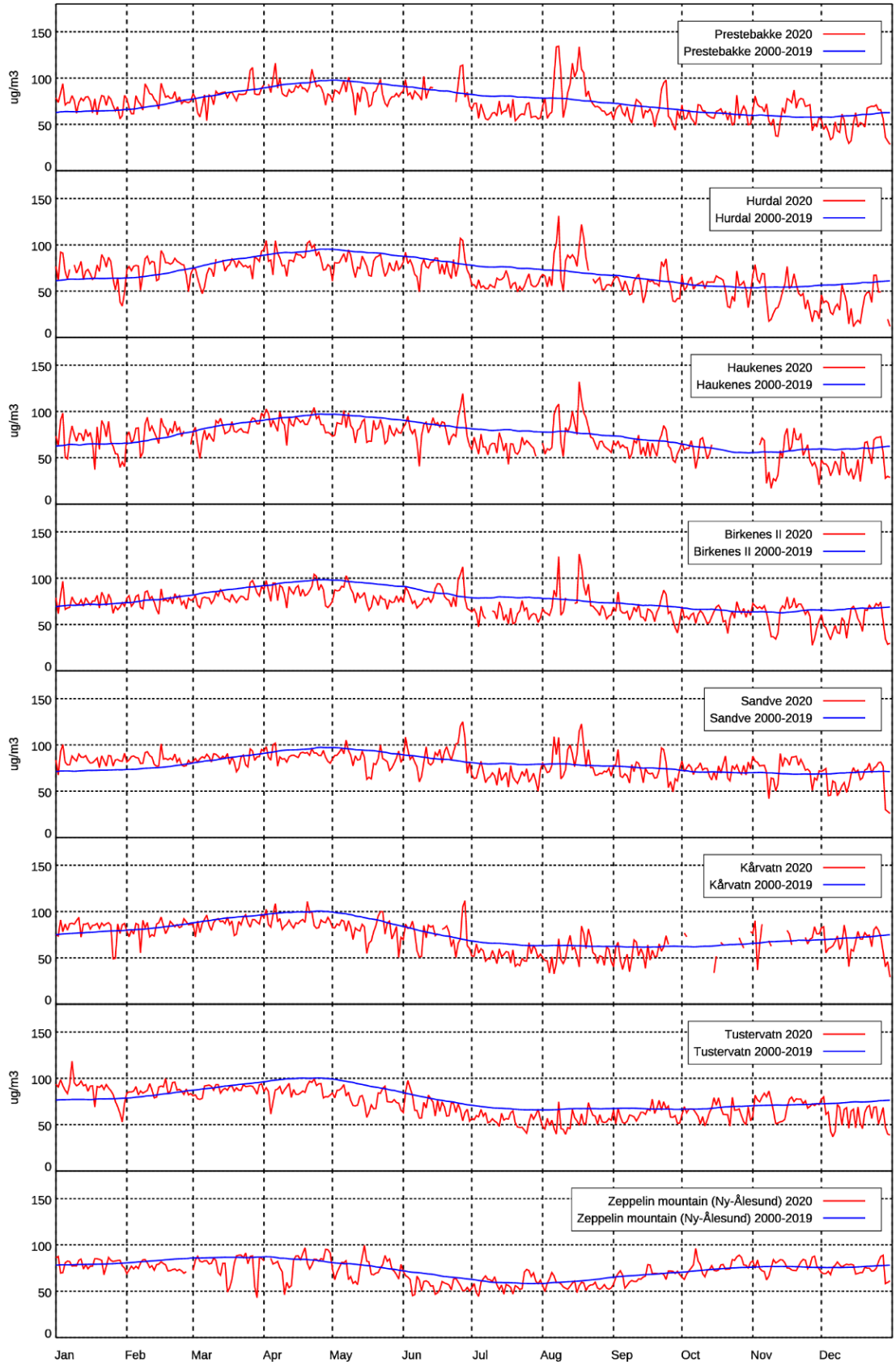


Figure 6.1: Daily maximum ozone concentrations in 2020 (red) together with the 30 days' running mean of the daily maxima for the years 2000-2019 (blue).

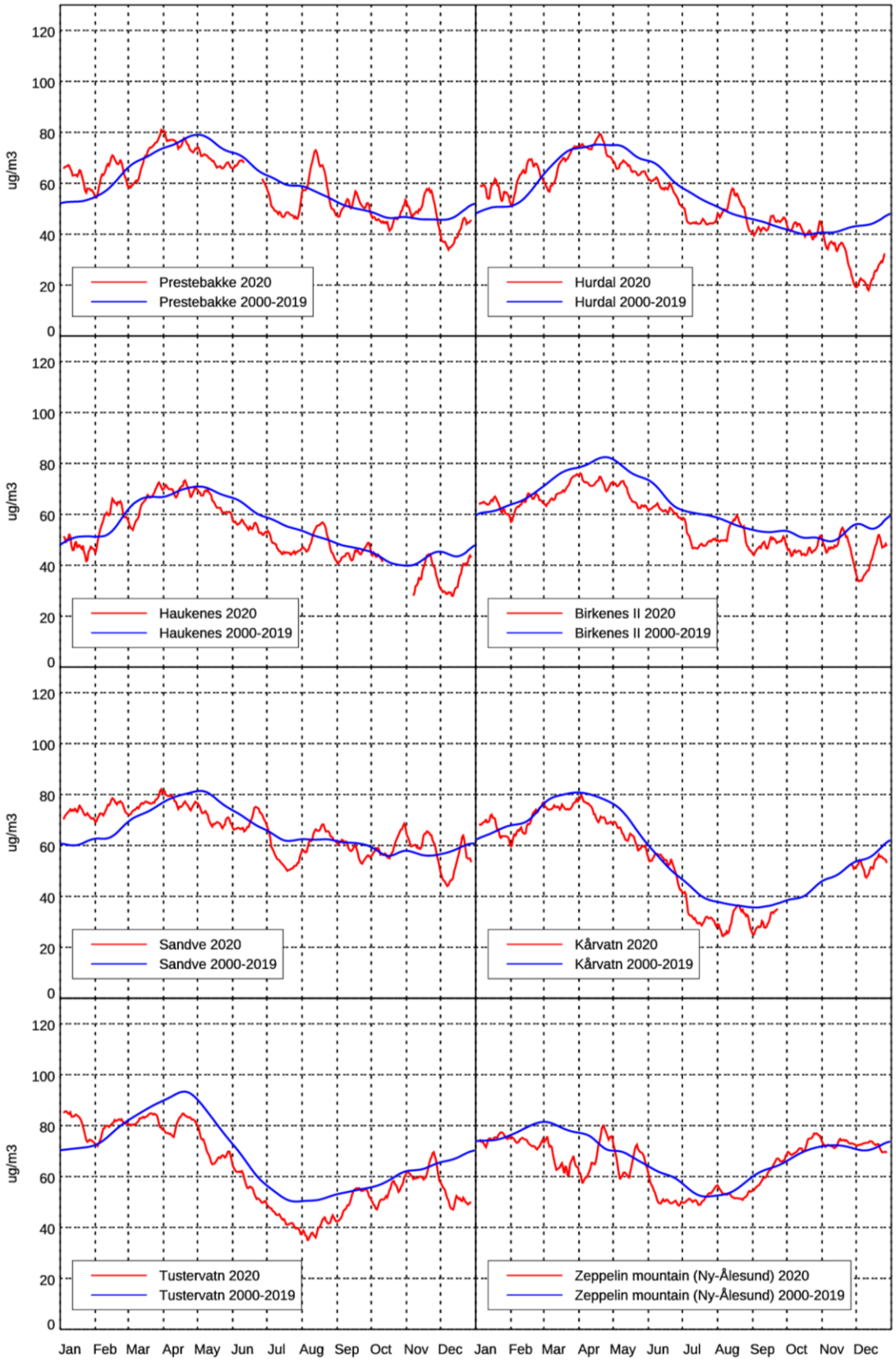


Figure 6.2: The 14 days' running mean ozone concentrations in 2020 (red) together with the corresponding mean concentrations based on all years 2000-2019 (blue).

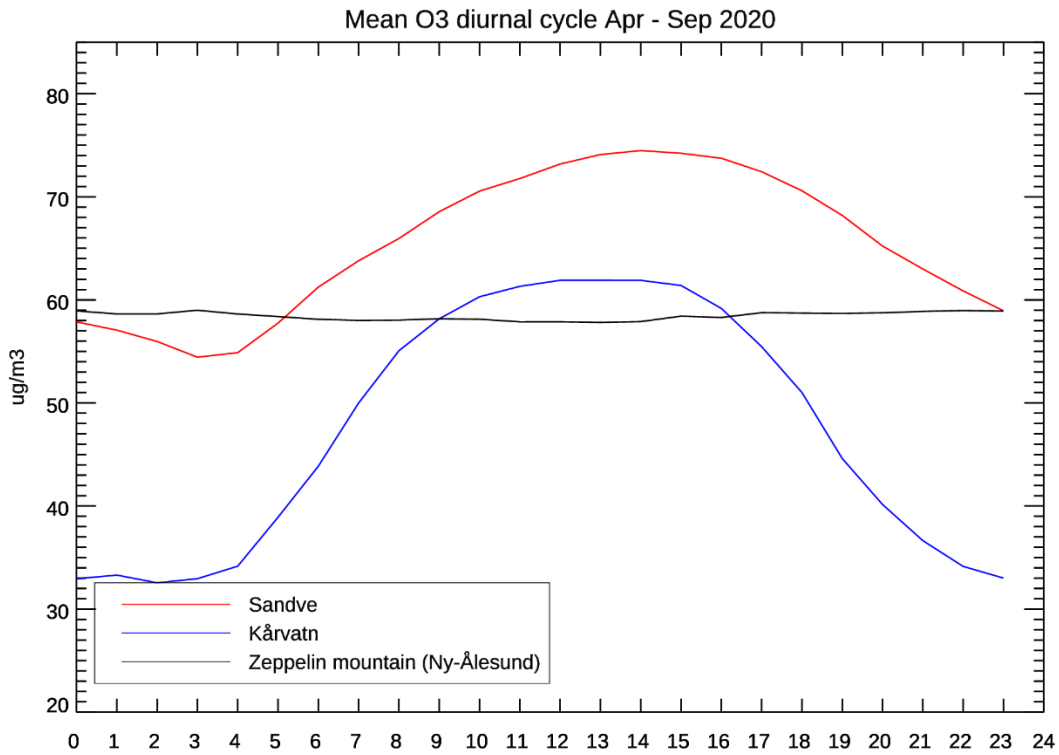


Figure 6.3: The mean diurnal cycle in ozone at three of the monitoring sites; Sandve, Kårvatn and Zeppelin Mountain during April-September 2020.

6.4 Exceedances of the limit values for protection of human health

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

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

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

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

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

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

Table 6.3: For all sites in 2020 the number of hours with data and the number of days with at least 75% data capture together with the exceedances of health related air quality limits; national air quality guidelines, WHO guideline and EU's limit values as given in Table 6.2 as well as the annual maximum and the date when it occurred.

			National AQ guidelines		WHO	EU directive			
Station	Hours	Days	Days	Hours	Days	Days	Hours	Max. hourly value (µg/m^3)	Date
		>75%	8h > 80 µg/m^3	1h > 100 µg/m^3	8h > 100 µg/m^3	8h > 120 µg/m^3	1h > 180 µg/m^3		
Prestebakke	8525	359	97	112	15	3	0	134	08.08.2020
Hurdal	8676	366	70	49	6	0	0	131	08.08.2020
Haukenes	8247	348	79	37	3	0	0	132	17.08.2020
Birkenes II	8665	365	65	48	5	1	0	126	17.08.2020
Sandve	8738	366	147	62	5	0	0	125	27.06.2020
Kårvatn	8105	352	119	39	4	0	0	112	28.06.2020
Tustervatn	8741	366	118	5	2	0	0	118	08.01.2020
Zeppelin	8723	366	86	0	0	0	0	100	15.05.2020

EU's information threshold (hourly value > 180 µg/m^3) has not been exceeded since 2006 and in 2020 the highest hourly ozone level was 134 µg/m^3. Only two years (2012 and 2013) have had a lower annual maximum level than this.

EU's target value for the protection of human health are met in Norway with a very good margin. The long-term objective (=LTO, i.e. max 8h value < 120 µg/m^3) and thereby also WHO's and Norwegian air quality guidelines is on the other hand exceeded to a variable extent every year. In 2020 the LTO was exceeded at only two stations: Prestebakke and Birkenes. The highest number of days with exceedances was seen at Prestebakke with 3 days.

The WHO guideline was exceed at all sites except Zeppelin Mountain in 2020. This reflects that the WHO guideline level of 100 µg/m^3 as an 8-hours mean is close to the baseline level, implying that a small change in the mean level will lead to a large change in the number of days with exceedances.

The ozone levels and exceedances vary strongly from year to year which is also indicated by Figure 6.4, showing the number of days with exceedance of the 8-hour mean value of 120 µg/m^3 for the period 2000-2020. Table 6.4 gives the annual peak values and number of days with exceedance of the LTO from 2006 to 2020. The main reason for the inter-annual variations is variations in the large-scale weather conditions from one year to another. Over time, long-term changes in the European emissions of NOx and VOC as well as gradual trends in the hemispheric baseline level of ozone will be important.

Table 6.4: The annual maximum hourly ozone concentration and the number of days that EU's long-term objective was exceeded during 2006-2020 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	2020
Annual hourly max. (µg/m^3)	186	139	160	142	145	168	130	124	147	148	140	135	148	165	134
Number of dates with exceedance of EU's long-term objective of 120 µg/m^3 [a)]	28	8	16	9	3	12	2	2	4	2	4	1	22	17	3

[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 exceeded in the last five years. As shown in Figure 6.4, this limit value has been exceeded at all stations the last five years.

The updated national guidelines (FHI, 2013) are even stricter than the WHO guideline (Table 6.2) and the 80 µg/m^3 (8-h mean) and 100 µg/m^3 (1-h mean) were exceeded for long periods of the year in the whole country as shown by Table 6.3 except for the Zeppelin Mountain which had no ozone levels above 100 µg/m^3 in 2020.

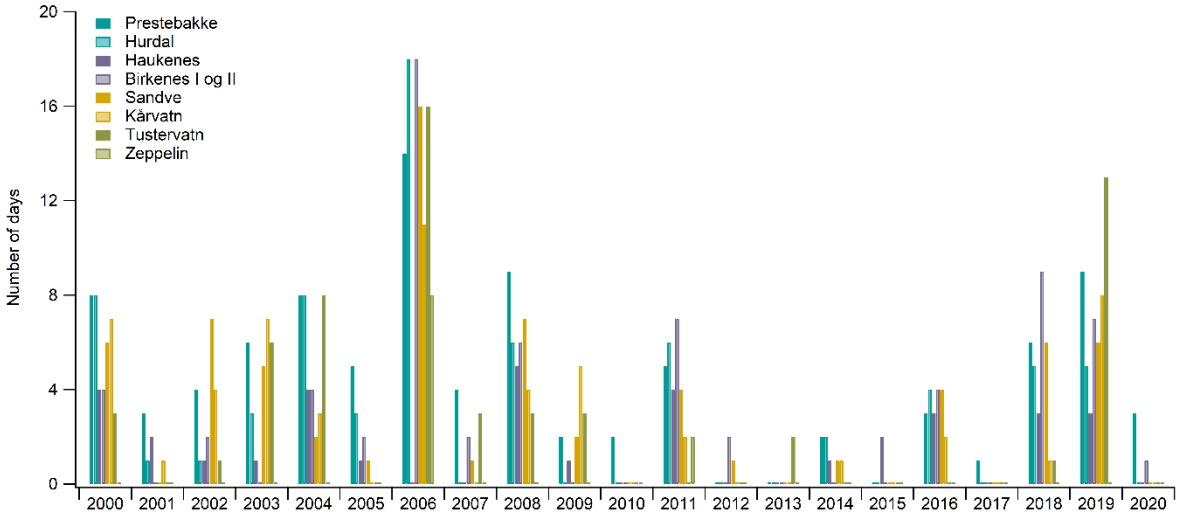


Figure 6.4: The number of days with a maximum daily 8-h mean ozone concentration above 120 µg/m^3 for the period 2000-2019. Note that the Birkenes site has been moved, and data before 2010 refer to the old location. See text for more explanations.

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 µg/m^3) and the parameter is termed AOT40 ("Accumulated exposure over the threshold of 40 ppb") as listed in Table 6.5. AOT40 is calculated as the sum of the differences between the hourly mean concentration and 40 ppb for each hour where the ozone concentration exceeds 40 ppb during a certain pre-defined growing season.

EU's air quality directive (EU, 2008) includes both a target value and a long-term objective for a 3-months AOT40 value relevant for semi-natural vegetation (Table 6.5). UN-ECE (the Mapping Manual published by Mills et al., 2017) also provides 3-months critical levels for agricultural crops and semi-natural vegetation as well as a 6-months critical level for forests.

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

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

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

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

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

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

Table 6.6 shows the 3-months AOT40 values based on the definition in the EU directive (08:00-20:00 CET) for the period 1 May – 31 July 2020. Figure 6.5 shows the same 3-months AOT40 value for the years 2000-2020. EU's target value of 9000 ppb hours has not been exceed for many years in Norway. The long-term objective of 3000 ppb hours was not exceeded in 2020 and the values were substantially below this limit value at all stations (Sandve was highest with 1508 ppb hours).

Table 6.7 shows the 6 months AOT40 values for forests (April-September) 2020 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 Figure 6.6 . The critical level of 5000 ppb hours for forests was not exceeded in 2020. The highest 6-months AOT40 value was seen at Prestebakke with 2952 ppb hours.

Table 6.6: Data capture and 3-month's AOT40 values for vegetation for the period 1 May - 31 July 2020 (unit: ppb hours) according to the definitions in the EU directive.

Station	*Data capture (%)*	*AOT40 (corrected for data capture)*
Prestebakke	90	1134
Hurdal	99	483
Haukenes	98	808
Birkenes II	97	798
Sandve	99	1508
Kårvatn	98	521
Tustervatn	99	258
Zeppelin	99	47

Table 6.7: Data capture and 6-month's AOT40 values for forests for the period 1 April – 30 September 2020 (unit: ppb hours) according to the definitions in UN-ECE's Mapping Manual.

Station	Data capture (%)	AOT40 (corrected for data capture)
Prestebakke	94	2952
Hurdal	99	1409
Haukenes	99	1930
Birkenes II	97	1756
Sandve	99	2766
Kårvatn	97	1483
Tustervatn	99	875
Zeppelin	100	317

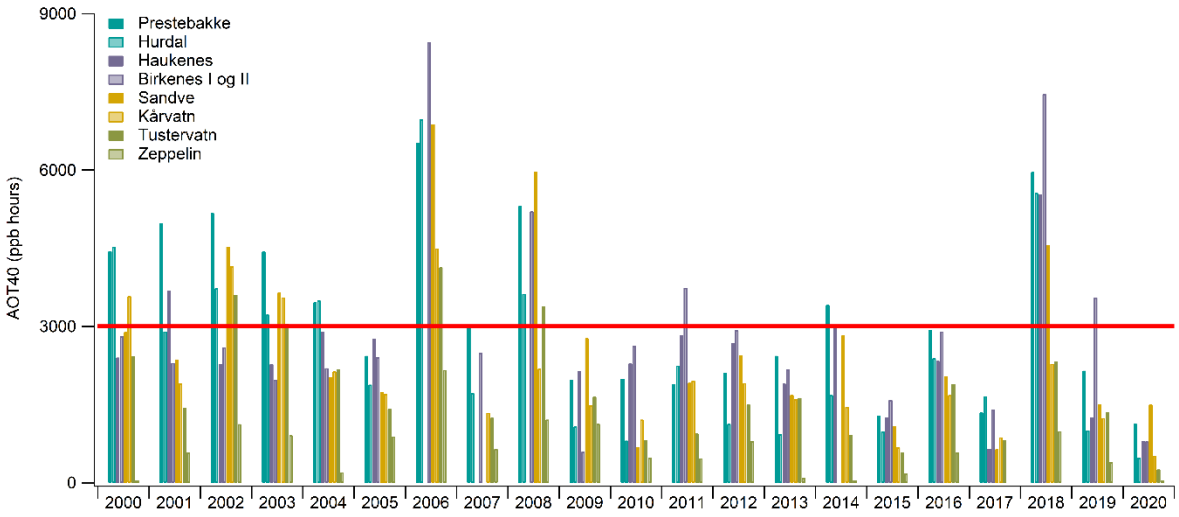


Figure 6.5: 3 months' AOT40 values (1 May - 31 July) for the years 2000 - 2020 (based on UN-ECE's definition of daylight hours). The EU directive's long-term objective of 3000 ppb hours is indicated by the line. Note that the Birkenes site has been moved, and data before 2010 refer to the old location. See text for more explanations.

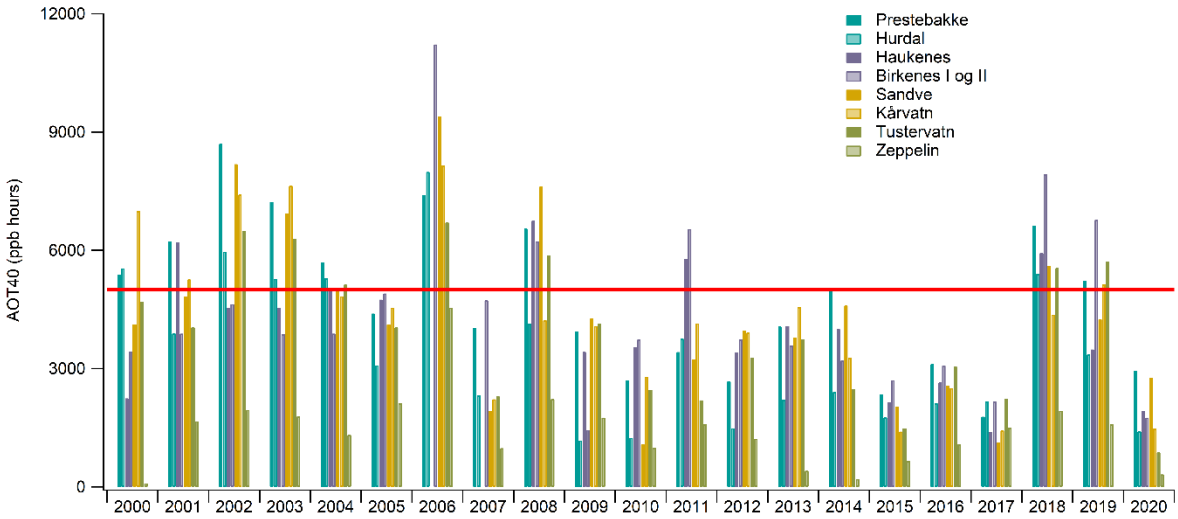


Figure 6.6: 6 months' AOT40 values (1 April - 30 September) for the years 2000 - 2020 (based on UN-ECE's definition of daylight hours, > 50 W/m^2). The critical level for forests (5000 ppb hours) is indicated by the line. Note that the Birkenes site has been moved, and data before 2010 refer to the old location.

6.6 Long-term trends in ground level ozone

Owing to its long atmospheric lifetime the long-term trends of ground-level ozone in Norway are the net result of large-scale trends in the hemispheric baseline level with regional/European effects superimposed. Recent studies of the hemispheric baseline ozone 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 2020; 3-months AOT40 (May-July), the number of days with an 8-h running max exceeding 100 µg/m^3 (WHO guideline) and the 97-percentile of the daily max 8-h running mean April-September. The latter metric corresponds approximately to the annual 4th highest value used in the ozone trend assessment within the EMEP TFMM (Colette et al., 2016) and IGAC TOAR (Tropospheric ozone assessment research) 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, and all are found to be statistically significant (p=0.05) with very consistent rates (2.3-3.0 %/y). A similar pattern is found for the number of days with a maximum 8-h concentration exceeding 100 ug/m^3. This also shows a significant reduction at all sites with rates of 2.4-3.7 %/y. The data also gives a decline in the annual 97 percentile of the daily max 8-h running mean April-September but are found to be statistically significant only for Prestebakke and Kårvatn.

A reduction in high ozone concentrations are expected due to the substantial reduction in European man-made emissions of NOx and VOC the last decades. The analyses shown here are in line with this. The selection of ozone metric, time period, station and the monitoring procedures are, however, crucial for the estimated trend values. Within the IGAC initiative TOAR a long list of various ozone metrics was 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.

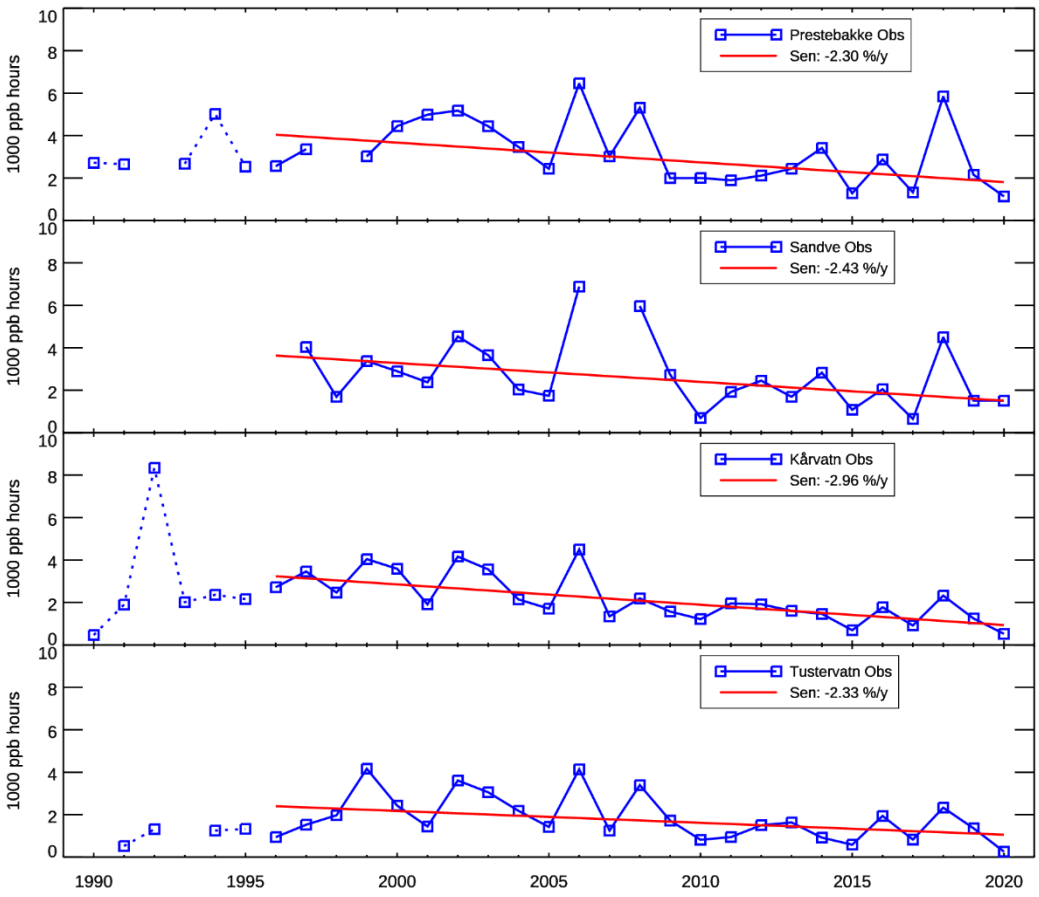


Figure 6.7: *The 3-months AOT40 value according to the EU directive (May - July, hours 8-20 CET) during 1990-2020 for four sites. The estimated Sen's slope based on annual data for 1996-2020 are marked in red. Data from the first years (1990-1995) are uncertain and not included in the trend calculations and marked with a dotted line. Note also that all data from Prestebakke in 1998 were not used due to data quality concerns. The percentage trend value refers to 1995 as the start year.*

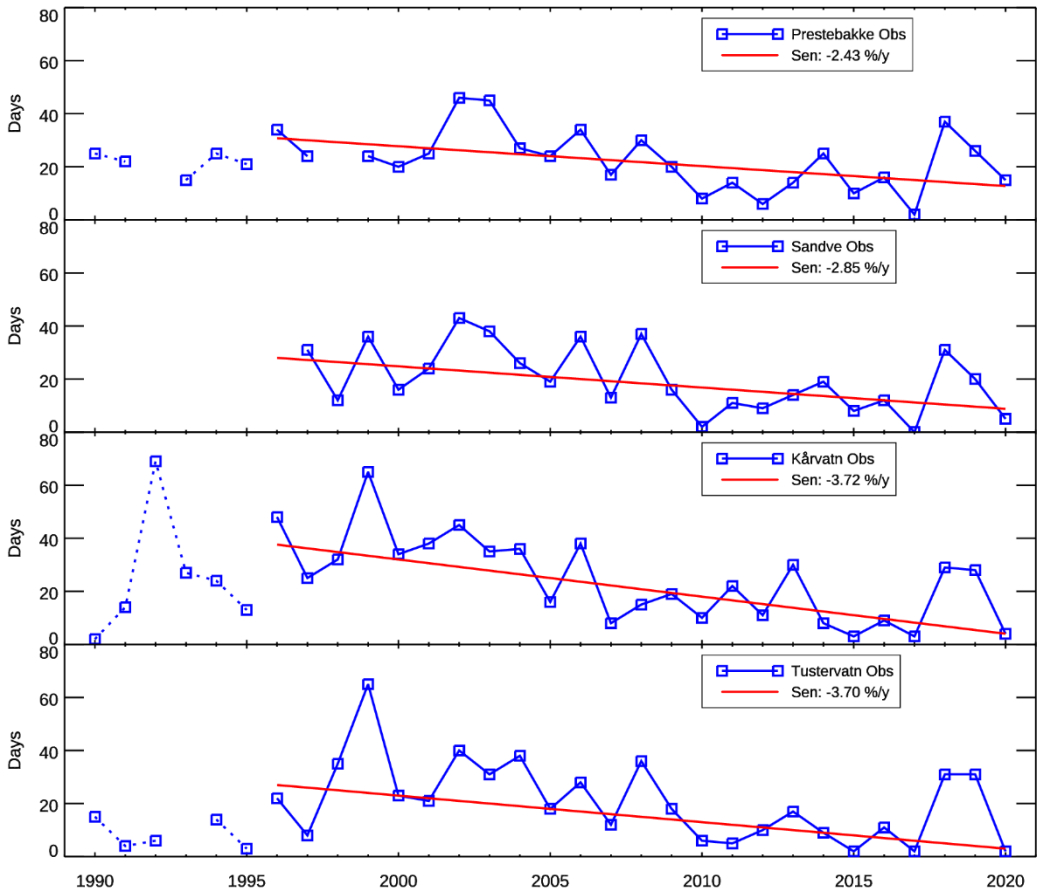


Figure 6.8: Same as Figure 6.7 for the number of days with a maximum 8-h running mean ozone concentration exceeding 100 µg/m^3 (WHO guideline).

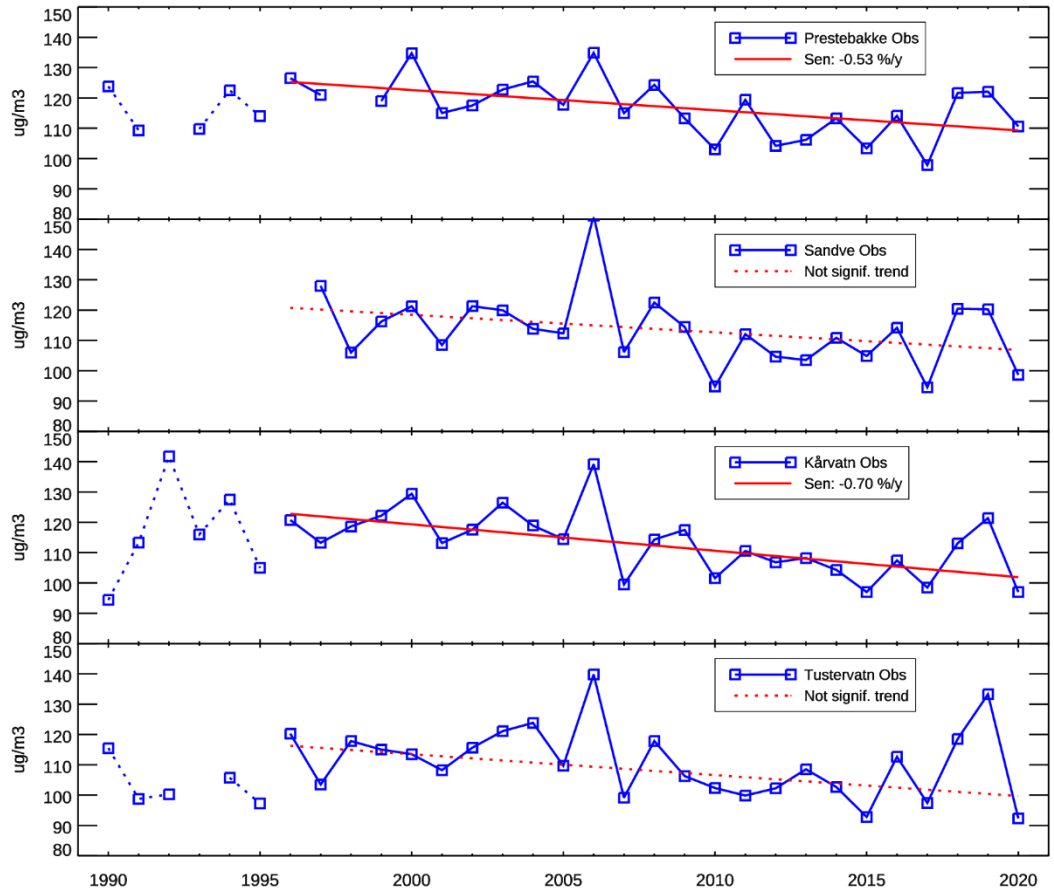


Figure 6.9: Same as Figure 6.7 for the 97-percentile of the daily maximum 8-h running mean ozone concentration April-September.

6.7 Summary

The surface ozone levels in Norway 2020 were characterized by few high episodes, low mean levels during the summer season and higher levels in mid-winter compared to previous years. Neither the critical level for vegetation linked to 3-months AOT40 for plants (May-July) or the 6-months AOT40 for forest (April-September) were exceeded. The highest hourly ozone concentration in 2020 was 134 µg/m^3 (at Prestebakke) which is the third lowest maximum level since the start of the ozone monitoring. EU's long-term objective of max 8-hours daily max of 120 µg/m^3 was exceeded at only 3 days in 2020 and at only 2 sites.

In Norway, the levels of ground level ozone are determined by a baseline-level varying between 50-100 µg/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.

In 2020, the particularly low ozone levels were a net result of few episodes as well as low mean levels during most of the summer season. It is likely that the consistently lower ozone levels seen during March-July is a combined effect of the long-term precursor emission reductions in Europe the last decades and the effect of the Covid-19 lockdown which lead to strong restrictions on the society, in particular on road traffic and air transport. Numerical models are required to quantify these effects for the Norwegian ozone levels in 2020.

7 The October 2020 episode

At the beginning of October 2020, an exceptional air pollution episode was observed in Norway, and elsewhere in northern Europe. Visibility was obscured and reasons for this were discussed in the media. The episode was also clearly visible in records of PM_{10} and $PM_{2.5}$. The EU health limit value of a daily averaged PM_{10} concentration of 50 µg m^{-3} was exceeded at 38 out of 47 urban Norwegian sites and at the one rural background site (Birkenes) performing high time resolution PM_{10} measurements. Daily averaged PM_{10} values reached up to 97 µg m^{-3} and the median value for all sites was 59 µg m^{-3} on 2 and 3 October 2020. The spatial extent of the region with elevated PM concentrations and the similar PM values at background and urban sites indicate that this was an episode of long-range transported air pollution. Indeed, satellite images show that aerosols were not only present near the surface, but also at higher elevations above the cloud layer (Figure 7.1). Also at the Zeppelin observatory (Svalbard), where there are no regular $PM_{2.5}$ or PM_{10} measurements, elevated levels of several pollutants were observed in this period, (with a slight delay compared to the Norwegian mainland). Further analysis of this episode based on surface observations in Norway and at Svalbard and atmospheric transport modelling reveals likely sources of the pollution.

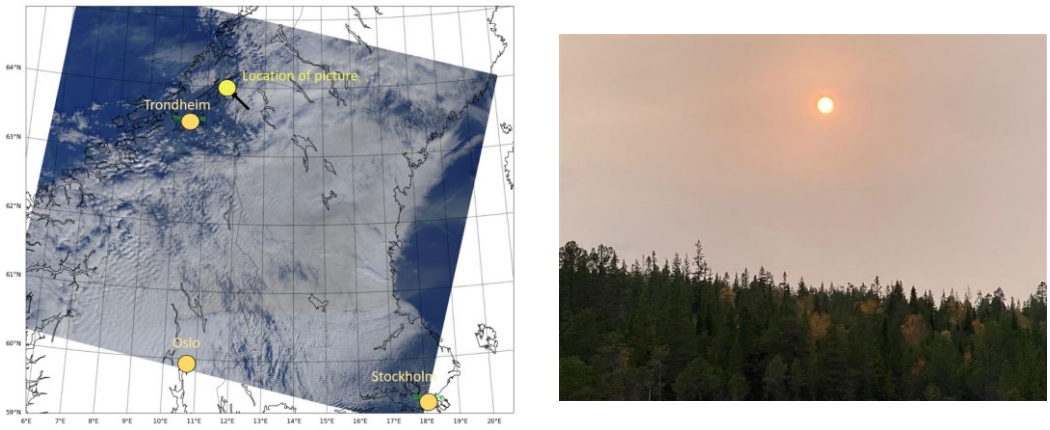


Figure 7.1: RGB (Red, Green, Blue) composite from the Ocean and Land Colour instrument (OLCI) on board the Sentinel-3 satellite. Data from 2 Oct 2020, 09:33 UTC (left) and a picture from the middle parts of Norway, showing the visual effect of the episode 2 Oct 2020, 16:55 UTC (right).

Chemical speciation of weekly samples from rural background stations Birkenes Observatory, Hurdal and Kårvatn and the remote Arctic Zeppelin Observatory, were compared to long-term records for the period September to November of the respective stations. This is visualised in Figure 7.2, where the weekly samples from this episode reach maximum values for PM_{10} and crustal elements and are above 75 percentiles of long-term observations for organic and elemental carbon. The high values of levoglucosan point to a strong contribution of some type of biomass burning, like wildfires. The very high values of crustal elements, which exceed 16 to 30 times the long-term mean of the respective elements, point to the presence of mineral dust.

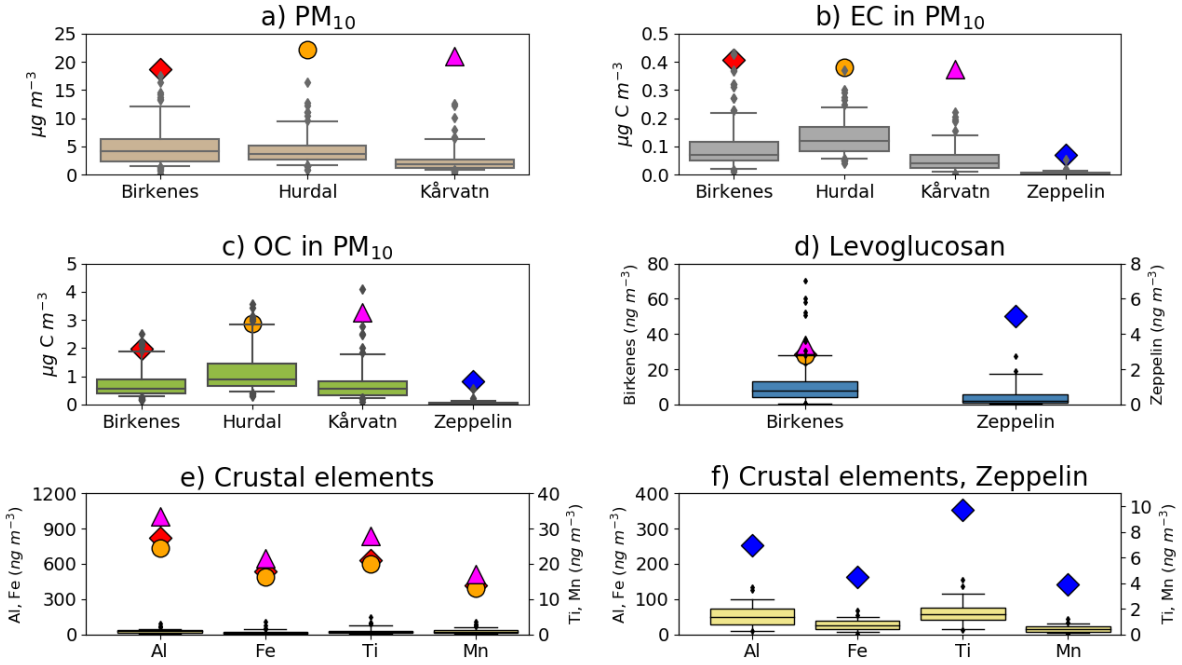


Figure 7.2: Panels show concentrations observed in the October 2020 episode (red diamonds: Birkenes, orange circles: Hurdal, purple triangles: Kårvatn, blue diamonds: Zeppelin) along with box plots (5, 25, 50, 75, 95 percentiles and outliers) at the rural background sites Birkenes, Hurdal and Kårvatn and remote site Zeppelin of weekly data in the period Sept.-Nov. for a) PM_{10} mass concentration (2010-2019); b) Elemental Carbon (EC) in PM_{10} (2010-2019 for Birkenes, 2011-2019 for Hurdal and Kårvatn, 2017-2019 for Zeppelin); c) Organic Carbon (OC) in PM_{10} (similar as for b); d) Levoglucosan in PM_{10} (2010-2019 for Birkenes, 2017-2019 for Zeppelin); Crustal elements in PM_{10} (Long term means for 2014-2019 for Birkenes only); f) Crustal elements in PM_{10} at Zeppelin (2018-2019).

We here aim to quantify the contribution of mineral dust and biomass burning aerosol to the PM_{10} mass concentration. We assume that Al, Fe, Mn and Ti are exclusively associated with mineral dust and that these elements are present as Al_2O_3, Fe_2O_3, MnO and TiO_2 (Alastuey et al., 2016). Besides these, we estimate contributions of SiO_2 based on an empirical factor relative to Al_2O_3 (Alastuey et al., 2016), since Si is not included in the measurements. Finally, CO_3^{2-} is present in different forms and can be associated with both mineral dust and wildfire emissions. We thus calculate both lower (excluding CO_3^{2-}) and upper estimates (including CO_3^{2-}) of mineral dust. With this method, we found that weekly average mineral dust concentrations in PM_{10} ranged from 5.6 to 9.4 μg m^{-3} at rural background sites and from 1.9 to 2.5 μg m^{-3} at the remote Arctic site. This means that mineral dust contributed 25 to 45% to PM_{10} at background sites and 32 to 41% to the reconstructed PM_{10} at the remote site. The elemental ratio could not clearly reveal a specific source region, but was quite similar at all background stations, indicating a common source. We therefore complement the observations with atmospheric transport simulations, for which we used the Lagrangian particle dispersion model FLEXPART (Pisso et al., 2019) in combination with the FLEXDUST emission module (Groot Zwaaftink et al., 2016). These simulations show that a dust plume originating in Central Asia, during a dust storm between 25 September and 3 October, was forced towards northern Europe in between a high-pressure system over Russia and a low-pressure system over Europe (Figure 7.3). There are several natural dust sources in Central Asia that are part of the global dust belt, including the Karakum and Aralkum deserts in Turkmenistan and Kazahkstan, and most of these sources are active between March and October. Transport events of dust from Central Asia to Norway appear to be rarely described.

The FLEXPART modelled surface concentrations of mineral dust at Birkenes were in good agreement with the observations from weekly samples. By comparing a simulation with global dust emissions and a simulation that only included dust emissions in Central Asia, we could estimate that roughly 88% of the surface dust concentrations were due to emissions in Central Asia. This was similar at all rural background stations.

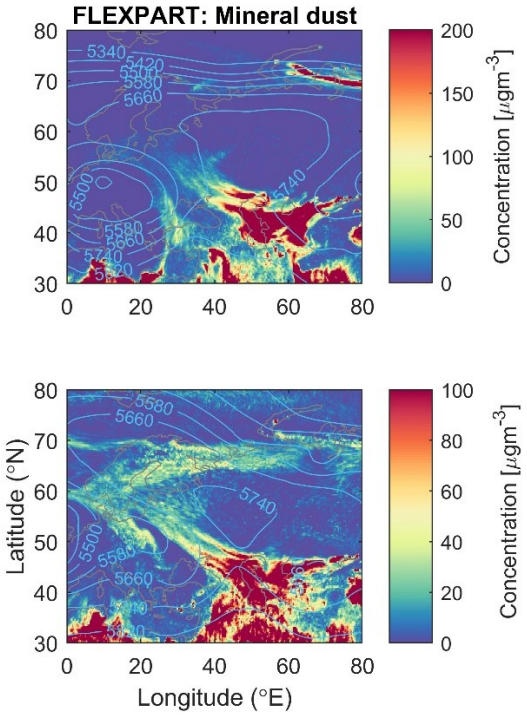


Figure 7.3: Modelled surface concentrations of mineral dust on 27 September (top) and 2 October (bottom). Blue contours: ECMWF 500 hPa geopotential height (m).

Besides the mineral dust, we quantified the influence of biomass burning on the surface PM_{10} concentrations. This was done based on observations of levoglucosan, a biomass burning tracer, and we estimate that 8-21% of weekly PM_{10} concentrations around 2 October 2020 originated from biomass burning contributions. The lowest estimate was calculated for the remote site and was explained by a more pronounced degradation of levoglucosan. At the Birkenes and Zeppelin observatories, we used high time resolution absorption coefficient measurements to derive the fraction of equivalent black carbon explained by biomass burning, seeing values exceeding 150 ng m^{-3} at Zeppelin (Figure 4.1) and close to 700 ng m^{-3} at Birkenes. With backwards simulations of the FLEXPART model at Zeppelin Observatory we can trace back air masses to analyse possible sources.

A so-called footprint (Figure 7.4) shows where air masses may have picked up BC emissions before reaching Zeppelin. In combination with estimates of BC emissions from wildfires in the Copernicus Atmosphere Monitoring Services (CAMS) Global Fire Assimilation System (GFAS) inventory, we could identify relevant sources in the region of Ukraine and southern Russia, where several wildfires were reported during this period. Similar results were obtained for the Birkenes Observatory. Since our modelled BC concentrations at Zeppelin are somewhat lower than the observations, we cannot exclude other sources that are not included in the emission inventory.

This episode thus was an example of a rare combination of independent pollution sources and long-range transport that caused elevated levels of PM_{10} and related poor air quality in Norway.

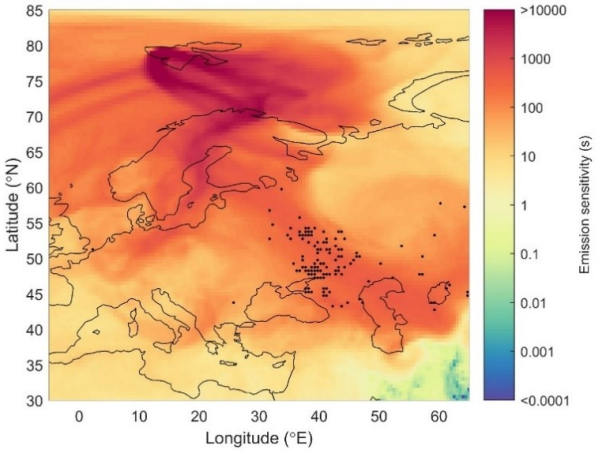


Figure 7.4: BC source-receptor relationship at Zeppelin (2-8 October 2020) as modelled with FLEXPART in backwards mode. The black dots indicate regions with considerable BC biomass burning emissions contributing to BC concentrations at Zeppelin

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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	2020
Birkenes	4.97	5.33	5.24	5.18	5.64	5.31	5.22	5.20	5.23	5.16	5.05	4.74	5.04
Vatnedalen	5.67	5.54	5.44	6.19	5.72	5.31	5.74	5.84	5.83	5.78	5.38	5.05	5.53
Treungen	5.11	5.39	5.27	5.58	5.80	5.24	5.36	5.33	5.07	5.58	5.32	4.81	5.21
Løken	5.11	5.39	5.39	5.53	5.63	5.26	5.44	5.93	5.64	5.32	5.29	4.79	5.19
Hurdal	5.10	5.40	5.24	5.61	5.51	5.26	5.49	5.69	5.41	5.24	5.14	4.90	5.20
Brekkebygda	5.12	5.33	5.26	5.55	5.63	5.25	5.33	5.23	5.41	5.23	5.21	4.99	5.22
Vikedal	5.37	5.45	5.47	6.09	5.63	5.52	5.51	5.83	5.48	5.47	5.49	5.15	5.44
Nausta	5.48	5.45	5.66	5.81	5.46	5.13	5.50	5.36	5.42	5.47	5.51	5.17	5.48
Kårvatn	5.54	5.57	5.46	5.47	5.27	5.43	5.42	5.46	5.71	5.57	5.56	5.60	5.49
Høylandet	5.64	5.73	5.84	5.86	6.21	6.31	5.56	5.30	5.41	5.54	5.55	-	5.62
Tustervatn	5.51	5.62	5.42	5.50	5.67	5.68	5.68	5.41	5.46	5.53	5.51	5.03	5.49
Karpbukt	5.03	4.85	4.86	4.63	4.90	6.05	6.02	4.87	4.82	5.26	4.99	4.78	4.95
Ny-Ålesund	5.98	6.13	5.87	5.92	6.89	5.92	-	6.28	5.63	5.61	5.68	5.75	5.76

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	2020
Birkenes	0.13	0.05	0.12	0.16	0.15	0.18	0.10	0.12	0.16	0.20	0.18	0.24	0.16
Vatnedalen	0.02	-0.01	0.04	0.19	0.19	0.09	0.05	0.10	0.21	0.10	0.04	0.08	0.07
Treungen	0.06	0.03	0.06	0.19	0.10	0.11	0.06	0.08	0.13	0.19	0.05	0.08	0.09
Løken	0.10	0.04	0.11	0.16	0.12	0.12	0.09	0.17	0.13	0.09	0.08	0.13	0.10
Hurdal	0.07	0.05	0.08	0.16	0.10	0.08	0.10	0.14	0.12	0.07	0.09	0.18	0.10
Brekkebygda	0.05	0.03	0.04	0.05	0.06	0.14	0.06	0.11	0.14	0.10	0.07	0.12	0.09
Vikedal	0.03	-0.01	0.09	0.14	0.10	0.19	0.16	0.13	0.08	0.02	0.05	0.04	0.06
Nausta	0.00	0.01	0.06	0.06	0.11	0.57	0.08	0.10	0.05	0.03	0.02	0.02	0.04
Kårvatn	0.00	0.01	0.04	0.02	0.07	0.14	0.07	0.11	0.04	0.03	0.01	0.01	0.04
Høylandet	-0.04*	0.01	0.02	-0.01*	0.20	0.16	0.08	0.07	0.03	0.03	0.01	-	0.02
Tustervatn	0.01	0.03	0.03	0.02	0.07	0.09	0.10	0.07	0.03	0.05	0.01	0.07	0.03
Karpbukt	0.10	0.15	0.23	0.56	0.27	0.49	0.32	0.60	0.43	0.12	0.14	0.07	0.31
Ny-Ålesund	0.27	-0.17	-0.03	0.14	0.88	0.22	-	0.28	0.08	0.13	0.03	0.03	0.11

*negative values caused by uncertainties in sea salt correction

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	2020
Birkenes	0.34	0.16	0.38	0.25	0.25	0.19	0.14	0.23	0.37	0.30	0.34	0.39	0.29
Vatnedalen	0.06	0.03	0.05	0.25	0.54	0.07	0.02	0.06	0.08	0.02	0.04	0.11	0.06
Treungen	0.19	0.11	0.17	0.31	0.15	0.13	0.06	0.15	0.37	0.17	0.09	0.19	0.15
Løken	0.41	0.17	0.35	0.23	0.16	0.12	0.13	0.33	0.20	0.17	0.22	0.28	0.22
Hurdal	0.25	0.16	0.25	0.15	0.14	0.08	0.12	0.25	0.22	0.19	0.25	0.27	0.20
Brekkebygda	0.23	0.17	0.15	0.10	0.09	0.12	0.03	0.15	0.14	0.16	0.18	0.21	0.15
Vikedal	0.13	0.08	0.20	0.25	0.11	0.24	0.07	0.07	0.01	0.05	0.12	0.14	0.11
Nausta	0.05	0.04	0.12	0.10	0.09	0.73	0.05	0.11	0.07	0.06	0.04	0.11	0.07
Kårvatn	0.02	0.02	0.05	0.03	0.06	0.16	0.04	0.06	0.04	0.08	0.04	0.04	0.04
Høylandet	0.04	0.07	0.06	0.06	0.09	0.19	0.03	0.01	0.04	0.02	0.03	-	0.04
Tustervatn	0.02	0.06	0.05	0.03	0.04	0.13	0.05	0.07	0.03	0.07	0.06	0.19	0.05
Karpbukt	0.07	0.13	0.12	0.10	0.07	0.10	0.00	0.13	0.07	0.08	0.09	0.14	0.08
Ny-Ålesund	0.04	0.06	0.06	0.09	0.16	0.12	-	0.19	0.04	0.11	0.06	0.02	0.07

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

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	0.21	0.09	0.32	0.43	0.65	0.31	0.15	0.33	0.42	0.32	0.34	0.32	0.28
Vatnedalen	0.06	0.02	0.02	0.40	0.08	0.05	0.01	0.02	0.01	0.02	0.01	0.01	0.03
Treungen	0.11	0.09	0.14	0.61	0.41	0.15	0.05	0.19	0.38	0.33	0.09	0.06	0.16
Løken	0.31	0.15	0.42	0.47	0.26	0.11	0.19	0.73	0.24	0.22	0.21	0.19	0.23
Hurdal	0.15	0.12	0.20	0.33	0.23	0.08	0.21	0.44	0.32	0.13	0.19	0.22	0.19
Brekkebygda	0.10	0.10	0.06	0.06	0.16	0.14	0.06	0.17	0.17	0.12	0.11	0.13	0.12
Vikedal	0.17	0.09	0.40	1.13	0.24	0.35	0.14	0.11	0.13	0.05	0.17	0.10	0.19
Nausta	0.06	0.04	0.25	0.24	0.21	0.85	0.16	0.18	0.09	0.07	0.05	0.05	0.12
Kårvatn	0.07	0.14	0.12	0.11	0.11	0.21	0.06	0.13	0.09	0.07	0.05	0.02	0.09
Høylandet	0.14	0.13	0.19	0.40	0.98	0.73	0.07	0.03	0.06	0.04	0.10	-	0.17
Tustervatn	0.07	0.08	0.10	0.11	0.24	0.17	0.29	0.15	0.06	0.10	0.10	0.06	0.11
Karpbukt	0.02	0.03	0.13	0.16	0.02	0.02	0.01	0.04	0.10	0.03	0.03	0.04	0.05
Ny-Ålesund	0.05	0.30	0.21	0.07	0.11	0.04	-	0.33	0.04	0.12	0.03	0.02	0.08

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	2020
Birkenes	0.15	0.16	0.15	0.09	0.08	0.18	0.08	0.13	0.26	0.26	0.15	0.12	0.16
Vatnedalen	0.12	0.06	0.17	1.89	1.24	0.10	0.03	0.10	0.33	0.09	0.06	0.09	0.17
Treungen	0.08	0.06	0.07	0.20	0.08	0.10	0.06	0.08	0.11	0.27	0.06	0.05	0.10
Løken	0.19	0.13	0.15	0.32	0.27	0.16	0.06	0.17	0.24	0.13	0.12	0.07	0.14
Hurdal	0.08	0.09	0.10	0.17	0.11	0.09	0.12	0.25	0.12	0.10	0.08	0.08	0.10
Brekkebygda	0.11	0.10	0.09	0.27	0.15	0.13	0.04	0.07	0.15	0.11	0.08	0.10	0.10
Vikedal	0.25	0.22	0.17	0.30	0.27	0.21	0.23	0.50	0.22	0.18	0.15	0.08	0.21
Nausta	0.15	0.12	0.12	0.13	0.12	0.54	0.06	0.09	0.09	0.06	0.11	0.03	0.11
Kårvatn	0.16	0.05	0.11	0.11	0.05	0.27	0.09	0.13	0.12	0.22	0.14	0.09	0.11
Høylandet	0.18	0.13	0.12	0.25	0.26	0.76	0.12	0.06	0.13	0.14	0.18	-	0.16
Tustervatn	0.14	0.28	0.10	0.06	0.05	0.18	0.09	0.07	0.07	0.12	0.16	0.11	0.12
Karpbukt	0.13	0.09	0.22	0.29	0.08	0.07	0.04	0.09	0.16	0.24	0.09	0.11	0.14
Ny-Ålesund	0.82	1.77	1.05	2.79	3.34	0.60	-	0.90	0.60	0.62	0.64	0.26	1.00

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	2020
Birkenes	0.07	0.11	0.08	0.08	0.09	0.08	0.03	0.08	0.18	0.09	0.08	0.09	0.09
Vatnedalen	0.04	0.06	0.12	1.55	0.99	0.10	0.04	0.07	0.33	0.17	0.10	0.11	0.15
Treungen	0.02	0.03	0.02	0.10	0.12	0.07	0.03	0.07	0.04	0.11	0.03	0.02	0.05
Løken	0.09	0.06	0.11	0.17	0.21	0.20	0.06	0.24	0.59	0.09	0.06	0.04	0.12
Hurdal	0.06	0.07	0.07	0.13	0.10	0.11	0.06	0.15	0.09	0.04	0.05	0.04	0.07
Brekkebygda	0.08	0.08	0.05	0.19	0.08	0.12	0.02	0.06	0.07	0.21	0.05	0.15	0.11
Vikedal	0.20	0.22	0.17	0.31	0.15	0.25	0.24	0.53	0.22	0.13	0.10	0.07	0.19
Nausta	0.12	0.11	0.16	0.18	0.13	1.05	0.06	0.08	0.09	0.06	0.10	0.03	0.11
Kårvatn	0.16	0.06	0.10	0.13	0.05	0.14	0.05	0.10	0.16	0.22	0.12	0.05	0.11
Høylandet	0.19	0.08	0.10	0.24	0.35	0.50	0.08	0.06	0.08	0.07	0.13	-	0.14
Tustervatn	0.13	0.09	0.08	0.07	0.05	0.20	0.11	0.10	0.09	0.07	0.15	0.03	0.10
Karpbukt	0.10	0.04	0.13	0.17	0.02	0.03	0.07	0.12	0.11	0.07	0.04	0.09	0.09
Ny-Ålesund	0.28	0.92	0.53	1.77	0.16	0.06	-	0.29	0.07	0.13	0.24	0.09	0.34

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	2020
Birkenes	0.18	0.25	0.23	0.12	0.05	0.08	0.04	0.17	0.36	0.13	0.13	0.18	0.17
Vatnedalen	0.05	0.07	0.06	0.20	0.13	0.02	0.01	0.03	0.07	0.02	0.08	0.02	0.05
Treungen	0.05	0.06	0.06	0.09	0.05	0.03	0.01	0.04	0.03	0.06	0.04	0.03	0.04
Løken	0.14	0.10	0.13	0.07	0.11	0.05	0.03	0.13	0.12	0.06	0.07	0.04	0.07
Hurdal	0.05	0.05	0.07	0.06	0.05	0.02	0.03	0.17	0.04	0.03	0.04	0.02	0.04
Brekkebygda	0.06	0.04	0.04	0.03	0.03	0.03	0.01	0.04	0.03	0.02	0.03	0.01	0.03
Vikedal	0.64	0.62	0.35	0.57	0.24	0.10	0.09	0.16	0.18	0.13	0.13	0.09	0.31
Nausta	0.36	0.30	0.22	0.21	0.26	0.29	0.05	0.06	0.07	0.03	0.20	0.03	0.20
Kårvatn	0.48	0.09	0.28	0.32	0.10	0.07	0.05	0.04	0.05	0.32	0.23	0.09	0.20
Høylandet	0.54	0.22	0.26	0.64	0.44	0.10	0.05	0.06	0.21	0.15	0.37	-	0.33
Tustervatn	0.32	0.25	0.21	0.18	0.11	0.05	0.03	0.03	0.10	0.04	0.35	0.02	0.20
Karpbukt	0.28	0.12	0.33	0.48	0.07	0.02	0.01	0.03	0.07	0.14	0.11	0.25	0.15
Ny-Ålesund	0.94	2.80	1.63	7.56	1.38	0.32	-	0.69	0.30	0.43	0.84	0.34	1.29

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	2020
Birkenes	1.48	2.24	2.15	1.05	0.43	0.54	0.28	1.45	3.02	1.16	1.09	1.44	1.41
Vatnedalen	0.83	1.52	1.13	2.18	2.18	0.25	0.56	0.82	1.06	0.65	0.89	0.68	0.94
Treungen	0.43	0.62	0.58	0.58	0.48	0.14	0.08	0.29	0.20	0.39	0.31	0.19	0.32
Løken	1.09	0.85	1.00	0.38	0.72	0.17	0.16	1.03	0.57	0.49	0.52	0.33	0.52
Hurdal	0.45	0.55	0.73	0.35	0.42	0.09	0.17	1.49	0.38	0.22	0.37	0.17	0.35
Brekkebygda	0.49	0.39	0.34	0.31	0.23	0.06	0.05	0.15	0.19	0.15	0.25	0.25	0.20
Vikedal	5.54	5.84	2.96	4.84	2.09	0.76	0.82	1.20	1.64	1.16	1.20	0.82	2.72
Nausta	3.18	2.55	1.91	1.87	2.22	1.40	0.40	0.44	0.71	0.30	1.77	0.27	1.74
Kårvatn	4.17	0.82	2.36	2.76	0.83	0.43	0.42	0.30	0.59	1.65	2.19	0.80	1.67
Høylandet	5.09	2.04	2.18	5.75	4.04	0.49	0.36	0.57	1.85	1.31	3.16	-	3.05
Tustervatn	2.80	2.19	1.82	1.55	0.98	0.24	0.18	0.13	0.93	0.35	3.19	0.08	1.73
Karpbukt	2.40	1.05	2.58	4.11	0.68	3.18	2.16	1.77	0.44	1.19	0.96	2.11	1.80
Ny-Ålesund	8.10	21.82	11.89	60.79	5.48	1.53	-	4.75	1.75	3.05	6.71	2.63	9.71

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	2020
Birkenes	2.56	3.91	3.59	1.72	0.71	0.92	0.48	2.29	5.73	1.94	1.79	2.51	2.43
Vatnedalen	1.05	1.87	1.37	4.49	2.75	0.20	0.29	0.61	0.94	0.49	1.36	0.75	1.08
Treungen	0.80	1.07	1.02	1.11	0.77	0.25	0.13	0.50	0.33	0.63	0.56	0.37	0.55
Løken	1.89	1.45	1.73	0.68	1.15	0.28	0.29	1.67	0.95	0.88	0.95	0.62	0.91
Hurdal	0.76	0.90	1.18	0.49	0.69	0.17	0.28	2.28	0.62	0.33	0.60	0.32	0.56
Brekkebygda	0.81	0.62	0.49	0.46	0.37	0.11	0.08	0.25	0.31	0.27	0.41	0.37	0.32
Vikedal	9.54	10.28	5.30	7.95	3.43	1.24	1.36	1.96	2.82	1.98	2.06	1.41	4.69
Nausta	5.49	4.74	3.35	3.07	3.69	2.20	0.64	0.70	1.14	0.54	3.10	0.51	3.04
Kårvatn	7.23	1.43	4.18	4.68	1.41	0.75	0.74	0.48	0.97	4.84	3.62	1.40	2.98
Høylandet	8.42	3.52	3.78	9.29	7.10	0.96	0.62	0.85	3.03	2.28	5.40	-	5.08
Tustervatn	4.86	3.79	3.21	2.62	1.64	0.36	0.33	0.22	1.59	0.62	5.47	0.19	2.98
Karpbukt	4.42	1.93	4.72	6.80	0.81	1.60	1.09	0.80	0.79	2.10	1.68	3.69	2.36
Ny-Ålesund	13.37	38.53	20.97	104.95	9.20	2.72	-	7.54	3.00	5.23	11.36	4.47	16.72

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	2020
Birkenes	208	287	149	57	54	171	185	86	110	257	207	514	2286
Vatnedalen	148	240	69	17	32	157	81	76	131	135	143	51	1280
Treungen	86	151	74	18	55	176	156	55	47	267	266	237	1587
Løken	67	87	51	27	25	87	108	24	60	204	89	172	1000
Hurdal	86	90	71	38	37	115	139	58	108	286	177	236	1441
Brekkebygda	59	70	72	19	70	140	157	120	109	251	134	219	1420
Vikedal	507	489	292	107	128	145	341	150	258	315	498	330	3560
Nausta	588	393	388	172	113	6	195	193	348	182	354	113	3047
Kårvatn	207	206	115	246	158	31	176	138	136	104	188	67	1773
Høylandet	358	111	139	98	41	12	149	80	100	37	81	0	1207
Tustervatn	285	102	126	150	71	22	63	63	252	38	163	26	1360
Karpbukt	58	25	26	44	61	19	54	69	48	61	18	19	504
Ny-Ålesund	6	14	14	16	13	13	0	6	45	21	60	20	228

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

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	2228	1333	657530	376	53	835	1082	542	656	1881	1794	9389	21107
Vatnedalen	315	1093495	1805	2315883	669303	25588	736	563870	252684	561120	9028	308	3816
Treungen	668	599	396	48	356	1013	670	1867	402	685	1899	3630	9801
Løken	512	344	9613	80	208	476	387	7705	136	3917	447	2788	6490
Hurdal	687	353	1049	95	3969	626	452	119	423	1652	2227	2931	9175
Brekkebygda	454	311	390	54	2453	785	726	703	426	1483	809	2224	8569
Vikedal	2153	3435	11598	2020319	570634	437	69061	223	2025120	116414	127028	2327	12988
Nausta	1941	2290	847	2362	978	22385	616	836	1315	31933	2372	769	10126
Kårvatn	602	553	401	833	853	116	38374	479	263	277	525	7547	5738
Høylandet	816	45808	5213	134	126383	6	408	425	412	105	3091	0	2931
Tustervatn	885	242	475	5617	151	46	131	244	875	112	505	216	4383
Karpbukt	545	354	360	1042	767	17	52	932	737	336	186	322	5646
Ny-Ålesund	6	11	10597	19	5642	233949	0	3	107	120	53025	64484	395

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

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	27	13	17	9	8	31	18	11	18	51	37	124	363
Vatnedalen	2	-2*	3	3	6	13	4	7	27	14	5	4	88
Treungen	5	5	5	3	5	19	9	4	6	50	14	20	145
Løken	7	4	5	4	3	10	9	4	8	18	7	22	101
Hurdal	6	5	6	6	4	9	14	8	13	21	15	43	149
Brekkebygda	3	2	3	1	4	20	10	14	15	25	9	26	132
Vikedal	13	-7*	25	15	12	28	53	19	20	7	26	12	224
Nausta	2	4	24	10	13	4	16	18	17	5	6	3	120
Kårvatn	0	3	5	6	11	4	13	15	5	3	2	1	68
Høylandet	-13*	1	2	-1*	8	2	11	5	3	1	1	0	21
Tustervatn	2	3	4	4	5	2	6	4	8	2	1	2	44
Karpbukt	6	4	6	25	16	9	17	41	21	7	3	1	157
Ny-Ålesund	2	-2*	0	2	11	3	0	2	3	3	2	1	25

*negative values caused by uncertainties in sea salt correction

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

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	70	45	56	14	14	33	26	20	41	76	71	199	664
Vatnedalen	8	7	4	4	17	10	1	4	10	2	5	6	81
Treungen	16	17	12	6	8	22	10	8	17	46	25	45	233
Løken	28	15	18	6	4	10	14	8	12	35	19	49	217
Hurdal	22	14	18	6	5	9	17	15	24	54	44	63	290
Brekkebygda	14	12	11	2	6	16	5	18	15	41	24	46	210
Vikedal	67	39	58	27	14	34	24	11	3	16	57	47	396
Nausta	27	16	47	17	10	5	9	20	24	10	16	12	212
Kårvatn	4	4	5	8	9	5	6	8	5	9	8	2	74
Høylandet	13	8	8	6	4	2	4	1	4	1	2	0	53
Tustervatn	6	6	6	5	3	3	3	5	8	3	10	5	63
Karpbukt	4	3	3	4	4	2	0	9	3	5	2	3	42
Ny-Ålesund	0	1	1	1	2	2	0	1	2	2	4	0	16

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

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	44	26	47	25	35	52	28	28	46	83	70	163	646
Vatnedalen	9	4	1	7	3	8	1	2	1	3	1	1	41
Treungen	9	13	11	11	22	25	8	10	18	88	23	14	253
Løken	21	13	21	13	6	10	20	17	14	46	19	33	233
Hurdal	13	10	14	12	9	10	29	26	34	36	34	51	277
Brekkebygda	6	7	4	1	11	19	9	21	19	30	15	29	172
Vikedal	84	43	115	121	30	51	49	16	34	15	85	32	683
Nausta	35	16	98	42	24	5	32	34	32	12	19	6	355
Kårvatn	14	29	14	26	17	6	11	18	13	7	10	1	167
Høylandet	51	15	27	39	40	9	10	2	6	2	8	0	208
Tustervatn	19	8	13	17	17	4	18	10	15	4	17	2	143
Karpbukt	1	1	3	7	1	0	0	3	5	2	0	1	25
Ny-Ålesund	0	4	3	1	1	0	0	2	2	2	2	0	19

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

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	32	47	22	5	4	30	15	11	29	67	31	60	355
Vatnedalen	18	15	12	32	40	15	3	7	43	13	9	4	211
Treungen	7	10	5	4	4	17	10	4	5	72	15	11	164
Løken	13	11	8	9	7	14	7	4	15	27	11	12	136
Hurdal	7	8	7	6	4	10	17	14	13	29	14	18	148
Brekkebygda	7	7	6	5	10	18	5	9	16	27	10	23	143
Vikedal	124	106	48	32	35	30	77	75	58	56	73	25	740
Nausta	89	46	48	22	14	3	11	17	30	10	37	3	330
Kårvatn	34	9	12	26	7	8	15	18	16	22	27	6	201
Høylandet	66	14	16	24	10	9	18	5	13	5	14	0	196
Tustervatn	40	29	12	9	3	4	5	5	18	5	25	3	159
Karpbukt	7	2	6	13	5	1	2	6	8	15	2	2	69
Ny-Ålesund	5	26	15	44	42	8	0	6	27	13	39	5	229

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

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	14	30	12	5	5	14	6	7	20	23	15	48	199
Vatnedalen	6	13	8	26	32	16	4	5	43	23	14	5	196
Treungen	2	5	1	2	6	12	4	4	2	30	7	5	84
Løken	6	5	5	5	5	18	7	6	35	17	5	7	121
Hurdal	5	6	5	5	4	13	9	9	9	12	9	10	96
Brekkebygda	5	6	3	4	6	16	2	7	8	54	7	32	149
Vikedal	103	105	49	33	19	37	83	79	57	42	51	23	673
Nausta	71	43	61	31	14	7	12	16	32	10	37	3	336
Kårvatn	33	11	11	32	8	4	10	14	21	22	22	3	192
Høylandet	67	9	14	23	14	6	12	5	8	2	11	0	171
Tustervatn	38	9	10	10	3	5	7	7	23	3	24	1	140
Karpbukt	6	1	3	7	1	1	4	8	5	4	1	2	44
Ny-Ålesund	2	13	7	28	2	1	0	2	3	3	14	2	77

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

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	38	73	35	7	3	13	7	15	39	33	27	90	380
Vatnedalen	7	16	4	3	4	3	1	3	9	3	11	1	64
Treungen	5	10	5	2	3	6	2	2	1	16	11	6	67
Løken	9	9	7	2	3	4	3	3	7	12	6	7	70
Hurdal	4	5	5	2	2	3	4	10	5	8	7	5	58
Brekkebygda	4	3	2	1	2	5	2	4	3	6	4	2	37
Vikedal	325	305	103	61	30	14	31	23	47	39	66	28	1092
Nausta	209	117	85	35	29	2	9	11	25	4	71	3	601
Kårvatn	100	17	33	79	16	2	8	6	6	33	44	6	351
Høylandet	193	25	35	63	18	1	7	5	21	6	30	0	403
Tustervatn	92	25	27	27	8	1	2	2	25	2	58	0	268
Karpbukt	16	3	9	21	4	0	1	2	3	9	2	5	74
Ny-Ålesund	6	41	23	120	18	4	0	4	14	9	51	7	295

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

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	308	642	320	59	23	93	51	125	333	297	226	740	3218
Vatnedalen	123	366	78	37	69	39	46	63	138	87	128	34	1208
Treungen	37	93	43	11	26	25	12	16	9	103	84	44	504
Løken	72	75	51	10	18	14	17	25	34	99	47	57	518
Hurdal	39	50	51	13	16	11	24	87	41	63	66	39	497
Brekkebygda	29	27	24	6	16	8	8	18	20	38	34	55	282
Vikedal	2809	2859	863	519	267	110	280	180	423	367	598	270	9673
Nausta	1870	1001	741	320	252	9	78	85	246	55	625	30	5311
Kårvatn	864	169	272	679	132	13	74	41	81	170	413	53	2963
Høylandet	1823	227	302	565	164	6	54	46	186	48	256	0	3676
Tustervatn	798	223	229	231	70	5	11	8	233	13	518	2	2346
Karpbukt	139	27	67	182	41	62	118	122	21	73	18	41	906
Ny-Ålesund	50	316	165	964	69	20	0	29	79	63	404	52	2217

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

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	532	1122	534	98	38	157	88	197	632	498	371	1289	5558
Vatnedalen	155	448	94	77	88	31	24	47	122	67	194	38	1384
Treungen	69	161	76	20	42	44	20	28	15	168	150	86	879
Løken	126	127	88	18	28	24	31	40	57	180	84	106	909
Hurdal	66	81	83	19	26	19	39	133	67	94	106	76	805
Brekkebygda	48	43	35	9	26	15	13	29	34	68	55	81	454
Vikedal	4833	5027	1548	853	439	180	462	294	726	625	1025	466	16703
Nausta	3229	1864	1298	528	419	14	126	135	397	98	1098	58	9263
Kårvatn	1498	295	482	1150	223	23	131	66	133	501	681	93	5275
Høylandet	3016	391	523	913	289	12	92	68	304	84	437	0	6127
Tustervatn	1386	385	405	392	117	8	21	14	400	24	889	5	4050
Karpbukt	256	48	123	300	49	31	59	55	38	128	31	72	1190
Ny-Ålesund	83	558	290	1664	116	35	0	47	136	108	683	89	3818

Table A.1.20: The 10 highest daily wet deposition of sea salt corrected sulfate, 2020.

Site	Date	SO_4 wet dep mgS/m^2	Precip mm'	% av annual SO_4 dep	pH
Birkenes	07.12.2020	28.8	38.2	7.9	4.68
	03.12.2020	14.5	60.8	4.0	4.62
	01.10.2020	12.7	26.4	3.5	5.98
	04.10.2020	11.5	39.0	3.2	5.46
	12.11.2020	10.1	15.9	2.8	4.53
	26.01.2020	9.3	16.3	2.6	4.54
	10.12.2020	8.8	22.3	2.4	4.77
	13.06.2020	8.3	39.3	2.3	5.54
	04.12.2020	8.3	14.8	2.3	4.20
	05.12.2020	8.2	14.5	2.3	4.50
	sum			33.2	
Hurdal	04.12.2020	9.3	10.2	6.2	4.45
	04.10.2020	8.4	25.1	5.6	5.41
	03.12.2020	7.4	11.8	5.0	4.49
	15.11.2020	7.1	36.8	4.8	5.19
	21.08.2020	4.6	36.3	3.1	5.64
	06.12.2020	4.5	8.3	3.0	4.48
	08.12.2020	4.4	16.9	2.9	4.78
	10.12.2020	4.0	11.1	2.7	4.81
	24.09.2020	3.8	17.1	2.5	5.10
	26.07.2020	3.7	20.8	2.5	5.81
	sum			38.4	

Site	Date	SO_4 wet dep mgS/m^2	Precip mm'	% av annual SO_4 dep	pH
Tustervatn	24.09.2020	3.2	25.5	7.2	5.39
	06.02.2020	2.2	8.0	5.1	6.78
	19.01.2020	1.8	84.5	4.0	5.45
	22.07.2020	1.6	17.8	3.6	6.04
	07.07.2020	1.1	6.3	2.5	5.45
	29.06.2020	0.9	13.4	2.0	5.68
	28.05.2020	0.9	11.5	2.0	6.08
	19.08.2020	0.7	1.7	1.7	6.83
	07.04.2020	0.7	6.7	1.7	5.59
	06.11.2020	0.7	36.3	1.7	5.58
	sum			31.3	

Table A.1.20 continued:

Site	Date	SO4 wet dep mgS/m2	Precip mm'	% av annual SO4 dep	pH
Kårvatn	19.08.2020	6.9	24.9	10.1	5.21
	06.07.2020	2.6	27.9	3.8	5.20
	02.08.2020	2.3	45.6	3.4	5.47
	26.05.2020	2.2	1.2	3.2	-
	26.07.2020	1.6	34.6	2.3	5.46
	29.03.2020	1.5	9.1	2.3	5.31
	28.03.2020	1.5	42.3	2.2	5.54
	22.07.2020	1.4	23.9	2.1	5.48
	21.06.2020	1.3	6.7	2.0	5.47
	02.05.2020	1.2	21.1	1.7	5.49
	sum			33.1	

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 1987-2020.

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

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m²	NO_3-N mg/m²	NH_4-N mg/m²	H+ mekv/m²	S mg/m²	N mg/m²
Birkenes	2014	0.31	0.35	0.35	0.16	0.18	4.77	2331	732	813	818	17	71	193
(cont.)	2015	0.18	0.29	0.28	0.15	0.16	4.91	2173	387	633	614	27	48	165
	2016	0.17	0.35	0.29	0.15	0.16	4.91	1414	245	489	414	12	37	133
	2017	0.20	0.31	0.29	0.17	0.14	4.95	2088	408	648	611	11	39	102
	2018	0.20	0.43	0.44	0.14	0.18	4.95	1515	310	655	673	11	49	152
	2019	0.16	0.26	0.24	0.12	0.09	4.99	2010	313	526	481	10	37	109
	2020	0.16	0.29	0.28	0.16	0.17	5.04	2286	363	664	646	9	37	128
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		

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m²	NO_3-N mg/m²	NH_4-N mg/m²	H+ mekv/m²	S mg/m²	N mg/m²
Vatnedalen	2012	0.08	0.13	0.12	0.15	0.04	5.44	828	67	109	95	3		
(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		
	2020	0.07	0.06	0.03	0.17	0.05	5.53	1280	88	81	41	3		
Treungen	1974	0.94	0.38	0.33	0.14	0.07	4.27	1039	977	395	343	56		
	1975	0.91	0.37	0.34	0.15	0.06	4.26	894	814	331	304	49		
	1976	1.05	0.50	0.42	0.11	0.06	4.20	706	741	353	297	45		
	1977	0.81	0.44	0.39	0.11	0.05	4.32	1165	944	513	454	56		
	1978	0.87	0.38	0.41	0.14	0.04	4.21	945	822	359	387	58		
	1979													
	1980	0.88	0.37	0.39	0.14	0.04	4.23	759	668	281	296	45		
	1981	0.86	0.39	0.46	0.12	0.05	4.29	949	816	370	437	49		
	1982	0.84	0.45	0.50	0.14	0.07	4.32	1130	948	504	563	54		
	1983	0.83	0.40	0.43	0.18	0.05	4.35	1091	908	431	471	48		
	1984	0.77	0.36	0.27	0.15	0.05	4.27	1196	919	436	325	64		
	1985	0.68	0.39	0.37	0.13	0.04	4.33	892	608	350	333	41		
	1986	1.07	0.57	0.63	0.14	0.07	4.19	1030	1097	582	650	66		
	1987	0.68	0.37	0.37	0.13	0.07	4.39	1133	768	424	418	46		
	1988	0.75	0.50	0.45	0.10	0.05	4.27	1348	1006	670	612	73		
	1989	0.76	0.61	0.44	0.10	0.06	4.26	754	572	456	329	41		
	1990	0.63	0.42	0.37	0.06	0.07	4.37	1184	747	503	433	51		
	1991	0.59	0.42	0.34	0.13	0.06	4.42	811	480	343	278	31		
	1992	0.60	0.40	0.34	0.08	0.05	4.44	923	556	365	310	33		
	1993	0.59	0.41	0.32	0.11	0.09	4.46	803	472	329	258	28		
	1994	0.54	0.44	0.35	0.08	0.05	4.49	1016	544	448	356	33		
	1995	0.50	0.44	0.40	0.09	0.08	4.48	903	452	394	361	30		
	1996	0.49	0.40	0.37	0.10	0.05	4.49	838	408	335	312	27		
	1997	0.41	0.37	0.32	0.12	0.06	4.56	887	364	330	282	24		
	1998	0.48	0.40	0.41	0.09	0.04	4.53	959	462	386	397	28		
	1999	0.35	0.32	0.31	0.06	0.06	4.67	1329	463	427	406	28		
	2000	0.33	0.36	0.31	0.08	0.07	4.59	1563	510	566	483	40		
	2001	0.30	0.28	0.27	0.05	0.04	4.77	1141	346	324	314	19		
	2002	0.32	0.27	0.28	0.08	0.04	4.79	933	295	251	262	15		
	2003	0.35	0.36	0.35	0.09	0.04	4.67	1002	349	366	350	22		
	2004	0.31	0.30	0.26	0.10	0.06	4.79	1271	393	379	336	21		
	2005	0.34	0.38	0.37	0.11	0.06	4.75	897	308	338	329	16		
	2006	0.23	0.28	0.20	0.09	0.05	4.79	1522	355	433	310	25		
	2007	0.23	0.24	0.18	0.08	0.04	4.82	1006	226	243	178	15		
	2008	0.21	0.28	0.26	0.11	0.08	4.93	1150	239	318	294	13		
	2009	0.21	0.34	0.25	0.07	0.06	4.82	1213	260	408	302	18		

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m²	NO_3-N mg/m²	NH_4-N mg/m²	H+ mekv/m²	S mg/m²	N mg/m²
Treungen	2010	0.28	0.34	0.32	0.07	0.03	4.79	849	241	289	271	14		
(cont.)	2011	0.19	0.26	0.23	0.09	0.05	4.95	1177	227	308	270	13		
	2012	0.15	0.28	0.23	0.07	0.05	4.96	1092	167	307	247	12		
	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		
	2020	0.09	0.15	0.16	0.10	0.04	5.21	1587	145	233	253	6		
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		

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m²	NO_3-N mg/m²	NH_4-N mg/m²	H+ mekv/m²	S mg/m²	N mg/m²
Løken	2007	0.24	0.30	0.28	0.16	0.06	4.92	727	177	216	204	9		
(cont.)	2008	0.19	0.28	0.22	0.13	0.09	4.90	997	192	283	223	13		
	2009	0.17	0.32	0.29	0.11	0.06	5.06	837	140	267	247	7		
	2010	0.23	0.29	0.24	0.12	0.04	4.95	664	150	193	158	8		
	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		
	2020	0.10	0.22	0.23	0.14	0.07	5.19	1000	101	217	233	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

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m²	NO_3-N mg/m²	NH_4-N mg/m²	H+ mekv/m²	S mg/m²	N mg/m²
Hurdal	2018	0.17	0.30	0.31	0.14	0.06	5.04	901	156	270	278	9	29	151
(cont.)	2019	0.14	0.20	0.20	0.13	0.03	5.12	1260	181	254	258	8	23	123
	2020	0.10	0.20	0.19	0.10	0.04	5.20	1441	149	290	277	6	18	96
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		

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m²	NO_3-N mg/m²	NH_4-N mg/m²	H+ mekv/m²	S mg/m²	N mg/m²
Brekkebygda	2016	0.15	0.23	0.24	0.10	0.03	5.01	892	136	209	217	10		
(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		
	2020	0.09	0.15	0.12	0.10	0.03	5.22	1420	132	210	172	6		
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		
	2020	0.06	0.11	0.19	0.21	0.31	5.44	3560	224	396	683	4		

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m²	NO_3-N mg/m²	NH_4-N mg/m²	H+ mekv/m²	S mg/m²	N mg/m²
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		
	2020	0.04	0.07	0.12	0.11	0.20	5.48	3047	120	212	355	3		
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		

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m²	NO_3-N mg/m²	NH_4-N mg/m²	H+ mekv/m²	S mg/m²	N mg/m²
Kårvatn	1986	0.20	0.07	0.13	0.10	0.11	4.95	1277	260	89	162	14		
(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
	2020	0.04	0.04	0.09	0.11	0.20	5.49	1773	68	74	167	3	15	90
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		

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m²	NO_3-N mg/m²	NH_4-N mg/m²	H+ mekv/m²	S mg/m²	N mg/m²
Høylandet	1997	0.14	0.10	0.22	0.17	0.32	5.25	1418	196	145	308	8		
(cont.)	1998	0.12	0.08	0.22	0.13	0.19	5.46	1456	173	123	316	5		
	1999	0.14	0.10	0.27	0.13	0.19	5.41	1195	171	125	342	5		
	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		
	2020	0.02	0.04	0.17	0.16	0.33	5.62	1207	21	53	208	2		
Tustervatn	1973	0.24				0.18	4.94	1336	321			15		
	1974	0.28				0.11	4.88	695	195			9		
	1975	0.25				0.33	4.91	1756	439			22		
	1976	0.27				0.16	4.97	1064	287			11		
	1977	0.30	0.09	0.11	0.17	0.16	4.91	1111	333	100	122	14		
	1978	0.23	0.08	0.10	0.16	0.16	4.85	1128	259	90	113	16		
	1979	0.28	0.08	0.13	0.15	0.11	4.73	1168	327	93	152	22		
	1980	0.27	0.08	0.14	0.47	0.16	4.98	858	229	71	122	9		
	1981	0.18	0.07	0.10	0.21	0.15	5.00	1099	198	77	110	11		
	1982	0.16	0.08	0.09	0.22	0.47	4.98	1385	227	109	121	15		
	1983	0.20	0.06	0.09	0.16	0.22	4.90	1665	337	101	142	21		
	1984	0.24	0.09	0.09	0.12	0.10	4.85	1056	250	94	89	15		
	1985	0.22	0.08	0.10	0.12	0.15	4.93	1344	298	107	132	16		
	1986	0.26	0.09	0.12	0.12	0.15	4.88	1060	278	94	131	14		
	1987	0.22	0.08	0.11	0.12	0.12	4.89	1163	253	98	133	15	96	
	1988	0.13	0.07	0.09	0.13	0.15	5.04	1159	145	83	106	10	88	131
	1989	0.19	0.08	0.10	0.18	0.40	5.00	1825	346	137	178	18	40	119
	1990	0.16	0.09	0.14	0.11	0.21	4.99	1508	245	133	214	16	65	125
	1991	0.17	0.10	0.14	0.14	0.21	5.04	1400	242	137	197	13	62	148
	1992	0.15	0.08	0.15	0.19	0.37	5.12	1507	223	126	221	11	49	123
	1993	0.14	0.08	0.16	0.24	0.50	5.19	1340	182	111	209	9	44	126

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S	NO_3-N	NH_4-N	Ca	Mg	pH		SO_4-S	NO_3-N	NH_4-N	H+	S	N
		mg/l	mg/l	mg/l	mg/l	mg/l		mm	mg/m²	mg/m²	mg/m²	mekv/m²	mg/m²	mg/m²
Tustervatn	1994	0.10	0.08	0.13	0.12	0.15	5.24	1117	114	87	144	6	48	147
(cont.)	1995	0.09	0.06	0.12	0.13	0.21	5.22	1515	136	96	186	9	47	132
	1996	0.12	0.09	0.16	0.15	0.18	5.11	1084	132	97	176	8	44	139
	1997	0.08	0.06	0.18	0.17	0.30	5.34	1528	121	98	271	7	44	199
	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
	2020	0.03	0.05	0.11	0.12	0.20	5.49	1360	44	63	143	3	14	75
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		

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S	NO_3-N	NH_4-N	Ca	Mg	pH		SO_4-S	NO_3-N	NH_4-N	H+	S	N
		mg/l	mg/l	mg/l	mg/l	mg/l		mm	mg/m^2	mg/m^2	mg/m^2	mekv/m^2	mg/m^2	mg/m^2
Karpbukt	2009	0.41	0.12	0.09	0.12	0.20	4.88	526	218	64	47	7		
(cont.)	2010	0.30	0.07	0.07	0.12	0.21	4.83	595	178	45	43	9		
	2011	0.38	0.11	0.15	0.12	0.15	4.76	553	212	61	85	10		
	2012	0.20	0.07	0.13	0.12	0.21	4.91	593	117	44	76	7		
	2013	0.33	0.09	0.16	0.25	0.44	4.93	516	170	44	84	6		
	2014	0.40	0.11	0.15	0.18	0.21	4.84	571	229	64	88	14		
	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		
	2020	0.31	0.08	0.05	0.14	0.15	4.95	504	157	42	25	11		
Ny-Ålesund	1981	0.24	0.05	0.05	1.03	0.41	5.11	366	88	20	17	3		
(tørr-avsetning	1982	0.39	0.08	0.05	0.92	2.01	5.01	206	80	16	10	2		
fra Zeppelin)	1983	0.25	0.05	0.10	0.40	0.42	5.13	237	59	11	24	2		
	1984	0.64	0.17	0.21	0.71	0.93	4.60	366	233	62	76	9		
	1985	0.61	0.14	0.13	0.71	1.29	4.72	237	144	33	31	5		
	1986	0.40	0.07	0.49	0.55	0.58	4.98	306	122	20	150	3		
	1987	0.69	0.12	0.10	0.64	0.91	4.63	390	271	46	40	9		
	1988	0.27	0.07	0.21	0.54	0.58	5.18	307	84	21	64	2		
	1989	0.38	0.05	0.06	0.87	1.48	5.55	295	113	15	19	1	35	
	1990	0.33	0.07	0.06	0.52	0.79	4.92	410	137	30	26	5	41	20
	1991	0.34	0.11	0.10	0.80	1.13	4.96	424	145	47	44	5	35	27
	1992	0.43	0.10	0.11	0.80	1.03	5.11	272	116	27	29	2	31	21
	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	

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S	NO_3-N	NH_4-N	Ca	Mg	pH		SO_4-S	NO_3-N	NH_4-N	H+	S	N
		mg/l	mg/l	mg/l	mg/l	mg/l		mm	mg/m^2	mg/m^2	mg/m^2	mekv/m^2	mg/m^2	mg/m^2
Ny-Ålesund	2012	0.06	0.06	0.05	0.3	0.47	5.51	373	23	22	17	1.1	20	
(tørr-avsetning	2013	0.10	0.07	0.09	0.47	0.63	5.38	268	27	18	24	1.1	19	
fra Zeppelin)	2014	0.47	0.09	0.08	0.44	0.6	4.78	311	145	29	25	16.6	35	
(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	
	2020	0.11	0.07	0.08	1.00	1.29	5.76	228	25	16	19	1.7	17	

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

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

Table A.1.21b, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S	NO_3-N	NH_4-N	Ca	Mg	pH		SO_4-S	NO_3-N	NH_4-N	H+	S	N
		mg/l	mg/l	mg/l	mg/l	mg/l		mm	mg/m²	mg/m²	mg/m²	mekv/m²	mg/m²	mg/m²
Skreådalen	1981	0.49	0.20	0.28	0.16	0.18	4.58	2260	1107	452	633	59		
cont.	1982	0.57	0.28	0.37	0.17	0.22	4.52	2519	1436	709	933	76		
	1983	0.43	0.19	0.26	0.18	0.23	4.70	2843	1221	551	734	57		
	1984	0.46	0.24	0.23	0.16	0.21	4.59	1762	802	415	401	46		
	1985	0.59	0.32	0.33	0.15	0.12	4.48	1895	1117	610	616	63		
	1986	0.53	0.29	0.30	0.15	0.19	4.51	2439	1289	698	734	75		
	1987	0.47	0.28	0.29	0.14	0.16	4.54	1639	767	451	471	48	152	
	1988	0.41	0.28	0.28	0.12	0.14	4.55	2255	926	622	632	64	153	
	1989	0.43	0.28	0.28	0.15	0.20	4.56	2519	1087	704	696	70	143	355
	1990	0.39	0.23	0.22	0.13	0.26	4.61	3346	1293	775	732	82	170	415
	1991	0.41	0.27	0.25	0.15	0.24	4.61	2172	894	583	547	53	125	279
	1992	0.37	0.24	0.23	0.12	0.16	4.70	2728	1017	647	627	55	118	254
	1993	0.29	0.22	0.25	0.30	0.56	4.81	2006	586	437	493	31	82	256
	1994	0.38	0.28	0.31	0.31	0.25	4.77	2214	842	619	695	37	104	330
	1995	0.30	0.24	0.24	0.16	0.21	4.75	2083	624	510	500	37	96	257
	1996	0.30	0.28	0.31	0.14	0.12	4.78	1463	438	404	455	25	91	329
	1997	0.25	0.23	0.29	0.21	0.33	4.92	2071	508	472	609	25	73	280
	1998	0.32	0.27	0.31	0.17	0.15	4.83	1961	636	525	621	29	53	254
	1999	0.25	0.23	0.24	0.14	0.23	4.93	2521	618	583	606	30	60	229
	2000	0.23	0.24	0.25	0.14	0.21	4.90	2997	671	705	750	37	58	225
	2001	0.23	0.23	0.33	0.12	0.11	5.10	1887	424	435	619	15	56	260
	2002	0.22	0.23	0.35	0.19	0.20	5.17	1996	443	461	698	14	63	270
	2003	0.24	0.26	0.28	0.14	0.14	4.89	2115	501	545	600	27	48	165
	2004	0.16	0.19	0.21	0.14	0.15	5.07	2531	401	487	528	22	50	239
Valle	1990	0.40	0.27	0.20	0.07	0.11	4.51	1504	607	409	306	46		
	1991	0.47	0.32	0.25	0.14	0.10	4.52	912	432	287	227	28		
	1992	0.46	0.28	0.22	0.13	0.10	4.59	1120	519	318	242	29		
	1993	0.42	0.26	0.23	0.19	0.27	4.66	1052	445	276	243	23		
	1994	0.49	0.37	0.30	0.17	0.11	4.58	1230	608	461	373	32		
	1995	0.33	0.28	0.20	0.13	0.11	4.63	926	303	256	183	22		
	1996	0.38	0.33	0.25	0.17	0.07	4.60	836	316	273	206	21		
	1997	0.30	0.26	0.20	0.12	0.11	4.70	1085	323	280	220	22		
	1998	0.33	0.28	0.29	0.09	0.05	4.67	1179	393	330	336	25		
	1999	0.28	0.22	0.15	0.08	0.07	4.74	1284	335	281	192	23		
	2000	0.26	0.29	0.24	0.10	0.07	4.70	1618	422	467	395	32		
Solhomfjell	1991	0.63	0.44	0.40	0.14	0.08	4.44	878	552	389	355	32		
	1992	0.69	0.47	0.39	0.12	0.07	4.44	958	662	447	376	35		
	1993	0.66	0.45	0.38	0.15	0.08	4.47	920	611	412	347	31		
	1994	0.60	0.48	0.38	0.12	0.06	4.50	1150	686	550	442	36		
	1995	0.55	0.45	0.43	0.14	0.08	4.51	1073	590	484	464	33		
	1996	0.61	0.45	0.41	0.17	0.07	4.46	908	551	410	377	31		
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	Annual total wet deposition				Dry deposition	
		SO_4-S	NO_3-N	NH_4-N	Ca	Mg	pH	precip	SO_4-S	NO_3-N	NH_4-N	H+	S	N
		mg/l	mg/l	mg/l	mg/l	mg/l		mm	mg/m²	mg/m²	mg/m²	mekv/m²	mg/m²	mg/m²
Haukeland	2000	0,20	0,15	0,15	0,13	0,28	4,95	3692	752	557	539	41		
cont.	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	Annual total wet deposition				Dry deposition	
		SO_4-S	NO_3-N	NH_4-N	Ca	Mg	pH		SO_4-S	NO_3-N	NH_4-N	H+	S	N
		mg/l	mg/l	mg/l	mg/l	mg/l		mm	mg/m²	mg/m²	mg/m²	mekv/m²	mg/m²	mg/m²
Fagernes	2000	0.19	0.19	0.19	0.10	0.02	4.85	757	150	147	145	11		
(cont.)	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	Annual total wet deposition				Dry deposition	
		SO_4-S	NO_3-N	NH_4-N	Ca	Mg	pH		SO_4-S	NO_3-N	NH_4-N	H+	S	N
		mg/l	mg/l	mg/l	mg/l	mg/l		mm	mg/m^2	mg/m^2	mg/m^2	mekv/m^2	mg/m^2	mg/m^2
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	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m^2	NO_3-N mg/m^2	NH_4-N mg/m^2	H+ mekv/m^2	S mg/m^2	N mg/m^2
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: µg S/m^3.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes II	0.021	0.032	0.067	0.086	0.112	0.132	0.040	0.143	0.036	0.027	0.018	0.034	0.060
Hurdal	0.012	0.014	0.024	0.040	0.032	0.051	0.035	0.050	0.020	0.012	0.010	0.022	0.027
Kårvatn	0.015	0.017	0.025	0.023	0.043	0.061	0.031	0.045	0.014	0.016	0.010	0.018	0.027
Tustervatn	0.047	0.012	0.026	0.036	0.026	0.056	0.037	0.019	0.029	0.017	0.010	0.021	0.028
Zeppelin	0.173	0.291	0.093	0.055	0.039	0.025	0.037	0.032	0.013	0.015	0.014	0.042	0.069

Table A.1.23: Monthly and annual mean concentration of sulfate in aerosol at Norwegian background stations. Unit: µg S/m^3.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes II	0.149	0.121	0.186	0.141	0.172	0.229	0.162	0.416	0.236	0.181	0.158	0.208	0.190
Hurdal	0.067	0.046	0.144	0.066	0.085	0.150	0.064	0.206	0.129	0.110	0.043	0.106	0.102
Kårvatn	0.035	0.025	0.049	0.100	0.094	0.133	0.103	0.104	0.152	0.018	0.023	0.038	0.073
Tustervatn	0.099	0.054	0.066	0.129	0.107	0.118	0.070	0.071	0.047	0.065	0.031	0.048	0.076
Zeppelin	0.155	0.199	0.145	0.135	0.125	0.043	0.160	0.082	0.043	0.066	0.059	0.101	0.109

Table A.1.24: Monthly and annual mean concentration of nitrogen dioxide in air at Norwegian background stations. Unit: µg N/m^3.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes II	0.13	0.24	0.40	0.27	0.23	0.25	0.22	0.38	0.26	0.33	0.32	0.59	0.30
Hurdal	0.58	0.49	0.37	0.33	0.17	0.23	0.20	0.26	0.34	0.36	0.38	0.50	0.35
Kårvatn	0.14	0.14	0.16	0.14	0.12	0.12	0.12	0.20	0.14	0.16	0.13	0.19	0.15
Tustervatn	0.16	0.07	0.14	0.12	0.14	0.13	0.15	0.21	0.13	0.17	0.10	0.17	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: µg N/m^3.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes II	0.135	0.099	0.268	0.159	0.116	0.157	0.089	0.326	0.240	0.133	0.152	0.163	0.165
Hurdal	0.086	0.059	0.247	0.062	0.052	0.070	0.033	0.094	0.078	0.061	0.063	0.056	0.080
Kårvatn	0.024	0.024	0.028	0.047	0.043	0.066	0.043	0.042	0.040	0.020	0.023	0.021	0.035
Tustervatn	0.028	0.032	0.029	0.046	0.029	0.051	0.025	0.026	0.064	0.031	0.020	0.023	0.034
Zeppelin	0.028	0.025	0.024	0.029	0.025	0.021	0.025	0.023	0.021	0.036	0.020	0.021	0.025

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

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes II	0.117	0.085	0.244	0.135	0.093	0.100	0.064	0.18	0.153	0.108	0.14	0.152	0.130
Hurdal	0.073	0.046	0.227	0.042	0.037	0.041	0.022	0.052	0.061	0.047	0.051	0.044	0.062
Kårvatn	0.013	0.014	0.017	0.036	0.022	0.043	0.034	0.026	0.029	0.010	0.013	0.011	0.022
Tustervatn	0.017	0.022	0.019	0.035	0.019	0.036	0.015	0.016	0.012	0.021	0.01	0.011	0.019
Zeppelin	0.018	0.015	0.014	0.018	0.015	0.011	0.012	0.012	0.011	0.025	0.010	0.011	0.014

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

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes II	0.397	0.170	0.539	0.520	0.372	0.552	0.360	0.834	0.454	0.310	0.163	0.242	0.397
Hurdal	0.075	0.048	0.295	0.233	0.178	0.248	0.188	0.315	0.246	0.121	0.065	0.123	0.179
Kårvatn	0.416	0.389	0.414	0.370	0.323	1.042	0.706	0.870	0.375	0.185	0.180	0.241	0.460
Tustervatn	0.056	0.176	0.220	0.501	0.723	0.981	0.479	0.349	0.214	0.121	0.111	0.063	0.331
Zeppelin	0.120	0.174	0.145	0.170	0.084	0.134	0.302	0.272	0.222	0.233	0.030	0.035	0.164

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

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes II	0.052	0.062	0.211	0.150	0.125	0.146	0.121	0.301	0.190	0.089	0.136	0.222	0.146
Hurdal	0.046	0.026	0.213	0.058	0.065	0.090	0.051	0.114	0.089	0.052	0.039	0.097	0.079
Kårvatn	0.005	0.005	0.011	0.071	0.052	0.067	0.045	0.056	0.069	0.008	0.007	0.019	0.035
Tustervatn	0.026	0.012	0.016	0.070	0.081	0.060	0.028	0.022	0.008	0.029	0.005	0.024	0.032
Zeppelinfjellet	0.039	0.068	0.014	0.028	0.044	0.005	0.027	0.011	0.007	0.013	0.005	0.013	0.023

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

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes II	0.14	0.11	0.15	0.06	0.06	0.06	0.05	0.08	0.09	0.07	0.07	0.06	0.08
Hurdal	0.04	0.03	0.06	0.03	0.02	0.02	0.01	0.02	0.02	0.02	0.01	0.01	0.03
Kårvatn	0.03	0.02	0.03	0.04	0.02	0.02	0.02	0.02	0.03	0.01	0.01	0.01	0.02
Tustervatn	0.07	0.05	0.05	0.08	0.03	0.02	0.01	0.03	0.02	0.01	0.03	0.01	0.03
Zeppelinfjellet	0.04	0.10	0.11	0.07	0.05	0.02	0.02	0.02	0.03	0.03	0.07	0.04	0.05

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

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes II	0.05	0.04	0.08	0.05	0.04	0.09	0.03	0.13	0.08	0.12	0.03	0.03	0.06
Hurdal	0.02	0.02	0.05	0.04	0.02	0.05	0.02	0.05	0.05	0.10	0.01	0.01	0.04
Kårvatn	0.02	0.01	0.02	0.03	0.03	0.05	0.02	0.02	0.11	0.01	0.02	0.01	0.03
Tustervatn	0.02	0.02	0.02	0.04	0.02	0.03	0.01	0.02	0.02	0.04	0.02	0.01	0.02
Zeppelinfjellet	0.06	0.05	0.05	0.06	0.08	0.03	0.04	0.02	0.02	0.08	0.14	0.02	0.06

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

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes II	0.08	0.06	0.11	0.05	0.05	0.08	0.06	0.10	0.08	0.07	0.06	0.05	0.07
Hurdal	0.04	0.02	0.06	0.09	0.02	0.04	0.04	0.06	0.11	0.04	0.03	0.04	0.05
Kårvatn	0.03	0.01	0.03	0.03	0.02	0.05	0.05	0.05	0.05	0.01	0.01	0.03	0.03
Tustervatn	0.04	0.02	0.02	0.03	0.02	0.02	0.02	0.03	0.02	0.02	0.01	0.02	0.02
Zeppelinfjellet	0.04	0.05	0.05	0.08	0.06	0.02	0.07	0.04	0.09	0.06	0.04	0.02	0.05

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

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes II	1.63	1.56	1.77	0.63	0.49	0.35	0.37	0.52	0.91	0.64	0.91	0.60	0.87
Hurdal	0.43	0.35	0.64	0.19	0.15	0.05	0.06	0.12	0.18	0.09	0.14	0.04	0.20
Kårvatn	0.46	0.17	0.38	0.54	0.18	0.06	0.17	0.06	0.24	0.12	0.13	0.04	0.21
Tustervatn	1.01	0.75	0.62	0.95	0.35	0.12	0.10	0.26	0.31	0.06	0.47	0.04	0.42
Zeppelinfjellet	0.28	0.78	0.75	0.55	0.26	0.23	0.08	0.18	0.41	0.21	0.94	0.47	0.42

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

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes II	1.20	0.98	1.24	0.49	0.47	0.37	0.34	0.52	0.66	0.48	0.63	0.48	0.66
Hurdal	0.32	0.26	0.48	0.16	0.15	0.09	0.08	0.14	0.16	0.08	0.10	0.04	0.17
Kårvatn	0.28	0.12	0.23	0.36	0.14	0.11	0.45	0.06	0.16	0.07	0.07	0.04	0.18
Tustervatn	0.64	0.46	0.40	0.63	0.25	0.14	0.09	0.18	0.19	0.04	0.29	0.03	0.28
Zeppelinfjellet	0.22	0.53	0.44	0.39	0.24	0.17	0.10	0.11	0.25	0.13	0.55	0.25	0.28

Table A.1.34a: Annual mean concentrations of sulfur and nitrogen components in air at Norwegian background stations from 1973-2020. Units μg S/m³ and μg N/m³.

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

Table A.1.34a, cont.

Site	År	Annual mean concentrations of main components in air (µg/m³)					
		SO_2-S	SO_4-S	NO_2-N	(HNO_3+NO_3)-N	(NH_4+NH_3)-N	NH_4-N
Birkenes II	2016	0.05	0.20	0.30	0.25	0.40	0.23
(cont.)	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	0.20	0.32	0.15	0.32	0.16
	2020	0.06	0.19	0.30	0.17	0.40	0.15
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
	2020	0.03	0.10	0.35	0.08	0.18	0.08
Kårvatn	1979	0.48	0.48				
	1980	0.54	0.55				
	1981	0.51	0.47				
	1982	0.29	0.40				

Table A.1.34a, cont.

Site	År	Annual mean concentrations of main components in air (µg/m³)					
		SO_2-S	SO_4-S	NO_2-N	(HNO_3+NO_3)-N	(NH_4+NH_3)-N	NH_4-N
Kårvatn	1983	0.19	0.38				
(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
	2020	0.03	0.07	0.15	0.04	0.46	0.04
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				

Table A.1.34a, cont.

Site	År	Annual mean concentrations of main components in air (µg/m³)					
		SO_2-S	SO_4-S	NO_2-N	(HNO_3+NO_3)-N	(NH_4+NH_3)-N	NH_4-N
Tustervatn	1987	0.72	0.59				
(cont.)	1988	0.67	0.54				
	1989	0.16	0.23	0.29	0.04	0.52	
	1990	0.29	0.36	0.37	0.08	0.53	
	1991	0.25	0.38	0.32	0.08	0.68	
	1992	0.15	0.28	0.26	0.07	0.54	
	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
	2020	0.03	0.08	0.14	0.03	0.33	0.03
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 (µg/m³)					
		SO_2-S	SO_4-S	NO_2-N	(HNO_3+NO_3)-N	(NH_4+NH_3)-N	NH_4-N
Zeppelin	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
	2020	0.07	0.11		0.03	0.16	0.02

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

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

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

Table A.1.34b, cont.

Site	År	Annual mean concentrations of main components in air at closed sites, (µg/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, (µg/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
	2009	0.18	0.25	0.15	0.09	0.12
Andøya	2010	0.11	0.20		0.05	
	2011	0.05	0.17		0.06	0.11

1) Measured from 25 May 2003.

** One month missing.*

*** Two months missing.*

Table A.1.35: Annual and monthly mean concentrations of OC, EC and TC in PM_{10} and $PM_{2.5}$ at the sites Birkenes, Hurdal, Kårvatn and Zeppelin for 2020.

Month	PM_{10}			$PM_{2.5}$		
	OC	EC	TC	OC	EC	TC
Birkenes						
January	0.25	0.05	0.30	0.22	0.05	0.26
February	0.31	0.05	0.36	0.17	0.04	0.21
March	1.11	0.14	1.24	0.45	0.10	0.55
April	0.50	0.08	0.58	0.42	0.06	0.48
May	1.26	0.08	1.34	0.97	0.07	1.04
June	2.05	0.06	2.11	1.65	0.07	1.73
July	0.56	0.03	0.58	0.37	0.03	0.40
August	1.46	0.09	1.55	0.99	0.08	1.07
September	0.80	0.07	0.86	0.49	0.05	0.54
October	0.81	0.12	0.94	0.39	0.08	0.47
November	0.48	0.08	0.56	0.33	0.06	0.40
December	0.36	0.08	0.44	0.33	0.07	0.40
Annual mean	**0.82**	**0.08**	**0.90**	**0.57**	**0.06**	**0.63**
Hurdal						
January	0.36	0.06	0.43	0.32	0.06	0.38
February	0.34	0.07	0.41	0.29	0.06	0.36
March	0.55	0.09	0.64	0.46	0.08	0.54
April	0.54	0.07	0.60	0.38	0.06	0.44
May	0.80	0.04	0.84	0.44	0.04	0.48
June	2.25	0.09	2.34	1.42	0.08	1.50
July	1.18	0.06	1.20	0.61	0.04	0.65
August	1.77	0.08	1.83	1.01	0.08	1.08
September	1.23	0.10	1.33	0.62	0.09	0.71
October	1.15	0.12	1.27	0.50	0.10	0.60
November	0.76	0.09	0.85	0.47	0.07	0.54
December	0.51	0.08	0.59	0.46	0.08	0.54
Annual mean	**0.95**	**0.08**	**1.03**	**0.58**	**0.07**	**0.65**
Kårvatn						
January	0.14	0.01	0.16	-	-	-
February	0.19	0.03	0.22	-	-	-
March	0.18	0.02	0.20	-	-	-
April	0.26	0.02	0.28	-	-	-
May	0.40	0.02	0.42	-	-	-
June	2.19	0.07	2.26	-	-	-
July	0.85	0.02	0.86	-	-	-
August	1.23	0.04	1.27	0.72*	0.03*	0.75*
September	1.22	0.07	1.28	0.63	0.05	0.69
October	0.90	0.08	0.97	0.58	0.06	0.64
November	0.35	0.01	0.37	0.21	0.01	0.22
December	0.21	0.03	0.24	0.22	0.03	0.25
Annual mean	**0.68**	**0.03**	**0.71**			
Zeppelin						
January	0.067*	0.010*	0.077*			
February	0.086	0.018	0.103			
March	0.155	0.041	0.195			
April	0.202*	0.029*	0.231*			
May	0.085	0.008	0.093			
June	0.091*	0.002*	0.094*			
July	0.621	0.020	0.641			
August	0.236	0.008	0.244			
September	0.061	0.002	0.063			
October	0.331	0.027	0.358			
November	0.250*	0.003*	0.253*			
December	0.120*	0.015*	0.135*			
Annual mean	**0.197**	**0.016**	**0.214**			

*Data capture <75%

Table A.1.36: Annual mean concentrations of OC, EC and TC in PM_{10} and $PM_{2.5}$ at Birkenes Hurdal, Kårvatn and Zeppelin for the period 2001 - 2020.

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
2020	0.82	0.08	0.90	0.57	0.06	0.63
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
2020	0.95	0.08	1.03	0.58	0.07	0.65
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
2020	0.68	0.03	0.71	-	-	-
Zeppelin						
2019	0.102	0.013	0.115	-	-	-
2020	0.197	0.016	0.214	-	-	-

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 2020. Unit µg/m³.

Month	***Birkenes***			***Hurdal***			***Kårvatn***		
	$PM_{2.5}$	$PM_{10-2.5}$	PM_{10}	$PM_{2.5}$	$PM_{10-2.5}$	PM_{10}	$PM_{2.5}$	$PM_{10-2.5}$	PM_{10}
JAN	1.7	3.2	5.1	1.3	1.1	2.4			2.0
FEB	1.9	3.3	4.4	1.2	1.7	2.9			1.0*
MAR	3.9	3.7	7.6	3.3	2.3	5.6			1.5
APR	2.4	2.0	4.4	1.6	1.5	3.2			2.2
MAY	3.5	1.5	5.0	1.8	1.5	3.3			2.5
JUN	5.1	2.5	7.6	4.1	2.3	6.4			7.1
JUL	1.5	1.5	3.0	1.4	2.0	3.4			3.0
AUG	3.0*	2.9	7.2	3.5	2.4	5.9	1.2*	0.5*	3.7*
SEP	2.4	3.1	5.6	2.5	3.1	5.6	4.0	3.8	7.8
OCT	1.6	3.9	5.5	2.0	3.1	5.1	0.9	0.6	1.5
NOV	1.2	2.7	3.9	2.3	1.1	2.9	0.6	0.5	1.1
DEC	0.9	1.0	2.4	1.7	0.2	1.9	0.6	0.1*	0.6
2020	*2.5*	*2.7*	*5.2*	*2.2*	*1.9*	*4.1*			*2.9*

*Data capture <75%

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 – 2020.

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
2020		2.5	2.7	5.2
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
2020		2.2	1.9	4.1
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
2020		-	-	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 2020, including the environmental contaminants reported in Nizzetto et al. (2020).

	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 Hurdal	X	X 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, SO_4, NO_3, Cl, NH_4, Ca, K, Mg, Na

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

HM [a] = Pb, Cd and Zn

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

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

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

[e] = α- og γ-HCH, HCB, PCB

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

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

Annex 3

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

Main components in precipitation

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

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

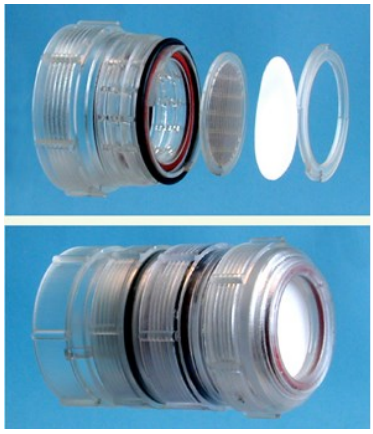
pH is measured with potentiometric method and conductivity with a conductivity meter. Anions and cations are measured with an ion chromatograph. The detection limit for the different ions are given in the table below:

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

Main components in air

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

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



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

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

Nitrogen dioxide

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

Ozone

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

Particles (Mass, EC/OC, and levoglucosan)

Background

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

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

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

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

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

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

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

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

Levoglucosan is considered the most robust and reliable tracer of biomass burning, and is commonly used to trace biomass burning aerosol, not only qualitatively, but also quantitatively by combing ambient concentrations with emission ratios, or as input along with other species to e.g. positive matrix factorization (PMF). For studies using levoglucosan as biomass burning tracer in Norway, see Yttri et al., 2005, 2007a, b, 2009, 2011a, b, 2014, 2019, in prep. Although levoglucosan appears to be best suited to trace biomass burning emissions in winter and on a local to regional scale, conservative estimates of the biomass burning aerosol concentration can still be provided for the remote environment. Emission ratios used to convert observed ambient concentrations of levoglucosan to OC and EC from biomass burning, are associated with great uncertainty. In the present report, we use an OC/levoglucosan ratio of 12.7 for PM_{10} and 11.1 for $PM_{2.5}$ and an

EC/levoglucosan ratio of 2. These ratios are based on positive matrix factorization (PMF) analysis results for PM and PM species observed at Birkenes (Yttri et al., 2021), which are consistent with results presented in the scientific literature e.g., by Zotter et al. (2017). A factor of 2 was used to convert biomass burning OC to OM, and a factor of 1.1 for biomass burning EC.

Sampling and chemical analysis

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

Number concentration measurements at Birkenes dates to 2010. The number concentration of ultrafine particles (D_p <0.1 µm), accumulation mode particles (0.1 µm < D_p < 1.0 µm) and coarse mode particles (D_p = 1.0 - 10 µm) are obtained by combined measurements of a Differential Mobility Particle Spectrometer (DMPS) and an Optical Particle Spectrometer (OPS). The DMPS measures the particle number size distribution ranging from 0.01 – 0.8 µm particle diameter, whereas the OPS covers the range from 0.25 µm to 30 µm. The DMPS and the OPS provide method specific measures of the particle diameter, i.e., the electrical mobility particle diameter and the optical particle diameter, respectively. Thus, when merging these two measures into one particle number size distribution (PNSD) time series, the PNSD must agree within 25% in particle diameter in their overlapping size range. For comparability of long-term measurements, the 0.01 – 0.02 µm size range is not reported.

In May 2017, a continuous, direct aerosol mass instrument was installed at Birkenes, a so-called tapered element oscillating microbalance (TEOM) instrument with a size cut off to measure PM_{10} mass. The TEOM Monitor draws (then heats) ambient air through a filter at constant flow rate, continuously weighing the filter and calculating near real-time mass concentrations of particulate matter. The mass is corrected with a factor 1.1 and -2.8 µg m^{-3} based on intercomparison with gravimetric measurements, which is the reference method.

Thermal-Optical Analysis of EC, OC and TC in PM_{10} and $PM_{2.5}$ are performed on the same filter samples as the mass concentration of PM_{10} and $PM_{2.5}$ are obtained from at the three rural background sites. For the remote site Zeppelin, analysis is performed on prefired (850 °C for 3 hrs) quartz fibre filters (PALLFLEX Tissuequartz 2500QAT-UP; 150 mm in diameter) obtained from a Digitel high-volume sampler with a PM_{10} inlet, operating at a flowrate of 40 m^3 h^{-1}, collecting aerosol filter samples on a weekly basis. The T-O analysis are performed according to the EUSAAR-2 protocol (Cavalli *et al*., 2010). The analytical detection limit of the TOA instruments is 0.2 µg C/cm^2. This corresponds to a methodological detection limit of 0.007 µg C m^{-3} for a sampling volume of 386 m^3 and an exposed filter area of 13.4 cm^2 for the rural background sites and, and a methodological detection limit of 0.005 µg C m^{-3} for a sampling volume of 6720 m^3 and an exposed filter area of 153.9 cm^2 for the remote site.

Concentrations of the biomass burning tracers levoglucosan, mannosan and galactosan are determined from the same PM_{10} filter samples as the mass concentration and EC/OC/TC at the rural background sites and from the same PM_{10} filter samples as EC/OC/TC at the remote site. Analysis is performed using ultra-high performance liquid chromatography (UHPLC) 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) (Yttri et al., 2021). The methodological detection limit is approximately 1-20 pg m^{-3} for the rural background sites and 1-4 pg m^{-3} for the remote site.

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NILU – Norwegian Institute for Air Research
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E-mail: nilu@nilu.no
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