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Annual Report 2017

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Monitoring of long-range transported air pollutants in Norway, Annual Report 2017
Overvåking av langtransportert forurenset luft og nedbør. Atmosfæriske tilførsler 2017

Summary - sammendrag

This report presents results from the monitoring of atmospheric composition and deposition of air pollution in 2017, 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 concentration levels were generally low in 2017 compared to previous years.

Denne rapporten omhandler resultater fra overvåkningsprogrammet for langtransportert forurenset luft og nedbør og atmosfæriske tilførsler i 2017 på norske bakgrunnsstasjoner. Rapporten presenterer målinger av uorganiske hovedkomponentene i luft og nedbør, partikulært karbonholdig materiale, partikkelmasse og bakkenært ozon. Konsentrasjonsnivået var generelt lavt i 2017 sammenlignet med tidligere år.

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

Front page photo

Birkenes Observatory

Content

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 17 norske bakgrunnsstasjoner. I tillegg rapporteres målinger av levoglukosan på Birkenes.

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

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

Sekundære uorganiske forbindelser (SIA: sulfat, nitrat og ammonium) utgjorde en større andel av PM_{10} (37%) på Birkenes enn på de to andre norske stasjonene, noe som reflekterer områdets nærhet til store antropogene utslippsområder på det europeiske kontinentet, mens organisk karbon materiale hadde en relativt større andel på Kårvatn (53%) og Hurdal (51%). Sjøsaltpartikler utgjorde en betydelig andel (27%) av PM_{10} på Birkenes, men fortsatt noe lavere enn andelen organisk karbon (34%).

Episoder
Det var bare noen få episoder med høye døgnverdier av svovel- og nitrogenforbindelser i 2017, og nivåene var generelt lavere sammenlignet med tidligere år. Kildeområdene for episodene i Sør-Norge er hovedsakelig kontinentet, mens de høyeste episodene på Tustervatn i Nordland og Zeppelin på Spitsbergen ofte skyldes forurenset luft fra Russland.

2017 var et år med svært få ozonepisoder. Bortsett fra en kortvarig topp i midten av mai på Prestebakke, viser dataene kun mindre "krusninger". Sommeren 2017 var antagelig ikke særlig gunstig for fotokjemiske ozonepisoder i Norge. Selv om gjennomsnittstemperaturen om sommeren var nær normalen, førte mangelen på lengre høytrykksepisoder til svært få episoder med forhøyede ozonnivåer.

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

Når det gjelder bakkenært ozon, har ikke EUs grenseverdi for helse (180 µg/m^3) blitt overskredet i Norge de siste årene. EUs langtidsmål (maks 8-timers verdi < 120 µg/m^3) ble overskredet kun én dag (18. mai) på én stasjon (Prestebakke). Luftkvalitetskriteriene for ozon satt av WHO (maks 8h verdi < 100 µg/m^3) og av Folkehelseinstituttet (maks 8h verdi < 80 µg/m^3), ble overskredet på alle målestasjoner på fastlandet utenom Sandve for WHO kriteriet. Hverken grenseverdien for planter (3 måneders AOT40 < 3000 ppb timer) eller grenseverdien for skog (6 måneders AOT40 < 5000 ppb timer) ble overskredet i 2017.

Trender

Konsentrasjonene av nitrogen- og svovelkomponenter i luft og nedbør i 2017 var noe lavere eller lik nivåene i 2016, mens våtavsetningen av sulfat var noe høyere på grunn av økt nedbørmengde. Årsmiddelkonsentrasjonene av PM_{10} og $PM_{2.5}$ i 2017 var de laveste som har vært observert på Birkenes, Hurdal og Kårvatn. EC- og OC-konsentrasjonene for 2017 følger langtidstrenden. Nivået av bakkenært ozon var spesielt lavt i 2017 og sannsynligvis det laveste gjennomsnitt og maksimum siden målingene startet på begynnelsen av syttitallet.

En oversikt over de langsiktige trendene er vist i tabell 1. Trendene gjenspeiler i stor grad utslippsreduksjonene som har skjedd på det europeiske kontinentet de siste tiårene, men årlige variasjoner i meteorologi kan skjule noe av effekten av utslippsreduksjonene, og det gjelder spesielt for ozon.

Summary

The atmospheric monitoring programme presented in this report includes observations of sulfur- and nitrogen compounds in air and precipitation, elemental- and organic carbon (EC/OC) in aerosols, ground level ozone, particulate matter (PM_{10} and $PM_{2.5}$) and aerosol size distribution, at a total of 17 sites in the Norwegian rural background environment. In addition, observations of levoglucosan at the Birkenes Observatory are reported.

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

Chemical composition and geographical distribution

The highest concentrations of sulfur, nitrogen and PM are often measured at Birkenes in Aust-Agder. However, some inland sites are influenced by regional agricultural activities and experience somewhat higher ammonium levels. The highest EC, OC and NO_2 levels are seen in Hurdal in Akershus, likely due to influence from the more densely populated region surrounding this site, including road traffic. Karpbukt 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 Aust-Agder to Hordaland.

Secondary inorganic aerosols (SIA: sulfate, nitrate and ammonium) is the most abundant fraction of PM_{10} (44%) at Birkenes, reflecting the site’s proximity to major anthropogenic emission regions in continental Europe, whereas organic carbon was relatively more abundant at Kårvatn (48%) and Hurdal (40%). Sea salt constitutes a substantial part of PM_{10} at Birkenes (23%), approaching that of organic carbon (29%).

Episodes

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

The time series indicates that 2017 was a year with very few high peak level ozone episodes. Except for a short term peak in the middle of May at Prestebakke the data shows only minor “ripples” above the baseline. The summer of 2017 was presumably not very favorable for photochemical ozone episodes in Norway. Although the mean temperatures in the summer was close to normal in the southern part, the lack of lasting high-pressure episodes lead to few episodes with elevated ozone levels.

Exceedances

For PM_{10} and $PM_{2.5}$, the observations at the three background PM-sites were all well below the EU limit-values, the national limit-values and the WHO and the National Air Quality Guidelines on an annual basis.

EU's target value for ozone for the protection of human health was met in Norway with a very clear margin. The EU long-term objective (i.e. max 8h value < 120 $\mu g/m^3$) was violated at one day (18 May) at one site (Prestebakke). The WHO guideline (max 8h value < 100 $\mu g/m^3$) and the national guidelines (max 8h value < 80 $\mu g/m^3$) was violated at all the mainland sites except Sandve for the WHO guidline. Neither the limit value for agricultural crops (3-months AOT40 < 3000 ppb hours) nor the limit value for forests (6-months AOT40 < 5000 ppb hours), were exceeded at Norwegian sites in 2017.

Trends

The concentration levels in 2017 were in general a bit lower or equal compared to 2016, but the wet deposition was a bit higher due to relatively high precipitation amounts. The annual mean concentrations of PM_{10} and $PM_{2.5}$ were the lowest ever observed at Birkenes and Hurdal. Also the EC and OC concentrations were low in 2017. 2017 was a year with particularly low ozone levels, and most likely the year with the lowest mean and maximum levels overall since the monitoring started in the 1970s.

An overview of the long-term trends are shown in Table 1. The trends reflect to a large extent the emission reductions which have taken place at the European continent the last decades, although inter-annual variations in meteorology could mask the effect of the emission reductions, particularly for ozone.

Table1: Trends in annual levels using Mann-Kendall test and Sen slope estimates. Note that trends are given for sites with significant change only.

Component	Sites	1980-2016	1990- 2016	2000-2017
SO_2	3-4 sites1)	almost 100%	-76% - -94%	-46% - -50%
SO_2	Zeppelin	-86%	-70%	-39%
SO_4^{2-} in aerosols	3-4 sites1)	-84 - -90%	-71% - -79%	-39% - -41%
SO_4^{2-} in aerosols	Zeppelin	-65%	-37%	-30%
SO_4^{2-} in precipitation	All (9 – 13 sites)	-79 - -96%	-51% - -90%	-35% --72%2)
NO_2	4 sites1)		-39% - -67%	-25% - -41%
NO_3^- in precipitation	All S and SW sites	-42 - -55%	-28% - -51%	-22% - -41%
$HNO_3+NO_3^-$ in air	4 sites1)		2 sites: +60% - -26%	2 sites: +64% - -17%
NH_4^+ in precipitation	All S and SW sites	-51 - -66%	+90% - -55%	Not sign.trend
$NH_3+NH_4^+$ in air	4 sites1)		3 sites: +68% - -37%	3 sites: +52% - -23%
PM_{10}	Birkenes			-31%
$PM_{2.5}$	Birkenes			-45% (2001-2017)
OC	Birkenes			-34% - -46% (2001-2017)
EC	Birkenes			-46% - -53% (2001-2017)
TC	Birkenes			-40% - -44% (2001-2017)
O_3, 6-months AOT40	3 sites3)			-55% - -60% (1996-2017)
O_3, 3-months AOT40	3 sites3)			-50% - -66% (1996-2017)
O_3, 8h >100 $\mu g/m^3$	3 sites3)			-71% - -90% (1996-2017)

1) Birkenes, Nordmoen/Hurdal, Kårvatn, Tustervatn. Nordmoen/Hurdal was not part of 1980-2016

2) Tustervatn without significant trend in this period

3) Kårvatn, Tustervatn and Prestebakke

1. The monitoring programme 2017

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

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

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

The measurements presented in the current report are part of different national projects and programmes:

- *The National monitoring programme on behalf of The Norwegian Environment Agency:*
    - Ozone at four sites (Birkenes, Tustervatn, Kårvatn, Zeppelin)
    - Daily measurements of NO_2 at four sites (Birkenes, Hurdal, Tustervatn, Kårvatn)
    - Weekly measurements of particulate matter (PM_{10} and $PM_{2.5}$) and EC/OC at three sites (Birkenes, Hurdal, Kårvatn)
    - High time-resolution measurements of particle number and size distribution at Birkenes
    - Daily measurements of particulate and gaseous inorganic compounds in air and precipitation at two sites (Birkenes and Zeppelin; weekly for precipitation at Ny-Ålesund)
    - Meteorology at three sites (Birkenes, Zeppelin and Hurdal)

- *Measurement programme to preserve long-time data series on behalf of the Ministry of Climate and Environment, co-financed by NILUs internal monitoring programme:*
    - Daily measurements of particulate and gaseous inorganic compounds in air and precipitation at three sites (Hurdal, Kårvatn and Tustervatn)
    - Weekly measurements of main inorganic ions in precipitation at eight sites (Vikedal, Treungen, Haukeland, Brekkebygda, Høylandet, Nausta, Vatnedalen, Løken)
    - Ozone at three sites (Hurdal, Sandve and Prestebakke)

- *Norway-Russia programme on behalf of The Norwegian Environment Agency:*
    - Weekly measurements of main inorganic ions in air and precipitation at Karpbukt

- *Local air pollution program, co-financed by the municipalities in Porsgrunn, Skien and Bamble:*
    - Ozone at Haukenes

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

The present report is one of four reports, which cover the national monitoring of atmospheric composition in the Norwegian rural background environment. The other three reports are published separately, of which the first focuses on persistent organic pollutants and heavy metals (Nizzetto et al., 2018), the second covers the monitoring of the ozone layer and UV (Svendby et al. 2017), whereas the third is on climate gases and aerosol particles influence on climate (Myhre et al., 2017). The site locations and key information on the monitoring programme at the actual sites are illustrated in Figure 1.1. Detailed station information, monitoring program and measurement frequencies are provided in Annex 2, whereas sampling methods and chemical analysis are described in Annex 3. There were no changes in the monitoring programme in 2017.

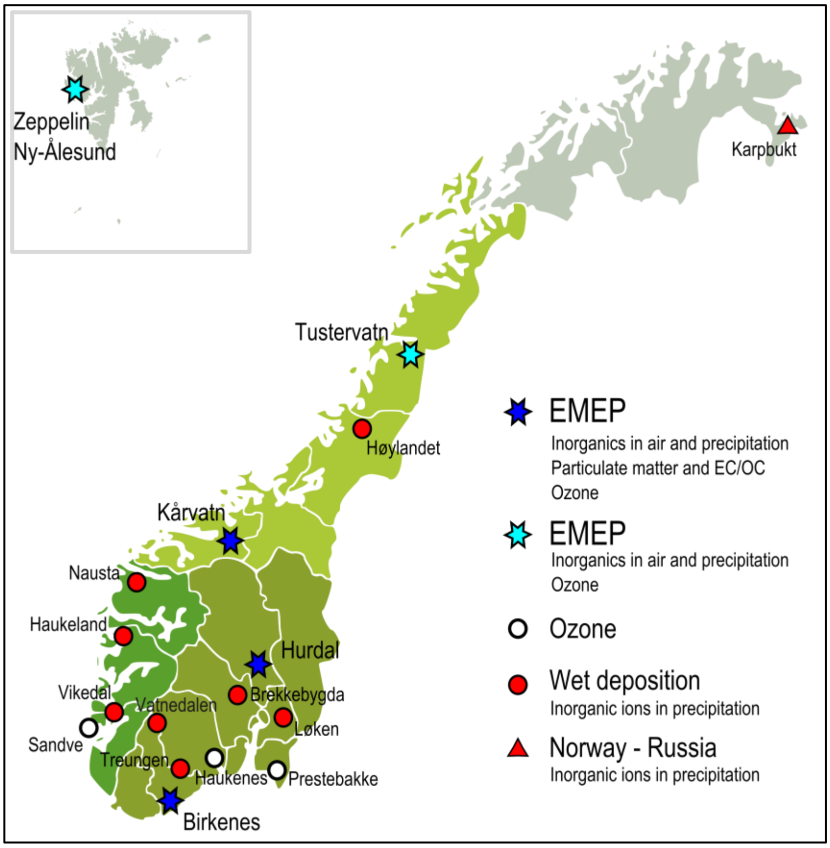


Figure 1.1: Norwegian background sites and their measurement programme 2017. Details are found in Annex 2. The colour codes indicate the different regions/zones used in EU's Ambient Air Quality Directive (2008).

2. The weather in Norway 2017

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

On average, the annual average temperature for the whole country was 1.1°C above the normal (all normals refer to the 1961-1990 period) while the average precipitation was 120% of the normal (Met. Institute, 2018). This makes 2017 the 20th warmest year and the 6th wettest year on average since 1900. The annual temperature anomaly was largest in southeast Norway (around 2°C above the normal) whereas Rogaland was the relative wettest area (125 - 175% of the normal). The highest daily precipitation was observed at Senumstad in Birkenes, Aust-Agder, with 175 mm on 1 October.

Also 2017 was a very warm year in the Norwegian Arctic although not as warm as 2016.
The annual mean temperature at the Arctic stations was 3 - 4°C above the normal.

On the mainland of Norway the period January - March was particularly warm with monthly mean temperatures for the whole country 2 - 3.9°C above the normal. January was on average very mild and wet in Northern Norway with mean temperatures of 5 - 6°C above the normal and with 2 - 3 times as much precipitation as normal. This was linked to frequent frontal passages with winds from the south and west. Southeast Norway was, on the other side, mild and dry in January with some stations receiving less than 30% of the normal precipitation. Also March was very mild, and the maximum temperature exceeded 20°C at the earliest date ever recorded in many areas. The pattern with very wet conditions in the north and dry conditions in southeast as seen in January was repeated in March. This was again associated with frequent episodes of passing low pressure systems causing inflow of marine air masses from the western sector.

April was characterized by temperatures more close to normal in the whole country whereas areas in the southwest received 250 - 350% of the mean precipitation. In May the country was divided in two parts weather-wise with Northern Norway experiencing 2°C below normal and Southern Norway 2°C above the normal. This was due to dominating winds from northwest in the north and from south and southwest in the south. Several stations in the south experienced their annual maximum temperature in May caused by a stagnant high-pressure area south of the country in the last part of the month.

The temperature in June was close to the average whereas areas in the south (Agder) received 200 -275% of the normal precipitation also this month. The mean temperatures in July was close to the normal in most of the country. The maximum temperatures were, however, lower than normal. A reason for this was presumably the lack of any lasting high-pressure systems in the country. The summer continued with a month of August with mean temperatures close to the normal whereas Southeast Norway was wet with 225 – 275% of the normal precipitation.

September was very mild and dry in West and North Norway with several areas experiencing a mean temperature 3°C above the normal and less than 25% of the normal precipitation. In the last part of the month a blocking high-pressure system was staying to the east of the country giving dry and warm conditions in many areas. Aust-Agder and Telemark, however, received twice the normal precipitation. Also in October areas in the south received more than twice the normal precipitation.

In November the mean temperature was close to the normal although some sites in the south experienced record-high maximum temperatures (around 17°C at sites in Agder). Some areas in the west received twice the normal precipitation, and in the north the weather Ylva caused extreme winds on the 22-24th. Also December was very wet in the west with 2-3 times the normal precipitation. The mean temperature was 1°C above the normal for the country as a whole, and several areas both in the south and the north experienced a mean temperature 3°C above the normal this month. Record-high temperatures were seen in Agder in December (as in November) with a maximum exceeding 14°C. These conditions were caused by unstable weather situations with passing low pressure systems and dominantly winds from the marine sector.

3. Inorganic components

3.1 Observations in 2017

3.1.1 Chemical composition in precipitation

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

Monthly and annual concentrations and wet depositions for all sites are listed in Annex A.1.1-A.1.19, and all years in A.1.21, while Table 3.1 lists the annual mean concentrations and depositions at all stations for 2017.

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 is influenced by emissions from Russia and the content of sulfate is particularly high.

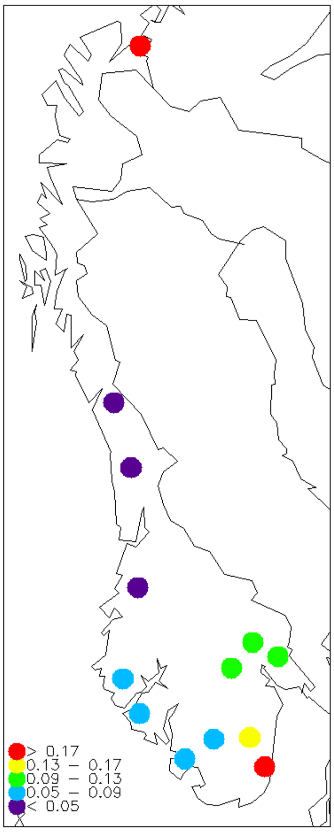
Table 3.1 shows that all regions, except the most continental parts of southern Norway and Finnmark, observed significant amounts of sea salts. At most sites, there was an excess of cations, which probably is due to the content of bicarbonate or other anions of weak acids that are not determined. At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

As seen for previous years, the highest annual mean concentrations for the major components were generally observed at the Birkenes site (Table 3.1); the exceptions were observed for sulfate, which was 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. Treungen, Hurdal and Løken. The highest wet deposition loads of sulfate, nitrogen components and strong acid occurred along the coast from Aust-Agder to Hordaland.

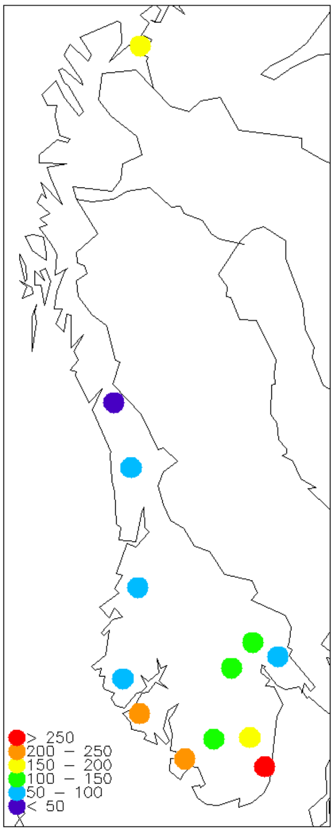
Table 3.1: Annual volume weighted mean concentrations and total wet deposition of inorganic ions at Norwegian background stations, 2017.
**: Corrected for contribution from sea salt.*

Site	Volume weighted annual mean concentrations (mg/L)									Wet deposition (mg/m^2 , H^+: µekv/m^2)										Volume weighted annual mean concentrations in equivalence units (µekv/)										Ion bal.
	pH	SO_4*	NO_3	NH_4	Ca	K	Mg	Na	Cl		H+	SO_4*	NO_3	NH_4	Ca	K	Mg	Na	Cl	H(+)	SO_4*(2-)	SO_4(2-)	NO_3(-)	NH_4(+)	Ca(2+)	K(+)	Mg(2+)	Na(+)	Cl(-)	
		mg S/l	mg N/l	mg N/l	mg/l	mg/l	mg/l	mg/l	mg/l	mm	µekv/m^2	mg S/m^2	mg N/m^2	mg N/m^2	mg/m^2	mg/m^2	mg/m^2	mg/m^2	mg/m^2	µekv/l	µekv/l	µekv/l	µekv/l	µekv/l	µekv/l	µekv/l	µekv/l	µekv/l	µekv/l	kat./an.
Birkenes	4,95	0,20	0,31	0,29	0,17	0,10	0,14	1,17	2,02	2088	23220	408	648	611	353	215	302	2440	4224	11	12	18	22	21	8	3	12	51	57	1,09
Vatnedalen	5,52	0,08	0,10	0,12	0,08	0,11	0,03	0,84	0,87	1272	3818	106	132	155	107	139	43	1071	1101	3	5	7	7	9	4	3	2	37	25	1,52
Treungen	5,12	0,14	0,22	0,24	0,11	0,07	0,05	0,27	0,45	1186	8951	169	265	288	127	82	53	317	532	8	9	10	16	17	5	2	4	12	13	1,27
Løken	5,12	0,12	0,25	0,21	0,18	0,17	0,06	0,40	0,68	797	6019	96	196	169	144	136	49	315	545	8	7	9	18	15	9	4	5	17	19	1,27
Hurdal	5,23	0,12	0,19	0,24	0,12	0,13	0,03	0,23	0,37	956	5610	115	181	228	118	120	28	221	352	6	7	9	14	17	6	3	2	10	10	1,40
Brekkebygda	4,98	0,12	0,17	0,15	0,09	0,10	0,02	0,15	0,23	1092	11481	130	190	167	100	105	22	164	250	10	7	8	12	11	4	3	2	7	6	1,38
Vikedal	5,25	0,06	0,12	0,16	0,14	0,11	0,26	2,32	4,07	3570	19959	227	421	564	496	393	944	8266	14525	6	4	16	9	11	7	3	21	101	115	1,08
Haukeland	5,21	0,06	0,09	0,10	0,14	0,11	0,23	1,92	3,43	3607	22031	211	328	350	500	406	825	6933	12365	6	4	14	6	7	7	3	19	84	97	1,08
Nausta	5,17	0,08	0,10	0,15	0,10	0,16	0,16	1,29	2,36	1293	8715	99	126	196	133	206	201	1671	3055	7	5	12	7	11	5	4	13	56	67	1,13
Kårvatn	5,26	0,05	0,04	0,06	0,09	0,08	0,11	0,99	1,77	1758	9611	88	75	111	155	149	202	1736	3105	5	3	8	3	4	4	2	9	43	50	1,14
Høylandet	5,47	0,04	0,04	0,18	0,14	0,14	0,25	2,13	3,82	1502	5045	65	64	277	207	214	370	3201	5737	3	2	14	3	13	7	4	21	93	108	1,14
Tustervatn	5,34	0,04	0,05	0,10	0,10	0,11	0,16	1,44	2,51	1318	5982	50	72	125	137	148	214	1892	3305	5	2	10	4	7	5	3	13	63	71	1,15
Karpbukt	4,95	0,27	0,08	0,16	0,16	0,14	0,20	1,69	3,00	594	6689	159	46	96	94	82	121	1006	1782	11	17	26	6	11	8	4	16	74	85	1,08
Ny-Ålesund	5,20	0,13	0,09	0,07	0,37	0,18	0,53	4,02	7,31	313	1982	40	27	22	115	56	165	1257	2288	6	8	29	6	5	18	5	44	175	206	1,05

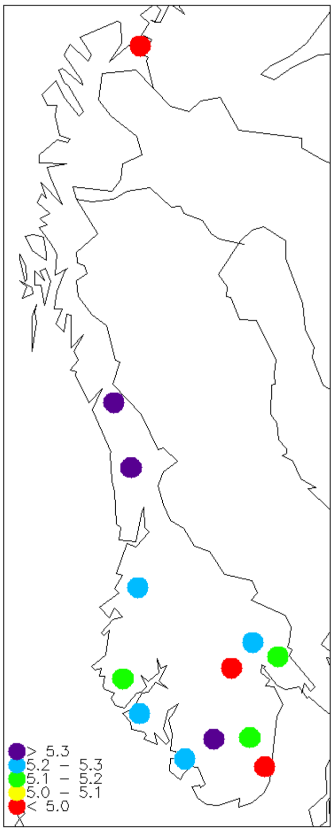
a) Sulfate concentration in precipitation, 2017 mg S/L



b) Sulfate – wet deposition. 2017 mg S/m^2



c) pH 2017



d) Strong acid (H^+) wet deposition, 2017 μekv/m^2

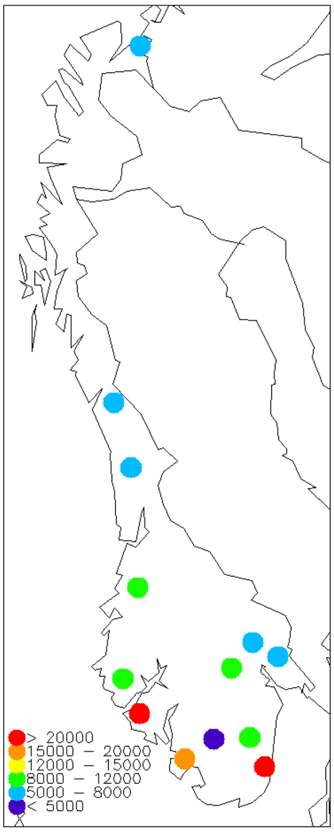
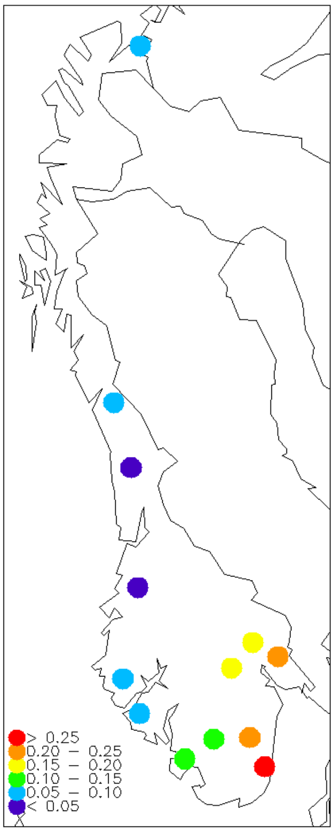
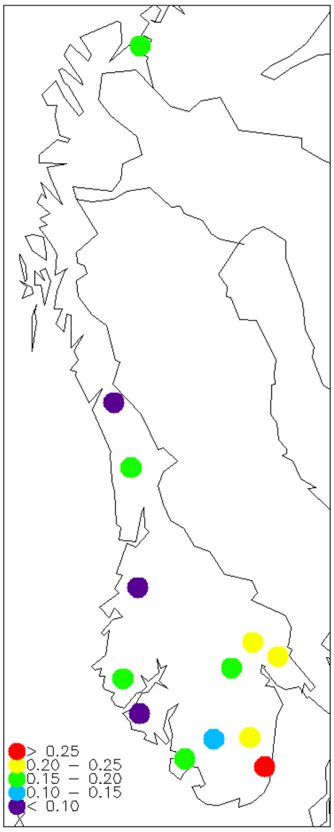


Figure 3.1: Annual volume weighted mean concentrations and total wet deposition of sulfate (sea salt corrected) and strong acid (pH), 2017. Note that the coulours only resemble the spatial distribution and do not indicate any exceedenes of limit values or similar.

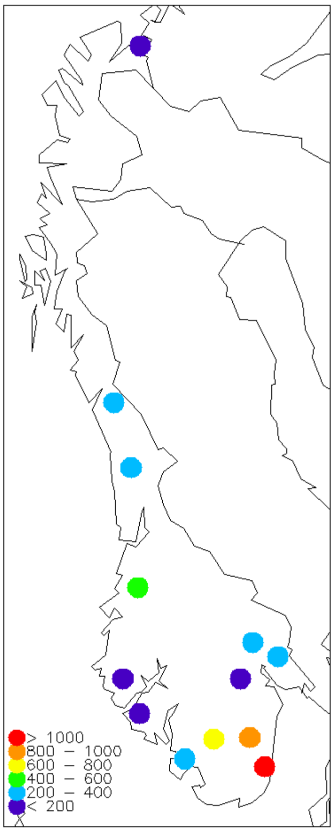
a) Nitrate concentration in precipitation, 2017 mg N/l



b) Ammonium concentration in precipitation, 2017 mg N/l



c) Sum nitrate and ammonium wet deposition 2017 mg N/m^2



d) Chloride concentration in precipitation, 2017 mg /l

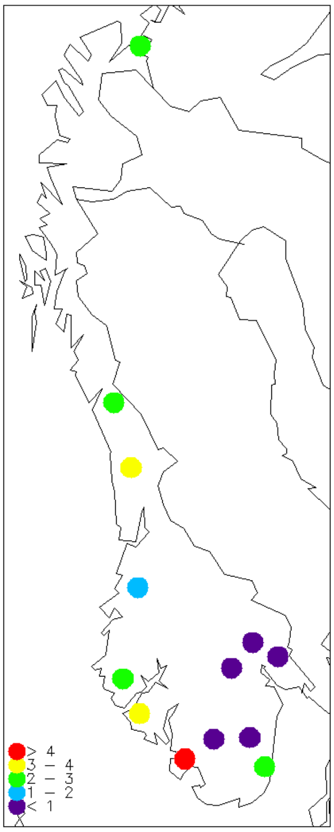


Figure 3.2: Annual volume weighted mean concentrations of nitrate, ammonium, chloride and total wet deposition of nitrogen (nitrate + ammonium), 2017.Note that the colours only resemble the spatial distribution and do not indicate any exceedenes of limit values or similar.

Figure 3.3 shows monthly volume weighted mean concentrations and wet deposition of sulfate, nitrate and ammonium in different parts of Norway, 2017. All the monthly data are given in the tables in Annex 1. There are quite large variabilities in the concentrations as well as depositions throughout the year, though it is not a general pattern common for all regions and components. In 2017, the highest concentrations were for most ions seen in March to May, whereas in East Norway high levels were also seen in September. For wet deposition the high levels in 2017 were seen in May-June and September though this varies between regions and components. The measured wet deposition of sulfate , shows that between 27% and 45% 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).

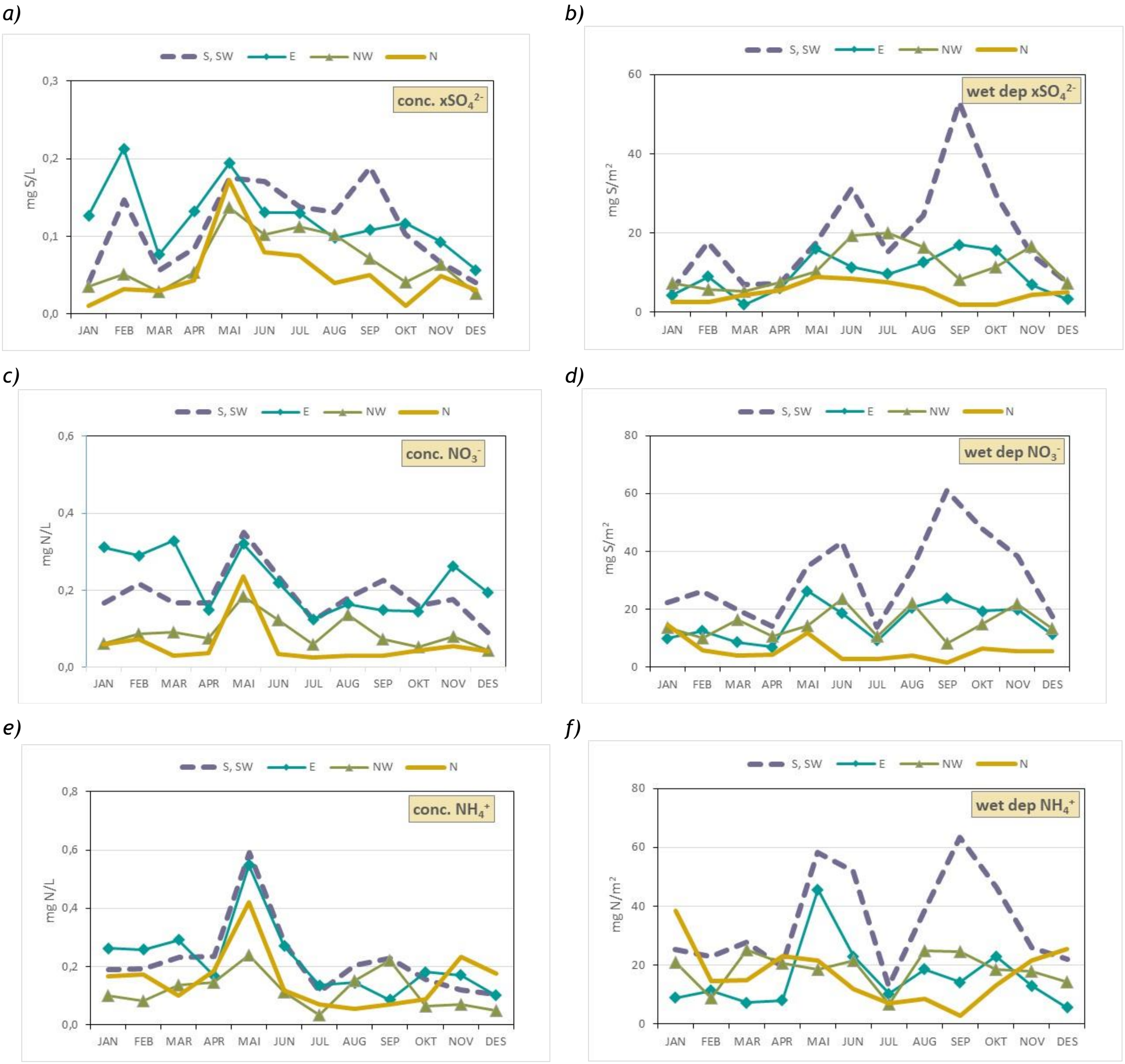

a) *b)* *c)* *d)* *e)* *f)*

Figure 3.3: Monthly volume weighted mean concentrations (left: a),c),e)) and wet deposition (right: b),d),f)) of sea salt corrected sulfate (top) nitrate (middle), ammonium (bottom) in different parts of Norway, 2017, S, SW: South and South west is the average of the sites Birkenes, Vatnedalen, Treungen and Vikedal; E: East (Løken, Hurdal, Brekkebygda); NW: Northwest (Haukeland, Nausta and Kårvatn); N: North (Høylandet and Tustervatn).

3.1.2 Chemical composition in air

Daily measurements of inorganic components in air was carried out at five sites in 2017, And all of these are EMEP sites (Figure 1.1). Table 3.2 shows the annual mean concentrations while the monthly data are given in A.1.22-A.1.33. The monthly means of the sulfur and nitrogen components are illustrated in Figure 3.4. The maximum and percentile concentrations of SO_2, SO_4^{2-}, sum of (NO_3- + HNO_3), NH_4^+ and sum of (NH_3 + NH_4^+) are given in Table 3.3 to Table 3.8.

Table 3.2: Annual mean concentrations of inorganic components in air at Norwegian background stations, 2017.

	SO_2 µg-S/m³	SO_4^{2-} µg-S/m³	NO_2 µg-N/m³	sum NO_3 µg-N/m³	NO_3 µg-N/m³	sum NH_4 µg-N/m³	NH_4 µg-N/m³	Mg µg/m³	Ca µg/m³	K µg/m³	Cl µg/m³	Na µg/m³
Birkenes II	0.06	0.22	0.27	0.15	0.12	0.27	0.13	0.05	0.03	0.05	0.51	0.40
Hurdal	0.04	0.14	0.64	0.09	0.07	0.20	0.09	0.01	0.02	0.05	0.10	0.11
Kårvatn	0.06	0.09	0.17	0.04	0.02	0.36	0.03	0.02	0.02	0.02	0.19	0.14
Tustervatn	0.04	0.12	0.11	0.04	0.02	0.27	0.03	0.03	0.02	0.02	0.39	0.26
Zeppelin	0.12	0.14	-	0.04	0.02	0.16	0.03	0.04	0.05	0.05	0.38	0.26

Annual mean concentrations of sulfur dioxide in air are generally very low at the mainland, and in 2017 the highest mean concentration was observed at the most northern site Zeppelin Observatory with 0.12 µg S/m³. The highest daily average was also observed at Zeppelin with 3.3 µg S/m³ on 2 February. This day the air masses were transported from Russia. At Kårvatn relatively high SO_2 levels in August were caused by a period between 21-31 August with high levels (0.7-0.9 µg S/m³). The air masses arrived from various places during these days, and thus it is difficult to assess the reason(s) for this enhancement.

The highest annual mean particulate sulfate level was measured at Birkenes (0.14 µg S/m³), and also the highest episode was observed here with 4.1 µg S/m³ on 28 February with air masses transported from the continent.

Highest NO_2 levels were observed in Hurdal with an annual mean of 0.6 µg N/m³. This station is influenced by the relatively high traffic emissions in region. The highest daily mean level of NO_2 was also measured at Hurdal with 8.1 µg N/m³ on 15 February. The concentrations of NO_2 show an expected temporal pattern with a winter maximum and summer minimum (Figure 3.5). During winter, there is reduced vertical mixing and the atmospheric residence time is longer due to low photochemical activity.

The highest annual mean values for the sum of nitrate (NO_3^- + HNO_3), and NH_4^+ were observed at Birkenes with 0.15 µg N/m³ and 0.13 µg N/m³ respectively. The highest annual average of the sum of ammonium (NH_3 + NH_4^+) was observed at Kårvatn, probably due to the influence of agricultural activity in the region.

Table 3.3: Number of daily, observations 50-, 75-, 90-percentile concentrations, max and annual mean concentrations for SO_2 in air at Norwegian background station in 2017.

Site	No. of observations	SO_2 (µg S/m^3)					
		Percentile conc.			Max concentration	Date	Annual mean concentration
		50%	75%	90%			
Birkenes II	345	0.02	0.07	0.14	0.85	09.07.2017	0.06
Kårvatn	358	0.01	0.03	0.13	0.90	24.08.2017	0.06
Tustervatn	337	0.01	0.04	0.08	0.44	08.03.2017	0.04
Zeppelin	363	0.03	0.10	0.38	3.28	20.02.2017	0.12
Hurdal	359	0.01	0.04	0.09	0.41	06.03.2017	0.04

Table 3.4: Number of daily, observations 50-, 75-, 90-percentile concentrations, max- and annual mean concentrations for SO_4 in aerosols at Norwegian background station in 2017.

Site	No. of observations	SO_4^{2-} (µg S/m^3)					
		Percentile conc.			Max concentration	Date	Annual mean concentration
		50%	75%	90%			
Birkenes II	345	0.14	0.26	0.44	4.06	28.02.2017	0.22
Kårvatn	359	0.07	0.12	0.21	0.81	06.03.2017	0.09
Tustervatn	336	0.08	0.15	0.25	0.94	13.04.2017	0.12
Zeppelin	364	0.09	0.20	0.32	0.85	17.07.2017	0.14
Hurdal	359	0.09	0.16	0.32	2.49	03.02.2017	0.14

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 2017.

Site	No. of observations	NO_2 (µg N/m^3)					
		Percentile conc.			Max concentration	Date	Annual mean concentration
		50%	75%	90%			
Birkenes II	351	0.22	0.31	0.45	2.08	16.02.2017	0.27
Kårvatn	327	0.14	0.19	0.28	0.92	14.02.2017	0.17
Tustervatn	324	0.10	0.13	0.17	0.45	12.01.2017	0.11
Hurdal	358	0.32	0.64	1.50	8.06	15.02.2017	0.64

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 2017.

Site	No. of observations	NO_3^-+HNO_3 (µg N/m^3)					
		Percentile conc.			Max concentration	Date	Annual mean concentration
		50%	75%	90%			
Birkenes II	345	0.07	0.16	0.34	2.58	07.04.2017	0.15
Kårvatn	358	0.02	0.04	0.07	0.21	01.07.2017	0.04
Tustervatn	336	0.02	0.04	0.07	0.64	28.01.2017	0.04
Zeppelin	363	0.02	0.04	0.07	0.52	02.09.2017	0.04
Hurdal	359	0.06	0.12	0.22	1.06	03.02.2017	0.09

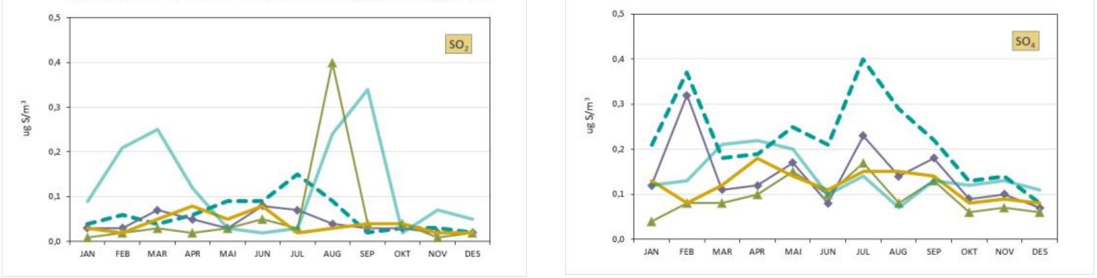
Table 3.7: Number of daily, observations 50-, 75-, 90-percentile concentrations, max- and annual mean concentrations of ammonium in aerosols at Norwegian background station in 2017.

Site	No. of observations	NH_4^+ +NH_3 (µg N/m^3)					
		Percentile conc.			Max concentration	Date	Annual mean concentration
		50%	75%	90%			
Birkenes II	343	0.12	0.31	0.65	5.52	19.08.2017	0.27
Kårvatn	359	0.27	0.43	0.65	3.18	15.02.2017	0.36
Tustervatn	335	0.19	0.32	0.46	4.69	04.10.2017	0.27
Zeppelin	364	0.09	0.15	0.25	8.08	07.04.2017	0.16
Hurdal	356	0.14	0.25	0.43	2.42	03.02.2017	0.20

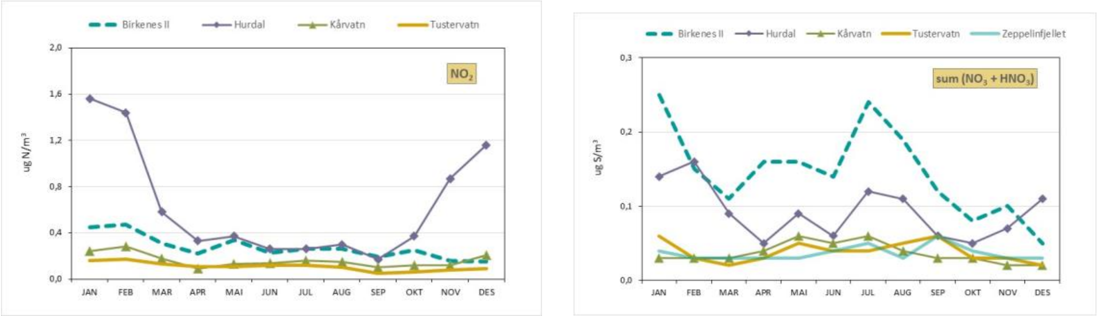
Table 3.8: Number of daily, observations 50-, 75-, 90-percentile concentrations, max- and annual mean concentrations of the sum of ammonium and ammonia in air at Norwegian background station in 2017.

Site	No. of observations	NH_4^+ (µg N/m^3)					
		Percentile conc.			Max concentration	Date	Annual mean concentration
		50%	75%	90%			
Birkenes II	343	0.03	0.14	0.31	2.99	07.04.2017	0.13
Kårvatn	359	0.01	0.03	0.11	0.58	06.03.2017	0.03
Tustervatn	335	0.01	0.04	0.10	0.47	28.01.2017	0.03
Zeppelin	364	0.01	0.04	0.07	0.26	01.10.2017	0.03
Hurdal	356	0.02	0.10	0.24	2.40	03.02.2017	0.09

a) SO_2 *b) SO_4 in aerosols*



c) NO_2 *d) sum (NO_3+HNO_3) in air*



e) NH_4 in aerosols *f) sum (NH_4+NH_3) in air*

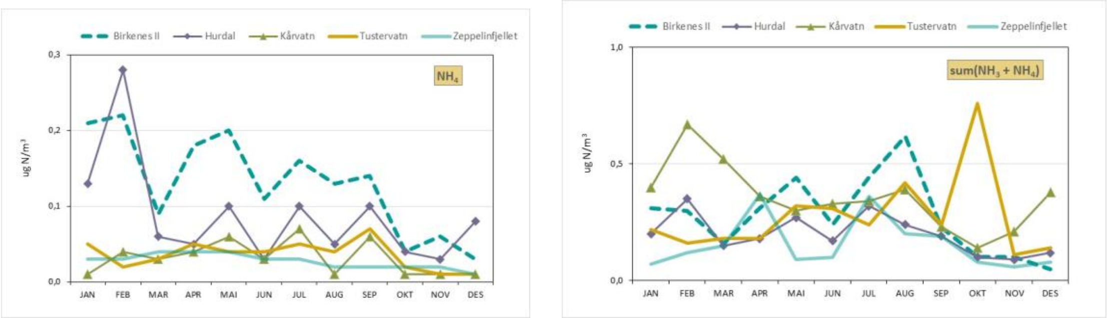


Figure 3.4: Monthly mean concentrations of sulfur- and nitrogen components in air at the five EMEP sites in Norway in 2017. Unit: μg(S or N)/m^3.

3.1.3 Total deposition of sulfur and nitrogen

Table 3.9 and Figure 3.5 present estimates of the total dry deposition of sulfur and nitrogen compounds and the measured wet deposition in the growing season from May to October (summer) and winter months from January to April and November to December. Dry deposition is calculated on the basis of the mean concentrations of SO_2, SO_4^{2-}, NO_2, sum of nitrate (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 believed that HNO_3 contributes with 25% and NO_3^- with 75%, whereas I for the sum of ammonium (NH_3 + NH_4^+) NH_3 is assumed 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 9-33% in summer and 6-18% in winter except at Svalbard where dry deposition is relatively much higher due low precipitation amount. Dry deposition of nitrogen contributes between 7-31% in summer and 6-19% 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 2017.

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

	Sulfur (mg S/m^2)						**Nitrogen (mg N/m^2)**					
	Dry deposition		Wet deposition		% dry deposition		Dry deposition		Wet deposition		% dry deposition	
	Winter	Summer	Winter	Summer	% W	% S	Winter	Summer	Winter	Summer	% V	% S
Birkenes	7	33	103	318	6	9	25	78	364	964	6	7
Hurdal	5	19	37	79	12	20	15	103	133	278	10	27
Kårvatn	3	22	30	68	8	24	19	45	81	131	19	25
Tustervatn	4	17	19	35	18	33	10	52	88	117	10	31
Zeppelin-fjellet*	7	25	21	19	25	56	-	-	22	27	-	-

*Used the wet deposition at Ny-Ålesund.

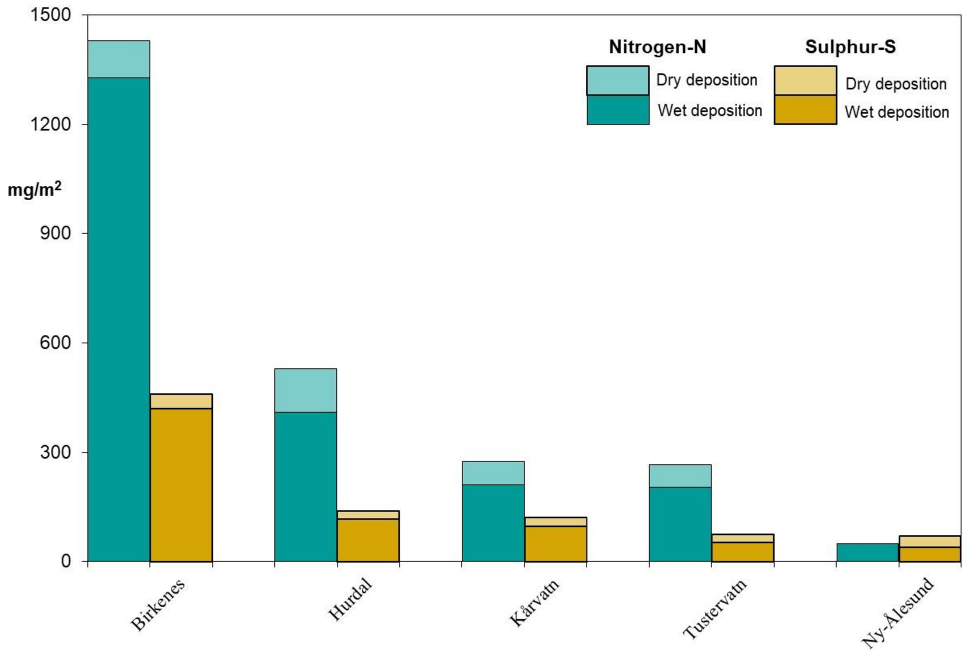


Figure 3.5: Total deposition (wet+ dry) of sulfur-S (SO_2, SO_4^{2-}) and nitrogen-N (NO_2, NH_4^+, NH_3, NO_3^-, HNO_3) at Norwegian background stations 2017.

3.2 Trends

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

Figure 3.6-Figure 3.8 show the time series of annual mean concentrations of main ions in precipitation, in air and total deposition at selected sites in Norway with long time series. The concentration levels in 2017 were in general a bit lower or equal compared to 2016, but the wet deposition was a bit higher due to relatively high precipitation amount (Figure 3.6).

Table 3.10 and 3.11 shows the trends for three different periods, 1980-, 1990-, and 2000-2017 for all sites with measurements in these respective periods.

For the statistical analysis, the non-parametric “Mann-Kendall Test” has been used on annual means for detecting and estimating trends (Gilbert, 1987). The Mann-Kendall test has become a standard method when missing values occurs and when data are not normally distributed. In parallel to this, the Sen’s slope estimator has been used to quantify the magnitude of the trends. Thus, the Sen’s slope is used to estimate the percent reduction in the concentration level while the Mann-Kendall test is used to indicate the significance level of the trend.

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 2017. Since 1980, the content of sulfate in precipitation in Norway has decreased by 79-96%. The reductions in airborne concentrations of sulfate have been similar, between 84% and 90% 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; 86% for sulfur dioxide and 64% for sulfate, Table 3.10.

The reductions since 1990 have been between 51% and 90% (sulfate in precipitation), 76-94% (sulfur dioxide) and 71-79% (sulfate in air) for the sites at the mainland. From 2000, all sites except Tustervatn have observed a significant reduction of sulfate in precipitation between 35% and 72%. For sulfur dioxide and sulfate in air, there are significant reductions at all mainland sites with 46-50% and 39-41%, respectively. Trends from 2005 are also calculated since this is the references year for the Gothenburg protocol. The observed sulfur reductions at most sites are smaller than the target of 59% emission reductions, which is to be reached within 2020.

The nitrate and ammonium concentrations in precipitation have significantly decreased at most sites south of Kårvatn, 42-55% for nitrate and 51-66% for ammonium since 1980. The air measurements did not start as early as the ones for precipitation, thus trend analysis for these have only been done from 1990.

For nitrate in precipitation, most sites show a significant decrease between 15% and 52% from 1990 to 2017. Most of the sites also show a decrease of ammonium, but some show a significant increase. There is a decrease in the observed ammonium in air for all the four sites at the mainland, between 47-71%, while the levels of sum nitrate and sum ammonium varied, some sites with a decrease and others with an increase. This might be due to changes in local emissions or changes in chemical regime; less sulfate cause more ammonium to be associated with particulate nitrate.

The NO_2 concentration has decreased at all four sites, between 39-67% from 1990 and 25-41% from 2000. The observed reductions in concentration levels of sulfur and nitrogen species are in agreement with reported downwards trends in pollutant emissions in Europe (Tørseth et al., 2012; Colette et al., 2016).

Calcium is significantly reduced at most sites since 1980, which is consistent with emission reductions from anthropogenic sources in Europe (Hellsten et al., 2007). The contribution of sea salts are influenced by meteorological conditions and vary from year to year. A significant reduction is seen at Løken from 1980-2017 and at Vatnedalen from 1990-2017 and at three other sites at the Norwegian mainland during 2000-2017.

Table 3.10: Trends in annual mean concentrations of inorganic ions in precipitation. Only significant trends are shown (p=0.1).Shaded area means not available data, while the signs indicate increase or decrease in percent change for the whole period.

	ssc SO_4^{2-}				NO_3^-				NH_4^+			
	1980-2017	1990-2017	2000-2017	2005-2017	1980-2017	1990-2017	2000-2017	2005-2017	1980-2017	1990-2017	2000-2017	2005-2017
Birkenes	-90	-79	-59	-54	-43	-41	-26	-27	-54	-38	-	-
Treungen	-93	-83	-63	-48	-44	-44	-25	-25	-51	-40	-	-
Vatnedalen	-86	-75	-52	-35	-42	-40	-	-40	-	-	-	-
Nordmoen/Hurdal	▨	-80	-55	-48	▨	-34	-24	-34	▨	-	-	-
Løken	-96	-87	-58	-48	-53	-47	-22	-23	-63	-44	-	-
Gulsvik/Brekkebygda	-95	-82	-61	-56	-55	-51	-	-36	-66	-55	-	-43
Vikedal	▨	-89	-72	-63	▨	-33	-36	-29	▨	-	-	-
Nausta	▨	-79	-63	-	▨	-28	-	-	▨	84	83	-
Høylandet	▨	-79	-68	-66	▨	-	-	-65	▨	89	-	-
Haukeland	-93	-90	-74	-60	-48	-44	-41	-41	-57	-47	-36	-
Kårvatn	-79	-51	-35	-	-	-	-	-	-	-	-	-
Tustervatn	-88	-69	-	-	-	-15	-	-24	-	-24	-40	-35
Ny-Ålesund	-85	-83	-54	-	-	-	-	-	-	-	-	-

Table 3.10 (cont.)
Trends in annual mean concentrations of inorganic ions in precipitation.

	mm				Mg^{2+}				Ca^{2+}			
	1980-2017	1990-2017	2000-2017	2005-2017	1980-2017	1990-2017	2000-2017	2005-2017	1980-2017	1990-2017	2000-2017	2005-2017
Birkenes	36	48	-	-	-	-	-	-	-35	-	72	60
Treungen	23	33	-	-	-	-	-	-	-35	-	-	-
Vatnedalen	-	-	-	-	-	-51	-	-	-	-	-	-
Nordmoen/Hurdal		20	-	-		-	-	-		66	-	-
Løken	-	-	-	-	-26	-	44	-	-50	-	38	-
Gulsvik/Brekkebygda	64	77	-	-	-	-	-40	-	-27	-	-	-
Vikedal		-	-	-		-	-	-		-	44	-
Nausta		-30	-	-49		-	-	-		-	-	-
Høylandet		-	-	-		-	-33	-		-	-	-
Haukeland	-	-	-	-	-	-	-	-	-	-	-	-
Kårvatn	-	-	-	-	-	-	-	-	-30	-	-	-
Tustervatn	-	-24	-22	-	-	-	-	-	-34	-	-	-
Ny-Ålesund	-	-	-	55	-	-39	-54	-48	-	-42	-75	-75

Table 3.11: Trends in annual mean concentrations of inorganic components in air.. Only significant trends are shown (p=0.1). Shaded area means not available data, while the signs indicate increase or decrease in percent change for the whole period.

	SO_2				SO_4^{2-}			
	1980-2017	1990-2017	2000-2017	2005-2017	1980-2017	1990-2017	2000-2017	2005-2017
Birkenes	~ -100%	-91	-49	-	-84	-73	-39	-35
Nordmoen/Hurdal		-94	-46	-55		-79	-41	-46
Kårvatn	~ -100%	-76	-50	-	-86	-71	-40	-45
Tustervatn	~ -100%	-89	-49	-44	-90	-78	-41	-63
Zeppelin	-86	-70	-39	-	-65	-37	-30	-

	NO_2				sum(NO_3+HNO_3)			
	1980-2017	1990-2017	2000-2017	2005-2017	1980-2017	1990-2017	2000-2017	2005-2017
Birkenes		-67	-37	-37		-	-	-
Nordmoen/Hurdal		-67	-41	-26		-26	-17	-
Kårvatn		-39	-25	-35		-	-	-
Tustervatn		-56	-31	-23		60	64	-
Zeppelin						142	189	-

	sum(NH_4^++NH_3)				NH_4^+			
	1980-2017	1990-2017	2000-2017	2005-2017	1980-2017	1990-2017	2000-2017	2005-2017
Birkenes		-28	-16	-47		-59	-30	-
Nordmoen/Hurdal		-37	-23	-48		-71	-35	-
Kårvatn		68	52	-52		-47	-25	-
Tustervatn		-	-	-62		-53	-28	-
Zeppelin		338	-850	-57		-	-	-

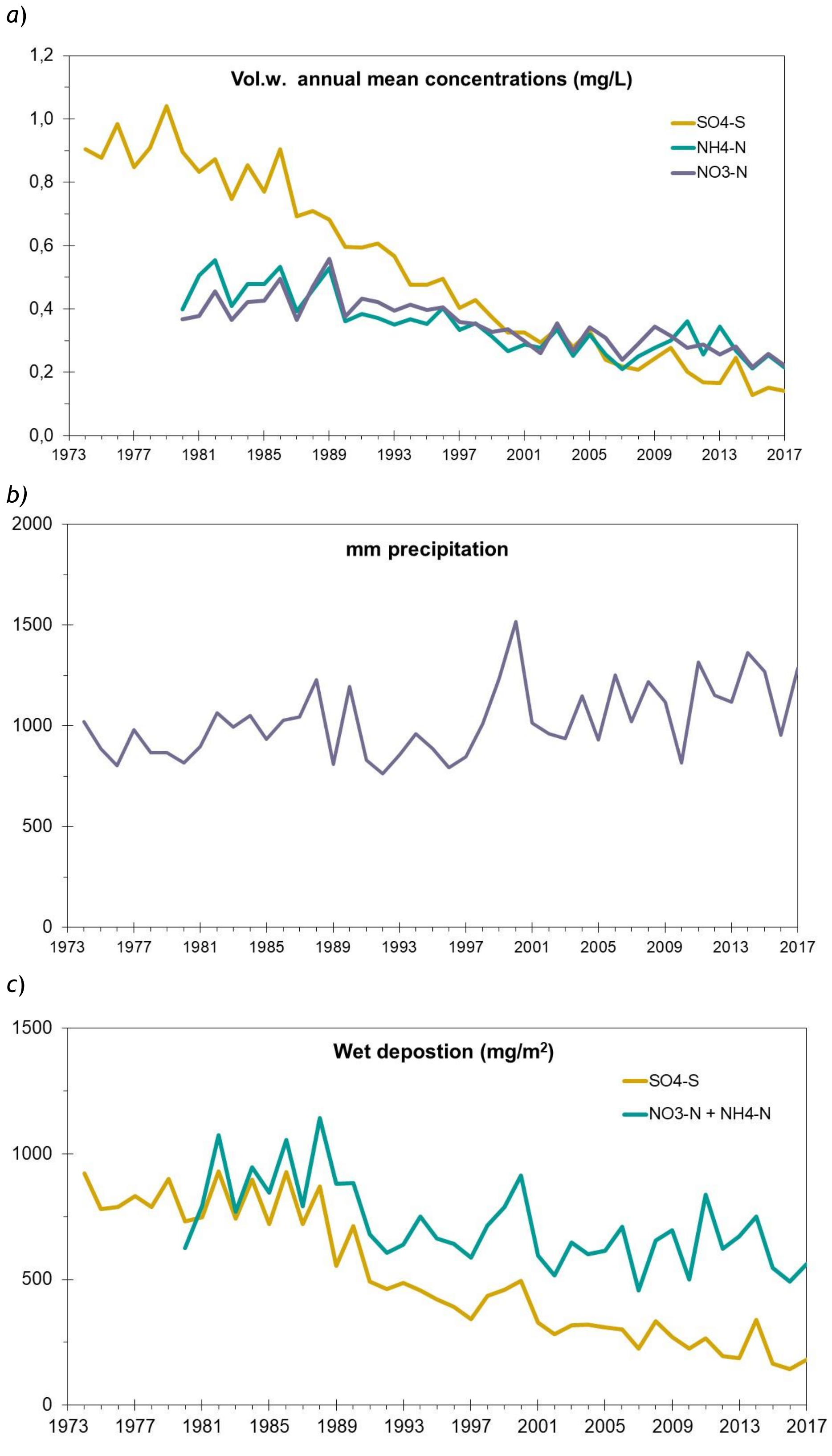
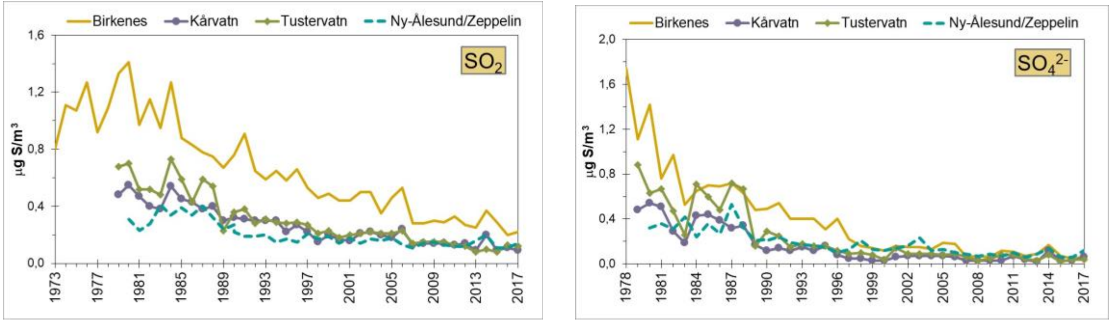


Figure 3.6: Average volume weighted annual mean concentrations (a), precipitation amount (b) and wet deposition (c) for sea salt corrected sulfate, nitrate and ammonium at five representative sites in southern Norway (Birkenes, Vatnedalen, Treungen, Gulsvik and Løken), 1974-2017.

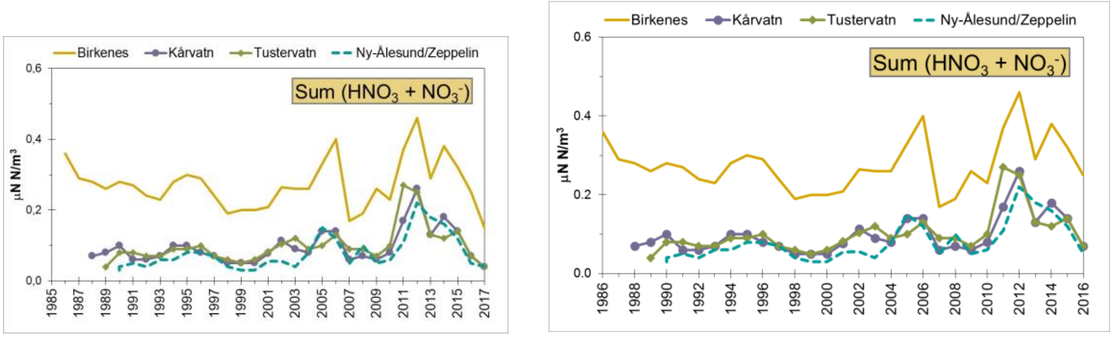
a) SO_2

b) SO_4 in aerosols



c) NO_2

d) sum (NO_3+HNO_3) in air



e) NH_4 in aerosols

f) sum (NH_4+NH_3) in air

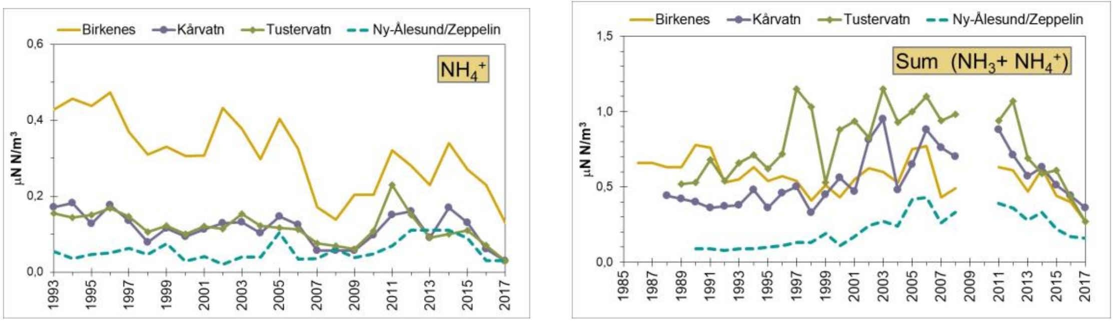


Figure 3.7: Annual mean concentrations of sulfur and nitrogen components in air at four Norwegian EMEP sites, 1973-2017.

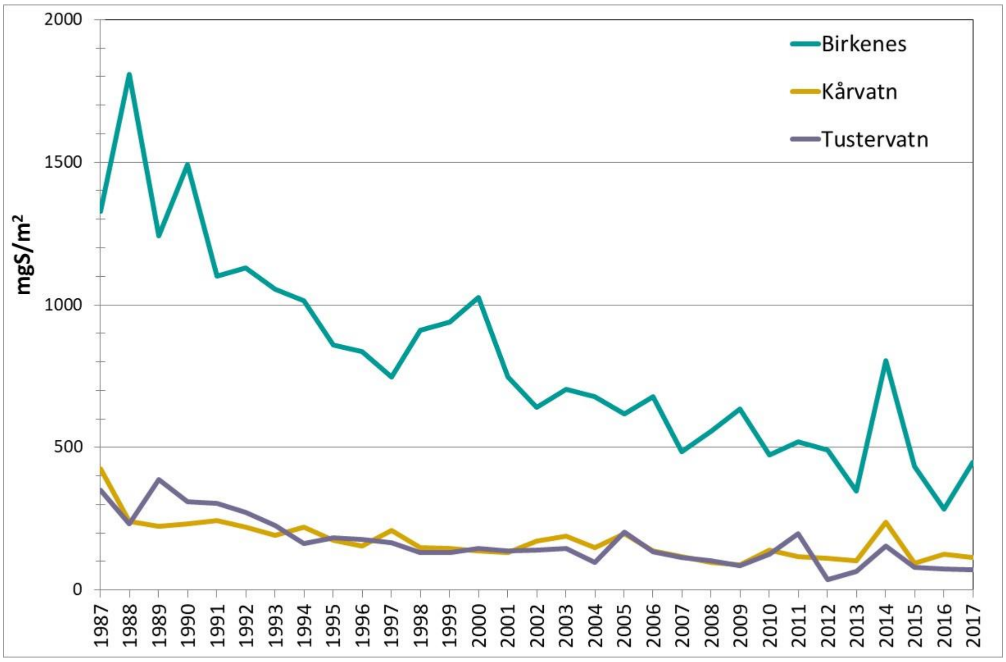


Figure 3.8: Trends in total deposition (wet + dry) of sulfur at three Norwegian EMEP sites, 1987-2017.

3.3 Summary

For most of the main inorganic components, the highest annual mean concentrations in 2017 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 2017 were in general a bit lower or equal compared to 2016, but the wet deposition was a bit higher due to relatively high precipitation amounts.

There are large reductions in sulfur in all parts of Norway, since 1980 more than 90%, since 1990 around 70% (depending on the compound), and since 2000 about 50-60% and from 2005 between 30-50%. Thus, most sites show smaller reduction trends than the European target of 59% emission reductions set by the Gothenburg protocol to be reached within 2020 using 2005 as the reference year.

Nitrate and ammonium concentrations in precipitation have decreased significantly at most sites in southern Norway, around 50% for both components since 1980, and somewhat less from 1990. The NO_2-concentration has also decreased significantly of the order of 36-67% from 1990. These observed reductions are in line with reported emission reduction at the European continent (Colette et al, 2015), although most sites show lower trends in oxidized nitrogen than the target of 43% reductions in NOx emissions set by the Gothenburg protocol.

4. EC and OC

4.1 Introduction

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

Annual and monthly mean concentrations of EC and OC in PM_{10} and $PM_{2.5}$ for 2017 are shown in Figure 4.1 and Table A.1.35:, whereas annual mean concentrations for EC and OC in PM_{10} and $PM_{2.5}$ for the period 2001 – 2017 are listed in Table A.1.36:.

Incidences of $PM_{2.5} > PM_{10}$ on a monthly basis are typically due to a different number of samples for the two size fractions, but for low levels, measurement uncertainties can have an influence as well, in particular for EC. OC in $PM_{10-2.5}$ 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: OC and EC) can be found in Annex 3.

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} (0.66 – 1.15 µg C/m^3) and $PM_{2.5}$ (0.50 – 0.74 µg C/m^3) at Norwegian rural background sites are amongst the lowest in Europe. Fine fraction OC (64 – 76%) was the major fraction of OC in PM_{10} at all sites on an annual basis. This is as expected as the major sources, primary emissions from combustion of fossil fuel and biomass and secondary particle formation from biogenic and anthropogenic precursors typically generate fine aerosol particles. Coarse fraction OC occasionally dominates on a monthly basis. This is observed for the second half of the vegetative season and is attributed to the presence of primary biological aerosol particles (PBAP).

The annual mean concentration of OC in PM_{10} at Hurdal was 60% higher than at Birkenes and 74% higher than at Kårvatn, and was attributed to higher levels of both its fine and coarse fraction (Table A.1.35:). We speculate that the more densely populated and anthropogenic influenced region surrounding the Hurdal site is the main explanation for the observed increment of fine fraction OC. This is also in line with the higher NO_2 concentrations seen for this site, which has been explained by high emissions from vehicular traffic in this region (see Chapter 3.1.2). Coarse OC are associated with PBAB, likely of local to regional origin, but there is no apparent explanation for why the source strength is stronger at Hurdal compared to the two others.

There was a seasonal variability with increased levels of OC in summer (April - September) compared to winter (October - March) for all sites and size fractions; the seasonality being substantially more pronounced for the coarse than the fine fraction, and with large variability between sites. This reflects increased levels of Secondary Organic Aerosols (SOA), and Biogenic Secondary organic Aerosols (BSOA) in particular, contributing to the fine fraction, and PBAP contributing to the coarse fraction during the vegetative season (See Yttri et al. 2011 a, b).

A certain level of covariance was observed between the sites, both with respect to seasonality and episodes of increased levels. Seasonal covariance is likely driven by the weather situation. As an example, temperature is decisive for the formation of SOA and pollen release in the summer half year as well as for the need for domestic heating in the winter half year. Episodes of long-range transported air pollution is well known to affect large regions. Finally, prolonged sampling time (here: weekly) could also contribute to mask differences between sites. Noticeably, the correlation seen for OC between the sites seems to be driven by its coarse fraction.

The annual mean concentration of OC in PM_{10}, $PM_{2.5}$ and $PM_{10-2.5}$ was within one standard deviation (±SD) of the long-term mean at all sites. The annual mean of OC was typically in the lower end of the long-term mean at Birkenes and Kårvatn, whereas it ranged around the long-term mean or higher at Hurdal. Note that the measurements for Hurdal and Kårvatn only dates back to 2010, whereas it dates back to 2001 for Birkenes.

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

The annual mean concentration of EC in PM_{10} (0.03 – 0.10 µg C/m^3) and $PM_{2.5}$ (0.04 – 0.09 µg C/m^3) at Norwegian rural background sites are amongst the lowest in Europe. EC is a result of incomplete combustion of fossil fuel and biomass and emissions are thus almost exclusively associated with the fine fraction of PM_{10}. EC levels at Hurdal were 80 - 100% higher than at Birkenes and 150 – 200% higher than at Kårvatn, considering both the PM_{10} and $PM_{2.5}$ size fractions. The wide ranges and differences between size fractions are misleading and result from the very low levels and “decimal-issues”. As argued for OC in Chapter 4.2, we assume that the higher levels of EC at Hurdal is caused by the more densely populated and anthropogenic influenced region surrounding the site; albeit crude, EC is regarded as a tracer of anthropogenic activity. EC was a minor contributor to the total carbon (TC) concentration; i.e., 6 – 8% (PM_{10}) and 6 – 11% ($PM_{2.5}$). The annual mean EC/TC ratio was below two standard deviations of the long-term EC/TC mean at Birkenes and below one standard deviation at Hurdal.

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

The annual mean concentration of EC was one standard deviation or below the long-term mean at all sites. All-time low annual means were observed for Birkenes, and for EC in $PM_{2.5}$ at Hurdal and Kårvatn. The annual mean EC in PM_{10} at Kårvatn equaled the previous all-time low, whereas at Hurdal, 2017 saw the second lowest annual mean ever.

4.4 Relative contribution of EC and OC to PM

The relative contribution of OC to PM_{10} (20 - 31%) and $PM_{2.5}$ (26 - 33%) annually was rather similar, and for Birkenes somewhat lower than for the two other sites, in particular for the PM_{10} size fraction. The highest OC fraction was seen for Kårvatn, but only marginally higher than at Hurdal. The OC fraction of PM_{10} was typically higher in summer than in winter, and largely explained by the coarse fraction, as the fine fraction was higher in winter for Birkenes and Kårvatn. The contribution of OC to PM showed a downward trend for PM_{10} (-7%) and an upward trend for $PM_{2.5}$ (3%) for 2001 – 2017 at Birkenes, but neither were statistically significant (Table 5.5.).

The relative contribution of OC to $PM_{10-2.5}$ was 11 - 26% on an annual basis, and the fraction was approximately 5 times higher in summer (20 – 32%) compared to winter (4 – 6%), thus explaining the more pronounced seasonality observed for OC in PM_{10} compared to $PM_{2.5}$. An upward trend (21%) was shown for the OC fraction in $PM_{10-2.5}$ at Birkenes for the period 2001 – 2017, but as for the OC fraction in PM_{10} and $PM_{2.5}$, the trend was not statistically significant.

EC accounted for 1.4 – 2.6% of PM_{10} annually and somewhat higher for $PM_{2.5}$ (2.6 – 3.8%), reflecting that EC is associated with fine aerosol particles. EC was more abundant in the winter-time aerosol (1.7 - 3.9% for PM_{10} and 3.4 – 6.7% for $PM_{2.5}$) than the summer-time aerosol (1.0 – 1.5% for PM_{10} and 1.3 – 2.4% for $PM_{2.5}$). A decrease in the relative contribution of EC to PM_{10} (-23%) and $PM_{2.5}$ (-12%) was observed for 2001 – 2017 at Birkenes, although only statistically significant for the PM_{10} size fraction.

4.5 Trends for concentrations of EC and OC

The Mann Kendall method described in Chapter 3.2 was used for trend analysis of concentrations of EC and OC. The shorter time series for the sites Hurdal and Kårvatn (7 years) allow for an assessment of the Birkenes site only (Table 4.1). The time series of OC in PM_{10}, $PM_{2.5}$ and $PM_{10-2.5}$, and that of EC in PM_{10} and $PM_{2.5}$, at the Birkenes Observatory are shown in Figure 4.1.

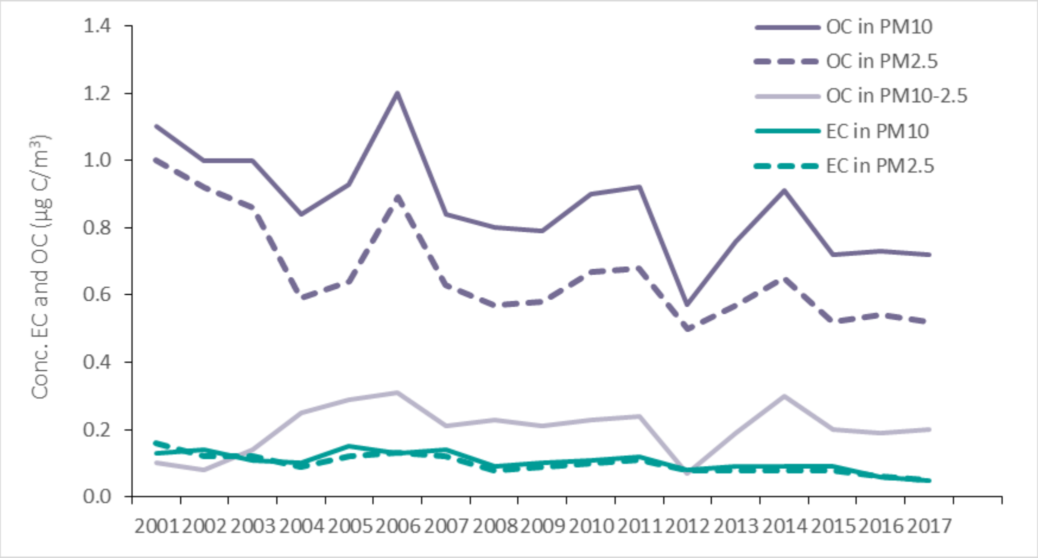


Figure 4.1: Annual mean time series of EC and OC, as observed at the Birkenes Atmospheric Observatory (2001 - 2017).

There was a statistically significant downward trend for the annual mean concentration of OC in both PM_{10} (-34%) and $PM_{2.5}$ (-46%) at Birkenes for the period 2001 – 2017. For OC in $PM_{10-2.5}$, a statistically non-significant increase of 20% was observed for the same period. EC showed a statistically significant downward trend for both PM_{10} (-46%) and $PM_{2.5}$ (-53%) for 2001 – 2017.

*Table 4.1: Trends in annual mean mass concentration of OC, EC and TC in PM10 (2001 - 2017) and PM2.5 (2001 - 2017) using Mann-Kendall test and Sen slope estimates; *** is significant level 0.001; ** significant level 0.01; * significant level 0.05; + significant level 0.1.*

Site	PM_{10}	% change	$PM_{2.5}$	% change
Birkenes				
OC	**	-34%	**	-46%
EC	**	-46%	***	-53%
TC	**	-40%	**	-44%

Trends are calculated for time series extending 10 years

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

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

The annual mean concentration of levoglucosan in PM_{10} observed at the Birkenes Observatory was 9.1 ng m^{-3} (Table 4.2). The seasonality was pronounced with higher levels in the heating season during winter (16.8 ng m^{3}) compared to summer (2.4 ng m^{-3}) in particular. Low levoglucosan levels in summer may partly reflect increased degradation by the OH radical, but higher emissions from residential wood burning in winter compared to summer explains most of the seasonality.

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

We estimate that biomass burning contributed 12-17% to OC and 35% to EC, annually, considering both PM_{10} and $PM_{2.5}$. The fraction attributed to biomass burning in winter was around 30% for OC and around 50% for EC, whereas it was <5% (OC) and <15% (EC) in summer, considering both size fractions. Spring and fall are transition seasons with relative contributions lower than in winter and higher than in summer. Biomass burning can be the major source of both OC and EC on a weekly basis in the heating season; i.e. emissions are attributed to wood burning for residential heating.

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

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

Year	Season	Levoglucosan	Mannosan	Galactosan
2017	Winter	16.8	2.7	0.70
	Spring	6.8	1.0	0.24
	Summer	2.4	0.49	0.06
	Fall	9.2	1.5	0.33
	Annual	9.1	1.5	0.35

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

4.7 Summary

Observed annual mean concentrations of carbonaceous aerosol in the Norwegian rural background environment are amongst the lowest in Europe (OC < 1.2 µg C m^{-3} and EC < 0.1 µg C m^{-3}), and a statistically significant downward trend was observed for OC (-34 - -46%) and EC (-46 - -53%) in PM_{10} and $PM_{2.5}$ for the period 2001 – 2017.

Measurements complementary to OC and EC are needed for an assessment of sources. Previous source apportionment studies of the carbonaceous aerosol in the Norwegian rural background environment show that natural sources, biogenic secondary organic aerosol (BSOA) and primary biological aerosol particles (PBAP), dominate the organic aerosol in summer, whereas anthropogenic sources, fossil fuel and biomass burning, dominate in winter. With a few exceptions, elemental carbon can be considered exclusively anthropogenic.

Estimates based on levoglucosan measurements suggest that biomass burning contributed 12-17% to OC and 35% to EC at the Birkenes Observatoty annually, considering both PM_{10} and $PM_{2.5}$, and around 30% for OC and around 50% for EC in winter.

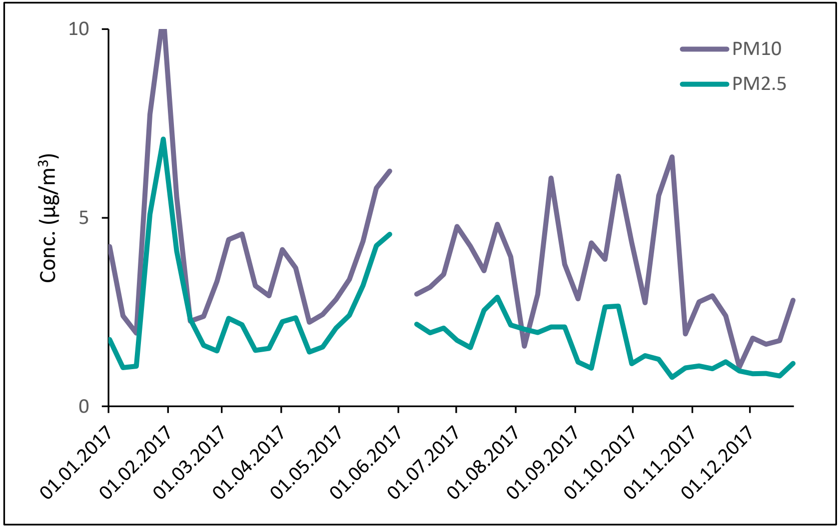
5. Particulate matter, mass concentrations

5.1 Introduction

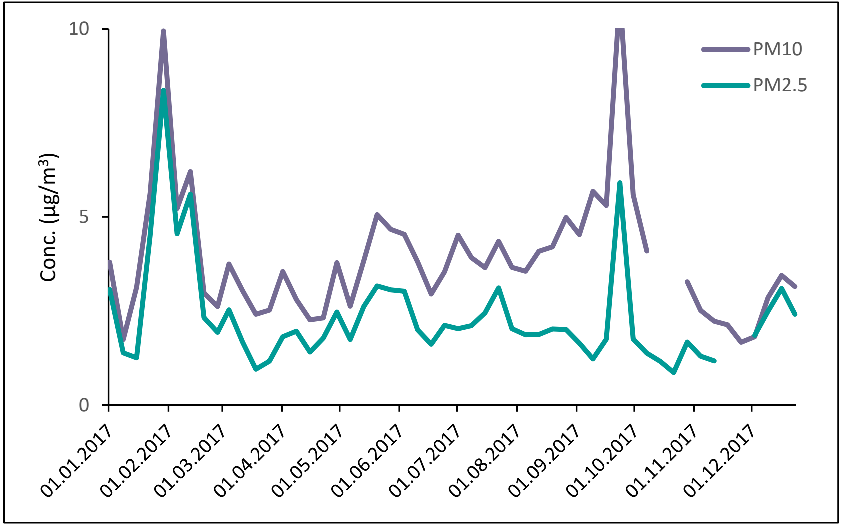
Monitoring of the PM_{10} and $PM_{2.5}$ mass concentration takes place at three rural background sites; the Birkenes Observatory and the Hurdal and Kårvatn sites. The time series at Birkenes dates back to 2000/1, whereas measurements were initiated in 2010 at the two other sites. At Birkenes, high time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

Annual and monthly mean mass concentrations of PM_{10}, $PM_{10-2.5}$ and $PM_{2.5}$ for 2017, obtained by gravimetric measurements, are shown in Table A.1.37:, whereas annual mean mass concentrations of PM_{10}, $PM_{10-2.5}$ and $PM_{2.5}$ for the time period 2000 – 2017 are listed in Table A.1.38:. Time series of PM_{10} and $PM_{2.5}$ for 2017 are shown in Figure 5.1. Note that $PM_{10-2.5}$ 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 $\Sigma PM_{2.5}$, $PM_{10-2.5} \neq PM_{10}$ on a monthly basis are typically due to a different number of samples for PM_{10} and $PM_{2.5,}$ but for low levels measurement uncertainties can have an influence as well. Annual means of aerosol particle number (*N*) concentrations for ultrafine ($0.02 < D_p < 0.1$ µm), accumulation mode ($D_p = 0.1 - 1.0$ µm) and coarse mode ($D_p = 1.0 – 10$ µm) particles, are shown in Table 5.4. 24 hours mean concentrations of PM_{10} derived from high time resolution measurements, were used to asses violation of national and international limit values and air quality guidelines. Background information on the PM can be found in Annex 3.

a) Birkenes



b) Hurdal



c) Kårvatn

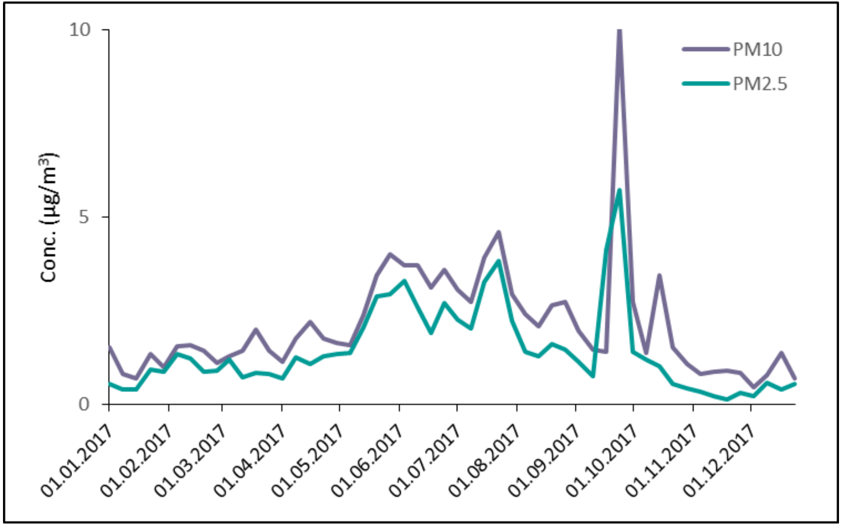


Figure 5.1: Time series of PM_{10} and $PM_{2.5}$ mass concentration for Birkenes (a), Hurdal (b) and Kårvatn (c) for 2017. Unit µg/m^3. Note that the time series have been harmonized in time for comparability; i.e. they all start on the same date (01.01.2017).

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

The annual mean mass concentration of PM_{10} (2.1 - 3.8 µg/m^3) and $PM_{2.5}$ (1.5 – 2.4 µg/m^3) at the Norwegian rural background sites are amongst the lowest in Europe. $PM_{2.5}$ was the major fraction of PM_{10} at all sites on an annual basis, accounting for 56% at Birkenes, 63% at Hurdal and 71% at Kårvatn. $PM_{10-2.5}$ was occasionally the major fraction of PM_{10} on a monthly basis, and are typically attributed to natural sources, such as sea salts and primary biological aerosol particles (PBAP).

The annual mean concentration of PM was the lowest reported so far for all sites and size fractions except for $PM_{10-2.5}$ at the Hurdal site. The annual mean was more than 60% (PM_{10}) and 40% ($PM_{2.5}$) lower at Birkenes compared to the long-term mean, and 20-30% lower at the Hurdal and Kårvatn sites. Note that the measurements for Hurdal and Kårvatn dates back to 2010, whereas measurements at Birkenes were initiated in 2000/2001.

Higher levels of PM_{10} at Birkenes compared to Hurdal and Kårvatn has been consistent in previous years, however, 2017 was the first year where the PM_{10} annual mean was highest at Hurdal, although marginally only. This is partly explained by the $PM_{10-2.5}$ fraction, which annual mean was only 0.1 µg m^{-3} higher at Birkenes than in Hurdal in 2017, compared to 0.5 – 1.6 µg m^{-3} in previous years, and the $PM_{2.5}$ fraction, which was highest at Hurdal, as seen for previous years.

The higher $PM_{10-2.5}$ fraction at Birkenes was largely attributed to the sea salt aerosol, which was 3-4 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. However, coarse fraction organic matter (OM), dominated by PBAP, was more than twice as high at Hurdal compared to Birkenes and Kårvatn, thus largely counteracting the lower sea salt aerosol contribution.

The annual mean $PM_{2.5}$ concentration was higher at Hurdal compared to Birkenes and Kårvatn, which is consistent with previous years. For Kårvatn the difference is explained by lower levels of OM, EC and secondary inorganic aerosol constituents (SIA) (i.e. SO_4^{2-}, NO_3^- and NH_4^+, typically residing in the fine fraction of PM_{10}). SIA levels are higher at Birkenes than at the two other sites, particularly compared to Kårvatn, even though a larger fraction of SIA, and NO_3^- in particular, likely is associated with the coarse fraction of PM_{10} at BirkenesThe higher PM2.5 levels at Hurdal compared to Birkenes is caused by higher OM levels. The higher $PM_{2.5}$ concentration at Hurdal compared to Birkenes is caused by a higher OM level. Differences in the OC to OM conversion factor, a factor used to account for other elements than carbon associated with OC, could contribute to the observed differences as well, but remains speculative.

The 2017 PM_{10} and $PM_{2.5}$ time series at Birkenes were episodic (Figure 5.1), reflecting episodes of long-range atmospheric transport, but also emissions from local to regional scale sources, such as e.g. sea spray. Some of these periods observed at Birkenes were also seen at Hurdal, and to some extent at Kårvatn. Weekly mean concentrations of PM_{10} exceeding 10 µg m^{-3} were observed at all sites, but not for $PM_{2.5}$. The highest weekly mean (12.9 µg m^{-3}) was observed at Birkenes.

Secondary inorganic aerosol (SIA) was the major fraction of PM_{10} for two of the three samples included in the 95 percentile at Birkenes (i.e. when PM_{10} levels were elevated), although nearly equaled by sea salt aerosol in one of them, whereas the last one was dominated by organic matter (OM). At Hurdal and Kårvatn, the highest weekly means were all dominated by OM, except one at the Hurdal site, which SIA dominated, and at Kårvatn they all appeared in the vegetative season.

The fine fraction of PM_{10} was typically the most abundant when peak levels of PM_{10} were observed, sometimes accounting for as much as 90%, though this is not always the case. Samples where the fine fraction is marginally higher compared to the coarse fraction are observed, and even cases where the fine fraction is nearly negligible. This reflects a noticeable influence of coarse fraction PM as well, originating mainly from sea salt aerosol, PBAP, and NO_3^-.

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

5.3 Trends

The Mann Kendall method described in Chapter 3.2 was used for trend analysis of PM concentrations. Only time series extending 10 years was assessed; i.e. Birkenes (Table 5.1). A statistically significant downward trend was observed for the annual mean concentration of PM_{10} at Birkenes, corresponding to a decrease of -31%. The observed downward trend for $PM_{2.5}$ was also statistically significant, corresponding to a decrease of -45%. A non-significant increase of 12% was calculated for $PM_{10-2.5}$.

*Table 5.1: Trends in annual mean mass concentration of PM_{10} (2000 - 2017) and $PM_{2.5}$ (2001 - 2017) at Birkenes) using Mann-Kendall test and Sen slope estimates; *** is significant level 0.001; ** significant level 0.01; * significant level 0.05; + significant level 0.1.*

Site	PM_{10}	% change	$PM_{2.5}$	% change
Birkenes	*	-31%	**	-45%

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

The EU annual limit value for PM_{10} and $PM_{2.5}$ (See Table 5.2 for EU limit values and Air-Quality Guidelines for PM_{10} and $PM_{2.5}$) was far from being violated at any of the three sites; the highest annual mean concentrations observed being approximately 10% of the annual limit values. This was also the case when compared to the WHO Air-Quality Guidelines (AQG); the highest annual mean concentrations accounting for 19 – 24% of the annual AQG. New national limit values for PM_{10} and $PM_{2.5}$ were implemented 1st of January 2016 (Table 5.2). These are less stringent than the WHO AQG, and thus far from being violated at any of the three sampling sites in 2017. 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 2017, accounted for no more than 19% and 30% of the PM_{10} and $PM_{2.5}$ National AQG, respectively.

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$^{1)}$		
PM_{10}	30 µg/m^3	20 µg/m^3
$PM_{2.5}$	15 µg/m^3	8 µg/m^3

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

5.5 Chemical composition of particulate matter

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

The annual mean chemical mass composition of PM_{10} is shown in Figure 5.2. The speciated mass explained 63 – 88% of the annual mean concentration of PM_{10} for the three sites, approaching full mass closure (85 – 100%) when allowing for other elements than carbon for

OC and EC. The PM_{10} SIA fraction (and levels) was noticeably higher at Birkenes (37%) compared to Hurdal (23%) and Kårvatn (20%), reflecting the proximity of Birkenes to important SIA-precursor source regions in continental Europe. For the first time since 2010, SO_4^{2-} was the most abundant single (SIA) species at Birkenes, reflecting a reduction in the NO_3^- concentration rather than the level of SO_4^{2-} increasing. At Hurdal, 2017 was the second year SO_4^{2-} exceeded NO_3^-, as emissions from the Bárðarbunga volcano (Iceland) caused SO_4^{2-} to be higher than NO_3^- in 2014. SO_4^{2-} was also higher than NO_3^- at Kårvatn. The relative composition of SIA was highly similar at Birkenes and Hurdal, whereas SO_4^{2-} was relatively larger than both NO_3^- and NH_4^+ at Kårvatn, compared to the two other sites.

Converting OC to OM using a factor of 1.7 (Yttri et al., 2007), made OM (53%) more than twice as abundant as SIA at Kårvatn, nearly (OM = 51%) twice as high as SIA at Hurdal, whereas OM (34%) nearly equaled the SIA contribution at Birkenes. The higher relative contribution of EC at Hurdal (2.9%) compared to Kårvatn (2.1%) and Birkenes (1.5%) is consistent with previous years, likely reflecting the more densely populated and anthropogenic influenced region surrounding the Hurdal site.

Situated approximately 20 km from the coastline, Birkenes experienced a substantial 27% sea salt aerosol contribution to PM_{10}, which is 1.6 times higher than at Kårvatn and 4.5 times higher than at Hurdal. The sea salt aerosol fraction of PM_{10} increases steadily at Birkenes, partly due to an increased sea salt aerosol level, but also due to lower PM_{10} levels.
Both the relative contribution of OC (20%) and sea salt aerosol (27%) to PM_{10} in 2017 were higher than + one standard deviation of the long-term mean (±SD) at Birkenes; Even + two standard deviations for OC. For the sea salt aerosol, this contributes to the significant upward trend observed for this fraction (Table 5.3) for the period 2001 - 2017. Despite the substantial drop in the NO_3^- level for 2017, there is still a significant upward trend for this species for the period 2001 – 2017.

The SO_4^{2-} (19%) and EC (1.4%) fractions of PM_{10} were the only ones with a statistically significant downward trend, but only the EC fraction had an annual mean for 2017 that was below one standard deviation of the long term mean. TC is the most robust species obtained from TOA, as it is not associated with the uncertainties in the split between OC and EC; No statistically significant up or downward trend was observed for the fraction of TC in PM_{10}, nor in $PM_{2.5}$.

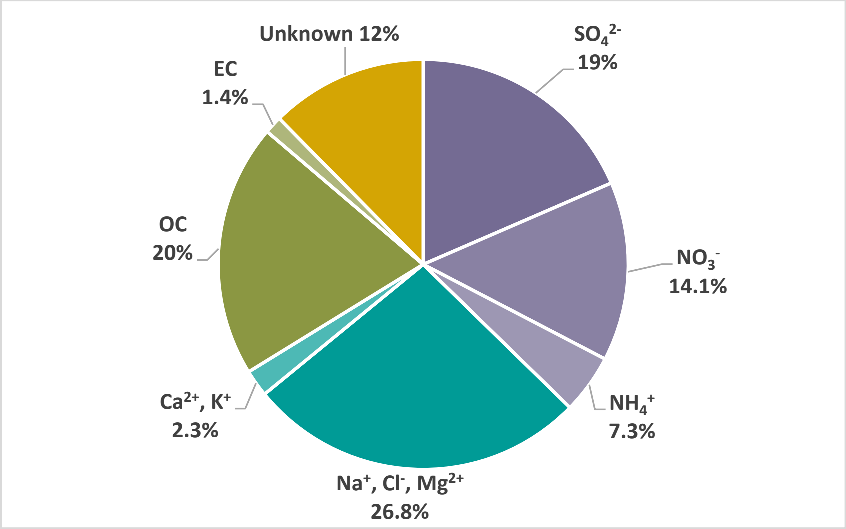
Based on levoglucosan (Table 4.2) we estimate that biomass burning emissions contributed 6-10% to PM annually, considering both PM_{10} and $PM_{2.5}$. The fraction attributed to biomass burning in winter was 10-17%, whereas it was 1.5-2.5% in summer, considering both size fractions. Spring and fall are transition seasons with relative contributions lower than in winter and higher than in summer. Biomass burning occasionally exceeded 20% on a weekly basis, all in the heating season, thus emissions are attributed to wood burning for residential heating.

*Table 5.3: Trends in relative contribution of selected aerosol particle species and fractions to mass concentration of PM_{10} and $PM_{2.5}$ using Mann-Kendall test and Sen slope estimates; *** is significant level 0.001; ** significant level 0.01; * significant level 0.05; + significant level 0.1.*

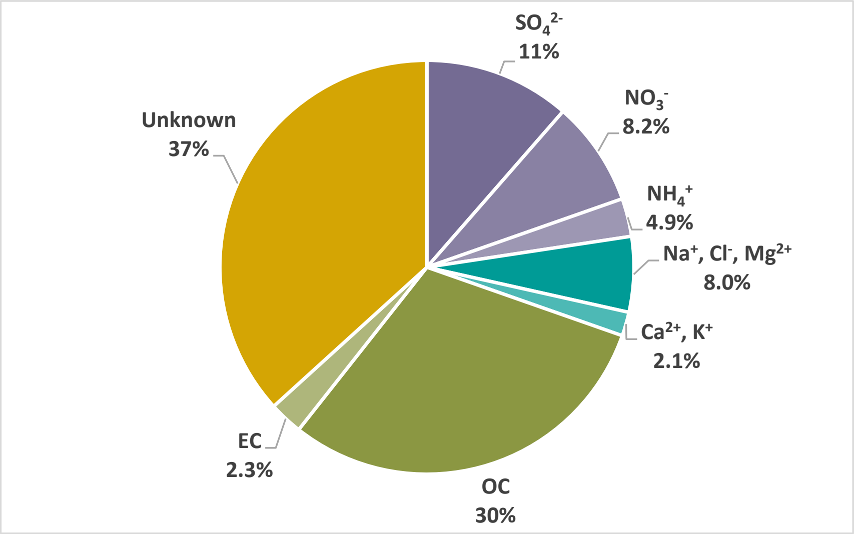
Site	Species/Fraction	Time period	Change (%)	
Birkenes	SO_4^{2-} to PM_{10}	2001 – 2017	*	-35%
	NO_3^- to PM_{10}	2001 – 2017	**	112%
	NH_4^+ to PM_{10}	2001 – 2017		16%
	$\Sigma Na^+, Cl^-, Mg^{2+}$	2001 – 2017	***	183%
	OC_{PM10} to PM_{10}	2001 – 2017		-7%
	EC_{PM10} to PM_{10}	2001 – 2017	+	-23%
	TC_{PM10} to PM_{10}	2001 – 2017		-20%
	$OC_{PM2.5}$ to $PM_{2.5}$	2001 – 2017		3%
	$EC_{PM2.5}$ to $PM_{2.5}$	2001 – 2017		-12%
	$TC_{PM2.5}$ to $PM_{2.5}$	2001 – 2017		3%

Trends are calculated for time series extending 10 years

a) Birkenes



b) Hurdal



c) Kårvatn

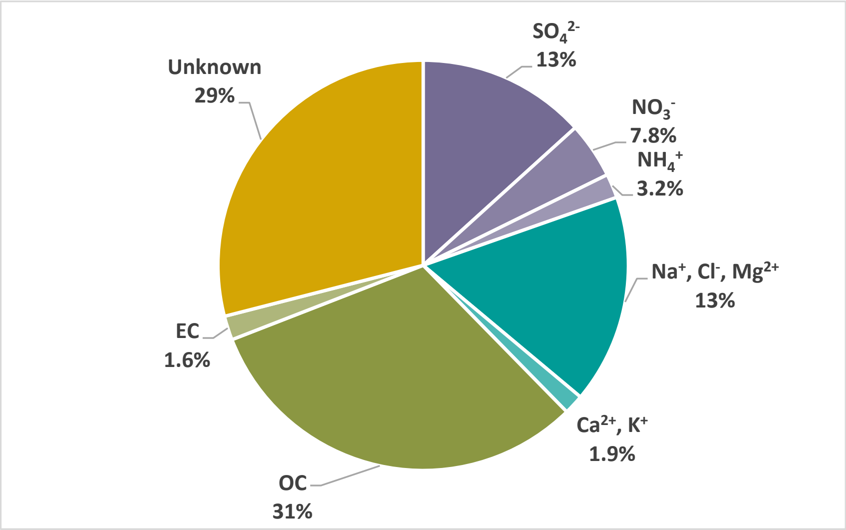
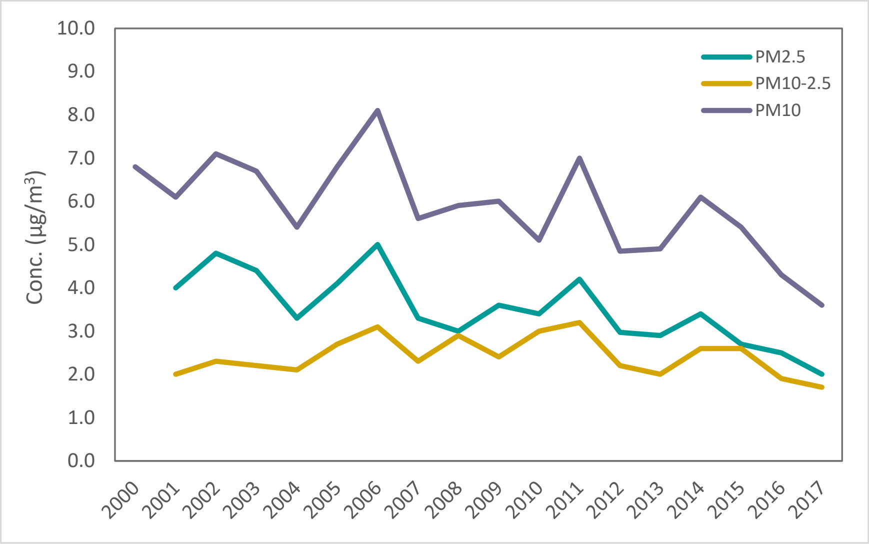
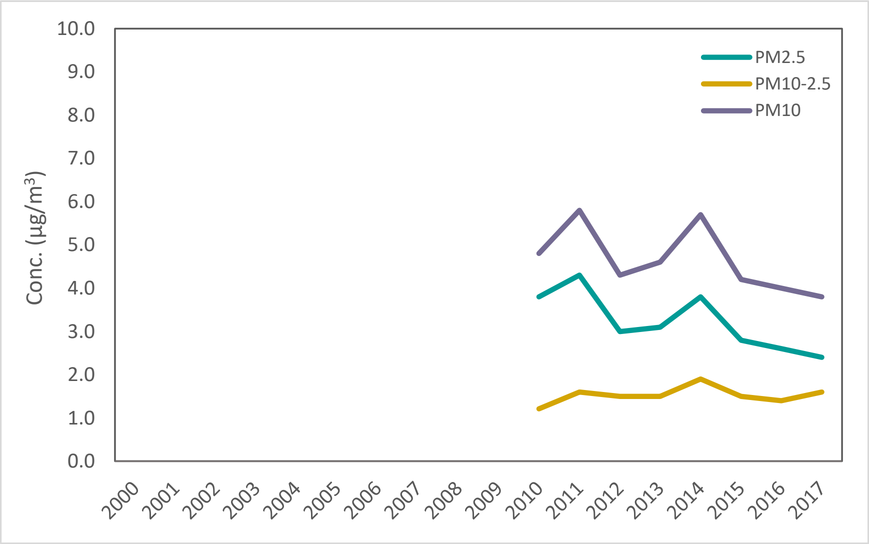


Figure 5.2: Annual mean chemical composition of PM_{10} at the Birkenes Observatory a), the Hurdal site b) and the Kårvatn site c) for 2017. The annual mean mass concentration for PM_{10} in 2016 was 3.6 µg/m^3 at the Birkenes Observatory, 3.8 µg/m^3 at the Hurdal site, and 2.1 µg/m^3 at the Kårvatn site.

a) Birkenes



b) Hurdal



c) Kårvatn

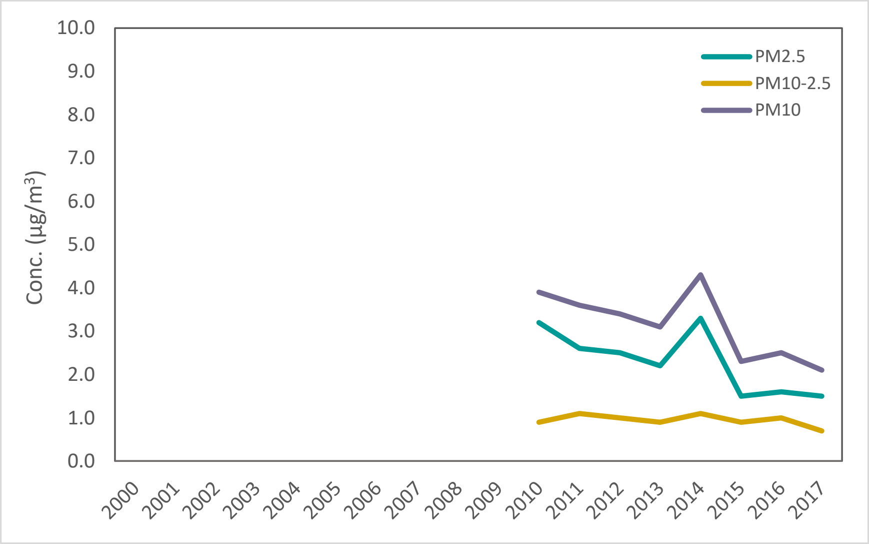


Figure 5.3: Annual mean time series of PM_{10}, $PM_{2.5}$ and $PM_{10-2.5}$ mass concentration for Birkenes (a), Hurdal (b) and Kårvatn (c) for 2001 - 2017. Unit µg/m3.

5.6 Particle number concentrations

The annual mean particle number concentration for the size range 0.02 – 10 µm (N_{Tot}) at Birkenes for 2017 was 14% lower than the long-term mean, but still within one standard deviation of the long-term mean. The annual mean N_{UF} (0.01 – 0.1 µm) (12% lower) and N_{Acc} (0.1 – 1.0 µm) (22% lower) size fractions 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, dominates the particle number concentration. The annual mean N_{CM} (0.1 – 1.0 µm) size fraction was 27% lower than the long-term mean, but has no influence on N_{Tot}. The low annual mean for 2017 was mainly attributed to low levels in spring and to some extent in fall. The low level in spring is explained by low data capture in May, when levels are high, due to instrument inter-calibration.

78% of N_{Tot} was attributed to $\mathrm{N_{UF}}$ and 22% to $\mathrm{N_{Acc}}$ at Birkenes for 2017, whereas a negligible fraction was assigned to particles in the range 1.0 – 10 µm; i.e. the coarse mode. The fraction of N_{tot} attributed to N_{UF} and N_{Acc} do not vary much between years, whereas the variability is slightly higher for N_{CM}, due to low levels and thus larger uncertainty. N_{UF} was the dominating fraction regardless of season, accounting for 70 – 80% of N_{tot}. The 80% contribution of N_{UF} to N_{tot}, and the corresponding 20% contribution of N_{Acc} to N_{Tot}, in summer 2017 is the highest and lowest percentages reported so far. Still, these are not considered major deviations compared to previous years. Typically, the N_{UF} fraction drops in winter, whereas the N_{Acc} fraction increases correspondingly, so also for 2017.

Table 5.4: Number concentrations for ultrafine, accumulation mode and coarse mode particles at Birkenes for 2010 – 2017 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* = 0.01 - 10 µm)**
2010	973	73	362	27	0.256	0	1336
2011	1047	74	371	26	0.565	0	1418
2012	889	77	263	23	0.375	0	1152
2013	1020	77	304	23	0.391	0	1324
2014	1279	74	456	26	0.338	0	1735
2015	1326	77	390	23	0.340	0	1717
2016	1063	75	357	25	0.392	0	1421
2017	943	78	272	22	0.267	0	1216

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 (< 4 µg/m^3), and did not exceed international and national limit values and air quality guidelines in 2017.

Secondary inorganic aerosol constituents dominated PM_{10} at the southernmost site, reflecting the proximity to major anthropogenic emission regions in continental Europe. The relative contribution if organic aerosol is marginally lower than the inorganic fraction, while sea salt constitutes slightly less. Organic aerosol dominated at the two other sites.

There was a significant downward trend for both PM_{10} and $PM_{2.5}$ (-31% - -45%) for the period 2000/01 – 2017, which is in line with emission reductions of primary and secondary sources in Europe. However, measurements of source specific compounds and high time-resolution measurements along with transport modelling, are needed for a more detailed assessment of sources and source regions. Estimates based on levoglucosan measurements, suggest that biomass contributed 6-10% to PM annually, considering both PM_{10} and $PM_{2.5}$. The fraction attributed to biomass burning in winter was 10-17%, whereas it was 1.5-2.5% in summer, considering both size fractions.

6. Ground-level ozone

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

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

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

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

6.1 Monitoring network

Measurements of ozone has been going on in Norway since 1975, first in Telemark and from 1977 also around the Oslo fjord and in subsequent years extended to the whole country. EU's air quality directive (AQD) (EU, 2008: Directive 2008/50/EC) which is implemented in

Norwegian legislation contains the thresholds and objectives regarding ozone levels and the requirements as to the number of monitoring sites. According to the directive, the country should be divided into a number of zones, and the zones presently used in Norway are shown in Table 6.1. The stations in the individual zones as of 2017 are indicated in the map in chapter 1 (Figure 1.1) and the details regarding the zone characteristics are given in Table 6.1. The directive gives requirements for the minimum number of monitoring sites within each zone and for the country as a whole, which is reflected in Table 6.1. As seen from Table 6.1 there is a small shortage of stations for ozone and VOC relative to the directive's requirements.

The ozone monitoring network in 2017 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. In addition there were a few urban sites relevant for the AQD, but not presented in this work, but indicated in Table 6.1.

Table 6.2 shows the monitoring sites and data capture for 2017, which was 95% or higher except for Haukenes and Zeppelin Mountain. The particularly low data capture at the Zeppelin Mountain was due to a failure in the inlet line in the period from early June to late November. The reduced data capture at Haukenes was due to missing data in the period from middle of August to the end of September.

Table 6.1: The Norwegian zones and the requirements as to the number of monitoring sites based on EU's ambient air quality directive, and stations in 2017 available in these zones. Zones 1-3 are just for information and not relevant for this report.

Zone	**Region**	**Type**	**Area (km^2)**	**Population (1000)**	**Ozone 1)**	**VOC 1)**	**Stations**
1	Greater Oslo	Urban/suburban		1030	2 (3)	0 (1)	Lommedalen2) Grønland2)
2	Bergen	Urban/suburban		270	1 (1)		Rådhuset2)
3	Trondheim	Urban/suburban		180	0 (0)		
4	Østlandet	Rural	110 000	1800	4 (4)		Prestebakke Hurdal Haukenes Birkenes
5	Rogaland, Hordaland, Sogn- og Fjordane	Rural	43 000	790	1 (2)		Sandve
6	Møre og Romsdal, S- og N-Trøndelag, Nordland	Rural	94 000	760	2 (2)		Kårvatn Tustervatn
7	Troms, Finnmark	Rural	74 000	230	0 (1)		
Total	Whole country	Rural background	385 000		11 (13)		All above + Zeppelin

1) The present number of stations with the EU directive's requirements in brackets.
2) Urban stations not discussed in this report

Table 6.2: Ozone monitoring sites and data capture based on hourly values in 2017.

St.nr.	Station name	Period	Data capture
NO0043	Prestebakke	01.01.17- 31.12.17	100%
NO0056	Hurdal	01.01.17 - 31.12.17	99%
NO0489	Haukenes	01.01.17 - 31.12.17	88%
NO0002	Birkenes II	01.01.17 - 31.12.17	95%
NO0052	Sandve	01.01.17 - 31.12.17	95%
NO0039	Kårvatn	01.01.17 - 31.12.17	99%
NO0015	Tustervatn	01.01.17 - 31.12.17	99%
NO0042	Zeppelin	01.01.17 - 31.12.17	47%

The measuring method and principles are given in Annex 3.

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 2017

Time series of daily maximum ozone values through 2017 are given in Figure 6.1 together with the climatological mean seasonal cycle (30 days running mean) based on the previous 17 years of data. Note that for Birkenes, the 2017 data are from the Observatory (Birkenes II), whereas the climatological means are based on measurements at the old location, which gave systematically lower levels due to stronger surface dry deposition.

The time series indicate that 2017 was a year with very few high peak level ozone episodes. Except for a short term peak in the middle of May at Prestebakke the data shows only minor “ripples” above the baseline.

The summer of 2017 was presumably not very favourable for photochemical ozone episodes in Norway and the time series in *Figure 6.1* reflects this. Although the mean temperatures in the summer was close to normal in the southern part, the lack of lasting high-pressure episodes lead to very few episodes with elevated ozone levels.

The seasonal cycles in ground-level ozone in 2017 are shown in Figure 6.2 together with the climatological mean seasonal cycles for the period 2000-2016 for each site. These figures give the 14 days centred running mean concentrations.

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 2017 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.

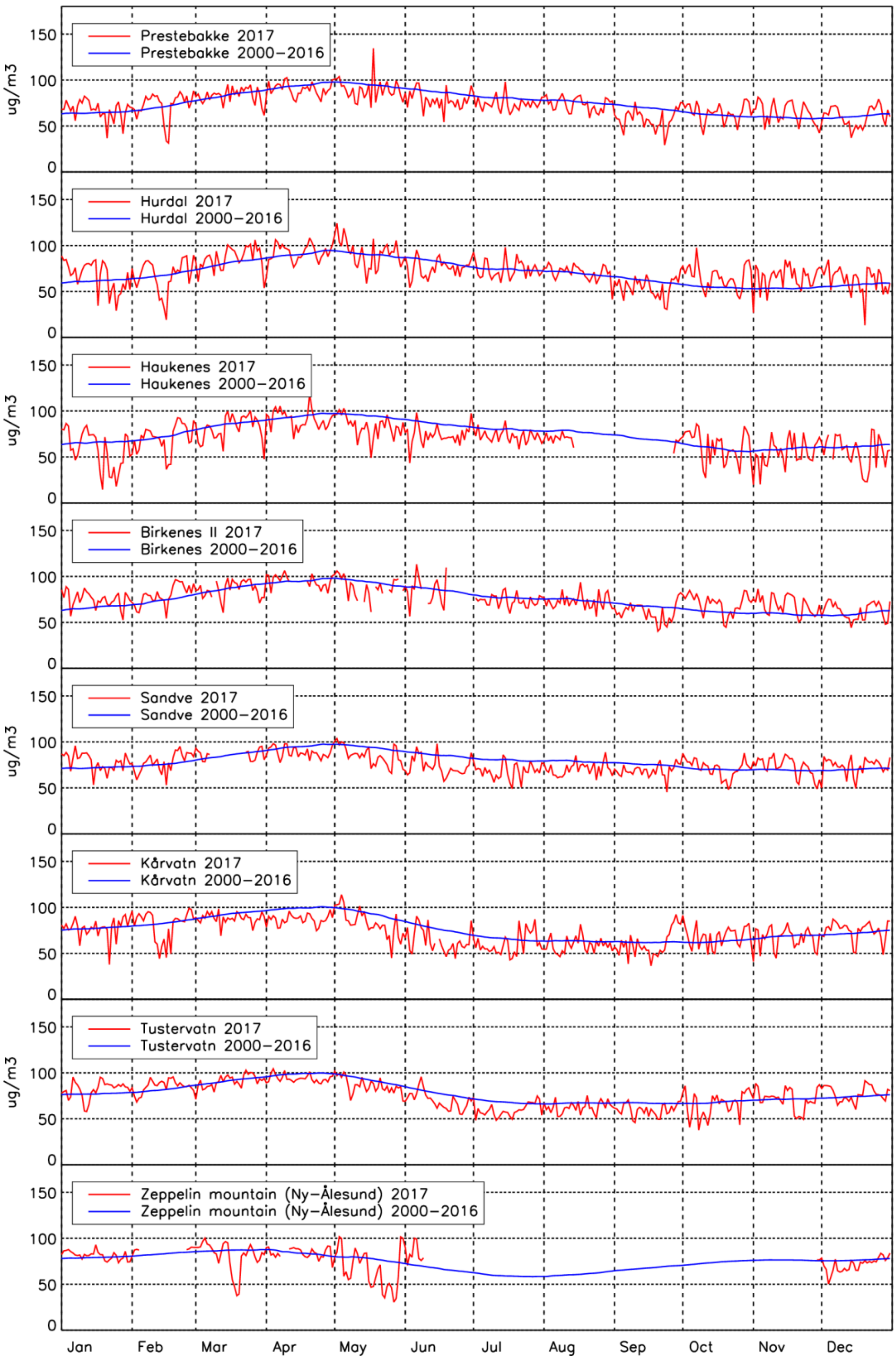


Figure 6.1: Daily maximum ozone concentrations in 2017 (red) together with the 30 days' running mean of the daily maxima for the years 2000-2016 (blue).

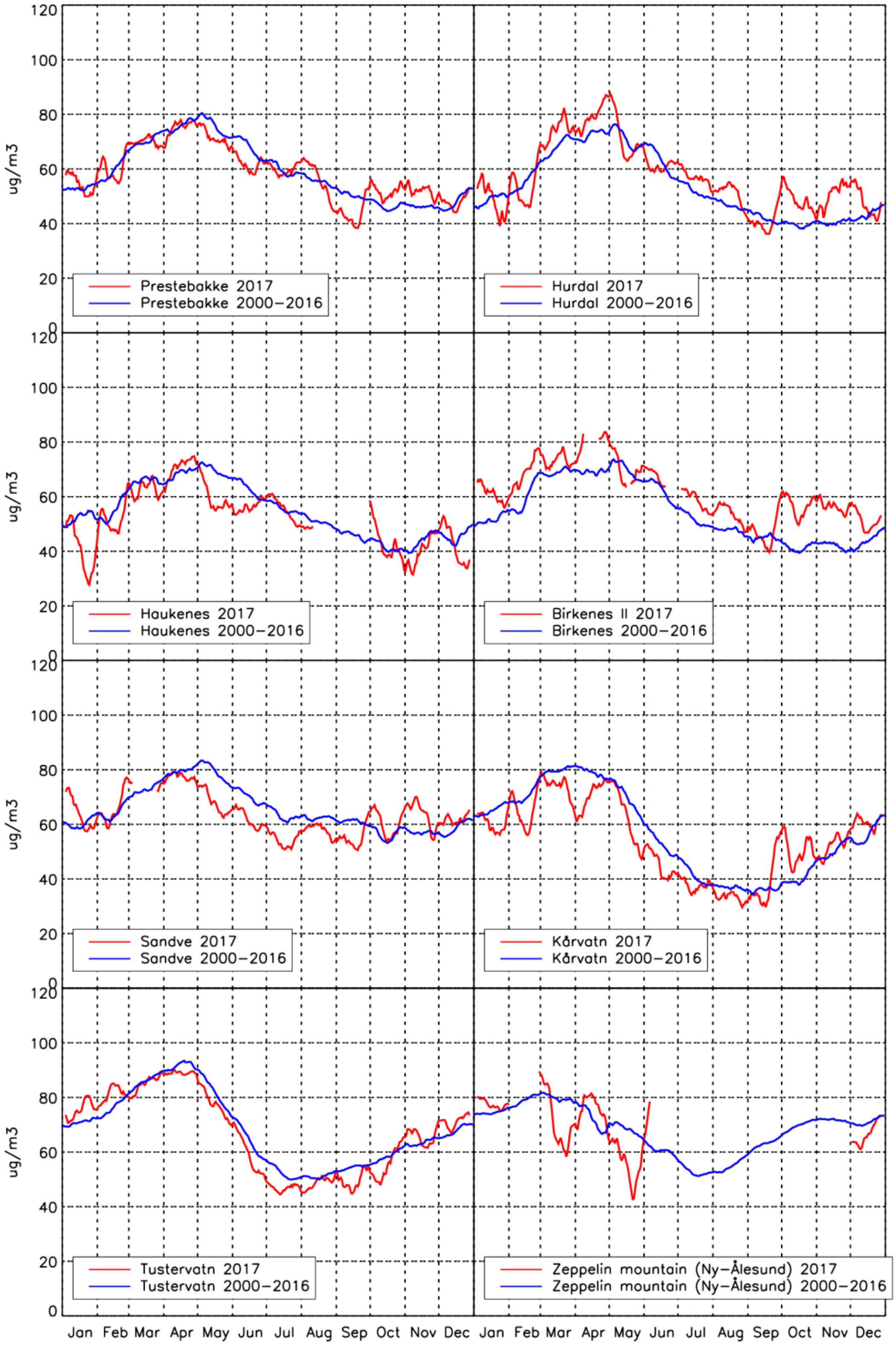


Figure 6.2: The 14 days' running mean ozone concentrations in 2017 (red) together with the corresponding mean concentrations based on all years 2000-2016 (blue).

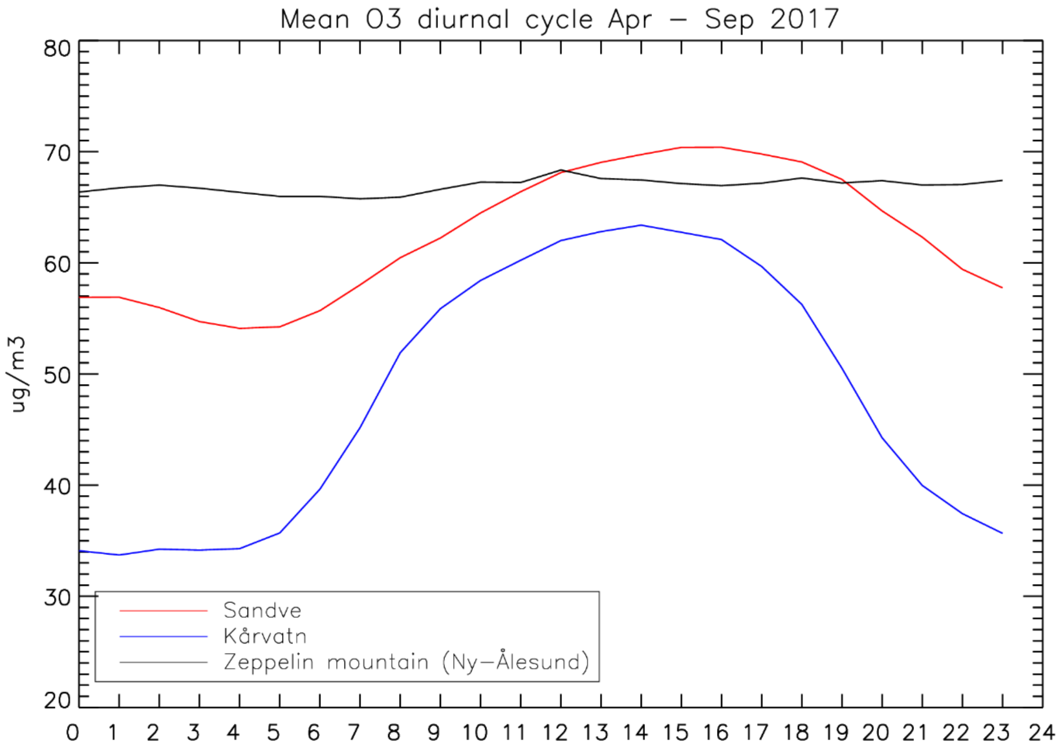


Figure 6.3: The mean diurnal cycle in ozone at three of the monitoring sites; Sandve, Kårvatn and Zeppelin Mountain during April-September 2017.

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 6.3. 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 6.3*.

Table 6.3: Limit values for ground-level ozone for the protection of human health.

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

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

The exceedances of the limit values for health are given in Table 6.4. The table shows the number of days with exceedance of WHO's air quality guideline of 100 µg/m^{3}and EU's long-term objective of 120 µg/m^3. The number of hours with exceedance of EU's information threshold of 180 µg/m^3 is also given as well as the annual hourly max value together with the date(s) that value occurred. The total number of hours with ozone data and days with at least 75% data capture through the year is given for reference. The exceedances based on the 8 hour mean values were only calculated for days with at least 75% data capture.

Table 6.4: For all sites in 2017 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 1.3 as well as the annual maximum and the date when it occurred.

			National AQ guidelines		WHO	EU directive			
Station	Hours	Days >75%	Days 8h > 80 µg/m^3	Hours 1h > 100 µg/m^3	Days 8h > 100 µg/m^3	Days 8h > 120 µg/m^3	Hours 1h > 180 µg/m^3	Max. hourly value (µg/m^3)	Date
Prestebakke	8717	365	78	28	2	1	0	135	18.05.2017
Hurdal	8698	365	94	87	9	0	0	124	02.05.2017
Haukenes	7733	324	69	15	2	0	0	119	20.04.2017
Birkenes II	8352	358	99	45	5	0	0	113	06.06.2017
Sandve	8364	352	88	4	0	0	0	104	02.05.2017
Kårvatn	8688	365	89	34	3	0	0	114	04.05.2017
Tustervatn	8698	365	145	24	2	0	0	104	04.04.2017
Zeppelin	4085	175	84	6	0	0	0	102	03.05.2017

The values in Table 6.4 reflect that 2017 was a year with particularly low ozone levels, and most likely the year with the lowest mean and maximum levels overall since the monitoring started in the 1970s. As an example, the number of hours with ozone levels exceeding 100 µg/m^3 was 146 at Prestebakke in 2016 vs only 28 in 2017, and the number of days with an 8-h mean value exceeding 100 µg/m^3 was 16 in 2016 and only 2 in 2017 at the same site.

The levels of surface ozone is closely linked to the large-scale weather conditions and often one sees regional differences in Norway, e.g. with a "good summer" in the southeast and a corresponding “bad summer” in the north etc. The results from the ozone monitoring indicate, however, generally low ozone levels all over the country in 2017 which is somewhat unusual.

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 2017 the LTO was exceeded at Prestebakke with one single day only.

The WHO guideline was broken at all sites except Sandve and Zeppelin Mountain in 2017 (note, however, that there is no data for the period early June to late November at the Zeppelin station). This reflects that the WHO guideline level of 100 µg/m^3 is close to the mean peak level, implying that a small reduction in the mean level will lead to a large reduction in the number of days with exceedances. The highest hourly ozone concentration in 2017 was 135 µg/m^3 observed at Prestebakke 18 May.

The ozone levels and exceedances vary strongly from year to year which is also indicated by Figure 6.4, showing the time trend of the number of days with exceedance of the 8-hour mean value of 120 µg/m^3. Table 6.5 gives the annual peak values and number of days with exceedance from 2004 to 2017. 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 6.5: The maximum hourly ozone value each year and the number of days exceeding EU’s long-term objective.

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Annual hourly max. (µg/m^3)	150	144	186	139	160	142	145	168	130	124	147	148	140	135
Number of dates with exceedance of EU’s long-term objective of 120 µg/m^3 [a)]	21	7	28	8	16	9	3	12	2	2	4	2	4	1

[a)] Running 8-h mean

EU’s long-term objective for the protection of health is the governing air quality requirement for ozone in Norway. The directive requires the countries to sustain monitoring stations in all air quality zones where the long-term objective has been broken in the last five years.
As shown in Figure 6.4, this limit value has been exceeded at all stations the last five years.

The updated national guidelines (FHI, 2013) are even stricter than the WHO guideline (Table 6.3) and both the 80 µg/m^3 (8-h mean) and 100 µg/m^3 (1-h mean) are exceeded for long periods of the year in the whole country (except on Spitsbergen) as shown by Table 6.4.

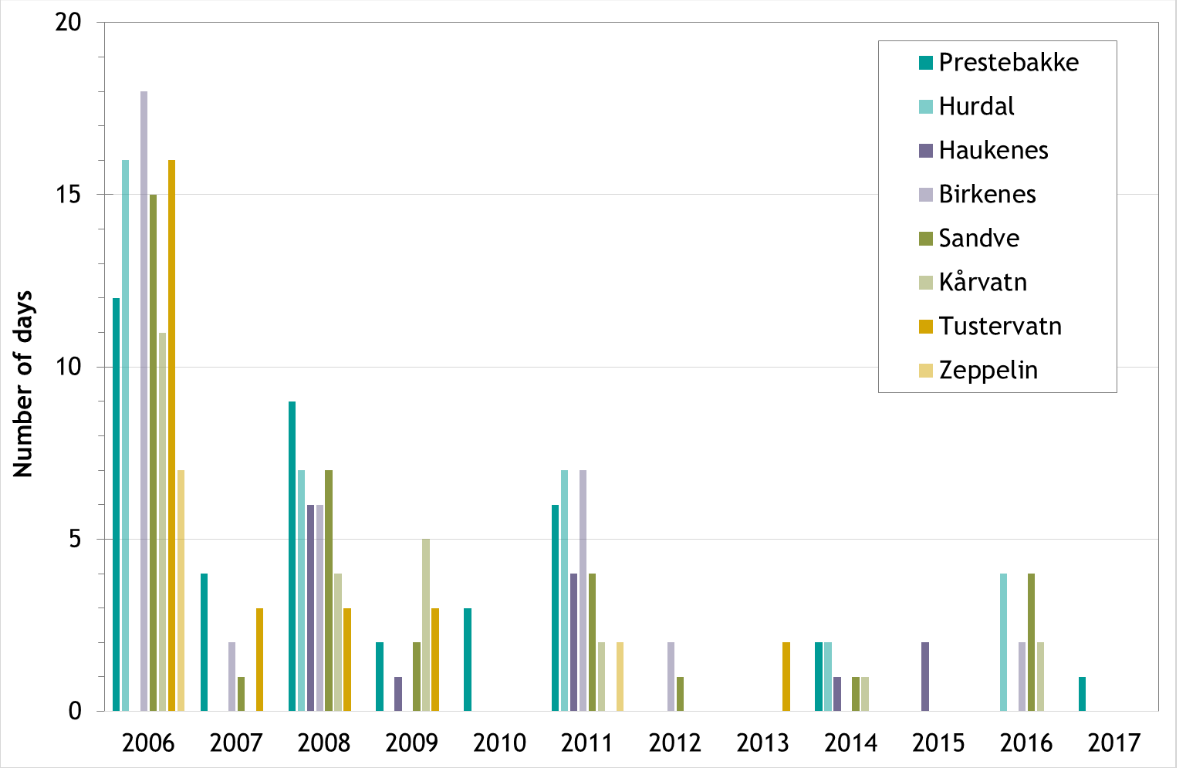


Figure 6.4: The number of days with a maximum daily 8-h mean ozone concentration above 120 µg/m^3 for the period 2006-2017. Note that the Birkenes site has been moved, and data before 2012 refer to the old location. See text for more explanations.

6.5 Exceedance of the threshold values for protection of vegetation

Threshold levels for ozone exposure to vegetation has been prepared by Kärenlampi and Skärby (1996). EU's air quality directive (EU, 2008) also lays down limit values for ozone related to protection of vegetation. The limit values by both UN-ECE and EU are based on 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"). 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.

Research in recent years have shown, however, that the AOT40 based critical levels for vegetation defined in the Gothenburg Protocol should be replaced with the so-called flux based critical levels. Flux based levels reflect better the real consequences of the ozone that is transported into the leaves, while AOT40 is only based on the concentration of ozone at the monitors inlet height (Mills et al., 2011).

Flux based critical levels for different types of vegetation have been approved by UN/ECE (LRTAP, 2011). Concentration based AOT40 values continue to be used, however, where the meteorological data and calculations from flux models are not available.

Flux based and concentration (AOT) based critical levels have been determined for both crops, forests and natural vegetation (LRTAP, 2011). The limits given by UN-ECE and EU are shown in Table 6.6. UN-ECE also recommends that the ozone levels should be based on the concentration at canopy height, while the ozone monitor's inlet height traditionally is at 2 m above ground. It is furthermore recommended to adjust the measurement data to values relevant for the canopy height by assumptions about the vertical distribution of ozone near the ground for different land use categories. This report only presents AOT40 values based on the actual measurements of ozone.

EU's air quality directive (EU, 2008) includes a 3-month's target value for AOT40 of 9 000 ppb hours (May-July) averaged over 5 years and a long-term objective of 3 000 ppb hours for the protection of vegetation. As opposed to UN-ECE's limit values the EU directive does not contain separate threshold values for crops and forests. Table 6.6 shows the various limit values for protection of vegetation.

Table 6.6: Limit values for the protection of vegetation from ozone exposure.

AOT40 (ppb hours)	Period	Reference	Comment
3000	15 May - 15 Aug	UN-ECE (1996)	Growing season for agricultural crops adjusted to Nordic conditions. 1)
5000	1 April - 1 Oct	UN-ECE (1996)	Growing season for forests 1,2)
9000	1 May – 1 Aug	EU (2008)	EU's target value for vegetation 3)
3000	1 May - 1 Aug	EU (2008)	EU's long-term objective for vegetation 3)

1) ECE's AOT values should be based on the hours with global incoming radiation > 50 W/m^2

2) Changed from 10 000 to 5000 ppb hours according to the Mapping manual (Mills et al., 2011)

3) EU's AOT values should be based on the period 08-20 CET

Table 6.7 shows the 3 months AOT40 values for daylight hours (global radiation > 50 W/m^2) for the period 15 May - 15 August (referring to Table 6.6). The limit value for agricultural crops of 3000 ppb hours was not exceeded at the Norwegian sites in 2017. The highest value occurred at Prestebakke with 693 ppb hours which is very low compared to previous years.

Table 6.8 shows the 6 months AOT40 values for daylight hours (April-September). The limit value of 5000 ppb hours for forests was not exceeded in 2017 at the Norwegian sites. The highest value of this parameter was seen at Prestebakke with 2167 ppb hours.

Table 6.7: Data capture and 3-month's AOT40 values for agricultural crops for the period 15 May - 15 August 2017 (unit: ppb hours). Note that no value was calculated for Zeppelin Mountain due to the many missing values.

Station	**Data capture (%)**	**AOT40 (corrected for data capture)**
Birkenes II	95	604
Tustervatn	99	201
Kårvatn	99	75
Zeppelin	29	-
Prestebakke	99	693
Sandve	99	141
Hurdal	99	496
Haukenes	100	160

Table 6.8: Data capture and 6-month's AOT40 values for forests for the period 1 April – 1 October 2017 (unit: ppb hours). Note that no value was calculated for Zeppelin Mountain due to the many missing values.

Station	**Data capture (%)**	**AOT40 (corrected for data capture)**
Birkenes II	93	2167
Tustervatn	99	2233
Kårvatn	99	1430
Zeppelin	40	-
Prestebakke	99	1781
Sandve	98	1120
Hurdal	99	2166
Haukenes	81	1391

EU's target value of 9000 ppb hours is met at all the Norwegian stations (Figure 6.5). Values above the long-term objective of 3000 ppb hours have, however, occurred in several of the past ten years. It should be noted that the AOT values shown in Figure 6.5 refer to the 3 month's period May-July as given in the EU directive without any "Nordic adaption" to the growing season. With a Nordic adaptation as given by UN-ECE, i.e. with the calculation period 15 May to 15 August, the AOT values would become somewhat lower since the ozone levels are generally lower in August than in May in Norway. One should also note that EU's directive gives a different definition on the hours of day that should be included in the AOT-calculation compared to the definition by UN-ECE. The values in Figure 6.5 are based on UN-ECE's definition (global radiation > 50 W/m2) and could therefore not be compared directly with the EU directive.

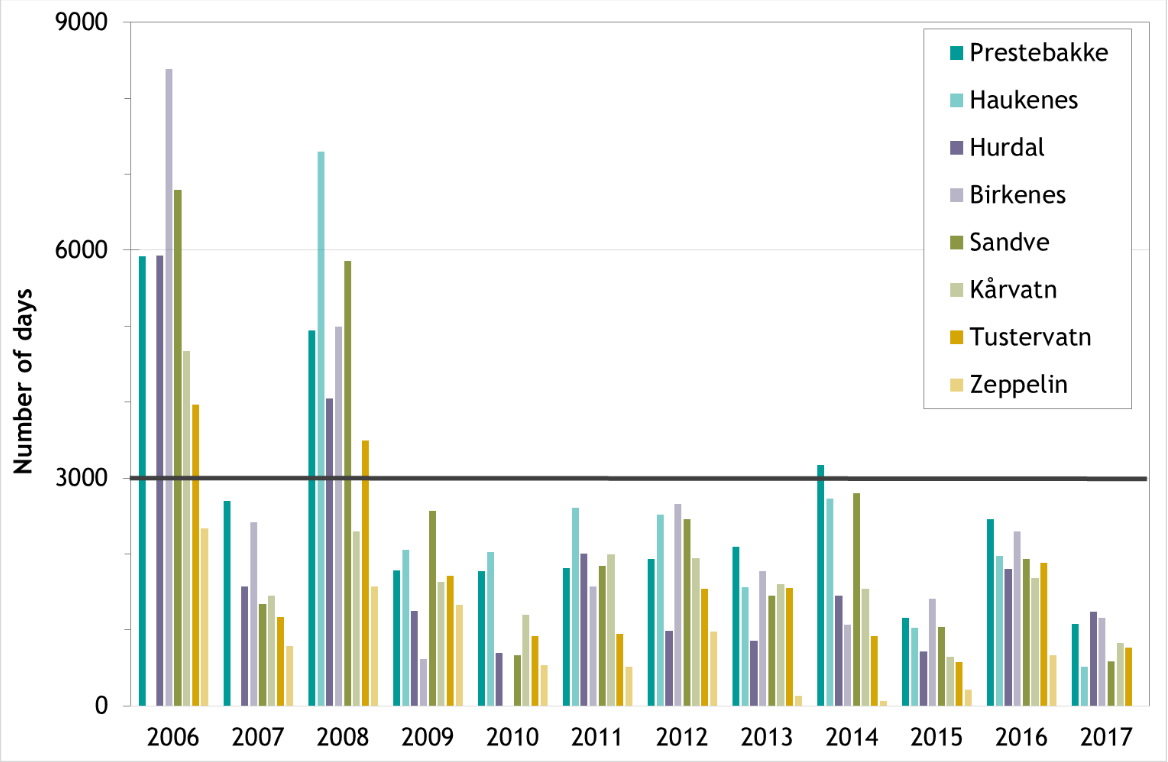


Figure 6.5: 3 months' AOT40 values (1 May - 31 July) for the years 2006 - 2017 (based on UN-ECE's definition of daylight hours). The EU directive's long-term objective of 3000 ppb hours is indicated by the line. The definition of daylight hours given by the EU directive differs somewhat from that given by UN-ECE. Note that the Birkenes site has been moved, and data before 2012 refer to the old location. See text for more explanations.

6.6 Long-term trends in ground level ozone

Owing to its long atmospheric lifetime the long-term trends of ground-level ozone in Norway are the net result of large-scale trends in the hemispheric baseline level with regional/European effects superimposed. Recent studies of the hemispheric baseline ozone indicates a doubling of the mean O_3 from the 1950s up to about the year 2000 followed by a decade with no growth or even reductions in O_3 at some sites, particularly in summer (Logan et al., 2012). Recent studies also indicate a change in the mean seasonal cycle of the baseline O_3 with the seasonal maximum being shifted from summer to spring in recent years.
In contrast to the consistent picture for the baseline, the findings are more mixed for European monitoring stations. Tørseth et al. (2012) found strong declines in the highest O_3 values in the UK and Netherlands and no clear trends in Austria and Switzerland for the period 1990-2010.

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

Figure 6.6 - Figure 6.9 show the development in four ozone metrics from 1990 to 2017; 6 months AOT40 (April-September), 3-months AOT40 (May-July), the number of days with an 8-h running max exceeding 100 $\mu g/m^3$ (WHO guideline) and the 97-percentile of the daily max 8-h running mean April-September. The latter metric corresponds approximately to the annual 4th highest value used in the ozone trend assessment within the EMEP TFMM (Colette et al., 2016) and IGAC TOAR (Tropospheric ozone assessment research) programs.

Results for three stations with long-term monitoring history are given: Prestebakke, 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. These calculations indicate a downward trend for all metrics/stations based on the 22-years period 1996-2017.

It should be stressed that with the more unreliable data from the first years (1990-1995) included, less significant trends would be found and that was the basis for the mentioned EMEP TFMM assessment. This reflects a general low level of ozone in 1990-1991 which very likely was a real effect. In addition comes the problem with more uncertain monitoring data in the same period making it somewhat uncertain to what extent these low ozone levels could be attributed to poorer data quality in the early years of monitoring. It is thus an open question whether the data from this first period should be included in the trend analyses or not.

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

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

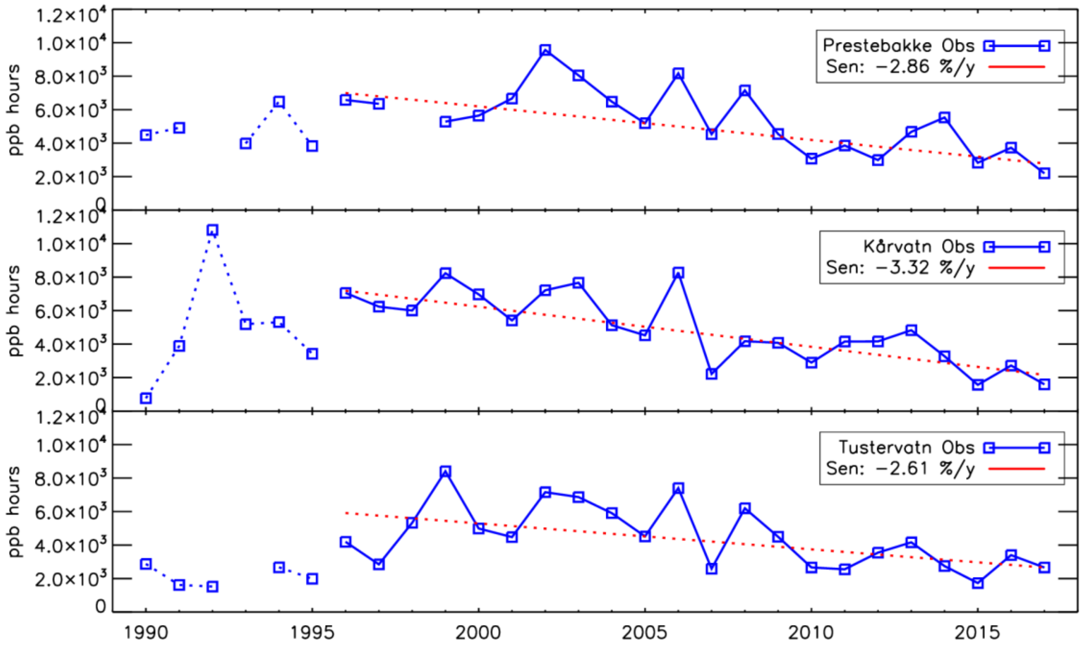


Figure 6.6: The 6-months AOT40 value (April - September, hours 8-20) during 1990-2017 for three sites. The estimated Sen's slope based on annual data for 1996-2017 are marked in red. Data from the first years (1990-1995) are uncertain and not included in the trend calculations and marked with a dotted line.

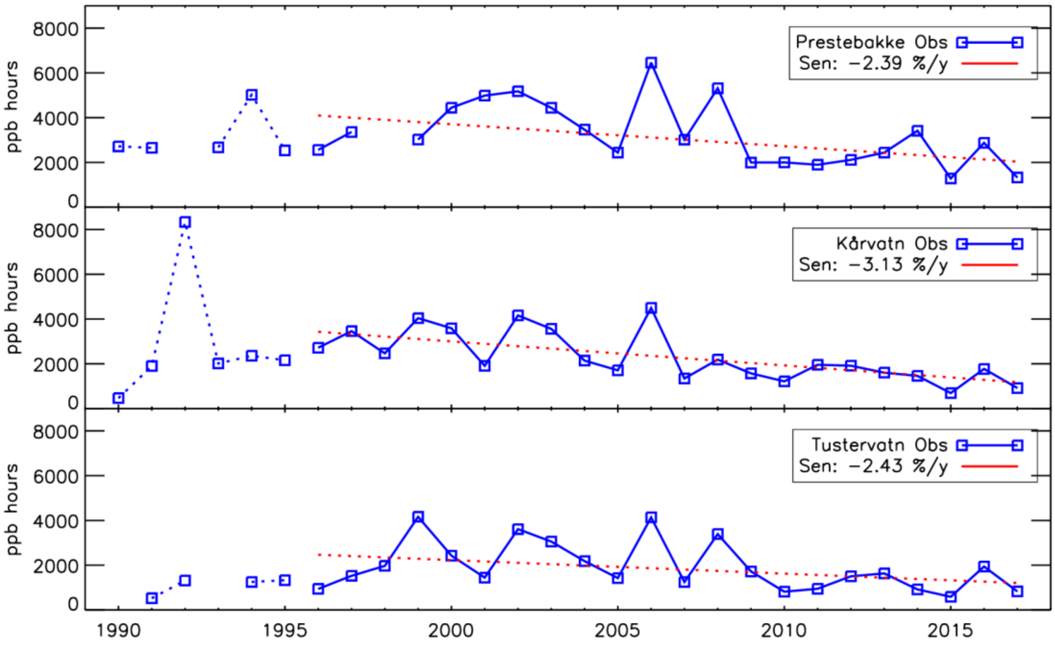


Figure 6.7: Same as Figure 6.6 for the 3-months AOT40 value (May - July, hours 8-20).

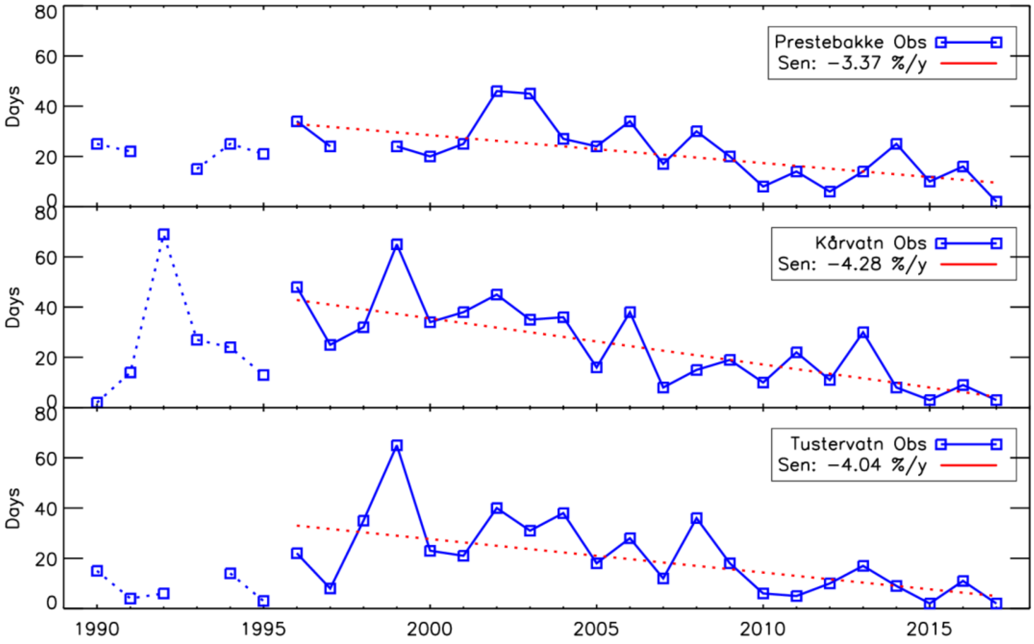


Figure 6.8: Same as Figure 6.6 for the number of days with a maximum 8-h running mean ozone concentration exceeding 100 µg/m^3 (WHO guideline).

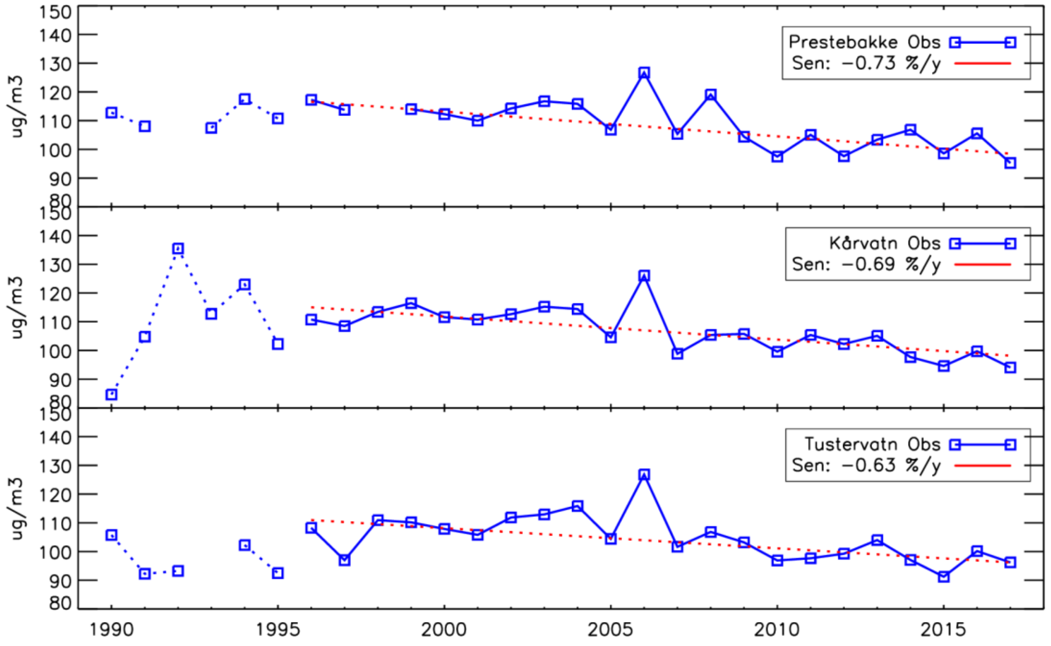


Figure 6.9: Same as Figure 6.6 for the 97-percentile of the daily maximum 8-h running mean ozone concentration April-September.

6.7 Summary

In Norway, the levels of ground level ozone is 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, whereas the photochemical episodes vary substantially with time depending on the summer weather conditions and the European emissions. Whereas the former vary more randomly, the European precursor emissions have been steadily reduced over the last 10-20 years, and thus the severity of the ozone episodes are expected to be reduced as well. The inter- annual variations in meteorology could, however, mask the effect of the emission reductions.

The ozone levels in 2017 were very low, probably the lowest since the monitoring started in the 1970s both with respect to peak values and mean values. The peak hourly maximum value was 135 µg/m^3 measured at Prestebakke. EU's target value (max 25 days with a max 8-h concentration exceeding 120 µg/m^3) and the 1-h information level (180 µg/m^3) has not been exceeded for several years in Norway. The much stricter long-term objective of EU (=LTO, i.e. max 8h value < 120 µg/m^3) and in particular the WHO and national guidelines, all related to human health, are exceeded every year, reflecting that these limit values are close to the baseline levels. EU's long-term objective was, however, exceed only one day at Prestebakke in 2017. None of the threshold values for vegetation as based on AOT40, were exceeded in 2017.

Calculation of long-term trends (1996-2017) for various ozone metrics show a statistically significant decline for all the metrics and stations included in this report.

7. References

Aas, W., Fiebig, M.,Platt, S., Solberg, S., Yttri, K.E. (2016) Monitoring of long-range transported air pollutants in Norway, annual report 2015. Kjeller, NILU (Miljødirektoratet rapport, M-562/2016) (NILU report, 13/2016).

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Mills, G., Pleijel, H., Braun, S., Büker, P., Bermejo, V., Calvo, E., Danielsson, H., Emberson, L., González Fernández, I., Grünhage L., Harmens, H., Hayes, F., Karlsson, P.-E., Simpson,

D. (2011) New stomatal flux-based critical levels for ozone effects on vegetation. *Atmos. Environ., 45*, 5064-5068.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Annex 1

Results from the monitoring programme

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

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes	4.77	4.56	5.16	4.70	5.37	5.01	4.80	5.07	5.03	5.09	4.95	5.06	4.95
Vatnedalen	5.21	5.19	5.44	5.01	5.24	5.57	5.83	5.98	5.83	5.73	5.62	5.65	5.52
Treungen	4.84	4.68	4.99	5.30	5.55	5.11	4.83	5.46	5.20	5.51	5.00	5.12	5.12
Løken	5.13	4.58	5.18	5.30	5.37	5.23	4.91	5.17	5.22	5.62	5.05	5.14	5.12
Hurdal	5.33	5.26	5.19	5.21	5.52	5.24	5.13	5.26	5.16	5.25	5.21	5.13	5.23
Brekkebygda	4.85	4.66	5.03	4.64	5.24	5.19	4.83	5.18	4.87	5.22	5.06	5.06	4.98
Vikedal	5.23	5.48	5.38	4.64	5.39	5.38	5.28	5.13	5.19	5.44	5.42	5.57	5.25
Haukeland	5.19	5.20	5.19	4.66	5.16	5.20	5.13	5.08	5.60	5.49	5.26	5.43	5.21
Nausta	5.50	5.62	5.54	4.72	5.49	4.87	5.02	5.14	6.20	5.66	5.57	5.45	5.17
Kårvatn	5.42	5.33	5.20	4.89	5.15	5.27	4.91	5.45	5.58	5.52	5.60	5.48	5.26
Høylandet	5.54	5.58	5.42	5.17	5.63	5.39	5.38	5.31	5.53	5.68	6.02	5.88	5.47
Tustervatn	5.27	5.39	5.27	5.09	5.44	5.49	5.24	5.34	5.42	5.57	5.49	5.56	5.34
Karpbukt	5.25	5.23	5.12	4.76	4.63	5.09	4.68	4.79	5.20	5.47	5.09	5.32	4.95
Ny-Ålesund	5.62	5.01	5.21	5.26	5.22	5.36	5.72	5.29	5.12	5.44	-	6.62	5.20

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	2017
Birkenes	0.12	0.26	0.10	0.12	0.34	0.28	0.18	0.13	0.29	0.15	0.14	0.14	0.20
Vatnedalen	0.02	0.04	0.02	0.11	0.08	0.13	0.12	0.14	0.14	0.11	0.00	0.03	0.08
Treungen	0.09	0.28	0.07	0.09	0.22	0.15	0.15	0.15	0.16	0.07	0.11	0.06	0.14
Løken	0.09	0.18	0.08	0.08	0.21	0.17	0.14	0.12	0.07	0.09	0.13	0.09	0.12
Hurdal	0.17	0.22	0.07	0.07	0.22	0.12	0.11	0.09	0.08	0.16	0.11	0.06	0.12
Brekkebygda	0.11	0.25	0.08	0.21	0.16	0.11	0.14	0.09	0.14	0.10	0.03	0.01	0.12
Vikedal	0.02	0.06	0.05	0.07	0.10	0.15	0.12	0.12	0.03	0.06	0.05	0.02	0.06
Haukeland	0.06	0.05	0.03	0.06	0.10	0.10	0.11	0.11	0.04	0.05	0.06	0.03	0.06
Nausta	0.01	0.10	0.01	0.05	0.15	0.10	0.11	0.10	0.16	0.04	0.13	0.02	0.08
Kårvatn	0.01	0.05	0.04	0.05	0.16	0.11	0.12	0.09	0.04	0.02	0.02	0.02	0.05
Høylandet	0.01	0.02	0.03	0.04	0.11	0.08	0.08	0.03	0.06	0.02	0.08	0.04	0.04
Tustervatn	0.01	0.05	0.03	0.05	0.24	0.08	0.07	0.05	0.04	0.00	0.02	0.02	0.04
Karpbukt	0.07	0.14	0.24	0.20	0.48	0.17	0.43	0.42	0.20	0.25	0.31	0.10	0.27
Ny-Ålesund	0.21	0.08	0.18	0.28	0.72	0.34	0.16	0.07	0.07	0.07	-	1.93	0.13

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	2017
Birkenes	0.39	0.33	0.21	0.19	0.70	0.46	0.19	0.22	0.35	0.26	0.38	0.24	0.31
Vatnedalen	0.06	0.09	0.10	0.20	0.19	0.15	0.06	0.12	0.07	0.11	0.08	0.05	0.10
Treungen	0.33	0.34	0.22	0.13	0.39	0.24	0.13	0.24	0.20	0.11	0.22	0.15	0.22
Løken	0.30	0.30	0.37	0.15	0.35	0.31	0.16	0.25	0.13	0.14	0.37	0.24	0.25
Hurdal	0.31	0.27	0.28	0.09	0.32	0.18	0.12	0.14	0.12	0.17	0.28	0.18	0.19
Brekkebygda	0.33	0.31	0.34	0.20	0.30	0.18	0.11	0.12	0.17	0.13	0.12	0.16	0.17
Vikedal	0.11	0.14	0.16	0.16	0.20	0.17	0.11	0.15	0.08	0.09	0.11	0.06	0.12
Haukeland	0.10	0.10	0.12	0.10	0.17	0.16	0.07	0.14	0.03	0.05	0.09	0.05	0.09
Nausta	0.03	0.26	0.07	0.09	0.20	0.09	0.07	0.20	0.17	0.07	0.09	0.06	0.10
Kårvatn	0.02	0.04	0.03	0.04	0.19	0.07	0.03	0.05	0.07	0.05	0.04	0.02	0.04
Høylandet	0.06	0.07	0.04	0.04	0.13	0.01	0.01	0.01	0.02	0.04	0.07	0.05	0.04
Tustervatn	0.06	0.08	0.02	0.03	0.35	0.08	0.04	0.05	0.04	0.05	0.04	0.03	0.05
Karpbukt	0.08	0.09	0.04	0.06	0.11	0.04	0.10	0.07	0.07	0.10	0.15	0.12	0.08
Ny-Ålesund	0.02	0.13	0.04	0.06	0.26	0.12	0.07	0.04	0.08	0.09	-	0.18	0.09

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	2017
Birkenes	0.25	0.28	0.21	0.19	1.26	0.46	0.1	0.18	0.38	0.22	0.23	0.17	0.29
Vatnedalen	0.08	0.05	0.14	0.26	0.22	0.13	0.02	0.15	0.09	0.16	0.08	0.09	0.12
Treungen	0.19	0.27	0.23	0.15	0.71	0.26	0.08	0.34	0.17	0.1	0.13	0.06	0.24
Løken	0.31	0.32	0.42	0.17	0.53	0.33	0.14	0.1	0.05	0.11	0.25	0.17	0.21
Hurdal	0.27	0.22	0.21	0.11	0.7	0.31	0.28	0.2	0.07	0.25	0.22	0.08	0.24
Brekkebygda	0.19	0.23	0.22	0.22	0.43	0.2	0.03	0.11	0.11	0.17	0.02	0.05	0.15
Vikedal	0.19	0.15	0.27	0.26	0.34	0.28	0.16	0.16	0.05	0.11	0.08	0.1	0.16
Haukeland	0.13	0.08	0.16	0.17	0.15	0.11	0.05	0.2	0.07	0.05	0.07	0.05	0.1
Nausta	0.1	0.43	0.15	0.18	0.39	0.12	0.02	0.12	0.64	0.14	0.1	0.08	0.15
Kårvatn	0.05	0.05	0.07	0.09	0.25	0.11	0.03	0.08	0.09	0.07	0.04	0.03	0.06
Høylandet	0.22	0.22	0.17	0.24	0.32	0.12	0.05	0.02	0.04	0.08	0.44	0.29	0.18
Tustervatn	0.12	0.1	0.04	0.08	0.53	0.12	0.09	0.09	0.1	0.1	0.04	0.03	0.1
Karpbukt	0.18	0.27	0.29	0.13	0.23	0.07	0.08	0.15	0.08	0.33	0.28	0.21	0.16
Ny-Ålesund	0.08	0.04	0.1	0.14	0.37	0.12	0.07	0.05	0.06	0.06	-	0.24	0.07

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	2017
Birkenes	0.11	0.08	0.06	0.06	0.17	0.16	0.09	0.09	0.25	0.16	0.19	0.25	0.17
Vatnedalen	0.08	0.05	0.09	0.16	0.12	0.07	0.07	0.07	0.11	0.13	0.06	0.03	0.08
Treungen	0.07	0.04	0.06	0.20	0.14	0.07	0.07	0.12	0.16	0.10	0.11	0.11	0.11
Løken	0.07	0.05	0.13	0.23	0.15	0.15	0.18	0.15	0.12	0.46	0.18	0.18	0.18
Hurdal	0.25	0.31	0.22	0.10	0.16	0.05	0.04	0.04	0.05	0.18	0.17	0.14	0.12
Brekkebygda	0.08	0.12	0.12	0.11	0.08	0.08	0.17	0.09	0.06	0.08	0.08	0.12	0.09
Vikedal	0.17	0.11	0.16	0.15	0.15	0.09	0.07	0.05	0.03	0.11	0.22	0.24	0.14
Haukeland	0.12	0.06	0.17	0.09	0.15	0.13	0.09	0.09	0.06	0.15	0.21	0.18	0.14
Nausta	0.04	0.04	0.08	0.13	0.08	0.03	0.06	0.11	0.16	0.12	0.25	0.09	0.10
Kårvatn	0.06	0.06	0.09	0.08	0.14	0.13	0.06	0.14	0.04	0.08	0.10	0.12	0.09
Høylandet	0.10	0.06	0.13	0.18	0.17	0.12	0.06	0.05	0.13	0.12	0.17	0.33	0.14
Tustervatn	0.15	0.06	0.10	0.09	0.14	0.16	0.06	0.10	0.07	0.09	0.09	0.11	0.10
Karpbukt	0.09	0.10	0.09	0.11	0.25	0.15	0.15	0.14	0.22	0.33	0.19	0.13	0.16
Ny-Ålesund	0.69	0.20	0.84	0.54	0.91	0.31	0.42	0.33	0.14	0.39	-	5.74	0.37

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	2017
Birkenes	0.08	0.09	0.05	0.09	0.27	0.24	0.08	0.06	0.14	0.06	0.10	0.14	0.10
Vatnedalen	0.09	0.05	0.15	0.24	0.05	0.08	0.16	0.07	0.11	0.08	0.17	0.13	0.11
Treungen	0.09	0.04	0.03	0.04	0.14	0.05	0.05	0.05	0.09	0.10	0.04	0.03	0.07
Løken	0.09	0.04	0.14	0.15	0.30	0.24	0.31	0.17	0.10	0.27	0.09	0.09	0.17
Hurdal	0.24	0.12	0.10	0.06	0.35	0.26	0.07	0.04	0.16	0.07	0.12	0.07	0.13
Brekkebygda	0.10	0.43	0.30	0.09	0.15	0.13	0.08	0.03	0.10	0.04	0.02	0.10	0.10
Vikedal	0.19	0.18	0.12	0.10	0.05	0.08	0.05	0.03	0.08	0.06	0.13	0.17	0.11
Haukeland	0.12	0.08	0.15	0.09	0.09	0.05	0.05	0.04	0.11	0.15	0.15	0.13	0.11
Nausta	0.04	0.08	0.08	0.09	0.08	0.02	0.36	0.05	0.66	0.06	0.17	0.08	0.16
Kårvatn	0.05	0.07	0.09	0.07	0.15	0.10	0.04	0.15	0.32	0.10	0.07	0.06	0.08
Høylandet	0.15	0.06	0.14	0.14	0.34	0.10	0.07	0.06	0.10	0.07	0.23	0.31	0.14
Tustervatn	0.14	0.04	0.10	0.09	0.14	0.12	0.07	0.12	0.21	0.21	0.03	0.06	0.11
Karpbukt	0.08	0.05	0.08	0.09	0.20	0.10	0.13	0.15	0.26	0.40	0.04	0.11	0.14
Ny-Ålesund	0.47	0.16	0.22	0.23	0.39	0.07	0.08	0.28	0.11	0.06	-	1.27	0.18

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	2017
Birkenes	0.19	0.13	0.08	0.06	0.03	0.08	0.05	0.06	0.15	0.12	0.24	0.40	0.14
Vatnedalen	0.14	0.04	0.08	0.06	0.01	0.01	0.02	0.01	0.02	0.02	0.06	0.02	0.03
Treungen	0.05	0.03	0.04	0.03	0.02	0.02	0.03	0.02	0.09	0.06	0.07	0.07	0.05
Løken	0.10	0.02	0.06	0.04	0.03	0.04	0.05	0.04	0.04	0.09	0.10	0.15	0.06
Hurdal	0.05	0.04	0.06	0.02	0.02	0.02	0.02	0.01	0.03	0.02	0.06	0.03	0.03
Brekkebygda	0.02	0.02	0.04	0.03	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02
Vikedal	0.49	0.24	0.35	0.26	0.02	0.08	0.10	0.08	0.01	0.19	0.38	0.50	0.26
Haukeland	0.28	0.16	0.43	0.24	0.03	0.05	0.10	0.04	0.02	0.17	0.43	0.31	0.23
Nausta	0.08	0.02	0.22	0.26	0.04	0.03	0.08	0.05	0.08	0.13	0.48	0.22	0.16
Kårvatn	0.12	0.10	0.23	0.20	0.06	0.07	0.03	0.04	0.01	0.12	0.11	0.15	0.11
Høylandet	0.28	0.14	0.40	0.26	0.04	0.06	0.03	0.05	0.07	0.18	0.27	0.74	0.25
Tustervatn	0.35	0.10	0.28	0.23	0.03	0.04	0.02	0.06	0.02	0.12	0.07	0.14	0.16
Karpbukt	0.25	0.12	0.26	0.21	0.63	0.29	0.08	0.10	0.25	0.36	0.09	0.09	0.20
Ny-Ålesund	1.57	0.56	0.72	0.59	1.07	0.27	0.31	0.45	0.23	0.25	-	4.12	0.53

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	2017
Birkenes	1.61	1.12	0.68	0.64	0.13	0.5	0.39	0.49	1.14	0.92	2.09	3.26	1.17
Vatnedalen	1.32	0.46	1.35	1.21	0.11	0.6	0.8	0.72	0.7	0.74	1.38	1.1	0.84
Treungen	0.42	0.3	0.37	0.12	0.09	0.09	0.21	0.21	0.42	0.19	0.5	0.52	0.27
Løken	0.81	0.22	0.35	0.17	0.11	0.2	0.23	0.29	0.32	0.33	0.76	1.17	0.4
Hurdal	0.5	0.3	0.38	0.13	0.13	0.08	0.15	0.13	0.3	0.11	0.54	0.3	0.23
Brekkebygda	0.22	0.43	0.61	0.3	0.07	0.13	0.11	0.09	0.17	0.08	0.12	0.2	0.15
Vikedal	4.29	1.95	3.1	2.18	0.14	0.69	0.81	0.69	0.11	1.53	3.4	4.51	2.32
Haukeland	2.34	1.5	3.9	1.98	0.3	0.35	0.84	0.36	0.13	1.34	3.59	2.52	1.92
Nausta	0.7	0.2	1.99	2.2	0.31	0.29	0.73	0.46	0.65	1.14	3.58	1.82	1.29
Kårvatn	1.01	0.85	1.98	1.65	0.57	0.64	0.25	0.28	0.33	1.07	0.99	1.24	0.99
Høylandet	2.41	1.14	3.34	2.21	0.51	0.54	0.24	0.48	0.58	1.61	2.38	6.39	2.13
Tustervatn	2.92	0.81	2.49	2	0.28	0.3	0.2	0.49	0.21	1.33	0.64	1.17	1.44
Karpbukt	2.08	0.98	2.16	1.87	5.19	2.7	0.54	0.74	1.9	2.92	0.66	0.76	1.69
Ny-Ålesund	12.03	4.42	5.17	4.61	8.03	1.62	1.59	3.61	1.94	1.63	-	33.62	4.02

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	2017
Birkenes	2.72	2	1.17	1.05	0.21	1.02	0.64	0.78	1.92	1.56	3.7	6	2.02
Vatnedalen	2.25	0.7	1.86	1.39	0.13	0.31	0.4	0.39	0.35	0.55	2.03	1.1	0.87
Treungen	0.72	0.54	0.63	0.21	0.15	0.16	0.34	0.27	0.7	0.31	0.95	0.94	0.45
Løken	1.34	0.39	0.57	0.27	0.18	0.31	0.43	0.43	0.52	0.55	1.42	2.19	0.68
Hurdal	0.77	0.5	0.57	0.16	0.2	0.13	0.25	0.17	0.48	0.21	0.9	0.51	0.37
Brekkebygda	0.34	0.66	0.94	0.3	0.12	0.14	0.2	0.14	0.27	0.15	0.2	0.34	0.23
Vikedal	7.09	3.36	5.33	3.73	0.27	1.2	1.36	1.18	0.18	2.8	6.15	8.2	4.07
Haukeland	4.02	2.58	6.49	3.48	0.46	0.57	1.4	0.71	0.22	2.41	6.7	4.69	3.43
Nausta	1.22	0.39	3.45	3.86	0.51	0.49	1.23	0.75	1.04	2.07	7.3	3.34	2.36
Kårvatn	1.73	1.58	3.54	2.96	0.9	1.13	0.43	0.47	0.45	1.93	1.85	2.3	1.77
Høylandet	4.03	2.11	6.12	3.95	0.86	0.92	0.4	0.8	1	2.87	4.64	11.7	3.82
Tustervatn	5.02	1.42	4.44	3.56	0.47	0.57	0.34	0.86	0.35	2.15	1.23	2.17	2.51
Karpbukt	3.61	1.74	4.11	3.18	9.29	4.68	0.91	1.24	3.47	5.22	1.34	1.46	3
Ny-Ålesund	22.11	8.22	9.43	8.26	14.2	2.86	2.9	6.29	3.53	2.85	-	58.82	7.31

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	2017
Birkenes	84.44	127.88	89.42	60.26	81.27	140.23	97.08	133.36	511.31	449.93	205.93	106.66	2087.76
Vatnedalen	43.77	58.84	82.45	35.51	119.39	151.94	68.1	98.07	156.5	163.87	175.4	117.87	1271.71
Treungen	40.6	78.94	58.25	36.07	105.1	158	64.36	174.8	192.8	143.38	76.8	56.72	1185.8
Løken	33.89	47.47	29.41	28.31	70.27	77.34	52.04	104.44	121.69	95.93	79.14	56.98	796.91
Hurdal	39.3	52.52	29.92	50.25	82.5	71.8	74.1	159.99	116.91	125.5	80.4	72.74	955.94
Brekkebygda	25.8	31.51	19.29	58.75	95.6	106.35	101.3	117.99	251.12	168.49	68.66	46.71	1091.58
Vikedal	364.51	212.45	248.42	208.13	89.6	289.03	212.79	340.62	239.53	427.43	420.51	516.79	3569.8
Haukeland	329.36	229.89	327.94	163.18	80.85	311.01	174.03	245.56	186.77	548.63	507.45	502.75	3607.43
Nausta	111.1	10.2	90.51	113.76	41.53	125.44	203.75	137.6	86	95.44	130.26	147.38	1292.97
Kårvatn	205.04	106.2	126.92	148.38	109.04	137.4	151.65	111.08	59.19	230.23	160.09	213.21	1758.44
Høylandet	223.97	98.1	140.88	167.12	53.98	131.32	97.7	139.38	42.34	158.78	88.2	160.67	1502.45
Tustervatn	240.74	63.74	157.17	85.57	49.9	66.13	103.98	148.88	41.94	136.79	95.21	127.8	1317.84
Karpbukt	47.51	30.39	35.82	27.81	23.08	99.94	74.86	108.76	44.04	37	34.28	30.62	594.11

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	2017
Birkenes	1447	3542	543	64803	348	1383	1555	1121	4797	3331	2292	934	23220
Vatnedalen	271	319	308	401517	667	46204	170362	2090574	1140508	147493	115876	611	3818
Treungen	582	1644	560	167	24135	1232	957	594	1202	429	772	426	8951
Løken	251	1242	185	7080	295	451	10215	711	725	233	713	407	6019
Hurdal	183	291	661	316	248	409	555	875	809	698	494	535	5610
Brekkebygda	368	686	133631	1338	543	677	1503	773	3362	975	591	408	11481
Vikedal	2161	701	1021	4860	362	1192	8168	2410	1532	1518	1577	1390	19959
Haukeland	2133	1175	1922	3412	565	1698	1179	925	785799	2441419	15210	2700	22031
Nausta	352	24	259	18479	115	1685	1941	989	54	209	347	521	8715
Kårvatn	779	495	804	28231	774	770	1828	396	15789	697	2743	1595	9611
Høylandet	639	256	532	1140	127	3201	404	680	127	91102	2181	210	5045
Tustervatn	1287	263	815	696	180	214	603	687	314	365	7225	350	5982
Karpbukt	265	21774	1394	488	537	799	1547	1746	267	124	276	146	6689
Ny-Ålesund	64	1255	93	66	32	9	78	144	574	100	-	0	1982

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	2017
Birkenes	10	33	9	7	28	40	17	17	150	66	29	15	408
Vatnedalen	1	3	2	4	10	19	8	14	22	18	1	4	106
Treungen	4	22	4	3	23	23	10	26	32	10	9	3	169
Løken	3	8	2	2	15	13	7	12	8	9	10	5	96
Hurdal	7	11	2	4	18	9	8	15	9	20	9	4	115
Brekkebygda	3	8	2	12	15	12	14	11	34	18	2	1	130
Vikedal	8	13	13	15	9	43	26	41	8	25	19	8	227
Haukeland	18	11	10	9	8	31	19	26	8	26	30	14	211
Nausta	1	1	1	6	6	12	22	13	14	4	16	3	99
Kårvatn	3	5	5	8	17	15	19	10	3	4	4	5	88
Høylandet	2	2	5	7	6	11	8	4	2	4	7	7	65
Tustervatn	3	3	4	4	12	6	7	8	2	0	2	3	50
Karpbukt	3	4	9	6	11	17	32	45	9	9	11	3	159
Ny-Ålesund	6	6	3	3	4	1	3	2	6	3	-	3	40

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	2017
Birkenes	33	43	19	11	57	64	19	30	177	118	78	26	648
Vatnedalen	3	5	8	7	23	23	4	12	10	18	14	5	132
Treungen	13	27	13	5	41	37	8	41	38	16	17	8	265
Løken	10	14	11	4	25	24	8	26	16	14	30	14	196
Hurdal	12	14	8	5	26	13	9	22	14	21	22	13	181
Brekkebygda	8	10	7	12	28	19	11	14	42	23	8	7	190
Vikedal	40	30	40	34	18	49	24	52	19	39	45	31	421
Haukeland	34	22	38	16	14	50	12	35	6	27	48	26	328
Nausta	3	3	7	10	8	11	15	27	15	7	11	9	126
Kårvatn	4	5	4	6	21	10	5	5	4	11	7	5	75
Høylandet	14	7	5	6	7	1	1	1	1	6	7	8	64
Tustervatn	15	5	3	3	17	5	5	7	2	7	4	3	72
Karpbukt	4	3	1	2	3	4	8	8	3	4	5	4	46
Ny-Ålesund	1	10	1	1	1	0	2	1	7	4	-	0	27

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	2017
Birkenes	22	36	19	11	102	65	10	25	196	101	47	19	611
Vatnedalen	4	3	12	9	26	20	2	15	14	26	14	11	155
Treungen	8	21	13	6	75	41	5	59	33	14	10	4	288
Løken	11	15	12	5	37	26	7	11	6	10	20	9	169
Hurdal	11	12	6	6	58	22	21	32	9	31	18	6	228
Brekkebygda	5	7	4	13	42	21	3	13	28	28	1	2	167
Vikedal	68	32	67	53	30	82	35	54	11	45	33	54	564
Haukeland	42	18	53	28	12	35	10	50	14	28	34	25	350
Nausta	11	4	14	21	16	16	5	17	55	13	13	12	196
Kårvatn	10	5	9	13	28	14	5	8	5	15	7	6	111
Høylandet	49	22	24	40	17	16	5	3	2	13	39	47	277
Tustervatn	28	7	6	6	26	8	9	14	4	13	4	4	125
Karpbukt	8	8	10	4	5	7	6	16	3	12	9	6	96
Ny-Ålesund	2	3	2	2	2	0	1	1	6	2	-	0	22

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

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes	9	10	6	4	14	23	9	12	126	74	39	27	353
Vatnedalen	4	3	7	6	14	11	5	7	17	21	10	3	107
Treungen	3	3	4	7	15	11	4	21	32	14	8	6	127
Løken	2	3	4	6	10	11	9	16	14	44	14	10	144
Hurdal	10	16	7	5	13	4	3	6	6	22	14	10	118
Brekkebygda	2	4	2	7	7	9	18	10	16	14	6	6	100
Vikedal	63	23	40	32	13	27	15	16	7	45	93	123	496
Haukeland	39	15	54	15	12	41	16	22	12	80	105	89	500
Nausta	5	0	8	15	3	3	11	15	14	11	33	13	133
Kårvatn	12	6	11	11	16	18	8	16	2	18	16	25	155
Høylandet	22	6	18	31	9	16	6	7	6	18	15	53	207
Tustervatn	36	4	15	8	7	11	7	15	3	12	8	14	137
Karpbukt	4	3	3	3	6	15	11	16	10	12	6	4	94
Ny-Ålesund	19	15	16	7	5	1	9	9	12	15	-	9	115

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

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes	7	12	4	6	22	34	8	8	73	26	20	15	215
Vatnedalen	4	3	13	9	6	12	11	7	17	14	30	15	139
Treungen	4	3	2	2	14	9	3	9	18	14	3	2	82
Løken	3	2	4	4	21	18	16	17	12	26	7	5	136
Hurdal	9	6	3	3	29	18	5	6	19	8	10	5	120
Brekkebygda	3	14	6	5	14	14	8	3	25	7	1	5	105
Vikedal	67	37	29	21	5	23	11	10	19	26	56	88	393
Haukeland	40	18	50	15	7	15	8	9	21	80	76	66	406
Nausta	5	1	7	10	3	3	73	7	57	6	23	12	206
Kårvatn	11	7	11	11	17	14	5	16	19	23	10	13	149
Høylandet	34	6	20	23	18	13	7	9	4	11	20	50	214
Tustervatn	35	3	15	8	7	8	7	18	9	28	3	8	148
Karpbukt	4	1	3	2	5	10	10	16	11	15	2	3	82
Ny-Ålesund	13	12	4	3	2	0	2	8	10	2	-	2	56

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	2017
Birkenes	16	17	7	4	2	11	5	8	79	52	49	42	302
Vatnedalen	6	2	6	2	2	2	1	1	3	4	11	2	43
Treungen	2	2	3	1	2	3	2	4	17	9	5	4	53
Løken	3	1	2	1	2	3	3	4	5	8	8	9	49
Hurdal	2	2	2	1	2	1	2	2	4	3	4	2	28
Brekkebygda	0	1	1	2	1	2	2	2	6	3	1	1	22
Vikedal	177	51	87	55	2	22	20	27	3	80	159	259	944
Haukeland	93	38	142	39	2	16	17	9	4	92	220	154	825
Nausta	9	0	20	29	2	4	17	7	7	12	62	32	201
Kårvatn	24	11	29	30	6	10	5	4	1	27	17	32	202
Høylandet	63	14	57	44	2	8	3	7	3	29	24	118	370
Tustervatn	84	6	44	20	2	2	2	8	1	17	6	17	214
Karpbukt	12	4	9	6	14	29	6	11	11	13	3	3	121
Ny-Ålesund	42	41	13	7	6	1	6	13	20	10	-	6	165

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	2017
Birkenes	136	143	61	38	11	70	38	65	583	414	431	348	2440
Vatnedalen	58	27	111	43	13	92	54	70	110	121	241	130	1071
Treungen	17	24	22	4	9	14	14	37	81	27	38	30	317
Løken	27	10	10	5	8	15	12	31	39	32	60	66	315
Hurdal	20	16	11	7	11	6	11	21	35	14	44	21	221
Brekkebygda	6	14	12	18	6	14	12	10	43	13	8	9	164
Vikedal	1564	415	771	454	13	200	172	236	26	654	1429	2333	8266
Haukeland	769	345	1279	323	24	107	146	88	25	737	1820	1268	6933
Nausta	78	2	180	251	13	36	149	64	56	109	466	268	1671
Kårvatn	208	90	251	245	62	88	38	32	20	247	158	264	1736
Høylandet	540	112	471	369	28	71	24	67	25	256	210	1027	3201
Tustervatn	704	51	391	171	14	20	20	73	9	182	61	150	1892
Karpbukt	99	30	77	52	120	270	41	80	84	108	23	23	1006
Ny-Ålesund	323	319	96	56	45	3	33	102	168	63	-	50	1257

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	2017
Birkenes	230	256	105	63	17	143	62	104	981	703	761	640	4224
Vatnedalen	98	41	154	49	15	47	27	39	56	90	356	130	1101
Treungen	29	43	37	7	16	25	22	48	135	45	73	53	532
Løken	45	18	17	8	13	24	22	44	63	53	113	125	545
Hurdal	30	26	17	8	17	9	19	27	56	27	73	37	352
Brekkebygda	9	21	18	18	11	15	20	17	67	25	14	16	250
Vikedal	2584	715	1324	776	24	347	290	403	42	1196	2587	4236	14525
Haukeland	1325	594	2127	568	37	177	243	173	42	1322	3398	2359	12365
Nausta	135	4	312	439	21	61	250	103	89	198	951	492	3055
Kårvatn	354	168	449	439	98	155	65	52	26	444	296	490	3105
Høylandet	903	207	862	660	46	121	39	112	42	455	409	1880	5737
Tustervatn	1208	90	697	305	23	37	35	129	15	294	117	278	3305
Karpbukt	172	53	147	88	214	468	68	135	153	193	46	45	1782
Ny-Ålesund	593	593	174	99	79	6	61	177	305	110	-	88	2288

Table A.1.20: The 10 highest daily wet deposition of sea salt corrected sulfate, 2017.

Site	Date	SO_4 wet dep mgS/m^2	Precip mm'	% av annual SO_4 dep	pH
Birkenes	29.09.2017	57.4	74.5	14.1	4.71
	30.09.2017	43.0	95.5	10.5	4.91
	26.09.2017	15.0	29.9	3.7	5.14
	27.09.2017	10.9	11.6	2.7	5.43
	20.10.2017	10.5	37.4	2.6	4.81
	17.05.2017	9.9	16.2	2.4	5.72
	04.11.2017	9.8	29.8	2.4	4.58
	01.10.2017	9.2	76.9	2.3	5.45
	21.10.2017	9.1	91.1	2.2	5.05
	22.11.2017	7.5	46.8	1.8	5.04
	Sum			44.7	

Site	Date	SO_4 wet dep mgS/m^2	Precip mm'	% av annual SO_4 dep	pH
Hurdal	01.10.2017	7.8	21.2	6.8	4.93
	29.05.2017	6.4	15.6	5.6	5.49
	17.05.2017	4.5	20.4	3.9	5.40
	16.10.2017	4.0	9.7	3.5	6.13
	15.08.2017	3.5	21.7	3.0	5.16
	05.11.2017	3.4	22.9	3.0	4.94
	22.10.2017	2.8	5.4	2.4	4.81
	18.05.2017	2.7	20.8	2.4	5.40
	22.11.2017	2.7	33.3	2.3	5.39
	29.01.2017	2.6	3.5	2.3	4.97
	sum			35.1	

Table A.1.20 continued:

Site	Date	SO4 wet dep mgS/m2	Precip mm'	% av annual SO4 dep	pH
Tustervatn	27.05.2017	7.8	28.0	15.7	5.50
	08.07.2017	1.7	8.6	3.4	5.35
	30.08.2017	1.4	34.7	2.8	5.10
	25.01.2017	1.1	35.5	2.1	5.19
	29.07.2017	1.0	19.3	1.9	5.02
	08.05.2017	1.0	2.6	1.9	5.37
	30.04.2017	0.9	0.8	1.8	0.00
	10.08.2017	0.9	9.9	1.8	5.58
	24.06.2017	0.9	21.7	1.7	5.52
	17.07.2017	0.9	3.4	1.7	4.62
	sum			34.9	

Site	Date	SO4 wet dep mgS/m2	Precip mm'	% av annual SO4 dep	pH
Kårvatn	18.08.2017	3.1	22.1	3.5	5.52
	11.07.2017	3.0	29.5	3.4	4.89
	25.06.2017	2.8	30.9	3.2	5.29
	30.06.2017	2.7	6.7	3.0	4.73
	24.02.2017	2.7	20.6	3.0	5.15
	12.07.2017	2.5	20.5	2.8	4.66
	31.05.2017	2.1	7.4	2.4	5.33
	15.07.2017	1.8	13.0	2.1	5.08
	23.07.2017	1.8	10.6	2.0	4.80
	10.04.2017	1.8	22.2	2.0	5.33
	sum			27.4	

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 1987-2016.

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	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
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
Vatnedalen	1974	0.54				0.06	4.59	884	477			23		
	1975	0.53	0.17	0.22		0.09	4.85	994	527	169	219	14		
	1976	0.50	0.20	0.36	0.12	0.10	4.85	715	358	143	257	10		
	1977	0.44	0.21	0.25	0.13	0.06	4.71	761	335	160	190	15		
	1978	0.41	0.17	0.23	0.14	0.10	4.62	862	353	147	198	21		
	1979	0.56	0.22	0.20	0.20	0.06	4.38	948	531	209	190	40		
	1980	0.45	0.16	0.10	0.14	0.06	4.55	799	360	128	80	23		
	1981	0.49	0.19	0.18	0.14	0.09	4.49	900	441	171	162	29		
	1982	0.38	0.18	0.17	0.13	0.08	4.62	967	366	174	159	23		
	1983	0.29	0.13	0.10	0.14	0.08	4.76	1249	363	166	130	22		
	1984	0.40	0.18	0.13	0.16	0.08	4.59	762	306	138	102	20		
	1985	0.43	0.22	0.18	0.15	0.04	4.57	794	343	173	145	21		
	1986	0.51	0.21	0.19	0.13	0.07	4.54	987	506	212	183	29		
	1987	0.41	0.17	0.15	0.12	0.04	4.60	732	298	122	107	19		
	1988	0.37	0.23	0.20	0.13	0.08	4.55	898	334	207	182	25		
	1989	0.34	0.22	0.29	0.13	0.08	4.78	980	337	218	285	16		
	1990	0.27	0.14	0.12	0.14	0.11	4.71	1465	394	203	169	28		
	1991	0.32	0.20	0.17	0.29	0.12	4.69	865	280	172	147	18		
	1992	0.29	0.17	0.11	0.15	0.10	4.75	1055	301	175	112	19		
	1993	0.23	0.18	0.10	0.23	0.44	4.82	891	203	159	92	13		
	1994	0.28	0.22	0.15	0.08	0.08	4.75	1006	286	217	155	18		
	1995	0.25	0.18	0.13	0.11	0.10	4.82	823	206	147	108	12		
	1996	0.32	0.23	0.21	0.16	0.04	4.78	601	191	140	124	10		
	1997	0.24	0.15	0.14	0.22	0.10	4.95	858	204	130	121	10		
	1998	0.25	0.18	0.28	0.13	0.06	5.01	903	232	163	260	9		
	1999	0.24	0.16	0.24	0.12	0.08	5.05	1132	265	184	277	10		
	2000	0.15	0.14	0.15	0.11	0.08	5.02	1296	199	184	189	12		
	2001	0.15	0.09	0.10	0.12	0.05	5.27	709	103	65	73	4		
	2002	0.22	0.14	0.17	0.15	0.08	5.02	590	129	82	98	6		
	2003	0.17	0.17	0.14	0.16	0.06	4.97	802	140	132	117	9		
	2004	0.16	0.12	0.20	0.19	0.06	5.30	970	158	122	192	5		
	2005	0.18	0.15	0.14	0.16	0.05	5.17	1071	197	161	148	7		
	2006	0.12	0.16	0.12	0.12	0.06	5.17	1011	119	163	116	7		
	2007	0.10	0.11	0.13	0.17	0.10	5.31	845	84	89	110	4		
	2008	0.10	0.17	0.13	0.24	0.14	5.35	1016	104	171	135	5		
	2009	0.17	0.18	0.15	0.20	0.04	5.35	815	139	147	120	4		
	2010	0.19	0.15	0.19	0.17	0.04	5.40	619	115	91	118	2		
	2011	0.09	0.11	0.24	0.17	0.07	5.51	1225	115	132	294	4		
	2012	0.08	0.13	0.12	0.15	0.04	5.44	828	67	109	95	3		
	2013	0.09	0.14	0.35	0.14	0.05	5.50	983	92	133	344	3		

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m^2	NO_3-N mg/m^2	NH_4-N mg/m^2	H+ mekv/m^2	S mg/m^2	N mg/m^2
Vatnedalen (cont.)	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		
Treungen	1974	0.94	0.38	0.33	0.14	0.07	4.27	1039	977	395	343	56		
	1975	0.91	0.37	0.34	0.15	0.06	4.26	894	814	331	304	49		
	1976	1.05	0.50	0.42	0.11	0.06	4.20	706	741	353	297	45		
	1977	0.81	0.44	0.39	0.11	0.05	4.32	1165	944	513	454	56		
	1978	0.87	0.38	0.41	0.14	0.04	4.21	945	822	359	387	58		
	1979													
	1980	0.88	0.37	0.39	0.14	0.04	4.23	759	668	281	296	45		
	1981	0.86	0.39	0.46	0.12	0.05	4.29	949	816	370	437	49		
	1982	0.84	0.45	0.50	0.14	0.07	4.32	1130	948	504	563	54		
	1983	0.83	0.40	0.43	0.18	0.05	4.35	1091	908	431	471	48		
	1984	0.77	0.36	0.27	0.15	0.05	4.27	1196	919	436	325	64		
	1985	0.68	0.39	0.37	0.13	0.04	4.33	892	608	350	333	41		
	1986	1.07	0.57	0.63	0.14	0.07	4.19	1030	1097	582	650	66		
	1987	0.68	0.37	0.37	0.13	0.07	4.39	1133	768	424	418	46		
	1988	0.75	0.50	0.45	0.10	0.05	4.27	1348	1006	670	612	73		
	1989	0.76	0.61	0.44	0.10	0.06	4.26	754	572	456	329	41		
	1990	0.63	0.42	0.37	0.06	0.07	4.37	1184	747	503	433	51		
	1991	0.59	0.42	0.34	0.13	0.06	4.42	811	480	343	278	31		
	1992	0.60	0.40	0.34	0.08	0.05	4.44	923	556	365	310	33		
	1993	0.59	0.41	0.32	0.11	0.09	4.46	803	472	329	258	28		
	1994	0.54	0.44	0.35	0.08	0.05	4.49	1016	544	448	356	33		
	1995	0.50	0.44	0.40	0.09	0.08	4.48	903	452	394	361	30		
	1996	0.49	0.40	0.37	0.10	0.05	4.49	838	408	335	312	27		
	1997	0.41	0.37	0.32	0.12	0.06	4.56	887	364	330	282	24		
	1998	0.48	0.40	0.41	0.09	0.04	4.53	959	462	386	397	28		
	1999	0.35	0.32	0.31	0.06	0.06	4.67	1329	463	427	406	28		
	2000	0.33	0.36	0.31	0.08	0.07	4.59	1563	510	566	483	40		
	2001	0.30	0.28	0.27	0.05	0.04	4.77	1141	346	324	314	19		
	2002	0.32	0.27	0.28	0.08	0.04	4.79	933	295	251	262	15		
	2003	0.35	0.36	0.35	0.09	0.04	4.67	1002	349	366	350	22		
	2004	0.31	0.30	0.26	0.10	0.06	4.79	1271	393	379	336	21		
	2005	0.34	0.38	0.37	0.11	0.06	4.75	897	308	338	329	16		
	2006	0.23	0.28	0.20	0.09	0.05	4.79	1522	355	433	310	25		
	2007	0.23	0.24	0.18	0.08	0.04	4.82	1006	226	243	178	15		
	2008	0.21	0.28	0.26	0.11	0.08	4.93	1150	239	318	294	13		
	2009	0.21	0.34	0.25	0.07	0.06	4.82	1213	260	408	302	18		
	2010	0.28	0.34	0.32	0.07	0.03	4.79	849	241	289	271	14		
	2011	0.19	0.26	0.23	0.09	0.05	4.95	1177	227	308	270	13		
	2012	0.15	0.28	0.23	0.07	0.05	4.96	1092	167	307	247	12		
	2013	0.17	0.27	0.30	0.09	0.06	5.12	1150	190	305	349	9		

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m^2	NO_3-N mg/m^2	NH_4-N mg/m^2	H+ mekv/m^2	S mg/m^2	N mg/m^2
Treungen (cont.)	2014	0.21	0.28	0.26	0.11	0.07	4.90	1463	312	406	384	13		
	2015	0.12	0.21	0.19	0.11	0.07	4.96	1153	143	243	214	13		
	2016	0.16	0.27	0.30	0.09	0.07	4.98	957	150	263	284	10		
	2017	0.14	0.22	0.24	0.11	0.05	5.12	1186	169	265	288	8		
Løken	1973	1.03				0.06	4.48	569	586			19		
	1974	0.94				0.08	4.43	831	781			31		
	1975	1.03	0.41	0.42		0.08	4.32	657	677	269	276	31		
	1976	1.20	0.49	0.50	0.40	0.09	4.39	533	640	261	267	22		
	1977	0.96	0.41	0.43	0.22	0.07	4.41	699	671	287	301	27		
	1978	1.10	0.48	0.52	0.24	0.07	4.25	597	657	287	310	34		
	1979	1.03	0.49	0.57	0.30	0.07	4.22	784	808	384	447	47		
	1980	0.97	0.39	0.49	0.25	0.08	4.33	695	674	271	341	33		
	1981	0.77	0.36	0.51	0.20	0.06	4.48	700	539	252	357	23		
	1982	1.06	0.60	0.79	0.24	0.11	4.33	885	908	515	679	40		
	1983	0.91	0.47	0.62	0.28	0.10	4.42	656	595	311	404	25		
	1984	0.91	0.49	0.76	0.30	0.10	4.45	747	678	365	567	27		
	1985	0.86	0.47	0.51	0.30	0.09	4.36	894	768	421	459	39		
	1986	0.96	0.57	0.56	0.26	0.08	4.31	701	671	399	391	34		
	1987	0.79	0.40	0.45	0.17	0.06	4.40	861	679	348	387	35		
	1988	0.76	0.49	0.49	0.20	0.08	4.31	882	669	435	429	43		
	1989	0.92	0.69	0.57	0.18	0.10	4.26	421	389	292	239	55		
	1990	0.74	0.47	0.44	0.12	0.08	4.36	719	530	337	313	31		
	1991	0.65	0.50	0.44	0.18	0.09	4.41	722	467	359	320	28		
	1992	0.61	0.44	0.38	0.11	0.05	4.46	686	418	302	261	24		
	1993	0.66	0.44	0.38	0.18	0.05	4.46	714	468	316	270	25		
	1994	0.43	0.37	0.29	0.30	0.06	4.64	740	316	277	213	17		
	1995	0.52	0.43	0.36	0.24	0.09	4.56	656	340	282	235	18		
	1996	0.51	0.39	0.39	0.28	0.09	4.62	673	344	264	264	16		
	1997	0.42	0.40	0.41	0.16	0.06	4.63	549	229	220	223	13		
	1998	0.45	0.39	0.38	0.14	0.07	4.63	717	319	278	272	17		
	1999	0.38	0.36	0.35	0.10	0.06	4.71	1011	383	362	353	20		
	2000	0.33	0.33	0.24	0.07	0.06	4.60	1053	332	349	249	26		
	2001	0.33	0.31	0.26	0.13	0.04	4.75	818	265	253	213	14		
	2002	0.26	0.29	0.25	0.12	0.04	4.84	856	226	244	215	12		
	2003	0.33	0.37	0.34	0.15	0.05	4.72	651	212	244	221	12		
	2004	0.23	0.28	0.20	0.13	0.07	4.80	953	222	267	189	15		
	2005	0.34	0.38	0.32	0.14	0.06	4.77	686	236	260	217	12		
	2006	0.21	0.34	0.30	0.09	0.06	4.79	967	205	324	287	16		
	2007	0.24	0.30	0.28	0.16	0.06	4.92	727	177	216	204	9		
	2008	0.19	0.28	0.22	0.13	0.09	4.90	997	192	283	223	13		
	2009	0.17	0.32	0.29	0.11	0.06	5.06	837	140	267	247	7		
	2010	0.23	0.29	0.24	0.12	0.04	4.95	664	150	193	158	8		
	2011	0.21	0.25	0.41	0.14	0.08	5.12	1100	228	278	452	8		

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m^2	NO_3-N mg/m^2	NH_4-N mg/m^2	H+ $mekv/m^2$	S mg/m^2	N mg/m^2
Løken (cont.)	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		
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/m^2	NO_3-N mg/m^2	NH_4-N mg/m^2	H+ mekv/m^2	S mg/m^2	N mg/m^2
Gulsvik	1974	0.81	0.38	0.28	0.13	0.04	4.28	783	634	298	219	41		
	1975	0.89	0.40	0.34	0.21	0.05	4.36	560	498	224	190	24		
	1976	0.85	0.38	0.30	0.10	0.03	4.35	641	545	244	192	29		
	1977	0.77	0.39	0.35	0.13	0.03	4.35	683	526	266	239	31		
	1978	0.94	0.40	0.38	0.16	0.03	4.22	693	651	277	263	42		
	1979	1.27	0.53	0.62	0.23	0.04	4.11	790	1003	419	490	61		
	1980	0.78	0.25	0.27	0.13	0.03	4.33	667	520	167	180	31		
	1981	0.86	0.35	0.40	0.13	0.03	4.30	628	540	220	251	31		
	1982	0.89	0.44	0.52	0.22	0.05	4.38	778	696	346	408	33		
	1983	0.94	0.40	0.58	0.25	0.05	4.39	664	623	263	384	27		
	1984	0.87	0.40	0.58	0.25	0.04	4.41	946	819	382	547	37		
	1985	0.73	0.35	0.72	0.16	0.04	4.55	686	499	240	492	20		
	1986	0.89	0.48	0.51	0.15	0.04	4.30	804	711	382	409	40		
	1987	0.74	0.37	0.46	0.14	0.03	4.42	916	679	337	421	35		
	1988	0.67	0.41	0.38	0.09	0.03	4.33	1023	688	420	386	48	136	
	1989	0.76	0.54	0.55	0.15	0.06	4.42	668	507	360	369	25	88	
	1990	0.75	0.45	0.53	0.09	0.03	4.43	753	562	338	398	28	100	
	1991	0.60	0.42	0.46	0.13	0.04	4.58	506	302	212	235	13	97	
	1992	0.56	0.35	0.38	0.13	0.03	4.60	666	371	235	255	17	83	
	1993	0.50	0.33	0.40	0.12	0.03	4.66	680	343	222	269	15	60	
	1994	0.50	0.43	0.39	0.23	0.03	4.61	643	320	277	249	16	72	
	1995	0.56	0.39	0.42	0.12	0.04	4.54	634	354	249	268	18	64	
	1996	0.48	0.37	0.51	0.16	0.06	4.71	657	318	241	335	13	67	
	1997	0.35	0.32	0.33	0.12	0.04	4.74	704	247	225	232	13	52	
Brekkebygda	1998	0.38	0.29	0.25	0.08	0.02	4.62	886	336	256	224	21	36	
	1999	0.38	0.30	0.27	0.09	0.02	4.71	845	318	254	227	16	41	
	2000	0.37	0.29	0.23	0.17	0.06	4.69	1261	451	363	285	26	40	
	2001	0.31	0.25	0.29	0.08	0.04	4.81	*865*	*269*	*223*	*265*	*13*		
	2002	0.25	0.18	0.30	0.15	0.04	5.10	*839*	*208*	*155*	*255*	*7*		
	2003	0.30	0.26	0.28	0.17	0.06	4.89	852	257	224	242	11		
	2004	0.26	0.19	0.21	0.22	0.07	5.03	851	218	159	180	8		
	2005	0.36	0.33	0.35	0.12	0.03	4.87	754	275	249	267	10		
	2006	0.26	0.26	0.29	0.12	0.04	4.92	934	243	247	268	11		
	2007	0.18	0.18	0.16	0.13	0.03	4.98	1093	201	196	175	11		
	2008	0.23	0.31	0.32	0.12	0.03	4.94	950	220	298	299	11		
	2009	0.25	0.33	0.25	0.09	0.03	4.96	924	233	308	228	10		
	2010	0.24	0.24	0.33	0.07	0.02	5.03	831	200	203	272	8		
	2011	0.23	0.28	0.45	0.09	0.03	5.04	1387	320	388	629	13		
	2012	0.15	0.26	0.27	0.16	0.03	5.17	1086	165	282	289	7		
	2013	0.17	0.22	0.25	0.13	0.04	5.21	1202	207	268	304	7		
	2014	0.24	0.25	0.21	0.24	0.05	4.94	1105	269	276	234	11		
	2015	0.10	0.18	0.19	0.14	0.04	5.13	997	105	178	187	7		
	2016	0.15	0.23	0.24	0.10	0.03	5.01	892	136	209	217	10		
	2017	0.12	0.17	0.15	0.09	0.02	4.98	1092	130	190	167	10		

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m^2	NO_3-N mg/m^2	NH_4-N mg/m^2	H+ mekv/m^2	S mg/m^2	N mg/m^2
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		

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m^2	NO_3-N mg/m^2	NH_4-N mg/m^2	H+ mekv/m^2	S mg/m^2	N mg/m^2
Haukeland	1974	0.31	0.13	0.15	0.17	0.29	4.70	3901	1207	522	582	78		
	1975	0.36	0.10	0.17	0.17	0.37	4.73	4551	1636	431	753	85		
	1976	0.59	0.23	0.45	0.18	0.25	4.59	1808	1060	417	813	46		
	1982	0.48	0.18	0.20	0.14	0.24	4.56	3688	1756	674	722	101		
	1983	0.32	0.14	0.14	0.15	0.26	4.70	4769	1536	647	687	96		
	1984	0.42	0.16	0.28	0.20	0.22	4.63	2792	1157	454	783	65		
	1985	0.44	0.21	0.26	0.13	0.15	4.61	2930	1276	606	768	71		
	1986	0.36	0.16	0.20	0.12	0.20	4.71	4009	1459	621	796	77		
	1987	0.44	0.20	0.28	0.16	0.18	4.61	2493	1100	498	692	61		
	1988	0.35	0.21	0.28	0.14	0.24	4.63	3123	1096	642	872	74		
	1989	0.32	0.18	0.15	0.13	0.26	4.71	4525	1426	798	691	88		
	1990	0.27	0.13	0.15	0.11	0.29	4.79	5017	1364	665	744	82		
	1991	0.30	0.16	0.18	0.15	0.29	4.75	3744	1126	617	678	66		
	1992	0.32	0.17	0.17	0.14	0.22	4.77	4436	1421	768	771	76		
	1993	0.34	0.19	0.26	0.26	0.65	4.77	2891	974	556	760	50		
	1994	0.30	0.18	0.20	0.16	0.28	4.83	3670	1108	668	751	55		
	1995	0.21	0.14	0.17	0.11	0.22	4.89	3631	766	505	616	47		
	1996	0.27	0.19	0.26	0.11	0.14	4.85	2201	586	416	566	31		
	1997	0.17	0.14	0.12	0.08	0.14	4.87	3569	769	550	844	36		
	1998	0.22	0.15	0.19	0.09	0.17	4.93	3492	760	513	649	41		
	1999	0.21	0.15	0.17	0.11	0.23	4.99	4315	864	641	743	44		
	2000	0.20	0.15	0.15	0.13	0.28	4.95	3692	752	557	539	41		
	2001	0.18	0.15	0.22	0.09	0.18	5.08	2865	518	442	637	24		
	2002	0.23	0.19	0.22	0.16	0.25	4.97	2644	603	496	576	29		
	2003	0.15	0.14	0.13	0.11	0.18	4.96	3624	540	496	476	40		
	2004	0.12	0.12	0.10	0.09	0.19	5.01	3669	436	452	372	36		
	2005	0.19	0.14	0.14	0.11	0.17	5.06	4394	818	624	610	39		
	2006	0.15	0.17	0.13	0.12	0.17	5.03	3454	504	594	462	32		
	2007	0.09	0.09	0.10	0.12	0.23	5.18	4124	367	374	424	27		
	2008	0.09	0.13	0.12	0.15	0.31	5.16	3649	342	475	441	25		
	2009	0.11	0.12	0.11	0.07	0.15	5.20	3105	335	362	328	19		
	2010	0.17	0.19	0.16	0.05	0.08	5.13	2355	407	438	375	18		
	2011	0.08	0.11	0.20	0.11	0.25	5.22	4196	343	465	823	25		
	2012	0.07	0.10	0.09	0.09	0.19	5.27	3707	254	383	336	20		
	2013	0.08	0.11	0.16	0.11	0.21	5.29	3415	259	360	557	17		
	2014	0.10	0.11	0.12	0.16	0.19	5.15	3512	359	400	437	7		
	2015	0.05	0.10	0.08	0.19	0.31	5.06	4324	230	440	364	7		
	2016	0.06	0.08	0.11	0.13	0.32	5.14	3230	207	267	350	7		
	2017	0.06	0.09	0.10	0.14	0.23	5.21	3607	211	328	350	6		

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m^2	NO_3-N mg/m^2	NH_4-N mg/m^2	H+ mekv/m^2	S mg/m^2	N mg/m^2
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		
Kårvatn	1978	0.16	0.05	0.09	0.11	0.13	4.98	1317	211	66	119	14		
	1979	0.23	0.09	0.08	0.10	0.10	4.63	1248	287	112	100	29		
	1980	0.20	0.07	0.08	0.11	0.13	4.88	1225	245	86	98	16		
	1981	0.20	0.08	0.15	0.17	0.25	4.96	1101	220	88	165	12		
	1982	0.26	0.08	0.11	0.15	0.16	4.87	995	256	78	112	13		
	1983	0.14	0.05	0.06	0.18	0.20	5.08	1918	265	100	106	16		
	1984	0.24	0.10	0.18	0.22	0.18	5.04	914	216	91	166	8		
	1985	0.20	0.07	0.10	0.15	0.11	5.00	1462	298	100	149	15		
	1986	0.20	0.07	0.13	0.10	0.11	4.95	1277	260	89	162	14		
	1987	0.24	0.09	0.12	0.15	0.17	4.87	1464	357	129	176	20	68	
	1988	0.11	0.06	0.09	0.13	0.19	5.09	1550	164	91	143	13	76	149

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m^2	NO_3-N mg/m^2	NH_4-N mg/m^2	H+ mekv/m^2	S mg/m^2	N mg/m^2
Kårvatn	1989	0.11	0.06	0.12	0.13	0.26	5.11	1539	168	97	187	12	55	116
(cont.)	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
Høylandet	1987*	0.34	0.15	0.36	0.14	0.18	4.98	803	269	124	292	9	97	
	1988	0.22	0.11	0.17	0.16	0.20	5.00	1311	283	147	224	13	95	
	1989	0.17	0.10	0.14	0.20	0.45	5.11	1590	270	162	220	12		
	1990	0.21	0.10	0.13	0.14	0.26	4.92	1605	337	162	214	19		
	1991	0.23	0.11	0.20	0.21	0.31	5.10	1312	302	146	257	10		
	1992	0.15	0.09	0.15	0.16	0.36	5.16	1415	214	122	215	10		
	1993	0.20	0.12	0.20	0.17	0.35	5.10	1145	230	138	234	9		
	1994	0.15	0.09	0.22	0.12	0.25	5.23	1182	175	107	265	7		
	1995	0.17	0.10	0.22	0.17	0.27	5.20	1509	259	153	332	9		
	1996	0.16	0.10	0.21	0.16	0.26	5.11	813	132	84	167	6		
	1997	0.14	0.10	0.22	0.17	0.32	5.25	1418	196	145	308	8		
	1998	0.12	0.08	0.22	0.13	0.19	5.46	1456	173	123	316	5		
	1999	0.14	0.10	0.27	0.13	0.19	5.41	1195	171	125	342	5		
	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		

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m^2	NO_3-N mg/m^2	NH_4-N mg/m^2	H+ mekv/m^2	S mg/m^2	N mg/m^2
Høylandet (cont.)	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		
Tustervatn	1973	0.24				0.18	4.94	1336	321			15		
	1974	0.28				0.11	4.88	695	195			9		
	1975	0.25				0.33	4.91	1756	439			22		
	1976	0.27				0.16	4.97	1064	287			11		
	1977	0.30	0.09	0.11	0.17	0.16	4.91	1111	333	100	122	14		
	1978	0.23	0.08	0.10	0.16	0.16	4.85	1128	259	90	113	16		
	1979	0.28	0.08	0.13	0.15	0.11	4.73	1168	327	93	152	22		
	1980	0.27	0.08	0.14	0.47	0.16	4.98	858	229	71	122	9		
	1981	0.18	0.07	0.10	0.21	0.15	5.00	1099	198	77	110	11		
	1982	0.16	0.08	0.09	0.22	0.47	4.98	1385	227	109	121	15		
	1983	0.20	0.06	0.09	0.16	0.22	4.90	1665	337	101	142	21		
	1984	0.24	0.09	0.09	0.12	0.10	4.85	1056	250	94	89	15		
	1985	0.22	0.08	0.10	0.12	0.15	4.93	1344	298	107	132	16		
	1986	0.26	0.09	0.12	0.12	0.15	4.88	1060	278	94	131	14		
	1987	0.22	0.08	0.11	0.12	0.12	4.89	1163	253	98	133	15	96	
	1988	0.13	0.07	0.09	0.13	0.15	5.04	1159	145	83	106	10	88	131
	1989	0.19	0.08	0.10	0.18	0.40	5.00	1825	346	137	178	18	40	119
	1990	0.16	0.09	0.14	0.11	0.21	4.99	1508	245	133	214	16	65	125
	1991	0.17	0.10	0.14	0.14	0.21	5.04	1400	242	137	197	13	62	148
	1992	0.15	0.08	0.15	0.19	0.37	5.12	1507	223	126	221	11	49	123
	1993	0.14	0.08	0.16	0.24	0.50	5.19	1340	182	111	209	9	44	126
	1994	0.10	0.08	0.13	0.12	0.15	5.24	1117	114	87	144	6	48	147
	1995	0.09	0.06	0.12	0.13	0.21	5.22	1515	136	96	186	9	47	132
	1996	0.12	0.09	0.16	0.15	0.18	5.11	1084	132	97	176	8	44	139
	1997	0.08	0.06	0.18	0.17	0.30	5.34	1528	121	98	271	7	44	199
	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

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m^2	NO_3-N mg/m^2	NH_4-N mg/m^2	H+ mekv/m²	S mg/m^2	N mg/m^2
Tustervatn (cont.)	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
Karpdalen	1991	0.91	0.16	0.14	0.16	0.28	4.33	256	233	42	36	12		
	1992	0.96	0.20	0.31	0.26	0.35	4.43	315	302	62	98	12		
	1993	0.86	0.24	0.23	0.29	0.43	4.41	258	223	61	59	10		
	1994	0.60	0.23	0.18	0.15	0.21	4.58	414	250	96	73	11		
	1995	0.63	0.19	0.18	0.35	0.31	4.52	383	241	71	69	11		
	1996	0.49	0.15	0.17	0.20	0.24	4.62	458	224	69	76	24		
	1997	0.60	0.12	0.13	0.17	0.31	4.52	264	158	31	34	8		
Karpbukt	1999	0.36	0.13	0.13	0.11	0.13	4.74	551	198	72	73	10		
	2000	0.38	0.10	0.10	0.11	0.20	4.66	507	193	52	52	11		
	2001	0.40	0.09	0.11	0.14	0.21	4.79	612	241	58	67	10		
	2002	0.25	0.18	0.30	0.15	0.04	5.10	839	208	155	255	7		
	2003	0.27	0.09	0.11	0.18	0.29	4.88	582	158	54	66	8		
	2004	0.34	0.09	0.06	0.19	0.22	4.85	613	208	56	35	9		
	2005	0.42	0.11	0.19	0.16	0.26	4.84	633	264	68	120	9		
	2006	0.39	0.14	0.11	0.12	0.21	4.73	506	195	71	54	9		
	2007	0.39	0.10	0.14	0.15	0.21	5.00	678	265	65	94	7		
	2008	0.37	0.12	0.12	0.19	0.29	4.83	507	186	60	60	8		
	2009	0.41	0.12	0.09	0.12	0.20	4.88	526	218	64	47	7		
	2010	0.30	0.07	0.07	0.12	0.21	4.83	595	178	45	43	9		
	2011	0.38	0.11	0.15	0.12	0.15	4.76	553	212	61	85	10		
	2012	0.20	0.07	0.13	0.12	0.21	4.91	593	117	44	76	7		
	2013	0.33	0.09	0.16	0.25	0.44	4.93	516	170	44	84	6		
	2014	0.40	0.11	0.15	0.18	0.21	4.84	571	229	64	88	14		
	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		

Table A.1.21a, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual precip	Annual total wet deposition				Dry deposition	
		SO_4-S mg/l	NO_3-N mg/l	NH_4-N mg/l	Ca mg/l	Mg mg/l	pH	mm	SO_4-S mg/m^2	NO_3-N mg/m^2	NH_4-N mg/m^2	H+ mekv/m^2	S mg/m^2	N mg/m^2
Ny-Ålesund (tørr-avsetning fra Zeppelin)	1981	0.24	0.05	0.05	1.03	0.41	5.11	366	88	20	17	3		
	1982	0.39	0.08	0.05	0.92	2.01	5.01	206	80	16	10	2		
	1983	0.25	0.05	0.10	0.40	0.42	5.13	237	59	11	24	2		
	1984	0.64	0.17	0.21	0.71	0.93	4.60	366	233	62	76	9		
	1985	0.61	0.14	0.13	0.71	1.29	4.72	237	144	33	31	5		
	1986	0.40	0.07	0.49	0.55	0.58	4.98	306	122	20	150	3		
	1987	0.69	0.12	0.10	0.64	0.91	4.63	390	271	46	40	9		
	1988	0.27	0.07	0.21	0.54	0.58	5.18	307	84	21	64	2		
	1989	0.38	0.05	0.06	0.87	1.48	5.55	295	113	15	19	1	35	
	1990	0.33	0.07	0.06	0.52	0.79	4.92	410	137	30	26	5	41	20
	1991	0.34	0.11	0.10	0.80	1.13	4.96	424	145	47	44	5	35	27
	1992	0.43	0.10	0.11	0.80	1.03	5.11	272	116	27	29	2	31	21
	1993	0.29	0.10	0.08	0.51	0.91	5.02	489	140	47	41	5	32	29
	1994	0.32	0.08	0.29	0.59	0.63	5.35	280	90	22	80	1	24	30
	1995	0.30	0.10	0.15	0.89	0.79	5.26	238	71	23	36	1	25	
	1996	0.36	0.13	0.32	0.56	0.90	4.92	504	181	64	162	6	26	
	1997	0.34	0.10	0.44	1.46	2.98	5.60	320	109	32	139	8	27	
	1998	0.27	0.13	0.19	0.78	1.18	5.24	193	42	24	35	1	31	
	1999	0.31	0.19	0.21	1.06	1.30	5.04	227	61	43	50	2	29	
	2000	0.16	0.08	0.10	0.47	0.49	5.37	423	63	32	42	2	24	
	2001	0.15	0.08	0.07	0.56	0.83	5.35	358	52	27	24	2	35	
	2002	0.10	0.08	0.11	1.31	1.34	5.41	544	53	44	61	2	30	
	2003	0.26	0.11	0.12	1.67	2.21	5.50	207	53	23	25	1	32	
	2004	0.23	0.12	0.10	0.93	1.01	5.13	253	57	29	25	2	26	
	2005	0.19	0.09	0.09	1.28	0.89	5.45	212	40	19	18	1	32	
	2006	0.20	0.08	0.18	1.21	1.19	5.43	341	70	27	61	1	22	
	2007	0.19	0.05	0.12	0.79	1.11	5.89	304	59	14	37	1	19	
	2008	0.11	0.1	0.26	1.09	0.8	5.74	282	32	28	72	1	22	
	2009	0.13	0.09	0.05	0.35	0.44	5.45	219	28	20	11	0.8	21	
	2010	0.11	0.11	0.2	0.51	1.21	5.23	211	23	22	42	1.2	18	
	2011	0.07	0.08	0.3	0.56	1	5.51	294	21	24	89	0.9	25	
	2012	0.06	0.06	0.05	0.3	0.47	5.51	373	23	22	17	1.1	20	
	2013	0.10	0.07	0.09	0.47	0.63	5.38	268	27	18	24	1.1	19	
	2014	0.47	0.09	0.08	0.44	0.6	4.78	311	145	29	25	16.6	35	
	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	

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/m^2	mg/m^2	mg/m^2	mekv/m^2	mg/m^2	mg/m^2
Lista	1973	1.01				1.31	4.33	851	860			40		
	1974	1.06				1.00	4.28	1208	1280			63		
	1975	1.10				1.06	4.30	1109	1220			56		
	1976	1.37				1.21	4.23	922	1263			54		
	1977	0.95				1.09	4.34	1114	1058			51		
	1978	1.01	0.50	0.45	0.51	1.07	4.27	931	940	466	419	50		
	1979	1.27	0.63	0.57	0.53	1.04	4.09	1157	1469	729	659	94		
	1980	1.05	0.59	0.54	0.47	1.00	4.22	953	1001	562	515	57		
	1981	0.90	0.47	0.50	0.60	1.36	4.34	1037	933	487	519	47		
	1982	1.09	0.65	0.60	0.85	1.82	4.29	1070	1161	699	645	55		
	1983	0.88	0.49	0.40	0.77	1.69	4.36	1198	1051	584	480	53		
	1984	0.92	0.61	0.47	0.86	2.12	4.28	1002	923	613	474	53		
	1985	1.11	0.80	0.68	0.76	1.74	4.20	996	1110	793	681	63		
	1986	0.95	0.63	0.57	1.06	2.66	4.30	1293	1230	816	739	65		
	1987	0.86	0.55	0.55	0.65	1.48	4.35	1169	1004	647	638	52		
	1988	0.75	0.67	0.57	0.82	2.02	4.28	1585	1189	1054	895	84		
	1989	0.83	0.86	0.52	1.21	3.23	4.30	1053	877	904	552	53		
	1990	0.74	0.55	0.42	1.07	3.01	4.38	1565	1156	856	653	65		
	1991	0.75	0.83	0.60	1.36	3.76	4.32	1031	771	858	615	49		
	1992	0.72	0.60	0.41	1.02	2.54	4.38	1376	985	826	561	57		
	1993	0.81	0.80	0.68	2.10	1.79	4.39	845	686	673	579	34		
	1994	0.56	0.57	0.52	0.91	2.37	4.56	1180	659	678	615	33		
	1995	0.67	0.73	0.62	1.15	3.05	4.48	896	599	658	555	30		
	1996	0.62	0.74	0.67	0.88	2.20	4.42	910	564	673	607	35		
	1997	0.55	0.55	0.56	0.94	2.54	4.52	1219	666	666	682	37		
	1998	0.59	0.62	0.53	0.97	2.44	4.46	1240	637	767	661	43		
	1999	0.44	0.60	0.48	1.11	3.00	4.63	1273	547	762	614	30		
	2000	0.45	0.64	0.49	1.28	3.45	4.54	1651	711	1064	808	47		
	2001	0.45	0.59	0.55	0.63	1.55	4.77	1428	639	847	787	24		
	2002	0.47	0.71	0.56	0.99	2.18	4.69	1132	534	808	628	23		
Søgne	1989	1.12	0.93	0.91	0.31	0.43	4.34	1151	1289	1067	1050	53	212	
	1990	0.79	0.60	0.48	0.25	0.52	4.33	1807	1425	1084	872	85	237	612
	1991	0.94	0.66	0.58	0.23	0.47	4.30	1133	1063	750	662	57	245	559
	1992	0.79	0.59	0.49	0.19	0.34	4.33	1280	1011	752	623	60	192	365
	1993	0.95	0.71	0.63	0.26	0.26	4.33	1112	1061	786	699	52	148	326
	1994	0.76	0.62	0.54	0.19	0.31	4.39	1441	1092	894	781	58	173	349
	1995	0.61	0.54	0.45	0.19	0.34	4.45	1213	735	651	552	43	151	350
	1996	0.87	0.75	0.69	0.31	0.36	4.32	1044	910	786	725	50	175	305
	1997	0.67	0.60	0.63	0.20	0.34	4.46	1215	809	733	760	42	123	304
	1998	0.70	0.60	0.55	0.24	0.39	4.45	1333	939	812	740	45	110	268
	1999	0.63	0.57	0.50	0.21	0.34	4.50	1667	1 053	947	840	53	112	249
	2000	0.47	0.54	0.48	0.21	0.38	4.53	2029	980	1100	975	60	96	245
	2001	0.48	0.52	0.47	0.14	0.21	4.61	1569	756	816	737	38	106	
	2002	0.44	0.42	0.34	0.20	0.28	4.64	1608	704	679	552	37	114	
	2003	0.59	0.68	0.68	0.29	0.28	4.59	1271	749	863	865	32	101	
	2004	0.43	0.47	0.45	0.24	0.36	4.72	1601	697	760	717	30	89	
	2005	0.46	0.59	0.55	0.28	0.44	4.64	1176	535	700	644	27	99	
	2006	0.41	0.52	0.41	0.23	0.37	4.68	1714	707	884	707	35	156	
	2007	0.31	0.43	0.29	0.23	0.40	4.80	1237	379	538	362	20	70	
	2008	0.36	0.40	0.35	0.28	0.54	4.83	1697	610	676	601	25	62	
	2009	0.36	0.47	0.43	0.25	0.38	4.77	1633	592	763	699	27	63	
Skreådalen	1973	0.50				0.19	4.60	2185	1093			55		
	1974	0.55				0.18	4.47	2460	1350			83		
	1975	0.57	0.18	0.17		0.19	4.55	2436	1389	438	414	69		
	1976	0.60	0.24	0.23		0.17	4.55	1687	1012	405	388	48		
	1977	0.57	0.27	0.28	0.15	0.13	4.55	2057	1174	550	569	57		
	1978	0.49	0.20	0.26	0.20	0.29	4.52	1769	867	354	460	53		
	1979	0.61	0.26	0.28	0.16	0.14	4.33	2311	1410	601	647	108		
	1980	0.48	0.21	0.21	0.15	0.17	4.54	1949	936	409	409	56		

Table A.1.21b, cont.

		Annual vol. weighted mean concentrations						Annual	Annual total wet deposition				Dry deposition	
Site	Year	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/m^2	mg/m^2	mg/m^2	mekv/m^2	mg/m^2	mg/m^2
Skreådalen cont.	1981	0.49	0.20	0.28	0.16	0.18	4.58	2260	1107	452	633	59		
	1982	0.57	0.28	0.37	0.17	0.22	4.52	2519	1436	709	933	76		
	1983	0.43	0.19	0.26	0.18	0.23	4.70	2843	1221	551	734	57		
	1984	0.46	0.24	0.23	0.16	0.21	4.59	1762	802	415	401	46		
	1985	0.59	0.32	0.33	0.15	0.12	4.48	1895	1117	610	616	63		
	1986	0.53	0.29	0.30	0.15	0.19	4.51	2439	1289	698	734	75		
	1987	0.47	0.28	0.29	0.14	0.16	4.54	1639	767	451	471	48	152	
	1988	0.41	0.28	0.28	0.12	0.14	4.55	2255	926	622	632	64	153	
	1989	0.43	0.28	0.28	0.15	0.20	4.56	2519	1087	704	696	70	143	355
	1990	0.39	0.23	0.22	0.13	0.26	4.61	3346	1293	775	732	82	170	415
	1991	0.41	0.27	0.25	0.15	0.24	4.61	2172	894	583	547	53	125	279
	1992	0.37	0.24	0.23	0.12	0.16	4.70	2728	1017	647	627	55	118	254
	1993	0.29	0.22	0.25	0.30	0.56	4.81	2006	586	437	493	31	82	256
	1994	0.38	0.28	0.31	0.31	0.25	4.77	2214	842	619	695	37	104	330
	1995	0.30	0.24	0.24	0.16	0.21	4.75	2083	624	510	500	37	96	257
	1996	0.30	0.28	0.31	0.14	0.12	4.78	1463	438	404	455	25	91	329
	1997	0.25	0.23	0.29	0.21	0.33	4.92	2071	508	472	609	25	73	280
	1998	0.32	0.27	0.31	0.17	0.15	4.83	1961	636	525	621	29	53	254
	1999	0.25	0.23	0.24	0.14	0.23	4.93	2521	618	583	606	30	60	229
	2000	0.23	0.24	0.25	0.14	0.21	4.90	2997	671	705	750	37	58	225
	2001	0.23	0.23	0.33	0.12	0.11	5.10	1887	424	435	619	15	56	260
	2002	0.22	0.23	0.35	0.19	0.20	5.17	1996	443	461	698	14	63	270
	2003	0.24	0.26	0.28	0.14	0.14	4.89	2115	501	545	600	27	48	165
	2004	0.16	0.19	0.21	0.14	0.15	5.07	2531	401	487	528	22	50	239
Valle	1990	0.40	0.27	0.20	0.07	0.11	4.51	1504	607	409	306	46		
	1991	0.47	0.32	0.25	0.14	0.10	4.52	912	432	287	227	28		
	1992	0.46	0.28	0.22	0.13	0.10	4.59	1120	519	318	242	29		
	1993	0.42	0.26	0.23	0.19	0.27	4.66	1052	445	276	243	23		
	1994	0.49	0.37	0.30	0.17	0.11	4.58	1230	608	461	373	32		
	1995	0.33	0.28	0.20	0.13	0.11	4.63	926	303	256	183	22		
	1996	0.38	0.33	0.25	0.17	0.07	4.60	836	316	273	206	21		
	1997	0.30	0.26	0.20	0.12	0.11	4.70	1085	323	280	220	22		
	1998	0.33	0.28	0.29	0.09	0.05	4.67	1179	393	330	336	25		
	1999	0.28	0.22	0.15	0.08	0.07	4.74	1284	335	281	192	23		
	2000	0.26	0.29	0.24	0.10	0.07	4.70	1618	422	467	395	32		
Solhomfjell	1991	0.63	0.44	0.40	0.14	0.08	4.44	878	552	389	355	32		
	1992	0.69	0.47	0.39	0.12	0.07	4.44	958	662	447	376	35		
	1993	0.66	0.45	0.38	0.15	0.08	4.47	920	611	412	347	31		
	1994	0.60	0.48	0.38	0.12	0.06	4.50	1150	686	550	442	36		
	1995	0.55	0.45	0.43	0.14	0.08	4.51	1073	590	484	464	33		
	1996	0.61	0.45	0.41	0.17	0.07	4.46	908	551	410	377	31		
Møsvatn	1993	0.28	0.22	0.14	0.07	0.07	4.69	699	194	155	99	14		
	1994	0.32	0.27	0.17	0.07	0.02	4.66	788	250	209	136	17		
	1995	0.28	0.22	0.14	0.06	0.02	4.65	660	186	147	92	15		
	1996	0.30	0.27	0.21	0.07	0.02	4.66	592	178	161	126	13		
	1997	0.21	0.22	0.18	0.08	0.03	4.77	705	150	155	129	12		
	1998	0.24	0.20	0.15	0.07	0.02	4.79	783	188	154	114	13		
	1999	0.22	0.21	0.16	0.08	0.03	4.89	777	171	169	125	10		
	2000	0.19	0.21	0.16	0.06	0.03	4.79	1000	189	212	159	16		
Lardal	1990	0.70	0.45	0.35	0.09	0.07	4.33	1340	938	599	469	62	99	199
	1991	0.72	0.47	0.36	0.12	0.08	4.38	847	609	401	306	35	144	231
	1992	0.68	0.47	0.38	0.13	0.07	4.42	892	610	421	338	34	91	154
	1993	0.65	0.42	0.32	0.09	0.05	4.45	967	625	402	313	35	66	134
	1994	0.52	0.45	0.35	0.08	0.05	4.53	1216	631	542	429	36	78	159
	1995	0.65	0.47	0.42	0.11	0.09	4.42	1179	764	556	497	45		
	1996	0.50	0.36	0.29	0.11	0.06	4.49	940	472	341	269	30		
	1997	0.58	0.45	0.43	0.31	0.17	4.61	640	373	288	276	16		
	1998	0.52	0.42	0.36	0.12	0.07	4.50	975	505	414	362	31		
	1999	0.43	0.36	0.31	0.08	0.05	4.61	1371	581	492	424	33		
	2000	0.39	0.38	0.30	0.09	0.09	4.54	1809	703	693	550	53		
	2001	0.36	0.33	0.31	0.09	0.05	4.71	1224	442	408	381	24		
	2002	0.34	0.25	0.25	0.10	0.04	4.82	1142	383	285	288	17		

Table A.1.21b, cont.

		Annual vol. weighted mean concentrations						Annual	Annual total wet deposition				Dry deposition	
Site	Year	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/m^2	mg/m^2	mg/m^2	mekv/m^2	mg/m^2	mg/m^2
Prestebakke	1986	1.08	0.54	0.47	0.23	0.19	4.20	699	753	380	328	44		
	1987	0.78	0.42	0.37	0.16	0.08	4.37	830	650	349	307	35	212	343
	1988	0.77	0.47	0.37	0.16	0.15	4.25	989	758	466	370	55	219	307
	1989	0.97	0.69	0.47	0.18	0.21	4.22	697	678	478	330	42	191	301
	1990	0.87	0.57	0.42	0.18	0.18	4.28	816	710	465	342	42	157	252
	1991	0.79	0.55	0.43	0.20	0.25	4.37	805	638	445	346	35	98	190
	1992	0.83	0.60	0.47	0.16	0.15	4.35	832	687	497	392	37	140	154
	1993	0.74	0.47	0.36	0.17	0.13	4.41	775	573	364	278	30	119	228
	1994	0.53	0.39	0.24	0.17	0.13	4.48	892	477	352	216	29	138	234
	1995	0.65	0.54	0.46	0.18	0.17	4.45	746	487	406	346	26	126	
	1996	0.64	0.56	0.43	0.27	0.18	4.42	656	419	368	283	25	126	
	1997	0.42	0.39	0.29	0.08	0.06	4.52	813	338	317	237	24	97	
	1998	0.53	0.45	0.38	0.32	0.20	4.66	842	449	377	328	18	77	
	1999	0.50	0.48	0.34	0.15	0.17	4.52	1182	590	564	394	36	90	
	2000	0.36	0.40	0.30	0.20	0.15	4.60	1181	449	474	351	30	84	
Fagernes	1990	0.41	0.22	0.16	0.10	0.02	4.53	550	228	119	86	16		
	1991	0.38	0.21	0.24	0.22	0.04	4.75	395	150	84	94	7		
	1992	0.43	0.24	0.19	0.10	0.01	4.63	656	279	160	126	15		
	1993	0.26	0.15	0.12	0.08	0.02	4.77	619	162	95	74	10		
	1994	0.28	0.25	0.15	0.08	0.02	4.70	586	166	146	88	12		
	1995	0.32	0.22	0.29	0.14	0.07	4.81	465	151	101	134	7		
	1996	0.25	0.23	0.20	0.17	0.03	4.78	635	159	145	124	11		
	1997	0.21	0.15	0.16	0.09	0.02	4.89	565	116	83	92	6		
	1998	0.21	0.17	0.16	0.13	0.03	4.87	583	125	97	92	8		
	1999	0.20	0.18	0.12	0.08	0.01	4.86	633	125	113	75	9		
	2000	0.19	0.19	0.19	0.10	0.02	4.85	757	150	147	145	11		
	2001	0.16	0.16	0.14	0.12	0.02	5.01	649	103	104	92	6		
	2002	0.19	0.15	0.15	0.13	0.02	4.99	632	119	94	96	6		
Osen	1988	0.53	0.31	0.26	0.13	0.02	4.43	832	442	254	215	31	139	
	1989	0.52	0.27	0.15	0.14	0.03	4.47	786	410	214	122	27	95	145
	1990	0.55	0.28	0.27	0.23	0.03	4.48	711	393	198	192	23	90	123
	1991	0.34	0.26	0.20	0.08	0.02	4.58	647	222	168	129	17	77	107
	1992	0.44	0.37	0.18	0.13	0.02	4.55	725	318	207	133	20	68	103
	1993	0.37	0.26	0.18	0.10	0.02	4.62	764	283	195	140	18	53	94
	1994	0.30	0.27	0.19	0.08	0.02	4.69	636	192	172	120	13	69	112
	1995	0.44	0.27	0.26	0.12	0.03	4.59	612	271	167	157	16	62	108
	1996	0.32	0.26	0.26	0.14	0.03	4.71	574	183	147	151	11	64	112
	1997	0.22	0.20	0.18	0.10	0.02	4.83	708	158	139	126	11	48	108
	1998	0.30	0.23	0.24	0.09	0.02	4.77	655	198	152	155	11	35	97
	1999	0.26	0.24	0.20	0.08	0.02	4.83	750	191	182	149	11	46	114
	2000	0.22	0.20	0.17	0.06	0.03	4.72	971	229	198	165	18	38	118
	2001	0.20	0.20	0.20	0.07	0.01	4.95	768	150	152	153	9	38	137
	2002	0.25	0.19	0.25	0.11	0.03	4.91	738	182	140	184	9	44	157
	2003	0.20	0.22	0.20	0.09	0.02	4.87	661	135	146	133	9	41	138
Valdalen	1994	0.32	0.29	0.19	0.10	0.03	4.70	536	172	153	103	11		
	1995	0.43	0.30	0.37	0.13	0.04	4.68	518	221	153	194	11		
	1996	0.27	0.20	0.29	0.11	0.03	4.91	724	193	142	211	9		
	1997	0.26	0.21	0.22	0.13	0.03	4.89	710	185	152	154	9		
	1998	0.22	0.19	0.16	0.08	0.02	4.88	700	156	130	115	9		
	1999	0.21	0.22	0.19	0.12	0.02	5.05	692	147	150	131	8		
	2000	0.20	0.19	0.20	0.07	0.03	4.92	817	165	154	165	10		
Ualand	1992	0.49	0.30	0.22	0.16	0.31	4.53	2404	1171	714	530	71		
	1993	0.49	0.32	0.24	0.22	0.56	4.53	1531	745	492	365	46		
	1994	0.52	0.38	0.30	0.15	0.33	4.51	2125	1106	802	630	65		
	1995	0.45	0.37	0.27	0.14	0.31	4.51	1838	824	682	499	57		
	1996	0.40	0.32	0.24	0.14	0.23	4.54	1561	631	496	375	45		
	1997	0.44	0.33	0.32	0.19	0.36	4.58	1948	855	648	622	51		
	1998	0.47	0.38	0.29	0.16	0.31	4.52	1992	928	761	584	59		
	1999	0.32	0.30	0.20	0.16	0.37	4.65	2487	798	736	509	55		
	2000	0.31	0.31	0.21	0.19	0.41	4.65	2681	819	832	572	61		

Table A.1.21b, cont.

		Annual vol. weighted mean concentrations						Annual	Annual total wet deposition				Dry deposition	
Site	Year	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/m^2	mg/m^2	mg/m^2	mekv/m²	mg/m^2	mg/m^2
Voss	1990	0.29	0.15	0.08	0.10	0.15	4.68	2053	595	300	169	43		
	1991	0.28	0.18	0.11	0.10	0.18	4.67	1214	342	213	130	26		
	1992	0.27	0.16	0.07	0.06	0.07	4.70	1627	436	255	110	32		
	1993	0.24	0.13	0.08	0.16	0.31	4.82	1162	282	148	96	17		
	1994	0.28	0.16	0.12	0.21	0.14	4.79	1473	408	234	178	24		
	1995	0.21	0.14	0.12	0.08	0.11	4.82	1439	303	208	168	22		
	1996	0.26	0.20	0.19	0.08	0.05	4.76	869	222	174	163	15		
	1997	0.22	0.15	0.24	0.16	0.34	5.00	1275	220	181	152	17		
	1998	0.18	0.14	0.11	0.06	0.10	4.87	1411	250	204	159	19		
	1999	0.18	0.13	0.09	0.06	0.11	4.88	1641	178	211	157	22		
	2000	0.16	0.14	0.12	0.08	0.13	4.91	1844	296	249	214	23		
	2001	0.15	0.13	0.11	0.06	0.07	5.02	1256	183	164	137	12		
	2002	0.18	0.14	0.13	0.08	0.10	4.92	1078	191	149	140	13		
Selbu	1990	0.16	0.06	0.02	0.06	0.10	4.84	1339	220	83	31	19		
	1991	0.18	0.09	0.06	0.11	0.22	4.94	1336	240	125	80	15		
	1992	0.14	0.07	0.03	0.11	0.20	4.95	1402	193	103	45	16		
	1993	0.15	0.09	0.06	0.11	0.17	5.01	1290	193	117	80	13		
	1994	0.16	0.09	0.11	0.07	0.12	5.02	1143	179	105	129	11		
	1995	0.15	0.08	0.12	0.08	0.13	5.01	1411	206	113	166	14		
	1996	0.13	0.08	0.13	0.19	0.18	5.15	1039	132	86	131	7		
	1997	0.11	0.06	0.10	0.16	0.20	5.26	1682	183	105	172	9		
	1998	0.10	0.06	0.10	0.09	0.13	5.20	1333	139	80	131	8		
	1999	0.10	0.07	0.06	0.09	0.10	5.17	1303	133	93	82	9		
	2000	0.14	0.08	0.09	0.15	0.26	5.11	1138	162	87	98	9		
	2001	0.11	0.05	0.06	0.15	0.22	5.19	1540	166	84	86	10		
Namsvatn	1991	0.18	0.11	0.20	0.08	0.12	5.13	1014	181	115	198	8		
	1992	0.14	0.10	0.12	0.12	0.19	5.12	1081	155	105	129	8		
	1993	0.14	0.10	0.17	0.15	0.16	5.20	1004	144	98	172	6		
	1994	0.14	0.10	0.17	0.29	0.11	5.18	902	129	94	152	6		
	1995	0.16	0.10	0.20	0.11	0.15	5.18	1201	188	121	243	8		
	1996	0.17	0.12	0.20	0.11	0.11	5.10	697	117	86	139	6		
Øverbygd	1987*	0.23	0.05	0.08	0.12	0.14	4.92	424	100	23	35	5		
	1988	0.20	0.06	0.05	0.09	0.10	4.84	555	112	33	30	8		
	1989	0.16	0.06	0.06	0.09	0.18	4.98	794	125	45	51	8		
	1990	0.22	0.06	0.07	0.10	0.15	4.90	708	152	44	52	9		
	1991	0.25	0.09	0.07	0.11	0.18	4.90	706	176	60	49	9		
	1992	0.17	0.07	0.06	0.12	0.18	5.08	662	109	44	38	6		
	1993	0.17	0.07	0.07	0.26	0.43	5.06	680	117	48	45	6		
	1994	0.20	0.10	0.13	0.12	0.14	5.03	538	108	56	68	5		
	1995	0.11	0.06	0.11	0.14	0.11	5.13	659	73	42	74	5		
	1996	0.14	0.07	0.10	0.10	0.15	5.01	527	72	35	52	5		
	1997	0.10	0.06	0.11	0.16	0.28	5.13	603	59	37	69	4		
	1998	0.13	0.05	0.06	0.08	0.07	5.13	576	73	32	34	4		
	1999	0.13	0.05	0.07	0.06	0.07	5.13	811	103	44	53	6		
	2000	0.10	0.04	0.05	0.06	0.09	5.18	750	76	33	39	5		
	2001	0.11	0.04	0.05	0.09	0.15	5.24	721	75	30	38	4		
	2002	0.12	0.05	0.07	0.15	0.15	5.30	654	79	33	47	3		
	2003	0.07	0.04	0.08	0.14	0.16	5.25	907	65	40	72	5		
	2004	0.10	0.04	0.05	0.08	0.10	5.23	818	82	35	44	5		
	2005	0.16	0.06	0.14	0.08	0.06	5.26	745	118	43	105	4		
	2006	0.11	0.07	0.10	0.10	0.15	5.26	671	76	47	68	4		
Jergul	1977	0.45	0.13	0.11	0.20	0.04	4.75	344	155	45	38	6		
	1978	0.43	0.10	0.11	0.13	0.02	4.52	351	151	35	39	11		
	1979	0.59	0.18	0.13	0.14	0.03	4.33	306	181	55	40	14		
	1980	0.42	0.12	0.09	0.12	0.03	4.57	262	110	31	24	7		
	1981	0.46	0.13	0.12	0.11	0.02	4.57	434	200	56	52	12		
	1982	0.36	0.13	0.14	0.10	0.03	4.65	473	172	62	65	11		
	1983	0.41	0.11	0.11	0.13	0.04	4.60	382	156	41	43	10		
	1984	0.50	0.15	0.22	0.14	0.03	4.50	342	172	50	76	11		
	1985	0.43	0.12	0.34	0.13	0.05	4.63	406	174	49	137	10		
	1986	0.49	0.16	0.14	0.12	0.04	4.60	250	122	40	34	6		
	1987	0.41	0.12	0.10	0.11	0.03	4.67	296	121	35	29	6	180	

Table A.1.21b, cont.

Site	Year	Annual vol. weighted mean concentrations						Annual	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/m^2	mg/m^2	mg/m^2	mekv/m^2	mg/m^2	mg/m^2
Jergul cont.	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
Andøya	2011	0.06	0.08	0.16	0.24	0.61	5.23	1345	75	102	212	8		
Svanvik	1987	0.68	0.12	0.21	0.13	0.10	4.49	365	247	42	76	12	711	173
	1988	0.57	0.13	0.13	0.18	0.14	4.49	390	221	52	50	13	602	160
	1989	0.72	0.12	0.10	0.19	0.12	4.47	424	306	50	42	14	571	130
	1990	0.48	0.13	0.08	0.11	0.13	4.50	266	127	36	22	8	691	123
	1991	0.56	0.14	0.16	0.08	0.09	4.55	389	218	55	61	11	652	139
	1992	0.51	0.12	0.22	0.10	0.10	4.71	432	220	53	93	8	422	165
	1993	0.62	0.16	0.23	0.16	0.14	4.66	331	207	52	78	7	530	135
	1994	0.58	0.17	0.35	0.12	0.12	4.71	379	219	66	132	7	541	111
	1995	0.59	0.11	0.19	0.13	0.13	4.62	395	233	45	74	9	642	133
	1996	0.44	0.16	0.22	0.22	0.17	4.73	352	154	57	76	7	471	125
	1997	0.48	0.14	0.29	0.20	0.14	4.79	278	134	39	82	4	637	145
	1998	0.50	0.13	0.27	0.13	0.15	4.74	346	168	44	89	6	947	157
	1999	0.36	0.13	0.18	0.08	0.07	4.86	463	164	59	84	6	444	175
	2000	0.52	0.15	0.24	0.11	0.10	4.69	436	222	64	106	9	388	159
	2001	0.65	0.13	0.30	0.15	0.14	4.90	374	239	50	114	5	461	
	2002	0.45	0.11	0.30	0.20	0.24	4.96	425	190	45	129	5	569	
	2003	0.33	0.13	0.27	0.17	0.16	4.97	371	121	47	99	4		
	2004-8													
	2009	0.82	0.14	0.16	0.13	0.09	4.40	323	257	44	51	13		
	2012	0.32	0.09	0.08	0.10	0.08	4.86	522	169	47	43	7		

Table A.1.22: Monthly and annual mean concentration of sulfur dioxide in air at Norwegian background stations. Unit: µg S/m^3.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes II	0.04	0.06	0.04	0.06	0.09	0.09	0.15	0.09	0.02	0.03	0.03	0.02	0.06
Hurdal	0.03	0.03	0.07	0.05	0.03	0.08	0.07	0.04	0.03	0.03	0.02	0.02	0.04
Kårvatn	0.01	0.02	0.03	0.02	0.03	0.05	0.03	0.4	0.04	0.04	0.01	0.02	0.06
Tustervatn	0.03	0.02	0.05	0.08	0.05	0.08	0.02	0.03	0.04	0.04	0.02	0.02	0.04
Zeppelin	0.09	0.21	0.25	0.12	0.03	0.02	0.03	0.24	0.34	0.02	0.07	0.05	0.12

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

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes II	0.21	0.37	0.18	0.19	0.25	0.21	0.4	0.29	0.22	0.13	0.14	0.08	0.22
Hurdal	0.12	0.32	0.11	0.12	0.17	0.08	0.23	0.14	0.18	0.09	0.1	0.07	0.14
Kårvatn	0.04	0.08	0.08	0.1	0.15	0.1	0.17	0.08	0.13	0.06	0.07	0.06	0.09
Tustervatn	0.13	0.08	0.12	0.18	0.14	0.11	0.15	0.15	0.14	0.08	0.09	0.08	0.12
Zeppelin	0.12	0.13	0.21	0.22	0.2	0.1	0.14	0.07	0.13	0.12	0.13	0.11	0.14

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

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes II	0.45	0.47	0.31	0.22	0.34	0.23	0.26	0.26	0.19	0.25	0.16	0.15	0.27
Hurdal	1.56	1.44	0.58	0.33	0.37	0.26	0.26	0.3	0.17	0.37	0.87	1.16	0.64
Kårvatn	0.24	0.28	0.18	0.09	0.13	0.14	0.16	0.15	0.1	0.12	0.12	0.21	0.17
Tustervatn	0.16	0.17	0.13	0.11	0.11	0.12	0.12	0.1	0.05	0.06	0.08	0.09	0.11

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

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes II	0.25	0.15	0.11	0.16	0.16	0.14	0.24	0.19	0.12	0.08	0.1	0.05	0.15
Hurdal	0.14	0.16	0.09	0.05	0.09	0.06	0.12	0.11	0.06	0.05	0.07	0.11	0.09
Kårvatn	0.03	0.03	0.03	0.04	0.06	0.05	0.06	0.04	0.03	0.03	0.02	0.02	0.04
Tustervatn	0.06	0.03	0.02	0.03	0.05	0.04	0.04	0.05	0.06	0.03	0.03	0.02	0.04
Zeppelin	0.04	0.03	0.03	0.03	0.03	0.04	0.05	0.03	0.06	0.04	0.03	0.03	0.04

Table A.1.26: Monthly and annual mean concentration of nitrate in aerosol at Norwegian background stations. Unit: µg N/m³.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes II	0.18	0.11	0.1	0.14	0.12	0.1	0.18	0.15	0.1	0.07	0.08	0.04	0.12
Hurdal	0.1	0.12	0.07	0.04	0.06	0.04	0.09	0.09	0.05	0.04	0.06	0.09	0.07
Kårvatn	0.01	0.02	0.01	0.02	0.05	0.03	0.04	0.03	0.02	0.01	0.01	0.01	0.02
Tustervatn	0.05	0.02	0.01	0.02	0.04	0.03	0.03	0.04	0.03	0.01	0.02	0.01	0.02
Zeppelin	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.04	0.03	0.02	0.01	0.02

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	2017
Birkenes II	0.31	0.3	0.16	0.31	0.44	0.24	0.44	0.62	0.23	0.1	0.1	0.05	0.27
Hurdal	0.2	0.35	0.15	0.18	0.27	0.17	0.32	0.24	0.19	0.1	0.09	0.12	0.2
Kårvatn	0.4	0.67	0.52	0.36	0.3	0.33	0.34	0.39	0.23	0.14	0.21	0.38	0.36
Tustervatn	0.22	0.16	0.18	0.18	0.32	0.31	0.24	0.42	0.24	0.76	0.11	0.14	0.27
Zeppelin	0.07	0.12	0.15	0.37	0.09	0.1	0.36	0.2	0.19	0.08	0.06	0.08	0.16

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	2017
Birkenes II	0.21	0.22	0.09	0.18	0.2	0.11	0.16	0.13	0.14	0.04	0.06	0.03	0.13
Hurdal	0.13	0.28	0.06	0.05	0.1	0.03	0.1	0.05	0.1	0.04	0.03	0.08	0.09
Kårvatn	0.01	0.04	0.03	0.04	0.06	0.03	0.07	0.01	0.06	0.01	0.01	0.01	0.03
Tustervatn	0.05	0.02	0.03	0.05	0.04	0.04	0.05	0.04	0.07	0.02	0.01	0.01	0.03
Zeppelin	0.03	0.03	0.04	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.01	0.03

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	2017
Birkenes II	0.05	0.03	0.06	0.04	0.02	0.04	0.07	0.07	0.03	0.07	0.06	0.04	0.05
Hurdal	0.01	0.01	0.02	0.01	0.01	0.01	0.03	0.02	0.01	0.01	0.01	0.01	0.01
Kårvatn	0.02	0.01	0.03	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02
Tustervatn	0.08	0.03	0.04	0.04	0.03	0.01	0.01	0.04	0.01	0.02	0.02	0.02	0.03
Zeppelin	0.06	0.06	0.07	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.05	0.05	0.04

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	2017
Birkenes II	0.02	0.02	0.03	0.02	0.04	0.04	0.06	0.04	0.04	0.03	0.02	0.02	0.03
Hurdal	0.01	0.02	0.02	0.02	0.03	0.02	0.03	0.03	0.04	0.02	0.02	0.01	0.02
Kårvatn	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.04	0.01	0.01	0.01	0.02
Tustervatn	0.02	0.01	0.02	0.02	0.03	0.02	0.01	0.02	0.05	0.02	0.01	0.01	0.02
Zeppelin	0.02	0.02	0.04	0.02	0.02	0.02	0.03	0.02	0.03	0.07	0.22	0.04	0.05

Table A.1.31: Monthly and annual mean concentrations of potassium in aerosols at Norwegian background stations. Unit: µg/m³.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes II	0.04	0.05	0.03	0.04	0.03	0.03	0.12	0.06	0.04	0.02	0.02	0.05	0.05
Hurdal	0.13	0.09	0.03	0.03	0.03	0.01	0.03	0.05	0.03	0.03	0.04	0.07	0.05
Kårvatn	0.01	0.01	0.01	0.02	0.01	0.02	0.03	0.03	0.02	0.01	0.01	0.01	0.02
Tustervatn	0.03	0.01	0.02	0.02	0.02	0.01	0.03	0.04	0.02	0.02	0.01	0.02	0.02
Zeppelin	0.04	0.04	0.05	0.04	0.03	0.02	0.17	0.03	0.03	0.03	0.03	0.02	0.05

Table A.1.32: Monthly and annual mean concentrations of chloride in aerosols at Norwegian background stations. Unit: µg/ m³.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes II	0.42	0.32	0.69	0.44	0.11	0.34	0.53	0.53	0.33	0.83	0.86	0.55	0.51
Hurdal	0.07	0.05	0.14	0.08	0.06	0.03	0.17	0.14	0.05	0.15	0.14	0.1	0.1
Kårvatn	0.27	0.13	0.38	0.32	0.19	0.12	0.13	0.15	0.04	0.12	0.17	0.25	0.19
Tustervatn	1.02	0.37	0.59	0.48	0.41	0.14	0.16	0.41	0.08	0.29	0.28	0.33	0.39
Zeppelin	0.63	0.62	0.52	0.31	0.2	0.19	0.31	0.38	0.29	0.3	0.34	0.49	0.38

Table A.1.33: Monthly and annual mean concentrations of sodium in aerosols at Norwegian background stations. Unit: µg/ m³.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes II	0.38	0.26	0.47	0.34	0.14	0.34	0.6	0.56	0.26	0.57	0.49	0.32	0.4
Hurdal	0.06	0.07	0.15	0.09	0.08	0.04	0.23	0.2	0.05	0.12	0.13	0.08	0.11
Kårvatn	0.18	0.09	0.26	0.22	0.16	0.11	0.14	0.14	0.03	0.08	0.13	0.15	0.14
Tustervatn	0.61	0.24	0.41	0.32	0.27	0.13	0.12	0.29	0.06	0.18	0.19	0.2	0.26
Zeppelin	0.38	0.4	0.34	0.19	0.18	0.18	0.26	0.24	0.23	0.2	0.22	0.28	0.26

Table A.1.34a: Annual mean concentrations of sulfur and nitrogen components in air at Norwegian background stations from 1973-2017. Units μg S/m^3 and μg N/m^3.

Site	År	Annual mean concentrations of main components in air (µg/m^3)					
		SO_2-S	SO_4-S	NO_2-N	(HNO_3+NO_3)-N	(NH_4+NH_3)-N	NH_4-N
Birkenes	1973		0.81				
	1974		1.11				
	1975		1.07				
	1976		1.27				
	1977		0.92				
	1978	1.74	1.09				
	1979	1.11	1.33				
	1980	1.42	1.41				
	1981	0.76	0.97				
	1982	0.97	1.15				
	1983	0.53	0.95				
	1984	0.65	1.27	1.17			
	1985	0.70	0.88	0.87			
	1986	0.69	0.83	1.12	0.36	0.66	
	1987	0.72	0.78	1.12	0.29	0.66	
	1988	0.63	0.75	1.26	0.28	0.63	
	1989	0.48	0.67	1.11	0.26	0.63	
	1990	0.49	0.76	1.00	0.28	0.78	
	1991	0.54	0.91	0.90	0.27	0.76	
	1992	0.40	0.65	0.69	0.24	0.53	
	1993	0.40	0.59	0.59	0.23	0.55	0.43
	1994	0.40	0.65	0.66	0.28	0.63	0.46
	1995	0.31	0.58	0.68	0.30	0.54	0.44
	1996	0.40	0.66	0.68	0.29	0.57	0.47
	1997	0.22	0.53	0.69	0.24	0.54	0.37
	1998	0.16	0.46	0.62	0.19	0.41	0.31
	1999	0.14	0.49	0.52	0.20	0.51	0.33
	2000	0.12	0.44	0.57	0.20	0.43	0.31
	2001	0.16	0.44	0.47	0.21	0.55	0.31
	2002	0.15	0.50	0.46	0.27	0.62	0.43
	2003	0.15	0.50	0.57	0.26	0.60	0.38
	2004	0.13	0.35	0.46	0.26	0.53	0.30
	2005	0.19	0.46	0.46	0.33	0.75	0.40
	2006	0.18	0.53	0.48	0.40	0.77	0.32
	2007	0.06	0.28	0.32	0.17	0.43	0.17
	2008	0.07	0.28	0.34	0.19	0.49	0.14
	2009	0.06	0.30	0.44	0.26		0.20
Birkenes II	2010	0.12	0.29	0.31	0.23		0.20
	2011	0.11	0.33	0.43	0.37	0.63	0.32
	2012	0.07	0.27	0.39	0.46	0.61	0.28
	2013	0.09	0.25	0.28	0.29	0.47	0.23
	2014	0.17	0.37	0.31	0.38	0.62	0.34
	2015	0.07	0.29	0.30	0.32	0.44	0.27
	2016	0.05	0.20	0.30	0.25	0.40	0.23
	2017	0.06	0.22	0.27	0.15	0.27	0.13

Table A.1.34a, cont.

Site	År	Annual mean concentrations of main components in air (µg/m^3)					
		SO_2-S	SO_4-S	NO_2-N	(HNO_3+NO_3)-N	(NH_4+NH_3)-N	NH_4-N
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
Kårvatn	1979	0.48	0.48				
	1980	0.54	0.55				
	1981	0.51	0.47				
	1982	0.29	0.40				
	1983	0.19	0.38				
	1984	0.43	0.54				
	1985	0.44	0.45				
	1986	0.39	0.43				
	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	

Table A.1.34a, cont.

Site	År	Annual mean concentrations of main components in air (µg/m^3)					
		SO_2-S	SO_4-S	NO_2-N	(HNO_3+NO_3)-N	(NH_4+NH_3)-N	NH_4-N
Kårvatn (cont.)	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
Tustervatn	1979	0.88	0.68				
	1980	0.63	0.70				
	1981	0.67	0.52				
	1982	0.47	0.52				
	1983	0.26	0.48				
	1984	0.71	0.73				
	1985	0.60	0.59				
	1986	0.48	0.43				
	1987	0.72	0.59				
	1988	0.67	0.54				
	1989	0.16	0.23	0.29	0.04	0.52	
	1990	0.29	0.36	0.37	0.08	0.53	
	1991	0.25	0.38	0.32	0.08	0.68	
	1992	0.15	0.28	0.26	0.07	0.54	
	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

Table A.1.34a, cont.

Site	År	Annual mean concentrations of main components in air (µg/m^3)					
		SO_2-S	SO_4-S	NO_2-N	(HNO_3+NO_3)-N	(NH_4+NH_3)-N	NH_4-N
Tustervatn (cont.)	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
Ny-Ålesund	1980	0.32	0.31				
	1981	0.36	0.23				
	1982	0.31	0.28				
	1983	0.42	0.41				
	1984	0.24	0.34				
	1985	0.36	0.39				
	1986	0.27	0.34				
	1987	0.53	0.40				
	1988	0.32	0.32				
	1989	0.21	0.24				
	1990	0.22	0.27		0.03		
Zeppelin	1990	0.21	0.22		0.04	0.09	
	1991	0.24	0.19	0.02	0.05	0.09	
	1992	0.19	0.19	0.02	0.04	0.08	
	1993	0.17	0.20	0.03	0.06	0.09	0.05
	1994	0.16	0.15	0.05	0.06	0.09	0.04
	1995	0.15	0.17		0.08	0.10	0.05
	1996	0.10	0.15		0.08	0.11	0.05
	1997	0.13	0.21		0.07	0.13	0.06
	1998	0.21	0.17		0.04	0.13	0.05
	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

Table A.1.34a, cont.

Site	År	Annual mean concentrations of main components in air (µg/m^3)					
		SO_2-S	SO_4-S	NO_2-N	(HNO_3+NO_3)-N	(NH_4+NH_3)-N	NH_4-N
Zeppelin (cont.)	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

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

Table A.1.34b: Annual mean concentrations of sulfur and nitrogen components in air at Norwegian background stations which has been closed down. Units $\mu g\ S/m^3$ and $\mu g\ N/m^3$.

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

Table A.1.34b, cont.

Site	År	Annual mean concentrations of main components in air at closed sites, (µg/m^3)				
		SO_2-S	SO_4-S	NO_2-N	(HNO_3+NO_3)-N	(NH_4+NH_3)-N
Osen	1988	0.67	0.72			
	1989	0.38	0.52	0.88	0.15	0.39
	1990	0.22	0.46	0.64	0.12	0.36
	1991	0.25	0.49	0.59	0.12	0.36
	1992	0.17	0.37	0.50	0.11	0.30
	1993	0.22	0.38	0.53	0.11	0.28
	1994	0.19	0.42	0.44	0.14	0.34
	1995	0.19	0.38	0.41	0.15	0.31
	1996	0.13	0.40	0.40	0.14	0.37
	1997	0.09	0.30	0.48	0.10	0.35
	1998	0.08	0.26	0.45	0.10	0.37
	1999	0.06	0.20	0.38	0.08	0.31
	2000	0.04	0.24	0.38	0.08	0.29
	2001	0.08	0.24	0.33	0.12	0.38
	2002	0.07	0.28	0.38	0.11	0.51
	2003	0.08	0.29	0.45	0.13	0.46
Svanvik	1987	6.40	0.90	1.00	0.10	0.60
	1988	5.80	0.90	0.9**	0.1**	0.5**
	1989	5.40	0.60	0.70	0.10	0.40
	1990	7.20	0.70	0.80	0.10	0.40
	1991	5.90	0.70	0.80	0.10	0.50
	1992	3.25	0.57	0.76	0.07	0.67
	1993	4.32	0.53	0.57	0.07	0.51
	1994	4.15	0.37	0.56	0.07	0.42
	1995	5.07	0.48	0.58	0.10	0.49
	1996	3.30	0.47	0.54	0.07	0.55
	1997	4.85	0.49	0.59	0.07	0.63
	1998	6.83	0.54	0.70	0.07	0.78
	1999	3.92	0.53	0.53	0.06	0.91
	2000	3.15	0.45	0.51	0.05	0.84
	2001	4.07	0.52		0.08	0.90
	2002	4.31	0.43		0.10	0.75
Jergul	1977		0.58			
	1978	0.89	0.54			
	1979	1.52	0.74			
	1980	1.55	0.75			
	1981	1.28	0.56			
	1982	0.79	0.54			
	1983	0.81	0.65			
	1984	1.18	0.79	0.43		
	1985	1.42	0.80	0.29		
	1986	1.01	0.69	0.46		
	1987	1.67	0.77	0.51		
	1988	1.23	0.66	0.45	0.09	0.22
	1989	0.40	0.39	0.28	0.08	0.20
	1990	0.81	0.45	0.35	0.07	0.19
	1991	0.80	0.47	0.31	0.08	0.18
	1992	0.53	0.40	0.28	0.07	0.17
	1993	0.58	0.44	0.21	0.08	0.17
	1994	0.44	0.31	0.16	0.09	0.16
	1995	0.59	0.34	0.16	0.11	0.15
	1996	0.32	0.30	0.18	0.08	0.15
Karasjok	1997	0.48	0.32	0.20	0.07	0.16
	1998	0.91	0.34	0.25	0.06	0.19
	1999	0.51	0.36	0.25	0.05	0.18
	2000	0.35	0.27	0.25	0.08	0.16
	2001	0.40	0.29	0.20	0.06	0.14
	2002	0.30	0.24	0.18	0.08	0.11
	2003 1)	0.20	0.26	0.21	0.08	0.14
	2004	0.32	0.25	0.19	0.11	0.15
	2005	0.31	0.30	0.17	0.11	0.16
	2006	0.29	0.28	0.14	0.16	0.12
	2007	0.19	0.19	0.14	0.08	0.11
	2008	0.35	0.22	0.19	0.07	0.10
	2009	0.18	0.25	0.15	0.09	0.12
Andøya	2010	0.11	0.20		0.05	
	2011	0.05	0.17		0.06	0.11

1) Measured from 25 May 2003.

* One month missing.

** Two months missing.

Table A.1.35: Annual and monthly mean concentrations of OC, EC and TC in PM_{10} and $PM_{2.5}$ at the sites Birkenes, Hurdal and Kårvatn for 2017.

Month	PM_{10}			$PM_{2.5}$		
	OC	EC	TC	OC	EC	TC
Birkenes						
January	0.61	0.07	0.68	0.56	0.08	0.64
February	0.79	0.09	0.88	0.68	0.09	0.77
March	0.41	0.05	0.46	0.32	0.04	0.36
April	0.45	0.05	0.50	0.40	0.05	0.45
May	1.24	0.06	1.30	0.95	0.07	1.03
June	0.76	0.04	0.80	0.51	0.04	0.55
July	0.96	0.03	0.99	0.66	0.03	0.69
August	0.96	0.03	1.00	0.54	0.03	0.57
September	1.30	0.08	1.38	0.60	0.06	0.65
October	0.66	0.07	0.73	0.47	0.04	0.52
November	0.37	0.04	0.41	0.33	0.04	0.37
December	0.32	0.04	0.37	0.36	0.05	0.41
Annual mean	**0.72**	**0.05**	**0.78**	**0.52**	**0.05**	**0.58**
Hurdal						
January	0.88	0.20	1.08	0.90	0.19	1.08
February	1.17	0.20	1.38	1.15	0.20	1.35
March	0.51	0.07	0.59	0.45	0.07	0.52
April	0.52	0.05	0.57	0.40	0.05	0.45
May	1.11	0.08	1.19	0.83	0.07	0.90
June	1.19	0.04	1.23	0.71	0.04	0.76
July	1.36	0.04	1.40	0.79	0.04	0.84
August	1.60	0.05	1.66	0.79	0.05	0.84
September	2.59	0.11	2.70	0.86	0.07	0.93
October	1.57	0.08	1.66	0.55	0.07	0.63
November	0.63	0.13	0.76	0.48	0.13	0.62
December	0.79	0.14	0.93	0.83	0.15	0.97
Annual mean	**1.15**	**0.10**	**1.25**	**0.74**	**0.09**	**0.84**
Kårvatn						
January	0.24	0.03	0.27	0.21	0.03	0.24
February	0.37	0.06	0.43	0.36	0.06	0.42
March	0.37	0.02	0.39	0.33	0.03	0.36
April	0.37	0.02	0.38	0.31	0.02	0.33
May	0.94	0.02	0.95	0.78	0.03	0.81
June	1.17	0.01	1.18	0.92	0.02	0.95
July	1.15	0.02	1.17	0.87	0.03	0.90
August	0.94	0.03	0.97	0.58	0.02	0.60
September	1.07	0.08	1.15	0.66	0.06	0.72
October	0.57	0.03	0.60	0.38	0.03	0.42
November	0.30	0.03	0.33	0.29	0.04	0.33
December	0.29	0.05	0.33	0.31	0.05	0.37
Annual mean	**0.66**	**0.03**	**0.69**	**0.50**	**0.04**	**0.53**

Table A.1.36: Annual mean concentrations of OC, EC and TC in PM_{10} and $PM_{2.5}$ at Birkenes Hurdal and Kårvatn for the period 2001 - 2017.

Year	PM_{10}			$PM_{2.5}$		
	OC	EC	TC	OC	EC	TC
Birkenes						
2001	1.10	0.13	1.3	1.00	0.16	1.20
2002	1.00	0.14	1.2	0.92	0.12	1.00
2003	1.00	0.11	1.2	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	0.8
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
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
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

Table A.1.37: Annual and monthly mean concentrations of PM10, PM10-2.5 and PM2.5 at Birkenes, Hurdal and Kårvatn for 2017. Unit µg/m^3.

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	2.9	2.1	4.9	3.0	1.1	4.1	0.6	0.5	1.1
FEB	3.0	1.1	4.1	4.6	0.8	5.4	1.1	0.3	1.4
MAR	1.9	1.9	3.7	1.7	1.3	2.9	0.9	0.6	1.5
APR	1.9	1.2	3.1	1.7	1.0	2.7	1.1	0.6	1.7
MAY	3.5	1.3	4.8	2.6	1.4	4.0	2.3	0.5	2.8
JUN	2.0	1.2	3.2	2.1	1.5	3.6	2.6	0.9	3.6
JUL	2.2	2.2	4.4	2.4	1.7	4.1	2.9	0.7	3.6
AUG	2.1	1.7	3.7	1.9	2.1	3.9	1.5	1.0	2.5
SEP	1.9	2.2	4.1	2.6	3.9	6.5	2.8	1.7	3.9
OCT	1.1	3.4	4.5	1.3	3.4	5.0	1.0	1.2	2.2
NOV	1.1	1.5	2.5	1.5	1.3	2.3	0.3	0.6	0.9
DEC	0.9	1.1	2.0	2.5	0.4	2.7	0.5	0.4	0.8
2017	*2.0*	*1.7*	*3.6*	*2.4*	*1.6*	*3.8*	*1.5*	*0.7*	*2.1*

Table A.1.38: Annual mean mass concentrations of PM10. PM10-2.5. PM2.5 and PM1 at Birkenes. Hurdal and Kårvatn for the period 2000 - 2017.

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
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
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

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	60º 22’	11º 04’	jan-97	Thomas Sørlien	2090 Hurdal
Brekkebygda	Buskerud	390	60° 18'	9° 44'	des-97	Anton Brekka	3534 Sokna
Vikedal II	Rogaland	60	59° 32'	5° 58'	jan-84	Harald Leifsen	4210 Vikedal
Sandve	Rogaland	40	59° 12'	5° 12'	jun-96	Jan M. Jensen	4272 Sandve
Haukeland	Hordaland	204	60° 49'	5° 35'	aug-81	Henning Haukeland	5198 Matredal
Nausta	Sogn og Fjordane	230	61° 34'	5° 53'	des.84	Sverre Ullaland	6043 Naustdal
Kårvatn	Møre og Romsdal	210	62° 47'	8° 53'	feb-78	Erik Kårvatn	6645 Todalen
Høylandet	Nord-Trøndelag	60	64° 39'	12° 19’	feb-87	Jakob Olav Almås	7977 Høylandet
Tustervatn	Nordland	439	65° 50'	13° 55'	des-71	Are Tustervatn	8647 Bleikvassli
Karpbukt	Finnmark	20	69º 40’	30º 22’	okt-98	Roy Hallonen	9900 Kirkenes
Ny-Ålesund	Svalbard	8	78° 55'	11° 55'	1974	NP forskningsst.	9173 Ny-Ålesund
Zeppelin	Svalbard	474	78° 54'	11° 53'	sep-89	NP forskningsst.	9173 Ny-Ålesund

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

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

Metr. = meteorology

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

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

HM [a] = Pb, Cd and Zn

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

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

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

[e] = α- og γ-HCH, HCB, PCB

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

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

Annex 3

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

Main components in precipitation

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

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

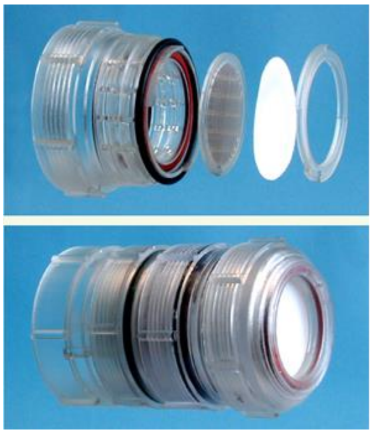
pH is measured with potentiometric method and conductivity with a conductivity meter. Anions and cations are measured with an ion chromatograph. The detection limit for the different ions are given in the table below:

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

Main components in air

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

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



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

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

Nitrogen dioxide

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

Ozone

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

Particles (Mass, EC/OC, and levoglucosan)

Background

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

The adverse health effects of the ambient aerosol is well recognized (e.g., Dockery et al., 1993; Schwarz et al., 1996), causing various types of cardiopulmonary diseases, e.g., chronical obstructive pulmonary disease, ischemic heart disease, lung cancer and pneumonia. Although the statistical evidence between ambient air particulate mass (e.g., PM_{10} and $PM_{2.5}$) and adverse health effects are well documented, there is considerable doubt concerning the causal relationship. Thus, other relevant parameters such as the particle number size distribution, the surface and the chemical composition of the aerosol must be considered when addressing this issue. There is strong evidence that fine particles are more hazardous than coarse ones (Schwartz et al., 1996, Schwartz and Neas, 2000), although coarse particles are associated with adverse health effects as well (Castillejos et al., 2000; Ostro et al., 2000). An increasing number of experimental studies have been devoted to the number of ultrafine particles (d_p< 100 nm), which potentially play a role in the cardiovascular effects commonly associated with exposure to particulate matter (Donaldson et al., 2001).

Concerning the chemical composition, WHO has given the general advice that that primary combustion derived particles are particularly important as they "*are often rich in transition metals and organic compounds, and also have a relatively high surface area*". However, more knowledge is needed concerning the ambient aerosol chemical composition and its contribution to the adverse effects seen on human health.

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

The tropospheric aerosol also plays an important role when it comes to acidification and eutrophication of water bodies. This is attributed to the content of secondary inorganic species such as SO_4^{2-}, NO_3^- and NH_4^+, which typically are associated with accumulation mode particles, enabling long-range transport and deposition in regions far from where the precursors where emitted.

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

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

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

Levoglucosan is considered the most robust and reliable tracer of biomass burning, and is commonly used to trace biomass burning aerosol, not only qualitatively, but also quantitatively by combing ambient concentrations with emission ratios, or as input along with other species to e.g. positive matrix factorization (PMF). For studies using levoglucosan as biomass burning tracer in Norway, see Yttri et al. (2005); Yttri et al. (2007a, b); Yttri et al. (2009); Yttri et al. (2011a, b); Yttri et al. (2014); Yttri et al. in prep. Although levoglucosan appears to be best suited to trace biomass burning emissions in winter and on a local to regional scale, conservative estimates of the biomass burning aerosol concentration can still be provided for the remote environment.
Emission ratios used to convert observed ambient concentrations of levoglucosan to OC and EC from biomass burning, are associated with great uncertainty. In the present report, we use an OC/levoglucosan ratio of 10 and an EC/levoglucosan ratio of 2. These ratios are based on non-published positive matrix factorization (PMF) analysis results for PM and PM species observed at Birkenes, which are consistent with results presented in the scientific literature e.g. by Zotter et al. (2017). A factor of 2 was used to convert biomass burning OC to OM, and a factor of 1.1 for biomass burning EC.

Sampling and chemical analysis

Daily measurements of PM_{10} at the Birkenes Observatory started in 1999 using a High-volume sampler. From 2000 – 2005, PM_{10} was obtained by a Ruprecht and Patashnick Dichotomus Partisol-plus, model 2025, which separated PM_{10} into its coarse ($PM_{10-2.5}$) and fine ($PM_{2.5}$) fraction. From 2006 (the Birkenes Observatory) and from 2010 (the Hurdal and Kårvatn sites), PM_{10} and $PM_{2.5}$ (PM_1 measurements at the Birkenes Observatory from 2006 - 2008) are obtained using Kleinfiltergerät samplers (one sampler pr. size faction), collecting filter samples on a weekly basis. The ambient aerosol particles are collected on prefired (850 °C for 3 hrs) quartz fibre filters (Whatman QM-A, 47 mm). The quartz fibre filters are conditioned (20 °C; 50% RH; 48 hrs) prior to and after being exposed. The mass concentration of the quartz fibre filters are determined gravimetrically. The uncertainty of the PM mass concentrations obtained for PM_{10} and $PM_{2.5}$ is estimated to be around 0.1 – 0.15 µg/m^3 for a sampling volume of 386 m^3.

At Birkenes, high-time resolution measurements of PM_{10}, $PM_{2.5}$ and PM_1 by an OPC (optical particle counter) (GRIMM 190) instrument were started in 2010. The detection limit of the OPC is approximately 0.1 µg/m^3.

In May 2017 a continuous direct aerosol mass instrument was installed at Birkenes, a so called tapered element oscillating microbalance (TEOM) instrument with a size cut off to measure

PM_{10} mass. The TEOM Monitor draws (then heats) ambient air through a filter at constant flow rate, continuously weighing the filter and calculating near real-time mass concentrations of particulate matter. The mass is corrected with a factor 1.1 based on a intercomparison campaign which the TEOM with gravimetric measurements, witch is the reference method.

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

Concentrations of the biomass burning tracer levoglucosan (mannosan and galactosan) is determined in the same PM_{10} filter samples as the mass concentration, EC, OC and TC, using ultra-performance liquid chromatography (UPLC) in combination with high-resolution time-of-flight mass spectrometry (HR-TOF MS) operated in the negative electrospray ionization (ESI-) mode, and according to a modified version of the analytical method described by Dye and Yttri (2005). The methodological detection limit is approximately 20 – 40 pg m^{-3} for a sampling volume of 386 m^3.

References:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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We are a government agency under the Ministry of Climate and Environment and have 700 employees at our two offices in Trondheim and Oslo and at the Norwegian Nature Inspectorate's more than sixty local offices.

We implement and give advice on the development of climate and environmental policy. We are professionally independent. This means that we act independently in the individual cases that we decide and when we communicate knowledge and information or give advice.

Our principal functions include collating and communicating environmental information, exercising regulatory authority, supervising and guiding regional and local government level, giving professional and technical advice, and participating in international environmental activities.