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Monitoring of environmental contaminants in air and precipitation

Annual report 2018

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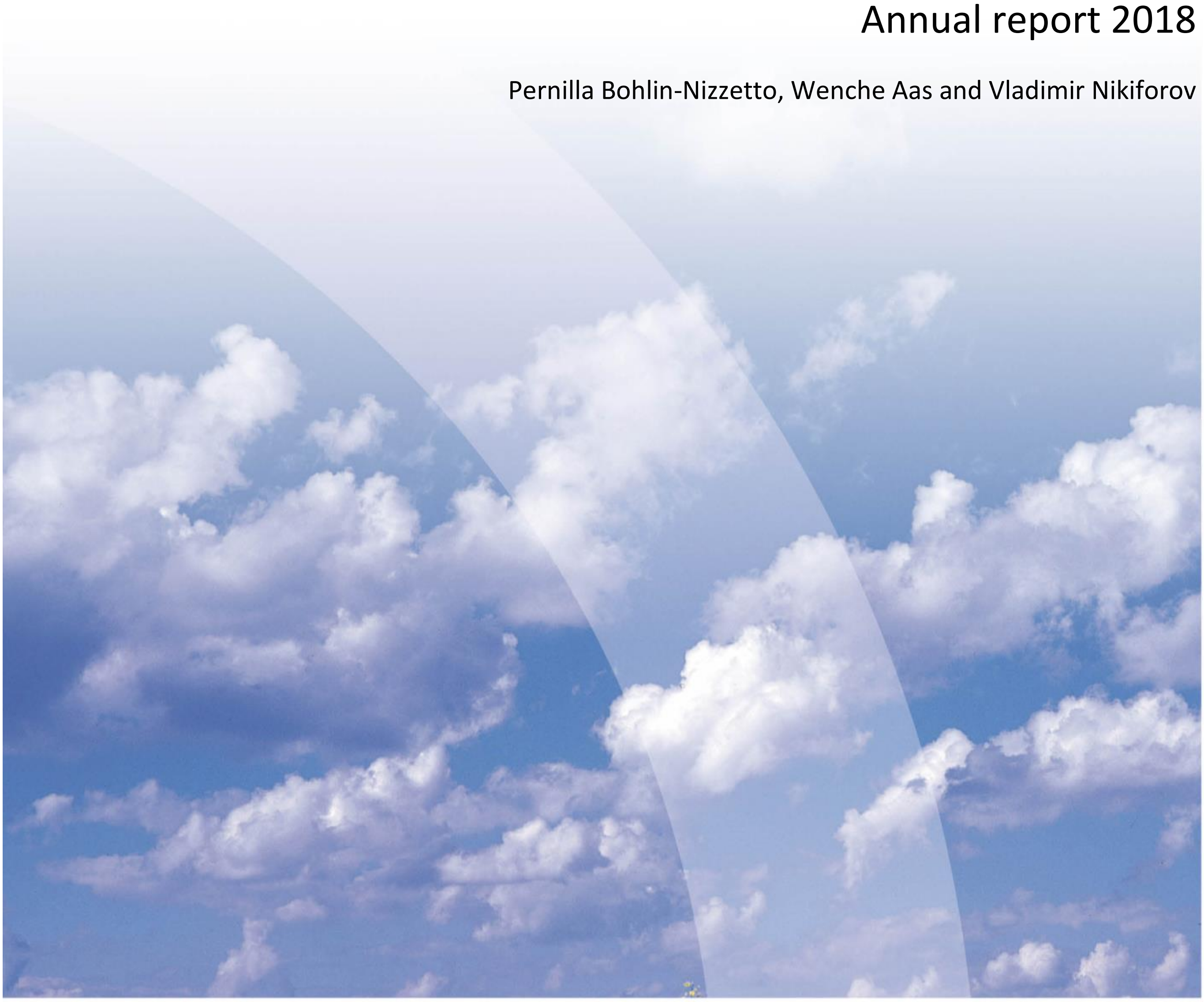

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ABSTRACT

This report presents environmental monitoring data from 2018 and time-trends for the Norwegian programme for Long-range atmospheric transported contaminants. The results cover 200 organic compounds (regulated and non-regulated), 11 heavy metals, and organic chemicals of potential Arctic concern.

NORWEGIAN TITLE

Overvåking av langtransporterte atmosfæriske miljøgifter i luft og nedbør, årsrapport 2018

KEYWORDS

Environmental chemistry/ Miljøkjemi	Long-range transport of air pollutants/ Langtransportert luftforurensning	Environmental monitoring Miljøovervåkning	Persistent pollutants Miljøgifter

ABSTRACT (in Norwegian)

Denne rapporten inkluderer miljøovervåkningsdata fra 2018 og tidstrender for programmet Langtransporterte atmosfæriske miljøgifter. Resultatene omfatter 200 organiske miljøgifter (regulerte og ennå ikke regulerte), 11 tungmetaller og et utvalg organiske kjemikalier som potensielt er bekymringsverdige for Arktisk miljø.

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Summary

This report presents monthly and annual concentrations of selected environmental contaminants in air and precipitation at Norwegian background sites in 2018. The monitoring is done for the Norwegian monitoring programme "*Long-range atmospheric transported contaminants",* together with the programmes for "*Long-term dataseries*" and "*the Norway-Russia measurements*". The overall purposes of the monitoring are to i) increase the knowledge on long-range transported contaminants as a source for pollution in Norway, ii) assess spatial variabilities of environmental contaminants in Norway, and iii) provide data for international conventions, programmes and networks.

The monitoring programme was revised and modified in 2017 to include an even greater number of organic contaminants of emerging concern, in order to support future regulations/measures on national and international levels. This modification affected both the types and number of organic contaminants as well as the sampling frequency. No changes were made for heavy metals and mercury, and the sampling sites in 2018 were the same as before. Air monitoring of persistent organic pollutants (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 in precipitation (i.e. Birkenes). In 2018, the monitoring programme was further extended with temporary seasonal measurements at Zeppelin of bisphenols, linear siloxanes and data-mining for new organic chemicals of potential emerging Arctic concern, and at Birkenes with phthalates, new brominated flame retardants (nBFRs) and organophosphorous flame retardants (OPFRs).

Long-term monitoring data of regulated organic contaminants

A number of regulated POPs and POP-like substances have been monitored in air for more than 15 years, before the Stockholm Convention came into force: Hexachlorobenzene (HCB) at Birkenes and Zeppelin, hexachlorohexanes (HCHs) at Birkenes and Zeppelin, dichlorodiphenyltrichloroethane (DDTs) at Zeppelin, chlordanes at Zeppelin, polychlorinated biphenyls (PCBs) at Zeppelin, and polycyclic aromatic hydrocarbons (PAHs) at Zeppelin. Long-term data is also available for HCHs and PCBs in precipitation from Birkenes. The results from the long-term monitoring, including trend analyses, show decreasing concentrations over time for HCHs and DDTs with short estimated half-lives around 5 years during the whole monitoring period. No significant change in trends (expressed as half-lives) are seen in the period after the Stockholm Convention came into force (2004-2018). For HCHs, DDTs, chlordanes and PCBs the monitoring results show only small decreases in concentrations or fluctuating concentrations over the last years. This suggests that these POPs have entered into a temporal remote state where the primary emissions have to a large extent stopped and the global concentrations now instead are controlled by emissions from secondary repositories. For HCB, increasing concentrations in air have been observed during a period of 15 years at Zeppelin and seven years at Birkenes, but this increase seems to have turned during the last two years when instead the concentrations are lower than previous years. The concentration of HCB in 2018 were one of the lowest since 2003. For PAHs and benzo(a)pyrene (B(a)P), an increase in concentrations is observed at Birkenes while a decrease is observed at Zeppelin.

Short-term monitoring of organic contaminants

For some compounds and some stations, the air monitoring has been performed for shorter time-periods than 15 years (i.e. 10 to 13 years), and monitoring started after Stockholm Convention came into force. No long-term trend analysis has been performed for these compounds; polybrominated diphenyl ethers (PBDEs) at Birkenes and Zeppelin, hexabromocyclododecanes (HBCDs) at Birkenes and Zeppelin, and ionic per- and polyfluorinated alkylsubstances (PFAS) at Birkenes, Andøya and Zeppelin.

In this report, all of the targeted ionic PFAS are grouped even if not all the compounds are subject to regulation. Many of the PBDEs, HBCDs and PFAS-compounds are below detection limit in the air samples, e.g. all three HBCDs and several BDE- and PFAS-compounds are showing very low levels in air at the background sites. Of the targeted PFAS, only PFOA is detected at all three sites, with the highest annual mean concentrations of PFOA measured at Birkenes (0.3 pg/m^3) compared to 0.1 pg/m^3 at Andøya and Zeppelin.

Monitoring of non-regulated organic contaminants of emerging concern

Two groups of non-regulated organic contaminants of emerging concern: Cyclic volatile methylsiloxanes (cVMS) and short- and medium chain chlorinated paraffins (SCCPs and MCCPs), have been monitored at Zeppelin since 2013, and at Birkenes since 2017. The non-regulated ionic PFAS monitored since 2006/2009, are grouped together with the regulated ionic PFAS above.

The annual concentrations for the two cVMS oligomers; D5 (1.6 ng/m^3) and D6 (0.3 ng/m^3), at Zeppelin in 2018, were higher than in 2017, but the concentrations during summer (July-August) were still significantly lower than the concentrations measured in previous years (2013-2016). The annual mean concentrations measured for SCCPs at Zeppelin do not show any significant difference between the years (2013-2018), but the MCCPs at Birkenes in 2018 were higher than previous years.

In 2018, nBFRs, OPFRs and phthalates were monitored in sampling campaigns in summer and winter at Zeppelin and Birkenes, and volatile PFAS were monitored every month at Birkenes, Andøya and Zeppelin. The results from these sampling campaigns show that the concentrations of the individual phthalates in air are high, in the same range as the cVMS (ng/m^3), at both Birkenes and Zeppelin. Only a few of the targeted OPFRs were detected in the air samples from Birkenes and Zeppelin. The concentrations of the detected individual OPFRs in air were, however, high, in the same range as the S/MCCPs (100s pg/m^3). Of the volatile PFAS, only FTOHs were detected in more than 50% of the samples and the dominant PFAS-compounds were 6:2 and 8:2 FTOH at all sites. Few of the targeted nBFRs were detected at Birkenes and Zeppelin (five and three of 14, respectively). The detected concentrations in air of nBFRs were 100-1000 times lower than OPFRs and phthalates, in the same range as the legacy POPs.

In 2018, two new groups of non-regulated organic contaminants of emerging concern were monitored for the first time at Zeppelin: Bisphenols and linear siloxanes. The measurements at Zeppelin show that all the three targeted linear siloxanes were below detection limit. Of the 18 targeted bisphenols, most were below detection in all samples, but bisphenol A were detected in all samples (0.7-2.2 pg/m^3) and bisphenol F were detected in 40% of the samples. This suggest presence of these bisphenols in Arctic air. This may suggest long-range transport of bisphenols, but it is important to also evaluate the influence of local sources in the Arctic (e.g. indoor environments) on these concentrations.

In 2018, air samples from Zeppelin were also analysed using a data-mining approach to identify new organic contaminants of interest and potential emerging Arctic concern. The results from the data-mining were compared to results from air measurements in the national screening programme in 2017 (Schlabach, 2018). The data from 2018, confirmed the findings of three volatile fluorinated substances in Arctic air (PFTBA, TCHFB and DCTFB). A list of 21 organic compounds that were detected in all the samples analysed with data-mining approach, is provided in this report.

Spatial distribution of organic contaminants

For HCHs, DDTs, PCBs, and PAHs, the concentrations in air were higher at Birkenes in southern Norway than at Zeppelin in the Arctic. This, together with episodes of high concentrations that were associated with transport of air masses from source regions, reflects Birkenes' closeness to potential source regions in continental Europe. Also most of the organic contaminants of emerging concern; cVMS, MCCPs, OPFRs and nBFRs, were observed at higher concentrations at Birkenes than at Zeppelin in most samples. In contrast, the observed concentrations of HCB, BDE-209, TBA, some FTOHs and phthalates were higher in the Arctic at Zeppelin than in southern Norway at Birkenes. The reason for this is not understood and further research is needed.

Long-term monitoring of heavy metals and mercury

In 2018, the concentrations of heavy metals in precipitation and in aerosols were highest at the sites in Sør-Varanger. The high levels here are further discussed in Berglen et al. (2019) and are due to emissions from smelters in Russia. The wet deposition of lead and cadmium in 2018, however, was highest at Birkenes in southern Norway due to more precipitation at this location. The lowest concentrations of heavy metals in precipitation were observed at Kårvatn, which is furthest away from emission sources. In general, the air concentrations of heavy metals were two-three times lower at Andøya and Zeppelin in the North than at Birkenes in the South, mainly due to closeness to the potential emission sources in continental Europe. For mercury, no significant spatial distribution is observed in Norway. This indicates that this pollutant has a large potential to be transported far from emission sources due to its longer atmospheric lifetime, and a lack of regional primary sources.

In 2018, the concentrations in precipitation were in general somewhat higher for most metals, except at Birkenes were there was a small decrease in lead and mercury. In a long term perspective, the concentrations of lead in precipitation have been reduced by almost 100% between 1980 and 2018; 51-96% since 1990, and 57-66% since 2000. Also for cadmium in precipitation, there are substantial reductions: 95-99% between 1980 and 2018; 42-75% since 1990, and 51-69% since 2000. When combining the datasets from Lista and Birkenes, mercury in precipitation has been significantly reduced by 60% since 1990, and by 40% since 2000.

The air concentrations for most of the trace elements at Birkenes where higher in 2018 compared to 2017. For the other sites, there are more variation depending on components. For mercury, there is almost no difference from the previous year. At Lista/Birkenes there has been a significant reduction in air concentrations for all the measured metals for the period 1991 to 2018. At Zeppelin, there has also been a significant reduction since 1994 for several elements (As, Cd, Cu, Pb, V). The reduction for lead has been 85% and 65% respectively at Birkenes and Zeppelin. For cadmium, the reductions were 67% and 57%, respectively. For mercury, small decreasing trends are observed at Birkenes (21%) and Zeppelin (12%)

Sammendrag

Denne rapporten presenterer månedlige and årlige data i luft og nedbør fra norske overvåkingsstasjoner i rural bakgrunn i 2018. Overvåkingen utføres for det nasjonale overvåkingsprogrammet for langtransporterte atmosfæriske miljøgifter, sammen med programmene «lange tidsserier» og «Norge-Russland overvåkning». Formålet med overvåkingen er å i) øke kunnskapen om langtransport av miljøgifter som kilde til forurensning i Norge, ii) fremskaffe informasjon om romlig fordeling av miljøgiftsnivåer i Norge, og iii) ivareta rapportering til internasjonale konvensjoner, programmer og nettverk. Fra 2017 har overvåkingen spesielt fokus på å fremskaffe luftdata om nye miljøgifter som ennå ikke er regulert på internasjonalt nivå. Dette for å støtte fremtidige tiltak på nasjonalt og internasjonalt nivå.

Overvåkingsprogrammet ble revidert i 2017 med endringer i antall komponenter og prøvetakingsfrekvenser for organiske miljøgifter. For tungmetaller og kvikksølv ble det ikke gjort noen endringer fra tidligere år. 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). Resultatene fra 2018 inkluderer 200 organiske komponenter og 11 tungmetaller. Nye miljøgifter i 2018 inkluderer: Flyktige PFAS, nye bromerte flammehemmere (nBFR), fosfororganiske flammehemmere (OPFR), ftalater, bisfenoler og lineære siloksaner. Alle ble målt med aktiv luftprøvetaking. I tillegg ble en opsjon gjennomført der aktive luftprøver fra Zeppelin ble screenet med hensyn på nye organiske miljøgifter. Formålet med dette var å identifisere nye organiske miljøgifter og sammenligne funnene mot en screeningstudie i 2017.

Lange tidsserier for regulerte organiske miljøgifter
Flere regulerte organiske miljøgifter har vært en del av overvåkingsprogrammet i mer enn 15 år, før Stockholmskonvensjonen trådte i kraft i 2004: HCB på Birkenes og Zeppelin, HCH på Birkenes og Zeppelin, DDT på Zeppelin, klordaner på Zeppelin, PCB på Zeppelin og PAH på Zeppelin. I tillegg finns lange tidsserier for HCH og PCB i nedbør fra Birkenes. Data fra lange tidsserier og resultater fra trendanalyser viser reduserte nivåer for HCH-er og DDT med estimerte halveringstider på 5 år for hele måleperioden samt for perioden etter Stockholmskonvensjonen (2004-2018). For HCHs, DDTs, klordaner and PCBs ses stabile nivåer eller små reduksjoner og dette tyder på at de har oppnådd temporal bakgrunnstilstand der nivåene fremst kontrolleres av sekundære kilder.

For HCB, har overvåkningen påvist økende nivåer i en periode på 15 år på Zeppelin og syv år på Birkenes, men de siste to årene ser det ut til at økningen har avtatt. I 2018 var nivåene av HCB de laveste noensinne eller de laveste siden 2003 på alle stasjonene. For PAHer og B(a)P ser man også en økning på Birkenes mens nivåene på Zeppelin er noe minskende.

Korte tidsserier for regulerte organiske miljøgifter
For noen organiske miljøgifter og noen stasjoner har overvåkingen pågått i kortere perioder enn 15 år (fra 10 til 13 år), etter at Stockholmskonvensjonen trådte i kraft, og lange trendanalyser kan da ikke utføres. Dette inkluderer PBDE på Birkenes og Zeppelin, HBCD på Birkenes og Zeppelin, og ioniske PFAS på Birkenes, Andøya og Zeppelin. Ingen ioniske PFAS er regulert, men inngår her sammen med den regulerte PFOA. Flere PBDE-, HBCD- og PFAS-komponenter blie ikke detektert i luftmålingene som viser at det er lave konsentrasjoner av disse i luft på norske bakgrunnsstasjoner. Kun PFOA er detektert på alle tre stasjonene med høyest konsentrasjoner på Birkenes (0.3 pg/m^3), sammenlignet med 0.1 pg/m^3 på Andøya og Zeppelin. Korte tidstrendsanalyser viser en svak reduksjon av BDE-47 med halveringstider på ca 10 år.

Overvåking av nye miljøgifter

To klasser av nye miljøgifter, siloksaner (cVMS) og klorparafiner, har blitt målt på Zeppelin siden 2013. Fra 2017 er målinger av disse to klassene også inkludert på Birkenes. De ikke-regulerte ioniske PFAS som har blitt målt siden 2006/2009, er gruppert sammen med den regulerte PFOA.

I 2018 var konsentrasjonene av D5 (1.6 ng/m^3) og D6 (0.3 ng/m^3) på Zeppelin høyere enn i 2017, men lavere enn de første årene i tidsserien (2013-2016), hvis man sammenligner samme måleperioder gjennom året. Dette tyder på redusert forekomst av D5 og D6 i arktisk luft under de siste årene, men fortsatte målinger trengs for å bevise dette. Ingen forskjell i perioden 2013-2018 på Zeppelin ses for SCCPs, mens nivåene av MCCPs i 2018 var noe høyere enn tidligere år.

I 2018, ble nBFRs, OPFRs og ftalater målt i en sommer- og en vinterkampanje på Zeppelin og Birkenes. Resultatene viser at det er høye konsentrasjoner av ftalater i luft, på samme nivå som siloksaner (ng/m^3). De OPFR som er detektert i prøvene måles i høye konsentrasjoner, på samme nivåer som klorparafiner (100-talls pg/m^3). Kun et fåtall nBFR er detektert i prøvene og da i konsentrasjoner som er 100-1000 ganger lavere enn OPFR og ftalater.

Flyktige PFAS ble målt i månedsprøver på Birkenes, Andøya og Zeppelin. Av de flyktige PFAS var det kun FTOHer som ble detektert i mer enn 50% av prøvene. De dominerende flyktige PFAS var 6:2 og 8:2 FTOH på alle stasjonene.

Av bisfenoler var det kun bisfenol A og bisfenol F som ble detektert. Ikke noen av de lineære siloksanene ble detektert i luftprøver fra Zeppelin. De lave deteksjonsgrensene tyder på at forekomst av lineære siloksaner i arktisk luft er lav.

Screening av nye organiske miljøgifter i luftprøver fra Zeppelin-stasjonen bekrefter funn av flyktige fluorerte komponenter i arktisk luft (PFTBA, TCHFB and DCTFB). I tillegg ble 21 komponenter detektert i luftprøver fra Zeppelin.

Romslig fordeling av organiske miljøgifter

Det observeres høyere konsentrasjoner av HCH, DDT og PAH i Sør-Norge på Birkenes sammenlignet med den nordlige stasjonen (Zeppelin). For disse komponentene sammenfaller høye episoder med frorekomst av luftmasser fra kildeområder på kontinentet på stasjonen. Også siloksaner, MCCPs og OPFRs måles i høyere konsentrasjoner på Birkenes enn på Zeppelin. For HCB, TBA, BDE-209, ftalater og noe FTOH var det derimot høyere nivåer i nord enn i sør.

Lange tidsserier for tungmetaller og kvikksølv

De årlige gjennomsnittskonsentrasjonene av tungmetaller i luft og nedbør i 2018 var høyest på målestasjonene i Sør-Varanger. Dette skyldes utslipp fra de nærliggende smelteverkene på russisk side. Våtavsetning av bly og kadmium er derimot høyest i Sør-Norge der nedbørmengden er høyest. Laveste konsentrasjoner i nedbør måles på Kårvatn som ligger lengst bort fra kildeområder. Konsentrasjonen av de fleste tungmetallene målt i luft på Andøya og Zeppelin er to til tre ganger lavere enn det som er observert ved Birkenes. For kvikksølv er det ikke store forskjeller mellom stasjonene da kvikksølv har stort potensiale for langtransport. Dette indikerer at det ikke er dominerende primære utslippskilder i regionen.

I 2018 var konsentrasjonen i nedbør generelt noe høyere for de fleste metaller utenom på Birkenes hvor det var en liten nedgang i bly og kvikksølv sammenlignet med året før. I et lengre perspektiv har det vært en betydelig reduksjon av tungmetaller i nedbør i Norge siden 1980; for bly opp mot 100% på Birkenes og Kårvatn. Fra 1990 har det for Birkenes og Kårvatn vært en reduksjon av bly mellom 51-96% og 57-66% for perioden 2000 til 2018. Det er også store reduksjoner for kadmium i nedbør, mellom

95% og 99% fra 1980 til 2018; 42-75% fra 1990, og 51-69% fra 2000. For kvikksølv har det vært en signifikant reduksjon på 60% siden 1990 og 40% fra 2000 når man kombinerer datasettene fra de nærliggende observatoriene Lista og Birkenes.

Luftkonsentrasjonene av de fleste metallene var høyere på Birkenes i 2018 sammenlignet med 2017. For de andre stasjonene var det større variasjoner avhengig av komponent. For kvikksølv var det veldig små forskjeller. På Lista/Birkenes har det vært en betydelig reduksjon i luftkonsentrasjon for tungmetaller som er målt for perioden 1991 til 2018. På Zeppelin har det også vært en betydelig reduksjon siden 1994 for flere tungmetaller (As, Cd, Cu, Pb, V). Reduksjonen av bly har vært på 85% og 65% henholdsvis på Birkenes og Zeppelin. For kadmium er det lignende store reduksjoner, henholdsvis 67% og 57%. For elementært kvikksølv i luft er det en svak nedadgående trend på 21% og 12% på hhv. Birkenes og Zeppelin.

air and precipitation
Annual report 2018

1 Monitoring programme for long-range transported atmospheric contaminants

The monitoring programme for long-range transported atmospheric contaminants was revised in 2017 in order to allow for expanded monitoring of organic contaminants of emerging concern. The programme is still designed to study long- and short-term time trends and spatial distribution of regulated persistent organic pollutants (POPs) and heavy metals, but there is from 2017 also an increased focus on organic contaminants of emerging concern. While the sampling frequency and sampling sites for some of the regulated POPs were reduced, the sampling frequency and sampling sites for emerging contaminants were expanded and new organic contaminants of emerging concern were added.

1.1 Background

The data from 2018, presented in this report, are a compilation of data from four different national projects and programs:

- The monitoring programme “Long-range transported atmospheric contaminants”, conducted by NILU on the behalf of the Norwegian Environment Agency. The programme covers heavy metals and POPs (except PAHs) in air at Birkenes, Andøya and Zeppelin, heavy metals in precipitation at Birkenes, and organic contaminants of emerging concern in air at Zeppelin and Birkenes;
- "The long-term dataseries", a programme covering legacy pollutants in precipitation and air (POPs in precipitation at Birkenes, heavy metals in precipitation at Hurdal and Kårvatn and PAHs in air at Zeppelin). The programme is conducted by NILU and funded by the Ministry of Climate and Environment and NILU;
- “NILUs internal monitoring programme” which covers PAHs in air at Birkenes;
- "The Norway-Russia measurement programme", conducted by NILU on behalf of The Norwegian Environment Agency. The programme covers heavy metals in precipitation at Svanvik and Karpdalen.

Heavy metals and POPs can undergo long-range environmental transport, are toxic, bioaccumulative and persistent in the environment. Due to their harmful impacts on the human health and/or on the environment together with their transboundary nature, monitoring of these contaminants 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 POPs. This in turn has contributed to the regulation of several of these contaminants both on a regional and global scale (Rottem et al., 2017; Downie & Fenge, 2003).

The use and emission of heavy metals and POPs are regulated through several 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 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 POP conventions today includes 28 and 23 substances/substance groups respectively and the number of chemicals included in the regulations are continuously expanded (UN/ECE, 2010, Stockholm Convention, 2015). For example, in 2017, the Conference of the Parties to the Stockholm Convention adopted decisions to list two new POPs in the convention; short-chain chlorinated paraffins (SCCPs) and decabromodiphenyl ether (deca-BDE), and 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 entered into force in 2018. In 2019, the parties to the Stockholm Convention agreed to list two new POPs; dicofol and perfluorooctanoic acid (PFOA). In addition, two chemicals are currently under review as potential POPs under the Stockholm Convention: Perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related compounds and dechlorane plus.

Monitoring data for the contaminants in air and precipitation within this monitoring programme supports policy makers with information on the contaminants’ concentrations in air at background sites on the Norwegian mainland and in the Arctic. This monitoring allows for i) the assessment of long-term trends and evaluation of effectiveness of regulatory actions of legacy POPs and heavy metals, ii) novel understanding of occurrence and distribution of organic contaminants of emerging concern in background air, iii) better understanding of the contaminants’ potential for long-range transport, iv) a better understanding of potential local sources for the organic contaminants of emerging concern in the Arctic. The data may also be used to provide insight into source regions for long-range environmental transport.

The updated monitoring programme in 2017, with the data presented in this report, has a special focus on organic contaminants of emerging concern. The purpose of expanded monitoring of these contaminants 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 in determining adequate policy measures and if necessary, make national or international regulations come into place.

The report is also important for monitoring the effectiveness of and 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) (AMAP, 2016). 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.

1.2 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 organic contaminants of emerging concern, it is important to evaluate possible influences of local sources in comparison to long-range transport since these contaminants still are in use and present in materials and products. Some organic contaminants of emerging concern have been found at elevated levels near Arctic settlements, indicating that these settlements may serve as point sources of new organic contaminants to the Arctic region (Warner et al., 2010; Carlsson et al., 2018).

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 included in this monitoring programme are to a large extent coordinated and thereby the same ones as those within "the national measurement programme of long-range transported air pollutants for main components in air and precipitation", which like this monitoring programme is conducted by NILU on behalf of the Norwegian Environment Agency, and the Ministry of Climate and Environment (Aas et al., 2019). 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 in southern Norway, and Andøya in northern Norway, and one is located on Svalbard in the Arctic: Zeppelin (Figure 1, Table 1). POPs in precipitation is only monitored at Birkenes while heavy metals in precipitation is monitored at four sites: Birkenes and Hurdal in the southern parts of Norway, Kårvatn and Svanvik in Finnmark in northern Norway (Figure 21, Table 1). This report also includes heavy metals in precipitation from Karpdalen in Sør-Varanger and heavy metals in air at Svanvik and Karpdalen (Berglen et al., 2019). Further information of the sampling sites are available at http://www.nilu.no/projects/ccc/sitedescriptions/.

Table 1: Information about the monitoring stations in the programme and list of measured contaminants at each station in 2018.

Monitoring station	**Birkenes**	**Andøya**	**Zeppelin**	**Hurdal**	**Kårvatn**	**Svanvik**	**Karpdalen**
Station code (EBAS)	NO0001R NO0002R	NO0090R	NO0042G	NO0056R	NO0039R	NO0047R	NO0098R
Lat	58 23 N	69 16 N	78 54 N	60 22 N	62 47 N	69 27 N	69 39 N
Long	8 15 N	16 0 E	11 53 E	11 4 E	8 53 E	30 2 E	30 26 E
m.a.s.l.	190/219	380	475	300	210	30	70
Organic contaminants - Air	HCB, HCH, DDTs, PCBs, PBDEs, HBCDs, PAHs, PFAS (ionic + volatile), cVMS, S/MCCPs, nBFRs, OPFRs, phthalates	HCB, PFAS (ionic + volatile)	HCB, HCH, DDTs, chlordanes, PCBs, PBDEs, HBCDs, PAHs, PFAS (ionic + volatile), cVMS, S/MCCPs, nBFRs, OPFRs, phthalates, bisphenols, linear siloxanes, data mining				
Organic contaminants - Precipitation	HCB, HCHs, PCBs						
Heavy metals - Air	As, Cd, Cr, Co, Cu, Pb, Ni, V, Zn, Hg	As, Cd, Cr, Co, Cu, Pb, Mn, Ni, V, Zn, Hg	As, Cd, Cr, Co, Cu, Pb, Mn, Ni, V, Zn, Hg			Al, As, Cd, Cr, Co, Cu, Pb, Ni, V, Zn	Al, As, Cd, Cr, Co, Cu, Pb, Ni, V, Zn
Heavy metals - Precipitation	As, Cd, Cr, Co, Cu, Pb, Mn, Ni, V, Zn, Hg			Cd, Pb, Zn	Cd, Pb, Zn	Al, As, Cd, Cr, Co, Cu, Pb, Mn, Ni, V, Zn	Al, As, Cd, Cr, Co, Cu, Pb, Ni, V, Zn

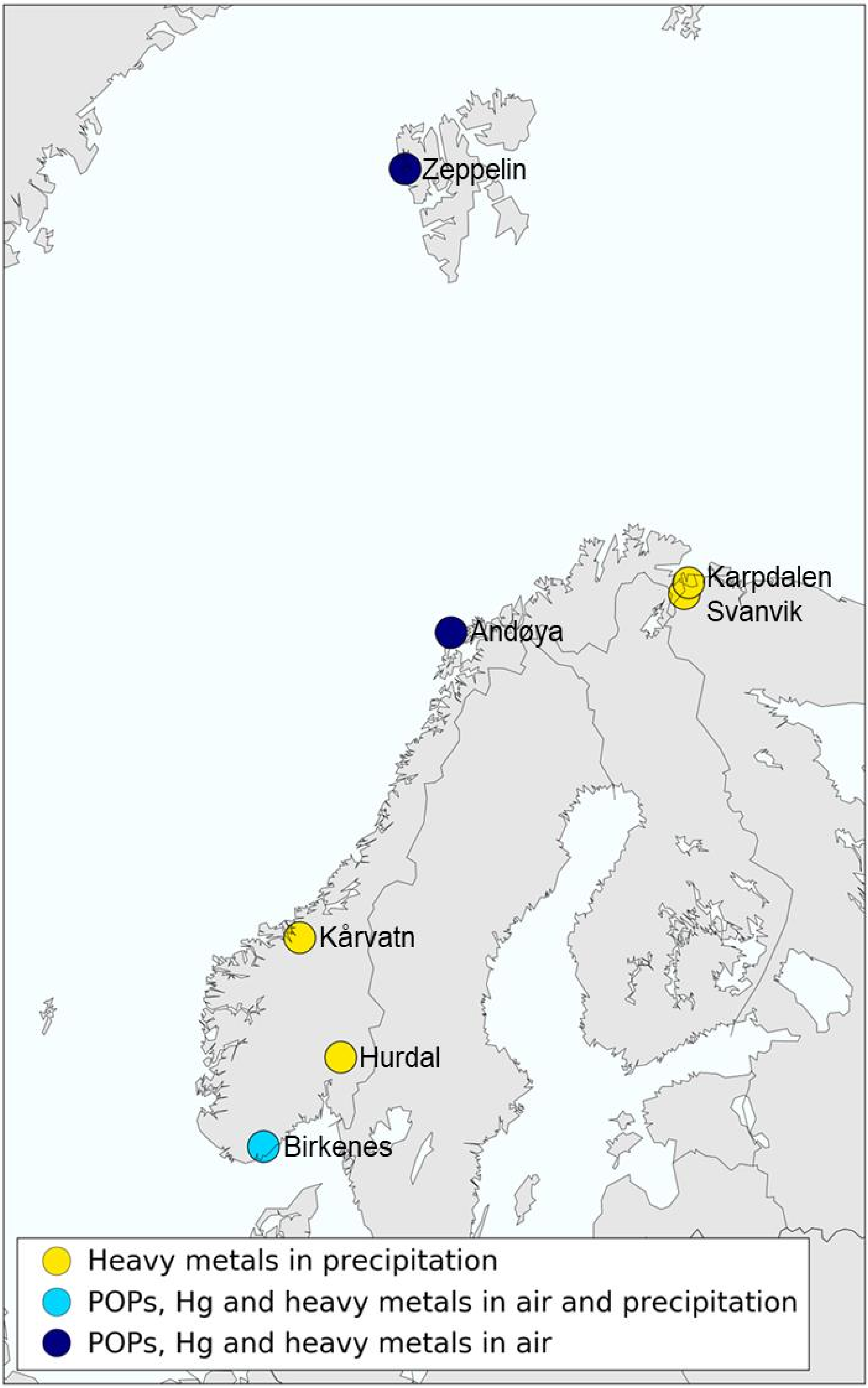


Figure 1: Norwegian background stations measuring environmental contaminants in 2018.

Air measurements of heavy metals and POPs started in 1991 at Lista observatory in southern Norway as part of a government program on environmental monitoring and were reported to 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). Birkenes and Zeppelin became part of EMEP (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 data from this monitoring station is besides its function as a national monitoring station, now also part of the EMEP programme.

Air samples for organic contaminants and heavy metals (excluding mercury) are collected using active air samplers at all three sites. The active air samples are collected on a weekly basis throughout the year with specific sampling lengths for each observatory and class of contaminant (Table A.3.4). For example, HCB, PCB, OCPs and PAHs are sampled on a weekly basis at Birkenes and Zeppelin, but with different sampling length at each observatory (e.g. 24-48 h). The sampling methodologies have been optimized to achieve maximum detection while minimizing the influence of possible sampling artefacts, such as breakthrough and degradation. The number of samples per year is compound and site specific (i.e. 12 to 52). Exceptions to the continuous weekly monitoring are the new organic contaminants of emerging concern 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 organic contaminants of emerging concern, the sampling and analytical methodologies are associated with 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 is constantly working on method improvements. Information about the sampling and analytical methodologies are given in Annex 3. All the POP data presented in this report are available at http://ebas.nilu.no/.

1.3 Organic contaminants

1.3.1 Regulated organic contaminants

The monitoring programme have included regulated organic contaminants (e.g. POPs) since the beginning of 1990s at Birkenes and Zeppelin and from 2009 at Andøya (Table 2). In 2017, the monitoring programme for the regulated contaminants was revised according to Table 2. The updated programme includes seven classes and one individual compound classified as POPs, and one POP-like class (i.e. PAHs). Most of the regulated contaminants are measured once per week at Birkenes and Zeppelin with some exceptions. Air samples for PBDEs, HBCD and the ionic PFOS (perfluorooctane sulfonic acid) are collected two times per month (every second week) and the two samples are combined in the lab to give an aggregated monthly concentration. The aim of this change was to improve detection of these compounds that previous years often have been below detection limit. At Birkenes, the measurements of HCHs and DDTs were reduced to one sample per month and chlordanes were excluded. At Andøya, only HCB and PFAS are monitored from 2017.

Table 2: Monitoring programme for regulated organic contaminants (e.g. POPs) in 2018.

	Birkenes		Andøya		Zeppelin	
POP class/compound	Start year	Sampling frequency	Start year	Sampling frequency	Start year	Sampling frequency
HCB - air	1993	weekly	2009	monthly*	1993	weekly
HCB - precipitation	1992	weekly	-	-	-	-
HCHs	1991	monthly*	2010-2016**	-	1993	weekly
HCHs - precipitation	1992	weekly	-	-	-	-
DDTs	2010	monthly*	2010-2016**	-	1994	weekly
Chlordanes	2010-2016**	-	-	-	1993	weekly
PCBs	2004	weekly	2009-2016**	-	2001***	weekly
PCB_7 - precipitation	2006	weekly	-	-	-	-
PBDEs	2008	monthly*	2009-2016**	-	2006	weekly
HBCD	2006	monthly*	-	-	2006	monthly*
PAHs	2009	weekly	2009-2012**	-	1994	weekly
PFOS (ionic)	2006	monthly*	2009	monthly*	2006	monthly*

*New sampling frequency from 2017
**Not included in the new monitoring programme from 2017.
***Data available before 2001 are classified as uncertain due to possible local contamination.

1.3.2 Organic contaminants of emerging concern

The monitoring programme “Long-range transported atmospheric contaminants” that provides an essential part of the data for this report also includes organic contaminants that are not yet regulated, but have been identified as contaminants of emerging concern in, for example, environmental national screening programmes (van Bavel et al., 2016; Schlabach et al., 2017a+b). The purpose for including these contaminants in the monitoring programme is to obtain data in air that can be used for possible future regulations on national and global level. Another aspect is that if monitoring is initiated before a regulation/measure enters into force it may also be possible to get a more complete picture of the time trends, and the effect of the regulations.

Two of the organic contaminants of emerging concern; cVMS and S/MCCPs, have been monitored as part of this programme since 2013, but was originally not part of the core programme. Similarly, another four contaminant classes have been included in monitored programme since 2017; volatile PFAS, novel brominated flame retardants (nBFRs), organophosphorous flame retardants (OPFRs) and phthalates. Lastly, bisphenols and linear siloxanes were included in the monitoring programme and monitored for the first time in 2018 (Table 3). Most of the target ionic PFAS are non-regulated and therefore fall under the category of contaminants of emerging concern in this monitoring programme.

For volatile and ionic PFAS, two samples were collected per month and the two samples were combined in the lab giving one aggregated concentration for each month. On the other hand, the monthly samples for cVMS and S/MCCPs at Birkenes only consist of one sample per month. Further details on the sampling strategies (sampling times, sampler type, adsorbents etc.) are given in Annex 3.

Table 3: Organic contaminants of emerging concern included in the monitoring programme "Long-range transported atmospheric contaminants" in 2018, year of first monitoring and sampling frequency at the different observatories

	Zeppelin		**Birkenes**		**Andøya**	
Organic contaminants of emerging concern, Class	Start year	Sampling frequency	Start year	Sampling frequency	Start year	Sampling frequency
cVMS	2013	weekly*	2017	monthly	-	-
S/MCCPs	2013	weekly	2017	monthly	-	-
PFAS (volatile)	2017	monthly	2017	monthly	2017	monthly
nBFRs	2017	summer + winter campaign**	2018	summer + winter campaign**	-	-
OPFRs	2017	summer + winter campaign**	2018	summer + winter campaign**	-	-
Phthalates	2017	summer + winter campaign**	2018	summer + winter campaign**	-	-
Bisphenols	2018	summer + winter campaign***	-	-	-	-
Linear siloxanes	2018	summer + winter campaign***	-	-	-	-
Data Mining/screening	2018	summer + winter campaign***				

*New sampling frequency from 2017.
**Six samples per campaign.
***Three sampler per campaign.

In 2018, the monitoring programme included analyses of Arctic air samples using data mining approaches in order to identify new organic contaminants of potential Arctic concern. The objective was also to verify the findings of new "greenhouse gases" in the national screening programme from 2017, conducted by NILU and NIVA for the Norwegian Environment Agency (Schlabach et al., 2018). Air samples for the data mining were collected using the same sampling techniques as for siloxanes in this monitoring programme and for the air samples in the screening programme from 2017: Active air sampling using ABN as adsorbent (Schlabach et al., 2018). Samples were collected for 72 hrs.

1.4 Heavy metals

Heavy metals in precipitation have been monitored at Norwegian observatories as a part of government funded monitoring programmes since 1980. The amendments to the "Long-range transported atmospheric contaminants" programme that were introduced in 2017 and that became effective in 2018 did not include any changes for heavy metals (Table 4).

Table 4: Monitoring of heavy metals in 2018.

Monitoring station	Birkenes	Andøya	Zeppelin	Hurdal	Kårvatn	Svanvik	Karpdalen
Heavy metals - air	Weekly	weekly	weekly	-	-	weekly	weekly
Heavy metals - precipitation	Weekly	-	-	weekly	weekly	weekly	weekly
Hg - air	continuously	-	continuously	-	-	-	-
-Hg - precipitation	Weekly	-	-	-	-	-	-

2 Regulated organic contaminants

The Stockholm Convention and the Aarhus protocol under the Convention on Long-range Transboundary Air Pollution regulates organic contaminants that show properties that can cause risk for human health or the environment. For example, the POPs regulated under the Stockholm Convention 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). Most of the regulated contaminants included in this monitoring are classified as POPs; hexachlorobenzene (HCB), hexachlorohexanes (HCHs), dichlorodiphenyl-trichloroethane (DDTs), chlordanes, polychlorinated biphenyls (PCBs), poly-brominated diphenyl ethers (PBDEs) hexabromocyclododecanes (HBCDs), and PFOS and PFOS related substances (ionic PFAS). In addition to those, also polycyclic aromatic hydrocarbons (PAHs) are included. The PAHs are listed in the Aarhus protocol, but not in the Stockholm Convention and are thereby not defined as a POP. The monitored regulated 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.

Data for the individual POP classes at each observatory are presented as annual mean concentrations, and as monthly mean concentrations in section 2.1-2.3. 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 1 (Table A1.1-A1.19). The results are presented in three sections; *2.1: Long-term monitoring in air* (covering POPs that have been monitored since before the Stockholm Convention), *2.2: Short-term monitoring in air* (covering POPs for which monitoring was initiated after the Stockholm Convention came into force), and *2.3: Long-term monitoring in precipitation* (covering POPs monitored in precipitation).

2.1 Long-term monitoring 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. From 2017, it is measured on monthly basis at Andøya (i.e. one sample per month) while on weekly basis, as previous years, at Birkenes and Zeppelin. It was detected in all samples from all sites in 2018. The weekly concentrations ranged between: 24-73 pg/m^3 at Birkenes and 43-83 pg/m^3 at Zeppelin. The monthly concentrations at Andøya ranged from 15-57 pg/m^3. The annual mean concentration of HCB for 2018 at Zeppelin (63 pg/m^3) is the lowest observed since 2004. The increase in HCB concentrations at Zeppelin that has been observed since 2003 seem to have flattened out or even turned to a reduction during the last years. Continued monitoring is needed to further evaluate its trend. A similar trend is observed at Birkenes, where the annual mean concentration in 2018 (48 pg/m^3) is one of the lowest measured during the monitoring period (1996-2018). This low concentration is in contrast to the increasing time-trend observed the previous years (2010-2016). At Andøya the annual mean concentrations in 2018 (29 pg/m^3) is lower than in 2017, but comparable with the previous seven years

(Figure 2). The annual mean concentrations of HCB in 2018 were, as previous years, lowest at Andøya (29 pg/m^3) and highest at Zeppelin (63 pg/m^3). The high concentrations observed for HCB at Zeppelin during the last years are in line with what has been observed at Station Nord on Greenland (Aas et al., 2018). 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 et al., 2011, Aas et al., 2018).

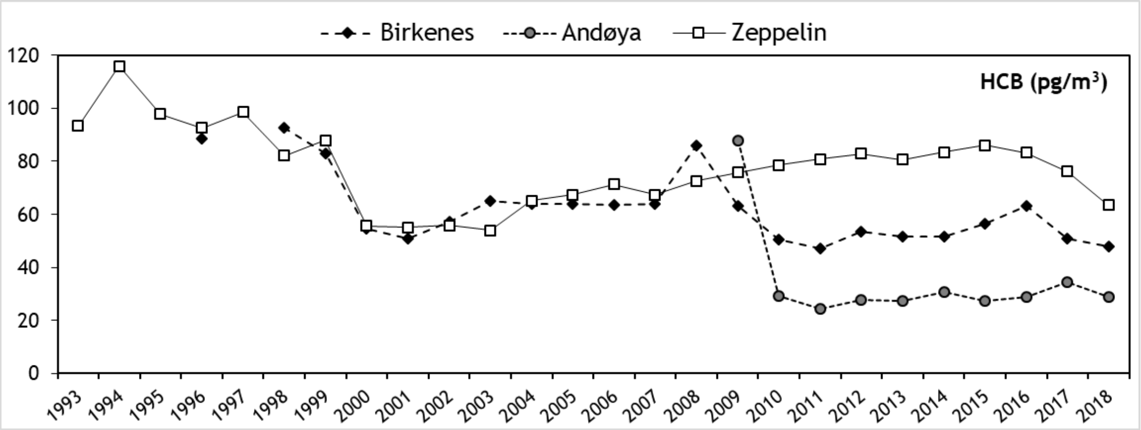


Figure 2: Annual mean concentrations of HCB (pg/m^3) in air.

Seasonal variations of HCB are observed at Birkenes, and to some extent at Andøya, with a factor of two lower concentrations in summer than in winter (Figure 3). 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. In contrast, no clear seasonal variations of HCB concentrations are seen at Zeppelin (Figure 3) although the individual lowest concentrations are observed during the coldest season and the individual highest concentrations are observed in late summer. The variability between the lowest and highest monthly concentrations is only 1.4 at Zeppelin while 2.6 at Birkenes.

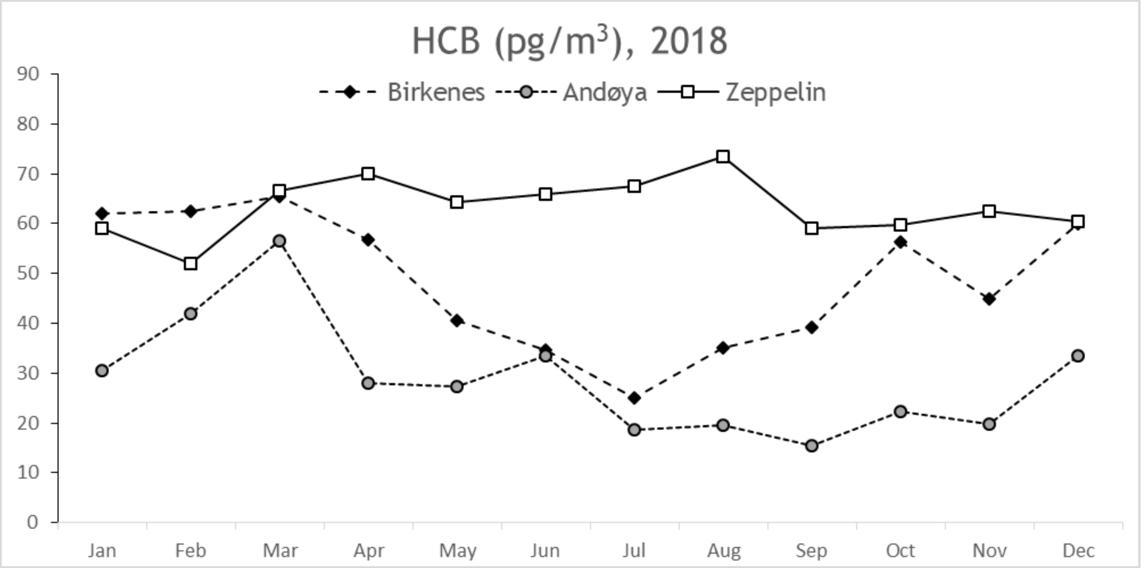


Figure 3: Seasonal variability of HCB at Birkenes, Andøya and Zeppelin in 2018.

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, 2013), and the use is now assumed to be phased out globally.

Two HCH isomers; α- and γ-HCH, have been monitored at Birkenes since 1991, at Zeppelin since 1993, and at Andøya since 2010. From 2017, monitoring of HCHs at Zeppelin continued with weekly samples as in previous years, while the monitoring at Birkenes was reduced to one sample per month and the monitoring at Andøya stopped. Both HCH isomers were above detection limit in all samples from Zeppelin and Birkenes in 2018. The monthly concentrations of sum HCHs (α+γ) in 2018 ranged from: 2.7-19 pg/m^3 at Birkenes (including one high episode in April). The high episode and the other high concentrations measured at Birkenes are associated with air masses coming from the European continent. Common for these episodes is also that the concentrations of γ-HCH is higher than α–HCH. This is in contrast to most of the other measurements when α-HCH is 1.1-4.7 times higher than γ-HCH. The weekly concentrations at Zeppelin ranged between 1.1 and 5.2 pg/m^3 in 2018. At Zeppelin, the annual mean concentration of sum HCHs (3.1 pg/m^3) and the individual isomers were lower than previous years continuing the slow decreasing trends (Figure 4). At Birkenes, the annual mean concentration of α-HCH was lower than previous years while sum HCHs (6.7 pg/m^3) and γ-HCH were instead the highest since 2014 and 2012. Overall, HCHs are the POPs that show the largest reduction in air concentrations since the beginning of the air monitoring at Zeppelin and Birkenes with short half-lives in the trend analysis (Bohlin-Nizzetto et al., 2018). The two monitored isomers; α- and γ-HCH, have declined with similar patterns at both observatories although a somewhat larger reduction has been observed for γ-HCH than for α-HCH. In 2018, γ-HCH was higher than the previous years at Birkenes for the first time during the monitoring period.

As in previous years, the average ratios of α-/γ-HCH were found to decrease from north to south; 7.7 (2.3-13.4) at Zeppelin; and 1.9 (0.3-4.7) at Birkenes. Even lower ratios are observed at more southern sites in continental Europe (Aas et al., 2018). 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, as a consequence of higher concentrations of γ-HCH in summertime and when episodic high concentrations of HCH are observed at Birkenes, suggests higher emission of lindane/γ-HCH from secondary repositories in continental Europe together with less scavenging during the warmer and dryer period. In contrast, the ratios at Zeppelin are higher in summertime than in wintertime. 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 et al., 2018).

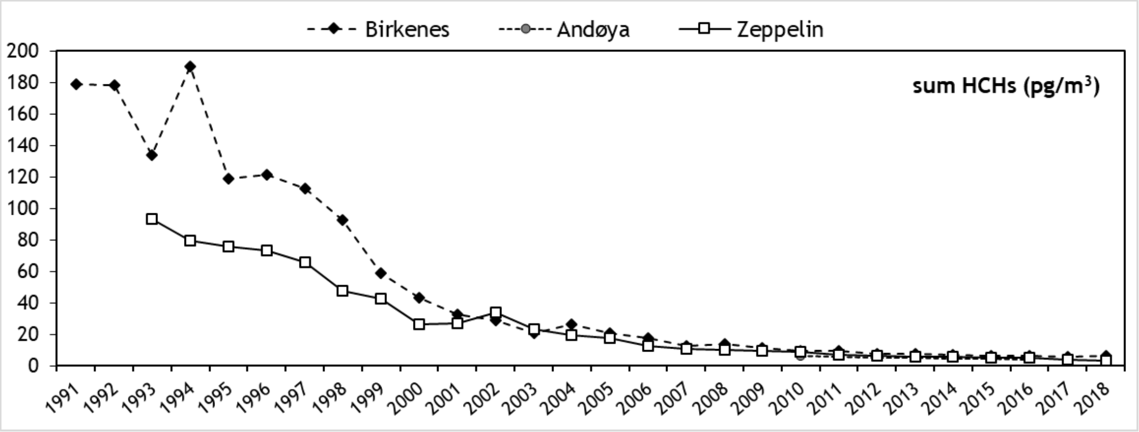


Figure 4: Annual mean concentrations of sum HCHs (pg/m^3) in air.

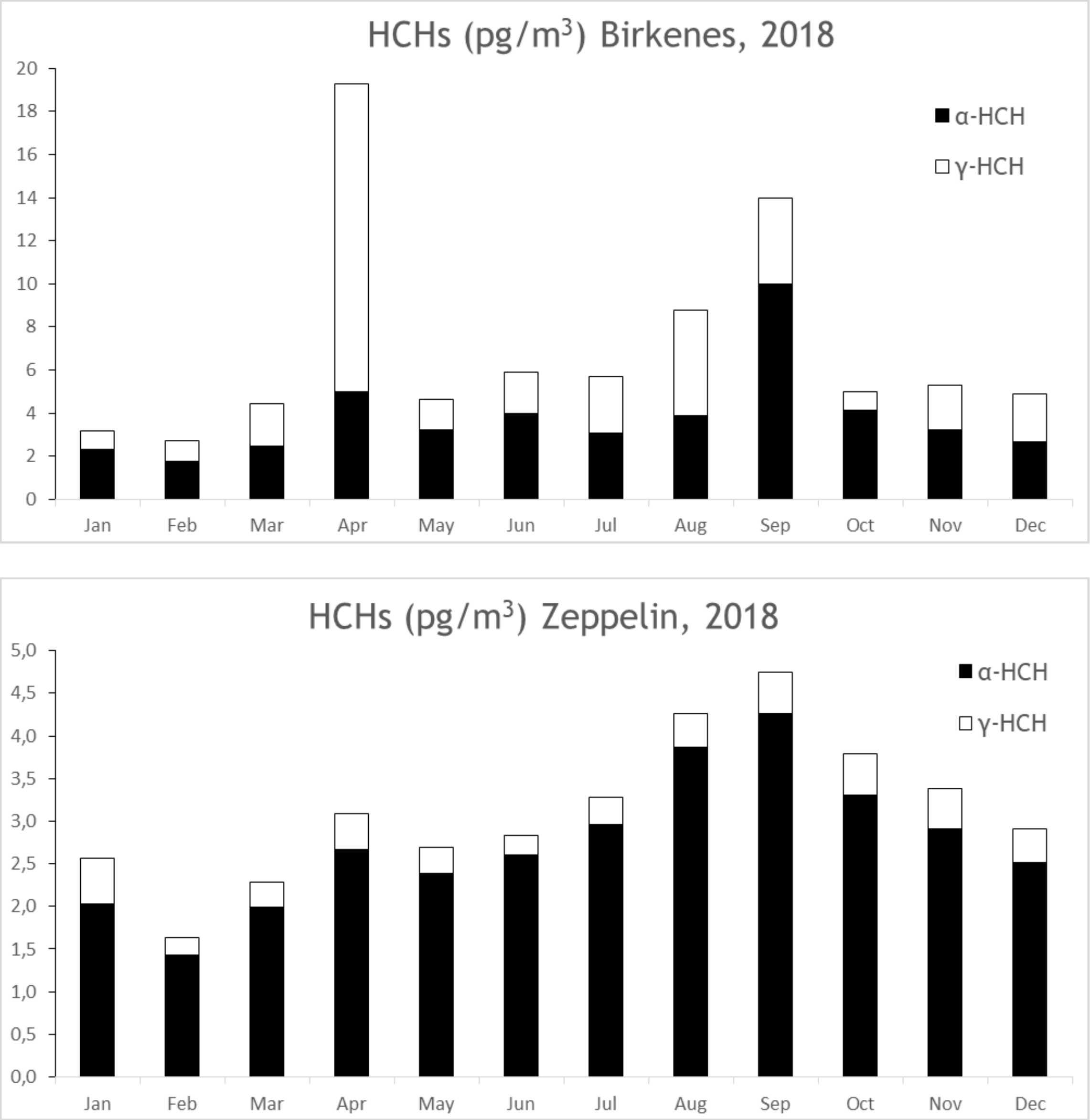


Figure 5: Seasonal variability of a- and g-HCH at Birkenes and Zeppelin in 2018.

In contrast to previous years, in 2018 there was not a strong seasonality of the HCHs concentrations at Birkenes with higher concentrations during summer than wintertime (Figure 5). The reason for this is not known. A small seasonality was observed at Zeppelin with higher concentrations in late summer (Figure 5).

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, the United States and Canada during 1970s to 2000 and is regulated by the Aarhus protocol on POPs (UN/ECE, 1998b) and the Stockholm Convention on POPs (Stockholm Convention, 2007). It is still in use in some parts of the world for disease vector control (primarily malaria). The Stockholm Convention allows the production of DDT for use in disease vector control and as an intermediate in the production of dicofol, although the latter use is anticipated to cease globally in the near future due to the inclusion of dicofol in the Stockholm Convention in May 2019. 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. From 2017, monitoring of DDTs at Zeppelin continued with weekly samples as in previous years while the monitoring at Birkenes was reduced to one sample per month. DDT was from 2017 no longer monitored at Andøya. The detection frequencies in 2018 varied among the individual congeners and between the sites. For example, o,p’-DDT and o,p’- and p,p’-DDE were detected in all samples at both 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 followed by o,p’-DDT at the two sites. The weekly concentrations of sum DDTs at Zeppelin in 2018 ranged between 0.08-2.1 pg/m^3 (including three high measurements in January). The episodes with high concentrations of DDTs at Zeppelin were mainly due to high levels of p,p’-DDE and coincides with an influx of air masses from central Russia and the countries south of this region. The monthly concentrations of sum DDTs at Birkenes ranged between 0.45-3.1 pg/m^3 (including one higher measurement in September). As for Zeppelin this high measurement coincides with air masses coming from central Russia and the countries south to this region.

The annual mean concentrations of sum DDTs and the individual congeners in 2018 were as in previous years higher at Birkenes (1.5 pg/m^3) compared to Zeppelin (0.4 pg/m^3) (Figure 6). The annual mean concentrations of sum DDTs and all congeners were the same as in 2017 and the two years (2017-2018) are the lowest observed at Zeppelin since the DDT measurements began. At Birkenes, instead, the annual mean concentration in 2018 was higher than in 2017 and similar to 2015-2016. The small changes observed at Birkenes and Zeppelin suggests that the concentrations of DDTs in air are in slow decline or have reached a temporal remote state, where reduction rates are controlled by degradation in secondary repositories (Stroebe et al., 2004). Although the concentrations observed at Birkenes are higher than at Zeppelin, they are still one to two orders of magnitude lower than the concentrations found on the European continent (Pribylova et al., 2012, Aas et al., 2018). The reason for higher concentrations at Birkenes compared to the more northern Norwegian sites may be explained by closer distances to possible emission sources (secondary repositories). The indicator ratio (p,p’-DDE+p,p’-DDD/p,p’-DDT) were high (5-18) at both sites in winter, spring and autumn indicating input only from aged DDT. The ratios were lower in summertime at both Birkenes and Zeppelin (2-4).

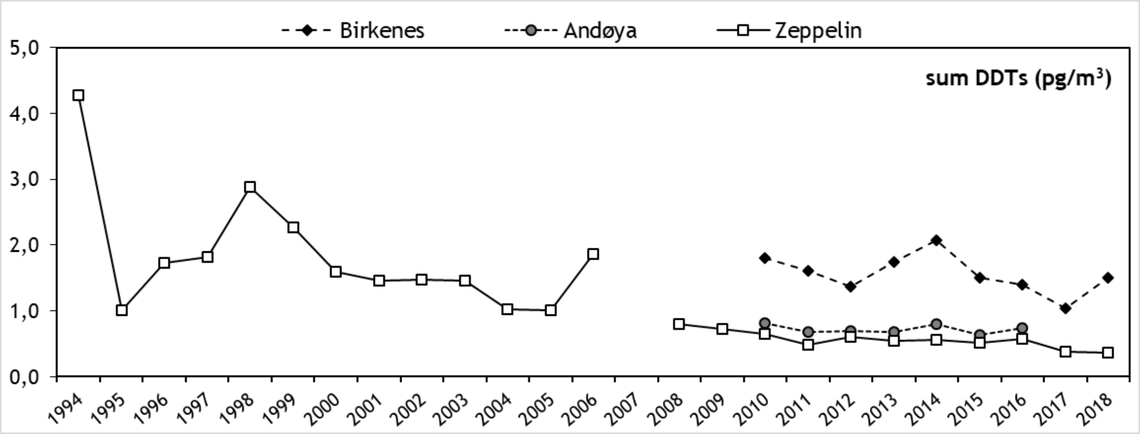
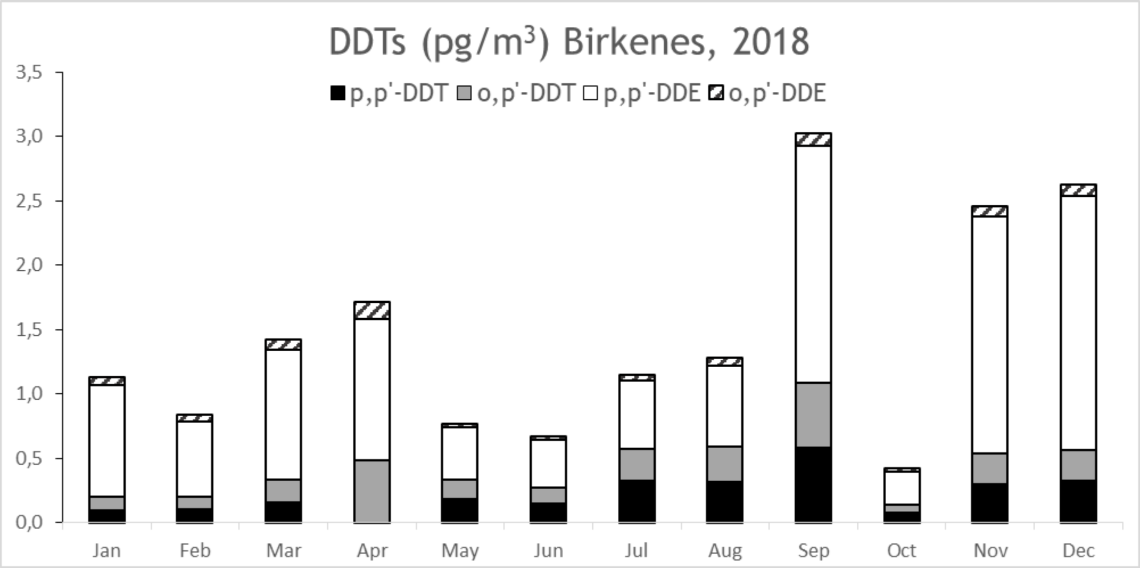


Figure 6: Annual mean concentrations of sum DDTs (pg/m^3) in air.

A strong seasonality of the DDT concentrations was observed at Zeppelin with five to ten times higher concentrations in wintertime (October-February) compared to warmer months (May-September) (Figure 7). 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. The higher concentrations at Zeppelin in winter than during summer 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 et al., 2016). However, this may not be the full explanation as DDTs tend to be found to larger extent in gas-phase than in particle phase. The lower temperature in winter may however shift the partitioning towards more particle bound DDTs which supports the explanation of the Arctic haze.



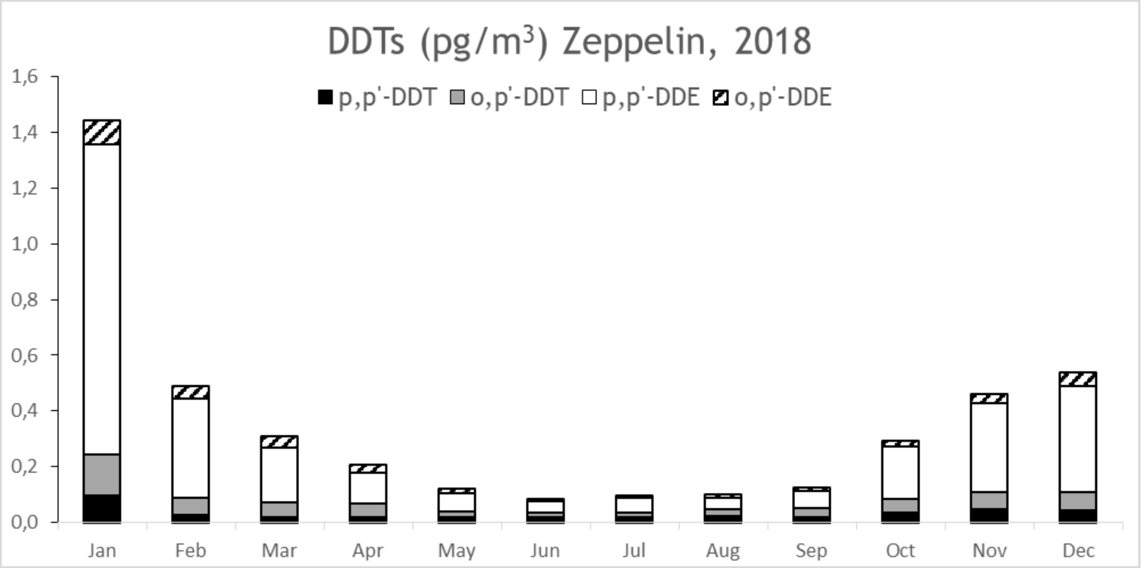


Figure 7: Seasonal variability of sum DDT and the four detected individual congeners at Birkenes and Zeppelin in 2018.

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, the chlordanes were monitored in the period 2010-2016. Three of the four isomers: cis-CD, trans-NO and trans-CD were detected in all samples at Zeppelin in 2018. The fourth isomer, cis-NO was, in 2018, <LOD in 25-50% of the samples from the winter months. The major isomers were the cis-CD and trans-NO, contributing to ~40% each to the sum of chlordanes. The weekly concentrations of sum chlordanes at Zeppelin in 2018 ranged between 0.4-0.9 pg/m^3. The annual mean concentrations of sum chlordanes (0.6 pg/m^3) and the individual stereoisomers at Zeppelin in 2018 were the lowest observed. This suggests that the concentrations of chlordanes still are declining or may have entered temporal remote state where the decline is controlled by degradation in and emission from secondary repositories (Figure 8).

The ratio of trans-CD and cis-CD was low at Zeppelin (0.1-0.7 compared to 1.17 in technical mixture) indicating input only from aged chlordanes, since trans-CD degrades faster than cis-CD in the environment. The ratio shows a seasonal trend with lower ratios in summertime and higher in wintertime. This is caused by lower concentrations of trans-CD in summertime than in wintertime. 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. In contrast, cis-NO is found in higher concentrations in summer (June-September) than in winter (November-March) (Figure 9). For sum chlordanes and the other two isomers, no seasonal trends were observed.

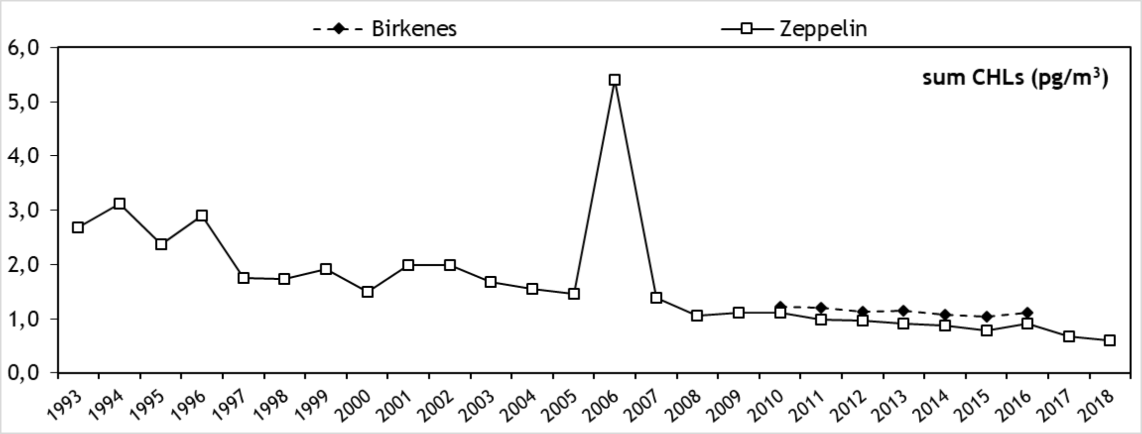


Figure 8: Annual mean concentrations of sum chlordanes (pg/m³) in air.

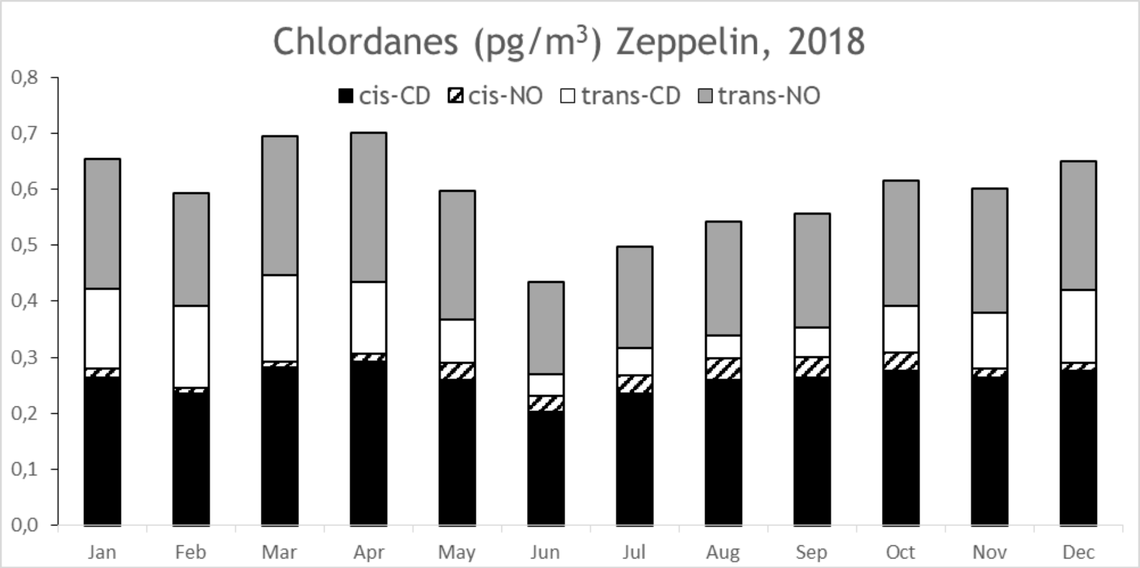


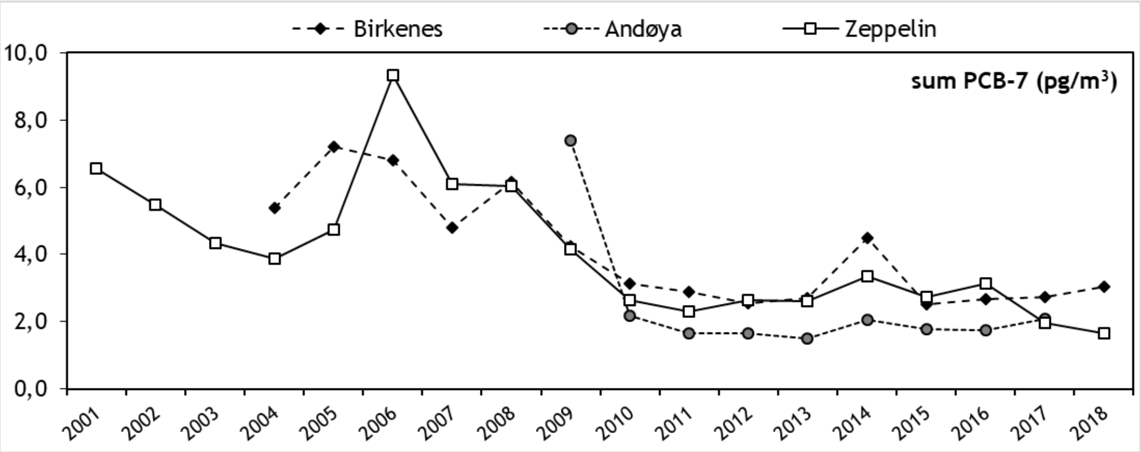
Figure 9: Seasonal variability of sum chlordanes and the four individual isomers at Zeppelin in 2018.

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 are also regulated by the Aarhus protocol on POPs (UN/ECE, 1998b) and the Stockholm Convention on POPs (Stockholm Convention, 2007). According to the Stockholm Convention, the production and new use of PCB is no longer allowed. Parties may however continue to use PCB containing articles that were already in use when the global regulation entered into force. By 2025, Parties shall have identified and removed from use, equipment containing greater than 0.005% PCB and volumes greater than 0.05 L. As soon as possible, but no later than 2028, Parties shall also make determined efforts designed to an environmentally sound management of PCB containing waste by management of liquids containing PCB and equipment contaminated with PCBs having a PCB content above 0.005% in accordance with paragraph 1 of Article 6 of the Convention. Current sources of emissions of PCBs 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 Birkenes and Zeppelin in 2018. These 32 congeners include the seven congeners (PCB-7) that are typically used as indicators in Europe; PCB 28, 52, 101, 118, 138, 153, 180, as well as eight of the dioxin-like and most toxic congeners according to WHO; PCB 105, 114, 118, 123, 156, 157, 167, 189. Data are reported for sum of 32 PCBs (sum PCB) as well as sum of PCB-7 (sum PCB$_7$). PCBs have been monitored at Zeppelin since 2001. At Birkenes, the seven indicator PCBs have been monitored since 2004 and all the 32 PCBs since 2010. The monitoring in 2018 continued with weekly measurements at both sites. The detection frequencies varied among PCB congeners as well as between sites. Generally, high detection frequencies were observed for tri-penta PCBs (until PCB 105) at all sites while low detection frequencies were observed for some of the penta-hepta PCBs (i.e. PCB, 114, 122, 123, 157, 167, 189, 194, 206, 209). As previous years, the tri- and tetra-PCBs were the most common PCBs, comprising 60-90% of sum PCB. The most abundant individual compounds were PCB 18, 28, 31, 47, 52. At Zeppelin also PCB 33 was abundant.

The weekly concentrations of sum PCB and sum PCB$_7$ at Birkenes in 2018 ranged between: 3.2-33 pg/m^3 and 0.8-12 pg/m^3, respectively (including four elevated episodes); and 4.1-14 pg/m^3 and 1.0-pg/m3, respectively, at Zeppelin (including three high episodes). The reasons for the high episodes not known as no clear pattern for air masses are observed for the same periods. The annual mean concentrations of sum PCB and sum PCB$_7$ in 2018 were lower at Zeppelin than at Birkenes (Figure 10). At Zeppelin, the annual mean concentrations of PCBs (sum PCBs: 6.9 pg/m^3, sum PCB$_7$: 1.7 pg/m^3) in 2018 were the lowest ever observed. This confirms a change in the increasing trend that was observed between 2011 and 2016 at Zeppelin. At Birkenes, the annual mean concentrations in 2018 (11.2 pg/m^3 and 3.1 pg/m^3) were similar to previous years. The observations suggest that a temporal remote state condition has been reached for the PCBs in which the concentrations in air are controlled by degradation and emission of PCBs in secondary repositories. The concentrations of sum PCB$_7$ at the Norwegian sites are up to one order of magnitude lower than the concentrations of sum PCB$_7$ reported to EMEP from sites in Germany and the Czech Republic (Aas et al., 2018).



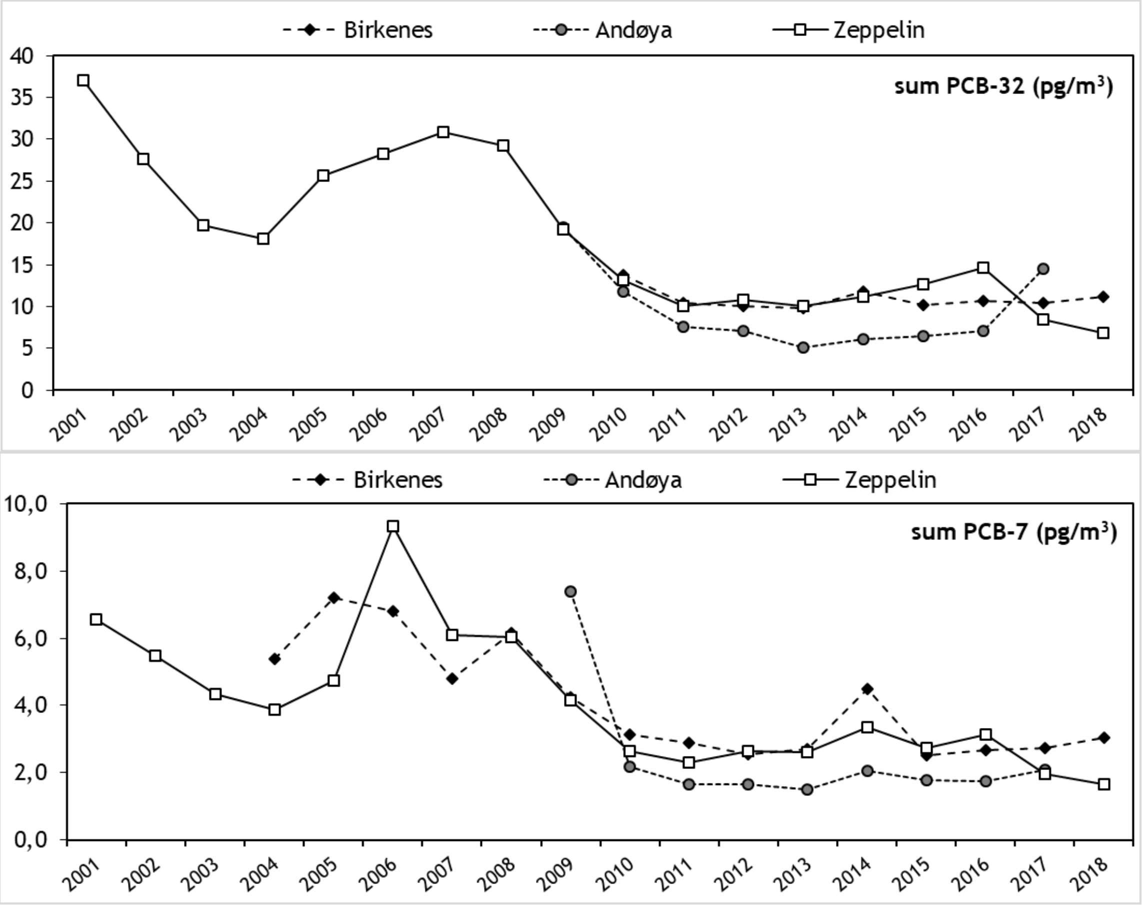
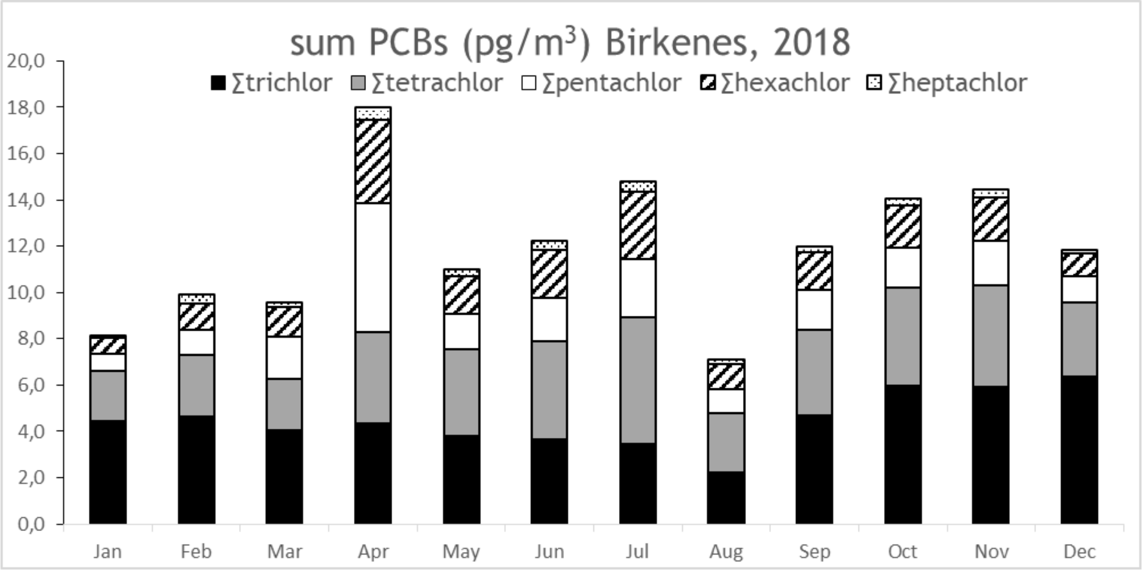


Figure 10: Annual mean concentrations of sum PCBs and sum PCB$_7$ (pg/m^3) in air.



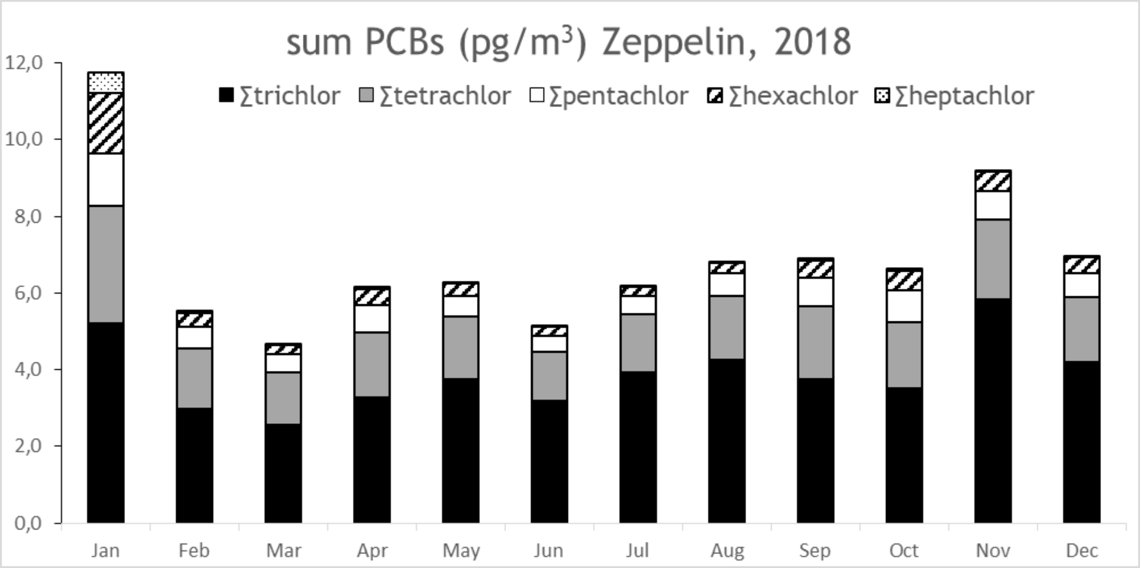
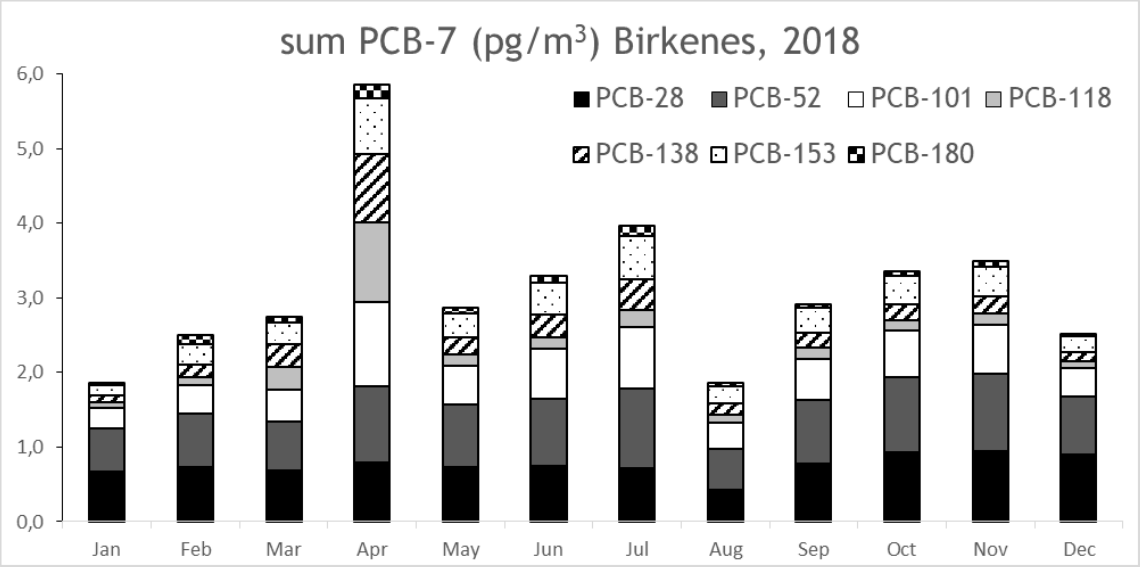


Figure 11: Seasonal variability of sum PCBs and homologue groups at Birkenes and Zeppelin in 2018.

No clear seasonality was observed for sum PCB-32 and sum PCB-7 at any of the two observatories (Figure 11-12). The lowest concentrations at Zeppelin were however consistently observed in summertime (June-September) and the highest in wintertime (January-March).



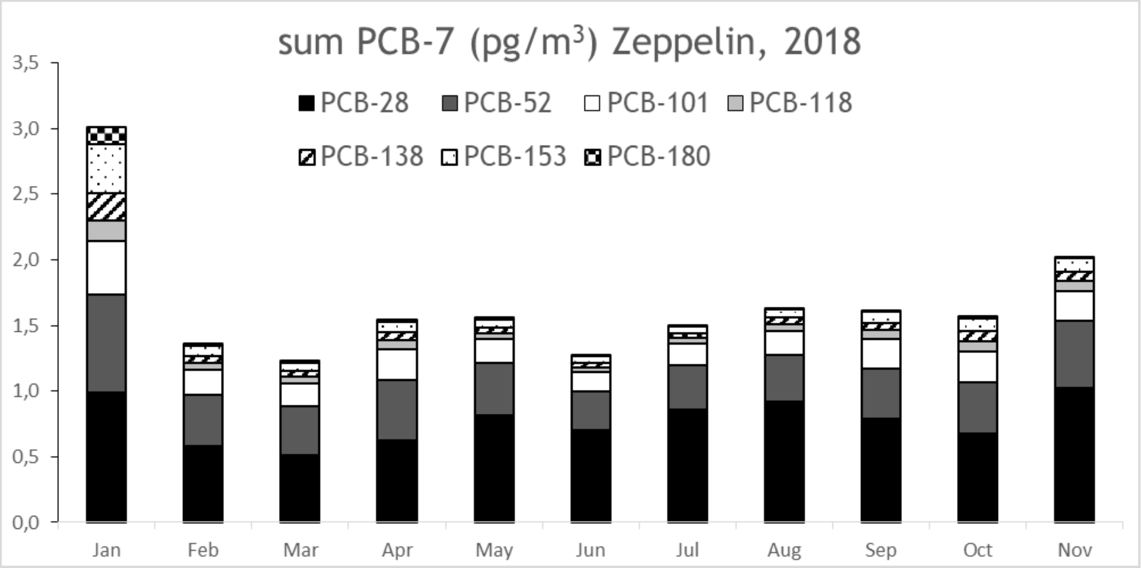


Figure 12: Seasonal variability of sum PCB$_7$ and the individual congeners at Birkenes and Zeppelin in 2018.

2.1.6 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 processes. 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 2018. 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 PAH compounds had low detection frequency and were below detection limit at Zeppelin (70% of the PAH compounds) than at Birkenes (~15% of the PAH compounds). This reflects higher concentrations at Birkenes than at Zeppelin. The most abundant PAHs at Birkenes are phenanthrene (30%), followed by dibenzofuran (16%), fluorene (14%) and fluoranthene (6%). At Zeppelin, the volatile PAHs are more abundant; dibenzofuran (31%), biphenyl (20%), fluorene (10 %) together with 1- and 2-methylnaphthalene (7 and 10%, respectively). The weekly concentrations of sum PAH in 2018 ranged between: 0.8-12 pg/m^3 at Birkenes (including three high episodes in February-March and one in December); and 0.08-4.1 pg/m^3 at Zeppelin. The weekly concentrations of sum PAH$_{16}$ in 2018 ranged between: 0.6-8.0 pg/m^3 at Birkenes (including three high episodes in February-March and one in December); and 0.03-1.0 pg/m^3 at Zeppelin. The annual mean concentrations of sum PAH (0.81 ng/m^3) and sum PAH$_{16}$ (0.17 ng/m^3) at Zeppelin in 2018 were the lowest ever observed, continuing the decline observed the last four years. At Birkenes, the annual mean concentrations of sum PAHs and sum PAH$_{16}$ in 2018 (3.9 and 2.5 ng/m^3) were higher than in 2017, but similar to most of the previous years. The concentrations observed at Birkenes are about eight-ten times higher than those at Zeppelin (Figure 13). The levels of benzo(a)pyrene at both stations are two-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).

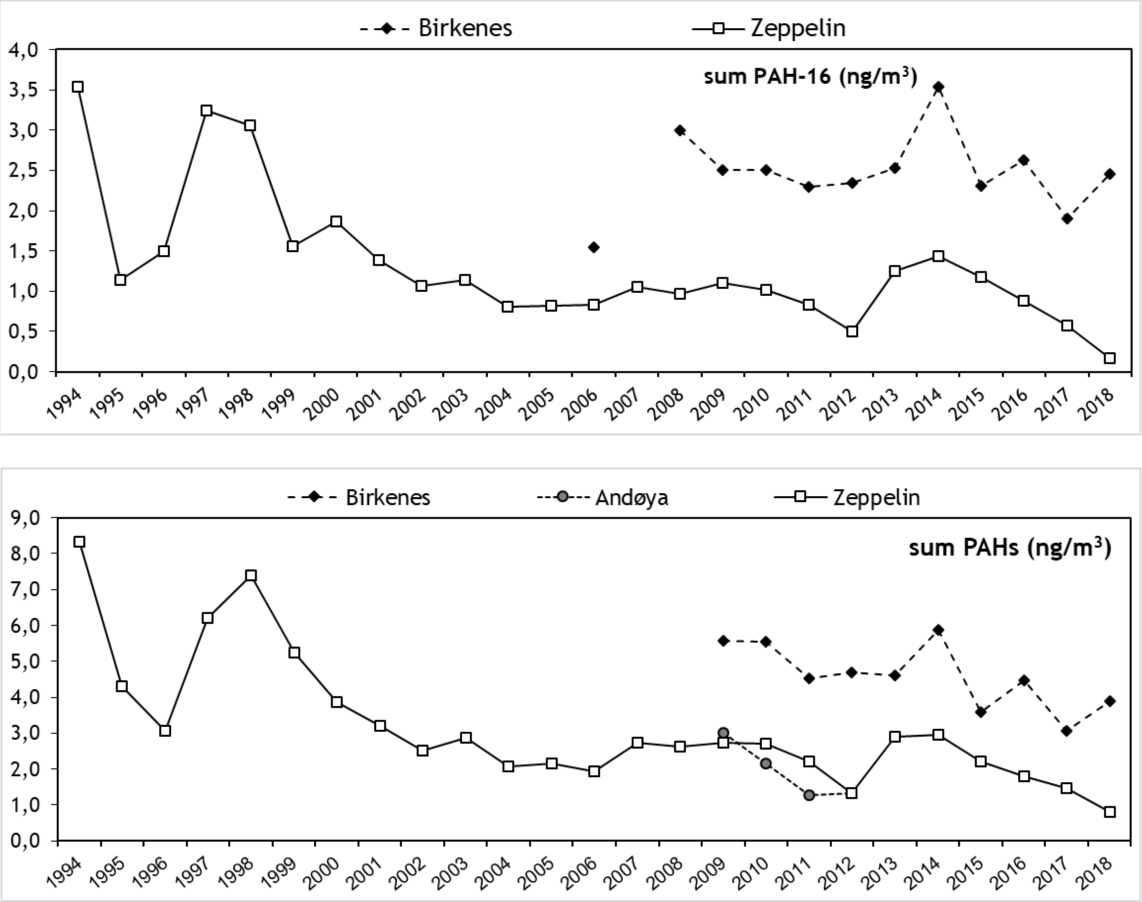
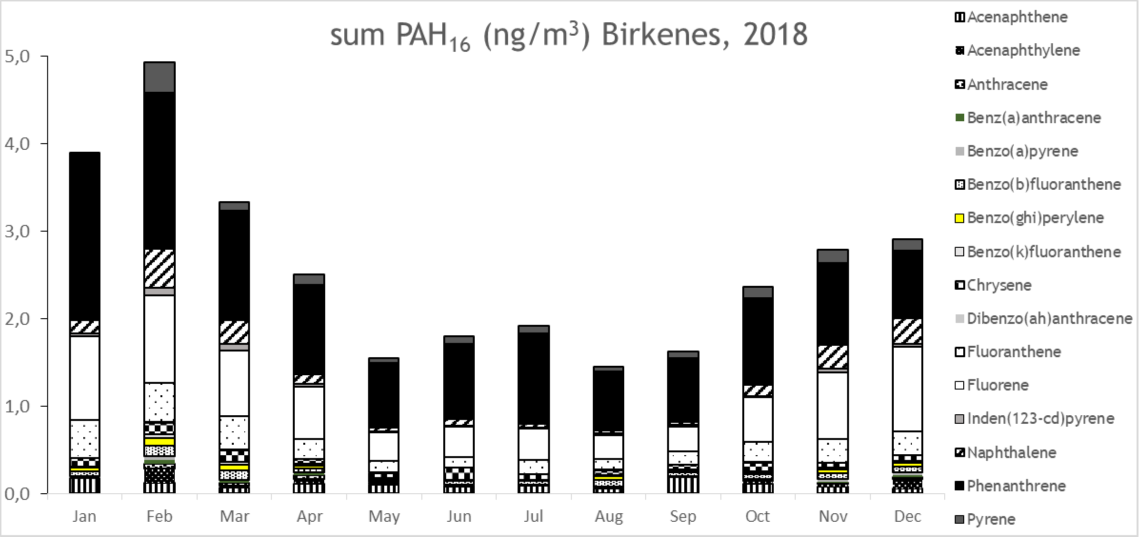


Figure 13: Annual mean concentrations of sum PAH and sum PAH-16 (ng/m^3) in air.

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 14). The same seasonality was seen for sum PAHs and the individual PAHs.



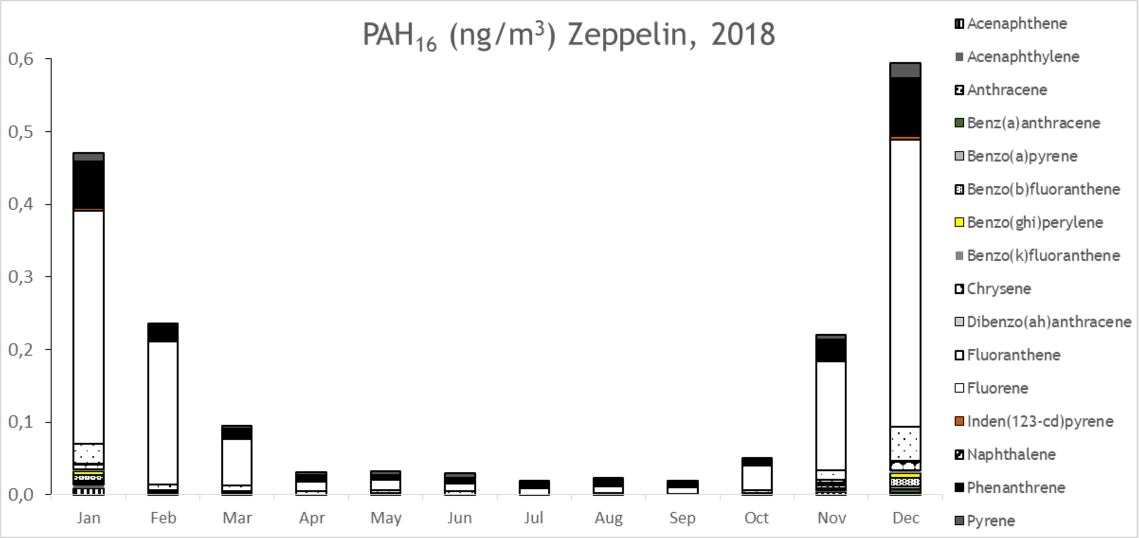


Figure 14: Seasonal variability of sum PAH16 at Birkenes and Zeppelin in 2018.

2.2 Short-term monitoring in air

2.2.1 Polybrominated diphenyl ethers (PBDEs)

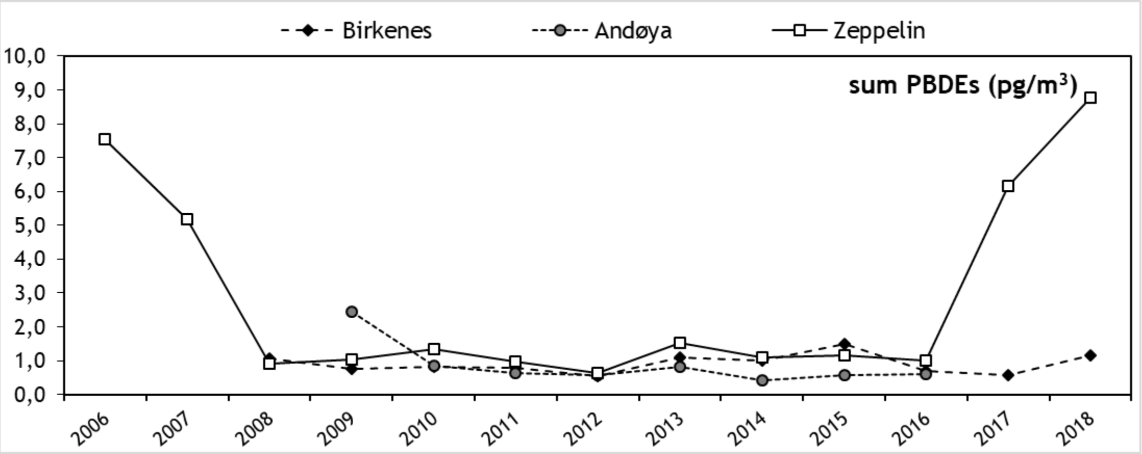
PBDEs are industrially produced chemicals that have been and still are used as flame retardants in a wide range of applications including in plastics, textiles and electrical and electronic products. The production and use of the commercial PBDE mixtures; penta- and octa-BDE, are regulated by the Aarhus 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. The global regulation entered into force in 2018, but includes several specific exemptions for production and use such as in vehicles and aircrafts. In Norway the use of deca-BDE, except for in means for transportation, have been banned since 2008.

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 between 2009 and 2016. In 2018, the monitoring included PBDEs at Birkenes and Zeppelin, but not at Andøya. PBDEs were measured on weekly basis at Zeppelin and on monthly basis at Birkenes. The monthly samples at Birkenes were obtained by combining two 48 hr-samples per month in the lab. This strategy resulted in a better detection than previous years at Birkenes with 12 congeners detected in more than 50% of the samples (i.e. 28, 47, 49, 66, 85, 99, 100, 153, 154, 183, 206, and 209). The detection frequencies were still low for the other five congeners; BDE-71, 77, 119, 138, and 196 at Birkenes. At Zeppelin ten congeners (i.e. 28, 47, 49, 66, 99, 100, 154, 183, 206 and 209) were detected in more than 50% of the samples while seven congeners (i.e. BDE-71, 77, 85, 119, 138, 153 and 196) were detected at low frequencies. The combination of low detection frequency and low detection limits for many of the PBDE congeners at Zeppelin indicates low concentrations of many PBDEs in Arctic air. As in 2017, BDE-209 was in 2018 above detection limit in all samples from Birkenes and Zeppelin and high concentrations were measured at both stations. As a result, the pattern at Zeppelin and Birkenes is dominated by BDE-209, contributing to 90% and 74% of sum PBDEs at the two stations respectively. At Birkenes and Zeppelin, BDE-47 and -206 had the highest concentrations after BDE-209 and contributed to about 7% each.

The weekly concentrations of sum PBDEs (excl. BDE-209) ranged between: 0.09-0.27 pg/m^3 at Birkenes, and 0.18-0.59 pg/m^3 at Zeppelin. The weekly ranges for BDE-209 were 0.14-3.0 pg/m^3 and 0.21-45 pg/m^3 at Birkenes, and Zeppelin respectively. The minimum in the ranges reflects the detection limits. The annual mean concentrations of sum PBDEs (including BDE-209) in 2018 were seven times higher at Zeppelin (8.8 pg/m^3) than at Birkenes (1.2 pg/m^3) (Figure 15). This difference becomes much smaller when excluding BDE-209 from the sum of BDEs (sumPBDE$_{excl209}$=0.2 and 0.6 pg/m^3 at Birkenes and Zeppelin, respectively). The concentrations of sum PBDEs and the individual congeners (except BDE-209) measured at Birkenes in 2018 were lower than previous years while higher than previous years at Zeppelin. The higher sum PBDEs in 2017 and 2018 are due to several episodes with high concentrations of BDE-209 at Zeppelin in combination with generally higher concentrations of BDE-209 than previous years. This results in a ten times higher annual mean concentration of BDE-209 in 2017 and 2018 than in 2016. The reason for elevated concentrations of BDE-209 is unknown, but elevated levels also in field blanks suggest possible influences during sampling or transportation. The levels in the high episodic samples are up to 100 times higher than the levels in field blanks suggesting other reasons as well. No correlation to specific air masses are seen for the high episodes, often the air masses for the sample periods comes from west to south-west (e.g. Iceland or Greenland).

The long-term time trends for sum PBDEs (excl. BDE-209) and BDE-47 at Zeppelin do not show any significant trends suggesting steady-state conditions for the PBDEs. The trend analyses for Birkenes however show decreasing trends for BDE-47 over the monitoring period.

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 the Arctic settlement of Longyearbyen in 2012-2013 (Salamova et al., 2014).



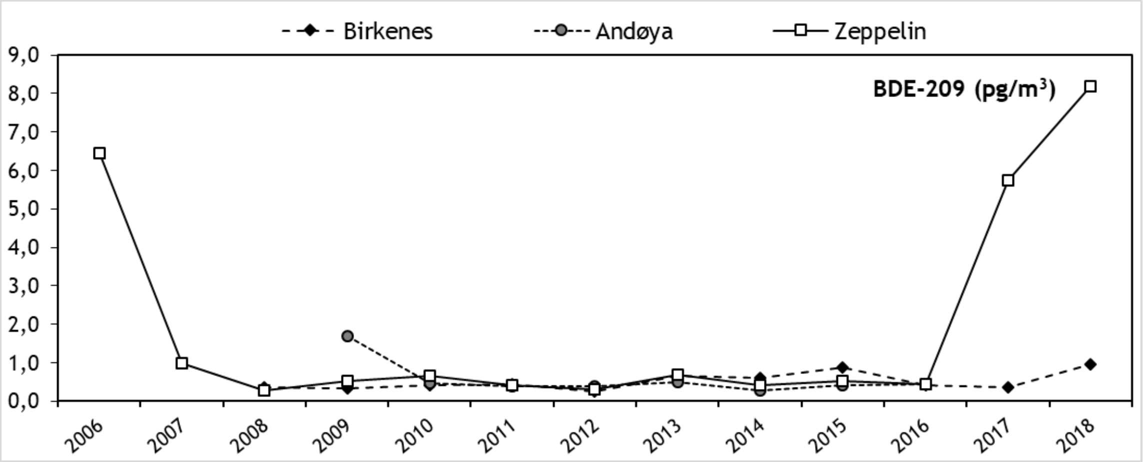
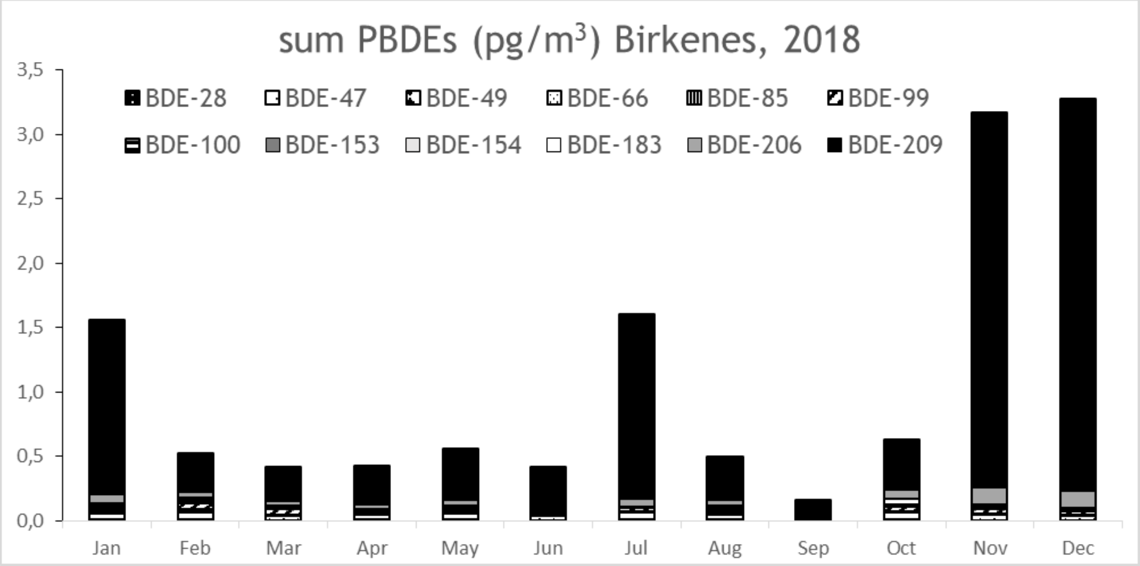


Figure 15: Annual mean concentrations of sum PBDEs and BDE-209 (pg/m³) in air.

The seasonal pattern is influenced by low detection frequencies of many BDE-congeners and a few individually high episodes. The seasonality seen in Figure 16 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 16). The reason for these individual high levels are not known.



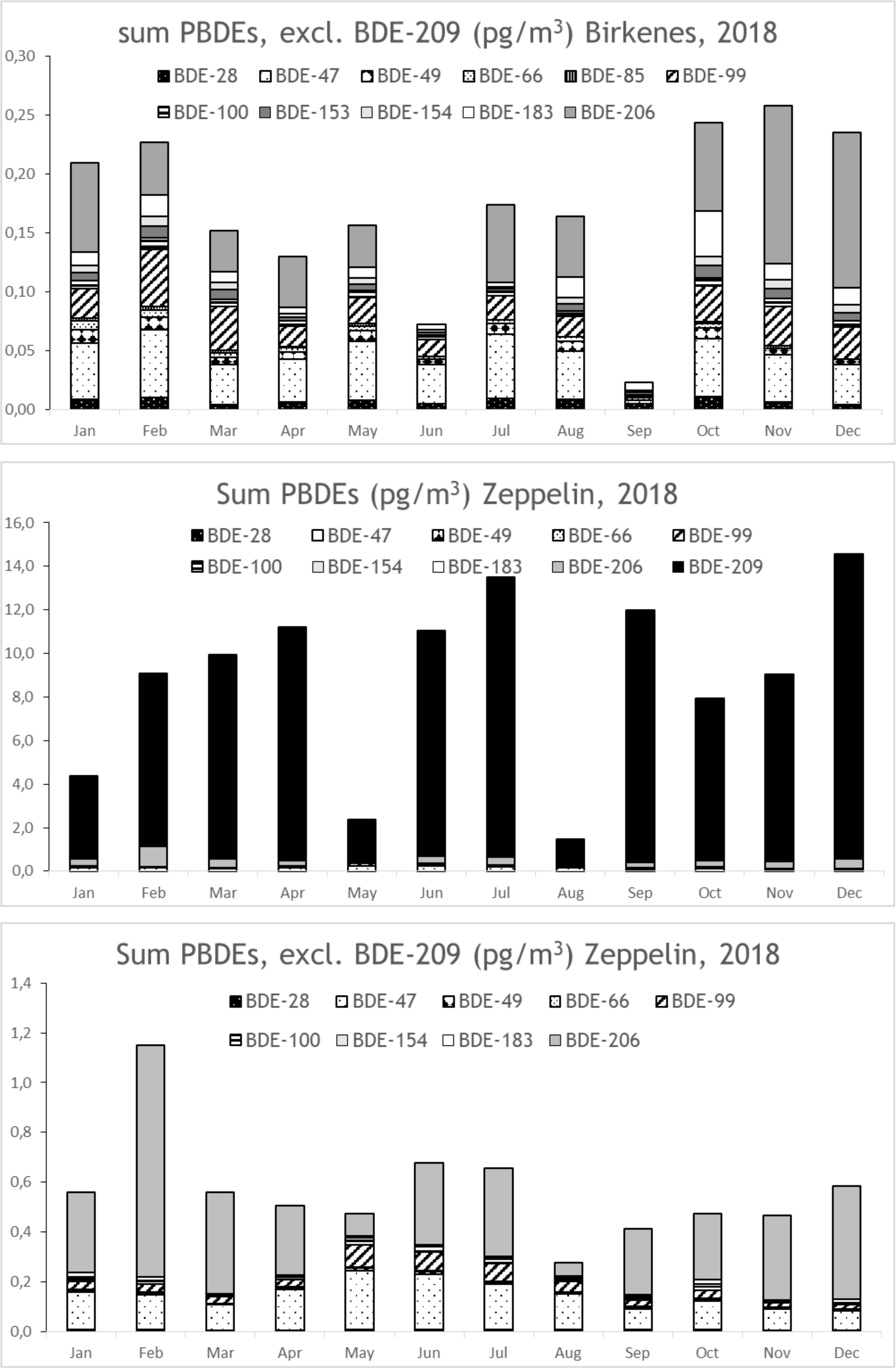


Figure 16: Seasonal variability of sum PBDEs (detected congeners) and sum PBDEs, excl. BDE-209 (detected congeners) at Birkenes and Zeppelin in 2018.

2.2.2 *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. Bromoanisoles 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 between 2010 and 2016. TBA was detected in all samples at all sites in 2018 and the weekly concentrations ranged between: 1.5-5.5 pg/m^3 at Birkenes; and 0.6-19 pg/m^3 at Zeppelin. The annual mean concentrations of TBA in 2018 were 3.6 and 4.8 pg/m^3 at Birkenes and Zeppelin respectively (Figure 17). The annual mean concentration at Zeppelin is lower than in 2017 and one of the lowest ever measured, but still in the same concentration range as most year in the monitoring period.

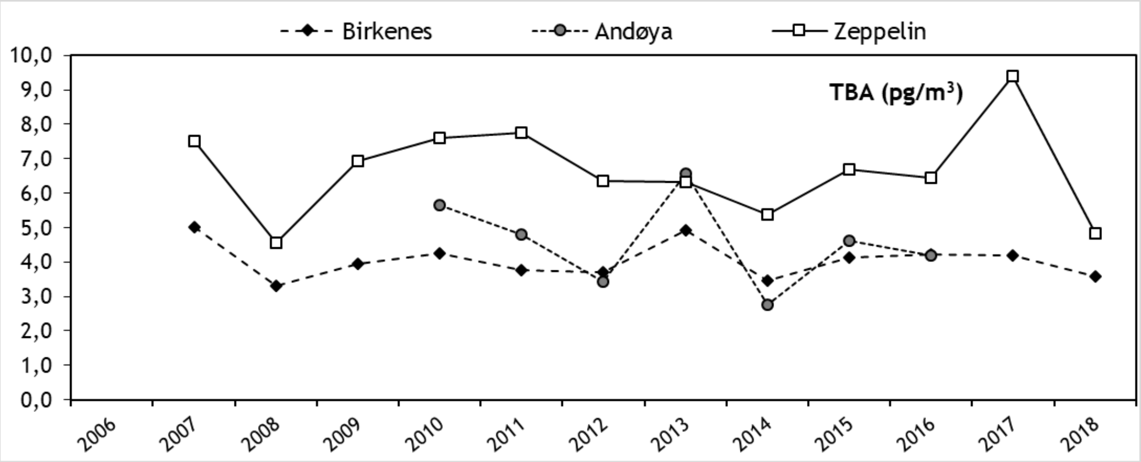


Figure 17: Annual mean concentrations of TBA (pg/m^3) in air.

At Zeppelin, the same seasonal trend as previous years was observed, lowest concentrations during winter and spring and increasing concentrations (4-5 times higher) during the summer and autumn (Figure 18). The higher levels in summertime may be a consequence of increased algal bloom during this period. In contrast to Zeppelin and to previous years, at Birkenes in 2018 the highest concentrations were observed in wintertime (January, February, October, November and December) and the lowest concentrations in summertime. The reason for this seasonality is not known.

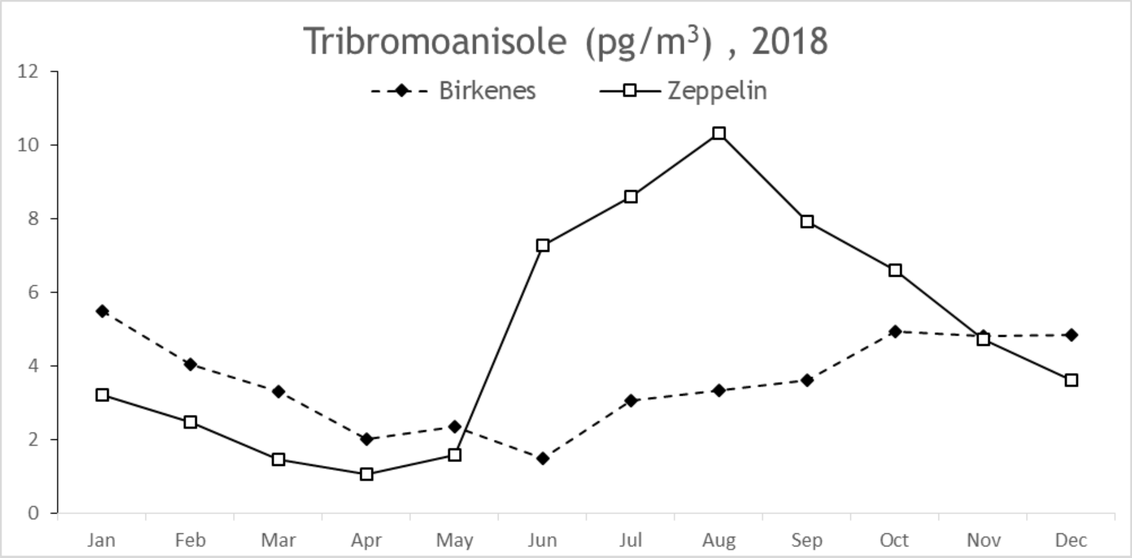


Figure 18: Seasonal variability of TBA at Birkenes and Zeppelin in 2018.

2.2.3 Hexabromocyclododecanes (HBCDs)

HBCD is an additive brominated flame retardant, with many applications. The main use is in extruded and expanded polystyrene used in building and construction materials for thermal insulation. 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. From 2017, the sampling volume for HBCDs were increased at both sites in order to improve detection (i.e. two samples were aggregated in the lab). Unfortunately this strategy did not result in any improvement of detection. The three HBCDs are still detected with a low frequency at both sites. At Birkenes, none of the HBCDs were detected in any of the samples in 2018. At Zeppelin, only α-HBCD was detected in one sample. As the LODs for all HBCDs are very low, this suggest very low concentrations of HBCD in background air. As a result, the annual mean concentrations in Figure 19 only reflects the analytical limit of detection (i.e. no real air concentrations).

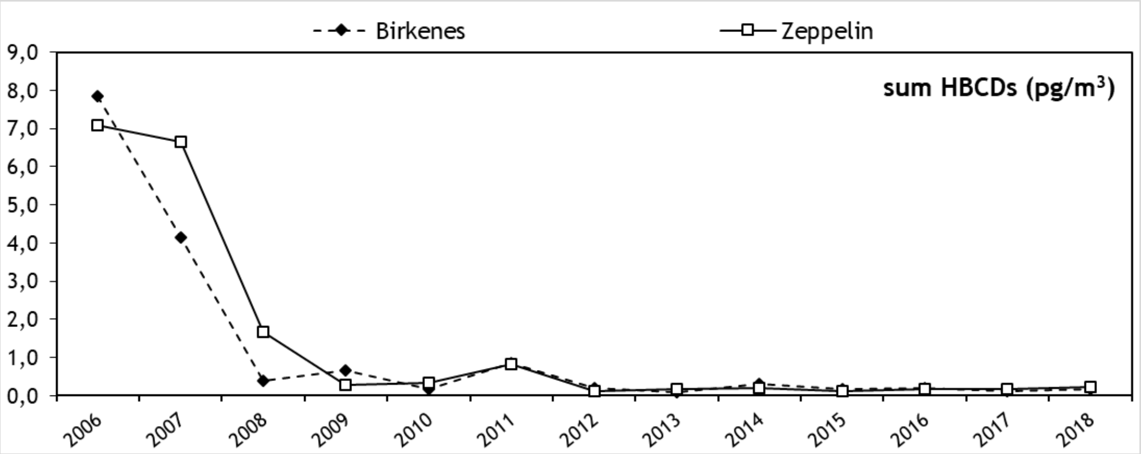


Figure 19: Annual mean concentrations of sum HBCDs (pg/m^3) in air.

No time-trend or seasonality could be obtained for HBCDs due to the low detection.

2.2.4 Per- and polyfluorinated alkyl substances (PFAS)

Ionic PFAS

PFASs comprise a large and complex group of industrially produced chemicals: Ionic compounds like perfluoroalkyl sulfonates (PFSA) 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. PFOS together with its salts and perfluorooctane sulfonyl fluoride (PFOS-F) has been regulated by the Stockholm Convention on POPs since 2009 (Stockholm Convention, 2013). It is also regulated by the Aarhus protocol (UN/ECE, 2010). PFOA was included as a POP under the Stockholm Convention in May 2019, furthermore PFHxS is currently under consideration for listing in 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).

Ionic PFASs have been monitored at Birkenes and Zeppelin since 2006 and at Andøya since 2009. The measurements of ionic PFAS (=sum PFASs) under the monitoring programme of "*Long-range atmospheric transported contaminants*" has until 2016 included 13 individual PFAS compounds. In 2018, the list was extended and 23 ionic PFAS compounds were measured (Table 5). Of the monitored PFAS only three are defined as "short-chain": PFBS, PFPeS, and PFHxA while the other seventeen are defined as "long-chain" (CnF2n+1SO3H, n ≥ 6, PFSAs, and CnF2n+1COOH, n ≥ 7, PFCAs) (Buck et al., 2011), but these definitions are currently under evaluation by authorities in Europe.

Table 5: Full names and abbreviations of targeted ionic PFAS in air at Birkenes, Andøya and Zeppelin in 2018.

Ionic PFAS	
Full name	**Abbreviation**
4:2 Fluorotelomer sulfonic acid	4:2 FTS
6:2 Fluorotelomer sulfonic acid	6:2 FTS
8:2 Fluorotelomer sulfonic acid	8:2 FTS
Perfluorobutane sulfonic acid	PFBS
Perfluoropentane sulfonic acid	PFPeS
Perfluorohexane sulfonic acid	PFHxS
Perfluoroheptane sulfonic acid	PFHpS
Perfluorooctane sulfonic acid	PFOS
Perfluorooctane sulfonic acid, linear	PFOS_{lin}
Perfluorononane sulfonic acid	PFNS
Perfluorodecane sulfonic acid	PFDS
Perfluorohexanoic acid	PFHxA
Perfluoroheptanoic acid	PFHpA
Perfluorooctanoic acid	PFOA
Perfluorononanoic acid	PFNA
Perfluorodecanoic acid	PFDA (PFDcA)

Perfluoroundecanoic acid	PFUnDA
Perfluorordodecanoic acid	PFDoDA
Perfluorotridecanoic acid	PFTrDA
Perfluorotetradecanoic acid	PFTeDA
Perfluorohexadecanoic acid	PFHxDA
Perfluorooctadecanoic acid	PFODcA
Perfluorooctane sulphonamide	FOSA (PFOSA)

Despite combining two samples to one and thereby increasing the sampling time, the detection was still low in 2018. At Zeppelin, only PFOA was detected (75%). At Birkenes and Andøya, PFOA together with PFHpA, PFNA, $PFOS_{lin}$ and PFDA were detected. PFHxS and PFNS were detected only at Andøya while PFUnA was detected only at Birkenes. The annual mean concentrations of PFOA was higher at Birkenes (0.28 pg/m^3) than at Andøya (0.12 pg/m^3) and Zeppelin (0.10 pg/m^3) (Figure 20). Also most of the other detected PFAS were higher at Birkenes than at Andøya. The concentrations at Birkenes were also higher in 2018 than the previous three years.

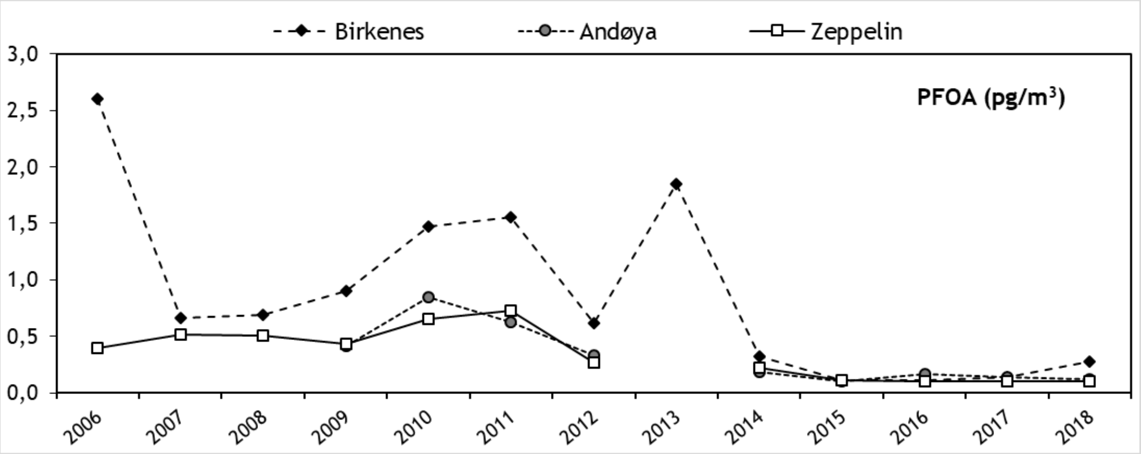


Figure 20: Annual mean concentrations of PFOA and sum ionic PFAS (pg/m^3) in air.

A seasonal trend was observed at Birkenes with more frequent detection and higher concentrations in summer than in winter (Figure 21). At Andøya and Zeppelin, the seasonality was not as clear, but the highest concentrations of PFOA were observed in the warmer month also at these stations.

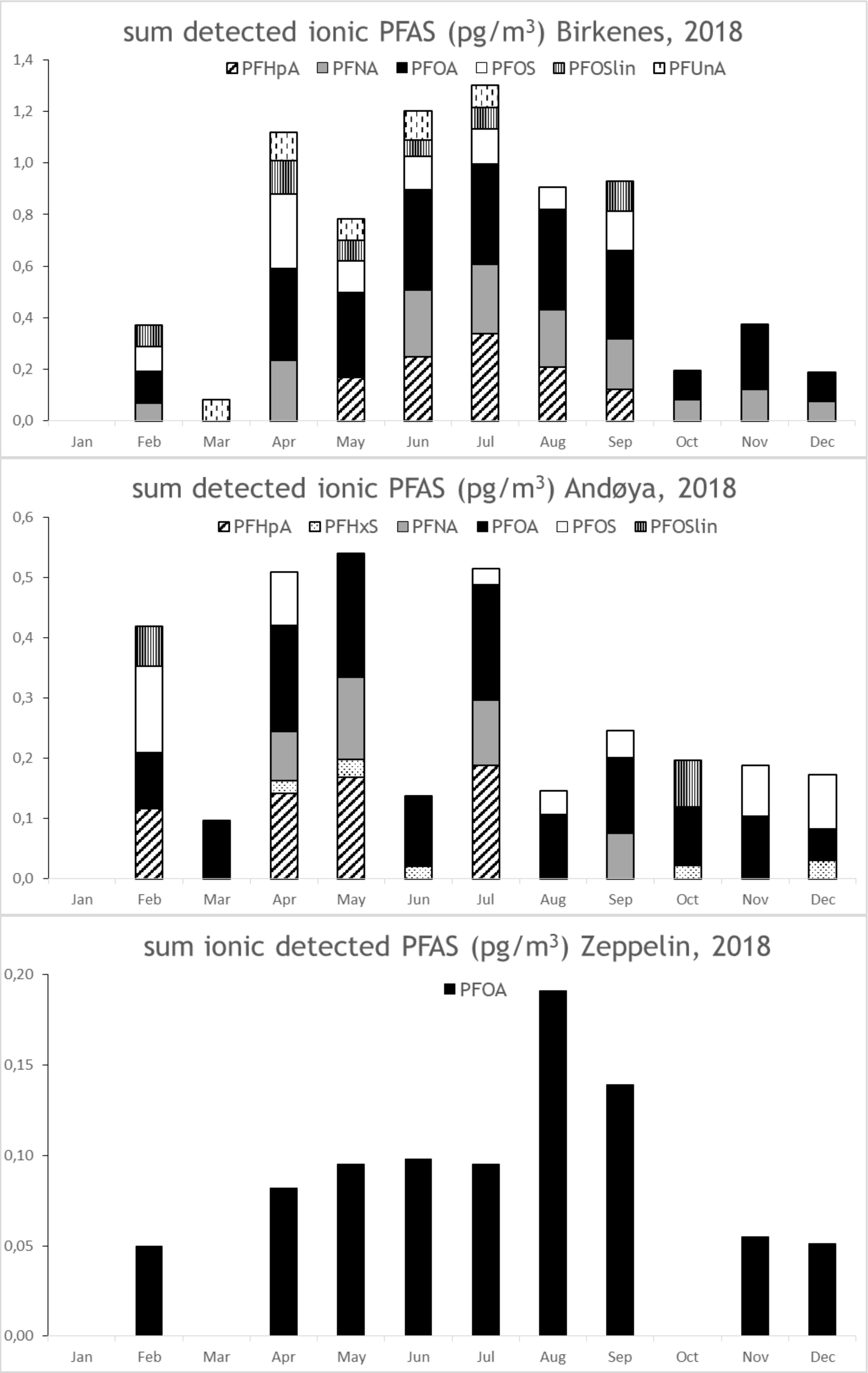


Figure 21: Seasonal variability of sum PFAS (detected congeners) at Birkenes and Zeppelin in 2018.

2.3 Long-term monitoring 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 1, and Table 1). 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.

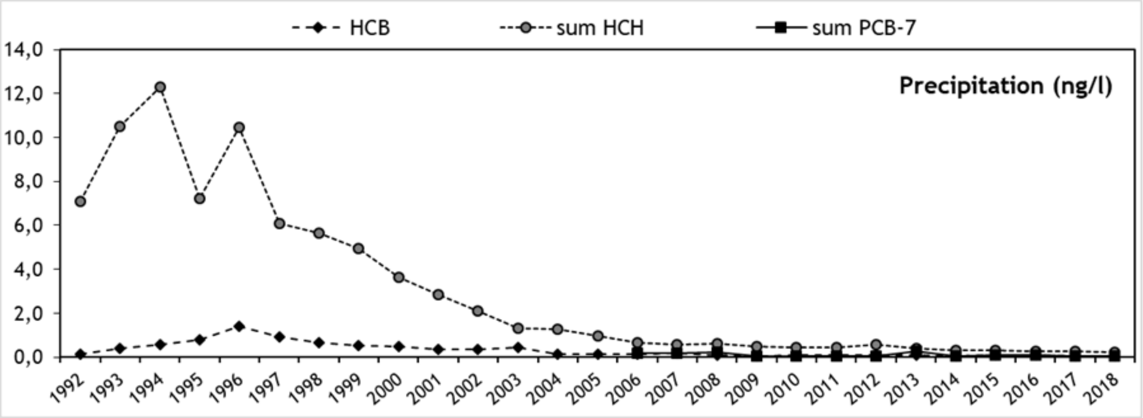


Figure 22: Annual mean concentrations of HCB, sum HCH and sum PCB-7 (ng/l) in precipitation at Birkenes.

HCB were below detection limit in 73% of the samples in 2018. Thus, the annual mean concentration reflects the detection limit. The annual mean concentrations of HCB in precipitation in 2018 were similar, but just lower than 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 22). No seasonal variability was observed for HCB, mainly due to low detection. The two HCH-isomers (α and γ) were detected in most of the samples in 2018. The annual mean concentration for sum HCHs was the lowest since the beginning of the monitoring (in 1992) and as in air they followed a decreasing time-trend at Birkenes. A seasonality was observed with high concentrations during spring- and summer and the low concentrations in winter (December-February). This seasonality is similar to that found for air concentrations at Birkenes. The PCB-congeners were only detected in 10-40% of the precipitation samples depending on congener. The detection was lowest in April-September, probably due to the low precipitation during that period in 2018. The annual mean concentration of PCB-7 in 2018 was similar to the previous years. No clear seasonality was observed (Figure 23).

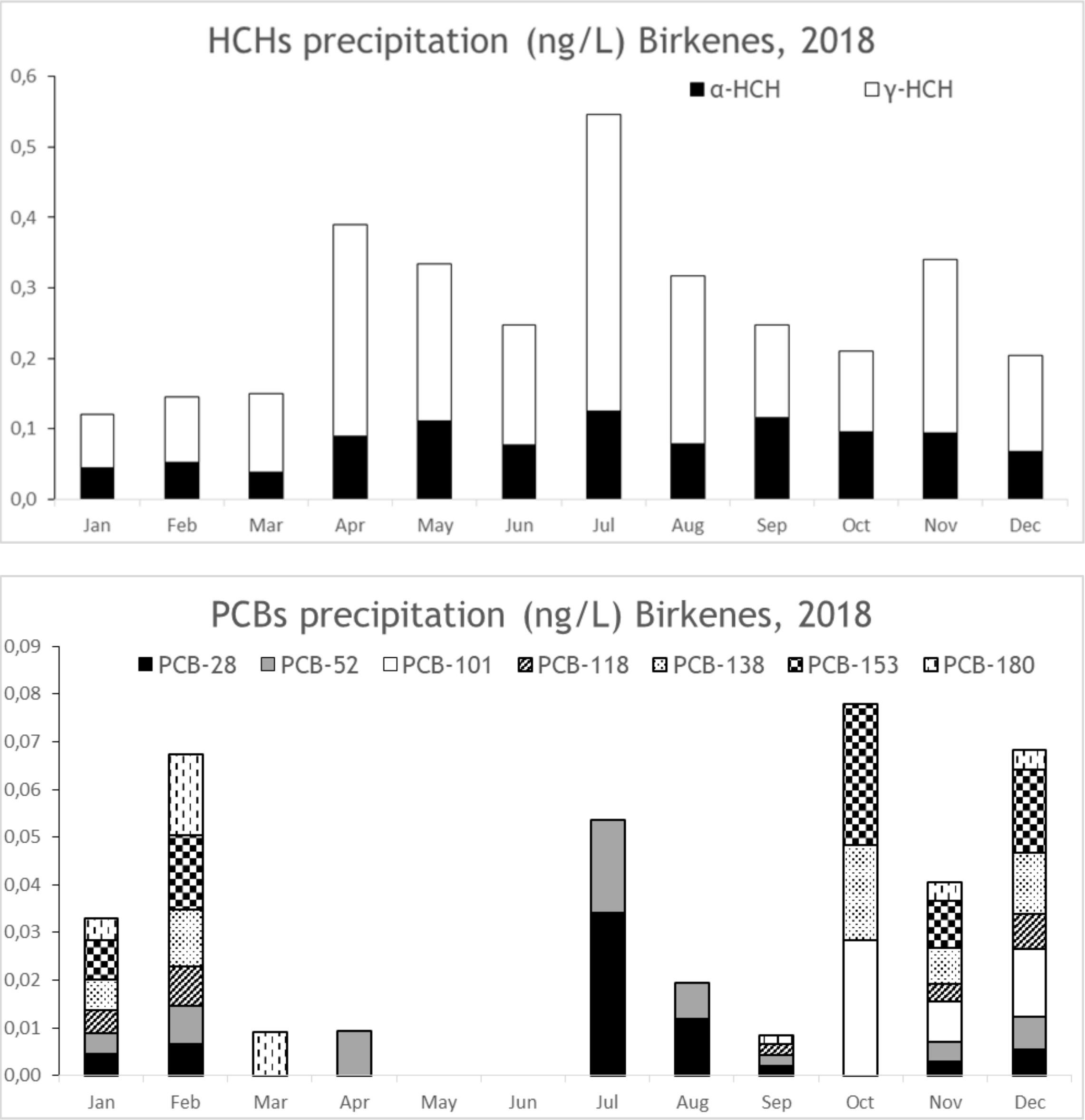


Figure 23: Seasonal variability of HCHs and PCBs (detected congeners) in precipitation (ng/L) at Birkenes in 2018.

3 Organic contaminants of emerging concern

New organic chemicals are constantly introduced on the market, either as replacements for regulated chemicals such as the POPs or for use in new materials as a demand for new technological needs and properties. Some of these chemicals have similar physical-chemical properties as regulated POPs and have thus received attention from regulatory agencies as well as the scientific community. Detection of such chemicals in screening programmes or case-studies have identified a need for environmental monitoring of these chemicals. The monitoring programme "Long-range atmospheric transported contaminants" is therefore continuously adapted to include new organic contaminants of emerging concern. For a few new organic contaminants of emerging concern, a short-term monitoring period (with data available since 2013) has been established within the monitoring programme while for some other new organic contaminants the monitoring was initiated in 2017 or in 2018.

3.1 Data on contaminants included in the monitoring in 2013

3.1.1 Cyclic Volatile methylsiloxanes (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., 2013a). The cyclic oligomers octamethylcyclotetrasiloxane (D4), decamethylcyclopenta-siloxane (D5), and dodecamethylcyclohexa-siloxane (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). As 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), their use in wash-off personal care products is now restricted in Europe (not to exceed 0.1%) as of January 2018 (European Chemical Agency, 2018). In addition, on May 3, 2017, ECHA started consultation on extending this proposed restriction to "leave-on" personal care products. All the three oligomers; D4-D6, are on Norway's priority substances list with the aim to stop emissions of these compounds by 2020 (Norwegian Environment Agency, 2015) and they are considered as chemicals of emerging Arctic concern by AMAP (AMAP, 2017). Restriction of D6 under REACH is also on its way.

The three oligomers D4, D5, and D6 have been monitored at Zeppelin since 2013. The monitoring in 2013-2016 was conducted in two sampling campaigns per year, one in summer and one in winter, with each campaign covering six-seven samples. From 2017, the monitoring was expanded so that D4-D5 were sampled every week at Zeppelin and once per month at Birkenes. The weekly sampling at Zeppelin aimed to better assess the seasonal variability and a better coverage of the levels in the Arctic. The monthly sampling at Birkenes aimed to assess spatial variability of D4-D5 and the influence of vicinity to source regions in order to better understand the potential for long-range transport as well as seasonality at this site. All samples were collected Friday-Monday (72 hr) in order to minimize the risk of contamination from activities at the stations during weekdays.

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). These findings have been further supported by mechanistic model simulations (Krogseth et al., 2013). The monitoring results from 2013-2016 have confirmed the presence of cVMS in Arctic air and the measured concentrations in the air have been shown to be three orders of magnitude higher than most regulated POPs. Whether the measured concentrations at Zeppelin in this monitoring programme are results of long-range transport or possibly influenced by local sources and emissions of cVMS within the Arctic itself, mainly from increased anthropogenic activities in the area, still needs to be studied. Knowledge on local sources for all new contaminants are of importance as there are no restrictions on their use, while the influence of local sources for regulated POPs is smaller. For example, inadequate wastewater treatment can potentially serve as point sources for non-regulated contaminants to the Arctic region (Krogseth et al., 2017; AMAP, 2017). For all background sites also other types of sources, such as building materials, may serve as point sources. 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 shown that D4, D5 and D6 can undergo atmospheric deposition. Instead, multimedia model predictions, based on the physical chemical properties of D4, D5 and D6, suggest the three of them to have a minimal deposition potential (Wania et al., 2003; Xu and Wania, 2013). 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. cVMS have nonetheless been detected in arctic biota at Svalbard (Warner et al. 2010; Warner et al. 2013). According to the authors, this may be a result of direct release of cVMS to aquatic systems in the region (point sources) and not due atmospheric deposition of long-range transported cVMS, but other findings of cVMS in Arctic cod from pristine areas instead suggest long-range transport of cVMS (Green et al., 2018). 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.

The concentrations for the investigated cVMS in 2018 were obtained by using the new adsorbent (ABN) which is less affected by degradation during storage. While D5 and D6 has been shown to be degraded during storage in the previously adsorbent (ENV+), the results from previous years are storage corrected in a semi-quantitative way, and the data for D4 is more uncertain as it has been shown to undergo losses (through volatilization) and be formed (through degradation of D5) during storage (Kierkegaard and McLachlan, 2013; Krogseth et al., 2013). Thus, the actual presence and the levels of D4 in the air at Zeppelin is therefore uncertain as D4 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). Due to the uncertainties introduced by ENV+-sorbent mediated degradation/formation mechanisms we evaluated a new adsorbent in 2017 (ABN) that was fully implemented for all air sampling of cVMS in 2018. The ABN adsorbent is less affected by degradation and therefore a better option for the monitoring. This allows for reporting of more accurate data for D4 from 2018.

D4 and D5 were detected in all samples from Birkenes and most samples from Zeppelin in 2018. D6 was however <LOD in 29% and 59% of the samples from Birkenes and Zeppelin, respectively. In contrast to 2017, the measured concentrations of D4 and D5 in air at Birkenes in 2018 were higher than those at Zeppelin for most months of the year. For D6 there was no difference between the sites. The range and annual mean concentrations of D4, D5 and D6 at Zeppelin were 0.09-1.0 ng/m^3 (0.4 ng/m^3), 0.05-12.3 ng/m^3 (1.6 ng/m^3), and 0.04-5.61 ng/m^3 (0.3 ng/m^3) , respectively (including a few high episodes of D5 and D6), with the highest levels measured in wintertime (November-April) and the lowest in summertime (May-September) for both oligomers (Figure 24). The concentrations of D4, D5 and D6 at Birkenes were 0.2-0.9 ng/m^3 (0.6 ng/m^3), 0.8-13 ng/m^3 (4.3 ng/m^3) and 0.09-0.81 ng/m^3 (0.3 ng/m^3), respectively. Similar to the observations made at Zeppelin station, the lowest concentrations at Birkenes were observed in summer (July-August) and the highest in winter (November-January) (Figure 24). The seasonality observed at Zeppelin with the large increase in November is in agreement with the modelled findings by Krogseth et al. (2013). Lower concentrations in summer can be explained by higher degree of photochemical atmospheric degradation during the light period.

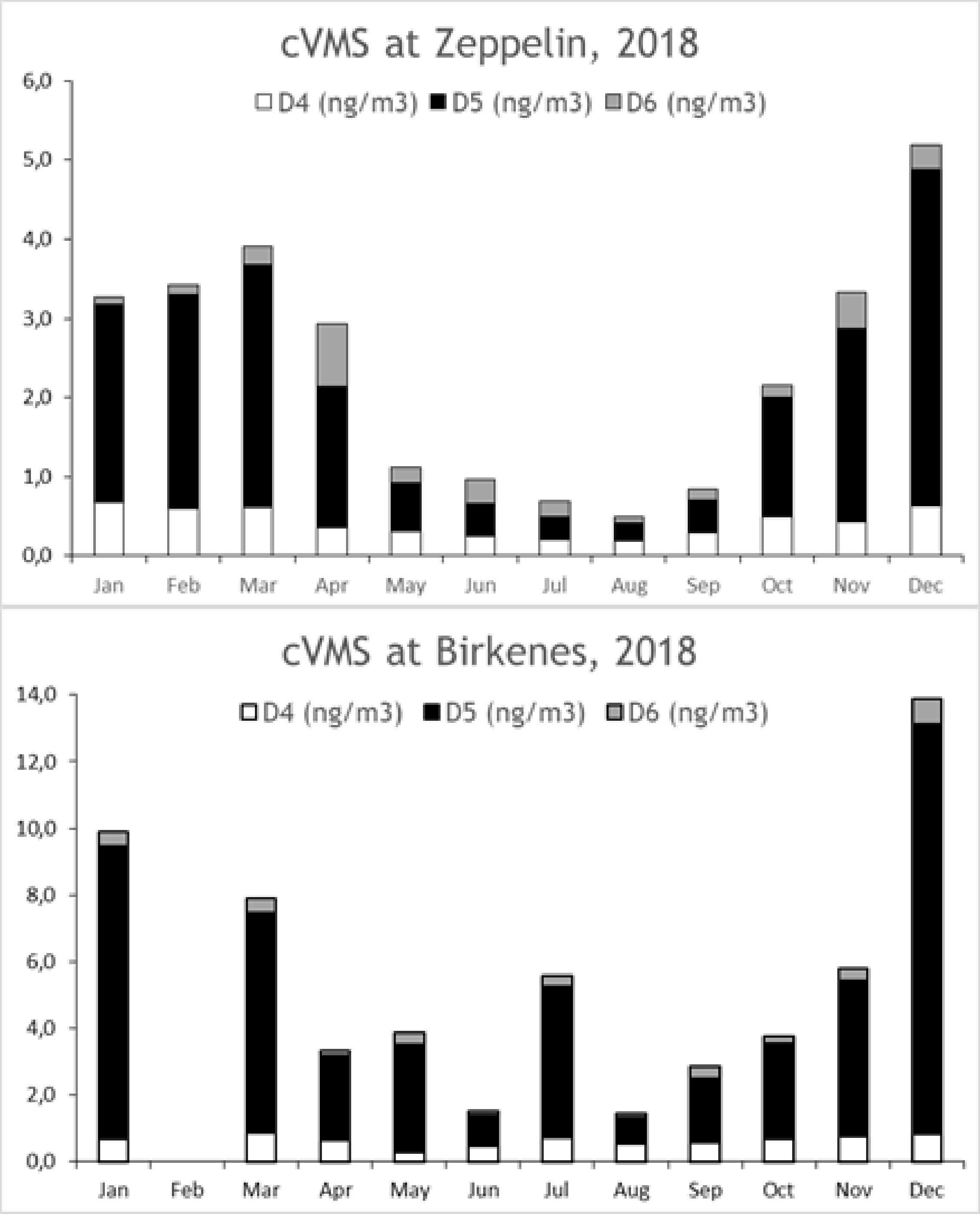


Figure 24: Monthly mean concentrations (ng/m^3) of D4, D5 and D6 at Zeppelin (top) and Birkenes (bottom) in 2018. Zeppelin represents the average of weekly samples while Birkenes represents one sample per month.

When comparing the data for cVMS over time we had to rely on data sampled during specific periods of the year: July-August (summer) and November-December (winter), as monitoring prior to 2017 was done only in one summer and one winter campaign (Figure 25) (Bohlin-Nizzetto et al. 2017; Nizzetto et al. 2016; Nizzetto et al. 2015; Nizzetto et al., 2014). This comparison shows higher concentrations of D6 in 2018 than in 2017 both in summer and winter, but the concentrations in summer are significantly lower than 2015-2016. In winter, the concentrations of D6 do not show any changes during the monitoring period (2015-2018). The same is seen for D5; significantly lower concentrations in summer in 2017-2018 than in 2015-2016, but no difference in winter in 2015-2018. These results suggest a decrease in atmospheric D6 and D5 in summer time, but the reason for different trends in summer and winter needs to be confirmed by continuous yearly monitoring. The lower concentrations in summer might be a reflection of the changes in product formulations or use of cVMS during these years.

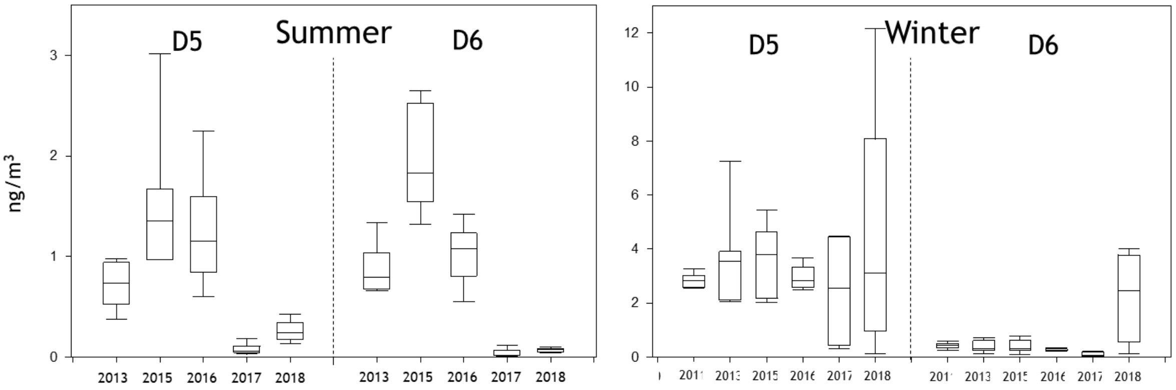


Figure 25: Box-plots of measured concentrations of D5 and D6 (ng/m^3) at Zeppelin in two periods of the year (Summer: July-August and Winter: November-December) in 2013-2018.

In 2018, also linear siloxanes were measured in a selection of the air samples from Zeppelin. These were analyzed in the same extract as the cVMS. The three linear oligomers (L3, L4 and L5) were all <LOQ in all samples (Table 6). This suggest that the linear siloxanes are not present in Arctic air.

Table 6: Linear siloxanes in Arctic air (pg/m3) from active air samplers at Zeppelin, 2018

	L3	L4	L5
Detection frequency (%)	0	0	0
Detected concentrations (pg/m^3)	<0.006-<0.03	<0.0007-<0.005	<0.02-<0.03

3.1.2 Short- and medium chain chlorinated paraffins (S/MCCPs)

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). Information on levels and distribution of SCCPs is still 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, from 2017 the monitoring programme also included measurements of M/SCCPs at Birkenes. The sampling at Zeppelin is done on a weekly basis while sampling at Birkenes is conducted on a monthly basis. At both sites M/SCCPs are sampled together with sampling of PCBs and OCPs. The monitoring data for M/SCCPs at Zeppelin are the first measurements of M/SCCPs in Arctic air. As in other published studies, the blank levels for the SCCPs and MCCPs are variable and high, resulting in relatively high average blank values (10-50% of detected masses). In 2018, the blank values varied over the year and each sample was compared to its corresponding lab blank (i.e. the lab blank that was extracted, cleaned and analysed in parallel with the sample). ~30% of the measurements for MCCPs were below the average blank while none of the measurements for SCCPs were below the average blank. 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 the future.

The annual mean concentrations at Zeppelin for 2018 were as observed also in previous years one to three orders of magnitude higher than the concentrations of most of the other studied POPs and one order of magnitude lower than the concentrations of cVMS and sum PAHs/PAH-16: 290 pg/m^3 for SCCPs and 120 pg/m^3 for MCCPs (Figure 26). The annual mean concentrations measured for SCCPs do not show any significant difference between the years (2013-2018), but the MCCPs are slightly higher the last two years. The levels of SCCPs are significantly higher than those of MCCPs (2-20 times), there are however a few occasions (<10% of the total samples) in which MCCPs are similar or higher than SCCPs. The reason for the higher MCCPs are not known.

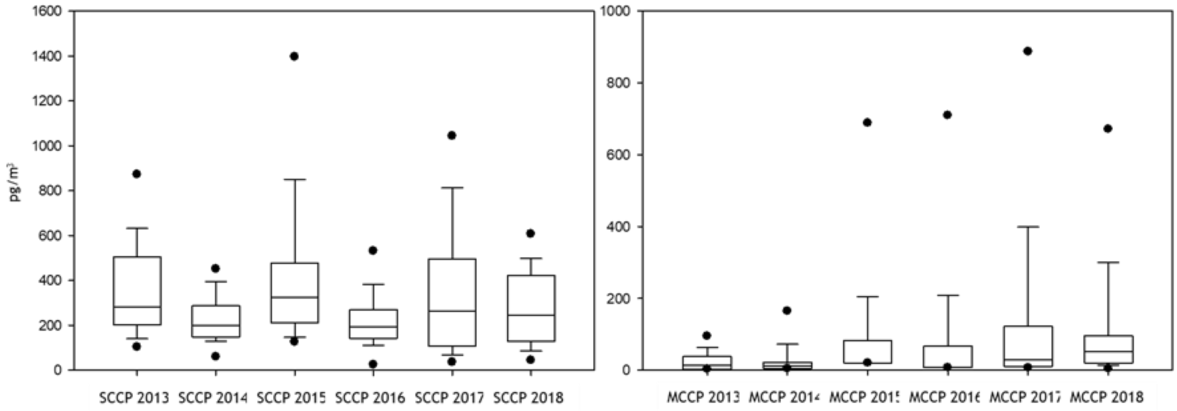


Figure 26: Box plot of measured SCCP and MCCP concentrations in air at Zeppelin in 2013-2018. The box-plots represents a range from 25-75% confidence interval while the error bars and points represent 5-95 percentile and min/max, respectively.

The annual mean concentrations at Birkenes in 2018 for SCCPs were 290 pg/m^3 if excluding one outlier (7100 pg/m^3 including the outlier) and for MCCPs 720 pg/m^3 excluding one outlier (960 pg/m^3 including the outlier) for MCCPs. The concentrations of SCCPs are similar at Birkenes and Zeppelin in 2018 with the exception of the outlier in April at Birkenes (Figure 27). The concentrations of MCCPs were however higher at Birkenes than at Zeppelin. In contrast to 2017 and to the observations at Zeppelin, the MCCPs were higher than SCCPs in ~50% of the samples at Birkenes. The reason may be that Birkenes is more in vicinity to source areas or presence of local sources around Birkenes.

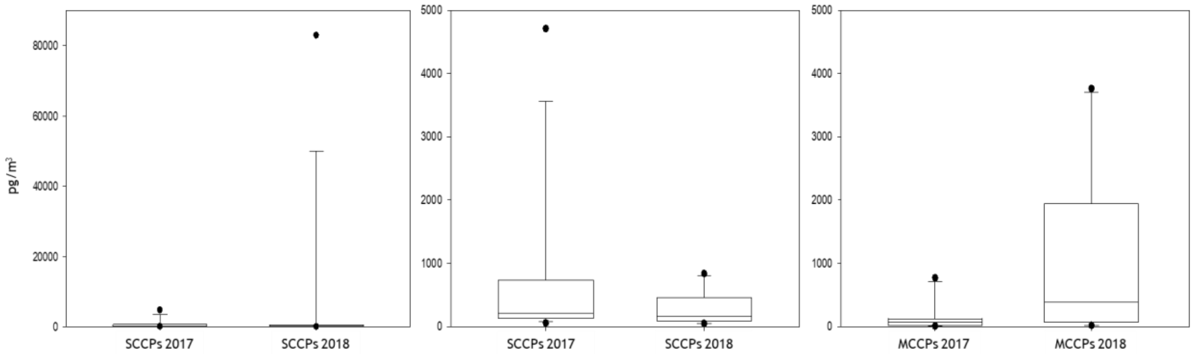


Figure 27: Box plot of measure SCCP and MCCP concentrations in air at Birkenes in 2018 (with and without an extreme value for SCCPs in 2018).

The concentrations of SCCPs and MCCPs measured at Zeppelin in 2013-2018 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., 2013b, Chaemfa et al., 2014). The monthly mean concentrations in 2018 fluctuated from month to month at both stations (Figure 28).

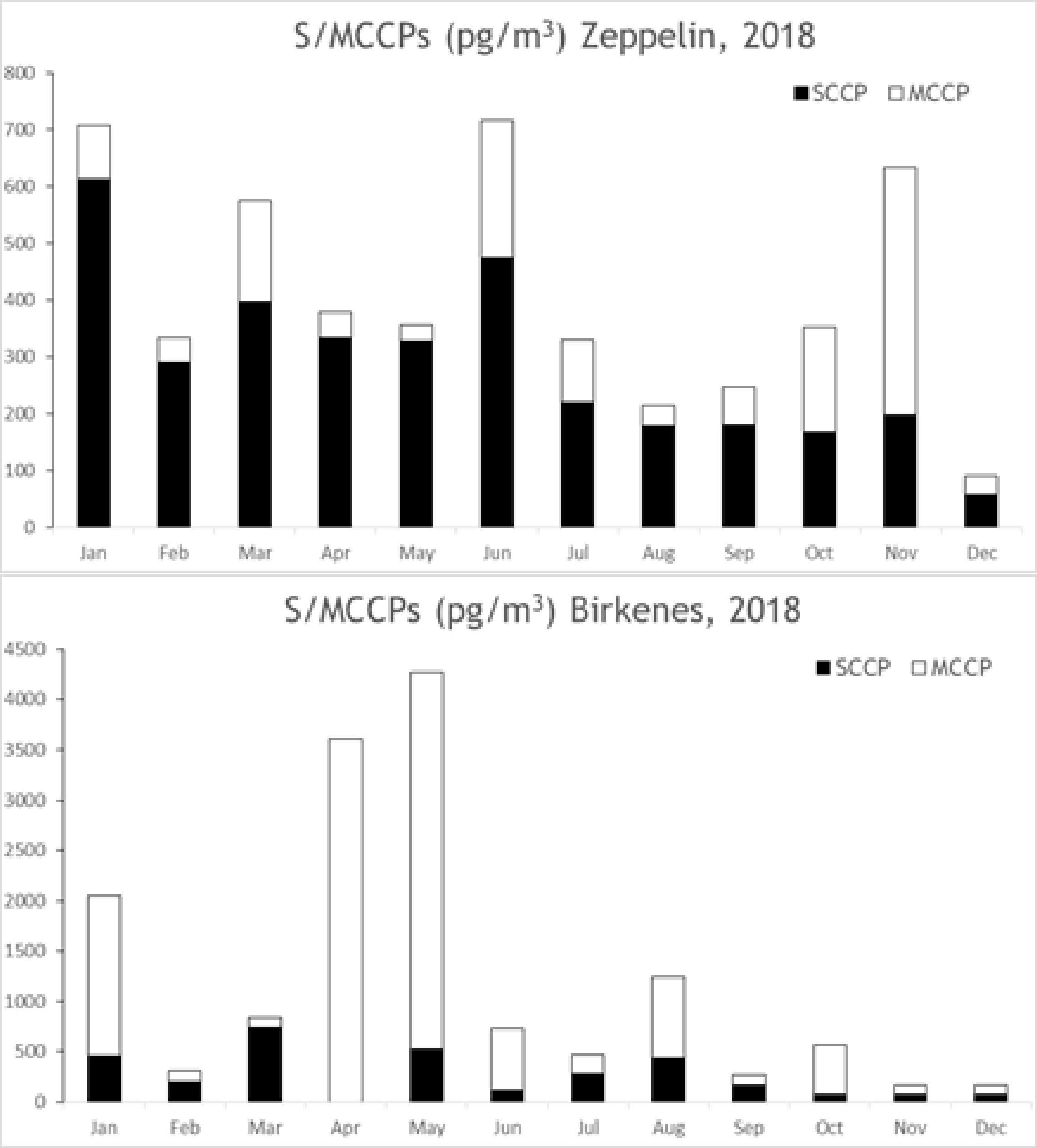


Figure 28: Seasonal variability of SCCPs and MCCPs at Birkenes and Zeppelin in 2018.

3.2 Data on contaminants included in the monitoring in 2017-2018

Six groups of non-regulated organic contaminants of emerging concern, covering 72 individual compounds, were monitored in 2018 (Table 7). These were volatile PFAS, new brominated flame retardants (nBFRs), organophosphorous flame retardants (OPFRs), phthalates, bisphenols and linear siloxanes. The linear siloxanes are presented together with the cVMS above (section 5.1.1). Air samples for nBFRs, OPFRs and phthalates were collected at Zeppelin and Birkenes in two campaigns, one summer campaign and one winter campaign. Six samples with a sampling time of 48-72 hr were taken during each campaign (Table 3). Each sample consisted of a glass fiber filter that collected compounds associated to particles and two PUF-plugs that collected compounds in gas-phase. The two phases were combined during analysis to provide bulk concentrations in air. The air samples for volatile PFAS were collected at Birkenes, Andøya and Zeppelin using PUF/XAD/PUF as adsorbents. Two samples were taken per month, each with a sampling time of 48-72 hr. The two monthly samples were combined during analysis and provided monthly concentrations. Air samples for linear siloxanes were taken at Zeppelin (together with the samples for cVMS) in one summer and one winter campaign (three samples per campaign).The bisphenols were sampled at Zeppelin in one summer and one winter campaign with three samples per campaign. Samples were taken on glass fiber filters only due to the physical-chemical properties of bisphenols. Air samples were also collected at Zeppelin to perform data mining analysis (suspect screening analysis). These samples were taken using the same sampling methodology as for siloxanes (ABN adsorbent). Each sample was taken for 72 hours in one summer campaign and one winter campaign.

Table 7: Full names and abbreviations of organic contaminants of emerging concern included in the monitoring from 2018.

Full name	Abbreviation
Volatile PFAS	
4:2 fluorotelomer alcohol	4:2 FTOH
6:2 fluorotelomer alcohol	6:2 FTOH
8:2 fluorotelomer alcohol	8:2 FTOH
10:2 fluorotelomer alcohol	10:2 FTOH
N-ethyl perfluorooctanesulfonamide	N-EtFOSA
N-ethyl perfluorooctane sulfonamidoethanol	N-EtFOSE
N-methylperfluoro-1-octansulfonamide	N-MeFOSA
N-Methylperfluorooctanesulfon-amidoethanol	N-MeFOSE
Novel brominated flame retardants - nBFRs	
Allyl 2,4,6-tribromophenyl ether	ATE (TBP-AE)
α-Tetrabromoethylcyclohexane	α-TBECH (DBE-DBCH)
ß-Tetrabromoethylcyclohexane	ß-TBECH (DBE-DBCH)
γ/δ-Tetrabromoethylcyclohexane	γ/δ-TBECH (DBE-DBCH)
2-Bromoallyl-2,4,6-tribromophenyl ether	BATE (TBP-BAE)
Pentabromotoluene	PBT
Pentabromoethylbenzene	PBEB
1,2,3,4,5-pentabromobenzene	PBBZ
Hexabromobenzene	HBB

Full name	Abbreviation
2,3-dibromopropyl-2,4,6-tribromophenyl ether	DPTE (TBP-DBPE)
2-ethylhexyl-2,3,4,5-tetrabromobenzoate	EHTBB
1,2-bis(2,4,6-tribromophenoxy)ethane	BTBPE
Bis(2-ethylhexyl)tetrabromophthalate	TBPH (BEH-TBP)
Decabromodiphenylethane	DBDPE
Organophosphorous flame retardants - OPFRs	
Triethyl phosphate	TEP
Tri(2-chloroethyl)phosphate	TCEP
Tripropyl phosphate	TPrP (TPP)
Tris(2-chloroisopropyl)phosphate	TCPP (TCIPP)
Triisobutyl phosphate	TBP (TiBP)
Butyl diphenyl phosphate	BdPhP
Triphenyl phosphate	TPP (TPhP)
Dibutylphenyl phosphate	DBPhP
Tri-n-butylphosphate	TnBP
Tris(1,3-dichloro-2-propyl)phosphate	TDCPP (TDCIPP)
Tris(2-butoxyethyl)phosphate	TBEP (TBOEP)
Tricresyl phosphate	TCP
2-ethylhexyldiphenyl phosphate	EHDP (EHDPP)
Trixylyl phosphate	TXP
Tris(4-isopropylphenyl)phosphate	TIPPP
Tris(4-tert-butylphenyl)phosphate	TTBPP
Tris(2-ethylhexyl)phosphate	TEHP
Phthalates	
Dimethyl phthalate	DMP
Diethyl phthalate	DEP
Dipropyl phthalate	DPP
Diallyl phthalate	DAIP
Di-iso-butylphthalate	DIBP
Dibutyl phthalate	DBP
Butylbenzyl phthalate	BBzP
Dihexyl phthalate	DHP
Di(2-ethylhexyl) phthalate	DEHP
Dicyclohexyl phthalate	DcHP
Bis(2-propylheptyl) phthalate	DPHP
Di-iso-nonyl phthalate	DINP
Bisphenols	
2,4’-Bisphenol A	2,4’-BPA
4,4’-Bisphenol A	4,4’-BPA
Bisphenol C	BPC
Bisphenol G	BPG

Full name	Abbreviation
Bisphenol BP	BPBP
Bisphenol FL	BPFL
Bisphenol PH	BPPH
Bisphenol TMC	BPTMC
Bisphenol B	BPB
Bisphenol E	BPE
2,4'-Bisphenol S	2,4'-BPS
4,4'-Bisphenol S	4,4'-BPS
2,2'-Bisphenol F	2,2'-BPF
Bisphenol P	BPP
Bisphenol M	BPM
Bisphenol Z	BPZ
Bisphenol AF	BPAF
Bisphenol AM	BPAM
Linear siloxanes	
	L3
	L4
	L5

3.2.1 Per- and polyfluorinated alkyl substances (PFAS)

Volatile PFAS

Volatile PFAS were included in the monitoring programme from 2017. They have been measured on monthly basis at Birkenes, Andøya and Zeppelin in 2017 and 2018. Two samples were taken per month and combined in the laboratory to provide monthly bulk concentrations.

In 2018, eight volatile PFAS were monitored at the three stations, in addition to the ionic PFAS reported in section 2.2.4 (Table 5): 4:2 FTOH, 6:2 FTOH, 8:2 FTOH, 10:2 FTOH, N-EtFOSA, N-EtFOSE, N-MeFOSA, and N-MeFOSE. A special sampler unit consisting of PUF/XAD/PUF in sandwich was used to sample the volatile PFAS as PUFs alone do not retain the volatile PFAS. A new analytical method with cold extraction was tested and developed in 2017 and used for all the volatile PFAS. This was done to limit the loss of volatile PFAS caused by evaporation and degradation during normal soxhlet extraction methodologies.

Of the eight targeted volatile PFAS only 8:2 FTOH was detected in all samples at all sites (Table 8). High detection was also observed for 6:2 FTOH (70-90%) and 10:2 FTOH (20-60%). N-Me-FOSA was not detected in any samples from any site. The detection frequency was also low for 4:2 FTOH, N-Et-FOSA, N-Me-FOSE and N-Et-FOSE (0-20%). 8:2 FTOH together with 6:2 FTOH were the dominating volatile PFAS, followed by 10:2 FTOH, and were also found in highest concentrations (Table 8). No clear spatial or seasonal variability were observed for the volatile PFAS. The concentrations measured at the three Norwegian sites in 2017 are similar to those measured in the atmosphere above the Chinese Sea (Zhao et al., 2017) and in rural Germany (Dreyer et al., 2008) for 6:2, 8:2 and 10:2 FTOH while lower for 12:2 FTOH. The obtained LODs for FOSE and FOSA are higher than the previously reported concentrations in air which reduce the comparability between new measurements and previous measurements.

Table 8: Volatile PFAS in air from active air samplers, presented as detection frequencies and ranges of monthly measurements (pg/m^3) at Birkenes, Andøya and Zeppelin, 2018.

	Birkenes		**Andøya**		**Zeppelin**	
	Detection frequency (%)	Range (pg/m^3)	Detection frequency (%)	Range (pg/m^3)	Detection frequency (%)	Range (pg/m^3)
4:2 FTOH	108	<0.4-7.5	0	<0.4-<4.5	20	<0.4-1.4
6:2 FTOH	90	<2.9-30	70	<3.0-16	90	<2.9-17
8:2 FTOH	100	4.2-21	100	2.6-220	100	3.0-160
10:2 FTOH	20	<1.8-2.3	60	<1.9-240	60	<1.9-8.5
N-EtFOSA	0	<0.7	0	<0.7	0	<0.7-<0.9
N-EtFOSE	20	<0.2-0.6	0	<0.2	20	<0.2-6.6
N-MeFOSA	0	<0.4-<1.5	10	<0.4-2.1	20	<0.4-16
N-MeFOSE	0	<0.7-<1.3	10	<0.8-2.0	20	<0.8-15

3.2.2 New brominated flame retardants (nBFRs)

New brominated flame retardants were included in the monitoring programme in 2017. They have been monitored at Zeppelin in 2017 and 2018, in one summer campaign (July-August) and one winter campaign (November-December) using active air sampler. At Birkenes, they have been monitored in 2018 in one summer and one winter campaign. Each campaign consisted of six samples taken over 48-72 hr at each station.

Of the targeted fourteen nBFRs (Table 7), only three were detected in more than 50% of the active air samples at Zeppelin in 2018 (Table 9): PBT, PBBZ, and HBB. In addition, DPTE, was detected in 45% of the samples and are included in Table 9. Also BTBPE and DBDPE were detected in 36 and 45% of the samples, but the results are uncertain due to elevated field blank levels. Low detection for BATE is attributed degradation during the chemical analysis and does not necessarily mean low presence in Arctic air. The highest detection frequency and highest concentrations were observed for HBB (mean for both sampling periods: 0.48 pg/m^3) and PBT (mean for both sampling periods: 0.39 pg/m^3), both in summer and winter, contributing with 54% and 34% to the sum of detected nBFRs, respectively. The detection frequency and most of the detected concentrations did not differ between the summer and winter campaign suggesting no strong seasonality in air concentrations at Zeppelin (Table 9). The profiles in the samples are consistent in summer and winter time. The measured concentrations of the individual nBFRs are 100-1000 times lower than the concentrations of the individual OPFRs and phthalates. The same has also been observed in Arctic air samples by Salamova et al. (2014) and Rauert et al. (2018).

Table 9: Detected nBFRs in air (pg/m^3) from active air sampling at Zeppelin in 2017-2018, presented as detection frequencies and average concentrations of individual measurements in summer and winter.

		PBT	**PBBZ**	**HBB**	**DPTE**	**BTBPE***	**Sum detected nBFRs (excl. DBDPE)**
		Detection frequency (%) in 2018					
		82	91	91	45	36	
Year	Sampling period	Concentration (pg/m^3)					
2018	06.07-27.08	0.24	0.09	0.39	0.02	0.20	0.9
2018	05.10-17.12	0.52	0.09	0.56	0.02	0.23	1.7
2017	28.06-18.08	0.06	0.03	0.07	0.02	0.22	0.4
2017	10.11-18.12	0.05	0.03	0.08	0.01	0.03	0.2

*Results uncertain due to elevated levels in field blanks.

At Birkenes, five of the fourteen targeted nBFRs were detected in 50% or more of the samples in 2018: α-TBECH, PBT, PBBZ, HBB and DPTE (Table 10). In addition, β-TBECH was detected in 42% of the samples and BTBPE and DBDPE were detected, but influenced by high levels in field blanks. The highest concentrations were observed for HBB (2.7 pg/m^3 in summer, and 0.32 pg/m^3 in winter) contributing to 64 and 52% in summer and winter time respectively. For all detected compounds there were higher concentrations in summer than in winter. This together with higher detection frequencies in summer suggest seasonality for the nBFRs at Birkenes. The detection frequencies and the concentrations at Birkenes in summer were significantly higher than the ones at Zeppelin with up to 10 times higher concentrations at Birkenes in summer time. In winter time however no significant difference was seen between the two sites.

Table 10: Detected nBFRs in air (pg/m3) from active air samplers at Birkenes, 2018, presented as detection frequencies and average concentrations of the individual measurements in summer and winter.

		α-TBECH	**ß-TBECH**	**PBT**	**PBBZ**	**HBB**	**DPTE**	**BTBPE***	**Sum detected nBFRs (excl. DBDPE)**
		Detection frequency in 2018 (%)							
		75	42	92	100	92	75	42	
Year	Sampling period	Concentration (pg/m^3)							
2018	06.07-27.08	0.19	0.09	0.55	0.83	2.67	0.04	0.22	4.6
2018	29.10-17.12	0.10	0.05	0.07	0.10	0.32	0.02	0.07	0.7

*Results uncertain due to elevated levels in field blanks.

3.2.3 Organophosphorous flame retardants (OPFRs)

Organophosphorous flame retardants (OPFRs) were included in the monitoring programme in 2017. They have been monitored at Zeppelin in 2017 and 2018, in one summer campaign (July-August) and one winter campaign (November-December) using active air sampler. At Birkenes, they have been monitored in 2018 in one summer and one winter campaign. Each campaign consisted of six samples taken over 24-48 hr at each station.

The analysis included a list of 17 OPFRs (Table 7). Of these, only four were detected in 50% or more of the active air samples from Zeppelin (TCEP, TCPP, TiBP, and TEHP) (Table 11), while the other 13 were below LOD in all or most of the samples (i.e. TEP, TPrP, TPP, BdPhP, DBPhP, TnBP, TDCPP, TBEP, TCP, EHDPP, TXP, TIPPP, TTBPP). Elevated LODs were obtained for TPP, TCP and EHDPP and TDCPP, TBEP and TTBPP, probably as a result of presence in products used during lab procedures. It should not be excluded that these compounds are present in the air at levels below these elevated LOD.

The measured concentrations of the detected OPFRs at Zeppelin were high, with concentrations for the individual compounds equal to or exceeding the levels observed for cVMS and CPs. The concentrations of the sum of the detected OPFRs over the two sampling periods (summer and winter) ranged from <LOD-700 pg/m^3 (mean: 410 pg/m^3, median: 490 pg/m^3). The concentrations measured in 2018 were 2-3 times higher than in 2017. The dominant OPFRs at Zeppelin were TCPP (<LOD-410 pg/m^3) and TCEP (<LOD-250 pg/m^3) contributing to 60% and 30%, respectively, of sum OPFRs in summer and winter time (Table 11). No seasonality was observed for any of the targeted OPFRs at Zeppelin. This is in contrast to 2017, when higher concentrations in summer were observed for TCEP, TCPP and TnBP.

Table 11: Detected OPFRs in air (pg/m^3) from active air samplers at Zeppelin in 2017- 2018, presented as detection frequencies and average concentrations of the individual measurements in summer and winter

Year	**Sampling period**	**TCEP**	**TCPP**	**TiBP**	**DBPhP**	**TnBP**	**TDCPP**	**TEHP**	**Sum detected OPFRs**
		Detection frequency (%) in 2018							
		83	67	50	0	33	42	50	
Year	Sampling period	Concentrations (pg/m^3)							
2018	13.07-06.09	101	235	16	<0.8	*13*	<7.2	37	410
2018	29.10-10.12	127	240	*15*	<1.1	*18*	11	83	490
2017	30.06-11.08	41	107	5.2	0.4	11	4.9	*0.2*	170
2017	10.11-18.12	*15*	<36	9.5	<0.5	<3.0	<10	<40	160

At Birkenes, only two OPFRs were detected in 50% or more of the samples in summer time (i.e. DBPhP and TCP) and only one in winter time (i.e. TnBP) (Table 12). Of the four detected at Zeppelin, three were below detection limit in most samples from Birkenes suggesting lower concentrations of these OPFRs at Birkenes than at Zeppelin (i.e. TCEP, TCPP and TiBP). The fourth detected OPFR at Zeppelin; TEHP, had elevated detection limit at Birkenes that were more than 10 times higher than the detected concentrations at Zeppelin, and no conclusion about concentrations at Birkenes can therefore be done. One possible reason for higher concentrations of most OPFRs at Zeppelin than at Birkenes might be influence from the monitoring station itself, but this needs further investigation. No further comparison of concentrations between Zeppelin and Birkenes could be done due to the low number of detected compounds

Table 12: OPFRs in air (pg/m^3) from active air samplers at Birkenes, 2018, presented as detection frequencies and average concentrations of the individual measurements in summer and winter.

		TCEP	**TCPP**	**TiBP**	**DBPhP**	**TnBP**	**TDCPP**	**TCP**	**TEHP**	**Sum detected OPFRs**
		Detection frequency (%) in 2018								
		0	17	25	33	25	0	33	0	
Year	Sampling period	Concentrations (pg/m^3)								
2018	09.07-03.09	<40	*67*	*14*	1.8	<11	<18	20	<990	48
2018	24.10-21.12	<45	*72*	*15*	*1.4*	15	<20	<10	<1100	42

Salamova et al. (2014) reported OPFRs in Arctic air measured in Longyearbyen. The concentrations of TCEP and TCPP in their study were similar to the concentrations measured in this monitoring programme at Zeppelin. In contrast, the concentrations of TnBP, TDCPP, TPP, TBEP and EHDPP were higher in their study than what is observed in this monitoring programme at Zeppelin (the last two substances not even detected at Zeppelin) (Salamova et al., 2014). The higher concentrations in Longyearbyen suggests presence of local sources of the latter compounds in Longyearbyen.

3.2.4 Phthalates

Phthalates were included in the monitoring programme in 2017. In 2018, they were measured in one summer campaign and one winter campaign at Zeppelin and Birkenes using active air samplers. Each campaign aimed at a number of six samples taken over 24-48 hr, but the winter campaign at Zeppelin only consist of two samples due to bad weather conditions in December 2018 at Zeppelin.

The measurements at Zeppelin and Birkenes both show that seven of the twelve targeted phthalates (Table 7) were detected in all or most of the active air samples in the summer and winter campaign (Table 13); DMP, DEP, DAIP, DIBP, DBP, DEHP, and DPHP. The other five compounds, DPP, DnHP, BBzP, DcHP and DINP were below LOD (2, 1, 2, 9 and 300 pg/m^3, respectively) in all or most samples. In the winter campaign at Birkenes, lower levels and lower detection frequencies were observed for most compounds indicating a seasonality of phthalates. In contrast to Birkenes and to the findings from 2017, no seasonality was observed at Zeppelin. All the data are blank adjusted.

The observed concentrations for the detected phthalates were high, even exceeding the individual concentrations for the OPFRs. At Zeppelin in 2018, the highest concentrations were observed for DiBP (0.4-8.6 ng/m^3), followed by DEHP (<0.1-2.4 ng/m^3) and DEP (0.2-1.9 ng/m^3) (Table 13). Contributing to 48%, 19% and 21% of the sum phthalate concentrations in summer and 62%, 15% and 14% in winter time, respectively. In addition, DBP (<0.02-1.3 ng/m^3) contributed to 10% of the sum of phthalates in summer and winter. The concentrations of the sum of the targeted phthalates (sum phthalates) ranged from 0.8-8.4 ng/m^3 (mean: 5.2 ng/m^3, median 5.6 ng/m^3) in summer and 5.2-14 ng/m^3 (mean+median 9.8 ng/m^3) in winter.

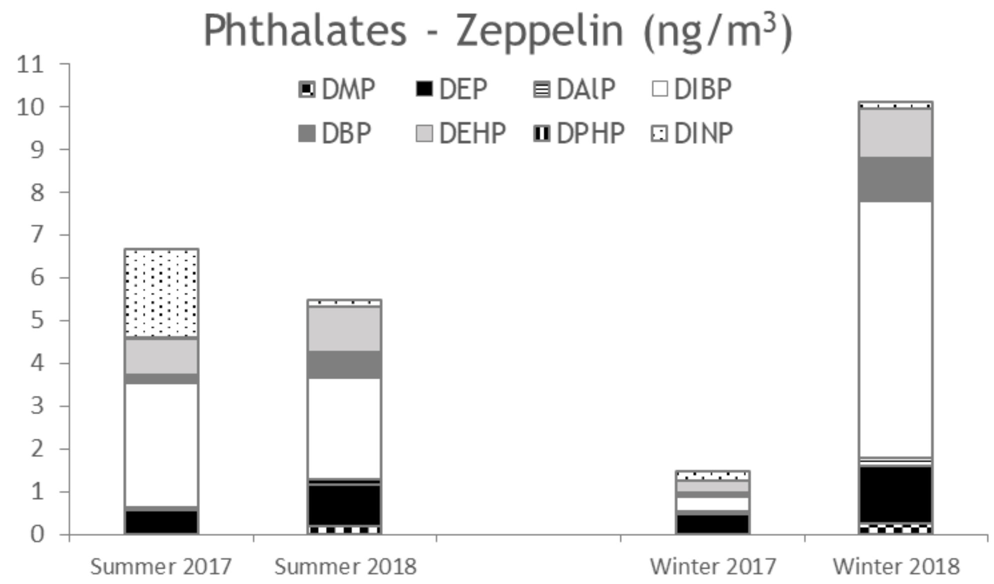


Figure 29: Mean concentrations of detected phthalates in air at Zeppelin in 2017 and 2018.

Table 13: Mean concentrations of detected phthalates in air (ng/m^3) from active air samplers at Zeppelin in 2017 and 2018. Concentrations in summer and winter are average of samples taken during each sampling campaign.

Sampling period		ng/m^3								
Year	**Sampling period**	**DMP**	**DEP**	**DAIP**	**DiBP**	**DBP***	**DEHP**	**DPHP**	**DINP**	**Sum phthalates**
2018	20.07-03.09	0.19	0.98	0.12	2.39	0.59	1.05	0.007	0.15	5.2
2018	28.11-07.12	0.26	1.34	0.17	6.02	1.01	1.13	0.02	0.15	9.8
2017	26.07-01.09		0.57	0.06	2.90	0.19	0.87	0.03	2.05	6.9
2017	15.11-17.12		0.48	0.06	0.35	0.08	0.29	0.004	0.21	1.6

*Italic: Influenced by blank levels.

At Birkenes in 2018, the highest concentrations were observed for DiBP (0.3-2.2 ng/m^3), followed by DEHP (<0.1-2.5 ng/m^3) and DEP (0.01-0.4 ng/m^3). Contributing to 58%, 33% and 7% of the sum phthalate concentrations in summer and 43%, 17% and 15% in winter time, respectively. In addition, although being below LOD in most samples, DINP were detected at high concentrations in a few samples in winter time (1.4-2.2 ng/m^3) resulting in being the most contributing phthalate in these samples. The concentrations of the sum of the targeted phthalates (sum phthalates) ranged from 2.3-3.6 ng/m^3 (mean+median 3.0 ng/m^3) in summer and 0.5-3.9 ng/m^3 (mean: 1.9 ng/m^3, median 0.7 ng/m^3) in winter (Table 14).

The measurements for DEP and DEHP are in agreement with the concentrations in Arctic air reported by Xie et al. (2007), while higher than those above the North Sea (Xie et al., 2007).

Table 14: Mean concentrations of detected phthalates in air (ng/m^3) from active air samplers at Birkenes, 2018. Concentrations are average of samples taken during each sampling campaign.

Sampling period		**ng/m^3**								
Start	**Stopp**	**DMP**	**DEP**	**DAIP**	**DiBP**	**DBP***	**DEHP**	**DPHP**	**DINP**	**Sum phthalates**
2018	27.07-31.08	0.03	0.19	0.004	1.57	*0.20*	*0.87*	0.02	0.15	3.0
2018	16.11-19.12	0.03	0.16	0.002	0.53	*0.05*	*0.15*	0.03	0.98	1.9

*Italic: Influenced by blank levels.

3.2.5 Bisphenols

Bisphenols were included in the monitoring programme of Zeppelin in 2018. They were measured in one summer and one winter campaign at Zeppelin using active air samplers, three samples per campaign. Each sample was taken over 72 hr. Due to their physical-chemical properties, only the filter and thereby the particles were analysed for bisphenols. The samples were analysed for 20 bisphenols and six other phenols.

The air sampling at Zeppelin show that most of the targeted 18 bisphenols were not detected or detected to very low extent. But 4,4’-bisphenol A was detected in all samples and the detected concentrations (0.65-2.18 pg/m^3) (Table 15) are similar to the few published concentrations on bisphenol A in remote and polar areas (Fu & Kawamura, 2010; Corrales et al., 2015). Also, 4,4’-bisphenol F, and 2,4’-bisphenol F were above the analytical detection limit in a few samples. This shows that bisphenol A is present in Arctic air.

Table 15: Bisphenols in atmospheric aerosols (pg/m^3) from active air samplers at Zeppelin, 2018

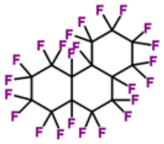
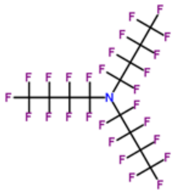
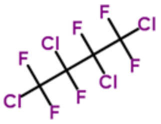
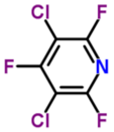
	4,4’-bisphenol A	**2,4’-bisphenol A**	**4,4’-bisphenol F**	**2,4-bisphenol F**
LOD	<0.40	<0.15	<0.18	<0.20
Detection frequency (%)	100	0	40	40
Detected concentrations (pg/m^3)	0.65-2.18	<0.15	<0.18-0.25	<0.20-0.24

3.2.6 Data mining

The aims of this activity were to if possible, i) verify the findings of fluorinated volatile chemicals in Arctic air detected previously in the national Screening Programme 2017 (Schlabach et al., 2018), and ii) identify new potential organic pollutants of Arctic concern. Air samples were collected at Zeppelin using the same sampling methodology as for siloxanes (cyclic and linear): two parallel ABN adsorbent cartridges were connected to low volume air samplers. Samples were collected during weekends (Friday afternoon to Monday morning, ca 70 hours) resulting in an air volume of 60-65 m^3. In total five duplicate samples were obtained in November-December 2018 and then analyzed for aim i), while two of those duplicate samples were analyzed for aim ii). All samples were extracted with hexane in the laboratory’s laminar flow clean cabinet that is fitted with HEPA and charcoal filter to remove dust and air contaminants of the laboratory air. A mixture of C13-labeled siloxanes was used as internal standards and 13C8-D4 was used for quantification of the fluorinated volatile substances (Table 16).

The results show presence of PFTBA (100% detection), TCHFB (70% detection) and DCTFP (30% detection, below LOQ) in Arctic air in 2018 (Table 16). These findings correlate with the results of the screening in 2017 when PFTBA, TCHFB and DCTFP were detected in 100, 100, and 80% of the air samples respectively, at concentrations of 15, 6.3 and 0.2 pg/m3. The confirmation suggests the presence of these compounds in Arctic air (and possibly long-range transport). The concentrations of PFTBA and TCHFB in 2018 are higher than those obtained in 2017. One compound, PFPHP, that was detected in the screening in 2017 was not detected in any air samples from 2018. One of the possible reasons for the difference between 2017 and 2018 can be higher LODs in 2018. Another possible factor can be a contribution of a local source (including the station itself), different from year to year.

Table 16: Fluorinated volatile substances targeted in data mining of Arctic air samples in 2018.

Full name (abbreviation)	**CAS**		**Results 2018 - this programme concentrations pg/m^3 (detection frequency)**	**Results 2017: concentrations pg/m^3 (detection frequency) (Schlabach et al. 2018)**
Perfluoroperhydro-phenanthrene **(PFPHP)**	306-91-2		<10-<110 pg/m^3, (0%) Not confirmed	<1-1.8 (60%)
Perfluorotributylamine **(PFTBA)**	311-89-7		14-1260 pg/m^3, (100%) Confirmed	9.7-89 (100%)
1,2,3,4-Tetrachloro-hexafluorobutane **(TCHFB)**	375-45-1		<4-228 pg/m^3, (70%) Confirmed	4.7-9.5 (100%)
3,5-Dichoro-2,4,6-trifluoropyridine **(DCTFP)**	1737-93-5		0.9-<11 pg/m^3, Detected in few samples below LOQ, Possibly confirmed	<0.5-0.25 (80%)

The data mining for new organic contaminants of potential emerging Arctic concern identified 21 polyhalogenated compounds that were detected in all of the studied samples (Table 17). The concentrations of these compounds ranged from 50-20 000 pg/m^3. In addition, six compounds were identified but only detected in 67% of the samples (Table 18). The concentrations of these ranged from 50 to 4200 pg/m^3. Five other compounds where detected in all samples but the identification was uncertain. Three of the identified compounds - pentachlorobenzene, hexachlorobenzene and hexachlorobutadiene are regulated under Stockholm Convention.

Table 17: Data mining of Arctic air samples in 2018. Compounds detected in all studied samples, sorted in declining concentrations. Exact structure of isomers requires confirmation.

	CAS	Concentration range (pg/m^3)
1,1,2,3,4,4-hexachloro-1,3-Butadiene	87-68-3	4500-20 000
1,2-dichlorobenzene	95-50-1	3000-14 000
dichlorobenzene	95-50-1	890-3100
hexachloroethane	67-72-1	640-4600
1,4-dichloro-2-methylbenzene	19398-61-9	570-2500
1,2,4-trichlorobenzene	120-82-1	320-1600
hexachlorobutadiene, unknown isomer		340-1800
1,3,5-trichloro-2-methoxybenzene	87-40-1	270 1500
dichlorobenzene	95-50-1	240-1090
Hexachlorobenzene	118-74-1	160-1200
2,4-dichloro-1-methoxybenzene	553-82-2	150-750
1,2,4-trichlorobenzene	120-82-1	100-490
1,5-dichloro-2-methoxy-3-methylbenzene	13334-73-1	100-700
Ethane, 1,1,2,2-tetrachloro-	79-34-5	100-540
1,2,4-trichloro-3-methylbenzene	2077-46-5	80-470
1,2,4,5-tetrachloro-3,6-dimethoxybenzene	944-78-5	50-270
1,2-dichloro-4-(chloromethyl)-benzene	102-47-6	50-300
2,3-Dichloro-5-trifluoromethylpyridine	69045-84-7	50-220
1,5-dichloro-2-methoxy-3-methylbenzene	13334-73-1	60-370
1,2,4,5-tetrachlorobenzene	95-94-3	50-240
1,2,3,5-tetrachlorobenzene	634-90-2	40-200

These substances form five groups:
- Hexachlorobutadiene and its previously unknown isomer
- Tetra- and hexachloroethane
- Di- to hexachlorobenzenes (8 substances)
- Di- to tetrachloro methyl- and/or methoxybenzenes (8 substances)
- 2,3-Dichloro-5-trifluoromethylpyridine

In general, these volatile and persistent substances were expected to be found in Arctic air – the isomers of tetra- to hexachloroethanes, di- to tetrachlorobenzenes, di- to tetrachloromethylbenzenes and di- to tetrachloromethoxybenzenes are included in the REACH Annex III Inventory, as well as hexachlorobutadiene and 2,3-dichloro-5-trifluoromethylpyridine. Thus all but one major poly-halogenated contaminants are already under attention. The results of NTS can be used for prioritization and correlation with production/consumption/release data and for selection of candidates for target screening or monitoring.

A special finding is a second isomer of hexachlorobutadiene, to the best of our knowledge this substance was not reported previously, though one possible candidate, hexachlorocyclobutene (CAS 6130-82-1) is in the Annex III as well. Noteworthy, here reported yet unknown contaminant is present at higher levels than hexachlorobenzene and its unequivocal identification can be a subject for a follow-up project.

The semi-quantitative estimate was made by using the ratio of the areas of total ion currents of identified peaks and of the internal standard – 13C-D5. This is a natural approach for quantification of unknown peaks, but it seems to give overestimations for halogenated aromatics: for example, estimate for hexachlororbenzene (160 – 1200 pg/m^3) is higher than value found in regular monitoring (43 – 83 pg/m3). Thus real concentrations of other substances in Table 17-18 might be lower, too.

Table 18: Data mining of Arctic air samples in 2018. Compounds that were detected in all samples, but not fully identified, or compounds that were identified, but not detected in all samples

	CAS	**Concentration ranges (pg/m3), (detection frequency)**
Methane, tribromo-	75-25-2	4200, (67%)
Unknown, m/z 158.91662		120-1800, (100%)
Unknown; m/z = 158.976288	51729-83-0	350-640, (67%)
Unknown; m/z = 179.929443	76588-95-9	60-250, (67%)
Unknown; m/z = 182.873276		70-660, (100%)
1,2-dichloro-4-methylbenzene	95-75-0	150, (67%)
Pentachlorobenzene	608-93-5	60-180, (67%)
Unknown, m/z = 222.843658	82221-32-7	30-130, (100%)
Unknown; m/z = 223.9555719		60-420, (100%)
Unknown, m/z = 188.882507		60-360, (67%)
S 421, Bis(2,3,3,3-tetrachloropropyl) ether	127-90-2	50-150, (67%)

4 Conclusion for organic contaminants

The overall annual mean concentrations in outdoor background air from active air samplers for 17 different organic contaminant classes and three observatories in 2018 are presented in Table 19.

Table 19: Annual mean concentrations in air for all targeted organic contaminants in 2018. The highest concentrations are marked with orange/pink while the lowest concentrations are marked with green.

Organic contaminants, Class	Annual mean concentration (pg/m3)		
	Birkenes	Andøya	Zeppelin
HCB	48	29	63
HCHs	6.7		3.1
DDTs	1.5		0.4
Chlordanes			0.6
PCB_7	3.1		1.7
PCB_{sum}	11.2		6.9
PAH-16	2500		170
PBDEs	1.2		8.8
TBA	3.6		4.8
HBCD	<0.2		<0.2
PFOA	0.3	0.1	0.1
cVMS	5300		2100
SCCPs/MCCPs	580		410
PFAS (volatile)	27	120	40
nBFRs	2.9		1.5
OPFRs	1100		400
Phthalates	1900		6400
Bisphenols			2.0

The highest concentrations in air of all the targeted contaminants were observed for phthalates, cVMS, PAHs, OPFRs, and SCCPs/MCCPs. Also the volatile PFAS (FTOHs) were detected at high concentrations. Most of these compounds are non-regulated contaminants that are still in use and the measured concentrations at Birkenes and Zeppelin are 100-10 000 times higher than the concentrations measured for the regulated POPs. In contrast, a few other non-regulated (i.e. nBFRs and bisphenols) contaminants were measured at low concentrations in Arctic air.

The results from the air monitoring in 2018 show that the concentrations of most legacy POPs in air and precipitation are declining or have stabilized (reached temporal remote state conditions) during the last years. Significant for temporal remote state is that the primary emissions has stopped and that the long-term slow decline (removal rate) of a chemical in the environment is controlled by degradation rates in secondary repositories (Stroebe et al., 2004).

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. However, the measurements from 2017 and 2018 suggests that the increasing trend for HCB has turned and is now apparently declining at Zeppelin and Birkenes.

5 Heavy metals

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 2018 are presented in Table 20. The wet depositions are obtained by multiplying the volume weighted concentrations with the precipitation amounts (ng-mg/m^2) and the results for 2018 are presented in Table 21. 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 due to high emissions from the smelters in Nikel (Russia) close to the Norwegian border. Significantly higher levels of the heavy metals are observed 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., 2019).

The levels and deposition of lead, cadmium and zinc observed are highest at Birkenes followed by Hurdal and Kårvatn reflecting the decreasing distances to the main emission sources in continental Europe.

Table 20: Annual average volume weighted mean concentrations of heavy metals (ug/l) and mercury (ng/L) in precipitation in 2018.

	Pb	Cd	Zn	Ni	As	Cu	Co	Cr	Mn	V	Al	Hg
Birkenes	0.60	0.022	4.0	0.18	0.1	1.4	0.03	0.07	1.3	0.14	-	5.4
Hurdal	0.51	0.019	4.4	-	-	-	-	-	-	-	-	-
Kårvatn	0.26	0.005	2.3	-	-	-	-	-	-	-	-	-
Svanvik	0.92	0.062	4.3	26.5	0.9	30.5	0.74	0.27	-	0.4	35.5	-
Karpdalen	0.79	0.063	8.1	22.5	0.7	21.9	0.66	0.44	-	0.5	66.9	-

Table 21: Total wet depostion of heavy metals (mg/m^2) and mercury (ng/L) in 2018.

	Pb	Cd	Zn	Ni	As	Cu	Co	Cr	Mn	V	Al	Hg
Birkenes	808	30	5404	241	129	1931	34	90	1693	194	-	8185
Hurdal	460	17	3958	-	-	-	-	-	-	-	-	-
Kårvatn	307	6	2767	-	-	-	-	-	-	-	-	-
Svanvik	384	26	1808	11068	375	12725	311	112	-	168	14828	-
Karpdalen	366	29	3771	10436	335	10164	308	206	-	240	31078	-

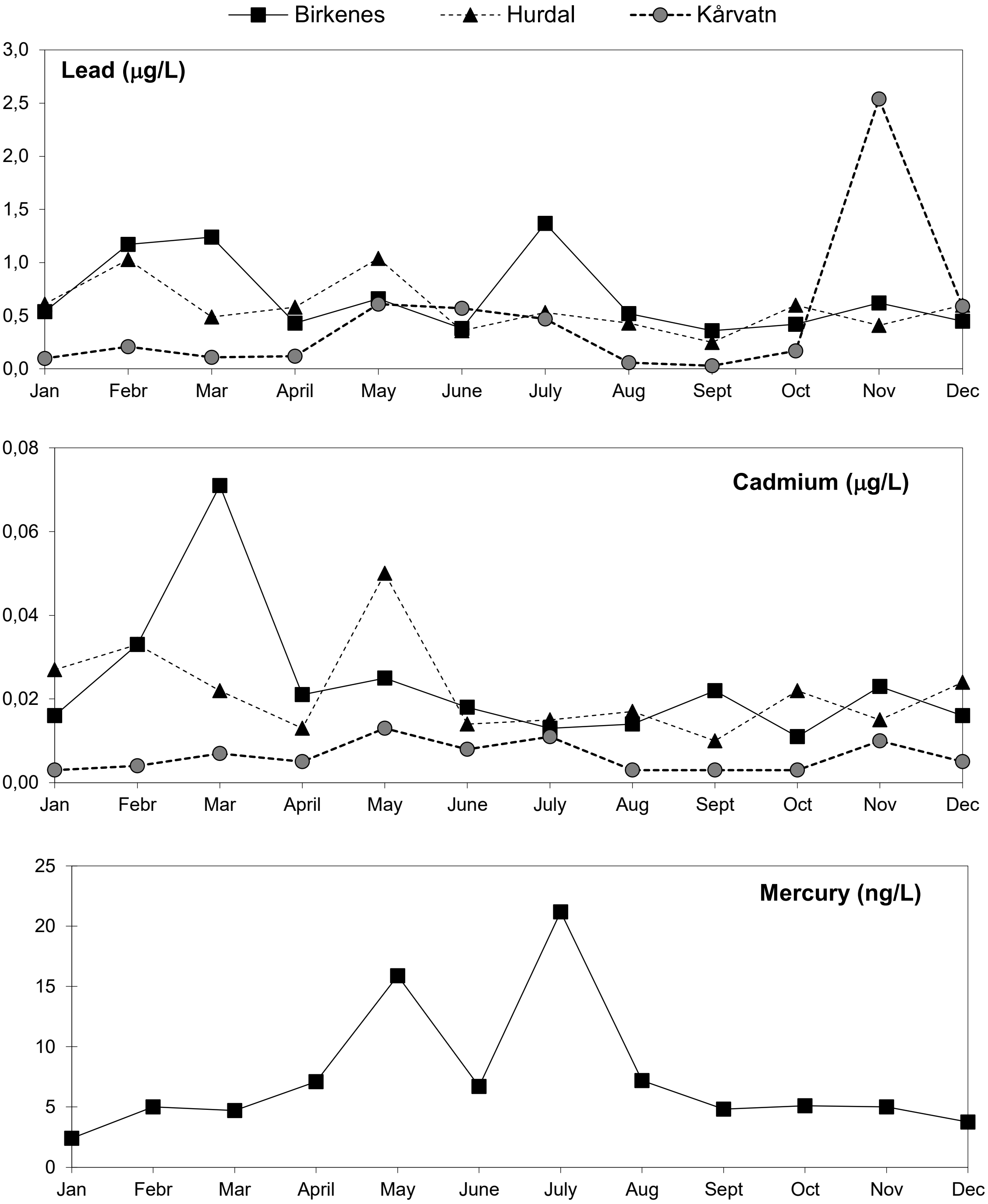


Figure 30: Volume weighted monthly mean concentrations of lead, cadmium and mercury in precipitation in 2018.

The monthly mean concentration for lead, cadmium and mercury are shown in Figure 2930. There is no clear seasonal variation, but elevated levels of lead are seen at Kårvatn in November, for cadmium at Birkenes in February, and in April and July for mercury at Birkenes. The reasons for these peaks are unclear.

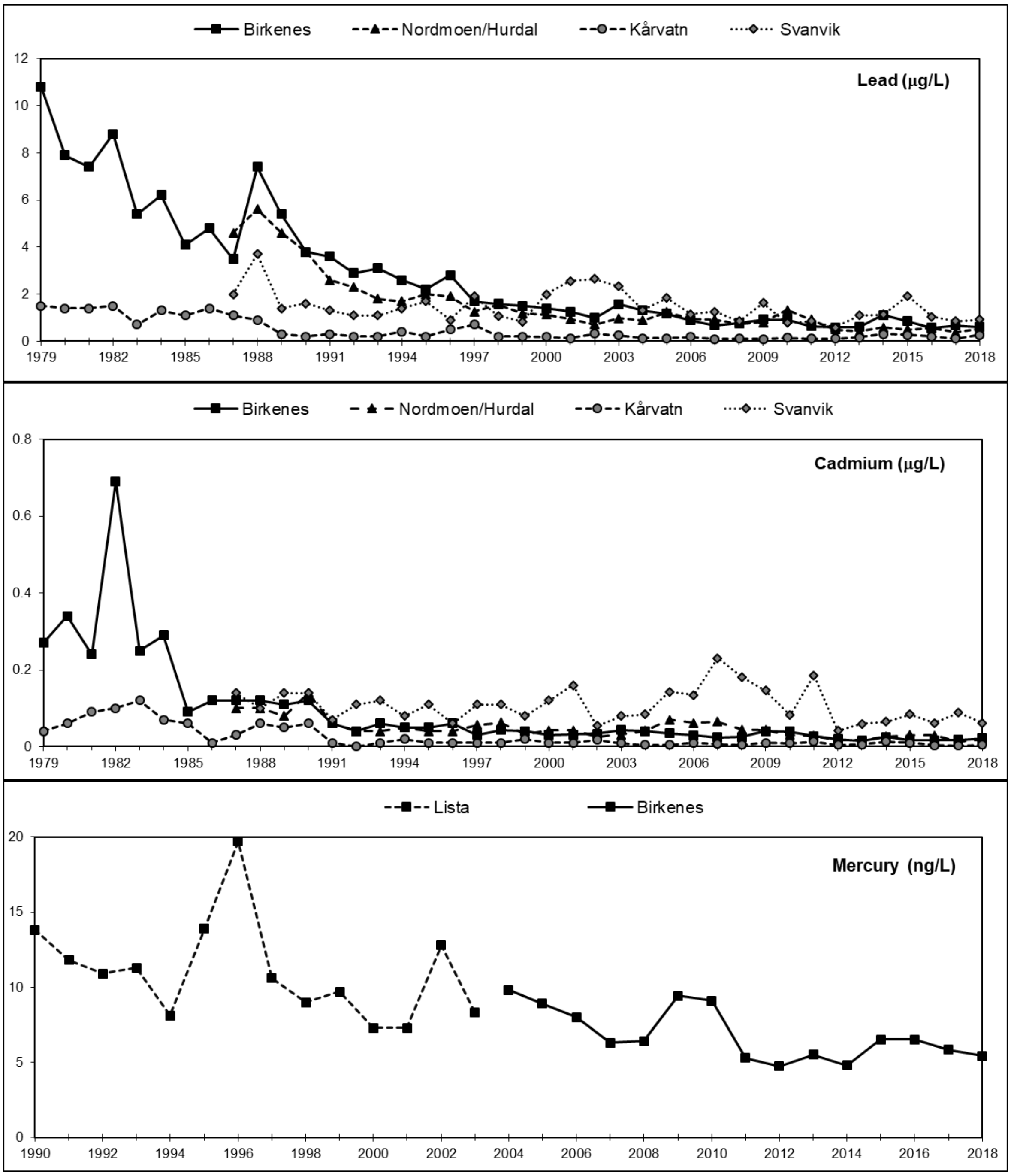


Figure 31: Time series of volume weighted annual mean concentrations of lead, cadmium and mercury in precipitation at Norwegian background stations.

Figure 31 and **Table A.2. 25** show volume weighted annual mean concentrations in precipitation from 1979 to 2018. In 2018, the concentrations were in general somewhat higher than in 2017 for most metals, except at Birkenes were there was a small decrease in lead and mercury. For deposition, it was an also an increase in concentrations in 2018 at Kårvatn, Hurdal and Karpdalen. At Birkenes instead, there was lower deposition for all elements in 2018, due to much less rain in 2018 at this site.

In a long term perspective, the concentrations of lead in precipitation at Birkenes and Kårvatn, (and Hurdal since 1990) have been largely reduced; almost 100% between 1980 and 2018; 51-96% since 1990, and 57-66% since 2000 (except at Kårvatn with no significant trend) (Table 23).

The concentrations of zinc in precipitation have been reduced by 67% since 1980 and 42% 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 23). There are quite large annual variations in zinc, with increases at some sites for some years. This may be due to possible contamination of zinc during sampling or influence of local sources.

The reductions in lead and cadmium are consistent with those observed at other EMEP sites with long-term measurements and can be explained by large European emission reductions of these elements (Tørseth et al., 2012; Colette et al., 2016). The trends for the concentrations are reflected in the trends for the wet deposition giving 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. There are also a decrease in mercury concentration at Birkenes from 2000 to 2018 with 40%.

At Svanvik there has been a reduction in lead and zinc from 2000, while no significant reduction trends for cadmium and the other trace elements. There are large annual variations in the concentration levels at this site, 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. (2019).

5.2 Heavy metals in air

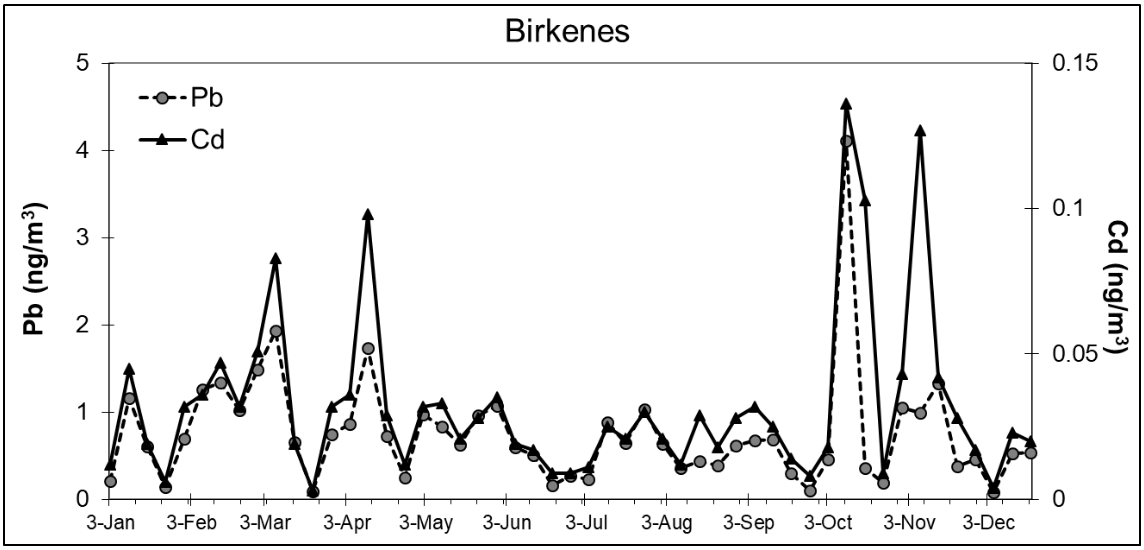
The annual mean concentrations of the heavy metals measured in air in 2018 are given in Table 22, and the weekly concentrations of lead and cadmium are illustrated in Figure 312. The monthly mean concentrations can be found in Annex 1, Table A.2 27 – Table A.2 33.

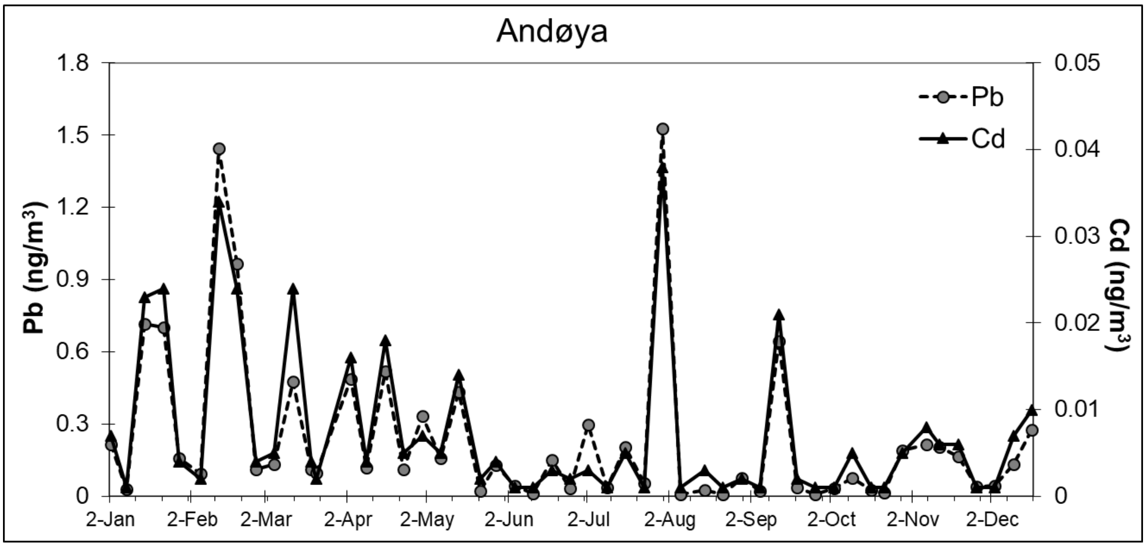
In general, the concentrations of most heavy metals in air at Birkenes in 2018 are two-three times higher than those observed at Andøya and Zeppelin. This is likely because Birkenes is closer to the emission sources at the European continent. In turn, at Svanvik and Karpdalen, the concentrations in air are about ten times higher than those observed at Birkenes depending on element. This suggest nearby sources in the area of these two sites. For mercury, similar air concentrations are observed at all three sites in Norway. A more homogeneous picture for gaseous mercury is 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. At the station in the Antarctica (Trollhaugen), the mercury concentration is much lower though. This is due to less emissions of mercury in the lower hemisphere compared to the more industrialised and populated northern hemisphere.

Table 22: Annual average mean concentrations of heavy metals in air and aerosols in 2018 Unit: ng/m^3.

	Pb	Cd	Zn	Ni	As	Cu	Co	Cr	Mn	V	Al	Fe	Hg(g)
Birkenes II	0.75	0.032	3.8	0.24	0.17	0.48	0.03	0.32	-	0.36	-	-	1.45
Andøya	0.23	0.007	1.0	0.15	0.04	0.19	0.02	0.19	0.53	0.18	-	-	1.40
Zeppelin	0.14	0.020	1.7	0.15	0.03	0.68	0.01	0.16	0.49	0.06	-	-	1.42
Trollhaugen													0.97
Karpdalen	1.59	0.108	5.9	7.2	1.1	5.7	0.29	0.31	0.84	2.0	42.2	54.6	-
Svanvik	3.47	0.237	10.2	8.8	2.2	7.6	0.34	0.28	0.69	3.6	29.7	52.1	-

As in previous years, the annual mean concentrations at Andøya and Zeppelin in 2018 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 elevated concentrations of heavy metals arriving to Zeppelin and Andøya, especially during the winter at Zeppelin in 2018, and these episodes are not coinciding at the two sites Figure 32. The episodes with high levels of cadmium and lead are however well correlated at the individual sites, Figure 32. This 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.





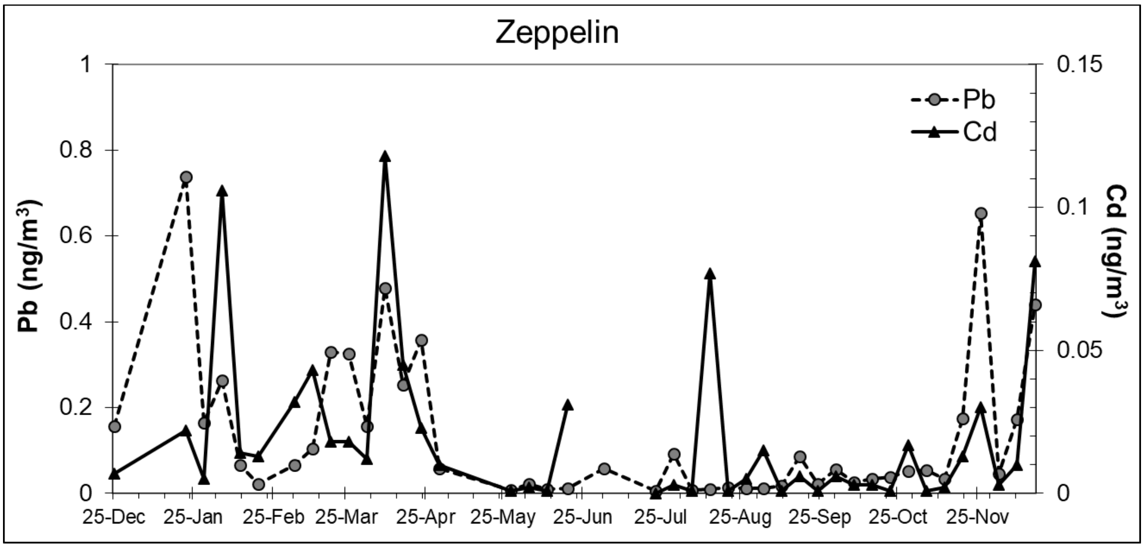


Figure 32: Weekly concentrations of lead and cadmium in air at Norwegian background stations in 2018, Unit: ng/m^3.

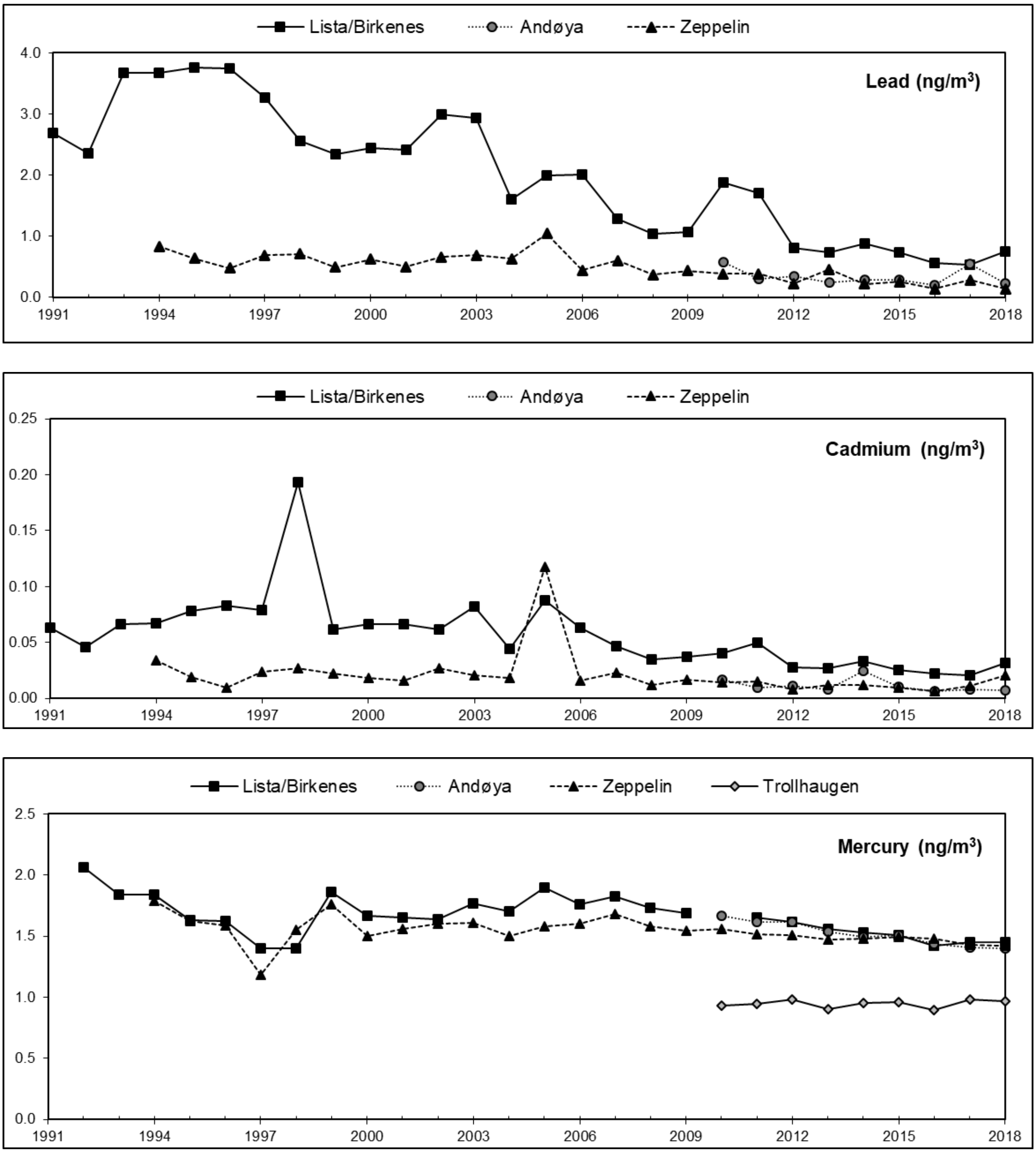


Figure 33: Time series of annual mean concentrations of lead, cadmium and mercury in air and aerosols, 1991-2018, Unit: ng/m^3.

The air concentrations at Birkenes where higher in 2018 compared to 2017. For the other sites, there are more variation depending on components. For mercury, there is almost no difference previous year. The long-term time series of the annual mean concentrations of lead, mercury are shown in Figure 33. The annual concentrations for all the elements for all can be found in Table A.2. 27 -

Table A.2. 323.

At Lista/Birkenes there has been a significant reduction in air concentrations for all the measured elements for the period 1991 to 2018. At Zeppelin, there has also been a significant reduction since 1994 for several elements (As, Cd, Cu, Pb, V). The reduction for lead has been 85% and 65% respectively at Birkenes and Zeppelin (Table 24). For cadmium, the reductions were 67% and 57%, respectively. For mercury, small decreasing trends are observed at Birkenes (21%) and Zeppelin (12%). 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. Most of the trends are also significant reductions for the period 2000-2018, though at Zeppelin there are positive trends for Cr, Mn and Ni.

Table 23: Trends in heavy metal concentrations in precipitation and air, only significant (p=0.1) trends are shown. Positive trends shown in red.

	Pb	**Cd**	**Zn**	**As**	**Co**	**Cr**	**Cu**	**Ni**	**Hg**
1980-2018									
Birkenes	almost -100	almost -100	-68						
Kårvatn	almost -100	-95	not sign						
1990-2018									
Birkenes	-96	-75	-39						-60
Hurdal	-91	-64	not sign						
Kårvatn	-51	-42	125						
Svanvik	not sign	not sign	not sign	150	not sign	176	113	-37	
2000-2018									
Birkenes	-57	-51	not sign						-40
Hurdal	-66	-69	not sign						
Kårvatn	not sign	not sign	173						
Svanvik	-65	not sign	-42	not sign	not sign	not sign	not sign	not sign	

Table 24: Time trends of heavy metal concentrations in air (in %), only significant (p=0.1) trends are shown. Increasing trends are shown in red and decreasing trends are shown in black.

	Pb	Cd	Zn	As	Co	Cr	Cu	Mn	Ni	V	Hg
1991(4)-2018											
Birkenes (from 1991)	-85	-67	-34	-67		-79	-44		-71		-21
Zeppelin (from 1994)	-65	-57	not sign	-70	not sign	not sign	-29	63	not sign	-62	-12
2000-2018											
Birkenes	-83	-73	-51	-63	-50	not sign	-55		-77	-95	-21
Zeppelin	-77	-58	not sign	-78	not sign	300	not sign	102	78	-39	-11

6 References

Aas, W., Nizzetto, P.B. (2018) Heavy metals and POP measurements, 2016. Kjeller, Norwegian Institute for Air Research (EMEP/CCC-Report 3/2018).

Aas, W., Fiebig, F., Solberg, S., Yttri, K.E. (2019) Monitoring of long-range transported air pollutants in Norway, annual report 2018. Kjeller, NILU (Miljødirektoratet rapport, M-1395/2019) (NILU report, 8/2019).

AMAP (2016) AMAP Assessment 2015: Temporal Trends in Persistent Organic Pollutants in the Arctic. Oslo: Arctic Monitoring and Assessment Programme.

AMAP (2017) Chemicals of emerging Arctic concern. Summary for policy-makers. Oslo: Arctic Monitoring and Assessment Programme.

Berglen, T.F., Nilsen, A.C., Våler, R.L., Vadset, M., Uggerud, H.T., Andresen, E. (2019) Grenseområdene Norge - Russland. Luft- og nedbørkvalitet, årsrapport 2018. Kjeller, NILU (Miljødirektoratet rapport, M-1415/2019) (NILU rapport, 15/2019).

Bidleman, T.F., Agosta, K., Andersson, A., Haglund, P., Nygren, O., Ripszam, M., Tysklind, M. (2014) Air-water exchange of brominated anisoles in the northern Baltic sea. Environ. Sci. Technol., 48, 6124-6132.

Bidleman, T.F., Agosta, K, Andersson, A., Haglund, P., Liljelind, P., Hegmans, A., Jantunen, L.M., Nygren, O., Poole, J., Ripszam, M., Tysklind, M. (2016) Sea-air exchange of bromoanisoles and methoxylated bromodiphenyl ethers in the Northern Baltic. M. Pollut. Bull. 112, 58-64.

Bloom, N.S. and Fitzgerald, W.F. (1988) Determination of volatile mercury species at the picogram level by low-temperature gas chromatography with cold vapor atomic fluorescence detection. Analytica Chimica Acta 209, 151-161.

Bohlin-Nizzetto, P., Aas, W., Warner, N. (2017) Monitoring of environmental contaminants in air and precipitation, annual report 2016. M-757/2017. NILU report 17/2017.

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

Breivik, K., Sweetman, A., Pacyna, J.M., Jones, K.C. (2002) Towards a global historical emission inventory for selected PCB congeners – a mass balance approach 2. Emissions. Sci. Total Environ., 290, 199-224.

Brooke, D., Crookes, M., Gray, D., Robertson, S. (2009a) Environmental risk assessment report: Decamethylcyclopentasiloxane. Bristol, Environment Agency.

Brooke, D., Crookes, M., Gray, D., Robertson, S. (2009b) Environmental risk assessment report: Dodecamethylcyclohexasiloxane. Bristol, Environment Agency.

Brooke, D., Crookes, M., Gray, D., Robertson, S. (2009c) Environmental risk assessment report: Octamethylcyclotetrasiloxane. Bristol, Environment Agency.

Buck, R.C., Franklin, J., Berger, U., Conder, J.M., Cousins, I.T., de Voogt, P., Astrup Jensen, A., Kannan, K., Mabury, S.A., van Leeuwen, S.PJ. (2011) Perfluoroalkyl and polyfluoroalkyl substances in the environment: terminology, classification, and origins. Integr. Environ. Assess. Manag., 7, 512-541.

Canada ECaH (2008a) Screening assessment for the challenge decamethylcyclopentasiloxane (D5). Gatineau, QC, Environment Canada (CAS RN 541-02-6).

Canada ECaH (2008b) Screening assessment for the challenge octamethylcyclotetrasiloxane (D4). Gatineau, QC, Environment Canada (CAS RN 556-67-2).

Carlsson, P., Vrana, B., Sobotka, J., Borgå, K., Bohlin Nizzetto, P., Varpe, Ø. (2018) New brominated flame retardants and dechlorane plus in the Arctic: Local sources and bioaccumulation potential in marine benthos. Chemosphere, 211, 1193-1202.

Chaemfa, C., Xu, Y., Li, J., Chakraborty, P., Syed, J.H., Malik, R.N., Wang, Y., Tian, C.G., Zhang, G., Jones, K.C. (2014) Screening of atmospheric short- and medium-chain chlorinated paraffins in India and Pakistan using polyurethane foam based passive air sampler. Environ. Sci. Technol., 48, 4799-4808.

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

Corrales, J., Kristofco, L. A., Baylor Steele, W., Yates, B.S., Breed, C.S., Williams, E.S., Brooks, B.W. (2015) Global assessment of Bisphenol A in the environment: A review and analysis of its occurrence and bioaccumulation. Dose-response, 13 (3).

Cousins I. T., Jones K. C. (1998) Air-soil exchange of semi-volatile organic compounds (SOCs) in the UK. Environ. Pollut., 102, 105-118.

Downie, D. L. & Fenge, T. (Eds.). (2003) Northern lights against POPs: combating toxic threats in the Arctic. Montreal, McGill- Queen's University Press.

Dreyer, A., Temme, C., Sturm, R., Ebinghaus, R. (2008) Optimized method avoiding solvent-induced response enhancement in the analysis of volatile and semi-voaltile polyfluorinated alkylated compounds using gas chromatography-mass spectrometry. J. Chrom. A., 1-2, 199-205.

ECHA (2015) Opinion of the member state committee on persistency and bioaccumulation of octamethylcyclotetrasiloxane (D4) and decamethylcyclopentasiloxane (D5).

EU (2004) Directive 2004/107/EC of the European Parliament and of the Council of 15 Dec. 2004 relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air. Off. J. Eur. Union., L 23, 3-16.

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

Fu, P., Kawamura, K. (2010) Ubiquity of bisphenol A in the atmosphere. Environ. Pollut., 158, 3138-3143.

Genualdi, S.G.S., Harner, T., Cheng, Y., MacLeod, M., Hansen, K.M., van Egmond, R., Shoeib, M., Lee, S.C. (2011) Global distribution of linear and cyclic volatile methyl siloxanes in air. Environ. Sci. Technol., 45, 3349-3354.

Green, N.W., Heldal, H.E., Måge, A., Aas, W., Gäfvert, T., Schrum, C., Boitsov, S., Breivik, K., Iosjpe, M. Yakushev, E., Skogen, M., Høgåsen, T., Eckhardt, S., Christiansen, A.B., Daae, K.L., Durand, D., Debloskaya, E. (2011) Tilførselsprogrammet 2010. Overvåking av tilførsler og miljøtilstand i Nordsjøen. Oslo, NIVA (Statlig program for forurensingsovervåking. Rapport 1097/2011. TA-2810/2011) (NIVA-rapport 6187 2011) (In Norwegian).

Green, N.W., Schøyen, M., Hjermann, D. Ø., Øxnevad, S., Ruus, A., Lusher, A., Beylich, B., Lund, E., Tveiten, L., Håvardstun, J., Jenssen, M. T. S., Ribeiro, A. L., Bæk, K. (2018) Contaminants in coastal waters of Norway 2017. Oslo, NIVA (Miljødirektoratet rapport, M-1120/2018) (NIVA-rapport 7302-2018)

Halse, A.K., Schlabach, M., Eckhardt, S., Sweetman, A., Jones, K.C., Breivik, K. (2011) Spatial variability of POPs in European background air. Atmos., Chem. Phys., 11, 1549-1564.

Hung, H., Katsoyiannis, A. A., Brorstrom-Lunden, E., Olafsdottir, K., Aas, W., Breivik, K., Bohlin-Nizzetto, P., Sigurdsson, A., Hakola, H., Bossi, R., Skov, H., Sverko, E., Barresi, E., Fellin, P., Wilson, S. (2016) Temporal trends of Persistent Organic Pollutats (POPs) in arctic air: 20 years of monitoring under the Arctic Monitoring and Assessment Programme (AMAP). Environ. Pollut., 217, 52-61.

Iverfeldt, Å. (1991a) Occurrence and Turnover of Atmospheric Mercury over Nordic Countries. Water, Air and Soil Pollution 56, 251-265.

Iverfeldt, Å. (1991b) Mercury in canopy throughfall water and its relation to atmospheric deposition. Water, Air, Soil Pollut. 56, 553-542.

Jensen, A. and Iverfeldt, Å.(1993) Atmospheric bulk deposition of mercury to the southern Baltic sea area. In: Mercury as a global pollutant. Huckabee, J. and Watras, C. (Eds) Cleveland, CRC Press.

Kierkegaard, A., McLachlan, M.S. (2013) Determination of linear and cyclic volatile methylsiloxanes in air at a regional background site in Sweden. Atmos. Environ., 80, 322-329.

Krogseth, I.S., Kierkegaard, A., McLachlan, M.S., Breivik, K., Hansen, K.M., Schlabach, M. (2013) Occurrence and seasonality of cyclic volatile methyl siloxanes in Arctic air. Environ. Sci. Technol., 47, 502-509.

Krogseth, I.S., Whelan, M. J., Christensen, G. N., Breivik, K., Evenset, A., Warner, N. A. (2017) Understanding of cyclic volatile methul siloxane fate in a high latitude lake is constrained by uncertainty in organic carbon-water partitioning. Environ. Sci. Technol., 51, 401-409.

Nizzetto, P.B., Aas, W., Krogseth, I.S. (2014) Monitoring of environmental contaminants in air and precipitation, annual report 2013. Kjeller, NILU (Miljødirektoratet rapport, M-202/2014) (NILU OR, 29/2014).

Nizzetto, P.B., Aas, W., Warner, N. (2015) Monitoring of environmental contaminants in air and precipitation, annual report 2014. Kjeller, NILU (Miljødirektoratet rapport, M-368/2015) (NILU OR, 19/2015)

Nizzetto, P.B., Aas, W. (2016) Monitoring of environmental contaminants in air and precipitation, annual report 2015. Kjeller, NILU (Miljødirektoratet rapport, M-579/2016) (NILU report, 14/2016)

Norwegian Environment Agency (2015) List of priority substances. Oslo, Norwegian Environment Agency. URL: http://www.miljostatus.no/prioritetslisten [Accessed May 2019] (In Norwegian).

Pribylova, P., Kares, R., Boruvkova, J., Cupr, Pmilj., Prokes, R., Kohoutek, J., Holoubek, I., Klanova, J. (2012) Levels of persistent organic pollutants and polycyclic aromatic hydrocarbons in ambient air of Central and Eastern Europe. Atmos. Pollut. Res., 3, 494-505.

Rauert, C., Schuster, J.K., Eng, A., Harner, T. (2018) Global atmospheric concentrations of brominated and chlorinated flame retardants and organophosphate esters. Environ. Si. Technol., 52, 2777-2789.

Rottem, S. V. (2017) The Use of Arctc Science: Pops, the Stockholm Convention and Norway. Arctic Review on Law and Politics, 8, 246-269.

Salamova, A., Hermanson, M.H., Hites, R.A. (2014) Organophosphate and halogenated flame retardants in atmospheric particles from a European Arctic site. Environ. Sci. Technol., 48, 6133-6140.

Schlabach, M., Bavel, B. van, Lomba, J. A. B., Borgen, A., Gabrielsen, G.W., Gotsch, A., Halse, A.-K., Hanssen, L., Krogseth, I.S., Nikiforov, V., Nygård, T., Bohlin- Nizzetto, P., Reid, M.J., Rostkowski, P., & Samanipour, S. (2018) Screening Programme 2017 – AMAP Assessment Compounds. Miljødirektoratet rapport, M-/2018 (NILU-report, 21/2018). NILU, Kjeller.

Schlabach, M., Bavel, B. van, Lomba, J. A. B., Borgen, A., Fjeld, E., Halse, A.-K., Nikiforov, V., Bohlin-Nizzetto, P., Reid, M., Rostkowski, P., & Vogelsang, C. (2017a) Screening programme 2016 - Selected compounds with relevance for EU regulation. Miljødirektoratet rapport, M-818/2017 (NILU-report, 34/2017). NILU, Kjeller.

Schlabach, M., Gabrielsen, G. W., Herzke, D., Hanssen, L., Routti, H., & Borgen, A. (2017b). Screening of PFAS and Dechlorane compounds in selected Arctic top predators. (Miljødirektoratet rapport, M-817/2017) (NILU report, 40/2017). Kjeller: NILU.

Stockholm Convention (2007) Stockholm Convention on Persistent Organic Pollutants. Châtelaine. URL: http://www.pops.int [Accessed May 2019].

Stockholm Convention (2013) The new POPs under the Stockholm Convention. Châtelaine. URL: http://chm.pops.int/TheConvention/ThePOPs/TheNewPOPs/tabid/2511/Default.aspx [Accessed May 2019].

Stockholm Convention (2015) Chemicals proposed for listing under the Convention. Châtelaine. URL: http://chm.pops.int/TheConvention/ThePOPs/ChemicalsProposedforListing/tabid/2510/Default.aspx [Accessed May 2019].

Stroebe, M., Scheringer, M., Hungerbühler, K. (2004) Measures of overall persistence and the temporal remote state. Environ. Sci. Technol. 38, 5665-5673.

Tomy, G.T., Stem, G.A., Muir, D.C.G., Fisk, A.T., Cymbalisty, C.D., Westmore, J.B. (1997) Quantifying C-10–C-13 polychloroalkanes in environmental samples by high-resolution gas chromatography/electron capture negative ion high resolution mass spectrometry. Anal. Chem., 69, 2762-2771.

Tran, T.M., Kannan K. (2015) Occurrence of cyclic and linear siloxanes in indoor air from Albany, New York, USA, and its implications for inhalation exposure. Sci. Total. Environ. 511, 138-144.

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

UN/ECE (1998a) The 1998 Aarhus Protocol on Heavy Metal. Geneva, United Nations Economic Commission for Europe.URL: http://www.unece.org/env/lrtap/hm_h1.html [Accessed May 2019].

UN/ECE (1998b) The 1998 Aarhus Protocol on Persistent Organic Pollutants (POPs). Geneva, United Nations Economic Commission for Europe.URL: http://www.unece.org/env/lrtap/pops_h1.html [Accessed May 2019].

UN/ECE (2010) The 1998 Aarhus Protocol on Persistent Organic Pollutants, including the amendments adopted by the Parties on 18 December 2009. Geneva, United Nations Economic Commission for Europe (EC/EB.AIR/104). URL: http://www.unece.org/fileadmin/DAM/env/lrtap/full%20text/ece.eb.air.104.e.pdf [Accessed May 2019].

UNEP (2010) Stockholm Convention on Persistent Organic Pollutants. Supporting document for the draft risk profile on short-chained chlorinated paraffins. Nairobi, United Nations Environment Programme (UNEP/POPS/POPRC.6/INF/15).

UNEP (2013) Minimata convention on Mercury. Geneva, United Nations Environment Programme. URL: http://www.mercuryconvention.org/Convention/tabid/3426/Default.aspx [Accessed May 2019].

van Bavel, B., Thomas, K.V., Langford, K., Reid, M., Vogelsang, C., Øxnevad, S., Bæk, K., Fjeld, E., Brooks, S., Schlabach, M., Rostkowski, P., Warner, N., Borgen, A., Halse, A.K., Davanger, K., Gundersen, H. (2016) Screening programme 2015. Benzothiazoles, siloxanes, pigments & PBT compounds. Miljødirektoratet rapport, M-596/2016.

Wang, D.-G., Norwood, W., Alaee, M., Byer, J.D., Brimble, S. (2013a) Review of recent advances in research on the toxicity, detection, occurrence and fate of cyclic volatile methyl siloxanes in the environment. Chemosphere, 93, 711-725.

Wang, Y., Li, J., Cheng, Z., Li, Q., Pan, X., Zhang, R., Liu, D., Luo, C., Liu, X., Katsoyiannis, A., Zhang, G. (2013b) Short- and medium-chain chlorinated paraffins in air and soil of subtropical terrestrial environment in the Pearl river delta, south China: Distribution, composition, atmospheric deposition fluxes, and environmental fate. Environ. Sci. Technol., 47, 2679-2687.

Wania, F. (2003) Assessing the potential of persistent organic chemicals for long-range transport and accumulation in Polar Regions. Environ. Sci. Technol., 37, 1344-1351.

Warner, N.A., Evenset, A., Christensen, G., Gabrielsen, G.W., Borga, K., Leknes, H. (2010) Volatile siloxanes in the European Arctic: Assessment of sources and spatial distribution. Environ. Sci. Technol., 44, 7705-7710.

Warner N.A., Kozerski, G., Durham, J., Koerner, M., Gerhards, R., Campbell, R., McNett, D.A. (2013) Positive vs. false detection: A comparison of analytical methods and performance for analysis of cyclic volatile methylsiloxanes (cVMS) in environmental samples from remote regions. Chemosphere 93, 749-756.

WHO (2006) Indoor residual spraying: Use of indoor residual spraying for scaling up global malaria control and elimination. Geneva, World Health Organization. URL: http://apps.who.int/iris/bitstream/10665/69386/1/WHO_HTM_MAL_2006.1112_eng.pdf [Accessed May 2019].

Wong, F., Jantunen, L.M., Pucko, M., Papakyriakou, T., Staebler, R.M., Stern, G.A., Bidleman, T. (2011) Air-water exchange of anthropogenic and natural organohalogens on international polar year (IPY) expeditions in the Canadian arctic. Environ. Sci. Technol., 45, 876-881.

Xie, Z., Ebinghaus, R., Temme, C., Lohmann, R., Caba, A., Ruch, W. (2007) Occurrence and air-sea exchange of phthalates in the Arctic. Environ. Sci. Technol. 41, 4555-4560.

Xu, S., Wania, F. (2013) Chemical fate, latitudinal distribution and long-range transport of cyclic volatile methylsiloxanes in the global environment: A modeling assessment. Chemosphere, 93, 835-843.

Yu, Y., Hung, H., Alexandrou, N., Roach, P., Nordin, K. (2015) Multiyear measurements of flame retardants and organochlorine pesticides in air in Canada's western sub-arctic. Environ. Sci. Technol., 49, 8623-8630.

Zhao, Z., Tang, J., Mi, L., Tian, C., Zhong, G., Zhang, G., Wang, S., Li, Q., Elbinghaus, R., Xie, Z., Sun, H. (2017) Perfluoroalkyl and polyfluoroalkyl substances in the lower atmosphere and surface waters of the Chinese Bohai Sea, Yellow Sea and Yangtze River estuary. Sci. Total. Environ., 599-600, 114-123.

Annex 1

Description of methods for sampling, chemical analysis and quality control

Table A.1. 1: Monthly and annual mean concentrations (pg/m^3) for organochlorine pesticides (OCPs) in air at Birkenes, 2018

Birkenes	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
HCB	61.9	62.5	65.4	56.8	40.6	34.5	25.0	35.1	39.3	56.2	45.0	59.9	47.8
α-HCH	2.31	1.75	2.49	4.99	3.22	4.00	3.05	3.87	10.00	4.11	3.24	2.69	3.73
γ-HCH	0.88	0.97	1.96	14.30	1.43	1.89	2.67	4.91	3.99	0.88	2.06	2.22	2.99
sum HCHs	3.19	2.72	4.45	19.29	4.65	5.89	5.72	8.78	13.99	4.99	5.31	4.91	6.72
p,p’-DDT	0.10	0.10	0.16	<0.01	0.18	0.15	0.33	0.32	0.59	0.08	0.30	0.33	0.22
o,p’-DDT	0.10	0.09	0.18	0.48	0.15	0.12	0.25	0.27	0.50	0.06	0.24	0.24	0.21
p,p’-DDE	0.87	0.59	1.01	1.10	0.41	0.38	0.54	0.63	1.84	0.26	1.84	1.97	0.94
o,p’-DDE	0.06	0.05	0.08	0.13	0.03	0.02	0.04	0.06	0.09	0.02	0.08	0.09	0.06
p,p’-DDD	0.01	0.01	0.02	<0.01	0.01	0.01	0.02	0.02	0.03	0.01	0.02	0.02	0.02
o,p’-DDD	0.02	0.01	0.02	<0.01	0.01	0.02	0.03	0.03	0.04	0.01	0.03	0.03	0.02
sum DDTs	1.16	0.86	1.46	2.28	0.80	0.70	1.20	1.33	3.09	0.45	2.50	2.69	1.50

Table A.1. 2: Monthly and annual mean concentrations (pg/m^3) for PCBs in air at Birkenes, 2018

Birkenes	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
PCB-18	1.516	1.485	1.209	1.159	1.013	0.859	0.775	0.610	1.399	1.715	1.657	2.061	1.254
PCB-28	0.666	0.732	0.684	0.788	0.730	0.742	0.719	0.422	0.784	0.935	0.949	0.907	0.745
PCB-31	0.623	0.701	0.646	0.721	0.677	0.685	0.669	0.393	0.727	0.878	0.888	0.841	0.696
PCB-33	0.351	0.408	0.385	0.412	0.360	0.373	0.367	0.215	0.390	0.481	0.492	0.490	0.389
PCB-37	0.043	0.056	0.049	0.058	0.063	0.070	0.070	0.040	0.064	0.079	0.083	0.071	0.062
PCB-47	0.358	0.448	0.329	0.522	1.115	1.295	1.927	0.866	0.653	0.770	0.698	0.494	0.802
PCB-52	0.587	0.723	0.661	1.030	0.836	0.910	1.059	0.551	0.845	1.001	1.039	0.768	0.827
PCB-66	0.104	0.131	0.135	0.239	0.195	0.215	0.239	0.121	0.209	0.206	0.224	0.169	0.181
PCB-74	0.080	0.105	0.107	0.206	0.148	0.162	0.178	0.085	0.159	0.174	0.187	0.132	0.142
PCB-99	0.108	0.131	0.178	0.483	0.169	0.187	0.238	0.115	0.195	0.196	0.219	0.144	0.191
PCB-101	0.276	0.376	0.429	1.121	0.531	0.662	0.832	0.360	0.552	0.621	0.652	0.381	0.556
PCB-105	0.020	0.031	0.141	0.499	0.041	0.046	0.065	0.028	0.044	0.038	0.042	0.028	0.077
PCB-114	0.005	0.005	0.010	0.027	*0.006*	0.006	0.008	0.005	*0.006*	0.005	0.006	0.005	*0.008*
PCB-118	0.070	0.100	0.306	1.067	0.139	0.164	0.226	0.099	0.149	0.140	0.154	0.099	0.210
PCB-122	0.003	0.002	*0.007*	0.002	0.004	0.004	0.009	0.003	*0.004*	0.005	0.006	0.004	*0.004*
PCB-123	*0.004*	0.002	0.005	0.024	0.003	*0.004*	0.005	0.004	*0.004*	0.005	0.005	0.005	*0.005*
PCB-128	0.012	0.020	0.058	0.284	0.027	0.033	0.044	0.018	0.025	0.023	0.026	*0.014*	0.040
PCB-138	0.091	0.181	0.303	0.924	0.231	0.297	0.415	0.154	0.201	0.212	0.224	0.117	0.269
PCB-141	0.022	0.047	0.047	0.123	0.064	0.099	0.120	0.040	0.070	0.065	0.066	0.034	0.065
PCB-149	0.167	0.278	0.246	0.558	0.387	0.509	0.695	0.270	0.376	0.416	0.445	0.226	0.380
PCB-153	0.145	0.270	0.289	0.746	0.330	0.426	0.584	0.225	0.333	0.382	0.400	0.211	0.357
PCB-156	0.005	0.011	0.032	*0.088*	0.010	0.013	0.016	0.006	0.010	0.014	0.010	0.007	0.018
PCB-157	0.001	0.002	*0.007*	0.018	0.001	*0.002*	0.002	0.001	*0.001*	0.002	0.003	0.002	*0.004*
PCB-167	0.003	0.004	*0.010*	*0.052*	0.005	0.007	0.009	*0.003*	*0.005*	0.006	0.006	0.004	0.008
PCB-170	0.008	0.034	0.023	0.056	0.027	0.030	0.043	0.014	0.021	0.022	*0.022*	*0.011*	0.026
PCB-180	0.033	0.126	0.074	0.182	0.074	0.095	0.134	0.045	0.057	0.068	0.078	0.034	0.084

PCB-183	0.010	0.032	0.020	0.042	0.030	0.047	0.053	0.020	0.026	0.041	0.040	0.017	0.031
PCB-187	0.034	0.099	0.056	0.117	0.082	0.100	0.146	0.061	0.073	0.085	0.104	0.049	0.085
PCB-189	0.002	0.003	0.002	0.003	0.002	*0.002*	0.002	0.002	0.002	0.002	0.003	0.002	*0.002*
PCB-194	0.004	0.015	*0.006*	0.013	*0.005*	*0.006*	0.005	0.004	*0.003*	0.006	0.012	0.004	*0.007*
PCB-206	0.003	*0.006*	0.004	0.003	0.003	*0.004*	0.005	0.004	*0.004*	0.005	0.007	0.004	*0.004*
PCB-209	0.002	0.003	0.006	0.014	*0.002*	*0.002*	0.007	0.002	*0.003*	0.003	0.003	0.002	*0.004*
sum-trichlor	4.44	4.65	4.04	4.32	3.80	3.63	3.47	2.20	4.71	5.95	5.94	6.37	4.369
sum-tetrachlor	2.15	2.67	2.24	3.95	3.74	4.28	5.48	2.58	3.70	4.25	4.37	3.19	3.529
sum-pentachlor	0.78	1.06	1.82	5.60	1.53	1.87	2.48	1.06	1.71	1.75	1.93	1.14	1.823
sum-hexachlor	0.66	1.13	1.26	3.56	1.62	2.09	2.90	1.07	1.60	1.80	1.89	0.96	1.684
sum-heptachlor	0.10	0.40	0.22	0.55	0.29	0.36	0.48	0.20	0.26	0.31	0.35	0.16	0.308
sum-PCB7	1.87	2.51	2.75	5.86	2.87	3.30	3.97	1.86	2.92	3.36	3.50	2.52	3.05
sum PCB	8.14	9.94	9.60	18.01	11.00	12.23	14.83	7.13	11.99	14.07	8.57	11.83	11.20

Table A.1. 3: Monthly and annual mean concentrations (pg/m^3) for PBDEs and TBA in air at Birkenes, 2018

Birkenes	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
BDE-28	0.009	0.010	0.004	0.007	0.008	0.005	0.009	0.008	0.004	0.011	0.006	0.004	0.007
BDE-47	0.048	0.058	0.034	0.036	0.050	0.033	0.055	0.041	0.021	0.050	0.041	0.034	0.042
BDE-49	0.011	0.011	0.006	0.006	0.009	0.004	0.009	0.009	0.004	0.009	0.005	0.005	0.007
BDE-66	0.008	0.006	0.004	0.003	0.004	0.002	0.004	0.004	0.002	0.004	NaN	NaN	0.004
BDE-71	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	NaN	0.001	0.001
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	0.003	0.003	0.002	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.002
BDE-99	0.025	0.048	0.037	0.018	0.022	0.014	0.021	0.018	0.008	0.031	0.034	0.027	0.024
BDE-100	0.007	0.010	0.007	0.004	0.007	0.004	0.005	0.005	0.002	0.007	0.007	0.006	0.006
BDE-119	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	NaN	0.001	*0.001*
BDE-138	0.003	0.003	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	*0.002*
BDE-153	0.007	0.010	0.008	0.003	0.005	0.003	NaN	0.006	0.002	0.011	0.009	0.006	0.006
BDE-154	0.006	0.008	0.006	0.003	0.005	0.002	0.002	0.005	0.002	0.007	0.007	0.007	0.005
BDE-183	0.012	0.018	0.009	0.006	0.009	0.005	0.004	0.018	0.007	0.038	0.014	0.015	0.013
BDE-196	0.005	0.004	0.003	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.007	NaN	*0.004*
BDE-206	0.076	0.045	0.035	0.043	0.036	0.032	0.066	0.051	0.032	0.075	0.134	0.132	0.064
BDE-209	1.35	0.30	0.27	0.29	0.40	0.35	1.43	0.33	0.14	0.39	2.91	3.04	0.96
sum BDE	1.57	0.54	0.43	0.43	0.57	0.46	1.61	0.51	0.23	0.64	3.18	3.28	1.15
sum BDE (excl. 209)	0.22	0.24	0.16	0.14	0.17	0.11	0.18	0.17	0.09	0.25	0.27	0.24	0.19
TBA	5.49	4.03	3.3	1.99	2.34	1.47	3.05	3.31	3.6	4.93	4.8	4.83	3.59

Table A.1. 4: Monthly and annual mean concentrations (pg/m³) for HBCDs in air at Birkenes, 2018

Birkenes	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
α-HBCD	<0.13	<0.12	<0.12	<0.13	<0.16	<0.13	<0.13	<0.13	<0.13	<0.13	<0.12	<0.12	<0.13
β-HBCD	<0.05	<0.05	<0.04	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
γ-HBCD	<0.15	<0.15	<0.14	<0.15	<0.16	<0.16	<0.16	<0.15	<0.15	<0.16	<0.15	<0.15	<0.15
Sum HBCD	<0.33	<0.32	<0.30	<0.33	<0.37	<0.34	<0.34	<0.33	<0.33	<0.34	<0.32	<0.32	<0.33

Table A.1. 5: Monthly and annual mean concentrations (ng/m^3) for PAHs in air at Birkenes, 2018

Birkenes	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
1-Methylnaphthalene	0.075	0.161	0.095	0.061	0.032	0.041	0.024	0.017	0.028	0.059	0.110	0.110	0.064
1-Methylphenanthrene	<0,01	0.220	0.047	0.091	0.030	0.045	0.040	0.018	0.030	0.053	0.038	0.047	0.052
2-Methylanthracene	0.003	0.002	0.002	0.002	0.002	0.012	0.003	0.002	0.002	0.002	0.003	0.003	0.003
2-Methylnaphthalene	0.095	0.182	0.108	0.082	0.046	0.069	0.039	0.022	0.035	0.072	0.116	0.120	0.078
2-Methylphenanthrene	0.156	0.141	0.089	0.084	0.048	0.101	0.104	0.034	0.050	0.093	0.057	0.053	0.081
3-Methylphenanthrene	0.129	0.111	0.071	0.061	0.041	0.094	0.092	0.031	0.046	0.081	0.053	0.045	0.069
9-Methylphenanthrene	0.047	0.042	0.025	0.021	0.016	0.042	0.031	0.012	0.017	0.024	0.020	0.019	0.026
Acenaphthene	0.175	0.126	0.069	0.112	0.107	0.080	0.089	0.057	0.190	0.118	0.085	0.060	0.102
Acenaphthylene	0.010	0.158	0.018	0.060	0.009	0.005	0.005	0.014	0.004	0.026	0.026	0.105	0.036
Anthanthrene	0.002	0.002	0.001	0.004	0.001	0.001	0.001	0.002	0.002	0.001	0.004	0.005	0.002
Anthracene	<0,01	0.058	0.035	0.037	0.006	0.011	0.007	0.003	0.006	0.010	0.011	0.023	0.018
Benz(a)anthracene	0.014	0.047	0.033	0.020	0.005	0.008	0.006	0.003	0.006	0.014	0.018	0.026	0.016
Benzo(a)fluoranthene	0.001	0.009	0.005	0.006	0.001	0.001	0.001	0.001	0.001	0.001	0.006	0.009	0.003
Benzo(a)fluorene	0.021	0.034	0.019	0.015	0.005	0.007	0.006	0.004	0.007	0.015	0.012	0.016	0.012
Benzo(a)pyrene	0.003	0.038	0.006	0.021	0.006	0.004	0.006	0.008	0.004	0.005	0.030	0.029	0.013
Benzo(b)fluoranthene	0.058	0.125	0.109	0.043	0.028	0.037	0.035	0.078	0.044	0.051	0.060	0.066	0.058
Benzo(b)fluorene	0.014	0.021	0.014	0.014	0.003	0.002	0.003	0.002	0.004	0.008	0.006	0.008	0.007
Benzo(e)pyrene	0.033	0.076	0.061	0.027	0.021	0.032	0.028	0.051	0.027	0.033	0.034	0.036	0.037
Benzo(ghi)fluoranthene	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
Benzo(ghi)perylene	0.034	0.083	0.060	0.029	0.013	0.013	0.012	0.039	0.020	0.023	0.044	0.043	0.032
Benzo(k)fluoranthene	0.015	0.050	0.039	0.018	0.006	0.005	0.007	0.015	0.009	0.010	0.025	0.025	0.017
Biphenyl	0.181	0.674	0.457	0.314	0.074	0.071	0.032	0.026	0.047	0.127	0.316	0.330	0.202
Chrysene	0.093	0.125	0.122	0.054	0.058	0.132	0.059	0.058	0.051	0.101	0.052	0.058	0.079
Coronene	0.017	0.033	0.033	0.012	0.004	0.004	0.003	0.010	0.006	0.008	0.024	0.022	0.013
Cyclopenta(cd)pyrene	<0,001	<0,001	<0,001	<0,001	<0,001	0.004	<0,001	<0,001	<0,001	<0,001	<0,001	0.001	0.003

Table A.1. 5. cont.

Birkenes	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Dibenzo(ae)pyrene	0.004	0.010	0.008	0.005	0.004	0.004	0.003	0.011	0.011	0.006	0.008	0.009	0.007
Dibenzo(ah)anthracene	0.004	0.011	0.010	0.005	0.003	0.004	0.003	0.005	0.005	0.005	0.007	0.008	0.006
Dibenzo(ah)pyrene	0.004	0.003	0.003	0.003	0.003	0.004	0.003	0.011	0.016	0.004	0.004	0.003	0.005
Dibenzo(ai)pyrene	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.010	0.014	0.004	0.004	0.004	0.005
Dibenzofuran	1.001	1.598	1.283	0.904	0.369	0.325	0.269	0.198	0.241	0.457	0.948	1.224	0.673
Dibenzothiophene	0.002	0.001	0.030	0.016	0.036	0.050	0.060	0.049	0.055	0.048	0.021	0.016	0.035
Fluoranthene	0.438	0.447	0.381	0.224	0.132	0.120	0.165	0.120	0.153	0.228	0.267	0.265	0.226
Fluorene	0.955	1.000	0.755	0.601	0.329	0.347	0.358	0.270	0.285	0.511	0.765	0.969	0.556
Inden(123-cd)pyrene	0.037	0.092	0.079	0.031	0.010	0.008	0.009	0.027	0.014	0.015	0.042	0.040	0.031
Naphthalene	0.150	0.444	0.271	0.116	0.042	0.085	0.042	0.029	0.036	0.131	0.268	0.290	0.148
Perylene	0.001	0.006	0.001	0.004	0.001	0.001	0.001	0.001	0.001	0.001	0.004	0.005	0.002
Phenanthrene	1.910	1.786	1.252	1.013	0.741	0.857	1.042	0.675	0.724	0.985	0.943	0.774	1.005
Pyrene	<0,05	0.339	0.098	0.126	0.057	0.087	0.085	0.057	0.085	0.140	0.145	0.124	0.115
Retene	0.142	0.125	0.048	0.153	0.037	0.025	0.037	0.019	0.044	0.072	0.060	0.042	0.060
Sum PAH	5.826	8.382	5.738	4.392	2.329	2.737	2.711	1.985	2.319	3.541	4.635	5.032	3.899
Sum PAH16	3.897	4.928	3.336	2.51	1.553	1.801	1.929	1.456	1.635	2.371	2.786	2.905	2.458

Table A.1. 6: Monthly and annual mean concentrations (pg/m^3) for PFAS in air at Birkenes, 2018

Birkenes	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
FTS 4:2		<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
FTS 6:2		<0.04	<0.04	0.08	<0.04	0.051	<0.04	<0.09	<0.04	<0.04	<0.04	<0.04	0.07
FTS 8:2		<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
PFBS		<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
PFPeS		<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
PFHxS		<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.022	0.02
PFHpS		0.088	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.09
PFOS		0.095	<0.05	0.291	0.121	0.131	0.137	0.086	0.153	<0.05	<0.05	<0.05	0.14
PFOSlin		0.084	<0.05	0.13	0.08	0.063	0.081	<0.05	0.118	<0.05	<0.05	<0.05	<0.05
PFNS		<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07
PFDS		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
PFHxA		<0.11	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11
PFHpA		<0.1	<0.1	<0.1	0.17	0.249	0.337	0.208	0.121	<0.1	<0.1	<0.1	0.22
PFOA		0.12	<0.05	0.355	0.328	0.39	0.39	0.391	0.341	0.113	0.25	0.111	0.28
PFNA		0.07	<0.07	0.234	0.164	0.257	0.269	0.222	0.197	0.081	0.123	0.076	0.17
PFDA		<0.05	<0.05	0.124	<0.05	0.115	0.133	0.116	0.085	<0.05	<0.05	<0.05	0.11
PFUnA		<0.05	<0.05	0.081	0.108	0.083	0.112	0.089	<0.05	<0.05	<0.05	<0.05	0.09
PFDoDA		<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
PFTrDA		<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07
PFTeDA		<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
PFHxDA		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
PFODcA		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
PFOSA		<0.05	<0.05	0.086	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.09
sum PFAS		1.54	1.35	2.32	1.95	2.23	2.39	2.14	1.99	1.42	1.60	1.42	1.85
sum PFASdet		0.61	0.46	1.40	1.06	1.34	1.50	1.25	1.10	0.53	0.71	0.53	0.95

Table A.1. 7: Monthly and annual mean concentrations (pg/m^3) for cVMSs in air at Birkenes, 2018

Zeppelin	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
D4	0.7		0.8	0.6	0.3	0.5	0.7	0.5	0.6	0.7	0.8	0.8	0.6
D5	8.8		6.6	2.5	3.2	1.0	4.6	0.8	1.9	2.9	4.7	12	4.5
D6	0.4		0.4	0.2	0.4	0.1	0.3	0.1	0.3	0.3	0.4	0.7	0.3

Table A.1. 8: Monthly and annual mean concentrations (pg/m^3) for M/SCCPs in air at Birkenes, 2018

Birkenes	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
SCCP	465	207	735	82791	524	119	277	441	170	70	70	70	242
MCCP	1586	100	100	3603	3754	609	190	803	100	499	100	100	344

Table A.1. 9: Monthly and annual mean concentrations (ng/l) for HCB, HCHs and PCBs in precipitation at Birkenes, 2018

Birkenes	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2018**
HCB	*0.05*	*0.06*	*<0.13*	*<0.10*	*<0.07*	*<0.06*	0.37	0.15	*0.03*	*<0.16*	*0.04*	*0.06*	*0.07*
α-HCH	0.04	0.05	0.04	0.09	0.11	0.08	0.13	0.08	0.12	0.10	0.09	0.07	0.08
γ-HCH	0.08	0.09	0.11	0.30	0.22	0.17	0.42	0.24	0.13	0.11	0.25	0.14	0.16
sum HCH	0.28	0.16	0.17	0.11	0.46	0.28	0.24	0.28	0.32	0.30	0.20	0.17	0.24
PCB-28	0.004	0.007	*<0.009*	*<0.008*	*<0.005*	*<0.004*	0.034	0.012	*0.002*	*<0.01*	0.003	0.006	*0.006*
PCB-52	0.004	0.008	<0.01	*0.009*	<0.006	<0.005	*0.019*	*0.008*	*0.002*	<0.01	0.004	0.007	*0.006*
PCB-101	*<0.008*	*<0.01*	*<0.02*	*<0.02*	*<0.01*	*<0.01*	*<0.03*	*<0.01*	*<0.005*	*0.028*	*0.008*	*0.014*	*0.011*
PCB-118	0.005	*0.008*	*<0.01*	*<0.009*	<0.006	*<0.005*	*<0.01*	<0.007	*0.002*	<0.01	0.004	0.007	*0.006*
PCB-138	*0.007*	*0.012*	*<0.02*	*<0.01*	*<0.009*	*<0.008*	*<0.02*	*<0.01*	*<0.003*	*0.020*	0.007	0.013	*0.009*
PCB-153	*0.008*	*0.015*	*<0.02*	*<0.02*	*<0.01*	*<0.01*	*<0.03*	*<0.01*	*<0.005*	*0.029*	*0.010*	*0.017*	*0.013*
PCB-180	0.004	0.017	*0.009*	*<0.007*	*<0.005*	*<0.004*	*<0.01*	*<0.005*	*0.002*	*<0.01*	0.004	*0.004*	*0.006*
sum PCB-7	0.028	0.050	0.000	0.009	0.000	0.000	0.053	0.019	0.007	0.078	0.037	0.064	0.057

Table A.1. 10: Monthly and annual mean concentrations (pg/m^3) for hexachlorobenzene (HCB) in air at Andøya, 2018

Andøya	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
HCB	30.4	41.9	56.6	28.0	27.4	33.5	18.7	19.5	15.4	22.2	19.7	33.5	28.9

Table A.1. 11: Monthly and annual mean concentrations (pg/m^3) for PFAS in air at Andøya, 2018

Andøya	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
FTS 4:2		<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
FTS 6:2		<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
FTS 8:2		<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
PFBS		<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
PFPS		<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
PFHxS		<0.02	<0.02	0.022	0.03	0.02	<0.02	<0.02	<0.02	0.022	<0.02	0.03	0.02
PFHpS		<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
PFOS		0.143	<0.05	0.088	<0.05	<0.05	0.027	0.04	0.046	<0.05	0.085	0.09	0.07
PFOSlin		0.066	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.078	<0.05	<0.05	0.07
PFNS		<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07
PFDS		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
PFHxA		<0.11	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11
PFHpA		0.116	<0.1	0.143	0.168	<0.1	0.188	<0.1	<0.1	<0.1	<0.1	<0.1	0.15
PFOA		0.093	0.096	0.178	0.205	0.118	0.191	0.106	0.124	0.097	0.103	0.053	0.12
PFNA		<0.07	<0.07	0.081	0.136	<0.07	0.108	<0.07	0.076	<0.07	<0.07	<0.07	0.10
PFDA		<0.05	<0.05	<0.05	0.056	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
PFUnA		<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
PFDoDA		<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
PFTrDA		<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07
PFTeDA		<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
PFHxDA		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
PFODcA		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
PFOSA		<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 PFAS		1.52	1.40	1.57	1.65	1.42	1.59	1.40	1.43	1.43	1.44	1.40	1.48
sum PFASdet		0.49	0.46	0.59	0.71	0.48	0.68	0.47	0.49	0.49	0.46	0.42	0.52

Table A.1. 12: Monthly and annual mean concentrations (pg/m^3) for organochlorine pesticides in air at Zeppelin, 2018

Zeppelin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2018**
HCB	59.0	52.0	66.6	69.9	64.3	65.9	67.6	73.5	59.0	59.7	62.6	60.4	63.4
α-HCH	2.03	1.43	2.00	2.67	2.39	2.60	2.95	3.87	4.27	3.31	2.90	2.51	2.76
γ-HCH	0.54	0.21	0.29	0.42	0.31	0.24	0.33	0.40	0.48	0.48	0.48	0.40	0.38
sum HCHs	2.57	1.63	2.28	3.09	2.69	2.84	3.28	4.27	4.75	3.79	3.38	2.91	3.15
cis-CD	0.26	0.23	0.28	0.29	0.26	0.20	0.24	0.26	0.26	0.28	0.26	0.28	0.26
cis-NO	0.02	0.01	*0.01*	0.01	0.03	0.03	0.03	0.04	0.04	0.03	0.02	*0.01*	0.02
trans-CD	0.14	0.15	0.15	0.13	0.08	0.04	0.05	0.04	0.05	0.08	0.10	0.13	0.10
trans-NO	0.23	0.20	0.25	0.27	0.23	0.16	0.18	0.20	0.20	0.22	0.22	0.23	0.22
sum CHLs	0.65	0.59	0.70	0.70	0.60	0.43	0.50	0.54	0.56	0.61	0.60	0.65	0.60
pp_DDT	0.10	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.05	0.04	0.03
op_DDT	0.15	0.06	0.05	0.05	0.02	0.02	0.02	0.03	0.03	0.05	0.06	0.07	0.05
pp_DDE	1.11	0.36	0.20	0.11	0.07	0.04	0.05	0.04	0.06	0.19	0.32	0.38	0.24
op_DDE	0.09	0.05	0.04	0.03	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.05	0.03
pp_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
op_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
sum DDTs	1.47	0.50	0.32	0.22	0.13	0.10	0.11	0.12	0.14	0.31	0.48	0.56	0.37

Table A.1.13: Monthly and annual mean concentrations (pg/m^3) for PCBs in air at Zeppelin, 2018

Zeppelin	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
PCB-18	1.173	0.603	0.585	0.813	0.610	0.491	0.633	0.616	0.583	0.808	1.473	1.229	0.813
PCB-28	0.990	0.585	0.508	0.626	0.812	0.699	0.859	0.916	0.790	0.672	1.027	0.710	0.766
PCB-31	0.868	0.527	0.459	0.565	0.725	0.618	0.770	0.824	0.713	0.593	0.938	0.647	0.688
PCB-33	0.655	0.383	0.314	0.381	0.574	0.499	0.609	0.653	0.505	0.399	0.676	0.430	0.505
PCB-37	0.174	0.092	0.072	0.073	0.130	0.120	0.141	0.164	0.128	0.088	0.117	0.069	0.113
PCB-47	0.338	0.196	0.193	0.219	0.215	0.182	0.206	0.223	0.211	0.199	0.272	0.206	0.221
PCB-52	0.742	0.391	0.376	0.461	0.398	0.295	0.337	0.356	0.382	0.395	0.505	0.430	0.422
PCB-66	0.232	0.112	0.096	0.115	0.116	0.095	0.113	0.137	0.141	0.121	0.132	0.101	0.125
PCB-74	0.157	0.075	0.070	0.076	0.076	0.064	0.075	0.095	0.103	0.088	0.094	0.078	0.087
PCB-99	0.150	0.071	0.067	0.095	0.063	0.048	0.052	0.066	0.077	0.087	0.088	0.082	0.079
PCB-101	0.414	0.186	0.176	0.231	0.183	0.147	0.162	0.188	0.220	0.230	0.232	0.199	0.213
PCB-105	0.050	0.015	0.013	0.019	0.014	0.012	0.013	0.015	0.022	0.030	0.025	0.018	0.021
PCB-114	0.004	0.002	0.003	0.003	0.002	0.002	0.002	0.002	0.003	0.003	*0.003*	*0.003*	*0.003*
PCB-118	0.154	0.053	0.047	0.068	0.050	0.041	0.046	0.051	0.071	0.086	0.078	0.058	0.067
PCB-122	0.004	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	*0.002*	*0.002*	*0.002*
PCB-123	0.005	*0.001*	0.002	0.002	0.001	*0.001*	0.001	0.001	0.002	0.002	0.003	0.002	*0.002*
PCB-128	0.021	0.007	0.007	0.008	0.006	0.005	0.005	0.007	0.008	0.013	0.011	0.008	0.009
PCB-138	0.210	0.055	0.042	0.059	0.044	0.035	0.039	0.048	0.056	0.076	0.070	0.055	0.065
PCB-141	0.068	0.011	0.013	0.013	0.010	0.008	0.009	0.011	0.016	0.018	0.017	0.013	0.017
PCB-149	0.391	0.090	0.082	0.109	0.081	0.062	0.070	0.083	0.107	0.117	0.114	0.096	0.115
PCB-153	0.369	0.078	0.069	0.085	0.062	0.045	0.052	0.059	0.082	0.097	0.100	0.086	0.097
PCB-156	0.009	0.002	0.002	0.003	0.002	0.002	0.002	*0.002*	*0.003*	0.006	0.005	0.003	0.004
PCB-157	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-167	*0.003*	*0.001*	0.001	*0.001*	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002	*0.002*

Table A.1. 13 cont.

Zeppelin	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
PCB-170	*0.025*	0.004	0.004	0.004	0.004	0.003	0.002	0.003	0.003	0.005	0.004	0.003	0.005
PCB-180	0.133	0.012	0.010	0.013	0.010	0.008	0.008	0.008	0.009	0.014	0.013	0.012	0.020
PCB-183	0.053	0.005	0.004	0.005	0.004	0.003	0.003	0.004	0.005	0.007	0.006	0.006	0.009
PCB-187	0.166	0.018	0.012	0.017	0.012	0.008	0.010	0.012	0.015	0.017	0.020	0.018	0.027
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	0.007	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
PCB-206	0.003	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
PCB-209	*0.002*	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.001	*0.001*	*0.002*	0.002	0.002
sum-trichlor	5.22	2.98	2.57	3.29	3.76	3.17	3.94	4.26	3.75	3.50	5.84	4.21	3.89
sum-tetrachlor	3.06	1.57	1.37	1.68	1.62	1.28	1.50	1.67	1.90	1.75	2.08	1.69	1.76
sum-pentachlor	1.34	0.56	0.46	0.72	0.55	0.44	0.49	0.58	0.76	0.82	0.75	0.63	0.67
sum-hexachlor	1.59	0.36	0.25	0.42	0.32	0.23	0.24	0.29	0.45	0.52	0.48	0.39	0.46
sum-heptachlor	0.53	0.05	0.02	0.05	0.03	0.02	0.03	0.03	0.05	0.06	0.04	0.05	0.08
sum-PCB7	3.01	1.36	1.23	1.54	1.56	1.27	1.50	1.63	1.61	1.57	2.03	1.55	1.65
sum PCB	11.76	5.52	4.67	6.16	6.29	5.15	6.20	6.83	6.91	6.65	9.20	6.98	6.86

Table A.1. 74: Monthly and annual mean concentrations (pg/m^3) for PBDEs and TBA in air at Zeppelin, 2018

Zeppelin	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
BDE-28	0.007	0.007	0.006	0.006	0.007	0.008	0.009	0.008	0.007	0.007	0.004	0.005	0.007
BDE-47	0.152	0.142	0.103	0.163	0.238	0.223	0.182	0.143	0.085	0.114	0.087	0.078	0.145
BDE-49	0.006	0.006	0.005	0.007	0.010	0.008	0.007	0.006	0.004	0.007	0.005	0.004	0.006
BDE-66	0.003	0.004	0.002	0.003	0.005	0.004	0.004	0.004	0.003	0.006	0.003	0.003	0.004
BDE-71	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.002	0.004	0.001	0.001	0.002
BDE-77	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.003	0.004	0.001	0.001	0.002
BDE-85	0.001	0.001	0.003	0.001	0.002	0.002	0.002	0.002	0.005	0.005	0.001	0.001	0.002
BDE-99	0.034	0.032	0.026	0.030	0.089	0.076	0.071	0.040	0.026	0.031	0.015	0.019	0.042
BDE-100	0.012	0.011	0.006	0.012	0.028	0.023	0.018	0.012	0.009	0.014	0.006	0.006	0.013
BDE-119	0.001	0.001	0.002	0.001	0.002	0.001	0.001	0.001	0.003	0.006	0.001	0.001	0.002
BDE-138	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.006	0.011	0.003	0.003	0.004
BDE-153	0.006	0.004	0.003	0.003	0.004	0.003	0.004	0.005	0.008	0.016	0.003	0.003	0.005
BDE-154	0.004	0.003	0.002	0.002	0.005	0.003	0.004	0.003	0.007	0.013	0.002	0.002	0.004
BDE-183	0.020	0.015	0.005	0.003	0.004	0.004	0.006	0.006	0.007	0.019	0.003	0.012	0.008
BDE-196	0.097	0.163	0.016	0.010	0.005	0.007	0.007	0.006	0.008	0.020	0.011	0.009	0.026
BDE-206	0.322	0.931	0.407	0.281	0.088	0.328	0.354	0.057	0.266	0.264	0.341	0.458	0.326
BDE-209	3.81	7.93	9.38	10.70	1.92	10.39	12.85	1.19	11.56	7.44	8.57	13.97	8.18
sum BDE	4.48	9.25	9.98	11.23	2.41	11.08	13.52	1.48	12.01	7.98	9.05	14.58	8.781
sum BDE (excl. 209)	0.67	1.32	0.59	0.53	0.49	0.69	0.67	0.30	0.45	0.54	0.49	0.61	0.60
TBA	3.20	2.45	1.46	1.05	1.58	7.27	8.59	10.30	7.90	6.60	4.69	3.59	4.82

Table A.1. 85: Monthly and annual mean concentrations (pg/m^3) for HBCDs in air at Zeppelin, 2018

Zeppelin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2018**
α-HBCD	*<0.17*	*0.75*	*<0.17*	*<0.17*	*<0.18*	*<0.17*	*<0.18*	*<0.18*	*<0.17*	<0.20	*<0.18*	*<0.17*	*<0.17*
β-HBCD	<0.06	*0.14*	<0.06	<0.06	<0.07	<0.07	<0.07	<0.06	<0.06	<0.06	<0.06	<0.06	*<0.06*
γ-HBCD	<0.20	<0.20	<0.20	<0.20	<0.22	<0.22	<0.21	<0.21	<0.21	<0.20	<0.20	<0.20	*<0.20*
Sum HBCD	*<0.43*	*0.99*	*<0.43*	*<0.43*	*<0.47*	*<0.46*	*<0.46*	*<0.45*	*<0.44*	*<0.46*	*<0.44*	*<0.43*	*<0.43*

Table A.1. 96: Monthly and annual mean concentrations (ng/m^3) for PAHs in air at Zeppelin, 2018

Zeppelin	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
1-Methylnaphthalene	0.130	0.071	0.029	0.024	0.010	0.009	0.010	0.016	0.021	0.019	0.072	0.205	0.053
1-Methylphenanthrene	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.002	0.003	0.002
2-Methylanthracene	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
2-Methylnaphthalene	0.154	0.080	0.038	0.038	0.016	0.015	0.018	0.026	0.036	0.031	0.085	0.204	0.063
2-Methylphenanthrene	0.004	0.002	0.002	0.002	0.001	0.002	0.002	0.003	0.001	0.002	0.003	0.005	0.002
3-Methylphenanthrene	0.003	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.003	0.004	0.002
9-Methylphenanthrene	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.002	0.002	0.001
Acenaphthene	0.009	0.004	0.003	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.003	0.003	0.003
Acenaphthylene	0.006	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.003	0.001	0.002
Anthanthrene	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.001
Anthracene	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
Benz(a)anthracene	0.003	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.004	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	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.003	0.001
Benzo(a)pyrene	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.004	0.001
Benzo(b)fluoranthene	0.008	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.004	0.012	0.003
Benzo(b)fluorene	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001
Benzo(e)pyrene	0.005	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.003	0.007	0.002
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	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.006	0.002
Benzo(k)fluoranthene	0.003	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.005	0.002
Biphenyl	0.586	0.584	0.334	0.057	0.023	0.011	0.008	0.022	0.031	0.072	0.291	0.598	0.219
Chrysene	0.007	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.003	0.011	0.003
Coronene	0.003	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.003	0.002

Table A.1. 16 cont.

Zeppelin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2018**
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
Dibenzo(ae)pyrene	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.004	0.001	0.001	0.001	0.002	0.002
Dibenzo(ah)anthracene	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.001
Dibenzo(ah)pyrene	0.002	0.002	0.002	0.002	0.002	0.002	0.004	0.006	0.002	0.002	0.002	0.001	0.002
Dibenzo(ai)pyrene	0.002	0.002	0.002	0.002	0.002	0.002	0.003	0.005	0.002	0.002	0.002	0.001	0.002
Dibenzofuran	0.708	0.602	0.416	0.125	0.048	0.025	0.019	0.040	0.057	0.109	0.352	0.740	0.271
Dibenzothiophene	0.007	0.003	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.004	0.007	0.003
Fluoranthene	0.028	0.008	0.007	0.004	0.004	0.004	0.004	0.003	0.004	0.004	0.013	0.048	0.011
Fluorene	0.320	0.197	0.065	0.014	0.015	0.011	0.009	0.009	0.009	0.034	0.150	0.395	0.108
Inden(123-cd)pyrene	0.005	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.005	0.002
Naphthalene													
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	0.064	0.021	0.013	0.010	0.007	0.008	0.008	0.011	0.007	0.011	0.028	0.080	0.023
Pyrene	0.012	0.003	0.004	0.004	0.004	0.006	0.003	0.002	0.003	0.003	0.007	0.021	0.006
Retene	0.002	0.001	0.001	0.002	0.001	0.002	0.002	0.002	0.001	0.001	0.001	0.003	0.002
Sum PAH	2.089	1.606	0.943	0.31	0.161	0.124	0.118	0.178	0.199	0.318	1.052	2.394	0.807
Sum PAH16	0.471	0.245	0.104	0.044	0.042	0.042	0.036	0.039	0.034	0.065	0.223	0.597	0.17

Table A.1. 107: Monthly and annual mean concentrations (pg/m^3) for PFAS in air at Zeppelin, 2018

Zeppelin	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
FTS 4:2	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
FTS 6:2	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
FTS 8:2	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
PFBS	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
PFPS	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
PFHxS	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.01
PFHpS	<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
PFOS	<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
PFOSlin	<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
PFNS	<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
PFDS	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
PFHxA	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11	<0.11
PFHpA	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.109	<0.1	<0.1	<0.1	<0.1	<0.1
PFOA	<0.05	0.05	<0.12	0.082	0.095	0.098	0.095	0.191	0.139	<0.05	0.055	0.051	0.10
PFNA	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	0.114	<0.07	<0.07	<0.07	<0.07
PFDA	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.083	<0.05	<0.05	<0.05	<0.05
PFUnA	<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
PFDoDA	<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
PFTrDA	<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
PFTeDA	<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
PFHxDA	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
PFODcA	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
PFOSA	<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 PFAS	1.35	1.35	1.41	1.38	1.40	1.40	1.39	1.50	1.52	1.35	1.36	1.35	1.40
sum PFASdet	0.27	0.27	0.33	0.30	0.32	0.32	0.31	0.42	0.44	0.27	0.28	0.27	0.32

Table A.1. 118: Monthly and annual mean concentrations (pg/m^3) for cVMSs in air at Zeppelin, 2018

Zeppelin	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
D4	0.7	0.6	0.6	0.4	0.3	0.2	0.2	0.2	0.3	0.5	0.4	0.6	0.4
D5	2.5	2.7	3.1	1.8	0.6	0.4	0.3	0.2	0.4	1.5	2.5	4.3	1.6
D6	0.1	0.1	0.2	0.8	0.2	0.3	0.2	0.1	0.1	0.2	0.5	0.3	0.3

Table A.1. 19: Monthly and annual mean concentrations (pg/m^3) for M/SCCPs in air at Zeppelin, 2018

Zeppelin	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
SCCP	614	289	398	333	328	476	220	180	181	168	198	57	290
MCCP	94	44	178	46	29	242	111	36	66	185	436	32	120

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 2018. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	0.54	1.17	1.24	0.43	0.66	0.38	1.37	0.52	0.36	0.42	0.62	0.45	0.6
Hurdal	0.61	1.03	0.49	0.58	1.04	0.36	0.53	0.43	0.25	0.6	0.41	0.6	0.51
Kårvatn	0.1	0.21	0.11	0.12	0.61	0.57	0.47	0.06	0.03	0.17	2.54	0.59	0.26
Svanvik	1.19	0.57	0.43	0.68	1.35	1.05	0.76	0.82	1.48	1.02	1.3	0.64	0.92
Karpbukt	0.63	0.47	0.5	0.55	1.1	0.98	0.96	1.43	0.72	0.43	0.45	0.67	0.79

Table A.2. 2: Monthly and annual volume weighted mean concentrations of cadmium in precipitation at Norwegian background stations 2018. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	0.016	0.033	0.071	0.021	0.025	0.018	0.013	0.014	0.022	0.011	0.023	0.016	0.022
Hurdal	0.027	0.033	0.022	0.013	0.05	0.014	0.015	0.017	0.01	0.022	0.015	0.024	0.019
Kårvatn	0.003	0.004	0.007	0.005	0.013	0.008	0.011	0.003	0.003	0.003	0.01	0.005	0.005
Svanvik	0.173	0.122	0.034	0.066	0.066	0.068	0.047	0.041	0.104	0.029	0.06	0.052	0.062
Karpbukt	0.079	0.062	0.036	0.052	0.078	0.09	0.048	0.122	0.069	0.02	0.042	0.06	0.063

Table A.2. 3: Monthly and annual volume weighted mean concentrations of zinc in precipitation at Norwegian background stations 2018. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OKT	NOV	DES	2018
Birkenes	3.2	6.2	8.7	6.6	4.1	3.7	4.8	3.3	2.5	3.8	3.6	3.9	4
Hurdal	5.2	5.8	3.4	4	7.7	3.7	4.5	6.9	2.9	5	2.6	6.4	4.4
Kårvatn	0.7	0.6	0.5	1.2	4.9	3.5	8.2	1.8	1.3	2.4	2.1	3.4	2.3
Svanvik	5.7	17.9	2.1	7.3	8	2.5	3.1	3	7.9	3.6	5.6	2.3	4.3
Karpbukt	8.7	9.1	3.5	11.2	15.8	15.9	5.2	9.4	9.4	4.3	4.4	7.7	8.1

Table A.2. 4: Monthly and annual volume weighted mean concentrations of nickel in precipitation at Norwegian background stations 2018. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	0.15	0.22	0.29	0.32	0.22	0.22	0.26	0.7	0.11	0.17	0.07	0.06	0.18
Svanvik	27.93	22.41	10.99	14.46	32.46	33.89	25.41	20.53	63.05	19.97	29.85	6.28	26.5
Karpbukt	16.63	29.57	15.65	27.98	70.34	16.8	16.21	36.94	26.59	6.23	24.31	14.81	22.48

Table A.2. 5: Monthly and annual volume weighted mean concentrations of arsenic in precipitation at Norwegian background stations 2018. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	0.06	0.29	0.16	0.07	0.09	0.04	0.07	0.06	0.04	0.05	0.12	0.07	0.1
Svanvik	0.82	0.55	0.34	1.24	1.19	1.46	0.66	0.82	2.1	0.36	0.4	0.22	0.9
Karpbukt	0.49	0.36	0.37	0.89	1.39	0.66	0.77	1.77	0.84	0.21	0.41	0.32	0.72

Table A.2. 6: Monthly and annual volume weighted mean concentrations of copper in precipitation at Norwegian background stations 2018. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	0.46	1.56	5.51	5	4.07	0.8	4.18	1.95	0.42	0.76	0.87	1.17	1.43
Svanvik	60.34	46.1	15.37	26.61	57.16	29.25	27.3	19.81	60.38	19.63	36.3	17.29	30.46
Karpbukt	23.84	31.4	17.18	22.12	37.71	20.28	14.18	34.02	23.32	13.81	24.97	19	21.89

Table A.2. 7: Monthly and annual volume weighted mean concentrations of cobalt in precipitation at Norwegian background stations 2018. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	0.009	0.011	0.025	0.040	0.034	0.041	0.076	0.026	0.013	0.022	0.012	0.072	0.025
Svanvik	0.970	0.731	0.286	0.384	0.984	0.931	0.672	0.541	1.708	0.563	1.039	0.254	0.745
Karpbukt	0.428	0.635	0.441	0.802	2.183	0.520	0.522	1.076	0.754	0.213	0.754	0.501	0.663

Table A.2. 8: Monthly and annual volume weighted mean concentrations of chromium in precipitation at Norwegian background stations 2018. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	0.04	0.05	0.17	0.15	0.09	0.13	0.19	0.05	0.05	0.06	0.06	0.05	0.07
Svanvik	0.1	0.09	0.09	0.09	0.32	0.4	0.31	0.11	0.55	0.38	0.61	0.07	0.27
Karpbukt	0.25	0.23	0.2	0.33	1.21	0.55	0.52	0.73	0.4	0.27	0.42	0.23	0.44

Table A.2. 9: Monthly and annual volume weighted mean concentrations of manganese in precipitation at Norwegian background stations 2018. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	0.43	0.99	1.77	2.17	3.61	3.6	5.5	2.13	1.25	1.32	0.62	0.35	1.25

Table A.2. 10: Monthly and annual volume weighted mean concentrations of vanadium in precipitation at Norwegian background stations 2018. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	0.1	0.12	0.33	0.17	0.16	0.23	0.35	0.18	0.12	0.09	0.16	0.1	0.14
Svanvik	1.67	0.71	0.43	0.66	0.6	0.24	0.14	0.09	0.46	0.44	0.94	0.34	0.4
Karpbukt	0.77	0.58	0.44	0.63	1.33	0.67	0.46	0.65	0.27	0.26	0.43	0.4	0.52

Table A.2. 11: Monthly and annual volume weighted mean concentrations of aluminium in precipitation at Svanvik and Karpdalen. 2018. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Svanvik	12.22	11.63	6.07	9.43	31.87	24.2	22.25	11.71	32.57	89.34	252.31	13.01	35.5
Karpbukt	9.94	11.15	15.86	31.14	167.29	90.47	105.4	145.58	50.59	43.43	39.31	19.11	66.94

Table A.2. 12: Monthly and annual average volume weighted mean concentrations of mercury in precipitation at Birkenes in 2018. Unit: ng/L

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	2.4	5.0	4.7	7.1	15.9	6.7	21.2	7.2	4.8	5.1	5.0	3.7	5.4

Table A.2. 13: Annual and monthly total precipitation in 2018. 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	2018
Birkenes	198.39	131.62	47.19	66.78	48.36	61.2	21.57	83.62	228.14	39.71	256.41	166.26	1349.24
Hurdal	132.32	50.64	20.64	60.19	24.36	49.52	44.23	60.04	151.79	55.32	161.2	85.1	895.36
Kårvatn	62.93	27.45	60.13	57.36	37.8	54.03	34.16	177.5	215.24	238.6	13.72	222.86	1201.76
Svanvik	21.5	8.92	35.99	23.47	11.08	49.43	71.62	87.71	38.66	30.7	22.04	16.62	417.74
Karpbukt	22.78	22.84	42.69	25.25	11.2	53.29	89.98	40.68	51.22	15.25	50.01	39.07	464.26

Table A.2. 14: Monthly- and annual wet deposition of lead at Norwegian background stations 2018. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	107	154	58	29	32	23	30	43	81	17	160	74	808
Hurdal	81	52	10	35	25	18	23	26	39	33	66	51	460
Kårvatn	6	6	7	7	23	31	16	10	6	41	35	132	307
Svanvik	26	5	16	16	15	52	54	72	57	31	29	11	384
Karpbukt	14	11	21	14	12	52	86	58	37	7	23	26	366

Table A.2. 15: Monthly- and annual wet deposition of cadmium at Norwegian background stations 2018. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	3.2	4.3	3.3	1.4	1.2	1.1	0.3	1.2	5.1	0.4	5.9	2.7	30
Hurdal	3.5	1.7	0.4	0.8	1.2	0.7	0.7	1	1.5	1.2	2.5	2	17.3
Kårvatn	0.2	0.1	0.4	0.3	0.5	0.4	0.4	0.5	0.7	0.8	0.1	1.1	5.5
Svanvik	3.7	1.1	1.2	1.6	0.7	3.4	3.4	3.6	4	0.9	1.3	0.9	25.7
Karpbukt	1.8	1.4	1.6	1.3	0.9	4.8	4.3	5	3.5	0.3	2.1	2.4	29.4

Table A.2. 16: Monthly- and annual wet deposition of zinc at Norwegian background stations 2018. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	634	822	412	439	197	225	104	278	573	150	920	649	5404
Hurdal	689	296	71	241	187	184	198	416	436	275	419	546	3958
Kårvatn	42	16	33	71	184	188	278	314	283	565	28	765	2767
Svanvik	122	160	76	171	89	125	223	262	304	110	123	37	1808
Karpbukt	198	208	150	282	177	847	466	382	482	66	222	300	3771

Table A.2. 17: Monthly- and annual wet deposition of nickel at Norwegian background stations 2018. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	29	29	14	21	11	13	6	59	25	7	17	10	241
Svanvik	601	200	396	339	360	1675	1820	1801	2438	613	658	104	11068
Karpbukt	379	675	668	707	788	895	1459	1503	1362	95	1216	579	10436

Table A.2. 18: Monthly- and annual wet deposition of arsenic at Norwegian background stations 2018. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	12	39	8	5	5	2	1	5	8	2	31	11	129
Svanvik	18	5	12	29	13	72	47	72	81	11	9	4	375
Karpbukt	11	8	16	22	16	35	69	72	43	3	21	12	335

Table A.2. 19: Monthly- and annual wet deposition of copper at Norwegian background stations 2018. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	90	205	260	334	197	49	90	163	95	30	222	195	1931
Svanvik	1297	411	553	625	634	1446	1955	1738	2334	603	800	287	12725
Karpbukt	543	717	734	559	422	1081	1276	1384	1194	211	1249	742	10164

Table A.2. 20: Monthly- and annual wet deposition of cobalt at Norwegian background stations 2018. Unit: $\mu g/m^2$.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	2	1	1	3	2	3	2	2	3	1	3	12	34
Svanvik	21	7	10	9	11	46	48	47	66	17	23	4	311
Karpbukt	10	15	19	20	24	28	47	44	39	3	38	20	308

Table A.2. 21: Monthly- and annual wet deposition of chromium at Norwegian background stations 2018. Unit: $\mu g/m^2$.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	9	6	8	10	4	8	4	4	11	2	15	8	90
Svanvik	2	1	3	2	4	20	23	9	21	12	14	1	112
Karpbukt	6	5	9	8	14	29	46	30	20	4	21	9	206

Table A.2. 22: Monthly- and annual wet deposition of manganese at Norwegian background stations 2018. Unit: $\mu g/m^2$.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	86	130	83	145	175	221	119	178	285	52	160	58	1693

Table A.2. 23: Monthly- and annual wet deposition of vanadium at Norwegian background stations 2018. Unit: $\mu g/m^2$.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	19	16	15	11	8	14	8	15	27	4	41	16	194
Svanvik	36	6	15	16	7	12	10	8	18	14	21	6	168
Karpbukt	18	13	19	16	15	36	42	26	14	4	21	16	240

Table A.2. 24: Monthly and annual wet deposition of mercury at Birkenes in 2018. Unit: ng/m^3

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2018
Birkenes	614	847	215	632	833	484	624	676	1204	261	1132	663	8185
Svanvik													
Karpbukt													

Table A.2. 25: Annual average volume weighed mean concentration of heavy metals in precipitation at Norwegian background sites. 1976, aug 1978-jun 1979; 1980 (feb - dec), 1981-2017

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								
Grey area	1980	7.9	0.34	15.7								
indicates	1981	7.4	0.24	6.2								
data from	1982	8.8	0.69	7								
Lista	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								13.8
	1991	3.6	0.06	7								11.8
	1992	2.9	0.04	5.2								10.9
	1993	3.1	0.06	6.5								11.3
	1994	2.6	0.05	5	0.3	0.2	1		0.2			8.1
	1995	2.2	0.05	6	0.4	0.4	1.1		0.8			13.9
	1996	2.8	0.06	4.9	0.4	0.4			0.3			19.7
	1997	1.7	0.03	4.2	0.4	0.5	1	0.04	0.2			10.6
	1998	1.59	0.043	4.9	0.59	0.2	1.13	0.03	0.58			9
	1999	1.5	0.040	4.4	0.4	0.2	1.7	0.03	0.2			9.7
	2000	1.39	0.030	3.2	0.34	0.28	1.13	0.03	<0.2			7.3
	2001	1.25	0.032	4.7	0.37	0.18	1.28	0.02	0.31			7.3
	2002	0.99	0.034	3.6	0.3	0.29	1.3	0.02	0.16			12.8
	2003	1.57	0.043	3.9	0.5	1.01	1.3	0.04	0.31			8.3
	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
	2017	0.67	0.018	2.9	0.2	0.09	2.37	0.02	0.10	0.16	-	5.8
	2018	0.60	0.022	4.0	0.18	0.10	1.4	0.03	0.07	0.14	-	5.4
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								

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	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								
	2003	0.97	0.032	3.7								
	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								
	2017	0.38	0.013	4.2								
	2018	0.51	0.019	4.4								
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								

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
Kårvatn (cont.)	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								
	2017	0.10	0.003	1.2								
	2018	0.26	0.005	2.3								
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	
	2017	0.85	0.088	4.2	27.6	1.21	34.0	0.85	0.25	0.47	20	
	2018	0.92	0.062	4.3	26.5	0.9	30.5	0.74	0.27	0.40	36	
Karpdalen	1991	1.93	0.432	5.6	6.87	1.10	11.0	0.22	0.69			
	1993	1.33	0.057	5.6	4.27	0.60	5.8	0.17	1.30			
	1994	1.45	0.067	5.4	9.13	0.80	9.2	0.32	0.73			
	1995	1.69	0.069	4.1	9.21	1.05	6.7	0.33	0.37			
	2015	1.14	0.061	7.4	24.2	1.04	26.1	0.79	0.44	0.53	47	
	2016	0.96	0.066	7.2	42.1	1.19	38.5	1.23	0.48	0.46	36	
	2017	0.77	0.060	5.0	20.2	0.80	25.5	0.63	0.32	0.45	48	
	2018	0.79	0.063	8.1	22.5	0.72	21.9	0.66	0.44	0.52	67	

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						

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
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
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 2018. Unit: ng/m^3

	As	Cd	Cr	Co	Cu	Pb	Ni	V	Zn	Hg(g)
JAN	0.08	0.020	0.42	0.009	0.20	0.50	0.12	0.10	3.3	1.39
FEB	0.20	0.037	0.43	0.057	0.50	1.11	0.18	0.24	4.4	1.50
MAR	0.16	0.038	0.48	0.021	0.43	0.99	0.22	0.35	5.3	1.45
APR	0.25	0.044	0.37	0.035	0.62	0.90	0.33	0.53	5.6	1.56
MAY	0.18	0.028	0.32	0.049	0.74	0.84	0.36	0.64	3.9	1.38
JUN	0.15	0.018	0.29	0.036	0.48	0.51	0.26	0.46	2.4	1.45
JUL	0.14	0.021	0.29	0.037	0.72	0.66	0.34	0.55	2.6	1.45
AUG	0.16	0.021	0.22	0.019	0.36	0.47	0.22	0.32	2.1	1.47
SEP	0.19	0.022	0.29	0.012	0.35	0.49	0.24	0.35	3.7	1.17
OCT	0.22	0.062	0.38	0.019	0.65	1.20	0.23	0.35	4.9	1.36
NOV	0.21	0.056	0.17	0.009	0.49	0.89	0.20	0.27	4.4	1.56
DEC	0.09	0.016	0.17	0.007	0.15	0.39	0.11	0.11	2.9	1.60
2018	0.17	0.032	0.32	0.026	0.48	0.75	0.24	0.36	3.8	1.45

Table A.2. 28: Monthly and annual average mean concentrations of heavy metals in aerosols and mercury in gas phase at Andøya in 2018. Unit: ng/m^3

	As	Cd	Cr	Co	Cu	Pb	Mn	Ni	V	Zn	Hg(g)
JAN	0.04	0.012	0.75	0.026	0.25	0.37	0.69	0.44	0.17	1.5	1.49
FEB	0.06	0.015	0.17	0.020	0.17	0.61	0.53	0.14	0.18	1.5	1.50
MAR	0.06	0.009	0.15	0.013	0.21	0.21	0.36	0.17	0.18	0.8	1.51
APR	0.07	0.010	0.17	0.030	0.19	0.29	0.88	0.15	0.22	1.1	1.42
MAY	0.05	0.006	0.19	0.024	0.16	0.21	0.80	0.14	0.28	0.8	1.45
JUN	0.02	0.002	0.21	0.024	0.12	0.06	0.89	0.19	0.25	0.5	1.42
JUL	0.05	0.009	0.13	0.020	0.21	0.39	0.93	0.18	0.42	1.1	1.38
AUG	0.02	0.003	0.05	0.004	0.08	0.08	0.19	0.03	0.09	0.5	1.35
SEP	0.04	0.006	0.12	0.010	0.14	0.18	0.43	0.09	0.10	1.0	1.28
OCT	0.01	0.003	0.05	0.005	0.06	0.07	0.12	0.04	0.05	0.3	1.34
NOV	0.02	0.005	0.09	0.004	0.42	0.16	0.16	0.09	0.06	0.9	1.34
DEC	0.04	0.006	0.06	0.006	0.36	0.15	0.19	0.09	0.08	1.7	1.39
2018	0.04	0.007	0.19	0.016	0.19	0.23	0.53	0.15	0.18	1.0	1.40

Table A.2. 29: Monthly and annual average mean concentrations of heavy metals in aerosols and mercury in gas phase at Zeppelin in 2018. Unit: ng/m^3

	As	Cd	Cr	Co	Cu	Pb	Mn	Ni	V	Zn	Hg(g)
JAN	0.07	0.014	0.13	0.014	1.13	0.45	0.55	0.15	0.17	0.9	1.47
FEB	0.02	0.044	0.45	0.016	2.58	0.12	1.02	0.43	0.08	3.8	1.46
MAR	0.04	0.028	0.26	0.008	0.70	0.21	0.51	0.17	0.06	1.5	1.45
APR	0.06	0.046	0.27	0.014	1.73	0.29	0.96	0.21	0.10	2.6	1.43
MAY	0.01	0.005	0.04	0.002	0.18	0.03	0.09	0.03	0.02	0.2	1.51
JUN	0.01	0.011	0.07	0.002	0.17	0.01	0.06	0.03	0.01	0.2	1.54
JUL	0.01	0.001	0.05	0.003	0.80	0.05	0.18	0.04	0.02	2.7	1.59
AUG	0.01	0.020	0.05	0.003	0.09	0.01	0.18	0.05	0.01	1.0	1.36
SEP	0.00	0.006	0.07	0.008	0.08	0.03	0.28	0.05	0.05	0.5	1.50
OCT	0.01	0.006	0.08	0.021	0.18	0.04	0.46	0.22	0.09	1.5	1.49
NOV	0.05	0.013	0.16	0.019	0.27	0.26	0.49	0.14	0.07	1.4	1.11
DEC	0.03	0.031	0.23	0.023	0.46	0.22	0.87	0.20	0.09	4.2	1.17
2018	0.03	0.020	0.16	0.012	0.68	0.14	0.49	0.15	0.06	1.7	1.42

Table A.2. 30: Monthly and annual average mean concentrations of heavy metals in aerosols at Svanvik in 2018. Unit: ng/m^3

	Al	As	Cd	Cr	Co	Cu	Fe	Pb	Mn	Ni	V	Zn
JAN	29	2.25	0.272	0.43	0.51	12.1	61	3.30	1.00	14.4	7.1	16.9
FEB	19	2.00	0.182	0.31	0.45	8.7	49	2.55	0.67	11.4	3.2	11.5
MAR	28	1.90	0.131	0.44	0.38	6.1	41	1.87	0.57	9.5	1.8	7.4
APR	80	0.88	0.078	0.35	0.47	8.7	102	1.24	1.26	12.0	4.6	4.6
MAY	75	1.72	0.139	0.38	0.41	7.3	100	1.97	1.36	9.4	1.4	6.5
JUN	60	0.69	0.059	0.37	0.27	5.0	49	1.01	0.77	6.9	0.5	2.4
JUL	70	1.48	0.106	0.36	0.35	6.3	91	2.07	1.46	8.0	0.7	4.8
AUG	13	0.23	0.025	0.30	0.03	0.8	15	0.54	0.43	0.7	0.2	1.4
SEP	35	0.40	0.063	0.19	0.11	2.9	36	0.95	0.78	2.7	0.5	3.0
OCT	25	0.25	0.031	0.18	0.07	1.3	28	0.62	0.44	1.8	0.6	2.9
NOV	33	0.77	0.130	0.12	0.12	3.6	34	1.41	0.51	3.0	0.9	4.9
DEC	18	0.20	0.053	0.16	0.08	2.5	22	1.03	0.43	2.3	1.8	2.8
2018	42	1.11	0.108	0.31	0.29	5.7	55	1.59	0.84	7.2	2.0	5.9

Table A.2. 31: Monthly and annual average mean concentrations of heavy metals in aerosols at Karpdalen in 2018. Unit: ng/m^3

	Al	As	Cd	Cr	Co	Cu	Fe	Pb	Mn	Ni	V	Zn
JAN	25	4.41	0.500	0.50	0.53	15.3	57	7.14	0.94	14.6	10.0	24.2
FEB	14	5.52	0.500	0.36	0.43	10.3	49	5.63	0.64	11.4	6.2	22.6
MAR	18	4.38	0.386	0.41	0.79	15.7	82	4.67	0.85	22.3	9.3	19.4
APR	29	0.93	0.101	0.41	0.30	6.9	48	1.98	0.52	9.9	9.8	5.5
MAY	39	1.05	0.087	0.26	0.24	4.1	54	1.23	0.68	5.6	0.8	3.6
JUN	63	0.66	0.069	0.30	0.20	3.1	69	1.17	1.02	4.2	0.5	2.9
JUL	214	0.53	0.054	0.46	0.26	3.2	226	1.04	3.20	4.1	1.0	2.6
AUG	15	3.58	0.396	0.33	0.57	10.8	52	8.10	0.57	12.2	0.7	11.6
SEP	30	1.06	0.154	0.19	0.30	6.2	43	2.35	0.67	7.2	0.8	5.5
OCT	10	0.44	0.095	0.09	0.14	2.8	20	1.24	0.24	3.5	1.1	3.9
NOV	14	1.10	0.188	0.10	0.25	5.6	31	1.99	0.30	6.6	2.0	8.1
DEC	10	1.78	0.193	0.21	0.30	7.3	40	4.17	0.47	8.2	3.0	8.2
2018	30	2.16	0.237	0.28	0.34	7.6	52	3.47	0.69	8.8	3.6	10.2

Table A.2. 32: Monthly and annual concentration of Mercury at Trollhaugen in 2018. Unit: ng/m^3

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	2018
Trollhaugen	0.99	1.02	1.02	0.94	0.95	1.00	0.92	0.95	0.94	0.97	0.79	-	0.97

Table A.2. 33: 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 PM(2.5)	1995	0.34	0.06	0.28		0.41	2.74		0.56	1.10	4.2	1.63		
	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-PM2.5)	1995	0.13	0.018	1.54		0.64	1.02		0.25	0.38	1.9			
	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		
	2017	0.14	0.021	2.91	0.013	0.31	0.54		0.15	0.20	3.2	1.45		
	2018	0.17	0.032	0.32	0.026	0.48	0.75		0.24	0.36	3.8	1.45		

Table A.2. 33 (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		
	2017	0.04	0.008	0.14	0.012	0.51	0.22	0.54	0.18	0.13	1.0	1.40		
	2018	0.04	0.007	0.19	0.016	0.19	0.23	0.53	0.15	0.18	1.0	1.40		
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		
	2017	0.06	0.011	0.29	0.015	0.28	0.28	0.86	0.36	0.09	1.6	1.43		
	2018	0.03	0.020	0.16	0.012	0.68	0.14	0.49	0.15	0.06	1.7	1.42		

Table A.2. 33 (cont.)

Site	Year	As	Cd	Cr	Co	Cu	Pb	Mn	Ni	V	Zn	Hg (g)	Hg (part)	RGM Apr-May
Svanvik	2011	3.11			0.43	11.3			13.0					
	2012	1.82			0.43	8.0			7.4					
	2013	2.04			0.38	9.4			9.9					
	2014	2.03			0.31	6.7			7.8					
	2015	1.22	0.11		0.31	5.7			7.8					
	2016	1.73	0.13	0.27	0.29	5.9	2.30	0.83	7.2	1.7	5.0			
	2017	1.93	0.18	0.29	0.38	8.1	2.39	0.84	9.9	2.5	8.6			
	2018	1.11	0.11	0.31	0.29	5.7	1.59	0.56	7.2	2.0	5.9			
Karpdalen	2011	3.08			0.24	5.4			5.8					
	2012	3.45			0.41	12.8			11.5					
	2013	8.19			-	30.5			-					
	2013	2.99			0.46	11.4			11.8					
	2014	11.66			1.94	-			-					
	2015	2.47			0.33	6.9			8.0					
	2016	2.25	0.16	0.26	0.31	6.3	2.6	-	7.6	1.9	5.3			
	2017	2.78	0.28	0.26	0.33	8.2	4.2	0.72	8.5	3.1	10.1			
	2018	2.16	0.24	0.28	0.34	7.6	3.5	0.69	8.8	3.6	10.2			
Troll / Trollhaugen	2010											0.93		
	2011											0.95		
	2012											0.98		
	2013											0.90		
	2014											0.95		
	2015											0.96		
	2016											0.89		
	2017											0.98		
	2018											0.97		

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)

Air sampling for the analysis of heavy metals in particles at Birkenes is done using a Kleinfiltergerät with a PM_{10}-impactor. Weekly samples (7 days) 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 air sampler without any defined size cut off. The airflow rate is 20-25 m^3/hour and Whatman 41 filters are used and samples are collected for 48 h. 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

Precipitation was collected using the IVL designed bulk sampler according to Iverfeldt, (1991a,b) and Jensen and Iverfeldt, (1993). The sampling system consists of a borosilicate glass funnel and bottle that are connected via a capillary tube. The capillary tube prevents the sample from evaporation. To preserve the collected precipitation, concentrated hydrochloric acid is added to the borosilicate glass bottle. The sampling train is housed in a polypropylene tube that is insulated and heated when temperature drops below 4°C. Duplicate samples were collected and field operators collect samples monthly using clean techniques and replace the collection bottles. The reported values are averages of the duplicate samples.

Precipitation samples were returned to NILUs accredited laboratory for analysis of total mercury using the US-EPA-method 1631. Briefly, this method utilizes BrCl oxidation, followed by SnCl2 reduction, dual gold trap amalgamation, thermal desorption and cold vapour atomic fluorescence spectrometry (CVAFS) (Iverfeldt, 1991b, Bloom and Fitzgerald, 1988, EMEP manual). The detection limit is 0.05 ng/L.

Gaseous elemental mercury (GEM) have been monitored using a Tekran 2537 Hg vapour analyzer. The sampling principle is as follows: ambient air is sampled at 1.5 l/min through a Teflon filter via a heated sampling line. A soda-lime trap is mounted in-line before the instrument filter. Hg in air is pre-concentrated for 5 minutes by amalgamation on two gold cartridges, which alternates between collection and thermal desorption, and detection by CVAFS continuous monitoring. The instruments are auto-calibrated every 25 hour using an internal Hg permeation source and verified during routine site audits by manual injections of Hg from an external source.

POPs and organic contaminants of emerging concern

Air sampling of HCB, OCPs, PCBs, PAHs, PBDEs, HBCDs, TBA, ionic and volatile PFASs, S/MCCPs, nBFRs, OPFRs, phthalates, and bisphenols

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 a set of two pre-cleaned PUF plugs or a set of PUF/XAD/PUF sandwich that collect the gas phase compounds. For ionic PFAS, only a GFF was used, and for volatile PFAS, only the PUF/XAD/PUF sandwich was used. Specification on each sampler type is given in

Table A.3. 3. Flow-rate and sampling conditions were digitally 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 for POPs and organic contaminants of emerging concern.

	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	Ionic and volatile PFAS, nBFRs, OPFRs, phthalates (Zeppelin) HCB, ionic and volatile PFAS (Andøya) HCB, OCPs, PCBs, PBDEs, HBCDs, TBA, PAHs, M/SCCPs, ionic and volatile PFAS, bisphenols (Birkenes)	HCB, OCPs, PCBs, PAHs, PBDEs, HBCDs, S/MCCPs (Zeppelin)

Sampling was done on a weekly or monthly basis for individual compounds and observatory according to Table 2. The sampling duration for each observatory and POP class varied according to Table A.3. 4. The variable sampling lengths resulted in 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
HCB	24 h	48 h	48 h
OCPs	24 h	-	48 h
PCBs	24 h	-	48 h
PAHs	24 h	-	48 h
PBDEs	48 h*	-	72 h
HBCDs	48 h*	-	72 h
PFAS*	48-72 h	48-72 h	48-72 h
S/MCCPs	24 h	-	48 h
Siloxanes	72 h	-	72 h**
nBFRs	48-72 h	-	48-72 h
OPFRs	48-72 h	-	48-72 h
Phthalates	48-72 h	-	48-72 h
Bisphenols	-	-	48-72 h

*Two samples are combined in the lab and extracted as one aggregated sample.
**Cyclic and linear siloxanes.

After sampling the exposed samples (GFF, PUFs, PUF/XAD/PUF) 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 samples were registered and stored cold (2ºC) 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 ionic PFAS for which only GFFs were used for ionic PFAS representing the particle phase concentrations only and PUF/XAD/PUF was used for volatile PFAS representing concentrations in the gas phase only.

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 ABN sorbent with a flow rate of 0.7 m^3 per hour. Sampling was done every week at Zeppelin and once per month at Birkenes. All the siloxane samples were taken from Friday-Monday (~70 h) at both sites, in order to minimize the risk of contamination during sampling. Normally there is no human activity at the stations during the weekends which reduces the risk of possible siloxane inputs. In addition, the sampling technicians were ordered not to use any personal-care products on the days of starting and stopping the siloxane samples.

Each sample was represented by three SPE-AAS cartridges: two used for sampling in parallel (pump 1 and pump 2) and one used as a field blank. This means one field blank per sample. Each of the cartridge sets were extracted individually.

All lab operations were strictly performed in a laminar flow clean cabinet that is fitted with HEPA and charcoal filter to remove dust and air contaminants of the laboratory air 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-labelled D4, D5 and D6 in acetone (1 ng/µl). Then the cartridge was eluted slowly with ca 5 ml of hexane, so that 3.5-4 ml of eluate was collected into a 4 ml screw-cap vial. Before quantitative analysis, 50 µl of a recovery standard containing M4T in hexane (0.2 ng/µl) 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 analyzed on an Agilent 7890A GC connected to an Agilent 5975C MS detector and a Turret 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 10 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 10 µl syringe was used to inject 5 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 90°C for 6.0 and 35 °C min-1 to 300 °C for with a final hold time of 2 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). 5-point calibration curves (5 ng/ml to 60 ng/ml) were used for quantification.

Analysis and quantification of HCB, OCPs, PCBs, S/MCCPs and nBFRs

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, before being 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 aggregate the sample. The samples for nBFRs were spiked with 20 uL of IS containing 13C-labelled nBFR congeners (~1000 pg/µL), and extracted in acetone/hexane (1:1, v:v). The extracts were 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 HCB, PCBs, OCPs and nBFRs 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 (EI) mode for PCBs, HCB, HCHs, DDTs and nBFRs using selected ion monitoring (SIM) for the respective compounds groups. Identification and quantification of chlordanes, SCCP, and MCCP was carried out using GC coupled to an Agilent HR qToF (time of flight) in Electron Capture Negative Ion (ECNI) mode. A mass window of ± 20 ppm were used for extraction of the ions for quantification. In total, 32 PCB congeners, 13 OCPs and 14 nBFRs were quantified.

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 IS containing 13C-labelled PBDE congeners (~270-2500 pg/µL) and 20 µL IS containing 13C-labelled HBCD congeners (α-, β-, γ-HBCD, ~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 aggregate 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 (d18-α,β,γ) 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 (R=10 000 FWHM). In total, three HBCDs (α,β,γ) were quantified.

Analysis and quantification OPFRs

All glass equipment were wrapped in aluminium foil and heated to 450°C for 8 hr and rinsed in acetonitrile before use. All lids lined with PTFE and metal was ultrasonicated for 10 min in acetonitrile before use.

Samples (PUF-filters and GFFs) were spiked with 10ng IS containing deuterium labelled OPFRs (d15-TEP, d12-TCEP, d18-TCPP, d27-TNBP, d15-TPP, d15-TDCPP, d51-TEHP), and then soxhlet extracted for 8 h in acetone/hexane (1:1, v:v).

All clean-up of samples was performed in a laminar flow clean cabinet fitted with HEPA and charcoal filter to remove dust and air contaminants of the laboratory air. SPE (solid phase extraction) columns were used prepacked with a mixture Z-sep and C18 silica and Florisil on top (EZ-POP from Supelco) which was washed with acetonitrile and dried at -15mmHg for 10min before use. After adding the extract onto the column, acetonitrile was used to elute out all the OPFRs. Samples was concentrated using centrifugal vacuum evaporation and transferred to analytical glass and 50uL of 0.2% formic acid in Milli-Q water.

Analysis and quantification of OPFRs was performed using UPLC-MSMS in ESI mode. Before quantitative analysis, 10 ng of d27-TDMPP was added as RS.

Analysis and quantification of ionic PFAS

The two filters (sampled during the same month) were combined and spiked with 20 µL of 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 unlabelled 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.

Analysis and quantification of volatile PFAS

Two sets of PUF/XAD/PUF (sampled during the same month) were combined and spiked with 50 µL of IS containing ^{13}C-labelled FTOH/FOSE/FOSA congeners (0.1 ng/µL). The PUFs and XAD were then extracted in acetone:MTBE (1:1) using a cold extraction technique based on Dreyer et al. (2008). The solvent mix was added and left for one hour then replaced by new solvent mix that was left for 30 min. The extracts were concentrated, solvent exchanged to ethyl acetate and cleaned with Envi-Carb. Before quantitative analysis, 20 µL of unlabelled 9:1 FTOH (0.1 ng/µL) was added as recovery standard.

Analysis and quantification of phthalates

All glass equipment were wrapped in aluminium foil and heated to 400°C for 8 hr. The aluminium foil prevents re-contamination of the equipment until used. All equipment made of Teflon and metal was washed with solvent before use.

In order to avoid contamination from the laboratory air during Soxhlet extraction, the outlet of the cooler was protected from ambient (contaminated) air by an activated charcoal column. In this manner the Soxhlet was working as a closed system. This is important since indoor air concentrations of phthalates generally are elevated.

During the whole analytical procedure samples, extracts, solvents and chemicals were carefully protected from air precipitation and dust that have been proved to be a sources of phthalates. This was accomplished by the covering of test tubs, jars and other equipment with clean aluminium foil.

All solvents used were of the highest quality available and were checked before used Ultra-pure water was produced by Milli-Q equipment. Batches of water from this equipment were stored under a hexane layer in glass containers and were checked prior to use. The checked batches of solvents and water were exclusively applied for this project. Chemicals and equipment such as Na_2SO_4 and aluminium foils were thermally treated at 400°C before use.

SPE (solid phase extraction) columns contained ethylenediamine-N-propyl modified silica (PSA) and were equipped with steel-frits. The columns were pre-cleaned carefully and activated prior to use.

Samples (PUF-filters and glass fiber filters) were spiked with IS containing d4-labelled DEP (110 ng), DBP (200 ng) and DEHP (200 ng) before being soxhlet extracted for 16 h in MTBE/n-hexan (90:10, v:v). The extract was concentrated and cleaned up on a SPE-PSA column. Before quantitative analysis, 200 ng of biphenyl (200 ng) was added as RS.
Identification and quantification of the phthalates was carried out using a GC-MS/MS in nuclear magnetic resonance (NMR). The analyses were performed in Electron Impact ionization mode.

Analysis and quantification bisphenols

Samples were spiked with 20 µL IS containing 13-labelled bisphenol congeners (~1 ng/µL), before extraction using ultrasonic bath with methanol as extraction solvent. The samples were volume reduced to 0.5 µL prior to further clean-up with sodium sulphate and a PDVF filter (0.1 µm) in order to remove particles. Before quantification analysis, 20 µL of deuterium labelled bisphenol congeners (~1 ng/µL) was added as RS.

Identification and quantification of bisphenols was carried out using a high-resolution liquid chromatography coupled to a high-resolution mass spectrometer as detector (HRLC/HRMS). The analyses were performed in electro spray ionization (ESI) negative mode. In total 18 bisphenols were analyzed. A mass window of ± 4 ppm were used for extraction of the ions for quantification.

Sampling, analysis and quantification 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.

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 accredited chemical analysis include heavy metals, mercury, PCBs, and organochlorine pesticides (HCB, HCHs, chlordanes, and 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) are routinely included to control for unintended contamination during storage, transport and analytical steps. Field blanks, consisting of the sampling material (e.g. pre-cleaned PUF plugs, filters, XAD, ABN), are sent to each station where they are handled and exposed as the real samples during assembly and retrieval. They are then transported, stored, extracted, cleaned and analysed in the same way as and in parallel with the real samples. The lab blanks are obtained by extracting pre-cleaned sampling material (e.g. PUFs, filters, XAD, ABN) in solvent and using the same clean-up and analytical procedures as real samples and field blanks.

The analytical procedure is 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 is determined by calculating the signal-to-noise ratio (S/N) > 3 for solvent blanks (using n-hexane). Based upon average concentrations in laboratory blanks, the limit of detection (LOD) and limit of quantification (LOQ) is calculated for all compounds. LOD = average blank concentrations plus 3 times standard deviations (STD) of the blank concentrations. LOQ = average blank concentrations plus 10 times STD. All samples within the range LOQ>×>LOD are considered to have higher uncertainties. All raw data for POPs and heavy metals 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 the organic contaminants of emerging concern (i.e. cVMS, S/MCCPs, nBFRs, OPFRs, phthalates, bisphenols) are associated with a bigger uncertainty than the well-established POPs. 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.

NILU – Norwegian Institute for Air Research

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