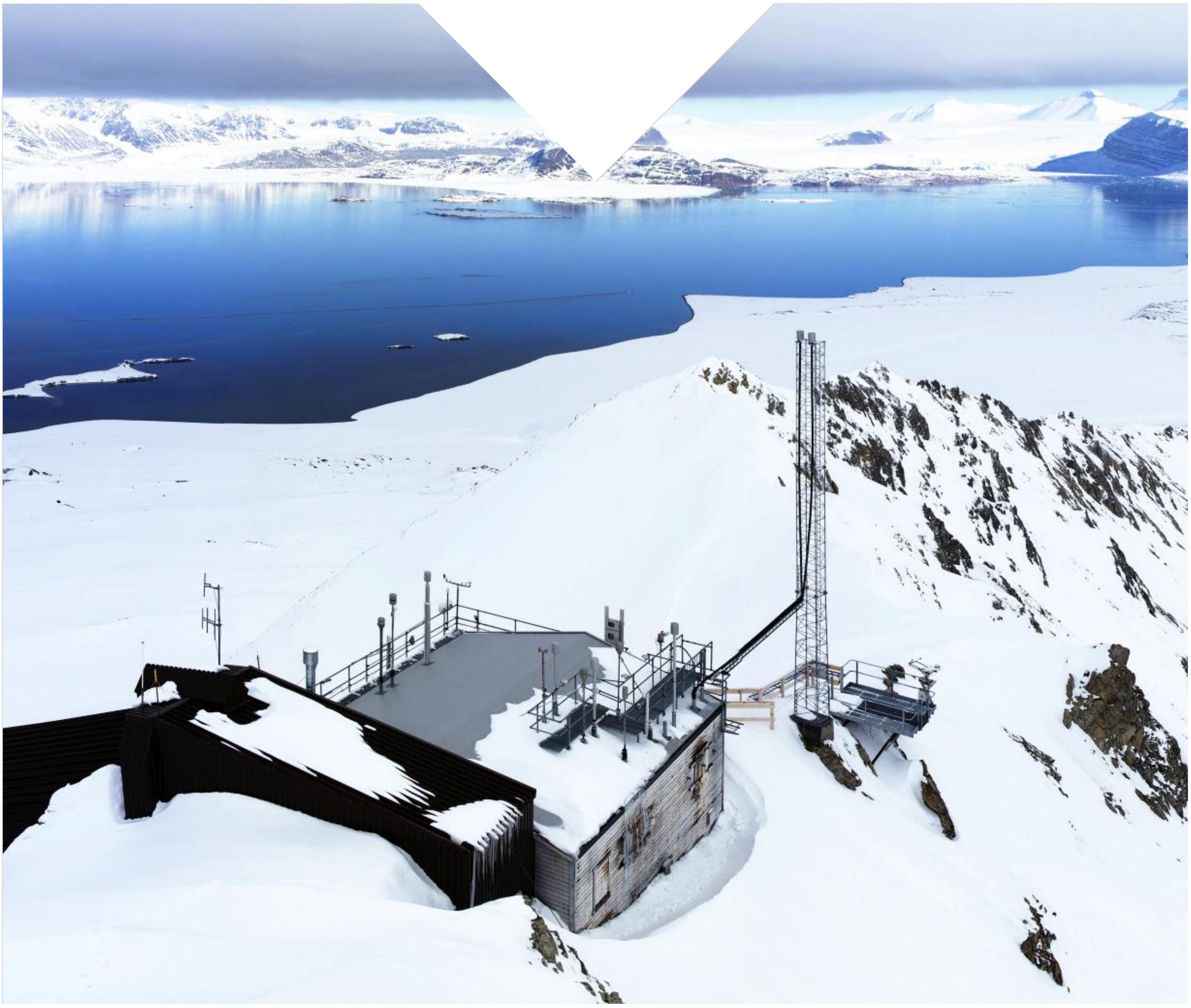
ENVIRONMENTAL MONITORING

M-1062 | 2018

Monitoring of environmental contaminants in air and precipitation

Annual report 2017



COLOPHON

Executive institution

NILU – Norwegian Institute for Air Research
P.O. Box 100, 2027 Kjeller

ISBN no. / ISSN no.

ISBN: 978-82-425-2931-2 (electronic)
ISSN: 2464-3327

Project manager for the contractor

Pernilla Bohlin-Nizzetto

Contact person in the Norwegian Environment Agency

Malene Vågen Dimmen

M-no	Year	Pages	Contract number
1062	2018	140	16078187

Publisher

NILU – Norsk institutt for luftforskning
NILU report 13/2018
NILU project no. O-110035

The project is funded by

Norwegian Environment Agency

Author(s)

Pernilla Bohlin-Nizzetto, Wenche Aas and Nicholas Warner

Title - Norwegian and English

Overvåking av langtransporterte atmosfæriske miljøgifter i luft og nedbør, årsrapport 2017
Monitoring of environmental contaminants in air and precipitation, annual report 2017

Summary - sammendrag

This monitoring report presents data from 2017 and time-trends for the Norwegian programme for Long-range atmospheric transported contaminants. The results cover 180 organic compounds and 11 heavy metals. The organic contaminants include regulated persistent organic pollutants (POPs) as well as POP-like contaminants not yet subjected to international regulations. Five groups of new POP-like contaminants were included for the first time in 2017.

Denne rapport inkluderer data fra 2017 og tidstrender for programmet Langtransporterte atmosfæriske miljøgifter. Resultatene omfatter 180 organiske miljøgifter og 11 tungmetaller. De organiske miljøgiftene inkluderer regulerte persistente organiske forbindelser (POPs) og POP-lignende forbindelser som ennå ikke har blitt regulerte på internasjonal nivå. I 2017, ble fem grupper med nye POP-lignende forbindelser inkludert for første gang.

4 emneord

Miljøkjemi, Langtransportert luftforurensning, Miljøovervåkning, Miljøgifter

4 subject words

Environmental chemistry, Long-range transport of air pollutants, Environmental monitoring, Persistent pollutants

Front page photo

Zeppelin Observatory

Content

1. Summary

This report presents monthly and annual concentrations of environmental contaminants in air and precipitation at Norwegian background sites in 2017. The monitoring is done as a part of the Norwegian programme for *Long-range atmospheric transported contaminants*. 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. From 2017, a particular focus of the monitoring is to obtain data for new classes of non-regulated organic contaminants in air in order to support future regulations/measures on national and international levels.

The monitoring programme was revised in 2017, with changes for the number of and sampling frequency for the organic contaminants. No changes were done for heavy metals and mercury and the sampling sites in 2017 were the same as before. Air monitoring of POPs and heavy metals including mercury was conducted using active air samplers at three sites (i.e. Birkenes, Andøya and Zeppelin) while monitoring of heavy metals in precipitation was conducted at five sites (i.e. Birkenes, Hurdal, Kårvatn, Svanvik and Karpdalen), and at one site for mercury and POPs (i.e. Birkenes). The major changes in 2017 compared to previous years were done for non-regulated organic contaminants: Siloxanes, chlorinated paraffins, and five new classes of organic contaminants – new brominated flame retardants (nBFRs), organophosphorous flame retardants (OPFRs), phthalates, dechloranes, and volatile per- and polyfluorinated alkyl substances (PFAS). An addition to the regular monitoring programme was also conducted at Zeppelin in 2017 with the purpose of evaluating the influence of local sources on the measurements of the non-regulated organic contaminants (siloxanes, chlorinated paraffins, nBFRs, OPFRs and phthalates).

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: 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 and trend analyses show decreasing concentrations over time for HCHs and DDTs with short estimated half-lives around 5 years during the whole monitoring period as well as after the Stockholm Convention came into force (2004-2017). For HCB, increasing concentrations in air have been observed during the last 10-15 years at Zeppelin and the last six years at Birkenes. The corresponding half-lives from long-term trend analyses for the period 2004-2017 suggest slow increases at Zeppelin with a negative half-life (-30 years) or stable concentrations at Birkenes with a half-life of 28 years, for this period. The last years increases are not fully captured by this trend analyses as it includes a period of stable concentrations before the period in which an increase was observed. Trend analyses for shorter periods are not appropriate. For benzo(a)pyrene (B(a)P), a small increase is seen at Zeppelin during the last years with a half-life of -81 years for the period 2004-2017.

Short-term monitoring of organic contaminants

For some compounds and some stations, the air monitoring have been performed for shorter periods than 15 years (i.e. eight to 14 years) and no long-term trend analysis can be performed. This includes monitoring of 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. All of the targeted ionic PFAS are grouped here despite not all being subject to regulation. Many of the PBDEs, HBCDs and PFAS compounds are below detection limits in the air samples, e.g. all three HBCDs and several BDE- and PFAS-compounds, showing very low levels in air. Short-term trend analyses show slow reductions for BDE-47 in air with half-lives of ~10 years.

Monitoring of non-regulated emerging organic contaminants

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

The concentrations for D5 and D6 at Zeppelin are lower than previous years when comparing the same time period of the year, suggesting a decrease in atmospheric concentrations of D5 and D6 over the monitored period. The annual mean concentrations measured for SCCPs at Zeppelin do not show any significant difference between the years (2013-2017), but the MCCPs at Zeppelin in 2017 were slightly higher than previous years.

In 2017, five new groups of emerging organic contaminants were included in the monitoring programme; nBFRs, OPFRs and phthalates - with sampling campaigns in summer and winter at Zeppelin, volatile PFAS that were monitored every month at Birkenes, Andøya and Zeppelin, and dechloranes that were monitored weekly at Zeppelin. The results from these monitoring activities show that the detected concentrations of phthalates are high, in the same range as the cVMS (ng/m^3), and that the concentrations of individual OPFRs also are high, in the same range as the S/MCCPs (100s pg/m^3). Of the volatile PFAS, only FTOHs were detected in some samples and the dominant PFAS compound was 8:2 FTOH at all sites. Concentrations of nBFRS were 100-1000 times lower than the concentrations of OPFRs and phthalates. Of the dechloranes, only dechlorane plus syn (syn-DP) and anti (anti-DP) were detected to some extent in air. The obtained concentrations for syn- and anti-DP were close to the analytical limit of detection suggesting a negligible presence of dechloranes in Arctic air.

An addition to the regular programme focused on studying the potential influence of local sources on the air measurements of the emerging organic contaminants at Zeppelin. Polyurethane foam passive air samplers (PUF-PAS) and XAD-based PAS were deployed at four sites at and around Zeppelin (including one indoor site) in two periods (July-September, and November-December). The PUF-PAS and XAD-PAS were successful in showing that the levels of the emerging contaminants are 10-1000 times higher in the indoor environment than at the outdoor sites. The indoor levels at Zeppelin observatory are in agreement with other indoor levels and show that the station represent a typical indoor environment despite cautionary actions during construction at the end of 1990s. Exceptions were PFAS and D5+D6 that were only slightly higher indoors than outdoors. This shows that actions taken regarding personal care products have given positive results.

Spatial distribution of organic contaminants

The concentrations were higher in the south (Birkenes) for HCHs, DDTs, and PAHs. This together with high episodes associated with air masses from source regions, reflects influences of the closeness to the continent. Also cVMS and S/MCCPs were higher at Birkenes on a few occasions, but the reasons for these episodes are not known. In contrast, HCB, TBA and some FTOHs were higher in the Arctic at Zeppelin than at Birkenes. Also BDE-209 was higher at Zeppelin in 2017 – this has not been observed in previous years and the reason for this is unknown.

Long-term monitoring of heavy metals and mercury

Heavy metals in precipitation and in aerosols from 2017 were highest at Svanvik and Karpdalen in Sør-Varanger. The high levels here are due to emissions from smelters in Russia. The wet deposition, however, was generally highest in Southern Norway where the precipitation amounts are highest. Lowest concentrations of heavy metals in precipitation was 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 have a large potential to be transported far from emission sources due to its longer atmospheric lifetime, and a lack of regional primary sources.

In 2017, the concentrations in precipitation were in general lower for most metals, except at Birkenes were there was a small increase in lead, cadmium and some other trace elements. For deposition, it was an increase at all sites for cadmium due to somewhat higher precipitation amounts in 2017 compared to 2016. In a long term perspective, the concentrations of lead in precipitation have been reduced by almost 100% between 1980 and 2017; 54-95% since 1990, and 55-58% since 2000. Cadmium in precipitation also has a substantial reduction: 95-99% between 1980 and 2017; 54-73% since 1990, and 52-54% since 2000. When combining the datasets from Lista and Birkenes, mercury in precipitation have been significantly reduced by 59% since 1990, and a 36% reduction since 2000.

The air concentrations for lead and cadmium in 2017 are somewhat lower at Birkenes compared to 2016 while higher at Andøya and Zeppelin. For mercury, it is the opposite with a small increase at Birkenes, while a decrease is seen at the two northern sites. At Lista/Birkenes there has been a significant reduction in air concentrations for almost all the elements (As, Cd, Cr, Pb, Ni, Zn and V) for the period 1991 to 2017. 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 84% and 60%, respectively, at Birkenes and Zeppelin. For cadmium, there were similar trends at the two sites, 66% and 58% reductions, respectively. For mercury, small decreasing trends are observed at Birkenes (19%) and Zeppelin (10%).

2. Sammendrag

Denne rapporten presenterer månedlige and årlige data i luft og nedbør fra norske overvåkingsstasjoner i rural bakgrunn i 2017. Overvåkingen utføres som del av det nasjonale overvåkingsprogrammet for Langtransporterte atmosfæriske miljøgifter. Formålet med overvåkingen er å i) øke kunnskapen om langtransport av miljøgifter som kilde til forurensning i Norge, ii) fremskaffe informasjon om romlige fordeling av miljøgiftsnivåer i Norge, og iii) ivareta rapportering til internasjonale konvensjoner, programmer og nettverk. I 2017 hadde 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 i forhold til 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 2017 inkluderer 180 organiske komponenter og 11 tungmetaller. Antall nye miljøgifter øktes fra to klasser (siloksaner og klorparafiner) til syv klasser der de nye klassene er: Flyktige PFAS, nye bromerte flammehemmere (nBFR), fosfororganiske flammehemmere (OPFR), ftalater, og dekloraner. Alle ble målt med aktiv luftprøvetaking. I tillegg ble et tillegg gjennomført der passive luftprøvetakere målte nye miljøgifter i og rundt Zeppelinstasjonen på Svalbard. Formålet med dette var vurdere om lokale kilder kan påvirke luftmålinger i Arktis.

Lange tidsserier for regulerte organiske miljøgifter

Flere regulerte organiske miljøgifter har vært en del av overvåkingsprogrammet i mer enn 15 år: 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 finnes 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 (2004-2017). For HCB, ser man økende nivåer de siste 10-15 årene på Zeppelin og de siste seks årene på Birkenes. Trendanalyser for perioden 2004-2017 viser på langsom økning eller stabile nivåer av HCB med halveringstider på ca. 30 år på Zeppelin og 28 år på Birkenes. De siste årenes økende nivåer fanges ikke helt opp av trendanalysen da denne inkluderer en periode med stabile nivåer før perioden med økende nivåer. Det er ikke hensiktsmessig å utføre trendanalyser for kortere perioder. For B(a)P ser man også en liten økning på Zeppelin med halveringstid på 81 år for perioden 2004-2017.

Korte tidsserier for regulerte organiske miljøgifter

For noen organiske miljøgifter og noen stasjoner har overvåkingen pågått i kortere perioder enn 15 år (fra 8 til 14 år) 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. Alle de ioniske PFAS er ikke regulert, men inngår her sammen med den regulerte PFOA. Flere PBDE, HBCD og PFAS-komponenter ble ikke detektert i luftmålingene og det viser at det er lave konsentrasjoner av disse i luft på norske bakgrunnsstasjoner. Korte tidstrendsanalyser viser en svak reduksjon av BDE-47 med halveringstid på ca. 10 år.

Overvåking av nye miljøgifter

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

Konsentrasjonene av D5 og D6 på Zeppelin er lavere enn tidligere år når man sammenligner samme måleperioder gjennom året. Dette tyder på redusert forekomst av D5 og D6 i arktisk luft i de siste årene, men fortsatte målinger trengs for å bevise dette. Ingen forskjell i perioden 2013-2017 på Zeppelin ses for SCCPs, mens nivåene av MCCPs i 2017 var noe høyere enn tidligere år.

For de fem nye miljøgiftklassene som ble inkludert i 2017, viser de første resultatene at det er høye konsentrasjoner av ftalater. De er på samme nivå som siloksaner. Også OPFR måles i høye konsentrasjoner, på samme nivåer som klorparafiner. Nivåene av nBFR var 100-1000 ganger lavere enn nivåene av OPFR og ftalater. Av de flyktige PFAS var det kun FTOHer som ble detektert. Den dominerende FTOH var 8:2 FTOH på alle stasjonene. Av dekloraner var det kun dekloran pluss syn og dekloran pluss anti som ble detektert. De detekterte konsentrasjonene av dekloraner var nære deteksjonsgrensene hvilket indikerer lav forekomst i arktisk luft.

Målingene av nye miljøgifter med passive prøvetakere inne på Zeppelin-stasjonen, ute på Zeppelinstasjonen, ute i Ny-Ålesund og ute i Longyearbyen viser at nivåene av de fleste nye miljøgiftene er 10-1000 ganger høyere innendørs enn utendørs. Nivåene som ble målt inne på Zeppelinstasjonen samsvarer med nivåer målt i andre innemiljøer og viser at stasjonen representerer et typisk innemiljø til tross for utslippsreduserende materiale og luftrensende tiltak ved konstruksjon av bygningen. For PFAS og D5+D6 var nivåene inne på stasjonen kun noe høyere enn ute. Dette viser at gjennomførte tiltak for å redusere bruken av hudpleieprodukter hos personell som arbeider på stasjonen har gitt positive resultater.

Romslig fordeling av organiske miljøgifter

Det observeres høyere konsentrasjoner av HCH, DDT og PAH i sør (Birkenes) sammenlignet med de nordlige stasjonene (Andøya og Zeppelin). For disse komponentene sammenfaller høye episoder med når det er luftmasser fra kildeområder på kontinentet. Også siloksaner og klorparafiner var høyere på Birkenes enn Zeppelin ved noe tilfeller, men årsaken til dette er ikke kjent. For HCB, TBA og noe FTOH var det derimot høyere nivåer i nord enn i sør. I 2017, ble det også målt høye konsentrasjoner av BDE-209 på Zeppelin, årsaken til dette er ikke kjent.

Lange tidsserier for tungmetaller og kvikksølv

De årlige gjennomsnittskonsentrasjonene av tungmetaller i nedbør i 2017 var høyest på Svanvik og Karpdalen i Sør-Varanger. Dette skyldes utslipp fra de nærliggende smelteverkene på russisk side. Våtavsetning er derimot generelt høyest i Sør-Norge der nedbørmengden er høyest. Laveste konsentrasjoner i nedbør måles på Kårvatn som ligger lengst borte fra kildeområder. Konsentrasjonen av de fleste tungmetallene målt i luft på Andøya og Zeppelin er to til tre ganger lavere enn de 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 for kvikksølv i regionen.

I 2017 var konsentrasjonen av bly, kadmium og vanadium i nedbør på fastlandsstasjonene lavere enn i 2015. 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 vært en reduksjon av bly mellom 54-95% og 55-58% siden 2000 til 2017. Det er også store reduksjoner for kadmium i nedbør, mellom 95-99% fra 1980; 54-73% fra 1990, og 52-54% fra 2000. For kvikksølv, HCB og HCH i nedbør, har det vært en signifikant reduksjon på 59% siden 1990 og 36% fra 2000 når man kombinerer datasettene fra de nærliggende observatoriene Lista og Birkenes.

Luftkonsentrasjonene av bly og kadmium var i 2017 noe lavere på Birkenes sammenlignet med 2016 mens de var høyere på Andøya og Zeppelin. For kvikksølv var det motsatt med en liten økning på Birkens mens det var en reduksjon på de to nordlige stasjonene.

På Lista/Birkenes har det vært en betydelig reduksjon i luftkonsentrasjon for nesten alle tungmetaller som er målt (As, Cd, Co, Cr, Pb, Ni, Zn og V) for perioden 1991 til 2017. På Zeppelin har det også vært en betydelig reduksjon siden 1994 for flere tungmetaller (As, Cd, Cu, Pb, Ni, V). Reduksjonen av bly har vært på 84% og 60% på henholdsvis Birkenes og Zeppelin. For kadmium er det lignende store reduksjoner, henholdsvis 66% og 58%. For elementært kvikksølv i luft er det en svak nedadgående trend på 19% og 10% på henholdsvis Birkenes og Zeppelin.

3. Monitoring programme

The monitoring programme for long-range transported atmospheric contaminants was revised in 2017 in order to allow for expanded monitoring of emerging organic contaminants. 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 new emerging organic contaminants. 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 emerging organic contaminants were added.

3.1 Background

The monitoring programme "Long-range transported atmospheric contaminants" is conducted by NILU on the behalf of the Norwegian Environment Agency, and the Ministry of Climate and Environment. In details, the data from 2017, presented in this report, are a compilation of data from three different national projects and programs:

- The national monitoring programme of environmental contaminants on behalf of The Norwegian Environment Agency (heavy metals and POPs (except PAHs) in air at Birkenes, Andøya and Zeppelin, heavy metals in precipitation at Birkenes, and emerging contaminants in air at Zeppelin and Birkenes);
- The long-term dataseries programme on behalf of the Ministry of Climate and Environment, as well as NILUs internal monitoring programme (POPs in precipitation at Birkenes, heavy metals in precipitation at Hurdal and Kårvatn and PAHs in air at Birkenes and Zeppelin);
- The Norway-Russia measurement programme on behalf of The Norwegian Environment Agency (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 or on the environment, monitoring of these pollutants is of high priority for Norwegian authorities. For many of these contaminants, long-range transport via air is the most important source to pollution in remote areas where there are few or no local sources. Recognition of long-range atmospheric transport of environmental contaminants to remote areas, such as the Arctic, has been vital in our understanding of the presence and environmental behaviour of POPs. This in turn has contributed to the regulation of several of these contaminants both on a regional and global scale.

The use and emission of heavy metals and POPs have been regulated through multilateral environmental agreements. Heavy metals are regulated by: i) the 1998 Aarhus Protocol on Heavy Metals under the Convention on Long-range Transboundary Air Pollution (LRTAP) (UN/ECE, 1998a), and ii) the Minimata Convention on mercury (UNEP, 2013). POPs are regulated or banned on a global scale by the Stockholm Convention on POPs (Stockholm Convention, 2007) and on a European scale by the 1998 Aarhus Protocol on POPs; "the POP-protocol", under LRTAP

(UN/ECE, 1998b). The two POP conventions today includes 26 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 is foreseen to enter into force in 2018. In addition another three chemicals are under review as potential POPs under the Stockholm Convention: dicofol, perfluorooctanoic acid (PFOA), it salts and PFOA-related compounds, and perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related compounds.

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 emerging organic contaminants in background air, iii) better understanding of the contaminants’ potential for long-range transport, iv) a better understanding on potential local sources for the new emerging organic contaminants 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 emerging organic contaminants. 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 to make national or international regulations to come into place.

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

3.2 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 new emerging organic contaminants, 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 emerging contaminants 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.

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

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	HCB, PFAS (ionic + volatile)	HCB, HCH, DDTs, chlordanes, PCBs, PBDEs, HBCDs, PAHs, PFAS (ionic + volatile), cVMS, S/MCCPs, nBFRs, OPFRs, phthalates, dechloranes				
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

The number of observatories and the geographical distribution are selected in order to represent different parts of Norway, and areas that receive air from different source regions globally. The observatories in this monitoring programme are to a large extent coordinated together with "the national measurement programme of long-range transported air pollutants for main components in air and precipitation", which similar to this monitoring programme is conducted by NILU on behalf of the Norwegian Environment Agency, and the Ministry of Climate and Environment (Aas 2016b). Three observatories are used for the monitoring of POPs and heavy metals in air, two of these are located on the mainland of Norway: Birkenes, and Andøya, and one is locates on Svalbard: Zeppelin (Figure 1, Table 1). POPs in precipitation is only monitored at Birkenes while heavy metals in precipitation is monitored at four sites: Birkenes, Hurdal, Kårvatn and Svanvik (Figure 2, Table 1). This report also includes heavy metals in precipitation from Karpdalen in Sør-Varanger and heavy metals in air at Svanvik and Karpdalen. Further information of the sampling sites, site descriptions are available at http://www.nilu.no/projects/ccc/sitedescriptions/.

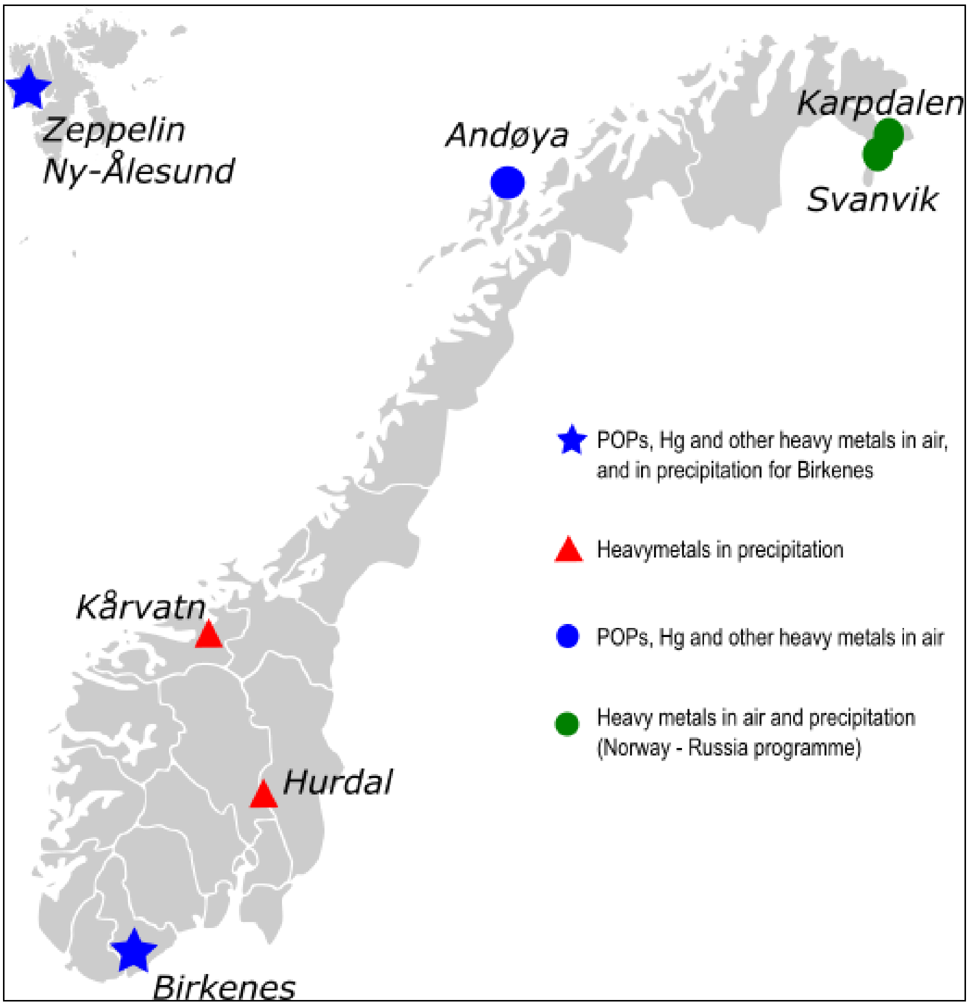


Figure 1: Norwegian background stations measuring environmental contaminants in 2017.

Air measurements of heavy metals and POPs started in 1991 at Lista observatory in southern Norway as part of the CAMP Programme under the OSPAR Convention (http://www.ospar.org). Lista closed down in 2004, but the extended measurement programme continued at the nearby observatory in Birkenes. In 1994, air measurements of heavy metals and POPs were included at the Zeppelin Observatory at Svalbard as part of the AMAP programme (http://www.amap.no). Both sites became part of 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 it is now a part of the regular EMEP programme.

Air samples of organic contaminants and heavy metals (excluding mercury) are collected using active air samplers at all sites. The active air samples are collected on a weekly basis throughout the year with specific sampling lengths for each observatory and class of contaminant. For example, HCB, PCB, and are sampled on a weekly basis at Birkenes and Zeppelin, but with different sampling length at the individual 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 emerging contaminants that are collected in one summer and one winter campaign, and mercury in air that is measured continuously using a Tekran Hg monitor. The precipitation samples are collected on weekly basis using bulk samplers. Active air samples and precipitation samples for POPs and heavy metals are extracted, analysed and quantified at NILU under strict quality control using accredited methods. For the emerging contaminants, the sampling and analytical methodologies are associated 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 are in the forefront in method developments for new organic contaminants and are constantly working on method improvements. Information about the sampling and analytical methodologies are given in Annex 3. All the data presented in this report are available at http://ebas.nilu.no/.

3.3 Organic contaminants

3.3.1 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 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 2017.

	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 in 2017

**Not included in the new monitoring programme for 2017.

***Data available before 2001 are classified as uncertain due to possible local contamination.

3.3.2 Non-regulated contaminants

The monitoring programme also includes organic contaminants that are not yet regulated, i.e. not included in the Stockholm Convention, but have been identified as potential POPs (emerging contaminants) by other studies, for example in environmental screening projects (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. If monitoring is initiated before a regulation/measure enters into force then it is also possible to get a more complete picture of the time trends.

In 2017, the regular monitoring programme includes two groups of emerging organic contaminants that have been included since 2013; cVMS and S/MCCPs, and five contaminants that are new since 2017; volatile PFAS, novel brominated flame retardants (nBFRs), organophosphorous flame retardants (OPFRs), phthalates and dechloranes (Table 3). In addition, most of the target ionic PFAS are non-regulated and therefore fall under this category of contaminants. 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. The monthly samples for cVMS and S/MCCPs at Birkenes instead 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
Monitoring programme for emerging organic contaminants in 2017.

	Zeppelin		Birkenes		Andøya	
Emerging organic contaminants, 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**	-	-	-	-
OPFRs	2017	summer + winter campaign**	-	-	-	-
Phthalates	2017	summer + winter campaign**	-	-	-	-
Dechloranes	2017	weekly	-	-	-	-

*New sampling frequency in 2017.
**Six samples per campaign.

The regular monitoring programme was expanded with an option in 2017. This option aimed to study whether the presence of the targeted emerging organic contaminants in Arctic air can be explained solely by long-range transport or may also be influenced by local sources. This study was performed by deploying passive air samplers at four locations in connection to Zeppelin: i) Zeppelin outdoors (representing the active air sampling site), ii) Zeppelin indoors (inside the room where samples for organic contaminants are taken), iii) Ny-Ålesund (centre of the village), and Longyearbyen (centre of the village). Two sampling campaigns were performed; one in summertime (July-August) and one in wintertime (November-December). This sampling strategy aimed to see whether indoor environments and populated areas (buildings and humans) may act as potential point sources for the emerging contaminants that are non-regulated and thereby possibly still in use. Targeted contaminants in this study were cVMS, S/MCCPs, nBFRs, OPFRs, phthalates, and PFAS.

Two types of PAS were chosen; i) PUF disks (PUF-PAS) were used to collect the semi-volatile non-polar contaminants (i.e. S/MCCPs, nBFRs, OPFRs, and phthalates), and ii) XAD-adsorbent (XAD-PAS) was used to collect the more volatile and more polar contaminants (i.e. cVMS and PFAS). While XAD is considered a pure gas-phase sampler, the PUF-PAS can also sample particle-associated compounds to some extent although with lower accuracy (Bohlin et al., 2014; Melymuk et al., 2016). The use of PAS for volatile-semivolatile organic contaminants is considered as a good sampling strategy for screening at several sites simultaneously (Melymuk et al., 2016). It is important to highlight that the PAS are designed as complementary tools to active air samplers and that the PAS provide semi-quantitative levels which should be treated with caution in further analyses. The data from PAS can be compared between sampling sites when normalized to ng/day or further converted to estimated concentrations in air (pg/m^3). Conversion to estimated concentrations is done using class-specific uptake rates obtained from calibration studies (Bohlin et al. 2014; Melymuk et al., 2016). A direct comparison of estimated air concentrations from PAS with data from active samplers should be done with caution as the accumulation in PAS and the applied uptake rates introduce factors of uncertainty.

3.4 Heavy metals

Heavy metals in precipitation have been monitored at the Norwegian sites as a part of the Norwegian national monitoring programme since 1980. The new monitoring programme in 2017 did not include any changes for heavy metals (Table 4).

Table 4
Monitoring programme for heavy metals in 2017.

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	-	-	-	-	-	-

4. 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 4.1-4.3. 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. The results are presented in three sections; i) long-term monitoring in air (covering POPs that have been monitored since before the Stockholm Convention), ii) short-term monitoring in air (covering POPs for which monitoring was initiated after the Stockholm Convention came into force), and iii) long-term monitoring in precipitation (covering POPs monitored in precipitation).

4.1 Long-term monitoring in air

4.1.1 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 2017. The weekly concentrations ranged between: 30-77 pg/m^3 at Birkenes; and 61-91 pg/m^3 at Zeppelin. The monthly concentrations at Andøya ranged from 20-47 pg/m^3. The annual mean concentration of HCB for 2017 at Zeppelin (76 pg/m^3) is the lowest observed since 2009. The increase in HCB concentrations at Zeppelin that has been observed since 2003 seem to have flattened out during the last years. Continued monitoring is needed to further evaluate its trend. The levels of HCB measured at Zeppelin between 2012 and 2017 are similar to the levels measured in the end of 1990s, but are still below those observed in the beginning-middle of 1990s. At Birkenes, the annual mean concentration in 2017 is lower than in 2015 and 2016 and one of the lowest observed since 1996. This low concentration is in contrast to the increasing time-trend observed the previous years (2010-2016). In contrast, at Andøya the annual mean concentrations are higher in 2017 compared to the previous seven years (Figure 2). This can be influenced by the new sampling scheme with only one measurement per month instead of weekly samples. The annual mean concentrations of HCB in 2017 were, as previous years, lowest at Andøya (35 pg/m^3) and highest at Zeppelin (76 pg/m^3). The high concentrations observed for HCB at Zeppelin during the last years are in line to what has been observed at Station Nord on Greenland. Such high concentrations have also been observed at Kosetice, Czech Republic in central Europe while the concentrations at other sites in Europe are two to three times lower and similar to those observed at Birkenes (Halse et al., 2011, Aas et al., 2016a).

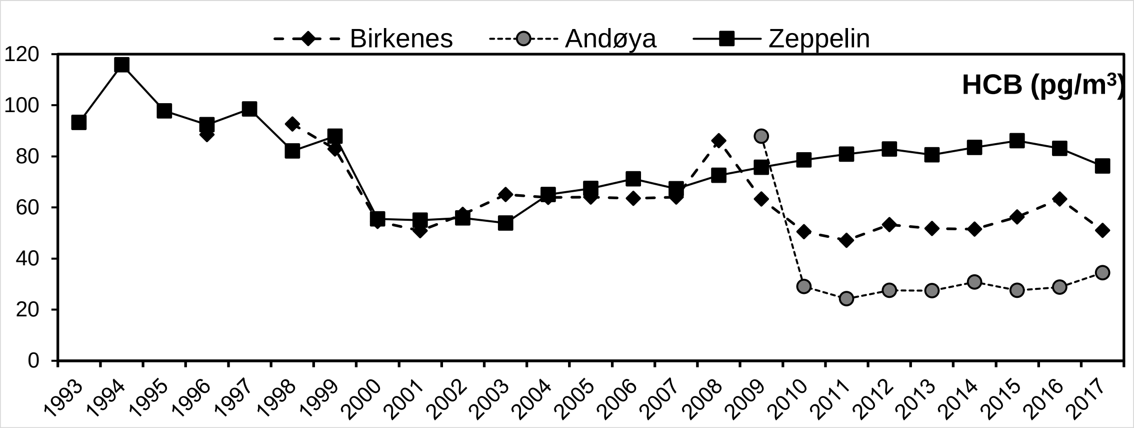


Figure 2: Annual mean concentrations of HCB (pg/m^3) in air.

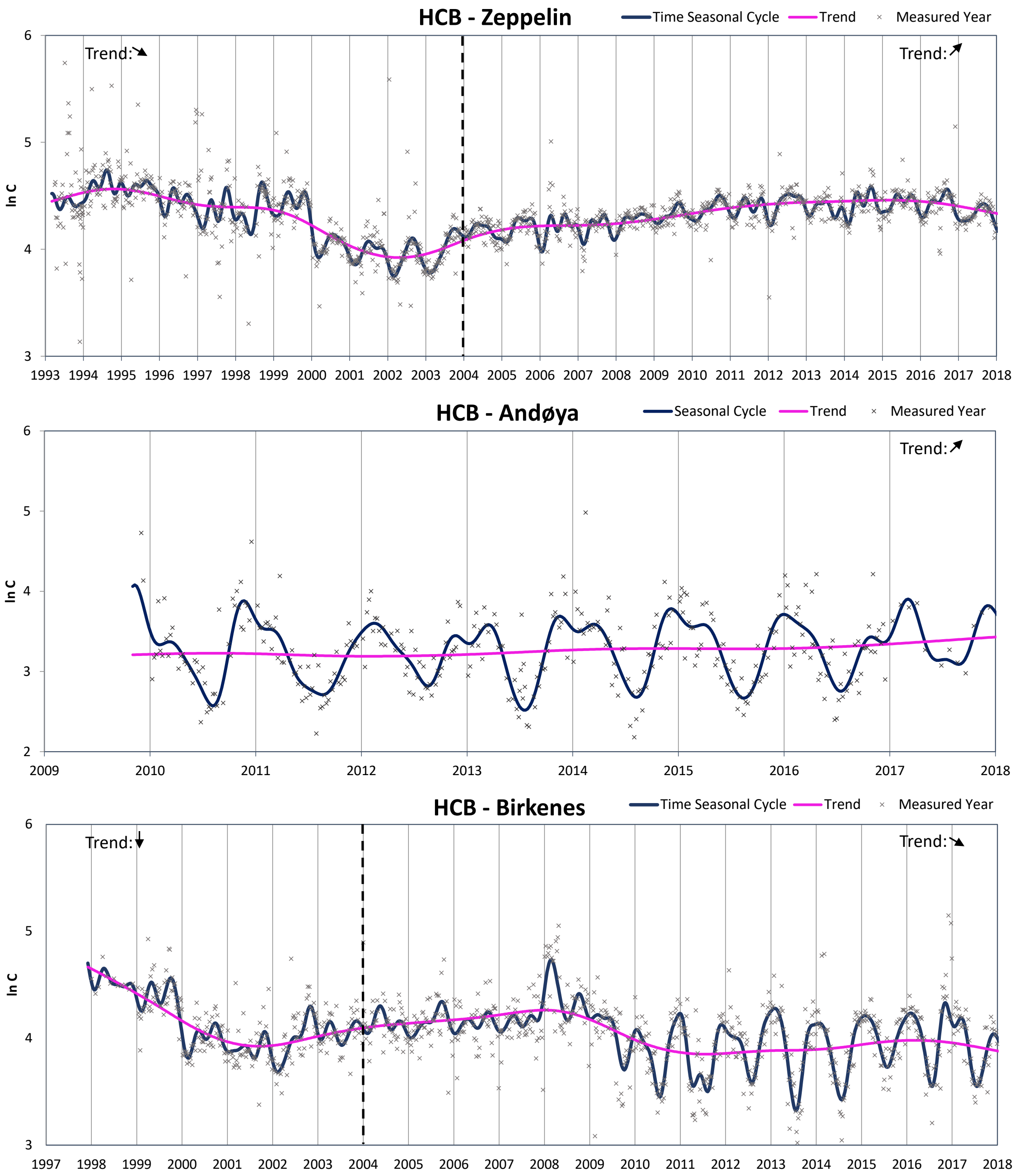


Figure 3: Temporal trends of HCB at Birkenes, Andøya and Zeppelin. Air concentrations are presented in natural log of concentration (ln C) on the y-axis. The dashed line indicates the year when Stockholm Convention was taken into force for HCB (2004). The results of trend analyses: before and after HCB was listed in the Stockholm Convention, are indicated by four types of arrows (⬇: decrease, ↘: small decrease, ↗: small increase and ⬆: increase) or NST when no significant trend was detected.

Seasonal variations are observed at both Andøya and Birkenes with a factor of two lower concentrations in summer than in winter (Figure 4). 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 4) 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 concentrations is only 1.5 at Zeppelin while 2.6 at Birkenes.

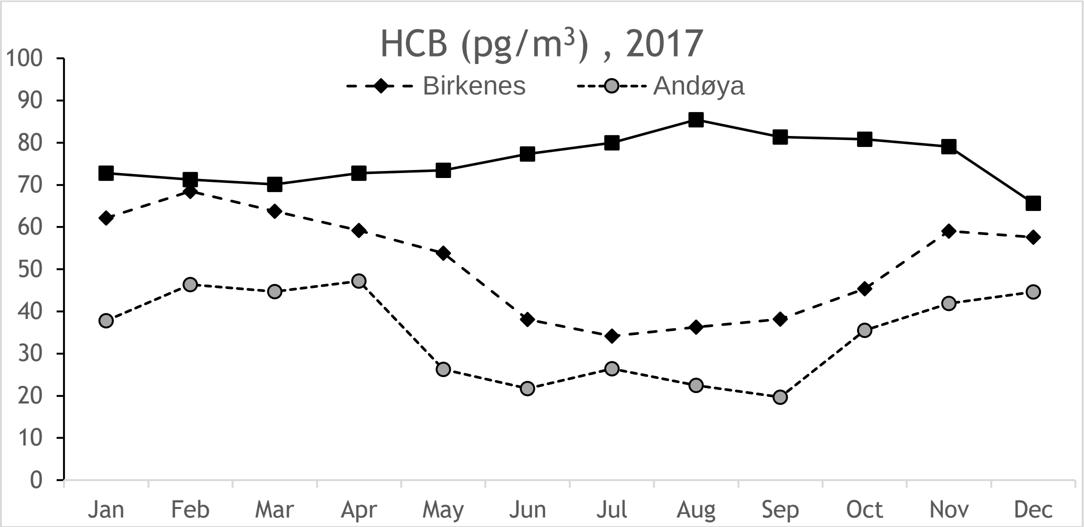


Figure 4: A Seasonal variability of HCB at Birkenes, Andøya and Zeppelin in 2017.

4.1.2 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). However, the Stockholm Convention still accept the use of lindane/γ-HCH for pharmaceutical control of head lice and scabies and as a result it is still allowed in some countries. Countries are allowed to register specific exemptions for specific time periods.

Two HCH isomers; α- and γ-HCHs, have been monitored at Birkenes since 1991, at Zeppelin since 1993, and at Andøya since 2010. In 2017, monitoring of HCHs at Zeppelin continued with weekly samples as previous years while the monitoring at Birkenes was reduced to one sample per month and not included at Andøya. Both HCH isomers were above detection limit in all samples from all sites in 2017. The monthly concentrations of sum HCHs (α+γ) in 2017 ranged from: 0.2-20 pg/m^3 at Birkenes (including one high episode in May). The high episode and the highest 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 1.5-6 times higher than γ-HCH. The weekly concentrations at Zeppelin ranged between 2.6 and 5.4 pg/m^3 at Zeppelin. The annual mean concentrations of sum HCHs (4.0-6.1 pg/m^3) and the individual isomers in 2017 were in the same range at both observatories and in agreement or slightly lower than previous years continuing the decreasing trends (Figure 5). 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 small half-lives in the trend analysis (see section 4.3). The two isomers are declining with similar pattern at both observatories although a somewhat larger reduction is observed for γ-HCH than for α-HCH.

As previous years, the average ratios of α-/γ-HCH were found to decrease from north to south; 8.4 at Zeppelin; and 2.9 at Birkenes. Even lower ratios are observed at more southern sites in continental Europe (Aas et al., 2016a). The larger ratios in the north might be a result of γ-HCH being less prone to long-range transport and more efficiently scavenged by wet deposition, which in turn is a result of its lower Henry's law constant. Lower ratios in the high episode and concentrations at Birkenes as well as in summertime, as a consequence of higher concentrations of γ-HCH, suggests higher emission of lindane/γ-HCH from secondary sources 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., 2016a).

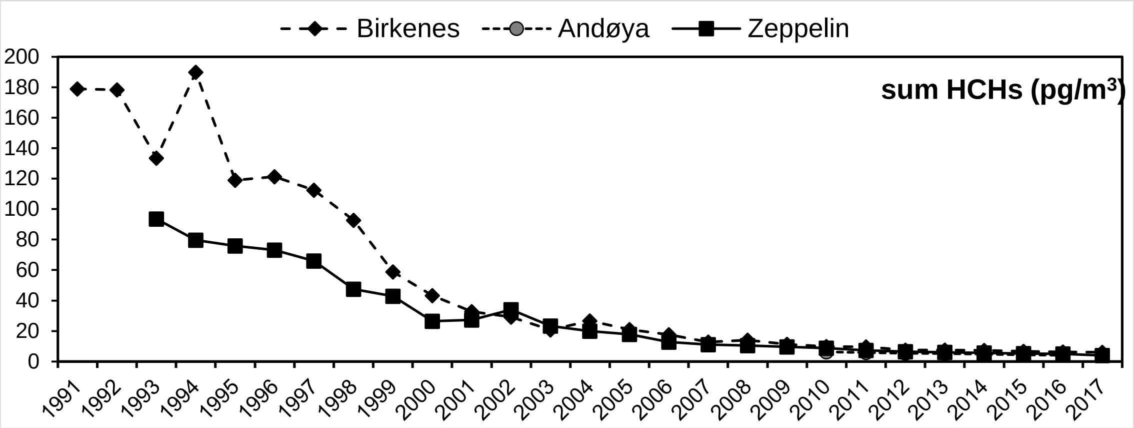


Figure 5: Annual mean concentrations of sum HCHs (pg/m^3) in air.

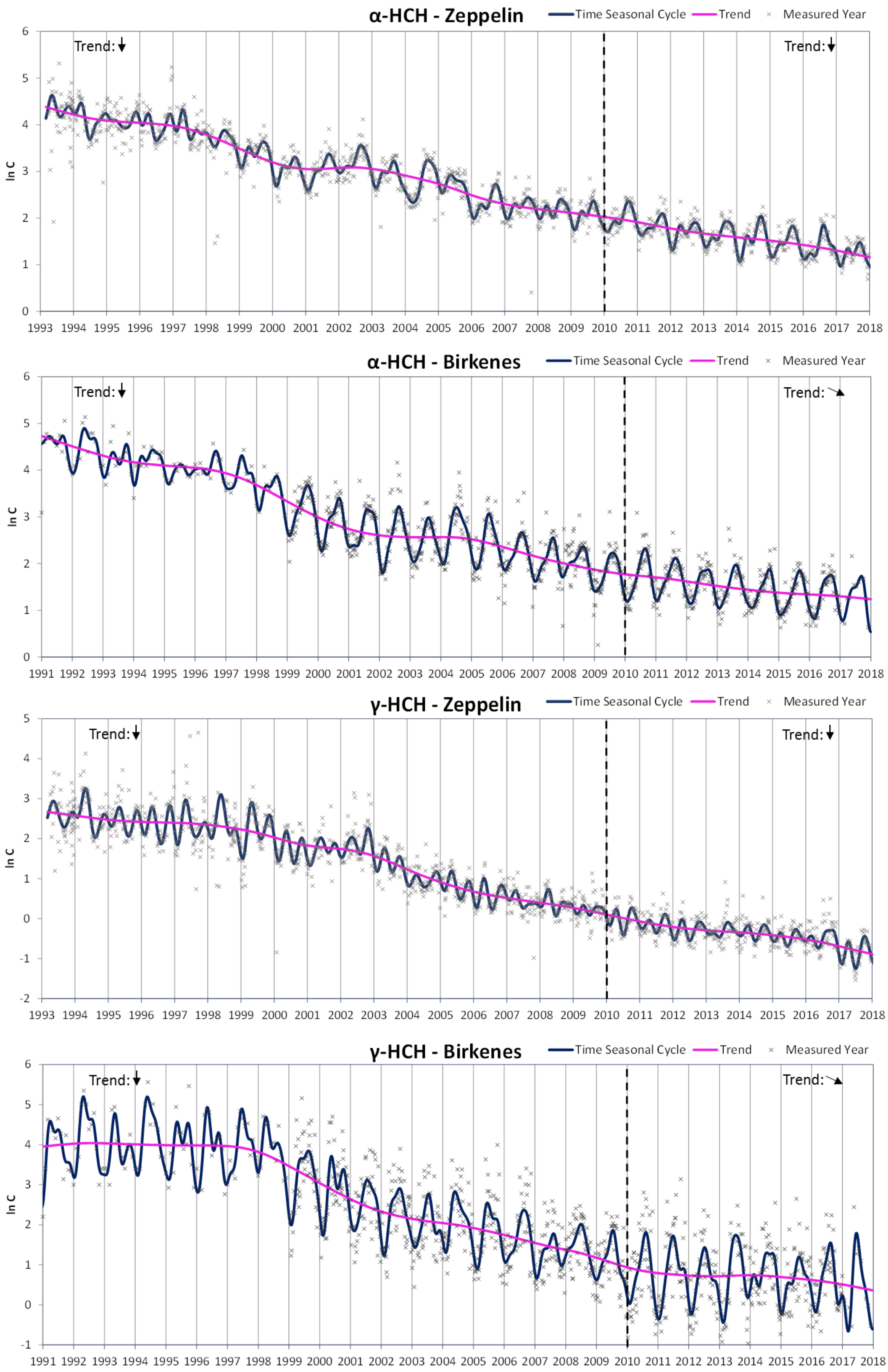


Figure 6: Temporal trends of a- and γ-HCH at Birkenes and Zeppelin. Air concentrations are presented in natural log of concentration (ln C) on the y-axis. The dashed line indicates the year when Stockholm Convention was taken into force for HCHs (2010). The results of trend analyses: before and after the HCHs were listed in the Stockholm Convention, are indicated by four types of arrows (⬇ : decrease, ⬊: small decrease, ⬈ small increase and ⬆ increase) or NST when no significant trend was detected.

Strong seasonality of the HCHs concentrations was observed at Birkenes, with up to ten times higher concentrations during summer than wintertime (Figure 7). No seasonality was observed at Zeppelin (Figure 7). The seasonality is less pronounced for α-HCH than for γ-HCH which is reflected in the lower α/γ-ratios in summertime. Higher concentrations during warmer periods may be due to re-volatilization from soil or other environmental surface media during warmer periods (i.e. secondary emissions) (Halse et al., 2012).

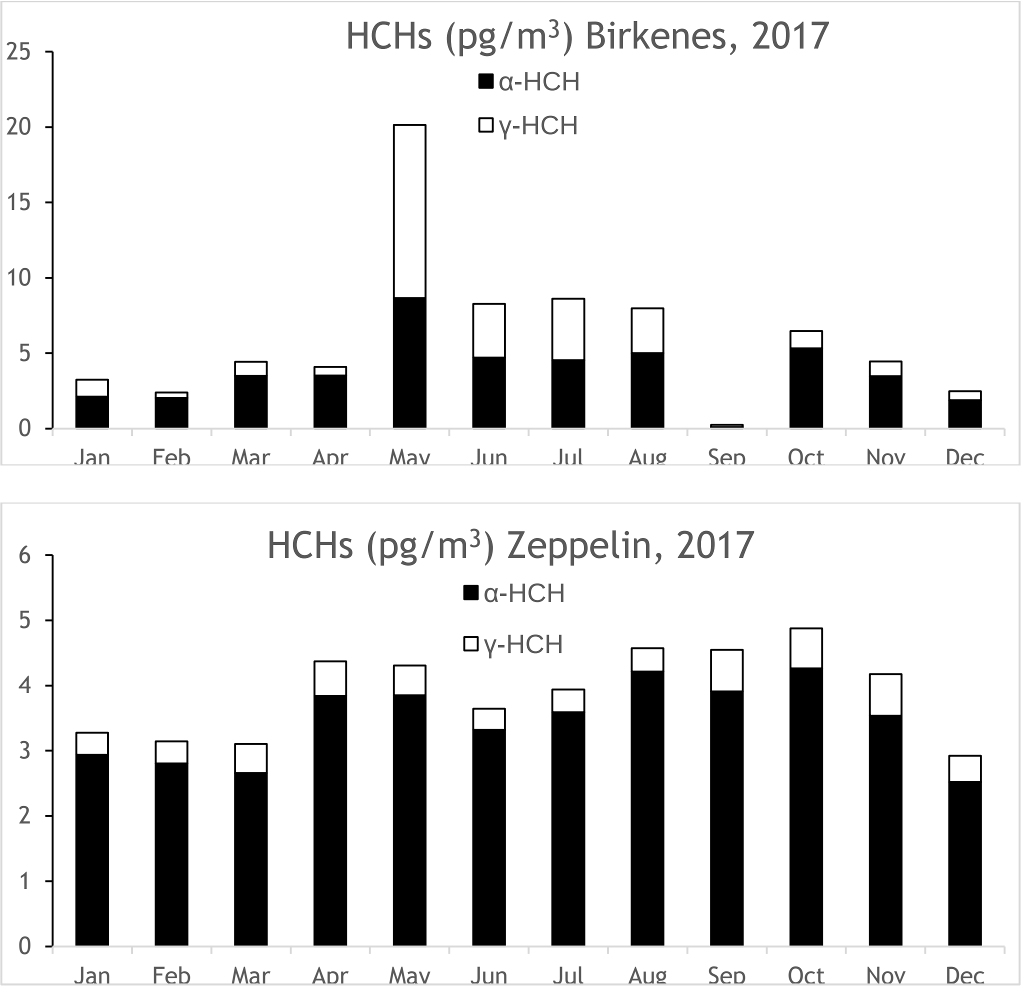


Figure 7: Seasonal variability of a- and g-HCH at Birkenes and Zeppelin in 2017.

4.1.3 Dichlorodiphenyltrichloroethane (DDTs)

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

The six DDT congeners; o,p'- and p,p'- DDT, DDD, and DDE, have been monitored at Zeppelin since 1994, and at Birkenes and Andøya since 2010. In 2017, monitoring of DDTs at Zeppelin continued with weekly samples as previous years while the monitoring at Birkenes was reduced to one sample per month and not included at Andøya. The detection frequencies in 2017 varied among the individual congeners and between the sites. For example, p,p'-DDE and o,p'-DDT 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 at the two sites. The weekly concentrations of sum DDTs in 2017 ranged between 0.12-2.3 pg/m^3 at Zeppelin (including one high episode in November). The high episode of DDTs was due to high levels of p,p'-DDT and p,p'-DDE and coincides with air masses from central Russia. The monthly concentrations of sum DDTs at Birkenes ranged between 0.24-3.9 pg/m^3 (including one high measurement in May). As for HCHs this high measurement coincides with air masses from central Europe. The annual mean concentrations of sum DDTs and the individual congeners in 2017 were as previous years higher at Birkenes (1.0 pg/m^3) compared to Zeppelin (0.4 pg/m^3) (Figure 8). The annual mean concentrations of sum DDTs and all congeners were the lowest observed at both stations. This suggests that the concentrations of DDTs in air are in slow decline or have reached steady-state after the long-term declining trends. 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 (Halse et al., 2011, Pribylova et al., 2012, Aas et al., 2016a). The reason for higher concentrations at Birkenes compared to the more northern Norwegian sites may be explained by closer distances to possible emission sources, but more research is needed before any firm conclusions can be drawn. The indicator ratio (p,p'-DDE+p,p'-DDD/p,p'-DDT) were high (4-10) 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).

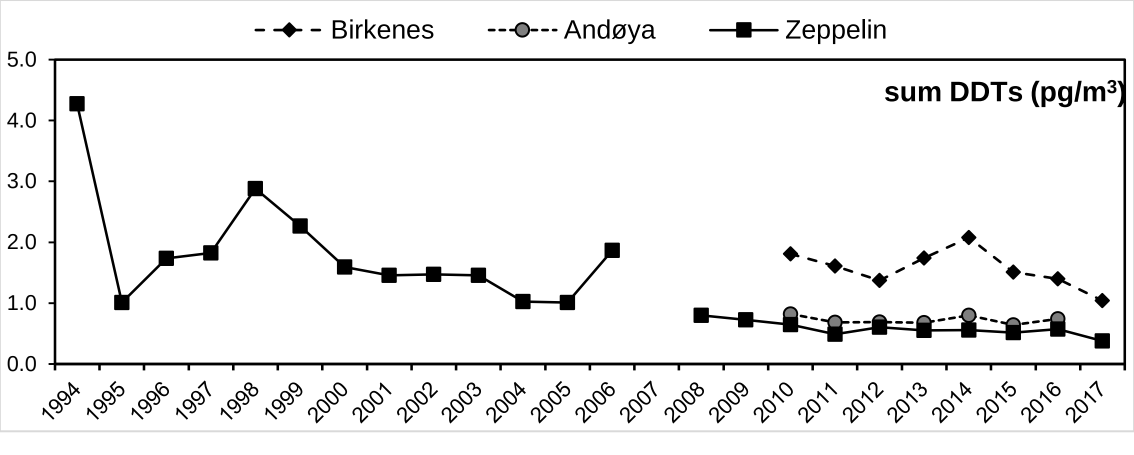


Figure 8: Annual mean concentrations of sum DDTs (pg/m^3) in air.

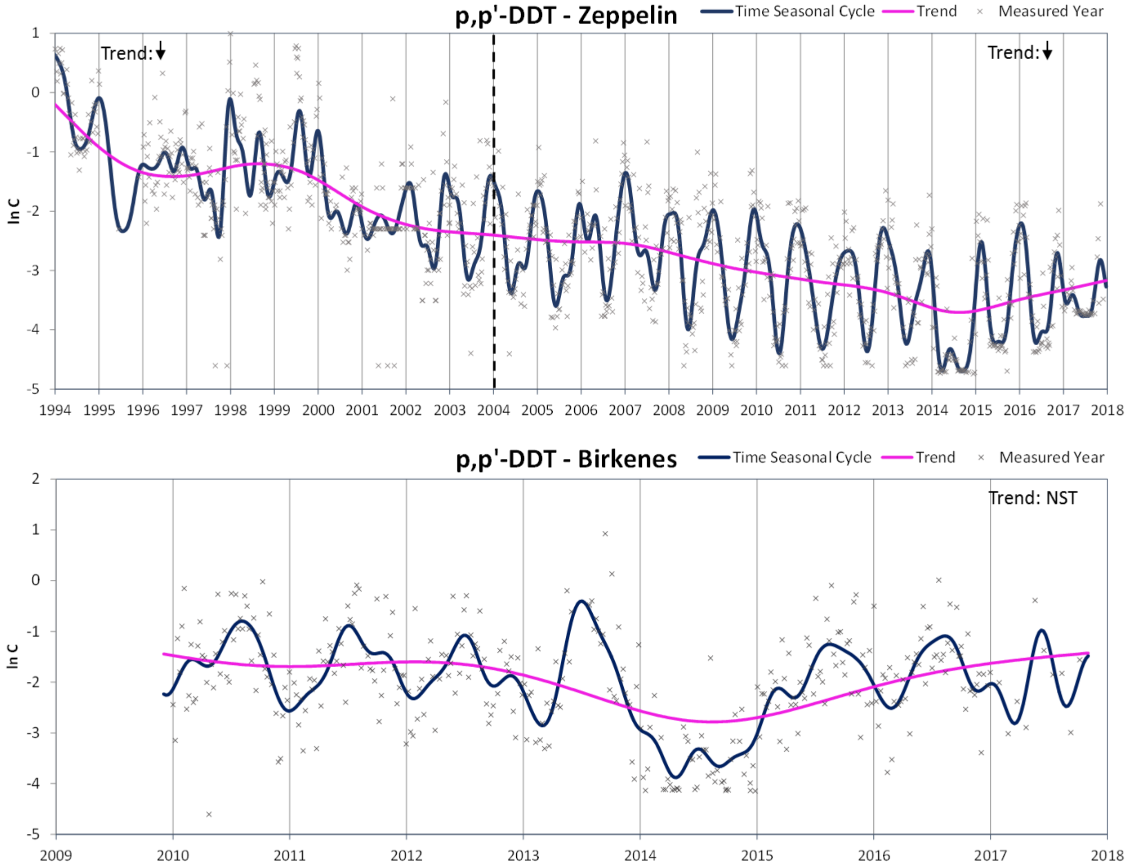


Figure 9: Temporal trends of p,p'-DDT at Birkenes and Zeppelin. Air concentrations are presented in natural log of concentration (ln C) on the y-axis. The dashed line indicates the year when Stockholm Convention was taken into force for DDTs (2004). The results of trend analyses: before and after the DDTs were listed in the Stockholm Convention, are indicated by four types of arrows (⬇: decrease, ⬊: small decrease, ⬈: small increase and ⬆: increase) or NST when no significant trend was detected.

A 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 10). 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 wintertime than summertime 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). This is not the full explanation as DDTs tend to be found to larger extent in gas-phase then particle phase.

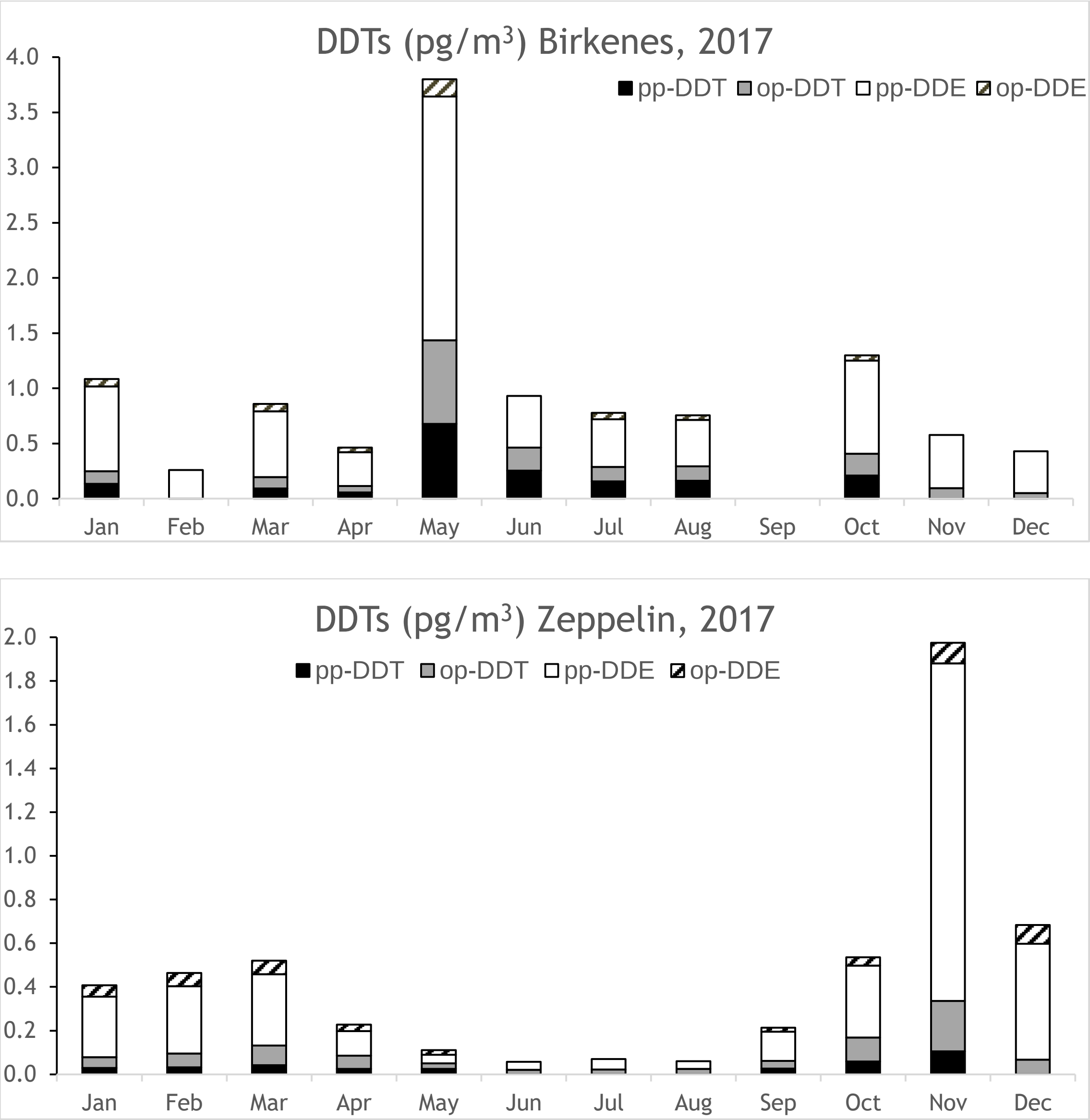


Figure 10: Seasonal variability of sum DDT and the four detected individual congeners at Birkenes and Zeppelin in 2017.

4.1.4 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 and monitoring continued in 2017. At Birkenes the chlordanes have been monitored in the period 2010-2016, but not included from 2017. All of the four isomers: cis-CD, cis-NO, trans-NO and trans-CD were detected in all samples at Zeppelin in 2017. 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 2017 ranged between 0.4-1.1 pg/m^3. The annual mean concentrations of sum chlordanes (0.7 pg/m^3) and the individual stereoisomers at Zeppelin in 2017 were the lowest observed. This suggests that the concentrations of chlordanes still are declining or may have reached steady-state (Figure 11).

The ratio of trans-CD and cis-CD was low at Zeppelin (0.1-0.6 compared to 1.17 in technical mixture) indicating input only from aged CHLs, 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 summertime (June-September) than in wintertime (November-March) (Figure 11). For sum chlordanes and the other two isomers, no seasonal trends were observed.

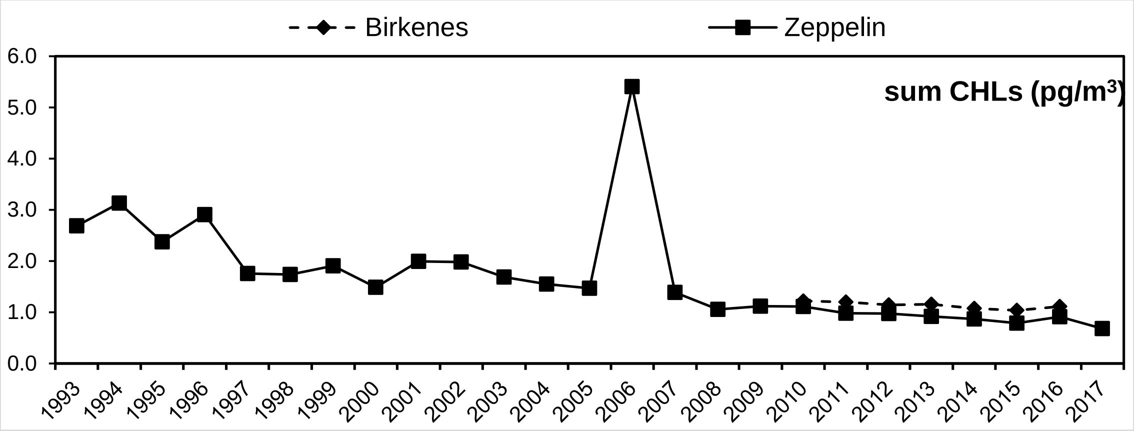


Figure 11: Annual mean concentrations of sum chlordanes (pg/m^3) in air.

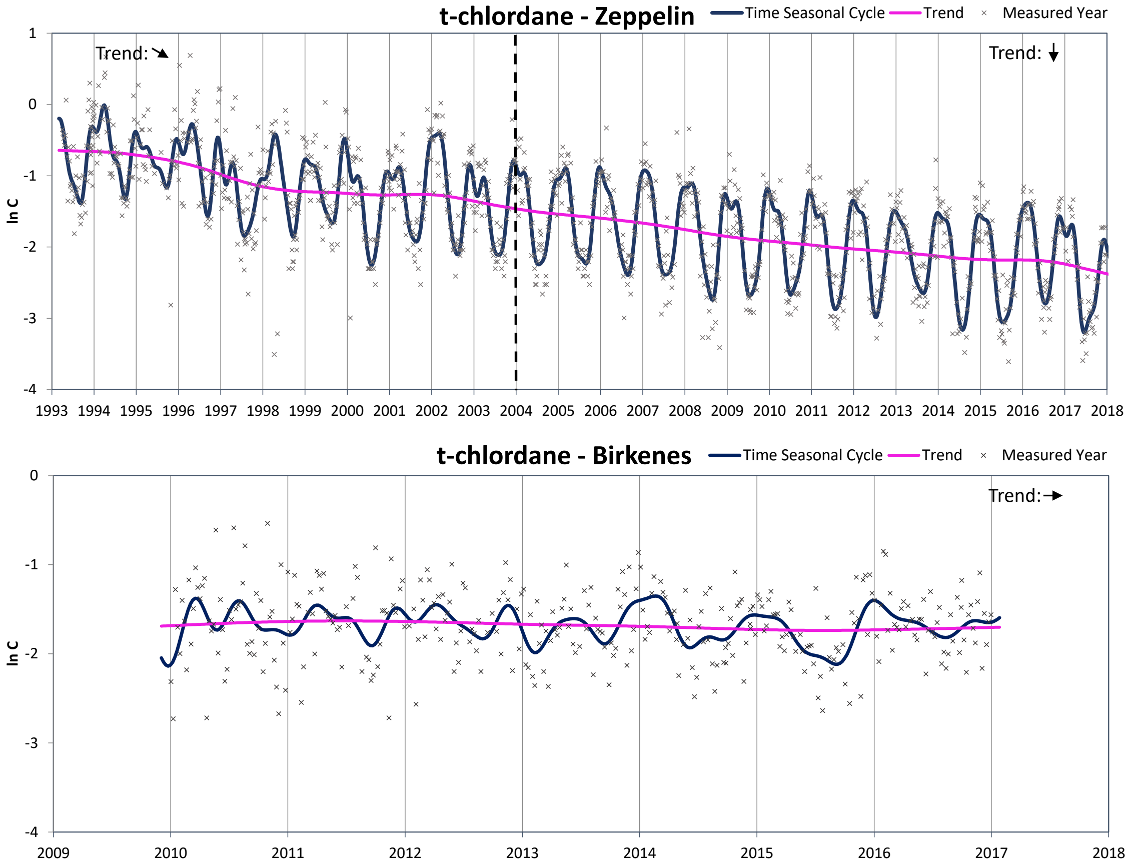


Figure 12: Temporal trends of trans-chlordane at Birkenes and Zeppelin. Air concentrations are presented in natural log of concentration (ln C) on the y-axis. The dashed line indicates the year when Stockholm Convention was taken into force for chlordanes (2004). The results of trend analyses: before and after the chlordanes were listed in the Stockholm Convention, are indicated by four types of arrows (↓: decrease, ↘: small decrease, ↗: small increase and ↑: increase) or NST when no significant trend was detected.

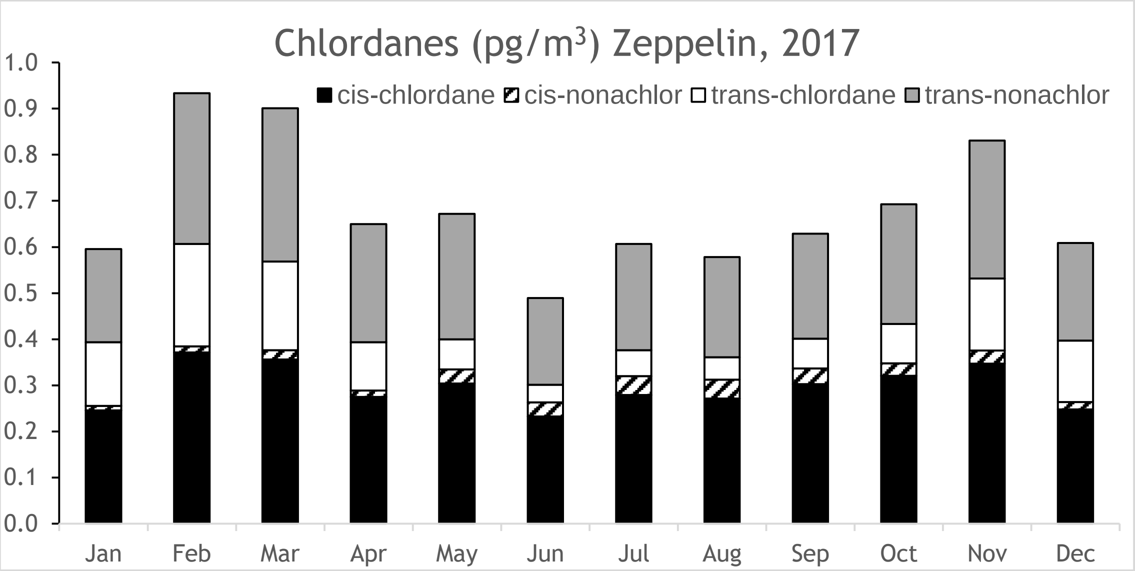


Figure 13: Seasonal variability of sum chlordanes and the four individual isomers at Zeppelin in 2017.

4.1.5 Polychlorinated biphenyls (PCBs)

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

The PCBs theoretically consists of a group of 209 congeners. 32 of these (=sum PCB-32) were measured at Birkenes and Zeppelin in 2017. These 32 congeners include the seven European indicator congeners (PCB-7); PCB 28, 52, 101, 118, 138, 153, 180, as well as the 12 dioxin-like and most toxic congeners according to WHO; PCB 77, 81, 126, 169, 105, 114, 118, 123, 156, 157, 167, 189. Data are reported for sum of 32 PCBs (sum PCB-32) as well as PCB-7 (sum PCB-7). PCBs have been monitored at Zeppelin since 2001. At Birkenes, the seven indicator PCBs have been monitored since 2004 and all the 32 PCBs since 2010. The monitoring in 2017 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-32 during 2017 ranged between: 3.7-37 pg/m^3 at Birkenes (including three high episodes); and 3.5-18 pg/m^3 at Zeppelin (including one high episode 1-3 May). The reasons for the high episodes are not known as no clear pattern for air masses are observed for the same periods. The annual mean concentrations of sum PCB-32 and PCB-7 in 2017 were in the same range at Birkenes and Zeppelin (Figure 14). At Zeppelin, the annual mean concentrations of PCBs (sum PCBs: 8.5 pg/m^3, sum PCB$_7$: 2.0 pg/m^3) in 2017 were the lowest ever observed. This cuts the increasing trend that has been observed between 2011 and 2016. At Birkenes the annual mean concentrations were similar to previous years. The observations suggest that a steady-state condition has been reached for the PCBs. The concentrations of PCB-7 (i.e. PCB 28, 52, 101, 118, 138, 153, 180) at the Norwegian sites are up to one order of magnitude lower than the concentrations of PCB-7 reported to EMEP from sites in Germany and Czech Republic (Aas et al., 2016a).

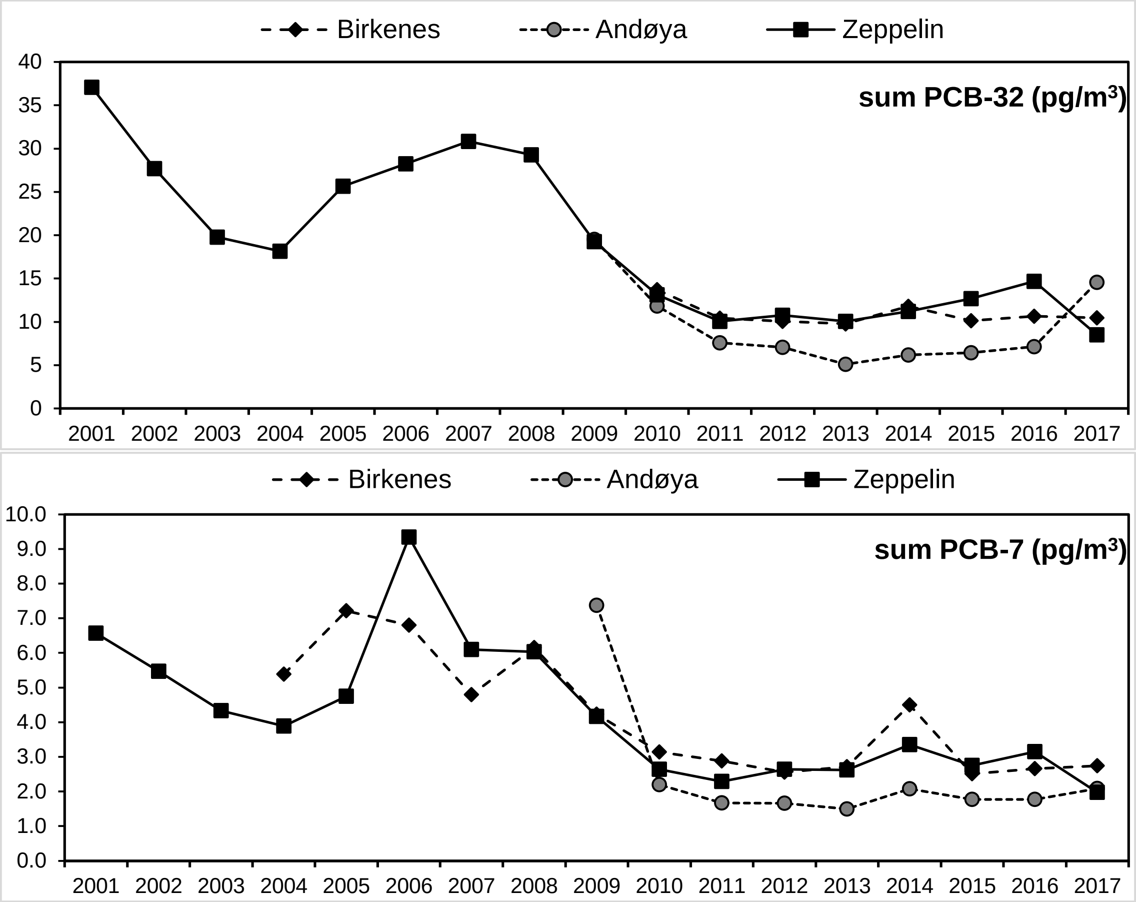


Figure 14: Annual mean concentrations of sum PCBs and sum PCB-7 (pg/m^3) in air.

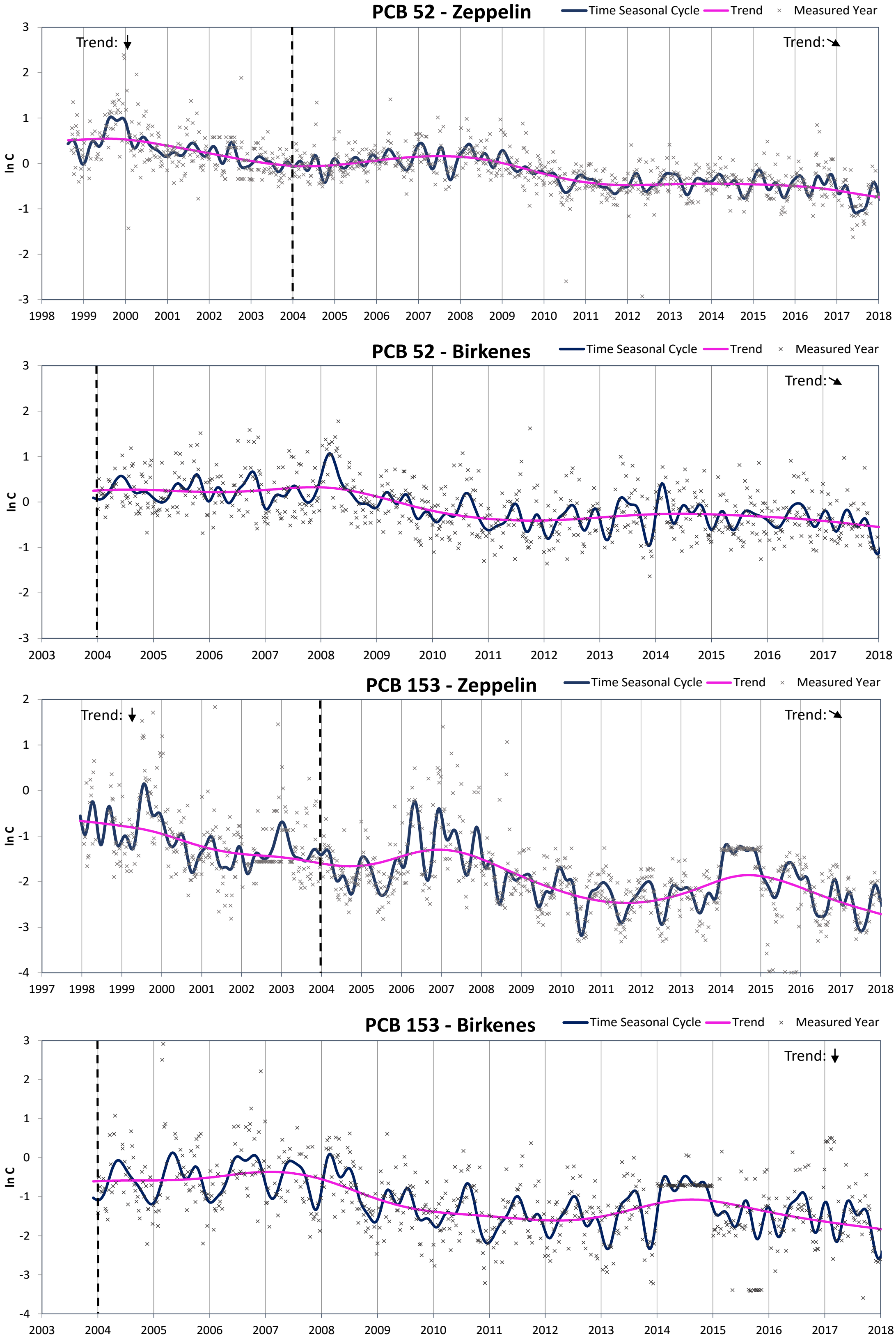


Figure 15: Temporal trends of PCB 52 and PCB 153 at Birkenes and Zeppelin. Air concentrations are presented in natural log of concentration (ln C) on the y-axis. The dashed line indicates the year when Stockholm Convention was taken into force for PCBs (2004). The results of trend analyses: before and after the PCBs were listed in the Stockholm Convention, are indicated by four types of arrows (↓: decrease, ↘: small decrease, ↗: small increase and ↑: increase) or NST when no significant trend was detected.

No clear seasonality was observed for sum PCB-32 and sum PCB-7 at any of the two observatories (Figure 16). The lowest concentrations at Zeppelin were however consistently observed in summertime (June-September) and the highest in wintertime (January-March).

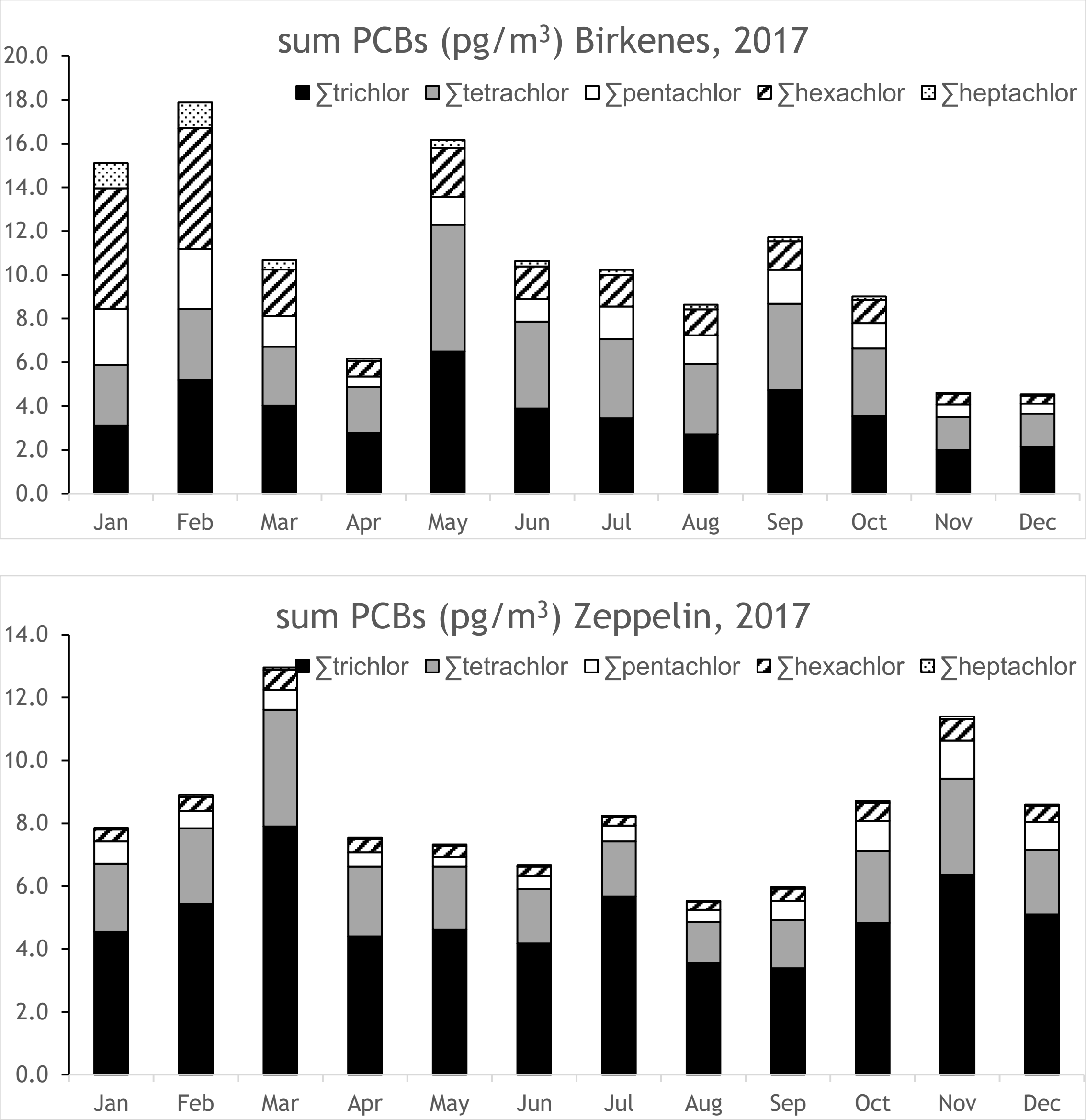


Figure 16: Seasonal variability of sum PCBs and homologue groups at Birkenes and Zeppelin in 2017.

4.1.6 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 causes. They are regulated in the Aarhus protocol on POPs (UN/ECE, 1998b) and the EU air quality directive (AQD) (EU, 2004). They show POP like characteristics, but are less persistent than other POPs.

Seven methyl-PAH and 32 PAHs (=sum PAHs) including the 16 EPA-PAHs (=sum PAH-16) were measured at Birkenes and Zeppelin during 2017. PAHs have been monitored at Zeppelin since 1994, at Birkenes since 2009, and at Andøya between 2009 and 2012. The detection frequencies varied among PAH compounds and between the sites. Generally, more compounds had low detection frequency and were below detection limit at Zeppelin (70% of the compounds) than at Birkenes (~15% of the compounds). The most abundant PAHs at Birkenes are phenanthrene, dibenzofuran and fluorene. At Zeppelin, the volatile PAHs are more abundant; naphthalene and biphenyl together with dibenzofuran and fluorene. The weekly concentrations of sum PAH in 2017 ranged between: 0.2-10 pg/m^3 at Birkenes (including two high episodes; 24-25 January and 14-15 February); and 0.12-7.0 pg/m^3 at Zeppelin. The weekly concentrations of sum PAH$_{16}$ in 2017 ranged between: 0.4-7.0 pg/m^3 at Birkenes (including two high episodes: 24-25 January and 14-15 February); and 0.06-3.0 pg/m^3 at Zeppelin. The annual mean concentrations of sum PAH and sum PAH-16 in 2017 were, as previous years, about two-three times higher at Birkenes than at Zeppelin (Figure 17). At both Zeppelin and Birkenes, the annual mean concentration was the lowest or one of the lowest ever observed. 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).

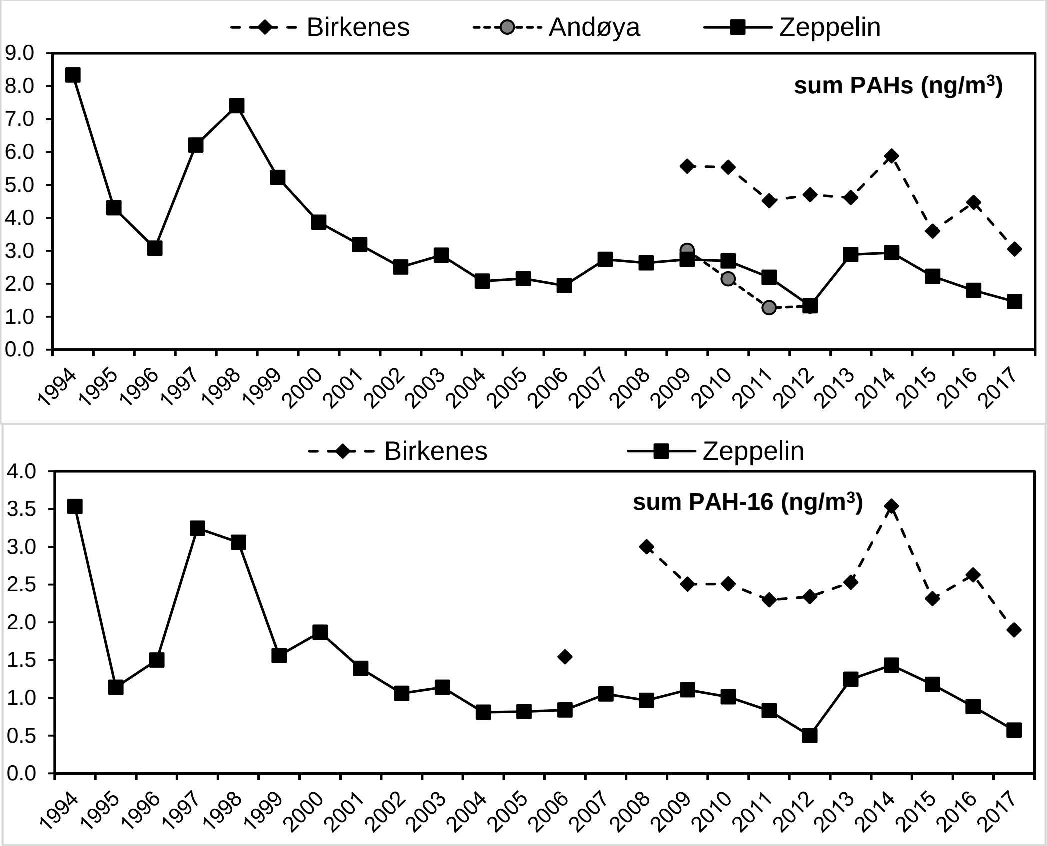


Figure 17: Annual mean concentrations of sum PAH and sum PAH-16 (ng/m^3) in air.

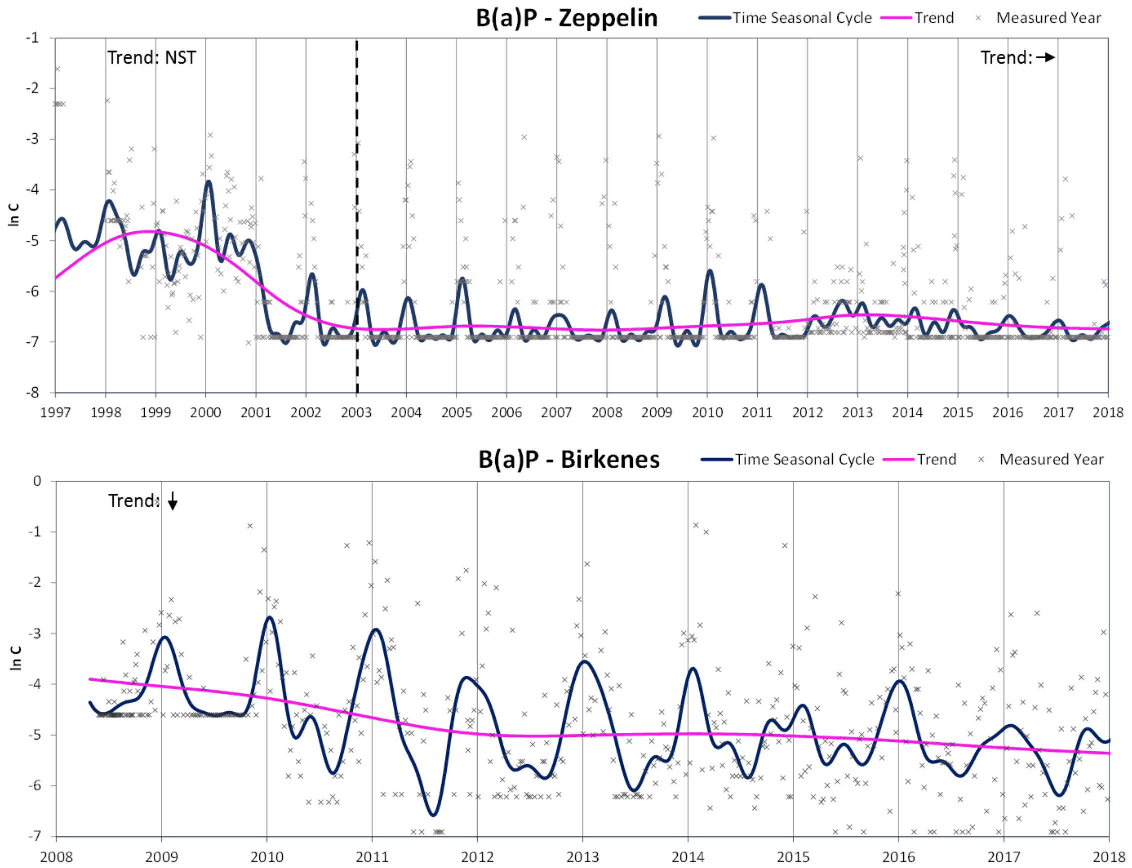


Figure 18: Temporal trends of benzo(a)pyrene (B(a)P) at Birkenes and Zeppelin. Air concentrations are presented in natural log of concentration (ln C) on the y-axis. The dashed line indicates the year when regulations of PAHs was taken into force by the "POP protocol", under LRTAP (2003). The results of trend analyses are indicated by four types of arrows (⬇: decrease, ↘: small decrease, ↗: small increase and ⬆: increase) or NST when no significant trend was detected.

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

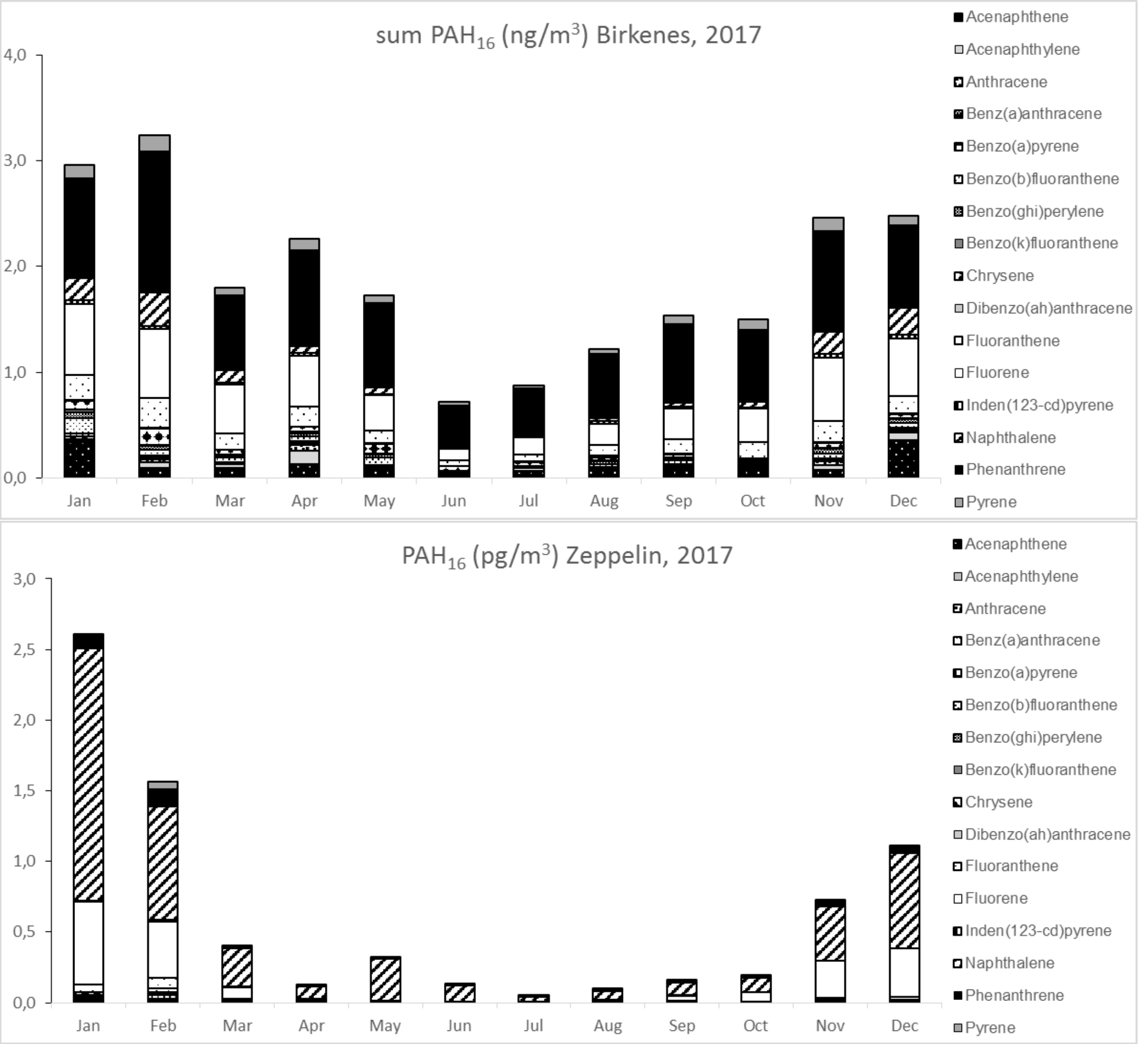


Figure 19: Seasonal variability of sum PAH16 at Birkenes and Zeppelin in 2017.

4.2 Short-term monitoring in air

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

PBDEs theoretically comprise 209 congeners with different degrees of bromination from tetra- to deca-BDE. 17 of these congeners (=sum PBDEs) have been monitored at Zeppelin since 2006, at Birkenes since 2008, and at Andøya between 2009 and 2016. In 2017, 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 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, 71, 99, 100, 153, 154, 183, 206, and 209). The detection frequencies were still low for BDE-77, 85, 119, 138, and 196 at Birkenes. In addition to these also 66, 71, 153 and 183 were detected at low frequencies at Zeppelin. At Zeppelin seven congeners (i.e. 28, 47, 49, 99, 100, 206, and 209) were detected in more than 50% of the samples. The combination of low detection frequency and low detection limits for most of the PBDE congeners at Zeppelin indicates low concentrations of many PBDEs in Arctic air. In contrast to previous years, BDE-209 was in 2017 above detection limit in most of the samples at Birkenes and Zeppelin with high concentrations measured at Zeppelin. As a result the pattern at Zeppelin is dominated by BDE-209, contributing to 90% of sum PBDEs. At Birkenes BDE-209 contributes to 50% while BDE-47, -206, and -99 contribute to 10% each.

The weekly concentrations of sum PBDEs ranged between: 0.1-1.1 pg/m^3 at Birkenes, and 0.2-35 pg/m^3 at Zeppelin. The weekly ranges for sum PBDEs excluding BDE-209 (sum PBDE$_{excl209}$) were 0.1-0.4 pg/m^3 and 0.1-1.1 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 2017 were ten times higher at Zeppelin (6.2 pg/m^3) than at Birkenes (0.6 pg/m^3) (Figure 20). This difference becomes much smaller when excluding BDE-209 from the sum of BDEs (sumPBDE$_{excl209}$=0.2 and 0.4 pg/m^3 at Birkenes and Zeppelin, respectively). The concentrations of sum PBDEs and the individual congeners measured at Birkenes in 2017 were lower than previous years while higher than previous years at Zeppelin. The higher sum PBDEs in 2017 is due to several high episodes 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 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 Longyearbyen in 2012-2013 (Salamova et al., 2014).

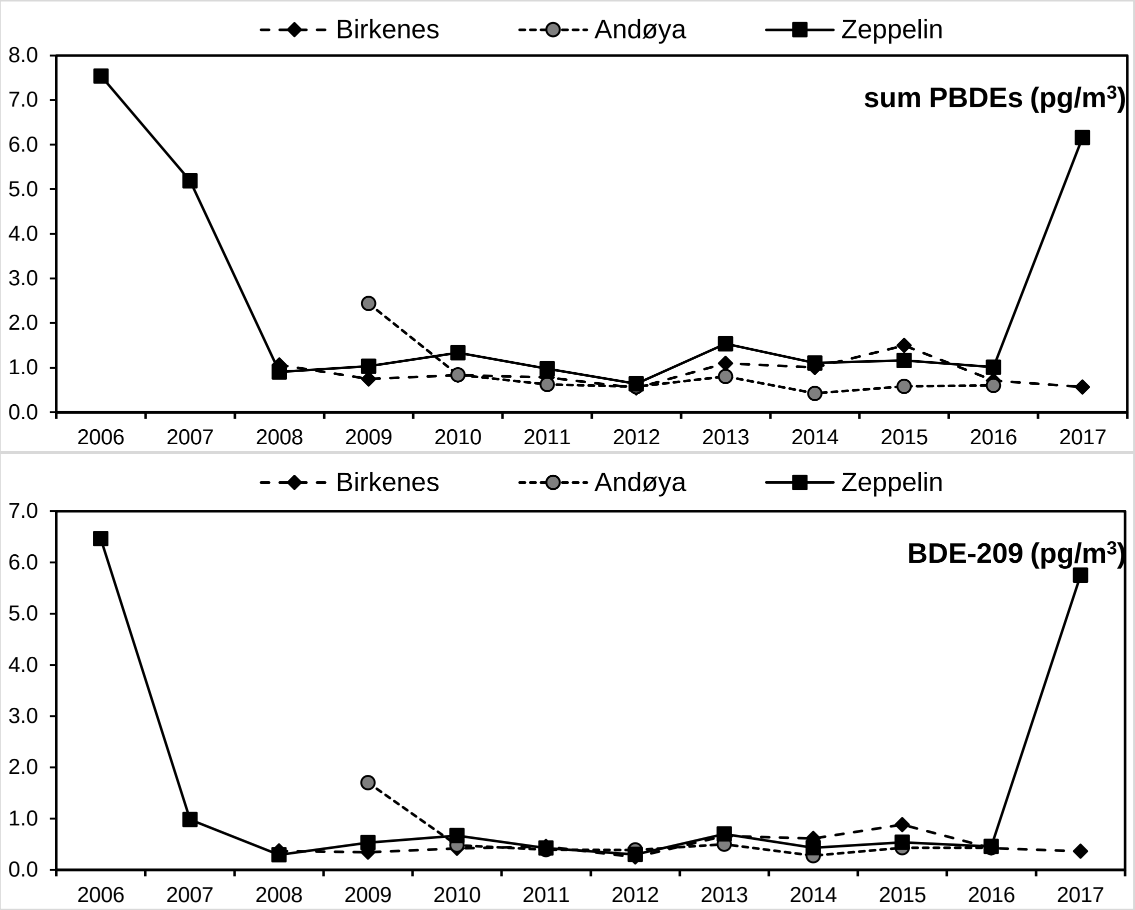


Figure 20: Annual mean concentrations of sum PBDEs and BDE-209 (pg/m^3) in air.

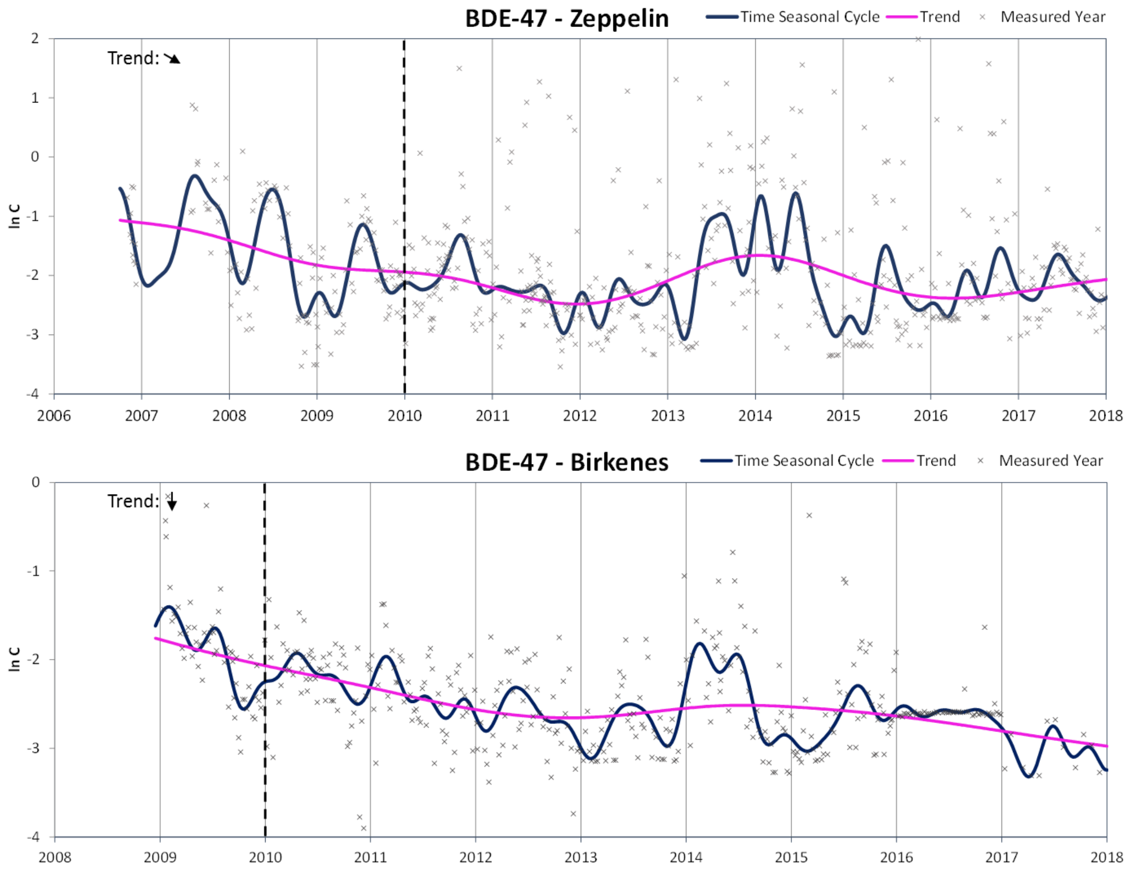
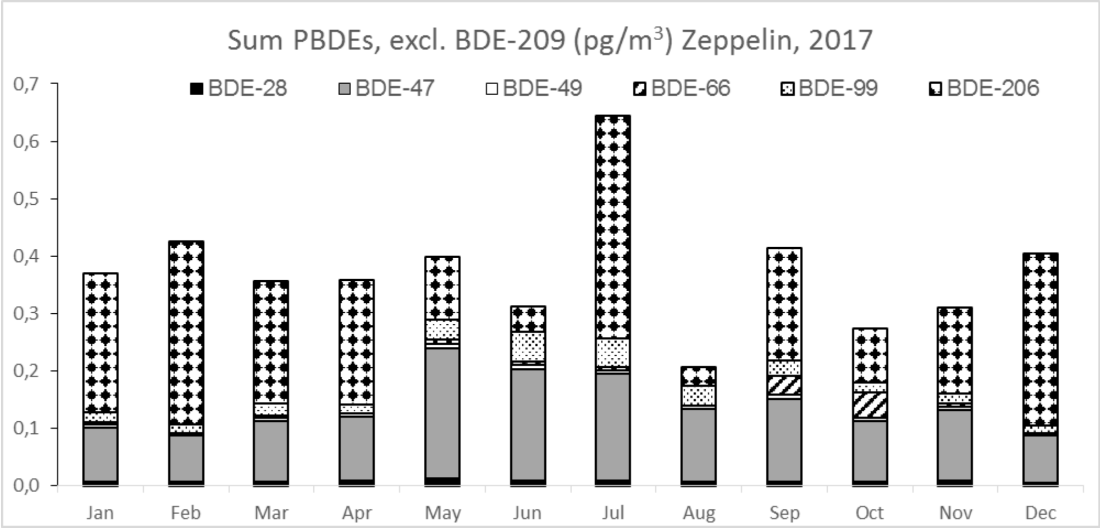
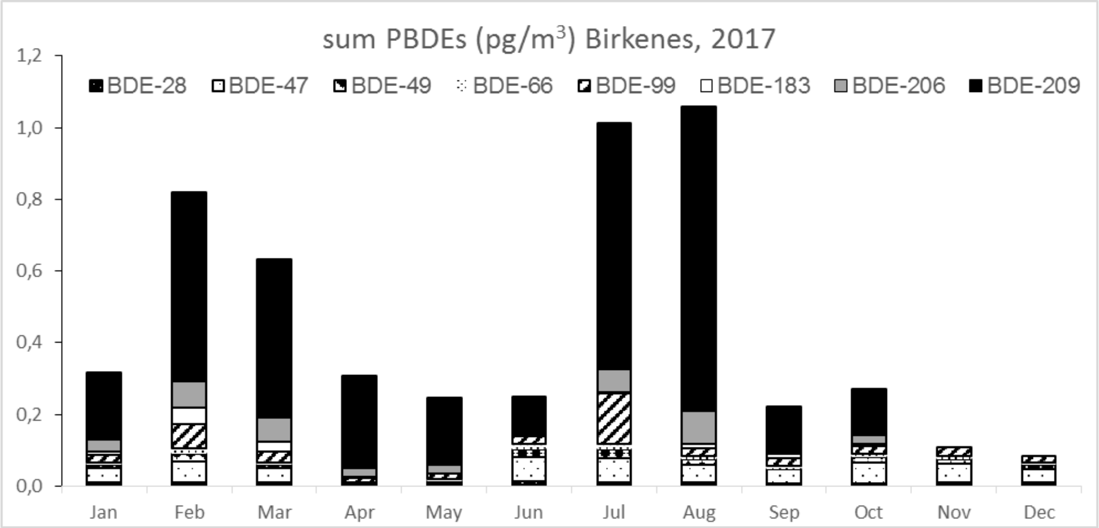


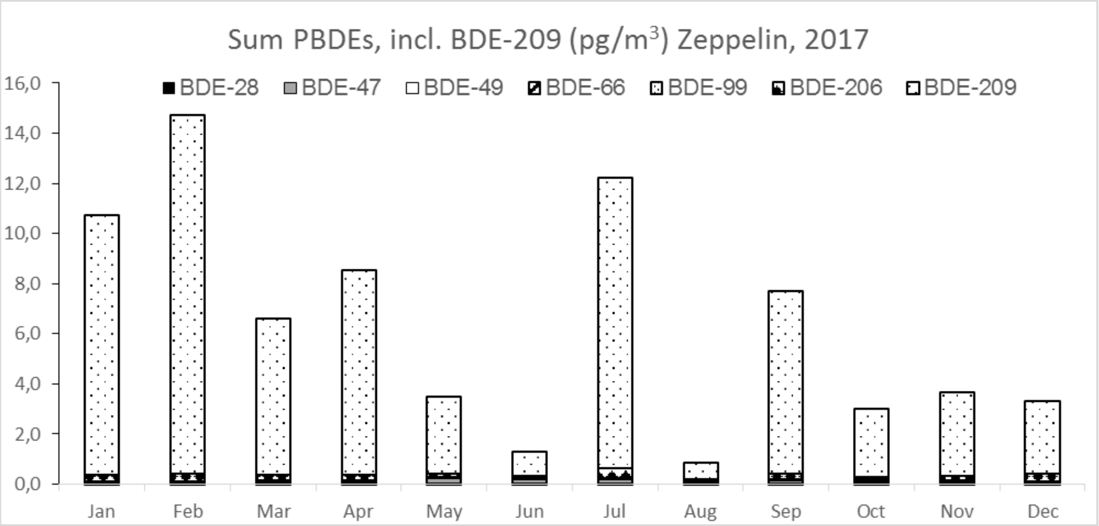
Figure 21: Temporal trends of BDE-47 at Birkenes and Zeppelin. Air concentrations are represented in natural log of concentration (ln C) on the y-axis. The dashed line indicates the year when Stockholm Convention was taken into force for PBDEs (2010). The results of trend analyses for the full monitoring period, are indicated by four types of arrows (⬇: decrease, ⬊: small decrease, ⬈: small increase and ⬆: increase) or NST when no significant trend was detected.

The seasonal pattern is influenced by generally low detection frequencies of many BDE-congeners and a few individually high episodes. The seasonality seen in Figure 22 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 22). The reason for these individual high levels are not known.





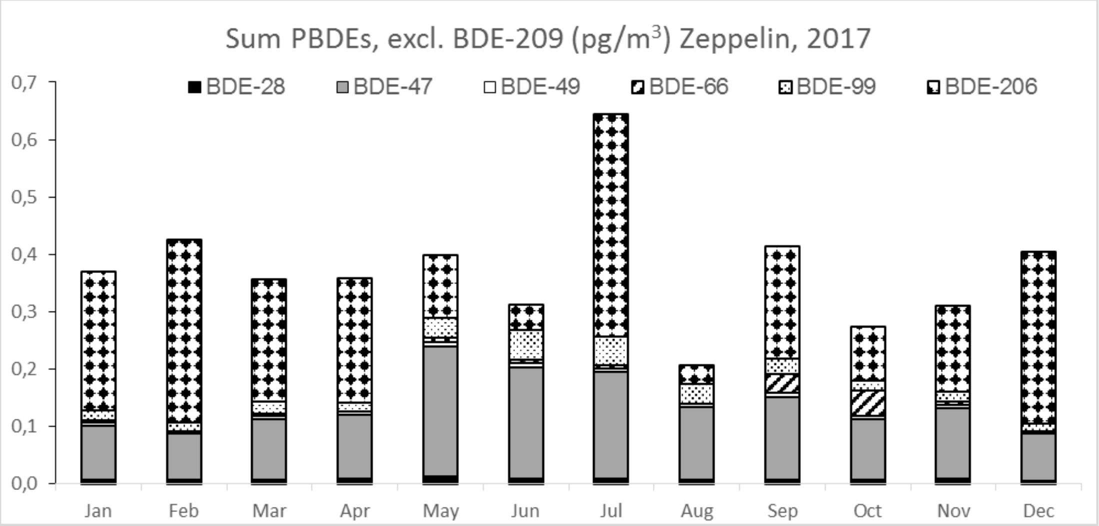


Figure 22: Seasonal variability of sum PBDEs (detected congeners) at Birkenes and Zeppelin in 2017. At Zeppelin, the results excluding BDE-209 are also shown.

4.2.2 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. BAs show POP like characteristics, such as toxic properties, half-lives exceeding the 2 d half-life criterion for long-range transport according to the Stockholm Convention, and have similar structure to other brominated pollutants. As such, it has received attention during the last years both in research and assessment work under AMAP (Wong et al., 2011; Bidleman et al., 2014). AMAP has considered HNPs (including TBA) as a group of contaminants of emerging concern in the Arctic. A reason for this is findings of other HNPs (OH-BDEs and MeO-BDEs) in Arctic biota and a possible concern for their role in ozone regulation.

TBA has been monitored at Birkenes and Zeppelin since 2007 and at Andøya between 2010 and 2016. TBA was detected in all samples at all sites in 2017 and the weekly concentrations ranged between: 0.9-10 pg/m^3 at Birkenes; and 0.4-60 pg/m^3 at Zeppelin (including four high episodes in August, 2017). The annual mean concentrations of TBA in 2017 were 4.2 and 9.4 pg/m^3 at Birkenes and Zeppelin respectively (Figure 23). Higher concentrations at Zeppelin have been observed also previous years, but the annual mean concentration at Zeppelin in 2017 is higher than previous years.

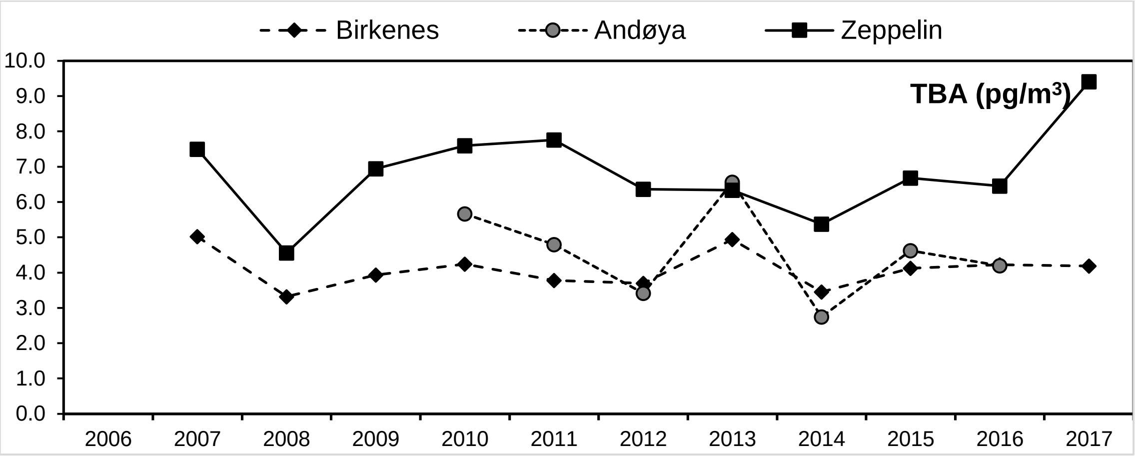


Figure 23: Annual mean concentrations of TBA (pg/m^3) in air.

At Zeppelin, the same seasonal trend as previous years was observed, lowest concentrations during winter and spring and increasing concentrations during the summer and autumn (Figure 24). 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 2017 the highest concentrations were observed in wintertime (January, February, November and December) and the lowest concentrations in summertime. The reason for this seasonality is not known.

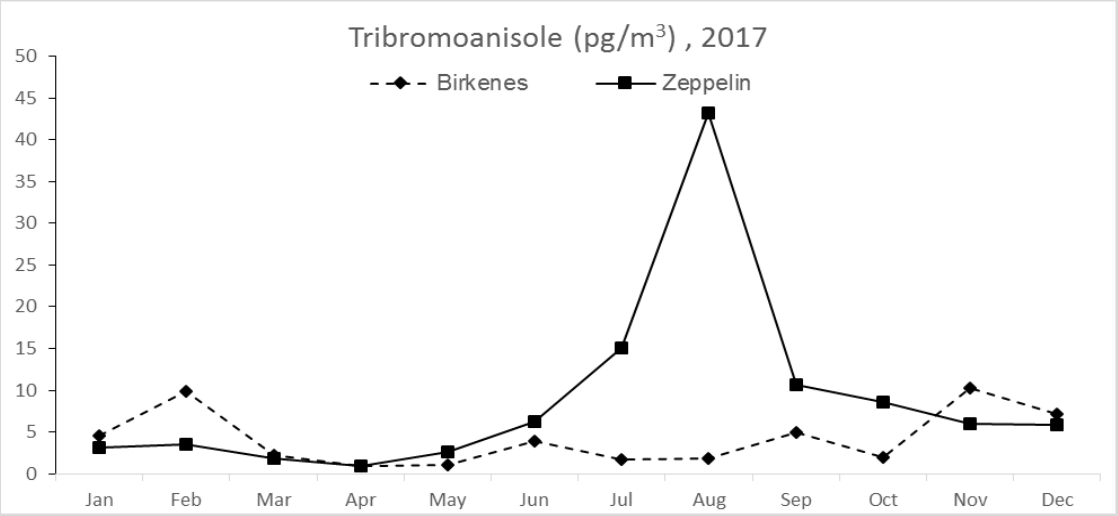


Figure 24: Seasonal variability of TBA at Birkenes and Zeppelin in 2017.

4.2.3 Hexabromocyclododecanes (HBCDs)

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

The three main diastereomers: α-, β-, and γ-HBCD (=sum HBCDs) have been monitored at Birkenes and Zeppelin since 2006, but are from 2017 not included at Andøya. In 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. Very low concentrations (i.e. levels below detection limit) are observed in a majority of the samples: 85-100% for α-, β-, and γ-HBCD. As a result, the annual mean concentrations in Figure 25 only reflects the analytical limit of detection (i.e. no real air concentrations).

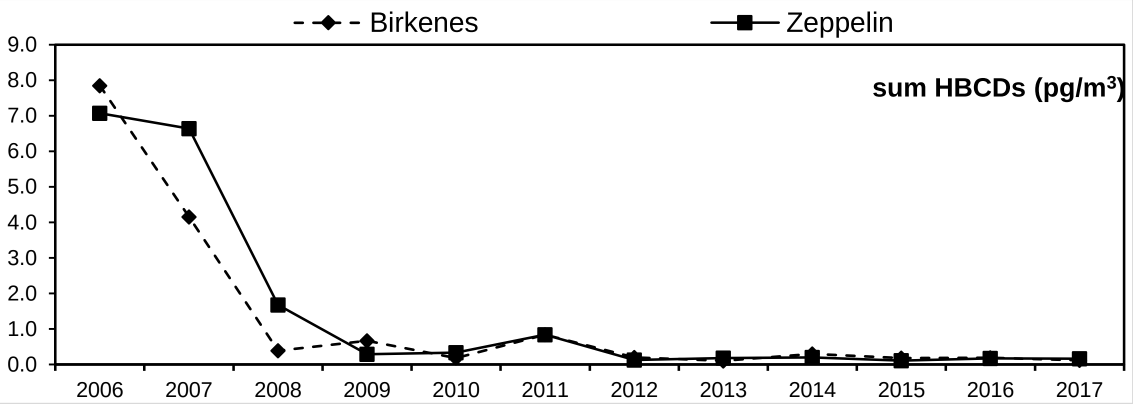


Figure 25: Annual mean concentrations of sum HBCDs (pg/m³) in air.

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

4.2.4 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. Currently, PFOS together with its salts and perfluorooctane sulfonyl fluoride (PFOS-F) are the only PFASs that are regulated by the Stockholm Convention on POPs (Stockholm Convention, 2013) and the Aarhus protocol (UN/ECE, 2010). However, PFOA is currently being considered for listing as a POP under the Stockholm Convention. In Norway, both PFOS and PFOA are banned, and the C9-C14 PFCAs are on the Norway's Priority List of Hazardous substances ("Prioritetslisten") (Norwegian Environment Agency, 2015).

Table 5
Full names and abbreviations of targeted ionic PFAS in air at Birkenes, Andøya and Zeppelin in 2017.

Ionic PFAS		
Full name	**Abbreviation**	**New in 2017**
6:2 Fluorotelomer sulfonic acid	6:2 FTS	
8:2 Fluorotelomer sulfonic acid	8:2 FTS	X
Perfluorobutane sulfonic acid	PFBS	
Perfluoropentane sulfonic acid	PFPeS	X
Perfluorohexane sulfonic acid	PFHxS	
Perfluoroheptane sulfonic acid	PFHpS	X
Perfluorooctane sulfonic acid	PFOS	
Perfluorononane sulfonic acid	PFNS	X
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	X
Perfluorotetradecanoic acid	PFTeDA	X
Perfluoropentadecane acid	PFPeA	X
Perfluorooctane sulphonamide	FOSA (PFOSA)	

Ionic PFASs have been monitored at Birkenes and Zeppelin since 2006 and at Andøya since 2009. The ionic PFAS (=sum PFASs) has until 2016 included 13 individual PFAS compounds, but in 2017 the list was expanded with seven new PFAS compounds (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.

Despite combining two samples to one and thereby increasing the sampling time in 2017, the detection was still low. Only a few of the monitored PFASs were above the analytical detection limit: PFHpA, PFHxA, PFNA, PFOA, PFUnA and PFDA. The other 14 PFAS were below the analytical detection limit. As previous years, PFOA was above the detection limit in all samples from all sites. The increased sampling time in 2017 resulted in improved detection for PFNA, above detection limit in all samples from Andøya and almost all samples at Birkenes and Zeppelin, PFHpA and PFHxA, above detection limit in 67-100% and 43-86% respectively, and PFUnA and PFDA, above detection in 0-19% and 43-57% respectively. PFHxS was not detected at any site in 2017 indicating low presence of PFHxS in Norwegian background air. The concentrations of the four PFAS with highest detection did not differ significantly. The monthly concentrations of PFOA ranged between 0.04 and 0.42 pg/m^3 at the three stations, resulting in homogeneous annual mean concentrations of PFOA all sites; 0.14 pg/m^3 at Birkenes, 0.14 pg/m^3 at Andøya, and 0.10 pg/m^3 at Zeppelin. PFHxA ranged between <0.03 and 0.31 pg/ m^3 at all sites, PFHpA ranged between <0.03 and 0.18 pg/ m^3, and PFNA ranged between <0.02 and 0.17 pg/ m^3. The homogeneous distribution of the detected PFAS at the three sites suggest the input from current use and ongoing emission from anthropogenic applications in populated areas to be of minor importance. As most of the PFASs are and have been below detection limits it is not appropriate to compare the annual mean concentrations of sum PFAS in order to look for time-trends. Instead PFOA is used as a representative for sum PFAS.

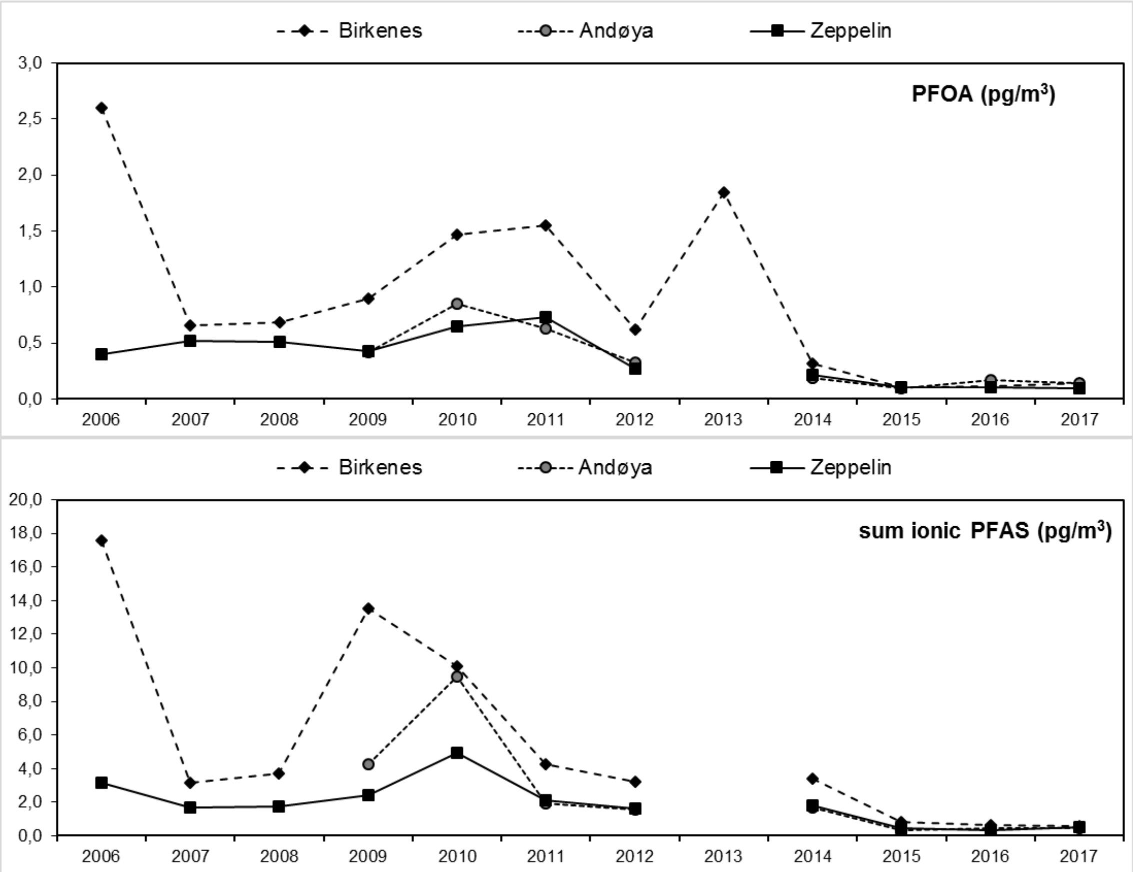


Figure 26: Annual mean concentrations of PFOA and sum ionic PFAS (pg/m^3) in air.

The seasonal variations for sum PFAS are neither being captured when most of the PFAS compounds are below detection in a majority of the samples. For the compounds with detection in all samples from all sites; i.e. PFOA, PFHpA, PFHxA and PFNA a seasonality with higher concentrations in summer is observed at Zeppelin (Figure 27). The same seasonality is observed for PFOA, PFHpA and PFNA at Birkenes while the seasonality at Andøya is affected by high concentrations also in January.

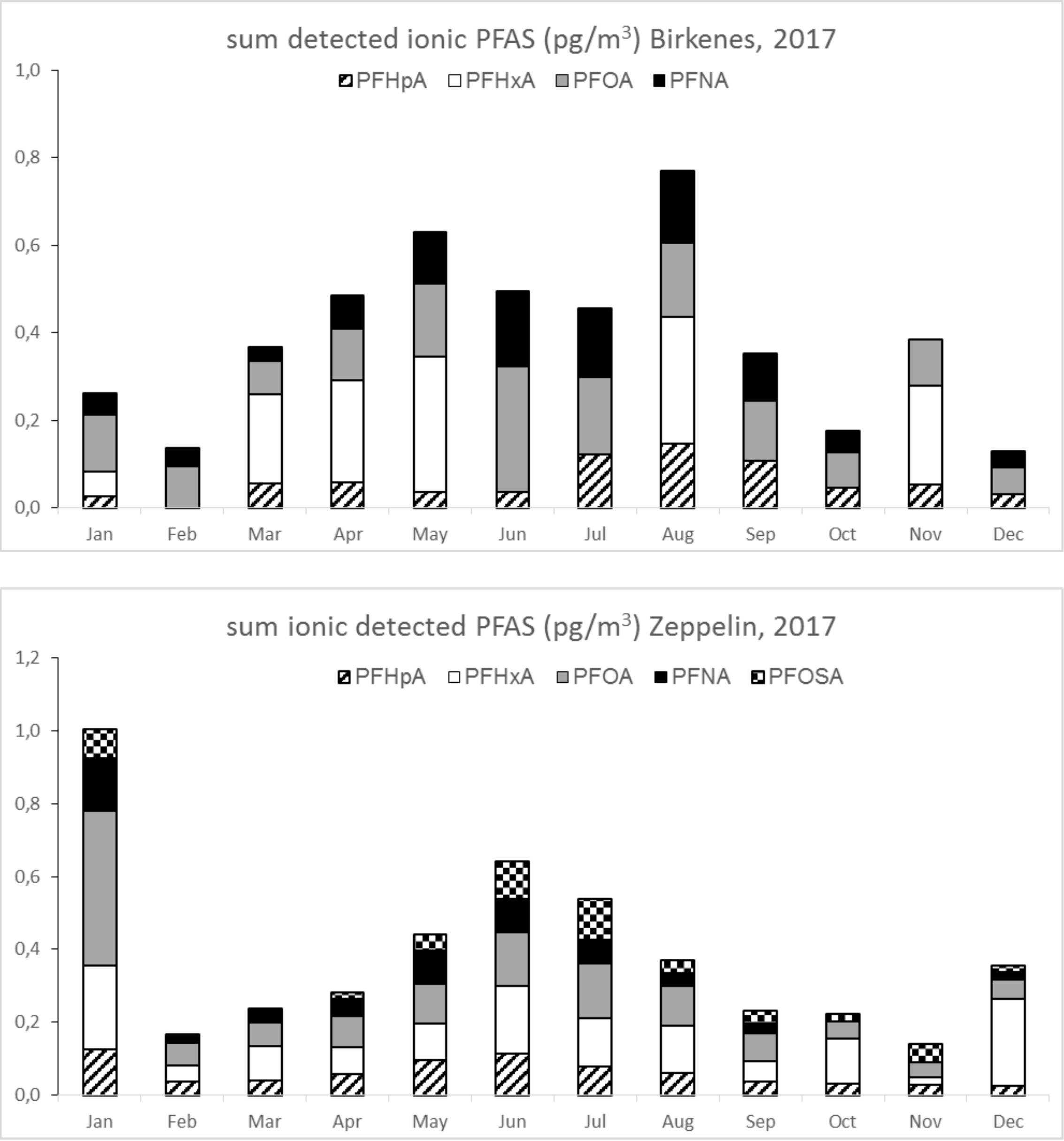


Figure 27: Seasonal variability of sum PFAS (detected congeners) at Birkenes and Zeppelin in 2017.

4.3 Summary of short- and long-term time trends

The long-term time trends were derived using the same technique as has been used for POPs by AMAP network (AMAP, 2016); the Digital Filtration (DF) Technique. The DF technique fits seasonal cycles and inter-annual trends or time series with statistical techniques. An apparent first order half-life, t1/2, is calculated by dividing ln2 with the negative value of the linear regression slope of the trend between the natural log of air concentrations, ln C (pg/ m^3), and time (year). Long-term time trends for individual POPs are expressed as apparent first order half-lives (t1/2, y). It should be noted that the compounds do not necessarily decline/increase linearly or consistently in the first order manner throughout the entire monitoring period. The obtained half lives does not give precise information, but can be used to compare the relative rates of decline or increase of concentrations between the compounds, e.g. a smaller positive number means that the decrease has been sharper than a larger positive number. In contrast, negative values indicate increasing trends. The absolute values of these half-lives or doubling times should be used with caution.

For this report the trends and half lives have been obtained for three different scenarios, when possible; i) the whole monitoring period (if started before 2000), ii) from the starting year of the monitoring to the Stockholm Convention or POP-protocol under LRTAP was taken into force for the individual compounds (2003, 2004, 2010), and iii) from the Stockholm Convention or POP-protocol under LRTAP was taken into force for the individual compounds (2003, 2004, 2010) until the end of 2017. The three scenarios aimed to access information about i) trend for long-term monitoring, ii) trends before global regulations, and iii) trends after global regulations. The half-lives for a selection of individual POPs at Birkenes, Andøya and Zeppelin are presented in Table 6 while seasonal cycles and time trends are presented in Figures under the individual POP classes above.

The results from the DF technique show that HCB at Zeppelin has been increasing since the introduction of Stockholm Convention, but when analyzing scenario ii (until 2004) instead a small decrease is seen. At Birkenes, a decrease is seen for HCB during the first 12 years, but the decrease has been reduced after the SC entered into force. This is opposite to the aim of the SC and the reason is not known. Also B(a)P shows very slow decline (with large half-lives) or even increase in scenario iii) (with negative half-lives). Instead the other organochlorine pesticides; HCHs, p,p'-DDT, and t-chlordane, and PCBs decline at all scenarios at Zeppelin with small half lives that indicate sharp declines. Also at Birkenes a similar decline is observed for all but t-chlordane which seem to have a smaller decline. At Zeppelin, the decline is somewhat sharper during the first period (before SC) than the second period (after SC) for HCHs, p,p-DDT, and PCBs.

The slower decline for t-chlordane in the air with half-lives around or longer than 10 years is consistent with findings in Hung et al. (2016). This has been attributed to their persistence in the Arctic, although chlordane has been banned in western industrialized countries since the 1980s. Slow decline in trends also indicate tendency towards equilibrium with surface media.

Table 6

Long-term time trends for individual POPs and three different time periods: 1) the whole monitoring period (Table 2); 2) from the starting year of the monitoring to the year global regulation was taken into force for for the individual compound, and 3) from the year global regulation was taken into force for the individual compounds until the end of 2017. The trends are expressed as apparent first order halflives (t1/2, y). Positive values indicate decreasing trends and negative values indicate increasing trends. The lower value the bigger decrease or increase. Colour codes and arrows help to interpret the data: yellow (big decrease), green (smaller decrease), blue (minimal change/steady-state), red (small increase). The empty white cells mean that no data is available for this time period.

POP	Birkenes			Andøya			Zeppelin		
	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3
	$t_{1/2}$	$t_{1/2}$	$t_{1/2}$	$t_{1/2}$	$t_{1/2}$	$t_{1/2}$	$t_{1/2}$	$t_{1/2}$	$t_{1/2}$
HCB	*NST*	6.8 ↓	28 ↘	-30 ↗		-30 ↗	*NST*	10 ↘	-30 ↗
a-HCH	5.1 ↓	4.4 ↓	10 ↘				5.3 ↓	4.8 ↓	6.9 ↓
g-HCH	4.2 ↓	3.7 ↓	14 ↘				4.4 ↓	4.2 ↓	6.7 ↓
p,p'-DDT	*NST*		*NST*				5.6 ↓	3.9 ↓	7.5 ↓
Sum DDT	*NST*		*NST*				7.4 ↓	5.1 ↓	7.3 ↓
t-chlordane	47 →		47 →				10 ↘	11 ↘	8.7 ↓
PCB-52	11 ↘		11 ↘	*42* →			11 ↘	5.3 ↓	11 ↘
PCB-153	7.6 ↓		7.6 ↓	*139* →			8.5 ↘	4.1 ↓	9.5 ↘
PCB-180	5.4 ↓		5.4 ↓	5.2 ↓		5.2 ↓	5.1 ↓	1.9 ↓	5.5 ↓
BaP	5.2 ↓		5.2 ↓				*NST*	*NST*	*-75* →
BDE-47	7.3 ↓		7.3 ↓				*9.5* ↘		*9.5* ↘

NST: no significant trend

4.4 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.

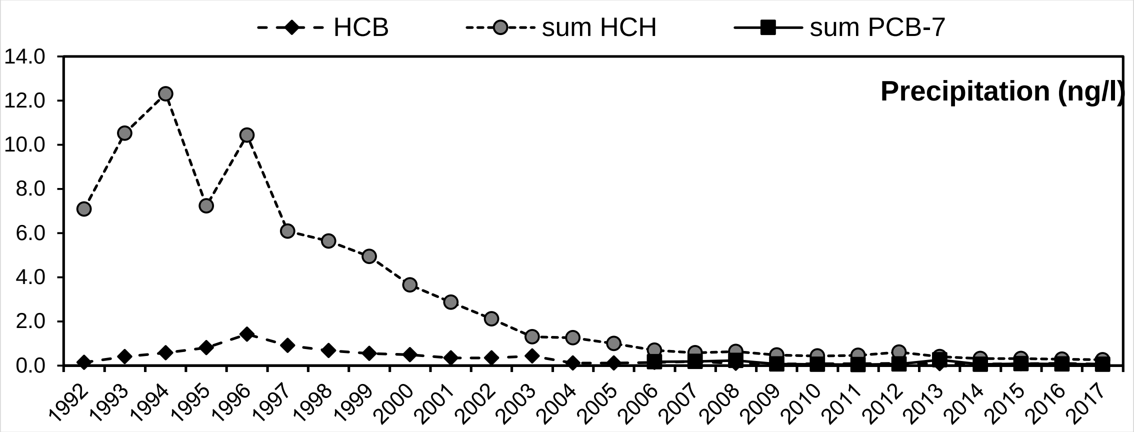


Figure 28: Annual mean concentrations of HCB, sum HCH and sum PCB-7 (ng/l) in precipitation at Birkenes in 2017.

HCB were below detection limit in 89% of the samples in 2017. Thus, the annual mean concentration reflects the detection limit. The annual mean concentrations of HCB in precipitation in 2017 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 28). No seasonal variability was observed for HCB, mainly due to low detection (Figure 29).The two HCH-isomers (α and γ) were detected in ~90% of the samples in 2017. The annual mean concentration for sum HCHs was the lowest since the beginning of the monitoring (in 1992) and as in air they followed the decreasing time-trend at Birkenes. The seasonality was less distinct in 2017 than previous years, but the highest concentrations are still observed during spring- and summertime and the lowest concentrations during wintertime (December-February). This seasonality is similar to that found for air concentrations at Birkenes. The PCB-congeners were detected in 10-40% of the precipitation samples depending on congener. The annual mean concentration of PCB-7 in 2017 was similar to that observed in 2015. No clear seasonality was observed.

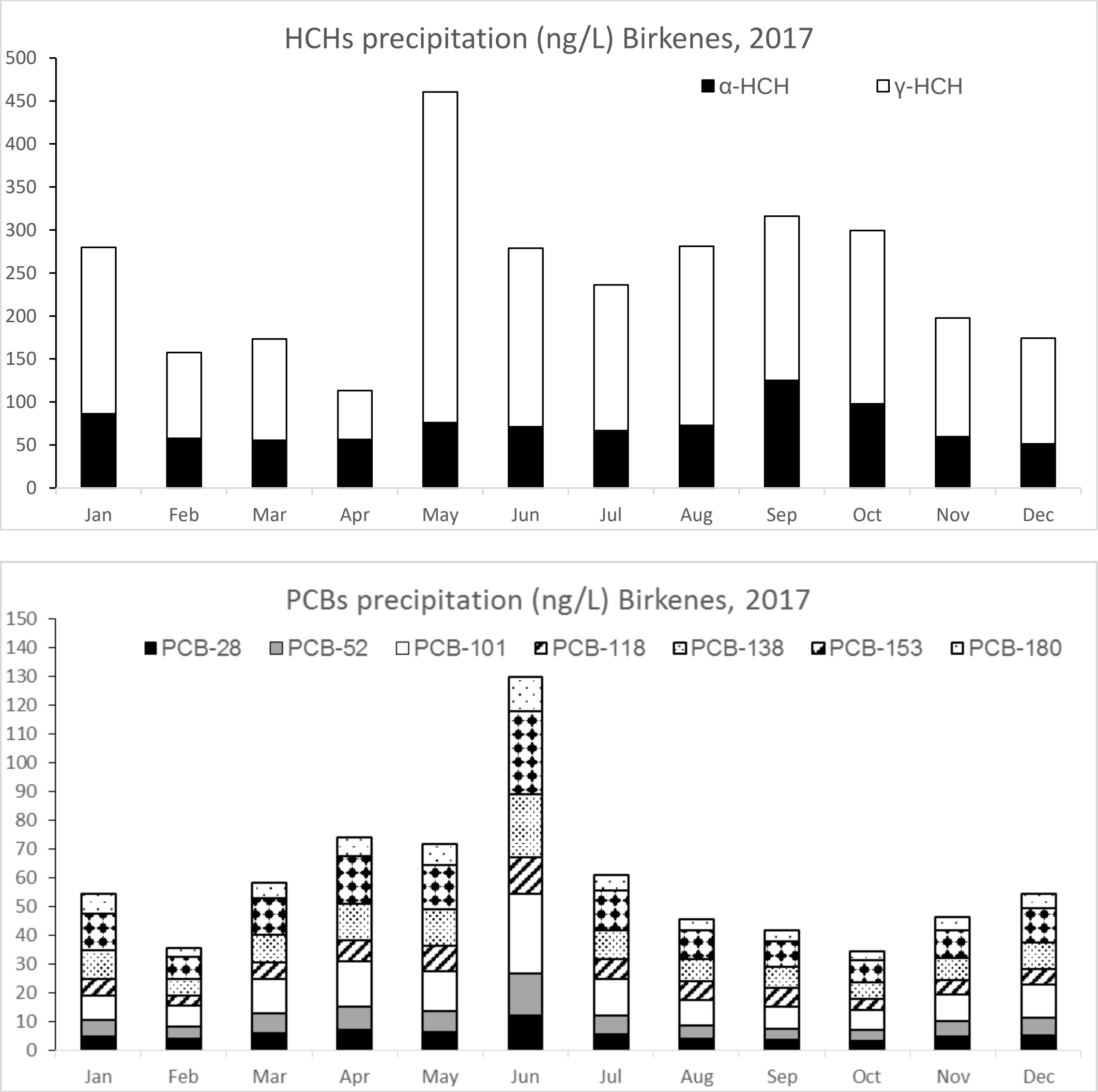


Figure 29: Seasonal variability of HCHs and PCBs (detected congeners) in precipitation (ng/l) at Birkenes in 2017.

5. Non-regulated emerging organic contaminants

New organic chemicals are constantly introduced on the market, either as replacements for the regulated of POPs or in new materials as a demand for new technological needs. Some of these chemicals have similar physical-chemical properties as the 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 created a ground for the need of monitoring on these chemicals. This particular monitoring programme is therefore continuously enlarged with new organic contaminants. For a few, a short-term monitoring has been established while for some others the monitoring was initiated in 2017.

5.1 Short-term monitoring in air

5.1.1 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 dodecamethylcyclohexasiloxane (D6) have received increased attention from regulatory agencies and the scientific community regarding their environmental persistence (P), bioaccumulation (B), toxicity (T), and long range transport (LRT) potential (Brooke et al., 2009a; Brooke et al., 2009b; Brooke et al., 2009c; Canada, 2008a; Canada, 2008b). 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 has recently started consultation on extending this proposed restriction to “leave-on” personal care products. D4 and D5 are also on Norway's priority substances list with the aim to stop emissions of these compounds by 2020 (Norwegian Environment Agency, 2015) and they are considered as chemicals of emerging Arctic concern by AMAP (AMAP, 2017).

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 summertime and one in wintertime, 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, 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 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 is 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. 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. Properties responsible for this low deposition potential are their high volatility, short atmospheric half-lives, high KAW values and relatively low KOA values compared to legacy POPs (Wania, 2003; Xu and Wania, 2013). cVMS have nonetheless been detected in arctic biota at Svalbard (Warner et al. 2010; Warner et al. 2013). This has been shown to 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. 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. An option to the monitoring programme in 2017 aimed to measure cVMS in fresh snow in the vicinity to Zeppelin in order to better understand the potential for atmospheric deposition. A snow sampler was developed in the first half of 2017, but no samples could be taken due to lack of fresh snow in the second half of 2017. Monitoring in 2018 will try to obtain fresh snow.

The concentrations for the investigated cVMS in 2017 have, as in previous years, been corrected for sorbent related degradation during storage using methodology reported by Krogseth et al. (2013). While D5 and D6 has been shown to be degraded during storage and therefore can be storage corrected in a semi-quantitative way, the data for D4 is more uncertain as it has been shown to 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 of D4 in the air at Zeppelin is therefore still uncertain as it might be present in the samples only as a degradation product from D5. The degradation process is related to the adsorbent in the sampler (ENV+) and the source of the degradation is expected to be a result of an acid catalysed reaction with a substituted OH group located in the phenyl substructure of the ENV+ sorbent. This interaction causes the hydrogen to be acidic and facilitate breakdown of the siloxanes (as they are not stable under acidic conditions). Due to the uncertainties introduced by sorbent mediated degradation/formation mechanisms and the need for increased atmospheric monitoring of cVMS, efforts are currently underway to validate new adsorbents for cVMS sampling/analysis. Results from parallel sampling with ENV+ and ABN in 2017 have shown that the ABN adsorbent is less affected by degradation and therefore a better option for the monitoring. From 2018, all samples will be collected on ABN.

D5-D6 were detected in all samples from Zeppelin and Birkenes in 2017. No significant difference was observed between the measured concentrations in air at Birkenes and Zeppelin despite Birkenes being closer to source regions. This suggests that the time taken for cVMS to reach equilibrium in the atmosphere is short and that the concentrations in air reflect background levels relatively short distances from emission source regions. The ranges of D5 and D6 at Zeppelin were 0.02-4.5 ng/m^3 and 0.003-0.21 ng/m^3, respectively, with the highest levels measured in wintertime (November-February) and the lowest in summertime (May-August) for both oligomers (Figure 30). The ranges at Birkenes were 0.4-6.7 ng/m^3 and 0.01-0.27 ng/m^3 for D5 and D6, respectively. Similar to Zeppelin station, the lowest concentrations at Birkenes were observed in summertime (July-August) and the highest in wintertime (November-January) (Figure 30). Two extreme measurements were observed at Birkenes in September and December. These were two-three times higher than the other months at Birkenes and the measurements at Zeppelin. Whether this is real or a consequence of a high exposure event (e.g. contamination due to activities on the station) is unknown. 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.

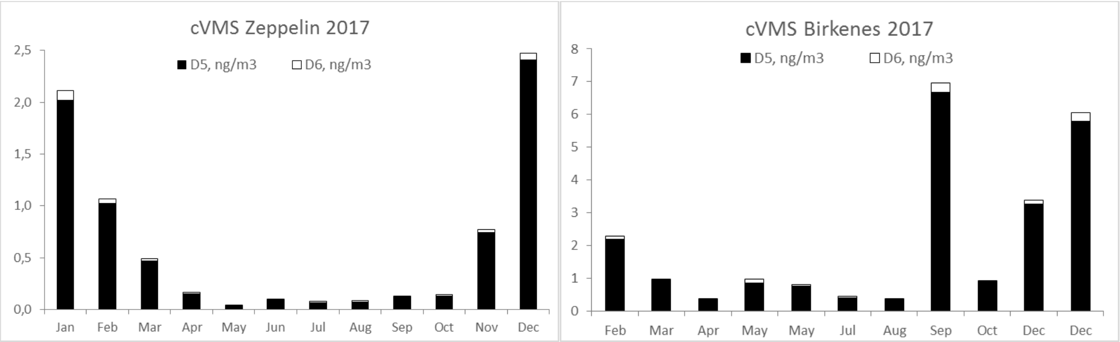


Figure 30: Monthly mean concentrations (ng/m^3) of D5 and D6 at Zepppelin (left) and Birkenes (right) in 2017. Zeppelin represents the average of weekly samples while Birkenes represents one sample per month.

The results from 2017 cannot be directly compared to the monitoring from 2013-2016 when the sampling was conducted in two campaigns covering only three-four months of the year at Zeppelin (Nizzetto et al. 2017; Nizzetto et al. 2016; Nizzetto et al. 2015; Nizzetto et al., 2014). However, the data for 2017 from the same periods of the year (July-August and November-December) can be compared with data from 2015 and 2016 (Figure 31). This comparison shows significantly lower concentrations of D6 in 2017 than the previous years, both in summer and winter. D5 is significantly lower in summer, but not in winter 2017. These results suggest a decrease in atmospheric D6 and D5 over time, but this needs to be confirmed by continuous yearly monitoring. Such a decrease may be a reflection of the changes in product formulations or use of cVMS during these years.

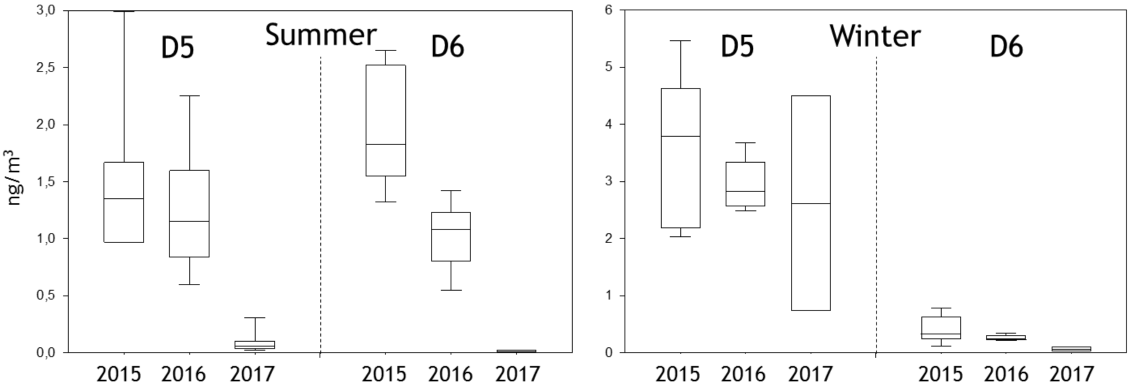


Figure 31: Box-plots of measured concentrations of D5 and D6 (ng/m^3) in two periods of the year (Summer: July-August and Winter: November-December) in 2015-2017.

In 2017, two passive air sampling (XAD-PAS) campaigns were performed at Longyearbyen, Ny-Ålesund, Zeppelin outdoors and Zeppelin indoors, one in summer time (July-August) and one in winter time (November-December). The aim of these was to study potential influence of local sources for cVMS at Zeppelin. XAD-PAS has been shown to provide more reliable data for D4 than the active sorbent ENV+ as no degradation has been observed after 30 days of storage (Krogseth et al. 2013). D4 is therefore reported for the XAD-PAS, but not for the active ENV+. The results from the summer and winter campaigns show that the levels of cVMS are ten times higher at the indoor site than the three outdoor sites, with the difference being highest for D4 and smallest for D5. The indoor/outdoor ratios for the cVMS (~10) are smaller than those observed for the other emerging contaminants (~100 times for S/MCCPs, OPFRs, Phtalates). The pattern of the cVMS oligomers was significantly different between the indoor source area and the outdoor sites with D4 being dominant at the indoor site and D5 being dominant in the outdoor sites. The ratio of D5/D4 can be used as an indicator of distance to source areas as D5 often is dominant in currently used products and D5 has a much shorter atmospheric half-life compared to D4. The ratio in this study decreases for the outdoor sites from the most populated sites (Longyearbyen) to the most remote site (Zeppelin) (Figure 32). This is in agreement with previous findings and in accordance with the theory. The low ratios observed at Zeppelin suggest that the local sources do not influence signatures observed at this outdoor remote sampling site, but instead reflect a long-range transport signature where D4 is more dominant than D5. The ratios as well as the measured concentrations were lower at all sites in summer than in winter. This is in agreement with the findings from the active air measurements and suggests a higher degree of photochemical atmospheric degradation to occur in summer than in winter time.

A very low D5/D4 ratio (0.2 and 0.3) was consistently observed from the measurements indoors at Zeppelin station in summer and winter. While the low ratio outdoors suggests long-range transport and long distance to source areas, the low ratios in the indoor environment are combined with high indoor levels of D4 and therefore suggests presence of primary sources of D4 in the indoor environment. The high D4 signature at Zeppelin station most likely come from emission from electronics and/or laboratory equipment in the station and not from personal-care products and is in agreement with findings from Tran & Kannan (2015). In addition, the use of personal-care products at Zeppelin is restricted and if being used the signature from D5 would have been higher as D5 is dominant in personal-care products. Lower levels of D4 outdoors at Zeppelin than at the more populated sites suggests that the outdoor measurements at Zeppelin is not affected by the indoor environment.

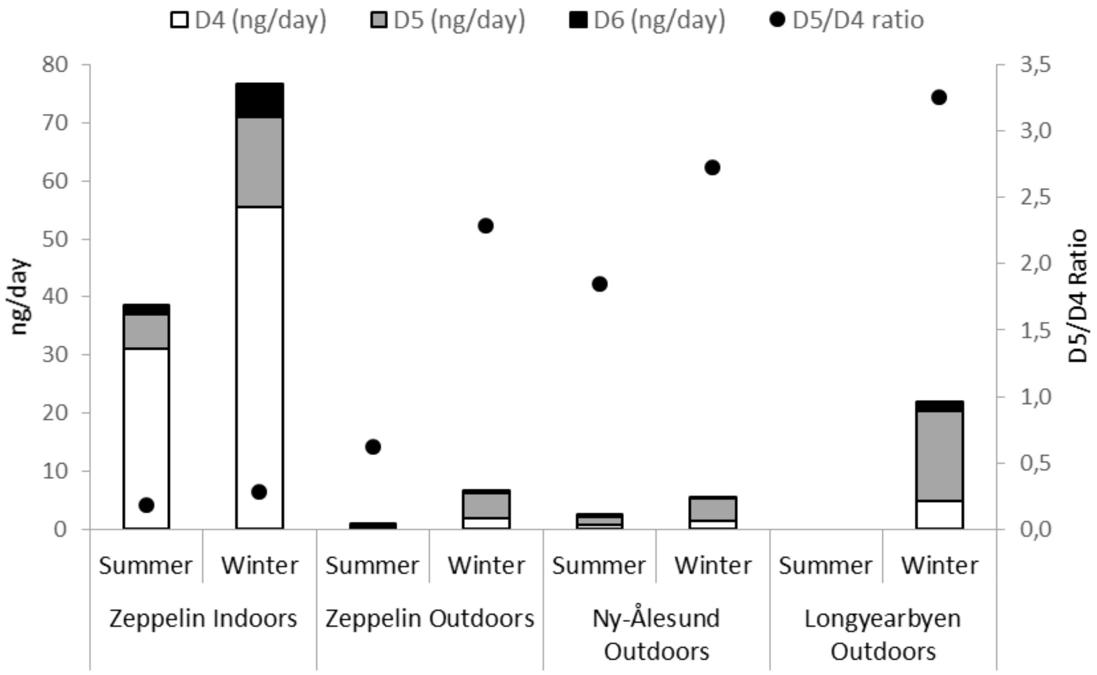


Figure 32: Levels in air (ng/day) and ratios (●) of D5/D4 from PUF-PAS at four Arctic sites in summer (July-August) and winter (November-December) 2017.

5.1.2 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). The global regulation is foreseen to enter into force by the end of 2018. Information regarding levels and distribution of SCCPs in the environment still remain limited, mainly due to analytical challenges (Tomy et al., 1997). The atmosphere is usually considered to be the main transport medium for SCCP, but overall very few studies have been conducted to investigate the atmospheric levels and distribution of SCCPs.

SCCPs (C10-C13) and MCCPs (C14-C17) were included in the monitoring programme at Zeppelin in 2013, 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 was conducted on a monthly basis. At both sites the M/SCCPs are taken 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 LOD values (10-50% of detected masses). In 2017, 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). In 2017, ~25% of the measurements for MCCPs were below LOD while none of the measurements for SCCPs below LOD. The presented data should be considered as semi-quantitative as the contribution of possible contamination during sampling and analyses have not yet been fully validated. Ongoing work at NILU aims to further improve the quality control in 2017-2020.

The annual mean concentrations at Zeppelin for 2017 were as 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 concentrations of cVMS and sum PAHs/PAH-16: 350 pg/m^3 for SCCPs and 130 pg/m^3 for MCCPs (Figure 33). The annual mean concentrations measured for SCCPs do not show any significant difference between the years (2013-2017), but the MCCPs in 2017 were slightly higher than previous years. The levels of SCCPs are significantly higher than those of MCCPs, there are however a few occasions (<10% of the total samples) in which MCCPs are higher than SCCPs. The reason for the higher MCCPs are not known.

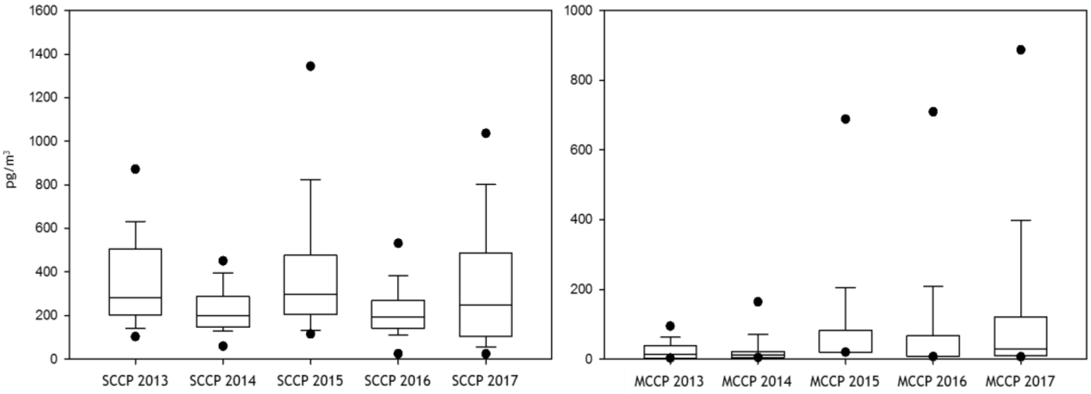


Figure 33: Box plot of measured SCCP and MCCP concentrations in air at Zeppelin in 2013-2017. The box-plots represents a range from 25-75% confidence interval while the error bars and points represent 5-95 percentile and min/max, respectively.

The annual mean concentrations at Birkenes for 2017 were 690 pg/m^3 (320 pg/m^3 excl one outlier) for SCCPs and 160 pg/m^3 (120 pg/m^3 excl. one outlier) for MCCPs. The concentrations observed are very similar to those observed at Zeppelin in 2017, with the exception of the high levels in September at Birkenes (Figure 34). The SCCPs levels were however two to 30 times higher than MCCPs with only levels in December being slightly higher for MCCPs than SCCPs. These data are the first measurements of M/SCCPs in air at Birkenes.

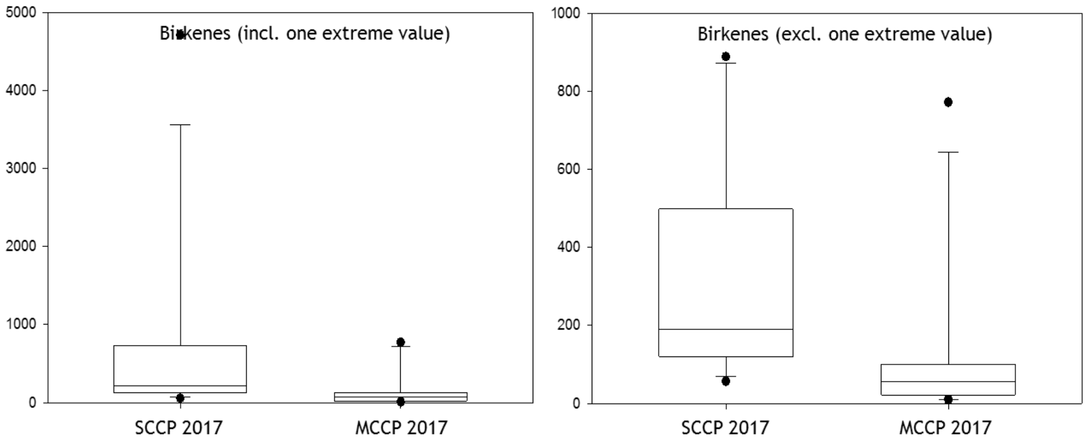


Figure 34: Box plot of measure SCCP and MCCP concentrations in air at Birkenes in 2017 (with and without extreme values, ●).

The concentrations of SCCPs and MCCPs measured at Zeppelin in 2013-2017 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 2017 fluctuated from month to month and higher levels were observed in the second half of 2017 (Figure 35). Higher levels in the second half of 2017 were also observed at Birkenes with levels in September to December being up to one order of magnitude higher than the previous month. Whether this is real or due to influences from new local sources is not known. One potential reason for higher concentrations in September with high but, declining concentrations in October-December can be reformations done at the Birkenes observatory in this period. All products were checked for no content of CPs in the information sheet before being used.

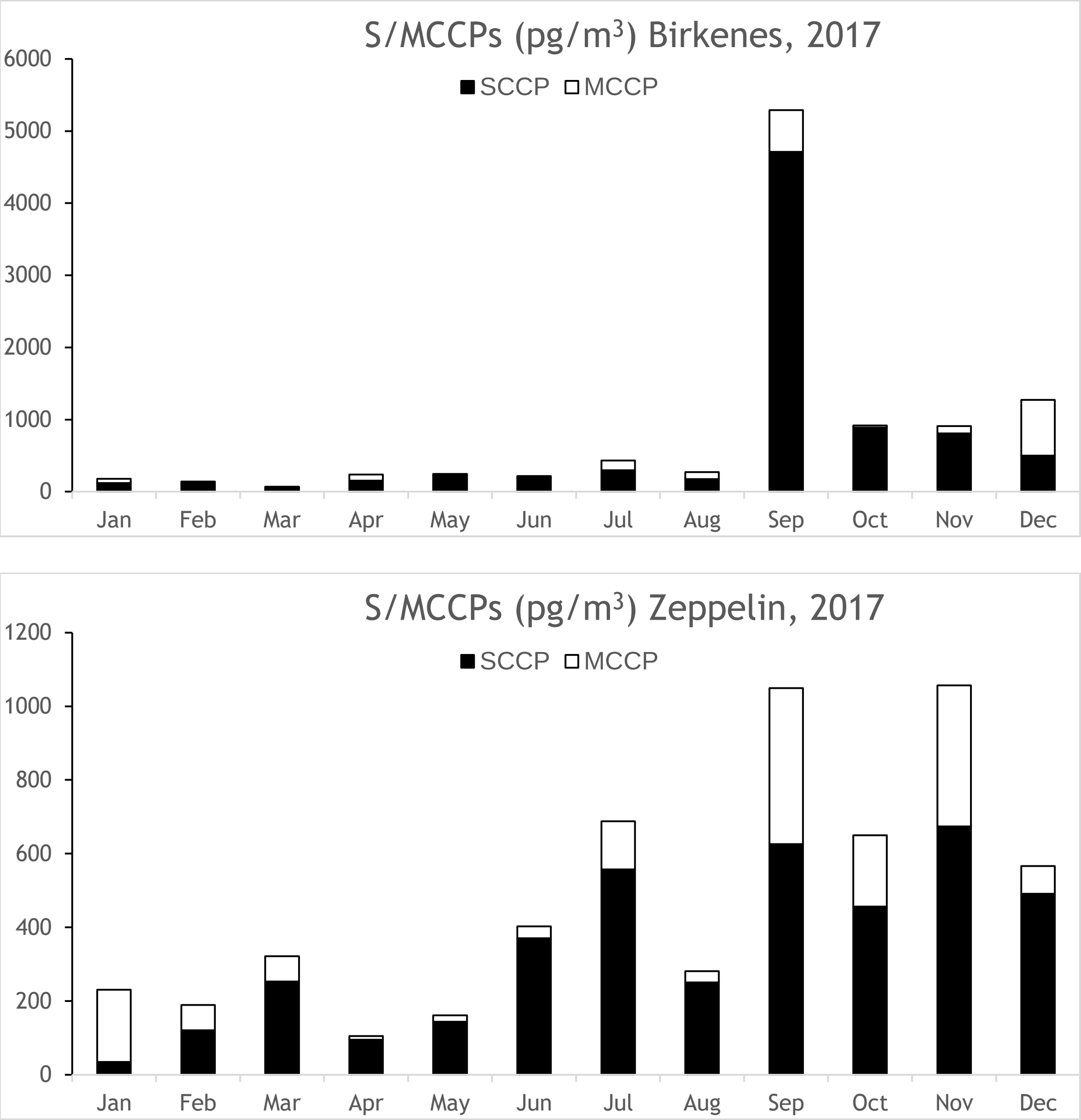


Figure 35: Seasonal variability of SCCPs and MCCPs at Birkenes and Zeppelin in 2017.

At Zeppelin, in 2017, it was also conducted a study to look for potential local sources of CPs in order to be able to give more information on their potential for long-range transport in comparison to influence of local sources. The results of the two passive air sampling campaigns in summer and winter at Zeppelin station (indoors and outdoors), Ny-Ålesund (outdoors), and Longyearbyen (outdoors) show that the concentrations of SCCPs and MCCPs inside the Zeppelin station are significantly higher than the outdoor concentrations with 100-1000 times higher concentrations of SCCPs and 10-100 times higher concentrations of MCCPs. This suggests that indoor environments are potential sources for S/MCCPs in the Arctic. The high levels inside the stations does not seem to affect the outdoor measurements as the i) the air outlet from the station is located downhill from the station, and ii) the concentrations outside Zeppelin are lower than in Longyearbyen and similar or slightly lower than in Ny-Ålesund.

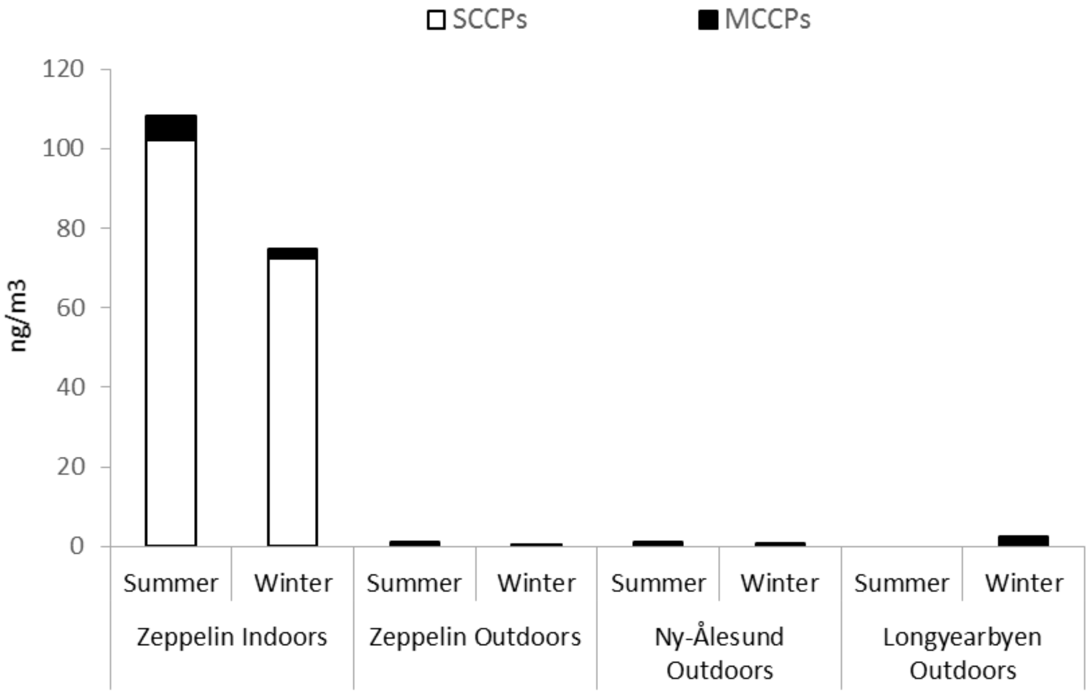


Figure 36: Levels in air (ng/m^3) of SCCP and MCCP from PUF-PAS at four Arctic sites in summer (July-August) and winter (November-December) 2017

5.2 New monitoring in air

Five new groups of non-regulated organic contaminants, covering 57 individual compounds, were included in the monitoring programme in 2017 (Table 7). These were volatile PFAS, new brominated flame retardants (nBFRs), organophosphorous flame retardants (OPFRs), phthalates and dechloranes. Air samples for nBFRs, OPFRs and phthalates were collected at Zeppelin 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 dechloranes were taken on weekly basis at Zeppelin (together with the samples for S/MCCPs, PCBs, HCB, OCPs). The dechloranes were included in the end of 2017 and the analyses of these were therefore performed on two types of samples; i) samples already extracted without internal standard for dechloranes, and ii) samples not yet extracted for which dechlorane internal standard could be added for extraction. This gives a somewhat higher uncertainty for samples i). Air samples were also collected at four sites in Svalbard with increasing distance from Zeppelin observatory in order to assess the influence of local sources on the measurements from Zeppelin. The sites were: Zeppelin station – outdoors; Zeppelin station – indoors, Ny Ålesund – outdoors; and Longyearbyen – outdoors. For this sampling, two types of passive air samples were used, one based on PUF-material and the other based on XAD-adsorbent. Each sampler type was exposed for 10-14 weeks in one summer campaign and one winter campaign.

Table 7
Full names and abbreviations of targeted new organic contaminants in 2017.

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
12:2 fluorotelomer alcohol	12:2 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	
α-Tetrabromoethylcyclohexane	α-TBECH (DBE-DBCH)
β-Tetrabromoethylcyclohexane	β-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
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	
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	DIDP
Dechloranes	
Dechlorane plus syn	syn-DP
Dechlorane plus anti	anti-DP
Dechlorane 601	Dec-601
Dechlorane 602	Dec-602
Dechlorane 603	Dec-603
Dechlorane 604	Dec-604
Dibromo-aldrin	Dba

5.2.1 Per- and polyfluorinated alkyl substances (PFAS)

Volatile PFAS

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

In 2017, nine volatile PFAS were monitored at the three stations, in addition to the ionic PFAS (Table 7): 4:2 FTOH, 6:2 FTOH, 8:2 FTOH, 10:2 FTOH, 12:2 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 ensure as little losses as possible of the volatile PFAS caused by evaporation and degradation during normal soxhlet extraction methodologies.

Of the nine targeted volatile PFAS only three were detected in the active air samples: 6:2-10:2 FTOH. Highest detection frequency (42-100%) was observed for 6:2 FTOH (Table 8). However, despite fewer samples with detected concentrations of 8:2 FTOH and 10:2 FTOH, the individual highest concentrations of volatile PFAS at Andøya and Zeppelin were observed for 8:2 and 10:2 FTOH (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 these measurements and previous measurements.

Table 8

Volatile PFAS in air from active air samplers, presented as detection frequencies and ranges of monthly measurements (pg/m3) at Birkenes, Andøya and Zeppelin, 2017.

	Birkenes		Andøya		Zeppelin	
	Detection frequency (%)	Range (pg/m^3)	Detection frequency (%)	Range (pg/m^3)	Detection frequency (%)	Range (pg/m^3)
4:2 FTOH	0	<3.1	0	<3.1	0	<3.1
6:2 FTOH	75	<3.1-35	100	5.3-14	42	<3.1-28
8:2 FTOH	8	<4.7-7.1	33	<4.7-240	42	<4.7-360
10:2 FTOH	17	<4.7-16	17	<4.7-63	33	<4.7-110
12:2 FTOH	0	<6.3	0	<6.3	0	<6.3
N-EtFOSA	0	<4.7	0	<4.7	0	<4.7
N-EtFOSE	0	<4.7	0	<4.7	0	<4.7
N-MeFOSA	0	<4.7	0	<4.7	0	<4.7
N-MeFOSE	0	<4.7	0	<4.7	0	<4.7

The results of the two passive air sampling campaigns in summer and winter at Zeppelin station (indoors and outdoors), Ny-Ålesund (outdoors), and Longyearbyen (outdoors) show that the levels of PFAS inside the monitoring station were the same as or even slightly lower than the levels outside the station and outdoors in Ny-Ålesund. This suggest no or minor indoor sources of PFAS at the station or other buildings in Svalbard and that the outdoor measurements are not be affected by indoor sources.

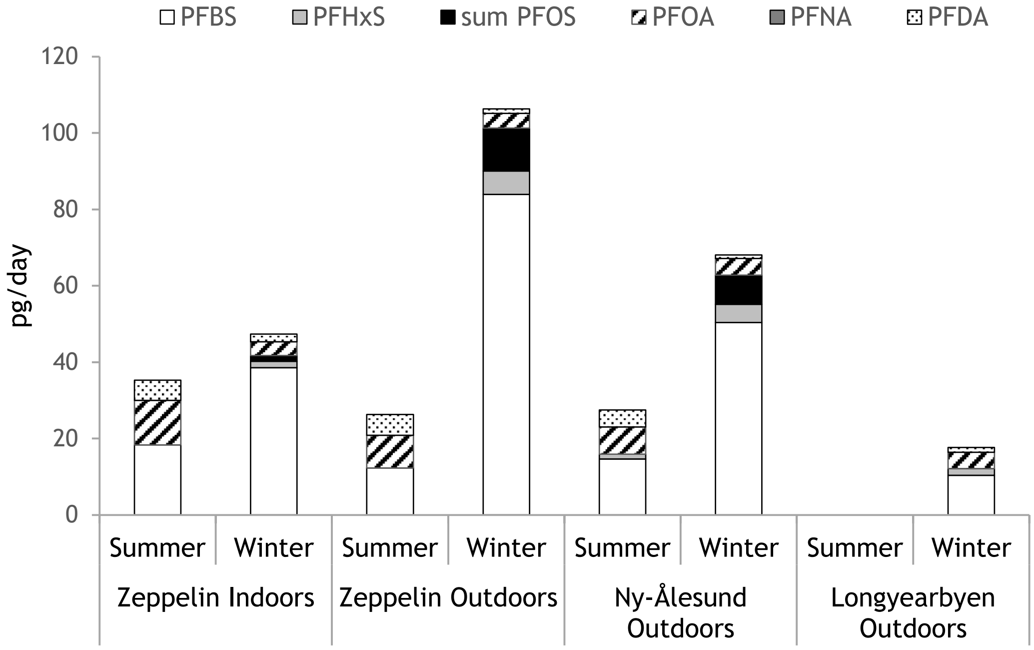


Figure 37: Levels of detected PFAS in air (pg/day) from XAD-PAS at four Arctic sites in summer (July-August) and winter (November-December) 2017.

5.2.2 New brominated flame retardants (nBFRs)

New brominated flame retardants were included in the monitoring programme in 2017. They were measured in one summer campaign and one winter campaign at Zeppelin using active air sampler. Each campaign consisted of six samples taken over 24-48 hr. They were also measured using passive air samplers at four sites in one summer and one winter campaign.

Of the targeted thirteen nBFRs (Table 7), only eight were detected in more than 50% of the active air samples in 2017 (Table 9): α-TBECH, β-TBECH, γ/δ-TBECH, PBT, PBBZ, HBB, DPTE, and EHTBB. In addition, PBEB, was detected in 42% of the samples and included in Table 9. Low detection for BATE is attributed degradation during the chemical analysis and does not necessarily mean low presence in Arctic air. Highest detection frequency and highest concentrations were observed for HBB, both in summer and winter (mean: 0.08 pg/m^3), contributing with 20-26% to the sum of nBFRs. The detection frequency and most of the detected concentrations were lower during the summer campaign than the winter campaign, but this is mainly caused by somewhat higher analytical detection limits in summer than in winter and not by a strong seasonality in air concentrations (Table 9). The profiles in the samples are consistent in summer and winter time. The measured concentrations of the individual nBFRs are 100-10000 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/m3) from active air samplers at Zeppelin, 2017, presented as detection frequencies and concentrations of individual measurements.

		a-TBECH	b-TBECH	g/d-TBECH	PBT	PBEB	PBBZ	HBB	DPTE	EHTBB
		Detection frequency (%)								
		67	50	50	92	42	50	100	67	54
Start	Stopp	Concentration (pg/m^3)								
28.06	30.06	<0.04	<0.03	<0.02	0.110	<0.01	0.04	0.12	0.02	<0.005
10.07	12.07	<0.04	<0.03	<0.02	0.05	<0.01	0.04	0.09	0.02	<0.007
14.07	17.07	<0.04	<0.03	0.03	<0.03	<0.01	<0.02	0.05	<0.008	<0.004
24.07	26.07	0.28	<0.03	<0.02	0.03	<0.01	0.03	0.05	<0.008	<0.005
04.08	07.08	0.28	<0.03	<0.02	0.03	<0.01	0.03	0.05	<0.008	<0.005
16.08	18.08	<0.02	<0.03	<0.02	0.07	0.02	0.04	0.11	<0.008	<0.008
10.11	13.11	0.06	0.02	0.01	0.05	0.03	<0.05	0.12	0.02	0.008
17.11	20.11	0.05	0.02	0.01	0.05	0.03	0.06	0.07	0.002	0.005
24.11	27.11	0.06	0.03	<0.006	0.04	<0.007	<0.05	0.08	0.001	0.005
01.12	04.12	0.04	0.02	0.01	0.03	<0.006	<0.04	0.07	0.004	0.004
08.12	11.12	0.05	0.01	0.01	0.04	0.009	<0.05	0.08	0.003	0.004
15.12	18.12	0.06	0.02	0.01	0.05	<0.005	<0.04	0.07	0.007	0.003

The measurements with passive air samplers around and at Zeppelin showed that levels inside the monitoring station were more than ten times higher than outside the station and that highest levels outdoor were observed at Longyearbyen. This indicates presence of sources of nBFRs in indoor environments, both at the monitoring station and the populated village Longyearbyen. The pattern at the indoor site is different to the pattern at the outdoor sites suggesting different sources indoors and outdoors. While EHTBB, BTBPE and a-TBECH are dominant outdoors, HBB, and PBT are dominant at the indoor sites. These findings suggest that the outdoor measurements are not affected by the indoor environment.

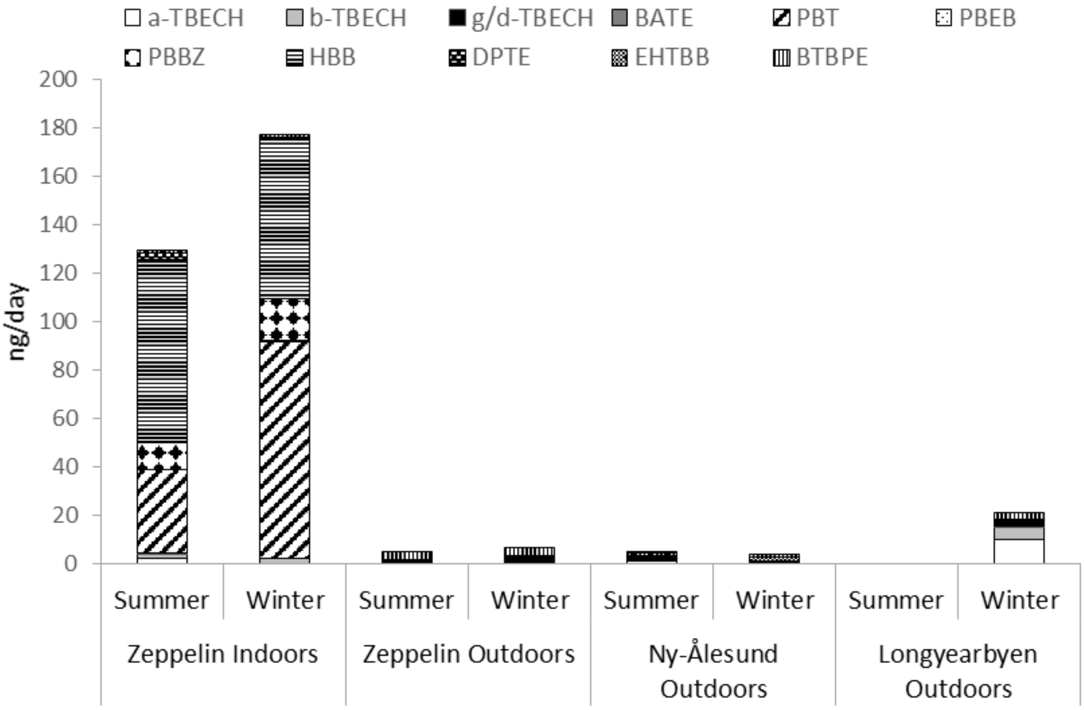


Figure 38: Levels of detected nBFRs in air (ng/day) from PUF-PAS at four Arctic sites in summer (July-August) and winter (November-December) 2017.

5.2.3 Organophosphorous flame retardants (OPFRs)

Organophosphorous flame retardants (OPFRs) were included in the monitoring programme in 2017. They were measured in one summer campaign and one winter campaign at Zeppelin using active air samplers. Each campaign consisted of six samples taken over 24-48 hr. They were also measured using passive air samplers at four sites in one summer and one winter campaign.

The analysis included a list of 17 OPFRs (Table 7). Of these, seven were detected in 50% or more of the active air samples (TEP, TCEP, TCPP, TiBP, DBPhP, TnBP, and TDCPP), one was close to detection limits (TPP) while nine were below LOD in all or most of the samples (i.e. TPrP, BdPhP, TBEP, TCP, EHDPP, TXP, TIPPP, TTBPP, TEHP). Elevated LODs for EHDPP depends on presence during lab procedures and it should not be excluded that it is present in the air at levels below the LOD.

The dominant OPFRs were TCPP (38-200 pg/m^3) and TCEP (12-97 pg/m^3) contributing to 60% and 20%, respectively, of sum OPFRs in summer time. The same compounds were below LOD in the winter campaign. Lower detection during the winter campaign was also observed for DBPhP, TPP, TDCPP and TCP. This was caused by elevated LODs in the winter period. Higher concentrations in summer were observed for three of the OPFRs: TCEP, TCPP and TnBP, while for TEP and TiBP no seasonality was observed. This resulted in different patterns of OPFR compositions in air in summer and winter. In winter, the most dominant compounds were TCP (<170-830 pg/m^3) and TPP (<70-760 pg/m^3) although these compounds were only detected in two of six samples.

The measured concentrations of the detected OPFRs at the Arctic site 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 OPFRs ranged from 60-340 pg/m^3 (mean+median: 170 pg/m^3) in summer, and 2.6-1600 pg/m^3 (mean: 310 pg/m^3, median: 11 pg/m^3) in winter. Previous measurements of OPFRs in Arctic air found similar concentrations of TCEP and TCPP as was observed at Zeppelin. In contrast, the concentrations of TnBP, TDCPP, TPP, TBEP and EHDPP at Zeppelin are lower than those reported from Longyearbyen (the last two not being detected at Zeppelin) (Salamova, 2014).

Table 10

OPFRs in air (pg/m3) from active air samplers at Zeppelin, 2017

Sampling period		pg/m^3								
Start	Stopp	TEP	TCEP	TCPP	TiBP	DBPhP	TPP	TnBP	TDCPP	TCP
30.06.2017	03.07.2017	7.8	42	100	5.2	0.4	5.0	8.9	1.9	<0.3
07.07.2017	10.07.2017	<3.3	13	48	1.9	0.3	<2.6	8.1	2.6	<0.3
12.07.2017	14.07.2017	10	39	110	5.6	0.6	5.1	16	7.2	1.0
21.07.2017	24.07.2017	23	30	110	8.4	0.5	4.4	12	9.2	<0.3
28.07.2017	31.07.2017	4.3	21	63	4.0	0.3	3.4	8.5	3.1	1.4
09.08.2017	11.08.2017	11	98	210	6.2	0.5	8.6	15	5.6	<0.3
10.11.2017	13.11.2017	15	70	<36	15	<0.5	1700	29	<10	1800
17.11.2017	20.11.2017	9.5	<9.1	<36	7.7	<0.5	<82	<3.0	<10	<35
24.11.2017	27.11.2017	<4.1	<9.1	<36	8.3	<0.5	<82	<3.0	<10	<35
01.12.2017	04.12.2017	22	<9.1	<36	7.8	<0.5	<82	<3.0	<10	<35
08.12.2017	11.12.2017	13	<9.1	<36	7.3	<0.5	<82	<3.0	<10	<35
15.12.2017	18.12.2017	18	<9.1	<36	11	<0.5	<82	<3.0	<10	<35

The results of the two passive air sampling campaigns in summer and winter at Zeppelin station (indoors and outdoors), Ny-Ålesund (outdoors), and Longyearbyen (outdoors) show that none of the OPFR compounds was detected in all of the passive air samplers. Five were detected in the two passive air samplers indoors; TEP, TCEP, TCPP, TPP, and TnBP. In addition, TiBP, DBPhP and TCP were detected in one of the indoor samplers. The passive air samplers outdoors only detected TCEP, TiBP, TBEP and TCP. Outdoors at Zeppelin also TPP was detected both in summer and winter. The highest levels of OPFRs were observed in the indoor environment, 2-350 times higher than the three outdoor sites. TCPP and TCEP were the most abundant compounds indoors, contributing to more than 90% of the total OPFRs. This indicates presence of sources of these OPFRs inside the air monitoring station. Low detection of OPFRs outdoors using the passive air samplers hamper the comparison of the indoor and outdoor sites. It suggests that passive air samplers are not yet suitable for measurements of OPFRs at remote sites with low concentrations. Mainly due to influence of blank contamination in the adsorbent.

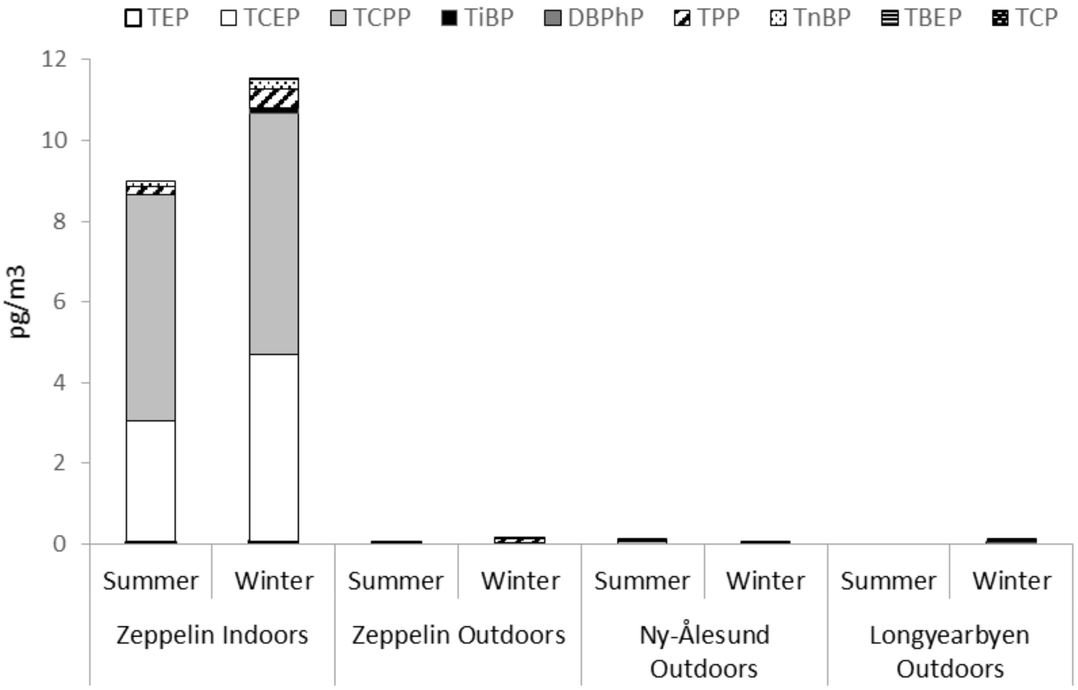


Figure 39: Levels of detected OPFRs in air (pg/m^3) from PUF-PAS at four Arctic sites in summer (July-August) and winter (November-December) 2017.

5.2.4 Phthalates

Phthalates were included in the monitoring programme in 2017. They were measured in one summer campaign and one winter campaign at Zeppelin using active air samplers. Each campaign consisted of six samples taken over 24-48 hr. They were also measured using passive air samplers at four sites in one summer and one winter campaign.

The measurements at Zeppelin show that eight of the eleven targeted phthalates (Table 7) were detected in all or most of the active air samples in the summer and winter campaign (Table 11); DEP, DAIP, DIBP, BBzP, DHP, DEHP, and DPHP. BBzP was close to or below LOD while the other seven phthalates were well above LOD and blank levels. In addition, two compounds, DBP and DINP were detected in most samples in summer, but not in winter. Only DPP and DcHP were below LOD (2 and 9 pg/m^3 respectively) in all or most samples. In the winter campaign, lower levels and lower detection frequencies were observed for most compounds indicating a seasonality of phthalates in Arctic air. In contrast, BBzP was higher in winter than in summer. All the data are blank adjusted.

The observed concentrations for the detected phthalates were high, even exceeding the individual concentrations for the OPFRs. Highest concentrations were observed for DiBP both in summer and winter (0.8-7.7 ng/m^3; 0.06-0.9 ng/m^3), DEHP both summer and winter (0.3-1.5 ng/m^3; <0.1-1 ng/m^3) and DEP both summer and winter (0.2-1.2 ng/m^3; <0.01-1.6 ng/m^3). Contributing to 39%, 12% and 8% of the sum phthalate concentrations in summer and 36%, 26% and 22% in winter time, respectively. In addition, in summer DINP (0.2-4.2 ng/m^3) contributed to 34% of the sum of phthalates while only with 3% in winter. The concentrations of the sum of the targeted phthalates (sum phthalates) ranged from 2.9-10 ng/m^3 (mean+median 6.9 ng/m^3) in summer and 0.2-3.7 ng/m^3 (mean: 1.4 ng/m^3, median 0.6 ng/m^3) in winter.

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. 2005).

Table 11
Phthalates in air (pg/m3) from active air samplers at Zeppelin, 2017

Sampling period		ng/m^3								
Start	Stopp	DEP	DAIP	DiBP	DBP*	BBzP*	DHP	DEHP	DPHP	DINP
26.07.2017	28.07.2017	600	13	1800	*200*	<2	140	2600	52	2900
02.08.2017	04.08.2017	530	36	2200	*140*	*4.2*	110	920	40	*2500*
07.08.2017	08.08.2017	430	8.2	3300	*180*	<2	74	880	*20*	*950*
21.08.2017	23.08.2017	1200	260	7700	*380*	<2	330	*410*	37	*<300*
23.08.2017	25.08.2017	160	14	780	*74*	*4.4*	66	*140*	*8*	*1600*
30.08.2017	01.09.2017	490	35	1600	*170*	<2	480	*220*	*22*	4200
15.11.2017	17.11.2017	1600	270	910	310	<2	250	*340*	*<3*	*<300*
24.11.2017	24.11.2017	680	38	260	*<24*	*17*	28	*<100*	*<3*	*<300*
29.11.2017	29.11.2017	620	21	590	*99*	43	70	1000	*10*	*520*
06.12.2017	06.12.2017	*<10*	*6*	*91*	*<24*	*8*	11	*120*	*6*	*<300*
11.12.2017	11.12.2017	*<10*	*13*	200	*<24*	*13*	19	*<100*	*<3*	*<300*
13.12.2017	13.12.2017	*<10*	*4*	*60*	*<24*	*7*	*8*	*120*	*5*	*<300*

*Italic: Influenced by blank levels.

The results of the two passive air sampling campaigns in summer and winter at Zeppelin station (indoors and outdoors), Ny-Ålesund (outdoors), and Longyearbyen (outdoors) show good detection for DEP, DiBP, DBP, and DHP in most or all of the passive air samplers. DiBP, DHP and DBP were the most abundant compounds indoors. When detected also DEHP and DEP were observed in similar levels. The highest levels of phthalates were observed in the indoor environment, 4-90 times higher than the three outdoor sites. This indicates presence of sources of phthalates inside the air monitoring station. The pattern in the indoor site is similar to the patterns at the outdoors sites suggesting possible common origin.

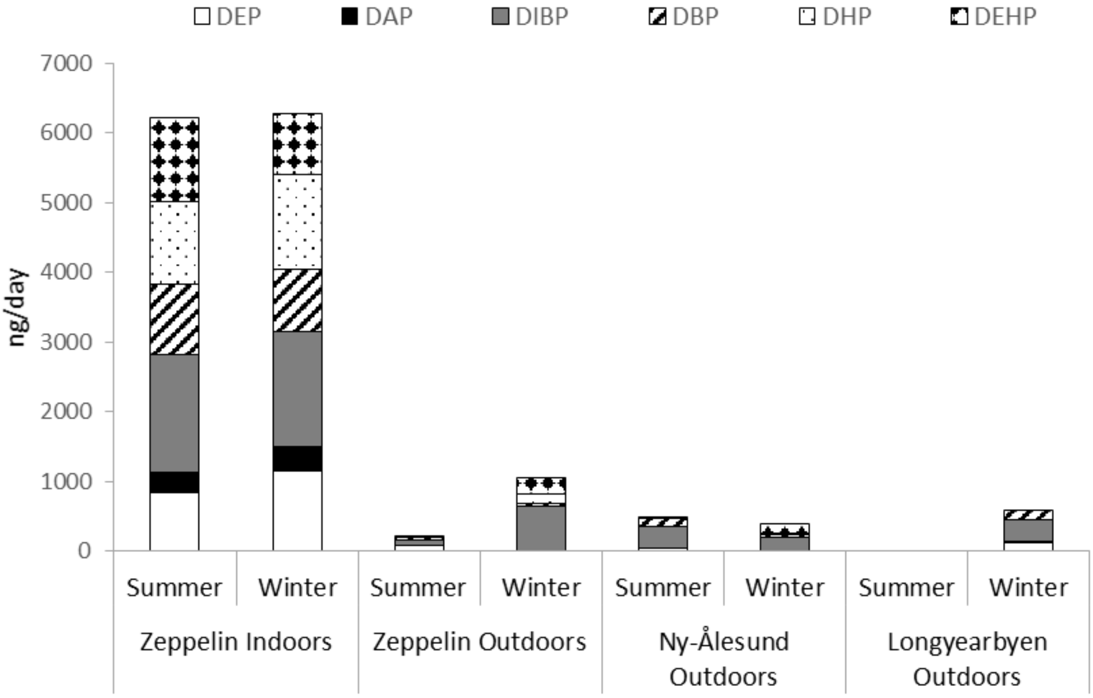


Figure 40: Levels in air (ng/day) of detected phthalates from PUF-PAS at four Arctic sites in summer (July-August) and winter (November-December) 2017

5.2.5 Dechloranes

Dechloranes were included in the monitoring programme of Zeppelin in 2017. They were measured on weekly basis at Zeppelin using active air samplers. Each sample was taken over 48 hr.

The air sampling at Zeppelin show that the targeted dechloranes were not detected or detected to very low extent. Only dechlorane plus syn and plus anti were above the analytical detection limit, but most of the detected concentrations were lower or similar to the levels in field blanks (0.04 and 0.02 pg/m^3 for Dechlorane plus syn and plus anti, respectively). Syn- and anti-dechlorane plus have been detected in Arctic air at concentrations between 0.02 and 4.1 pg/m^3 (Møller et al. 2010) with the lowest concentrations measured outside Svalbard in the Greenland sea.

Table 12
Dechloranes in air (pg/m3) from active air samplers at Zeppelin, 2017

	Dechlorane plus syn	Dechlorane plus anti	Dechlorane 601	Dechlorane 602-603	Dechlorane 604	Dibromoaldrin
LOD	<0.02	<0.05	<0.0005	<0.0001	<0.001	<0.001
Detection frequency (%)	35	30	0	0	0	0
Detected concentrations (pg/m^3)	0.04-0.16	0.09-0.21	-	-	-	-

6. 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 2017 are presented in Table 13.

Table 13

Annual mean concentrations in air for all targeted organic pollutants, (pg/m3), 2017.

Organic contaminants, class	Annual mean concentration		
	Birkenes	Andøya	Zeppelin
HCB	51	36	76
HCHs	6.1		4.0
DDTs	1.0		0.4
Chlordanes			0.7
PCBs	10		8.5
PAH-16	1900		600
PBDEs	0.6		6
TBA	4.2		9.4
HBCD	0.1		0.1
PFOA	0.1	0.1	0.1
cVMS	2200		630
S/MCCPs	850		480
PFAS (volatile)	30	60	70
nBFRs			0.3
OPFRs			210
Phthalates			4100
Dechloranes			0.2

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

The results from the air monitoring in 2017 show that the concentrations of most legacy POPs in air and precipitation are declining or have stabilized (reached steady-state conditions) during the last years. For HCB, an increase in concentrations has been observed at Zeppelin, Svalbard, during the last ten years, and at Birkenes during the last five years. The increasing trend for HCB has flattened out in 2016 and 2017 at Zeppelin and also at Birkenes in 2017. On a longer perspective, long-term trend analysis using a DF technique shows significantly decreasing concentrations in air for organochlorine pesticides and PCBs, but not for HCB, and B(a)P.

7. Heavy metals

7.1 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 2017 are presented in Table 14. The wet depositions are obtained by multiplying the volume weighted concentrations with the precipitation amounts (ng-mg/m^2) and the results for 2017 are presented in Table 15. 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., 2018).

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

Table 14
Volume weighted annual mean concentrations of heavy metals (ug/L) and mercury (ng/L) in precipitation in 2017.

	Pb	Cd	Zn	Ni	As	Cu	Co	Cr	Mn	V	Al	Hg
Birkenes	0.67	0.018	2.9	0.2	0.09	2.4	0.02	0.1	1.5	0.16	-	5.8
Hurdal	0.38	0.013	4.2	-	-	-	-	-	-	-	-	-
Kårvatn	0.10	0.003	1.2	-	-	-	-	-	-	-	-	-
Svanvik	0.85	0.088	4.2	27.6	1.2	34.0	0.85	0.25	-	0.47	19.6	-
Karpdalen	0.77	0.059	5.0	20.2	0.8	25.5	0.63	0.32	-	0.45	48.4	-

Table 15
Total wet deposition of heavy metals (ug/m2) and mercury (ng/m2) in 2017.

	Pb	Cd	Zn	Ni	As	Cu	Co	Cr	Mn	V	Al	Hg
Birkenes	1306	36	5608	390	184	4623	39	201	3010	321	-	11407
Hurdal	353	12	3931	-	-	-	-	-	-	-	-	-
Kårvatn	172	5	2069	-	-	-	-	-	-	-	-	-
Svanvik	342	36	1703	11151	488	13708	343	102	-	189	7925	-
Karpdalen	269	21	1734	7054	280	8902	218	112	-	158	16873	-

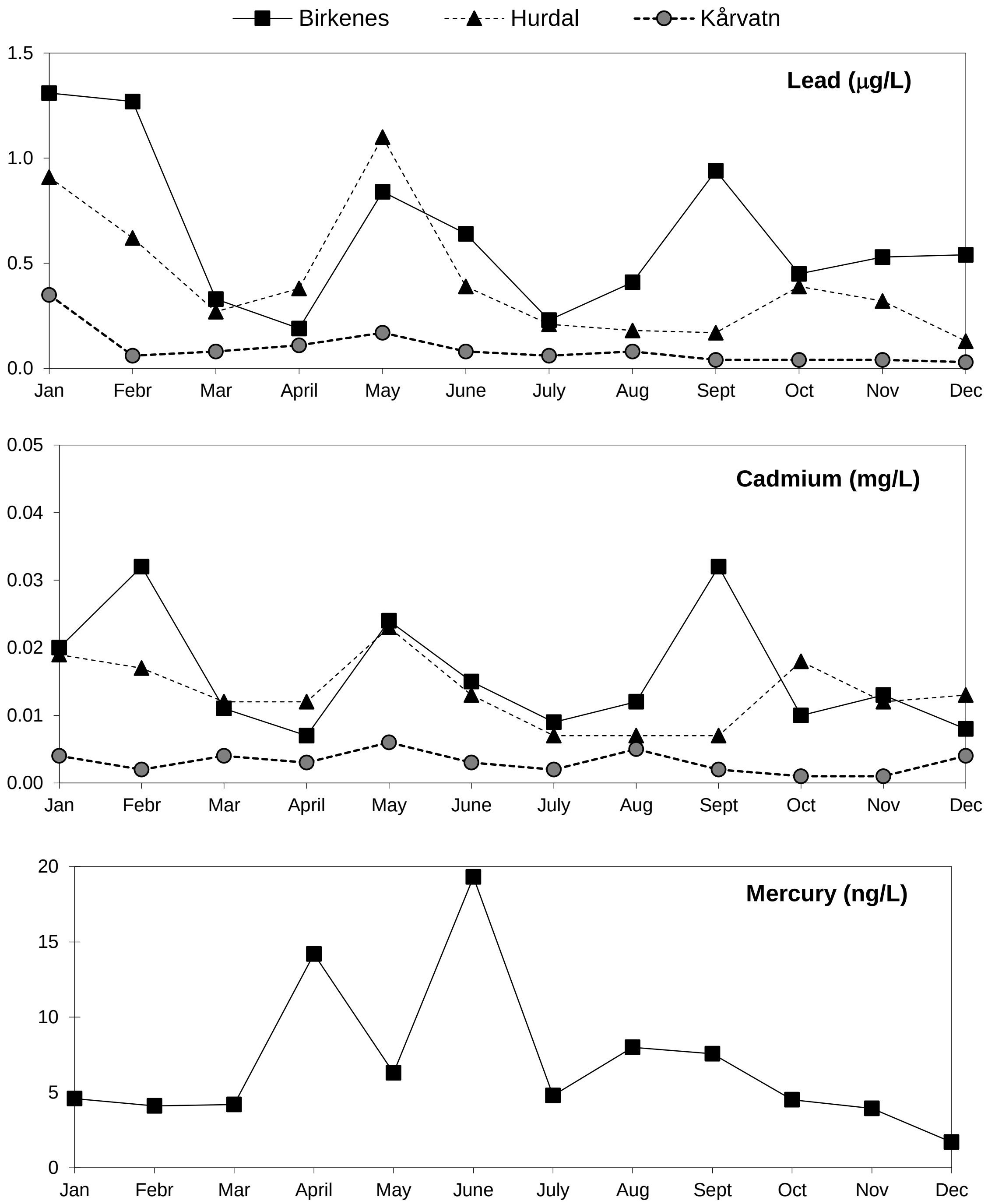


Figure 41: Volume weighted monthly mean concentrations of lead, cadmium and mercury in precipitation in 2017

The monthly mean concentration for lead, cadmium and mercury are shown in Figure 41. There is no clear seasonal variation, but elevated levels of lead and cadmium are seen in September at Birkenes and Hurdal, and in April for mercury at Birkenes. The reasons for these peaks are unclear.

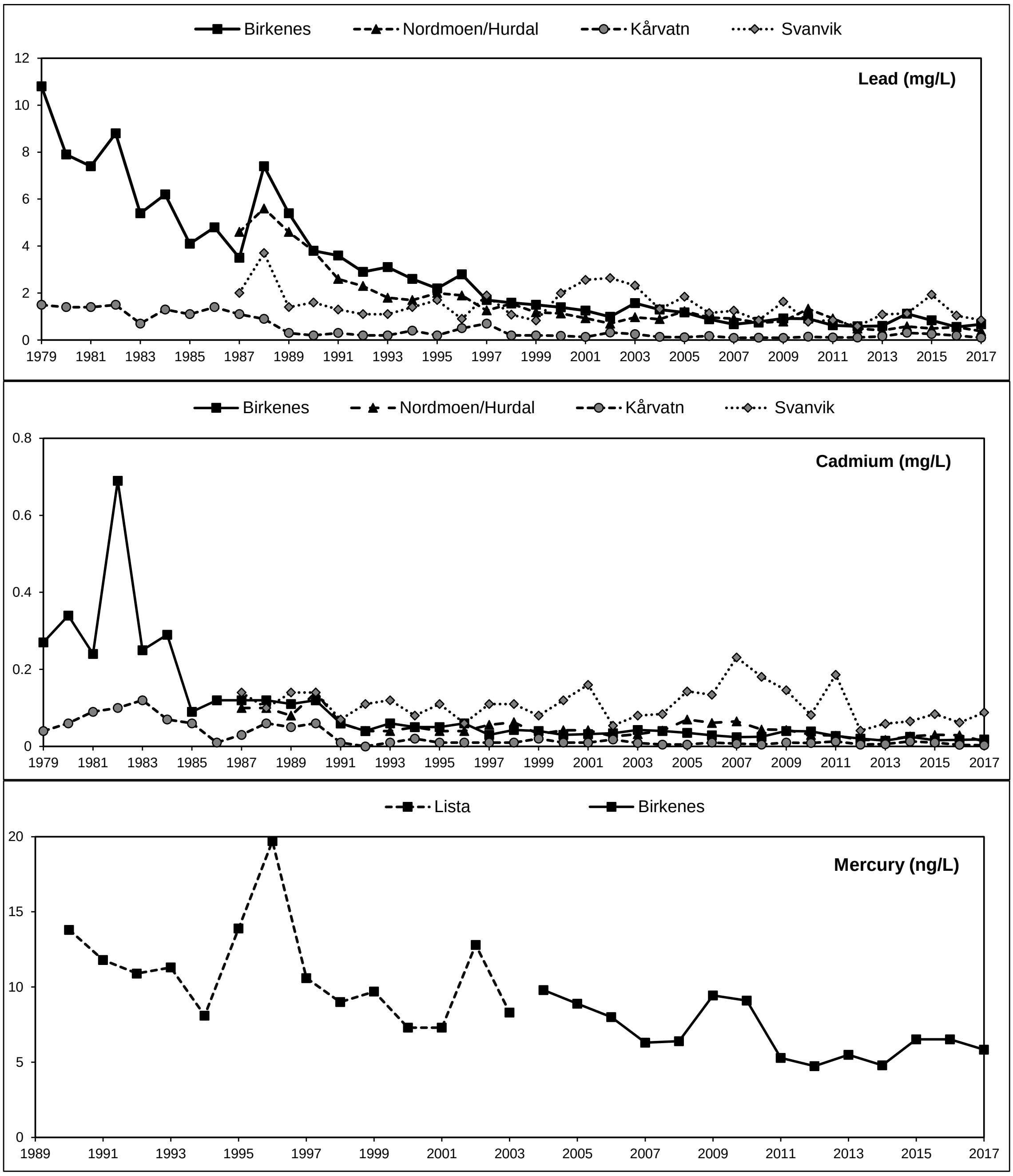


Figure 42: Time series of volume weighted annual mean concentrations of lead, cadmium and mercury in precipitation at Norwegian background stations.

Figure 42 and Table A.2. 25 show volume weighted annual mean concentrations in precipitation from 1979 to 2017. In 2017, the concentrations were in general lower for most metals, except at Birkenes were there was a small increase in lead, cadmium and some other trace elements. For deposition, it was an increase at all sites for cadmium, and a decrease in zinc and lead (except at Birkenes). The increases in deposition are mainly due to somewhat higher precipitation amount in 2017 compared to 2016.

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 2017; 54-95% since 1990, and 55-58% since 2000 (except at Kårvatn with no significant trend) (Table 17).

The concentrations of cadmium in precipitation at Birkenes and Kårvatn, (and Hurdal since 1990) have been largely reduced; 95-99% between 1980 and 2017; 54-73% since 1990, and 52-54% since 2000 (except at Kårvatn with no significant trend) (Table 17). These reductions are consistent with those observed at other EMEP sites with long-term measurements and can be explained by large European emission reductions of lead and cadmium during this period (Tørseth et al., 2012; Colette et al., 2016). At Svanvik there has been a reduction in lead from 2000, while no significant reduction trends for cadmium have been observed at Svanvik.

The concentrations of zinc in precipitation have been reduced by 67% since 1980 and 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 17). 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 trends for the concentrations are reflected in the trends for the wet deposition which gives similar results. There are no significant changes in precipitation amount so the trends in wet deposition is controlled by the trends in concentration.

When combining the datasets from Lista and Birkenes, mercury levels appear to have been significantly reduced (59%) 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 2017 with 36%.

For the other elements, such as nickel, cobalt and copper, there has been an increase in concentrations at Svanvik since 1990, while decrease in chromium. There are large annual variations in the concentration levels, and this may be due to meteorological variations as well as changes in the composition of the ore used at the smelters in the Kola Peninsula. For further discussion, it is referred to the report by Berglen et al. (2018).

7.2 Heavy metals in air

The annual mean concentrations of the heavy metals measured in air in 2017 are given in Table 16, and the weekly concentrations of lead and cadmium are illustrated in Figure 42. The monthly mean concentrations can be found in Annex 1, tables A.2 27-33.

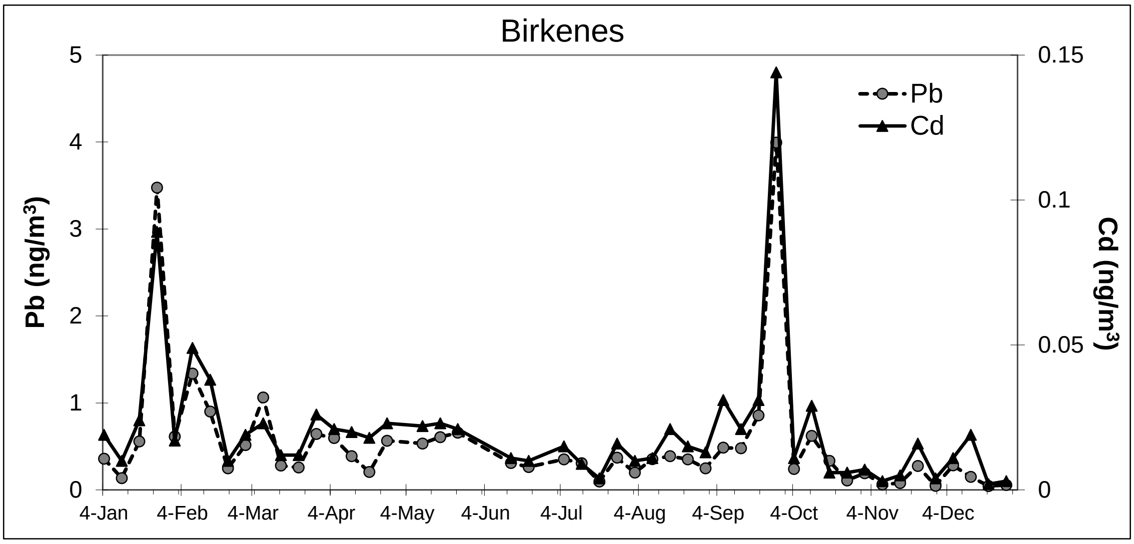
In general, the concentrations of most heavy metals in air at Birkenes in 2017 are two-three times higher than those observed at Andøya and Zeppelin. This is likely because Birkenes is closer to the emission sources at the European continent. In turn, at Svanvik and Karpdalen, the concentrations in air are about ten times higher than those observed at Birkenes. This suggest local sources 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 may be due to a longer residence time in the atmosphere for gaseous mercury than the particulate bound heavy metals, which results in a larger potential for long-range transport from emissions sources. As a consequence, mercury may be distributed over greater geographical distances and is a global pollutant to a greater extent than the other heavy metals.

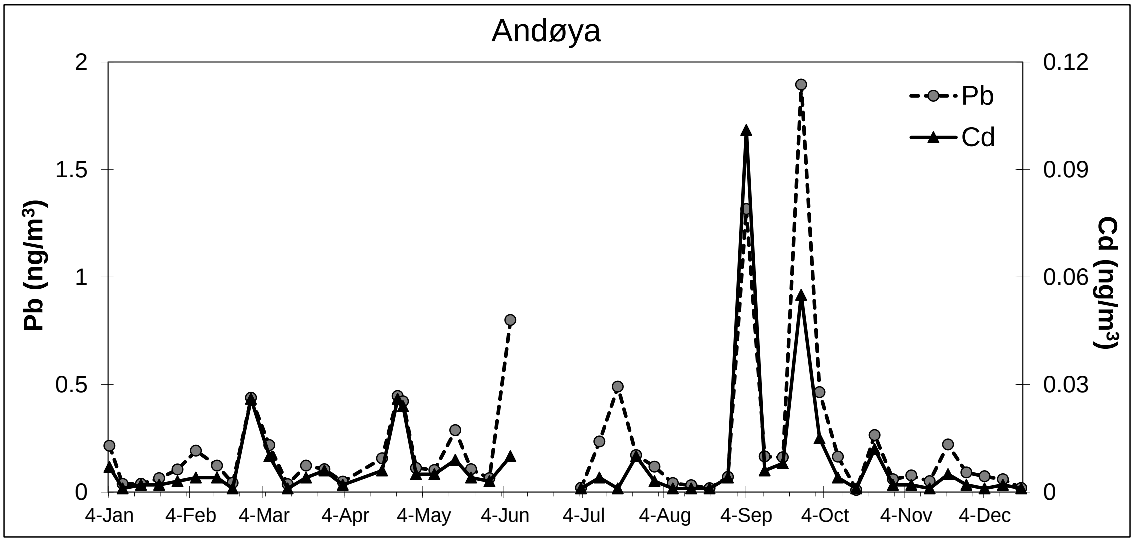
Table 16
Annual mean concentrations of heavy metals in air and aerosols in 2017, Unit: ng/m3.

	Al	As	Cd	Cr	Co	Cu	Pb	Mn	Ni	V	Zn	Hg(g)
Birkenes		0.14	0.021	2.91	0.013	0.31	0.54		0.15	0.20	3.2	1.45
Andøya		0.04	0.008	0.14	0.012	0.51	0.22	0.54	0.18	0.13	0.97	1.40
Zeppelin		0.06	0.011	0.29	0.015	0.28	0.28	0.86	0.36	0.09	1.6	1.43
Trollhaugen												0.98
Karpdalen*	36.9	2.78	0.278	0.26	0.333	8.22	4.24	0.72	8.47	3.13	10.05	
Svanvik*	39.4	1.93	0.180	0.29	0.383	8.13	2.39	0.83	9.85	2.50	8.64	

* Updated version. Original data of Pb, Mn, Ni, V and Zn published in October 2018, was corrected 27 March 2019

As in previous years, the annual mean concentrations at Andøya and Zeppelin in 2017 are comparable; some elements are higher at one of the sites while others are higher at the other site. These differences are due to individual episodes with high concentrations of heavy metals arriving to Zeppelin and Andøya, especially during the winter at Zeppelin in 2017, and these episodes are not coinciding at the two sites Figure 43. The episodes with high levels of cadmium and lead are however well correlated at the individual sites Figure 43. 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 favors long range transport from the emission sources at the continent. The episode observed at Zeppelin 17-19 April 2017 is related to air masses arriving from central part of Russia, while the two episodes in September at Andøya (4-6 and 25-27 sept), the are masses come from East and South-East. At Birkenes there are two main episodes, one in January where the air masses comes from UK while the one in September from Eastern Europe.





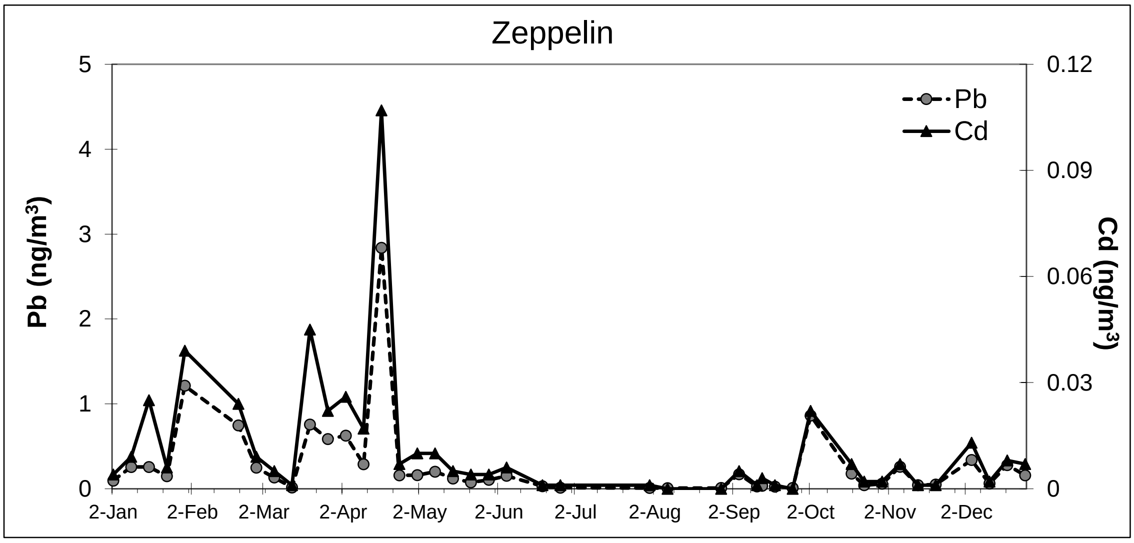


*Figure 43: **Weekly concentrations of lead and cadmium in air at Norwegian background stations in 2017, Unit: ng/m³.***

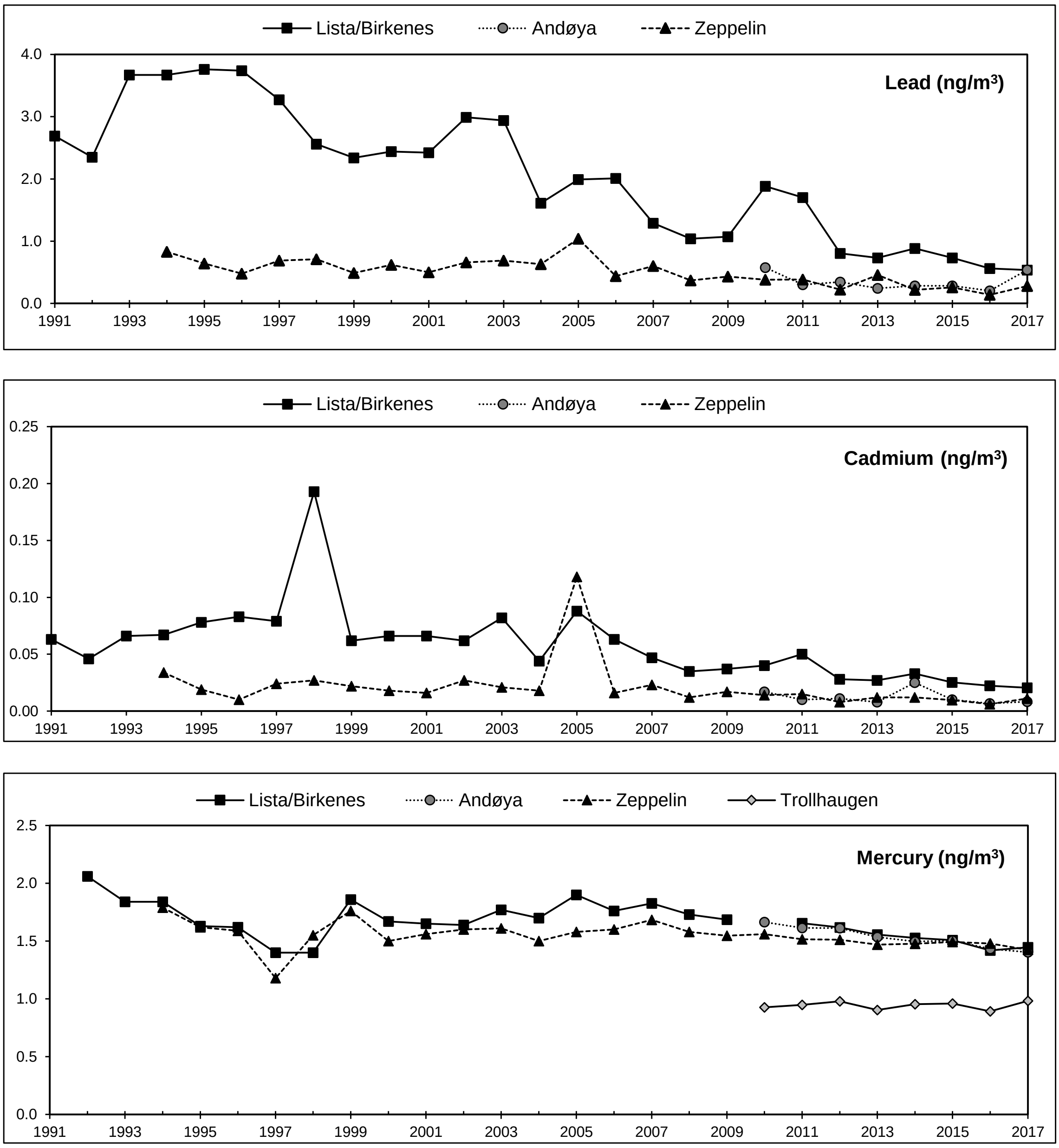


Figure 44: Time series of annual mean concentrations of lead, cadmium and mercury in air and aerosols, 1991-2017, Unit: ng/m^3.

The air concentrations for lead and cadmium 2017 are somewhat lower at Birkenes compared to 2016 while higher at the two other sites. For mercury it's the opposite with a small increase at Birkenes (and Trollhaugen) while a decrease at the two northern sites. The long-term time series of the annual mean concentrations of lead, cadmium and mercury are shown in Figure 44. The annual concentrations for all the elements for all years and sites can be found in Table A.2. 27 - Table A.2. 32.

At Lista/Birkenes there has been a significant reduction in air concentrations for almost all the elements (As, Cd, Cr, Pb, Ni, Zn and V) for the period 1991 to 2017. 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 84% and 60% respectively at Birkenes and Zeppelin (Table 18). For cadmium, there were similar trends at the two sites, 66% and 58% reductions respectively. For mercury, small decreasing trends are observed at Birkenes (19%) and Zeppelin (10%). 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 2000-2017, though at Zeppelin there are a positive trend for Cr, Mn and Ni. For some elements measured at Svanvik, there are observed increase in concentrations (Table 17). This can be due to 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. (2018).

Table 17

Time trends of heavy metal concentrations in precipitation (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	Ni	Hg
1980-2017									
Birkenes	~-100	-99	-67						
Kårvatn	~-100	-95	-						
1990-2017									
Birkenes	-95	-73	-42						-59
Hurdal	-88	-57	74						
Kårvatn	-54	-54	98						
Svanvik	-	-	-	-	113	-36	191	150	
2000-2017									
Birkenes	-55	-54	-						-36
Hurdal	-58	-52	-						
Kårvatn	-	-	113						
Svanvik	-67	-	-41						

Table 18

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)-2017											
Birkenes (from 1991)	-84	-66	-32	-68		-75	-42		-66		-19
Zeppelin (from 1994)	-60	-58	-	-64	-	-	-36	68	-	-61	-10
2000-2017											
Birkenes	-81	-71	-51	-62	-51	-	-56		-73	-94	-20
Zeppelin	-71	-59	-	-74	-	243	-42	136	65	-38	-9

8. References

Aas, W., Nizzetto, P.B. (2017) Heavy metals and POP measurements, 2015. Kjeller, Norwegian Institute for Air Research (EMEP/CCC-Report 4/2017).

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

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

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. Anal. Chim. Acta, 209, 151-161.

Bohlin, P., Audy, O., Skrdlikova L., Kukučka, P., Pribylova P., Prokes, R., Vojta S., Klánová, J. (2014) Outdoor passive air sampling of semi volatile organic compounds (SVOCs): a critical evaluation of performance and limitations of polyurethane foam (PUF) disks. Environ Sci. Process. Impacts, 16, 433-444.

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

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).

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.

CIRS. EU Includes decaBDE Restriction under REACH Annex XVII. URL: http://www.cirs-reach.com/news-and-articles/EU-Includes-decaBDE-Restriction-under-REACH-Annex-XVII.html [Assessed June 2018]

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).

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

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).

EMEP/CCC: Manual for sampling and chemical analysis, Norwegian Institute for Air Research, Kjeller, EMEP/CCC report 1/95 (Last rev. https://www.nilu.no/projects/ccc/manual/index.html), 2001.

European Chemicals Agency. URL: http://echa.europa.eu/about-us/who-we-are/member-state-committee/opinions-of-the-msc-adopted-under-specific-echa-s-executive-director-requests [Accessed May 2018].

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.

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).

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.

Halse, A.K., Schlabach, M., Sweetman, A.J., Jones, K.C., Breivik, K. (2012) Using passive air samplers to assess local sources versus long range atmospheric transport of POPs. J. Environ. Monit., 14, 2580-2590.

Hung, H., Kallenborn, K., Breivik, K., Su, Y., Brorstrom-Lunden, E., Olafsdottir, K., Thorlacius, J., Leppanen, S., Bossi, R., Skov, H., Mano, S., Patton, G., Stern, G., Sverko, E., Fellin, P. (2010) Atmospheric monitoring of organic pollutants in the Arctic under the Arctic Monitoring and Assessment Programme (AMAP): 1993-2006. Sci. Total Environ., 408, 2854-2873.

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, Soil Pollut., 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. (2010) Determination of decamethylcyclopentasiloxane in air using commercial solid phase extraction cartridges. J. Chromatogr. A., 1217, 3557-3560.

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.

Melymuk, L., Bohlin, P., Sanka O., Pozo K., Klánová, J. (2014) Current challenges in air sampling of semivolatile organic contaminants: sampling artifacts and their influence on data comparability. Environ. Sci. Technol.; 48, 14077-14091.

Möller, A., Xie, Z., Sturm, R., Ebinghaus, R. (2010) Large-scale distribution of dechlorane plus in air and seawater from the Arctic to Antarctica. Environ. Sci. Technol., 44, 8977-8982.

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 OR, 14/2016)

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 OR, 14/2016)

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

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., 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)

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 2018].

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 2018].

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 2018].

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 2018].

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 2018].

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 2018].

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 2018].

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 2017].

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, 2017

Birkenes	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
HCB	62.2	68.5	63.7	59.2	53.8	38.1	34.2	36.3	38.2	45.4	59.1	57.6	51.0
α-HCH	2.12	2.04	3.50	3.52	8.65	4.71	4.53	5.01	0.11	5.32	3.48	1.89	3.74
γ-HCH	1.12	0.35	0.94	0.58	11.50	3.57	4.09	2.98	0.13	1.16	0.98	0.59	2.33
sum HCHs	3.24	2.39	4.44	4.10	20.15	8.28	8.62	7.99	0.24	6.48	4.46	2.48	6.07
p,p'-DDT	0.13	<0.05	0.09	0.06	0.68	0.25	0.16	0.16	<0.05	0.21	<0.05	<0.05	0.18
o,p'-DDT	0.11	<0.04	0.10	0.06	0.76	0.21	0.13	0.13	<0.04	0.20	0.10	0.05	0.16
p,p'-DDE	0.77	0.26	0.60	0.31	2.21	0.47	0.43	0.42	<0.05	0.85	0.48	0.38	0.60
o,p'-DDE	0.07	<0.04	0.07	0.04	0.16	<0.04	0.06	0.04	<0.04	0.05	<0.04	<0.04	0.06
p,p'-DDD	<0.02	<0.02	<0.02	<0.03	0.03	<0.03	<0.02	<0.03	<0.03	<0.02	<0.02	<0.02	*0.03*
o,p'-DDD	<0.02	<0.02	<0.02	<0.03	0.05	<0.03	<0.02	<0.03	<0.03	<0.02	<0.02	<0.02	*0.03*
sum DDTs	1.13	*0.44*	0.91	0.51	3.88	1.02	0.83	0.81	<0.24	1.35	0.77	0.57	1.04

Table A.1. 2: Monthly and annual mean concentrations (pg/m^3) for PCBs in air at Birkenes, 2017

Birkenes	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2017**
PCB-18	0.969	1.755	1.414	0.875	1.786	1.014	0.795	0.636	1.194	0.953	0.635	0.649	1.049
PCB-28	0.473	0.732	0.554	0.428	1.094	0.676	0.621	0.476	0.948	0.667	0.355	0.347	0.611
PCB-31	0.475	0.759	0.613	0.409	1.040	0.622	0.567	0.449	0.780	0.569	0.305	0.341	0.574
PCB-33	0.246	0.405	0.292	0.215	0.547	0.348	0.322	0.248	0.407	0.303	0.155	0.182	0.304
PCB-37	0.043	0.066	0.044	0.026	0.082	0.064	0.073	0.054	0.072	0.056	0.023	0.030	0.053
PCB-47	0.601	0.542	0.500	0.448	1.168	1.005	1.087	0.975	0.823	0.667	0.313	0.292	0.703
PCB-52	0.629	0.813	0.639	0.478	1.290	0.791	0.687	0.619	0.797	0.659	0.380	0.366	0.675
PCB-66	0.135	0.168	0.128	0.099	0.283	0.203	0.194	0.162	0.218	0.162	0.073	0.074	0.158
PCB-74	0.127	0.157	0.117	0.068	0.191	0.131	0.144	0.122	0.178	0.131	0.063	0.062	0.125
PCB-99	0.140	0.156	0.140	0.097	0.237	0.170	0.151	0.135	0.185	0.140	0.076	0.064	0.141
PCB-101	1.085	1.130	0.550	0.257	0.796	0.515	0.484	0.420	0.486	0.387	0.203	0.177	0.540
PCB-105	0.058	0.061	0.030	0.017	0.043	0.034	0.036	0.029	0.043	0.029	0.014	0.011	0.034
PCB-114	<0.008	<0.008	<0.008	<0.008	*0.010*	<0.008	<0.008	<0.008	*0.009*	<0.008	<0.008	<0.008	*0.008*
PCB-118	0.291	0.299	0.139	0.062	0.161	0.124	0.129	0.104	0.149	0.104	0.053	0.040	0.139
PCB-122	0.017	0.018	*0.010*	<0.007	<0.007	<0.007	<0.007	<0.007	*0.009*	<0.007	<0.007	<0.007	*0.009*
PCB-123	*0.008*	<0.007	<0.007	<0.007	<0.007	*0.010*	<0.007	<0.007	*0.008*	<0.007	<0.007	<0.007	*0.008*
PCB-128	0.099	0.095	0.036	0.013	0.033	0.025	0.023	0.018	0.021	0.015	0.007	*0.006*	0.033
PCB-138	0.853	0.842	0.301	0.086	0.243	0.170	0.193	0.157	0.187	0.136	0.064	0.052	0.275
PCB-141	0.283	0.284	0.091	0.023	0.082	0.053	0.055	0.043	0.048	0.037	0.016	0.013	0.086
PCB-149	1.176	1.184	0.474	0.169	0.543	0.363	0.340	0.296	0.304	0.256	0.120	0.105	0.445
PCB-153	1.189	1.163	0.463	0.147	0.427	0.296	0.299	0.249	0.278	0.221	0.105	0.093	0.413
PCB-156	0.055	0.055	0.019	*0.006*	0.011	0.008	0.008	0.006	0.010	0.006	<0.005	<0.005	0.016
PCB-157	0.004	0.005	*0.003*	<0.003	<0.003	*0.004*	<0.003	<0.003	*0.003*	<0.003	<0.003	<0.003	*0.003*
PCB-167	0.027	0.026	*0.010*	*0.004*	0.007	0.006	0.004	*0.003*	*0.005*	0.004	<0.003	<0.003	0.008
PCB-170	0.101	0.097	0.032	0.010	0.024	0.018	0.016	0.013	0.015	0.010	*0.006*	*0.007*	0.029

Table A.1. 2, cont.

Birkenes	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2017**
PCB-180	0.279	0.272	0.098	0.029	0.083	0.056	0.053	0.041	0.046	0.035	0.015	0.016	0.087
PCB-183	0.117	0.120	0.045	0.013	0.036	0.025	0.023	0.019	0.018	0.014	0.006	0.008	0.038
PCB-187	0.238	0.240	0.105	0.036	0.102	0.075	0.066	0.061	0.047	0.043	0.020	0.022	0.088
PCB-189	0.005	0.005	<0.004	<0.004	<0.004	*0.004*	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	*0.004*
PCB-194	0.011	0.012	*0.007*	<0.006	*0.007*	*0.006*	<0.006	<0.006	*0.006*	<0.006	<0.006	<0.006	*0.007*
PCB-206	<0.004	*0.005*	<0.004	<0.004	<0.004	*0.004*	<0.004	<0.004	*0.004*	<0.004	<0.004	<0.004	*0.004*
PCB-209	<0.005	<0.005	<0.005	<0.005	*0.005*	*0.007*	<0.005	<0.005	*0.005*	<0.005	<0.005	<0.005	*0.005*
sum-trichlor	3.11	5.20	4.01	2.76	6.49	3.89	3.44	2.71	4.74	3.54	1.99	2.16	3.644
sum-tetrachlor	2.77	3.24	2.71	2.11	5.80	3.98	3.62	3.22	3.94	3.10	1.51	1.49	3.121
sum-pentachlor	2.55	2.75	1.39	0.48	1.27	1.03	1.50	1.31	1.55	1.16	0.58	0.47	1.353
sum-hexachlor	5.52	5.52	2.13	0.70	2.23	1.49	1.44	1.18	1.29	1.06	0.48	0.36	1.954
sum-heptachlor	1.14	1.16	0.45	0.12	0.37	0.26	0.24	0.21	0.19	0.15	0.07	0.06	0.370
Sum PCB$_7$	4.80	5.25	2.74	1.49	4.09	2.63	2.47	2.07	2.89	2.21	1.17	1.09	2.74
sum PCB	15.13	17.89	10.70	6.19	16.18	10.66	10.25	8.65	11.73	9.02	4.63	4.45	10.48

Table A.1. 3: Monthly and annual mean concentrations (pg/m^3) for PBDEs and TBA in air at Birkenes, 2017

Birkenes	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2017**
BDE-28	0.009	0.010	0.010	0.005	0.006	0.012	0.010	0.011	0.008	0.008	0.010	0.010	0.009
BDE-47	0.040	0.058	0.040	<0.037	<0.037	0.068	0.069	0.050	0.040	0.058	0.051	0.038	0.049
BDE-49	0.012	0.021	0.010	0.005	0.008	0.023	0.023	0.014	NaN	0.014	0.013	0.011	0.014
BDE-66	0.005	0.014	0.006	<0.004	0.006	0.015	0.016	0.009	0.008	0.010	0.009	0.006	0.009
BDE-71	<0.001	0.003	0.001	<0.001	<0.001	0.003	0.003	0.002	0.002	0.002	<0.001	0.002	0.002
BDE-77	<0.001	0.004	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	NaN	0.001	<0.001	<0.001	0.001
BDE-85	<0.001	0.004	0.002	<0.001	<0.001	<0.001	0.007	<0.001	<0.001	<0.001	<0.001	0.001	0.002
BDE-99	0.021	0.069	0.029	0.012	0.014	0.023	0.140	0.021	0.022	0.021	0.025	0.018	0.035
BDE-100	0.003	0.011	0.006	0.003	0.003	0.005	0.012	0.005	0.003	0.005	0.004	0.003	0.005
BDE-119	<0.001	0.004	<0.001	<0.001	<0.001	0.002	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	*0.001*
BDE-138	<0.002	0.004	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	*0.002*
BDE-153	0.004	0.021	0.008	<0.002	<0.002	<0.002	0.015	0.003	0.005	0.003	<0.002	<0.002	0.007
BDE-154	0.007	0.024	0.006	0.002	0.002	0.002	0.013	0.004	0.003	0.002	<0.002	<0.002	0.006
BDE-183	0.011	0.046	0.030	0.003	0.002	0.004	0.004	0.011	0.012	0.008	<0.002	<0.002	0.013
BDE-196	<0.004	0.006	0.023	<0.004	<0.004	<0.005	<0.004	0.010	<0.004	<0.004	<0.004	<0.004	*0.008*
BDE-206	0.032	0.073	0.066	0.026	0.024	<0.022	0.064	0.093	<0.022	0.024	NaN	NaN	0.045
BDE-209	0.19	0.53	0.44	0.26	0.19	0.10	0.69	0.85	0.13	0.13	NaN	NaN	0.36
sum BDE	0.34	0.90	0.68	0.36	0.30	0.29	1.07	1.09	0.26	0.29	0.12	0.09	0.57
sum BDE (excl. 209)	0.15	0.37	0.24	0.11	0.11	0.19	0.38	0.24	0.13	0.16	0.12	0.09	0.21
TBA	4.56	9.87	2.26	0.925	1.06	3.9	1.65	1.86	4.94	1.95	10.2	7.19	4.19

Table A.1. 4: Monthly and annual mean concentrations (pg/m^3) for HBCDs in air at Birkenes, 2017

Birkenes	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2017**
α-HBCD	<0.04	0.06	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.18	<0.04	*0.05*
ß-HBCD	<0.03	NaN	<0.03	<0.03	<0.03	<0.04	<0.03	<0.03	0.04	<0.03	<0.04	<0.03	*0.04*
γ-HBCD	0.09	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	*0.03*
Sum HBCD	*0.16*	*0.09*	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	*0.26*	<0.10	*0.12*

Table A.1. 5: 2015 Monthly and annual mean concentrations (ng/m^3) for PAHs in air at Birkenes, 2017

Birkenes	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2017**
1-Methylnaphthalene	0.086	0.095	0.042	0.026	0.036	0.011	0.015	0.020	0.025	0.033	0.087	0.150	0.052
1-Methylphenanthrene	0.046	0.079	0.032	0.065	0.043	0.017	0.022	0.026	0.037	0.042	0.122	0.048	0.044
2-Methylanthracene	<0.004	<0.022	<0.007	<0.002	<0.007	<0.004	<0.002	<0.006	<0.004	<0.002	<0.006	<0.002	<0.005
2-Methylnaphthalene	0.124	0.122	0.059	0.039	0.056	0.018	0.022	0.026	0.031	0.046	0.098	0.169	0.067
2-Methylphenanthrene	0.059	0.099	0.033	0.056	0.073	0.040	0.048	0.041	0.053	0.058	0.072	0.056	0.057
3-Methylphenanthrene	0.051	0.057	0.038	0.049	0.061	0.035	0.039	0.037	0.047	0.051	0.056	0.044	0.047
9-Methylphenanthrene	0.018	0.034	0.014	0.020	0.019	0.013	0.015	0.015	0.020	0.020	0.023	0.017	0.019
Acenaphthene	0.340	0.093	0.096	0.124	0.076	0.029	0.053	0.076	0.099	0.073	0.070	0.351	0.124
Acenaphthylene	0.016	0.054	0.031	0.131	0.017	<0.002	*0.003*	*0.008*	0.010	0.016	0.047	0.076	0.033
Anthanthrene	*0.003*	*0.004*	*0.002*	*0.005*	*0.002*	<0.001	<0.001	*0.013*	*0.002*	*0.001*	*0.002*	*0.003*	*0.003*
Anthracene	0.007	0.029	0.006	0.052	0.010	0.003	0.003	*0.006*	0.008	0.015	0.036	0.016	0.015
Benz(a)anthracene	0.029	0.019	0.008	0.017	0.011	*0.004*	0.002	0.006	0.008	0.009	0.018	0.015	0.012
Benzo(a)fluoranthene	0.005	*0.004*	*0.001*	*0.006*	*0.001*	<0.001	<0.001	<0.004	0.002	0.002	0.003	0.005	0.003
Benzo(a)fluorene	0.016	0.012	0.007	0.012	0.008	0.003	0.002	0.006	0.006	0.007	0.012	0.010	0.008
Benzo(a)pyrene	0.024	0.013	0.006	0.023	0.006	0.004	0.003	0.006	0.008	0.005	0.012	0.018	0.011
Benzo(b)fluoranthene	0.152	0.054	0.042	0.041	0.070	0.019	0.031	0.029	0.031	0.021	0.048	0.043	0.048
Benzo(b)fluorene	0.011	0.008	0.004	0.007	0.004	0.002	0.001	0.004	0.005	0.005	0.006	0.005	0.005
Benzo(e)pyrene	0.071	0.049	0.028	0.027	0.053	0.014	0.021	0.023	0.020	0.015	0.032	0.030	0.032
Benzo(ghi)fluoranthene	NaN	NaN	NaN	NaN	NaN	0.001	0.001	0.001	NaN	NaN	NaN	NaN	<0.001
Benzo(ghi)perylene	0.050	0.035	0.023	0.030	0.025	0.006	0.013	0.021	0.020	0.017	0.039	0.033	0.026
Benzo(k)fluoranthene	0.032	0.015	0.009	0.016	0.008	0.003	0.005	0.009	0.010	0.006	0.016	0.016	0.012
Biphenyl	0.210	0.459	0.218	0.128	0.088	0.023	0.022	0.032	0.055	0.070	0.238	0.228	0.145
Chrysene	0.077	0.155	0.042	0.045	0.094	0.039	0.038	0.032	0.030	0.022	0.046	0.035	0.055
Coronene	0.020	0.020	0.008	0.011	0.007	*0.004*	0.004	0.027	0.009	*0.005*	0.013	0.009	0.012
Cyclopenta(cd)pyrene	NaN	0.009	NaN	NaN	0.002	<0.001	<0.001	<0.001	NaN	NaN	<0.001	NaN	*0.002*

Table A.1. 5. cont.

Birkenes	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2017**
Dibenzo(ae)pyrene	0.012	0.009	*0.004*	0.005	*0.007*	*0.004*	*0.005*	*0.038*	0.005	*0.004*	*0.005*	0.006	0.009
Dibenzo(ah)anthracene	0.008	0.007	0.003	0.005	0.009	*0.002*	0.002	*0.017*	0.003	0.003	0.004	0.004	0.006
Dibenzo(ah)pyrene	<0.005	<0.009	<0.005	<0.004	<0.004	<0.004	<0.004	<0.053	<0.005	<0.004	<0.004	<0.004	<0.009
Dibenzo(ai)pyrene	*0.005*	<0.009	<0.004	<0.004	<0.004	<0.004	<0.004	<0.050	<0.005	<0.004	<0.004	<0.004	*0.009*
Dibenzofuran	0.754	1.320	0.788	0.655	0.442	0.133	0.157	0.175	0.281	0.329	0.819	0.689	0.538
Dibenzothiophene	0.033	0.033	0.028	0.021	0.063	0.022	0.033	0.031	0.020	0.035	0.010	0.023	0.030
Fluoranthene	0.241	0.283	0.151	0.184	0.117	0.059	0.064	0.095	0.139	0.151	0.207	0.169	0.155
Fluorene	0.669	0.654	0.468	0.486	0.335	0.110	0.168	0.208	0.287	0.317	0.593	0.546	0.402
Inden(123-cd)pyrene	0.041	0.021	0.017	0.030	0.016	0.005	0.009	0.021	0.018	0.014	0.037	0.032	0.022
Naphthalene	0.207	0.321	0.121	0.061	0.062	<0.028	<0.028	*0.034*	0.038	0.054	0.208	0.250	0.116
Perylene	0.004	*0.003*	*0.002*	0.004	*0.001*	*0.001*	<0.001	*0.004*	0.002	0.002	0.003	0.004	0.003
Phenanthrene	0.945	1.341	0.704	0.908	0.794	0.400	0.452	0.606	0.751	0.682	0.958	0.782	0.776
Pyrene	0.129	0.149	0.072	0.112	0.079	0.036	0.029	0.047	0.076	0.094	0.126	0.095	0.086
Retene	0.061	0.063	0.029	0.051	0.044	0.012	0.019	0.040	0.060	0.077	0.115	0.079	0.054
Sum PAH	4.57	5.76	3.15	3.46	2.75	1.12	1.34	1.89	2.23	2.31	4.19	4.06	3.05
Sum PAH16	2.97	3.24	1.80	2.27	1.73	0.75	0.90	1.22	1.53	1.50	2.46	2.48	1.90

Table A.1. 6: Monthly and annual mean concentrations (pg/m^3) for PFAS in air at Birkenes, 2017

Birkenes	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2017**
6:2 FTS	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	0.03	<0.03	<0.03	<0.03	<0.03	<0.03	0.03
8:2 FTS	<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
PFBS	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
PFDoDA	0.02	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
PFHpA	0.027	<0.03	0.055	0.059	0.035	0.035	0.122	0.147	0.107	0.045	0.054	0.032	0.059
PFHxA	0.055	<0.03	0.205	0.231	0.311	<0.03	<0.03	0.288	<0.03	<0.03	0.224	<0.03	0.125
PFHxS	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
PFNA	0.05	0.042	0.032	0.076	0.117	0.172	0.157	0.165	0.108	0.049	<0.03	0.039	0.083
PFOA	0.13	0.095	0.074	0.119	0.166	0.287	0.177	0.169	0.138	0.081	0.107	0.059	0.135
PFOS	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.057	<0.05	<0.05	<0.05	<0.05
PFOSA	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
PFUnA	<0.02	<0.03	<0.03	<0.03	0.045	<0.03	0.027	0.043	0.029	<0.03	<0.03	<0.03	0.029
PFPS	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
PFHpS	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
PFNS	<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
PFPeA													
PFTrDA	<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
PFTeDA	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
sum PFAS	*0.45*	*0.38*	*0.55*	*0.67*	*0.83*	*0.71*	*0.68*	*0.97*	*0.57*	*0.39*	*0.6*	*0.35*	*0.60*

Table A.1. 7: Monthly and annual mean concentrations (pg/m^3) for M/SCCPs in air at Birkenes, 2017

Birkenes	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2017**
SCCP	120	119	57	154	229	189	297	173	4709	889	809	499	380
MCCP	56	22	10	85	15	25	133	96	579	28	101	772	120

Table A.1. 8: Monthly and annual mean concentrations (ng/l) for HCB, HCHs and PCBs in precipitation at Birkenes, 2017

Birkenes	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2017**
HCB	*0.06*	*0.04*	*0.07*	*0.09*	*0.08*	*0.16*	*0.07*	*0.05*	*0.05*	*0.05*	*0.08*	0.07	*0.06*
α-HCH	0.09	0.06	0.06	0.06	0.08	0.07	0.07	0.07	0.13	0.10	0.06	0.05	0.09
γ-HCH	0.19	0.10	0.12	0.06	0.38	0.21	0.17	0.21	0.19	0.20	0.14	0.12	0.18
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	0.27
PCB-28	0.005	*0.004*	*0.006*	*0.007*	*0.006*	*0.012*	*0.005*	*0.004*	*0.004*	*0.003*	*0.005*	*0.005*	0.004
PCB-52	*0.006*	0.004	0.007	0.008	0.007	0.015	0.007	0.005	0.004	0.004	0.005	0.006	0.005
PCB-101	*0.009*	*0.007*	*0.012*	*0.016*	*0.014*	*0.028*	*0.013*	*0.009*	*0.007*	*0.007*	*0.009*	*0.012*	*0.009*
PCB-118	*0.005*	0.003	*0.006*	*0.007*	0.009	*0.013*	*0.007*	0.007	0.007	0.004	*0.005*	*0.005*	0.006
PCB-138	*0.010*	0.006	*0.010*	*0.013*	*0.013*	*0.022*	*0.010*	*0.008*	*0.008*	0.006	*0.008*	*0.009*	0.008
PCB-153	0.013	*0.008*	*0.013*	*0.016*	*0.016*	*0.029*	*0.014*	*0.010*	*0.009*	*0.007*	*0.010*	*0.012*	0.010
PCB-180	0.007	0.003	*0.005*	*0.007*	*0.007*	*0.012*	*0.005*	*0.004*	*0.004*	*0.003*	*0.004*	*0.005*	0.004
sum PCB-7	0.054	0.036	0.058	0.074	0.072	0.130	0.061	0.046	0.042	0.034	0.046	0.054	0.047

Table A.1. 9: Monthly and annual mean concentrations (pg/m^3) for hexachlorobenzene (HCB) in air at Andøya, 2017

Andøya	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2017**
HCB	37.8	46.4	44.7	47.2	26.3	21.7	26.4	22.5	19.7	35.5	41.9	44.6	34.5

Table A.1. 10: Monthly and annual mean concentrations (pg/m^3) for PCBs in air at Andøya, 2017

Andøya	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2017**
PCB-18	1.820	1.550	3.280	2.540	2.170	0.250	0.401	0.266	0.799	1.060	0.825	1.660	1.385
PCB-28	0.851	0.678	1.570	1.140	0.848	0.162	0.376	0.177	0.538	0.702	0.619	1.040	0.725
PCB-31	0.842	0.784	1.740	1.250	0.975	0.179	0.389	0.172	0.515	0.578	0.572	0.944	0.745
PCB-33	0.509	0.398	0.911	0.619	0.493	0.104	0.189	0.096	0.288	0.302	0.329	0.541	0.398
PCB-37	0.081	0.045	0.119	0.067	0.059	0.021	0.035	0.021	0.051	0.047	0.057	0.094	0.058
PCB-47	6.120	8.060	11.600	9.850	15.800	1.370	1.840	0.780	1.270	0.540	5.590	5.550	5.700
PCB-52	0.799	0.679	1.300	1.010	0.876	0.209	0.452	0.217	0.551	0.571	0.612	0.885	0.680
PCB-66	0.126	0.083	0.227	0.135	0.120	0.045	0.072	0.050	0.137	0.141	0.131	0.205	0.123
PCB-74	0.106	0.071	0.179	0.113	0.094	0.035	0.057	0.039	0.112	0.121	0.109	0.165	0.100
PCB-99	0.154	0.112	0.276	0.206	0.168	0.037	0.107	0.046	0.123	0.132	0.108	0.185	0.138
PCB-101	0.388	0.340	0.682	0.504	0.487	0.103	0.281	0.128	0.298	0.278	0.301	0.461	0.354
PCB-105	NaN	0.016	0.054	0.030	0.026	0.006	0.017	0.008	0.023	0.026	0.018	0.032	0.023
PCB-114	NaN	<0.004	0.005	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	0.004	*0.004*
PCB-118	NaN	0.064	0.193	0.123	0.107	0.024	0.072	0.031	0.081	0.091	0.070	0.125	0.089
PCB-122	NaN	<0.003	0.005	0.004	<0.004	<0.004	<0.003	<0.004	<0.003	<0.004	<0.004	0.004	*0.004*
PCB-123	NaN	<0.003	0.004	<0.003	<0.003	<0.004	<0.003	<0.003	0.004	<0.004	<0.004	<0.004	*0.004*
PCB-128	NaN	0.007	0.020	0.012	0.011	0.004	0.010	0.006	NaN	0.010	0.007	0.012	0.010
PCB-138	NaN	0.059	0.163	0.098	0.093	0.031	0.094	0.044	0.089	0.081	0.062	0.123	0.085
PCB-141	NaN	0.019	0.039	0.025	0.026	0.007	0.022	0.011	0.019	0.017	0.014	0.026	0.020
PCB-149	NaN	0.139	0.289	0.183	0.201	0.061	0.165	0.086	0.159	0.137	0.142	0.245	0.164
PCB-153	NaN	0.108	0.249	0.164	0.154	0.050	0.147	0.070	0.128	0.121	0.106	0.207	0.137
PCB-156	NaN	0.003	0.007	0.004	0.004	<0.002	0.003	<0.002	0.005	0.004	0.003	0.005	0.004
PCB-157	NaN	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.004	<0.001	<0.001	<0.001	*0.002*
PCB-167	NaN	0.002	0.003	0.002	0.002	<0.002	<0.001	<0.002	0.004	0.002	<0.002	0.003	0.002
PCB-170	NaN	0.005	0.011	0.006	0.008	0.004	0.009	0.004	0.007	0.006	0.004	0.007	0.006

Table A.1. 10, cont.

Andøya	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
PCB-180	NaN	0.016	0.031	0.018	0.020	0.009	0.024	0.012	0.016	0.016	0.011	0.025	0.018
PCB-183	NaN	0.008	0.015	0.009	0.011	0.004	0.011	0.005	0.009	0.008	0.006	0.012	0.009
PCB-187	NaN	0.022	0.047	0.028	0.034	0.011	0.029	0.016	0.025	0.022	0.020	0.038	0.026
PCB-189	NaN	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.004	<0.002	<0.002	<0.002	*0.002*
PCB-194	NaN	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
PCB-206	NaN	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
PCB-209	NaN	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.017	<0.002	<0.002	*0.004*
sum-trichlor	6.07	4.81	10.40	7.66	6.36	1.10	1.89	1.09	3.15	3.79	3.57	6.08	4.662
sum-tetrachlor	9.18	10.70	16.50	13.50	19.70	2.21	3.21	1.63	3.37	2.43	8.41	9.14	8.334
sum-pentachlor	NaN	0.88	1.99	1.41	1.31	0.31	0.81	0.38	0.96	0.94	0.89	1.43	1.028
sum-hexachlor	NaN	0.54	1.20	0.72	0.79	0.25	0.64	0.35	0.59	0.59	0.55	1.02	0.658
sum-heptachlor	NaN	0.07	0.15	0.09	0.11	0.04	0.11	0.05	0.09	0.07	0.06	0.12	0.088
sum PCB$_7$	2.038	1.944	4.188	3.057	2.584	0.589	1.446	0.678	1.701	1.86	1.781	2.866	2.088
sum PCB	NaN	17.01	30.25	23.39	28.28	3.91	6.66	3.50	8.16	7.85	13.49	17.80	14.58

Table A.1. 11: Monthly and annual mean concentrations (pg/m^3) for PFAS in air at Andøya, 2017

Andøya	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2017**
6:2 FTS	<0.02	<0.02	<0.02	0.09	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
8:2 FTS	<0.03	<0.03	<0.03	0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
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
PFDoDA	<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
PFHpA	0.07	0.03	0.08	0.13	0.15	0.18	0.14	0.07	0.06	0.06	0.06	0.05	0.09
PFHxA	<0.02	0.07	<0.02	<0.02	0.13	0.14	0.16	0.08	<0.02	<0.02	0.11	<0.02	0.07
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	<0.02
PFNA	0.07	0.02	0.06	0.09	0.11	0.16	0.12	0.02	0.05	0.04	0.03	0.04	0.07
PFOA	0.14	0.05	0.09	0.16	0.2	0.24	0.2	0.13	0.09	0.09	0.12	0.09	0.14
PFOS	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
PFOSA	<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
PFUnA	<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
PFHpS	<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
PFNS	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
PFPeA	<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
PFTrDA	<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
PFTeDA	<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
sum PFAS	*0.41*	*0.25*	*0.36*	*0.50*	*0.71*	*0.84*	*0.74*	*0.42*	*0.33*	*0.31*	*0.43*	*0.31*	*0.47*

Table A.1. 12: Monthly and annual mean concentrations (pg/m^3) for organochlorine pesticides in air at Zeppelin, 2017

Zeppelin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2017**
HCB	72.7	71.3	70.1	72.8	73.5	77.3	80.0	85.4	81.3	80.8	79.0	65.6	76.2
α-HCH	2.94	2.81	2.66	3.84	3.85	3.32	3.59	4.21	3.91	4.26	3.53	2.52	3.51
γ-HCH	0.34	0.34	0.45	0.53	0.46	0.32	0.35	0.36	0.64	0.61	0.64	0.40	0.45
sum HCHs	3.28	3.15	3.10	4.37	4.31	3.64	3.94	4.57	4.55	4.88	4.17	2.92	3.96
cis-CD	0.25	0.37	0.36	0.27	0.30	0.23	0.28	0.27	0.30	0.32	0.35	0.25	0.30
cis-NO	0.01	0.01	0.02	0.01	0.03	0.03	0.04	0.04	0.03	0.03	0.03	0.02	0.03
trans-CD	0.14	0.22	0.19	0.10	0.07	0.04	0.06	0.05	0.06	0.08	0.16	0.13	0.10
trans-NO	0.20	0.33	0.33	0.26	0.27	0.19	0.23	0.22	0.23	0.26	0.30	0.21	0.25
sum CHLs	0.60	0.93	0.90	0.65	0.67	0.49	0.61	0.58	0.63	0.69	0.83	0.61	0.68
p,p'-DDT	0.03	0.03	0.04	*0.02*	*0.03*	<0.02	<0.02	<0.02	0.03	0.06	0.11	NaN	0.04
o,p'-DDT	0.05	0.06	0.09	0.06	*0.03*	*0.02*	*0.02*	*0.02*	0.04	0.11	0.23	0.07	0.06
p,p'-DDE	0.28	0.31	0.33	0.11	*0.04*	0.04	0.05	0.04	0.13	0.33	1.54	0.53	0.23
o,p'-DDE	0.05	0.06	0.06	0.03	*0.02*	<0.02	<0.02	<0.02	*0.02*	0.04	0.09	0.09	0.04
p,p'-DDD	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
o,p'-DDD	<0.01	<0.01	*0.01*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	*0.02*	<0.01	*0.01*
sum DDTs	0.43	0.49	0.55	0.25	0.14	*0.12*	*0.14*	*0.13*	0.18	0.60	1.53	0.69	0.38

Table A.1. 13: Monthly and annual mean concentrations (pg/m^3) for PCBs in air at Zeppelin, 2017

Zeppelin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2017**
PCB-18	1.305	1.206	1.415	1.053	0.754	0.633	0.656	0.537	0.565	1.145	1.842	1.590	1.094
PCB-28	0.765	1.008	1.520	0.801	0.951	0.901	1.391	0.805	0.751	0.971	1.143	0.841	0.993
PCB-31	0.756	0.956	1.316	0.700	0.829	0.773	1.283	0.744	0.714	0.880	1.023	0.795	0.898
PCB-33	0.457	0.685	1.130	0.489	0.618	0.610	0.932	0.546	0.485	0.587	0.659	0.494	0.641
PCB-37	0.089	0.135	0.274	0.093	0.161	0.165	0.210	0.120	0.107	0.120	0.114	0.087	0.140
PCB-47	0.259	0.299	0.437	0.233	0.251	0.241	0.277	0.188	0.206	0.268	0.373	0.266	0.277
PCB-52	0.521	0.526	0.712	0.495	0.386	0.355	0.415	0.305	0.379	0.561	0.751	0.577	0.500
PCB-66	0.122	0.147	0.292	0.146	0.139	0.140	0.126	0.089	0.111	0.160	0.192	0.133	0.153
PCB-74	0.105	0.107	0.168	0.100	0.089	0.092	0.090	0.066	0.085	0.120	0.147	0.105	0.107
PCB-99	0.095	0.093	0.136	0.107	0.065	0.057	0.058	0.045	0.067	0.115	0.158	0.123	0.094
PCB-101	0.228	0.229	0.334	0.237	0.180	0.177	0.185	0.143	0.203	0.287	0.357	0.270	0.239
PCB-105	0.019	0.017	0.031	0.022	0.015	0.015	0.014	0.009	0.014	0.027	0.037	0.027	0.022
PCB-114	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	*0.004*	*0.004*	*0.004*
PCB-118	0.068	0.062	0.100	0.074	0.050	0.049	0.048	0.032	0.051	0.092	0.124	0.092	0.073
PCB-122	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	*0.004*	*0.004*	*0.004*
PCB-123	<0.004	*0.005*	0.006	<0.004	<0.004	*0.004*	<0.004	<0.004	<0.003	<0.004	<0.004	<0.004	*0.004*
PCB-128	0.008	0.009	0.014	0.009	0.008	0.007	0.006	0.004	0.006	0.011	0.012	0.010	0.009
PCB-138	0.052	0.057	0.084	0.059	0.043	0.040	0.042	0.041	0.048	0.078	0.095	0.074	0.060
PCB-141	0.011	0.014	0.020	0.013	0.011	0.010	0.010	0.008	0.013	0.019	0.022	0.015	0.015
PCB-149	0.097	0.113	0.158	0.103	0.084	0.079	0.072	0.069	0.105	0.141	0.164	0.121	0.114
PCB-153	0.079	0.093	0.127	0.089	0.061	0.056	0.055	0.045	0.074	0.113	0.137	0.105	0.090
PCB-156	0.003	0.004	0.005	0.003	0.003	0.003	0.002	*0.003*	*0.002*	0.004	0.005	0.004	0.004
PCB-157	<0.002	<0.001	<0.001	<0.001	*0.002*	<0.001	<0.001	<0.001	<0.001	<0.001	*0.001*	<0.001	*0.001*
PCB-167	*0.002*	*0.002*	<0.002	*0.002*	0.002	<0.002	<0.002	<0.002	<0.002	0.002	0.002	0.002	*0.002*

Table A.1. 13 cont.

Zeppelin	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
PCB-170	*0.003*	0.005	0.005	0.004	0.004	0.004	0.003	<0.003	0.003	0.005	0.005	0.004	0.004
PCB-180	0.010	0.014	0.020	0.012	0.010	0.009	0.008	0.006	0.011	0.017	0.018	0.014	0.013
PCB-183	0.005	0.007	0.008	0.006	0.005	0.004	0.004	0.004	0.005	0.008	0.009	0.006	0.006
PCB-187	0.014	0.022	0.028	0.016	0.012	0.010	0.011	0.010	0.016	0.021	0.024	0.019	0.017
PCB-189	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
PCB-194	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
PCB-206	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
PCB-209	*0.003*	0.003	0.004	0.003	<0.002	0.003	<0.002	<0.002	<0.002	*0.003*	*0.003*	0.004	0.003
sum-trichlor	4.55	5.44	7.90	4.40	4.63	4.17	5.67	3.56	3.39	4.83	6.37	5.10	5.07
sum-tetrachlor	2.16	2.40	3.72	2.23	1.99	1.73	1.75	1.30	1.53	2.29	3.06	2.06	2.19
sum-pentachlor	0.71	0.55	0.63	0.45	0.32	0.41	0.50	0.40	0.61	0.95	1.21	0.88	0.65
sum-hexachlor	0.38	0.45	0.64	0.42	0.34	0.31	0.28	0.25	0.40	0.58	0.69	0.50	0.46
sum-heptachlor	0.04	0.07	0.07	0.05	0.04	0.04	0.03	0.03	0.04	0.07	0.08	0.06	0.05
sum PCB_7	1.724	1.989	2.897	1.767	1.681	1.588	2.144	1.377	1.517	2.119	2.625	1.973	1.968
sum PCB	7.85	8.91	12.96	7.56	7.33	6.62	NaN	5.08	5.98	8.73	11.90	8.61	8.51

Table A.1. 14: Monthly and annual mean concentrations (pg/m^3) for PBDEs and TBA in air at Zeppelin, 2017

Zeppelin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2017**
BDE-28	0.007	0.006	0.006	0.008	0.012	0.008	0.010	0.006	0.007	0.007	0.010	0.005	0.008
BDE-47	0.094	0.081	0.107	0.113	0.226	0.195	0.185	0.127	0.144	0.106	0.121	0.083	0.134
BDE-49	0.005	0.005	0.005	0.005	0.009	0.008	0.007	0.006	0.007	0.005	0.006	0.004	0.006
BDE-66	*0.005*	<0.005	*0.005*	<0.005	*0.006*	0.005	*0.005*	<0.005	0.033	*0.045*	*0.005*	<0.005	*0.011*
BDE-71	0.003	*0.001*	<0.001	<0.001	*0.002*	*0.001*	<0.001	<0.001	0.002	*0.003*	<0.001	<0.001	*0.002*
BDE-77	*0.001*	*0.001*	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	*0.001*
BDE-85	*0.001*	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	*0.002*	<0.001	<0.001	<0.001	<0.001	*0.001*
BDE-99	0.017	*0.014*	0.020	0.017	0.035	0.053	0.049	0.035	0.027	0.018	0.019	0.013	0.027
BDE-100	0.006	0.005	0.007	0.006	0.014	0.015	0.014	0.009	0.008	0.006	0.006	0.005	0.008
BDE-119	*0.001*	*0.001*	<0.001	<0.001	*0.001*	<0.001	<0.001	<0.001	0.002	*0.003*	<0.001	<0.001	*0.001*
BDE-138	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	*0.003*
BDE-153	*0.004*	*0.006*	<0.003	0.003	0.005	0.005	*0.003*	*0.003*	*0.003*	*0.004*	0.003	<0.003	*0.004*
BDE-154	0.002	0.003	*0.002*	0.002	0.003	0.004	0.003	0.003	0.002	*0.002*	*0.002*	<0.002	0.002
BDE-183	*0.003*	*0.003*	*0.003*	0.003	*0.004*	<0.003	*0.004*	<0.003	0.004	*0.004*	0.005	<0.003	*0.004*
BDE-196	<0.008	*0.009*	<0.007	<0.007	*0.011*	<0.006	*0.009*	<0.006	<0.006	<0.006	<0.006	<0.007	*0.007*
BDE-206	0.241	0.320	0.213	0.217	0.110	*0.043*	0.388	*0.032*	0.195	0.094	0.150	0.299	0.188
BDE-209	10.37	14.30	6.26	8.17	3.11	1.00	11.60	0.67	7.28	2.74	3.38	2.90	5.75
sum BDE	10.77	14.76	6.64	8.57	3.56	1.35	12.29	0.91	7.72	3.05	3.72	3.34	6.159
sum BDE (excl. 209)	0.40	0.46	0.38	0.39	0.44	0.35	0.69	0.24	0.45	0.31	0.34	0.43	0.41
TBA	3.07	3.48	1.84	0.96	2.57	6.25	15.02	43.21	10.61	8.61	5.92	5.90	9.41

Table A.1. 15: Monthly and annual mean concentrations (pg/m^3) for HBCDs in air at Zeppelin, 2017

Zeppelin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2017**
α-HBCD	*0.11*	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.05	0.32	*0.08*
ß-HBCD	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.06	*0.05*
γ-HBCD	<0.03	<0.03	<0.04	<0.04	<0.04	<0.03	<0.04	<0.04	<0.04	<0.04	<0.03	0.06	*0.04*
Sum HBCD	*0.19*	<0.126	<0.132	<0.131	<0.135	<0.129	<0.137	<0.134	<0.133	<0.139	*0.13*	0.44	*0.16*

Table A.1. 16: Monthly and annual mean concentrations (ng/m^3) for PAHs in air at Zeppelin, 2017

Zeppelin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2017**
1-Methylnaphthalene	0.364	0.134	0.032	0.016	0.019	0.010	0.007	0.014	0.020	0.025	0.076	0.158	0.069
1-Methylphenanthrene	0.003	0.005	*0.001*	*0.007*	<0.001	*0.001*	0.002	0.002	0.001	0.001	*0.003*	0.003	0.002
2-Methylanthracene	NaN	NaN	<0.001	<0.001	<0.001	*0.001*	<0.001	<0.001	<0.001	<0.001	<0.008	<0.008	*0.001*
2-Methylnaphthalene	0.386	0.141	0.041	0.022	0.036	0.018	0.011	0.022	0.034	0.039	0.105	0.187	0.083
2-Methylphenanthrene	0.004	0.007	*0.002*	*0.007*	*0.001*	0.002	0.003	0.002	0.003	0.002	0.003	0.005	0.003
3-Methylphenanthrene	0.004	0.005	*0.002*	*0.008*	<0.001	0.002	0.003	0.002	0.002	0.002	*0.004*	0.006	0.003
9-Methylphenanthrene	0.003	0.003	*0.001*	*0.006*	<0.001	*0.001*	0.002	0.002	0.002	0.001	*0.002*	0.002	0.002
Acenaphthene	0.010	*0.005*	*0.006*	<0.022	*0.002*	<0.004	<0.004	*0.002*	*0.002*	0.003	0.005	0.006	*0.006*
Acenaphthylene	0.004	*0.005*	*0.004*	<0.008	*0.001*	<0.002	<0.001	<0.001	<0.001	<0.001	*0.002*	*0.002*	*0.003*
Anthanthrene	*0.001*	*0.002*	<0.001	<0.006	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.003	<0.001	*0.002*
Anthracene	*0.002*	<0.001	<0.001	<0.006	*0.002*	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.001	*0.002*
Benz(a)anthracene	0.005	0.007	<0.001	<0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	*0.002*	*0.002*	*0.002*
Benzo(a)fluoranthene	0.001	*0.002*	<0.001	<0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	*0.001*
Benzo(a)fluorene	0.003	*0.003*	<0.001	<0.004	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	*0.001*	*0.002*
Benzo(a)pyrene	0.004	*0.009*	<0.001	<0.004	<0.001	<0.001	<0.001	<0.001	*0.001*	<0.001	*0.001*	*0.002*	*0.002*

Table A.1. 16 cont.

Zeppelin	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Benzo(b)fluoranthene	0.019	0.030	0.002	0.002	<0.001	<0.001	<0.001	<0.001	*0.002*	<0.001	*0.002*	0.003	*0.004*
Benzo(b)fluorene	0.002	*0.002*	<0.001	<0.004	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	*0.001*
Benzo(e)pyrene	0.009	0.012	0.002	*0.001*	<0.001	<0.001	<0.001	<0.001	*0.001*	<0.001	*0.002*	0.002	*0.003*
Benzo(ghi)fluoranthene	<0.001	<0.001	<0.001	<0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Benzo(ghi)perylene	0.008	0.012	0.002	<0.005	<0.001	<0.001	<0.001	<0.001	*0.001*	<0.001	*0.003*	0.002	*0.003*
Benzo(k)fluoranthene	0.006	0.009	*0.001*	<0.004	<0.001	<0.001	<0.001	<0.001	*0.001*	<0.001	*0.002*	0.001	*0.002*
Biphenyl	1.168	0.974	0.446	0.057	0.017	0.009	0.007	0.023	0.064	0.133	0.469	0.559	0.308
Chrysene	0.016	0.022	0.002	0.002	<0.001	<0.001	<0.001	<0.001	*0.001*	<0.001	*0.002*	0.003	*0.004*
Coronene	0.004	*0.006*	<0.002	<0.012	<0.001	<0.001	<0.001	<0.001	*0.001*	<0.001	<0.005	*0.002*	*0.003*
Cyclopenta(cd)pyrene	*0.002*	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	*0.001*
Dibenzo(ae)pyrene	*0.002*	*0.003*	<0.003	<0.022	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.007	<0.003	*0.004*
Dibenzo(ah)anthracene	0.001	*0.002*	<0.001	<0.009	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.003	<0.001	*0.002*
Dibenzo(ah)pyrene	<0.002	<0.002	<0.004	<0.03	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.009	<0.003	<0.005
Dibenzo(ai)pyrene	<0.002	<0.002	<0.003	<0.03	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.008	0.003	<0.005
Dibenzofuran	1.284	1.213	0.620	0.129	0.029	0.027	0.023	0.048	0.154	0.206	0.577	0.604	0.376
Dibenzothiophene	0.011	0.008	0.002	<0.004	<0.001	<0.001	*0.001*	<0.001	0.003	0.002	0.005	0.005	0.003

Table A.1. 16 cont.

Zeppelin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2017**
Fluoranthene	0.052	0.076	0.007	*0.005*	<0.004	<0.004	<0.004	*0.005*	*0.005*	*0.005*	*0.013*	0.017	*0.015*
Fluorene	0.589	0.398	0.086	0.014	0.007	0.010	0.010	0.014	0.036	0.066	0.263	0.344	0.140
Inden(123-cd)pyrene	0.008	0.011	0.001	*0.001*	<0.001	<0.001	<0.001	<0.001	*0.001*	<0.001	*0.003*	0.002	*0.003*
Naphthalene	1.784	0.802	0.271	0.093	0.302	0.113	0.032	0.064	0.090	0.104	0.382	0.672	0.348
Perylene	*0.001*	*0.002*	<0.001	<0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	*0.001*
Phenanthrene	0.101	0.122	0.017	0.011	0.007	0.010	0.013	0.012	0.015	0.017	0.038	0.046	0.031
Pyrene	<0.003	0.055	0.004	<0.004	<0.003	<0.003	<0.003	*0.003*	*0.003*	<0.003	*0.004*	0.006	*0.006*
Retene	0.003	0.002	*0.002*	*0.007*	*0.002*	<0.002	*0.002*	0.002	*0.002*	<0.002	0.002	*0.002*	*0.002*
Sum PAH	5.87	4.09	1.58	0.57	0.46	0.24	0.15	0.24	0.46	0.64	2.02	2.67	1.45
Sum PAH16	2.61	1.57	0.41	0.19	0.34	0.16	0.08	0.11	0.16	0.21	0.73	<0.003	0.57

Table A.1. 17: Monthly and annual mean concentrations (pg/m^3) for PFAS in air at Zeppelin, 2017

Zeppelin	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
6:2 FTS	<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
8:2 FTS	<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
PFDoDA	0.13	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
PFHpA	0.13	0.04	0.04	0.06	0.10	0.11	0.08	0.06	0.04	0.03	0.03	0.03	0.06
PFHxA	0.23	0.05	0.10	0.07	0.10	0.19	0.13	0.13	0.06	0.12	0.02	0.24	0.13
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	<0.02
PFNA	0.15	0.02	0.04	0.05	0.09	0.09	0.06	0.04	0.03	<0.02	<0.02	0.02	0.05
PFOA	0.42	0.06	0.06	0.09	0.11	0.15	0.15	0.11	0.07	0.05	0.04	0.05	0.10
PFOS	<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
PFOSA	0.08	<0.01	<0.01	0.02	0.04	0.10	0.11	0.04	0.04	0.02	0.05	0.02	<0.02
PFUnA	<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
PFHpS	<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
PFNS	<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
PFPeA	<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
PFTrDA	<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
PFTeDA	<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
sum PFAS	1.13	0.30	0.37	0.40	0.56	0.76	0.66	0.49	0.35	0.36	0.28	0.48	0.51

Table A.1. 18: Monthly and annual mean concentrations (pg/m^3) for M/SCCPs in air at Zeppelin, 2017

Zeppelin	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**2017**
SCCP	35	121	253	95	144	370	558	251	626	457	674	491	350
MCCP	196	69	69	10	17	33	131	30	423	193	383	75	130

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 2017. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes	1.31	1.27	0.33	0.19	0.84	0.64	0.23	0.41	0.94	0.45	0.53	0.54	0.67
Hurdal	0.91	0.62	0.27	0.38	1.1	0.39	0.21	0.18	0.17	0.39	0.32	0.13	0.38
Kårvatn	0.35	0.06	0.08	0.11	0.17	0.08	0.06	0.08	0.04	0.04	0.04	0.03	0.1
Svanvik	1.28	0.85	1.02	0.59	1.11	0.41	0.86	1.21	0.96	0.96	0.62	0.65	0.85
Karpbukt	0.75	0.66	3.79	1	0.58	0.31	0.96	1.05	0.28	0.71	0.89	0.63	0.77

Table A.2. 2: Monthly and annual volume weighted mean concentrations of cadmium in precipitation at Norwegian background stations 2017. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes	0.02	0.032	0.011	0.007	0.024	0.015	0.009	0.012	0.032	0.01	0.013	0.008	0.018
Hurdal	0.019	0.017	0.012	0.012	0.023	0.013	0.007	0.007	0.007	0.018	0.012	0.013	0.013
Kårvatn	0.004	0.002	0.004	0.003	0.006	0.003	0.002	0.005	0.002	0.001	0.001	0.004	0.003
Svanvik	0.065	0.104	0.069	0.092	0.112	0.024	0.054	0.112	0.185	0.12	0.088	0.116	0.088
Karpbukt	0.107	0.059	0.232	0.101	0.022	0.011	0.061	0.06	0.018	0.109	0.083	0.068	0.059

Table A.2. 3: Monthly and annual volume weighted mean concentrations of zinc in precipitation at Norwegian background stations 2017. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OKT	NOV	DES	2017
Birkenes	3.6	5.5	3.1	4.2	6.1	3.5	1.8	2.1	3.7	1.4	2.2	1.4	2.9
Hurdal	6.3	10.6	6.5	6	6.6	3.8	3.3	1.9	1.9	3.1	2.6	7	4.2
Kårvatn	2.3	1	1.2	0.8	1.5	1.1	1.4	1.9	1	0.6	0.3	1.2	1.2
Svanvik	4.3	7.7	3.8	3.8	5.6	2.3	3.5	5.2	5.8	4.3	5.2	2.8	4.2
Karpbukt	3.3	6.2	6.8	8	3.7	2.4	4.5	3.4	3.7	13.7	9.7	3.5	5

Table A.2. 4: Monthly and annual volume weighted mean concentrations of nickel in precipitation at Norwegian background stations 2017. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes	0.77	0.46	0.17	0.19	0.19	0.29	0.24	0.15	0.13	0.17	0.14	0.12	0.2
Svanvik	19.32	36.94	9.25	17.68	54.69	13.35	34.42	35.43	30.77	44.28	26.88	12.42	27.62
Karpbukt	15.7	13.69	79.25	27.81	16.77	11.07	20.1	31.09	9.83	50.55	18.5	17.56	20.22

Table A.2. 5: Monthly and annual volume weighted mean concentrations of arsenic in precipitation at Norwegian background stations 2017. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes	0.15	0.28	0.05	0.05	0.11	0.07	0.06	0.05	0.14	0.04	0.06	0.04	0.09
Svanvik	0.59	0.5	0.81	0.66	1.73	0.4	1.35	2.06	1.82	1.77	1.13	0.5	1.21
Karpbukt	0.42	0.3	2.63	0.87	0.71	0.44	1.16	1.48	0.34	1.42	0.96	0.56	0.8

Table A.2. 6: Monthly and annual volume weighted mean concentrations of copper in precipitation at Norwegian background stations 2017. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes	7.56	5.62	4.15	0.58	1.94	0.94	0.67	3.11	2.97	0.31	2.18	0.76	2.37
Svanvik	17.99	92.76	10.93	37.32	72.01	12.37	35.24	43.31	41.89	45.5	31.16	25.37	33.95
Karpbukt	18.85	23.56	71.04	20.39	17.43	14.85	22.59	53.97	10.22	74.84	25.87	22.53	25.51

Table A.2. 7: Monthly and annual volume weighted mean concentrations of cobalt in precipitation at Norwegian background stations 2017. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes	0.07	0.03	0.02	0.02	0.02	0.04	0.02	0.01	0.02	0.01	0.01	0.01	0.02
Svanvik	0.61	1.15	0.33	0.57	1.62	0.4	1.04	1.08	0.91	1.34	0.92	0.44	0.85
Karpbukt	0.51	0.41	2.02	0.8	0.52	0.38	0.71	0.96	0.31	1.6	0.55	0.48	0.63

Table A.2. 8: Monthly and annual volume weighted mean concentrations of chromium in precipitation at Norwegian background stations 2017. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes	0.33	0.13	0.07	0.08	0.14	0.08	0.06	0.05	0.14	0.08	0.04	0.06	0.1
Svanvik	0.38	0.22	0.1	0.17	0.45	0.09	0.22	0.25	0.56	0.43	0.23	0.05	0.25
Karpbukt	0.23	0.18	0.58	0.37	0.32	0.27	0.57	0.3	0.24	0.81	0.15	0.09	0.32

Table A.2. 9: Monthly and annual volume weighted mean concentrations of manganese in precipitation at Norwegian background stations 2017. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes	2.41	0.78	0.66	0.88	4.64	3.76	2.15	1.22	2.18	1.17	0.67	0.47	1.54

Table A.2. 10: Monthly and annual volume weighted mean concentrations of vanadium in precipitation at Norwegian background stations 2017. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes	0.49	0.36	0.11	0.11	0.22	0.32	0.16	0.13	0.13	0.11	0.17	0.16	0.16
Svanvik	0.89	1.01	0.37	0.61	1.32	0.27	0.25	0.18	0.3	0.7	0.82	0.51	0.47
Karpbukt	0.5	0.52	0.77	0.31	0.36	0.35	0.57	0.26	0.21	1.04	0.63	0.53	0.45

Table A.2. 11: Monthly and annual volume weighted mean concentrations of aluminium in precipitation at Svanvik and Karpdalen. 2017. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Svanvik	74.13	30.11	7.64	19.14	28.44	9.78	24.05	18.6	19.85	22.55	12.65	8.04	19.63
Karpbukt	29.5	14.23	25.52	21.91	31.71	63.52	122.32	23.76	48.14	84.71	14.85	10.5	48.36

Table A.2. 12: Monthly and annual average volume weighted mean concentrations of mercury in precipitation at Birkenes in 2017.. Unit: ng/L

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes	4.6	4.1	4.2	14.2	6.3	19.3	4.8	8.0	7.6	4.5	3.9	1.7	5.8

Table A.2. 13: Annual and monthly total precipitation in 2017. 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	2017
Birkenes	84	111	108	59	58	26	98	132	539	422	206	111	1954
Hurdal	39	55	30	48	82	46	74	161	116	125	80	77	934
Kårvatn	194	106	127	148	111	137	150	113	57	232	161	208	1746
Svanvik	17	10	28	18	20	71	56	59	40	32	37	17	404
Karpbukt	25	34	11	15	25	45	54	30	50	13	29	20	349

Table A.2. 14: Monthly- and annual wet deposition of lead at Norwegian background stations 2017. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes	110	140	35	11	49	17	23	54	506	190	110	60	1306
Hurdal	36	34	8	18	91	18	16	29	20	48	25	10	353
Kårvatn	68	6	10	16	19	11	8	9	2	10	7	6	172
Svanvik	22	8	28	10	22	29	48	71	39	31	23	11	342
Karpbukt	19	23	41	15	14	14	51	31	14	9	26	12	269

Table A.2. 15: Monthly- and annual wet deposition of cadmium at Norwegian background stations 2017. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes	1.7	3.5	1.1	0.4	1.4	0.4	0.9	1.6	17.2	4.3	2.6	0.9	36.1
Hurdal	0.7	1	0.3	0.6	1.9	0.6	0.5	1.1	0.8	2.2	1	1	11.8
Kårvatn	0.7	0.2	0.5	0.4	0.7	0.4	0.3	0.5	0.1	0.3	0.2	0.9	5.3
Svanvik	1.1	1	1.9	1.6	2.2	1.7	3	6.6	7.4	3.9	3.2	1.9	35.7
Karpbukt	2.6	2	2.5	1.5	0.5	0.5	3.3	1.8	0.9	1.4	2.4	1.3	20.8

Table A.2. 16: Monthly- and annual wet deposition of zinc at Norwegian background stations 2017. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes	305	606	330	244	356	90	178	284	1999	601	459	154	5608
Hurdal	247	588	192	286	542	173	241	301	222	389	212	540	3931
Kårvatn	443	110	148	116	167	155	216	213	56	138	55	252	2069
Svanvik	73	76	105	66	111	161	197	304	233	139	191	46	1703
Karpbukt	82	212	74	119	92	107	240	101	186	175	278	68	1734

Table A.2. 17: Monthly- and annual wet deposition of nickel at Norwegian background stations 2017. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes	65	51	19	11	11	8	23	20	68	72	30	14	390
Svanvik	329	363	258	311	1077	952	1930	2081	1237	1422	983	207	11151
Karpbukt	387	468	859	416	414	498	1079	917	496	647	529	343	7054

Table A.2. 18: Monthly- and annual wet deposition of arsenic at Norwegian background stations 2017. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes	12	31	6	3	7	2	6	6	74	19	12	5	184
Svanvik	10	5	23	12	34	28	75	121	73	57	41	8	488
Karpbukt	10	10	29	13	18	20	62	44	17	18	27	11	280

Table A.2. 19: Monthly- and annual wet deposition of copper at Norwegian background stations 2017. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes	638	621	448	34	114	25	65	412	1600	132	450	84	4623
Svanvik	306	913	305	657	1418	883	1976	2543	1685	1460	1139	423	13708
Karpbukt	465	805	770	305	430	669	1213	1592	516	957	740	440	8902

Table A.2. 20: Monthly- and annual wet deposition of cobalt at Norwegian background stations 2017. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes	6	3	2	1	1	1	2	2	12	5	3	1	39
Svanvik	10	11	9	10	32	28	58	63	37	43	34	7	343
Karpbukt	13	14	22	12	13	17	38	28	16	20	16	9	218

Table A.2. 21: Monthly- and annual wet deposition of chromium at Norwegian background stations 2017. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes	28	14	8	5	8	2	6	6	73	35	9	6	201
Svanvik	6	2	3	3	9	6	12	14	22	14	9	1	102
Karpbukt	6	6	6	6	8	12	31	9	12	10	4	2	112

Table A.2. 22: Monthly- and annual wet deposition of manganese at Norwegian background stations 2017. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes	203	86	72	52	272	98	211	161	1173	493	139	52	3010

Table A.2. 23: Monthly- and annual wet deposition of vanadium at Norwegian background stations 2017. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes	42	40	12	7	13	8	16	18	68	44	34	18	321
Svanvik	15	10	10	11	26	19	14	11	12	22	30	9	189
Karpbukt	12	18	8	5	9	16	31	8	10	13	18	10	158

Table A.2. 24: Monthly and annual wet deposition of mercury at Birkenes in 2017. Unit: ng/m^3

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2017
Birkenes	388	550	355	835	369	506	470	1058	4081	1906	812	188	11407
Svanvik	1261	296	213	337	560	698	1349	1092	798	724	463	134	7925
Karpbukt	727	486	277	327	783	2861	6568	701	2429	1083	425	205	16873

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
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								
Kårvatn	1979	1.5	0.04	3								
	1980	1.4	0.06	4.2								
	1981	1.4	0.09	3								
	1982	1.5	0.10	3.1								
	1983	0.7	0.12	2.9								
	1984	1.3	0.07	3.6								
	1985	1.1	0.06	4								
	1986	1.4	0.01	3.2								
	1987	1.1	0.03	2.5								
	1988	0.9	0.06	4.2								
	1989	0.3	0.05	1.8								
	1990	0.2	0.06	1								
	1991	0.3	0.01	1								
	1992	0.2	<0.01	0.8								
	1993	0.2	0.01	0.6								
	1994	0.4	0.02	1.2								
	1995	0.2	0.01	1.2								
	1996	0.5	0.01	1.4								
	1997	0.7	0.01	1.6								
	1998	0.2	0.01	1.3	0.1	0.1	0.1	0.01	0.3		0.3	
	1999	0.2	0.02	2.1								
	2000	0.18	0.01	1								
	2001	0.13	0.01	1.4								
	2002	0.32	0.018	1.2								
	2003	0.25	0.009	1								
	2004	0.13	0.005	1.2								
	2005	0.12	0.005	0.9								
	2006	0.17	0.010	1.9								
	2007	0.09	0.007	0.9								
	2008	0.1	0.005	1.2								
	2009	0.09	0.010	1.3								
	2010	0.14	0.009	3.7								
	2011	0.11	0.013	1.4								
	2012	0.11	0.005	1.5								
	2013	0.16	0.006	6.5								

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.)	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								
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	

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

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

Table A.2. 26. cont.

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

Table A.2. 27: Monthly and annual average mean concentrations of heavy metals in PM10 and mercury in gas phase at Birkenes in 2017. Unit: ng/m^3

	As	Cd	Cr	Co	Cu	Pb	Ni	V	Zn	Hg(g)
JAN	0.26	0.034	3.06	0.015	0.55	1.09	0.17	0.26	3.4	1.63
FEB	0.18	0.029	3.35	0.011	0.30	0.78	0.15	0.22	3.7	1.66
MAR	0.16	0.017	3.34	0.013	0.25	0.54	0.15	0.24	2.4	1.57
APR	0.17	0.021	3.01	0.018	0.38	0.46	0.16	0.21	2.3	1.48
MAY	0.21	0.022	2.56	0.021	0.36	0.59	0.24	0.34	2.5	1.61
JUN	0.11	0.011	2.55	0.016	0.19	0.29	0.14	0.20	3.3	1.58
JUL	0.10	0.011	2.55	0.017	0.25	0.28	0.20	0.30	2.9	1.51
AUG	0.13	0.014	2.56	0.013	0.34	0.32	0.18	0.21	1.8	1.40
SEP	0.17	0.041	3.81	0.018	0.41	1.00	0.20	0.21	9.9	1.31
OCT	0.12	0.026	3.80	0.013	0.44	0.68	0.14	0.15	4.0	1.28
NOV	0.04	0.008	1.93	0.004	0.09	0.15	0.05	0.04	0.9	1.24
DEC	0.03	0.008	2.24	0.003	0.09	0.12	0.05	0.03	0.9	1.27
2017	0.14	0.021	2.91	0.013	0.31	0.54	0.15	0.20	3.2	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 2017. Unit: ng/m^3

	As	Cd	Cr	Co	Cu	Pb	Mn	Ni	V	Zn	Hg(g)
JAN	0.02	0.003	0.13	0.006	0.32	0.09	0.31	0.09	0.09	0.8	1.49
FEB	0.05	0.009	0.10	0.010	0.61	0.20	0.44	0.12	0.12	1.4	1.50
MAR	0.02	0.005	0.09	0.007	0.37	0.12	0.32	0.07	0.06	0.9	1.51
APR	0.09	0.015	0.27	0.021	0.82	0.27	0.63	0.37	0.34	2.2	1.42
MAY	0.03	0.005	0.21	0.016	0.43	0.13	0.90	0.21	0.11	1.0	1.45
JUN	0.05	0.010	0.21	0.017	0.41	0.80	0.87	0.16	0.16	0.7	1.42
JUL	0.03	0.004	0.08	0.009	0.67	0.22	0.48	0.22	0.19	0.7	1.38
AUG	0.02	0.002	0.07	0.003	0.21	0.05	0.35	0.22	0.08	0.5	1.35
SEP	0.10	0.043	0.24	0.034	0.87	0.88	1.67	0.20	0.24	2.0	1.28
OCT	0.03	0.007	0.07	0.011	0.97	0.19	0.43	0.15	0.09	0.8	1.34
NOV	0.02	0.003	0.12	0.004	0.13	0.11	0.10	0.22	0.10	0.3	1.34
DEC	0.01	0.001	0.23	0.004	0.08	0.05	0.12	0.15	0.05	0.3	1.39
2017	0.04	0.008	0.14	0.012	0.51	0.22	0.54	0.18	0.13	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 2017. Unit: ng/m^3

	As	Cd	Cr	Co	Cu	Pb	Mn	Ni	V	Zn	Hg(g)
JAN	0.09	0.017	0.33	0.010	0.34	0.39	1.00	0.19	0.07	2.5	1.55
FEB	0.12	0.017	0.57	0.013	0.39	0.50	0.89	0.25	0.09	2.0	1.58
MAR	0.11	0.018	0.23	0.006	1.00	0.37	0.50	0.96	0.05	1.3	1.34
APR	0.19	0.039	0.47	0.018	0.39	0.98	0.96	0.34	0.15	2.3	1.50
MAY	0.03	0.007	0.18	0.007	0.19	0.13	0.64	0.32	0.05	0.6	1.07
JUN	0.02	0.003	0.04	0.002	0.05	0.06	0.23	0.04	0.02	0.1	1.60
JUL	0.01	0.001	0.14	0.003	0.14	0.00	0.61	0.02	0.02	2.0	1.53
AUG	0.00	0.000	0.07	0.001	0.05	0.00	0.34	0.08	0.01	2.3	1.47
SEP	0.01	0.002	0.05	0.006	0.09	0.05	0.38	0.10	0.04	1.9	1.40
OCT	0.03	0.008	0.47	0.015	0.19	0.29	0.61	0.72	0.11	2.1	1.31
NOV	0.04	0.004	0.59	0.054	0.20	0.14	2.25	0.58	0.27	1.4	1.38
DEC	0.05	0.008	0.37	0.038	0.19	0.21	1.70	0.33	0.19	0.8	1.43
2017	0.06	0.011	0.29	0.015	0.28	0.28	0.86	0.36	0.09	1.6	1.43

Table A.2. 30: Monthly and annual average mean concentrations of heavy metals in aerosols at Svanvik in 2017. Unit: ng/m^3

	Al	As	Cd	Cr	Co	Cu	Pb	Ni	V	Zn
JAN	4	0.75	0.093	0.15	0.08	3.2	12	2.01	0.32	2.2
FEB	12	1.28	0.101	0.20	0.28	6.5	33	2.14	0.41	8.8
MAR	11	1.26	0.102	0.22	0.23	4.5	27	2.27	0.36	6.2
APR	73	1.04	0.085	0.40	0.52	10.2	100	1.86	1.14	15.0
MAY	116	3.60	0.282	0.69	1.08	17.5	179	4.27	1.86	26.9
JUN	59	1.50	0.144	0.39	0.55	10.1	99	1.81	1.02	14.0
JUL	85	0.69	0.078	0.39	0.36	6.6	114	0.97	1.72	8.7
AUG	29	1.46	0.142	0.20	0.33	6.1	56	1.75	0.71	7.8
SEP	50	0.67	0.098	0.27	0.28	5.7	77	1.28	1.01	6.2
OCT	30	1.61	0.155	0.24	0.36	7.6	54	2.47	0.73	9.3
NOV	11	8.93	0.805	0.27	0.55	18.0	49	7.24	0.43	13.4
DEC	10	0.53	0.074	0.17	0.15	3.6	24	1.36	0.32	4.0
2017	39	1.93	0.180	0.29	0.38	8.1	68	2.39	0.83	9.9

Table A.2. 31: Monthly and annual average mean concentrations of heavy metals in aerosols at Karpdalen in 2017. Unit: ng/m^3

	Al	**As**	**Cd**	**Cr**	**Co**	**Cu**	**Pb**	**Ni**	**V**	**Zn**
JAN	9	2.50	0.272	0.19	0.25	14.0	27	4.78	0.40	6.8
FEB	13	1.68	0.184	0.25	0.26	7.1	30	2.86	0.38	8.5
MAR	15	6.49	0.541	0.25	0.34	7.7	38	12.27	0.38	10.0
APR	22	0.60	0.065	0.16	0.20	4.0	27	1.35	0.36	5.2
MAY	37	0.56	0.046	0.18	0.22	3.5	40	0.82	0.53	5.4
JUN	118	0.80	0.093	0.32	0.30	5.7	111	1.41	1.64	7.0
JUL	110	1.00	0.124	0.38	0.39	7.0	118	1.52	1.87	8.9
AUG	14	2.16	0.132	0.23	0.33	6.7	35	2.16	0.48	8.4
SEP	64	1.95	0.192	0.39	0.45	9.9	81	2.26	1.13	10.5
OCT	22	1.03	0.106	0.25	0.21	5.9	33	1.88	0.55	6.0
NOV	7	8.63	0.773	0.22	0.42	12.8	39	8.34	0.33	10.4
DEC	12	5.86	0.789	0.34	0.63	14.4	58	10.81	0.55	14.7
2017	37	2.78	0.278	0.26	0.33	8.2	53	4.24	0.72	8.5

Table A.2. 32: Monthly and annual concentration of Mercury at Trollhaugen in 2017. Unit: ng/m^3

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	2017
Trollhaugen	0.96	1.01	0.98	1.02	1.02	0.99	0.99	0.97	0.99	0.93	0.95	0.98	0.98

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		

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		
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		
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		

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 emerging pollutants

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

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 emerging organic pollutants.

	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 (Birkenes)	HCB, OCPs, PCBs, PAHs, PBDEs, HBCDs, ionic and volatile PFAS, S/MCCPs, dechloranes (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 actual total air volumes of 600-1950 m^3 (as reported on sampling protocols).

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

	Birkenes	Andøya	Zeppelin
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
OPFRs	-	-	48-72 h
Phthalates	-	-	48-72 h
Dechloranes	-	-	48 h

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

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

Sampling of Cyclic volatile methyl siloxanes (cVMS)

Sampling of cVMS differed from the rest of the compounds. Sampling was done with a solid-phase extraction active air sampling (SPE-AAS) method with an ENV+ sorbent (hydroxylated polystyrene divinylbenzene copolymer) (Kierkegaard and McLachlan, 2010, Krogseth et al., 2013) with a flow rate of 1.0 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 (72 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 blanks for each sample. In a few occasions, a new type of adsorbent (ABN) was used in one of the two samples. This was done to evaluate the performance of this new improved adsorbent in comparison to the ENV+ adsorbent used so far. When using the ABN adsorbent, the air flow was reduced from 0.7 m^3 per hour (as a result of increased resistance in the sampler). This volume was used to calculate the air concentrations. Each of the cartridge sets were extracted individually.
All lab operations were strictly performed in a clean cabinet and of laboratory personnel without personal-care products in order to reduce the risk of contamination during the preparation and analytical steps.

All samples were spiked to the upper frit of a cartridge with 20 µL of internal standard (IS) containing 13C-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 analysed on an Agilent 7890A GC connected to an Agilent 5975C MS detector and a Gerstel MPS3 autosampler. Helium (purity 5.0) was used as carrier gas (constant flow rate 1.0 mL min-1). The GC injector was equipped with a Merlin microseal septum and a 5.0 mm I.D. gooseneck splitless liner with deactivated glass wool (Restek, USA), while a 5 m Rxi guard column (Restek, 0.32 mm I.D.) was connected to a 30 m DB-5 column (Agilent Technologies, 0.25 mm I.D., 0.25 µm film thickness). A 100 µl syringe was used to inject 10 µL sample at an injector temperature of 200 °C. The GC oven started at 40 °C for 1 min, followed by 10 °C min-1 up to 150 °C and 35 °C min-1 to 300 °C with a final hold time of 4 min. The MS ion source was operated at 230 °C and the quadrupole at 150 °C. Two ions were monitored for each compound (m/z 281 and 282 for D4, 285 and 286 for 13C4-D4, 267 and 355 for D5, 364 and 365 for 13C10-D5, 341 and 429 for D6, 434 and 435 for 13C6-D6). Seven-point calibration curves (5 ng/ml to 200 ng/ml) were used for quantification.

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

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, 20 µL IS containing ^{13}C-labelled trans-CD (~500 pg/µL) for MCCP and 20 µL 13C-labelled Dechlorane plus syn for Dechloranes, 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 extract was concentrated and cleaned by acid treatment and silica fractionation. Before quantitative analysis, 20 µL of unlabelled tetrachloronaphthalene (TCN, 100 pg/µL) was added as recovery standard (RS).

Identification and quantification of HCB, the PCBs and OCPs was carried out using a high-resolution gas chromatography coupled to a high-resolution mass spectrometer as detector (HRGC/HRMS). The analyses were performed in Electron Impact ionization (EI) mode for PCBs, HCB, HCHs, and DDTs using selected ion monitoring (SIM) for the respective compounds groups. Identification and quantification of chlordanes, SCCP, MCCP and dechloranes 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 and 13 organochlorine pesticides (OCPs) 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 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.

Sampling of POPs in precipitation

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

Analysis and quantification of POPs in precipitation

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

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

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

Quality assurance/Quality control (QA/QC)

NILU’s laboratories; the organic and inorganic chemical analyses, are accredited in accordance to NS-EN ISO/IEC 17025. The accredited sampling and analytical methods are to be found under accreditation number TEST 008 and includes P12 chemical analysis and P3002 air sampling. The chemical analysis, in turn, include heavy metals, mercury, PCBs, and organochlorine pesticides (HCB, HCHs, chlordanes, DDTs).

All sampling equipment at the monitoring stations undergo routine controls and calibration of flow rates.

Field blank samples (n=3) and lab blank samples (n=12) were routinely included in order to control unintended contamination during storage, transport and analytical steps. Field blanks, consisting of pre-cleaned PUF plugs and filters, were sent to each station where they were exposed during the assembly and retrieval of the PUF plugs and filters in field, but kept unexposed in foil and air tight bags during the exposure time. They were then transported, stored, extracted, cleaned and analyzed in the same way as and parallel with the real samples.

The lab blanks were obtained by extracting pre-cleaned PUFs and filters in solvent and using the same clean-up and analytical procedures as real samples and field blanks.

The analytical procedure was accompanied by a comprehensive quality control program based on the requirements of NILU's accreditation, according to EU standard EN 45001. The instrument limit of detection (LOD) was determined by calculating the signal-to-noise ratio (S/N) > 3 for solvent blanks (using n-hexane). Based upon average blank concentrations (laboratory blanks) the limit of quantification (LOQ) was calculated for all compounds with LOQ = average blank value plus 3 standard deviations (STD) of the blank concentrations.

All samples within the range LOQ>×>LOD are considered to have high uncertainties and are reported as <LOQ. All raw data 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 emerging organic contaminants (i.e. cVMS, S/MCCPs, nBFRs, OPFRs, phthalates, dechloranes) 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.

Norwegian Environment Agency
Telephone: +47 73 58 05 00 | Fax: +47 73 58 05 01
E-mail: post@miljodir.no
Web: www.environmentagency.no
Postal address: Postboks 5672 Sluppen, N-7485 Trondheim
Visiting address Trondheim: Brattørkaia 15, 7010 Trondheim
Visiting address Oslo: Grensesvingen 7, 0661 Oslo

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

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

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

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