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Monitoring of environmental contaminants in air and precipitation

Annual report 2020

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ABSTRACT

This report presents environmental monitoring data from 2020 and time-trends for the Norwegian programme for Long-range atmospheric transported contaminants. The results cover 200 organic compounds (regulated and non-regulated), 11 heavy metals, and organic chemicals of potential Arctic concern.

NORWEGIAN TITLE

Overvåking av langtransporterte atmosfæriske miljøgifter i luft og nedbør, årsrapport 2020.

KEYWORDS

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

ABSTRACT (in Norwegian)

Denne rapporten inkluderer miljøovervåkningsdata fra 2020 og tidstrender for programmet Langtransporterte atmosfæriske miljøgifter. Resultatene omfatter 200 organiske miljøgifter (regulerte og ennå ikke regulerte), 11 tungmetaller og et utvalg organiske kjemikalier som potensielt er av bekymring for Arktisk miljø.

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Summary

This report presents monthly and annual mean concentrations of selected environmental pollutants in air and precipitation at Norwegian background sites in 2020. The monitoring is done for the Norwegian Environment Agency and is part of the national environmental monitoring in Norway. This report covers findings from two different monitoring programmes "*Long-range atmospheric transported contaminants"* and "*the Norway-Russia measurements*". The overall purposes of the monitoring are to i) assess long-term temporal trends of contaminants in Norway, ii) increase the knowledge on long-range transported contaminants as a source for pollution in Norway, iii) assess spatial variabilities of environmental contaminants in Norway, and iv) provide data for international conventions, programmes and networks.

The monitoring programme in 2020 was the same as in 2017-2019. Air monitoring of persistent organic pollutants (POPs) and heavy metals including mercury, was conducted using active air samplers at three sites (i.e. Birkenes, Andøya and Zeppelin), while monitoring of heavy metals in precipitation was conducted at five sites (i.e. Birkenes, Hurdal, Kårvatn, Svanvik and Karpdalen), and monitoring of mercury and POPs in precipitation was conducted at one site (i.e. Birkenes). The monitoring programme also included measurements of i) phthalates, new brominated flame retardants (nBFRs) and organophosphorous flame retardants (OPFRs) at Birkenes; ii) dechloranes at Zeppelin and Birkenes, and iii) volatile fluorinated substances at Zeppelin and Birkenes.

Long-term monitoring data of regulated organic pollutants
A number of regulated POPs and POP-like substances have been monitored in air for about 20 years or more, before the Stockholm Convention came into force: hexachlorobenzene (HCB) at Birkenes and Zeppelin, hexachlorohexanes (HCHs) at Birkenes and Zeppelin, dichlorodiphenyltrichloroethane (DDTs) and chlordanes at Zeppelin and polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) at Zeppelin. Long-term data is also available for HCHs and HCB in precipitation from Birkenes. The results from the long-term monitoring, including trend analyses, show decreasing concentrations over time for HCHs with short, estimated half-lives around 5 years during the whole monitoring period. No significant changes in trends (expressed as half-lives) are seen in the period after the Stockholm Convention came into force (2004-2020). For most of the POPs in the monitoring programme, the monitoring results over the last five years show smaller decreases in concentrations or fluctuating concentrations from year to year. This suggests that these POPs have entered into a temporal remote state where the primary emissions have to a large extent stopped and the global concentrations now instead are controlled by emissions from secondary repositories. Exceptions are HCB and DDTs. For HCB, an increase was seen in 2004-2015 followed by a decrease after 2015. The concentrations of HCB are now the lowest ever measured at all stations. For DDTs, an increase has been observed at Birkenes during the last three years, but the concentrations in 2020 were lower than in 2019.

Short-term monitoring of organic pollutants
For some compounds and some stations, the air monitoring has been performed for shorter time-periods than 15 years (i.e. 11 to 15 years), and monitoring started after the Stockholm Convention came into force: polybrominated diphenyl ethers (PBDEs) at Birkenes and Zeppelin, hexabromocyclododecanes (HBCDs) at Birkenes and Zeppelin, and ionic per- and polyfluorinated alkylsubstances (PFAS) at Birkenes, Andøya and Zeppelin. In this report, all of the targeted ionic PFAS-compounds are grouped and presented together although not all are 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 are showing very low levels in air at the background

sites. Of the targeted PFAS-compounds, only PFOA is detected at all three sites. The annual mean concentrations of PFOA in 2020 is significantly higher at Birkenes (0.12 pg/m^3) than at Andøya and Zeppelin (0.05 and 0.07 pg/m^3, respectively).

Cyclic volatile methylsiloxanes (cVMS) and short- and medium chain chlorinated paraffins (SCCPs and MCCPs), have been monitored at Zeppelin since 2013, and at Birkenes since 2017. The annual mean concentrations for the three cVMS oligomers at Zeppelin in 2020, D4 (0.5 ng/m^3), D5 (1.0 ng/m^3) and D6 (0.3 ng/m^3), are lower than in 2019, but similar to 2017 and 2018. The same was observed at Birkenes, with lower concentrations compared to 2019, but similar or somewhat higher concentrations than in 2017-2018. The concentrations of cVMS were higher at Birkenes (1.3, 4.9 and 0.5 pg/m^3 for D4-D6, respectively) than at Zeppelin.

The annual mean concentrations measured for SCCPs at Zeppelin and Birkenes do not show any significant difference between the years (2013-2020). The MCCPs at Birkenes and Zeppelin in 2020 were higher than previous years. The data for MCCPs are, however, associated with uncertainties due to high and inconsistent levels in field and lab blanks.

Monitoring of non-regulated organic contaminants of emerging concern

Four groups of non-regulated organic contaminants of emerging concern have been included in the monitoring at Zeppelin since 2017: nBFRs, OPFRs, phthalates and volatile PFAS. The nBFRs, OPFRs and phthalates have been monitored in sampling campaigns in summer and winter at Zeppelin and Birkenes. The results from these sampling campaigns show that the concentrations of the individual phthalates in air are high, in the same range as the cVMS (ng/m^3), at both Birkenes and Zeppelin. Only a few of the targeted OPFRs were detected in the air samples from Birkenes and Zeppelin. One reason for low detection of OPFRs is high levels in lab and field blanks resulting in high limit of detections (LODs) and large uncertainty of the OPFR data. The concentrations of the detected individual OPFRs in air were, however, high, in the same range as the S/MCCPs (100s pg/m^3).

The volatile PFAS-compounds have been monitored every month at Birkenes, Andøya and Zeppelin. Only FTOHs were detected in more than 50% of the samples and the dominant PFAS-compounds were 6:2 and 8:2 FTOH at all sites.

In 2020, one additional group, dechloranes, were monitored weekly at Zeppelin and monthly at Birkenes. Of the targeted 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 at both Birkenes and Zeppelin suggesting low concentrations of dechloranes in air at these sites.

A mast was constructed at Birkenes in summer 2020, to meet the criteria to receive the label for a standardized greenhouse gas measurement station under the European greenhouse gas network, ICOS. During the construction period, there was building activities with drilling, large vehicles, and new equipment at the station. Despite avoidance of collecting air sampling at the dates of the building activities, the results for nBFRs and phthalates during the summer campaign show that the building activities have affected the measurements at Birkenes. Some of the individual nBFRs and phthalates were significantly higher in summer 2020 than in winter 2020 and summer measurements in 2017-2019.

Analyses of ten volatile fluorinated or chlorinated substances in air samples at Zeppelin and Birkenes in summer and winter 2020 show that the highest concentrations are found for hexachlorobutadiene

(HCBD) and perfluorotributylamine (PFTBA) followed by tetrachlorohexafluorobutane (TCPFB) and perfluorotripentylamine (PFTPeA). The data mining also showed that dichlorobenzene and hexachloroethane are present in similar concentrations as PFTBA and HCBD.

Spatial distribution of organic pollutants and contaminants of emerging concern

Higher concentrations at Birkenes in southern Norway than at Zeppelin in the Arctic was observed for μ-HCH, DDTs, PAHs, PFOA and cVMS. This spatial distribution, together with episodes of high concentrations that were associated with air mass trajectories from source regions in central and Eastern Europe, calculated using the FLEXTRA trajectory model (https://projects.nilu.no/ccc/trajectories/) (Stohl et. al., 1995; Stohl and Seibert, 1998), reflects Birkenes' closeness to potential source regions in continental Europe. Some, but not all, of the organic contaminants of emerging concern: FTOHs, and nBFRs, are observed at higher concentrations at Birkenes than at Zeppelin in most samples. In contrast, the observed concentrations of HCB, TBA, some OPFRs and phthalates are higher in the Arctic at Zeppelin than in southern Norway at Birkenes. The reason for this is not understood and further research is needed. α-HCH and many PCBs are measured at similar concentrations at both sites. For α-HCH this is explained by long half-live and long-range transport potential while for PCBs this may be attributed to local sources of PCBs at Svalbard (e.g. Pyramiden).

Long-term monitoring of heavy metals and mercury

In 2020, the concentrations of heavy metals in precipitation and in aerosols were highest at the sites in Sør-Varanger. The high levels are due to emissions from smelters in Russia. The wet deposition of lead and cadmium in 2020, however, was highest at Birkenes in southern Norway due to more precipitation at this location. The lowest concentrations of heavy metals in precipitation were observed at Kårvatn, which is farthest away from emission sources. In general, the air concentrations of heavy metals were two-three times lower at Andøya and Zeppelin in the North than at Birkenes in the South, mainly due to closeness to the potential emission sources in continental Europe. For mercury, no significant spatial distribution is observed in Norway. This indicates that this pollutant has a large potential to be transported far from emission sources due to its longer atmospheric lifetime, and a lack of regional primary sources.

In 2020, the concentrations of lead in precipitation were slightly higher compared to 2019 at Birkenes and Hurdal, while at Kårvatn it was much lower. For cadmium there is a similar level in 2020 and 2019 at Birkenes, but substantially lower concentrations at both Hurdal and Kårvatn in 2020 than in 2019. These annual differences are mainly due to variabilities in meteorology, i.e. favourable conditions for transport of air pollution from major emission sources, and the amount of precipitation. In a long-term perspective, the concentrations of lead in precipitation have been largely reduced in Norway; almost 100% from both 1980 and1990 to 2020; and 59-64% since 2000 (except Kårvatn). Also, for cadmium in precipitation, there are substantial reductions: almost 100% since 1980; 53-81% since 1990, and 57-70 % since 2000, (except Kårvatn). Kårvatn differs from the other two sites being farther from the emission sources and the concentration levels, especially after 2000, are very low and it is difficult to detect trends. When combining the datasets from Lista and Birkenes, mercury has been significantly reduced since 1990 (64%) and since 2000 (52%).

The air concentrations of lead and cadmium were slightly lower in 2020 compared to 2019 except at Zeppelin where cadmium was almost three times higher in 2020. At Lista/Birkenes there has been a significant reduction in air concentrations for all the measured elements for the period 1991 to 2020. At Zeppelin, there has also been a significant reduction since 1994 for the elements which do not have crustal origin. The reduction for lead has been 88% and 67% respectively at Birkenes and Zeppelin. For cadmium, the reductions were 73% and 49%, respectively. For mercury, a relatively small decreasing trend is observed both at Birkenes (23%) and Zeppelin (13%).

Sammendrag

Denne rapporten presenterer månedlige and årlige data for miljøgifter og tungmetaller i luft og nedbør fra norske overvåkingsstasjoner i bakgrunnsområder i 2020. Overvåkingen utføres for det nasjonale overvåkingsprogrammet for langtransporterte atmosfæriske miljøgifter, sammen med programmet «Norge-Russland overvåkning». Formålet med overvåkingen er å i) evaluere lange tidstrender for miljøgifter i Norge, ii) øke kunnskapen om langtransport av miljøgifter som kilde til forurensning i Norge, iii) fremskaffe informasjon om romlig fordeling av miljøgiftnivåer i Norge, og iv) ivareta rapportering til internasjonale konvensjoner, programmer og nettverk. Fra 2017 har overvåkingen spesielt fokus på å fremskaffe luftdata om nye miljøgifter som ennå ikke er regulert på internasjonalt nivå. Dette for å støtte fremtidige tiltak nasjonalt og internasjonalt.

Overvåkingsprogrammet i 2020 var det samme som i 2017-2019. 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 2020 inkluderer 200 organiske komponenter og 11 tungmetaller. Nye miljøgifter i 2020 inkluderer: flyktige PFAS-forbindelser, nye bromerte flammehemmere (nBFR), fosfororganiske flammehemmere (OPFR), ftalater og dekloraner. Alle ble målt med aktiv luftprøvetaking. I tillegg ble flyktige fluororganiske stoffer målt på Zeppelin og Birkenes i en sommer- og en vinterkampanje.

Lange tidsserier for regulerte organiske miljøgifter
Flere regulerte organiske miljøgifter har vært en del av overvåkingsprogrammet i mer enn 20 år, før Stockholmskonvensjonen trådte i kraft i 2004: HCB på Birkenes og Zeppelin, HCH på Birkenes og Zeppelin, DDT på Zeppelin, klordaner på Zeppelin, PCB på Zeppelin og PAH på Zeppelin. I tillegg finns lange tidsserier for HCH og PCB i nedbør fra Birkenes. Data fra lange tidsserier og resultater fra trendanalyser viser reduserte nivåer for HCH-er med estimerte halveringstider på 5 år for hele måleperioden samt for perioden etter Stockholmskonvensjonen (2004-2018). For flere av POP-ene, viser måleprogrammet stabile nivåer eller små reduksjoner i de siste fem årene, hvilket tyder på at de har oppnådd temporal bakgrunnstilstand der nivåene fremst kontrolleres av sekundære kilder.

For HCB har overvåkningen vist økende nivåer i 2004-2015 på Zeppelin og 2011-2015 på Birkenes, men trenden etter 2015 har snudd. I 2020 var nivåene av HCB de laveste noensinne på alle stasjonene.

Korte tidsserier for regulerte organiske miljøgifter
For noen organiske miljøgifter og noen stasjoner har overvåkingen pågått i kortere perioder enn 15 år (fra 11 til 15 år). Dette inkluderer PBDE på Birkenes og Zeppelin, HBCD på Birkenes og Zeppelin, og ioniske PFAS på Birkenes, Andøya og Zeppelin. Ingen ioniske PFAS-forbindelser er regulert, men inngår her sammen med den regulerte PFOA. Flere PBDE-, HBCD- og PFAS-komponenter blir ikke detektert i luftmålingene som viser at det er lave konsentrasjoner av disse i luft på norske bakgrunnsstasjoner. PFOA er detektert i alle prøver på alle tre stasjonene. Konsentrasjonene av PFOA er signifikant høyere på Birkenes enn på Zeppelin og Andøya.

Siloksaner (cVMS) og klorparafiner har blitt målt på Zeppelin siden 2013 og på Birkenes siden 2017. I 2020 var konsentrasjonene av D4 (0.5 ng/m^3), D5 (1.0 ng/m^3) og D6 (0.3 ng/m^3) på Zeppelin lavere enn i 2019, men på samme nivåer som i 2017 og 2018. Nivåene var høyere på Birkenes (1.3, 4.9, and 0.5 pg/m^3 for D4-D6) enn på Zeppelin, men også der på samme nivåer som i 2017-2018. For SCCPs ses ingen forskjell i perioden 2013-2020 på Zeppelin og Birkenes, mens nivåene av MCCPs i 2020 var noe høyere enn tidligere år.

Overvåking av nye miljøgifter

Fire klasser med nye miljøgifter har vært en del av måleprogrammet på Zeppelin siden 2017: nBFRs, OPFRs, ftalater og flyktige PFAS. I 2020 ble nBFRs, OPFRs og ftalater målt i en sommer- og en vinterkampanje på Zeppelin og Birkenes. Resultatene viser at det er høye konsentrasjoner av ftalater i luft, på samme nivå som siloksaner (ng/m^3). De OPFR-komponentene som er detektert i prøvene, måles i høye konsentrasjoner og på samme nivåer som klorparafiner (100-talls pg/m^3). Kun et fåtall nBFR er detektert i prøvene og da i konsentrasjoner som er 100-1000 ganger lavere enn OPFR og ftalater. Nivåene av noen ftalater og nBFR-forbindelser ble målt i signifikant høyere nivåer sommeren 2020 sammenlignet med vintermålingene og tidligere sommermålinger. Årsaken til dette kan være forurensninger knyttet til installasjon av en ny målemast for det europeiske ICOS-nettverket for klimagasser på Birkenes under sommeren 2020.

Flyktige PFAS-komponenter ble målt i månedsprøver på Birkenes, Andøya og Zeppelin. Av de flyktige PFAS-komponentene var det kun FTOH-er som ble detektert i mer enn 50% av prøvene. De dominerende komponentene var 6:2 og 8:2 FTOH på alle stasjonene. Dekloraner ble i 2020 målt i ukesprøver på Zeppelin og i månedsprøver på Birkenes. Av dekloraner var det kun syn- og anti-dekloran plus som ble detektert. Nivåene av disse var lave, nær den analytiske deteksjonsgrensen

Målinger av ti flyktige fluororganiske stoffer viser høyeste nivåer av HBCD og PFTBA (2 ng/m^3) fulgt av TCPFB og PFTPeA på både Birkenes og Zeppelin. «Data mining» påviser også diklorbenzen og heksakloroetan i samme nivåer som PFTBA og HBCD.

Romlig fordeling av organiske miljøgifter

Det observeres høyere konsentrasjoner av HCH, DDT, PAH, PFOA og cVMS i Sør-Norge på Birkenes sammenlignet med den nordlige stasjonen (Zeppelin). For disse komponentene sammenfaller høye episoder på stasjonen med forekomst av luftmasser fra kildeområder på kontinentet. Også FTOHs og nBFRs måles i høyere konsentrasjoner på Birkenes enn på Zeppelin. For HCB, TBA, noen OPFRs og ftalater var det derimot høyere nivåer i nord enn i sør.

Lange tidsserier for tungmetaller og kvikksølv

De årlige gjennomsnittskonsentrasjonene av tungmetaller i luft og nedbør i 2020 var høyest på målestasjonene i Sør-Varanger. Dette skyldes utslipp fra de nærliggende smelteverkene på russisk side. Våtavsetning av bly og kadmium er derimot høyest i Sør-Norge der nedbørmengden er høyest. Laveste konsentrasjoner i nedbør måles på Kårvatn som ligger lengst bort fra kildeområder. Konsentrasjonen av de fleste tungmetallene målt i luft på Andøya og Zeppelin er to til tre ganger lavere enn det som er observert ved Birkenes. For kvikksølv er det ikke store forskjeller mellom stasjonene da kvikksølv har stort potensiale for langtransport. Dette indikerer i tillegg at det ikke er dominerende primære utslippskilder for kvikksølv i regionen.

I 2020 var konsentrasjonene av bly i nedbør noe høyere sammenlignet med 2019 på Birkenes og Hurdal, mens konsentrasjonene på Kårvatn er mye lavere. For kadmium er det tilsvarende nivåer i 2020 som i 2019 på Birkenes, men vesentlig lavere konsentrasjoner både på Hurdal og Kårvatn. I et lengre perspektiv har det vært en betydelig reduksjon i konsentrasjonen av tungmetaller i nedbør i Norge; nesten 100% fra både 1980 og 1990 til 2020; og 59-64% siden 2000 (unntatt Kårvatn). Også for kadmium i nedbør er det betydelige reduksjoner: Nesten 100% siden 1980; 53 - 81% siden 1990, og 57-70% siden 2000, (unntatt Kårvatn). Når man kombinerer datasettene fra Lista og Birkenes, har kvikksølv blitt betydelig redusert siden 1990 (64%) og siden 2000 (52%).

Luftkonsentrasjonene av bly og kadmium var litt lavere i 2020 sammenlignet med 2019 bortsett fra på Zeppelin hvor kadmium var nesten tre ganger høyere i 2020. På Lista/Birkenes har det vært en betydelig reduksjon i luftkonsentrasjon for tungmetaller som er målt for perioden 1991 til 2020. På

Zeppelin har det også vært en betydelig reduksjon siden 1994 for elementene som ikke er tilknyttet kilder for mineralstøv. Reduksjonen for bly har vært henholdsvis 88% og 67% på Birkenes og Zeppelin. For kadmium var reduksjonene henholdsvis 73% og 49%. For elementært kvikksølv i luft er det en svak nedadgående trend på 23% og 13% på henholdsvis Birkenes og Zeppelin.

Monitoring of environmental contaminants in air and precipitation

Annual report 2020

1 Monitoring programme for long-range transported atmospheric contaminants

The monitoring programme for long-range transported atmospheric contaminants is designed to study long- and short-term time trends and spatial distribution of regulated persistent organic pollutants (POPs), heavy metals, and more recently also organic contaminants of emerging concern.

1.1 Background

The data from 2020, presented in this report, are a compilation of data from two different monitoring programs:

- The monitoring programme “Long-range transported atmospheric contaminants”, conducted by NILU on the behalf of the Norwegian Environment Agency. The programme covers heavy metals and POPs (except PAHs) in air at Birkenes, Andøya and Zeppelin, heavy metals in precipitation at Birkenes, and organic contaminants of emerging concern in air at Zeppelin and Birkenes. It also covers POPs in precipitation at Birkenes, heavy metals in precipitation at Hurdal and Kårvatn, and PAHs in air at Zeppelin;

- "The Norway-Russia measurement programme", conducted by NILU on behalf of The Norwegian Environment Agency. The programme covers heavy metals in precipitation at Svanvik and Karpdalen.

In addition, “NILUs internal monitoring programme” covers monitoring of PAHs in air at Birkenes.

Heavy metals and POPs can undergo long-range environmental transport, are toxic, bioaccumulative and persistent in the environment. Monitoring of these contaminants is of high priority for Norwegian authorities due to their harmful impacts on human health and/or on the environment together with their transboundary nature. 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 and Hg. This in turn has contributed to the regulation of several of these contaminants both on a regional and global scale (Rottem et al., 2017; Downie & Fenge, 2003; AMAP, 2018).

The use and emission of heavy metals and POPs are regulated through several multilateral environmental agreements. Heavy metals are regulated by: i) the 1998 Aarhus Protocol on Heavy Metals under the Convention on Long-range Transboundary Air Pollution (LRTAP) (UN/ECE, 1998a), and ii) the Minimata Convention on mercury (UNEP, 2013). POPs are regulated on a global scale by the Stockholm Convention on POPs (Stockholm Convention, 2007) and on a European scale by the 1998 Aarhus Protocol on POPs; “the POP-protocol”, under LRTAP (UN/ECE, 1998b). The two POP conventions today include 30 and 23 substances/substance groups respectively and the number of chemicals included in the regulations are continuously expanded (UN/ECE, 2010, Stockholm Convention, 2019a). For example, in 2017, the Conference of the Parties to the Stockholm Convention

adopted decisions to list two new POPs in the convention; short-chain chlorinated paraffins (SCCPs) and decabromodiphenyl ether (deca-BDE), and agreed to take measures to restrict the unintentional production of the chemical hexachlorobutadiene (HCBD) whose production and use is already banned globally through the Stockholm Convention. The global regulation of these chemicals entered into force in 2018. In 2019, the parties to the Stockholm Convention agreed to list two new POPs; dicofol and perfluorooctanoic acid (PFOA) (Stockholm Convention, 2019a). In addition, new chemicals under consideration as potential POPs under the Stockholm Convention including perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related compounds, methoxychlor and dechlorane plus (Stockholm Convention, 2019b).

Several of the substances covered by this report are listed on Norway's Priority List of Hazardous substances ("Den norske prioritetslista") (Norwegian Environment Agency, 2021). Norway implements obligations under the Stockholm Convention on POPs, the Convention on Long-range Transboundary Air Pollution (LRTAP), the Minamata Convention and other international treaties in national law.

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

The updated monitoring programme in 2017, with the data presented in this report, has an increased focus on organic contaminants of emerging concern. The purpose of including monitoring of these contaminants has been to cover the large data gap that exist on the environmental occurrence and distribution for new contaminants. Increased knowledge for contaminants of emerging concern will help authorities in determining adequate policy measures and if necessary, make national or international regulations come into place.

The findings from this monitoring are also important for monitoring the effectiveness of and compliance with existing abatement strategies. Data and results from the national monitoring program are reported and used in several international fora including: The Global Monitoring Programme (GMP) of the Stockholm Convention on POPs, the European Monitoring and Evaluation Programme (EMEP) under the Convention on Long-range Transboundary Air Pollution, the Comprehensive Atmospheric Monitoring Programme (CAMP) under the Convention for the Protection of the marine Environment of the North-East Atlantic (OSPAR) and the Arctic Monitoring and Assessment Program (AMAP) (AMAP, 2016). A subset of the data is also reported to the European Commission as defined in the air quality directive (EU, 2008), and to the Environmental monitoring at Svalbard and Jan Mayen (MOSJ). Nationally, the data are used to assess the achievement towards obtaining priority environmental goals for environmental pollution and the Arctic.

1.2 Monitoring strategies

To document the long-range transport of the environmental contaminants, the monitoring stations/observatories in this report have been placed/located, as far as possible, in areas that are not influenced by local sources for the regulated and long-term monitored contaminants. For example, the occurrence of organic pollutants in the Arctic region has mostly been attributed to long-range transport from distantly located, industrial and agricultural areas. However, for the organic contaminants of emerging concern, it is important to continuously 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. Consequently, measures to remove specific material and products are taken both at sampling stations and in the analytical laboratories when such are identified. Some organic contaminants of emerging concern have been found at elevated levels near Arctic settlements, indicating that these settlements may serve as point sources of new organic contaminants to the Arctic region (Warner et al., 2010; Carlsson et al., 2018). However, Xu et al. (2019) gathered air data from several sites and showed that long-range transport is dominant for siloxanes in the Arctic (Xu, 2019). The same approaches are needed also for other contaminants of emerging concern but requires international collaboration.

The number of observatories and the geographical distribution are selected in order to represent different parts of Norway, and areas that receive air from different source regions globally. The observatories included in this monitoring programme are to a large extent coordinated and thereby the same ones as those within "*the national measurement programme of long-range transported air pollutants for main components in air and precipitation*", which like this monitoring programme is conducted by NILU on behalf of the Norwegian Environment Agency, and the Ministry of Climate and Environment (Aas et al., 2019). Three observatories are used for the monitoring of POPs and heavy metals in air; two of these are located on the mainland of Norway: Birkenes in southern Norway, and

Andøya in northern Norway, and one, Zeppelin, is located on Svalbard, an archipelago in the Arctic Ocean (

Figure 1, Table 1). POPs in precipitation is only monitored at Birkenes while heavy metals in precipitation is monitored at four sites: Birkenes and Hurdal in the southern parts of Norway, Kårvatn

and Svanvik in Finnmark in northern Norway (

Figure 1, Table 1). This report also includes heavy metals in precipitation from Karpdalen in Sør-Varanger and heavy metals in air at Svanvik and Karpdalen (Berglen et al., 2019). Further information of the sampling sites is available at: http://www.nilu.no/projects/ccc/sitedescriptions/.

Table 1: Information about the monitoring stations and list of measured contaminants at each station in 2020.

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

Figure 1: Norwegian background stations measuring environmental contaminants in 2020.

Air measurements of heavy metals and POPs started in 1991 at Lista observatory in southern Norway as part of a government program on environmental monitoring and were reported to the CAMP Programme under the OSPAR Convention (http://www.ospar.org). Lista was closed in 2004, but the extended measurement programme continued at the nearby observatory in Birkenes. In 1994, air measurements of heavy metals and POPs were included at the Zeppelin Observatory at Svalbard as part of the AMAP programme (http://www.amap.no). Birkenes and Zeppelin became part of EMEP (http://www.emep.int) under the LRTAP (http://www.unece.org/env/lrtap) in 1999, (Tørseth et al., 2012). In the end of 2009, a new monitoring station for heavy metals and POPs was established at Andøya as part of the national Marine Pollution Monitoring Programme for the Norwegian Environment Agency (Green et al., 2011) and data from this monitoring station is besides its function as a national monitoring station, now also part of the EMEP programme.

Air samples for organic contaminants and heavy metals (excluding mercury) are collected using active air samplers at all three sites. The active air samples are collected on a weekly basis throughout the year with specific sampling lengths for each observatory and class of contaminant (Table A.3.4). For example, HCB, PCB, OCPs and PAHs are sampled on a weekly basis at Birkenes and Zeppelin, but with different sampling length at each observatory (e.g. 24-48 h). The sampling methodologies have been optimized to achieve maximum detection while minimizing the influence of possible sampling artefacts, such as breakthrough and degradation. The number of samples per year is compound and site specific (i.e. 12 to 52). Exceptions to the continuous weekly monitoring are the new organic

contaminants of emerging concern that are collected in one summer and one winter campaign, and mercury in air that is measured continuously using a Tekran Hg monitor. The precipitation samples are collected on weekly basis using bulk precipitation samplers. Active air samples and precipitation samples for POPs and heavy metals are extracted, analysed and quantified at NILU under strict quality control using accredited methods. For the organic contaminants of emerging concern, the sampling and analytical methodologies are associated with a larger degree of uncertainty than for the well-established methods (e.g. PCBs). It is a long process to establish methods with similar quality assurance as for PCBs, but the analytical laboratory at NILU is constantly working on method improvements. Information about the sampling and analytical methodologies are given in Annex 3. All the POP data presented in this report are available at http://ebas.nilu.no/.

1.3 Organic contaminants

1.3.1 Regulated organic pollutants

In Norway, organic pollutants (e.g. POPs) in air and precipitation have been monitored since the beginning of 1990s. Monitoring first begun at Birkenes and Zeppelin and from 2009 Andøya was included (Table 2). From 2017, the monitoring was adjusted compared to the previous years (Table 2). Adjustments were made to improve and strengthen the monitoring of contaminants of emerging concern, while reducing the sampling frequency for some of the legacy pollutants. 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 pollutants 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. Data from the air measurements are presented as bulk concentrations (i.e. sum of gas- and particle phase) for most of the regulated compounds (Table 2). Exceptions are the ionic PFAS which are covering only the particle phase.

Table 2: Monitoring programme for regulated organic pollutants (e.g. POPs) in 2020.

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

*New sampling frequency from 2017

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

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

1.3.2 Organic contaminants of emerging concern

The monitoring programme "*Long-range transported atmospheric contaminants*" that provides an essential part of the data for this report also includes organic contaminants that are not yet regulated, but have been identified as contaminants of emerging concern in, for example, environmental screening programmes in Norway (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 at national, EU- and/ or global level. Another aspect is that if monitoring is initiated before a regulation/measure enters into force it may also be possible to get a more complete picture of the time trends, and the effect of the regulations.

Two of the organic contaminants of emerging concern; cVMS and S/MCCPs, have been monitored as part of this programme since 2013. Similarly, another four contaminant classes have been included in monitored programme since 2017; volatile PFAS, novel brominated flame retardants (nBFRs), organophosphorous flame retardants (OPFRs) and phthalates. In 2020, also volatile fluorinated substances were included. Most of the target ionic PFAS are non-regulated and therefore fall under the category of contaminants of emerging concern in this monitoring programme.

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

Table 3: Organic contaminants of emerging concern included in the monitoring programme "Long-range transported atmospheric contaminants" in 2020, year of first monitoring, sampling frequency and sample matrix at the different observatories.

Organic contaminants of emerging concern, Class	Matrix	Zeppelin		Birkenes		Andøya	
		Start year	Sampling frequency	Start year	Sampling frequency	Start year	Sampling frequency
cVMS	Gas phase	2013	weekly*	2017	monthly	-	-
S/MCCPs	Gas+particle phase	2013	weekly	2017	monthly	-	-
PFAS (volatile)	Gas phase	2017	monthly	2017	monthly	2017	monthly
nBFRs	Gas+particle phase	2017	summer + winter campaign**	2018	summer + winter campaign**	-	-
OPFRs	Gas+particle phase	2017	summer + winter campaign**	2018	summer + winter campaign**	-	-
Phthalates	Gas+particle phase	2017	summer + winter campaign**	2018	summer + winter campaign**	-	-
Dechloranes	Gas+particle phase	2019	weekly	2019	monthly		
Volatile fluorinated substances	Gas phase	2020	summer + winter campaign	2020	summer + winter campaign		

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

1.4 Heavy metals

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

Table 4: Monitoring of heavy metals in 2020.

Monitoring station	Matrix	Birkenes	Andøya	Zeppelin	Hurdal	Kårvatn	Svanvik	Karpdalen
Heavy metals - air	Particle phase	weekly	weekly	weekly	-	-	Weekly	weekly
Heavy metals - precipitation	Precipitation	weekly	-	-	weekly	weekly	Weekly	weekly
Hg - air	Gas phase	continuously	-	continuously	-	-	-	-
Hg - precipitation	Precipitation	weekly	-	-	-	-	-	-

2 Results and discussion for regulated organic pollutants

The organic pollutants included in this report represent a range of different sources, uses and applications. Most of the substances are intentionally produced substances such as pesticides, biocides, flame retardants, etc., while other the substances are unintentionally produced chemicals that are 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 diffuse emission/release from products in which they are used; and waste.

Data for the individual POP classes at each observatory are presented as annual mean concentrations, and as monthly mean concentrations in section 2.1-2.3. Detailed data (monthly mean concentrations for individual components within each class) are presented in Annex 1 (Table A1.1-A1.17). For classes with more than 50% of the observations below detection limits, half of the detection limit is used for further analyses and the monthly and annual mean concentration in Annex 1 are for these compounds highlighted in Italic. The results are presented in three sections; *2.1: Long-term monitoring in air* (covering POPs that have been monitored since before the Stockholm Convention), *2.2: Short-term monitoring in air* (covering POPs for which monitoring was initiated after the Stockholm Convention came into force), and *2.3: Long-term monitoring in precipitation* (covering POPs monitored in precipitation). In addition, trend analyses are performed for a selection of POPs and results are presented in section *3: Time-trend analyses of a selection of POPs* as well as under the individual compound groups in section 2.1.

Detailed descriptions of methods for sampling, chemical analysis and quality control are provided in Annex 3 of this report.

2.1 Long-term monitoring in air

2.1.1 Hexachlorobenzene (HCB)

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

HCB has been monitored at Birkenes and Zeppelin since 1993, and at Andøya since 2009. In 2020, it was measured on monthly basis at Andøya (i.e. one sample per month) and on weekly basis, as previous years, at Birkenes and Zeppelin. HCB in air is sampled on filter and polyurethane foam (PUF) plugs and thus the concentrations of HCB in air in this monitoring programme represent the bulk phase (i.e. gas+particle phase).

In 2020, HCB was detected in all samples from all sites (i.e. 100% >LOD). The weekly concentrations ranged between 15-55 pg/m^3 at Birkenes and 34-72 pg/m^3 at Zeppelin. The monthly concentrations at Andøya ranged between 15-39 pg/m^3. The annual mean concentration of HCB in 2020 at Zeppelin (55 pg/m^3) is one of the lowest annual mean concentrations during all the monitoring period (since 1993) (Figure 2). The increase in HCB concentrations at Zeppelin that was observed between 2003 and 2016 have turned to a reduction during the last years. This is confirmed by trend analysis which now shows stable concentrations at Zeppelin since the last 15 years. A similar trend is observed at Birkenes, where the annual mean concentration in 2020 (37 pg/m^3) is lower than in 2019 and the lowest measured

during the whole monitoring period (1996-2020). This low concentration is in contrast to the increasing time-trend observed the previous years (2010-2016) when trend analyses at Birkenes have shown slow decrease of HCB during the last 15 years. The reason for these changes is unknown.

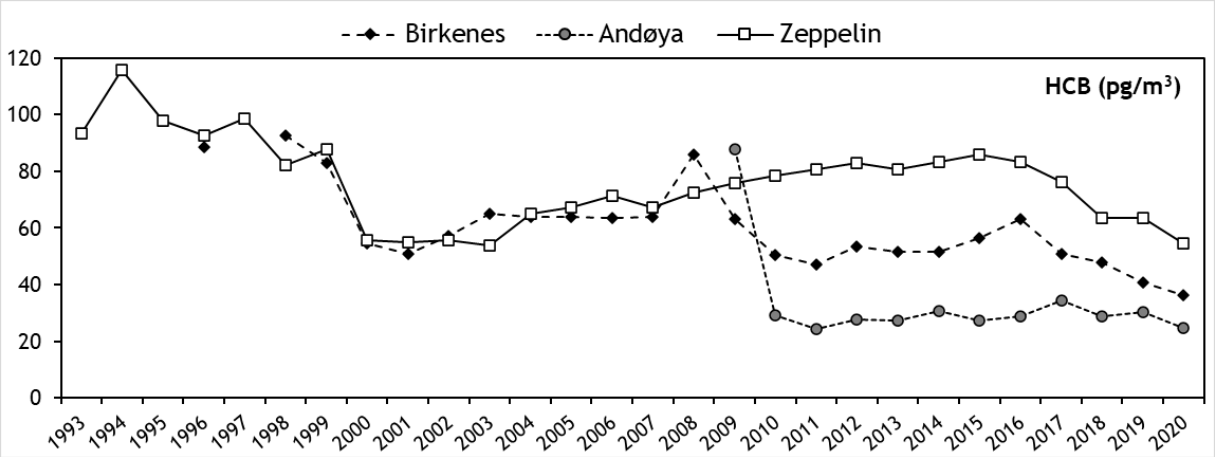


Figure 2: Annual mean concentrations of HCB (pg/m^3) in air.

FLEXPART trajectories shows that periods with higher concentrations of HCB in air at Zeppelin and Birkenes are associated with transport of air masses from the central European to the Asian region (Figure 3). In contrast, periods with lower concentrations of HCB at Zeppelin and Birkenes (Figure 3) are largely attributed to transport from ocean areas around Svalbard, the North Atlantic Ocean and the North American continent (e.g. Alaska). This suggests that emissions in Asian regions and central/east Europe largely explain the highest concentrations of HCB at Zeppelin and Birkenes.

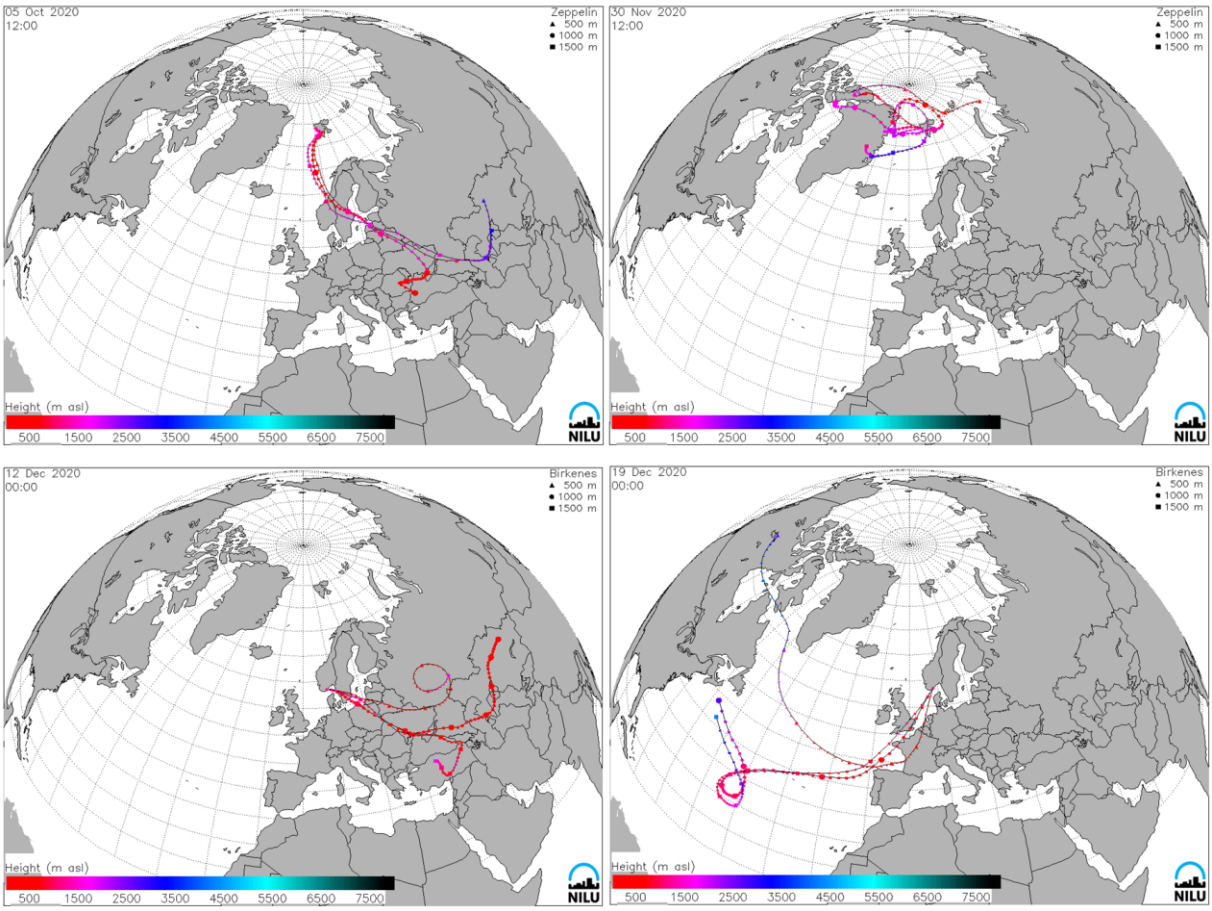


Figure 3: *Air mass trajectories calculated using the FLEXTRA model and using meteorological data provided from ECMWF (European Centre for Medium Range Weather Forecast) (https://projects.nilu.no/ccc/trajectories/). Air mass trajectories from the Eurasian continent (left) are seen when high concentrations of HCB are measured at Zeppelin and Birkenes while air mass trajectories from the North Atlantic and the oceans around Svalbard are seen (right) when concentrations of HCB are lowest.*

At Andøya, the annual mean concentrations in 2020 (25 pg/m^3) is comparable with the last decade (Figure 2). The annual mean concentrations of HCB in 2020 were, as previous years, lowest at Andøya (25 pg/m^3) and highest at Zeppelin (55 pg/m^3) although the differences are smaller. The higher concentrations observed in the Arctic for HCB are in line with what is observed within EMEP (Aas et al., 2019). High concentrations of HCB 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 than in the Arctic and similar to those observed at Birkenes (Halse et al., 2011, Aas et al., 2019).

Seasonal variations of HCB are observed at Birkenes and at Andøya, with a factor of two-three 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 a result of increased breakthrough in the sampler during warmer periods and thereby underestimations of the summer concentrations. This needs to be confirmed by additional scientific studies. In contrast to Birkenes and Andøya, at Zeppelin the highest concentrations are observed in August-October (Figure 4) while the concentrations are stable for the rest of the year. The variability between the lowest and highest monthly concentrations is smaller at Zeppelin (1.7) than at Birkenes and Andøya (2.5).

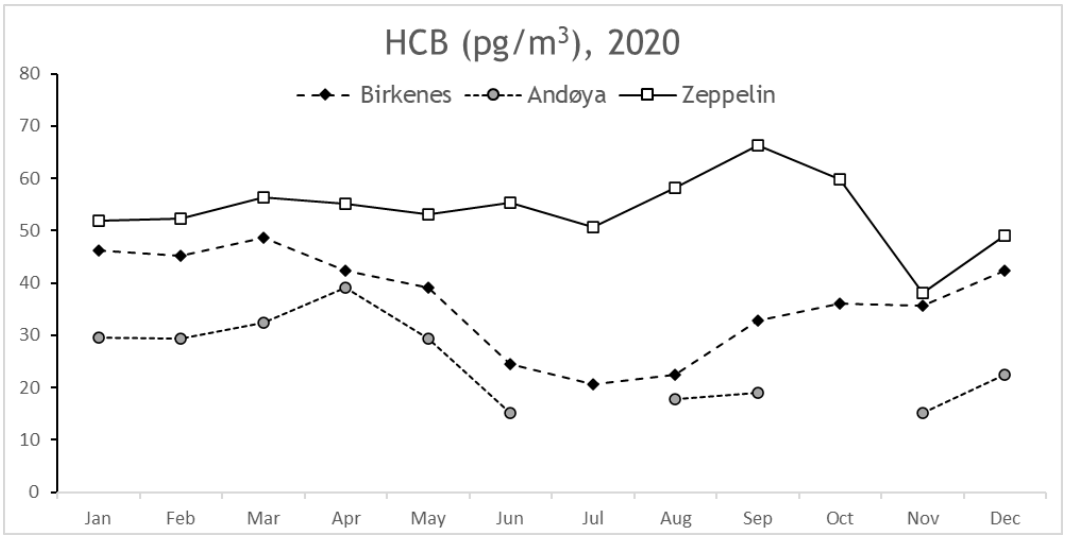


Figure 4: Seasonal variability of HCB at Birkenes, Andøya and Zeppelin in 2020.

2.1.2 Hexachlorohexanes (HCHs)

HCHs are intentionally produced chemicals that have been and are to some extent still used as insecticides worldwide. The technical mixture consists of five stable isomers: α-, β-, γ-, δ-, and ε-HCH. The dominating isomers in the mixture are α-HCH (60-70%) and γ-HCH (10-15%). γ-HCH, also known as lindane, has been used individually both as an agricultural insecticide and as a pharmaceutical treatment for lice and scabies. The production and use of HCHs are regulated regionally and globally by the Aarhus protocol on POPs (UN/ECE, 1998b) and the Stockholm Convention on POPs (Stockholm Convention, 2013), and the use is now assumed to be phased out globally.

Two HCH isomers; α- and γ-HCH, have been monitored at Birkenes since 1991, at Zeppelin since 1993, and at Andøya since 2010. In 2020, monitoring of HCHs at Zeppelin continued with weekly samples and the monitoring at Birkenes continued with one sample per month (as from 2017). HCHs in air are sampled on filter and polyurethane foam (PUF) plugs and thus the concentrations of HCHs in air in this monitoring programme represent the bulk phase (i.e. gas+particle phase).

Both α - and γ-HCH isomers were above detection limit in all samples from Zeppelin and Birkenes in 2020 (i.e. 100% >LOD). The monthly concentrations of sum HCHs (α+γ) in 2020 ranged from: 0.7-16 pg/m^3 at Birkenes. The weekly concentrations of sum HCHs at Zeppelin ranged between 1.1-9.4 pg/m^3 in 2020. At Zeppelin, the annual mean concentration of sum HCHs (3.1 pg/m^3) and the individual isomers are lower than previous years continuing the slow decreasing trends (Figure 5). At Birkenes, the annual mean concentration of sum HCHs (6.5 pg/m^3), γ-HCH (2.7 pg/m^3) and α-HCH (3.8 pg/m^3) were similar to the last years (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 short half-lives in the trend analysis (see section 3). This is likely due to declining global emissions of HCHs (technical HCHs and lindane). The two monitored isomers; α- and γ-HCH, have declined with similar patterns at both observatories with half-lives of 4-5 years over the whole monitoring period (see section 3). The decrease of HCHs at Birkenes seems to have slowed down after the Stockholm Convention entering into force as half-lives have increased from around 4-5 years for the period before the SC to 9 years for α-HCH and 25 years for γ-HCH for the period after the SC (see section 3).

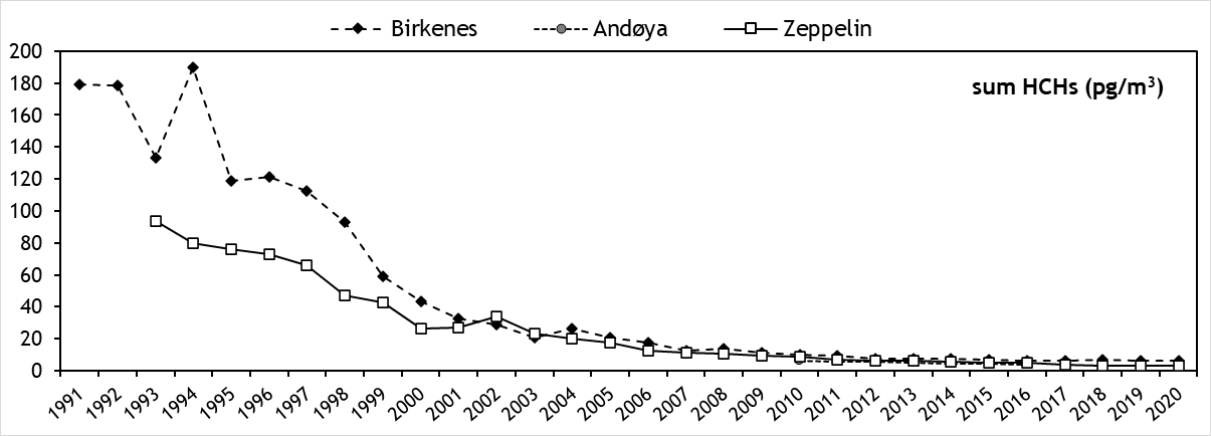


Figure 5: Annual mean concentrations of sum HCHs (pg/m³) in air.

FLEXPART trajectories shows that periods with higher concentrations of HCHs in air at Birkenes are associated with transport of air masses from the central-eastern European to the central Asian region (Figure 6). As for HCB, periods with lower concentrations of HCH at Birkenes (Figure 6) are attributed to transport from the North Atlantic Ocean and the North American continent (e.g. Alaska). This suggests that emissions in Central-eastern Europe and Asian regions largely explain elevated concentrations of HCHs observed at Birkenes.

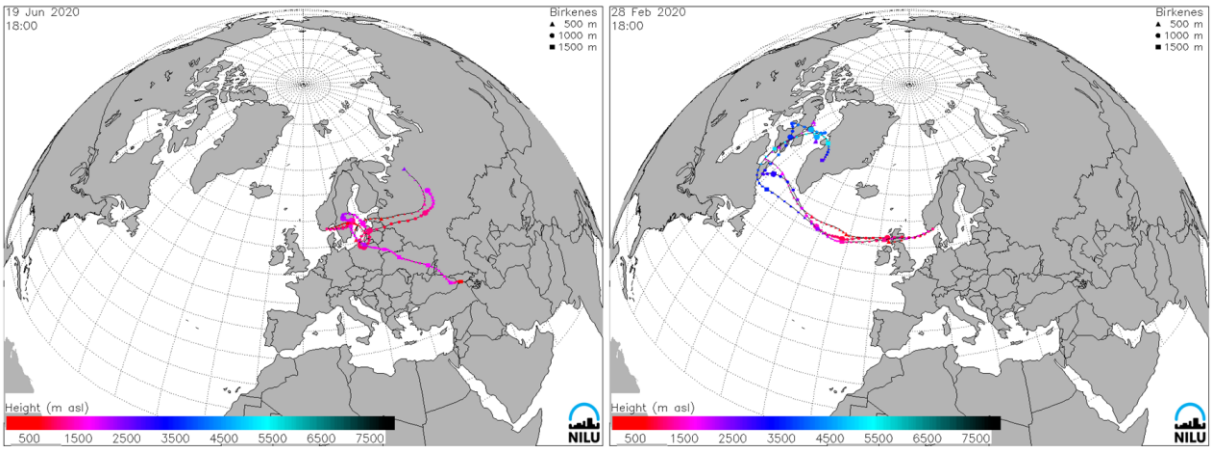


Figure 6: Air mass trajectories calculated using the FLEXTRA model and using meteorological data provided from ECMWF (European Centre for Medium Range Weather Forecast) (https://projects.nilu.no/ccc/trajectories/). Air mass trajectories from the European continent (left) are seen when high concentrations of HCHs are measured at Birkenes while air mass trajectories from the North Atlantic Ocean and North America are seen (right) when concentrations of HCHs are lower.

As in previous years, the average ratios of α-/γ-HCH was found to decrease from north to south; 6.8 (5.1-9.0) at Zeppelin; and 2.0 (0.5-3.8) at Birkenes. Even lower ratios are observed at more southern sites in continental Europe (Aas et al., 2019). The larger ratio in the north is a result of decreasing concentrations of γ-HCH with latitude while constant concentrations of α-HCH with latitude. The decrease in γ-HCH concentrations with latitude is caused by 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 (Xiao et al. 2004). A larger ratio is an indication of higher age of γ-HCH/Lindane and thereby a longer distance from source areas. Lower ratios are observed at Birkenes in summertime and when also the highest concentrations of HCH are observed (May-August) (Figure 7). This is a

consequence of higher concentrations of γ-HCH in summertime and suggests higher emission of lindane/γ-HCH from secondary repositories in continental Europe together with less scavenging during the warmer and dryer period. In contrast, no strong seasonality of the HCHs were observed at Zeppelin although the highest concentrations (especially for α-HCH) and the highest ratios are observed in late summer/early autumn (July-October). 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., 2019).

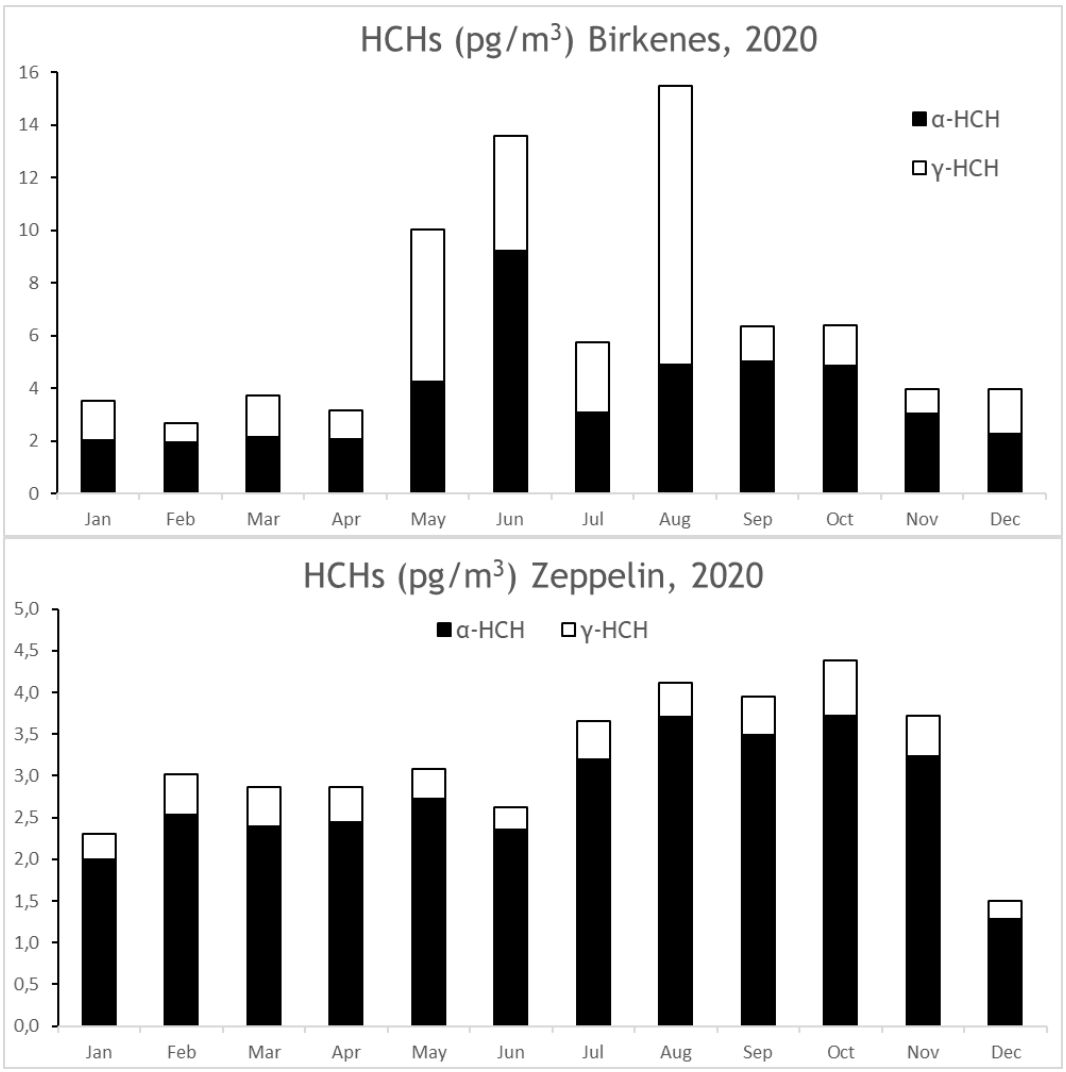


Figure 7: Seasonal variability of α- and γ-HCH at Birkenes and Zeppelin in 2020.

2.1.3 Dichlorodiphenyltrichloroethane (DDTs)

DDTs are intentionally produced chemicals that have been used worldwide as a pesticide to protect humans and agricultural crops from vector-borne diseases. The production and use of DDTs were banned in Norway, other European countries, the United States and Canada during 1970s to 2000. DDT is regulated by the Aarhus protocol on POPs (UN/ECE, 1998b) and the Stockholm Convention on POPs (Stockholm Convention, 2007). DDT is currently included the Stockholm Convention with its production and/or use restricted for disease vector control purposes in accordance with related recommendations and guidelines from the World Health Organization (WHO) (WHO, 2006). Countries that are party to the Stockholm Convention can produce and/or use DDT for disease vector control when locally safe, effective and affordable alternatives are not available. Parties are required to notify the Convention of such production or use or the intention to use DDT. 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 2020, monitoring of DDTs at Zeppelin continued with weekly samples and the monitoring at Birkenes consisted of one sample per month, as the last years. The DDTs in air are sampled on filter and polyurethane foam (PUF) plugs and thus the concentrations of DDTs in air in this monitoring programme represent the bulk phase (i.e. gas+particle phase).

The detection frequencies in 2020 varied among the individual congeners and between the sites. For example, o,p'- and p,p'-DDT, and o,p'- and p,p'-DDE were detected in most samples at both sites. Low detection frequency (i.e. more than 50% of the samples <LOD) was only observed for p,p'-DDD at Zeppelin. p,p'-DDE was the most abundant congener (contributing to >50% of sum DDTs) at both sites followed by o,p'- and p,p'-DDT at Birkenes and o,p'-DDT at Zeppelin.

The weekly concentrations of sum DDTs at Zeppelin in 2020 ranged between 0.07-4.0 pg/m^3 with one high episode in October. The monthly concentrations of sum DDTs at Birkenes ranged between 0.38-4.7 pg/m^3. The high episode at Zeppelin as well as the highest concentrations at Birkenes are associated with air masses from Eastern Europe and central Asia (Figure 8). The lowest concentrations at both sites are associated with air masses from the oceans around Svalbard and the North Atlantic.

The annual mean concentrations of sum DDTs and the individual congeners in 2020 were as in previous years higher at Birkenes (1.6 pg/m^3) than at Zeppelin (0.4 pg/m^3) (Figure 9). The reason for higher concentrations at Birkenes compared to the more northern Norwegian sites may be explained by closer distances to possible emission sources (secondary repositories) and is also seen by the spatial distribution of DDTs in annual monitoring programmes and scientific case-studies within the EMEP region (Aas, 2019, Halse et al. 2011). Although the concentrations observed at Birkenes are higher than at Zeppelin, they are still one to two orders of magnitude lower than the concentrations found on the European continent (Pribylova et al., 2012, Aas et al., 2019).

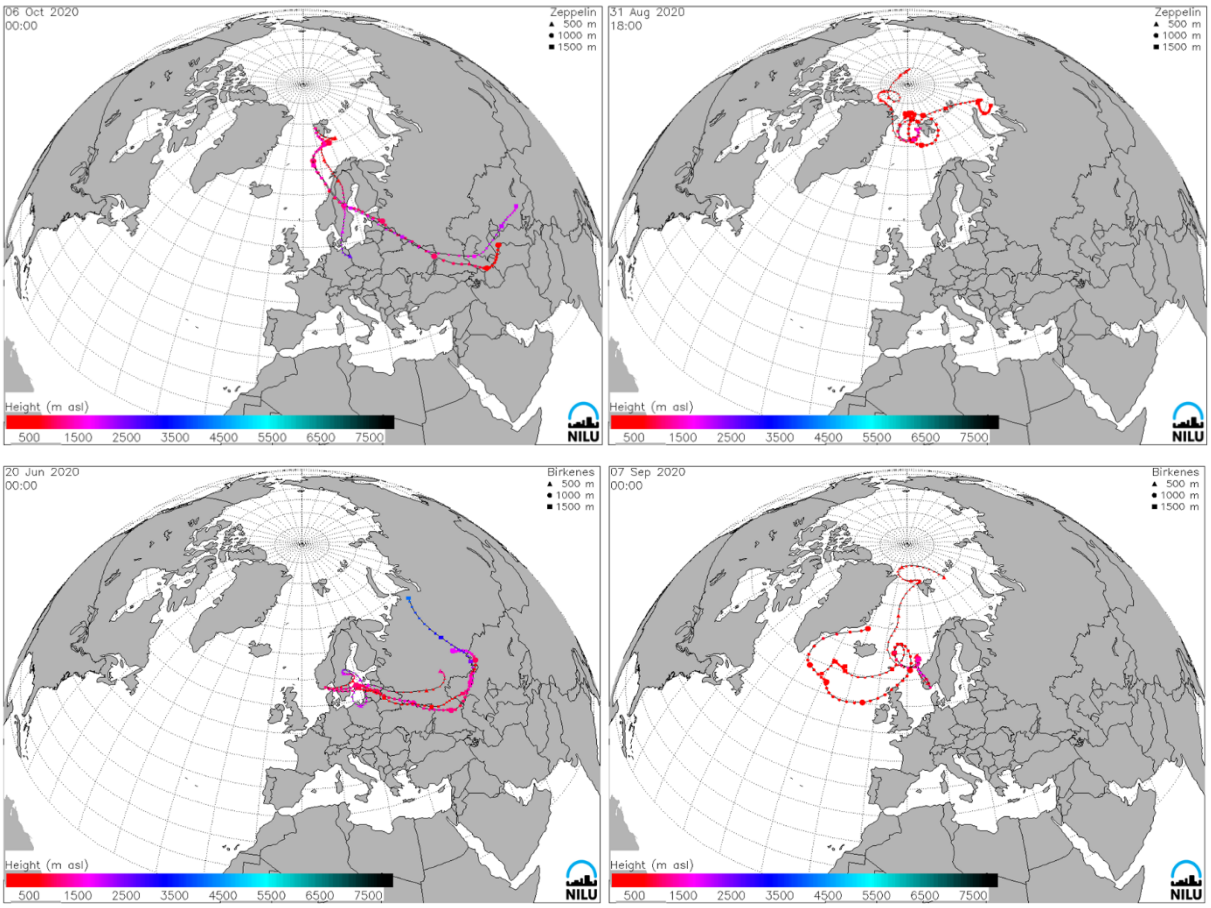


Figure 8: *Air mass trajectories calculated using the FLEXTRA model and using meteorological data provided from ECMWF (European Centre for Medium Range Weather Forecast) (https://projects.nilu.no/ccc/trajectories/). Air mass trajectories from the Eurasian continent (left) are seen when high concentrations of DDTs are measured at Zeppelin and Birkenes while air mass trajectories from the oceans are seen (right) when concentrations of DDTs are low.*

The annual mean concentrations of sum DDTs and all congeners at Zeppelin were the same as the last three years (2017-2019), which are also the lowest concentrations measured at Zeppelin (Figure 9). A decreasing trend for p,p'-DDE and p,p'-DDT is observed at Zeppelin with half-lives of 4-6 years for the period before the Stockholm convention entered into force (1994-2004) and half-lives of 8 years for the period after (2004-2020) (Figure 10, Figure 11, section 3). At Birkenes, the annual mean concentration in 2020 was lower than 2019, but higher than 2015-2018. The trend-analyses covering 2010-2020 consequently result in no significant trend for neither p,p'-DDE nor p,p'-DDT at Birkenes (Figure 10, Figure 11, section 3). The indicator ratio (p,p'-DDE+p,p'-DDD/p,p'-DDT) were high (3-14) at both sites in winter, spring and autumn indicating input only from aged DDT. The ratios were lower in summertime at Birkenes and Zeppelin (2-4) indicating more fresh input in summertime.

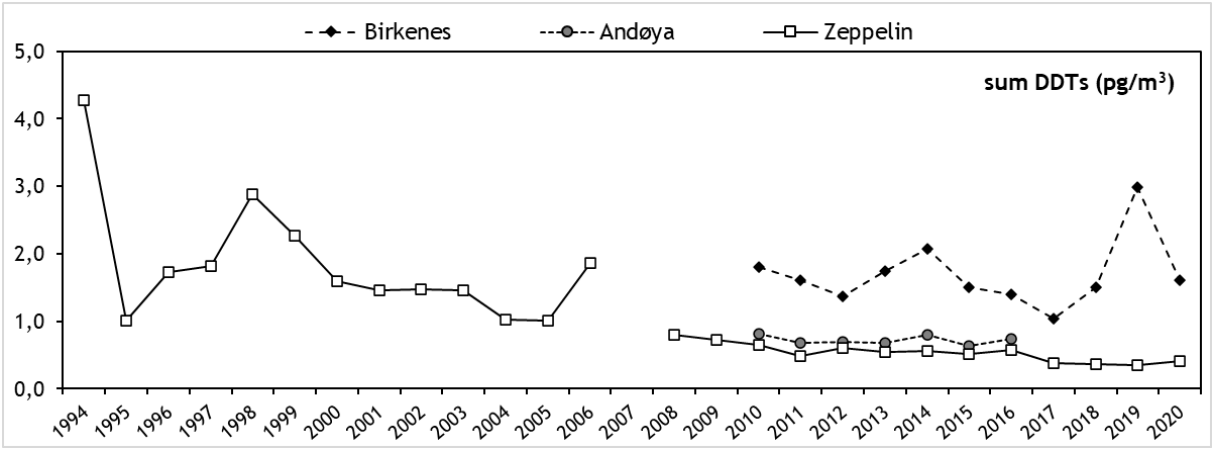


Figure 9: Annual mean concentrations of sum DDTs (pg/m³) in air. 2007 at Zeppelin is excluded as it is an unexplained high outlier. The annual mean includes all six congeners although some congeners are <LOD in most samples at some sites and for some years.

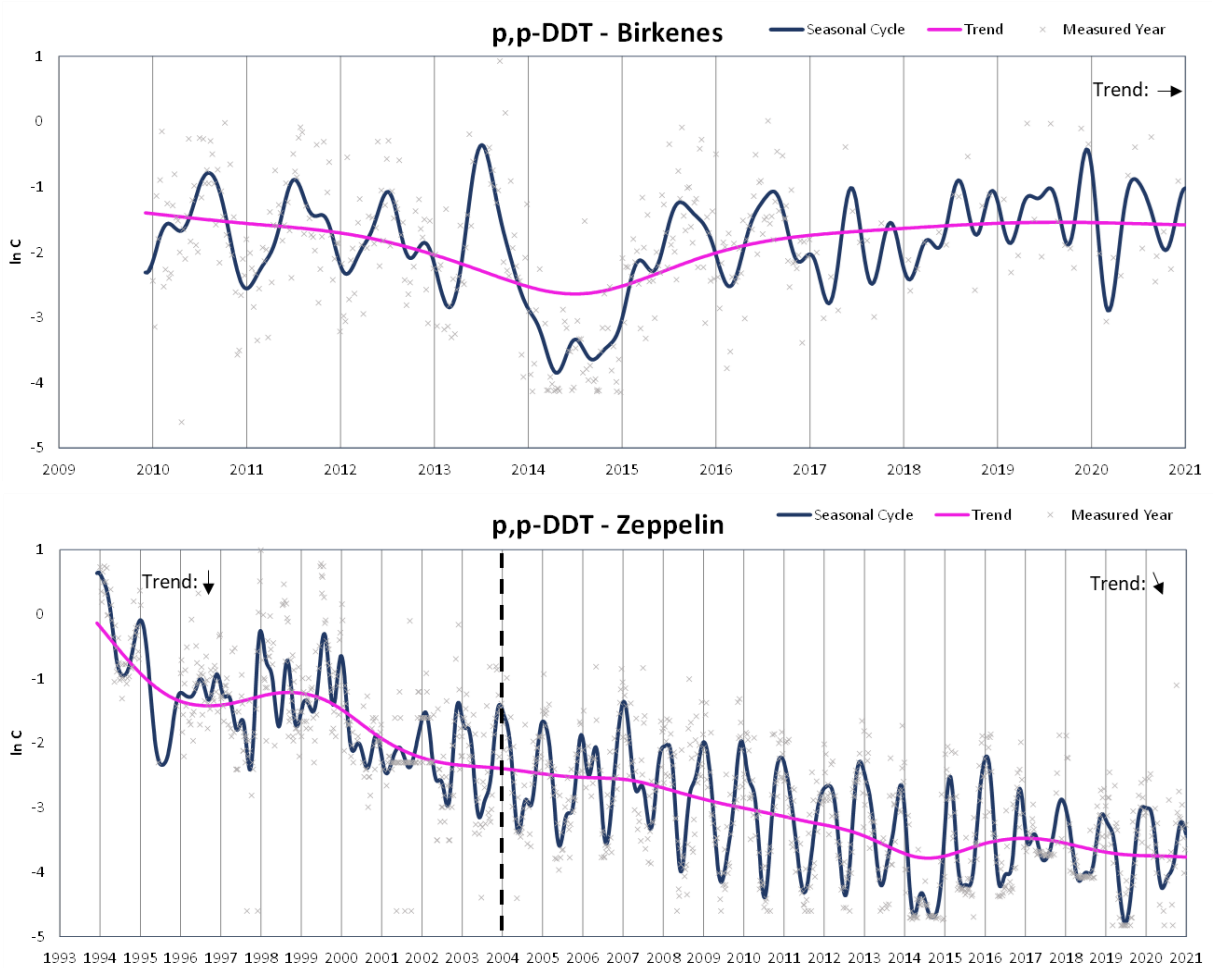


Figure 10: Temporal trends of p,p'-DDT at Birkenes and Zeppelin. Air concentrations are presented in natural log of concentration (ln C) on the y-axis. The dashed line indicates the year when Stockholm Convention was taken into force for DDTs (2004). The results of trend analyses: before and after the 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.

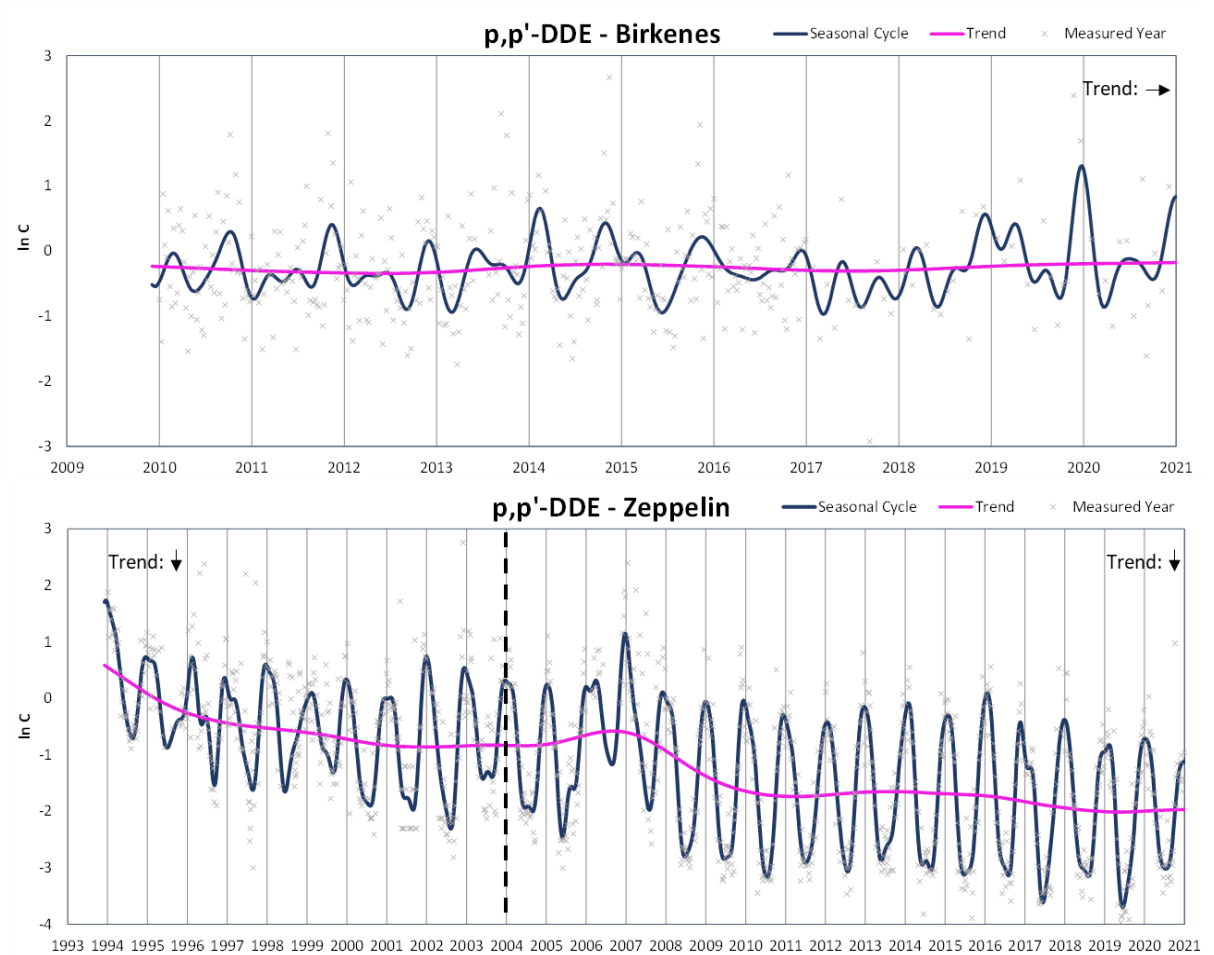


Figure 11: *Temporal trends of p,p'-DDE at Birkenes and Zeppelin. Air concentrations are presented in natural log of concentration (ln C) on the y-axis. The dashed line indicates the year when Stockholm Convention was taken into force for DDTs (2004). The results of trend analyses: before and after the 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 strong seasonality of the DDT concentrations was observed at Zeppelin with five to ten times higher concentrations in wintertime (October-April) compared to warmer months (May-September) (Figure 12). The higher concentrations in winter at Zeppelin can be connected to the Arctic Haze season in the Arctic area during wintertime in which the transportation of particles to the Arctic is higher and removal rates of the DDTs are lower than in summertime (Hung et al., 2016). However, this may not be the full explanation as DDTs tend to be found to larger extent in gas-phase than in particle phase. The lower temperature in winter may however shift the partitioning towards more particle bound DDTs which supports the explanation of the Arctic haze. At Birkenes instead, where the DDT is measured in only one sample per month, higher concentrations are observed in summer.

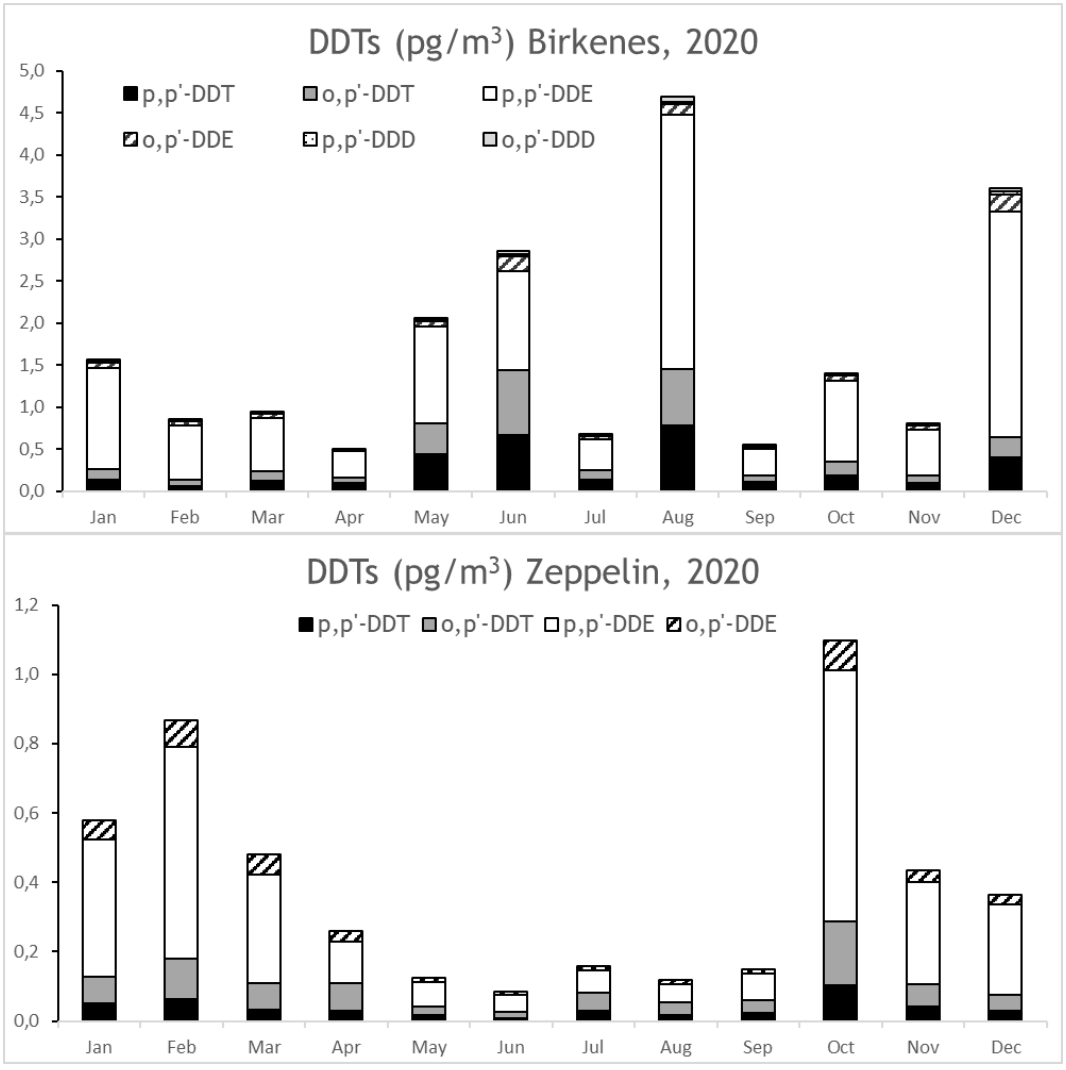


Figure 12: Seasonal variability of sum DDT and the four detected individual congeners at Birkenes and Zeppelin in 2020. Only congeners with detection in more than 50% of the samples are included.

2.1.4 Chlordanes

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

The four stereoisomers of chlordane (i.e. cis- and trans-chlordane (CD), and cis- and trans-nonachlor (NO)) have been monitored in weekly samples at Zeppelin since 1993 and weekly samples were continuously taken in 2020. At Birkenes, the chlordanes were monitored in the period 2010-2016. The chlordanes in air are sampled on filter and polyurethane foam (PUF) plugs and thus the concentrations of chlordanes in air in this monitoring programme represent the bulk phase (i.e. gas+particle phase).

Three of the four isomers; cis-CD, trans-NO and trans-CD, were detected in all samples at Zeppelin in 2020 (i.e. 100% >LOD). The fourth isomer, cis-NO was, in 2020, <LOD in 9% of the samples, all of those from the winter months. The major isomers at Zeppelin in 2020 were as previous years the cis-CD and trans-NO, contributing to ~40% each to the sum of chlordanes. Trans-CD contributed to 25% in winter (October-March), but only 10% in summer (May-September).

The weekly concentrations of sum chlordanes at Zeppelin in 2020 ranged between 0.3-1.0 pg/m^3. The annual mean concentrations of sum chlordanes (0.6 pg/m^3) and the individual stereoisomers at Zeppelin in 2020 were the same as in 2017-2019 (Figure 13). This suggests that the concentrations of chlordanes still are declining or may have entered temporal remote state where the decline is controlled by degradation in and emission from secondary repositories.

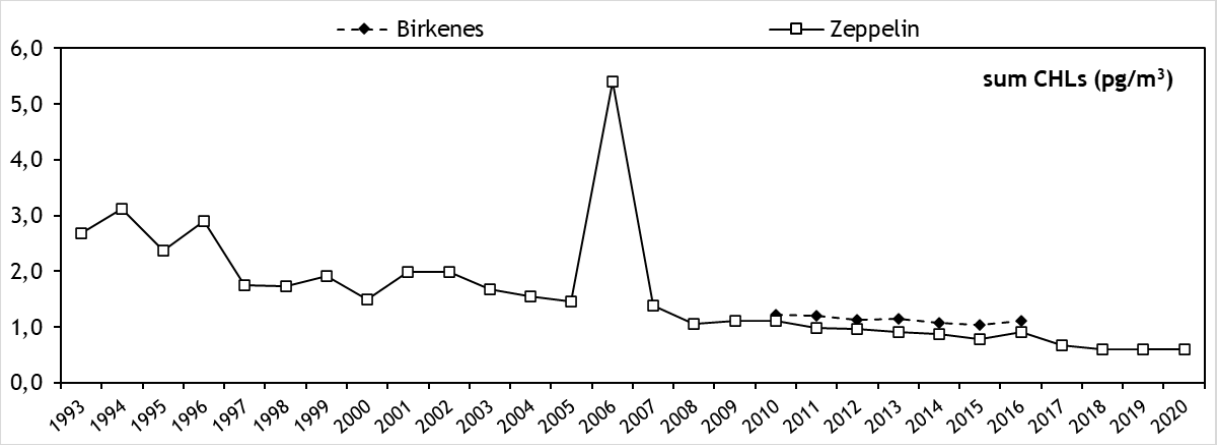


Figure 13: Annual mean concentrations of sum chlordanes (pg/m^3) in air. The data from 2006 at Zeppelin is excluded as it is an unexplained high outlier.

The ratio of trans-CD and cis-CD was, as previous years, low at Zeppelin also in 2020 (0.2-0.6 compared to 1.17 in technical mixture) indicating input only from aged chlordanes, since trans-CD degrades faster than cis-CD in the environment (Bidleman et al. 2002). The ratio shows a seasonal trend with lower ratios in summertime (0.2) and higher in wintertime (0.5-0.6). This is caused by lower concentrations of trans-CD in summertime than in wintertime and stable concentrations of cis-CD over the year (Figure 14). 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, as also shown by Bidleman et al. (2002). In contrast, cis-NO is found in higher concentrations in summer (June-September) than in winter (November-March) (Figure 13). For cis-CD and trans-NO, no seasonal trends were observed.

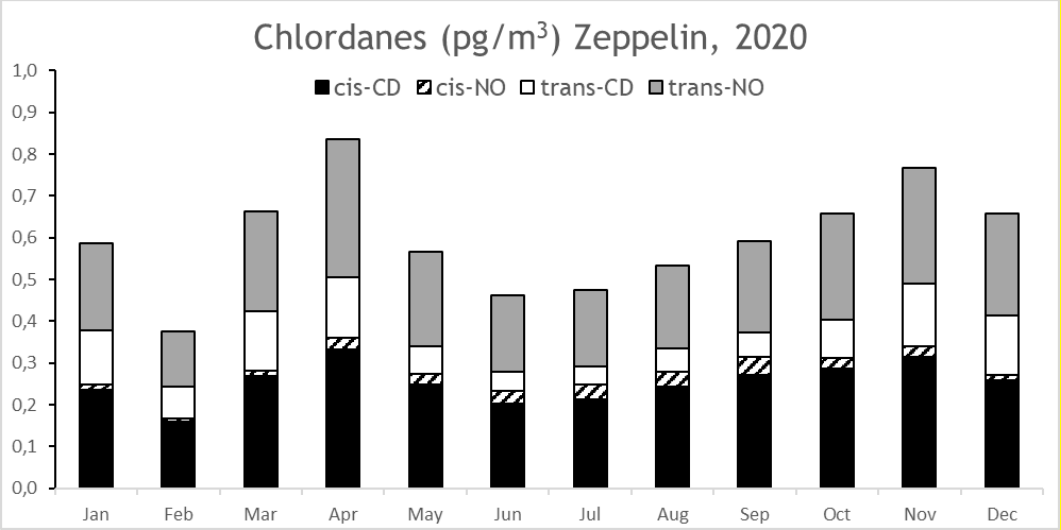


Figure 14: Seasonal variability of sum chlordanes and the four individual isomers at Zeppelin in 2020.

2.1.5 Polychlorinated biphenyls (PCBs)

PCBs are industrially produced chemicals that have been used in a variety of industrial applications. They have been banned from active use in most countries since the mid-1970s and are also regulated by the Aarhus protocol on POPs (UN/ECE, 1998b) and the Stockholm Convention on POPs (Stockholm Convention, 2007). According to the Stockholm Convention, the production and new use of PCB is no longer allowed. Parties may however continue to use PCB containing articles that were already in use when the global regulation entered into force. By 2025, Parties shall have identified and removed from use, equipment containing greater than 0.005% PCB and volumes greater than 0.05 L. As soon as possible, but no later than 2028, Parties shall also make determined efforts designed to lead to environmentally sound waste management of liquids containing PCB and equipment contaminated with PCBs having a PCB content above 0.005%, in accordance with paragraph 1 of Article 6 of the Convention. Parties shall also provide a report every five years on the progress in eliminating PCBs. Taking into account these reports the Conference of the Parties to the Convention reviews the progress towards elimination of PBCs at five-year intervals.

Current sources of emissions of PCBs to the environment are mainly from places where they have been disposed of or stored, such as landfills or contaminated 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 2020. These 32 congeners include the seven congeners (PCB-7) that are typically used as indicators in Europe; PCB 28, 52, 101, 118, 138, 153, 180, as well as eight dioxin-like; PCB 105, 114, 118, 123, 156, 157, 167, 189. The dioxin-like PBCs are considered the most toxic congeners (WHO, 2002). Data are herein reported for sum of 32 PCBs (sum PCB) as well as sum of PCB-7 (sum PCB_7).

PCBs have been monitored at Zeppelin since 2001. At Birkenes, the seven indicator PCBs have been monitored since 2004 and all the 32 PCBs since 2010. The monitoring in 2020 continued with weekly measurements at both sites. The PCBs in air are sampled on filter and polyurethane foam (PUF) plugs and thus the concentrations of PCBs in air presented in this report represent the bulk phase (i.e. gas+particle phase).

The detection frequencies varied among PCB congeners as well as between sites. Generally, high detection frequencies were observed for most of the PCBs at both sites. Low detection frequencies (30-100% of the samples being <LOD) were observed for nine of the penta-deca 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.

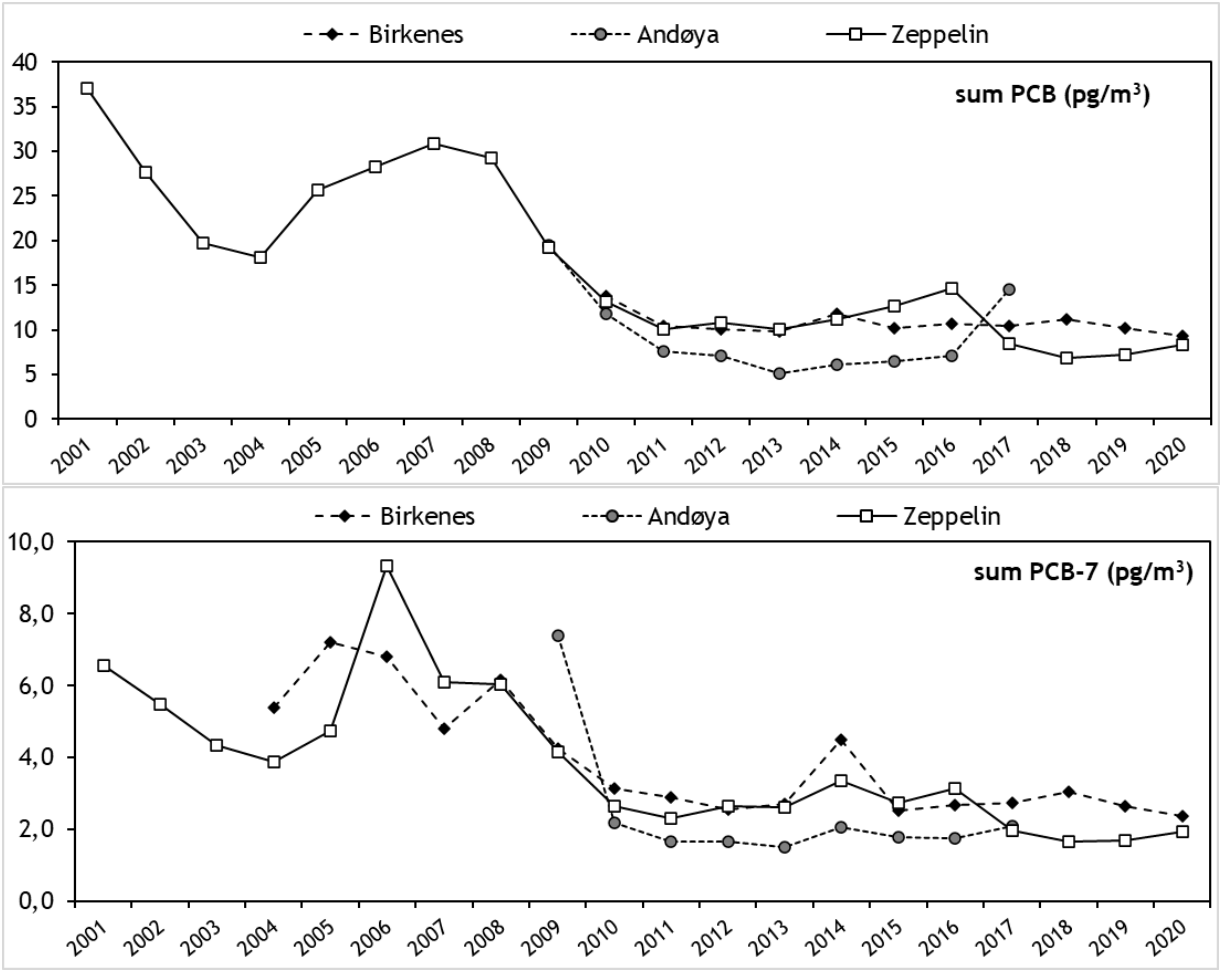


Figure 15: Annual mean concentrations of sum PCBs and sum PCB-7 (pg/m³) in air. Sum PCBs represents the sum of all detected PCB peaks.

The weekly concentrations of sum PCB and sum PCB_7 at Birkenes in 2020 ranged between: 1.0-38 pg/m³ and 0.4-8.9 pg/m³, respectively. The ranges at Zeppelin were similar to Birkenes: 4.6-37 pg/m³ and 1.1-7.7 pg/m³, respectively. The annual mean concentrations of sum PCB and sum PCB_7 in 2020 were similar at Zeppelin (8.4 and 2.0 pg/m³) and Birkenes (9.3 and 2.4 pg/m³) (Figure 15). This is in line with 2008-2016 when the concentrations of PCBs also were similar at Birkenes and Zeppelin. The reason for similar concentrations of PCBs at Zeppelin and Birkenes may be presence of local PCB sources at Svalbard (e.g. Pyramiden and Barentsburg) (Jartun et al. 2009).

At Zeppelin, the annual mean concentrations of PCBs in 2020 were higher than in 2018 and 2019 but similar to 2017 (Figure 15). At Birkenes, the annual mean concentrations in 2020 were the lowest measured so far. The observations during the last years (2017-2019) suggest that a temporal remote state condition has been reached for the PCBs in which the concentrations in air are controlled by degradation and emission of PCBs in secondary repositories (Stroebe et al. 2004). The trend analyses

however show decreases of PCB-52, 118 and 153 over the last 15 years at both Zeppelin and Birkenes with half-lives of 10-15 years (Figure 16, section 3). The concentrations of sum PCB_7 at the Norwegian sites are up to one order of magnitude lower than the concentrations of sum PCB_7 reported to EMEP from sites in Germany and the Czech Republic (Aas et al., 2019).

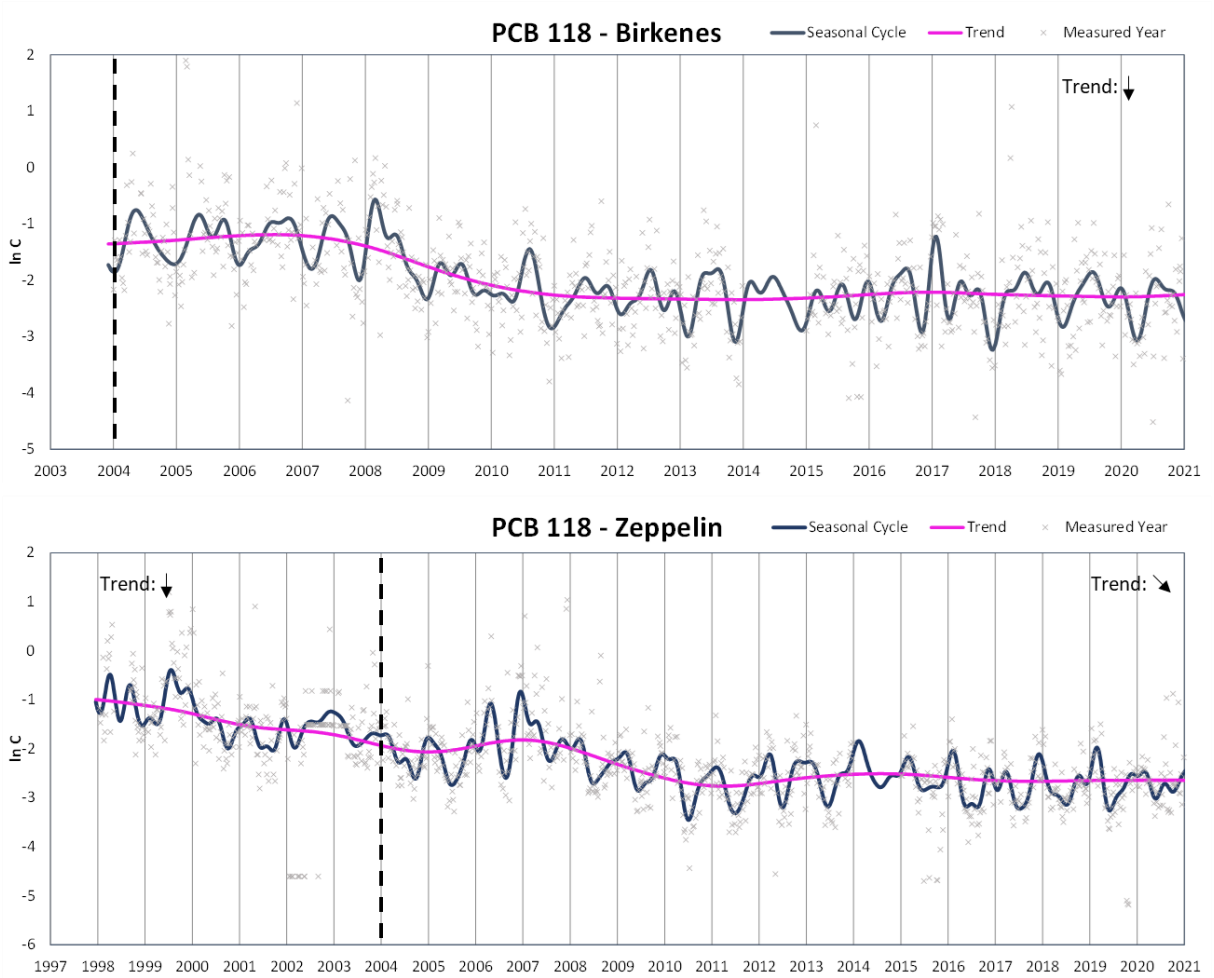


Figure 16: Temporal trends of PCB 118 at Birkenes and Zeppelin. Air concentrations are presented in natural log of concentration (ln C) on the y-axis. The dashed line indicates the year when Stockholm Convention was taken into force for PCBs (2004). The results of trend analyses: before and after the 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 PCBs and sum PCB-7 at any of the two sites in 2019 (Figure 17-18). The lowest concentrations at Zeppelin were however observed in summertime (May-June) and the highest in wintertime (January-March).

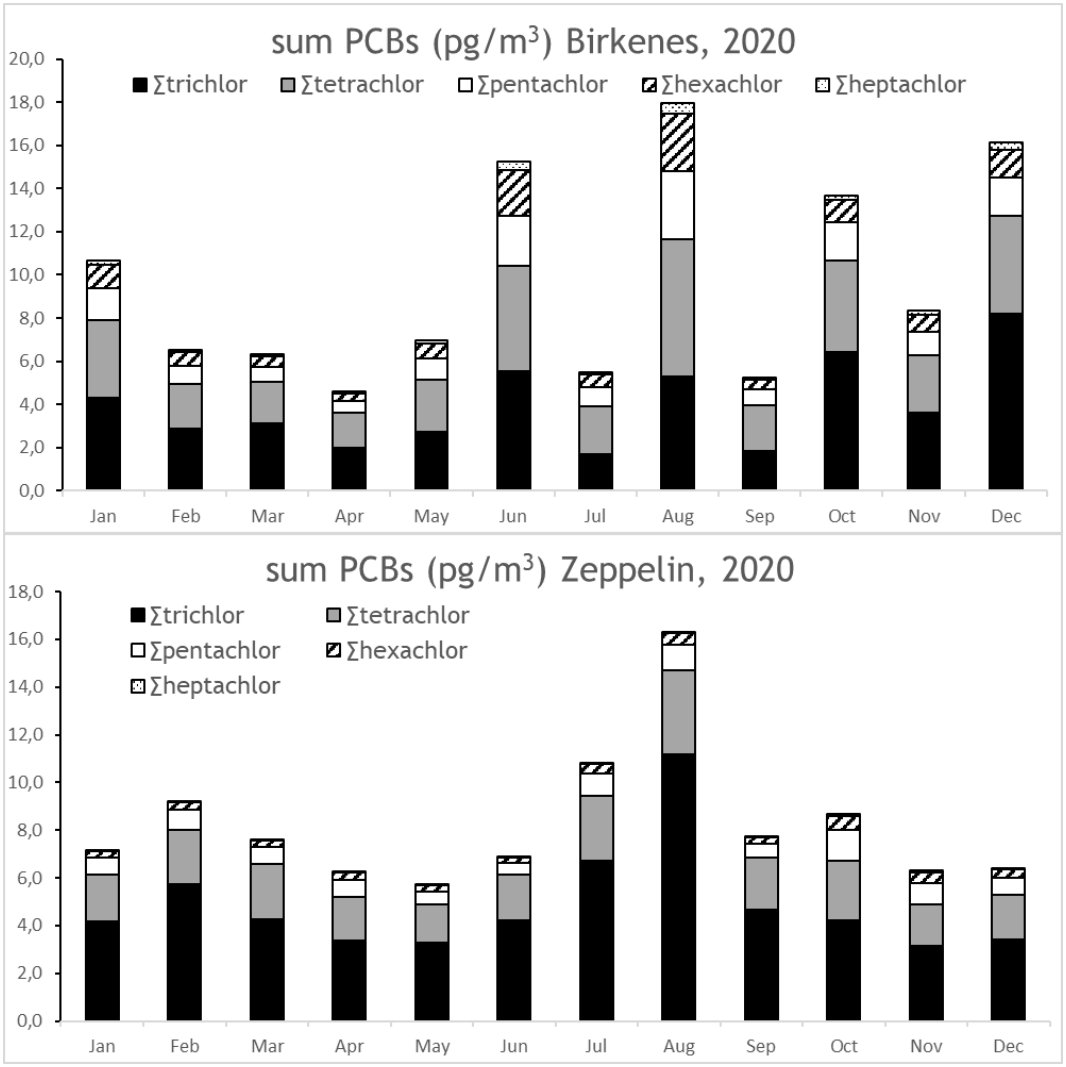


Figure 17: Seasonal variability of sum PCBs (the sum of all detected PCB peaks) and homologue groups at Birkenes and Zeppelin in 2020.

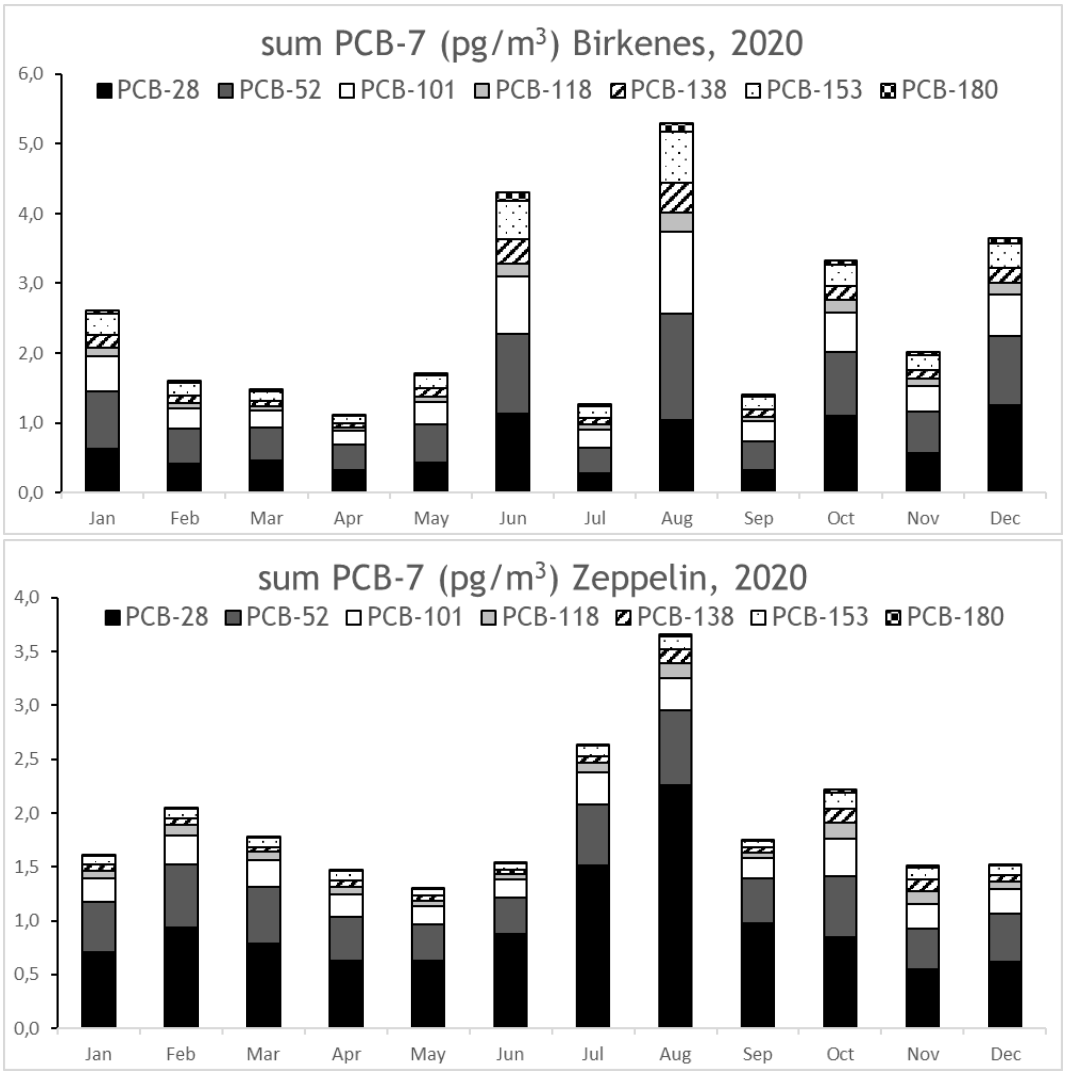


Figure 18: Seasonal variability of sum PCB_7 and the individual congeners at Birkenes and Zeppelin in 2020.

2.1.6 Polycyclic aromatic hydrocarbons (PAHs)

PAHs are mainly produced through incomplete combustion of organic materials, both through anthropogenic (i.e. industrial and domestic use) and natural processes. They are regulated in the Aarhus protocol on POPs (UN/ECE, 1998b) and the EU air quality directive (AQD) (EU, 2004). PAHs are categorized as POPs due to their inclusion in the Aarhus protocol on POPs 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 in weekly samples at Birkenes and Zeppelin in 2020. PAHs have been monitored in weekly samples at Zeppelin since 1994, at Birkenes since 2009, and at Andøya between 2009 and 2012. The PAHs in air are sampled on filter and polyurethane foam (PUF) plugs and thus the concentrations of PAHs in air in this monitoring programme represent the bulk phase (i.e. gas+particle phase).

The detection frequencies varied among PAH compounds and between the sites. Generally, more PAH compounds had low detection frequency and were below the detection limit at Zeppelin (67% of the

PAH compounds were below the detection limit in more than 50% of the samples) than at Birkenes (~18% of the PAH compounds were below the detection limit in more than 50% of the samples). This reflects higher concentrations of PAHs at Birkenes than at Zeppelin. The individual compounds with low detection (>50% of samples <LOD) are marked in Annex 1.

The most abundant PAHs at Birkenes are phenanthrene (0.8 ng/m^3), followed by dibenzofuran (0.5 ng/m^3), fluorene (0.4 ng/m^3) and fluoranthene (0.2 ng/m^3). At Zeppelin, the volatile PAHs are more abundant; dibenzofuran (0.4 ng/m^3), biphenyl (0.3 ng/m^3), naphthalene (0.3 ng/m^3), fluorene (0.2 ng/m^3) together with 1- and 2-methylnaphthalene (0.08-0.09 ng/m^3, respectively). The weekly concentrations of sum PAH in 2020 ranged between: 0.5-12.4 ng/m^3 at Birkenes; and 0.1-9.2 ng/m^3 at Zeppelin.

The weekly concentrations of sum PAH_{16} in 2020 ranged between: 0.5-7.4 ng/m^3 at Birkenes; and 0.07-4.1 ng/m^3 at Zeppelin. The highest concentrations of PAHs at Birkenes are associated with air masses from the European and central Asian region (Figure 19).

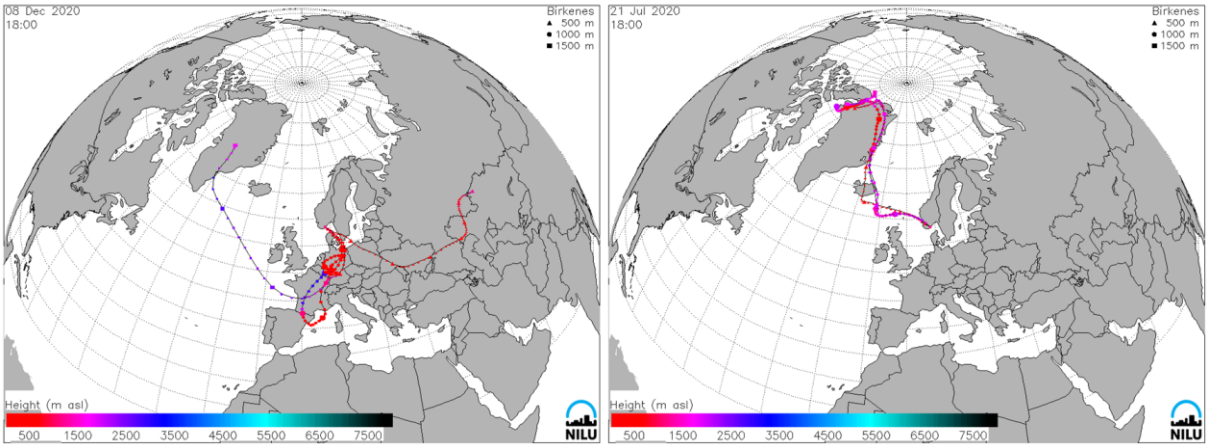


Figure 19: Air mass trajectories calculated using the FLEXTRA model and using meteorological data provided from ECMWF (European Centre for Medium Range Weather Forecast) (https://projects.nilu.no/ccc/trajectories/). Air mass trajectories from the Europe continent (left) are seen when high concentrations of PAHS are measured at Birkenes while air mass trajectories from the Atlantic Ocean are seen (right) when concentrations of PAHs are low.

The annual mean concentrations of sum PAH (1.4 ng/m^3) and sum PAH_{16} (0.60 ng/m^3) at Zeppelin in 2020 were higher than in 2018 and 2019. At Birkenes, the annual mean concentrations of sum PAHs and sum PAH_{16} in 2020 (2.9 and 1.9 ng/m^3) were instead lower than in 2018 and 2019 and the lowest observed since the monitoring started in 2008 (Figure 20). For Fluorene and Fluoranthene, no significant trend is observed at Birkenes while a small decrease is observed at Zeppelin (half-life=14 and 12 years, respectively) (Figure 21, Figure 22). For benzo(a)pyrene a significant decrease is seen at Birkenes (half-life=6.8 years) (Figure 23).

The concentrations observed at Birkenes are about two to three times higher than those at Zeppelin (Figure 20). 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).

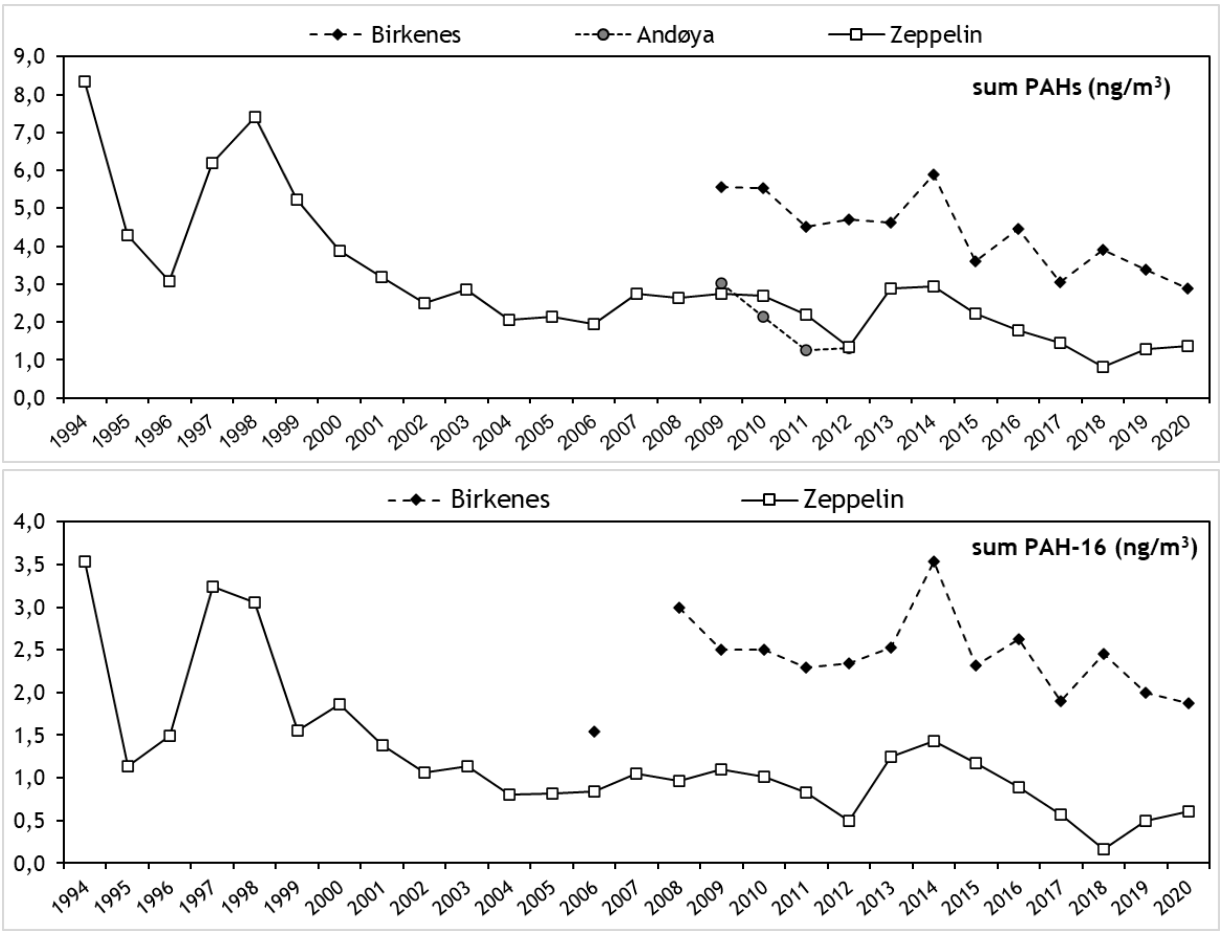


Figure 20: Annual mean concentrations of sum PAH and sum PAH-16 (ng/m^3) in air.

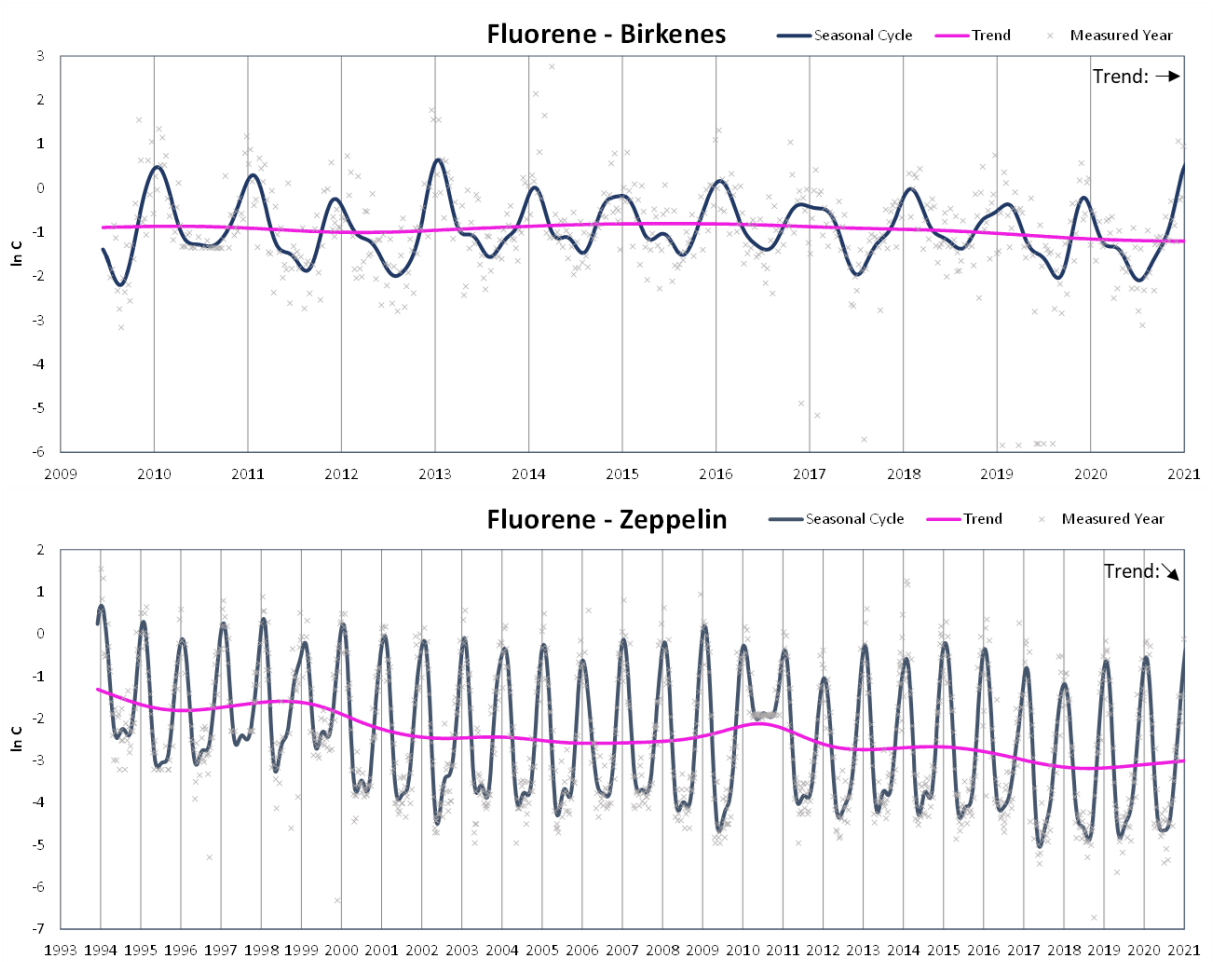


Figure 21: Temporal trends of Fluorene at Birkenes and Zeppelin. Air concentrations are presented in natural log of concentration (ln C) on the y-axis. The results of trend analyses for the whole monitoring period are indicated by four types of arrows (⬇ : decrease, ↘ : small decrease, ⬈ : small increase and ⬆ : increase) or NST when no significant trend was detected.

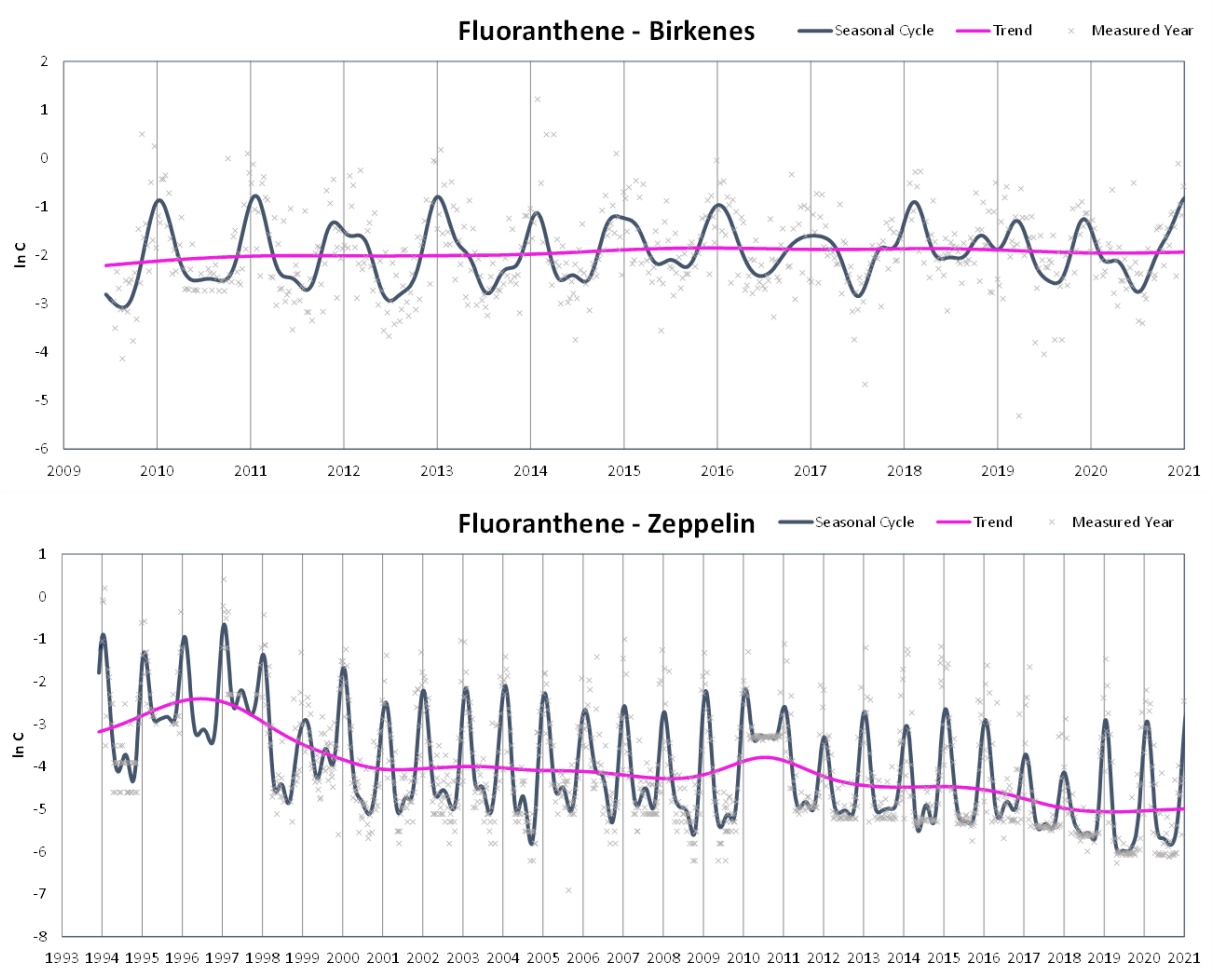


Figure 22: Temporal trends of Fluoranthene at Birkenes and Zeppelin. Air concentrations are presented in natural log of concentration (ln C) on the y-axis. The results of trend analyses for the whole monitoring period are indicated by four types of arrows (⬇ : decrease,↘ : small decrease,⬈: small increase and ⬆: increase) or NST when no significant trend was detected.

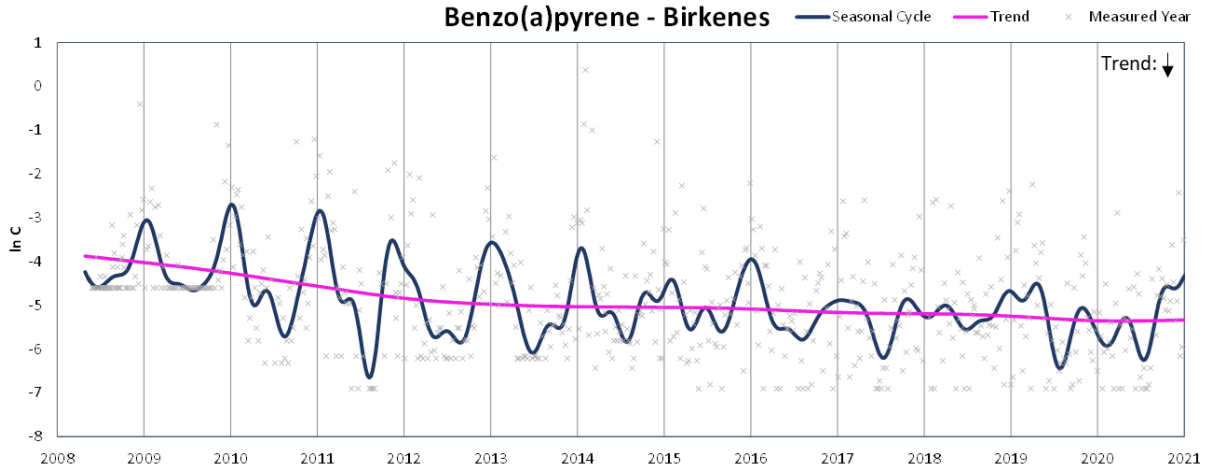


Figure 23: Temporal trends of benzo(a)pyrene at Birkenes and Zeppelin. Air concentrations are presented in natural log of concentration (ln C) on the y-axis. The results of trend analyses, are indicated by four types of arrows (⬇: decrease, ↘: small decrease,⬈ : small increase and ⬆ : increase) or NST 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 at Zeppelin in wintertime (November-March) than in summertime (Figure 24). The difference was smaller for Birkenes (factor of 5), but still significant. The same seasonality was seen for sum PAHs and the individual PAHs.

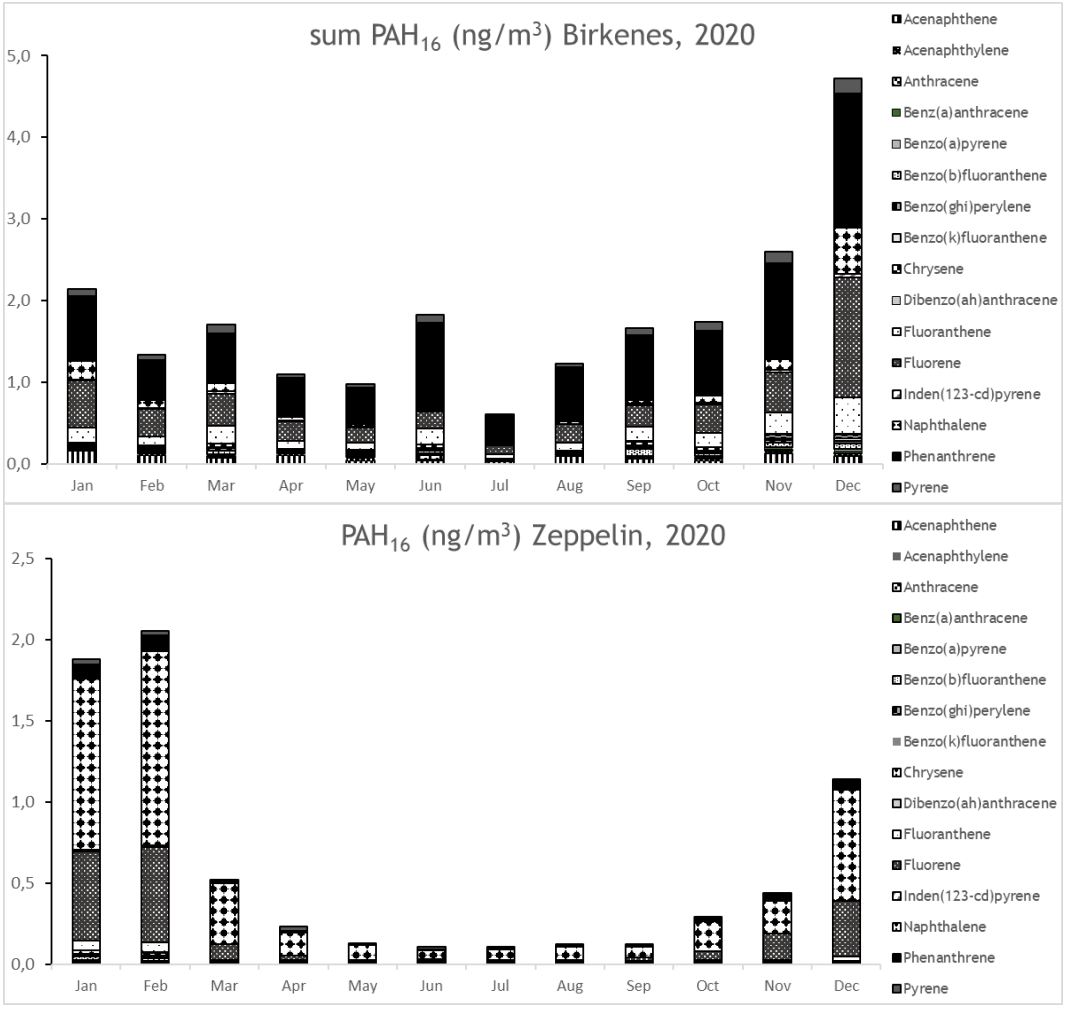


Figure 24: Seasonal variability of sum PAH16 at Birkenes and Zeppelin in 2020.

2.2 Short-term monitoring in air

2.2.1 Polybrominated diphenyl ethers (PBDEs)

PBDEs are industrially produced chemicals that have been and still are used as flame retardants in a wide range of applications including in plastics, textiles and electrical and electronic products. The production and use of the commercial PBDE mixtures; penta- and octa-BDE, are regulated by the Aarhus protocol on POPs (UN/ECE, 2010) and the Stockholm Convention on POPs (Stockholm Convention, 2013) and banned in most countries worldwide. The commercial PBDE mixture, deca-BDE, was included as a POP in the Stockholm Convention in May 2017. The global regulation entered into force in 2018, but includes several specific exemptions for production and use including in vehicles and aircrafts. In Norway, the use of deca-BDE, except for in means for transportation, have been banned since 2008.

PBDEs theoretically comprise 209 congeners with different degrees of bromination from tetra- to deca-BDE. 17 of the BDE-congeners (=sum PBDEs) have been monitored at Zeppelin since 2006, at Birkenes since 2008, and at Andøya between 2009 and 2016. In 2020, PBDEs were monitored at Birkenes and Zeppelin, but not at Andøya. The PBDEs in air are sampled on filter and polyurethane foam (PUF) plugs and thus the concentrations of PBDEs in air in this monitoring programme represent the bulk phase (i.e. gas+particle phase). PBDEs were measured on weekly basis at Zeppelin and on monthly basis at Birkenes. The monthly samples at Birkenes were obtained by combining two 48 hr-samples per month in the lab.

At Birkenes in 2020, only nine congeners were detected in more than 50% of the samples (i.e. 28, 47, 49, 66, 99, 100, 153, 154 and 183). The detection frequencies were low (<50%) for the other six congeners; BDE-71, 77, 85, 119, 138, and 196 at Birkenes. At Zeppelin, six congeners (i.e. 28, 47, 49, 99, 100, and 206) were detected in more than 50% of the samples while ten congeners (i.e. BDE-66, 71, 77, 85, 119, 138, 153, 154, 183, 196 and 206) were detected at low frequencies. The combination of low detection frequency and low detection limits for many of the PBDE congeners at Zeppelin indicates low concentrations of many PBDEs in Arctic air.

High concentrations of BDE-209 were found in the field blanks from both sites (0.4-40 pg/m^3). This indicates contamination in sample material along the chain from sample preparation, transportation, sampling, storage, and analysis. The BDE-209 concentrations from 2020 are therefore considered invalid.

The highest concentrations at Birkenes and Zeppelin in 2020, when excluding BDE-209, were observed for BDE-206 and -47.

The weekly concentrations of sum PBDEs (excl. BDE-209) at Zeppelin, ranged between: 0.11-0.49 pg/m^3 at Birkenes, and 0.16-1.39 pg/m^3. The annual mean concentrations of sum PBDEs (excluding BDE-209) in 2020 at Zeppelin was 0.51 pg/m^3 and at Birkenes 0.24 pg/m^3. The concentrations of sum PBDEs and the individual congeners (except BDE-209) measured at Birkenes and Zeppelin in 2020 were lower than in 2019, but similar to previous years. 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 (Bohlin-Nizzetto, 2018). The trend analyses for Birkenes however have shown decreasing trends for BDE-47 over the monitoring period (Figure 25).

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

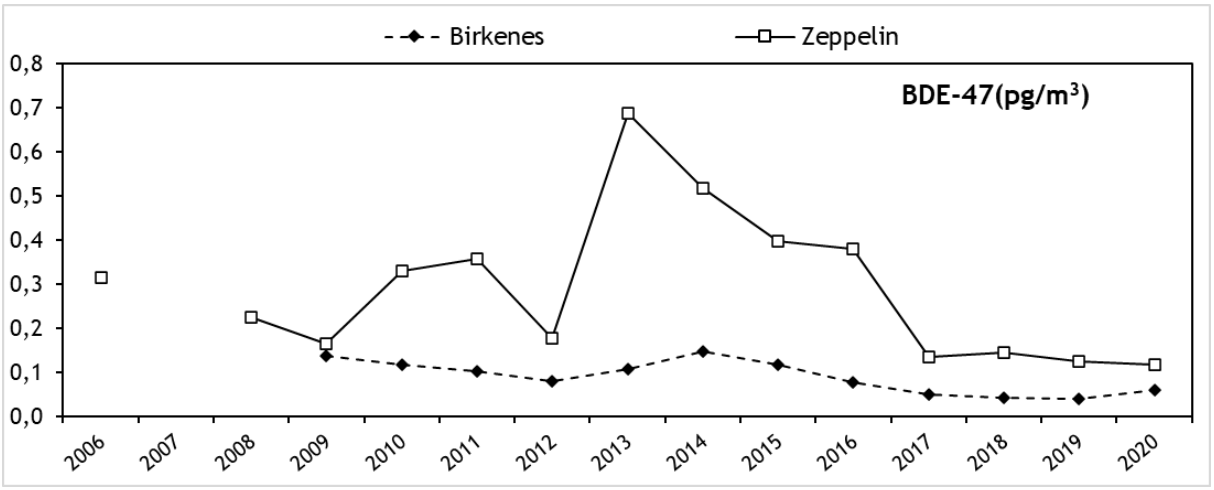
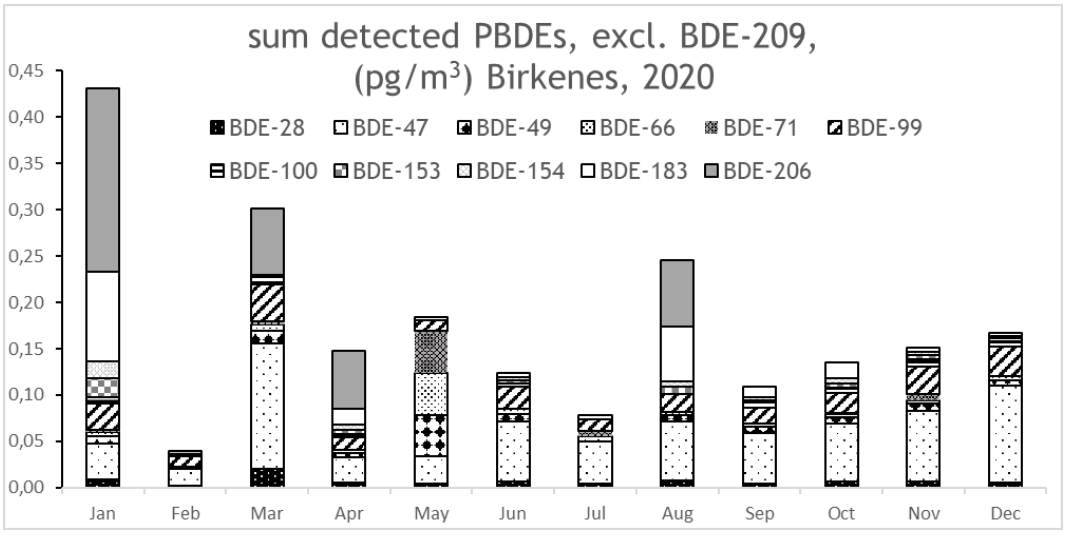


Figure 25. Annual mean concentrations of BDE-47 (pg/m³) in air.

The seasonal pattern is influenced by low detection frequencies of many BDE-congeners and a few individually high episodes, especially of BDE-206. The seasonality seen in Figure 26 should be interpreted with caution. In general, no seasonality is observed for sum $PBDEs_{excl209}$ nor for the individual congeners at any site, instead the concentrations fluctuated according to episodic events (Figure 26). The reason for the individual high levels is not known.



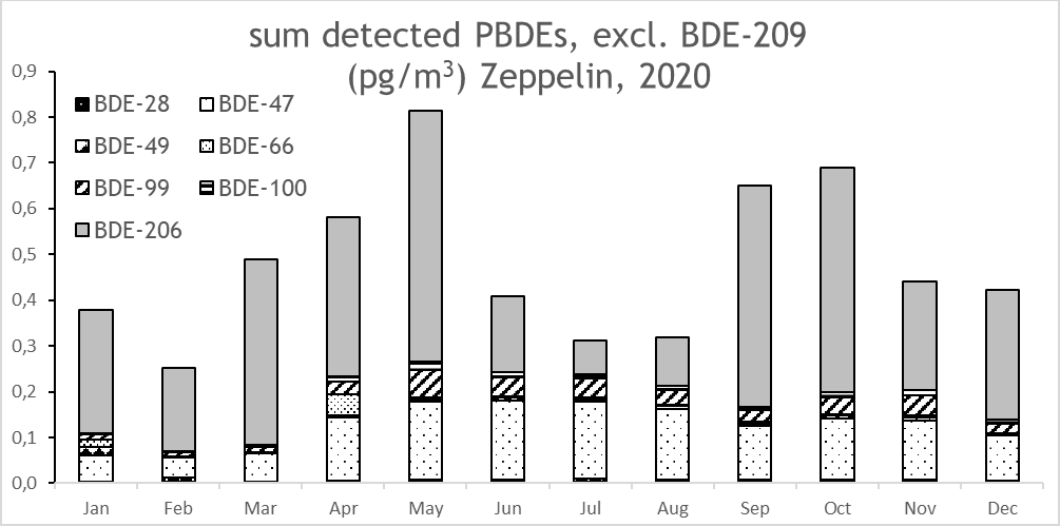


Figure 26: Seasonal variability of sum PBDEs, excl. BDE-209 (congeners detected in more than 50% of the samples) at Birkenes and Zeppelin in 2020.

2.2.2 Tribromoanisol (TBA)

TBA is a halogenated natural product (HNP) produced by marine phytoplankton, macro algae, bacteria and some benthic invertebrates. It is also an industrial intermediate and a potential break-down product of some non-BDE flame retardants (e.g. 2,3-dibromopropyl-2,4,6-tribromophenyl ether DPTE/TBP-DBPE). The marine HNPs have been shown to volatilize from the sea and are transported by air (Bidleman et al., 2014, 2016). Air measurements of TBA are therefore good indicators for general changes (e.g. climate changes) in the HNP picture of oceans. Bromoanisoles show POP like characteristics, such as toxic properties, half-lives exceeding the 2 day 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 in air are sampled on filter and polyurethane foam (PUF) plugs and thus the concentrations of TBA in air in this monitoring programme represent the bulk phase (i.e. gas+particle phase).

TBA was detected in all samples at both sites in 2020 (100% of all samples >LOD). The monthly concentrations at Birkenes ranged between: 1.3-8.6 pg/m^3; and the weekly concentrations at Zeppelin ranged between 0.99-23 pg/m^3. The annual mean concentrations of TBA in 2020 were 4.3 and 8.2 pg/m^3 at Birkenes and Zeppelin respectively (Figure 27). The annual mean concentration at Zeppelin is the highest ever observed. The concentrations at Birkenes are stable over the monitoring period while they fluctuate more at Zeppelin. The high concentration in 2019 is due to a doubling of concentrations in the summer peak June-September compared to 2018.

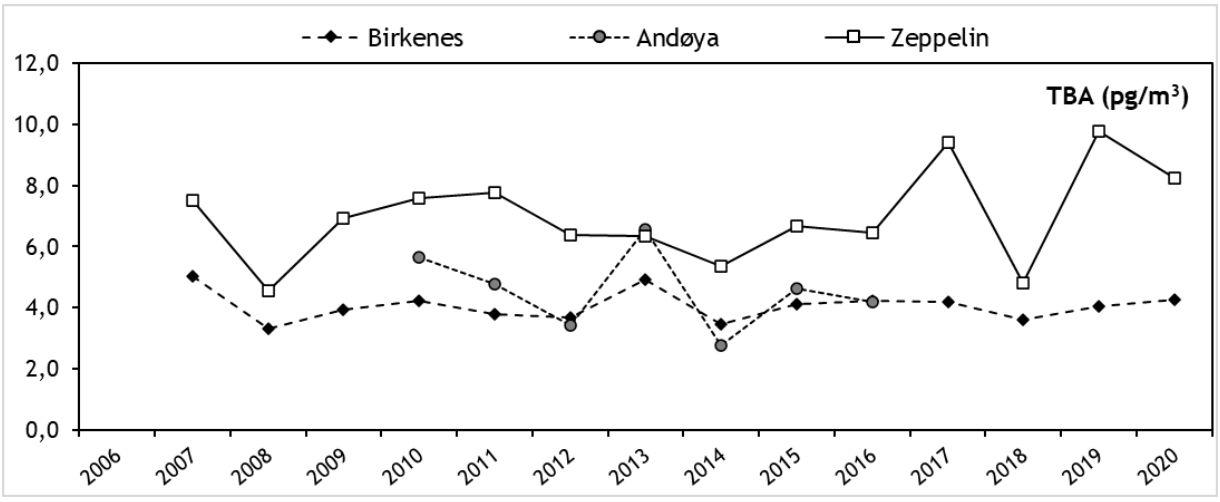


Figure 27: Annual mean concentrations of TBA (pg/m³) in air.

At Zeppelin, the same seasonal trend as previous years was observed, with low concentrations during winter and spring and increasing concentrations (5-10 times higher) during the summer and autumn (Figure 28). The higher concentrations in summertime may be a consequence of increased algal bloom during this period. In contrast to Zeppelin, at Birkenes the highest concentrations were observed in winter and autumn time (January-March and September-December) and the lowest concentrations in summertime. The reason for this seasonality is not known.

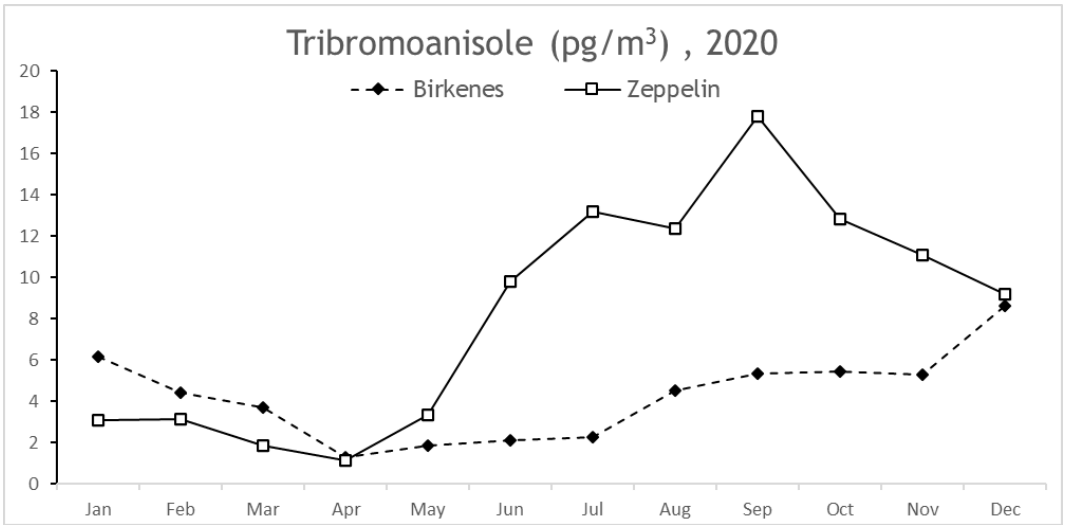


Figure 28: Seasonal variability of TBA at Birkenes and Zeppelin in 2020.

2.2.3 Hexabromocyclododecanes (HBCDs)

HBCD is an additive brominated flame retardant, with many applications. The main use is in extruded and expanded polystyrene used in building and construction for thermal insulation. HBCD was listed in the Stockholm Convention on POPs in 2013 with a time-limited exemption for production and use in expanded and extruded polystyrene in buildings. The global ban entered into force in November 2014 (Stockholm Convention, 2013). HBCD, like other POPs, are in Norway regulated through the POP Regulation (EU) No 2019/1021 in Chapter 4 of the Product Regulation. The POPs Regulation bans or restricts the production and use of POPs.

The three main diastereomers: α-, β-, and γ-HBCD (=sum HBCDs) have been monitored at Birkenes and Zeppelin since 2006. The HBCDs in air are sampled on filter and polyurethane foam (PUF) plugs and thus the concentrations of HBCDs in air in this monitoring programme represent the bulk phase (i.e. gas+particle phase). From 2017, the sampling volume for HBCDs were increased at both sites in order to improve detection (i.e. two samples were aggregated in the lab). Unfortunately, this strategy has not result in any improvement of detection. The three HBCDs are detected with a low frequency at Birkenes in 2020, only α-HBCD was detected (>LOD in 55% of the samples). In contrast, at Zeppelin all diastereomers were detected in >50% of the samples in 2020.

Although detected at Zeppelin, the observed concentrations for α- and β-HBCD were still low (0.012-3.69 pg/m^3 and <0.003-0.66 pg/m^3, respectively). The low detected concentrations and the low detection despite low LODs for all HBCDs suggests very low concentrations of HBCD in background air. As a result, the annual mean concentrations in Figure 29 for Birkenes only reflects the analytical limit of detection (i.e. no real air concentrations) while at Zeppelin it is influenced by real air concentrations.

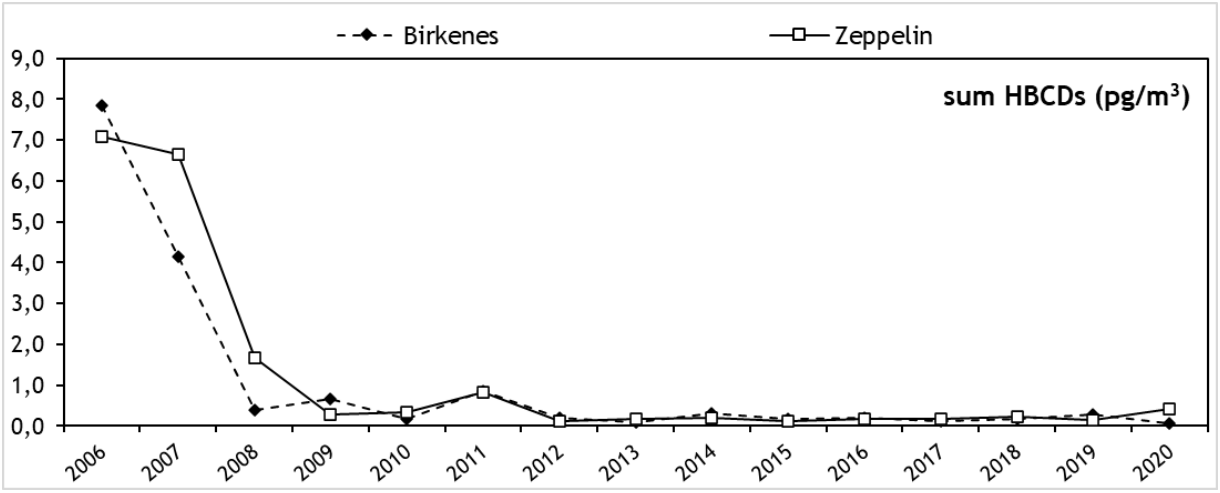


Figure 29: Annual mean concentrations of sum HBCDs (pg/m^3) in air. The annual mean includes all three diastereomers although some are <LOD in most samples at some sites and for some years. Specifically, from 2008-2020, most of the measurements are <LOD and the annual mean concentrations represents the analytical LOD with some influence by detected concentrations.

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

2.2.4 Per- and polyfluorinated alkyl substances (PFAS)

Ionic PFAS

PFAS comprise a large and complex group of industrially produced chemicals: Ionic compounds like perfluoroalkyl sulfonates (PFSA) and perfluoroalkyl carboxylic acids (PFCAs); and neutral, volatile compounds like fluorotelomer alcohols (FTOHs) and N-alkylated fluorooctane sulphonamides and sulfonamidoethanols (FOSAs/FOSEs). During the last 50 years, PFAS compounds such as PFOS, perfluorooctanoic acid (PFOA) and their related products, have been widely used in consumer products. PFOS together with its salts and perfluorooctane sulfonyl fluoride (PFOS-F) has been regulated by the Stockholm Convention on POPs since 2009 (Stockholm Convention, 2013). It is also regulated by the Aarhus protocol (UN/ECE, 2010). PFOA was included as a POP under the Stockholm Convention in May 2019, furthermore PFHxS is currently under consideration for listing in the Stockholm Convention. In Norway, both PFOS and PFOA are banned, and several PFAS are listed on Norway's Priority List of Hazardous substances ("Den norske Prioritetslista"): PFOS, PFOA, PFHxS, PFBS, PFHxA, HFPO-DA, and C9-C14 PFCAs (Norwegian Environment Agency, 2021).

Table 5: Full names and abbreviations of targeted ionic PFAS in air at Birkenes, Andøya and Zeppelin in 2020.

Ionic PFAS	
Full name	**Abbreviation**
4:2 Fluorotelomer sulfonic acid	4:2 FTS
6:2 Fluorotelomer sulfonic acid	6:2 FTS
8:2 Fluorotelomer sulfonic acid	8:2 FTS
Perfluorobutane sulfonic acid	PFBS
Perfluoropentane sulfonic acid	PFPeS
Perfluorohexane sulfonic acid	PFHxS
Perfluoroheptane sulfonic acid	PFHpS
Perfluorooctane sulfonic acid	PFOS
Perfluorooctane sulfonic acid, linear	$PFOS_{lin}$
Perfluorononane sulfonic acid	PFNS
Perfluorodecane sulfonic acid	PFDS
Perfluorohexanoic acid	PFHxA
Perfluoroheptanoic acid	PFHpA
Perfluorooctanoic acid	PFOA
Perfluorononanoic acid	PFNA
Perfluorodecanoic acid	PFDA (PFDcA)
Perfluoroundecanoic acid	PFUnDA
Perfluorordodecanoic acid	PFDoDA
Perfluorotridecanoic acid	PFTrDA
Perfluorotetradecanoic acid	PFTeDA
Perfluorohexadecanoic acid	PFHxDA
Perfluorooctadecanoic acid	PFODcA
Perfluorooctane sulphonamide	FOSA (PFOSA)

Ionic PFASs have been monitored at Birkenes and Zeppelin since 2006 and at Andøya since 2009. The measurements of ionic PFAS (=sum PFASs) under the monitoring programme of "*Long-range atmospheric transported contaminants*" includes 23 ionic PFAS compounds (Table 5). The ionic PFAS in air are sampled on filter only and thus the concentrations of ionic PFAS in air in this monitoring programme represent the particle phase. Of the monitored PFAS only four are defined as "short-chain": PFBS, PFPeS, PFHxA and PFHpA while the other sixteen are defined as "long-chain" (CnF2n+1SO3H, n ≥ 6, PFSAs, and CnF2n+1COOH, n ≥ 7, PFCAs) (Buck et al., 2011, ITCR, 2020).

Despite combining two samples to one and thereby increasing the sampling time, the detection was still low in 2020. Only PFOA was detected in all samples at all sites. Also, PFHxA was detected in some samples at all sites and PFDA, PFHpA and PFNA at Birkenes and Zeppelin. The other targeted ionic PFAS were <LOD in more than 50% of the samples (for details see Annex 1).

The concentrations of PFOA were significantly higher at Birkenes in 2020 (0.12 pg/m^3) than at Andøya (0.05 pg/m^3) and Zeppelin (0.07 pg/m^3) (Figure 30). The trend analyses for PFOA show decreasing trends at all sites since the start of the monitoring. The concentrations are however stable over the last six years at all sites (Section 3).

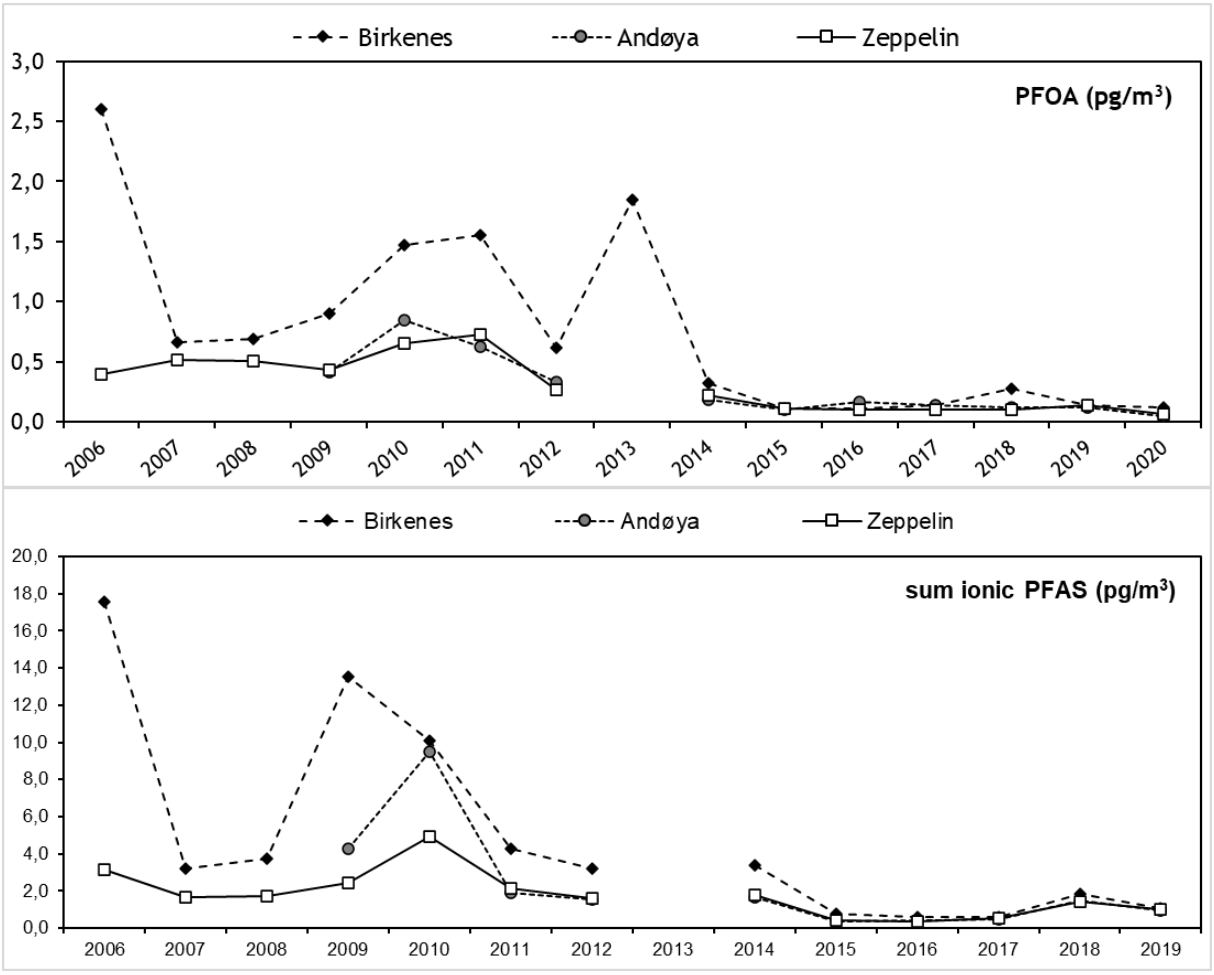


Figure 30: Annual mean concentrations of PFOA and sum ionic PFAS (pg/m^3) in air. The annual mean for sum ionic PFAS includes all targeted ionic PFAS, both those detected in most samples and those below the LOD (as LOD/2).

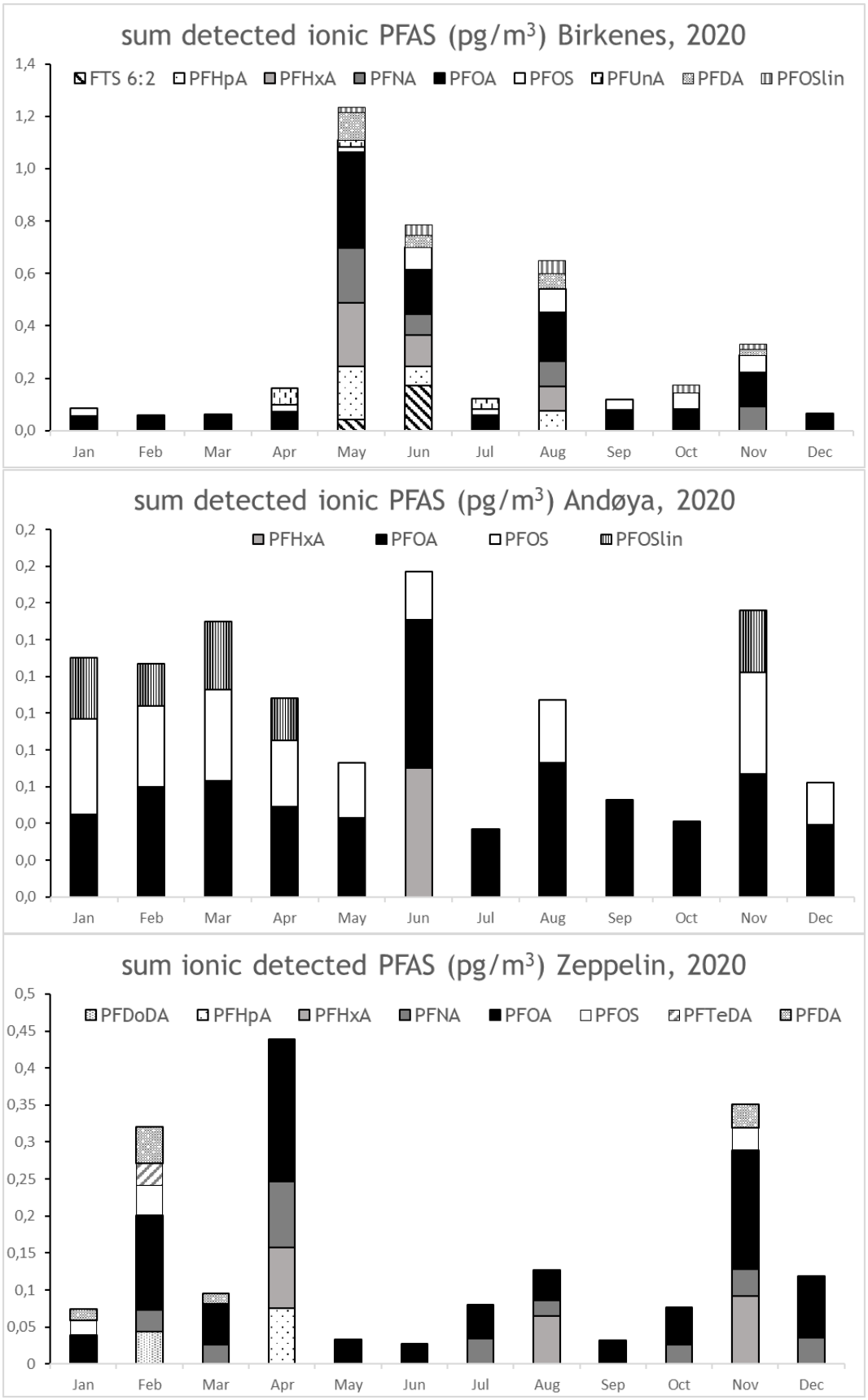


Figure 31: Seasonal variability of sum PFAS (based on detected congeners) at Birkenes and Zeppelin in 2020.

A seasonal trend was observed at Birkenes and Andøya with more frequent detection and higher concentrations in summer than in winter (Figure 31). At Zeppelin, the seasonality was the opposite with the highest concentrations and higher detection in winter than in summer.

2.2.5 Cyclic Volatile methylsiloxanes (cVMS)

Cyclic volatile methyl siloxanes (cVMS) represent a subgroup of a large class of compounds called dimethylsiloxanes. These compounds are produced in large volumes worldwide and are used in various applications, particularly in cosmetics and personal-care products where they are often referred to as cyclomethicones, although various other trade names exist (Wang et al., 2013a). The cyclic oligomers octamethylcyclotetrasiloxane (D4), decamethylcyclopenta-siloxane (D5), and dodecamethylcyclohexa-siloxane (D6) have received increased attention from regulatory agencies and the scientific community regarding their environmental persistence, bioaccumulation, toxicity, and long-range transport 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 content in wash-off personal care products is now restricted within European Union (not to exceed 0.1%) as of February 2020 (ECHA, 2018). The restrictions have also been proposed to include D6 which also meet the vPvB criteria (ECHA, 2019). All the three oligomers; D4-D6, 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. From 2017, the cVMS have been sampled on weekly basis at Zeppelin and monthly basis at Birkenes. All samples are collected Friday-Monday (72 hr) in order to minimize the risk of contamination from activities at the stations during weekdays. Air samples are collected on ABN adsorbent and thus the concentrations of cVMS in air in this monitoring programme represent the gas phase only (Warner et al. 2020).

Long-range atmospheric transport of cVMS to Arctic regions has been suggested by a few studies that 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 2013-2019 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. Despite being present in Arctic air, no direct evidence has shown that D4, D5 and D6 can undergo atmospheric deposition. Instead, multimedia model predictions, based on the physical chemical properties of D4, D5 and D6, suggest the three of them to have a minimal deposition potential (Wania et al., 2003; Xu and Wania, 2013). Properties responsible for this low deposition potential from models are their high volatility, short atmospheric half-lives, high K_{AW} values and relatively low K_{OA} values compared to legacy POPs. cVMS have nonetheless been detected in arctic biota at Svalbard (Warner et al. 2010; Warner et al. 2013). According to the authors, this may be a result of direct release of cVMS to aquatic systems in the region (point sources) and not due atmospheric deposition of long-range transported cVMS, but other findings of cVMS in Arctic cod from pristine areas instead suggest long-range transport of cVMS (Green et al., 2018). More research is needed to understand if the model predictions of low deposition potential can be confirmed by measurements and further what is the exposure pathways for cVMS for the Arctic biota.

The concentrations for the investigated cVMS in 2020 were, as in 2018-2019, obtained by using the new adsorbent (ABN) which is less affected by degradation during sampling and storage and therefore a better option for the monitoring (Warner et al. 2020). This allows for reporting of more accurate data for D4 from 2018 when ABN was taken into routine use.
D4 and D5 were detected in all samples from Birkenes in 2020 while D6 was below detection limit (<LOD) in 30% of the samples. At Zeppelin, D5 was detected in most samples while D6 was <LOD in

70% and D4 was <LOD in 50% of the samples. The concentrations of all oligomers are higher at Birkenes than at Zeppelin. The range and the annual mean concentrations of D4, D5 and D6 at Zeppelin in 2020 were 0.10-3.5 ng/m^3 (0.5 ng/m^3), 0.06-9.5 ng/m^3 (1.0 ng/m^3), and 0.08-1.5 ng/m^3 (0.2 ng/m^3), respectively. The highest levels were measured in the dark period, without sunlight, (October-February) and the lowest in light period, with midnight sun, (March-September). This was especially evident for D5 (Figure 32). The concentrations of D4, D5 and D6 at Birkenes were 0.50-3.1 ng/m^3 (1.3 ng/m^3), 1.6-12 ng/m^3 (4.9 ng/m^3) and 0.11-1.8 ng/m^3 (0.5 ng/m^3), respectively. Similar to the observations made at Zeppelin station, the lowest concentrations at Birkenes were observed in spring/summer (March-October) and the highest in winter (December-February) (Figure 32**Error! Reference source not found.**). Data from Birkenes in November 2020 is missing due to a lost sample. 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.

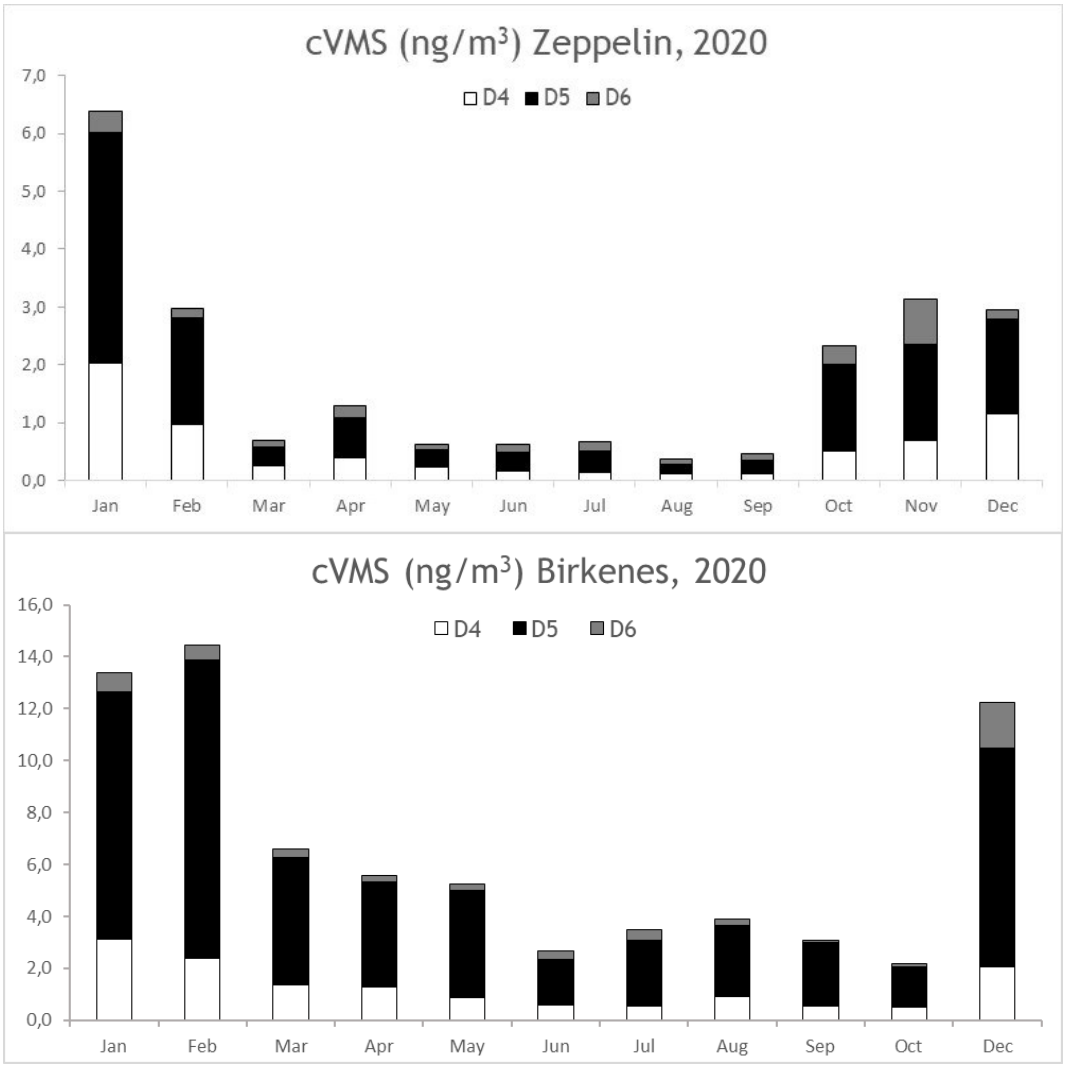


Figure 32: Monthly mean concentrations (ng/m^3) of D4, D5 and D6 at Zeppelin (top) and Birkenes (bottom) in 2020. Zeppelin represents the average of weekly samples while Birkenes represents one sample per month. For Birkenes, November is missing due to lost sample.

The concentrations over the last four years have been compared for Zeppelin and Birkenes respectively (Figure 32-33). In this period, samples have been collected weekly/monthly which provides a better picture of the time trend, than when comparing to previous years when samples only were collected

in summer and winter campaigns. At both sites, the concentrations were highest in 2019, while the 2020 concentrations being similar to 2017-2018 (Figure 33, Figure 34). The higher concentrations of D4 in 2017 may be influenced by the sampler used in 2017 (ENV+). The trend is most significant for D5 which also has the highest detection frequency.

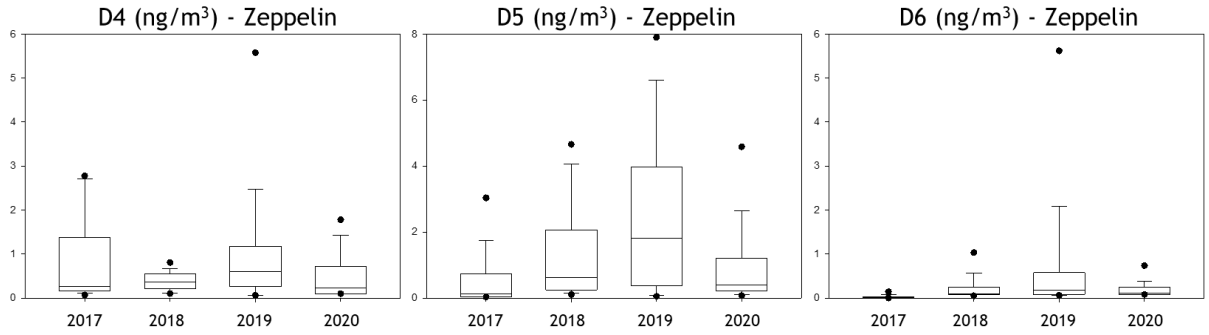


Figure 33: Box-plots of measured concentrations of D4, D5 and D6 (ng/m^3) at Zeppelin in 2017-2020 when weekly sampling has been conducted. The box-plots represents a range from 25-75% confidence interval with the center line representing the median concentrations and the error bars and points represent 10-90 percentile and 5-95 percentile, respectively.

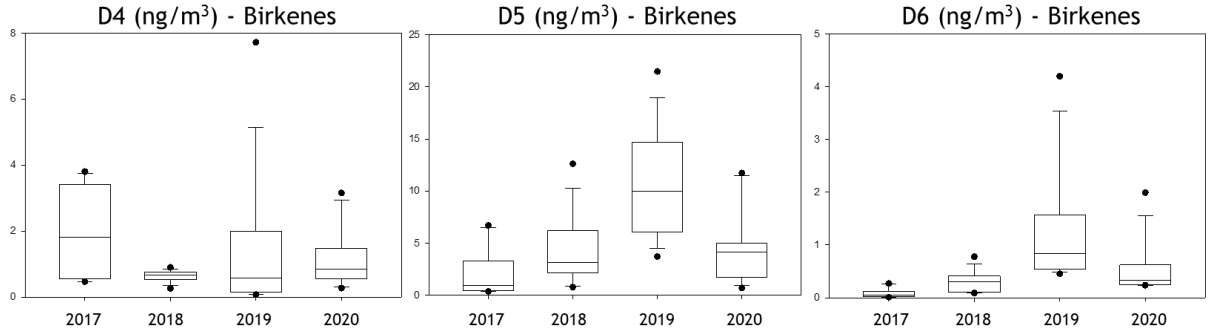


Figure 34: Box-plots of measured concentrations of D4, D5 and D6 (ng/m^3) at Birkenes in 2017-2020 when monthly sampling has been conducted. The box-plots represents a range from 25-75% confidence interval with the center line representing the median concentrations and the error bars and points represent 10-90 percentile and 5-95 percentile, respectively.

2.2.6 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 (UN/ECE, 2010). In May 2017, the SCCPs were also included as POPs in the Stockholm Convention (Stockholm Convention, 2017). Information on levels and distribution of SCCPs is still limited, mainly due to analytical challenges (Tomy et al., 1997). The atmosphere is usually considered to be the main transport medium for SCCP, but overall 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 and from 2017 the monitoring programme also included measurements of M/SCCPs at Birkenes. The sampling at Zeppelin is done on a weekly basis while sampling at Birkenes is done on monthly basis since 2017. At both sites M/SCCPs are sampled together with samples for PCBs and OCPs; on glass fibre filters and PUF plugs, and thus the concentrations of M/SCCPs in air in this monitoring programme represent the bulk phase (i.e. gas+particle phase). The sampler head of the active air sampler has a cut-off of 10 µm which mean that all particles collected are smaller than PM10. 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, with average blank values 10-100% of detected masses. All samples are therefore blank corrected for the average blanks.

At Zeppelin, ~20% of the measurements for SCCPs were <LOD while 50% of the measurements for MCCPs were <LOD. At Birkenes, MCCPs were <LOD in 90% of the samples and SCCPs in 50% of the samples. One reason for higher % of samples <LOD for MCCPs at Birkenes is a shorter sampling time that results in a bigger contribution of blanks and a higher LOD at Birkenes (average LOD=1100 pg/m^3). At Zeppelin where the sampling time is the double, the average LOD is 490 pg/m^3.

The presented data should be considered as semi-quantitative as the contribution of possible contamination during sampling and analyses is uncertain. Ongoing work at NILU aims to further improve the quality control in the future. New routines in the laboratory during 2020 have resulted in more stable blank levels but further improvements are need, possibly by introducing new sampling methodologies.

The annual mean concentrations of S/MCCPs at Zeppelin for 2020 were, as observed also in previous years, one to three orders of magnitude higher than the concentrations of most of the other studied POPs and one order of magnitude lower than the concentrations of cVMS and sum PAHs/PAH-16. The annual mean concentration of SCCPs at Zeppelin were 510 pg/m^3 (median 310 pg/m^3, range: <120-6600 pg/m^3) including two high episodes (6600 pg/m^3 in August and 2700 pg/m^3 in September) (Figure 35**Error! Reference source not found.**). For MCCPs the annual mean concentration at Zeppelin in 2020 were 750 pg/m^3 (median 280 pg/m^3, range <320-5200 pg/m^3) including two high episodes (5200 pg/m^3 in August and 4200 pg/m^3 in July) (Figure 35).

The annual mean concentrations measured for SCCPs do not show any significant difference between the years (2013-2020). In contrast, the concentrations of MCCPs are higher during the last years, indicating an increasing trend for MCCPs. MCCPs are also higher than SCCPs in most samples from Zeppelin in 2020. In 2019, it was also observed higher or similar concentrations of MCCPs than SCCPs

in 42% of the samples. This is in contrast to the initial years of the monitoring of CPs at Zeppelin when, the concentrations of SCCPs were significantly higher than those of MCCPs (2-7 times) in a majority of the samples (55%), especially during the summer months. This together with the increase of concentrations as observed in Figure 35 may suggest higher emission of MCCPs. This needs to be confirmed by further studies.

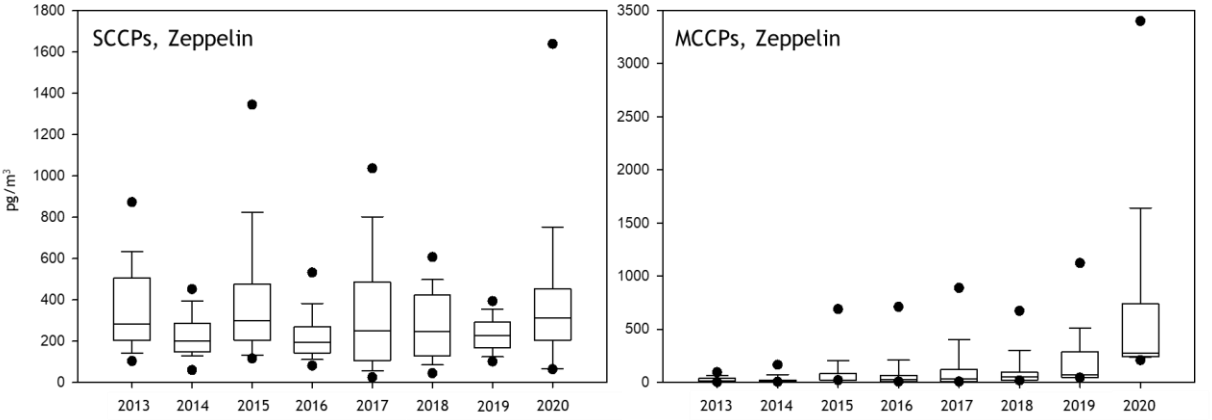


Figure 35: Box plot of measured SCCP and MCCP concentrations in air at Zeppelin in 2013-2020. The box-plots represents a range from 25-75% confidence interval with the center line representing the median concentrations and the error bars and points represent 10-90 percentile and 5-95 percentile, respectively.

The annual mean concentrations of SCCPs at Birkenes in 2020 were 150 pg/m^3 (median 94 pg/m^3 range <120-550 pg/m^3) (Figure 36). The annual mean concentration of MCCPs were influenced by low detection. Only one sample from Birkenes was >LOD for MCCPs in 2020 (i.e. 2612 pg/m^3 in May). The concentrations of SCCPs are lower at Birkenes than at Zeppelin in 2020, and no episodes are seen at Birkenes.

The concentrations of SCCPs and MCCPs measured at Zeppelin in 2013-2020 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).

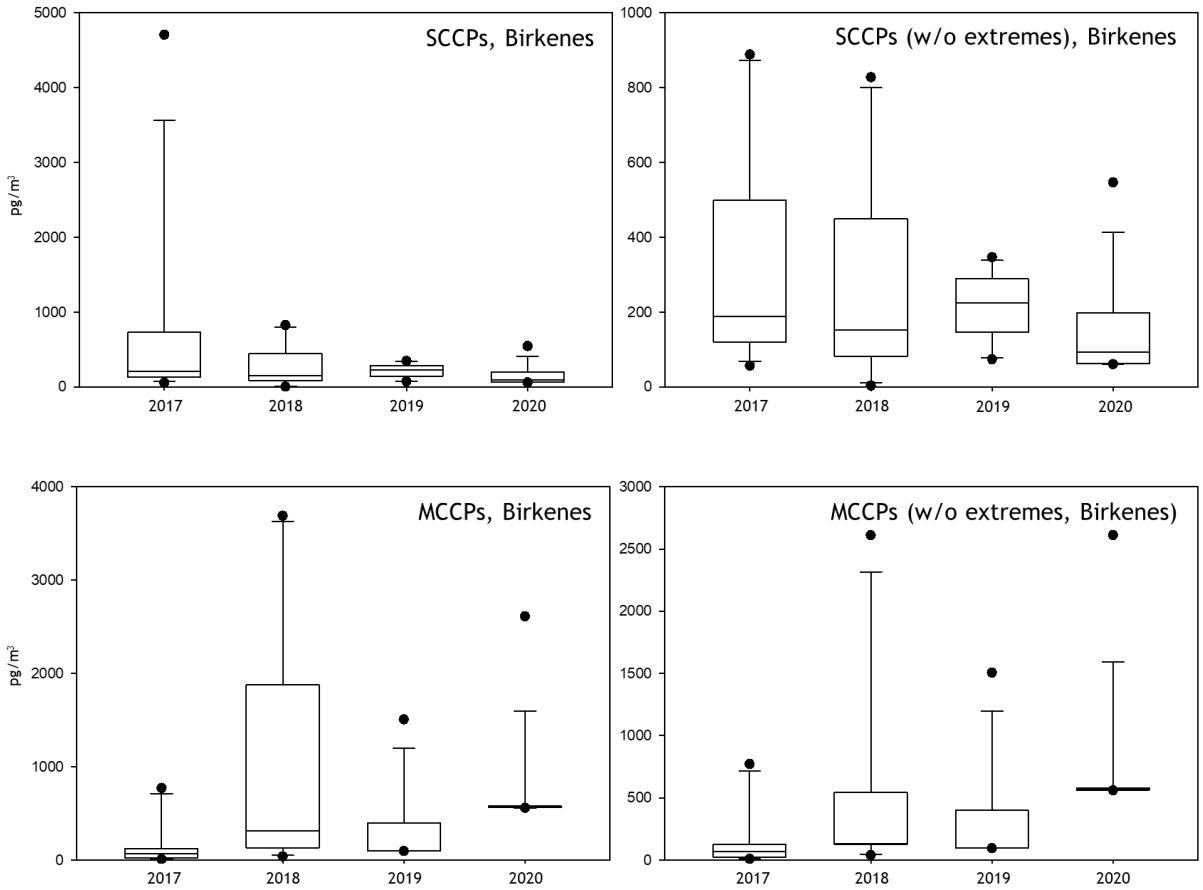


Figure 36: Box plot of measure SCCP and MCCP concentrations in air at Birkenes in 2017-2020 (with and without an extreme values for SCCPs in 2017 and for MCCPs in 2018). The MCCPs at Birkenes is influenced by many samples being below the detection limit. The box-plots represents a range from 25-75% confidence interval with the center line representing the median concentrations and the error bars and points represent 10-90 percentile and 5-95 percentile, respectively.

The highest concentrations of SCCPs were observed in summertime at both observatories (Figure 37).

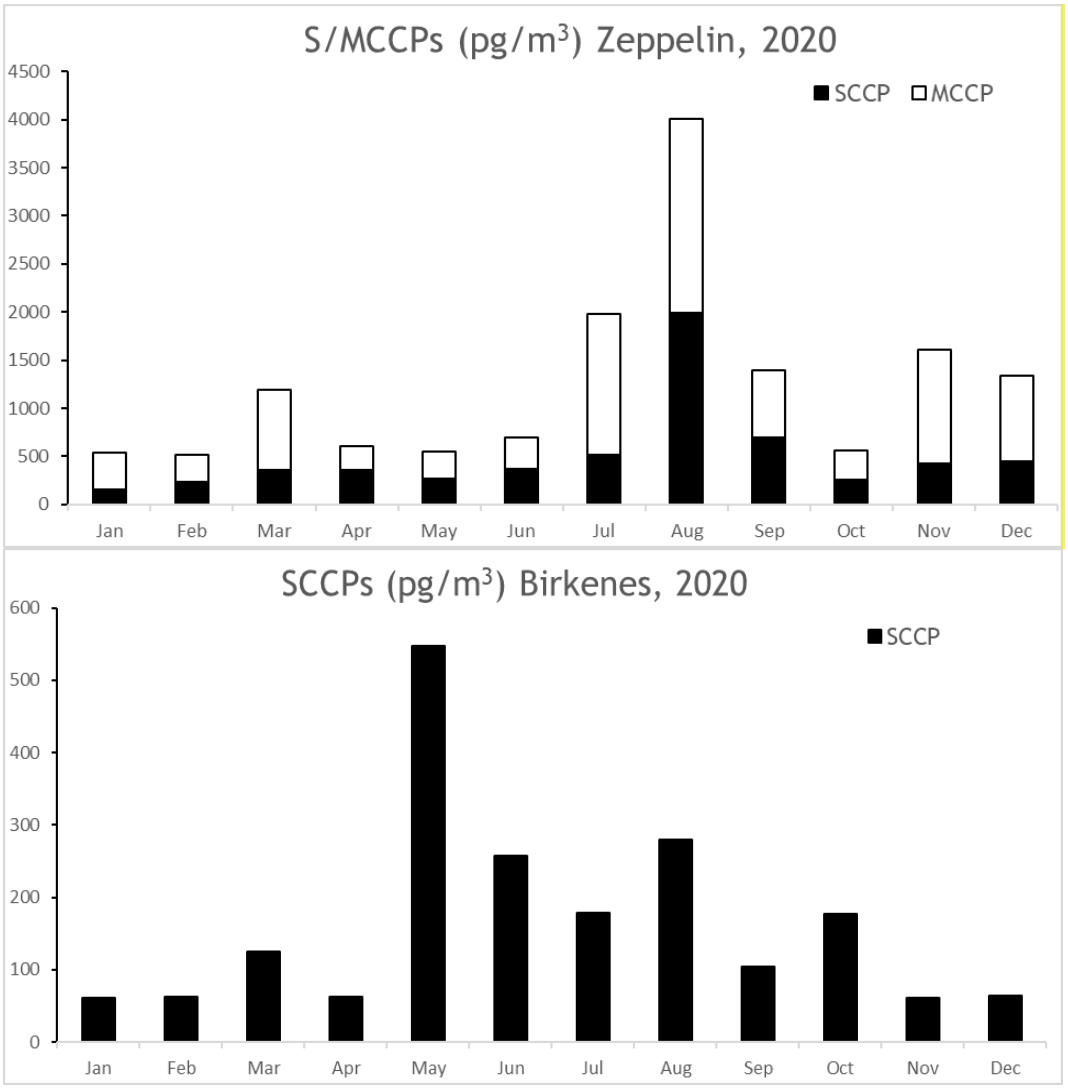


Figure 37: Seasonal variability of SCCPs and MCCPs at Zeppelin and SCCPs at Birkenes in 2020. MCCPs at Birkenes are not included as most samples were below the detection limit.

2.3 Long-term monitoring in precipitation

Precipitation samples for POPs were as previous years collected at Birkenes and analysed for HCB, α- and γ-HCH, and the seven indicator PCBs (PCB-7) (Annex 1, and Table 1). HCB and HCHs have been monitored since 1992 while PCB-7 since 2006. Wet deposition can be an important mechanism for inputs of particle-associated and relatively polar POP compounds in Norway (Wania & Haugen, 1999). 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.

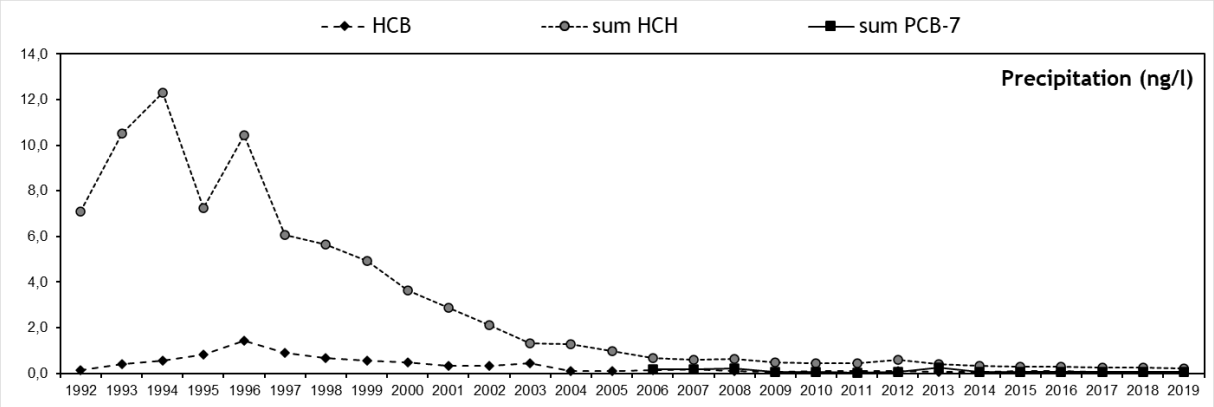


Figure 38: Annual mean concentrations of HCB, sum HCH and sum PCB-7 (ng/l) in precipitation at Birkenes. The annual mean concentrations include all targeted compounds, both those detected in most samples and those below the LOD (as LOD/2).

HCB was below detection limit in 67% of the samples in 2020. The annual mean concentration of HCB in precipitation in 2020 was similar to results from the last 12 years. Stable annual mean concentrations of HCB 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 38). No seasonal variability was observed for HCB, mainly due to low detection. The two HCH-isomers (α and γ) were detected in most samples in 2020. The annual mean concentration for sum HCHs was higher than in 2019, but similar to the previous four years and as in air they follow a decreasing time-trend at Birkenes. A seasonality was observed with high concentrations during spring- and summer and low concentrations in winter (December-February). This seasonality is similar to that found for HCHs in air at Birkenes. The PCB-congeners were only detected in 20-50% of the precipitation samples depending on congener with highest detection for PCB-180. The annual mean concentration of PCB-7 in 2020 was similar to the previous years. A seasonality with higher concentrations in winter and lower in summer was observed (Figure 39). This was also reflected by higher detection in winter than summer for all congeners.

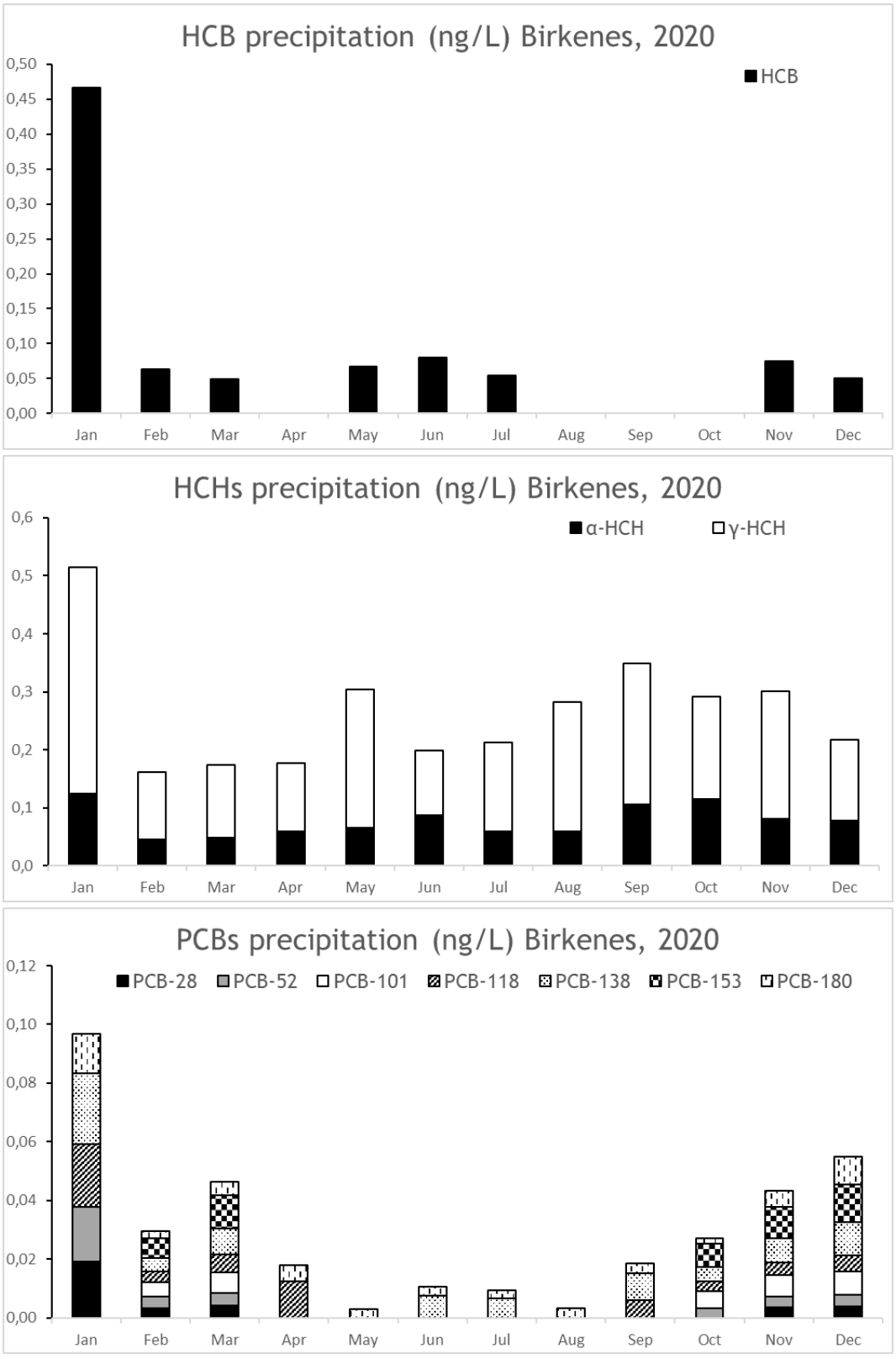


Figure 39: Seasonal variability of HCB, HCHs and PCBs (detected congeners) in precipitation (ng/L) at Birkenes in 2020.

3 Time trend analyses of a selection of POPs

The long-term time trends were derived using the same technique as has been used for POPs by the AMAP network and in the monitoring report of data from 2017 (AMAP, 2016; Hung et al. 2016, Bohlin-Nizzetto, 2018); 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 do 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. When the r2-value for the trend analysis is too low there is no significant trend for the time period (NST in Table 6).

For this report, as for analysis done on data from 2017 and 2019, the trends and half-lives were 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) (Up to EoF), 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 2020 (After EoF). 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 second scenario did not change from the report in 2017 while the first and the third has been prolonged in the data from additional two years (2019-2020). 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 table also include results from trend analyses performed on data from 2019 for comparison.

The results from the trend analysis using DF show no significant changes in concentrations for HCB at Zeppelin and Birkenes, for p,p'-DDE and p,p'-DDT at Birkenes. Significant decreases (i.e. small half-lives that indicate sharp declines) are seen for α- and γ-HCH, PFOA at both stations and for p,p'-DDE and p,p'-DDT at Zeppelin. At Zeppelin, the decline of HCB, HCHs, DDTs and PCBs are somewhat sharper during the first period (before SC) than the second period (after SC).

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 entered into force for the individual compound (Up to Eof), and 3) from the year global regulation was taken into force for the individual compounds until the end of 2020 (After EoF). The trends are expressed as apparent first order half-lives (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. The empty white cells mean that no data is available for this time period.*

POP	Birkenes			Andøya			Zeppelin		
	Whole period	Up to EoF	After EoF	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	*39** ↘	6.8 ↓	*24** ↘				*NST* →	10 ↘	*NST* →
α-HCH	5.3 ↓	4.3 ↓	9.4 ↘				5.4 ↓	4.8 ↓	6.5 ↓
γ-HCH	4.5 ↓	3.7 ↓	*25** ↘				4.5 ↓	4.2 ↓	6.2 ↓
p,p'-DDE	*NST* →		*NST* →				8.9 ↓	5.9 ↓	8.1 ↓
p,p'-DDT	*NST* →		*NST* →				5.9 ↓	3.9 ↓	7.7 ↓
PCB-52	*14** ↘		*14** ↘				11 ↘	5.3 ↓	11 ↘
PCB-118	*9.5* ↘		*9.5* ↘				*9.7* ↘	4.5 ↓	*15* ↘
PCB-153	*10** ↓		*10** ↓				*9.5** ↘	4.1 ↓	*12** ↘
Fluorene	*NST* →						*14* ↘		
Fluoranthene	*NST* →						*12* ↘		
Benzo(a)pyrene	*6.8* ↓								
PFOA	*5.2** ↓		*5.2** ↓	*2.9** ↓		*2.9** ↓	3.5 ↓		3.5 ↓

*R^2<0.9

NST: no significant trend

4 Results and discussions for organic contaminants of emerging concern

New organic chemicals are constantly introduced on the market, either as replacements for regulated chemicals such as the POPs for use in new materials or new types of use as a demand for new technological needs and properties. Some of these chemicals have similar physical-chemical properties as regulated POPs and have thus received attention from regulatory agencies as well as the scientific community. Detection of such chemicals in screening programmes or case-studies have identified a need for environmental monitoring of these chemicals. The monitoring programme "Long-range atmospheric transported contaminants" is therefore continuously adapted to include new organic contaminants of emerging concern.

Five groups of non-regulated organic contaminants of emerging concern, covering 58 individual compounds, were monitored in 2020 (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 and Birkenes in two campaigns, one summer campaign and one winter campaign. Six samples with a sampling time of 48-72 hr were taken during each campaign (Table 3). Each sample consisted of a glass fiber filter that collected compounds associated to particles and two PUF-plugs that collected compounds in gas-phase. The two phases were combined during analysis to provide bulk concentrations in air. The air samples for volatile PFAS were collected at Birkenes, Andøya and Zeppelin using PUF/XAD/PUF as adsorbents. Two samples were taken per month, each with a sampling time of 48-72 hr. The two monthly samples were combined during analysis and provided monthly concentrations. Air samples for dechloranes were taken weekly at Zeppelin and monthly at Birkenes (together with the samples for S/MCCPs). Air samples were also collected at Birkenes and Zeppelin for analyses of volatile fluorinated substances and data mining analysis (suspect screening analysis). These samples were taken using a modified version of the sampling methodology that is used for siloxanes (ABN adsorbent). Each sample was taken for 72 hours in one summer campaign and one winter campaign.

Table 7: Full names and abbreviations of organic contaminants of emerging concern included in the monitoring in 2020.

Full name	Abbreviation	CAS
Volatile PFAS		
4:2 fluorotelomer alcohol	4:2 FTOH	2043-47-2
6:2 fluorotelomer alcohol	6:2 FTOH	647-42-7
8:2 fluorotelomer alcohol	8:2 FTOH	678-39-7
10:2 fluorotelomer alcohol	10:2 FTOH	865-86-1
N-ethyl perfluorooctanesulfonamide	N-EtFOSA	4151-50-2
N-ethyl perfluorooctane sulfonamidoethanol	N-EtFOSE	1691-99-2
N-methylperfluoro-1-octansulfonamide	N-MeFOSA	31506-32-8
N-Methylperfluorooctanesulfon-amidoethanol	N-MeFOSE	24448-09-7
Novel brominated flame retardants - nBFRs		
Allyl 2,4,6-tribromophenyl ether	ATE (TBP-AE)	3278-89-5
α-Tetrabromoethylcyclohexane	α-TBECH (DBE-DBCH)	1232836-48-4, 3322-93-8
ß-Tetrabromoethylcyclohexane	ß-TBECH (DBE-DBCH)	1232836-49-5, 3322-93-8
γ/δ-Tetrabromoethylcyclohexane	γ/δ-TBECH (DBE-DBCH)	

Full name	Abbreviation	CAS
2-Bromoallyl-2,4,6-tribromophenyl ether	BATE (TBP-BAE)	99717-56-3
Pentabromotoluene	PBT	87-83-2
Pentabromoethylbenzene	PBEB	85-22-3
1,2,3,4,5-pentabromobenzene	PBBZ	608-90-2
Hexabromobenzene	HBB	87-82-1
2,3-dibromopropyl-2,4,6-tribromophenyl ether	DPTE (TBP-DBPE)	35109-60-5
2-ethylhexyl-2,3,4,5-tetrabromobenzoate	EHTBB	183658-27-7
1,2-bis(2,4,6-tribromophenoxy)ethane	BTBPE	37853-59-1
Bis(2-ethylhexyl)tetrabromophthalate	TBPH (BEH-TBP)	26040-51-7
Decabromodiphenylethane	DBDPE	84852-53-9
Organophosphorous flame retardants - OPFRs		
Triethyl phosphate	TEP	78-40-0
Tri(2-chloroethyl)phosphate	TCEP	115-96-8
Tripropyl phosphate	TPrP (TPP)	513-08-6
Tris(2-chloroisopropyl)phosphate	TCPP (TCIPP)	13674-84-5
Triisobutyl phosphate	TBP (TiBP)	126-71-6
Butyl diphenyl phosphate	BdPhP	2752-95-6
Triphenyl phosphate	TPP (TPhP)	115-86-6
Dibutylphenyl phosphate	DBPhP	2528-36-1
Tri-n-butylphosphate	TnBP	126-73-8
Tris(1,3-dichloro-2-propyl)phosphate	TDCPP (TDCIPP)	13674-87-8
Tris(2-butoxyethyl)phosphate	TBEP (TBOEP)	78-51-3
Tricresyl phosphate	TCP	1330-78-5
2-ethylhexyldiphenyl phosphate	EHDP (EHDPP)	1241-94-7
Trixylyl phosphate	TXP	25155-23-1
Tris(4-isopropylphenyl)phosphate	TIPPP	68937-41-7
Tris(2-ethylhexyl)phosphate	TEHP	78-42-2
Phthalates		
Dimethyl phthalate	DMP	131-11-3
Diethyl phthalate	DEP	84-66-2
Dipropyl phthalate	DPP	131-16-8
Diallyl phthalate	DAIP	131-17-9
Di-iso-butylphthalate	DIBP	84-69-5
Dibutyl phthalate	DBP	84-74-2
Butylbenzyl phthalate	BBzP	85-68-7
Dihexyl phthalate	DHP	84-75-3
Di(2-ethylhexyl) phthalate	DEHP	117-81-7

Full name	Abbreviation	CAS
Dicyclohexyl phthalate	DcHP	84-61-7
Bis(2-propylheptyl) phthalate	DPHP	53306-54-0
Di-iso-nonyl phthalate	DINP	68515-48-0, 28553-12-0
Dechloranes		
Dechlorane plus syn	syn-DP	135821-03-3
Dechlorane plus anti	anti-DP	135821-74-8
Dechlorane 601	Dec-601	13560-90-2
Dechlorane 602	Dec-602	31107-44-5
Dechlorane 603	Dec-603	13560-92-4
Dechlorane 604	Dec-604	34571-16-9
Dibromo-aldrin	Dba	20389-65-5

4.1 Per- and polyfluorinated alkyl substances (PFAS)

Volatile PFAS

Volatile PFAS were included in the monitoring programme from 2017. They have been measured on monthly basis at Birkenes, Andøya and Zeppelin in 2017-2020. Two samples were taken per month and combined in the laboratory to provide monthly bulk concentrations. PUFs alone do not retain the volatile PFAS, and a special sampler unit consisting of XAD/PUF/XAD in sandwich was therefore used for sampling. Thus, the concentrations of the volatile PFAS in air in this monitoring programme represent the gas phase.

In 2020, eight volatile PFAS were monitored at the three stations, in addition to the ionic PFAS reported in section 2.2.4 (Table 5): 4:2 FTOH, 6:2 FTOH, 8:2 FTOH, 10:2 FTOH, N-EtFOSA, N-EtFOSE, N-MeFOSA, and N-MeFOSE (Table 7-8). A new analytical method with cold extraction, compatible with the XAD/PUF/XAD sample matrix, was tested and developed in 2017 and used for all the volatile PFAS. This was done to limit the loss of volatile PFAS caused by evaporation and degradation during normal soxhlet extraction methodologies.

Table 8: Volatile PFAS in air from active air samplers, presented as detection frequencies, ranges and annual mean concentration of monthly measurements (pg/m^3) at Birkenes, Andøya and Zeppelin, 2020. The LOD presented is based on average air sample volumes. Low detection is marked with stripes.

		Birkenes			Andøya			Zeppelin		
	LOD (pg/m^3)	Detection frequency (%)	Range (pg/m^3)	Annual mean (pg/m^3)	Detection frequency (%)	Range (pg/m^3)	Annual mean (pg/m^3)	Detection frequency (%)	Range (pg/m^3)	Annual mean (pg/m^3)
4:2 FTOH	0.4-0.8	33	<0.4-1.5	0.7	8	<0.4-51	*4.7*	0	<0.4-<1.6	<0.6
6:2 FTOH	2.2-3.3	100	3.5-12	6.3	100	2.1-23	6.0	82	<2.4-10	4.9
8:2 FTOH	0.9	100	2.9-37	13	100	2.5-330	52	100	2.3-110	21
10:2 FTOH	1.4-14	50	<2.6-51	17	75	<1.3-510	59	45	<3.4-84	17
N-EtFOSA	1.9-3.9	25	<0.3-0.7	*0.4*	8	<0.3-0.5	*0.3*	36	<0.3-3.3	*0.7*
N-EtFOSE	0.6	8	<0.7-1.5	*0.8*	8	<0.7-2.1	*0.9*	36	<0.6-8.2	*2.0*
N-MeFOSA	2.8-4.7	0	<0.8-<1.7	*<0.9*	0	<0.8-<1.1	*<0.9*	9	<0.7-3.0	*1.3*
N-MeFOSE	0.3	17	<0.5-1.4	*0.6*	17	<0.5-2.0	*0.7*	45	<0.5-5.6	1.4
Sum FTOHs			12-72	37		6.4-860	120		11-140	40

Of the eight targeted volatile PFAS only 8:2 FTOH and 6:2 FTOH were detected in all or most samples at all sites (Table 8). High detection was also observed for 10:2 FTOH (45-75%). N-MeFOSA was not detected in any samples from any site. The other four volatile PFAS; 4:2 FTOH, N-EtFOSA, N-EtFOSE and N-MeFOSE were detected occasionally (0-45%). 8:2 FTOH together with 6:2 FTOH and 10:2 were detected at highest concentrations of the volatile PFAS (Table 8). The annual mean concentration of FTOHs in 2020 were highest at Andøya (120 pg/m^3) followed by Zeppelin (40 pg/m^3) and Birkenes (37 pg/m^3). The high annual mean concentration at Andøya is influenced by high concentrations in April and July. No clear seasonal variability was observed for the volatile PFAS, instead there are episodes with high concentrations of individual FTOHs over the year (Figure 40). The concentrations measured at the three Norwegian sites in 2017-2020 are similar to those measured in the atmosphere above the Chinese Bohai Sea (Zhao et al., 2017) and in rural Germany (Dreyer et al., 2008) for 6:2, 8:2 and 10:2 FTOH while lower for 12:2 FTOH. The obtained LODs for FOSE and FOSA are higher than the previously reported concentrations in air which reduce the comparability between new measurements and previous measurements.

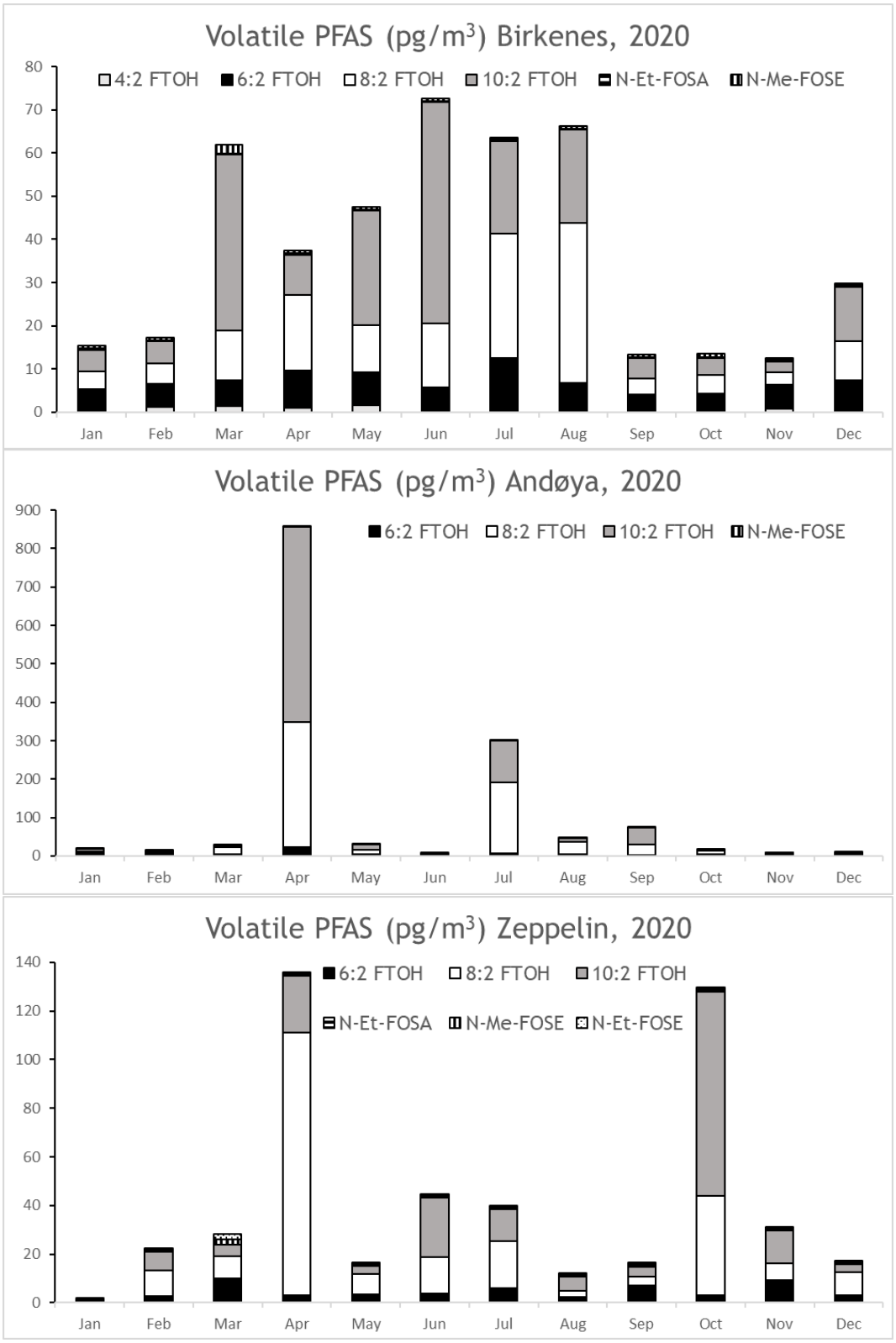


Figure 40: Seasonal variability of the detected volatile PFAS at Birkenes, Andøya and Zeppelin in 2020.

4.2 New brominated flame retardants (nBFRs)

New brominated flame retardants were included in the monitoring programme in 2017. They have been monitored at Zeppelin in 2017-2020 and at Birkenes in 2018-2020, in one summer campaign (July-August) and one winter campaign (November-December) using active air sampler. Each campaign aimed at collection six samples over a period of 48-72 hr per campaign. However, during harsh weather at Zeppelin in winter precipitation on the filters caused the sampler to stop, and two samples had to be excluded. The nBFRs in air are sampled on filter and polyurethane foam (PUF) plugs and thus the concentrations of nBFRs in air in this monitoring programme represent the bulk phase (i.e. gas+particle phase).

Of the targeted fourteen nBFRs (Table 9), eight were detected in more than 50% of the active air samples at Zeppelin in 2020 (Table 9). DBDPE was also detected, but was strongly influenced by high levels in field blanks. TBPH was detected in 36 and 45% of the samples, while α-/β-/γ-/δ-TBECH, PBBZ and DBDPE were not detected in 2020. The highest concentrations were observed for HBB (0.19 pg/m^3 in summer, and 0.11 pg/m^3 in winter) and PBT (0.11 pg/m^3 in summer, and 0.08 pg/m^3 in winter). HBB, PBT and EHTBB were higher during the summer campaign than the winter campaign in 2019 and 2020 suggesting possible seasonality for these compounds at Zeppelin. The profiles in the samples are however consistent in summer and winter time (Figure 41). The measured concentrations of the individual nBFRs are similar or lower than the concentrations of individual phthalates and the detected OPFRs.

Table 9: Detected nBFRs in air (pg/m^3) from active air sampling at Zeppelin in 2017-2020, presented as detection frequencies and average concentrations of individual measurements in summer and winter. The LOD presented is based on average air sample volumes. Low detection is marked with stripes.

	LOD 2020	Detection frequency 2020	Summer 2020	Winter 2020	Summer 2019	Winter 2019	Summer 2018	Winter 2018	Summer 2017	Winter 2017
	pg/m^3	%	pg/m^3	pg/m^3	pg/m^3	pg/m^3	pg/m^3	pg/m^3	pg/m^3	pg/m^3
ATE	0.006-0.010	70	0.03	0.04						
BATE	0.007-0.01	70	0.01	0.02						
PBT	0.01-0.02	100	0.11	0.08	0.26	0.05	0.24	0.52	0.06	0.05
PBEB	0.008-0.01	60	0.01	0.01						
PBBZ	0.12-0.18	10	<0.14	<0.14	0.12	<0.11	0.09	0.09	0.03	0.03
HBB	0.05-0.07	80	0.19	0.11	0.45	0.13	0.39	0.56	0.07	0.08
DPTE	0.006-0.009	100	0.02	0.01	0.01	0.006	0.02	0.02	0.02	0.01
EHTBB	0.006-0.009	90	0.07	0.04	0.15	0.04	0.2	0.23	0.22	0.03
BTBPE	0.01-0.02	80	0.08	0.10						
Sum nBFRs			0.5	0.4	0.9	0.4	0.9	1.7	0.4	0.2

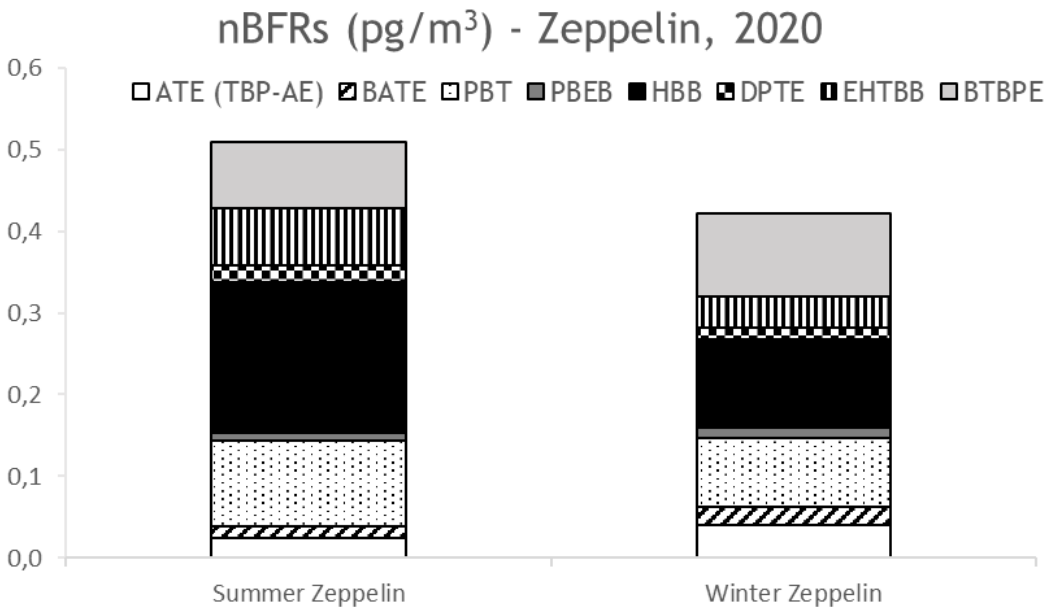


Figure 41: Mean concentrations of detected nBFRs in air at Zeppelin in 2020.

At Birkenes, 11 of the 14 targeted nBFRs were detected in 50% or more of the samples in 2020 (Table 10). DBDPE was also detected, but was strongly influenced by high levels in field blanks. The detected concentrations were higher in summer than in winter, with the concentrations in summer being strongly dominated by HBB (48 pg/m^3), followed by PBT (3.9 pg/m^3), PBBZ (2.1 pg/m^3) and DPTE (1.3 pg/m^3) (Figure 42). Also, the field blanks had elevated concentrations for several nBFRs, and the concentrations in summer were therefore blank corrected. It is likely that the unexpected high levels measured during summer are due to the construction upgrade at the sampling site.

The detected concentrations in winter were in the same range as previous years. The highest concentrations were observed for HBB (0.27 pg/m^3), α-TBECH (0.25 pg/m^3), and PBBZ (0.13 pg/m^3). While HBB also was dominating at Zeppelin, α-TBECH or PBBZ were detected only in one sample at Zeppelin in 2020. The sum nBFRs was approximately two times higher at Birkenes than at Zeppelin.

Table 10: Detected nBFRs in air (pg/m^3) from active air samplers at Birkenes, 2018-2020, presented as detection frequencies and average concentrations of the individual measurements in summer and winter. The LOD presented is based on average air sample volumes. Low detection is marked with stripes.

	LOD 2020	Detection frequency 2020	Summer 2020	Winter 2020	Summer 2019	Winter 2019	Summer 2018	Winter 2018
	pg/m^3	%	pg/m^3	pg/m^3	pg/m^3	pg/m^3	pg/m^3	pg/m^3
ATE	0.006-0.010	67	<0.007	0.01				
α-TBECH	0.05-0.08	100	1	0.25	0.1	0.12	0.19	0.1
ß-TBECH	0.04-0.05	67	0.32	0.04	0.07	0.09	0.09	0.05
BATE	0.007-0.01	67	0.01	0.01				
PBT	0.01-0.02	100	3.9	0.06	0.23	0.09	0.55	0.07
PBEB	0.008-0.012	75	0.06	0.01	0.03	0.01	0.22	0.07
PBBZ	0.12-0.18	83	2.1	0.13	0.39	0.13	0.83	0.1
HBB	0.05-0.07	100	48	0.27	1.07	0.23	2.67	0.32
DPTE	0.006-0.009	100	1.3	0.06	0.03	0.02	0.04	0.02
EHTBB	0.008-0.013	67	0.07	0.01				
BTBPE	0.01-0.02	83	<0.02	0.02				
Sum nBFRs			57	0.9	2	0.8	4.6	0.7

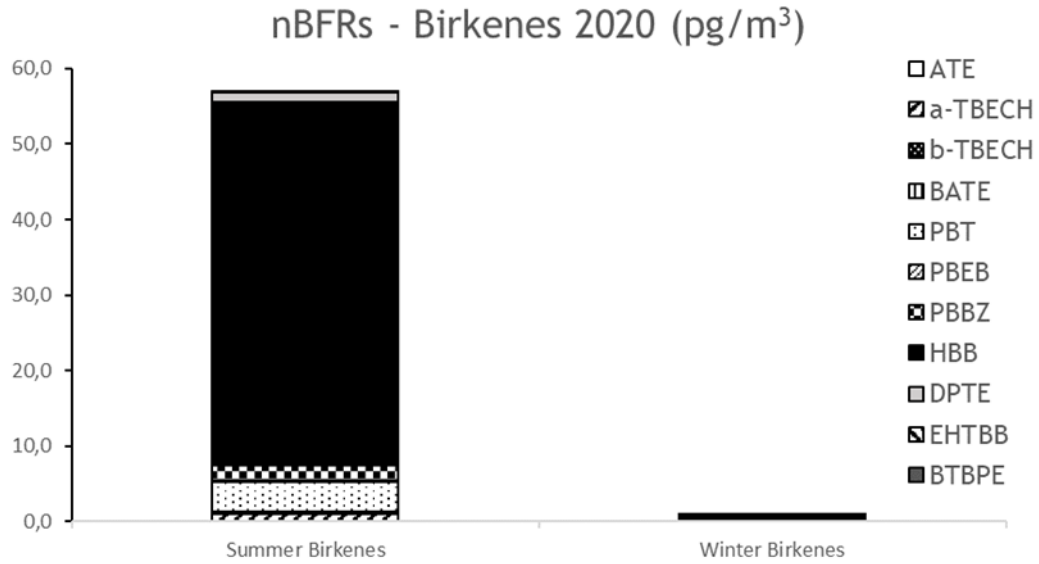


Figure 42: Mean concentrations of detected nBFRs in air at Birkenes and Zeppelin in 2020.

4.3 Organophosphorous flame retardants (OPFRs)

Organophosphorous flame retardants (OPFRs) were included in the monitoring programme in 2017. They have been monitored at Zeppelin in 2017-2020 and at Birkenes in 2018-2020, in one summer campaign (July-August) and one winter campaign (November-December) using active air sampler. Each campaign consisted of six samples taken over 48-72 hr at each station. The OPFRs in air are sampled on filter and polyurethane foam (PUF) plugs and thus the concentrations of OPFRs in air in this monitoring programme represent the bulk phase (i.e. gas+particle phase).

In 2020, the analysis included 16 OPFRs (Table 7). Of these, only TCEP and TCPP were detected in 50% or more of the active air samples from Zeppelin (Table 11), while the others were below LOD in all or most of the samples. High and inconsistent concentrations are found in blanks resulting in elevated LODs for many OPFRs, and especially for TCEP, TCPP and EHDP. Still, it should not be excluded that these compounds are present in the air at levels below these elevated LOD. The high blank level is probably a result of presence in the sample matrix and/or products used during lab procedures. NILU has in 2020 taken measures to reduce the blank contamination during analysis, by introducing extra cleaning procedures of both equipment and fume hood cabinets before sample preparation. However, by doing so it was identified that a large contribution comes from the PUF material itself where measures are not yet in place. A solution may be a new sampling adsorbent but to take such into practice requires pre-studies to make sure it does not introduce other issues. NILU will have master student projects the following year to test new adsorbents.

The measured concentrations of the detected OPFRs at Zeppelin were high, with concentrations for the individual compounds equal to or exceeding the levels observed for cVMS and CPs. The concentrations of the sum of the detected OPFRs should be taken with caution as they can be a consequence of the high levels in blanks and thereby high LODs. The obtained concentrations over the two sampling periods (summer and winter) ranged 74 to 460 pg/m^3 (mean: 195 pg/m^3, median: 106 pg/m^3). The dominant OPFRs at Zeppelin were TCEP (<LOD-39 pg/m^3) and TCPP (<LOD-405 pg/m^3) (Table 11). A few high measurements were also observed for other OPFRs. In both 2017, 2019 and 2020, higher concentrations of TCEP and TCPP were observed in summer than in winter. Both substances have previously been reported to have air-seawater exchange fluxes dominated by volatilization from seawater to air (Li et al. 2017), and the seasonality may therefore be due to e.g. melting sea ice during summer. In the same study, the fluxes of TCPP were reported to be significantly higher than the fluxes of TCEP, which may explain the observed higher concentrations of TCPP compared to TCEP during summer in this monitoring programme. EHDP which was detected in high amounts in 2019, was below LOD in 2020. This may be due to high analysis uncertainty and/or interfering substances for this component in 2019.

At Birkenes, two OPFRs were detected in 50% or more of the samples in 2020 (i.e. TPP and TCP) (Table 12). While TCEP and TCPP were the most abundant substances at Zeppelin, they were not detected at Birkenes. This may substantiate melting sea ice as a possible explanation of the high concentrations at Zeppelin. At Birkenes, the concentrations of TPP and EHDP were the most dominating in summer. The results for EHDP were blank corrected, due to elevated field blanks. In winter, TPP was still dominating, but the concentrations were lower than in summer. EHDP was not detected in winter. The concentrations of TCP at summer and winter were similar. The low and inconsistent detection hamper the comparison over year.

Table 11: Detected OPFRs in air (pg/m^3) from active air samplers at Zeppelin in 2017-2020, presented as detection frequencies and average concentrations of the individual measurements in summer and winter. The LODs presented is based on average air sample volumes. Low detection is marked with stripes.

	LOD 2020	Detection frequency 2020	Summer 2020	Winter 2020	Summer 2019	Winter 2019	Summer 2018	Winter 2018	Summer 2017	Winter 2017
	pg/m^3	%	pg/m^3	pg/m^3	pg/m^3	pg/m^3	pg/m^3	pg/m^3	pg/m^3	pg/m^3
TCEP	3-10	58	12	6.1	52	<26	101	127	41	15
TCPP	40-117	50	152	<53	190	<133	235	240	107	<36
TiBP	2-5	8	<2	3.2	9.6	<8.0	16	15	5.2	9.5
DBPhP	0.2-0.6	0	<0.3	<0.3	<0.6	2.5	<0.8	<1.1	0.4	<0.5
TnBP	2-6	0	<3	<3	<11	<11	13	18	11	<3.0
TDCPP	5-13	8	<6	<6	4.9	2.1	<7.2	11	4.9	<10
EHDP	38-111	0	<50	<50	*190*	*460*				
TEHP	5-15	17	75	<7	1.5	<1.2	37	83	0.2	<40
Sum OPFRs			310	81	240	460	410	490	170	160

Table 12: OPFRs in air (pg/m^3) from active air samplers at Birkenes, 2018-2020, presented as detection frequencies and average concentrations of the individual measurements in summer and winter. The LODs presented is based on average air sample volumes. Low detection is marked with stripes.

	LOD 2020	Detection frequency 2020	Summer 2020	Winter 2020	Summer 2019	Winter 2019	Summer 2018	Winter 2018
	pg/m^3	%	pg/m^3	pg/m^3	pg/m^3	pg/m^3	pg/m^3	pg/m^3
TCEP	5-14	0	<6	<6	<28	<28	<40	<45
TCPP	57-169	0	<76	<76	<143	<143	67	72
TPP	5-15	100	86	12	83	<5.8		
TiBP	2-5	33	<2	3	<8.6	<8.6	14	15
DBPhP	0.2-0.6	33	<0.3	<0.3	<0.7	12	1.8	1.4
TnBP	2-6	8	7	<3	<12	<12	<11	15
TDCPP	5-13	17	<6	<6	5.7	7.4	<18	<20
TCP	0.4-1.1	92	2	3	0.85	3	20	<10
TEHP	5-15	0	<7	<7	<1.2	<1.2	<990	<1100
EHDP	30-88	33	67	<40				
Sum OPFRs			222	100	190	190	48	42

As mentioned, Li et al. (2017) reported OPFRs in Arctic air during an expedition cruise. The concentrations of TCEP in their study was similar or higher to the concentrations measured in this monitoring programme at Zeppelin, while the concentrations of TCPP were similar or lower. Also Salamova et al. (2014) reported OPFRs in Arctic air measured in Longyearbyen. The concentrations of TCEP and TCPP in their study were in the same range as the concentrations measured in this monitoring

programme at Zeppelin. In contrast, the concentrations of TnBP, TDCPP, TPP, TBEP and EHDPP were higher in their study than what is observed in this monitoring programme at Zeppelin (not even detected at Zeppelin in 2020). The higher concentrations in Longyearbyen likely suggests the presence of local sources of TnBP, TDCPP, TPP, TBEP and EHDPP in Longyearbyen.

4.4 Phthalates

Phthalates were included in the monitoring programme in 2017. In 2020, they were measured in one summer campaign and one winter campaign at Zeppelin and Birkenes using active air samplers. Each campaign aimed at a number of six samples taken over 48-72 hr. The phthalates in air are sampled on filter and polyurethane foam (PUF) plugs and thus the concentrations of phthalates in air in this monitoring programme represent the bulk phase (i.e. gas+particle phase).

The measurements at Zeppelin show that four of the twelve targeted phthalates (Table 7) were detected in 50% or more of the active air samples in the summer and winter campaign (Table 13); DEP, BzBP, DEHP, and DPHP. Four compounds; DnBP, DIBP, DnHP and DINP, were detected in a few samples. The other four compounds; DMP, DPP, DAP and DcHP were below LOD in all samples (40, 2, 2 and 9 pg/m^3, respectively). Detection frequencies were higher in winter than in summer.

The observed concentrations for the detected phthalates were high, even exceeding the detected concentrations of individual OPFRs. At Zeppelin in 2020, the highest concentrations were observed for DEHP (<0.1-4.2 ng/m^3), followed by DEP (<0.5-1.5 ng/m^3), DnBP (<0.1-0.7 ng/m^3), and DIBP (<0.2-0.7 ng/m^3) (Table 13). The concentrations of the sum of the targeted phthalates (sum phthalates) at Zeppelin varied almost within a factor of two between summer and winter from 0.9-1.2 ng/m^3 (mean: 1.1 ng/m^3, median 1.2 ng/m^3) in summer and 0.8-7.5 ng/m^3 (mean: 3.3 ng/m^3, median 2.4 ng/m^3) in winter (Figure 43). The higher concentrations in winter may be a result of precipitation being collected (wet filters) during harsh weather at the station.

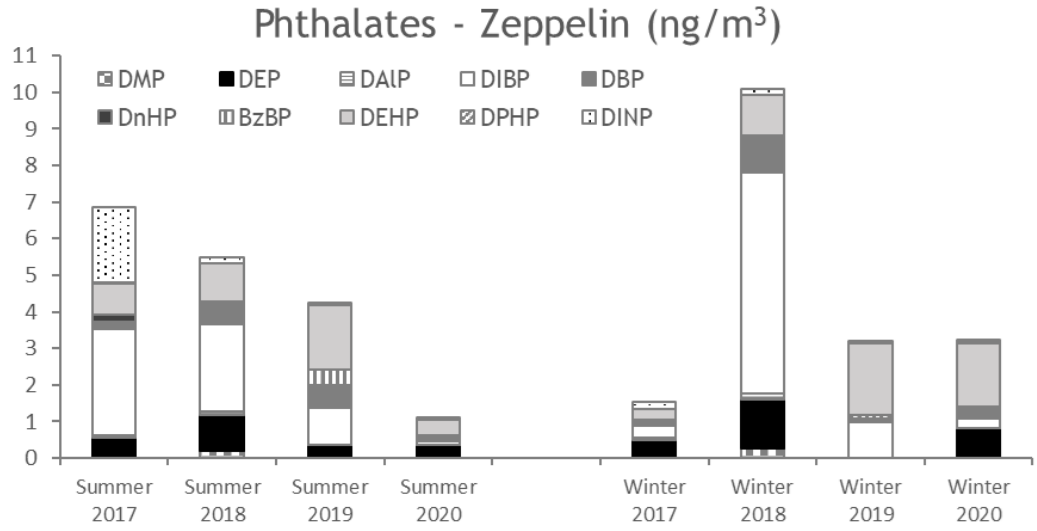


Figure 43: Mean concentrations of detected phthalates in air at Zeppelin in 2017-2020.

Table 13: Mean concentrations of detected phthalates in air (ng/m^3) from active air samplers at Zeppelin in 2017-2020. Concentrations in summer and winter are average of samples taken during each sampling campaign. The LOD presented is based on average air sample volumes. Low detection is marked with stripes.

Year	DMP	DEP	DAIP	DiBP	DBP	DnHP	BzBP	DEHP	DPHP	DINP	Sum phthalates
	LOD (ng/m^3) in 2020										
	0.04	0.5	0.002	0.2	0.1	0.002	0.004	0.1	0.003	0.03	
	Detection frequency (%) in 2020										
	0	50	0	13	38	13	100	75	63	25	
	Concentration (ng/m^3)										
2020	<0.02	0.33	<0.001	<0.12	0.10	<0.002	0.05	0.44	0.002	0.04	1.1
2020	<0.02	0.80	<0.001	0.26	0.28	0.003	0.04	1.74	0.06	0.05	3.3
2019	0.12	0.29	0.006	1.02	0.61	0.006	0.42	1.78	<0.001	0.04	4.3
2019	<0.02	<0.01	<0.002	<0.008	0.08	<0.004	0.10	1.97	0.004	0.07	2.3
2018	0.19	0.98	0.12	2.39	0.59	<0.001	<0.002	1.05	0.007	0.15	5.5
2018	0.26	1.34	0.17	6.02	1.01	<0.001	<0.002	1.13	0.002	0.15	10
2017	n.a.	0.57	0.06	2.90	0.19	0.20	0.002	0.87	0.03	2.05	6.9
2017	n.a.	0.48	0.06	0.35	0.08	0.07	0.02	0.29	0.004	0.21	1.6

At Birkenes, detection frequencies were higher in summer than in winter. Ten of the targeted phthalates were detected in all or most of the samples in summer. Only DPP and DcHP were not detected in any samples. In winter, most phthalates were below LOD in all samples. Only DPHP were detected in 50% of the winter samples, and DINP and DBP in 17% of the winter samples. In addition to high detection frequencies during the summer also significantly higher concentrations were measured in the summer 2020 at Birkenes than previous years, with ranges of sum of the targeted phthalates 15-52 ng/m^3 (mean: 24 ng/m^3, median 19 ng/m^3) in winter (Table 14). The highest concentrations were observed for DEP (3.8-15 ng/m^3), DiBP (6.0-21 ng/m^3), DnBP (3.0-11 ng/m^3) and DMP (0.5-3.9 ng/m^3). Significantly lower concentrations were observed in winter at Birkenes with ranges from 0.5-0.7 ng/m^3 (mean: 0.6 ng/m^3, median 0.6 ng/m^3). In winter, the concentrations of the sum of the targeted phthalates (sum phthalates) were also lower than at Zeppelin (Figure 44).

The high concentrations at Birkenes in summer 2020, may be explained by building activities at the station in this period. A mast was built to meet the criteria to become a labelled station under the European greenhouse gas network, ICOS.

Table 14: Mean concentrations of detected phthalates in air (ng/m³) from active air samplers at Birkenes, 2018-2020. Concentrations are average of samples taken during each sampling campaign. The LOD presented is based on average air sample volumes. Low detection is marked with stripes.

Year	DMP	DEP	DAlP	DiBP	DBP	DnHP	BzBP	DEHP	DPHP	DINP	Sum phthalates
	LOD (ng/m³) in 2020										
	0.04	0.5	0.002	0.2	0.1	0.002	0.004	0.1	0.003	0.03	
	Detection frequency (%) in 2020										
	50	50	50	50	58	50	58	50	75	50	
	Concentration (ng/m³)										
2020	1.35	6.49	0.01	9.64	*5.58*	*0.01*	*0.11*	*0.68*	0.03	0.06	24
2020	<0.04	<0.5	<0.002	<0.2	*0.10*	<0.002	*0.002*	<0.1	0.004	0.02	0.55
2019	0.04	0.06	<0.002	0.74	*0.36*	*0.005*	*0.01*	*1.18*	0.005	0.07	2.5
2019	0.05	0.57	<0.002	0.32	*0.18*	*0.002*	*0.007*	*0.54*	0.006	0.05	1.7
2018	0.03	0.19	0.004	1.57	*0.20*	*0.002*	*0.001*	*0.87*	0.02	0.15	3.0
2018	0.03	0.16	0.002	0.53	*0.05*	*0.005*	*0.001*	*0.15*	0.03	0.98	1.9

*Italic: Influenced by blank levels.

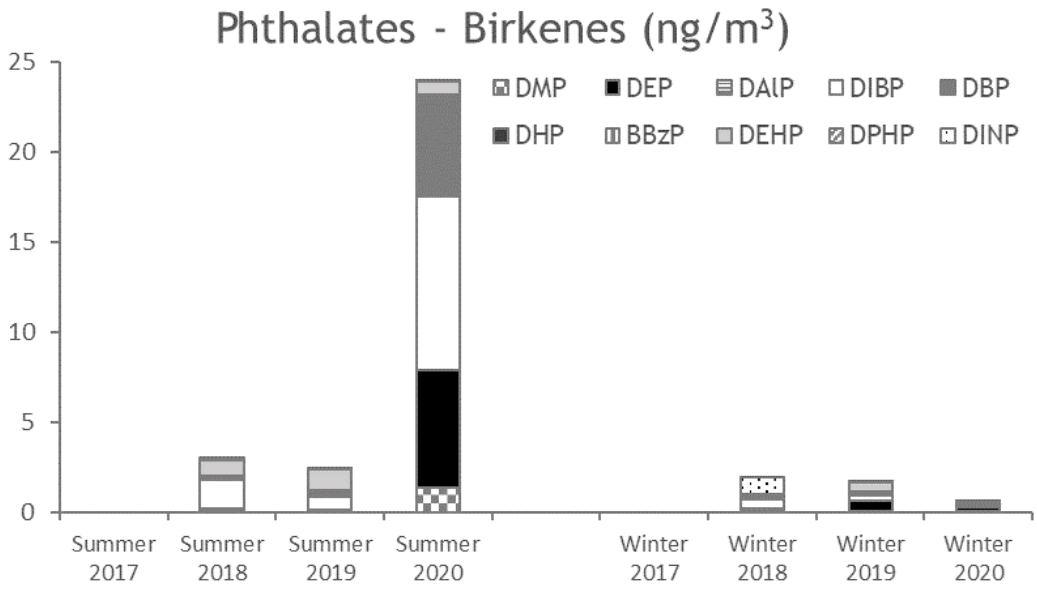


Figure 44: Mean concentrations of detected phthalates in air at Birkenes in 2018-2020.

4.5 Dechloranes

Dechloranes have been included in the monitoring programme of Zeppelin since 2017 and Birkenes since 2019. They were measured in weekly samples at Zeppelin and monthly samples at Birkenes using active air samplers both in 2019 and 2020. The sampling time at Zeppelin was 48 hr while only 24 hr at Birkenes. The dechloranes in air are sampled on filter and polyurethane foam (PUF) plugs and thus the concentrations of dechloranes in air in this monitoring programme represent the bulk phase (i.e. gas+particle phase). The samples were analysed for seven dechloranes (Table 15).

Five of the targeted seven dechloranes were not detected in any of the air samples from Zeppelin. Only the syn- and anti- isomers of dechlorane plus (syn- and anti-DP) were detected in a few samples i.e. 22% and 41% of the samples, respectively. The detected concentrations of anti-DP ranged from 0.05 to 0.46 pg/m^3 if excluding one outlier (1.89 pg/m^3). The detected concentrations of anti-DP were similar or higher than those measured for syn-DP which ranged from 0.06 to 0.27 pg/m^3 (Table 15). The variation in concentrations is not related to season. The detection frequencies of syn-DP and anti-DP have declined from 2017, when comparing with dechloranes measured at Zeppelin in 2017 and 2019 as a part of this monitoring programme. While the detected concentrations in 2019 were higher than in 2017, the concentrations in 2020 are lower than 2019. Syn- and anti-DP have previously 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 15: Dechloranes in air (pg/m^3) from active air samplers at Zeppelin, 2020. Low detection is marked with stripes.

	Dba	Dec-602	Dec-603	Dec-604	Dec-601	syn-DP	anti-DP
LOD	<0.02-<0.12	<0.003-<0.025	<0.004-<0.030	<0.1-<0.9	<0.02-<0.16	<0.02-<0.12	<0.05-<0.15
Detection frequency (%)	0	0	0	0	0	22	41
Detected concentrations (pg/m^3)	<0.12	<0.025	<0.030	<0.9	<0.16	<0.02-0.27	<0.05-1.89*

*Including one outlier.

Also at Birkenes, only DP-syn and DP-anti were detected while the other dechloranes were below the detection limit (Table 16). The detected concentrations of anti-DP (0.21-0.95 pg/m^3) were higher than those measured for syn-DP (0.13-0.27 pg/m^3), and with the highest levels measured in the summer (May-September) (Figure 45). The detection frequencies at Birkenes in 2020 were higher compared to Zeppelin for syn-DP and somewhat higher for anti-DP. The concentrations of both syn- and anti-DP were significantly higher at Birkenes than at Zeppelin, when comparing with Wilcoxon rank sum test.

Table 16: Dechloranes in air (pg/m^3) from active air samplers at Birkenes, 2020

	Dba	Dec-602	Dec-603	Dec-604	Dec-601	syn-DP	anti-DP
LOD	<0.08-<0.13	<0.02-<0.03	<0.02-<0.03	<0.38-<0.93	<0.09-<0.17	<0.12-<0.16	<0.15-<0.18
Detection frequency (%)	0	0	0	0	0	29	43
Detected concentrations (pg/m^3)	<0.13	<0.03	<0.03	<0.93	<0.17	<0.16-0.27	<0.18-0.95

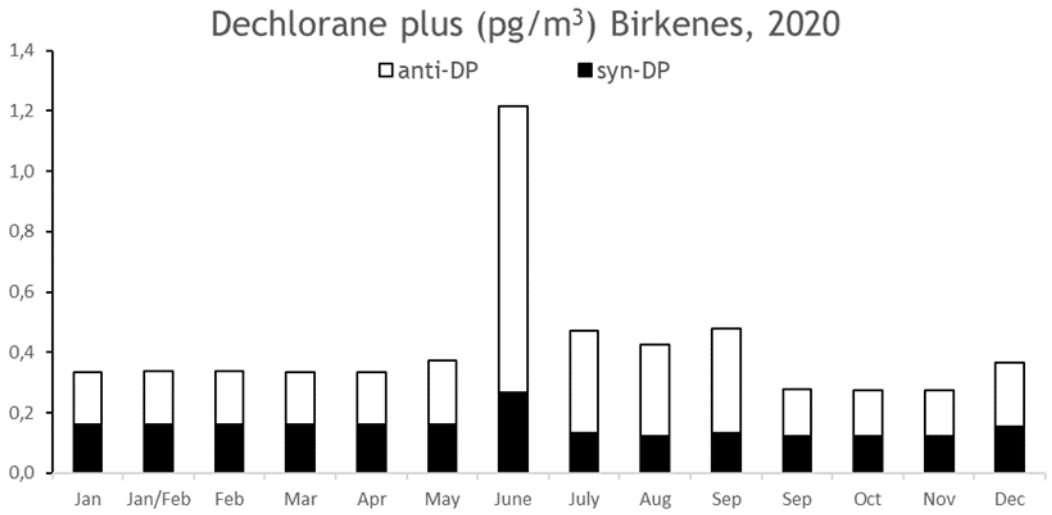


Figure 45: Monthly mean concentrations of syn-DP and anti-DP at Birkenes in 2020.

4.6 Volatile fluorinated substances and data mining

In 2020, the method validated in 2019 for volatile fluorinated substances was applied to air samples from Birkenes and Zeppelin. The air samples were collected using an active low volume sampler with ABN as adsorbent, in one summer campaign (July-August) and one winter campaign (November-December) at each station with a total number of 16 samples per station in 2020. Each sample was collected in duplicate (i.e. two ABN adsorbent) and had an individual field blank. The sampling time was 72 hrs for all samples. This resulted in a total number of 96 ABN cartridges from 2020. Each cartridge underwent target analyses and further data mining.

4.6.1 Target analyses of eight volatile per- and polyfluorinated substances and two per- and polychlorinated substances of emerging Arctic concern

The air samples were analysed for ten selected substances based on those detected in data mining in 2018 (

Table 17). Eight of these were fluorine-containing suspected Arctic contaminants and two were known and suspected chlorinated Arctic contaminants (HCBD and DCBTC). HCBD, despite being known for decades has not been properly evaluated in the Arctic air. After extraction with pentane, the extracts were analysed without further clean-up or pre-concentration steps in order to preserve their integrity. This resulted in high quality results for PFTBA, TCPFB, PFTPeA and HCBD. The other six analytes were below LOD. The summer samples were therefore carefully pre-concentrated by a factor of 50 and re-analysed. With this additional step it was possible to achieve lower detection limits and thereby detectable levels also for PFPHP, DCTFP and suspected DCBTC. Results are summarized in Table 18.

Table 17: Volatile per- and polyfluorinated substances and per- and polychlorinated substances analysed for in air samples from Birkenes and Zeppelin in 2020.

Short name	Full name	CAS number	Formula
PFTBA	Perfluorotributylamine	311-89-7	C12F27N
TCPFB	Tetrachlorohexafluorobutane	375-45-1	C4F6Cl4
PFTPeA	Perfluorotripentylamine	338-84-1	C15F33N
HCBD	Hexachlorobutadiene	87-68-3	C4Cl6
PFPHP	Perfluoroperhydrophenanthrene	306-91-2	C14F24
DCTFP	Dichlorotrifluoropyridene	1737-93-5	C5NF3Cl2
DCBTC	Dichlorobenzotrichloride, 2,3- Dichlorobenzotrichloride, 3,4-	13014-24- 84613-97-8	C7H3Cl5
DCPFcH	Dichloroperfluorocyclohexene	336-19-6	C6F8Cl2
PFBB	Pentafluorobromobenzene	344-04-7	C6F5Br
bisTFMBB	3,5-bis-(trifluoromethyl)bromobenzene	328-70-1	C8H3F6Br

Table 18: Concentrations of volatile per- and polyfluorinated substances and per- and polychlorinated substances in air (pg/m^3) from active air samplers at Birkenes and Zeppelin, 2020.

	LOD (pg/m^3)		Concentrations (pg/m^3)			
			Birkenes		Zeppelin	
	Summer	Winter	22.06-12.08	16.11-30.12	22.06-12.08	16.11-30.12
PFTBA	**5**	**5**	1700	1700	1400	1700
TCPFB	**5**	**5**	68	140	140	240
PFTPeA	**5**	**5**	81	90	84	95
HCBD	**5**	**5**	1800	1700	1900	1800
PFPHP	**5**	**100**	*69**	*<100*	*61**	*<100*
DCTFP	**0.5***	**0.5***	*<0.5**	*<5*	*1.5**	*<5*
DCBTC	**0.5***	**0.5***	*1.6**	*<5*	*1.5**	*<5*
DCPFcH	**5**	**5**	*<5*	*<5*	*<5*	*<5*
PFBB	**5**	**5**	*<5*	*<5*	*<5*	*<5*
bTFMBB	**5**	**5**	*<5*	*<5*	*<5*	*<5*

*Lower LODs and thereby detectable levels in summer samples as the summer samples were further pre-concentrated and re-analysed.

Four substances were detected in all samples (i.e. PFTBA, TCPFB, PFTPeA and HCBD). PFTBA and HCBD were found in highest concentrations in all samples from both sites (8-2415 pg/m^3 and 960-2700 pg/m^3, respectively). Three substances were not detected in any samples (100% <LOD), i.e DCPFcH, PFBB and bTFMBB. The other three substances; PFPHP, DCTFP and DCBTC, were detected in all summer samples after an additional pre-concentration was added. They are 100% <LOD in all winter samples from both sites due to higher LODs in winter samples.

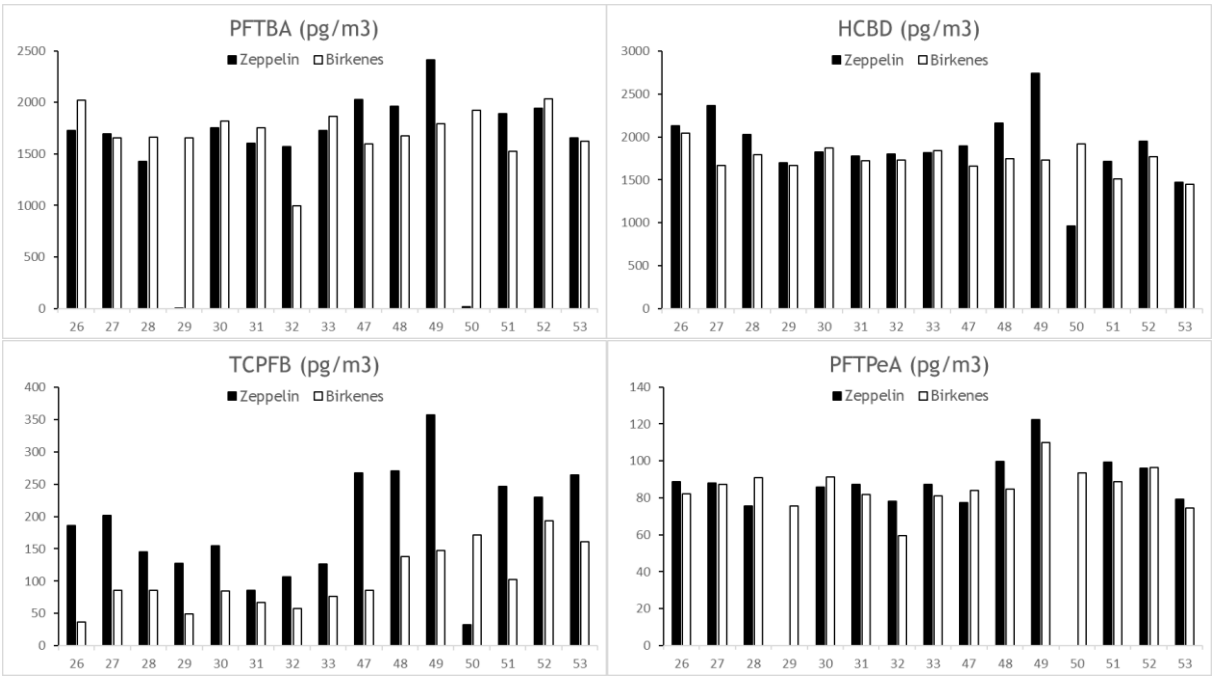


Figure 46: Temporal variation of PFTBA, HCBD, TCPFB and PFTPeA at Birkenes and Zeppelin, 2020.

TCPFB was found in significantly higher concentrations in winter than in summer at both stations (Figure 46). TCBFB was also significantly higher at Zeppelin than at Birkenes for both seasons. PFTBA was significantly higher in winter than summer at Zeppelin, but no difference was observed at Birkenes. No temporal or spatial difference was observed for PFTPeA and HBCD (Figure 46).

A careful conclusion can be made that PFTBA and HCBD are likely major contaminants of this class.

4.6.2 Suspect screening

The air samples from Birkenes and Zeppelin underwent further suspect screening analysis for a set of 20 substances – major organochlorine components in the air, based on the NTS findings of the previous years. This analysis was based on the same GC-MS method as above, although no optimization of the method was made towards these substances.

The results of the suspect screening shows that the major substances are the isomers of dichlorobenzene and hexachloroethane (

Table 19). The highest concentrations were observed for dichlorobenzene and hexachloroethane, in the same concentration ranges as PFTBA and HBCD. The lower levels of hexachloroethane observed in 2019 is due to less accurate quantification method in 2019 (i.e. lack of internal standard). For dichlorobenzene and its isomers, the concentrations were the same at both stations, but higher in winter than in summer at both stations. The chloroaliphatic compounds (i.e. tetra- and hexachloroethane) were higher at Zeppelin than at Birkenes, both in winter and summer, and as for dichlorobenzenes concentrations were higher in winter than in summer.

Table 19: Levels of 20 chlorinated substances from suspect screening of active air sample extracts from ABN adsorbents at Zeppelin and Birkenes in 2020, by order of concentration. Data from Kjeller 2019 is included for comparison.

		Zeppelin Summer 2020	Zeppelin Winter 2020	Birkenes Summer 2020	Birkenes Winter 2020	Kjeller 2019
	CAS	Concentrations (pg/m^3)				
Dichlorobenzene	95-50-1	817	2263	544	2427	1872
Hexachloroethane	67-72-1	1061	2206	833	1683	175
1,2-dichlorobenzene	95-50-1	173	617	116	716	544
1,4-dichloro-2-methylbenzene	19398-61-9	12	556	28	499	366
Ethane, 1,1,2,2-tetrachloro-	79-34-5	31	276	13	146	18
1,2,4-trichlorobenzene	120-82-1	77	178	77	189	222
1,3,5-trichloro-2-methoxybenzene	87-40-1	109	133	261	433	245
1,2,4-trichloro-3-methylbenzene	2077-46-5	12	102	14	85	42
Hexachlorobenzene	118-74-1	38	62	36	61	19
1,5-dichloro-2-methoxy-3-methylbenzene	13334-73-1	0	60	27	357	454
2,3-Dichloro-5-trifluoromethylpyridine	69045-84-7	43	54	43	45	21
2,4-dichloro-1-methoxybenzene	553-82-2	46	50	138	195	193
1,2,4,5-tetrachloro-3,6-dimethoxybenzene	944-78-5	37	35	103	177	42
1,2,4-trichlorobenzene	120-82-1	11	29	10	30	51
1,2,4,5-tetrachlorobenzene	95-94-3	12	28	10	31	24
1,2,3,5-tetrachlorobenzene	634-90-2	11	24	9	39	15
1,5-dichloro-2-methoxy-3-methylbenzene	13334-73-1	1	18	4	79	98
1,2-dichloro-4-(chloromethyl)-benzene	102-47-6	1	10	4	10	29
1,1,2,3,4,4-hexachloro-1,3-Butadiene	87-68-3					655
hexachlorobutadiene, unknown isomer	unknown					99

The measured concentrations of dichlorobenzene at Birkenes and Zeppelin are one-three orders of magnitude lower than concentrations measured in indoor and urban environments (Chin, 2013). The findings of these organochlorine xenobiotics in background and remote air samples do however show that they are ubiquitous in the atmosphere around the globe and that exposure thereby occurs on global level. They are associated with negative health effects but the concentrations here are below reported limit values for individual substances. Their cocktail effects are not known.

Target analysis is recommended in future monitoring for:
Dichlorobenzenes (95-50-1),
hexachloroethane (67-72-1),
hexachlorobenzene (118-74-1),

2,3-dichloro-5-trifluoromethylpyridine (69045-84-7 and possible isomers),
1,3,5-trichloro-2-methoxybenzene (trichloroanisole) (87-40-1 and possible isomers)

In addition, the results of this suspect screening shows just a fraction of recently available technical possibilities to be applied for air monitoring.

5 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 2020 are presented in Table 20.

Table 20: Annual mean concentrations in air for all targeted organic contaminants in 2020. The highest concentrations are marked with orange/pink while the lowest concentrations are marked with green.

Organic contaminants, Class	Annual mean concentration (pg/m^3)		
	Birkenes	Andøya	Zeppelin
HCB	37	25	55
HCHs	6.5		3.1
DDTs	1.6		0.4
Chlordanes			0.6
PCB_7	2.4		2.0
PCB_{sum}	9.3		8.4
PAH-16	1900		600
PBDEs (excl. BDE-209)	0.2		0.5
TBA	4.3		8.2
HBCD	0.1		0.4
PFOA	0.1	0.05	0.07
cVMS	6600		1700
SCCPs/MCCPs	850		1200
PFAS (volatile)	37	120	40
nBFRs			
OPFRs	200		160
Phthalates	12300		2200
Dechloranes	0.6		0.2

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

The results from the air monitoring in 2020 show that the concentrations of most legacy POPs in air and precipitation are declining or have stabilized (reached temporal remote state conditions) during the last years. Significant for temporal remote state is that the primary emissions have stopped and that the long-term slow decline (removal rate) of a chemical in the environment is controlled by degradation rates in secondary repositories (Stroebe et al., 2004).

HCB is decreasing after a decade of increasing concentrations and is now as low as before this increase started. An increase is instead observed for DDTs at Birkenes during the last three years.

6 Heavy metals

6.1 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 2020 are presented in Table 21. The wet depositions are obtained by multiplying the volume weighted concentrations with the precipitation amounts (ng-mg/m^2) and the results for 2020 are presented in Table 22. Calculated volume weighted monthly mean concentrations and wet depositions for all the elements are shown in Annex A.2.1-A.2.33.

The results show that the highest annual mean concentrations of all heavy metals, are observed at Svanvik and Karpdalen and reflect 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. The influence from the Russian smelters on the eastern Finnmark environment has been repeatedly demonstrated through the national moss surveys (Steinnes et al. 2016). Further details and discussion of the data from Svanvik and Karpdalen can be found in the annual report for the programme "Russian-Norwegian ambient air monitoring in the border areas" (Berglen et al., 2020).

The levels and deposition of lead, cadmium and zinc observed are highest at Birkenes followed by Hurdal and Kårvatn reflecting the decreasing distances to the main emission sources in continental Europe (EMEP, 2020).

Table 21: Annual average volume weighted mean concentrations of heavy metals (µg/l) and mercury (ng/L) in precipitation in 2020.

	Pb	Cd	Zn	Ni	As	Cu	Co	Cr	Mn	V	Al	Hg
Birkenes	0.62	0.015	3.7	0.66	0.07	2.4	0.025	0.136	1.4	0.20	-	3.7
Hurdal	0.47	0.017	4.8	-	-	-	-	-	-	-	-	-
Kårvatn	0.14	0.003	1.4	-	-	-	-	-	-	-	-	-
Svanvik	1.05	0.058	5.3	14.7	0.37	28.2	0.50	0.27	-	0.50	29	-
Karpdalen	0.64	0.034	5.2	9.5	0.22	15.0	0.35	0.38	-	0.43	65	-

Table 22: Total wet deposition of heavy metals (µg/m^2) and mercury (ng/m^2) in 2020.

	Pb	Cd	Zn	Ni	As	Cu	Co	Cr	Mn	V	Al	Hg
Birkenes	1260	30	7560	1345	137	4967	50	276	2918	397	-	8490
Hurdal	670	24	6772	-	-	-	-	-	-	-	-	-
Kårvatn	255	6	2434	-	-	-	-	-	-	-	-	-
Svanvik	379	21	1929	5335	132	10215	180	98	-	182	10563	-
Karpdalen	348	18	2827	5179	117	8158	189	206	-	233	35456	-

The monthly mean concentration for lead, cadmium and mercury are shown in Figure 47. There is no clear visual seasonal variation, except for mercury which has higher concentrations during spring and summer.

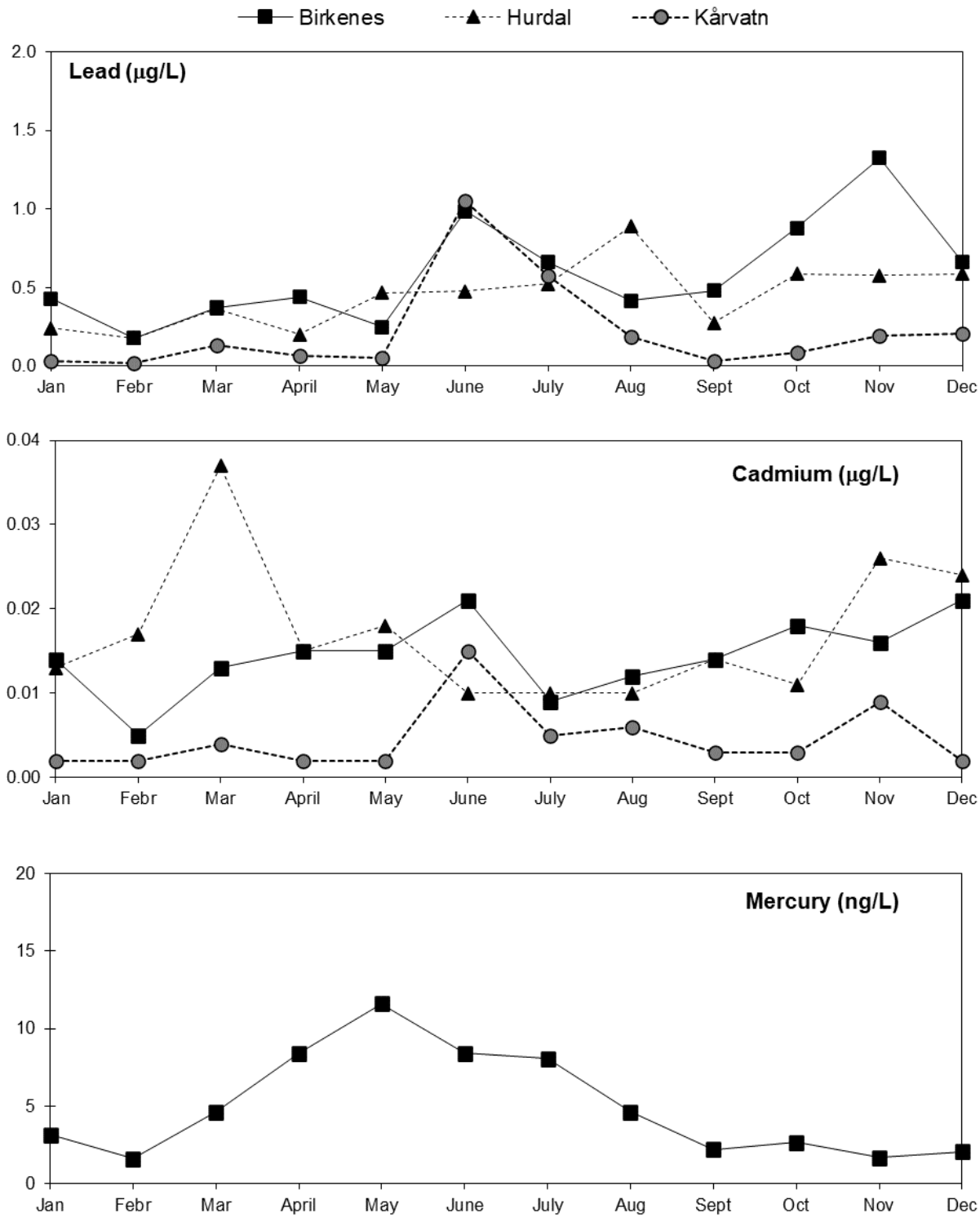


Figure 47: Volume weighted monthly mean concentrations of lead, cadmium and mercury in precipitation in 2020.

Figure 48 and Table A.2.26 show volume weighted annual mean concentrations in precipitation from 1979 to 2020. In 2020, the concentrations of lead were slightly higher in 2020 compared to 2019 at Birkenes and Hurdal, while at Kårvatn it is much lower. For cadmium it is similar level at Birkenes, but substantially lower concentrations at both Hurdal and Kårvatn in 2020 compared to 2019.These annual differences are mainly due to variabilities in meteorology, i.e. favourable conditions for transport of air pollution from major emission sources, and the amount of precipitation.

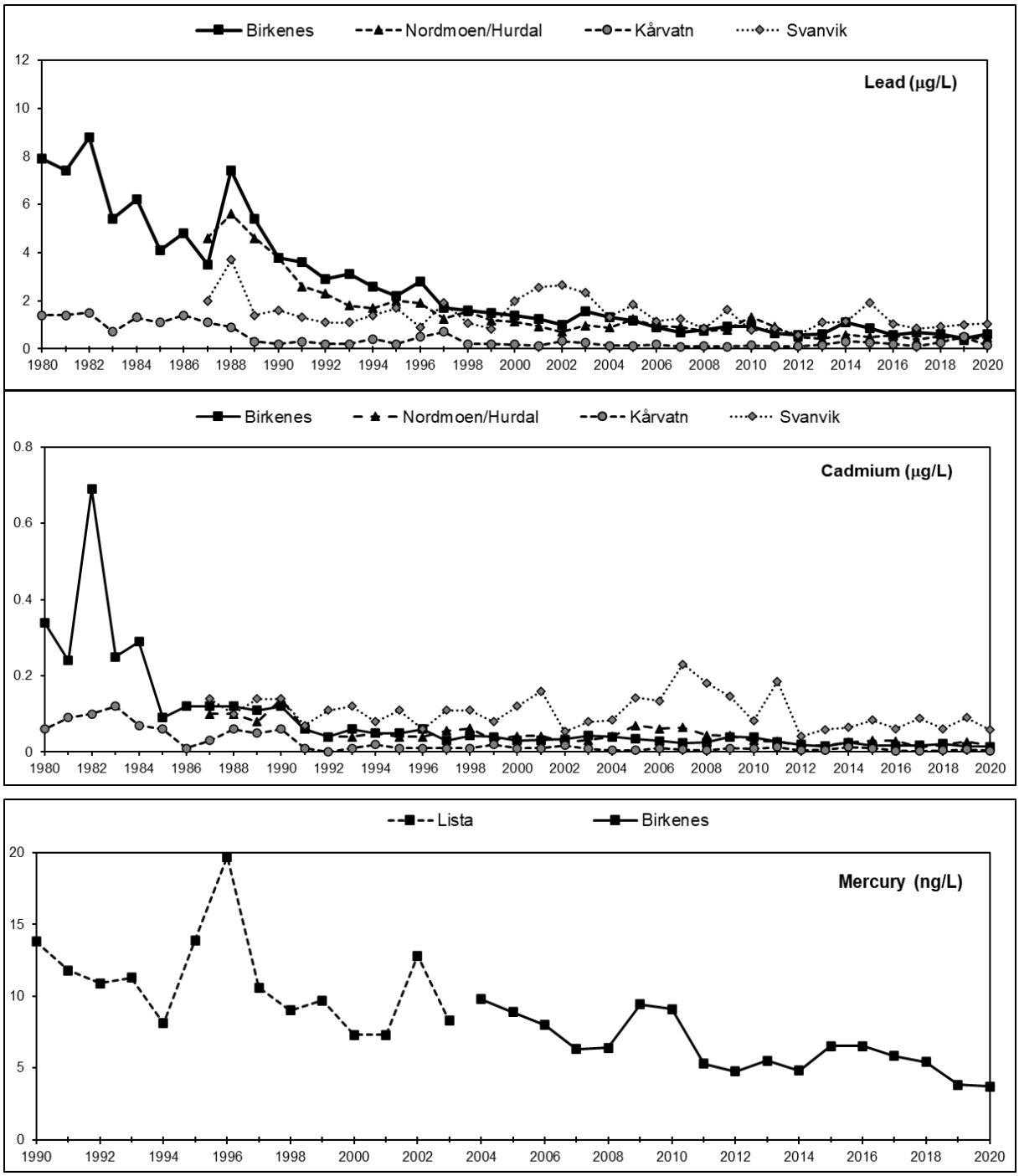


Figure 48: Time series of volume weighted annual mean concentrations of lead, cadmium and mercury in precipitation at Norwegian background stations.

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

In a long-term perspective, the concentrations of lead in precipitation have been largely reduced; almost 100% from 1980/1990 to 2020; and 59-64% since 2000 (except at Kårvatn with no significant trend since 1990 nor 2000 (Table 23). For cadmium in precipitation there are also substantial reductions: almost 100% since 1980; 53-81% since 1990, and 57-70 % since 2000, except at Kårvatn with no significant trend since 2000.

When combining the datasets from Lista and Birkenes, a significant reduction of mercury is seen for 1990-2020 (64%) and for 2000-2020 (52%). However, this reduction might be influenced by different precipitation amounts and deposition rates at the two sites. For example, slightly lower precipitation amounts are seen at Lista than at Birkenes. The results from a trend analysis that combines the datasets is therefore somewhat uncertain, though there is no apparent change in the concentration or deposition timeseries when sampling collection was relocated. 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. While the concentration of mercury in precipitation have decreased in a long-term perspective, the precipitation amount has increased in the same time period (Table 22 and Figure 49). Wet deposition is a combination of the two and the wet deposition of mercury is less pronounced than the changes in concentration, 28% reduction compared to 64% for the period 1990-2020, though the inter-annual variation in wet deposition is large (Figure 49).

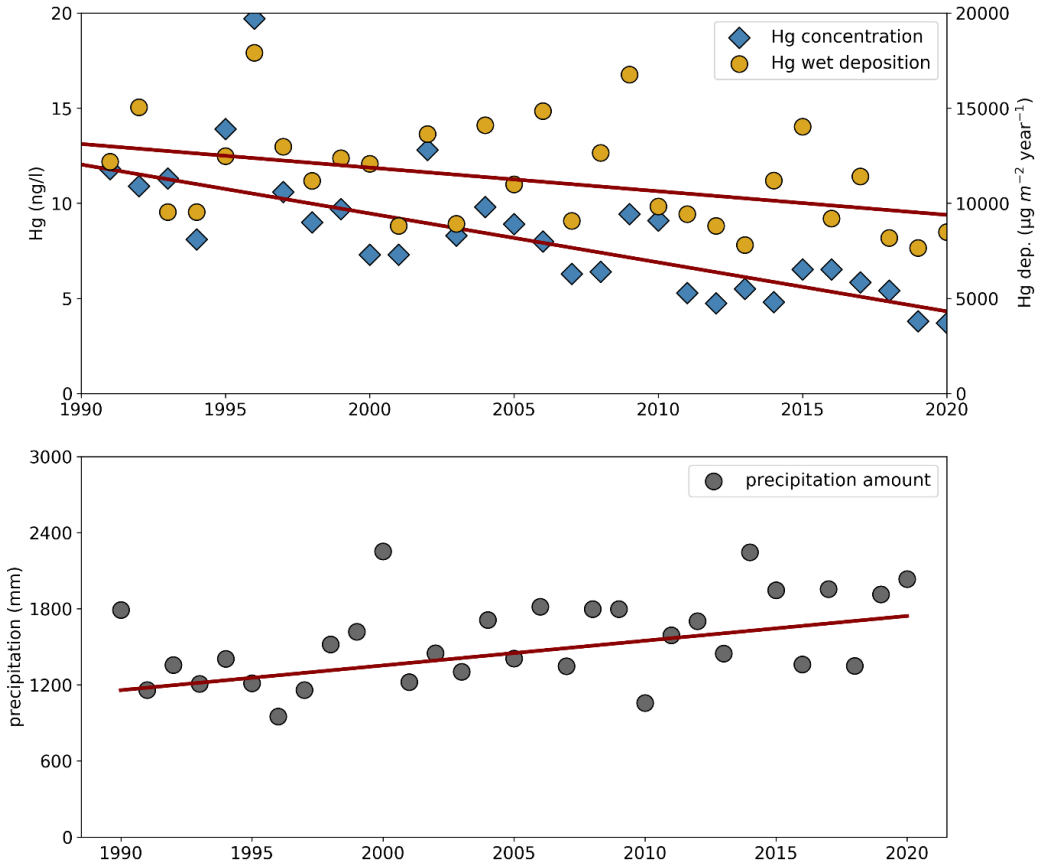


Figure 49: *Time series of volume weighted annual mean concentration and the wet deposition of mercury (top) and the precipitation amount (bottom), at Lista (1989-2003) and Birkenes (2004-2020). The solid red lines indicate the significant Sen slope.*

The concentrations of zinc in precipitation have been reduced by 72% since 1980 and 41% since 1990 at Birkenes. In contrast, a significant increase of zinc has been observed in precipitation at Kårvatn during the last periods (Table 24). One should notice that the concentration level at Kårvatn is relatively low and that it is in general 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, e.g. from resuspension of contaminated dust, thus the choice of time period for the trend analysis may influence whether one detect trends or not.

The reductions in lead and cadmium are consistent with those observed at other EMEP sites with long-term measurements and can be explained by large European emission reductions of these elements (Tørseth et al., 2012; Colette et al., 2016).

At Svanvik there has been a reduction in lead, zinc and arsenic from 2000 while no significant reduction trends for cadmium and the other trace elements. There are large annual variations in the concentration levels at this site, and this may be due to meteorological variations as well as changes in the composition of the ore used at the smelters in the Kola Peninsula. For further discussion, it is referred to the report by Berglen et al. (2020).

6.2 Heavy metals in air

The annual mean concentrations of the heavy metals measured in air in 2020 are given in Table 23 and the weekly concentrations of lead and cadmium are illustrated in Figure 50. The monthly mean concentrations can be found in Annex 1, Table A.2 28 – Table A.2 34.

In general, the concentrations of most heavy metals in air at Birkenes in 2020 are two-three times higher than those observed at Andøya and Zeppelin. This is because Birkenes is closer to the emission sources at the European continent (EMEP, 2020). This is also repeatedly demonstrated through the national moss surveys where the highest concentrations of heavy metals in moss are found in the southern part of Norway (Steinnes et al. 2016). In turn, at Svanvik and Karpdalen, the concentrations in air are about ten times higher than those observed at Birkenes depending on element. This suggests nearby sources in Russia as discussed by Berglen et al. (2019). For some of the crustal elements (Al, Fe, Cr) the concentrations at Zeppelin are much higher than at Andøya and Birkenes in 2020, suggesting episodes and sources of mineral dust in the Arctic which has not been observed in southern Norway. But it is important to notice that the sampling frequency at Zeppelin and Andøya is 2 days a week compared to weekly at Birkenes, thus the representativity of the air masses differ.

For mercury, similar air concentrations are observed at all three sites in Norway. A more homogeneous picture for gaseous mercury is due to a longer residence time in the atmosphere for gaseous mercury than the particulate bound heavy metals, which results in a larger potential for long-range transport from emissions sources. As a consequence, mercury may be distributed over greater geographical distances and is a global pollutant to a greater extent than the other heavy metals. At the station in the Antarctica (Trollhaugen), the mercury concentration is much lower though. This is due to less emissions of mercury in the lower hemisphere compared to the more industrialised and populated northern hemisphere and slow inter-hemispheric mixing.

Table 23: Annual average mean concentrations of heavy metals in air and aerosols in 2020 Unit: ng/m^3.

	Pb	Cd	Zn	Ni	As	Cu	Co	Cr	Mn	V	Al	Fe	Hg(g)
Birkenes II	0.57	0.019	4.1	0.15	0.16	0.33	0.020	0.19	1.07	0.28	47	35	1.495
Andøya	0.17	0.005	0.7	0.10	0.04	0.61	0.009	0.11	0.37	0.06	28	16	1.415
Zeppelin	0.26	0.059	1.8	0.79	0.06	0.31	0.039	0.31	1.64	0.22	173	86	1.444
Trollhaugen	-	-	-	-	-	-	-	-	-	-	-	-	0.998
Svanvik	0.96	0.059	3	2.74	0.34	4.54	0.12	0.20	0.68	1.04	37	41	-
Karpdalen	2.09	0.126	5.4	4.6	0.6	7.7	0.20	0.27	0.88	2.1	56	61	-

The annual mean concentrations at Andøya are slightly lower than at Zeppelin in 2020 (Table 23). These differences are due to individual episodes with elevated concentrations of heavy metals arriving to Zeppelin and Andøya. Though all the sites measure high episodes in September and October, Figure 50. This is not necessarily because they have similar emission sources, but because the polluted air is well mixed, and the episodes with high levels are happening when the meteorology favours long-range transport from the emission sources at the continent.

In the beginning of October 2020, an exceptional air pollution episode was observed in Norway, and elsewhere in northern Europe. The episode caused high aerosol concentrations at all the sites in Norway, including urban sites as well as in the Arctic (Aas et al. 2021). The episode originating in Central Asia during a dust storm, and besides mineral dust the plume carried pollution from several wildfires in Ukraine and southern Russia as well as anthropogenic sources from Eastern Europe along the way.

This also affect all the trace elements presented here even though the sampling interval at Andøya and Zeppelin (5-7 October) miss out the major part of the plume which arrived a couple of days before.

The air concentrations of lead and cadmium were slightly lower in 2020 compared to 2019 except for cadmium which was almost three times higher at Zeppelin in 2020. There are some large episodes of Cd in August and September influencing the annual mean. In 2020, it was special weather conditions in the first months with mostly clean, marine air from the west. Especially for lead the low concentrations during these months are contributing to the relatively low annual concentrations. This is also seen for other air pollutants in Norway (Aas et al 2021). This illustrates that weather conditions favouring or not favouring long rang transport of air pollution has an important impact on the annual variability in the concentration levels. The annual mean mercury concentration in 2020 was somewhat higher than 2019 for all sites.

The long-term time series of the annual mean concentrations of lead, cadmium and mercury are shown in Figure 51, and the annual concentrations for all the elements for all years and sites can be found in Table A.2.28 - Table A.2.33

At Lista/Birkenes there has been a significant reduction in air concentrations for all the measured elements for the period 1991 to 2020. At Zeppelin, there has also been a significant reduction since 1994 for several elements (As, Cd, Pb, V and Hg). The reduction for lead has been 88% and 67% respectively at Birkenes and Zeppelin (Table 25). For cadmium, the reductions were 73% and 49%, respectively. For mercury, relatively small decreasing trends are observed both at Birkenes (23%) and Zeppelin (13%). 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 2000-2019, though at Zeppelin there are positive trends for elements which also has crustal origin (Cr, Mn and Ni). The reason for this increase needs to be further investigated.

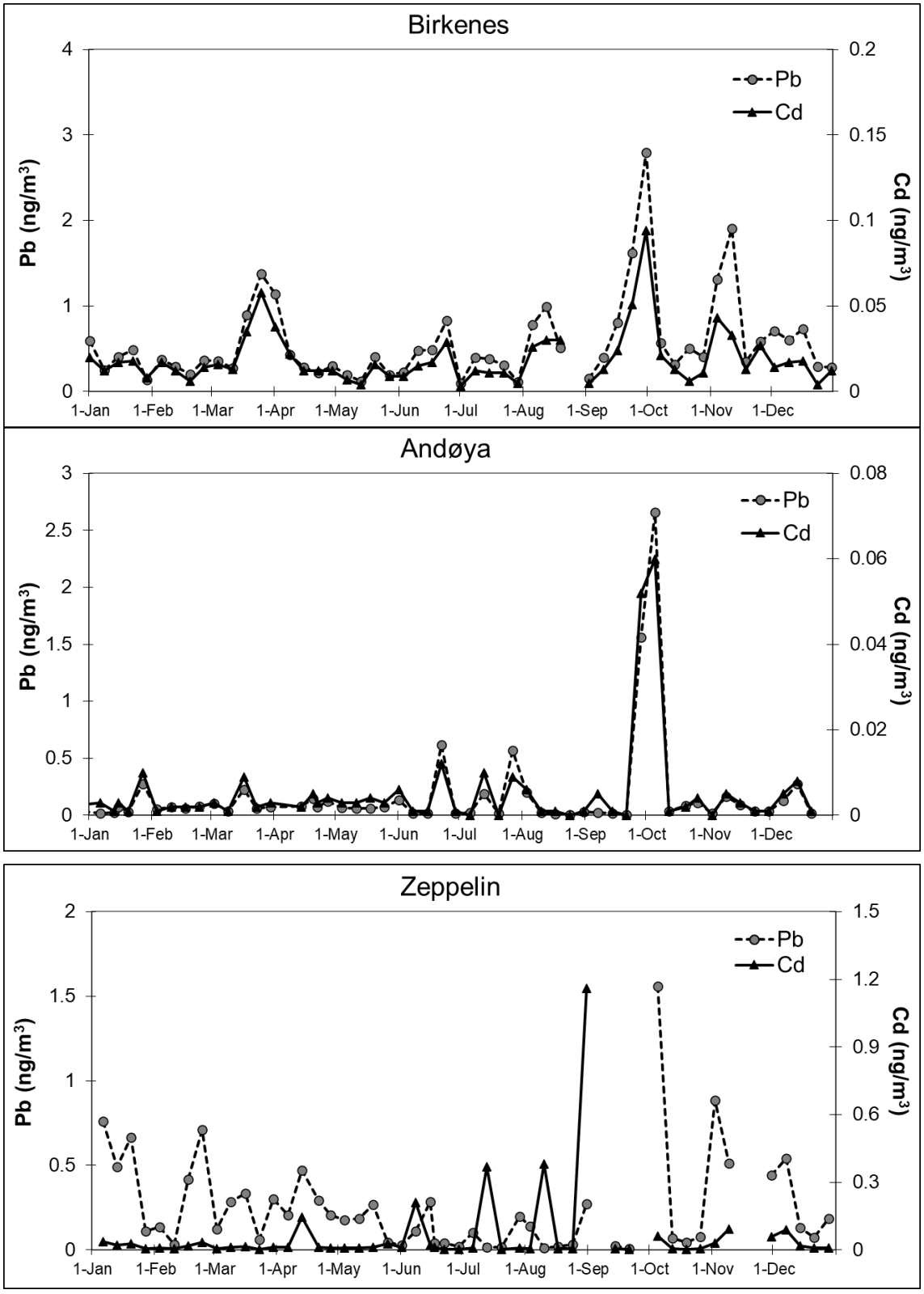


Figure 50: Weekly concentrations of lead and cadmium in air at Norwegian background stations in 2020, Unit: ng/m³.

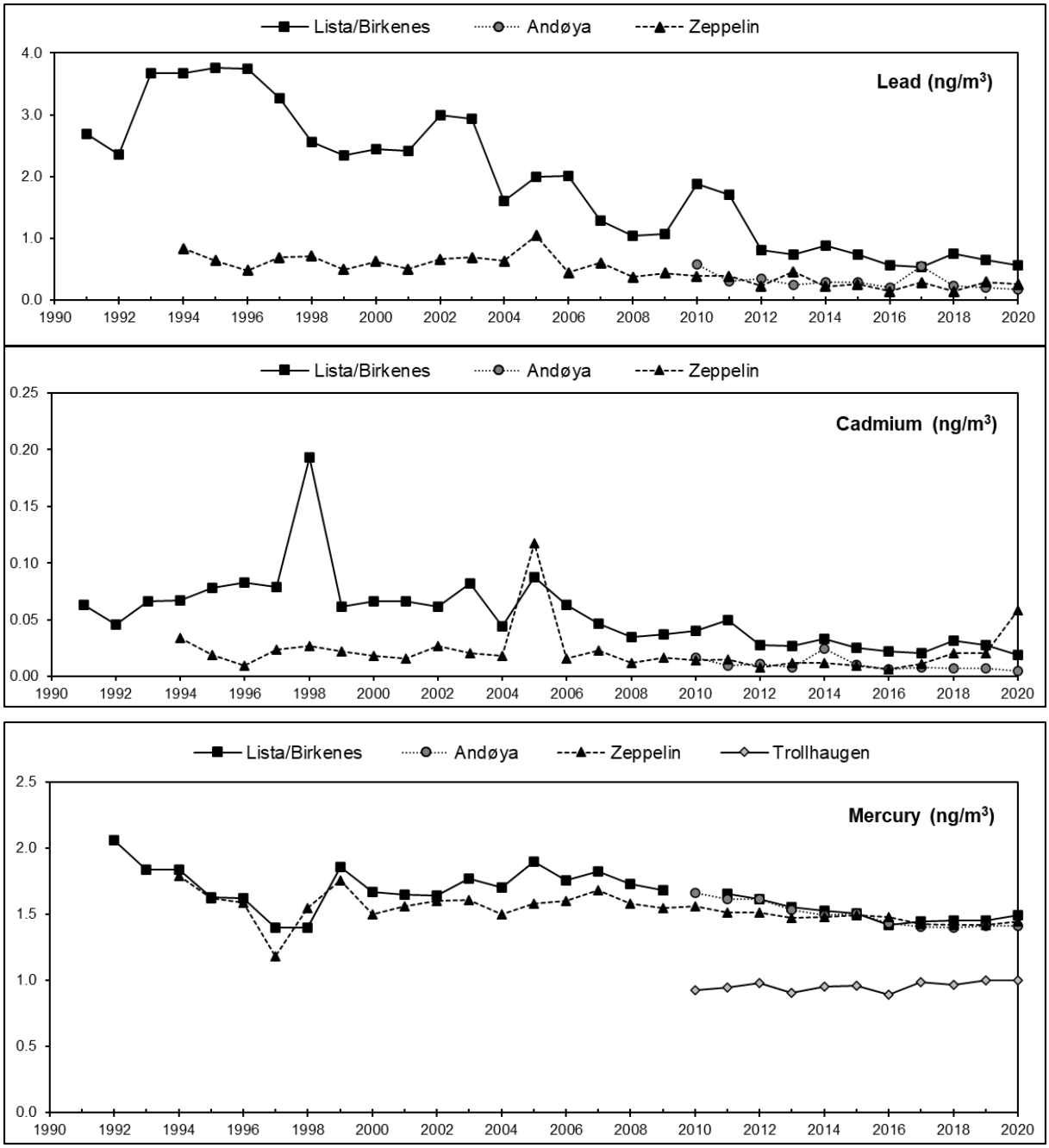


Figure 51: Time series of annual mean concentrations of lead, cadmium and mercury in air and aerosols, 1991-2020, Unit: ng/m^3.

Table 24: Trends in heavy metal concentrations in precipitation, only significant (p=0.05) trends are shown. Positive trends shown in red.

Trends in precipitation, per cent change										
	Pb	**Cd**	**Zn**	**As**	**Co**	**Cr**	**Cu**	**Ni**	**Hg**	**mm**
1980-2020										
Birkenes	almost -100	almost -100	-72							32
Kårvatn	almost -100	almost -100	-							-
1990-2020										
Birkenes	almost -100	-81	-41						-64[1)]	51
Hurdal	-96	-65	-							55
Kårvatn	-	-53	171							-
Svanvik	-	-	-	-	114	-32	177	189		-
2000-2020										
Birkenes	-64	-57	-						-52[1)]	-
Hurdal	-59	-70	-							-
Kårvatn	-	-	182							-
Svanvik	-69	-	-38	-52	-	-	-	-		-

1) Observations of Hg at Lista from 1990-2004

2) From 1990 to 1997 the observations was done at Nordmoen

Table 25: Time trends of heavy metal concentrations in air (in %), only significant (p=0.05) trends are shown. Increasing trends are shown in red and decreasing trends are shown in black.

Trends in air, per cent change											
	Pb	**Cd**	**Zn**	**As**	**Co**	**Cr**	**Cu**	**Mn**	**Ni**	**V**	**Hg**
1991(4)-2020											
Birkenes (from 1991)	-88	-73	-37	-72	-58	-85	-49		-77	ca -100	-23
Zeppelin (from 1994)	-67	-49	-	-78	-	-	-	91	-	-61	-13
2000-2020											
Birkenes	-97	-82	-48	-65	-50	-72	-64		-78	ca -100	-21
Zeppelin	-79	-	-	-83	-	576	-	174	167	-	-12

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Annex 1

Monthly and annual mean concentrations and ranges of POPs in air and precipitation, 2020

Table A.1.1:Monthly and annual mean concentrations (pg/m^3) for organochlorine pesticides (OCPs) in air at Birkenes, 2020.

Birkenes	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020	Min.	Max.
HCB	46.3	45.2	48.6	42.4	39.0	24.5	20.7	22.4	32.7	36.1	35.7	42.3	36.5	14.7	54.9
α-HCH	2.03	1.97	2.16	2.08	4.26	9.24	3.08	4.90	5.03	4.85	3.06	2.26	3.81	1.96	9.24
γ-HCH	1.50	0.70	1.56	1.07	5.79	4.33	2.66	10.60	1.31	1.54	0.93	1.71	2.68	0.53	10.6
sum HCHs	3.53	2.68	3.72	3.15	10.1	13.6	2.66	15.5	6.34	6.39	3.99	3.97	6.49	0.74	15.5
p,p'-DDT	0.132	0.062	0.124	0.094	0.437	0.674	0.143	0.787	0.107	0.185	0.104	0.401	0.257	0.047	0.787
o,p'-DDT	0.133	0.081	0.118	0.072	0.369	0.766	0.108	0.670	0.077	0.171	0.089	0.241	0.228	0.058	0.766
p,p'-DDE	1.200	0.640	0.633	0.315	1.150	1.170	0.367	3.020	0.316	0.962	0.543	2.680	1.014	0.199	3.020
o,p'-DDE	0.068	0.053	0.046	0.019	0.064	0.186	0.033	0.120	0.024	0.063	0.044	0.199	0.072	0.015	0.199
p,p'-DDD	0.009	*0.007*	0.009	<0.007	0.017	0.021	0.010	0.032	*0.011*	<0.007	0.010	0.045	0.015	0.007	0.045
o,p'-DDD	0.018	0.012	0.013	<0.007	0.026	0.039	0.018	0.059	0.016	0.017	0.016	0.032	0.022	0.007	0.059
sum DDTs	1.560	0.856	0.943	0.513	2.062	2.856	0.679	4.688	0.550	1.405	0.805	3.598	1.608	0.378	4.688

Table A.1.2: Monthly and annual mean concentrations (pg/m^3) for PCBs in air at Birkenes, 2020.

Birkenes	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020	Min.	Max.
PCB-18	1.318	0.888	1.018	0.628	0.809	1.381	0.347	1.232	0.446	1.644	0.949	2.198	1.065	0.131	4.810
PCB-28	0.629	0.421	0.452	0.315	0.422	1.130	0.283	1.044	0.323	1.100	0.564	1.249	0.651	0.089	3.310
PCB-31	0.646	0.423	0.444	0.310	0.428	0.990	0.253	0.972	0.294	0.946	0.512	1.102	0.597	0.080	2.800
PCB-33	0.340	0.219	0.230	0.144	0.216	0.512	0.143	0.529	0.169	0.544	0.290	0.662	0.328	0.050	1.650
PCB-37	0.059	0.036	0.025	0.018	0.037	0.079	0.028	0.095	0.044	0.105	0.062	0.134	0.060	0.012	0.318
PCB-47	0.720	0.359	0.335	0.326	0.553	1.279	0.597	1.380	0.638	0.607	0.453	0.637	0.626	0.176	2.200
PCB-52	0.821	0.499	0.479	0.378	0.550	1.149	0.361	1.522	0.416	0.920	0.599	1.003	0.688	0.103	2.310
PCB-66	0.182	0.109	0.093	0.071	0.115	0.278	0.098	0.356	0.119	0.274	0.160	0.275	0.171	0.028	0.748
PCB-74	0.134	0.081	0.069	0.056	0.087	0.204	0.067	0.250	0.085	0.196	0.112	0.201	0.124	0.020	0.535
PCB-99	0.190	0.118	0.089	0.071	0.107	0.234	0.094	0.357	0.089	0.238	0.134	0.223	0.155	0.026	0.623
PCB-101	0.507	0.294	0.243	0.191	0.329	0.816	0.254	1.171	0.279	0.559	0.370	0.594	0.435	0.060	1.530
PCB-105	0.034	0.022	0.016	0.014	0.023	0.053	*0.016*	0.076	0.021	0.053	0.025	0.045	0.031	0.004	0.164
PCB-114	0.005	*0.003*	<0.003	*0.003*	0.004	*0.006*	*0.004*	<0.006	*0.005*	0.008	<0.003	0.008	*0.005*	<0.003	0.022
PCB-118	0.124	0.077	0.058	0.046	0.081	0.190	0.075	0.273	0.070	0.180	0.095	0.156	0.114	0.022	0.518
PCB-122	0.005	0.004	<0.003	*0.003*	0.004	<0.005	<0.004	<0.006	<0.005	0.006	0.004	*0.007*	*0.004*	<0.003	0.012
PCB-123	0.005	0.004	*0.003*	*0.004*	*0.003*	0.006	*0.005*	0.014	<0.005	0.004	0.004	0.007	0.005	0.003	0.024
PCB-128	0.023	0.014	0.009	0.007	0.018	0.025	0.009	0.052	*0.009*	0.024	0.019	0.031	0.018	0.004	0.067
PCB-138	0.177	0.106	0.082	0.063	0.116	0.351	0.105	0.432	0.111	0.208	0.128	0.219	0.164	0.034	0.641
PCB-141	0.042	0.024	0.022	0.017	0.032	0.111	*0.019*	0.130	0.025	0.053	0.034	0.054	0.044	0.004	0.202
PCB-149	0.328	0.197	0.148	0.111	0.213	0.657	0.173	0.867	0.191	0.316	0.243	0.365	0.292	0.041	1.110
PCB-153	0.303	0.179	0.140	0.103	0.184	0.551	0.166	0.736	0.171	0.302	0.218	0.349	0.264	0.055	0.954
PCB-156	0.009	0.006	0.005	0.004	0.006	0.010	*0.003*	0.015	*0.004*	0.011	0.006	0.013	0.007	0.003	0.032
PCB-157	<0.003	<0.003	*0.003*	<0.003	*0.003*	<0.003	<0.003	*0.003*	<0.003	<0.003	*0.003*	0.004	*0.003*	0.002	0.006
PCB-167	0.008	0.004	0.004	*0.003*	0.004	0.006	*0.004*	*0.007*	*0.003*	0.006	0.004	0.008	0.005	0.003	0.018
PCB-170	0.015	0.009	0.010	0.007	0.012	0.036	*0.008*	0.035	*0.008*	0.022	0.013	0.027	0.016	0.005	0.068

Table A.1.2 (cont.):

Birkenes	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020	Min.	Max.
PCB-180	0.044	0.026	0.027	0.019	0.036	0.117	0.030	0.113	0.033	0.055	0.037	0.077	0.050	0.010	0.215
PCB-183	0.021	0.013	0.011	0.009	0.016	0.045	*0.007*	0.062	0.013	0.024	0.018	0.030	0.020	0.004	0.081
PCB-187	0.078	0.049	0.035	0.028	0.047	0.117	0.038	0.163	0.037	0.058	0.059	0.092	0.062	0.012	0.213
PCB-189	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	0.004	*0.003*	<0.003	0.004
PCB-194	*0.004*	<0.003	*0.003*	<0.003	*0.004*	0.008	<0.003	*0.005*	<0.003	*0.006*	<0.003	0.013	*0.005*	<0.003	0.016
PCB-206	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	*0.006*	<0.006	0.007	*0.006*	<0.006	0.010
PCB-209	0.004	0.003	*0.004*	*0.003*	<0.003	*0.003*	<0.003	*0.003*	*0.003*	*0.003*	<0.003	0.006	*0.004*	<0.003	0.010
∑trichlor	4.28	2.86	3.10	2.00	2.74	5.53	1.69	5.28	1.85	6.43	3.59	8.21	3.98	0.75	19.1
∑tetrachlor	3.62	2.07	1.94	1.60	2.41	4.90	2.23	6.37	2.13	4.25	2.66	4.52	3.11	0.95	11.3
∑pentachlor	1.45	0.84	0.68	0.55	0.96	2.28	0.86	3.16	0.70	1.77	1.09	1.80	1.28	0.18	4.60
∑hexachlor	1.11	0.64	0.51	0.37	0.71	2.12	0.58	2.66	0.47	1.00	0.81	1.27	0.95	0.14	3.50
∑heptachlor	0.21	0.13	0.10	0.08	0.16	0.41	0.11	0.47	0.07	0.19	0.18	0.32	0.19	0.04	0.65
sum-PCB7	2.60	1.60	1.48	1.11	1.72	4.31	1.27	5.29	1.40	3.32	2.01	3.65	2.37	0.38	8.90
sum PCB	10.7	6.55	6.35	4.60	6.99	15.3	4.35	18.0	5.23	13.66	8.33	16.2	9.33	0.97	37.6

Table A.1.3: Monthly and annual mean concentrations (pg/m^3) for PBDEs and TBA in air at Birkenes, 2020.

Birkenes	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020	Min.	Max.
BDE-28	0.008	0.003	0.020	0.005	0.005	0.006	0.005	0.007	0.005	0.006	0.007	0.006	0.007	0.003	0.020
BDE-47	0.039	0.018	0.136	0.028	0.030	0.066	0.045	0.064	0.055	0.063	0.076	0.104	0.059	0.018	0.136
BDE-49	0.009	0.002	0.013	0.005	0.044	0.008	0.006	0.007	0.007	0.007	0.007	0.007	0.010	0.002	0.044
BDE-66	0.005	<0.001	0.007	0.003	0.046	0.005	NaN	0.004	0.004	0.004	0.004	0.004	0.009	<0.001	0.046
BDE-71	0.002	<0.001	0.004	<0.001	0.046	<0.001	0.005	<0.001	<0.001	0.001	0.007	<0.001	0.006	<0.001	0.046
BDE-77	0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	*0.001*	<0.001	0.002
BDE-85	0.002	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.003	<0.001	0.001	0.001	0.001	*0.001*	<0.001	0.003
BDE-99	0.028	0.011	0.040	0.013	0.010	0.025	0.014	0.019	0.017	0.021	0.029	0.032	0.021	0.010	0.040
BDE-100	0.007	0.003	0.010	0.003	0.004	0.003	0.004	<0.002	0.005	0.006	0.007	0.010	0.006	0.002	0.010
BDE-119	0.002	<0.002	<0.002	<0.002	0.006	<0.002	0.006	<0.002	<0.002	<0.002	<0.002	<0.002	*0.003*	<0.002	0.006
BDE-138	0.009	<0.002	<0.005	<0.002	<0.002	<0.002	<0.002	<0.003	<0.002	<0.002	<0.002	<0.002	*0.003*	<0.002	0.009
BDE-153	0.021	0.003	<0.004	0.004	<0.002	0.003	<0.002	0.008	0.003	0.005	0.005	<0.002	0.005	<0.002	0.021
BDE-154	0.018	<0.002	<0.002	0.006	<0.002	0.003	<0.002	0.006	0.003	0.005	0.003	0.002	0.005	<0.002	0.018
BDE-183	0.097	<0.002	<0.003	0.017	<0.003	0.005	NaN	0.059	0.012	0.017	0.005	0.003	0.019	<0.002	0.097
BDE-196	0.046	<0.004	<0.007	<0.004	<0.004	<0.004	<0.004	<0.012	<0.004	0.013	<0.004	<0.004	*0.009*	<0.004	0.046
BDE-206	0.198	<0.053	0.072	0.063	<0.054	<0.055	<0.055	0.071	<0.055	<0.055	<0.054	<0.054	*0.071*	<0.053	0.198
BDE-209	1.14	<0.56	0.68	0.66	<0.57	<0.58	<0.58	<0.58	<0.58	<0.58	<0.57	<0.57	*0.64*	<0.56	1.14
sum BDE	1.63	0.67	1.01	0.82	0.83	0.77	0.73	0.85	0.75	0.78	0.78	0.80	0.88	0.67	1.63
sum BDE (excl. 209)	0.49	0.11	0.33	0.16	0.26	0.19	0.15	0.27	0.18	0.21	0.21	0.23	0.24	0.11	0.49
TBA	6.15	4.39	3.67	1.27	1.87	2.13	2.28	4.52	5.32	5.44	5.29	8.61	4.27	1.27	8.61

Table A.1.4: Monthly and annual mean concentrations (pg/m^3) for HBCDs in air at Birkenes, 2020.

Birkenes	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020	Min.	Max.
α-HBCD	0.037	<0.049	0.036	0.007	NaN	<0.007	<0.005	<0.005	<0.005	0.007	0.006	0.009	*0.013*	*<0.005*	0.004
β-HBCD	<0.008	<0.002	<0.010	<0.002	NaN	<0.042	<0.002	<0.002	<0.002	<0.002	<0.002	<0.003	*<0.004*	*<0.002*	<0.010
γ-HBCD	*<0.008*	*<0.003*	*<0.02*	*<0.003*	*NaN*	*<0.006*	*<0.003*	*<0.003*	*<0.003*	*<0.003*	*<0.003*	*<0.003*	*<0.003*	*<0.003*	<0.02
sum HBCD	*0.05*	*<0.010*	*0.07*	0.01		*<0.017*	*<0.010*	*<0.011*	*<0.011*	*0.01*	*0.01*	*0.01*	*0.02*	*<0.01*	*0.07*

Table A.1.5: Monthly and annual mean concentrations (ng/m^3) for PAHs in air at Birkenes, 2020.

Birkenes	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020	Min.	Max.
1-Methylnaphthalene	0.102	0.037	0.043	0.028	*0.018*	*0.015*	*0.015*	*0.021*	0.025	0.043	0.071	0.198	0.054	0.013	0.382
1-Methylphenanthrene	0.037	0.026	0.034	0.027	0.022	0.110	0.015	0.016	0.030	0.045	0.053	0.058	0.041	0.008	0.386
2-Methylanthracene	<0.003	<0.002	<0.002	<0.002	*0.002*	<0.003	<0.002	<0.002	<0.002	*0.003*	*0.003*	<0.003	*0.002*	<0.002	0.005
2-Methylnaphthalene	0.123	0.047	0.052	0.039	0.025	0.020	*0.017*	*0.024*	0.031	0.051	0.082	0.210	0.062	0.013	0.409
2-Methylphenanthrene	0.055	0.031	0.055	0.030	0.028	0.087	0.022	0.039	0.051	0.068	0.077	0.091	0.054	0.014	0.238
3-Methylphenanthrene	0.050	0.028	0.047	0.024	0.024	0.062	0.020	0.036	0.048	0.062	0.074	0.077	0.047	0.012	0.148
9-Methylphenanthrene	0.018	0.011	0.016	0.009	0.010	0.022	0.009	0.011	0.017	0.020	0.026	0.030	0.017	0.006	0.056
Acenaphthene	0.163	0.104	0.079	0.106	0.039	0.044	0.032	0.100	0.068	0.045	0.134	0.093	0.083	0.019	0.334
Acenaphthylene	0.004	0.030	0.008	0.019	0.050	0.007	0.007	0.003	0.005	0.024	0.027	0.037	0.018	0.002	0.152
Anthanthrene	<0.001	*0.001*	*0.002*	<0.001	*0.001*	*0.001*	<0.001	*0.001*	0.001	<0.002	*0.002*	*0.004*	*0.002*	<0.001	0.011
Anthracene	0.005	0.013	0.006	0.014	0.019	0.057	0.005	0.003	0.007	*0.007*	*0.018*	0.006	0.014	0.001	0.221
Benz(a)anthracene	0.007	0.007	0.012	0.002	0.003	0.011	0.002	0.003	0.011	0.012	0.017	0.024	0.010	0.001	0.059
Benzo(a)fluoranthene	*0.001*	*0.002*	*0.003*	*0.001*	*0.002*	*0.001*	<0.001	*0.001*	0.002	0.002	0.003	0.009	*0.002*	<0.001	0.023
Benzo(a)fluorene	0.008	0.005	0.009	0.003	0.006	0.008	0.002	0.002	0.010	0.010	0.014	0.021	0.009	0.001	0.041
Benzo(a)pyrene	0.003	0.005	0.014	0.003	0.005	0.007	0.001	0.005	0.010	0.008	0.013	0.026	0.009	0.001	0.070
Benzo(b)fluoranthene	0.027	0.023	0.045	0.014	0.019	0.042	0.004	0.017	0.079	0.033	0.058	0.058	0.037	0.001	0.193
Benzo(b)fluorene	0.006	0.003	0.005	0.002	0.005	0.005	0.001	0.002	0.006	0.005	0.010	0.010	0.005	0.001	0.020
Benzo(e)pyrene	0.016	0.013	0.026	0.009	0.012	0.026	0.003	0.012	0.042	0.024	0.035	0.033	0.022	0.001	0.093
Benzo(ghi)fluoranthene	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN		
Benzo(ghi)perylene	0.016	0.014	0.026	0.010	0.011	0.018	0.006	0.009	0.029	0.025	0.031	0.042	0.021	0.001	0.106
Benzo(k)fluoranthene	0.008	0.007	0.015	0.004	0.005	0.010	0.001	0.005	0.017	0.011	0.018	0.024	0.011	0.001	0.064
Biphenyl	0.212	0.146	0.136	0.069	0.053	0.024	0.019	0.020	0.045	0.109	0.129	0.443	0.123	0.011	0.788
Chrysene	0.024	0.021	0.045	0.013	0.016	0.042	0.005	0.017	0.051	0.038	0.048	0.053	0.032	0.004	0.120
Coronene	0.006	0.006	0.011	0.004	0.003	0.005	0.002	0.004	0.010	0.010	0.012	0.007	0.007	0.001	0.031
Cyclopenta(cd)pyrene	<0.001	NaN	<0.001	<0.001	NaN	NaN	<0.001	<0.001	NaN	NaN	NaN	NaN	<0.001	<0.001	<0.001

Table A.1.5. cont.

Birkenes	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020	Min.	Max.
Dibenzo(ae)pyrene	0.003	0.002	0.004	*0.003*	0.002	0.004	*0.001*	0.003	0.007	0.005	0.005	0.008	0.004	0.001	0.02
Dibenzo(ah)anthracene	0.002	0.002	0.003	*0.001*	0.002	0.003	<0.001	*0.002*	0.004	0.004	0.004	0.006	0.003	0.001	0.016
Dibenzo(ah)pyrene	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	*0.002*	*0.001*	<0.001	0.02
Dibenzo(ai)pyrene	<0.001	<0.001	*0.001*	<0.001	<0.001	<0.001	<0.001	<0.001	*0.001*	<0.001	*0.001*	*0.002*	*0.001*	<0.001	0.004
Dibenzofuran	0.657	0.465	0.553	0.334	0.277	0.201	0.115	0.171	0.250	0.425	0.486	1.731	0.494	0.058	2.980
Dibenzothiophene	0.026	0.012	0.032	0.009	0.010	0.042	0.014	0.031	0.038	0.035	0.028	0.023	0.025	0.004	0.060
Fluoranthene	0.192	0.116	0.210	0.100	0.088	0.197	0.055	0.101	0.177	0.173	0.263	0.445	0.184	0.035	0.717
Fluorene	0.568	0.329	0.396	0.238	0.184	0.206	0.114	0.220	0.261	0.350	0.490	1.465	0.419	0.061	2.570
Inden(123-cd)pyrene	0.013	0.014	0.026	0.009	0.010	0.015	0.002	0.006	0.022	0.022	0.029	0.044	0.019	0.001	0.113
Naphthalene	0.233	0.104	0.100	0.043	*0.040*	<0.028	<0.028	*0.029*	*0.041*	0.091	0.135	0.572	0.127	<0.028	1.092
Perylene	*0.001*	*0.001*	*0.002*	<0.001	*0.001*	<0.001	<0.001	*0.001*	0.002	0.001	0.002	0.004	*0.002*	<0.001	0.011
Phenanthrene	0.797	0.488	0.615	0.481	0.441	1.075	0.350	0.666	0.794	0.786	1.180	1.638	0.797	0.200	2.560
Pyrene	0.084	0.058	0.102	0.043	0.043	0.092	0.028	0.038	0.090	0.108	0.133	0.185	0.087	0.017	0.298
Retene	0.044	0.025	0.032	0.026	0.015	0.157	0.022	0.015	0.053	0.054	0.060	0.053	0.049	0.009	0.491
Sum PAH	3.52	2.20	2.77	1.72	1.49	2.65	0.93	1.64	2.34	2.71	3.77	7.74	2.89	0.55	12.42
Sum PAH16	2.14	1.33	1.70	1.10	0.97	1.85	0.64	1.22	1.67	1.74	2.60	4.72	1.87	0.50	7.42

Table A.1.6: Monthly and annual mean concentrations (pg/m^3) for PFAS in air at Birkenes, 2020.

Birkenes	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020	Min.	Max.
FTS 4:2	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
FTS 6:2	<0.04	<0.04	<0.04	<0.04	0.042	0.171	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	*0.05*	<0.04	0.171
FTS 8:2	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<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	<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	<0.02	<0.02
PFHpA	<0.05	<0.05	<0.05	<0.05	0.203	0.074	<0.05	0.075	<0.05	<0.05	<0.05	<0.05	*0.07*	<0.05	0.203
PFHxA	<0.05	<0.05	<0.05	<0.05	0.241	0.119	<0.05	0.095	<0.05	<0.05	<0.05	<0.05	*0.08*	<0.05	0.241
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	<0.02	<0.02
PFNA	<0.05	<0.05	<0.05	<0.05	0.212	0.081	<0.05	0.095	<0.05	<0.05	0.093	<0.05	*0.07*	<0.05	0.21
PFOA	0.057	0.058	0.061	0.071	0.364	0.17	0.058	0.185	0.078	0.081	0.128	0.067	0.12	0.06	0.36
PFOS	0.028	<0.02	<0.02	0.028	0.022	0.084	0.024	0.092	0.039	0.063	0.067	<0.02	0.04	<0.02	0.09
PFOSA	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
PFUnA	<0.02	<0.02	<0.02	<0.02	0.064	0.025	<0.02	0.041	<0.02	<0.02	<0.02	<0.02	*0.02*	<0.02	0.064
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	<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	<0.02	<0.02
PFNS	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07
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	<0.05	<0.05
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	<0.02	<0.02
PFHxDA	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07
PFODcA	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07
PFDS	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07
PFOSlin	<0.02	<0.02	<0.02	<0.02	0.02	0.04	<0.02	0.05	<0.02	0.03	0.02	<0.02	*0.02*	*<0.02*	0.05
PFDA	<0.02	<0.02	<0.02	<0.02	0.104	0.047	<0.02	0.056	<0.02	<0.02	0.021	<0.02	*0.03*	*<0.02*	0.104
sum PFAS	0.50	0.48	0.49	0.51	1.57	1.10	0.50	1.00	0.53	0.58	0.70	0.49	0.70	0.48	1.57
sum PFAS$_{det}$	0.08	0.06	0.06	0.10	1.28	0.81	0.08	0.69	0.12	0.17	0.33	0.07	0.32	0.06	1.28

Table A.1.7: Monthly and annual mean concentrations (pg/m^3) for M/SCCPs in air at Birkenes, 2020.

Birkenes	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020	Min.	Max.
SCCPs	***<123***	***<125***	124	***<124***	547	258	179	280	*104*	177	***<124***	***<127***	153	<120	547
MCCPs	***<1120***	***<1135***	***<1120***	***<1130***	2612	***<1160***	***<1120***	***<1160***	***<1140***	***<1130***	***<1130***	***<1160***	715	<1120	2612

Table A.1.8: Monthly and annual mean concentrations (ng/m^3) for cVMS in air at Birkenes, 2020.

Birkenes	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020	Min.	Max.
D4	3.12	2.37	1.36	1.29	0.89	0.58	0.56	0.91	0.56	0.50	NA	2.05	1.29	0.50	3.12
D5	9.54	11.50	4.90	4.04	4.10	1.76	2.50	2.74	2.43	1.58	NA	8.46	4.87	1.58	11.50
D6	0.75	0.58	0.32	0.24	0.25	0.34	0.42	0.24	0.11	0.11	NA	1.75	0.46	0.11	1.75
sum cVMS	13.40	14.45	6.58	5.57	5.23	2.51	3.38	3.77	2.99	2.08	NA	12.25	6.56	2.08	14.45

Table A.1.9: Monthly and annual mean concentrations (ng/l) for HCB, HCHs and PCBs in precipitation at Birkenes, 2020.

Birkenes	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020	Min.	Max.
HCB	0.466	0.063	*0.050*	<0,125	*0.068*	0.080	*0.055*	<0.068	<0.072	<0.037	*0.076*	0.051	*0.088*	*0.030*	3.4
α-HCH	0.124	0.046	0.048	0.060	0.065	0.088	0.059	0.059	0.106	0.115	0.082	0.077	0.078	0.040	0.636
γ-HCH	0.391	0.116	0.126	0.117	0.239	0.111	0.153	0.223	0.243	0.177	0.219	0.140	0.177	0.050	2.07
sum HCH	0.515	0.161	0.175	0.177	0.304	0.199	0.213	0.283	0.349	0.292	0.300	0.217	0.256	0.04	2.71
PCB-28	0.019	0.003	*0.004*	<0.012	<0.006	<0.006	<0.005	<0.006	<0.007	<0.003	*0.004*	0.004	*0.006*	*0.002*	*0.119*
PCB-52	0.019	0.004	0.004	<0.011	<0.006	<0.005	<0.005	<0.006	<0.006	*0.003*	0.004	0.004	*0.006*	*0.002*	*0.112*
PCB-101	<0.030	*0.005*	*0.007*	<0.019	<0.010	<0.009	<0.008	<0.011	<0.011	*0.006*	0.007	0.008	*0.009*	*0.004*	*0.195*
PCB-118	0.022	0.004	0.006	0.012	<0.005	<0.005	<0.004	<0.006	*0.006*	*0.003*	0.004	0.006	*0.006*	*0.002*	*0.151*
PCB-138	0.024	0.005	0.009	<0.016	<0.008	*0.008*	*0.007*	<0.009	*0.009*	*0.005*	0.008	0.011	*0.009*	*0.004*	*0.158*
PCB-153	<0.040	*0.007*	0.011	<0.026	<0.014	<0.013	<0.011	<0.014	<0.015	*0.008*	0.011	0.013	*0.013*	*0.005*	*0.264*
PCB-180	0.014	0.003	0.005	*0.006*	*0.003*	*0.003*	*0.003*	*0.003*	*0.003*	*0.002*	0.006	0.009	0.005	0.001	*0.094*
sum PCB-7	0.097	0.030	0.046	0.018	0.003	0.011	0.009	0.003	0.019	0.027	0.043	0.055	0.053	0.020	0.63

Table A.1.10: Monthly and annual mean concentrations (pg/m^3) for hexachlorobenzene (HCB) in air at Andøya, 2020.

Andøya	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020	Min.	Max.
HCB	29.6	29.4	32.4	39.1	29.3	15.2		17.7	19.0		15.1	22.4	24.7	15.1	39.1

Table A.1.11: Monthly and annual mean concentrations (pg/m^3) for PFAS in air at Andøya, 2020.

Andøya	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
FTS 4:2	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
FTS 6:2	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
FTS 8:2	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
PFBS	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
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	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
PFHxA	<0.05	<0.05	<0.05	<0.05	<0.05	0.07	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	*0.05*
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	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
PFOA	0.045	0.06	0.063	0.049	0.043	0.081	0.037	0.073	0.053	0.041	0.067	0.039	0.05
PFOS	0.052	0.044	0.05	0.036	0.03	0.026	<0.02	0.034	<0.02	<0.02	0.055	0.023	0.03
PFOSA	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
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	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07
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	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
PFHxDA	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07
PFODcA	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07
PFDS	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07
PFOSlin	0.033	0.023	0.037	0.023	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.034	<0.02	0.02
PFDA	<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	0.53	0.53	0.56	0.51	0.49	0.57	0.46	0.52	0.48	0.47	0.56	0.48	*0.51*
sum $PFAS_{det}$	0.13	0.13	0.15	0.11	0.07	0.18	0.04	0.11	0.05	0.04	0.16	0.06	0.10

Table A.1.12: Monthly and annual mean concentrations (pg/m^3) for organochlorine pesticides in air at Zeppelin, 2020.

Zeppelin	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020	Min.	Max.
HCB	51.9	52.3	56.4	55.1	53.0	55.3	50.6	58.2	66.4	59.8	38.1	49.1	54.5	33.9	72.3
α-HCH	2.00	2.53	2.39	2.45	2.73	2.36	3.20	3.71	3.49	3.71	3.24	1.29	2.67	0.87	7.73
γ-HCH	0.30	0.48	0.47	0.42	0.35	0.27	0.46	0.41	0.46	0.67	0.48	0.21	0.40	0.19	1.70
sum HCHs	2.30	3.02	2.87	2.87	3.08	2.63	3.66	4.12	3.94	4.38	3.72	1.50	3.07	1.06	9.43
cis-CD	0.236	0.159	0.270	0.331	0.249	0.203	0.213	0.243	0.270	0.287	0.314	0.258	0.250	0.150	0.400
cis-NO	0.013	0.009	0.013	0.029	0.025	0.031	0.035	0.037	0.044	0.026	0.025	0.014	0.024	0.006	0.049
trans-CD	0.131	0.076	0.141	0.145	0.065	0.046	0.044	0.056	0.058	0.091	0.150	0.143	0.096	0.023	0.225
trans-NO	0.207	0.131	0.241	0.330	0.227	0.182	0.184	0.197	0.220	0.254	0.279	0.244	0.222	0.119	0.389
sum CHLs	0.586	0.374	0.664	0.836	0.566	0.461	0.476	0.533	0.592	0.657	0.768	0.659	0.593	0.318	1.041
p,p'-DDT	0.052	0.063	0.032	0.029	0.017	0.009	0.030	0.018	0.024	0.103	0.042	0.028	0.040	0.008	0.332
o,p'-DDT	0.076	0.117	0.078	0.080	0.024	0.016	0.053	0.035	0.037	0.184	0.066	0.046	0.065	0.010	0.653
p,p'-DDE	0.396	0.609	0.313	0.121	0.072	0.050	0.064	0.054	0.077	0.724	0.293	0.262	0.258	0.037	2.650
o,p'-DDE	0.056	0.079	0.058	0.029	0.013	0.008	0.013	0.012	0.011	0.087	0.033	0.027	0.036	0.006	0.334
p,p'-DDD	<0.006	<0.005	<0.004	<0.005	<0.003	<0.003	<0.003	<0.003	<0.003	*0.008*	*0.004*	*0.003*	*0.004*	*<0.003*	0.023
o,p'-DDD	0.011	*0.008*	0.006	*0.006*	*0.004*	*0.003*	*0.004*	*0.004*	*0.005*	0.012	0.007	0.005	*0.006*	*0.003*	0.032
sum DDTs	0.607	0.854	0.491	0.255	0.130	0.091	0.163	0.128	0.153	1.118	0.443	0.373	0.406	0.070	4.024

Table A.1.13: Monthly and annual mean concentrations (pg/m^3) for PCBs in air at Zeppelin, 2020.

Zeppelin	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020	Min.	Max.
PCB-18	1.004	1.467	1.042	0.708	0.620	0.599	1.066	2.194	0.737	0.882	0.682	0.875	1.003	0.359	5.141
PCB-28	0.705	0.941	0.790	0.627	0.628	0.874	1.511	2.257	0.981	0.843	0.545	0.616	0.963	0.451	5.554
PCB-31	0.639	0.847	0.707	0.556	0.562	0.780	1.325	2.092	0.889	0.725	0.482	0.548	0.864	0.398	5.192
PCB-33	0.437	0.583	0.507	0.400	0.417	0.642	1.053	1.711	0.704	0.483	0.344	0.393	0.657	0.256	4.342
PCB-37	0.086	0.101	0.094	0.099	0.105	0.184	0.282	0.393	0.227	0.125	0.091	0.101	0.161	0.056	0.925
PCB-47	0.224	0.284	0.363	0.211	0.187	0.265	0.369	0.490	0.278	0.249	0.220	0.249	0.286	0.160	1.134
PCB-52	0.468	0.583	0.529	0.409	0.338	0.341	0.565	0.693	0.414	0.566	0.384	0.449	0.482	0.264	1.476
PCB-66	0.125	0.150	0.153	0.132	0.114	0.163	0.219	0.271	0.181	0.194	0.124	0.124	0.165	0.090	0.560
PCB-74	0.095	0.114	0.117	0.092	0.078	0.102	0.140	0.171	0.123	0.146	0.088	0.092	0.115	0.069	0.344
PCB-99	0.096	0.122	0.106	0.088	0.067	0.056	0.097	0.089	0.063	0.156	0.089	0.092	0.094	0.045	0.353
PCB-101	0.216	0.265	0.243	0.210	0.172	0.173	0.300	0.300	0.184	0.353	0.228	0.225	0.240	0.138	0.740
PCB-105	0.023	0.030	0.021	0.023	0.016	0.016	0.025	0.052	0.017	0.051	0.044	0.023	0.028	0.010	0.141
PCB-114	0.003	*0.005*	0.007	0.002	0.002	0.003	*0.002*	0.003	*0.002*	0.005	0.005	0.003	0.004	0.001	0.020
PCB-118	0.076	0.097	0.078	0.067	0.048	0.050	0.086	0.139	0.054	0.149	0.114	0.075	0.086	0.037	0.347
PCB-122	<0.001	*0.003*	<0.009	0.002	<0.001	*0.002*	*0.002*	0.004	*0.002*	0.003	0.002	0.002	*0.003*	<0.001	0.025
PCB-123	0.002	0.003	0.007	0.003	0.002	0.002	*0.002*	0.004	0.003	0.005	0.004	0.003	0.003	0.001	0.020
PCB-128	0.009	0.009	0.011	0.009	0.007	0.007	0.010	0.026	0.010	0.028	0.025	0.010	0.013	0.004	0.078
PCB-138	0.058	0.066	0.045	0.065	0.046	0.039	0.068	0.127	0.046	0.126	0.113	0.061	0.071	0.023	0.338
PCB-141	0.013	0.012	0.013	0.011	0.011	0.010	0.016	0.025	0.014	0.025	0.024	0.015	0.016	0.006	0.057
PCB-149	0.090	0.098	0.096	0.109	0.082	0.074	0.134	0.153	0.089	0.172	0.126	0.104	0.110	0.063	0.350
PCB-153	0.081	0.084	0.088	0.086	0.063	0.053	0.095	0.124	0.065	0.155	0.113	0.090	0.091	0.044	0.344
PCB-156	0.004	0.005	0.008	0.003	0.002	0.002	0.003	0.012	0.003	0.009	0.012	0.004	0.005	0.001	0.038
PCB-157	*0.001*	0.002	*0.004*	0.001	<0.001	<0.001	<0.001	*0.003*	<0.001	*0.002*	0.004	*0.001*	*0.002*	<0.001	0.013
PCB-167	0.002	0.003	0.005	0.002	*0.001*	0.002	*0.002*	*0.004*	*0.002*	0.004	0.005	0.002	0.003	0.001	0.012

Table A.1.13 (cont.)

Zeppelin	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020	Min.	Max.
PCB-170	0.004	0.005	0.007	0.004	0.004	0.003	*0.004*	0.009	*0.004*	0.009	0.010	0.004	0.006	0.003	0.024
PCB-180	0.011	0.010	0.011	0.011	0.009	0.007	0.011	0.018	0.008	0.023	0.020	0.012	0.013	0.005	0.052
PCB-183	0.005	0.006	0.007	0.007	0.005	0.004	0.006	0.006	0.004	0.009	0.008	0.006	0.006	0.003	0.018
PCB-187	0.015	0.013	0.016	0.019	0.013	0.011	0.015	0.015	0.012	0.026	0.020	0.016	0.016	0.007	0.050
PCB-189	<0.001	<0.003	<0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	0.002	<0.001	*0.002*	<0.001	0.009
PCB-194	<0.002	<0.002	<0.004	<0.002	<0.001	<0.002	<0.002	*0.002*	<0.002	*0.002*	0.002	<0.002	*0.002*	<0.001	0.010
PCB-206	<0.002	<0.005	<0.005	<0.003	<0.002	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.001	0.011
PCB-209	0.004	0.006	0.005	0.002	0.002	*0.002*	0.002	*0.001*	*0.001*	*0.002*	0.003	0.003	0.003	0.001	0.007
∑trichlor	4.16	5.74	4.25	3.38	3.26	4.22	6.72	11.2	4.65	4.20	3.13	3.42	4.94	2.39	28.0
∑tetrachlor	1.96	2.26	2.34	1.81	1.60	1.90	2.73	3.52	2.18	2.51	1.77	1.86	2.23	1.31	7.52
∑pentachlor	0.71	0.86	0.69	0.71	0.56	0.53	0.93	1.08	0.59	1.31	0.89	0.74	0.80	0.41	2.83
∑hexachlor	0.30	0.29	0.27	0.32	0.26	0.21	0.40	0.49	0.28	0.57	0.44	0.34	0.35	0.15	1.19
∑heptachlor	0.04	0.04	0.04	0.05	0.03	0.02	0.05	0.06	0.04	0.09	0.07	0.05	0.05	0.02	0.21
sum-PCB7	1.62	2.05	1.78	1.48	1.30	1.54	2.64	3.66	1.75	2.22	1.52	1.53	1.95	1.10	7.71
sum PCB	7.18	9.20	7.59	6.27	5.72	6.88	10.8	16.3	7.74	8.69	6.31	6.42	8.37	4.61	37.2

Table A.1.14:: Monthly and annual mean concentrations (pg/m^3) for PBDEs and TBA in air at Zeppelin, 2020.

Zeppelin	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020	Min.	Max.
BDE-28	0.004	0.013	0.004	0.006	0.008	0.009	0.010	0.008	0.008	0.009	0.009	0.007	0.008	0.003	0.025
BDE-47	0.056	0.044	0.061	0.136	0.170	0.173	0.167	0.155	0.117	0.132	0.128	0.097	0.118	0.036	0.242
BDE-49	0.019	0.002	0.003	0.005	0.006	0.006	0.007	0.006	0.006	0.008	0.006	0.004	0.007	0.002	0.035
BDE-66	*0.017*	<0.002	<0.002	*0.045*	0.003	0.004	0.004	0.004	0.004	0.003	0.004	0.002	0.008	<0.001	0.116
BDE-71	*0.018*	<0.001	<0.001	*0.002*	<0.001	<0.001	<0.001	*0.001*	*0.001*	*0.001*	<0.001	<0.001	*0.003*	<0.001	0.034
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*	<0.001	0.001
BDE-85	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	*0.001*	*0.001*	*0.001*	<0.001	*0.002*	<0.001	*0.001*	<0.001	0.003
BDE-99	0.010	0.009	0.011	0.028	0.061	0.041	0.040	0.032	0.025	0.037	0.044	0.021	0.029	0.008	0.096
BDE-100	0.004	0.003	0.004	0.012	0.018	0.012	0.010	0.009	0.007	0.010	0.011	0.008	0.009	0.003	0.028
BDE-119	*0.003*	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.002	<0.003	<0.002	*0.003*	<0.001	0.004
BDE-138	<0.002	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.002	<0.003	<0.002	<0.003	<0.001	<0.004
BDE-153	<0.002	<0.003	<0.003	*0.003*	*0.004*	*0.003*	<0.003	<0.004	*0.003*	*0.004*	*0.005*	<0.002	*0.003*	<0.002	0.010
BDE-154	<0.002	<0.002	<0.003	<0.003	*0.003*	*0.003*	*0.003*	*0.003*	*0.003*	*0.003*	*0.004*	<0.002	*0.003*	<0.001	0.010
BDE-183	<0.003	<0.003	<0.003	*0.003*	*0.004*	*0.004*	<0.003	<0.004	*0.004*	<0.003	*0.011*	<0.003	*0.004*	<0.002	0.026
BDE-196	<0.005	<0.006	<0.006	*0.009*	*0.013*	<0.007	<0.005	<0.006	<0.009	<0.010	<0.008	<0.010	*0.008*	<0.004	0.021
BDE-206	0.268	*0.182*	0.406	0.348	*0.548*	*0.166*	*0.075*	*0.106*	*0.484*	0.491	0.237	0.284	0.306	0.063	1.145
BDE-209	*16.2*	*10.2*	*24.5*	*19.4*	*25.6*	*6.54*	*1.18*	*3.30*	*24.8*	*25.7*		*14.7*	*28.4*	*1.040*	
sum BDE	16.6	10.5	25.0	20.0	26.4	7.0	1.5	3.6	25.5	26.5	170.7	15.1	28.9	1.3	470
sum BDE (excl. 209)	0.41	0.28	0.51	0.61	0.85	0.43	0.34	0.34	0.68	0.72	0.48	0.45	0.5122	0.161	1.391
TBA	3.10	3.15	1.84	1.14	3.32	9.82	13.20	12.34	17.79	12.80	11.06	9.18	8.23	0.988	23.12

Table A.1.15: Monthly and annual mean concentrations (pg/m^3) for HBCDs in air at Zeppelin, 2020.

Zeppelin	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020	Min.	Max.
α-HBCD	0.120	0.309	0.838	0.844	0.140	0.426	0.015	0.091	0.165	0.482	0.255	0.076	0.323	0.012	3.69
β-HBCD	0.017	0.053	0.150	0.152	0.025	0.083	<0.005	0.021	0.032	0.083	0.045	0.014	0.058	0.003	0.662
γ-HBCD	*0.014*	0.041	*0.076*	0.079	0.012	0.051	<0.014	0.016	*0.018*	*0.059*	0.030	0.028	0.038	*0.004*	0.330
sum HBCD	0.150	0.403	1.064	1.076	0.177	0.560	0.015	0.128	0.215	0.624	0.330	0.118	0.418	0.02	4.68

Table A.1.16: Monthly and annual mean concentrations (ng/m^3) for PAHs in air at Zeppelin, 2020.

Zeppelin	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020	Min.	Max.
1-Methylnaphthalene	0.268	0.209	0.055	0.028	0.019	0.010	0.012	0.021	0.014	0.042	0.049	0.158	0.076	0.006	0.459
1-Methylphenanthrene	0.005	0.003	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.002	0.002	0.002	0.001	0.008
2-Methylanthracene	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.003
2-Methylnaphthalene	0.298	0.216	0.076	0.045	0.029	0.016	0.020	0.034	0.021	0.059	0.066	0.168	0.090	0.010	0.446
2-Methylphenanthrene	0.006	0.005	0.002	0.001	0.001	0.002	0.002	0.003	0.002	0.002	0.004	0.003	0.003	0.001	0.009
3-Methylphenanthrene	0.005	0.004	0.001	0.001	0.001	0.002	0.002	0.002	0.001	0.002	0.003	0.002	0.002	0.001	0.007
9-Methylphenanthrene	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.001	0.001	0.004
Acenaphthene	0.009	0.005	0.004	0.002	0.002	0.002	0.003	0.003	0.004	0.004	0.005	0.004	0.004	0.001	0.010
Acenaphthylene	0.004	0.003	0.002	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.002	0.002	0.002	0.001	0.008
Anthanthrene	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	0.001	0.001
Anthracene	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.006	0.007	0.002	0.001	0.002	0.001	0.027
Benz(a)anthracene	0.007	0.005	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.007
Benzo(a)fluoranthene	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.003
Benzo(a)fluorene	0.004	0.003	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.009
Benzo(a)pyrene	0.006	0.005	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.013
Benzo(b)fluoranthene	0.021	0.021	0.003	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.004	0.005	0.001	0.045
Benzo(b)fluorene	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005
Benzo(e)pyrene	0.011	0.010	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.003	0.001	0.025
Benzo(ghi)fluoranthene	NaN	NaN	0.001	0.005	0.001	0.003	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.016
Benzo(ghi)perylene	0.011	0.010	0.002	0.006	0.001	0.003	0.001	0.001	0.001	0.001	0.001	0.002	0.004	0.001	0.026
Benzo(k)fluoranthene	0.008	0.007	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.018
Biphenyl	0.882	1.069	0.503	0.136	0.022	0.011	0.016	0.014	0.038	0.224	0.249	0.569	0.314	0.009	2.10
Chrysene	0.018	0.016	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.003	0.004	0.001	0.039
Coronene	0.006	0.005	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.013
Cyclopenta(cd)pyrene	0.001	NaN	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001

Table A.1.16 cont.

Zeppelin	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020	Min.	Max.
Dibenzo(ae)pyrene	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.00
Dibenzo(ah)anthracene	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.004
Dibenzo(ah)pyrene	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Dibenzo(ai)pyrene	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Dibenzofuran	1.04	1.41	0.624	0.221	0.039	0.026	0.033	0.031	0.073	0.249	0.394	0.698	0.404	0.014	2.06
Dibenzothiophene	0.008	0.009	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.003	0.005	0.003	0.001	0.014
Fluoranthene	0.061	0.062	0.010	0.011	0.003	0.006	0.003	0.003	0.003	0.005	0.012	0.026	0.018	0.002	0.111
Fluorene	0.546	0.586	0.097	0.026	0.012	0.011	0.010	0.011	0.021	0.055	0.159	0.343	0.159	0.004	0.845
Inden(123-cd)pyrene	0.011	0.010	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.003	0.001	0.023
Naphthalene	1.05	1.20	0.371	0.139	0.091	0.053	0.066	0.081	0.065	0.185	0.203	0.685	0.354	0.020	2.95
Perylene	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002
Phenanthrene	0.089	0.095	0.019	0.011	0.006	0.010	0.012	0.012	0.012	0.020	0.041	0.060	0.033	0.004	0.131
Pyrene	0.031	0.030	0.006	0.029	0.003	0.015	0.003	0.003	0.002	0.003	0.003	0.007	0.012	0.002	0.107
Retene	0.005	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.004
Sum PAH	4.03	4.43	5.01	1.80	0.69	0.256	0.196	0.211	0.248	0.29	0.885	1.22	1.39	0.137	9.20
Sum PAH16	1.88	2.06	0.521	0.233	0.127	0.109	0.107	0.123	0.122	0.289	0.435	1.14	0.605	0.07	4.07

Table A.1.17: Monthly and annual mean concentrations (pg/m^3) for PFAS in air at Zeppelin, 2020

Zeppelin	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
FTS 4:2	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
FTS 6:2	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
FTS 8:2	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
PFBS	<0.02	<0.02	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.023	<0.02	*0.02*
PFDoDA	<0.02	0.044	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	*0.02*
PFHpA	<0.05	<0.05	<0.05	0.075	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	*0.05*
PFHxA	<0.05	<0.05	<0.05	0.083	<0.05	<0.05	<0.05	0.065	<0.05	<0.05	0.092	<0.05	*0.06*
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	<0.02	0.029	0.026	0.088	<0.02	<0.02	0.034	0.021	<0.02	0.026	0.036	0.035	0.03
PFOA	0.039	0.128	0.055	0.193	0.033	0.027	0.046	0.041	0.032	0.05	0.161	0.084	0.07
PFOS	0.02	0.04	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.03	<0.02	*0.01*
PFOSA	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
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	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07
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	<0.02	0.03	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	*0.02*
PFHxDA	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07
PFODcA	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07
PFDS	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07
PFOSlin	<0.02	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	*0.01*
PFDA	0.015	0.049	0.014	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.032	<0.02	*0.02*
sum PFAS	0.47	0.69	0.49	0.79	0.44	0.44	0.48	0.50	0.44	0.48	0.73	0.52	0.54
sum PFAS$_{det}$	0.08	0.34	0.11	0.44	0.03	0.03	0.08	0.13	0.03	0.08	0.39	0.12	0.15

Table A.1.18: Monthly and annual mean concentrations (pg/m^3) for M/SCCPs in air at Zeppelin, 2020.

Zeppelin	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020	Min	Max
SCCP	159	238	357	364	270	369	515	1992	699	253	428	452	507	<120	6560
MCCP	381	***284***	832	***246***	***284***	333	1466	2019	696	***314***	1186	883	748	<320	5200

Concentrations marked as bold and italic are <LOD in more than 60% of the samples for that month. The presented concentrations represent LOD/2.

Table A.1.19: Monthly and annual mean concentrations (ng/m^3) for cVMS in air at Zeppelin, 2020.

Zeppelin	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020	Min.	Max.
D4	2.03	0.97	0.25	0.41	0.25	0.17	0.15	0.11	0.13	0.50	0.71	1.17	0.50	0.10	3.53
D5	3.99	1.85	0.34	0.69	0.29	0.33	0.37	0.18	0.23	1.51	1.64	1.62	1.04	0.06	9.45
D6	0.37	0.17	0.11	0.21	0.08	0.14	0.16	0.08	0.11	0.31	0.79	0.16	0.21	0.08	1.46
sum cVMS	5.81	2.86	0.71	1.31	0.62	0.64	0.68	0.38	0.47	2.33	3.15	2.75	1.74	0.25	11.4

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 2020. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	0.43	0.18	0.37	0.44	0.25	0.99	0.66	0.42	0.48	0.88	1.33	0.66	0.62
Hurdal	0.24	0.18	0.37	0.20	0.47	0.48	0.53	0.89	0.28	0.59	0.58	0.59	0.47
Kårvatn	0.03	0.02	0.13	0.06	0.05	1.05	0.57	0.18	0.03	0.09	0.20	0.21	0.14
Svanvik	0.71	-	0.81	0.81	0.80	2.52	1.23	0.92	0.46	0.76	0.61	0.96	1.05
Karpbukt	0.86	1.07	1.41	0.96	0.39	0.59	0.83	0.79	0.32	0.19	0.81	0.32	0.64

Table A.2.2: Monthly and annual volume weighted mean concentrations of cadmium in precipitation at Norwegian background stations 2020. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.02
Hurdal	0.01	0.02	0.04	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.03	0.02	0.02
Kårvatn	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.01	0.00	0.00	0.01	0.00	0.00
Svanvik	0.08	-	0.11	0.05	0.11	0.05	0.05	0.05	0.03	0.07	0.02	0.10	0.06
Karpbukt	0.04	0.05	0.11	0.04	0.03	0.02	0.02	0.04	0.02	0.02	0.08	0.03	0.03

Table A.2.3: Monthly and annual volume weighted mean concentrations of zinc in precipitation at Norwegian background stations 2020. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OKT	NOV	DES	2020
Birkenes	3.1	1.2	2.5	4.5	6	4.3	1.8	2.1	3.3	3.9	3.5	6.8	3.7
Hurdal	4.4	6.1	11	8.1	4.3	3.5	2.3	2.8	3	2.3	4.6	6.6	4.8
Kårvatn	1.3	0.7	1.1	0.9	0.9	6.3	1.1	1.6	1.6	2.5	2.2	1.8	1.4
Svanvik	2.5	-	12.4	5.7	6.5	5.4	6.1	6	6.8	4.3	2.4	3.4	5.3
Karpbukt	9.6	4.4	17.6	7.8	5.9	5.4	1.8	3.9	2.6	3.7	5.9	2.9	5.2

Table A.2.4: Monthly and annual volume weighted mean concentrations of nickel in precipitation at Norwegian background stations 2020. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	0.15	0.06	0.11	0.16	0.24	0.33	0.15	0.16	0.16	0.31	0.49	2.60	0.66
Svanvik	15.38	-	19.91	13.32	26.56	11.90	17.33	20.07	3.94	8.54	13.36	18.68	14.75
Karpbukt	8.26	14.07	23.57	12.42	9.54	7.59	5.03	11.21	7.08	7.34	20.97	8.89	9.55

Table A.2.5: Monthly and annual volume weighted mean concentrations of arsenic in precipitation at Norwegian background stations 2020. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	0.04	0.03	0.06	0.06	0.06	0.08	0.05	0.06	0.07	0.07	0.09	0.11	0.07
Svanvik	0.40	-	0.51	0.38	0.59	0.39	0.33	0.35	0.14	0.44	0.28	0.39	0.37
Karpbukt	0.21	0.28	0.60	0.32	0.13	0.15	0.10	0.27	0.24	0.18	0.36	0.14	0.22

Table A.2.6: Monthly and annual volume weighted mean concentrations of copper in precipitation at Norwegian background stations 2020. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	0.81	0.24	0.66	1.08	1.32	5.56	3.06	1.82	1.98	5.46	4.33	2.18	2.44
Svanvik	41.04	-	49.46	19.28	67.93	21.51	30.43	27.77	10.61	13.97	16.27	46.58	28.23
Karpbukt	12.58	17.53	38.94	15.86	18.79	13.42	10.97	18.02	9.04	8.53	32.53	13.11	15.04

Table A.2.7: Monthly and annual volume weighted mean concentrations of cobalt in precipitation at Norwegian background stations 2020. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	0.01	0.01	0.01	0.03	0.06	0.05	0.02	0.03	0.02	0.05	0.03	0.02	0.03
Svanvik	0.50	-	0.65	0.38	0.92	0.46	0.58	0.68	0.15	0.31	0.44	0.65	0.50
Karpbukt	0.24	0.45	0.77	0.40	0.40	0.31	0.21	0.48	0.26	0.24	0.75	0.24	0.35

Table A.2.8: Monthly and annual volume weighted mean concentrations of chromium in precipitation at Norwegian background stations 2020. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	0.07	0.05	0.05	0.11	0.23	0.29	0.20	0.08	0.06	0.39	0.13	0.07	0.14
Svanvik	0.06	-	0.31	0.28	0.46	0.63	0.38	0.26	0.10	0.09	0.14	0.12	0.27
Karpbukt	0.27	0.40	0.54	0.43	0.69	0.56	0.30	0.49	0.13	0.12	0.60	0.22	0.38

Table A.2.9: Monthly and annual volume weighted mean concentrations of manganese in precipitation at Norwegian background stations 2020. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	0.73	0.37	0.59	2.28	4.15	4.43	1.26	1.84	2.11	2.59	0.93	0.38	1.43

Table A.2.10: Monthly and annual volume weighted mean concentrations of vanadium in precipitation at Norwegian background stations 2020. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	0.14	0.10	0.21	0.22	0.36	0.29	0.22	0.22	0.18	0.28	0.22	0.15	0.20
Svanvik	0.95	-	0.94	0.35	0.90	0.49	0.24	0.24	0.14	0.37	0.25	2.61	0.50
Karpbukt	0.58	0.70	1.25	0.37	0.60	0.38	0.20	0.49	0.14	0.14	0.91	0.67	0.43

Table A.2.11: Monthly and annual volume weighted mean concentrations of aluminium in precipitation at Svanvik and Karpdalen. 2020. Unit: µg/l.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Svanvik	5	-	19	17	39	99	27	23	15	12	18	12	29
Karpbukt	22	13	179	33	119	85	64	125	15	11	100	31	65

Table A.2.12: Monthly and annual average volume weighted mean concentrations of mercury in precipitation at Birkenes in 2020. Unit: ng/l

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	3.1	1.6	4.6	8.4	11.6	8.4	8.1	4.6	2.2	2.7	1.7	2	3.7

Table A.2.13: Annual and monthly total precipitation in 2020. 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	2020
Birkenes	208.46	246.69	145.78	61.21	55.58	178.94	175.20	88.01	101.46	244.57	161.01	367.57	2034
Hurdal	115.19	130.66	82.00	40.66	32.25	102.70	118.47	55.00	81.10	243.41	119.34	291.91	1413
Kårvatn	270.34	243.06	126.54	229.19	174.82	27.08	179.57	76.63	137.00	124.34	144.22	55.14	1788
Svanvik	45.33	9.55	8.81	35.28	21.83	46.30	46.43	55.68	34.89	31.52	16.37	9.79	362
Karpbukt	49.67	20.65	21.99	34.41	66.09	49.27	67.95	71.52	68.19	59.96	16.26	16.51	542

Table A.2.14: Monthly- and annual wet deposition of lead at Norwegian background stations 2020 Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	90	44	54	27	14	177	116	37	49	215	214	243	1260
Hurdal	28	23	30	8	15	49	62	49	22	143	69	171	670
Kårvatn	9	5	17	14	9	28	103	14	5	11	28	11	255
Svanvik	32	-	7	29	17	117	57	51	16	24	10	9	379
Karpbukt	43	22	31	33	26	29	56	56	22	12	13	5	348

Table A.2.15: Monthly- and annual wet deposition of cadmium at Norwegian background stations 2020. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	3	1.3	1.9	0.9	0.8	3.7	1.5	1.1	1.4	4.5	2.6	7.9	30.3
Hurdal	1.5	2.2	3	0.6	0.6	1	1.1	0.6	1.1	2.5	3.1	7	24.3
Kårvatn	0.4	0.4	0.5	0.5	0.4	0.4	0.9	0.5	0.4	0.3	1.3	0.1	6
Svanvik	3.5	-	1	1.8	2.4	2.2	2.4	2.7	1	2.1	0.3	1	21
Karpbukt	1.8	1.1	2.3	1.4	1.8	1.1	1.3	3.1	1.6	1.2	1.3	0.4	18.4

Table A.2.16: Monthly- and annual wet deposition of zinc at Norwegian background stations 2020. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	647	293	360	275	332	767	319	182	334	964	566	2515	7560
Hurdal	511	794	902	331	140	363	278	157	247	568	554	1934	6772
Kårvatn	343	160	140	201	154	170	202	120	218	312	319	98	2434
Svanvik	115	-	110	201	142	251	283	333	238	136	39	33	1929
Karpbukt	476	91	386	268	389	267	126	278	174	222	95	48	2827

Table A.2.17: Monthly- and annual wet deposition of nickel at Norwegian background stations 2020. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	31	15	16	10	14	59	27	14	16	76	79	954	1345
Svanvik	697	-	175	470	580	551	804	1118	138	269	219	183	5335
Karpbukt	410	291	518	427	631	374	341	801	483	440	341	147	5179

Table A.2.18: Monthly- and annual wet deposition of arsenic at Norwegian background stations 2020. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	8	6	8	3	3	15	9	5	7	18	14	41	137
Svanvik	18	-	4	13	13	18	15	19	5	14	5	4	132
Karpbukt	10	6	13	11	9	7	7	19	16	11	6	2	117

Table A.2.19: Monthly- and annual wet deposition of copper at Norwegian background stations 2020. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	168	60	95	66	73	995	537	160	201	1336	697	800	4967
Svanvik	1860	-	436	680	1483	996	1413	1546	370	440	266	456	10215
Karpbukt	625	362	856	546	1242	661	745	1289	616	511	529	216	8158

Table A.2.20: Monthly- and annual wet deposition of cobalt at Norwegian background stations 2020. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	3	1	1	2	3	9	4	2	2	12	5	7	50
Svanvik	23	-	6	14	20	21	27	38	5	10	7	6	180
Karpbukt	12	9	17	14	27	15	14	34	18	14	12	4	189

Table A.2.21: Monthly- and annual wet deposition of chromium at Norwegian background stations 2020. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	14	11	7	7	12	52	35	7	7	96	21	26	276
Svanvik	3	-	3	10	10	29	18	15	4	3	2	1	98
Karpbukt	13	8	12	15	45	28	20	35	9	7	10	4	206

Table A.2.22: Monthly- and annual wet deposition of manganese at Norwegian background stations 2020. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	152	92	86	140	231	792	220	162	214	634	150	140	2918

Table A.2.23: Monthly- and annual wet deposition of vanadium at Norwegian background stations 2020. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	29	24	31	13	20	52	39	19	18	69	36	55	397
Svanvik	43	-	8	12	20	23	11	14	5	12	4	26	182
Karpbukt	29	14	28	13	40	19	13	35	9	8	15	11	233

Table A.2.24: Monthly- and annual wet deposition of aluminium at Norwegian background stations 2020. Unit: µg/m^2.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2019
Svanvik	233	-	167	607	850	4563	1264	1298	517	377	292	120	10563
Karpbukt	1069	264	3925	1120	7836	4204	4341	8919	995	680	1618	506	35456

Table A.2.25: Monthly and annual wet deposition of mercury at Birkenes in 2020. Unit: ng/m^2

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	2020
Birkenes	658	488	610	558	516	1463	1469	396	249	690	344	1048	8490

Table A.2.26: Annual average volume weighed mean concentration of heavy metals in precipitation at Norwegian background sites. 1976, Aug 1978-Jun 1979; 1980 (Feb-Dec), 1981-2020.

Site	Year	Pb µg/l	Cd µg/l	Zn µg/l	Ni µg/l	As µg/l	Cu µg/l	Co µg/l	Cr µg/l	V µg/l	Al µg/l	Hg ng/l
Birkenes	1976	12.7	0.27	28.9								
	1978	10.8	0.27	17.9								
Grey area	1980	7.9	0.34	15.7								
indicates	1981	7.4	0.24	6.2								
data from	1982	8.8	0.69	7								
Lista	1983	5.4	0.25	6.6								
	1984	6.2	0.29	12.1								
	1985	4.1	0.09	9.4								
	1986	4.8	0.12	9								
	1987	3.5	0.12	9.2								
	1988	7.4	0.12	14.1								
	1989	5.4	0.11	11.4								
	1990	3.8	0.12	9.5								13.8
	1991	3.6	0.06	7								11.8
	1992	2.9	0.04	5.2								10.9
	1993	3.1	0.06	6.5								11.3
	1994	2.6	0.05	5	0.3	0.2	1		0.2			8.1
	1995	2.2	0.05	6	0.4	0.4	1.1		0.8			13.9
	1996	2.8	0.06	4.9	0.4	0.4			0.3			19.7
	1997	1.7	0.03	4.2	0.4	0.5	1	0.04	0.2			10.6
	1998	1.59	0.043	4.9	0.59	0.2	1.13	0.03	0.58			9
	1999	1.5	0.040	4.4	0.4	0.2	1.7	0.03	0.2			9.7
	2000	1.39	0.030	3.2	0.34	0.28	1.13	0.03	<0.2			7.3
	2001	1.25	0.032	4.7	0.37	0.18	1.28	0.02	0.31			7.3
	2002	0.99	0.034	3.6	0.3	0.29	1.3	0.02	0.16			12.8
	2003	1.57	0.043	3.9	0.5	1.01	1.3	0.04	0.31			8.3
	2004	1.3	0.040	4.1	0.21	0.12	0.35	0.01	0.11	0.61		9.8
	2005	1.17	0.035	5.3	0.47	0.26	0.76	0.01	0.30	1.11		8.9
	2006	0.88	0.029	3.4	0.2	0.20	0.51	0.01	0.15	0.76		8.0
	2007	0.67	0.024	2.8	0.23	0.10	0.37	0.02		0.64		6.3
	2008	0.78	0.025	2.9	0.13	0.16	0.39	0.01	0.12	0.78		6.4
	2009	0.92	0.04	3.9	0.19	0.18	0.46	0.01	0.12	0.75		9.4
	2010	0.91	0.039	4.3	0.2	0.18	0.54	0.02	0.13	0.51		9.1
	2011	0.63	0.027	3.5	0.15	0.12	0.58	0.01	0.10	0.52		5.3
	2012	0.58	0.02	4.4	0.25	0.08	0.52	0.01	0.06	0.21		4.7
	2013	0.6	0.015	5.3	0.21	0.05	1.00	0.02	0.06	0.21		5.5
	2014	1.12	0.025	5.0	0.16	0.1	1.35	0.01	0.06	0.21		4.8
	2015	0.84	0.016	3.7	0.15	0.08	1.33	0.03	0.16	0.23		6.5
	2016	0.56	0.017	5.2	0.24	0.08	2.55	0.02	0.10	0.15	-	6.5
	2017	0.67	0.018	2.9	0.2	0.09	2.37	0.02	0.10	0.16	-	5.8
	2018	0.60	0.022	4.0	0.18	0.10	1.4	0.03	0.07	0.14	-	5.4
	2019	0.44	0.014	3.1	0.16	0.06	4.5	0.02	0.09	0.15	-	3.8
	2020	0.62	0.015	3.7	0.66	0.07	2.4	0.025	0.14	0.195	-	3.7
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								

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	V µg/l	Al µg/l	Hg ng/l
Nordmoen	1995	2	0.04	5.2								
(cont.)	1996	1.9	0.04	4.3								
Hurdal	1997	1.26	0.056	4.4								
	1998	1.55	0.063	4.9								
	1999	1.18	0.032	6.3								
	2000	1.13	0.042	4.2								
	2001	0.93	0.042	4.8								
	2002	0.7	0.026	4.1								
	2003	0.97	0.032	3.7								
	2004	0.89	0.041	10								
	2005	1.23	0.070	10.3								
	2006	0.96	0.061	8.4								
	2007	0.91	0.065	10.3								
	2008	0.74	0.044	7								
	2009	0.79	0.043	7.4								
	2010	1.33	0.030	8.9								
	2011	0.92	0.028	6.4								
	2012	0.49	0.017	6.8								
	2013	0.41	0.017	8								
	2014	0.58	0.026	6.4								
	2015	0.49	0.030	6.3								
	2016	0.55	0.029	7.7								
	2017	0.38	0.013	4.2								
	2018	0.51	0.019	4.4								
	2019	0.38	0.027	3.8								
	2020	0.47	0.017	4.8								
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								

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	V µg/l	Al µg/l	Hg ng/l
Kårvatn	2003	0.25	0.009	1								
(cont).	2004	0.13	0.005	1.2								
	2005	0.12	0.005	0.9								
	2006	0.17	0.010	1.9								
	2007	0.09	0.007	0.9								
	2008	0.1	0.005	1.2								
	2009	0.09	0.010	1.3								
	2010	0.14	0.009	3.7								
	2011	0.11	0.013	1.4								
	2012	0.11	0.005	1.5								
	2013	0.16	0.006	6.5								
	2014	0.31	0.013	2.9								
	2015	0.26	0.010	2.2								
	2016	0.19	0.004	2.2								
	2017	0.10	0.003	1.2								
	2018	0.26	0.005	2.3								
	2019	0.50	0.007	2.6								
	2020	0.14	0.0034	1.4								
Svanvik	1987	2	0.14	6	19.9*	2.4*	21.8*					
	1988	3.7	0.1	7.4	12.8	1.6	14.6					
	1989	1.4	0.14	4.6	15.5	1.3	14.4					
	1990	1.6	0.14	6.2	11.4	1.8	13.6	0.4	0.5			
	1991	1.3	0.07	3.4	9.3	1.1	10.4	0.3	0.4			
	1992	1.1	0.11	2.8	8.0	1.1	11.9	0.3	0.5			
	1993	1.1	0.12	3	10.9	1.2	13.4	0.4	0.6			
	1994	1.4	0.08	5	13.4	1.4	12.5	0.4	0.4			
	1995	1.7	0.11	5.4	17.4	1.8	17.4	0.6	0.4			
	1996	0.9	0.06	3.3	17.5	1.1	18.7	0.6	0.4			
	1997	1.9	0.11	3.8	17.3	1.8	21.4	0.6	0.3			
	1998	1.08	0.11	4.1	23.7	2.34	28.1	0.72	0.39			
	1999	0.83	0.08	8.4	11.1	1.41	14.0	0.37	0.32			
	2000	1.99	0.12	5.4	17.8	1.85	20.3	0.53	0.25			
	2001	2.56	0.16	8.5	20.7	2.31	20.2	0.65	0.39			
	2002	2.64	0.054	7	11.1	1.26	12.0	0.32	0.21			
	2003	2.32	0.08	6.2	10.6	0.85	12.0	0.34	0.22			
	2004	1.32	0.084	6.5	36.9	0.91	31.0	0.95	0.39			
	2005	1.84	0.143	5.2	55.3	1.72	58.0	1.59	0.41			
	2006	1.15	0.134	8.5	33.4	1.31	44.5	1.14	0.31			
	2007	1.25	0.231	4.5	45.2	1.83	41.6	1.14	0.61			
	2008	0.84	0.181	4.7	29.8	1.3	25.4	0.90	0.48			
	2009	1.63	0.146	3.8	42.0	2.21	32.6	1.13	0.85	0.56	15	
	2010	0.78	0.082	4.2	22.6	0.64	11.9	0.50	3.12	0.66	31	
	2011	0.85	0.186	3.9	17.5	1.06	30.1	0.58	0.34	0.46	22	
	2012	0.59	0.041	2.9	15.7	0.81	24.5	0.47	0.18	0.33	22	
	2013	1.09	0.059	3.9	26.0	1.7	51.1	0.78	0.23	0.79	23	
	2014	1.13	0.065	5.2	17.7	1.21	28.7	0.52	0.22	0.48	22	
	2015	1.93	0.084	5	29.3	1.49	33.5	0.89	0.36	0.47	35	
	2016	1.04	0.062	5.2	26.5	1.29	29.5	0.83	0.26	0.34	24	
	2017	0.85	0.088	4.2	27.6	1.21	34.0	0.85	0.25	0.47	20	
	2018	0.92	0.062	4.3	26.5	0.9	30.5	0.74	0.27	0.40	36	
	2019	1.01	0.09	4.4	40.9	0.65	56.0	1.18	0.39	0.77	89	
	2020	1.047	0.0581	5.3	14.7	0.366	28.2	0.498	0.272	0.50	29	

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	V µg/l	Al µg/l	Hg ng/l
Karpdalen	1991	1.93	0.432	5.6	6.87	1.10	11.0	0.22	0.69			
	1993	1.33	0.057	5.6	4.27	0.60	5.8	0.17	1.30			
	1994	1.45	0.067	5.4	9.13	0.80	9.2	0.32	0.73			
	1995	1.69	0.069	4.1	9.21	1.05	6.7	0.33	0.37			
	2015	1.14	0.061	7.4	24.2	1.04	26.1	0.79	0.44	0.53	47	
	2016	0.96	0.066	7.2	42.1	1.19	38.5	1.23	0.48	0.46	36	
	2017	0.77	0.060	5.0	20.2	0.80	25.5	0.63	0.32	0.45	48	
	2018	0.79	0.063	8.1	22.5	0.72	21.9	0.66	0.44	0.52	67	
	2019	1.06	0.038	6.5	14.9	0.32	21.9	0.43	0.31	0.40	126	
	2020	0.64	0.034	5.2	9.5	0.22	15.0	0.35	0.38	0.43	65	

Table A.2.27: Annual average volume weighed mean concentration of heavy metals in precipitation at Norwegian background sites that have been closed.

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

Table A.2.27: cont.

Site	Year	Pb µg/l	Cd µg/l	Zn µg/l	Ni µg/l	As µg/l	Cu µg/l	Co µg/l	Cr µg/l
Valdalen	1994	1	0.03	4.2	0.1	0.1	0.6	0.01	0.1
	1995	1.4	0.03	4.6	0.4	0.1	0.8	0.02	0.2
	1996	1.1	0.03	4.1	0.3	0.1	1	0.03	0.2
	1997	1.1	0.05	6.2	0.4	0.1	0.1	0.02	0.2
	1998	0.76	0.03	4.8	0.17	0.09	0.57	0.02	0.16
	1999	0.69	0.1	9.6	0.47	<0.1	1.13	0.02	0.37
	2000	1.01	0.026	4.2	<0.2	<0.1	0.47	0.02	<0.2
Namsvatn	1994	0.5	0.03	2.3	0.2	0.1	0.4	0.02	0.1
	1995	0.5	0.01	2.3	0.3	0.1	0.2	0.01	0.1
	1996	0.5	0.02	3	0.1	0.1	0.5	0.01	<0.2
Øverbygd	1995	0.4	0.01	2.3	0.4	0.1	0.5	0.02	0.1
	1996	0.5	0.03	3.5	0.4	0.1	1.3	0.02	0.3
	1997	0.5	0.01	2.7	0.1	0.1	0.3	0.01	0.1
	1998	0.4	0.01	3.8	0.2	0.1	0.6	0.02	0.1
	1999	0.54	0.01	5	<0.2	<0.1	0.33	0.01	<0.2
	2000	0.37	0.02	1.9	0.21	<0.1	0.38	0.01	<0.2
Jergul	1979	3.5	0.22	7.8					
	1980	2.6	0.08	4.5					
	1981	1.8	0.05	3.5					
	1982	2.3	0.11	3.1					
	1983	1.5	0.07	3.6					
	1984	2.2	0.09	9.8					
	1985	2	0.08	5					
	1986	2	0.03	5.2					
	1987	1.3	0.07	4.6					
	1988	1.3	0.07	5.1					
	1989	1.3	0.05	3.3					
	1990	0.7	0.16	2.7					
	1991	0.7	0.02	2.2					
	1992	0.5	0.05	1.6					
	1993	0.5	0.05	2.4					
	1994	0.5	0.03	4.1					
	1995	0.8	0.04	3.5					
	1996	0.5	0.02	3.3					
Karasjok	1997	0.6	0.02	3.1					
	1998	0.8	0.04	3.5					
	1999	0.44	0.03	5.8					
	2000	0.57	0.02	11.6					
	2001	0.67	0.03	4.8					
	2002	0.58	0.033	6.4					
	2003	0.59	0.013	3.4					
	2004	0.74	0.014	4					
	2005	0.5	0.019	4.3					
	2006	0.37	0.02	2.8					
	2007	0.47	0.029	4.7					
	2008	0.38	0.017	7.6					
	2009	0.28	0.024	4.7					

Table A.2.28: Monthly and annual average mean concentrations of heavy metals in PM10 and mercury in gas phase at Birkenes in 2020. Unit: ng/m³

	Al	As	Cd	Cr	Co	Cu	Fe	Pb	Mn	Ni	Ti	V	Zn	Hg(g)
JAN	13	0.08	0.016	0.08	0.011	0.18	10	0.41	0.42	0.10	0.80	0.10	1.5	1.45
FEB	9	0.06	0.011	0.16	0.008	0.15	6	0.28	0.36	0.08	0.44	0.11	1.3	1.46
MAR	33	0.19	0.029	0.28	0.022	0.48	28	0.68	1.06	0.19	1.74	0.31	3.0	1.49
APR	59	0.15	0.021	0.14	0.025	0.22	41	0.51	1.28	0.12	3.35	0.23	2.5	1.46
MAY	42	0.08	0.010	0.12	0.017	0.22	34	0.24	0.90	0.10	3.32	0.26	1.4	1.40
JUN	73	0.14	0.017	0.12	0.029	0.61	54	0.48	1.35	0.22	3.86	0.37	2.0	1.48
JUL	14	0.13	0.009	0.13	0.008	0.17	13	0.29	0.43	0.10	1.04	0.19	1.2	1.49
AUG	66	0.33	0.025	0.29	0.030	0.64	58	0.65	1.50	0.33	3.39	0.81	3.1	1.32
SEP	68	0.22	0.025	0.23	0.025	0.35	48	0.79	1.37	0.17	2.57	0.29	3.6	1.47
OCT	173	0.24	0.029	0.42	0.052	0.40	118	0.93	3.38	0.24	4.78	0.47	9.9	1.67
NOV	9	0.26	0.027	0.15	0.007	0.29	11	0.99	0.55	0.08	0.52	0.19	6.4	1.75
DEC	5	0.07	0.014	0.13	0.006	0.24	8	0.57	0.26	0.09	0.26	0.10	13.0	1.62
2020	47	0.16	0.019	0.19	0.020	0.33	35	0.57	1.07	0.15	2.16	0.28	4.1	1.50

Table A.2.29: Monthly and annual average mean concentrations of heavy metals in aerosols and mercury in gas phase at Andøya in 2020. Unit: ng/m³

	Al	As	Cd	Cr	Co	Cu	Fe	Pb	Mn	Ni	Ti	V	Zn	Hg(g)
JAN	12	0.02	0.004	0.04	0.004	0.30	9	0.08	0.14	0.09	0.55	0.09	0.5	1.52
FEB	22	0.01	0.002	0.07	0.005	0.80	9	0.07	0.20	0.06	0.69	0.04	0.3	1.55
MAR	43	0.01	0.004	0.49	0.013	1.88	13	0.10	0.71	0.41	0.92	0.05	1.7	1.53
APR	30	0.02	0.004	0.05	0.012	0.11	19	0.10	0.32	0.06	1.55	0.06	0.3	1.39
MAY	21	0.02	0.003	0.05	0.008	0.18	13	0.07	0.24	0.06	1.00	0.06	0.2	1.34
JUN	28	0.08	0.004	0.16	0.010	1.02	19	0.17	0.37	0.11	1.38	0.07	1.0	1.44
JUL	13	0.04	0.005	0.10	0.008	1.83	11	0.19	0.24	0.14	0.71	0.07	0.5	1.43
AUG	8	0.02	0.002	0.03	0.003	0.11	9	0.06	0.12	0.02	0.57	0.03	0.3	1.36
SEP	79	0.04	0.013	0.10	0.014	0.31	34	0.35	0.86	0.08	2.05	0.11	1.2	1.27
OCT	66	0.11	0.017	0.12	0.020	0.22	39	0.72	0.91	0.08	2.25	0.12	1.4	1.30
NOV	16	0.02	0.002	0.06	0.005	0.22	10	0.07	0.18	0.05	0.73	0.03	0.3	1.36
DEC	8	0.02	0.004	0.03	0.003	0.17	8	0.12	0.12	0.03	0.41	0.03	0.4	1.48
2020	28	0.03	0.005	0.11	0.009	0.61	16	0.17	0.37	0.10	1.07	0.06	0.7	1.41

Table A.2.30: Monthly and annual average mean concentrations of heavy metals in aerosols and mercury in gas phase at Zeppelin in 2020. Unit: ng/m³

	Al	As	Cd	Cr	Co	Cu	Fe	Pb	Mn	Ni	Ti	V	Zn	Hg(g)
JAN	203	0.14	0.026	0.37	0.041	0.23	95	0.56	1.94	0.17	4.12	0.25	1.6	1.54
FEB	22	0.06	0.015	0.09	0.006	0.10	12	0.30	0.29	0.04	0.78	0.05	0.8	1.56
MAR	14	0.04	0.009	0.13	0.004	0.37	7	0.22	0.19	0.07	0.48	0.04	0.8	1.25
APR	246	0.07	0.043	0.54	0.046	0.40	101	0.29	1.88	0.29	5.75	0.26	3.2	1.39
MAY	160	0.04	0.014	0.53	0.042	0.21	72	0.17	1.25	0.34	5.45	0.24	1.0	1.24
JUN	49	0.01	0.044	0.12	0.010	0.47	21	0.09	0.41	0.06	1.69	0.06	0.5	1.63
JUL	25	0.03	0.087	0.06	0.008	0.40	14	0.09	0.44	0.06	0.81	0.05	1.0	1.54
AUG	42	0.03	0.149	0.06	0.014	0.18	24	0.10	0.52	0.07	1.47	0.07	1.4	1.32
SEP	85	0.02	0.285	0.18	0.023	0.26	39	0.08	0.99	0.15	2.50	0.09	2.9	1.34
OCT	131	0.08	0.019	0.22	0.030	0.16	69	0.44	1.59	0.13	3.62	0.19	1.4	1.42
NOV	1510	0.25	0.061	1.89	0.350	0.76	827	0.66	14.82	10.53	31.89	1.80	6.9	1.50
DEC	280	0.06	0.035	0.43	0.056	0.35	128	0.26	2.16	0.25	6.19	0.30	4.0	1.50
2020	173	0.06	0.059	0.31	0.039	0.31	86	0.26	1.64	0.79	4.17	0.22	1.8	1.44

Table A.2.31: Monthly and annual average mean concentrations of heavy metals in aerosols at Svanvik in 2020. Unit: ng/m^3

	Al	As	Cd	Cr	Co	Cu	Fe	Pb	Mn	Ni	V	Zn
JAN	8	0.49	0.074	0.19	0.13	6.8	18	1.32	0.28	4.0	4.0	5.0
FEB	6	0.13	0.025	0.16	0.03	0.9	11	0.53	0.19	0.8	0.3	1.8
MAR	16	0.23	0.050	0.20	0.11	3.4	24	0.77	0.36	2.8	1.0	3.2
APR	41	0.38	0.076	0.14	0.13	4.7	42	0.81	0.61	3.2	1.5	2.7
MAY	64	0.21	0.054	0.26	0.12	7.5	68	0.61	0.99	2.4	1.2	2.2
JUN	51	0.28	0.050	0.25	0.20	9.7	66	0.76	0.92	4.4	0.4	2.0
JUL	45	0.37	0.063	0.20	0.13	4.1	50	1.15	0.84	2.7	0.4	3.4
AUG	52	0.41	0.055	0.29	0.22	5.6	70	1.12	1.02	5.1	0.5	2.8
SEP	19	0.22	0.039	0.13	0.07	2.3	25	0.70	0.54	1.6	0.3	2.6
OCT	105	0.90	0.150	0.40	0.11	3.8	75	2.64	1.70	2.5	1.2	7.3
NOV	16	0.09	0.028	0.09	0.04	1.0	14	0.45	0.22	0.9	0.6	1.5
DEC	-	-	-	-	-	-	-	-	-	-	-	-
2020	38	0.33	0.059	0.21	0.12	4.6	42	0.97	0.69	2.8	1.0	3.1

Table A.2.32: Monthly and annual average mean concentrations of heavy metals in aerosols at Karpdalen in 2020. Unit: ng/m^3

	Al	As	Cd	Cr	Co	Cu	Fe	Pb	Mn	Ni	Ti	V	Zn
JAN	14	1.00	0.175	0.25	0.21	15.6	24	3.14	0.30	6.6	0.4473	7.5	7.8
FEB	8	0.67	0.117	0.26	0.16	4.1	19	2.14	0.20	3.9	0.145	1.8	4.8
MAR	14	0.52	0.105	0.20	0.15	4.8	24	1.21	0.30	3.9	0.2956	1.5	4.4
APR	28	0.32	0.068	0.15	0.13	5.9	30	0.83	0.45	3.3	0.9733	1.8	2.7
MAY	189	0.54	0.143	0.66	0.46	11.8	200	1.56	2.58	9.5	10.6957	2.3	6.4
JUN	66	0.30	0.049	0.20	0.15	3.2	67	0.80	0.97	3.2	3.7153	0.4	2.4
JUL	157	0.54	0.087	0.49	0.27	7.9	149	1.52	2.20	5.2	8.4859	0.7	3.9
AUG	93	0.78	0.138	0.27	0.23	12.6	95	2.37	1.34	4.7	4.9549	0.6	5.5
SEP	43	1.04	0.225	0.31	0.23	8.9	49	3.35	0.88	5.3	1.4065	1.1	9.2
OCT	18	0.97	0.161	0.14	0.14	5.9	22	2.38	0.39	3.4	0.5603	1.5	6.7
NOV	15	0.42	0.140	0.12	0.13	4.9	19	2.75	0.26	2.7	0.4227	1.7	5.9
DEC	12	0.66	0.101	0.15	0.09	7.5	18	3.20	0.35	3.2	0.2889	5.5	5.4
2020	56	0.64	0.126	0.27	0.20	7.7	61	2.09	0.88	4.6	2.7976	2.1	5.4

Table A.2.33: Monthly and annual concentration of Mercury at Trollhaugen in 2020. Unit: ng/m^3

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	2020
Trollhaugen	1.023	1.020	1.101	1.074	1.086	1.064	1.020	0.999	0.983	0.859	0.898	0.855	0.998

Table A.2.34: Annual mean concentration of heavy metals in air and aerosols at Norwegian background sites. Unit: ng/m^3

Site	Year	As	Cd	Cr	Co	Cu	Pb	Mn	Ni	V	Zn	Hg (g)	Hg (part)	RGM Apr-May
Lista	1991	0.77	0.063	1.86		0.80	2.69		0.59		4.4			
	1992	0.19	0.046	1.79		0.47	2.35		1.33		3.9	2.06		
	1993	0.41	0.066	3.67		0.85	3.67		0.81		7.0	1.84		
	1994	0.36	0.067	2.80		0.90	3.67		0.88		4.5	1.84		
finfraksjon	1995	0.34	0.06	0.28		0.41	2.74		0.56	1.10	4.2	1.63		
PM(2.5)	1996	0.35	0.068	0.32		0.42	2.95		0.58	1.51	4.3	1.62		
	1997	0.24	0.063	0.57	0.02	0.50	2.55		0.68	1.29	5.0	1.40		
	1998	0.21	0.045	0.61	0.01	0.39	1.94		0.21	0.98	3.9	1.40		
	1999	0.19	0.05	0.18	0.02	0.27	1.82		0.30	0.66	3.9	1.86		
	2000	0.22	0.052	0.82	0.02	0.29	1.92		0.65	1.04	4.3	1.67		
	2001	0.49	0.055	0.37	0.02	0.32	1.98		0.62	6.40	5.4	1.65		
	2002	0.24	0.053	0.30	0.02	0.49	2.43		0.53	1.15	4.2	1.64		
	2003	0.40	0.073	0.28	0.02	0.48	2.47		0.94	1.98	7.5	1.77		
grovfraksjon (PM10-PM2.5)	1995	0.13	0.018	1.54		0.64	1.02		0.25	0.38	1.9			
	1996	0.10	0.015	0.77		0.46	0.79		0.26	0.33	1.5			
	1997	0.08	0.016	0.50	0.03	0.73	0.72		0.23	0.36	2.2			
	1998	0.06	0.148	0.93	0.02	0.40	0.62		0.41	0.25	3.1			
	1999	0.08	0.012	1.36	0.04	0.47	0.52		0.27	0.38				
	2000	0.07	0.014	0.69	0.01	0.37	0.52		0.10	0.35	1.8			
	2001	0.17	0.011	0.64	0.01	0.32	0.44		0.13	1.69	1.6			
	2002	0.06	0.009	0.74	0.01	0.44	0.56		0.11	0.33	1.6			
	2003	0.10	0.009	0.47	0.02	0.37	0.47		0.18	0.58	1.9			
Birkenes	2004	0.20	0.044	<DL		0.83	1.61		0.57	0.70	3.9	1.70		
	2005	0.52	0.088	1.07	0.08	3.45	1.99		2.18	1.44	15.1	1.90		
	2006	0.31	0.063	1.16	0.05	1.56	2.01		0.75	1.20	5.8	1.76		
	2007	0.21	0.047	0.52	0.029	0.82	1.29		0.61	0.81	4.3	1.83		
	2008	0.20	0.035	-	0.030	0.83	1.04		0.55	0.66	3.6	1.73		
	2009	0.21	0.037	1.45	0.028	0.71	1.07		0.66	0.82	5.4	1.69		
Birkenes II	2010	0.18	0.040	0.39	0.033	0.82	1.88		0.50	0.61	4.1	(1.66)		
	2011	0.33	0.050	0.71	0.039	0.93	1.70		0.61	0.61	6.1	1.65		
	2012	0.15	0.028	0.55	0.019	0.52	0.80		0.29	0.35	3.1	1.62		
	2013	0.15	0.027	0.33	0.026	0.52	0.73		0.38	0.39	3.9	1.56		
	2014	0.21	0.033	0.18	0.025	0.59	0.88		0.40	0.45	4.5	1.53		
	2015	0.16	0.025	0.73	0.014	0.50	0.73		0.19	0.21	4.0	1.51		
	2016	0.14	0.022	1.05	0.014	0.41	0.56		0.16	0.26	3.3	1.42		
	2017	0.14	0.021	2.91	0.013	0.31	0.54		0.15	0.20	3.2	1.45		
	2018	0.17	0.032	0.32	0.026	0.48	0.75		0.24	0.36	3.8	1.45		
	2019	0.14	0.028	0.29	0.020	0.41	0.65		0.18	0.32	4.3	1.45		
	2020	0.16	0.019	0.19	0.020	0.33	0.57	1.07	0.15	0.28	4.1	1.50		

Table A.2.34: (cont.)

Site	Year	As	Cd	Cr	Co	Cu	Pb	Mn	Ni	V	Zn	Hg (g)	Hg (part)	RGM Apr-May
Andøya	2010	0.07	0.017	0.44	0.011	0.53	0.58	0.38	0.32	0.25	1.3	1.67		
	2011	0.06	0.010	0.17	0.008	0.27	0.30	0.37	0.12	0.19	0.9	1.61		
	2012	0.06	0.011	0.24	0.013	0.49	0.34	0.58	0.17	0.15	1.5	1.61		
	2013	0.04	0.008	0.11	0.011	0.24	0.24	0.41	0.14	0.12	1.4	1.54		
	2014	0.07	0.025	0.10	0.037	0.25	0.28	0.46	0.13	0.15	1.3	1.50		
	2015	0.06	0.010	0.08	0.006	0.17	0.28	0.23	0.10	0.11	0.8	1.50		
	2016	0.06	0.007	0.16	0.011	0.23	0.20	0.39	0.21	0.16	1.2	1.43		
	2017	0.04	0.008	0.14	0.012	0.51	0.22	0.54	0.18	0.13	1.0	1.40		
	2018	0.04	0.007	0.19	0.016	0.19	0.23	0.53	0.15	0.18	1.0	1.40		
	2019	0.04	0.007	0.20	0.015	1.14	0.20	0.51	0.21	0.23	1.1	1.41		
	2020	0.03	0.005	0.11	0.009	0.61	0.17	0.37	0.10	0.06	0.7	1.41		
Zeppelin	1994	0.23	0.034	0.20	0.01	0.32	0.83	0.37	0.19	0.17	1.9	1.79		
	1995	0.14	0.019	0.22	0.01	0.31	0.64	0.42	0.15	0.19	1.5	1.62		
	1996	0.05	0.01	0.23	0.02	0.28	0.48	0.57	0.14	0.12	1.5	1.59		
	1997	0.13	0.024		0.02	0.40	0.69	0.34	0.13	0.20	1.5	1.18		
	1998	0.12	0.027	0.16	0.14	0.35	0.71	0.34	0.12	0.11	1.4	1.55		
	1999	0.10	0.022	0.14	0.06	0.33	0.49	0.47	0.14	0.17	1.6	1.76		
	2000	0.30	0.018	0.06	0.01	0.41	0.62	0.34	0.09	0.07	1.5	1.50		
	2001	0.40	0.016	0.04	0.01	0.31	0.50	0.24	0.08	0.12	1.3	1.56	1.62	
	2002	0.39	0.027	0.04	0.01	0.25	0.66	0.26	0.07	0.08	1.2	1.60	5.3	6.0
	2003	0.12	0.021	0.09	0.01	0.23	0.69	0.34	0.10	0.14	1.3	1.61	2.2	14.5
	2004	0.07	0.018	0.11	0.04	0.31	0.63	0.40	0.10	0.08	4.1	1.50		42.4
	2005	0.11	0.118	0.13	0.03	0.92	1.04	0.40	0.13	0.13	3.2	1.58		
	2006	0.05	0.016	0.08	0.01	0.30	0.44	0.34	0.05	0.10	1.6	1.60		
	2007	0.05	0.023	0.08	0.01	0.61	0.60	0.20	0.09	0.06	1.4	1.68		
	2008	0.05	0.012	0.07	0.007	0.37	0.37	0.23	0.08	0.08	1.6	1.58		
	2009	0.06	0.017	0.14	0.013	0.30	0.43	0.43	0.13	0.13	1.5	1.55		
	2010	0.05	0.014	0.10	0.013	0.17	0.38	0.45	0.14	0.10	1.0	1.56		
	2011	0.07	0.015	0.11	0.010	0.16	0.38	0.45	0.09	0.08	1.0	1.52		
	2012	0.04	0.008	0.09	0.008	0.13	0.22	0.35	0.07	0.05	1.2	1.51		
	2013	0.10	0.012	0.16	0.012	0.25	0.46	0.62	0.12	0.07	2.3	1.47		
	2014	0.05	0.012	0.14	0.012	0.22	0.22	0.60	0.14	0.06	1.7	1.48		
	2015	0.07	0.010	0.16	0.009	0.29	0.26	0.49	0.11	0.06	1.4	1.49		
	2016	0.04	0.006	0.14	0.007	0.18	0.14	0.46	0.11	0.05	1.4	1.48		
	2017	0.06	0.011	0.29	0.015	0.28	0.28	0.86	0.36	0.09	1.6	1.43		
	2018	0.03	0.020	0.16	0.012	0.68	0.14	0.49	0.15	0.06	1.7	1.42		
	2019	0.05	0.021	0.32	0.015	0.46	0.29	0.56	0.23	0.08	2.1	1.42		
	2020	0.06	0.059	0.31	0.039	0.31	0.26	1.64	0.79	0.22	1.8	1.44		

Table A.2.34: (cont.)

Site	Year	As	Cd	Cr	Co	Cu	Pb	Mn	Ni	V	Zn	Hg (g)	Hg (part)	RGM Apr-May
Svanvik	2011	3.11			0.43	11.3			13.0					
	2012	1.82			0.43	8.0			7.4					
	2013	2.04			0.38	9.4			9.9					
	2014	2.03			0.31	6.7			7.8					
	2015	1.22	0.11		0.31	5.7			7.8					
	2016	1.73	0.13	0.27	0.29	5.9	2.30	0.83	7.2	1.7	5.0			
	2017	1.93	0.18	0.29	0.38	8.1	2.39	0.84	9.9	2.5	8.6			
	2018	1.11	0.11	0.31	0.29	5.7	1.59	0.56	7.2	2.0	5.9			
	2019	0.79	0.11	0.20	0.28	5.7	1.82	0.55	6.6	2.0	5.2			
	2020	0.33	0.06	0.21	0.12	4.6	0.97	0.69	2.8	1.0	3.1			
Karpdalen	2011	3.08			0.24	5.4			5.8					
	2012	3.45			0.41	12.8			11.5					
	2013	8.19			-	30.5			-					
	2013	2.99			0.46	11.4			11.8					
	2014	11.66			1.94	-			-					
	2015	2.47			0.33	6.9			8.0					
	2016	2.25	0.16	0.26	0.31	6.3	2.6	-	7.6	1.9	5.3			
	2017	2.78	0.28	0.26	0.33	8.2	4.2	0.72	8.5	3.1	10.1			
	2018	2.16	0.24	0.28	0.34	7.6	3.5	0.69	8.8	3.6	10.2			
	2019	1.29	0.17	0.20	0.28	6.4	2.5	0.41	7.2	2.6	7.4			
	2020	0.64	0.13	0.27	0.20	7.7	2.1	0.88	4.6	2.1	5.4			
Troll / Trollhaugen	2010											0.93		
	2011											0.95		
	2012											0.98		
	2013											0.90		
	2014											0.95		
	2015											0.96		
	2016											0.89		
	2017											0.98		
	2018											0.97		
	2019											1.00		
	2020											0.998		

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 and an airflow of 2.3 m^3/hour. 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. At Andøya and the Zeppelin Observatory, sampling of heavy metals on particles are done using a Digitel high volume air sampler without any defined size cut off. Samples are collected on Whatman 41 filters for 48 hours with an airflow rate of 20-25 m^3/hour. 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 $SnCl_2$ reduction, dual gold trap amalgamation, thermal desorption and cold vapour atomic fluorescence spectrometry (CVAFS) (Iverfeldt, 1991b, Bloom and Fitzgerald, 1988, EMEP manual). The detection limit is 0.05 ng/L.

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

POPs and organic contaminants of emerging concern

Air sampling of HCB, OCPs, PCBs, PAHs, PBDEs, HBCDs, TBA, ionic and volatile PFASs, S/MCCPs, nBFRs, OPFRs, phthalates, and 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 most POPs and emerging organic contaminants data are reported for sum gas- and particle phase (i.e. bulk concentrations). For ionic PFAS, only a GFF was used and data are reported for particle phase only, and for volatile PFAS, only the PUF/XAD/PUF sandwich was used and data are reported for gas phase only. Specification on each sampler type is given in Table A.3.3. Flow-rate and sampling conditions were digitally monitored and documented (e.g. power failures, etc.) as an integrated part of the sampling and quality control procedure.

Table A.3.3: Specification on air samplers for POPs and organic contaminants of emerging concern.

	DIGITEL	NILU sampler
Flow rate	~25 m^3/hour	~25 m^3/hour
Filter	GFF: Whatman Type GF/C	GFF: Gelman Type AE
PUF plugs	Diameter 75 mm, length 40 mm, density 25 kg/m^3	Diameter 110 mm, length 50 mm, density 25 kg/m^3
Usage	Ionic and volatile PFAS, nBFRs, OPFRs, phthalates (Zeppelin) HCB, ionic and volatile PFAS (Andøya) HCB, OCPs, PCBs, PBDEs, HBCDs, TBA, PAHs, M/SCCPs, ionic and volatile PFAS, nBFRs, OPFRs, phthalates, dechloranes (Birkenes)	HCB, OCPs, PCBs, PAHs, PBDEs, HBCDs, 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 total air volumes of 600-1950 m^3 (as reported on sampling protocols).

Table A.3.4: Sampling durations for individual POP classes at each sampling station.

	Birkenes	Andøya	Zeppelin
HCB	24 h	48 h	48 h
OCPs	24 h	-	48 h
PCBs	24 h	-	48 h
PAHs	24 h	-	48 h
PBDEs	48 h*	-	72 h
HBCDs	48 h*	-	72 h
PFAS*	48-72 h	48-72 h	48-72 h
S/MCCPs	24 h	-	48 h
Siloxanes**	72 h	-	72 h
nBFRs	48-72 h	-	48-72 h
OPFRs	48-72 h	-	48-72 h
Phthalates	48-72 h	-	48-72 h
Dechloranes	24 h	-	48 h

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

After sampling the exposed samples (GFF, PUFs, PUF/XAD/PUF) were sealed separately in gas-tight containers and transported to NILU's laboratory for further processing and quantification. In addition, a number of field blank samples followed the yearly sample batch in order to control potential contamination risks (as a part of the extensive control procedures of the accredited quality system). All exposed samples were registered and stored cold (2˚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 for ionic PFAS representing the particle phase concentrations only and PUF/XAD/PUF was used for volatile PFAS representing concentrations in the gas phase only.

Sampling of Cyclic volatile methyl siloxanes (cVMS)

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

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

All lab operations were strictly performed in a laminar flow clean cabinet that is fitted with HEPA and charcoal filter to remove dust and air contaminants of the laboratory air and of laboratory personnel without personal-care products in order to reduce the risk of contamination during the preparation and analytical steps.

All samples were spiked to the upper frit of a cartridge with 20 µL of internal standard (IS) containing 13C-labelled D4, D5 and D6 in acetone (1 ng/µl). Then the cartridge was eluted slowly with ca 5 ml of

hexane, so that 3.5-4 ml of eluate was collected into a 4 ml screw-cap vial. Before quantitative analysis, 50 µl of a recovery standard containing M4T in hexane (0.2 ng/µl) was added to the vial and the vial was sealed immediately with a crimp cap. An aliquot was taken and transferred to a crimped cap GC vial prior to instrumental analysis.

Extracts were analyzed on an Agilent 7890A GC connected to an Agilent 5975C MS detector and a Turret autosampler. Helium (purity 5.0) was used as carrier gas (constant flow rate 1.0 mL min-1). The GC injector was equipped with a Merlin microseal septum and a 5.0 mm I.D. gooseneck splitless liner with deactivated glass wool (Restek, USA), while a 10 m Rxi guard column (Restek, 0.32 mm I.D.) was connected to a 30 m DB-5 column (Agilent Technologies, 0.25 mm I.D., 0.25 µm film thickness). A 10 µl syringe was used to inject 5 µL sample at an injector temperature of 200 °C. The GC oven started at 40 °C for 1 min, followed by 10 °C min-1 up to 90°C for 6.0 and 35 °C min-1 to 300 °C for with a final hold time of 2 min. The MS ion source was operated at 230 °C and the quadrupole at 150 °C. Two ions were monitored for each compound (m/z 281 and 282 for D4, 285 and 286 for 13C4-D4, 267 and 355 for D5, 364 and 365 for 13C10-D5, 341 and 429 for D6, 434 and 435 for 13C6-D6). 5-point calibration curves (5 ng/ml to 60 ng/ml) were used for quantification.

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

Samples were spiked with 20 µL of internal standards (IS) containing ^{13}C-labelled PCB congeners (~230 pg/µL), 20 µL IS containing ^{13}C-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, 20 µL ^{13}C-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 samples for nBFRs were spiked with 20 uL of IS containing ^{13}C-labelled nBFR congeners (~1000 pg/µL), and extracted in acetone/hexane (1:1, v:v). All the extracts were concentrated and cleaned by acid treatment and silica fractionation. Before quantitative analysis, 20 µL of unlabelled tetrachloronaphthalene (TCN, 100 pg/µL) was added as recovery standard (RS).

Identification and quantification of HCB, PCBs, OCPs and nBFRs was carried out using a high-resolution gas chromatography coupled to a high-resolution mass spectrometer as detector (HRGC/HRMS). The analyses were performed in Electron Impact ionization (EI) mode for PCBs, HCB, HCHs, DDTs and nBFRs using selected ion monitoring (SIM) for the respective compounds groups. Identification and quantification of chlordanes, SCCP, 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, 13 OCPs and 14 nBFRs were quantified.

Analysis and quantification of PAHs

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

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

Analysis and quantification PBDEs, TBA, HBCDs

Samples were spiked with 20 µL of IS containing ^{13}C-labelled PBDE congeners (~270-2500 pg/µL) and 20 µL IS containing ^{13}C-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 compound groups. In total, 17 PBDE congeners plus TBA were quantified.

For identification and quantification of HBCDs, an aliquot of the final sample extract was solvent exchanged into methanol. The extract was then analysed using high performance liquid chromatography system in combination with a time-of-flight high resolution mass spectrometer as detector (HPLC/MS-TOF). The analyses were performed with Electrospray ionisation (ESI) in negative ion mode using full scan mass detection (R=10 000 FWHM). In total, three HBCDs (α, β, γ) were quantified.

Analysis and quantification OPFRs

All glass equipment were wrapped in aluminium foil and heated to 450°C for 8 hr and rinsed in acetonitrile before use. All lids lined with PTFE and metal was ultrasonicated for 10 min in acetonitrile before use. The Soxhlet units are further cleaned by a pre-extraction with Acetone without samplers.

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

All clean-up of samples was performed in a laminar flow clean cabinet fitted with HEPA and charcoal filter to remove dust and air contaminants of the laboratory air. SPE (solid phase extraction) columns were used prepacked with a mixture Z-sep and C18 silica and Florisil on top (EZ-POP from Supelco) which was washed with acetonitrile and dried at -15mmHg for 10min before use. After adding the extract onto the column, acetonitrile was used to elute out all the OPFRs. Samples was concentrated using centrifugal vacuum evaporation and transferred to analytical glass and 50uL of 0.2% formic acid in Milli-Q water.
Analysis and quantification of OPFRs was performed using UPLC-MSMS in ESI mode. Before quantitative analysis, 10 ng of d27-TDMPP was added as RS.

Analysis and quantification of ionic PFAS

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

Analysis and quantification of volatile PFAS

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

Analysis and quantification of phthalates

Phthalates are analysed at a sub-contractor (i.e. IVL, Sweden).
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 use. 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, analysis and quantification of POPs in precipitation

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

The precipitation samples were spiked with 20 µL of IS containing ^{13}C-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, as described above. 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 analytical methods are to be found under accreditation number TEST 008 and includes P12 chemical analysis and P3002 air sampling. The accredited chemical analyses include heavy metals, mercury, PCBs, organochlorine pesticides (HCB, HCHs, chlordanes, and DDTs), and PAHs.

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

Field blank samples (n=3-4 per year) and lab blank samples (n=12 per year) are routinely included to control for unintended contamination during storage, transport and analytical steps. Field blanks, consisting of the sampling material (e.g. pre-cleaned PUF plugs, filters, XAD, ABN), are sent to each station where they are handled and exposed as the real samples during assembly and retrieval. They are then transported, stored, extracted, cleaned and analysed in the same way as and in parallel with the real samples. The lab blanks are obtained by extracting pre-cleaned sampling material (e.g. PUFs, filters, XAD, ABN) in solvent and using the same clean-up and analytical procedures as real samples and field blanks.

The analytical procedure is accompanied by a comprehensive quality control program based on the requirements of NILU's accreditation. The instrument limit of detection is determined by calculating the signal-to-noise ratio (S/N) > 3 for solvent blanks (using n-hexane). Based upon average concentrations in laboratory blanks, the limit of detection (LOD) and limit of quantification (LOQ) is calculated for all compounds. LOD = average blank concentrations plus 3 times standard deviations (STD) of the blank concentrations. LOQ = average blank concentrations plus 10 times STD. All samples within the range LOQ>×>LOD are considered to have higher uncertainties. All raw data for POPs and heavy metals are openly accessible from the NILU database (http://ebas.nilu.no) for thorough examinations. Values below LOD were used as LOD/2 in further statistical treatment.

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

Sampling and analysis of the organic contaminants of emerging concern (i.e. cVMS, S/MCCPs, nBFRs, OPFRs, phthalates, dechloranes) are associated with a bigger uncertainty than the well-established POPs. This is due to more diffuse sources in laboratories and sampling facilities (e.g., the use of CPs has increased again in a lot of different industrial, household products and consumer goods during the last years) that results in a larger risk for contamination. NILU is continuously taking actions to minimize this influence. Examples of such measures are improved pre-cleaning of analytical equipment, isolated work in clean cabinet facilities and removal of some materials and products where the chemicals are in use. However, samples cannot be sampled, stored, extracted and prepared for analysis without any physical contact with a lot of different materials and instruments. This causes a raising number of blank samples exceeding the acceptance level, which in consequence raises the limit of detection for samples analyzed in parallel with those blank samples. Therefore, for most of the emerging contaminants we

adopt a sample blank treatment commonly used for non-regulated contaminants. The mass of the target compounds in each sample is compared to the average mass in the field blanks (on a site specific basis) and treated as follows: If the blank level is <20% of the measured level, no correction is done. If the blank level is 20–100% of the measured level, the blank level is subtracted from the measured level.

NILU – Norwegian Institute for Air Research

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