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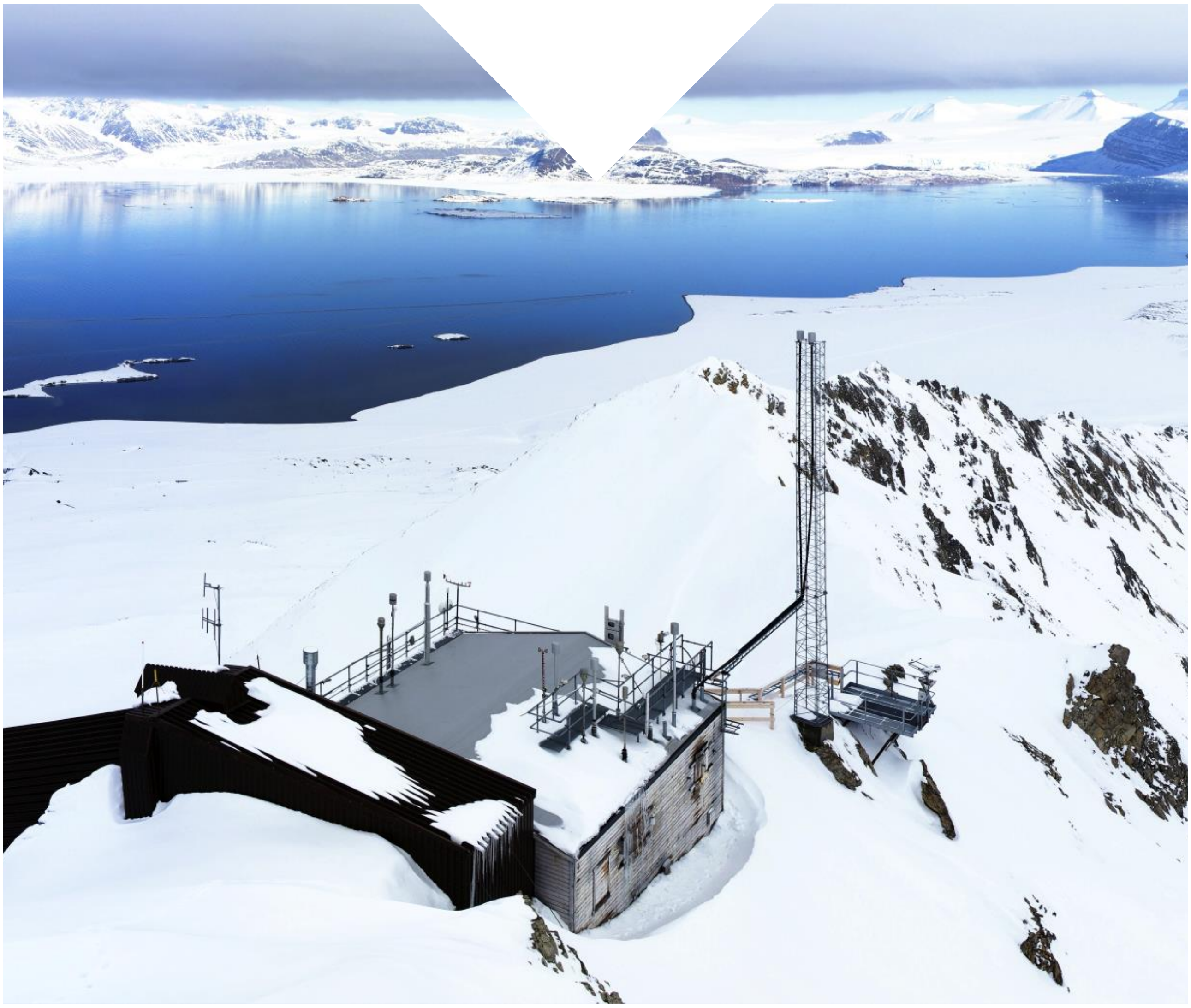
Monitoring of environmental contaminants in air and precipitation

Annual Report 2016



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Overvåkning av miljøgifter i luft og nedbør, årsrapport 2016
Monitoring of environmental contaminants in air and precipitation, annual report 2016

Summary - sammendrag

This monitoring report presents 2016 data and time-trends for the Norwegian programme for long-range atmospheric transported contaminants. The results cover 122 organic compounds and 11 heavy metals. The organic contaminants includes regulated persistent organic pollutants (POPs) as well POP-like contaminants not yet subjected to international regulations.

Denne rapport inkluderer data fra 2016 og tidstrender for programmet Langtransporterte atmosfæriske miljøgifter. Resultatene omfatter 122 organiske miljøgifter og 11 tungmetaller. De organiske miljøgiftene inkluderer regulerte persistente organiske forbindelser (POPs) og POP-lignende forbindelser som ennå ikke har blitt regulerte på internasjonal nivå.

4 emneord	4 subject words
Miljøkjemi	Environmental chemistry
Langtransportert luftforurensning	Long-range transport of air pollutants
POP - Persistente organiske miljøgifter	POP - Persistent Organic Pollutants
Miljøovervåkning	Environmental monitoring

Front page photo

Zeppelin Observatory

Content

Summary

This report presents data of environmental contaminants in air and precipitation at Norwegian background sites in 2016. The monitoring is done for the Norwegian programme for Long-range atmospheric transported contaminants. The purpose of the monitoring is to i) increase the knowledge on long-range transported contaminants as a source for pollution in Norway, and ii) provide data for international conventions, programmes and networks. The results from 2016 includes 122 organic compounds and eleven heavy metals. The organic contaminants covers regulated persistent organic pollutants (POPs) as well as new contaminants not yet subjected to international regulations. The new contaminants show POP-like characteristics and this monitoring contributes to the evaluation of their potential for long-range transport. In 2016, air monitoring of POPs and heavy metals including mercury was conducted using active air samplers at three sites (i.e. Birkenes, Andøya and Zeppelin) while monitoring of heavy metals in precipitation was conducted at five sites (i.e. Birkenes, Hurdal, Kårvatn, Svanvik and Karpdalen), and at one site for mercury and POPs (i.e. Birkenes).

POPs

In general, regulated POPs in air, for which long-term data exists, show decreasing trends since the beginning of the 1990s. Since the beginning of the monitoring in 1992, the largest reduction in concentration has been observed for hexachlorohexanes (HCHs) at Birkenes and Zeppelin. Reduced concentrations have also been observed for dichlorodiphenyltrichloroethane (DDTs), chlordanes, and polychlorinated biphenyls (PCBs), but trends are not as significant due to more fluctuating concentrations from year to year. The data for 2016 shows continuously decreasing trends for HCHs and per- and polyfluorinated alkyl substances (PFASs). The data for DDTs, chlordanes, polybrominated diphenyl ethers (PBDEs), tribromoanisole (TBA) and hexabromocyclododecanes (HBCDs) indicate that steady-state conditions have been reached. The annual mean concentrations for these contaminants were similar or slightly higher in 2016 than in 2015 and the concentrations have been fluctuating without any clear trend during the last five to ten years. This is a result of very low concentrations where most measurements are below detection limits (i.e. PBDEs and HBCDs) or stable levels above detection limits (i.e. DDTs, chlordanes, TBA). For PCBs at Zeppelin the data from 2016 indicate a continuation of a small increasing trend during the last five years. The PCB concentrations at Birkenes and Andøya were also higher in 2016 than 2015, but the differences were too small to see a trend. For PAHs, the annual mean concentration at Zeppelin in 2016 was one of the lowest ever observed while the concentration at Birkenes were similar as the last years. The increasing concentrations observed for hexachlorobenzene (HCB) at Zeppelin during the last ten years flattened out in 2016 while HCB at Birkenes in 2016 confirm the upward trend during the last six years.

The spatial distribution of the organic contaminants varied by type of contamination. In 2016, PAHs, γ-HCH, DDTs and PFAS (especially perfluorooctanoic acid (PFOA)) were highest at Birkenes in southern Norway. This indicates ongoing emission in source regions. HCB, PCB, PBDE and TBA were instead highest in northern Norway, at Zeppelin, Svalbard. For the other POPs (HCHs, chlordanes and HBCDs) similar concentrations were observed at all the sites.

Emerging contaminants

Two groups of emerging contaminants have been included in the monitoring programme since 2013, the short and medium chained chlorinated paraffins (S/MCCPs) and the cyclic volatile

methyl siloxanes (cVMS) D4-D6. M/SCCPs are measured on weekly basis while the cVMS are measured in one summer and one winter campaign. The annual mean concentrations for 2016 based on these measurements were lower than those in 2015 for S/MCCPs and D6.For D6, this is caused by lower concentrations during the summer campaign in 2016 than 2015. The reason for this difference is not known, but it can be seen that the levels in summer in 2016 are similar to those in 2013. For, S/MCCPs the difference to previous years is minor. D5 is instead found at similar concentrations as previous years, both in summer and winter. For S/MCCPs and D5-D6, no significant time-trends can be seen from this monitoring period (2013-2016) as the results have been fluctuating from year to year.

As in 2013-2015, the concentrations of M/SCCPs and cVMS in 2016 are at the same levels as PAHs, which in turn are up to three orders of magnitude higher than the concentrations of legacy POPs (i.e. PCBs, organochlorine pesticides (OCPs), PBDEs, and PFAS). This suggests ongoing emission of both cVMS and S/MCCPs. It also emphasizes the importance of continuous monitoring of these emerging POPs to follow their emission trends, but also to understand the influence of possible local emission on the levels measured at Zeppelin.

Heavy metals

Heavy metals in precipitation from 2016 were highest at Svanvik and Karpdalen in Sør-Varanger. The high levels here are due to emissions from smelters in Russia. The wet deposition (concentration times precipitation amount), however, was generally highest in Southern Norway as a result of higher precipitation amounts in this region. The inclusion of air measurements of heavy metals at Svanvik and Karpdalen in 2016 confirms the results in precipitation with more than one order of magnitude higher concentrations of heavy metals at these two sites compared to Birkenes, Andøya and Zeppelin. The lowest concentrations of heavy metals in precipitation was observed at Kårvatn, which is furthest away from the emission sources in continental Europe. The air concentrations of heavy metals were two-three times lower at Andøya and Zeppelin in the North than at Birkenes in the south. This is in agreement with the results for PAHs, γ-HCH, DDTs and PFAS. Higher levels in southern Norway for heavy metals and organic contaminants with ongoing use are mainly due to closeness to the potential emission sources in continental Europe. For other legacy POPs as well as mercury, no significant spatial distribution is observed in Norway. This indicates that these pollutants have a large potential to be transported far from emission sources, and a lack of regional primary sources.

In 2016, the concentrations of cadmium, lead and vanadium in precipitation at Birkenes were substantially lower than in 2015, and among the lowest ever observed. In a longer perspective there has been a significant reduction of heavy metals in precipitation in Norway. Lead has a reduction of more than 90% at Birkenes and Kårvatn since 1980, and reductions between 52-94% since 1990. In contrast, at Svanvik no significant trend for lead during this period has been observed. Similar reductions have also been observed for cadmium in precipitation, 42-73% from 1990. The concentration levels of mercury in precipitation in southern Norway (i.e. Lista + Birkenes observatories) have been significantly reduced since the beginning of the monitoring in 1990.

The concentrations in air for many heavy metals in 2016 were among the lowest ever observed at Birkenes and Zeppelin (As, Cd, Co, Pb, V). At Lista/Birkenes there has been a significant reduction in air concentration for most heavy metals (As, Cd, Co, Cr, Pb, Ni and V) in the period 1991 to 2015. At Zeppelin, there has also been a significant reduction since 1994 for several heavy metals (As, Cd, Cu, Pb, Ni and V). The reduction of lead has been 84% and 62%, at Birkenes and Zeppelin respectively. For cadmium, similar trends have been observed, with 64% and 59% reductions respectively. Weak significant decreasing trends were found for mercury with 16% and 9% respectively at Birkenes and Zeppelin.

Sammendrag

Denne rapporten presenterer data fra 2016 for det nasjonale overvåkingsprogrammet for Langtransporterte atmosfæriske miljøgifter. Formålet med overvåkingen er å fremskaffe kunnskap om langtransport av miljøgifter som kilde til forurensning i Norge og ivareta rapportering til internasjonale konvensjoner, programmer og nettverk. Resultatene fra 2016 inkluderer 122 organiske komponenter og elleve tungmetaller. De organiske komponentene omfatter både regulerte POP-er og nye miljøgifter som ennå ikke er regulert på internasjonalt nivå. Overvåkingsprogrammet inkluderer observasjoner av i) organiske miljøgifter, tungmetaller og kvikksølv i luft på tre stasjoner (Birkenes, Andøya og Zeppelin), ii) organiske miljøgifter og kvikksølv i nedbør på en stasjon (Birkenes), samt iii) tungmetaller i nedbør på fem stasjoner (Birkenes, Hurdal, Kårvatn, Svanvik og Karpdalen). To klasser av nye miljøgifter (siloksaner og klorparafiner) er inkludert på én lokalitet (Zeppelin) siden 2013.

Organiske miljøgifter

De organiske miljøgiftene i luft viser forskjellige tidstrender. Generelt, så har de fleste komponenter som har blitt målt over lang tid gått ned i konsentrasjon, spesielt siden begynnelsen av 1990-tallet. Den største reduksjonen observeres for HCH-er på Birkenes og Zeppelin. Reduserte nivåer observeres også for DDT, klordaner og PCB. Data fra 2016 viser at reduksjonen fortsatt pågår for HCH-er og PFAS. Dataene for DDT, klordaner, PBDE, TBA og HBCD indikerer at en likevektstilstand er nådd. Årsmiddel for disse komponentene i 2016 er på samme nivå eller noe høyere enn i 2015 og fluktuerende årsmiddel ses over tid. Dette beror på lave konsentrasjoner (mesteparten under deteksjonsgrenser), men også på stabile konsentrasjoner over deteksjonsgrenser (DDT, klordaner, TBA). For PCB indikerer data fra 2016 en oppadgående trend på Zeppelin. Nivåene av PCB i 2016 var høyere enn i 2015 også på Birkenes og Andøya, men her dominerer årlige variasjoner uten trender. PAH-er indikerer nedadgående nivåer på Zeppelin under de siste fem årene mens ingen trender kan ses på Birkenes. De økende nivåene av HCB på Zeppelin ses flate ut i 2016 mens de fortsatt øker på Birkenes.

Den romlige fordelingen varierer med komponent. PAH, γ-HCH, DDT og PFAS (PFOA) er høyest på Birkenes i sør mens nivåene av HCB, PCB, PBDE og TBA er høyest på Zeppelin i nord. De andre komponentene (HCH, klordaner og HBCD) er jevnt fordelt mellom stasjonene.

Nye miljøgifter

Årsmiddel og sesongmiddel for siloksanet D6 og klorerte parafiner var lavere i 2016 enn i 2015. For D6 skyldes dette lavere nivåer under sommeren i 2016 enn i 2015. For siloksanet D5, er nivåene i 2016 på samme nivå som tidligere år. Ingen trender observeres for disse nye miljøgiftene i perioden 2013-2016. Selv om det er usikkerheter knyttet til måle- og analysemetodene, kan man observere at nivåene av disse uregulerte miljøgiftene er på samme konsentrasjonsnivå som sum PAH, det vil si opp til en faktor tusen ganger høyere enn de regulerte POP-ene (PCB, OCP, PBDE, PFAS). Dette viser viktigheten av å inkludere nye stoffer i overvåkingen og å fortsatte overvåking av disse nye stoffene for å følge utviklingen fremover.

Tungmetaller

De årlige gjennomsnittskonsentrasjonene av tungmetaller i nedbør i 2016 var høyest på Svanvik og Karpdalen i Sør-Varanger. Dette skyldes utslipp fra de nærliggende smelteverkene på russisk side. Lavest konsentrasjoner i nedbør måles på Kårvatn som ligger lengst bort fra kildeområder.

Våtavsetning er derimot generelt høyest i Sør-Norge der nedbørmengden er høyest. Inkludering av luftmålinger på Svanvik og Karpdalen i 2016 bekrefter resultatene i nedbør. Over 10 ganger høyere konsentrasjoner i luft måles på disse to stasjonene sammenlignet med Birkenes, Andøya og Zeppelin. Konsentrasjonen av de fleste tungmetallene målt i luft på Andøya og Birkenes er to til tre ganger lavere enn de som er observert ved Birkenes. Det samme observeres også for de organiske miljøgiftene: PAHs, HCHs, DDTs og PFAS. En årsak kan være at Birkenes er nærmere utslippskildene på det europeiske kontinentet. For de andre internasjonalt regulerte organiske miljøgiftene samt kvikksølv er det ikke store forskjeller mellom stasjonene da de har stort potensiale for langtransport og det indikerer at det ikke er dominerende primære utslippskilder i regionen.

I 2016 var konsentrasjonen av bly, kadmium og vanadium i nedbør på fastlandsstasjonen lavere enn i 2015. I et lengre perspektiv har det vært en betydelig reduksjon av tungmetaller i nedbør i Norge siden 1980; for bly mer enn 90% på Birkenes og Kårvatn. Fra 1990 har det vært en reduksjon av bly mellom 52-94%, unntatt på Svanvik der det ikke er noen signifikant trend for denne perioden. Det er også store reduksjoner for kadmium i nedbør, mellom 42 og 73% fra 1990. For kvikksølv, HCB og HCH i nedbør, har det vært en signifikant reduksjon siden 1990 hvis man kombinerer datasettene fra de nærliggende observatoriene Lista og Birkenes.

Nivåene i luft i 2016 var blant de laveste hittil observert på Birkenes og Zeppelin for As, Cd, Co, Pb, V. På Lista/Birkenes har det vært en betydelig reduksjon i luftkonsentrasjon for nesten alle tungmetaller som er målt (As, Cd, Co, Cr, Pb, Ni og V) for perioden 1991 til 2015. På Zeppelinobservatoriet, har det også vært en betydelig reduksjon siden 1994 for flere tungmetaller (As, Cd, Cu, Pb, Ni, V). Reduksjonen av bly har vært på 84 og 62% hhv. på Birkenes- og Zeppelinobservatoriet. For kadmium er det lignende store reduksjoner, hhv. 64% og 59%. For elementært kvikksølv i luft er det en svak nedadgående trend på 16 og 9% på hhv. Birkenes og Zeppelin.

1. The monitoring programme

Background

Heavy metals and persistent organic pollutants (POPs) can undergo long-range environmental transport, are toxic, bioaccumulative and persistent in the environment. Due to their harmful impacts on the human health or on the environment, monitoring of these pollutants is of high priority for Norwegian authorities. For many of these contaminants, long-range transport via air is the most important source to pollution in remote areas where there are few or no local sources. Recognition of long-range atmospheric transport of environmental contaminants to remote areas, such as the Arctic, has been vital in our understanding of the presence and environmental behaviour of persistent organic pollutants (POPs) which in turn has contributed to the regulation of several of these contaminants both on a regional and global scale.

The use and emission of heavy metals and POPs have been regulated through multilateral environmental agreements. Heavy metals are regulated by: i) the 1998 Aarhus Protocol on Heavy Metals under the Convention on Long-range Transboundary Air Pollution (LRTAP) (UN/ECE, 1998a), and ii) the Minimata convention on mercury (UNEP, 2013). POPs are regulated or banned on a global scale by the Stockholm Convention on POPs (Stockholm Convention, 2007) and on a European scale by the 1998 Aarhus Protocol on POPs; “the POP-protocol”, under LRTAP (UN/ECE, 1998b). The two conventions today includes 26 and 23 substances/substance groups respectively and the number of chemicals regulated are continuously extended (UN/ECE, 2010, Stockholm Convention, 2013). In 2015, the Conference of the Parties to the Stockholm Convention adopted decisions to list three new POPs in the convention; hexachlorobutadiene, polychlorinated napthalenes and pentachlorophenol, including its salts and esters (Stockholm Convention, 2015). The global ban on these chemicals entered into force in 2016. In May 2017 another two chemicals were added to the Stockholm Convention; short-chain chlorinated paraffins (SCCPs) and decabromodiphenyl ether (deca-BDE). In addition, the parties to the Stockholm Convention agreed to take measures to restrict the unintentional production of the chemical hexachlorobutadiene (HCBD) whose production and use is already banned globally through the Stockholm Convention. The global regulation of these chemicals is foreseen to enter into force in 2018. In addition another two chemicals are under review as potential POPs under the Stockholm Convention: dicofol, and perfluorooctanoic acid (PFOA), it salts and PFOA-related compounds.

Monitoring of the contaminants in air and precipitation within this monitoring programme supports policy makers with information on the contaminants’ concentrations in air on the Norwegian mainland and in the Arctic. This monitoring allows for i) the assessment of long-term trends and effectiveness of regulatory actions of legacy compounds, as well as ii) novel understanding of occurrence and distribution of new organic contaminants.

Purpose

This report presents data from 2016 for POPs and heavy metals in air and precipitation from the *national monitoring programme of long-range atmospheric transported contaminants*, which is conducted by NILU on behalf of The Norwegian Environment Agency, and the Ministry of Climate and Environment. The purpose of this monitoring programme is to provide authorities with data that can help to increase the knowledge about:

i) the atmospheric contribution of regulated and emerging contaminants to the Norwegian environment;
ii) the contaminant's potential for long-range transportation;
iii) changes in levels over time and space;
iv) new organic contaminants.

The data may also be used to provide insight into source regions for long-range environmental transport. The monitoring performed in 2016 and presented in this report had a special focus on new organic contaminants. The purpose was to cover the large data gap that exist on the environmental occurrence and distribution for new contaminants. Increased knowledge for these contaminants will help authorities to make national or international regulations to come into place.

The report is also important for monitoring compliance with existing abatement strategies. Data and results from the national monitoring program are reported and used in several international fora, including: the Global Monitoring Programme (GMP) of the Stockholm Convention on POPs, the European Monitoring and Evaluation Programme (EMEP) under the Convention on Long-range Transboundary Air Pollution, the Comprehensive Atmospheric Monitoring Programme (CAMP) under the Convention for the Protection of the marine Environment of the North-East Atlantic (OSPAR) and the Arctic Monitoring and Assessment Program (AMAP). A subset of the data are also reported to the European Commission as defined in the air quality directive (EU, 2008), and to the Environmental monitoring at Svalbard and Jan Mayen (MOSJ). Nationally, the data are used to assess the achievement towards obtaining priority environmental goals for environmental pollution and the Arctic.

Monitoring strategies

To document the long-range transport of the environmental contaminants, the monitoring stations/observatories in this report have been placed/located, as far as possible, in areas that are not influenced by local sources for the regulated and long-term monitored contaminants. For example, the occurrence of organic contaminants in the Arctic region has mostly been attributed to long-range transport from distantly located, industrial and agricultural areas. However, for the new organic contaminants, it is important to evaluate possible influence of local sources in comparison to long-range transport since some chemicals of emerging concern have been found at elevated levels near Arctic settlements, indicating those may also serve as point sources of new organic contaminants to the Arctic region.

The number of observatories and the geographical distribution are selected in order to represent different parts of Norway, and areas that receive air from different source regions globally. The observatories in this monitoring programme are to a large extent coordinated together with "*the national measurement programme of long-range transported air pollutants for main components in air and precipitation*", which similar to this monitoring programme is conducted by NILU on behalf of the Norwegian Environment Agency, and the Ministry of Climate and Environment (Aas 2016b).

No changes in the monitoring programme have been made between 2013 and 2016. Three observatories are used for the monitoring of POPs and heavy metals in air, two of these are located on the mainland of Norway: Birkenes, and Andøya, and one is locates on Svalbard: Zeppelin (Figure 1.1, Table 1). POPs in precipitation is only monitored at Birkenes while heavy metals in precipitation is monitored at four sites: Birkenes, Hurdal, Kårvatn and Svanvik (Figure

1.1, Table 1). This report, for the first time, also includes heavy metals in precipitation from Karpdalen in Sør-Varanger and active air measurements of heavy metals at Svanvik and Karpdalen. Further information of the sampling sites, site descriptions are available at http://www.nilu.no/projects/ccc/sitedescriptions/.

Air samples of organic contaminants and heavy metals (excluding mercury) are collected using active air samplers at all sites. The active air samples are collected on a weekly basis throughout the year with specific sampling lengths for each observatory. The contaminants monitored varies slightly from station to station. In general, 52 samples for each contaminant is collected per year. Exceptions are the cyclic volatile methylsiloxanes (cVMS) that are collected in one summer and one winter campaign, and mercury in air that is measured continuously using a Tekran Hg monitor. The precipitation samples are collected on weekly basis using bulk samplers. Active air samples and precipitation samples for POPs and heavy metals are extracted, analysed and quantified at NILU under strict quality control using accredited methods. For the emerging contaminants, the sampling and analytical methodologies are associated to a larger degree of uncertainty than for the well-established methods (e.g. PCBs). It is a long process to establish methods with similar quality assurance as for PCBs but the analytical laboratory at NILU are in the forefront in method developments for new organic contaminants and are constantly working on method improvements. Information about the sampling and analytical methodologies are given in Annex 3. All the data presented in this report are available at http://ebas.nilu.no/.

Monitoring of heavy metals in precipitation has been part of *the Norwegian national monitoring programme* since 1980, while the POP-measurements in precipitations were initiated in 1992. Air measurements of heavy metals and POPs started in 1991 at Lista observatory in southern Norway as part of the CAMP Programme under the OSPAR Convention (http://www.ospar.org). Lista closed down in 2004, but the extended measurement programme continued at the nearby observatory in Birkenes. In 1994, air measurements of heavy metals and POPs were included at the Zeppelin Observatory at Svalbard as part of the AMAP programme (http://www.amap.no). Both sites became part of the EMEP programme (http://www.emep.int) under the LRTAP (http://www.unece.org/env/lrtap) in 1999, (Tørseth et al, 2012). In the end of 2009, a new monitoring station for heavy metals and POPs was established at Andøya as part of *the national Marine Pollution Monitoring Programme* for the Norwegian Environment Agency (Green et al., 2011) and it is now a part of the regular EMEP programme.

The data from 2016, presented in this report, are a compilation of results from three different national projects and programs:

- Measurements of heavy metals and POPs (except PAHs) in air at Birkenes, Andøya and Zeppelin, heavy metals in precipitation at Birkenes, and emerging substances (i.e. cyclic volatile methyl siloxanes and short and medium chained chlorinated paraffins) at Zeppelin are part of *The national monitoring programme of environmental contaminants* on behalf of The Norwegian Environment Agency;
- Measurements of POPs in precipitation at Birkenes, heavy metals in precipitation at Hurdal and Kårvatn and PAHs in air at Zeppelin are part of *The long-term dataseries programme* on behalf of the Ministry of Climate and Environment, as well as NILUs internal monitoring programme;
- Measurements of heavy metals in precipitation at Svanvik and Karpdalen are part of *The Norway-Russia measurement programme* on behalf of The Norwegian Environment Agency.

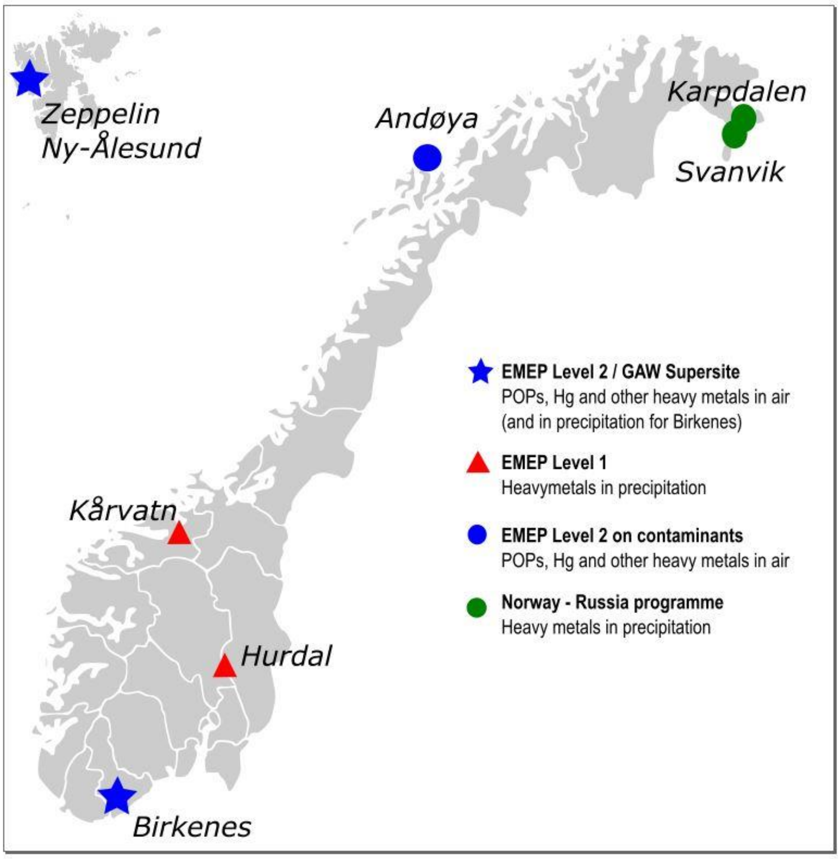

Figure 1.1: Norwegian background stations measuring environmental contaminants in 2016.

Table 1.1: Norwegian monitoring stations and the sampling programme of persistent organic pollutants and heavy metals at the individual sites, 2016.

Station code and name					Heavy metals		Persistent Organic Pollutants (POPs)*	
		Lat	Long	Hasl	Precipitation	Air + aerosols	Precipitation	Air + aerosols
NO0001R/ NO0002R	Birkenes	58 23 N	8 15 E	190 / 219	As, Cd, Cr, Co, Cu, Pb, Hg, Mn, Ni, V, Zn	As, Cd, Cr, Co, Cu, Pb, Hg, Ni, V, Zn	HCB, HCHs, PCBs	HCB, HCHs, DDTs, CHLs, PCBs, PBDEs, HBCDs, PAHs, PFAS
NO0056R	Hurdal	60 22 N	11 4 E	300	Cd, Pb, Zn			
NO0039R	Kårvatn	62 47 N	8 53 E	210	Cd, Pb, Zn			
NO0047	Svanvik	69 27 N	30 2 E	30	Al, As, Cd, Cr, Co, Cu, Pb, Mn, Ni, V, Zn			
NO0098	Karpdalen	69 39 N	30 26 E	70	Al, As, Cd, Cr, Co, Cu, Pb, Ni, V, Zn	Al, As, Cd, Cr, Co, Cu, Pb, Ni, V, Zn		
NO0090R	Andøya	69 16 N	16 0 E	380		As, Cd, Cr, Co, Cu, Pb, Mn, Hg, Ni, V, Zn		HCB, HCHs, DDTs, PCBs, PBDEs, PFAS
NO0042G	Zeppelin	78 54 N	11 53 E	474		As, Cd, Cr, Co, Cu, Pb, Mn, Hg, Ni, V, Zn		HCB, HCHs, DDTs, CHLs, PCBs, PBDEs, HBCDs, PAHs, PFAS, Siloxanes, S/MCCP

* Full names given in Chapter 2.1.

2. Persistent organic pollutants (POPs)

This monitoring report includes 12 classes of organic contaminants, of these, eight are regulated and classified as POPs and four are not yet subjected to regulation, but show POP-like characteristics. POPs are characterized by being persistent in the environment, bio-accumulative, toxic to humans and wildlife, and having potential for long-range atmospheric transport (Stockholm Convention, 2007). The regulated POPs are herein represented by hexachlorobenzene (HCB), hexachlorohexanes (HCHs), dichlorodiphenyltrichloroethane (DDTs), chlordanes, polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs) hexabromocyclo-dodecanes (HBCDs), polycyclic aromatic hydrocarbons (PAHs) and PFOS and PFOS related substances. The four new, not yet regulated, organic contaminants include chlorinated paraffins (CPs), decabromodiphenyl ether (deca-BDE), cyclic volatile methylsiloxanes (cVMS), tribromoanisole (TBA) and several PFAS. The monitored organic contaminants represent a range of different sources such as intentionally produced chemicals used as pesticides, biocides, flame retardants, etc., and unintentionally produced chemicals generated as by-products of various industrial/combustion processes. The intentionally produced POPs are released to the environment in different ways depending on their application; from industrial point sources; by direct spreading in the nature (e.g. pesticides); by emission/release from products in which they are used; and waste.

POPs in air have been monitored at Zeppelin since 1991, while the monitoring started later at Birkenes and Andøya (see details in section 3.1). The contaminant classes included in the monitoring at each observatory are presented together with heavy metals in Table 1.1. In general, HCB, HCHs, DDTs, PCBs, PBDEs, TBA and PFAS are monitored at all three observatories while chlordanes, HBCDs and PAHs are only monitored at Birkenes and Zeppelin. In addition, two groups of emerging organic contaminants have been included in the monitoring programme at Zeppelin since 2013; i.e. cVMS and short and medium chained chlorinated paraffins (SCCP, MCCP) (see Chapter 4).

Sampling of POPs and S/MCCPs is continuously done on a weekly basis throughout the year with specific sampling lengths for each observatory and class of pollutant. For example, PCB, HCB, DDT, HCH are sampled on a weekly basis at all three observatories, but with different sampling length at the individual observatory (e.g. 24-72 h). The sampling methodologies have been optimized to achieve maximum detection while minimizing the influence of possible sampling artefacts, such as breakthrough and degradation. Sampling of the cVMS does not follow the weekly sampling frequency, instead they have been sampled in one summer and one winter campaign between 2013 and 2016. Details on sampling and analyses are given in Annex 3, Table A.3 4.

Data for the individual POP classes at each observatory are presented as annual mean concentrations, and as monthly mean concentrations in section 2.1-3.3. Exceptions are those classes for which more than 50% of the observations are below detection limits. Detailed data (monthly mean concentrations for individual components within each class) are presented in Annex 2. The results are presented below on POP class basis due to the high amount of POP classes and individual components within each class.

2.1 Persistent organic pollutants in air

2.1.1 Hexachlorobenzene (HCB)

HCB is produced both as an unintentional by-product and as an intentionally made chemical mainly used as a fungicide for crop seed as well as to make fireworks, ammunition, and synthetic rubber. The intentional use and production of HCB is regulated by the Aarhus Protocol on POPs under LRTAP (UN/ECE, 1998b) and the Stockholm Convention on POPs (Stockholm Convention, 2007). Intentional production and use of HCB is therefore assumed to have ceased globally. However, HCB may still be unintentionally produced and released as a by-product during manufacture of other chemicals as well as through incomplete combustion from old dumpsites.

HCB has been monitored at Birkenes and Zeppelin since 1993, and at Andøya since 2009. It was detected in all samples from all sites in 2016. The weekly concentrations ranged between: 25-172 pg/m^3 at Birkenes (including one high episode 2-3 December); 11-68 pg/m^3 at Andøya; and 58-172 pg/m^3 at Zeppelin (including one high episode 2-4 December). The high individual episodes at Birkenes and Zeppelin are both associated with air masses for the specific period from northeast of Russia.

The annual mean concentration of HCB for 2016 at Zeppelin is lower than that observed in 2015, but similar to the previous five years. The increase in HCB concentrations at Zeppelin that has been observed since 2003 seem to have flattened out during the last years. Continued monitoring is needed to address this hypothesis. The levels of HCB measured at Zeppelin between 2012 and 2016 are similar to the levels measured in the end of 1990s, but are still below those observed in the beginning-middle of 1990s. At Birkenes, the annual mean concentration in 2016 is higher than in 2015 and the highest since 2009. The time-trend from 2010 indicates a small increase at this site similar to what has been observed at Zeppelin. The reason for the increasing trends is unknown, suggestions are increased re-emissions from deposited HCB due to higher temperature and ice-free winters, or a continuous release of HCB in some parts of the world, but these hypotheses need further research to be proven (Hung et al., 2010). The association of high episodic levels and air masses from the north-east parts of Russia indicates continuous releases in this area, but a more detailed study is needed to verify this. In contrast, at Andøya the annual mean concentrations are stable during the last six years (Figure 2.1). The stable concentrations at Andøya might be influenced by breakthrough of HCB in the sampler at this site due to a higher sample volume compared to Birkenes and Zeppelin.

The annual mean concentrations of HCB in 2016 were, as previous years, lowest at Andøya (29 pg/m^3) and highest at Zeppelin (83 pg/m^3). The high concentrations observed for HCB at Zeppelin during the last years are in line to what has been observed at Station Nord on Greenland. Such high concentrations have also been observed at Kosetice, Czech Republic in central Europe while the concentrations at other sites in Europe are two to three times lower and similar to those observed at Birkenes (Halse 2011, Aas 2016a).

No clear seasonal variations of HCB concentrations are seen at Zeppelin (Figure 2.2) although the individual lowest concentrations are observed during the coldest season (i.e. January and February) and the individual highest concentrations are observed during spring and summer. In contrast, seasonal variations are observed at both Andøya and Birkenes with a factor of 1.5 to two lower concentrations in summer than in winter (Figure 2.2). The seasonal variations at

Birkenes and Andøya may be a result of higher emissions from combustions during colder periods and thereby higher levels in wintertime or as a result of increased breakthrough in the sampler during warmer periods and thereby underestimations of the summer concentrations.

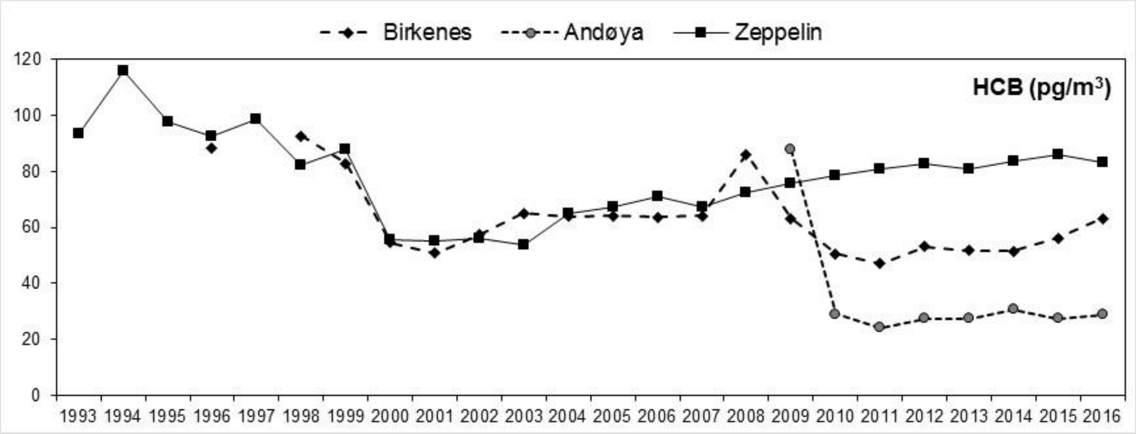

Figure 2.1: Annual mean concentrations of HCB (pg/m^3) in air.

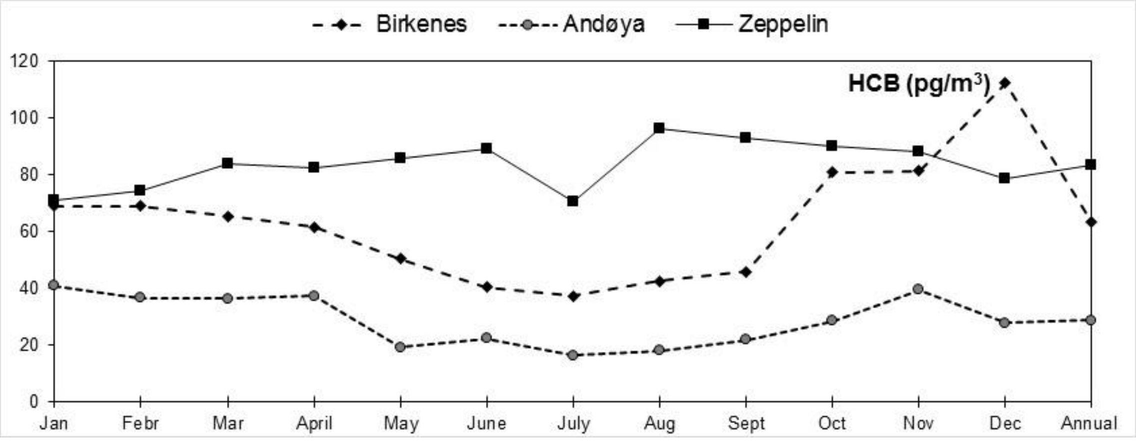

Figure 2.2: Monthly and annual mean concentrations (pg/m^3) of HCB in air for 2016.

2.1.2 Hexachlorohexanes (HCHs)

HCHs are intentionally produced chemicals that have been and are to some extent still used as insecticides worldwide. The technical mixture consists of five stable isomers: α-, β-, γ-, δ-, and ε-HCH. γ-HCH, also known as lindane, has been used both as an agricultural insecticide and as a pharmaceutical treatment for lice and scabies. The production and use of HCHs are regulated regionally and globally by the Aarhus protocol on POPs (UN/ECE, 1998b) and the Stockholm Convention on POPs (Stockholm Convention, 2007). However, the Stockholm Convention still accept the use of lindane/γ-HCH for pharmaceutical control of head lice and scabies and as a result it is still allowed in some countries. Countries are allowed to register specific exemptions for specific time periods.

Two HCH isomers; α- and γ-HCHs, have been monitored at Birkenes since 1991, at Zeppelin since 1993, and at Andøya since 2010. Both isomers were above detection limit in all samples from all sites in 2016. The weekly concentrations of sum HCHs (α+γ) in 2016 ranged from: 2.5-16 pg/m^3 at Birkenes (including two high episode in June and August); 2.6-7.6 pg/m^3 at Andøya; and 3.1-12 pg/m^3 at Zeppelin (including one high episode 30 November-1 December). The highest levels of HCHs at Birkenes are associated with air masses coming from the European continent. Common for these episodes is also that the concentrations of γ-HCH are similar or higher than α-HCH. This is in contrast to most of the other measurements when α-HCH is 1.5-3 times higher than γ-HCH. The reason for the high episode at Zeppelin is unknown. In contrast to the high episodes at Birkenes, the one at Zeppelin is mainly caused by an increase in α-HCH and not in γ-HCH.

The annual mean concentrations of sum HCHs (4.0-6.3 pg/m^3) and the individual isomers in 2016 were in the same range at all observatories and in agreement or slightly lower than in 2015 continuing the decreasing trends from previous years (Figure 2.3:). Overall, HCHs are the POPs that have shown the largest reduction in air concentrations since the beginning of the air monitoring at Zeppelin and Birkenes (a factor of 15 and 25, respectively). The two isomers are declining with similar pattern at both observatories although a somewhat larger reduction is observed for γ-HCH than for α-HCH. As previous years, the average ratios of α-/γ-HCH were found to decrease from north to south; 6.5 at Zeppelin; 4.8 at Andøya; and 2.5 at Birkenes. Even lower ratios are observed at more southern sites in continental Europe (Aas 2016a). The larger ratios in the north might be a result of γ-HCH being less prone to long-range transport and more efficiently scavenged by wet deposition, which in turn is a result of its lower Henry's law constant. Lower ratios in the high episodes at Birkenes as well as in summertime suggests higher emission of lindane/γ-HCH from secondary sources in continental Europe together with less scavenging during the warmer and dryer period.

The concentrations observed in Norway are similar to those observed in Sweden while up to an order lower than those observed at some sites in continental Europe (Aas 2016a).

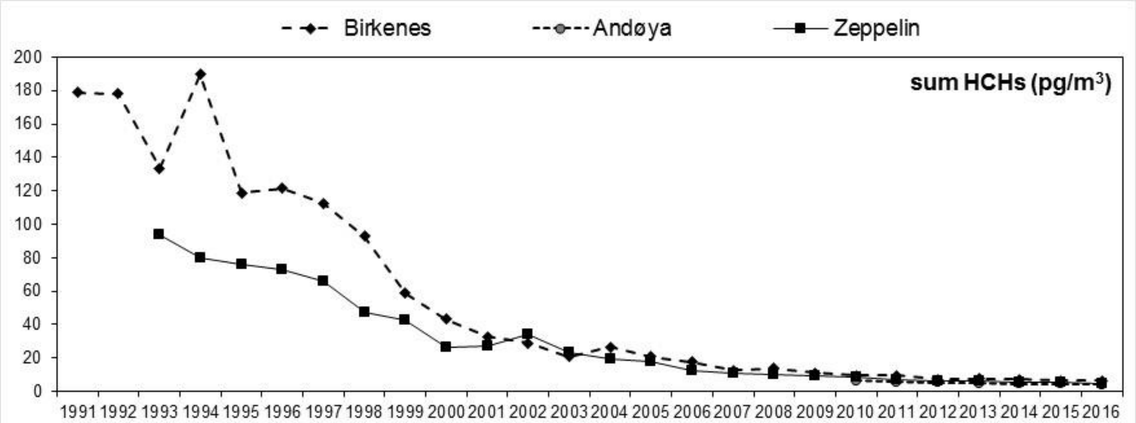

Figure 2.3: Annual mean concentrations of sum HCHs (pg/m^3) in air.

Strong seasonality of the HCHs concentrations was observed at Birkenes, with up to three times higher concentrations during summer than wintertime. A similar seasonality, although less strong, was also observed at Andøya and Zeppelin with lower concentrations in wintertime and higher in summertime (Figure 2.4). The seasonality is less pronounced for γ-HCH than for α-HCH which is reflected in the lower α/γ-ratios in summertime. Higher concentrations during warmer periods may be due to re-volatilization from soil or other environmental surface media during warmer periods (i.e. secondary emissions) (Halse 2012).

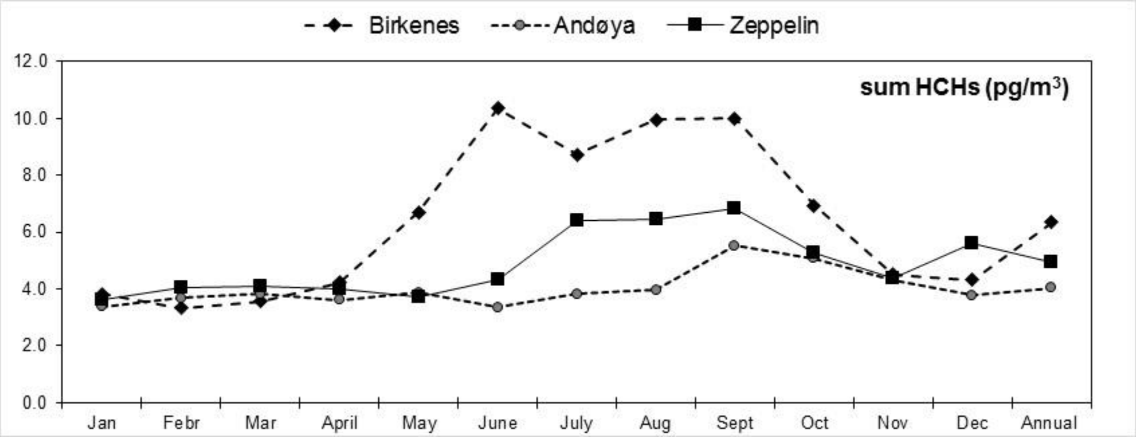

Figure 2.4: Monthly and annual mean concentrations (pg/m3) of sum HCH in air for 2016.

2.1.3 Dichlorodiphenyltrichloroethane (DDTs)

DDTs are intentionally produced chemicals that have been used worldwide as a pesticide to protect humans and agricultural crops from vector-borne diseases. The production and use of DDTs were banned in Europe, US and Canada during 1970s to 2000 and is further regulated by the Aarhus protocol on POPs (UN/ECE, 1998b) and the Stockholm Convention on POPs (Stockholm Convention, 2007), but is still in use in some parts of the world for disease (primarily malaria) vector control. The Stockholm Convention allows the production of DDT for use in disease vector control and as an intermediate in the production of dicofol. Furthermore, the World Health Organization (WHO) recommends indoor residual spraying with DDT as one of three primary means of malaria control, the others being use of insecticide treated bednets and prompt treatment of confirmed cases with artemisinin-based combination therapies (WHO, 2006). The Conference of the Parties to the Stockholm Convention on POPs evaluates the continued need for DDT for disease vector control approximately every second year in consultation with WHO.

The six DDT congeners; o,p’- and p,p’- DDT, DDD, and DDE, have been monitored at Zeppelin since 1994, and at Birkenes and Andøya since 2010. The detection frequencies in 2016 varied among the individual congeners and between the sites. For example, p,p’-DDE and o,p’-DDT were detected in all samples at all sites, while low detection frequencies (i.e. low concentrations) were observed for p,p’-and o,p’-DDD at Birkenes and Zeppelin. p,p’-DDE was the most abundant congener at all sites. The weekly concentrations of sum DDTs in 2016 ranged between: 0.4-4.4 pg/m^3 at Birkenes; 0.08-2.1 pg/m^3 at Andøya; and 0.08-2.3 pg/m^3 at Zeppelin. No clear high episodes of DDTs were observed at any of the sites.

The annual mean concentrations of sum DDTs and the individual congeners in 2016 were as previous years higher at Birkenes (1.4 pg/m^3) compared to Andøya (0.7 pg/m^3) and Zeppelin (0.6 pg/m^3) (Figure 2.5:). The annual mean concentrations of sum DDTs and all congeners at all stations were in the same ranges as those observed since 2010. This suggests that the concentrations of DDTs in air have reached steady-state after the long-term declining trends. Although the concentrations observed at Birkenes are higher than at Andøya and Zeppelin, they are still one to two orders of magnitude lower than the concentrations found on the European continent (Halse 2011, Pribylova 2012, Aas 2016a). The reason for higher concentrations at Birkenes compared to the more northern Norwegian sites may be explained by closer distances to possible emission sources, but more research is needed before any firm conclusions can be drawn. The indicator ratio (p,p'-DDE+p,p'-DDD/p,p'-DDT) were high (~5) at all sites throughout the year indicating input only from aged DDT.

A strong seasonality of the DDT concentrations was observed at Zeppelin and Andøya with five to ten times higher concentrations in wintertime (November-February) compared to warmer months (May-September) (Figure 2.6). This seasonality was seen for sum DDTs as well as o,p'- and p,p'-DDE and DDT, but not for DDD. No such seasonality was observed at Birkenes in 2016. The higher concentrations at Zeppelin and Andøya in winter time than summer time can be connected to the Arctic Haze season in the Arctic area during winter time in which the transportation of particles to the Arctic is higher and removal rates of the DDTs are lower than in summer time (Hung, 2016). This is not the full explanation as DDTs tend to be found to larger extent in gas-phase then particle phase.

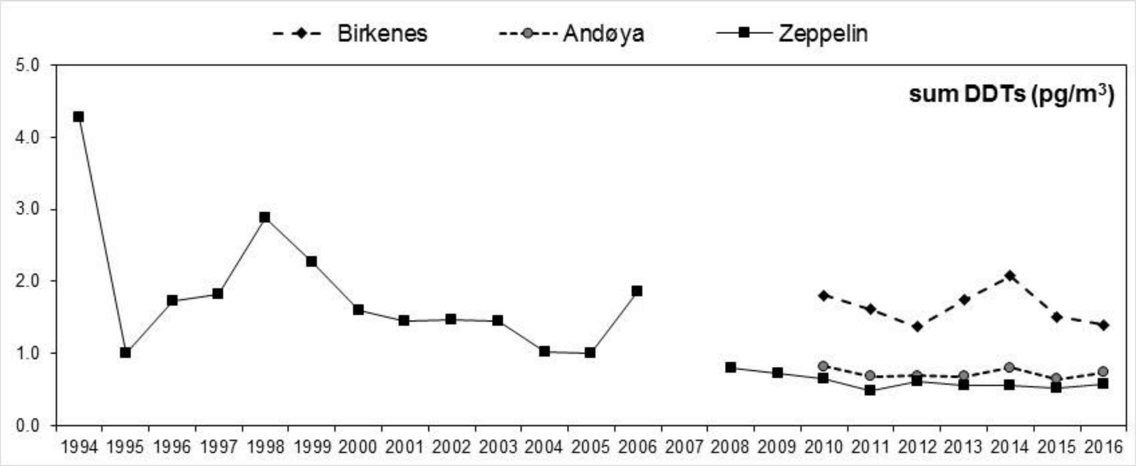

Figure 2.5: Annual mean concentrations of sum DDTs (pg/m^3) in air.

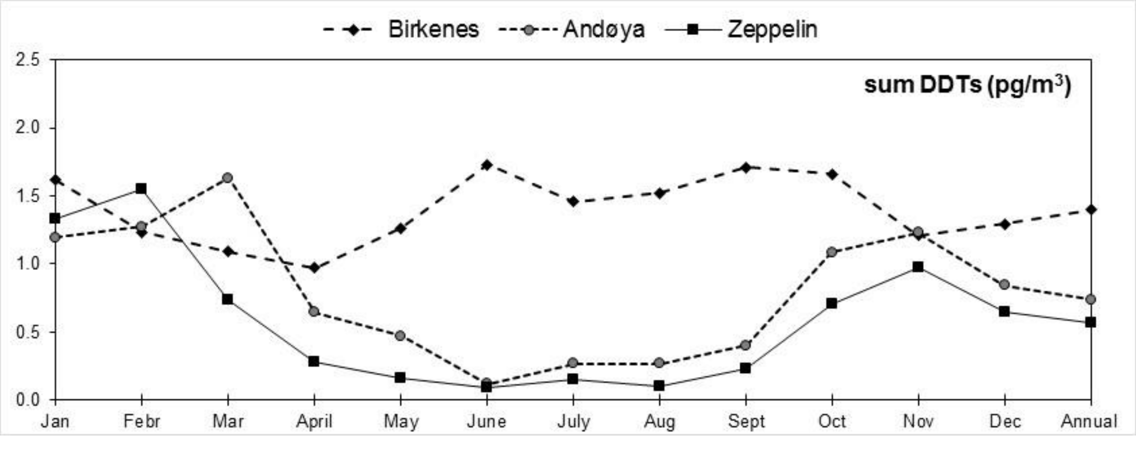

Figure 2.6: Monthly and annual mean concentrations (pg/m^3) of sum DDT in air for 2016.

2.1.4 Chlordanes

Chlordanes are intentionally produced chemicals that have been used extensively as pesticides (insecticides). The use and production of chlordanes have been banned under the Aarhus protocol on POPs (UN/ECE, 1998b) and the Stockholm Convention on POPs (Stockholm Convention, 2007).

The four stereoisomers of chlordane (i.e. cis- and trans-chlordane (CD), and cis- and trans-nonachlor (NO)) have been monitored at Zeppelin since 1993, at Birkenes since 2010 and are not included at Andøya. The three isomers: cis-CD, trans-NO and trans-CD were detected in all samples at both sites. Cis-NO were instead detected with low frequencies at both sites. The major isomers were the cis-CD and trans-NO contributing ~40% each to the sum of chlordanes. The weekly concentrations of sum chlordanes in 2016 ranged between: 0.6-2.1 pg/m^3 at Birkenes; and 0.6-1.4 pg/m^3 at Zeppelin.

The annual mean concentrations of sum chlordanes in 2016 were in the same range at the two sites (Figure 2.7), but two to three orders lower than concentrations recently observed in continental Europe (Aas 2016a). The concentrations of sum chlordanes and the individual stereoisomers at Zeppelin and Birkenes in 2016 were higher than in 2015, but in the same range as previous years. This suggests that the concentrations of chlordanes may have reached steady-state after the long-term declining trends, but more data are needed to confirm this (Figure 2.7:). The ratio of trans-CD and cis-CD was low at Birkenes as well as Zeppelin (0.2-0.8 compared to 1.17 in technical mixture) indicating input only from aged CHLs, since trans-CD degrades faster than cis-CD in the environment.

Higher concentrations in summertime (June-September) than in wintertime (November-March) were observed for sum chlordanes and two of the three detected isomers; cis-CD, and trans-NO at Birkenes in 2016 (Figure 2.8). An opposite seasonality was observed at Zeppelin for sum chlordanes as well as the three detected isomers; cis-CD, trans-CD and trans-NO. This trend was most explicit for trans-CD that had three times lower concentrations in summer than in winter. The lower concentrations of trans-CD in summertime can be a result of more daylight and thereby more photo-degradation of the less stable trans-CD during the Arctic summer.

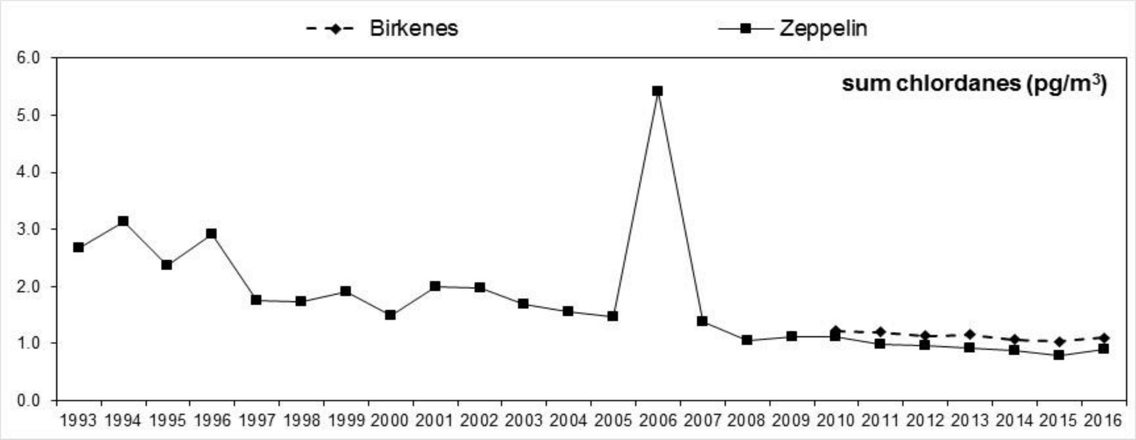

Figure 2.7: Annual mean concentrations of sum chlordanes (pg/m^3) in air.

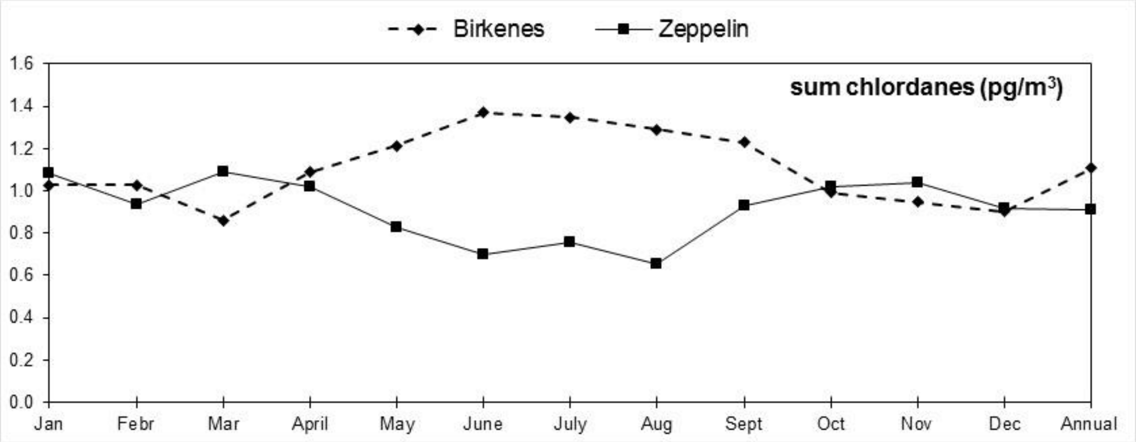

Figure 2.8: Monthly and annual mean concentrations (pg/m^3) of sum chlordanes in air for 2016.

2.1.5 Polychlorinated biphenyls (PCBs)

PCBs are industrially produced chemicals that have been used in a variety of industrial applications. They have been banned from active use in most countries since the mid-1970s and were further banned by the Aarhus protocol on POPs (UN/ECE, 1998b) and the Stockholm Convention on POPs (Stockholm Convention, 2007). Current sources of emissions to the environment are mainly from places where they have been disposed or stored, such as landfills or exposed soils, or from open burning of products containing PCBs, waste incinerations and accidental fires (Breivik et al., 2002; Cousins and Jones, 1998).

The PCBs theoretically consists of a group of 209 congeners. 32 of these (=sum PCB-32) were measured at all three observatories in 2016. These 32 congeners include the seven European indicator congeners (PCB-7); PCB 28, 52, 101, 118, 138, 153, 180, as well as the 12 dioxin-like and most toxic congeners according to WHO; PCB 77, 81, 126, 169, 105, 114, 118, 123, 156, 157, 167, 189. Data are reported for sum of 32 PCBs (sum PCB-32) as well as PCB-7 (sum PCB-7).

PCBs have been monitored at Zeppelin since 2001 and Andøya since 2009. At Birkenes, the seven indicator PCBs have been monitored since 2004 and all the 32 since 2010.

The detection frequencies varied among PCB congeners as well as between sites. Generally, high detection frequencies were observed for tri-penta PCBs (until PCB 114) at all sites while low detection frequencies were observed for some of the penta-hepta PCBs (from PCB 118). As previous years, the tri- and tetra-PCBs were the most common PCBs, comprising 70-80% of sum PCB. The weekly concentrations of sum PCB-32 during 2016 ranged between: 3.8-35 pg/m^3 at Birkenes (including one high episode 3-4 June); 1.2-21 pg/m^3 at Andøya (including one high episode 4-6 January); and 5.8-40 pg/m^3 at Zeppelin (including one high episode 1-3 August). The reasons for the high episodes are not known.

The annual mean concentrations of sum PCB-32 and PCB-7 in 2016 were a factor of two higher at Birkenes and Zeppelin than at Andøya and the highest concentrations were observed at Zeppelin (Figure 2.9:). Reasons for this geographic difference is unknown. The annual mean concentration at Zeppelin in 2016 is higher than in 2015 and the highest since 2009. The data since 2011 indicates an increasing trend at Zeppelin with 1.5 times higher concentrations in

2016 compared to 2011. Also at Birkenes and Andøya the annual mean concentrations were slightly higher than in 2015. In fact, no decline of the PCBs has been observed since 2010 at any of the sites. This suggests that a steady-state condition has been reached for the PCBs at Birkenes and Andøya. The reason for the small increase at Zeppelin is unknown.

The concentrations of PCB-7 (i.e. PCB 28, 52, 101, 118, 138, 153, 180) at the Norwegian sites are up to one order of magnitude lower than the concentrations of PCB-7 reported to EMEP from sites in Germany and Czech Republic (Aas 2016a).

No clear seasonality was observed for sum PCB-32 and sum PCB-7 at any of the observatories. As previous years, the lowest concentrations at Andøya were consistently observed in summertime (June-September) and the highest in wintertime (January-March). In contrast, at Zeppelin and Birkenes the highest individual concentrations were observed in summertime (June-September).

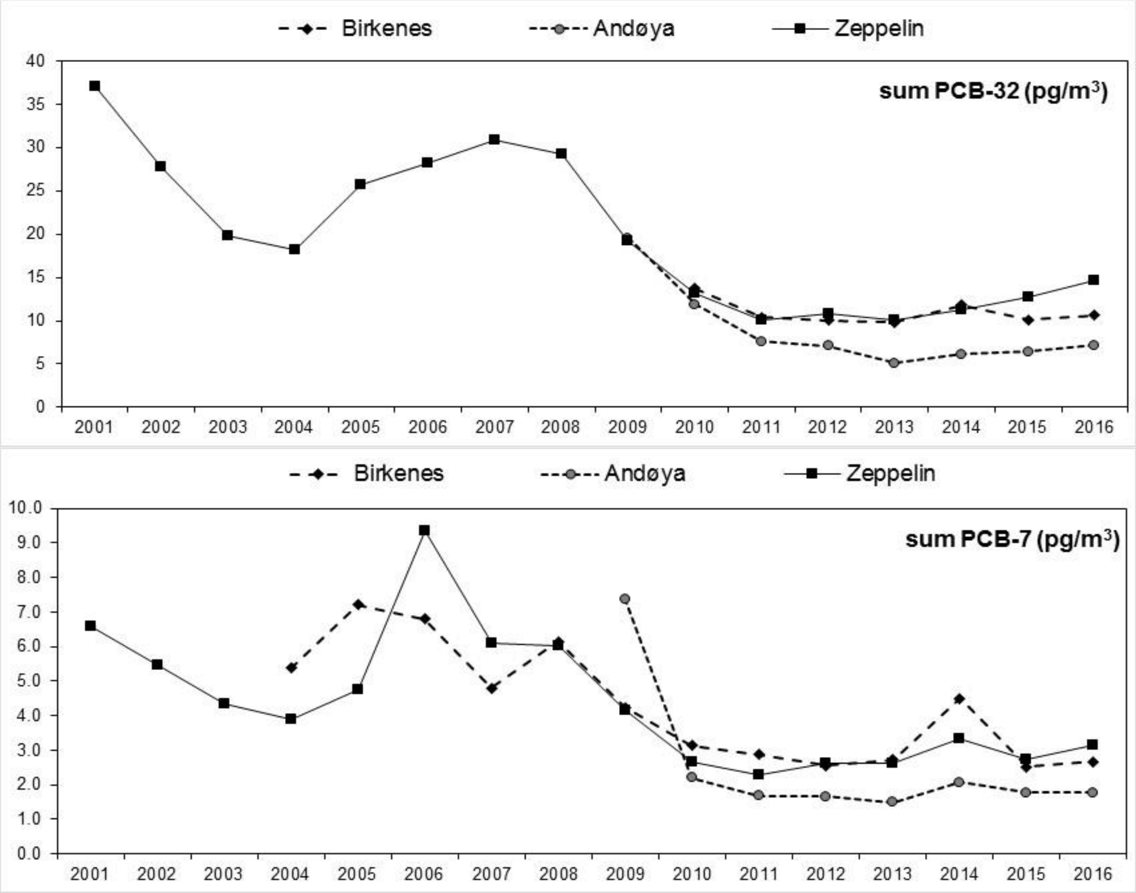

Figure 2.9: Annual mean concentrations of sum PCBs and sum PCB-7 (pg/m^3) in air.

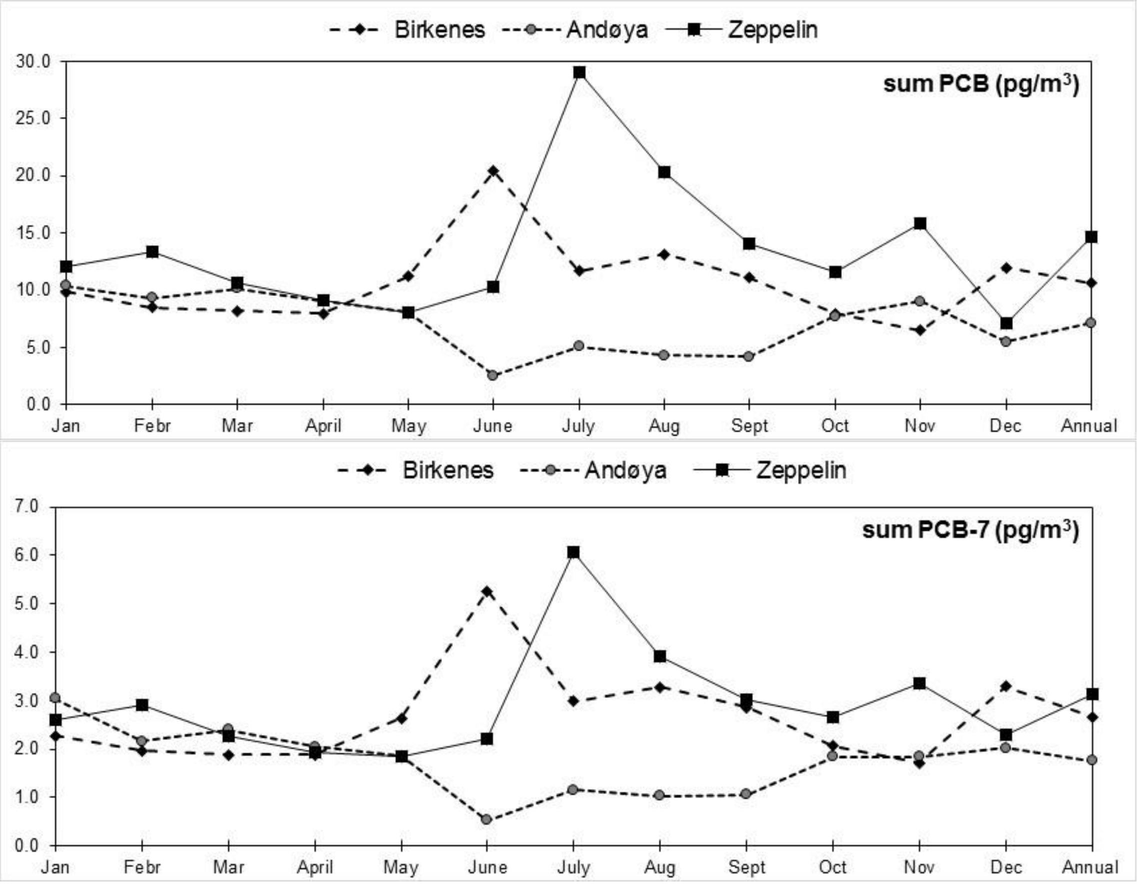

Figure 2.10: Monthly and annual mean concentrations (pg/m^3) of sum PCB and sum PCB-7 in air for 2016.

2.1.6 Polybrominated diphenyl ethers (PBDEs)

PBDEs are industrially produced chemicals that have been and still are used as flame retardants in a wide range of applications including plastics, textiles and electrical and electronic products. The production and use of the commercial PBDE mixtures; penta- and octa-BDE, are regulated by the Aarhus protocol on POPs (UN/ECE, 2010) and the Stockholm Convention on POPs (Stockholm Convention, 2013) and banned in most countries worldwide. The commercial PBDE mixture, deca-BDE, was included as a POP in the Stockholm Convention in May 2017. However, the global regulation includes several specific exemptions for production and use and will not enter into force in most countries before in 2018. Steps to limit or ban the use have been taken in some countries and regions including Norway where its use, except for in means for transportation, have been banned since 2008. Furthermore, its use in electrical and electronic products at concentrations above 0.1 % are banned in the EU and some other countries globally. The EU has also adopted a wider regulation under REACH, but this regulation will not enter into force before 2 March 2019 (CRS, 2017).

PBDEs theoretically comprise 209 congeners with different degrees of bromination from tetra- to deca-BDE. 17 of these congeners (=sum PBDEs) have been monitored at Zeppelin since 2006, at Birkenes since 2008, and at Andøya since 2009.

The detection frequencies were low for most PBDE congeners at all three sites in 2016. None of the 17 targeted congeners were observed frequently at any site. Only BDE-154, and -183 were detected in more than 50% of the samples at Birkenes and only BDE-28 and -47 in more than 50% of the samples at Zeppelin. At Andøya, none of the individual 17 congeners were detected in more than 50% of the samples. The combination of low detection frequency and low detection limits for most of the PBDE congeners indicates low concentrations at the monitoring sites. BDE-209 was below detection limit in 83%, 62% and 87% of the samples at Birkenes, Andøya and Zeppelin respectively. The detection limit for BDE-209 is 10-100 times higher than that of the other congeners and this is a result of i) background contamination and ii) analytical interferences that together cause elevated detection limits of BDE-209. For example, BDE-209 is an ubiquitous contaminant also in indoor environments and high detection limits are common issues for analytical laboratories. As for the other congeners, the low detection of BDE-209 can be a real result of low concentrations at the sites but higher levels than the other congeners close to the detection limits of BDE-209 cannot be excluded. The actual levels of BDE-209 are therefore uncertain. The high detection limit for BDE-209 suggests that the reported levels for BDE-209 (and sum PBDEs) might be biased too high. This means that the high concentrations of BDE-209 should be treated with caution as it is not clear whether they are a result of true air concentrations or of analytical challenges e.g. contamination or interferences. Uncertainties for data on BDE-209 is a global problem with available data on BDE-209.

The weekly concentrations of sum PBDEs ranged between: 0.1-2.3 pg/m^3 at Birkenes (including three high episodes in April, October and December); 0.1-2.2 pg/m^3 at Andøya (including four high episodes in March, April, November and December); and 0.2-3.2 pg/m^3 at Zeppelin (excluding one outlier). The weekly ranges for sum PBDEs excluding BDE-209 (sum PBDE$_{excl209}$) were 0.1-1.0 pg/m^3, 0.1-0.4 pg/m^3, and 0.1-2.1 pg/m^3 at Birkenes, Andøya and Zeppelin respectively. The minimum in the ranges reflects the detection limits.

The annual mean concentrations of sum PBDEs in 2016 were two times higher at Zeppelin (1.0 pg/m^3) than at Birkenes (0.7 pg/m^3) and Andøya (0.6 pg/m^3) (Figure 2.11:). This difference becomes even larger when excluding BDE-209 from the sum of BDEs (sumPBDE$_{excl209}$=0.2-0-6 pg/m^3 at all sites). The concentrations of sum PBDEs and the individual congeners measured at Birkenes and Zeppelin in 2016 were lower than in 2015 while similar to previous years at Andøya. The variabilities are within annual variability during the last eight years. The lack of significant long-term trends for sum PBDEs and BDE-209 suggest steady-state conditions for the PBDEs.

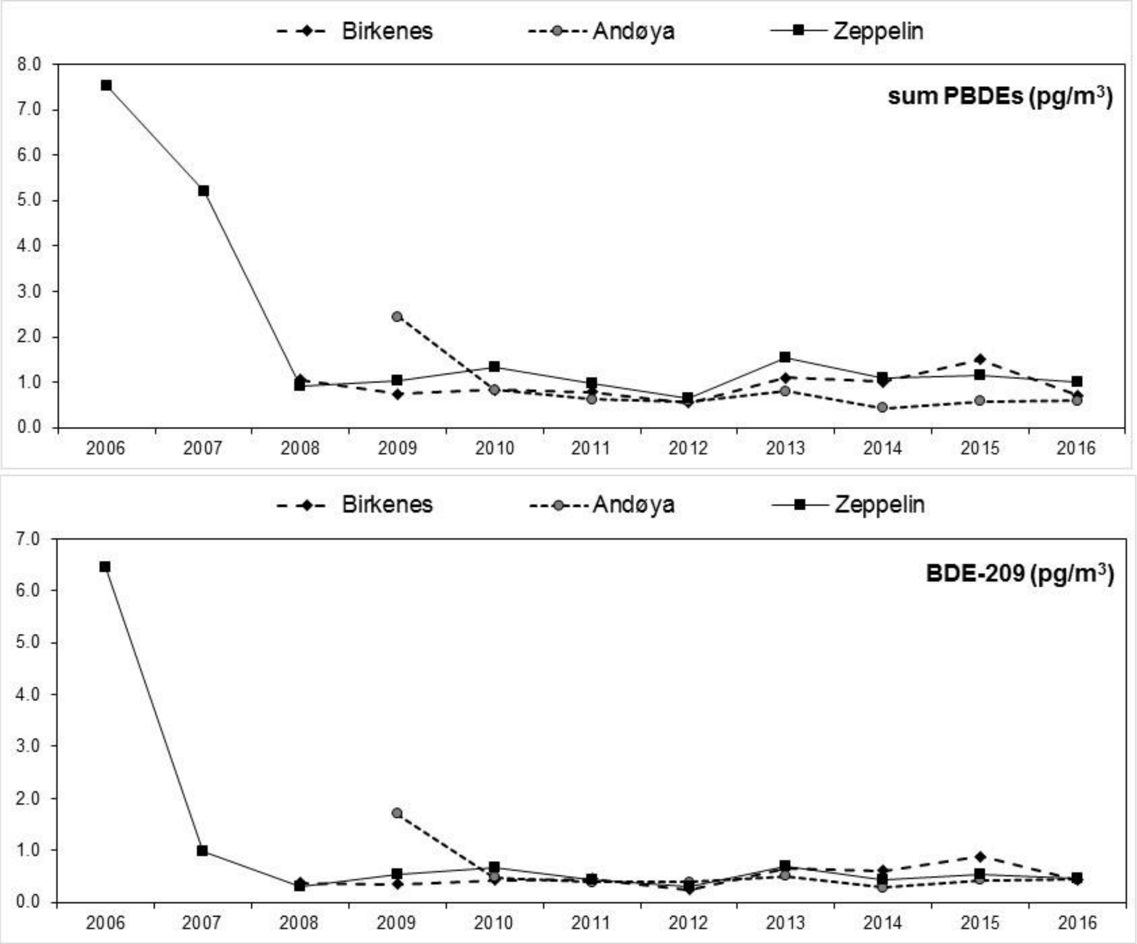

Figure 2.11: Annual mean concentrations of sum PBDEs and BDE-209 (pg/m^3) in air.

The concentrations of sum PBDEs at the Norwegian sites are similar to those observed in the Canadian Western sub-arctic region (Yu et al., 2015), but lower than those measured in Longyearbyen in 2012-2013 (Salamova et al., 2014).

The seasonal pattern is influenced by generally low detection frequencies of the BDE-congeners and a few individually high episodes. The seasonality seen in Figure 2.12 should be interpreted with caution. In general, no seasonality is observed for sum PBDEs, sum PBDEs$_{excl209}$ nor for the individual congeners (including BDE-209) at any site, instead the concentrations fluctuated according to episodic events (Figure 2.12). The reason for these individual high levels are not known.

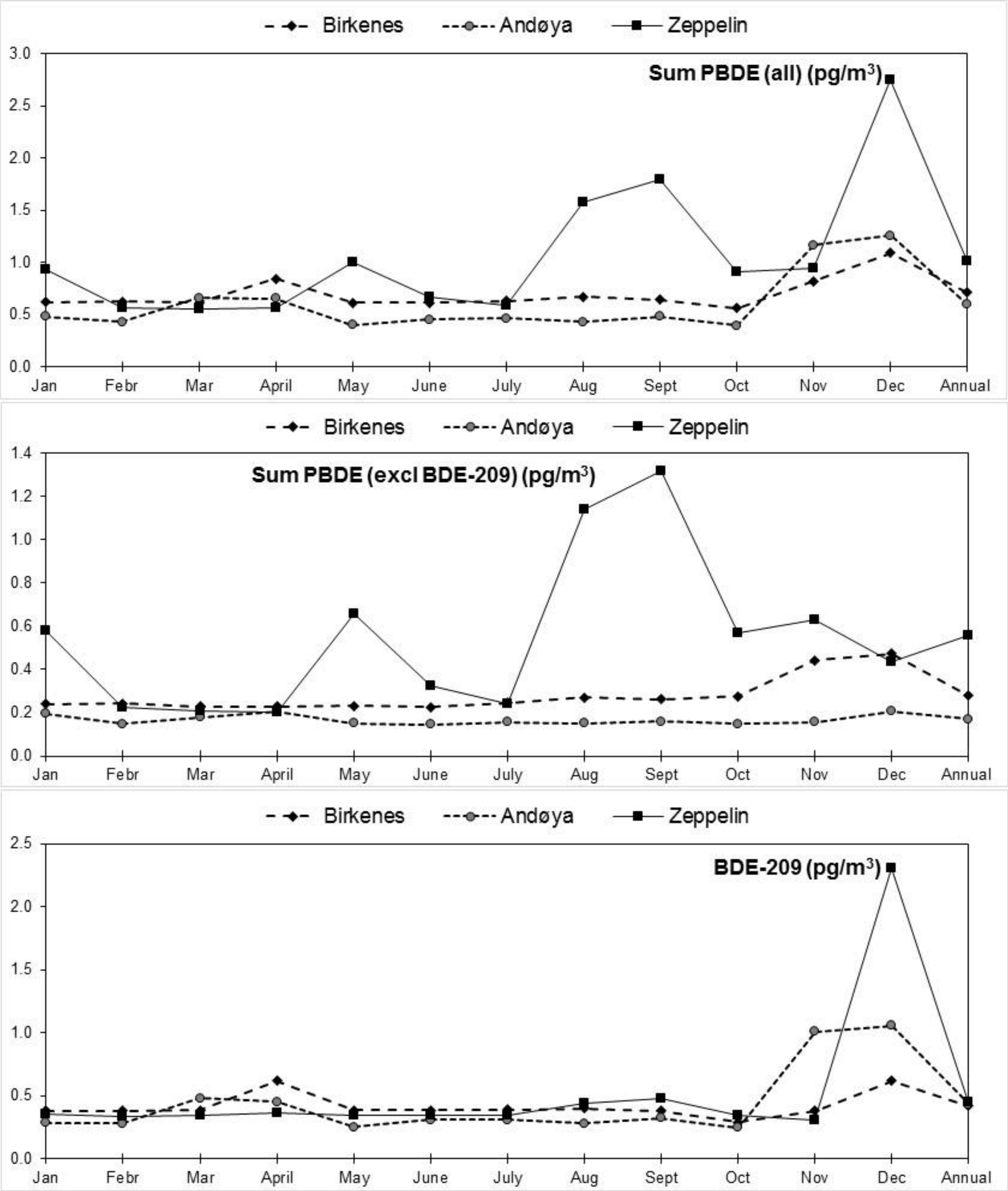

Figure 2.12: Monthly and annual mean concentrations (pg/m³) of sum PBDE (all), sum PBDE$_{excl\ 209}$, and BDE-209 in air for 2016.

2.1.7 Tribromoanisol (TBA)

TBA is a halogenated natural product (HNP) produced by marine phytoplankton, macro algae, bacteria and some benthic invertebrates. It is also an industrial intermediate and a potential break-down product of some non-BDE flame retardants (e.g. 2,3-dibromopropyl-2,4,6-tribromophenyl ether DPTE/TBP-DBPE). The marine HNPs have been shown to volatilize from the sea and are transported by air (Bidleman et al. 2014, 2016). Air measurements of TBA are therefore good indicators for general changes (e.g. climate changes) in the HNP picture of oceans. BAs show POP like characteristics, such as toxic properties, half-lives exceeding the 2 d half-life criterion for long-range transport according to the Stockholm Convention, and have similar structure to other brominated pollutants. As such, it has received attention during the last years both in research and assessment work under AMAP (Wong et al., 2011; Bidleman et al., 2014). AMAP has considered HNPs (including TBA) as a group of contaminants of emerging concern in the Arctic. A reason for this is findings of other HNPs (OH-BDEs and MeO-BDEs) in Arctic biota and a possible concern for their role in ozone regulation.

TBA has been monitored at Birkenes and Zeppelin since 2007 and at Andøya since 2010. TBA was detected in all samples at all sites in 2016 and the weekly concentrations ranged between: 2.4-8.1 pg/m^3 at Birkenes; 0.9-8.9 pg/m^3 at Andøya; and 0.8-14 pg/m^3 at Zeppelin. The annual mean concentrations of TBA in 2016 were 4.2, 4.2, and 6.5 pg/m^3 at Birkenes, Andøya and Zeppelin respectively (Figure 2.13:). These are similar to the concentrations observed in 2015.

The same seasonal trends were observed at all sites, lowest concentrations during spring and increasing concentrations during the summer and autumn (Figure 2.14). This is in agreement with previous years. The higher levels in summertime may be a consequence of increased algal bloom during this period.

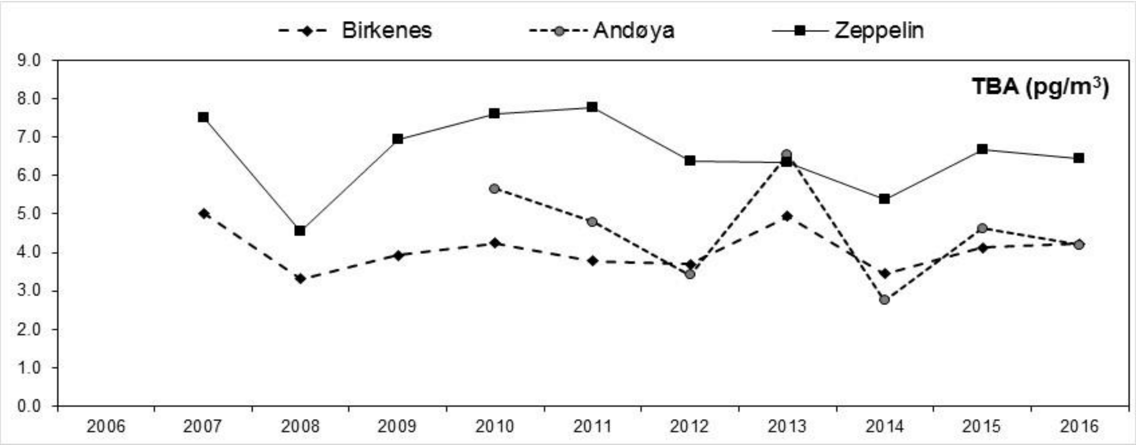

Figure 2.13: Annual mean concentrations of TBA (pg/m^3) in air.

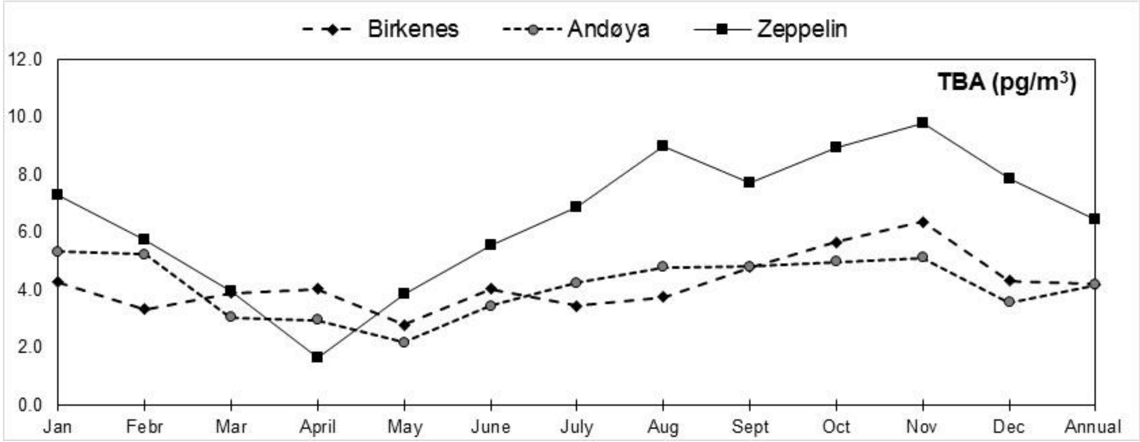

Figure 2.14: Monthly and annual mean concentrations (pg/m^3) of TBA in air for 2016.

2.1.8 Hexabromocyclododecane (HBCD)

HBCD is an additive brominated flame retardant, with many applications. The main use is in extruded and expanded polystyrene used for thermal insulation in building and construction materials. HBCD was listed in the Stockholm Convention on POPs in 2013 with a time-limited exemption for production and use in expanded and extruded polystyrene in buildings. The global ban entered into force in November 2014 (Stockholm Convention, 2013).

The three main diastereomers: α-, β-, and γ-HBCD (=sum HBCDs) have been monitored at Birkenes and Zeppelin since 2006, but are not included at Andøya. The HBCDs are detected with a low frequency at both sites. Very low concentrations (i.e. levels below detection limit) are observed in a majority of the samples: 70-100% for α-, β-, and γ-HBCD. As a result, the annual mean concentrations in Figure 2.15 only reflects the analytical limit of detection (i.e. no real air concentrations).

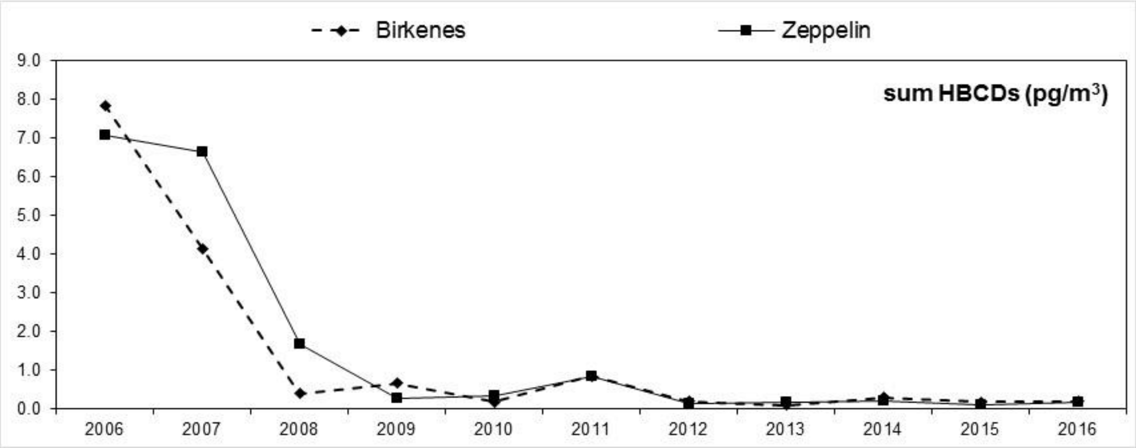

Figure 2.15: Annual mean concentrations of sum HBCDs (pg/m^3) in air.

2.1.9 Polycyclic aromatic hydrocarbons (PAHs)

PAHs are mainly produced through incomplete combustion of organic materials, both through anthropogenic (i.e. industrial and domestic use) and natural causes. They are regulated in the Aarhus protocol on POPs (UN/ECE, 1998b) and the EU air quality directive (AQD) (EU, 2004). They show POP like characteristics, but are less persistent than other POPs.

Seven methyl-PAH and 32 PAHs (=sum PAHs) including the 16 EPA-PAHs (=sum PAH-16) were measured at Birkenes and Zeppelin during 2016. PAHs have been monitored at Zeppelin since 1994, at Birkenes since 2009, and at Andøya between 2009 and 2012. The detection frequencies varied among PAH compounds and between the sites. Generally, more compounds had low detection frequency and were below detection limit at Zeppelin (60% of the compounds) than at Birkenes (~20% of the compounds). The weekly concentrations of sum PAHs in 2016 ranged between: 0.7-19 pg/m^3 at Birkenes (including two high episodes: 12-13 January and 18-19 October); and 0.2-11 pg/m^3 at Zeppelin.

The annual mean concentrations of sum PAHs and sum PAH-16 in 2016 were, as previous years, about two-three times higher at Birkenes than at Zeppelin (Figure 2.15:6). At Zeppelin, the annual mean concentration was one of the lowest ever observed. At Birkenes the concentrations were similar to previous years. The levels of benzo(a)pyrene at both stations are two to three orders of magnitude below the European Air Quality Standard (1 ng/m^3) (EEA) as defined by the 4th air quality daughter directive or Directive 2004/107/EC (EU, 2004).

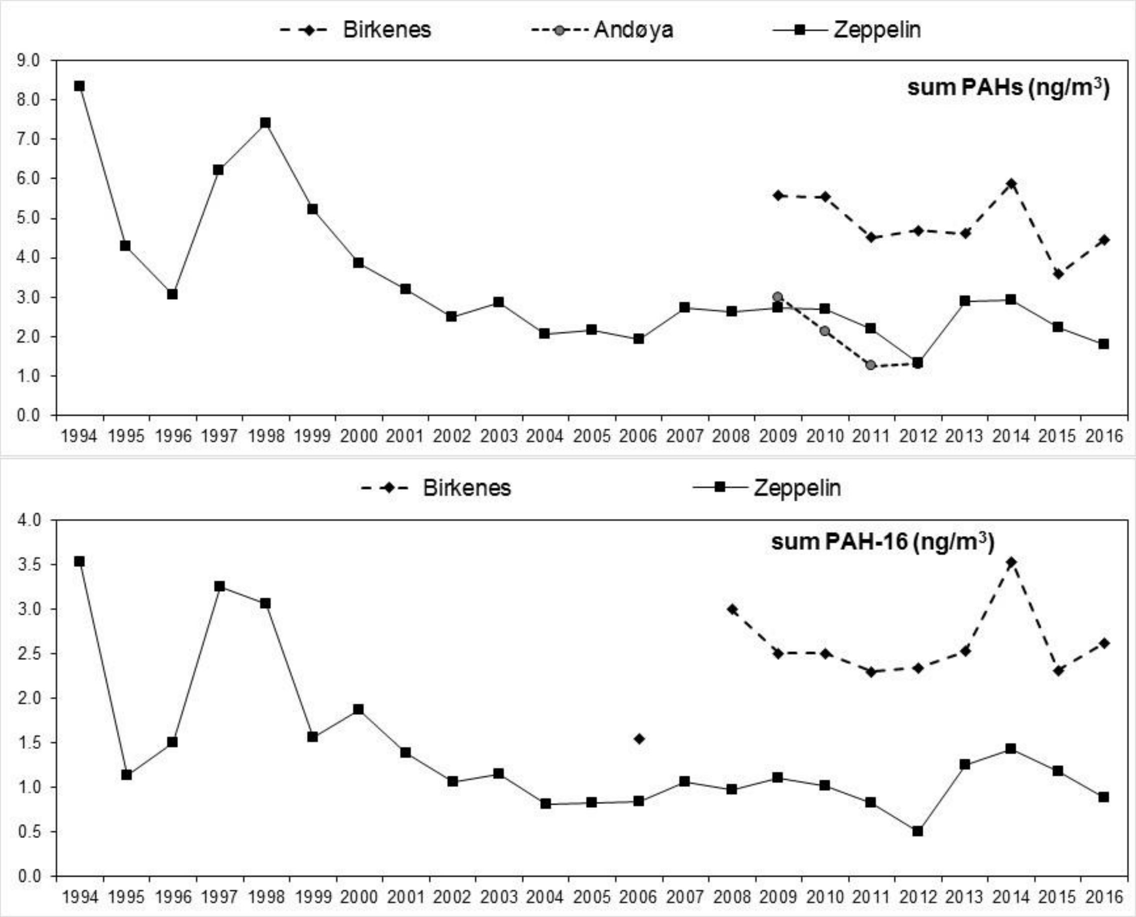

Figure 2.16: Annual mean concentrations of sum PAH and sum PAH-16 (ng/m^3) in air.

A strong seasonality was observed for all PAHs at Zeppelin and Birkenes with up to one order of magnitude higher concentrations in wintertime (November-March) than in summertime (Figure 2.167). The same seasonality was seen both for sum PAHs and the individual PAHs.

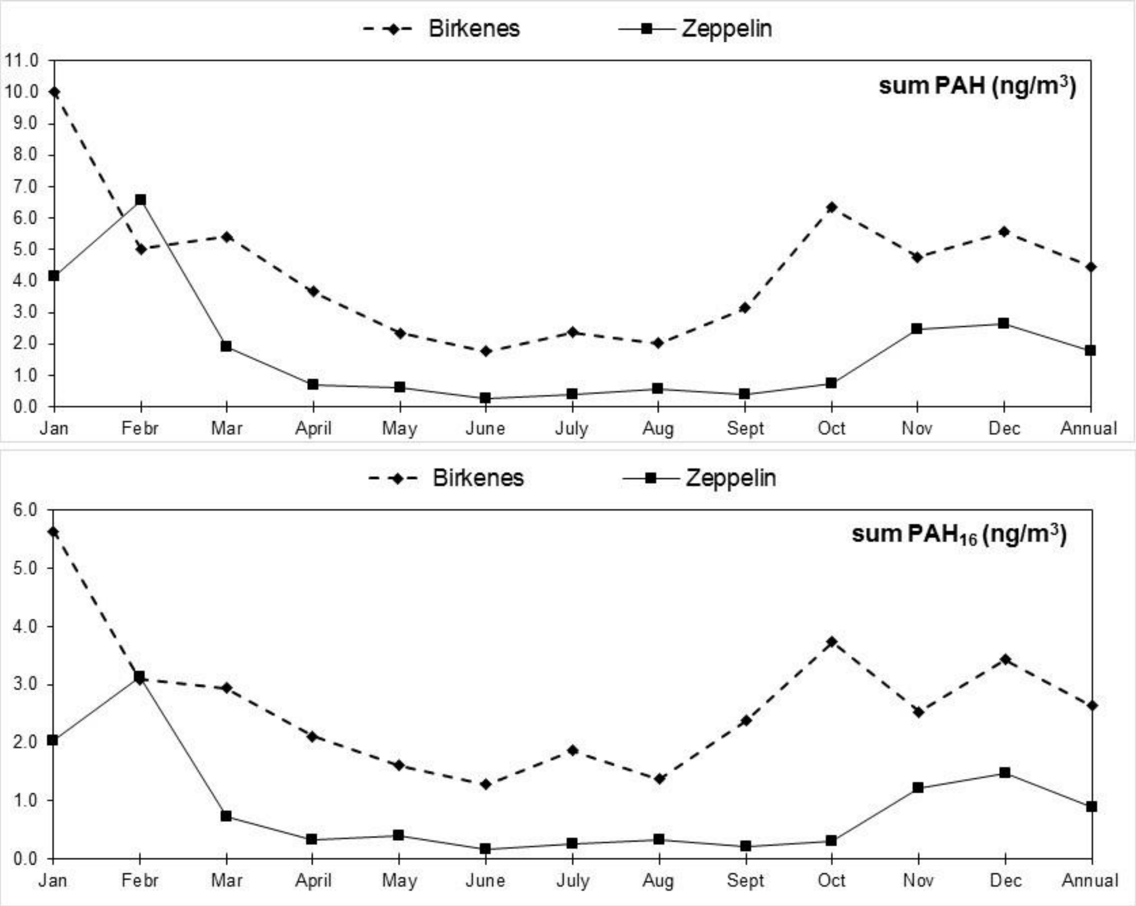

Figure 2.17: Monthly and annual mean concentrations (ng/m^3) of sum PAH and sum PAH-16 in air for 2016.

2.1.10 Per- and Polyfluorinated Alkyl Substances (PFASs)

PFASs comprise a large and complex group of industrially produced chemicals: Ionic compounds like perfluoroalkyl sulfonates (PFSO) and perfluoroalkyl carboxylic acids (PFCAs); and neutral, volatile compounds like fluorotelomer alcohols (FTOHs) and N-alkylated fluorooctane sulphonamides and sulfonamidoethanols (FOSAs/FOSEs). During the last 50 years, PFAS compounds such as PFOS, perfluorooctanoic acid (PFOA) and their related products, have been widely used in consumer products. Currently, PFOS together with its salts and perfluorooctane sulfonyl fluoride (PFOS-F) are the only PFASs that are regulated by the Stockholm Convention on POPs (Stockholm Convention, 2013) and the Aarhus protocol (UN/ECE, 2010). However, PFOA is currently being considered for listing as a POP under the Stockholm Convention. In Norway, both PFOS and PFOA are banned, and the C9-C14 PFCAs are on the Norway's Priority List of Hazardous substances ("Prioritetslisten") (Norwegian Environment Agency, 2015).

The monitoring included 12 ionic PFAS compounds (=sum PFASs) at all three stations in 2016: 6:2 FTS (6:2 fluorotelomer sulfonic acid), PFBS (perfluorobutane sulfonic acid), PFHxS (perfluorohexane sulfonic acid), PFOS (perfluorooctane sulfonic acid), PFDcS (perfluorodecane sulfonic acid), PFHxA (perfluoro¬hexanoic acid), PFHpA (perfluoroheptanoic acid), PFOA (perfluorooctanoic acid), PFNA (perfluorononanoic acid), PFDA (perfluorodecanoic acid, previously called PFDcA), PFUnDA (perfluoroundecanoic acid, previously called PFUnA) and FOSA (perfluorooctane sulphonamide, previously called PFOSA). Five of these are defined as "short-chain": 6:2 FTS, PFBS, PFHxS, PFHxA and PFHpA while the other seven are defined as "long-chain" (Buck et al. 2011) but these definitions are currently under evaluation by authorities in Europe. The 12 ionic PFASs have been monitored at Birkenes and Zeppelin since 2006 and at Andøya since 2009.

In 2016, most of the monitored PFASs were below the analytical detection limit in all samples at all sites. PFOA was the only PFAS compound above the detection limit in all samples from all sites. At Birkenes, elevated field blanks of PFOA were observed for the first half of 2016, but this have not affected the data from Birkenes significantly. Detection in more than 50% of the samples was also observed for PFDcA, PFNA, and PFHpA at two of the sites. PFHxS was detected with low frequency at all sites and the concentrations in detected samples were generally more than ten times lower than the concentrations of PFOA. These observations indicates low presence of PFHxS in Norwegian background air. The weekly concentrations of PFOA ranged from 0.02-0.54 pg/m^3 at the three stations. Homogeneous annual mean concentrations of PFOA were found at all sites; 0.11 pg/m^3 at Birkenes, 0.17 pg/m^3 at Andøya, and 0.11 pg/m^3 at Zeppelin.

As most of the PFASs are below detection limits it is not appropriate to compare the annual mean concentrations of sum PFAS in order to look for time-trends. Nor are the seasonal variations being captured when most of the PFAS compounds are below detection in a majority of the samples. For the compound with detection in all samples from all sites; i.e. PFOA, the annual mean concentrations in 2016 were the lowest observed since the start of the monitoring in 2006 and 2009 respectively (Figure 2.18). The highest concentrations of PFOA are observed in summertime at Andøya and Birkenes (Figure 2.19). In contrast, at Zeppelin the monthly variations fluctuate over the year.

Most of the PFAS compounds were below the detection limit in all samples at Andøya and Zeppelin in 2016 and as such the annual mean concentration reflects the analytical detection limit and is similar at both sites. The higher annual mean concentration observed at Birkenes is a result of more compounds being detected at this site and thereby contributing to the sum PFASs concentrations. Higher detection at Birkenes might indicate current use and ongoing emission from anthropogenic applications in populated areas. The lower annual and monthly mean concentrations for sum PFASs in 2015 and 2016 compared to previous years are results of improved analytical procedures and lowered limits of detection. The concentrations of most of the PFASs have consistently been below the analytical detection limit during all years of monitoring. The higher sum PFAS concentrations detected in the past reflects that the analytical detection limits at the time were higher. In calculations for annual and monthly mean concentrations, the concentrations below detection limits are assigned a value equal to LOD/2.

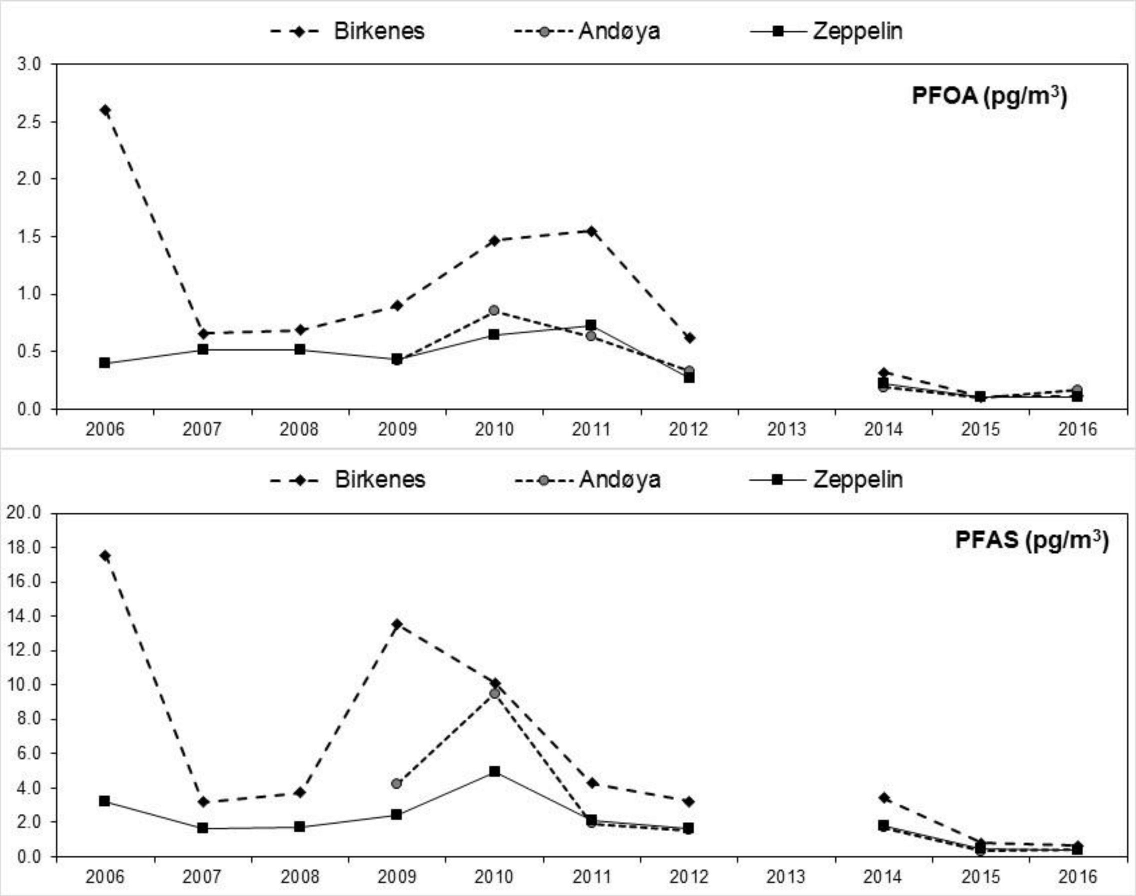

Figure 2.18: Annual mean concentrations of PFOA and sum PFAS (pg/m^3) in air.

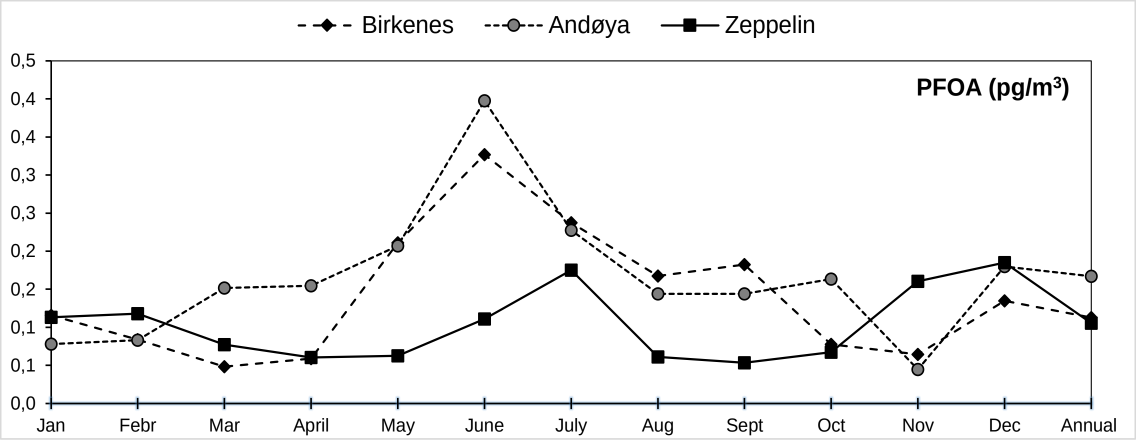

Figure 2.19: Monthly and annual mean concentrations (pg/m^3) of sum PFOA in air for 2016.

2.2 Persistent organic pollutants in precipitation

Precipitation samples for POPs were as previous years collected at Birkenes and analysed for HCB, α- and γ-HCH, and the seven indicator PCBs (PCB-7) (Annex 2, and Table A.2.6). HCB and HCHs have been monitored since 1992 while PCB-7 since 2006. Wet deposition can be an important mechanism for inputs of particle-associated and relatively polar POP compounds in Norway. While this is an established method for assessing the input of heavy metals, the measurements of POPs in precipitation are associated with more uncertainties such as re-volatilization and adsorption during sampling, and a potential for reversible atmospheric deposition, which hamper the ability to assess the input through precipitation measurements only.

HCB were below detection limit in 74% of the samples in 2016. Thus, the annual mean concentration reflects the detection limit. The annual mean concentrations of HCB in precipitation in 2016 were similar to those observed during the last eight years. Stable annual mean concentrations are a result of low detection. A significant reduction of HCB concentrations was observed during the 1990s and the beginning of 2000 while the concentrations seem to have reached a plateau during the last eight to eleven years (Figure 2.20). No seasonal variability was observed for HCB, mainly due to low detection (Figure 2.201).

The two HCH-isomers (α and γ) were detected in all samples in 2016. The annual mean concentration for sum HCHs was the lowest since the beginning of the monitoring (in 1992) and as in air they followed the decreasing time-trend at Birkenes. The seasonality was less distinct in 2016 than previous years, but the highest concentrations are still observed during spring- and summertime and the lowest concentrations during wintertime (December-February). This seasonality is similar to that found for air concentrations at Birkenes.

The PCB-congeners were detected in 30-60% of the precipitation samples depending on congener. The annual mean concentration of PCB-7 in 2016 was similar to that observed in 2015. No clear seasonality was observed.

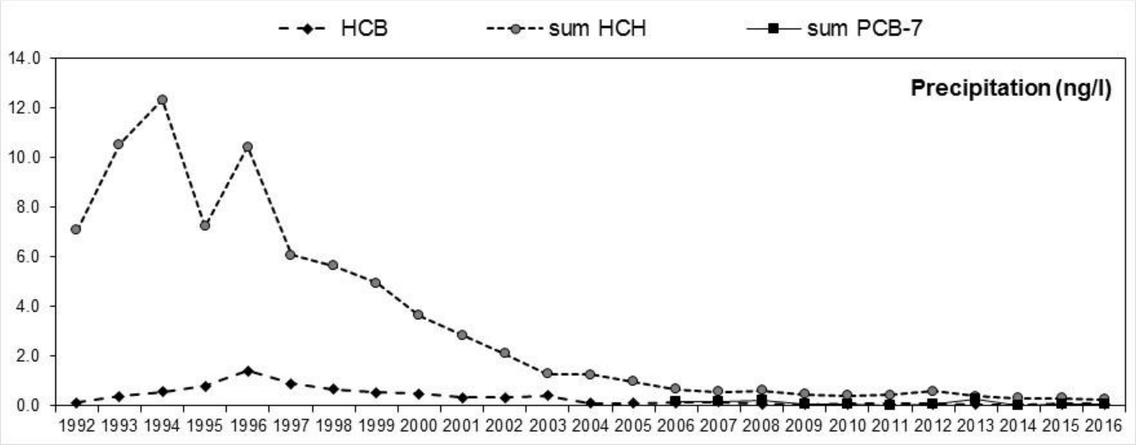

Figure 2.20: Annual mean concentrations of HCB, sum HCH and sum PCB-7 (ng/l) in precipitation.

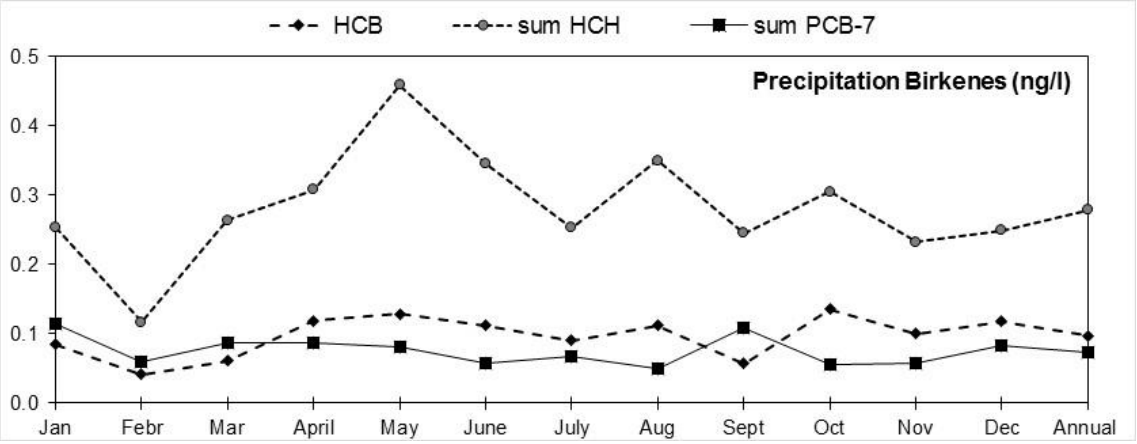

Figure 2.21: Monthly and annual mean concentrations (ng/l) of HCB, sum HCH and sum PCB-7 in precipitation at Birkenes, 2016.

3. Emerging contaminants

3.1 Cyclic volatile methyl siloxanes (cVMS)

Cyclic volatile methyl siloxanes (cVMS) represent a subgroup of a large class of compounds called dimethylsiloxanes. These compounds are produced in large volumes worldwide and are used in various applications, particularly in cosmetics and personal-care products where they are often referred to as cyclomethicones, although various other trade names exist (Wang et al., 2013). Currently, there are no regulations on the production and use of cVMS within industrial and consumer products. However, the cyclic oligomers octamethylcyclotetrasiloxane (D4), decamethylcyclopentasiloxane (D5), and dodecamethylcyclohexasiloxane (D6) have received increased attention from regulatory agencies and the scientific community regarding their environmental persistence (P), bioaccumulation (B), toxicity (T), and long range transport (LRT) potential (Brooke et al., 2009a; Brooke et al., 2009b; Brooke et al., 2009c; Canada, 2008a; Canada, 2008b). Due to concerns over the environmental risks cVMS may pose, proposals regarding restricting their use in wash-off personal care products (not to exceed 0.1%) were submitted within the EU on April 15, 2015. The ECHA Member State Committee (MSC) came to an agreement on April 22, 2015 that D4 and D5 meet the criteria for very bioaccumulative (vB) and persistent (vP) substances defined in the REACH Regulation (EC) No 1907/2006 (ECHA, 2015). The restriction is likely to be adopted by the end of 2017. In addition, on May 3, 2017, ECHA has recently started consultation on extending this proposed restriction to “leave-on” personal care products as well. D4 and D5 are also on Norway's priority substances list with the aim to stop emissions of these compounds by 2020 (Norwegian Environment Agency, 2015) and considered as chemicals of emerging Arctic concern by AMAP (AMAP, 2017).

Long-range atmospheric transport of cVMS to Arctic regions has been suggested by a few studies that have reported their presence in Arctic air (Genualdi et al., 2011; Krogseth et al., 2013), and the findings have been supported by mechanistic model simulations (Krogseth et al., 2013). However, it is also important to further study the possible influences of local sources and emissions of cVMS within the Arctic itself, mainly from increased anthropogenic activities in the area, in comparison to the influence of long-range atmospheric transport. Knowledge on local sources are of importance for all new contaminants that have not yet been regulated and are still in use while the influence of local sources is smaller for regulated POPs. For example, inadequate wastewater treatment or building materials can potentially serve as point sources for non-regulated contaminants to the Arctic region. The importance of local sources have been highlighted by findings of elevated levels of new contaminants including cVMS in various media near Arctic settlements. Despite being present in Arctic air, no direct evidence has been reported that D4, D5 and D6 can undergo atmospheric deposition. Multimedia model predictions, based on the physical chemical properties of D4, D5 and D6, suggests the three of them to have a minimal deposition potential. Properties responsible for this low deposition potential are their high volatility, short atmospheric half-lives, high K_{AW} values and relatively low K_{OA} values compared to legacy POPs (Wania, 2003; Xu and Wania, 2013). cVMS have nonetheless been detected in arctic biota at Svalbard (Warner et al. 2010). This is most likely a result of direct release of cVMS to aquatic systems in the region and not due atmospheric deposition of long-range transported cVMS. More research is needed to understand if the model predictions can be confirmed by measurements and further what is the exposure pathways for cVMS for the Arctic biota.

In 2016, like the previous years (2013-2015), measurements of cVMS were carried out in one summer campaign and one winter campaign. The summer campaign consisted of six samples and the winter campaign of seven samples. The sampling time for each sample was two to four days, in total each monitoring campaign covered a period of two to three weeks. All samples from both campaigns were above detection limits. The results for D5 and D6 from 2016 are compared to the previous results from air monitoring conducted in 2015, 2014, 2013 (Nizzetto et al. 2016; Nizzetto et al. 2015; Nizzetto et al., 2014) and 2011 (Krogseth et al., 2013) in figure 3.1. The reported concentrations have been corrected for sorbent related degradation during storage using methodology reported by Krogseth et al. (2013). While D5 and D6 has been shown to be degraded during storage and therefore can be storage corrected in a semi-quantitative way, the data for D4 is more uncertain as it has been shown to be both degraded and formed (through degradation of D5 and D6) during storage and the relative amount of the two processes are difficult to assess. The actual presence of D4 in the air at Zeppelin is therefore uncertain as it might be present in the samples only as a degradation product from D5. The degradation process is related to the adsorbent in the sampler (ENV+) and the source of the degradation is expected to be a result of an acid catalysed reaction with a substituted OH group located in the phenyl substructure of the ENV+ sorbent. This interaction causes the hydrogen to be acidic and facilitate breakdown of the siloxanes (as they are not stable under acidic conditions). As a result of the uncertainties due to degradation and an increased interest for air measurements of cVMS, efforts are currently undertaken to validate new adsorbents for cVMS.

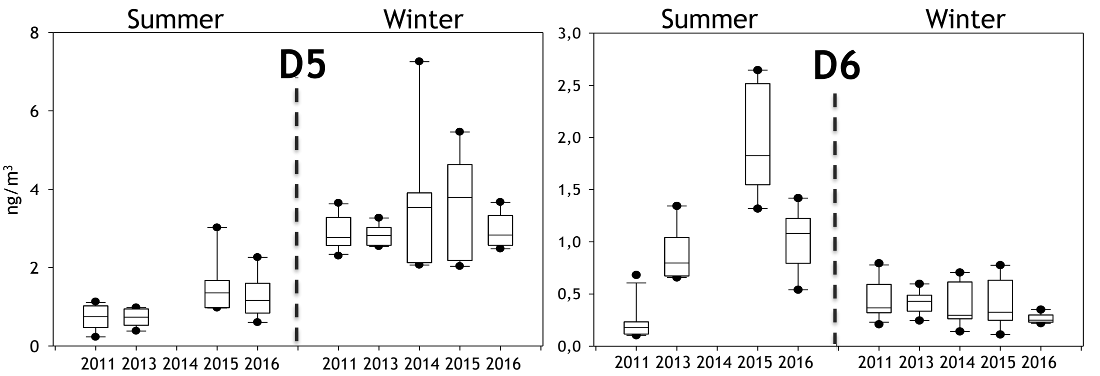

Figure 3.1: Measured concentrations (point estimates) of D5 and D6 at Zeppelin during 2011-2016. The box-plots represent a storage-corrected point-estimate with a 25-75% confidence interval of the storage correction, while the error bars and points represent 5-95 percentile and min/max, respectively.

The annual mean concentrations for 2016 based on the two sampling campaigns were 2.2 ± 1.0 ng/m^3 for D5 and 0.6 ± 0.4 ng/m^3 for D6. These are up to three orders of magnitude higher than the concentrations observed for legacy POPs at Zeppelin. The annual mean concentration as well as the summer and winter concentrations for D5 in 2016 are all similar to previous year. For D6, the summer concentrations in 2016 are lower than in 2015, but similar to 2013, while the winter concentrations are similar to previous year (Figure 3.1) (Nizzetto et al., 2014; Krogseth et al., 2013). The reason for higher concentrations in 2015 is unknown. The measured concentrations of D5 and D6 at Zeppelin are up to two orders of magnitude lower than those measured in urban regions (Genualdi et al., 2011; Buser et al., 2013). The concentrations of D6 at Zeppelin are similar to those measured using sorbent impregnated PUF passive air samplers (SIP-PAS) at two other Arctic sites included in the GAPS network: Alert, Canada and Storhofdi, Iceland (Genualdi et al., 2011). D5, however, seem to be higher at Zeppelin than those reported for Alert and Storhofdi, although comparability is hampered by different sampling and analytical methodologies. Higher concentrations of D5 at Zeppelin has to be confirmed and further studied.

Table 3.1: Air concentrations of D5 and D6 (ng/m3) from Zeppelin in summer and winter 2016. Concentrations reported represent average of two parallel samples. Data for D4 is reported as a range (lower-upper boundary), and concentrations of D4 are expected to be somewhere below this boundary.

Date		**Air concentrations (ng/m^3)**				
		D4	**D5**		**D6**	
Start	***End***	***Range (lower-upper boundary)***	***Point estimate***	***Range (low-high estimate)***	***Point estimate***	***Range (low-high estimate)***
18.07.2016	21.07.2016	n.d-0,96	2,25	1,24-4,10	1,17	0,52-2,61
21.07.2016	25.07.2016	n.d-0,69	1,30	0,76-2,21	1,15	0,56-2,34
25.07.2016	28.07.2016	n.d-0,64	1,01	0,64-1,61	0,89	0,48-1,65
28.07.2016	01.08.2016	n.d-1,06	1,38	0,93-2,05	1,42	0,84-2,41
01.08.2016	04.08.2016	n.d-0,61	0,92	0,67-1,27	1,01	0,66-1,57
04.08.2016	08.08.2016	n.d-0,56	0,60	0,46-0,77	0,55	0,39-0,77
25.11.2016	29.11.2016	n.d-2,13	3,33	2,46-4,52	0,24	0,16-0,36
29.11.2016	30.11.2016	n.d-1,87	3,26	2,47-4,32	0,25	0,17-0,36
30.11.2016	02.12.2016	n.d-1,91	3,67	2,87-4,70	0,25	0,18-0,35
02.12.2016	05.12.2016	n.d-1,66	2,83	2,34-3,43	0,30	0,23-0,39
05.12.2016	07.12.2016	n.d-1,88	2,48	2,14-2,87	0,22	0,18-0,27
07.12.2016	09.12.2016	n.d-1,97	2,57	2,35-2,81	0,35	0,31-0,40
09.12.2016	12.12.2016	n.d-1,94	2,67	2,44-2,72	0,23	0,21-0,24

Seasonality in atmospheric concentrations of cVMS can be investigated for 2011, 2013, 2015 and 2016 (Figure 3.1). In 2014, no measurement campaign of cVMS were conducted in summer time and no seasonality can therefore be studied for that year. The seasonality for the four years shows that significantly higher concentrations are observed for D5 during winter time (3.0 ± 0.5 ng/m^3) compared to the summertime (1.2 ± 0.6 ng/m^3) (Table 3.1). This is attributed to the lower atmospheric concentration of hydroxyl radicals during this time of year, resulting in lower photo-degradation of D5 (McLachlan et al., 2010). In contrast, the concentrations of D6 are higher in summertime (1.0 ± 0.3 ng/m^3) compared to in wintertime (0.3 ± 0.05 ng/m^3) in 2016 as well as in 2015 and 2013. These findings are contrary to observations in 2011 and to known emission profiles and atmospheric behaviour of D5 and D6. The reason for this is unclear. Warner et al. (2010) observed higher concentrations of D6 compared to D5 in fish collected near the community of Ny Ålesund located below the Zeppelin station. This suggests that a different emission profile for D5 and D6 may occur locally to the aquatic environment. However, the atmospheric measurements at Zeppelin, which is located above the boundary layer of Ny-Ålesund, should in theory not be impacted by such an aquatic source. These findings highlight the need for future monitoring campaigns to evaluate differences in annual seasonal patterns for D6 as well as to evaluate the influence of possible local sources on the air measurements.

This would also contribute to increased understanding of the atmospheric behaviour of D6 which is less well understood than that of D5.

The upper boundary limits for D4 in 2016 (1.4 ± 0.6 ng/m^3) were similar to those reported in 2013 (1.0 ± 0.3 ng/m^3) and 2011 (0.8 ± 0.4 ng/m^3), but lower than in 2014 and 2015. The data for D4 should be treated with caution as the measured concentrations of D4 might be influenced by effects during storage (degradation and creation) as mentioned above and shown by validation tests of the sampling methodology in Kierkegaard et al. (2013) and Krogseth et al. 2013. Thus no firm conclusions can be made regarding the presence of D4 in Arctic air nor any trends in concentration based on findings in this monitoring study.

3.2 Short and medium chained chlorinated paraffins (SCCP, MCCP)

Chlorinated paraffins (CPs), also referred to as polychlorinated n-alkanes, are semivolatile organic compounds (SVOCs) that have been used in large amounts for several decades in commercial products such as plasticizers, flame retardants, sealants and paints, and in industrial processes such as metalworking fluids and drilling (UNEP, 2010). Commercial mixtures of CPs are usually classified into three groups according to their carbon chain length; short chained CPs (SCCPs) with C10-C13, medium chain CPs (MCCPs) with C14-C17, and long chain CPs (LCCPs) with C18-C30. Some of the CPs have been found to be toxic, persistent in the environment, subject to long-range transport and bioaccumulative. Due to their harmful properties SCCPs are included in the Aarhus protocol on POPs under LRTAP (UN/ECE, 2010) and on Norway's priority list (Norwegian Environment Agency, 2015). In May 2017, the SCCPs were also included as POPs in the Stockholm Convention (Stockholm Convention, 2017). The global regulation is foreseen to enter into force in 2018. Information regarding levels and distribution of SCCPs in the environment still remain limited, mainly due to analytical challenges (Tomy et al., 1997). The atmosphere is usually considered to be the main transport medium for SCCP, but overall very few studies have been conducted to investigate the atmospheric levels and distribution of SCCPs.

SCCPs (C10-C13) and MCCPs (C14-C17) were included in the monitoring programme at Zeppelin in 2013. The monitoring data for M/SCCPs from 2013-2016 are the first measurements of M/SCCPs in Arctic air. Sampling has been done on a weekly basis in parallel with sampling of PCBs and OCPs (Annex 3). As in other published studies, the blank levels for the SCCPs and MCCPs are variable and high, resulting in relatively high LOD values (10-50% of detected masses). In 2016, the LODs were lower than in 2015. This is attributed to more stable and lower levels in both lab and field blanks which are results of efforts done at NILUs laboratory to improve the quality control. In 2016, ~35% of the measurements for MCCPs below LOD and 2% of the measurements for SCCPs below LOD. The presented data should be considered as semi-quantitative as the contribution of possible contamination during sampling and analyses have not yet been fully validated. Ongoing work at NILU aims to further improve the quality control in 2017-2020.

The annual mean concentrations for 2016 were 210 pg/m^3 for SCCPs and 70 pg/m^3 for MCCPs (Figure 3.2). These are lower than in 2015. A reason for lower annual mean concentrations are lower LODs in 2016 compared to 2015 (as mentioned above). The levels of SCCPs are higher than those of MCCPs in 90% of the samples. The levels of S/MCCPs are one to three orders of magnitude higher than the concentrations of most of the other studied POPs, but one order of magnitude lower than concentrations of sum PAHs and sum PAH-16. The annual mean concentrations of SCCPs does not show any significant difference between the three years monitored so far (Figure 3.2). The concentrations of SCCPs and MCCPs measured at Zeppelin in 2013-2016 in this study are similar to those observed in rural air in Canada, but almost three orders of magnitude lower than recent results from urban to rural sites in China and India (Wang et al., 2013, Chaemfa et al., 2014). The monthly mean concentrations in 2016 fluctuated from month to month and were influenced by individual high episodes (Figure 3.3).

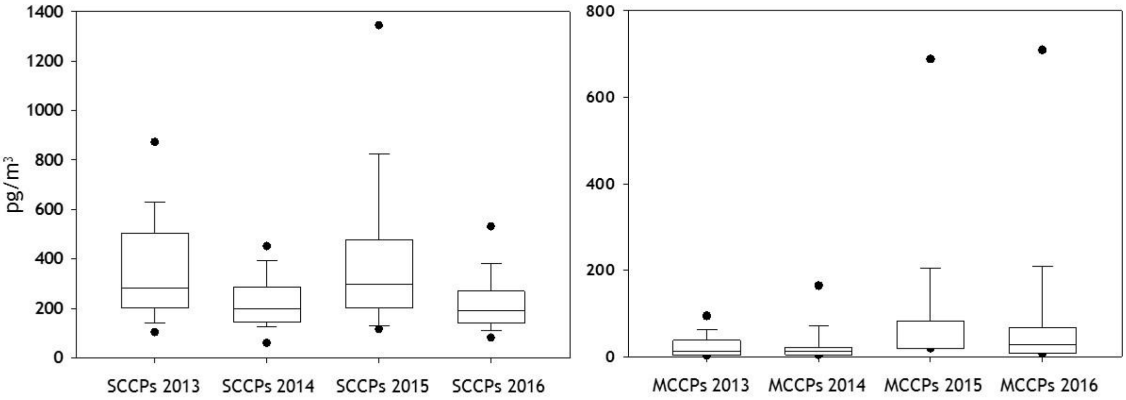

Figure 3.2: Measured concentrations of SCCPs and MCCPs at Zeppelin during 2013-2015. The box-plots represents a range from 25-75% confidence interval while the error bars and points represent 5-95 percentile and min/max, respectively.

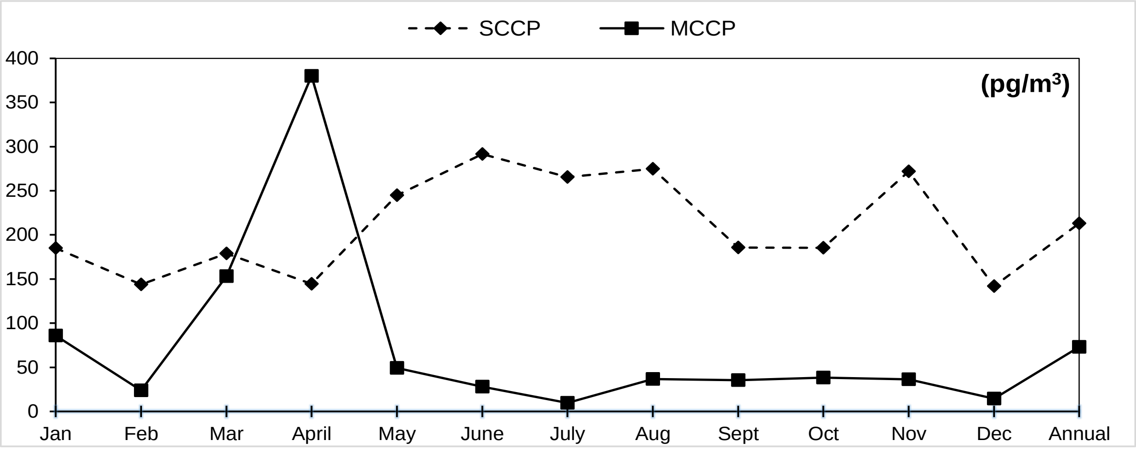

Figure 3.3: Monthly mean concentrations (pg/m^3) of short- and medium chained chlorinated paraffins (S/MCCP) in air at Zeppelin, 2016.

4. Conclusions for organic contaminants

The overall annual mean concentrations for the different organic pollutant classes and observatories in 2016 are presented in Table 4.1. In summary, the results from the air monitoring in 2016 show that the concentrations of most legacy POPs in air and precipitation are declining or have stabilized (reached steady-state conditions) during the last years. The exception are HCB, PCBs and PAHs. For HCB, an increase in concentrations has been observed at Zeppelin, Svalbard, during the last ten years, and at Birkenes during the last five years. The increasing trend for HCB flattened out in 2016 at Zeppelin, but in contrast seemed to further increase in 2016 at Birkenes. The reasons for these increases are not known, climate change with ice melting or continuous releases as bi-products have been suggested, but further research is needed to find out in detail. At Zeppelin, the combination of the PCB data from 2016 with previous years indicates an increase in concentrations during the last five years (factor of 1.5) while for PAHs the concentrations at Zeppelin are decreasing in 2015-2016 compared to 2013-2014. A small increase in concentrations of PCBs are also seen at Birkenes and Andøya, but whether this is real or within the annual variability of concentrations during steady-state has to be further investigated by future monitoring. The reason for higher concentrations of PCBs at Zeppelin is not known. Figure 4.1 shows that the total concentrations of legacy POPs (excluding PAHs) at Birkenes are higher in 2016 than 2011-2015. This is mainly attributed to increased HCB levels at this site. The total concentration of legacy POPs at Andøya and Zeppelin have been constant during the last six years with stable or fluctuating concentrations for the individual classes from year to year.

Table 4.1: Annual mean concentrations (pg/m^3) for all studied organic pollutants in air, 2016

pg/m^3	HCB	sum HCH	sum DDT	sum CHL	sum PCB_{32}	sum PCB_7	sum PBDE*	Sum PBDE $_{excl209}$	TBA	Sum HBCD*	sum PAH_{39}	sum PAH_{16}	sum PFAS	SCCP	MCCP	cVMS (D5)	cVMS (D6)
Birkenes	63	6.3	1.4	1.1	10.7	2.7	0.7	0.3	4.2	0.2	4500	2600	0.6				
Andøya	29	4.0	0.7		7.1	1.8	0.6	0.2	4.2				0.5				
Zeppelin	83	5.0	0.6	0.9	14.7	3.2	1.0	0.6	6.5	0.2	1800	900	0.3	210	70	2200	600

*More than 50% of the samples below detection limit.

The lower concentrations observed for D6 (cVMS) in 2016 compared to in 2015 contributed to a different pattern of organic contaminants at Zeppelin in 2016 than in previous years. D5 is still the predominant pollutant, but this year followed by sum PAHs, D6, SCCP, MCCPs and the legacy POPs (Table 4.1 and Figure 4.1). cVMS as a group is found at levels double to those of sum PAHs. HCB, PCBs, PBDEs, and TBA were found at highest level at Zeppelin, while DDTs, PAHs, γ-HCH and PFAS were found at highest levels at Birkenes. The other organic contaminant classes (i.e. α-HCH, CHLs and HBCDs) were homogeneously distributed at all observatories. The concentrations of the emerging contaminants cVMS and S/MCCPs were up to three orders of magnitude higher than the concentrations of the legacy POPs (Figure 4.2). The observation of high levels of emerging contaminants at Zeppelin at Svalbard, emphasizes the importance of continuous monitoring of these emerging POPs to follow their emission trends. The initiation of weekly monitoring of cVMS at Zeppelin in 2017 will provide more detailed data on the cVMS.

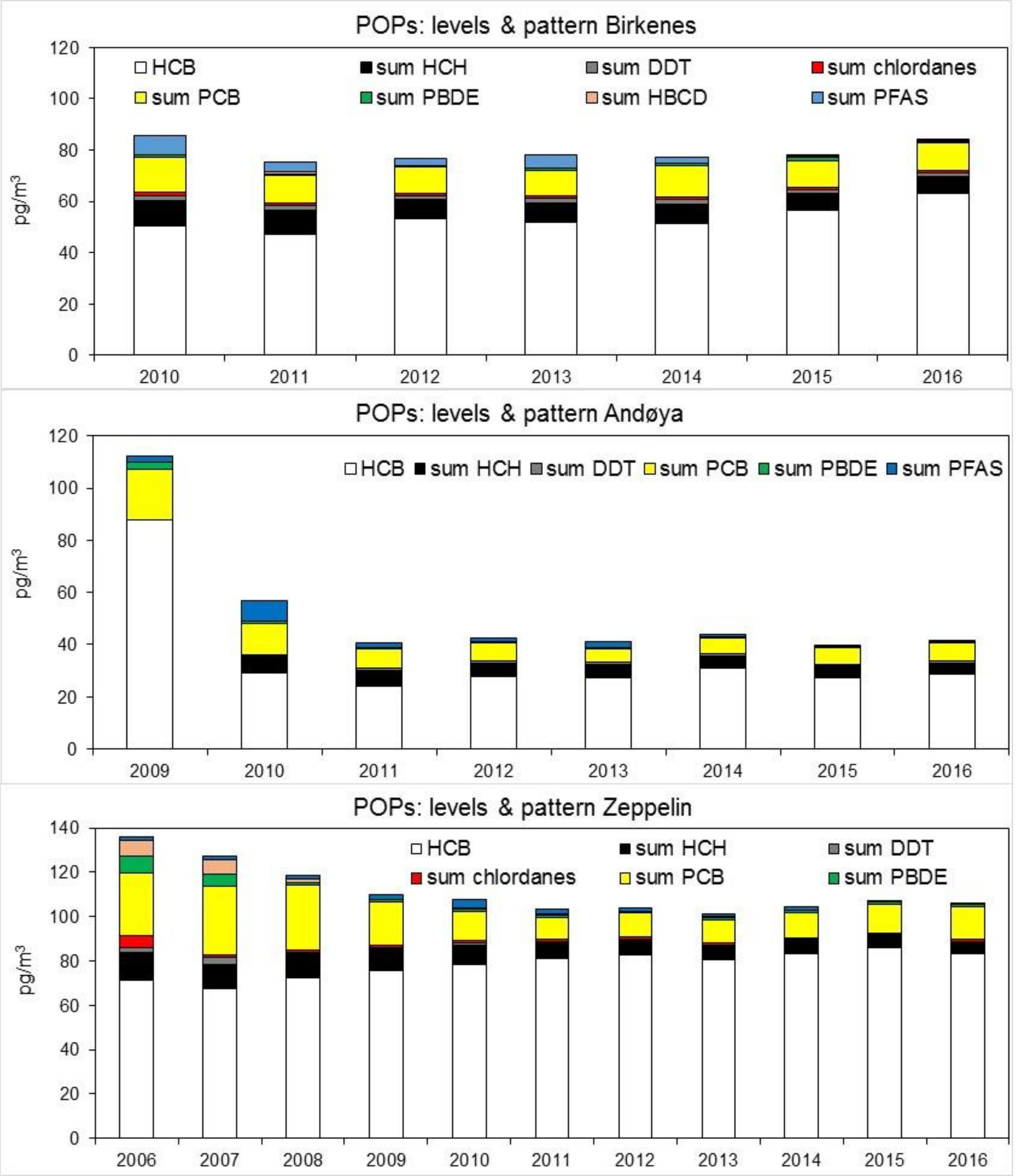

Figure 4.1: Annual mean concentrations of sum POPs (eight POP classes) with the contribution from individual POP classes.

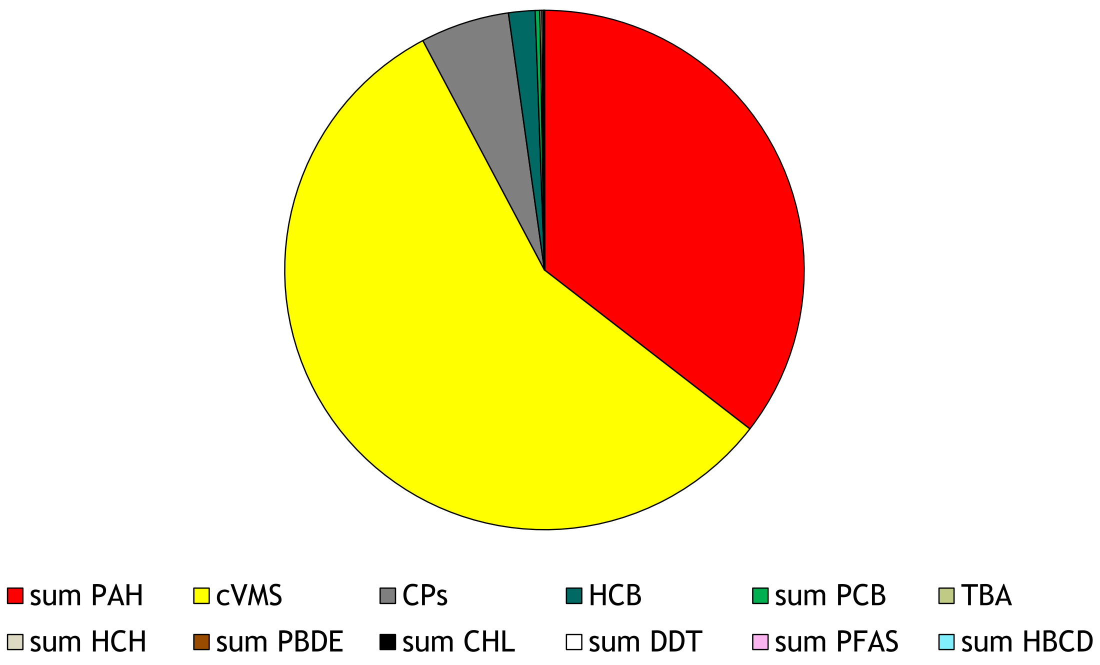

Figure 4.2: Comparison of annual mean concentrations in air for the non-regulated cVMS and S/MCCPs, and the more regulated POP classes monitored at Zeppelin.

5. Heavy metals

Heavy metals have been part of the Norwegian national monitoring programme since 1980. Measurements of lead, zinc and cadmium in weekly precipitation samples were initiated in February 1980 at Birkenes and Kårvatn, in October 1986 at Nordmoen/Hurdal, and in March 1987 at Svanvik. Measurements of heavy metals in air were included in the programme in 1991 at Lista, 1994 at Zeppelin, and 2010 at Andøya. There are also measurements of heavy metals in Finnmark as part of the air quality monitoring in the border areas of Norway and Russia (Berglen, 2017). In addition to Svanvik, this year's report also includes precipitation data from Karpdalen. Further, heavy metals have been analyzed in PM_{10} aerosol filters since autumn 2011 at both Svanvik and Karpdalen. For the first time, data from these air measurements are included in this report. Further presentation of these data are found in Berglen et al. (2017).

5.1 Heavy metals in precipitation

The data of annual mean concentrations in precipitation are weighted using the weekly concentrations and precipitation amounts to derive so called volume weighted concentrations (ng-µg/L). The volume weighted annual mean concentrations in precipitation for 2016 are presented in Table 5.1. The wet depositions are obtained by multiplying the volume weighted concentrations with the precipitation amounts (ng-mg/m^2) and the results for 2016 are presented in

Table 5.2. Calculated volume weighted monthly mean concentrations and wet depositions for all the elements are shown in Annex A.2.1-A.2.24.

The results show that the highest annual mean concentrations of all heavy metals are observed at Svanvik and Karpdalen. While the levels of lead, cadmium, zink, chromium and vanadium are up to three times higher at Svanvik and Karpdalen compared to Birkenes, Hurdal and Kårvatn, the levels of arsenic, copper, and cobalt are up to 60 times higher and the levels of nickel are up to 175 times higher. The high levels at Svanvik and Karpdalen are due to high emissions from the smelters in Nikel (Russia) close to the Norwegian border. Significantly higher levels of the heavy metals are observed at the Norwegian side of the border when there is easterly wind from Russia and the Kola Peninsula. Further details and discussion of these data can be found in the annual report for the programme "*Russian-Norwegian ambient air monitoring in the border areas*" (Berglen et al., 2017).

The levels and deposition of lead, cadmium and zinc observed at Hurdal and Birkenes are comparable while three to four times lower levels are observed at Kårvatn, which is also furthest away from the main emission sources in continental Europe.

Table 5.1: Volume weighted annual mean concentrations of heavy metals (µg/L) and mercury (ng/L) in precipitation in 2016.

Site	Pb	Cd	Zn	Ni	As	Cu	Co	Cr	Mn	V	Al	Hg
Birkenes	0.56	0.017	5.2	0.24	0.08	2.55	0.02	0.1	1.23	0.15	-	6.5
Hurdal	0.55	0.029	7.7	-	-	-	-	-	-	-	-	-
Kårvatn	0.19	0.004	2.2	-	-	-	-	-	-	-	-	-
Svanvik	1.04	0.062	5.2	26.49	1.29	29.45	0.83	0.26	-	0.34	24.0	-
Karpdalen	0.96	0.066	7.2	42.1	1.19	38.6	1.23	0.48	-	0.46	36.4	-

Table 5.2: Total wet deposition of heavy metals (mg/m^2) and mercury (ng/m^2) in 2016.

Site	Pb	Cd	Zn	Ni	As	Cu	Co	Cr	Mn	V	Al	Hg
Birkenes	765	24	7035	324	112	3479	23	133	1680	211	-	9197
Hurdal	460	25	6536	-	-	-	-	-	-	-	-	-
Kårvatn	298	7	3542	-	-	-	-	-	-	-	-	-
Svanvik	586	35	2922	14884	726	16547	464	145	-	191	13471	-
Karpdalen	599	41	4507	26235	741	24041	767	301	-	287	22694	-

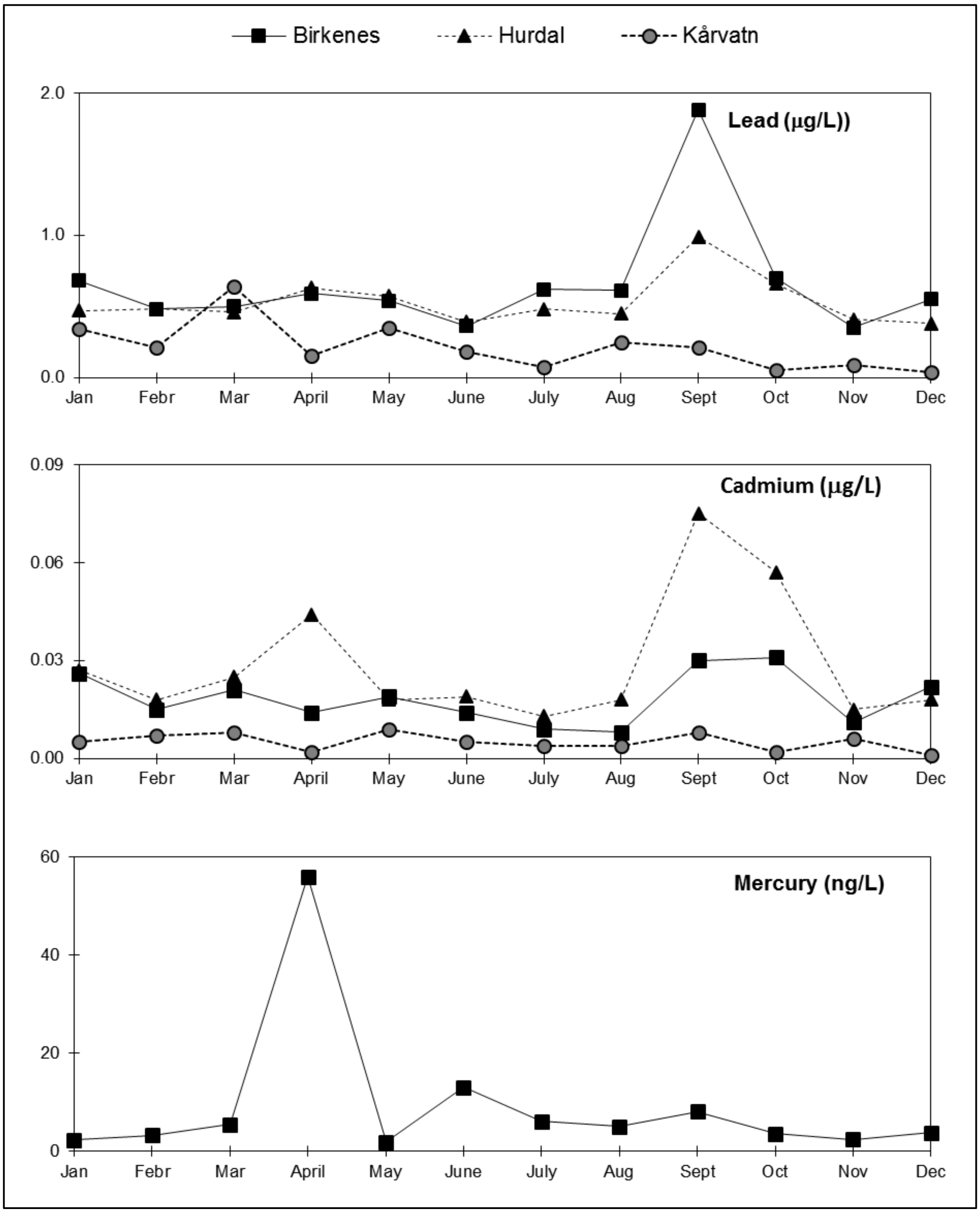

Figure 5.1: Volume weighted monthly mean concentrations of lead, cadmium and mercury in precipitation in 2016

The monthly mean concentration for lead, cadmium and mercury are shown in Figure 5.1. There is no clear seasonal variation, but elevated levels of lead and cadmium are seen in September at Birkenes and Hurdal, and in April for mercury at Birkenes. The reasons for these peaks are unclear.

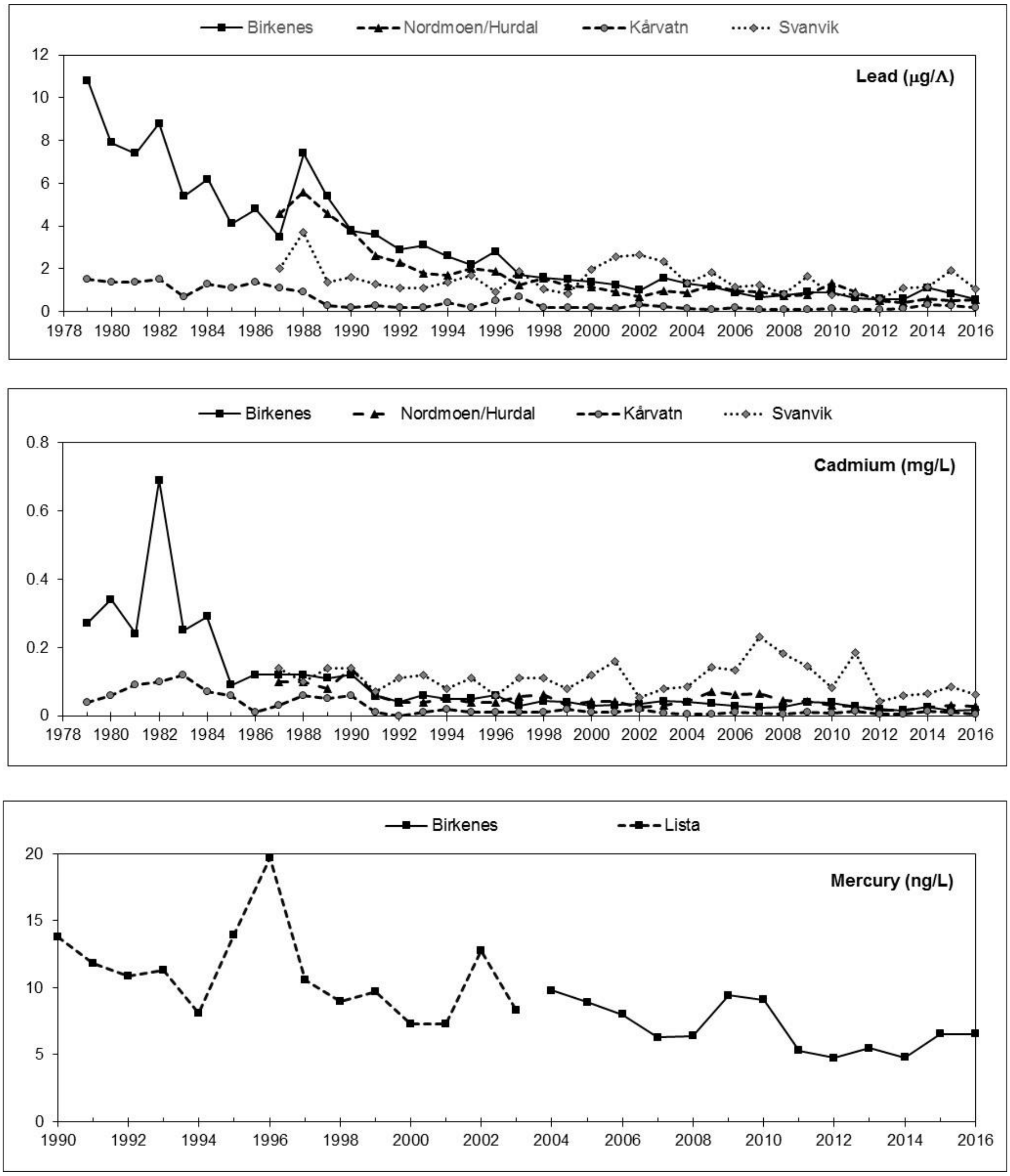

Figure 5.2: Time series of volume weighted annual mean concentrations of lead, cadmium and mercury in precipitation at Norwegian background stations.

Figure 5.2 and Table A.2 25 show volume weighted annual mean concentrations in precipitation from 1979 to 2016. In 2016, the concentrations of lead, chromium and vanadium in precipitation at Birkenes were noticeably lower than in 2015. In contrast, a small increase in concentrations was observed for nickel and cobber. For the other elements the levels were similar to previous years. At Hurdal, the lead concentration in 2016 was slightly higher than in 2015 while no difference for cadmium and zinc was found. At Kårvatn, a decrease in lead and cadmium was observed. At Svanvik, the levels for most heavy metals were lower in 2016 compared to 2015.

In a long term perspective, the concentrations of lead in precipitation at Birkenes and Kårvatn have been largely reduced; more than 90% between 1980 and 2016 and 52-94% since 1990 (Table 2.4). These reductions are consistent with those observed at other EMEP sites with long-term measurements and can be explained by large European emission reductions of lead during this period (Tørseth et al., 2012; Colette et al., 2016). In contrast, at Svanvik, no significant trend has been observed since 1990. This can be explained by influence from emission sources in the nearby area (e.g. Russian smelters). The levels of cadmium at Birkenes and Kårvatn have also been reduced with more than 90% since 1980, and between 42 and 73% since 1990. As for lead, this is also consistent with European emission reductions for cadmium (Tørseth et al., 2012; Colette et al., 2016). No significant reduction trends for cadmium have been observed at Svanvik.

The concentrations of zinc in precipitation have been reduced by 67% since 1980 and 36% since 1990 at Birkenes. In contrast, a significant increase of zinc has been observed in precipitation at Hurdal and Kårvatn during the last period (Table 3.4). There are quite large annual variations in zinc, with increasing levels at some sites for some years. This may be due to possible contamination of zinc during sampling or influence of local sources.

The trends for the concentrations are reflected in the trends for the wet deposition which gives similar results. There are no significant changes in precipitation amount so the trends in wet deposition is controlled by the trends in concentration.

When combining the datasets from Lista and Birkenes, mercury levels appear to have been significantly reduced (60%) since 1990. However, this reduction might be influenced (up or down) by different precipitation amounts and deposition rates at the two sites. The results from a trend analysis that combines the datasets is therefore somewhat uncertain. On the other hand, it is believed that Lista and Birkenes are influenced by similar air masses as the two observatories are situated at the south coast of Norway.

For the other elements, such as nickel, cobalt and copper, there has been an increase in concentrations at Svanvik since the monitoring started in 1987. There are large annual variations in the concentration levels, and this may be due to meteorological variations as well as changes in the composition of the ore used at the smelters in the Kola Peninsula. For further discussion, it is referred to the report by Berglen et al. (2017).

5.2 Heavy metals in air

The annual mean concentrations of the heavy metals measured in air in 2016 are given in Table 5.3, and the weekly concentrations of lead and cadmium are illustrated in Figure 5.3. The monthly mean concentrations can be found in Annex 1, tables A.1 26-31.

In general, the concentrations of most heavy metals in air at Birkenes in 2016 are two-three times higher than those observed at Andøya and Zeppelin. This is likely because Birkenes is closer to the emission sources at the European continent. In turn, at Svanvik and Karpdalen, the concentrations in air are about ten times higher than those observed at Birkenes. This suggest local sources, high emissions from the smelters in Nikel (Russia) close to the Norwegian border. For mercury, similar air concentrations are observed at all three sites in Norway. A more homogeneous picture for gaseous mercury may be due to a longer residence time in the atmosphere for gaseous mercury than the particulate bound heavy metals, which results in a larger potential for long-range transport from emissions sources. As a consequence, mercury may be distributed over greater geographical distances and is a global pollutant to a greater extent than the other heavy metals.

Table 5.3: Annual mean concentrations of heavy metals in air and aerosols in 2016, Unit: ng/m^3.

	Al	As	Cd	Cr	Co	Cu	Pb	Mn	Ni	V	Zn	Hg(g)
Birkenes II		0.14	0.022	1.05	0.014	0.41	0.56		0.16	0.26	3.3	1.42
Andøya		0.06	0.007	0.16	0.011	0.23	0.20	0.39	0.21	0.16	1.2	1.43
Zeppelin		0.04	0.006	0.14	0.007	0.18	0.14	0.46	0.11	0.05	1.4	1.48
Karpdalen	26.2	2.25	0.163	0.26	0.308	6.27	2.56		7.56	1.91	5.3	
Svanvik	32.3	1.86	0.134	0.29	0.312	6.26	2.47		7.68	1.77	5.3	

As in previous years, the annual mean concentrations at Andøya and Zeppelin in 2016 are comparable; some elements are higher at one of the sites while others are higher at the other site. These differences are due to individual episodes with high concentrations of heavy metals arriving to Zeppelin and Andøya, especially during the winter at Zeppelin in 2016, and these episodes are not coinciding at the two sites (Figure 5.3).

The episodes with high levels of cadmium and lead at Birkenes and Zeppelin at the individual sites are well correlated (Figure 5.3). This is not necessarily because they have similar emission sources, but because the polluted air is well mixed, and the episodes with high levels are happening when the meteorology favours long range transport from the emission sources at the continent. For example, the large episode observed at Zeppelin 21-23 March 2016 is related to air masses arriving from central part of Russia, while during the episode at Andøya 2-4 May 2016 the air masses are from central and Eastern Europe.

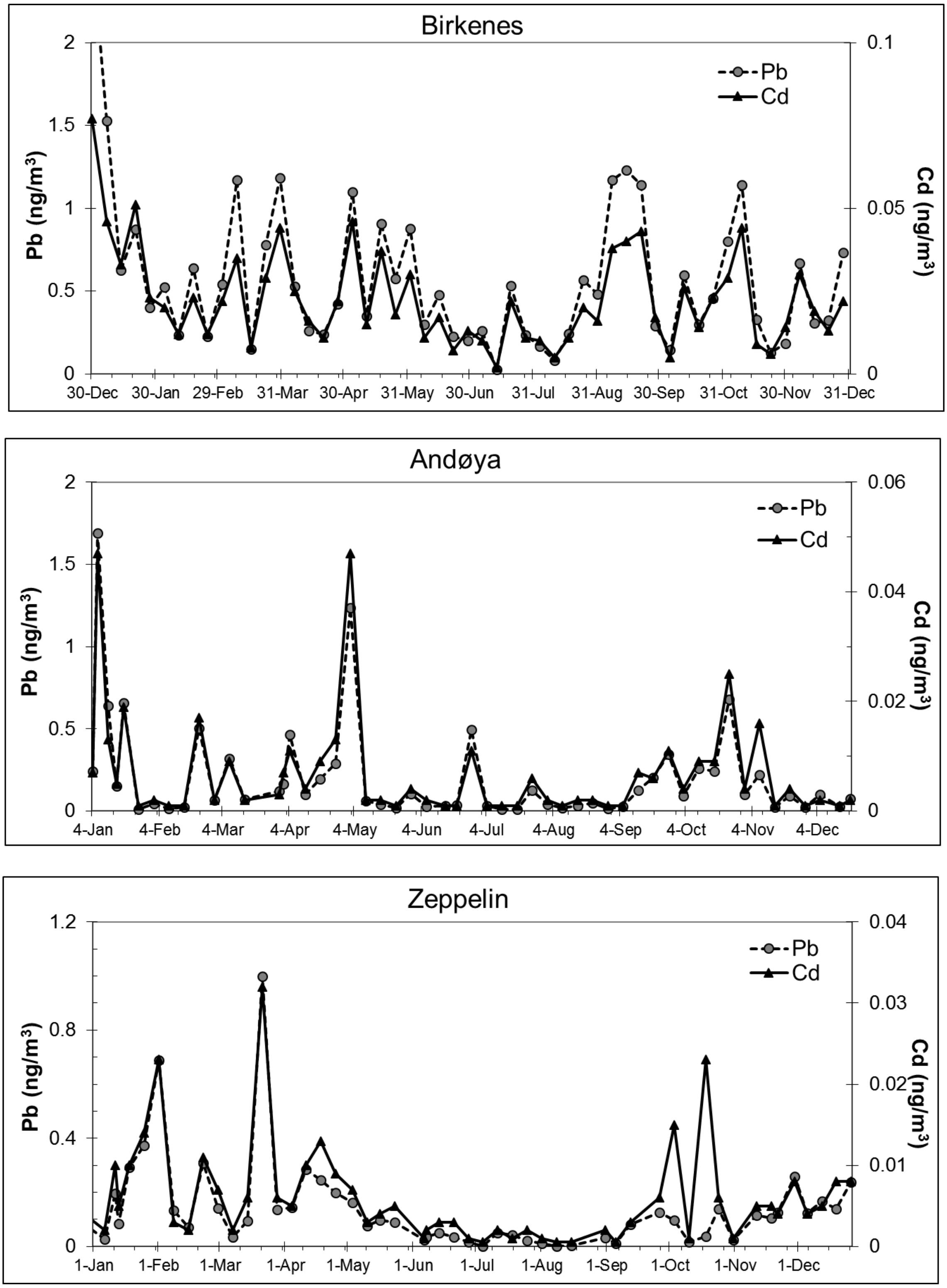

Figure 5.3: Weekly concentrations of lead and cadmium in air at Norwegian background stations in 2016, Unit: ng/m^3.

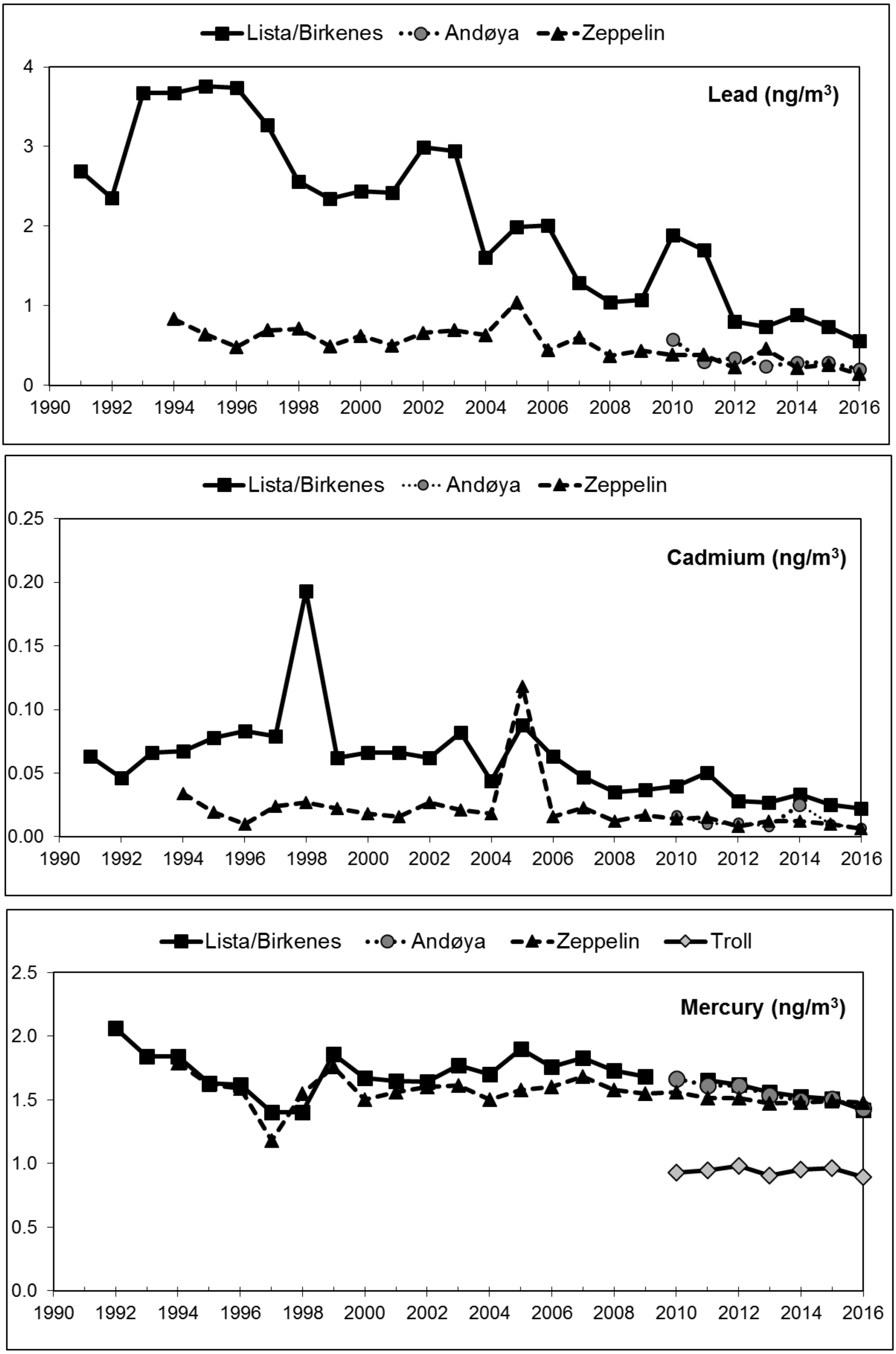

Figure 5.4: Time series of annual mean concentrations of lead, cadmium and mercury in air and aerosols, 1991-2016, Unit: ng/m^3.

The air concentrations for lead, cadmium and mercury in 2016 are somewhat lower at all three sites compared to previous years 2016. For all compounds the annual mean concentrations in 2016 are the lowest observed since the beginning of the monitoring.

The long-term time series of the annual mean concentrations of lead, cadmium and mercury are shown in Figure 5.4. The annual concentrations for all the elements for all years and sites can be found in Table A.2 27 - Table A.2 32.

At Lista/Birkenes there has been a significant reduction in air concentrations for almost all the elements (As, Cd, Co, Cr, Pb, Ni, Zn and V) for the period 1991 to 2016. At Zeppelin, there has also been a significant reduction since 1994 for several elements (As, Cd, Co, Cu, Pb, V). The reduction for lead has been 84% and 61% respectively at Birkenes and Zeppelin (Table 2.4). For cadmium, there were similar trends, 64% and 59% reductions respectively. For mercury, small decreasing trends are observed at Birkenes (16%) and Zeppelin (9%). A larger decreasing trend is observed in precipitation than in air for mercury at Lista/Birkenes. The trends are however not directly comparable since Hg(g) is a global pollutant with long atmospheric lifetime, and the wet deposition of mercury on the other hand is scavenging oxidized gaseous mercury and particulate mercury.

Table 5.4: Trends in annual mean concentrations of heavy metals in air and precipitation using Mann Kendall test and Sen slope estimates. Numbers in red indicate positive trends.

	Air		*Precipitation*			
	Birkenes	*Zeppelin*	*Birkenes*	*Hurdal*	*Kårvatn*	*Svanvik*
	1991-2015	*1994-2015*	*1990-2015*	*1990-2015*	*1990-2015*	*1990-2015*
Pb	*-84.3%*	*-61.8%*	*-94 %*	*-86 %*	*-52 %*	*not sign.*
Cd	*-64.2%*	*-59.1%*	*-73 %*	*-49 %*	*-42 %*	*not sign.*
Cu	*-33.1%*	*-40.6%*	-	-	-	*183.5%*
Zn	*-26.6%*	*not sign.*	*-36 %*	*86 %*	*116 %*	*not sign.*
Ni	*-63.2%*	*not sign.*	-	-	-	*146 %*
Hg	*-16.2%*	*-8.9%*	*-60 %*	-	-	-

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Annex 1

Monthly and annual concentrations of persistent organic pollutants in air and precipitation

Table A.1 1: Monthly and annual mean concentrations (pg/m^3) for organochlorine pesticides (OCPs) in air at Birkenes, 2016

Birkenes	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2016**
HCB	68.85	69.02	65.45	61.68	50.35	40.32	37.34	42.45	45.82	80.84	81.24	112.18	63.32
α-HCH	2.59	2.35	2.41	2.71	3.93	5.72	4.87	5.70	6.21	5.50	3.56	2.99	4.03
γ-HCH	1.23	0.99	1.16	1.53	2.78	4.64	3.86	4.25	3.78	1.44	0.94	1.32	2.32
sum HCHs	3.82	3.33	3.57	4.24	6.71	10.36	8.73	9.95	10.00	6.94	4.50	4.31	6.34
cis-CD	0.35	0.40	0.33	0.40	0.49	0.56	0.60	0.57	0.54	0.42	0.36	0.36	0.45
cis-NO	*0.02*	*0.02*	*0.01*	*0.03*	*0.04*	0.07	0.07	0.07	0.06	*0.04*	*0.04*	*0.04*	*0.04*
trans-CD	0.24	0.25	0.19	0.21	0.18	0.20	0.18	0.15	0.21	0.19	0.23	0.18	0.20
trans-NO	0.42	0.36	0.33	0.44	0.50	0.54	0.50	0.50	0.42	0.35	0.32	0.32	0.42
sum CHLs	1.03	1.03	0.86	1.09	1.21	1.37	1.35	1.29	1.23	0.99	0.95	0.90	1.11
p,p-DDT	0.20	*0.09*	*0.11*	0.13	0.24	0.38	0.37	0.33	0.32	0.17	0.13	*0.12*	0.22
o,p-DDT	0.13	0.10	0.11	0.13	0.21	0.36	0.28	0.30	0.31	0.22	0.13	0.13	0.20
p,p-DDE	1.14	0.93	0.78	0.63	0.73	0.87	0.71	0.80	0.99	1.16	0.86	0.93	0.88
o,p-DDE	0.09	0.08	0.07	*0.05*	*0.05*	0.07	*0.05*	*0.05*	*0.05*	0.07	0.07	0.07	0.06
p,p-DDD	*0.02*	*0.02*	*0.01*	*0.02*	*0.02*	*0.02*	*0.02*	*0.02*	*0.02*	*0.02*	*0.01*	*0.02*	*0.02*
o,p-DDD	*0.02*	*0.02*	*0.01*	*0.02*	*0.02*	*0.03*	*0.03*	*0.03*	*0.03*	*0.02*	*0.02*	*0.03*	*0.02*
sum DDTs	1.62	1.24	1.09	0.97	1.26	1.73	1.46	1.52	1.71	1.66	1.21	1.30	1.40

Table A.1 2: Monthly and annual mean concentrations (pg/m^3) for PCBs in air at Birkenes, 2016

Birkenes	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2016
PCB-18	1.242	1.096	1.033	0.910	1.026	1.540	0.787	1.091	0.848	1.036	0.960	0.859	1.026
PCB-28	0.697	0.610	0.579	0.533	0.705	1.390	0.672	0.787	0.685	0.795	0.673	0.823	0.740
PCB-31	0.648	0.565	0.545	0.501	0.659	1.243	0.619	0.706	0.610	0.630	0.542	0.708	0.660
PCB-33	0.396	0.330	0.318	0.278	0.362	0.662	0.340	0.351	0.335	0.328	0.260	0.391	0.361
PCB-37	0.073	0.051	0.050	0.042	0.063	0.110	0.065	0.072	0.062	0.041	0.031	0.076	0.062
PCB-47	0.422	0.372	0.454	0.503	0.821	1.541	1.146	1.157	1.375	0.551	0.292	0.777	0.786
PCB-52	0.693	0.631	0.605	0.603	0.787	1.489	0.898	0.988	0.905	0.638	0.533	1.009	0.810
PCB-66	0.175	0.143	0.142	0.136	0.210	0.390	0.234	0.258	0.210	0.134	0.101	0.215	0.195
PCB-74	0.111	0.093	0.091	0.090	0.136	0.279	0.148	0.163	0.172	0.120	0.094	0.178	0.139
PCB-99	0.161	0.145	0.124	0.130	0.176	0.302	0.191	0.256	0.138	0.101	0.080	0.224	0.164
PCB-101	0.390	0.340	0.327	0.347	0.509	1.032	0.616	0.665	0.533	0.297	0.240	0.628	0.491
PCB-105	0.033	0.023	0.022	0.022	0.035	0.065	0.042	0.043	0.032	0.022	0.014	0.047	0.033
PCB-114	0.004	0.004	0.003	0.003	0.005	0.009	0.006	0.006	0.006	0.004	0.002	0.006	0.005
PCB-118	0.111	0.084	0.080	0.081	0.124	0.240	0.152	0.161	0.117	0.078	0.053	0.166	0.120
PCB-122	<0.002	<0.002	<0.002	<0.002	<0.002	0.006	*0.003*	*0.002*	0.005	*0.003*	<0.002	0.006	*0.003*
PCB-123	0.003	*0.003*	*0.002*	*0.003*	0.003	0.004	0.003	0.003	<0.002	*0.002*	<0.002	*0.004*	0.003
PCB-128	0.021	0.014	0.014	0.015	0.024	0.043	0.030	0.031	0.020	0.011	0.008	0.029	0.022
PCB-138	0.127	0.099	0.099	0.105	0.171	0.382	0.217	0.231	0.188	0.079	0.063	0.214	0.164
PCB-141	0.032	0.025	0.027	0.030	0.053	0.123	0.068	0.073	0.056	0.021	0.018	0.063	0.049
PCB-149	0.222	0.201	0.197	0.215	0.345	0.735	0.435	0.470	0.393	0.153	0.129	0.372	0.321
PCB-153	0.211	0.176	0.170	0.181	0.285	0.612	0.362	0.384	0.390	0.159	0.128	0.395	0.286
PCB-156	0.009	0.005	0.006	0.006	0.008	0.016	0.009	0.010	0.009	0.005	0.003	0.010	0.008
PCB-157	0.002	0.002	<0.001	*0.002*	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.003	0.002
PCB-167	0.005	0.003	0.003	0.003	0.005	0.009	0.006	0.006	0.004	0.002	0.002	0.006	0.005
PCB-170	0.018	0.010	0.011	0.011	0.019	0.037	0.021	0.021	0.017	0.008	0.006	0.022	0.017

Table A.1 2, cont.

Birkenes	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2016**
PCB-180	0.048	0.032	0.033	0.035	0.061	0.123	0.071	0.075	0.053	0.020	0.025	0.055	0.052
PCB-183	0.015	0.013	0.013	0.014	0.023	0.054	0.030	0.032	0.023	0.007	0.008	0.021	0.021
PCB-187	0.050	0.045	0.041	0.044	0.074	0.145	0.087	0.093	0.066	0.020	0.021	0.074	0.063
PCB-189	*0.002*	<0.002	<0.002	<0.002	<0.002	*0.002*	<0.002	<0.002	*0.002*	<0.002	<0.002	<0.002	*0.002*
PCB-194	0.007	0.004	0.004	0.003	0.005	0.007	0.004	0.004	0.004	0.003	0.003	0.005	0.004
PCB-206	0.004	*0.003*	*0.002*	<0.002	<0.002	0.003	<0.002	<0.002	0.003	*0.002*	*0.002*	0.004	*0.003*
PCB-209	0.005	0.004	0.002	0.002	0.002	0.003	0.002	0.002	0.002	0.002	0.003	0.004	0.003
sum-trichlor	4.55	3.93	3.70	3.29	4.07	6.88	3.45	4.31	3.54	3.82	3.35	3.93	4.039
sum-tetrachlor	2.95	2.60	2.63	2.64	3.88	6.94	4.33	4.72	4.39	2.70	2.00	3.96	3.631
sum-pentachlor	1.14	0.96	0.91	0.97	1.47	2.96	1.73	1.78	1.44	0.81	0.61	1.82	1.373
sum-hexachlor	1.01	0.85	0.83	0.91	1.49	3.06	1.83	1.98	1.52	0.57	0.46	1.64	1.339
sum-heptachlor	0.19	0.14	0.14	0.15	0.27	0.55	0.32	0.34	0.23	0.07	0.08	0.23	0.224
sum PCB_7	2.28	1.97	1.89	1.89	2.64	5.27	2.99	3.29	2.87	2.07	1.72	3.29	2.66
sum PCB	9.85	8.49	8.22	7.98	11.18	20.41	11.66	13.13	11.12	7.97	6.50	11.95	10.65

Table A.1 3: Monthly and annual mean concentrations (pg/m^3) for PBDEs and TBA in air at Birkenes, 2016

Birkenes	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2016**
BDE-28	*0.006*	*0.006*	<0.006	<0.006	<0.006	<0.006	0.007	0.012	0.010	0.008	0.009	0.011	0.008
BDE-47	*0.075*	<0.073	<0.074	<0.074	<0.074	<0.075	<0.075	*0.080*	<0.074	<0.074	*0.101*	*0.076*	*0.077*
BDE-49	*0.007*	<0.006	<0.006	<0.006	<0.006	*0.007*	0.007	0.012	0.011	0.008	0.011	0.014	0.008
BDE-66	<0.021	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	<0.022	*0.022*
BDE-71	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	0.002	0.002	0.002	*0.002*	0.002	*0.002*
BDE-77	*0.001*	*0.001*	<0.001	<0.001	<0.001	<0.001	0.001	0.001	0.001	0.001	*0.001*	0.003	*0.001*
BDE-85	*0.002*	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	*0.002*	0.002	*0.006*	*0.003*	*0.002*
BDE-99	0.023	0.023	*0.018*	<0.016	<0.016	<0.016	*0.019*	0.025	0.023	0.036	0.135	0.042	0.032
BDE-100	*0.008*	<0.007	*0.008*	<0.008	<0.008	<0.008	*0.008*	0.008	0.008	0.009	*0.029*	0.009	*0.009*
BDE-119	*0.002*	<0.002	<0.002	<0.002	<0.002	<0.002	*0.002*	*0.002*	*0.002*	*0.002*	<0.002	0.003	*0.002*
BDE-138	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.005	<0.004	*0.011*	*0.005*
BDE-153	*0.005*	*0.008*	<0.004	<0.004	<0.004	<0.004	0.005	0.005	<0.004	0.010	0.018	0.019	*0.008*
BDE-154	0.004	0.005	0.004	*0.003*	*0.003*	<0.003	0.004	0.004	0.005	0.007	0.014	0.022	0.007
BDE-183	0.010	*0.010*	*0.006*	0.008	0.008	<0.003	0.014	0.010	0.016	0.022	0.015	0.084	0.018
BDE-196	*0.019*	<0.019	<0.019	<0.019	*0.022*	<0.019	<0.019	*0.020*	0.021	<0.019	<0.019	*0.025*	*0.020*
BDE-206	*0.052*	<0.052	<0.053	<0.053	<0.053	<0.053	0.055	0.062	0.060	0.050	*0.057*	0.128	*0.062*
BDE-209	*0.38*	<0.38	<0.38	0.62	<0.38	<0.39	<0.39	*0.40*	<0.38	0.29	<0.38	0.62	*0.42*
sum BDE	0.62	0.63	0.61	0.84	0.62	0.61	0.63	0.67	0.64	0.56	0.82	1.09	0.71
sum BDE$_{\text{excl 209}}$	0.24	0.24	0.23	0.23	0.23	0.23	0.25	0.27	0.26	0.28	0.44	0.47	0.28
TBA	4.29	3.34	3.92	4.05	2.79	4.04	3.46	3.77	4.81	5.67	6.39	4.33	4.22

Table A.1 4: Monthly and annual mean concentrations (pg/m^3) for HBCDs in air at Birkenes, 2016

Birkenes	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2016**
α-HBCD	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.08	<0.08	<0.07	<0.07	<0.07	<0.07	<0.07
ß-HBCD	*0.07*	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07
γ-HBCD	*0.05*	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
sum HBCD	*0.20*	*0.19*	*0.19*	*0.20*	*0.20*	*0.20*	*0.20*	*0.20*	*0.20*	*0.19*	*0.19*	*0.19*	*0.19*

Table A.1 5: 2015 Monthly and annual mean concentrations (ng/m^3) for PAHs in air at Birkenes, 2016

Birkenes	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2016**
1-Methylnaphthalene	0.293	0.094	0.111	0.069	0.031	0.021	0.029	0.029	0.020	0.110	0.083	0.147	0.086
1-Methylphenanthrene	0.081	0.067	0.073	0.075	0.030	0.021	0.035	0.037	0.051	0.050	0.038	0.116	0.055
2-Methylanthracene	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.002	<0.003	<0.008	<0.002	<0.009	<0.005	<0.004
2-Methylnaphthalene	0.383	0.121	0.149	0.107	0.050	0.033	0.041	0.043	0.028	0.146	0.111	0.227	0.119
2-Methylphenanthrene	0.104	0.085	0.111	0.090	0.053	0.031	0.047	0.038	0.092	0.088	0.089	0.100	0.076
3-Methylphenanthrene	0.082	0.075	0.089	0.072	0.046	0.028	0.043	0.032	0.081	0.070	0.102	0.086	0.066
9-Methylphenanthrene	0.029	0.031	0.028	0.028	0.018	0.013	0.016	0.014	0.029	0.029	0.042	0.035	0.026
Acenaphthene	0.203	0.159	0.128	0.141	0.137	0.093	0.190	0.112	0.108	0.082	0.229	0.174	0.146
Acenaphthylene	0.045	0.056	0.065	0.026	*0.007*	*0.004*	*0.006*	0.007	0.004	0.017	0.027	0.068	0.028
Anthanthrene	0.004	0.005	0.003	*0.002*	<0.001	<0.001	*0.002*	<0.002	0.002	*0.002*	0.006	0.004	*0.003*
Anthracene	0.018	0.033	0.025	0.018	0.006	0.007	0.008	0.014	0.007	0.015	0.057	0.038	0.021
Benz(a)anthracene	0.023	0.018	0.010	0.007	0.002	0.002	0.004	0.003	0.006	0.010	0.014	0.018	0.010
Benzo(a)fluoranthene	0.006	0.005	0.002	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	0.002	0.004	0.003
Benzo(a)fluorene	0.015	0.018	0.010	0.008	0.002	0.003	0.005	0.004	0.006	0.007	0.012	0.016	0.009
Benzo(a)pyrene	0.028	0.017	0.010	0.009	0.004	0.004	0.008	0.004	0.004	0.012	0.007	0.016	0.010
Benzo(b)fluoranthene	0.068	0.071	0.049	0.029	0.013	0.033	0.122	0.033	0.043	0.026	0.047	0.056	0.045
Benzo(b)fluorene	0.008	0.010	0.004	0.004	0.001	0.001	0.003	0.002	0.004	0.003	0.015	0.008	0.005
Benzo(e)pyrene	0.043	0.046	0.045	0.024	0.012	0.019	0.047	0.021	0.034	0.017	0.062	0.048	0.034
Benzo(ghi)fluoranthene	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.137	NaN	0.137
Benzo(ghi)perylene	0.053	0.044	0.032	0.021	0.009	0.016	0.045	0.016	0.022	0.023	0.032	0.044	0.029
Benzo(k)fluoranthene	0.026	0.023	0.012	0.008	0.003	0.007	0.016	0.007	0.009	0.011	0.021	0.018	0.013
Biphenyl	0.934	0.316	0.446	0.188	0.068	0.043	0.038	0.058	0.051	0.465	0.804	0.334	0.310
Chrysene	0.072	0.072	0.073	0.045	0.019	0.026	0.042	0.023	0.052	0.029	0.041	0.099	0.049
Coronene	0.022	0.017	0.011	0.008	0.003	0.005	0.020	0.005	0.007	0.011	0.012	0.025	0.012
Cyclopenta(cd)pyrene	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.097	<0.001	*0.025*

Table A.1 5. cont.

Birkenes	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2016**
Dibenzo(ae)pyrene	0.010	0.010	*0.009*	*0.005*	0.003	0.004	0.011	*0.006*	0.005	0.004	0.005	0.014	0.007
Dibenzo(ah)anthracene	0.006	0.007	0.007	0.005	0.002	*0.002*	0.005	0.002	0.005	0.004	0.003	0.011	0.005
Dibenzo(ah)pyrene	<0.012	<0.011	<0.010	<0.004	<0.003	<0.003	<0.007	<0.008	<0.008	<0.005	*0.005*	<0.014	*0.008*
Dibenzo(ai)pyrene	<0.011	<0.001	<0.001	<0.004	<0.003	<0.003	<0.006	<0.007	<0.007	<0.004	*0.005*	<0.013	*0.007*
Dibenzofuran	2.424	1.118	1.374	0.821	0.395	0.275	0.225	0.317	0.367	1.579	0.645	1.005	0.878
Dibenzothiophene	0.023	0.021	0.056	0.041	0.027	0.022	0.022	0.006	0.013	0.011	0.026	0.032	0.026
Fluoranthene	0.448	0.277	0.246	0.174	0.113	0.088	0.130	0.090	0.183	0.290	0.192	0.252	0.204
Fluorene	1.632	0.748	0.813	0.515	0.361	0.295	0.317	0.336	0.377	1.266	0.512	0.664	0.650
Inden(123-cd)pyrene	0.055	0.044	0.026	0.017	0.007	0.014	0.026	0.013	0.017	0.022	0.018	0.044	0.024
Naphthalene	1.057	0.281	0.160	0.136	<0.062	<0.062	*0.063*	<0.062	<0.062	0.371	0.297	0.419	0.247
Perylene	0.005	0.004	0.002	0.002	<0.001	<0.001	0.002	<0.001	0.001	0.002	0.002	0.003	0.002
Phenanthrene	1.730	1.089	1.164	0.857	0.821	0.586	0.800	0.601	1.406	1.477	0.932	1.398	1.052
Pyrene	0.175	0.156	0.121	0.099	0.044	0.047	0.077	0.047	0.070	0.076	0.098	0.117	0.094
Retene	0.056	0.041	0.060	0.093	0.021	0.025	0.078	0.080	0.060	0.063	0.045	0.065	0.057
Sum PAH	10.02	5.03	5.40	3.67	2.35	1.77	2.36	2.02	3.14	6.33	4.77	5.55	4.47
Sum PAH$_{16}$	5.64	3.10	2.94	2.11	1.61	1.29	1.86	1.37	2.37	3.73	2.53	3.43	2.63

Table A.1 6: Monthly and annual mean concentrations (pg/m^3) for PFAS in air at Birkenes, 2016

Birkenes	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2016**
6:2 FTS	<0.346	<0.346	<0.346	<0.346	<0.346	<0.346	<0.346	<0.346	<0.346	<0.346	<0.346	<0.346	<0.346
PFBS	<0.017	*0.023*	*0.019*	<0.017	<0.017	*0.024*	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	*0.018*
PFDcA	*0.015*	*0.023*	0.037	0.032	0.057	0.055	0.033	0.032	0.043	0.012	<0.009	<0.009	0.030
PFDcS	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.039	<0.035	<0.035	<0.035	<0.035	<0.035
PFHpA	*0.032*	0.037	<0.026	0.045	0.051	*0.045*	0.107	0.045	<0.026	<0.026	<0.026	<0.026	*0.041*
PFHxA	*0.540*	*0.230*	*0.550*	*0.660*	0.07	0.04	0.130	<0.04	*0.035*	0.040	0.093	0.067	0.058
PFHxS	<0.017	<0.018	<0.014	<0.014	*0.016*	0.035	*0.024*	<0.014	0.027	<0.014	*0.014*	*0.016*	*0.018*
PFNA	0.018	0.027	0.044	0.024	0.080	0.057	0.065	0.036	0.047	0.018	0.023	0.036	0.039
PFOA	0.120	0.080	0.050	0.060	0.210	0.330	0.240	0.170	0.180	0.080	0.070	0.140	0.110
PFOS	<0.017	*0.019*	*0.071*	0.048	0.034	*0.037*	*0.023*	<0.017	*0.042*	<0.017	<0.017	<0.017	*0.029*
PFOSA	<0.017	<0.017	<0.017	*0.019*	<0.017	*0.043*	*0.033*	<0.017	<0.017	*0.022*	<0.017	<0.017	*0.021*
PFUnA	<0.009	<0.009	<0.009	<0.009	0.014	*0.011*	*0.021*	*0.010*	<0.009	<0.009	<0.009	<0.009	*0.011*
sum PFAS	*0.523*	*0.554*	*0.618*	*0.587*	0.668	0.687	0.703	*0.573*	*0.826*	*0.634*	*0.670*	*0.730*	*0.627*

Table A.1 7: Monthly and annual mean concentrations (ng/l) for HCB, HCHs and PCBs in precipitation at Birkenes, 2016

ng/l	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2016**
HCB	<0.11	<0.06	<0.08	0.21	0.25	0.17	*0.21*	*0.14*	<0.21	*0.08*	*0.10*	<0.15	*0.13*
α-HCH	0.08	0.04	0.06	0.12	0.13	0.11	0.09	0.11	0.06	0.13	0.10	0.12	0.10
γ-HCH	0.17	0.07	0.20	0.19	0.33	0.23	0.16	0.24	0.19	0.17	0.13	0.13	0.18
sum HCH	0.25	0.12	0.26	0.31	0.46	0.35	0.25	0.35	0.25	0.31	0.23	0.25	0.28
PCB-28	0.012	0.005	0.007	0.012	0.008	*0.005*	*0.008*	*0.004*	<0.009	0.004	0.005	<0.006	0.007
PCB-52	0.014	0.007	0.009	0.012	0.009	*0.006*	*0.007*	*0.005*	<0.011	0.005	0.007	<0.008	0.008
PCB-101	0.021	0.013	0.014	*0.018*	0.018	*0.013*	<0.014	<0.012	<0.026	0.012	0.013	<0.018	0.015
PCB-118	0.013	0.005	0.008	0.009	0.011	0.008	0.010	<0.005	*0.012*	0.007	0.005	<0.008	0.008
PCB-138	0.019	0.009	0.017	0.013	0.012	0.009	0.009	0.007	<0.015	0.009	0.009	0.013	0.011
PCB-153	0.024	0.014	0.018	*0.017*	0.018	0.013	*0.014*	<0.012	<0.026	0.013	0.013	0.019	0.016
PCB-180	0.011	0.006	0.013	0.007	0.006	0.005	*0.005*	0.004	<0.009	0.005	0.006	0.009	0.007
sum PCB$_7$	0.114	0.059	0.086	0.087	0.081	0.058	0.067	0.05	0.109	0.056	0.058	0.082	0.072

Table A.1 8: Monthly and annual mean concentrations (pg/m^3) for organochlorine pesticides (OCPs) in air at Andøya, 2016

Andøya	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2016**
HCB	41.00	36.53	36.38	37.22	19.24	22.44	16.29	17.98	21.77	28.48	39.47	27.73	28.8
α-HCH	2.87	2.96	2.83	2.86	2.60	2.97	2.76	3.28	4.03	4.14	3.65	3.00	3.18
γ-HCH	0.51	0.73	1.00	0.75	1.28	0.38	1.05	0.70	1.49	0.93	0.68	0.78	0.87
sum HCHs	3.38	3.69	3.84	3.62	3.88	3.36	3.82	3.97	5.52	5.07	4.33	3.77	4.04
p,p-DDT	0.10	0.11	0.16	0.07	0.06	0.01	0.05	0.05	0.06	0.10	0.10	0.07	0.08
o,p-DDT	0.17	0.15	0.22	0.12	0.10	0.02	0.06	0.08	0.09	0.15	0.14	0.11	0.11
p,p-DDE	0.80	0.90	1.11	0.37	0.26	0.07	0.13	0.12	0.20	0.61	0.81	0.57	0.48
o,p-DDE	0.10	0.10	0.11	0.06	0.04	0.01	0.02	0.02	0.03	0.06	0.07	0.07	0.06
p,p-DDD	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.01
o,p-DDD	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01
sum DDTs	1.19	1.27	1.63	0.64	0.47	0.12	0.27	0.27	0.40	1.08	1.23	0.85	0.74

Table A.1 9: Monthly and annual mean concentrations (pg/m^3) for PCBs in air at Andøya, 2016

Andøya	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2016**
PCB-18	0.967	1.425	1.265	1.004	0.633	0.240	0.305	0.295	0.322	1.194	1.099	0.839	0.794
PCB-28	0.610	0.750	0.787	0.684	0.498	0.144	0.258	0.314	0.274	0.704	0.675	0.620	0.522
PCB-31	0.566	0.689	0.711	0.629	0.476	0.150	0.247	0.263	0.247	0.644	0.608	0.575	0.480
PCB-33	0.343	0.411	0.413	0.355	0.262	0.076	0.127	0.140	0.118	0.352	0.348	0.340	0.271
PCB-37	0.056	0.054	0.052	0.047	0.040	0.011	0.022	0.023	0.015	0.035	0.043	0.059	0.038
PCB-47	0.375	0.576	0.835	0.897	0.918	0.505	0.962	0.597	0.708	0.468	0.377	4.003	0.857
PCB-52	0.691	0.669	0.733	0.641	0.586	0.194	0.380	0.314	0.343	0.560	0.574	0.654	0.527
PCB-66	0.157	0.140	0.158	0.146	0.145	0.037	0.082	0.076	0.062	0.113	0.103	0.122	0.112
PCB-74	0.123	0.118	0.134	0.114	0.101	0.027	0.058	0.060	0.047	0.080	0.083	0.106	0.087
PCB-99	0.164	0.141	0.145	0.142	0.139	0.035	0.079	0.075	0.061	0.103	0.108	0.142	0.111
PCB-101	0.627	0.340	0.402	0.342	0.357	0.091	0.230	0.184	0.215	0.289	0.277	0.370	0.314
PCB-105	0.056	0.030	0.028	0.028	0.026	0.007	0.015	0.016	0.009	0.017	0.022	0.029	0.024
PCB-114	0.006	0.004	0.004	0.004	0.003	0.001	0.002	0.003	0.001	0.002	0.002	0.003	0.003
PCB-118	0.219	0.107	0.103	0.097	0.090	0.022	0.055	0.053	0.039	0.071	0.086	0.102	0.089
PCB-122	0.003	0.003	0.004	0.002	*0.001*	<0.001	0.002	0.002	*0.001*	0.002	0.002	0.004	0.002
PCB-123	0.003	0.002	0.002	0.002	0.002	<0.001	0.001	0.002	<0.001	*0.001*	0.001	0.002	0.002
PCB-128	0.046	0.014	0.016	0.014	0.017	0.004	0.011	0.008	0.005	0.007	0.008	0.014	0.014
PCB-138	0.337	0.108	0.129	0.101	0.115	0.027	0.083	0.062	0.061	0.074	0.081	0.096	0.111
PCB-141	0.098	0.021	0.030	0.024	0.033	0.007	0.023	0.015	0.015	0.015	0.013	0.026	0.029
PCB-149	0.420	0.170	0.234	0.183	0.222	0.056	0.167	0.113	0.140	0.134	0.130	0.219	0.188
PCB-153	0.460	0.169	0.209	0.160	0.184	0.045	0.135	0.096	0.120	0.134	0.138	0.166	0.175
PCB-156	0.022	0.005	0.005	0.005	0.006	0.001	0.003	0.003	0.002	0.003	0.003	0.003	0.006
PCB-157	0.003	0.001	0.001	*0.001*	0.001	<0.001	*0.001*	*0.001*	<0.001	<0.001	<0.001	<0.001	*0.001*
PCB-167	0.010	0.002	0.003	0.003	0.003	<0.001	0.002	0.002	0.001	0.001	0.001	0.003	0.003
PCB-170	0.032	0.007	0.010	0.009	0.012	0.003	0.009	0.004	0.005	0.003	0.003	0.008	0.010

Table A.1 9, cont.

Andøya	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2016
PCB-180	0.103	0.026	0.034	0.027	0.036	0.009	0.026	0.014	0.013	0.015	0.011	0.021	0.030
PCB-183	0.031	0.011	0.015	0.011	0.013	0.004	0.012	0.007	0.008	0.007	0.008	0.011	0.012
PCB-187	0.076	0.036	0.048	0.033	0.042	0.013	0.037	0.021	0.026	0.023	0.026	0.032	0.036
PCB-189	0.002	<0.001	<0.001	*0.001*	*0.001*	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	*0.001*
PCB-194	0.003	0.002	0.002	0.002	0.003	*0.001*	0.002	0.001	0.001	0.001	<0.001	0.001	0.002
PCB-206	0.001	0.001	0.001	0.001	0.001	<0.001	0.001	*0.001*	*0.001*	<0.001	0.001	<0.001	*0.001*
PCB-209	0.003	0.002	0.002	0.002	0.003	*0.001*	0.002	0.002	0.001	0.001	0.001	0.002	0.002
sum-trichlor	3.55	4.64	4.46	3.85	2.75	0.87	1.34	1.44	1.31	4.09	3.90	3.60	2.957
sum-tetrachlor	2.59	2.75	3.41	3.23	3.16	1.14	2.26	1.70	1.78	2.23	2.18	6.55	2.652
sum-pentachlor	1.80	1.08	1.20	1.06	1.05	0.26	0.68	0.60	0.56	0.81	0.89	1.15	0.938
sum-hexachlor	2.10	0.75	0.95	0.78	0.97	0.22	0.69	0.47	0.49	0.51	0.52	0.48	0.789
sum-heptachlor	0.35	0.12	0.16	0.12	0.16	0.04	0.13	0.07	0.07	0.07	0.07	0.05	0.127
sum-PCB$_7$	3.05	2.17	2.40	2.05	1.87	0.53	1.17	1.04	1.07	1.85	1.84	2.03	1.77
sum PCB	10.39	9.34	10.17	9.04	8.09	2.53	5.09	4.29	4.22	7.71	9.04	5.48	7.14

Table A.1 10: Monthly and annual mean concentrations (pg/m^3) for PBDEs in air at Andøya, 2016

Andøya	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2016**
BDE-28	0.006	*0.004*	0.006	*0.006*	<0.004	*0.004*	0.005	*0.004*	0.005	0.005	0.005	0.027	0.006
BDE-47	0.070	<0.048	<0.054	<0.068	<0.049	<0.048	<0.051	<0.049	<0.052	<0.048	<0.048	0.059	*0.054*
BDE-49	0.005	*0.004*	0.020	<0.006	<0.004	<0.004	0.005	0.005	0.005	*0.004*	0.005	0.010	*0.006*
BDE-66	<0.016	<0.014	<0.016	<0.020	<0.015	<0.014	<0.015	<0.015	<0.016	<0.014	<0.014	<0.015	*0.016*
BDE-71	<0.001	<0.001	0.001	<0.001	*0.004*	*0.001*	<0.001	*0.001*	<0.001	<0.001	<0.001	<0.001	*0.002*
BDE-77	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	*0.001*	<0.001	*0.001*	<0.001	<0.001	*0.001*
BDE-85	<0.001	0.002	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	*0.001*
BDE-99	0.018	<0.011	<0.012	*0.015*	<0.011	*0.011*	0.013	*0.011*	*0.012*	0.011	0.011	0.015	*0.013*
BDE-100	0.006	<0.005	<0.005	<0.007	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	*0.006*	*0.005*
BDE-119	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	*0.002*	<0.001	<0.001	<0.001	*0.002*	<0.001	*0.001*
BDE-138	<0.005	<0.003	<0.003	<0.004	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	*0.003*
BDE-153	*0.004*	<0.003	<0.003	<0.004	<0.003	<0.003	<0.003	<0.003	<0.003	0.003	<0.003	0.003	*0.003*
BDE-154	*0.003*	<0.002	<0.002	<0.003	<0.002	<0.002	<0.002	<0.002	<0.002	0.002	*0.004*	0.002	*0.002*
BDE-183	0.003	<0.002	<0.002	<0.003	*0.003*	<0.002	0.002	0.002	0.003	0.004	0.003	0.003	0.003
BDE-196	<0.015	<0.013	<0.014	<0.018	<0.013	<0.013	<0.013	<0.013	<0.014	<0.012	<0.012	<0.013	*0.014*
BDE-206	<0.039	<0.034	<0.038	<0.048	<0.034	<0.034	<0.036	<0.035	<0.037	<0.034	0.040	0.044	*0.038*
BDE-209	<0.29	*0.28*	0.48	*0.45*	<0.25	*0.31*	0.31	0.28	0.32	<0.25	1.01	1.05	0.43
sum BDE	0.48	0.43	0.66	0.66	0.40	0.46	0.46	0.43	0.48	0.40	1.17	1.26	0.60
sum BDE$_{\text{excl. 209}}$	0.19	0.15	0.18	0.21	0.15	0.15	0.16	0.15	0.16	0.15	0.16	0.21	0.17
TBA	5.34	5.24	3.05	2.97	2.19	3.45	4.26	4.80	4.83	4.98	5.13	3.58	4.19

Table A.1 11: Monthly and annual mean concentrations (pg/m^3) for PFAS in air at Andøya, 2016

Andøya	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2016**
6:2 FTS	<0.150	<0.150	<0.150	<0.150	<0.150	<0.150	<0.150	<0.150	<0.150	<0.150	<0.150	<0.150	*0.150*
PFBS	0.006	0.005	0.020	0.024	0.030	0.037	0.043	0.021	0.022	0.015	0.006	0.009	0.020
PFDcA	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	*0.015*
PFDcS	<0.007	<0.007	*0.021*	0.022	*0.010*	0.008	0.015	*0.007*	*0.007*	<0.007	<0.007	<0.007	*0.011*
PFHpA	0.027	0.022	0.048	0.073	0.104	0.186	0.140	<0.011	<0.011	<0.011	<0.011	<0.011	0.057
PFHxA	*0.018*	0.019	*0.032*	0.048	0.120	0.172	0.120	*0.021*	0.082	0.045	0.018	0.025	0.062
PFHxS	*0.012*	<0.006	0.008	0.013	*0.008*	0.011	0.008	*0.010*	<0.006	0.010	<0.006	*0.008*	*0.009*
PFNA	*0.010*	0.015	0.082	0.056	0.034	0.191	0.113	0.039	0.060	0.050	*0.012*	0.120	0.062
PFOA	0.078	0.083	0.152	0.155	0.207	0.398	0.228	0.144	0.144	0.163	0.045	0.180	0.167
PFOS	<0.007	*0.010*	<0.007	0.015	<0.007	<0.007	<0.007	*0.007*	*0.009*	*0.014*	<0.007	*0.013*	*0.009*
PFOSA	<0.007	<0.007	0.014	0.018	*0.008*	*0.011*	*0.014*	<0.007	*0.014*	*0.009*	<0.007	*0.008*	*0.011*
PFUnA	<0.004	<0.004	0.006	0.006	*0.006*	0.020	0.015	0.008	*0.009*	<0.004	<0.004	*0.010*	*0.008*
sum PFAS	*0.340*	0.342	0.553	0.594	0.699	1.205	0.866	0.439	0.528	0.493	*0.288*	0.556	0.448

Table A.1 12: Monthly and annual mean concentrations (pg/m^3) for organochlorine pesticides in air at Zeppelin, 2016

Zeppelin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2016**
HCB	71.01	74.19	83.86	82.42	85.87	89.09	70.38	96.19	93.00	90.21	88.06	78.71	83.14
α-HCH	3.08	3.32	3.53	3.45	3.17	3.93	5.48	5.80	5.83	4.44	3.74	3.95	4.21
γ-HCH	0.57	0.75	0.60	0.55	0.56	0.42	0.94	0.64	1.00	0.83	0.64	1.64	0.76
sum HCHs	3.64	4.06	4.12	4.01	3.73	4.35	6.42	6.44	6.83	5.28	4.38	5.59	4.96
cis-CD	0.41	0.35	0.43	0.40	0.35	0.30	0.35	0.32	0.44	0.45	0.42	0.38	0.38
cis-NO	0.02	0.03	0.03	0.03	0.04	0.05	0.05	0.05	0.06	0.05	0.03	0.02	0.04
trans-CD	0.27	0.22	0.25	0.18	0.10	0.07	0.06	0.07	0.11	0.16	0.22	0.19	0.16
trans-NO	0.39	0.34	0.39	0.41	0.33	0.29	0.30	0.23	0.32	0.37	0.36	0.32	0.33
sum CHLs	1.09	0.93	1.09	1.02	0.83	0.70	0.76	0.65	0.93	1.02	1.04	0.92	0.91
p.p-DDT	0.09	0.12	0.04	0.02	0.02	*0.01*	0.03	0.01	0.03	0.06	0.08	0.04	0.21
o.p-DDT	0.15	0.17	0.12	0.07	0.03	0.01	0.05	0.02	0.05	0.11	0.11	0.08	0.21
p.p-DDE	0.94	1.12	0.48	0.14	0.08	0.04	0.06	0.04	0.11	0.48	0.71	0.44	0.45
o.p-DDE	0.12	0.12	0.08	0.04	0.02	*0.01*	*0.01*	<0.01	0.02	0.04	0.06	0.07	0.09
p.p-DDD	0.01	*0.01*	<0.01	*0.01*	<0.01	<0.01	<0.01	<0.01	*0.01*	0.01	0.01	0.01	*0.01*
o.p-DDD	0.02	0.02	0.01	*0.01*	<0.01	<0.01	*0.01*	<0.01	0.01	0.01	0.01	0.01	*0.01*
sum DDTs	1.33	1.55	0.73	0.28	0.16	0.10	0.15	0.10	0.23	0.71	0.97	0.65	0.57

Table A.1 13: Monthly and annual mean concentrations (pg/m^3) for PCBs in air at Zeppelin, 2016

Zeppelin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2016**
PCB-18	1.687	1.856	1.604	1.400	1.154	1.568	4.600	3.177	2.558	1.742	2.761	0.911	2.282
PCB-28	1.137	1.224	1.013	0.887	0.969	1.435	4.238	2.726	1.729	1.375	1.893	1.190	1.829
PCB-31	1.053	1.121	0.931	0.833	0.895	1.330	4.017	2.621	1.711	1.234	1.793	0.847	1.708
PCB-33	0.743	0.790	0.676	0.600	0.651	1.030	3.142	2.019	1.191	0.827	1.257	0.525	1.262
PCB-37	0.119	0.127	0.087	0.071	0.097	0.152	0.409	0.245	0.142	0.114	0.154	0.076	0.167
PCB-47	0.318	0.360	0.293	0.252	0.231	0.258	0.638	0.509	0.328	0.308	0.401	0.281	0.368
PCB-52	0.726	0.800	0.670	0.558	0.508	0.508	1.265	0.865	0.754	0.716	0.875	0.600	0.776
PCB-66	0.188	0.215	0.150	0.113	0.107	0.111	0.262	0.162	0.139	0.155	0.178	0.101	0.165
PCB-74	0.128	0.149	0.110	0.084	0.084	0.078	0.190	0.118	0.112	0.134	0.146	0.109	0.126
PCB-99	0.168	0.189	0.130	0.115	0.066	0.043	0.110	0.056	0.100	0.098	0.103	0.089	0.107
PCB-101	0.360	0.401	0.295	0.258	0.196	0.150	0.328	0.191	0.276	0.259	0.279	0.243	0.275
PCB-105	0.037	0.047	0.024	0.019	0.012	0.008	0.020	0.009	0.021	0.023	0.027	0.023	0.023
PCB-114	0.004	0.005	0.003	0.002	0.003	0.002	0.004	0.003	0.004	0.004	0.004	0.003	0.004
PCB-118	0.122	0.147	0.081	0.066	0.044	0.030	0.070	0.033	0.069	0.077	0.089	0.069	0.076
PCB-122	0.002	0.002	<0.001	0.002	<0.001	<0.001	0.002	<0.001	0.002	0.003	0.003	0.002	0.002
PCB-123	0.003	0.003	0.002	0.002	<0.001	<0.001	0.001	<0.001	0.002	0.002	0.002	0.002	0.002
PCB-128	0.016	0.021	0.012	0.011	0.006	0.003	0.009	0.004	0.009	0.011	0.011	0.012	0.011
PCB-138	0.097	0.122	0.076	0.064	0.047	0.028	0.061	0.031	0.069	0.082	0.079	0.063	0.069
PCB-141	0.021	0.028	0.018	0.015	0.012	0.008	0.015	0.010	0.019	0.022	0.021	0.017	0.017
PCB-149	0.157	0.191	0.139	0.116	0.099	0.064	0.128	0.082	0.150	0.166	0.154	0.133	0.133
PCB-153	0.142	0.176	0.119	0.095	0.078	0.047	0.094	0.054	0.111	0.139	0.128	0.110	0.109
PCB-156	0.006	0.008	0.004	0.003	0.002	0.002	0.003	0.002	0.003	0.004	0.004	0.004	0.004
PCB-157	0.001	0.002	*0.001*	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.001	*0.001*	*0.001*
PCB-167	0.003	0.004	0.002	0.002	*0.001*	<0.001	0.001	*0.001*	0.002	0.002	0.002	0.002	0.002
PCB-170	0.006	0.010	0.006	0.005	0.004	0.003	0.004	0.003	0.006	0.008	0.006	0.005	0.006

Table A.1 13. cont.

Zeppelin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2016**
PCB-180	0.020	0.030	0.019	0.014	0.011	0.008	0.012	0.009	0.017	0.023	0.019	0.013	0.016
PCB-183	0.009	0.012	0.009	0.007	0.005	0.004	0.006	0.004	0.008	0.010	0.009	0.006	0.007
PCB-187	0.028	0.037	0.027	0.022	0.017	0.010	0.018	0.012	0.024	0.028	0.024	0.017	0.022
PCB-189	<0.001	<0.001	*0.001*	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	*0.001*
PCB-194	0.001	0.003	0.001	*0.001*	*0.001*	<0.001	*0.001*	<0.001	0.001	0.002	0.002	*0.001*	0.001
PCB-206	0.001	0.002	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	0.001	0.001	0.001	0.001	*0.001*
PCB-209	0.004	0.005	0.003	0.002	0.002	0.002	0.002	0.001	0.003	0.003	0.003	0.002	0.003
sum-trichlor	7.00	7.54	6.30	5.53	5.19	7.68	22.76	14.70	9.94	7.20	10.83	4.66	10.09
sum-tetrachlor	3.01	3.41	2.72	2.21	1.89	1.98	4.73	3.28	2.69	2.80	3.42	2.24	3.01
sum-pentachlor	1.17	1.34	0.89	0.77	0.58	0.41	0.98	0.51	0.82	0.79	0.85	0.73	0.84
sum-hexachlor	0.72	0.89	0.61	0.48	0.37	0.23	0.49	0.29	0.59	0.68	0.64	0.52	0.55
sum-heptachlor	0.09	0.13	0.09	0.06	0.05	0.03	0.06	0.04	0.08	0.10	0.08	0.05	0.07
sum-PCB$_7$	2.60	2.90	2.27	1.94	1.85	2.21	6.07	3.91	3.02	2.67	3.36	2.29	3.15
sum PCB	12.01	13.32	10.61	9.07	8.08	10.34	29.02	20.33	14.12	11.58	15.83	7.12	14.66

Table A.1 14: Monthly and annual mean concentrations (pg/m^3*) for PBDEs and TBA in air at Zeppelin, 2016*

Zeppelin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2016**
BDE-28	*0.008*	<0.006	*0.006*	<0.006	*0.008*	0.007	<0.006	0.007	0.018	0.011	0.010	0.013	0.009
BDE-47	0.429	0.092	<0.077	<0.066	0.516	0.177	0.103	0.927	0.971	0.361	0.470	0.244	0.381
BDE-49	*0.009*	<0.006	<0.006	<0.006	*0.008*	0.007	<0.006	0.018	0.029	0.014	0.016	0.011	0.011
BDE-66	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	*0.025*	0.026	*0.021*	*0.020*	<0.017	*0.021*
BDE-71	<0.001	<0.001	<0.001	<0.001	<0.001	*0.001*	<0.001	*0.003*	0.003	0.004	<0.001	0.002	*0.002*
BDE-77	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	*0.001*	<0.001	<0.001	0.003	*0.001*
BDE-85	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	*0.002*	*0.003*	<0.001	0.001	*0.002*
BDE-99	*0.019*	<0.015	<0.014	<0.015	<0.015	0.025	<0.015	*0.028*	0.101	0.040	0.022	0.026	0.028
BDE-100	*0.011*	<0.007	<0.007	<0.007	<0.007	0.008	<0.007	*0.024*	0.069	0.018	0.016	0.013	0.016
BDE-119	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	*0.032*	*0.006*	0.015	0.004	0.003	*0.006*
BDE-138	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	*0.004*
BDE-153	<0.003	<0.003	<0.003	<0.003	<0.003	*0.004*	<0.004	<0.004	<0.004	*0.004*	<0.003	0.004	*0.004*
BDE-154	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	0.004	<0.003	<0.003	<0.003	*0.003*
BDE-183	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	0.003	*0.003*
BDE-196	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	*0.017*	<0.018	<0.016	0.015	*0.017*
BDE-206	<0.048	<0.047	<0.047	<0.047	<0.047	<0.047	<0.048	<0.048	*0.064*	<0.048	<0.0425	0.083	*0.050*
BDE-209	<0.35	<0.34	<0.34	<0.36	<0.34	<0.34	<0.35	*0.44*	0.48	<0.35	<0.31	2.31	*0.45*
sum BDE	*0.93*	*0.57*	*0.55*	*0.56*	*1.00*	*0.67*	*0.59*	*1.58*	1.80	0.91	0.94	2.74	*1.01*
sum $\text{BDE}_{\text{excl. 209}}$	*0.58*	*0.23*	*0.21*	*0.20*	*0.66*	*0.33*	*0.24*	*1.14*	1.32	0.57	0.63	0.44	*0.56*
TBA	7.31	5.74	3.97	1.65	3.88	5.59	6.87	8.98	7.72	8.97	9.82	7.85	6.46

Table A.1 15: Monthly and annual mean concentrations (pg/m^3) for HBCDs in air at Zeppelin, 2016

Zeppelin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2016**
α-HBCD	*0.11*	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07
ß-HBCD	<0.07	*0.04*	<0.06	<0.06	<0.06	<0.07	<0.06	<0.06	<0.06	<0.06	<0.06	<0.05	<0.06
γ-HBCD	<0.05	*0.04*	<0.05	<0.05	<0.05	<0.05	*0.05*	<0.05	<0.05	<0.05	<0.04	<0.04	<0.05
sum HBCD	*0.24*	*0.14*	*0.17*	*0.18*	*0.18*	*0.18*	*0.18*	*0.18*	*0.18*	*0.18*	*0.16*	*0.15*	*0.18*

Table A.1 16: Monthly and annual mean concentrations (ng/m^3) for PAHs in air at Zeppelin, 2016

Zeppelin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2016**
1-Methylnaphthalene	0.150	0.218	0.046	0.028	0.022	0.016	0.019	0.037	0.018	0.023	0.091	0.084	0.063
1-Methylphenanthrene	0.004	0.006	0.003	0.003	0.006	0.002	0.003	0.003	0.002	0.002	0.002	0.007	0.004
2-Methylanthracene	<0.001	<0.002	<0.002	<0.002	<0.002	<0.001	<0.005	<0.003	<0.002	<0.002	<0.002	<0.005	*0.003*
2-Methylnaphthalene	0.205	0.309	0.069	0.051	0.040	0.030	0.036	0.072	0.036	0.035	0.132	0.108	0.095
2-Methylphenanthrene	0.006	0.009	0.003	0.004	0.009	0.003	0.006	0.006	0.004	0.003	0.004	0.017	0.006
3-Methylphenanthrene	0.004	0.006	0.003	0.003	0.008	0.003	0.004	0.005	0.003	0.003	0.003	0.015	0.005
9-Methylphenanthrene	0.003	0.003	0.002	0.003	0.005	0.002	0.003	0.003	0.002	0.002	0.002	0.008	0.003
Acenaphthene	0.008	0.014	*0.005*	0.005	*0.010*	<0.006	0.003	0.004	*0.004*	<0.003	0.006	0.005	0.006
Acenaphthylene	*0.003*	*0.003*	*0.003*	0.002	0.002	*0.004*	0.003	*0.003*	<0.003	0.005	0.004	0.010	0.004
Anthanthrene	<0.001	<0.002	<0.002	<0.001	<0.001	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	*0.001*
Anthracene	0.002	*0.002*	*0.001*	<0.002	0.002	*0.001*	<0.003	*0.002*	<0.001	<0.002	0.002	<0.002	*0.002*
Benz(a)anthracene	0.003	0.006	*0.001*	<0.001	*0.001*	<0.001	<0.001	*0.001*	<0.001	*0.001*	0.002	<0.001	*0.002*
Benzo(a)fluoranthene	*0.001*	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	*0.001*
Benzo(a)fluorene	*0.002*	0.003	<0.001	<0.001	*0.001*	<0.001	<0.001	<0.002	<0.001	<0.001	0.001	<0.001	*0.001*
Benzo(a)pyrene	*0.002*	0.003	*0.002*	<0.001	*0.003*	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	*0.002*
Benzo(b)fluoranthene	0.008	0.014	0.004	<0.001	*0.011*	<0.001	<0.001	*0.001*	<0.001	*0.001*	0.003	*0.001*	*0.004*
Benzo(b)fluorene	*0.001*	0.002	<0.001	<0.001	<0.001	<0.001	<0.002	<0.002	<0.001	<0.001	*0.001*	<0.001	*0.001*
Benzo(e)pyrene	0.005	0.009	0.002	<0.001	*0.007*	<0.001	<0.001	*0.001*	<0.001	0.001	0.002	*0.001*	*0.003*
Benzo(ghi)fluoranthene	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	*0.001*
Benzo(ghi)perylene	0.005	0.009	*0.002*	<0.001	*0.004*	<0.001	<0.001	<0.002	<0.001	0.001	0.002	*0.001*	*0.003*
Benzo(k)fluoranthene	0.003	0.006	0.002	<0.001	*0.003*	<0.001	<0.001	<0.001	<0.001	*0.001*	0.001	<0.001	*0.002*
Biphenyl	0.732	1.169	0.424	0.091	0.028	0.017	0.020	0.031	0.029	0.118	0.392	0.368	0.284
Chrysene	0.007	0.014	0.004	0.001	0.007	*0.001*	0.001	0.002	<0.001	*0.002*	0.003	*0.001*	0.004
Coronene	*0.004*	0.006	<0.004	<0.002	<0.001	<0.002	<0.001	<0.003	<0.002	<0.002	*0.002*	<0.003	*0.003*
Cyclopenta(cd)pyrene	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	*0.001*

Table A.1 16. cont.

Zeppelin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2016**
Dibenzo(ae)pyrene	<0.005	<0.006	<0.006	<0.003	*0.002*	<0.003	<0.002	<0.006	<0.003	<0.003	<0.003	<0.003	*0.004*
Dibenzo(ah)anthracene	*0.001*	*0.002*	<0.002	<0.001	*0.001*	<0.002	<0.001	<0.003	<0.002	<0.002	<0.002	<0.002	*0.002*
Dibenzo(ah)pyrene	<0.006	<0.007	<0.008	<0.004	<0.002	<0.004	<0.003	<0.008	<0.004	<0.004	<0.004	<0.004	*0.005*
Dibenzo(ai)pyrene	<0.005	<0.006	<0.007	<0.003	<0.002	<0.004	<0.003	<0.007	<0.003	<0.003	<0.004	<0.004	*0.004*
Dibenzofuran	0.981	1.709	0.589	0.162	0.077	0.028	0.038	0.058	0.088	0.250	0.614	0.508	0.425
Dibenzothiophene	*0.004*	0.005	0.003	<0.001	0.004	<0.001	*0.001*	*0.001*	*0.001*	0.002	0.007	0.011	0.004
Fluoranthene	0.043	0.088	0.016	0.006	0.022	*0.005*	0.008	0.010	<0.005	0.009	0.018	0.011	0.020
Fluorene	0.433	0.736	0.114	0.023	0.060	0.014	0.016	0.028	0.026	0.085	0.288	0.181	0.172
Inden(123-cd)pyrene	0.006	0.008	*0.002*	<0.001	*0.004*	<0.001	<0.001	*0.001*	<0.001	*0.001*	0.002	<0.001	*0.003*
Naphthalene	1.415	1.959	0.536	0.255	0.112	0.104	0.183	0.223	0.136	0.156	0.825	1.162	0.592
Perylene	<0.001	*0.001*	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	*0.001*
Phenanthrene	0.085	0.232	0.032	0.025	0.136	0.016	0.028	0.034	0.016	0.024	0.043	0.080	0.064
Pyrene	0.015	0.027	0.008	0.004	0.011	0.005	0.005	0.006	<0.004	*0.005*	*0.006*	0.005	0.009
Retene	*0.003*	0.003	*0.003*	<0.003	0.004	0.003	*0.004*	*0.004*	<0.003	<0.003	<0.002	<0.004	*0.003*
Sum PAH	4.14	6.56	1.90	0.70	0.59	0.29	0.41	0.58	0.41	0.76	2.47	2.62	1.79
Sum PAH$_{16}$	2.04	3.12	0.73	0.33	0.39	0.16	0.26	0.32	0.20	0.30	1.21	1.47	0.89

Table A.1 17: Monthly and annual mean concentrations (pg/m^3) for PFAS in air at Zeppelin, 2016

Zeppelin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2016**
6:2 FTS	<0.154	<0.154	<0.154	<0.154	<0.154	<0.154	<0.154	<0.154	<0.154	<0.154	<0.154	<0.154	<0.154
PFBS	<0.008	<0.008	<0.008	<0.008	*0.008*	*0.010*	*0.008*	<0.008	<0.008	<0.008	<0.008	<0.008	*0.008*
PFDcA	<0.004	0.011	0.012	0.023	0.013	0.011	0.033	0.016	0.017	0.009	0.026	0.079	0.022
PFDcS	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015
PFHpA	*0.013*	*0.015*	0.058	0.036	0.036	0.051	0.060	0.028	*0.014*	0.020	0.030	0.072	0.037
PFHxA	<0.015	<0.015	*0.019*	<0.015	0.025	0.025	0.047	0.029	*0.017*	0.028	*0.017*	<0.015	*0.022*
PFHxS	*0.007*	*0.010*	*0.008*	<0.006	<0.006	<0.006	<0.006	*0.006*	*0.006*	*0.006*	<0.006	<0.006	*0.007*
PFNA	<0.008	0.011	*0.013*	0.010	<0.008	0.030	0.024	*0.013*	*0.013*	0.017	0.048	0.093	0.026
PFOA	0.113	0.118	0.077	0.061	0.063	0.111	0.175	0.061	0.054	0.068	0.160	0.185	0.106
PFOS	0.043	<0.015	<0.015	<0.015	<0.015	*0.015*	0.021	<0.015	<0.015	<0.015	*0.015*	0.029	*0.019*
PFOSA	<0.008	0.030	*0.025*	*0.021*	0.121	0.158	0.177	0.060	0.046	0.040	<0.008	*0.029*	0.060
PFUnA	<0.004	<0.004	*0.007*	<0.004	<0.004	*0.005*	<0.004	<0.004	<0.004	*0.006*	<0.004	*0.014*	*0.006*
sum PFAS	*0.391*	*0.404*	*0.412*	*0.367*	0.468	0.590	0.724	0.410	*0.364*	0.386	*0.491*	0.699	0.349

Table A.1 18: Monthly and annual mean concentrations (pg/m^3) for M/SCCPs in air at Zeppelin. 2016

Zeppelin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2016**
SCCP	185	144	179	145	245	292	266	275	186	186	272	142	213
MCCP	86	24	153	380	49	28	10	37	36	38	36	14	73

Annex 2

Monthly and annual averages of heavy metals in air and precipitation

Table A.2 1: Monthly and annual volume weighted mean concentrations of lead in precipitation at Norwegian background stations 2016. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2016
Birkenes	0.68	0.48	0.5	0.59	0.54	0.36	0.62	0.61	1.88	0.7	0.35	0.55	0.56
Hurdal	0.47	0.48	0.46	0.63	0.57	0.39	0.48	0.45	0.99	0.66	0.41	0.38	0.55
Kårvatn	0.34	0.21	0.64	0.15	0.35	0.18	0.07	0.25	0.21	0.05	0.09	0.04	0.19
Svanvik	0.67	0.71	1	1.54	1.18	0.83	1.36	1.46	1.05	0.28	0.84	0.26	1.04
Karpdalen	0.9	1.3	1.4	1.63	1.67	0.46	0.95	1.33	0.82	1.13	0.57	0.42	0.96

Table A.2 2: Monthly and annual volume weighted mean concentrations of cadmium in precipitation at Norwegian background stations 2016. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2016
Birkenes	0.026	0.015	0.021	0.014	0.019	0.014	0.009	0.008	0.03	0.031	0.011	0.022	0.017
Hurdal	0.027	0.018	0.025	0.044	0.018	0.019	0.013	0.018	0.075	0.057	0.015	0.018	0.029
Kårvatn	0.005	0.007	0.008	0.002	0.009	0.005	0.004	0.004	0.008	0.002	0.006	0.001	0.004
Svanvik	0.041	0.044	0.02	0.189	0.064	0.046	0.088	0.059	0.103	0.044	0.088	0.017	0.062
Karpdalen	0.089	0.123	0.152	0.147	0.114	0.03	0.087	0.048	0.084	0.128	0.039	0.041	0.066

Table A.2 3: Monthly and annual volume weighted mean concentrations of zinc in precipitation at Norwegian background stations 2016. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OKT	NOV	DES	2016
Birkenes	6.4	2.8	7.6	5.8	4	3.3	2.6	9.8	6.9	3.8	3	9	5.2
Hurdal	11.1	8.5	10.2	5.1	4	4.4	3.6	7.7	13.9	10.8	5.4	17.1	7.7
Kårvatn	1.9	1.7	1.1	1	2.4	2.6	1.9	2.6	9.7	2.1	2.3	1.4	2.2
Svanvik	2.1	2.6	5.9	13	3	2.2	4.3	9.7	5.8	6.7	4	2.5	5.2
Karpdalen	14.6	9.5	4	32.6	9.5	3.4	5.8	2.2	5.1	12.1	9.4	8.3	7.2

Table A.2 4: Monthly and annual volume weighted mean concentrations of nickel in precipitation at Norwegian background stations 2016. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2016
Birkenes	0.14	0.2	0.1	0.18	0.18	0.13	0.18	0.88	0.25	0.12	0.19	0.33	0.24
Svanvik	5.17	14.05	5.7	62.79	33.57	29.85	32.61	17.32	65.48	96.76	33.12	8	26.49
Karpdalen	20	49.8	118.9	147.62	111.71	21.27	82.94	24.9	64.59	102.09	15.05	7.63	42.06

Table A.2 5: Monthly and annual volume weighted mean concentrations of arsenic in precipitation at Norwegian background stations 2016. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2016
Birkenes	0.11	0.06	0.09	0.09	0.07	0.09	0.06	0.08	0.1	0.1	0.08	0.06	0.08
Svanvik	0.39	0.58	0.23	2.6	1.57	1.17	2.61	1.25	1.75	1.21	0.71	0.26	1.29
Karpdalen	0.63	1.24	1.75	3.17	2.41	0.59	1.96	1.34	1.83	1.91	0.41	0.29	1.19

Table A.2 6: Monthly and annual volume weighted mean concentrations of copper in precipitation at Norwegian background stations 2016. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2016
Birkenes	1.59	0.76	0.82	7.14	1.1	1.69	2.31	5.92	1.93	0.76	1.89	7.33	2.55
Svanvik	11.66	26.8	18.41	102.26	34.5	26.65	38.61	19.78	60.45	32.32	38.39	10.23	29.45
Karpdalen	26.49	68.05	121.54	111.02	94.2	21.12	79.09	22.38	50.98	88.14	17.19	9.67	38.55

Table A.2 7: Monthly and annual volume weighted mean concentrations of cobalt in precipitation at Norwegian background stations 2016. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2016
Birkenes	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.04	0.03	0.01	0.01	0.02	0.02
Svanvik	0.23	0.54	0.22	2.71	1.11	0.85	1.03	0.49	1.9	2.48	1.16	0.23	0.83
Karpdalen	0.53	1.4	3.11	4.6	3.23	0.63	2.3	0.72	1.79	3.3	0.5	0.23	1.23

Table A.2 8: Monthly and annual volume weighted mean concentrations of chromium in precipitation at Norwegian background stations 2016. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2016
Birkenes	0.11	0.07	0.08	0.1	0.09	0.11	0.07	0.18	0.16	0.05	0.1	0.1	0.1
Svanvik	0.04	0.06	0.32	1.85	0.31	0.15	0.25	0.28	0.46	0.34	0.12	0.06	0.26
Karpdalent	0.1	0.24	0.49	3.9	0.9	0.27	1.01	0.36	0.42	0.9	0.27	0.11	0.48

Table A.2 9: Monthly and annual volume weighted mean concentrations of manganese in precipitation at Norwegian background stations 2016. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2016
Birkenes	0.69	0.62	0.8	1.11	2.56	1.43	2.66	1.24	3.03	0.62	0.78	0.77	1.23

Table A.2 10: Monthly and annual volume weighted mean concentrations of vanadium in precipitation at Norwegian background stations 2016. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2016
Birkenes	0.13	0.23	0.12	0.16	0.2	0.13	0.11	0.2	0.31	0.14	0.12	0.12	0.15
Svanvik	0.48	0.57	0.32	0.8	0.59	0.15	0.25	0.24	0.34	0.4	0.81	0.26	0.34
Karpdalen	0.9	0.92	0.96	1.48	0.9	0.21	0.72	0.27	0.27	0.75	0.35	0.22	0.46

Table A.2 11: Monthly and annual volume weighted mean concentrations of aluminium in precipitation at Svanvik and Karpdalen. 2016. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2016
Svanvik	2.21	5.49	61.49	44.92	32.57	15.04	13.92	45.41	25.56	61.01	17.27	5.35	23.98
Karpdalen	7.33	15.22	24.97	71.93	56.49	39.42	162.22	35.86	34.9	73.85	24.18	9.96	36.39

Table A.2 12: Monthly and annual average volume weighted mean concentrations of mercury in precipitation at Birkenes in 2016.. Unit: ng/L

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2016
Birkenes	2.3	3.2	5.4	56.0	1.8	13.0	6.1	5.0	8.1	3.6	2.4	3.7	6.5

Table A.2 13: Annual and monthly total precipitation in 2016. measured using the bulk collector which is used for sampling of heavy metals. Unit mm.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2016
Birkenes	137	141	131	108	128	123	110	130	27	108	153	65	1362
Hurdal	60	32	76	106	113	59	62	90	77	49	86	35	844
Kårvatn	109	194	120	119	41	41	121	183	83	127	144	319	1600
Svanvik	37	26	5	14	47	75	76	142	48	3	21	66	562
Karpdalen	46	21	8	20	58	101	15	152	50	21	48	84	624

Table A.2 14: Monthly- and annual wet deposition of lead at Norwegian background stations 2016. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2016
Birkenes	93	68	66	64	69	44	68	80	50	75	53	36	765
Hurdal	28	15	35	66	64	23	30	40	76	32	36	13	460
Kårvatn	37	40	77	18	14	7	9	46	18	6	13	12	298
Svanvik	25	19	5	22	56	62	103	208	50	1	18	17	586
Karpdalen	41	28	11	32	98	46	14	202	41	23	28	36	599

Table A.2 15: Monthly- and annual wet deposition of cadmium at Norwegian background stations 2016. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2016
Birkenes	3.6	2.2	2.7	1.5	2.5	1.7	1	1.1	0.8	3.3	1.6	1.5	23.5
Hurdal	1.6	0.6	1.9	4.6	2.1	1.1	0.8	1.6	5.8	2.8	1.3	0.6	24.8
Kårvatn	0.5	1.3	0.9	0.3	0.4	0.2	0.5	0.7	0.7	0.3	0.9	0.4	7
Svanvik	1.5	1.2	0.1	2.7	3	3.4	6.7	8.4	4.9	0.1	1.9	1.1	35
Karpdalen	4	2.6	1.2	2.9	6.7	3	1.3	7.3	4.2	2.6	1.9	3.4	41.2

Table A.2 16: Monthly- and annual wet deposition of zinc at Norwegian background stations 2016. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2016
Birkenes	882	396	994	624	513	412	286	1283	184	414	465	584	7035
Hurdal	664	273	777	535	456	259	225	692	1065	526	467	594	6536
Kårvatn	205	336	135	118	101	106	228	469	803	267	333	442	3542
Svanvik	77	69	31	184	141	169	329	1378	277	18	84	166	2922
Karpdalen	664	204	31	642	553	346	87	328	260	250	452	691	4507

Table A.2 17: Monthly- and annual wet deposition of nickel at Norwegian background stations 2016. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2016
Birkenes	19	28	13	20	23	16	20	115	7	13	30	22	324
Svanvik	193	371	30	890	1592	2253	2480	2459	3126	256	699	531	14884
Karpdalen	911	1070	913	2910	6535	2140	1243	3792	3260	2104	725	638	26235

Table A.2 18: Monthly- and annual wet deposition of arsenic at Norwegian background stations 2016. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2016
Birkenes	15	8	12	10	9	11	7	11	3	11	12	4	112
Svanvik	15	15	1	37	74	88	199	178	84	3	15	17	726
Karpdalen	29	27	13	62	141	60	29	204	92	39	20	24	741

Table A.2 19: Monthly- and annual wet deposition of copper at Norwegian background stations 2016. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2016
Birkenes	218	107	108	772	140	208	253	772	51	82	290	478	3479
Svanvik	435	708	97	1449	1638	2011	2937	2808	2886	85	811	678	16547
Karpdalen	1207	1463	933	2189	5510	2125	1185	3409	2573	1817	828	809	24041

Table A.2 20: Monthly- and annual wet deposition of cobalt at Norwegian background stations 2016. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2016
Birkenes	2	2	1	2	2	2	2	5	1	1	2	1	23
Svanvik	9	14	1	38	53	64	78	69	91	7	25	15	464
Karpdalen	24	30	24	91	189	63	34	110	90	68	24	20	767

Table A.2 21: Monthly- and annual wet deposition of chromium at Norwegian background stations 2016. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2016
Birkenes	15	9	10	11	11	14	8	23	4	6	16	7	133
Svanvik	2	1	2	26	15	11	19	40	22	1	3	4	145
Karpdalen	5	5	4	77	52	27	15	55	21	19	13	9	301

Table A.2 22: Monthly- and annual wet deposition of manganese at Norwegian background stations 2016. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2016
Birkenes	95	87	105	120	327	175	292	162	81	67	119	50	1680

Table A.2 23: Monthly- and annual wet deposition of vanadium at Norwegian background stations 2016. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2016
Birkenes	18	32	16	17	25	16	12	25	8	15	19	8	211
Svanvik	18	15	2	11	28	12	19	34	16	1	17	17	191
Karpdalen	41	20	7	29	52	21	11	41	14	15	17	18	287

Table A.2 24: Monthly and annual wet deposition of mercury at Birkenes in 2016. Unit: ng/m^3

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2016
Birkenes	331	484	681	5796	199	1277	676	693	380	440	487	199	9197

Table A.2 25: Annual average volume weighed mean concentration of heavy metals in precipitation at Norwegian background sites. 1976, aug 1978-june 1979; 1980 (febr - dec), 1981-2016

Site	Year	Pb µg/l	Cd µg/l	Zn µg/l	Ni µg/l	As µg/l	Cu µg/l	Co µg/l	Cr µg/l	V µg/l	Al µg/l	Hg ng/l
Birkenes	1976	12.7	0.27	28.9								
	1978	10.8	0.27	17.9								
	1980	7.9	0.34	15.7								
	1981	7.4	0.24	6.2								
	1982	8.8	0.69	7								
	1983	5.4	0.25	6.6								
	1984	6.2	0.29	12.1								
	1985	4.1	0.09	9.4								
	1986	4.8	0.12	9								
	1987	3.5	0.12	9.2								
	1988	7.4	0.12	14.1								
	1989	5.4	0.11	11.4								
	1990	3.8	0.12	9.5								
	1991	3.6	0.06	7								
	1992	2.9	0.04	5.2								
	1993	3.1	0.06	6.5								
	1994	2.6	0.05	5								
	1995	2.2	0.05	6								
	1996	2.8	0.06	4.9								
	1997	1.7	0.03	4.2								
	1998	1.59	0.043	4.9								
	1999	1.5	0.040	4.4								
	2000	1.39	0.030	3.2								
	2001	1.25	0.032	4.7								
	2002	0.99	0.034	3.6								
	2003	1.57	0.043	3.9								
	2004	1.3	0.040	4.1	0.21	0.12	0.35	0.01	0.11	0.61		9.8
	2005	1.17	0.035	5.3	0.47	0.26	0.76	0.01	0.30	1.11		8.9
	2006	0.88	0.029	3.4	0.2	0.20	0.51	0.01	0.15	0.76		8.0
	2007	0.67	0.024	2.8	0.23	0.10	0.37	0.02		0.64		6.3
	2008	0.78	0.025	2.9	0.13	0.16	0.39	0.01	0.12	0.78		6.4
	2009	0.92	0.04	3.9	0.19	0.18	0.46	0.01	0.12	0.75		9.4
	2010	0.91	0.039	4.3	0.2	0.18	0.54	0.02	0.13	0.51		9.1
	2011	0.63	0.027	3.5	0.15	0.12	0.58	0.01	0.10	0.52		5.3
	2012	0.58	0.02	4.4	0.25	0.08	0.52	0.01	0.06	0.21		4.7
	2013	0.6	0.015	5.3	0.21	0.05	1.00	0.02	0.06	0.21		5.5
	2014	1.12	0.025	5.0	0.16	0.1	1.35	0.01	0.06	0.21		4.8
	2015	0.84	0.016	3.7	0.15	0.08	1.33	0.03	0.16	0.23		6.5
	2016	0.56	0.017	5.2	0.24	0.08	2.55	0.02	0.10	0.15	-	6.5
Nordmoen	1987	4.6	0.10	8.4								
	1988	5.6	0.10	11								
	1989	4.6	0.08	7.3								
	1990	3.8	0.14	5.6								
	1991	2.6	0.06	4.3								
	1992	2.3	0.04	4.4								
	1993	1.8	0.04	3.5								
	1994	1.7	0.05	4								
	1995	2	0.04	5.2								
	1996	1.9	0.04	4.3								
Hurdal	1997	1.26	0.056	4.4								
	1998	1.55	0.063	4.9								
	1999	1.18	0.032	6.3								
	2000	1.13	0.042	4.2								
	2001	0.93	0.042	4.8								
	2002	0.7	0.026	4.1								

Table A.2 25. cont.

Site	Year	Pb µg/l	Cd µg/l	Zn µg/l	Ni µg/l	As µg/l	Cu µg/l	Co µg/l	Cr µg/l	V µg/l	Al µg/l	Hg ng/l
Hurdal	2003	0.97	0.032	3.7								
(cont.)	2004	0.89	0.041	10								
	2005	1.23	0.070	10.3								
	2006	0.96	0.061	8.4								
	2007	0.91	0.065	10.3								
	2008	0.74	0.044	7								
	2009	0.79	0.043	7.4								
	2010	1.33	0.030	8.9								
	2011	0.92	0.028	6.4								
	2012	0.49	0.017	6.8								
	2013	0.41	0.017	8								
	2014	0.58	0.026	6.4								
	2015	0.49	0.030	6.3								
	2016	0.55	0.029	7.7								
Kårvatn	1979	1.5	0.04	3								
	1980	1.4	0.06	4.2								
	1981	1.4	0.09	3								
	1982	1.5	0.10	3.1								
	1983	0.7	0.12	2.9								
	1984	1.3	0.07	3.6								
	1985	1.1	0.06	4								
	1986	1.4	0.01	3.2								
	1987	1.1	0.03	2.5								
	1988	0.9	0.06	4.2								
	1989	0.3	0.05	1.8								
	1990	0.2	0.06	1								
	1991	0.3	0.01	1								
	1992	0.2	<0.01	0.8								
	1993	0.2	0.01	0.6								
	1994	0.4	0.02	1.2								
	1995	0.2	0.01	1.2								
	1996	0.5	0.01	1.4								
	1997	0.7	0.01	1.6								
	1998	0.2	0.01	1.3	0.1	0.1	0.1	0.01	0.3		0.3	
	1999	0.2	0.02	2.1								
	2000	0.18	0.01	1								
	2001	0.13	0.01	1.4								
	2002	0.32	0.018	1.2								
	2003	0.25	0.009	1								
	2004	0.13	0.005	1.2								
	2005	0.12	0.005	0.9								
	2006	0.17	0.010	1.9								
	2007	0.09	0.007	0.9								
	2008	0.1	0.005	1.2								
	2009	0.09	0.010	1.3								
	2010	0.14	0.009	3.7								
	2011	0.11	0.013	1.4								
	2012	0.11	0.005	1.5								
	2013	0.16	0.006	6.5								
	2014	0.31	0.013	2.9								
	2015	0.26	0.010	2.2								
	2016	0.19	0.004	2.2								

Table A.2 25. cont.

Site	Year	Pb μg/l	Cd μg/l	Zn μg/l	Ni μg/l	As μg/l	Cu μg/l	Co μg/l	Cr μg/l	V μg/l	Al μg/l	Hg ng/l
Svanvik	1987	2	0.14	6	19.9*	2.4*	21.8*					
	1988	3.7	0.1	7.4	12.8	1.6	14.6					
	1989	1.4	0.14	4.6	15.5	1.3	14.4					
	1990	1.6	0.14	6.2	11.4	1.8	13.6	0.4	0.5			
	1991	1.3	0.07	3.4	9.3	1.1	10.4	0.3	0.4			
	1992	1.1	0.11	2.8	8.0	1.1	11.9	0.3	0.5			
	1993	1.1	0.12	3	10.9	1.2	13.4	0.4	0.6			
	1994	1.4	0.08	5	13.4	1.4	12.5	0.4	0.4			
	1995	1.7	0.11	5.4	17.4	1.8	17.4	0.6	0.4			
	1996	0.9	0.06	3.3	17.5	1.1	18.7	0.6	0.4			
	1997	1.9	0.11	3.8	17.3	1.8	21.4	0.6	0.3			
	1998	1.08	0.11	4.1	23.7	2.34	28.1	0.72	0.39			
	1999	0.83	0.08	8.4	11.1	1.41	14.0	0.37	0.32			
	2000	1.99	0.12	5.4	17.8	1.85	20.3	0.53	0.25			
	2001	2.56	0.16	8.5	20.7	2.31	20.2	0.65	0.39			
	2002	2.64	0.054	7	11.1	1.26	12.0	0.32	0.21			
	2003	2.32	0.08	6.2	10.6	0.85	12.0	0.34	0.22			
	2004	1.32	0.084	6.5	36.9	0.91	31.0	0.95	0.39			
	2005	1.84	0.143	5.2	55.3	1.72	58.0	1.59	0.41			
	2006	1.15	0.134	8.5	33.4	1.31	44.5	1.14	0.31			
	2007	1.25	0.231	4.5	45.2	1.83	41.6	1.14	0.61			
	2008	0.84	0.181	4.7	29.8	1.3	25.4	0.90	0.48			
	2009	1.63	0.146	3.8	42.0	2.21	32.6	1.13	0.85	0.56	15	
	2010	0.78	0.082	4.2	22.6	0.64	11.9	0.50	3.12	0.66	31	
	2011	0.85	0.186	3.9	17.5	1.06	30.1	0.58	0.34	0.46	22	
	2012	0.59	0.041	2.9	15.7	0.81	24.5	0.47	0.18	0.33	22	
	2013	1.09	0.059	3.9	26.0	1.7	51.1	0.78	0.23	0.79	23	
	2014	1.13	0.065	5.2	17.7	1.21	28.7	0.52	0.22	0.48	22	
	2015	1.93	0.084	5	29.3	1.49	33.5	0.89	0.36	0.47	35	
	2016	1.04	0.062	5.2	26.5	1.29	29.5	0.83	0.26	0.34	24	

Table A.2 26. Annual average volume weighed mean concentration of heavy metals in precipitation at Norwegian background sites, which have been closed down.

Site	Year	Pb µg/l	Cd µg/l	Zn µg/l	Ni µg/l	As µg/l	Cu µg/l	Co µg/l	Cr µg/l	Hg ng/l
Lista	1990									13.8
	1991									11.8
	1992									10.9
	1993									11.3
	1994	2.7	0.05	7.8	0.3	0.2	1		0.2	8.1
	1995	2.3	0.06	8.6	0.4	0.4	1.1		0.8	13.9
	1996	3	0.07	8.6	0.4	0.4			0.3	19.7
	1997	2.8	0.05	6.6	0.4	0.5	1	0.04	0.2	10.6
	1998	2.08	0.047	8.8	0.59	0.2	1.13	0.03	0.58	9
	1999	1.5	0.03	7.4	0.4	0.2	1.7	0.03	0.2	9.7
	2000	1.57	0.037	6.6	0.34	0.28	1.13	0.03	<0.2	7.3
	2001	1.52	0.056	7.4	0.37	0.18	1.28	0.02	0.31	7.3
	2002	2.15	0.033	6.8	0.3	0.29	1.3	0.02	0.16	12.8
	2003	1.92	0.063	7.5	0.5	1.01	1.3	0.04	0.31	8.3
Ualand	1994	2	0.04	4	0.2	0.1	0.5	0.02	0.1	
	1995	1.7	0.03	3.3	0.2	0.1	0.3	0.01	0.1	
	1996	1.3	0.03	2.5	0.2	0.1	0.9	0.01	0.2	
	1997	2.77	0.02	2.6	0.2	0.1	0.4	0.01	0.1	
	1998	1.24	0.024	2.7	0.19	0.1	0.3	0.02	0.17	
	1999	0.88	0.023	2.3	<0.2	<0.1	0.23	0.01	<0.2	
	2000	0.71	0.021	1.5	<0.2	<0.1	0.23	0.01	<0.2	
Solhomfjell	1994	2.4	0.06	6	0.2	0.1	0.7	0.02	0.1	
	1995	1.9	0.07	6	0.6	0.2	1.1	0.03	0.2	
	1996	2.3	0.05	5.7	0.3	0.2	0.9	0.02	<0.2	
Møsvatn	1994	1	0.04	2.9	0.6	0.1	0.5	0.03	<0.1	
	1995	0.9	0.03	2.8	0.3	0.1	0.9	0.01	0.1	
	1996	1	0.02	4.5	0.4	0.1	1	0.02	0.1	
	1997	1	0.02	4.5						
	1998	0.88	0.044			0.07		0.03	0.13	
	1999	1.05	0.042	5.7	0.29	<0.1	1.65	0.02	<0.2	
	2000	1.02	0.042	6.2	0.29	<0.1	1.72	0.01	<0.2	
Osen	1988	4.7	0.31	12.7						
	1989	2.7	0.08	5.4						
	1990	2.7	0.09	5.6						
	1991	2	0.03	4.2						
	1992	1.6	0.05	5.5						
	1993	1.2	0.06	3.5						
	1994	1.4	0.05	5.9						
	1995	2.1	0.07	8.8						
	1996	1.5	0.03	4.4						
	1997	0.9	0.02	4						
	1998	0.87	0.033	4.7						
	1999	1.05	0.042	7.1						
	2000	1.37	0.047	5.5						
	2001	0.59	0.019	3.3						
	2002	0.87	0.029	4.3						
	2003	0.61	0.031	5.1						
Valdalen	1994	1	0.03	4.2	0.1	0.1	0.6	0.01	0.1	
	1995	1.4	0.03	4.6	0.4	0.1	0.8	0.02	0.2	
	1996	1.1	0.03	4.1	0.3	0.1	1	0.03	0.2	
	1997	1.1	0.05	6.2	0.4	0.1	0.1	0.02	0.2	
	1998	0.76	0.03	4.8	0.17	0.09	0.57	0.02	0.16	
	1999	0.69	0.1	9.6	0.47	<0.1	1.13	0.02	0.37	
	2000	1.01	0.026	4.2	<0.2	<0.1	0.47	0.02	<0.2	

Table A.2 26. cont.

Site	Year	Pb µg/l	Cd µg/l	Zn µg/l	Ni µg/l	As µg/l	Cu µg/l	Co µg/l	Cr µg/l
Namsvatn	1994	0.5	0.03	2.3	0.2	0.1	0.4	0.02	0.1
	1995	0.5	0.01	2.3	0.3	0.1	0.2	0.01	0.1
	1996	0.5	0.02	3	0.1	0.1	0.5	0.01	<0.2
Øverbygd	1995	0.4	0.01	2.3	0.4	0.1	0.5	0.02	0.1
	1996	0.5	0.03	3.5	0.4	0.1	1.3	0.02	0.3
	1997	0.5	0.01	2.7	0.1	0.1	0.3	0.01	0.1
	1998	0.4	0.01	3.8	0.2	0.1	0.6	0.02	0.1
	1999	0.54	0.01	5	<0.2	<0.1	0.33	0.01	<0.2
	2000	0.37	0.02	1.9	0.21	<0.1	0.38	0.01	<0.2
Jergul	1979	3.5	0.22	7.8					
	1980	2.6	0.08	4.5					
	1981	1.8	0.05	3.5					
	1982	2.3	0.11	3.1					
	1983	1.5	0.07	3.6					
	1984	2.2	0.09	9.8					
	1985	2	0.08	5					
	1986	2	0.03	5.2					
	1987	1.3	0.07	4.6					
	1988	1.3	0.07	5.1					
	1989	1.3	0.05	3.3					
	1990	0.7	0.16	2.7					
	1991	0.7	0.02	2.2					
	1992	0.5	0.05	1.6					
	1993	0.5	0.05	2.4					
	1994	0.5	0.03	4.1					
	1995	0.8	0.04	3.5					
	1996	0.5	0.02	3.3					
Karasjok	1997	0.6	0.02	3.1					
	1998	0.8	0.04	3.5					
	1999	0.44	0.03	5.8					
	2000	0.57	0.02	11.6					
	2001	0.67	0.03	4.8					
	2002	0.58	0.033	6.4					
	2003	0.59	0.013	3.4					
	2004	0.74	0.014	4					
	2005	0.5	0.019	4.3					
	2006	0.37	0.02	2.8					
	2007	0.47	0.029	4.7					
	2008	0.38	0.017	7.6					
	2009	0.28	0.024	4.7					

Table A.2 27: Monthly and annual average mean concentrations of heavy metals in PM10 and mercury in gas phase at Birkenes in 2016. Unit: ng/m^3

	As	Cd	Cr	Co	Cu	Pb	Ni	V	Zn	Hg(g)
JAN	0.22	0.046	2.16	0.011	0.80	1.17	0.15	0.28	6.3	1.47
FEB	0.10	0.017	1.05	0.011	0.28	0.41	0.10	0.17	3.1	1.48
MAR	0.16	0.025	0.98	0.013	0.31	0.70	0.16	0.24	3.9	1.48
APR	0.17	0.022	1.45	0.015	0.38	0.49	0.19	0.26	2.4	1.43
MAY	0.17	0.030	1.64	0.028	0.57	0.73	0.26	0.43	2.6	1.40
JUN	0.10	0.015	0.92	0.020	0.40	0.42	0.12	0.28	2.0	1.48
JUL	0.08	0.012	0.91	0.011	0.29	0.25	0.20	0.35	0.9	1.43
AUG	0.09	0.012	0.57	0.006	0.22	0.27	0.11	0.22	1.1	1.41
SEP	0.24	0.033	0.42	0.024	0.80	0.95	0.34	0.56	4.4	1.47
OCT	0.10	0.017	0.41	0.008	0.25	0.36	0.09	0.08	4.6	1.37
NOV	0.13	0.022	1.23	0.010	0.35	0.58	0.12	0.11	5.1	1.36
DEC	0.09	0.020	0.89	0.012	0.28	0.42	0.10	0.17	3.2	1.29
2016	0.14	0.022	1.05	0.014	0.41	0.56	0.16	0.26	3.3	1.42

Table A.2 28: Monthly and annual average mean concentrations of heavy metals in aerosols and mercury in gas phase at Andøya in 2016. Unit: ng/m^3

	As	Cd	Cr	Co	Cu	Pb	Mn	Ni	V	Zn	Hg(g)
JAN	0.17	0.015	0.25	0.008	0.42	0.53	0.51	0.23	0.24	2.4	1.43
FEB	0.05	0.005	0.06	0.004	0.23	0.14	0.15	0.11	0.11	0.7	1.49
MAR	0.02	0.004	0.45	0.009	0.21	0.16	0.39	0.21	0.09	4.0	1.42
APR	0.10	0.009	0.16	0.024	0.37	0.24	0.45	1.13	0.24	0.9	1.35
MAY	0.07	0.011	0.13	0.027	0.28	0.29	0.85	0.18	0.22	1.2	1.43
JUN	0.02	0.004	0.13	0.009	0.12	0.15	0.19	0.10	0.15	0.5	1.53
JUL	0.02	0.002	0.12	0.003	0.12	0.04	0.13	0.06	0.10	0.4	1.47
AUG	0.02	0.002	0.18	0.009	0.17	0.03	0.36	0.08	0.16	0.5	1.40
SEP	0.04	0.006	0.13	0.004	0.16	0.18	0.31	0.08	0.14	1.0	1.37
OCT	0.05	0.011	0.12	0.007	0.20	0.29	0.38	0.07	0.15	1.5	1.41
NOV	0.03	0.005	0.12	0.016	0.17	0.09	0.51	0.07	0.14	0.4	1.43
DEC	0.01	0.002	0.12	0.006	0.12	0.07	0.22	0.05	0.11	0.2	1.45
2016	0.06	0.007	0.16	0.011	0.23	0.20	0.39	0.21	0.16	1.2	1.43

Table A.2 29: Monthly and annual average mean concentrations of heavy metals in aerosols and mercury in gas phase at Zeppelin mountain in 2016. Unit: ng/m^3

	As	Cd	Cr	Co	Cu	Pb	Mn	Ni	V	Zn	Hg(g)
JAN	0.07	0.008	0.31	0.011	0.55	0.19	0.84	0.29	0.08	3.1	1.59
FEB	0.14	0.009	0.16	0.006	0.17	0.28	0.41	0.11	0.09	1.4	1.59
MAR	0.07	0.011	0.14	0.008	0.29	0.30	0.51	0.13	0.05	1.8	1.62
APR	0.04	0.009	0.04	0.006	0.14	0.22	0.20	0.08	0.05	0.6	1.26
MAY	0.03	0.005	0.06	0.006	0.13	0.11	0.26	0.04	0.04	0.5	1.46
JUN	0.01	0.002	0.02	0.002	0.05	0.03	0.14	0.01	0.01	0.4	1.54
JUL	0.01	0.001	0.03	0.009	0.05	0.03	0.12	0.10	0.02	0.3	-
AUG	0.01	0.001	0.02	0.001	0.04	0.01	0.08	0.02	0.01	0.1	1.40
SEP	0.01	0.003	0.02	0.002	0.04	0.07	0.16	0.02	0.02	0.5	1.46
OCT	0.01	0.010	0.15	0.008	0.28	0.07	0.64	0.13	0.05	3.5	1.41
NOV	0.03	0.005	0.29	0.011	0.09	0.14	0.69	0.15	0.07	1.1	1.39
DEC	0.03	0.006	0.36	0.016	0.21	0.17	1.25	0.14	0.09	2.1	1.44
2016	0.04	0.006	0.14	0.007	0.18	0.14	0.46	0.11	0.05	1.4	1.48

Table A.2 30: Monthly and annual average mean concentrations of heavy metals in aerosols at Svanvik in 2016. Unit: ng/m³

	Al	**As**	**Cd**	**Cr**	**Co**	**Cu**	**Pb**	**Ni**	**V**	**Zn**
JAN	18.1	2.43	0.176	0.44	0.405	7.97	3.48	10.90	4.07	8.6
FEB	20.8	6.57	0.384	0.62	1.014	18.05	7.68	25.13	4.57	12.4
MAR	15.7	1.02	0.066	0.14	0.132	2.25	1.51	3.02	0.75	3.0
APR	125.5	2.12	0.131	0.51	0.478	9.40	2.22	11.20	2.77	6.0
MAY	70.2	1.45	0.088	0.46	0.252	5.00	1.56	5.81	1.43	4.1
JUN	38.4	0.91	0.071	0.19	0.201	4.16	1.23	4.45	0.45	2.7
JUL	17.5	0.33	0.028	0.11	0.093	1.63	0.45	2.13	0.27	1.0
AUG	25.2	1.39	0.076	0.21	0.276	5.00	1.42	6.64	0.48	3.5
SEP	6.1	0.56	0.049	0.06	0.077	1.89	1.25	1.92	0.35	1.7
OCT	23.8	1.22	0.132	0.21	0.180	3.56	2.41	4.31	0.74	5.3
NOV	8.6	2.08	0.209	0.19	0.372	9.26	3.06	9.55	2.40	8.2
DEC	5.0	1.06	0.107	0.15	0.111	3.50	1.74	3.16	1.72	3.9
2016	32.3	1.86	0.134	0.29	0.312	6.26	2.47	7.68	1.77	5.3

Table A.2 31: Monthly and annual average mean concentrations of heavy metals in aerosols at Karpdalen in 2016. Unit: ng/m³

	Al	**As**	**Cd**	**Cr**	**Co**	**Cu**	**Pb**	**Ni**	**V**	**Zn**
JAN	19.0	6.02	0.465	0.47	0.470	10.37	7.43	11.46	8.18	13.9
FEB	13.7	8.43	0.550	0.46	0.910	17.44	7.98	20.72	5.85	13.2
MAR	13.7	8.43	0.550	0.46	0.910	17.44	7.98	20.72	5.85	13.2
APR	64.6	3.09	0.219	0.41	0.584	11.11	2.96	13.05	3.43	6.9
MAY	87.2	2.09	0.138	0.43	0.413	8.01	2.13	9.82	1.52	5.3
JUN	32.0	1.18	0.085	0.18	0.233	4.70	1.30	6.06	0.48	2.8
JUL	25.8	1.10	0.096	0.20	0.249	5.43	1.34	6.65	0.46	3.7
AUG	20.6	3.03	0.182	0.29	0.449	8.46	2.96	11.61	0.59	5.2
SEP	8.4	1.20	0.086	0.19	0.236	4.61	1.26	6.02	0.64	3.2
OCT	15.8	0.79	0.070	0.19	0.167	3.13	1.57	4.30	0.70	3.4
NOV	1.6	0.42	0.035	0.04	0.046	1.31	0.60	1.23	0.63	1.4
DEC	3.6	1.61	0.134	0.10	0.114	3.51	2.16	2.91	1.38	4.4
2016	26.2	2.25	0.163	0.26	0.308	6.27	2.56	7.56	1.91	5.3

Table A.2 32: Annual mean concentration of heavy metals in air and aerosols at Norwegian background sites. Unit: ng/m^3

Site	Year	As	Cd	Cr	Co	Cu	Pb	Mn	Ni	V	Zn	Hg (g)	Hg (part)	RGM Apr-May
Lista	1991	0.77	0.063	1.86		0.80	2.69		0.59		4.4			
	1992	0.19	0.046	1.79		0.47	2.35		1.33		3.9	2.06		
	1993	0.41	0.066	3.67		0.85	3.67		0.81		7.0	1.84		
	1994	0.36	0.067	2.80		0.90	3.67		0.88		4.5	1.84		
finfraksjon	1995	0.34	0.06	0.28		0.41	2.74		0.56	1.10	4.2	1.63		
PM(2.5)	1996	0.35	0.068	0.32		0.42	2.95		0.58	1.51	4.3	1.62		
	1997	0.24	0.063	0.57	0.02	0.50	2.55		0.68	1.29	5.0	1.40		
	1998	0.21	0.045	0.61	0.01	0.39	1.94		0.21	0.98	3.9	1.40		
	1999	0.19	0.05	0.18	0.02	0.27	1.82		0.30	0.66	3.9	1.86		
	2000	0.22	0.052	0.82	0.02	0.29	1.92		0.65	1.04	4.3	1.67		
	2001	0.49	0.055	0.37	0.02	0.32	1.98		0.62	6.40	5.4	1.65		
	2002	0.24	0.053	0.30	0.02	0.49	2.43		0.53	1.15	4.2	1.64		
	2003	0.40	0.073	0.28	0.02	0.48	2.47		0.94	1.98	7.5	1.77		
grovfraksjon (PM10-	1995	0.13	0.018	1.54		0.64	1.02		0.25	0.38	1.9			
PM2.5)	1996	0.10	0.015	0.77		0.46	0.79		0.26	0.33	1.5			
	1997	0.08	0.016	0.50	0.03	0.73	0.72		0.23	0.36	2.2			
	1998	0.06	0.148	0.93	0.02	0.40	0.62		0.41	0.25	3.1			
	1999	0.08	0.012	1.36	0.04	0.47	0.52		0.27	0.38				
	2000	0.07	0.014	0.69	0.01	0.37	0.52		0.10	0.35	1.8			
	2001	0.17	0.011	0.64	0.01	0.32	0.44		0.13	1.69	1.6			
	2002	0.06	0.009	0.74	0.01	0.44	0.56		0.11	0.33	1.6			
	2003	0.10	0.009	0.47	0.02	0.37	0.47		0.18	0.58	1.9			
Birkenes	2004	0.20	0.044	<DL		0.83	1.61		0.57	0.70	3.9	1.70		
	2005	0.52	0.088	1.07	0.08	3.45	1.99		2.18	1.44	15.1	1.90		
	2006	0.31	0.063	1.16	0.05	1.56	2.01		0.75	1.20	5.8	1.76		
	2007	0.21	0.047	0.52	0.029	0.82	1.29		0.61	0.81	4.3	1.83		
	2008	0.20	0.035	-	0.030	0.83	1.04		0.55	0.66	3.6	1.73		
	2009	0.21	0.037	1.45	0.028	0.71	1.07		0.66	0.82	5.4	1.69		
Birkenes II	2010	0.18	0.040	0.39	0.033	0.82	1.88		0.50	0.61	4.1	(1.66)		
	2011	0.33	0.050	0.71	0.039	0.93	1.70		0.61	0.61	6.1	1.65		
	2012	0.15	0.028	0.55	0.019	0.52	0.80		0.29	0.35	3.1	1.62		
	2013	0.15	0.027	0.33	0.026	0.52	0.73		0.38	0.39	3.9	1.56		
	2014	0.21	0.033	0.18	0.025	0.59	0.88		0.40	0.45	4.5	1.53		
	2015	0.16	0.025	0.73	0.014	0.50	0.73		0.19	0.21	4.0	1.51		
	2016	0.14	0.022	1.05	0.014	0.41	0.56		0.16	0.26	3.3	1.42		

Table A.2 32. cont.

Site	Year	As	Cd	Cr	Co	Cu	Pb	Mn	Ni	V	Zn	Hg (g)	Hg (part)	RGM Apr-May
Andøya	2010	0.07	0.017	0.44	0.011	0.53	0.58	0.38	0.32	0.25	1.3	1.67		
	2011	0.06	0.010	0.17	0.008	0.27	0.30	0.37	0.12	0.19	0.9	1.61		
	2012	0.06	0.011	0.24	0.013	0.49	0.34	0.58	0.17	0.15	1.5	1.61		
	2013	0.04	0.008	0.11	0.011	0.24	0.24	0.41	0.14	0.12	1.4	1.54		
	2014	0.07	0.025	0.10	0.037	0.25	0.28	0.46	0.13	0.15	1.3	1.50		
	2015	0.06	0.010	0.08	0.006	0.17	0.28	0.23	0.10	0.11	0.8	1.50		
	2016	0.06	0.007	0.16	0.011	0.23	0.20	0.39	0.21	0.16	1.2	1.43		
Zeppelin	1994	0.23	0.034	0.20	0.01	0.32	0.83	0.37	0.19	0.17	1.9	1.79		
	1995	0.14	0.019	0.22	0.01	0.31	0.64	0.42	0.15	0.19	1.5	1.62		
	1996	0.05	0.01	0.23	0.02	0.28	0.48	0.57	0.14	0.12	1.5	1.59		
	1997	0.13	0.024		0.02	0.40	0.69	0.34	0.13	0.20	1.5	1.18		
	1998	0.12	0.027	0.16	0.14	0.35	0.71	0.34	0.12	0.11	1.4	1.55		
	1999	0.10	0.022	0.14	0.06	0.33	0.49	0.47	0.14	0.17	1.6	1.76		
	2000	0.30	0.018	0.06	0.01	0.41	0.62	0.34	0.09	0.07	1.5	1.50		
	2001	0.40	0.016	0.04	0.01	0.31	0.50	0.24	0.08	0.12	1.3	1.56	1.62	
	2002	0.39	0.027	0.04	0.01	0.25	0.66	0.26	0.07	0.08	1.2	1.60	5.3	6.0
	2003	0.12	0.021	0.09	0.01	0.23	0.69	0.34	0.10	0.14	1.3	1.61	2.2	14.5
	2004	0.07	0.018	0.11	0.04	0.31	0.63	0.40	0.10	0.08	4.1	1.50		42.4
	2005	0.11	0.118	0.13	0.03	0.92	1.04	0.40	0.13	0.13	3.2	1.58		
	2006	0.05	0.016	0.08	0.01	0.30	0.44	0.34	0.05	0.10	1.6	1.60		
	2007	0.05	0.023	0.08	0.01	0.61	0.60	0.20	0.09	0.06	1.4	1.68		
	2008	0.05	0.012	0.07	0.007	0.37	0.37	0.23	0.08	0.08	1.6	1.58		
	2009	0.06	0.017	0.14	0.013	0.30	0.43	0.43	0.13	0.13	1.5	1.55		
	2010	0.05	0.014	0.10	0.013	0.17	0.38	0.45	0.14	0.10	1.0	1.56		
	2011	0.07	0.015	0.11	0.010	0.16	0.38	0.45	0.09	0.08	1.0	1.52		
	2012	0.04	0.008	0.09	0.008	0.13	0.22	0.35	0.07	0.05	1.2	1.51		
	2013	0.10	0.012	0.16	0.012	0.25	0.46	0.62	0.12	0.07	2.3	1.47		
	2014	0.05	0.012	0.14	0.012	0.22	0.22	0.60	0.14	0.06	1.7	1.48		
	2015	0.07	0.010	0.16	0.009	0.29	0.26	0.49	0.11	0.06	1.4	1.49		
	2016	0.04	0.006	0.14	0.007	0.18	0.14	0.46	0.11	0.05	1.4	1.48		

Annex 3

Description of methods for sampling, chemical analysis and quality control

Heavy metals

For heavy metals, there are specific requirements for cleanliness for preparation and treatment of the equipment to avoid contamination, i.e. acid-washed equipment is used for sampling and preparations.

Except for mercury, all the trace elements are analysed by inductively coupled plasma mass spectrometry (ICP-MS). The ion optic is optimized for 115 In. The samples are preserved with 1% HNO_3 and an internal standard is used (indium).

For precipitation, a bulk sampler (funnel+collector) from Innovation NILU is used. Precipitation amount is determined by weighing. The entire sample is sent to NILUs laboratory at Kjeller.

Table A.3 1: Quantification limits for heavy metals in precipitation.

Parameter	Lower quantification limit	
As	0.3	(µg As/l)
Zn	0.4	(µg Zn/l)
Pb	0.2	(µg Pb/l)
Ni	0.07	(µg Ni/l)
Cd	0.03	(µg Cd/l)
Cu	0.3	(µg Cu/l)
Cr	0.3	(µg Cr/l)
Co	0.01	(µg Co/l)
V	0.02	(µg V/l)

Sampling of air for the analysis of heavy metals in the particles at Birkenes occurs by means of a Kleinfiltergerät with a PM_{10}-impactor. Weekly samples on Whatman quartz 47 mm filter are collected. This is the same sampler and filter as is used to collect EC/OC. The airflow is 2.3 m^3/hour. At Andøya and the Zeppelin Observatory, sampling of heavy metals in particles are done using a Digitel high volume sampler without any defined size cut off. The airflow rate is 20 m^3/hour and Whatman 41 filters are used. The filters are digested with nitric acid by Ultraclave, a microwave based decomposition technique.

Table A.3 2: Quantification limit for heavy metals in aerosols.

	Lower quantification limit (ng/m^3)		
	Birkenes	Andøya	Zeppelin
Pb	0.15	0.04	0.01
Cd	0.002	0.0003	0.0006
Zn	0.27	1.37	0.79
Cu	0.11	0.42	0.13
Ni	0.67	0.15	0.04
Cr	0.23	0.24	0.02
Co	0.005	0.004	0.0005
As	0.01	0.006	0.002
Mn		1.19	0.04
V	0.005	0.006	0.0007

Mercury

For precipitation sampling of mercury, the IVLs (Swedish Environmental Research Institute AB, Sweden) sampler designed for this element is used. The collector is produced from quartz. The sampler is protected against sunlight and it is located 2 meters above the ground.

Mercury in precipitation is preserved with HCl. A day before analysis, BrCl is added to oxidise all the mercury in precipitation to Hg^{2+}. During the analysis all the mercury is reduced to Hg^0 and absorbed on gold trap. Hg is desorbed form the gold traps using heat and detected using atomfluorescens spectrophotometry. The detection limit for the method is 0.2 ng Hg absolute amount.

Total gaseous mercury (TGM) is measured with a Tekran Hg monitor where the mercury is collected on gold traps in time intervals of 5 minutes at a sampling rate of 1.5 l / min. Mercury is desorbed from the gold traps using heat and detected using atomfluorescens-spectrophotometry. The detection limit for the method is 0.2 ng Hg absolute amount.

POPs and emerging pollutants

Sampling of OCPs, PCBs, PBDEs, HBCDs, TBA, PAHs, PFASs and S/MCCPs

Air samples were collected with two types of high volume air samplers: Digitel and NILU sampler. The samplers consist of a pump that draws air through the samplers with an average air flow rate of 25 m^3/hour; a glass fiber filter (GFF) that collects the particle-associated compounds; and two pre-cleaned PUF plugs that collect the gas phase compounds. For PFAS, only a GFF was used. Specification on each sampler type is given in Table A.3 3. Flow-rate and sampling conditions were digitaly monitored and documented (e.g. power failures, etc.) as an integrated part of the sampling and quality control procedure.

Table A.3 3: Specification on air samplers.

	DIGITEL	NILU sampler
Flow rate	~25 m^3/hour	~25 m^3/hour
Filter	GFF: Whatman Type GF/C	GFF: Gelman Type AE
PUF plugs	Diameter 75 mm, length 40 mm, density 25 kg/m^3	Diameter 110 mm, length 50 mm, density 25 kg/m^3
Usage	PBDEs, HBCDs, TBA (Zeppelin) OCPs, PCBs, PBDEs, HBCDs, TBA, PAHs, PFAS (Andøya) OCPs, PCBs, PBDEs, HBCDs, TBA, PAHs (Birkenes)	OCPs, PCBs, PAHs, PFAS, S/MCCPs (Zeppelin) PFAS (Birkenes)

Sampling was done on a weekly basis for each POP class at each observatory. The sampling duration for each sampling station and POP class varied according to Table A.3 4. The variable sampling lengths resulted in actual total air volumes of 600-1950 m^3 (as reported on sampling protocols).

Table A.3 4: Sampling durations for individual POP classes at each sampling station.

	Birkenes	Andøya	Zeppelin
OCPs	24 h	72 h	48 h
PCBs	24 h	72 h	48 h
PAHs	24 h	-	48 h
PBDEs	48 h	72 h	72 h
HBCDs	48h	-	72 h
PFAS	24 h	48 h	48 h
S/MCCPs	24 h	-	-

After sampling the exposed filters (GFF and PUFs) were sealed separately in gas-tight containers and transported to NILU's laboratory for further processing and quantification. In addition, a number of field blank samples followed the yearly sample batch in order to control potential contamination risks (as a part of the extensive quality control procedure of the NILU monitoring program). All exposed filters were registered and stored frozen (−20°C) prior to analysis and quantification. The GFF and PUFs were extracted in the same solvent to obtain the bulk concentration (gas+particle phase) of the individual target compounds (below). Exceptions were PFAS for which only GFFs were used during sampling and the obtained concentrations represent the particle phase concentrations.

Sampling of Cyclic volatile methyl siloxanes (cVMS)

Sampling of cVMS differed from the rest of the compounds. Sampling was done with a solid-phase extraction active air sampling (SPE-AAS) method with an ENV+ sorbent (hydroxylated polystyrene divinylbenzene copolymer) (Kierkegaard and McLachlan, 2010, Krogseth et al., 2013a) with a flow rate of 1.0 m^3 per hour. Sampling was done during two sampling campaigns; one in summer (18th July-8th August) and one in early winter (25th Nov-13th Dec) 2016. The summer and winter campaign contained six and seven individual sampling events, respectively, The average sampling time was 82.3 ± 15.8 h, and the average volume of air sampled was 87.3 ± 17 m^3.

Each sample was represented by three SPE-AAS cartridges: From pump 1, from pump 2 and a field blank. This means six field blanks for the summer campaign and seven field blanks for the winter campaign. Each of the cartridge sets were extracted individually.

All operations were strictly performed in a clean cabinet and of laboratory personnel without personal-care products in order to reduce the risk of contamination during the preparation and analytical steps.

All samples were spiked to the upper frit of a cartridge with 20 µL of internal standard (IS) containing 13C-isotope labeled D4, D5 and D6 in acetone (1ng/µl). Then the cartridge was eluted slowly with ca 3 ml of hexane, so that 1.5 ml of eluate was collected into a glass vial. Before quantitative analysis, 50µl of a recovery standard containing M4T in hexane (0.2 ng/ul) was added to the vial and the vial was sealed immediately with a crimp cap. An aliquot was taken and transferred to a crimped cap GC vial prior to instrumental analysis.

Extracts were analysed on an Agilent 7890A GC connected to an Agilent 5975C MS detector and a Gerstel MPS3 autosampler. Helium (purity 5.0) was used as carrier gas (constant flow rate 1.0 mL min-1). The GC injector was equipped with a Merlin microseal septum and a 5.0 mm I.D. gooseneck splitless liner with deactivated glass wool (Restek, USA), while a 5 m Rxi guard column (Restek, 0.32 mm I.D.) was connected to a 30 m DB-5 column (Agilent Technologies, 0.25 mm I.D., 0.25 µm film thickness). A 100 µl syringe was used to inject 10 µL sample at an injector temperature of 200 °C. The GC oven started at 40 °C for 1 min, followed by 10 °C min-1 up to 150 °C and 35 °C min-1 to 300 °C with a final hold time of 4 min. The MS ion source was operated at 230 °C and the quadrupole at 150 °C. Two ions were monitored for each compound (m/z 281 and 282 for D4, 285 and 286 for 13C4-D4, 267 and 355 for D5, 364 and 365 for 13C10-D5, 341 and 429 for D6, 434 and 435 for 13C6-D6). Seven-point calibration curves (5 ng ML-1 to 200 ng ML-1) were used for quantification.

Analysis and quantification of OCPs, PCBs and S/MCCPs

Samples were spiked with 20 µL of internal standards (IS) containing 13C-labelled PCB congeners (~230 pg/µL), 20 µL IS containing 13C-labelled OCP congeners (~100-2500 pg/µL), 50 µL IS containing ^{13}C-labelled hexachlorodecane (~1000 pg/µL) for SCCP and 20 µL IS containing ^{13}C-labelled trans-CD (~500 pg/µL) for MCCP, and then Soxhlet extracted for 8 h in diethylether/*n*-hexan (10:90, v:v). The filters and the corresponding PUF plugs were extracted separately, but in the same solvent in order to unify the sample. The extract was concentrated and cleaned by acid treatment and silica fractionation. Before quantitative analysis, 20 µL of unlabelled tetrachloronaphthalene (TCN, 100 pg/µL) was added as recovery standard (RS).

Identification and quantification of the PCBs and OCPs was carried out using a high-resolution gas chromatography coupled to a high-resolution mass spectrometer as detector (HRGC/HRMS). The analyses were performed in Electron Impact ionization mode (EI: PCBs, HCB, HCHs, DDTs) and Negative Ion Chemical Ionization mode (NICI: Chlordanes) using selected ion monitoring (SIM) for the respective compounds groups. In total, 32 PCB congeners and 13 organochlorine pesticides (OCPs) were quantified.

SCCPs and MCCPs were identified and quantified using a GC coupled to a VG AutoSpec, HRMS operating in ECNI mode (GC/HRMS-ECNI).

Analysis and quantification of PAHs

Samples were spiked with 20 µL of IS containing deuterated PAH congeners (10 ng/µL) and then Soxhlet extracted for 8 h in cyclohexane. The filters and the corresponding PUF plugs were extracted separately, but in the same solvent in order to unify the sample. The extract was then concentrated and cleaned by silica fractionation. Before quantitative analysis, 20 µL RS containing deuterated PAH congeners (1.5 ng/µL) was added.

Identification and quantification of the PAHs was carried out using a high-resolution gas chromatography coupled to a low-resolution mass spectrometer as detector (GC/LRMS). The analyses were performed in EI mode using SIM. In total, 28 PAH and 7 methyl-PAH were quantified.

Analysis and quantification PBDEs, TBA, HBCDs

Samples were spiked with 20 µL of internal standards (IS) containing 13C-labelled PBDE congeners (~270-2500 pg/µL) and 20 µL IS containing 13C-labelled HBCD congeners (100 pg/µL), and then Soxhlet extracted for 8 h in in diethylether/*n*-hexan (10:90, v:v). The filters and the corresponding PUF plugs were extracted separately, but in the same solvent in order to unify the sample. The extract was then concentrated and cleaned by acid treatment and silica fractionation. Before quantitative analysis, the extract was split in two; one for PBDE/TBA and one for HBCD analysis. The extract for PBDE/TBA was spiked with 20 µL of unlabelled TCN (100 pg/µL) as recovery standard, and the extract for HBCD analysis was spiked with 20 µL RS containing deuterated ß-HBCD (130 pg/µL).

Identification and quantification of the PBDEs and TBA was carried out using a HRGC/HRMS operating in EI mode using SIM for the respective compounds groups. In total,17 PBDE congeners plus TBA were quantified.

For identification and quantification of HBCDs, an aliquot of the final sample extract was solvent exchanged into methanol. The extract was then analysed using high performance liquid chromatography system in combination with a time-of-flight high resolution mass spectrometer as detector (HPLC/MS-TOF). The analyses were performed with Electrospray ionisation (ESI) in negative ion mode using full scan mass detection. In total 3 HBCDs were quantified.

Analysis and quantification PFAS

The filters were spiked with 20 µL of internal standards (IS) containing ^{13}C-labelled PFAS congeners (0.1 ng/µL) and then extracted using sonication bath for 3x10 min in methanol. The extract was then concentrated and cleaned with acidified Envi-Carb. Before quantitative analysis, 10 µL of unlabeled 3.7-dimethyl PFOA (0.1 ng/µL) was added as recovery standard.
Identification and quantification of the PFASs was carried out using UHPLC/MS-MS with ESI in negative ion mode using selected-reaction monitoring (SRM). In total, 12 PFASs were quantified.

Sampling and analysis of POPs in precipitation

Precipitation samples were collected at Birkenes using bulk samplers. This sampler consists of a glass cylinder (60 mm height, 285 mm inner diameter), a glass funnel and a Pyrex glass bottle (1-2 L). The sampler is installed on a supporting system about 2 m above the ground level. Samples are collected on a weekly basis starting on Mondays, resulting in samples composed of one or more bottles depending on the amount of rain. The samplers are continuously open, both during dry and wet periods. It may result in non-wanted dry deposition in some samples.

Analysis and quantification of POPs in precipitation

The precipitation samples were spiked with 20 µL of IS containing 13C-labelled PCB/HCB/HCH/PAH congeners (0.1 ng/ µL) and then liquid extracted in cyclohexane for 4 h. After separation and removal of the water phase the solvent extract is split for further cleanup for PAHs and PCB/HCB/HCH separately. The PAH extract is cleaned by silica fractionation and the PCB/HCB/HCH extract is cleaned by acid treatment and silica fractionation.

Identification and quantification of the PCBs, HCB and HCHs was carried out using a HRGC/HRMS. The analyses were performed in EI mode for PCBs and HCB, and in NICI mode for HCHs. In total, seven PCB congeners, HCB and two HCHs were quantified.

Identification and quantification of the PAHs was carried out using a GC/LRMS. The analyses were performed in EI mode using SIM. In total, 28 PAH and 7 methyl-PAH were quantified.

Quality assurance/Quality control (QA/QC)

NILU's laboratories; the organic and inorganic chemical analyses, are accredited in accordance to NS-EN ISO/IEC 17025. The accredited sampling and analytical methods are to be found under accreditation number TEST 008 and includes P12 chemical analysis and P3002 air sampling. The chemical analysis, in turn, include heavy metals. Mercury, PCBs, and organochlorine pesticides (HCB, HCHs, chlordanes, DDTs).
All sampling equipment at the monitoring stations undergo routine controls and calibration of flow rates.
Field blank samples (n=3) and lab blank samples (n=12) were routinely included in order to control unintended contamination during storage, transport and analytical steps. Field blanks, consisting of pre-cleaned PUF plugs and filters, were sent to each station where they were exposed during the assembly and retrieval of the PUF plugs and filters in field, but kept unexposed in foil and air tight bags during the exposure time. They were then transported, stored, extracted, cleaned and analyzed in the same way as and parallel with the real samples. The lab blanks were obtained by extracting pre-cleaned PUFs and filters in solvent and using the same clean-up and analytical procedures as real samples and field blanks.
The analytical procedure was accompanied by a comprehensive quality control program based on the requirements of NILU's accreditation, according to EU standard EN 45001. The instrument limit of detection (LOD) was determined by calculating the signal-to-noise ratio (S/N) > 3 for solvent blanks (using n-hexane). Based upon average blank concentrations (laboratory blanks) the limit of quantification (LOQ) was calculated for all compounds with LOQ = average blank value plus 3 standard deviations (STD) of the blank concentrations.

All samples within the range LOQ>×>LOD are considered to have high uncertainties and are reported as <LOQ. All raw data are openly accessible from the NILU database (http://ebas.nilu.no) for thorough examinations. Values below LOD were used as LOD/2 in further statistical treatment.

The laboratory is routinely participating in laboratory performance studies for POPs and heavy metals through QUASIMEME (Quality Assurance of Information for Marine Environmental Monitoring in Europe).

Sampling and analysis of new organic contaminants (i.e. cVMS and S/MCCPs) are associated with a bigger uncertainty than the well-established contaminants. This is due to more diffuse sources in laboratories and sampling facilities that results in a larger risk for contamination. NILU is continuously taking actions to minimize this influence.

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The Norwegian Environment Agency is working for a clean and diverse environment. Our primary tasks are to reduce greenhouse gas emissions. manage Norwegian nature, and prevent pollution.

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.